Measurement of $\sin^2 2\theta_{13}$ via neutron capture on hydrogen at Daya Bay

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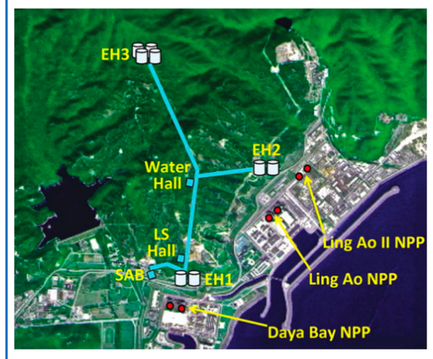
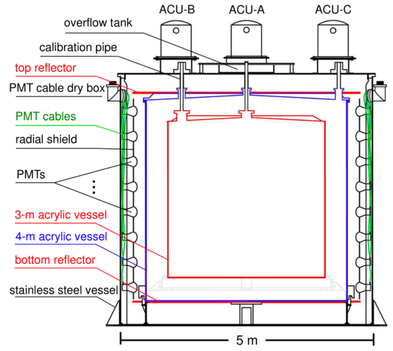
(on behalf of the Daya Bay Collaboration)

1. Daya Bay Reactor Neutrino Experiment [1]

The Daya Bay Experiment provides precise measurement of reactor anti-neutrino disappearance via Inverse Beta Decays (IBDs), and the IBDs are tagged by neutron capture on gadolinium (nGd) or on hydrogen (nH).





- Next to 6 x 2.9 GW_{th} reactors providing large flux of $\bar{\nu}_e$
- 8 identical-design antineutrino detectors (ADs) deployed in three sites up to 330 m over-burden for cosmic-ray shielding

2. nH IBD Selection [2, 3]

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

Prompt: kinetic energy of e^+, and annihilation gammas

Delayed: neutron-capture gamma

Merits:

- Large statistically independent sample
- Largely different systematics from nGd

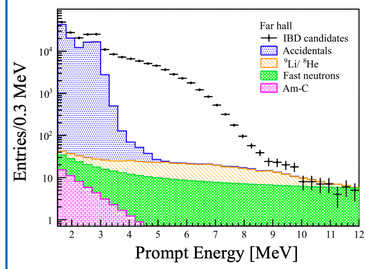
Challenges:

- Large accidental background
- Sizeable energy leakage

Selection Criteria:

- Flasher cut & Muon Veto
- Energy cut: 1.5 MeV< E_p < 12 MeV, $\mu - 3\sigma < E_d < \mu + 3\sigma$
- Coincidence time: [1, 400] us
- Coincidence distance: [0, 500] mm
- Multiplicity cut: reject ≥ 3 coincidence

3. Background Analysis [2, 3]

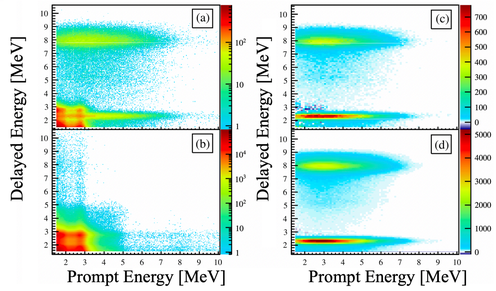


Correlated backgrounds:

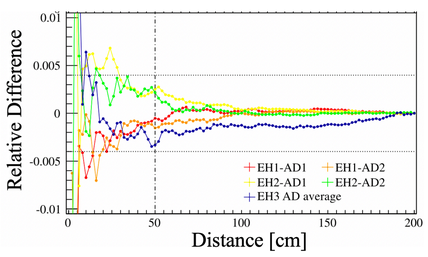
- Muon-induced ^{9}Li/ ^{8}He:
  Fit to the time since the preceding muon
- Muon-induced fast-neutron:
  Study the prompt spectrum with E_p >12 MeV
- Am-C calibration source
  Study with a strong Am-C source

Dominated accidental background

- ~50 % of IBD candidates at far site
- The rate estimation was validated by distance, time distributions (data) and MC.
- The background shape was also studied carefully.



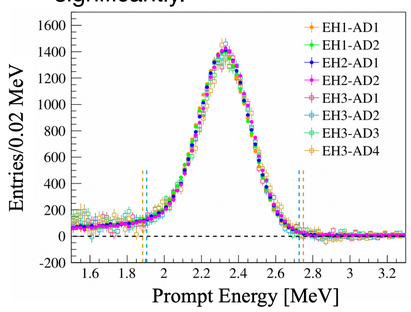
4. Detection Efficiency and Identicalness [3]



- Delayed-energy cut efficiency is calculated based on MC. But its AD-uncorrelated uncertainty can also be estimated by comparison among 8 ADs with data.
- Prompt-energy cut efficiency and also its uncertainty are calculated by MC. The uncertainty is fully due to the energy-scale variation among 8 ADs.

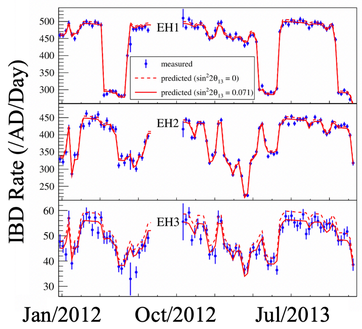
	Uncertainty (%)
Target protons ($N_{p,\mathrm{GdLS}}$)	0.03
Target protons ($N_{p,\mathrm{LS}}$)	0.13
Target protons ($N_{p,\mathrm{acrylic}}$)	0.50
Prompt energy (ε_{E_p})	0.10
Coincidence time (ε_T)	0.14
Delayed energy (ε_{E_d})	0.35
Coincidence distance (ε_D)	0.40
Combined (N_e)	0.57

- The distance and time distributions of IBDs can be obtained from data for each AD. Then the cut efficiencies uncertainty (AD-uncorrelated) can be estimated by comparing among 8 ADs.
- In our new analysis, the uncertainty of this part is reduced significantly.

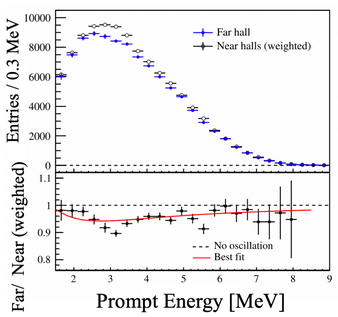


- Other IBD selection cuts have negligible uncertainty, such as: multiplicity cut, muon veto, etc.
- In our last publication, the uncertainty of distance cut and delayed energy cut are dominated in final analysis. New analysis is expected to yield a significant improvement.

5. Rate-only Analysis Result [3]



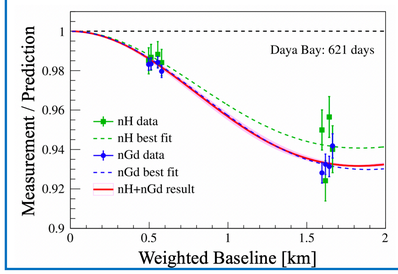
Measured IBD rate vs. time for each experimental hall (EH). Each point spans one week and the error bars are purely statistical.



Reconstructed prompt-energy spectrum of the far hall and the expectation based on the measurements of the two near halls.

χ^2 function of the rate-only analysis

$$\chi^2 = \sum_{\text{detector}} \frac{\text{Measurement} - \text{Prediction} \times (1 + \varepsilon_{\text{reactor}} + \varepsilon_{\text{efficiency}}) - \text{Background} \times (1 + \varepsilon_{\text{bkg}})}{\sqrt{\text{Measurement}}} + \text{pull terms}$$



- Using 621 days of data, and ~1.0 million antineutrino interactions, we measured that $\sin^2 2\theta_{13} = 0.071 \pm 0.011$.

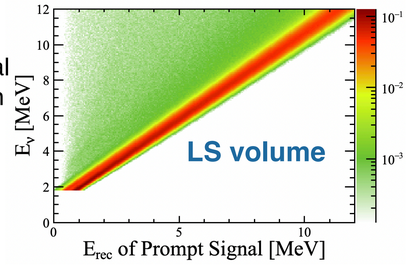
6. Towards a Rate & Spectral Shape Measurement

Rate analysis

- Total deficit of IBD rate at each AD
- No measurement of energy spectral distortion due to neutrino oscillation

Rate & Shape analysis

- Deficit of IBD rate at different neutrino energy range
- Need good understanding of detector energy response



Understanding of detector response

- Minor energy leakage in nGd analysis
- Large energy leakage in nH analysis
- Basis of predicting prompt spectrum without neutrino oscillation
- The main target volume of of nH analysis is LS volume, and its response matrix is shown. Apparent energy leakage can be observed.

Spectral shape uncertainties are studied

- Energy non-linearity
- Detector geometry
- Energy scale
- Non-uniformity, etc.

We expect an updated nH result soon.

7. References

[1] F.P. An et al, Nucl. Instrum. Meth. A **811**, (2016) 133-161
[2] F.P. An et al, Phys. Rev. D **90** (2014) 071107(R)
[3] F.P. An et al, Phys. Rev. D **93** (2016) 072011