LAWRENCE RADIATION LABORATORY • UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

NFD

MEMO NO. ~~451~~ 541

PAGE 1

SUBJECT

OPERATORS GUIDE TO THE SPIRAL READER

NAME GLENN ARMSTRONG

DATE February 10, 1965

MACHINE DESCRIPTION

The Spiral Reader is a machine designed for fast measurement of 72 inch bubble chamber film. Measurement is by the digitization of darkened points on the film as a slit admitting light to a system of photomultipliers is spiraled out from an event vertex. Coordinates of digitized points are recorded, stored, and output on magnetic tape. The Spiral Reader is operated in conjunction with a PDP-4 computer which partially controls machine functions and stores data prior to its output.

A 7094 computer program called POOH sorts the digitized points into tracks and decides which are associated with the event whose vertex was measured. The result is data which resembles Franckenstein output and can be operated upon by the normal Panal and Package programs for analysis.

PREPARATIONS FOR MEASUREMENT

No measurements can be made unless an output tape is readied and the measuring program loaded in the computer. If you are the first operator of the day it may be necessary to do both of the above.

OUTPUT TAPE

To begin a new output tape select a blank tape from the rack on the tape unit and label it according to the example in the Output Tape Log. Number it one greater than the previous tape which has been removed and fill in the required information in the Output Tape Log. The tape is hung according to the diagram on the unit and made ready by pushing in sequence the buttons, "Reset", "Low Speed Rewind", and "Start", so that the "Ready" light comes on. There is a location in the measurement log for entering the tape number "S.R.No.".

Output tapes are to be hung, ended, and disposed of as follows: When the machine is run only at night (weekdays), tapes are to be ended at 6:00 a. m. and a new one hung. The operator is to fill out the computer job sheet and designated computer output tape labels and then deliver the Spiral Reader output tape to the computer center input-output area on the first floor of Bldg. 50-A. When the Reader runs 24 hours a day (weekends), the tape is to be ended and the above procedure followed twice daily, at 6:00 a. m. and 6:00 p. m. Examples of the jobsheet and labels are posted at the Spiral Reader.

A tape is ended by writing an "End of File" on the tape. This can be done after the completion of an event by typing nine X's on the typewriter at which point the machine will respond with "Magnetic tape ended, unload it".

LOADING THE MEASURING PROGRAM

The measuring program (PDQ) is loaded into the computer via paper tape. This is accomplished through the following steps:

1. Check that lights in aluminum box near computer console read "OK", if "ERROR", call Electronic Maintenance.

2. Find the current version tape of PDQ in the racks on the front of the computer.

3. Press "Examine" switch on the computer console.

4. Load the paper tape into the reader, placing the tape in the box on the right side of the reader. Flip up the handle in the center of the reader and insert the tape such that the drive holes in the blank leader on the beginning of the tape are nearest the back of the reader. <u>The tape must be pushed all the way back over the reading head</u> and the handle flipped back to its original position.

5. Set the address switches on the computer console to the octal location 17770_8. This is accomplished by putting the left ten switches in the up position and the right 3 down.

6. Press the "Start" switch on the computer console. Paper tape should now begin passing through the reader. If no response, check switches and tape reader and press "Start" again. If the tape still doesn't begin reading, refer to page two of the binder labeled "Operator Instructions". A successful start is evidenced by the printing out on the typewriter near the Reader console of the following:

DC # ____

GREETINGS

OP (3)

If the tape cannot be made to load, call a programmer for assistance.

<u>FILM HANDLING</u>

Film is handled in the reader in much the same way as on a Franckenstein except that the film drive is put in the loading mode by raising the drive lid. Closing the lid enables the drive. Film is loaded according to the diagram taped inside the drive unit. The film is advanced by means of the film joystick on the left side of the console. To find a specific frame, push the view three button with the stage moved all the way forward. The proper frame will then be found by moving the film so that the data box appears closest to the operator in the image projected on the Spiral Reader table.

<u>MEASUREMENT</u>

Locate the listed event on the frame by moving the stage using the joystick on the right. Close examination of the image in the center of the table is afforded by the magnified picture shown on the television monitor in front of the operator. If for some reason the event should not be measured, ignore it and move to the next event on the list.

<u>INDICATIVE DATA</u>

Type in the indicative data in response to the machine according to the specified format. See the following page for an example:

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```
"GREETINGS"
OP (3)Ø88
YYMMDD)641210
EX(2)Ø7
TP(3)Ø35
ROLL(4)33Ø6

FR(4)Ø396
ET(3)Ø22
BT(2)Ø1

FFFFFF 3VCCC 2VCCC 1VCCC   224 SEC.
FR(4)Ø4Ø1
ET(3)Ø22
BT(2)Ø1
FFFFFF 3VCCC 2VCCC 1VCCC   156 SEC.
```

Each word of indicative data is entered by pressing the space bar. The machine responds by asking for the next word. If a mistake is made typing indicative data and you realize it:

(a) before depressing the space bar after the mistake, press "Line Feed" and type in the correct information

(b) after the space bar has been pushed, continue pushing the space bar until the comment BT(2) has been passed. Now type the letter "S". The machine should again ask for OP(3).

FIDUCIALS

Depress the three buttons labeled: "Group 3", "Group 2", "Group 1", so that all are blue. Press the button labeled "View 3".

The next step is the measurement of fiducials. Six in all are measured. The order of their measurement is as follows:

FID near rake 13	View 3
" " " "	" 2
" " " "	" 1
FID near rake 2	View 1
" " " "	" 2
" " " "	" 3

(The Spiral Reader switches views automatically for fiducials)

The actual measurement of a fiducial is effected by centering the television screen image by use of the joystick and handwheels so that the crosshairs center on the fiducial mark and pressing the button marked "FID". Each time the button is pushed, an "F" is typed out on the typewriter.

VERTEX

When all fiducials have been measured, the next step is to center the television screen crosshairs on the vertex of the event in view 3. Press the "Vertex" button. The view number is then typed out. If the measurement is successful, the letter "V" will follow the view number after a few seconds. Occasionally the machine returns an error comment. What to do in this event will be explained later. Note that a display of the vertex measurement appears on an oscilloscope in front of the operator. This is a plot of increasing azimuth along the X-axis, and increasing radius along the Y-axis. The display should be consistent between views. If there are horizontal bands showing no points or the display is chopped off, call Electronic Maintenance.

CRUTCH POINTS

After the vertex measurement in view 3, crutch points in that view are taken. They are recorded by pushing the button marked "X-Y". Place one point on each track of the event beginning with the beam track, moving clockwise around the event vertex. It is essential that crutchpoints in views 2 and 1 be put on tracks in the same order as in view 3.

POOH is assisted in its job of sorting and reconstruction by the placement of "crutchpoints" on each of the tracks of an event. The operator is required to manually measure one point on each track to label for POOH those tracks which are associated with the pertinent event. POOH discards all data on a track which are beyond the crutch point. To get the most meaningful data, crutch points must be placed as far out on the track from the vertex as possible while keeping the event vertex within the circle drawn on the Spiral Reader table upon which the film image is projected. If the track leaves the chamber, stops, decays or scatters, then the best placement of the crutch point is near the point of decay, interaction, etc. Also a crutchpoint should not be put past a point on a track where it has curved through more than 20° of arc from the vertex.

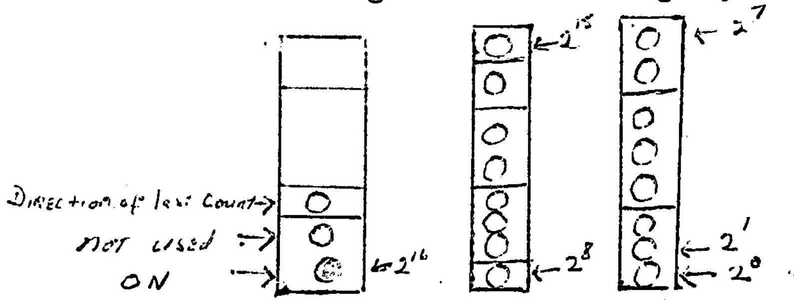
After measuring all crutchpoints in view 3, push the button labeled "View Complete" and change to view 2 by pushing the appropriate button. Follow the same procedure as in view 3 starting with the vertex. Push "View Complete" and move to view 1. Finish view 1 and push "View Complete". Now depress the button marked "ADV" (advance) to move on to the next event. All events are measured in all 3 views.

Should you measure some part of the event incorrectly, you can at any point up to pressing of the "ADV" button delete the event by means of the "Delete Frame" button. You must then begin the measurement over, starting with the fiducials in view 3. When you are finished measuring for the day fold up the paper printed by the typewriter and place it in the binder labeled "Online".

FERRANTI CHECK

Every hour on the Spiral Reader a light labeled "Ferranti Check" (red) comes on and the logic prevents the measurement of any events past the one which might be in progress. At the completion of the event a scalar return check of the Ferranti system is to be made. A check should also be made after the first event measured. There is no manual reset in the system, but a reset occurs with the measurement of the first fiducial of an event.

Behind the operator in the electronic racks are two groups of lights each of three columns. The top group is the X-display, the lower is the Y-display. Each group contains 18 lights of interest. These lights display the coordinates of the crosshairs on the stage in the following way:



Ferranti reset position

Lights on = 0
Lights off = 2^n

Octal location indicated here equals 177777

When the Ferranti display shows the reset coordinates (before moving the stage after the first fiducial of any event), only the light labeled here as "2^{16}" should be on. The light labeled "direction of last count" indicates which way the stage is moving. On indicates the stage is moving to increasing values of x or y, off indicates decreasing values. The test consists of driving the stage around randomly for a short period and then centering again carefully on the first fiducial. If the Ferranti display doesn't agree with the reset pattern to within ± 5 counts, you should run the test after the next event also. If the test again fails call Electronic Maintenance.

Error comments typed by the machine under certain circumstances are listed below:

Measure vertex again - insufficient data

Timer overflow from vertex

Error stop, no data input, continue starq

Binary scalar error

Tape is busy when it shouldn't be

Output buffer not ready

The operator response to the above comments is to measure the point again. If the error comes often call Electronic Maintenance. If you get the comment:

Error stop, see PDQT

try restarting the program. If restarting doesn't help call a programmer.

The comments:

Vertex expected

Fiducial expected

Crutch points expected

indicate probable operator error. The proper point can be measured as the machine ignores the wrong sequence measurement.

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If the machine gives trouble which you cannot correct, make sure that someone on the list below is notified:

Machine Trouble

Electronic Maintenance	5864
Mechanical Maintenance	5289
Jerry Butler	522-4873

Program Trouble

Jim Baldridge
Jon Stedman
Programmer's Office: Jim Burkhard) 5711
Frank Hodgson)

Other Trouble

Glenn Armstrong	5711, 843-3216
Willard McCarty	5885, 843-5165
Jack Lloyd	5885, YE4-2745
Gerry Lynch	5001, LA6-5260

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SUBJECT: INSTRUCTIONS FOR SCANNING AMBIGUITIES		NAME: Hardy/Hess/ Emerson	
		DATE: Feb. 11, 1965	

I. Introduction

The first few steps in the analysis of bubble chamber film are fairly standard. Events are scanned and then measured; the output from the measuring machines is fed into a computer, and a set of interpretations is tried for each event. Fitted physical quantities such as momenta, coordinates, and angles of the tracks, and statistical results from trying the various hypotheses are stored on data summary tapes; and the set of summary tapes serves as a basis for the physics to be extracted from the experiment.

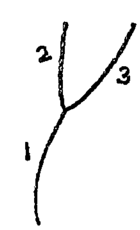
At the foundation of all subsequent analysis, however, lies the problem of identifying the particle that made each track in a given event, i.e. which hypothesis is the correct one. The computer unambiguously identifies many events by conserving energy and momentum, but some events still remain ambiguous after the computer has processed them. Looking at these ambiguities is one of the ways in which we "clean up" the data and make our interpretations more likely to be the correct ones.

II. How the Computer Fits Events

Consider the case of a simple two-prong in anti-proton film. The two simplest interpretations are:

1) $\overline{P} + P \rightarrow \overline{P} + P$

2) $\overline{P} + P \rightarrow \pi^- + \pi^+$



From measuring machine data we can find the components of momentum of each of the three tracks -- nine pieces of information in all: P_{1x}, P_{1y}, P_{1z}, P_{2x}, P_{2y}, P_{2z}, P_{3x}, P_{3y}, P_{3z}. For each track the computer calculates the momentum midway along the track. The momentum at the beginning of each track is then extrapolated from the midpoint value using an energy loss formula which depends on the mass of the particle assumed. So the sets of nine momentum components will be different for the two interpretations. We can also calculate the energy of each track using a well-known relativistic formula:

$$3)\quad e_1 = \sqrt{m_1^2 + P_{1x}^2 + P_{1y}^2 + P_{1z}^2}$$

$$4)\quad e_2 = \sqrt{m_2^2 + P_{2x}^2 + P_{2y}^2 + P_{2z}^2}$$

$$5)\quad e_3 = \sqrt{m_3^2 + P_{3x}^2 + P_{3y}^2 + P_{3z}^2}$$

Now our interaction must conserve momentum and energy, so we can write:

$$6)\quad P_{1x} = P_{2x} + P_{3x}$$

$$7)\quad P_{1y} = P_{2y} + P_{3y}$$

$$8)\quad P_{1z} = P_{2z} + P_{3z}$$

$$9)\quad e_1 = e_2 + e_3$$

The computer now compares the left and right hand side of each equation. If our measurements were infinitely accurate, the problem would be solved. One (or both if some other reaction took place) of our sets of values just would not match up and we could discard that possibility. Unfortunately things aren't that simple; because of errors in measuring, turbulence in the bubble chamber, etc, neither set of values will match up exactly.

For each hypothesis the values of the p's and e's are pulled from their measured values until there is agreement in all equations; then a quantitative measure of how much pulling was done is calculated. This measure, a function of measured values, pulled or fitted values, and errors of the measured values, is called chi-square. It is so constructed that "good" fits have low values of chi-square and "bad" fits have high values. We expect the correct interpretation to have the lowest chi-square most of the time.

Suppose now we include the possibility of a third reaction into our set:

10) $\overline{P} + P \rightarrow \pi^+ + \pi^- + \pi^0$

Here we cannot measure P_{4x}, P_{4y}, or P_{4z} so, roughly speaking, we proceed as follows. We use the three equations of momentum conservation to solve for the values of P_{4x}, P_{4y} and P_{4z} and then use these results to find e_4. ($e_4 = \sqrt{m_4^2 + P_{4x}^2 + P_{4y}^2 + P_{4z}^2}$) Now we can still test the energy balance equation for consistency, but it is the only one we have left to make such a test. Again we can form a chisquare, but since chisquare is a sum of positive terms, one for each equation, (or constraint as it is called) it is incorrect to compare the chisquare for reaction (10) having one constraint with chisquare for reactions (1) or (2) having four constraints. For comparison purposes there is another function, called confidence level, which depends upon chisquare and the number of constraints. Confidence levels can be compared directly and, if no additional information is available, the computer chooses the interpretation with the highest confidence level.

Finally, suppose we add one more pi zero to the right side of our reaction

11) $\overline{P} + P \rightarrow \pi^+ + \pi^- + \pi^0 + \pi^0$

In this case we are stuck. We have six unmeasured momentum components, (three for each pi zero) and using all of our equations we cannot reconstruct the event, let alone have any equations left over to check for agreement. What is done is to use the four conservation equations to calculate what mass one neutral particle would have in order to conserve momentum and energy in the reaction. This mass is called the missing mass. Note here that no quantities are pulled and we cannot form a chisquare as we can with the fitted hypotheses. So that we can compare reaction (11) with (1), (2), or (10), a specially constructed confidence level is computed.

Hyperon events are more complicated than the simple two-prongs described so far because they involve more than one vertex and momentum-energy conservation applies to each. Hyperons are fitted by two different techniques: CPM chains and multi-vertex fits. In CPM chains some of the tracks are fitted first; the fitted momentum of one of the particles is then used as input "measured" momentum at the next vertex and so on. For example, in an event type 32, the vee is tried alternately as a kaon and a lambda decay, and then the fitted momentum of the kaon or lambda is used for checking the momentum-energy conservation at the production vertex. In the case of sigma decays the length of the sigma track is often so short that an accurate momentum measurement is impossible. Therefore in addition to trying a decay fit and then moving back to the production vertex, a two-vertex fit is also applied in which all of the tracks of both the production and decay vertices are used at the same time.

For a great number of events, all but one of the hypotheses tried will fail (failing hypotheses are those which have extremely high chisquares and hence extremely low confidence levels), and the event is called unambiguous. For other events two or more interpretations will have confidence levels above a chosen cut off point and these are labeled ambiguous. For these events it is desirable to use whatever additional information we have at our disposal to eliminate hypotheses so that we may be more sure of selecting the correct interpretation.

III. The Computer Printout

For each event that is ambiguous and that is "potentially resolvable" (one or more of the hypotheses could possibly be eliminated) we obtain a page or two of pertinent information from the data summary tapes. These data are divided into several blocks of varying importance.

A. Identification Data

ROLL, FRAME, BEAM TRACK, and EVENT TYPE give the usual information. The number following MEAS is how many times the event has been measured. CL is increased each time the event goes through Program 19, and this happens each time the event is looked at on the scanning table. MPNO and OPNO are the numbers of the measuring machine and the measurer respectively.

B. CPM Data and Coordinate Data

The CHISQ, RJ/COMB, LC, and TRACKS are given for each CPM. This information will not be used in ambiguity resolution work. The beam average and error give the approximate momentum of the beam for that roll and the error associated with it. The beam average momentum is averaged with the measured beam momentum for a given event so that short inaccurately measured beam tracks still have good momentum estimates. The coordinates of the beginning (measured point closest to the window) and the end (point at the production vertex) of the beam track are given. The origin of the coordinate system is on the bottom of the chamber between rakes 7 and 8 and approximately midway between the sides of the chamber. The scale of the system is in centimeters. It is a right handed coordinate system as seen on the scanning table. X runs from left to right ranging from -21 cm. to +21 cm. Y runs the length of the chamber from -85 to +93 cm. Z runs from the bottom to the top of the chamber ranging from 0 to 39 cm. The dip, azimuth and momentum at the end of the beam track are also given. The dip (also called lambda) is the angle the track makes with the X-Y plane. Positive dip means that the track is rising. The azimuth (also called phi) is the angle between the X-axis and the projection of the track in the X-Y plane. Both azimuth and dip are measured in degrees. The dip ranges from -90 to +90 degrees and the azimuth ranges from 0 to 360 degrees. The information in CODE and WEIGHT have to do with fiducial volumes, escape corrections and other related matters that do not concern ambiguity scanning.

C. Pang Data

This block gives information about <u>measured</u> (as distinguished from fitted) values for each track. For each track number the first quantity given is the mass in

Mev of a particle that could have made it. A minus sign indicates that the charge of the track is negative. The second quantity is the length of the track in cm. This is the length in space along the track from the first point measured on it to the last one measured. Next come the beginning and ending momenta of the track. They are different because of energy loss, and different for particles of different mass because the energy loss will not be the same. The next quantity DP/P is very important. It is the uncertainty in the momentum divided by the momentum itself. When this quantity is above .5 it means that the momentum of the track is difficult to determine from the measurement. The dip and azimuth are values at the track beginning.

PARC and KPTEST give information on the range of tracks. Using the length of the track as given earlier and the range-energy relationship, the starting momentum that would cause a particle to travel just that far is calculated and listed under PARC. To see if the track really did stop PARC is compared to PBEG. The difference of these two numbers is divided by the estimated error in the quantity and the result written under KPTEST (actually the reciprocals of the momenta are used but the concept is the same). When this number is negative it means that PBEG is smaller than PARC and the particle assumed for that track in actuality did not have enough momentum to make a track as long as measured. This is probably as hard to understand as to explain, and you are best off by setting up a few hypothetical examples and thinking them through until you are convinced that for most tracks the KPTEST will be large and positive, for stopping particles it will be near zero, and for incorrect assignments it will sometimes be negative.

The quantity *DENS* gives the expected ionization density of a track corresponding to the measured value of momentum and is explained in the section on ionization. The column headed PRANG gives the production angle in degrees of each track leaving the production vertex. For tracks leaving a decay vertex PRANG gives the angle between the parent particle track and the decay product track. For those tracks which decay (including neutrals) EFM gives the effective mass of the particle a computed from the decay product tracks. For tracks from a vee decay EFM gives the opening angle. PRANG and EFM are used primarily in failing event analysis.

D. Fitted Data

Following the bank of Pang information is a set of information for each "still-possible" CPM. For fitted CPM's "still-possible" means that χ^2 isn't too high. For missing mass hypotheses "still-possible" means that all connected CPM's are "still-possible".

A CPM is either a vertex fit or a missing mass hypothesis. There are three kinds of vertex fits.

1. Decay fits: The fit of a decaying particle will always be listed as a vertex fit. TARGET 1 will = 0. and TARGET 2 will = -1.0 (meaning no target 2). Next will appear CHISQ (LC = N) = X where N is the number of constraints and X is chisquare for the fit. The confidence level will not be calculated for a decay fit. Next are given the mass, azimuth (PHI), dip (LAMBDA), and momentum of each track in the fit. The quantities XI(PHI), XI(S), and XI(K) are a measure of how much the azimuth energy, and curvature had to be changed to satisfy the constraints. The number given is how much you changed the quantity divided by what you would expect to change it by. Lastly, the ionization density based on the <u>fitted</u> value of momentum is given. The ionization from fitted momentum, rather than measured data should be used when resolving ambiguities.

2. One-vertex production fits: An ordinary production fit will have TARGET 1 = 938.2 and TARGET 2 = -1.0. Chisquare and the number of constraints are given and used to compute the confidence level. The confidence level is the probability that chisquare with that many constraints would be higher than the one calculated.

3. Two-vertex fits: These fit a production and decay simultaneously.

TARG 1 = 938.2 and TARG 2 = 0.0. On two vertex fits the measured momentum of the decaying particle is not used in the fit. Two vertex fits are used only in 62's, 72's, 82's, 84's, 92's, and 94's.

A CPM can also be a missing mass hypothesis. This means that at least two neutral particles went off and were undetected. The momenta and energies of the detectable particles are added up to see what energy and momentum has to be included to conserve momentum and energy. These numbers are written as missing energy ± its error, and missing momentum ± its error. Another quantity and its error is also calculated from these. It is the missing mass squared calculated by taking $E_m^2 - P_m^2$. Also written down is the minimum possible value for this quantity and a confidence level for the CPM. The values of momentum used for the detected particles come from previous decay fits or from the measured values.

IV. Test and Techniques

Ambiguity resolving consists of applying as many as possible of the following tests to each CPM of an event and discarding those hypotheses which are inconsistent with your observations.

A. Ionization Density

This is the strongest test that is applied to ambiguity resolution but it must be understood and used with care since the tendency to rely on it too heavily is strong.

To a very good approximation the density of bubbles along a track is given by I_o/β^2 where I_o is the minimum ionization density and β is the particle's velocity divided by c. In terms of momentum and mass

(12) $$\beta^2 = \frac{(P/m)^2}{1 + (P/m)^2}$$ (P and M given in MeV/c and MeV/c^2 as on the printout)

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Note that for a given momentum, heavier particles will have a smaller β than lighter ones and hence ionize more. From (12) can also be seen the rule of thumb that the density will equal $2I_0$ when P is equal to the particle's rest mass. In the bubble chamber we of course will not view each track perpendicular to its line of flight and the apparent density will depend upon the angle of dip of the track. On the printout for each track of each hypothesis is printed the "apparent" density factor $1/\beta^2 \cos\lambda$ where λ is the dip angle. Since the views are different the $\cos\lambda$ factor is just an average over the three views. For nearly horizontal tracks the variation in density from view to view will not be much but extreme care needs to be taken for steeply dipping tracks.

To apply the ionization criterion, look at the density factor computed for a given track under the various hypotheses; the vertex fits and the missing masses. The ionization as seen on the table must be consistent with the factor presented in the fit. In some cases there will be no problems; a track will be minimum ionizing when a hypothesis calls for 8.0. In most situations, however, the selection will be much more difficult. Almost all of the time you should be able to tell a 2.0 from a 1.0 and almost none of the time can you tell 1.4 from 1.0, or 8.0 from anything higher. To check what 2.0 looks like you can look at two superimposed beam tracks since single beam tracks in this experiment are always minimally ionizing. Use tracks which you know to compare unknown tracks. For example, if you have a known 1.5 you can see if the unknown track ionization is lighter or heavier to decide between 1.2 and 1.9. For lightly ionizing tracks pay attention to the frequency and lengths of gaps.

Try to compare the ionization near the beginning of the track. Tracks at the top of the chamber have a higher apparent density because of different hydrogen conditions, and a rising track can change ionization noticeably. Be careful of very short tracks since the density factor represents an average. (Bubble formation is a statistical process and we expect statistical fluctuations to occur. On long tracks we sometimes see long gaps or dense spots but are able to judge the density over a long enough region to see that those segments are atypical. On short tracks we have no such recourse). For a short track, a deviation from the average could significantly change your estimation of the ionization.

Bubble chamber conditions can change from roll to roll and even from frame to frame, having a drastic effect on bubble density. Always use nearby beam tracks and known tracks to calibrate yourself for each event.

B. Delta Rays

A δ-ray of given radius can be produced by a particle of given mass only if that particle has at least a given minimum momentum. For a particle of momentum P, energy W, and mass M,

$$\rho_{MAX}\text{(INCHES)} = \frac{2 m_e P (W + m_e)}{22.3 \left[(M + m_e)^2 + 2 m_e (W - M) \right]}$$

The exact formula can be approximated fairly well by

$$\rho_{MAX}\text{(INCHES)} = \frac{\eta \gamma}{22.3} \quad \text{WHERE } \eta = \frac{P}{M} \; ; \; \gamma = \sqrt{1+\eta^2}$$

The factor 22.3 is from the templates which give P(MeV/c) = 22.3 ρ (IN.) This takes into account scanning table magnification but is only exact in the middle of the chamber. At the top the factor should be 18.0 and at the bottom it is 24.0.

Look along all tracks except the incident beam to see if delta rays are present. Use the circle template attached to this memo to find the minimum momenta different particles must have to cause such delta rays. Note that for a given momentum lighter particles can produce bigger delta rays than heavier ones. This test can be used only to rule out the heavier, not the lighter of two particles. Be sure that the circle selected fits snugly along the beginning of the ray and for dipping deltas and hard to measure ones be conservative by using a smaller circle. The momentum for a track of a given hypothesis must be larger than the minimum from the template. The two numbers given on the template refer to δ -rays made in the top and the middle of the chamber. For δ -rays at the bottom of the chamber use the momentum value for the middle of the chamber.

C. Information from Range

In addition to calculation of the momentum from the curvature of the tracks, a momentum is computed by making the assumption (usually false) that the particle stopped at its last measured point, using the mass dependent range-energy formula. In most cases this momentum will be less than the one calculated from curvature since most particles leave the chamber rather than stop. For a correctly identified stopping particle, the values should be very close to one another. In some cases, however, this momentum will be higher than the one from curvature, i.e. the particle should have stopped before getting that far. To facilitate using this test, the printout in the Pang data section contains a heading of KP test. Large positive values of KP give no information; values near zero indicate that the track should be checked for stopping. Large negative values (more negative than -3.0) state that the track is inconsistent with the given particle interpretation. In computing the KP test, PARC is calculated using the measured length of the tracks. It sometimes happens that the actual length as seen on the scanning table is longer than the measured length because tracks are chopped or are longer in one of the views. Also if a track has a secondary interaction we can infer that it would have been longer had it not interacted. If, in computing PARC we somehow were able to use these lengths rather than the measured ones, we would obtain a larger value of PARC. This in turn would make the value of KP less positive or more negative since PARC is subtracted from PBEG. Therefore, when a borderline case occurs (i.e., KP = -2.7) and we see that the measured length is less than the true length we can throw the hypothesis out since the KP should actually be more negative.

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

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SUBJECT: INSTRUCTIONS FOR SCANNING AMBIGUITIES		NAME: Hardy/Hess/Emerson	DATE: Feb. 11, 1965

D. Stopping and Decaying Charged Tracks

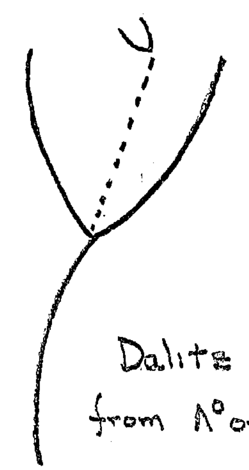
A stopping positive track must be a proton. Check all heavily ionizing tracks to see if they are stopping. If they are, use a stopping template to identify it. Remember that the template agrees very well only for tracks with small dip angle.

A μ-e decay can identify the particle as a kaon or a pion. The μ from a kaon can go much farther than a μ from a pion; the μ from a pion at rest will go about 1.1 cm.

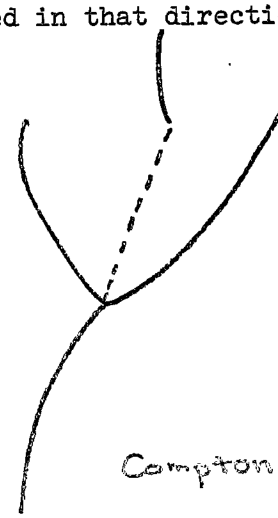
Information can be gained by observation of secondary interactions. For example when a positive particle interacts and two protons leave the vertex the incoming positive particle must have been a proton in order to conserve baryons. (Only true in H_2 film).

E. Neutral Tracks

A Dalitz pair at the productuion vertex indicates either a Σ^0 was produced ($\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^-$) or a π^0 was produced ($\pi^0 \rightarrow \gamma + e^+ + e^-$) and only CPM's consistent with the production of one of these particles should be kept. MM hypotheses are always consistent with π^0 production. When you see a mid-air Dalitz pair it could have come from a Λ^0 ($\Lambda^0 \rightarrow n + \pi^0 \rightarrow n + \gamma + e^+ + e^-$) or from a K^0 ($K^0 \rightarrow \pi^0 + \pi^0 \rightarrow 3\gamma + e^+ + e^-$). Since a π^0 travels only a short distance (10^{-4} cm) before decaying you can check the output for a Λ^0 or a K^0 produced in the direction of the Dalitz pair. (Favoring a CPM with the neutral produced in that direction).



Dalitz pair from Λ^0 or K^0



Compton electron

Slightly less useful than Dalitz pairs are pair productions ($\gamma \rightarrow e^{+}+e^{-}$). The vee will point to where the γ was produced. A pair production Vee pointing to the production vertex indicates production of a π^{0} or a Σ^{0}. $e^{-}e^{-}e^{+}$ triplets and Compton electrons convey the same information as $e^{+}e^{-}$ pairs except Compton electrons don't point back to production.

When a neutron is produced (at production vertex or decay vertex of a Σ) it can react with a proton making a recoil proton visible in the chamber or a neutron star (if it has more than 790 MeV/c). Observation of these interactions lets one pick CPM's with neutrons going off in the direction of the interaction.

F. Computer Oversights

In the fitting of events, the length of decaying tracks is not taken into account and extremely long tracks are less likely to be decays than short ones. The mean free path for a decay is given by

$$\lambda = \frac{PC\tau}{M}$$

For a Σ^{-}, λ = 4.8 cm, for a Σ^{+}, 2.4 cm (when P = M). In deciding between a Σ^{-} and a K^{-} the particle has to go about 5.2 Σ^{-} mean free paths before it becomes more likely to be a K^{-}. (6.0 mean lives for a Σ^{+}). A particle will travel more than 6 mean free paths only $\frac{1}{4}$ percent of the time.

In missing mass hypotheses, since no fits are made, kinematically unallowed situations sometimes get confidence levels above the minimum limits. Check the production angles of baryons to see that none come backwards in the lab. For a given beam momentum and production hypothesis more stringent conditions exist (see graphs at the end of this memo) but the forward production rule will always apply in hydrogen film.

In two vertex fits of sigma hypotheses, the magnitude of the sigma momentum measurement is always thrown away. For most events the tracks are so short, the measured momentum is very inaccurate and nothing is really lost by doing this. For longer tracks, however, the momentum is known fairly well. For some of these events the momentum as fitted in the CPM will be inconsistent with the measured value and the CPM should be rejected. On two vertex fits, therefore, check the error DP/P of the kinked track and if it is $< .3$, see that the fitted momentum is within the range of the measured momentum ± 2DP (DP = DP/P XP)

G. Confidence levels

You need not investigate CPM's which have a confidence level of 0. or 0.000. The computer automatically considers them as eliminated.

In deciding between CPM's in general, you should completely <u>ignore</u> the confidence levels; do not let them bias your decisions. It is to be exptected that occasionally a CPM with a confidence level of .99 is thrown out while one of .01 is retained.

V. Comments on the Printout

For each event cross out each CPM that is inconsistent with your observations of the event. Cross out also each CPM that depends upon the ones already eliminated. For example, if you decide that the vee in an event type 30 is a kaon rather than a lambda, eliminate all production CPM's that have track 4 as a lambda. Refer to Scanning Memo 507 to see which CPM's are connected to one another. Pay particular attention to event types 6x, 7x, 8x, and 9x, for which the connections cannot always be directly inferred from the output.

Occasionally you will decide that the information for the event is totally in error. The event should be completely crossed out and an appropriate comment made at the bottom of the printout. Comments are: remeasure, remeasure as an event type xx, discard (with explanation), or zoon.

SUBJECT: INSTRUCTIONS FOR SCANNING AMBIGUITIES

NAME: Hardy/Hess/Emerson

DATE: feb. 11, 1965

Events should be remeasured if any of the Pang data is in error such as an obviously wrong momentum, too large an error on a long track, a stopping track not measured along its entire length, too small an error on a short track, or tracks too drastically chopped to give good fits.

The most common event type mislabeling occurs in event types 82, 92 and 30 in which an associated vee is missed. Check carefully in the direction of "missing" strange particle (as determined in the fits). If a vee is found, have the event remeasured with the appropriate event type. Less common are other errors such as calling a 30 with a vertex Dalitz pair a 32 and labeling an 82 as a 92.

Discard events are events for which the correct interpretation is something of no interest to the experiment. For example, a two prong with the subsequent scatter of a pi minus will sometimes be called a 92, or the vee for a 30 may be an electron-positron pair. Note that events should be junked only if the correct interpretation is no longer of value. A 72 whose vee turns out to be an electron pair should be given the comment Remeasure as a 92.

Discard events which are outside of the fiducial volume or fail the beam criteria as stated in Memo 507. If an event should actually be a zoon for some reason, label it as such.

For events in which a neutral interacts, process the event as you would normally (using what information you can from the interaction) and make a comment at the bottom of the output for the event.

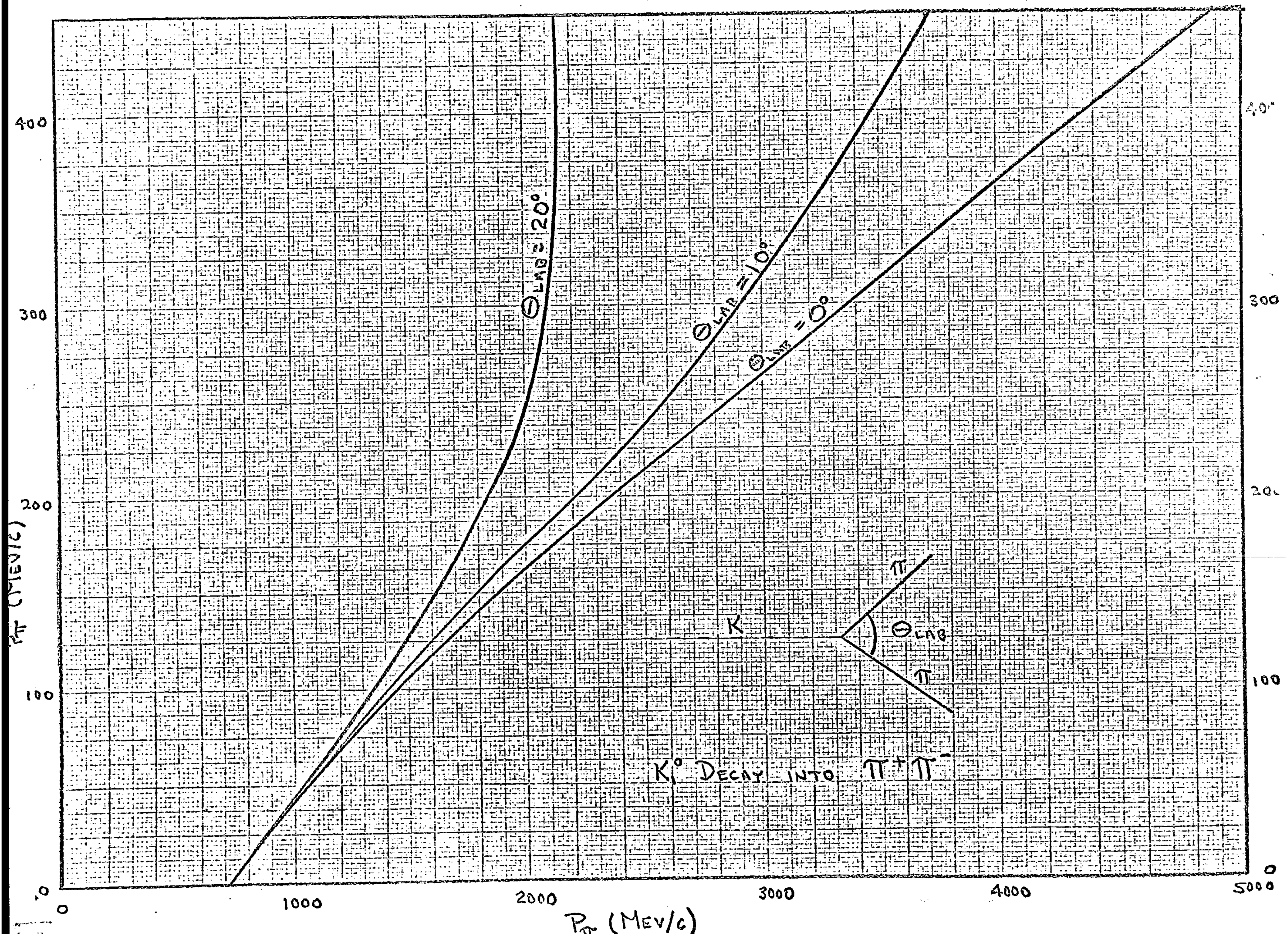
For events with vees and for which both the lambda and kaon hypotheses have high chisquares ($\geq$ 20) examine the event carefully to see if both decaying tracks are properly measured and the proper vertex is used with the vee. If you find a sloppily measured track or an alternate vertex, have the event remeasured making a note as to how the remeasurement is to be done (take care on tract 5, vertex is in C12, etc.)

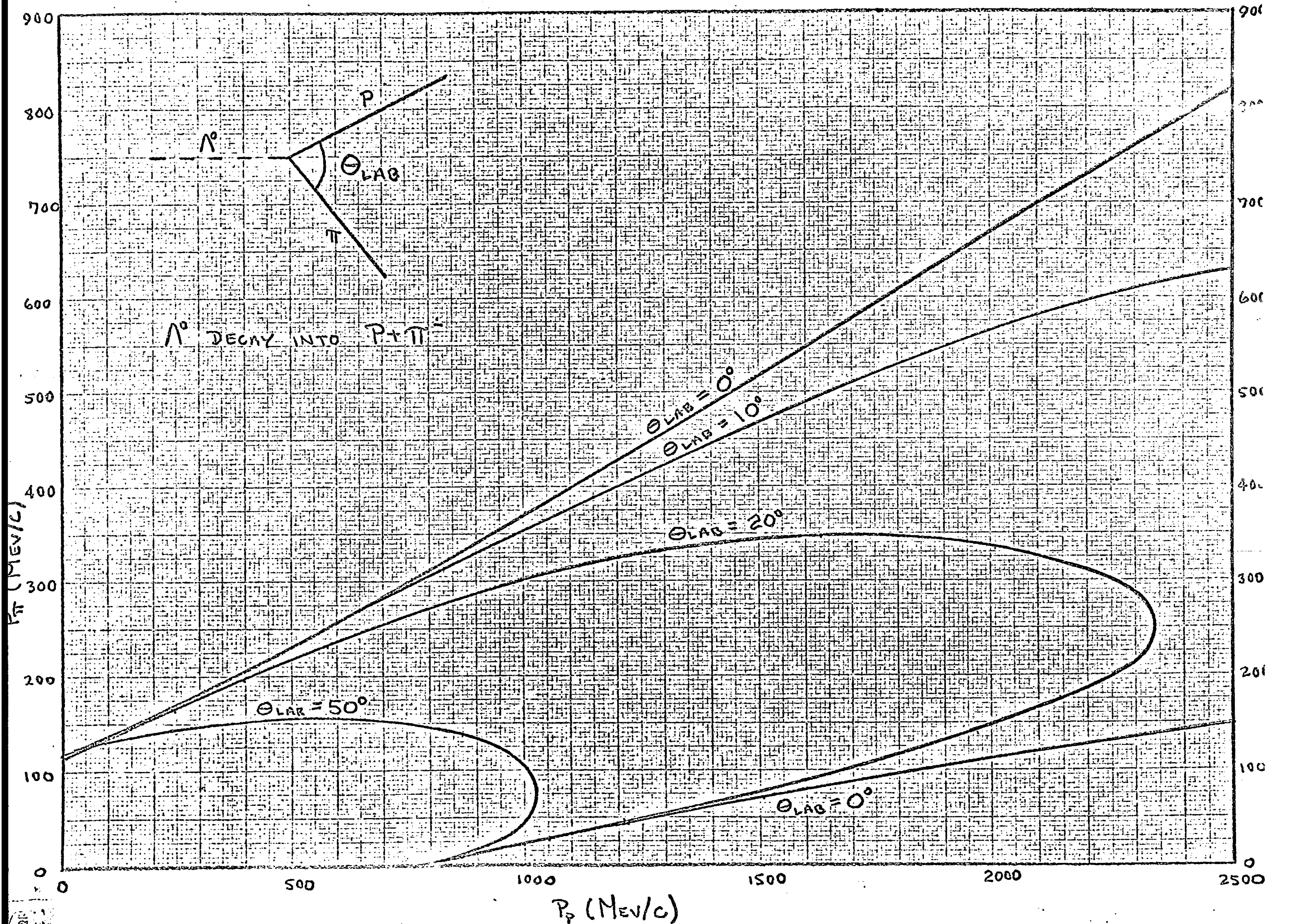
Finally, initial each event after you have completed it.

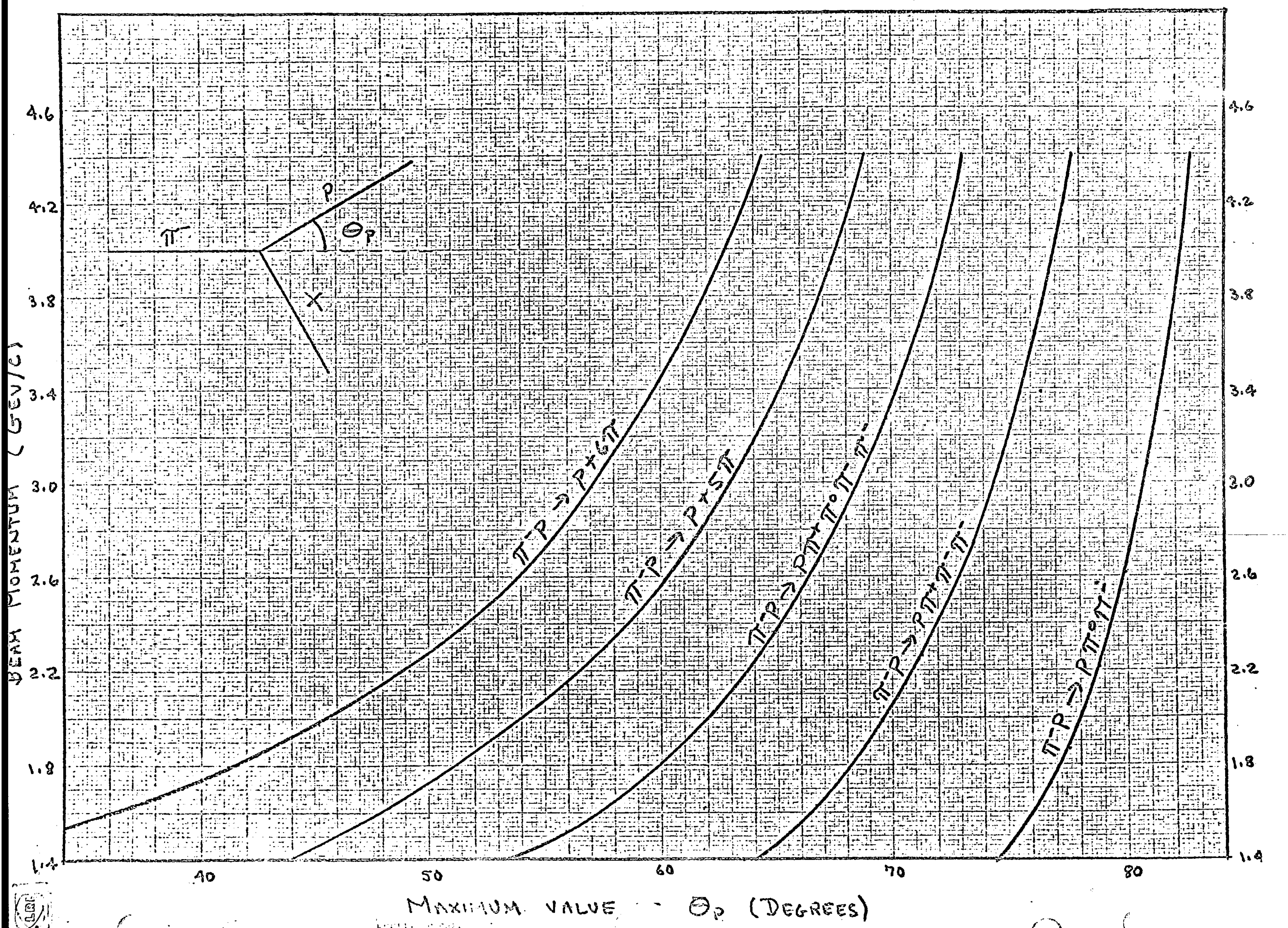
MINIMUM MOMENTUM NECESSARY TO MAKE A δ-RAY OF THE INDICATED SIZE (MEV/c). [TOP MIDDLE]

	π	K	P
	80.0 95.0	290.0 345.0	555.0 650.0
	95.0 115.0	335.0 375.0	640.0 770.0
	110.0 125.0	400.0 425.0	755.0 860.0
	115.0 130.0	415.0 465.0	795.0 890.0
	120.0 140.0	435.0 495.0	825.0 940.0
	135.0 145.0	485.0 510.0	920.0 980.0
	140.0 160.0	500.0 560.0	955.0 1060.0
	145.0 175.0	520.0 630.0	990.0 1200.0
	160.0 185.0	570.0 650.0	1090.0 1230.0
	170.0 190.0	600.0 665.0	1150.0 1265.0
	180.0 200.0	630.0 695.0	1200.0 1340.0
	185.0 205.0	645.0 725.0	1230.0 1385.0
	190.0 215.0	670.0 755.0	1270.0 1445.0
	195.0 225.0	695.0 790.0	1320.0 1500.0
	200.0 230.0	715.0 815.0	1365.0 1545.0
	210.0 240.0	740.0 840.0	1405.0 1610.0
	215.0 245.0	760.0 860.0	1430.0 1650.0
	220.0 250.0	775.0 875.0	1470.0 1680.0
	225.0 260.0	805.0 910.0	1530.0 1730.0
	235.0 270.0	835.0 960.0	1585.0 1825.0
	245.0 285.0	865.0 1010.0	1640.0 1915.0
	255.0 295.0	905.0 1035.0	1715.0 1960.0
	270.0 305.0	950.0 1070.0	1800.0 2030.0
	280.0 315.0	985.0 1115.0	1860.0 2120.0

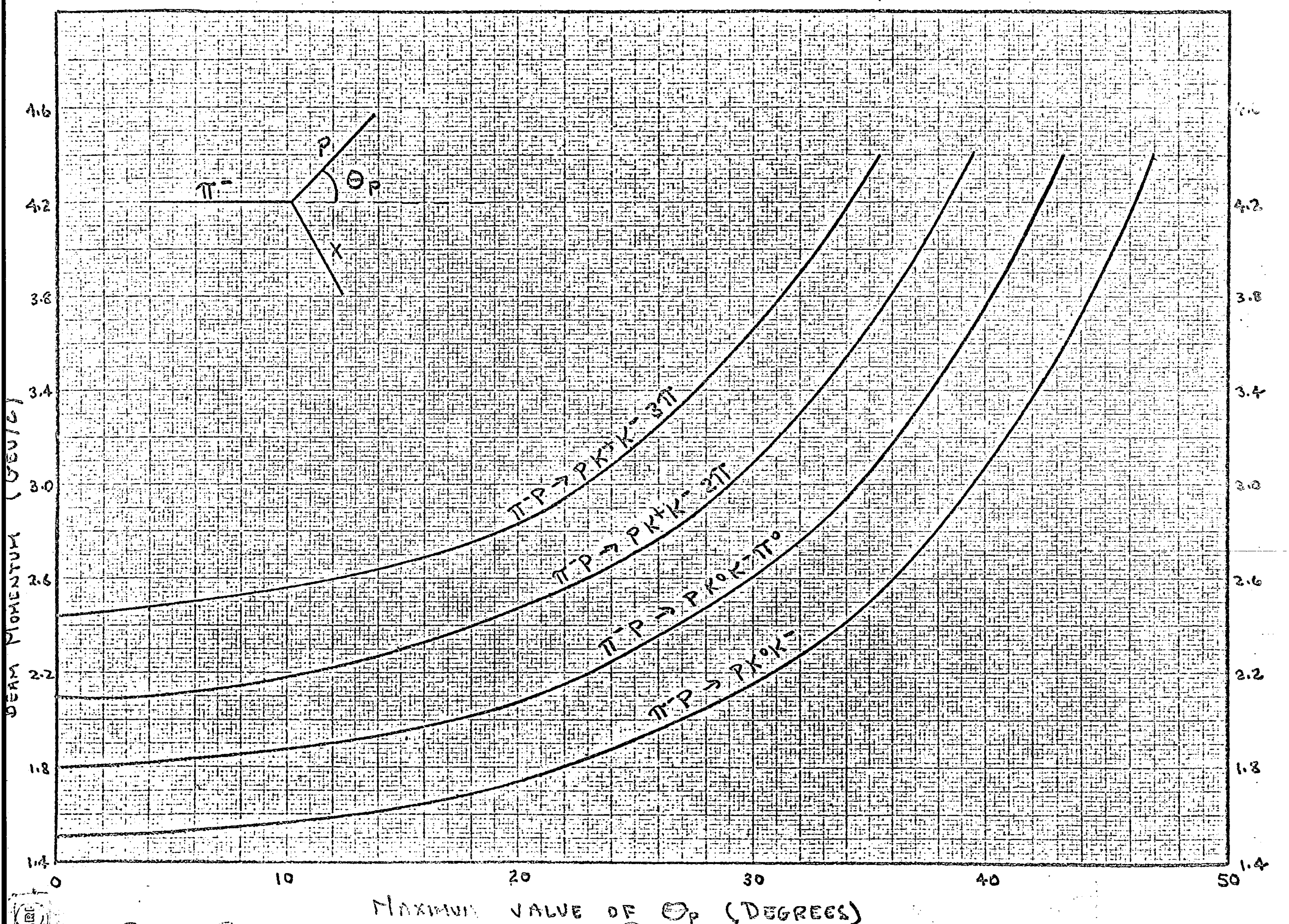
	π	K	P
	290.0 330.0	1025.0 1160.0	1950.0 2200.0
	300.0 340.0	1060.0 1200.0	2010.0 2270.0
	305.0 350.0	1080.0 1230.0	2040.0 2330.0
	315.0 360.0	1120.0 1265.0	2120.0 2400.0
	325.0 365.0	1150.0 1295.0	2180.0 2450.0
	335.0 375.0	1185.0 1325.0	2250.0 2510.0
	345.0 385.0	1210.0 1350.0	2290.0 2560.0
	350.0 395.0	1230.0 1375.0	2330.0 2600.0
	365.0 410.0	1280.0 1440.0	2430.0 2730.0
	380.0 425.0	1345.0 1505.0	2560.0 2860.0
	410.0 455.0	1440.0 1595.0	2730.0 3025.0
	435.0 485.0	1525.0 1700.0	2900.0 3220.0
	460.0 515.0	1610.0 1800.0	3060.0 3410.0
	480.0 540.0	1695.0 1900.0	3210.0 36[illegible]0.0

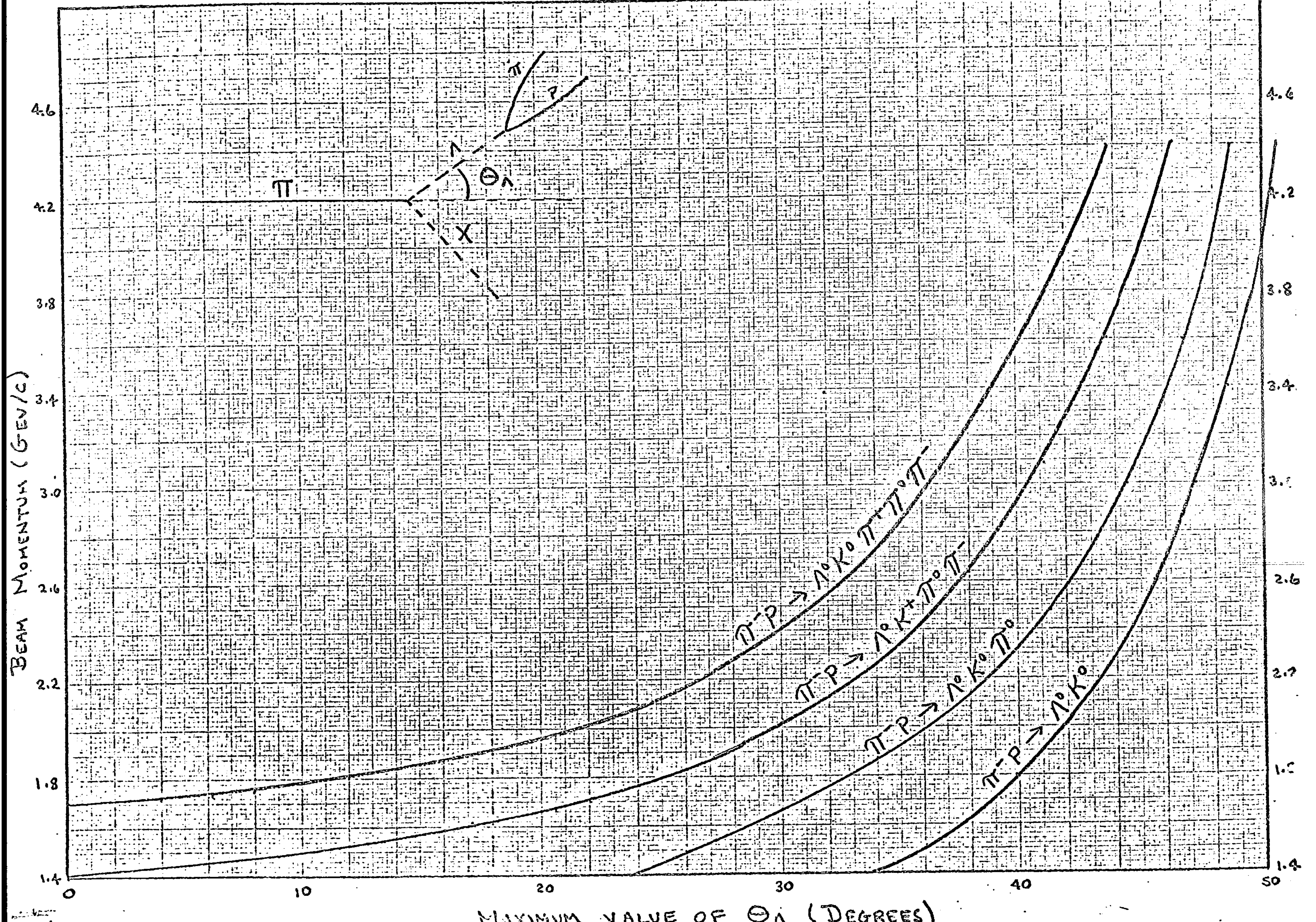

P_π (MeV/c)
0
100
200
300
400
1000
2000
3000
4000
5000
$\Theta_{LAB} = 20°$
$\Theta_{LAB} = 10°$
$\Theta_{LAB} = 0°$
K
π
π
Θ_{LAB}
K_1^0 DECAY INTO $\pi^+\pi^-$


Λ°
P
π
θ LAB
Λ° DECAY INTO P+π⁻
θ LAB = 0°
θ LAB = 10°
θ LAB = 20°
θ LAB = 50°
θ LAB = 0°
P_π (MeV/c)
P_p (MeV/c)
0
100
200
300
400
500
600
700
800
900
0
500
1000
1500
2000
2500

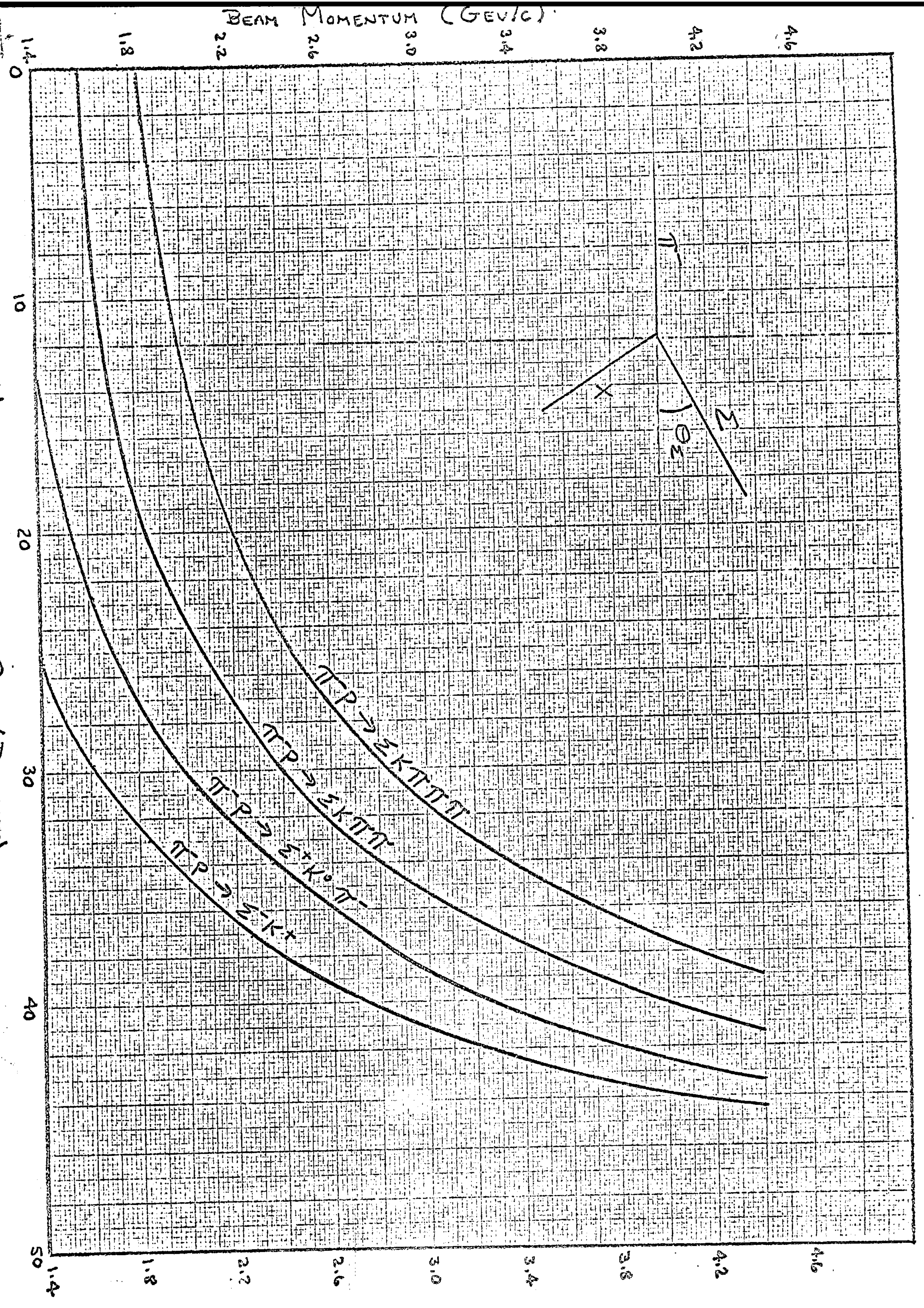


BEAM MOMENTUM (GEV/C)
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
40
50
60
70
80
MAXIMUM VALUE - Θ_P (DEGREES)
π^-
P
X
Θ_P
$\pi^- P \rightarrow P + 6\pi$
$\pi^- P \rightarrow P + 5\pi$
$\pi^- P \rightarrow P\pi^+\pi^0\pi^-\pi^-$
$\pi^- P \rightarrow P\pi^+\pi^-\pi^-$
$\pi^- P \rightarrow P\pi^0\pi^-$


BEAM MOMENTUM (GEV/C)
MAXIMUM VALUE OF Θ_p (DEGREES)
π^-
P
Θ_p
X
$\pi^- P \to P K^+ K^- 3\pi$
$\pi^- P \to P K^+ K^- 2\pi$
$\pi^- P \to P K^0 K^- \pi^0$
$\pi^- P \to P K^0 K^-$
0
10
20
30
40
50
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6



BEAM MOMENTUM (GEV/C)
MAXIMUM VALUE OF Θλ (DEGREES)
0
10
20
30
40
50
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
π
X
Λ
Θλ
π
P
π⁻P → Λ°K°π⁺π°π⁻
π⁻P → Λ°K⁺π°π⁻
π⁻P → Λ°K°π°
π⁻P → Λ°K°



BEAM MOMENTUM (GEV/C)
1.4
1.8
2.2
2.6
3.0
3.4
3.8
4.2
4.6
MAXIMUM VALUE OF Θ_Σ (DEGREES)
0
10
20
30
40
50
π^-
Σ
Θ_Σ
$\pi^- p \to \Sigma K \pi\pi\pi$
$\pi^- p \to \Sigma K \pi\pi$
$\pi^- p \to \Sigma^+ K^0 \pi^-$
$\pi^- p \to \Sigma^- K^+$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

MEMO NO.	PAGE
543	1

SUBJECT ADDENDUM TO K-63 SCANNING INSTRUCTIONS FOR 1.7 BeV/c, ROLLS 9043-9211, 9400 - 9479

NAME Alston, and Shafer

DATE 2/13/65

This addendum pertains to the first scan of the 1.7 BeV/c film. General procedures for this scan are given in Memos 456 and 472 (the usual K-63 scan instructions). Some slight modifications and additional instructions are presented in the following pages of this memo.

PHYSICS

Some of the physics projects which motivated the picture-taking at 1.7 BeV/c are the following:

1.	the rare decay mode $\omega \rightarrow Z\pi$	(not firmly established)
2.	the Y* (1660) $\rightarrow \Sigma^0 \pi^+$ and other states	(existence established, but quantum numbers uncertain)
3.	the Y* (1765) $\rightarrow \Sigma^0 \pi^-$ and other states	(existence fairly well established, but quantum numbers and branching rations unknown)
4.	a π-π resonance at 650 MeV	(some evidence seen, but not established)
5.	leptonic decays and usual	(not yet seen at this laboratory)
	and usual (non-leptonic) decays of the Ξ	(useful for better estimates of spin and decay parameters)

The first three of these phenomena are found in Event Type 32 (a vee-two-prong); items (2) and (3) involve a Σ^0, and any conversion of a γ (from the decay $\Sigma^0 \rightarrow \Lambda + \gamma$) into an electron-position pair - in hydrogen or in the lead plate - will provide useful additional information.

Projects (2) and (3) will also be pursued through the study of Λ-multipion events (types 32 and 34) and $\Sigma^{\pm}$-multipion events (types 82, 84, 92, and 94). Project (4) involves type 82.

GENERAL REMARKS

As we are in competition with other laboratories, especially on the first three projects, it is important that the scanning for the event types indicated be done efficiently (but carefully).

PLEASE CONSULT WITH PHYSICISTS IF YOU HAVE ANY QUESTIONS. Those you should contact are Janice Shafer, Lina Galtieri, Stan Flatte and Deane Merrill (or Margaret Alston, Dick Hubbard, and Peter Wohlmut).

Some K-72 physicists (M.A., D.H., P.W.), as well as a few of the K-63 physicists, wish to have the extra scanning described in the following pages carried out. This should not detract significantly from the speedy accomplishment of the work discussed above.

CHANGES FROM OLD INSTRUCTIONS

1. The primary interaction must be in the region below rake 14 (not 15) and the beam track must be at least 2 cms. long. (Beam track is defined in Memo. 456).

2. γ-rays and V's

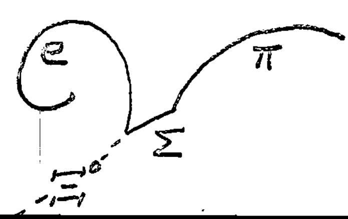
See page 11 of Memo. 456, paragraph 3 (c) delete "or one track is clearly greater than 1 BeV/c and one is clearly less than 150 MeV/c"; i.e. paragraph 3 (c) should read: Both tracks have momenta clearly less than 1 BeV/c.

3. In addition to the use of Binary code # 8 and # 17 when required, see Memo. 456, page 12, paragraph 4 (c); use binary code # 19 if the probable origin of a V is off the line of flight.

4. When you see what you think is a $\pi \to \mu \to e$ in space check the following:

a. That the "π" becomes more curved at the μ end of the track (i.e. it really is a stopping π).

b. The "μ" does not point within $\pm$ 10° of a primary interaction. This is required in case we can find examples of $\Xi^0 \to \Sigma^{\pm} + e^{\mp} + \nu$;



SUBJECT ADDENDUM TO K-63 SCANNING INSTRUCTION TO BE USED FOR 1.7BeV/c ROLLS 9043 - 9211, 9400 - 9479

NAME Alston and Shafer

DATE 2/13/65

The occurence of this decay mode of the Ξ has never been observed but is predicted by theory so if you find any event that looks possible, call it a ZOON (ET 200) and tell Peter Wohlmut, Dick Hubbard or Jan Shafer. (The leptonic decay $\Xi^- \to \Lambda + e^- + \nu$ is also of considerable interest. Use binary switch 15 if the negative secondary is possibly an electron.)

5. Be sure to record all V's beyond the lead plate.

   a. In most cases this will be a normal event type where the V is associated with a primary interaction below rake 14.

   b. If there is no obvious interaction below rake 14, or the primary interaction is above the lead plate record only the V as an event type # 300.

ADDITIONS

We are eager to look at Λ (and K^o and Ξ^o) interactions in the chamber; and to find rare leptonic decay modes. It is very important to record binary switches properly and to look for recoils, (π^+, K+ or P,) and golf clubs.

The following event types are necessary additions:

PET 130	Op and V where the V comes from a "recoil", (π^+,K+p) (PET 30 with recoil)
132	2p and V where the V comes from a "recoil" (PET 32 with recoil)
330	Op and golf club
332	2p and golf club

In addition all other events with an associated recoil should be called ET 200 and put in the Zoo book.

ADDITIONAL RESTRICTIONS

There are several rules to be strictly adhered to in deteriming if an event is a valid 130, 132, etc.

1. Unless the vee is a definite K^o, construct a trapezoid or triangle whose boundaries lie along the tangents to the prongs of the vee and

the perpendiculars to those lines through the primary vertex. If a pi plus, K plus or proton recoil occur anywhere in this area on all three views, record the event as the appropriate 100 event type.

2. In cases where the construction presents the choice of two areas, chose the larger one.

Examples of the above are shown on the next page.

3. For definite K^o's, scan carefully for any possible recoils on the whole frame.

4. For vees whose prongs cross over, it will suffice to look for recoils along the line of flight.

5. Call events 100's, (i.e. 140's, 130's, etc.) if there exists one or more recoils greater than 2 mm in length within the boundaries in all three views, and if the gaps between primary vertex, recoil, and vee are all greater than 2 mm. Any event that fails this criterion should be called as a 100 event type with B.C. 25 (i.e. short gap).

6. If one end of a recoil is within the defined area, and the other is out, remember that the recoil has to have positive charge (curl counter clockwise). Do not attempt to determine curvature on a recoil less than 2 cm. long.

NOTE that after some practice the trapezoid need not be actually constructed, you can estimate by eye except for borderline cases.

Feel free to make comments in the appropriate places, and scan carefully for all vee type events.

If there are any questions refer them either to Margaret Alston (ext.5711), Room 360, Peter Wohlmut (rm. 330A) or Buz Marten, Dick Hubbard or Jan Shafer (226 ext. 5001).

A list of neutral interactions in which we are interested is appended.

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

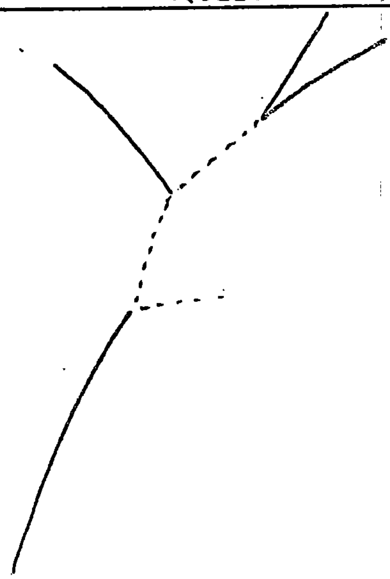
MEMO NO. 543

PAGE 5

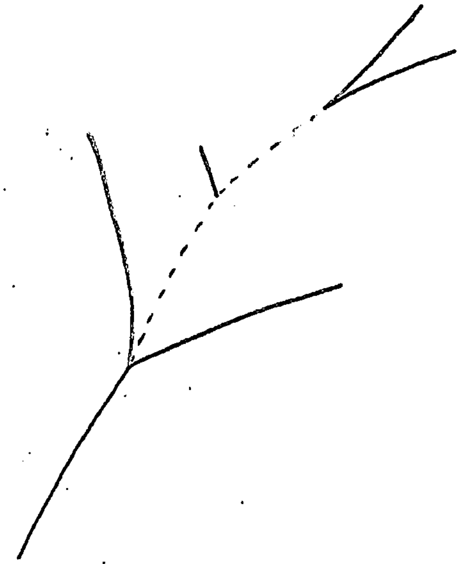
SUBJECT: ADDENDUM TO K63 SCANNING INSTRUCTIONS 1.7 BEV/c ROLLS 9093-9479

NAME: Alston & Shafer

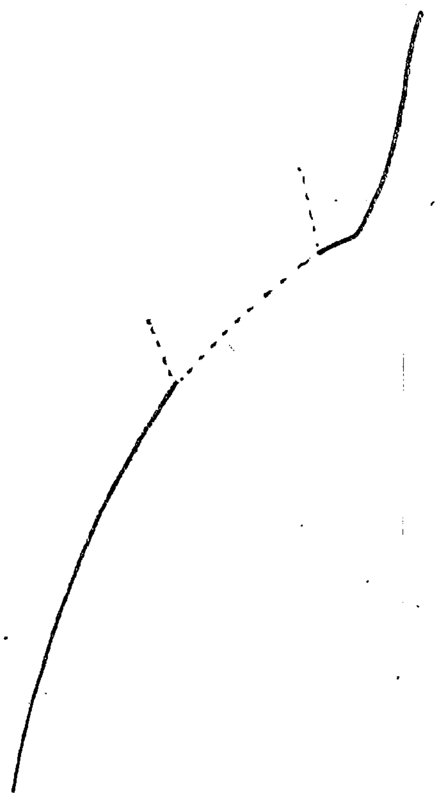
DATE: 2/12/65



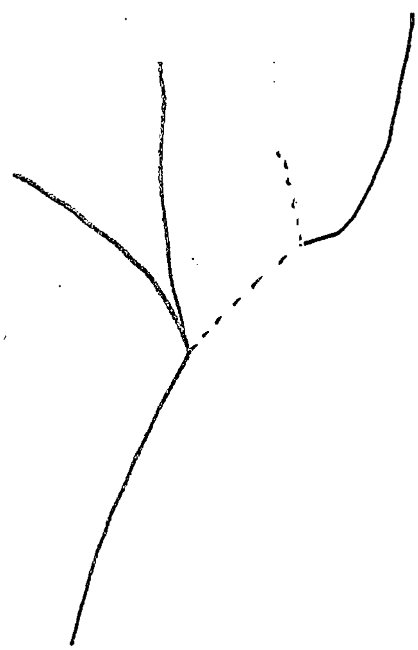
PET 130



PET 132

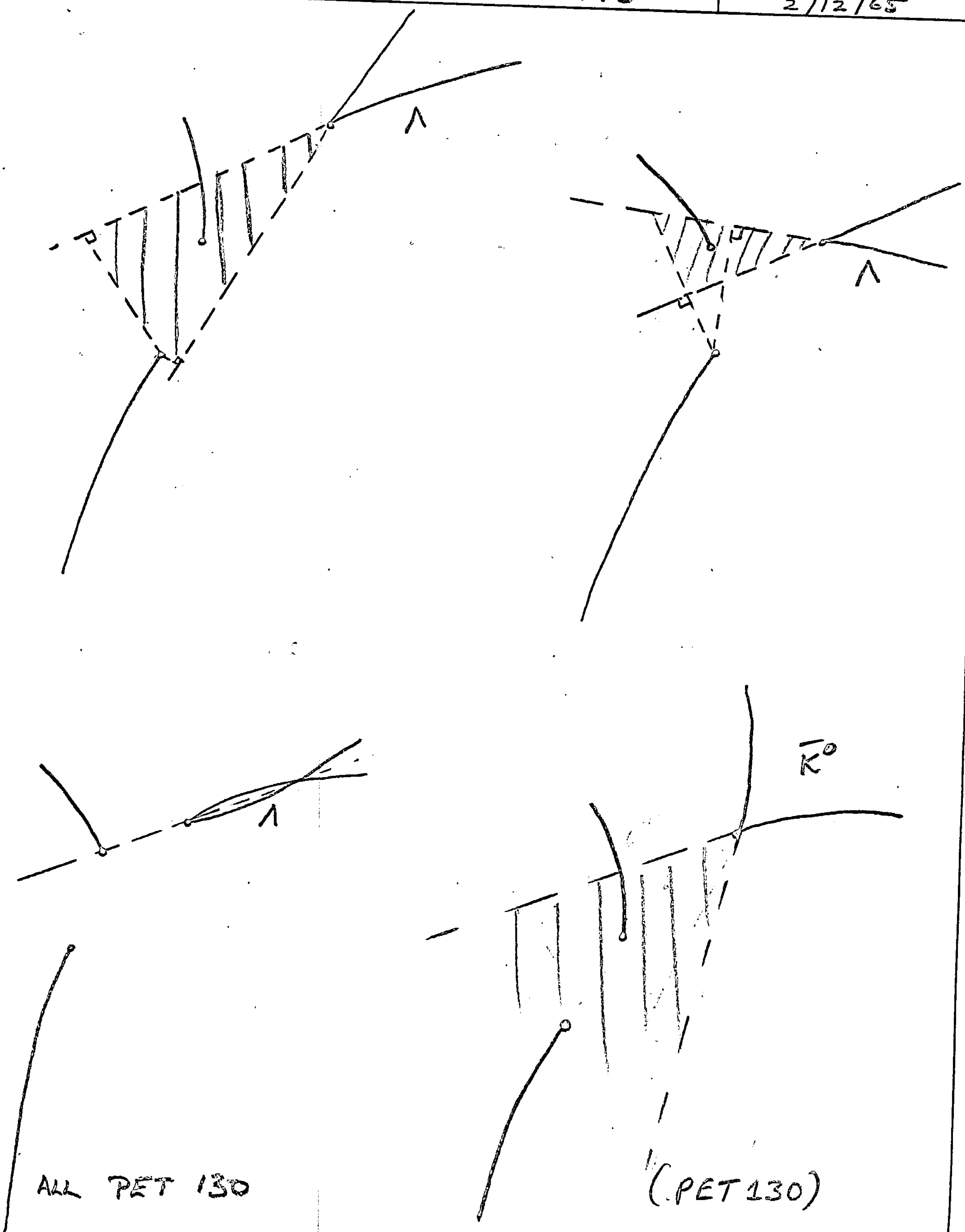


PET 330



PET 332

SUBJECT	MEMO NO.	PAGE
ADDENDUM TO K63 SCANNING INSTRUCTIONS 1.7 BEV/c ROLLS 9043-9479	543	6
	NAME: Alston & Shafe	
	DATE: 2/12/65	



NAME Alston and Shafer

SUBJECT ADDENDUM TO K63 INSTRUCTIONS 1.7 BeV/c

DATE 2-12-65

ADDITIONAL PROCESSES OF INTEREST

1. NEUTRAL INTERACTIONS:

$$\Lambda + p \to \Lambda + p$$
$$\to \Lambda + p + \pi^0$$
$$\to \Lambda + n + \pi^+$$
$$\to \Sigma^0 + p$$
$$\to \Sigma^+ + n$$

$$\bar{K}^0 + p \to \bar{K}^0 + p$$
$$\to \bar{K}^0 + p + \pi^0$$
$$\to \bar{K}^0 + \pi^+ + n$$
$$\to \Lambda + \pi^+$$
$$\to \Lambda + \pi^+ + \pi^0$$
$$\to \Sigma^0 + \pi^+$$
$$\to \Sigma^+ + \pi^0$$
$$\to \Xi^0 + K^+$$

2. LEPTONIC DECAYS

$$\Xi^0 \to \Sigma^\pm + e^\mp + \nu$$
$$\Xi^- \to \Lambda + e^- + \bar{\nu}$$
$$\Xi^- \to \Sigma^0 + e^- + \bar{\nu}$$
$$\Lambda \to p + e^- + \bar{\nu}$$
$$\Sigma^\pm \to n + e^\pm + \nu$$
$$\Sigma^\pm \to \Lambda + e^\pm + \nu$$
$$\Sigma^0 \to p + e^- + \bar{\nu}$$

also same decays with μ instead of e

SUBJECT: A Proposal to "X-ray" the Egyptian Pyramids to Search for Presently Unknown Chambers.
NAME: Luis W. Alvarez
DATE: March 1, 1965

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I. Introduction

The purpose of this proposal is to show that by the use of modern physical methods, it is possible to examine the interiors of the three large pyramids, in search for presently unknown chambers. The author can state quite unequivocally, as a physicist, that if such chambers exist, they can be found by the methods described in this proposal. When he is discussing the reasons for thinking that such chambers might exist, he is of course not speaking with any authority at all, and he begs the indulgence of his archeological friends on those few occasions when he may appear to be injecting his own ideas into what is properly an area for debate only by qualified experts.

The Egyptian pyramids are associated in the lay mind with the name Cheops, the builder of the "Great Pyramid", in about 2600 B. C. We shall be primarily concerned, in this proposal, with three pyramids: the Great Pyramid of Cheops, and the pyramids built by his father and by his son. The "Bent Pyramid" at Dahshur was built by Sneferu, the father of Cheops, and the "Second Pyramid" was built by Chephren, the son of Cheops, adjacent to his father's pyramid, at Gizeh. To a casual student of the pyramids, there is an enormous difference in the presently known complicated internal structure of the two earlier pyramids, as compared with the apparent internal simplicity of the latest of the three (Chephren's pyramid). Figures 1, 2 and 3 show what is known today of the systems of chambers and passages of the three pyramids.

Two contrasting explanations can be given for the qualitative difference observable in the three sets of plans. The one that is apparently favored by modern Egyptologists is that Chephren, who was probably aware that his father's pyramid was robbed almost immediately after the burial ceremony, concluded that his pyramid could not be made secure. He therefore abandoned the attempt to mislead potential robbers, and had himself buried in a chamber centrally located

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SUBJECT "BENT PYRAMID" OF SNEFERU AT DAHSHUR

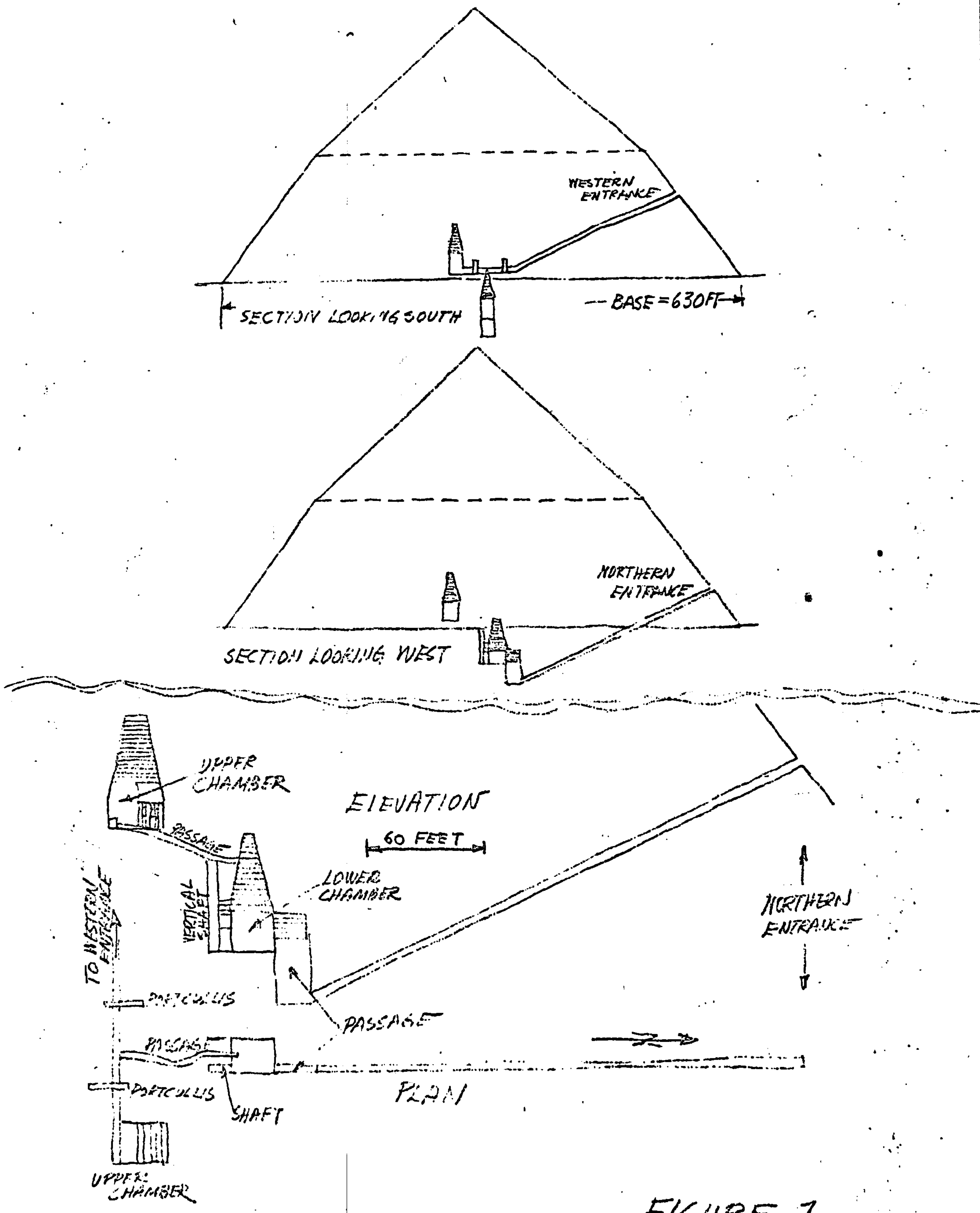

FIGURE 1

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SUBJECT: "GREAT PYRAMID" OF CHEOPS AT GIZEH

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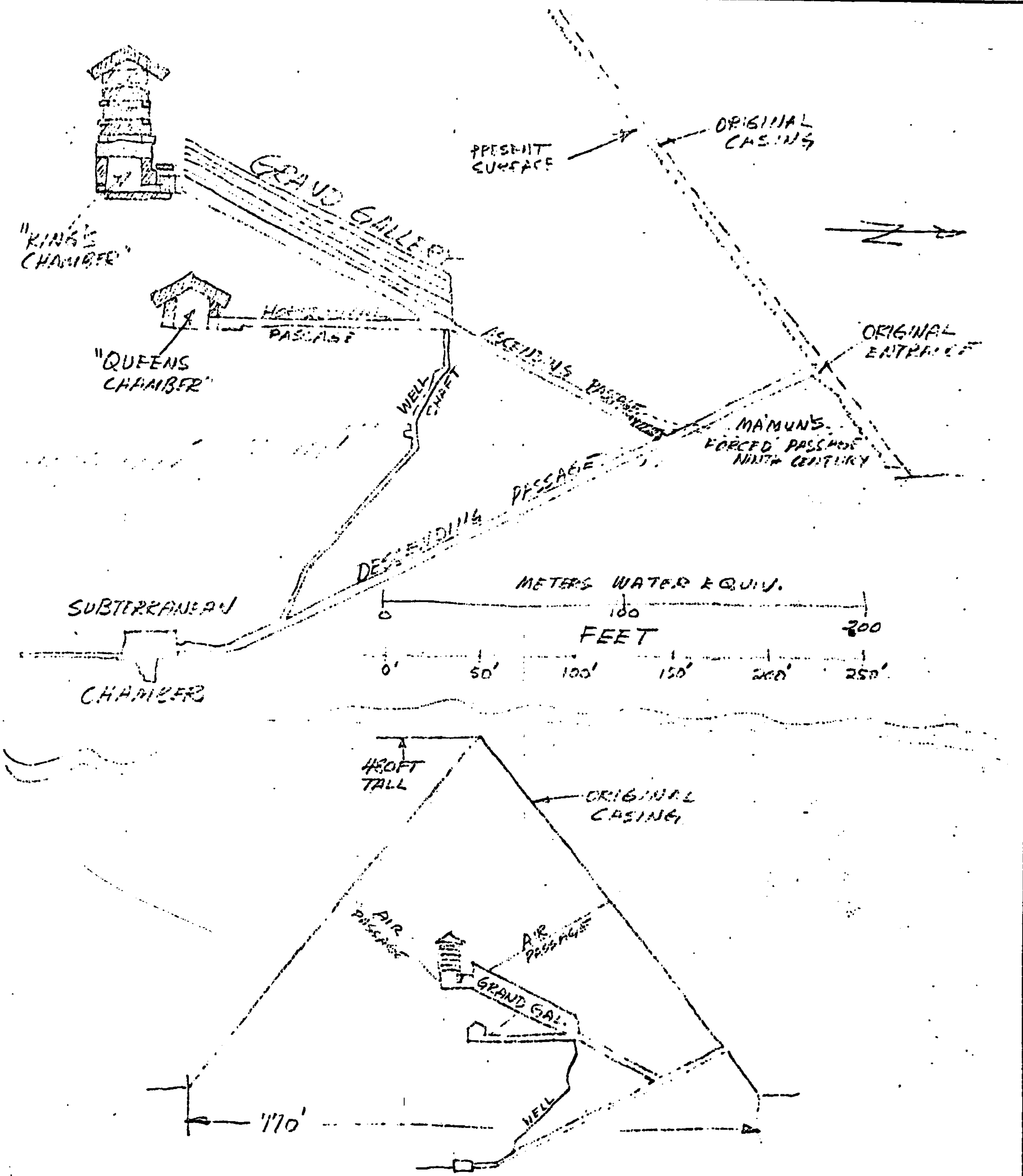

FIGURE 2

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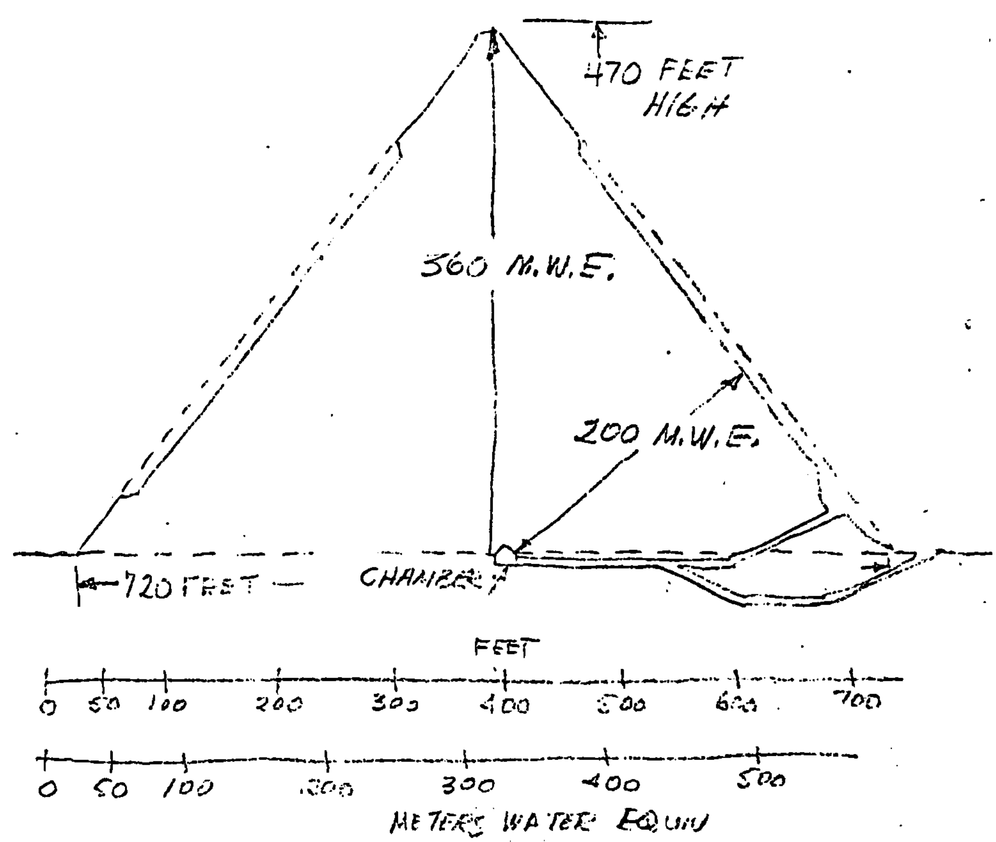

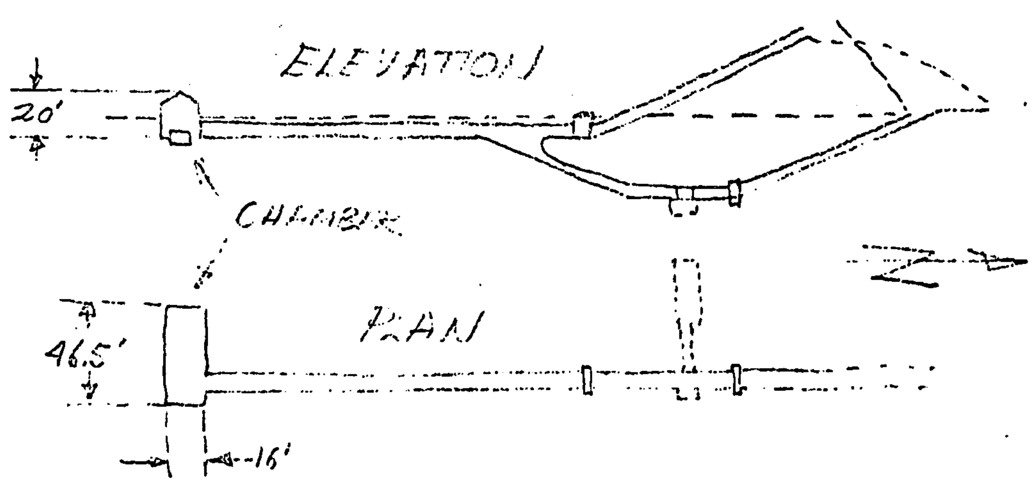

FIGURE 3

on the "ground floor" of his pyramid. This theory accounts for all the known facts, but it does not answer the question, "Why did Chephren expend the great effort required to erect his pyramid if he did not believe that it would preserve his body for the future life?"

An alternative theory that has had many adherents among past generations of archeologists is that each of the three kings encouraged his pyramid architects to use all their ingenuity to mislead future grave robbers into believing that someone had sacked the burial chamber before they arrived on the scene. This would, of course, convince the robbers that it was useless to probe further into the pyramid structure. One can use the presently known internal structure of the Great Pyramid as evidence for, but certainly not proof of, this second theory. The fact that the subterranean chamber of the Great Pyramid was known to Herodotus in the fifth century B. C., but that the upper two chambers were not discovered until the ninth century A. D., is consistent with the second theory. The passage to the upper chambers was so well concealed that it was only by accident that Ma'mun's tunnelers found it in the ninth century; this is again consistent with the deception hypothesis.

If one adopts this hypothesis, then the apparent barrenness of the Second Pyramid at Gizeh can be attributed to the greater success of Chephren's architects in hiding their upper chambers from grave robbers. If one does not adopt this hypothesis, then he should answer the following difficult question: "Why would Chephren, after a boyhood spent watching his father's slaves erecting a beautiful and complex series of chambers and passages in the Great Pyramid, be content to erect a solid and uninteresting pile of limestone blocks as his own pyramid?"

As stated in the opening paragraph, the purpose of this proposal is merely to point out that with modern techniques, one can probe the Second Pyramid, and decide unambiguously whether or not there is a presently unknown burial chamber somewhere in the huge volume of the pyramid. If a chamber were observed, its position would be located accurately enough so that tunnelers could dig directly to it on the first attempt.

One could, alternatively, try the device first in the Great Pyramid, to confirm that the detector would find the internal structure known to exist in that pyramid. However, the physics and engineering aspects of the device are so straightforward that such a preliminary test does not appear to be worth the effort. The effort arises from the fact that the equipment must be set up in the subterranean chamber of the pyramid being probed. This chamber in the Second Pyramid is now accessible, and free from debris, and it is not normally visited by tourists. For these reasons, it is ideally suited for the first attempt at "X-raying" a pyramid. There is the additional incentive to probe the Second Pyramid that stems from its complete absence of known structure above the ground level.

The subterranean chamber of the Great Pyramid is largely filled with rocks that were taken from a shaft excavated in the floor of the chamber by Col. Howard Vyse and Perring in 1837. (Incidentally, Howard Vyse and Perring expended a great deal of effort in digging and blasting a series of shafts and tunnels in the Great Pyramid, looking for the "true burial chamber" of Cheops.) If the examination of the Second Pyramid were to reveal the presence of a new Chamber, one would certainly probe the Great Pyramid and the Bent Pyramid in a similar fashion. Under these circumstances, one would be happy to expend the effort required to clear Cheop's Subterranean Chamber of its accumulated debris. But until that time, we shall assume that we are planning to probe the interior of the Second Pyramid.

Several criteria must be met before the "Pyramid Project" can be started. First, of course, the project must have the official blessing of the United Arab Republic. One of the reasons for writing this proposal in such detail is so that Egyptian archeologists may have the opportunity to study it at their leisure, and to confer with their colleagues in the field of cosmic ray instrumentation concerning the validity of the calculations. It is to be hoped that if and when they are satisfied with the physical measurements aspects of the project, they would recommend to President Nasser that the project be supported.

The author has discussed the project in some detail with Dr. A. R. Fikry Hassan, an Egyptian high energy physicist with experience at the CERN laboratory in Geneva. Dr. Hassan has worked with spark chambers and electronic data analysis, and he has expressed an interest in the project. He has recently written that he has heard from Dr. F. Bedewi, the Head of the Physics Department, Faculty of Science, Ein Shams University in Egypt. He says, "Dr. Bedewi informed me that Ein Shams University would fully cooperate with your Group in carrying out your Project inside the Pyramid. Dr. Mofty has not written to me yet." (Dr. El Mofty received his Ph.D. degree in Physics at the University of California, for work performed at the Lawrence Radiation Laboratory, and he is a member of the Atomic Energy Commission of the United Arab Republic.)

From what has been said above, it seems that unless some unforseen difficulty arises, the project apparently appeals to competent Egyptian physicists as an interesting one.

The present document will also be sent to a number of American archeologists, particularly to those who have access to independent judgements from high energy physicists on their own campuses. (For example, the Oriental Institute and the Enrico Fermi Institute for Nuclear Studies are only a few blocks apart at the University of Chicago.) If the project appears worthwhile to the archeological community, both Egyptian and American, then it is possible that one of the philanthropic foundations might arrange to set up a cooperative project with participation by the University of California and an appropriate organization in the United Arab Republic. It is to this end that this proposal is addressed.

II. "X-raying" the pyramids.

The English language has no simple word or phrase to describe the process we propose to employ in probing the interiors of the large pyramids. Our use of the word X-ray in quotes come closest to the mark, because the end result of the program will be a photographic transparency showing the known chambers and passages, and hopefully, the presently unknown chambers this proposal is designed to find. (In fact, the program will produce a pair of stereo X-ray photographs, so that the chambers can be located in all three dimensions.) If we constructed an exact scale model of the Bent Pyramid, according to figure 1, and asked to have this model X-rayed by a specialist in industrial radiography, we would be presented with an almost exact duplicate of the "X-ray photographs" mentioned earlier in this paragraph. In figure 4a, the industrial radiologist has placed a small "radioactive source" of X-rays in the Lower Chamber of the model, and the X-ray film is placed so that it touches the apex of the model pyramid. (We use the Bent Pyramid, rather than the Second Pyramid in this example, because the latter has no known upper chambers to show on the X-ray film.) With this technique, we can say that the process of taking the photograph "projects", or "maps" the pyramid onto the X-ray film. Just as there are many ways of mapping the spherical surface of the earth onto a plane surface (e.g. Mercator's projection and conical projection), there are many ways to map the interior structure of a pyramid onto an X-ray film.

To make a map or projection, we need three things: (1) a point from which to project the "rays", (2) the object to be projected, and (3) the surface on which to make the projection. We are fortunate in having point sources of X-rays available, so we can perform the "projection operation" illustrated

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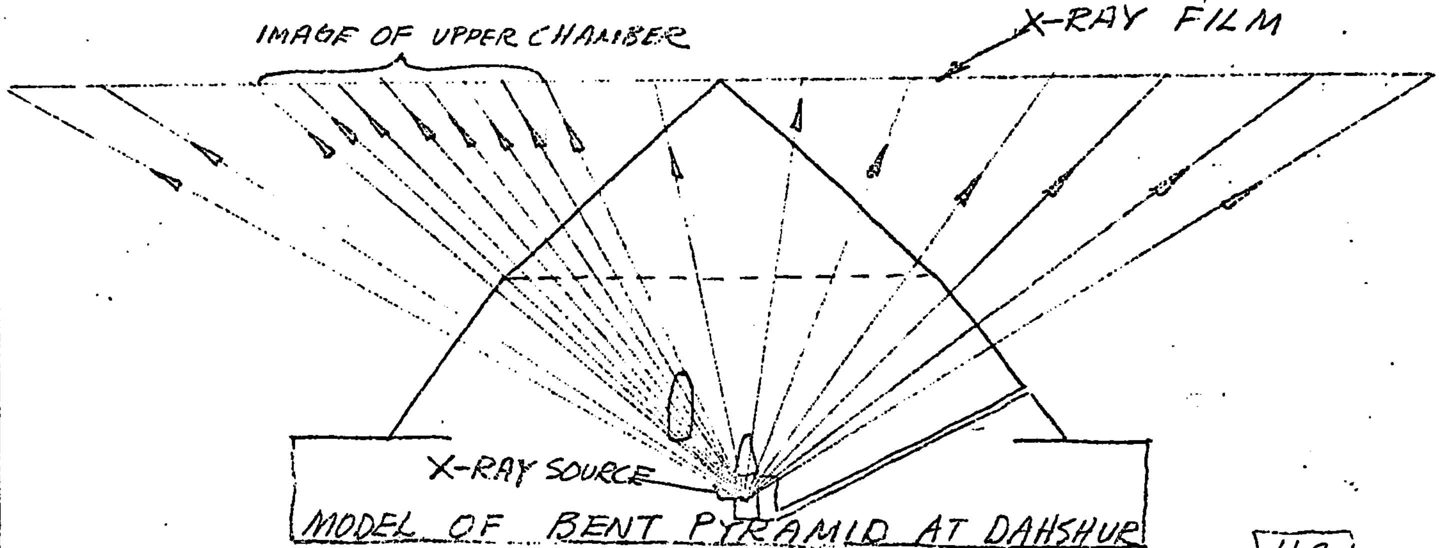
X-RAY MAPPING PROJECTIONS



4a

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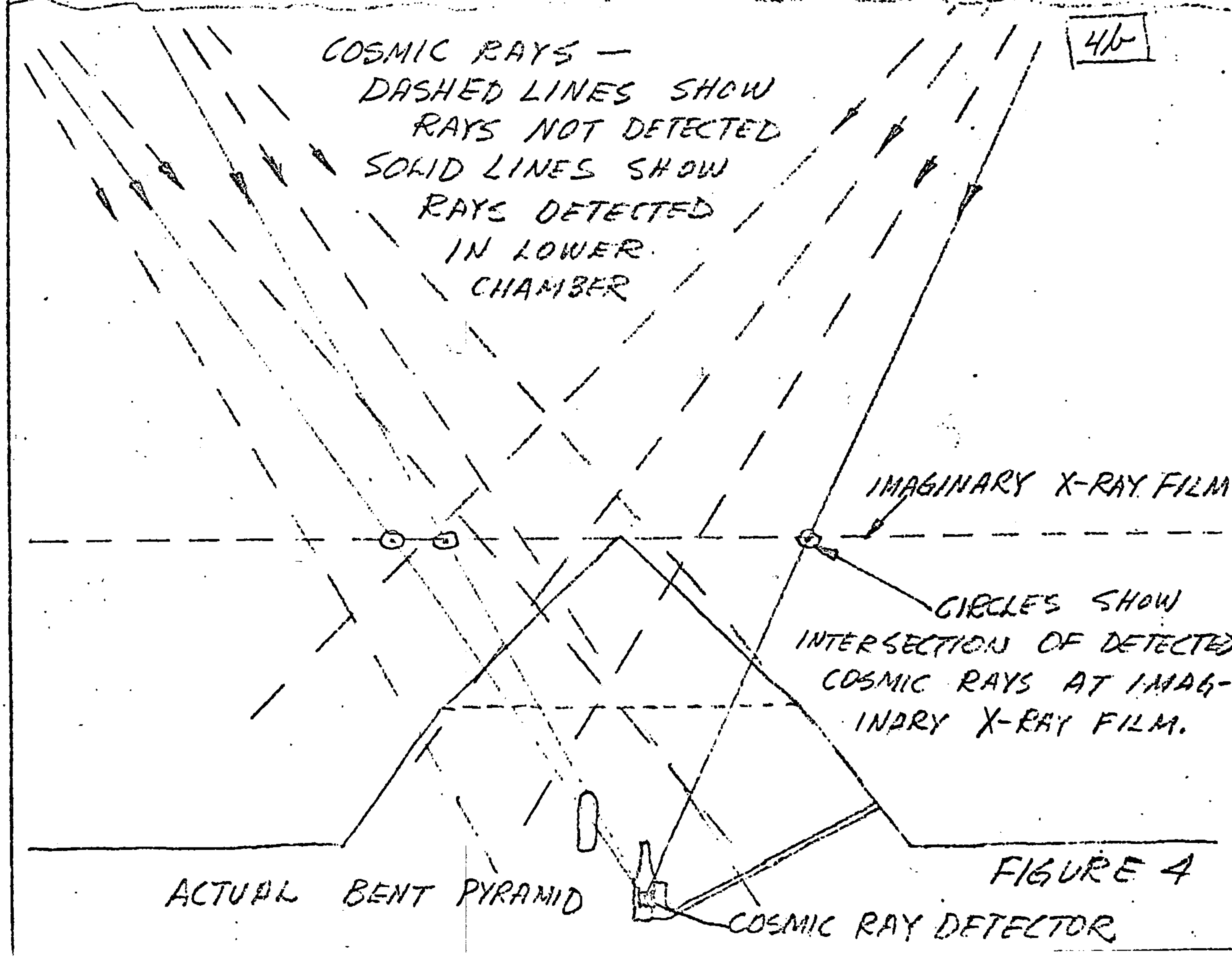

FIGURE 4

in figure 4a. But we have no point sources of the very penetrating radiation needed to probe the interior of a large limestone pyramid. For this reason, we can't duplicate the projection of figure 4a, "on full scale". The cosmic radiation with which nature provides us appears to come with "equal brightness" from all points in the sky. Such an "isotropic" radiation can be used in a mapping operation, but only if we measure the direction of approach of each cosmic ray, as it is recorded in the subterranean chamber of figure 4b. The projection operation is mathematically equivalent to that of figure 4a, but the directions of all useful rays are reversed in the two examples.

The details of the cosmic ray detectors are described in sections IV and V, and in more detail, in Appendix C. Section V also describes a modified form of the mapping scheme shown in figure 4, that has the advantage of keeping the map dimensions finite; the map generated in figure 4a extends almost to infinity, if the whole volume of the pyramid is to be recorded on the X-ray film.

For the present, we need only remember that the cosmic ray detector is located near the center of the ground level section of the Second Pyramid (figure 3), and that it is capable of recording the azimuth and elevation angles of approach of each recorded cosmic ray. Fortunately, appropriately located chambers are accessible in each of the three pyramids discussed in the introductory section of this proposal.

III. Properties of the cosmic radiation.

The "penetrating component" of the cosmic rays is now known to consist of a stream of electrically charged particles of a rare variety - the mu mesons, or muons as they have recently been rechristened. Energetic muons are born high in the earth's atmosphere, as the result of collisions between still more energetic "primary cosmic rays," and the nuclei of air atoms. (The origin of the primary cosmic rays is of great cosmological interest, but it is a bit far afield from pyramids, and so won't be discussed here.)

Muons lose energy by friction, just as a rifle bullet does when it bores its way into a fence post. The laws governing the rate at which a muon loses energy are particularly simple; every time a muon penetrates one meter of water, it loses 200 million electron volts (MeV) of energy. Therefore, if it has 200 MeV to start with, it stops after penetrating one meter of water; a physicist would say "A 200 MeV muon has a range of 1 meter of water." By the same token, a 2000 MeV muon has a range of ten meters of water. If a particular muon is slowed down by passage through rock of density 3, its range will be one third as great as it would have been in water. Conversely, if we find a muon that has a range of 10 meters of such rock, we know that it originally has three times as much energy as the 2000 MeV a muon needs to penetrate 10 meters of water.

Because of the simplicity of the laws relating energy and range of muons, it is customary to express the range of a muon in "meters of water equivalent" (m.w.e.). (For example, 100 meters of rock with a density of 2.5 has a "thickness" of 250.m.w.e.) We then need only a single range-energy curve (figure 5) to tell us all that is known about the penetration of muons into any material.

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RANGE — ENERGY CURVE FOR MUONS

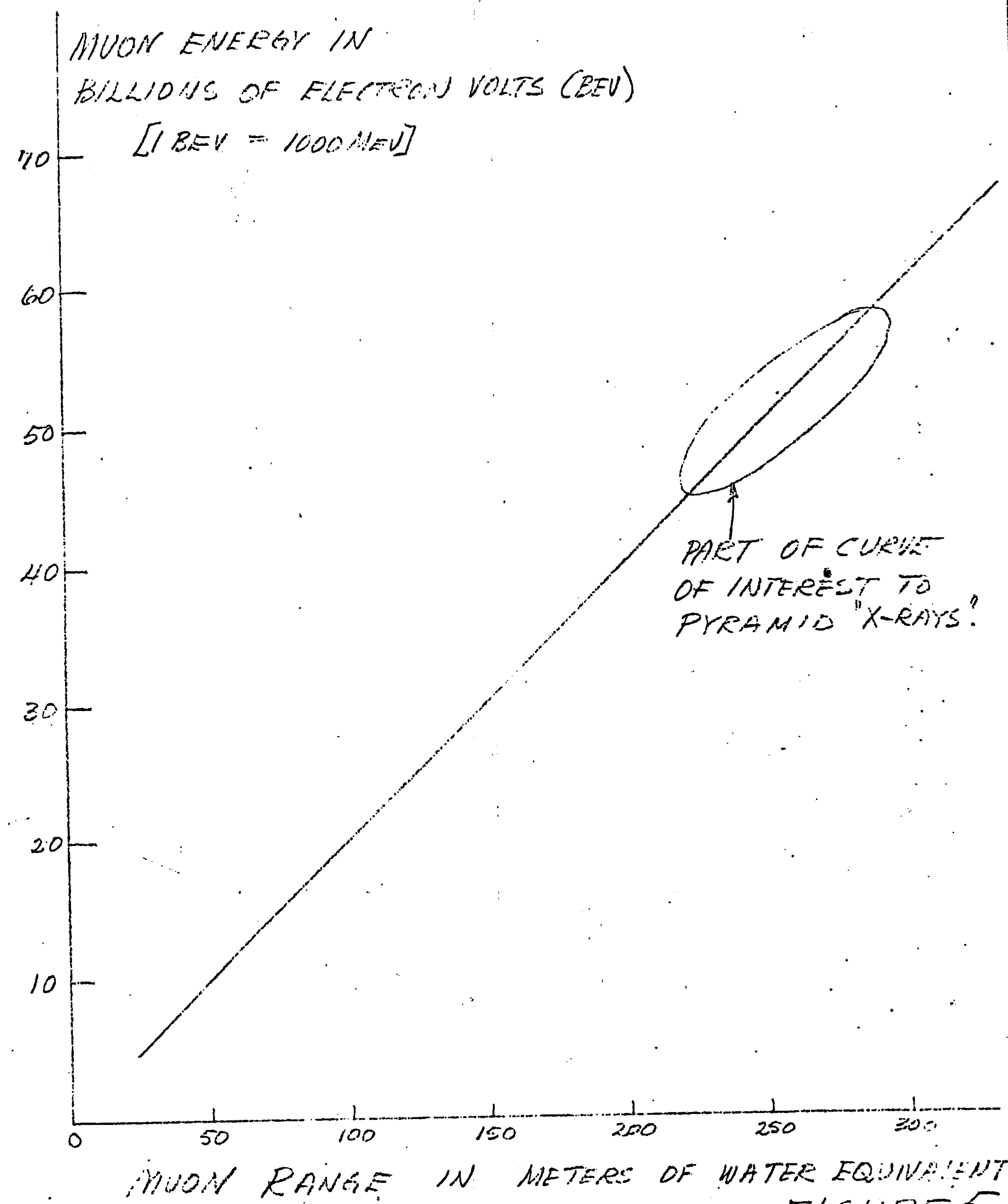

FIGURE 5

All muons of a particular energy have the same range (if it is measured in m.w.e.), regardless of the density of the material into which they are penetrating. For convenience in designing the pyramid experiment, scales of m.w.e. have been added to figures 2 and 3. The Great Pyramid has a present day height of 137 meters. Since the density of limestone is 2.66, the height of the pyramid, or any other relevant distance through the core to be measured directly (in meters of water equivalen without recourse to calculation.

In the 1930's, soon after the Geiger counter had been developed into a reliable detector of electrically charged particles, physicists made the first good measurements of the relationship between cosmic ray intensity, and depth underground, measured in m.w.e. The measurements were often made in the sloping shaft of an abondoned mine. A "Geiger counter telescope," sensitive only to muons from within perhaps a 15 degree cone about the vertical direction, was placed on a mine car, so that the whole apparatus could be moved easily from one depth to another. The result of several months of operation of such an experiment was a curve like that shown in figure 6. (Dr. S. A. Goudsmit a distinguished physicist and amateur archeologist, once proposed making such measurements in the pyramids.)

Figure 6 is called a range spectrum, or an intensity-depth curve, because it tells how many cosmic ray muons penetrate at least as far as the indicated depth. Until now, we have been treating cosmic rays as though they were a downward stream of almost vertically directed muons. But in fact, we have implicitly been selecting a vertically directed stream from the totality of cosmic rays, by the use of a "telescope" - an arrangement of Geiger counters that is sensitive only to muons arriving nearly parallel to its axis. As long as we make our measurements with nothing but air above the apparatus, we

SUBJECT INTENSITY - DEPTH CURVE, OR RANGE SPECTRUM OF COSMIC RAYS

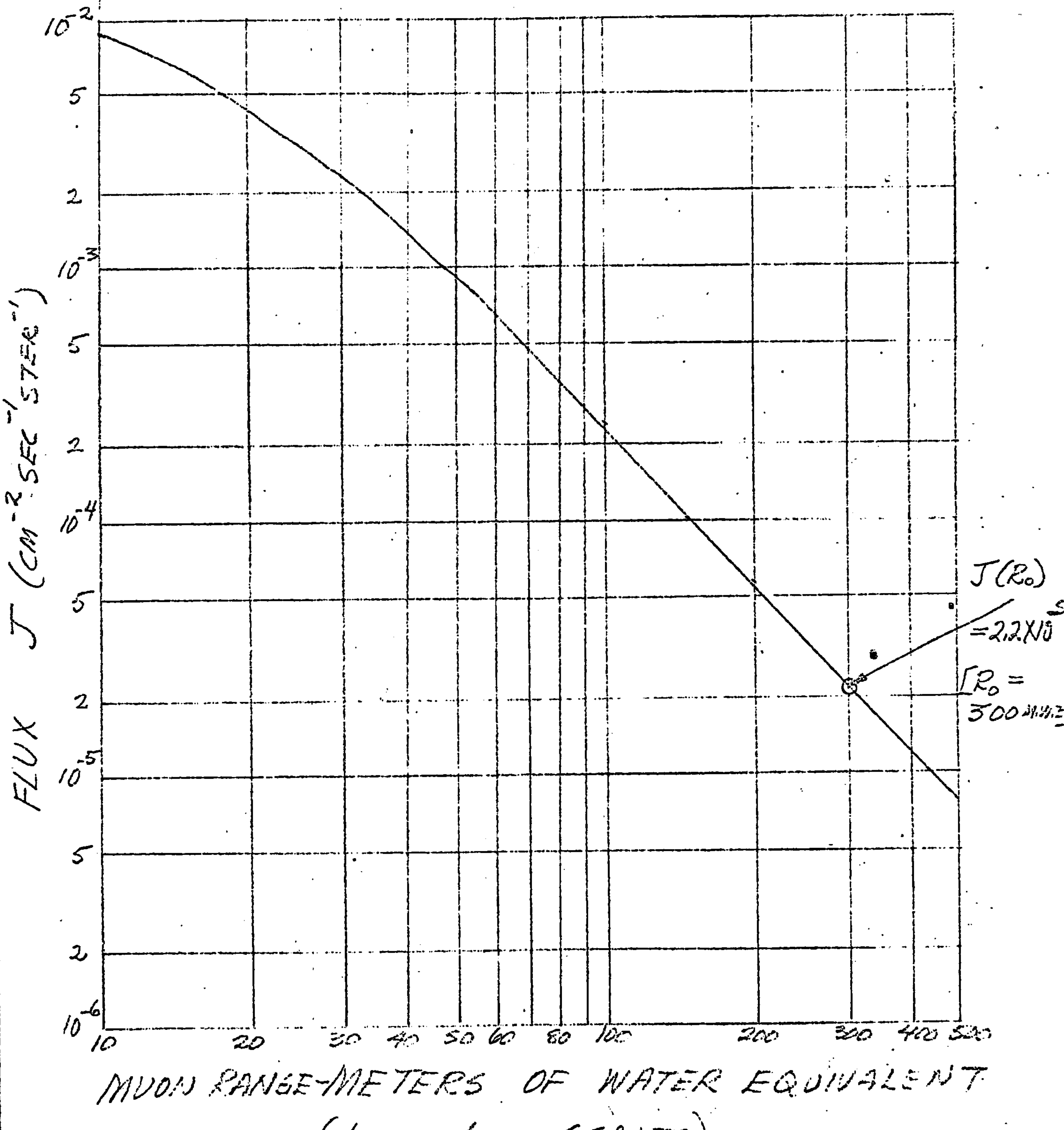

FIGURE 6

find that we observe the same counting rate, no matter what direction our "counter telescope" is pointing. (This was suggested in the earlier discussion concerning the mapping procedure.) It is furthermore true that the counting rates in two identical "telescopes" - one pointing vertically and the other inclined at any angle above the horizon, will be the same, not only when there is nothing but air above them, but also when the same thickness of rock is introduced into, and along the two "lines of sight" (Figure 7). It is this fortunate aspect of the cosmic radiation that makes the pyramid project so easy to investigate by mathematical methods. We need only a single curve (figure 6) to tell us what counting rate to expect when "looking through" the pyramid in any direction; it is sufficient to measure the thickness of rock in that direction, from the subterranean chamber to the surface of the pyramid.

A more mathematical description of the properties of cosmic rays will be given in Appendix A. The brief summary given in this section should suffice to show that:

1) Cosmic rays are able to penetrate rock thickness as great as those encountered in the pyramids.

2) If the rock thickness is decreased (as for example, by creating a hollow chamber in the line of sight) the counting rate increases.

If the method is to be successful, two further criteria must be met:

3) The counting rate, in apparatus that can be placed in the subterranean chamber, must be high enough to yield a "grainless" X-ray picture in less than a year of operation. The effects of "statistical fluctuations" in the cosmic ray counting rate will be dealt with in Appendix B, and the conclusion will be reached that the fluctuations will not be large enough to indicate the presence of non-

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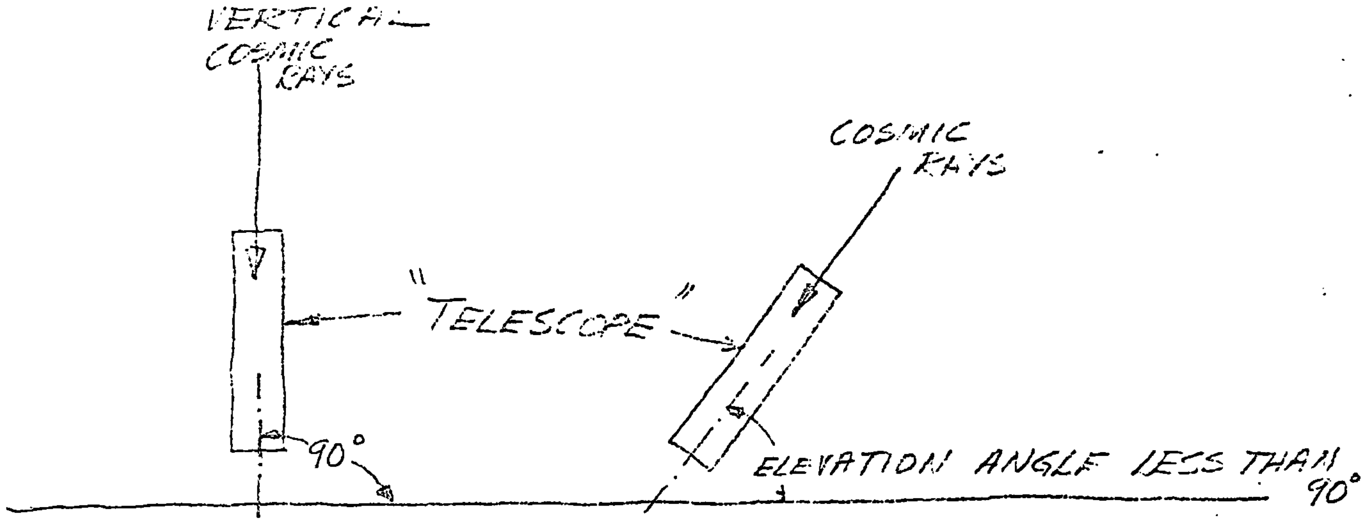
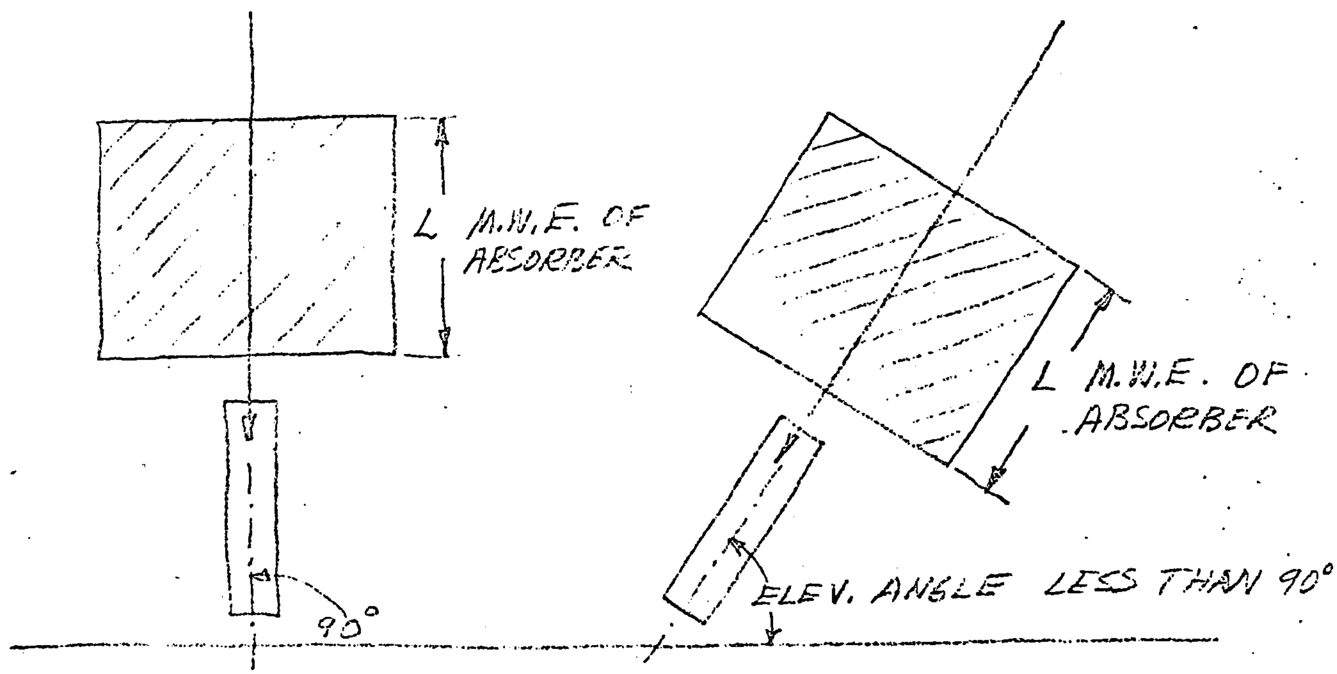
COSMIC RAY TELESCOPES & ABSORBERS



Two identical counter telescopes pointing at different angles count the same number of muons, independent of the angle, when they are in the open air.



Identical counter telescopes have same counting rate for equal thicknesses of absorber (measured along line of sight) independent of elevation angle.

FIGURE 7

existent chambers.

4) Random deflections of the cosmic ray muons as they pass through the rock must be small enough to keep the images of the chambers from being "washed out" on the X-ray plates. The random "scattering" of muons is understood mathematically, and although it could give trouble in the simplest kind of apparatus, the trouble is easily eliminated in the proposed design.

We can therefore conclude the non-mathematical sections of this proposal by stating that there are no technical reasons why the proposed experiment would not detect the chambers it is designed to find.

IV. Cosmic ray detectors.

If we merely had to count cosmic ray muons in the Subterranean Chamber, Geiger counters would do the job admirably. But in order to reconstruct the X-ray picture of figure 4b, we must also measure the two angles that specify the direction of arrival of each muon. The recently invented spark chamber does this job so much better than Geiger counters could possible do, that we shall confine our attention from here on to spark chambers alone.

The simplest variety of spark chamber consists of two flat metal plates spaced about a centimeter apart. When a muon penetrates the two plates, an electronic circuit suddenly applies a high voltage between the two plates. The high voltage causes a spark to jump between the plates, very nearly along the trajectory of the muon. The spark can easily be seen with the naked eye, and it is customarily recorded by two cameras. The two cameras look into the narrow gap, with their optical axes at right angles to each other, so that the true position of the spark can be located by "stereoscopic reprojection."

Many millions of spark chamber photographs have been taken in the last three years, but the present day trend is toward bypassing the photographic process altogether, and recording the coordinates of the spark directly on magnetic tape. So instead of sensing the recording the light from each spark, we plan to sense the electric current that flows, and record the signal electromagnetically. This proceudre obviates the need for the time-consuming and expensive use of technicians to measure and record the positions of millions of individual sparks.

The electrical and mechanical designs of the spark chambers to be employed in X-raying the pyramids are described in some detail in Appendix C.

Of the various techniques presently available for eliminating photography, we have chosen the "Nickel wire - Magnetostrictive readout." This ingenious method has been developed within the past year at the Lawrence Radiation Laboratory, by Dr. Victor Perez-Mendez and his co-workers. A detailed description of the modus operandi of a Perez-Mendez spark chamber would be out of place in a proposal of this sort. It should suffice to say that if a muon traverses two such spark chambers (both of which are horizontally oriented, and spaced a foot apart in the vertical or Z direction), the x and y coordinates of the sparks in the two planes will automatically be recorded on magnetic tape. The accuracy of each coordinate measurement, (x_1, y_1, x_2, y_2) will be better than one millimeter, so if the two horizontal spark chambers are spaced 12 inches apart, the desired angular information concerning the muon will have errors less than three milliradians - quite small compared to other errors we shall soon discuss.

We shall digress for a moment to the subject of angular errors, because it is important that we be aware of the magnitude of what might be called "tolerable angular errors." The three known "burial chambers" in the two large pyramids are roughly the same size, and it is reasonable to expect that any as yet undiscovered "true burial chambers" in either pyramid would not be very much smaller than these known chambers. The three chambers of interest are the King's and Queen's chambers of the Great Pyramid, and the Subterranean Chamber in the second Pyramid. All three chambers are about 18 feet in height, and 17 feet in width, their lengths are 33 feet (K), 18 feet (Q), and 46 feet (S_2). We shall therefore assume we are looking for a chamber that is 17 feet by 25 feet in floor area, and 18 feet high. We will furthermore assume that this chamber is 300 feet from the subterranean chamber (in either pyramid). (The maximum distance containable within the Great Pyramid is about 600 feet; the corresponding length is about 400 feet for the Second Pyramid.) The angle subtended by the "standard chamber" at the muon detectors is therefore assumed to be about 20 feet/300 feet, or 67 milliradians, or 3.8 degrees.

One would have serious reservations about attempting to probe the pyramids with a detecting device whose ability to certify angles was poor compared to this value of 67 milliradians. But on the other hand, one would not be willing to pay much to improve the angular uncertainty from 20 milliradians to 2 milliradians; with either of these small values, the unknown chamber could be detected unambiguously.

It is a simple matter to design the spark chamber system so that output data supplied to the magnetic tape recorder is accurate to a few milliradians. This is true, if by accuracy, we mean the ability of the apparatus to record the trajectory of the muon as it passed through the two spark chambers, within the quoted angular limits. An additional angular error must now be investigated; it can best be appreciated by asking the question, "How nearly true is it that the muon we record in our spark chambers is still moving along the same straight line that defined its trajectory as it passed through the burial chamber?" Whenever electrically charged particles pass through matter, they suffer random and normally small changes in direction. Such angular dispersions are calculable from what physicists call "Scattering Theory". The comparison of experimental scattering observations with theoretical predictions has been exceedingly fruitful - the atomic nucleus was discovered by Rutherford in this manner, in 1911.

The scattering of muons in rock is described by a particularly simple mathematical equation that has been found experimentally to agree with the theory. As long as the muon has enough energy to penetrate at least a few tens of meters of water equivalent, its path will almost indistinguishable from a straight line. But as the muon traverses its last few meters of water equivalent, it scatters (on the average) through ever larger angles. Let us now remind ourselves that the muons we are most interested in are those which would have stopped in the rock just above our spark chambers if no burial chamber were present along the "line of sight". The existence of the void in the rock allows these particular muons to pass through the spark chambers, and gives us more counts than we would otherwise have recorded from that direction. We see, then, that all the "useful information"about the burial chamber is carried by muons that are just able to penetrate the spark chamber system, and stop in the rock just below the detectors. Unfortunately these are just the mesons that pass through the spark chambers with the greatest angular scattering from their original direction through the pryamid and from the burial chamber to the subterranean chamber. An optical analogy would be a 35mm colored slide projector that was out of focus. We must therefore, seek a way to "sharpen the focus" of our "muon projector system". We have seen that the scattering difficulty arises from the fact that we are looking at muons very near the "end of their range." We therefore, cure the difficulty by measuring the trajectories of the muons several meters of water equivalent before they end their range. We could do this in principle by moving our spark chambers into a newly excavated chamber some meters above the subterranean chamber. If we made sure that the muons were still able to penetrate down into the original subterranean chamber, we could use the angular information we obtained "up above," with confidence that it represented the true direction of the muon, before scattering in the underlying rock had changed that direction.

Fortunately, the subterranean chambers in all three pyramids are high enough that we needn't cut any more holes in the pyramid. We place our spark chambers near the roof of the subterranean chamber, and stack iron bars between these angle detecting devices and another set of simple ordinary detectors near the floor level. The iron bars and the detector below simply assure us that any muon whose direction we sense in the spark chambers has enough energy left in it to penetrate the several feet of iron, and be counted in the floor level detection device. A physicist would say, "We've 'hardened the beam' with the iron absorber, so it's less subject to scattering errors."

In the mathematical Appendix B, we shall calculate the "mean projected scattering angle", $< \theta >$, of a muon that has come from a burial chamber 18 feet tall, located 300 feet from the subterranean chamber. We shall also demand that the muon be able to penetrate at least five feet of iron after its direction has been measured. The result will be that the mean projected scattering angle is 33 milliradians, which is equivalent to saying that at 300 feet, the "fuzziness of the image" of the chamber edges on the simulated X-ray picture would correspond to a linear distance of 10 feet. This result means that there should be no difficulty in observing an unknown burial chamber, by looking at the "X-ray photograph." We would not have been much better off if the "spread" had been 1 foot, but the project would not be worth talking about if this number had turned out to be 100 feet. The scattering of muons in the rock presented the only potential hazard to the theoretical success of the project. As we have just noted, if the scattering had been worse by a single order of magnitude (factor of 10), the pyramids could not have been probed by any presently known radiation.

V. Operations and data analysis.

In the first two appendices, the basic parameters of the detection apparatus have been discussed, one by one, and their values have been chosen to optimize the overall design: Two square spark chambers, each seven feet on a side, will be mounted horizontally, and spaced a foot apart. Under the lower spark chamber will be a layer of iron about five feet thick, and below the iron will be a simple layer of scintillation counters. The general layout is shown in figures 10 and 11. The detectors will be set up near the western wall of the subterranean chamber in the second pyramid. If the image of an unknown chamber appears on the "X-ray photograph," as it should do in a month's time, if the chamber exists, the detector will be moved about 35 feet eastward, to the far wall of the same chamber. The angular displacement of the chamber image, caused by this detector displacement, will allow the elevation of the new chamber above the subterranean chamber to be determined by a simple trigonometric calculation.

All of the apparatus has been designed so that it can be carried through the entrance passages of the three pyramids of interest. The spark chambers will have to be dismantled and reassembled inside the subterranean chamber. The tape recorders can best be installed in a wooden hut near the entrance to the pyramid, and connected to the detectors by cables which thread the passage to the subterranean chamber.

After all the apparatus has been installed and checked out, the further operations could be carried out by a single individual living in Egypt. He would verify that the equipment was working each day, and would hang a new magnetic tape on the recorder. The inscribed tape would probably be duplicated in Cairo, so the original would be available for analysis by our Egyptian associates; the duplicate would be sent to Berkeley for similar processing.

Many ways to display the data are available. The most meaningful would be to print out the number of counts obtained in each "elementary unit of solid angle," much like the "pressure map" printed by the weather bureau. In Appendix A, we have suggested that 1600 counts per element of 8.5 x 8.5 square feet would be adequate to locate a "standard burial chamber." The last digit in this count is certainly of no significance, but the second digit, representing the number of tens of counts is of some significance; we expect to have an extra 160 counts if we are looking through a "standard chamber." The apparent magnitude of the fluctuations can be increased by a simple operation; the computer can subtract some constant number of counts from each sample, or more correctly, some number that varies smoothly from one direction to another, so that the residual number of counts is essentially constant over the whole "map" of the pyramid. It is a simple matter to generate, by the computer, the proper number to be subtracted. This number would be an analytic function of the pyramid geometry and the cosmic ray spectrum. When it was subtracted from the experimentally observed matrix of counts, the resulting matrix would be an almost constant set of individual counts, with an enhanced fractional increase from the direction of an existing burial chamber.

The data analysts in Berkeley and Cairo would devote most of their attention to the printed matrix of "differential counts," looking for small regions in which several neighboring cells had statistically significant counts over the "background." If such a region of interest showed up, it would be a simple matter to convert the matrix of numbers into a simulated X-ray photograph. One would simply program the computer to display the matrix on its cathode ray oscilloscope, and the display would be photographed by a camera.

Such procedures are common in the author's specialty of high energy physics. The cathode ray oscilloscope spot would be programmed to move over the whole range of x and y variables (North-South and East-West), remaining at each spot for a time proportional to the number of counts recorded from that direction (minus the slowly varying baseline count). The result would hardly be distinguishable from the X-ray photograph of the model pyramid discussed earlier, except that its "contrast" would be considerably enhanced; a smaller chamber would show an amplified change in intensity relative to that from neighboring directions through the pyramid.

This is an appropriate place to discuss in more detail how one would map the pyramid onto a flat photographic film. In figure 4, the X-ray photograph of the model pyramid would extend nearly "out to infinity," if one wished to map regions of the pyramid down to the same altitude as the subterranean chamber, which in the second pyramid is almost at ground level. (This difficulty with some kinds of maps is well known in the Mercator's Projection, where the polar regions are greatly distorted, and the two poles are "plotted on the map at infinity.")

A simple way to map the interior volume of the pyramid onto a finite area of photographic film is to adopt the following procedure: calculate from the angles of arrival of a cosmic ray muon where that muon first penetrated the rock surface of the pyramid; project that point of entry onto the base of the pyramid, to give an x and y "base coordinate." Plot that particular count on the "X-ray film," at those two "base coordinates." From what has just been said, it is obvious that all counted muons will give rise to points plotted within the square base contour of the pyramid. From the x and y coordinates of the sparks in the two spark chambers, plus the stored equations of the four flat faces of the pyramid, the computer can calculate the "base coordinates" for each muon in a few millionths of a second. The computer will then immediately add one count to the number of counts previously stored at that "base x and y address" in its memory.

For purposes of orientation, we need to know approximately how many words in the computer memory are required to store all the information in the simulated X-ray photograph. If we use our "resolution area" of 72 square feet ($8\frac{1}{2}$ foot square), we note that the base of the largest pyramid contains 8,300 such unit areas. A typical modern computer has 16,384 words in its "fast memory," each word with 36 binary bits. According to Appendix A we wish to store approximately 1600 counts in each memory location. If we assume we may allow that number to increase to 8,000, we still need only 13 of the 36 bits in each word to accomodate that amount of storage, ($2^{13} = 8,192$). From this we see that there is vastly more storage capability in the computer than we can possible use; we use less than one third of each word, and about one half of all the available words. There is, therefore, more than enough memory capacity available to store the arithmetic program, the input and output routines, and the display program for the cathode ray oscilloscope.

A typical day at the computer would involve the following operations: The operator would unpack the tape just arrived from Egypt, and would hang it on a tape transport unit at the computer. He would at the same time hang the "library tape," with its complete "memory dump" from the last day's computer run. The library tape would then be "read into core," so that the state of the memory on the previous day would be recreated, just as though no time had elapsed between the previous run and the present one. The program in the memory would "step the new tape forward," looking for coordinates of spark chamber sparks - the "end of record" mark on the previous day's tape would have told the computer that no more spark coordinates were available, and that it was time to "dump the memory" onto the library tape, and let some other user have the computer. Now, with a new tape to read, a "start" instruction from the operator will put the computer to digesting a new day's accumulation of data on the direction of arrival of muons at the pyramid.

It is probable that the operator would not be able to restrain his curiosity, so he would ask for a print-out of the numbers in the memory "bins." It would take only a few minutes to print all the information available in the memory, so the operator would have a day by day record showing the growth of any "suspicious enhancement" to a statistically significant signal, as more data arrived from Cairo, with the passage of time.

Until now, it has been assumed that the spark chamber trays are oriented horizontally. This is certainly the way one would start operating, but it is also likely that if no burial chamber was found overhead, the spark chambers would be reoriented with their perpendicular axes pointing successively at about 30° from the horizon along the 4 cardinal compass directions. The effective detecting area of the spark chamber system for muons coming in at large angles to its perpendicular axis is greatly reduced from its geometrical area. But by looking successively in five directions, with overlapping coverage (Vertical plus N, E, S and W at 30°), the whole volume of the pyramid can be probed for unknown chambers in any possible location.

Appendix A

Mathematical description of the penetrating cosmic rays.

Figure 6, the intensity depth curve, has been discussed qualitatively in section III. The intensity as plotted in figure 6 is more properly called the "integral flux," where the word "integral" comes from the fact that at a particular depth, we plot the flux of particles with ranges from that depth all the way to infinity. The flux is defined as the number of particles crossing a square centimeter per second, and per unit solid angle.

The curve in figure 6 is seen to be approximately straight, and certainly quite straight in the range of interest to pyramid probing. As long as the curve can be considered to be straight, it can be approximated by the power law

$$J(R) = J(R_o)\left(\frac{R_o}{R}\right)^n$$

where n is called the "spectral index." We can assign R_o the value of 300 m.w.e., since that is some sort of mean range of interest to a "pyramid prober," as can be ascertained by inspection of figures 2 and 3. The index of the distribution in the neighborhood of 300 m.w.e. is close to 2, and we shall assume it to be exactly 2 in the calculations to follow.

We can now obtain a mathematical formula that closely approximates the integral flux in the interval of range given by 300 m.w.e. ± a factor of 2, i.e. from 150 m.w.e. to 600 m.w.e. This expression is obviously the first term in the Taylor expansion about the point R_o = 300 m.w.e. From figure 6, we then have:

$$J(R) = 2.2 \times 10^{-5}\left(\frac{300 \text{ m.w.e.}}{R}\right)^2 \qquad \text{(A-2)}$$

$$J(R) = \frac{2.0}{R^2} \qquad \text{(A-3)}$$

where R is in m.w.e., and J(R) is in $cm^{-2}\ sec^{-1}\ ster^{-1}$.

It is now important to note that if we decrease R by a small fraction (for example 10 o/o), the flux will increase by twice that fraction (for example 20 o/o). This relationship comes from the definition of n:

$$n = \frac{-d \log J}{d \log R} \qquad \text{(A-4)}$$

Since $d \log J = \frac{dJ}{J}$, and $d \log R = \frac{dR}{R}$,

$$\frac{dJ}{J} = \frac{-2dR}{R}, \qquad \text{(A-5)}$$

as noted in the example. The spectral index is fortunately greater than 1, so that a given fractional change in range (caused by the presence of a burial chamber) is turned into a fractional intensity change that is twice as large. If one were greedy, he might wish for a larger index, to yield a higher "magnification factor." But if the index were higher, the intensity at 300 m.w.e. would be less, and one would have fewer counts in a given interval of time; he would therefore be troubled with statistical problems. Fortunately, nature has provided us with a cosmic ray spectrum that is admirably suited to the job at hand, and it is idle to speculate on its improvement.

We shall now calculate how large a spark chamber we need to accumulate a statistically significant increase in the number of counts from the direction of a suspected "void," or chamber in the otherwise solid rock. In the next appendix, we assume that we are looking for a "standard chamber" with a size that is found three times in the two large pyramids. The "standard chamber" has a floor area of 25 feet x 17 feet, and a height of 18 feet. We further assume that the chamber is physically 300 feet from the cosmic ray detector. For statistical redundancy, we shall assume that we are looking for six "sub-chambers," each one being part of the main chamber, and each having a floor area of 8.5 feet x 8.5 feet. The chance that any observed increase in intensity along a particular direction is due to a statistical fluctuation is greatly decreased if we can say, "We have six independent indications that a chamber exists in a particular direction, and each of these indications is larger than the statistical fluctuations we see in any other direction." (The fact that we may be looking diagonally through a burial chamber does not invalidate the argument just given--the "signal" observed by the detecting device actually depends almost entirely on the volume of rock missing from the solid pyramid, and scarcely at all on its distribution in height and floor area.)

We may now assume that we are looking at a series of "cells in solid angle," each subtended by an 8.5 foot square at a distance of 300 feet. The element in solid angle is then

$$\Delta\Omega = \frac{8.5^2}{300^2} = 8 \times 10^{-4} \text{ steradians.} \qquad \text{(A-6)}$$

From equation (A-2) we find the integral flux at 300 m.w.e. to be

$$J(300) = 2.2 \times 10^{-5} \text{ cm}^{-2} \text{ sec}^{-1} \text{ ster}^{-1}. \qquad \text{(A-7)}$$

In the solid angle given by (A-6), and assuming a detector with an area of A cm^2, we have a counting rate given by

$$M = 8 \times 10^{-4} \times 2.2 \times 10^{-5} \text{ A counts/sec} \qquad \text{(A-8)}$$

$$M = 1.75 \times 10^{-8} \text{ A counts/sec.} \qquad \text{(A-9)}$$

We must now determine the product of the area A and the observation time T, that will yield a statistically significant number of counts, N, from the small element of solid angle defined by 1 "sub-chamber." We first estimate the "magnitude of the signal," from equation (A-5); we take the thickness of rock that the cosmic rays have traversed to be 350 feet, and the height of the burial chamber to be 18 feet. Therefore $\Delta R/R = 18/350 = 5.1$ °/o. Consequently, the increase in counting rate along this line will be about 10 °/o. If the expected number of muons in a counted sample is 100, we expect a "standard deviation" of 10 counts in a family of many such counted samples. If we wish to be more and more sure that our observed "10 °/o signal" is real, and not of statistical origin, we must accumulate a larger sample of counts--the standard deviation, expressed as a fraction of the total counts, is given by

SUBJECT
NAME Luis W. Alvarez
DATE March 1, 1965

$$\frac{\Delta N}{N} = \frac{1}{\sqrt{N}} \qquad \text{(A-10)}$$

Tables of the "Probability of occurance of deviations" shows the following probability, f_n, of finding a deviation larger than n standard deviations:

n	3	4	5	6	7
f_n	2.7×10^{-3}	6×10^{-5}	6×10^{-7}	2×10^{-9}	3×10^{-12}

If we were unprotected by the redundancy of the 6 "sub-chambers" and had to be quite sure that an observed 10 $^{o}/o$ increase in counting rate was due to a real void, we might be tempted to make f_n less than 10^{-8}. But with the redundancy, it seems perfectly safe to ask that n be only about 4, so f_n is one chance in 16,000 for each sub-chamber. A closer look at the statistical problem shows that the main gain in designing to look at "sub-chambers," is that we insist on having enough spatial resolution to see the finite extent of the burial chamber--we actually don't gain anything significant in insurance against statistical fluctuation; the 6 times larger number of counts for the complete chamber would reduce the standard deviation by a factor of $\sqrt{6} = 2.45$. Therefore we would pass from 4 standard deviations on each of the six sub-chambers to 10 standard deviations for the chamber as a whole. As one can see from the table, a 10 standard deviation effect can always be taken to be real; the probability against a statistical fluctuation is less than 1 in 10^{23}!

Now that we want our signal to be 4 times the standard deviation, we need $4^2 = 16$ times our original count of 100 per "element of solid angle." From this fact, and equation (A-9), we may now write

$$N = 1600 = 1.75 \times 10^{-8}\ AT \qquad \text{(A-11)}$$

where T is the total time of observation (in seconds). The product AT is now

$$AT = 10^{11}\ cm^2\ sec. \qquad \text{(A-12)}$$

If A is 1 square meter = 10^4 cm^2, T = 10^7 sec = 4 months. If A = 4 square meters, T = 1 month. This seems to be a good compromise; if we make A less than

1/3 square meter, the observation time is greater than a year, which appears to be going in the wrong direction. At the other extreme, if we try to shorten the observation time to one week, the counter area becomes larger than the "resolution area," which we have chosen to be a square 8.5 feet on a side. We therefore see reasons against making A too large or too small, and a reasonable compromise seems to be to use a pair of square spark chambers each about 2 meters on a side.

We are most fortunate that the intensity of the naturally occurring cosmic rays fit our needs so well. A two order of magnitude decrease (factor of 100) in intensity at 300 m.w.e. would have made the experiment quite impossible, and a one order of magnitude decrease (factor of 10) would have made it exceedingly difficult.

Appendix B.

Mathematical analysis of the scattering problem.

Before attacking the problem of the "multiple scattering" of muons in the pyramidal limestone, it will be profitable to understand in a bit more detail the "signal" modulated onto the cosmic ray beam by the presence of a burial chamber. Figure 8 shows a portion of the intensity-depth curve (figure 6), plotted on linear graph paper, as distinguished from the log-log paper employed in the original figure. Figure 8 shows that $J(R)$ varies as R^{-2} near R_o, which we have defined in Appendix A to be 300 m.w.e. We also check that $\Delta J/J(R_o) = -2 \Delta R/R_o$, as demanded by equation (A-5).

We now assume a detector with an area of 1 cm^2, subtending a solid angle of 1 steradian, and a counting period of 1 second; under these conditions, every unit of $J(R)$ corresponds to a single muon. In the absence of a void, and assuming the rock thickness to be R_o, the number of muons passing through the spark chambers is $J(R_o)$. With the void excavated, we count an additional number of muons equal to ΔJ, the altitude of the shaded triangle. The muons with range less than $R_o - \Delta R$

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MEMO NO.

SUBJECT ILLUSTRATION THAT THE "INTERESTING MUONS" ARE "GENERATED IN" THE CHAMBER.

NAME

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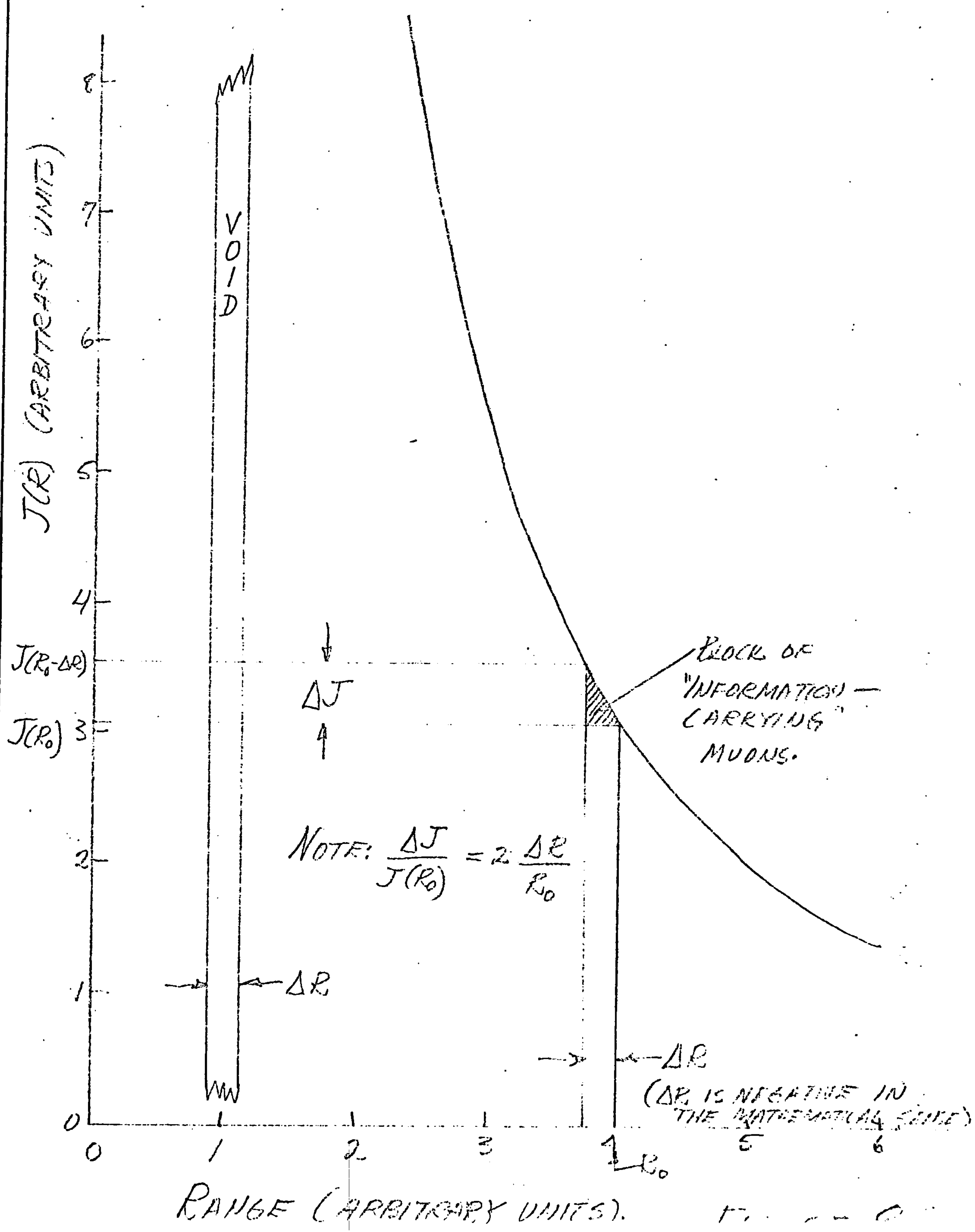

never reach the spark chambers, either with or without the void. The muons with range greater than R_o always pass through the spark chambers, with or without the void.

The analysis just presented shows that we can divide the muon flux into three components: one we never see because its range is always too short; the third we always see, regardless of the existence of a void, so it can be considered to be a background that tells us nothing about the internal structure of the pyramid. The middle class of muons either registers in our detector, or is prevented from reaching it, depending on the existence of a burial chamber. Under such circumstances, it is useful to postulate that this flux of muons originates in the void, and to treat it as if it were a new flux superimposed on the constant background of muons with a range greater than R_o.

We can now inquire into the properties of this "new flux" of muons, which carries all the information concerning the void in the rock. We see immediately that this component has a distribution in range in rock below the detector that is uniform from zero to a distance equal to the height of the burial chamber. The two extremes are the following: a) a muon with a range just larger than R_o would have missed the detector in the absence of the void, but a void of height ΔR will endow the muon with a range of ΔR beyond the detector. b) A muon with a range $R - \Delta R$ will just reach the detector if the void is present, and consequently its extra range in the rock below the detector is zero. In the linear approximation we are using, the range distribution of "new muons" in the rock below the detector is "flat" from zero to a value equal to the height of the void.

We must now investigate the scattering of the "new muons" in their passage from the burial chamber to the detector. (One might think that the scattering should be calculated from the surface of the pyramid to the detector, but any scattering between the surface and the burial chamber is of no significance--the "geometry is poor," so that as many muons "scatter in" as "scatter out," and we can take the flux of muons at the depth of the burial chamber to be the random "parent population." In addition to what has just been said, the scattering of these high energy muons is so small as to be inconsequential.)

As was discussed in section IV, we shall reduce the scattering of the "new muons", by not allowing any of them to approach closer than 11.5 m.w.e. to the end of their range. In this appendix, we shall show that 11.5 m.w.e. (5 feet of iron) is a reasonable amount of absorber to use as a "beam hardener," by calculating the mean scattering angle as a function of "hardener thickness."

The "multiple scattering" of muons in passing through rock is a random process, consisting of millions of small deflections, each of which adds to or subtracts from the scattering angle already accumulated. The magnitude of such a sum of random but inherently equal deflections will increase as the square root of the thickness of the rock. But as the muon approaches the end of its range, it becomes "softer," and the individual scattering events cannot be treated as "inherently equal;" each succeeding scattering event becomes larger as the muon approaches the end of its range, so the mean angle increases faster than the square root of the thickness of rock.

The basic formula applicable to the multiple scattering of muons is the following:

$$\langle\theta\rangle_{proj} = \frac{15\ \text{Mev}}{E\ (\text{Mev})}\sqrt{\frac{L}{L\ (\text{RAD})}} \quad \text{(B-1)}$$

$\langle\theta\rangle_{proj}$ is the mean scattering angle (in radians) projected onto a single coordinate axis. E is the energy of the muon, measured in millions of electron volts. L is the thickness of a thin "slab" of material, so the muon energy can be considered to be constant as it traverses the slab. L (rad) is the "radiation length" of the material. For limestone ($CaCO_3$), L(rad) = 0.26 m.w.e.

From the published range-energy curves for muons[1], we find that it is sufficiently accurate to use the expression:

$$E(\text{MeV}) = 200\ R\ (\text{m.w.e.}) \qquad \text{(B-2)}$$

which was introduced in section III. If we measure all distances, χ, in m.w.e., we may make the following substitutions into equation (B-1):

$$E = 200\,\chi$$

$$L = \Delta\chi$$

$$L(\text{rad}) = 0.26$$

Furthermore, since both E and 15 MeV are in the same units, we can ignore the dimensions, MeV. Finally, we can square both sides of the equation, preparatory to integration

$$\langle\theta^2\rangle_{proj} = 2.16 \times 10^{-2}\ \frac{\Delta\chi}{\chi^2} \qquad \text{(B-3)}$$

Equation (B-3) gives the mean square projected angle of scattering of a muon with range χ, when it traverses a thin slab of thickness $\Delta\chi$. If we wish to find the scattering of a muon in a thick absorber, we must integrate (B-3) between the limits χ_1, and χ_2, the residual ranges the muon has when it enters and leaves the thick absorber. Thus,

$$\langle\theta^2\rangle_p = 2.16 \times 10^{-2} \int_{\chi_1}^{\chi_2} \frac{d\chi}{\chi^2} \qquad \text{(B-4)}$$

$$\langle\theta\rangle_p = 0.147 \sqrt{\frac{1}{\chi_1} - \frac{1}{\chi_2}} \qquad \text{(B-5)}$$

We shall now evaluate equation (B-5), numerically, assuming χ_2 to be equal to 200 m.w.e. (Within the accuracy of the experimentally available numbers, we might as well have taken χ_2 to be infinite; this confirms the earlier statements

1. A. Buhler, T. Massam, Th. Muller and A. Zichichi. Range Measurements for muons in the GeV (10^3 MeV) Region, CERN preprint 64-31 NP Division, 24, June 1964.

that the scattering contributed by the energetic muons is quite negligible).

Figure 9 is the result of the numerical evaluation of equation (B-5); it shows $\langle\theta\rangle_{proj}$ as a function of χ_1, the residual range of a muon. As numerical examples, we see that a muon whose direction of travel is measured while it still has a residual range of 22 m.w.e., can be expected to show its original direction to within a mean uncertainty of 30 milliradians. If we didn't measure its direction until it had only 1 m.w.e. of residual range, the measured angle would depart from the original direction by an average angle of 143 milliradians, or 8.2 degrees. The marked effect of the 5 feet of iron absorber is easily seen in figure 9. The somewhat unexpected effect of the chamber height in hardening the muons can also be seen. If the burial chamber being postulated were only 1 m.w.e. in height (rather than 14.5 m.w.e), the value of $\langle\theta\rangle_p$ in the presence of the iron hardener would be 40 mr., rather than 33 mr. But in the absence of the iron hardener, the values of $\langle\theta\rangle_p$ for high and low chambers would differ by about a factor of two.

There is no way to determine the optimum value for the thickness of the iron hardener. The value of $\langle\theta\rangle_p$ would drop from 33 to 25 mr., if the iron thickness was doubled to 10 feet. This does not appear to be a worthwhile return on the invested iron. One would probably start the measurements with one or two feet of iron under the spark chambers, and gradually pile in more iron, until the thickness was five or six feet.

One might suppose that a giventhickness of lead would be more effective in reducing scattering, than is the proposed iron. But in fact, the two materials are almost equally effective; the increased density of lead just makes up for an effect we have so far been able to overlook in the present analysis--elements of higher atomic weight are slightly less effective absorbers, on a m.w.e. basis, than are lighter elements.

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PHYSICS NOTES

MEMO NO. 32

NAME

DATE

SUBJECT

MUON SCATTERING IN LIMESTONE

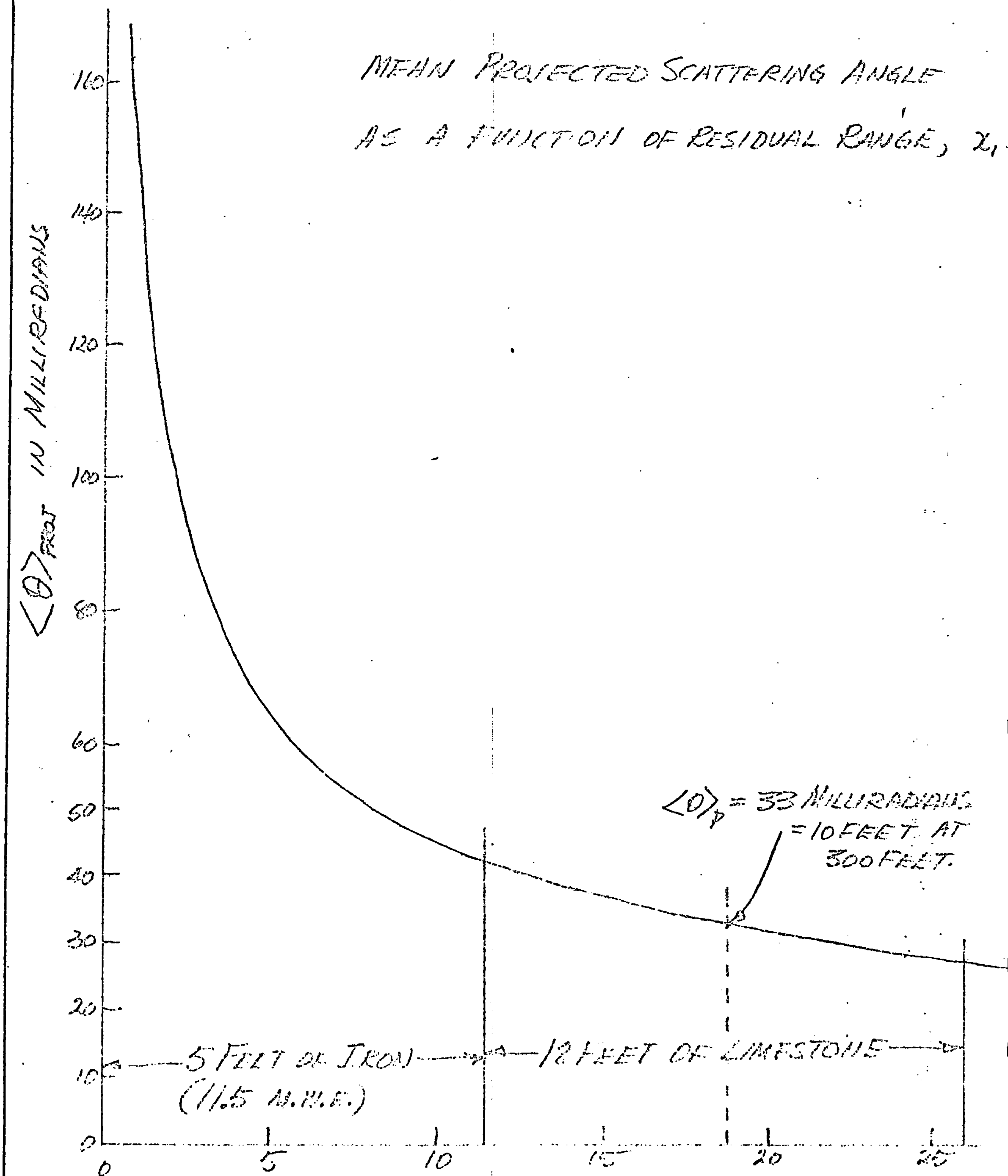


FIGURE 9

Appendix C.

Mechanical and electronic design studies, and cost estimates.

The main body of this appendix is a paper prepared by two members of the Physics Instrumentation Group at the Lawrence Radiation Laboratory, Dick A. Mack, and Fred Kirsten. The author is very grateful to them for their comprehensive and authoritative estimate of the cost of mounting the experimental program outlined in this proposal. Their costs were estimated on the assumption that considerably larger spark chambers were to be used--5 meters on a side rather than the 2 meter design that finally emerged from the main study. An examination of the detailed cost figures does not show that very substantial savings result from the change in size. The chamber costs are reduced by about $4,000, and the scintillator costs are reduced by $15,000. All other costs are unchanged. The total savings are thus about 10 °/o of the estimated cost, which is less than the "20 °/o Contingency" of $27,400, and the "15 °/o Miscellaneous Items" of $20,500. We shall therefore quote the estimated cost, under the following assumptions, to be $170,000.

The cost estimates of Mack and Kirsten were based on the assumption that the equipment was designed and fabricated in the (non-profit) shops of the Lawrence Radiation Laboratory. Since most of the mechanical and electronic devices are standard laboratory "off-the-shelf items", the estimates are certainly realistic. Similar equipment is available commercially from a number of suppliers, so the commercial prices have been kept competitive with those of the laboratory.

An alternative method of cost estimation can be contemplated if for some reason, the Atomic Energy Commission might authorize the Lawrence Radiation Laboratory to lend the (standard) electronic equipment to the "Pyramid Project". Such loans have been authorized in the past, when the receiving agency has been a Government-supported university project, with interests paralleling those of the Lawrence Radiation Laboratory. (Such university loans are of course not restricted to the University of California.) In the event that such a loan program might be implemented, the estimated cost of the program would drop below $100,000.

October 6, 1964

MEMORANDUM

TO: L. W. Alvarez

FROM: Dick A. Mack and Fred Kirsten

RE: Cost Estimate for Pyramid Spark Chamber and Electronics

Based on the discussions we have had, the following estimates the cost of a spark-chamber array and the associated pulsing and readout circuits to be used in your proposed experiment in Egypt. Each part of the system is based upon known experimental techniques which have been used at this Laboratory. We believe the extrapolations that have been made for the larger chambers and scintillation counters are entirely feasible. A block diagram is shown in Fig. 1.

It is assumed that the equipment would operate around the clock for approximately a year, and that once a day local personnel would change magnetic tapes and make routine operational checks. All electronic circuits would be constructed in modular form so that the required maintenance and repair skill would be a mimimum. One spare chassis or printed circuit board has been included for each function. If a spare unit is placed in service, the original unit can presumably be returned either to Cairo or Berkeley for service.

All material, components and test equipment have been estimated at the present net cost to the Laboratory. Labor charges have been estimated at $12 per hour. Certain assumptions that have been made in the estimate are given in the last paragraph.

The grand total is estimated to be $184,800
(THIS TOTAL IS REDUCED TO $ 170,000, ON THE BASIS OF REDUCED CHAMBER SIZE - L.W. ALVAREZ.) FEB 28, 1965

Dick A. Mack
Physics Instrumentation Group

DAM:mt

Fred Kirsten/m.

Fred Kirsten
Physics Instrumentation Systems Group

A. SPARK-CHAMBER CONSTRUCTION

It is proposed that the spark-chamber array consist of two chambers each capable of yielding both the X and Y coordinate position for each spark. The construction must lend itself to rapid assembly and disassembly in the field. (Auxiliary electronic circuits will ignore events where a) each chamber does not fire or b) more than one spark occurs in a chamber.)

The best chamber construction appears to be that of using etched (or if necessary milled) copper strips on long mylar sheets, as described by Victor Perez-Mendez and others. This method of construction for a large demountable chamber is less fragile and appears preferable to a chamber with wires strung from supports.

Rectangular coordinates for each spark could be obtained by running the etched wires at the top and bottom of the chamber transverse to each other. This method has been described by Neumann for stretched wire chambers. See Fig. 2.

Several methods of readout might be employed:

1. A memory core attached to each chamber wire and subsequently scanned in a coincident-current readout system, or
2. Coded arrays of cores yielding the spark address with a smaller amount of scanning required than required in (1), or
3. A magnetostrictive wire transverse to each set of chamber wires and giving a single-coordinate address for each spark.

Method 3, first described by Gianelli and refined by Perez-Mendez, appears to offer the simplest system and is recommended for this set-up.

For two 5 x 5 meter, etched-wire chambers the construction costs have been estimated as follows:

	Master etching template	$ 500
*	Etching costs ($50 for a 1.5' x 1.5' sheet)	2400
*	Copper-clad mylar cost ($3/ft²)	3300
	Material cost for chamber frames	200
5	Magnetostrictive readout transducers and high-voltage connectors	300
	Design time of chambers	2000
*	Machining and assembly costs for 2 demountable chambers each 5 x 5 meters	2000
		$10,700

*For chambers of different dimensions these costs can be pro-rated.

B. SCINTILLATION COUNTER CONSTRUCTION

It is proposed that two scintillation counters be employed to encompass the same solid angle as subtended by the spark chamber array and used to trigger the spark-chamber pulser.

COSTS:

Pilot Y Scintillator

* 1) 5 x 5 meters x 0.625 cm thick ($125 for 1 x 4 feet x 1/4")

* 2) 5 x 5 meters x 0.625 cm thick plus 4 sections 2 x 5 meters around edges of iron shield.

Total of $90\ m^2 \cdot \frac{10.8\ ft.^2}{m^2} \cdot \$31.25/ft^2$	$30,400	
* Machining edges of scintillator (assume 1 x 4' sheets require 1.5 hours machining each)	$ 4,400	
* Gluing scintillator to make 5 m long strips	$ 900	
Light proofing to be done with aluminum foil and black cardboard at site --		$35,700

*For scintillators of different dimensions these costs can be pro-rated.

C. ELECTRONICS EQUIPMENT

1. Spark-chamber pulser and power supplies.

The Spark Chamber pulsers can be triggered with a scintillation-counter coincidence circuit, see Fig. 1. The following standard units (including spares) are recommended for this use:

18	Phototubes and shields	$4400	
18	Phototube bases	3600	
4	Pulse OR Circuits	800	
2	Pulse AND Circuits	300	
2	Spark-chamber trigger amplifiers	6400	
3	Spark-chamber distribution boxes	1800	
2	High-voltage power supplies for spark chambers	800	
2	Clearing field power supplies	400	
2	High-voltage power supplies for phototubes	1200	
2	Phototube voltage - divider panels	500	
2	Bins and power supplies for fast electronics	1000	
	Assembly and checkout time for pulser and coincidence system.	4000	$25,200

2. Spark-chamber Read-out Equipment - per Fred Kirsten

To record the coordinates of each event it is proposed that the magnetostrictive readout signals be used to gate time-interval scalers. The spark-chamber trigger signal would gate on each of four scalers with a capacity of 1024 counts. The magnetostrictive readout would gate each scaler off at a time corresponding to the position of the spark in that chamber. For a time base the scalers would count from a 1-Mc clock oscillator.

The following readout logic circuits (including spares) would be required:

	Amplifier and discriminator circuits	$1400	
4	Scales of 1024	1700	
	Tape transport control circuits	1400	
	Spare boards	3000	
	Test routine equipment	2300	
	Power supplies	1200	
2	Incremental magnetic tape transports with drive electronics.	12,000	
	Engineering design and checkout of individual chassis	7500	$30,500

C. ELECTRONICS EQUIPMENT (Continued)

3. Magnetic Tape

It is estimated that in the most compact data format, one 2500 ft. reel of tape would be required per day. At $25/reel, tape costs for 200 day's operation would be -- $5000

(The tape is, of course, reusable as soon as the raw data have been read into a computer.) $5000

D. ELECTRIC POWER AND LINE REGULATORS

Adequate power with sufficiently good regulation may be available at the site. However, for this estimate it is assumed that we would have to generate our own power. A diesel generator with an output of 10 kVA, 115/230 volts, 1 phase, 60 cycle with ± 10% load regulation should be adequate.

Paul Breitenbach supplied the following figures:

Diesel-generator	5 kVA	$1200	
	10 kVA	1800	$1800
	15 kVA	2600	
	30 kVA	5000	

Operating costs including fuel, maintenance and depreciation $ .054/kWh.

This assumes fuel costs $.50/gal., the usage is 0.1 gal/kWh, and depreciation is 20%/year.

For 1 year's operation at an average power consumption of 5 kVA, the power cost is --- $ 500

A 5 kVA line voltage regulator is essential for the correct operation of the electronics equipment; a second unit would be used for standby operation.

Stabiline line voltage regulators with protection and control circuits, $3200 each --- $6400.

Cabling, coaxial and power -- $2000

$10,700

E. TEST EQUIPMENT, TOOLS, SPARE PARTS

1. It is recommended that the following test equipment be assigned to the experiment:

   1 - 30-Mc bandwidth oscilloscope with 2 plug-in amplifiers, high voltage and low voltage probes.

   2 - High impedance voltmeters with HV probes.

   2 - Volt-ohm milliammeters.

   1 - Pulse generator. Total $3600

   1 - Radioactive source for checking scintillation counters.- Borrowed

2. It is recommended that the following amount be included for hand tools, electric drills and associated equipment $ 300

3. It is recommended that some spare electronic components (e.g., transistors and tubes) be included for repair of chassis in Egypt ---- $ 500

$4400

F. TESTING

It is recommended that the entire spark-chamber, scintillation counter and electronics array be first checked out at LRL and then be field tested at an underground location nearby. It is estimated that 12 man weeks of time would be required for these tests. $6000

G. SETUP AND INITIAL OPERATION

It is recommended that one man from LRL go to the site to assist in unpacking, assembly and early operation. A maximum of three months has been estimated for this period. $8700

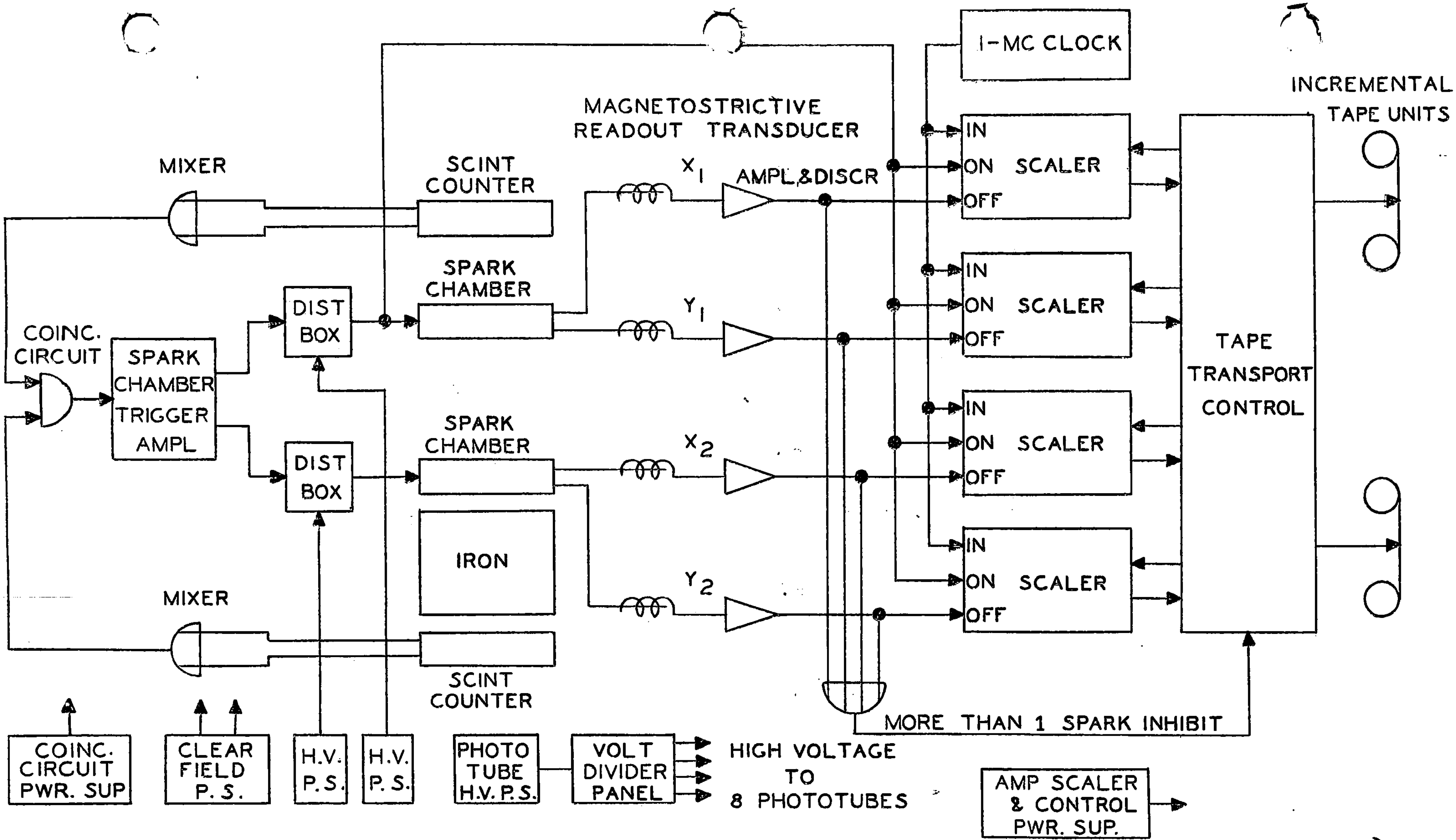
H. EXCEPTIONS

The following items have not been included in this estimate and are assumed to be covered elsewhere:

1. Transportation of equipment and personnel to site.
2. Packing and insurance for equipment.
3. Any procurement costs of equipment and components.
4. Storage and equipment operating hut.
5. Iron shield in spark-chamber array.
6. Air-conditioning for equipment.
7. Electric lights at site; however, 5 kVA of power is available for this purpose.
8. Gas supplies for spark chambers.
9. Fresh-air supply in spark chamber area.
10. Operating personnel at site beyond one electronics man for 3 months to supervise unpacking, assembly, and initial checkout of equipment.

I. TOTAL

TOTAL ----------------------	$136,900
20 °/o Contingency	27,400
15 °/o Miscellaneous items	20,500
GRAND TOTAL --------------	$184,800

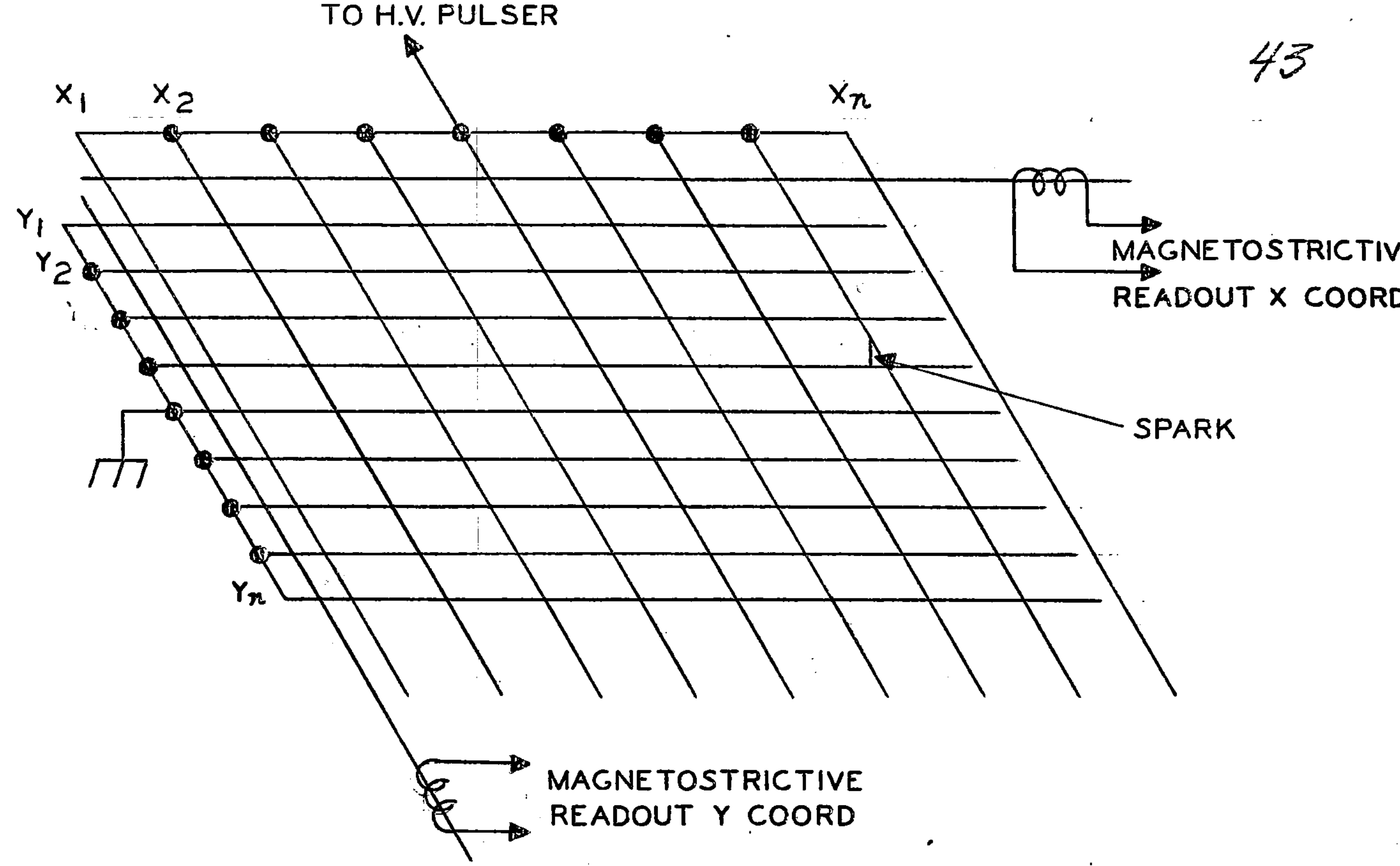


p 42

SPARK CHAMBER & READOUT ELECTRONICS

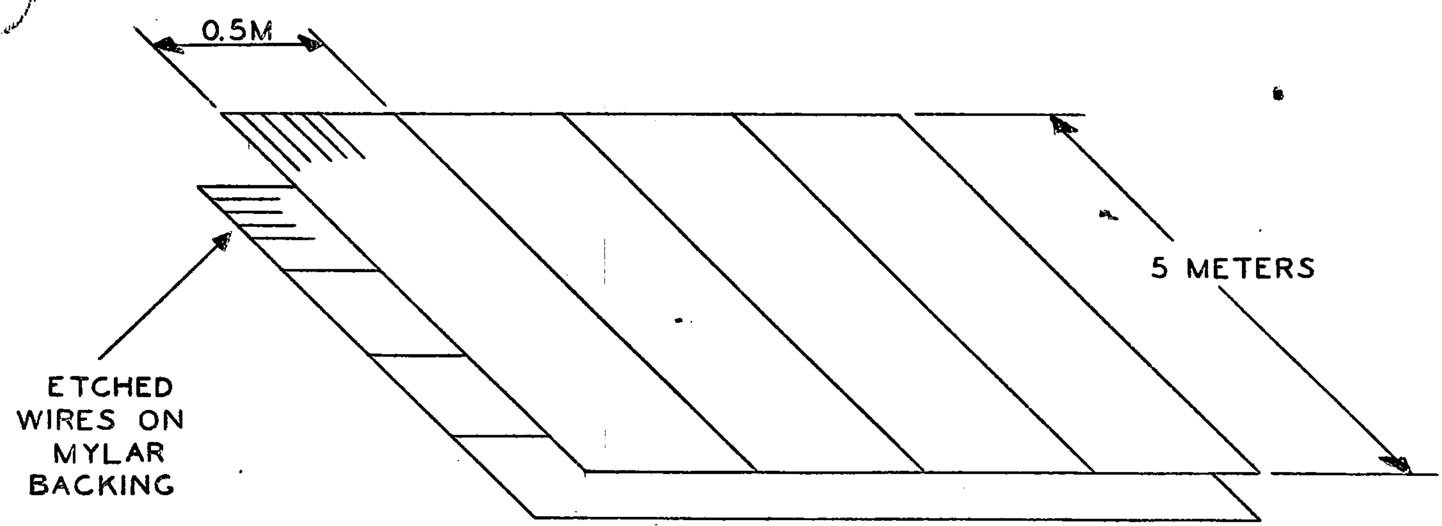
FIG. 10

D. MACK 10-5-64



MAGNETOSTRICTIVE READOUT

FIG. ~~2A~~ 11



SPARK CHAMBER CONSTRUCTION

FIG. ~~2B~~ 12

Luis memo 545

Testimony for Joint Committee on Atomic Energy, Subcommittee on Research Development, and Radiation.

Hearings on
High Energy Physics
March 4, 1965

PROCESSING AND ANALYSIS OF DATA FROM PHOTOGRAPHS made by Bubble Chambers and Spark Chambers

A. H. Rosenfeld
Professor of Physics
University of California at Berkeley

INTRODUCTION

At present U. S. high energy physicists measure and process between one and two million bubble chamber events each year. It is likely that this measurement rate can double every two years for a few years. I would like to try to answer two questions:

1. What is the point of processing more millions of events each year?

2. What level of support will be needed to raise our measurement rate for bubble chamber and spark chamber film, and how should the support be divided between the universities and the national laboratories?

I. WHY IS THERE A NEED TO PROCESS MILLIONS OF EVENTS EACH YEAR?

Gell-Mann, on Tuesday, showed you a slide displaying 18 lines, each line representing a state of strongly interacting matter, either a "meson" or a "baryon". He explained that we have been able to find relative order between some of these states, so that we have discovered "meson familes", and "baryon families" and classified them according to the Eightfold Way, or the newer scheme called SU(6).

In order to identify each of these new states one usually needs a clean sample of hundreds, and sometimes tens of thousands, of events. This should not be so surprising; we are used to doing even micro-chemical analysis with samples containing far more than a thousand atoms. A familiar analogy would be that to predict mortality rates -- or the outcome of an election -- one has to interview a sample containing thousands of people.

The current difficulty in particle physics is that very many different things happen in a high-energy interaction, so that to find a clean sample of a thousand events of a given sort, one may well have to sort through tens or hundreds of thousands of measurements. All this work may permit us to establish the properties of <u>one</u> new state. But in order to complete the new "periodic table" and have a chance to understand the order behind it, we have to deal with tens or hundreds of new states. Hence millions of measurements are called for.

* * *

Instead of just reasoning by analogy, let me show you two slides which tell how many events were involved in the discovery in 1964 of the "A meson", which subsequently, with more events turned out to be two mesons now called A1 and A2.

The first figure involves what we call a scatter plot, so let me explain what that means. Suppose you take a sample of 100 men, and you ask them each their age and their salary. You can then lay out the scales where salary is plotted vertically and age horizontally. This plot would have a hundred points, and might look like Fig. 1. It is a scatter plot and would tell you quite a lot about the relation between age and salary.

The plot that I am going to show next, Fig. 2, instead of 100 points representing 100 men, has 1784 points representing measurements of the 1784 events in bubble chamber film measured by the Trilling/Goldhaber group at LRL (Berkeley), and the scales, instead of being salary and age, are the masses of pairs of particles leaving the interaction. If these particles did not interact in an interesting way the density of population would be nearly uniform over the allowed triangle. You can see that instead there is a distinct structure: a horizontal band which represents a proton-pion resonance (unstable state of strongly interacting matter) and a vertical band which represents a two-pion resonance known as the rho-meson. The Trilling/Goldhaber group were looking for a clean sample of rho-mesons so that they could investigate in turn whether the rho resonated with any other pions leaving the interaction to form a new rho-pi meson. Unfortunately the physics is complicated where the two population bands cross (i.e., where most of the events fall), so they had to select for their sample just the 400 events in the vertical band above the horizontal band.

Note that each dot (event) of which they could use only 400, represents a lot of work. Perhaps 250,000 pictures had been scanned to find 4000 candidate events, which were then measured on a digitized microscope in two or three stereo views. These measurements were then fed to a computer which worked for about a minute to reconstruct each event. During this time each event went through about 85,000 words of computer program involving several million actual computations (add, subtract, multiply, etc.). The computer certified only 1784 of the 4000 events as simple enough to be eligible to go on the scatter plot.

For each of the 400 rho's the Trilling/Goldhaber Group computed the mass of the combination of the rho with another pion and plotted their result in Fig. 3a (top). You can see the peak at the left, which the group named the "A meson". With only 100 A-mesons they could barely establish its existence and mass, and could not possibly discover the rest of its properties (there remain six other "quantum numbers" to be established). It is as if one were driving through the fog and just made out a shape ahead, without being able to tell whether it is a signboard or a car, or a truck, or which way it is going. In summary, 4000 measurements yielded an inadequate sample of 100 A mesons.

As soon as the A-meson was reported, members of the Alvarez group, also at Berkeley, realized that they has relevant data. They already had measured and cataloged a large number of events with rho's. These libraries of measurements stored on magnetic tape are extremely valuable. Several times, after some other group announced the existence of a new particle, we have been able to use existing measurements to establish all its remaining properties ("quantum numbers") almost overnight.

Adding some new events, the Alvarez group started with 7000 measurements, and their final result is shown in Fig. 3b. The improved statistics revealed that there was not one "A-meson" peak but two separate peaks, fairly well resolved. The leftmost peak (containing about 100 events) they called A1, the righthand one (with 200 events) they called A2. The 200 events were enough to suggest the other properties of the A2.

To complete the story, it then became apparent that if the A2 had the quantum numbers suggested by the 200 events, then it should have a certain rare decay mode into two K mesons. The group then [redacted] scanned 180,000 pictures, and found 5000 to 6000 candidates for this decay mode. Measurement and processing of the candidates showed that about 30 of them were really decay products of A2, establishing all the rest of its properties. Nobody has yet found enough A1 decays to sort out its properties -- in fact it is not yet sure that it is really a resonance. Perhaps a new experiment starting with 70,000 events instead of 7000 will answer these questions.

A European collaboration (Aachen, Berlin, CERN) has just measured 7000 more events bearing on A1 and A2. They found about 200 clean rho's and their final mass distribution is shown in Fig. 4. They confirm the two peaks, but can determine no new properties of either meson.

In summary, to find a clean sample of perhaps a thousand events one may have to start by measuring tens or hundreds of thousands of events, and then make several different selections along the way, each time throwing out the majority of these painfully acquired measurements.

II. PAST, PRESENT AND FUTURE DATA PROCESSING EFFORT

A. Nationwide Totals

In April 1964 I asked friends in the dozen largest bubble chamber groups in the U.S. for estimates of their measuring rates, personnel, etc. Adding their answers I found the following totals:

Estimated events measured in Calendar 1964	1,000,000
Ph.D. physicists heavily involved with data processing	125
(Total Ph.D.'s in High Energy Physics ~1000)	
Full-time-equivalent scanning and measuring technicians	300
Measuring projectors (these average $50,000)	65

By now I would guess that the annual measurement rate has grown to perhaps 1.5 million, but I doubt if the other totals have greatly changed. Probably, to take into account the efforts of all the other smaller groups one should raise the totals above by 30% to 50%.

Of the 300 technicians, I would guess that at any given time perhaps 50 are scanning pictures (looking for interesting events), 125 are measuring, and 125 are involved in data processing (programming and dealing with computers and their output).

B. Historic Trends

Fig. 5 shows the recent history for the group in which I work and with which I happen to be most familiar -- the Alvarez group at LRL, Berkeley. Its measurements have risen from 80,000 events in FY'61 to 300,000 in FY'65. This represents a doubling every two years. Since 1962 the amount of computing that we do has been going up along with the measurement rate. (Before 1962 our computer programs were not yet working). Currently, to compute 300,000 events per year, we use more than half the time on the IBM 7090 or an IBM 7044. Such computers cost about $1 million, after educational discount.

Fig. 5 shows two very encouraging facts -- although our measuring rate, and the amount of computing that we do, has been doubling every two years, the number of physicists needed, and the cost for computer time, have both remained nearly constant. The reason that our computer costs have not doubled along with the measurement rate is the rapid rise in computing power per dollar -- every year sees the announcement of new, faster computers, for about the same price as current models. Specifically the data processing capacity (we call it "throughput") per dollar of U.S. computers has been doubling every two years during the last decade, and it looks as if the trend will continue.

I have discussed one group, that of Alvarez, but I think its trends will apply for most other groups.

C. The Future

Dr. William Fowler, of the Shutt Group, has recently made an estimate that the number of bubble chamber pictures produced per year will rise from 10 million in 1965 to 40 million in 1975. But the average chamber running now is a few feet long; the chambers of 1975 will be between 10 and 20 feet long, so they will produce about 3 times as many events per picture. In addition the events will be more complicated, and in the bigger chambers there will be more secondary interaction to measure and analyze. So I conclude that the number of events available per year will double roughly every three years for the next ten years, and the actual data analysis load will rise slightly faster than that -- perhaps it will double every two years. This is our raw material input; how shall we keep up with it?

Let me state my conclusions at the outset, then return to justify them.

I predict that the scanning load will be handled simply by increasing the number of people who scan. However one full time person can scan about 100,000 pictures a year, and so 50 people probably handle the national scanning load now. I think we'll have to increase this to 200 in the next 5-10 years.

I predict that the measuring will be handled at little increase in expense by the computer-controlled automatic measuring devices known as FSD and PEPR. These cost $200,000 each and would be installed at 10-20 universities and at the national laboratories.

I predict that the computing load will be handled by one or two million dollars of computing equipment at each of 10-20 universities and at the national laboratories.

* * *

The Advent of Automatic Measuring Systems

Prof. John Pasta will discuss semi-automatic and automatic measuring. But to expand on my predictions I shall show some pictures made with the computer-controlled measuring device that I know best -- PEPR, which is being developed at MIT in collaboration with Berkeley and Yale. It consists of a cathode-ray tube (precise TV tube) controlled by a computer costing about $325,000. We hope that in 5-6 hours a day PEPR can measure about a thousand events. (This is typically the output of a dozen conventional measuring machines, staffed around the clock.) The computer would then spend the rest of the time doing the necessary calculations on the measurements.

Fig. 6a shows a bubble chamber photograph we recently gave PEPR to process. To save it some time, we told it that there was an event about one third of the way "downbeam". Fig. 6b shows the region the computer scanned. This figure is not a photograph of the film; rather it is a playback on the computer's display 'scope of data scanned by PEPR and stored in the memory of the computer.

Fig. 6c shows how the computer disentangled and measured the event. It discarded the spiralling electron, the "through" beam tracks, and the fiducial mark near the interaction of interest. Then it found the vertex of the interaction and the outgoing prongs, and followed them to their end in a most satisfactory manner.

Even older than PEPR, is a very similar cooperative development called FSD, which is now installed and running at BNL, LRL, CERN, etc. The next generation of these computer-controlled measurers will doubtless incorporate the better features of FSD and PEPR. With 10-20 of such devices I am confident that we can raise our national measuring rate from the current 1-2 million events annually to 10-20 million in the next 5-10 years. These automatic measurers will also be in demand to measure spark chamber photographs, particularly if wide-gap spark chambers fulfill their present promise, so this load may become as large as the bubble chamber load.

You may note that I have spoken of these automatic devices as measuring machines, and not as scanning machines, although the figures show that the machines can scan. But it does not yet appear to be economical. My present feeling is that human beings, after 100,000 generations' experience, are still better at recognizing bubble-chamber events than are computers, which have only had about 5 generations to evolve. For the case of spark chamber photographs scanning by computers is already economical.

* * *

Universities vs National Laboratories

These new automatic measuring devices are cheap enough that there is no reason why they should not be installed on university campuses, where the physicists and graduate students can keep in day-to-day touch with what they're doing (it is still a rather tricky business). And of course the scanning and data processing should be done on campus too, for the same reasons.

However, I should point out that most of the important developments in data processing in the last decade have been made at the strong centers in the national laboratories, where big groups have the resources and equipment to innovate. (There are of course notable exceptions, the inventions of the bubble chamber, the spark chamber, and PEPR). The university users groups and the groups at the national laboratories have published comparable amounts of physics, but I think it is fair to say that the techniques have been developed mainly at the national laboratories. Hence, in addition to the campus groups, the AEC should continue extensive support to a few very strong centers, equipping them not only with modern computers, with the new peripheral equipment whose importance is now becoming apparent: mass memories and the time-shared consoles with display 'scopes and light pens.

Finally as to my prediction that it will not take much more than $1 million of computer on each campus to process the measurements. I come to this conclusion simply by noting that the rise in computer throughput per dollar is about the same as the rate of rise in our measuring power. Of course if this happy trend in the computer industry should not continue, then our computer expense will go up steeply. It will mount in any case, since as we process more and more events we will have less time to handle any part of an event by hand -- this will put more load on the computer. Further at higher energies it becomes more difficult to interpret the events.

Biographical Notes: Arthur H. Rosenfeld

Ph.D. in Physics under E. Fermi, University of Chicago, 1954.

Co-author with Fermi, Orear, and Schluter, of "Nuclear Physics", a standard text in English, French, Japanese, Russian.

Author of more than 60 publications in particle physics and data processing.

Currently Professor of Physics and staff member at the Radiation Laboratory, University of California, Berkeley. Work in mainly the field of experimental particle physics, using hydrogen bubble chamber as a research tool.

Member of the National Academy of Sciences' Committee on the Uses of Computers.

Fig. 1. Illustration of a Scatter Plot

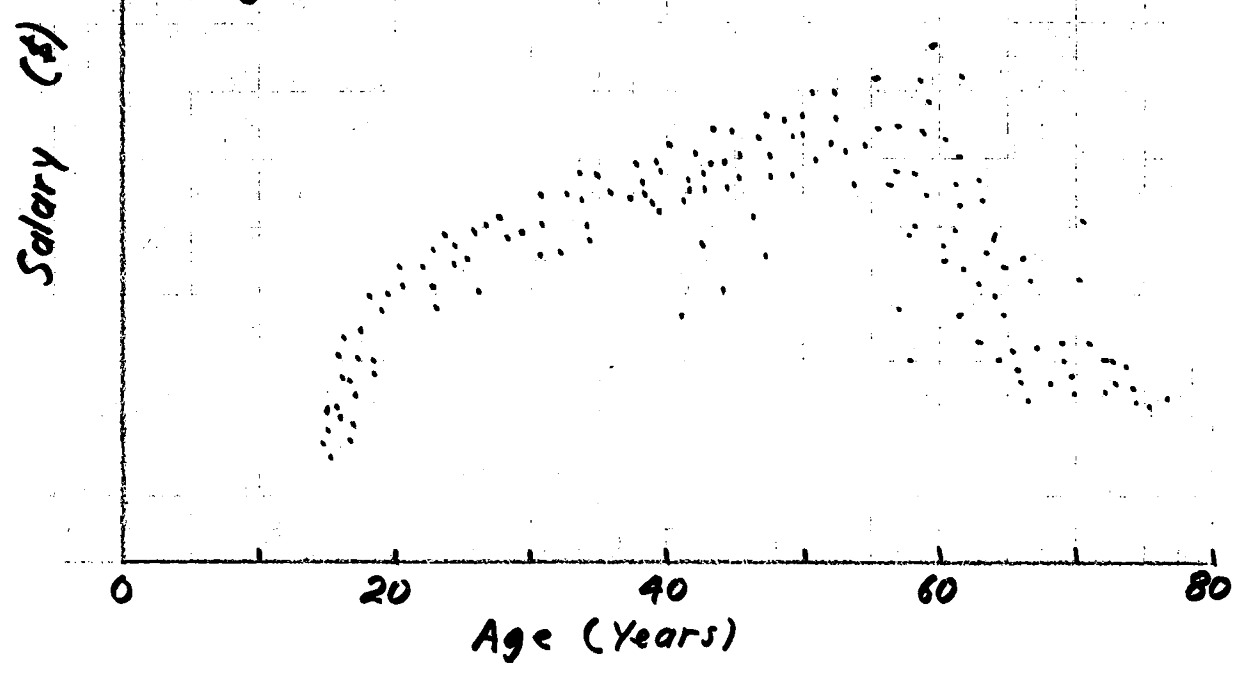


Fig. 2. Scatter plot of 1784 events from 4000 measurements. The vertical band of points is the rho meson, the horizontal band in the "delta" baryon.

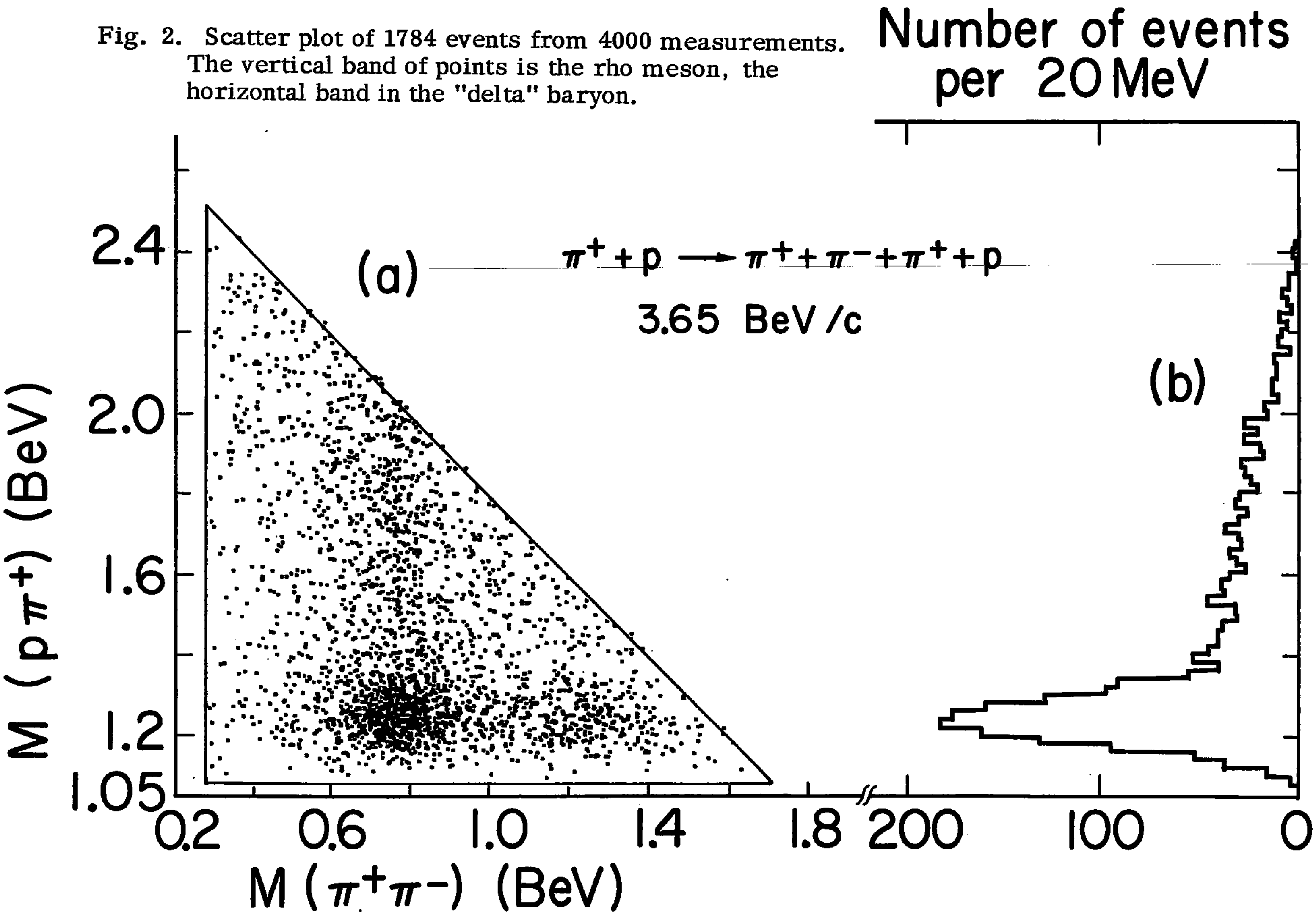
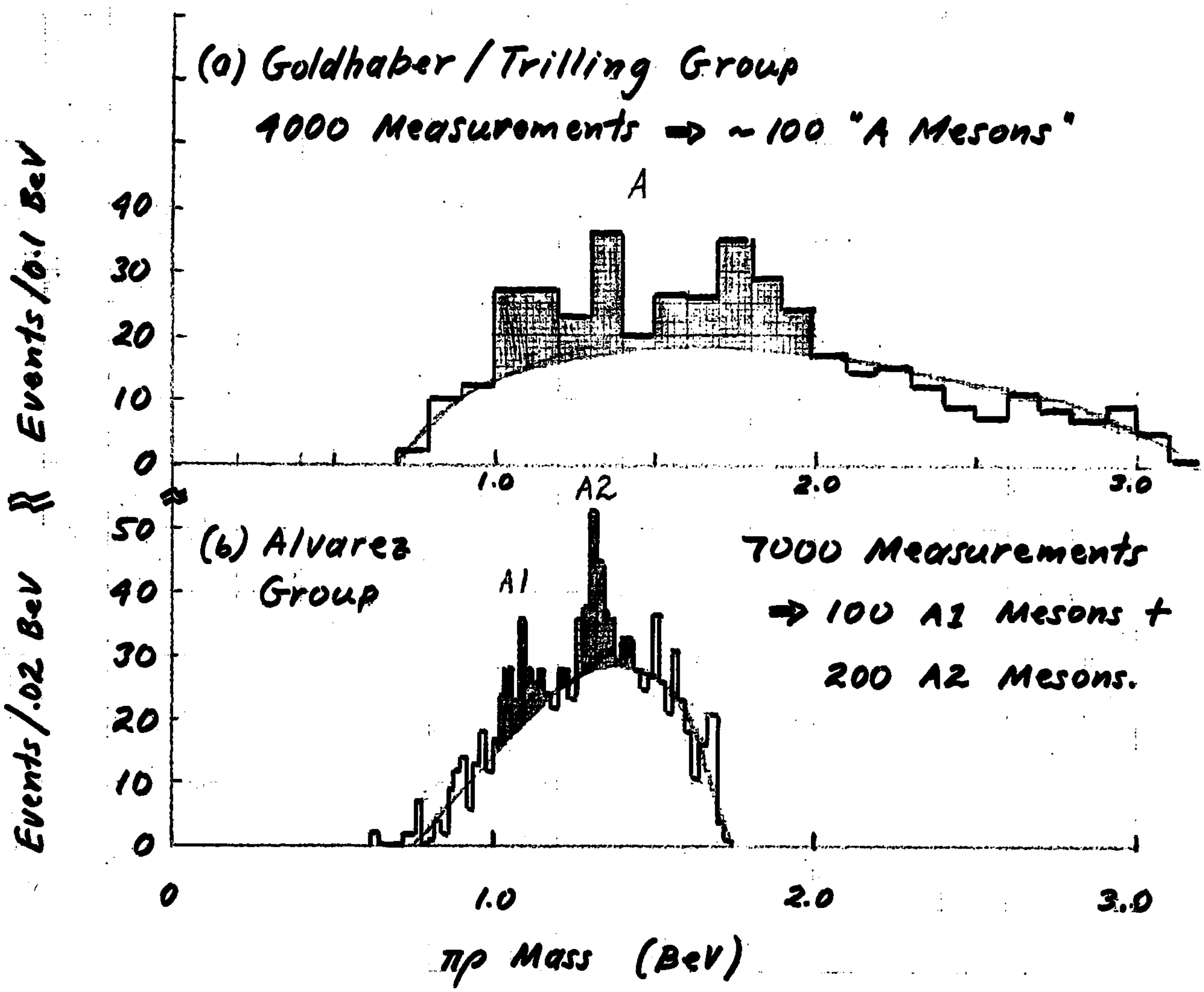


Fig 3. Discovery of the A Mesons



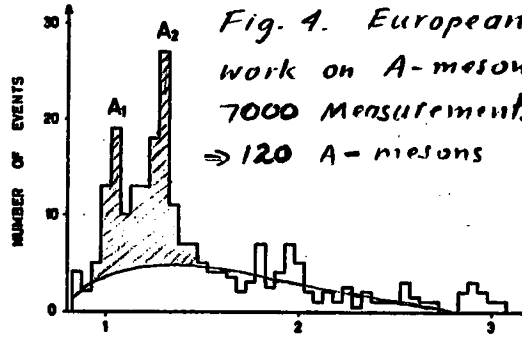
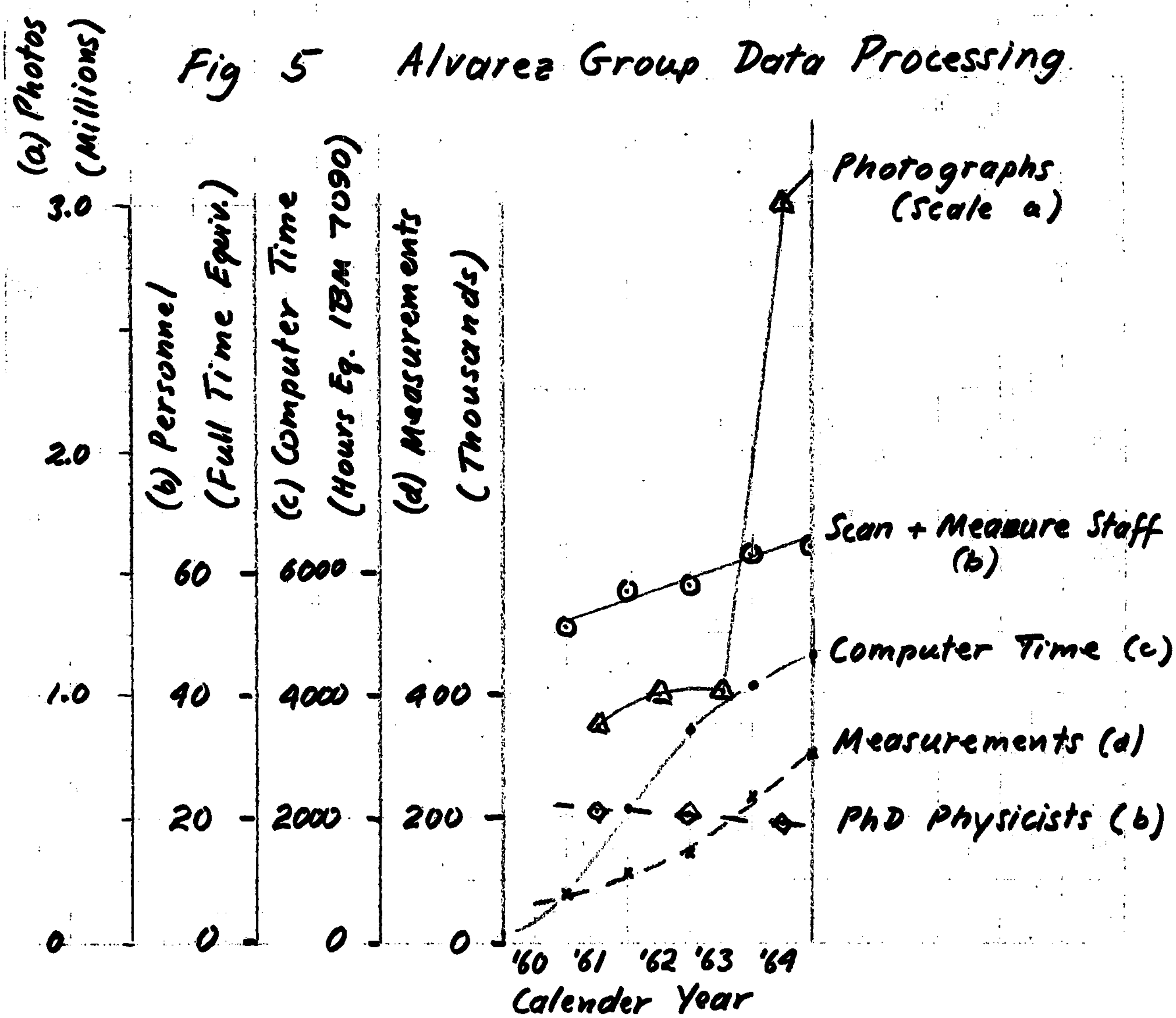


Fig. 4. European work on A-mesons. 7000 Measurements ⇒ 120 A-mesons

Fig 5 Alvarez Group Data Processing



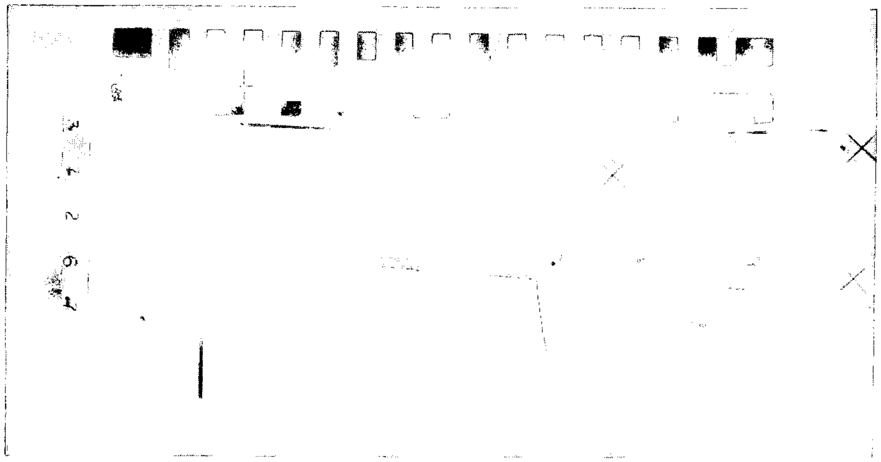


Fig. 6a. Original bubble chamber photograph scanned by PEPR. PEPR was instructed to scan the beam area about 1/3 of the way from left to right.

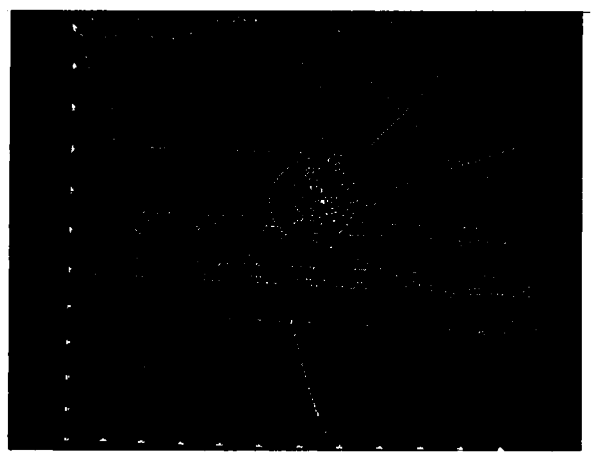


Fig. 6b. Redisplay of data on the PEPR display oscilloscope. PEPR read in all the bubbles in the area of interest, stored them in the computer core, and re-displayed them. In addition to an interaction with one incoming and four outgoing tracks, there is visible an electron spiral, many non-interacting beam tracks, and an "x" fiducial mark on the bubble chamber glass.

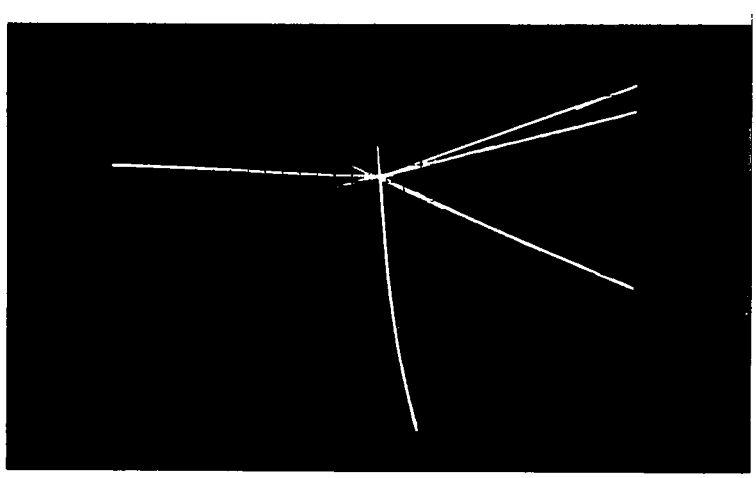
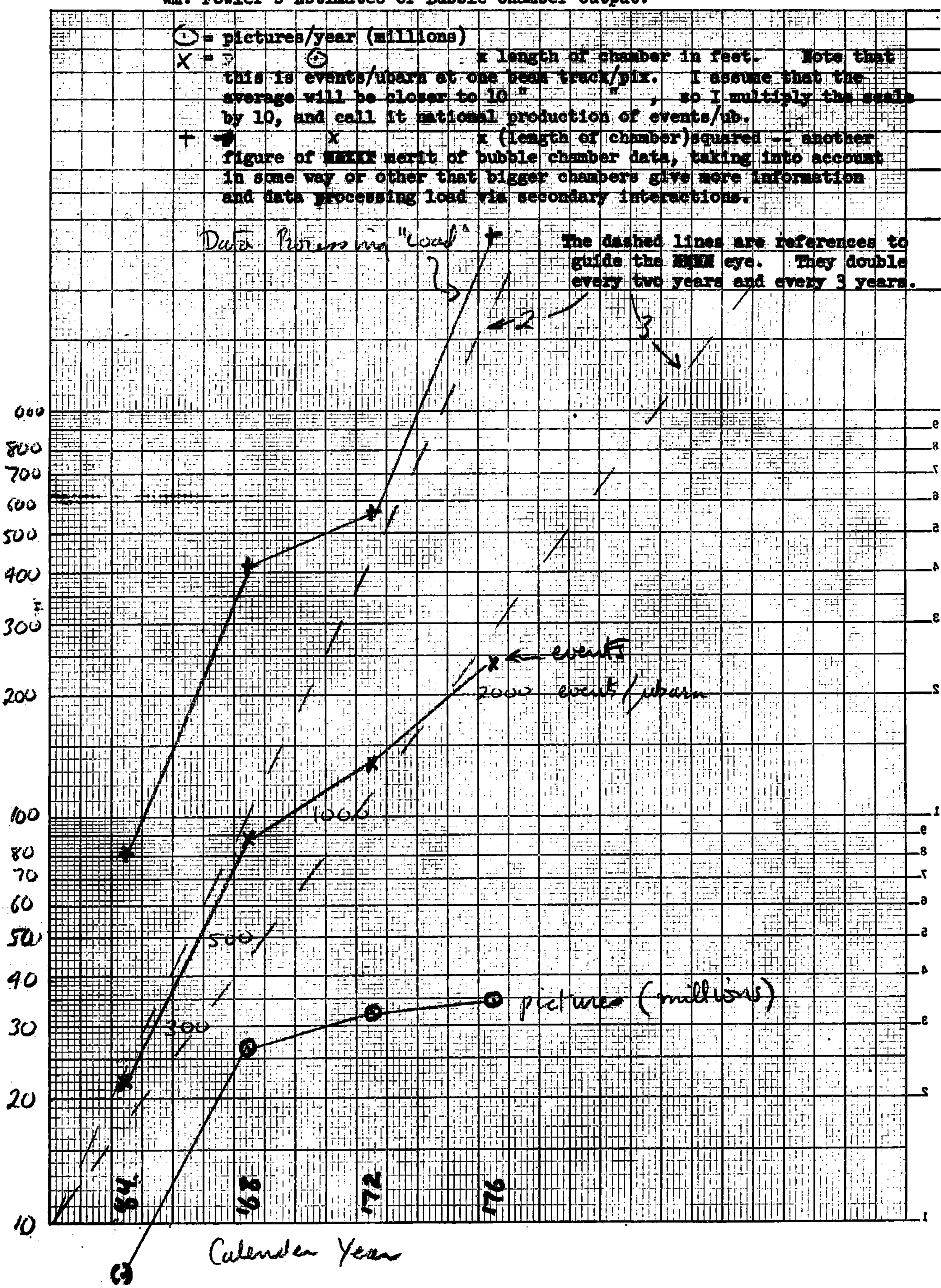


Fig. 6c. Tracks of interest as filtered, followed, and measured by the PEPR computer.

[redacted]

Rosenfeld 3/8/65

Wm. Fowler's Estimates of Bubble Chamber Output.



MEMO NO. 546 PAGE 1

SUBJECT Tabulation and Derivation of $Y_{LM}(\theta,\phi)$ and $\mathcal{D}^L_{MM'}$ Functions

NAME J. B. Shafer

DATE March 24, 1965

I. Spherical harmonics $Y_{LM}(\theta,\phi)$ up to order $L=5$ (and all permitted M values) are presented.

II. "Symmetrical-top functions" $\mathcal{D}^L_{MM'}(\phi,\theta,0)$ are described, and several examples are presented. (These $\mathcal{D}$ functions are matrix elements for rotation operators – for a system with total angular momentum L; their arguments α, β, γ are Euler angles.*)

Recursion relations presented in Sections I and II permit the construction of Y_{LM}'s and $\mathcal{D}^L_{MM'}$'s for any values of indices from those functions presented here.

An IBM computer program is being written to calculate all desired functions for given arguments θ and ϕ.

* See Rose, Ang. Momentum, p. 50

[illegible]
(checked against Condon-Shortley) – $Y_{\ell 0} = \sqrt{\frac{2\ell+1}{4\pi}}\, P_\ell(\cos\theta)$

I.

$(Y_{LM})^* = (-)^M\, Y_{L,-M}$, $\quad Y_{\ell m} = (-)^m \left[\frac{(2\ell+1)(\ell-m)!}{4\pi\,(\ell+m)!}\right]^{\frac{1}{2}} P_\ell^m(\cos\theta)\, e^{im\phi}$

$Y00 \quad \sqrt{1/4\pi}$

$Y11 \quad -\sqrt{3/8\pi}\, \sin\theta\, e^{i\phi}$ $\qquad Y_{1,-1} = +\sqrt{\frac{3}{8\pi}}\, \sin\theta\, e^{-i\phi}$

$Y10 \quad \sqrt{3/4\pi}\, \cos\theta$

$Y22 \quad \frac{1}{4}\sqrt{\frac{15}{2\pi}}\, \sin^2\theta\, e^{2i\phi}$

$Y21 \quad -\sqrt{\frac{15}{8\pi}}\, \sin\theta\, \cos\theta\, e^{i\phi}$

$Y20 \quad \sqrt{5/4\pi}\, (3/2\, \cos^2\theta - 1/2)$

$Y44 \quad \sqrt{\frac{1}{70\pi}} \left(\frac{105}{16}\right) \sin^4\theta\, e^{4i\phi}$

$Y43 \quad -\sqrt{\frac{1}{35\pi}} \left(\frac{105}{8}\right) \sin^3\theta\, \cos\theta\, e^{3i\phi}$

$Y42 \quad \sqrt{\frac{1}{10\pi}} \left(\frac{15}{8}\right) \sin^2\theta\, (7\cos^2\theta - 1)\, e^{2i\phi}$

$Y41 \quad -\sqrt{\frac{1}{5\pi}} \left(15/8\right) \sin\theta\, (7\cos^3\theta - 3\cos\theta)\, e^{i\phi}$

$Y40 \quad \sqrt{\frac{1}{\pi}} \left(\frac{3}{16}\right) (35\cos^4\theta - 30\cos^2\theta + 3)$

$Y66 \quad \sqrt{\frac{3003}{\pi}} \left(\frac{1}{64}\right) (-x^6 + 3x^4 - 3x^2 + 1)\, e^{6i\phi}$

$Y65 \quad -\sqrt{\frac{1001}{\pi}} \left(3/32\right) \sin\theta\, (x^5 - 2x^3 + x)\, e^{5i\phi}$

$Y64 \quad \sqrt{\frac{91}{2\pi}} \left(3/32\right) (11x^6 - 23x^4 + 13x^2 - 1)\, e^{4i\phi}$

$Y63 \quad -\sqrt{\frac{1365}{\pi}} \left(\frac{1}{32}\right) \sin\theta\, (-11x^5 + 14x^3 - 3x)\, e^{3i\phi}$

$Y62 \quad \sqrt{\frac{1365}{\pi}} \left(\frac{1}{64}\right) (-33x^6 + 51x^4 - 19x^2 + 1)\, e^{2i\phi}$

$Y61 \quad -\sqrt{\frac{273}{2\pi}} \left(\frac{1}{16}\right) \sin\theta\, (33x^5 - 30x^3 + 5x)\, e^{i\phi}$

$Y60 \quad \sqrt{\frac{13}{\pi}} \left(\frac{1}{32}\right) (231x^6 - 315x^4 + 105x^2 - 5)$

$Y33 \quad -\sqrt{\frac{35}{\pi}} \left(\frac{1}{8}\right) \sin^3\theta\, e^{3i\phi}$

$Y32 \quad \sqrt{\frac{105}{2\pi}} \left(\frac{1}{4}\right) \sin^2\theta\, \cos\theta\, e^{2i\phi}$

$Y31 \quad -\sqrt{\frac{21}{\pi}} \left(\frac{1}{8}\right) \sin\theta\, (5\cos^2\theta - 1)\, e^{i\phi}$

$Y30 \quad \sqrt{\frac{7}{\pi}} \left(\frac{1}{4}\right) (5\cos^3\theta - 3\cos\theta)$

$Y55 \quad -\sqrt{\frac{77}{\pi}} \left(\frac{3}{32}\right) \sin^5\theta\, e^{5i\phi}$

$Y54 \quad \sqrt{\frac{385}{2\pi}} \left(\frac{3}{16}\right) \sin^4\theta\, \cos\theta\, e^{4i\phi}$

(over)

$$Y_{53} = -\sqrt{\frac{385}{\pi}}\left(\frac{1}{32}\right)\sin\theta\,(-9\cos^4\theta + 10\cos^2\theta - 1)\,e^{3i\phi}$$

$$Y_{52} = \sqrt{\frac{1155}{2\pi}}\left(\frac{1}{8}\right)(-3\cos^5\theta + 4\cos^3\theta - \cos\theta)\,e^{2i\phi}$$

$$Y_{51} = -\sqrt{\frac{165}{2\pi}}\left(\frac{1}{16}\right)\sin\theta\,(21\cos^4\theta - 14\cos^2\theta + 1)\,e^{i\phi}$$

$$Y_{50} = \sqrt{\frac{11}{\pi}}\left(\frac{1}{16}\right)(63\cos^5\theta - 70\cos^3\theta + 15\cos\theta)$$

For higher-order functions, see recursion relations for Legendre polynomials on next page.

Legendre polynomials:

<u>Recursion</u> relations (Jahnke + Emde) with $x = \cos\theta$

① $$P_n^{m+2}(x) - 2(m+1)\cot\theta \, P_n^{m+1}(x) + (n-m)(n+m+1)\, P_n^{m}(x) = 0$$

② $$(2n+1)\, x \, P_n^{m} - (n-m+1)\, P_{n+1}^{m} - (n+m)\, P_{n-1}^{m} = 0$$

③ also $$n P_n + (n-1) P_{n-2} - (2n-1)\, x \, P_{n-1} = 0$$

Thus $$P_n^{0} = \left(\frac{2n-1}{n}\right) x \, P_{n-1}^{0} - \left(\frac{n-1}{n}\right) P_{n-2}^{0}$$

~~$P_{n+1}^{1} = \left(\frac{2n+1}{n}\right) x \, P_n^{1} - \left(\frac{n+1}{n}\right) P_{n-1}^{1} = 0$~~

or $$P_n^{1} = \left(\frac{2n-1}{n-1}\right) x \, P_{n-1}^{1} - \left(\frac{n}{n-1}\right) P_{n-2}^{1}$$

also $$P_n^{m+2} = 2(m+1)\cot\theta \, P_n^{m+1} - (n-m)(n+m+1)\, P_n^{m}$$

II. The $\mathcal{D}^L_{MM'}$ functions. All decay problems may be treated with the use of only the $\mathcal{D}$ functions with integer indices. (See Byers and Fenster, unpublished appendix of May, 1963, UCLA report; or see UCLRL-11903.) If half-integer indices appear on $\mathcal{D}$ functions one desires to evaluate, low-order functions may be found at back of Jacob and Wick and recursion relations below applied to these.

The general expression for $\mathcal{D}^L_{MM'}(\alpha,\beta,\gamma)$ is $e^{-iM\alpha} d^L_{MM'}(\beta) e^{-iM\gamma}$. Also,

$$d^L_{M0}(\theta) = [4\pi/(2L+1)]^{1/2} Y_{LM}(\theta,0)$$

$$d^L_{M1}(\theta) = [L(L+1)]^{-1/2}\{-M(1+\cos\theta)\, d^L_{M0}/\sin\theta - \sqrt{(L-M)(L+M+1)}\, d^L_{M+1,0}(\theta)\}$$

$$d^L_{-M\lambda}(\theta) = (-)^{L+\lambda} d^L_{M\lambda}(\pi-\theta) \quad \text{or} \quad \mathcal{D}^L_{-M\lambda}(\phi,\theta,0) = (-)^{L+\lambda}\mathcal{D}^{L*}_{M\lambda}(\phi,\pi-\theta,0)$$

(The first of these is given in Edmonds, ANGULAR MOMENTUM IN QUANTUM MECHANICS, p. 59; the second and third relation may be obtained from Eqs. (A1), (A2), and (A5) of Jacob and Wick, *Annals of Physics* 7, 404 (1959).

Examples of $\mathcal{D}^L_{MM'}(\phi,\theta,0)$:

$$\mathcal{D}^l_{00} = P_l(\cos\theta)$$

$$\mathcal{D}^1_{01} = d^1_{01} = -d^1_{10} = \frac{1}{\sqrt{2}}\sin\theta$$

$$\mathcal{D}^2_{01} = d^2_{01} = -d^2_{10} = \sqrt{3/2}\,\sin\theta\cos\theta$$

$$\mathcal{D}^3_{01} = d^3_{01} = -d^3_{10} = \sqrt{3/4}\,\sin\theta(5\cos^2\theta - 1)$$

$$\mathcal{D}^3_{21} = e^{-2i\phi}\frac{\sqrt{10}}{8}\sin\theta\{-3\cos^2\theta - 2\cos\theta + 1\}$$

etc.

Other useful relations (Jacob + Wick):

$$d^L_{\lambda\mu}(\theta) = (-)^{\lambda-\mu} d^L_{\mu\lambda}(\theta)$$

Recursion —

$$2[(L+\mu)(L+\mu-1)]^{1/2} d^L_{\lambda\mu}(\theta) = [(L+\lambda)(L+\lambda-1)]^{1/2}(1+\cos\theta)\, d^{L-1}_{\lambda-1,\mu-1}(\theta)$$
$$+ 2(L^2-\lambda^2)^{1/2}\sin\theta\, d^{L-1}_{\lambda,\mu-1}(\theta)$$
$$+ [(L-\lambda)(L-\lambda-1)]^{1/2}(1-\cos\theta)\, d^{L-1}_{\lambda+1,\mu-1}(\theta).$$

Above relations are adequate for all $d^L_{MM'}$ functions; another relation is J.+W.'s Eq. (A5), given on next page.

Proofs of some special relations:

JBS.

To derive from recursion relation:

[A]

$$[(\ell+1)\ell]^{1/2} d^{\ell}_{m1} = -[(\ell-m)(\ell+m+1)]^{1/2} d^{\ell}_{m+1,0} - m\,\frac{(1+\cos\theta)}{\sin\theta}\, d^{\ell}_{m0}$$

[in Table I of Jacob + Wick]

$\propto Y_{\ell,m+1}(\theta,0)$ $\propto Y_{\ell m}(\theta,0)$

Eq. (A5) 1) $[(j+1)j]^{1/2} d^{j}_{\lambda 1} = -\frac{\lambda}{\sin\theta} d_{\lambda 0} - \frac{\partial}{\partial\theta} d_{\lambda 0}$

2) $[(j+\mu+1)(j-\mu)]^{1/2} d^{j}_{0,\mu+1} = \mu\cot\theta\, d_{0,\mu} - \frac{\partial}{\partial\theta} d_{0,\mu}$

or (2)' $[(j+\lambda+1)(j-\lambda)]^{1/2} d_{\lambda+1,0} \frac{(-)^{\lambda+1}}{(-)} = \lambda\cot\theta\, d_{\lambda 0} (-)^{\lambda} - \frac{\partial}{\partial\theta} d_{\lambda 0} (-)^{\lambda}$

---

① − ②' ⇒ $[(j+1)j]^{1/2} d^{j}_{\lambda 1} = -[(j+\lambda+1)(j-\lambda)]^{1/2} d^{j}_{\lambda+1,0} - \lambda\left(\frac{1}{\sin\theta} + \cot\theta\right) d^{j}_{\lambda 0}$

[B] To show: $d^{L}_{-M1}(\theta) = (-)^{L+1} d^{L}_{M1}(\pi-\theta)$

$$d^{L}_{1,-M}(\theta)\,(-)^{+M-1} = (-)^{L+1}(-)^{1-M} d^{L}_{1M}(\pi-\theta)$$
$$= (-)^{L+M}(-)^{L+1} d_{1,-M}(\theta)$$

and L.H.S. obviously = R.H.Side of this eq'n.

(where $d^{j}_{\lambda\mu}(\theta) = (-)^{j+\lambda} d_{\lambda,-\mu}(\pi-\theta)$ was used)

---

or, more generally, $d^{L}_{-M\nu}(\theta) = (-)^{-M-\nu} d^{L}_{\nu,-M} = (-)^{-M-\nu}(-)^{L+\nu} d^{L}_{\nu M}(\pi-\theta)$
$= (-)^{L-M} d^{L}_{M\nu}(\pi-\theta)\,(-)^{\nu-M}$

[B']

$$d^{L}_{-M\nu}(\theta) = (-)^{L+\nu} d^{L}_{M\nu}(\pi-\theta)$$

[Fo]llowing proof was due to J. R. Morris: [definition of $d^L_{M1}(\theta)$ from Edmonds book]

$$d^L_{M1}(\theta) = \left\{(L+1)!\,(L-1)!\,(L-M)!\,(L+M)!\right\}^{1/2} \sum_k \frac{(-1)^k}{(L-M-k)!\,(L+1-k)!\,(k+M-1)!\,k!} \left(\cos\tfrac{\theta}{2}\right)^{2L+1-M-2k} \left(-\sin\tfrac{\theta}{2}\right)^{M-1+2k}$$

Let $k' = L+1-k$

$$d^L_{M1}(\theta) = \{\ \}^{1/2} \sum_{k'} \frac{(-1)^{L+1-k'}}{(k'-1-M)!\,(k')!\,(L+M-k')!\,(L+1-k)!} \left(\cos\tfrac{\theta}{2}\right)^{2k'-1-M} \left(-\sin\tfrac{\theta}{2}\right)^{M+1+2L-\dots}$$

But then,

$$d^L_{-M1}(\theta) = \{\ \}^{1/2} \sum_{k'} \frac{(-)^{L+1}\,(-1)^{k'}}{(L-M-k')!\,(L+1-k')!\,(k'+M-1)!\,k'!} \left[\sin\left(\frac{\pi-\theta}{2}\right)\right]^{2k'-1+M} \left[(-)\cos\left(\frac{\pi-\theta}{2}\right)\right]^{-M+1+2L-2k'}$$

Thus

$$d^L_{-M1}(\theta) = (-)^{L+1}\{\ \}^{1/2} \sum_{k'} \frac{(-1)^{k'}}{(\ )(\ )(\ )\,k'!} \left[\cos\frac{\pi-\theta}{2}\right]^{2L+1-M-2\dots} \left[\sin\frac{\pi-\theta}{2}\right]^{M-1+\dots}$$

B or

$$\boxed{d^L_{-M1}(\theta) = (-)^{L+1}\, d^L_{M1}(\pi-\theta)}$$

and

$$\mathcal{D}^L_{-M1}(\phi,\theta,0) = (-)^{L+1}\, \mathcal{D}^{L*}_{M1}(\phi,\pi-\theta,0)$$

SUBJECT: PRELIMINARY PROPOSAL FOR A 100 CUBIC METER LIQUID HYDROGEN AND DEUTERIUM BUBBLE CHAMBER (6 TONS OF HYDROGEN)

NAME: M. L. Stevenson

DATE: 12-20-64

A. The Interesting Physics

The need for a large liquid hydrogen (deuterium) chamber for use with the 200-Gev proton sychrotron is based on the necessity to further our understanding of weak, strong, and electromagnetic interactions. Notable among the experiments for which the bubble chamber is ideally suited are the following:

1. Neutrino interactions
2. Decay of strange particles
3. Electromagnetic decay of strongly produced resonant states
4. Strong-interaction reactions with outgoing neutral and charged particles

B. The Experimental Difficulties of Bubble Chamber Physics at High Energy

The experimental difficulties can be summarized as follows:

1. The loss of vital information about a reaction because outgoing neutral particles escape detection in the chamber.
2. The difficulty of identifying outgoing charged particles as pions, kaons, protons, muons or electrons.
3. Momentum measurement accuracy of charged particles of high momentum.
4. The small production cross section of neutrino interactions.

C. How the 100 cubic meter chamber can solve these difficulties.

Considered in the above order, the solutions are:

1. Neutrons, neutral pions $\rightarrow \gamma$ rays, and neutral strange particles can be detected provided sufficient path length exists between the primary interaction and the walls of the chamber. Keeping in mind that, a) the neutron -proton mean free path is 10 meters, b) the γ-ray radiation length is 10 meters, c) the mean decay length of a 15 Gev/c K_1^0 meson is one meter, and d) roughly one meter of high momentum track length is

necessary for accurate momentum measurement of the secondary tracks, one realizes that 3 meters from the primary interaction to the nearest wall would be very helpful. Twenty to thirty per cent of all neutrons and γ rays will convert in this distance. For those experiments that would require a larger γ conversion efficiency there would be sufficient space to put lead plates.

2. The existence of lead plates surrounding the primary interaction volume would also aid in the identification of electrons. Additional plates, provided they were thick enough, would aid in the identification of muons. In practice the best way of identifying the leptons emerging from neutrino interactions is to use a beam known to consist of either neutrinos or antineutrinos. If lepton conservation is strictly obeyed, then in most reactions the negative (positive) particle emerging from a neutrino (antineutrino) interaction is a lepton. For this reason it is essential to produce the neutrino beams from momentum analyzed meson beams as described in section X of the main report.

3. The value of having long, unobstructed, tracks in liquid hydrogen for the purpose of determining both direction and magnitude of momentum hardly needs mentioning.

4. The need for large volume is usually considered to be required primarily by the low neutrino cross section. We place it last in importance because the reason we propose a 100 m^3 chamber rather than 50 m^3 is because of topics 1, 2, and 3 above. The 200 Gev accelerator will produce adquate neutrino fluxes to give reasonable counting rates for both 50 m^3 and 100 m^3 chambers.

D. Estimated Construction Cost

Detailed proposals for 40 m^3 and 26.5 m^3 chambers have been made by the BNL and Argonne laboratories, with estimated costs of $15 and $14 million respectively. The chamber configuration that we propose differs little from these proposals. The size is greater. A possible shape is that of a 6 meter diameter sphere with 1 meter sliced off both top and bottom to allow the pole tips of the magnet to be placed closer together.

Preliminary estimates, aided by the more detailed cost estimates of BNL, suggest a total cost of $38.5 million distributed as follows:

1.	Chamber and Expansion	$ 6.0 m.	9.0
2.	Magnet* (20 kilogauss) and Power Supply	11.2	10.0
3.	Cryogenics	4.7	6.7
4.	Optics	2.4	2.4
5.	Electronic controls	2.6	2.6
6.	Building	11.6	6.0
	Total	$38.5	34.7
		1st estimate	2nd estimate

* Conventional magnet. Development of cryogenic magnets for this purpose may alter this cost estimate.

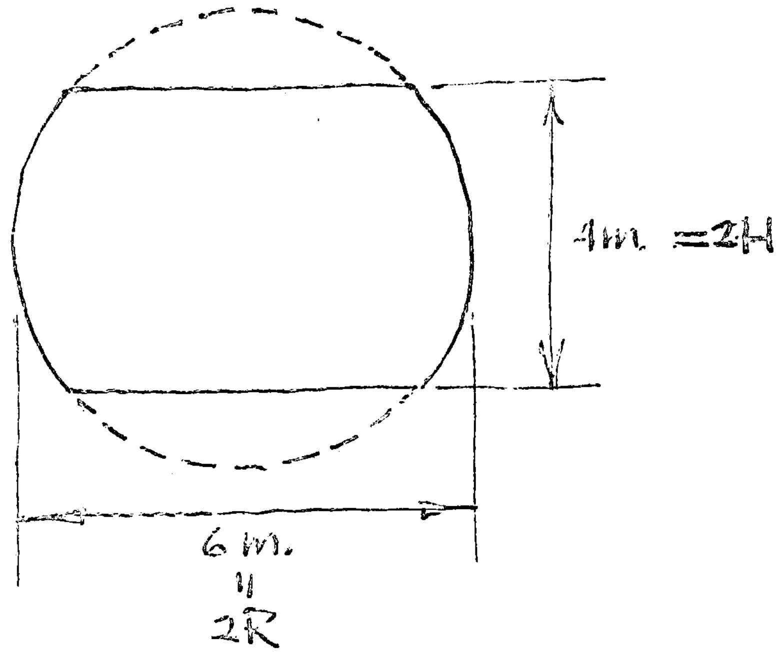
E. Operational costs

These costs are estimates assuming a full time crew of operators working three shifts. It is further assumed that the chamber will be taking pictures approximately fifty percent of the operating time of the accelerator ($\approx$ 4 million pictures/year).

1.	Magnet power + crew	$3.0 million
2.	Film (20 cm, 3 views/pulse)	3.0
	Total	$6.0

F. Appendices

1. Chamber configuration



$$V = 2\pi\left(R^2 H - 1/3\ H^3\right)$$

$R = 3m$

$H = 2m$

$V = 96\ m^3$

January 5, 1965

MEMORANDUM

To: M.L. Stevenson

From: H. Paul Hernandez

Subject: 100 Cubic Meter Liquid Hydrogen Bubble Chamber

The BNL report gives a chamber volume of 40 cubic meters and a cost of 15 million dollars. The ZGS report gives the chamber volume of 26.5 cubic meters and a cost of 14 million dollars.

The cost of the 100 cubic meter chamber might be as follows:

		Million Dollars
1.	Chamber and Expansion	6.00
2.	Magnet and Power Supply (20 kG)	11.2
3.	Cryogenics	4.7
4.	Optics	2.4
5.	Electronic Controls	11.6
6.	Building	2.6
7.	Beam Transport Equipment and Neutrino Shielding	1.5
	Total	40.0

Beam transport equipment and neutrino shielding might be low if this is a very complicated beam line and the shielding is massive. On the AGS studies, the shielding estimates have been running low.

The operating cost paragraph might read as follows:

> The chamber is assumed to have a full-time crew of operators working three shifts and will be taking pictures fifty per cent of the operating time of the accelerator. The operating cost will be about 3.3 million dollars per year, including film. The film* cost is estimated at around $300,000.

Paul Hernandez

* I gave Paul the wrong film size. It was a factor 3 too small.

MLS

NAME G.Smith,P.Wohlmut

DATE 3-5-65

SUBJECT

PROTON EXPERIMENT SCANNING INSTRUCTIONS I

A. TITLE:

The Alvarez Group proton experiment is designated P65, and will be called Experiment # 17.

B. OBJECTIVE:

1. The P65 experiment, utilizing a proton beam between 5.0 to 5.5 Bev/c and 6.5 to 7.0 Bev/c in momentum, is designed to systematically and comprehensively explore this region of high energy physics. In particular, it is expected to substantially increase the amount of data in this region (thus improving the statistics), and will analyze hyperon final states, baryon-meson and baryon-baryon resonances, meson resonances of a high mass, and determine cross-sections for a large number of interactions in proton-proton collisions.

2. The high momentum proton beam (7.0 Bev/c) represents the highest energy that may be obtained from the Bevatron, and covers an area of research not well developed at this time.

C. CHARACTERISTICS OF THE P65 EXPERIMENT:

1. The first distinction between this beam and other beams run by the Alvarez group is that the particles striking the Hydrogen target have a positive unit charge and baryon number. Thus the final states of all interactions must have a net charge of +2, and include two baryons or hyperons.

2. In addition, a proton-proton collision can produce a deuteron (charge +1 and baryon number +2), which will be observed as a track in the bubble chamber.

C. continued

3. Due to the high incident momentum, many particles may be produced in the final state (e.g. two protons plus 14 pions at the highest beam momentum). This will be seen later in the discussion of event types. Vees will usually appear with two or four prong events, but more charged prongs may appear with them.

D. GENERAL SCANNING INSTRUCTIONS:

1. The experiment will record about 500,000 frames of film, beginning in June 1965, which should take approximately 6 to 9 months to scan completely.

2. Rolls to be scanned will be listed in a binder in Room 303 labelled "P65 CURRENT SCAN", and each scanner will be assigned rolls. Each scanner will then mark the date when he begins and ends a roll in the appropriate places in that book.

3. Completed scan sheets should be placed in the "P65 ROLLS COMPLETE" binder. These scan sheets should be complete in all respects, containing all the appropriate information under the headings listed on the sheets. This will be discussed further.

4. Care should be taken in filling out the scanning room log book each time a scanner uses a scan table.

LAWRENCE RADIATION LABORATORY • UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

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D. continued

5. Any malfunction of a scan table should be reported to mechanical or electrical maintenance. Under no circumstances should a table be used which impedes the observation of the film in all three views, or prevents the views or the grid to be superimposed.

6. The following information should be recorded on each scan sheet:

Columns	Description
1-4	Number of roll being scanned
5-7	Frame number of event being described
8	Scan number (1 for 1st scan, 2 for second)
9-10	Beam track of event being described (~~used only if there is more than one event on frame~~).
11-12	Experiment number 17
13	ALWAYS EQUALS 1
14-15 17-18 27-28	Date the page is scanned
16	# VERTICES
19-21	Event type of event being described
22-24 32-34 43-45 51-53	Grid location of vertex being described
25-26 35-36 46-47 54-55	Flag numbers for vertex being described
37-39	Scanner number
56-60	Binary codes 1-10
61-65	Binary codes 11-20
66-70	Binary codes 21-30
71-80	Any scanner comments

All information must appear in the appropriate columns, or the error will be charged to the scanner in the computation of scanning efficiencies. Data which must appear at the top of each page includes the Roll, Date and Scanner number.

NAME G. Smith, P.Wohlmut

SUBJECT P65 SCANNING INSTRUCTIONS

DATE 3-5-65

D. continued

7. The bubble chamber volume to be considered in looking for primary event types lies between the beginning of the chamber and rake 15.

A frame should not be scanned if it contains:

a) Too many beam tracks (TMT) - the maximum allowed # is flexible - consult Experiment coordinator

b) Poor film quality (BAD)

c) No beam tracks (NT)

The scan sheet should contain however, the notation TMT,BAD,NT in columns 1-4 in red pencil for the appropriate frames.

8. Definitions:

a) A non-beam event is defined as an event with the incident beam direction deviating more than $\pm 5^{o}$ from the general beam direction.

b) A secondary event is one which is produced by one of the outgoing particles from a given primary interaction.

c) A ZOON is an event which cannot be described by a combination of primary event type, flags and binary switches.

d) A vee consists of two tracks originating at some point in space, and being oppositely charged.

9. The following criteria apply to valid events:

a) All events produced by true beam tracks, and all vees are considered valid events.

b) Secondary strange ~~[illegible]~~ particle events from charged tracks, should be recorded by using either BC20 or BC26. If the event is one that would normally be recorded you would indicate that there is a secondary strange ~~[illegible]~~ particle interaction by using BC 26. If the primary event is one that is not normally recorded you would record the secondary event type using BC 20. Neutral interactions require the usual E.T. plus B.C. 5. (plus B.C. 23 if appropriate).

c) All vees should be recorded.

D.9 continued

d) Primary events with the beam track less than 1 cm long in View 2 should not be recorded.

e) Pi-meson or charged K ($K^{\pm}$) decays should not be considered in determining the primary event type.

10. Other rules:

a) Assign beam track numbers successively with beam track number 1 assigned to the event closest to the beam entrance window. If several events occur the same distance from the window, assign the lower beam track number to the event closest to the rakes.

b) If in doubt as to where an electron or dalitz pair points, use the correct binary code with all the possible events.

c) Electron pairs at primary vertices are not considered prongs.

7

E. EVENT TYPES:

1. Secondary decays and interactions should be noted by means of one of the flag digits listed below. These should be recorded in the column labelled F_1 for the vertex they describe.

F_1	Description
1	One negative track interacts
2	Several negative tracks interact
3	One positive track interacts
4	Several positive tracks interact
5	One negative track decays
6	Several negative tracks decay
7	One positive track decays
8	Several positive tracks decay
9	Tracks of both charges interact or decay

2. In addition to F_1, a second flag F_2 will be used. This information should be entered in the F_2 coulumn for the vertex to which it applies.

F_2	Description
1 through 8	1,2,3,4,5,6,7 or 8 positive tracks are darker than minimum but are not pi-mesons.

3. Care should be exercised in using these flags correctly, and as often as they apply.

4. Binary codes are used to further describe a given event. Care must be taken in recording these binary switches since they add useful descriptions to an event.

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E.4 continued

Binary Switch	Description
4	Unmeasurable event
6	Frame number obscured
5	Secondary interaction of a neutral particle from primary vertex.
12	Dalitz pair at charged vertex
13	Electron pair associated with event
14	Vee possibly misidentified
15	Leptonic decay
16	Incident track possibly non-beam
17	Another interaction possibly produced vee
18	Mid-air dalitz pair
19	Vee does not point back to primary interaction
20	Secondary interaction of charged track of primary vertex strange particle
22	Vee points at negative decay vertex
23	Positive charged track in space (recoil) possibly associated with vee
24	Beam track has delta ray of greater momentum than allowed for proton.
25	Neutron star associated with event
26	Secondary strange particle interaction when primary event is recorded.

5. The following convention holds for describing events with event type numbers: from charged track

Each event will have assigned three digits which will uniquely describe it. The three digits are XYZ, where X refers to a code for charged decays, Y refers to the number of vees, and Z refers to the number of POSITIVE charged prongs at the production vertex. Thus:

PET XYZ	Description
0YZ	No charged decays from primary event, Y vees, Z positive prongs at production.
1YZ	1 positive decay, Y vees, Z positive tracks at production.
2YZ	2 positive decays, Y vees, Z positive tracks at production.
3YZ	1 negative decay, Y vees, Z positive tracks at production
4YZ	2 negative decays, Y vees, Z positive tracks at production.
5YZ	1 positive, 1 negative decay, Y vees, Z positive tracks at production.

E.5 continued

examples:

PET XYZ	Description
200	Zoon
002	no decays, no vees, 2 prong
008	no decays, no vees, 14 prongs (8 positive prongs)
024	no decays, 2 vees, 6 prongs
010	no decays, 1 vee, no prongs (unassociated vee)
133	1 positive decay, 3 vees, 4 prongs
316	1 negative decay, 1 vee, 10 prongs
507	1 positive decay, 1 negative decay, no vees, 12 tracks
001	NON INTERACTING B.T. WITH B.C. 24

6. THE EXPT. COORDINATOR WILL ANNOUNCE E.T.'s TO be Scanned - this may not be necessarily all possible E.T.'s.

7. Sketches of several event types are shown on the following pages.

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NAME G.Smith, P.Wohlmut

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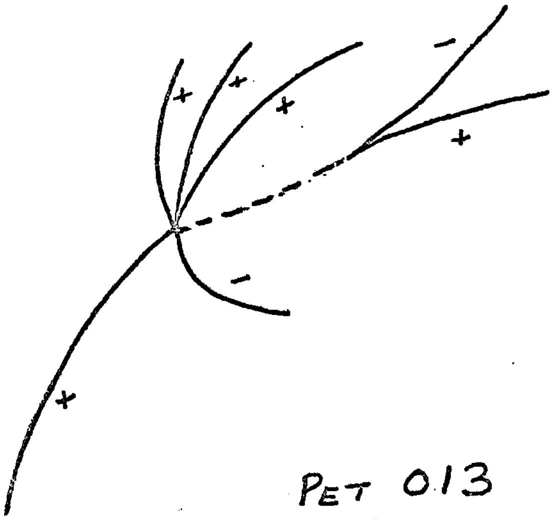
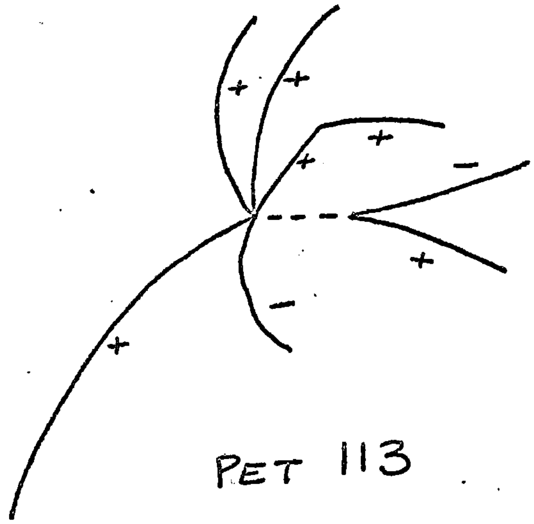
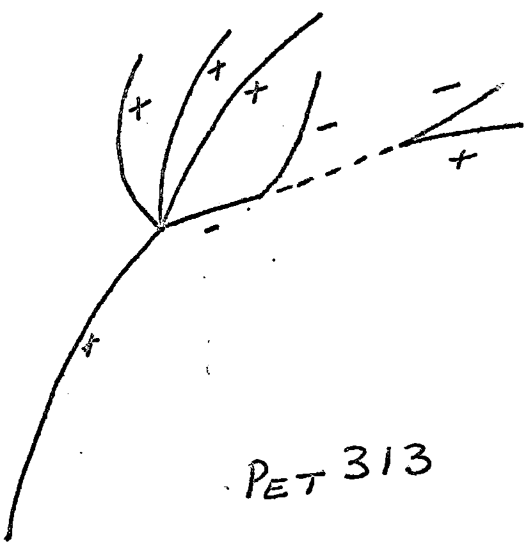


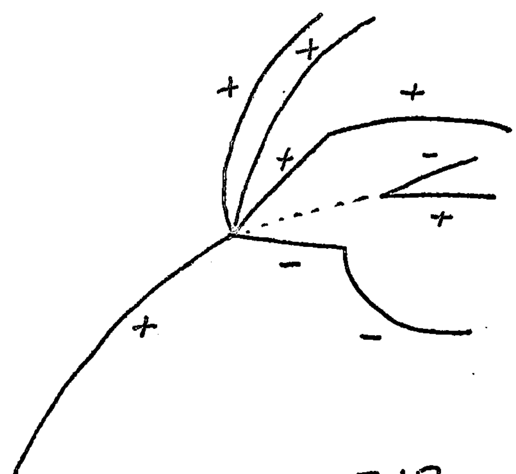
PET 013



PET 113



PET 313



PET 513

SUBJECT: PROTON EXPERIMENT SCANNING INSTRUCTIONS PART II

NAME: L.R. Paradis, et. al

DATE: October 29, 1965

F. General and Miscellaneous Instructions

1. Most of the scan sheet is self-explanatory; however, there are certain conventions which must be rigidly followed.

a) All the information recorded on the scan sheets must be placed in the proper columns. Measuring cards and permanent record cards are punched from the data on the sheets by persons who know little or nothing about the experiment. They are instructed to punch the data exactly as it appears on the scan sheet. Also errors in event type, beam track no., etc. can easily go unnoticed until a check is made.

b) The scan sheets are to be filled out in lead pencil only, preferably a dark lead. Other colors may be used by the library for specific purposes and should be absolutely avoided. In the top right corner of each sheet put the roll number, your initials and scanner number, and the date. Write neatly!

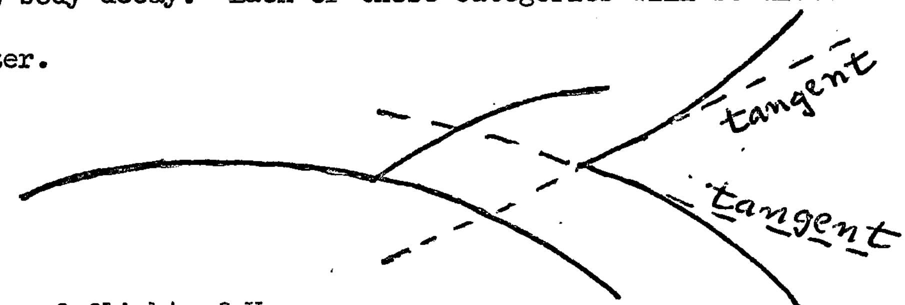
c) Note the first and last frame scanned and the total net number of frames scanned on each roll in the upper left hand corner of the sheet; these will be useful later in cross section determination. Do not sketch any events.

2. Charged Σ's, being short lived ($\Sigma^+ = 0.75 \times 10^{-10}$ sec., $\Sigma^- = 1.6 \times 10^{-10}$ sec.) often decay ($\sim$ 30-40%) close to the vertex (< 1 cm.). For this reason our scanning efficiency can be low, particularly for close in Σ^+ decays into $p\pi^0$ where the darkly ionizing proton makes it difficult to distinguish a kink. Carefully check for charged decays.

3. Association of V's with interactions

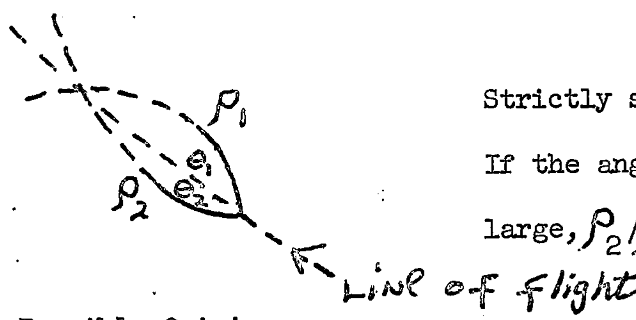
a) Origin of V's

Excluding a 3-body decay (discussed later), the following rule will help determine the origin of a V (not $e^\pm$): Draw tangents to each track at the vertex as shown in the diagram. The origin of the V will lie within the angle formed by the tangents. If you can find no such origin in the picture, this might suggest two possible explanations: (1) the V is "stray", having been produced outside the visible volume of the chamber or (2) it is a leptonic or 3-body decay. Each of these categories will be discussed in some detail later.



b) Line of flight of V:

If the two prongs of a V intersect (or can be made to intersect by extrapolation), the line of flight of the V is defined to be the line going through the vertex and the intersection point. If the two prongs do not intersect, the line of flight is the line which divides the opening angle roughly inversely as the radius of curvature (it is closer to the track with the larger radius of curvature).



Strictly speaking, $\rho_2/\rho_1 = \sin\theta_1/\sin\theta_2$

If the angles θ_1, θ_2 are not very large, $\rho_2/\rho_1 = \theta_1/\theta_2$

c) Several Possible Origins

If there are several interactions with which the V could be associated according to the previous instructions, it should be considered coming from the interaction point on, or closest to, the line of flight. If there is some doubt as to whether there might be another interpretation use Binary Code # 17.

4. Leptonic Decays:

If one of the tracks of a V curls up (hence is an e^+ or e^-) or decays into an e^+ or e^- (hence is a $\mu^\pm$) note this fact with Binary Code # 15. One half of all K^0's produced will be K_1^0's with a lifetime of 0.89×10^{-10} sec, small enough that essentially all K_1^0's will decay in the chamber. They will decay into 2π's > 99% of the time; occasionally they can go leptonically.

Its decay modes are

$$K_1^0 \rightarrow \pi^- + \pi^+$$
$$\rightarrow \pi^0 + \pi^0$$
$$\rightarrow \pi^\pm + \begin{Bmatrix} \mu^\mp \\ e^\mp \end{Bmatrix} + \nu \text{ (leptonic)}$$

The other half of the K^0's will be K_2^0's with a lifetime of about 6.8×10^{-8} sec, long enough that almost all K_2^0's escape from the chamber. However, a small number will decay in the chamber. The K_2^0 always decays via three-body modes:

$$K_2^0 \rightarrow \pi^\pm + \begin{Bmatrix} \mu^\mp \\ e^\mp \end{Bmatrix} + \nu \quad \text{(leptonic)}$$
$$\pi^+ + \pi^- + \pi^0$$
$$\pi^+ + \pi^0 + \pi^0$$

Three body decays quite often appear not to conserve momentum because there is a neutral track unobserved.

5. Unassociated or Stray V's

Sometimes you will find a V (meeting all the criteria for V's previously stated) which certainly has no possible origin in the frame, although one or more interactions are present in that frame. We are even excluding the possibility that the V is a leptonic decay, the general properties of which were described in the preceding section. It is difficult to rigorously define the differences between a possible leptonic decay (no curling $e^\pm$ or μ - e decay) and a "stray" V; however, certain cases are obvious. For example, suppose you found a lambda in a frame with one interaction, say a two prong. In addition, suppose that the lambda were upstream (toward beam entry window) from the two prong. Then, in this case the lambda could not be associated with the two prong from energy and momentum conservation and would truly fall into the category of "stray"V (E. T. 010).

SUBJECT: PROTON EXPERIMENT SCANNING INSTRUCTIONS PART II

NAME: L. R. Paradis

DATE: October 29, 1965

6. Dalitz pair in "mid-air":

If the two prongs of the V both curl up (and hence are $e^{\pm}$) but the opening angle is not zero, then we have a "Dalitz pair in mid-air". Note that in general such Dalitz pairs in mid-air". Note that in general such Dalitz pairs in mid-air (unlike γ-ray pairs) do not point at interactions and can therefore not be associated by inspection with a particular event. In a picture with a "Dalitz pair" in mid-air in which there is an event which you are asked to record, set Binary code 18, if there are several events set Binary code 18 for all of them, if no events - ignore Dalitz pair in mid-air.

7. List of Definitions

a) Unmeasureable event:

An event which is partly obscured by the rake, flare or other tracks in the chamber. These should be kept to a strict minimum. USE B.C. 4.

b) Dalitz Pair at Charged Vertex:

At the primary vertex if one or more tracks coming from the point of interaction curls up and hence is an $e^{\pm}$, we say that there is a Dalitz pair associated.

Dalitz pairs at a primary vertex will not be considered "prongs" in the determination of the event type. After the event type has been decided, ignoring the Dalitz pair, note the presence of the Dalitz pair by setting Binary Code 12. This change will make it necessary for everyone to be much more alert in order to catch all these Dalitz pairs, and to avoid many conflicts between the first and second scans.

SUBJECT: P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM #1

NAME: P. Wohlmut

DATE: 4-6-65

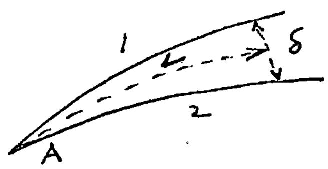
SCAN TABLE MEASUREMENTS

The optics of the bubble chamber system relate scan table measurements to real quantities as follows:

(i) Magnification on table: ≈ 0.69
(ii) Dip angle λ :

$$\tan \lambda = 4.25\ \delta / L$$

where



1,2, refers to some track superimposed in Views 1,2 at vertex A

The top plane of the bubble chamber glass is tilted to the horizontal at an angle of $7\frac{1}{2}^{\circ}$, and the camera lenses are in this plane. Thus measurements of tracks on the table are slightly skewed with respect to the direction of the magnetic field (vertical direction on the table).

Curvature templates are calibrated for the center of the chamber and may be in error as much as 25% at the top of the chamber. The corrected momentum from the measured template momentum is given by:

$$P_{(corrected)} = \frac{P_{(template)} \times Q}{\cos \lambda}$$

Q = depth correction
λ = dip angle
P = momentum

An additional source of error in scan table measurements occurs when the vertex being measured is not directly below the axis of the camera lens. The vertex then is being photographed obliquely and all angles and momenta have to be reconstructed taking the angle from the lenz axis into account.

For most purposes, measurements on the scan table ignoring all the above corrections suffice to give a general idea of the kinematics of an event. However, since substancial errors exist in relating scan table measurements to real value, no decisions should be made in discarding events on the basis of close tolerances. Thus it is not a good idea to eliminate events on the scan table when a 25% correction to some quantity yields an acceptable result.

SUBJECT P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM # 2

NAME Pete Wohlmut
DATE April 6, 1965

MAXIMUM LAB ANGLES FOR HYPERONS

Table I lists the maximum angle at which a hyperon can be produced in the laboratory.

TABLE I

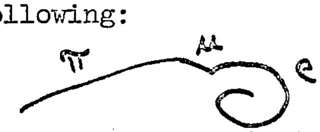
Beam Mom. Bev/c	Max. deg. Σ	Lab Max. d Λ	Max. deg. Ξ
5.0	35.0	38.5	12.2
7.0	39.0	46.0	24.2

These upper limits were calculated from the reactions which involve the production of the hyperon, plus the least number of additional particles:

$$p + p \rightarrow p + k^{+} + \Lambda$$
$$\rightarrow p + k^{+} + \Sigma^{o}$$
$$p + k^{+} + \Xi^{o} + k^{o}$$

From the table above then, it is obvious that a decaying track from a proton-proton primary interaction produced at more than 45^{o} is not a hyperon.

$\pi\ \mu\ e$ decays look like the following:



Stopping π's are dark and produce a μ approximately 0.7 cm. long on the scan table. However, leptonic decays of hyperons, various decay modes of the K meson, and decays where the electron is not observed (only one kink), may look like π decays.

There may be some pion contamination in the proton beam, but this should represent a small percentage of the total flux. Hyperons produced by pion interactions may be producded at angles up to about 55^{o} (for the Lambda particle). Therefore, to include all hyperon decays we should consider the pion interactions as well. Thus, the first criterion in determining whether a decaying track is a π (or $K^{\pm}$) or not is the production angle of the track. If it is more than 60^{o} with respect to the beam direction,

SUBJECT P65 SCANNING INSTRUCTIONS | NAME Pete Wohlmut
P65 SCANNERS, MANUAL ADDENDUM # 2 | DATE April 6, 1965

a hyperon decay may be excluded.

The decay code of the event type XYZ only refers to hyperons, and so the decaying track whose production angle is greater than 60^{o} is not to be considered in the event type.

If the decaying track lies within 60^{o} of the beam direction, a further test may be applied based on ionization and curvature. See Addendum # 6 for explicit instructions.

SUBJECT P65 SCANNING INSTRUCTIONS

P65 SCANNERS MANUAL, ADDENDUM # 3

NAME Pete Wohlmut

DATE April 6, 1965

DELTA RAYS

The association of a delta ray with a beam track yields some information as to the mass of the beam particle when its momentum is known.

There is an upper limit to the energy a proton of a given momentum may impart to an electron. Thus knowing the number of beam tracks which produce delta rays of momentum greater than that allowed for protons yields a measure of the contamination of other particles in the beam. (k^+'s, π^+'s, μ^+'s, e^+'s).

Table I summarizes the maximum momenta for delta rays produced by protons of a given beam momentum, and gives the scan table diameter of the delta ray.

TABLE I

Beam Momentum Bev/c	Max delta ray momentum Mev/c	Table Diam. inches
5.0	25.5	2.5
5.5	30.5	3.0
6.5	43.0	4.2
7.0	49.5	4.9

A delta ray template is given on page 3.3 for the various beam momenta. If a delta ray of greater diameter than that shown for the given beam momentum is found on any beam track, the event should be recorded with binary switch 24. If the beam track does not interact, the event type is 001, binary switch 24 (no decays, no vees, 1 positive track).

It is understood that the electron momenta drawn are the maximum allowable for the proton beam given. A proton may produce a delta ray of lower momentum.

There will also be π^+, μ^+, e^+ contamination in the beam to a small extent. Table II summarizes the maximum momenta that the above particles can impart to electrons:

SUBJECT P65 SCANNING INSTRUCTIONS

P65 SCANNERS MANUAL, ADDENDUM # 3

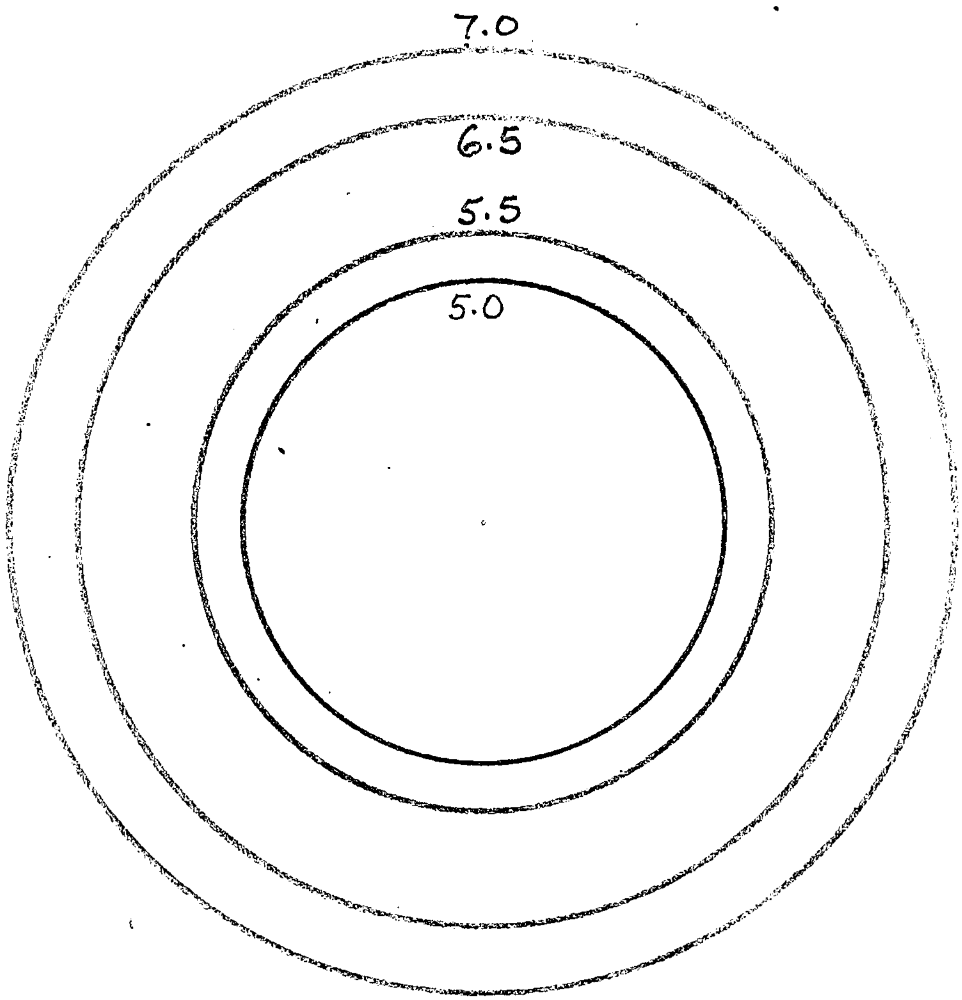
NAME Pete Wohlmut

DATE April 6, 1965

TABLE II

Particle	Momentum Bev/c
π^+	2.5
μ^+	4.5
e^+	7.0

Obviously a delta ray produced by one of the above particles will be of sufficiently high momentum to be indistinguishable from other negative tracks. However, the net charge of the supposed interaction will be zero, and again the event type should be a 001, Binary Switch 24.



Circles represent maximum δ ray momentum from proton of given momentum.

SUBJECT
P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM # 4

NAME Pete Wohlmut
DATE April 6, 1965

PRELIMINARY STUDY OF THE REACTION:

$$p + p \rightarrow d + \pi^+ + n\pi^0$$

The total cross-section for the production of a deuteron at a proton incident momentum of 7.0 Bev/c has been quoted as approximately 100 microbarns.[1] This number seems adequately high to justify scanning at least a special subset of two prong events, to search for the reaction:

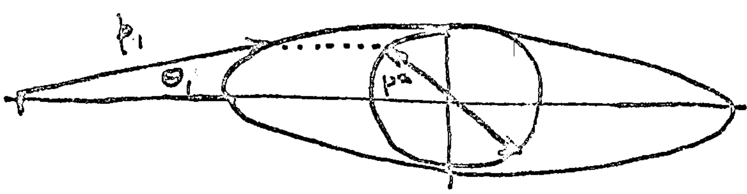
$$p + p \rightarrow d + \pi^+ \; \pi \; n\pi^0; \quad n = 0, 1, 2 \ldots$$

The kinematics for the above reaction with no π^0's is shown in Table I, and the accompanying figures. When additional π^0's are produced, the limits of maximum lab angle are restricted further.

TABLE I

Beam Momentum Bev/c	Lab max. p_d Bev/c	Lab min. p_d Bev/c	Lab min. p_{π^+} Bev/c	Lab max. p_{π^+} Bev/c	$\%p_d <$ 1.876 B/c	Deuteron Lab. θ max. deg.	$P\pi^+$ Bev/c at $\theta_d = \theta$ max.
5.0	5.330	1.186	0.337	3.800	14.70	25.0	3.35
5.5	5.854	1.234	0.374	4.260	10.80	24.5	3.88
6.5	6.859	1.247	0.384	5.250	7.60	24.0	4.86
7.0	7.381	1.275	0.366	5.750	5.25	23.5	5.62

The graphs may be read in a polar coordinate system:



where θ_1 = lab angle of particle$_1$
p_1 = momentum

Ref. 1: Extrapolated from:
C. Cocconi, E. Lillethum, J.P. Scallon, C.A. Stahlbrandt, C.C. Ting, J. Walters, A.M. Wetherell. "Proceedings of the Sionna Conference, 1963". International Conference on Elementary Particles. Sionna 1963.

SUBJECT P65 SCANNING INSTRUCTIONS

NAME Pete Wohlmut

P65 SCANNERS MANUAL, ADDENDUM # 4

DATE April 6, 1965

The calculation of % deuterons with momentum less or equal to 1.876 Bev/c is calculated with the assumption that the production of the deuteron at any center of mass angle is equally probable. This is somewhat in error, but will suffice for the first approximate analysis.

If it is assumed that the cross-section for the above reaction is 100 microbarns over the momentum interval 5.0 to 7.0 Bev/c, we expect approximately 4,000 events of the above type in 500,00 frames of film. Restricting ourselves to deuterons which are darker than minimum ionizing, (approximately 10% on the average of the total sample) we hope to find approximately 400 events in this subclass.

Therefore, when scanning, all two prong events with a positive track darker than minimum, and greater than 1 Bev/c in momentum should be recorded. If there is any doubt as to the ionization of a track, it should be assumed darker than minimum.

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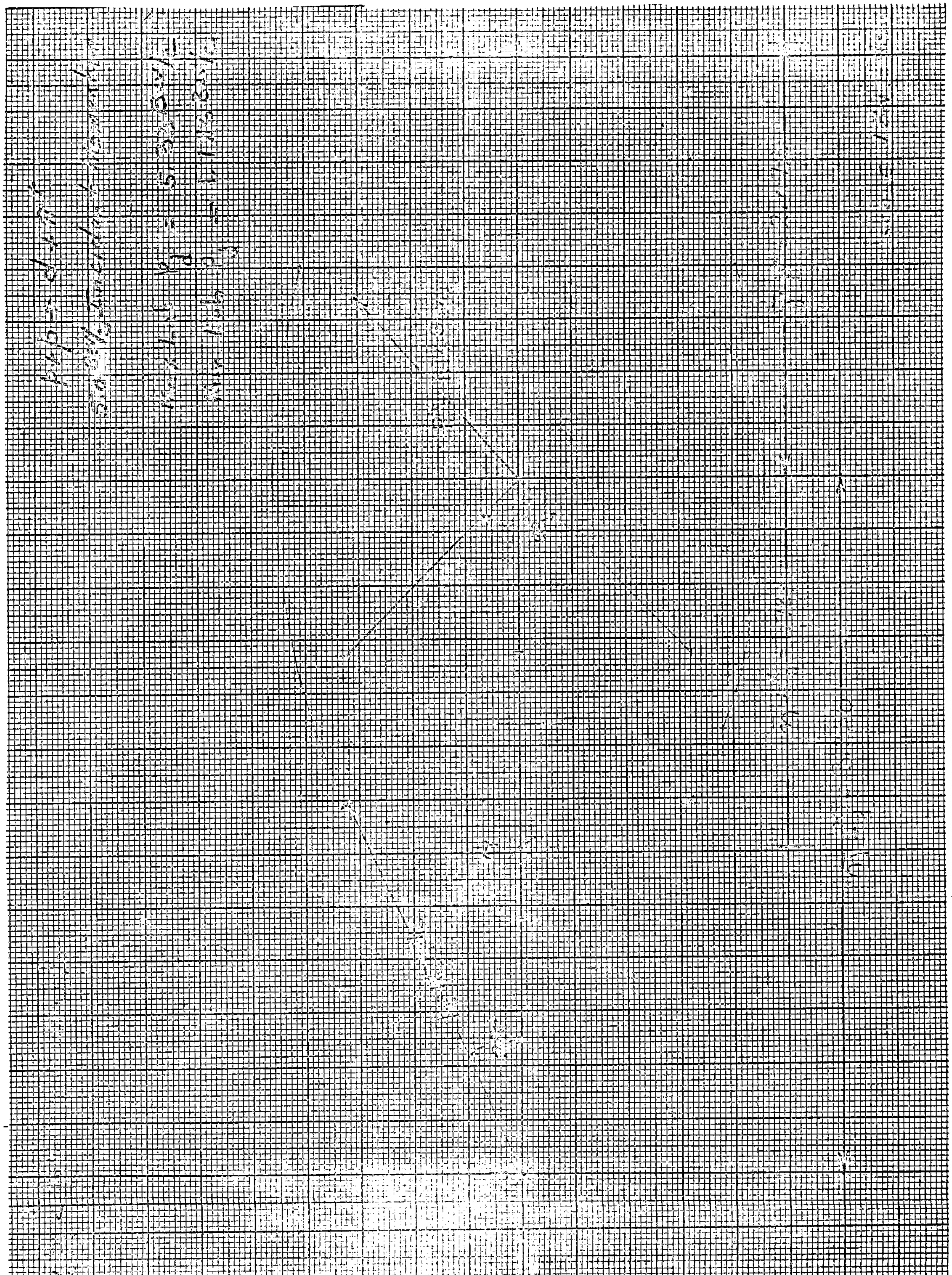
NAME P. WOHLMUT

DATE 4-6-65



RL-2187

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NAME P. WOHLMUT

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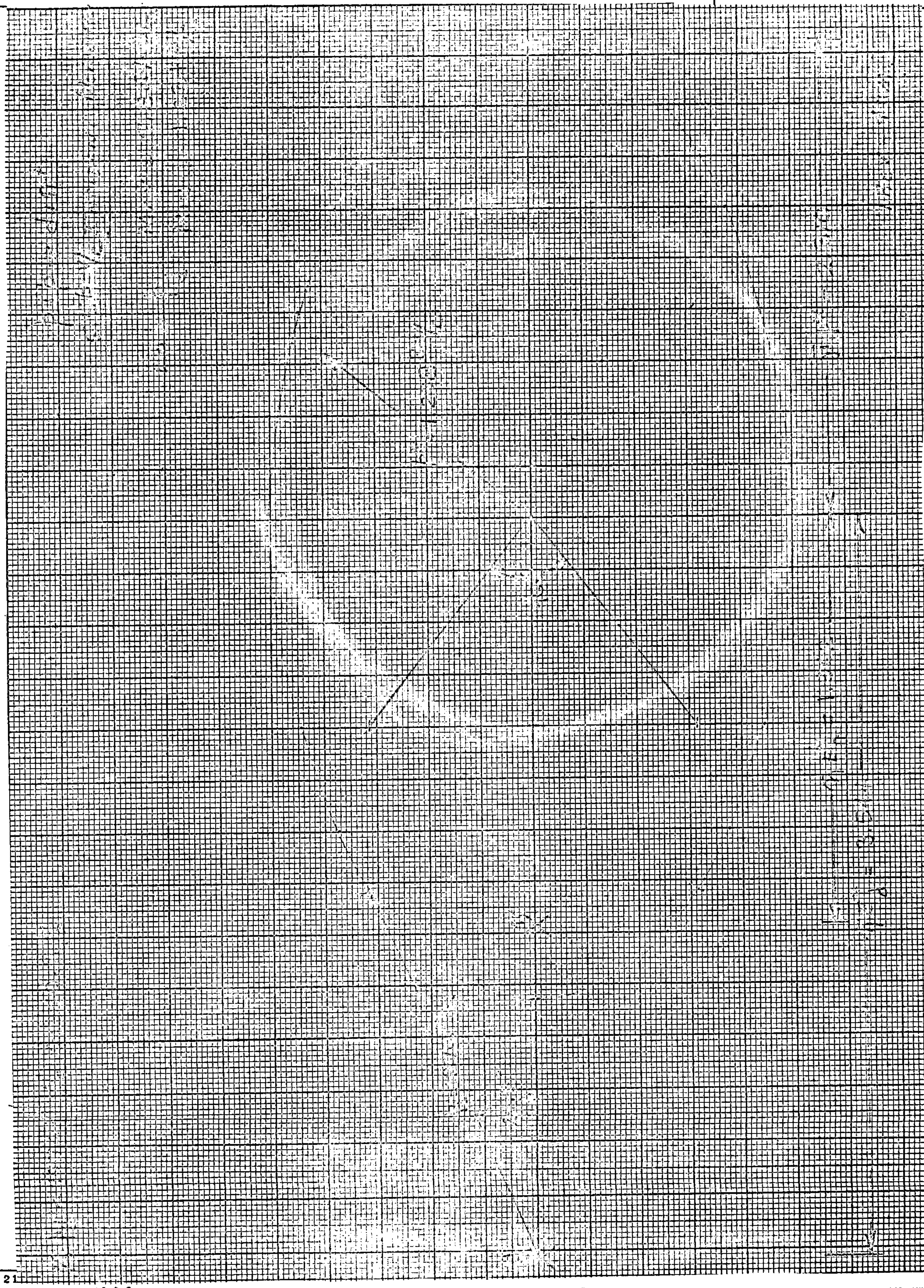

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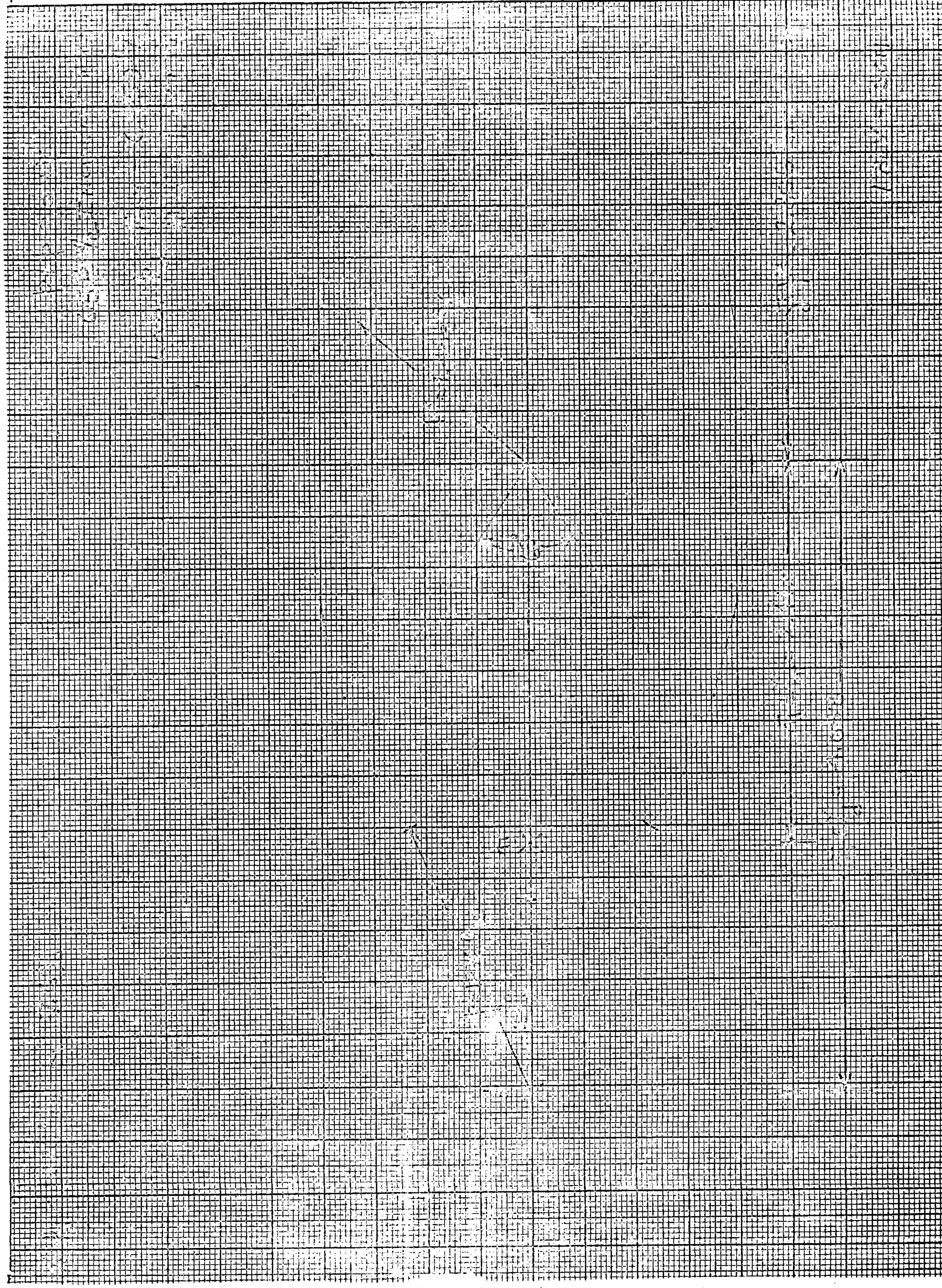

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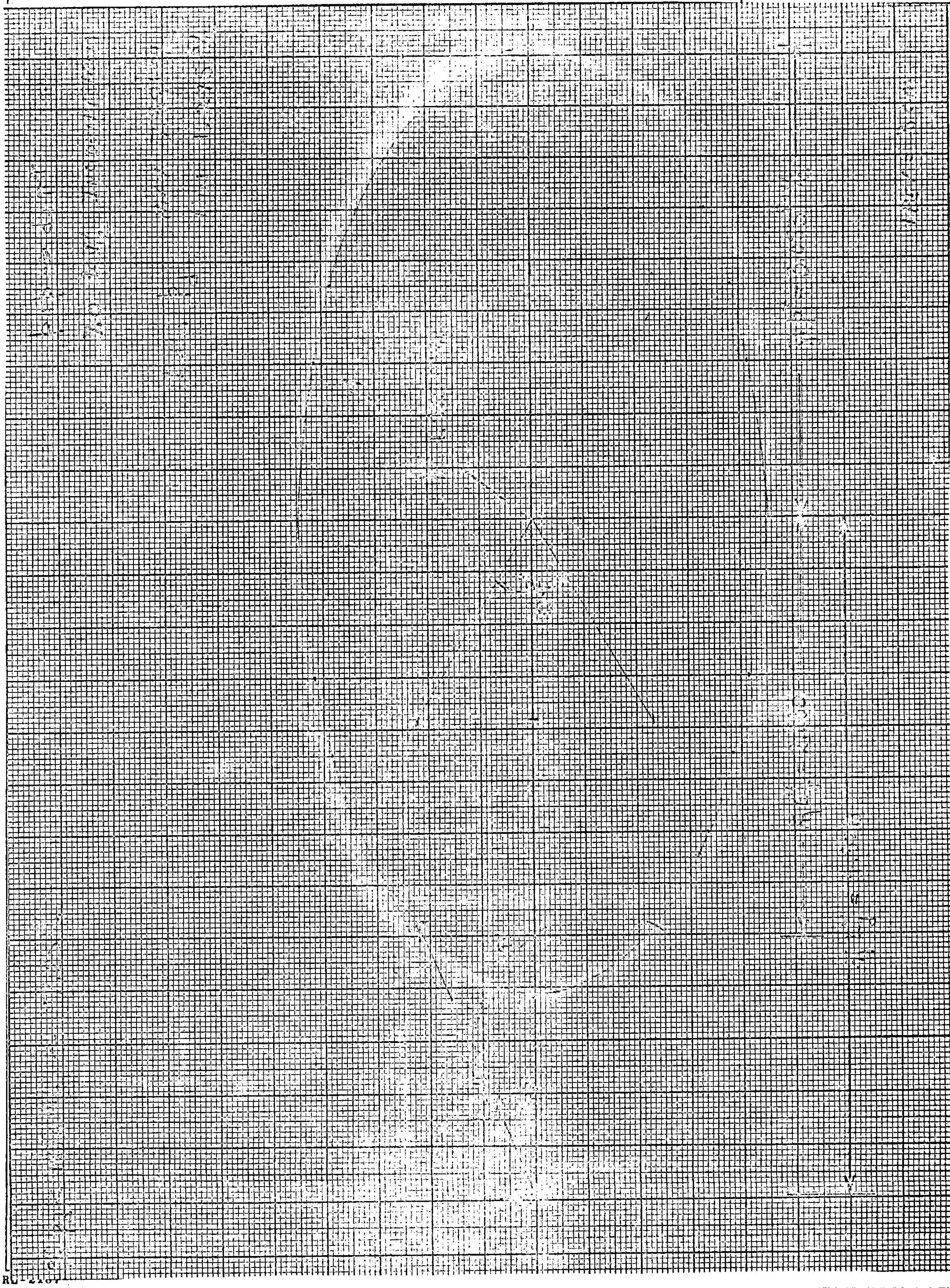

SUBJECT
P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM # 5

NAME J. Manning

DATE October 25, 1965

WHEN IS A VEE A GAMMA RAY PAIR?

In this addendum methods are presented which aid in distinguishing some vees as electron pairs. These instructions supercede previous instructions (K-63, Memo # 456, p. 11), although the K63 instructions are embodied in our new instructions. We present four methods of electron pair detection, any one of which is sufficient to identify a pair.

METHOD I (Kinematics and Ionization)

The standard method of K63 should be well known. In this method one of the members of zero degree-opening angle vee has momentum less than 150 MeV/c and both tracks are minimum ionizing. It is not necessary that the high momentum track be greater than 1 BeV/c, as stated in the K63 instructions. The vee is then identified as an electron pair since pions are twice minimum at a momentum of 150 MeV/c. (see Fig. 1a)

Also, if both members of a zero degree-opening angle vee have momentum less than 1 BeV/c and are both minimum ionizing, the vee is identified as an electron pair. The reasons for this are: (1) since a proton from lambda decay is twice minimum ionizing or darker at a proton momentum of 1 BeV/c or less, the vee cannot be a lambda and (2) kinematics require that there cannot be a zero degree-opening angle decay of a K_1^0 with both pions having less than 1 BeV/c momentum without one of the pions being darker than twice minimum (less than 150 MeV/c). (see Fig. 1b)

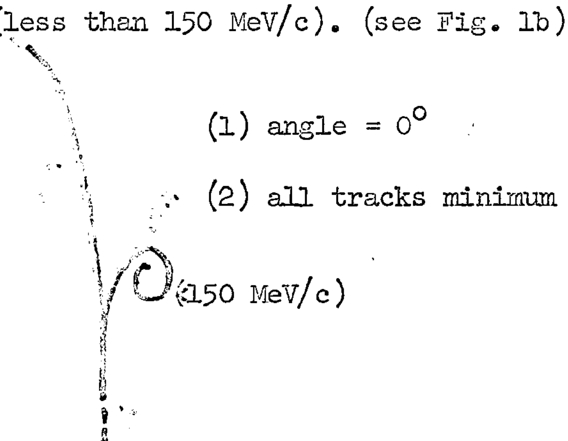

Fig. 1a

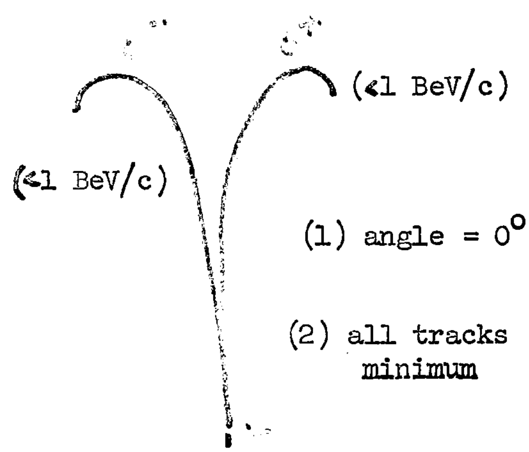

Fig. 1b

METHOD II (Kinematics alone)

If application of Method I fails to identify the vee as an electron pair, Method II should be tried. The momentum of the positive (p_+) and the negative (p_-) members of zero degree-opening angle vees resulting from lambda and K_1^o decays is plotted in Fig. 2. An error of 25% in the measurement of momenta with templates on the scanning table has been allowed for. Any zero degree-opening angle vee with both tracks of minimum ionization (and not having been rejected by Method I) lying outside the shaded area can be identified as an electron pair.

METHOD III (Delta-rays from vees)

It is conceivable that some electron pairs may not be identified by Methods I and II. For example, the rather conservative error of 25% on momentum measurements could permit some electron pairs to slip through our net. Method III is a helpful, although probably not frequently used, technique of identifying electrons. For E. T. 012 it has been calculated that the maximum momentum delta-ray which can be produced by any track from a lambda decay or K_1^o decay is 773 Me V/c at 6.6 BeV/c incident proton momentum and 467 MeV/c at 5.45 BeV/c. It has also been calculated that the maximum total momentum of an electron pair is 5360 MeV/c at 6.6 BeV/c and 4255 MeV/c at 5.45 BeV/c, which may be shared in any proportion between the electron and positron. This means that the maximum momentum delta-ray which can be produced by a member of an electron pair is 5360 MeV/c at 6.6 BeV/c and 4255 MeV/c at 5.45 BeV/c.

All this proves that if the negative member of a zero-opening angle vee of minimum ionization on both tracks makes a delta-ray and both outgoing tracks from the scattering are greater than 773 MeV/c at 6.6 BeV/c or greater than 467 MeV/c at 5.45 BeV/c, than the vee is identified as an electron pair (both outgoing tracks from the scattering must be greater than the given values since the two electrons involved in the collision are indistiguishable). (see Fig. 3a).

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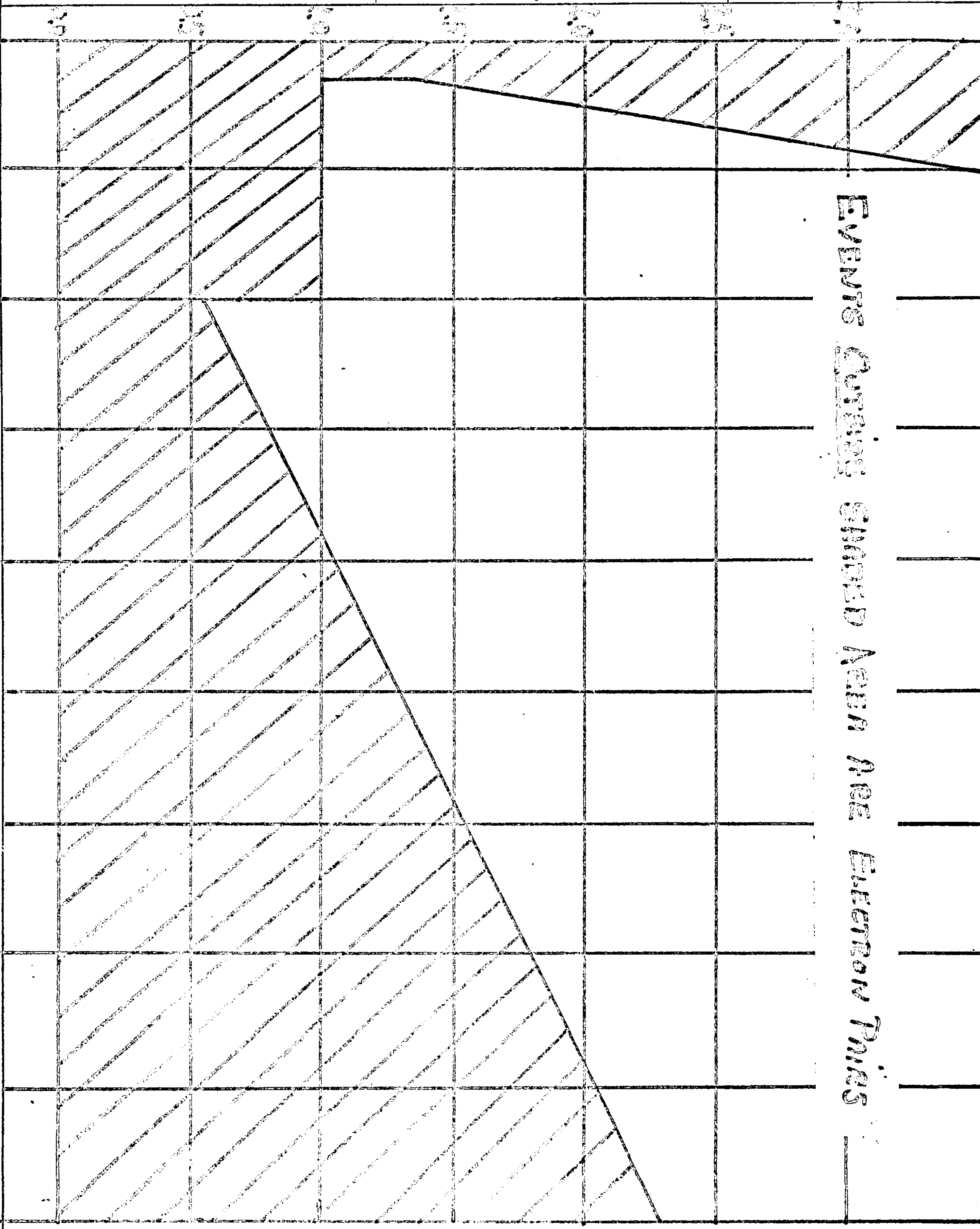

SUBJECT
P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM # 5

NAME J. Manning

DATE October 25, 1965

If the positive member of a zero degree-opening angle vee of minimum ionization on both tracks makes a delta-ray greater than 773 MeV/c at 6.6 BeV/c or greater than 467 MeV/c at 5.45 BeV/c the vee is an electron pair. (see Fig. 3b). An extreme example of this is the case where the incident positron transfers all its energy to a delta-ray (see Fig. 3c).

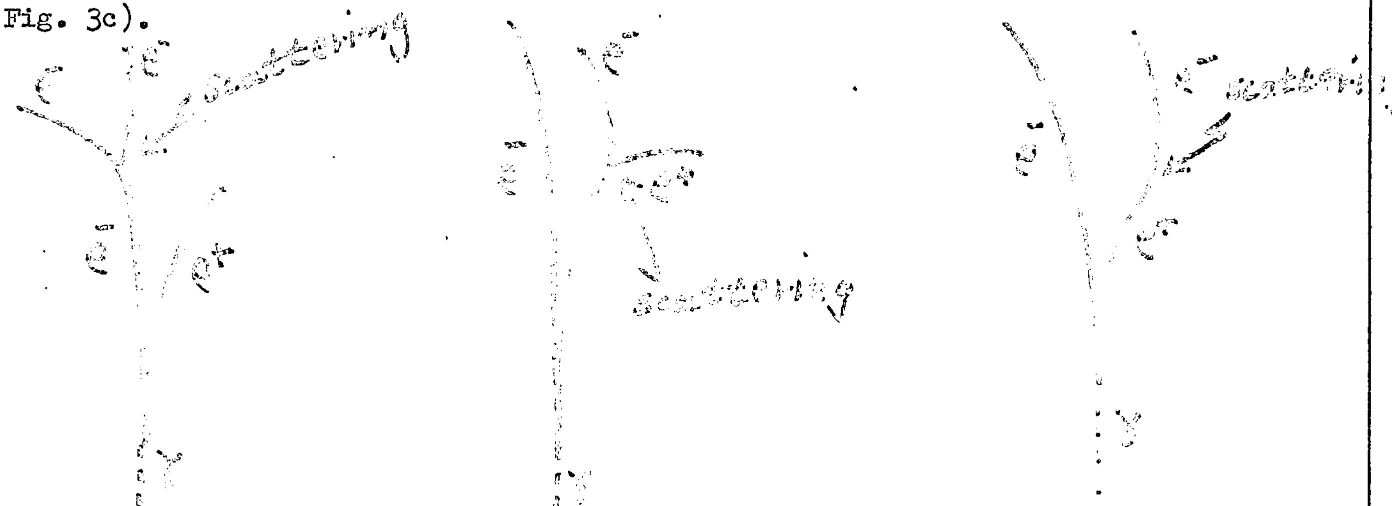

Fig. 3a Fig. 3b Fig. 3c

Similar calculations can be done for other topologies containing vees. However, since 012's are the dominant topology (~ 75%) of all events with vees, we request that scanners apply the above criteria to all events with vees (except 010's whose origin we do not know). This will not result in any systematic errors in judgment, but only in a slightly reduced efficiency for detection of electron pairs in topologies other than 012's.

METHOD IV (Identification of positrons by pair annihilation)

When a positive member of a vee of zero-degree opening angle with both tracks minimum ionizing ends in the chamber, the vee is an electron pair. The positron has interacted with a hydrogen electron to produce $e^+ + e^- \rightarrow \quad + \quad$. You may observe one or two or no associated electron pairs (see Fig. 4). This process is relatively rare.

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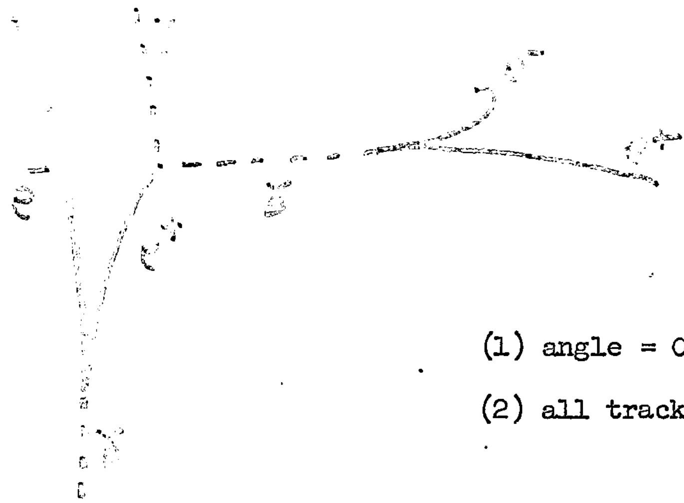
DATE October 25, 1965



(1) angle = 0°

(2) all tracks minimum

Fig. 4

COMMENTS ON METHODS I - IV

(1) If you are in doubt concerning a particular event, don't spend more than 10 minutes or so puzzling over it. Consult a physicist, experiment coordinator or supervisor. If still in doubt, consider the vee legitimate and proceed scanning.

(2) You may throw away an occasional leptonic decay by applying the above tests. We have considered this and feel this is necessary in order to clean out unwanted electron pair background.

(3) In addendum #1, p. 1.1 you are told " Thus it is not a good idea to eliminate events on the scan table when a 25% correctio n to some quantity yields an acceptable result". In general, this is correct. However, for electron pair identification we believe the following technique is more appropriate: In measuring the momentum of a track find the curve on the template which is least curved and most curved and just consistent with the curvature of the track. This defines a range of possible momenta for the track. In subsequent tests involving this measurement if any value in this range indicates that the vee is legitimate, then record the vee as such.

SUBJECT
P65 SCANNING INSTRUCTIONS
P65 SCANNERS :MANUAL, ADDENDUM # 6

NAME G.Smith, B. Wicklund

DATE October 27, 1965

IDENTIFICATION OF SIGMAS BY CURVATURE AND IONIZATION

As described in Addendum # 2, if the laboratory angle of a suspected hyperon as measured with respect to the incoming beam track is greater than 60°, the decaying particle is not to be considered in the event type. If it is less than 60°, the following four tests are individually sufficient to rule out charged sigmas:

(I) The decay has the characteristics of a π-μ-e decay. See page 2.1 of Addendum #2.

(II) The decay has the characteristics of a stopping $K^{\pm}$ decay and fits the stopping K template. The decays shown in Figs. 1a and 1b include approximately 94% of all possible charged K decays at rest

$K^{\pm} \rightarrow \mu^{\pm}\nu$ 63%
$\pi^{\pm}\pi^{0}$ 21%

Fig. 1a

τ- decays
$K^{\pm} \rightarrow \pi^{\pm}\pi^{\pm}\pi^{-}$ 6%
$\pi^{\pm}\pi^{+}e^{\pm}$ 4%

Fig. 1b

(III) The curvature of the decaying track is clearly greater than that of a stopping proton at 17.95 Kg. The minimum sigma momentum in this experiment is approximately 300 MeV/c, well above that of a stopping proton template (approximately 250 MeV/c). This should not be attempted if the decaying track is less than 2 cm. long.

(IV) If the previous 3 tests do not apply, the following test should be made. In Fig. 2 we have plotted the momentum of the decaying track versus the ionization (relative to a beam track) that one would expect for a charged sigma. Permitting dip angles up to 45° on the scan table and uncertainties of 30% on the measurement of momentum with templates for tracks of length greater than 6 cm. and ionization by eye, the allowed region for sigmas is the shaded area. In summary, if a decaying track of length 6 cm. or greater with a dip angle less than 45°

is found to lie outside the shaded area, the decay is not to be considered in the event type.

COMMENTS ON TESTS (I) - (IV)

(I) Same as comment (I), addendum #5, p. 5.5.

(2) We have not provided you with an explicit way of measuring ionization, and therefore your results can only be interpreted as estimates. However, you may find it helpful to know that under most bubble chamber running conditions a track of greater than 3.5 - 4 times minimum is almost solid black. This may be an aid in calibrating yourselves to ionization reading.

(3) Charged $K^{\pm}$ decays (clearly not [illegible] decays) have no bearing on the determination of the event type.

(4) The same applies for sigma momentum measurements as discussed with regard to electron pairs, addendum #5, p. 5.5. As the decaying track gets shorter (down to 6 cm.) the range of possible momenta will increase, particularly for high momentum tracks.

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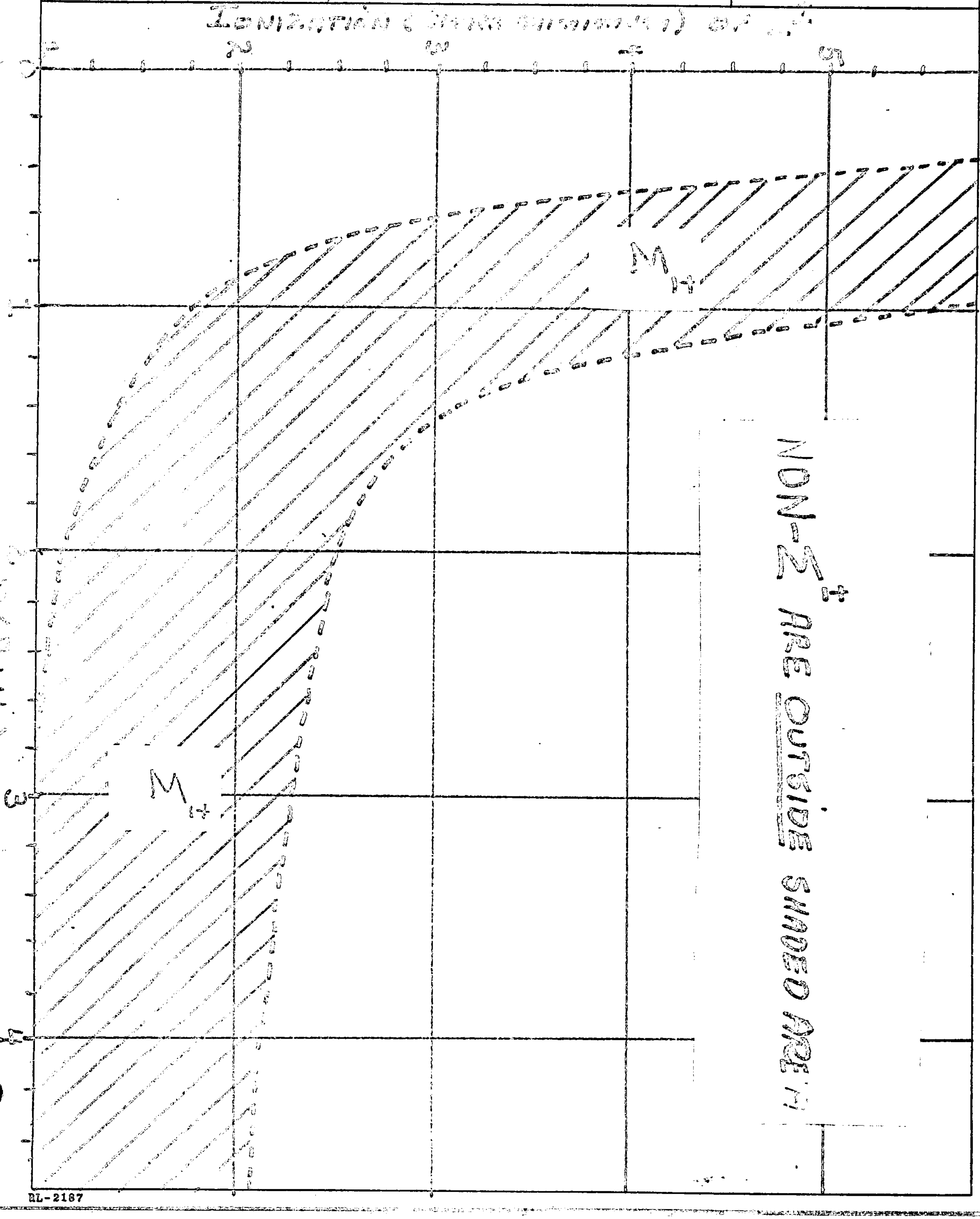

UL-2187

SUBJECT P65 SCANNING INSTRUCTIONS
P65 SCANNERS MANUAL, ADDENDUM # 5

NAME Pete Wohlmut
DATE April 6, 1965

LIST OF POSSIBLE PROTON INTERACTIONS

This addendum provides a list of all the interactions which may be observed in the P65 run in Hydrogen. The checks in the left column indicate which hypothesis is tried in the 7094, 7044 Package. CONST. refers to the number of constraints in the production fit, MULT. refers to the multiplicity or the number of combinations of mass assignments at the production vertex. MASS is the mass of the final states in BEV.

If any reactions have been omitted, they should be brought to the attention of Gerry Smith.

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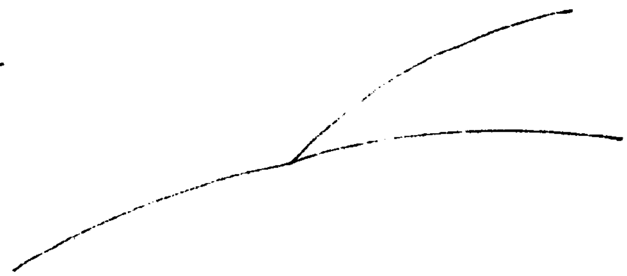
MEMO NO. 548 | PAGE 5.2

NAME F. WOHLMUT

DATE 4-6-65

SUBJECT

PET 002



		REACTION	CONST.	MULT.	MASS
1	✓	$p+p \longrightarrow p+p$	4	1	1876
2	✓	$\longrightarrow p+p+\pi^0$	1	1	2011
3	✓	$\longrightarrow p+\pi^+ + n$	1	2	2018
4	✓	$\longrightarrow d+\pi^+$	4	2	2018
5	✓	$\longrightarrow d+\pi^+ + \pi^0$	1	2	2153
6	✓	$\longrightarrow p+K^+ + \Lambda$	1	2	2547
7	✓	$\longrightarrow p+K^+ + \Sigma^0$	1	2	2625
8	✓	$\longrightarrow d+K^+ + \bar{K}^0$	1	2	2870
9	✓	$\longrightarrow p+p+MM$	4	1	
10	✓	$\longrightarrow p+\pi^+ + MM$	↓	2	
11	✓	$\longrightarrow d+\pi^+ + MM$	↓	2	
12	✓	$\longrightarrow p+K^+ + MM$	↓	2	
13	✓	$\longrightarrow d+K^+ + MM$	↓	2	
14	✓	$\longrightarrow \pi^+ + \pi^+ + MM$	↓	1	
	24			24	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

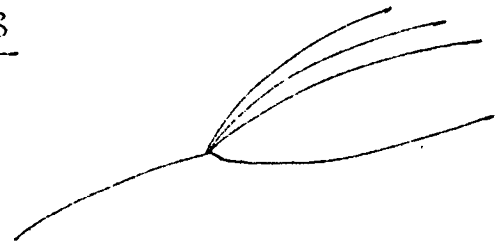
MEMO NO. 548 | PAGE 5.3

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 003



		REACTION	CONST.	MULT.	MASS
1	✓	$p+p \rightarrow p+p+\pi^++\pi^-$	4	3	2156
2	✓	$\rightarrow p+p+\pi^++\pi^-+\pi^0$	1	3	2291
3	✓	$\rightarrow p+\pi^++\pi^++\pi^-+n$	1	3	2298
4	✓	$\rightarrow d+\pi^++\pi^++\pi^-$	4	3	2298
5	✓	$\rightarrow d+\pi^++\pi^++\pi^-+\pi^0$	1	3	2433
6	✓	$\rightarrow p+K^++\pi^++\pi^-+\Lambda$	1	6	2827
7	✓	$\rightarrow p+p+K^++K^-$	4	3	2864
8		$\rightarrow p+K^++\pi^++\pi^-+\Sigma^0$	1	6	2905
9		$\rightarrow p+p+K^++K^-+\pi^0$	1	3	2999
10		$\rightarrow d+K^++\pi^++K^-$	4	6	3006
11		$\rightarrow p+K^++\pi^++K^-+n$	1	6	3006
12		$\rightarrow p+p+K^++\pi^-+\bar{K}^0$	1	3	3008
13		$\rightarrow p+p+\pi^++K^-+K^0$	1	3	3008
14		$\rightarrow d+K^++\pi^++K^-+\pi^0$	1	6	3141
15		$\rightarrow p+K^++K^++\pi^-+\Xi^0$	1	3	3381
16		$\rightarrow p+K^++K^++K^-+\Lambda$	1	3	3535
17		$\rightarrow d+K^++K^++K^-+\bar{K}^0$	1	3	3858
18		$\rightarrow p+p+\pi^++\pi^-+MM$	4	3	
19		$\rightarrow p+\pi^++\pi^++\pi^-+MM$		3	
20		$\rightarrow d+\pi^++\pi^++\pi^-+MM$		3	
21		$\rightarrow p+K^++\pi^++\pi^-+MM$		6	
22		$\rightarrow p+p+K^++K^-+MM$		3	
23		$\rightarrow d+K^++\pi^++K^-+MM$		6	
24		$\rightarrow p+K^++\pi^++K^-+MM$		6	
25		$\rightarrow p+p+K^++\pi^-+MM$		3	
26		$\rightarrow p+p+\pi^++K^-+MM$		3	
27		$\rightarrow p+K^++K^++\pi^-+MM$		3	
27		$\rightarrow p+K^++K^++K^-+MM$		3	
29		$\rightarrow d+K^++K^++K^-+MM$		3	
	24			111	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

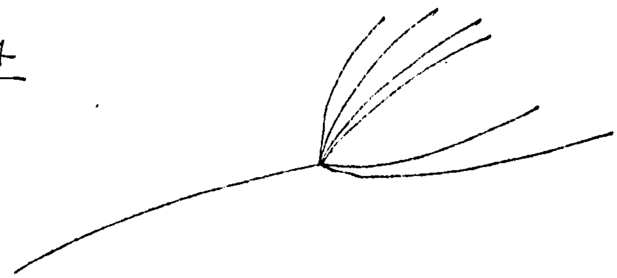
MEMO NO. 548 | PAGE 5.4

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 004



	REACTION	CONST.	MULT.	MASS
✓	$p+p \rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-$	4	6	2436
✓	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-$	4	4	2568
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+\pi^0$	1	6	2571
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+n$	1	4	2518
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^0$	1	4	2703
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+\Lambda$	1	12	3107
	$\rightarrow p+p+K^++\pi^++K^-+\pi^-$	4	24	3148
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+\Sigma^0$	1	12	3185
	$\rightarrow d+K^++\pi^++\pi^++K^-+\pi^-$	4	24	3276
	$\rightarrow p+K^++\pi^++\pi^++K^-+\pi^-+n$	1	24	3276
	$\rightarrow p+p+K^++\pi^++K^-+\pi^-+\pi^0$	1	24	3279
	$\rightarrow p+p+K^++\pi^++\pi^-+\pi^-+\bar{K}^0$	1	12	3288
	$\rightarrow p+p+\pi^++\pi^++K^-+\pi^-+K^0$	1	12	3288
	$\rightarrow d+K^++\pi^++\pi^++K^-+\pi^-+\pi^0$	1	24	3411
	$\rightarrow d+\pi^++\pi^++\pi^++K^-+\pi^-+K^0$	1	8	3420
	$\rightarrow d+K^++\pi^++\pi^++\pi^-+\pi^-+\bar{K}^0$	1	12	3420
	$\rightarrow p+K^++K^++\pi^++\pi^-+\pi^-+\Xi^0$	1	12	3661
	$\rightarrow p+K^++K^++\pi^++K^-+\pi^-+\Lambda$	1	24	3815
	$\rightarrow p+p+K^++K^++K^-+K^-$	4	6	3852
	$\rightarrow p+K^++K^++\pi^++K^-+\pi^-+\Sigma^0$	1	24	3893
✓	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+MM$	4 ↓	6	
✓	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		4	
✓	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		4	
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+MM$		12	
	$\rightarrow p+p+K^++\pi^++K^-+\pi^-+MM$		24	
	$\rightarrow d+K^++\pi^++\pi^++K^-+\pi^-+MM$		24	
	$\rightarrow p+K^++\pi^++\pi^++K^-+\pi^-+MM$		24	
	$\rightarrow p+p+K^++\pi^++\pi^-+\pi^-+MM$		12	
	$\rightarrow p+p+\pi^++\pi^++K^-+\pi^-+MM$		12	
	$\rightarrow d+K^++\pi^++\pi^++K^-+\pi^-+MM$		24	

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PHYSICS NOTES

MEMO NO. 548 | PAGE 5.5

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 004 CONT.

	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow d+\pi^++\pi^++\pi^++K^-+\pi^-+MM$	4	8	
	$\rightarrow d+K^++\pi^++\pi^++\pi^-+\pi^-+MM$	↓	12	
	$\rightarrow p+K^++K^++\pi^++\pi^-+\pi^-+MM$	↓	12	
	$\rightarrow p+K^++K^++\pi^++K^-+\pi^-+MM$	↓	24	
	$\rightarrow p+p+K^++K^++K^-+K^-+MM$	↓	6	
24			486	

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PHYSICS NOTES

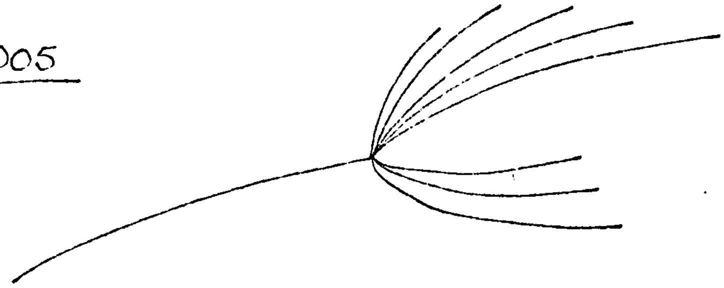
MEMO NO. 548 | PAGE 5.6

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 005



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-$	4	10	2716
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-$	4	5	$28\overset{5}{4}8$
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^0$	1	10	2851
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+n$	1	5	2858
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^0$	1	5	2983
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda$	1	20	3387
	$\longrightarrow p+p+K^++\pi^++\pi^++K^-+\pi^-+\pi^-$	4	90	3428
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Sigma^0$	1	20	3465
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-$	4	60	3566
	$\longrightarrow p+p+K^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^0$	1	90	3559
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+n$	1	60	3566
	$\longrightarrow p+p+K^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\bar{K}^0$	1	30	3568
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+K^-+\pi^-+K^0$	1	30	3568
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^0$	1	60	3691
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+K^0$	1	15	3700
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\bar{K}^0$	1	20	3700
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$	4 ↓	10	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		5	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		5	
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		20	
	$\longrightarrow p+p+K^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		90	
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		60	
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		60	
	$\longrightarrow p+p+K^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		30	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		30	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		15	
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		20	
			875	

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PHYSICS NOTES

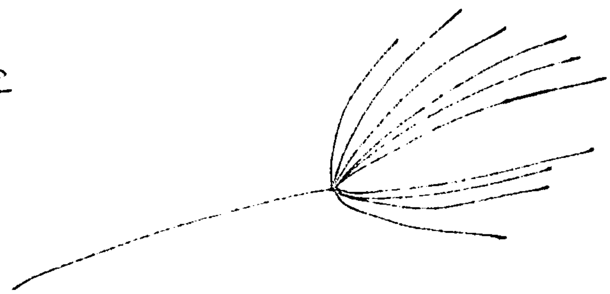
MEMO NO. 548 | PAGE 5.7

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 006



	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-$	4	15	2996
	$\rightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^0$	1	15	3131
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-$	4	6	3138
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+n$	1	6	3138
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^0$	1	6	3263
	$\rightarrow p+K^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Lambda$	1	30	3667
	$\rightarrow p+p+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-$	4	240	3708
	$\rightarrow p+K^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Sigma^0$	1	30	3745
	$\rightarrow p+p+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+\pi^0$	1	240	3839
	$\rightarrow d+K^++\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-$	4	120	3846
	$\rightarrow p+K^++\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+n$	1	120	3846
	$\rightarrow p+p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\bar{K}^0$	1	60	3848
	$\rightarrow p+p+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+K^0$	1	60	3848
	$\rightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	4	15	
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	6	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	6	
	$\rightarrow p+K^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	30	
	$\rightarrow p+p+K^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+MM$	↓	240	
	$\rightarrow d+K^++\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+MM$	↓	120	
	$\rightarrow p+K^++\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+MM$	↓	120	
	$\rightarrow p+p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	60	
	$\rightarrow p+p+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+\pi^-+MM$	↓	60	
			1605.	

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PHYSICS NOTES

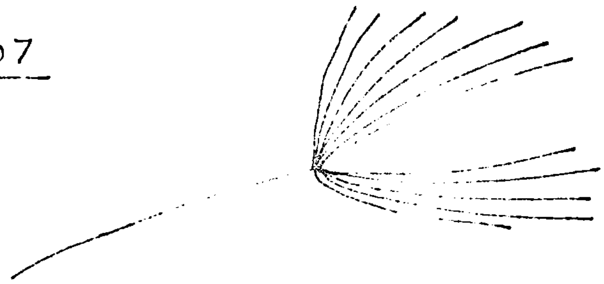
MEMO NO.	PAGE
548	5.8

SUBJECT

NAME: P. WOHLMUT

DATE: 4-6-65

PET 007



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^-$	4	21	3276
	$\longrightarrow p+p+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +\pi^0$	1	21	3411
	$\longrightarrow d+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^-$	4	7	3418
	$\longrightarrow p+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +n$	1	7	3418
	$\longrightarrow d+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +\pi^0$	1	7	3543
	$\longrightarrow p+p+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +MM$	4	21	
	$\longrightarrow d+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +MM$	↓	7	
	$\longrightarrow p+\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\pi^- +\pi^- +\pi^- +MM$	↓	7	

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PHYSICS NOTES

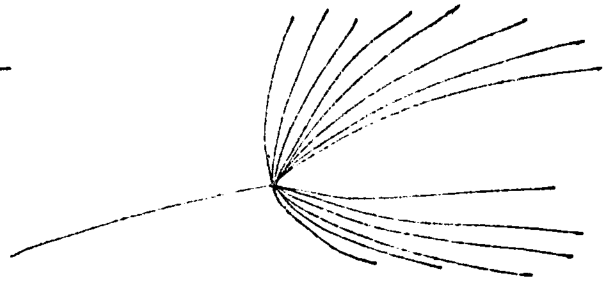
MEMO NO. 548 | PAGE 5.9

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 008



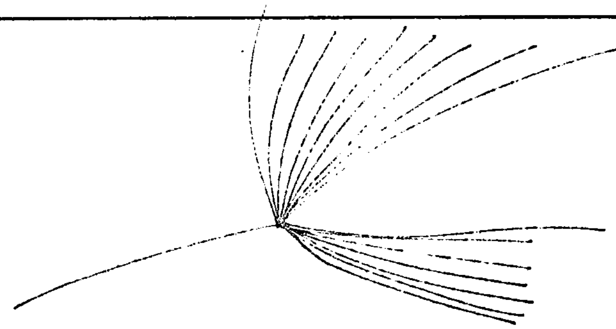
	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-$	4	28	3556
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^0$	1	28	3691
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-$	4	8	3698
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+n$	1	8	3698
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^0$	1	8	3823
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+MM$	4	28	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	8	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+MM$	↓	8	
			124	

SUBJECT

NAME: P. WOHLMUT

DATE: 4-6-65

PET 009



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-$	4	36	3836
	$\longrightarrow p\,p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+\pi^-+MM$	4	36	
			72	

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PHYSICS NOTES

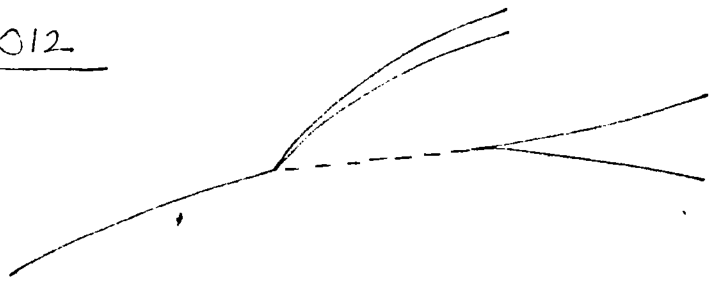
MEMO NO. 548 | PAGE 5.11

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 012



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p+\pi^-$	3	1	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
✓	$p+p \longrightarrow p+K^+ +\Lambda$	4	2	2547
✓	$\longrightarrow p+K^+ + \Sigma^0$	2	~~4~~ 2	2625
✓	$\longrightarrow p+K^+ + \Lambda + \pi^0$	1	2	2682
✓	$\longrightarrow K^+ + \pi^+ + \Lambda + n$	1	2	2689
✓	$\longrightarrow p+\pi^+ + \Lambda + K^0$	1	4	2691
✓	$\longrightarrow p+\pi^+ + \Sigma^0 + K^0$	1	2	2769
✓	$\longrightarrow d + K^+ + \bar{K}^0$	4	2	2870
✓	$\longrightarrow p + K^+ + \bar{K}^0 + n$	1	2	2870
✓	$\longrightarrow p+p+K^0+\bar{K}^0$	1	1	2872
✓	$\longrightarrow d+K^+ + \bar{K}^0 + \pi^0$	1	2	3005
✓	$\longrightarrow d+\pi^+ + K^0 + \bar{K}^0$	1	2	3009
	$\longrightarrow K^+ + K^+ + \Lambda + \Lambda$	1	1	3218
	$\longrightarrow K^+ + K^+ + \Lambda + \Sigma^0$	1	1	3296
	$\longrightarrow p+K^+ + \Lambda + MM$	4	2	
	$\longrightarrow p+K^+ + MM$	↓	2	
	$\longrightarrow K^+ + \pi^+ + \Lambda + MM$		2	
	$\longrightarrow K^+ + \pi^+ + MM$		2	
	$\longrightarrow p+\pi^+ + \Lambda + MM$		2	
	$\longrightarrow p+\pi^+ + K^0 + MM$		2	
	$\longrightarrow p+\pi^+ + MM$		2	
	$\longrightarrow d+K^+ + \bar{K}^0 + MM$		2	
	$\longrightarrow d+K^+ + MM$		2	
	$\longrightarrow p+K^+ + \bar{K}^0 + MM$		2	
	$\longrightarrow p+p+K^0+MM$		1	
	$\longrightarrow p+p+MM$		1	
	$\longrightarrow d+\pi^+ + K^0 + MM$		2	
	$\longrightarrow d+\pi^+ + MM$		2	
	$\longrightarrow K^+ + K^+ + \Lambda + MM$	↓	1	

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PHYSICS NOTES

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SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 012 CONT.

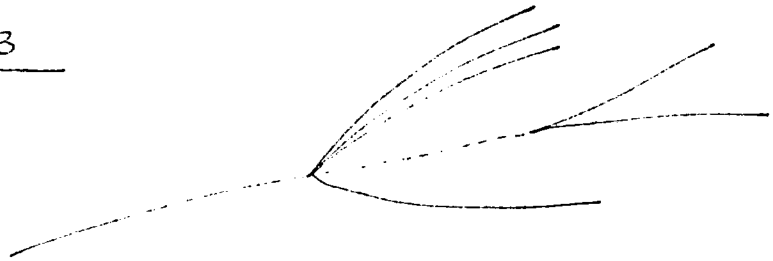
	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow K^+ + K^+ + MM$	4	1	
	$\longrightarrow \pi^+ + \pi^+ + \Lambda + MM$	↓	1	
	$\longrightarrow \pi^+ + \pi^+ + K^0 + MM$	↓	1	
	$\longrightarrow \pi^+ + \pi^+ + MM$	↓	1	
			58	
25			~~60~~	

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 013



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p+\pi^-$	3	1	
·	$\Lambda \longrightarrow p+\pi^-$	1	1	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
✓	$p+p \longrightarrow p+K^+ + \pi^+ + \pi^- + \Lambda$	4	6	2827
✓	$\longrightarrow p+K^+ + \pi^+ + \pi^- + \Sigma^0$	2	6	2905
✓	$\longrightarrow p+K^+ + \pi^+ + \pi^- + \Lambda + \pi^0$	1	6	2962
✓	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + n$	1	3	2969
	$\longrightarrow p+\pi^+ + \pi^+ + \pi^- + \Lambda + K^0$	1	6	2971
✓	$\longrightarrow p+p+K^+ + \pi^- + \bar{K}^0$	4	3	3008
✓	$\longrightarrow p+p+\pi^+ + K^- + K^0$	4	3	3008
	$\longrightarrow p+\pi^+ + \pi^+ + \pi^- + \Sigma^0 + K^0$	1	3	3049
	$\longrightarrow p+p+K^+ + \pi^- + \bar{K}^0 + \pi^0$	1	3	3143
	$\longrightarrow p+p+\pi^+ + K^- + K^0 + \pi^0$	1	3	3143
	$\longrightarrow p+\pi^+ + \pi^+ + K^- + K^0 + n$	1	3	3150
	$\longrightarrow p+K^+ + \pi^+ + \pi^- + \bar{K}^0 + n$	1	6	3150
	$\longrightarrow d+K^+ + \pi^+ + \pi^- + \bar{K}^0$	4	6	3150
	$\longrightarrow d+\pi^+ + \pi^+ + K^- + K^0$	4	3	3150
	$\longrightarrow p+p+\pi^+ + \pi^- + K^0 + \bar{K}^0$	1	3	3152
	$\longrightarrow d+K^+ + \pi^+ + \pi^- + \bar{K}^0 + \pi^0$	1	6	3285
	$\longrightarrow d+\pi^+ + \pi^+ + K^- + K^0 + \pi^0$	1	3	3285
	$\longrightarrow d+\pi^+ + \pi^+ + \pi^- + K^0 + \bar{K}^0$	1	3	3294
	$\longrightarrow p+K^+ + K^+ + \pi^- + \Xi^0$	3	3	3381
✓	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^- + \Lambda + \Lambda$	1	3	3498
	$\longrightarrow p+K^+ + \pi^+ + \pi^- + \Xi^0 + K^0$	1	6	3525
	$\longrightarrow p+K^+ + K^+ + K^- + \Lambda$	4	3	3535
	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^- + \Lambda + \Sigma^0$	1	3	3576
	$\longrightarrow p+K^+ + K^+ + K^- + \Sigma^0$	2	3	3613
	$\longrightarrow p+K^+ + K^+ + K^- + \Lambda + \pi^0$	1	3	3670
	$\longrightarrow K^+ + K^+ + \pi^+ + K^- + \Lambda + n$	1	3	3677
	$\longrightarrow p+K^+ + \pi^+ + K^- + \Lambda + K^0$	1	12	3679

PET 013 CONT.

	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^++\pi^++K^-+\Sigma^0+K^0$	1	6	3757
	$\longrightarrow p+p+K^++K^-+K^0+\bar{K}^0$	1	3	3854
	$\longrightarrow p+K^++K^++K^-+\bar{K}^0+n$	1	3	3858
	$\longrightarrow d+K^++K^++K^-+\bar{K}^0$	4	3	3858
	$\longrightarrow p+K^++\pi^++\pi^-+\Lambda+MM$	4	6	
	$\longrightarrow p+K^++\pi^++\pi^-+MM$	↓	6	
	$\longrightarrow K^++\pi^++\pi^++\pi^-+\Lambda+MM$		3	
	$\longrightarrow K^++\pi^++\pi^++\pi^-+MM$		3	
	$\longrightarrow p+\pi^++\pi^++\pi^-+\Lambda+MM$		3	
	$\longrightarrow p+\pi^++\pi^++\pi^-+K^0+MM$		3	
	$\longrightarrow p+\pi^++\pi^++\pi^-+MM$		3	
	$\longrightarrow p+p+K^++\pi^-+\bar{K}^0+MM$		3	
	$\longrightarrow p+p+K^++\pi^-+MM$		3	
	$\longrightarrow p+p+\pi^++K^-+K^0+MM$		3	
	$\longrightarrow p+p+\pi^++K^-+MM$		3	
	$\longrightarrow p+\pi^++\pi^++K^-+K^0+MM$		3	
	$\longrightarrow p+\pi^++\pi^++K^-+MM$		3	
	$\longrightarrow p+K^++\pi^++\pi^-+\bar{K}^0+MM$		6	
	$\longrightarrow d+K^++\pi^++\pi^-+\bar{K}^0+MM$		6	
	$\longrightarrow d+K^++\pi^++\pi^-+MM$		6	
	$\longrightarrow p+p+\pi^++\pi^-+K^0+MM$		3	
	$\longrightarrow p+p+\pi^++\pi^-+MM$		3	
	$\longrightarrow d+\pi^++\pi^++K^-+K^0+MM$		3	
	$\longrightarrow d+\pi^++\pi^++K^-+MM$		3	
	$\longrightarrow d+\pi^++\pi^++\pi^-+K^0+MM$		3	
	$\longrightarrow d+\pi^++\pi^++\pi^-+MM$		3	
	$\longrightarrow p+K^++K^++\pi^-+MM$		3	
	$\longrightarrow K^++K^++\pi^++\pi^-+\Lambda+MM$		3	
	$\longrightarrow K^++K^++\pi^++\pi^-+MM$		3	
	$\longrightarrow p+K^++K^++K^-+\Lambda+MM$	↓	3	

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SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 013 CONT.

	REACTION	CONST.	MULT.	MASS
	$p + p \longrightarrow p + K^+ + K^+ + K^- + MM$	4	3	
	$\longrightarrow K^+ + K^+ + \pi^+ + K^- + \Lambda + MM$		3	
	$\longrightarrow K^+ + K^+ + \pi^+ + K^- + MM$		3	
	$\longrightarrow p + K^+ + \pi^+ + K^- + \Lambda + MM$		6	
	$\longrightarrow p + K^+ + \pi^+ + K^- + K^0 + MM$		6	
	$\longrightarrow p + K^+ + \pi^+ + K^- + MM$		6	
	$\longrightarrow p + p + K^+ + K^- + K^0 + MM$		3	
	$\longrightarrow p + p + K^+ + K^- + MM$		3	
	$\longrightarrow p + K^+ + K^+ + K^- + \bar{K}^0 + MM$		3	
	$\longrightarrow d + K^+ + K^+ + K^- + \bar{K}^0 + MM$		3	
	$\longrightarrow d + K^+ + K^+ + K^- + MM$		3	
23			267	
25			[illegible]	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

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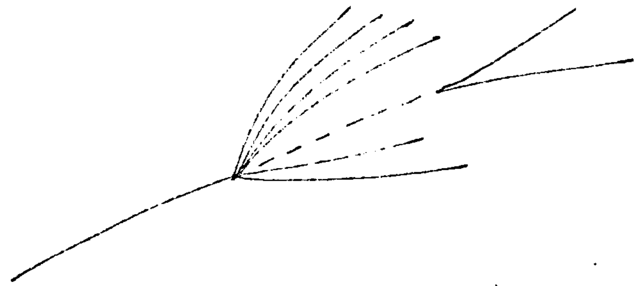
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 014



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	1	
	$\Lambda \longrightarrow p + \pi^-$	1	1	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda$	4	12	3107
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Sigma^0$	2	12	3185
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + \pi^0$	1	12	3242
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + n$	1	4	3249
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + K^0$	1	8	3251
	$\longrightarrow p + p + K^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0$	4	12	3288
	$\longrightarrow p + p + \pi^+ + \pi^+ + K^- + \pi^- + K^0$	4	12	3288
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Sigma^0 + K^0$	1	4	3329
	$\longrightarrow p + p + K^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + \pi^0$	1	12	3423
	$\longrightarrow p + p + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + \pi^0$	1	12	3423
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + n$	1	8	3430
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + n$	1	12	3430
	$\longrightarrow d + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0$	4	12	3430
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + K^0$	4	8	3430
	$\longrightarrow p + p + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + \bar{K}^0$	1	6	3452
	$\longrightarrow d + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + \pi^0$	1	12	3565
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + \pi^0$	1	8	3565
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + \bar{K}^0$	1	4	3574
	$\longrightarrow p + K^+ + K^+ + \pi^+ + \pi^- + \pi^- + \Xi^0$	3	12	3661
	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + \Lambda$	1	6	3778
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Xi^0 + K^0$	1	12	3805
	$\longrightarrow p + K^+ + K^+ + K^- + \pi^+ + \pi^- + \Lambda$	4	24	3815
	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + \Sigma^0$	1	6	3856
	$\longrightarrow p + K^+ + K^+ + \pi^+ + K^- + \pi^- + \Sigma^0$	1	24	3893
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + MM$	4	12	
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$	↓	12	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + MM$	↓	4	

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PHYSICS NOTES

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SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 014 CONT

	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$	4	4	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + MM$		4	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$		4	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		4	
	$\rightarrow p + p + K^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + MM$		12	
	$\rightarrow p + p + K^+ + \pi^+ + \pi^- + \pi^- + MM$		12	
	$\rightarrow p + p + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + MM$		12	
	$\rightarrow p + p + \pi^+ + \pi^+ + K^- + \pi^- + MM$		12	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + MM$		8	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + MM$		8	
	$\rightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + MM$		12	
	$\rightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		12	
	$\rightarrow d + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \bar{K}^0 + MM$		12	
	$\rightarrow d + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + K^0 + MM$		8	
	$\rightarrow d + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		12	
	$\rightarrow d + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + MM$		8	
	$\rightarrow p + p + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$		6	
	$\rightarrow p + p + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		6	
	$\rightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$		4	
	$\rightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		4	
	$\rightarrow p + K^+ + K^+ + \pi^+ + \pi^- + \pi^- + MM$		12	
	$\rightarrow K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + MM$		6	
	$\rightarrow K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		6	
	$\rightarrow p + K^+ + K^+ + K^- + \pi^+ + \pi^- + \Lambda + MM$		24	
	$\rightarrow p + K^+ + K^+ + \pi^+ + K^- + \pi^- + MM$		24	
			521	

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PHYSICS NOTES

MEMO NO.	PAGE
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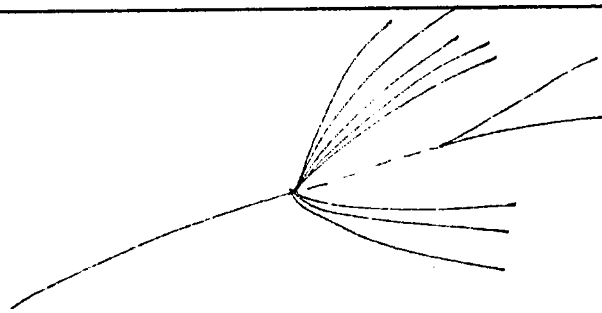
NAME: P. WOHLMUT

DATE: 4-6-65

SUBJECT

PET 015



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p+\pi^-$	3	1	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p+p \longrightarrow p+K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda$	4	20	3387
	$\longrightarrow p+K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Sigma^0$	2	20	3465
	$\longrightarrow p+K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + \pi^0$	1	20	3522
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + n$	1	5	3529
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + K^0$	1	10	3531
	$\longrightarrow p+p+K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0$	4	30	3568
	$\longrightarrow p+p+\pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0$	4	30	3568
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Sigma^0 + K^0$	1	5	3609
	$\longrightarrow p+p+K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0 + \pi^0$	1	30	3703
	$\longrightarrow p+p+\pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0 + \pi^0$	1	30	3703
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0 + n$	1	15	3710
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0 + n$	1	20	3710
	$\longrightarrow d + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0$	4	20	3710
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0$	4	15	3710
	$\longrightarrow p+p+\pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + \bar{K}^0$	1	10	3732
	$\longrightarrow d + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0 + \pi^0$	1	20	3845
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0 + \pi^0$	1	15	3845
	$\longrightarrow d + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + \bar{K}^0$	1	5	3854
	$\longrightarrow p+K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + MM$	4	20	
	$\longrightarrow p+K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		20	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + MM$		5	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		5	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \Lambda + MM$		5	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + MM$		5	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		5	
	$\longrightarrow p+p+K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \bar{K}^0 + MM$		30	
	$\longrightarrow p+p+K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		30	
	$\longrightarrow p+p+\pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + K^0 + MM$	↓	30	

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NAME: P. WOHLMUT
DATE: 4-6-65
SUBJECT:

PET015 CONT.

	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$	4	30	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+K^0+MM$		15	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		15	
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\bar{K}^0+MM$		20	
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\bar{K}^0+MM$		20	
	$\longrightarrow d+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		20	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+K^0+MM$		15	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++K^-+\pi^-+\pi^-+MM$		15	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		10	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		10	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		5	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		5	
			657	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

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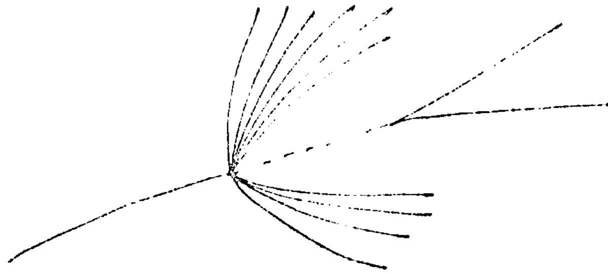
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 016



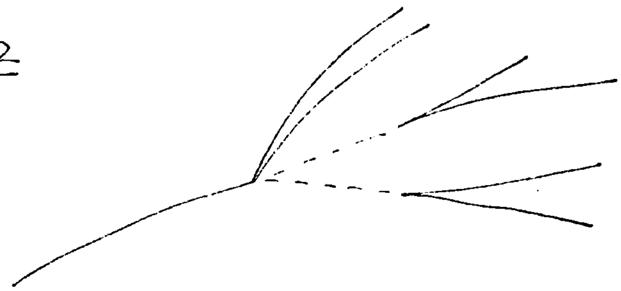
	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	1	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda$	4	30	3667
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Sigma^0$	2	30	3745
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + \pi^0$	1	30	3802
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + n$	1	6	3809
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + K^0$	1	12	3811
	$\longrightarrow p + p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \bar{K}^0$	4	60	3848
	$\longrightarrow p + p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + \pi^- + K^0$	4	60	3848
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Sigma^0 + K^0$	1	6	3889
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + MM$	4	30	
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + MM$		30	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + MM$		6	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + MM$		6	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \Lambda + MM$		6	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + MM$		6	
	$\longrightarrow p + p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + \bar{K}^0 + MM$		60	
	$\longrightarrow p + p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + MM$		60	
	$\longrightarrow p + p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + \pi^- + K^0 + MM$		60	
	$\longrightarrow p + p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + K^- + \pi^- + \pi^- + \pi^- + MM$		60	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0 + MM$		6	
			566	

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 022



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p+\pi^-$	3	2	
	$\Lambda \longrightarrow p+\pi^-$	1	2	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
✓	$p+p \longrightarrow p+\pi^+ + \Lambda + K^0$	4	4	2691
✓	$\longrightarrow p+\pi^+ + \Sigma^0 + K^0$	2	4	2769
✓	$\longrightarrow p+\pi^+ + \Lambda + K^0 + \pi^0$	1	4	2826
✓	$\longrightarrow \pi^+ + \pi^+ + \Lambda + K^0 + n$	1	2	2833
✓	$\longrightarrow p+p+K^0+\bar{K}^0$	4	1	2872
✓	$\longrightarrow p+p+K^0+\bar{K}^0+\pi^0$	1	1	3007
✓	$\longrightarrow p+n+\pi^+ + K^0+\bar{K}^0$	1	2	3014
✓	$\longrightarrow d+\pi^+ + K^0+\bar{K}^0$	4	2	3014
	$\longrightarrow d+\pi^+ + K^0+\bar{K}^0+\pi^0$	1	2	3149
	$\longrightarrow K^+ + K^+ + \Lambda + \Lambda$	4	1	3218
	$\longrightarrow p+K^+ + \Xi^0 + K^0$	3	4	3247
	$\longrightarrow K^+ + K^+ + \Lambda + \Sigma^0$	2	2	3296
	$\longrightarrow K^+ + K^+ + \Lambda + \Lambda + \pi^0$	1	1	3353
	$\longrightarrow K^+ + \pi^+ + \Lambda + K^0 + \Lambda$	1	6	3362
	$\longrightarrow K^+ + K^+ + \Lambda + K^0 + n$	1	2	3541
	$\longrightarrow p+K^+ + \Lambda + K^0 + \bar{K}^0$	1	6	3543
	$\longrightarrow p+K^+ + \Sigma^0 + K^0 + \bar{K}^0$	1	2	3621
	$\longrightarrow d+K^+ + K^0 + \bar{K}^0 + \bar{K}^0$	1	2	3866
	$\longrightarrow p+\pi^+ + \Lambda + K^0 + MM$	4	4	
	$\longrightarrow p+\pi^+ + \Lambda + MM$	↓	4	
	$\longrightarrow p+\pi^+ + K^0 + MM$	↓	4	
	$\longrightarrow p+\pi^+ + MM$	↓	2	
	$\longrightarrow \pi^+ + \pi^+ + \Lambda + K^0 + MM$	↓	2	
	$\longrightarrow \pi^+ + \pi^+ + \Lambda + MM$	↓	2	
	$\longrightarrow \pi^+ + \pi^+ + K^0 + MM$	↓	2	
	$\longrightarrow \pi^+ + \pi^+ + MM$	↓	1	
	$\longrightarrow p+p+K^0+\bar{K}^0+MM$	↓	1	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

MEMO NO.	PAGE
548	5.22

NAME: P. WOHLMUT

DATE: 4-6-65

SUBJECT

PET 022 CONT.

	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+p+K^0+MM$	4	2	
	$\longrightarrow p+p+MM$		1	
	$\longrightarrow p+\pi^++K^0+\bar{K}^0+MM$		2	
	$\longrightarrow d+\pi^++K^0+\bar{K}^0+MM$		2	
	$\longrightarrow d+\pi^++K^0+MM$		4	
	$\longrightarrow d+\pi^++MM$		2	
	$\longrightarrow K^++K^++\Lambda+\Lambda+MM$		1	
	$\longrightarrow K^++K^++\Lambda+MM$		2	
	$\longrightarrow K^++K^++MM$		1	
	$\longrightarrow p+K^++K^0$		4	
	$\longrightarrow p+K^++MM$		2	
	$\longrightarrow K^++\pi^++\Lambda+\Lambda+MM$		2	
	$\longrightarrow K^++\pi^++\Lambda+K^0+MM$		4	
	$\longrightarrow K^++\pi^++\Lambda+MM$		4	
	$\longrightarrow K^++\pi^++K^0+MM$		4	
	$\longrightarrow K^++\pi^++MM$		2	
	$\longrightarrow K^++K^++\bar{K}^0+MM$		2	
	$\longrightarrow p+K^++\Lambda+K^0+MM$		4	
	$\longrightarrow p+K^++\Lambda+MM$		4	
	$\longrightarrow p+K^++K^0+\bar{K}^0+MM$		2	
	$\longrightarrow d+K^++K^0+\bar{K}^0+MM$		2	
	$\longrightarrow d+K^++K^0+MM$		4	
	$\longrightarrow d+K^++MM$		2	
			135	
24				

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PHYSICS NOTES

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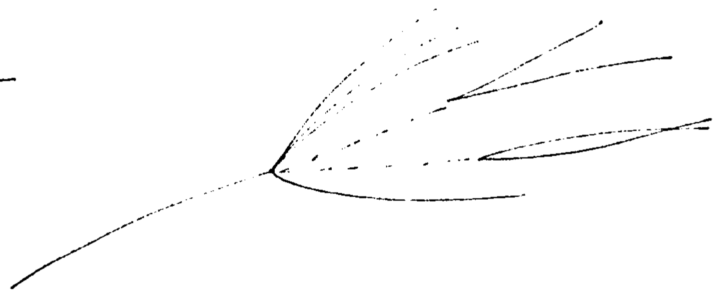
NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 023



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \rightarrow p+\pi^-$	3	2	
	$\Lambda \rightarrow p+\pi^-$	1	2	
✓	$K^0 \rightarrow \pi^+ + \pi^-$	3	2	
✓	$p+p \rightarrow p+\pi^++\pi^++\pi^-+\Lambda+K^0$	4	6	2971
	$\rightarrow p+\pi^++\pi^++\pi^-+\Sigma^0+K^0$	2	6	3049
	$\rightarrow p+\pi^++\pi^++\pi^-+\Lambda+K^0+\pi^0$	1	6	3106
	$\rightarrow \pi^++\pi^++\pi^++\pi^-+\Lambda+K^0+n$	1	2	3113
✓	$\rightarrow p+p+\pi^++\pi^-+K^0+\bar{K}^0$	4	3	3152
	$\rightarrow p+p+\pi^++\pi^-+K^0+\bar{K}^0+\pi^0$	1	3	3287
	$\rightarrow p+\pi^++\pi^++\pi^-+K^0+\bar{K}^0+n$	1	3	3294
✓	$\rightarrow d+\pi^++\pi^++\pi^-+K^0+\bar{K}^0$	4	3	3294
	$\rightarrow d+\pi^++\pi^++\pi^-+K^0+\bar{K}^0+\pi^0$	1	3	3429
✓	$\rightarrow K^++K^++\pi^++\pi^-+\Lambda+\Lambda$	4	3	3498
	$\rightarrow p+K^++\pi^++\pi^-+\Xi^0+K^0$	3	12	3527
	$\rightarrow K^++K^++\pi^++\pi^-+\Sigma^0+\Lambda$	2	6	3575
	$\rightarrow K^++K^++\pi^++\pi^-+\Lambda+\Lambda+\pi^0$	1	3	3633
	$\rightarrow K^++\pi^++\pi^++\pi^-+\Lambda+\Lambda+K^0$	1	9	3642
	$\rightarrow p+\pi^++\pi^++\pi^-+K^0+K^0+\Xi^0$	1	3	3669
	$\rightarrow p+K^++\pi^++K^-+K^0+\Lambda$	4	12	3679
	$\rightarrow p+K^++\pi^++K^-+K^0+\Sigma^0$	2	12	3756
	$\rightarrow p+K^++\pi^++K^-+K^0+\Lambda+\pi^0$	1	12	3814
	$\rightarrow p+\pi^++\pi^++K^-+K^0+K^0+\Lambda$	1	9	3823
✓	$\rightarrow p+p+\pi^++K^-+K^0+\bar{K}^0$	4	3	3860
	$\rightarrow p+\pi^++\pi^++\pi^-+\Lambda+K^0+MM$	4	6	
	$\rightarrow p+\pi^++\pi^++\pi^-+\Lambda+MM$	↓	6	
	$\rightarrow p+\pi^++\pi^++\pi^-+K^0+MM$	↓	6	
✓	$\rightarrow p+\pi^++\pi^++\pi^-+MM$	↓	3	
✓	$\rightarrow \pi^++\pi^++\pi^++\pi^-+\Lambda+K^0+MM$	↓	2	
	$\rightarrow \pi^++\pi^++\pi^++\pi^-+\Lambda+MM$	↓	2	
	$\rightarrow \pi^++\pi^++\pi^++\pi^-+K^0+MM$	↓	2	

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PET 023 CONT.

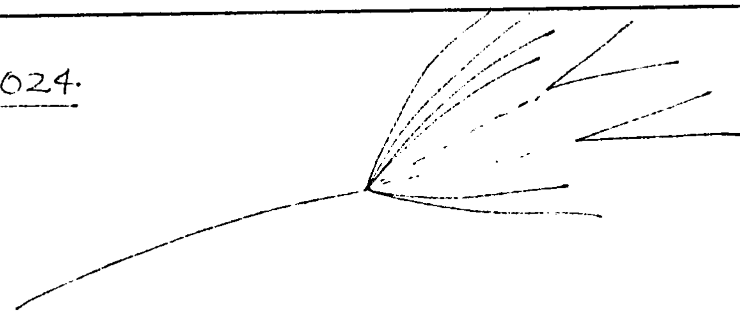
	REACTION	CONST.	MULT.	MASS
✓	$p+p \rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + MM$	4	P	
	$\rightarrow p+p+\pi^+ + \pi^- + K^0 + \bar{K}^0 + MM$	|	3	
	$\rightarrow p+p+\pi^+ + \pi^- + K^0 + MM$	|	6	
	$\rightarrow p+p+\pi^+ + \pi^- + MM$	|	3	
	$\rightarrow p+\pi^+ + \pi^+ + \pi^- + K^0 + \bar{K}^0 + MM$	|	3	
	$\rightarrow d+\pi^+ + \pi^+ + \pi^- + K^0 + \bar{K}^0 + MM$	|	3	
	$\rightarrow d+\pi^+ + \pi^+ + \pi^- + K^0 + MM$	|	6	
	$\rightarrow d+\pi^+ + \pi^+ + \pi^- + MM$	|	3	
	$\rightarrow K^+ + K^+ + \pi^+ + \pi^- + \Lambda + \Lambda + MM$	|	3	
	$\rightarrow K^+ + K^+ + \pi^+ + \pi^- + \Lambda + MM$	|	6	
	$\rightarrow K^+ + K^+ + \pi^+ + \pi^- + MM$	|	3	
	$\rightarrow p+K^+ + \pi^+ + \pi^- + K^0 + MM$	|	12	
	$\rightarrow p+K^+ + \pi^+ + \pi^- + MM$	|	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + MM$	|	3	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$	|	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$	|	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	|	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + MM$	|	3	
	$\rightarrow p+K^+ + \pi^+ + K^- + K^0 + \Lambda + MM$	|	12	
	$\rightarrow p+K^+ + \pi^+ + K^- + K^0 + MM$	|	12	
	$\rightarrow p+K^+ + \pi^+ + K^- + \Lambda + MM$	|	12	
	$\rightarrow p+K^+ + \pi^+ + K^- + MM$	|	6	
	$\rightarrow p+\pi^+ + \pi^+ + K^- + K^0 + K^0 + MM$	|	3	
	$\rightarrow p+\pi^+ + \pi^+ + K^- + K^0 + \Lambda + MM$	|	6	
	$\rightarrow p+\pi^+ + \pi^+ + K^- + K^0 + MM$	|	6	
	$\rightarrow p+\pi^+ + \pi^+ + K^- + \Lambda + MM$	|	6	
	$\rightarrow p+\pi^+ + \pi^+ + K^- + MM$	|	3	
	$\rightarrow p+p+K^+ + K^- + K^0 + \bar{K}^0 + MM$	|	3	
	$\rightarrow p+p+K^+ + K^- + K^0 + MM$	|	6	
	$\rightarrow p+p+K^+ + K^- + MM$	↓	3	
25			[illegible]	

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 024



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p+\pi^-$	3	2	
	$\Lambda \rightarrow p+\pi^-$	1	2	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	2	
	$p+p \rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+K^0$	4	8	3251
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\Sigma^0+K^0$	2	16	3329
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+K^0+\pi^0$	1	8	3386
	$\rightarrow \pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+K^0+n$	1	2	3393
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0$	4	6	3432
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+\pi^0$	1	6	3567
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+n$	1	4	3574
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0$	4	4	3574
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+\pi^0$	1	4	3709
	$\rightarrow K^++K^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+\Lambda$	4	6	3778
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+\Xi^0+K^0$	3	24	3807
	$\rightarrow K^++K^++\pi^++\pi^++\pi^-+\pi^-+\Sigma^0+\Lambda$	2	12	3855
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+K^0+MM$	4 ↓	8	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+MM$		8	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+MM$		8	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		4	
	$\rightarrow \pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+K^0+MM$		2	
	$\rightarrow \pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+MM$		2	
	$\rightarrow \pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+MM$		2	
	$\rightarrow \pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		1	
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+MM$		6	
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+K^0+MM$		12	
	$\rightarrow p+p+\pi^++\pi^++\pi^-+\pi^-+MM$		6	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+MM$		4	
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+\bar{K}^0+MM$		4	
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+K^0+MM$		8	
	$\rightarrow d+\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		4	

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PET 024 CONT

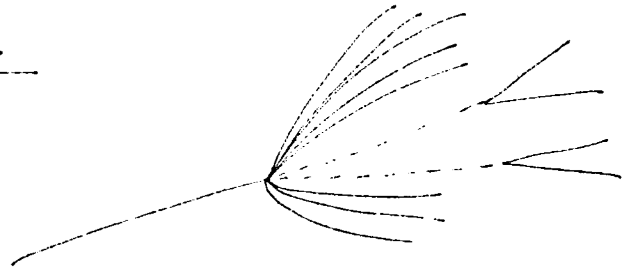
	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow K^++K^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+\Lambda+MM$	4	6	
	$\rightarrow K^++K^++\pi^++\pi^++\pi^-+\pi^-+\Lambda+MM$		12	
	$\rightarrow K^++K^++\pi^++\pi^++\pi^-+\pi^-+MM$		6	
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+K^0+MM$		24	
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+\pi^-+MM$		12	

NAME F. WOHLMUT

DATE 4-6-65

SUBJECT

PET 025



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p+\pi^-$	3	2	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p+p \longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+K^0$	4	10	3531
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Sigma^0+K^0$	2	20	3609
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+K^0+\pi^0$	1	10	3666
	$\longrightarrow \pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+K^0+n$	1	2	3673
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0$	4	10	3712
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0+\pi^0$	1	10	3847
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0+n$	1	5	3854
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0$	4	5	3851
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+K^0+MM$	4	10	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+MM$	↓	10	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		10	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		5	
	$\longrightarrow \pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+K^0+MM$		2	
	$\longrightarrow \pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\Lambda+MM$		2	
	$\longrightarrow \pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		2	
	$\longrightarrow \pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		1	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0+MM$		10	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		20	
	$\longrightarrow p+p+\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$		10	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0+MM$		5	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+MM$		10	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+K^0+\bar{K}^0+MM$		5	
	$\longrightarrow d+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+MM$	↓	5	

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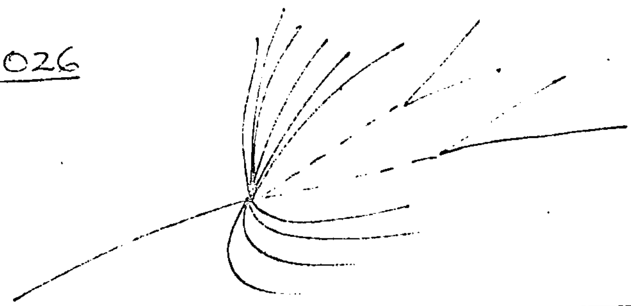
<u>PET 026</u>



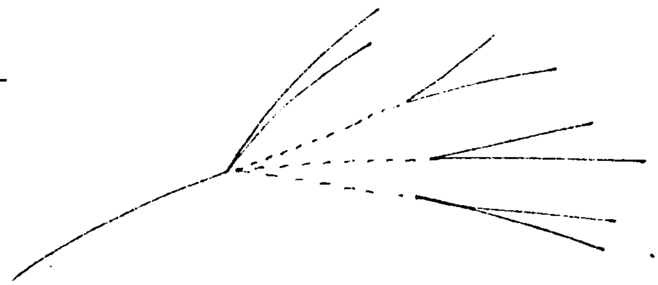
	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	2	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Lambda+K^0$	4	12	3811
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Sigma^0+K^0$	2	24	3889
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Lambda+K^0+MM$	4	12	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+\Lambda+MM$		12	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+K^0+MM$		12	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$		6	

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 032



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \rightarrow p+\pi^-$	3	3	
✓	$\Lambda \rightarrow p+\pi^-$	1	3	
✓	$K^0 \rightarrow \pi^+ + \pi^-$	3	3	
✓	$p+p \rightarrow K^+ + \pi^+ + \Lambda + \Lambda + K^0$	4	6	3364
	$\rightarrow p+\pi^+ + \Xi^0 + K^0 + K^0$	3	6	3389
	$\rightarrow K^+ + \pi^+ + \Lambda + \Sigma^0 + K^0$	2	12	3440
	$\rightarrow K^+ + \pi^+ + \Lambda + \Lambda + K^0 + \pi^0$	1	6	3499
✓	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + K^0$	1	6	3506
✓	$\rightarrow p + K^+ + \Lambda + K^0 + \bar{K}^0$	4	6	3543
	$\rightarrow \pi^+ + \pi^+ + \Sigma^0 + \Lambda + K^0 + K^0$	1	6	3584
	$\rightarrow p + K^+ + \Sigma^0 + K^0 + \bar{K}^0$	2	12	3622
	$\rightarrow p + K^+ + \Lambda + K^0 + \bar{K}^0 + \pi^0$	1	6	3678
	$\rightarrow p + \pi^+ + \Lambda + K^0 + K^0 + \bar{K}^0$	1	8	3687
	$\rightarrow p + \pi^+ + \Sigma^0 + K^0 + K^0 + \bar{K}^0$	1	8	3765
✓	$\rightarrow p + K^+ + K^0 + \bar{K}^0 + \bar{K}^0 + n$	1	2	3866
✓	$\rightarrow d + K^+ + K^0 + \bar{K}^0 + \bar{K}^0$	4	2	3866
	$\rightarrow p + p + K^0 + K^0 + \bar{K}^0 + \bar{K}^0$	1	2	3868
	$\rightarrow K^+ + \pi^+ + \Lambda + \Lambda + K^0 + MM$	4	6	
	$\rightarrow K^+ + \pi^+ + \Lambda + \Lambda + MM$	↓	6	
	$\rightarrow K^+ + \pi^+ + \Lambda + K^0 + MM$		12	
	$\rightarrow K^+ + \pi^+ + \Lambda + MM$		6	
	$\rightarrow K^+ + \pi^+ + K^0 + MM$		6	
	$\rightarrow K^+ + \pi^+ + MM$		2	
	$\rightarrow p + \pi^+ + K^0 + K^0 + MM$		6	
	$\rightarrow p + \pi^+ + K^0 + MM$		6	
	$\rightarrow p + \pi^+ + MM$		2	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + K^0 + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + K^0 + MM$		6	

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	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow \pi^+ + \pi^+ + K^0 + K^0 + MM$	4	3	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + MM$		1	
	$\rightarrow p + K^+ + \Lambda + K^0 + \bar{K}^0 + MM$		6	
	$\rightarrow p + K^+ + \Lambda + K^0 + MM$		12	
	$\rightarrow p + K^+ + K^0 + \bar{K}^0 + MM$		6	
	$\rightarrow p + K^+ + \Lambda + MM$		6	
	$\rightarrow p + K^+ + K^0 + MM$		6	
	$\rightarrow p + K^+ + MM$		2	
	$\rightarrow p + \pi^+ + \Lambda + K^0 + K^0 + MM$		6	
	$\rightarrow p + \pi^+ + K^0 + K^0 + K^0 + MM$		2	
	$\rightarrow p + \pi^+ + \Lambda + K^0 + MM$		12	
	$\rightarrow p + \pi^+ + \Lambda + MM$		6	
	$\rightarrow p + K^+ + K^0 + \bar{K}^0 + \bar{K}^0 + MM$		2	
	$\rightarrow d + K^+ + K^0 + \bar{K}^0 + \bar{K}^0 + MM$		2	
	$\rightarrow d + K^+ + K^0 + \bar{K}^0 + MM$		6	
	$\rightarrow d + K^+ + K^0 + MM$		6	
	$\rightarrow d + K^+ + MM$		2	
✓	$\rightarrow p + p + K^0 + K^0 + \bar{K}^0 + MM$		1	
	$\rightarrow p + p + K^0 + \bar{K}^0 + MM$		3	
	$\rightarrow p + p + K^0 + MM$		3	
	$\rightarrow p + p + MM$		1	
25			264	

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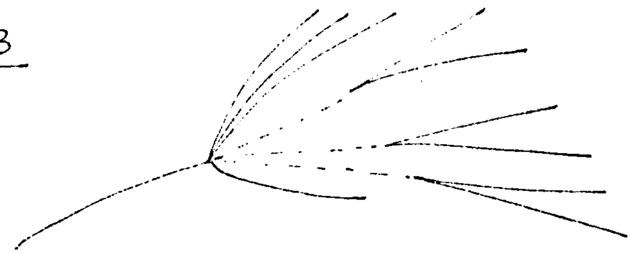
PET 033



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p+\pi^-$	3	3	
	$\Lambda \rightarrow p+\pi^-$	1	3	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	3	
	$p+p \rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0$	4	9	3644
	$\rightarrow p+\pi^+ + \pi^+ + \pi^- + \Xi^0 + K^0 + K^0$	3	9	3669
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Sigma^0 + K^0$	2	18	3720
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + \pi^0$	1	9	3779
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + K^0$	1	6	3786
	$\rightarrow p + K^+ + \pi^+ + \pi^- + \Lambda + K^0 + K^0$	4	18	3828
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Sigma^0 + \Lambda + K^0 + K^0$	1	3	3864
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + MM$	4	9	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + MM$		9	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$		18	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$		9	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$		9	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \pi^- + MM$		3	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$		9	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^- + K^0 + MM$		9	
	$\rightarrow p + \pi^+ + \pi^+ + \pi^- + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$		6	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$		3	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + MM$		1	
	$\rightarrow p + K^+ + \pi^+ + \pi^- + \Lambda + K^0 + K^0$		18	
	$\rightarrow p + K^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$		36	
	$\rightarrow p + K^+ + \pi^+ + \pi^- + K^0 + \bar{K}^0 + MM$		18	

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DATE 4-6-65

FE.T 033 CONT.

	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^{+}+\pi^{+}+\pi^{-}+\Lambda+MM$	4	18	
	$\longrightarrow p+K^{+}+\pi^{+}+\pi^{-}+K^{0}+MM$		18	
	$\longrightarrow p+K^{+}+\pi^{+}+\pi^{-}+MM$		6	
			298	

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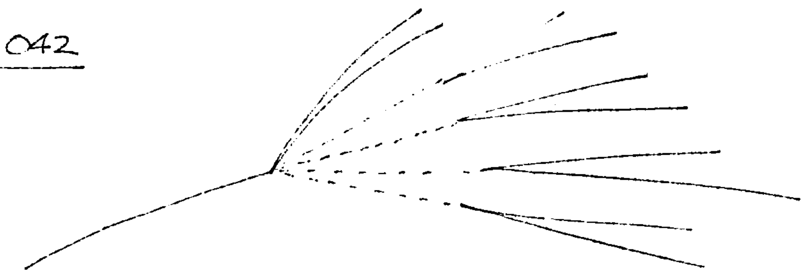
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 042



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p+\pi^-$	3	4	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	4	
	$p+p \rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + K^0$	4	6	3506
	$\rightarrow \pi^+ + \pi^+ + \Sigma^0 + \Lambda + K^0 + K^0$	2	12	3584
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + K^0 + \pi^0$	1	6	3641
	$\rightarrow p + \pi^+ + \Lambda + K^0 + \bar{K}^0 + K^0$	4	8	3687
	$\rightarrow p + \pi^+ + \Sigma^0 + K^0 + \bar{K}^0 + K^0$	2	16	3765
	$\rightarrow p + \pi^+ + \Lambda + K^0 + \bar{K}^0 + K^0 + \pi^0$	1	8	3820
	$\rightarrow p + p + K^0 + \bar{K}^0 + K^0 + \bar{K}^0$	4	1	3868
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + K^0 + MM$	4	6	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + K^0 + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + \Lambda + MM$		6	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + K^0 + K^0 + MM$		6	
	$\rightarrow \pi^+ + \pi^+ + \Lambda + MM$		4	
	$\rightarrow \pi^+ + \pi^+ + K^0 + MM$		4	
	$\rightarrow \pi^+ + \pi^+ + MM$		1	
	$\rightarrow p + \pi^+ + \Lambda + K^0 + \bar{K}^0 + K^0 + MM$		8	
	$\rightarrow p + \pi^+ + \Lambda + K^0 + \bar{K}^0 + MM$		24	
	$\rightarrow p + \pi^+ + K^0 + K^0 + \bar{K}^0 + MM$		8	
	$\rightarrow p + \pi^+ + \Lambda + K^0 + MM$		24	
	$\rightarrow p + \pi^+ + K^0 + K^0 + MM$		12	
	$\rightarrow p + \pi^+ + \Lambda + MM$		8	
	$\rightarrow p + \pi^+ + K^0 + MM$		8	
	$\rightarrow p + \pi^+ + MM$		2	
	$\rightarrow p + p + K^0 + \bar{K}^0 + K^0 + \bar{K}^0 + MM$		1	
	$\rightarrow p + p + K^0 + \bar{K}^0 + K^0 + MM$		4	
	$\rightarrow p + p + K^0 + \bar{K}^0 + MM$		6	
	$\rightarrow p + p + K^0 + MM$		4	
	$\rightarrow p + p + MM$	↓	1	

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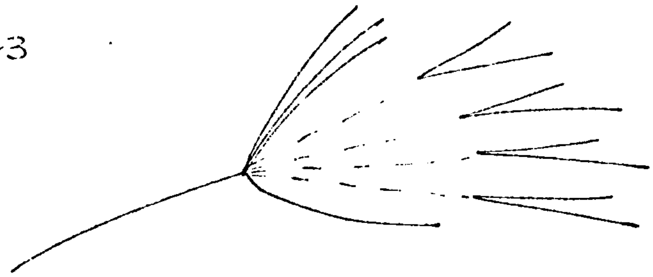
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 043



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p+\pi^-$	3	4	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	4	
	$p+p \rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + K^0$	4	6	3786
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Sigma^0 + \Lambda + K^0 + K^0$	2	12	3864
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + K^0 + MM$	4	6	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + \Lambda + MM$		6	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$		12	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$		6	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$		4	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$		4	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + MM$		1	
			89	

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NAME P. WOHLMUT

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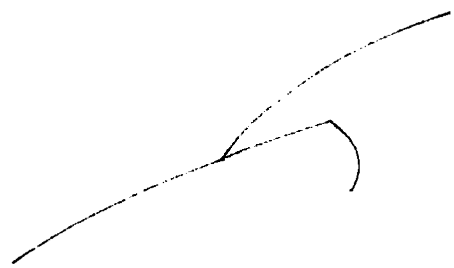
PET 102



	REACTION	CONST.	MULT.	MASS
✓	$p+p \longrightarrow \Sigma^+ + K^+ + n$	1	4	2623
✓	$\longrightarrow \Sigma^+ + p + K^0$	1	4	2625

8

8

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NAME P. WOHLMUT

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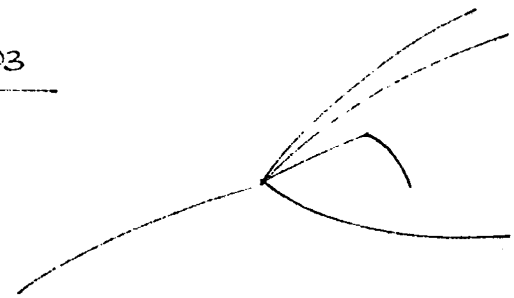
PET 103



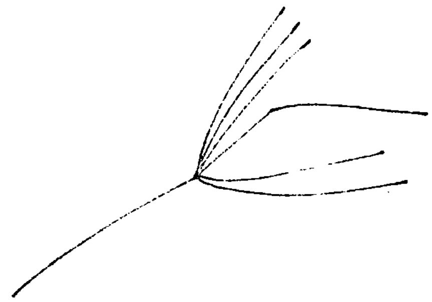
	REACTION	CONST.	MULT.	MASS
✓	$p+p \longrightarrow p+\Sigma^{+}+K^{+}+\pi^{-}$	4	4	2761
	$\longrightarrow p+\Sigma^{+}+K^{+}+\pi^{-}+\pi^{0}$	1	8	2896
	$\longrightarrow \Sigma^{+}+K^{+}+\pi^{+}+\pi^{-}+n$	1	8	2903
	$\longrightarrow p+\Sigma^{+}+\pi^{+}+\pi^{-}+K^{0}$	1	8	2905
	$\longrightarrow \Sigma^{+}+K^{+}+K^{+}+\pi^{-}+\Lambda$	1	4	3432
	$\longrightarrow K^{+}+K^{+}+\Sigma^{+}+\pi^{-}+\Sigma^{0}$	1	4	3510
	$\longrightarrow K^{+}+K^{+}+\Sigma^{+}+K^{-}+n$	1	4	3611
✓	$\longrightarrow p+K^{+}+\pi^{-}+MM$	4	2	
✓	$\longrightarrow K^{+}+\pi^{+}+\pi^{-}+MM$		2	
✓	$\longrightarrow p+\pi^{+}+\pi^{-}+MM$		2	
✓	$\longrightarrow K^{+}+K^{+}+\pi^{-}+MM$		1	
✓	$\longrightarrow K^{+}+K^{+}+K^{-}+MM$		1	
12				
~~25~~			34	

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 104



	REACTION	CONST.	MULT.	MASS
	$p+p \to p+K^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}$	4	12	3041
	$\to p+K^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{0}$	1	24	3176
	$\to K^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+n$	1	12	3183
	$\to p+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+K^{0}$	1	12	3185
	$\to K^{+}+K^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\Lambda$	1	12	3712
	$\to p+K^{+}+K^{+}+\Sigma^{+}+K^{-}+\pi^{-}$	4	12	3749
	$\to K^{+}+K^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\Sigma^{0}$	1	12	3790
	$\to p+K^{+}+K^{+}+\Sigma^{+}+K^{-}+\pi^{-}+\pi^{0}$	1	24	3884
	$\to K^{+}+K^{+}+\pi^{+}+\Sigma^{+}+K^{-}+\pi^{-}+n$	1	24	3891
	$\to p+K^{+}+\pi^{+}+\Sigma^{+}+K^{-}+\pi^{-}+K^{0}$	1	48	3893
	$\to p+K^{+}+\pi^{+}+\pi^{-}+\pi^{-}+MM$	4	6	
	$\to K^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+MM$	↓	3	
	$\to p+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+MM$	↓	3	
	$\to K^{+}+K^{+}+\pi^{+}+\pi^{-}+\pi^{-}+MM$	↓	3	
	$\to p+K^{+}+K^{+}+K^{-}+\pi^{-}+MM$	↓	6	
	$\to p+K^{+}+\pi^{+}+K^{-}+\pi^{-}+MM$	↓	12	
			225	

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NAME P. WOHLMUT
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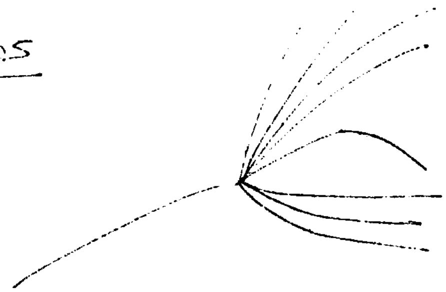
PET 105



	REACTION	CONST.	MULT.	MASS
	$p+p \rightarrow p+K^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}$	4	24	3321
	$\rightarrow p+K^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{0}$	1	48	3456
	$\rightarrow K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+n$	1	16	3463
	$\rightarrow p+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+K^{0}$	1	16	3465
	$\rightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+MM$	4	12	
	$\rightarrow K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+MM$	↓	4	
	$\rightarrow p+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+MM$		4	
			124	

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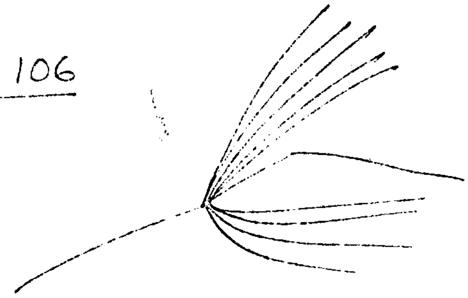
PET 106



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}$	4	40	3601
	$\longrightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{0}$	1	80	3736
	$\longrightarrow K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+n$	1	20	3743
	$\longrightarrow p+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+K^{0}$	1	20	3745
	$\longrightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+MM$	4	20	
	$\longrightarrow K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+MM$		5	
	$\longrightarrow p+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+MM$		5	

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NAME F. WOHLMUT

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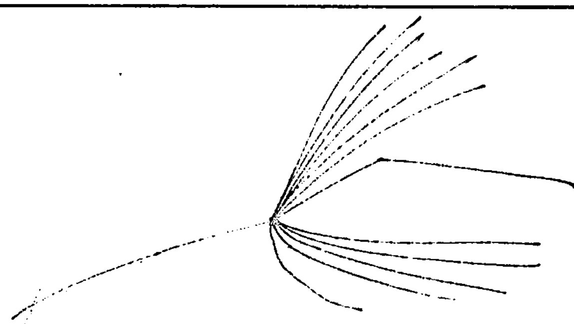
PET 107



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\Sigma^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}$	4	60	3881
	$\longrightarrow p+K^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{+}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+\pi^{-}+MM$	4	30	
			90	

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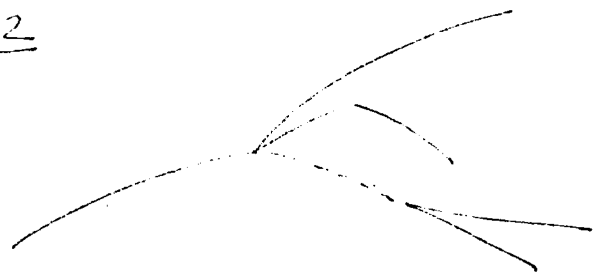
PET 112



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p + \pi^-$	3	1	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
✓	$p + p \longrightarrow p + \Sigma^{+} + K^0$	4	2	2625
✓	$\longrightarrow p + \Sigma^{+} + K^0 + \pi^0$	1	4	2760
✓	$\longrightarrow \pi^+ + \Sigma^{+} + K^0 + n$	1	4	2767
✓	$\longrightarrow K^+ + \Sigma^{+} + \Lambda + K^0$	1	8	3296
✓	$\longrightarrow p + K^0 + MM$	4	1	
✓	$\longrightarrow \pi^+ + K^0 + MM$		1	
✓	$\longrightarrow K^+ + \Lambda + MM$		1	
✓	$\longrightarrow K^+ + K^0 + MM$		1	
24			24	

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PHYSICS NOTES

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NAME P. WOHLMUT

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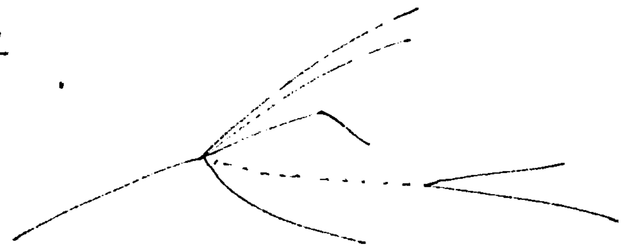
SUBJECT

PET 113



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	1	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow p + \pi^+ + \Sigma^+ + \pi^- + K^0$	4	4	2905
	$\longrightarrow p + \pi^+ + \Sigma^+ + \pi^- + K^0 + \pi^0$	1	8	3040
	$\longrightarrow \pi^+ + \pi^+ + \Sigma^+ + \pi^- + K^0 + n$	1	4	3047
	$\longrightarrow K^+ + K^+ + \Sigma^+ + \pi^- + \Lambda$	4	2	3432
	$\longrightarrow K^+ + K^+ + \Sigma^+ + \pi^- + \Sigma^0$	2	8	3510
	$\longrightarrow K^+ + K^+ + \Sigma^+ + \pi^- + \Lambda + \pi^0$	1	4	3567
	$\longrightarrow K^+ + \pi^+ + \Sigma^+ + \pi^- + \Lambda + K^0$	1	16	3576
	$\longrightarrow p + K^+ + \Sigma^+ + K^- + K^0$	4	4	3613
	$\longrightarrow p + K^+ + \Sigma^+ + K^- + K^0 + \pi^0$	1	8	3748
	$\longrightarrow K^+ + \pi^+ + \Sigma^+ + K^- + K^0 + n$	1	8	3755
	$\longrightarrow p + K^+ + \Sigma^+ + \pi^- + K^0 + \bar{K}^0$	1	8	3757
	$\longrightarrow p + \pi^+ + \Sigma^+ + K^- + K^0 + K^0$	1	8	3757
	$\longrightarrow p + \pi^+ + \pi^- + K^0 + MM$	4	2	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + K^0 + MM$		1	
	$\longrightarrow K^+ + K^+ + \pi^- + \Lambda + MM$		1	
	$\longrightarrow K^+ + \pi^+ + \pi^- + K^0 + MM$		2	
	$\longrightarrow K^+ + \pi^+ + \pi^- + \Lambda + MM$		2	
	$\longrightarrow p + K^+ + K^- + K^0 + MM$		2	
	$\longrightarrow K^+ + \pi^+ + K^- + K^0 + MM$		2	
	$\longrightarrow p + K^+ + \pi^- + K^0 + MM$		2	
	$\longrightarrow p + \pi^+ + K^- + K^0 + MM$		2	
			92	
			~~60~~	

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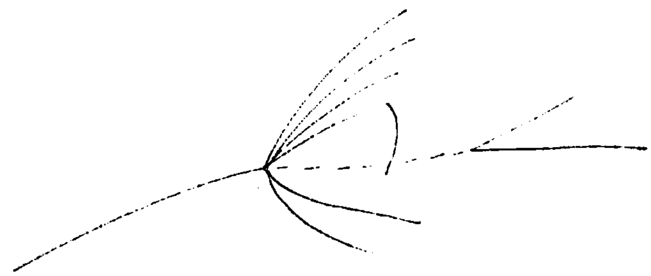
PET 114



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p+\pi^-$	3	1	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
$p+p$	$\longrightarrow p+\pi^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +K^0$	4	6	3185
	$\longrightarrow p+\pi^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +K^0+\pi^0$	1	12	3320
	$\longrightarrow \pi^+ +\pi^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +K^0+n$	1	4	3327
	$\longrightarrow K^+ +K^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +\Lambda$	4	6	3712
	$\longrightarrow K^+ +K^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +\Sigma^0$	2	24	3790
	$\longrightarrow K^+ +K^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +\Lambda+\pi^0$	1	12	3847
	$\longrightarrow K^+ +\pi^+ +\pi^+ +\Sigma^+ +\pi^- +\pi^- +\Lambda+K^0$	1	24	3856
	$\longrightarrow p+K^+ +\pi^+ +\Sigma^+ +K^- +\pi^- +K^0$	4	[illegible]	3893
	$\longrightarrow p+\pi^+ +\pi^+ +\pi^- +\pi^- +K^0 + MM$	4	3	
	$\longrightarrow K^+ +K^+ +\pi^+ +\pi^- +\pi^- +\Lambda + MM$		3	
	$\longrightarrow K^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +\Lambda + MM$		3	
	$\longrightarrow K^+ +\pi^+ +\pi^+ +\pi^- +\pi^- +K^0 + MM$		3	
	$\longrightarrow p+K^+ +\pi^+ +K^- +\pi^- +K^0 + MM$		12	
			138	
			~~[illegible]~~	

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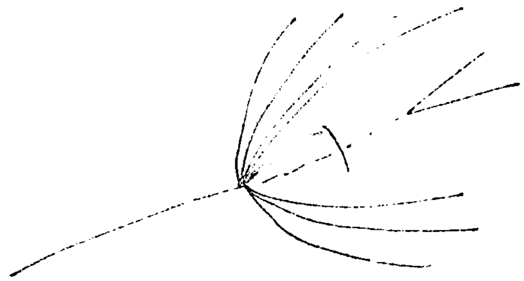
PET 115



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + K^0$	4	[illegible]	3465
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + K^0 + \pi^0$	1	16	3600
	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + K^0 + n$	1	4	3607
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + MM$	4	4	
	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + MM$	↓	1	

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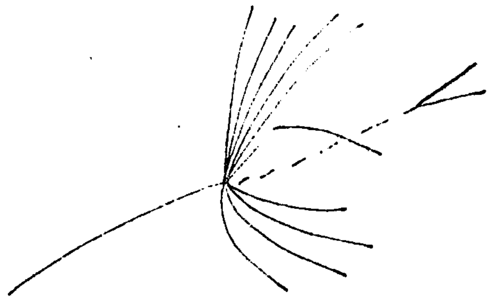
PET 116



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0$	4	[illegible]	3745
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0 + \pi^0$	1	20	3880
	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0 + n$	1	4	3887
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0 + MM$	4	5	
	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + \pi^- + K^0 + MM$	↓	1	

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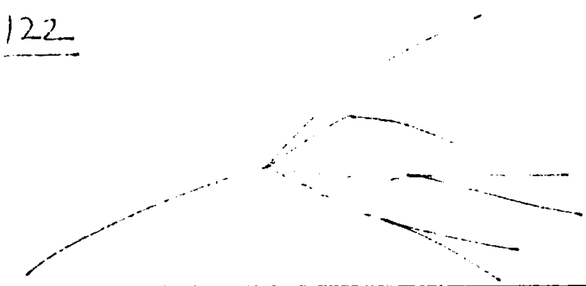
PET 122



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p+\pi^-$	3	2	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
✓	$p+p \longrightarrow K^+ + \Sigma^+ + \Lambda + K^0$	4	4	3296
	$\longrightarrow K^+ + \Sigma^+ + \Sigma^0 + K^0$	2	16	3374
	$\longrightarrow K^+ + \Sigma^+ + \Lambda + K^0 + \pi^0$	1	8	3431
	$\longrightarrow \pi^+ + \Sigma^+ + \Lambda + K^0 + K^0$	1	12	3440
	$\longrightarrow p + \Sigma^+ + K^0 + K^0 + \bar{K}^0$	1	4	3621
✓	$\longrightarrow K^+ + \Lambda + K^0 + MM$	4	2	
✓	$\longrightarrow K^+ + \Lambda + MM$	↓	2	
✓	$\longrightarrow K^+ + K^0 + MM$	↓	2	
✓	$\longrightarrow \pi^+ + \Lambda + K^0 + MM$	↓	2	
✓	$\longrightarrow \pi^+ + K^0 + K^0 + MM$	↓	1	
✓	$\longrightarrow \pi^+ + \Lambda + MM$	↓	2	
✓	$\longrightarrow \pi^+ + K^0 + MM$	↓	2	
✓	$\longrightarrow p + K^0 + K^0 + MM$	↓	1	
✓	$\longrightarrow p + K^0 + MM$	↓	2	
24			48	

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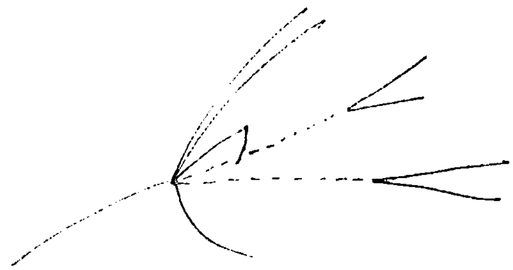
PET 123



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	2	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow K^+ + \pi^+ + \Sigma^+ + \pi^- + \Lambda + K^0$	4	[illegible]	3572
	$\longrightarrow K^+ + \pi^+ + \Sigma^+ + \pi^- + \Sigma^0 + K^0$	2	[illegible]	3650
	$\longrightarrow K^+ + \pi^+ + \Sigma^+ + \pi^- + \Lambda + K^0 + \pi^0$	1	16	3707
	$\longrightarrow \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \Lambda + K^0 + K^0$	1	12	3720
	$\longrightarrow p + K^+ + \Sigma^+ + \pi^- + K^0 + \bar{K}^0$	4	[illegible]	3757
	$\longrightarrow p + K^+ + \Sigma^+ + \pi^- + K^0 + \bar{K}^0 + \pi^0$	1	8	3892
	$\longrightarrow p + \pi^+ + \Sigma^+ + K^- + K^0 + K^0 + \pi^0$	1	8	3892
	$\longrightarrow K^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$	4	4	
	$\longrightarrow K^+ + \pi^+ + \pi^- + \Lambda + MM$		4	
	$\longrightarrow K^+ + \pi^+ + \pi^- + K^0 + MM$		4	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$		2	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$		1	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + \Lambda + MM$		2	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + K^0 + MM$		2	
	$\longrightarrow p + K^+ + \pi^- + K^0 + \bar{K}^0 + MM$		2	
	$\longrightarrow p + K^+ + \pi^- + K^0 + MM$		4	
	$\longrightarrow p + \pi^+ + K^- + K^0 + \bar{K}^0 + MM$		2	
	$\longrightarrow p + \pi^+ + K^- + K^0 + MM$		4	

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PHYSICS NOTES

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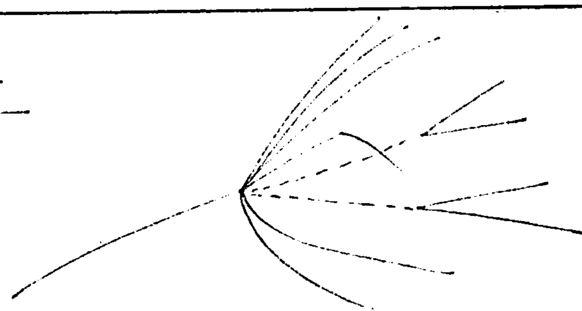
548	5.48

NAME: P. WOHLMUT

DATE: 4-6-65

SUBJECT

PET 124



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	2	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow K^+ + \pi^+ + \pi^+ + \Sigma^+ + \pi^- + \pi^- + \Lambda + K^0$	4	[illegible]	3852
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + K^0 + MM$	4	6	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \Lambda + MM$	↓	6	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$	↓	6	

34

~~46~~

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PHYSICS NOTES

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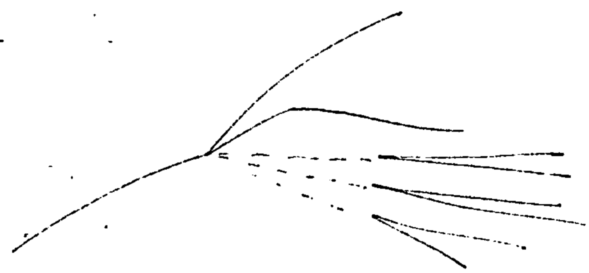
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 132



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p+\pi^-$	3	3	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	3	
	$p+p \rightarrow \pi^+ + \Sigma'^{+} + \Lambda + K^0 + K^0$	4	6	3440
	$\rightarrow \pi^+ + \Sigma'^{+} + \Sigma^0 + K^0 + K^0$	2	24	3518
	$\rightarrow \pi^+ + \Sigma'^{+} + \Lambda^0 + K^0 + K^0 + \pi^0$	1	12	3575
	$\rightarrow p + \Sigma'^{+} + K^0 + K^0 + \bar{K}^0$	4	2	3621
	$\rightarrow p + \Sigma'^{+} + K^0 + K^0 + \bar{K}^0 + \pi^0$	1	4	3756
	$\rightarrow \pi^+ + \Sigma'^{+} + K^0 + K^0 + \bar{K}^0 + n$	1	4	3763
	$\rightarrow \pi^+ + \Lambda + K^0 + K^0 + MM$	4	3	
	$\rightarrow \pi^+ + \Lambda + K^0 + MM$		6	
	$\rightarrow \pi^+ + K^0 + K^0 + MM$		3	
	$\rightarrow p^{+} + K^0 + K^0 + \bar{K}^0 + MM$		1	
	$\rightarrow p + K^0 + K^0 + MM$		3	
	$\rightarrow \pi^+ + K^0 + K^0 + \bar{K}^0 + MM$		1	
			75	

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PHYSICS NOTES

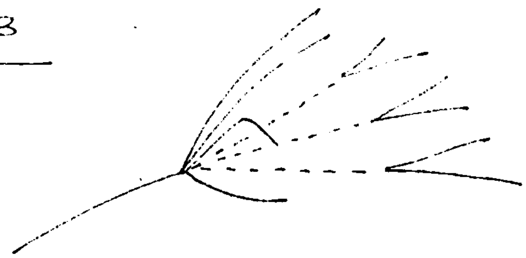
MEMO NO.	PAGE
548	5.50

NAME: P. WOHLMUT

DATE: 4-6-65

SUBJECT:

PET 133



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	3	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	3	
	$p + p \longrightarrow \pi^+ + \pi^+ + \Sigma'^+ + \pi^- + \Lambda + K^0 + K^0$	4	~~[illegible]~~ 6	3720
	$\longrightarrow \pi^+ + \pi^+ + \Sigma'^+ + \pi^- + \Sigma'^0 + K^0 + K^0$	2	24	3798
	$\longrightarrow \pi^+ + \pi^+ + \Sigma'^+ + \pi^- + \Lambda + K^0 + K^0 + \pi^0$	1	12	3855
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + K^0 + MM$	4	3	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$	↓	6	
	$\longrightarrow \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$	↓	3	
			60	
			~~66~~	

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PHYSICS NOTES

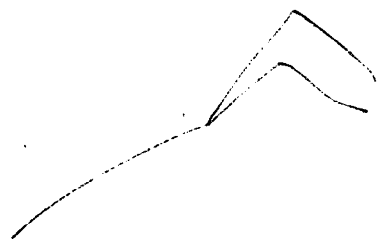
MEMO NO.	PAGE
548	5.51

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 202



	REACTION	CONST	MULT.	MASS
	This reaction may be observed in the experiment, but is kinematically underconstrained.			

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NAME P. WOHLMUT

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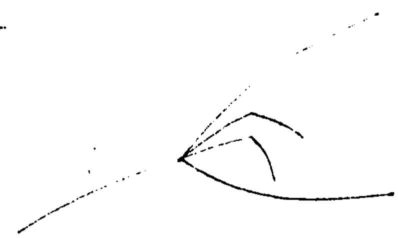
PET 203



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow \Sigma_1^{+} + \Sigma_2^{+} + K^{+} + \pi^{-} + K^{0}$	1	32*	3510
	* There are 32 combinations since to obtain a 2vertex fit at production, OC fits on one Σ^{+} decay must be performed. To insure consistency the OC fits should be tried on both Σ^{+}'s.			
			32	

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PHYSICS NOTES

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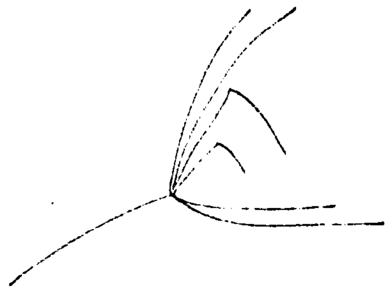
PET 204



	REACTION	CONST.	MULT.	MASS
[illegible]	$p + p \rightarrow \Sigma'^{+} + \Sigma'^{+} + K^{+} + K^{+} + \pi^{-} + \pi^{-}$	4	[illegible]	3646
	$\rightarrow \Sigma^{+} + \Sigma'^{+} + K^{+} + \pi^{+} + \pi^{-} + \pi^{-} + K^{0}$	1	.64	3790
	$\rightarrow \Sigma'^{+} + \Sigma'^{+} + K^{+} + K^{+} + \pi^{-} + \pi^{-} + \pi^{0}$	1	32	3781
			112	
			~~156~~	

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PHYSICS NOTES

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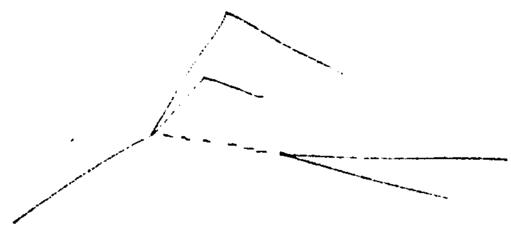
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 212



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow \Sigma^{?+} + \Sigma^{?+} + K^0 + K^0$	1	32	3374
			33	

RL-2187

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PHYSICS NOTES

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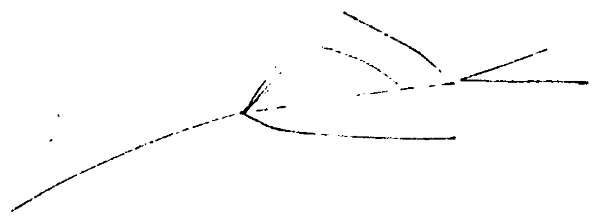
NAME P. WOHLMUT
DATE 4-6-65

PET 213



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$\longrightarrow \Sigma^+ + \Sigma^+ + K^+ + \pi^- + K^0$	4	~~3~~ 16	3510
	$\longrightarrow \Sigma^+ + \Sigma^+ + K^+ + \pi^- + K^0 + \pi^0$	1	32	3645
	$\longrightarrow \Sigma^+ + \Sigma^+ + \pi^+ + \pi^- + K^0 + K^0$	1	32	3654
			81	
			~~32~~	

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PHYSICS NOTES

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NAME P. WOHLMUT

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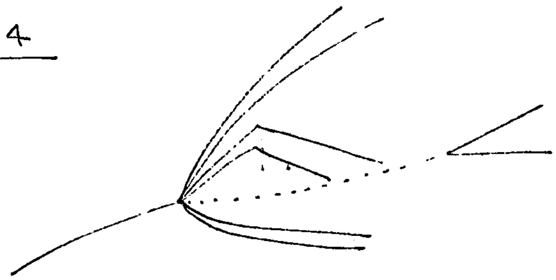
PET 214



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow \Sigma^+ + \Sigma^+ + K^+ + \pi^+ + \pi^- + \pi^- + K^0$	4	~~64~~ 32	3790
			33	
			~~65~~	

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PHYSICS NOTES

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NAME P. WOHLMUT

DATE 4-6-65

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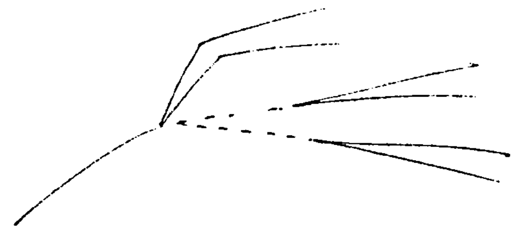
PET 222



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow \Sigma^+ + \Sigma^+ + K^0 + K^0$	4	[illegible]	3374
	$\longrightarrow \Sigma^+ + \Sigma^+ + K^0 + K^0 + \pi^0$	1	32	3509
	$\longrightarrow K^0 + K^0 + MM$	4	1	
			50	
			EG.	

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NAME P. WOHLMUT

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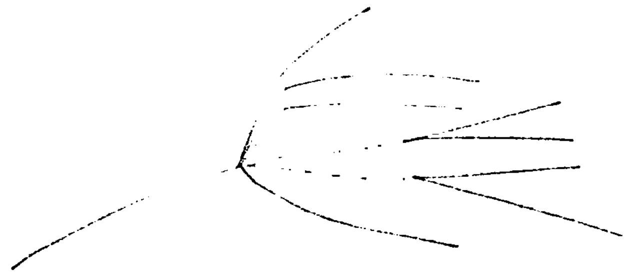
PET 223



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow \Sigma^+ + \Sigma^+ + \pi^+ + \pi^- + K^0 + K^0$	4	~~2~~ 16	3654
	$\longrightarrow \Sigma^+ + \Sigma^+ + \pi^+ + \pi^- + K^0 + K^0 + \pi^0$	1	32	3780
			~~66~~ 50	

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NAME: P. WOHLMUT

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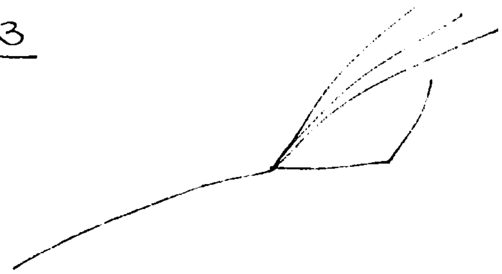
PET 303



	REACTION	CONST.	MULT.	MASS
✓	$p+p \longrightarrow p+K^++\pi^++\Sigma^-$	4	6	2769
	$\longrightarrow p+K^++\pi^++\Sigma^-+\pi^0$	1	12	2904
	$\longrightarrow K^++\pi^++\pi^++\Sigma^-+n$	1	6	2911
	$\longrightarrow p+\pi^++\pi^++\Sigma^-+K^0$	1	6	2913
✓	$\longrightarrow p+K^++K^++\Xi^-$	4	3	3250
	$\longrightarrow p+K^++K^++\Xi^-+\pi^0$	1	6	3385
	$\longrightarrow p+K^++\pi^++\Xi^-+K^0$	1	12	3394
	$\longrightarrow K^++K^++\pi^++\Sigma^-+\Lambda$	1	6	3440
	$\longrightarrow K^++K^++\pi^++\Sigma^-+\Sigma^0$	1	6	3518
	$\longrightarrow p+K^++K^++\Sigma^-+\bar{K}^0$	1	6	3621
✓	$\longrightarrow p+K^++\pi^++MM$	4	6	
✓	$\longrightarrow K^++\pi^++\pi^++MM$	↓	3	
✓	$\longrightarrow p+\pi^++\pi^++MM$	↓	3	
✓	$\longrightarrow p+K^++K^++MM$	↓	3	
	$\longrightarrow K^++K^++\pi^++MM$	↓	3	

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~~96~~

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PHYSICS NOTES

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NAME P. WOHLMUT

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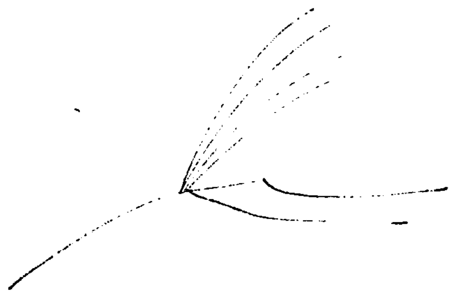
SUBJECT

PET 304



	Reaction	Const.	Mult.	Mass
	$p+p \rightarrow p+K^++\pi^++\pi^++\Sigma^-+\pi^-$	4	~~[illegible]~~ 12	3049
	$\rightarrow p+K^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^0$	1	24	3184
	$\rightarrow K^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+n$	1	8	3191
	$\rightarrow p+\pi^++\pi^++\pi^++\Sigma^-+\pi^-+K^0$	1	8	3193
	$\rightarrow p+K^++K^++\pi^++\Xi^-+\pi^-$	4	~~[illegible]~~ 12	3530
	$\rightarrow p+K^++K^++\pi^++\Xi^-+\pi^-+\pi^0$	1	24	3665
	$\rightarrow p+K^++\pi^++\pi^++\Xi^-+\pi^-+K^0$	1	24	3674
	$\rightarrow K^++K^++\pi^++\pi^++\Xi^-+\pi^-+n$	1	12	3684
	$\rightarrow K^++K^++\pi^++\pi^++\Sigma^-+\pi^-+\Lambda$	1	12	3720
	$\rightarrow p+K^++K^++\pi^++\Sigma^-+K^-$	4	~~[illegible]~~ 12	3757
	$\rightarrow K^++K^++\pi^++\pi^++\Sigma^-+\pi^-+\Sigma^0$	1	12	3798
	$\rightarrow p+K^++K^++\pi^++\Sigma^-+K^-+\pi^0$	1	24	3892
	$\rightarrow p+K^++\pi^++\pi^++\pi^-+MM$	4 ↓	12	
	$\rightarrow K^++\pi^++\pi^++\pi^++\pi^-+MM$		4	
	$\rightarrow p+\pi^++\pi^++\pi^++\pi^-+MM$		4	
	$\rightarrow p+K^++K^++\pi^++\pi^-+MM$		12	
	$\rightarrow K^++K^++\pi^++\pi^++\pi^-+MM$		6	
	$\rightarrow p+K^++K^++\pi^++K^-+MM$		12	
			228	
			~~[illegible]~~	

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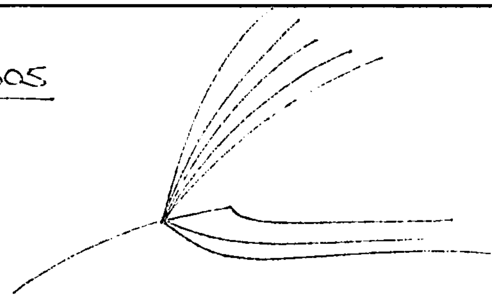
NAME P. WOHLMUT

DATE 4-6-65

PET 305



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^-$	4	~~10~~ 20	3329
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^-+\pi^0$	1	40	3464
	$\longrightarrow K^++\pi^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^-+n$	1	10	3471
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^-+K^0$	1	10	3473
	$\longrightarrow p+K^++K^++\pi^++\pi^++\Xi^-+\pi^-+\pi^-$	4	~~6~~ 30	3810
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$	4	20	
	$\longrightarrow K^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$	↓	5	
	$\longrightarrow p+\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+MM$		5	
	$\longrightarrow p+K^++K^++\pi^++\pi^++\pi^-+\pi^-+MM$	↓	30	
			170	
			~~220~~	

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NAME P. WOHLMUT

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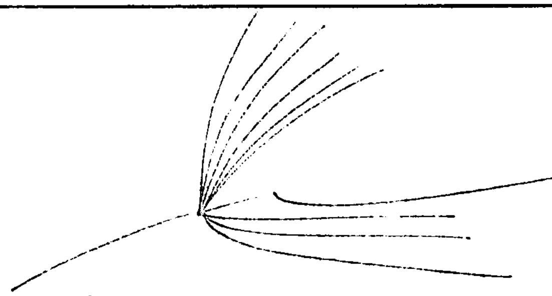
PET 306



	REACTION	CONST.	MULT.	MASS
	$p + p \longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^-$	4	[illegible]	3609
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^- + \pi^0$	1	60	3744
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^- + n$	1	12	3751
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^- + K^0$	1	12	3753
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$	4	30	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		6	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + MM$		6	
			156	
			~~156~~	

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PHYSICS NOTES

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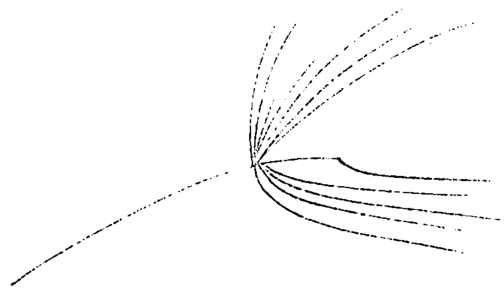
DATE 4-6-65

SUBJECT

PET 307



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^++\pi^++\Sigma^-+\pi^-+\pi^-+\pi^-+\pi^-$	4	[illegible]	3889
	$\longrightarrow p+K^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^++\pi^-+\pi^-+\pi^-+\pi^-+MM$	4	42	

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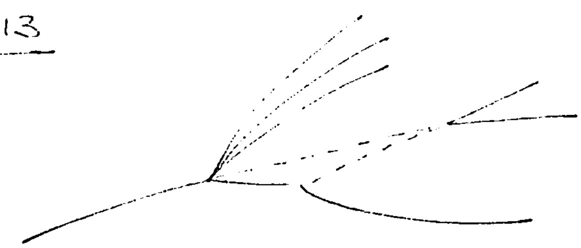
	DATE	4-6-65

PET 313



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \longrightarrow p + \pi^-$	3	2	
✓	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
✓	$\Xi^- \longrightarrow \Lambda + \pi^-$	3	1	
	$p + p \longrightarrow p + \pi^+ + \pi^+ + \Sigma^- + K^0$	4	3	2913
	$\longrightarrow p + \pi^+ + \pi^+ + \Sigma^- + K^0 + \pi^0$	1	6	3048
	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + \Sigma^- + K^0 + n$	1	2	3055
✓	$\longrightarrow p + K^+ + K^+ + \Xi^-$	4	3	3250
	$\longrightarrow p + K^+ + K^+ + \Xi^- + \pi^0$	1	3	3385
✓	$\longrightarrow K^+ + K^+ + \pi^+ + \Xi^- + n$	1	3	3392
	$\longrightarrow p + K^+ + \pi^+ + \Xi^- + K^0$	4	6	3394
✓	$\longrightarrow p + K^+ + \pi^+ + \Xi^- + K^0$	1	3	3394
	$\longrightarrow K^+ + \pi^+ + K^+ + \Sigma^- + \Lambda$	4	6	3440
	$\longrightarrow K^+ + K^+ + \pi^+ + \Sigma^- + \Sigma^0$	2	12	3518
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \Xi^- + K^0 + n$	1	6	3536
	$\longrightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0$	1	6	3538
	$\longrightarrow K^+ + \pi^+ + K^+ + \Sigma^- + \Lambda + \pi^0$	1	6	3575
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \Sigma^- + \Lambda + K^0$	1	12	3584
✓	$\longrightarrow p + \pi^+ + \pi^+ + K^0 + MM$	4	3	
✓	$\longrightarrow p + \pi^+ + \pi^+ + MM$	↓	3	
✓	$\longrightarrow \pi^+ + \pi^+ + \pi^+ + K^0 + MM$	↓	1	
✓	$\longrightarrow p + K^+ + K^+ + MM$	↓	3	
	$\longrightarrow K^+ + K^+ + \pi^+ + MM$	↓	3	
	$\longrightarrow p + K^+ + \pi^+ + K^0 + MM$	↓	6	
	$\longrightarrow p + K^+ + \pi^+ + MM$	↓	6	
	$\longrightarrow K^+ + K^+ + \pi^+ + \Lambda + MM$	↓	3	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + K^0 + MM$	↓	3	
23			112	
~~25~~			~~127~~	

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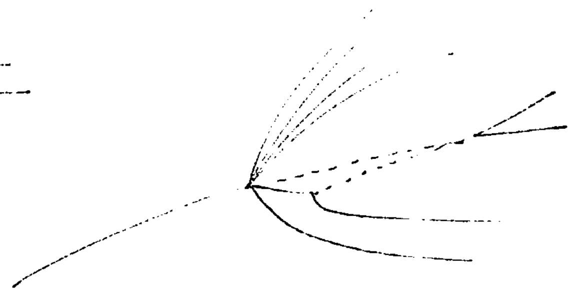
PET 314



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \to p + \pi^-$	3	2	
✓	$\Xi^- \to \Lambda + \pi^-$	3	1	
	$K^0 \to \pi^+ + \pi^-$	3	1	
	$p + p \to p + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + K^0$	4	24	3193
	$\to p + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + K^0 + \pi^0$	1	8	3328
	$\to \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + K^0 + n$	1	2	3335
✓	$\to p + K^+ + K^+ + \pi^+ + \Xi^- + \pi^-$	4	12	3530
	$\to p + K^+ + K^+ + \pi^+ + \Xi^- + \pi^- + \pi^0$	1	12	3665
	$\to K^+ + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + n$	1	6	3672
	$\to p + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0$	4	~~24~~ 12	3674
	$\to p + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0$	1	~~12~~ 6	3674
	$\to K^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \Lambda$	4	12	3720
	$\to K^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \Sigma^0$	2	24	3798
	$\to K^+ + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + n$	1	8	3816
	$\to p + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + K^0$	1	8	3818
	$\to K^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \Lambda + \pi^0$	1	12	3855
	$\to K^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \Lambda + K^0$	1	16	3864
✓	$\to p + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	4	4	
	$\to \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	↓	1	
	$\to p + K^+ + K^+ + \pi^+ + \pi^- + MM$	↓	12	
✓	$\to K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + MM$	↓	6	
	$\to p + K^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	↓	12	
	$\to K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$	↓	6	
	$\to K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	↓	4	
	$\to K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$	↓	4	
25			195	
~~20~~			~~277~~	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

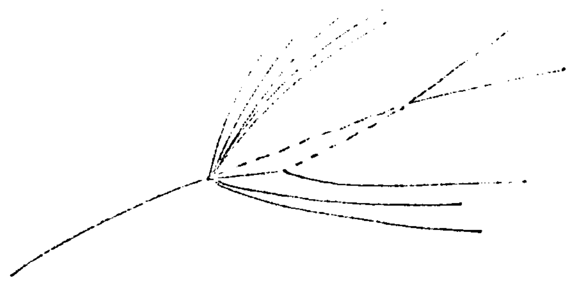
MEMO NO.	PAGE
548	5.66

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 315



	REACTION	CONST.	MULT.	MASS
	$\Lambda \rightarrow p + \pi^-$	3	2	
	$\Xi^- \rightarrow \Lambda + \pi^-$	3	1	
	$K^0 \rightarrow \pi^+ + \pi^-$	3	1	
	$p + p \rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + K^0$	4	5	3473
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + K^0 + \pi^0$	1	10	3608
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + K^0 + n$	1	2	3615
	$\rightarrow p + K^+ + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + \pi^-$	4	30	3810
	$\rightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$	4	5	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + K^0 + MM$	↓	1	
	$\rightarrow p + K^+ + K^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + MM$		30	
			85	
			~~90~~	

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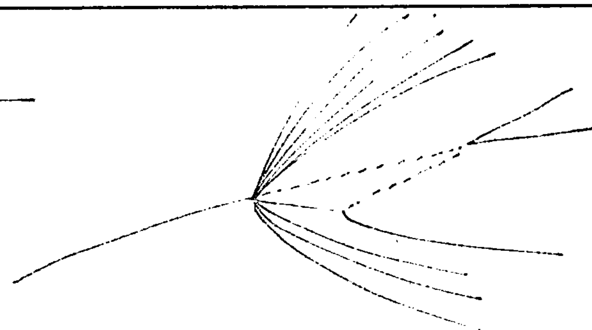
SUBJECT	NAME P. WOHLMUT	DATE 4-6-65

PET 316



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^- + K^0$	4	~~12~~ 6	3753
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \pi^- + \pi^- + K^0 + \pi^0$	1	12.	3888
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \pi^- + \pi^- + K^0 + mm$	4	6	
			25	
			37	

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PHYSICS NOTES

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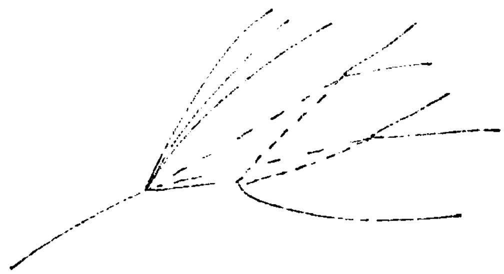
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 323



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \rightarrow p + \pi^-$	3	4	
✓	$\Xi^- \rightarrow \Lambda + \pi^-$	3	2	
✓	$K^0 \rightarrow \pi^+ + \pi^-$	3	2	
✓	$p + p \rightarrow p + K^+ + \pi^+ + \Xi^- + K^0$	4	12	3394
	$\rightarrow p + K^+ + \pi^+ + \Xi^- + K^0 + \pi^0$	1	12	3529
✓	$\rightarrow K^+ + \pi^+ + \pi^+ + \Xi^- + K^0 + n$	1	6	3536
	$\rightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0$	4	6	3538
	$\rightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0$	1	6	3538
	$\rightarrow K^+ + \pi^+ + \pi^+ + \Sigma^- + \Lambda + K^0$	4	6	3584
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0 + n$	1	2	3680
	$\rightarrow K^+ + \pi^+ + \pi^+ + \Sigma^- + \Lambda + K^0 + \pi^0$	1	12	3719
	$\rightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0 + \pi^0$	1	6	3773
	$\rightarrow p + K^+ + \pi^+ + K^0 + mm$	4	12	
	$\rightarrow K^+ + \pi^+ + \pi^+ + K^0 + mm$	↓	6	
	$\rightarrow p + \pi^+ + \pi^+ + K^0 + K^0 + mm$	↓	3	
	$\rightarrow p + \pi^+ + \pi^+ + K^0 + mm$	↓	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \Lambda + K^0$	↓	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + \Lambda + mm$	↓	6	
	$\rightarrow K^+ + \pi^+ + \pi^+ + K^0 + mm$	↓	6	
	$\rightarrow \pi^+ + \pi^+ + \pi^+ + K^0 + K^0 + mm$	↓	1	
24			122	

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PHYSICS NOTES

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NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 324

	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	4	
	$\Xi^- \longrightarrow \Lambda + \pi^-$	3	2	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow p + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0$	4	24	3674
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + \pi^0$	1	24	3809
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + n$	1	8	3816
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + K^0$	4	8	3818
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + K^0$	1	8	3818
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + \Lambda + K^0$	4	[illegible]	3864
	$\longrightarrow p + K^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	4	24	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	↓	8	
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + MM$	↓	4	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + K^0 + MM$	↓	8	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + \Lambda + MM$	↓	8	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + MM$	↓	8	
			146	
			~~156~~	

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PHYSICS NOTES

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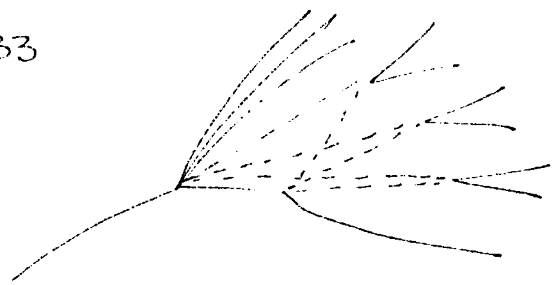
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 333



	REACTION	CONST.	MULT.	MASS
✓	$\Lambda \rightarrow p + \pi^-$	3	3	
✓	$K^0 \rightarrow \pi^+ + \pi^-$	3	3	
✓	$\Xi^- \rightarrow \Lambda + \pi^-$	3	3	
✓	$p + p \rightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0$	4	9	3538
	$\rightarrow p + \pi^+ + \pi^+ + \Xi^- + K^0 + K^0 + \pi^0$	1	9	3673
	$\rightarrow p + \pi^+ + \pi^+ + K^0 + K^0 + MM$	4	9	

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PHYSICS NOTES

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NAME: P. WOHLMUT
DATE: 4-6-65

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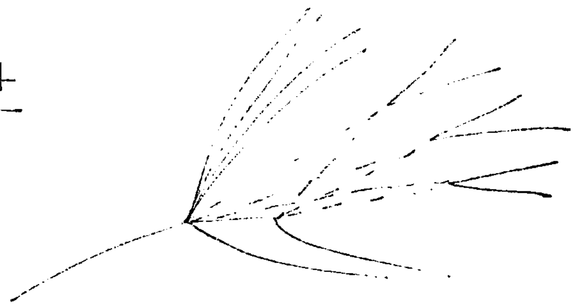
PET 334



	REACTION	CONST.	MULT.	MASS
	$\Lambda \longrightarrow p + \pi^-$	3	3	
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	3	
	$\Xi^- \longrightarrow \Lambda + \pi^-$	3	3	
	$p + p \longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \Xi^- + \pi^- + K^0 + K^0$	4	12	3818
	$\longrightarrow p + \pi^+ + \pi^+ + \pi^+ + \pi^- + K^0 + K^0 + mm$	4	12	

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PHYSICS NOTES

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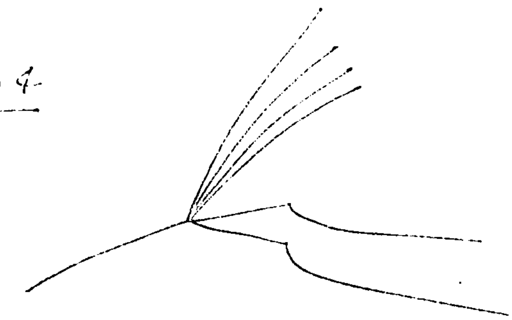
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 404



	REACTION	CONST.	MULT.	MASS
	$p + p \longrightarrow K^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \Sigma^-$	4	[illegible]	3662
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \Sigma^- + K^0$	1	32	3806
	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^+ + MM$	4	6	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + MM$	↓	4	
			66	
			90	

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PHYSICS NOTES

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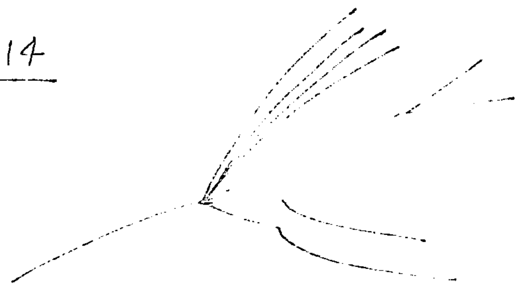
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 414



	REACTION	CONST	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + \Sigma^- + \Sigma^- + K^0$	4	16	
	$\longrightarrow K^+ + \pi^+ + \pi^+ + \pi^+ + K^0 + MM$	4	4.	
			21	
			~~37~~	

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PHYSICS NOTES

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NAME	P. WOHLMUT
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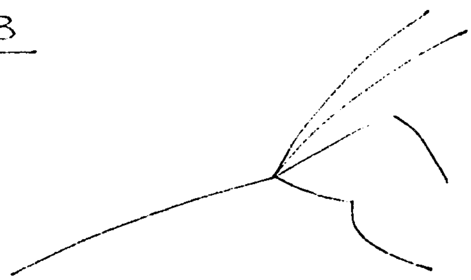
SUBJECT	

PET 503



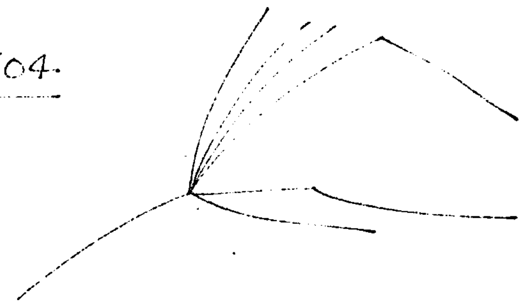
	REACTION	CONST.	MULT.	MASS
✓	$p+p \longrightarrow \Sigma_1^{+} + K^{+} + K^{+} + \Sigma_1^{-}$	4	~~16~~ 8	3374
✓	$\longrightarrow \Sigma_1^{+} + K^{+} + K^{+} + \Sigma_1^{-} + \pi^{0}$	1	16	3509
	$\longrightarrow \Sigma_1^{+} + K^{+} + \pi^{+} + \Sigma_1^{-} + K^{0}$	1	32	3518
✓	$\longrightarrow K^{+} + K^{+} + MM$	4	1	
	$\longrightarrow K^{+} + \pi^{+} + MM$	↓	2	
			59	
33 25			~~67~~	

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 504.



	REACTION	CONST.	MULT.	MASS
	$p+p \longrightarrow \Sigma^+ + K^+ + K^+ + \pi^+ + \Sigma^+ + \pi^-$	4	[illegible]	3654
	$\longrightarrow \Sigma^+ + K^+ + K^+ + \pi^+ + \Sigma^- + \pi^- + \pi^0$	1	48	3789
	$\longrightarrow \Sigma^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + K^0$	1	48	3798
	$\longrightarrow K^+ + K^+ + \pi^+ + \pi^- + MM$	4	3	

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PHYSICS NOTES

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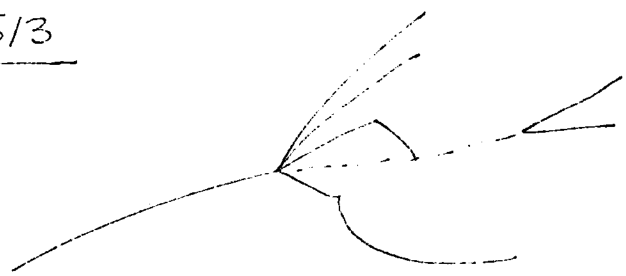
NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 513



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$\longrightarrow \Sigma^+ + K^+ + \pi^+ + \Sigma^- + K^0$	4	16	3518
	$\longrightarrow \Sigma^+ + K^+ + \pi^+ + \Sigma^- + K^0 + \pi^0$	1	32	3653
	$\longrightarrow \Sigma^+ + \pi^+ + \pi^+ + \Sigma^- + K^0 + K^0$	1	16	3662
	$\longrightarrow K^+ + \pi^+ + K^0 + MM$	4	2	

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PHYSICS NOTES

MEMO NO.	PAGE
548	5.77

NAME: T. WOH : MUT

DATE: 4-6-65

SUBJECT

PET 514

	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	1	
	$p + p \longrightarrow \Sigma^+ + K^+ + \pi^+ + \pi^+ + \Sigma^- + \pi^- + K^0$	4	[illegible]	3708
	$\longrightarrow \pi^+ + K^+ + \pi^+ + \pi^- + K^0$ + mm	4	3	

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PHYSICS NOTES

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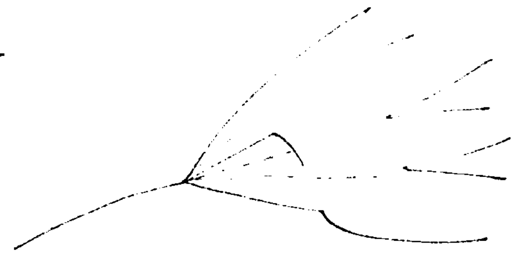
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

Pict 523



	REACTION	CONST.	MULT.	MASS
	$K^0 \longrightarrow \pi^+ + \pi^-$	3	2	
	$p + p \longrightarrow \Sigma^+ + \pi^+ + \pi^+ + \Sigma^- + K^0 + K^0$	4	16	3662
	$\longrightarrow \Sigma^+ + \pi^+ + \pi^+ + \Sigma^- + K^0 + K^0 + \pi^0$	1	16	3797
	$\longrightarrow \pi^+ + \pi^+ + K^0 + K^0 + MM$	4	1	

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

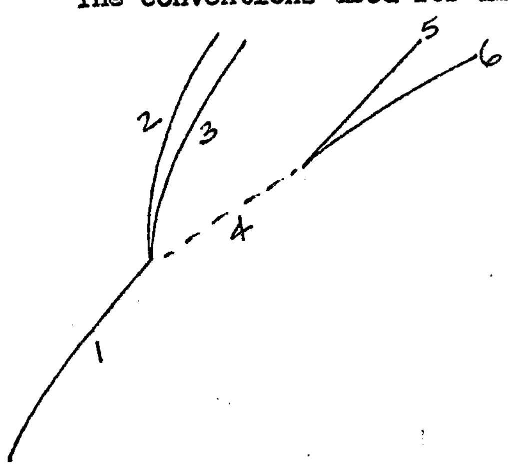
LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA PHYSICS NOTES	NFD	MEMO NO. 549	PAGE 1
SUBJECT: EXPERIMENT 17 (P65) EVENT TYPE MEMO		NAME: P. Wohlmut	
		DATE: 4-6-65	

The event types discussed here refer to the P65 Experiment (see scanning instructions, Memo # 548).

All the possible reactions for a specified topology are given in Addendum #5 of the P65 Scanners Manual (Memo 548). From this addendum it can be seen that the number of reactions, and multiplicities of given topologies are excessively large---too large for the current data processing systems to handle.

This memo will appear in three parts. The first (pages 1-17) restricts itself to those event types compatible with PACKAGE and DST-EXAMIN as they now exist. Due to the restrictions in the above systems, severe editing of reactions and event types is necessary. Only those interactions complying with current program restrictions and which are likely to occur in this experiment have been programmed. The second part of this memo will describe TVGP-WAMPUM event types when the system is ready. The third part will incorporate the changes in the conversion to the CDC 6600 system.

The conventions used for listing a given reaction are shown below:



CPM	HYPOTHESIS
1	$\Lambda_{④} \rightarrow p_6 + \pi^-_5$
2	$p_1 + p_T \rightarrow p_2 + K^+_3 + {}_1\Lambda_4$

$\Lambda_{④}$ means: store values of track 4

${}_1\Lambda_4$ means: use swum values of tr. 4 from cpm 1

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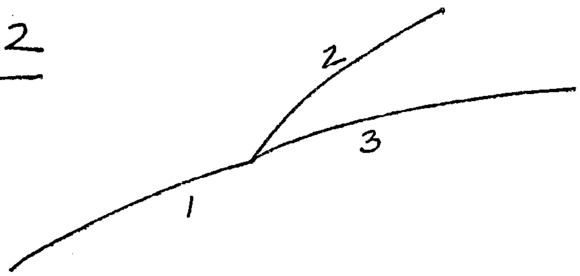
PHYSICS NOTES

MEMO NO. 549 PAGE 2
NAME P. WOHLMUT
DATE 4-6-65
SUBJECT

PET 002



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
d		5
π^+	3	6
K^+		7
p		10_8
d		11_8

CPM	HYPOTHESIS
1	$p_1 + p_T \rightarrow p_2 + p_3$
2	$\rightarrow p_2 + p_3 + \pi^0_{31}$
3	$\rightarrow p_2 + n_{31} + \pi^+_3$
4	$\rightarrow p_3 + n_{31} + \pi^+_2$
5	$\rightarrow d_2 + \pi^+_3$
6	$\rightarrow d_3 + \pi^+_2$
7	$\rightarrow d_2 + \pi^+_3 + \pi^0_{31}$
8	$\rightarrow d_3 + \pi^+_2 + \pi^0_{31}$
9	$\rightarrow d_2 + K^+_3 + \bar{K}^0_{31}$
10	$\rightarrow d_3 + K^+_2 + \bar{K}^0_{31}$
11	$\rightarrow \Lambda_{31} + p_2 + K^+_3$
12	$\rightarrow \Lambda_{31} + p_3 + K^+_2$
13	$\rightarrow \Sigma^0_{31} + p_2 + K^+_3$
14	$\rightarrow \Sigma^0_{31} + p_3 + K^+_2$
15	$\rightarrow p_2 + p_3 + MM$
16	$\rightarrow p_2 + K^+_3 + MM$
17	$\rightarrow p_3 + K^+_2 + MM$
18	$\rightarrow p_2 + \pi^+_3 + MM$
19	$\rightarrow p_3 + \pi^+_2 + MM$
20	$\rightarrow d_2 + \pi^+_3 + MM$
21	$\rightarrow d_3 + \pi^+_2 + MM$
22	$\rightarrow d_2 + K^+_3 + MM$
23	$\rightarrow d_3 + K^+_2 + MM$
24	$\rightarrow \pi^+_2 + \pi^+_3 + MM$

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PHYSICS NOTES

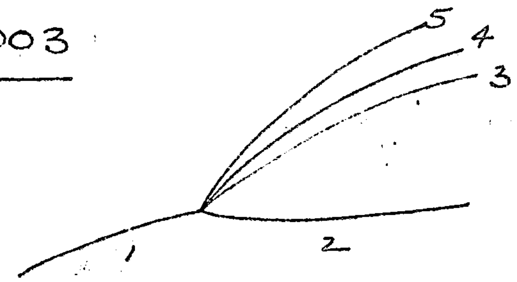
MEMO NO. 549 | PAGE 3

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 003



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^-	2	2
K^-		3
π^+	3	4
K^+		5
p		6
d		7
π^+	4	10_8
K^+		11_8
p		12_8
d		13_8
π^+	5	14_8
K^+		15_8
p		16_8
d		17_8

CPM	HYPOTHESIS
1	$p_1+p_T \longrightarrow p_3+p_4+\pi^+_5+\pi^-_2$
2	$\longrightarrow p_3+p_5+\pi^+_4+\pi^-_2$
3	$\longrightarrow p_4+p_5+\pi^+_3+\pi^-_2$
4	$\longrightarrow p_3+p_4+\pi^+_5+\pi^0_{31}+\pi^-_2$
5	$\longrightarrow p_3+p_5+\pi^+_4+\pi^0_{31}+\pi^-_2$
6	$\longrightarrow p_4+p_5+\pi^+_3+\pi^0_{31}+\pi^-_2$
7	$\longrightarrow p_3+n_{31}+\pi^+_4+\pi^+_5+\pi^-_2$
8	$\longrightarrow p_4+n_{31}+\pi^+_3+\pi^+_5+\pi^-_2$
9	$\longrightarrow p_5+n_{31}+\pi^+_3+\pi^+_4+\pi^-_2$
10	$\longrightarrow d_3+\pi^+_4+\pi^+_5+\pi^-_2$
11	$\longrightarrow d_4+\pi^+_3+\pi^+_5+\pi^-_2$
12	$\longrightarrow d_5+\pi^+_3+\pi^+_4+\pi^-_2$
13	$\longrightarrow d_3+\pi^+_4+\pi^+_5+\pi^0_{31}+\pi^-_2$
14	$\longrightarrow d_4+\pi^+_3+\pi^+_5+\pi^0_{31}+\pi^-_2$
15	$\longrightarrow d_5+\pi^+_3+\pi^+_4+\pi^0_{31}+\pi^-_2$
16	$\longrightarrow \Lambda_{31}+p_3+K^+_4+\pi^+_5+\pi^-_2$
17	$\longrightarrow \Lambda_{31}+p_3+K^+_5+\pi^+_4+\pi^-_2$
18	$\longrightarrow \Lambda_{31}+p_4+K^+_3+\pi^+_5+\pi^-_2$
19	$\longrightarrow \Lambda_{31}+p_4+K^+_5+\pi^+_3+\pi^-_2$
20	$\longrightarrow \Lambda_{31}+p_5+K^+_3+\pi^+_4+\pi^-_2$
21	$\longrightarrow \Lambda_{31}+p_5+K^+_4+\pi^+_3+\pi^-_2$
22	$\longrightarrow p_3+p_4+K^+_5+K^-_2$
23	$\longrightarrow p_3+p_5+K^+_4+K^-_2$
24	$\longrightarrow p_4+p_5+K^+_3+K^-_2$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

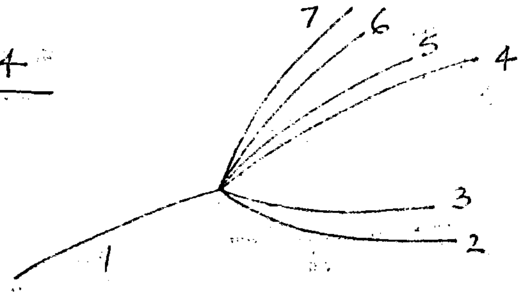
MEMO NO. 549 PAGE 4

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 004



PANG DATA		
MASS	TRK NO.	TRK BANK
p	1	1
π^-	2	2
π^-	3	3
π^+	4	4
p		5
d		6
π^+	5	7
p		10_8
d		11_8
π^+	6	12_8
p		13_8
d		14_8
π^+	7	15_8
p		16_8
d		17_8

CPM	HYPOTHESIS
1	$p_1 + p_T \longrightarrow p_4 + p_5 + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
2	$\longrightarrow p_4 + p_6 + \pi_5^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
3	$\longrightarrow p_4 + p_7 + \pi_5^+ + \pi_6^+ + \pi_2^- + \pi_3^-$
4	$\longrightarrow p_5 + p_6 + \pi_4^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
5	$\longrightarrow p_5 + p_7 + \pi_4^+ + \pi_6^+ + \pi_2^- + \pi_3^-$
6	$\longrightarrow p_6 + p_7 + \pi_4^+ + \pi_5^+ + \pi_2^- + \pi_3^-$
7	$\longrightarrow d_4 + \pi_5^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
8	$\longrightarrow d_5 + \pi_4^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
9	$\longrightarrow d_6 + \pi_4^+ + \pi_5^+ + \pi_7^+ + \pi_2^- + \pi_3^-$
10	$\longrightarrow d_7 + \pi_4^+ + \pi_5^+ + \pi_6^+ + \pi_2^- + \pi_3^-$
11	$\longrightarrow p_4 + p_5 + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
12	$\longrightarrow p_4 + p_6 + \pi_5^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
13	$\longrightarrow p_4 + p_7 + \pi_5^+ + \pi_6^+ + \pi_2^- + \pi_3^- + MM$
14	$\longrightarrow p_5 + p_6 + \pi_4^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
15	$\longrightarrow p_5 + p_7 + \pi_4^+ + \pi_6^+ + \pi_2^- + \pi_3^- + MM$
16	$\longrightarrow p_6 + p_7 + \pi_4^+ + \pi_5^+ + \pi_2^- + \pi_3^- + MM$
17	$\longrightarrow p_4 + \pi_5^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
18	$\longrightarrow p_5 + \pi_4^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
19	$\longrightarrow p_6 + \pi_4^+ + \pi_5^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
20	$\longrightarrow p_7 + \pi_4^+ + \pi_5^+ + \pi_6^+ + \pi_2^- + \pi_3^- + MM$
21	$\longrightarrow d_4 + \pi_5^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
22	$\longrightarrow d_5 + \pi_4^+ + \pi_6^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
23	$\longrightarrow d_6 + \pi_4^+ + \pi_5^+ + \pi_7^+ + \pi_2^- + \pi_3^- + MM$
24	$\longrightarrow d_7 + \pi_4^+ + \pi_5^+ + \pi_6^+ + \pi_2^- + \pi_3^- + MM$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
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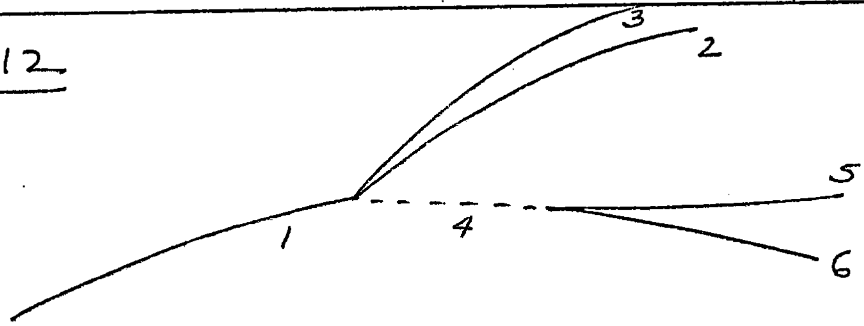
MEMO NO. 549 | PAGE 5

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 012



PANG	DATA	
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
d		5
π^+	3	6
K^+		7
p		10_8
d		11_8
K^0	4	12_8
Λ		13_8
π^-	5	14_8
π^+	6	15_8
p		16_8

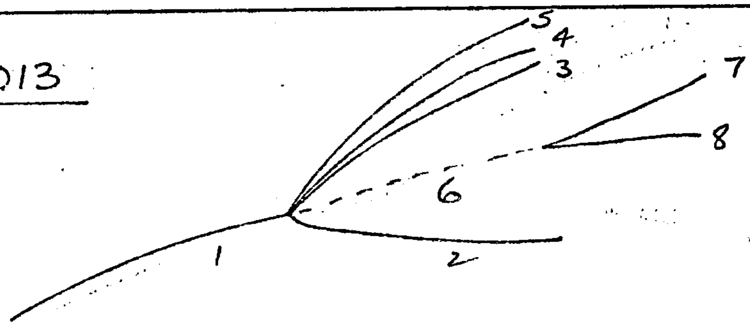
CPM	HYPOTHESIS
1	$\Lambda_{④} \to p_6 + \pi^-_5$
2	$K^0_{④} \to \pi^+_6 + \pi^-_5$
3	$p_1 + p_T \to {}_1\Lambda_4 + p_2 + K^+_3$
4	$\to {}_1\Lambda_4 + p_3 + K^+_2$
5	$\to \Sigma^0_{31} + p_2 + K^+_3 ; \Sigma^0_{31} \to {}_1\Lambda_4 + \gamma_{30}$
6	$\to \Sigma^0_{31} + p_3 + K^+_2 ; \Sigma^0_{31} \to {}_1\Lambda_4 + \gamma_{30}$
7	$\to {}_1\Lambda_4 + p_2 + K^+_3 + \pi^0_{31}$
8	$\to {}_1\Lambda_4 + p_3 + K^+_2 + \pi^0_{31}$
9	$\to {}_1\Lambda_4 + n_{31} + K^+_2 + \pi^+_3$
10	$\to {}_1\Lambda_4 + n_{31} + K^+_3 + \pi^+_2$
11	$\to {}_1\Lambda_4 + p_2 + K^0_{31} + \pi^+_3$
12	$\to {}_1\Lambda_4 + p_3 + K^0_{31} + \pi^+_2$
13	$\to \Lambda_{31} + p_2 + {}_2K^0_4 + \pi^+_3$
14	$\to \Lambda_{31} + p_3 + {}_2K^0_4 + \pi^+_2$
15	$\to \Sigma^0_{31} + p_2 + {}_2K^0_4 + \pi^+_3$
16	$\to \Sigma^0_{31} + p_3 + {}_2K^0_4 + \pi^+_2$
17	$\to d_2 + K^+_3 + {}_2\bar{K}^0_4$
18	$\to d_3 + K^+_2 + {}_2\bar{K}^0_4$
19	$\to p_2 + n_{31} + K^+_3 + {}_2\bar{K}^0_4$
20	$\to p_3 + n_{31} + K^+_2 + {}_2\bar{K}^0_4$
21	$\to p_2 + p_3 + {}_2K^0_4 + \bar{K}^0_{31}$
22	$\to d_2 + K^+_3 + {}_2\bar{K}^0_4 + \pi^0_{31}$
23	$\to d_3 + K^+_2 + {}_2\bar{K}^0_4 + \pi^0_{31}$
24	$\to d_2 + {}_2\bar{K}^0_4 + K^0_{31} + \pi^+_3$
25	$\to d_3 + {}_2\bar{K}^0_4 + K^0_{31} + \pi^+_2$

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

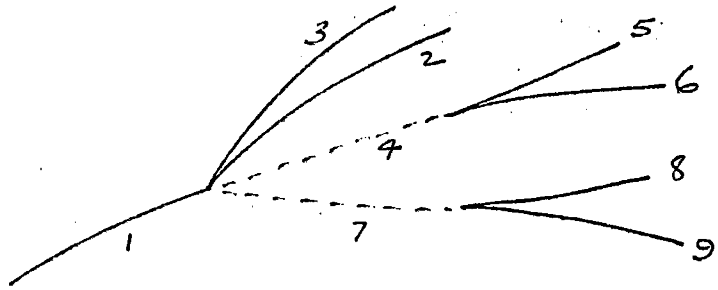
PET 013



PANG DATA		
MASS	TRK. NO.	TRK. BANK.
p	1	1
π^-	2	2
K^-		3
π^+	3	4
K^+		5
p		6
π^+	4	7
K^+		10_8
p		11_8
π^+	5	12_8
K^+		13_8
p		14_8
K^0	6	15_8
Λ		16_8
π^-	7	17_8
π^+	8	20_8
p		21_8

CPM	HYPOTHESIS
1	$\Lambda_{(6)} \longrightarrow p_8 + \pi^-_7$
2	$K^0_{(6)} \longrightarrow \pi^+_8 + \pi^-_7$
3	$p_1 + p_T \longrightarrow {}_1\Lambda_6 + p_3 + K^+_4 + \pi^+_5 + \pi^-_2$
4	$\longrightarrow {}_1\Lambda_6 + p_3 + K^+_5 + \pi^+_4 + \pi^-_2$
5	$\longrightarrow {}_1\Lambda_6 + p_4 + K^+_3 + \pi^+_5 + \pi^-_2$
6	$\longrightarrow {}_1\Lambda_6 + p_4 + K^+_5 + \pi^+_3 + \pi^-_2$
7	$\longrightarrow {}_1\Lambda_6 + p_5 + K^+_3 + \pi^+_4 + \pi^-_2$
8	$\longrightarrow {}_1\Lambda_6 + p_5 + K^+_4 + \pi^+_3 + \pi^-_2$
9	$\longrightarrow {}_1\Lambda_6 + p_3 + K^+_4 + \pi^+_5 + \pi^0_{31} + \pi^-_2$
10	$\longrightarrow {}_1\Lambda_6 + p_3 + K^+_5 + \pi^+_4 + \pi^0_{31} + \pi^-_2$
11	$\longrightarrow {}_1\Lambda_6 + p_4 + K^+_3 + \pi^+_5 + \pi^0_{31} + \pi^-_2$
12	$\longrightarrow {}_1\Lambda_6 + p_4 + K^+_5 + \pi^+_3 + \pi^0_{31} + \pi^-_2$
13	$\longrightarrow {}_1\Lambda_6 + p_5 + K^+_3 + \pi^+_4 + \pi^0_{31} + \pi^-_2$
14	$\longrightarrow {}_1\Lambda_6 + p_5 + K^+_4 + \pi^+_3 + \pi^0_{31} + \pi^-_2$
15	$\longrightarrow {}_1\Lambda_6 + n_{31} + K^+_3 + \pi^+_4 + \pi^+_5 + \pi^-_2$
16	$\longrightarrow {}_1\Lambda_6 + n_{31} + K^+_4 + \pi^+_3 + \pi^+_5 + \pi^-_2$
17	$\longrightarrow {}_1\Lambda_6 + n_{31} + K^+_5 + \pi^+_3 + \pi^+_4 + \pi^-_2$
18	$\longrightarrow p_3 + p_4 + K^+_5 + {}_2\bar{K}^0_6 + \pi^-_2$
19	$\longrightarrow p_3 + p_5 + K^+_4 + {}_2\bar{K}^0_6 + \pi^-_2$
20	$\longrightarrow p_4 + p_5 + K^+_3 + {}_2\bar{K}^0_6 + \pi^-_2$
21	$\longrightarrow p_3 + p_4 + {}_2\bar{K}^0_6 + K^-_2 + \pi^+_5$
22	$\longrightarrow p_3 + p_5 + {}_2\bar{K}^0_6 + K^-_2 + \pi^+_4$
23	$\longrightarrow p_4 + p_5 + {}_2\bar{K}^0_6 + K^-_2 + \pi^+_3$

PET 022



PANG DATA		
MASS	TRK. No.	TRK. BANK
p	1	1
π^+	2	2
p		3
d		4
π^+	3	5
p		6
d		7
K^0	4	10_8
Λ		11_8
π^-	5	12_8
π^+	6	13_8
p		14_8
K^0	7	15_8
Λ		16_8
π^-	8	17_8
π^+	9	20_8
p		21_8

CRM	HYPOTHESIS
1	$\Lambda_{(4)} \rightarrow p_6 + \pi^-_5$
2	$\Lambda_{(7)} \rightarrow p_9 + \pi^-_8$
3	$K^0_{(4)} \rightarrow \pi^+_6 + \pi^-_5$
4	$K^0_{(7)} \rightarrow \pi^+_9 + \pi^-_8$
5	$p_1 + p_T \rightarrow {}_1\Lambda_4 + p_2 + {}_4K^0_7 + \pi^+_3$
6	$\rightarrow {}_1\Lambda_4 + p_3 + {}_4K^0_7 + \pi^+_2$
7	$\rightarrow {}_2\Lambda_7 + p_2 + {}_3K^0_4 + \pi^+_3$
8	$\rightarrow {}_2\Lambda_7 + p_3 + {}_3K^0_4 + \pi^+_2$
9	$\rightarrow \Sigma^0_{31} + p_2 + {}_4K^0_4 + \pi^+_3 ; \Sigma^0_{31} \rightarrow {}_1\Lambda_4 + \gamma^1_{30}$
10	$\rightarrow \Sigma^0_{31} + p_3 + {}_4K^0_7 + \pi^+_2 ;$ — " —
11	$\rightarrow \Sigma^0_{31} + p_2 + {}_3K^0_4 + \pi^+_3 ; \Sigma^0_{31} \rightarrow {}_2\Lambda_7 + \gamma^1_{30}$
12	$\rightarrow \Sigma^0_{31} + p_3 + {}_3K^0_4 + \pi^+_2 ;$ — " —
13	$\rightarrow {}_1\Lambda_4 + p_2 + {}_4K^0_7 + \pi^+_3 + \pi^0_{31}$
14	$\rightarrow {}_1\Lambda_4 + p_3 + {}_4K^0_7 + \pi^+_2 + \pi^0_{31}$
15	$\rightarrow {}_2\Lambda_7 + p_2 + {}_3K^0_4 + \pi^+_3 + \pi^0_{31}$
16	$\rightarrow {}_2\Lambda_7 + p_3 + {}_3K^0_4 + \pi^+_2 + \pi^0_{31}$
17	$\rightarrow {}_1\Lambda_4 + n_{31} + {}_4K^0_7 + \pi^+_2 + \pi^+_3$
18	$\rightarrow {}_2\Lambda_7 + n_{31} + {}_3K^0_4 + \pi^+_2 + \pi^+_3$
19	$\rightarrow p_2 + p_3 + {}_3K^0_4 + {}_4\bar{K}^0_7$
20	$\rightarrow p_2 + p_3 + {}_3K^0_4 + {}_4\bar{K}^0_7 + \pi^0_{31}$
21	$\rightarrow p_2 + n_{31} + {}_3K^0_4 + {}_4\bar{K}^0_7 + \pi^+_3$
22	$\rightarrow p_3 + n_{31} + {}_3K^0_4 + {}_4\bar{K}^0_7 + \pi^+_2$
23	$\rightarrow d_2 + {}_3K^0_4 + {}_4\bar{K}^0_7 + \pi^+_3$
24	$\rightarrow d_3 + {}_3K^0_4 + {}_4\bar{K}^0_7 + \pi^+_2$

LAWRENCE RADIATION LABORATORY • UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

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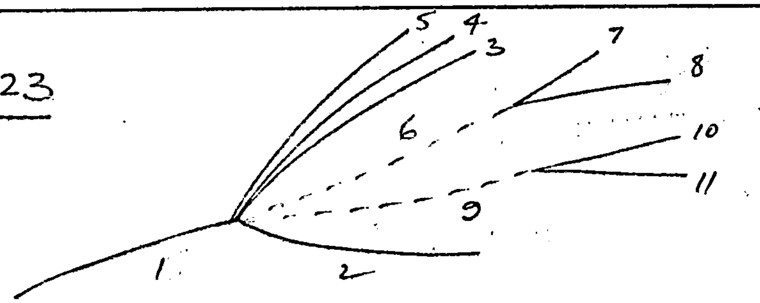
SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 023



PANG DATA

MASS	TRK. NO.	TRK. BANK
p	1	1
π^-	2	2
K^-		3
π^+	3	4
K^+		5
p		6
d		7
π^+	4	10_8
K^+		11_8
p		12_8
d		13_8
π^+	5	14_8
K^+		15_8
p		16_8
d		17_8
K^0	6	20_8
Λ		21_8
π^-	7	22_8
π^+	8	23_8
p		24_8
K^0	9	25_8
Λ		26_8
π^-	10	27_8
π^+	11	30_8
p		31_8

CPM	HYPOTHESIS
1	$\Lambda_{(6)} \longrightarrow p_8 + \pi^-_7$
2	$\Lambda_{(9)} \longrightarrow p_{11} + \pi^-_{10}$
3	$K^0_{(6)} \longrightarrow \pi^+_8 + \pi^-_7$
4	$K^0_{(9)} \longrightarrow \pi^+_{11} + \pi^-_{10}$
5	$p_1 + p_T \longrightarrow {}_1\Lambda_6 + p_3 + {}_4K^0_9 + \pi^+_4 + \pi^+_5 + \pi^-_2$
6	$\longrightarrow {}_1\Lambda_6 + p_4 + {}_4K^0_9 + \pi^+_3 + \pi^+_5 + \pi^-_2$
7	$\longrightarrow {}_1\Lambda_6 + p_5 + {}_4K^0_9 + \pi^+_3 + \pi^+_4 + \pi^-_2$
8	$\longrightarrow {}_2\Lambda_9 + p_3 + {}_3K^0_6 + \pi^+_4 + \pi^+_5 + \pi^-_2$
9	$\longrightarrow {}_2\Lambda_9 + p_4 + {}_3K^0_6 + \pi^+_3 + \pi^+_5 + \pi^-_2$
10	$\longrightarrow {}_2\Lambda_9 + p_5 + {}_3K^0_6 + \pi^+_3 + \pi^+_5 + \pi^-_2$
11	$\longrightarrow p_3 + p_4 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_5 + \pi^-_2$
12	$\longrightarrow p_3 + p_5 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_4 + \pi^-_2$
13	$\longrightarrow p_4 + p_5 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_3 + \pi^-_2$
14	$\longrightarrow d_3 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_4 + \pi^+_5 + \pi^-_2$
15	$\longrightarrow d_4 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_3 + \pi^+_5 + \pi^-_2$
16	$\longrightarrow d_5 + {}_3K^0_6 + {}_4\bar{K}^0_9 + \pi^+_3 + \pi^+_4 + \pi^-_2$
17	$\longrightarrow {}_1\Lambda_6 + {}_2\Lambda_9 + K^+_3 + K^+_4 + \pi^+_5 + \pi^-_2$
18	$\longrightarrow {}_1\Lambda_6 + {}_2\Lambda_9 + K^+_3 + K^+_5 + \pi^+_4 + \pi^-_2$
19	$\longrightarrow {}_1\Lambda_6 + {}_2\Lambda_9 + K^+_4 + K^+_5 + \pi^+_3 + \pi^-_2$
20	$\longrightarrow p_3 + p_4 + K^+_5 + {}_3K^0_6 + {}_4\bar{K}^0_9 + K^-_2$
21	$\longrightarrow p_3 + p_5 + K^+_4 + {}_3K^0_6 + {}_4\bar{K}^0_9 + K^-_2$
22	$\longrightarrow p_4 + p_5 + K^+_3 + {}_3K^0_6 + {}_4\bar{K}^0_9 + K^-_2$
23	$\longrightarrow p_3 + \pi^+_4 + \pi^+_5 + \pi^-_2 + MM$
24	$\longrightarrow p_4 + \pi^+_3 + \pi^+_5 + \pi^-_2 + MM$
25	$\longrightarrow p_5 + \pi^+_3 + \pi^+_4 + \pi^-_2 + MM$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

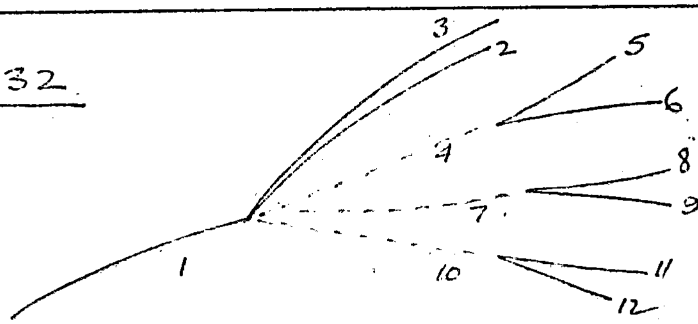
MEMO NO. 549 PAGE 9

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 032



	PANG DATA	
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
π^+	3	5
K^+		6
p		7
K^0	4	10_8
Λ		11_8
π^-	5	12_8
π^+	6	13_8
p		14_8
K^0	7	15_8
Λ		16_8
π^-	8	17_8
π^+	9	20_8
p		21_8
K^0	10	22_8
Λ		23_8
π^-	11	24_8
π^+	12	25_8
p		26_8

CPM	HYPOTHESIS
1	$\Lambda_{④} \longrightarrow p_6 + \pi^-_5$
2	$\Lambda_{⑦} \longrightarrow p_9 + \pi^-_8$
3	$\Lambda_{⑩} \longrightarrow p_{12} + \pi^-_{11}$
4	$K^0_{④} \longrightarrow \pi^+_6 + \pi^-_5$
5	$K^0_{⑦} \longrightarrow \pi^+_9 + \pi^-_8$
6	$K^0_{⑩} \longrightarrow \pi^+_{12} + \pi^-_{11}$
7	$p_1 + p_T \longrightarrow {}_1\Lambda_4 + {}_2\Lambda_7 + K^+_2 + {}_6K^0_{10} + \pi^+_3$
8	$\longrightarrow {}_1\Lambda_4 + {}_2\Lambda_7 + K^+_3 + {}_6K^0_{10} + \pi^+_2$
9	$\longrightarrow {}_1\Lambda_4 + {}_3\Lambda_{10} + K^+_2 + {}_5K^0_7 + \pi^+_3$
10	$\longrightarrow {}_1\Lambda_4 + {}_3\Lambda_{10} + K^+_3 + {}_5K^0_7 + \pi^+_2$
11	$\longrightarrow {}_2\Lambda_7 + {}_3\Lambda_{10} + K^+_2 + {}_4K^0_4 + \pi^+_3$
12	$\longrightarrow {}_2\Lambda_7 + {}_3\Lambda_{10} + K^+_3 + {}_4K^0_4 + \pi^+_2$
13	$\longrightarrow {}_1\Lambda_4 + {}_2\Lambda_7 + {}_6K^0_{10} + K^0_{31} + \pi^+_2 + \pi^+_3$
14	$\longrightarrow {}_1\Lambda_4 + {}_3\Lambda_{10} + {}_5K^0_7 + K^0_{31} + \pi^+_2 + \pi^+_3$
15	$\longrightarrow {}_2\Lambda_7 + {}_3\Lambda_{10} + {}_4K^0_4 + K^0_{31} + \pi^+_2 + \pi^+_3$
16	$\longrightarrow {}_1\Lambda_4 + \Lambda_{31} + {}_5K^0_7 + {}_6K^0_{10} + \pi^+_2 + \pi^+_3$
17	$\longrightarrow {}_2\Lambda_7 + \Lambda_{31} + {}_4K^0_4 + {}_6K^0_{10} + \pi^+_2 + \pi^+_3$
18	$\longrightarrow {}_3\Lambda_{10} + \Lambda_{31} + {}_4K^0_4 + {}_5K^0_7 + \pi^+_2 + \pi^+_3$
19	$\longrightarrow {}_1\Lambda_4 + p_2 + K^+_3 + {}_5K^0_7 + {}_6\bar{K}^0_{10}$
20	$\longrightarrow {}_1\Lambda_4 + p_3 + K^+_2 + {}_5K^0_7 + {}_6\bar{K}^0_{10}$
21	$\longrightarrow {}_2\Lambda_7 + p_2 + K^+_3 + {}_4K^0_4 + {}_6\bar{K}^0_{10}$
22	$\longrightarrow {}_2\Lambda_7 + p_3 + K^+_2 + {}_4K^0_4 + {}_6\bar{K}^0_{10}$
23	$\longrightarrow {}_3\Lambda_{10} + p_2 + K^+_3 + {}_4K^0_4 + {}_5\bar{K}^0_7$
24	$\longrightarrow {}_3\Lambda_{10} + p_3 + K^+_2 + {}_4K^0_4 + {}_5\bar{K}^0_7$
25	$\longrightarrow p_2 + p_3 + {}_4K^0_4 + {}_5K^0_7 + {}_6\bar{K}^0_{10} + MM$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
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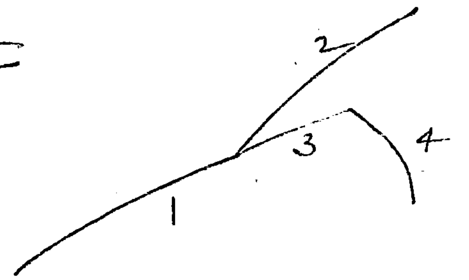
MEMO NO. 549 | PAGE 10
NAME P. WOHLMUT
DATE 4-6-65
SUBJECT

PET 102



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
K^+	2	2
p		3
Σ^+	3	4
π^+	4	5
p		6

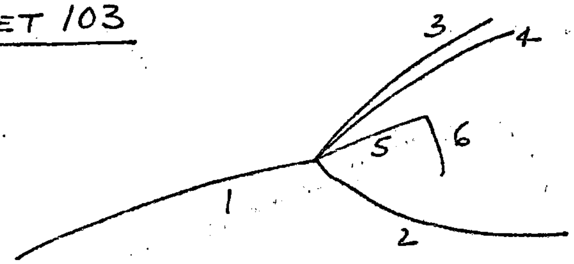
CPM	HYPOTHESIS
1	$p_1 + p_T \longrightarrow \Sigma_3^+ + n_{31} + K_2^+$; $\Sigma_3^+ \to p_4 + \pi^0_{30}$ oc+
2	$\longrightarrow$ — " — ; $\Sigma_3^+ \to p_4 + \pi^0_{30}$ oc−
3	$\longrightarrow$ — " — ; $\Sigma_3^+ \to n_{30} + \pi^+_4$ oc+
4	$\longrightarrow$ — " — ; $\Sigma_3^+ \to n_{30} + \pi^+_4$ oc−
5	$\longrightarrow \Sigma_3^+ + p_2 + K^0_{31}$; Same oc fits as above.
6	$\longrightarrow$ — " —
7	$\longrightarrow$ — " —
8	$\longrightarrow$ — " —

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 103

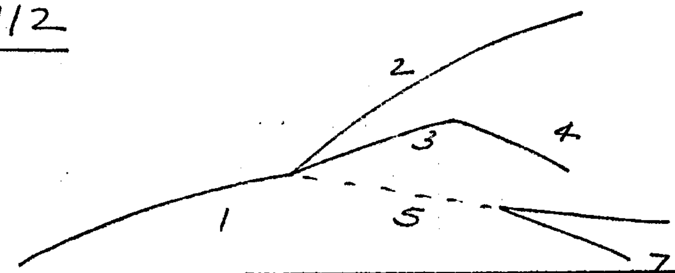


PANG DATA		
MASS	TRK. NO.	TRK. BANK.
p	1	1
π^-	2	2
K^-		3
π^+	3	4
K^+		5
p		6
π^+	4	7
K^+		10_8
p		11_8
Σ^+	5	12_8
π^+	6	13_8
p		14_8

CPM	HYPOTHESIS
1	$p_1 + p_T \longrightarrow \Sigma^+_5 + p_3 + K^+_4 + \pi^-_2$; $\Sigma^+_5 \rightarrow p_6 + \pi^0_{31}$
2	$\longrightarrow$ —— " —— ; $\Sigma^+_5 \rightarrow n_{31} + \pi^+_6$
3	$\longrightarrow \Sigma^+_5 + p_4 + K^+_3 + \pi^-_2$; $\Sigma^+_5 \rightarrow p_6 + \pi^0_{31}$
4	$\longrightarrow$ —— " —— ; $\Sigma^+_5 \rightarrow n_{31} + \pi^+_6$
5	$\longrightarrow p_3 + K^+_4 + \pi^-_2 + MM$
6	$\longrightarrow p_4 + K^+_3 + \pi^-_2 + MM$
7	$\longrightarrow K^+_3 + \pi^+_4 + \pi^-_2 + MM$
8	$\longrightarrow K^+_4 + \pi^+_3 + \pi^-_2 + MM$
9	$\longrightarrow p_3 + \pi^+_4 + \pi^-_2 + MM$
10	$\longrightarrow p_4 + \pi^+_3 + \pi^-_2 + MM$
11	$\longrightarrow K^+_3 + K^+_4 + \pi^-_2 + MM$
12	$\longrightarrow K^+_3 + K^+_4 + K^-_2 + MM$

SUBJECT

PET 112



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
Σ^+	3	5
π^+	4	6
p		7
K^0	5	10_8
Λ		11_8
π^-	6	12_8
π^+	7	13_8
p		14_8

CPM	HYPOTHESIS
1	$\Lambda_{(S)} \rightarrow p_7 + \pi^-_6$
2	$K^0_{(S)} \rightarrow \pi^+_7 + \pi^-_6$
3	$p_1 + p_T \rightarrow \Sigma^+_3 + p_2 + {}_2K^0_5$; $\Sigma^+_3 \rightarrow p_4 + \pi^0_{31}$
4	$\rightarrow$ —"— ; $\Sigma^+_3 \rightarrow n_{31} + \pi^+_4$
5	$\rightarrow \Sigma^+_3 + p_2 + {}_2K^0_5 + \pi^0_{31}$; $\Sigma^+_3 \rightarrow p_4 + \pi^0_{30}$ OC+
6	$\rightarrow$ —"— ; $\Sigma^+_3 \rightarrow p_4 + \pi^0_{30}$ OC−
7	$\rightarrow$ —"— ; $\Sigma^+_3 \rightarrow n_{30} + \pi^+_4$ OC+
8	$\rightarrow$ —"— ; $\Sigma^+_3 \rightarrow n_{30} + \pi^+_4$ OC−
9	$\rightarrow \Sigma^+_3 + n_{31} + {}_2K^0_5 + \pi^+_2$; same OC fits as above
10	$\rightarrow$ —"— ;
11	$\rightarrow$ —"— ;
12	$\rightarrow$ —"— ;
13	$\rightarrow \Sigma^+_3 + {}_1\Lambda_5 + K^+_2 + K^0_{31}$ same OC fits as above
14	$\rightarrow$ —"—
15	$\rightarrow$ —"—
16	$\rightarrow$ —"—
17	$\rightarrow \Sigma^+_3 + \Lambda_{31} + K^+_2 + {}_2K^0_5$ same OC fits as above
18	$\rightarrow$ —"—
19	$\rightarrow$ —"—
20	$\rightarrow$ —"—
21	$\rightarrow p_2 + {}_2K^0_5 + MM$
22	$\rightarrow \pi^+_2 + {}_2K^0_5 + MM$
23	$\rightarrow K^+_2 + {}_1\Lambda_5 + MM$
24	$\rightarrow K^+_2 + {}_2K^0_5 + MM$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

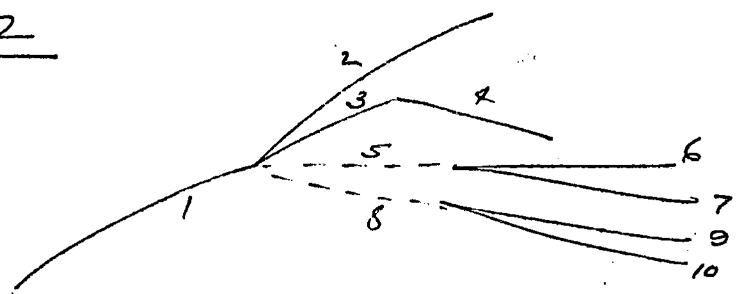
MEMO NO.	PAGE
549	13

NAME: P. WOHLMUT

DATE: 4-6-65

SUBJECT:

PET 122



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
Σ^+	3	5
π^+	4	6
p		7
K^0	5	10_8
Λ		11_8
π^-	6	12_8
π^+	7	13_8
p		14_8
K^0	8	15_8
Λ		16_8
π^-	9	17_8
π^+	10	20_8
p		21_8

CPM.	HYPOTHESIS
1	$\Lambda_{⑤} \longrightarrow p_7 + \pi^-_6$
2	$\Lambda_{⑧} \longrightarrow p_{10} + \pi^-_9$
3	$K^0_{⑤} \longrightarrow \pi^+_7 + \pi^-_6$
4	$K^0_{⑧} \longrightarrow \pi^+_{10} + \pi^-_9$
5	$p_1 + p_T \longrightarrow \Sigma^+_3 + {}_1\Lambda_5 + K^+_2 + {}_4K^0_8$; $\Sigma^+_3 \rightarrow p_4 + \pi^0_{31}$
6	$\longrightarrow$ —— " —— ; $\Sigma^+_3 \rightarrow n_{31} + \pi^+_4$
7	$\longrightarrow \Sigma^+_3 + {}_2\Lambda_8 + K^+_2 + {}_3K^0_5$; } same OC's
8	$\longrightarrow$ —— " —— } as above
9	$\longrightarrow {}_1\Lambda_5 + K^+_2 + {}_4K^0_8 + MM$
10	$\longrightarrow {}_2\Lambda_8 + {}_3K^0_5 + K^+_2 + MM$
11	$\longrightarrow {}_1\Lambda_5 + K^+_2 + MM$
12	$\longrightarrow {}_2\Lambda_8 + K^+_2 + MM$
13	$\longrightarrow K^+_2 + {}_4K^0_8 + MM$
14	$\longrightarrow K^+_2 + {}_3K^0_5 + MM$
15	$\longrightarrow {}_1\Lambda_5 + {}_4K^0_8 + \pi^+_2 + MM$
16	$\longrightarrow {}_2\Lambda_8 + {}_3K^0_5 + \pi^+_2 + MM$
17	$\longrightarrow {}_3K^0_5 + {}_4K^0_8 + \pi^+_2 + MM$
18	$\longrightarrow {}_1\Lambda_5 + \pi^+_2 + MM$
19	$\longrightarrow {}_2\Lambda_8 + \pi^+_2 + MM$
20	$\longrightarrow {}_3K^0_5 + \pi^+_2 + MM$
21	$\longrightarrow {}_4K^0_8 + \pi^+_2 + MM$
22	$\longrightarrow p_2 + {}_3K^0_5 + {}_4K^0_8 + MM$
23	$\longrightarrow p_2 + {}_3K^0_5 + MM$
24	$\longrightarrow p_2 + {}_4K^0_8 + MM$

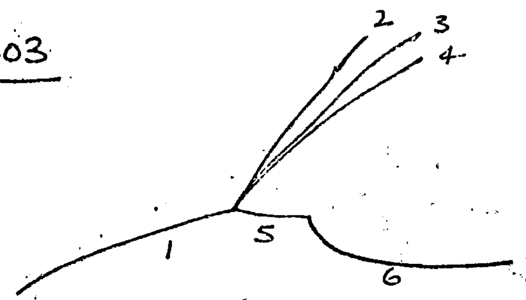
MEMO NO. 549 | PAGE 14

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 303



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
π^+	3	5
K^+		6
p		7
π^+	4	10_8
K^+		11_8
p		12_8
Σ^-	5	13_8
Ξ^-		14_8
π^-	6	15_8

CPM	HYPOTHESIS
1	$p_1 + p_T \rightarrow \Sigma_5^- + p_2 + K_3^+ + \pi_4^+ ;\ \Sigma_5^- \rightarrow n_{31} + \pi_6^-$
2	$\rightarrow \Sigma_5^- + p_2 + K_4^+ + \pi_3^+ ;$ — " —
3	$\rightarrow \Sigma_5^- + p_3 + K_2^+ + \pi_4^+ ;$ — " —
4	$\rightarrow \Sigma_5^- + p_3 + K_4^+ + \pi_2^+ ;$ — " —
5	$\rightarrow \Sigma_5^- + p_4 + K_2^+ + \pi_3^+ ;$ — " —
6	$\rightarrow \Sigma_5^- + p_4 + K_3^+ + \pi_2^+ ;$ — " —
7	$\rightarrow \Xi_5^- + p_2 + K_3^+ + K_4^+ ;\ \Xi_5^- \rightarrow \Lambda_{31} + \pi_6^-$
8	$\rightarrow \Xi_5^- + p_3 + K_2^+ + K_4^+ ;$ — " —
9	$\rightarrow \Xi_5^- + p_4 + K_2^+ + K_3^+ ;$ — " —
10	$\rightarrow p_2 + K_3^+ + \pi_4^+ + MM$
11	$\rightarrow p_2 + K_4^+ + \pi_3^+ + MM$
12	$\rightarrow p_3 + K_2^+ + \pi_4^+ + MM$
13	$\rightarrow p_3 + K_4^+ + \pi_2^+ + MM$
14	$\rightarrow p_4 + K_2^+ + \pi_3^+ + MM$
15	$\rightarrow p_4 + K_3^+ + \pi_2^+ + MM$
16	$\rightarrow K_2^+ + \pi_3^+ + \pi_4^+ + MM$
17	$\rightarrow K_3^+ + \pi_2^+ + \pi_4^+ + MM$
18	$\rightarrow K_4^+ + \pi_2^+ + \pi_3^+ + MM$
19	$\rightarrow p_2 + \pi_3^+ + \pi_4^+ + MM$
20	$\rightarrow p_3 + \pi_2^+ + \pi_4^+ + MM$
21	$\rightarrow p_4 + \pi_2^+ + \pi_3^+ + MM$
22	$\rightarrow p_2 + K_4^+ + K_3^+ + MM$
23	$\rightarrow p_3 + K_2^+ + K_4 + MM$
24	$\rightarrow p_4 + K_2^+ + K_3^+ + MM$

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PHYSICS NOTES

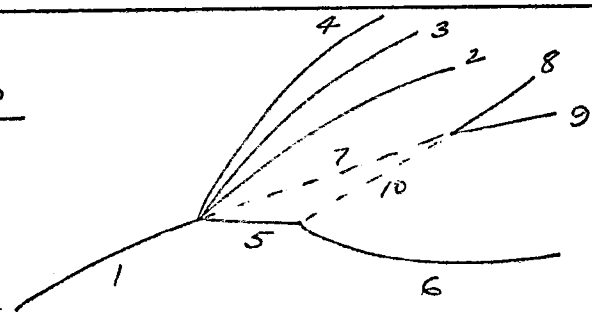
MEMO NO. 549 PAGE 15

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 313



PANG DATA

MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
π^+	3	5
K^+		6
p		7
π^+	4	10_8
K^+		11_8
p		12_8
Σ^-	5	13_8
Ξ^-		14_8
π^-	6	15_8
K^0	7	16_8
π^-	8	17_8
π^+	9	20_8
p		21_8
Λ	10	22_8

CPM	HYPOTHESIS
1	$\Lambda_{(10)} \rightarrow p_9 + \pi^-_8$
2	$K^0_{(7)} \rightarrow \pi^+_9 + \pi^-_8$
3	$\Xi^-_{(5)} \rightarrow {}_1\Lambda_{10} + \pi^-_6$
4	$p_1 + p_T \rightarrow {}_3\Xi^-_5 + p_2 + K^+_3 + K^+_4$
5	$\rightarrow {}_3\Xi^-_5 + p_3 + K^+_2 + K^+_4$
6	$\rightarrow {}_3\Xi^-_5 + p_4 + K^+_2 + K^+_3$
7	$\rightarrow {}_3\Xi^-_5 + n_{31} + K^+_2 + K^+_3 + \pi^+_4$
8	$\rightarrow {}_3\Xi^-_5 + n_{31} + K^+_2 + K^+_4 + \pi^+_3$
9	$\rightarrow {}_3\Xi^-_5 + n_{31} + K^+_3 + K^+_4 + \pi^+_2$
10	$\rightarrow {}_3\Xi^-_5 + p_2 + K^+_3 + K^0_{31} + \pi^+_4$
11	$\rightarrow {}_3\Xi^-_5 + p_2 + K^+_4 + K^0_{31} + \pi^+_3$
12	$\rightarrow {}_3\Xi^-_5 + p_3 + K^+_2 + K^0_{31} + \pi^+_4$
13	$\rightarrow {}_3\Xi^-_5 + p_3 + K^+_4 + K^0_{31} + \pi^+_2$
14	$\rightarrow {}_3\Xi^-_5 + p_4 + K^+_2 + K^0_{31} + \pi^+_3$
15	$\rightarrow {}_3\Xi^-_5 + p_4 + K^+_3 + K^0_{31} + \pi^+_2$
16	$\rightarrow p_2 + {}_2K^0_7 + \pi^+_3 + \pi^+_4 + MM$
17	$\rightarrow p_3 + {}_2K^0_7 + \pi^+_2 + \pi^+_4 + MM$
18	$\rightarrow p_4 + {}_2K^0_7 + \pi^+_2 + \pi^+_3 + MM$
19	$\rightarrow p_2 + \pi^+_3 + \pi^+_4 + MM$
20	$\rightarrow p_3 + \pi^+_2 + \pi^+_4 + MM$
21	$\rightarrow p_4 + \pi^+_2 + \pi^+_3 + MM$
22	$\rightarrow {}_2K^0_7 + \pi^+_2 + \pi^+_3 + \pi^+_4 + MM$
23	$\rightarrow p_2 + K^+_3 + K^+_4 + MM$
24	$\rightarrow p_3 + K^+_2 + K^+_4 + MM$
25	$\rightarrow p_4 + K^+_2 + K^+_3$

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PHYSICS NOTES

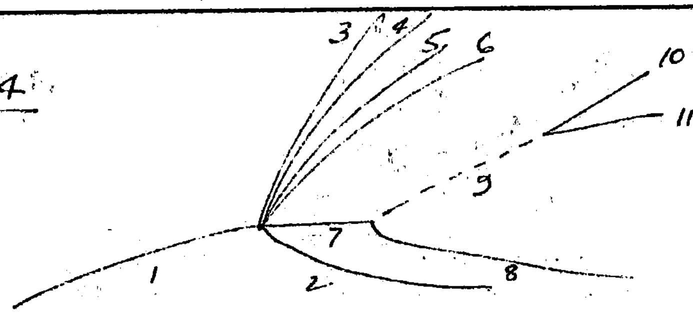
MEMO NO. 549 | PAGE 16

NAME P. WOHLMUT

DATE 4-6-65

SUBJECT

PET 314



PANG DATA		
MASS	TRK. NO.	TRK. BANK.
p	1	1
π^-	2	2
π^+	3	3
K^+		4
p		5
π^+	4	6
K^+		7
p		10_8
π^+	5	11_8
K^+		12_8
p		13_8
π^+	6	14_8
K^+		15_8
p		16_8
$\bar{\Xi}^-$	7	17_8
π^-	8	20_8
Λ	9	21_8
π^-	10	22_8
p	11	23_8

CPM	HYPOTHESIS
1	$\Lambda_{(9)} \to p_{11} + \pi^-_{10}$
2	$\bar{\Xi}_{(7)} \to \Lambda_9 + \pi^-_8$
3	$p_1 + \bar{p}_T \to {}_2\bar{\Xi}^-_7 + p_3 + K^+_4 + K^+_5 + \pi^+_6 + \pi^-_2$
4	$\to {}_2\bar{\Xi}^-_7 + p_3 + K^+_5 + K^+_6 + \pi^+_4 + \pi^-_2$
5	$\to {}_2\bar{\Xi}^-_7 + p_3 + K^+_4 + K^+_6 + \pi^+_5 + \pi^-_2$
6	$\to {}_2\bar{\Xi}^-_7 + p_4 + K^+_3 + K^+_5 + \pi^+_6 + \pi^-_2$
7	$\to {}_2\bar{\Xi}^-_7 + p_4 + K^+_5 + K^+_6 + \pi^+_3 + \pi^-_2$
8	$\to {}_2\bar{\Xi}^-_7 + p_4 + K^+_3 + K^+_6 + \pi^+_5 + \pi^-_2$
9	$\to {}_2\bar{\Xi}^-_7 + p_5 + K^+_3 + K^+_4 + \pi^+_6 + \pi^-_2$
10	$\to {}_2\bar{\Xi}^-_7 + p_5 + K^+_4 + K^+_6 + \pi^+_3 + \pi^-_2$
11	$\to {}_2\bar{\Xi}^-_7 + p_5 + K^+_3 + K^+_6 + \pi^+_4 + \pi^-_2$
12	$\to {}_2\bar{\Xi}^-_7 + p_6 + K^+_3 + K^+_4 + \pi^+_5 + \pi^-_2$
13	$\to {}_2\bar{\Xi}^-_7 + p_6 + K^+_4 + K^+_5 + \pi^+_3 + \pi^-_2$
14	$\to {}_2\bar{\Xi}^-_7 + p_6 + K^+_3 + K^+_5 + \pi^+_3 + \pi^-_2$
15	$\to K^+_3 + K^+_4 + \pi^+_5 + \pi^+_6 + \pi^-_2 + MM$
16	$\to K^+_3 + K^+_5 + \pi^+_4 + \pi^+_6 + \pi^-_2 + MM$
17	$\to K^+_3 + K^+_6 + \pi^+_4 + \pi^+_5 + \pi^-_2 + MM$
18	$\to K^+_4 + K^+_5 + \pi^+_3 + \pi^+_6 + \pi^-_2 + MM$
19	$\to K^+_4 + K^+_6 + \pi^+_3 + \pi^+_5 + \pi^-_2 + MM$
20	$\to K^+_5 + K^+_6 + \pi^+_3 + \pi^+_4 + \pi^-_2 + MM$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA

PHYSICS NOTES

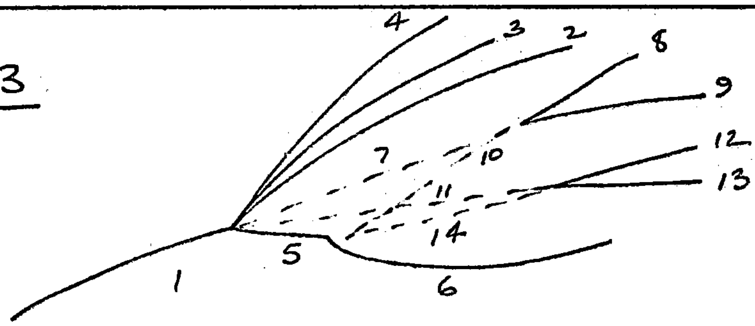
MEMO NO. 549 | PAGE 17

SUBJECT

NAME P. WOHLMUT

DATE 4-6-65

PET 323



PANG DATA		
MASS	TRK. NO.	TRK. BANK
p	1	1
π^+	2	2
K^+		3
p		4
π^+	3	5
K^+		6
p		7
π^+	4	10_8
K^+		11_8
p		12_8
$\bar{\Xi}^-$	5	13_8
π^-	6	14_8
K^0	7	15_8
π^-	8	16_8
π^+	9	17_8
p		20_8
Λ	10	21_8
K^0	11	22_8
π^-	12	23_8
π^+	13	24_8
p		25_8
Λ		26_8

CPM	HYPOTHESIS
1	$\Lambda_{(10)} \longrightarrow p_9 + \pi^-_8$
2	$\Lambda_{(14)} \longrightarrow p_{13} + \pi^-_{12}$
3	$K^0_{(7)} \longrightarrow \pi^+_9 + \pi^-_8$
4	$K^0_{(11)} \longrightarrow \pi^+_{13} + \pi^-_{12}$
5	$\bar{\Xi}^-_{(5)} \longrightarrow {}_1\Lambda_{10} + \pi^-_6$
6	$\bar{\Xi}^-_{(5)} \longrightarrow {}_2\Lambda_{14} + \pi^-_6$
7	$p_1 + p_T \longrightarrow {}_5\bar{\Xi}^-_5 + p_2 + K^+_3 + {}_4K^0_{11} + \pi^+_4$
8	$\longrightarrow {}_5\bar{\Xi}^-_5 + p_2 + K^+_4 + {}_4K^0_{11} + \pi^+_3$
9	$\longrightarrow {}_5\bar{\Xi}^-_5 + p_3 + K^+_2 + {}_4K^0_{11} + \pi^+_4$
10	$\longrightarrow {}_5\bar{\Xi}^-_5 + p_3 + K^+_4 + {}_4K^0_{11} + \pi^+_2$
11	$\longrightarrow {}_5\bar{\Xi}^-_5 + p_4 + K^+_2 + {}_4K^0_{11} + \pi^+_3$
12	$\longrightarrow {}_5\bar{\Xi}^-_5 + p_4 + K^+_3 + {}_4K^0_{11} + \pi^+_2$
13	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_2 + K^+_3 + {}_3K^0_7 + \pi^+_4$
14	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_2 + K^+_4 + {}_3K^0_7 + \pi^+_3$
15	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_3 + K^+_2 + {}_3K^0_7 + \pi^+_4$
16	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_3 + K^+_4 + {}_3K^0_7 + \pi^+_2$
17	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_4 + K^+_2 + {}_3K^0_7 + \pi^+_3$
18	$\longrightarrow {}_6\bar{\Xi}^-_5 + p_4 + K^+_3 + {}_3K^0_7 + \pi^+_2$
19	$\longrightarrow {}_5\bar{\Xi}^-_5 + n_{31} + K^+_2 + {}_4K^0_{11} + \pi^+_3 + \pi^+_4$
20	$\longrightarrow {}_5\bar{\Xi}^-_5 + n_{31} + K^+_3 + {}_4K^0_{11} + \pi^+_2 + \pi^+_4$
21	$\longrightarrow {}_5\bar{\Xi}^-_5 + n_{31} + K^+_4 + {}_4K^0_{11} + \pi^+_2 + \pi^+_3$
22	$\longrightarrow {}_6\bar{\Xi}^-_5 + n_{31} + K^+_2 + {}_3K^0_7 + \pi^+_3 + \pi^+_4$
23	$\longrightarrow {}_6\bar{\Xi}^-_5 + n_{31} + K^+_3 + {}_3K^0_7 + \pi^+_2 + \pi^+_4$
24	$\longrightarrow {}_6\bar{\Xi}^-_5 + n_{31} + K^+_4 + {}_3K^0_7 + \pi^+_2 + \pi^+_3$

LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA PHYSICS NOTES	MFD	MEMO NO. 550	PAGE 1
SUBJECT INSTRUCTIONS FOR CHANGING THE DMT		NAME Bill Donovan DATE May 11, 1965	

I. Introduction

The purpose of this memo is to provide explicit and detailed instructions for any operator who has occasion to change the DMT. It is important that these instructions be followed to the letter; a failure to do so will often result in hours of unnecessary work for the libraries.

There are two tape transports in the DMT room. Each is used for a different franckenstein under normal circumstances. Occasionally maintenance may have both franckensteins writing on the same output tape, thus using only one tape transport. The tape transports are otherwise exactly alike. The following instructions apply equally to both.

II. When to End the DMT Tape

The DMT tape for a franckenstein should be ended when:

1. The "end of tape" light goes on.
2. A note from the library on a measurement card asks that the DMT be changed.
3. Maintenance asks that the tape be changed.

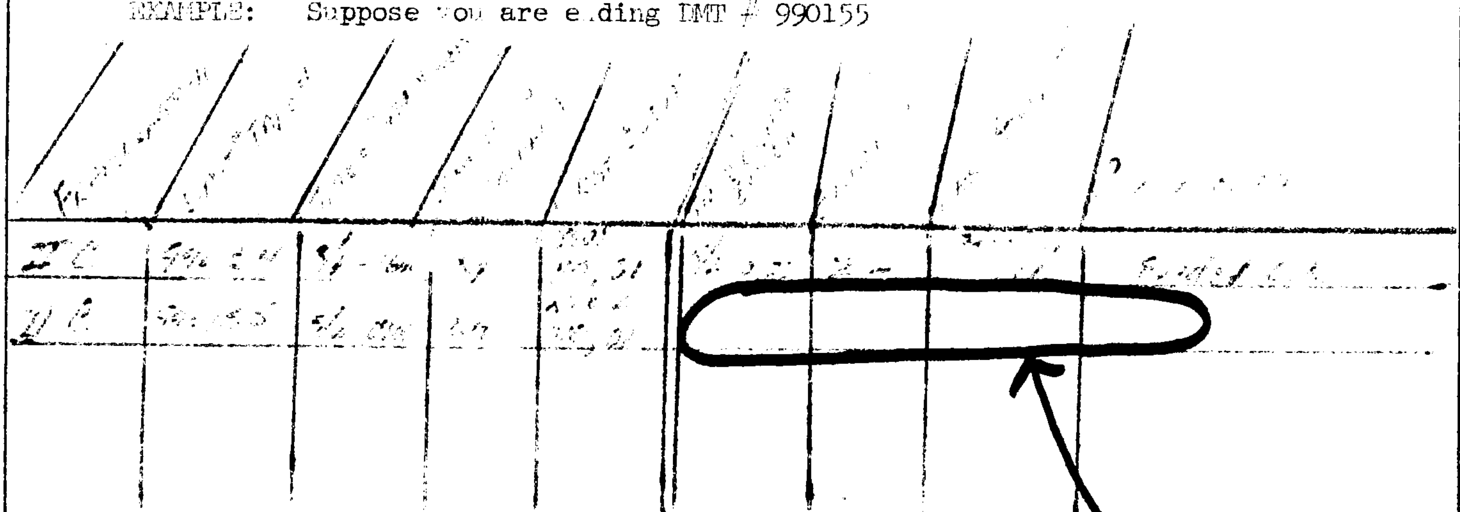
LAWRENCE RADIATION LABORATORY - UNIVERSITY OF CALIFORNIA
PHYSICS NOTES

RPD	MEMO NO. 550	PAGE 2
SUBJECT: INSTRUCTIONS FOR CHANGING THE IMT	NAME: Bill Donovan	DATE: May 11, 1965

III. How to End the IMT Tape

1. Look in the "IMT Tape Log" (kept in the IMT room) to determine the number of the IMT tape that you are ending.
2. Go to the franckenstein and dial this IMT tape number in as a "special word".
3. Press the following buttons:
   a. special word (3 times)
   b. track complete (once)
   c. special word (3 times)
   d. track complete (once)
   e. special word (3 times)
   f. event complete (once)
4. If a parity error occurs while you are doing the above, acknowledge and go on.
5. Go to the IMT room and fill out the "IMT Tape Log", listing all pertinent information.

EXAMPLE: Suppose you are ending IMT # 990155



FILL IN THESE COLUMNS

The comments column should explain any trouble that you had in starting or ending the tape.

SUBJECT: INSTRUCTIONS FOR CHANGING THE IMT

NAME: Bill Donovan

DATE: May 11, 1965

6. Push the black "rewind" button on the IMT control panel.

7. After the tape has rewound, open the plastic door of the tape transport. Turn the handle labeled "Tension" (between the upper and lower tape reels) in the clockwise direction. This releases the tension on the tape and you may now rewind the last few feet of tape by hand.

8. Remove the full tape reel from the upper bulb.

9. Write the following information on the tape label:

   a. the R, F, E, of the last event

   b. the number of events on the tape

      (obtain this figure from the counter to the left of the plastic door)

   c. the date and time ended

10. Put the tape into a plastic case and leave it in the proper library.

11. If you have trouble with any of the above steps, see your Shift Supervisor.

SUBJECT: INSTRUCTIONS FOR CHANGING THE DMT

NAME: Bill Donovan

DATE: May 11, 1965

IV How to Start a New DMT Tape

1. Clean the magnetic recording head on the tape transport to be loaded. Do this carefully with a cotton swab and alcohol or trichlorethylene.

2. Take the ring out of a blank tape and attach a tape label containing the following information:

   a. the R, F, B of the first event

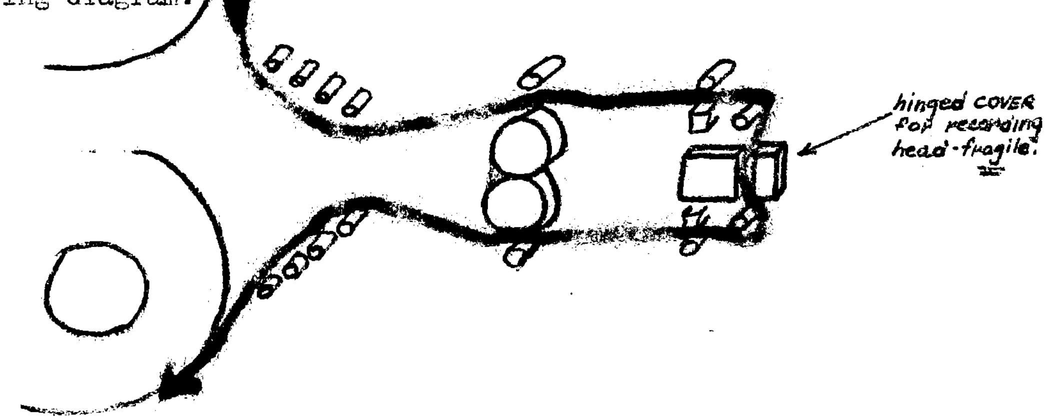
   b. the date and time started

   c. the DMT tape number

[redacted]

3. Hang the tape on the upper hub of the tape transport. If the reel is hung correctly, the tape will come off the top of the reel and to the right.

4. Be sure that the "Tension" handle between the upper and lower tape reels is in its fully clockwise position. Turn the upper reel until there is enough free tape to thread the transport. Thread the tape according to the following diagram.



SUBJECT INSTRUCTIONS FOR CHANGING THE DMT

5. Wind the tape onto the lower reel until the silver strip is visible, but has not yet passed through the recording head.
6. Turn the "Tension" handle fully counter-clockwise. The reels and tape tension arms should then take their proper positions.
7. Press the black "start" button to the left of the transport being loaded. The tape will advance a short distance and then stop.
8. Go to the franckenstein and dial the DMT tape number in as a "special word".
9. Press the following buttons:
   a. special word (3 times)
   b. track complete (once)
   c. special word (3 times)
   d. track complete (once)
   e. special word (3 times)
   f. event complete (once)
10. If a parity error occurs while you are pressing the above buttons, do the following:
    a. Press the black "rewind" button on the DMT control panel.
    b. After the tape has rewound, open the plastic door of the tape transport. Turn the "Tension" handle in the clockwise direction and rewind the tape until the silver strip is onto the upper reel.
    c. Follow steps 5 - 9 above.
11. IMPORTANT - Fill out the "DMT Tape Log", listing all pertinent information.

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SUBJECT

INSTRUCTIONS FOR CHANGING THE DMT

NAME Bill Donovan

DATE May 11, 1965

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Comments
I C	990154	5/1-1600	XY	9401, 003,01	5/2-0900	ZA	9950, 600,01	ended ok
II C								

EXAMPLE: Suppose you are starting DMT # 990155

FILL IN THESE COLUMNS

12. If you have trouble with any of the above steps, see your Shift Supervisor.