URR measurements, evaluation, and testing for tantalum

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**Now at Oak Ridge National Laboratory*

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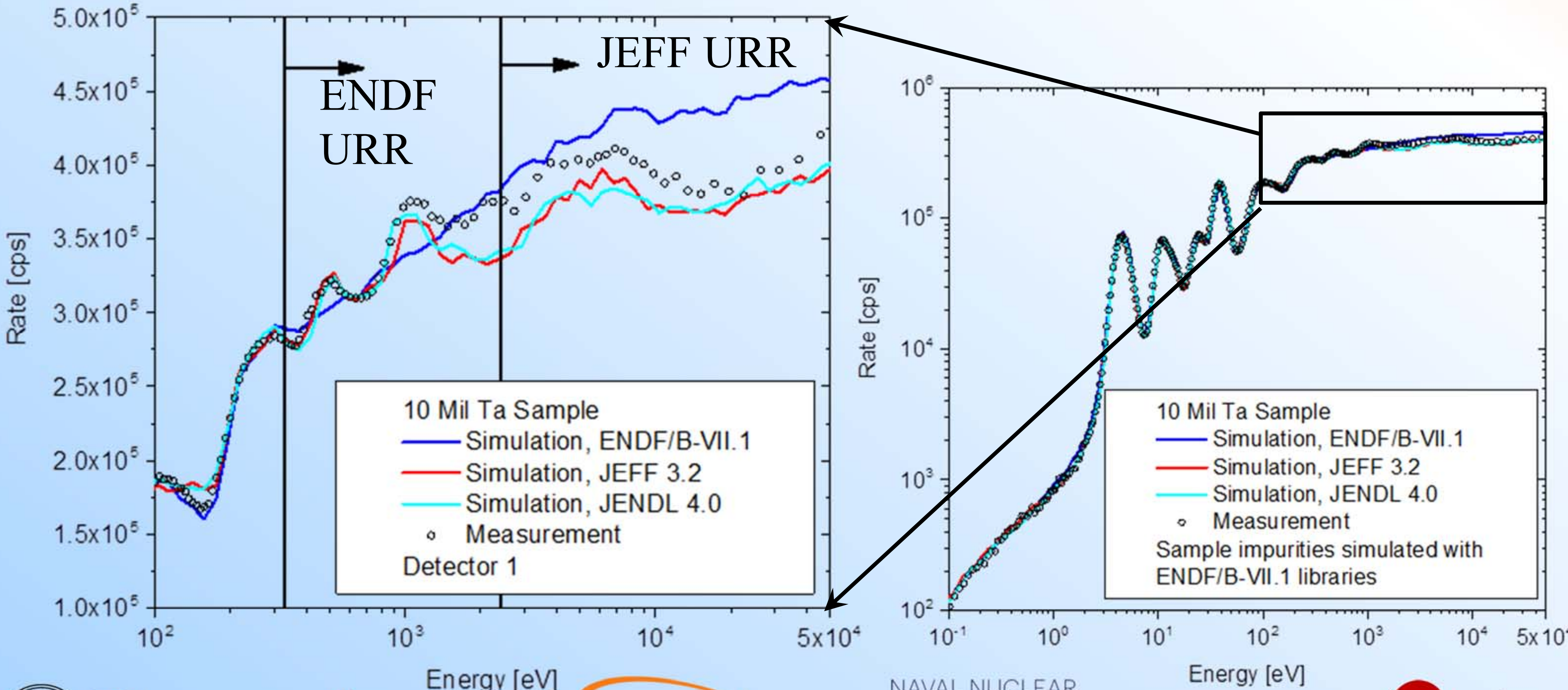
Motivation

- Tantalum was chosen:
  - On NCSP list of nuclear data needs
  - Single isotope and thus easier analysis
  - Has some cross section fluctuations in the URR
    - Similar to some actinides
- Develop methodology to test the URR self shielding accuracy
- The validation method can be used for actinides such as U-238 and U-235.

Motivation: LSDS capture rate measurements

- Discrepant evaluated libraries
- Lead Slowing Down Spectrometer (LSDS) study: Discrepancies between libraries in simulated capture rate



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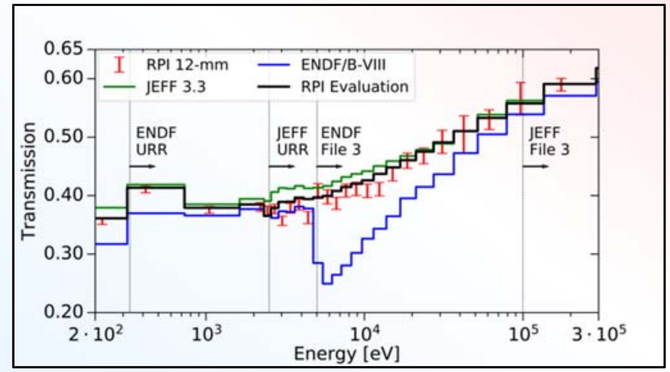
URR options

- LSSF=0 (what we used for Ta)
  - File 2 – URR parameters
    - Used to generate probability tables (or self-shielding factors)
  - File 3 – background cross section (zero here)
  - Cross section = (File 2 generated cross section) + (File 3)
- LSSF=1
  - File 2 – URR parameters
    - Used to calculated self-shielding factor SF= <F2 shielded>/<F2 not shielded>
  - File 3 – Gross structure infinite dilution cross section
  - Cross section = SF x (File 3) (fixes the energy grid)
- Probability tables and self-shielding factors are generated in application codes
  - Used NJOY 21 (LSSF=0) + MCNP 6.1

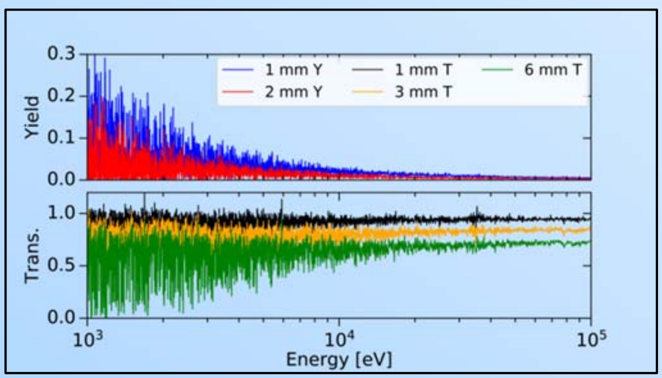
The big picture

Measurements

Validation



Evaluation



SAMMY/FITACS

NJOY21

MCNP 6.1

Novel Use of Thick-Sample Transmission Measurement: Validating the URR

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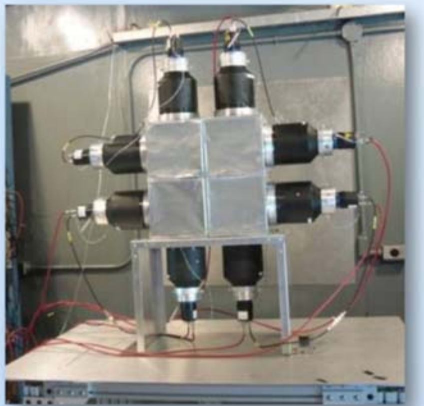
Detectors and Measurements

MELINDA (100m)

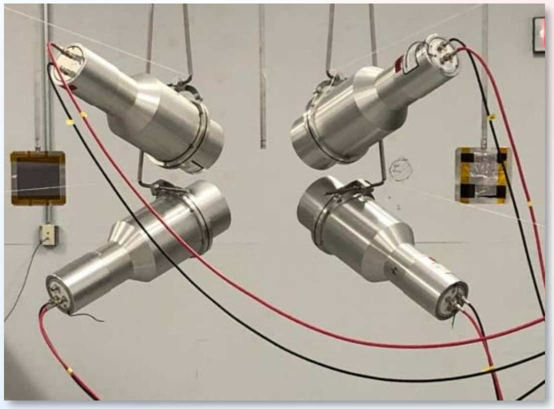


- High energy resolution
- Fast timing
- Large active detector area
- Data-processing well understood

^{6}Li glass (35m)

- Relatively good energy resolution
- Fast timing
- Shorter flight-path enables greater count rate
- Better count rate allows freedom of neutron targets

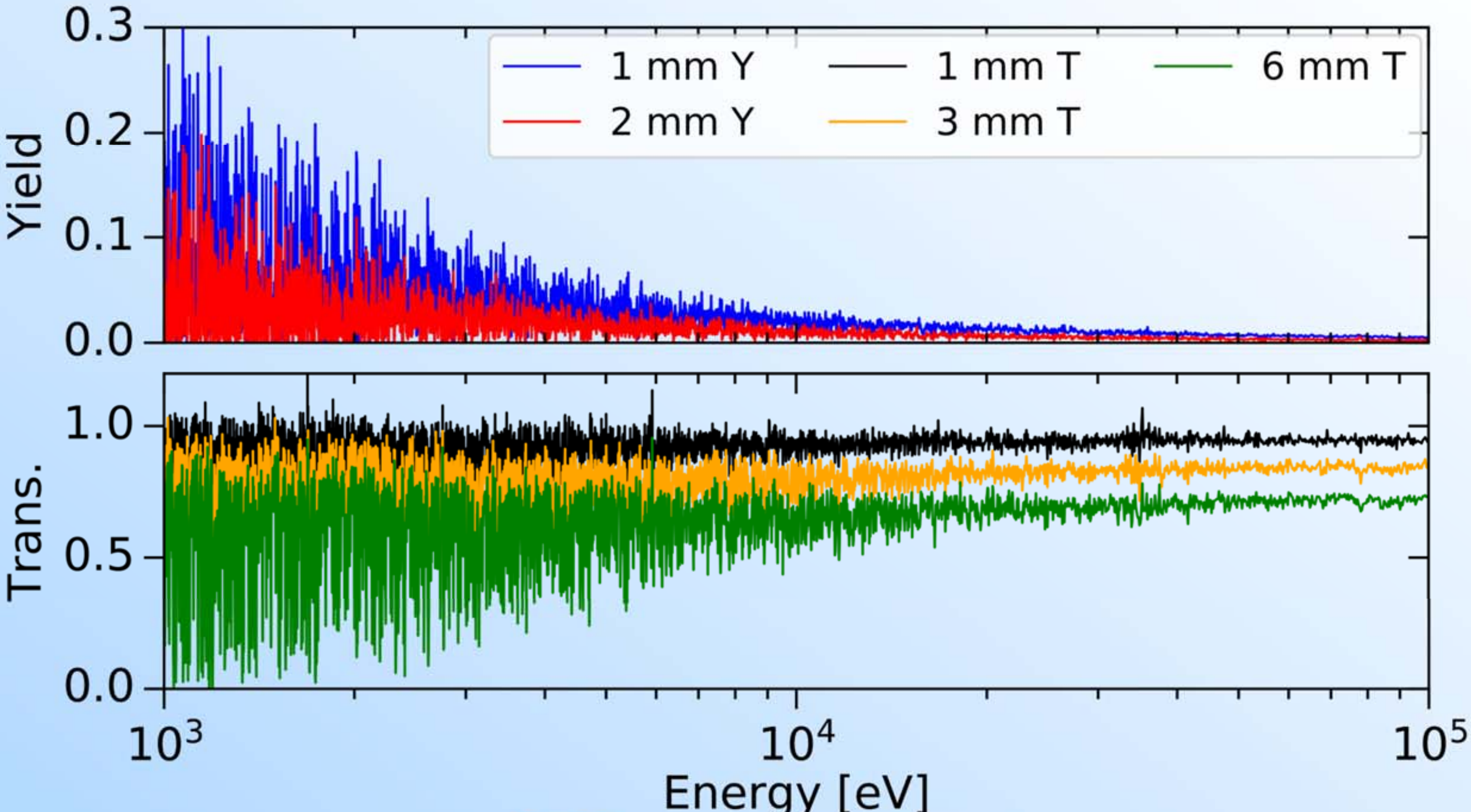
C_6D_6 Detector (45m)



- Highest energy resolution for capture at RPI
- Low neutron sensitivity
- Designed with digital acquisition system

Data to Evaluate

- ^{181}Ta Evaluation Datasets:
- Capture Yield: 1 and 2 mm
- Transmission: 1, 3, and 6 mm



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SAMMY Evaluation

RRR

Input:
- Resonance Parameters
- Data Reduction Parameters
- Experimental Conditions
- Experimental Data: Transmission and Capture Yield

→

SAMMY:
R-matrix Bayesian Fitting Program

→

New Resonance Parameters

URR

Input:
- Average Resonance Parameters
- Experimental Conditions
- Experimental Data: Total and Capture cross section

→

SAMMY/FITACS & SESH:
- **Hauser Feshbach Bayesian Fitting Program**
- **MC Self-Shielding Code**

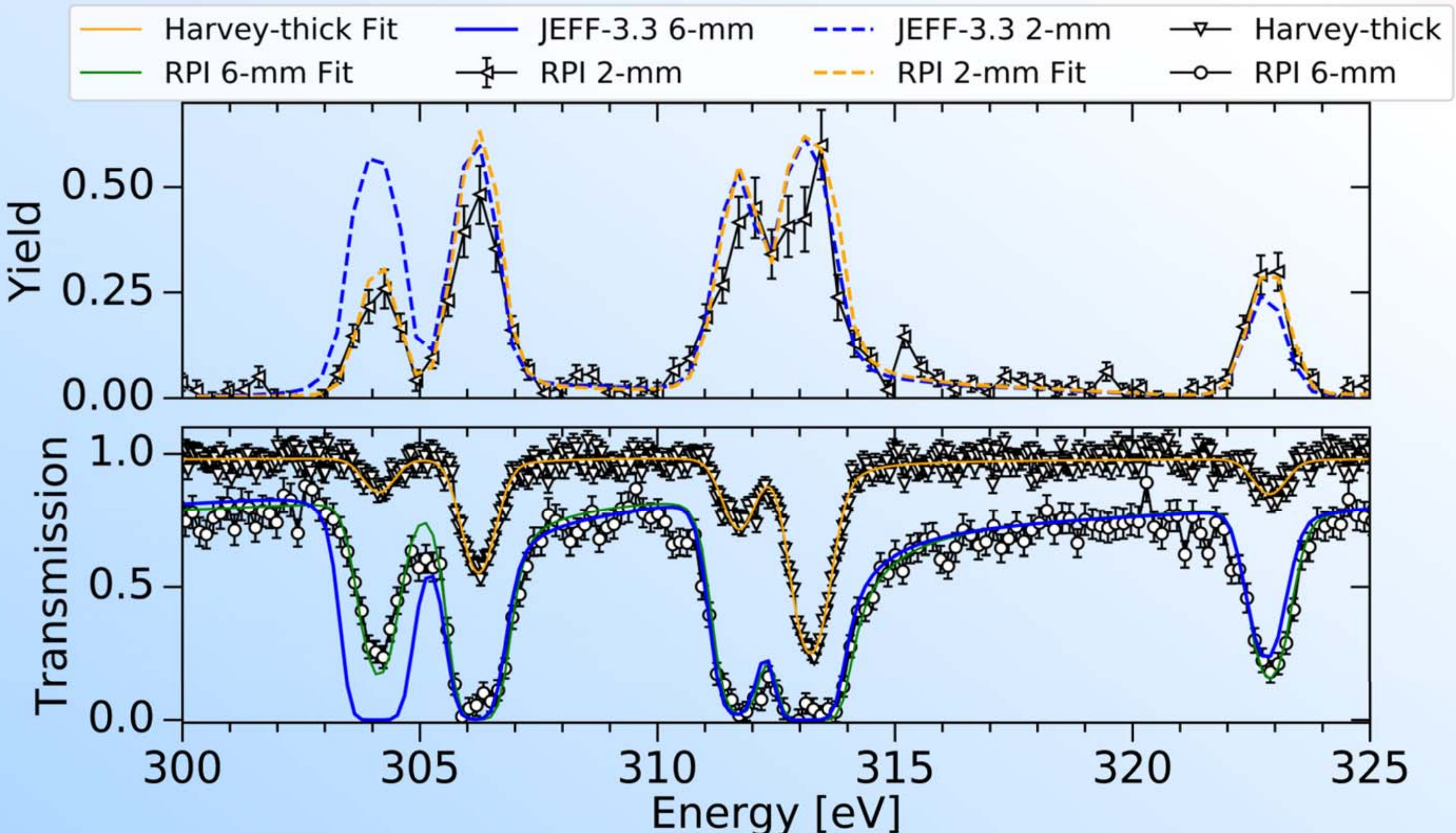
→

New Average Resonance Parameters

Data to Evaluate: RRR (one example)

End of ENDF/B-VIII.0 RRR:

- 304 eV resonance updated
- Transmission and capture yield are well resolved



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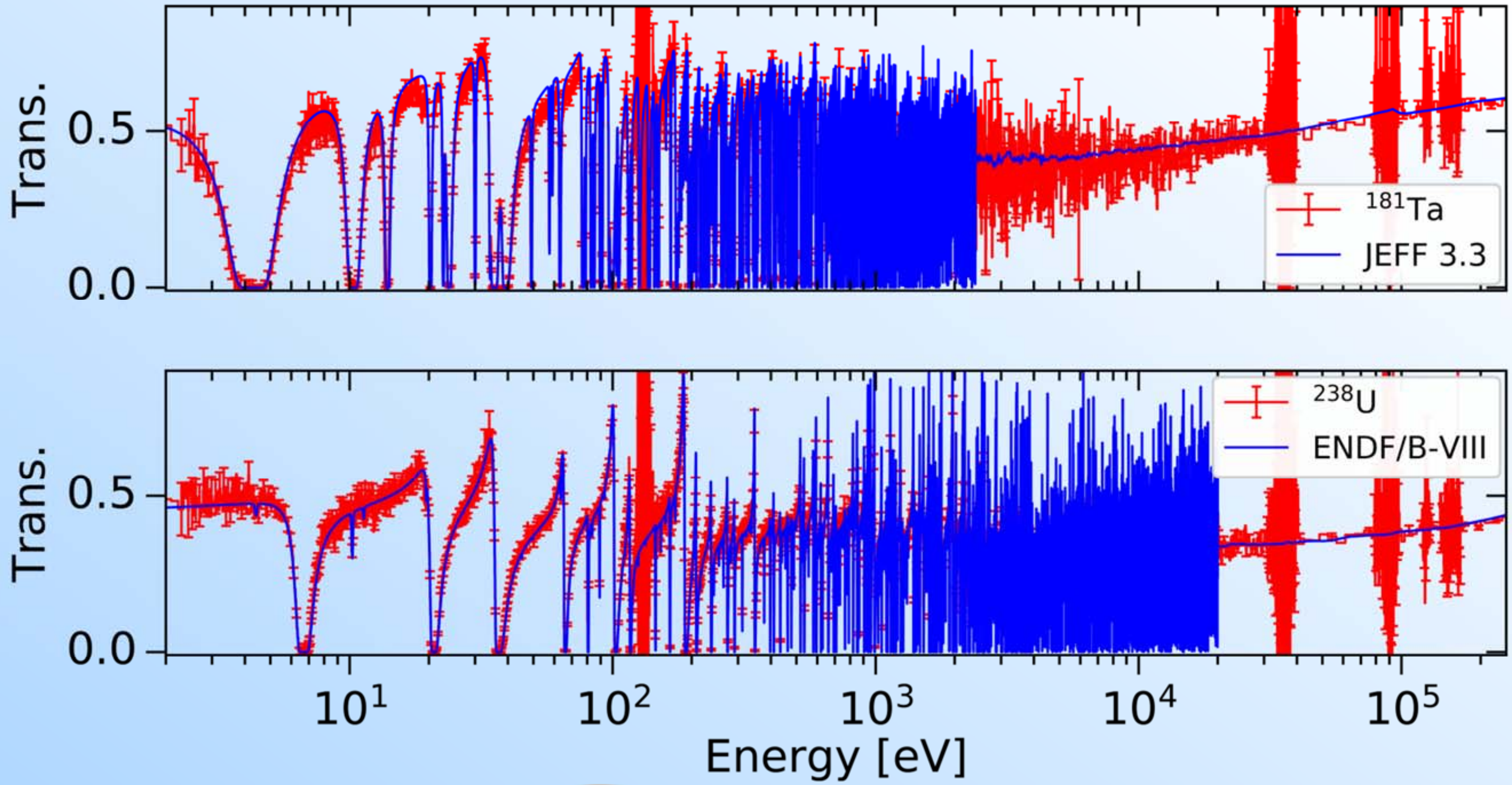
Validation transmission data

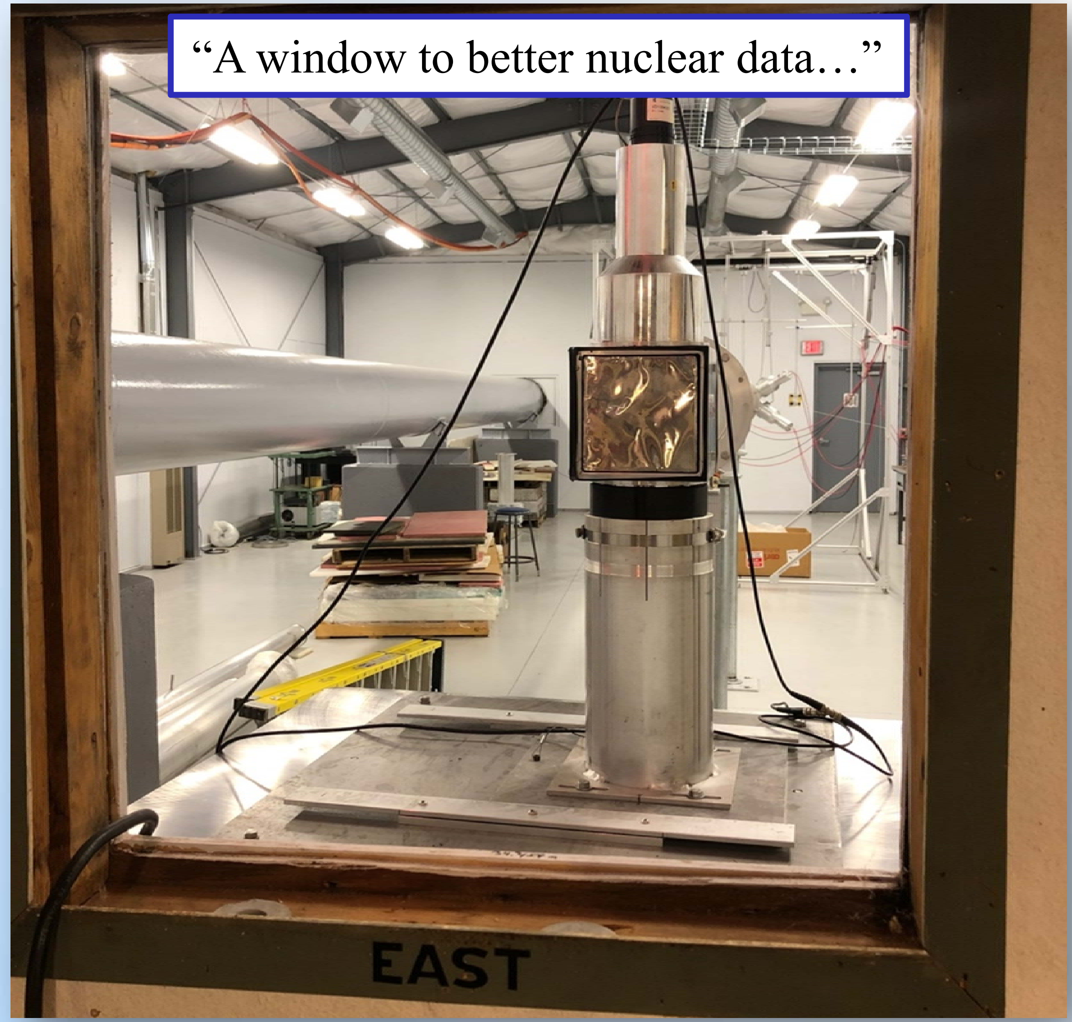
- ^{181}Ta Validation Dataset:
  - Transmission: 12 mm
  - ^{238}U verification dataset



Transmission for validation

^{6}Li doped scintillating glass detector

- 2 PMT's viewing a light tight aluminum case



URR Transmission Enhancement Math

Neutron transmission through a sample: $T(E) = e^{-n\sigma_t(E)}$

The "true" average transmission from energy E_1 to E_2

$$\langle T\rangle = \frac{1}{E_2-E_1}\int_{E_1}^{E_2} e^{-n\sigma_t(E)}dE = \frac{1}{E_2-E_1}\int_{E_1}^{E_2} e^{-n[\sigma_t(E)+\langle\sigma_t\rangle-\langle\sigma_t\rangle]}\,dE$$

Enhancement due to $\sigma_t(E)$ fluctuations

$$\langle T\rangle = e^{-n\langle\sigma_t\rangle}\frac{1}{E_2-E_1}\int_{E_1}^{E_2} e^{-n[\sigma_t(E)-\langle\sigma_t\rangle]}dE$$

Note: positive and negative contributions

$$\text{sft(E)}= \frac{1}{E_2-E_1}\int_{E_1}^{E_2} e^{-n[\sigma_t(E)-\langle\sigma_t\rangle]}dE$$

$$\bar{T} = e^{-n\langle\sigma_t\rangle}$$

Self-shielded

$\langle T\rangle = \bar{T} * sft(E)$ where $\text{sft}(E) > 1, \rightarrow$ $\langle T\rangle > \bar{T}$ $\rightarrow$ $\langle\sigma_t\rangle < \bar{\sigma}_t$

Evaluation procedure must preserve the fluctuations of $\sigma_t(E)$

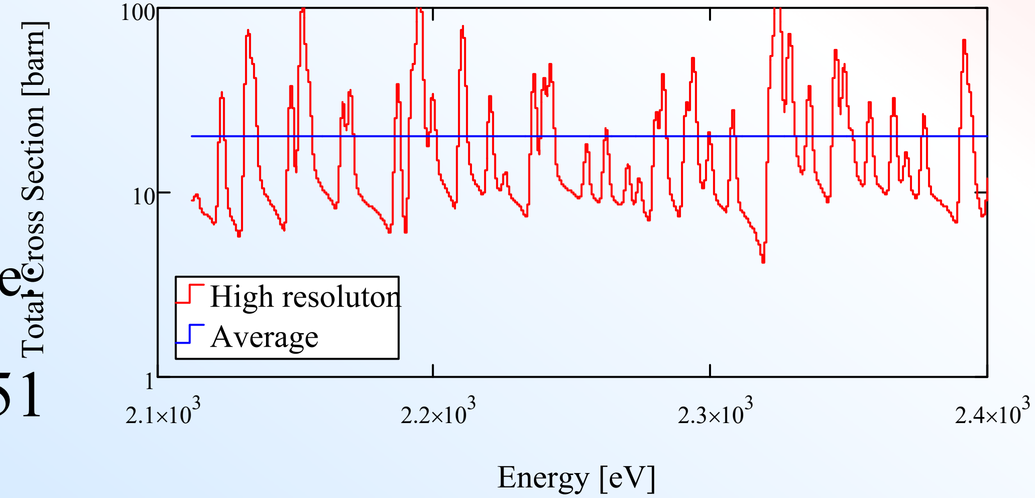
URR Transmission Enhancement Example

- Example calculating neutron transmission through a 6 mm Ta sample
- If the cross section was known in high energy resolution, the “true” transmission:

$$\langle T \rangle = \frac{1}{E_2 - E_1} \int_{E_1}^{E_2} e^{-N \cdot \sigma_t(E)} dE = 0.59$$

- If we use only the cross section average

$$\bar{T} = \frac{1}{E_2 - E_1} \int_{E_1}^{E_2} e^{-N \cdot \langle \sigma_t \rangle} dE = e^{-N \cdot \langle \sigma_t \rangle} = 0.51$$

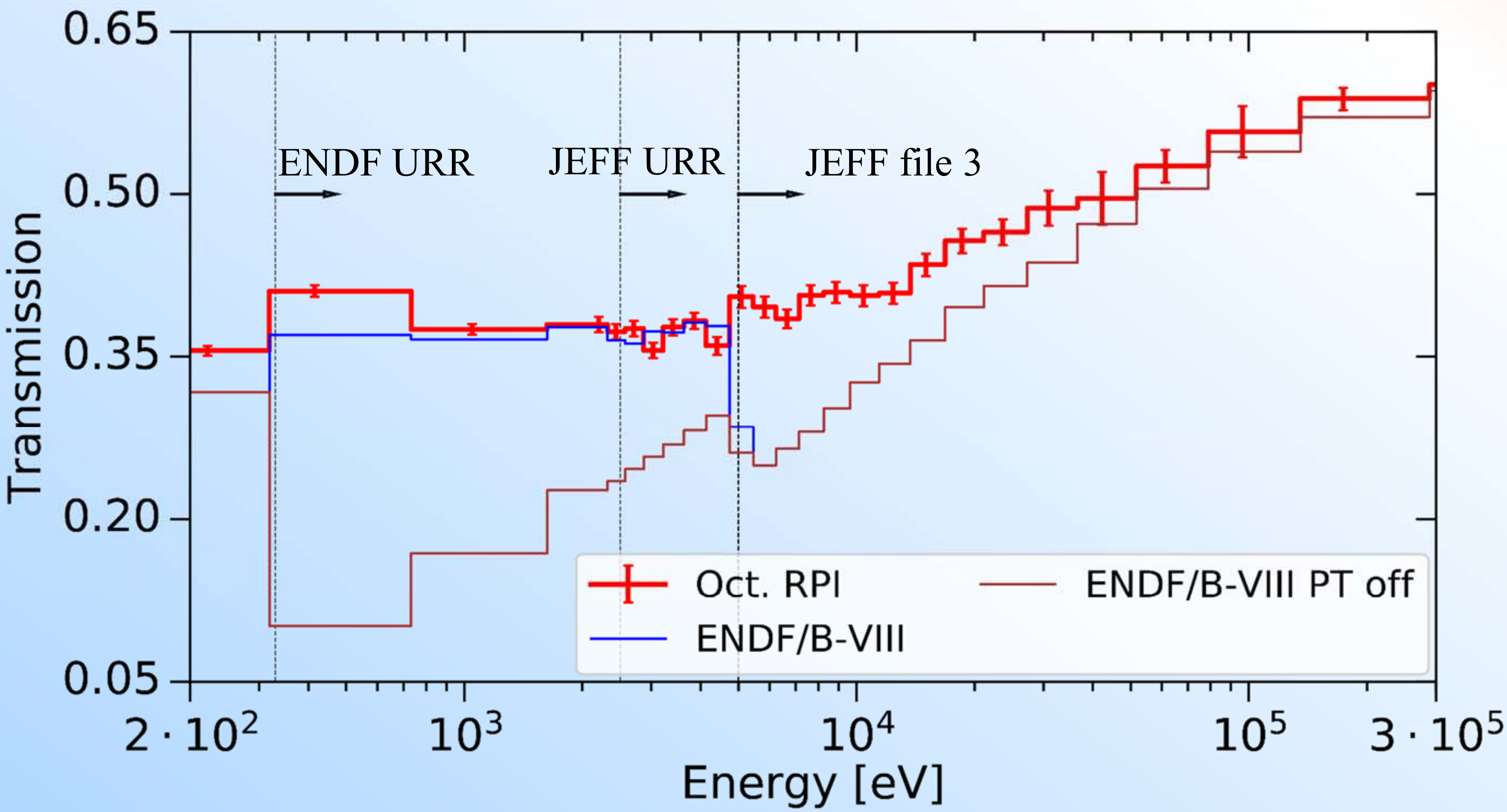


- Fluctuations enhance transmission and thus reduce the effective cross section (relative to the average) hence the term self shielding
- When measuring the total cross section with a thick sample a correction for the self shielding is needed.
  - Can use two sample thicknesses →
  - Can use a model based approach → SESH

Froehner, et al, “Cross-section fluctuations and self-shielding effects in the unresolved resonance region “, International Evaluation Co-operation volume 15 (NEA-WPEC--15), Nuclear Energy Agency of the OECD, NEA, (1995).

Resonance Self-Shielding effect in Ta

- The effect of self shielding is shown by turning off the URR treatment in MCNP
- Near 400 eV self-shielding reduces the transmission by a factor of about 4



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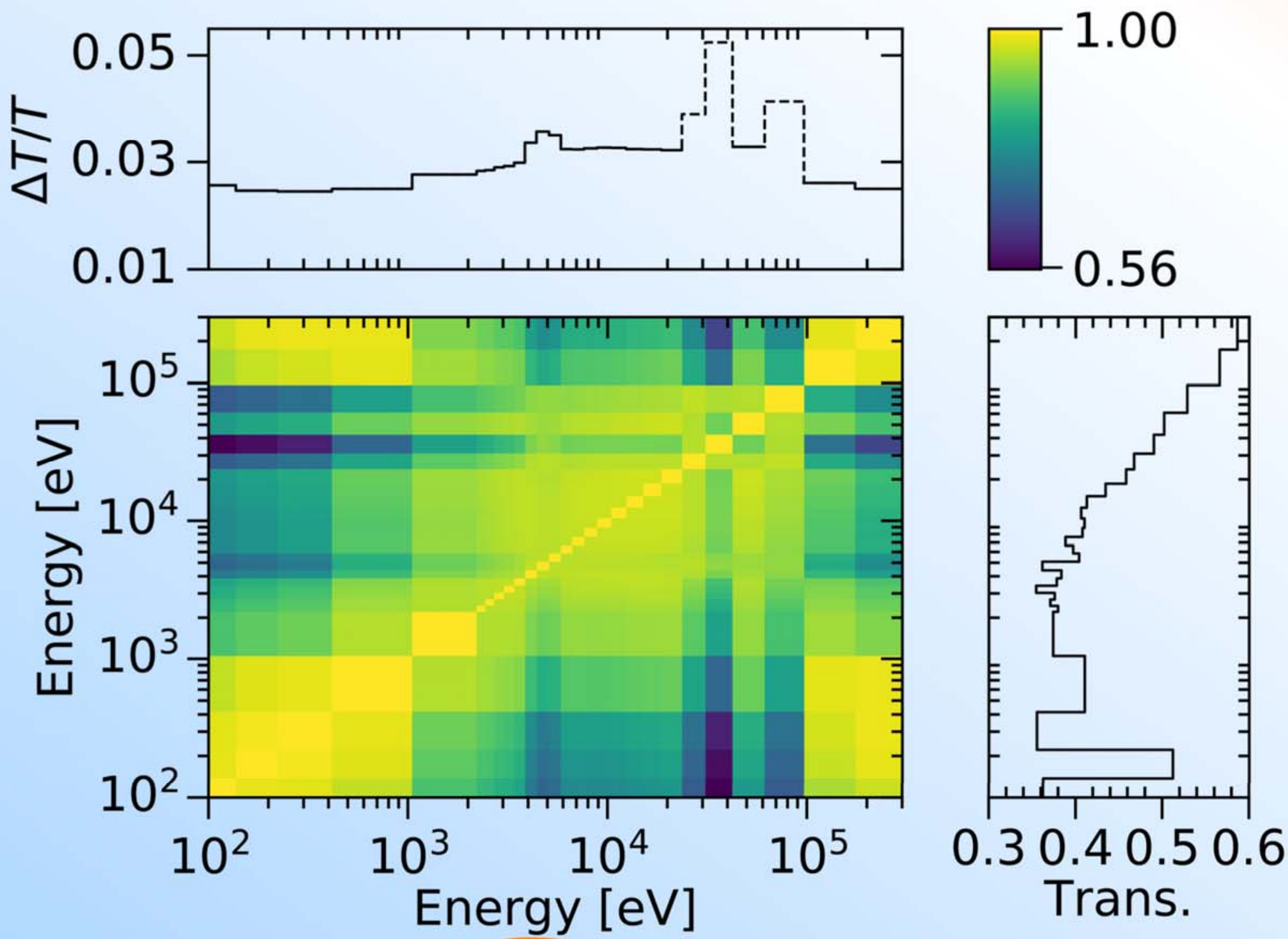
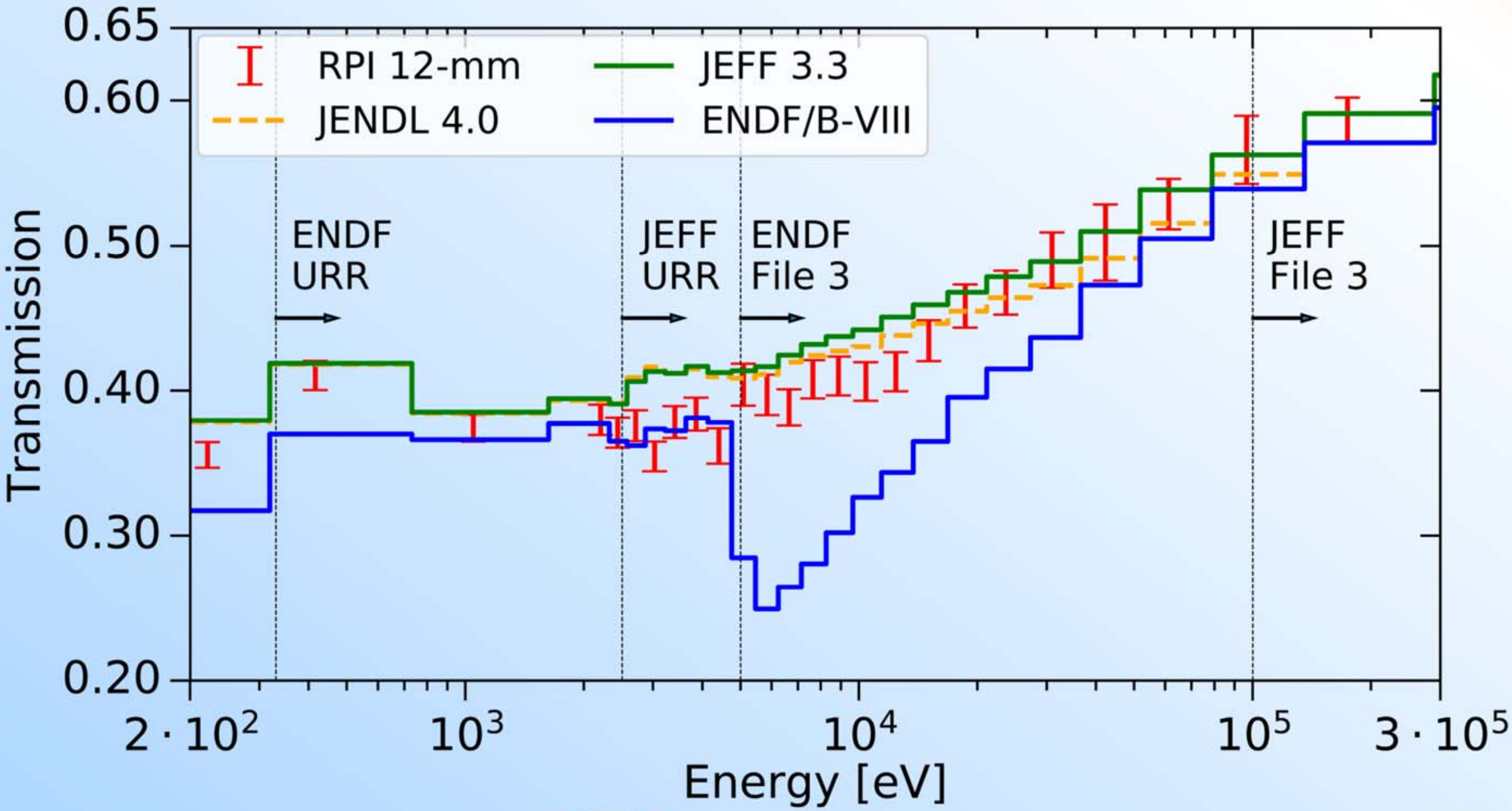
Validation Transmission Measurement

$$C_y = F_x C_x F_x^T = F_{x,stat} C_{x,stat} F_{x,stat}^T + F_{x,sys} C_{x,sys} F_{x,sys}^T$$



Validation Transmission and evaluations

- Transmission for 12 mm sample
  - Grouped to have about 50 resonances per bin
- Observe the limitations of the URR treatment using JEFF-3.3, JENDL-4.0, and ENDF/B-VIII.0



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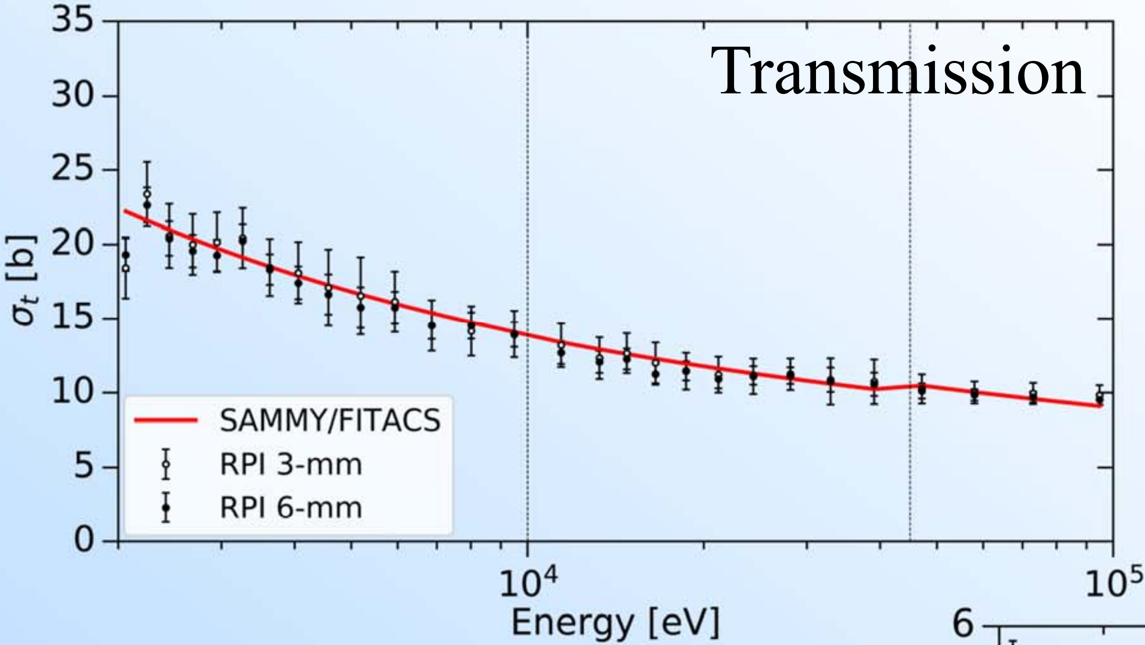
Multi-Region URR

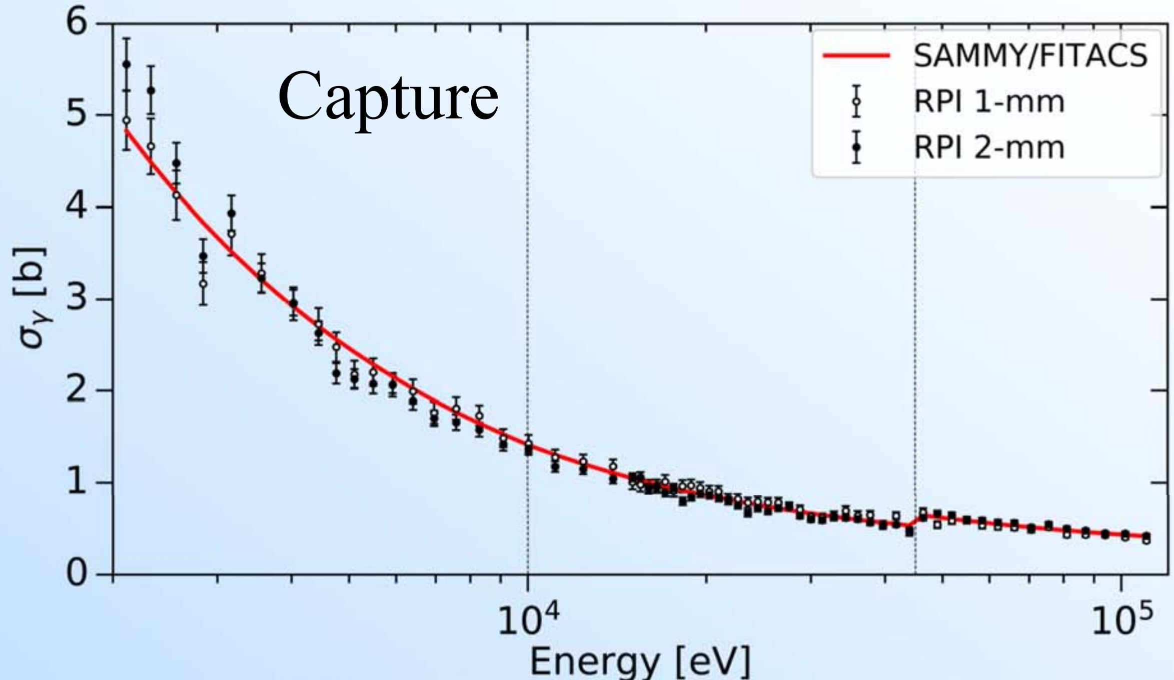


Options considered

1. One region URR
2. Multi Region URR
3. Extended RRR

E-regions fit:

- 2-10 keV
- 10-45 keV
- 45-120 keV



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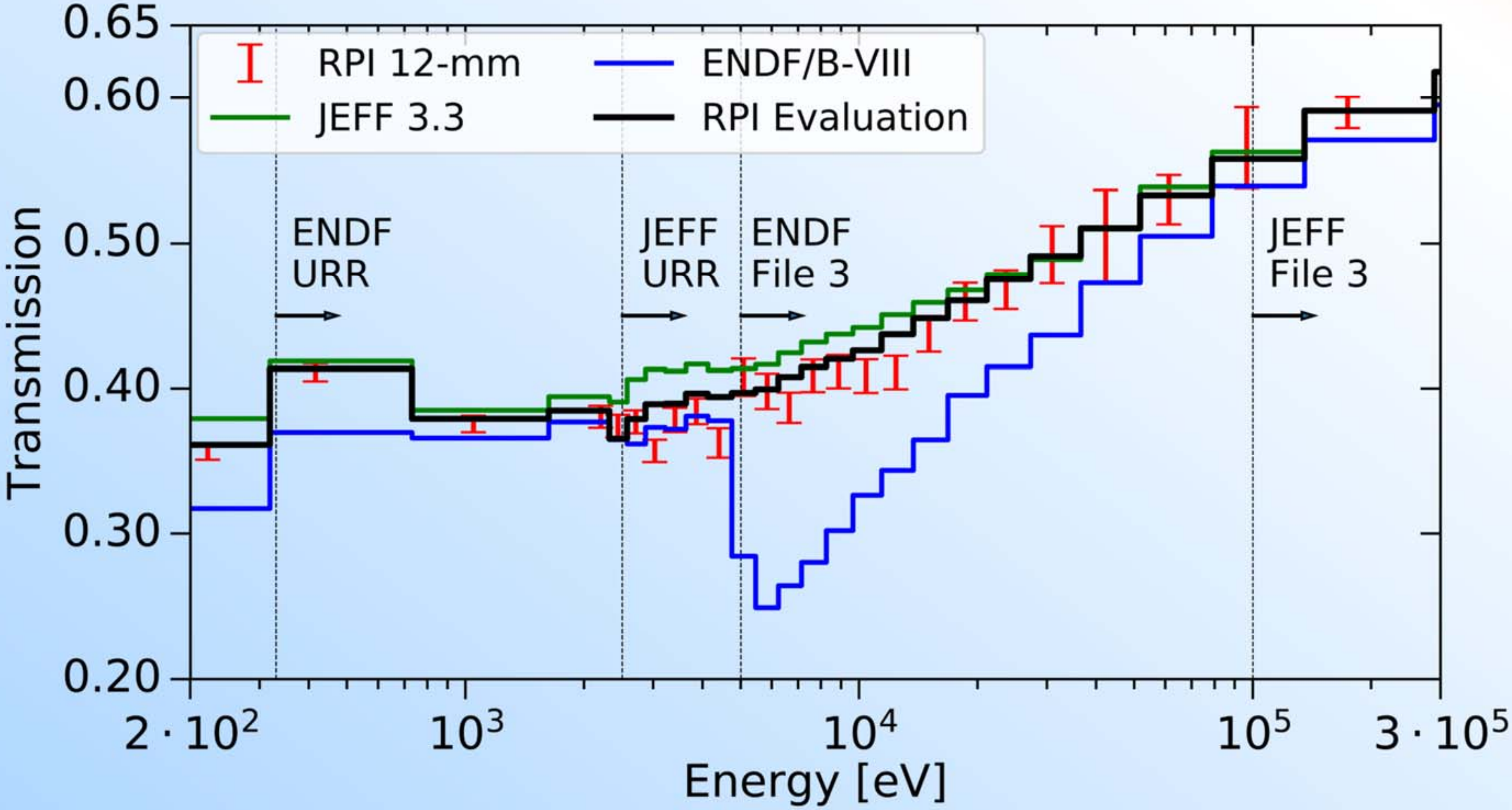
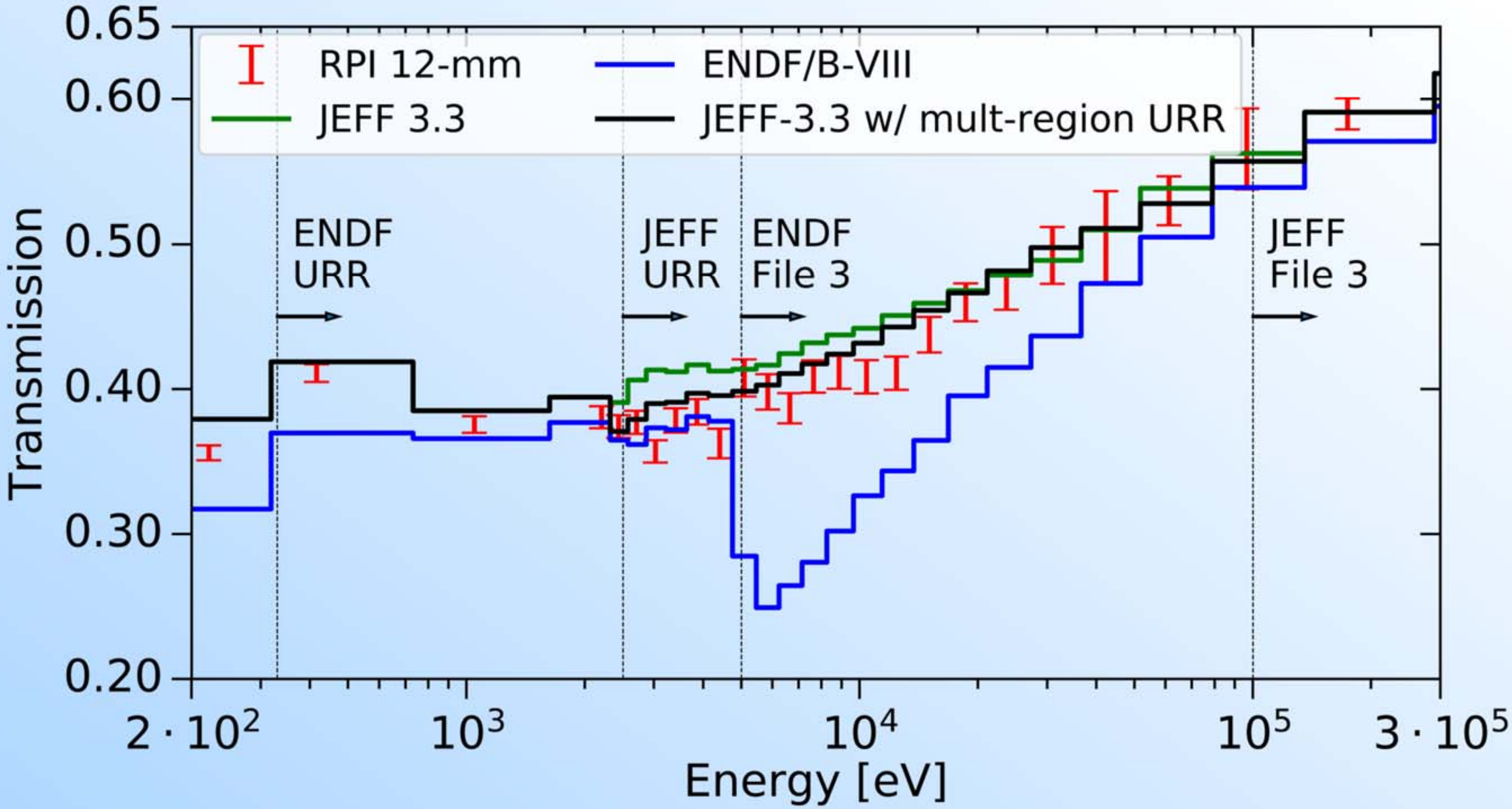
RPI Evaluation: Updated JEFF-3.3

- Updated RRR and URR parameters
- Very sensitive to a_c, D and other $\langle Pars \rangle$
- Using the RPI evaluation we can improve agreement with measured data



Multi-Region URR

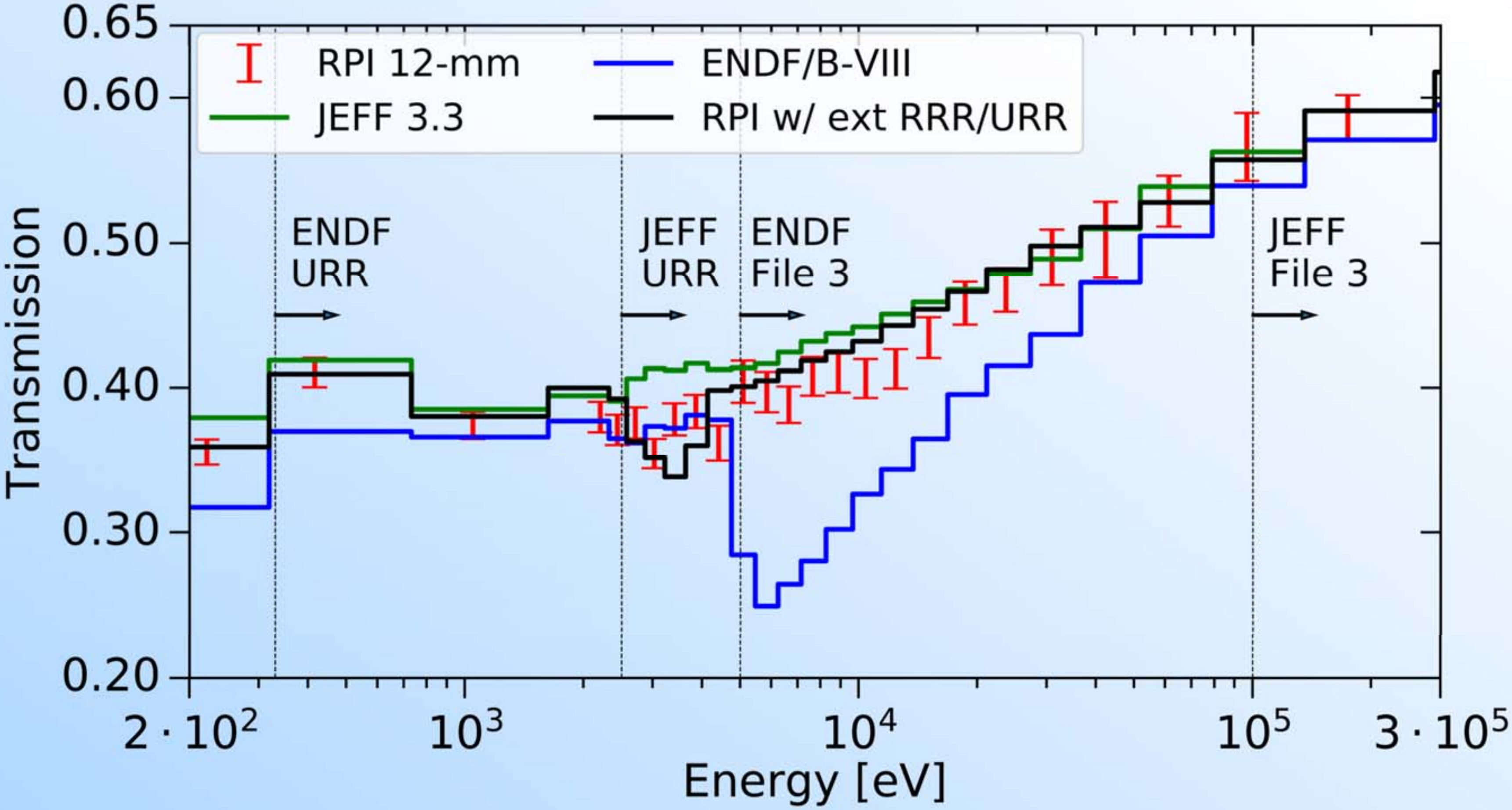
- Performs reasonably well compared to thick-sample transmission
- $\langle Pars \rangle$ for each region are less constrained
- Separated parameters do not significantly improve overall shape



Extended RRR fit

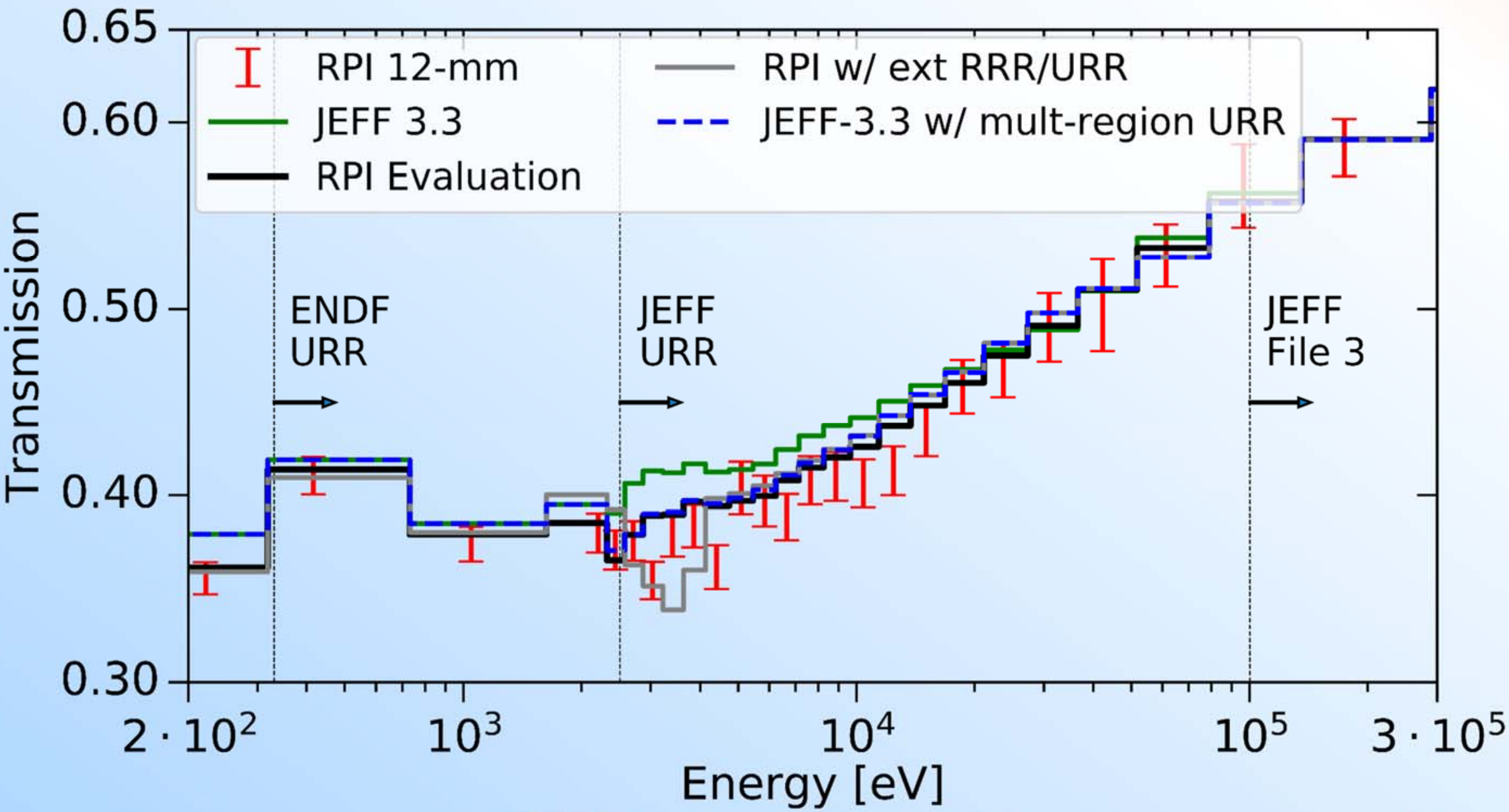
RRR parameter fit to 4 keV

- Mughabghab publishes parameters up to 4 keV
- Fit $E_\lambda, \Gamma_\gamma, \Gamma_n$
- No significant improvement



Summary of all evaluations

- Look very similar
  - extended resonance evaluation seems to under predict shelf shielding



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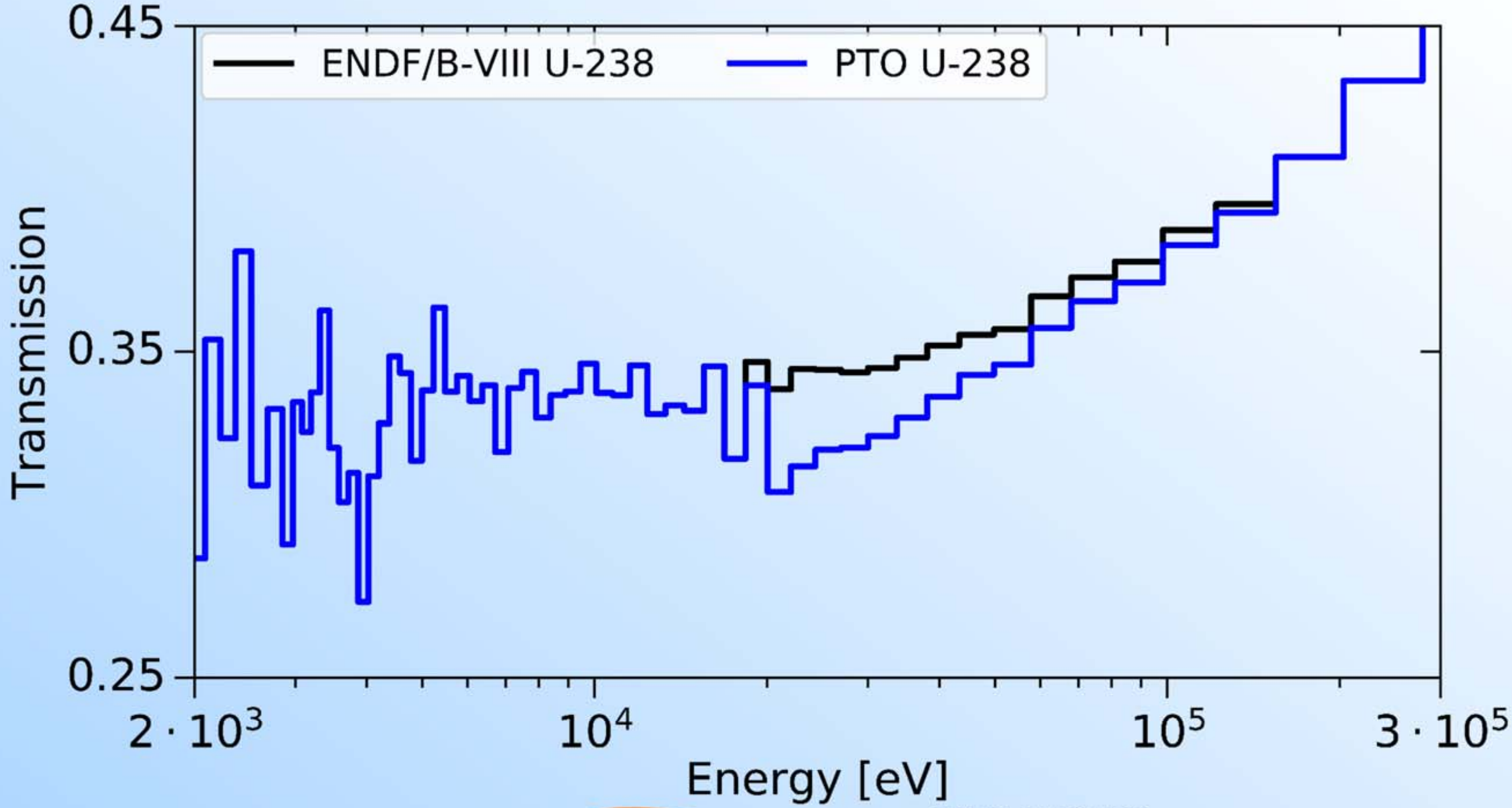
Example for U-238

- MCNP simulation
  - Used 17 mm thick sample (can use thicker)
  - The self shielding effect is visible in the URR (E>20 keV)



Conclusions

^{181}Ta

- RRR representation is more accurate for calculating transmission (up to 2.4 keV)
- ENDF/B-VIII.0 needs to be updated
  - RRR treatment for ENDF/B evaluation should be extended (JEFF and JENDL → 2.4 keV)
  - URR treatment for ENDF/B evaluation should be extended beyond 5 keV (JEFF and JENDL → 100 keV)
- **New RPI data** provide best resolution to date and can be used to create a better ^{181}Ta evaluation

Transmission Validation

- Thick sample transmission measurement capable of validating the URR and RRR/URR boundary
  - Better targeted for validating the URR than previous high energy benchmark experiments
- Validation transmission is very sensitive to resonance self-shielding, a_c, R' and other URR parameters
- A novel method that can help improve cross section evaluations that affect criticality