Neutron Capture and Transmission Measurements and Evaluation of ^{54}Fe at the RPI LINAC

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Presented by:

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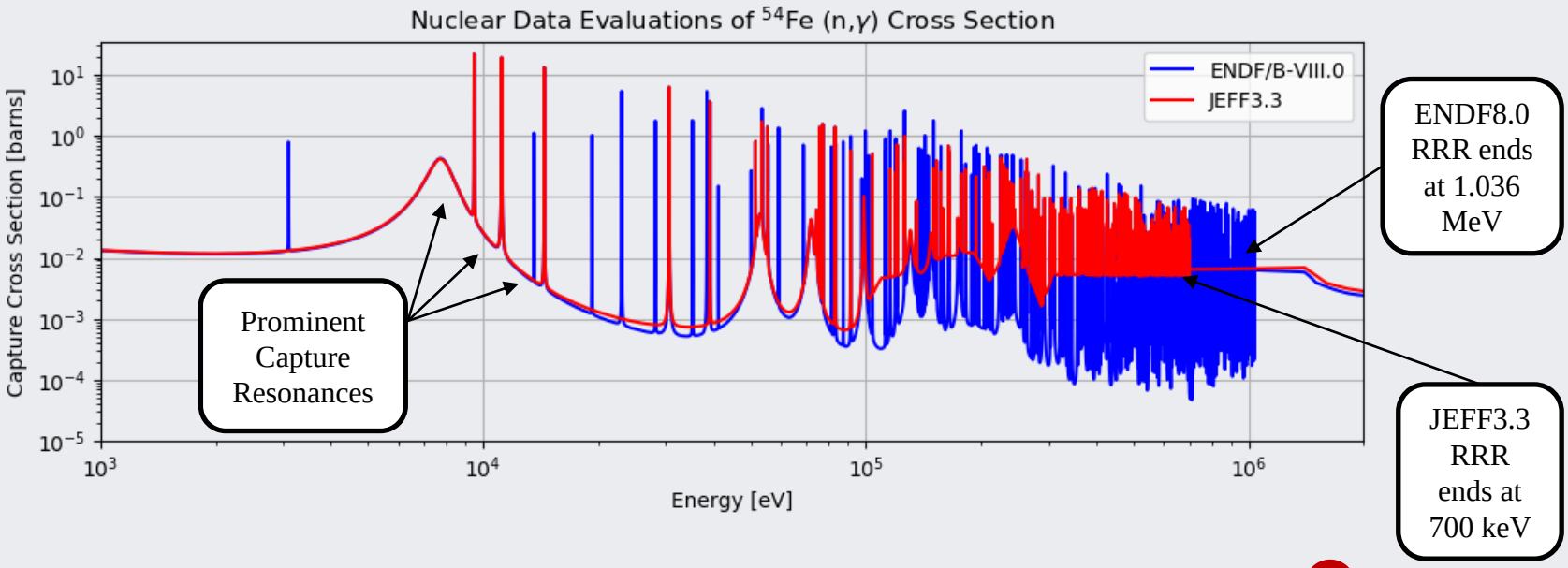
Major Accomplishments in 2022

- Completed RPI ^{54}Fe transmission data reduction.
  - Compared data to other experiments and completed preliminary evaluation work.
- Selected useful ^{54}Fe capture and transmission experiments from EXFOR for preliminary evaluation.
  - Reproduced experiments using SAMMY and resonance parameters were fit to some data.
- Identified and fixed discrepancy between n_TOF and RPI capture measurements.
  - Corrected absolute normalization issue in n_TOF data on EXFOR.
- Developing a neutron beam imaging system to improve future capture measurements.
- Completed RPI candidacy exam in December 2022.

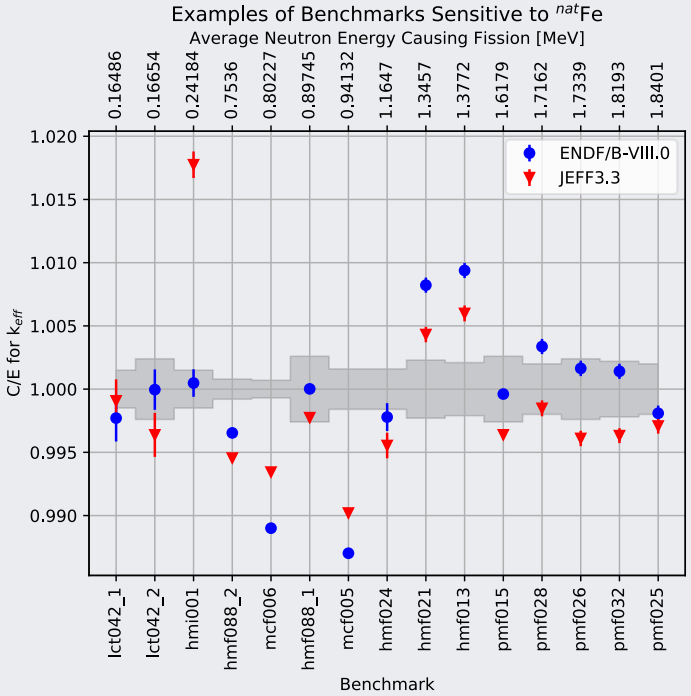
Project Overview

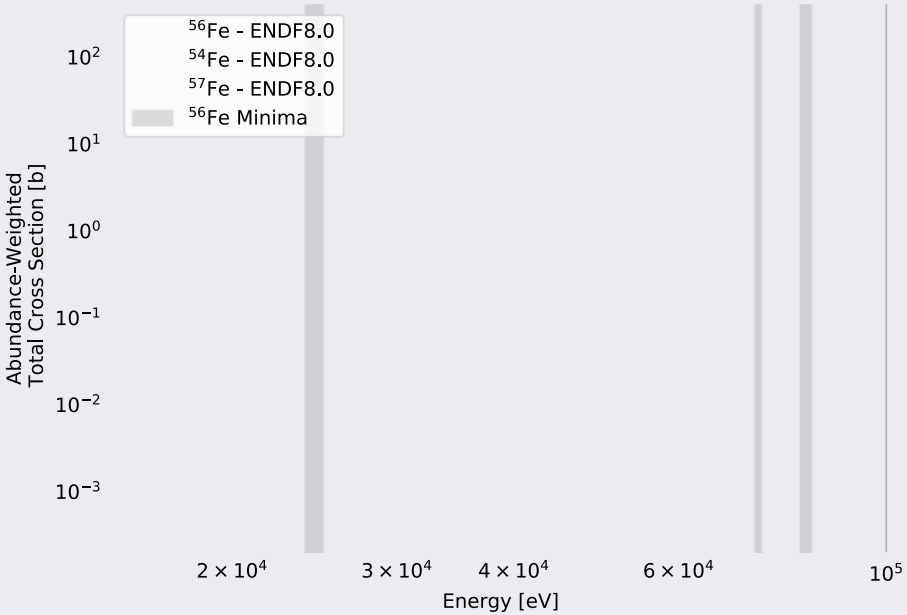
- Motivation:
  - Criticality safety calculations require high accuracy nuclear data to reduce uncertainties
  - ^{54}Fe neutron cross sections have not been well-studied relative to ^{56}Fe.
    - Iron is important in shielding, criticality safety, and stellar nucleosynthesis
- Project Goals:
  - Perform resonance analysis and fitting for ^{54}Fe cross section in the keV region using RPI and EXFOR nuclear data
  - Perform radiative capture and transmission measurements of ^{54}Fe in the keV energy region



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

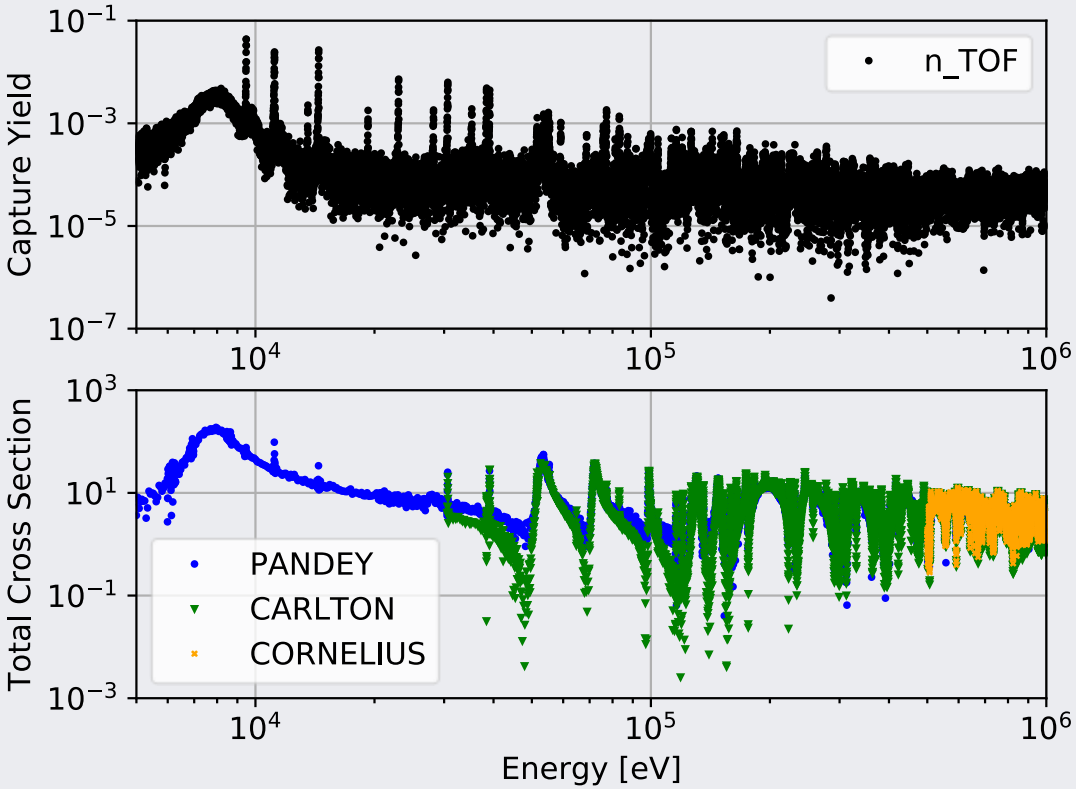
- Iron is very important to study with respect to radiation shielding, criticality safety, and stellar nucleosynthesis.
- Since Iron is an important structural material in nuclear reactors, benchmarks can be shown to have sensitivity to ^{nat}Fe cross sections.
- In the minima of ^{56}Fe cross sections, neutrons can stream through a shielding wall and pose a health risk.
  - **The cross sections of minor isotopes is important in the minima of ^{56}Fe.**





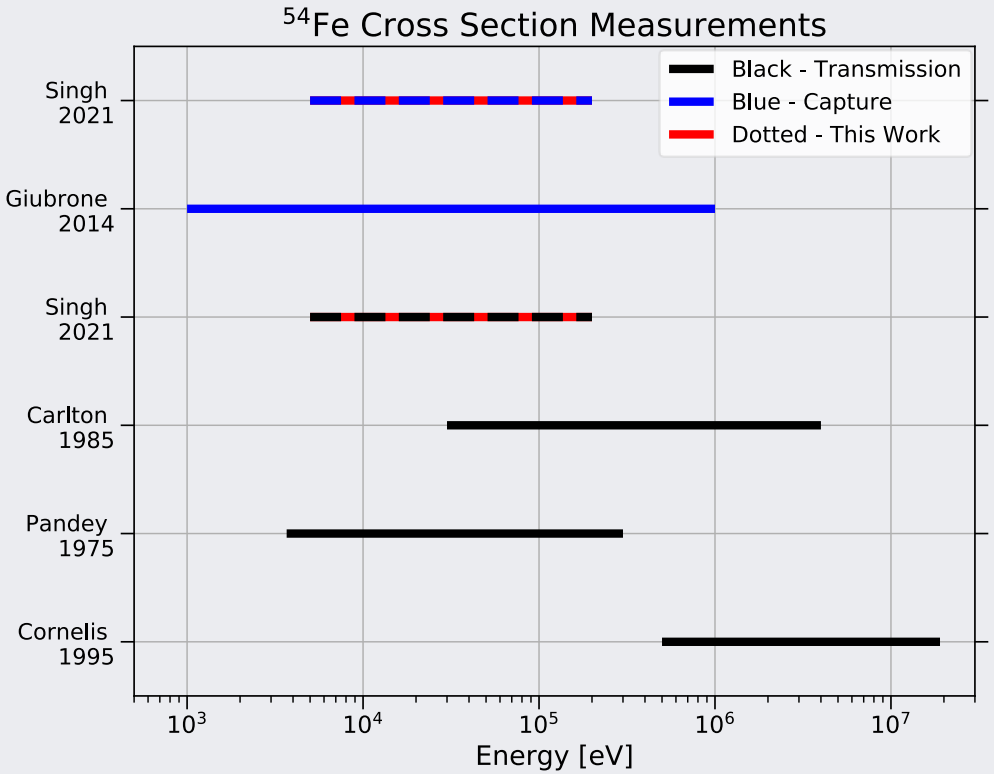
Existing ^{54}Fe Measurements

- Examination of existing measurements on EXFOR was completed, some of these measurements will be used in the RPI RRR evaluation.
- **Radiative Capture:**
  - A single high-resolution dataset from n_TOF was uploaded to EXFOR following RPI capture measurements.
  - Data are reported up to 1 MeV, will be used in RPI evaluation.
- **Transmission:**
  - Several excellent transmission measurements exist in EXFOR, with varying energy resolution.
  - Pandey data below 30 keV has issues that need to be investigated.
  - All three measurements shown will eventually be considered in the RPI ^{54}Fe evaluation.



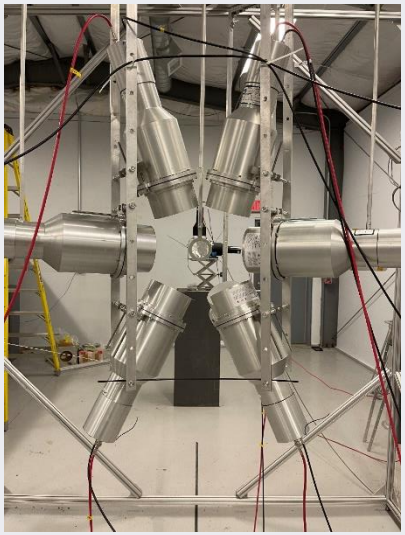
RPI ^{54}Fe Measurement Campaign Overview

- The RPI capture and transmission measurements both provide valuable insight and address deficiencies in EXFOR.
- RPI capture measurement provides additional data for evaluation work and comparison to the n_TOF experiment.
- RPI transmission measurement provides valuable data below 30 keV, a region where prominent capture resonance occur
  - Will help in evaluation work.



RPI ^{54}Fe Measurement Campaign Overview

- Capture data were taken of a ~0.021 [a/b] 96% enriched ^{54}Fe sample.
  - Open, Pb samples used for background corrections
  - B_4C sample used for the relative flux shape.
  - Absolute normalization was made to a Au sample.
  - 11.2 ns pulse width was selected as a trade-off between beam power and resolution.
  - C_6D_6 capture array was used with digital electronics for data collection.
- Transmission measurement was done using the same enriched sample.
  - Li-glass detector was used with a depleted uranium sample for validation, open, and ^{nat}Fe sample.
  - Analog electronics used to collect data.



RPI Capture Data Reduction

- Reduction of the raw digital capture data to a yield is very tedious.
- Pulse height weighting technique (PHWT) is used to weight each detector pulse.
  - Needed to ensure unbiased capture measurements are being taken.

$$Y_i = \frac{R^{Fe}_{Fe\,i} - R^{Fe}_{O\;i}\frac{M_{Fe}}{M_O} - k_p\left(R^{Pb}_{Pb\,i}\frac{M_{Fe}}{M_{Pb}} - R^{Pb}_{O\;i}\frac{M_{Fe}}{M_O}\right)}{f_n\,\frac{R^{UW}_{B4C\,i} - R^{UW}_{O\;i}\frac{M_{B4C}}{M_O}}{Y_{B4C\,i}}}$$

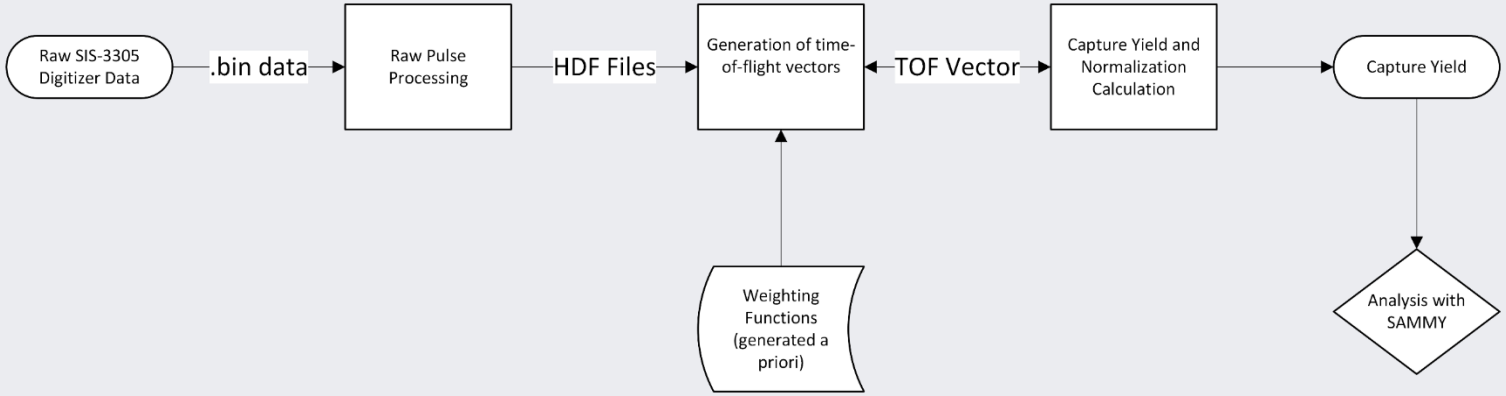
$f_n = Normalization\ Factor$

$k_p = In\ Beam\ Gamma\ Correction\ Factor$

$R^x_y = Count\ Rate\ of\ sample\ y\ weighted\ by\ x$

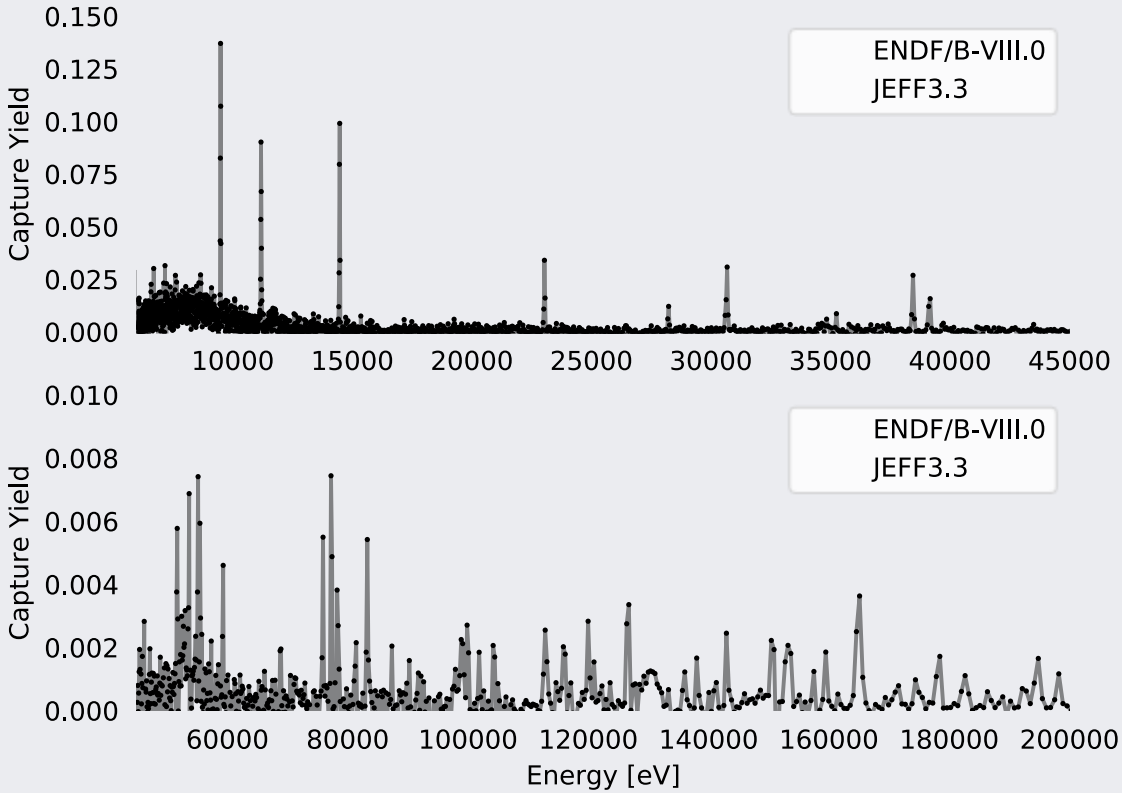
$M_x = Monitor\ to\ trigger\ ratio\ of\ sample\ x$

$Y_{B4C} = MCNP\ calculated\ yield\ from\ B_4C\ sample$



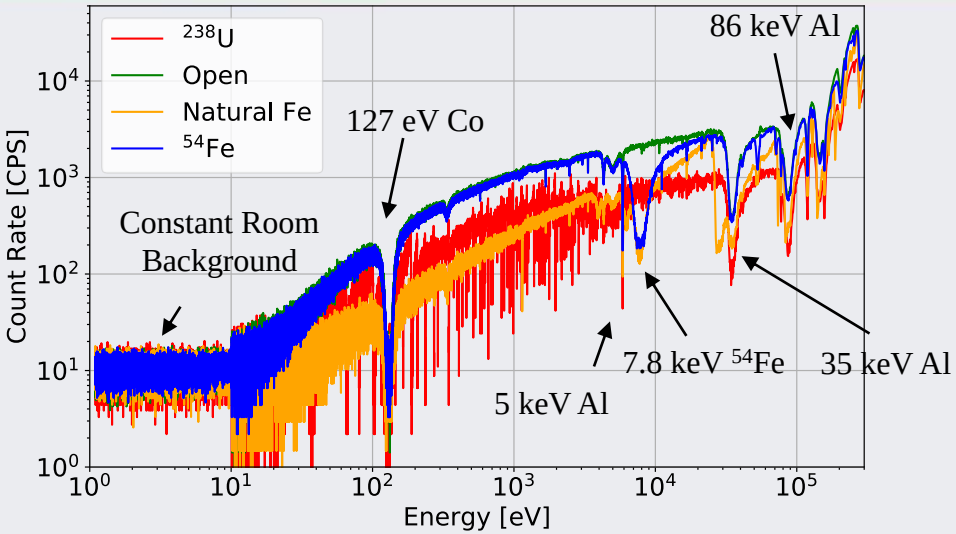
^{54}Fe (n, γ) Measurement – Results

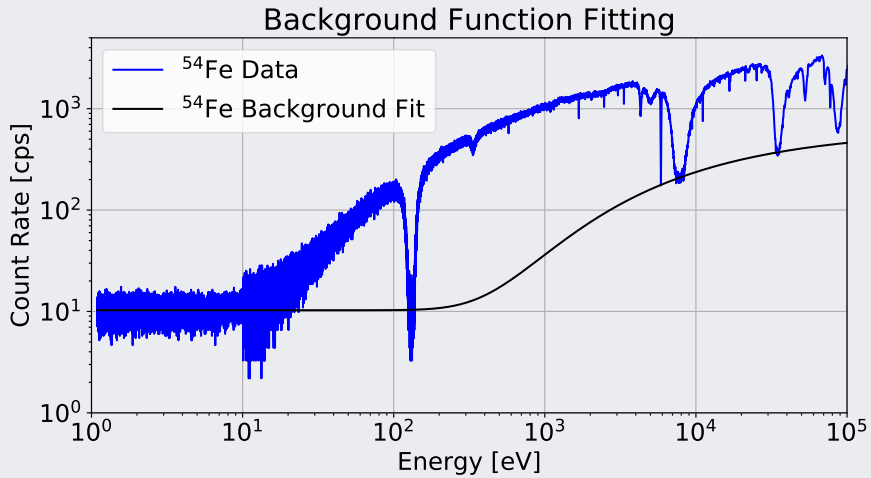
- The RPI capture data was normalized to the saturated resonance of Au and weighted using the PHWT.
- The RPI capture yield disagrees with JEFF and ENDF evaluations at prominent capture resonances.
- Missing resonances from JEFF3.3 can be seen in RPI experiment.
- The energy resolution of the experiment is limited at higher energies (> 200 keV).
- Covariance matrix is being generated before data is released.



Transmission Data Reduction

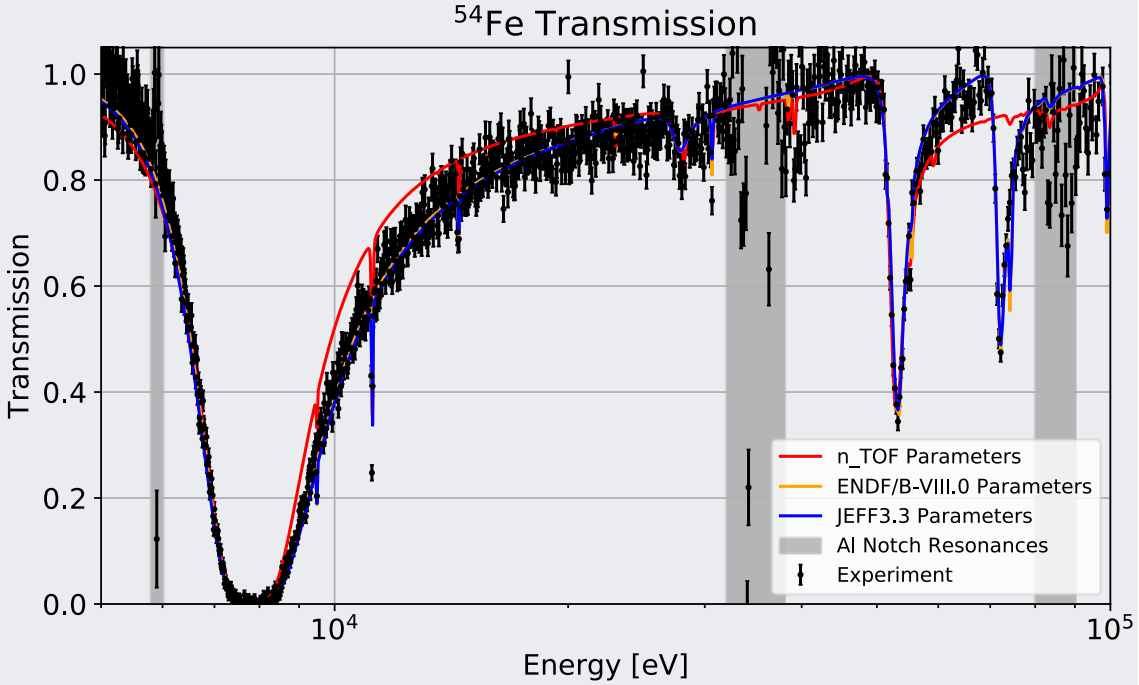
- Reduction of the transmission data requires a background shape to be fit to each sample.
- Black notch resonances are observed in the raw transmission data, which can then be used to fit the background shapes
  - Co and Al fixed notches were kept in-beam throughout the duration of the experiment.
- Background shape was an exponential function
  - $B(t) = ae^{-bt} + B0$





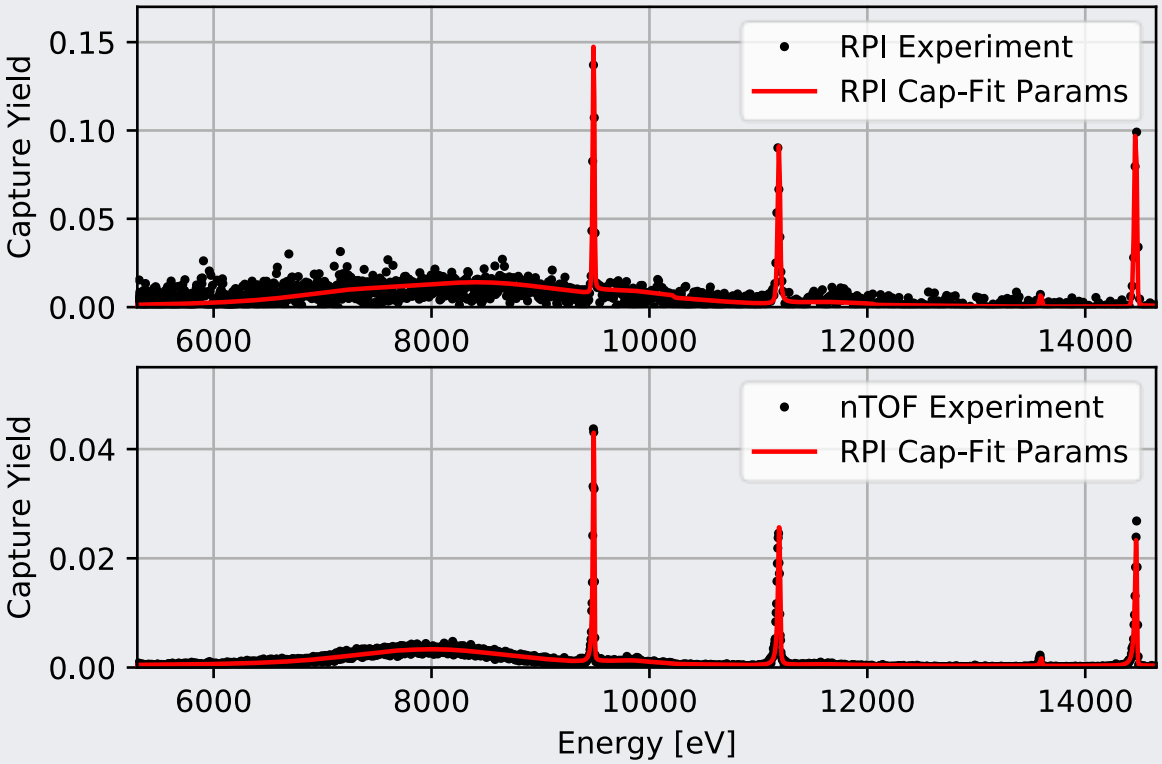
^{54}Fe Transmission Experiment - Results

- 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.



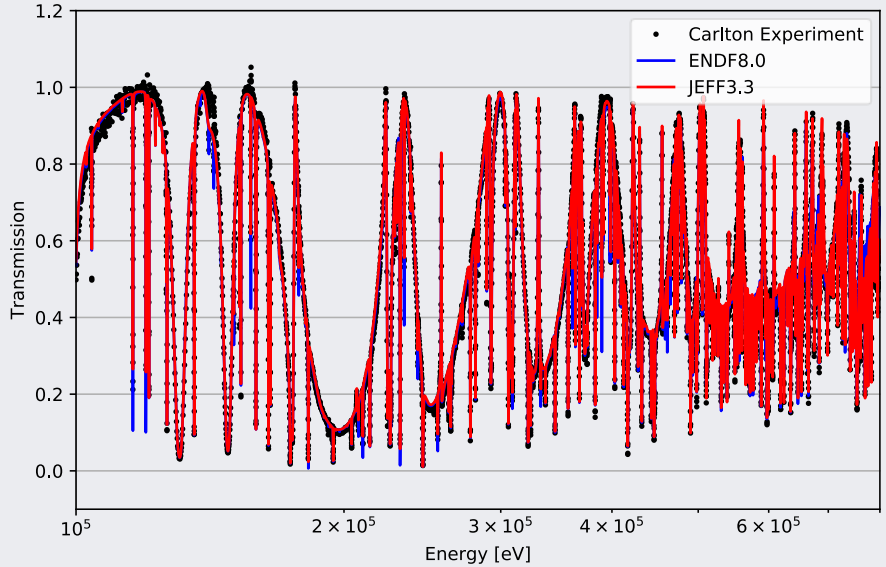
RPI Capture Yield Comparison

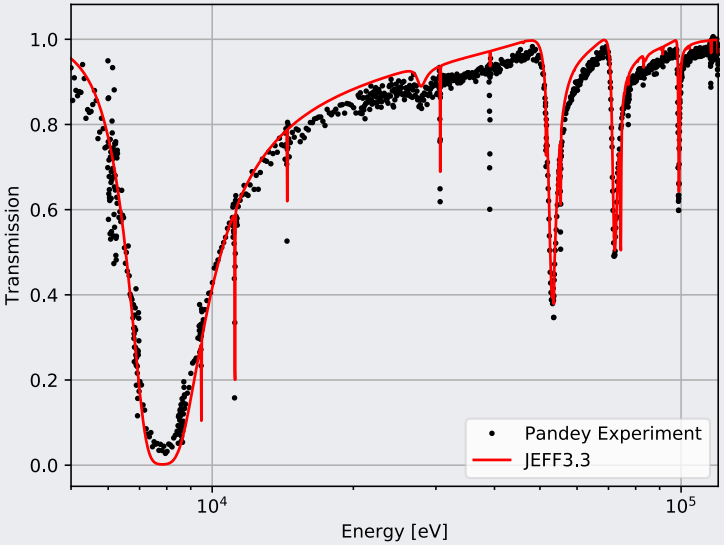
- n_TOF and RPI experiments can be fit simultaneously and show first-order agreement with one another.
- Radiation widths of p,d-wave resonances will need changes to fit both sets of available capture data.
- **n_TOF data requires additional normalization for correct absolute capture yield.**
- **Work Needed:** Extend RRR analysis to 1 MeV and consider RPI data covariances once available.



EXFOR Transmission Experiments

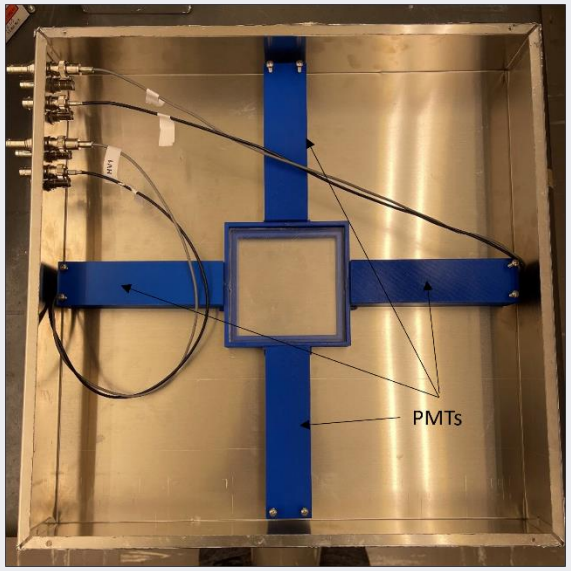
- RPI data is useful up to 150 keV, and can be supplemented with Pandey, Carlton, and Cornelius transmission measurements.
  - Carlton experiment has thicker sample and good resolution.
  - Pandey experiment has discrepancies between experiment and SAMMY calculation.
- Fitting of these other experiments will be completed following delivery of RPI measurement data.

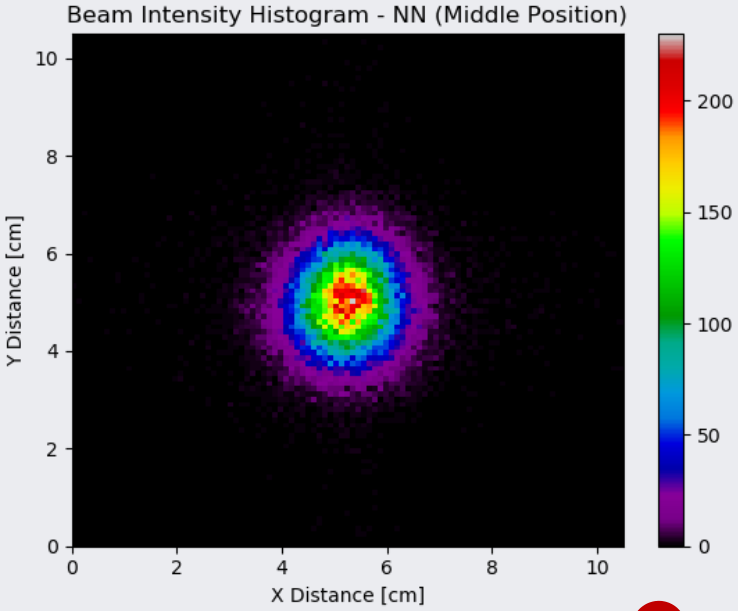




Neutron Beam Imaging System

- **Motivation:** During capture measurements, it is difficult to align samples in the most intense part of the neutron beam.
- **Objective:** Develop a system to provide a time-dependent neutron beam image.
- **System:** 4 PMTs are coupled to a scintillator (EJ-204)
- **Methods:** Neural network has been trained on pulse integrals in coincidence events to predict (x,y) coordinates of a source.
- Improvements to the physical system and algorithms can yield high resolution beam images.





Conclusions and Future Work

- ^{54}Fe measurement campaign at RPI is near its conclusion, covariance matrix generation is needed for both experiments before data is made available and released. (Completion by April 2023).
- RPI will be conducting a full RRR evaluation following release of data. (Completion by September 2023).
  - Evaluation will make use of RPI and EXFOR measurements.
- Neutron beam imager shows promise in providing an easy way to align samples in the most intense part of the neutron beam.
- A new evaluation will offer improvements in crit safety, shielding, and stellar applications.
- RPI graduate school commitments need to be completed by May 2024.