Latest Results of Reactor Antineutrino Flux and Spectrum at Daya Bay

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Abstract

The latest measurement of the reactor antineutrino flux and energy spectrum by the Daya Bay reactor neutrino experiment is reported. The antineutrinos were generated by six 2.9 GW_{th} nuclear reactors and detected by eight antineutrino detectors deployed in two near (500 m and 600 m flux-weighted baselines) and one far (1600 m flux-weighted baseline) underground experimental halls. An improvement on the neutron detection efficiency determination was performed using a new neutron calibration campaign and dedicated data-simulation comparison. With a 1230-day data set, the IBD yield was measured to be $(5.91\pm0.09)\times10^{-43}\,cm^2$/fission. The ratio between the measured to predicted reactor antineutrino yield is $0.952\pm0.014(exp.)\pm0.023(model)$. The comparison of the measured IBD positron energy spectrum with the predictions is also reported with a previous 621-day data set. A reactor antineutrino spectrum weighted by the IBD cross section is extracted for model-independent predictions.

Reactor Antineutrinos at Daya Bay

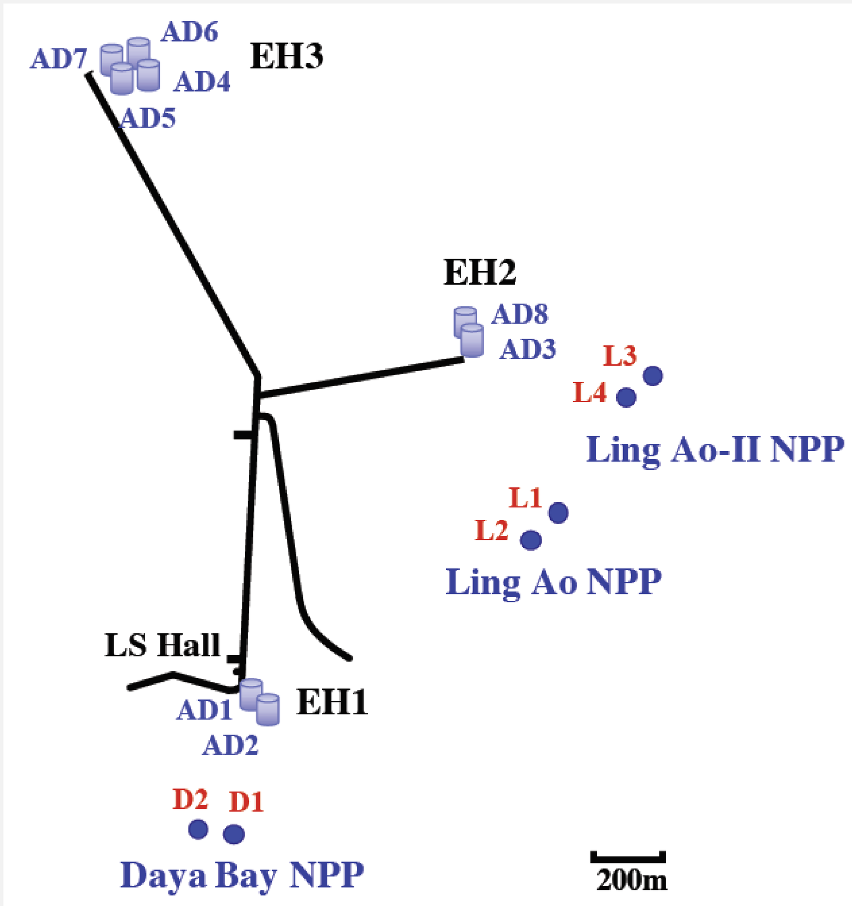
- Six reactors with a total thermal power of 17.4 GW
- Antineutrino flux produced by fissions of isotopes: ^{235}U, ^{238}U, ^{239}Pu , and ^{241}Pu

$$S(E_\nu) = \frac{W_{th}}{\sum_i (f_i/F) e_i} \sum_i^{\text{isotopes}} (f_i/F) S_i(E_\nu)$$

- Reactor operator provides generated thermal power (**W_{th}**) and fission fraction (**f_i/F**)

$$F_i(t) = \frac{W_{th}}{\sum_i \alpha_i(t)\cdot e_i}\cdot \alpha_i(t)$$

- **e_i :** Energy release per fission for isotope i
- **$S_i(E_\nu)$** : Antineutrino energy spectrum for each isotope
- **α_i :** fission fraction



Reactors: D1, D2, L1, L2, L3, and L4
Detectors: AD1, AD2, …, AD8

Reactor Antineutrino Detection

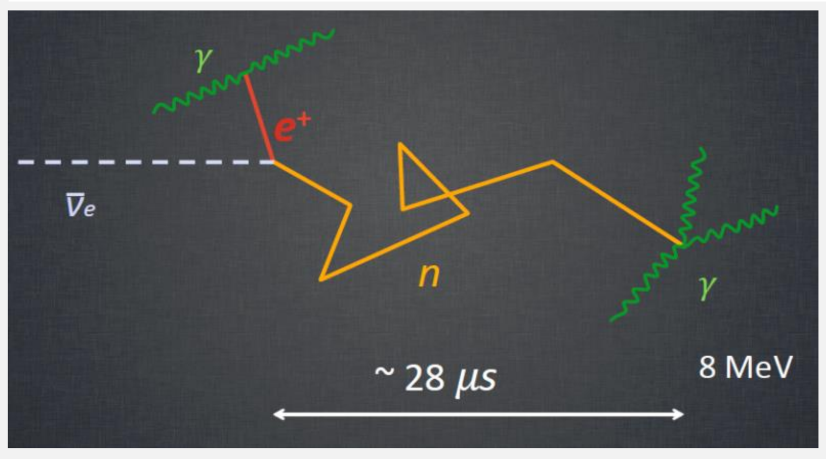
- Antineutrino detected by inverse beta reaction (IBD) in Gd-loaded liquid scintillator

- Prompt e$^+$ signal : 1-10 MeV, determined by antineutrino energy
- Delayed neutron capture signal: 8 MeV @ Gd
- Time correlation: capture time is about 28 μs in 0.1% Gd-LS

$$E_p = T_{e^+} + 1.022\text{ MeV} = E_{\bar\nu_e} - 0.78\text{ MeV} - T_n$$

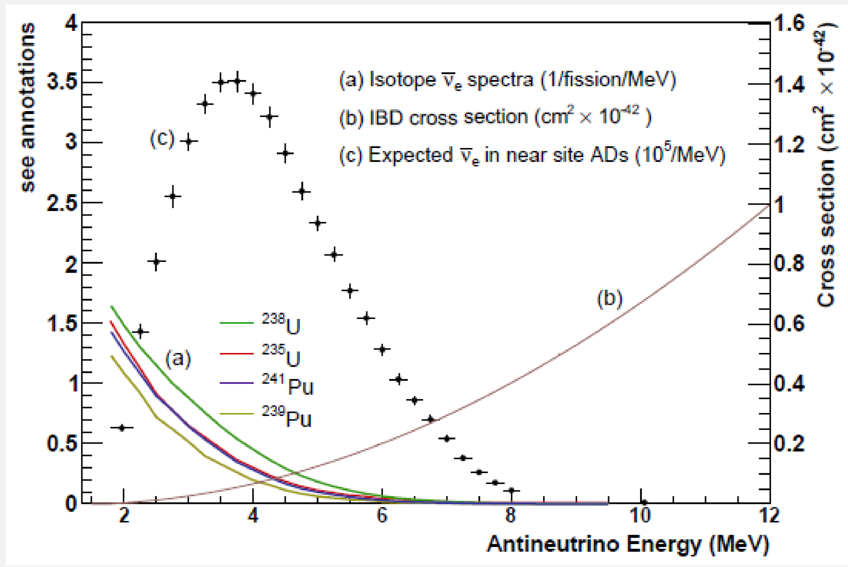
$\bar\nu_e$ + p → e$^+$ + n (prompt)
→ +p → D + γ (2.2 MeV delayed)
→ + Gd → Gd*
→ Gd + γ's (8 MeV delayed)

$$N_{det} = \frac{N_p}{4\pi L^2}\int \epsilon\sigma P_{sur} S dE$$



S: antineutrino flux from reactors
σ: cross section of inverse beta decay.
L: baseline, surveyed with a precision of 28 mm.
P_{sur} : antineutrino survival probability, including the fit parameter $\sin^2 2\theta_{13}$
N_p: number of target protons, determined by target mass.
ϵ: detection efficiency

- Antineutrino spectrum of IBD reactions



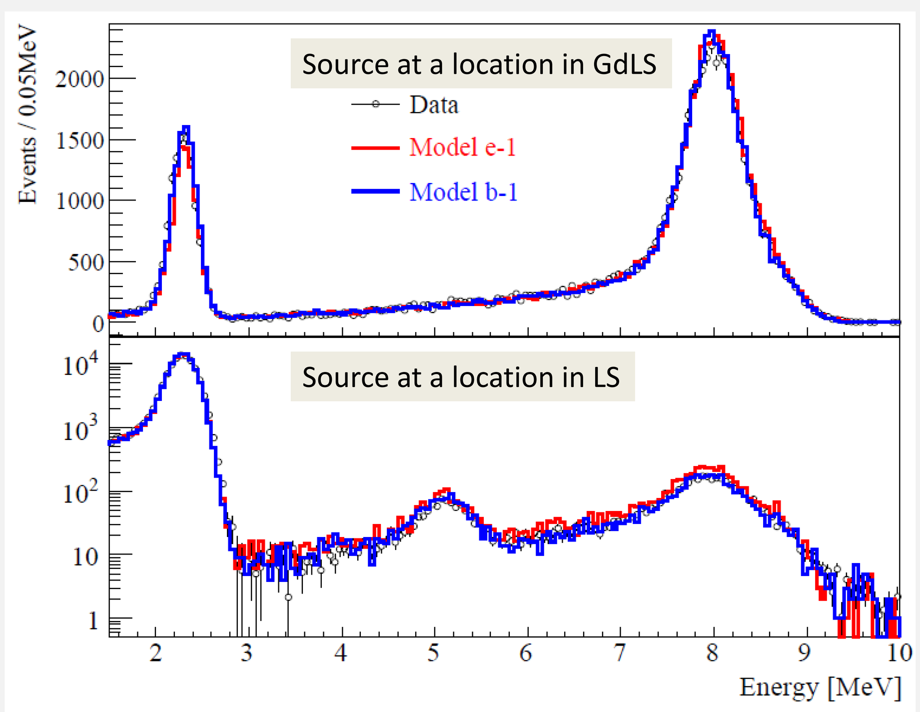
An improvement on the determination of the neutron detection efficiency was performed compared with previous publication

source	v	$\delta v/v$	new v	new $\delta v/v$
statistic	-	0.1%	same	same
oscillation	-	0.1%	same	same
reactor	-	0.9%	same	same
target proton	-	0.92%	same	same
neutron selection	81.83%	1.69%	81.48%	0.74%
other efficiency	98.49%	0.16%	same	same
total	-	2.1%	-	1.5%

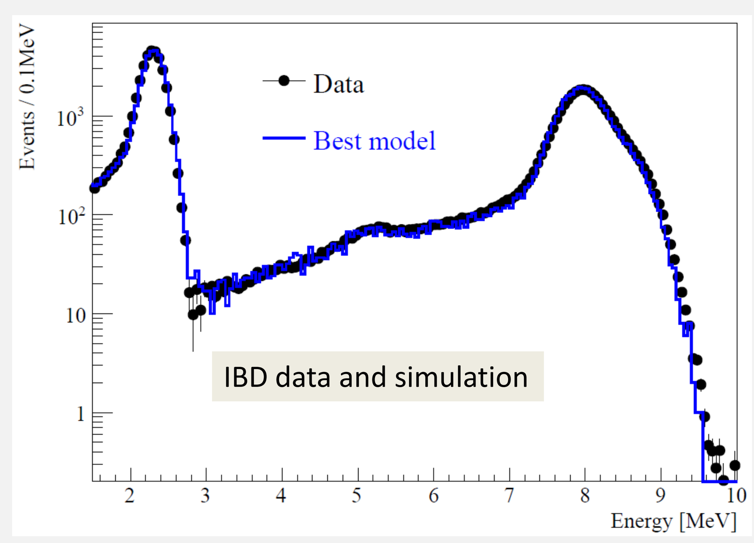
Reactor Antineutrino Flux Measurement

- Determination of the neutron detection efficiency was improved using a new neutron calibration campaign and dedicated data-simulation comparison.
- An extensive neutron calibration campaign was carried out in Daya Bay at the end of 2016. Two types of neutron sources (^{241}Am-^{13}C and ^{241}Am-^{9}Be) were deployed vertically in three calibration axis and the data in 59 different combinations of sources and locations was collected.

- A variety of simulation models are studied including 20 combinations of five neutron scattering and four Gd capture gamma emission models



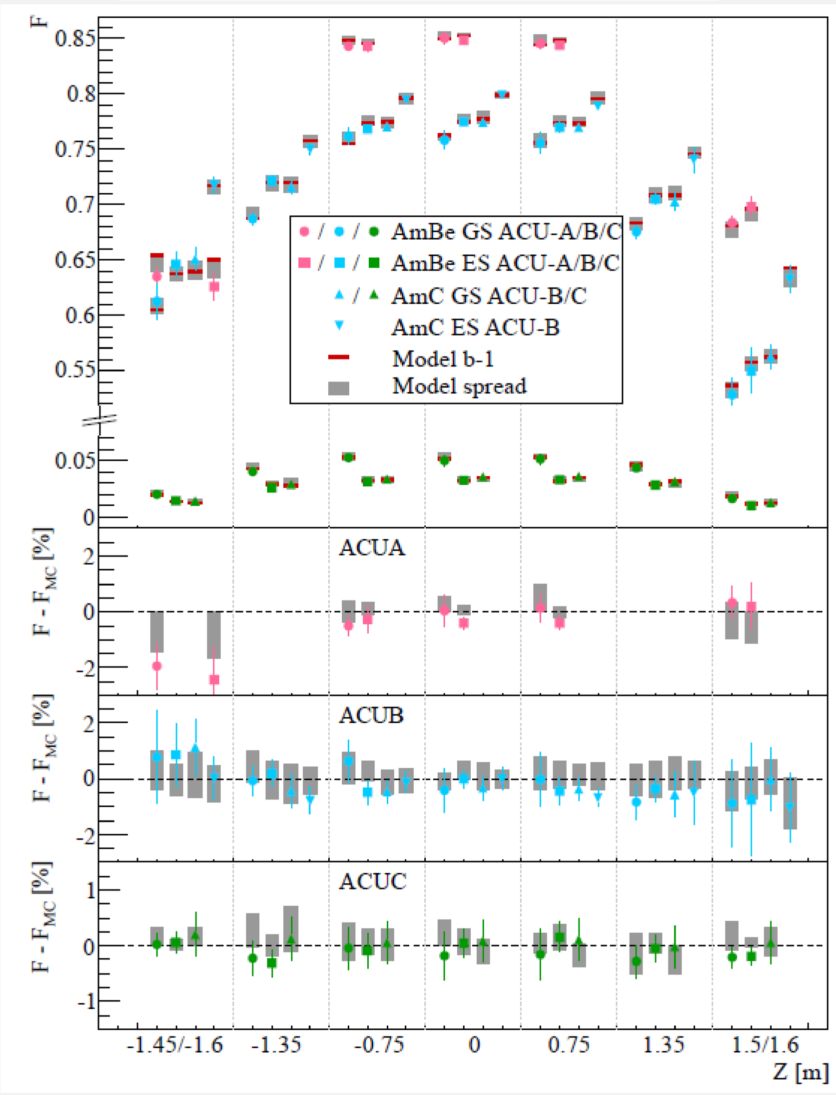
- Good agreement between calibration data and simulation on the energy spectrum and F.



- The neutron detection efficiency was determined to be (81.48%±0.60%) with a reduction in the uncertainty by 56%.

- A benchmark quantity was defined on the neutron capture energy spectrum.

$$F = N([6,12]\text{ MeV})/N([1.5,12]\text{ MeV})$$



- A new measurement on the reactor antineutrino yield was performed using the 1230-day data which has average fission fractions of (0.571, 0.076, 0.299, and 0.054) for (^{235}U, ^{238}U, ^{239}Pu , and ^{241}Pu)
- The IBD reaction yield per nuclear fission was measured to be

$$\sigma_f = (5.91\pm0.09)\times10^{-43}\text{ cm}^2/\text{fission}$$

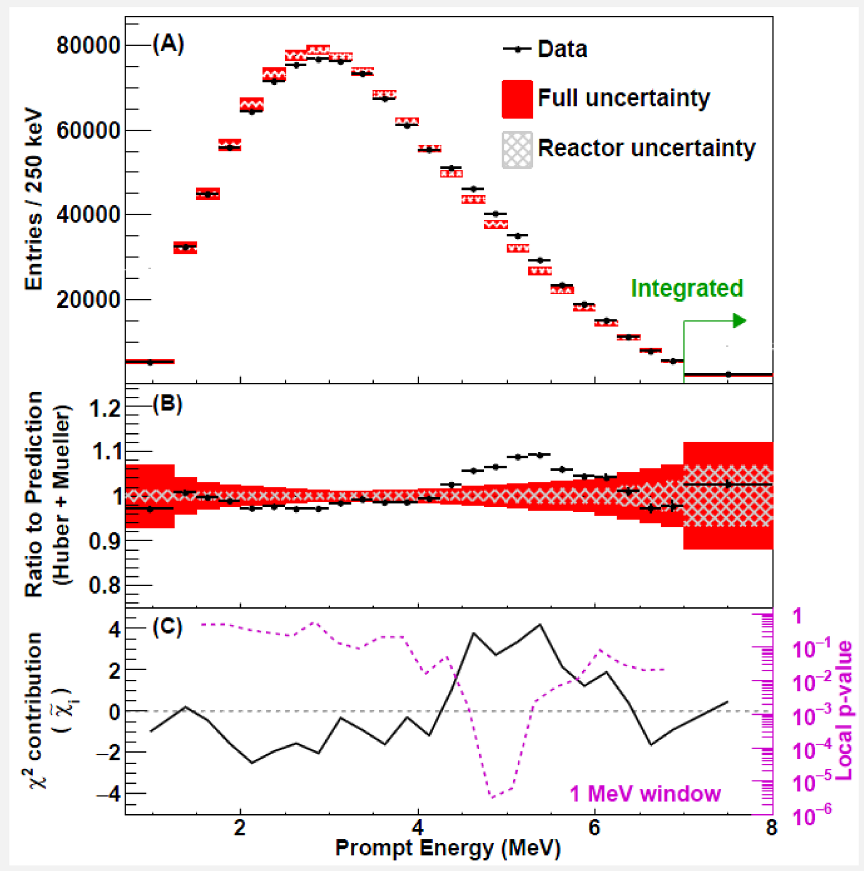
- The ratio of measured IBD yield to the prediction of Huber+Mueller model is

R = 0.952±0.014(exp.)±0.023(model)

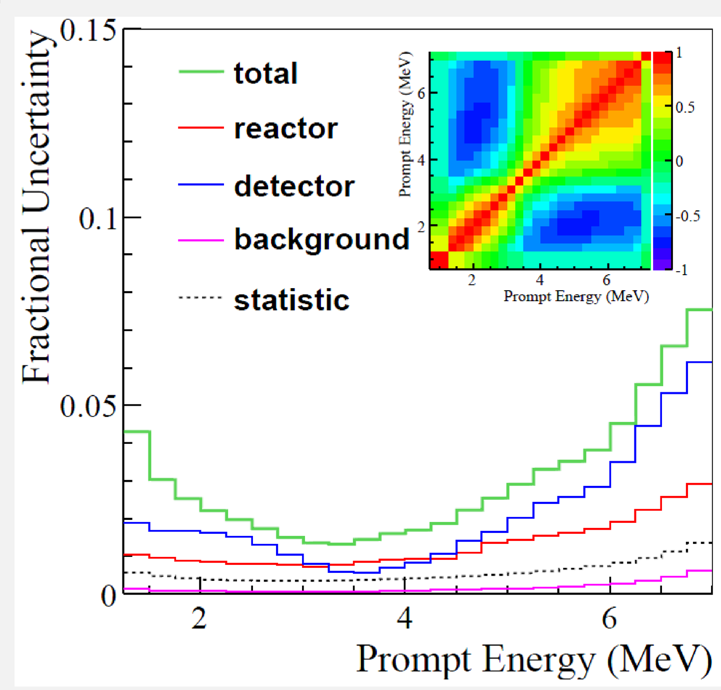
Reactor Antineutrino Spectrum Measurement

Results published in Chin. Phys. C41, 013002 (2017), arXiv:1607.05378

- Measured IBD prompt energy spectrum vs. prediction after normalization



- Uncertainty of the prompt energy spectrum

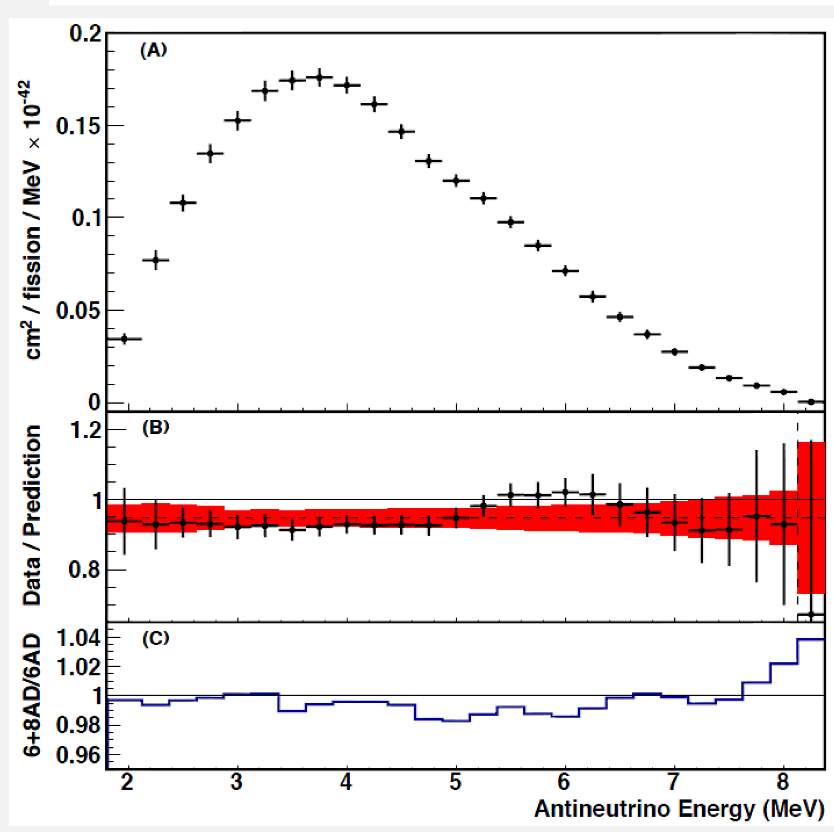


- Obvious discrepancy between data and prediction, significance was evaluated.

- 3 σ for the whole spectrum
- 4.4 σ for a 2-MeV energy window around 5 MeV

$$\tilde\chi_i = \frac{N_i^{obs}-N_i^{pred}}{|N_i^{obs}-N_i^{pred}|}\sqrt{\sum_j \chi^2_{ij}},$$

$$\chi^2_{ij} = (N_i^{obs}-N_i^{pred})(V^{-1})_{ij}(N_j^{obs}-N_j^{pred}).$$



- An antineutrino spectrum of IBD reactions is provided as an input for reactor neutrino experiments after unfolding the IBD prompt energy spectrum to antineutrino energy.
- Consistent results by two unfolding methods: singular value decomposition (SVD) and Bayesian iteration