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

July 12, 2021
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DPF 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
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 $^{235}\text{U}$ neutrino energy spectra

Daya Bay  PROSPECT  STEREØ*

*More information on joint PROSPECT + STEREØ 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
- $^{235}\text{U}$ spectrum extracted from full measured spectrum using isotope fission fraction information and model constraints on $^{238}\text{U}$ and $^{241}\text{Pu}$

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 $^{235}\text{U}$
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 mapped from one energy space into the other through detector response functions

\[ R_{\text{map}} = R_{\text{PRO}} (R_{\text{DYB}})^{-1} \]
Prompt Shape Compatibility

- PROSPECT rate scaled to match Daya Bay
- $\chi^2$/dof = 25.4/31
- p-value of 0.75
- Daya Bay and PROSPECT $^{235}\text{U}$ measurements in good agreement

**Graph**

*PROSPECT prompt energy [MeV]*

*Daya Bay*

*PROSPECT*

$\sigma \times 10^{-13}$ [cm$^2$/fission/MeV]

Ratio

PROSPECT prompt energy [MeV]

e-Print: arXiv:2106.12251
Power Reactor Deconvolution

- Daya Bay total spectrum grouped by fission fraction and used to deconvolve $^{235}$U and $^{239}$Pu contributions

*D. Adey et al., Phys Rev Lett 123, 111801*
Power Reactor Deconvolution

- Pure $^{235}\text{U}$ measurement from PROSPECT constrains Daya Bay isotopic deconvolution

\[ \text{PROSPECT }^{235}\text{U} \]

\[ \text{Fission Fraction} \]

\[ \text{PROSPECT }^{239}\text{Pu} \]

\[ \text{Fission Fraction} \]

\[ D. \text{ Adey et al., Phys Rev Lett 123, 111801} \]
Power Reactor Deconvolution

- New results consistent with previous results
- Local deviations from scaled model (2 MeV wide windows) increase by 0.2-0.5σ at all energies for $^{235}\text{U}$
- No significant change for $^{239}\text{Pu}$

**New Results**

`e-Print: arXiv:2106.12251`
Power Reactor Deconvolution

Difference from Previous Results

- Relative shape uncertainty of $^{235}$U improves to 3%, no significant change to $^{239}$Pu shape uncertainty
- Isotopic degeneracy improved by ~20%

**e-Print: arXiv:2106.12251**
Unfolded Spectra

- Deconvolved spectra unfolded and regularized via Wiener-SVD* technique

- $A_c$ smearing matrix encodes effect from unfolding regularization into any model

- Rate constraint from Daya Bay

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

• Precision measurements needed to resolve tension between current models and measurements of reactor neutrino spectra.

• Daya Bay and PROSPECT $^{235}$U measurements are compatible with each other.

• A jointly deconvolved reactor antineutrino spectrum improves both $^{235}$U shape uncertainty to 3% and $^{235}$U-$^{239}$Pu correlations are reduced by ~20% from Daya Bay-only results.
Thanks!

See Other PROSPECT Talks:

- Latest Reactor Antineutrino Spectrum and Boosted Dark Matter Results: P. Weatherly
- Reactor Position Reconstruction Study: D. C. Venegas-Vargas
- Joint Analysis by PROSPECT and STEREO: B. Foust
- Physics Opportunities with a PROSPECT Upgrade: R. Carr