Overview of Nuclear Data Measurement and Analysis at RPI

Y. Danon, R. Block, K. Cook, D Fritz, S. Singh, B. Wang

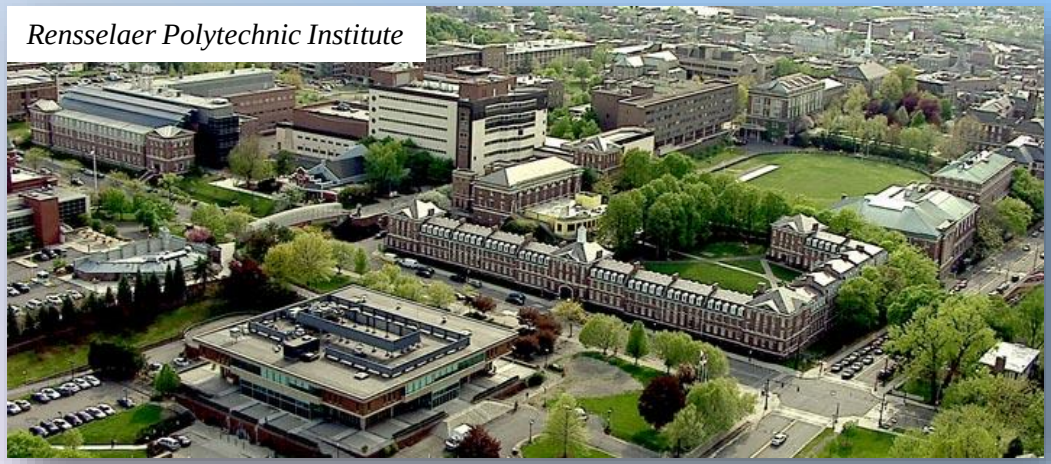
Gaerttner LINAC Center, Rensselaer Polytechnic Institute, Troy, NY, 12180

and

D. Barry, A. Daskalakis, B. Epping, A. Lewis, M. Rapp, and T. Trumbull

Naval Nuclear Laboratory, P.O. Box 1072, Schenectady, NY 12301

Rensselaer Polytechnic Institute



Gaerttner LINAC Center

CSEWG meeting, November 15-19, 2021

This work was partially supported by the Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the U.S. Department of Energy and Naval Reactors.

Rensselaer

NCSP NUCLEAR CRITICALITY SAFETY PROGRAM

NAVAL NUCLEAR LABORATORY

linac The Gaerttner LINAC Center

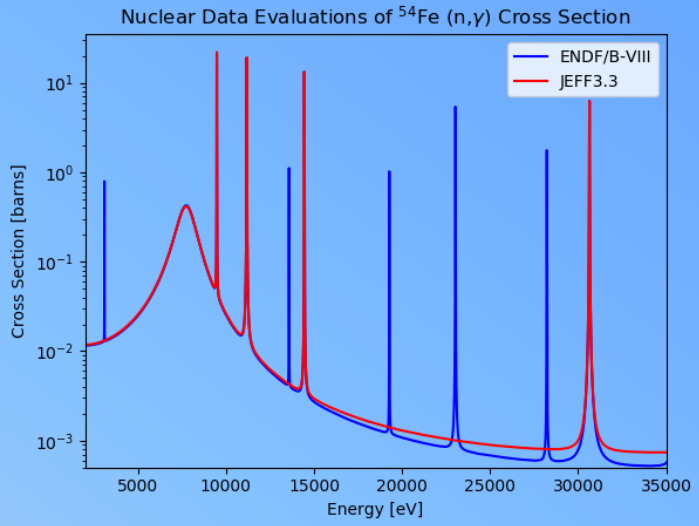
Outline

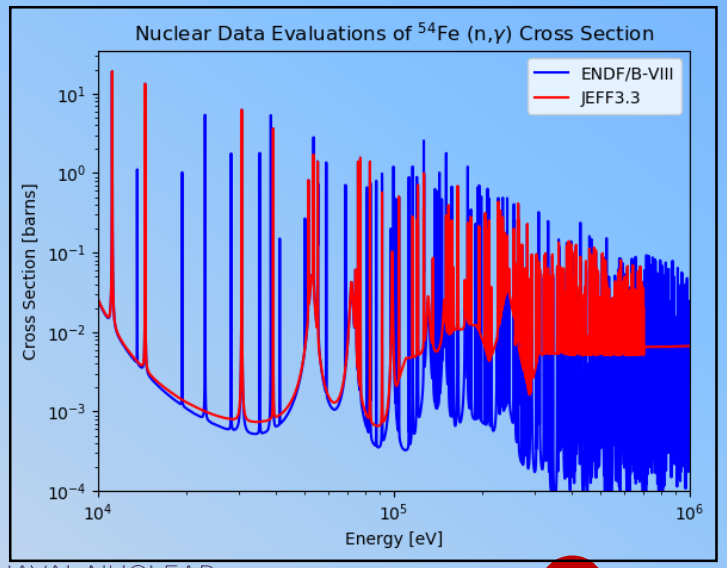
- Neutron capture in ^{54}Fe (S. Singh)
- Thermal total cross section measurements (D. Fritz)
- Thermal neutron die-away measurements (B. Wang)
- Neutron capture measurements on ^{nat}Ta, ^{238}U, and ^{235}U. (K. Cook)

Neutron capture in ^{54}Fe

^{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
  - nTOF data from 2014 was recently added to EXFOR after measurements began at the RPI LINAC
- There are various discrepancies between different evaluated data libraries, where some resonances are present in one evaluation and not the other



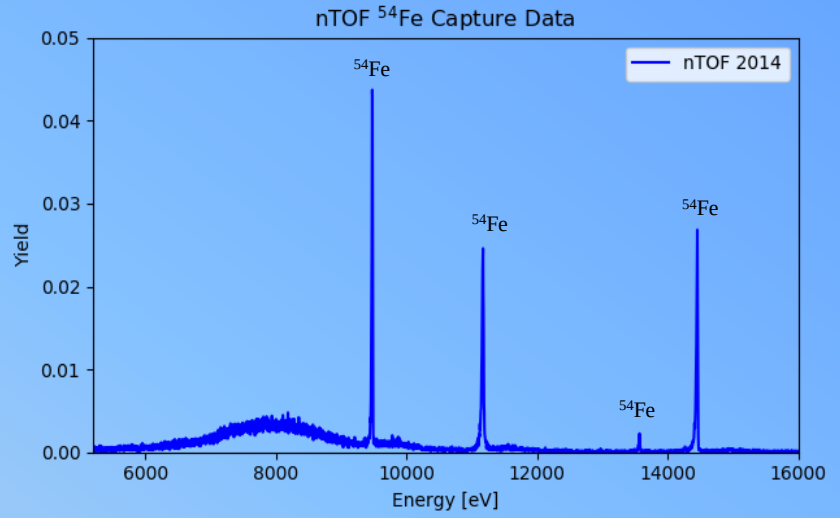


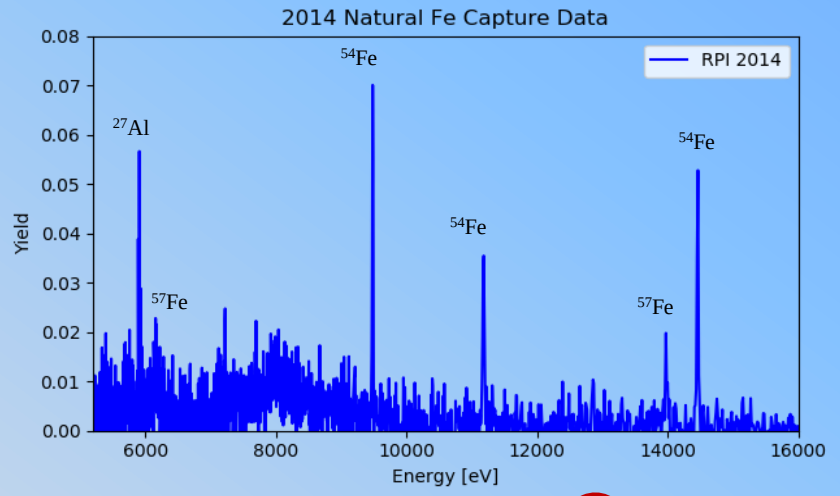
Overview of C_6D_6 Capture Array

- An array of seven C_6D_6 liquid scintillators surrounding the sample of interest at a flight path of 45m
- The system is designed to perform radiative capture in the keV – low MeV energy range
- All the detector structural materials have a low capture cross section to minimize neutron sensitivity
  - Materials are mostly thin Al
- System is based on the principle of the total energy method
  - Pulse weighting is required

^{54}Fe (n, γ) Measurement – Prior Data

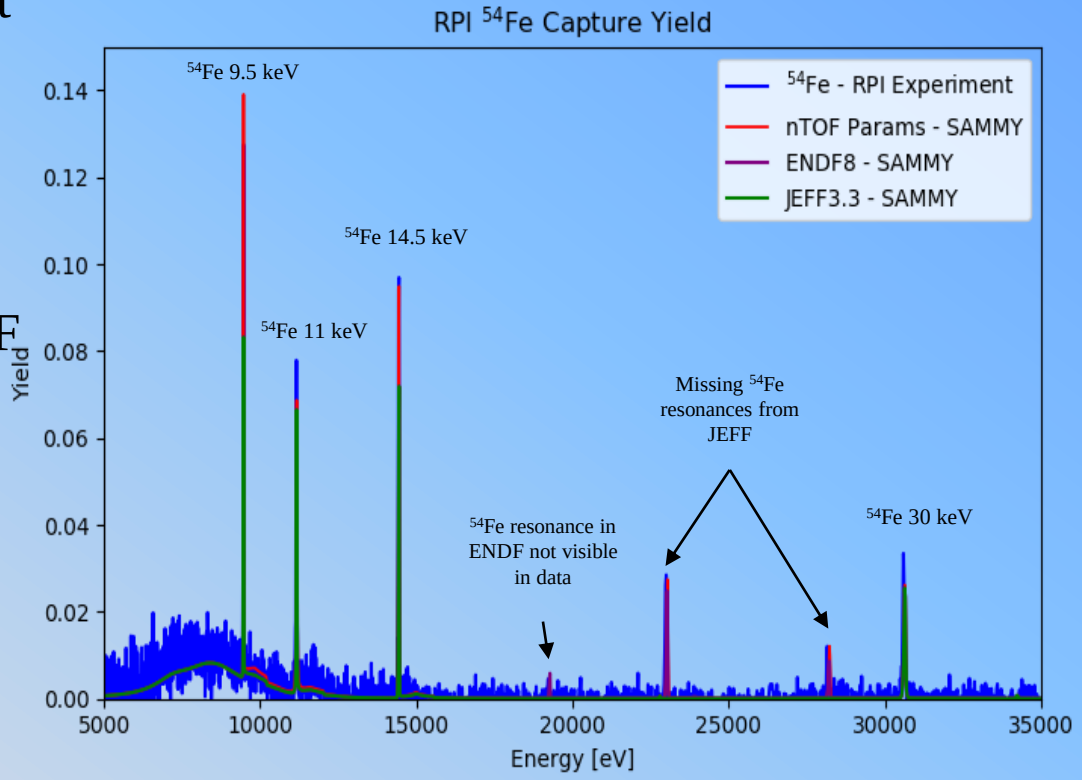
- **nTOF ^{54}Fe Measurement (2014):**
  - ~0.007 at/b 99.7% enriched ^{54}Fe sample was measured at nTOF in 2014
  - High resolution data (185m flight path) taken
  - Normalized to saturated resonance in Au
  - How does RPI data compare to nTOF?
- **RPI Natural Fe Measurement (2014):**
  - Older version of keV capture system was used to measure a thick natural Fe sample
  - Analysis was focused on ^{56}Fe capture cross section
  - ^{54}Fe resonances are clearly visible in capture data
  - Is it possible to cross-normalize this measurement to ^{54}Fe data?





^{54}Fe (n, γ) measured and calculated Yield

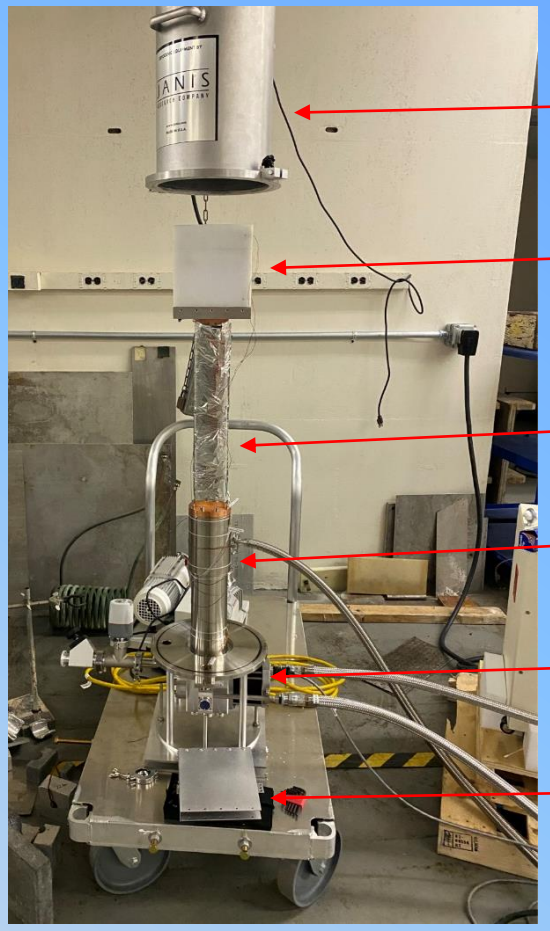
- nTOF resonance parameters seem to provide better agreement to RPI experiment than JEFF or ENDF resonance parameters
- Some missing resonances from JEFF evaluation can be clearly seen in RPI and nTOF experiments
- A new set of resonance parameters will be fitted to RPI data



Thermal total cross section measurements

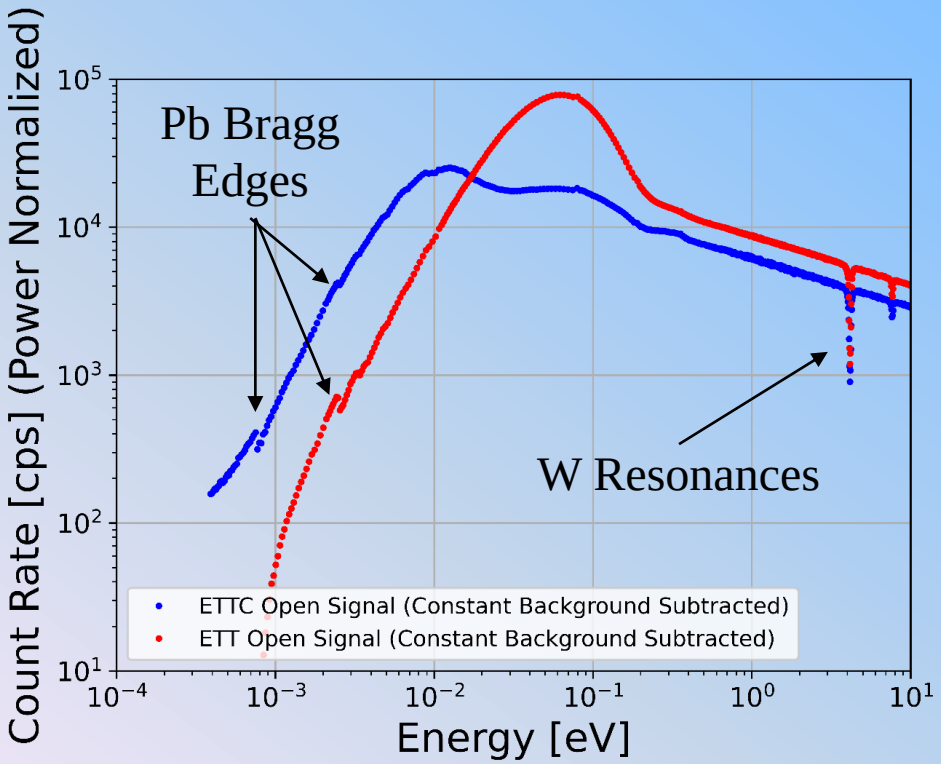
New cold moderator (ETTC)

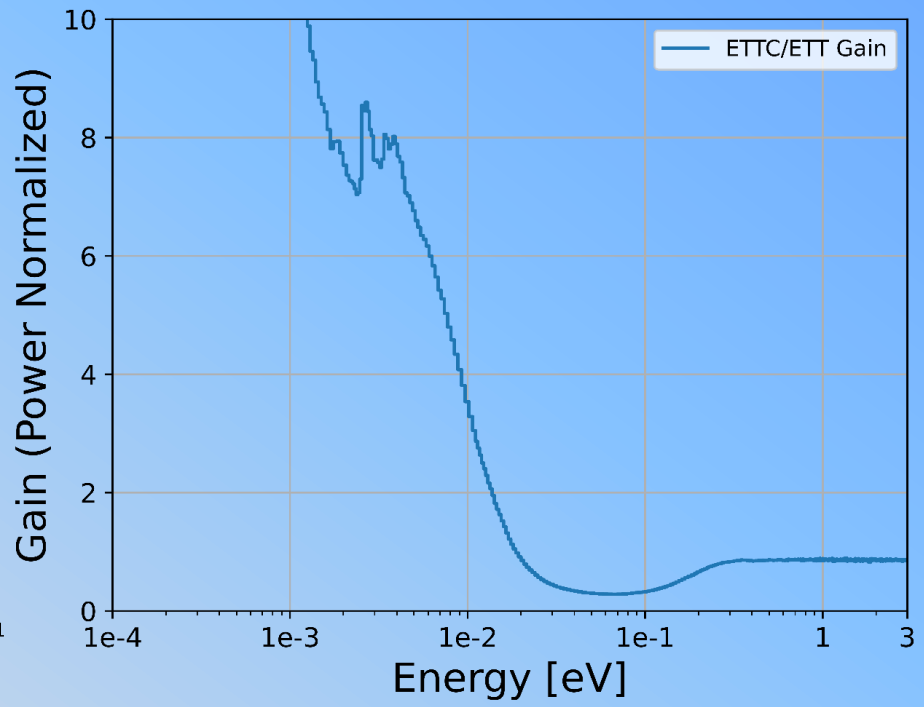
- Neutronics
  - Polyethylene
    - Large enough to cover collimation
    - As close to source of neutrons as possible
    - As cold as possible in a consistent fashion
  - Maximize gain over existing source (ETT)
  - Metric: Integral counts in 1 – 5 meV range
- System
  - High density polyethylene (HDPE)
    - < 30 K w/ 1.5 kW on target
    - Good connection to cryostat
  - Long cold finger → protect cold head from radiation
  - Large cold finger cross-sectional area
  - Portable; Minimal material; Can withstand High-Vacucum
  - Single Stage Cryo-cooler



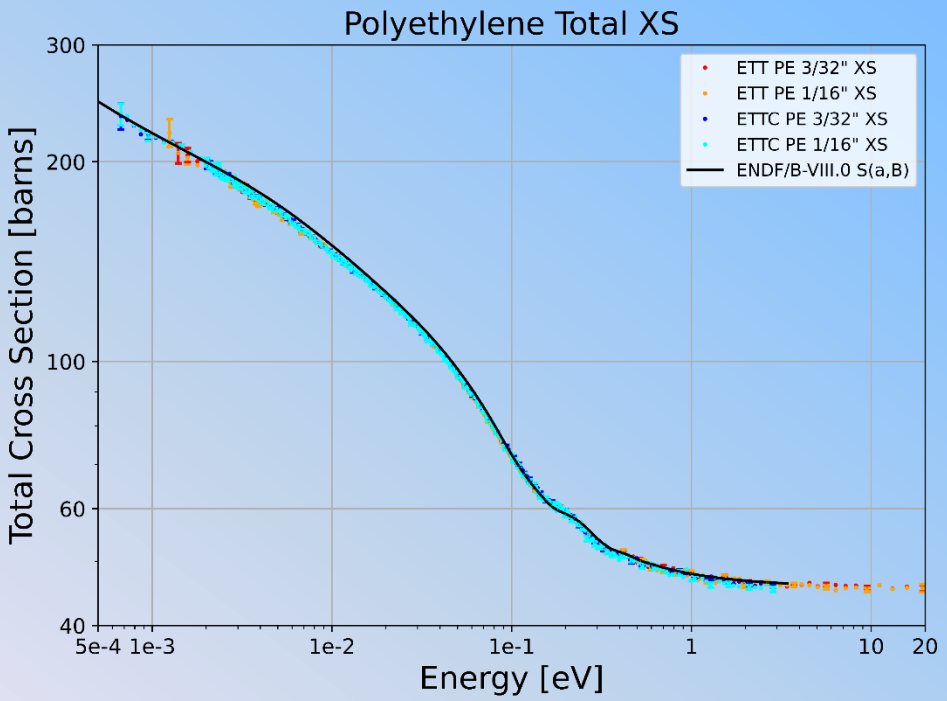
Experimental gain verification

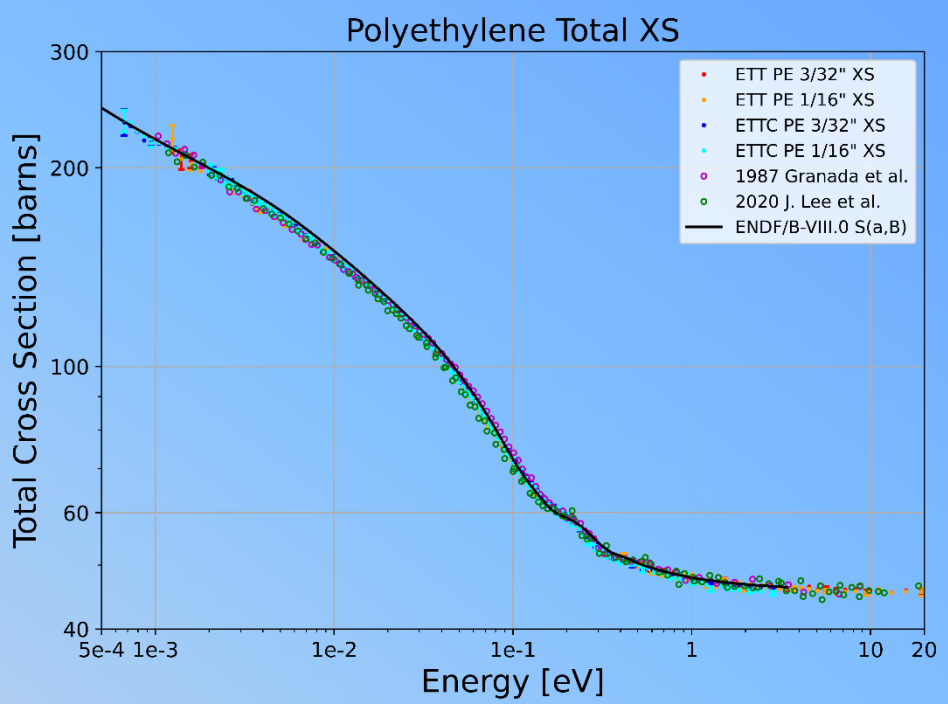
- After LINAC power normalization the ETTC achieves a gain up to 8 over the ETT
- ETTC extends the usable flux below 1 meV





Polyethylene total cross section

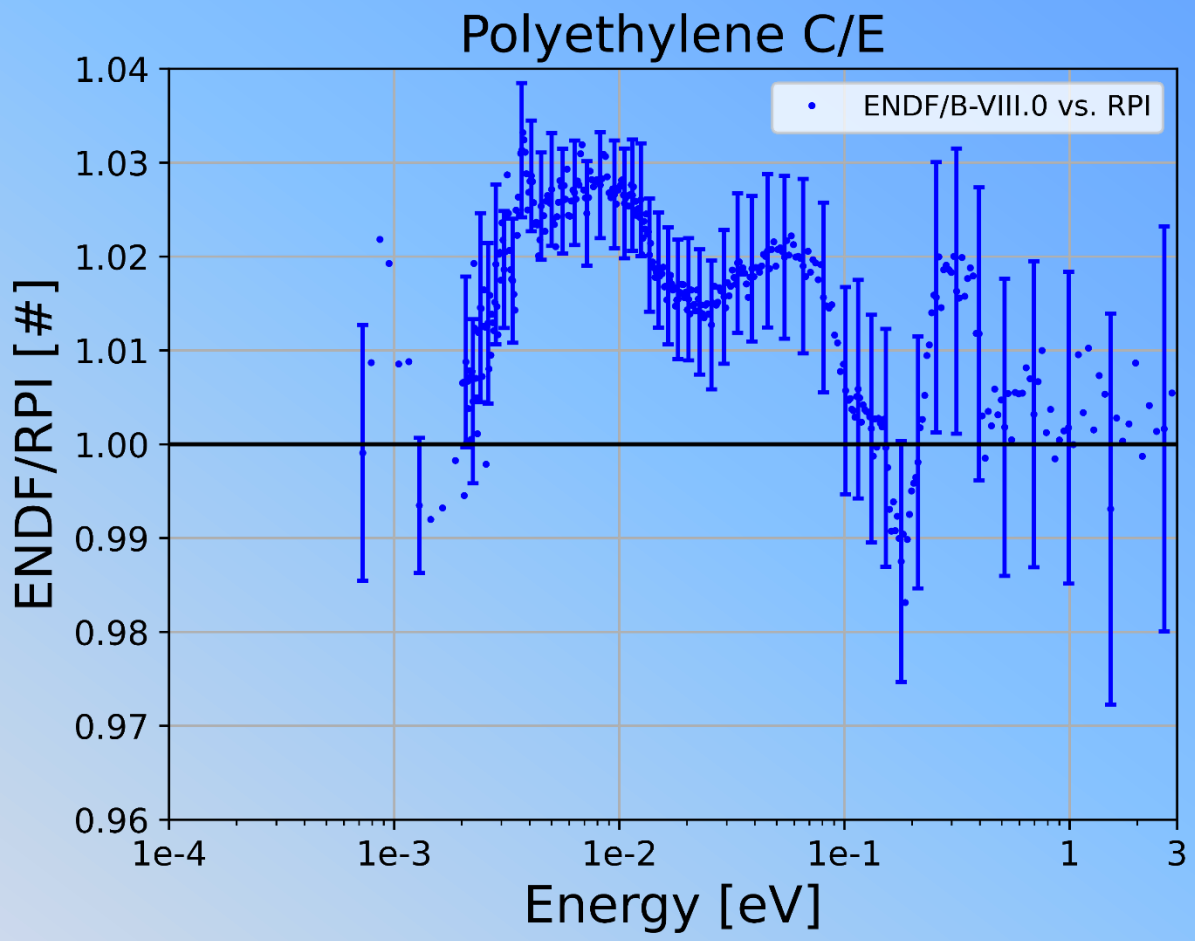




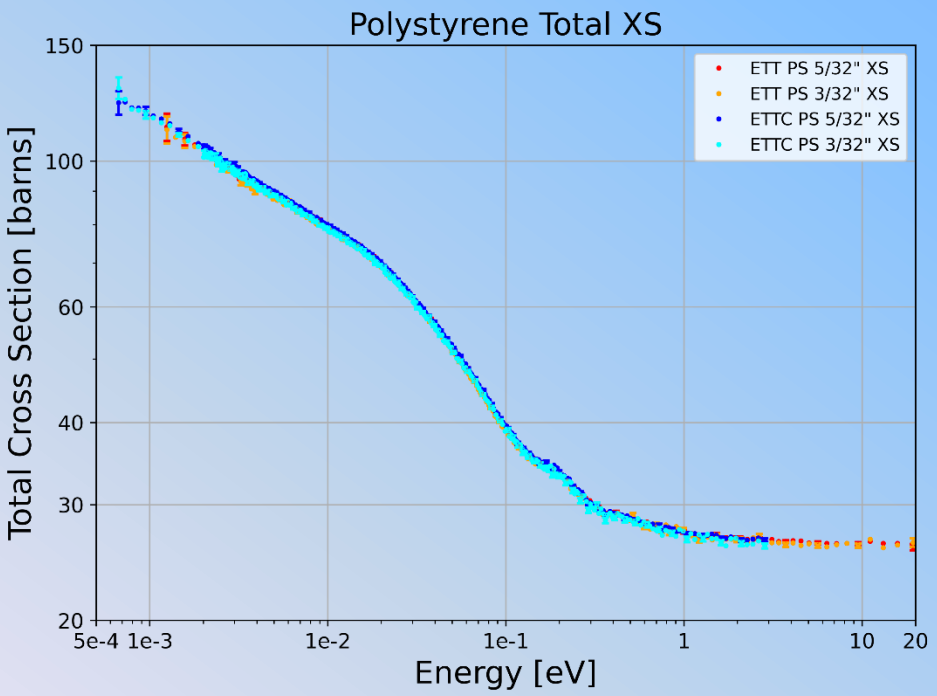
- Excellent agreement between ETT and ETTC cross section for polyethylene (PE)
- Good agreement between all RPI measured cross sections, other measured cross section, and evaluated thermal scattering libraries (TSL)
- Experimental error bars account for all statistical and areal density uncertainty

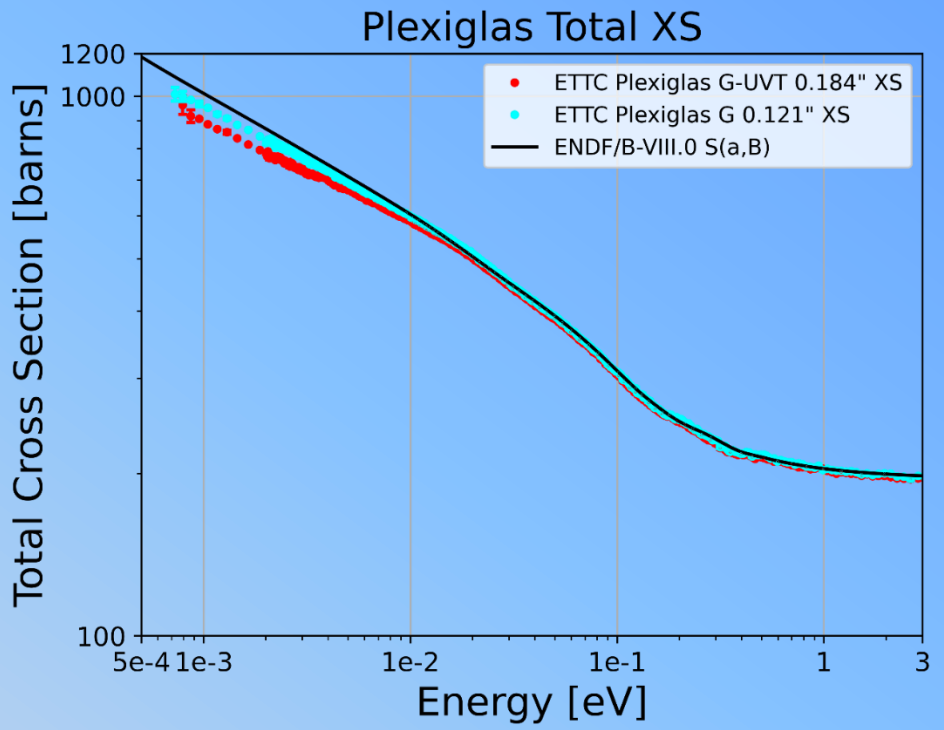
Polyethylene detailed comparison to ENDF/B-VIII.0

- High accuracy (~ 1%) measured total cross section shows differences when compared to the evaluation
- Overall, the evaluation is higher than the experiment
- About 2.8 % discrepancy near 0.01 eV



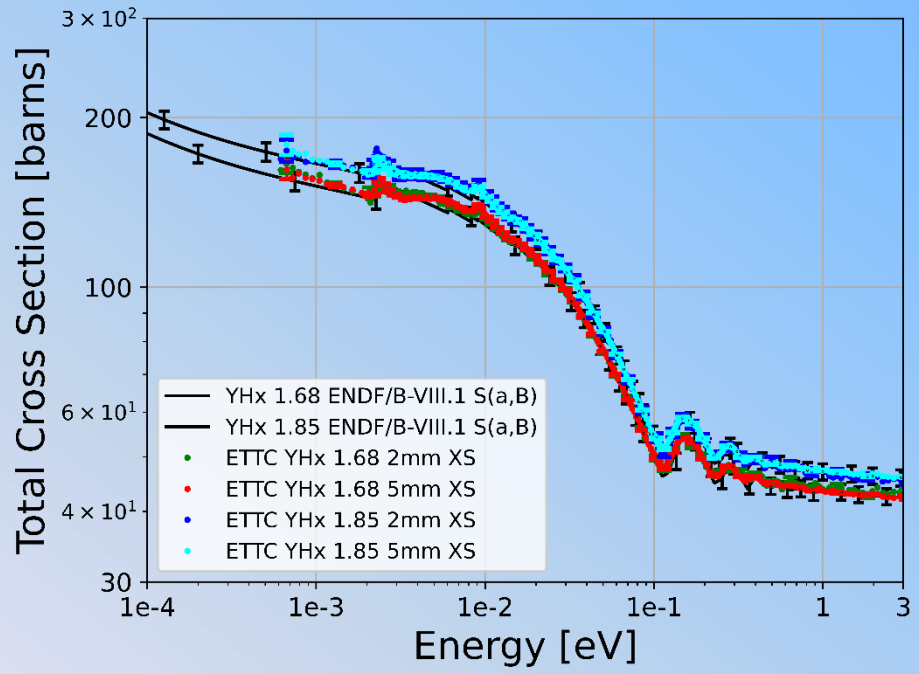
Polystyrene and Plexiglas total cross section

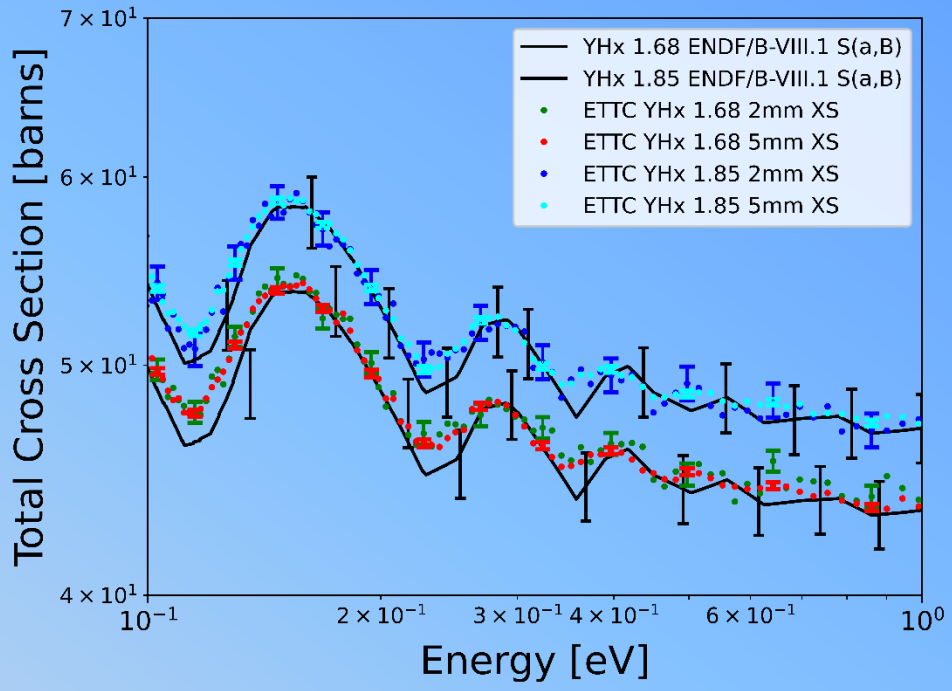




- Generally good agreement between measured cross section and TSL evaluation for polymers
- Differences in cross section between Plexiglas G and Plexiglas G-UVT
- Experimental error bars account for all statistical and areal density uncertainty

YHx total cross section



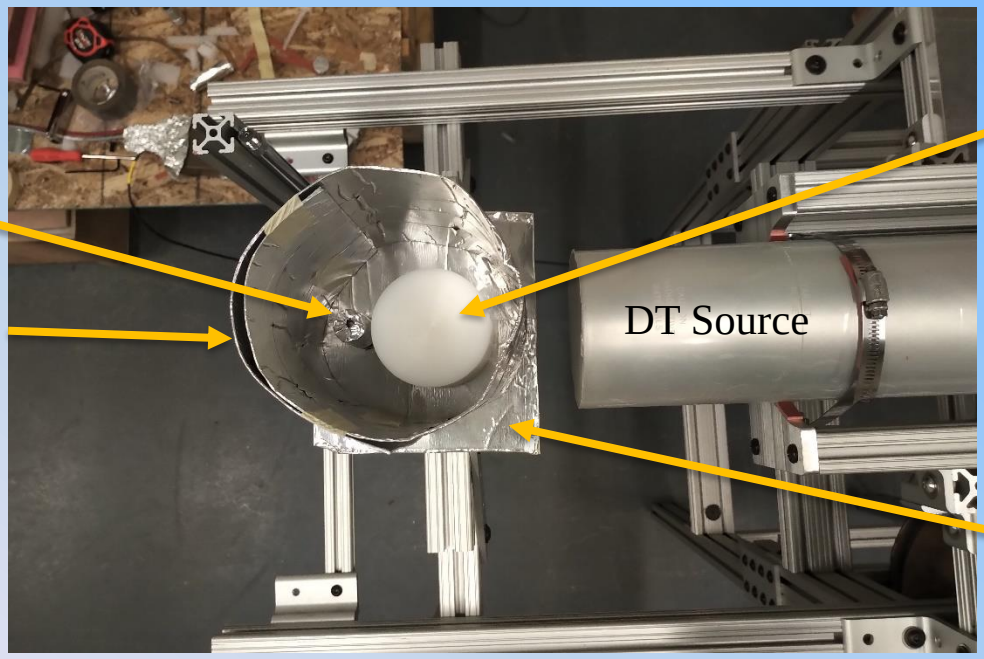


- Generally good agreement between yttrium hydride measured cross section and TSL evaluation for both concentrations
- Experimental error bars account for all statistical and areal density uncertainty
- Error bars on evaluation represent estimated uncertainty on H/Y ratio from samples

Thermal neutron die-away measurements

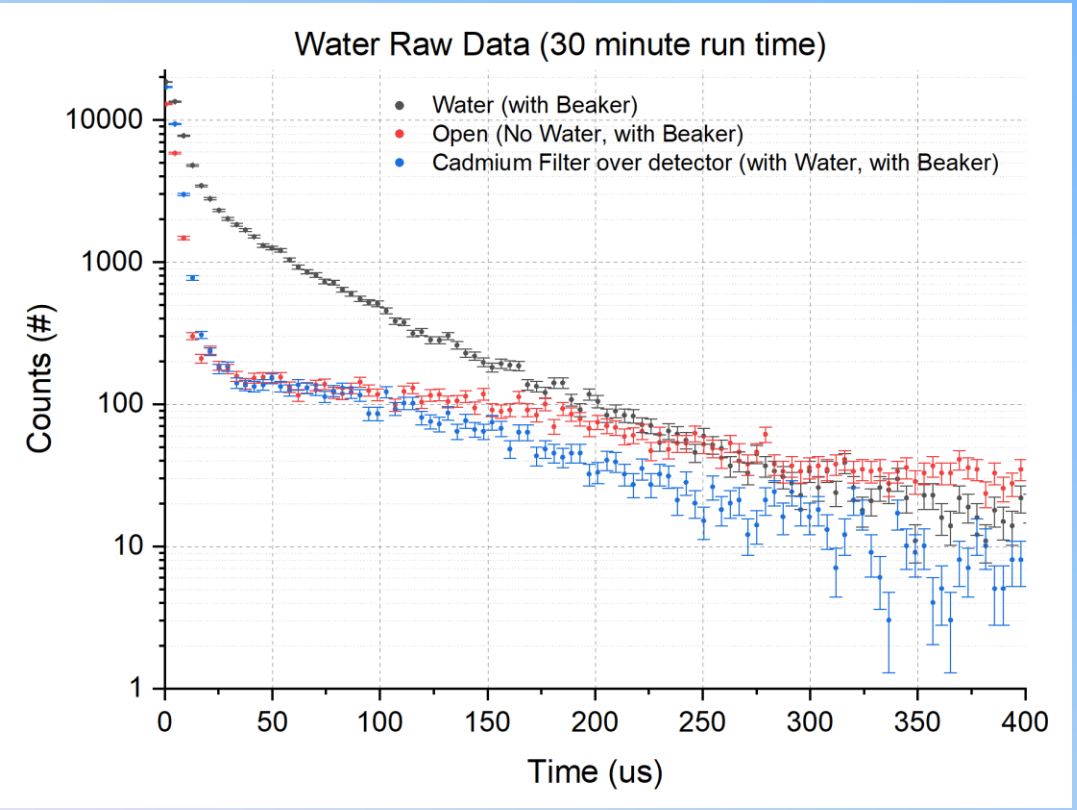
Motivation and setup

- Provide a low-cost experiment to validate the preference of Thermal Scattering Libraries (TSL).
- Use a DT source to pulse a moderator material and measure the thermal leakage
- Compare to (MCNP) simulations.



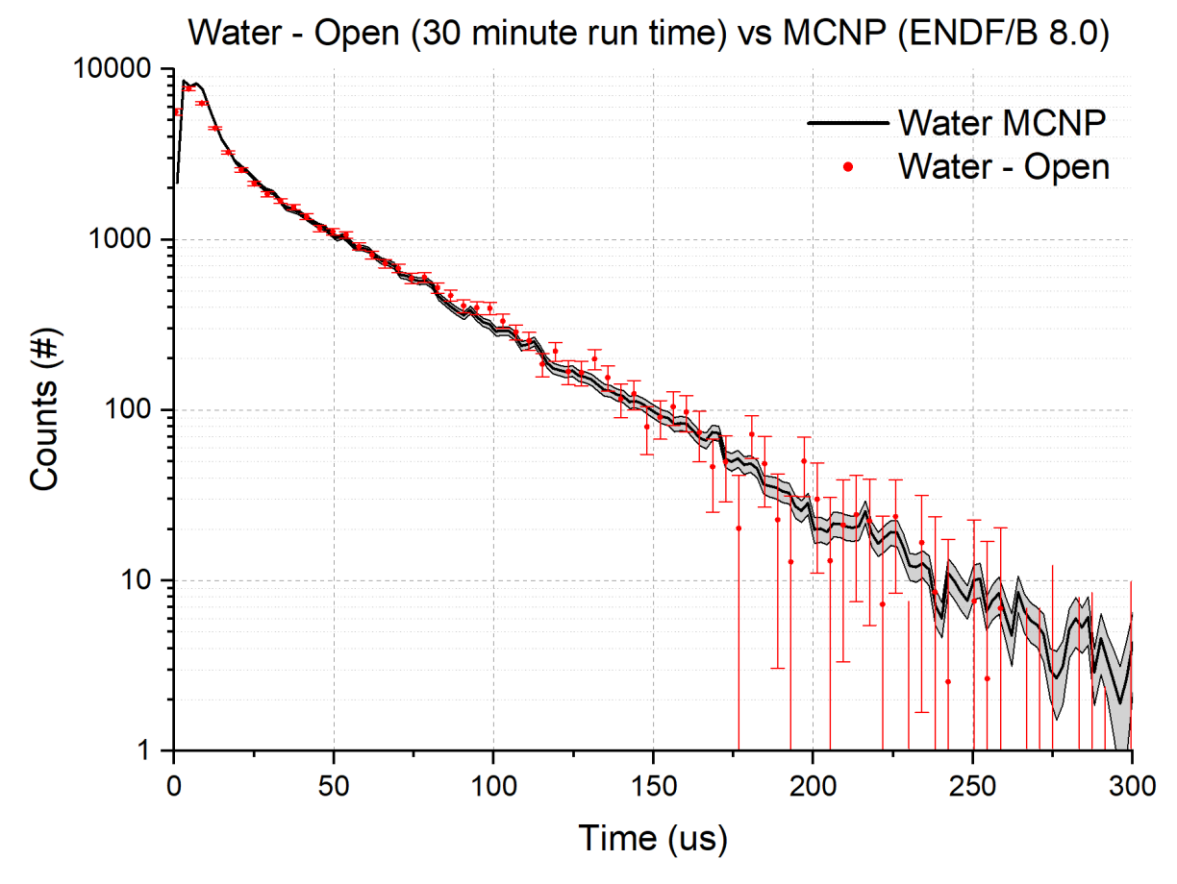
Raw data for water

- Enables measurement between 30-150 micro-seconds
- Room background is dominated by source return



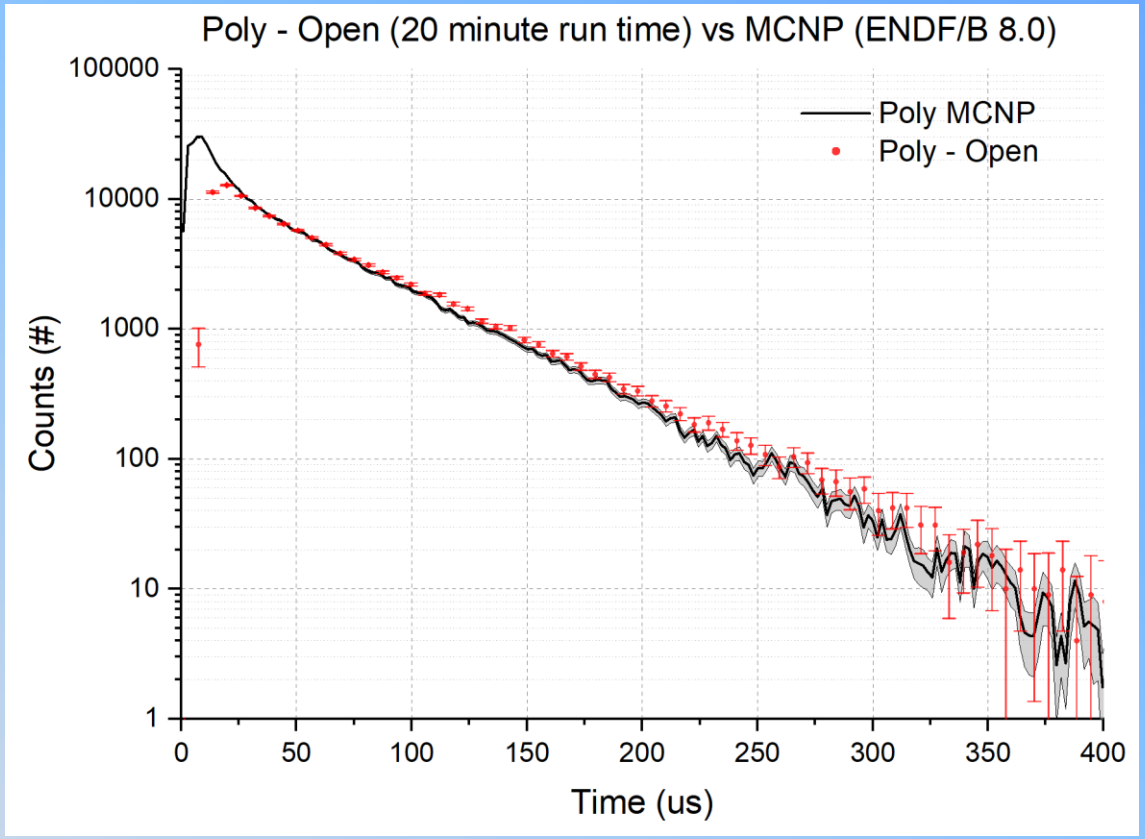
Distilled Water Experiment

- Simulation
  - Source (Flux monitor data)
  - Sample (Water only, no beaker)
  - 3He Detector
  - Air
  - No structures or Cadmium Shield
- Experimental Data shows good agreement with MCNP



Polyethylene Experiment

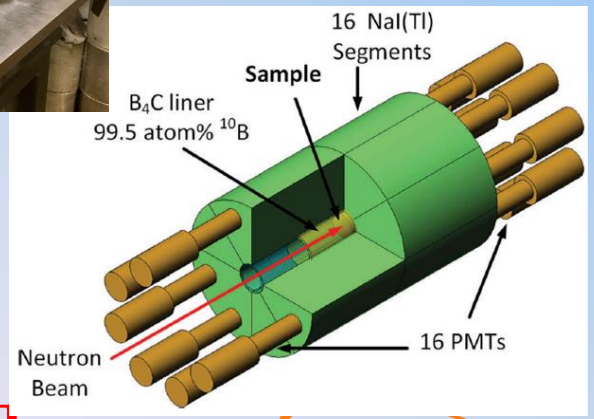
- Pulse discrepancy (0 to 25 μs)
- Simulation results show faster die away (steeper slope)
- Sources of discrepancies may be:
  - Higher total cross section shown before
  - Sample Crystalline structures (affects angular dependent scattering)

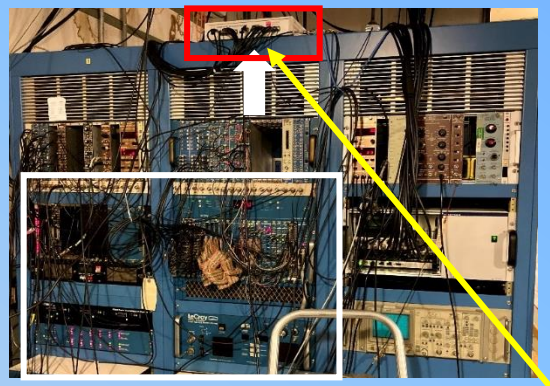


Neutron capture measurements on ^{nat}Ta and ^{238}U

RPI γ-Multiplicity Detector

- 16 segment NaI(Tl) multiplicity detector
  - Total volume: 20 L of NaI(Tl) surrounding the sample
  - Inside of the detector is lined (~1 cm) with a B_4C ceramic sleeve which is enriched 98.4% in ^{10}B to absorb scattered neutrons
  - Greater than 95% efficiency (compared to C_6D_6 which is less than 10%)
- Detector was used for capture yield measurements in 0.01 - 3 keV energy range
- **Detector electronics was upgraded from analog to a 14 bit 250 Mhz Digitizer**

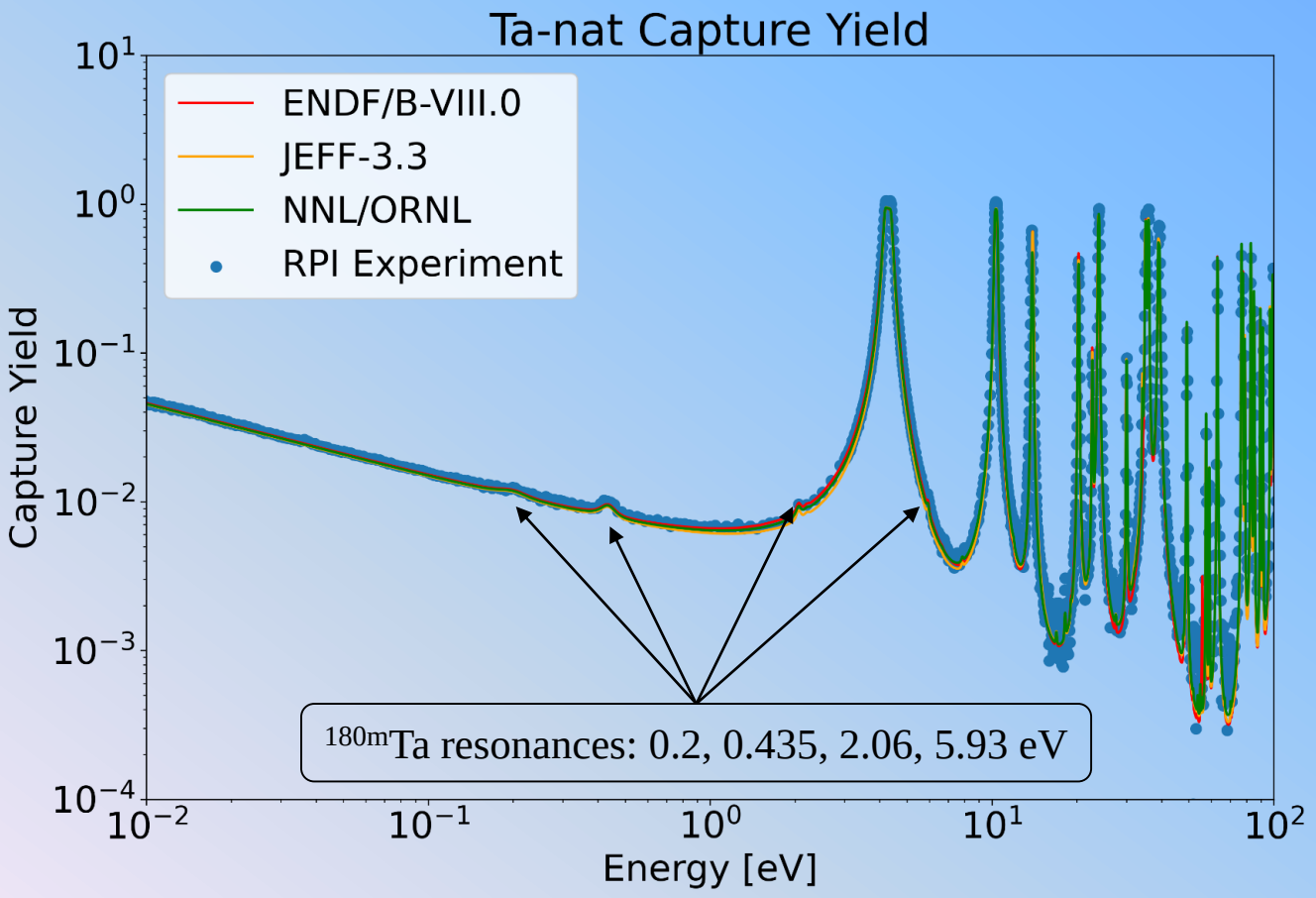




OLD

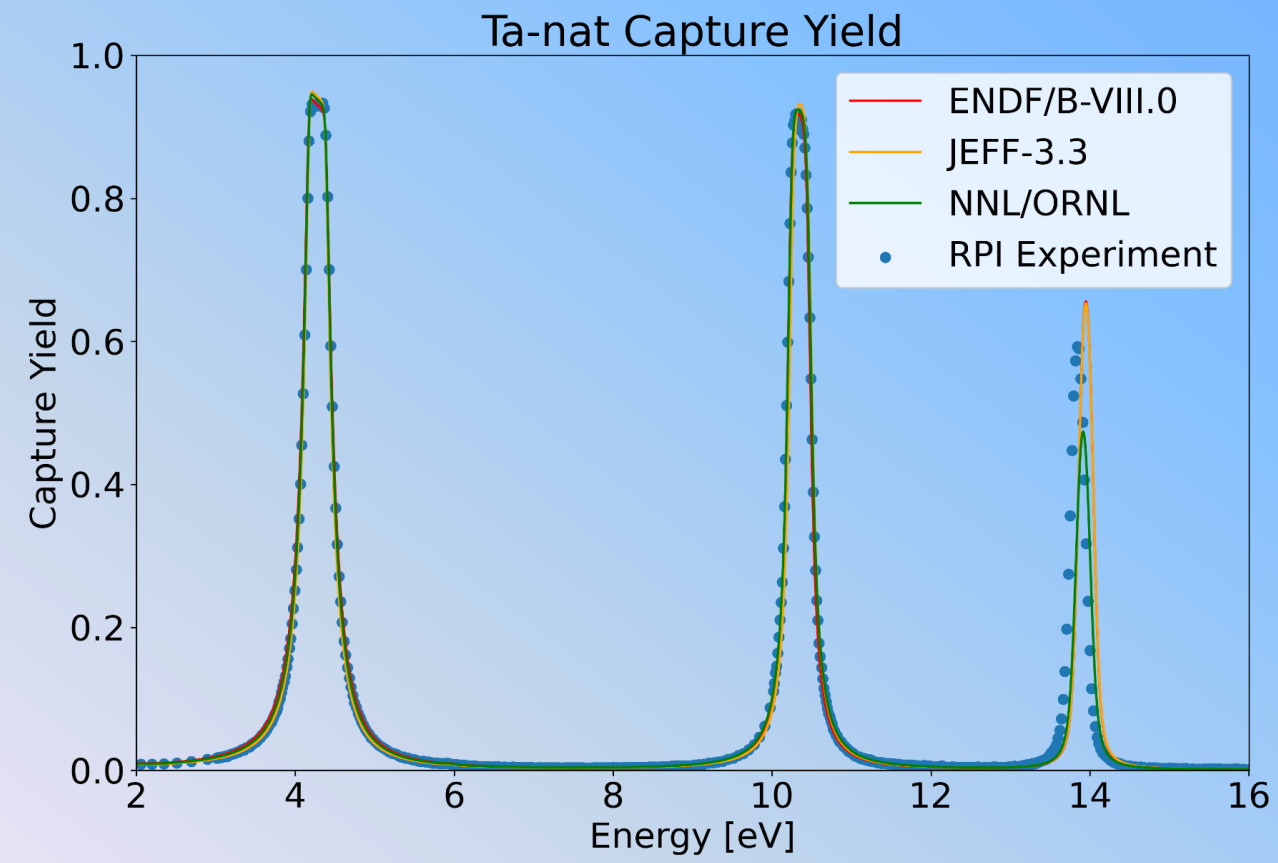
New

Thermal Capture Yield Measurement: ^{nat}Ta



- 10 mil thick ^{nat}Ta
  - 0.012% 180mTa
- Energy Range: 0.01 – 100 eV
- 10 mil natural sample: includes ^{180m}Ta & ^{181}Ta
- ^{180m}Ta evaluation is in JEFF only
- First-order calculated capture yield is shown for evaluations.

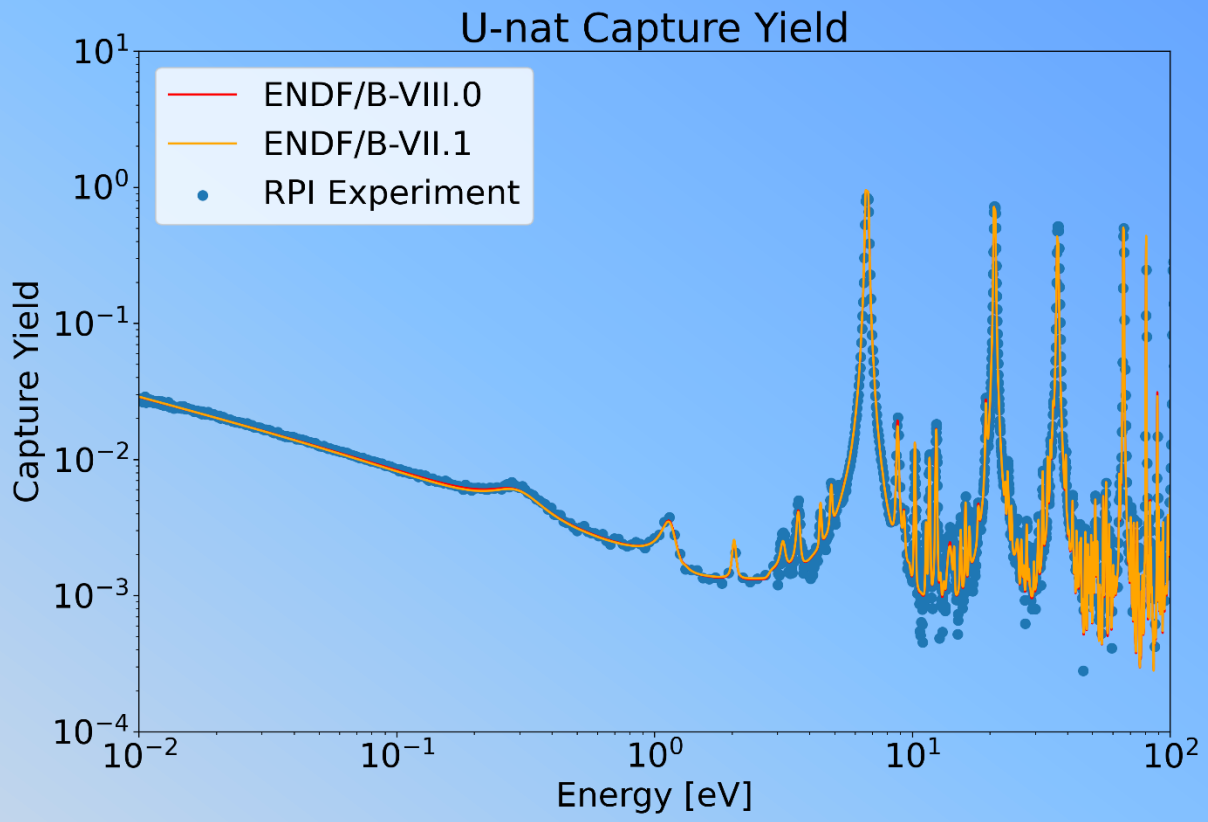
Shifted Ta-181 Resonance: 13.95 eV



- NNL/ORNL evaluation is in better agreement compared to ENDF and JEFF but still does not match the data

^{nat}U Thermal Capture Yield

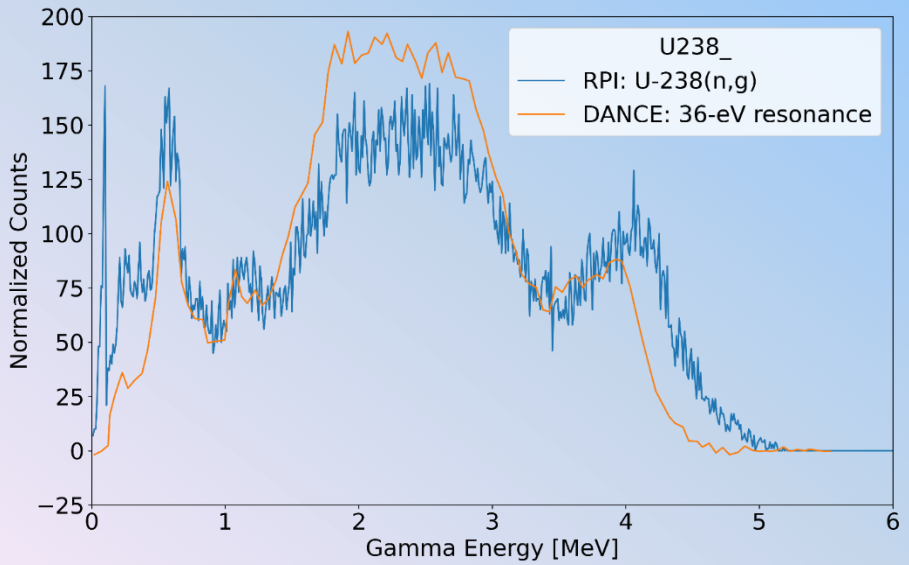
- Sample thickness: 20 mil
- Sample mass: ~18.2 g
- Natural sample: 0.7% ^{235}U
- Validation of the new DAQ system and processing codes (Julia based)



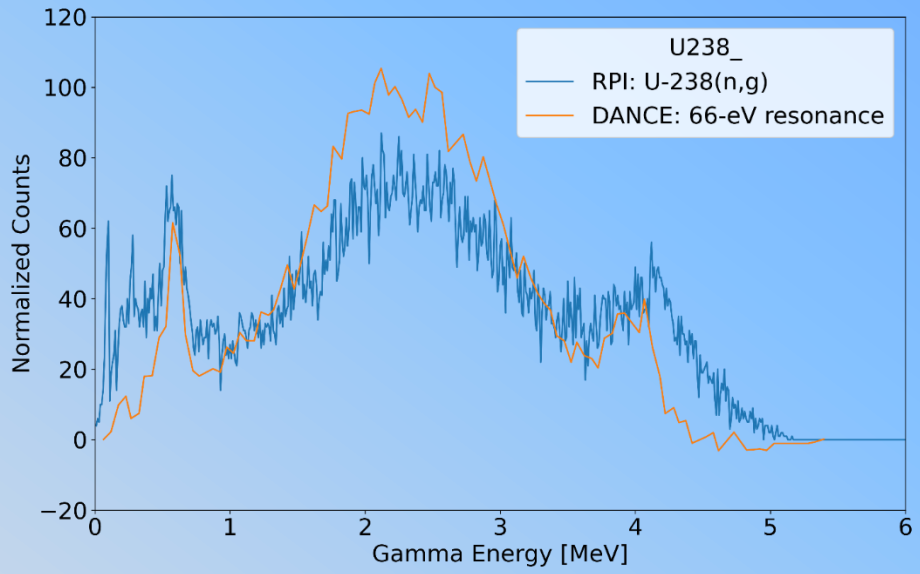
^{238}U γ-emission energy spectra for a two step cascade

- Compared to a measurement using the Detector for Advanced Neutron Capture Experiments (DANCE) array at Los Alamos Neutron Science Center (LANSCE)
  - J.L. Ullmann et al. Nucl. Data Sheets 119, 22–25 (2014)
- General agreement with the LANSCE shape
  - Sum of the low and high peaks is the neutron separation energy of 4.8 MeV

36-eV resonance (window 30-42 eV)



66-eV resonance (window 58-72 eV)



Summary

- A new capture measurement of ^{54}Fe will help improve resonance parameters
- Total cross section was measured for polyethylene, polystyrene, plexiglas and YHx
- Neutron die-away method was developed to provide data for validation of TSLs
- Neutron multiplicity detector improvements were validated with ^{238}U and provided new ^{nat}Ta capture yield in the thermal region.