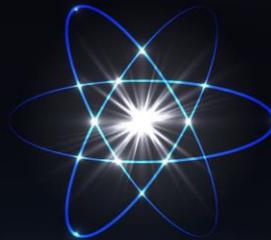# Neutron Capture and Transmission Measurements of ^{54}Fe at the RPI LINAC

February 15-17th, 2022

Presented by:
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- Motivation:
  - Criticality safety calculations require high accuracy nuclear data to reduce uncertainties
  - Recent evaluation work has found a need for new measurement data of the ^{54}Fe (n,γ) neutron cross section.
    - Iron is a part of many structural materials

- Project Goals:
  - Perform radiative capture neutron cross section measurements of ^{54}Fe in the keV energy region
  - Resolve differences between evaluated nuclear data libraries
  - Perform resonance analysis and fitting for ^{54}Fe cross section in the keV region using RPI nuclear data
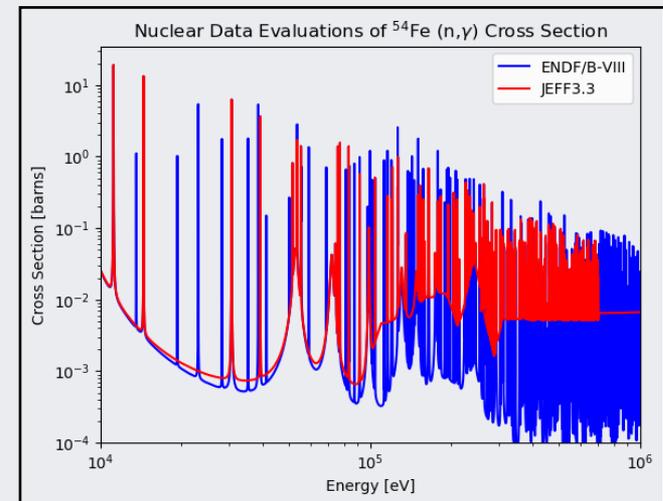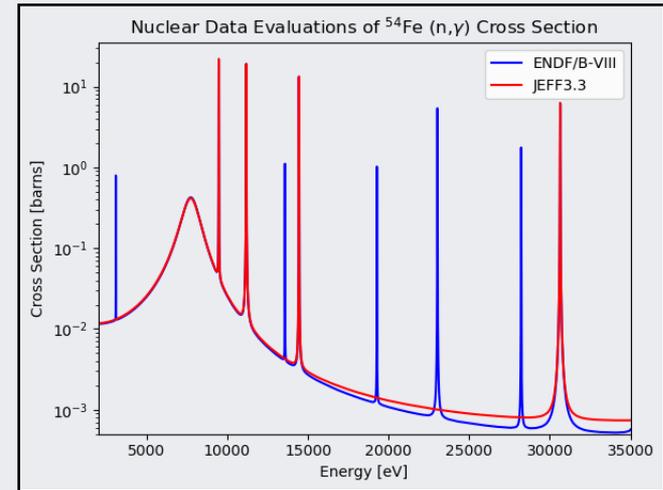

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Introduction to C_6D_6 capture system

- An array of seven C_6D_6 liquid scintillators surround the investigated sample at a flight path of ~45m.

- The system is designed for radiative capture measurements in the mid-energy region (keV-low MeV)

- All structural materials have a low capture cross section to minimize neutron sensitivity
  - Materials are all Al

- System is based on the principle of the total energy method
  - Requires employment of the PHWT

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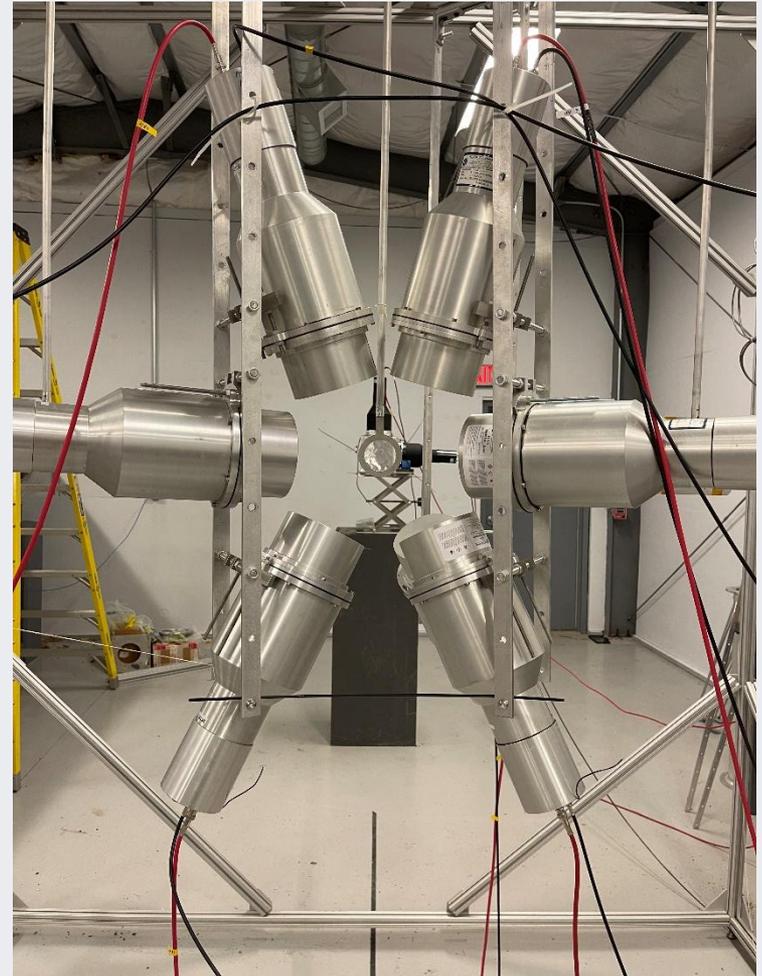
$^{54}Fe\,(n,\gamma)$ Measurement - Motivation

- Fe is an important constituent of various 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 $^{54}Fe(n,\gamma)$ cross section
  - ^{56}Fe evaluation work has highlighted need for new measurements and evaluation for ^{54}Fe
  - nTOF data from 2014 was added recently 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


Nuclear Data Evaluations of $^{54}Fe\,(n,\gamma)$ Cross Section

Nuclear Data Evaluations of $^{54}Fe\,(n,\gamma)$ Cross Section

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- Capture data were taken of a ~0.021 atom/barn 96% enriched ^{54}Fe sample

- Total data collection time was ~100 hours across multiple samples
  - ^{54}Fe, Open, B_4C, Pb

- 400 Hz, 11.2 ns pulse width, ~44 MeV electrons, and ~15 μA of beam current

- Capture data were normalized using the saturated resonance method
  - Another experiment with Au and Ta samples was designed for normalization

STABLE ISOTOPE

Batch No.:	177602
Isotope:	Fe-54
Form:	Fe2O3
Net Wt:	38,345.4 MG
Delivery:	7003866
ORNL - Oak Ridge, TN	

wght: 38.3454 gm
φ: 50.91 mm
h (avg.): 2.498 mm

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# $^{54}Fe\ (n, \gamma)$ Measurement – Raw Data

- Room background rate remains a challenge with mid-energy measurements

- Resonance structure clearly observed in RRR

- Data analysis at higher energies still in progress, data should be useful until ~2 MeV

Raw TOF Data - ^{54}Fe Sample
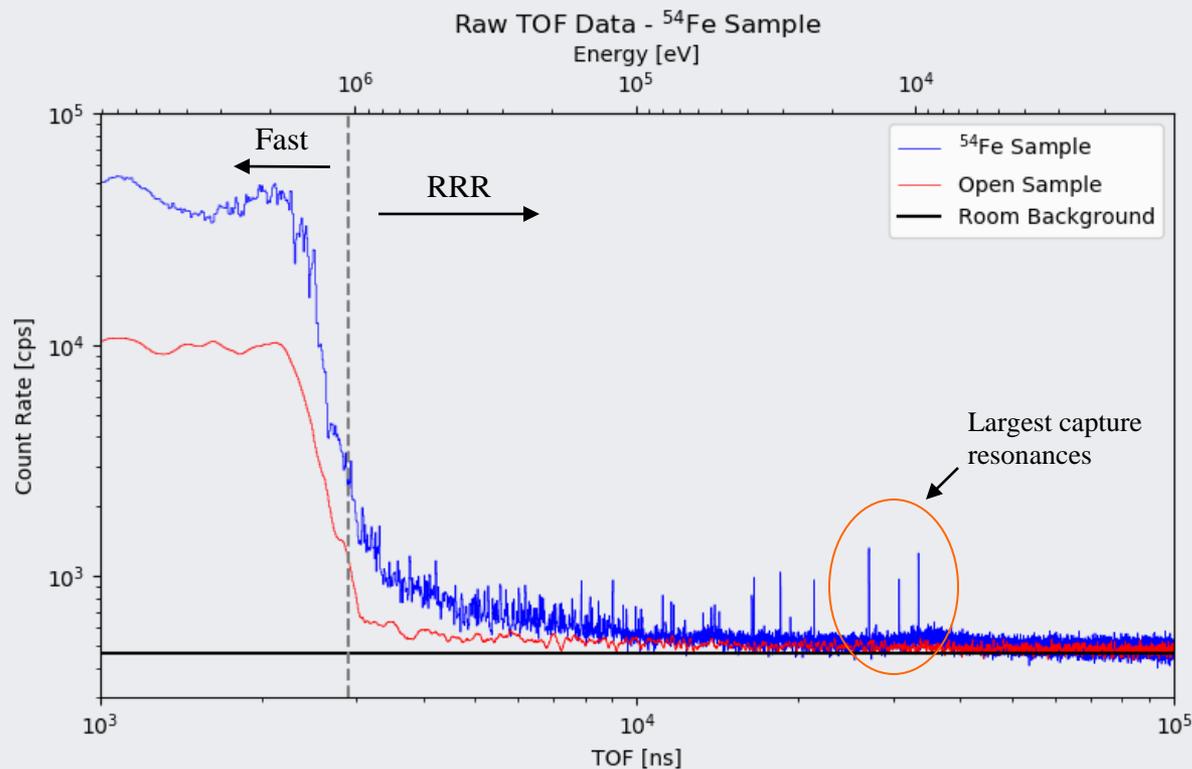
- The saturated resonance method was used to get an absolute normalization factor f_n for the ^{54}Fe data.

- Neutron flux is normalized by observing the black resonances in the experiment with known capture yields

- Au and Ta were both measured during the experiment to cross-validate the computed normalization factors.

  - Analysis thus far shows reasonable agreement

- An additional correction is applied to account for different binding energies of a normalizer and the ^{54}Fe

Normalization of Au and Ta Samples
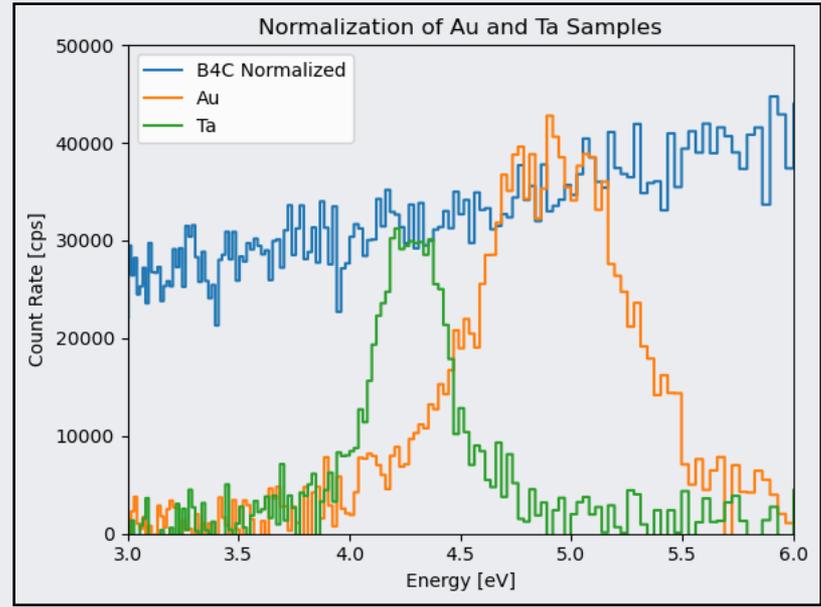
$$f_n = \frac{\sum_{E_1}^{E_2} \dot{C}_{Normalizer}}{\sum_{E_1}^{E_2} \dot{C}_{B_4C}} \frac{\langle Y_{B_4C} \rangle}{\langle Y_{Normalizer} \rangle}$$

$$f_n^{\,^{54}Fe} = f_n \frac{S_n^{\,^{54}Fe}}{S_n^{Normalizer}}$$

Experiment Capture Yield Calculation

- All sample count rates are normalized by monitor/trigger ratios for between samples

- Open beam background and in-beam time dependent gamma background are both subtracted

- Weighting functions are calculated and applied to more heavily weight high energy photons that normally have low detection efficiency

  - Relies on the theory of the total energy method

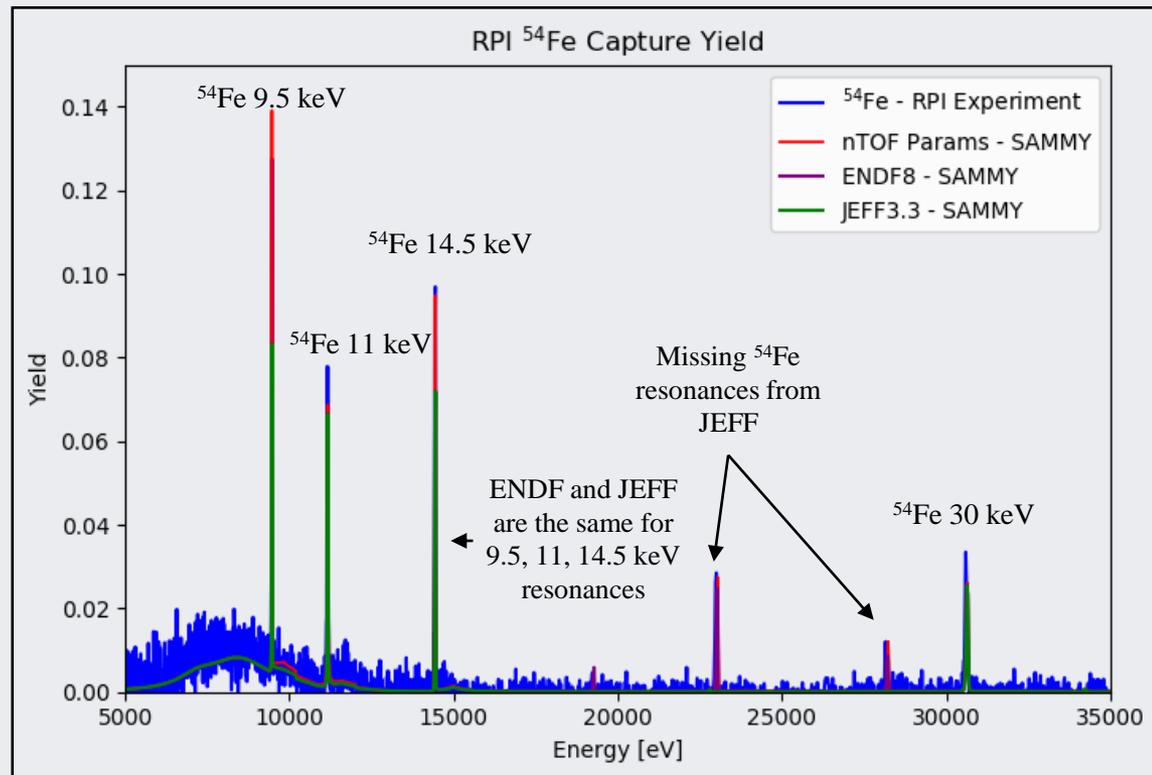- Weighting functions require accurate MCNP simulations of individual detector responses

Detector 1 Response to Different Monoenergetic Photons [F8]
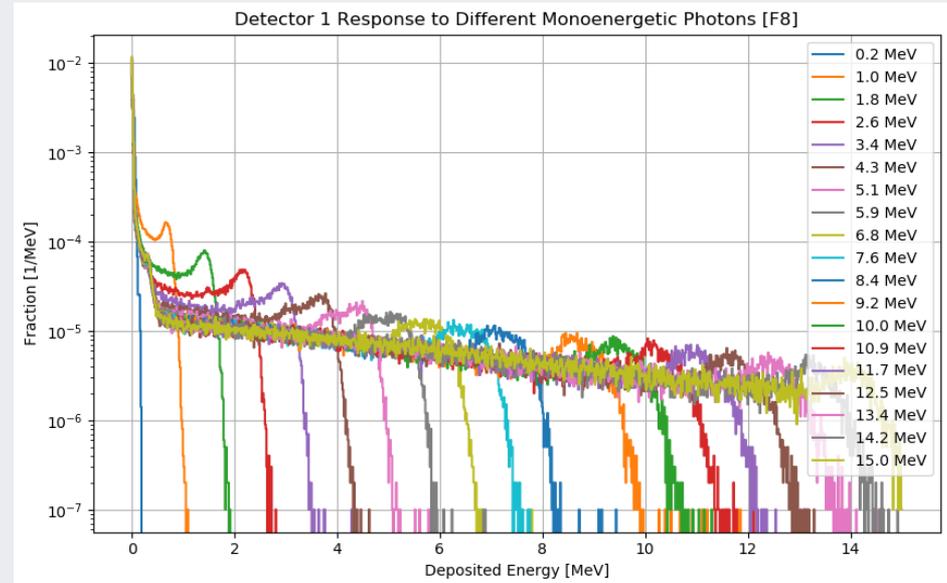
$$\eta_\gamma = kE_\gamma = \sum_i W(E_d)R(E_d, E_\gamma)dE_d$$

$R(E_d, E_\gamma) = Detector\ Response\ Function$
$for\ a\ given\ source\ energy\ E_\gamma$
$W(E_d) = Polynomial\ Weighting\ Function$

- Three largest capture resonances are discrepant between ENDF8 and the 2021 RPI experiment
  - ENDF8 and JEFF3.3 in agreement for three largest capture resonances
  - nTOF resonance parameters seem to provide better agreement to RPI experiment than JEFF or ENDF resonance parameters
  - A new set of resonance parameters will be fit to RPI data
- Some missing resonances from JEFF evaluation can be clearly in ENDF evaluation and in RPI and nTOF experiments
- To fit properly, it is necessary to consider multiple datasets

RPI ^{54}Fe Capture Yield

- ^{54}Fe - RPI Experiment
- nTOF Params - SAMMY
- ENDF8 - SAMMY
- JEFF3.3 - SAMMY

^{54}Fe 9.5 keV
^{54}Fe 14.5 keV
^{54}Fe 11 keV
Missing ^{54}Fe resonances from JEFF
ENDF and JEFF are the same for 9.5, 11, 14.5 keV resonances
^{54}Fe 30 keV

- To improve the fitting of the ^{54}Fe capture data, a transmission measurement to obtain total cross section data was conducted.

  - Transmission data will help validate RPI capture yield and further justify that changes are needed in resonance parameters

- A Li-Glass detector at 35m was used to collect data, sample placed at 15m flight path.

- 2cm of natural Fe, 625 mil of depleted Uranium, 0.25 cm of ^{54}Fe all measured during experiment.
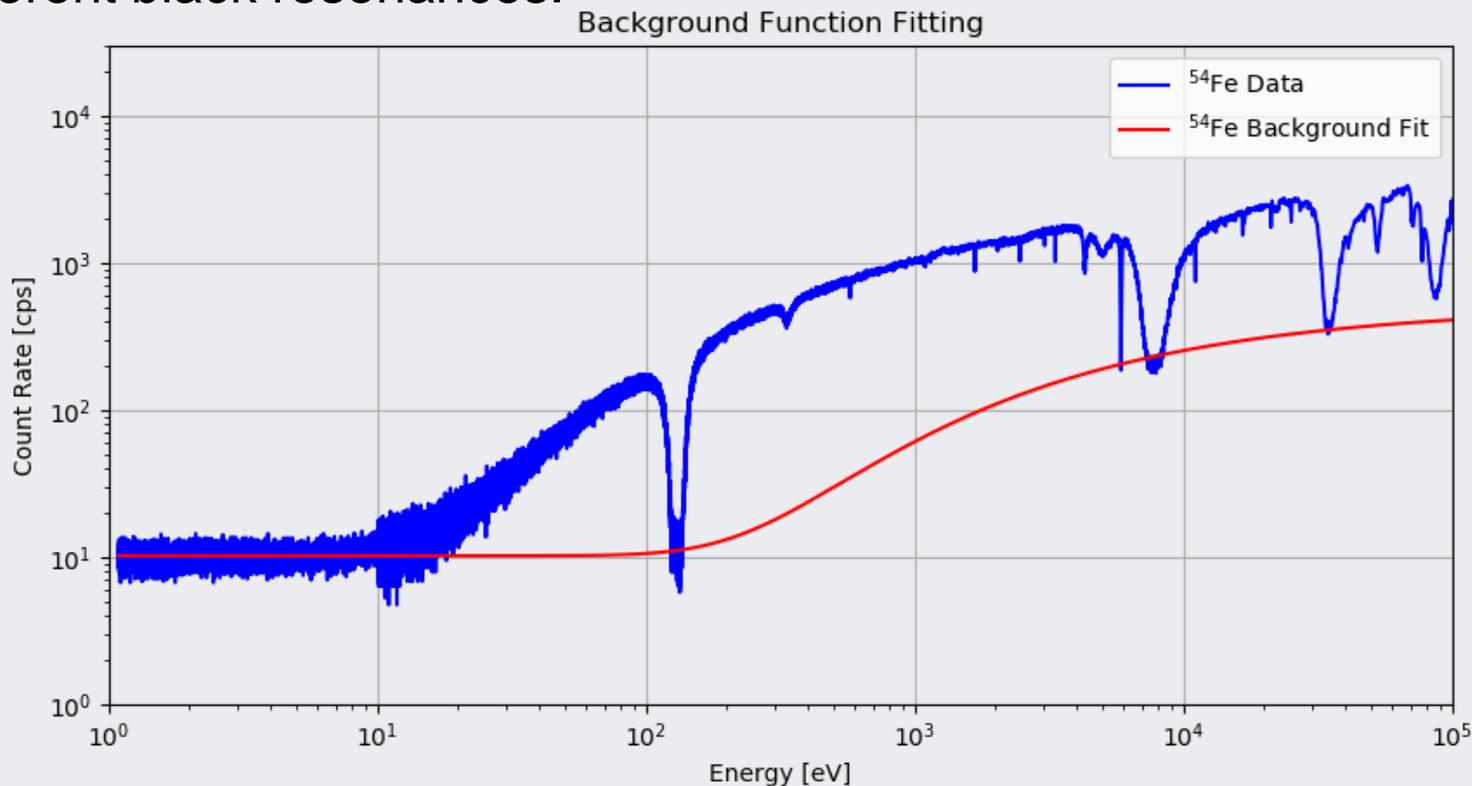
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Transmission Raw Data
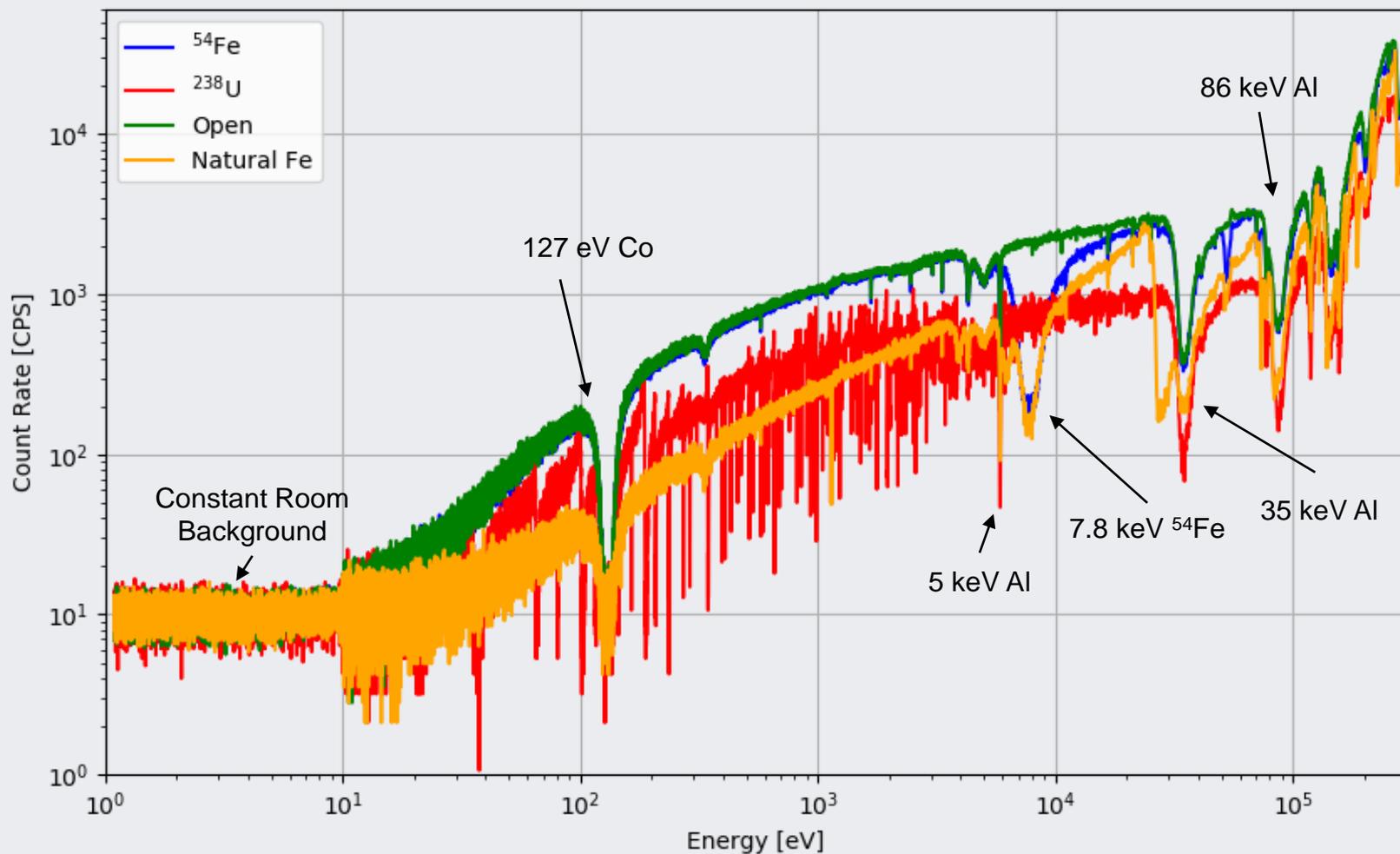
- To correct for background, an exponential function is fit for each sample using the constant background rate and the count rates in different black resonances.

Background Function Fitting

- nTOF resonance parameters do not perform well when looking at transmission data in SAMMY

- Moving forward, RPI's combination of capture and transmission data will enable a more wholistic approach to resonance evaluation and fitting.
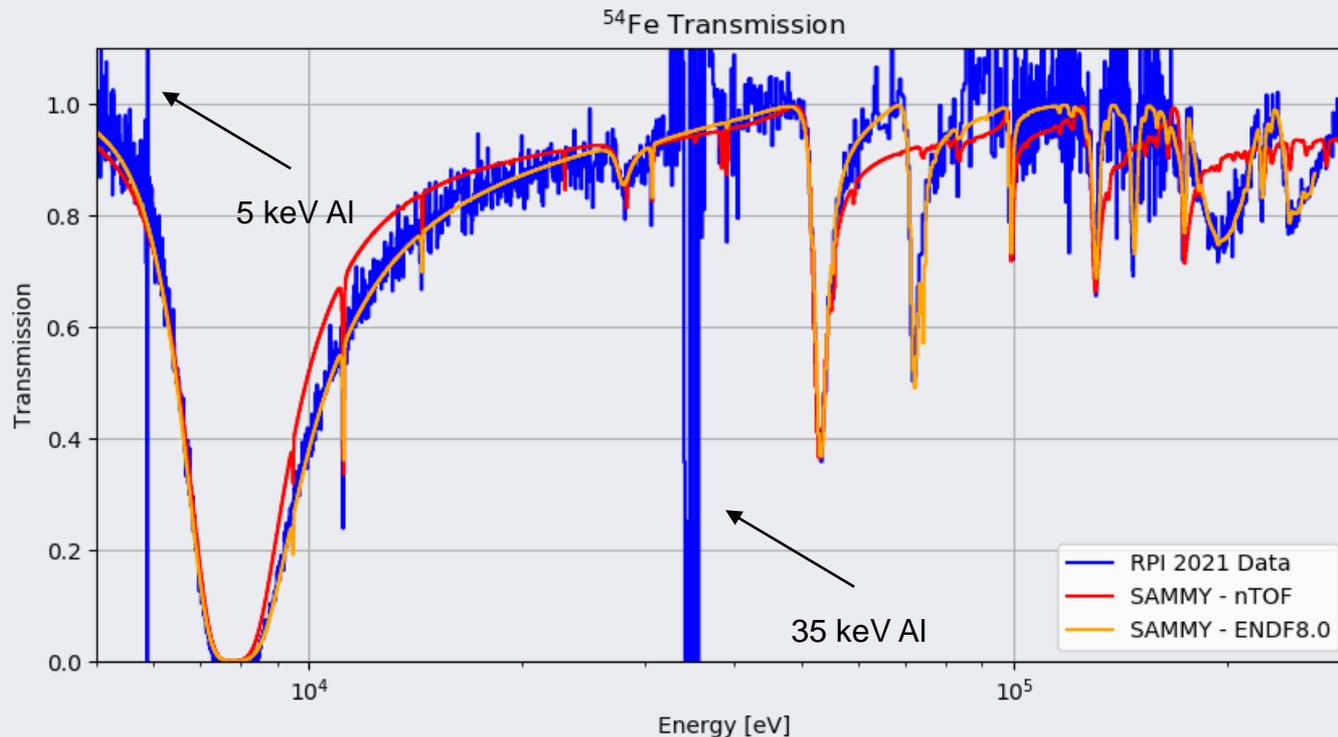
^{54}Fe Transmission

Accomplishments and Future Work

- Conclusions
  - Transmission and capture measurements provide a wholistic set of experimental data to start resonance evaluation on ^{54}Fe
  - Analysis thus far supports that changes are needed in ^{54}Fe evaluation

- Major Accomplishments
  - Completion of radiative capture measurements of ^{54}Fe
  - Completion of total cross section measurements of ^{54}Fe

- Future Work
  - Completion of data analysis relevant to capture and transmission measurements (May 2022)
  - Complete fitting of new resonance parameters to ^{54}Fe data (Early 2023)
  - Complete all required deliverables for graduation (May 2023)

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