Wright Laboratory

Joint Isotope-Dependent Analysis of the Daya Bay and PROSPECT Reactor Antineutrino Spectra

Apr 17, 2021

Jeremy Gaison, Yale University, Wright Laboratory

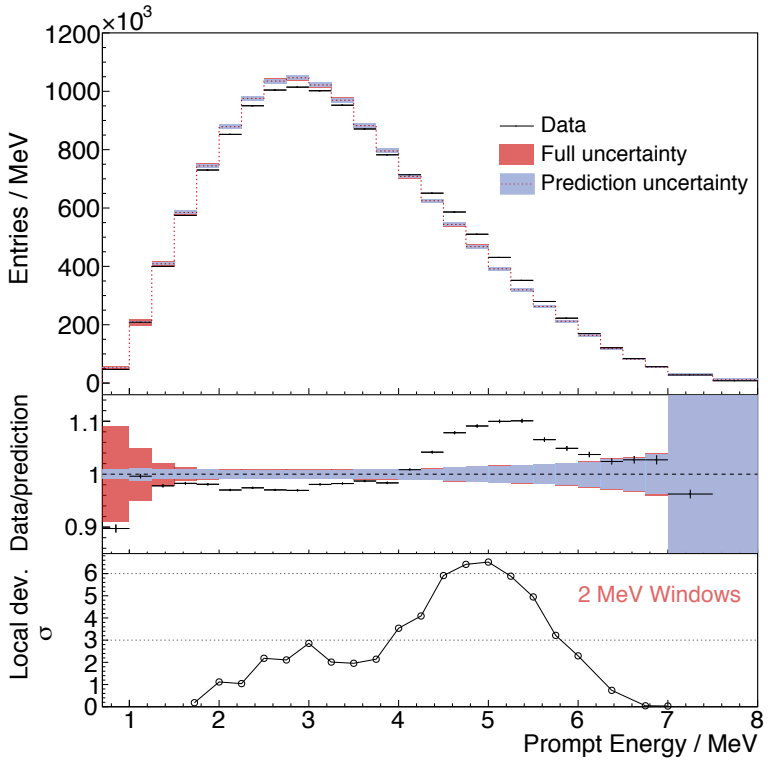
APS April Meeting 2021

Model - Measurement Disagreements

- Recent measurements of the neutrino energy spectrum from nuclear reactors deviates from model predictions

- What are the contributions from each fissile isotope?
- Deficiencies in the model prediction / input databases?
- **More precise spectral measurements are needed to help resolve these issues**

Daya Bay Measurement

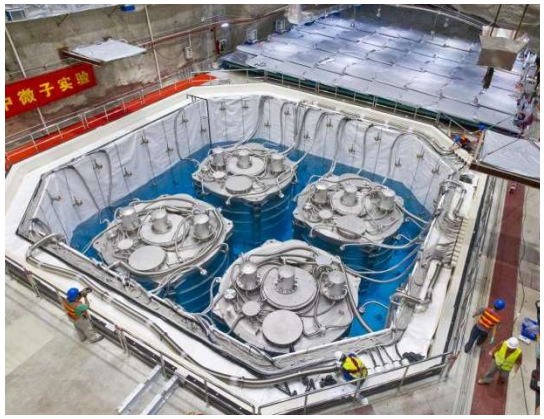


[D. Adey et al., Phys Rev Lett 123, 111801]

Reactor Measurements

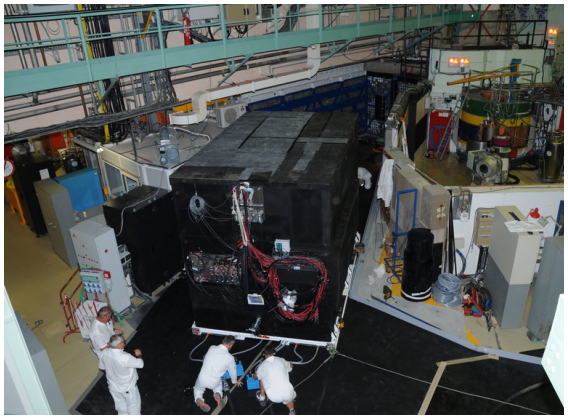
- Neutrinos identified via inverse beta decay (IBD)
- Detect positron events in coincidence with neutron events as tagged by neutron capture agent to determine neutrino energies
- Multiple recent experiments have measured ^{235}U neutrino energy spectra

Daya Bay



PROSPECT

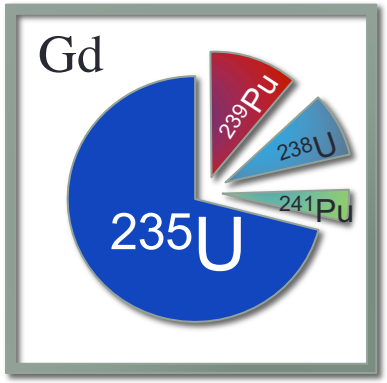
STEREO*

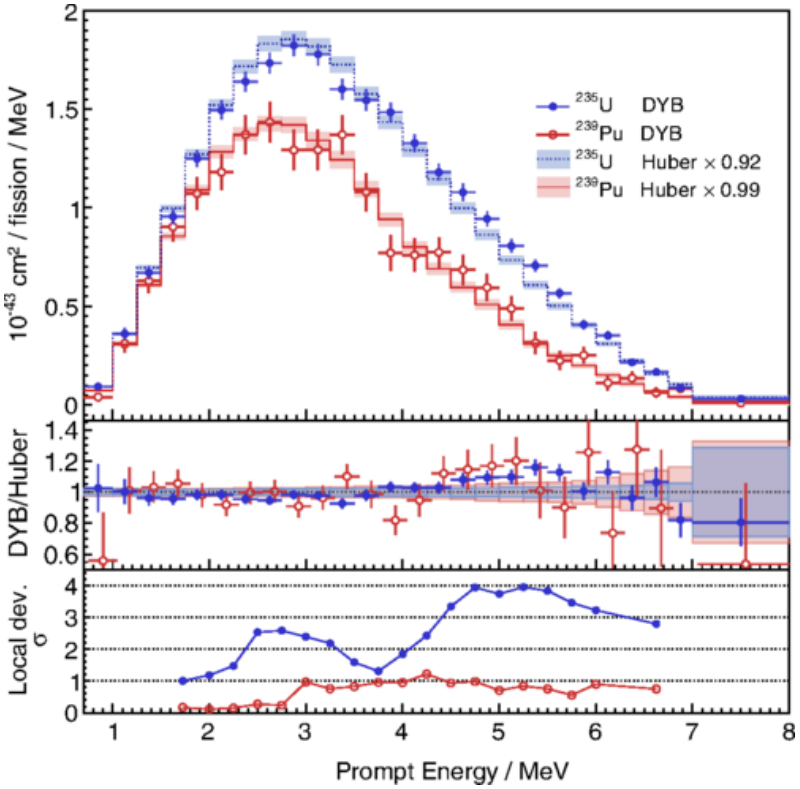


*More information on joint PROSPECT + STEREO analysis in next talk by B. Foust

Daya Bay

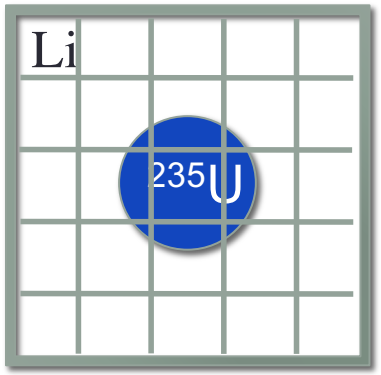
- Gd-loaded scintillator
- Multiple monolithic detectors
- Hundreds of meters from source
- 3.5 million antineutrinos detected
- Measurement of Low Enriched Uranium (LEU) power reactors with evolving fuel composition
- ^{235}U spectrum extracted from full measured spectrum using isotope fission fraction information and model constraints on ^{238}U and ^{241}Pu



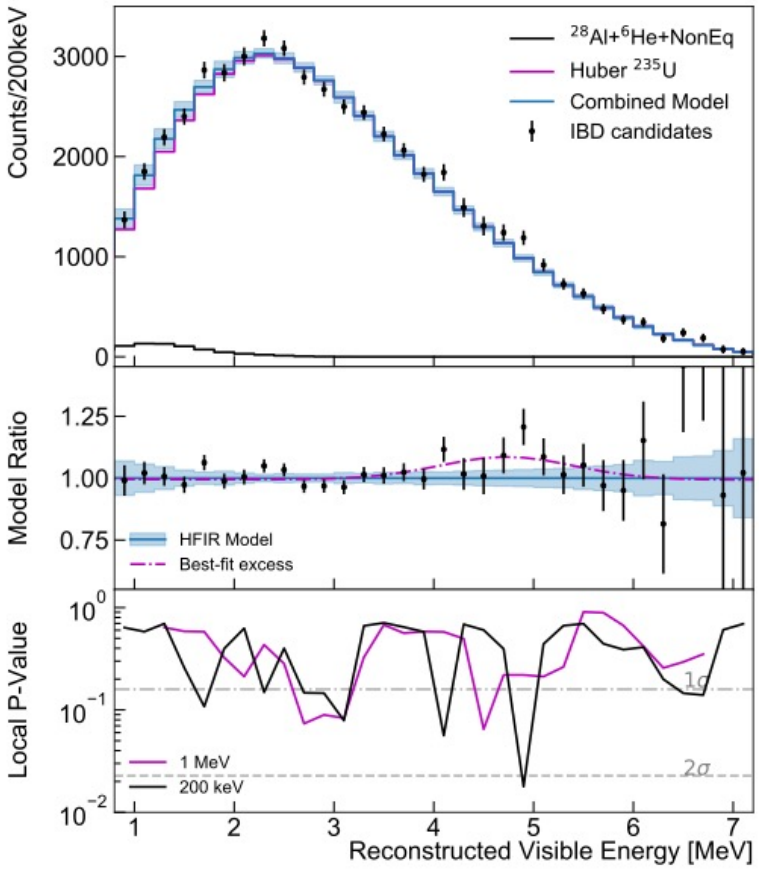


D. Adey et al., Phys Rev Lett 123, 111801

PROSPECT



- Li-loaded liquid scintillator
- Single, segmented detector
- 96 days of reactor-on data taking
- 50,000 antineutrinos
- ~10m from HEU reactor, direct measurement of ^{235}U



M. Andriamirado et al., Phys Rev D 103, 032001

Prompt Energy Definitions

- Published neutrino spectra are in different energy spaces, and must be transformed in order to compare and combine
  - Daya Bay: positron energy
  - PROSPECT: visible energy in detector

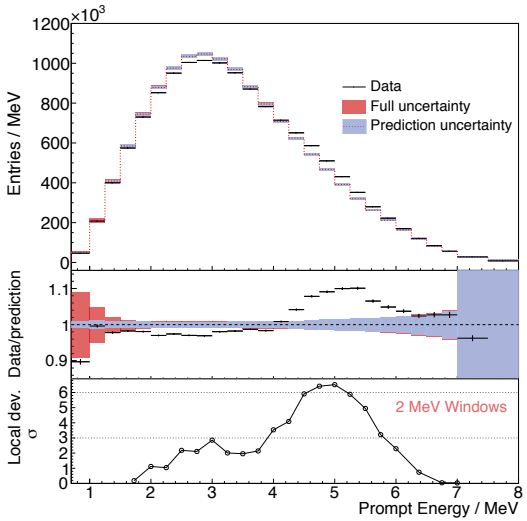
- Measurements cannot be directly compared as is, but can be transformed from one energy space into the other through detector response functions

$$\boldsymbol{R}^{\mathrm{m}} = \boldsymbol{R}^{\mathrm{PRO}} \left(\boldsymbol{R}^{\mathrm{DYB}} \right)^{-1}$$

Analyses in Transformed Prompt energy

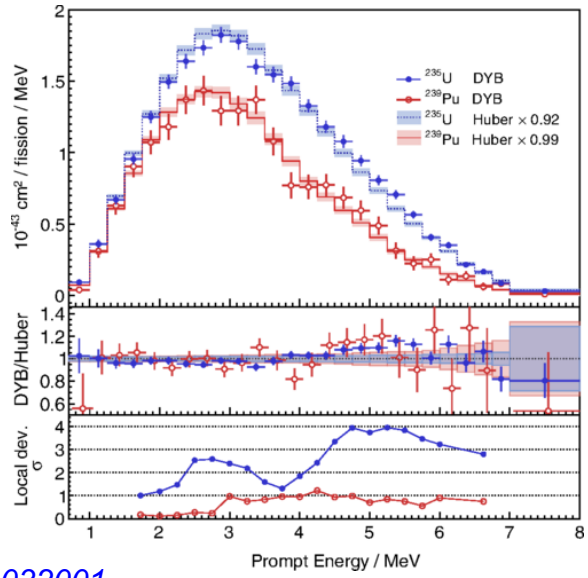
- Comparison of ^{235}U measurements between HEU and LEU reactors
- Pure ^{235}U shape constraint from PROSPECT on Daya Bay isotopic deconvolution

LEU Prompt Spectrum



Fission fraction based deconvolution from reactor fuel burnup

Deconvolved Prompt Spectra



D. Adey et al., Phys Rev Lett 123, 111801 M. Andriamirado et al., Phys Rev D 103, 032001

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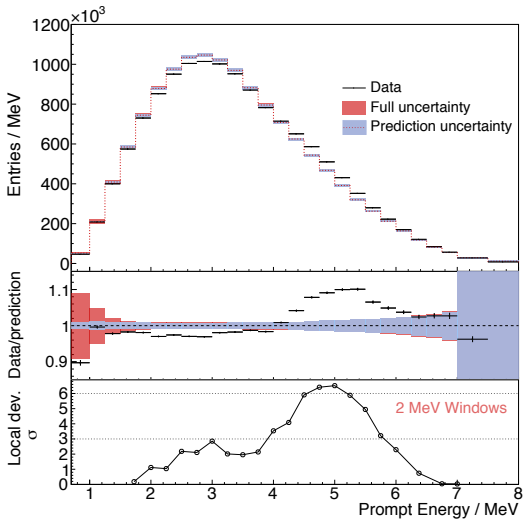
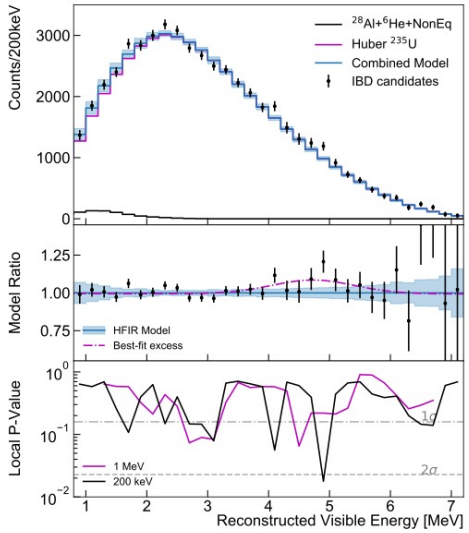
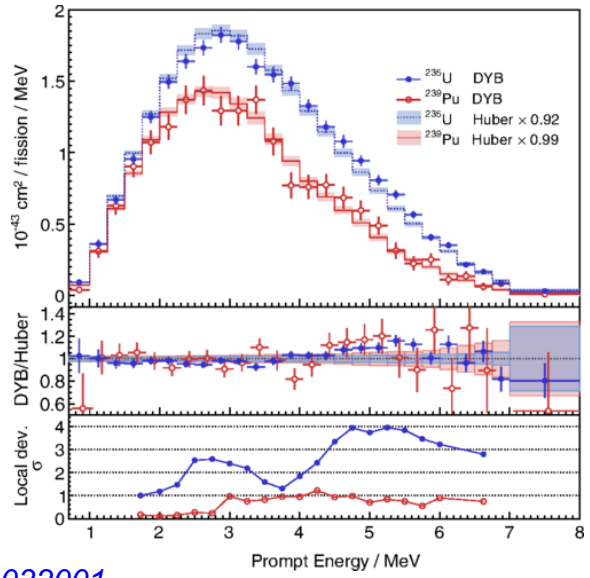
LEU Prompt Spectrum



HEU Prompt Spectrum



Deconvolved Prompt Spectra



[D. Adey et al., Phys Rev Lett 123, 111801](#) [M. Andriamirado et al., Phys Rev D 103, 032001](#)

Spectrum Unfolding into Neutrino Energy

Simplified Wiener SVD* Unfolding Schematic:

Real measurement: $m = Rs + n$

Simple inversion ignores noise: $s_{naive} = R^{-1}m$

Must incorporate a regularization: $s_{neutrino} \approx WR^{-1}m$

$$W_{ii} = \frac{(\text{Expected Signal})_i^2}{(\text{Expected Signal})_i^2 + (\text{Expected Noise})_i^2}$$

As noise gets larger relative to expected signal, W incorporates more suppression into the unfolding

*W. Tang et al, JINST 12, P10002 (2017)

Jointly Unfold ^{235}U Spectrum

- A joint unfolding can be done by combining measured spectra, response functions, and covariance matrices

$$\boldsymbol{S}^{\text{sum}} = \begin{bmatrix} \boldsymbol{S}^{\text{DYB}} \\ \boldsymbol{S}^{\text{PRO}} \end{bmatrix}$$

$$\boldsymbol{R}^{\text{sum}} = \begin{bmatrix} \boldsymbol{R}^{\text{DYB}} & \boldsymbol{R}^{\text{PRO}} \end{bmatrix}$$

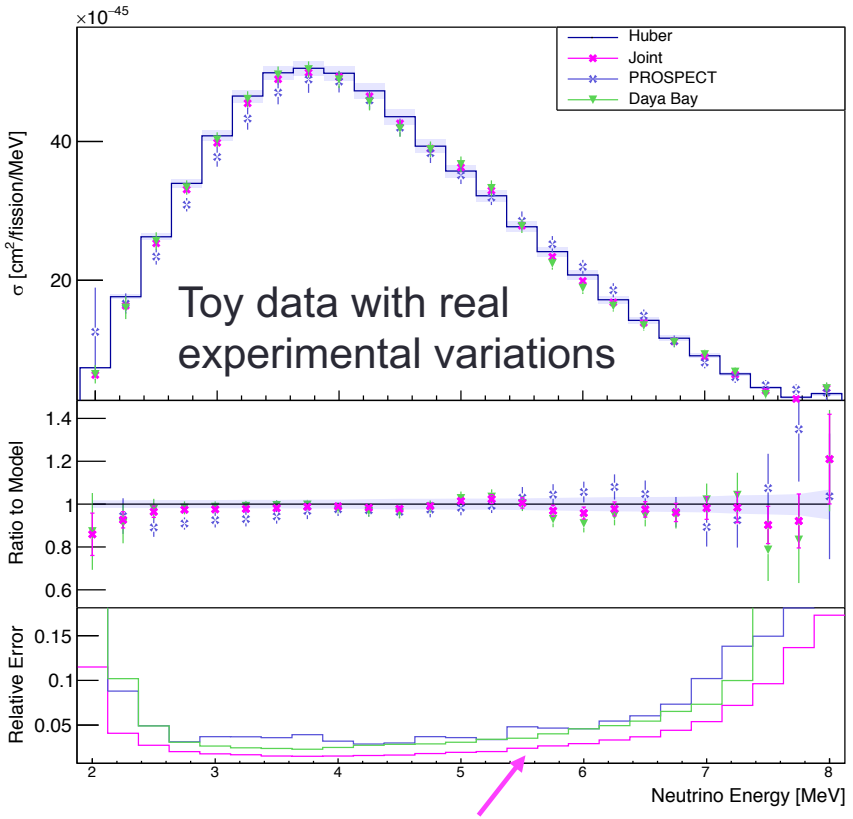
$$\mathbf{Cov}^{\text{sum}} = \begin{bmatrix} \mathbf{Cov}^{\text{DYB}} & 0 \\ 0 & \mathbf{Cov}^{\text{PRO}} \end{bmatrix}$$

- Smearing matrix A_c obtained through Wiener-SVD procedure can incorporate effects from regularization into any reference model or measurement

Benefits the unfolding by optimizing the expected signal vs the combined statistics of both measurements

Projected Results

- Toy-based studies indicate significant improvement in spectral uncertainties
  5% -> 3%
- Two independent analysis frameworks are in internal review
- See next talk for sensitivity studies for spectral distortions
- Results coming soon!



Conclusions

- Precision measurements needed to resolve tension between current models and measurements of reactor neutrino spectra
- Prompt measurements from Daya Bay and PROSPECT can combined into jointly constrained deconvolution of isotopic contributions to the full LEU spectrum
- A jointly unfolded measurement gives an improved data-driven prediction for other experiments to use
- Results expected soon!

Thanks!

Other Talks:

Saturday, April 17
PROSPECT-II Detector Upgrade Design and Expanded Physics: C Roca
PROSPECT / STEREO Joint Analysis: B Foust
Daya Bay Recent Results: O Dalager
PROSPECT-II Calibration System: X Lu
Machine Learning Analysis for PROSPECT: B Heffron

Tuesday, April 20
Cosmic Ray Boosted DM at PROSPECT Theory: C Cappiello
Cosmic Ray Boosted DM at PROSPECT Analysis: M Andriamirado
PROSPECT Latest Results: J Palomino
Improving PROSPECT Neutrino Measurements: X Zhang

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