Measurement of the evolution of reactor antineutrino flux and spectrum at Daya Bay

Phys. Rev. Lett. 118, 251801

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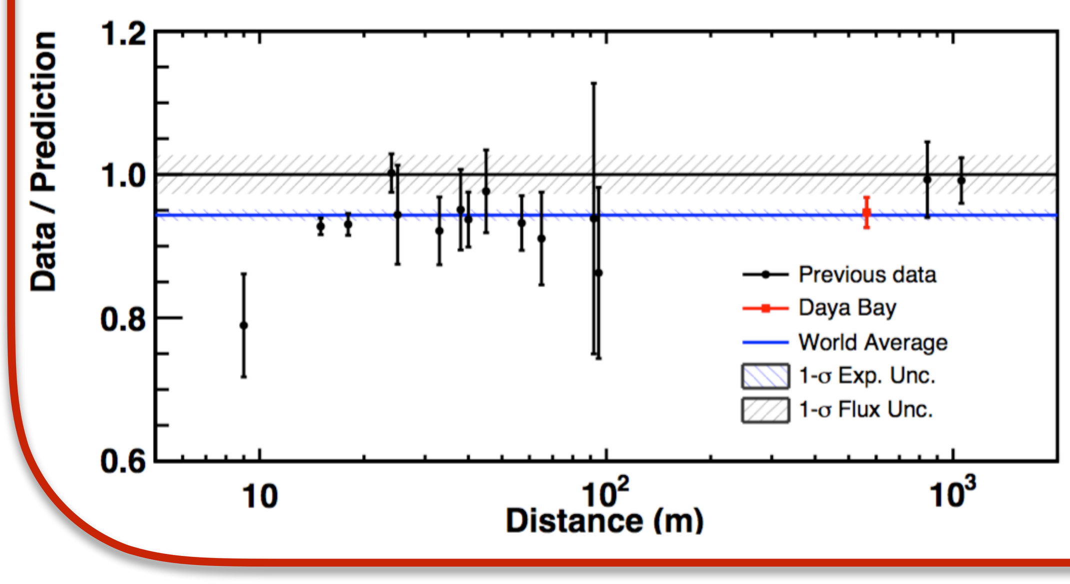
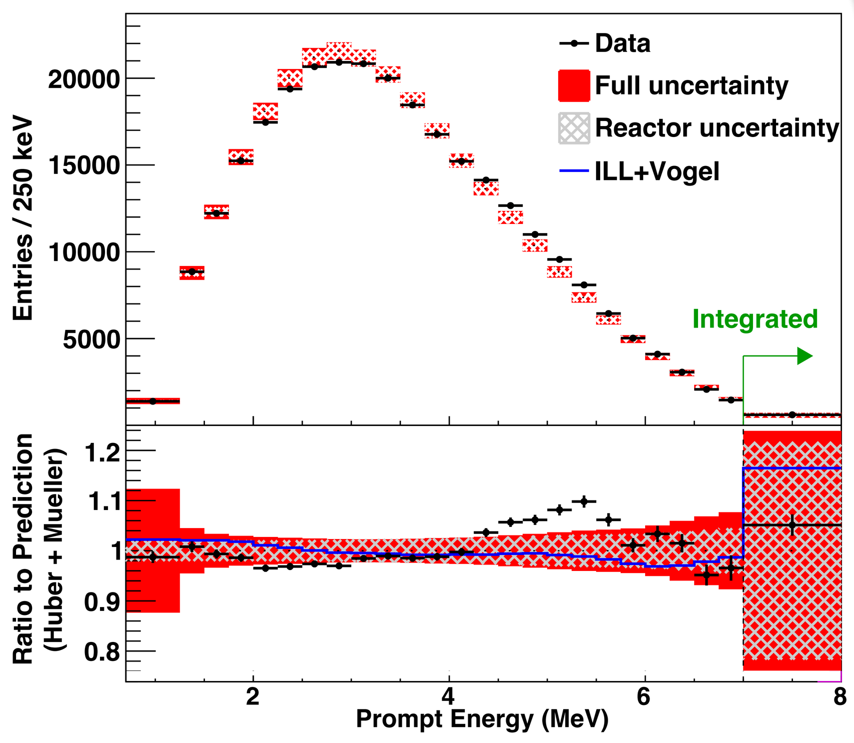
on behalf of Daya Bay Collaboration

Introduction

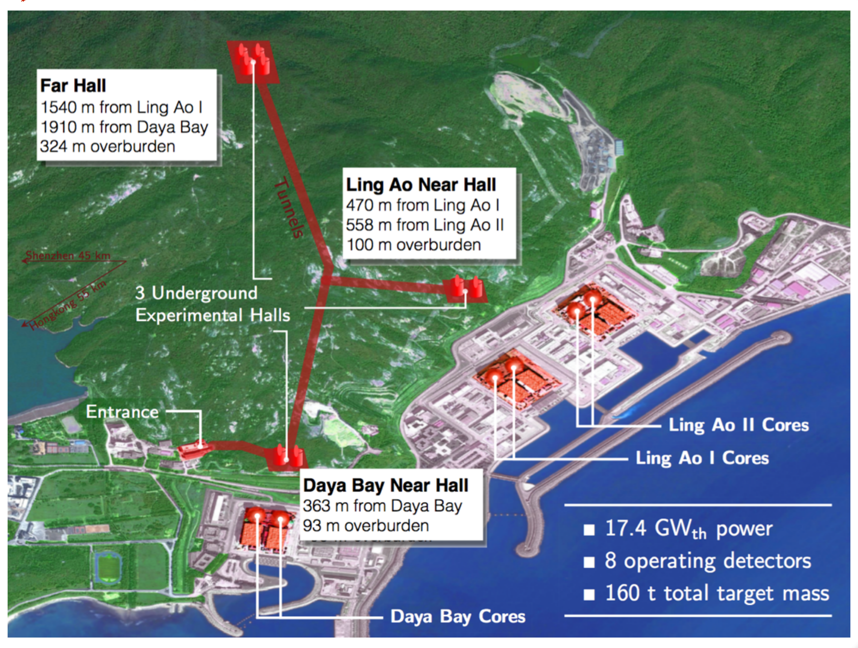
- Reactor antineutrino experiments observed deficit in antineutrino rates compared with predictions
- Experiments at Low Enriched Uranium (LEU) reactors, including Daya Bay, observed spectral deviations



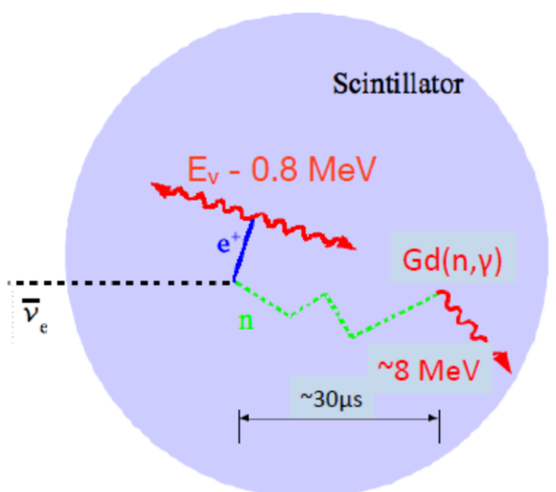


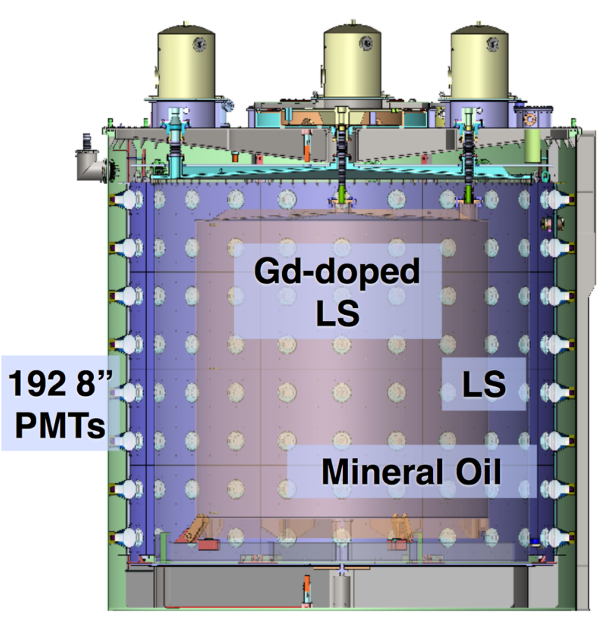
Daya Bay Experiment

- 8 ‘identical’ detectors adjacent to the Daya Bay Power Plant in China:
  - 4 near detectors constrain reactor antineutrino flux.
  - 4 far detectors see if any neutrinos have disappeared.



IBD Event Selection





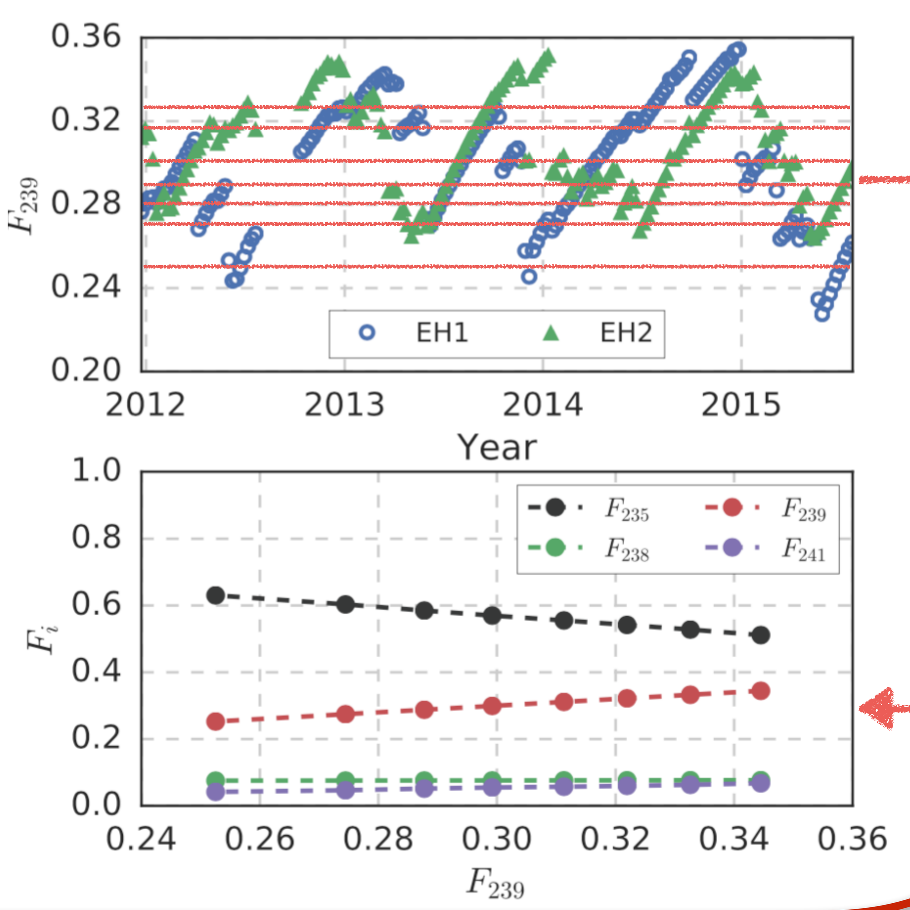
- Detect inverse beta decay (IBD) with liquid scintillator: $\overline{\nu}_e + p \rightarrow e^+ + n$
- Coincidence of the prompt scintillation from the positron and the delayed neutron capture on Gadolinium provides a distinctive ν_e signature.
- IBD positron is direct proxy for antineutrino energy
- Veto (Cosmogenic backgrounds)
- Apply time coincidence and energy cuts
- Time difference between prompt and delayed signals: 1 us< Δ_t < 200 us
- 2.5 million of IBDs in 1230 days of data taking

Fuel Evolution Analysis

- **Calculate ‘effective fission fraction’ observed by each detector:**

$$\boxed{F_i(t) = \sum_{r=1}^{6} \frac{W_{\mathrm{th},r}(t)\bar{p}_r f_{i,r}(t)}{L_r^2 \bar{E}_r(t)} \Big/ \sum_{r=1}^{6} \frac{W_{\mathrm{th},r}(t)\bar{p}_r}{L_r^2 \bar{E}_r(t)}}$$

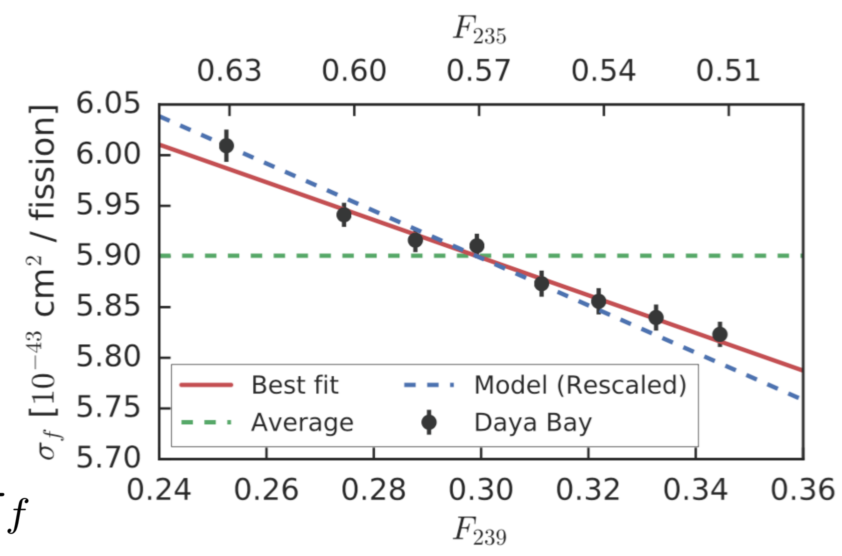
- We have fission fractions and IBDs versus time
- Compare IBDs from periods of differing effective fission fractions!
- Doing this by combining periods of common fission fraction.
- We chose 8 bins in ^{239}Pu effective fission fraction, F_{239}



Results: Flux Evolution

- IBD/day depends on many time-dependent quantities:
  - Reactor status and thermal power
  - Power released per fission
  - Detector livetime
- Results in terms of IBD/fission σ_f
  - Take IBD/day and correct for time-dependent quantities on a week-by-week basis

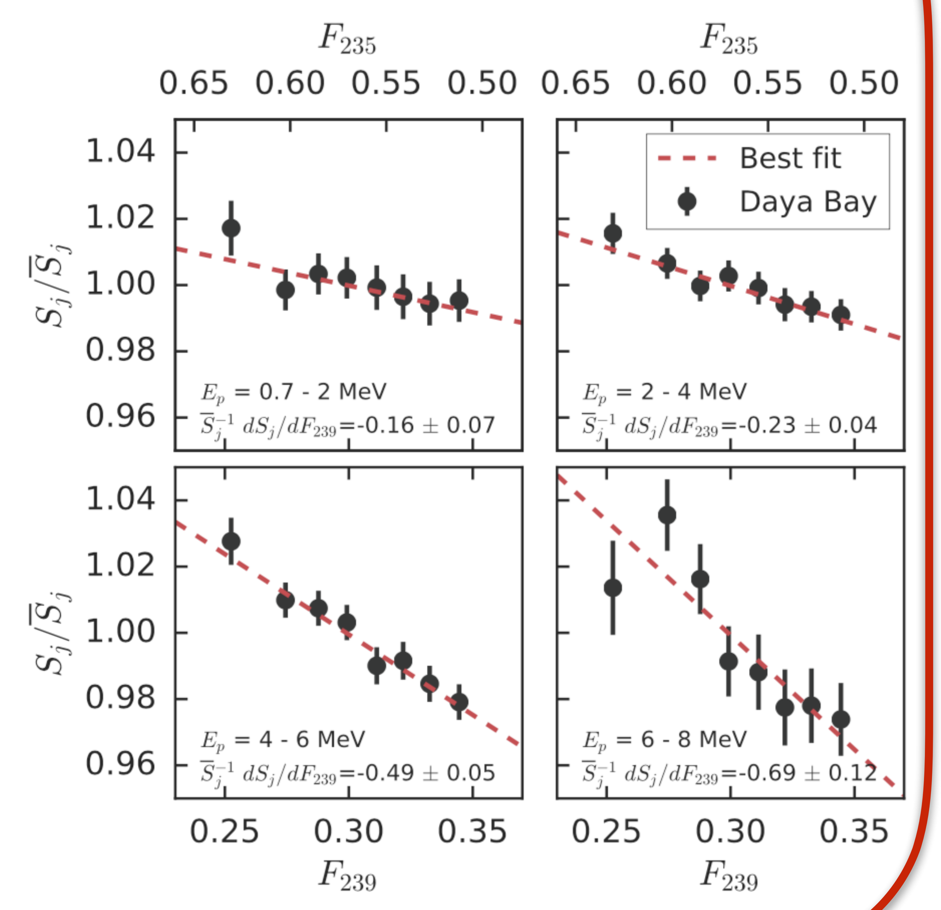
$$\boxed{\sigma_f = \sum_i F_i \sigma_i}$$



Measured slope is different from Huber-Mueller model prediction at 3.1 σ

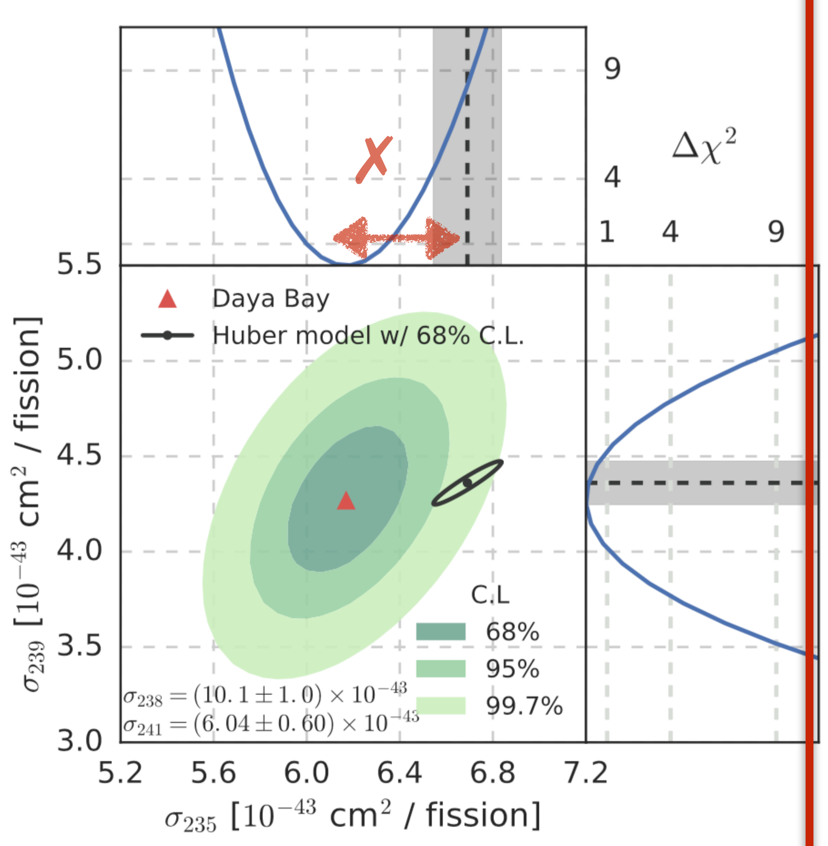
Results: Spectrum Evolution

- Analyze IBD prompt energy
  - Examine evolution in 4 separate energy ranges
- Slope is different for different energy ranges.
- IBD spectrum is changing with F_{239}
  - **This is the first unambiguous measurement of this behavior**
  - **Highly relevant to $\overline{\nu}_e$ based nuclear non-proliferation**



Results: Fitting Individual Isotopes

- Use the data to explicitly fit IBD/fission for ^{235}U, ^{239}Pu
  - Assume loose (10%) uncertainties on sub-dominant ^{238}U, ^{241}Pu
- Dominant uncertainties:
  - Statistics
  - Absolute detection efficiency
- The hypothesis of ^{235}U only being wrong fits the data well.
  - ^{239}Pu matches model well
- Other hypothesis can fit the data
  - ^{239}Pu + steriles, ^{235}U + steriles, between others



Equal deficit of all isotopes disfavored at 2.8 σ

Summary

- Various reasons to question reactor ν_e models: “The Reactor Antineutrino Anomaly” and “Spectrum anomalies”
- Daya Bay flux and spectrum evolution results uncover another flaw: **flux evolution is incorrectly predicted.**
  - Indicates that incorrect flux predictions are partially responsible for reactor flux anomaly
- SBL reactor measurements at HEU cores are necessary for probing the nature of the spectral anomaly

References

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