Overview of Nuclear Data Measurement and Analysis at RPI

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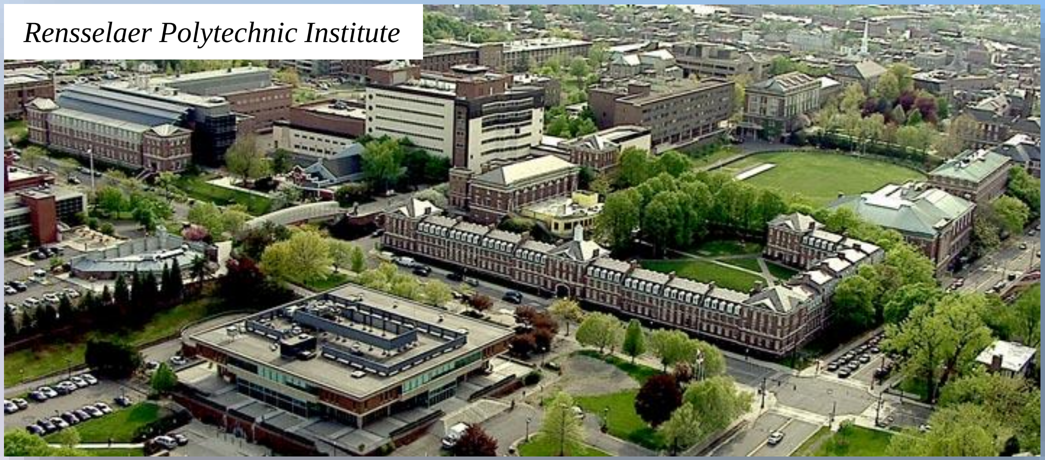

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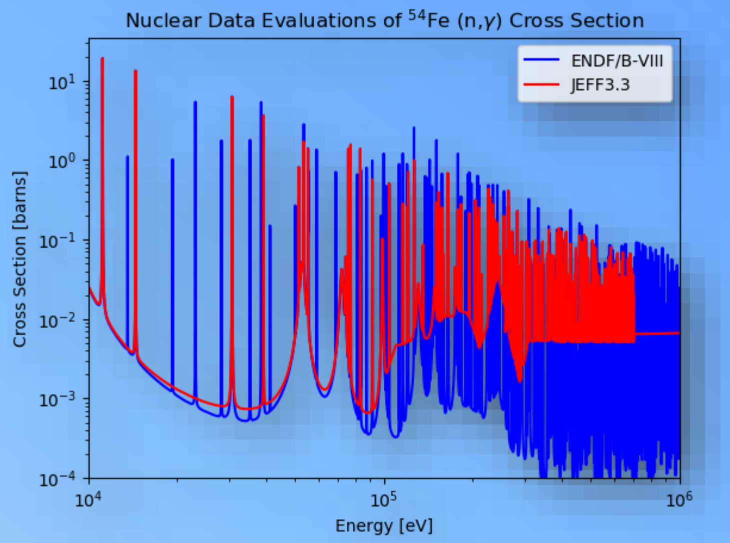
Outline

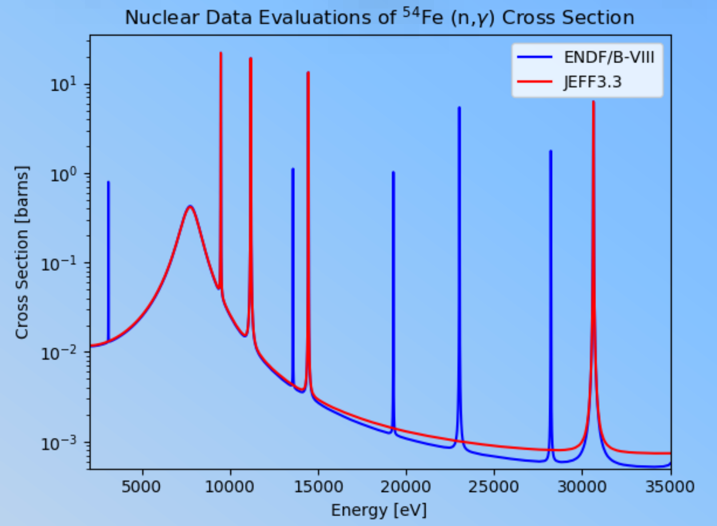
- Neutron capture in ^{54}Fe (S. Singh)
- Neutron capture yield and gamma cascade spectra measurements (K. Cook)
- Thermal neutron die-away measurements (B. Wang)

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
- There are **various discrepancies between different evaluated data libraries**, where some resonances are present in one evaluation and not the other





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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

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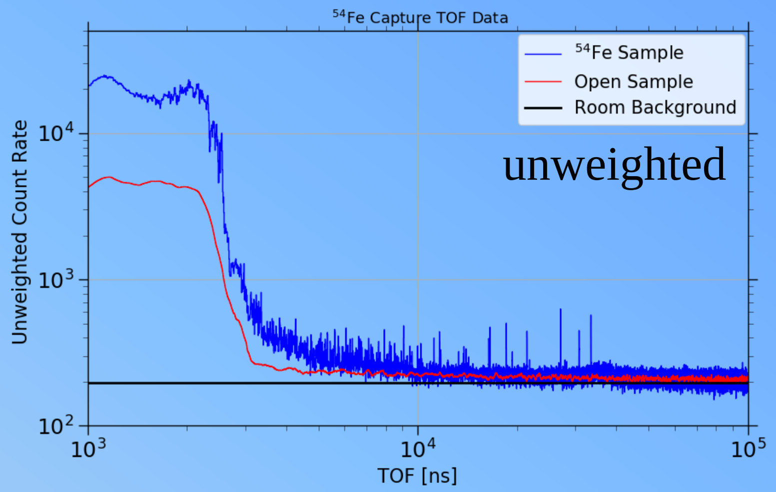
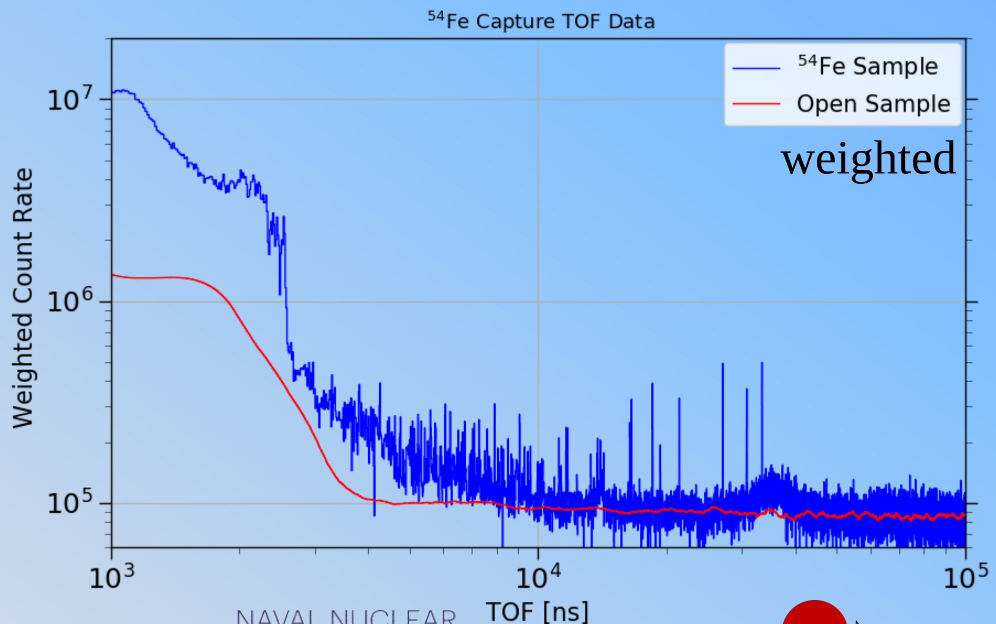
Capture Raw Data

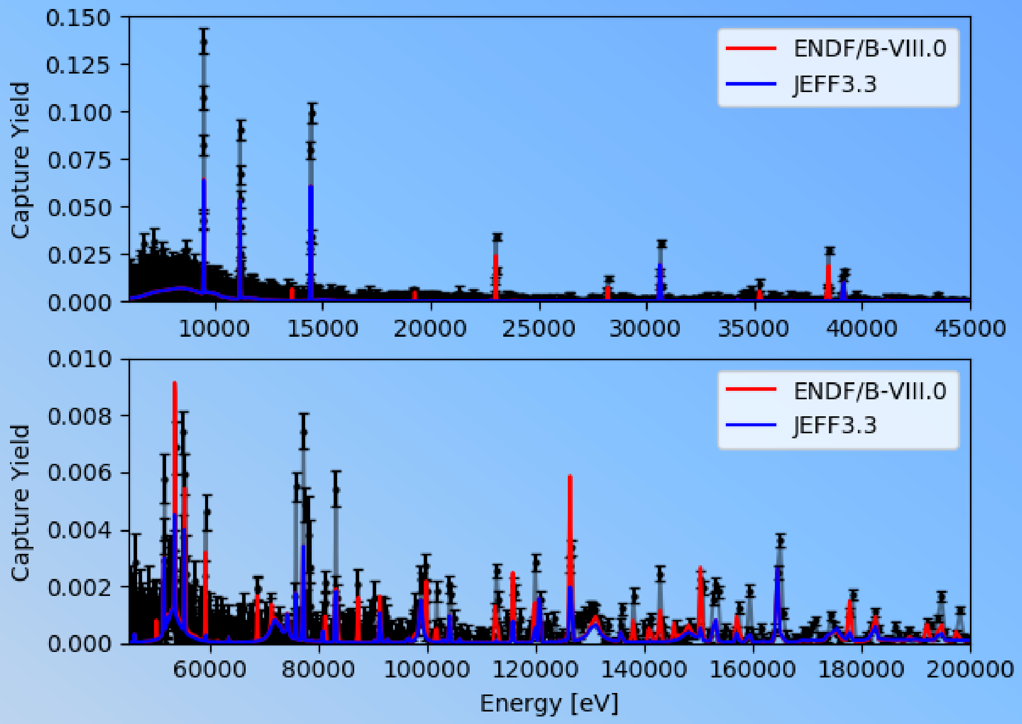
- Resonance structure is clearly observed in the raw ^{54}Fe data.
- Pulse height weighting technique (PHWT) is utilized when processing raw data.
  - Higher energy photon events are weighted more heavily to achieve proportionality of photon energy and detection efficiency.





^{54}Fe Radiative Capture – Results

- RPI capture yield disagrees with evaluations at prominent capture resonances.
- Some missing resonances from JEFF3.3 can be seen in RPI experiment.
- Capture data were normalized to black resonance of Au.
- Energy resolution is limited at higher neutron energies.
- Covariance matrix generation is planned before data is released.



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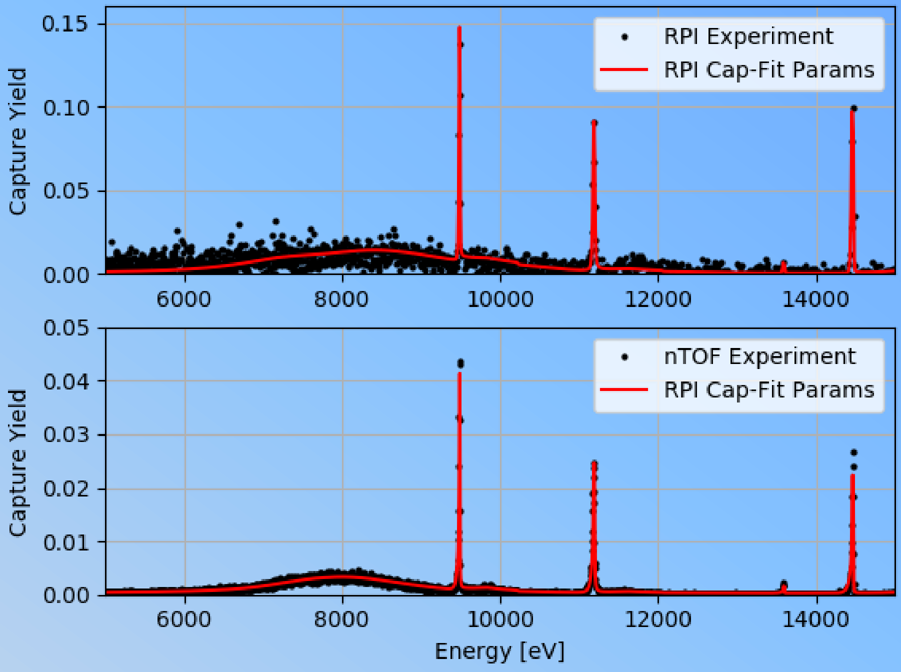
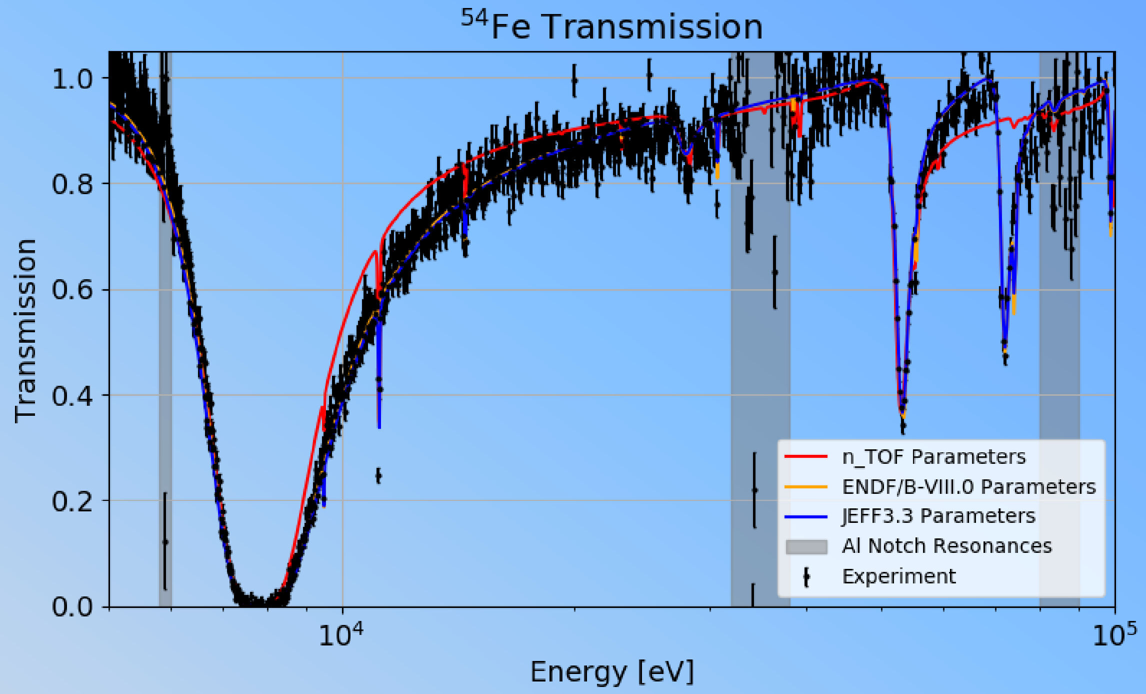
^{54}Fe Capture Data Evaluation

- n_TOF and RPI experiments can be fit simultaneously and agree with one another.
- n_TOF data available in EXFOR needs additional normalization to obtain absolute capture yield
- **Observation:** Some p,d-wave resonances will require large changes in Γ_γ
- **Work Needed:** Extend evaluation up to 1 MeV w/ consideration of data covariances when available.



Transmission Experiment

- Experiment is most useful below 30 keV, where there is very limited previous data available
- Data between 30-150 keV can be used to support higher energy resolution measurements
- Limited energy resolution above 150 keV
- RPI's approach of combining capture and transmission data will improve resonance evaluation effort for ^{54}Fe.
- Covariance matrix will be generated before data is fully released.



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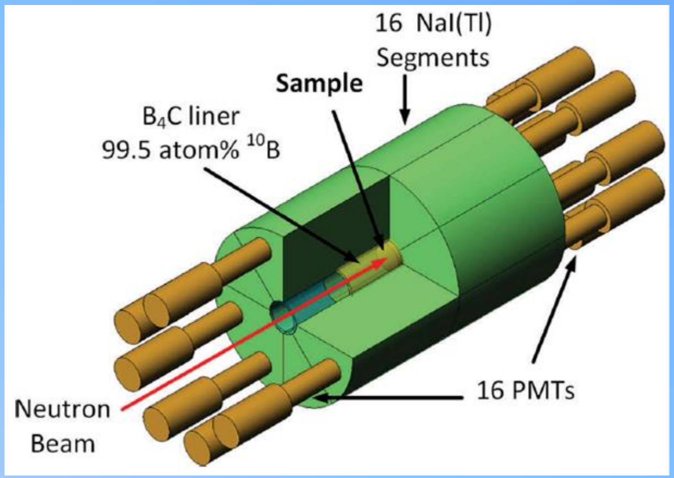
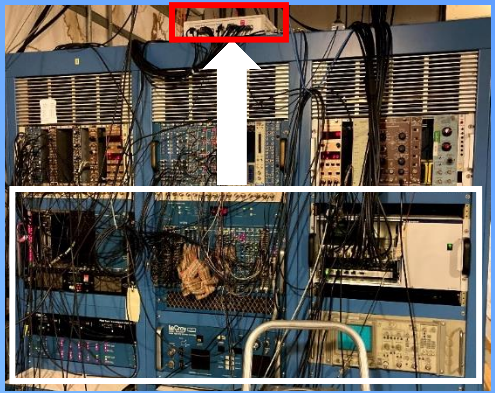
Neutron capture yield and gamma cascade spectra measurements

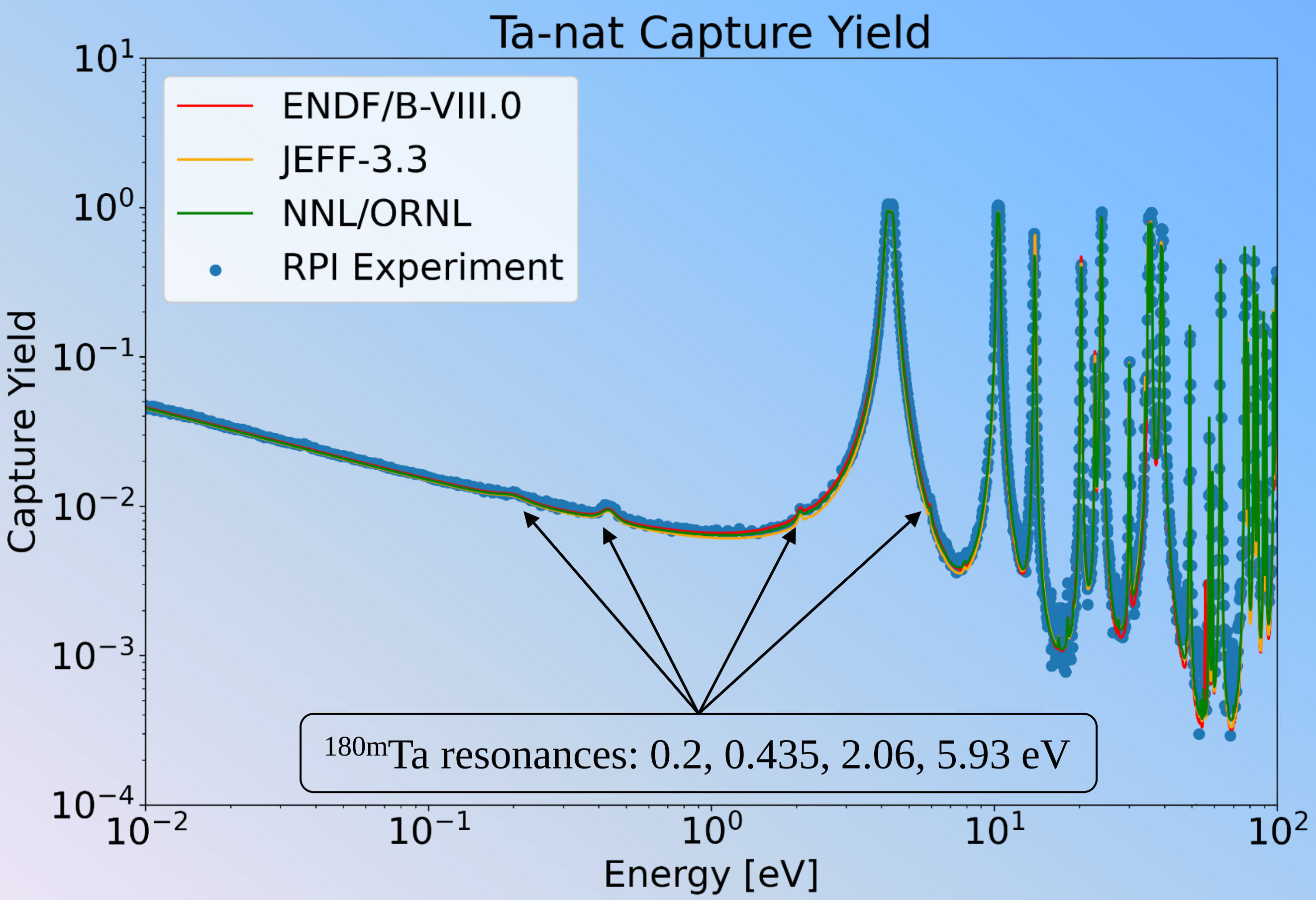
RPI γ-Multiplicity Detector





- **16 segment NaI(Tl) γ-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 99.5 atom% in ^{10}B to absorb scattered neutrons from the sample
  - Up to 96% efficiency for detecting γ-cascades
- **Detector is used for capture yield and γ-spectra measurements**
  - useful neutron energy range: 0.01 eV – 3 keV
- **New digitizer system**
  - Digitize pulse wave for all events on all detectors & obtain the energy of each detected event

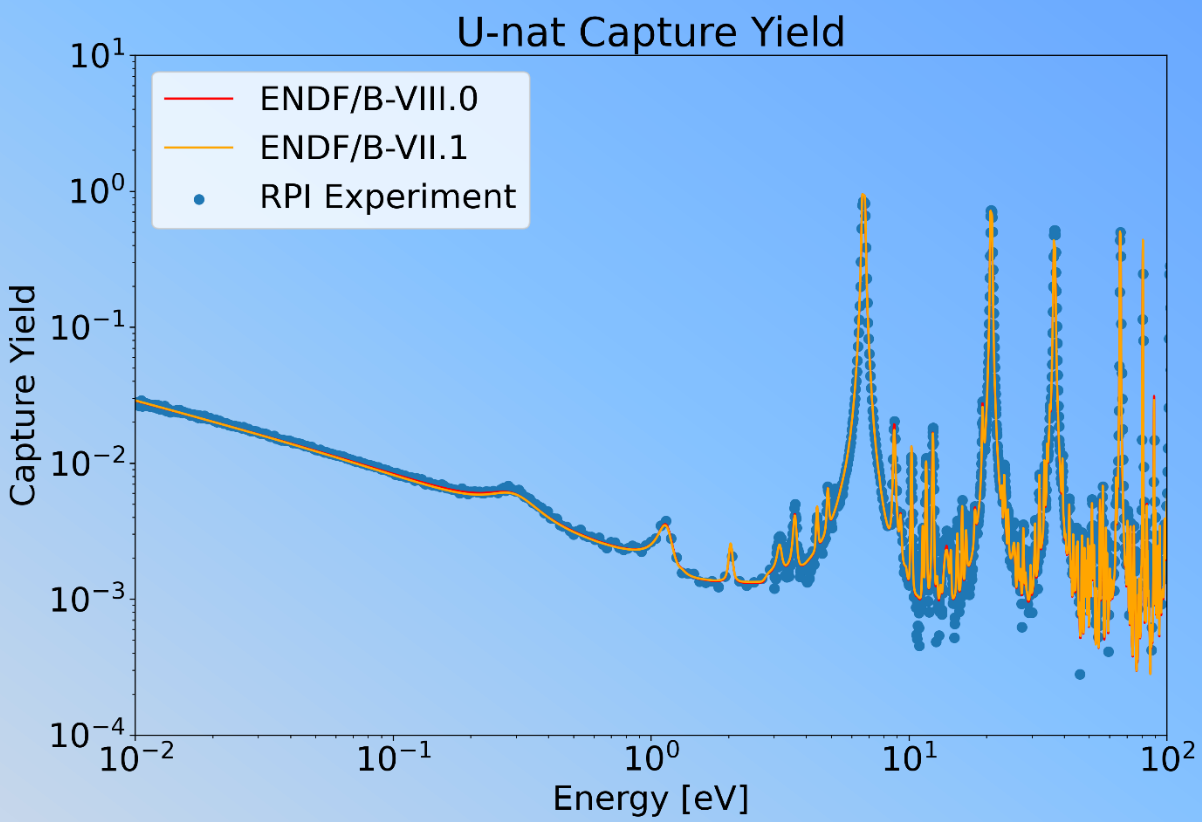
Thermal Capture Yield Measurement: ^{nat}Ta



- 10 mil thick ^{nat}Ta
  - 0.012% 180mTa
- Useful energy range: 0.01 – 100 eV
- **^{180m}Ta evaluation is in JEFF 3.3 but not ENDF-8.0**
- First-order calculated capture yield is shown for evaluations.

^{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)
- **EXFOR does not have ^{238}U or ^{nat}U continues capture yield data below 1 eV. (existing sets include the thermal point only)**



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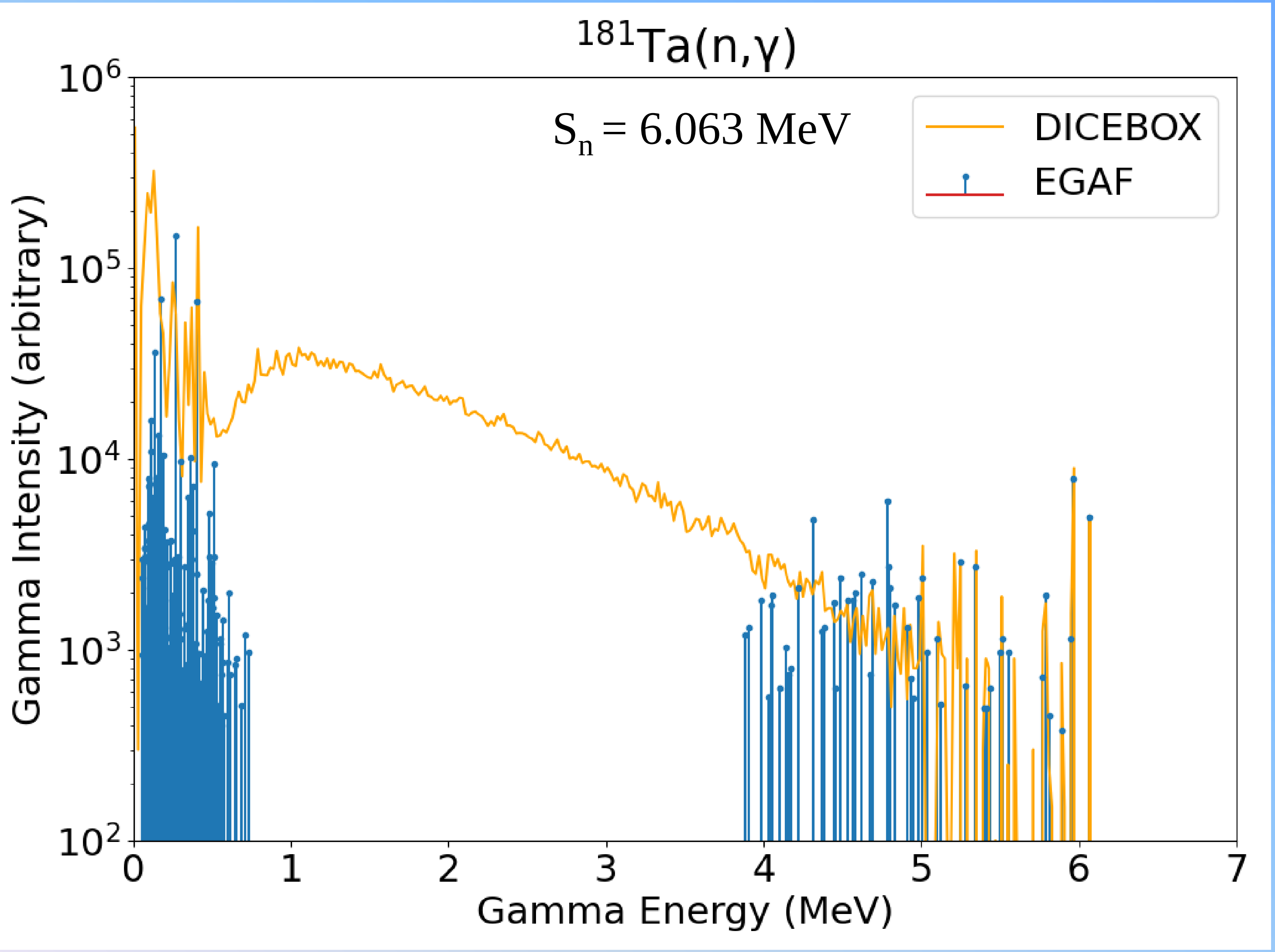
Nuclear Data (structure) Validation

Challenges: Deficiencies in evaluated γ-ray data



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Compare the measured gamma spectra to MCNP 6.2 simulations

Regular MCNP-6.2

Extracts γ-ray data from ACE files (ENDF/B-VIII.0)

MCNP-6.2 with CGM

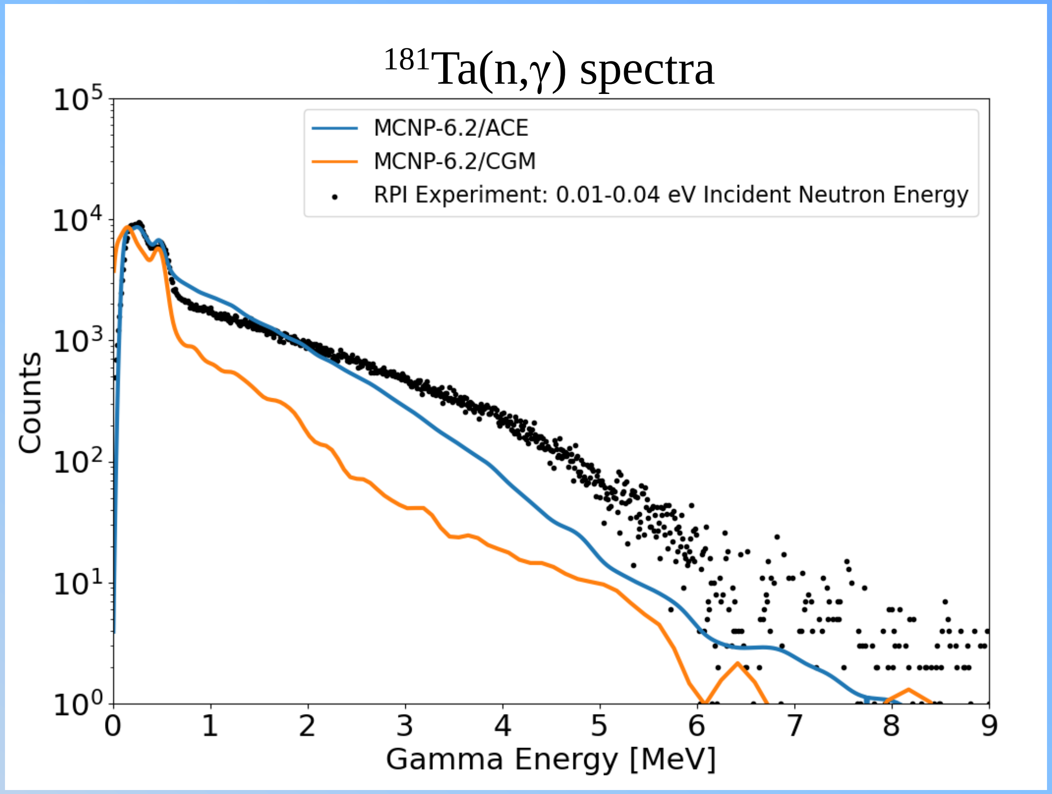
(Cascading Gamma-Ray Multiplicity) Produces correlated secondary γ-emissions

CGM is not working well for capture cascades

binding energy issue was fixed for these calculations

Modified MCNP

Next slide



Large discrepancy between experimental and simulated γ-spectra for ^{181}Ta(n,γ)

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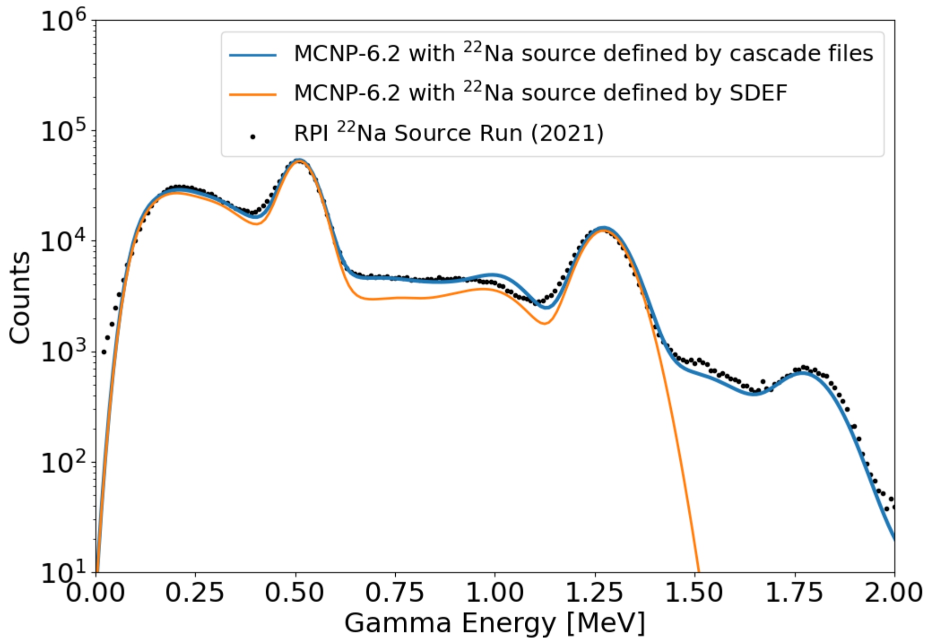
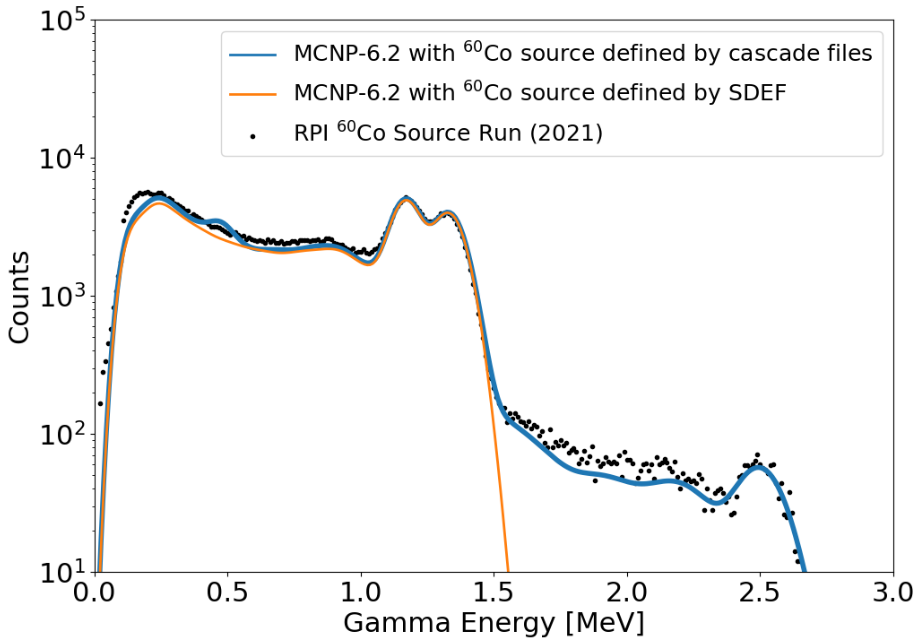
Simulation Methodology
Updates to MCNP-6.2

- Step 1
  - γ-cascades are generated using an external code (i.e., DICEBOX) and written to a file.
- Step 2
  - Modification to MCNP-6.2, for each capture event:
    - Read in a γ-cascade from a cascade file.
    - γ-cascades are transported through the detector geometry.
- Step 3
  - Additional modification to MCNP-6.2.
    - Generate an output file to tally γ-energy deposition in each of the 16 detector segments which enables event-by-event analysis including coincidence.

Simulation Validation

Test Cases: ^{22}Na & ^{60}Co coincidence γ-sources

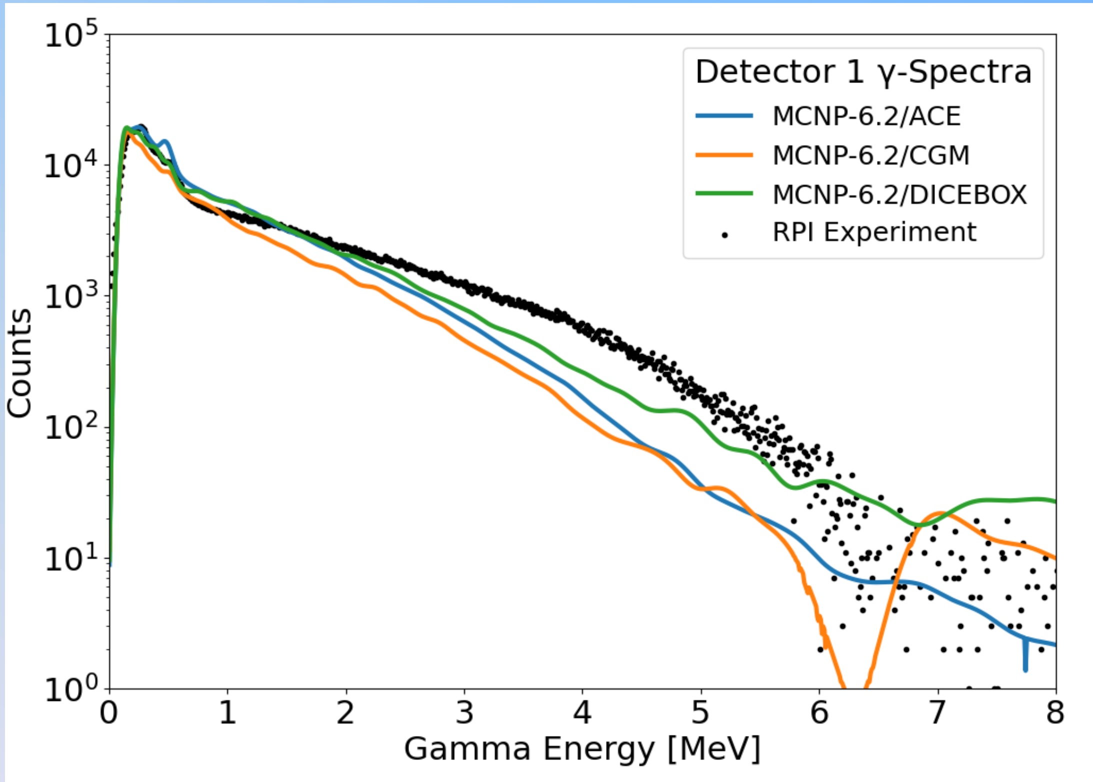




Modified MCNP-6.2 accounts for the high energy sum peak resulting from coincidence

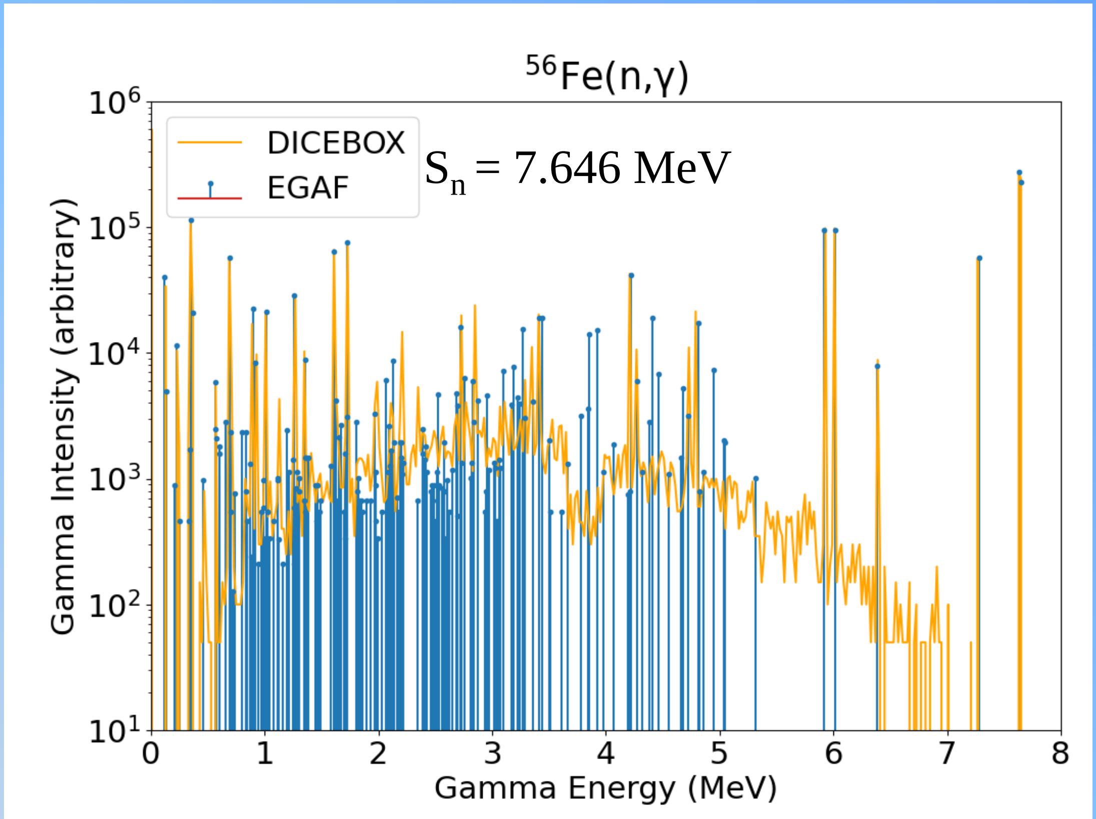
Dicebox and Modified MCNP for ^{181}Ta

- Some improvement but the cascade data is incomplete
- Need to find a material that is known better and easy to measure



Test on something that is better know like ^{56}Fe

- **DICEBOX**
  - models full γ-cascades using evaluated nuclear data
- **EGAF**
  - shows experimentally measured γ-ray lines
  - (does not represent the full cascade)



To qualify the methodology of comparing experimental results to modified MCNP simulations, **the system needs to be benchmarked by isotopes with well-known γ-ray data**

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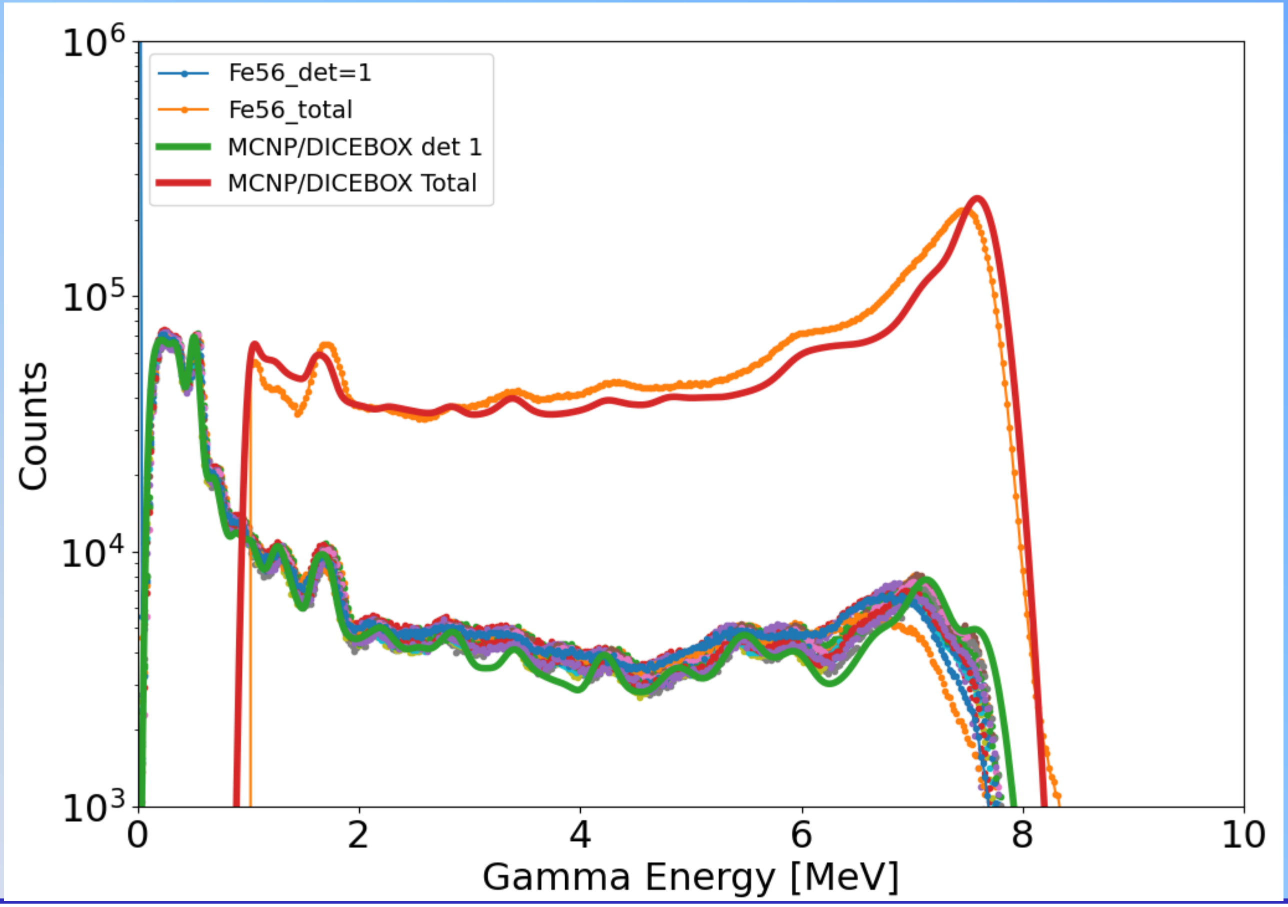
Nuclear Data Validation

^{56}Fe(n,γ) spectra compared to MCNP-6.2/DICEBOX



Minor discrepancies between experimental and simulated γ-spectra for ^{56}Fe(n,γ)

Conclusion: experimental γ-spectra agree with MCNP-6.2/DICEBOX calculations for isotopes with well-known γ-ray data

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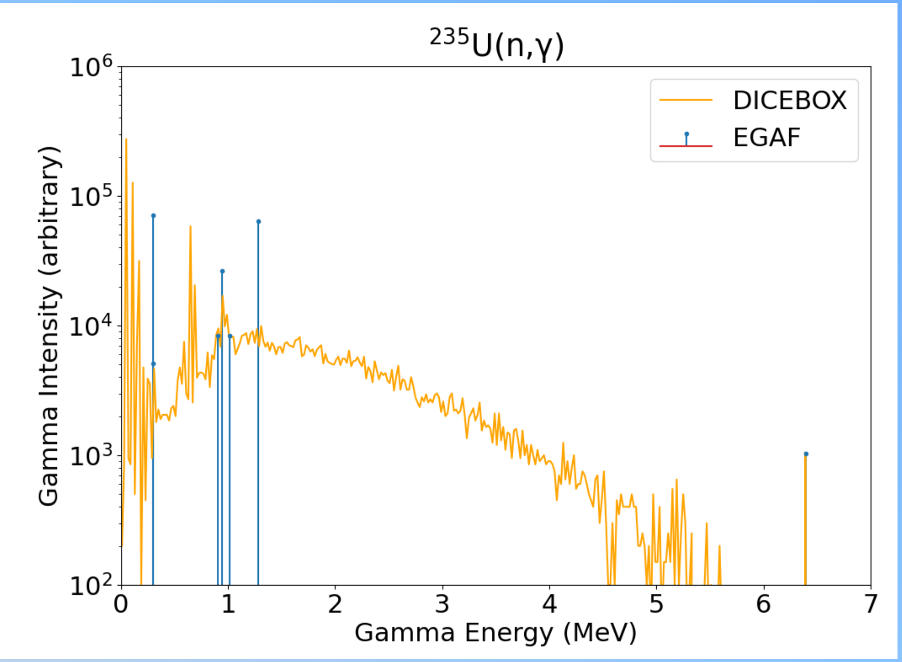
Conclusions

- The experimental, simulation and nuclear data methods were validated for the RPI γ-Multiplicity Detector
- **When the neutron capture γ-cascade data is well-known, the γ-emission spectra can be accurately calculated using the modified simulation tools**
- RPI γ-Multiplicity Detector system is now ready for analysis and recommendations for isotopes with deficiencies in γ-ray data

Future Work

- Develop a method for analyzing and adjusting nuclear data for ^{59}Co, ^{55}Mn and other measured isotopes including **^{181}Ta**
- Compare experimental γ-emission spectra with MCNP-6.2/DICEBOX simulations for **^{238}U and ^{235}U**
  - Most interesting for reactor applications, most difficult to measure and simulate (due to the fission contribution)



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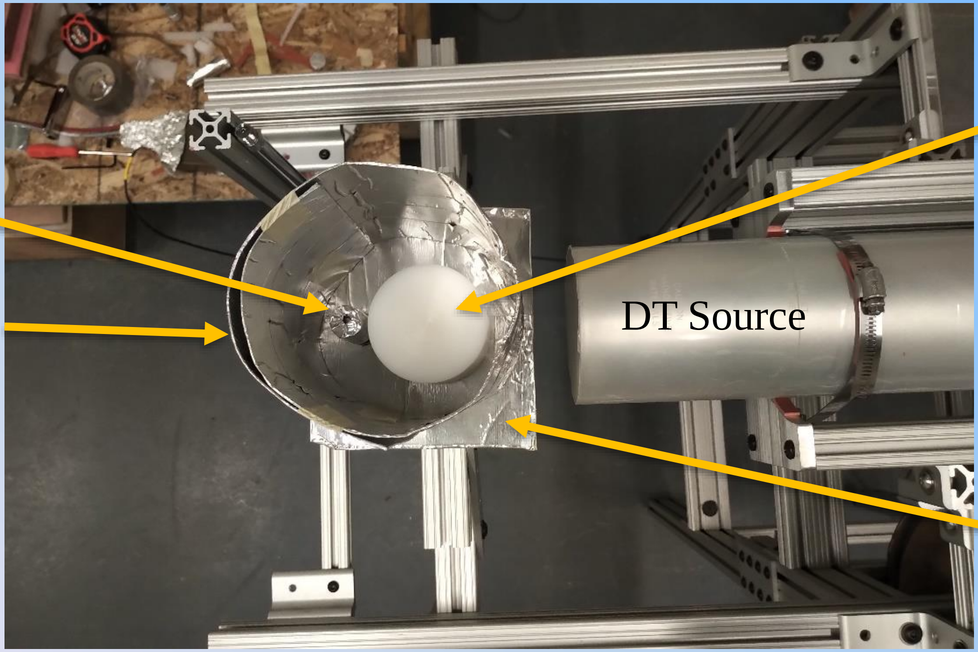
Thermal neutron die-away measurements

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.

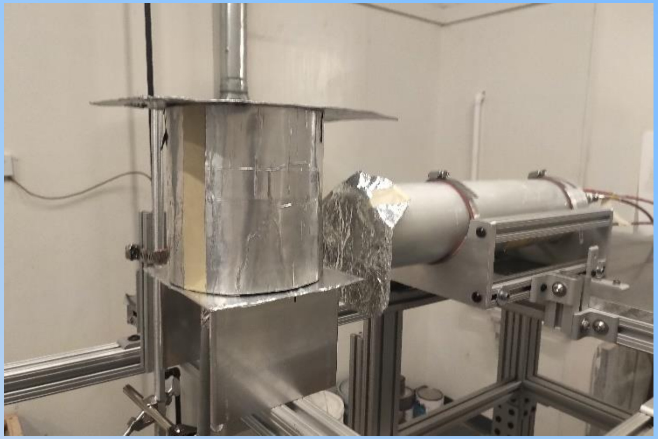


Water Measurements

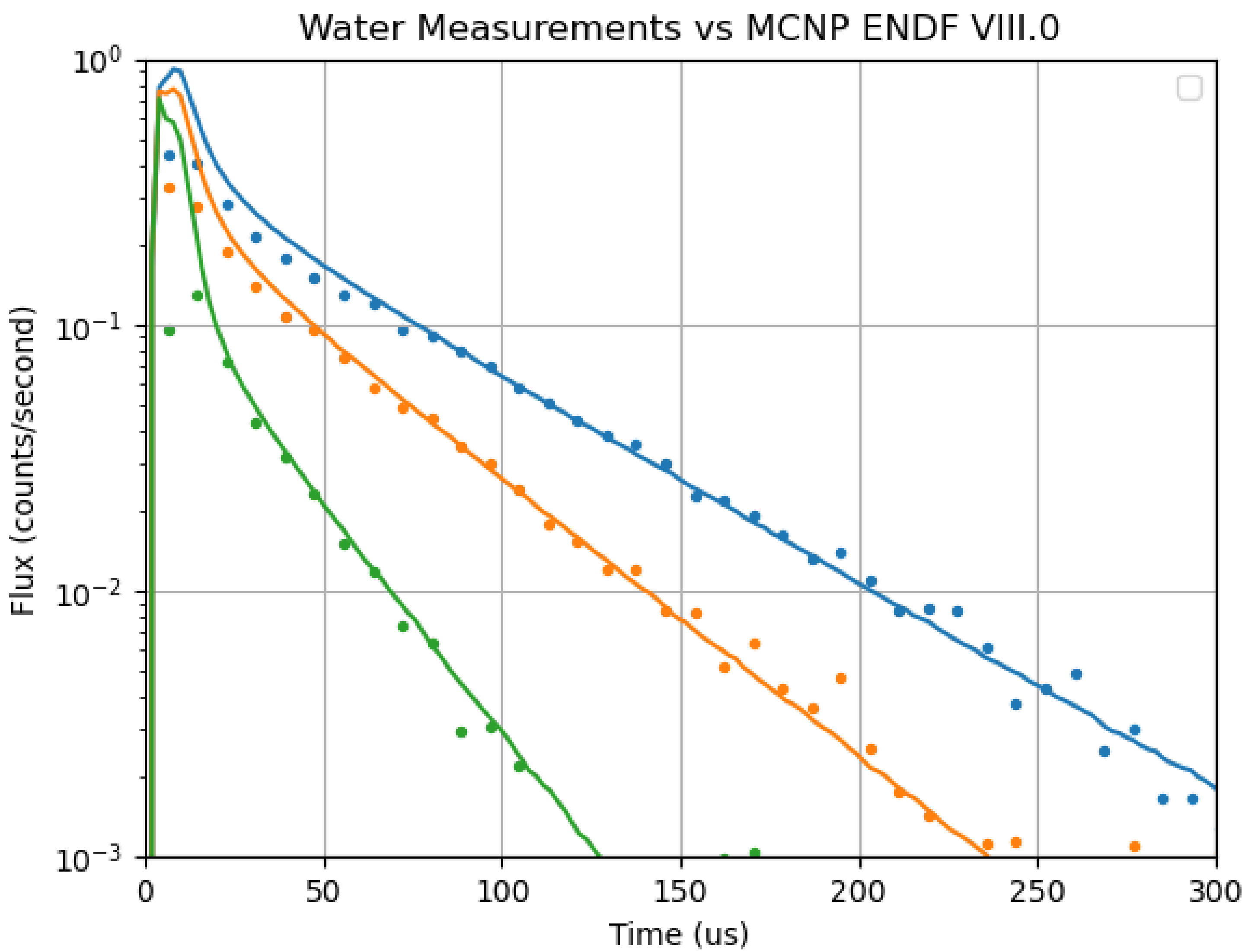
Aluminum Containers: 600ml, 315ml, 125ml

600ml container on experimental table

125ml container on experimental table

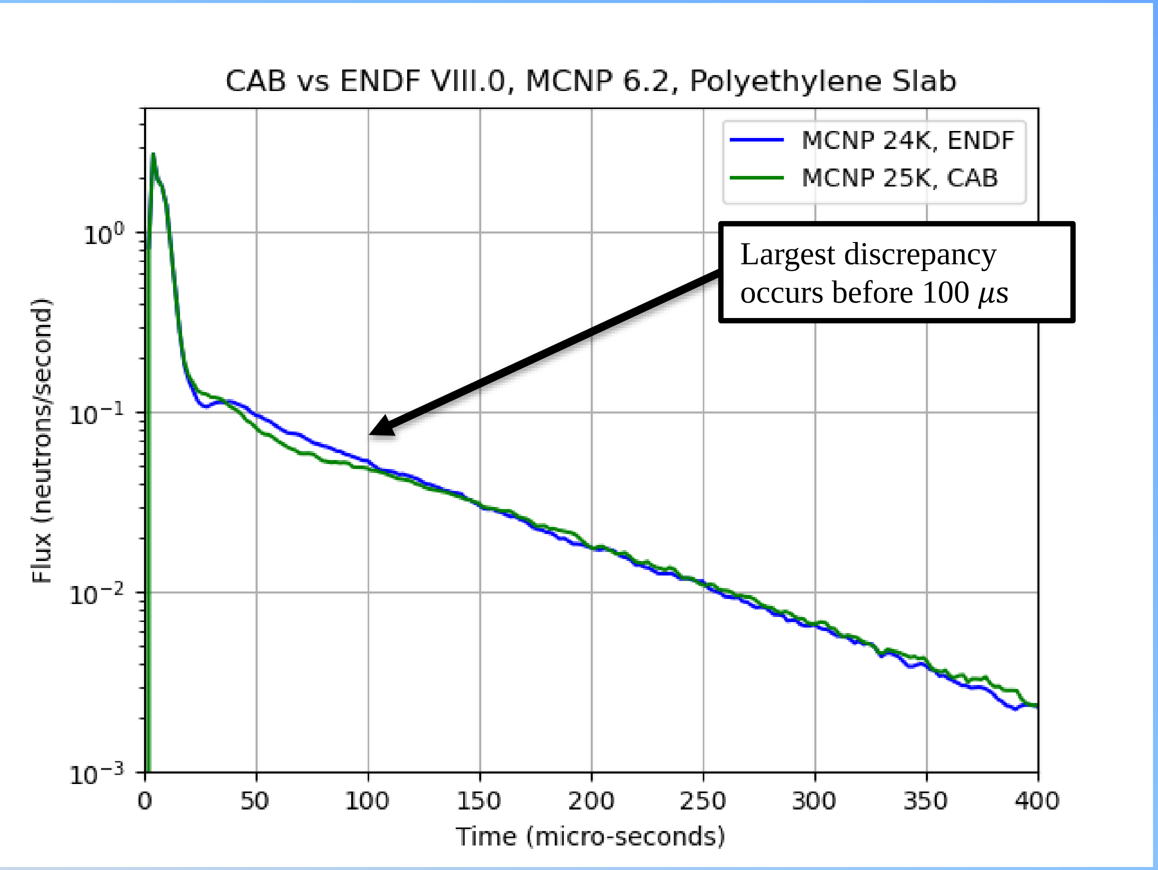


Experimental setup with full shielding


Water Measurements vs MCNP ENDF VIII.0
Flux (counts/second)
Time (us)
10^0
10^{-1}
10^{-2}
10^{-3}
0
50
100
150
200
250
300

Low Temperature Measurements

- Noticeable short time discrepancies between CAB and ENDF evaluations for low temperate Polyethylene
- Seen as an opportunity due to TSL discrepancy and available equipment
- Can a PNDA experiment discern the differences?



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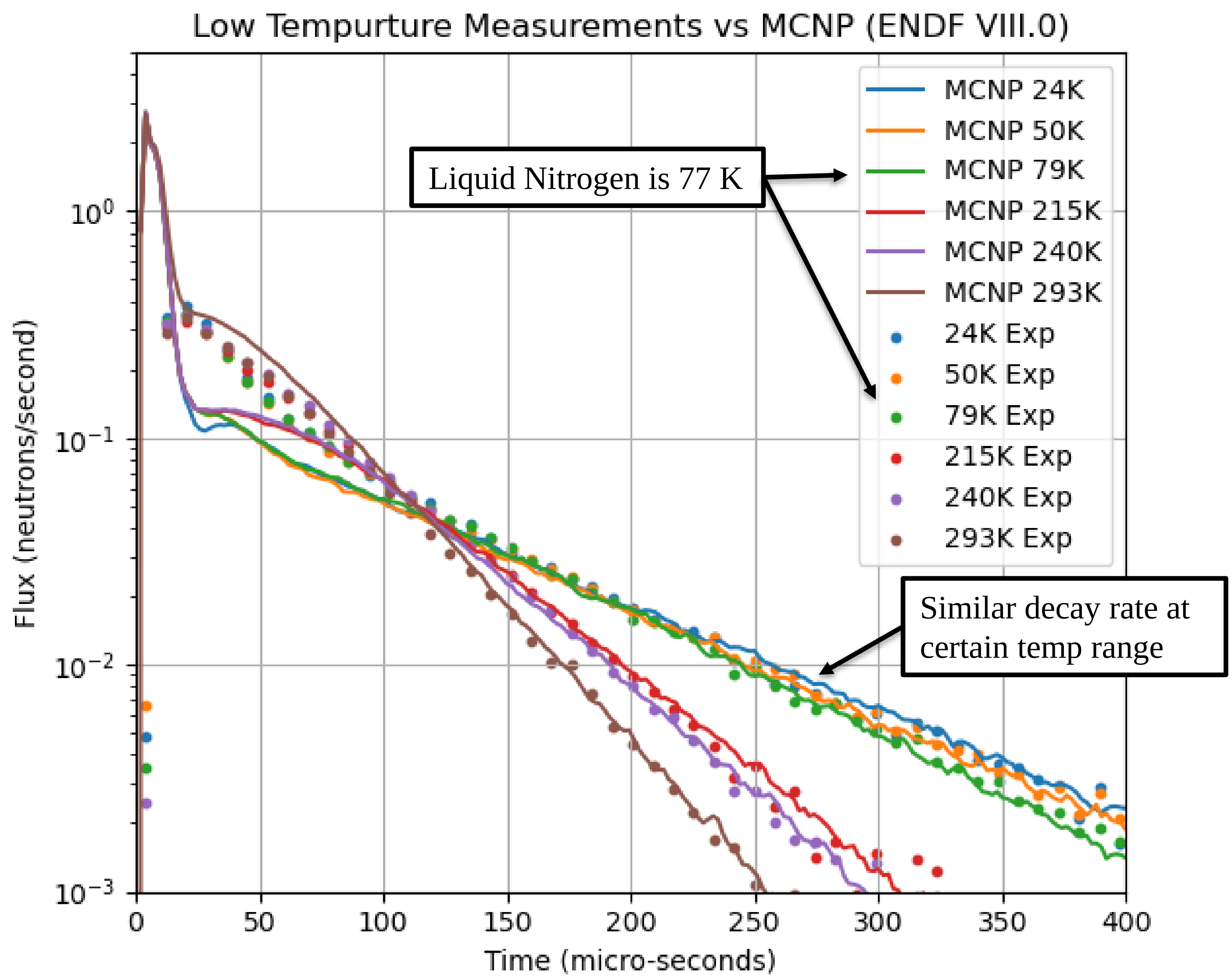

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Summary

- New capture and transmission measurements for ^{54}Fe will help improve resonance parameter evaluation

- Neutron capture gamma cascade spectra and yields were measured in the resolved resonance region and compared to evaluations
  - Helps test current structure data.
  - MCNP6.2 event be event simulation was developed.

- Pulsed neutron die-away method was developed as a tool to provide data for validation of TSLs

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