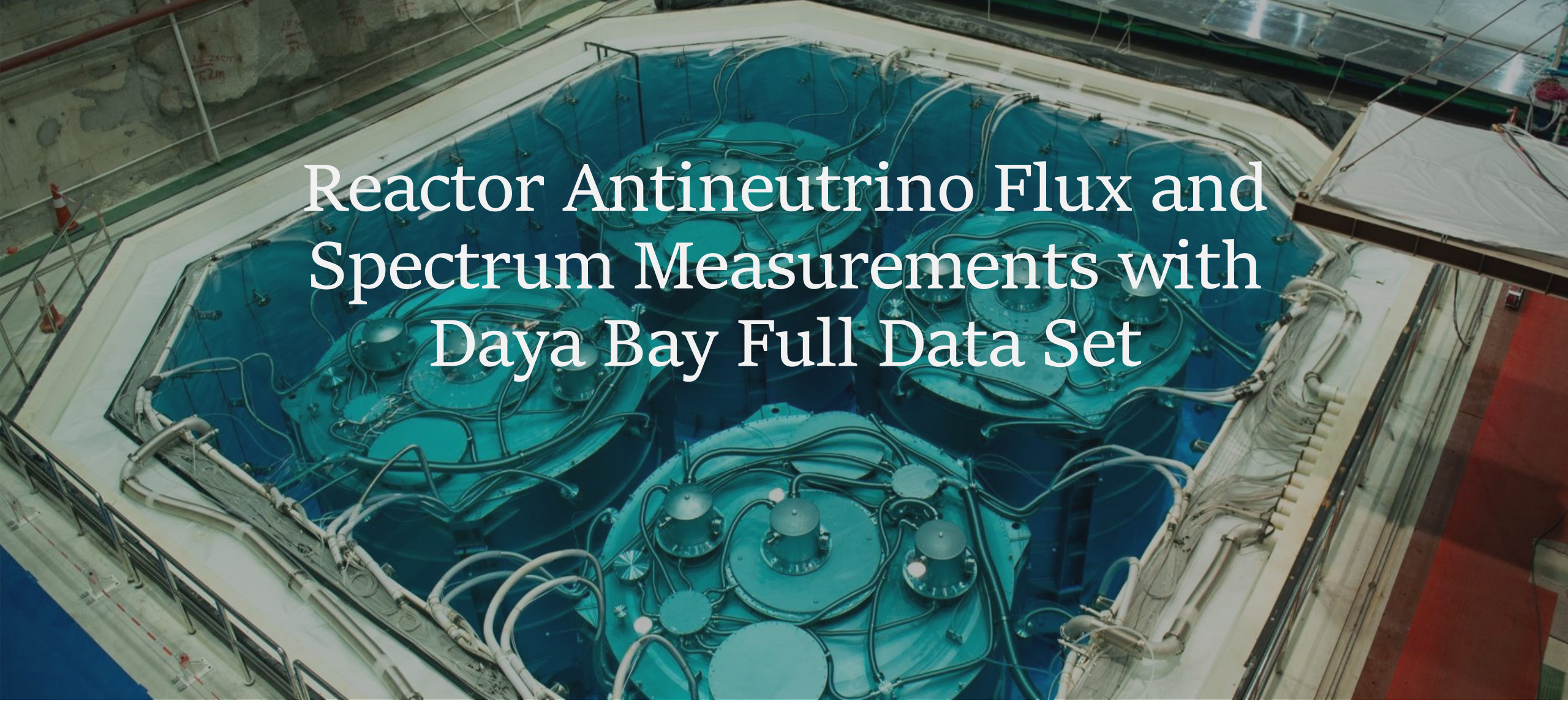


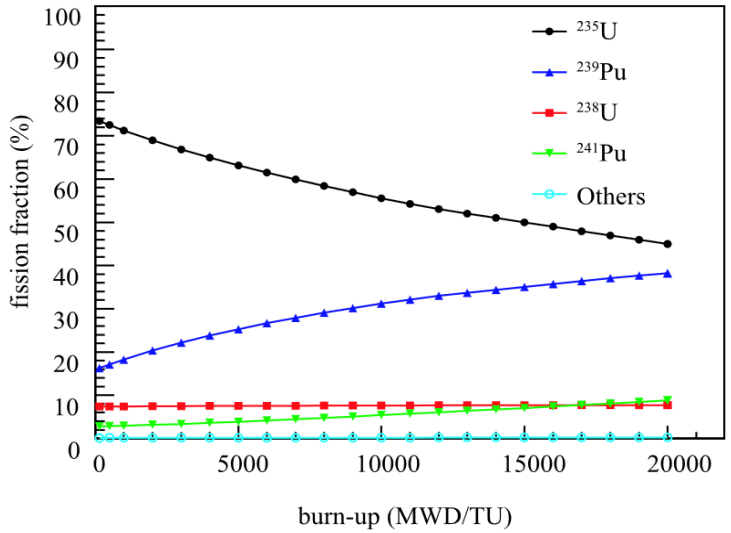
Reactor Antineutrino Flux and Spectrum Measurements with Daya Bay Full Data Set

Jinhao Huang* (IHEP), Yang Han (SYSU)

(On behalf of the Daya Bay Collaboration)

ICHEP 2024, 18 July

Reactor $\bar{\nu}_e$ detection



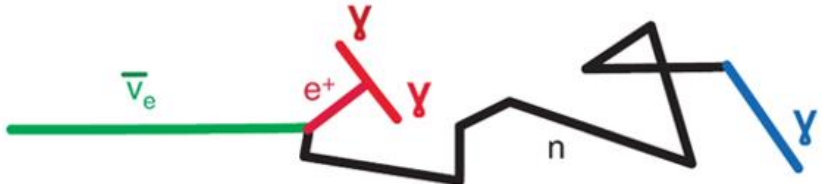
Chinese Phys. C 41 013002 (2017)

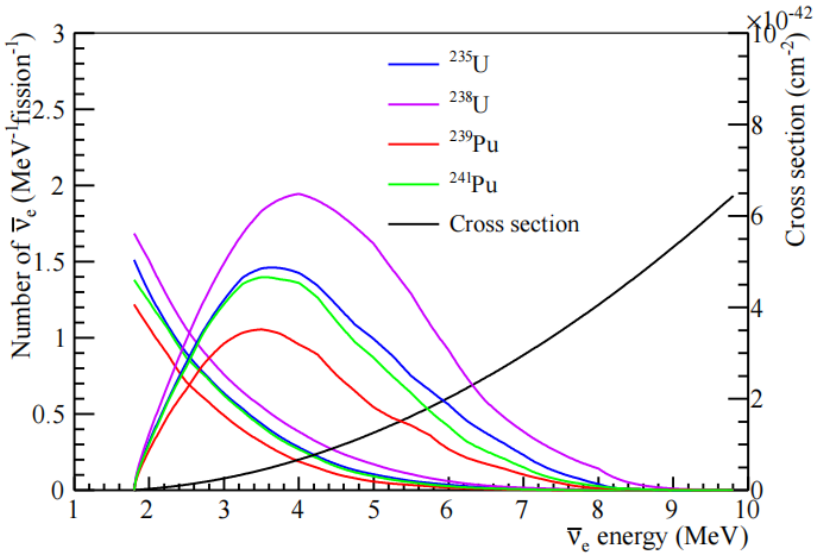
More than 99% $\bar{\nu}_e$ originate from the beta decays of fission fragments of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu

Inverse Beta Decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

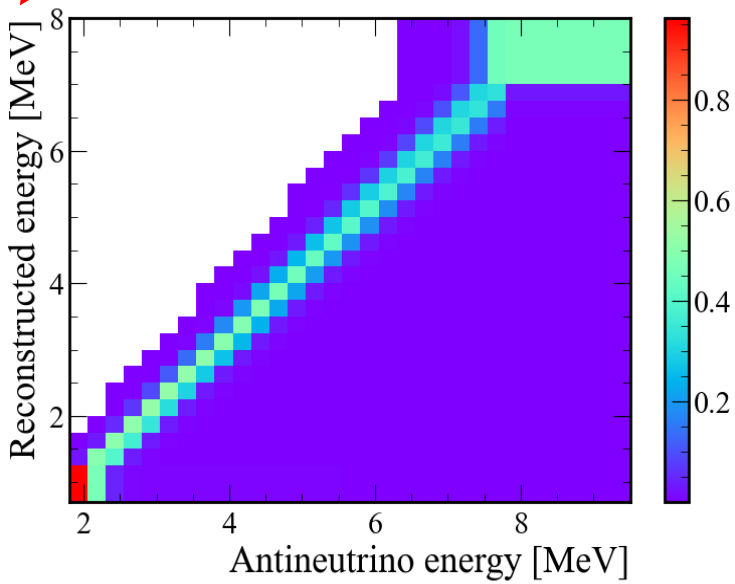
Prompt Delayed





- e^+ preserves the energy information of incoming $\bar{\nu}_e$
  - $E_{dep} \approx E_{\bar{\nu}_e} - 0.8$ MeV

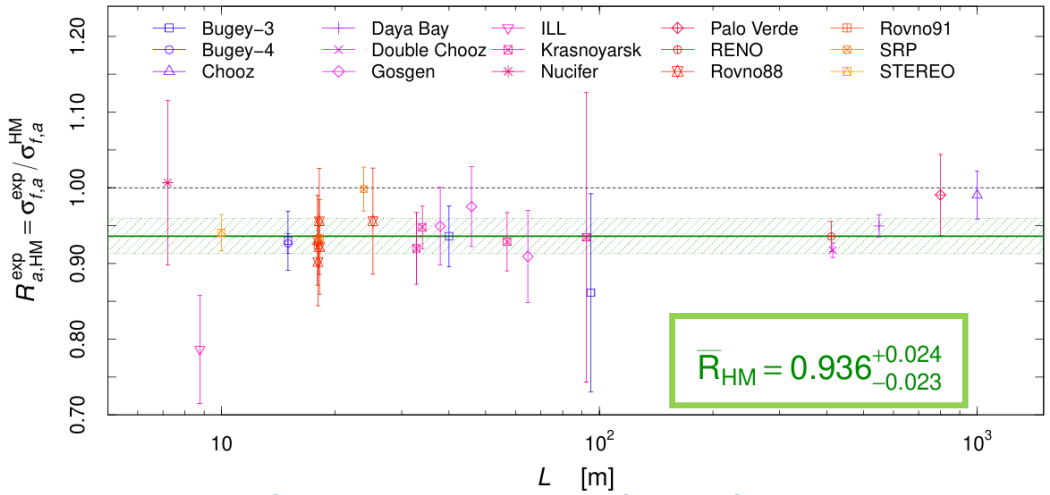
Response matrix



Flux and spectrum anomalies

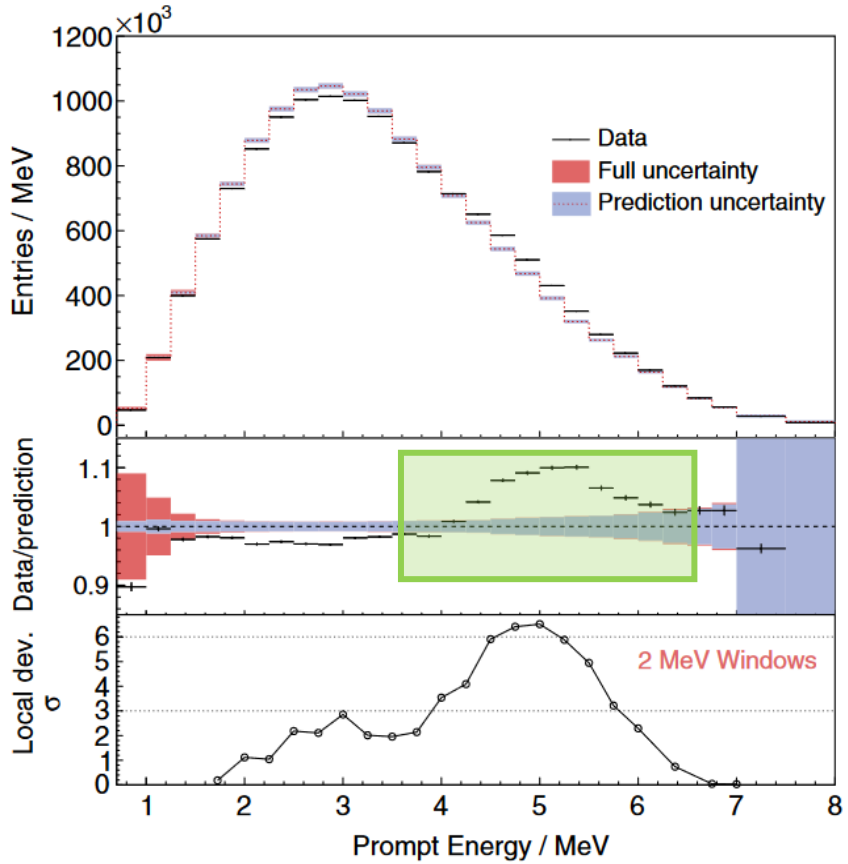
- Two types of models:
  - **Conversion:** Huber-Mueller(HM), KI, …
  - **Summation:** SM2018, …

Flux deficit



Phys. Lett. B 829 (2022) 137054

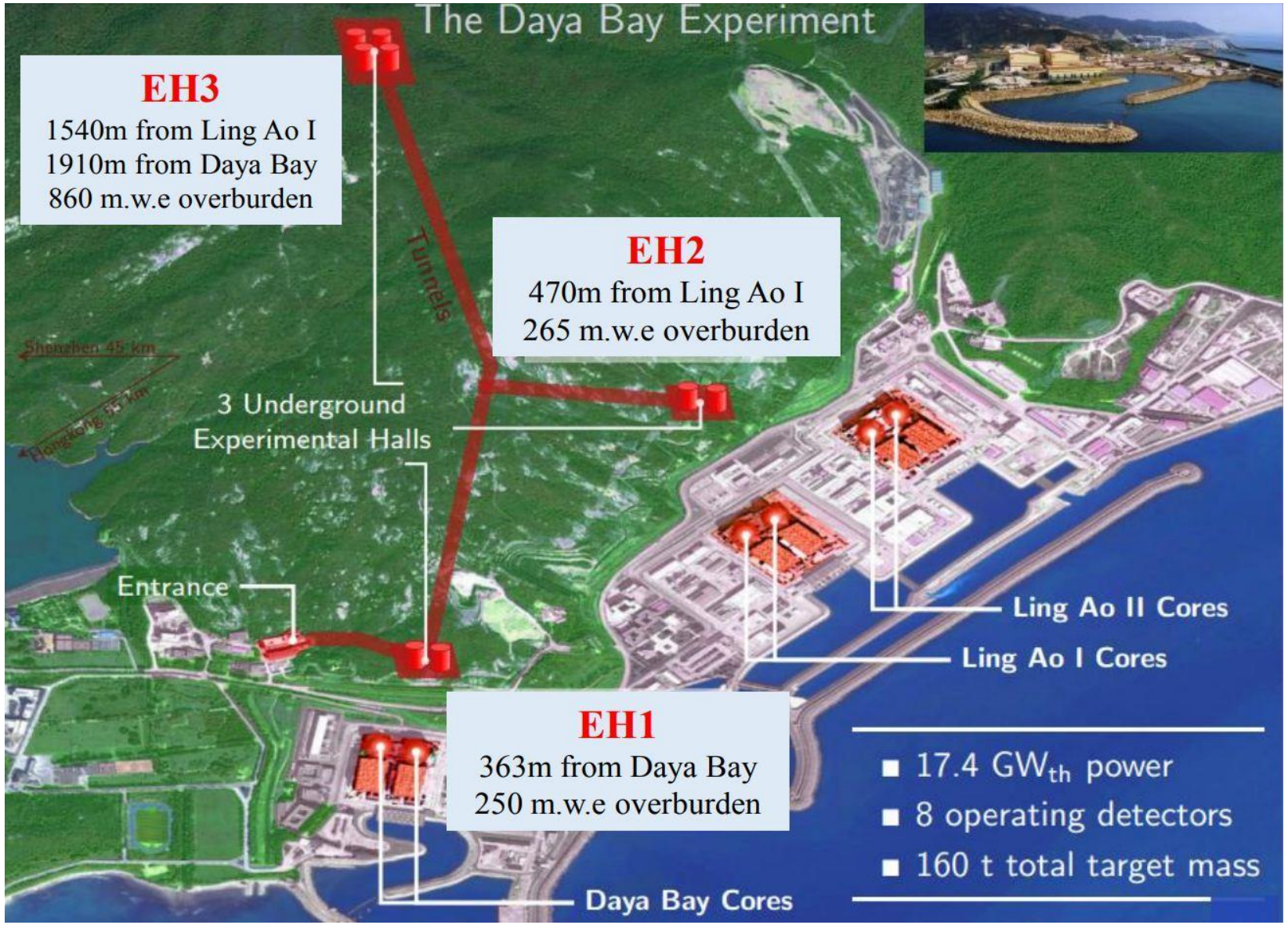
"5 MeV bump"

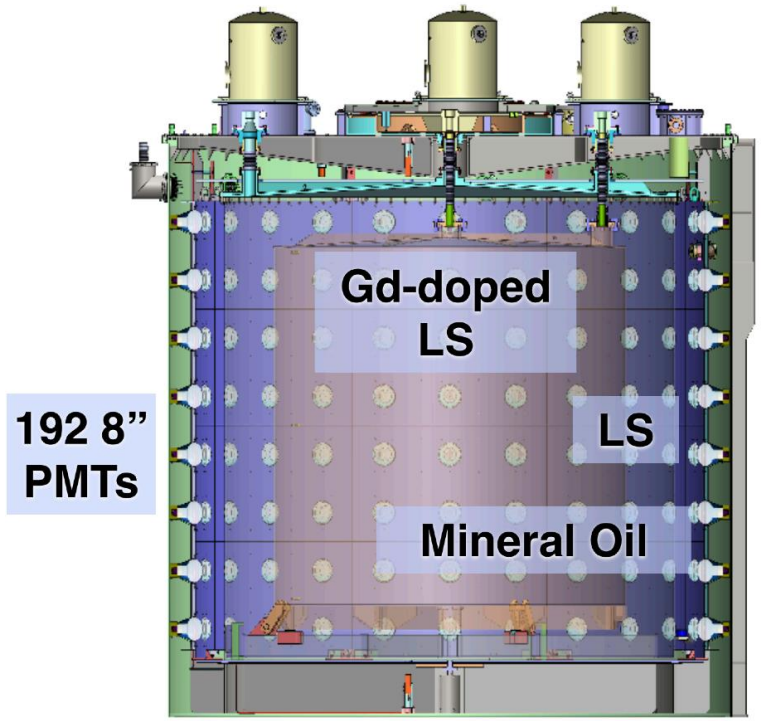


Phys. Rev. Lett. 123, 111801 (2019)

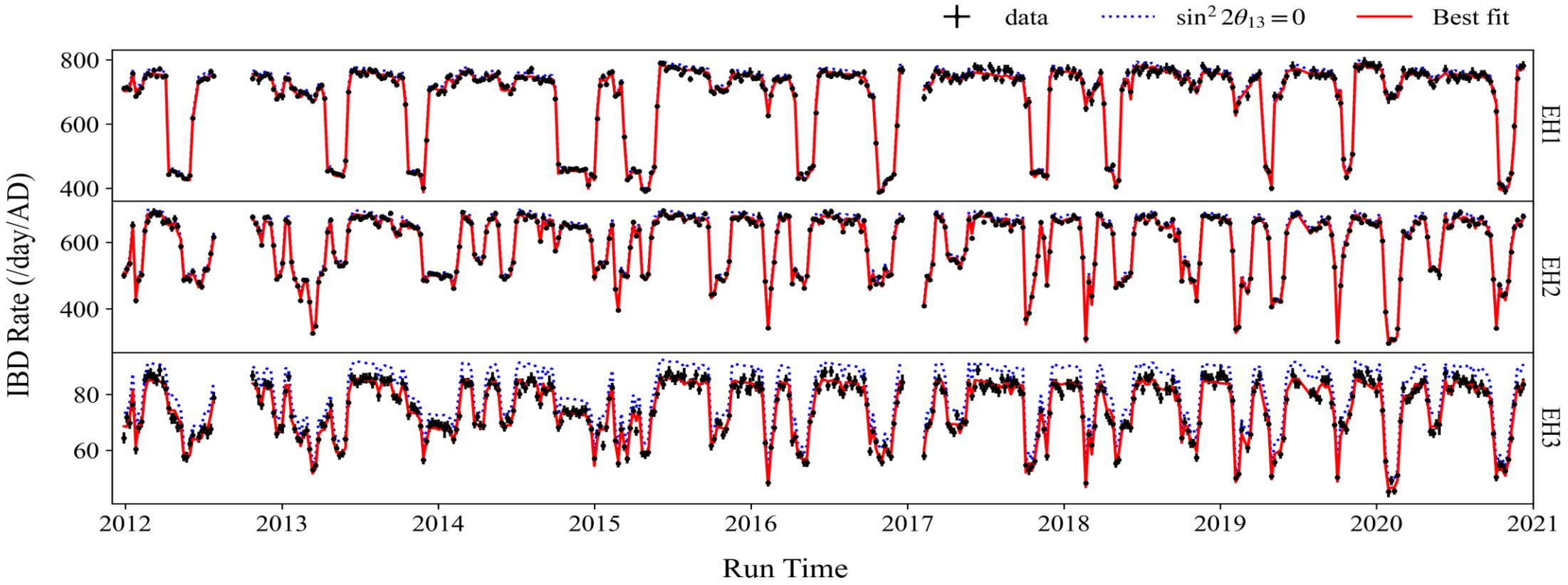
Precise measurements are necessary to provide inputs!

Daya Bay Experiment



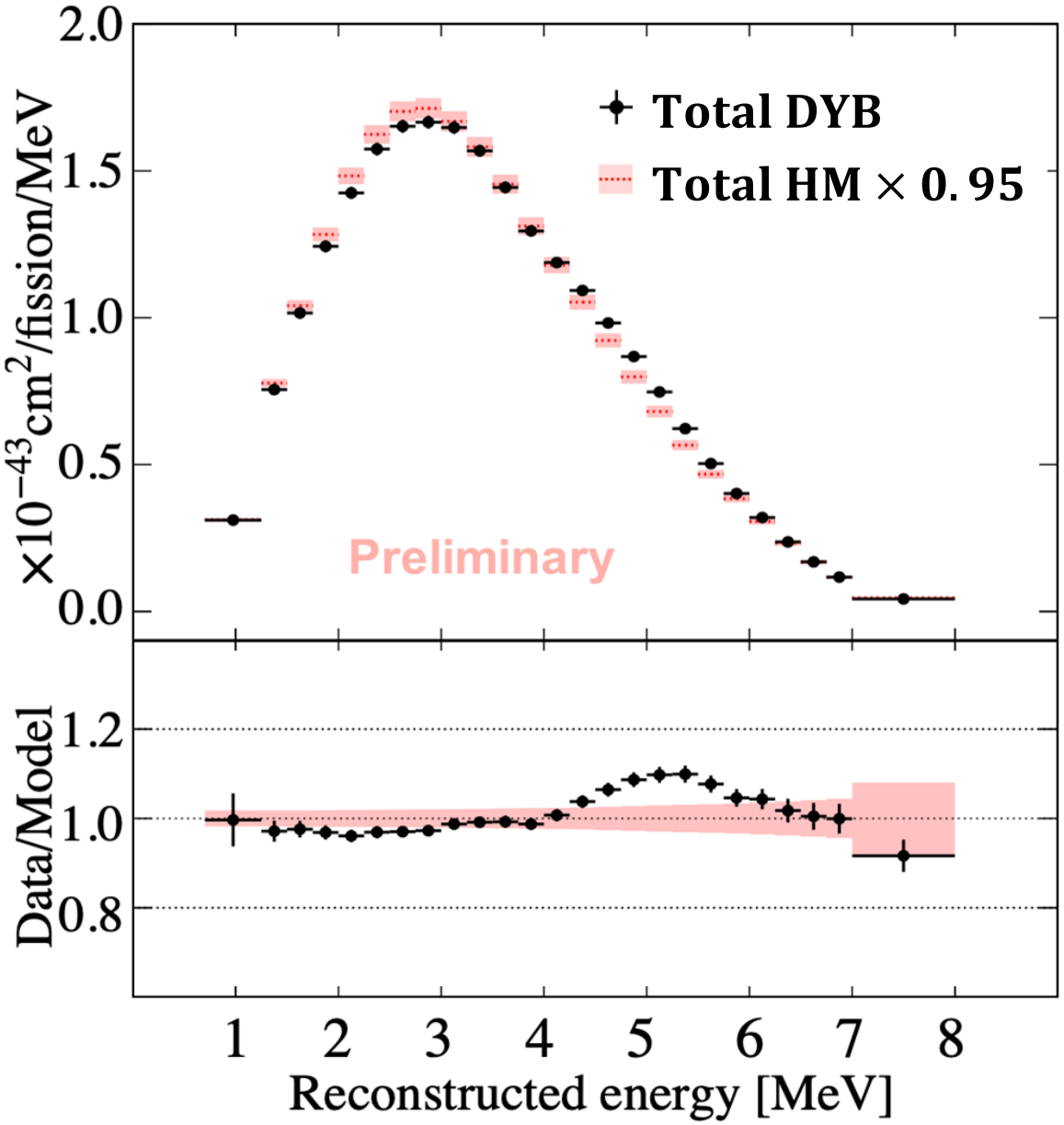


Daya Bay Experiment



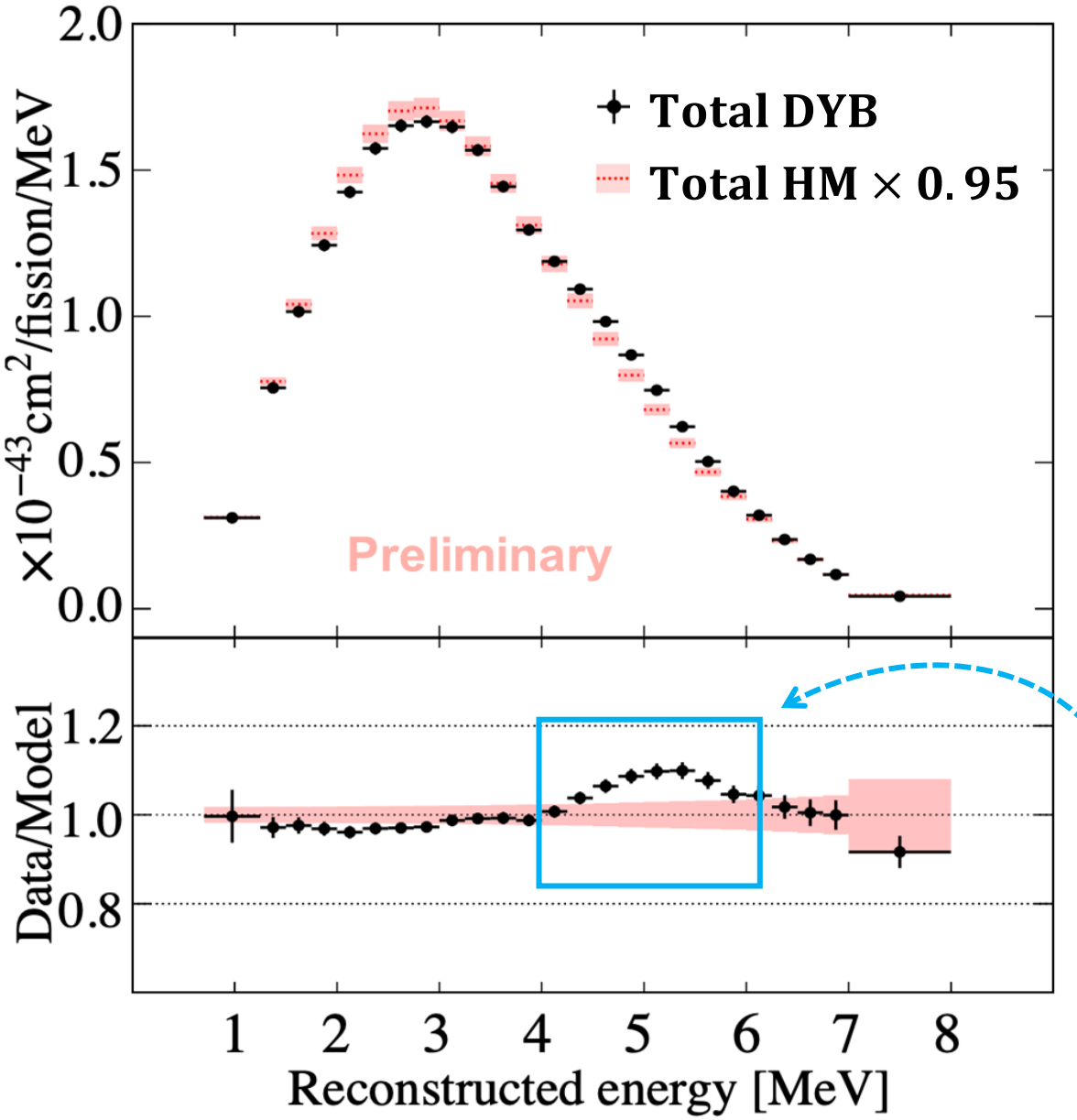
- ✓Operated for **3,158 days** (Dec. 2011 ~ Dec. 2020)
- ✓Collected **4.7 million** IBD candidates (nGd) at 4 near ADs
  - ✓The statistic has increased by 34% compared to the previous publication (1958 days)

Total spectrum



- Corrected oscillation, spent nuclear fuel (SNF) and non-equilibrium effects
- ~1.4% precision in 2 to 5 MeV

Total spectrum



- Corrected oscillation, spent nuclear fuel (SNF) and non-equilibrium effects
- ~1.4% precision in 2 to 5 MeV

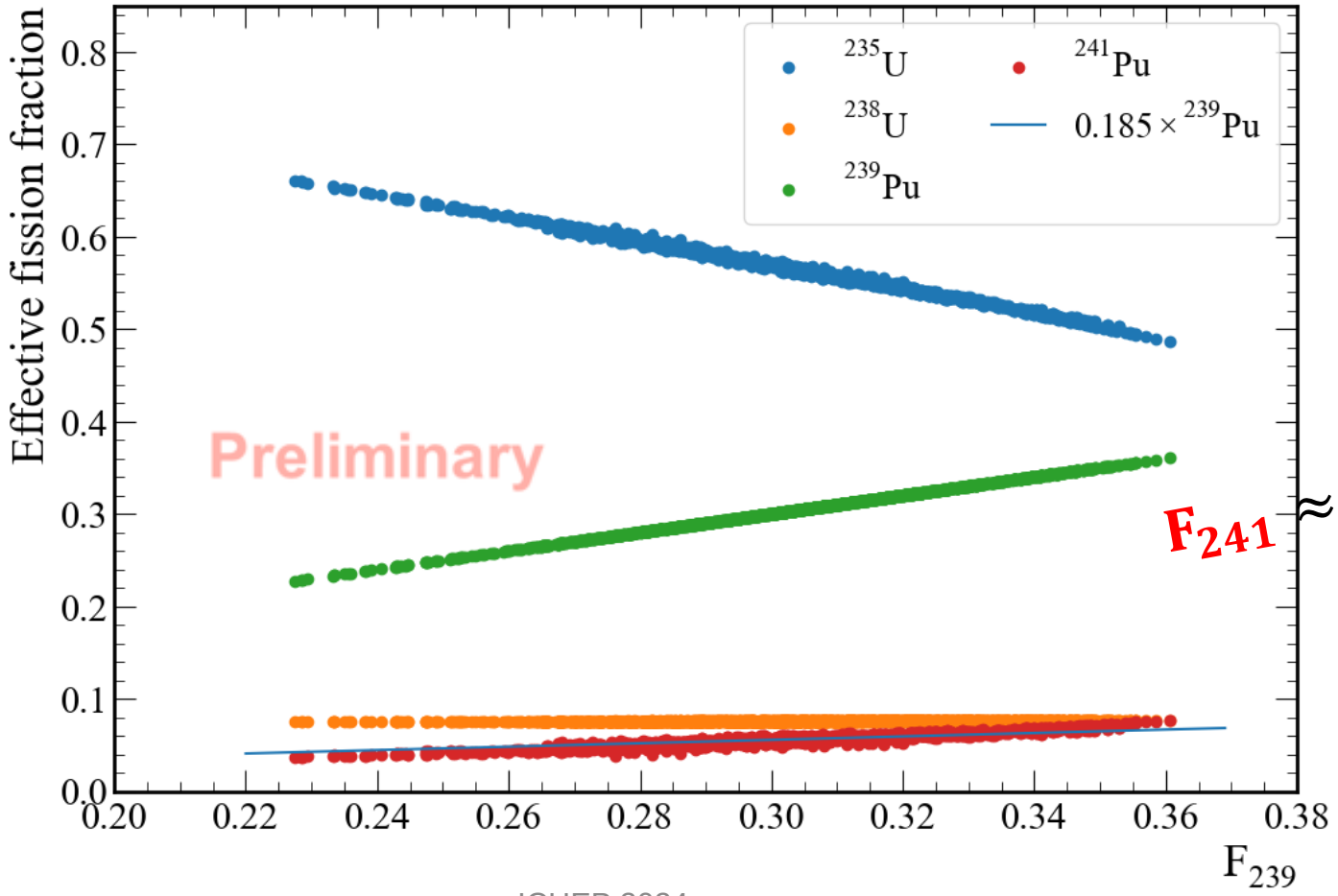
~10σ shape discrepancy compared with HM around 5 MeV

Still not explained

Fuel evolution

- The **weekly power and fission fraction** provided by nuclear power plant
- Able to study the **variation of flux and spectrum with fission fraction**

Effective fission fraction F_i: fraction of fission isotopes expected in detectors. (weekly basis)



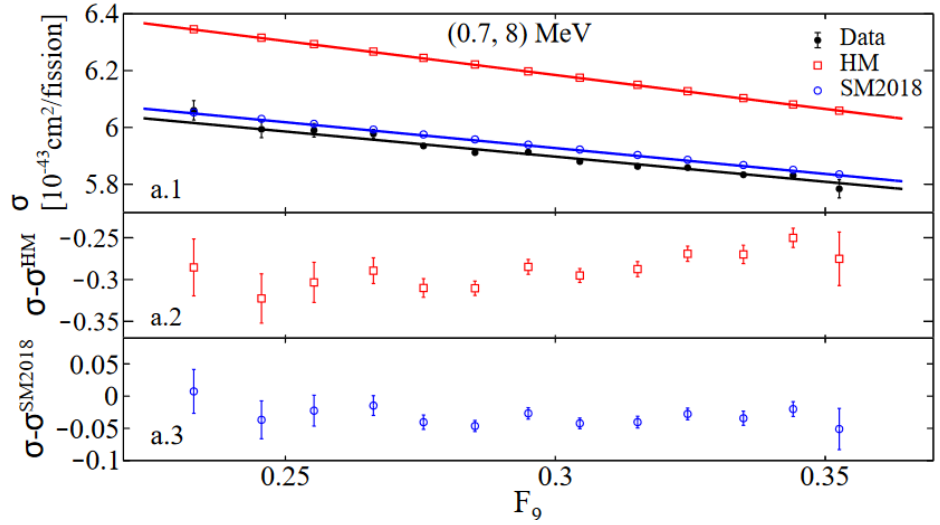
$$F_{241} \approx 0.185 \times F_{239}$$

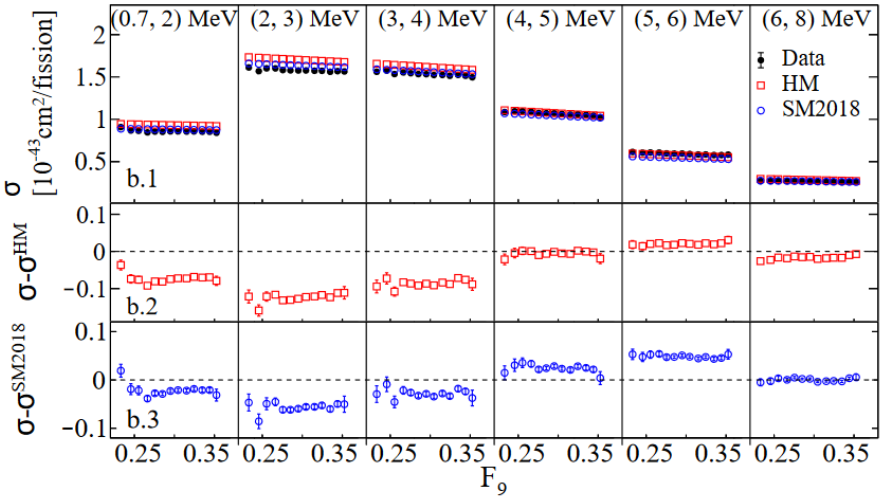
Evolution of the flux and spectrum

Phys. Rev. Lett. 130, 211801 (2023)

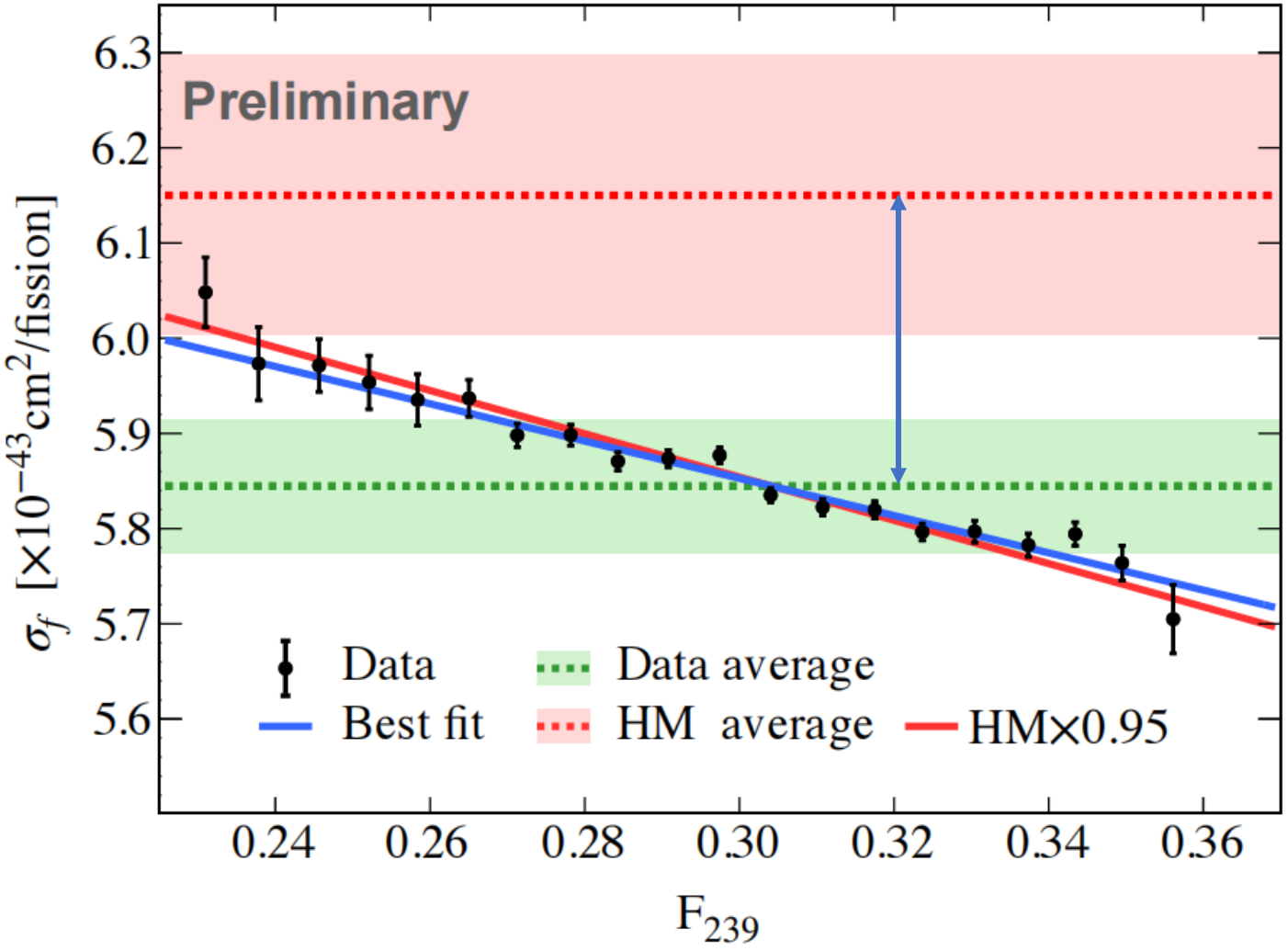
- Measurements of the **average flux and spectrum, as well as their evolution with ^{239}Pu isotopic fraction**.
- The measurements are compared with SM2018 model and HM model.

Use **1958-day** data sample taken from Dec. 2011 to Aug. 2017





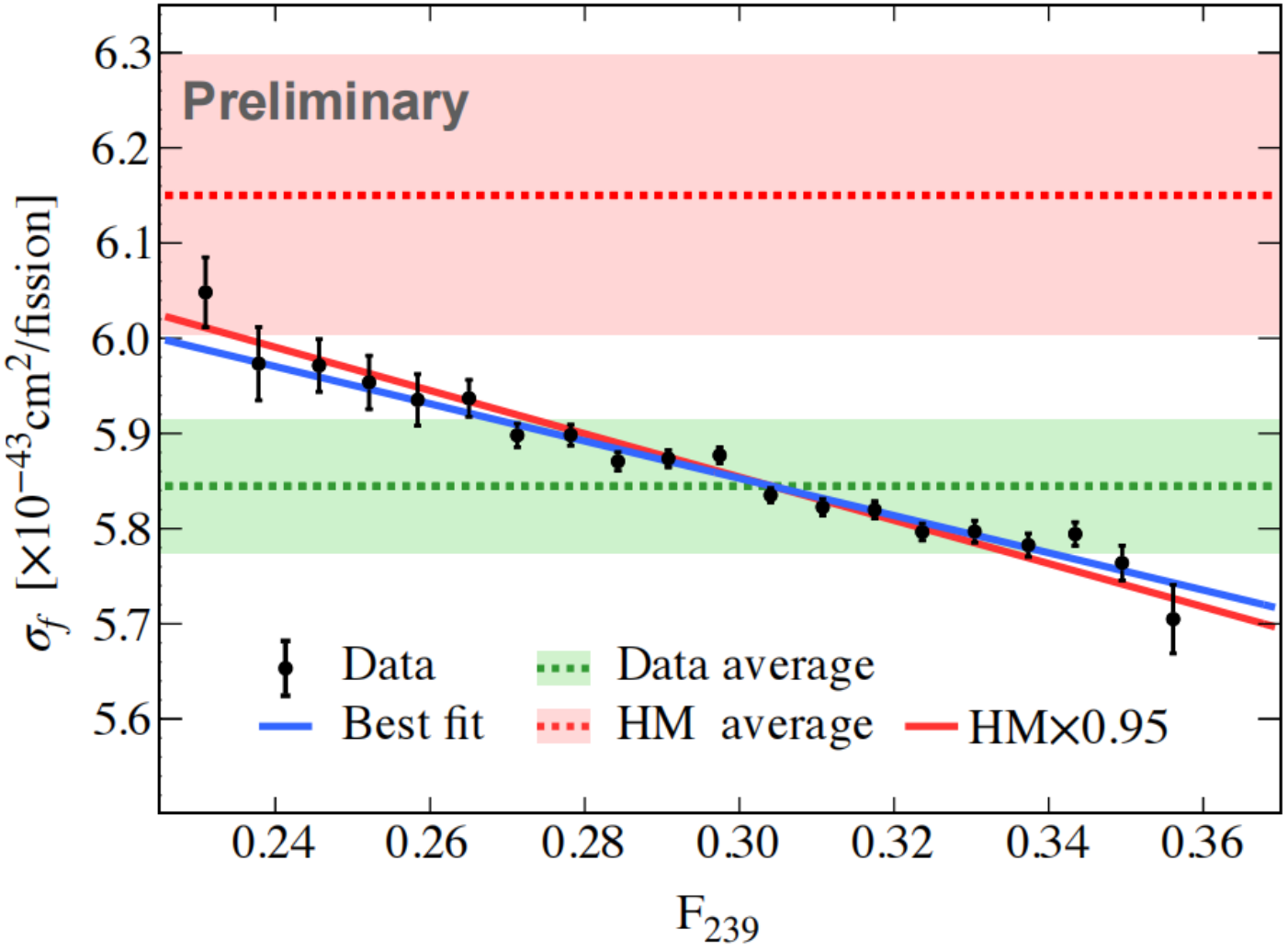
IBD yield as a function of F_{239}



5.0% deficit compared with HM

$\overline{\sigma_f} = (5.84 \pm 0.07) \times 10^{-43} cm^2/fission$

IBD yield as a function of F_{239}

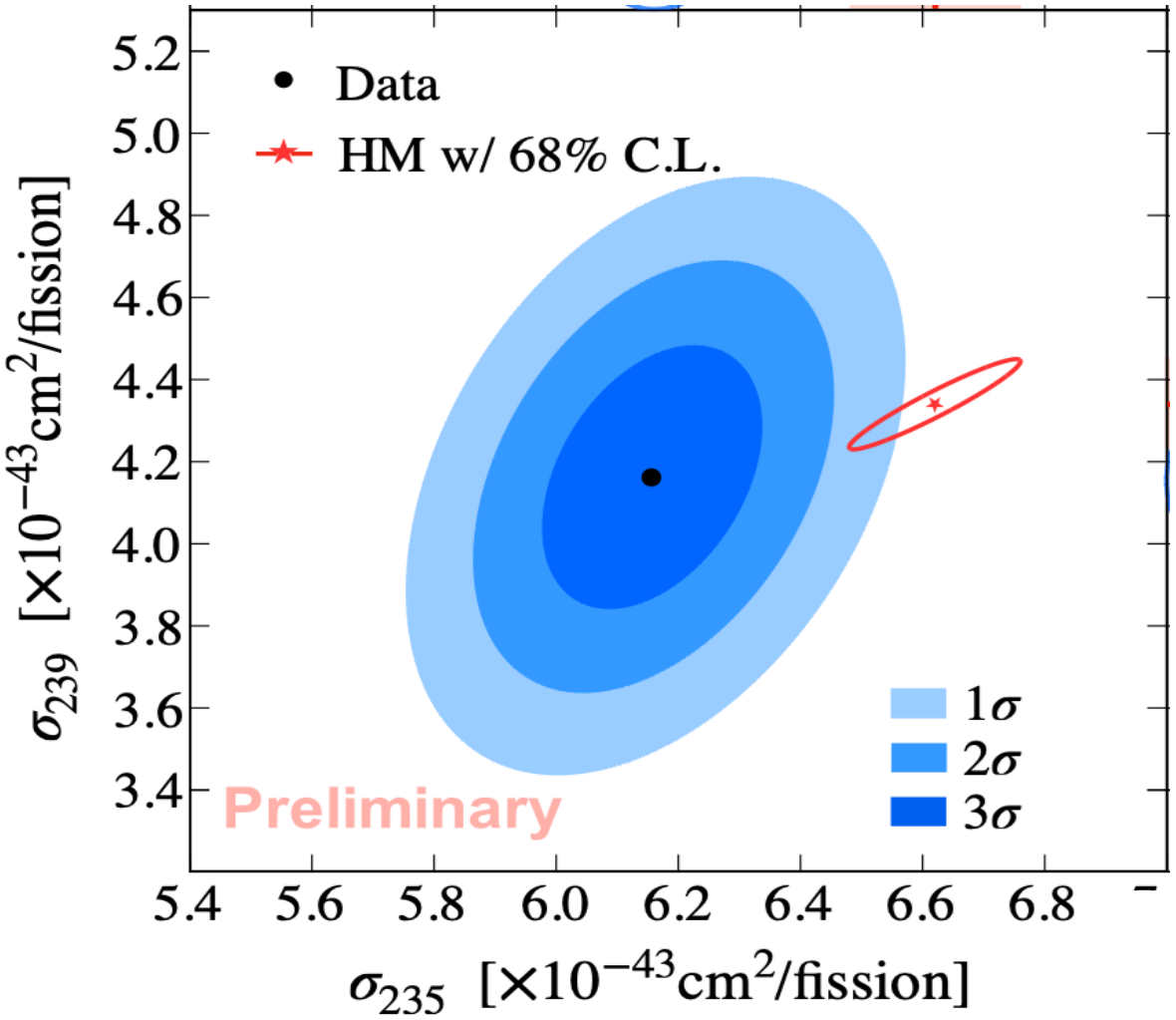


	$\frac{d\sigma}{dF_{239}}\left(\times 10^{-43}\text{cm}^2/\text{fission}\right)$
HM	-2.46
SM2018	-1.82
1230 days	-1.86 ± 0.18
This work (3158 days)	$\mathbf{-1.96 \pm 0.13}$

Indicates ^{235}U contributes more on the deficit.

Phys. Rev. Lett. 118, 251801 (2017)

Extract ^{235}U and ^{239}Pu yields

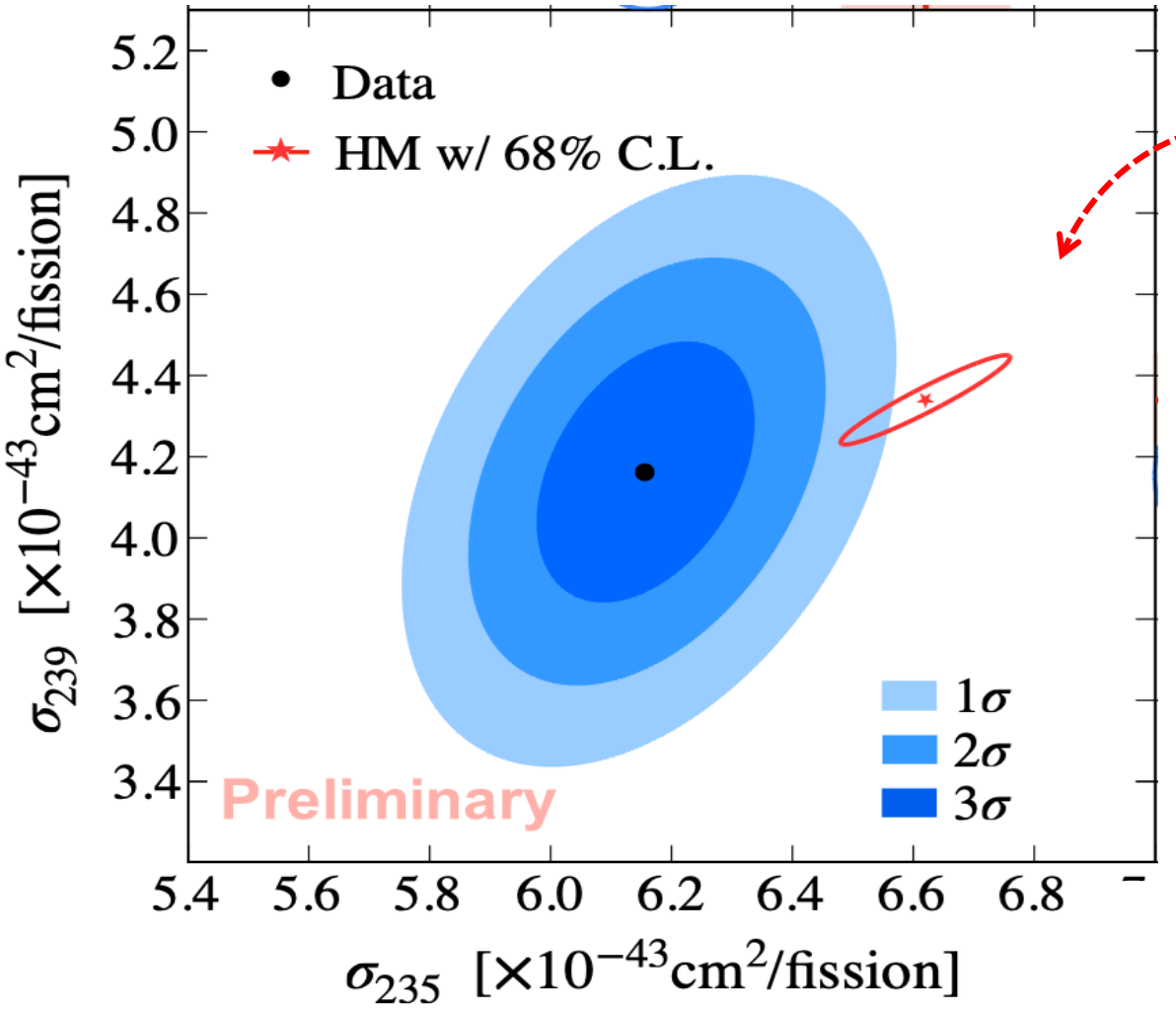


$$\sigma_{235} = (6.16 \pm 0.12) \times 10^{-43}$$
$$\sigma_{239} = (4.16 \pm 0.21) \times 10^{-43}$$
$$(\text{unit: cm}^2/\text{fission})$$

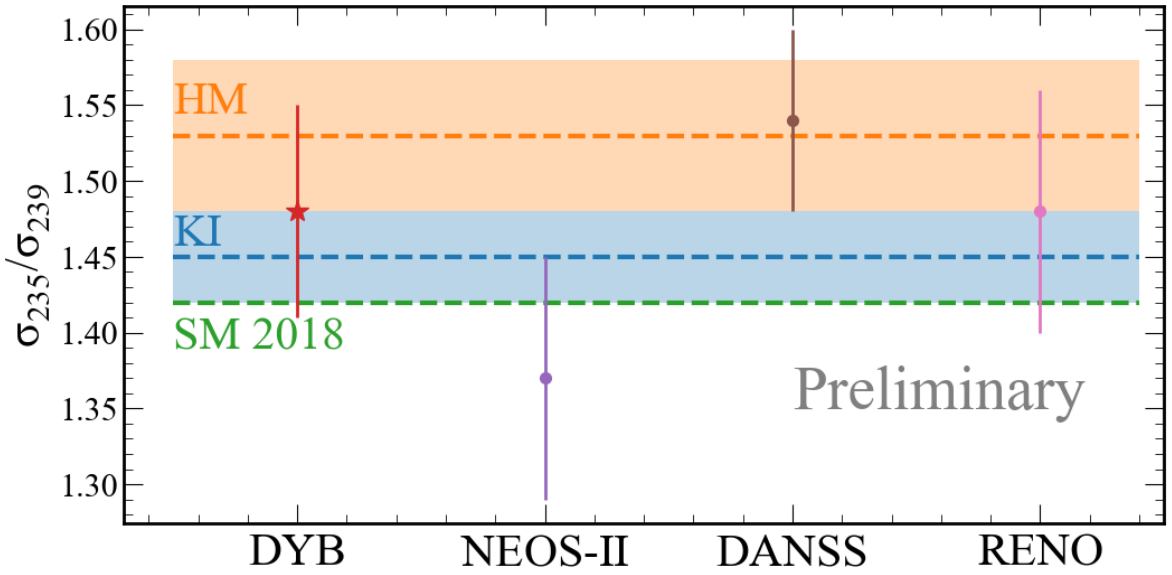
Phys. Rev. Lett. 123, 111801 (2019)

- Compared to the results of 1958 days data set
  - σ_{235} ↑ 1%, σ_{239} ↓ 4%
  - the precisions of σ_{235} and σ_{239} improved by **25%** and **19%**, respectively

Extract ^{235}U and ^{239}Pu yields

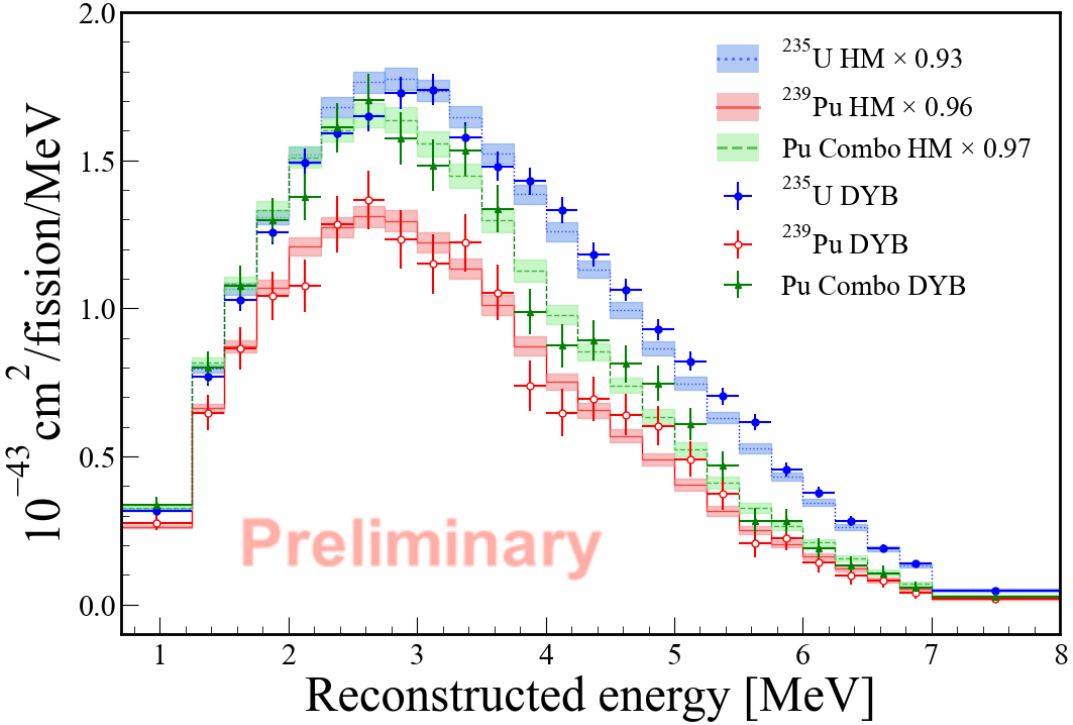


- Compare with HM:
  - 7.0% deficit (3σ) for σ_{235}
  - 4.2% deficit (1σ) for σ_{239}



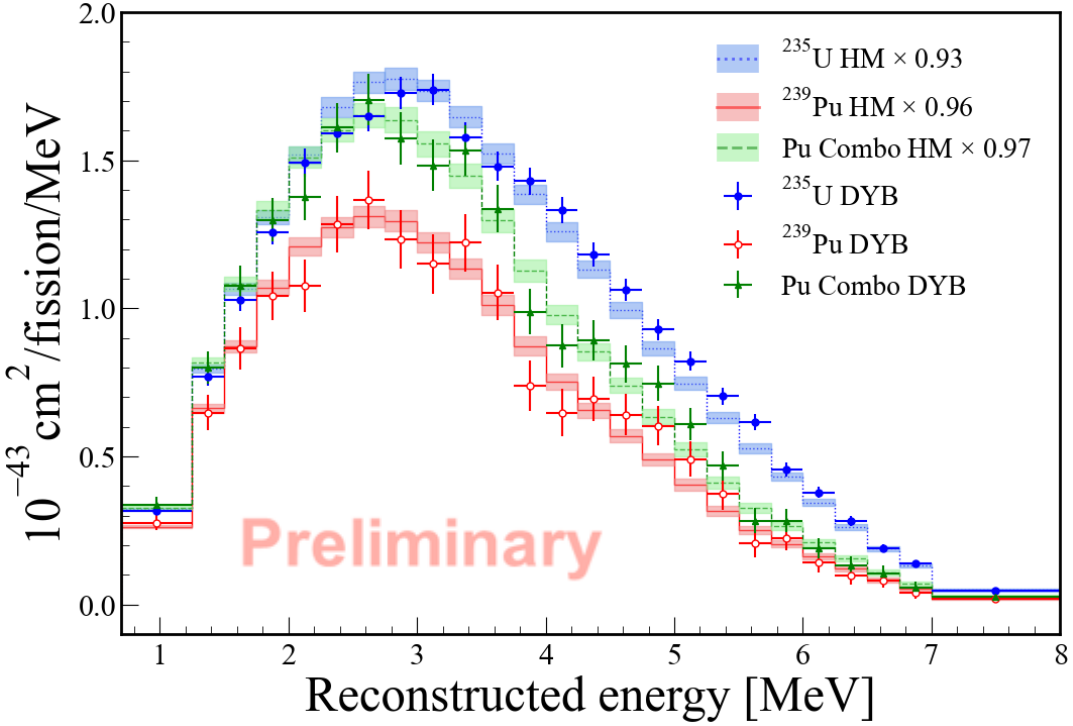
Exp. data from Neutrino 2022, 2024

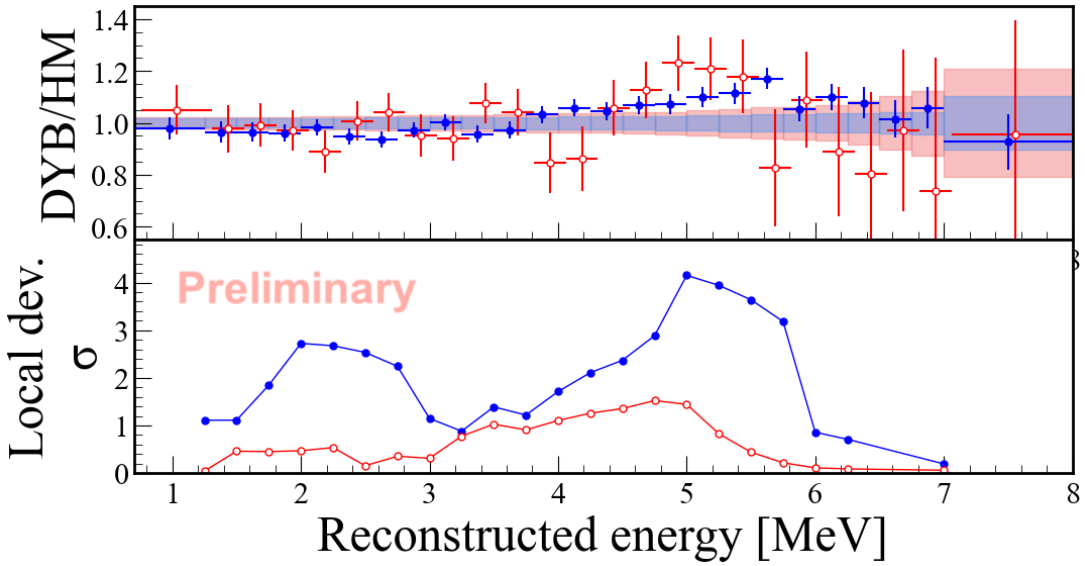
Extract ^{235}U and ^{239}Pu spectra



- The precisions in 2 to 5 MeV are 3% and 8% for ^{235}U and ^{239}Pu, respectively

Extract ^{235}U and ^{239}Pu spectra

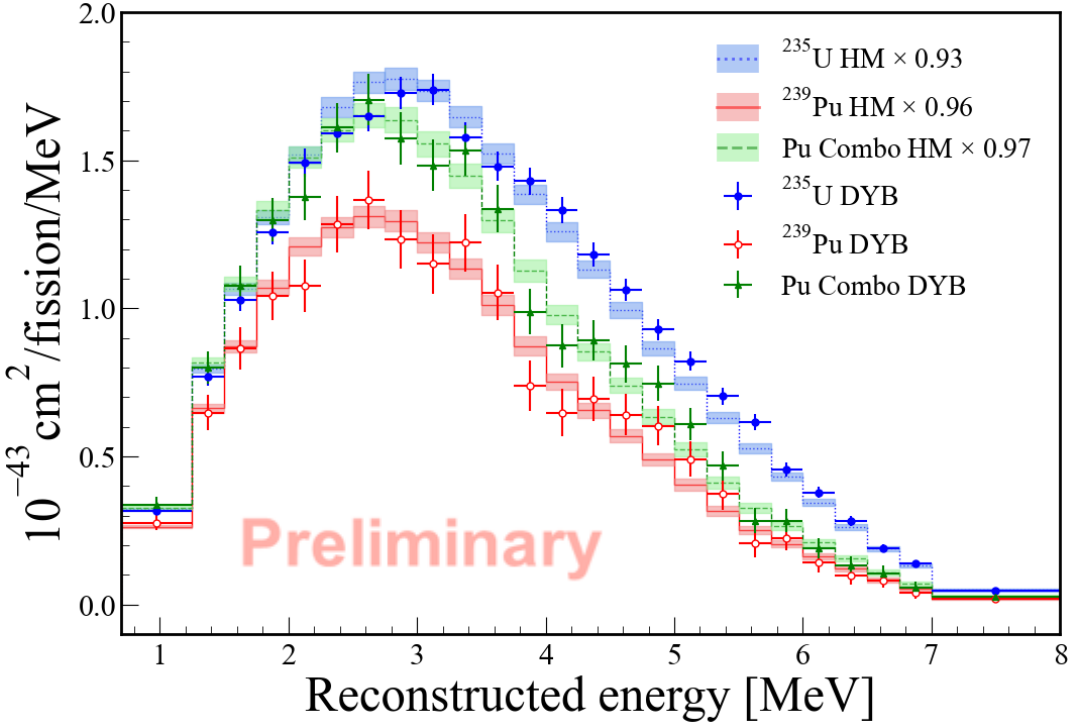




- The precisions in 2 to 5 MeV are 3% and 8% for ^{235}U and ^{239}Pu, respectively
- The significances w.r.t. the HM model are 4σ and 1σ for ^{235}U and ^{239}Pu, respectively

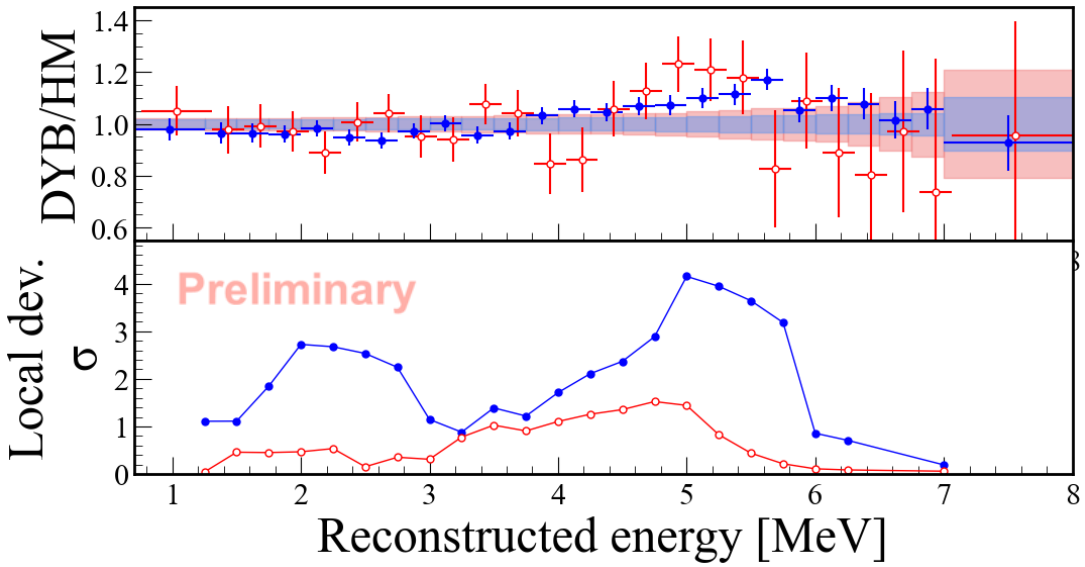
Data consist with “5 MeV bump” in both spectra, more significantly with ^{235}U

Extract ^{235}U and ^{239}Pu spectra



$$S_{combo} = S_{239} + 0.185 \times S_{241}$$

- Significantly reduces the reliance on the model input of S_{241}
  - The relative uncertainty of S_{combo} is reduced by 30% relative to S_{239}



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Data-based antineutrino spectrum

- SVD unfolding method
  - Minimizing $(S^{rec} - RS^{\nu})^{T} V^{-1} (S^{rec} - RS^{\nu}) + \tau (CS^{\nu})^{T} (CS^{\nu})$
- Total, ^{235}U and ^{239}Pu spectra are unfolded together
  - A proper treatment on the shape correlation between different spectra
  - The smoothness correlation between different spectra is avoided

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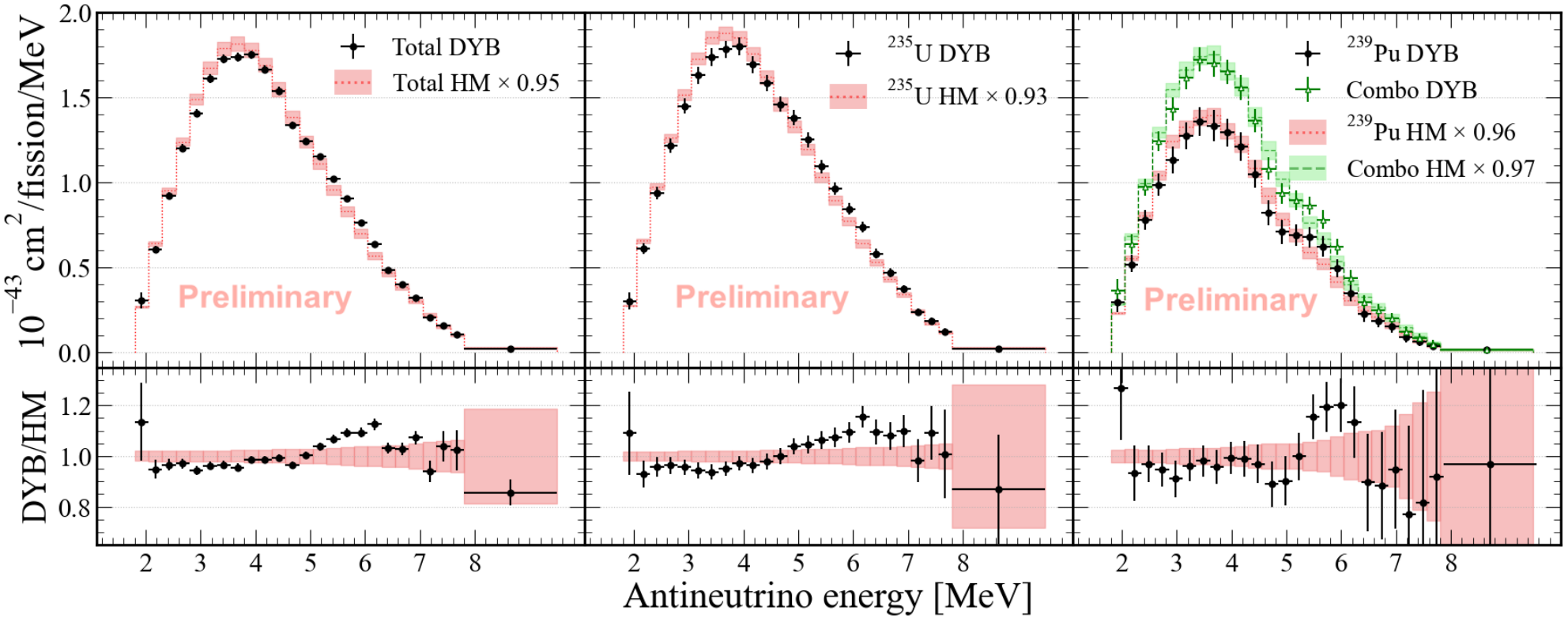
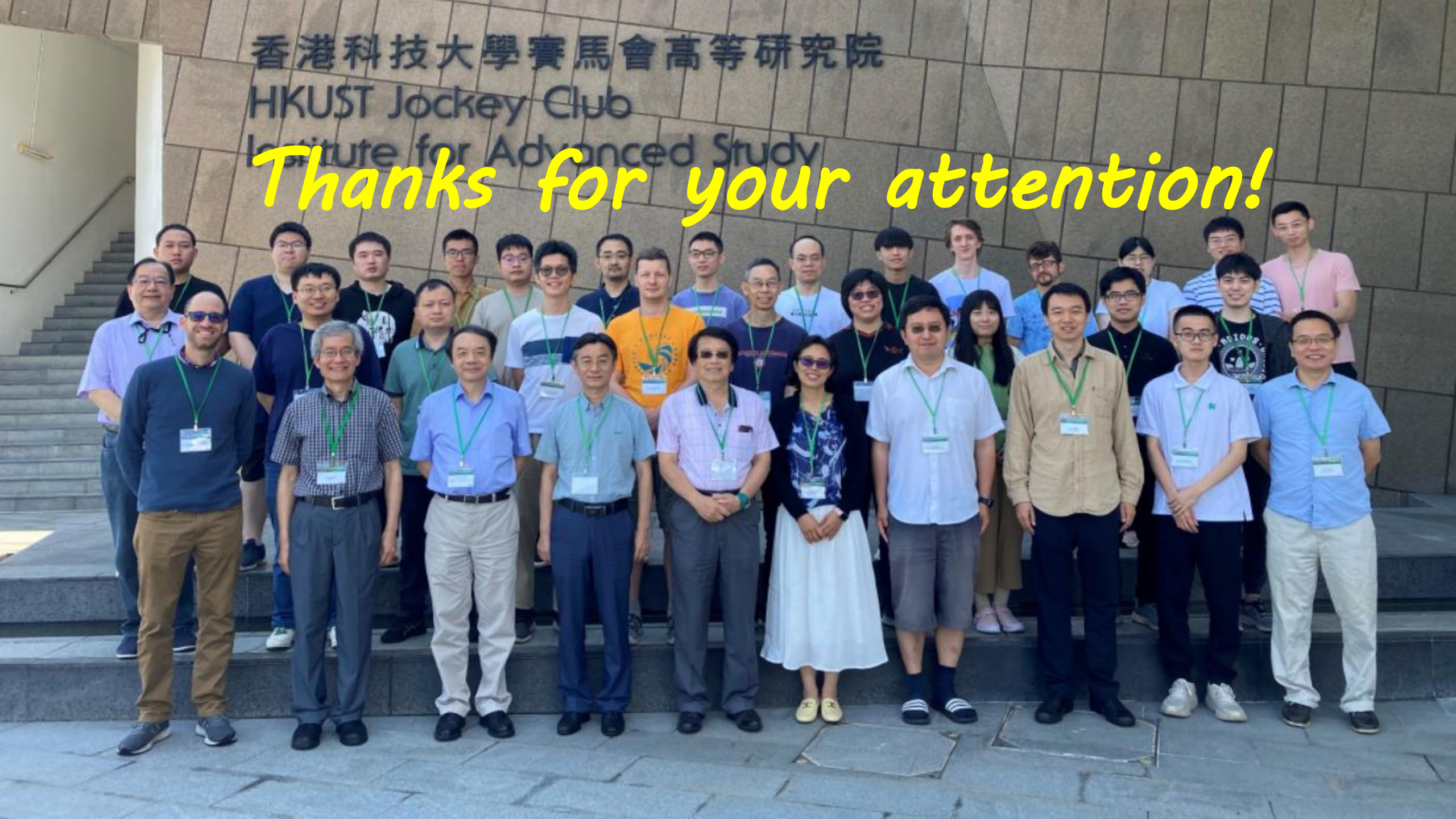
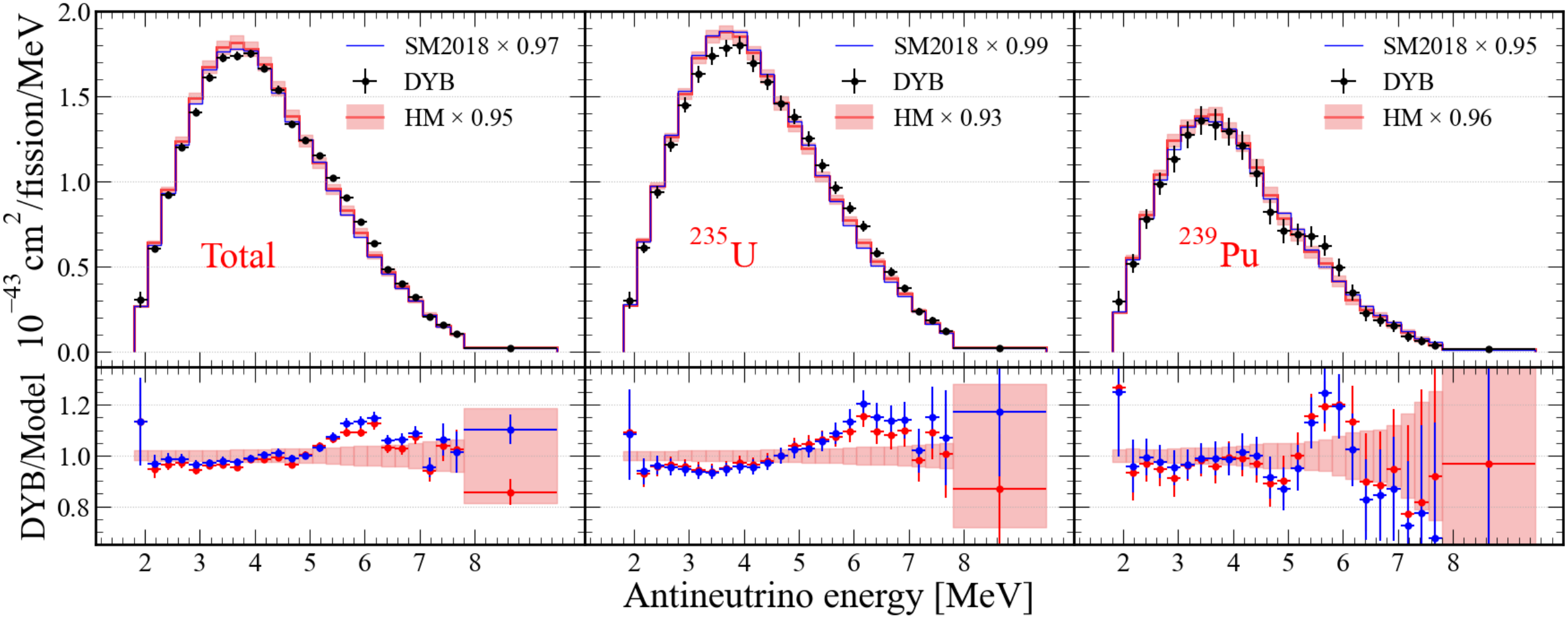


Summary

- Flux and spectrum measurements with full data set
  - Total reactor antineutrino spectrum, average yield and $\frac{\mathbf{d\sigma}}{\mathbf{dF_{239}}}$
  - Extraction of antineutrino yields and spectra for ^{235}U and ^{239}Pu
- First simultaneous unfolding of the total, ^{235}U and ^{239}Pu spectra
- Provides a data-driven input for future reactor antineutrino studies


香港科技大學賽馬會高等研究院
HKUST Jockey Club
Institute for Advanced Study
Thanks for your attention!

Back up


SM2018 × 0.97
DYB
HM × 0.95
Total
SM2018 × 0.99
DYB
HM × 0.93
235U
SM2018 × 0.95
DYB
HM × 0.96
239Pu
10−43 cm2/fission/MeV
DYB/Model
Antineutrino energy [MeV]