Snowmass2021 - Letter of Interest

Legacy of the Daya Bay Reactor Neutrino Experiment

NF Topical Groups: (check all that apply ☐/■)

■ (NF1) Neutrino oscillations
■ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
☐ (NF4) Neutrinos from natural sources
☐ (NF5) Neutrino properties
☐ (NF6) Neutrino cross sections
■ (NF7) Applications
☐ (NF8) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
☐ (NF10) Neutrino detectors
☐ (Other) *[Please specify frontier/topical group(s)]*

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Abstract: The Daya Bay Reactor Antineutrino Experiment consists of eight identically-designed detectors deployed in three underground sites at different baselines from six nuclear reactors in China. Daya Bay is the world's leading experiment for measuring the θ_{13} mixing angle and the Δm^2_{32} mass-splitting with reactor antineutrinos, as well as for searching for sterile-neutrino mixing in the $10^{-3} \lesssim |\Delta m^2_{41}| \lesssim 0.2$ eV^2 range. With the largest library of reactor antineutrinos ever collected, Daya Bay is also able to measure the absolute rate and energy spectrum of reactor antineutrinos, as well as their evolution with nuclear fuel composition, with leading precision. No experiment in the foreseeable future will be able to improve the precision of several of these measurements and to collect a comparable sample of reactor antineutrinos at similar baselines. Accordingly, the collaboration plans for a comprehensive release of its final data set once it has ceased to operate and the final results have been published.

The Daya Bay Reactor Neutrino Experiment

Daya Bay utilizes up to four liquid-scintillator detectors placed in two underground near halls for measuring the flux and energy spectrum of low-energy electron antineutrinos emitted from three pairs of twin 2.9-GW$_{th}$, pressurized-water commercial nuclear reactors. Disappearance of reactor antineutrinos is studied with up to four more identically-designed detectors installed in a far site with well-determined baselines of $O(1$ km). Through an aggressive calibration program relying on natural and artificial radioactive sources, as well as on spallation products, Daya Bay has achieved an energy resolution of about 8.5% at 1 MeV and an absolute energy scale of better than 1%, with less than 0.2% systematic variation in energy response across detectors. Daya Bay began data taking on 24 December 2011, and plans to end operation in December 2020. More information about the experiment can be found in Ref. [1].

Neutrino Oscillation Measurements

After discovering a relatively large θ_{13} in 2012 [2], Daya Bay has been providing the world with the most precise determination of this mixing angle. The latest result [3] uses about 4M antineutrino interactions collected over 1958 days to measure the disappearance of antineutrinos at the Daya Bay far site, relative to the signal detected at the near sites. The size of this disappearance gives $\sin^2 2\theta_{13} = 0.0856 \pm 0.0029$, which is consistent with other measurements as shown on the left panel of Fig. 1. In addition, Daya Bay has determined the wavelength of the oscillation, which is directly related to the mass-squared difference Δm^2_{32}. The latest result is $\Delta m^2_{32} = (2.471^{+0.068}_{-0.070}) \times 10^{-3}$ eV^2 under the assumption of the normal mass ordering, or $\Delta m^2_{32} = -(2.575^{+0.068}_{-0.070}) \times 10^{-3}$ eV^2 for the inverted mass ordering, on-par with the precision of accelerator-muon-neutrino-based measurements of this parameter, as shown on the right of Fig. 1. The consistency of measured parameters using MeV-scale electron antineutrinos and GeV-scale accelerator/atmospheric muon neutrinos strongly supports the three-flavor model of neutrino oscillation and places stringent constraints on non-standard models.

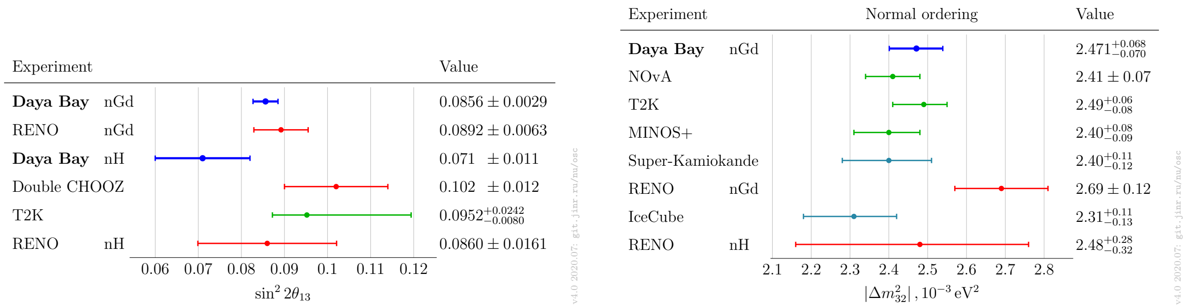

FIG. 1. Comparison of the most recent measurements of $\sin^2 2\theta_{13}$ (left) [4–7] and Δm^2_{32} (right) [4, 8–10].

A 50% increase in statistics with the complete dataset and reduction of systematic uncertainties will give Daya Bay the potential to measure $\sin^2 2\theta_{13}$ to a precision of about 0.002, the best-known neutrino mixing angle. It will remain the best determination of $\sin^2 2\theta_{13}$ for the foreseeable future well into or beyond DUNE/T2HK results [11, 12]. Daya Bay anticipates to reach its ultimate precision of about 5×10^{-5} eV^2 for Δm^2_{32}, a level that would be sensitive to the mass ordering when compared to the muon-neutrino disappearance results with similar precision.

Given the clear characteristics of low-energy electron antineutrino inverse-beta decay interactions and negligible background, the Daya Bay measurements do not suffer from the interaction model uncertainties that can plague high-energy neutrino experiments. This clear and precise determination of θ_{13} helps resolve the degeneracies in accelerator and atmospheric muon-neutrino measurements, and enhances the reach of current and future experiments to precisely determine the CP-violating phase [11–14]. The complementary measurement of θ_{13} from Daya Bay and DUNE/T2HK will also offer a unique test of unitarity of the neutrino mixing matrix, providing another window sensitive to sterile neutrinos and other non-standard neutrino interactions.

Daya Bay's precision data have also allowed to set some of the world's leading constraints on reactor antineutrino disappearance beyond what is expected from the three-neutrino mixing framework. In particular, the experiment's unique configuration of eight detectors at multiple baselines from six nuclear reactors allows it to cover over three orders of magnitude in $|\Delta m^2_{41}|$ when searching for sterile-neutrino mixing. The most recently reported limits [15], which were obtained using a 1230-day data set and already stand as the world's most stringent in the $10^{-3} \lesssim |\Delta m^2_{41}| \lesssim 0.2$ eV^2 range, are still expected to be improved with a larger data set and a reduction of systematic uncertainties. These tight limits have become an essential ingredient in joint analyses with other disappearance experiments [15, 16] that probe the parameter space allowed by the LSND [17] and MiniBooNE experiments [18, 19] with unprecedented sensitivity. At this point there is no experiment in the horizon that will be able to supersede Daya Bay's sterile neutrino mixing constraints in the aforementioned range of $|\Delta m^2_{41}|$.

Reactor Antineutrino Measurements

Daya Bay has provided some of the world's most precise measurements of the flux and spectrum of electron antineutrinos emitted from nuclear reactors [20, 21]. Daya Bay's determination of time-integrated reactor $\overline{\nu}_e$ flux [20, 22], in excellent agreement with the past measurements at short baselines, confirmed the existence of a deficit in measured $\overline{\nu}_e$ fluxes with respect to current predictions [23], and provided further motivation for a new generation of reactor-based short-baseline sterile-neutrino oscillation search experiments [24–28]. Its precise low-enriched-uranium fuel spectrum measurements [20, 21] helped uncover differences in predicted and measured $\overline{\nu}_e$ spectra [29, 30] that remain an unresolved and intense topic of investigation for nuclear and particle communities [31–39]. Its groundbreaking measurements of the evolution of $\overline{\nu}_e$ production with reactor fuel burn-up have greatly enhanced understanding of the reactor $\overline{\nu}_e$ flux anomaly [40, 41], as well as the isotopic inverse beta-decay yields [42, 43] and spectra [44, 45] per fission, enabling an increasingly complete picture of $\overline{\nu}_e$ production largely independent of theoretical models [46, 47].

Improvements to these Daya Bay reactor antineutrino measurements can be expected in the coming years with modest research support. By analyzing changes in the observed spectrum with fuel burn-up, Daya Bay has performed a first measurement of antineutrino production by ^{235}U and ^{239}Pu separately [44]. These isotopic spectrum measurements will be substantially improved in the future through the enhanced statistics available in the final Daya Bay dataset, as well as through a joint analysis of Daya Bay data and the pure ^{235}U measurement of PROSPECT [45]. Such an analysis could also provide the first direct measurement of antineutrino production by the sub-dominant fission isotope ^{238}U. Daya Bay's absolute flux measurement may also be improved modestly beyond its current 1.5% precision in the future through the use of more efficient and robust inverse beta-decay selection criteria.

Data Archiving and Preservation

In summary, the Daya Bay data is at the basis of several key oscillation and reactor antineutrino measurements whose precision is unlikely to be challenged in the foreseeable future. Allowing the data to be re-examined as new information comes along, tested for new models, and used as a benchmark for other experiments, phenomenologists, and nuclear databases, is extremely valuable to the community. Accordingly, the collaboration plans for the comprehensive preservation and release of the full Daya Bay data set after operations have ceased at the end of 2020 and the final results have been published. The intention is to use a publicly-accessible archive that is supported for the long term. Different levels of data and metadata will be provided in order to maximize their possible uses, alongside suitable documentation. A detailed plan is still being formulated and will be communicated in the timescale of a year. In the meantime, input from the community is welcome on the scope, granularity, and format of the data to be released.

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