Los Alamos NATIONAL LABORATORY

Adjusting nuclear data to multiple responses beyond keff

Presenter: J. Hutchinson

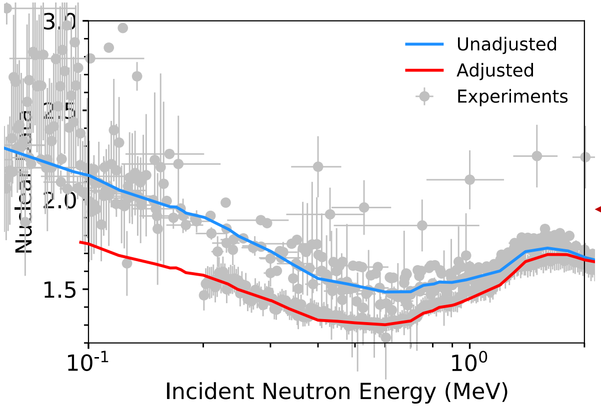
EUCLID team: J. Alwin, A. Clark, T. Cutler, M. Grosskopf, W. Haeck, M. Herman, N. Kleedtke, J. Lamproe, R.C. Little, I. Michaud, D. Neudecker, M. Rising, T. Smith, N. Thompson, S. Vander Wiel, N. Wynne

CSEWG 2022

LA-UR-22-

EUCLID will execute validation experiments optimized to resolve compensating errors & adjust nuclear data to experiments

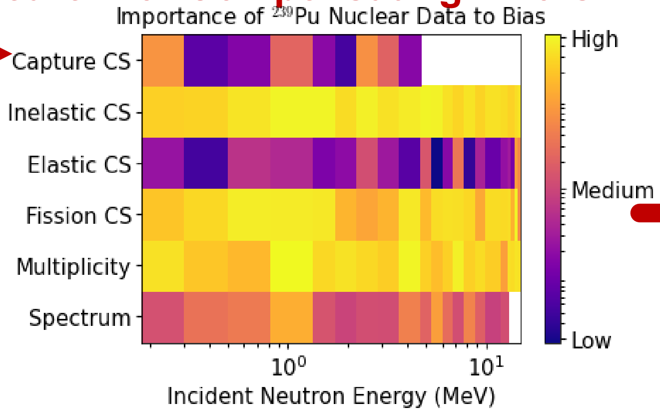
Neutron Transport Simulation (MCNP)



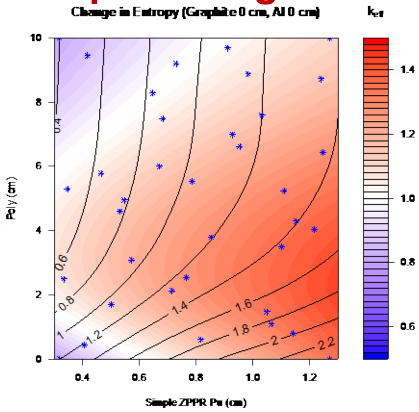
Experiment Refines Nuclear Data to Improve Simulations

Validation Experiments

ML-Augmented Search for Compensating Errors



ML-Optimally Designed Experiment to Resolve Compensating Errors



EUCLID provides sensitivities for many measurement responses. We will study a sub-set here.

Measurement Method	Observable			
	σ	ν	β	PFNS
Critical experiments	✓	✓		✓
Neutron Multiplication Measurements	✓	✓	✓	
Reaction rate ratios	✓	✓		✓
Pulsed Spheres	✓			
Gamma/Neutron Leakage Spectra	✓			✓
Delayed Neutron Measurements			✓	
Rossi-α	✓	✓	✓	
Reactivity Coefficient	✓		✓	

Different measurement types give complimentary data which we will use to constrain nuclear data and tease out compensating errors.

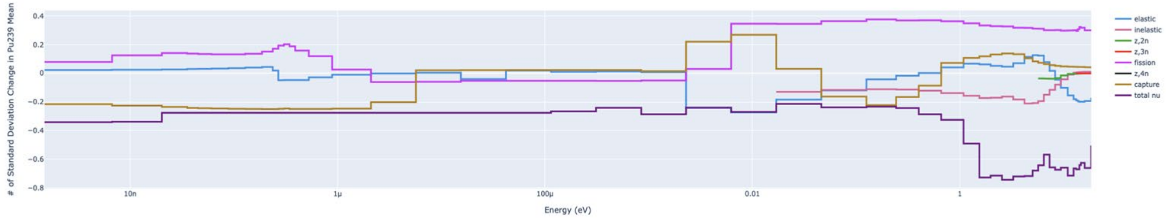
We needed for EUCLID applications sensitivities for many different responses on the same grid and for the same observables -> made a sensitivity library.

EUCLID extended adjustment with physics constraints compared to traditional techniques/ tools.

- 8 integral responses currently,
- Biases in exp. data modeled via Gaussian processes,
- Tools to study impact of varying sizes of unc. for exp. with unknown unc.,
- Algorithm extended to include sens. unc.,
- Shape data are treated correctly in the adjustment

EUCLID Adjustment Visualization

Nuclear Data Adjustment to Benchmark Data by Augmented GLLS



Select Isotope to View: Pu239

Select Reactions to View: All

Select Plot Type: # Sigma Change in Mean

Y-axis Scale: ◉ Log ○ Linear

Select Plot Benchmark: PU-MET-FAST-001-001-s

UPDATE | UPDATE D-OPTIMALITY IN TABLE | DOWNLOAD ADJUSTED ND | DOWNLOAD EXPT TABLE

Explore Added Sources of Uncertainty:

◉ Include Sensitivity Uncertainty ○ No Sensitivity Uncertainty

◉ Original ○ Inflate Uncertainty for Labeled Questionable Benchmarks

◉ No Correction ○ Full Covariance for Shape Correction

Set Pulsed Sphere Shape Uncertainty Standard Deviation (cm^-2 ns^-1):

1.0e-5 1.0e-4 1.0e-3 1.0e-2

◉ No Correction ○ Pulsed Sphere GP Correction for Long TOF

Set Gaussian Process TOF Correlation Length (ns):

10.0 25.0 50.0 100.0 150.0 200.0

Set TOF Gaussian Process Standard Deviation (cm^-2 ns^-1):

1.0e-5 1.0e-4 1.0e-3 1.0e-2

Additional Uncertainty for Reactivity Coefficients (%) for D-Optimality:

2.5 7.5 12.5

Additional Uncertainty for Beta Effective (%) for D-optimality

0.0 2.0 4.0 6.0

Additional Uncertainty for Reactivity Coefficients (%) for Adjustment:

2.5 7.5 12.5

Additional Uncertainty for Beta Effective (%) for Adjustment

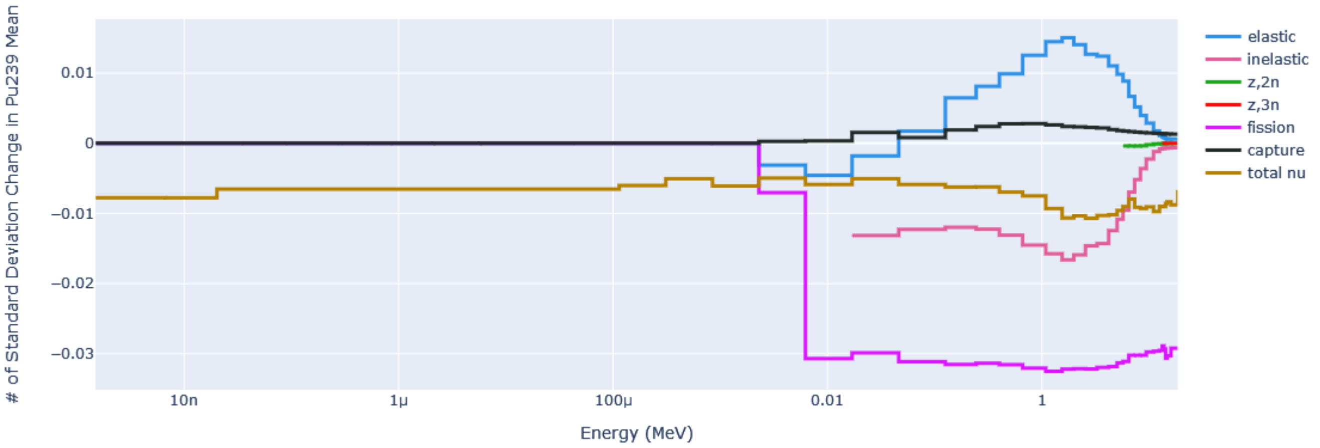
0.0 2.0 4.0 6.0

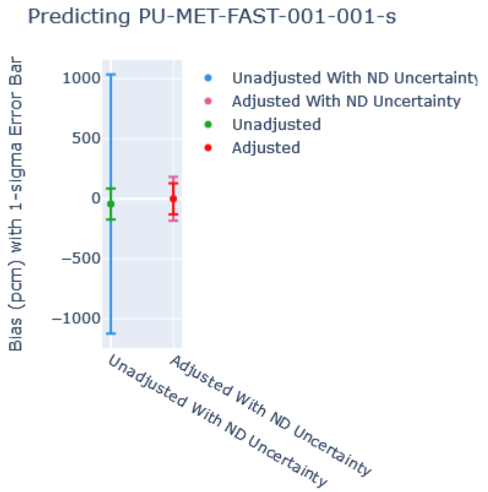
Select Benchmarks to Adjust To:

SELECT ALL | SELECT EUCLID SET | DESELECT ALL

	Benchmark Types	Experiment Names	Experimental Value	Expt. Uncertainty	Calculated Value	Calc. Uncertainty	Total Uncertainty	Bias (sigmas)	Pulsed Sphere Case
	filter data...								
☑	criticality	PU-MET-FAST-001-001-s	1	0.00129	1.00044	0.00008	0.0012924782396620841	0.34043126336504753	
☐	criticality	PU-MET-FAST-002-001	1	0.002	1.00133	0.00008	0.0020015993605114885	0.6644686375500166	
☐	criticality	PU-MET-FAST-005-001	1	0.0013	0.99927	0.00009	0.0013031116606031887	-0.5601975809671625	

Adjusting to: PMF001 keff



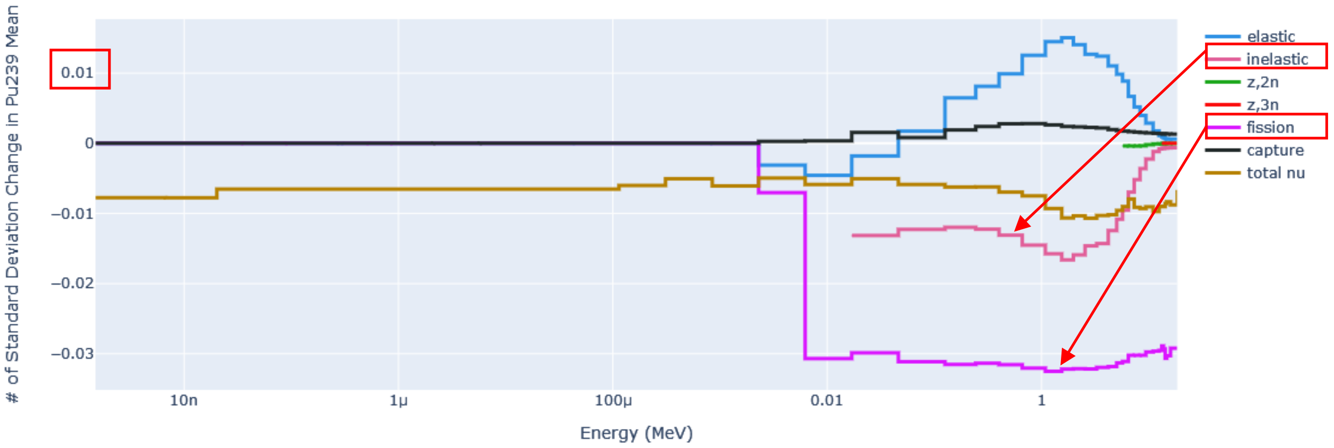


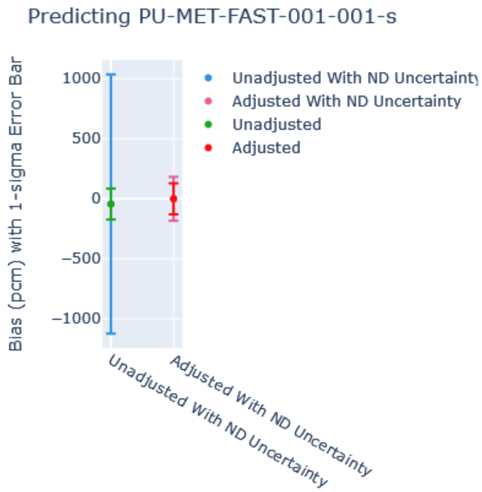
- Left is adjusted data, right is impact of adjustment
- Suggest focusing on inelastic scattering and fission for this presentation

Neudecker CW2022: Adjustment to k_{eff} of PMF001 (Jezebel) leads to small changes in ND mean values BUT large ones in covariances.

Note that this work uses a “toy example” that only includes PMF001 sensitivities in the adjustment.

Adjusting to: PMF001 keff





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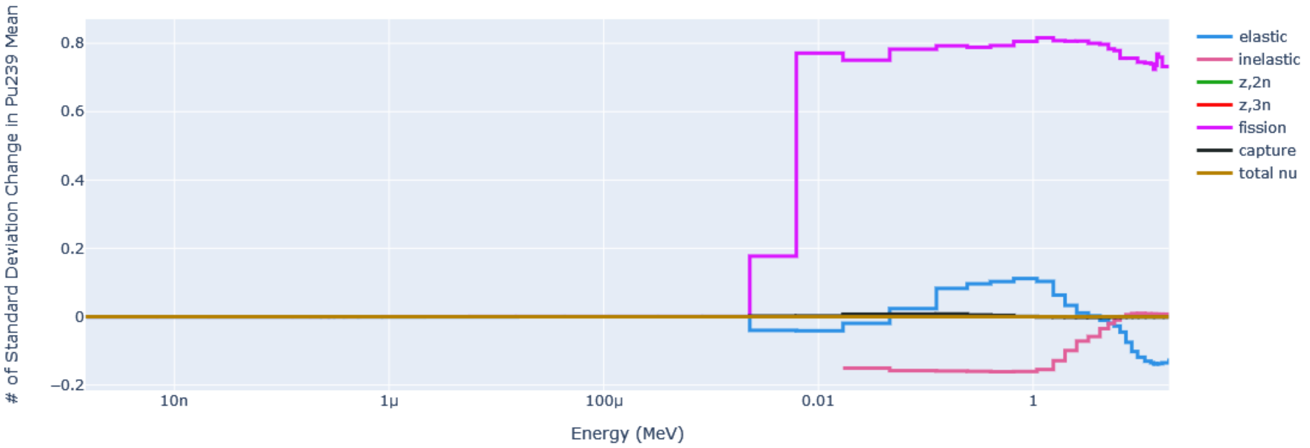
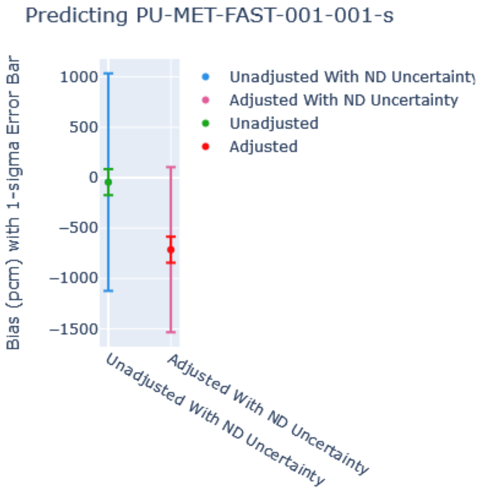
Adjusting to: PMF001 Pu239/U235 and U238/U235 RRR



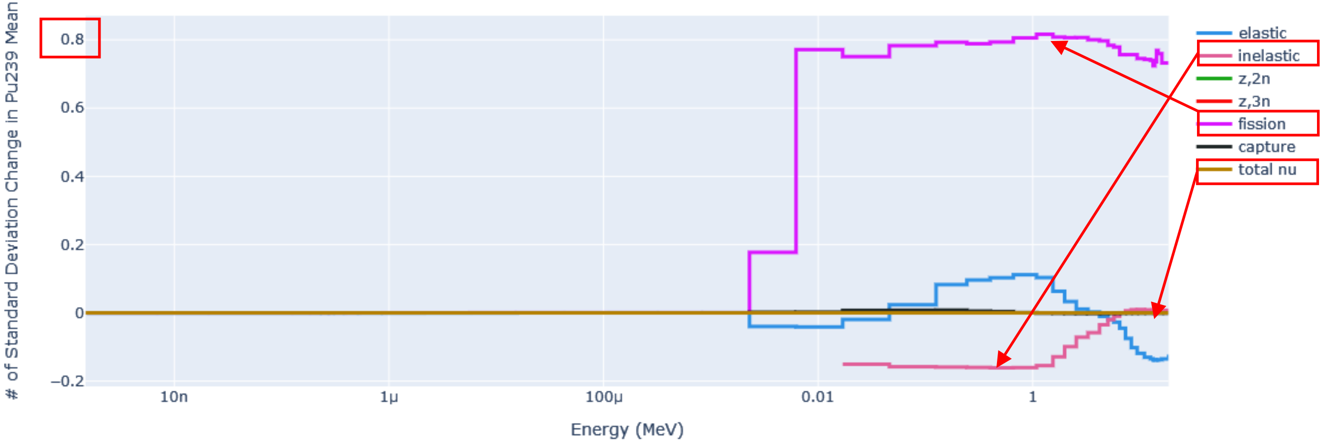


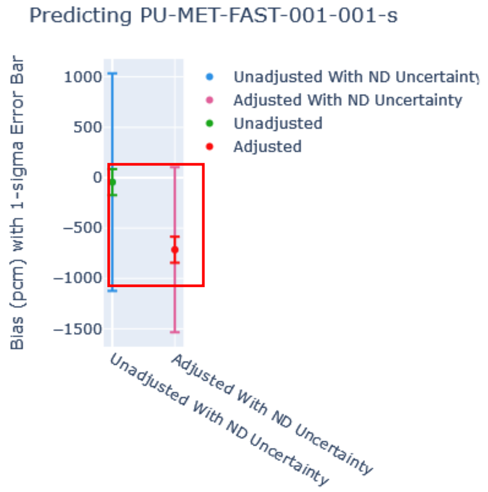
- Fission is in the opposite direction (now up)
- Inelastic is in the same direction (down)
- Note at right that this adjustment has a huge impact on Jezebel keff (down 715 pcm!)

Reaction rates in Jezebel allow us to study PFNS, (n,f), (n,in) and (n,el) cs independent from (n,g) cs and nu-bar.

LDRD

Adjusting to: PMF001 Pu239/U235 and U238/U235 RRR





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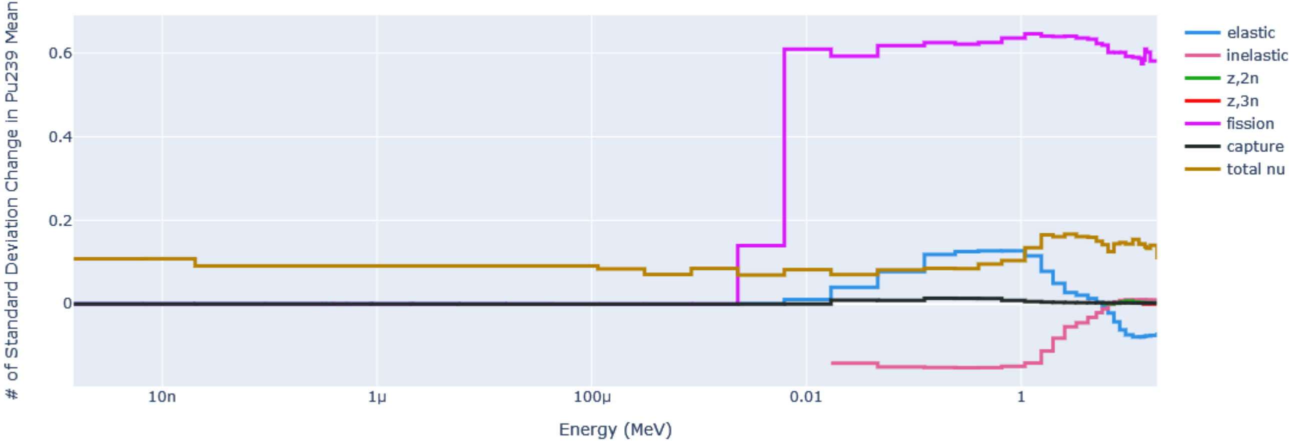
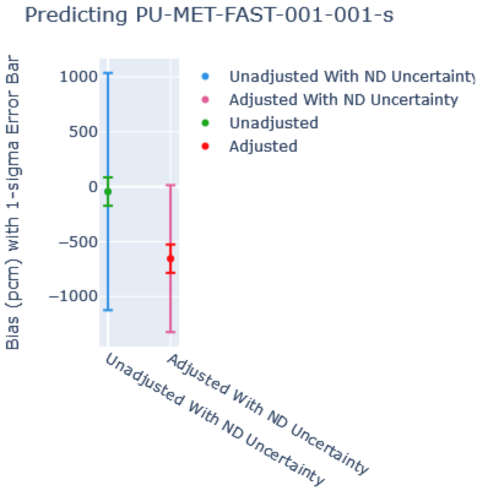
Adjusting to: PMF001 reactivity coefficient (Pu L1 only)





- Looks nearly identical to the last slide. Difference is that here fission is smaller and nubar is non-zero.
- This also has a huge impact on Jezebel keff (down 656 pcm!)

See notes in Neudecker CW2022 and Cutler ANS Annual 2022 on the impact of sensitivity uncertainties for reactivity coefficients

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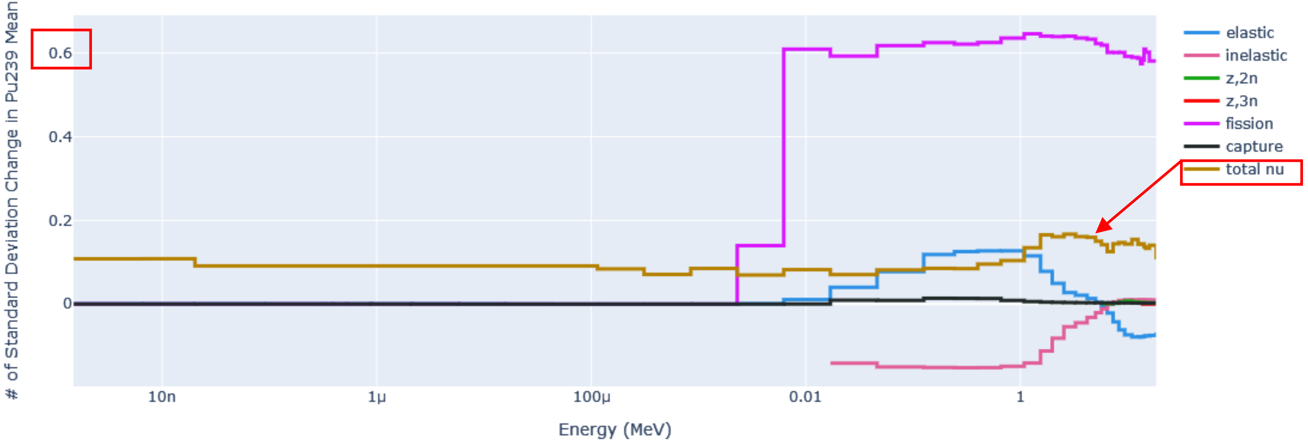

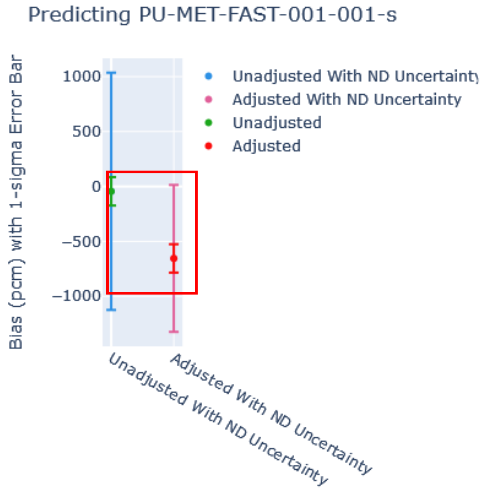

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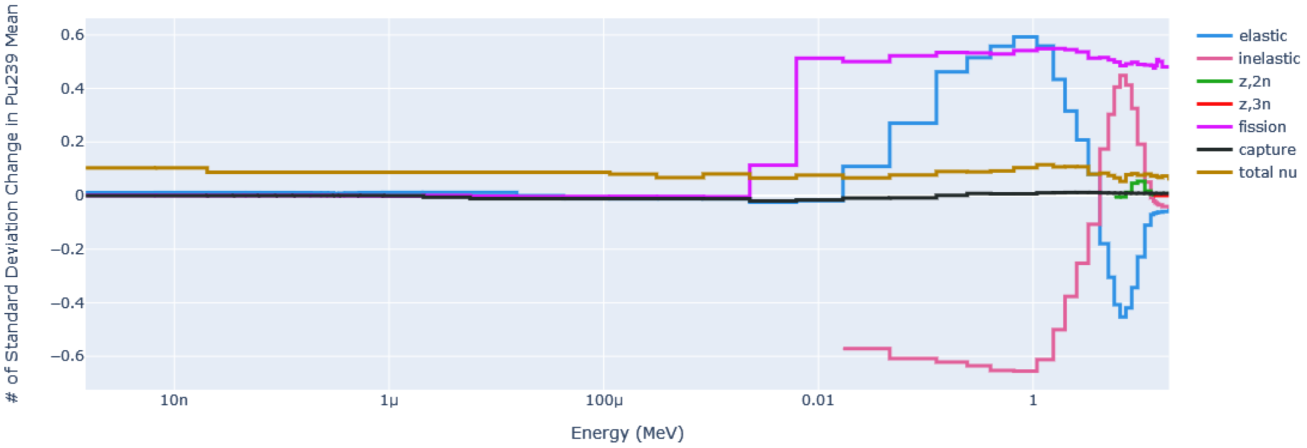
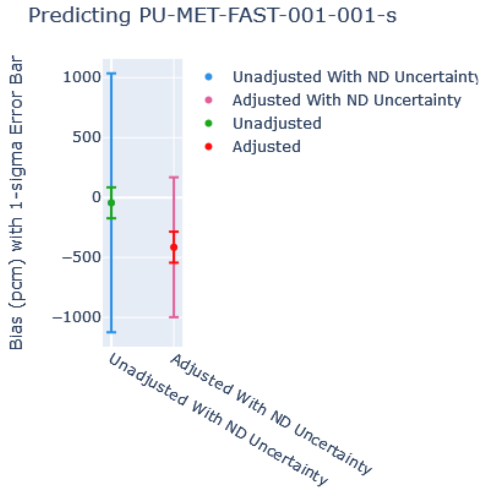
Adjusting to: PMF001 reactivity coefficient (Pu all locations)

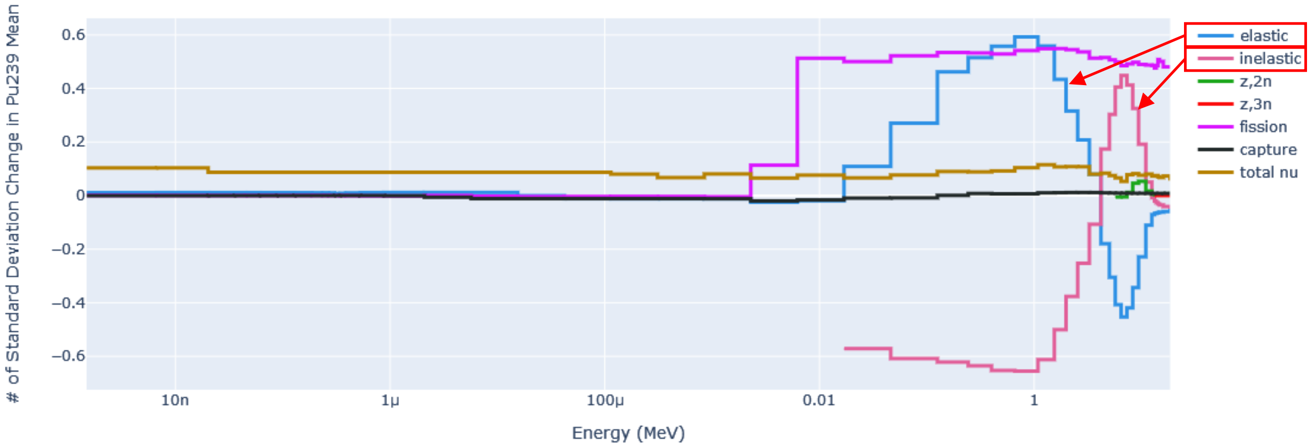


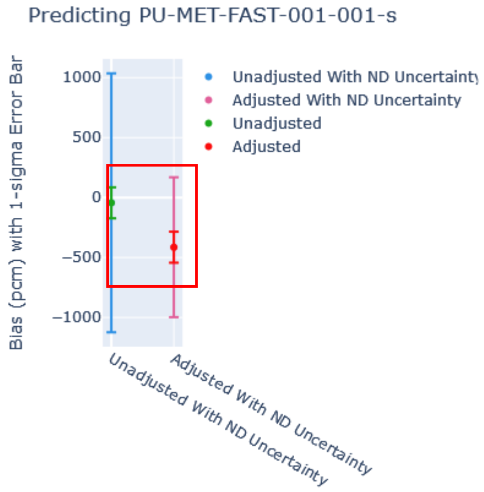


- Adding in all locations changes the shape of scattering data.
- Results in a slightly smaller impact on Jezebel keff (down 414 pcm)

LDRD

Adjusting to: PMF001 reactivity coefficient (Pu all locations)





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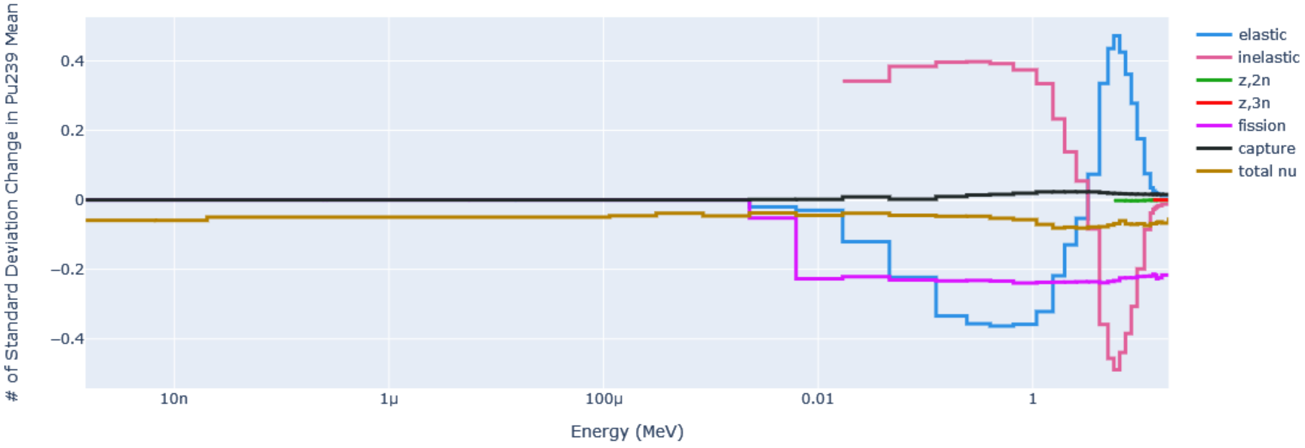
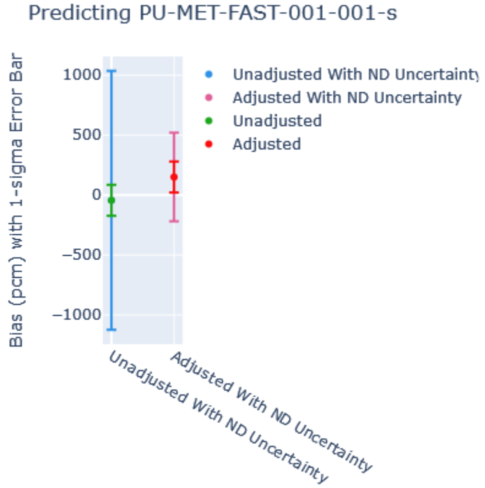
Adjusting to: PMF001 neutron leakage spectra

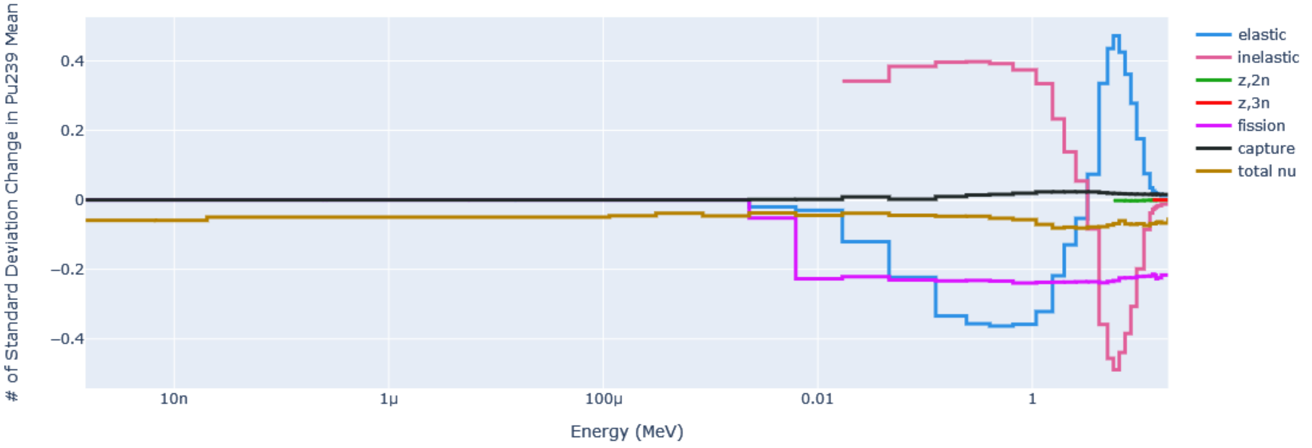


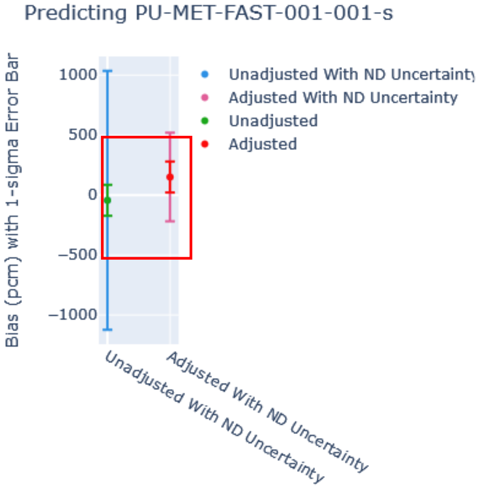


- Looks VERY different from the previous responses shown
  - More similar to Jezebel keff adjustment
- Smaller impact on Jezebel keff (up 150 pcm)

Neutron leakage spectra is most interesting for PFNS (not shown). See upcoming talk by Thompson at ANS Winter 2022.

Adjusting to: PMF001 neutron leakage spectra

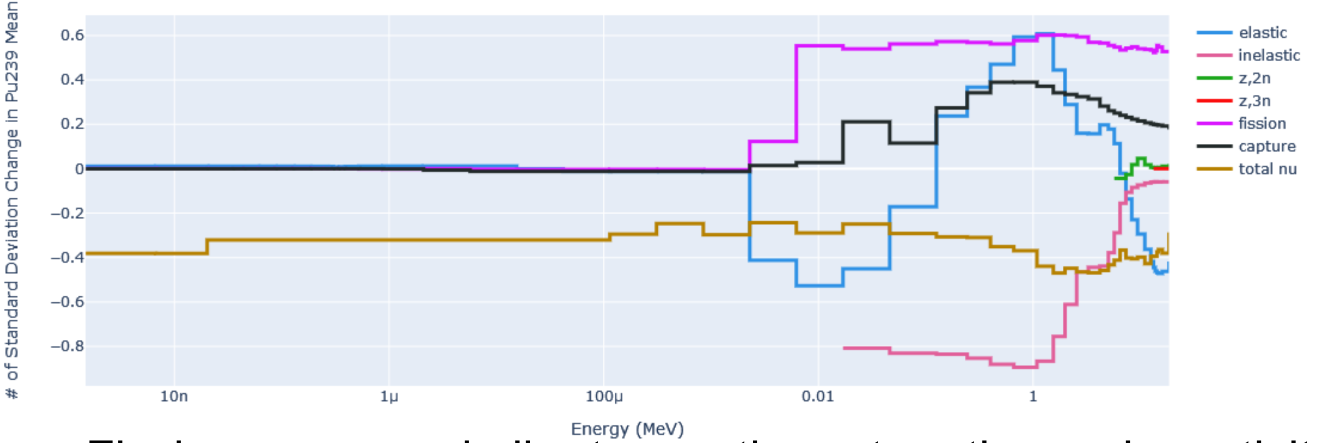


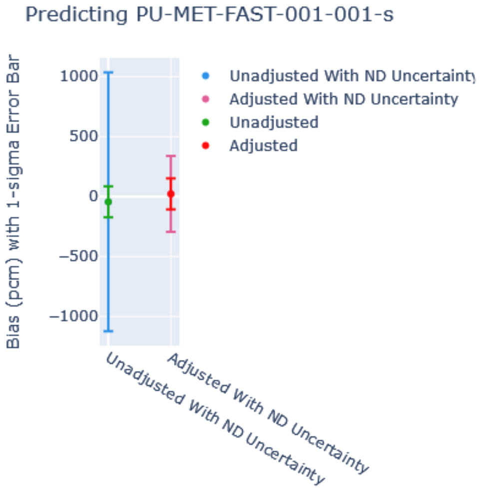


- Looks VERY different from the previous responses shown
  - Fission is somewhat similar to Jezebel keff adjustment
- Smaller impact on Jezebel keff (up 150 pcm)

Neutron leakage spectra is most interesting for PFNS (not shown). See upcoming talk by Thompson at ANS Winter 2022.

Adjusting to: PMF001 reaction rate ratios, reactivity coefficients (all locations, and neutron leakage spectra)





- Fission appears similar to reaction rate ratios and reactivity coefficients (up by ~0.6 starting just under 10 keV)
- Nubar seems to be most impacted by the neutron leakage spectra
- Scattering is a bit different than previous plots
- Jezebel keff is now only +22 pcm.

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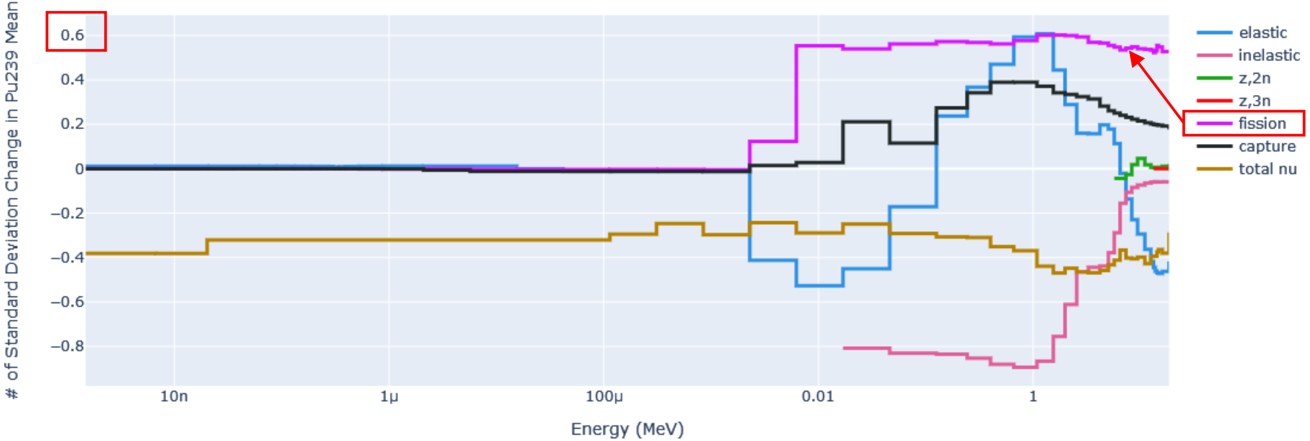

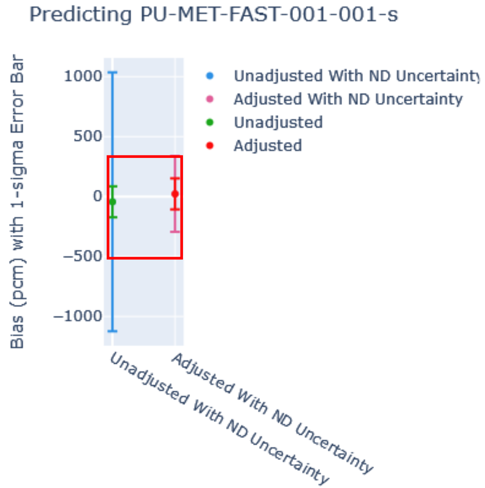

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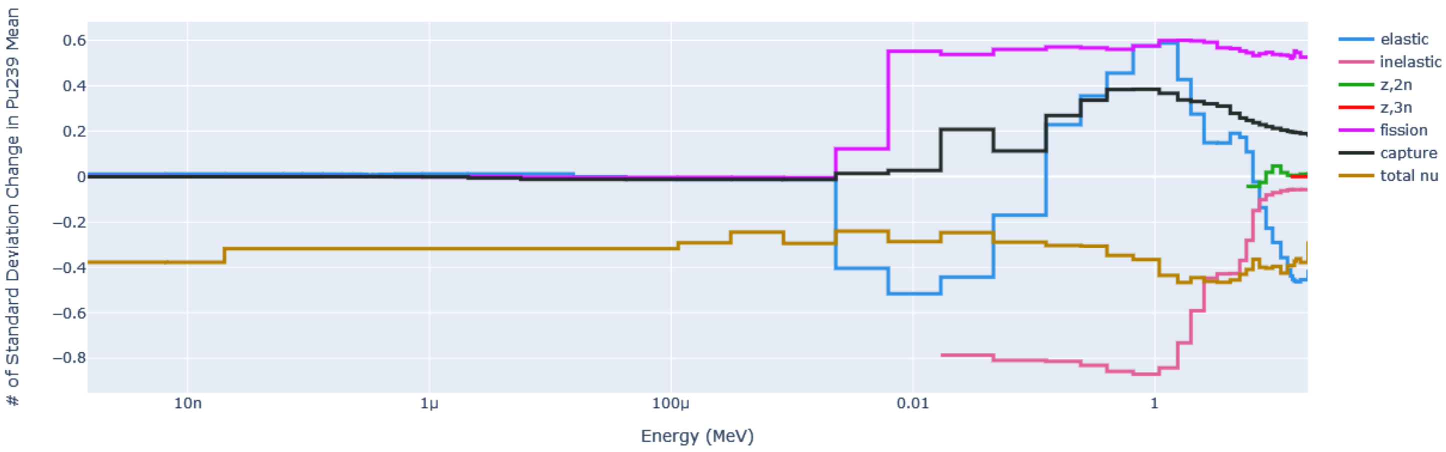
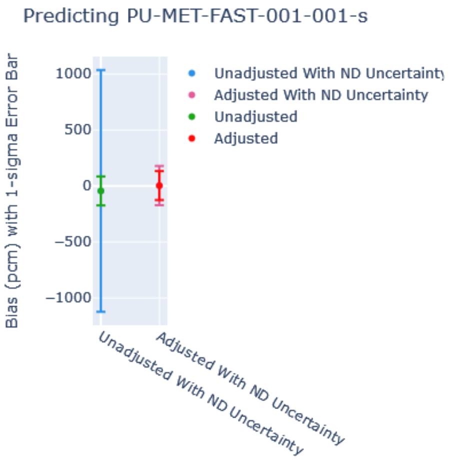
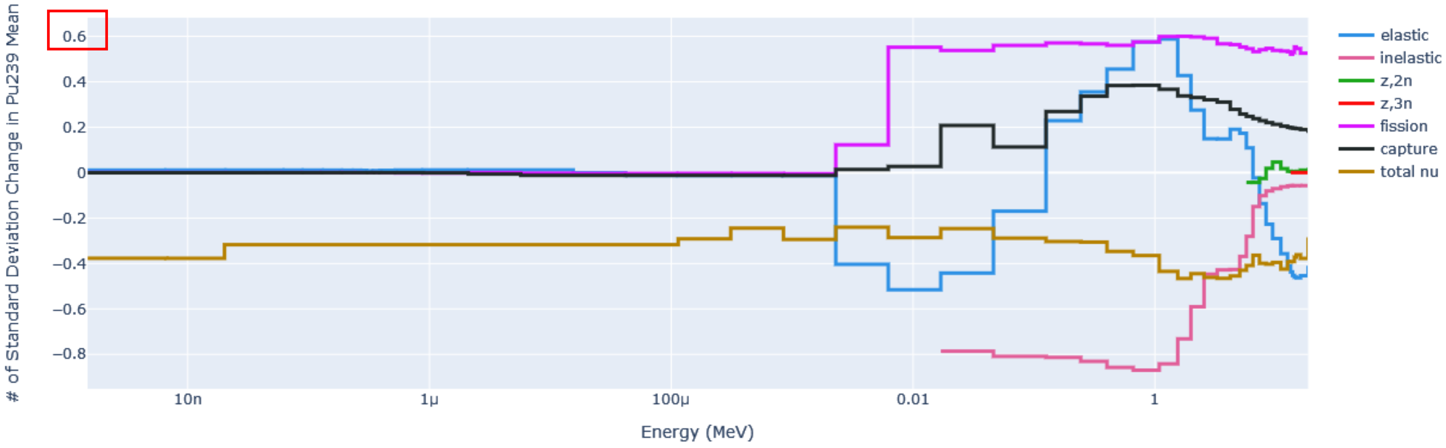
Adjusting to: everything on the previous slide plus PMF001 keff

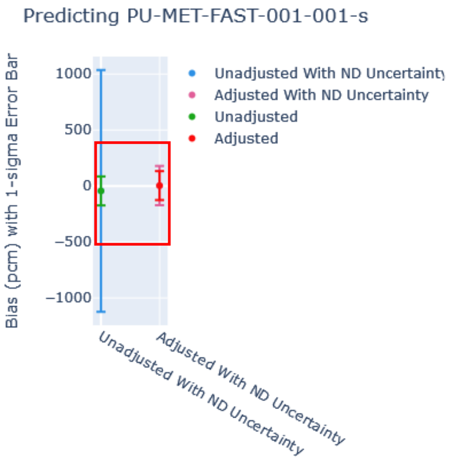




- Looks nearly identical to the last slide
- Jezebel keff is now only +4 pcm (compared to -1 pcm when adjusting only to Jezebel keff).

Adjusting to: everything on the previous slide plus PMF001 keff





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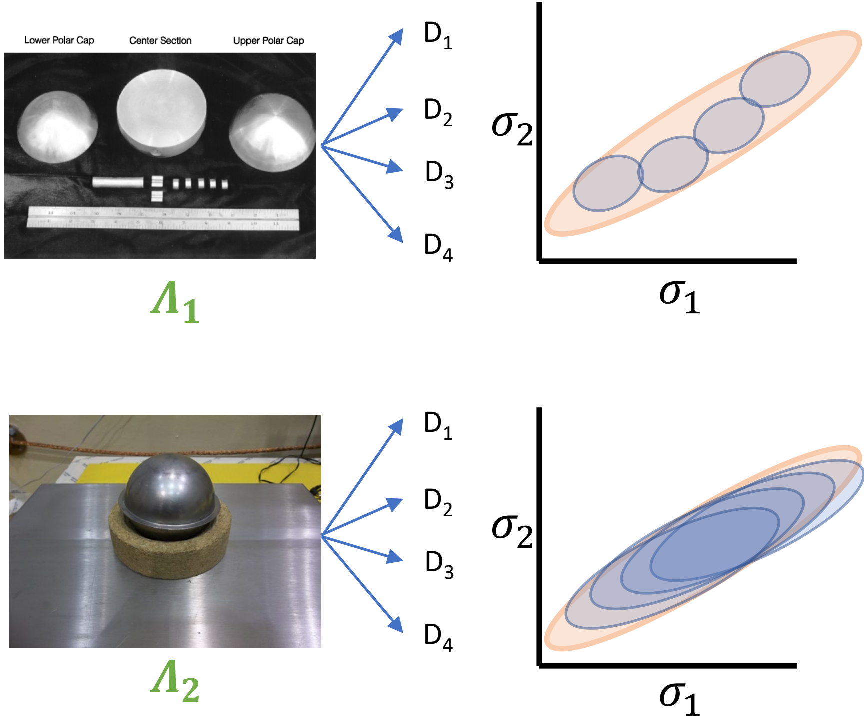
How do we design an experiment to optimally reduce unconstrained physics spaces?

- Question: what new experimental data would lead to the most constrained nuclear data?
- Combining statistical design of experiments with ML-driven design optimization

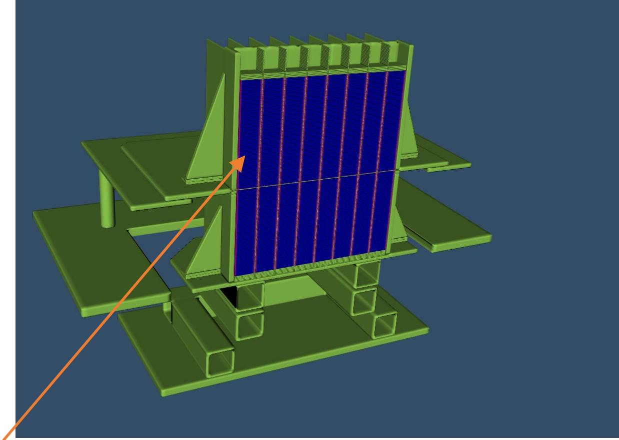
EUCLID has developed a Conditional D-optimality criteria to focus on the targeted subset of all ND reactions

Currently designing an experiment at NCERC focused on Pu239 reactions: PFNS, nu-bar, (n,el), (n,inl), (n,g), and (n,f).

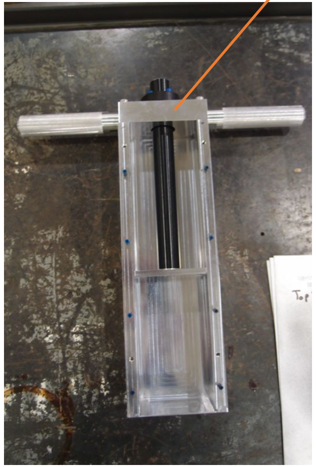


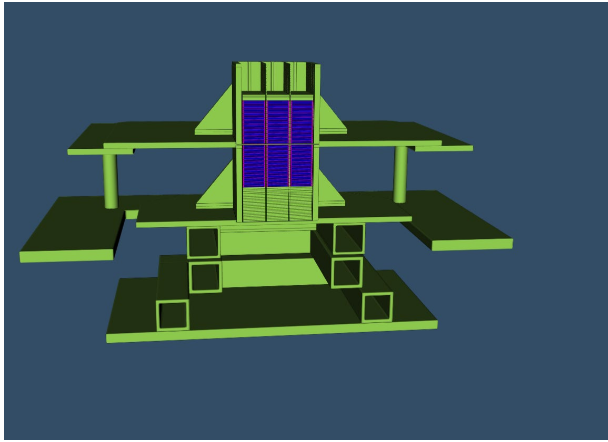
EUCLID configurations

- Two configurations will be built at NCERC
- Both utilize WG Pu ZPPR plates
- High mass configuration is slab-like: ~16 inches x 16 inches x 3 inches. >80 kg Pu!
  - Maximizes neutron leakage and minimizes scattering sensitivities
- Low mass configuration is cube-like: ~6 inches cubed.
  - Minimizes neutron leakage and maximizes scattering sensitivities (“Jezebel-like”)
- Both have some Al reflection



High mass configuration (8x1)





Low mass configuration (3x2)

Summary

- Sensitivities for various integral responses were obtained as part of the LDRD-DR project.
- Adjusting to other responses can be useful to constrain nuclear data.
    - We suggest to look into these (and other) responses for adjustment and validation
- But doing so will take a lot of iterative testing and expert judgement.
    - This talk is not meant to suggest that one uses the adjusted nuclear data shown, but more to describe such an approach to be used in the future to understand responses for validation.
- A new experiment was designed to maximally reduce compensating errors in Pu239 nuclear data and will be executed at NCERC
    - The EUCLID experiment data will be available for testing of Pu239 nuclear data

Acknowledgements

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- Los Alamos National Laboratory is operated by Triad National Security, LLC, for the National Nuclear Security Administration of the US Department of Energy under Contract No. 89233218CNA000001.