Neutrino Oscillation Analysis via Neutron Capture on Hydrogen at Daya Bay

Tong Xu, Tsinghua University, Beijing, China. Mail: xu-t18@mails.tsinghua.edu.cn

(On behalf of the Daya Bay collaboration)

ICHEP 2022 BOLOGNA

1. Daya Bay Experiment [1]

Fig 1. Layout of Daya Bay Experiment

- A new independent measurement of neutrino mixing angle θ_{13} at Daya Bay.
- 6 low enriched uranium (LEU) commercial reactors with 2.9 GW thermal power each.
- 3 experiment halls inside the adjacent mountains contains 8 identical designed anti-neutrino detectors(AD)

2. Anti-neutrino Detection [1,2]

- Inverse Beta Decay (IBD) :

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

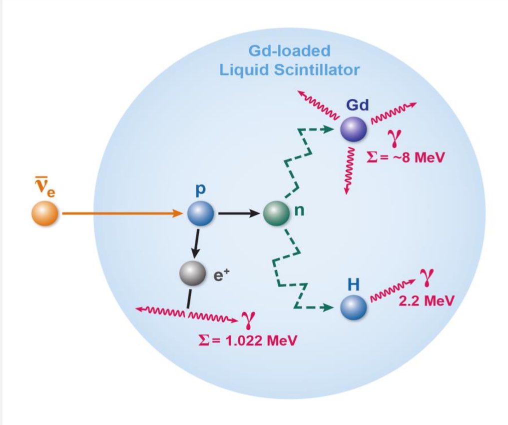

Fig 2. IBD interaction in detector

- **IBD events : Double coincidence in time, space and energy**
  - Prompt signal : kinetic energy of e+, and annihilation gammas
  - Delayed signal : neutron-capture gamma
- **Relationship between incident neutrino and prompt energy**
  - $E_\nu \approx E_{prompt} + 0.78MeV$

- Anti-neutrino Detector (AD):

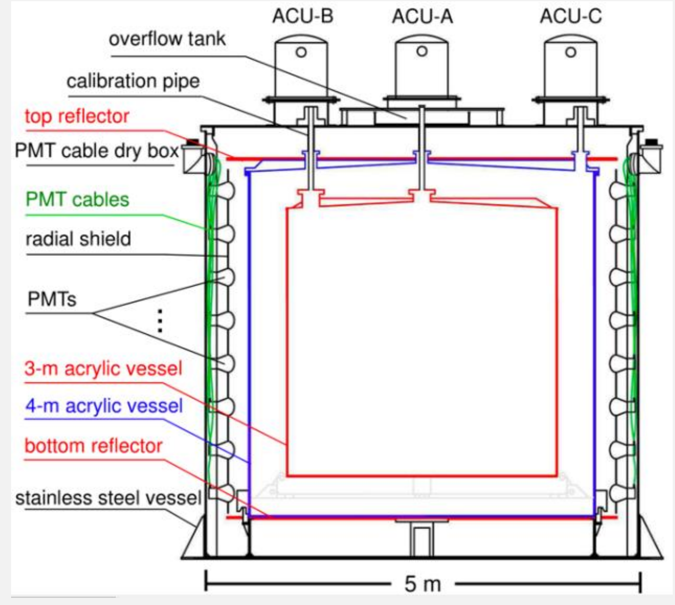

Fig 3. Schematic of an AD

- Each near(far) hall contains 2(4) Ads
- AD consists of three nested, coaxial cylindrical vessels : an inner and outer acrylic vessel(IAV and OAV) and a outmost stainless steel vessel (SSV)
  - IAV : 3m in diameter and height, contains 20 tons of gadolinium-doped liquid scintillator (GdLS)
  - OAV: 4m in diameter and height, contains 22 tons of liquid scintillator (LS)
  - SSV : 5m in diameter and height, contains 40 tons of mineral oil (MO)
- 192 20-cm PMTs arranged in 24 columns and 8 rings within MO
- Each AD submerged in a two-zone water Cherenkov detector which provide shielding against radiation and spallation products of nearby cosmogenic muons

3. IBD Selection [2,3]

- Selection Criteria :

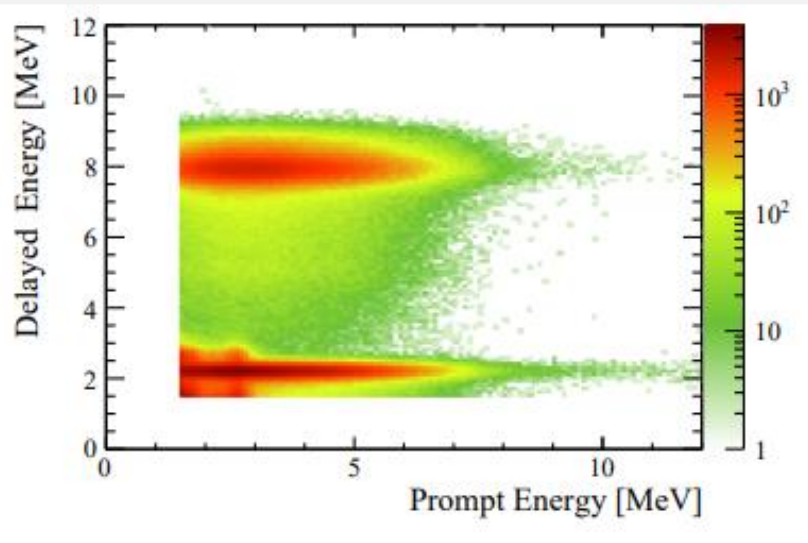

Fig 4. Delayed vs. prompt energy of all events after all cuts for EH1-AD1.

- Flasher cut
  - Remove spontaneous emissions of light from the voltage divider of a PMT
- Muon veto
  - Suppress backgrounds from muon-induced spallation neutrons and long-lived spallation products
- Energy cut :
  - $1.5MeV < E_p < 12MeV, \mu - 3\sigma < E_d < \mu + 3\sigma$
- Coincidence Time : $[1,1500]\mu s$
- Combined distance and time cut (DT cut)
  - $DT[mm] = d[mm] + \frac{1000[mm]}{600[\mu s]} \times t[\mu s] < 800mm$
  - DT cut utilized to improve IBD selection
- Multiplicity cut: reject ≥3 event coincidences

- Advantages :
- Large statistically independent sample
- Largely different systematics from nGd

- Challenges :
- Large accidental background
  - Improve the method to predict accidental background rate and shape, reduced the systematic error down to a negligible level and removed ~ 0.2% bias on the accidental rate in the near site.
- Sizeable energy leakage

4. Backgrounds [2,3]

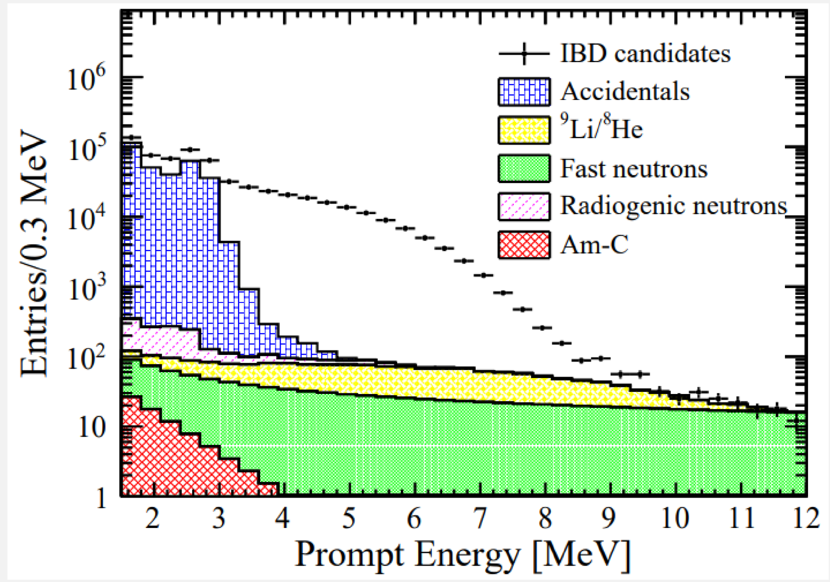

Fig 5. Energy spectrums of IBD, accidental background and correlated backgrounds for EH3(far site)

- Accidental background :
- Dominated background
- Update the rate calculation and spectral prediction method
- Correlated backgrounds :
- Muon-induced 9Li/8He
  - Fit to the time since the preceding muon
- Muon-induced fast neutrons
  - Study the prompt spectrum with Ep >12 MeV
- Am-C calibration source
  - Study with a strong Am-C source
- Radiogenic neutron background
  - Natural radioactivity from PMT glass form the background

5. Detection Efficiency [3]

	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_ε)	0.57

Table 1. The relative per-detector uncorrelated uncertainties for each detector-related quantity

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

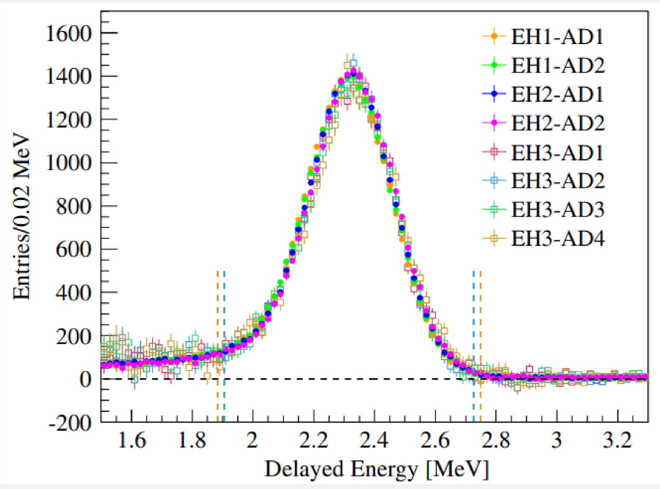

Fig 6. Delayed energy spectra of nH-IBDs in all ADs.

- 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.

6. Result

- χ^2 function of rate analysis :

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

- The χ^2 was constructed with pull terms for the background uncertainties and the AD- and reactor-uncorrelated uncertainties

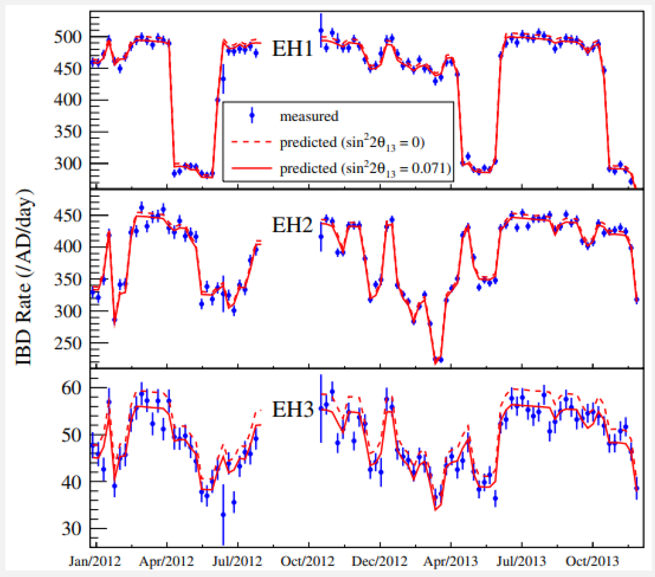

Fig 7. Measured IBD rate vs. time for each experimental hall (blue points).

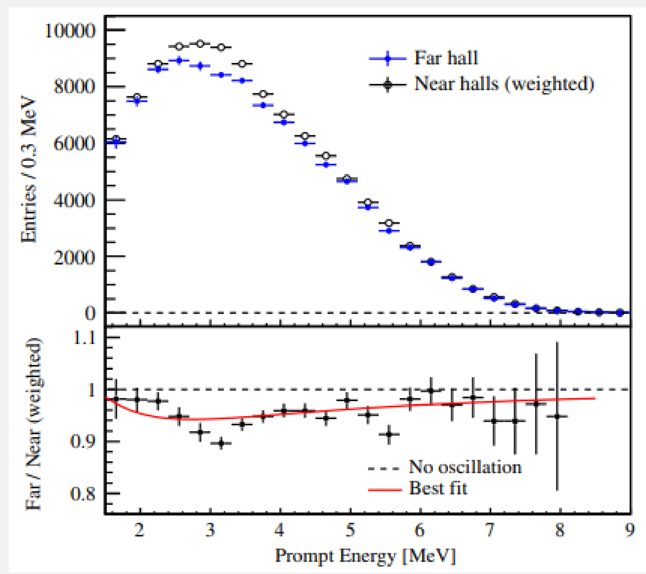

Fig 8. Reconstructed prompt-energy spectrum of the far hall and the expectation based on the measurements of the two near halls.

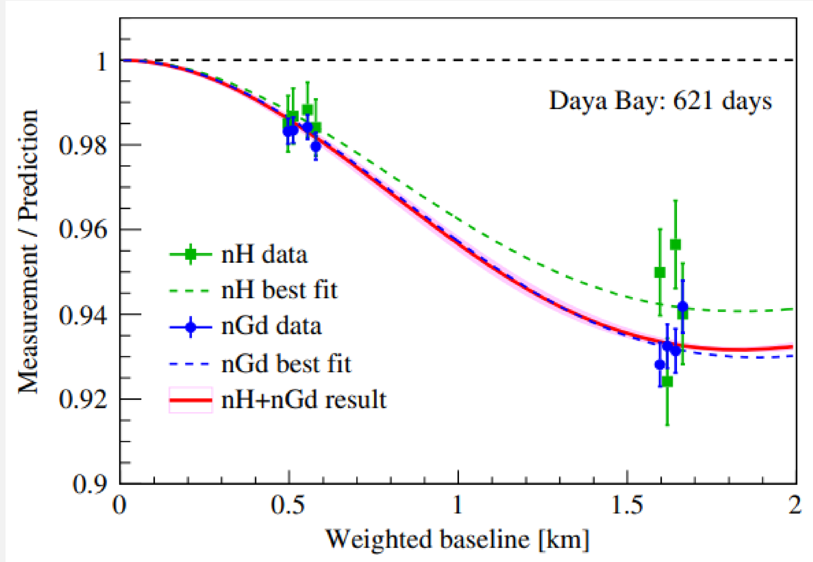

Fig 9. Ratio of measured to predicted IBD rate in each detector assuming no oscillation vs. flux-weighted baseline

We expect to update the nH result soon.

- Use 621 days of data we measured that $sin^2 2\theta_{13} = 0.071 \pm 0.011$ With χ^2 / Ndf =6.3/6

- Updated result :
- More statistics :1958 days of data
- Rate and shape analysis :
  - Ability to measure Δm^2_{32}
- Improved systematics
  - Better understanding of detector response
  - Spectral shape uncertainties are studied
  - Combined distance and time cut

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