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Announcing the First Results from Daya Bay

—— Discovery of a New Kind of Neutrino Transformation

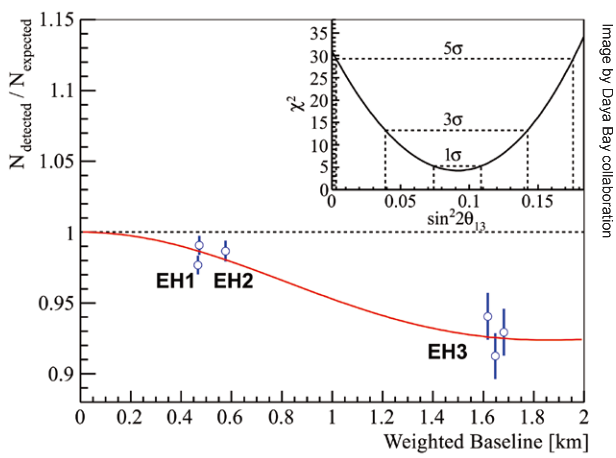
On March 8, 2012, the Daya Bay Reactor Neutrino Experiment, a multinational collaboration operating in the south of China, reported the first results of its search for the last, most elusive piece of a long-standing puzzle: how is it that neutrinos can appear to vanish as they travel? The surprising answer opens a gateway to a new understanding of fundamental physics and may eventually solve the riddle of why there is far more ordinary matter than antimatter in the universe today.

Traveling at close to the speed of light, the three basic neutrino "flavors" — electron, muon, and tau neutrinos, as well as their corresponding antineutrinos — mix together and oscillate (transform), but this activity is extremely difficult to detect. From December 24, 2011, until February. 17, 2012, scientists in the Daya Bay collaboration observed tens of thousands of interactions of electron antineutrinos, caught by six massive detectors buried in the mountains adjacent to the powerful nuclear reactors of the China Guangdong Nuclear Power Group. These reactors, at Daya Bay and nearby Ling Ao, produce millions of quadrillions of elusive electron antineutrinos every second.

The copious data revealed for the first time the strong signal of the effect that the scientists were searching for, a so called "mixing angle" named theta one-three (written θ_{13}), which the researchers measured with unmatched precision. Theta one-three, the last mixing angle to be precisely measured, expresses how electron neutrinos and their antineutrino counterparts mix and change into the other flavors. The Daya Bay collaboration's first results indicate that theta one-three, expressed as $\sin^2 2\theta_{13}$, is equal to 0.092 plus or minus 0.017.

"This is a new type of neutrino oscillation, and it is surprisingly large," says WANG Yifang of CAS Institute of High Energy Physics (IHEP), co-spokesperson and Chinese project manager of the Daya Bay experiment. "Our precise measurement will complete the understanding of the neutrino oscillation and pave the way for the future understanding of matter-antimatter asymmetry in the universe."

Neutrinos, the wispy particles that flooded the universe in the earliest moments after the big bang, are continually produced in the hearts of stars and other nuclear reactions. Untouched by electromagnetism, they respond only to the weak nuclear force and even weaker gravity, passing mostly unhindered through everything from planets to people. The challenge of capturing these elusive particles



Ratio of the observed neutrino rate to the expected one in six antineutrino detectors located in three underground experimental halls, labeled as EH1, EH2, and EH3, versus the flux-weighted distance from the reactor cores to the detectors. The deficit in the far hall (EH3) shows clear evidence of neutrino oscillation, compared to the two near halls (EH1 and EH2). The dashed line shows the expectation of no-oscillation and the red curve shows the best-fit oscillation. The x^2 curve that quantitates the statistical significance is shown in the inset.

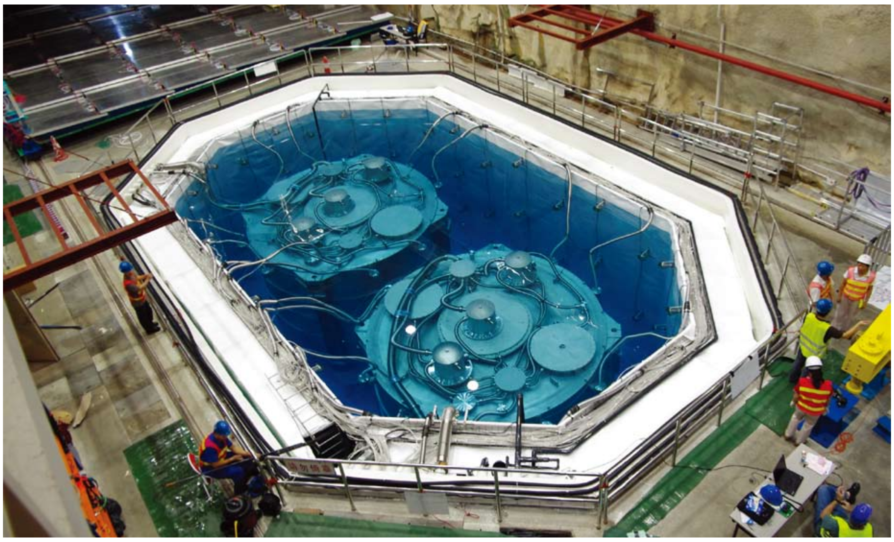


Image by Daya Bay collaboration

The antineutrino detectors are submerged in pools of water to shield them from radioactive decays in the surrounding rock.

inspired the Daya Bay collaboration in the design and precise placement of its detectors.

"Although we're still two detectors shy of the complete experimental design, we've had extraordinary success in detecting the number of electron antineutrinos that disappear as they travel from the reactors to the detectors two kilometers away," says Kam-Biu Luk of the U.S. Department of Energy's Lawrence Berkeley National Laboratory (Berkeley Lab) and the University of California at Berkeley. Luk is co-spokesperson of the Daya Bay experiment and heads U.S. participation. "What we didn't expect was the sizable disappearance, equal to about six percent. Although disappearance has been observed in another reactor experiment over large distances, this is a new kind of disappearance for the reactor electron antineutrino."

The Daya Bay experiment counts the number of electron antineutrinos detected in the halls nearest the Daya Bay and Ling Ao reactors and calculates how many would reach the detectors in the Far Hall if there were no oscillation. The number that apparently vanishes on the way (oscillating into other flavors, in fact) gives the value of theta one-three. Because of the near-hall/far-hall arrangement, it's not even necessary to have a precise estimate of the antineutrino flux from the reactors.

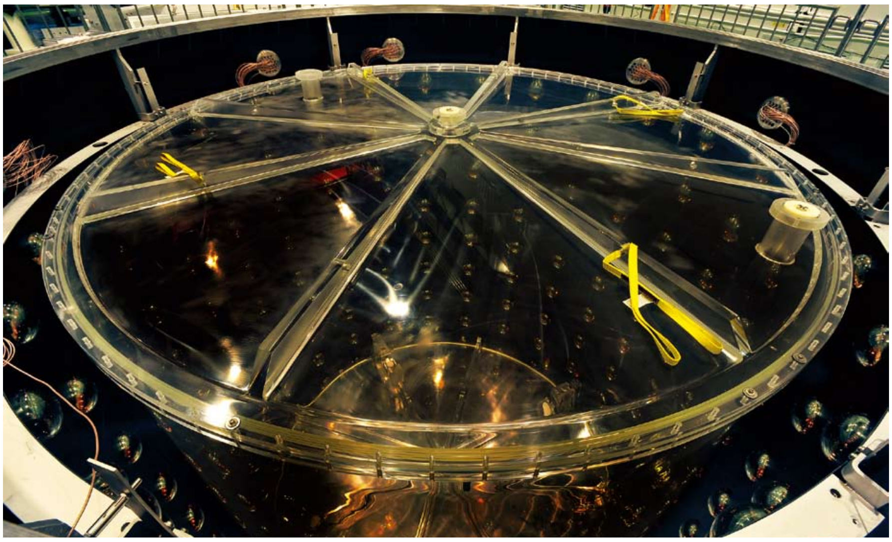
"Even with only the six detectors already operating, we have more target mass than any similar experiment, plus as much or more reactor power," says William Edwards of Berkeley Lab and UC Berkeley, the U.S. project and operations manager for the Daya Bay experiment. Since Daya Bay will continue to have an interaction rate higher than any other experiment, Edwards explains, "it is the leading theta one-three experiment in the world."

The first Daya Bay results show that theta one-three, once feared to be near zero, instead is "comparatively huge," Kam-Biu Luk remarks, adding that "Nature was good to us." In coming months and years the initial results will be honed by collecting far more data and reducing statistical and systematic errors.

"The Daya Bay experiment plans to stop the current data-taking this summer to install a second detector in the Ling Ao Near Hall, and a fourth detector in the Far Hall, completing the experimental design," says WANG.

Refined results will open the door to further investigations and influence the design of future neutrino experiments – including how to determine which neutrino flavors are the most massive, whether there is a difference between neutrino and antineutrino oscillations, and, eventually, why there is more matter than antimatter in the universe — because these were presumably created in equal amounts in the big bang and should have completely annihilated one another, the real question is why there is any matter in the universe at all.

"It has been very gratifying to be able to work with such an outstanding international collaboration at the world's most sensitive reactor neutrino experiment," says Steve Kettell of Brookhaven National Laboratory, the chief scientist for the U.S. effort. "This moment is exciting



The cylindrical antineutrino detectors.

because we have finally observed all three mixing angles, and now the way is cleared to explore the remaining parameters of neutrino oscillation."

"This is really remarkable," says ZHAN Wenlong, vice president of CAS and president of the Chinese Physical Society. "We hoped for a positive result when we decided to fund the project, but we never imagined it could come so quickly!"

"Exemplary teamwork among the partners has led to this outstanding performance," says James Siegrist, DOE Associate Director of Science for High Energy Physics. "These notable first results are just the beginning for the world's foremost reactor neutrino experiment."

The Daya Bay collaboration consists of scientists from the following countries and regions: mainland China, the United States, Russia, the Czech Republic, Hong Kong, and Taiwan. The Chinese effort is led by co-spokesperson, chief scientist, and project manager WANG Yifang with the IHEP, and the U.S. effort is led by co-spokesperson Kam-Biu Luk and project and operations manager William Edwards, both of Berkeley Lab and UC Berkeley, and by chief scientist Steve Kettell of Brookhaven.

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