Overview of Nuclear Data Measurement and Analysis at RPI

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Outline

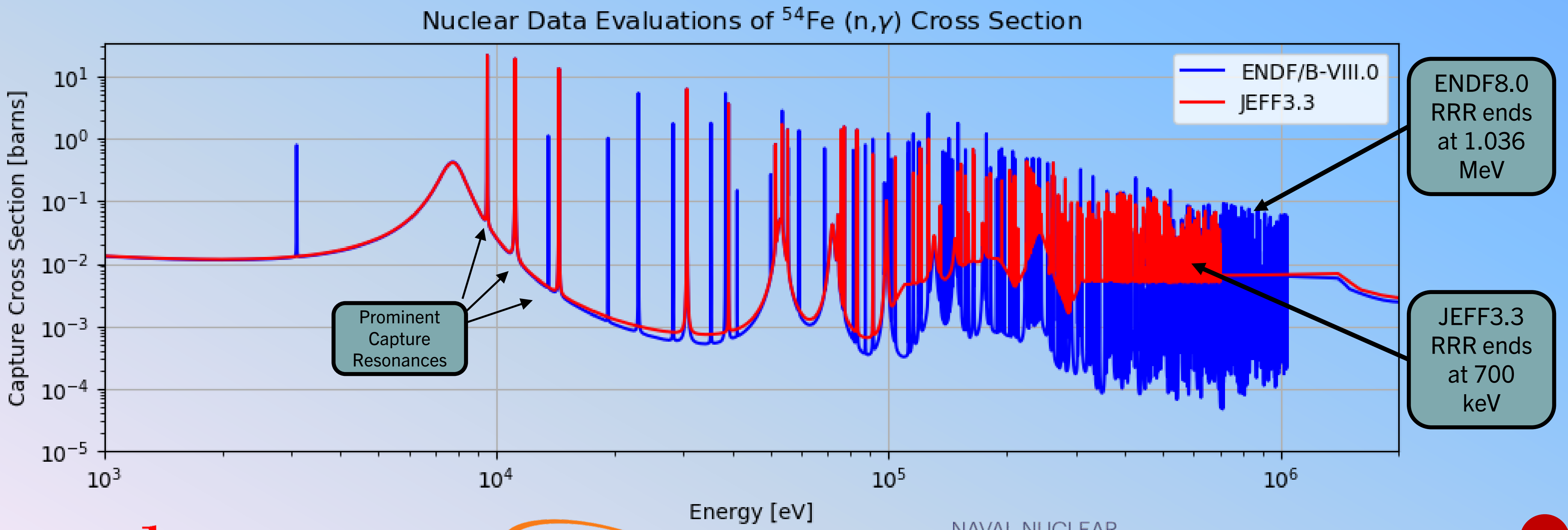
- Neutron capture in ^{54}Fe (S. Singh)
- Neutron capture yield and γ-ray cascade spectra measurements (K. Cook)
- Thermal neutron die-away measurements (B. Wang)
- URR improvement to SAMMY (A. Golas)

Neutron capture in ^{54}Fe

S. Singh

Overview and Project Goals

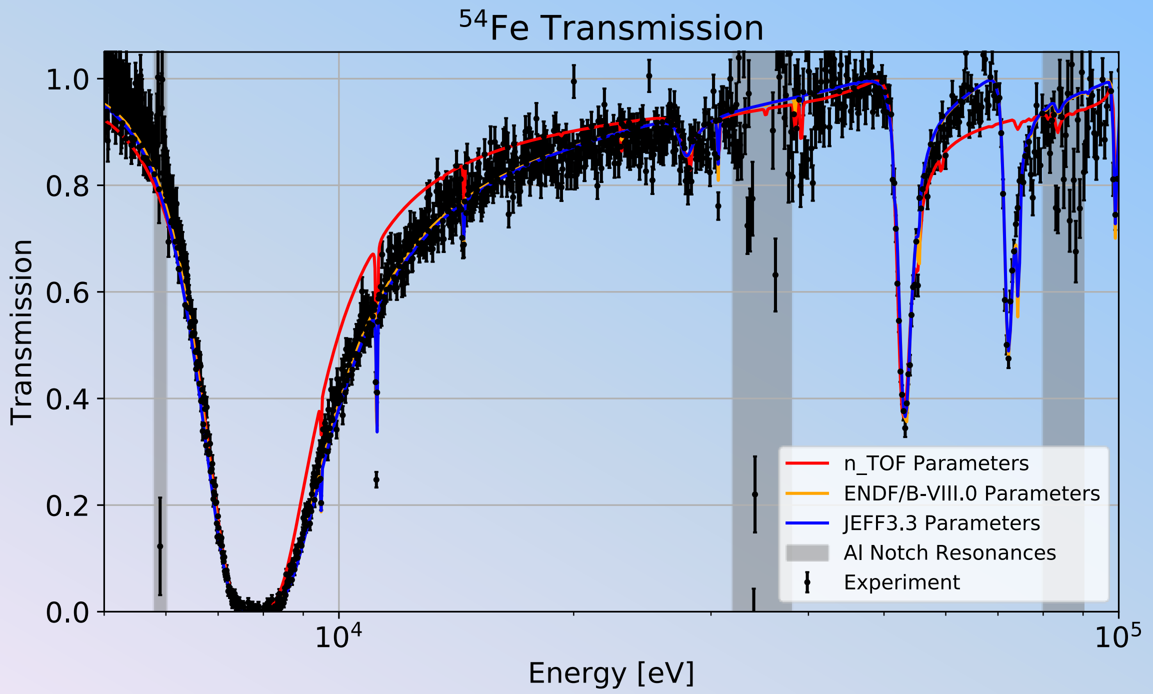
- Motivation:
  - Minor isotopes of Fe have a need for new nuclear data.
  - Fe is shown to be very important in criticality safety applications.
- Project Goals:
  - Perform radiative capture and transmission measurements using existing RPI infrastructure.
  - Generate IDCs for RPI experimental data for use in evaluation.
  - Perform RRR evaluation for ^{54}Fe using existing nuclear data on EXFOR and RPI measurements.

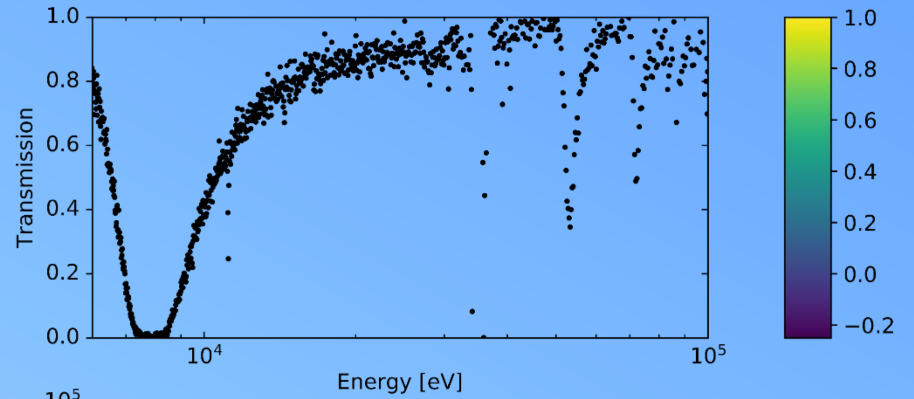


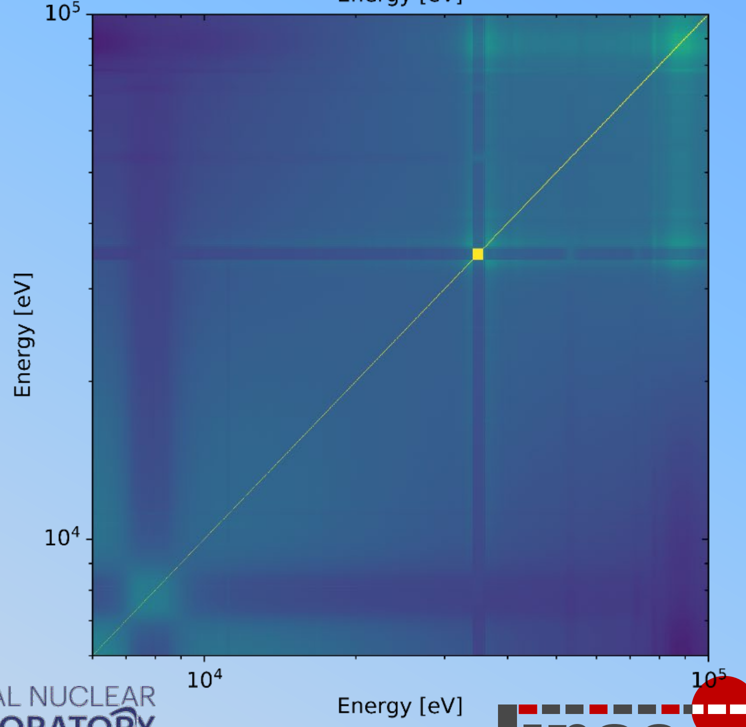
Overview of Transmission Results

- Transmission is less sensitive to changes in evaluations.
  - Covariance passes all mathematical checks.

- Small correlations are present in the transmission experiment.

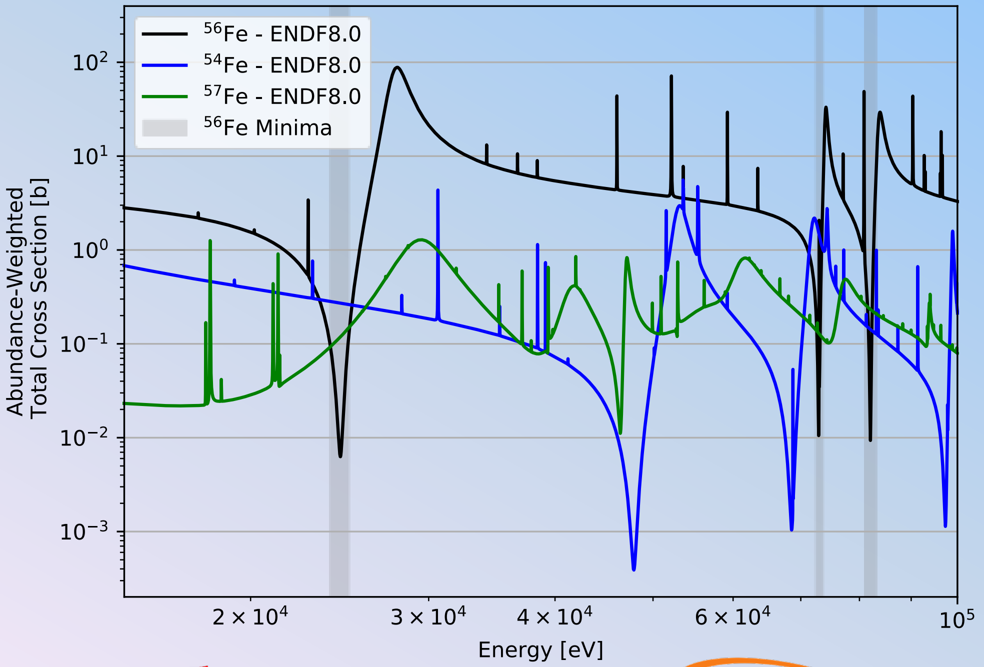


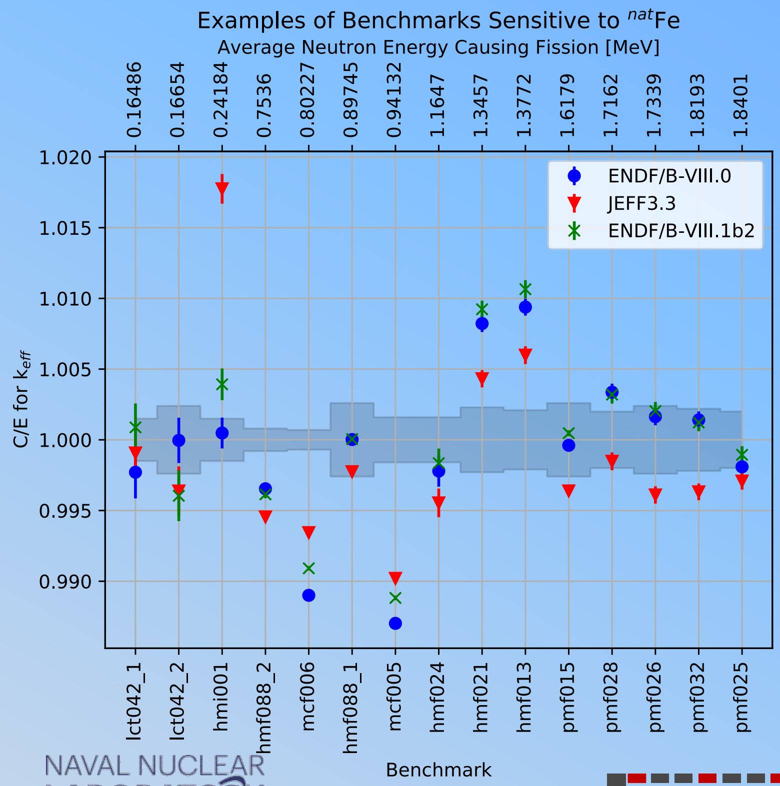




^{54}Fe (n,γ) Measurement - Motivation

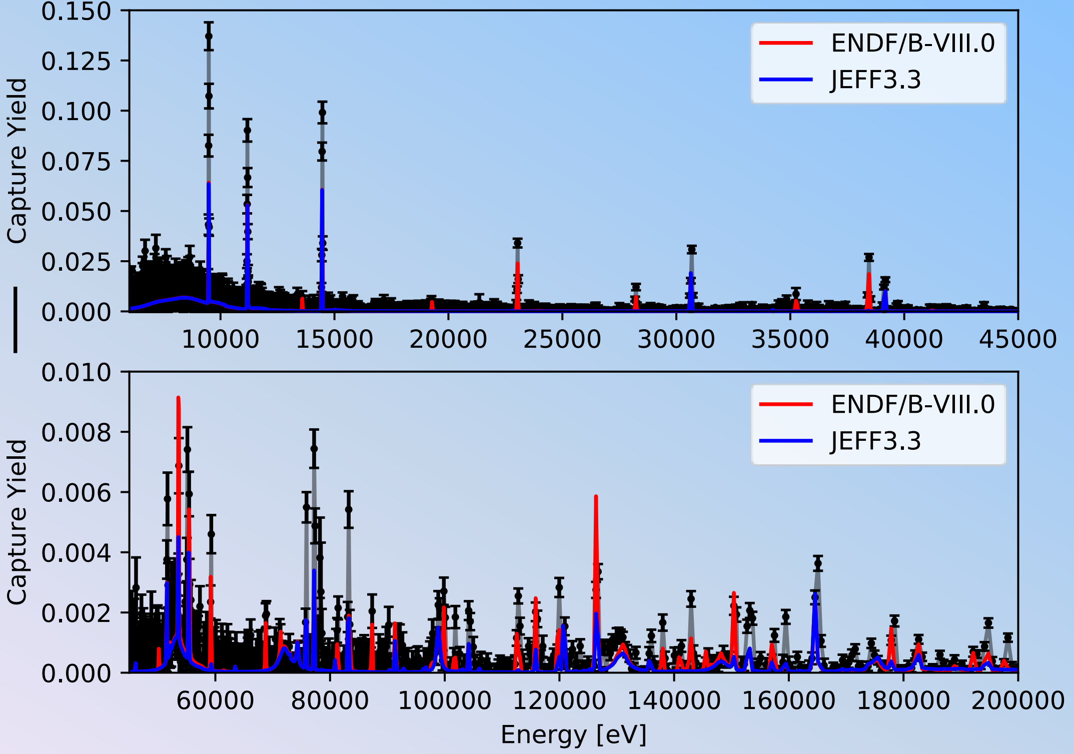
- Fe is an important constituent in many nuclear systems
- Natural Fe and ^{56}Fe cross sections have been studied extensively, but there is a lack of data available in EXFOR of the ^{54}Fe(n,γ) cross section
- There are **various discrepancies between different evaluated data libraries**, where some resonances are present in one evaluation and not the other

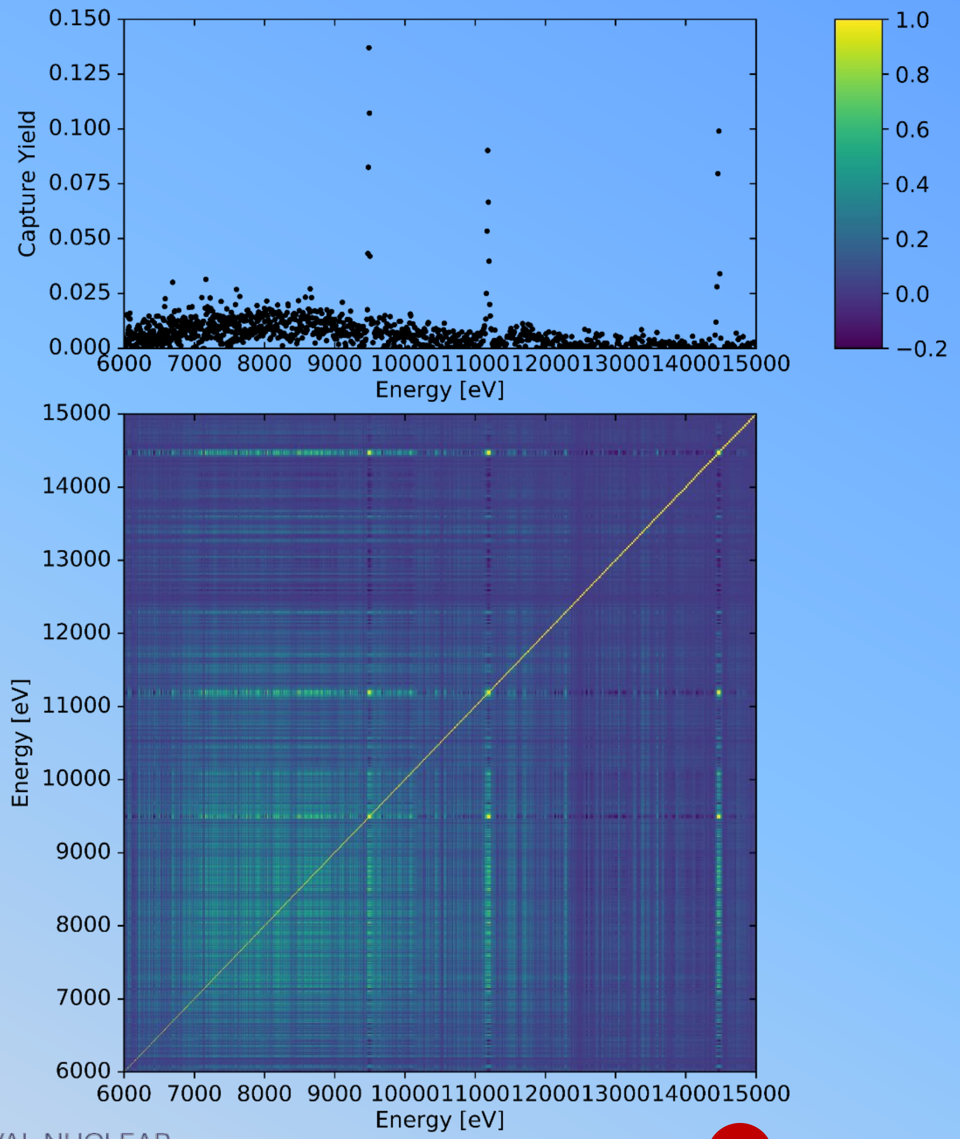




Overview of Capture Results

- Capture yield shows large discrepancies.
- Stronger correlations between resonances are present in the experiment.





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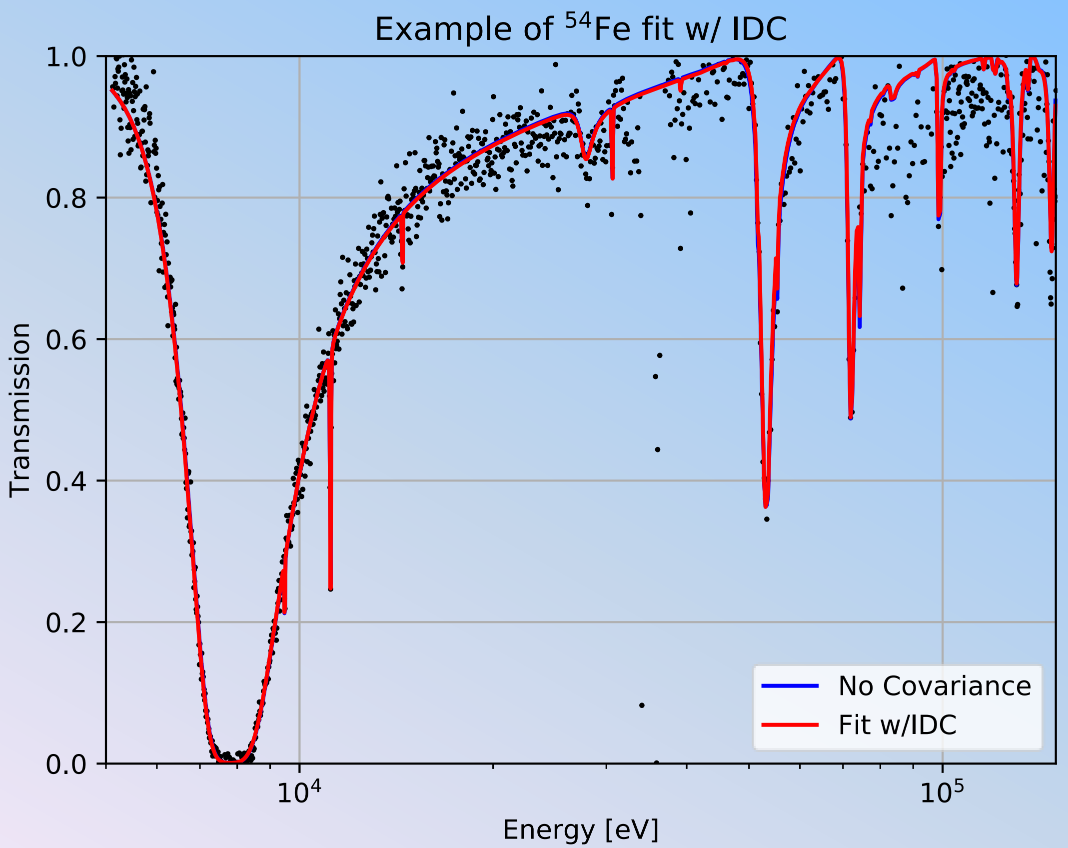
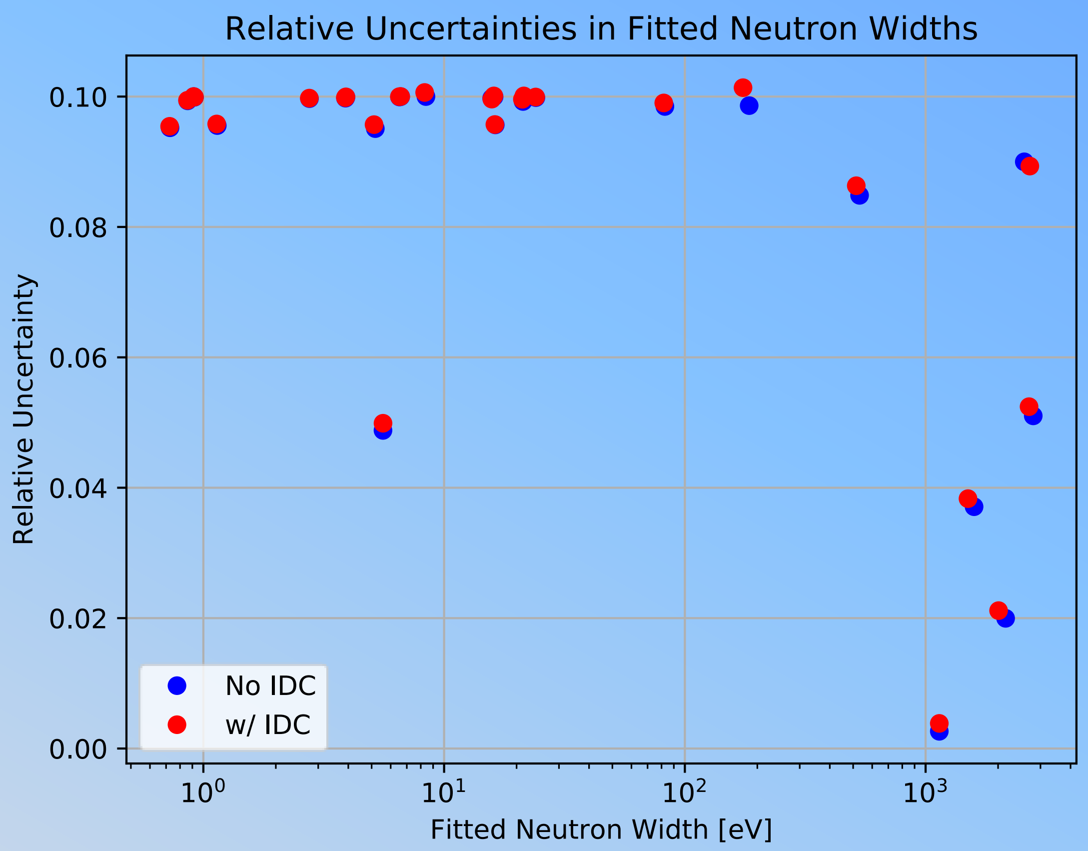
Effect of IDCs on Resonance Parameter Fits

Work thus far shows insensitivity of resonance parameters and uncertainties to the inclusion of correlations in time-of-flight experiments on Bayesian fitting.





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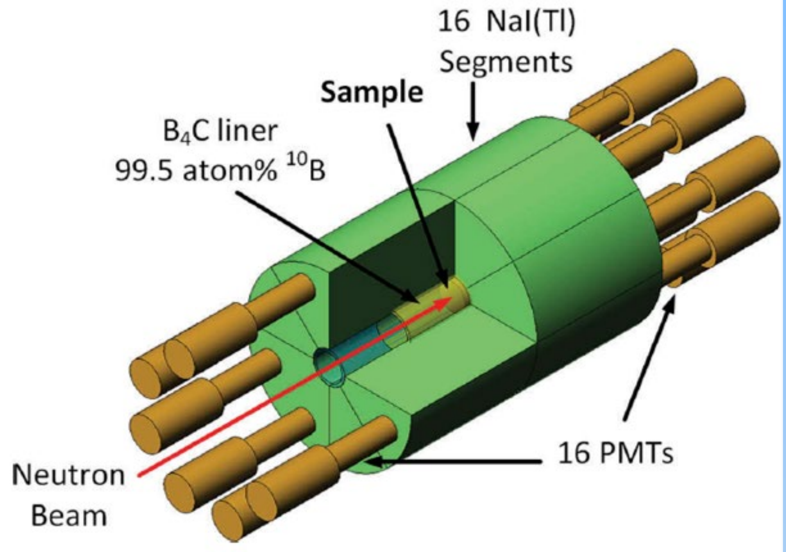
Future Work for ^{54}Fe

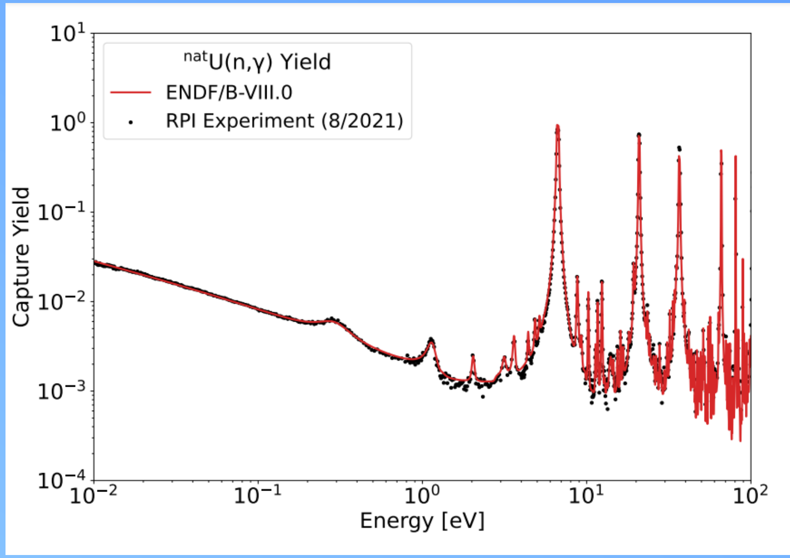
- Publish measurements of Fe to EXFOR and journal w/ experimental covariances. (November 2023)
- Complete RRR evaluation using RPI and EXFOR data w/ and w/o IDCs when available. (March 2024)
- Using SAMMY to fit nuclear data w/ IDCs is relatively unexplored.

Neutron capture yield and γ-ray cascade spectra measurements

K. Cook

RPI Capture γ-Ray Multiplicity Detector





- **16 segment NaI(Tl) γ-ray 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-ray cascades
  - Located 25 m from the neutron-producing tantalum target
- **Used for neutron capture yield and γ-ray spectra measurements**
  - Incident neutron energies: 0.01 eV – 3 keV
- **16 Channel 250 MHz 14-bit Digitizer (SIS3316-250-14)**
  - Digitize pulses generated for each event on all 16 detectors to determine the energy deposited in each detected event

Nuclear Data Validation Methodology

Compare Experimental Data to Simulated γ-Ray Spectra

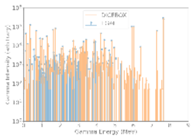
Experiment (RPI linac The Gaertner)

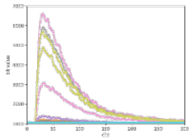
Experimental Data

Experimental Parameters

mod-MCNP-6.2

Simulated Results

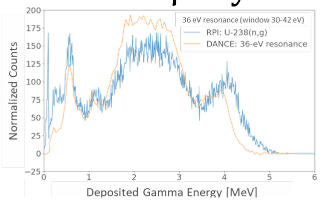


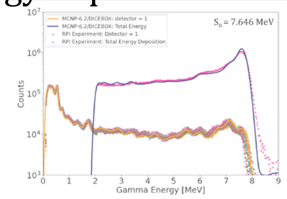


Processing Code (julia)

Compare various results:

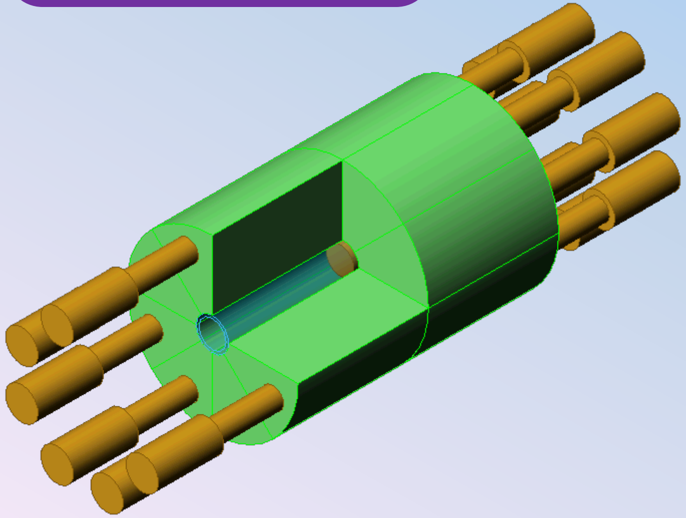
- Neutron capture γ-ray spectra
- γ-ray cascade multiplicity spectra
- Angular distributions of γ-rays
- Total γ-ray energy deposition





γ-ray cascades, Probability Distributions, etc…

Nuclear Data Evaluation from ENDF/B-VIII.0, DICEBOX (ENSDF + RIPL-3) or other sources



Generating Capture γ-Ray Cascades

for mod-MCNP-6.2/DICEBOX Simulation

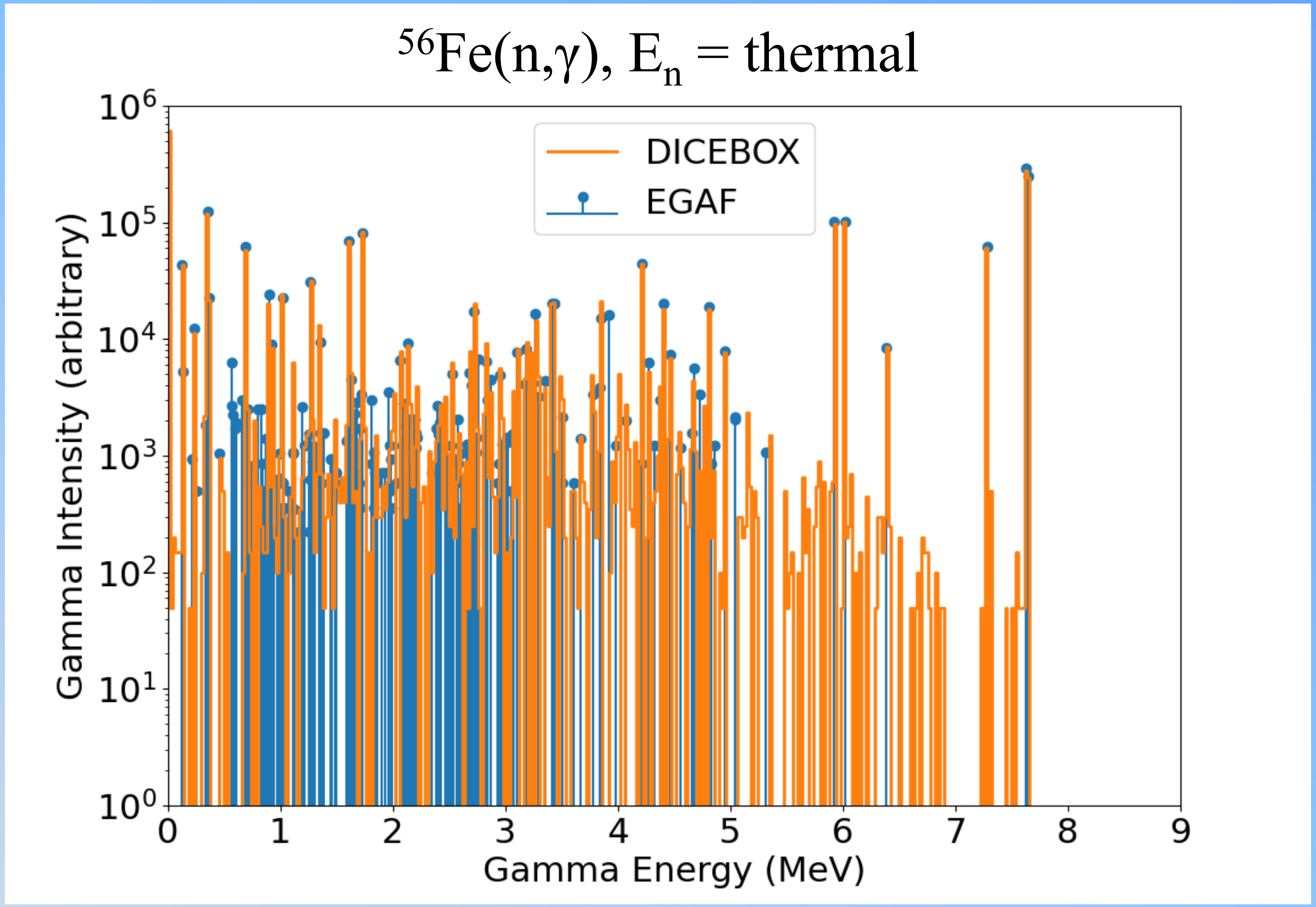
DICEBOX

Models full γ-ray cascades using evaluated nuclear data (ENSDF + RIPL-3)

EGAF

Shows experimentally measured γ-ray lines

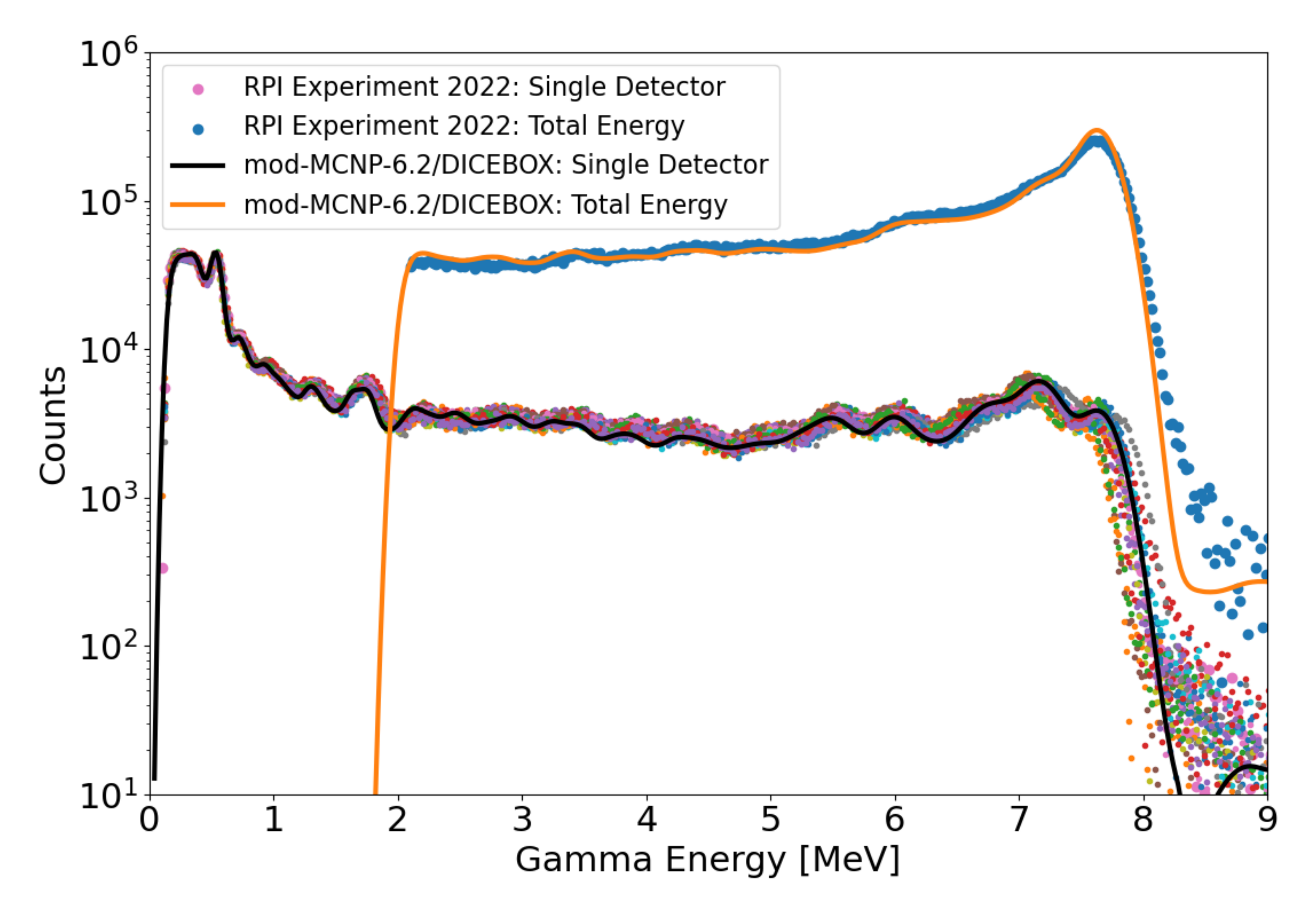
(does not necessarily represent the full cascade)



DICEBOX input tuned to R. B. Firestone et. al., Phys. Rev. C **95**, 014328 (2017) data

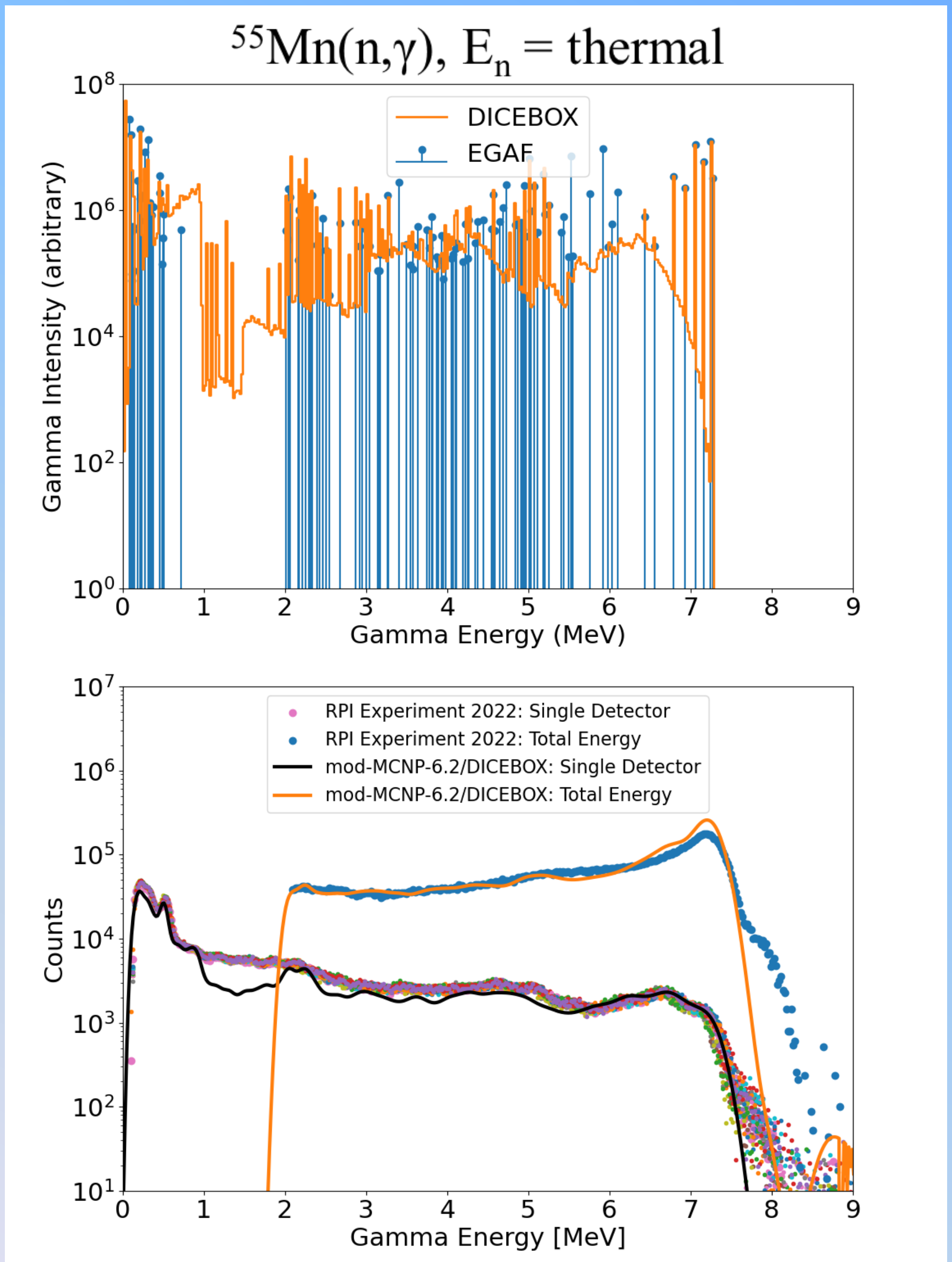
$^{56}Fe(n,\gamma)$ spectra

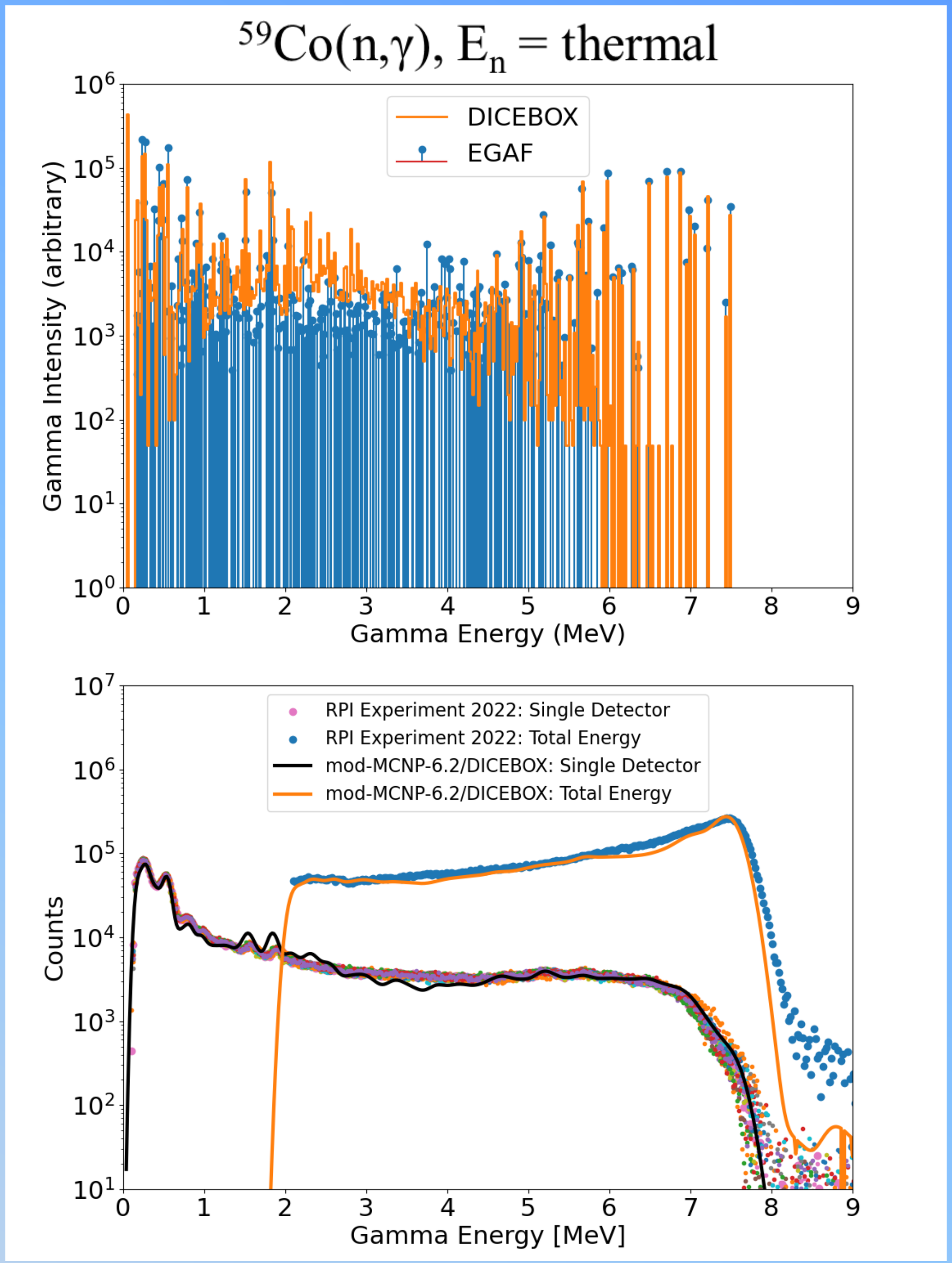
Compared to mod-MCNP-6.2/DICEBOX Simulation



Additional Measured Neutron Capture Spectra

Compared to mod-MCNP-6.2/DICEBOX Simulations





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Conclusions

- The experimental, simulation and nuclear data methods were validated for the RPI Capture γ-Ray Multiplicity Detector

- When the neutron capture γ-ray cascade data is well-known, the experimental γ-ray emission spectra can be accurately simulated using the modified simulation tools

Future Work

- Complete analysis for measured isotopes: ^{55}Mn, ^{59}Co, ^{181}Ta, ^{238}U, and ^{235}U

- **New FY23 NDIAWG FOA award (RPI/NNL/BNL): Development of Benchmark Measurements for Capture γ-Ray Cascades**
  - Continue this work by using the data and methods to develop benchmarks for neutron induced capture γ-ray cascade nuclear data

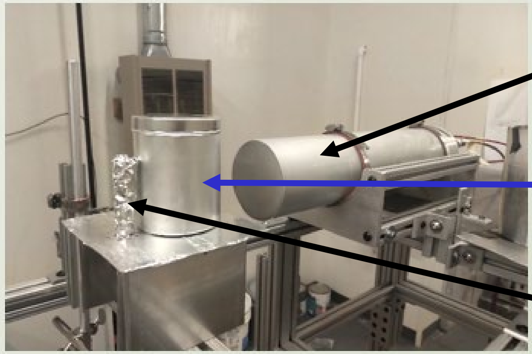
Thermal neutron die-away measurements

B. Wang

Motivation & Initial 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.

Aluminum Containers: 600ml, 315ml, 125ml



600ml container on experimental table

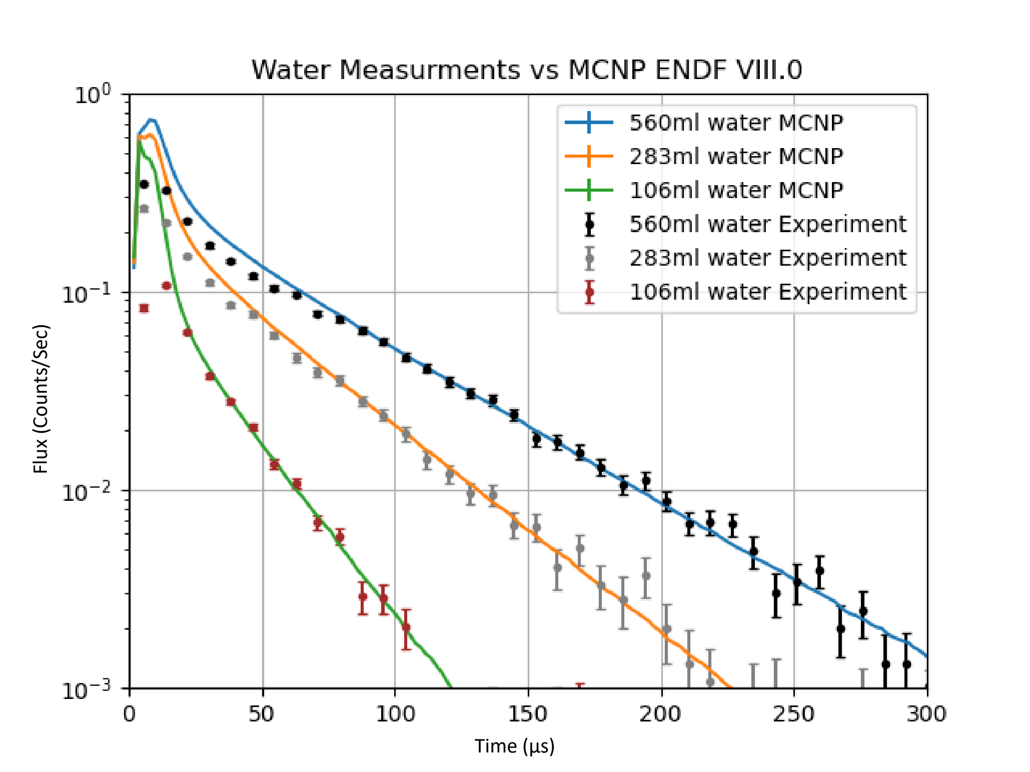
125ml container on experimental table

Experimental setup with full shielding

Preliminary Results

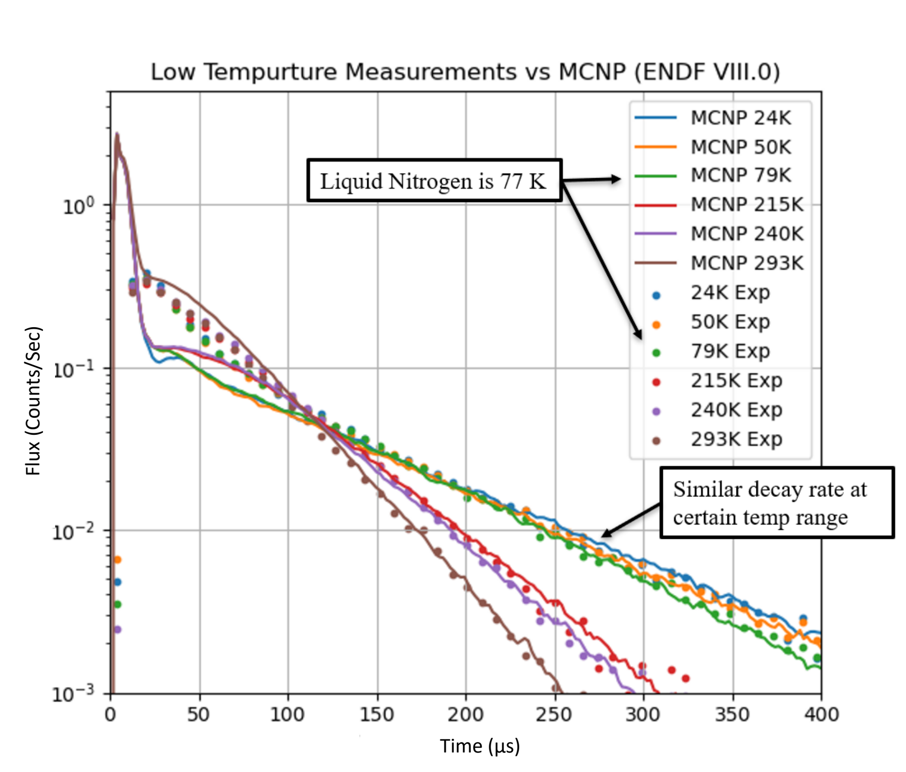
Initial water test results

- 3 different sample sizes
- Proof of concept for PNDA experiments



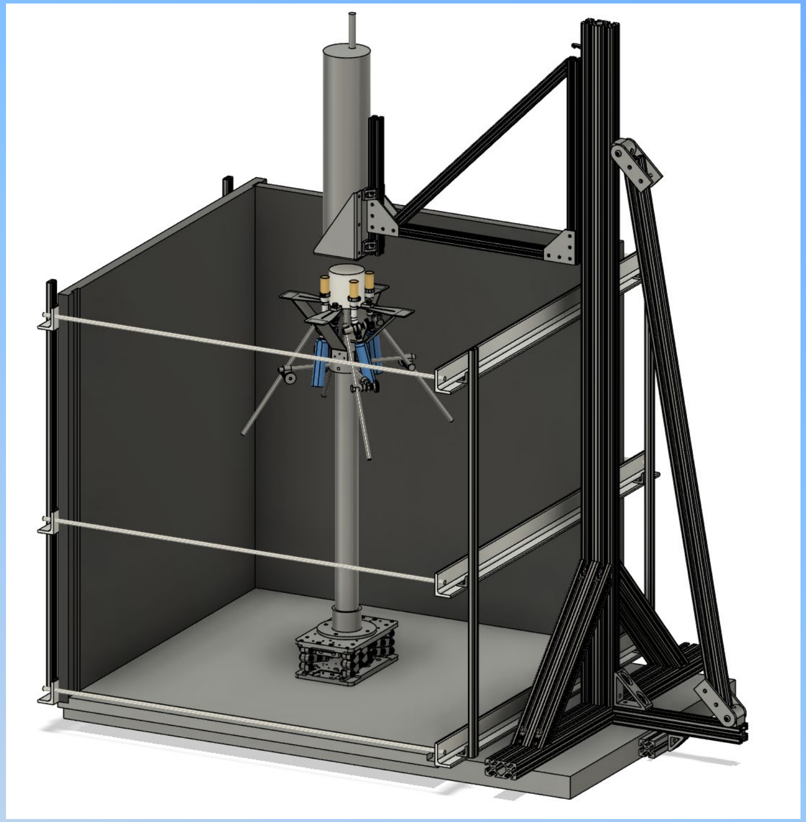
Low temperature measurements of Polyethylene

- Low temperate polyethylene moderator target
- Test PNDA temperature sensitivity



PNDA Design Full Assembly

- Room decoupler is 30% borated poly, no liner
- Digital integrated DAQ system from Queasta



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Improvements in SAMMY URR analysis

A. Golas

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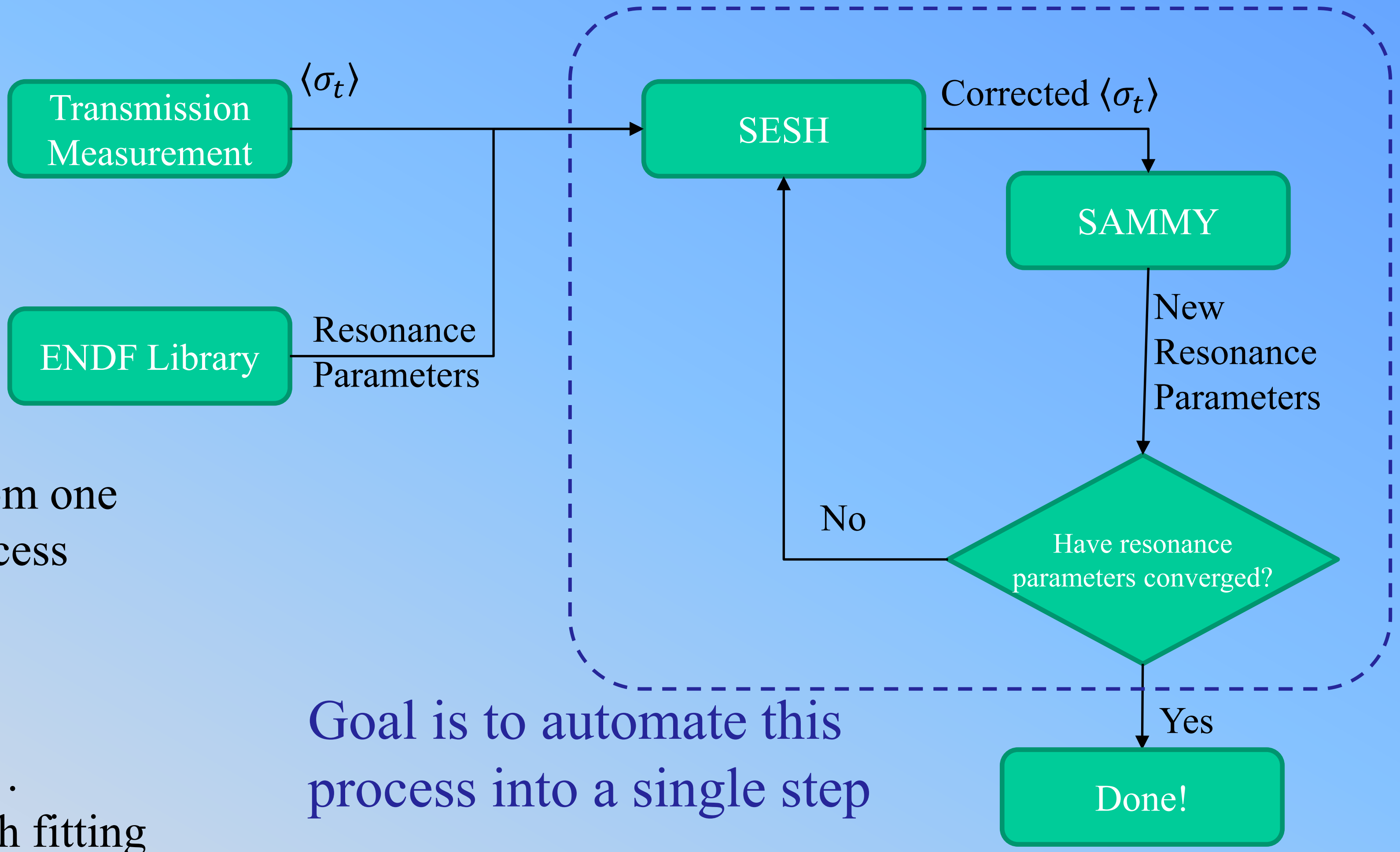
Self-Shielding Workflow



- This is primarily converting data from one format to another in an iterative process
- External loop
- Very tedious and time consuming
- Prone to user error
- Evaluators have better things to do…
- Very few evaluators are familiar with fitting URR

Goal is to automate this process into a single step

Fitting Transmission with SAMMY

- In order to fit with SAMMY two quantities need to be calculated:

1. The average transmission to be fitted to the experiment

$$\langle T(u)\rangle = C_T(u)e^{-n\,\langle\sigma(u)\rangle}$$

2. The derivative of the theoretical transmission needed for the fit procedure

$$\frac{\partial\langle T(u)\rangle}{\partial u} = e^{-n\langle\sigma\rangle}\left(\boxed{\frac{\partial C_T}{\partial u}} - nC_T\frac{\partial\langle\sigma\rangle}{\partial u}\right)$$

- u can be any URR parameter $(S_\ell, \Gamma_\gamma, R^\infty)$
- $C_T(u)$ is the self shielding correction factor
- $\frac{\partial\langle\sigma\rangle}{\partial u}$ is already provided in FITACS for all given parameters.
- $\frac{\partial C_T}{\partial u}$ does not have any sort of analytical form and must be estimated numerically

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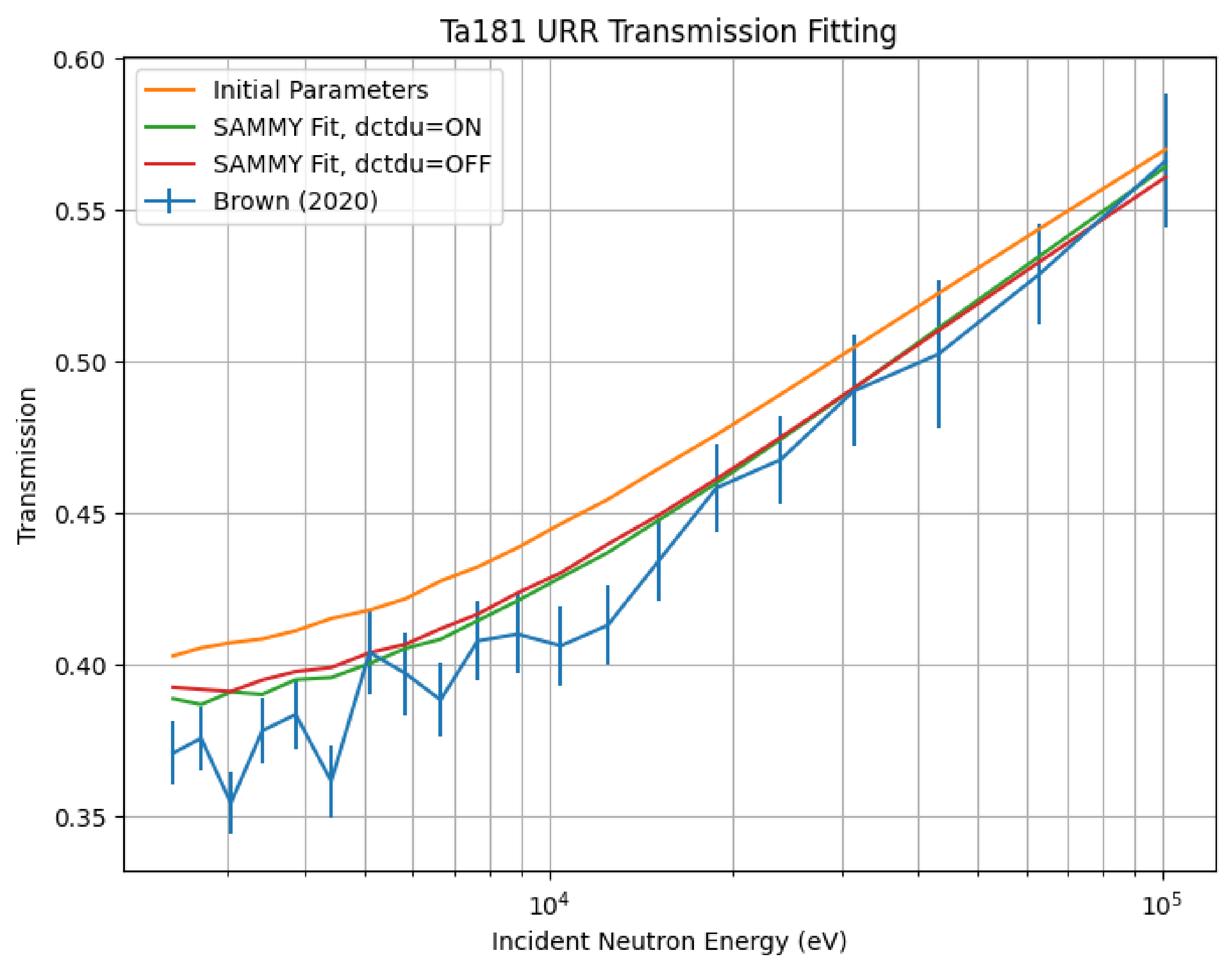
Verifying Transmission Fitting



- Actual fits are very similar
- Error while enabling $\frac{\partial C_T}{\partial u}$ calculation is marginally better than disabling derivative
- $\frac{\partial C_T}{\partial u}$ calculation is currently disabled in SAMMY until a testing suite is developed

Ta-181 Fitting Results (Strength Functions *1e-4)

	$\frac{\partial C_T}{\partial u}$=ON	$\frac{\partial C_T}{\partial u}$=OFF	ENDF-8.1
S_0	1.807	1.7517	1.740
S_1	0.620	0.7511	0.800
S_2	1.486	1.4986	1.690
χ^2/N	1.981	2.444	-

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Workshop on Elastic and Inelastic Neutron Scattering (WINS-2023)

October 10-12, 2023

- Hosted at RPI in NES building and included a tour of the LINAC
- International meeting postponed due to COVID from 2020 to this year.
- About 35 attendees from different laboratories
  - Brookhaven National Laboratory
  - Helmholtz-Zentrum Dresden Rossendoff, Germany
  - IRMM, Belgium
  - Horia Hulubei National Institute Romania, CNRS/IPHC, Strasbourg
  - US Naval Academy
  - Los Alamos National Laboratory
  - Naval Nuclear Laboratory (NNL)
- About 21 presentation
  - 7 talks form this group.
- Sponsored by RPI and NNL

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Summary

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

- Neutron capture γ-ray cascade spectra and yields were measured in the resolved resonance region and compared to evaluations using mod-MCNP-6.2/DICEBOX simulations
  - Helps assess current nuclear structure data
  - mod-MCNP6.2 event-by-event simulation techniques were developed
  - Work under the FY23 NDIAWG FOA will further develop the nuclear data and simulation methods to provide benchmarks for neutron induced capture γ-ray cascades

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

- New feature in SAMMY will enable fitting of neutron transmission and capture yield in the URR
  - Embedding self-shielding code SHESH in SAMMY