Reactor Antineutrino Spectrum and Flux Measurement at Daya Bay

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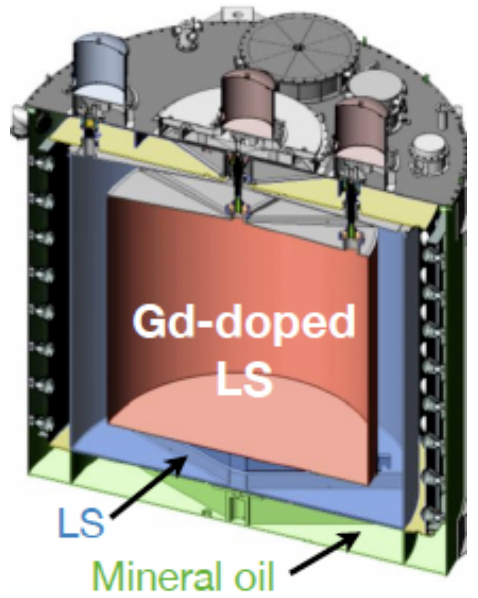
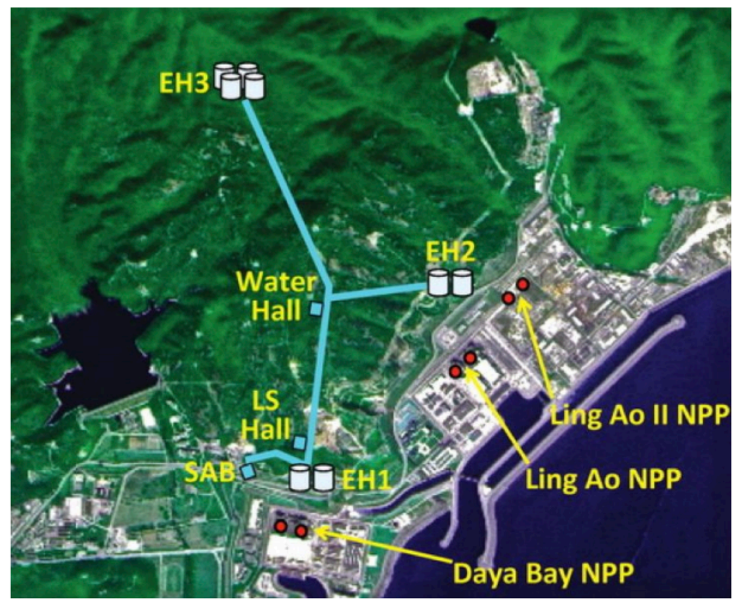
(on behalf of the Daya Bay collaboration)

1. Daya Bay Neutrino Experiment [1]

- Located in Southern China next to 6 x 2.9 GW_{th} reactors providing large $\bar{\nu}_e$ flux
- Primarily designed to precisely measure θ_{13} neutrino mixing angle
- 8 identically-designed antineutrino detectors (ADs) distributed in three experimental halls (EHs) up to 330 m underground for cosmic ray attenuation



Daya Bay AD cross section



Daya Bay EHs and power plant locations

2. Antineutrino Production and Detection [1,2]

- Reactor neutrinos come from beta decays, product of mainly ^{235}U, ^{239}U, ^{239}Pu, ^{241}Pu fissions
- $\bar{\nu}_e$ detected through Inverse Beta Decay (IBD): $\bar{\nu}_e + p \rightarrow e^+ + n$
- e^+ loses energy then quickly annihilates with e^- providing the prompt signal
- n gets captured on Gd or H, when nucleus de-excites we see the delayed signal
- IBD signature is the coincidence of the two signals within ~200 μs (results in poster for Gd sample)
- $E_{\bar{\nu}_e} \approx E_{prompt} + 0.78MeV$

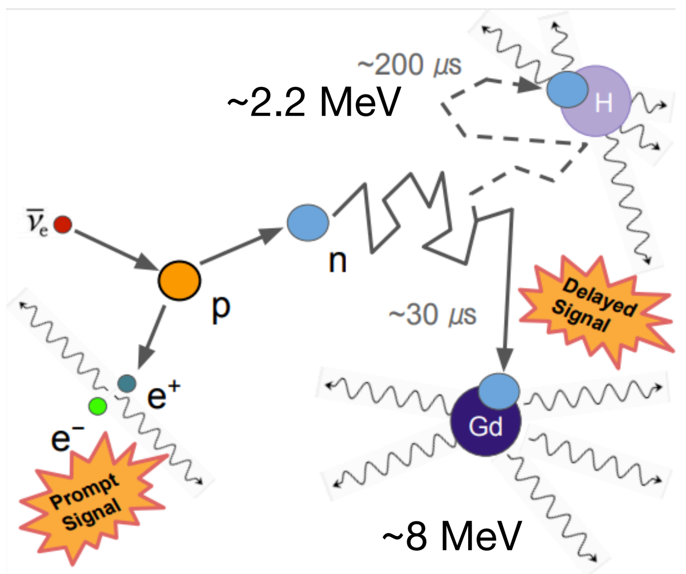


Figure of IBD and detection process

$$N_{IBD}(1 - c^{SNF}) = \sigma_f \sum_{d=1}^{4} \sum_{r=1}^{6} \frac{N_d^P \epsilon_{IBD} P_{sur}^{rd} N_r^f}{4\pi L_{rd}^2}$$

IBD detection efficiency; Survival Probability; Sum over 4 detectors and 6 reactors; Number of fissions in core r; Distance to detector; IBD yield per nuclear fission; Number of protons in detector

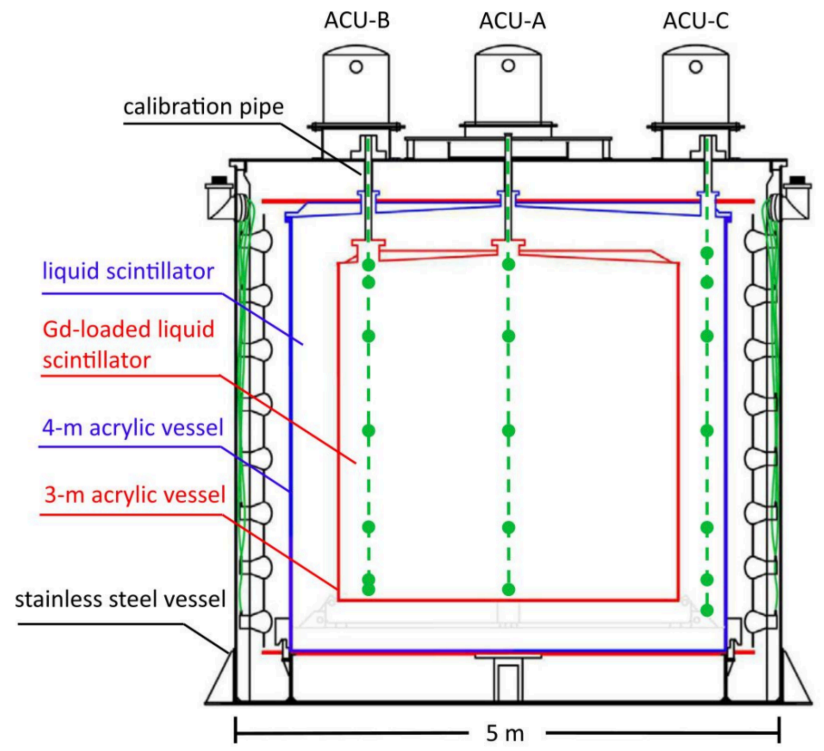
- Largest uncertainty on previous yield measurement was ϵ_{IBD} (1.69% out of 2.1% total relative uncertainty)

Neutron Detection Efficiency

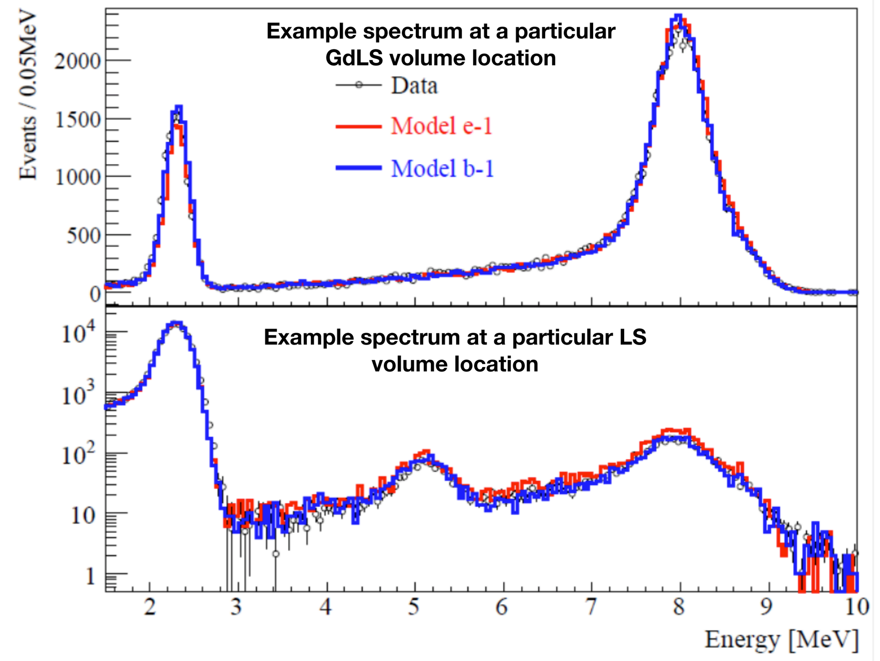
$$\epsilon_{IBD} = \epsilon_n \times \epsilon_{other}$$

3. Neutron Detection Efficiency Improvement [2]

- ϵ_n dominates total yield uncertainty, factors contributing to ϵ_n can be constrained using neutron source measurements
- Special calibration campaign performed in late 2016
- Measurements taken with strong Am-C and Am-Be neutron sources
- Automated Calibration Units (ACUs) deploy sources at different AD heights along three different axes (19 locations total)
- Benchmarked different neutron capture/scattering models with these measurements
- Efficiency estimated with best-fitting models
- Spread between models determines uncertainty



AD diagram with ACU positions



Relative Uncertainties on Yield		
Source	Previous	This Work
statistic	0.1%	0.1%
oscillation	0.1%	0.1%
target proton	0.92%	0.92%
reactor	0.89%	0.89%
ϵ_n	1.69%	0.74%
ϵ_{other}	0.16%	0.16%
total	2.1%	1.5%

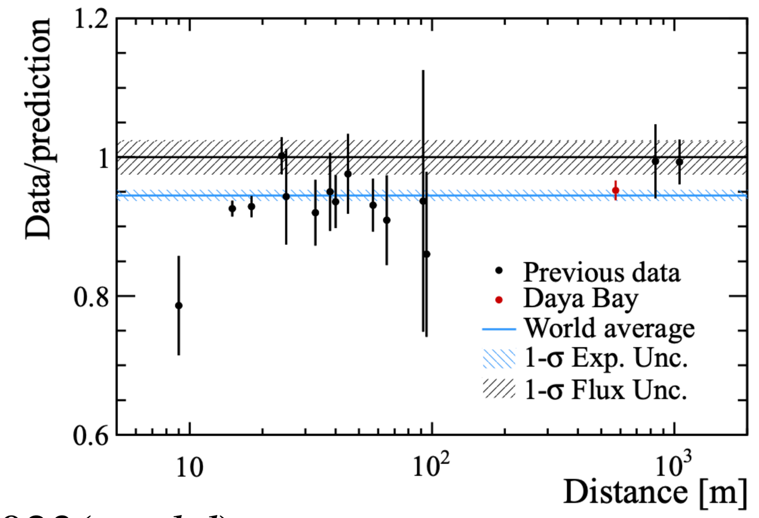
ϵ_n reduced by a factor of 2!

4. Yield Results [2,6]

- Total antineutrino yield

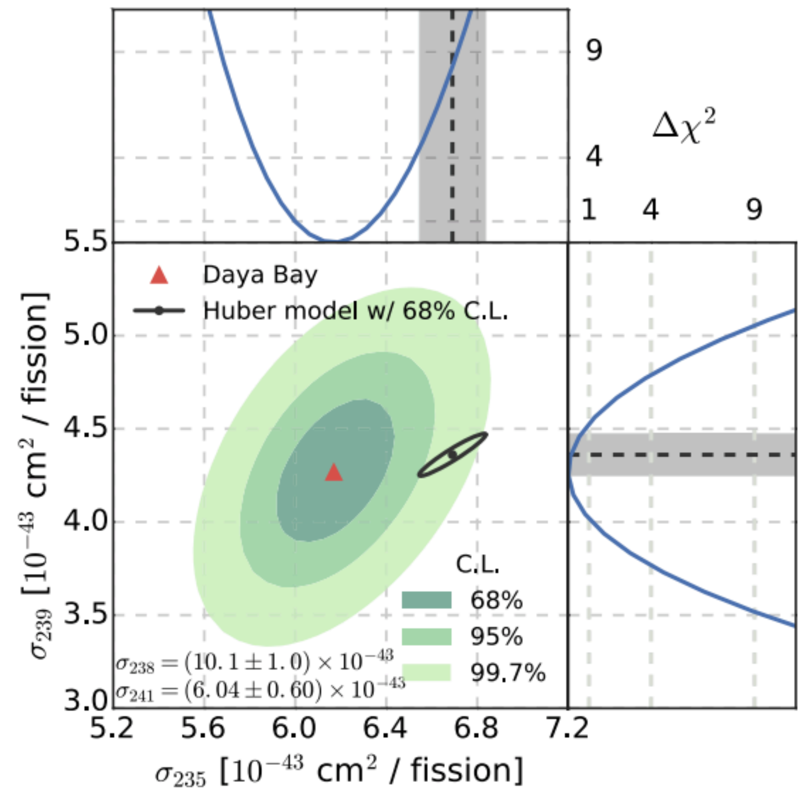
$$\sigma_f = (5.91 \pm 0.09) \times 10^{-43} \frac{cm^2}{fission}$$

from 1230 day data set agrees with world average, and deviates from Huber-Mueller (H-M) [4,5] model prediction



$$\frac{data}{prediction} = 0.952 \pm 0.014(exp) \pm 0.023(model)$$

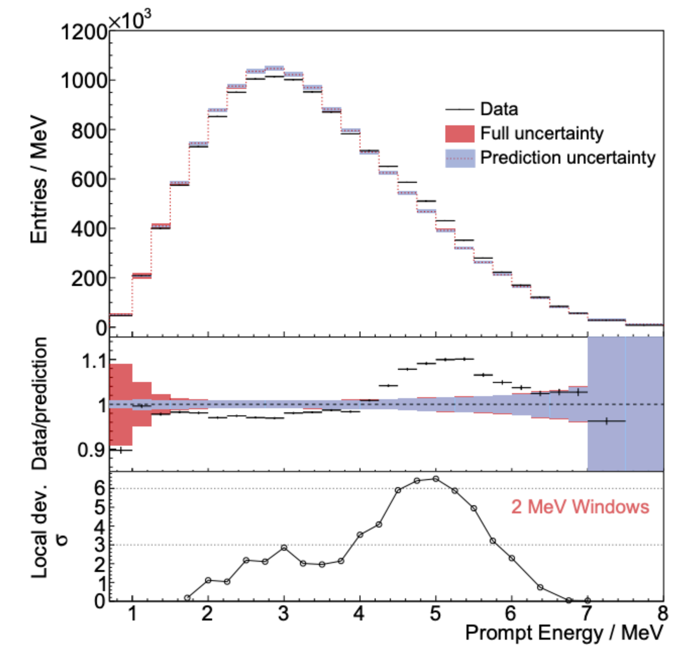
- ^{235}U and ^{239}Pu isotopic yields are extracted from measurement of total yield as a function of effective fission fraction
- Data favors ^{235}U as main contributor to reactor antineutrino anomaly
- Equal isotope deficit hypothesis, needed for sterile neutrino, disfavored at 2.8σ



^{235}U , ^{239}Pu and H-M yields with allowed regions

5. Spectrum Results [2,3]

- Full spectrum shape from 1958 days data deviates from H-M model
- Main feature is a ~5 MeV "bump"
- Local significance of 6.3σ between 4-6 MeV
- Global discrepancy significance of 5.3σ



- ^{235}U and ^{239}Pu spectra are extracted from evolution of total spectrum as a function of effective fission fraction
- First extraction of isotopic spectra from a commercial reactor
- Both spectra exhibit ~5 MeV bump
- For more information on isotopic yields, spectral decomposition and fuel evolution study, visit J. Hu's poster (ID:149)

References

[1] F.P. An et al, Nucl.Instrum.Meth.A **811**, (2016) 133-161
[2] D. Adey et al, Phys. Rev. D **100**, (2019) 052004
[3] D. Adey et al, Phys. Rev. Lett. **123**, (2019) 111801
[4] P. Huber, Phys. Rev. C **84**, (2011) 024617
[5] Th. A Mueller et al, Phys. Rev. C **83**, (2011) 054615
[6] F.P. An et al, Phys. Rev. Lett. **118**, (2017) 251801