CRISTIAN ROCA CATALA - 19.09.2023

Reactor antineutrino spectrum from reactor data

AAP York 2023

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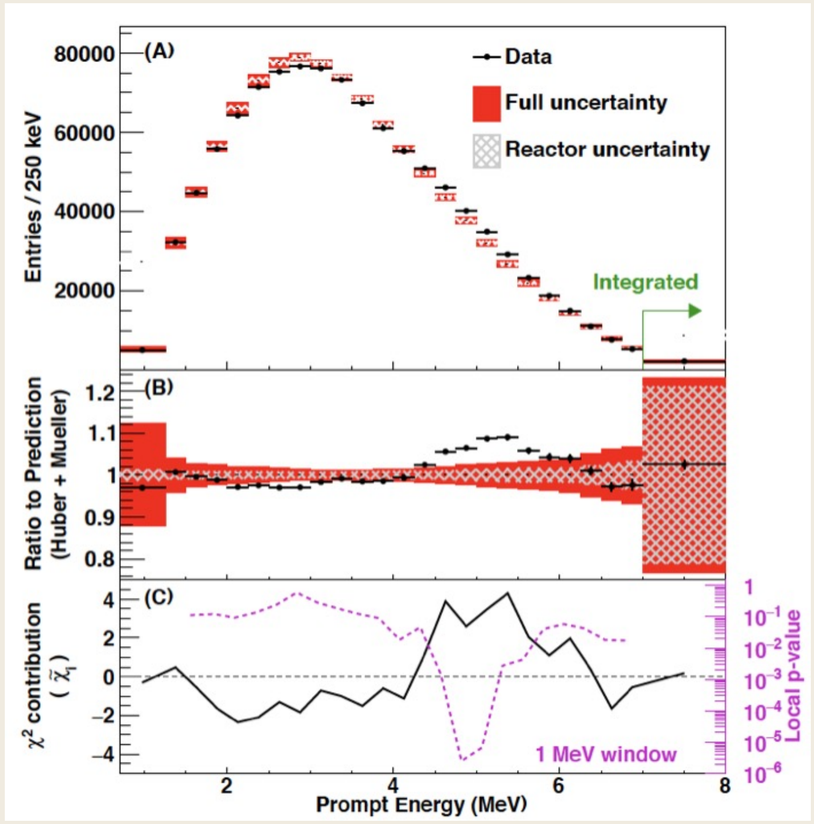
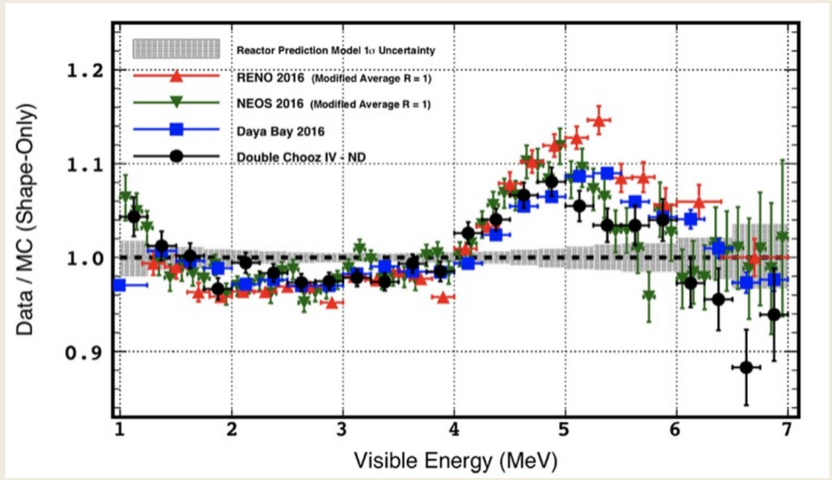
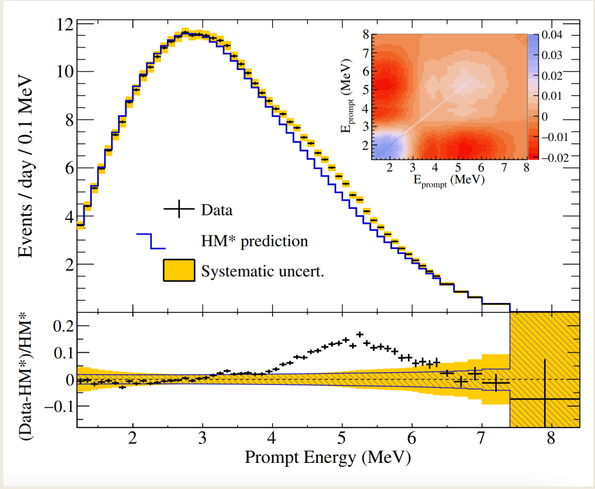
“The Bump” in LEU reactor data



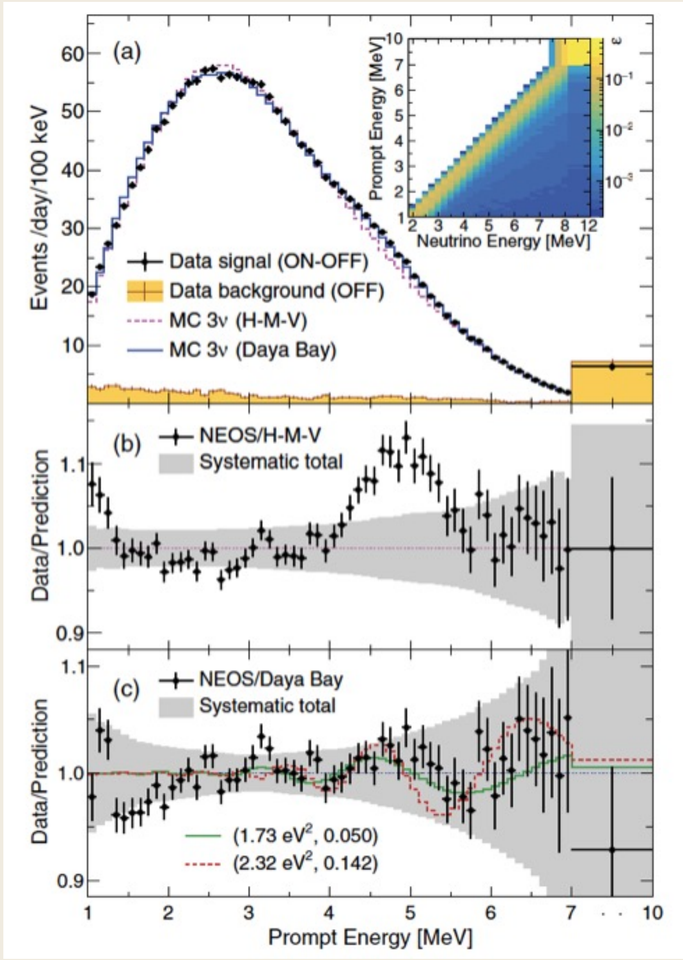
Daya Bay (2017), CPC: 41(1), 13002



Double Chooz (2020), Nature: 16,558



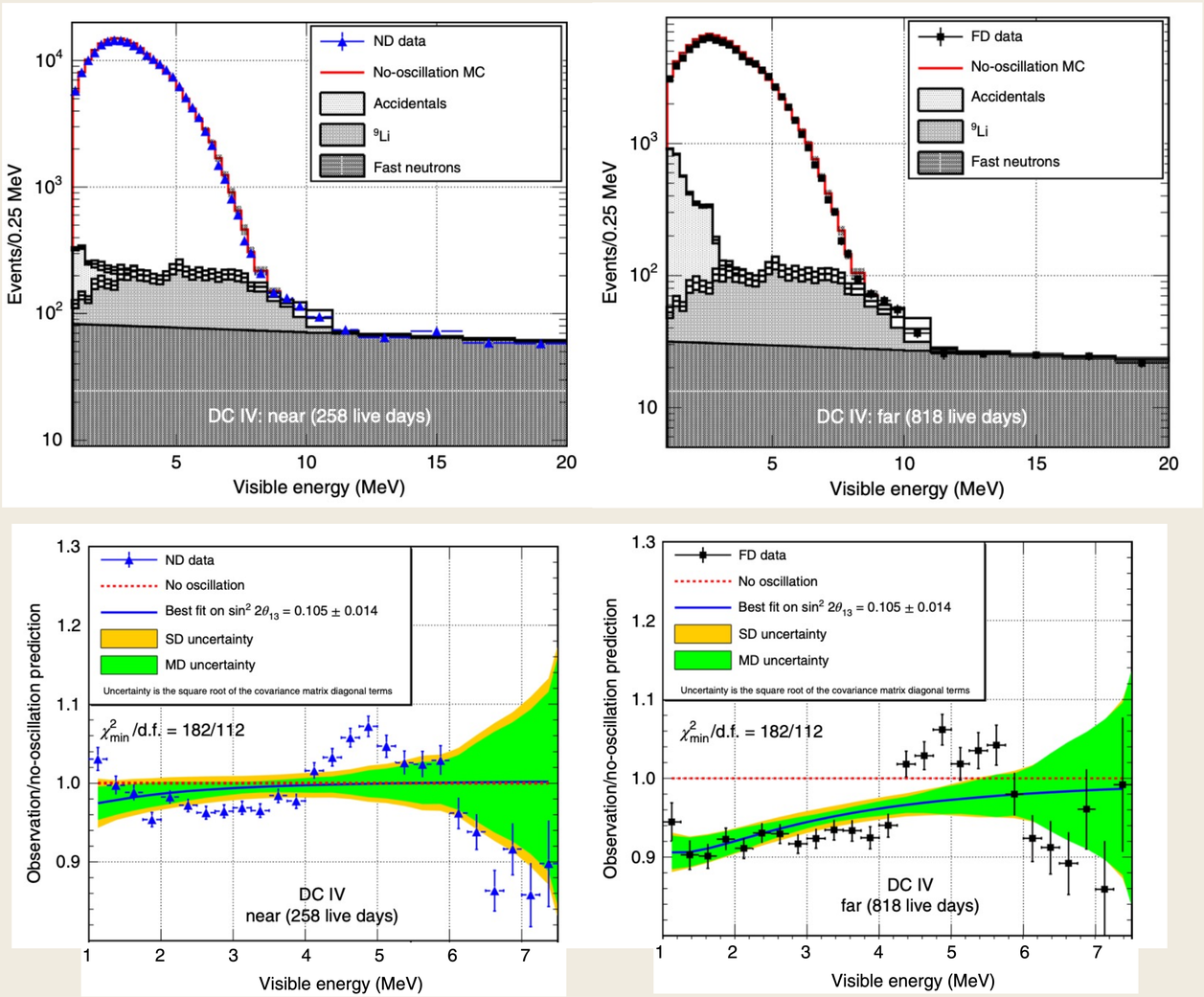
RENO (2021), PRD: 104, L111301



NEOS (2017), PRL: 118,121802

LEU Spectrum: Double Chooz

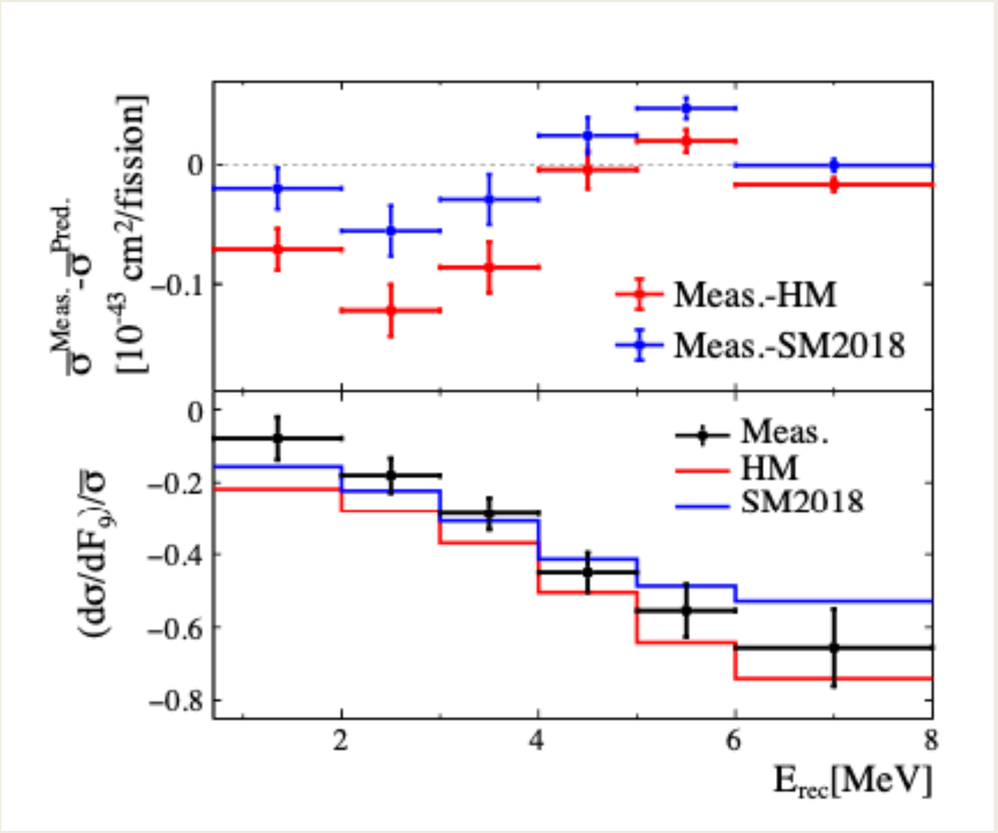
- Main disagreement with non-oscillation due to θ_{13} and 5MeV bump.
- Shape disagreement affects uncertainty budget in calculating θ_{13}
- Excesses observed at $6.7\sigma/7.1\sigma$ for ND and FD data.



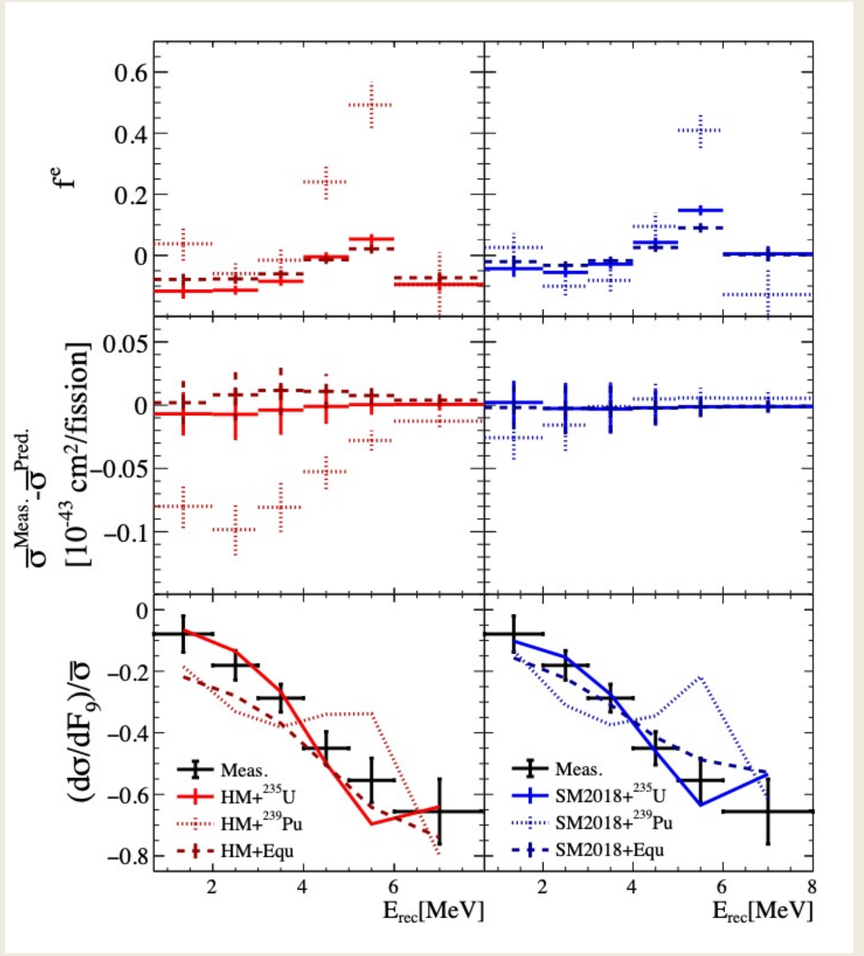
Double Chooz (2021), Nature: s41567-020-0831

LEU Spectrum: Daya Bay

Daya Bay (2019), PRL: 123, 111801



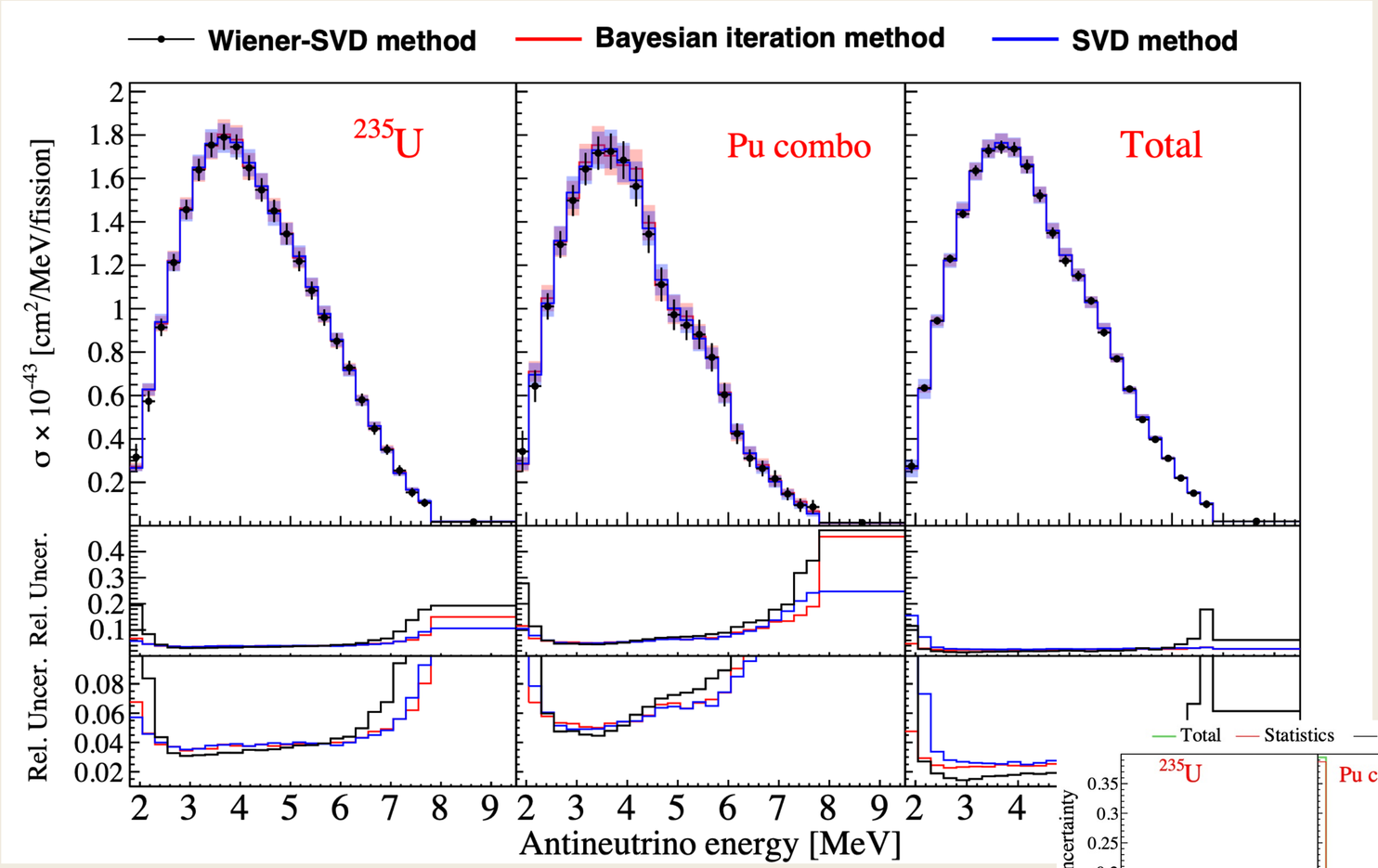
Model	χ^2/NDF	η
HM+^{235}U	83/71 (1.4)	0.985±0.021
	83/72 (1.4)	1 (fixed)
SM2018+^{235}U	80/71 (1.2)	0.997±0.021
	80/72 (1.2)	1 (fixed)
HM+^{239}Pu	116/71 (3.4)	0.935±0.014
	136/72 (4.5)	1 (fixed)
SM2018+^{239}Pu	126/71 (4.0)	0.995±0.014
	127/72 (4.0)	1 (fixed)
HM+Equ	89/72 (1.7)	NA
SM2018+Equ	82/72 (1.3)	NA



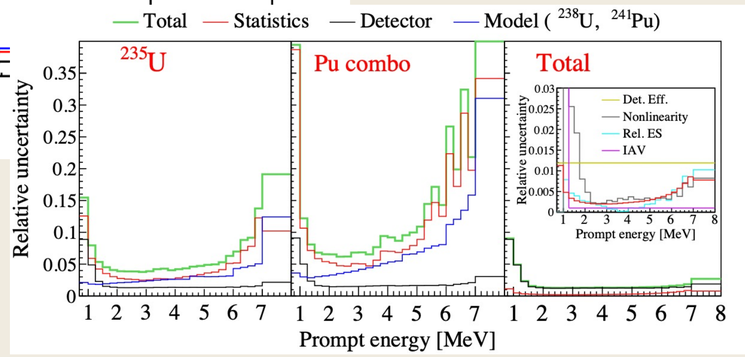
- While models don't properly predict shape, they show agreement on the fuel evolution
- Modified U235 and Eq give compatible spectral results between model and DB data

LEU Spectrum: Daya Bay

- F.F. evolution allows for isotopical spectrum separation.
- Each promt spectrum can be unfolded into antineutrino space!
- Wiener-SVD unfolding with 3% bin-to-bin uncorrelated fluctiation variation in model: “model independent”
- Wiener-SVD gives better performance between 3-6 MeV.

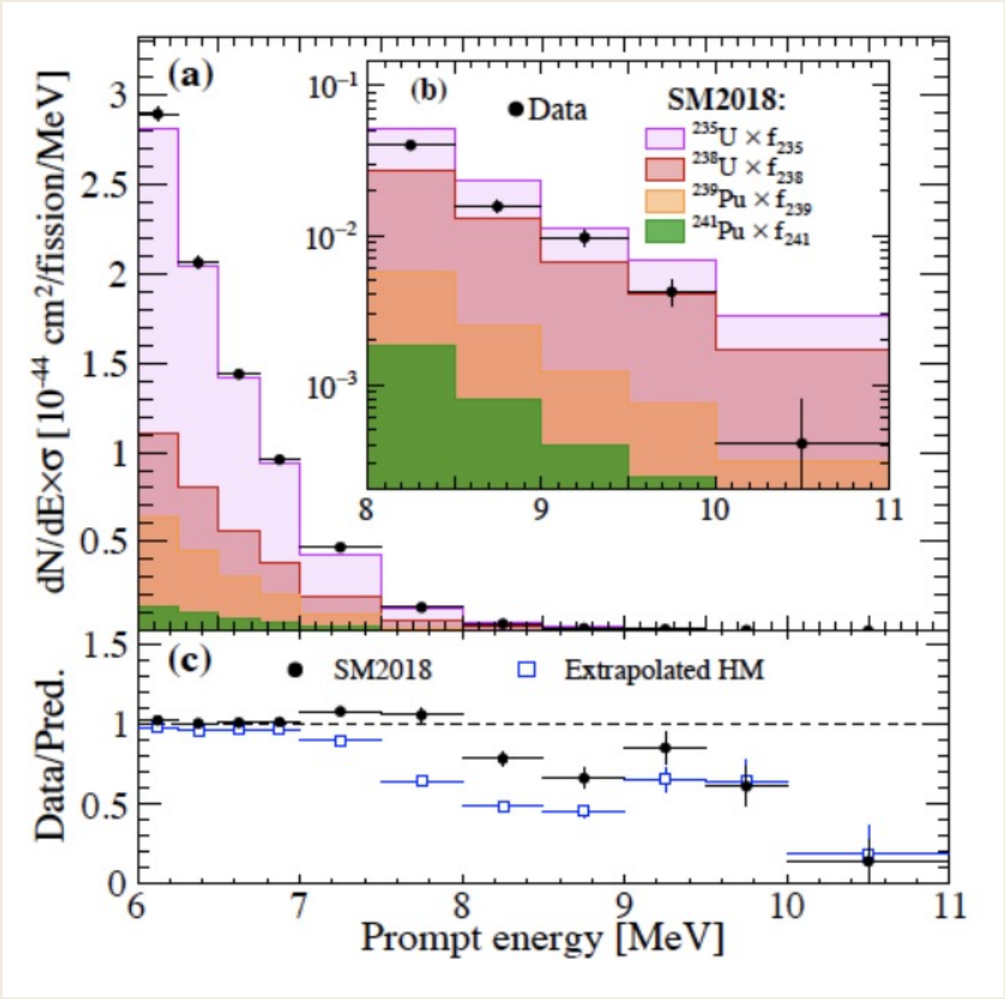


Daya Bay (2021), arXiv: v2102.04614v3



Daya Bay: High Energy RA

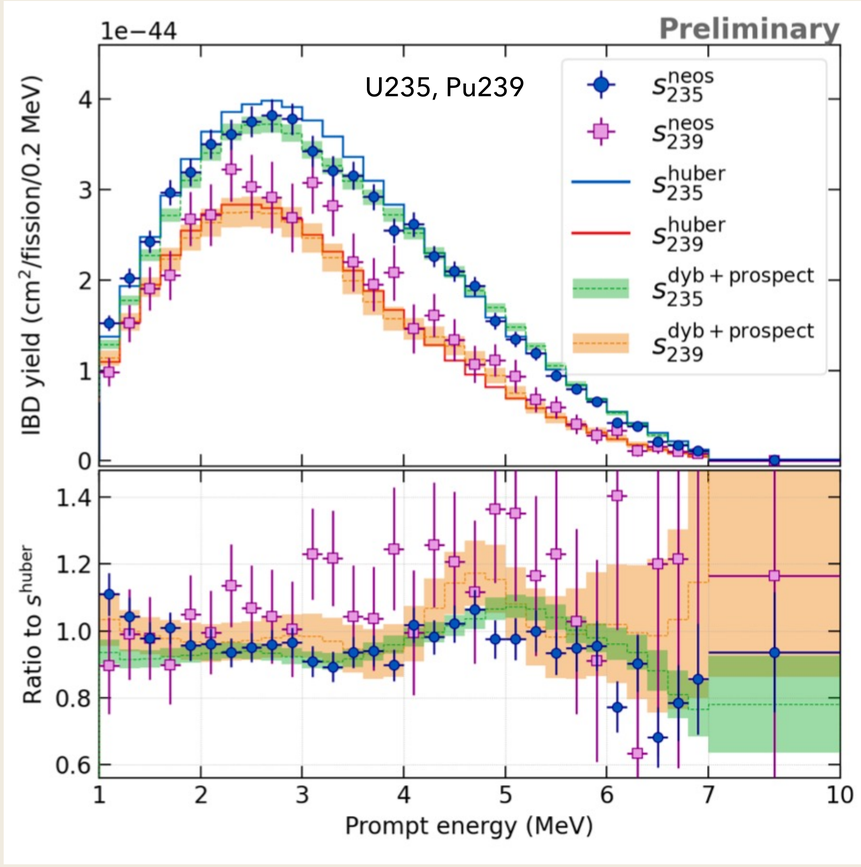
- Test of summation predictions in new regime
- Provides the first direct observation from several high Q isotopes in LEU reactors
- Hypothesis that no reactor neutrinos are present above 10MeV is rejected with 6.2s
- A 29% flux deficit between [8-11] MeV found with model predictions

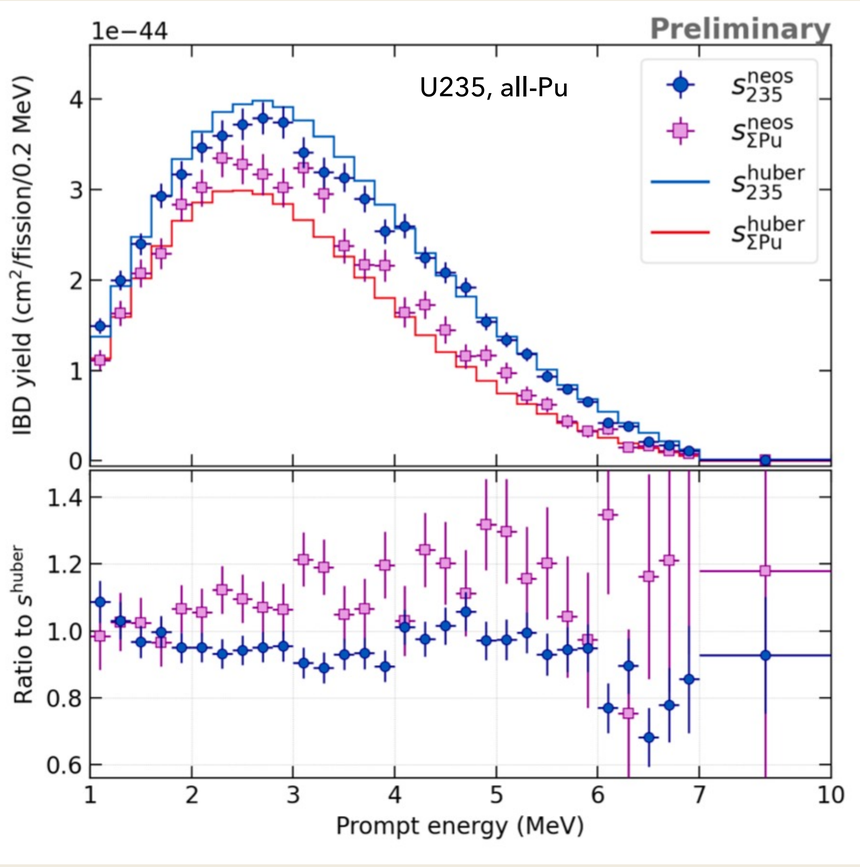


Daya Bay, arXiv: 2203.06686

LEU Spectrum: NEOS-II

- Spectral decomposition method expects uncertainties of ~4% and ~20% for U35 and Pu39 respectively
- Bump observed for both U235 and Pu239

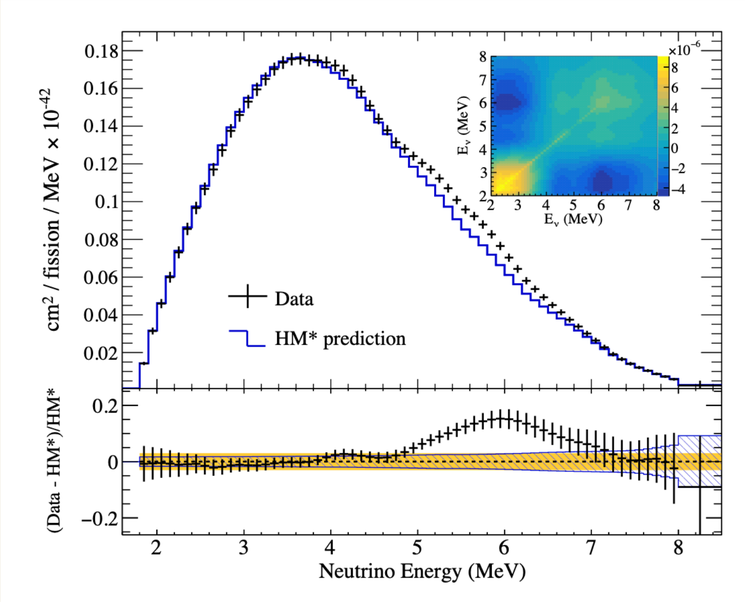




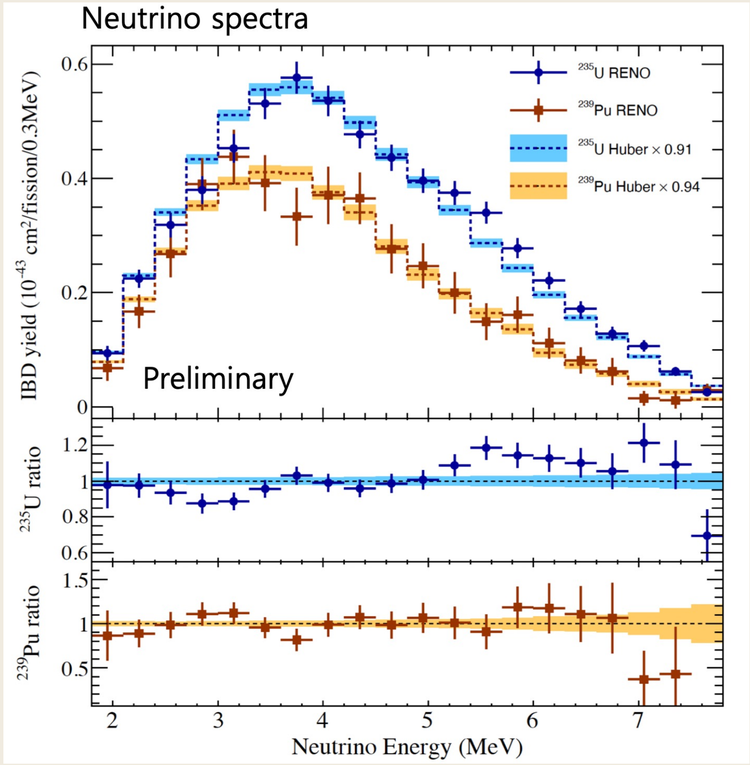
NEOS-II, Neutrino22: 6680618 Cristian Roca Catala - AAP York 2023

LEU Spectrum: RENO

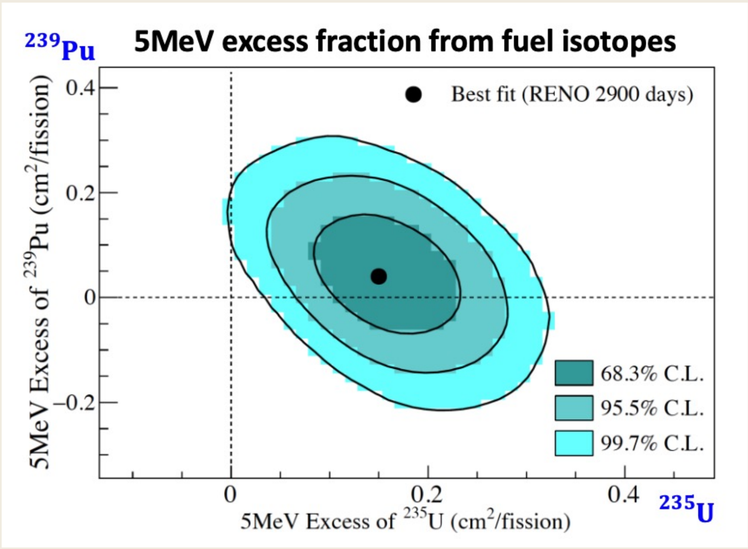
RENO, PRD: 04.L111301



- First report of RA spectrum.
- Oscillation removed using measured θ_{13}
- Clear excess observed at 6MeV



RENO, Neutrino22: 6683722



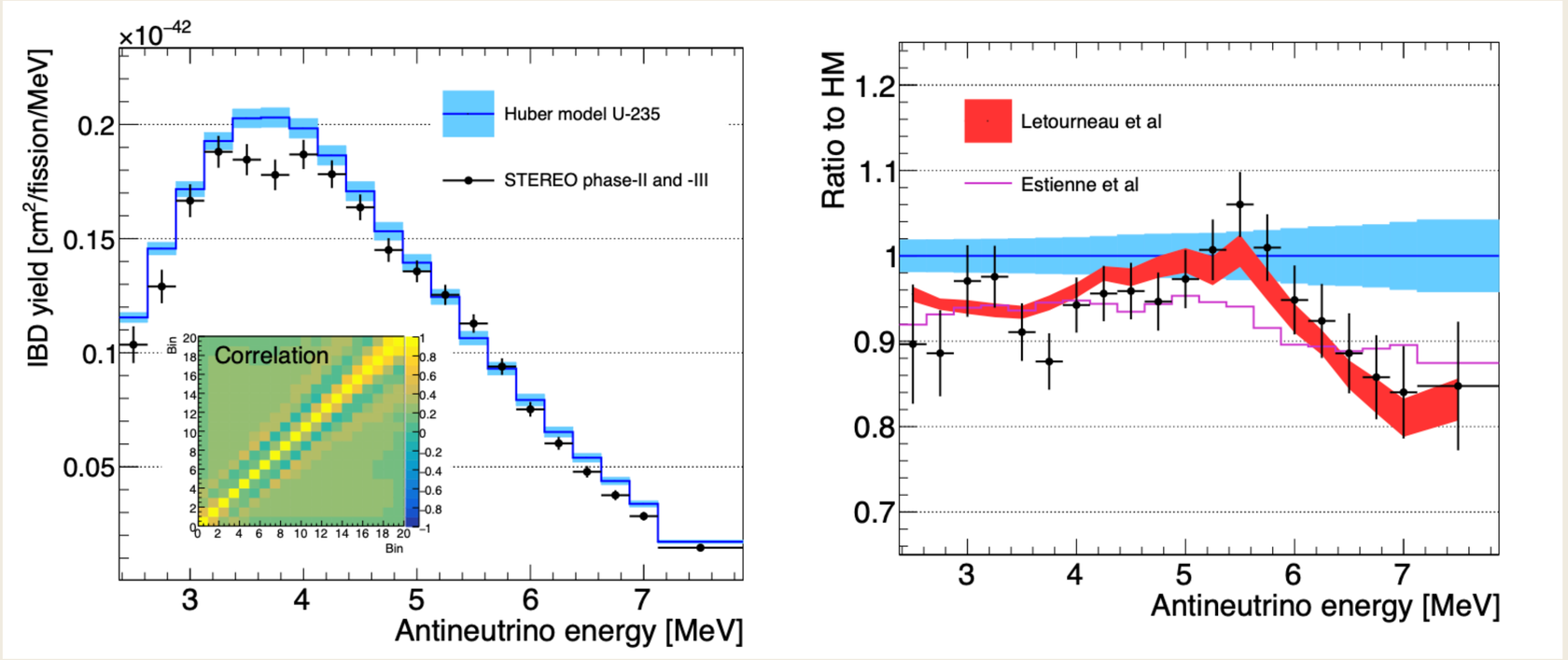
- Excess observed for all isotopes. However U235 appears to be the main contributor:

- **5 MeV excess :**
  - ^{235}**U** = **(2.5 ±0.7) %** of the observed total flux (**3.9σ**)
  - ^{239}**Pu** = **(0.9 ± 1.7) %** to the observed total flux (**0.6σ**)

HEU Spectrum - STEREO

STEREO, arXiv: 2210.07664

- 4.6σ for the 5.5 MeV bump with $15.6 \pm 5.3\%$wrt HM model
- Good agreement both in shape and normalization is found with recent summation models.

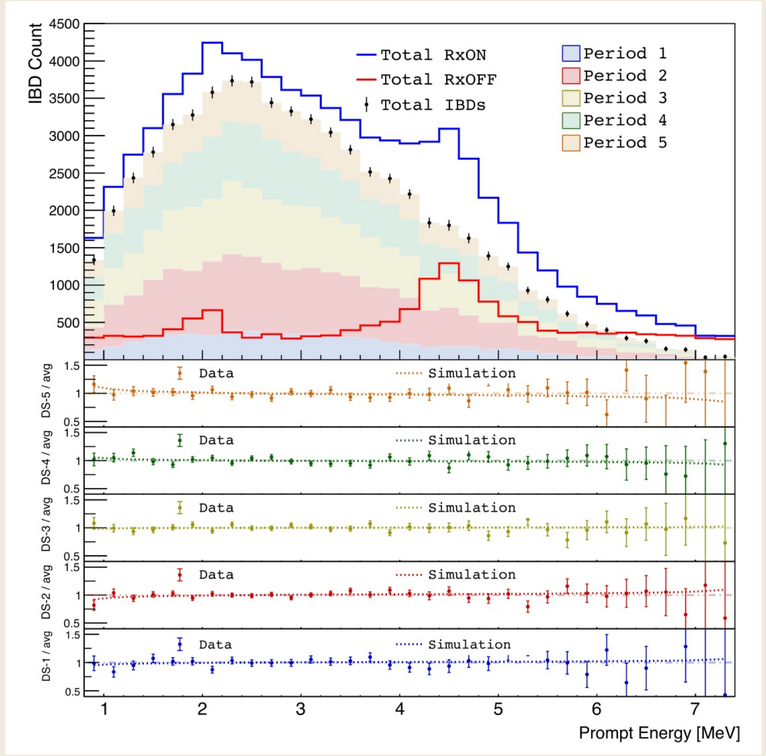


MODELS:

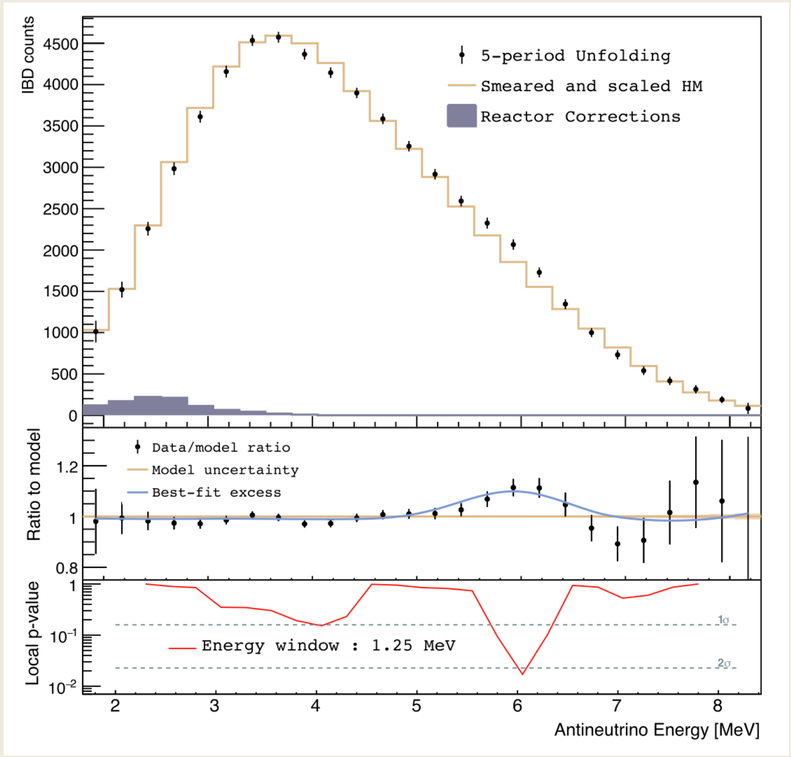
- Explains main deficit observed
- Shape distortion at high energies.

HEU Spectrum - PROSPECT

PROSPECT, PRL: [131.021802]



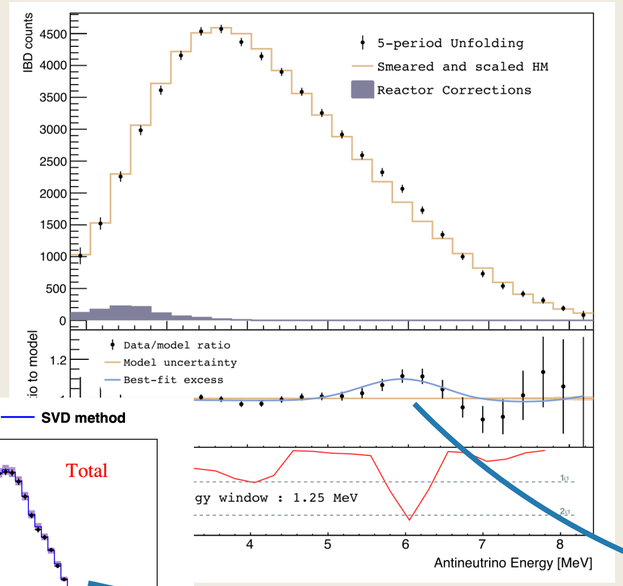
Wiener-SVD Unfolding



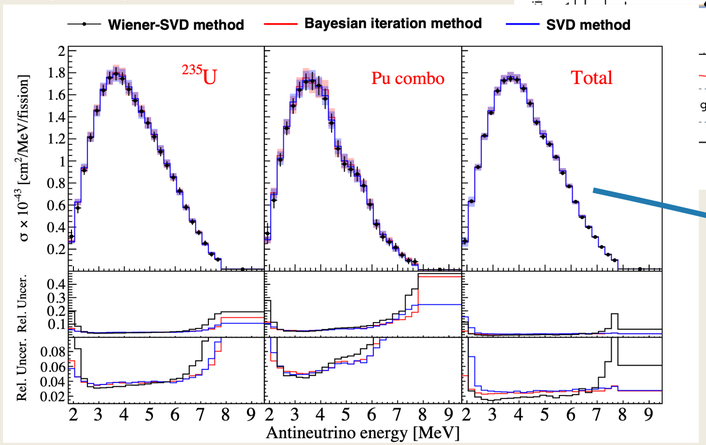
- Multi-period unfolding using Wiener-SVD technique
- Observed excess A = 11 +- 4% wrt conversion HM model
- Comparison between PRO and DYB allows for hypotheses constraining

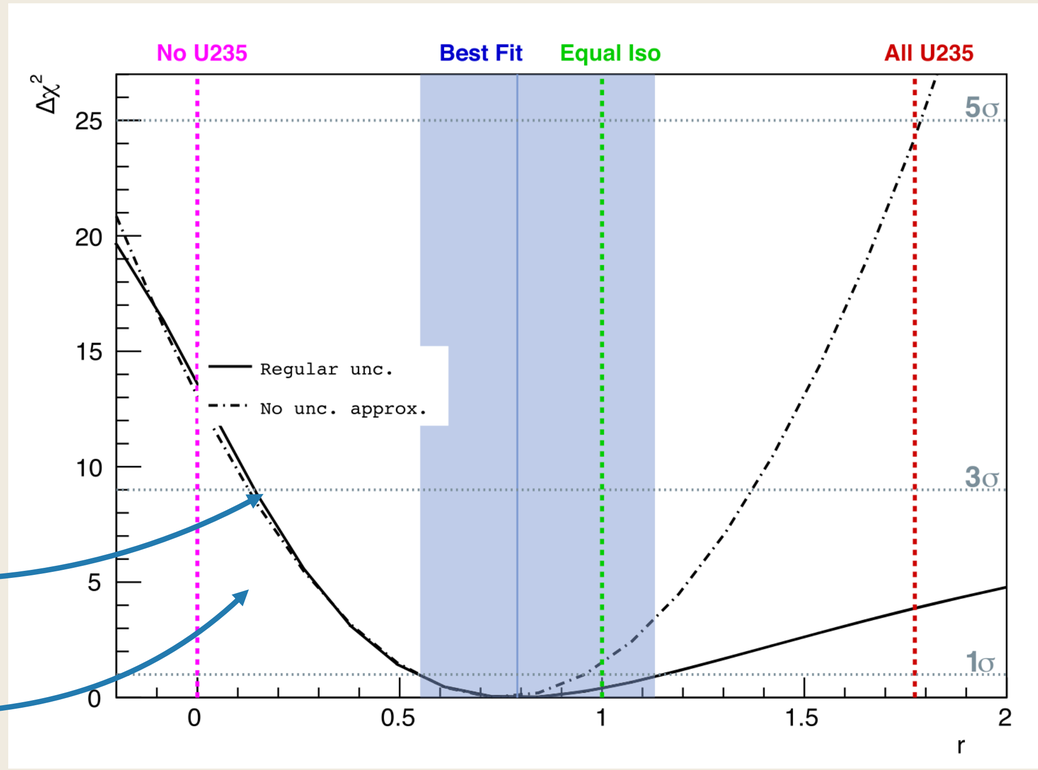
HEU Spectrum - PROSPECT

PROSPECT, PRL: 131.021802



Daya. Bay, arXiv: 2102.04614

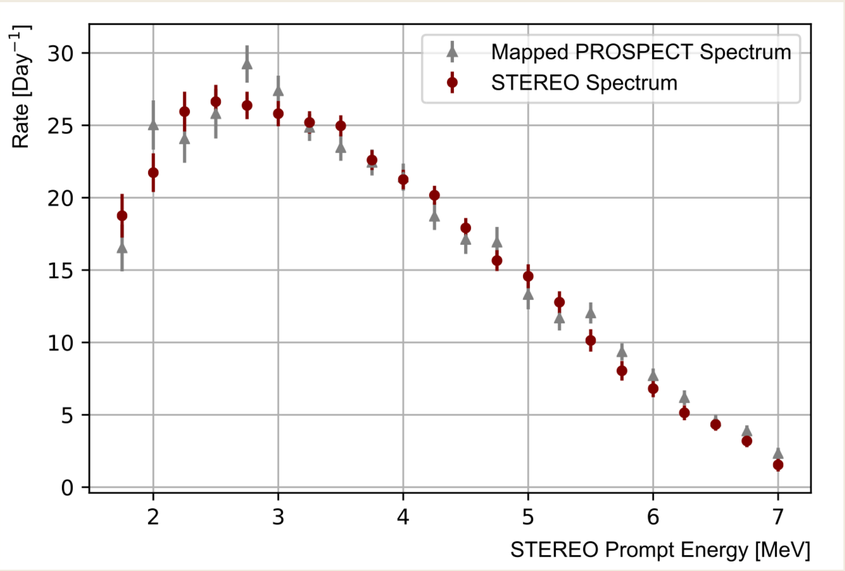




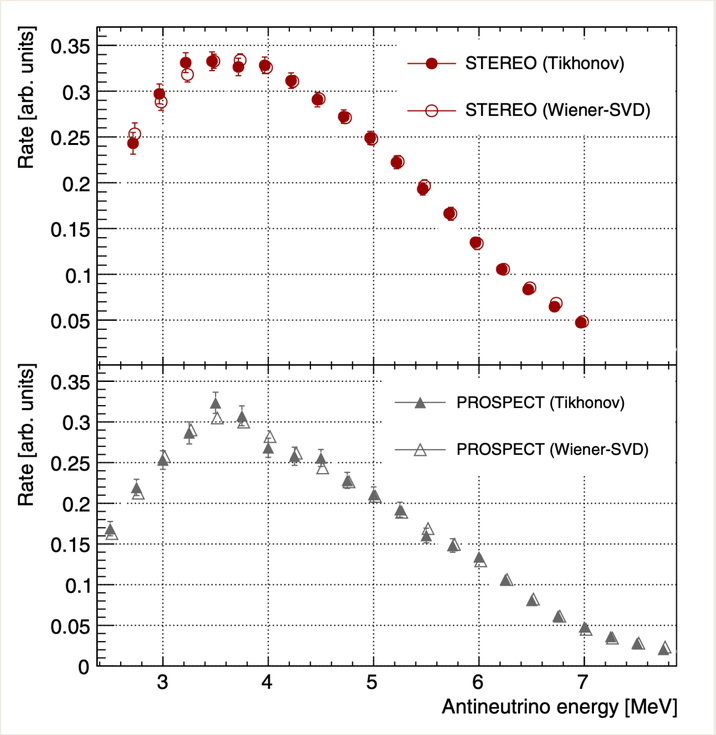
- Calculate r = A_PRO / A_DYB as bump amplitude ratio between HEU and LEU
- $r = 0.79^{+0.35}_{-0.25}$ >> 0 –> Rejects No-U235 hypothesis at 3.7σ
- << 1.7 –> Rejects All-U235 at ~ $2.0/5.0\sigma$ (with /without DYB sys. unc.)

HEU + HEU joint Analysis: PROSPECT + STEREO

- Multi-reactor and multi-detector dataset compatibility was verified:

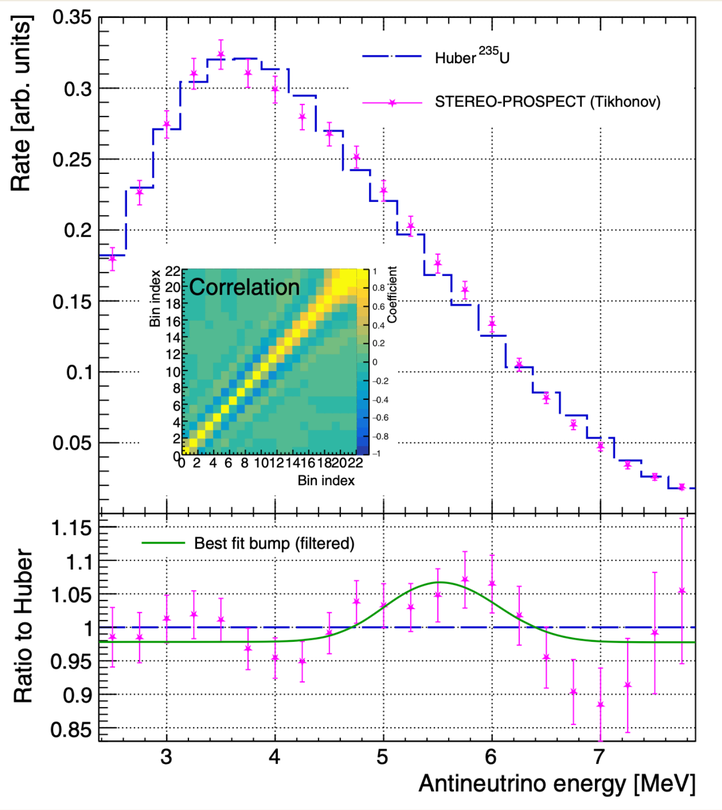


STEREO + PROSPECT (2021), PRL: 123, 111801

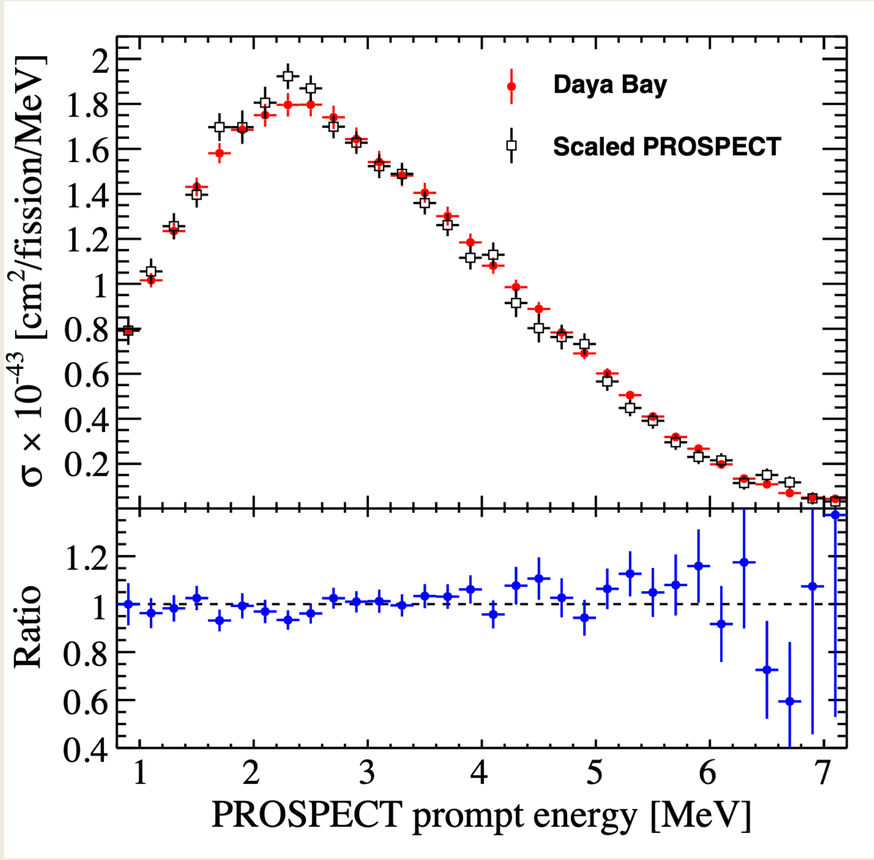


- Two unfolding methods tested, with compatibility between the two being stablished. Tikhonov used (introduction of less bias observed)

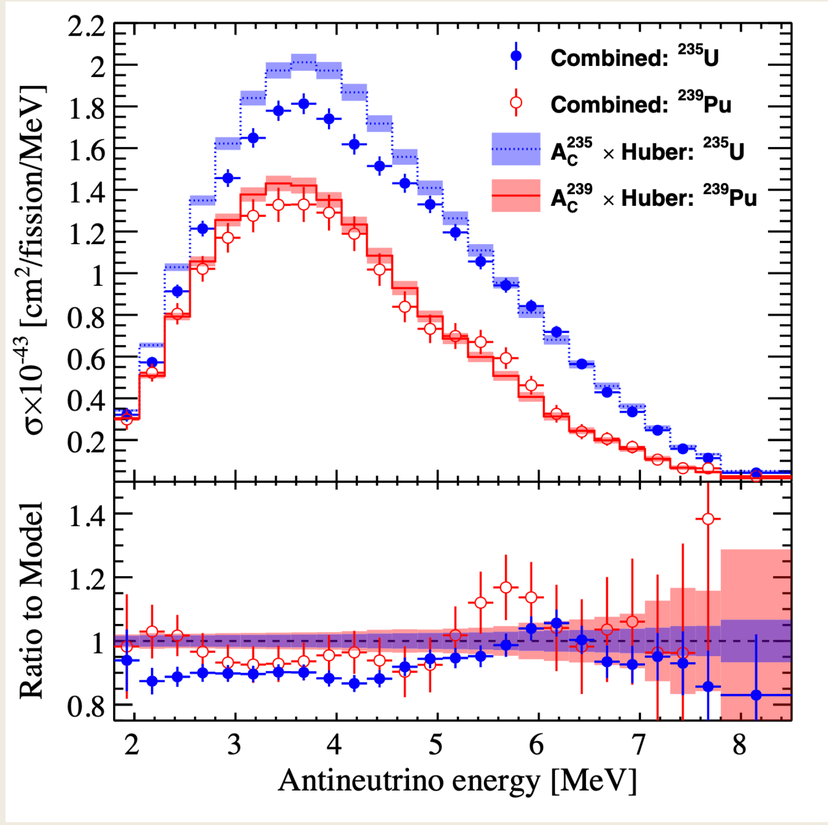
- Joint unfolding provides a reference of U235 spectrum for the community. Excess with 2.4σ



HEU + LEU joint analysis: PROSPECT + DAYA BAY



- First HEU + LEU combined analysis
- Compatibility between HEU and U235-LEU was verified in PROSPECT prompt space
- Combined analysis reduces degeneracy between dominant U235 and Pu238 isotopes
- Relative shape uncertainty of U235 improved to 3%. Excess significance improved
- WienerSVD used as unfolding technique.

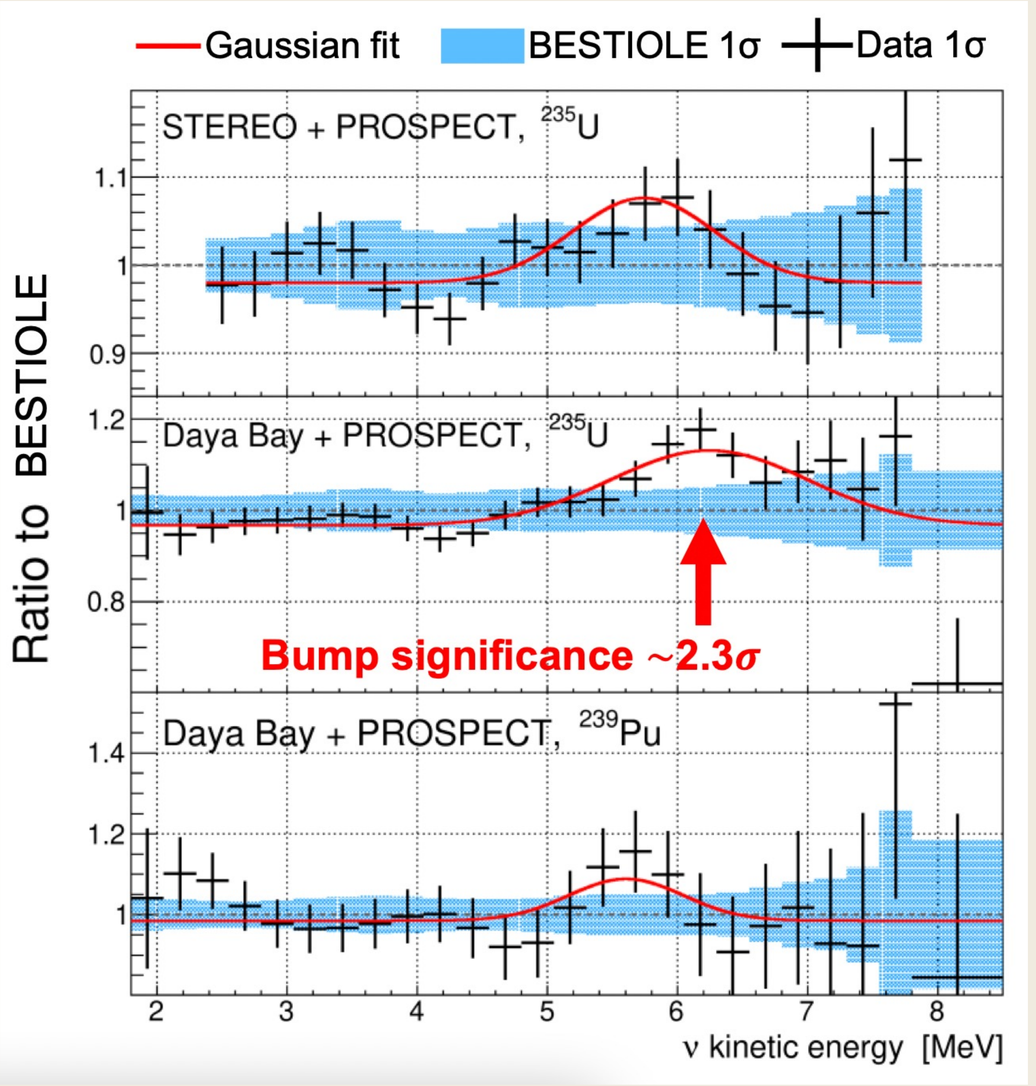


Data v Model comparison

- Significant bump observed time and time again when comparing data with HM conversion and common ab initio models (e.g. Estienne et. al)

- Recent summation model Letuourneau et. al. showed much better agreement with Stereo. BESTIOLE code shows relative agreement with HEU and LEU and no significant excess except for DB + PROSPECT data.

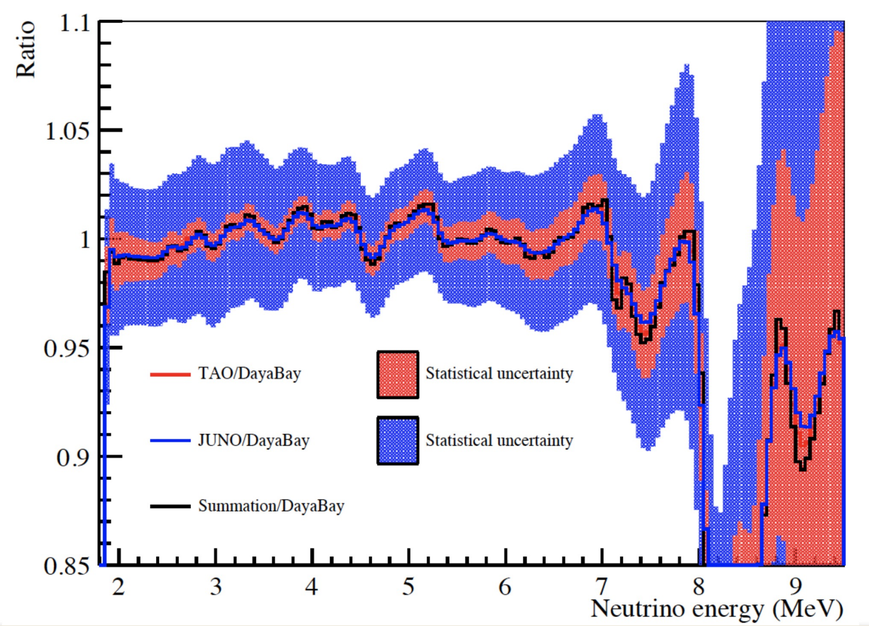
- BESTIOLE code finds tension with ILL data / HM model.



Future

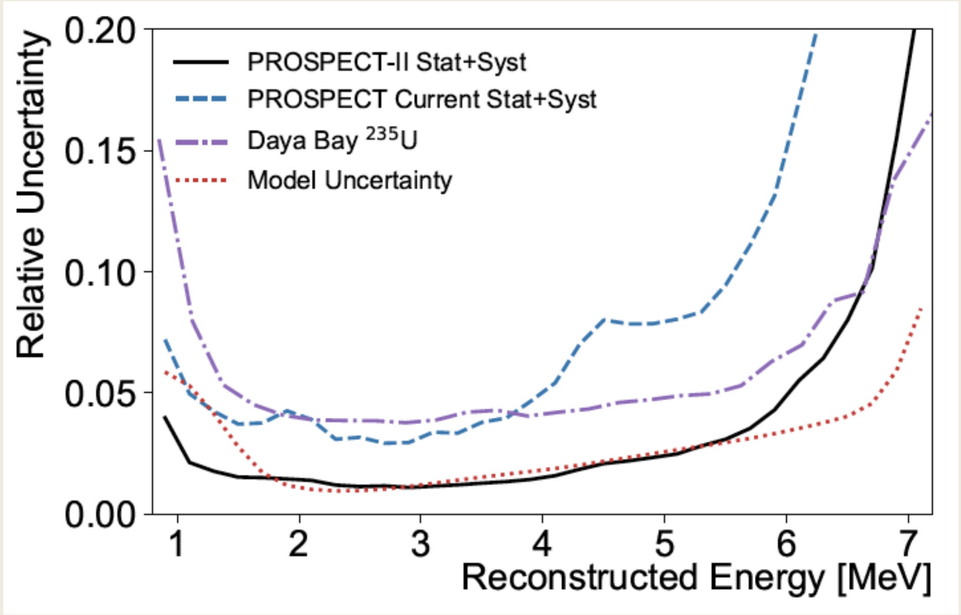
JUNO-TAO

- 1ton Gd-LS volume. Leveraging past experiments experience
- High resolution and statistics, wide range of f.f. at single reactor source will also improved extraction of isotope spectra



PROSPECT-II

- Address technical challenges of PROSPECT
- Relocatable between HEU and LEU reactors: address biggest challenge when combining datasets, combined systematic uncertainties



Conclusions

- Great world-wide effort into observing RA and their spectrum. Tremendous progress achieved in the last decade.
- High precision measurements put to manifest incomplete models: Spectrum “bump” anomaly
- More and more measurements have quantified the magnitude of the anomaly. Walls are closing in on the responsible isotopes and their particular contributions.
- Recent efforts in observing underlying nuclear data and updated predictions are narrowing down causes and solutions for the anomaly.
- International cooperation is creating a database of spectra that will be used as benchmark for many years.