JOINT MEASUREMENT OF THE $^{235}$U ANTI-NEUTRINO ENERGY SPECTRUM BY PROSPECT AND STEREO

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arXiv:2107.03371
NEUTRINO SPECTRUM MEASUREMENTS FROM POWER REACTORS

- Spectrum models don’t match experimental data in low enriched uranium (LEU) power reactors
- Poor fit overall to leading reactor models (Huber/Mueller).
- ‘Bump’ in 4-6 MeV (prompt energy) range
- Neutrino events come from a mixture of fissile isotopes: $^{235}\text{U}$, $^{238}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$
- Need new reactor data to clarify source of deviations
WHY A JOINT MEASUREMENT

- Reactor models do not provide a sufficient prediction of the antineutrino spectrum
- PROSPECT and STEREO are the leading measurements of the pure $^{235}U$ spectrum without significant contributions from other isotopes
- Both experiments’ spectrum measurements are still statistics limited with relatively low systematic uncertainties
- By combining the measurements, we can increase the statistical power and produce a reference spectrum of $^{235}U$ for use by the community
THE PROSPECT EXPERIMENT

- Experimental Site (HFIR, ORNL):
  - 85 MW HEU reactor core with 46% duty cycle
  - >99% of $\bar{\nu}_e$ flux from $^{235}U$ fissions

- Detector Design
  - Segmented design for calibration access
  - Optimized for background suppression
  - Particle identification with pulse shape discrimination

J. Ashenfelter et al., NIM A 2018.12.079
https://prospect.yale.edu/
THE STEREO EXPERIMENT

- Experimental site (RHF, ILL):
  - 58 MW HEU reactor
  - Compact core
  - >99% of flux from $^{235}U$ fissions

- Detector Design:
  - 6 fiducial cells
  - Liq. Scintillator + Gd
  - Pulse shape discrimination

arxiv:2010.01876
https://www.stereo-experiment.org/
PROSPECT PROMPT SPECTRUM

- 50560 +/- 406 IBD signal events
- Best fit bump size relative to Daya Bay: 84% +/- 39%
- Disfavor both ‘No $^{235}$U Contribution to’ and ‘Only $^{235}$U Contributes to’ LEU bump cases at >2$\sigma$
- Still statistics limited

M. Andriamirado et al., Phys Rev D 103, 032001
https://prospect.yale.edu/
STereo’s Prompt Spectrum

- 43,000 Antineutrinos detected
- Significant bump observed in antineutrino energy: $A = 12.1 \pm 3.4\% (3.5\sigma)$ of spectrum at peak
- Findings consistent with case of $^{235}$U equally contributing to LEU bump
- Still statistics limited

arxiv:2010.01876
https://www.stereo-experiment.org/
PROMPT COMPATIBILITY

- Prompt comparison avoids uncertainties of filtered unfolding!
- Move one experiment’s data into the prompt space of the other with unfiltered unfolding, then refolding with the other’s response

\[ R_{map} = R_{STE} \cdot R_{PRO}^{-1} \]
\[ M_{map} = R_{map} \cdot M_{PRO} \]

- Fit spectra with free floating normalization

\[ \chi^2/ndf = 24.1/21 \]
ANALYSIS METHOD: DATA UNFOLDING

- To create a measurement independent of factors unique to each experiment, we must convert from the prompt space of each to true antineutrino energy space via ‘unfolding’

- Ideal Case: \[ M = R \times S \Rightarrow S = R^{-1} \times M \]

  - \( S \) = true signal in neutrino energy
  - \( R \) = response matrix
  - \( M \) = measured signal in prompt energy

- Realistically:
  - \( R \) not necessarily invertible
  - \( M \) has non-signal noise elements which are blown out of proportions by \( R^{-1} \)
COMPARISON OF FRAMEWORKS

- Framework Validation:
  1. STEREO’s Tikhonov regularization
  2. PROSPECT’s WienerSVD unfolding method

![Cross-checked and Consistent Results]
UNFOLDED SPECTRUM

- Use the Tikhonov method to present result
- Using a free floating normalization, best fit to Huber model gives $\chi^2/n_{df} = 30.8/21$

- Results available (arXiv:2107.03371)
- Thorough supplemental materials, including filter matrix
- Can be directly compared to $^{235}$U model predictions
Find an excess in the 5-6 MeV range

Fit a Gaussian with free amplitude, mu, and sigma values to the excess

The addition of the best-fit Gaussian to the Huber model gives $\Delta \chi^2/\Delta ndf = 12.0/3$ (2.4$\sigma$ significance)

Consistent with the Daya Bay 235U spectrum in shape-only comparison ($\chi^2/ndf = 21.0/21$)

Find an excess with significance 2.4$\sigma$

Consistent with $^{235}$U equally contributing to LEU excess
CLOSING STATEMENTS

- New results posted to arxiv just last week!

- PROSPECT and STEREO datasets found to be statistically compatible

- PROSPECT and STEREO have successfully combined their separately measured high precision $^{235}U$ spectra

- The publication of the jointly unfolded result includes filter matrix for comparing to $^{235}U$ antineutrino models, can be used as a reference spectrum by community

- Find an excess with 2.4σ significance in the 5-6 MeV energy range