The first particle physics experiment with leadership almost equally split between China and the United States would be located deep beneath the mountains of Southern China, looking for mysterious neutrino interactions.

CATCHING NEUTRINOS IN CHINA

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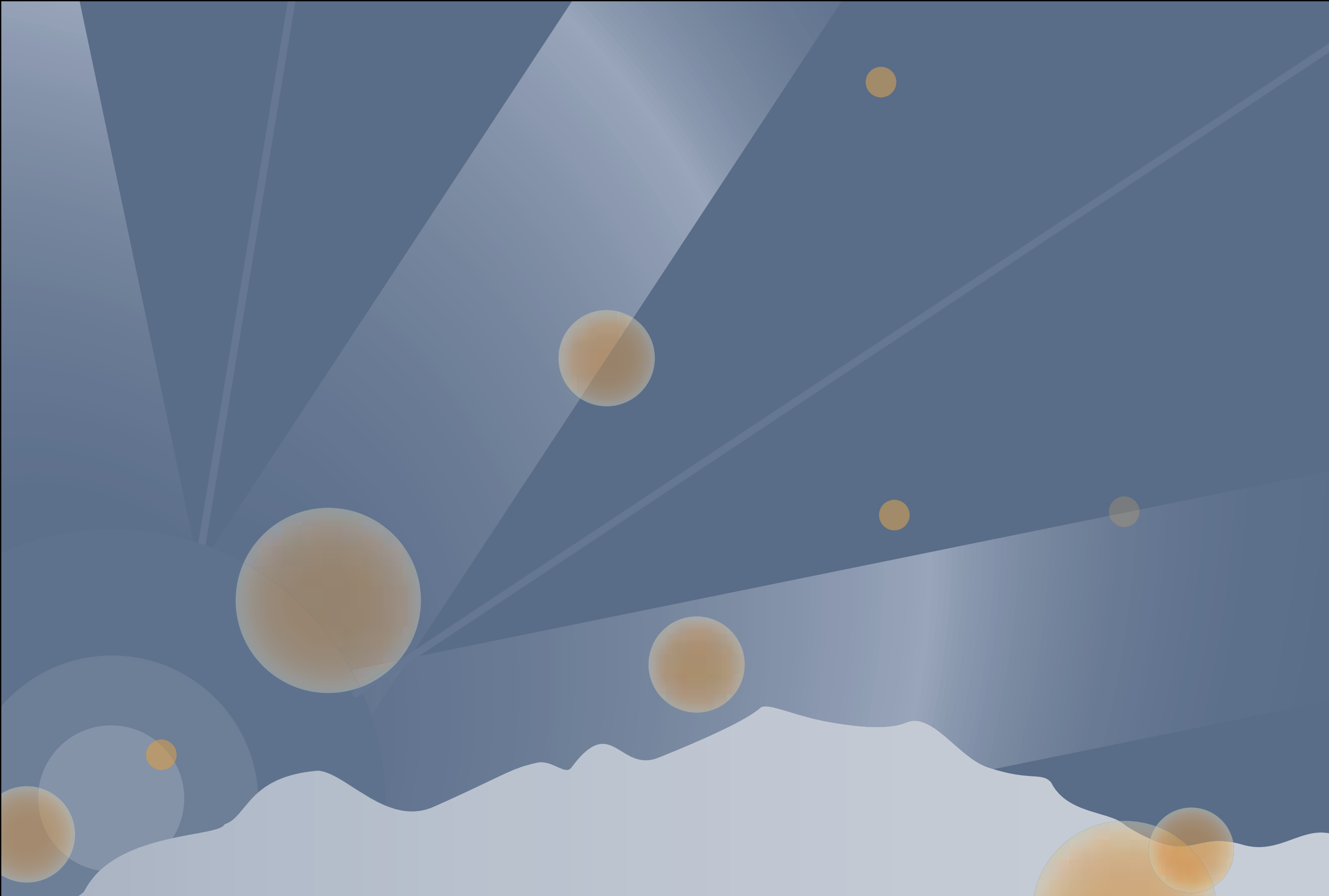
Illustrations: Sandbox Studio



Buried deep in the mountains of southern China, a new neutrino experiment would rely on a series of Chinese nuclear reactors and the brains of scientists from several countries.

The proposed Daya Bay neutrino experiment is one of many particle physics projects with an international backing, an increasing necessity as experiments grow in size, price, and complexity. Yet unlike its predecessors, Daya Bay is the first particle physics experiment with leadership almost equally split between the United States and China, a move some hope will strengthen the scientific relationship between the two economic powerhouses.

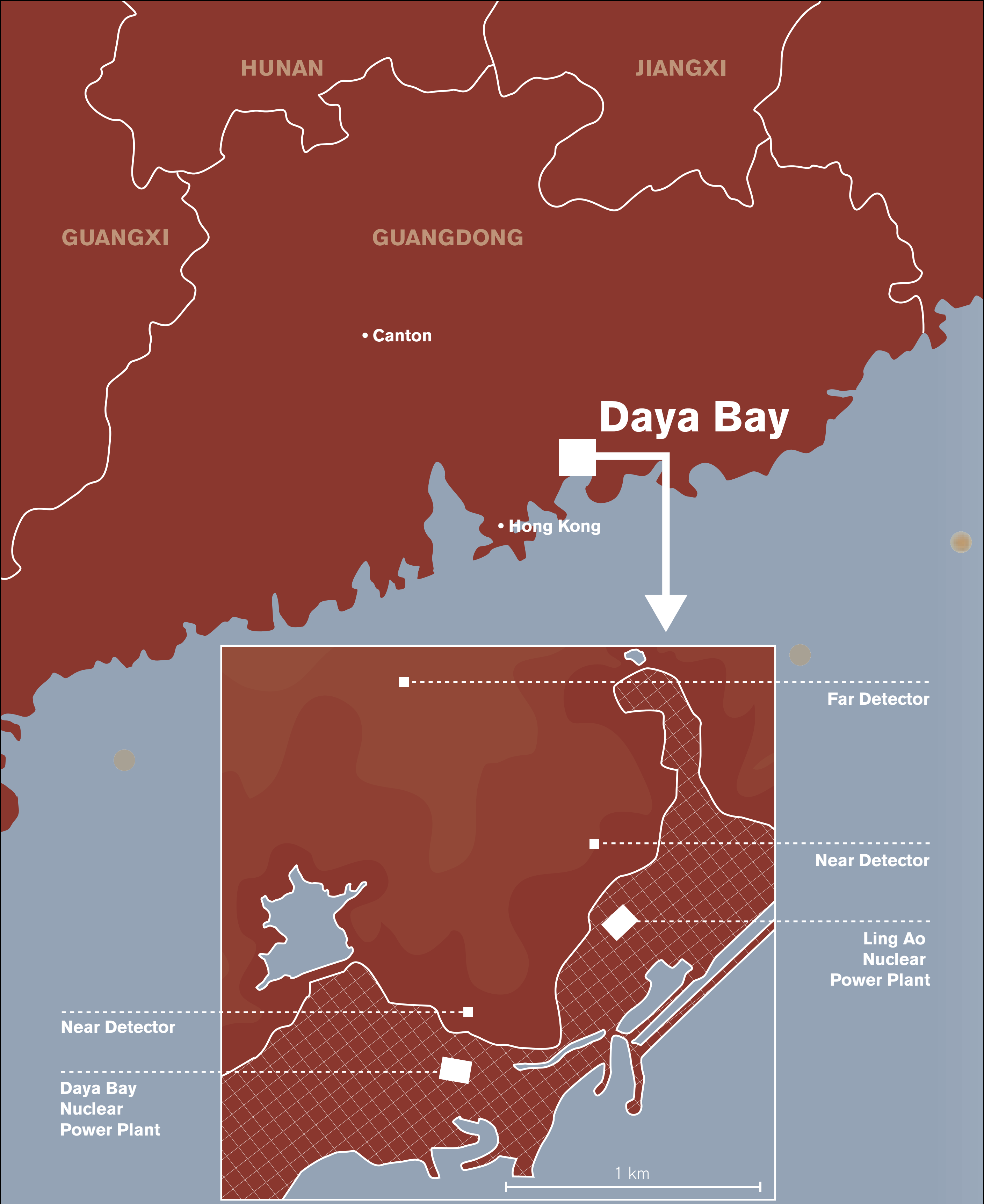
"We expect this to be the largest international collaboration in basic science in China and the biggest US-China collaboration," says Yifang Wang, deputy director of the Institute of High Energy Physics (IHEP), Beijing.

Lawrence Berkeley National Laboratory physicist Kam-Biu Luk, one of two scientific spokesmen for the Daya Bay project, says, "Science is getting a lot of attention in China. They are investing more and more in basic research as well as in technology. This is a good time to work with China, and it may create a lot of opportunities for the United States in the future."

With almost two miles of underground tunnels and eight identical 100-ton detectors, the Daya Bay project awaits results from an important US review conducted in the middle of October. In the mean time, US and Chinese scientists, technicians, and engineers, along with their counterparts from Hong Kong, Taiwan, Russia, and the Czech Republic, are working to make the project a reality, and ultimately answer some of the most puzzling questions about one of nature's most elusive particles—the neutrino.

Small particle, big questions

Neutrinos are uncharged elementary particles produced naturally from the sun and cosmic rays. The particles morph, or oscillate, among three flavors—electron, muon, and tau—as they travel through space, people, buildings, and even Earth itself, interacting rarely with other matter. Scientists have characterized two of these oscillations in detail, and are seeking to measure details of the third, the switching of tau-type neutrinos to electron-type neutrinos. A crucial quantity related to this oscillation—known as the mixing



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angle θ_{13} (pronounced "theta-one-three")—is not yet known. As long as this mixing angle is not zero, or incredibly close to zero, the Daya Bay project is poised to measure it to a level about an order of magnitude better than previous experiments, and well enough to resolve numerous mysteries of neutrinos.

"Neutrinos are very hot right now," says Brookhaven National Laboratory physicist Laurence Littenberg, a Daya Bay collaborator. "It was only in the last decade that we learned they have mass, and there's still so much that we don't know about them."

Knowing the actual value of the mixing angle θ_{13} would help scientists understand more about neutrino behavior and possibly the early history of the universe. One of the most perplexing questions has to do with the matter we're made of. The big bang should have created equal amounts of matter and antimatter, and they should have annihilated each other completely. Yet today, the universe still contains plenty of matter while the antimatter has disappeared. Some scientists believe that this puzzling phenomenon is tied to the properties of neutrinos.

"At the moment, we don't know why the universe is dominated only with matter," Luk says. "It's a good thing, because I don't have to worry about shaking hands with a friend and being annihilated. It's the reason that everyone and everything exists. This is very exciting and important, and I would love to be part of the team that finds out why we are here."

A mountainous experiment

Still in the planning stage, the Daya Bay experiment would look for the third type of neutrino oscillation by studying antineutrinos, the antimatter counterparts of neutrinos. Antineutrinos are produced in nuclear reactions at power stations such as the cluster of reactors in southern China. "This is a good opportunity to begin non-accelerator particle physics, which is not well-developed in our country," says Wang.

Groups of detectors, eight in all, each weighing 100 tons, will sit beneath granite mountains at different distances from the reactors. A set of detectors near the nuclear power stations will measure the flux and energy of the electron antineutrinos emerging from the reactors, and a set of far detectors will be positioned about 2 kilometers away. The largest fraction of electron antineutrinos are expected to "have disappeared" at that distance, having turned into tau antineutrinos. The detectors cannot detect the tau antineutrinos, but they will measure the fraction of electron antineutrinos that did not disappear. Placed on multi-wheeled carriages, the detectors can be exchanged in the tunnel system to cancel systematic errors.

Described as "liquid onions," each detector will contain three layers. In the center will be 20 tons of organic liquid scintillator that contains gadolinium, a heavy metal. Next is a layer of liquid scintillator without gadolinium. The outer layer uses mineral oil to act as shielding. When an antineutrino interacts with an atom inside the detector, it produces a positron and a neutron. The energy from the positron is deposited in the scintillator, which creates a burst of light. About 30 microseconds later, a second burst of light is produced as the gadolinium captures the neutron and amplifies the signal. Photomultiplier tubes that line the mineral-oil-filled outer detector tank record the light produced in this reaction. Both light flashes must be present to indicate an electron antineutrino event.

In order to find a value for the mixing angle, scientists will compare the number of electron antineutrinos produced in the reactors and the number expected to arrive at each detector to how many events are actually detected. "Basically it comes down to how many antineutrinos disappear," Luk says.

Strengthening ties

The Daya Bay project is far from the first physics collaboration involving both US and Chinese scientists, engineers, and technicians. The United States and China partnered with various other countries to work on the

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Beijing Electron Spectrometer (BES) and its current upgrade, BES-III, at IHEP, Beijing. Chinese physicists and technical staff work with their US counterparts on particle detector components at the CERN research laboratory in Switzerland, in preparation for experiments at the Large Hadron Collider. And the two countries will soon team up to produce particle detectors for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory.

"Even though the United States and China have a long history of collaboration, many people are unfamiliar with working with China and some are a little scared of doing so," says Brookhaven's Littenberg. "But I think Daya Bay will open those doors. Once we pioneer the techniques and establish this relationship, it will make it possible for more collaborations."

The Daya Bay experiment is the first collaboration where the countries will equally share leadership and responsibilities, possibly a sign of things to come. "The US and China have been trying to get more and more scientific exchanges between them, and this is another step in that direction," says Randy Johnson, the US Department of Energy (DOE) program manager for the Daya Bay project. The DOE has an office in Beijing to keep track of the ever-growing activity and, in May, the National Science Foundation followed its lead. Upon opening its Beijing office, the NSF noted that China ranked fourth in the world in the year 2000 in research and development, with $48.9 billion in expenditures. Two years later, the country ranked third, behind the United States and Japan, spending an estimated $72.0 billion on R&D.

"The Chinese are certainly interested and eager in science," says the Daya Bay US project manager Bill Edwards, an engineer at Lawrence Berkeley National Laboratory. "We fight to keep the status quo in terms of funding in the US. And the Chinese seem much more willing to spend a greater portion of their budget on science than the US."

China has the Daya Bay project on a fast track, with hopes to start digging the experiment's tunnel system this spring. The Chinese Academy of Sciences has already made a financial commitment, with other Chinese funding agencies and regional governments following suit. The DOE has supplied R&D money for Daya Bay, but the project first must pass the review of its science goals before it receives further US support. Upon a successful review, the project would proceed through the "Critical Decision" stepping stones. "We passed CD-0 in the fall of 2005, and we hope to have a CD-1 review in early 2007, to evaluate the design and cost range of the project," Edwards says. Because of a later start in the United States and the extensive scientific approval steps, full US funding isn't expected for at least a year or two.

This "phasing problem" worries some collaborators that the United States won't be financially able to contribute within the timescale set out by the Chinese. "The Chinese don't have the extent of project management experience that the US has," says US Daya Bay chief scientist Steve Kettell, a Brookhaven National Laboratory physicist. "Our system is thorough and deliberate. It's really phenomenal how quickly the Chinese were able to pull everything together. Now we've got to try to catch up."

A bright future

If recent events are any indication, the future scientific relationship between the United States and China looks bright. And Daya Bay would only help solidify it.

Every year, the People's Republic of China-United States Joint Committee for Cooperation in High Energy Physics meets to discuss ways to further Chinese-US cooperation in high-energy physics. "The US-PRC [effort] is a good way to promote collaboration and understanding because it continues despite any changes in government," says Hesheng Chen, director of IHEP, Beijing.

In June, the group held a special workshop in Beijing, bringing together scores of Chinese and US scientists to discuss Daya Bay and other opportunities for collaboration between the countries, including cosmic-ray studies in Tibet.

Another possibility is a US-Chinese charm physics project involving the BES-III spectrometer in Beijing. The project is meant to be a continuation of research currently done at the CLEO experiment at the Cornell Electron Storage Ring (CESR), a more than 25-year-old facility that might soon be phased out.

"Unfortunately, on CLEO we didn't make the luminosity that we hoped for, and we weren't able to pull off all of the measurements that we originally wanted to do," says Rensselaer Polytechnic Institute physicist Jim Napolitano, who is spearheading the collaboration and also is involved with Daya Bay. "BES-III should have more than a factor of 10 times the intensity of CLEO, so we hope to bring our expertise there." A group of US and IHEP scientists will meet with the NSF about the potential collaboration in November, and the DOE has already provided funding to the University of Hawaii for work on the experiment's detector.

As for Daya Bay, if the experiment passes the DOE physics review conducted in October, the project leaders hope to move through the series of critical decision steps as quickly as possible. The tentative project timeline sets construction to start in 2007, with data collection beginning in 2010.

"This kind of experiment is challenging," says Daya Bay spokesman Luk. "Having more manpower from different regions will be beneficial. The Chinese have a good site, and the US has a long history of experience in high-energy and low-energy experiments. It's really a win-win situation."

And despite the language barriers, the time-zone differences, and the basic challenges of coordinating experiments with colleagues halfway across the world, many scientists agree that establishing a US-Chinese scientific relationship will be essential to the future of particle physics.

"Whether it's charm physics at BES-III, neutrinos at Daya Bay, or cosmic rays in the mountains of Tibet, learning how to work with China toward the goal of increasing our understanding of the world is an opportunity we can't skip out on," Napolitano says.

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