High-energy reactor neutrino flux measurement at Daya Bay

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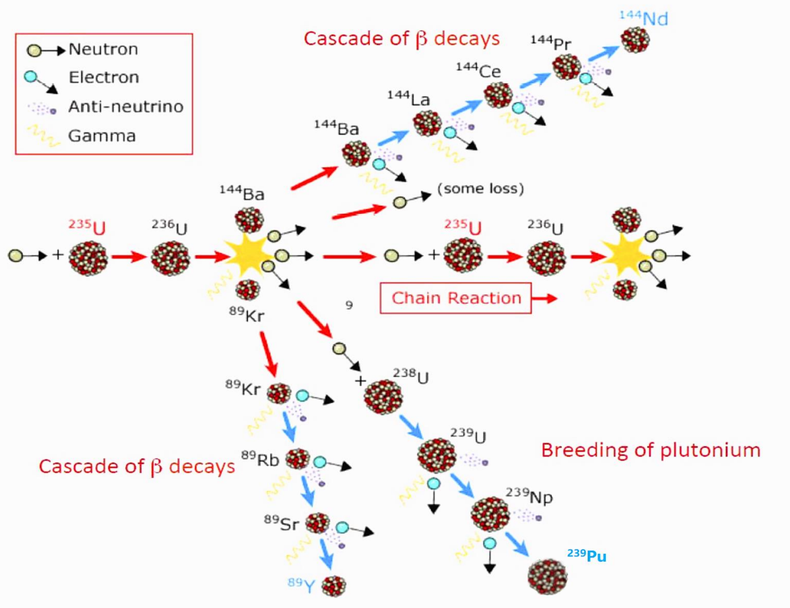
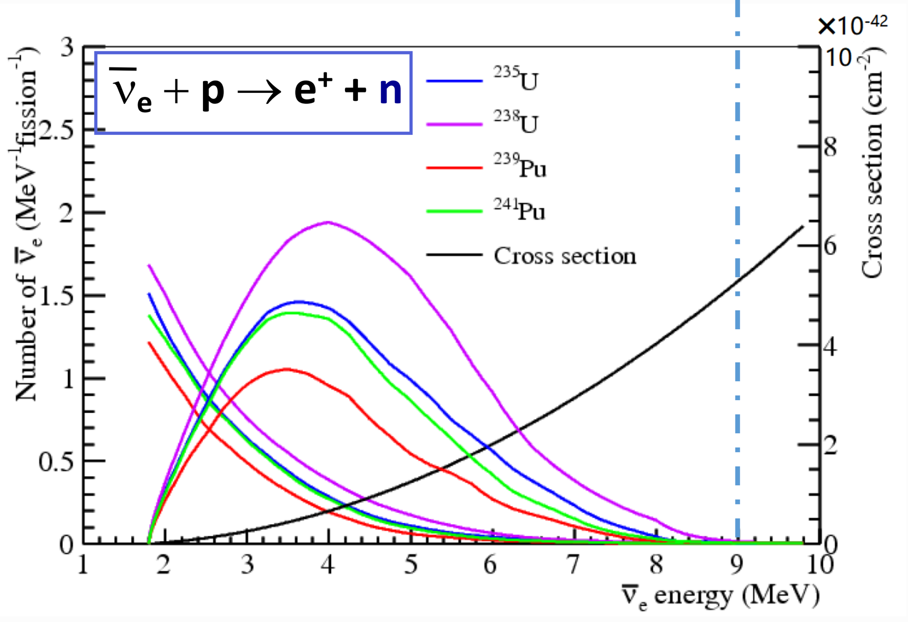
On behalf of the Daya Day collaboration

Reactor neutrinos

How about high-energy reactor neutrinos?

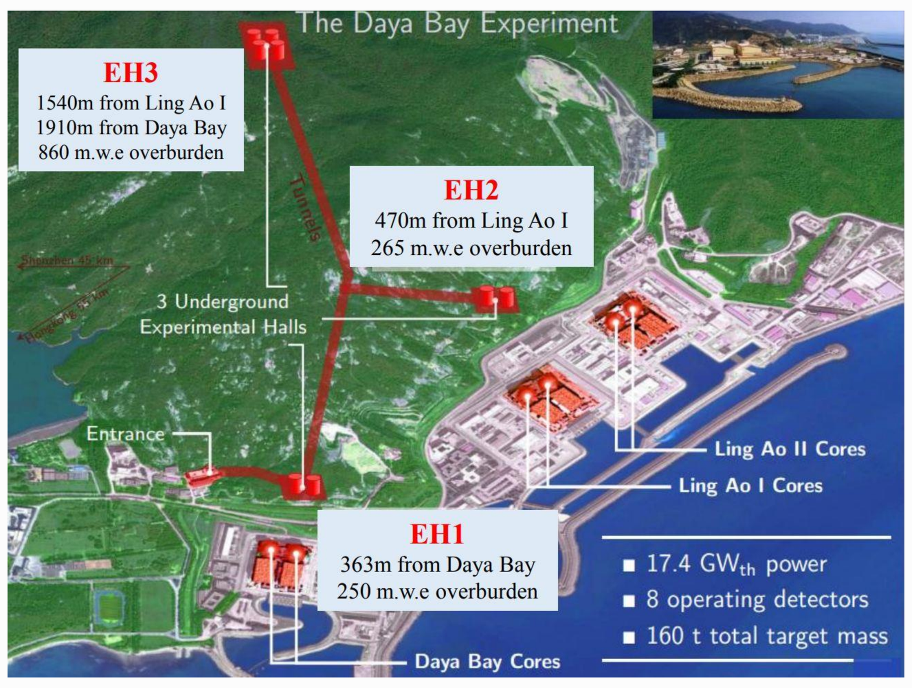


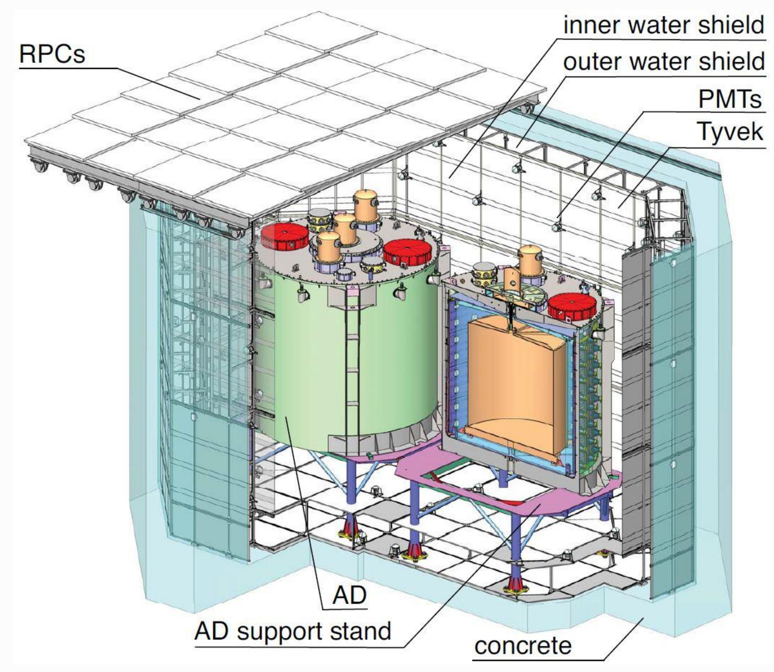


- Nuclear reactors produce pure $\overline{\nu}_e$ from beta decays of fission daughters.
- Reactor neutrinos have been an important tool for both discovery and precision measurement in the history of neutrino studies [1].
- Previous measurements of reactor neutrinos only focus on the prompt energy (E_p) less than 9 MeV.
  - Daya Bay's high statistic samples enable new studies for high energy reactor neutrinos > 9 MeV [2].

Daya Bay experiment

NIM A **773**, 8 (2015) NIM A **811**, 133 (2016)



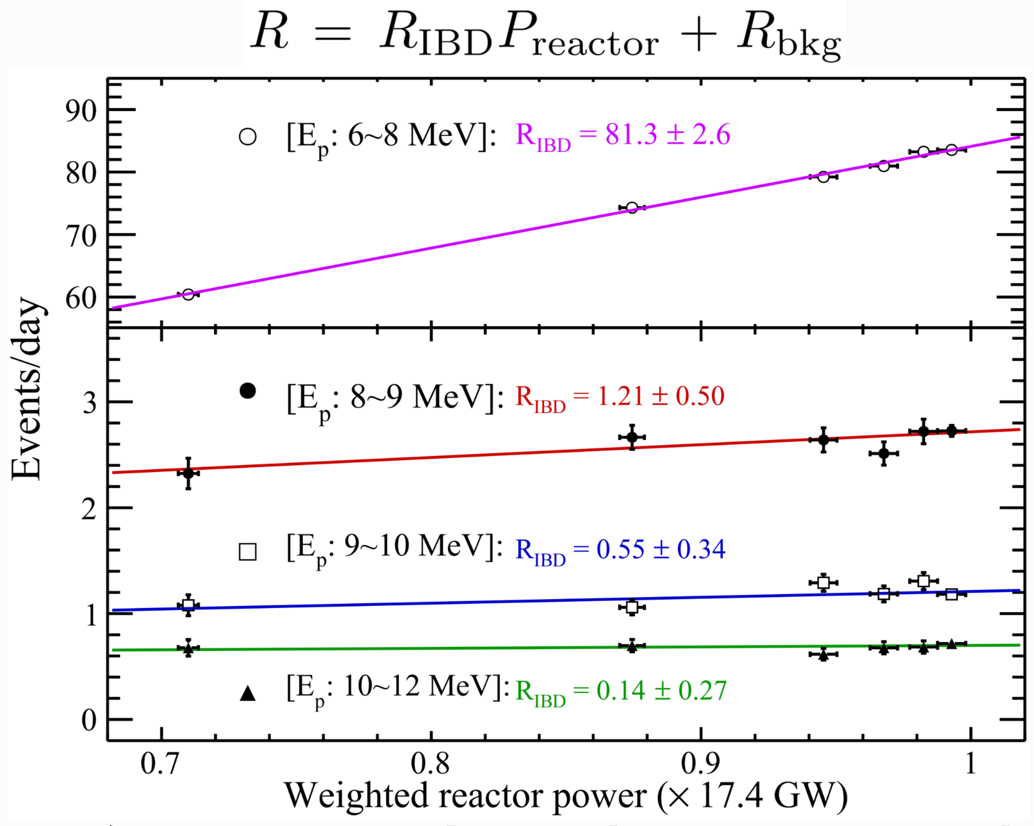


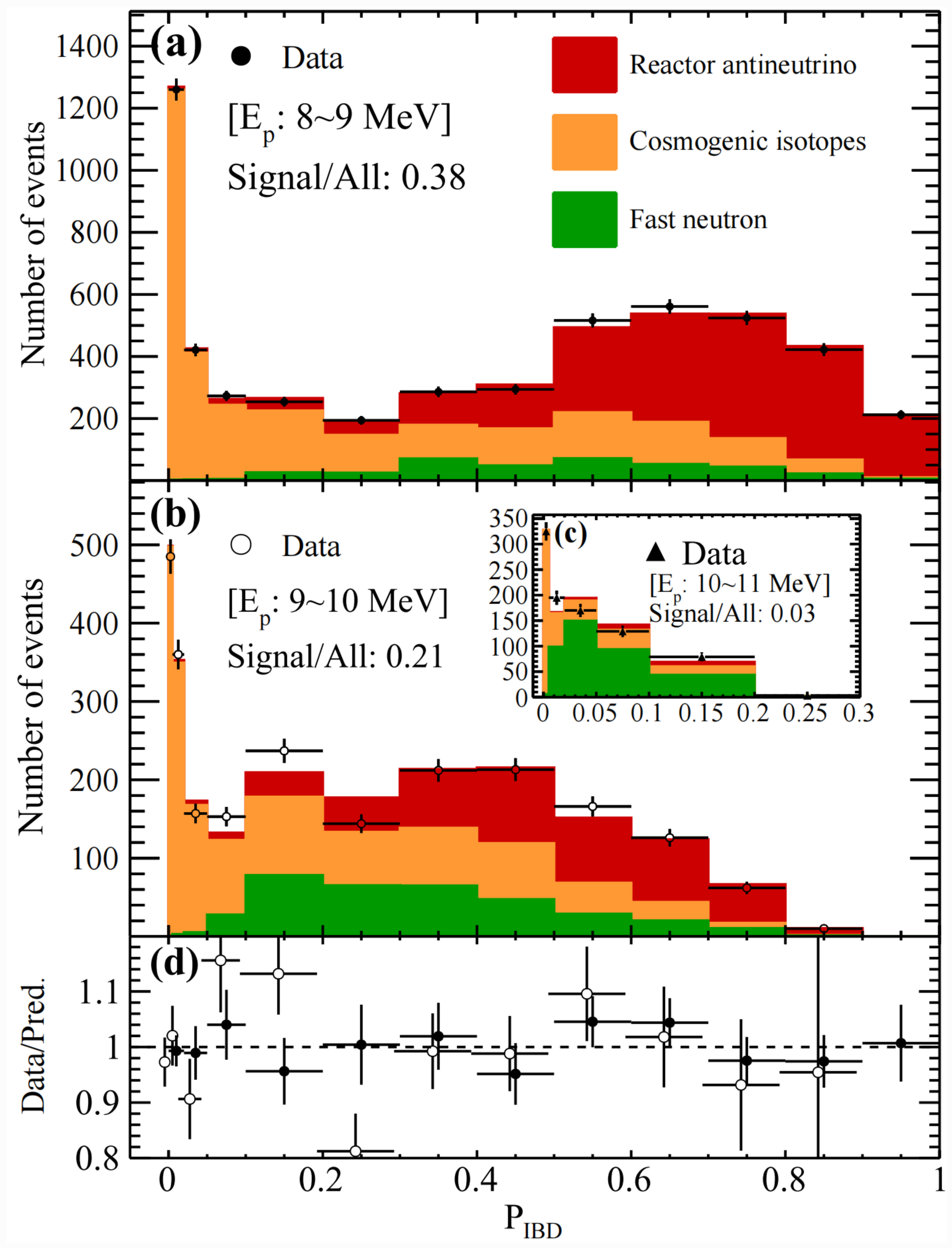
- 6 low enriched uranium (LEU) commercial reactors, each with 2.9 GW thermal power.
- Eight identically designed underground detectors deployed at different baselines [3].
- The largest dataset (~6 million) of reactor neutrinos collected from December 2011 to December 2022.

Data selection

- Inverse beta decay (IBD) events: the interaction candidates are selected following the criteria similar to "Selection A" described in Ref. [4]
  - $E_p \approx E_\nu - 0.8\ MeV$
- Main background: cosmogenic fast neutrons and cosmogenic isotopes.
- Challenge: large background to signal ratio in the 8-12 MeV prompt energy region.

$$R = R_{\rm IBD} P_{\rm reactor} + R_{\rm bkg}$$





Multivariate analysis

- The probability distribution function (PDF) $F(\boldsymbol{r};\ \Delta\boldsymbol{t}, z, w)$ is constructed in each prompt-energy bin for the multivariant event-by-event fitter with pull terms $g(\varepsilon)$:

$$F(\boldsymbol{r}; \boldsymbol{\Delta t}, z, w) = \sum_p r_p f_p(\boldsymbol{\Delta t}) h_p(z) k_p(w) \qquad \chi^2(\boldsymbol{r}) = -2\sum \left[\log F(\boldsymbol{r}; \boldsymbol{\Delta t}, z, w)\right] + g(\boldsymbol{\epsilon})$$

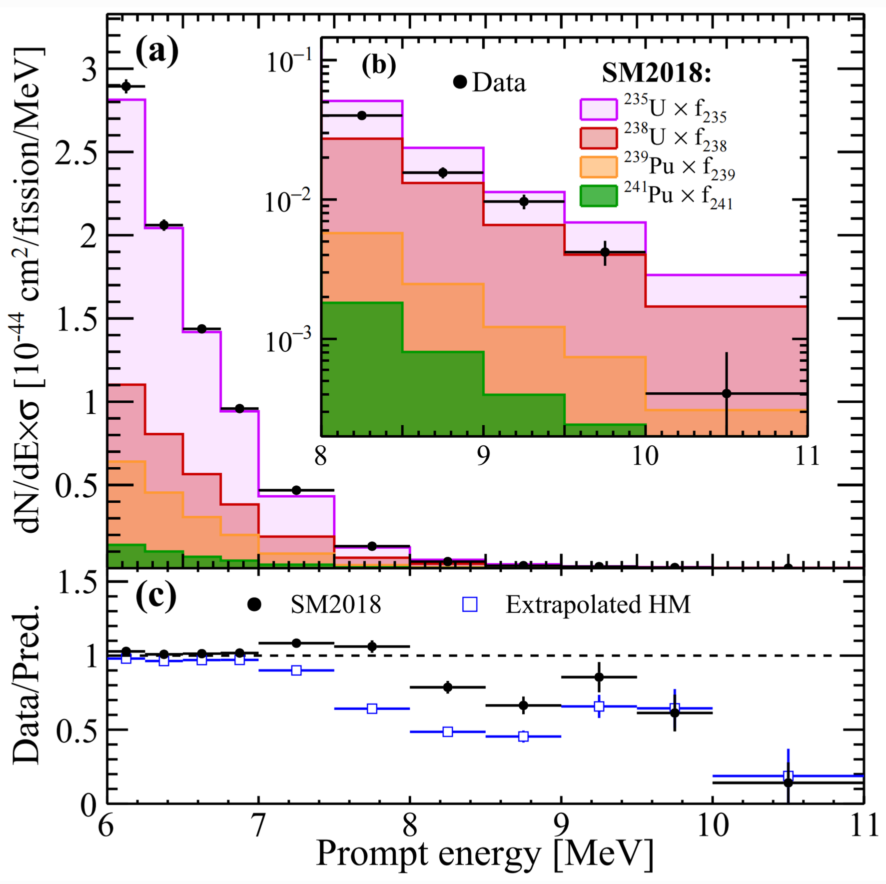
  - p: event types (IBD, cosmogenic isotopes, or fast neutron);
  - $\boldsymbol{r}$: vector of $\boldsymbol{r_p}$, the ratio of evens in type p over the total number of events in each E_p bin;
  - $\boldsymbol{\Delta t}$: vector for time difference between event and its preceding muon events;
  - z: vertical position of prompt signal;
  - w: weighted reactor power at the occurrence of the candidate;
- With the best-fit values of $\boldsymbol{r}$, the probability of being an IBD signal can be calculated for each event:

$$P_{\rm IBD} = \frac{r_{\rm IBD} f_{\rm IBD}(\boldsymbol{\Delta t}) h_{\rm IBD}(z) k_{\rm IBD}(w)}{F(\boldsymbol{r}; \boldsymbol{\Delta t}, z, w)}$$

  - $f_{IBD}(\Delta t)$: time to last muon PDF; $h_{IBD}(z)$: vertical position PDF; $k_{IBD}(w)$: reactor power PDF;
- Separate 2500 signal events from about 9000 IBD candidates above 8 MeV. (using the dataset taken in 1958 calendar days)
- The P_{IBD} distributions from data and predictions are consistent within statistical uncertainty.

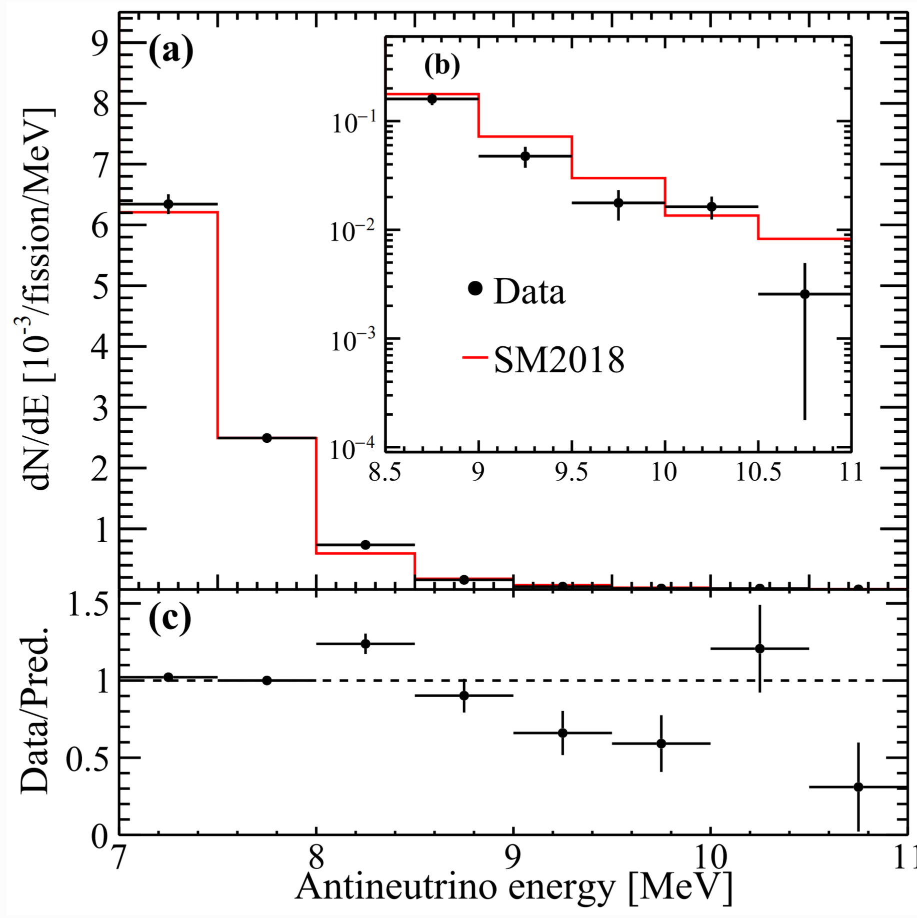
Prompt-energy Spectrum

- Measured IBD yield compared with a recent summation model (SM2018 [5]):
  - 3% larger for 6-8 MeV;
  - 29% smaller for 8-11 MeV;
- Above 10 MeV, a non-zero signal rate of greater than 5σ is predicted by the SM2018 model while the significance is only 1σ for the data.



Unfolded Antineutrino Spectrum

- We provide the unfolded antineutrino spectrum above 7 MeV as a data-based reference for other experiments.
- Significance in rejecting the hypothesis of no reactor antineutrinos above 10 MeV is determined to be 6.2σ.
- For the first time, this work extends the energy region of reactor antineutrinos above 10 MeV by direct measurement.



References:
1. L. J. Wen et al. Ann.Rev.Nucl.Part.Sci. 67 (2017) 183-211
2. F P. An et al. (Daya Bay Collaboration), arXiv:2203.06686 [hep-ex]
3. F P. An et al. (Daya Bay Collaboration), Phys. Rev. D 95, 072006 (2017)
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5. M. Estienne et al., Phys. Rev. Lett. 123, 022502 (2019)

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