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

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NEUTRINO SPECTRUM MEASUREMENTS FROM POWER REACTORS

- Spectrum models don’t match experimental data in low enriched uranium (LEU) power reactors
- Neutrino events come from a mixture of fissile isotopes: $^{235}\text{U}$, $^{238}\text{U}$, $^{239}\text{Pu}$, $^{241}\text{Pu}$
- ‘Bump’ in 4-6 MeV (prompt energy) range
- Poor fit overall to leading reactor models (Huber/Mueller).
- 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 $^{235}\text{U}$ 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 $^{235}\text{U}$ for use by the community
GOALS OF THE JOINT ANALYSIS

- Demonstrate Compatibility - We must show that the two experiments have measurements that are consistent with each other, and quantify their compatibility.

- Provide $^{235}U$ Antineutrino Spectrum - We must remove detector/site effects from the measurement by converting from the prompt space of each experiment to antineutrino energy, and provide a combined $^{235}U$ spectrum for reference by the community.

- Compare Joint Spectrum to Model and Estimate Excess - We must quantify how the joint measurement compares to leading reactor model, and relate this to previous reactor measurements.
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
- S:B of 1.4:1 in signal energy range (0.8-7.2 MeV)
- Best fit bump size relative to Daya Bay: 84% +/- 39%
- Disfavor both ‘No $^{235}$U Contribution’ and ‘Only $^{235}$U Contributes’ LEU bump cases at >2σ
- 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 between all isotope equal contribution ($\sim 9\%$) and only $^{235}U$ contributes ($\sim 16\%$)
- Still statistics limited

arxiv:2010.01876
https://www.stereo-experiment.org/
COMPARISON OF FRAMEWORKS

Framework Validation:

1. STEREO’s Tikhonov regularization
2. PROSPECT’s WienerSVD unfolding method
FRAMEWORK VALIDATION

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

- Comparison of PROSPECT and STEREO Datasets:
  - $\chi^2 = 22.3/17$

Statistically Compatible
UNFOLDED SPECTRUM

- Framework Validation:
  1. STEREO’s Tikhonov regularization
  2. PROSPECT’s WienerSVD unfolding method
- Comparison of PROSPECT and STEREO Datasets:
  \[ \chi^2 = 22.3/17 \]
- Joint fit:
  - To be published with smearing matrix
  - Can be directly compared to $^{235}\text{U}$ model predictions
CLOSING STATEMENTS

- Modern measurements from HEU reactors can investigate the LEU spectrum anomaly

- PROSPECT and STEREO have separately measured the $^{235}U$ spectrum at high precision, and can be further improved by combining

- PROSPECT and STEREO datasets are found to be statistically compatible

- Finalized results coming soon!
PROSPECT TALKS AT APS

Saturday, April 17

- C. Roca: PROSPECT-II Detector Upgrade Design and Expanded Physics
- J. Gaison: Joint Analysis of the Daya Bay and PROSPECT Spectra
- X. Lu: PROSPECT-II Calibration System
- B. Heffron: Machine Learning Analysis for PROSPECT

Tuesday, April 20

- C. Cappiello: Cosmic Ray Boosted DM at PROSPECT Theory
- M. Andriamirado: Cosmic Ray Boosted DM at PROSPECT Analysis
- J. Palomino: PROSPECT Latest Results
- X. Zhang: Improving PROSPECT Neutrino Measurements
BACKUP SLIDES
SMEARING MATRIX

- The Ac, or smearing, matrix is used to apply the bias and smoothing effect from unfolding to a given spectrum in antineutrino energy.

- This can and should be applied to models in true antineutrino energy to allow for an accurate comparison with the unfolded data.

- The Ac matrix for the WienerSVD is:

\[
D_{\text{int}} = A_{C\text{int}} \left( C^{-1} V_C W_C V_C^T C (R^T (R R^T)^{-1} M_{\text{int}}) \right)
\]

- For more information, please refer to arxiv:1705.03568.