ENDF/B-VIII.1 Validation using Recent RPI Quasi-Differential Neutron Scattering Measurements

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November 4-8, 2024

CSEWG Annual Meeting, Brookhaven, NY, USA

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Introduction

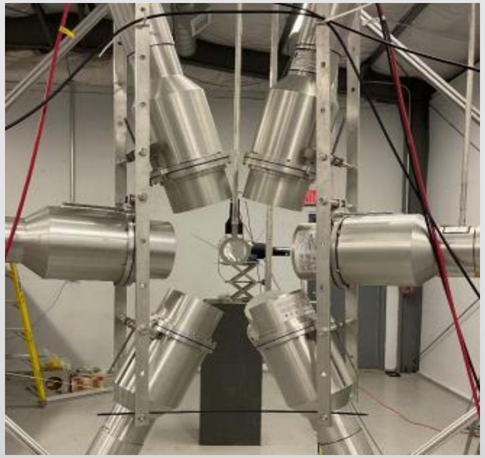
- Recent MeV and keV neutron scattering measurements performed at RPI were used to validate new evaluations in ENDF/B-VIII.1
  - Fast neutron scattering measurements of elemental Ta and Teflon (2023)
  - keV neutron scattering measurement of elemental copper (2019)[1]
- ENDF/B-VIII.1 ^{181}Ta, ^{19}F, ^{63,65}Cu evaluations improve agreement to the experimental neutron scattering data over ENDF/B-VIII.0

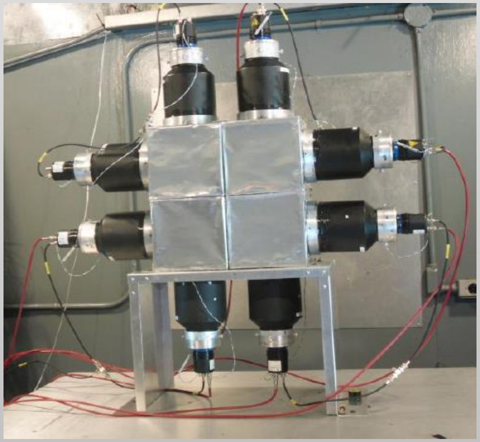
1. E. Blain et al, *Measurements of Neutron Scattering from a Copper Sample Using a Quasi-Differential Method in the Region from 2 keV to 20 MeV, Nuc. Sci. and Eng.*, **196**, 2,. 121-132 (2022)

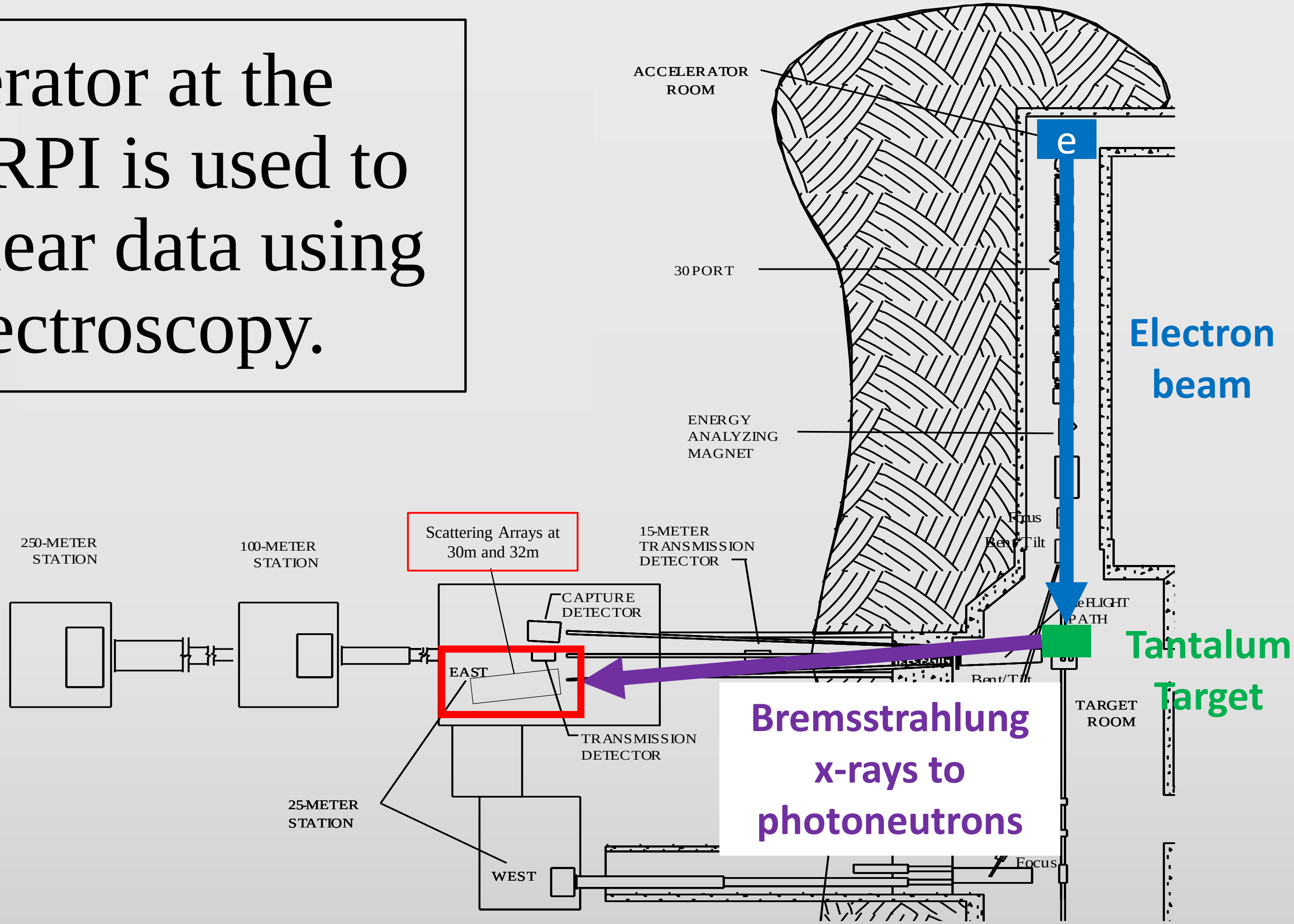
Quasi-Differential Measurement Methodology

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
   - Determine neutron flux and neutron detection efficiencies via modeling or experiment
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
   - Used to estimate the systematic uncertainty of the measurement
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

The electron linear accelerator at the Gaerttner LINAC center at RPI is used to produce high resolution nuclear data using neutron time-of-flight spectroscopy.

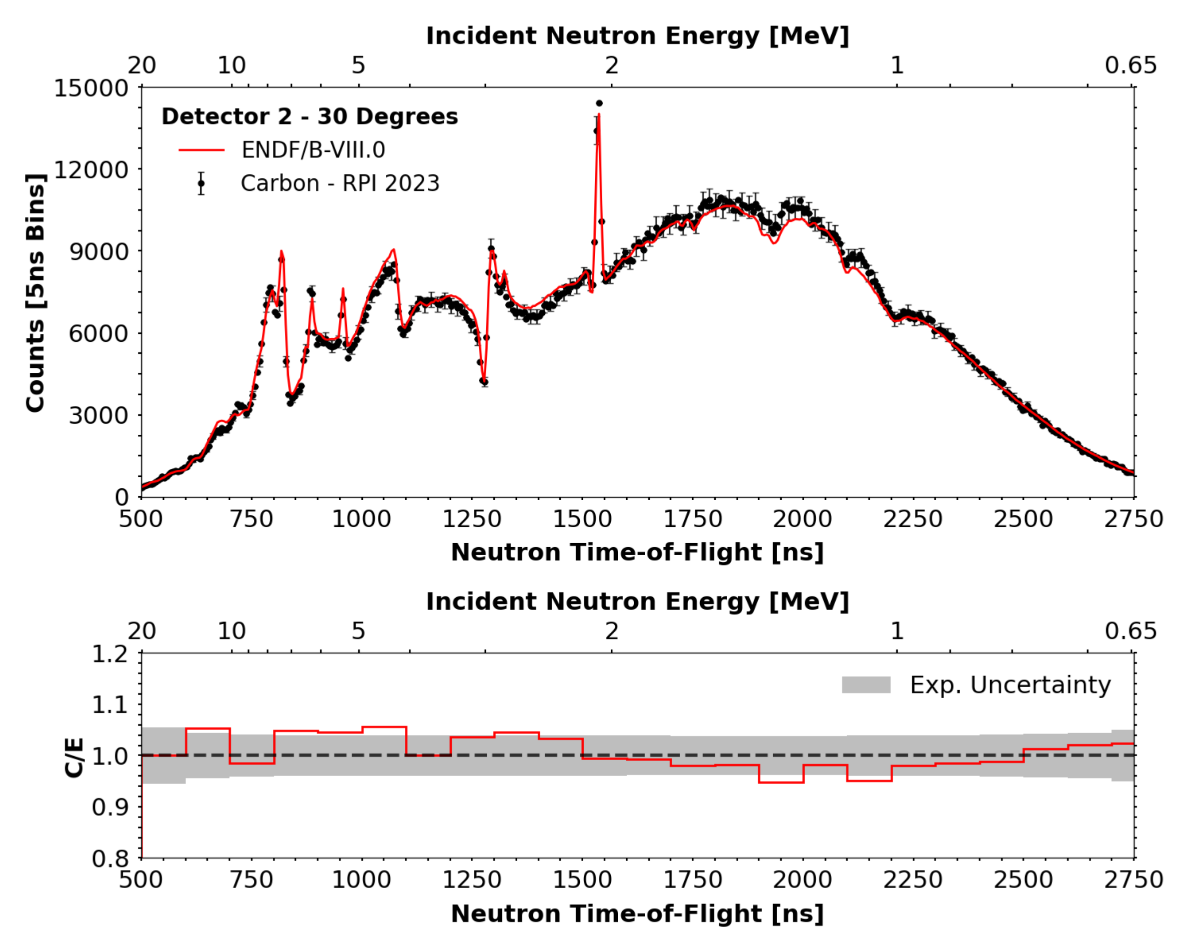




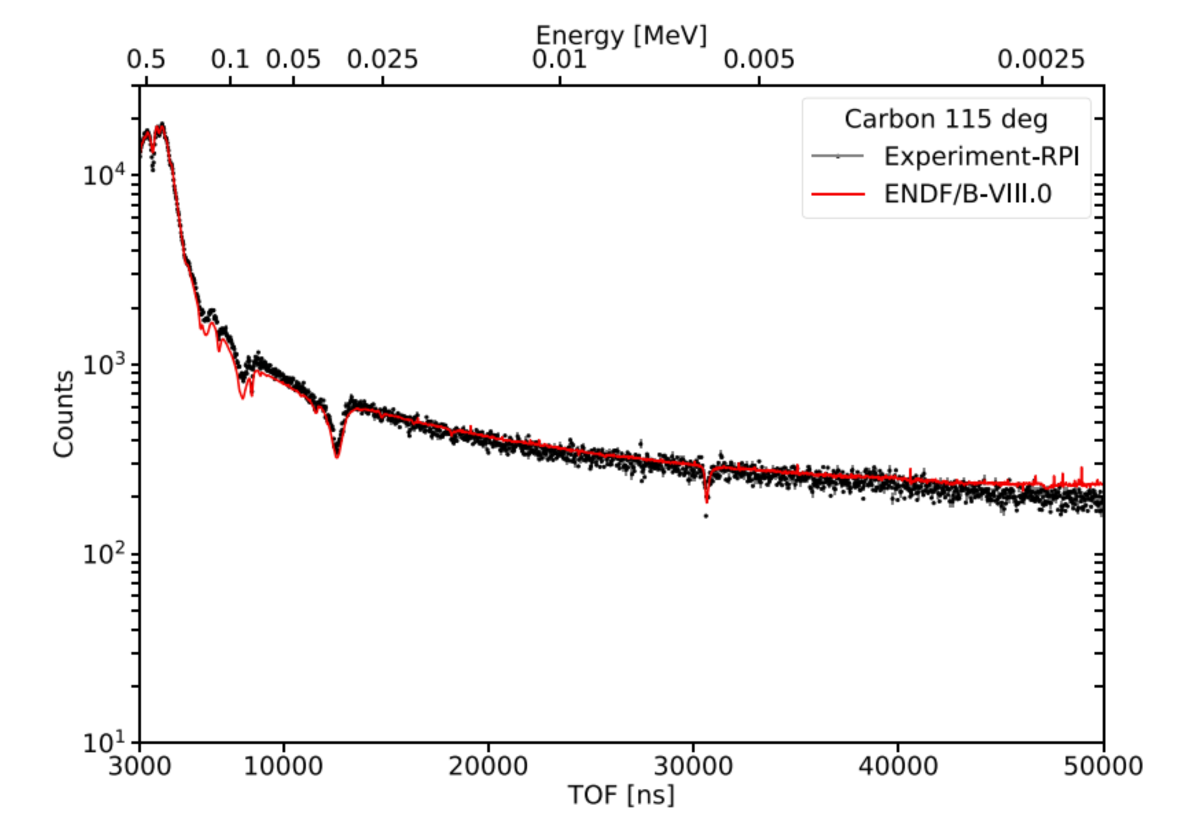


Validation Measurements of a Carbon Sample

MeV Carbon Neutron Scattering



keV Carbon Neutron Scattering



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Fast Neutron Scattering Measurements

Motivators for Fast Neutron Scattering Experiments

Tantalum

- Special material and nuclear properties of Ta allow for use in extreme environments such as:
    1. Neutron-producing targets for linear accelerators
    2. Recovering Uranium from machine turnings[1]
    3. Handling and casting of molten Plutonium metal[1,2]
        - Multiplication influenced significantly by neutron reflection from Ta

Teflon (^{19}Fluorine)

- Fluorine is relied on heavily in salts for Generation – IV reactor concepts:
    - Kairos Power – FHR
    - TerraPower – SFR and Natrium
    - Flibe LFTR (blanket and coolant)
- FLiBe salts also used in fusion reactor blankets for tritium breeding and neutron multiplication
- Fluorine can be present in both Uranium and Plutonium production processes[1,3]

[1]Chambers, A. (2024) - *Five Year Execution Plan – United States Department of Energy Nuclear Criticality Safety Program FY2025 though FY 2029* (https://ncsp.llnl.gov/sites/ncsp/files/2024-10/ncsp_five-year_execution_plan_fy2025-2029_-_r1.pdf)
[2]*DeGreazio, R.P. and Berry, J.W.. Recovery of Plutonium Metal From Tantalum Crucibles by Hydriding. United States: N. p., 1975* (https://doi.org/10.2172/4204600)
[3]*Kazanjian, A.R. and Stevens J.R. Dissolution of Plutonium oxide in Nitric Acid at High Hydrofluoric Acid Concentrations. United States: N.p., 1984* (https://doi.org/10.2172/7036488)

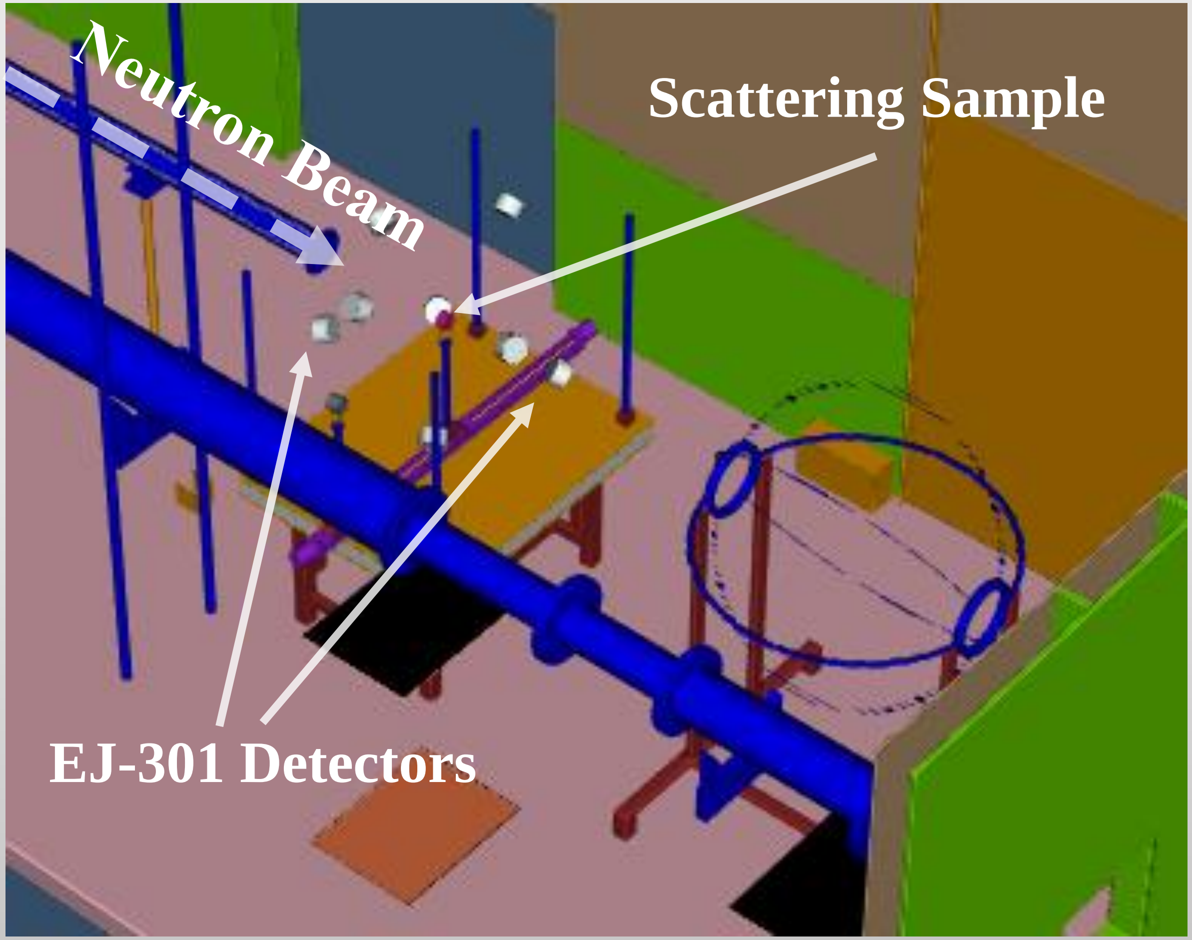
RPI Fast Neutron Scattering System

Neutron scattering array located ~30m from the neutron-producing target:

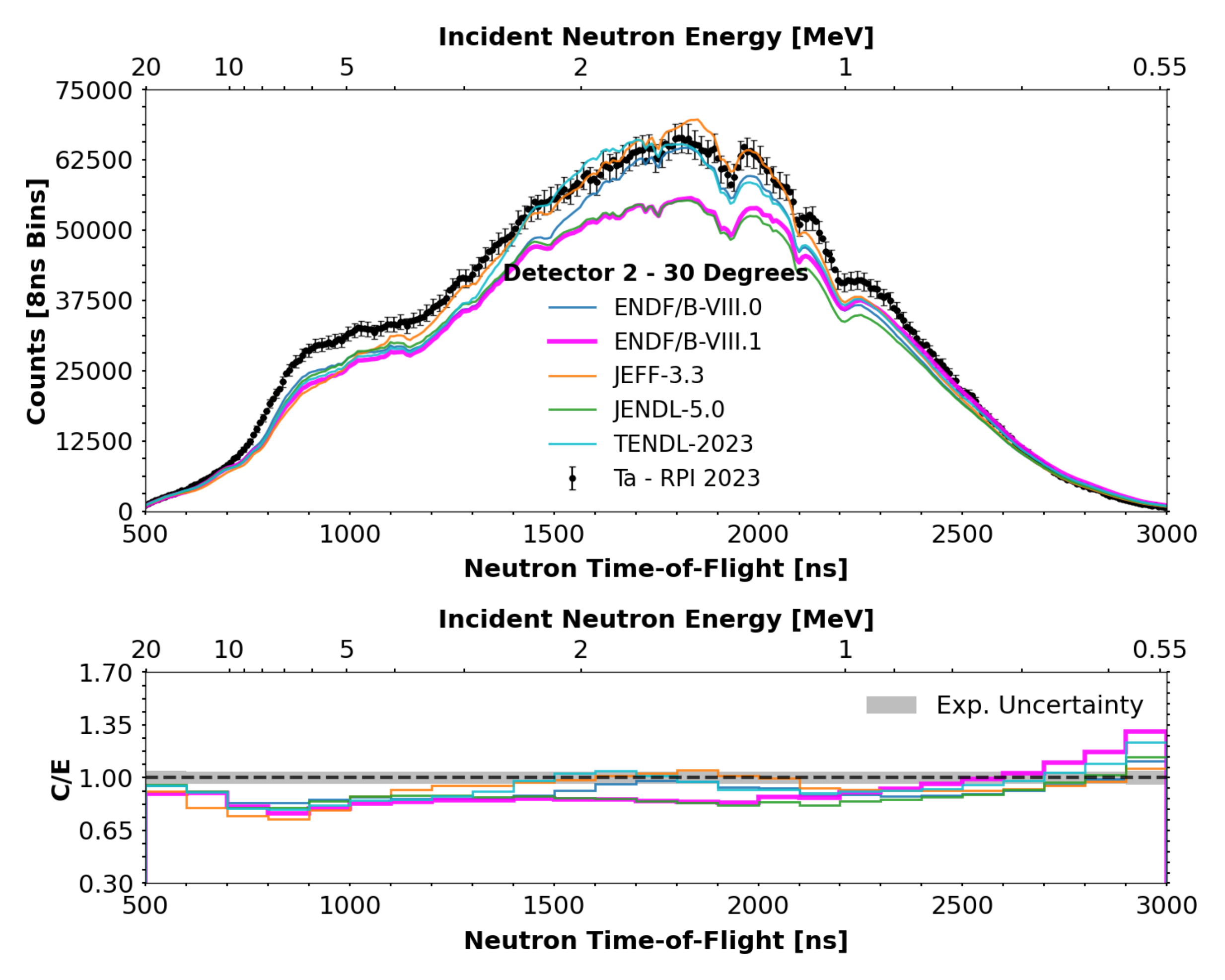
I. Eight 5in diameter x 3in depth EJ-301 organic liquid scintillator proton recoil detectors

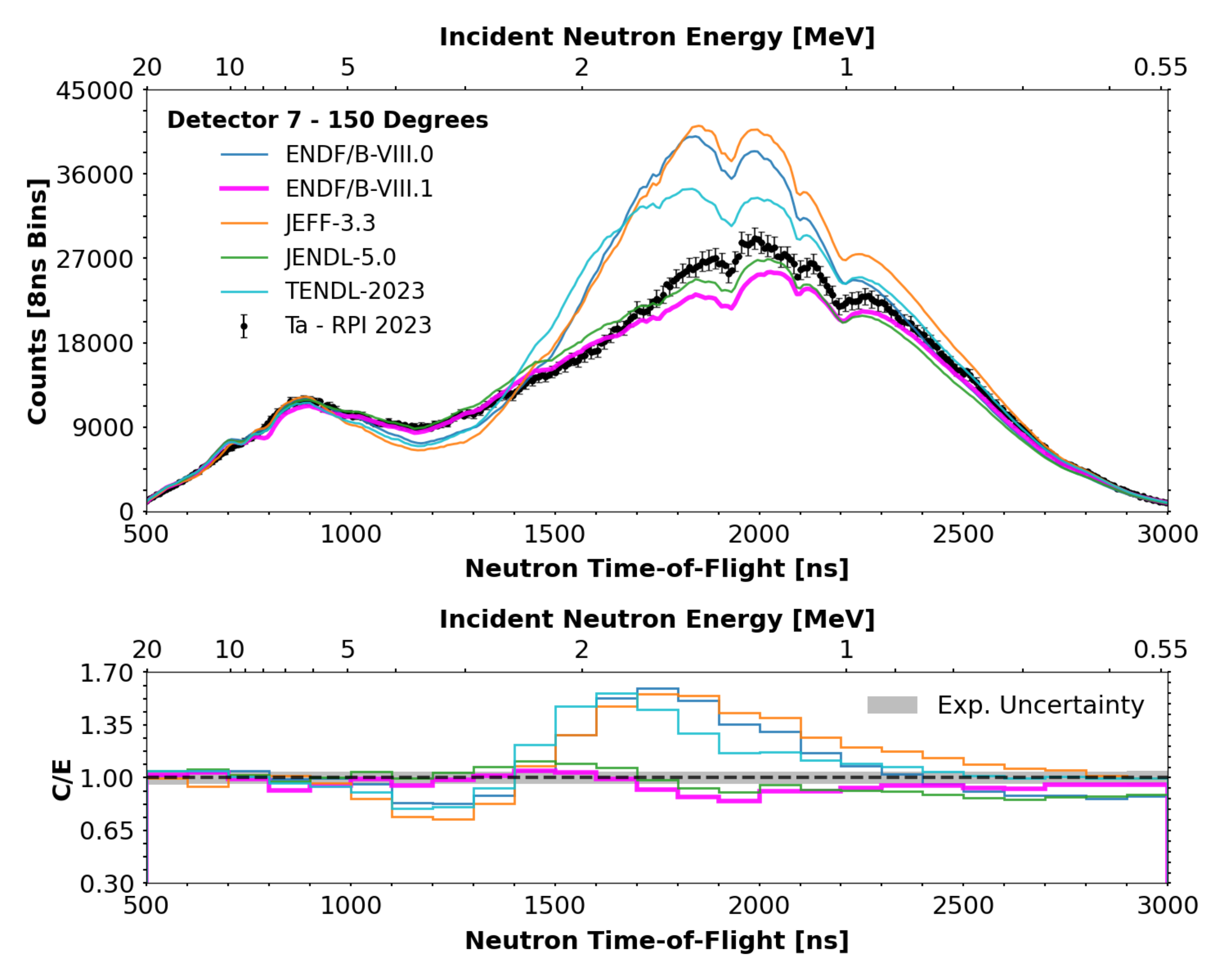
II. Struck SIS-3305 10-bit digitizer
   - Upgraded from 8-bit Acqiris for this experiment to increase efficiency

III. LINAC Beam Conditions
   - ~50 MeV electron energy at ~10μA
   - 8 ns pulse width at 400 Hz



Ta - Some Issues Remain at Forward Angles, but Large Improvements in Backward Angles





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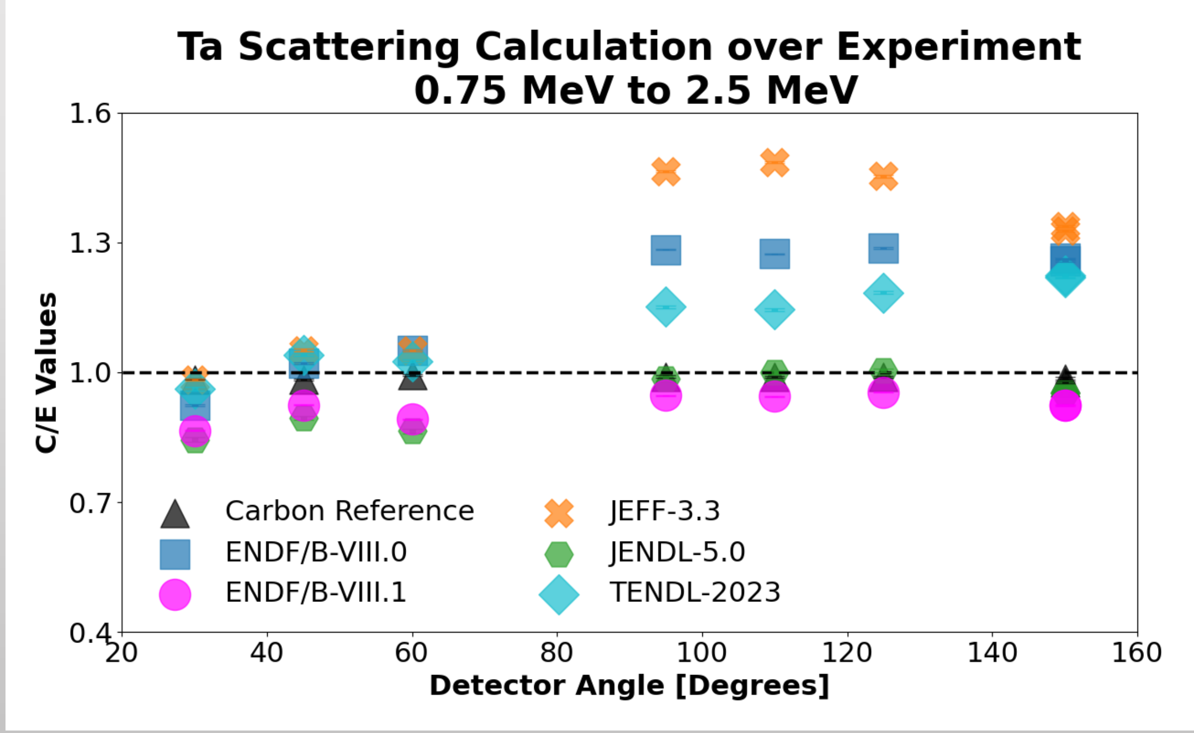
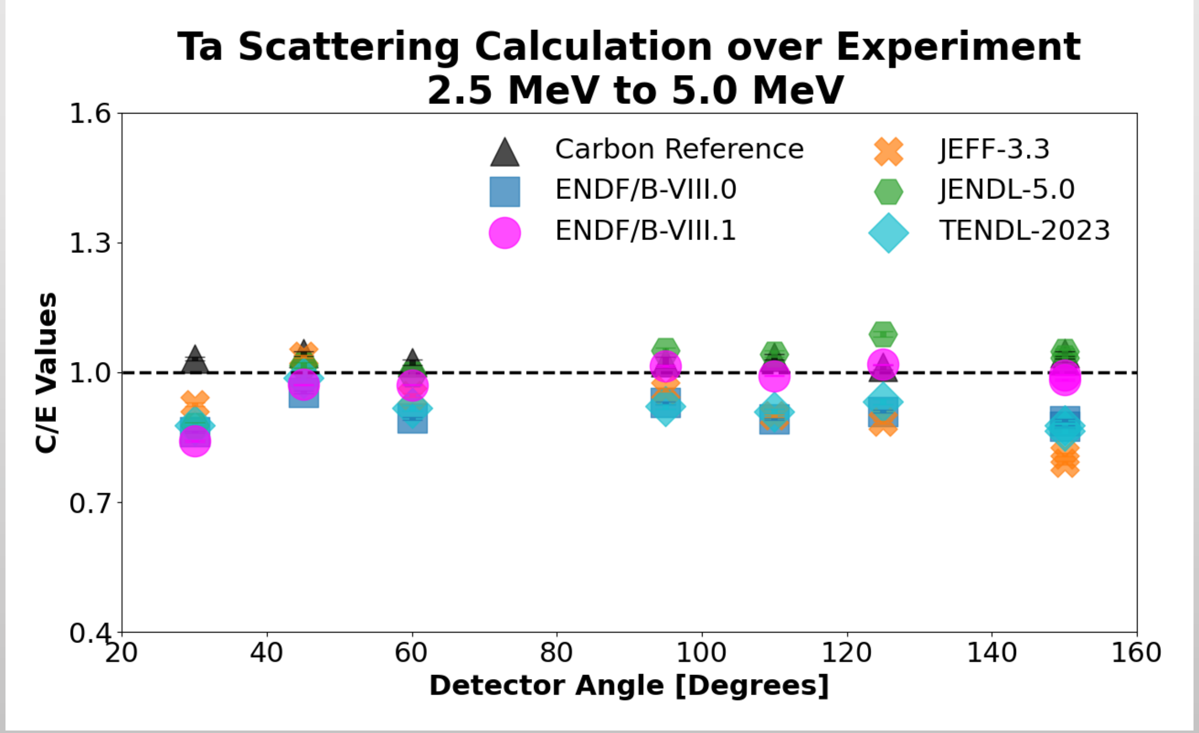
Tantalum Scattering Kernal Performance

Improvements made over previous ENDF/B-VIII.0 ^{181}Ta evaluation to resolve the significant overprediction of neutron scattering at backward angles in the fission neutron energy regime.





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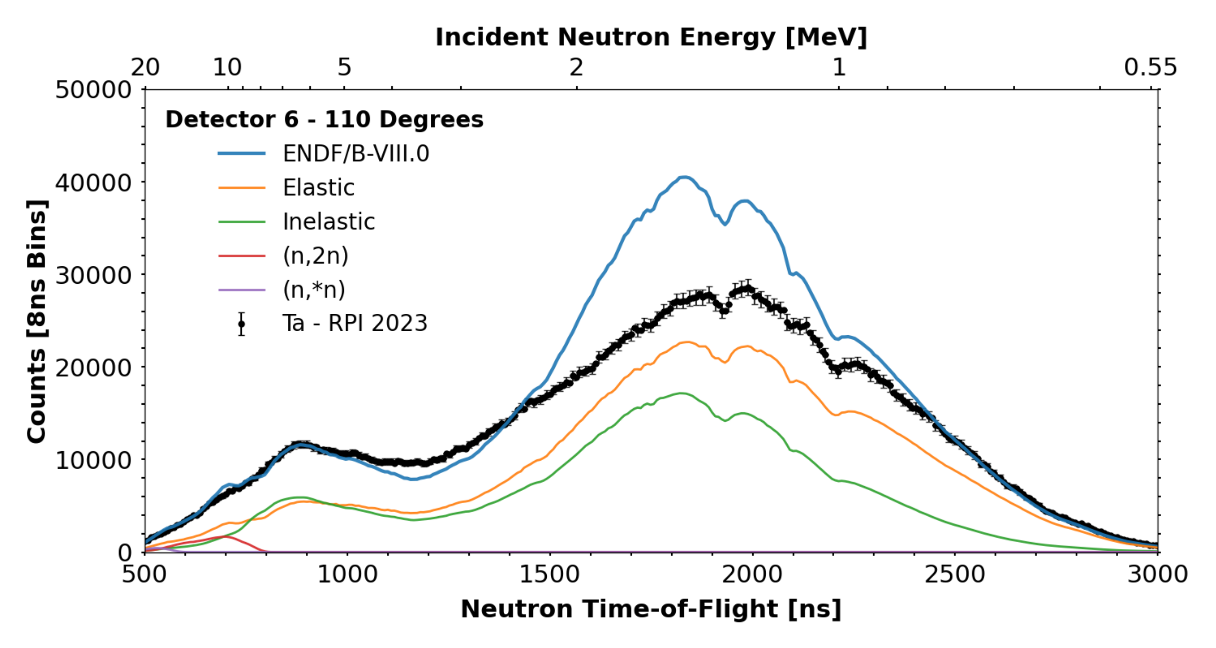
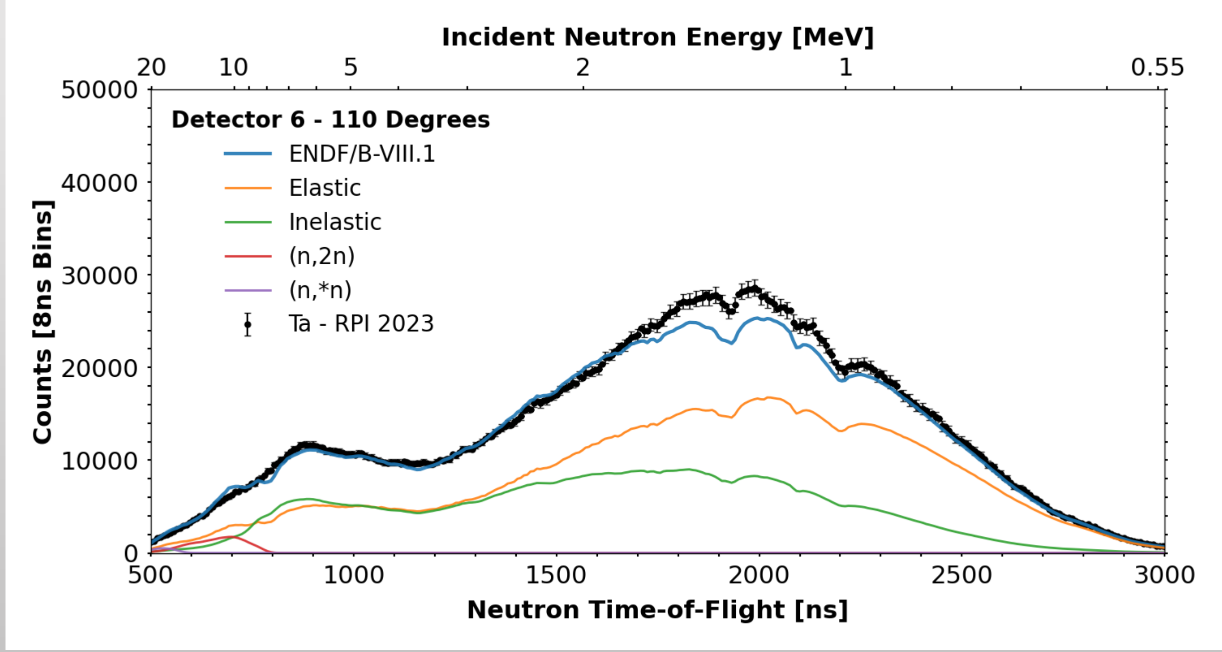
Changes Observed in Scattering Channels

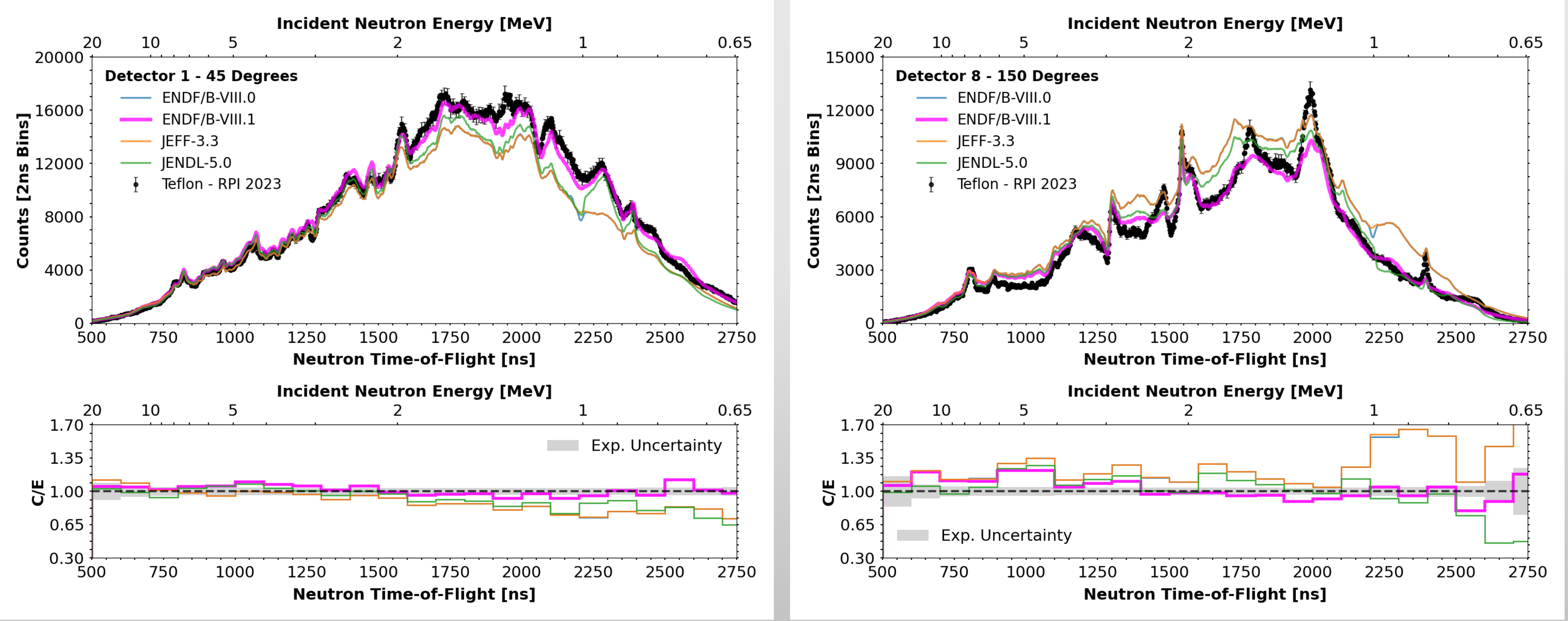
Moving from ENDF/B-VIII.0 to ENDF/B-VIII.1 a large reduction of both elastic and inelastic neutron scattering is observed below 3 MeV at backward scattering angles to correct the large imbalance in the tantalum scattering kernel.

ENDF/B-VIII.0 → **ENDF/B-VIII.1**



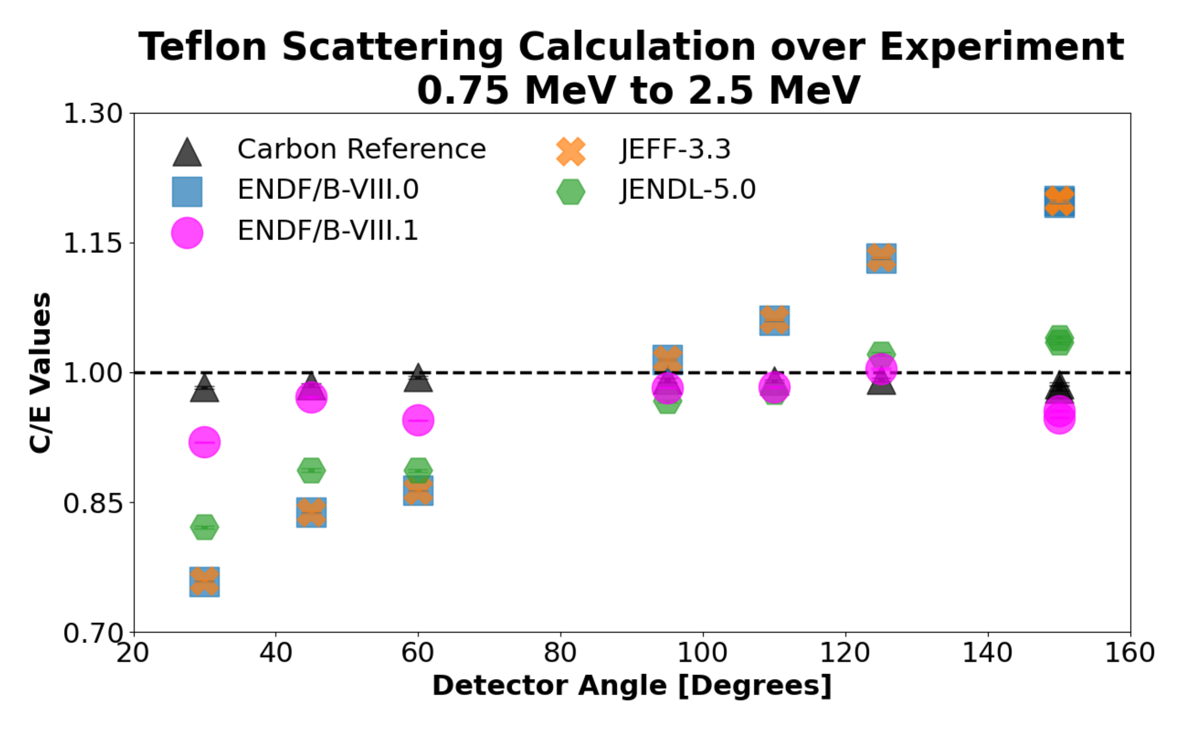


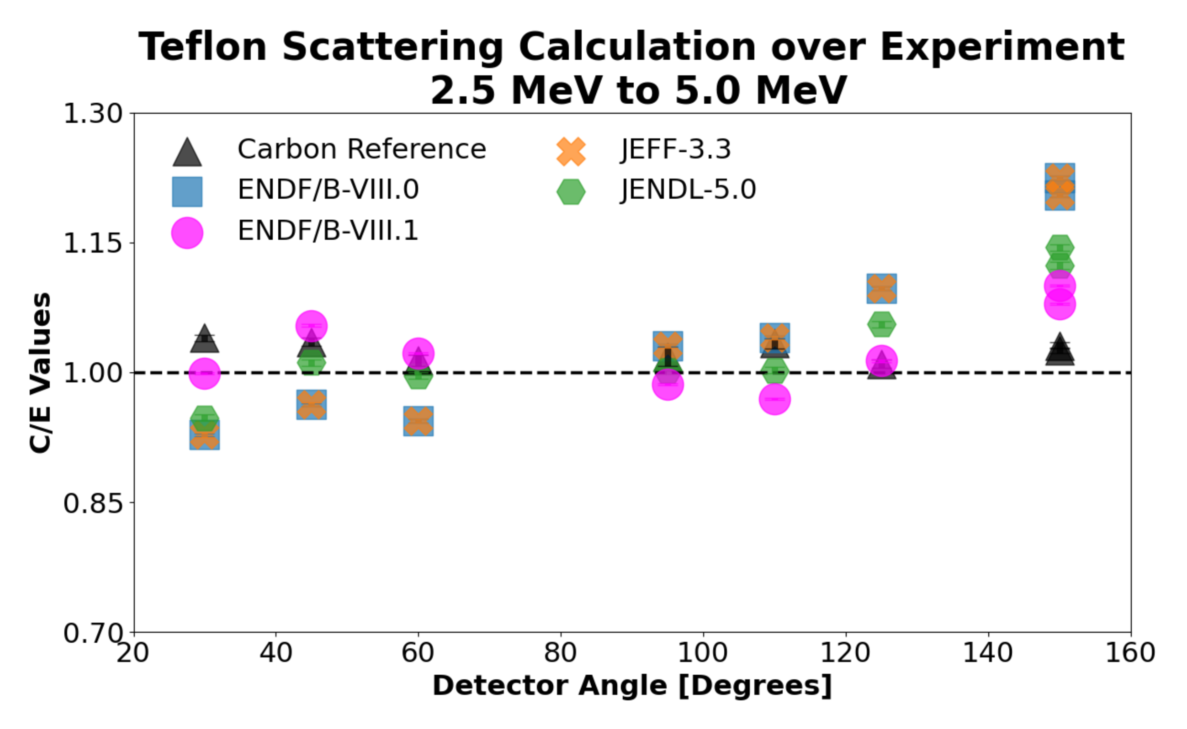
Teflon (^{19}F) – Good Performance at Forward Angles, But Issues With Resonance Anisotropy



^{19}Fluorine Scattering Kernal Performance

Adoption of INDEN ^{19}F evaluation yields improvement made over previous ENDF/B-VIII.0 ^{19}F evaluation with respect to the experimental data by addressing large scattering kernel imbalance in the fission neutron energy regime.





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keV Neutron Scattering Measurements

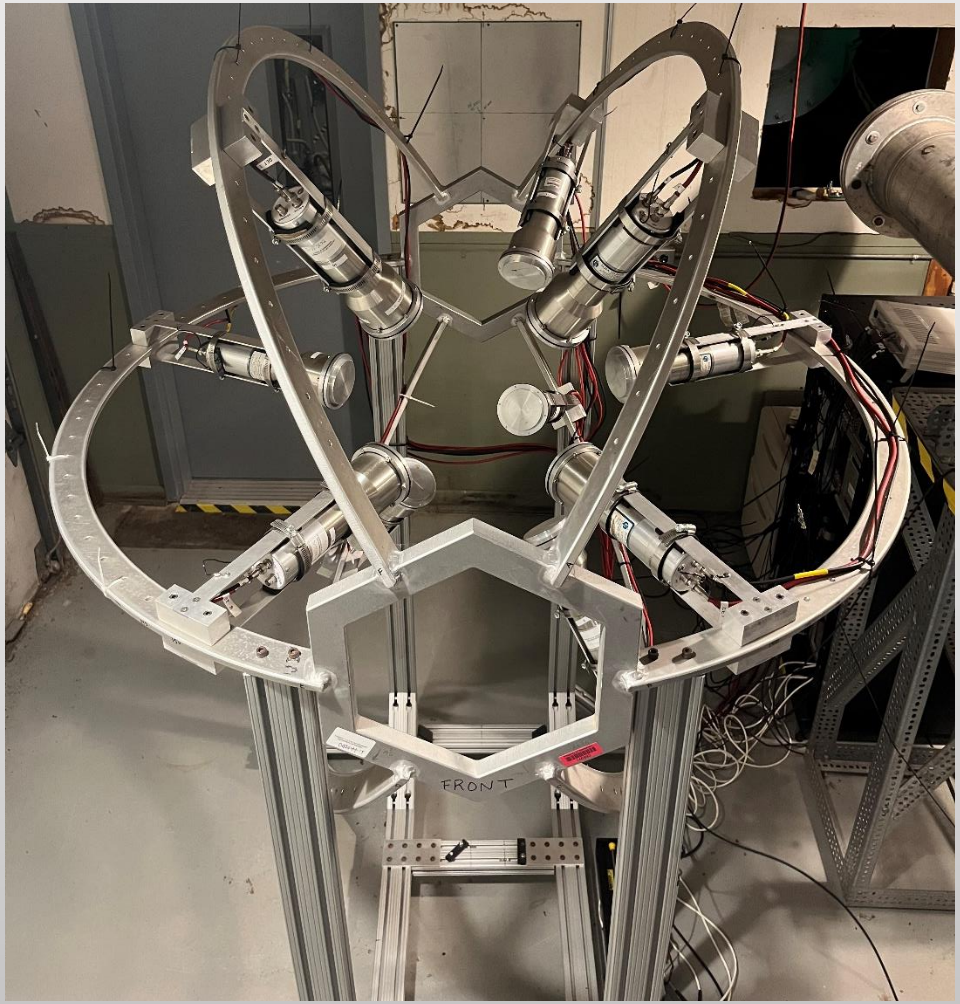
Copper keV Neutron Scattering Experiment

Motivation

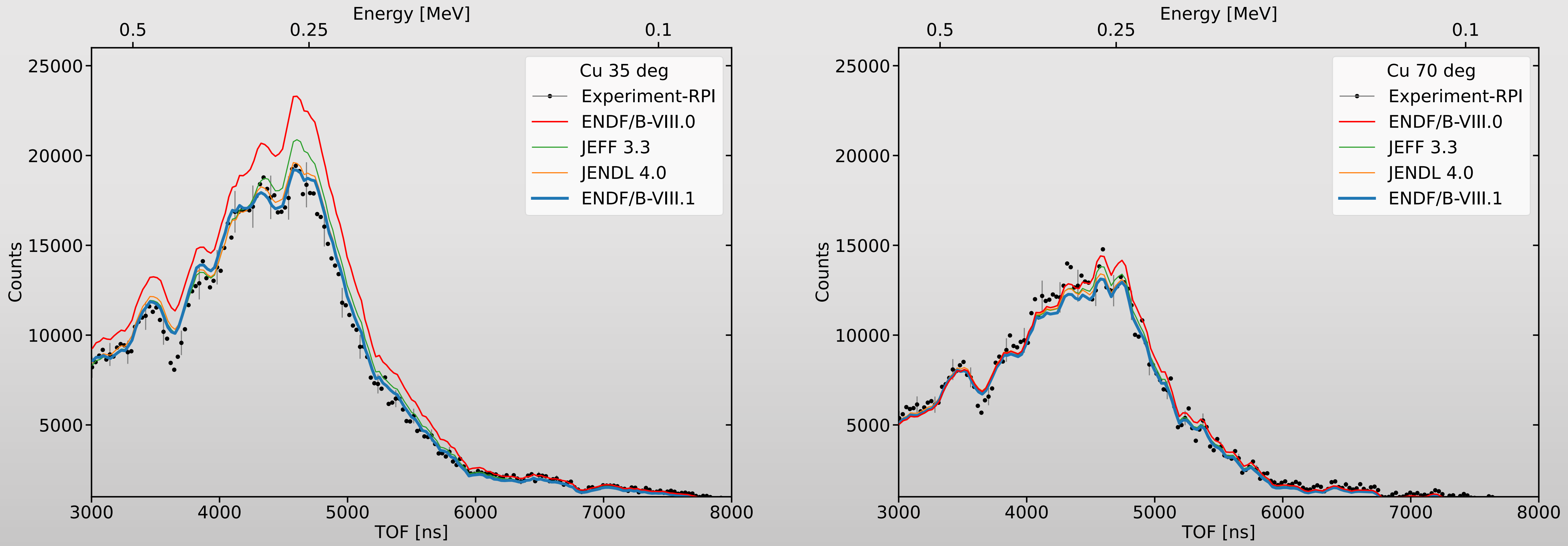
- Resolving Copper scattering cross sections and angular distributions believed to bias Zeus critical benchmark experiments
  - Intermediate energy benchmark with HEU, stainless steel, graphite moderator, and a large copper reflector

Experimental Apparatus

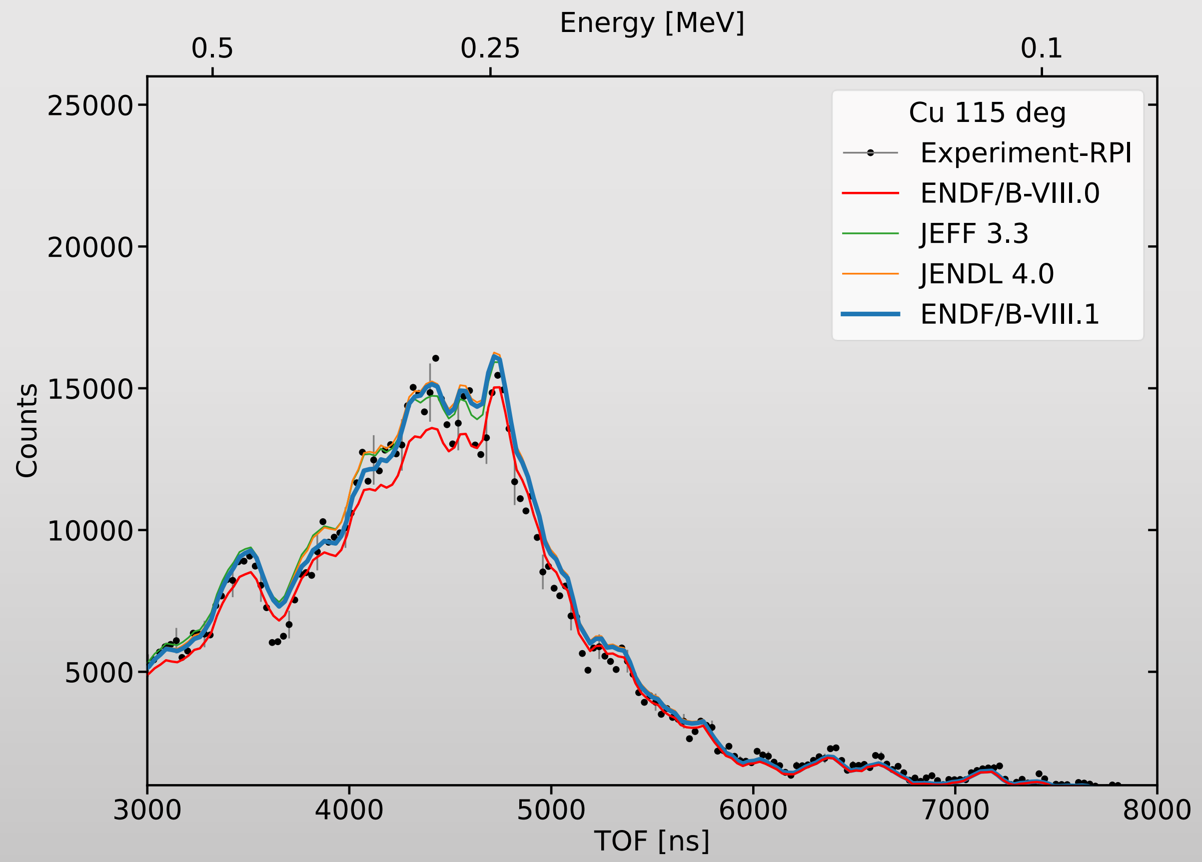
- keV neutron scattering array measures neutron scattering between 1 keV and 1 MeV
- Eight ^{6}Li and two ^{7}Li glass detectors for neutron and gamma signal measurements
- SIS3316 16-channel digitizer with 4ns sampling rate

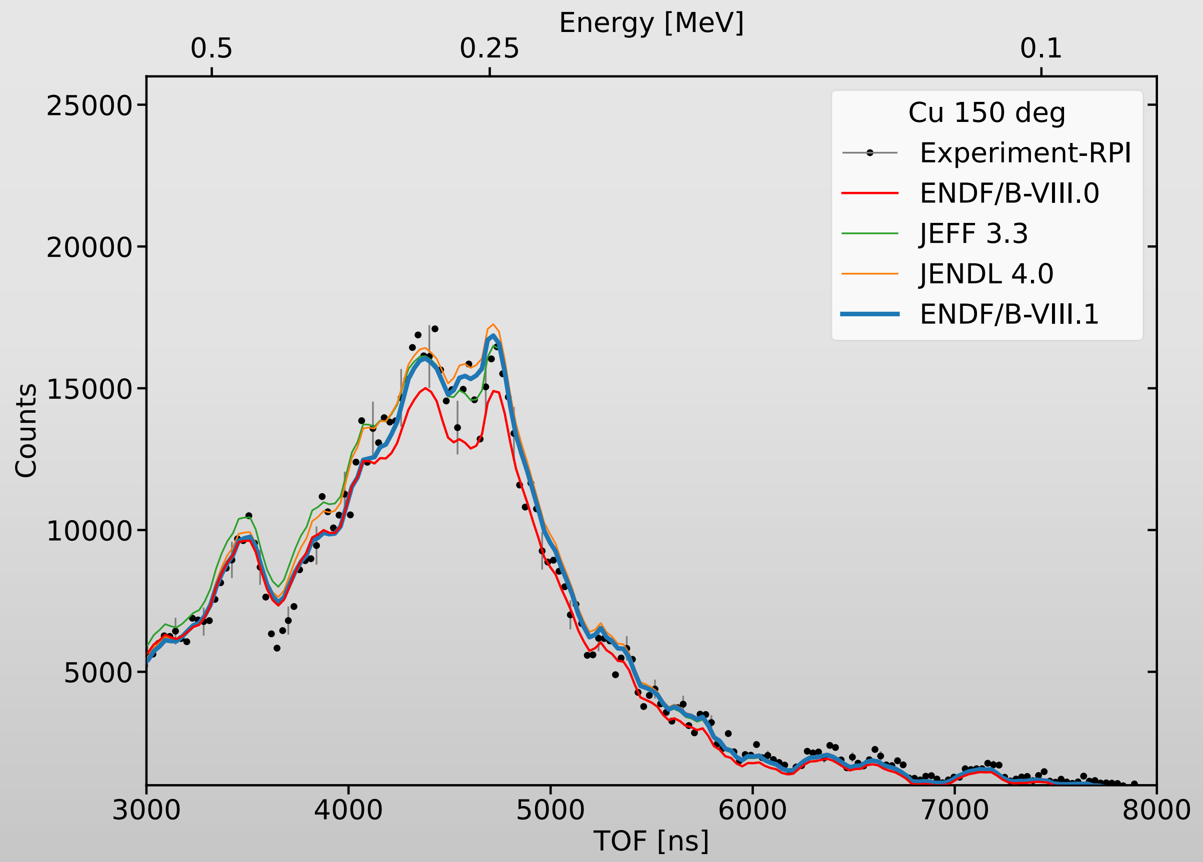


ENDF/B-VIII.1 Improves Agreement to keV Copper Scattering Data At Forward Angles



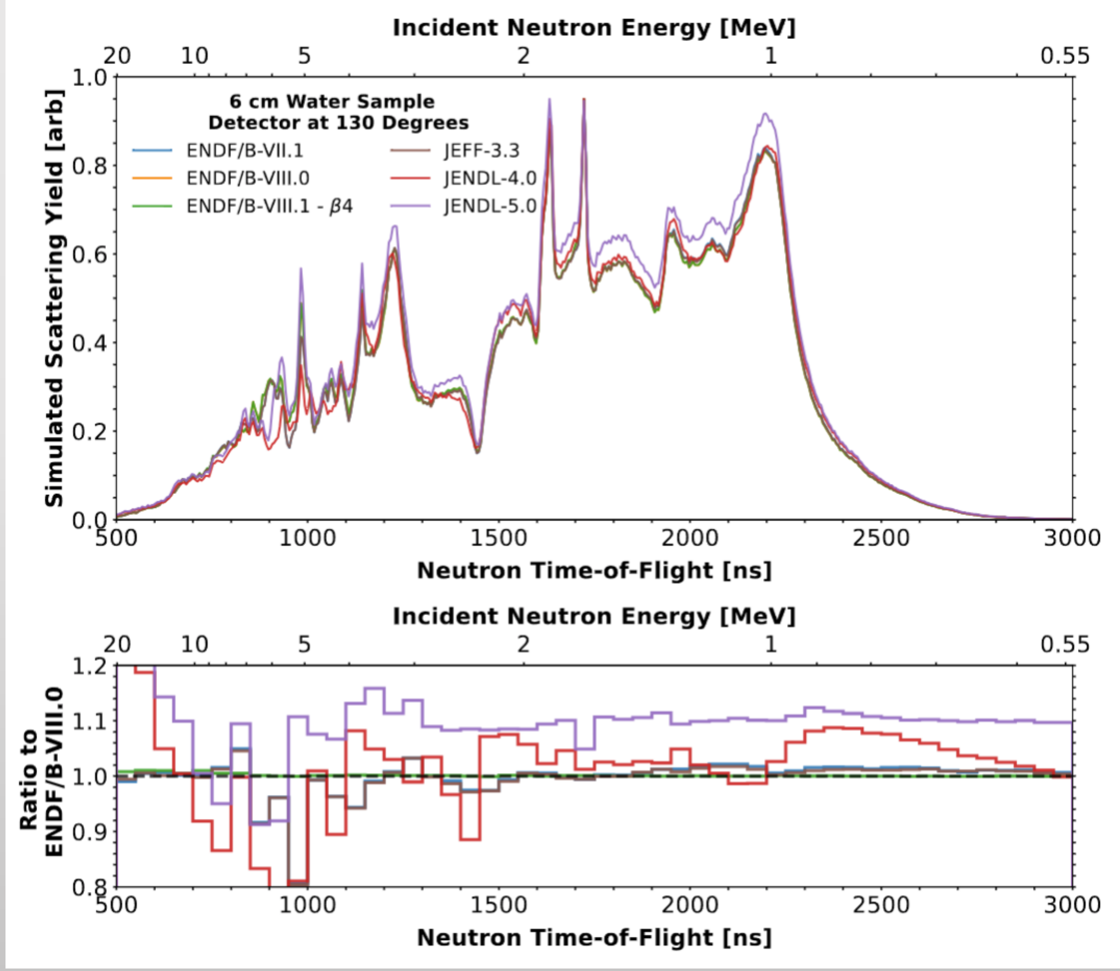
ENDF/B-VIII.1 Improves Agreement to keV Copper Scattering Data At Backward Angles



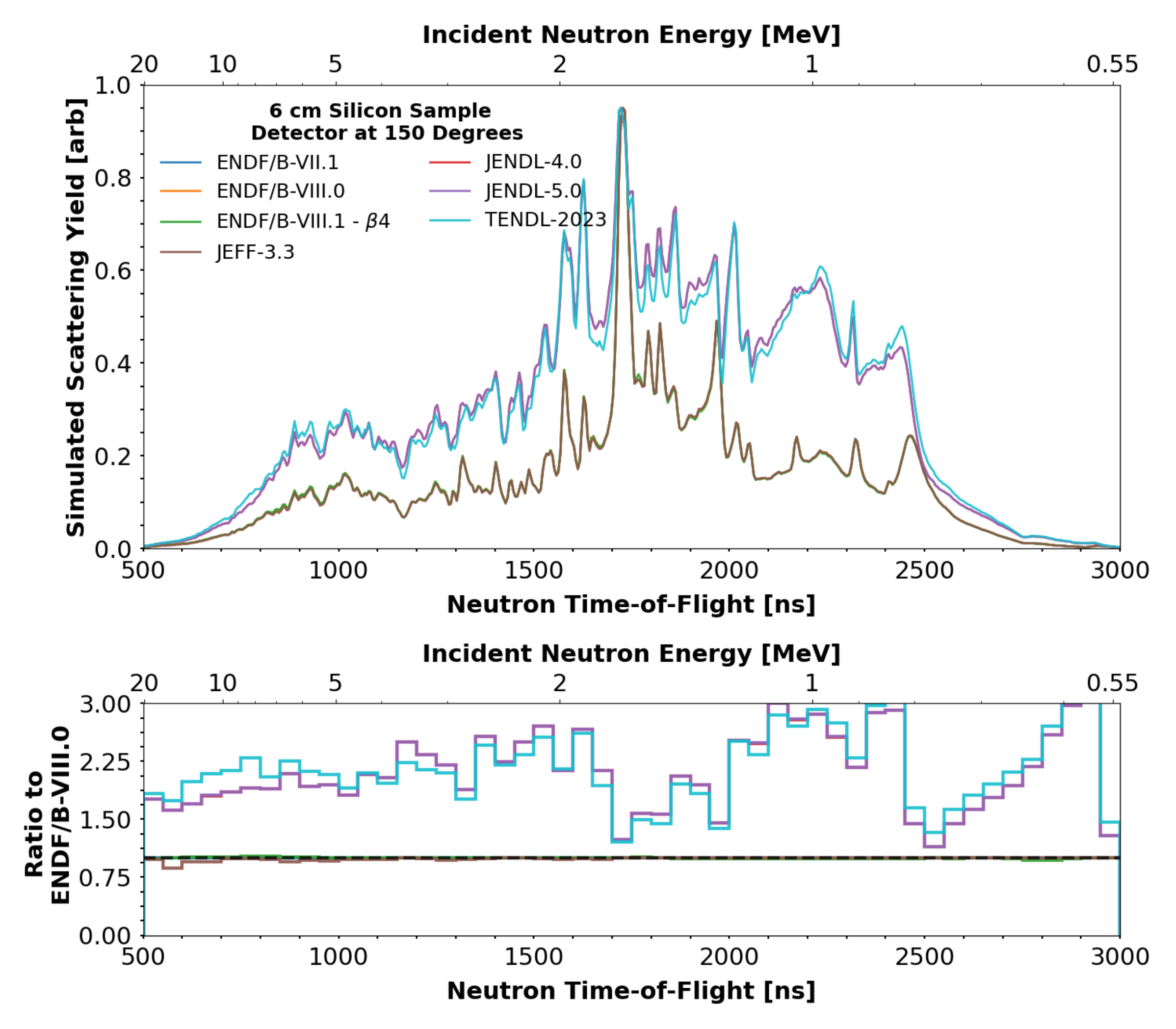


Conclusions and Future Experiments at RPI

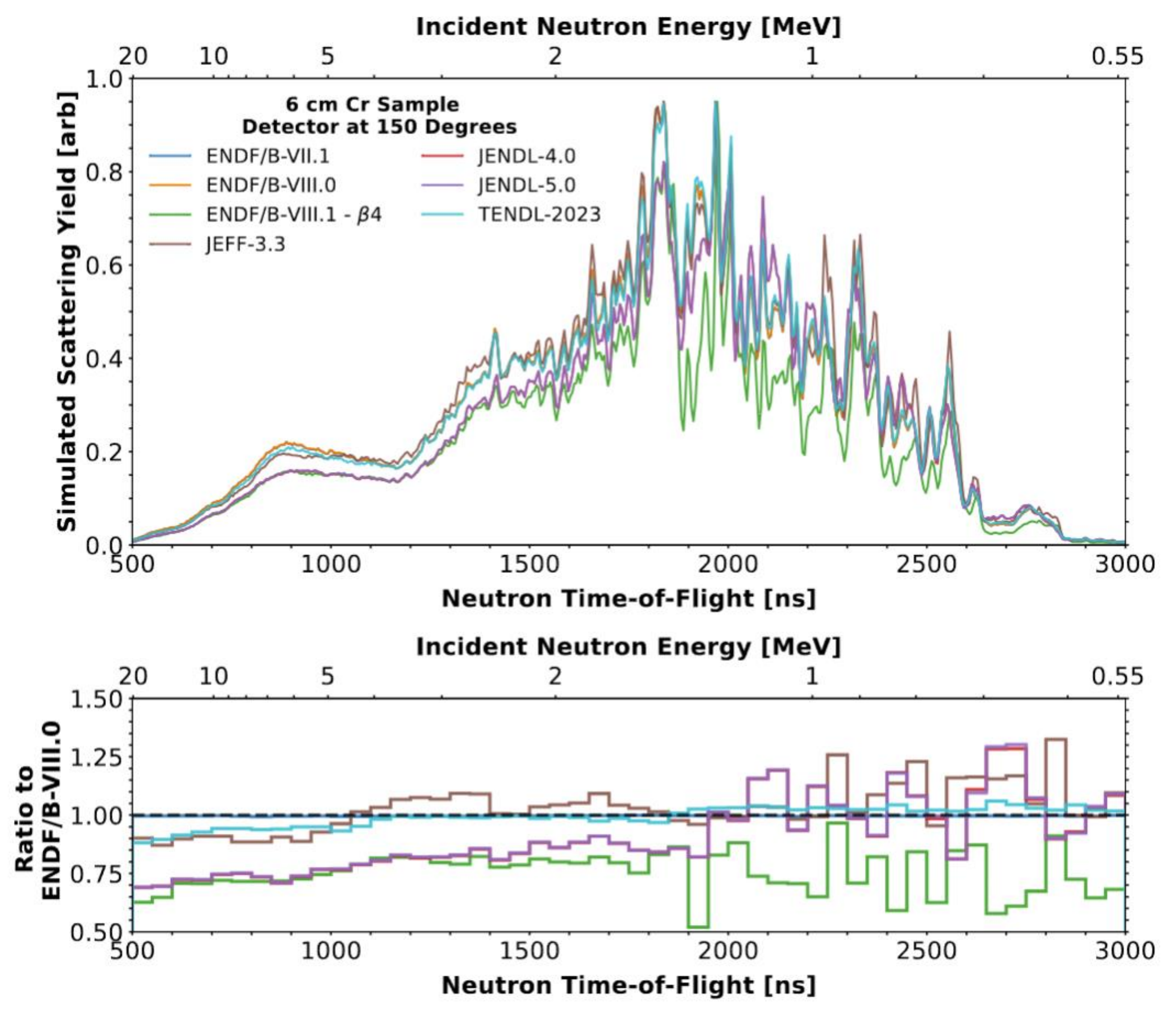
- RPI neutron scattering measurements of ^{nat}Ta, ^{nat}Cu, and Teflon were used as validation platforms for ENDF/B-VIII.1
  - Be experiment also used for validation in earlier beta versions
- RPI scattering experiments can be further improved by performing benchmark analysis
- Conflicts in evaluated nuclear datasets for the following elements can be resolved with RPI neutron scattering measurements:
  - ^{6,7}Li, B, N, O, Na, Mg, Al, Si, Cl, Ti, V, Ni, Mn, Nb, Cr, Y, Ba, Sn, Hf, W



Silicon



Chromium



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Acknowledgement

This work has been supported in part by:

- U.S. Nuclear Regulatory Commission (NRC-HQ-60-17-G-0006)
- Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the U.S. Department of Energy
- Naval Nuclear Laboratory

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