Daya Bay's Latest Oscillation Results Using Neutron Capture on Gadolinium

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(on behalf of the Daya Bay collaboration)

1. Daya Bay Reactor Neutrino Experiment

Daya Bay Reactor Neutrino Experiment was designed to precisely measure the neutrino mixing angle θ_{13}.

- Nuclear reactors produce a pure sample of electron antineutrinos
  - Six 2.9 GW_{th} reactors in 3 nuclear power plants (NPP)
  - $\sim 2\times 10^{20}\ \overline{\nu}_e/\text{second}/GW_{th}$
- 3 underground experimental halls (EHs) which house eight functionally identical antineutrino detectors (ADs)
  - 2 near halls (EH1 and EH2)
  - 1 far hall (EH3)

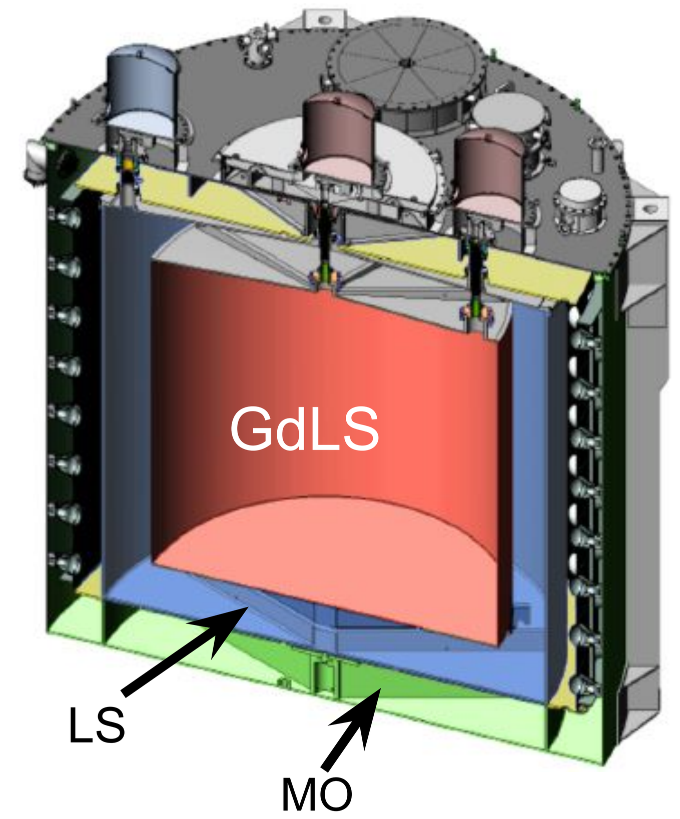
Locations of the three EHs and the nuclear reactors.

2. Antineutrino Detection

Each near hall has two ADs, while the far hall has four.

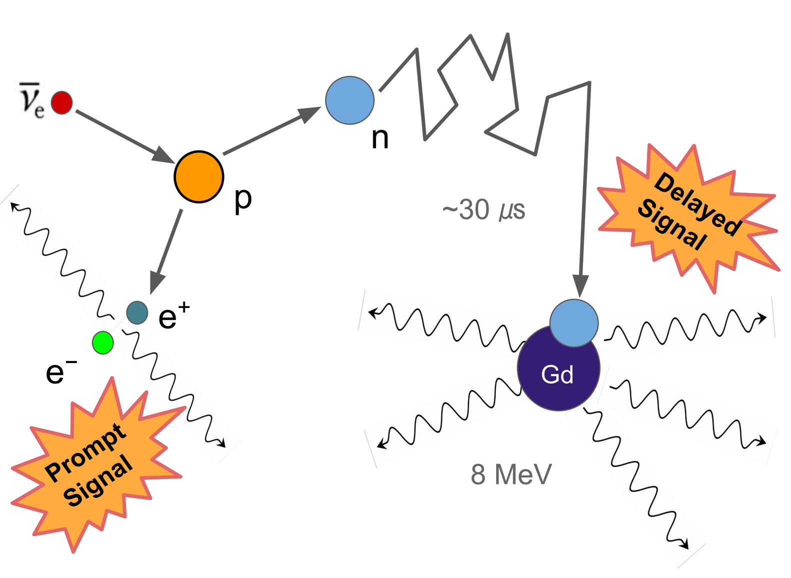
- Each AD has 3 zones:
  - **Gadolinium doped liquid scintillator (GdLS)** - 20 tons
    - Target volume
  - **Liquid scintillator (LS)** - 22 tons
    - γ catcher and target volume
  - **Mineral oil (MO)** - 40 tons
    - Buffer hosting PMTs
- 192 8-inch photomultiplier tubes (PMTs)
- The ADs are submerged in a water pool to provide shielding and allows for muon vetoing

Cross-Section of AD.



Antineutrino interactions are detected in the ADs via inverse beta decay (IBD) process:

$$\overline{\nu}_e + p \rightarrow e^+ + n$$



Schematic of IBD interaction within the AD with the neutron capture on Gadolinium.

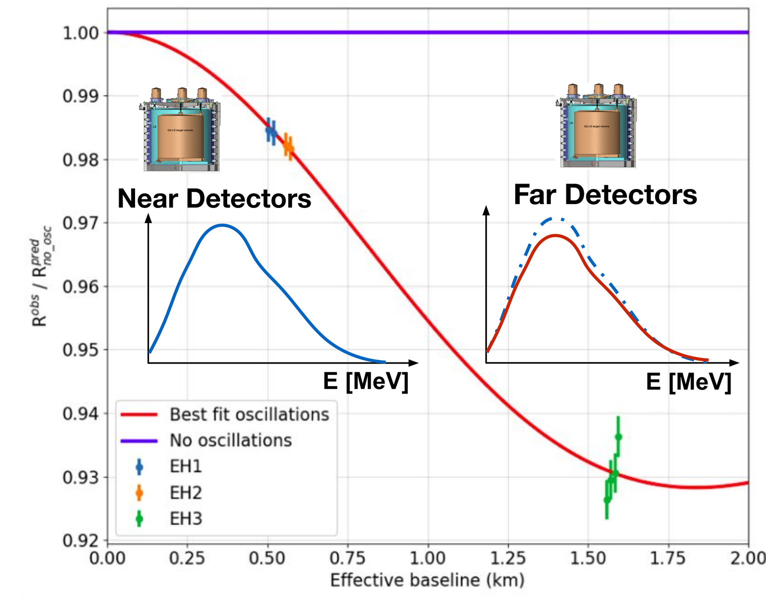
- The double coincidence signature of IBDs allow for better selection against background
  - Positron annihilation and loss of kinetic energy
  - Neutron capture on gadolinium: nGd
- Prompt energy directly related to antineutrino energy
  - $E_{\overline{\nu}_e} \approx E_p + 0.78\ \text{MeV}$

3. Relative Measurement @ Daya Bay

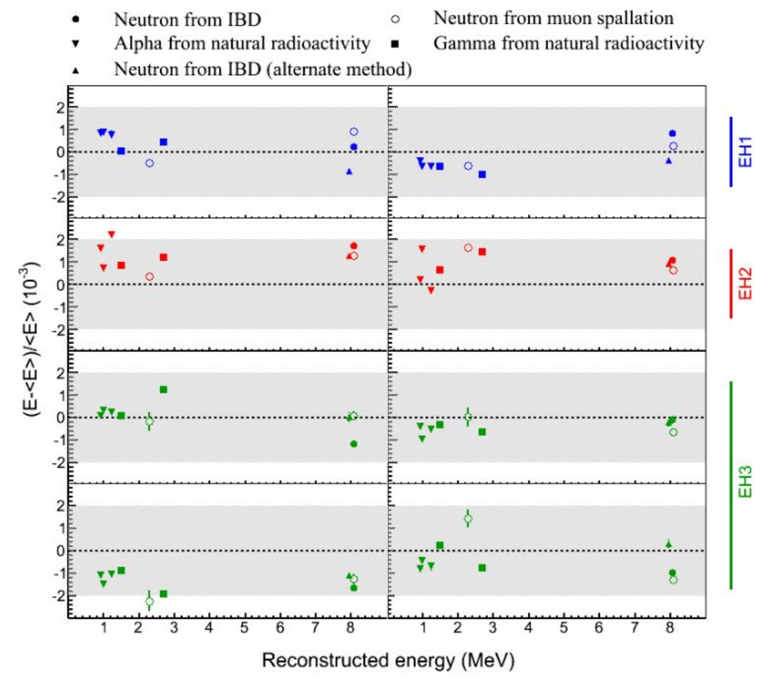
The survival probability of an electron antineutrino is:

$$P(\overline{\nu}_e \rightarrow \overline{\nu}_e) = 1 - \sin^2(2\theta_{13})\sin^2\left(\frac{\Delta m^2_{ee} L}{4E}\right) - \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$

where Δm^2_{ee} is the leading oscillation frequency observed in our experiment.



The locations of the near and far detectors related to survival probability for fixed energy of electron antineutrinos produced by the nuclear reactors. Near hall characterizes reactor flux; far hall location is optimized to maximally observe neutrino oscillations.

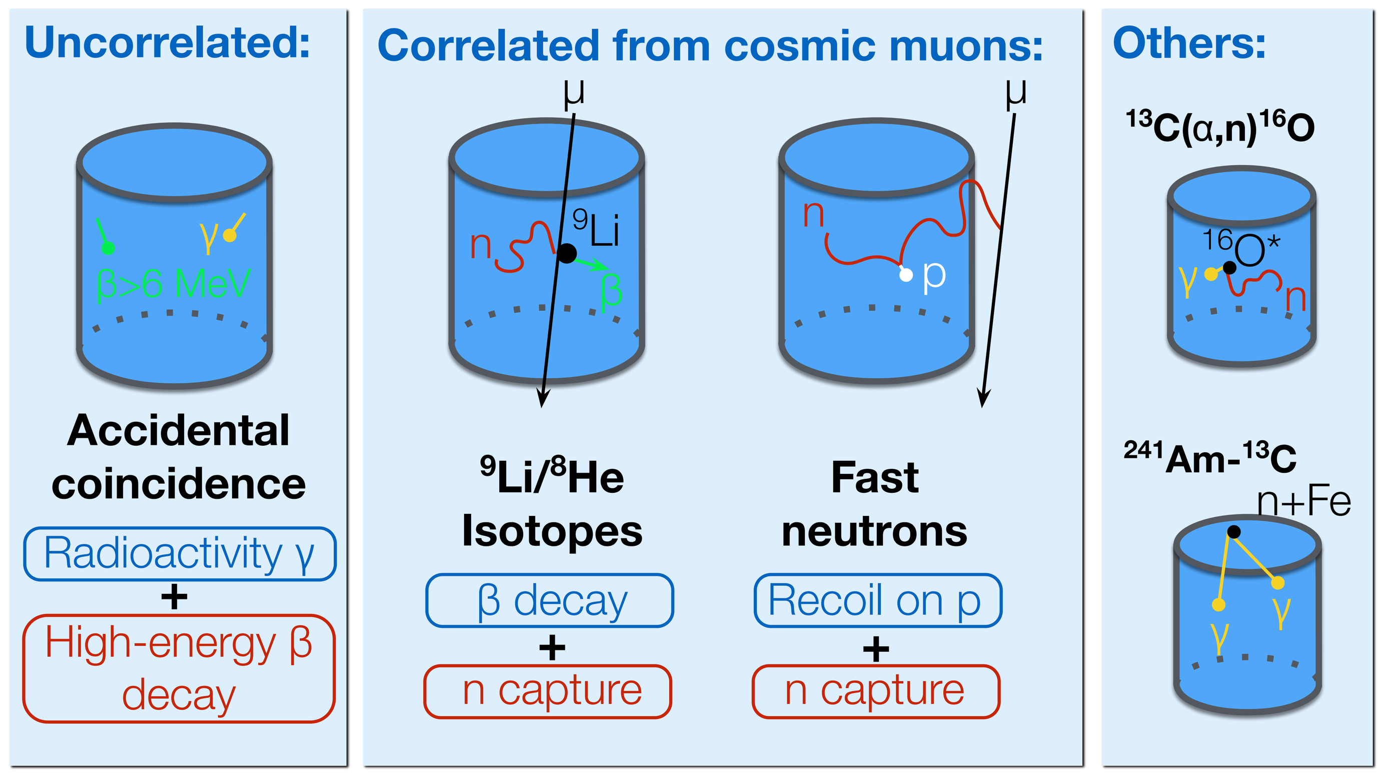


Fractional difference in energy for various types of events, demonstrating the relative energy scale uncertainty of <0.2%.

- Relative near-far measurement allows for precise observation of the disappearance of reactor electron antineutrinos while mitigating the reactor flux uncertainties and detector correlated uncertainties
  - Relative detection efficiency uncertainty: 0.13%
    - Relative Gd capture fraction uncertainty: <0.10%
    - Relative energy scale uncertainty: <0.2%

4. Backgrounds

Less than 2% background in all halls and backgrounds contributes <0.15% uncertainty to IBD rate.



Synopsis of the backgrounds observed by Daya Bay.

	$\overline{\nu}_e$ rate ($AD^{-1}day^{-1}$)	Accidentals ($AD^{-1}day^{-1}$)	Fast Neutron ($AD^{-1}day^{-1}$)	$^9Li/^8He$ ($AD^{-1}day^{-1}$)	Am-C correlated ($AD^{-1}day^{-1}$)	$^{13}C(\alpha,n)^{16}O$ ($AD^{-1}day^{-1}$)
EH 1	~ 670	~ 8	~ 0.79	~ 2.4	~ 0.16	~ 0.07
EH 2	~ 600	~ 6	~ 0.57	~ 1.6	~ 0.14	~ 0.05
EH 3	~ 75	~ 1	~ 0.05	~ 0.2	~ 0.05	~ 0.04

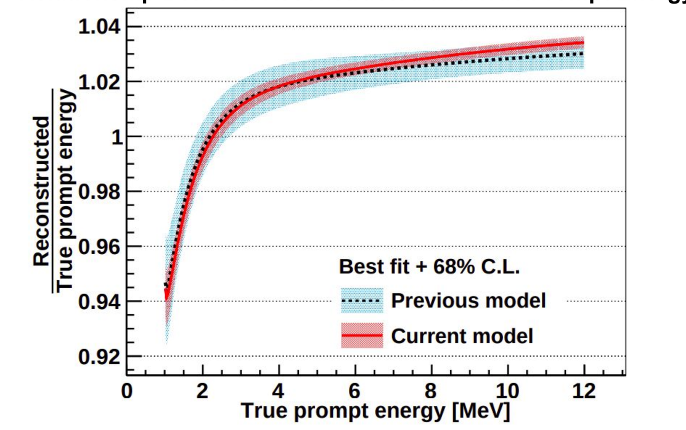
Summary of the antineutrino interaction rate and background rates for each hall. Background uncertainty in $\overline{\nu}_e$ rate is ~ 0.12%.

5. Major Systematics Improvements

Since the previous results, several systematics improvements have been made, in addition to increased statistics of ~60%.

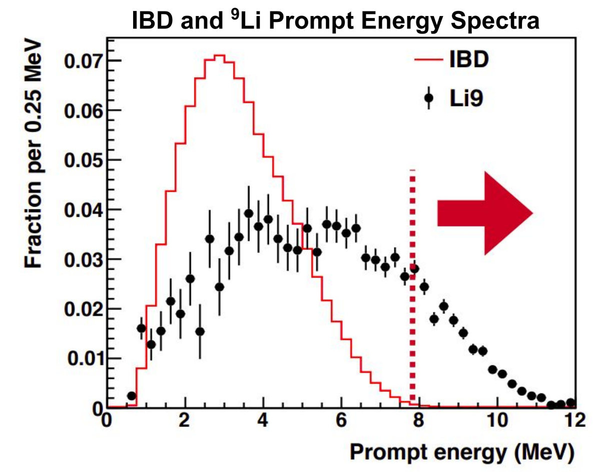
- Halved the uncertainty of absolute energy scale to ~0.5% compared to previous results
  - Installation of FADC readout provided measurement of electronics non-linearity
  - Special calibration runs acquired using ^{60}Co sources with different encapsulating materials

Relationship Between Reconstructed and True Prompt Energy

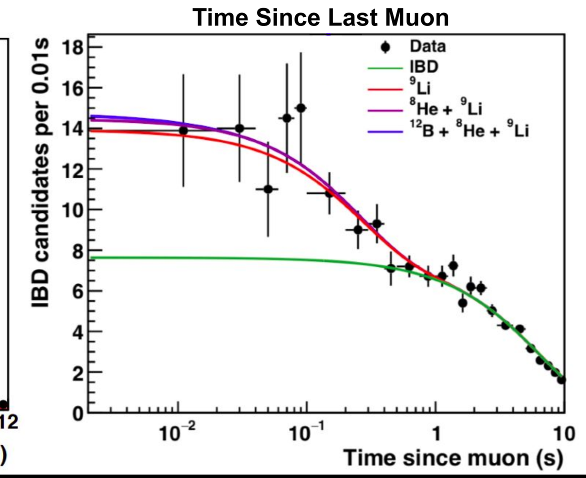


- Reduced $^9Li/^8He$ background uncertainty estimation from 50% to 30% in near ADs

IBD and ^9Li Prompt Energy Spectra



Time Since Last Muon



- Apply a prompt energy cut to enhance $^9Li/^8He$ fraction when fitting time-since-last-muon distributions

6. Results

Using **1958 days of data**, and **3.9 million antineutrino interactions**, the latest nGd results are consistent with the previous nGd measurements.

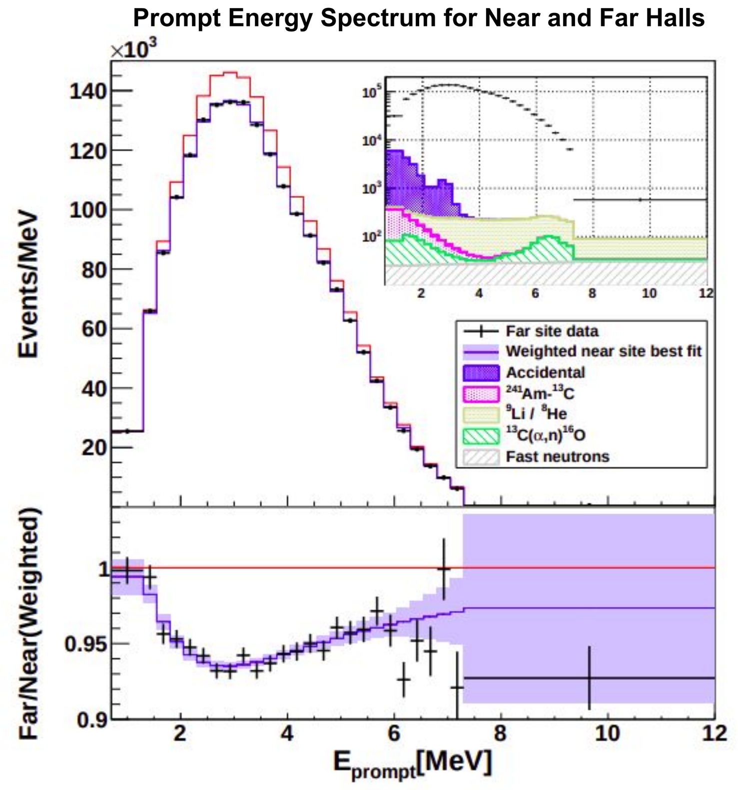
$$\sin^2(2\theta_{13}) = 0.0856 \pm 0.0029$$

- The most precise measurement in the world
- Systematic uncertainty is dominated by the detection efficiency uncertainty among the ADs
- Improved measurements will be the world's best for the foreseeable future (~3% uncertainty)

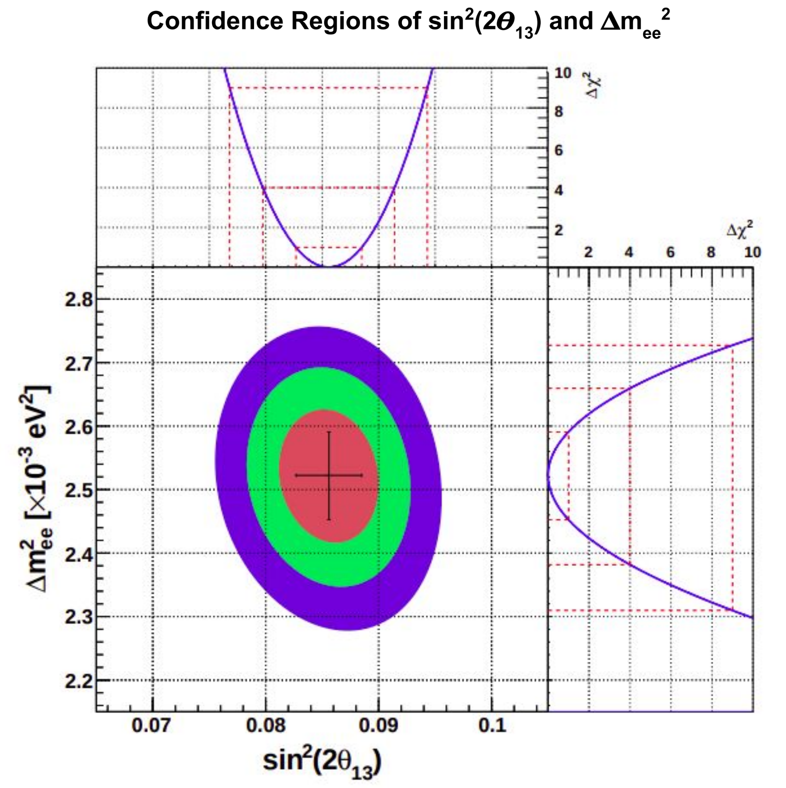
$$\Delta m^2_{ee} = \left(2.522^{+0.068}_{-0.070}\right) \times 10^{-3}\ \text{eV}^2$$

- Comparable precision to accelerator neutrino experiments
- Systematic uncertainty is dominated by the uncorrelated energy scale uncertainty

Prompt Energy Spectrum for Near and Far Halls



Confidence Regions of $\sin^2(2\theta_{13})$ and Δm^2_{ee}



References

D. Adey et al. (The Daya Bay Collaboration), Phys. Rev. Lett. 121, 241805 (2018)