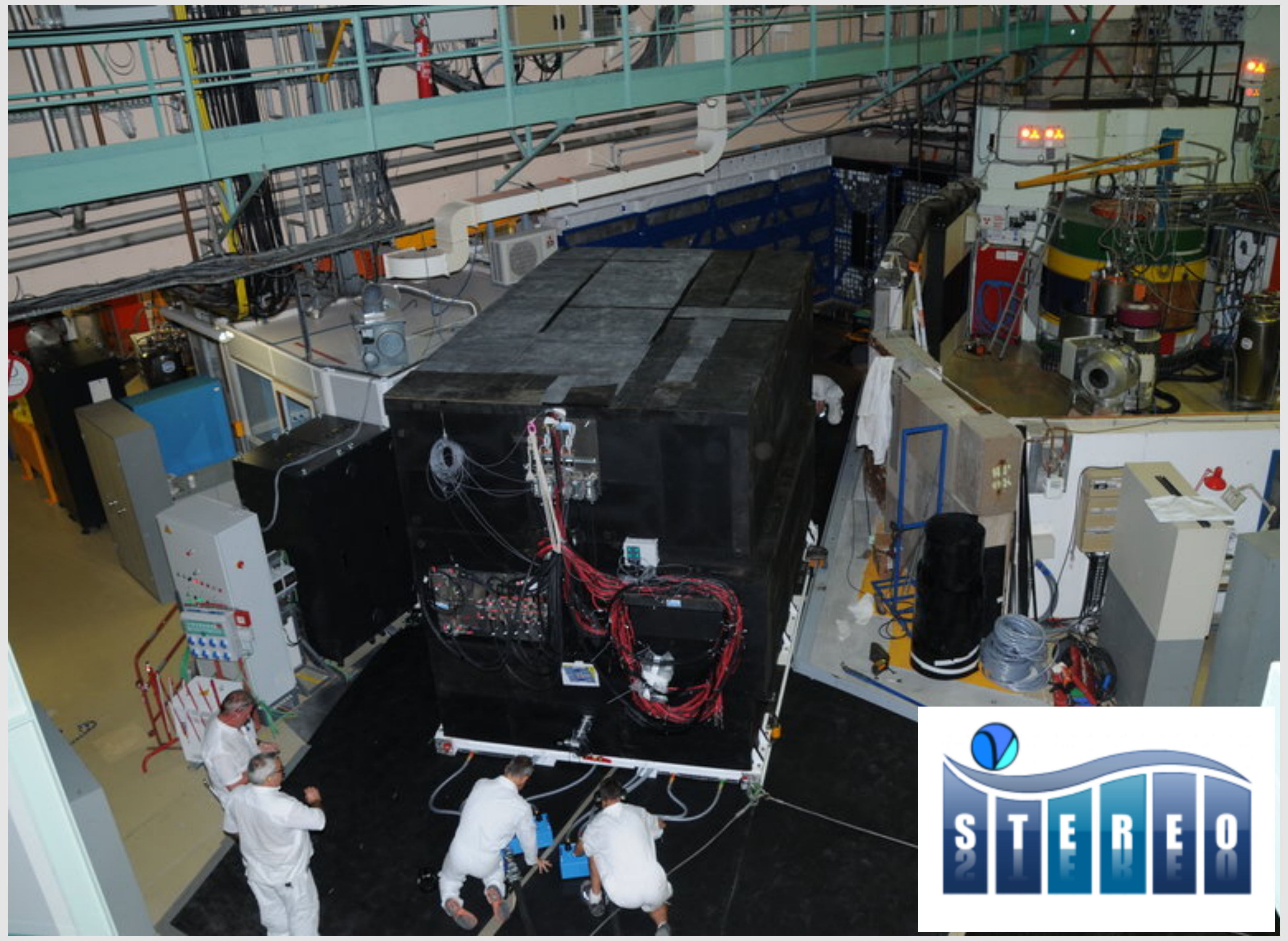
JOINT MEASUREMENTS OF THE ^{235}U ANTINEUTRINO ENERGY SPECTRUM, PROSPECT WITH STEREO AND DAYABAY



BEN FOUST
YALE UNIVERSITY
ON BEHALF OF THE PROSPECT COLLABORATION

Wright Laboratory

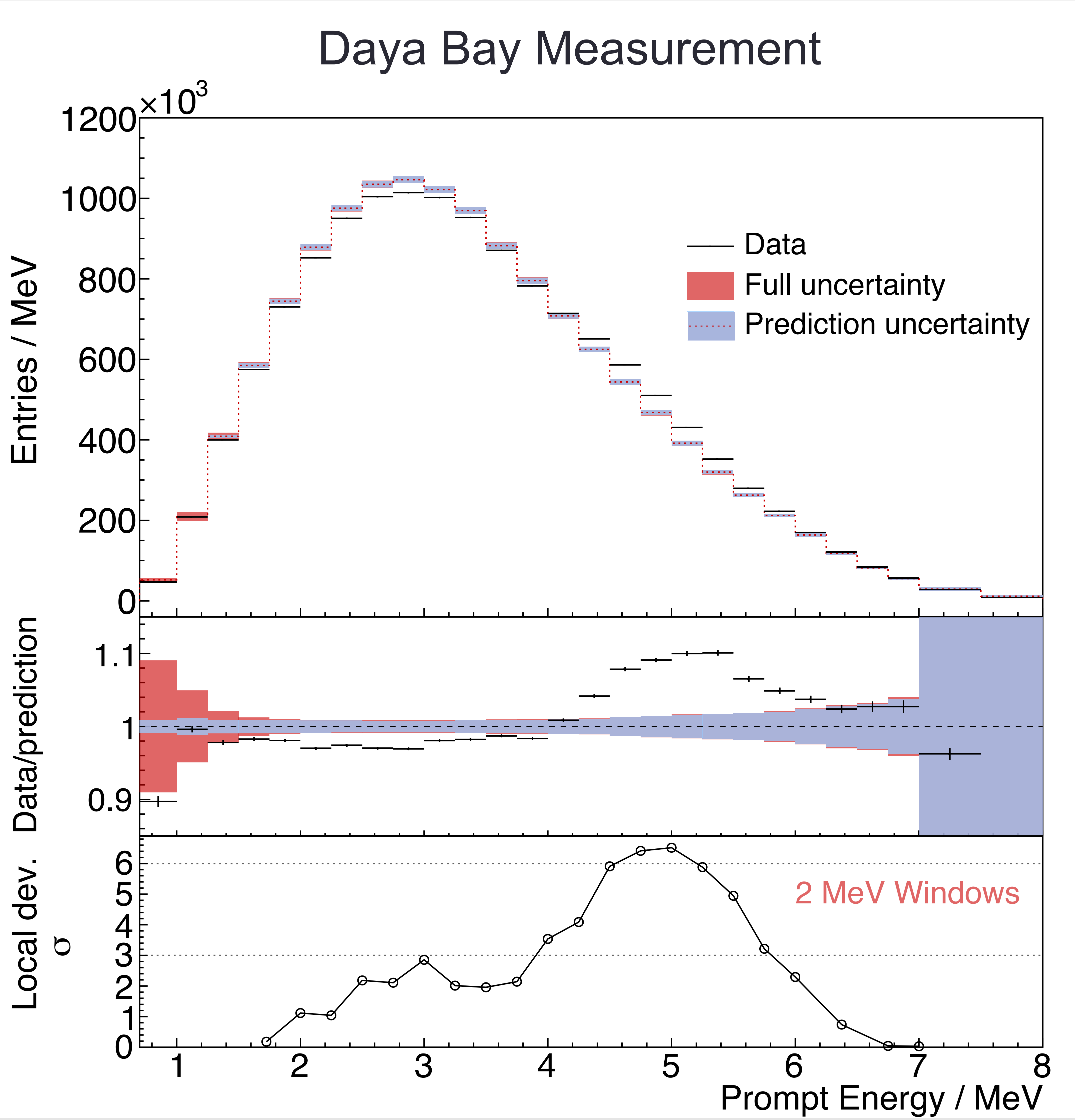
Two Independent Analyses of ^{235}U

[e-Print: arXiv:2106.12251](https://arxiv.org/abs/2106.12251)

[e-Print: arXiv:2107.03371](https://arxiv.org/abs/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}U, ^{238}U, ^{239}Pu, ^{241}Pu
- Need new reactor data to clarify source of deviations



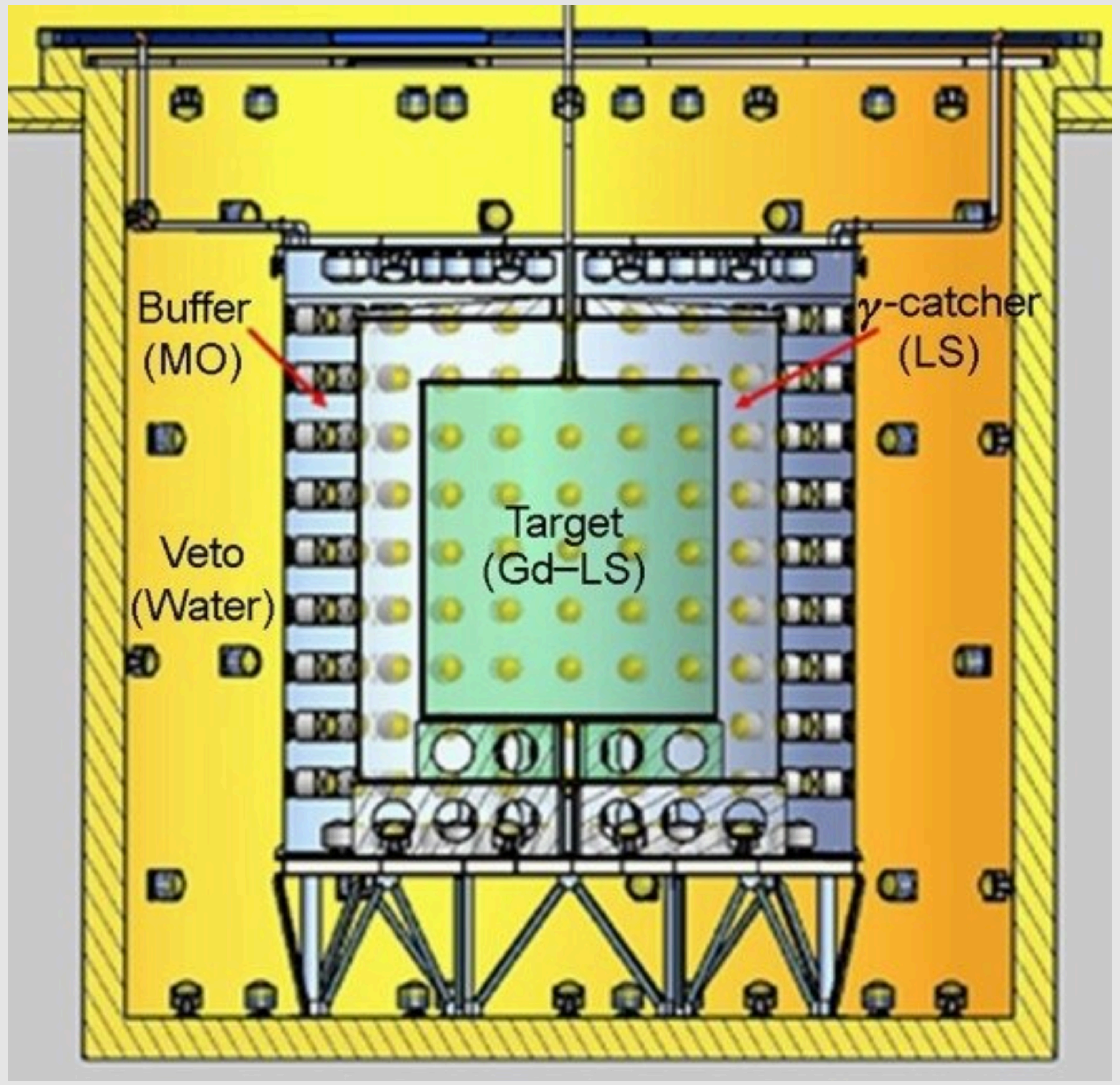
D. Adey et al., Phys Rev Lett 123, 111801

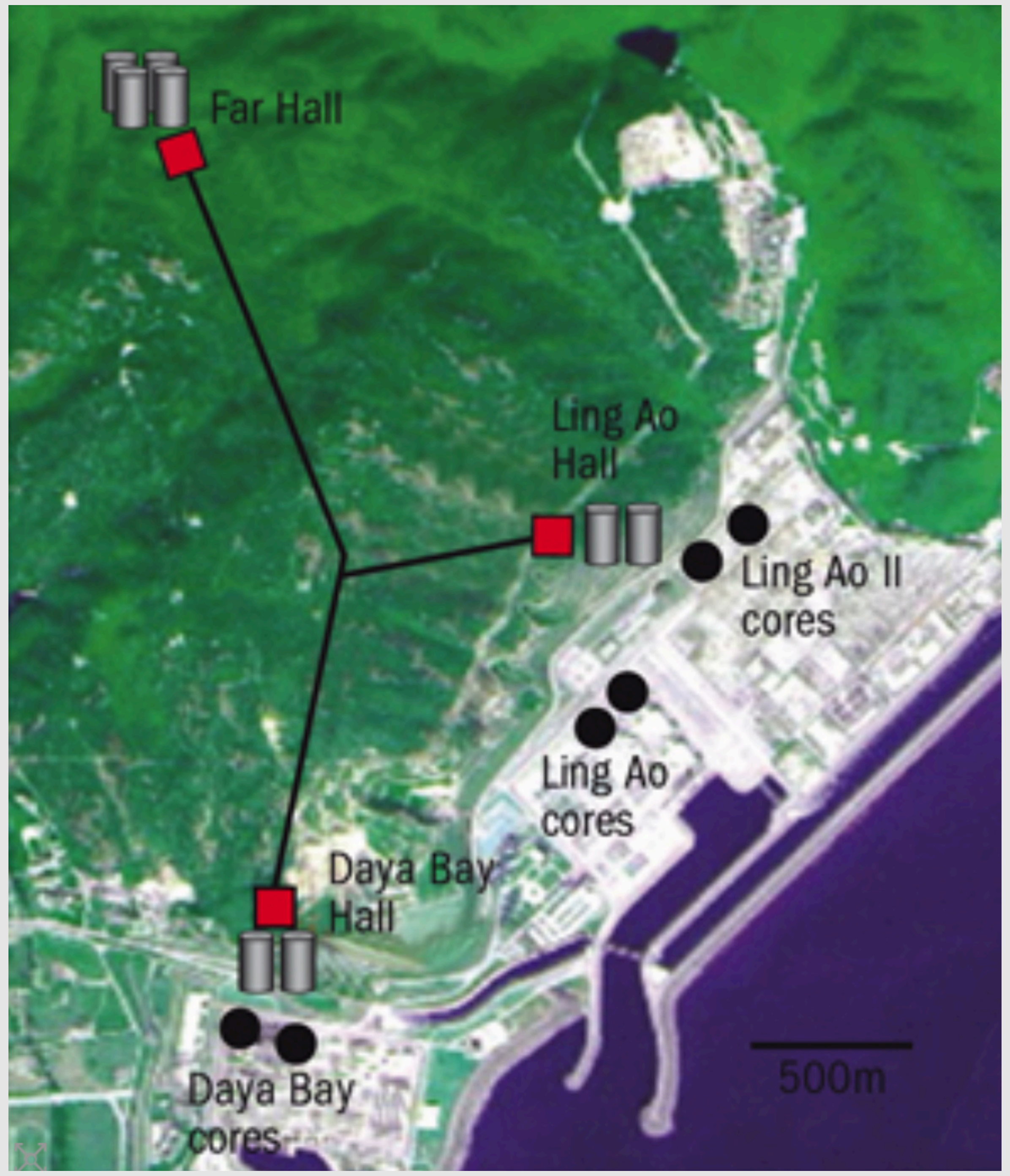
WHY JOINT MEASUREMENTS

- 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
- Daya Bay achieves a precise measurement of the LEU reactor spectrum with high statistics that allows the deconvolution into a ^{235}U spectrum
  - Adding PROSPECT into the deconvolution process gives a much better resulting DYB ^{235}U spectrum
  - Combining the resulting ^{235}U spectrum with PROSPECT results in an improved ^{235}U measurement in antineutrino energy

THE DAYA BAY EXPERIMENT

- Experimental site (Daya Bay, China):
  - Measurement of Low Enriched Uranium (LEU) power reactors with evolving fuel composition
  - Hundreds of meters from source



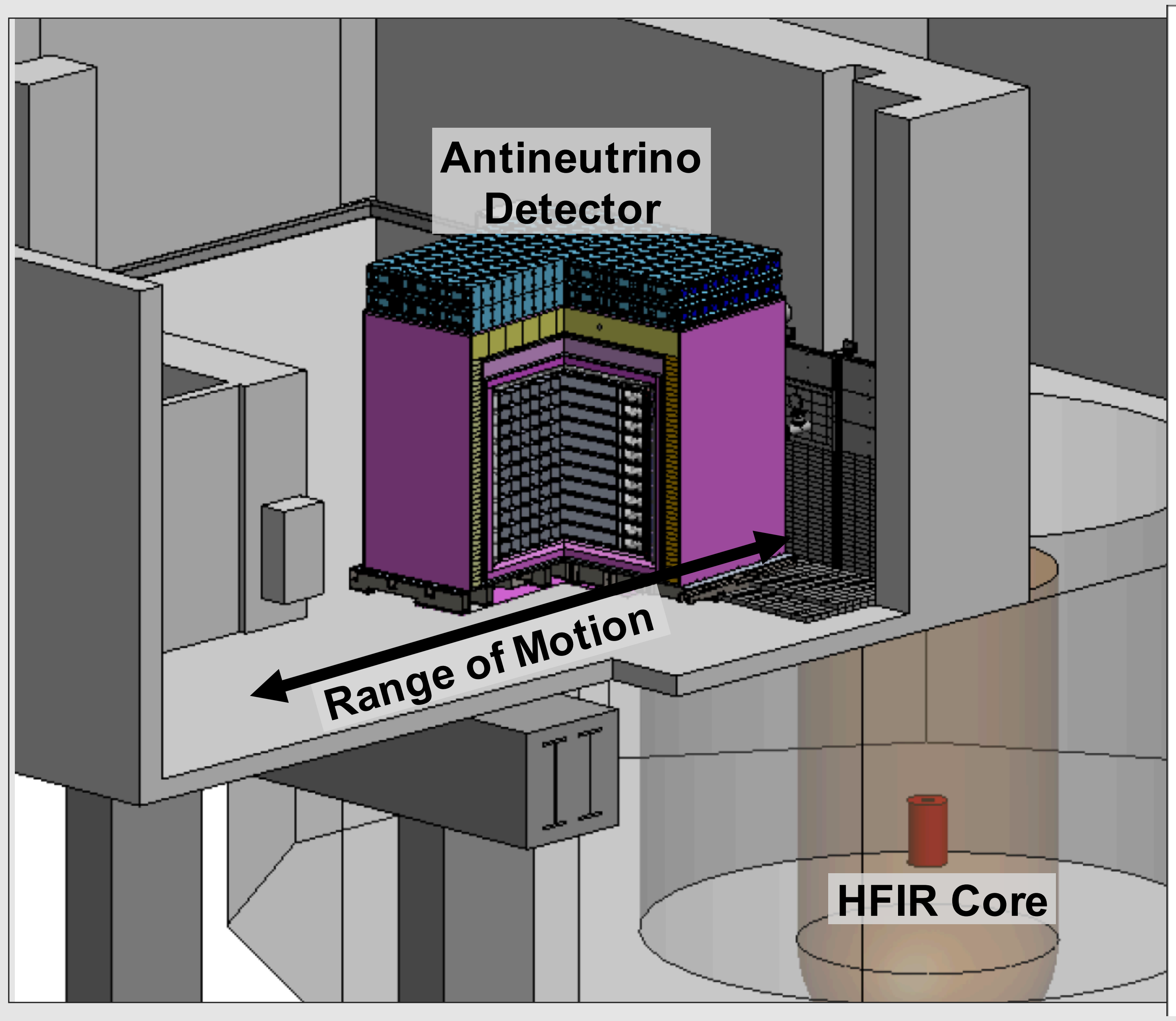


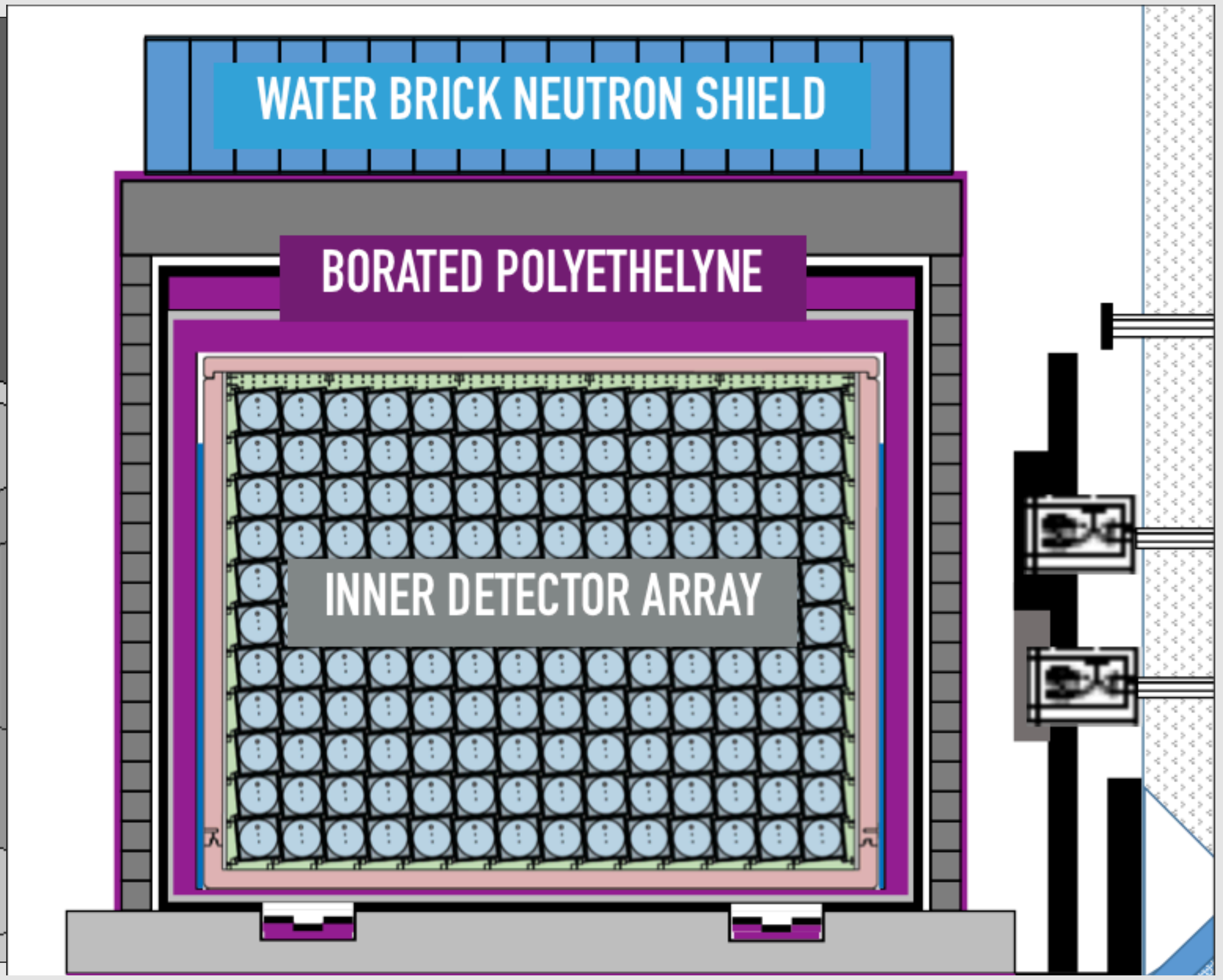
- Detector Design:
  - Gd-loaded scintillator
  - Multiple monolithic detectors
  - Detect events from mixture of isotopes

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

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



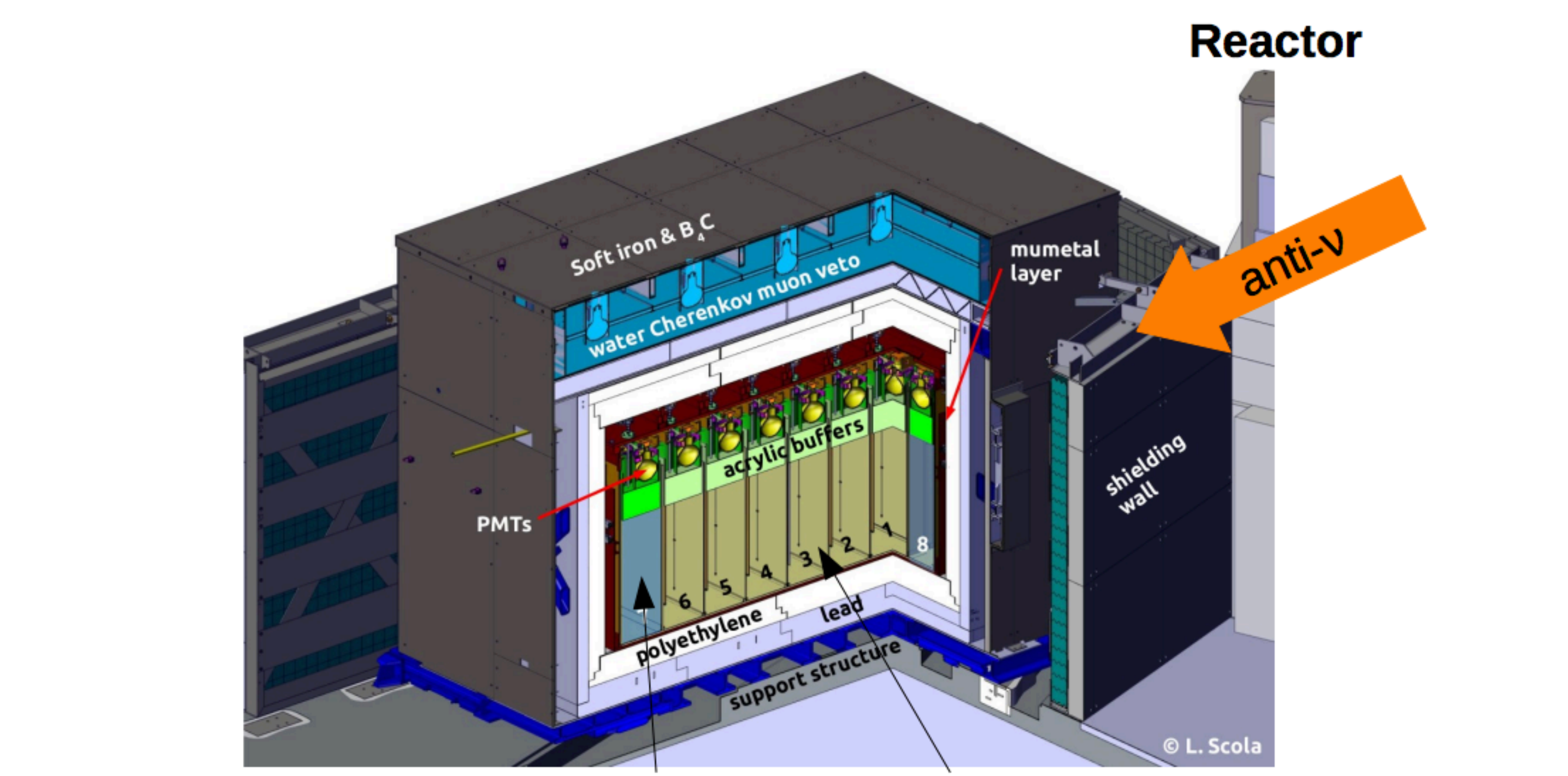


J. Ashenfelter et al., NIM A [2018.12.079]

[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



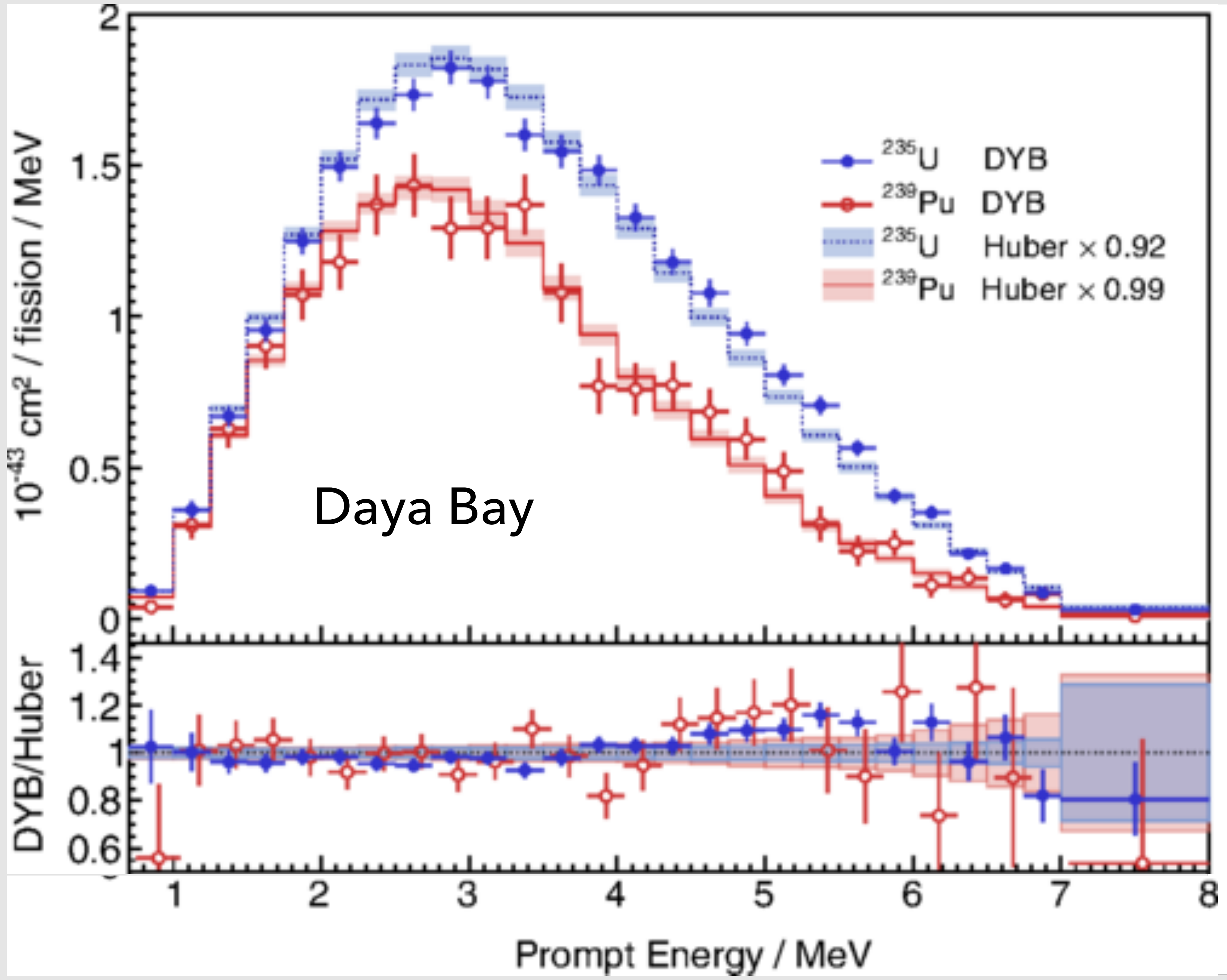
Gamma-Catcher: unloaded liquid scintillator **Target**: Gd-loaded liquid scintillator

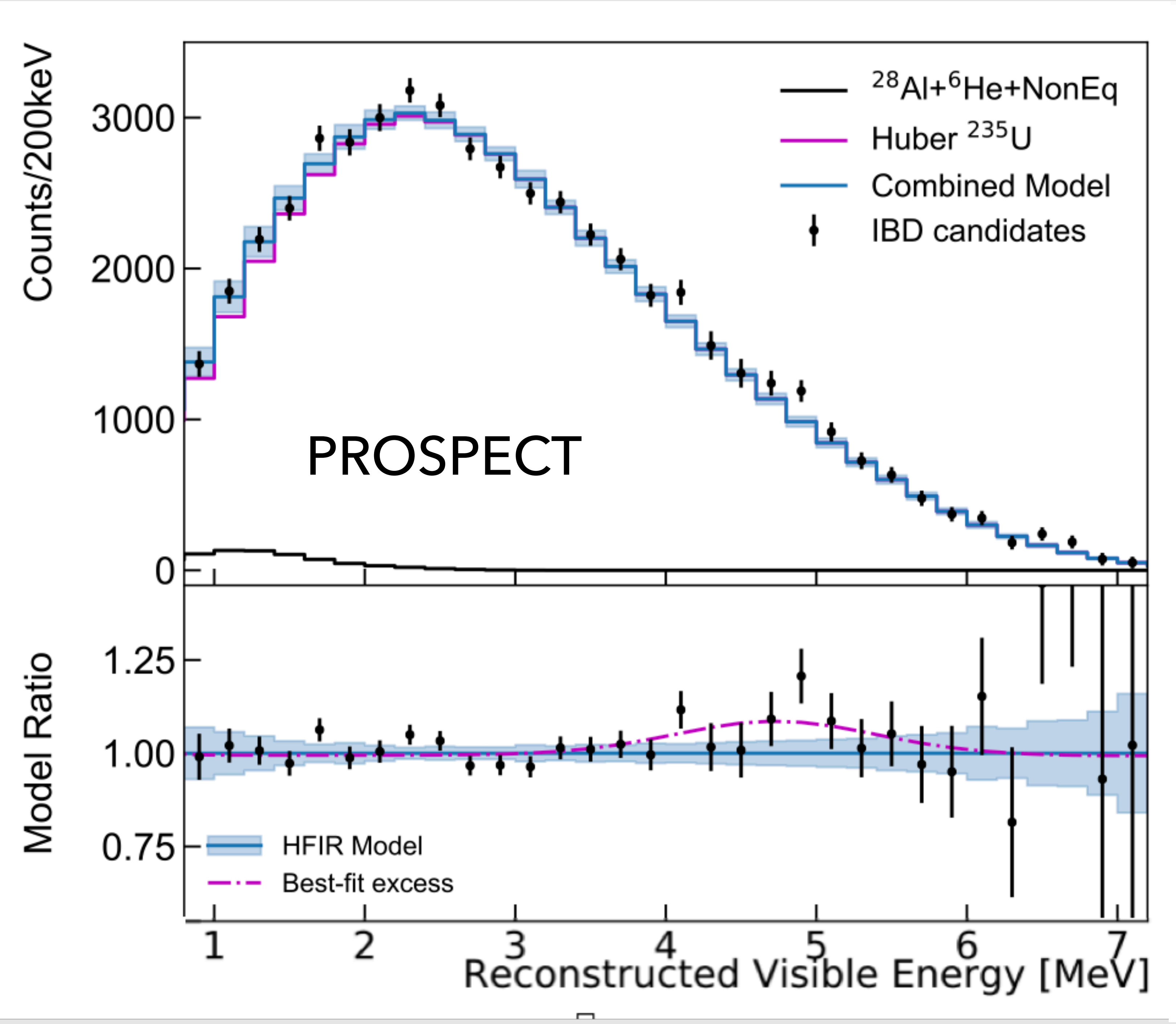
arxiv:2010.01876

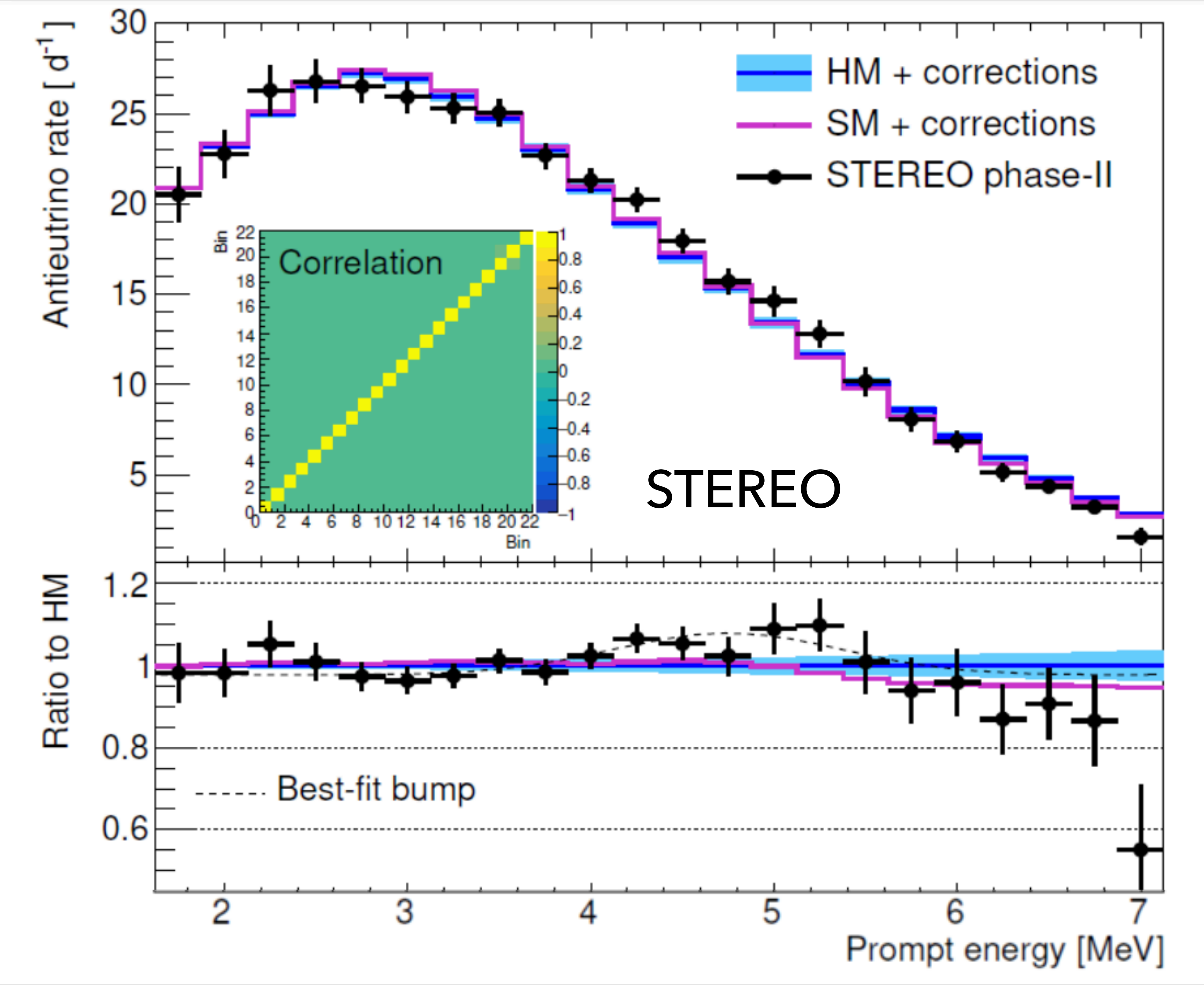
https://www.stereo-experiment.org/

PROMPT SPECTRUM MEASUREMENTS

- Daya Bay: 3.5 million antineutrinos detected, ^{235}U and ^{239}Pu spectrum extracted using isotope fission fraction information and model constraints on ^{238}U and ^{241}Pu, systematics limited
- PROSPECT: 50 thousand ^{235}U antineutrinos detected, sees excess most consistent with ^{235}U equally contributing to LEU, statistics limited
- STEREO: 43 thousand ^{235}U antineutrinos detected, sees excess most consistent with ^{235}U equally contributing to LEU, statistics limited







PROMPT COMPATIBILITY: PROSPECT-STEREO

- 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

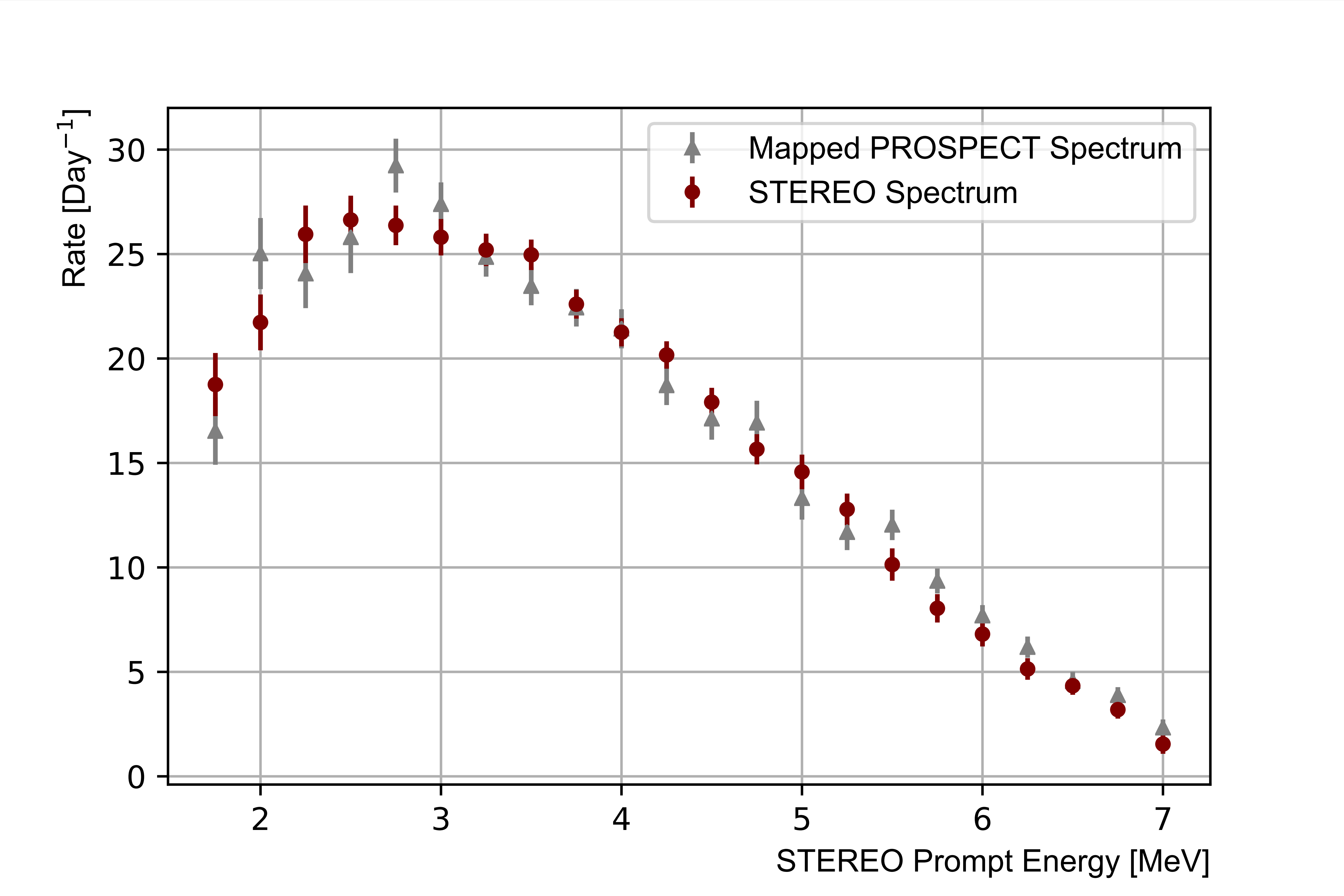
$$R_{map} = R_{STE} \cdot R_{PRO}^{-1}$$

$$M_{map} = R_{map} \cdot M_{PRO}$$

- No PROSPECT rate info: fit spectra with free floating normalization

$$\chi^2/ndf = 24.1/21$$

▶ Statistically Compatible Inputs



PROMPT COMPATIBILITY: DAYA BAY-PROSPECT

- 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

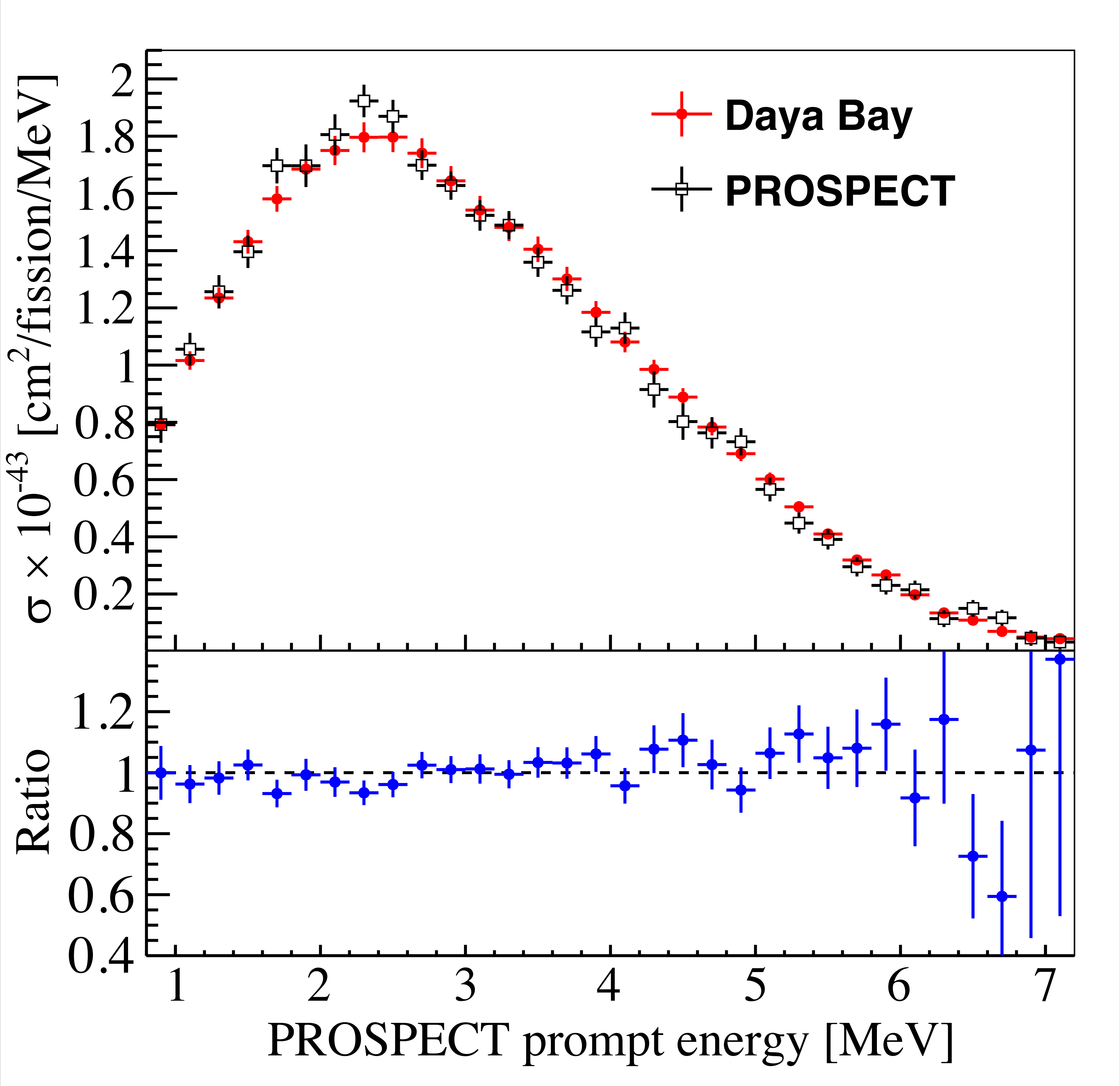
$$R_{map} = R_{PRO} \cdot R_{DYB}^{-1}$$

$$M_{map} = R_{map} \cdot M_{DYB}$$

- No PROSPECT rate info: fit spectra with free floating normalization

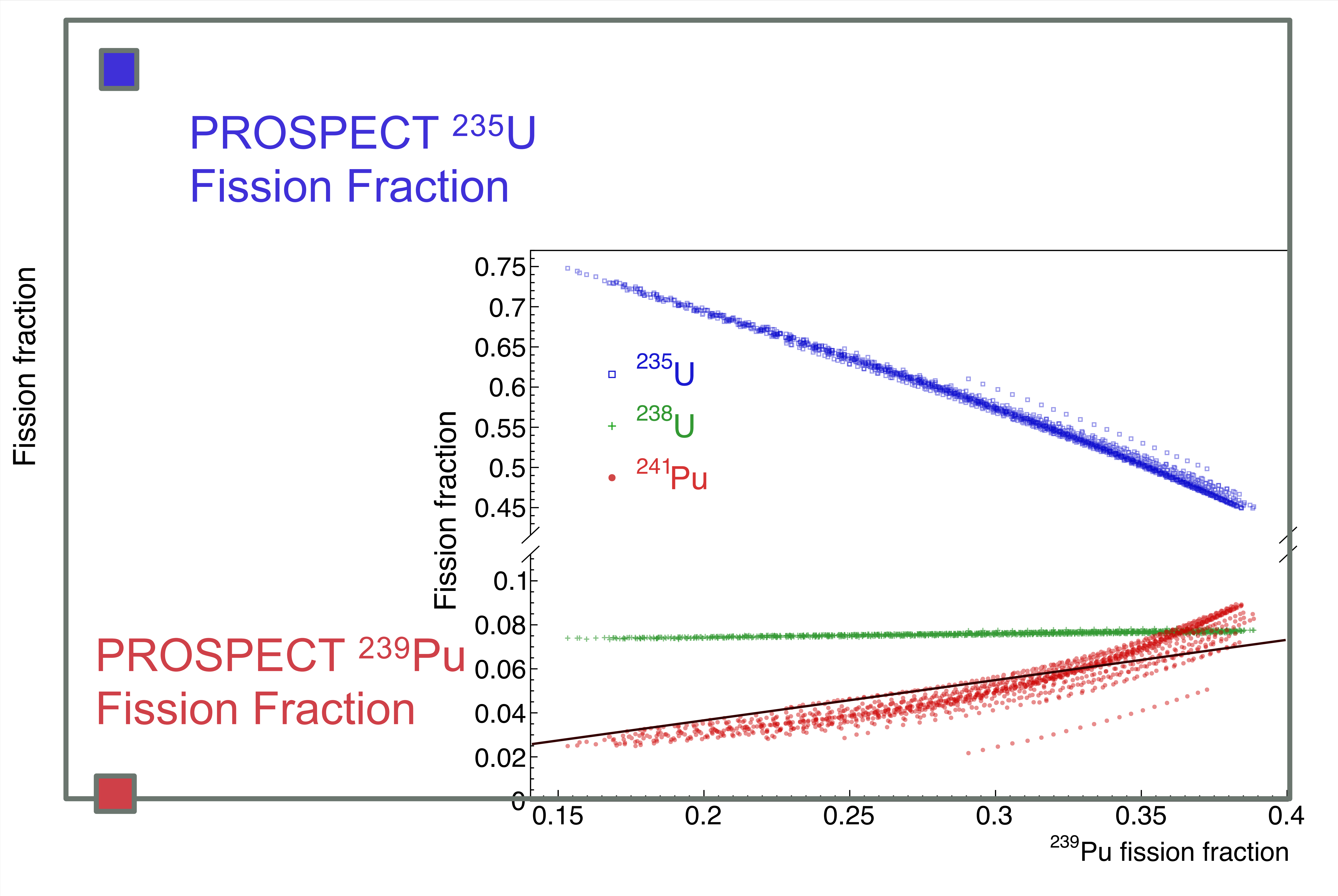
$$\chi^2/ndf = 25.4/31$$

Statistically Compatible Inputs



SPECTRAL DECONVOLUTION WITH EVOLVING FISSION FRACTIONS

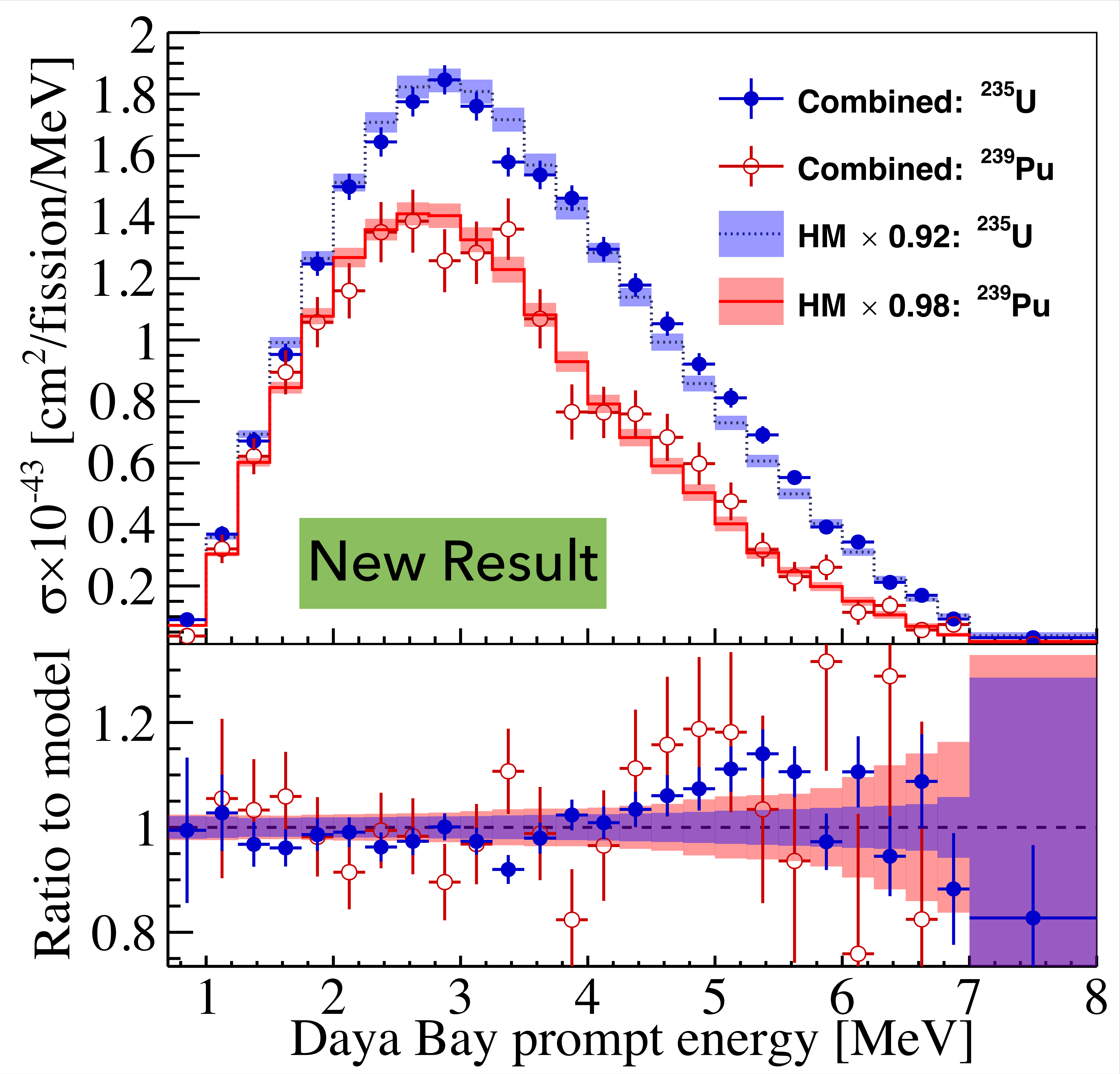
- Pure ^{235}U measurement from PROSPECT constrains Daya Bay isotopic deconvolution



DAYA BAY'S DECONVOLVED PROMPT ENERGY SPECTRUM – UPDATED

e-Print: arXiv:2106.12251

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

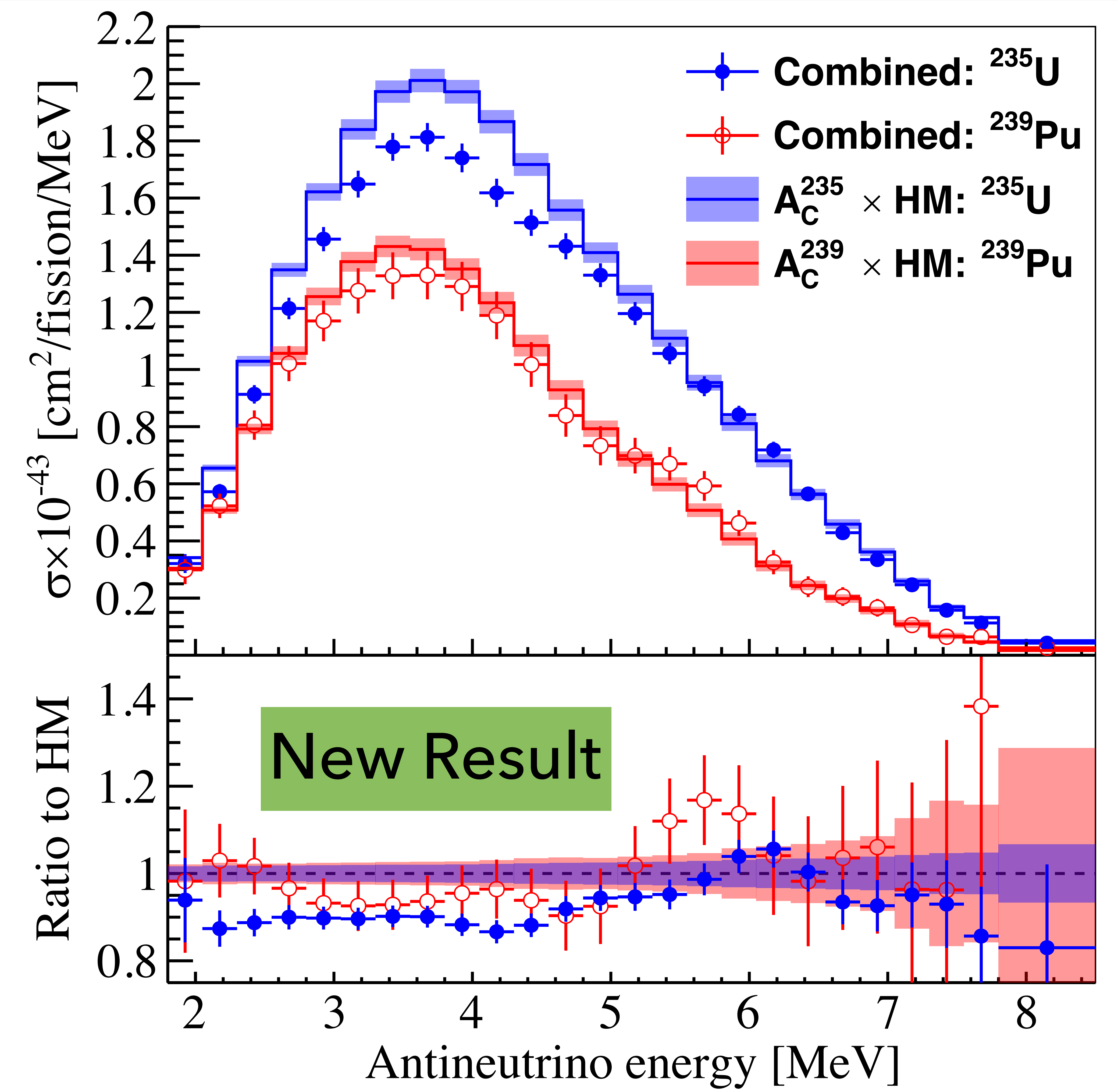


ANALYSIS METHOD: DATA UNFOLDING

- 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}

DAYA BAY – PROSPECT:
JOINT 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

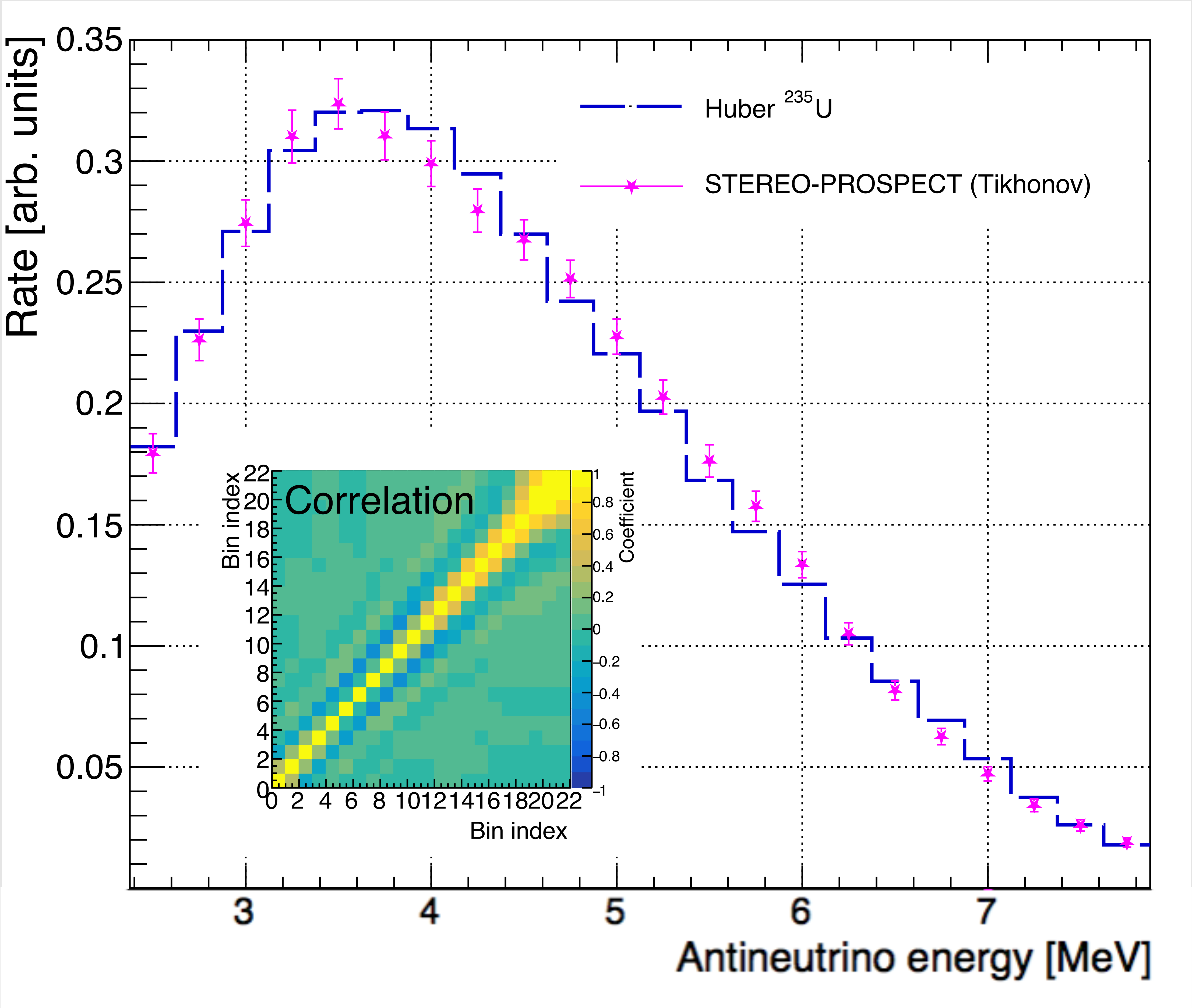


*W. Tang et al, JINST 12, P10002 (2017)

e-Print: arXiv:2106.12251

PROSPECT-STEREO: UNFOLDED SPECTRUM JOINT SPECTRUM

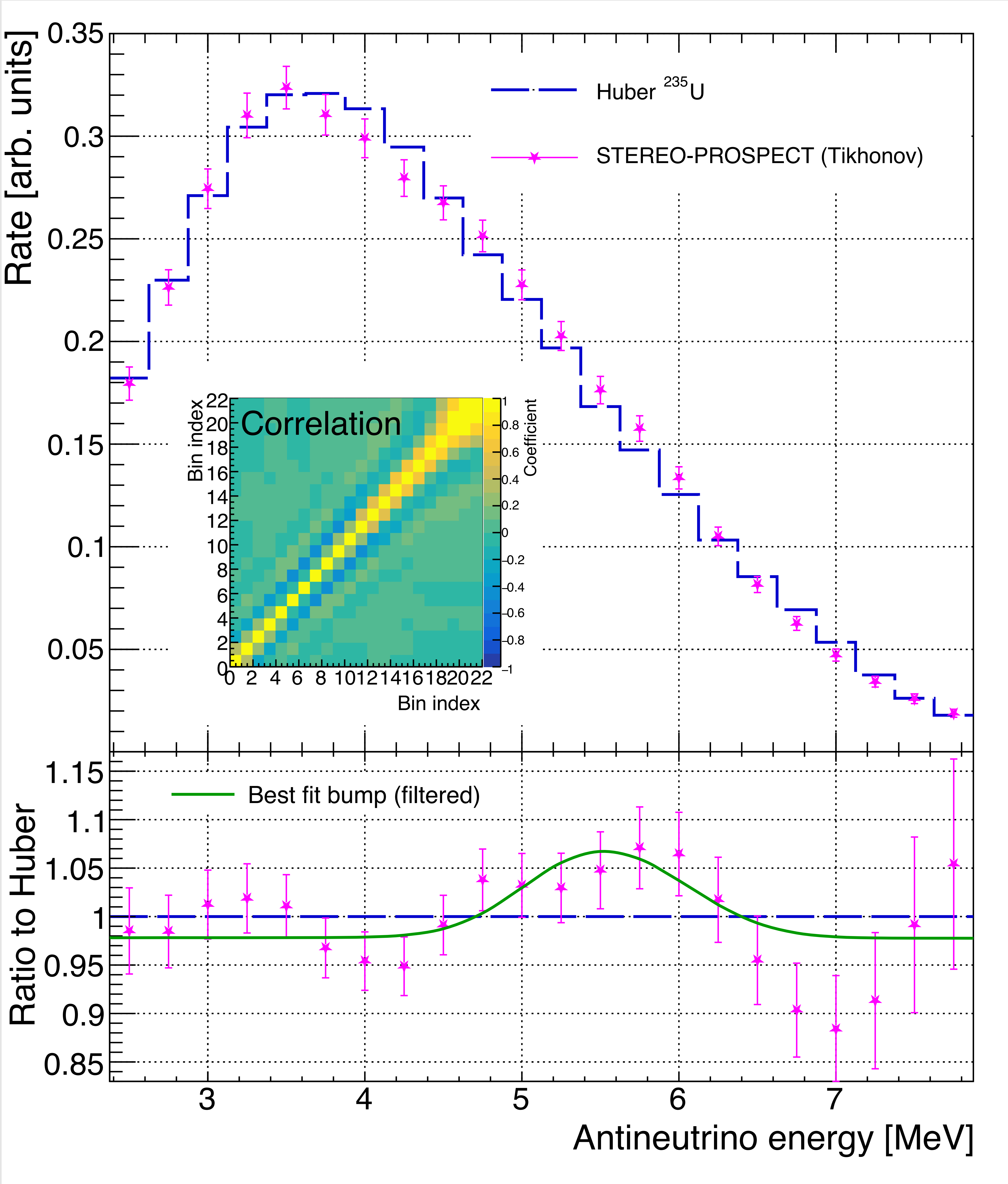
- Use the Tikhonov method to present result
- Using a free floating normalization, best fit to Huber model gives $\chi^2/ndf = 30.8/21$



- Results available (arXiv:2107.03371)
- Thorough supplemental materials, including filter matrix
- Can be directly compared to ^{235}U model predictions

PROSPECT-STEREO: BUMP SEARCH

- 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 $\Delta\chi^2/\Delta ndf = 12.0/3$ (2.4σ significance)



> Find an excess with significance 2.4σ
>
> Consistent with ^{235}U equally contributing to LEU excess

CLOSING STATEMENTS

- Precision measurements needed to resolve origin of the LEU excess
- PROSPECT dataset found to be statistically compatible with both Daya Bay and STEREO datasets
- PROSPECT and Daya Bay have produced a jointly deconvolved reactor antineutrino spectrum which improves both ^{235}U shape uncertainty to 3% and ^{235}U-^{239}Pu correlations by ~20% from Daya Bay-only results.
- PROSPECT and STEREO have successfully combined their separately measured high precision pure ^{235}U spectra, which finds an excess with 2.4σ significance in the 5-6 MeV energy range consistent with equal contribution to LEU excess
- Look out for STEREO's updated dataset, preliminary results shown at EPS-HEP!

OTHER PROSPECT TALKS AT DNP

- Today (Tues):
  - FK.00006: PROSPECT-II: Physics goals with an upgraded precision reactor oscillation and spectrum neutrino experiment - Thomas J Langford
  - FK.00007: Working Towards an Absolute Reactor Antineutrino Flux Measurement using PROSPECT-I Data - Paige Kunkle
  - FK.00008: Reactor Background Measurements at HFIR in Support of the PROSPECT-II Experiment - Blaine Heffron
  - Poster Session: HA.00031: Directional Neutrino Detection with PROSPECT - Manjinder Oueslati
- Tomorrow (Wed):
  - LK.00006: PROSPECT-II calibration strategy - Xiaobin Lu
  - LK.00007: Improved Event Reconstruction and Spectrum Analysis using PROSPECT Antineutrino Data - Christian Roca Catala
  - LK.00008: Improved Inverse Beta Decay event selection and its impact on the PROSPECT oscillation analysis - Diego C Venegas Vargas


PROSPECT
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