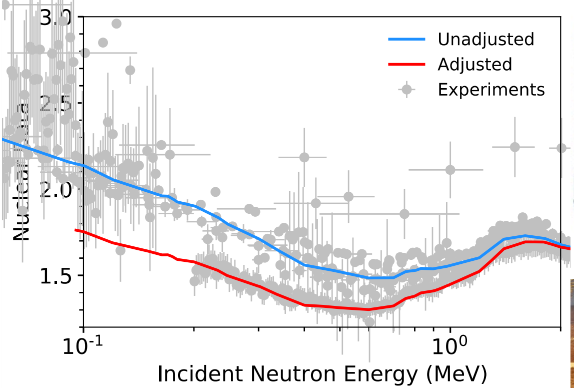

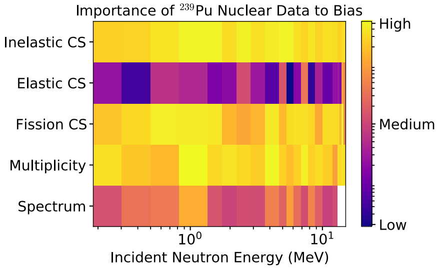

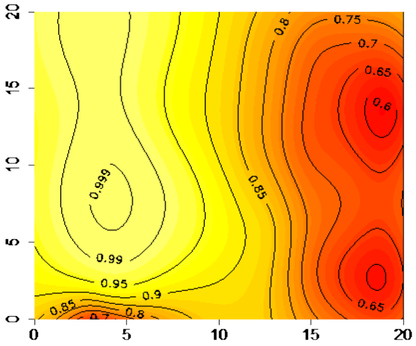

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EUCLID adjustment including multiple integral responses

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Mar 01 2022

EUCLID = Experiments Underpinned by Computational Learning for Improvements in nuclear Data

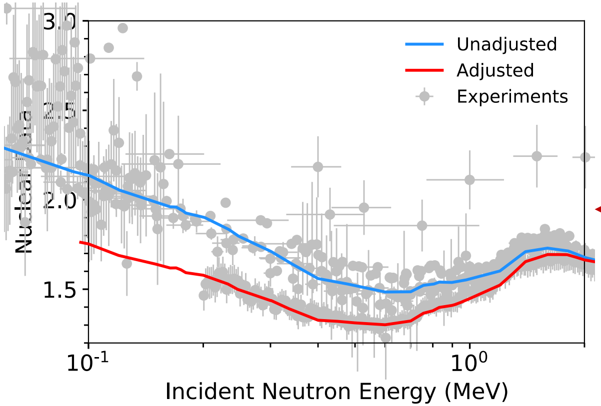
The use of adjustment using multiple responses (and underlying/required capabilities) benefits many applications

- Tools for adjustment using multiple integral responses: ND adjustment and validation community.
- Sensitivities of additional responses: ND adjustment and validation community.
- Sensitivity capabilities: users in many application areas including safeguards/nonproliferation, criticality safety, etc.
- Experiment optimization capability: applications which can benefit from integral experiments (criticality safety, advanced reactors, etc.)

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

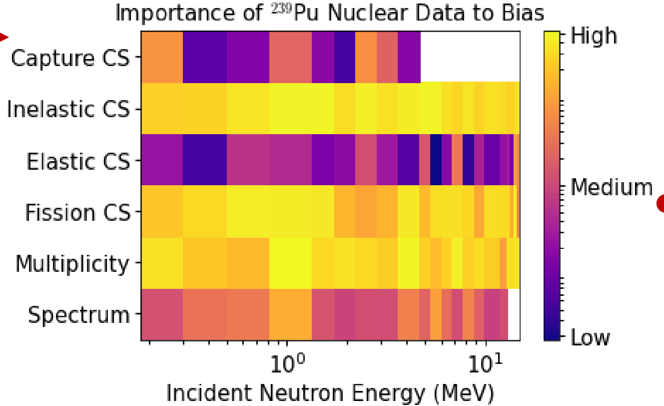
Neutron Transport Simulation (MCNP)

Validation Experiments

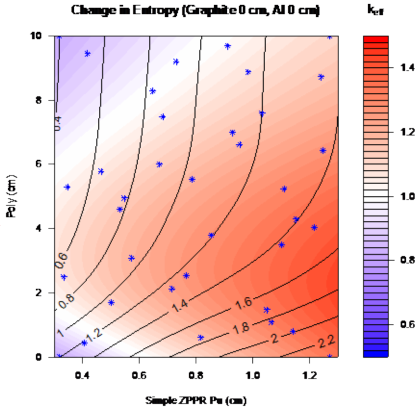


Experiment Refines Nuclear Data to Improve Simulations

ML-Augmented Search for Compensating Errors



ML-Optimally Designed Experiment to Resolve Compensating Errors



EUCLID incorporates many measurement responses

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	✓		✓	

Currently we have calculated sensitivities for and gained physics understanding for all eight types of integral responses listed above.

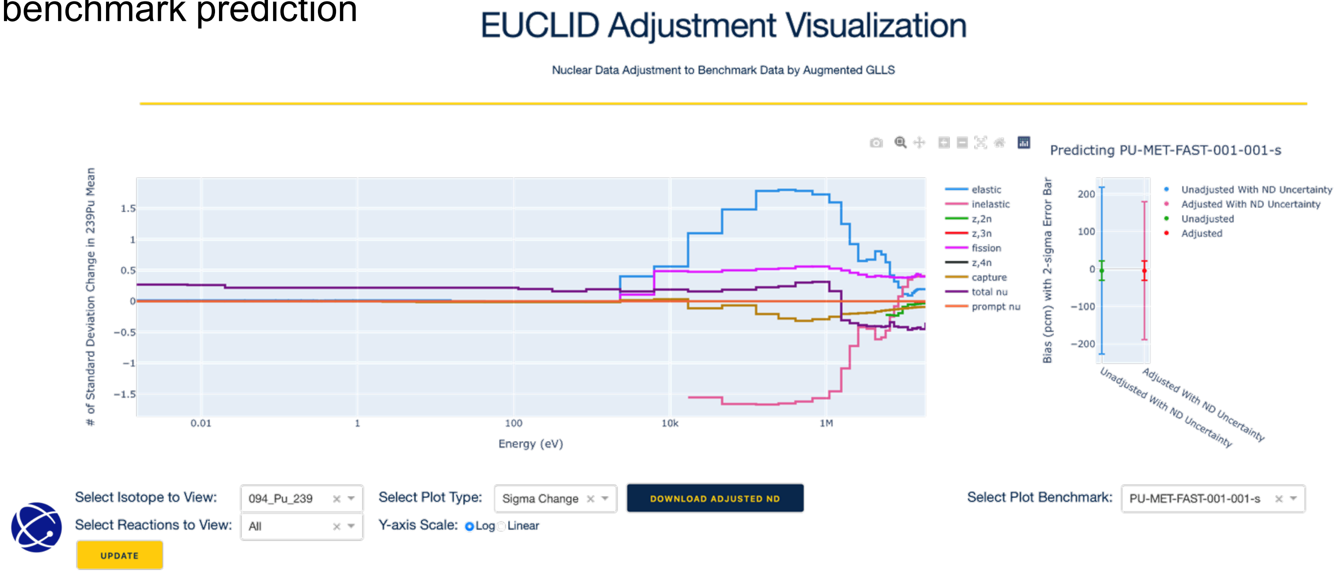
See the "expanded benchmarks" session from WANDA 2021.

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

EUCLID developed an online tool for exploring adjustment with many different responses

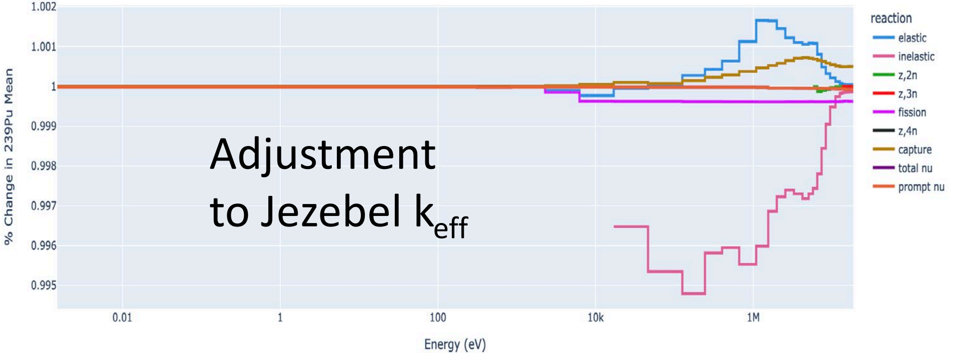
- Leverages GLLS-based adjustment with several expanded capabilities
  - 2111 total benchmark observations
  - 2579 nuclear data observables (isotope, reaction, energy group combinations)
- Can explore first-order impact of adjustment on benchmark prediction

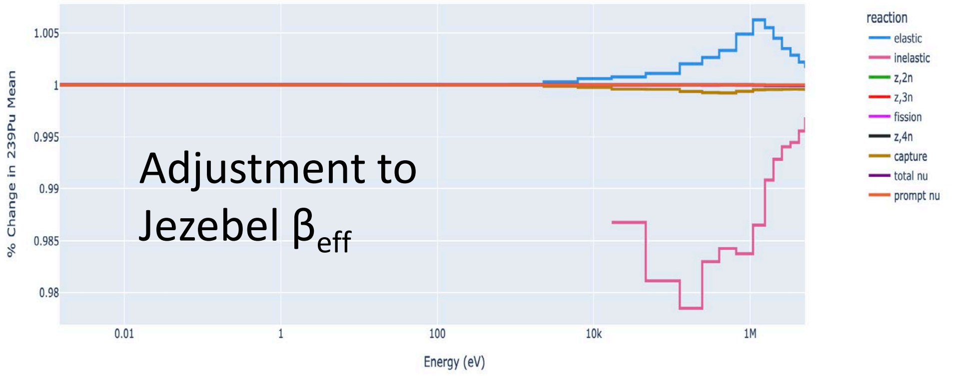
- Capability to explore several additional sources of uncertainty to assess impact on adjustment
  - Uncertainty on sensitivities
  - Enlarged uncertainties for observations based on ML-augmented benchmark review
  - Shape and time-of-flight uncertainty for pulsed sphere observations

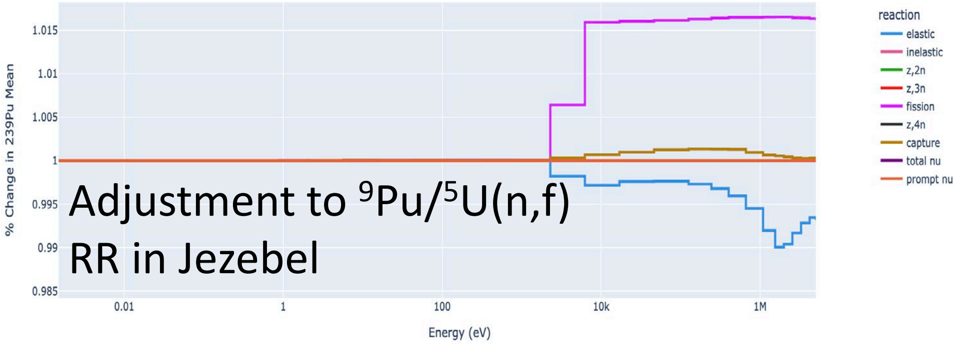


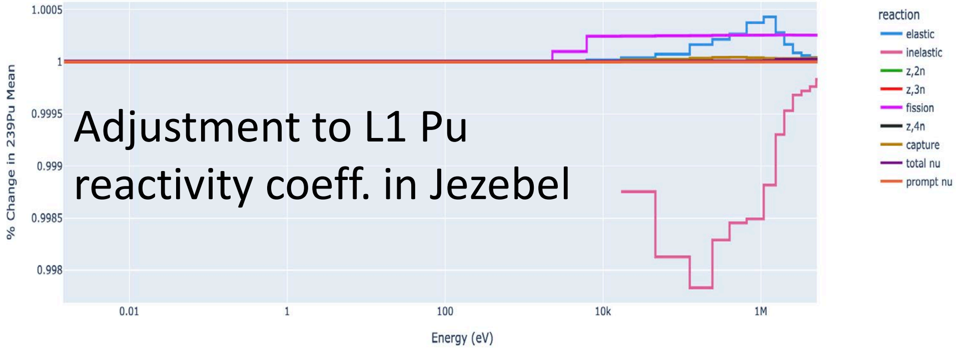
- Currently uses ENDF/B-VIII.0 nuclear data and covariances (51 group structure).
- Observations simulated using MCNP6.2 and SENSMG.

Adjustment with multiple responses can help constrain nuclear data and reduce compensating errors









One critical component for adjustment are sensitivities

Using k_{eff} sensitivities, we have been deriving simulating other response sensitivities

- Beta-effective

$$\beta = 1 - \frac{k_p}{k}$$

- Reactivity coefficients

$$\Delta\rho_{a-b} = \left(1 - \frac{1}{k^{(a)}}\right) - \left(1 - \frac{1}{k^{(b)}}\right)$$

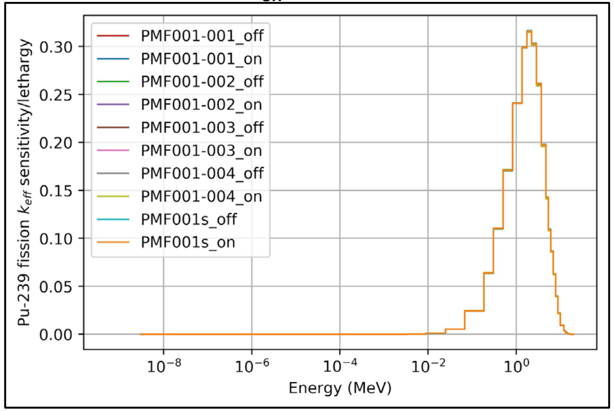
- Rossi-alpha

$$\alpha = \frac{k_p - 1}{l}$$

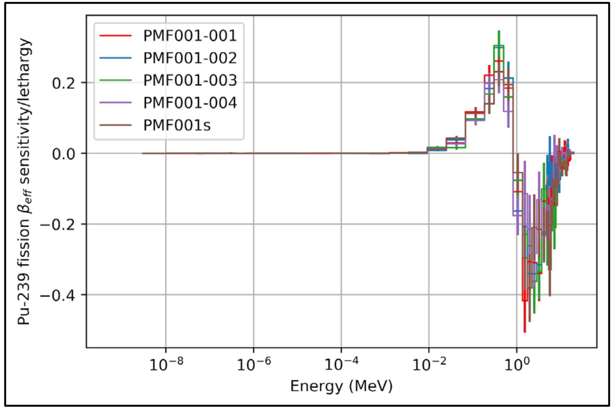
Sensitivities are being provided to the NEA and will be available to the nuclear data community.

PMF001 (Jezebel)

k_{eff} sensitivities



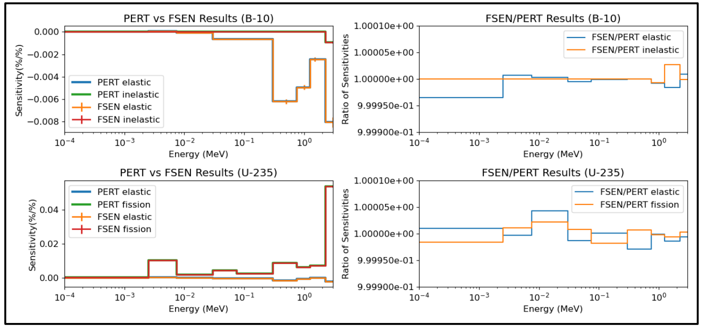
β_{eff} sensitivities

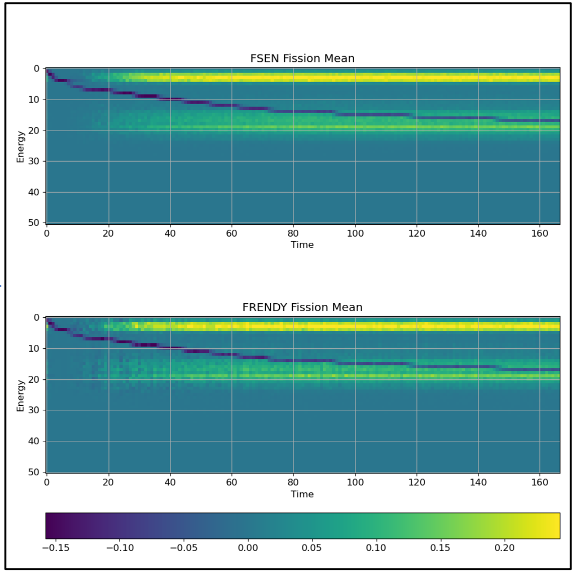


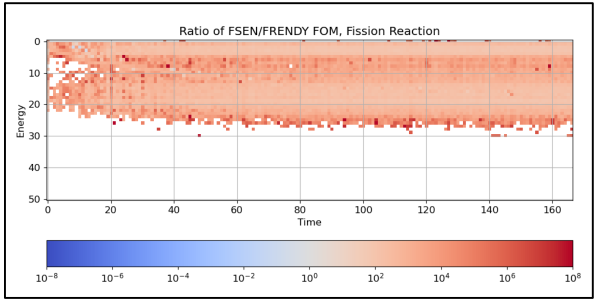
One critical component for adjustment are sensitivities

- New fixed-source sensitivity capability in MCNP6 is under development
- Performing extensive verification to provide a robust and accurate capability
  - Comparison between FSEN and PERT
- Comparison between FSEN and central difference
  - Verification of FSEN using FRENDY results

LLNL Pulsed Sphere of 0.7 MFP Pu





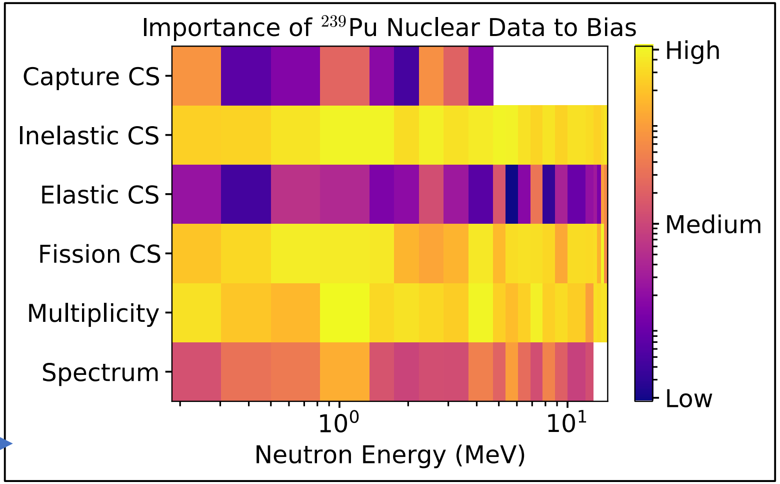


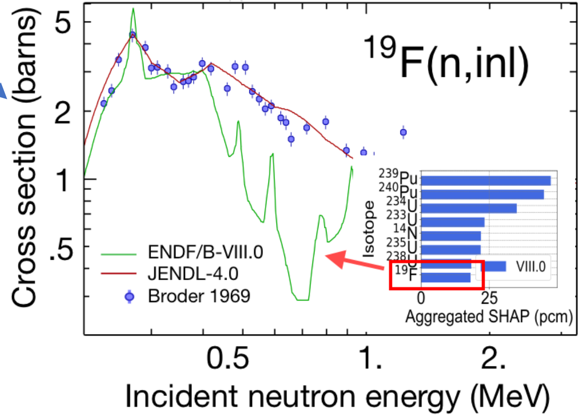
Average efficiency gain for fission is 7.3e5 x.

The same inputs used for adjustment can be utilized for validation for CSEWG

	RAFIEKI
Applies	Random forest & SHAP
Input	integral responses and sensitivities
Output	which nuclear data likely related to bias
Publication	DN, NDS 167, 36 (2020), DN, PRC 104, 034611 (2021)
Tool	Will eventually be open-source

Machine Learning can be very useful for ND validation.





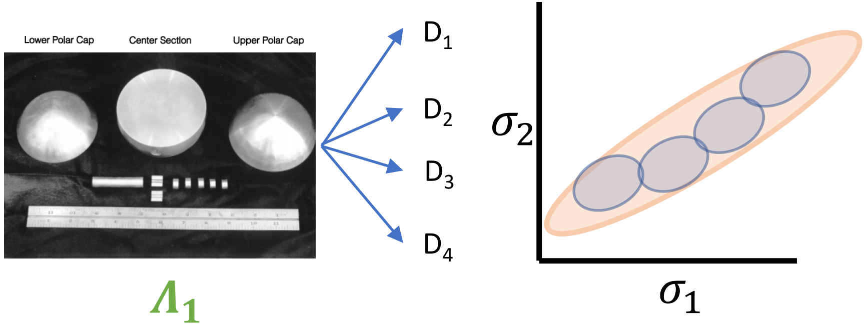
The same inputs used for adjustment can be utilized for validation for CSEWG

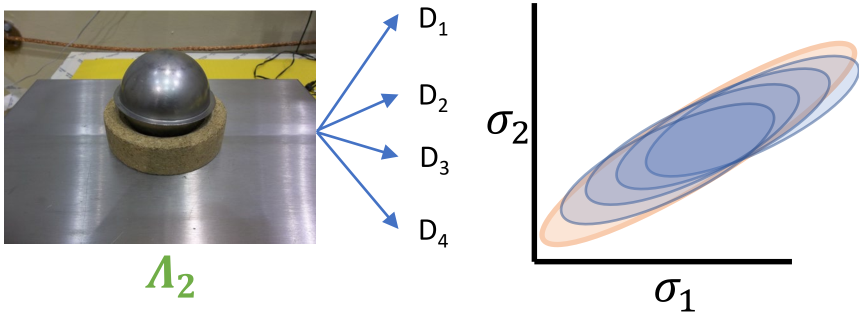
	FAUST & CRATER
Applies	1st-order forward-propagation
Input	integral responses and sensitivities
Output	impact of changes in nuclear data on simulated responses
Publication	W. Haeck, Trans. Am. Nucl. Soc. 123, 723 (2020)
Tool	Will eventually be open-source

```
====   Pu239   ====
Modified reaction(s):  ['total nu']

Benchmark Name              | Diff.    Old     New
                            |          Bias    Bias
                            | (pcm)    (pcm)   (pcm)
MIX-COMP-FAST-002-001       |  -27  |  -494  |  -521
MIX-COMP-FAST-003-001       |  -28  |   -73  |  -101
MIX-MET-INTER-004-001       |  -18  |   426  |   408
MIX-MET-MIXED-001-001       |   -3  |    81  |    78
. . .
PU-MET-FAST-001-001-s       |  -15  |    44  |    29
PU-MET-FAST-002-001         |  -14  |   133  |   119
PU-MET-FAST-005-001         |  -20  |   -73  |   -93
PU-MET-FAST-006-001         |  -22  |   -30  |   -52
PU-MET-FAST-008-001         |  -20  |  -239  |  -259
PU-MET-FAST-011-001         |  -13  |    77  |    64
PU-MET-FAST-012-001         |  -24  |   106  |    82
PU-MET-FAST-013-001         |  -23  |  -559  |  -582
PU-MET-FAST-015-001         |  -20  |   -39  |   -59
PU-MET-FAST-045-006-s       |  -19  |   723  |   704
PU-MET-FAST-045-007-s       |  -19  |   691  |   672
. . .
PU-MET-INTER-002-001        |  -20  |  1696  |  1676
PU-MET-INTER-003-001        |  -19  |   154  |   135
PU-MET-INTER-004-001        |  -19  |   -71  |   -90

====   Pu239   ====
Manually set changes
Modified reaction:  ['total nu'] 0.999 68-500 keV
90 experiments with absolute change > 0.0 pcm
                 Old        New
St. Deviation:   495   =>   490 pcm
Average Bias :   191   =>   176 pcm
```

Adjustment is also used to test impact of new proposed experiment designs

- Question: what new experimental data would lead to the most constrained nuclear data or application?
- Combining statistical design of experiments with ML-driven design optimization
- Adjustment is used for
  - Incorporating all information from ENDF/B-VIII.0 and previous integral data into an optimization
  - Quantifying impact of proposed experiments on nuclear data adjustment/validation





Adjustment and EUCLID nuclear data sensitivities can help the community to:

- Identify unconstrained physics spaces where compensating errors can hide,
- Design experiments optimized to answer nuclear questions for applications,
- Validate nuclear data and provide essential feedback to CSEWG how to improve the library

EUCLID sensitivities and tools will be provided to the nuclear data community at large.

Acknowledgements

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Adjustment with multiple responses can help constrain nuclear data and reduce compensating errors