Towards a Consistent Evaluation of Fission Observables

Status, Challenges, and Plans for Consistent Modeling and Evaluation of Fission Data: Nubar, PFNS, and FPY

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The importance of consistent evaluations for fission observables

- Currently, prompt fission quantities (e.g. neutron multiplicity, neutron energy spectrum, and fission product yields) are evaluated independently of one another, either with separate models or data-only/non-model evaluations (few – if any – shared model inputs).
- Inconsistencies can arise in evaluated data (e.g. *NSE* **190**, 258 (2018))
- Consistent, model-based evaluations lead to:
  - More physical constraints on free parameters in the model
  - More robust predictions for other observables and other isotopes
  - Correlations between the uncertainties on different observables
  - Uncertainties can be propagated to unmeasured quantities
- We are working on developing our models to the point where fission observables are calculated at the quality needed for an evaluation.

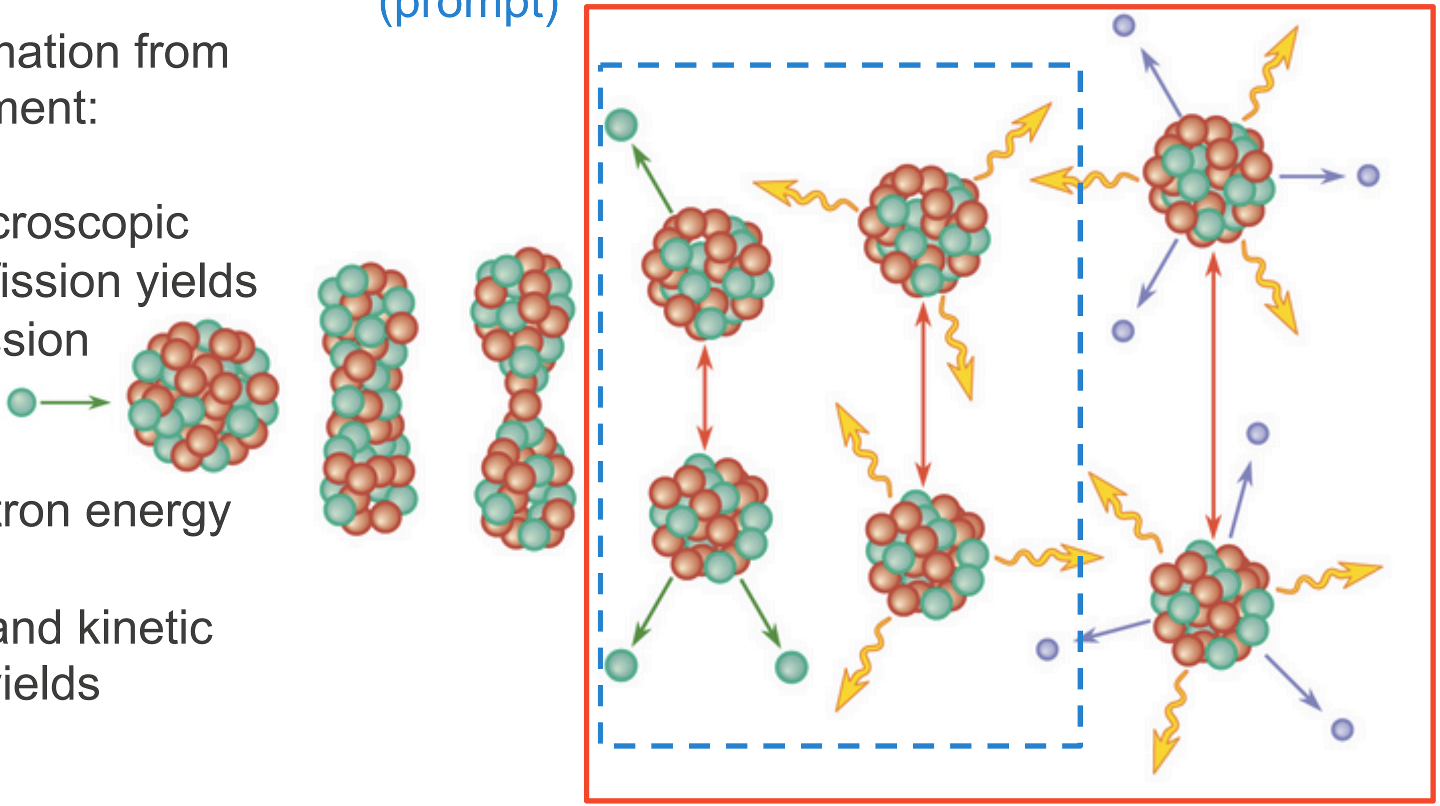
Monte Carlo and deterministic fission models at LANL

Monte Carlo: CGMF (prompt)

Deterministic: BeoH (prompt and delayed)

Pre-scission information from theory and experiment:

- Macroscopic-microscopic/microscopic calculations of fission yields
- Multi-chance fission probabilities
- Pre-fission neutron energy spectra
- Mass, charge, and kinetic energy fission yields



Comparison between CGMF and BeoH

CGMF

- Monte Carlo – event-by-event simulation, correlations between prompt observables can be reconstructed
- Low-yield observables take millions of events to adequately sample this part of the initial fragment conditions
- Multi-chance fission is taken into account exactly

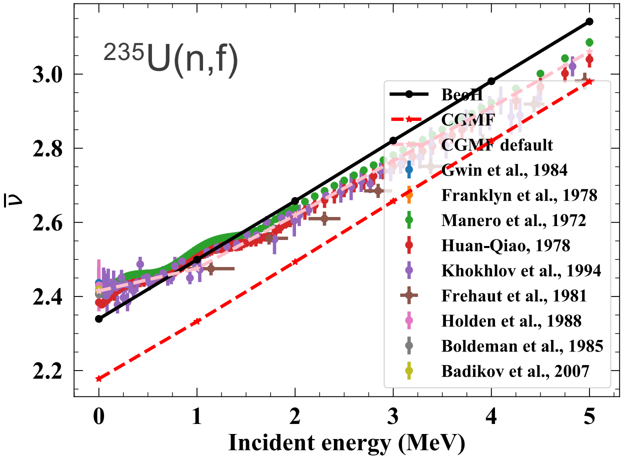
Good for $\bar{\nu}$ and PFNS

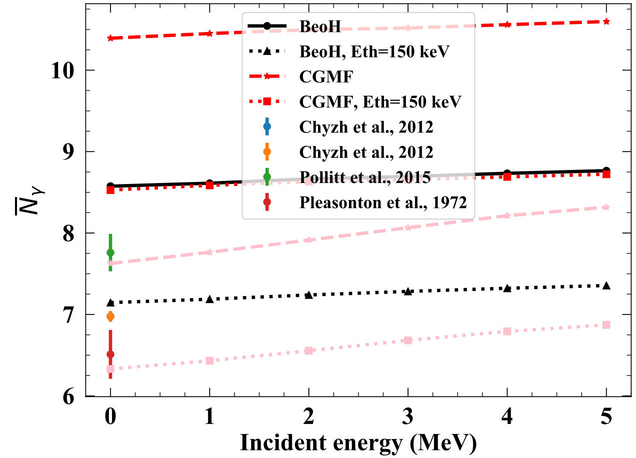
BeoH

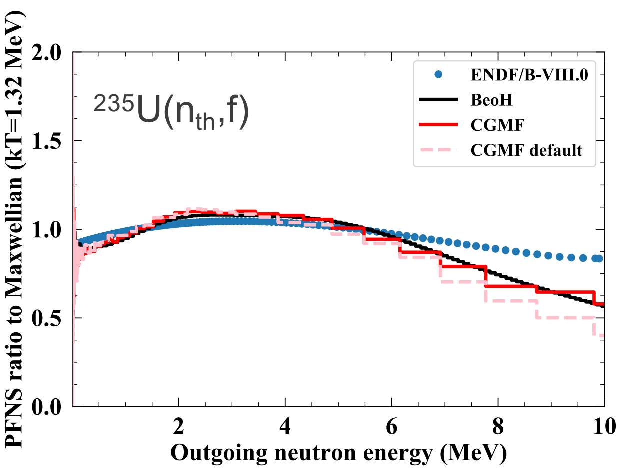
- Deterministic – no correlations between observables
- Low-yield fragments are calculated with the same precision as high-yield fragments (good for FPY calculations)
- Because of the internal bookkeeping, P(v) and PFNS do not yet take account for multi-chance fission correctly

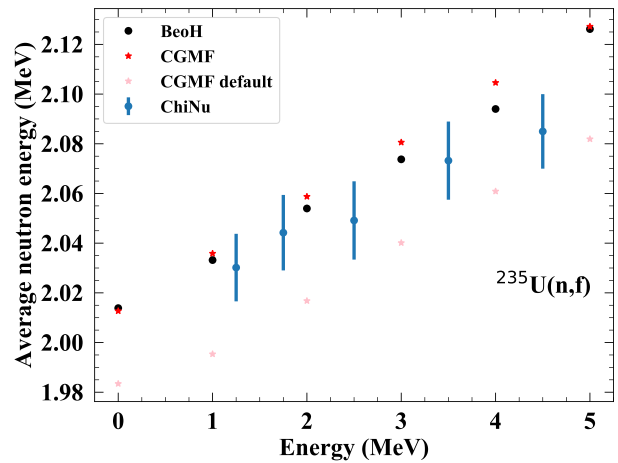
Good for FPY

Comparison between CGMF and BeoH for prompt observables





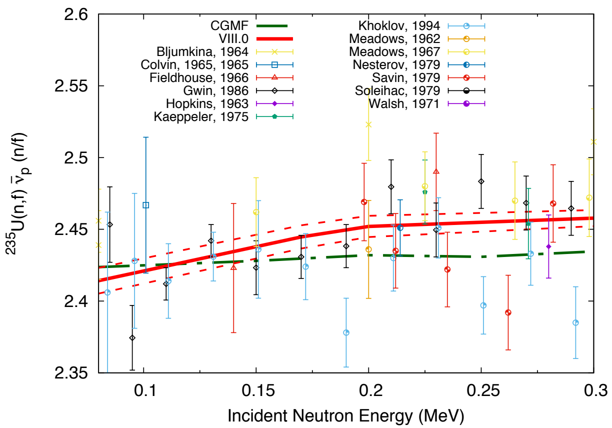




The input parametrizations are nearly identical between CGMF and BeoH.

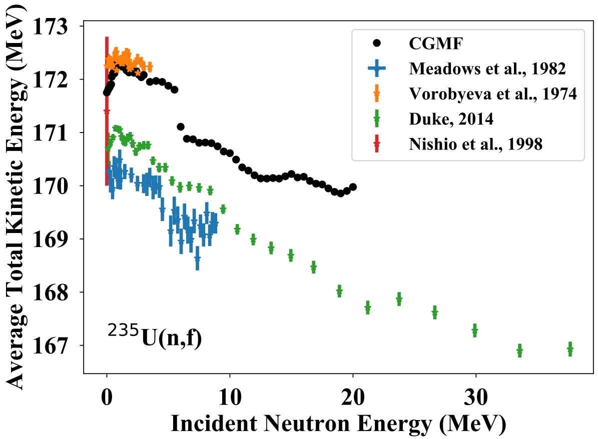
With the same set of input parameters, there is good agreement between CGMF and BeoH (except for, currently, the average multiplicities – being investigated further).

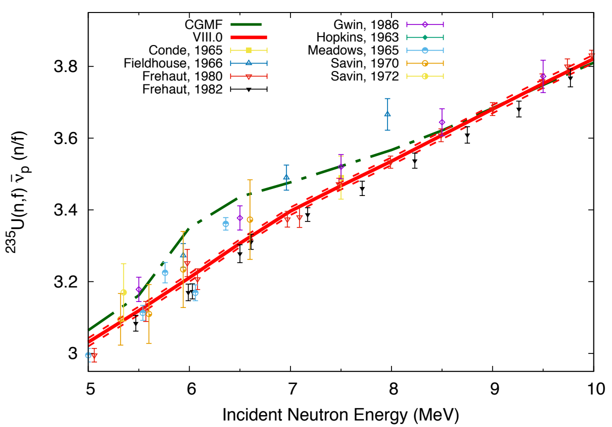
^{235}U(n,f) $\bar{\nu}$ comparisons (CGMF)

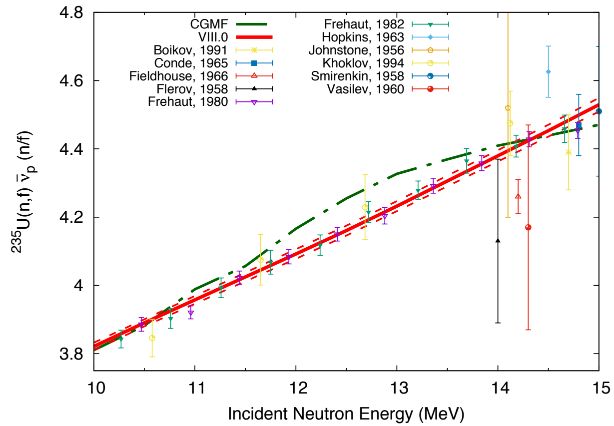


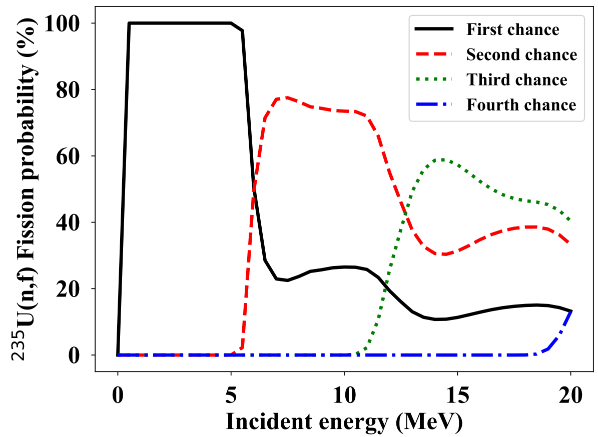
Prompt neutron multiplicity is close to ENDF/B-VIII.

The highest sensitivity to $\bar{\nu}$ in CGMF is to TKE, where there is room for adjustment.



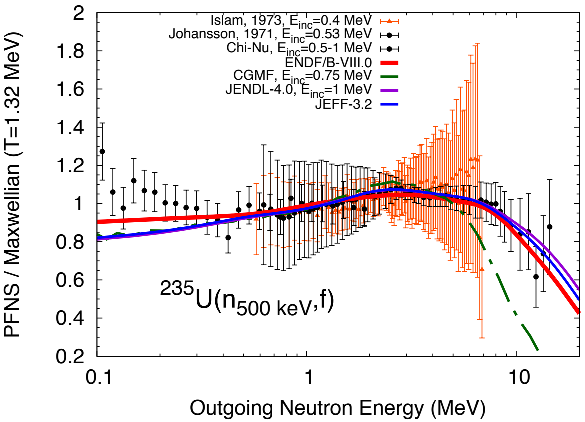


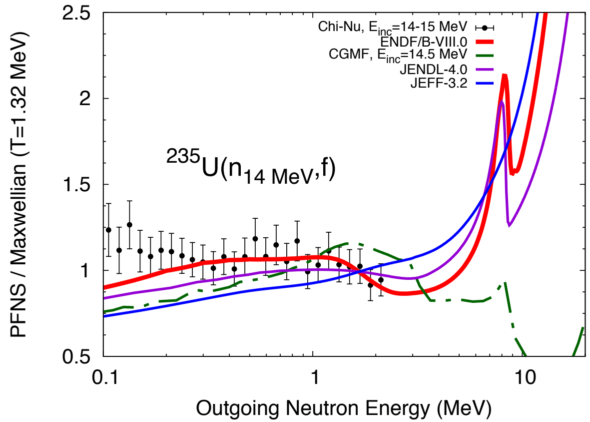




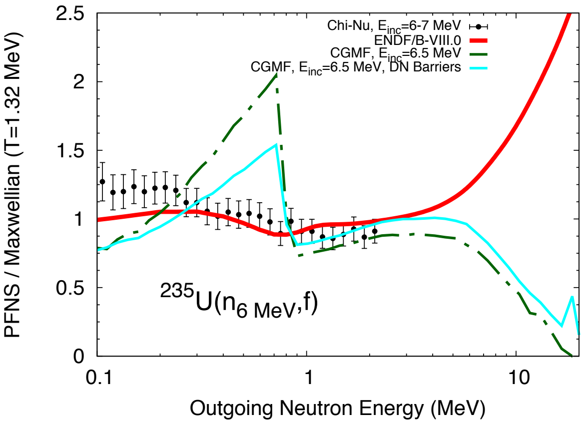
Data comparison by D. Neudecker

$^{235}U(n,f)$ PFNS comparison (CGMF)



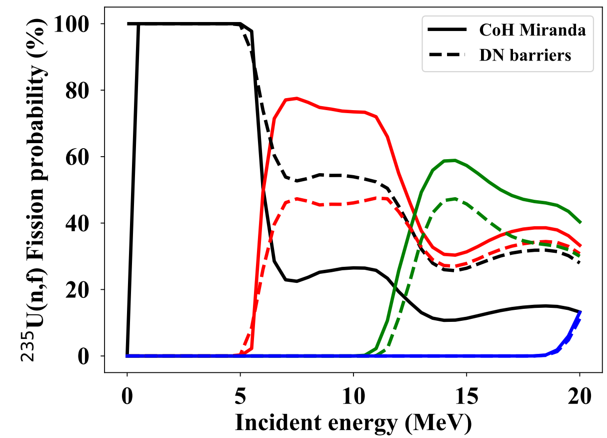


Multi-chance fission features can be adjusted with the fission probabilities. Other investigations are underway.



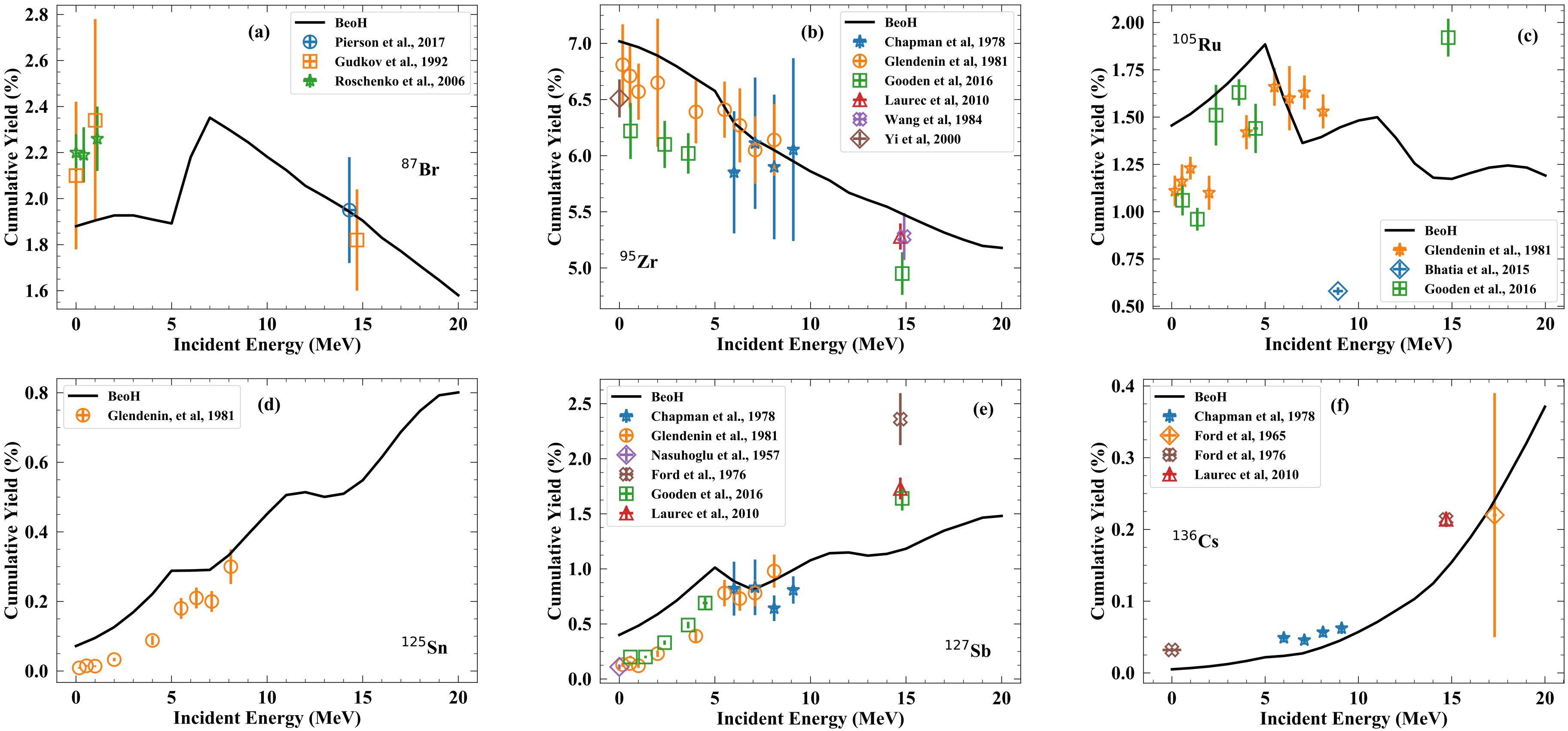
Data comparison by D. Neudecker

The PFNS calculated by CGMF is consistently too soft compared to data and evaluations. Multi-chance features do not appear at the correct energies.



-- Fission barriers from *Nucl. Data Sheets* **148**, 293 (2018)

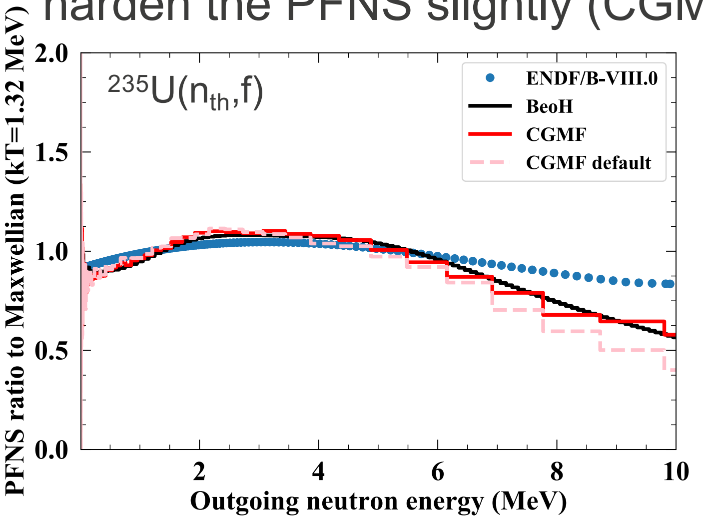
^{235}U(n,f) cumulative fission yield comparisons (BeoH)



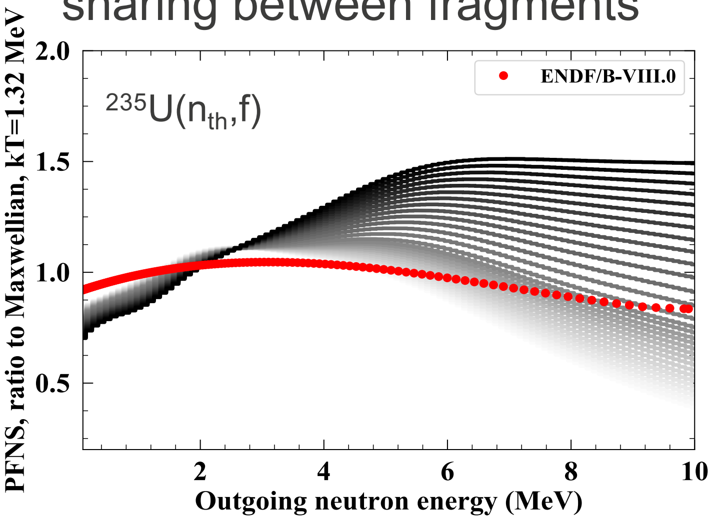
arXiv:2010.13913 (*PRC* in review)

Model investigations into changing the shape of the PFNS

Changes to the spin distribution harden the PFNS slightly (CGMF)



Changes to the excitation energy sharing between fragments



Also investigating:

- Optical model potential
- Level densities
- Pre-scission mass yields

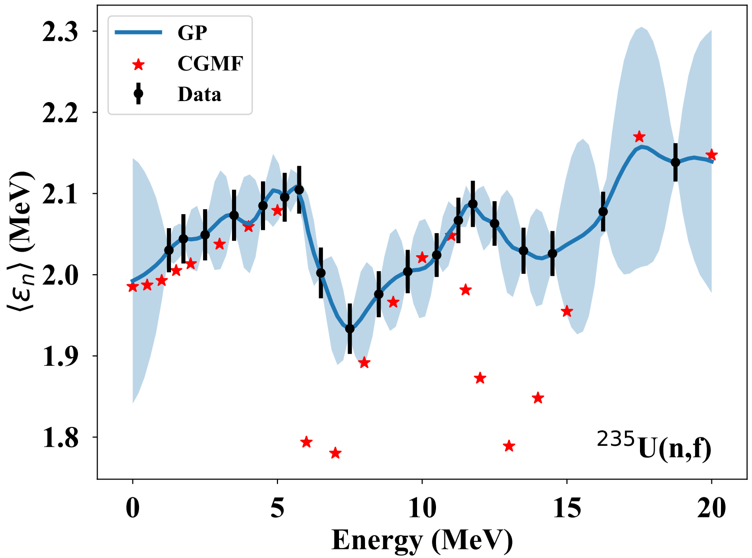
The PFNS cannot be changed in a vacuum – the effect on the neutron multiplicity and γ-ray observables must also be taken into account. Having multiple observables narrows down the possible parameter space.

Mitigation efforts for the PFNS evaluation

If the PFNS is not to the quality needed for an evaluation:

- Still have consistency between $\bar{\nu}$ and FPY (PFNS evaluated using the Los Alamos Model)
- Evaluate $\bar{\nu}$ consistently across isotope (with mass-dependent parameters)
- Model the discrepancy with Gaussian Processes (more studies are needed: interpolation quality, are features captured, etc.)

Preliminary GP studies: 2020 XCP Computational Workshop (S. Blade and S. Ozier) emulated the discrepancy between CGMF and experimental data for the average neutron energy (with Stetcu/Grosskopf)



Conclusions

- We are striving to consistently calculate fission observables, such as $\bar{\nu}$, PFNS, and FPY, *to a quality suitable for an evaluation*.
- Current evaluations for fission observables use separate models for each observable (with minimal shared input) or are purely data driven.
- LANL models, such as the Monte Carlo CGMF and deterministic BeoH, have different strengths; the similar fission fragment initial conditions and decay models leads to consistency between the two codes (FPY can be connected to $\bar{\nu}$ and PFNS, even when calculated by different codes).
- Work is underway to optimize the models (Lovell) and perform detailed uncertainty quantification (Neudecker). The PFNS, in particular, presents a significant challenge.

For more information see LANL report LA-UR-20-26932.

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