A Constrained Resonance Analysis Method Informed by New Transmission and Capture Measurements for Copper

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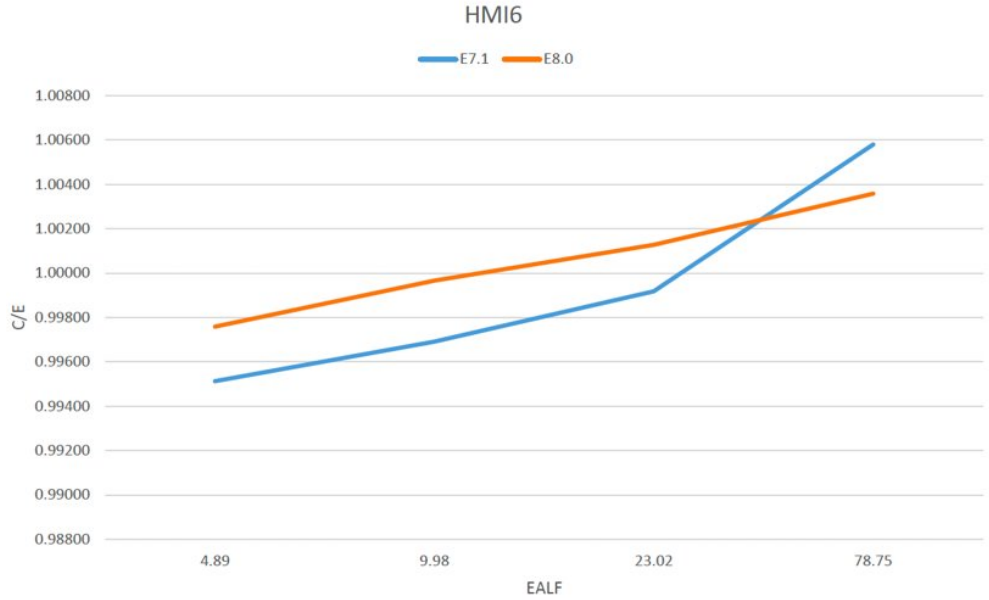
Outline

1. Copper motivation, PARADIGM project @ LANL
2. New differential data from LANSCE
    1. Well-resolved resonances up to 30 keV
3. Challenges with $^{63}\mathrm{Cu}\ (n,\gamma)$
4. How do we use average data in the RRR?
    1. Framework to connect to $\mathbf{COH_3}$ statistical model
    2. Partial contributions
    3. Connection to automated resonance fitting

Copper has been a longstanding challenge

- Common structural material
- Critical benchmarks bias
- Evaluation has been updated continuously
  - INDEN collaboration
  - ENDF 7.1 – 8.1
  - JENDL
  - JEFF

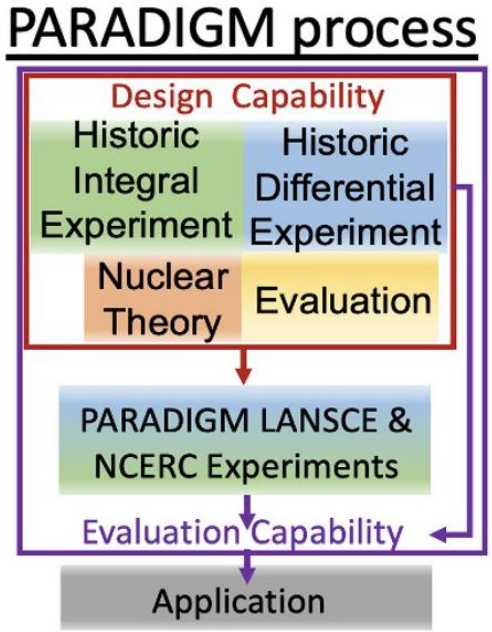
ZEUS HEU Benchmark, offset driven by Cu



PARADIGM Project selected ^{63}Cu to improve intermediate-energy nuclear data

P.I.'s: Denise Neudecker, Theresa Cutler, Matt Devlin

- Joint optimal **differential & integral** measurements
- AI/ML driven design
- Novel method for fluctuating URR calc
- Templates guided experimental UQ
- BLEND tool for joint evaluation

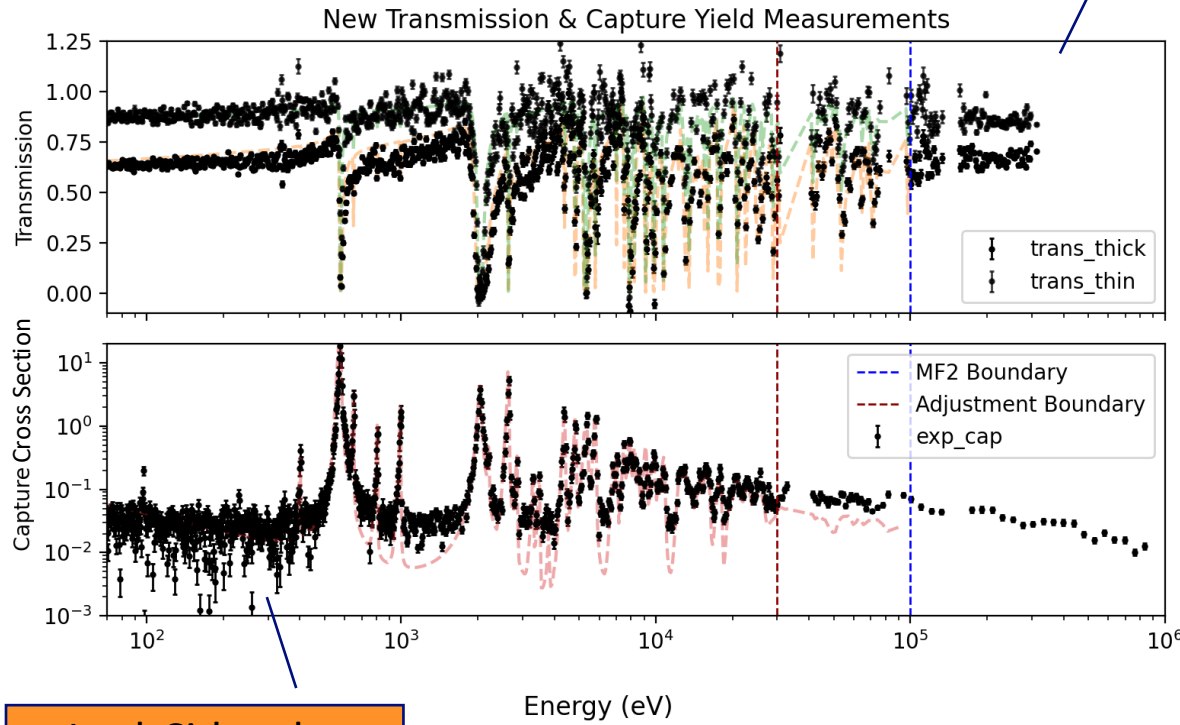


PARADIGM
PARallel Approach of Differential and InteGral Measurements

Updated resonance parameters < 30keV

Stamatopoulos

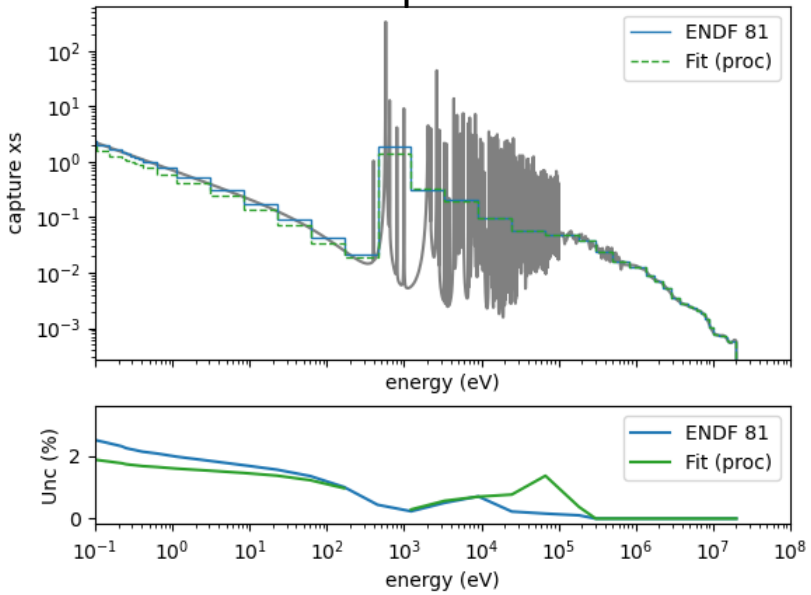
- Prior from ENDF/B-VIII.1
- Exact parameter uncertainties from MF32
- Does not address the under-predicted uncertainty in RRR
  - Future work? Uncertainty in avg xs added as MF3?



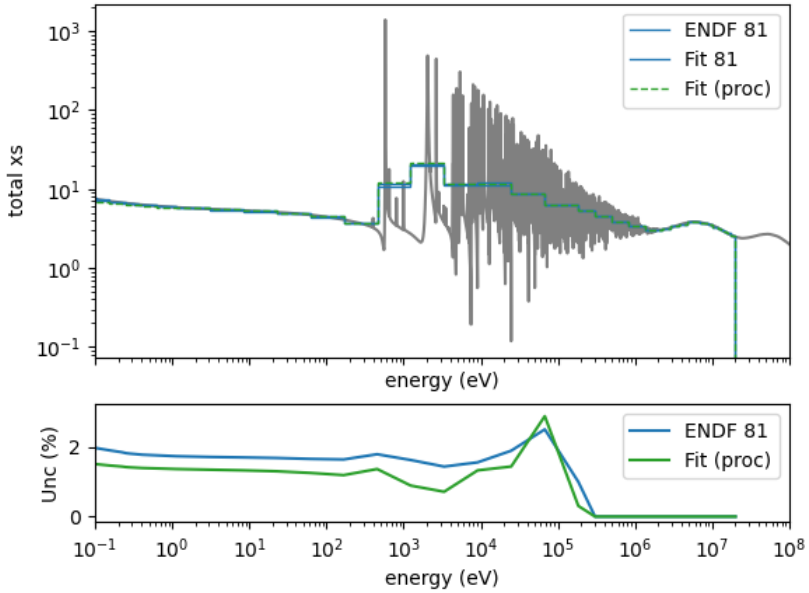
Leal-Cidoncha

Results in a small changes in the cross section and decrease in uncertainty

Capture



Total



New differential measurements @ LANSCE

- Transmission by Thanos Stamatopoulos
- Capture yield by Esther Leal-Cidoncha

- RRR extends to 100keV and fluctuations beyond that
  - BLEND framework implements RRR as average cross sections over broad E_{inc} bins for subsequent adjustment
  - New differential measurements do not resolve resonances past ~30keV

PARADIGM
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Addresses a broader question:

How do evaluators incorporate measurements of the average cross section in the RRR?

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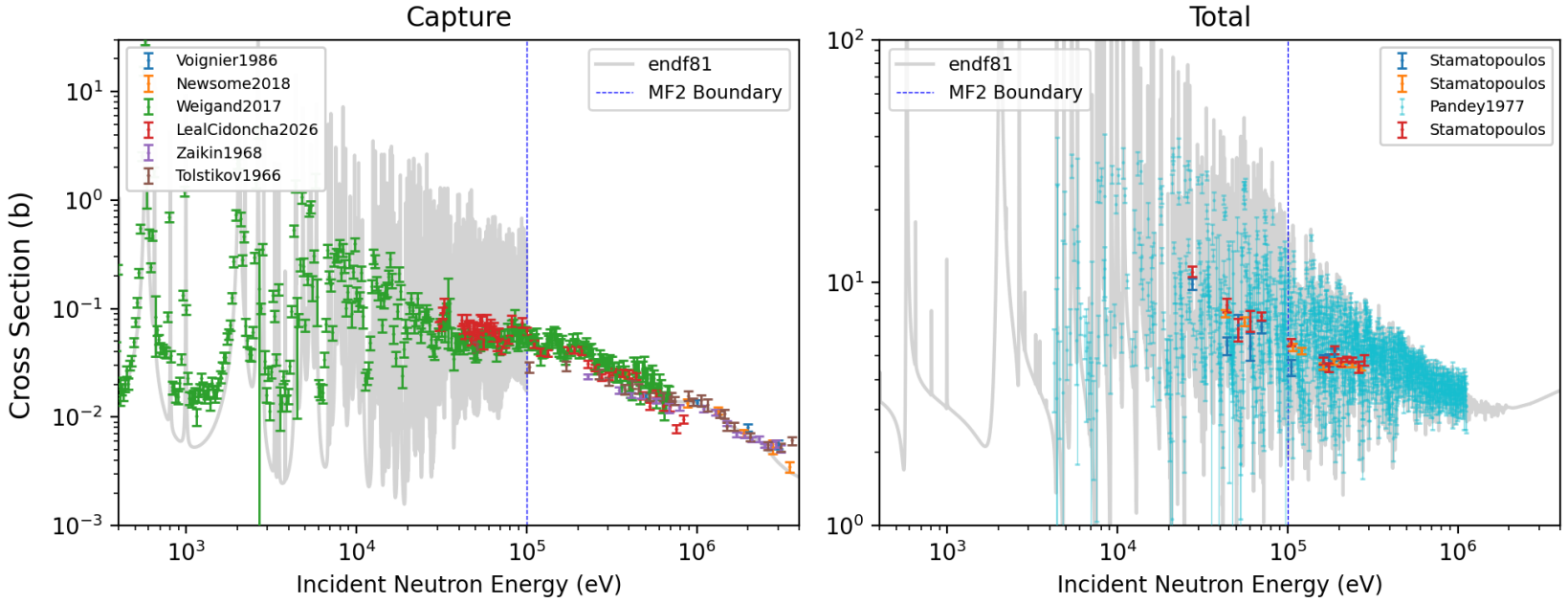
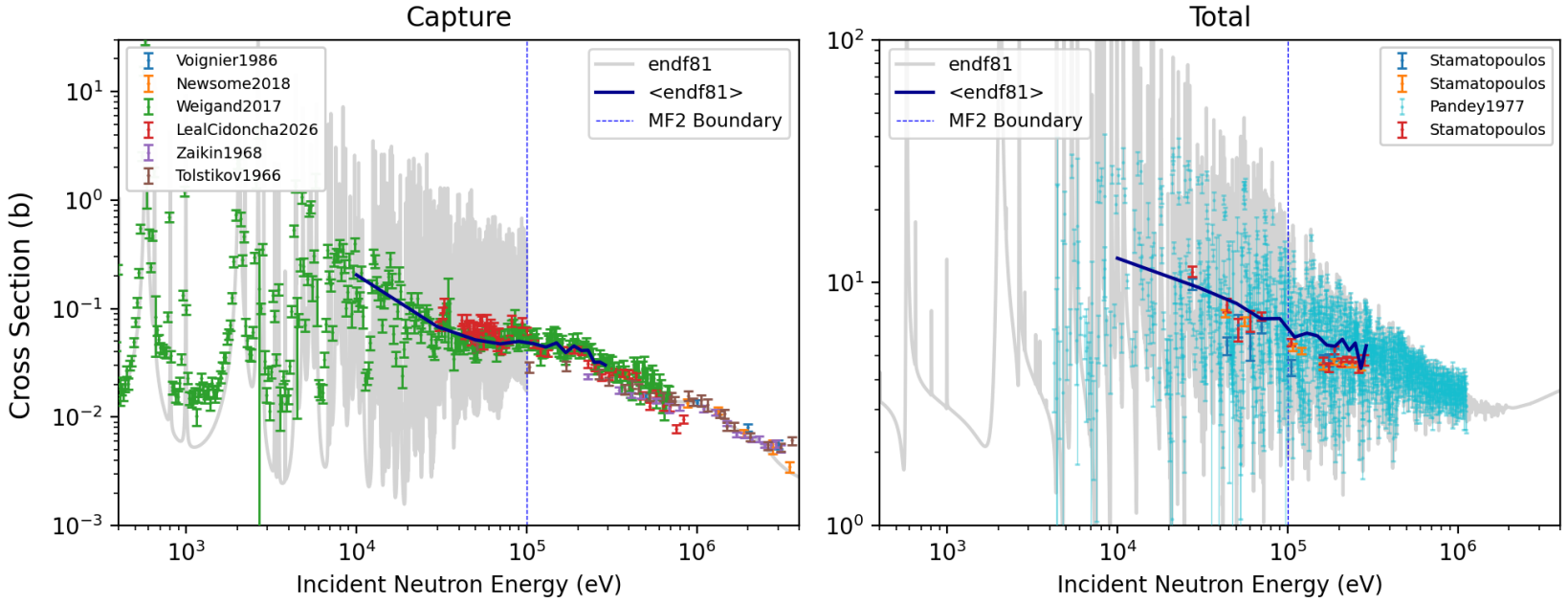
Past high-resolution data extend RRR to 100keV

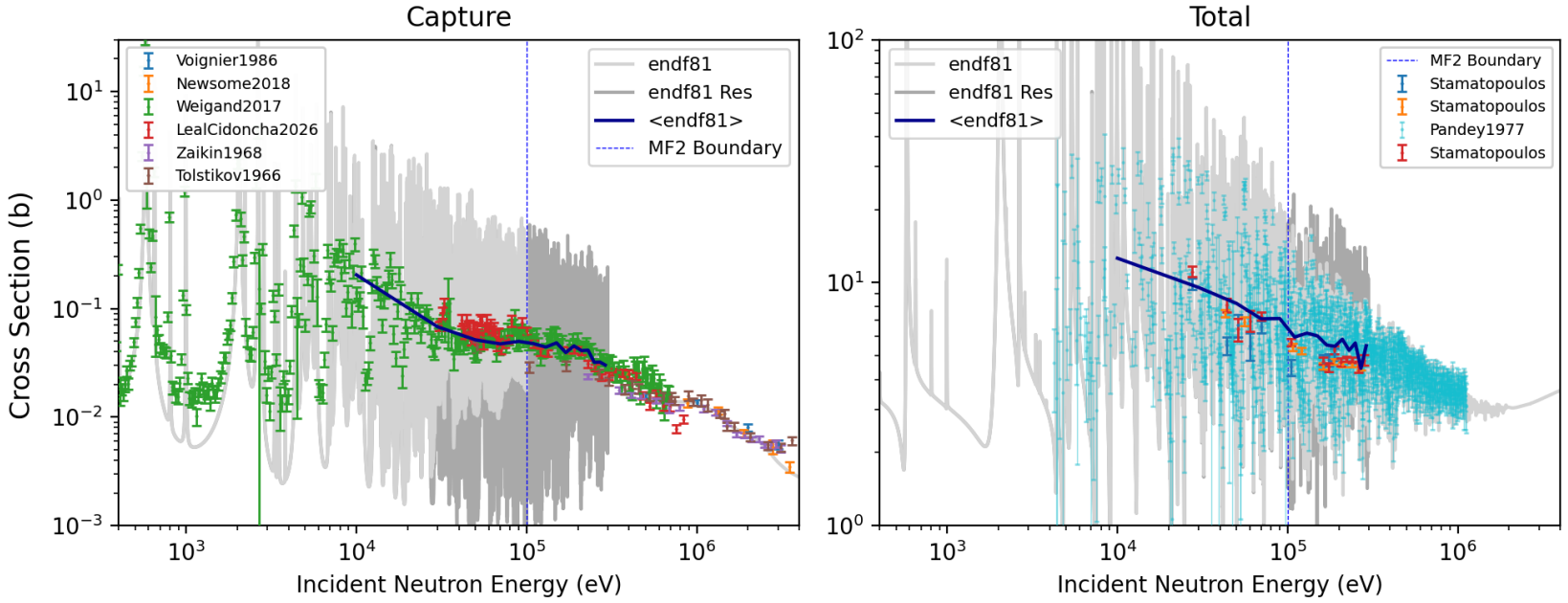
How can we incorporate new (and other) lower resolution data?



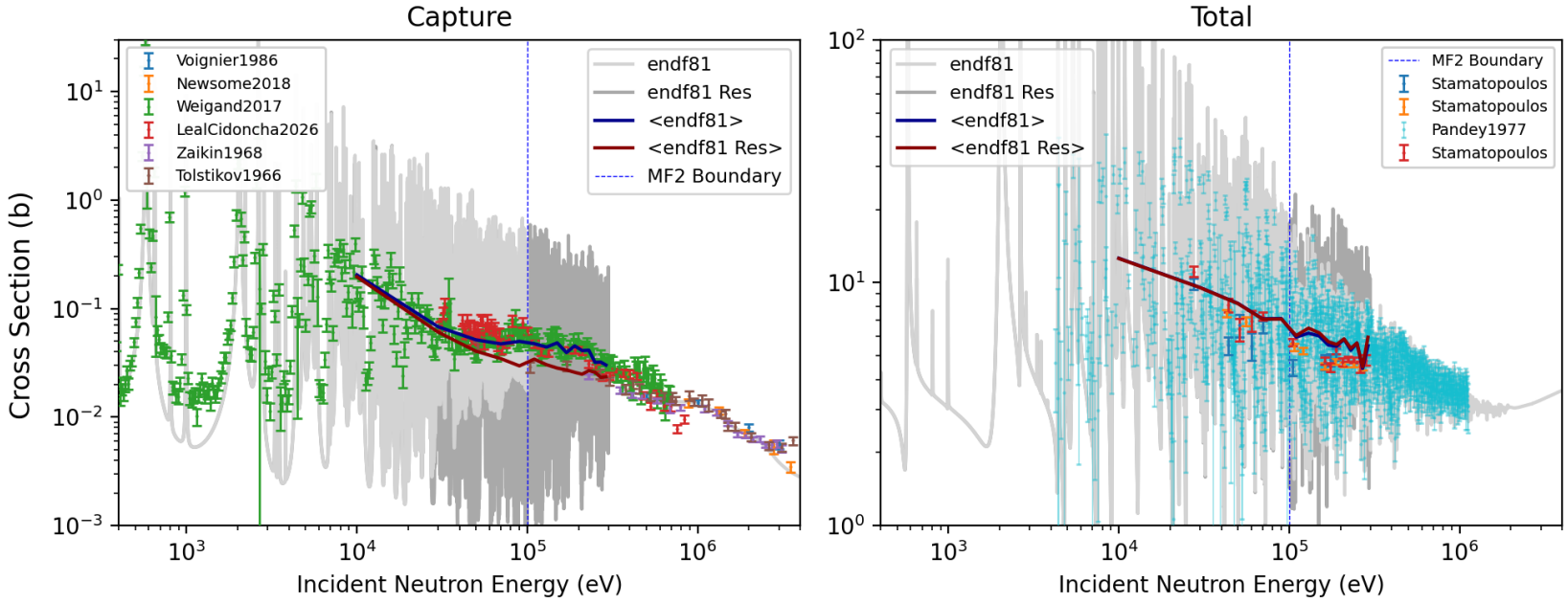
We can check the average after the fact, but that doesn't update the evaluation or uncertainty



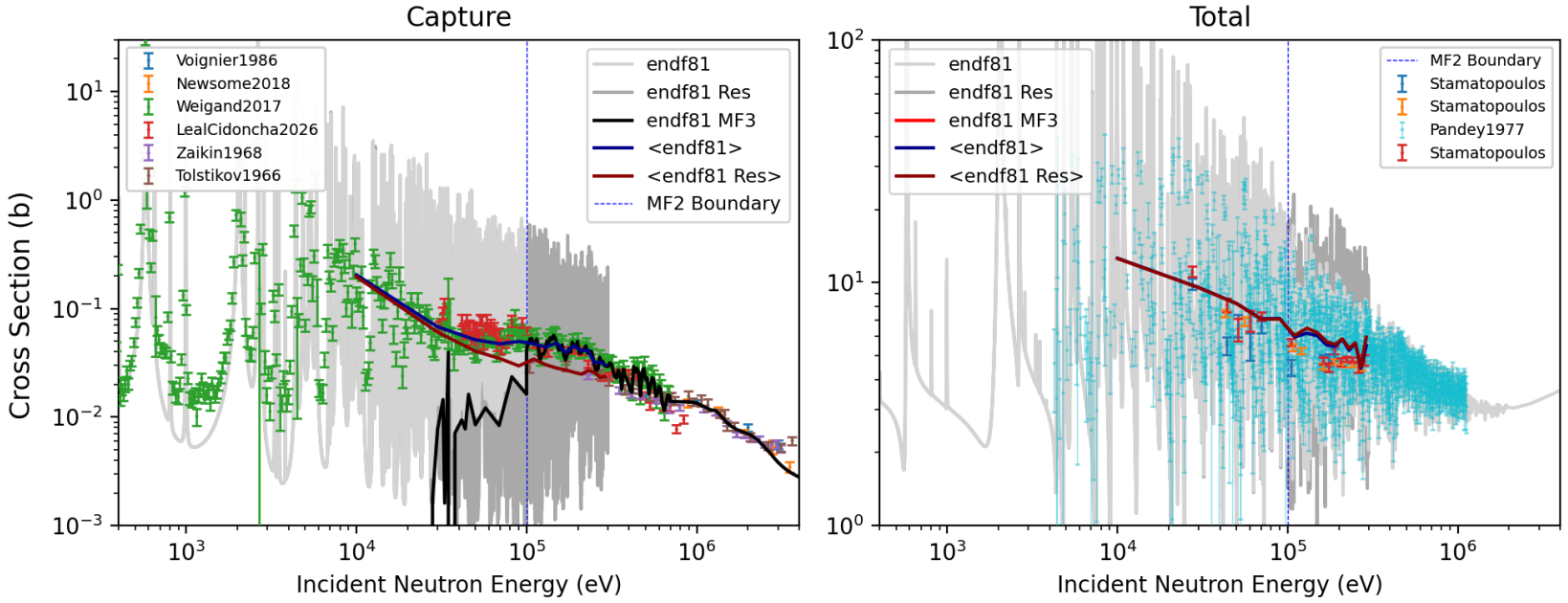
A separate challenge with the capture cross section



MF2 resonances extend to 300keV, but diverge from avg

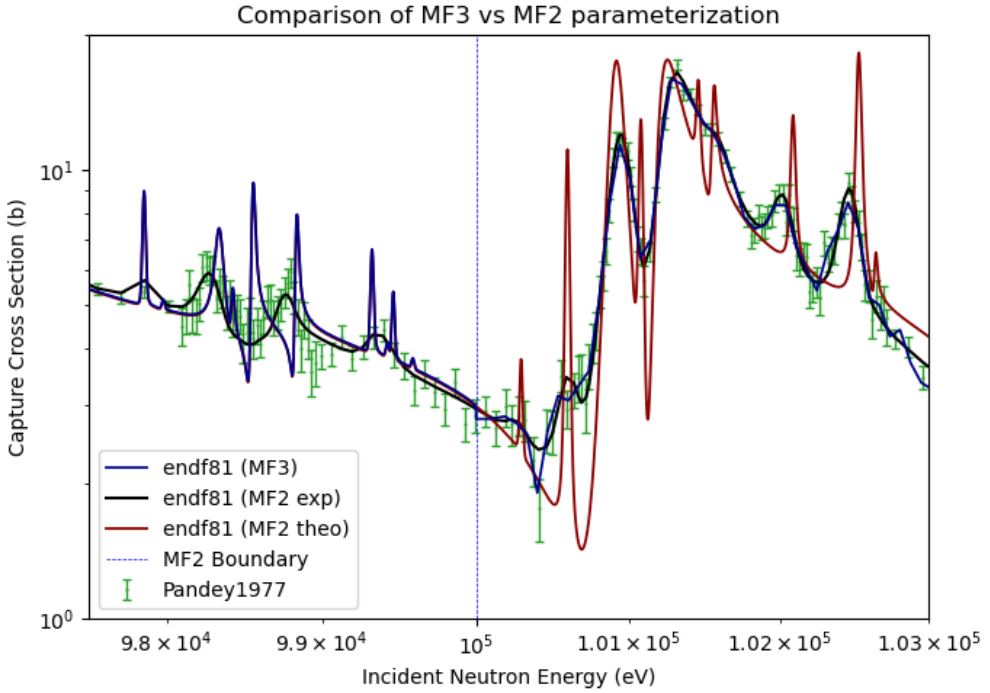


Additional MF3 component is used to compensate



MF3 Parameterization of fluctuating cross sections is undesirable

- Latent theoretical parameter space allows
  - Correction for resolution / other exp effects (i.e. reconstruction to theoretical, infinite dilute cross section)
  - Reconstruction of angular distributions
  - Consistent fluctuations across all channels

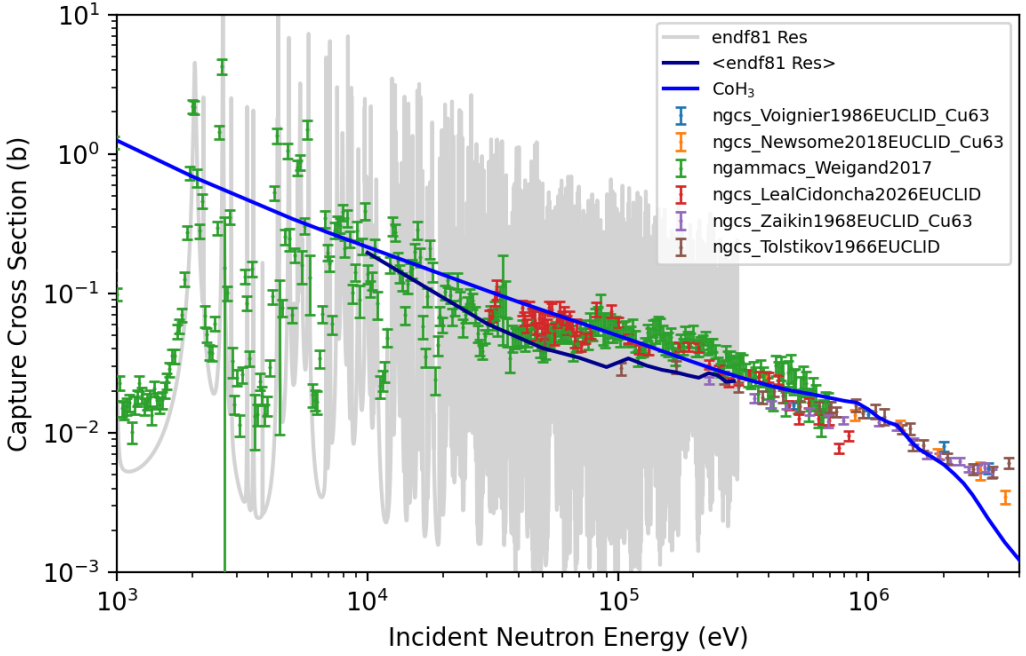


Broader challenges for intermediate evaluations when not using URR representation

- Incorporate new measurements of the average cross section into the resonance evaluation
- Shift structure from evaluation of high-resolution capture data onto the correct average without MF3 component
- For $^{63}\mathrm{Cu}$, can we extend RRR beyond 100keV to consistently explain fluctuations across all channels and better-recover infinite dilute cross section

Beginning of a framework to inform RRR evaluation from COH_3 statistical model calculations

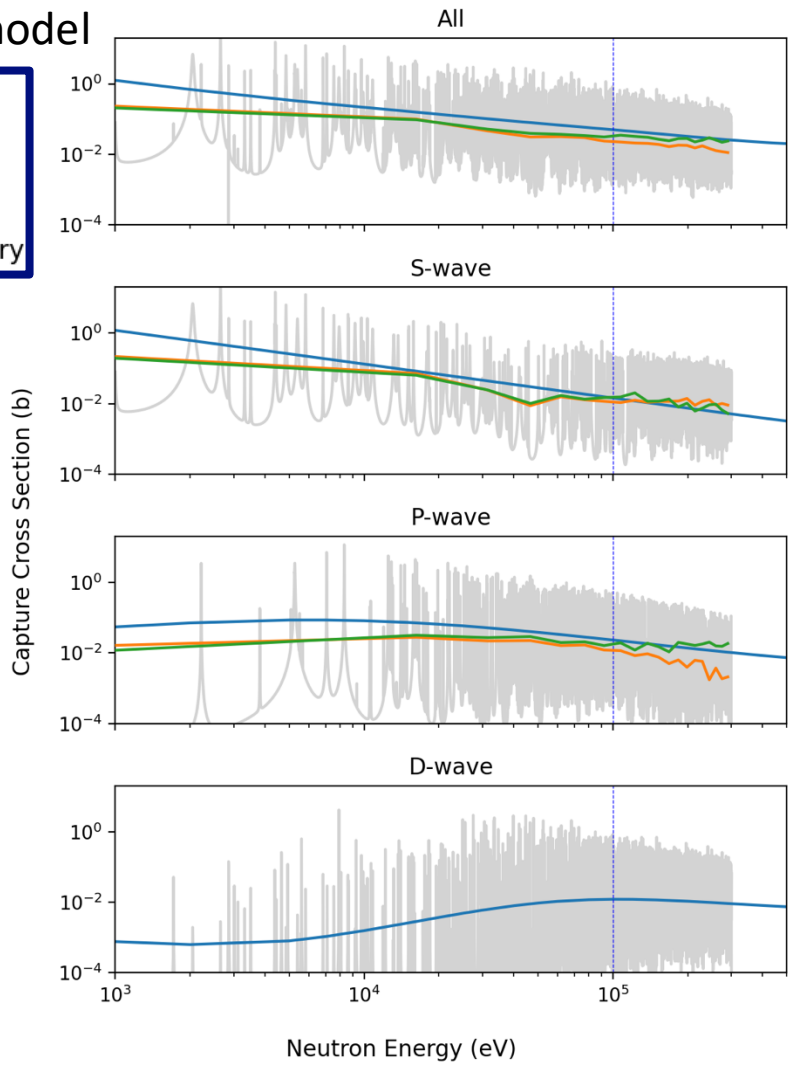
- Match HF statistical model to average data
- Inform $< \Gamma >$ and $< \sigma_{J^\pi} >$
- Constrain the resonance evaluation
  - This is not so straight-forward
  - Let's start with D-wave resonances



Adding a D-waves to RRR

From $\mathbf{COH_3}$ model

Statistical model indicates that
D-wave contribution shouldn't be neglected

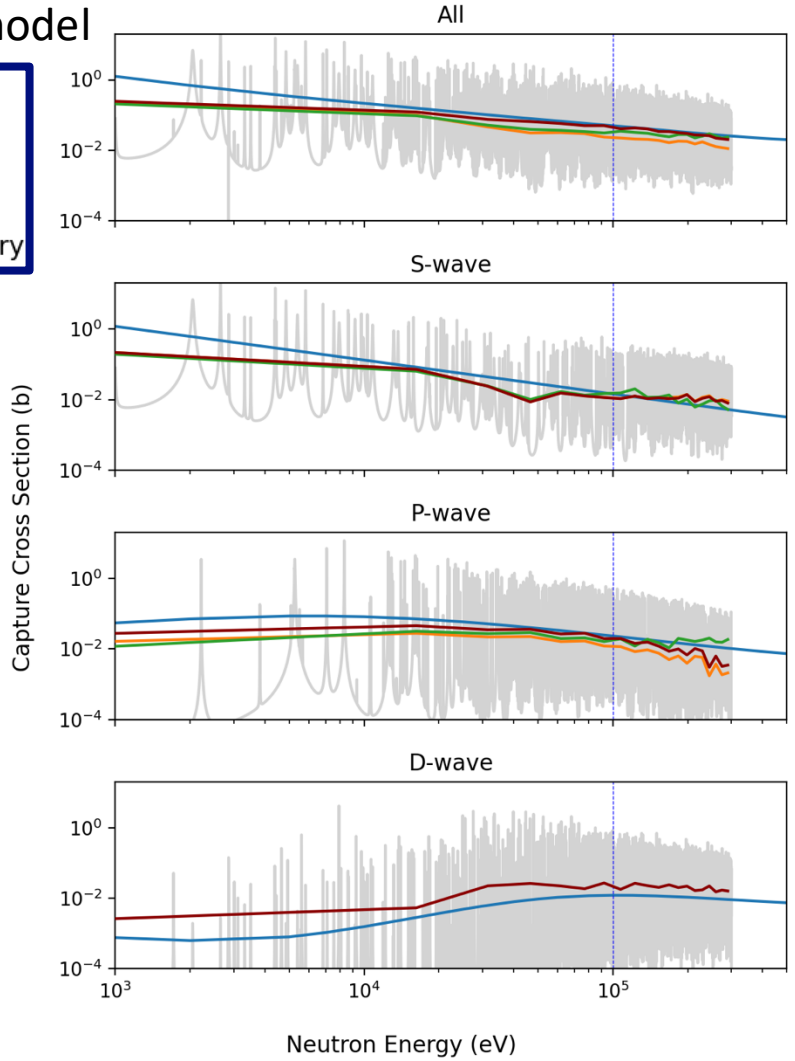


Adding a D-waves to RRR

From $\mathbf{COH_3}$ model

Statistical model indicates that
D-wave contribution shouldn't be neglected

- Statistically **sampled D-Wave** resonances
- **Reconcile** statistical D-wave widths with high resolution data by fitting w/SAMMY
- $< D >$ is automatically correct
- After fitting, $< \Gamma >$ and $< \sigma_{J^\pi} >$ are very close

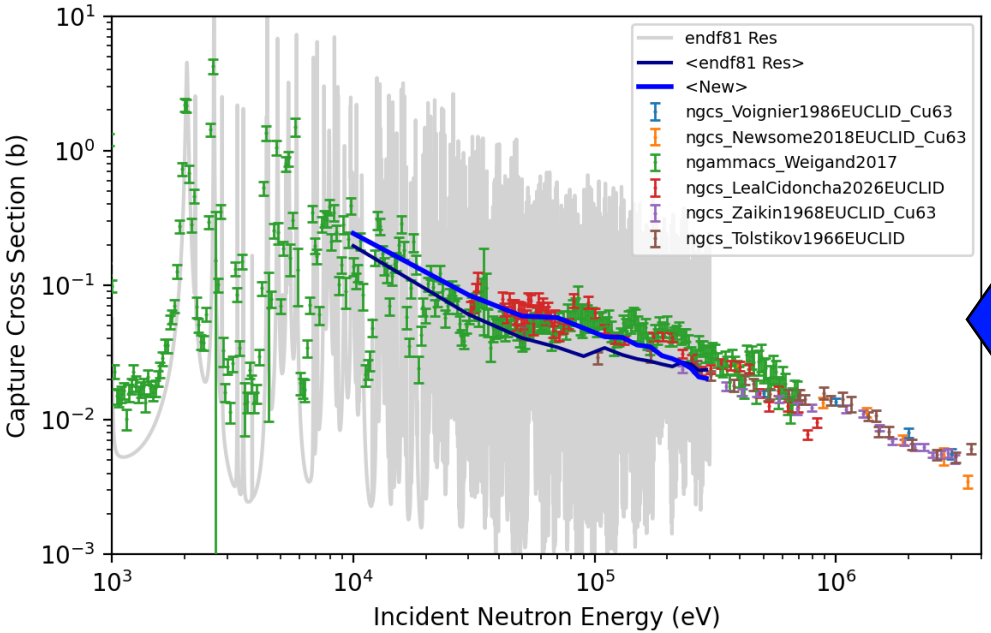


UTK Resonance Fitting Algorithm:

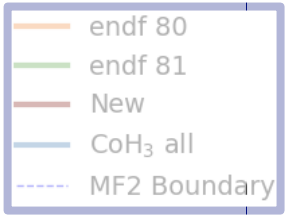
Walton, N.A.W., et al., "Automated Resonance Fitting for Nuclear Data Evaluation"
Nuclear Science and Engineering, *199*(7), (2025).
https://doi.org/10.1080/00295639.2024.2439700

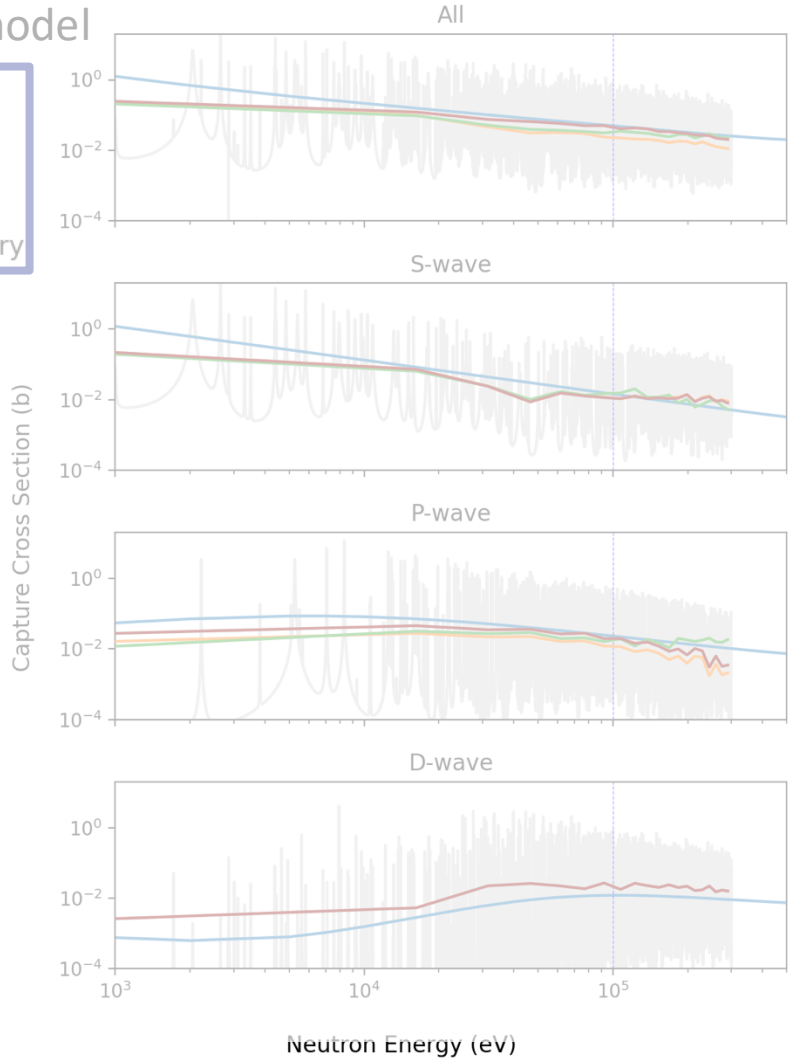
Better average capture

- Does not need MF3 component
- Same χ^2 with total/capture data



From COH_3 model



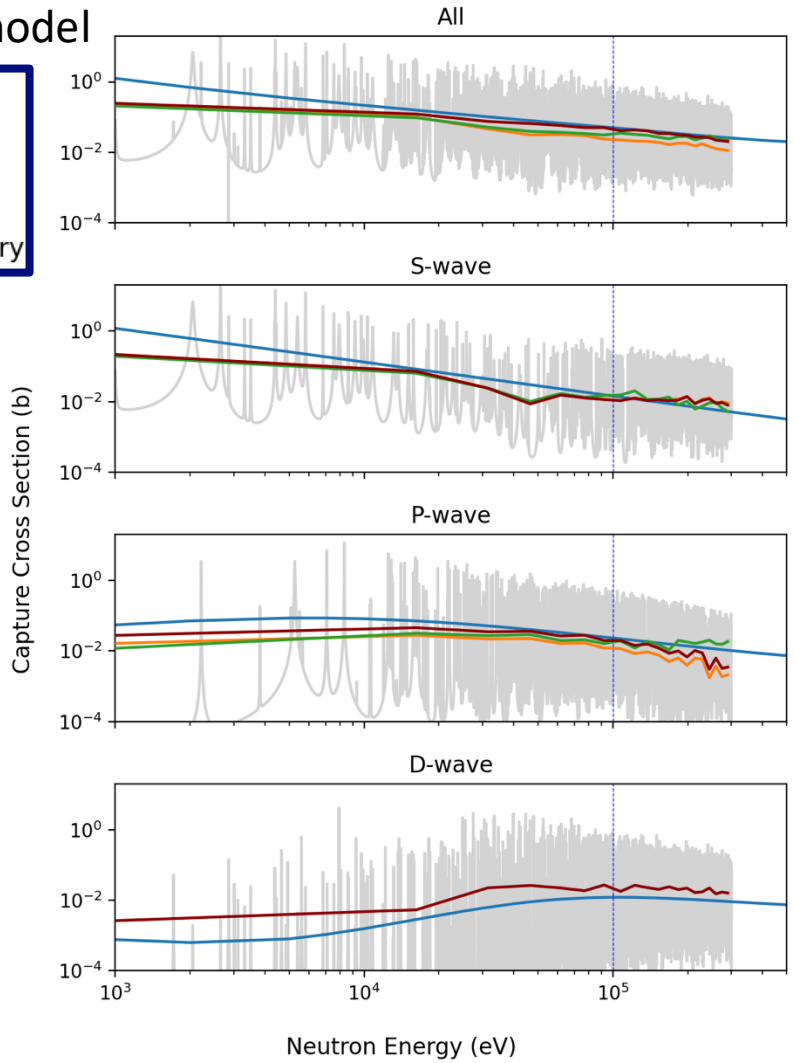


Los Alamos NATIONAL LABORATORY

Better average capture

- Does not need MF3 component
- Good χ^2 with total/capture data

From $\mathbf{COH_3}$ model



- Next: reconcile other partials (S & P waves) from existing evaluation
- Natural connection to automated resonance fitting algorithm @ UTK / ORNL

Summary

- PARADIGM project brought new $^{63}\mathrm{Cu}$ (n, tot) & (n, γ) measurements
- Can we be more proactive about how we use average information in RRR?
- $^{63}\mathrm{Cu}$ D-wave resonances explain the average w/o MF3 component

Future work

- Need to improve existing S & P-wave resonances
  - Shuffle some into D-waves
- Update $^{65}\mathrm{Cu}$ as well and use elemental data
- Can incorporate statistical model information to constrain automated resonance fitting?

Acknowledgements

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Other figures

- Residuals for d-wave model

Summary & Conclusions

- PARADIGM Project brought new Cu-63 measurements