Nuclear Data Needs for Interpreting Reactor Antineutrino Signals

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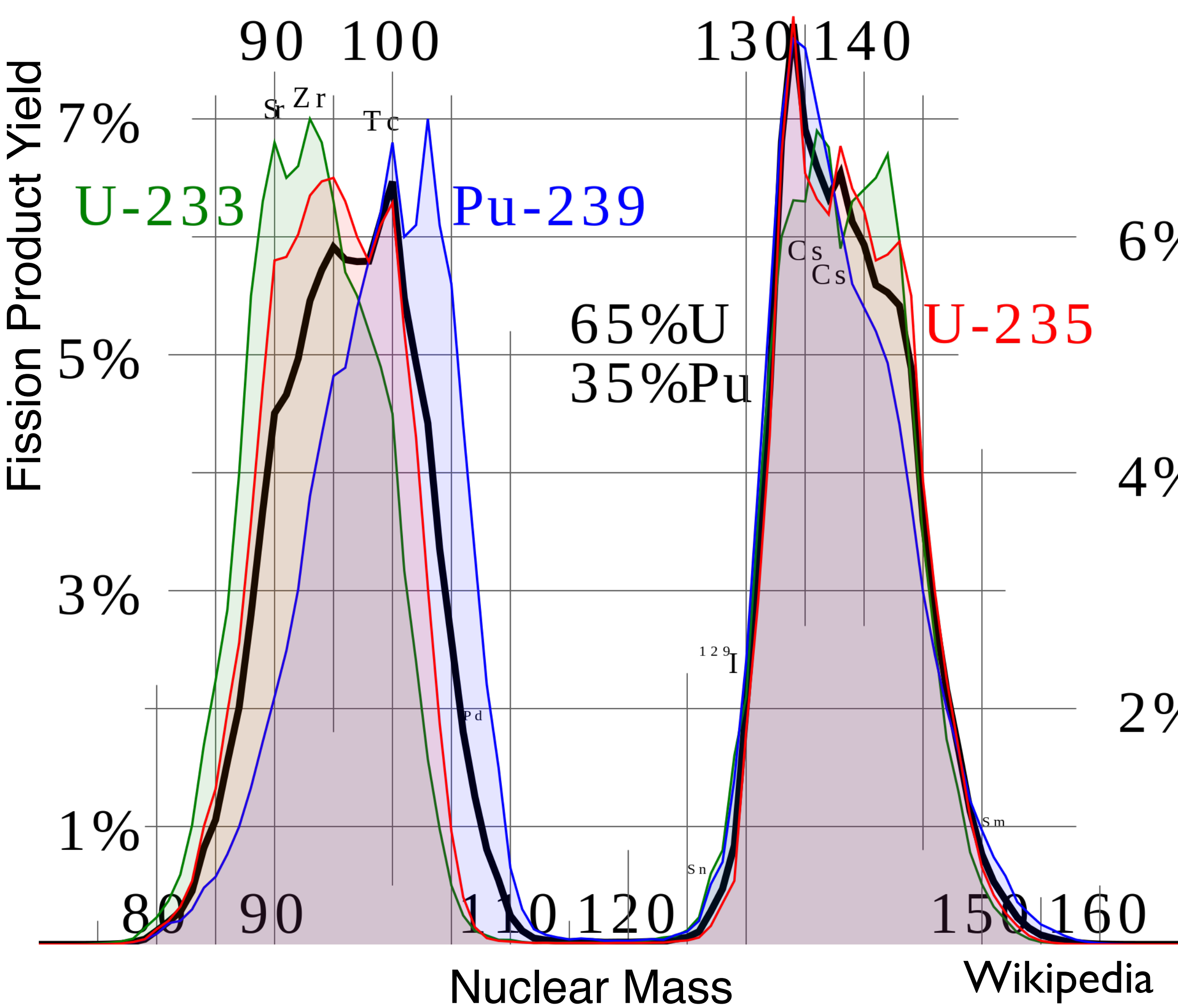
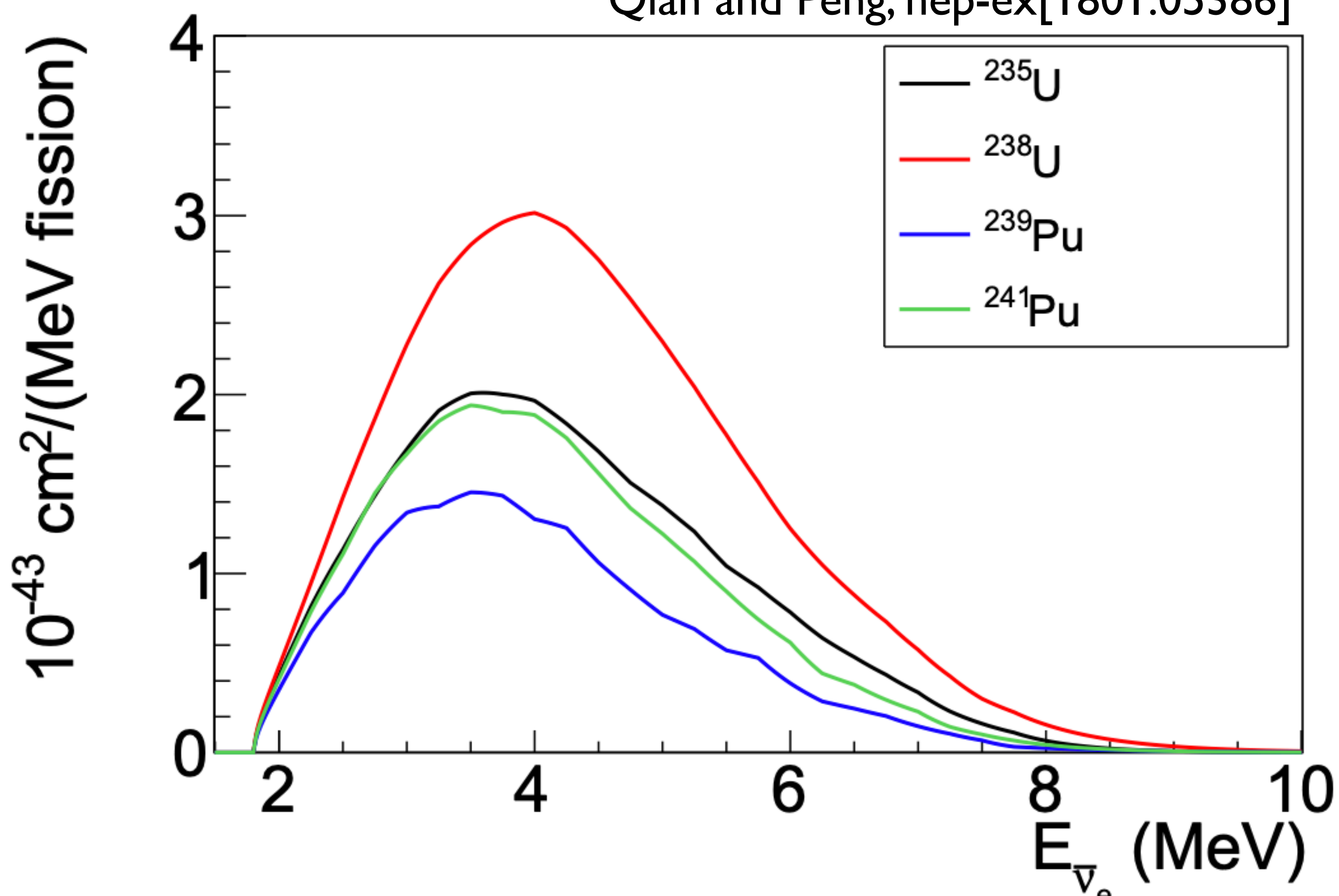
Differing Yields = Differing Neutrinos

- Semi-unique yields generate distinct neutrino fluxes and energy profiles for each fission isotope.
- Neutrinos easily escape the vessel and present a promising target for remote monitoring.
  - Reactor fission rates (i.e: thermal power)
  - Reactor core content (i.e: how much plutonium)



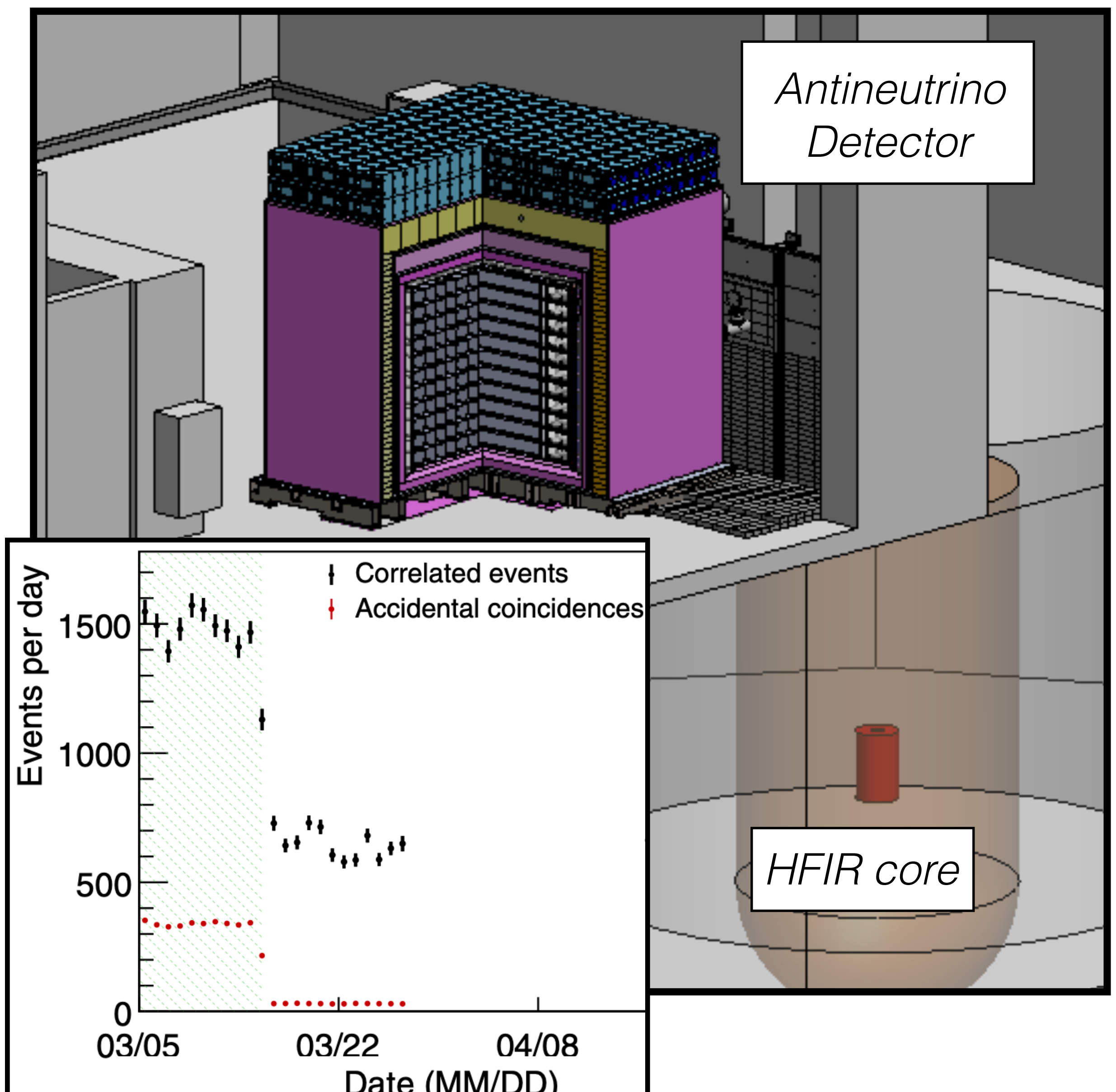
Wikipedia

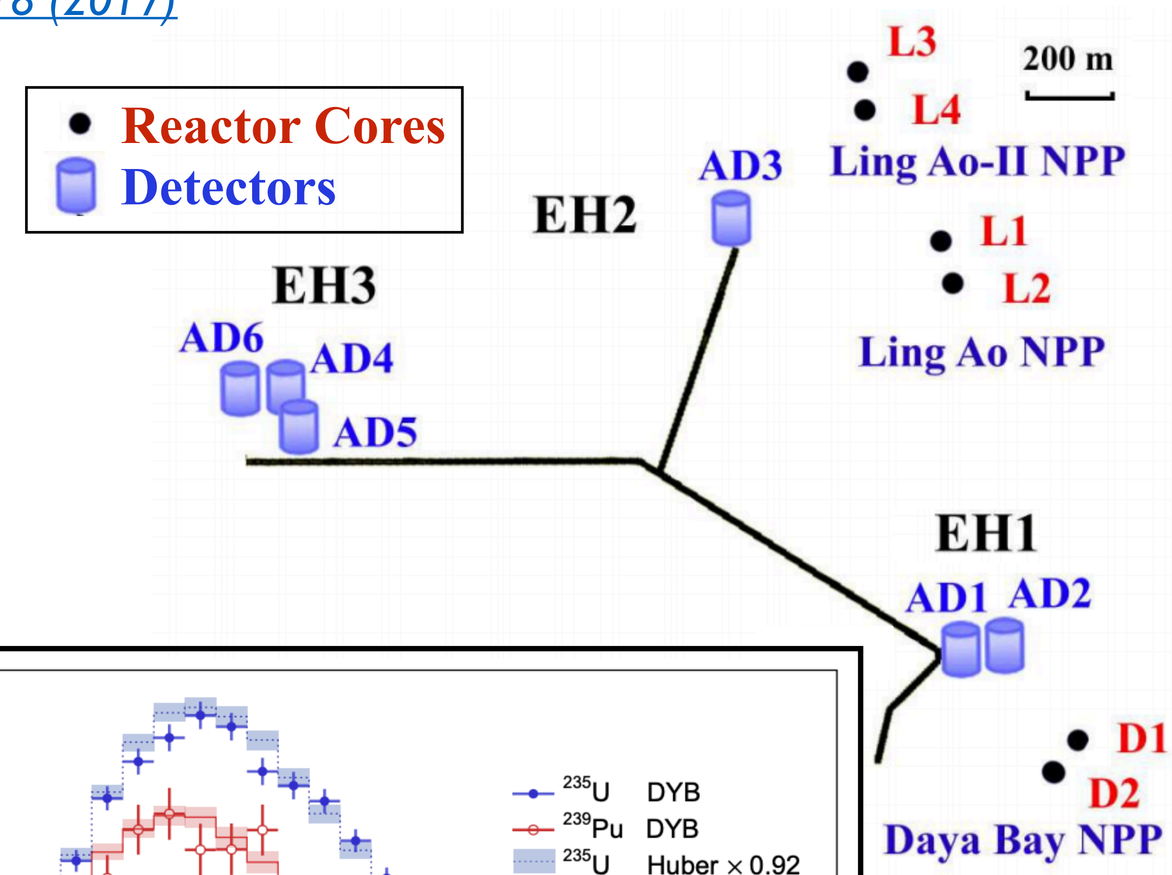


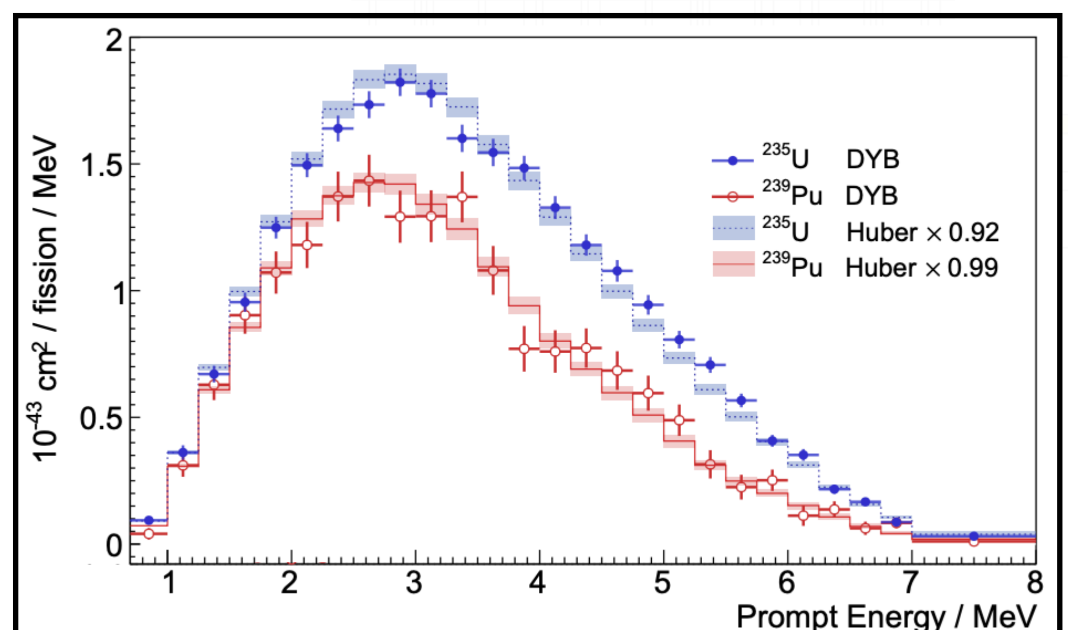
Qian and Peng, hep-ex[1801.05386]

Neutrino-Based Monitoring Validations

- **Existing experiments have validated feasibility of this approach.**
  - PROSPECT: demonstrated percent-level daily reactor power load following with an on-surface 4 ton scintillator detector [PROSPECT, PRL 121 (2018)]
  - Daya Bay: directly measured changes in neutrino flux/energy associated with fuel burn-up [Daya Bay, PRL 123 (2019); PRL 118 (2017)]



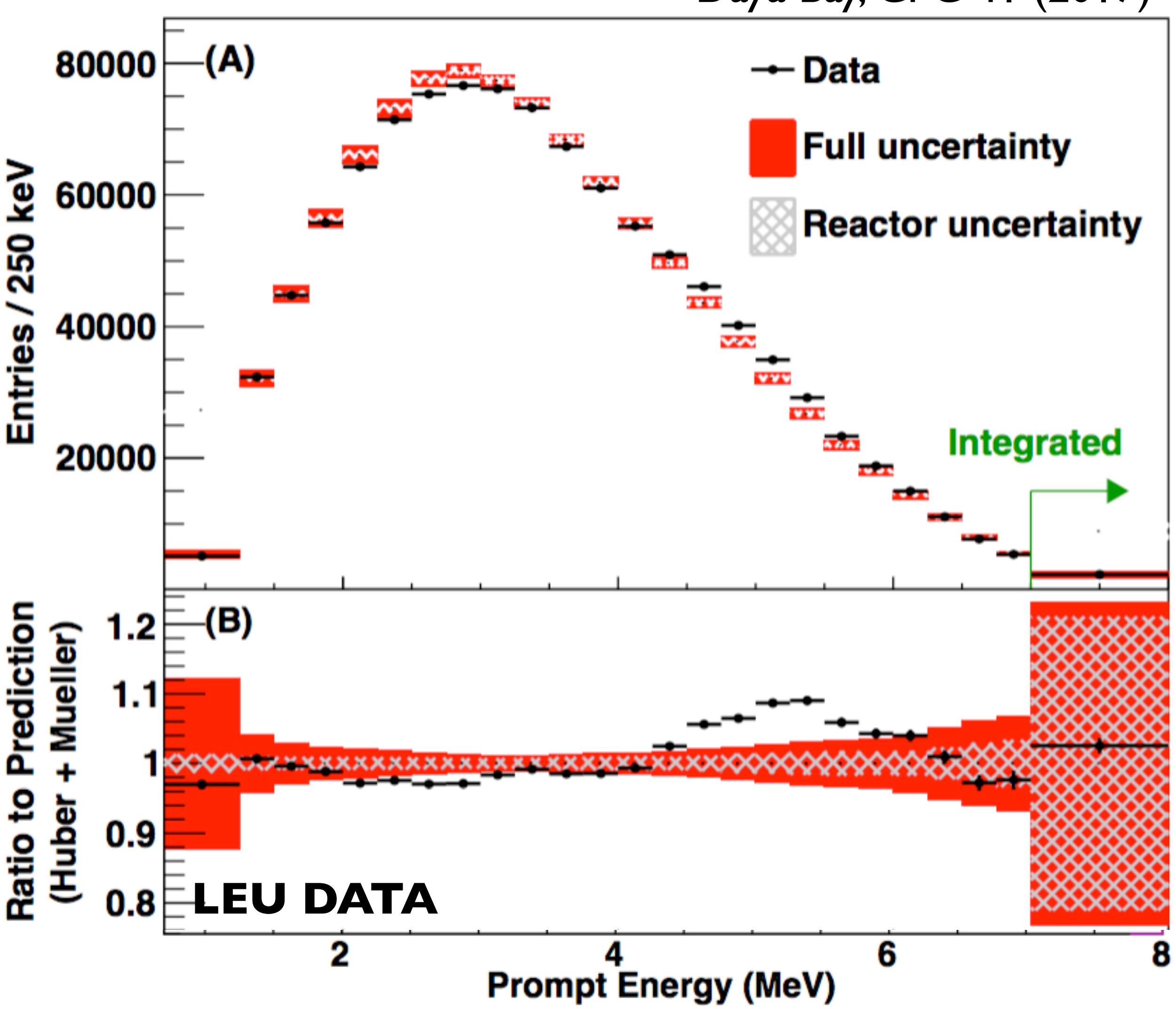




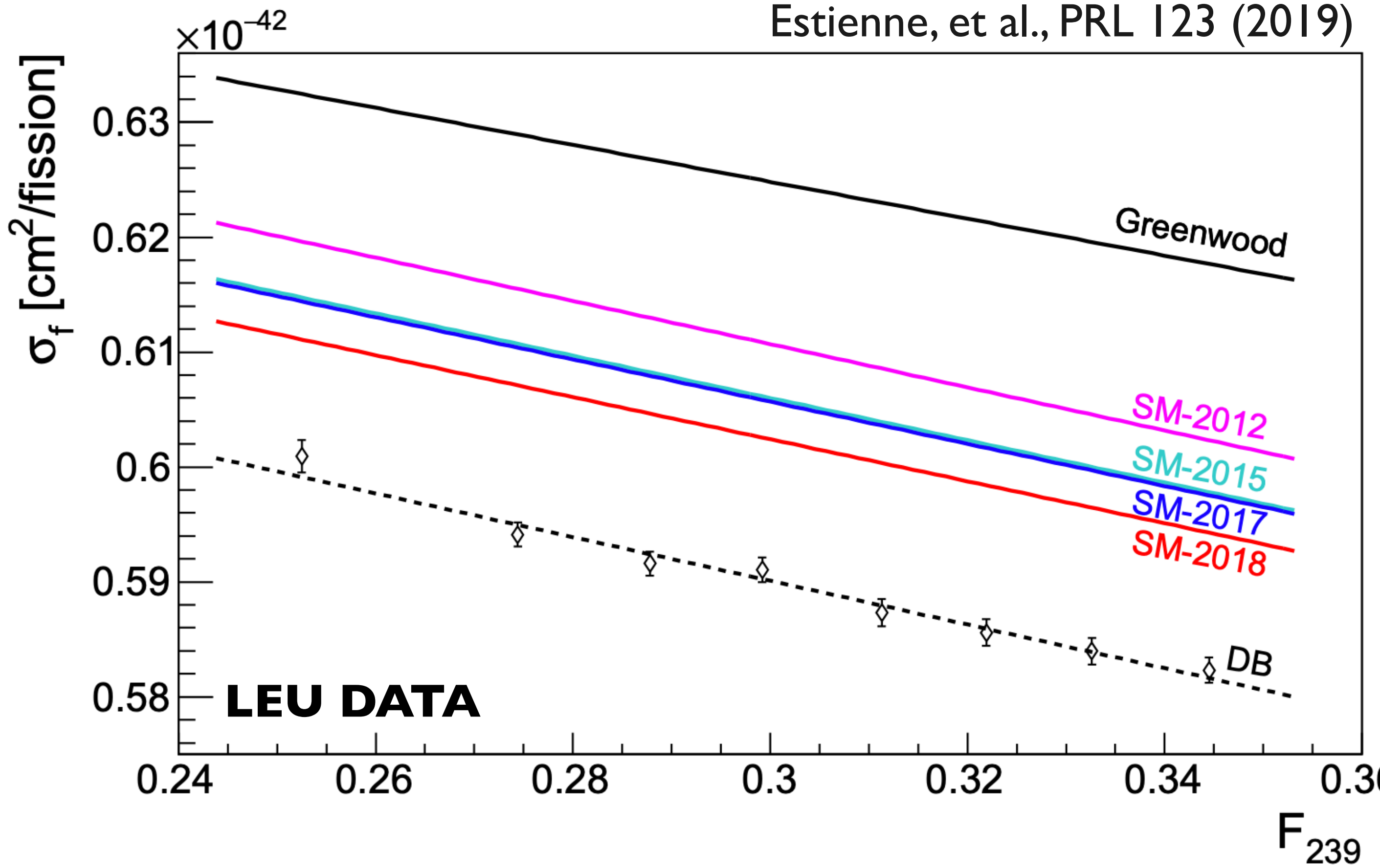
Interpreting Data: Current Limitations

- Better understanding of isotopic neutrino yields/spectra is required to achieve useful, reliable monitoring capabilities.
  - Models of antineutrino production — based on standard nuclear databases — fail to reproduce measured neutrino rates and energy spectra
  - Direct neutrino-based calibration of per-isotope fluxes and spectra is limited in precision by the lack of diversity in existing high-stats neutrino datasets

Daya Bay, CPC 41 (2017)



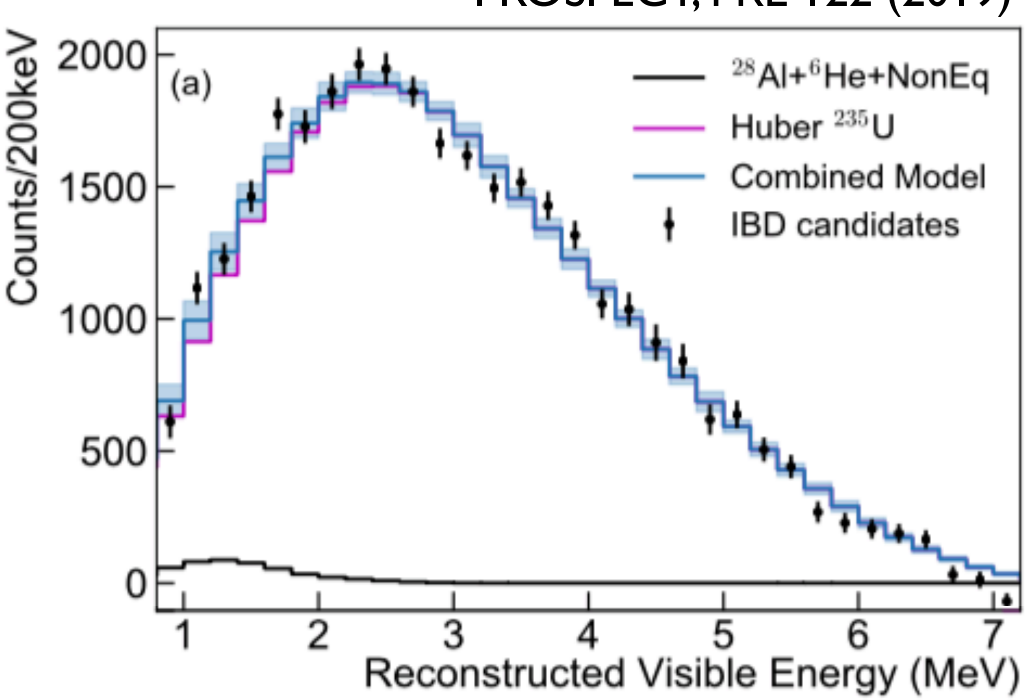
Estienne, et al., PRL 123 (2019)



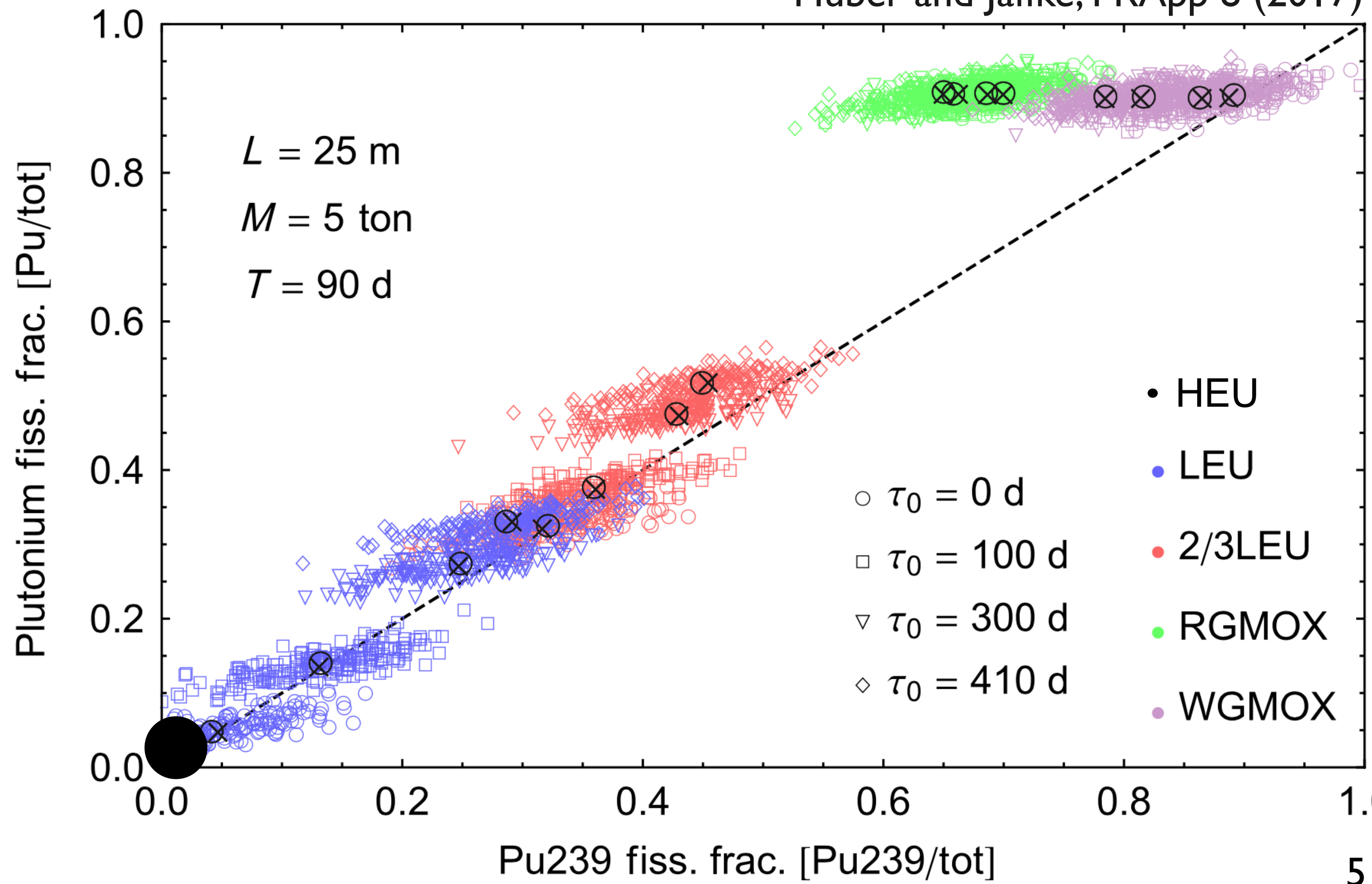
Future Measurements: Neutrinos

- A broad range of measurements can help address these issues.
- Neutrino side:
  - Higher-statistics datasets from reactors of more widely varying fuel content
    - **HEU** and single-core full-cycle **LEU** measurements with existing, future detectors
    - Detailed study of hypothetical measurements at **MOX** reactors
  - Self-consistent comparisons between existing **HEU** and **LEU** datasets

PROSPECT, PRL 122 (2019)



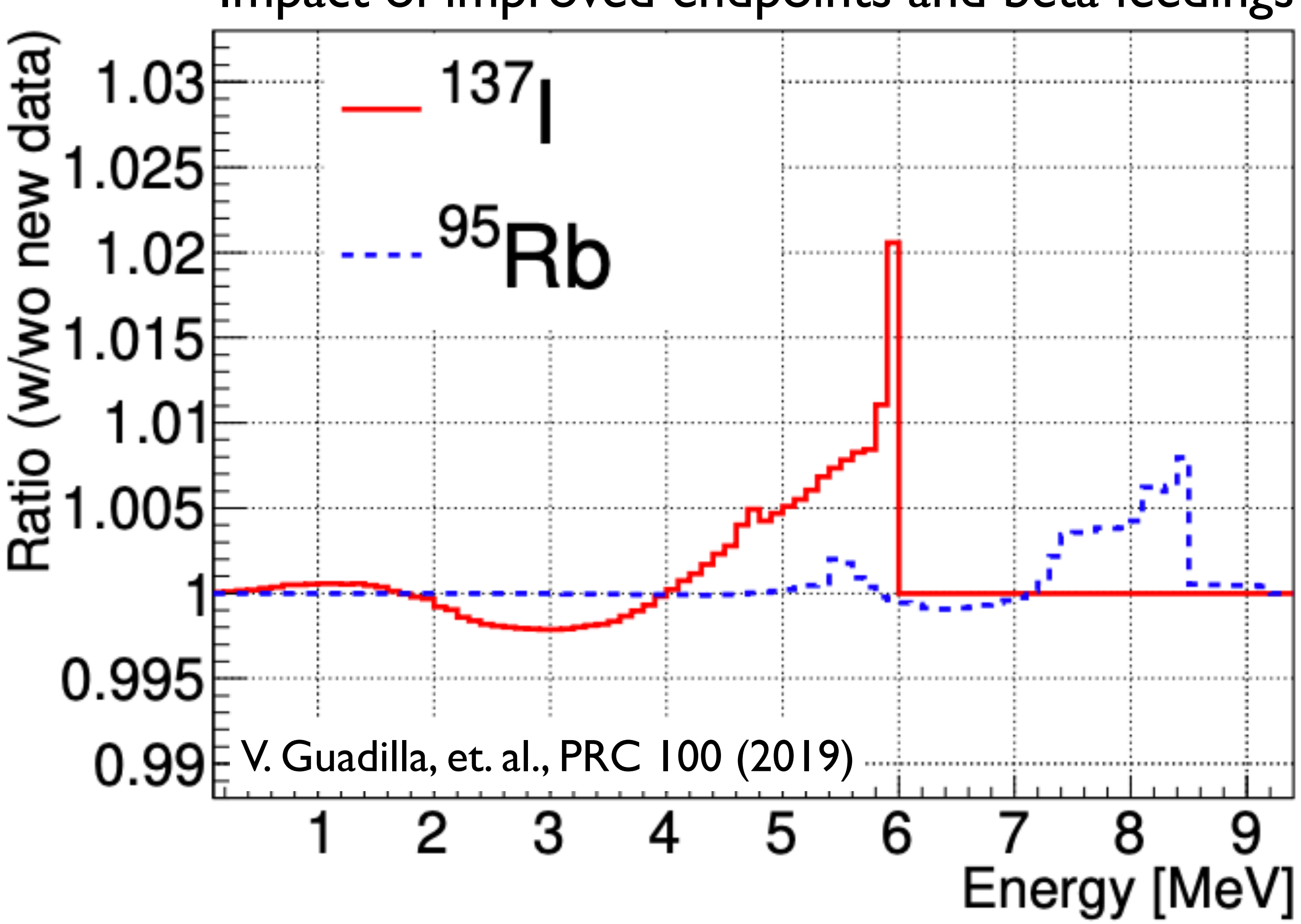
Huber and Jaffke, PRApp 8 (2017)



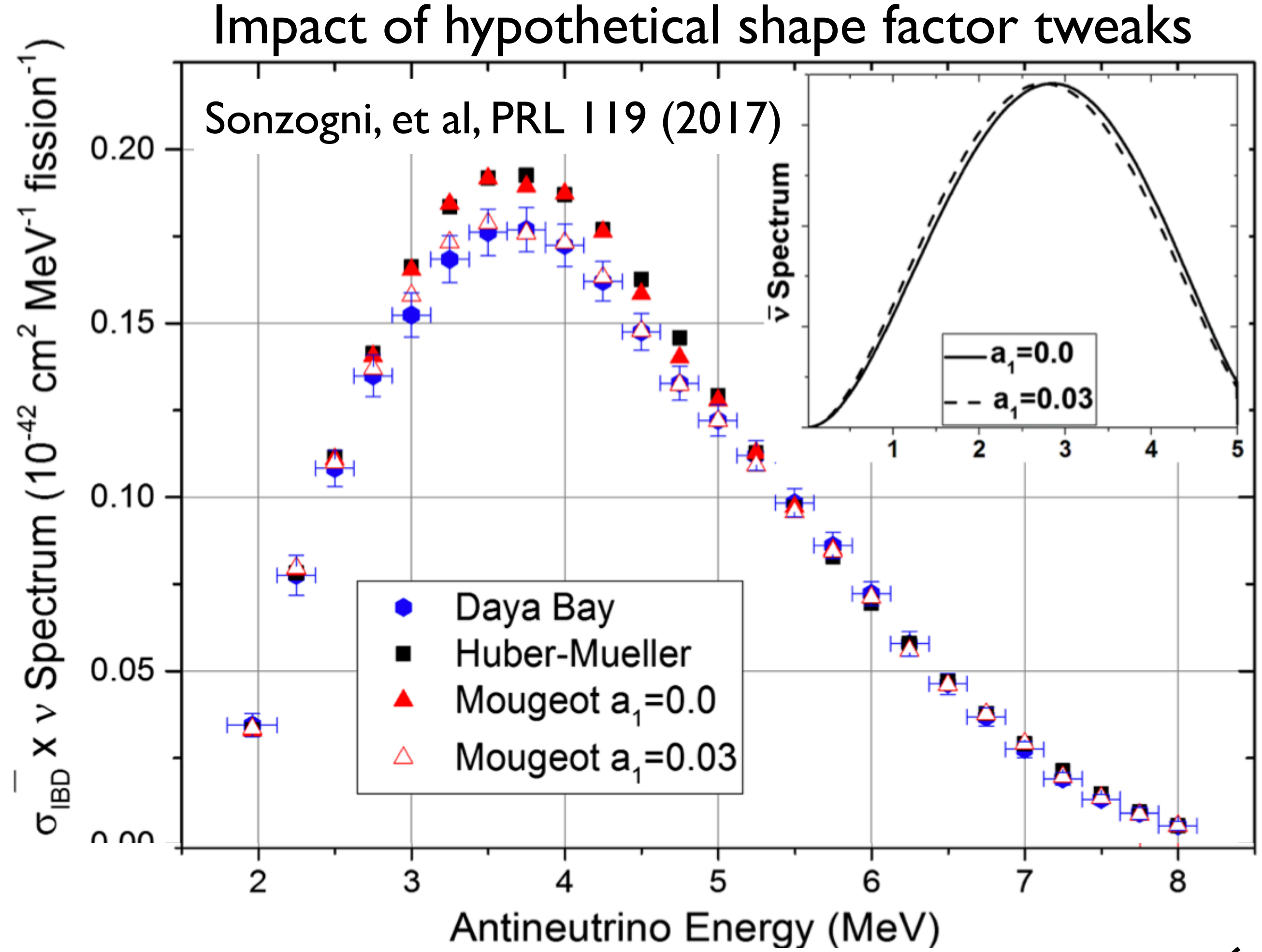
Future Measurements: Nuclear Physics

- A broad range of measurements can help address these issues.
- Nuclear physics measurements side:
  - Improved fission yield, beta feeding, and beta shape factor measurements
  - Fission delayed gamma spectrum measurements
  - Improved description of nuclear data uncertainties

Impact of improved endpoints and beta feedings



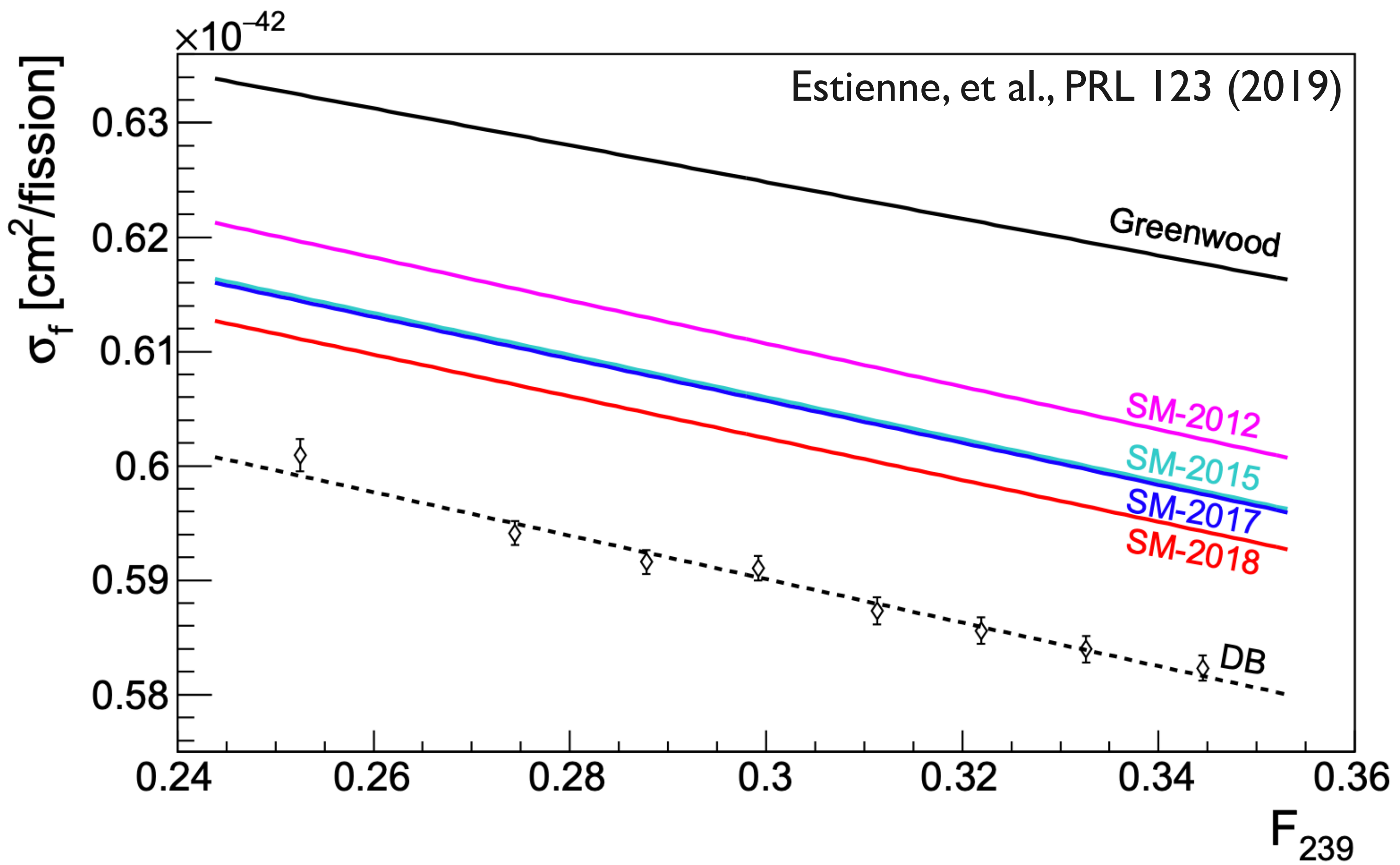
Impact of hypothetical shape factor tweaks



Synergies With Nuclear Data

- Matching increasingly precise neutrino data to improved reactor models can be an iterative, mutually beneficial process
  - **Better modeling and nuclear data** enables precise neutrino monitoring, better understanding of reactor neutrino properties
  - **Better neutrino data** enables new probes of weak points in existing nuclear datasets, robust assessment of new nuclear data measurements.

THANKS!



Backups

Predicting $S_i(E)$, Neutrinos Per Fission

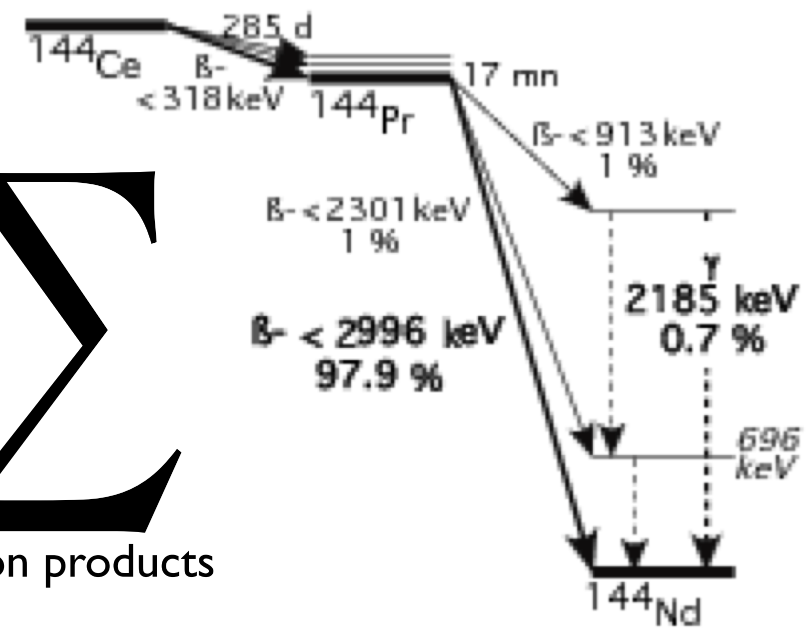
- Two main methods:

- *Ab Initio* approach:
  - Calculate spectrum branch-by-branch w/ databases: fission yields, decay schemes, …
  - **Problem:** rare isotopes / beta branches: missing, possibly incorrect info…

- Conversion approach
  - Measure beta spectra directly
  - Convert to $\overline{\nu}_e$ using 'virtual beta branches'
  - **Problem:** 'Virtual' spectra not well-defined: what forbiddenness, charge, etc. should they have?
  - 'Preferred' method: smaller error bars

Example: Ce-144 Decay Scheme

$\sum$ fission products



Example: Fit virtual beta branches