Measurements and evaluation of structural materials at RPI

Professor Y. Danon
Director, Gaerttner LINAC Center

International Nuclear Data Evaluation Network (INDEN) Evaluated Nuclear Data of the Structural Materials, December 18-21, 2023, IAEA, Vienna

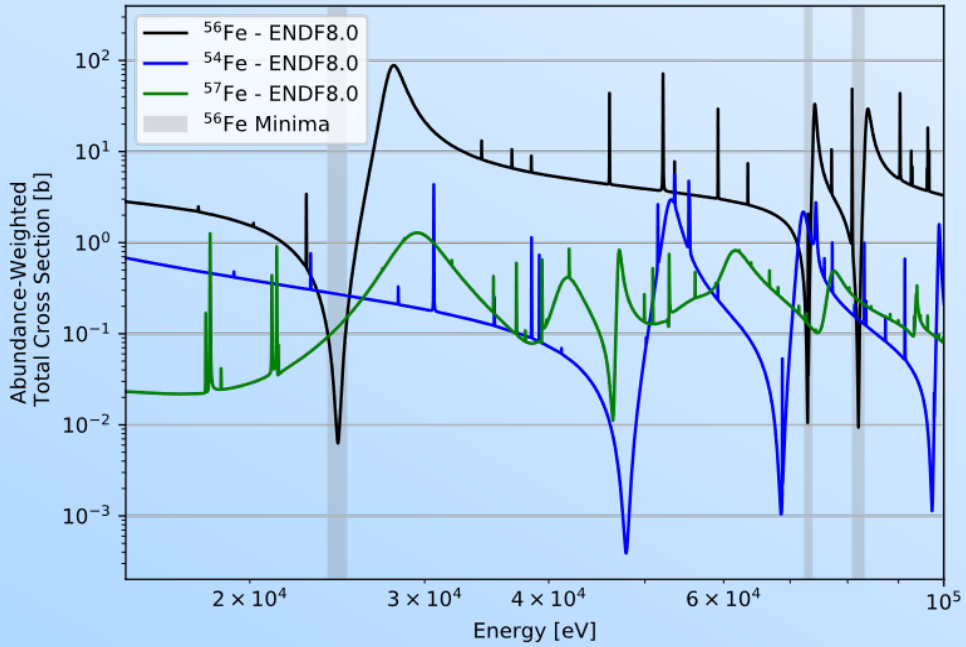
Recent relevant work

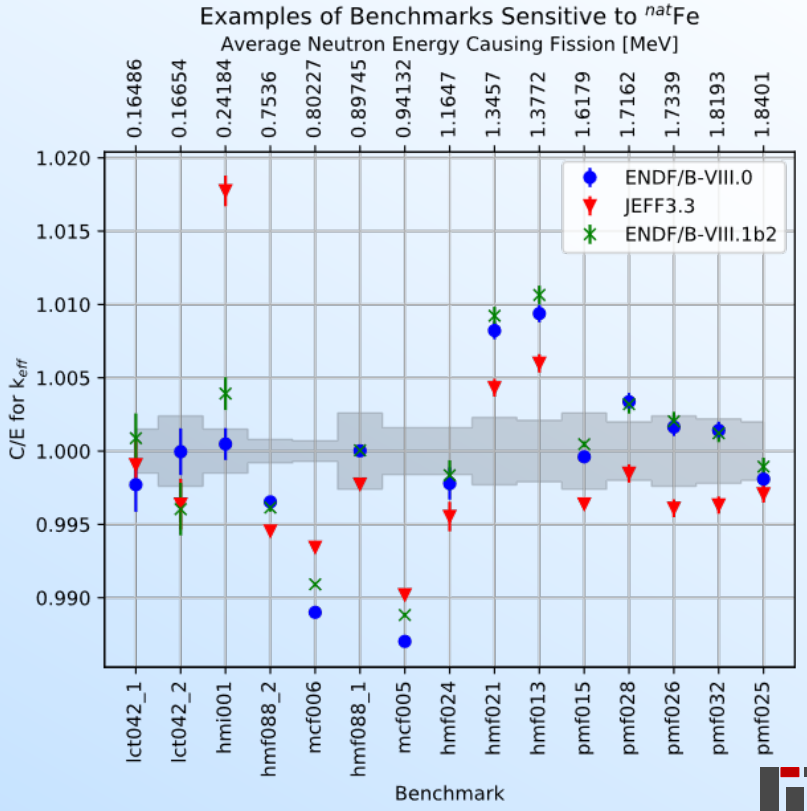
- Iron (Sukhjinder Singh)
  - Fe-56 capture from 1 keV to 2 MeV (previous work)
  - Fe-54 capture and transmission in the keV region.
  - Evaluation of RRR in progress
- Pb evaluation (Peter Brain)
  - Evaluation (RRR and fast) of ^{206,207,208}Pb
  - Completed and part of ENDF/B-VIII.1β3.
  - Presented last year.
- Zr evaluation (Greg Siemers)
  - New resolved resonance region evaluation in progress for ^{90}Zr
- Quasi differential scattering for F and Ta (Greg Siemers)

Fe-54 measurements and evaluation

^{54}Fe (n, γ) Measurement - Motivation

- Fe is an important constituent in many nuclear systems
  - Reactor, fuel storage, radiation shielding applications
- Natural Fe and ^{56}Fe cross sections have been studied extensively, but there is a lack of data available in EXFOR of the ^{54}Fe(n, γ) cross section
  - ^{56}Fe evaluation work has highlighted need for new measurements and evaluation for ^{54}Fe



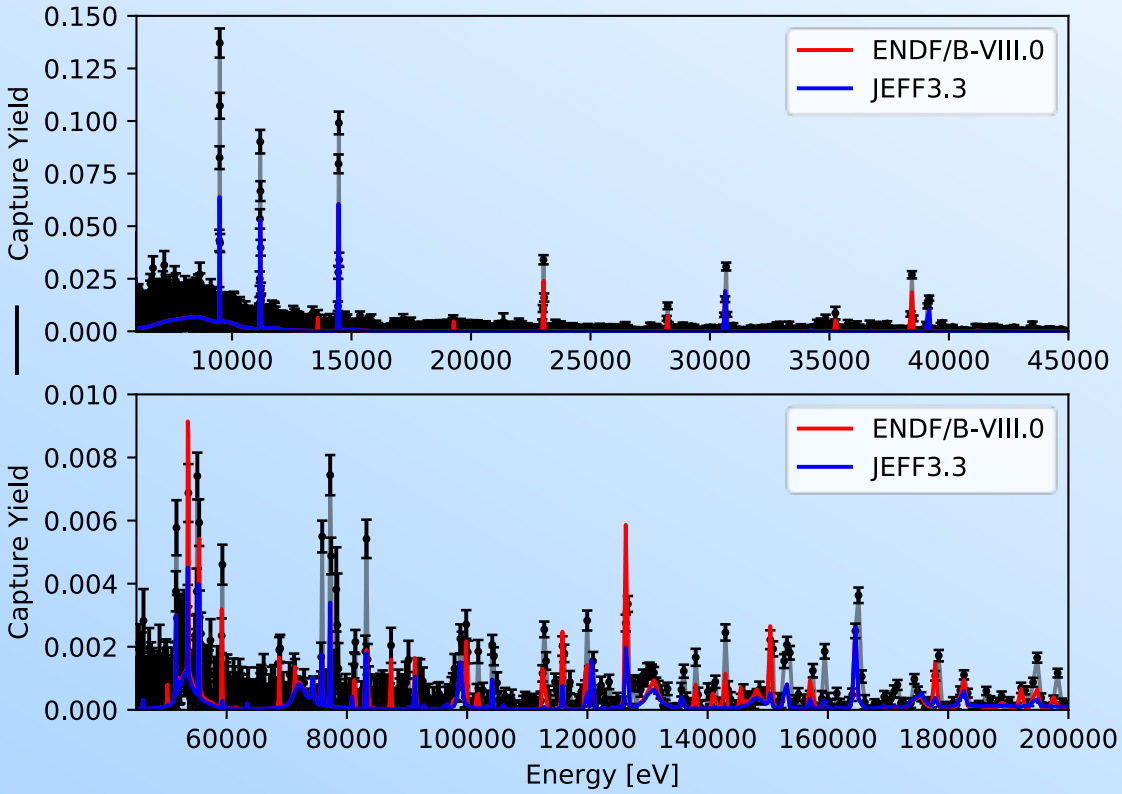


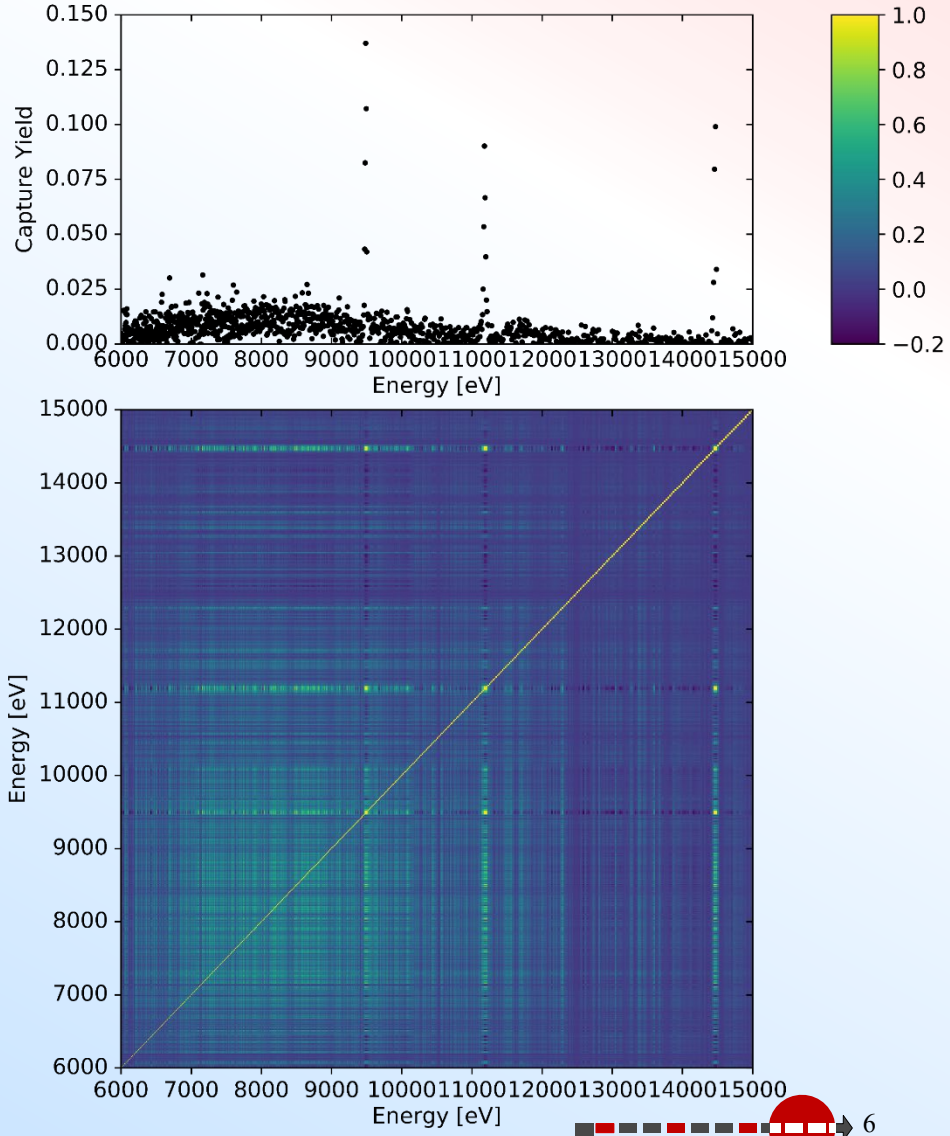
Overview of RPI Experiment Campaign

- Radiative Capture:
  - An array of seven C_6D_6 liquid scintillators surrounding the sample of interest at a flight path of 45m.
  - Enriched Fe-54 sample (~0.021 at/b) measured along with Open, Au, B_4C, Pb samples
  - Pulse height weighting used to reduce data down to capture yield
  - Useful to ~150 keV
- Transmission:
  - Li-6 glass detector at 35m used to collect sample-in, sample-out data using analog electronics.
  - Enriched Fe54 sample (~0.021 at/b) measured along with Open, Depleted Uranium, and Natural Fe.
  - Fixed notch materials kept in beam during the duration of the experiment.
  - Useful to about ~150 keV, will be used to fit resonance in the low energy region.

^{54}Fe Capture Experiment

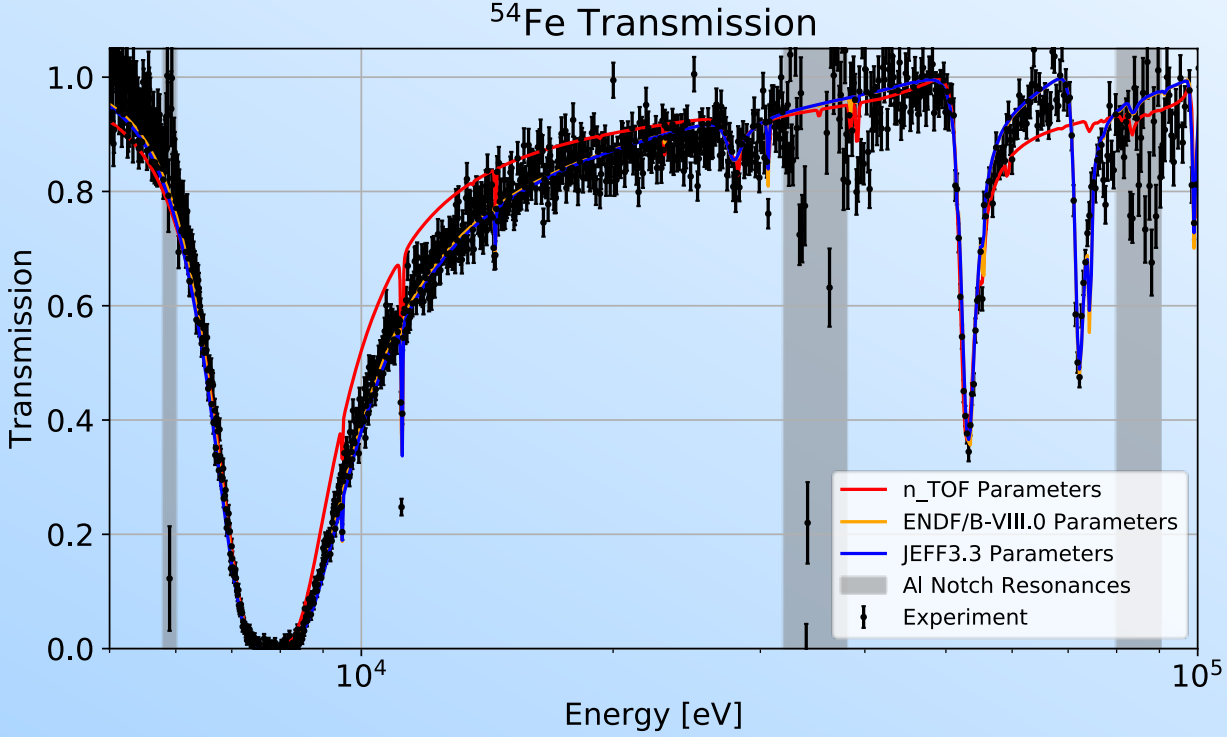
- Capture yield shows large discrepancies.
- Stronger correlations between resonances are present in the experiment.

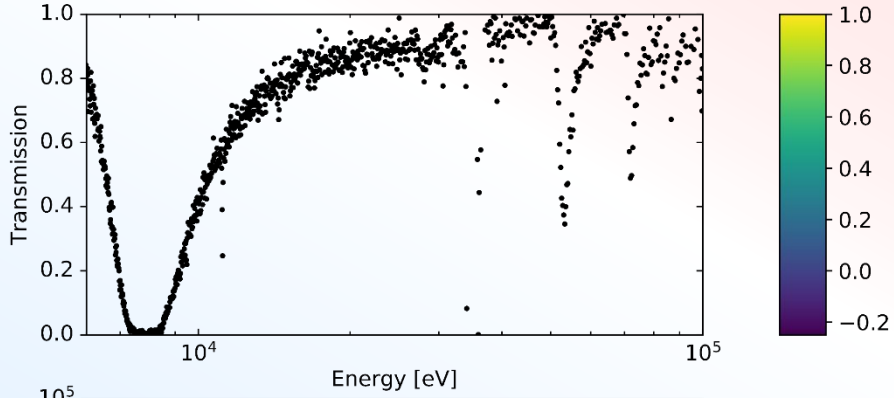


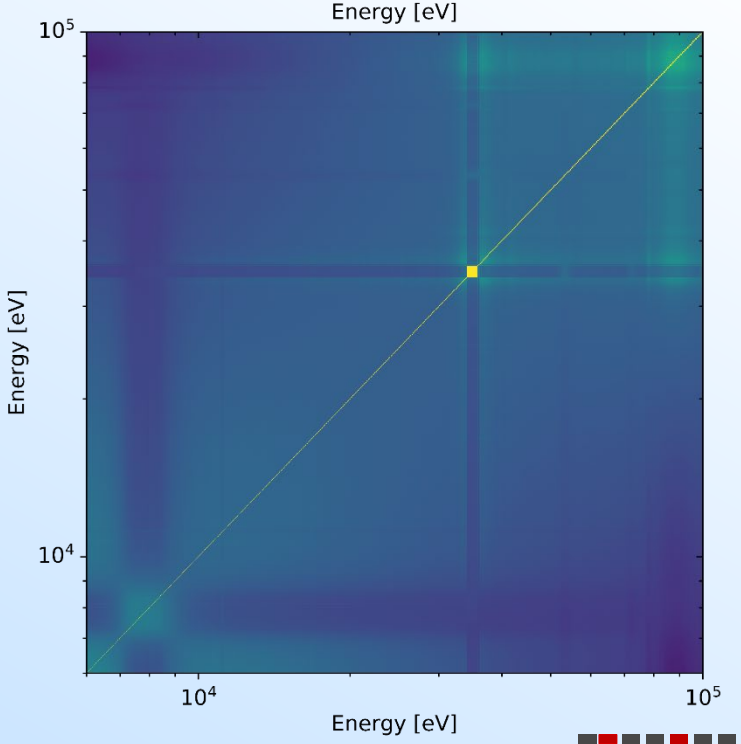


^{54}Fe Transmission Experiment

- Transmission is less sensitive to changes in evaluations.
- Covariance passes all mathematical checks.
- Small correlations are present in the transmission experiment.

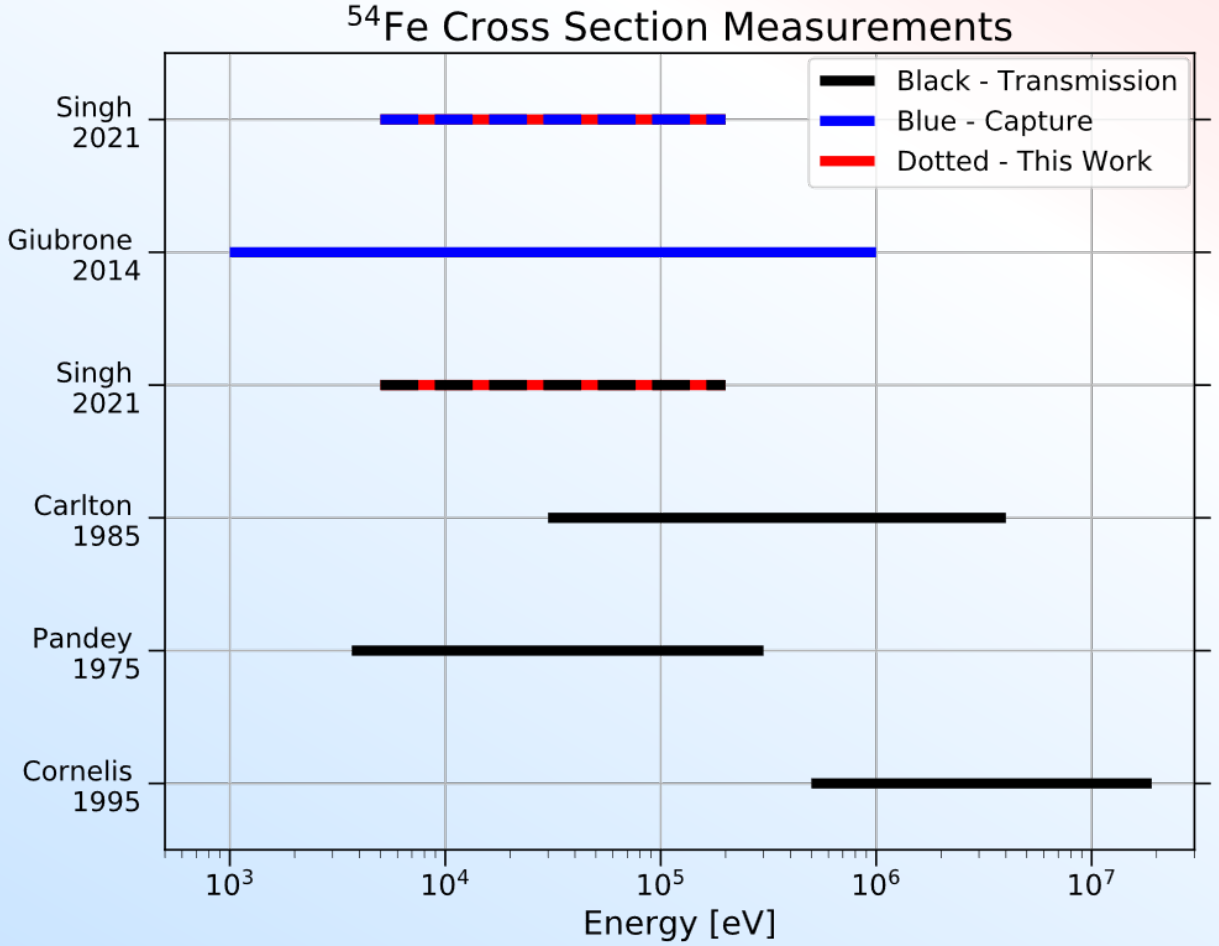






^{54}Fe RRR Evaluation

- New RRR evaluation using EXFOR and RPI data will be completed at RPI.
- Resonance parameters being fit using SAMMY R-Matrix code.
  - Evaluation will make use of experimental data covariances where they are available (i.e. RPI capture + transmission data)
- Preservation of total Fe cross section will be verified.
- Validation testing will be done on shielding benchmarks in SINBAD and ICSBEP critical benchmarks.



Pb isotopes evaluation

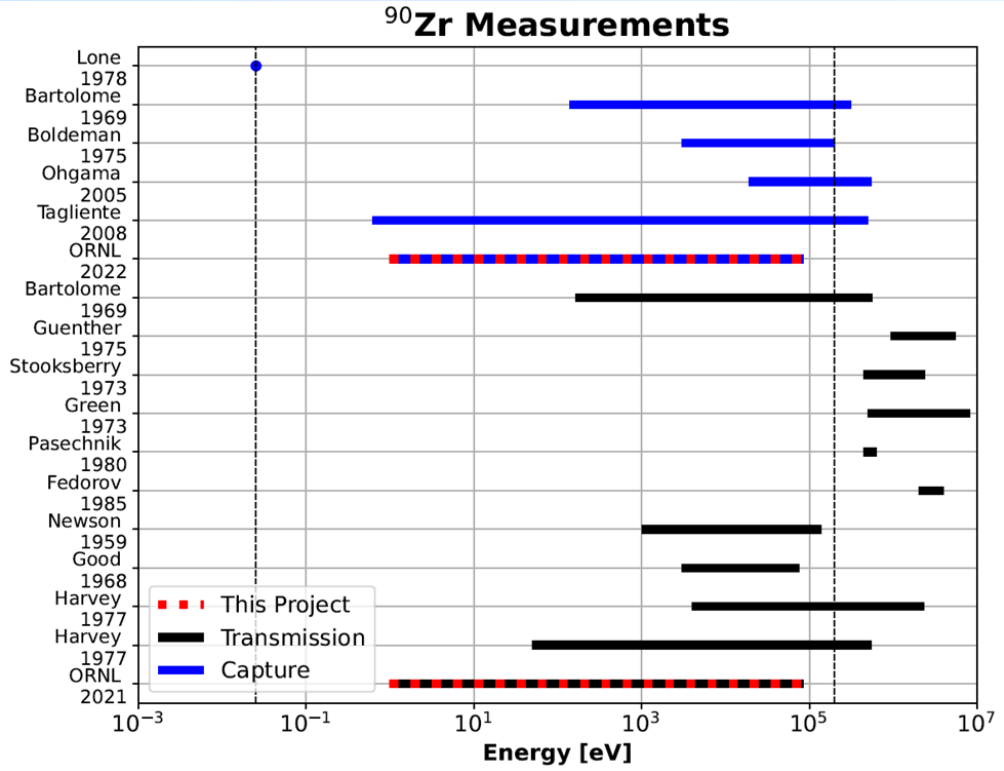
Pb isotopes evaluation

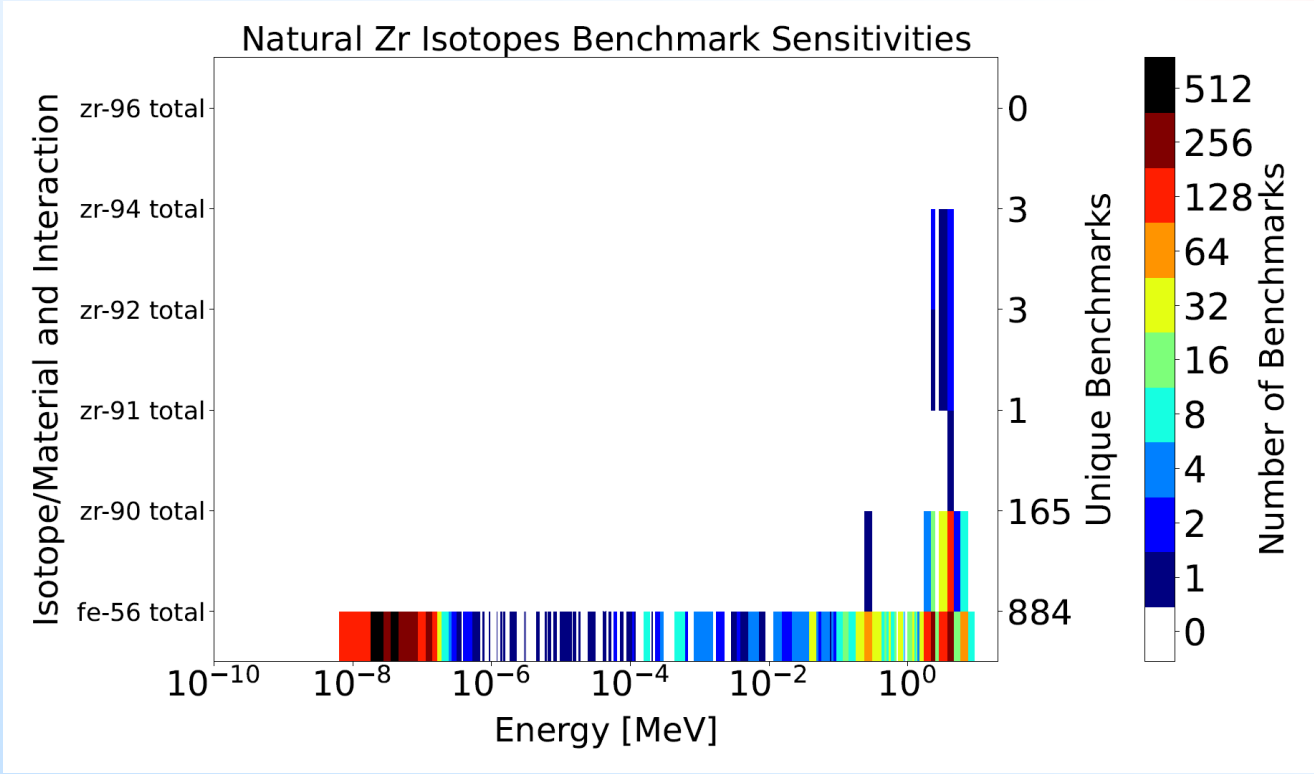
- Discussed in INDEN 2022
- Submitted to ENDF/B-8.1β3
- Summary:
  - Pb-208
    - Full RRR by RPI + MF-3 below 2.5 MeV (+ESAD)
    - Fast region by T. Kawano (LANL)
    - Covariance by RPI
  - Pb-207
    - Full RRR and Fast region by RPI
    - MF-4,MT-2 from ENDF/B-8 (<1.5 MeV)
    - Covariance by RPI
  - Pb-206
    - Full RRR and Fast region by RPI
    - MF-4, MT-2 from BROND-3.1 (< 3 MeV)
    - Covariance by RPI

^{90}Zr RRR Evaluation

Zr isotopes evaluation

- Zirconium is used in nearly all commercial light despite lacking nuclear data compared to other structural materials
- New NCSP/ORNL measurements at JRC-Geel leveraged in new evaluation efforts

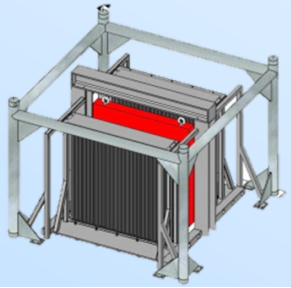


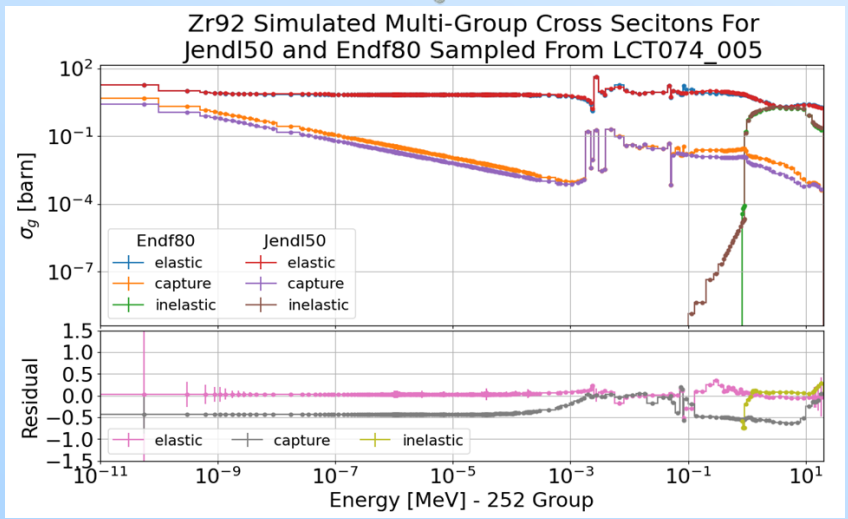


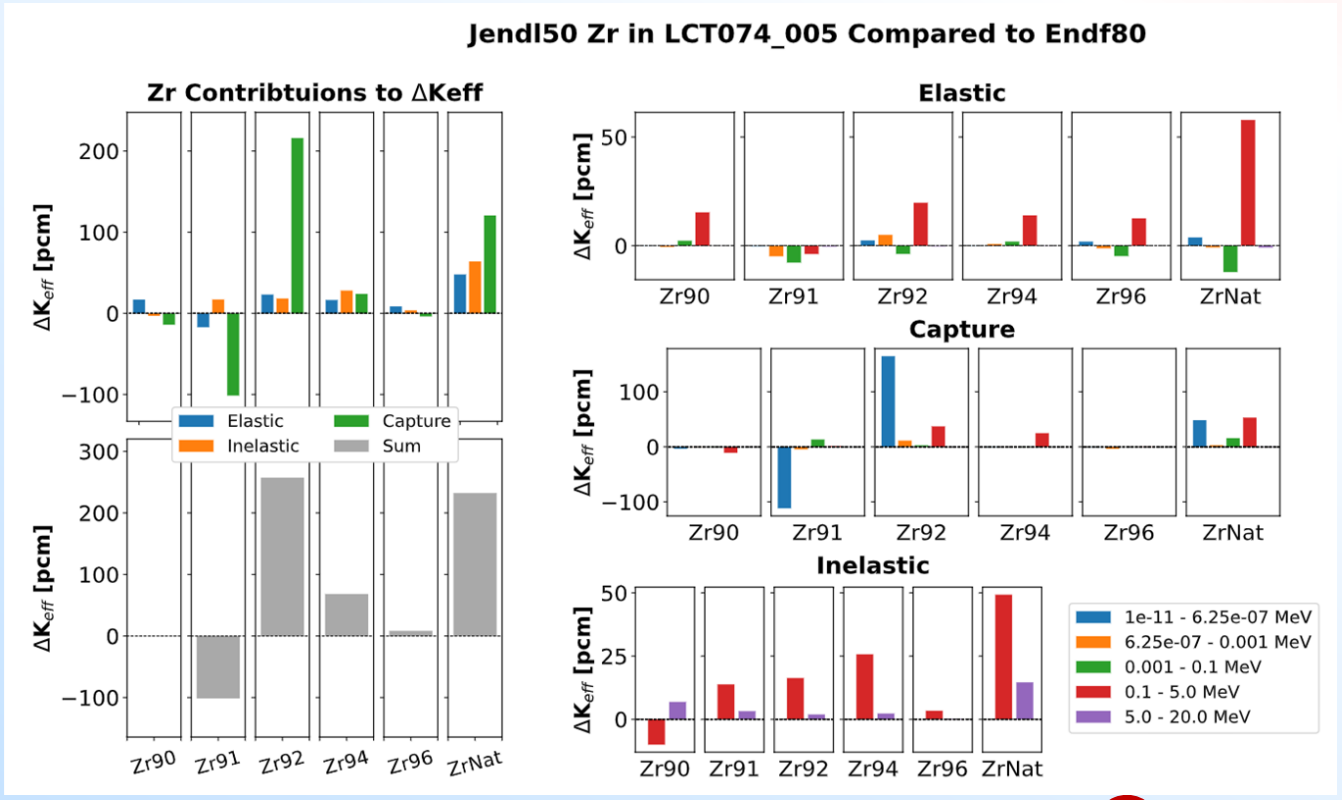
note that Bartolome data is only available as raw data

Pre-evaluation tool development

- Pre-evaluation tool developed to propagate and visualize impacts of differing nuclear data on critical benchmarks (using MCNP6)
- Results shown below are difference are due to change only in cross sections.
- Elastic scattering angular distributions observed to contribute 50-75% of difference in calculated system eigenvalue

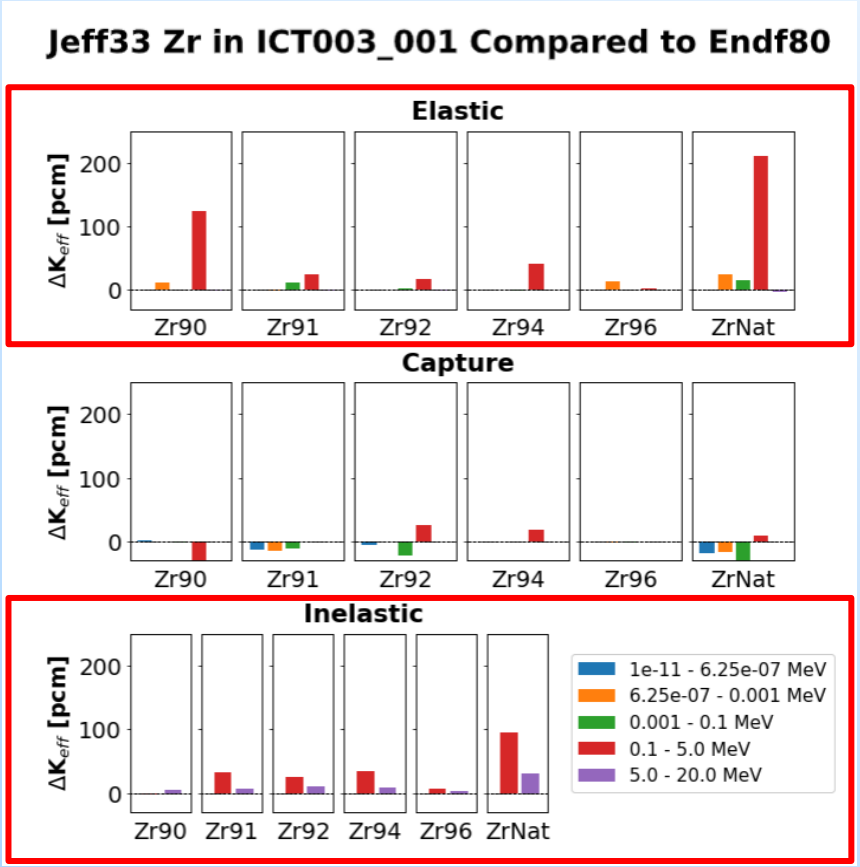


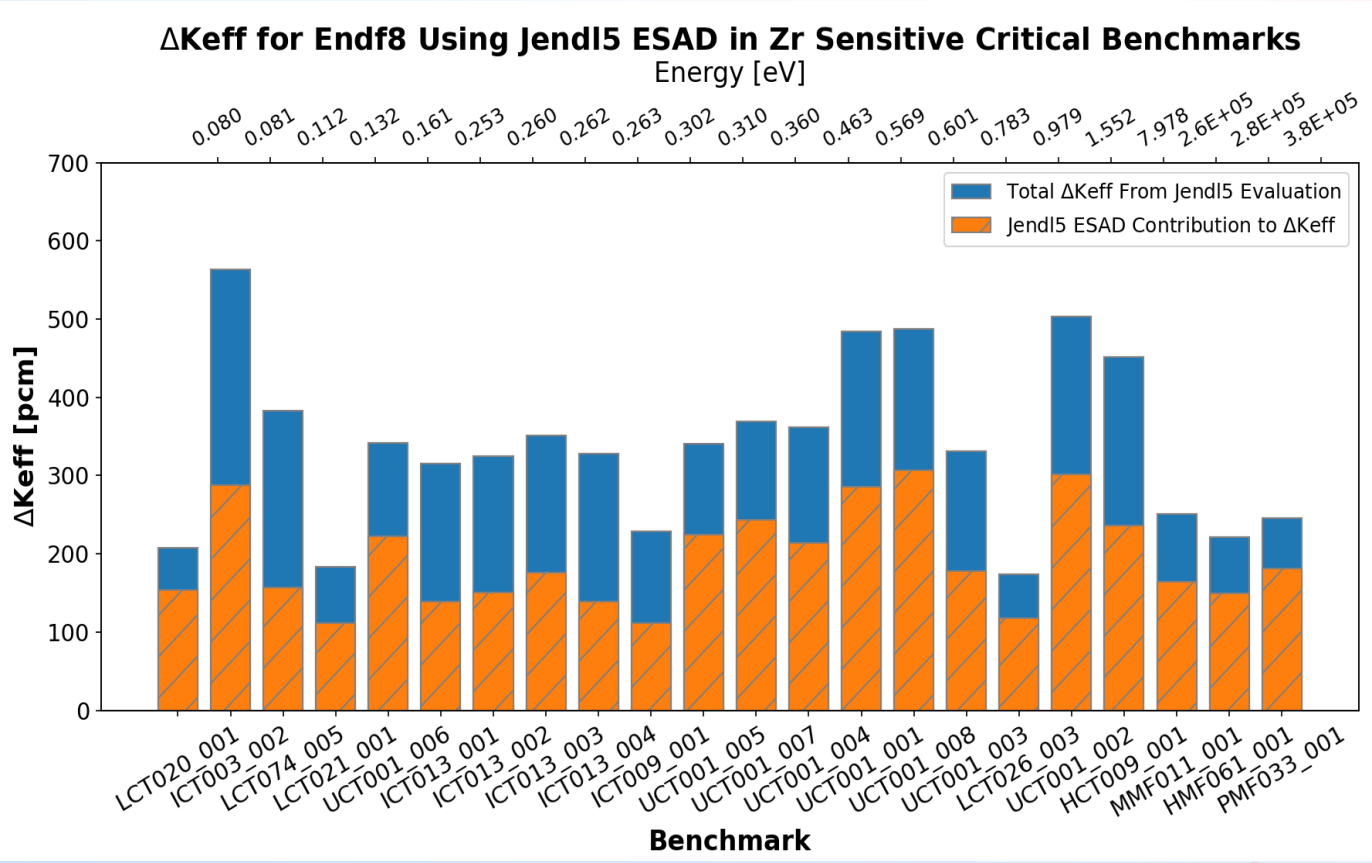




System eigenvalue differences observed from Zr

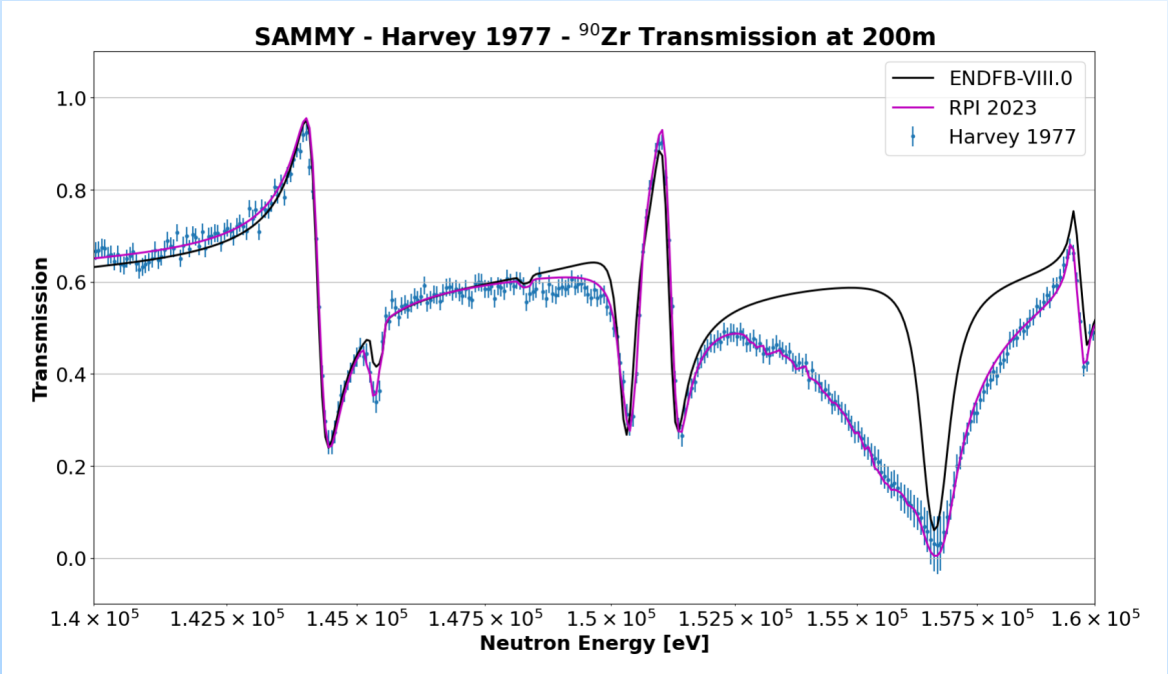
- Left ΔK_{eff} from differences in cross sections.
- Right ΔK_{eff} ENDF-8.0 vs JENDL-5 (blue). Angular distribution swapping JENL-5 ESAD to ENDF-8.0 (Orange)

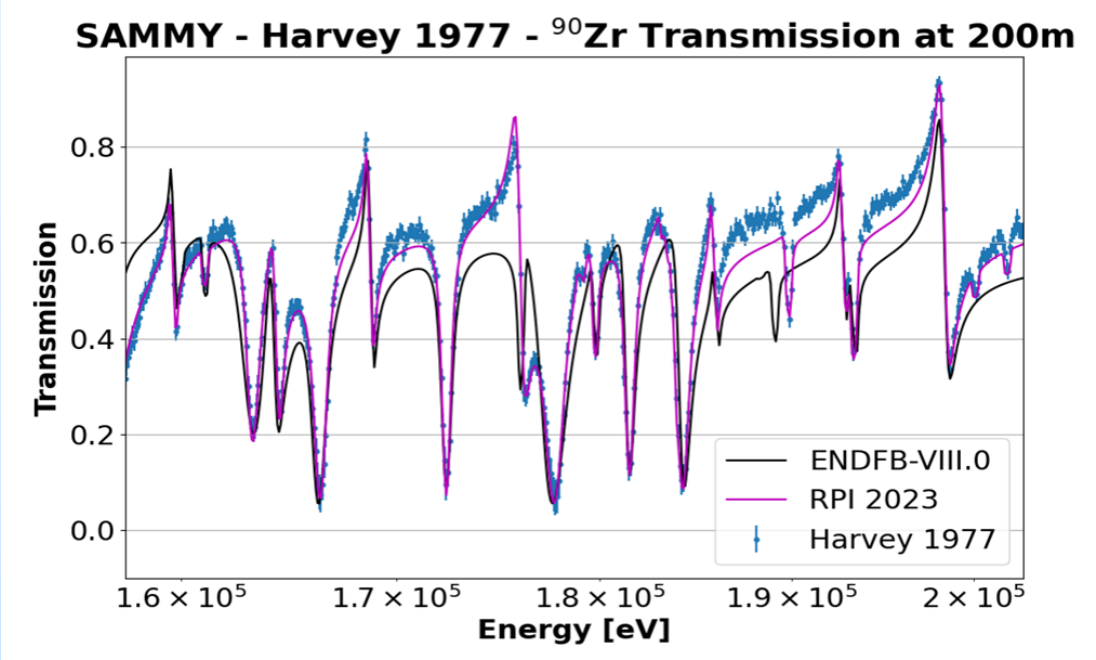




^{90}Zr RRR Evaluation Progress

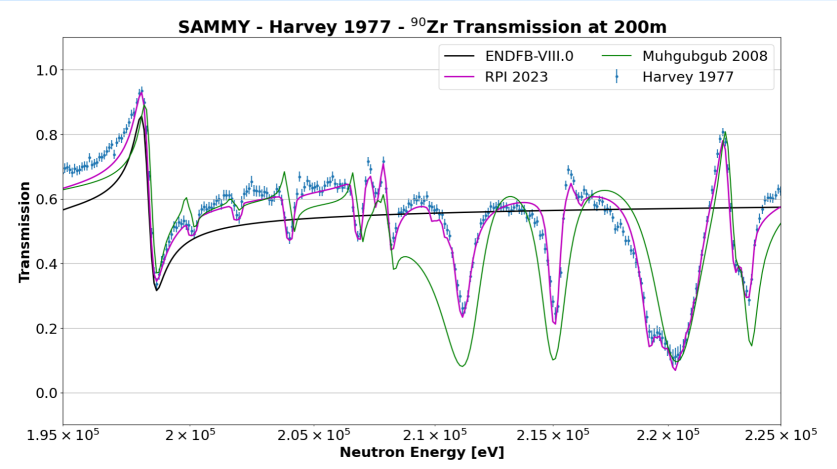
- *Final* resonance parameters determined below 150 keV
  - **Spin dependent average Γγ used above 100 keV**
  - **Biggest improvements are above 100 keV**
- Work remaining on thermal capture cross section and external/bound levels
  - **Finalizing parameters to 500 keV**

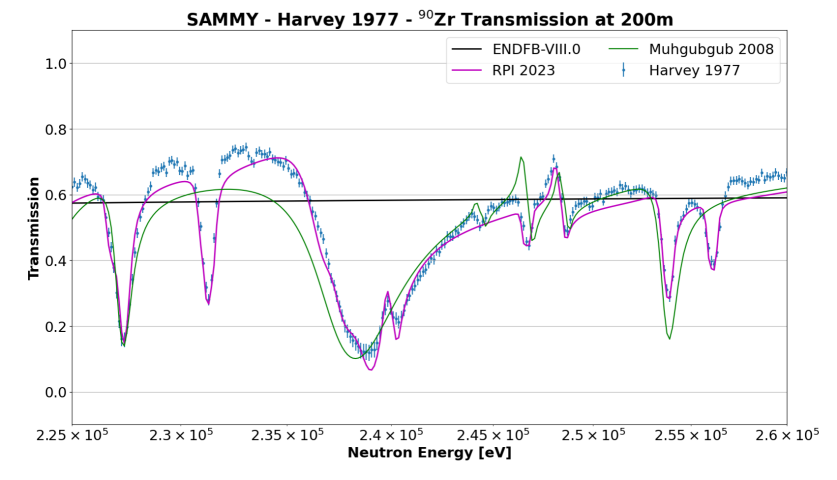


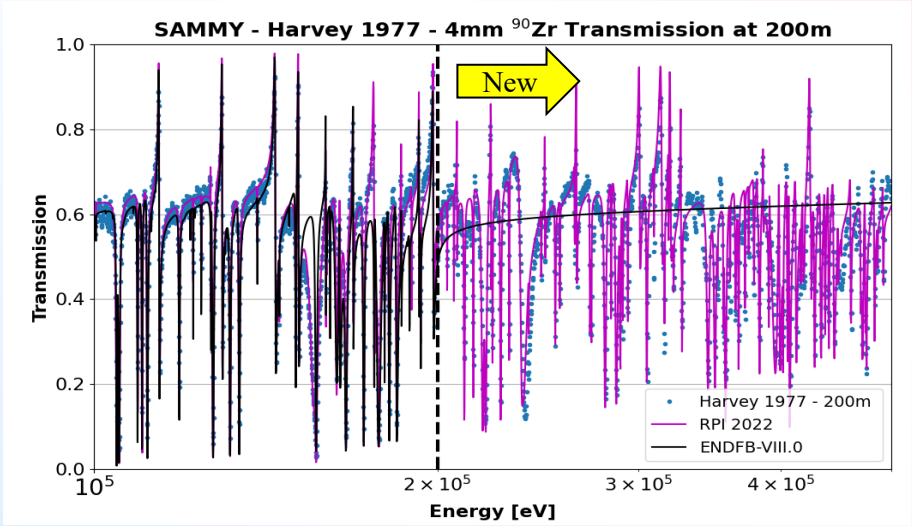


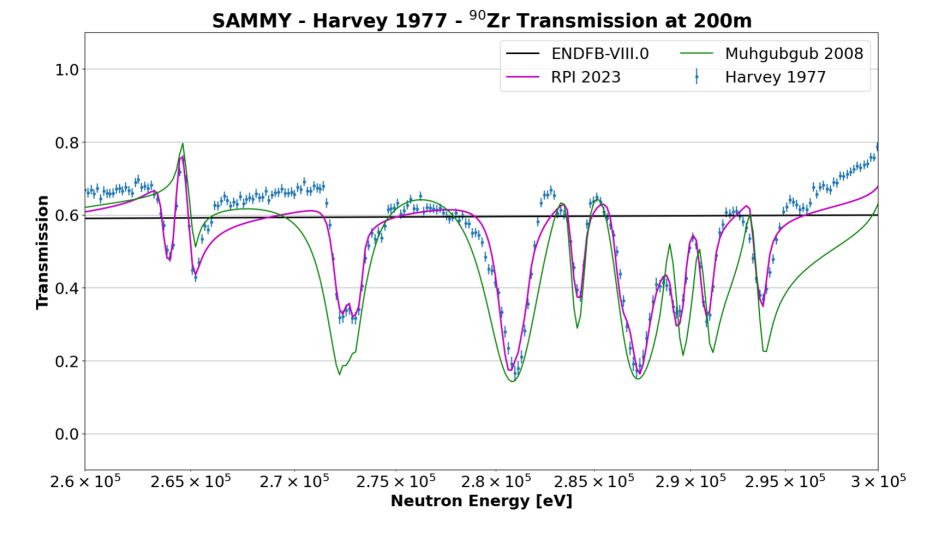
^{90}Zr RRR Evaluation Progress

- **Big improvements made to 300 keV over previous version of RPI evaluation – fitting is ongoing**









S.F. Mughabghab is parameters from the Atlas – Not in ENDF/B evaluations

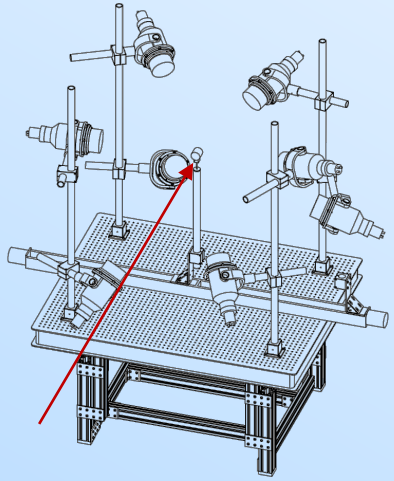
High Energy Quasi-Differential Neutron Emission Measurements form ^{181}Ta and ^{19}F

More details in CSEWG 2022 talk

Quasi-Differential Measurement Methodology

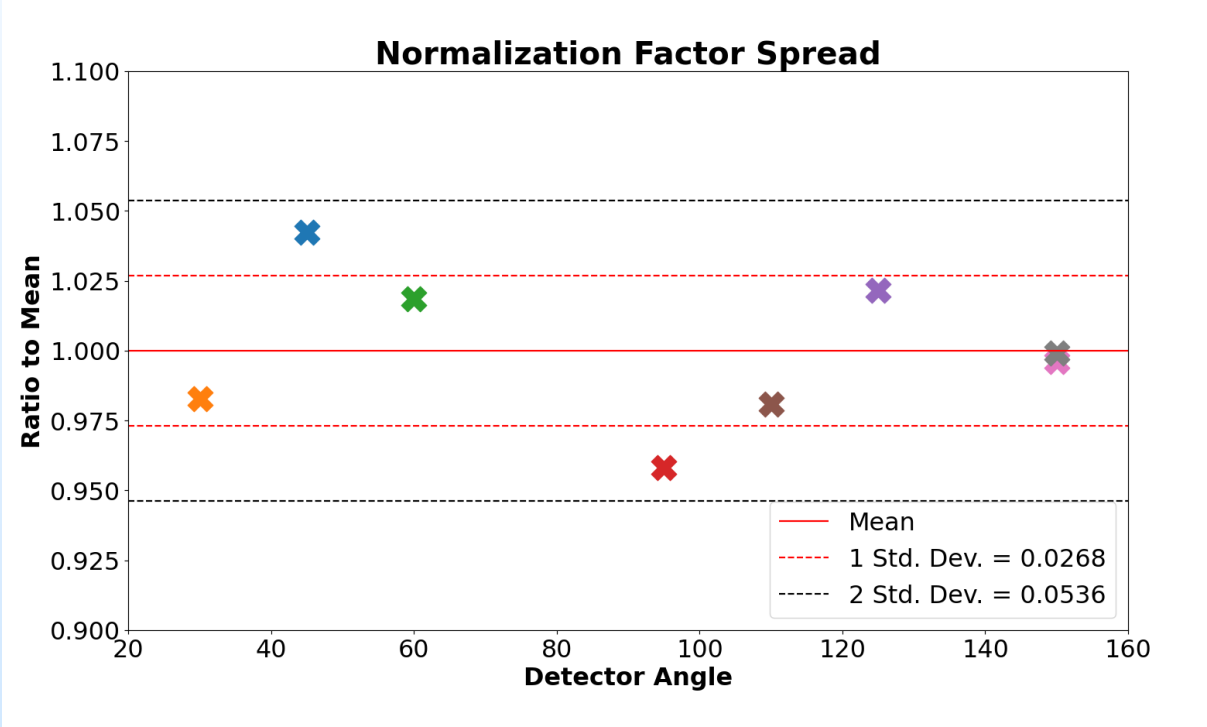
1. Conduct differential neutron time-of-flight experiment on sample of interest, validation sample, and open beam
   - Due to sample size, the experiment is dominated by multiple scattering interactions
2. Perform MCNP transport calculation of validation (Carbon) measurement using measured neutron flux and detector efficiencies
   - This validates experimental geometry and reproduction of known validations sample
3. Perform MCNP transport calculation of sample of interest measurement using measured neutron flux and detector efficiencies
   - Differences present in nuclear data evaluations of the sample of interest are compared to the experimental data to validate performance or show needs for improvement

Measured Ta-181 and TEFLON $(C_2F_4)_n$ with the objective of getting data on F.



Preliminary Experimental Uncertainty Quantification

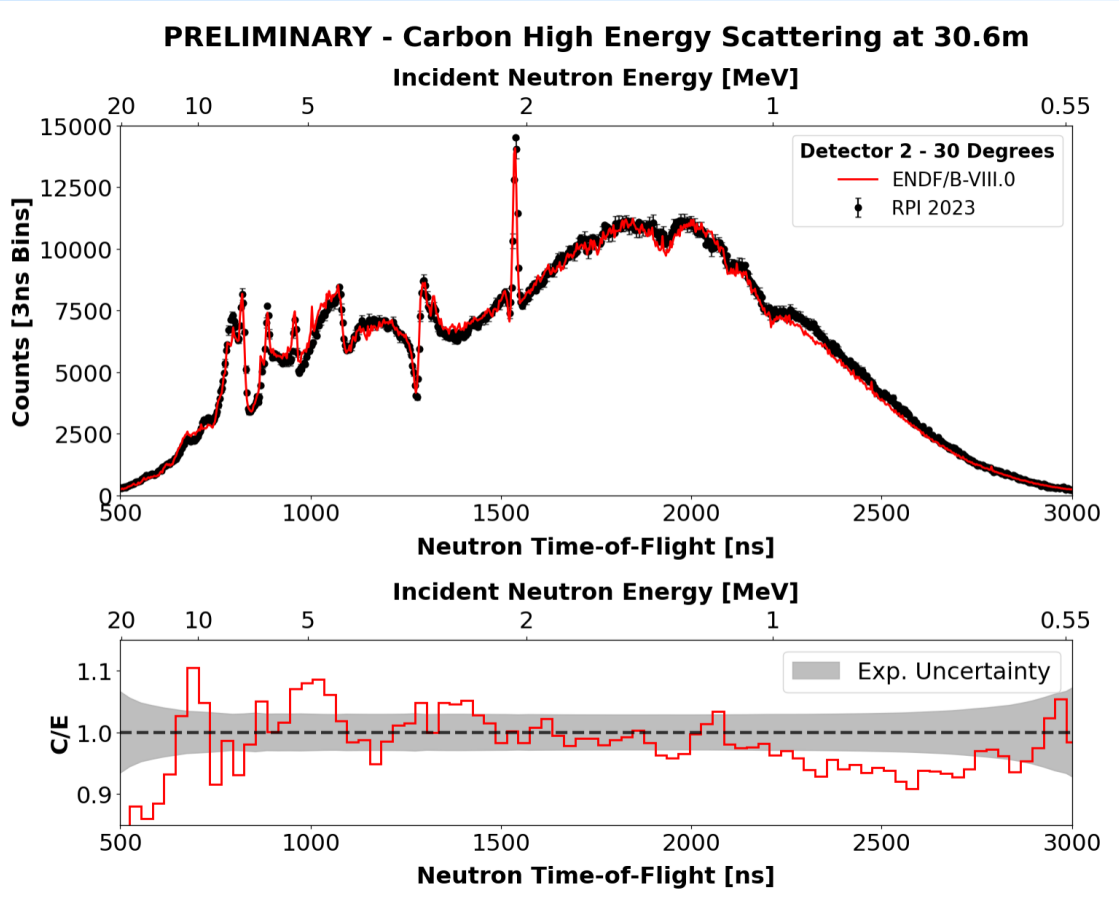
- Preliminary analysis suggests approximate systematic uncertainty has been reduced to approximately 2.5% – 3.5%
- Previous measurements in references1,2 arrived at systematic uncertainty of 6%
- Detector efficiencies determined from in-beam measurements
- Digitizer deadtime and PSD techniques used for deadtime correction

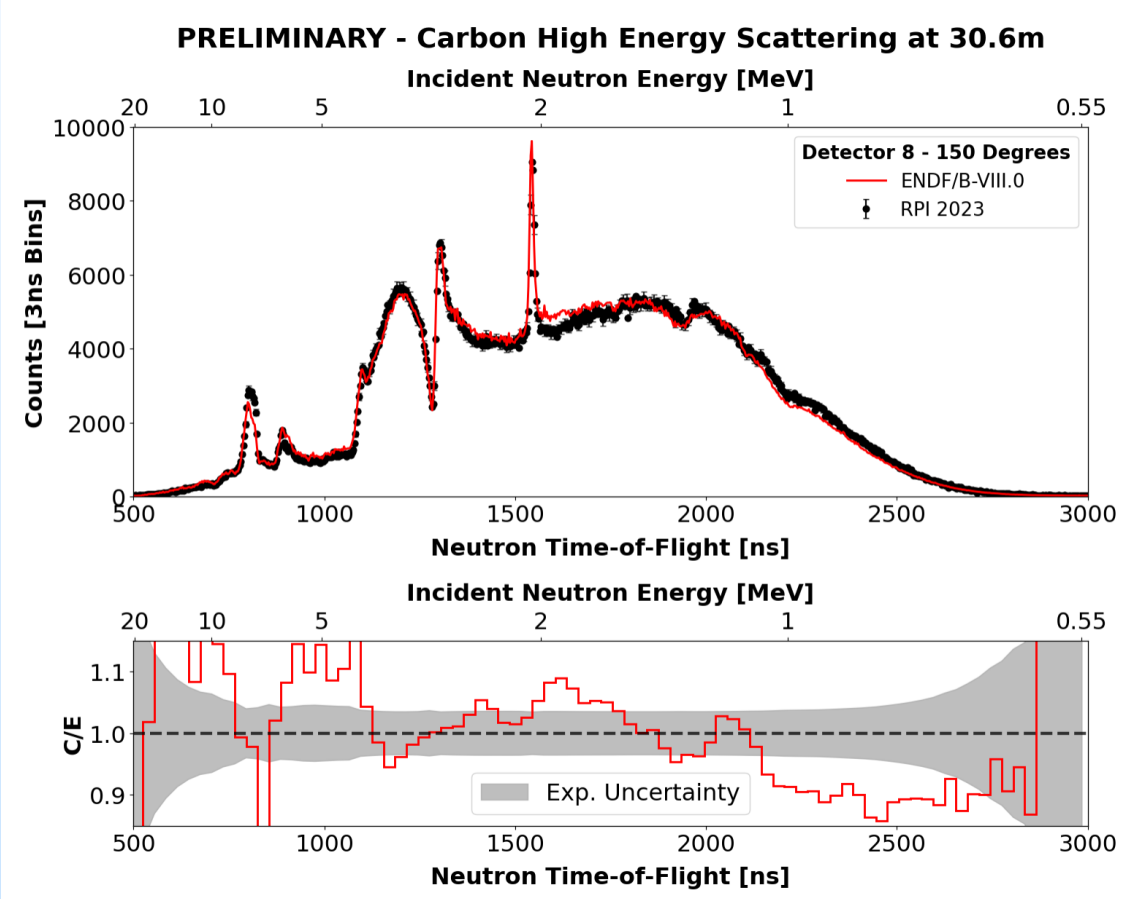


1. E. Blain, Y. Danon, D. P. Barry, B. E. Epping, A. Youmans, M. J. Rapp, A. M. Daskalakis and R. C. Block, "Measurements of Neutron Scattering from a Copper Sample Using a Quasi-Differential Method in the Region from 2 keV to 20 MeV", *Nuclear Science and Engineering*, vol. 196, no. 2, pp. 121-132, 2022, DOI:10.1080/00295639.2021.1961542
2. A. M. Daskalakis, E. J. Blain, B. J. McDermott, R. M. Bahran, Y. Danon, D. P. Barry, R. C. Block, M. J. Rapp, B. E. Epping and G. Leinweber, "Quasi-differential elastic and inelastic neutron scattering from iron in the MeV energy range", *Annals of Nuclear Energy*, vol. 110, pp. 603 - 612, 2017, DOI:10.1016/j.anucene.2017.07.007

Carbon Reference

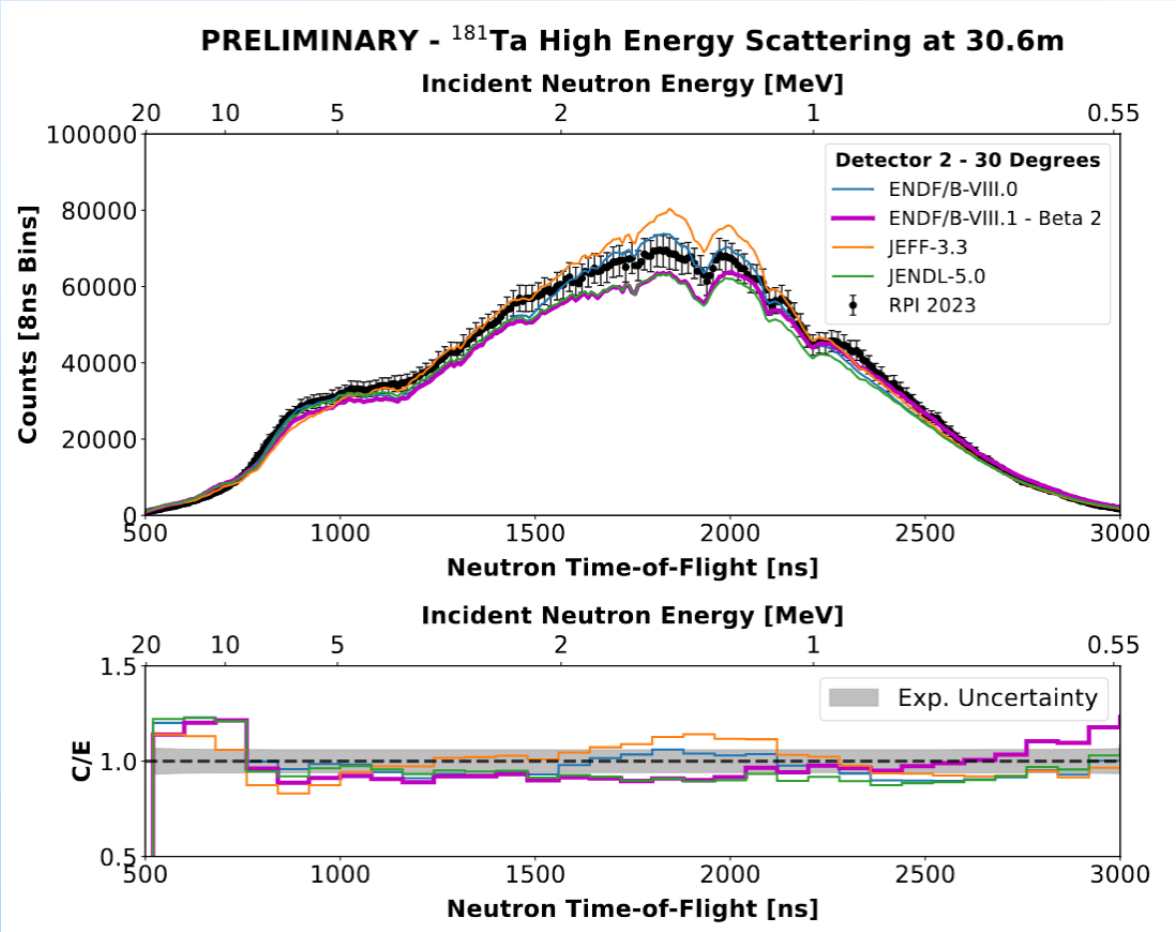
Carbon validation measurement shows simulation near agreement within experimental (~3%) uncertainty observed for all detectors between 1 MeV and 5 MeV.

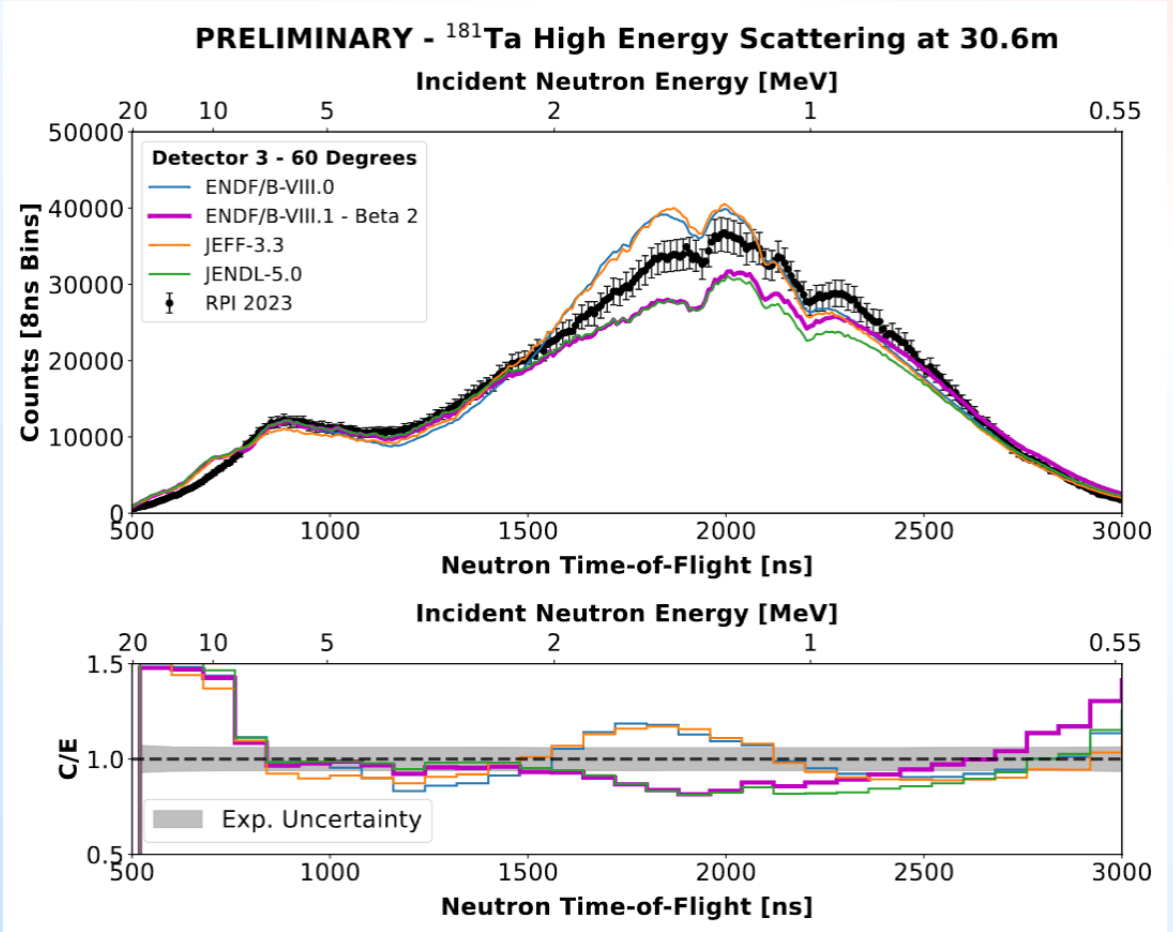




Ta – forward angles

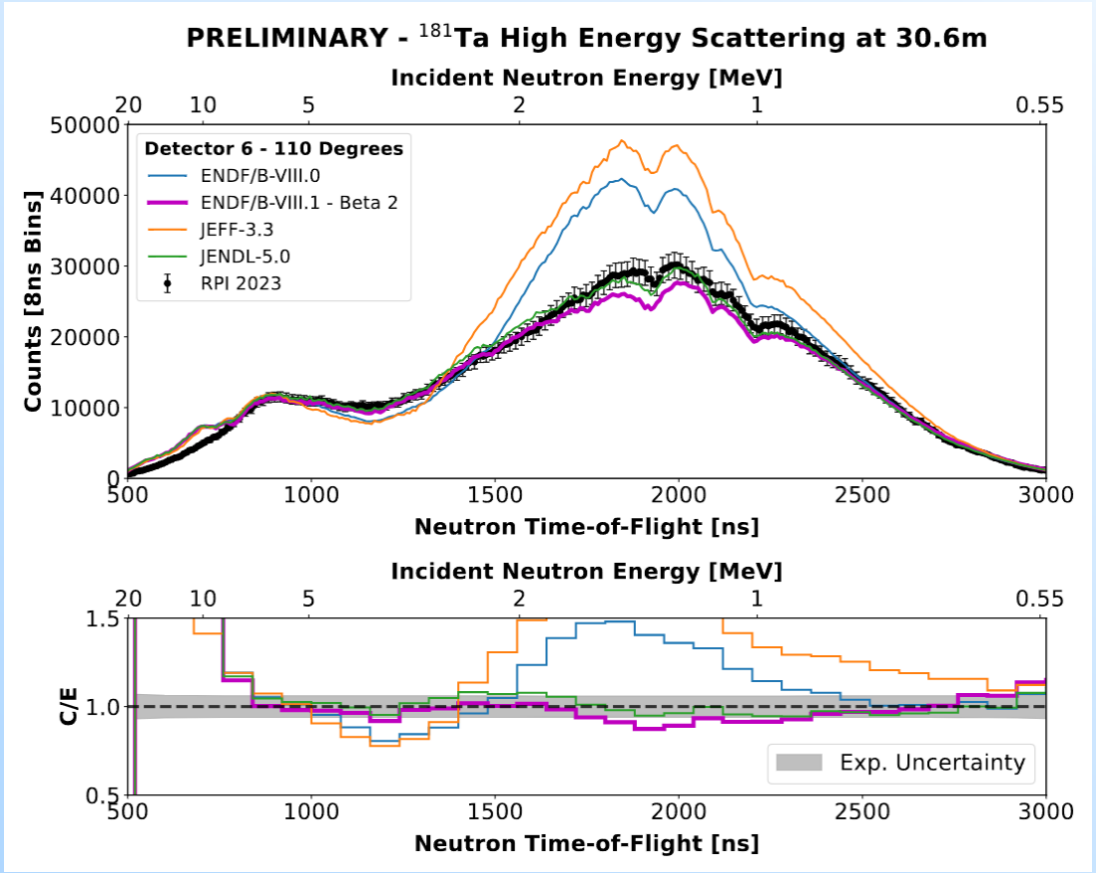
- ENDF/B-VIII.1β2 and JENDL-5.0 show good agreement to each other, but underpredict experimental data 0.75 MeV – 3 MeV at forward angles.

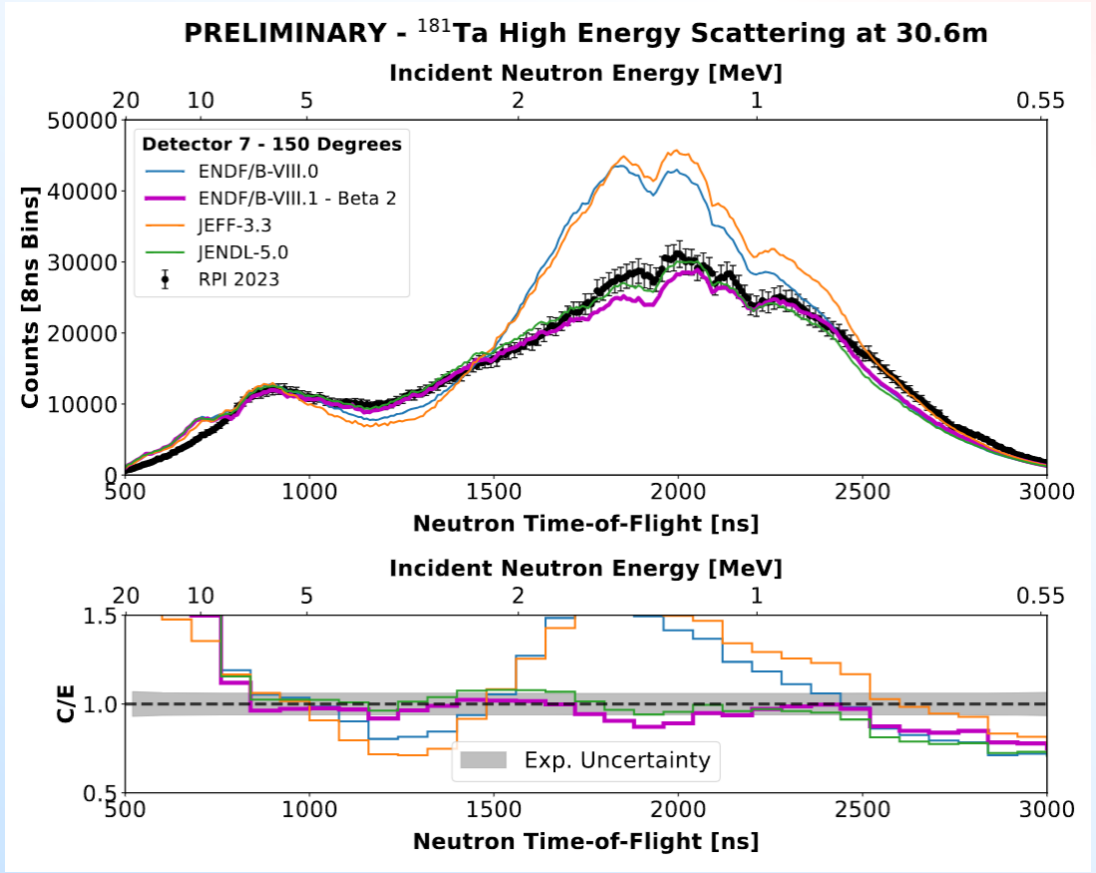




Ta back angles

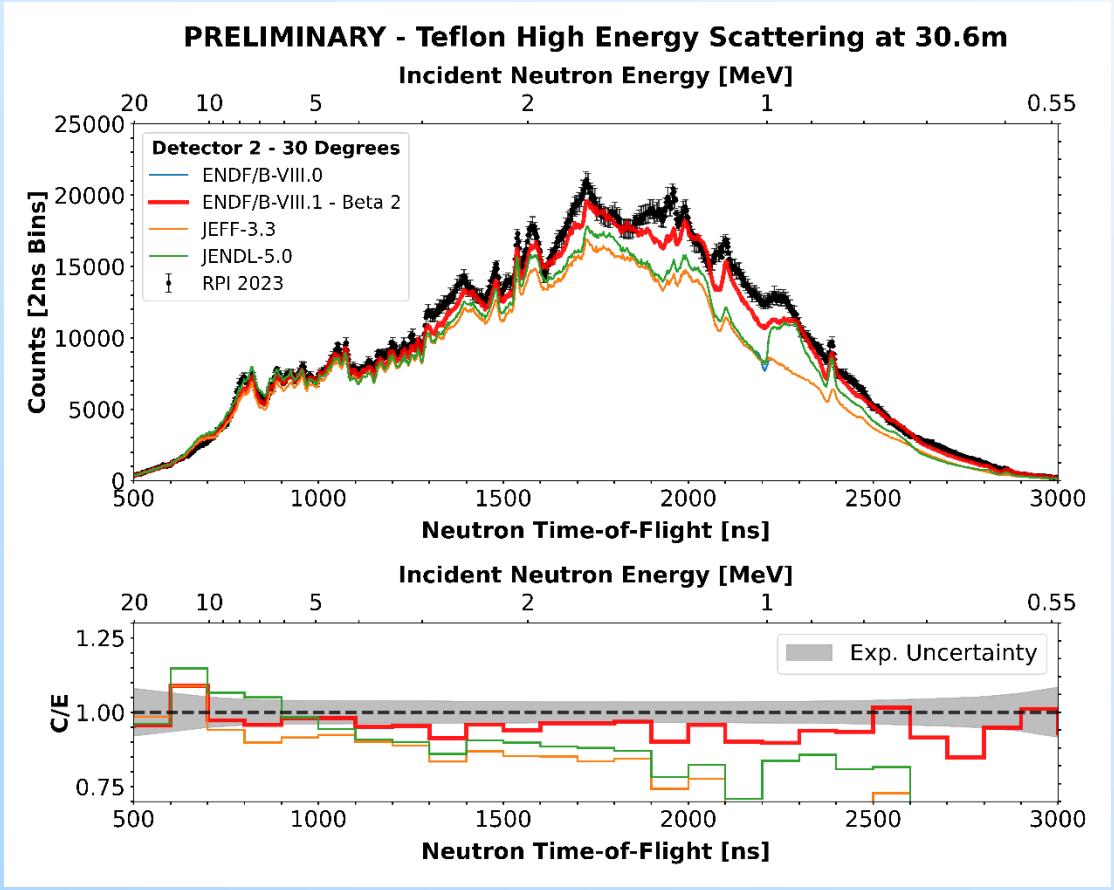
- ENDF/B-VIII.1β2 and JENDL-5.0 show good agreement to experimental data above 2 MeV at back angles. JENDL-5.0 shows best agreement below 2 MeV.

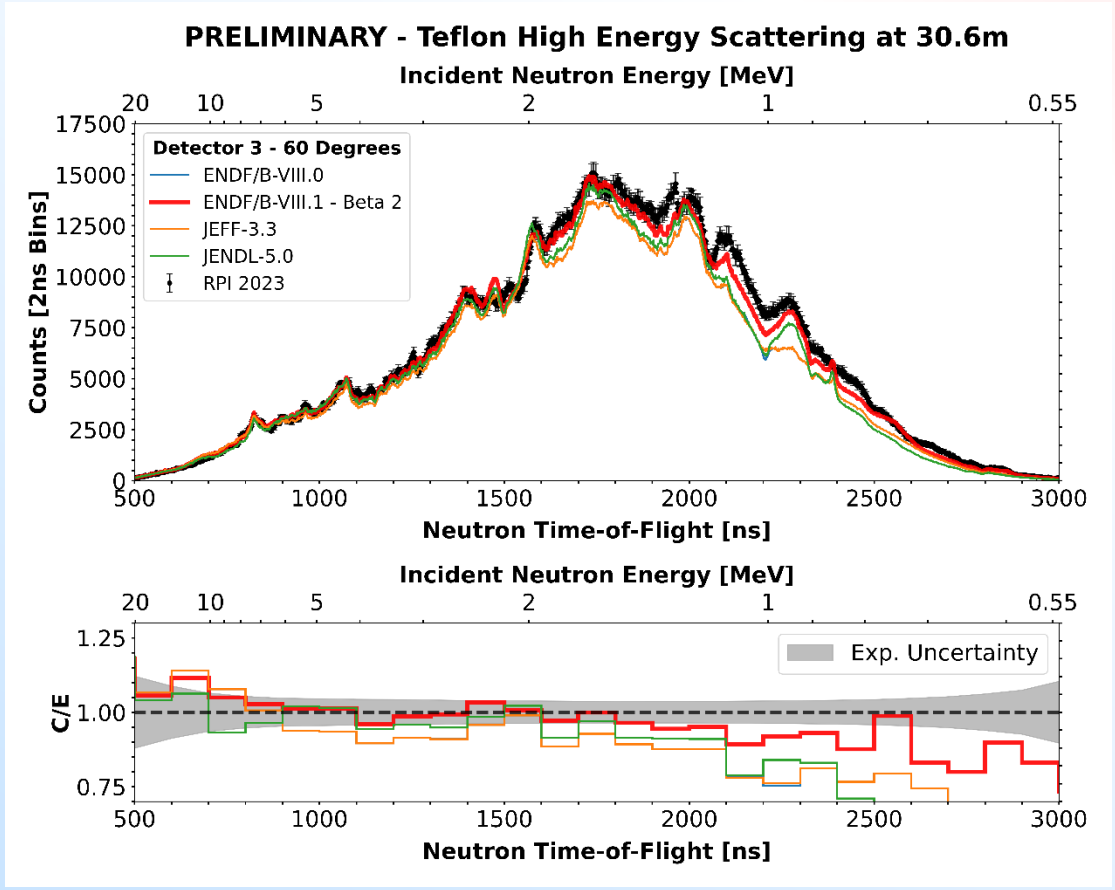




TEFLON forward angles

ENDF/B-VIII.1β2 and INDEN show good agreement to each other, and experimental data at forward angles. Issues observed in specific resonances.





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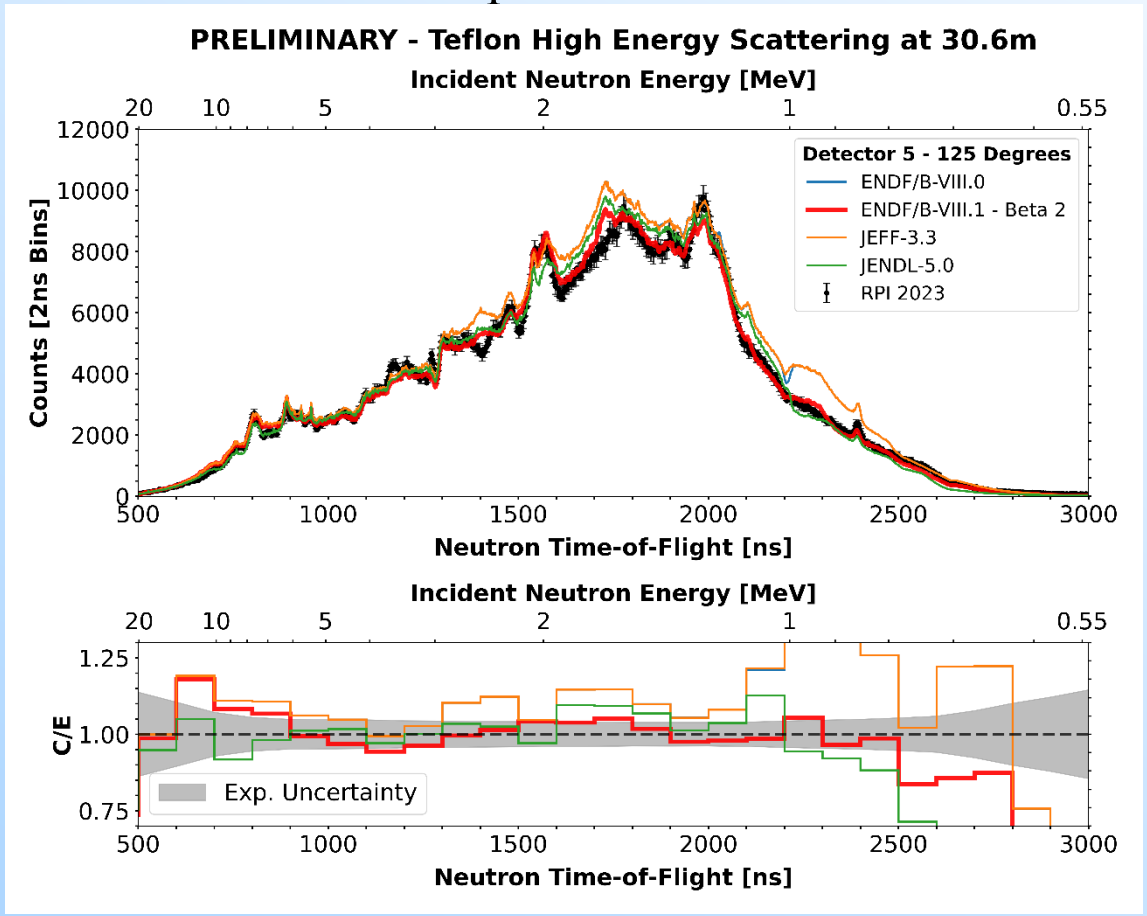

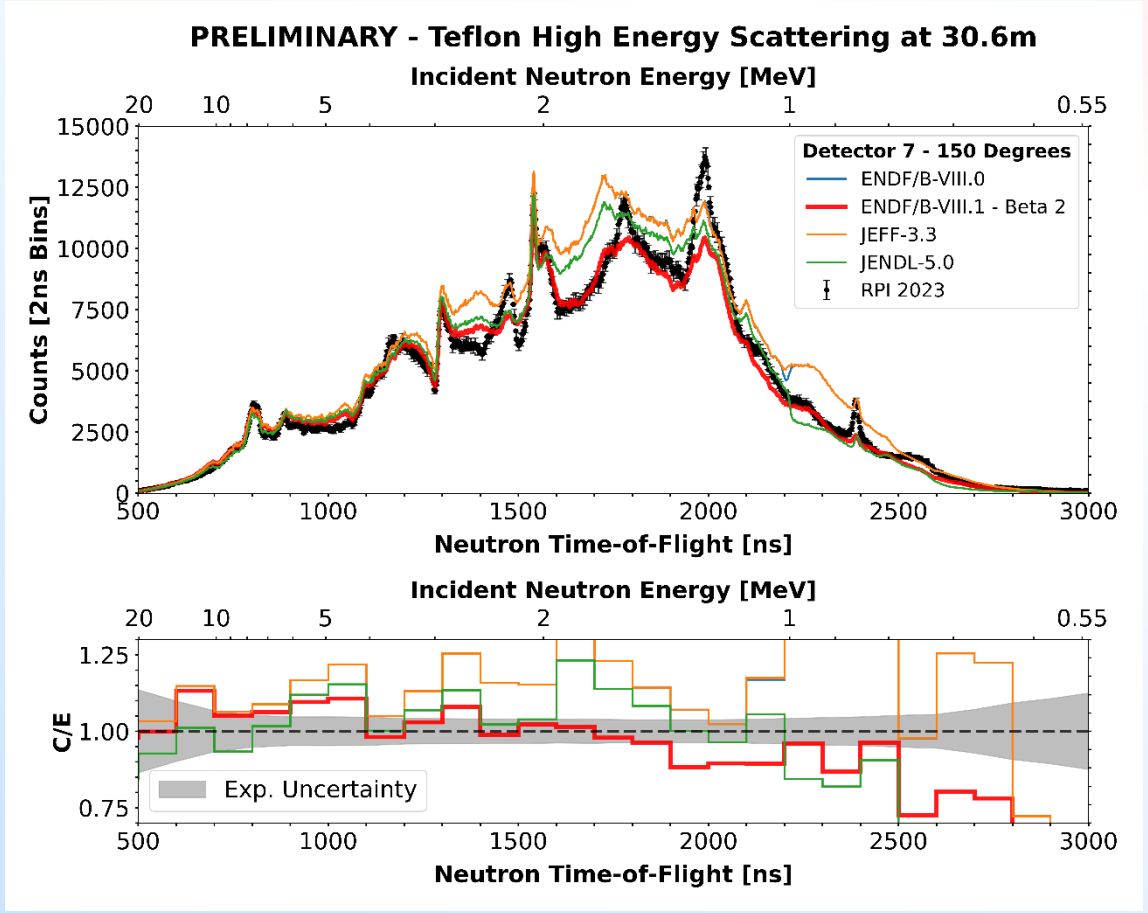

Summary

- RPI is working on several measurements and evaluations of structural materials

- Fe-54 measurements completed resonance evaluation is in progress.
  - New data capture and transmission data + previous data will result in new resonance parameters.

- ^{206,207,208}Pb evaluation completed and submitted to ENDF/B-VIII.1β2.
  - Improve criticality calculation of fast benchmarks.
- ^{90}Zr evaluation is progress
  - RRR being extended to 400 keV
  - Working on incorporating capture measurements.

- Ta and TEFLON quasi differential scattering
  - Completed both measurements
  - Ta - comparison with stimulation shows that ENDF/B-VIII.1β2 is a huge improvement over ENDF/B-VIII.0
  - F - comparison with simulation shows that ENDF/B-VIII.1β2 is an improvement but there is room for additional improvements that might require fitting resonances.