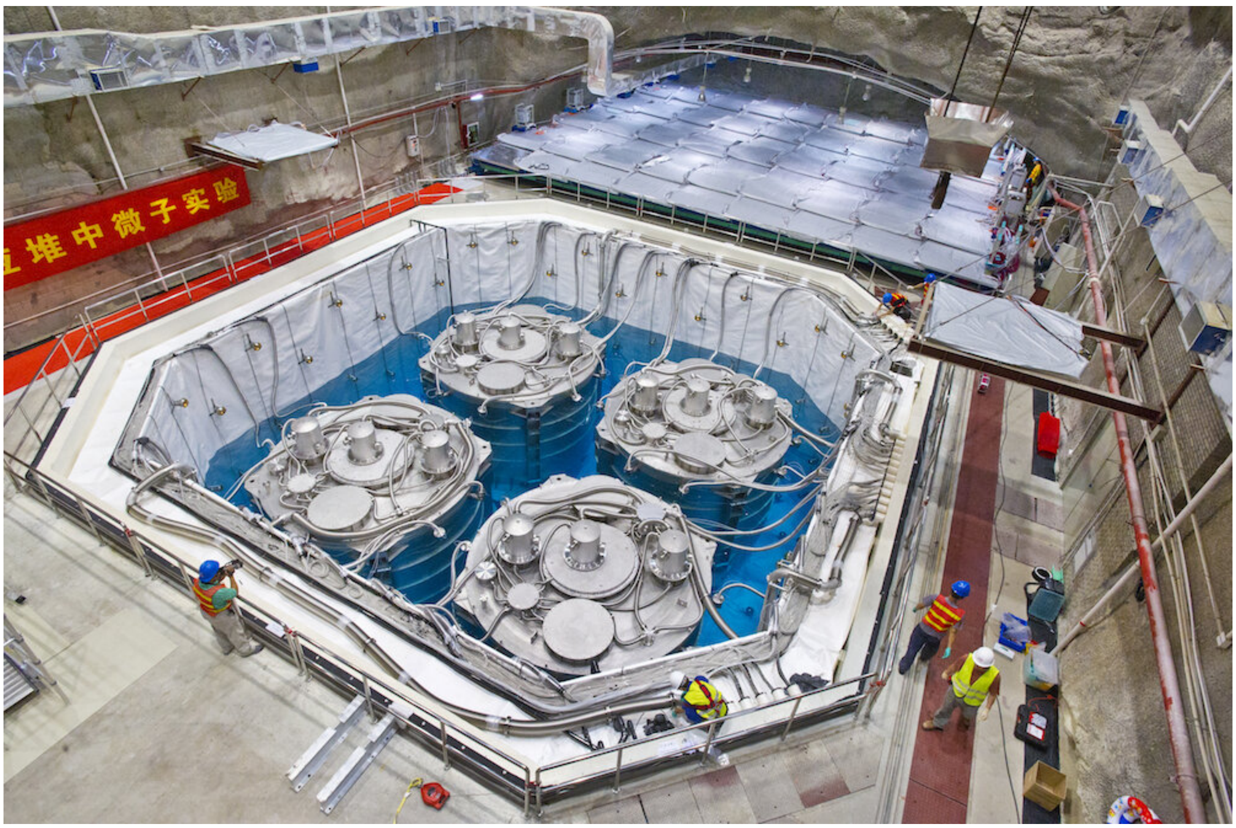
Scientists say farewell to Daya Bay site, proceed with final data analysis

December 11 2020, by Karen McNulty Walsh



Bird's-eye view of the underground Daya Bay far detector hall during installation. The four antineutrino detectors are immersed in a large pool filled with ultra-pure water. Credit: Roy Kaltschmidt, Berkeley Lab

The Daya Bay Reactor Neutrino Experiment collaboration—which made a precise measurement of an important neutrino property eight years ago, setting the stage for a new round of experiments and discoveries about these hard-to-study particles—has finished taking data. Though the experiment is formally shutting down, the collaboration will continue to analyze its complete dataset to improve upon the precision of findings based on earlier measurements.

The experiment collected enough data within its first 55 days of operation to announce an important discovery in early March 2012. To celebrate this success and others that followed, the Daya Bay collaboration and science-agency officials will participate in a ceremony on Dec. 12, to mark the end of operations at the site (see event details below).

International partnership enables experiment's successes

Operating in a cavernous underground space containing a series of large, drum-like particle detectors immersed in large pools of water in Guangdong, China, the experiment was built through an international effort that featured a first-of-its-kind equal partnership in a major physics project between the U.S. and China. The Beijing-based Institute of High Energy Physics (IHEP) of the Chinese Academy of Sciences leads China's role in the collaboration, while the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and Brookhaven National Laboratory (Brookhaven Lab) co-lead U.S. participation.

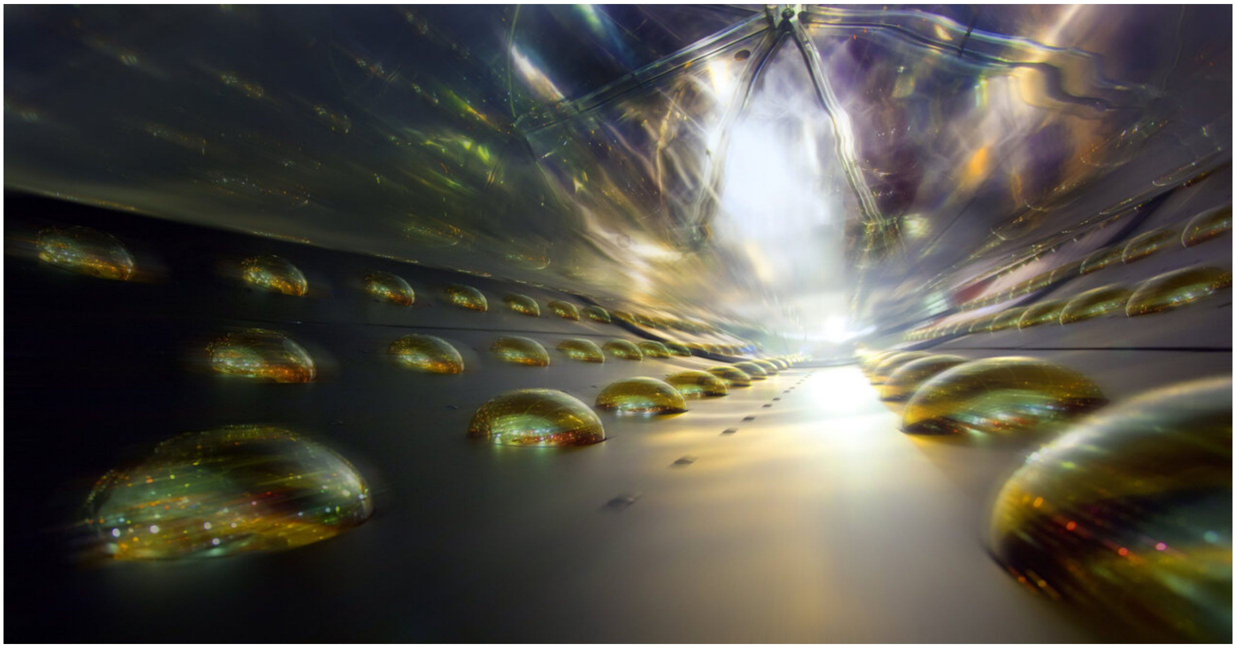
"We are so pleased to see the success of the experiment, which has made important scientific discoveries," said Yi-Fang Wang, a former spokesperson of the Daya Bay collaboration who is now director of IHEP. "The collaboration is truly international, and lessons we learned here are invaluable. We look forward to other collaborations in the future."

IHEP oversaw construction of the experimental site and half of the Daya Bay detectors, with the U.S. collaboration accounting for the other half. There were also significant contributions by scientists and institutions in Taiwan and Hong Kong, and in Chile, the Czech Republic, and Russia.

"This has been a tremendously successful and important experiment," said Kam-Biu Luk, the U.S. spokesman for the Daya Bay experiment and also a faculty senior scientist at Berkeley Lab and a UC Berkeley physics professor. "The precision measurements and discoveries at Daya Bay were made possible by the outstanding collaboration between the U.S. and China and all of our international partners."

Daya Bay's eight detectors are designed to pick up light signals within the scintillating liquids they contain. These signals are generated by interactions with antineutrinos streaming from six reactors at the nearby Daya Bay and Ling Ao nuclear power plants.

Nuclear reactors produce a huge number of antineutrinos via the nuclear fission process, and they do so in a precisely controlled way, which makes reactors an excellent place to conduct neutrino experiments and gather high-precision measurements.



Sensitive photomultiplier tubes lining the Daya Bay detector walls are designed to amplify and record the faint flashes that signify an antineutrino interaction. Credit: Roy Kaltschmidt, Berkeley Lab

Antineutrinos are the antiparticles of neutrinos—abundant subatomic particles that pass through most matter uninterrupted, so they are difficult to detect. Over the past seven decades, scientists have made great progress in designing detectors to pick up the elusive signals of these "ghostlike" particles.

"The Daya Bay detectors work remarkably well, exceeding our expectations," said Daya Bay U.S. Chief Scientist Steve Kettell of Brookhaven Lab. "This success is central to our discovery."

In search of theta 13

Located in three underground halls within a mile of the six reactors, the

Daya Bay experiment was designed to measure a property related to the particles' transformations, or oscillations, between three different types, known as "flavors": electron, muon, and tau. Daya Bay was the first experiment to successfully measure, with certainty, a "mixing angle" called theta 13. This mixing angle defines the rate at which neutrinos transform into the three flavors. Since its first measurement in 2012, the precision in Daya Bay's theta 13 measurement has improved sixfold.

To determine theta 13, scientists measured how many neutrinos of a specific flavor—in this case, electron antineutrinos—were produced by the nearby reactors. From that number they could determine how many electron antineutrinos they should expect to measure using Daya Bay's large detectors. Then, they compared the estimate to the actual, measured number.

The theta 13 measurement, and two other mixing angles measured by previous experiments, help us understand the role neutrinos played in the evolution of our universe. If scientists observe a difference in certain properties of neutrinos vs. antineutrinos, it could help our understanding of the excess of matter vs. antimatter in the universe.

Daya Bay scientists are now conducting an analysis of the data from the experiment's entire nine years of operations. This analysis will enable improved measurements of neutrino properties, including a new precision on theta 13 that is unlikely to be surpassed for decades to come.

Unexpected bonus

"The scientific productivity of Daya Bay has gone way beyond our imagination," said Daya Bay co-spokesperson Jun Cao, of IHEP. "Besides pinning down the value of theta 13, a surprising feature surfaced in the measured reactor antineutrino spectrum with Daya Bay's high-quality data."

The Daya Bay experiment measures the antineutrinos produced by the reactors of the Daya Bay Nuclear Power Plant and the Ling Ao Nuclear Power Plant in mainland China. The photo shows a panoramic view of the Daya Bay reactor complex. Credit: Roy Kaltschmidt, Berkeley Lab

A local excess of antineutrinos—about 10% above theoretical expectations at an energy of around 5 million electron volts (5 MeV) – shows up clearly, well beyond the uncertainties. The origin of this discrepancy is still unclear and requires further studies.

Meanwhile, determination of the antineutrino yield from the Daya Bay experiment also found a likely suspect for explaining a so-called "reactor antineutrino anomaly"—measurements of fewer antineutrinos than had been expected at the sites of many different nuclear reactors. While one possibility for this anomaly was that some antineutrinos had morphed into a hypothesized fourth type of neutrino called a sterile neutrino, Daya Bay researchers found it was most likely due to incomplete modeling of the predicted rate of antineutrino production for one component of the nuclear reactor fuel.

Additionally, teams of scientists from two major experiments studying neutrino oscillations—the Daya Bay experiment and the MINOS+ experiment at DOE's Fermi National Accelerator Laboratory (Fermilab) – joined forces to produce another analysis that largely ruled out any possibility of sterile neutrinos in their data.

Implications of the measurements

"The mixing-angle theta 13, which many scientists suspected would be zero, was fortunately found to be much larger than we anticipated when we planned the experiment," Luk said, which allowed scientists to precisely extract the oscillation frequency and confirm the theory of neutrino oscillation. This bodes well for other active and future neutrino experiments that will attempt to measure the ordering of the masses of the different neutrinos, for example.

It could also benefit experiments that explore neutrinos' possible relevance to the universe's matter-antimatter imbalance. Physicists believe that neutrinos may have played a role in this imbalance through the breaking of a fundamental physics law known as charge-parity (CP) violation. This violation implies that a particle and its antiparticle behave differently.

Daya Bay's theta 13 measurement is the most precise measurement so far among the three mixing-angle measurements related to neutrino oscillations. The Daya Bay collaboration was recognized for the success in precisely measuring theta 13 with the award of the prestigious 2016

Breakthrough Prize in Fundamental Physics.

"Now that we know theta 13 is not zero, we have developed new ways to study the neutrino mass ordering. It also allows us to search for CP violation in current and future experiments," Kettell said.

Existing experiments in neutrino oscillation, such as T2K in Japan and NOvA at Fermilab, benefit from this measurement, he noted, as will Jiangmen Underground Neutrino Observatory (JUNO), a next-generation experiment that will start taking data soon in China, the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) project under construction at Fermilab, and the upcoming Hyper-Kamiokande experiment in Japan.

Provided by Brookhaven National Laboratory