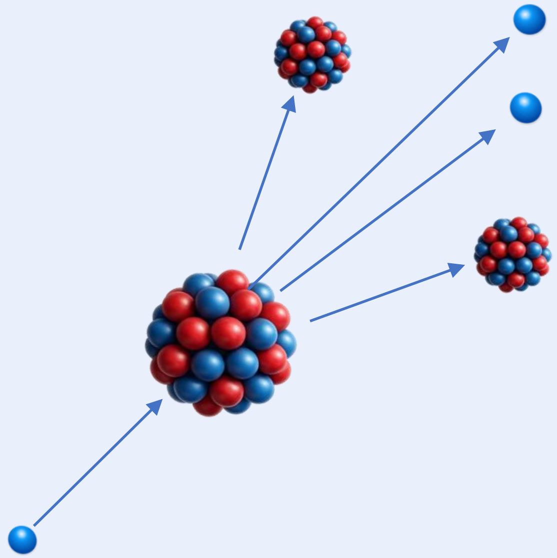
Adjustment of ^{239}Pu evaluations using Bayesian Inference

Cross Section Evaluation Working Group – Brookhaven National Lab, NY

November 4, 2025



Marc Salinas, Postdoctoral Researcher | SD
Design Physics Division

Calibrating to Criticality benchmarks with Bayesian Inference

- Use Importance sampling to estimate posterior means and covariances

Godiva (HEU-MET-FAST 001):
k_{eff} = 1.0 ± 0.00213
Jezebel (PU-MET-FAST 001):
k_{eff} = 1.0 ± 0.002

$$P(x|D) \propto \mathcal{L}(D|x)P(x)$$

$$p(x|D) \propto \underbrace{\prod_{i=1}^{N} \exp\left[-\frac{1}{2}\frac{\left(y_i^{(\text{th})}(\vec{x}) - y_i^{(\text{exp})}\right)^2}{\sigma_{e,i}^2 + \sigma_{m,i}^2}\right]}_{\text{Integral/Differential Data Likelihood}} \times \underbrace{\exp\left[-\frac{1}{2}\left(\vec{x}-\vec{\mu}\right)^T \Sigma^{-1}\left(\vec{x}-\vec{\mu}\right)\right]}_{\text{Nuclear Data Prior}}$$

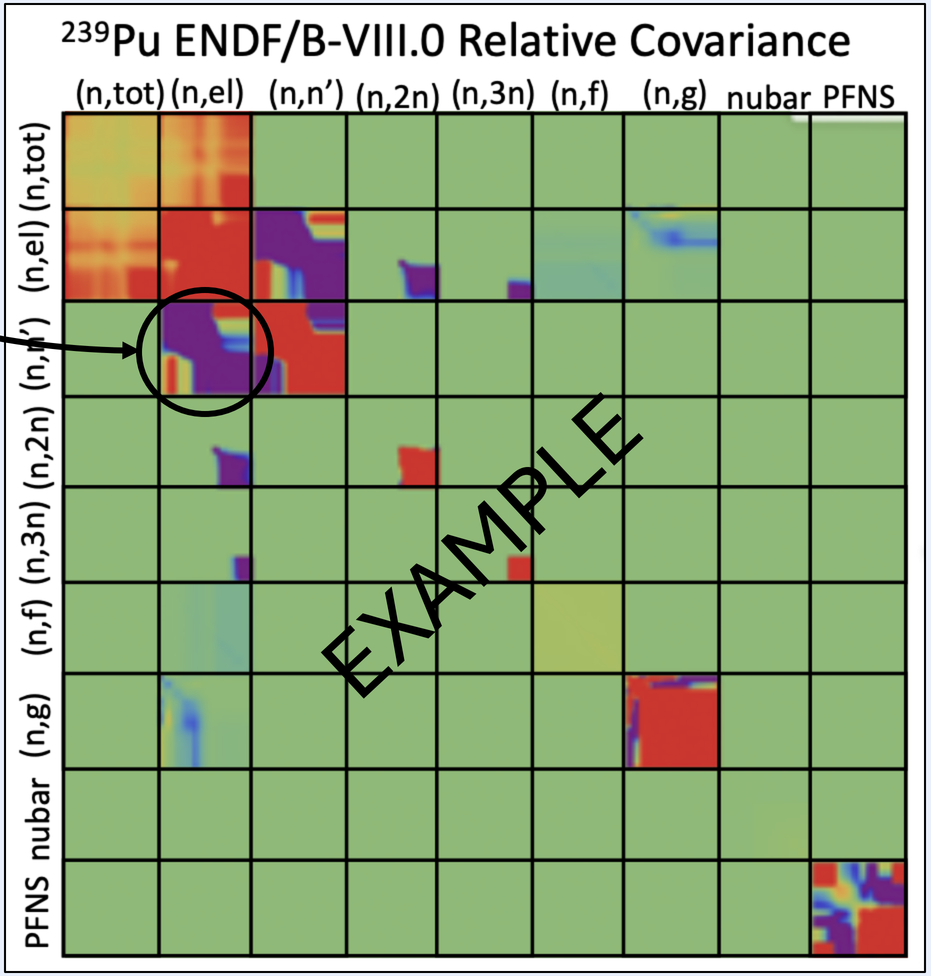
- Samples are drawn from the prior using new LLNL code EMU (Evaluated Means and Uncertainties)
- EMU can sample the ENDF covariance and generate stochastic libraries

Importance Sampling

$$\hat{\sigma}_y^2 = \sum_{i=1}^{N} \tilde{w}(x^{(i)}) \left[y(x^{(i)}) - \hat{\mu}_y\right]^2 \qquad \hat{\mu}_y = \sum_{i=1}^{N} \tilde{w}(x^{(i)}) y(x^{(i)})$$

Using EMU to generate samples

- Prior samples are taken from the ENDF/B-VIII.1 library
- Includes cross-channel correlations and constraints from the total cross section (no cross-material samples yet…)
- 1700 samples are taken to generate the prior distribution and each sample is weighted by the likelihood
- Sampling is expensive! **Importance sampling reduces this cost by weighting each sample appropriately**



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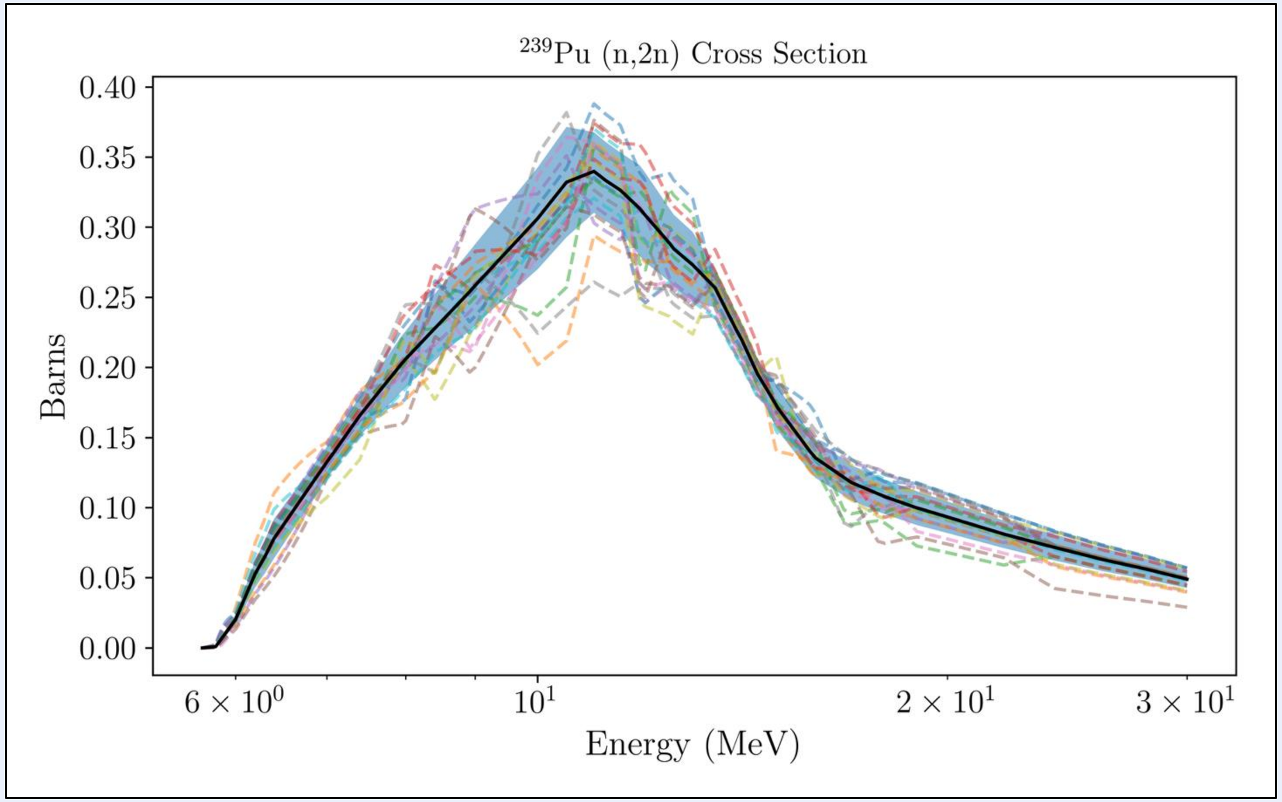
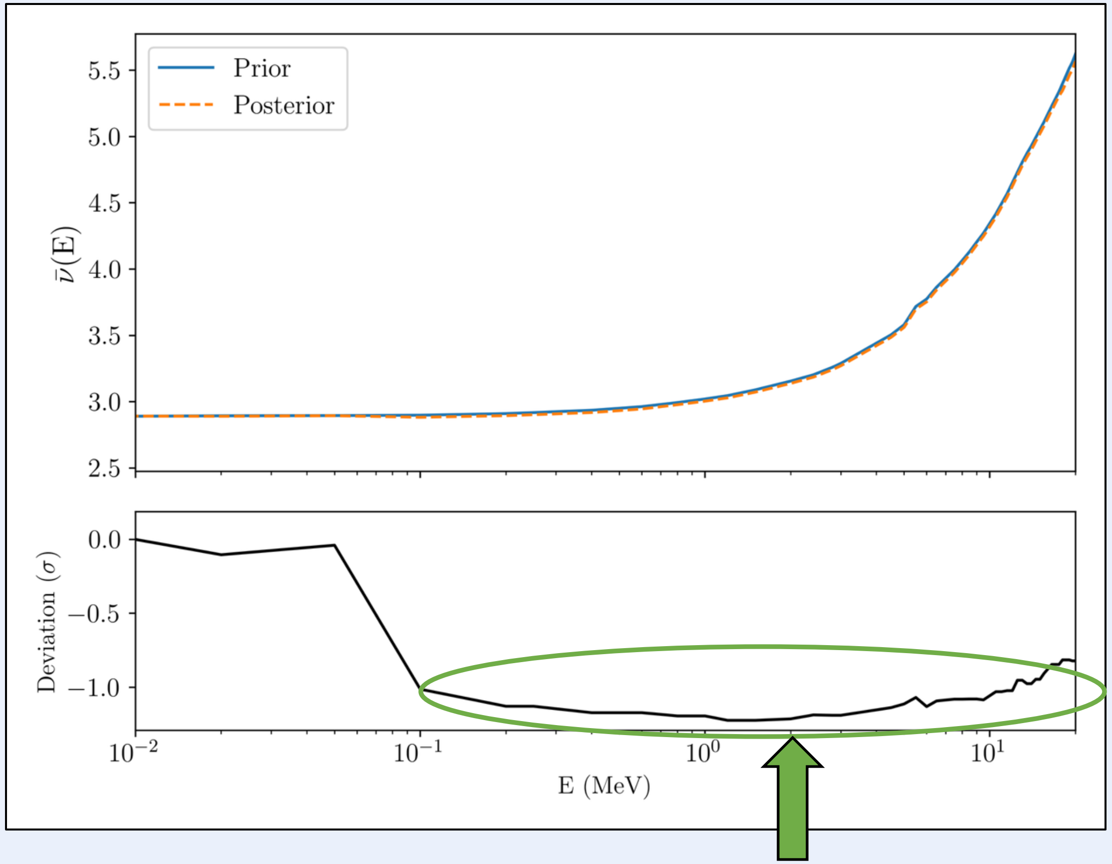


Taking fTPC as truth for ^{239}Pu fission cross section

- First calibration was done by adjusting the fission cross section of ^{239}Pu to fTPC data. Causes large discrepancies with Pu-based critical benchmark data, e.g. Jezebel ~ 1.01
- Bayesian inference is used to infer other ^{239}Pu degrees of freedom to match Jezebel benchmark again. These include: elastic, $\bar{\nu}$, capture, (n,2n), and inelastic
- Results show significant changes to $\bar{\nu}$ and inelastic cross section
- Some changes to elastic cross section and minor changes to capture, (n,2n)



Over 1σ change to $\bar{\nu}$!

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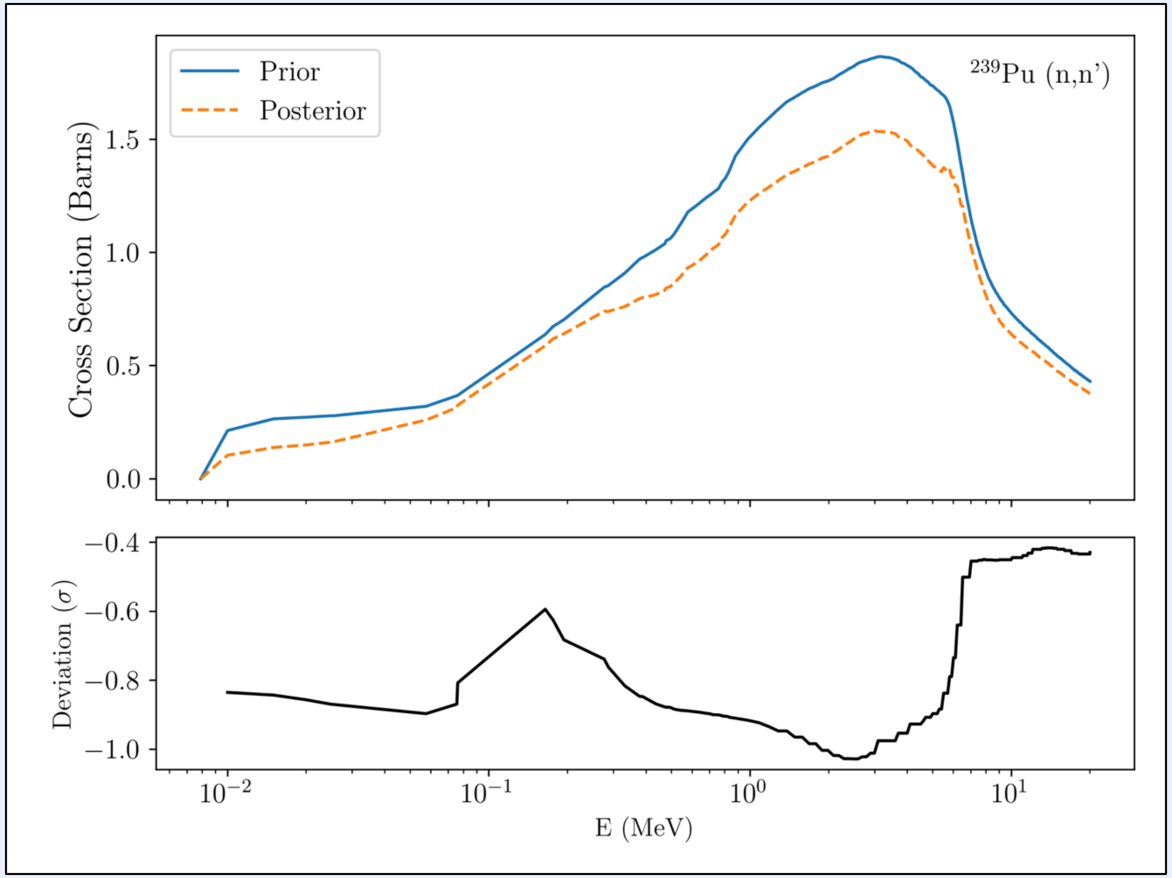
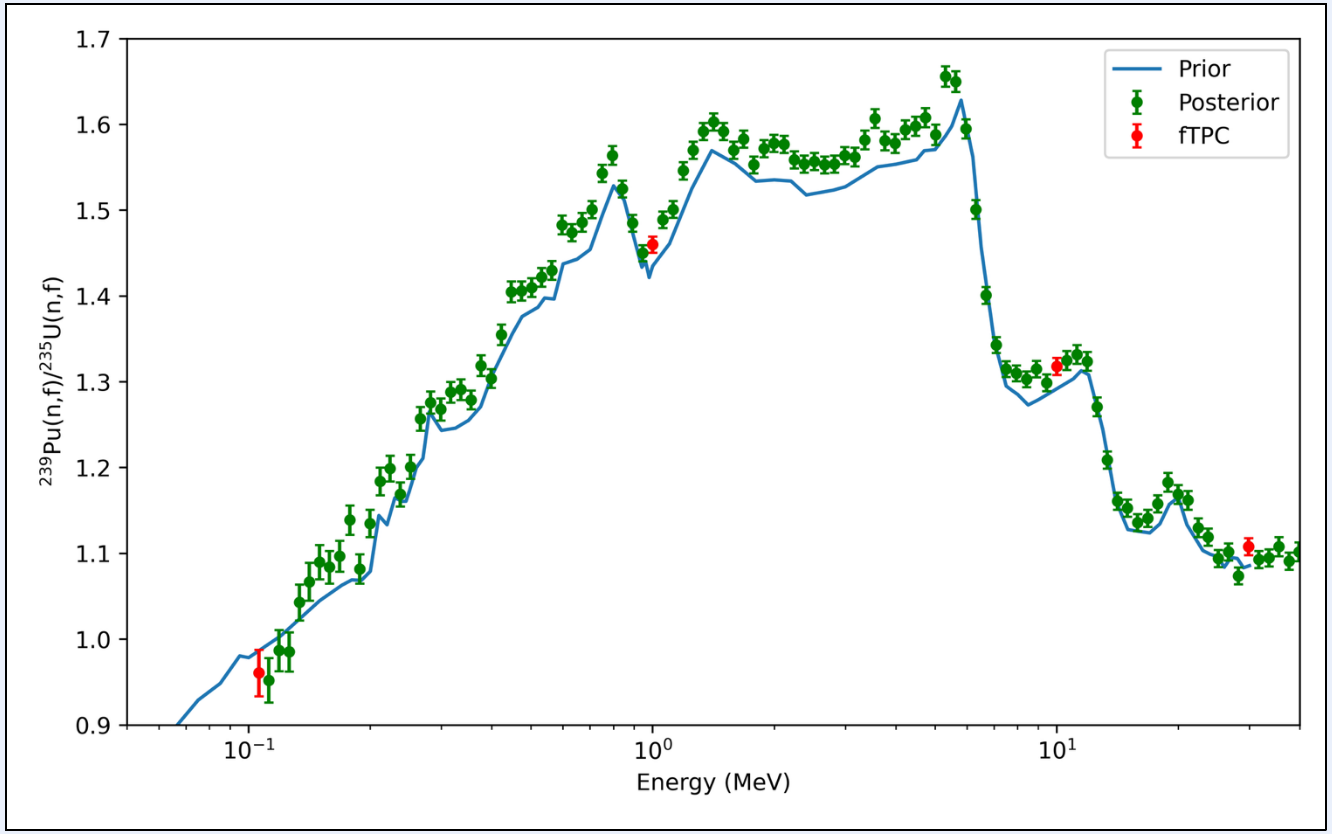


Explicit calibration to fTPC data

- **Allow both ^{239}Pu and ^{235}U to fully vary according to the ENDF covariance**
- fTPC data and Godiva/Jezebel benchmarks will determine what nuclear data needs to change to meet experimental constraints
- Changes to both the ^{239}Pu and ^{235}U fission cross sections
- Less extreme changes to other reaction channels (<1σ)
- New covariance data for posterior distributions informed from fTPC and criticality constraints



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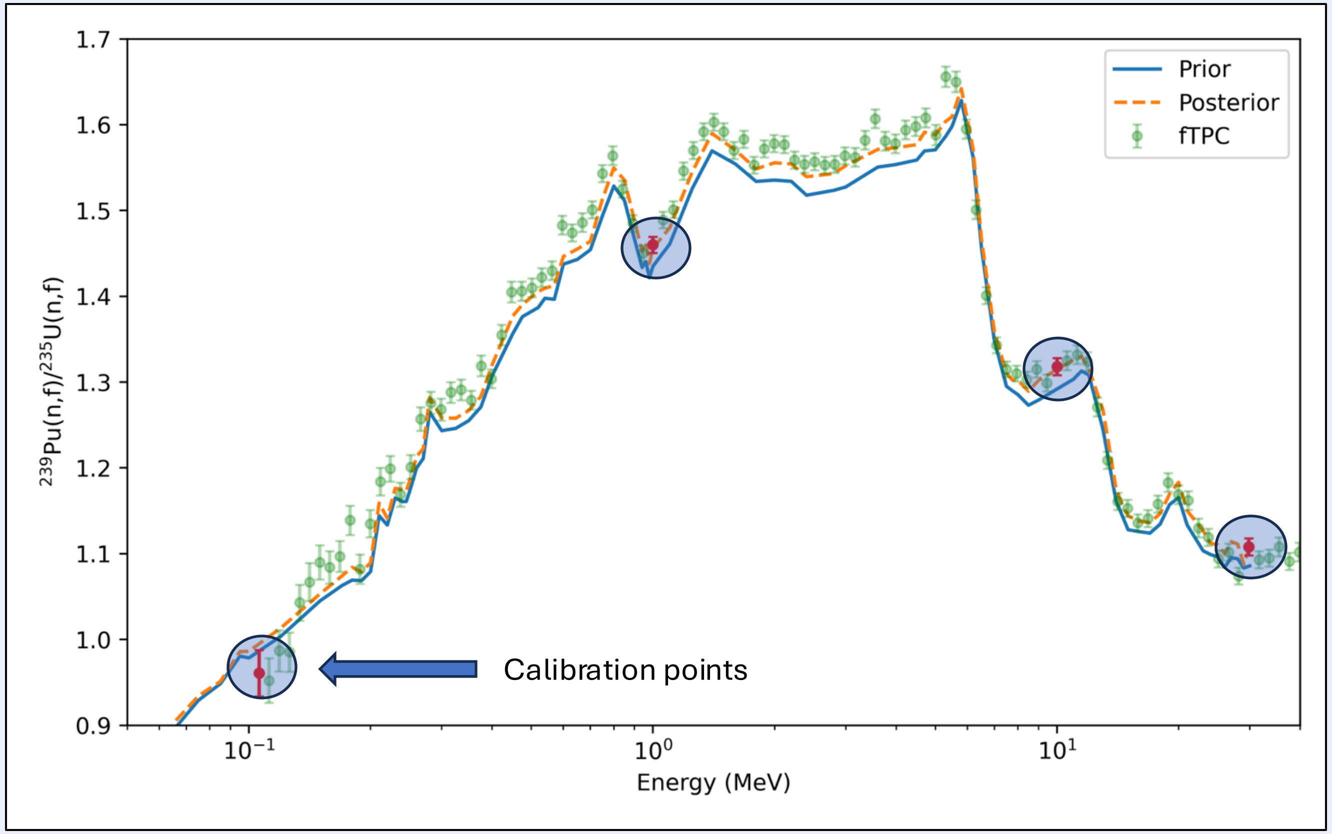

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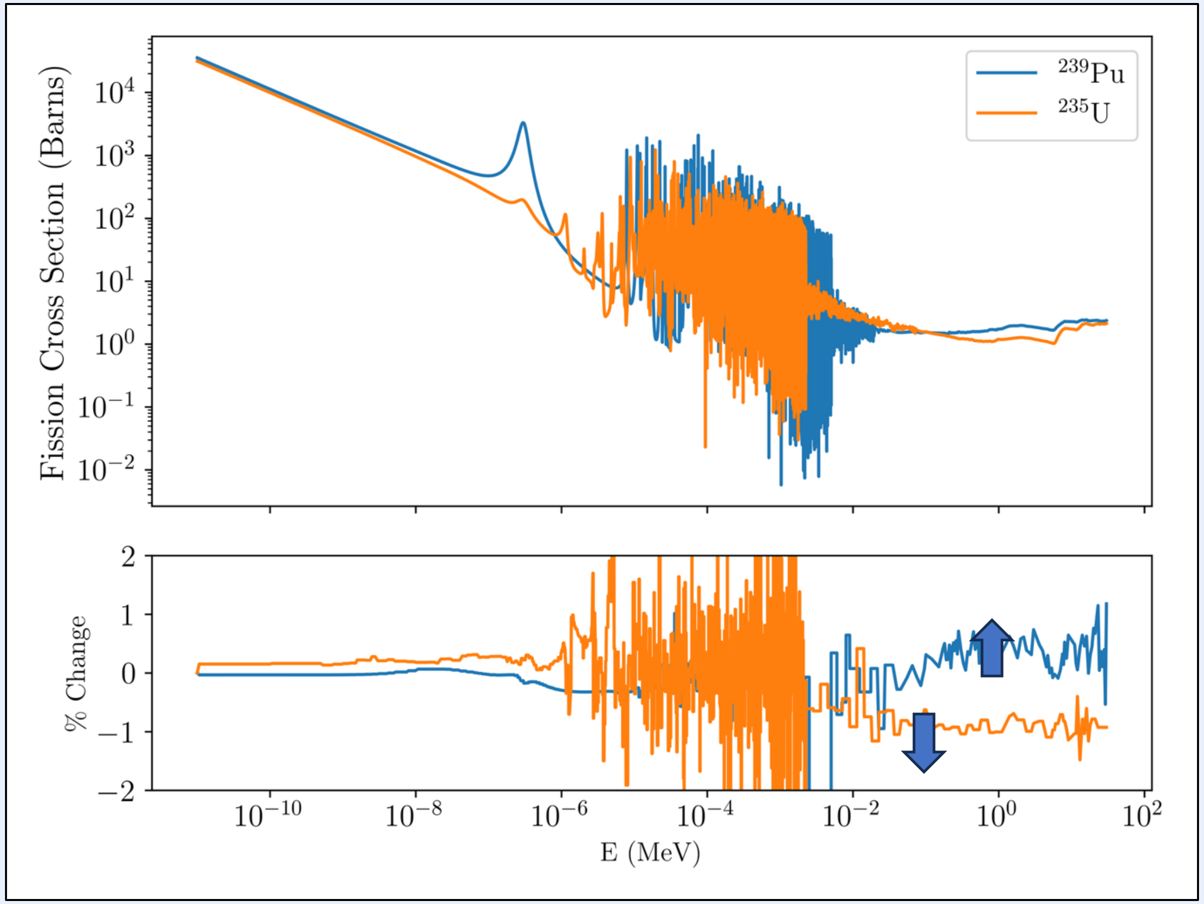

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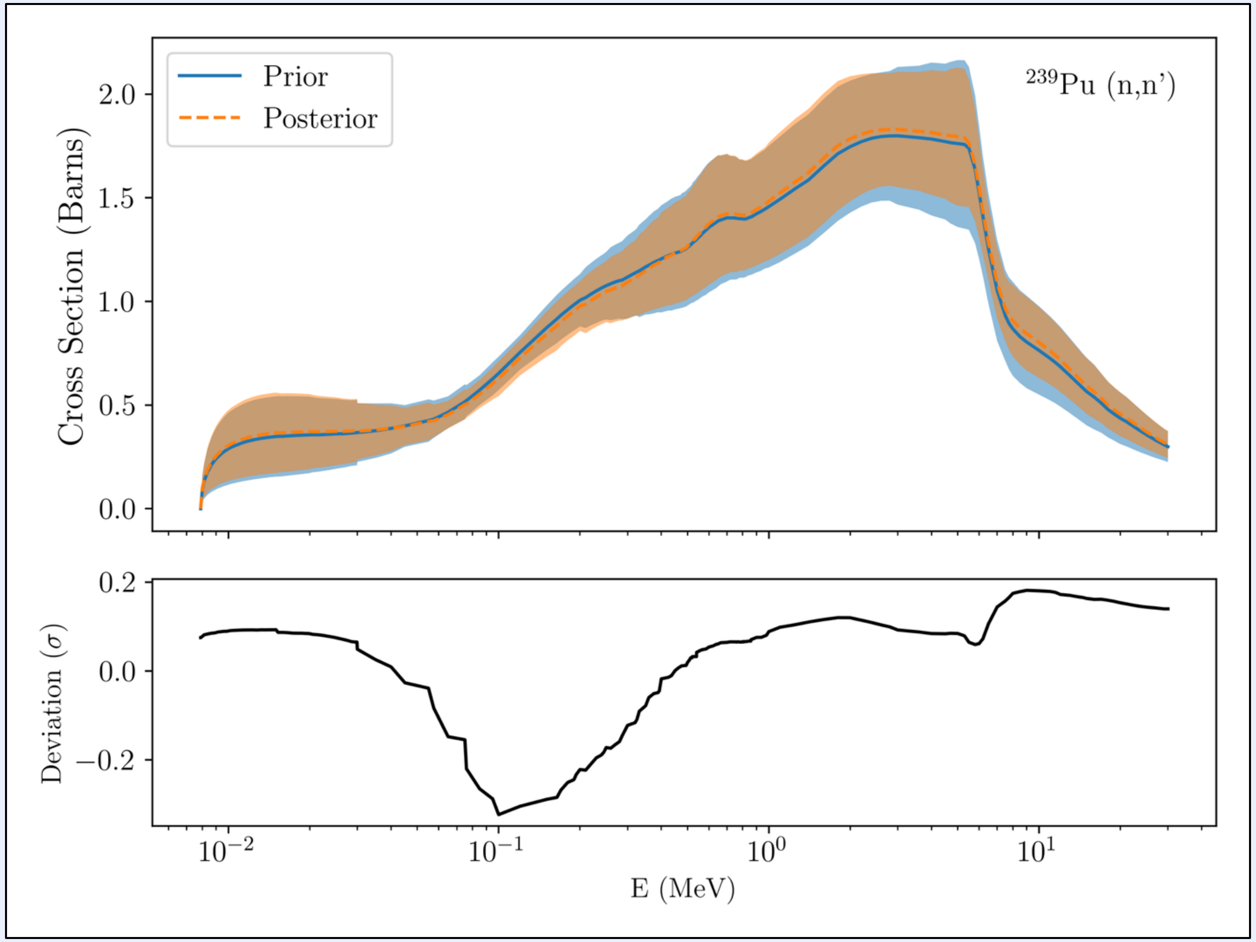

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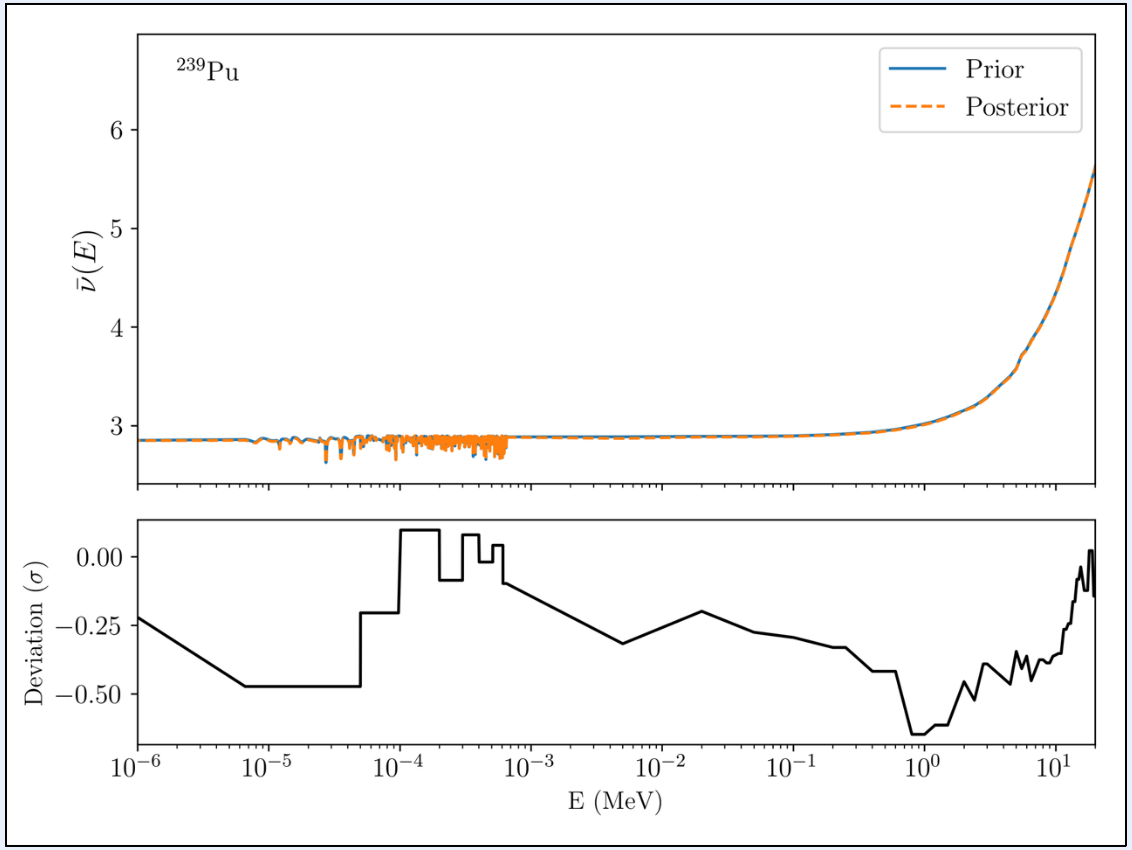
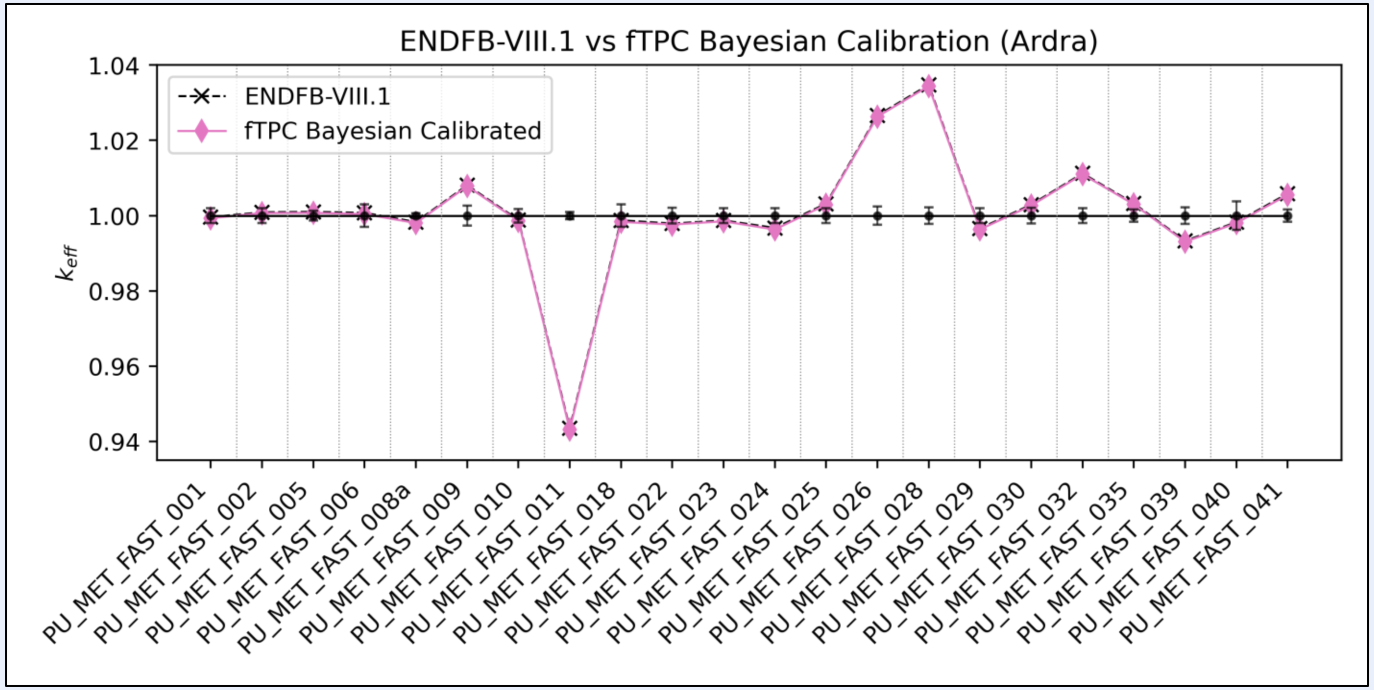


Takeaways and Comparison with ENDF for Critical Assemblies

- Bayesian Inference can be a valuable tool for informing which reaction channels/nuclear data needs to change due to new experimental/theoretical constraints
- Can provide new covariance data to relatively unconstrained reaction channels, given the experiment is sensitive to the underlying channel
- Also provides cross channel correlations that might be helpful to the evaluation/physics community



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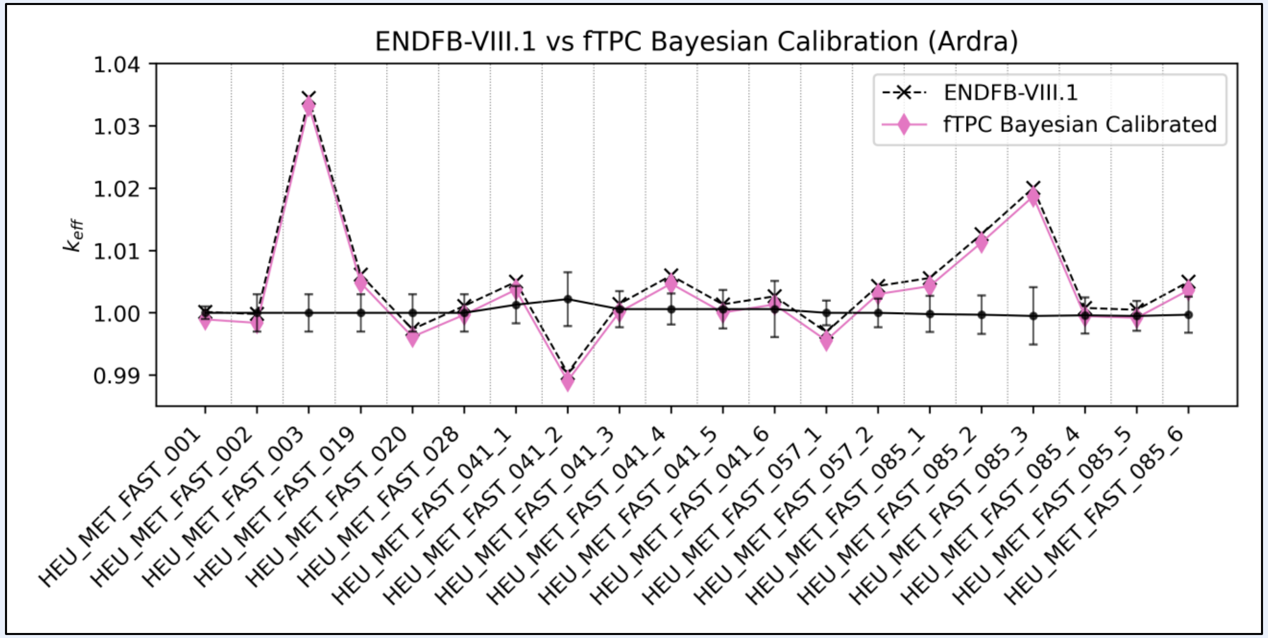

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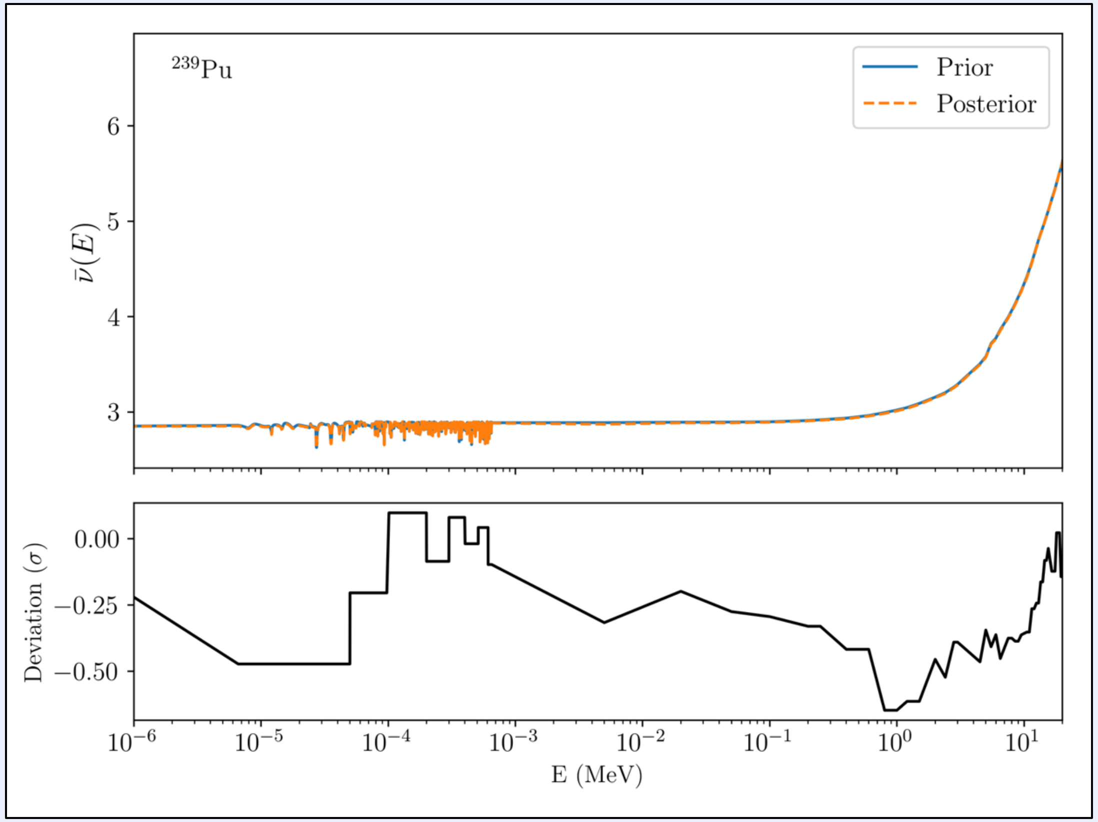
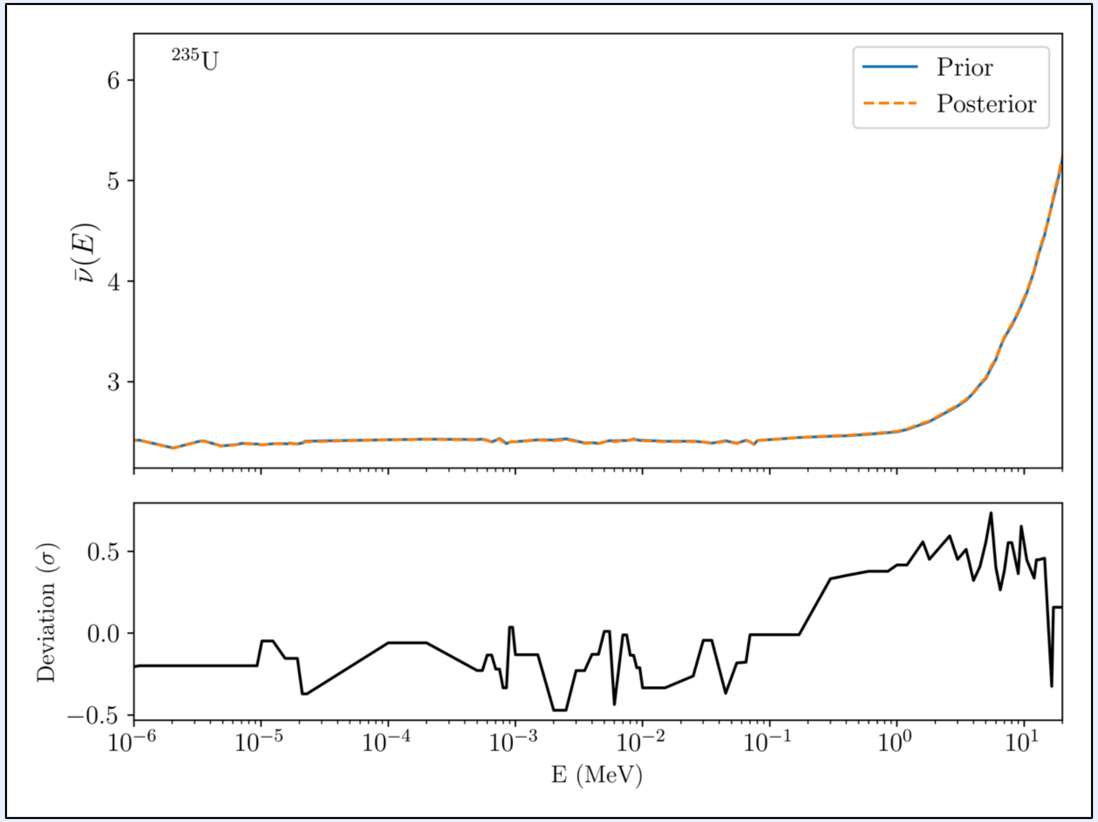
Neutron Multiplicities





Some backup sources

- Updated uncertainties for Godiva taken from
  Bess, J. D., Briggs, J. B., & Marshall, M. A. (2013)