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

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**Presented by:**

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# Acknowledgements


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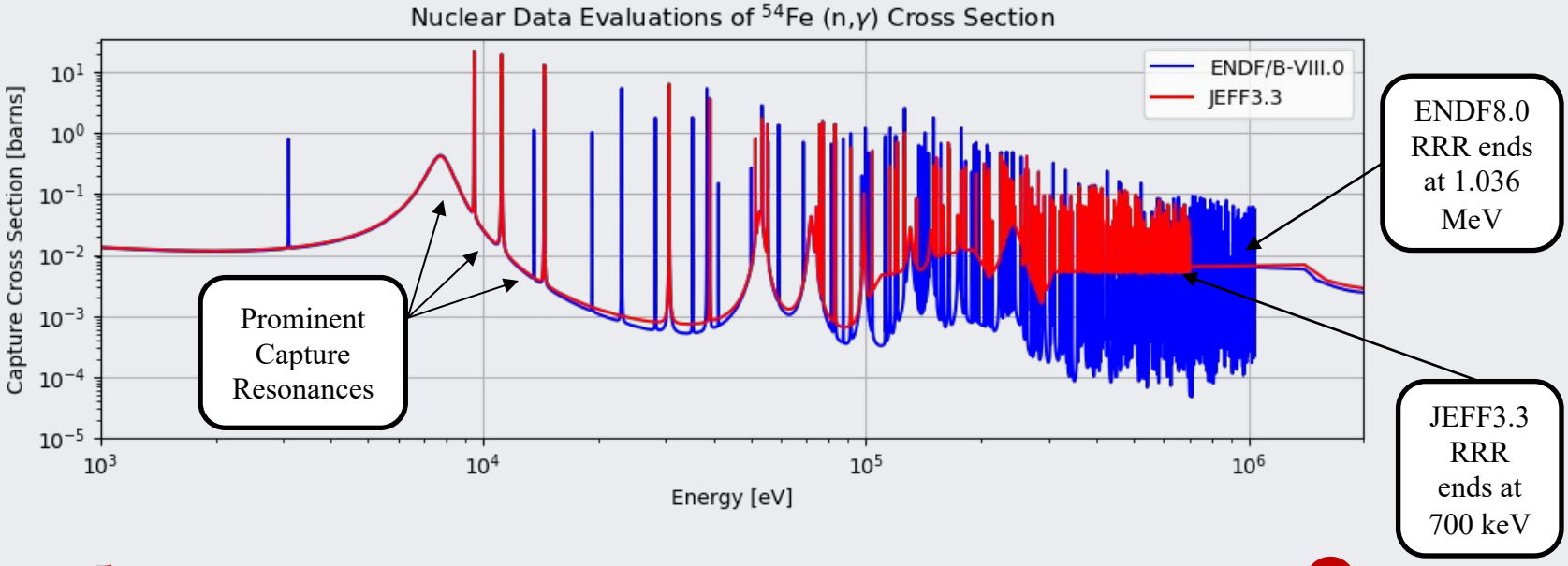
# Major Accomplishments in 2023

- RPI $^{54}$Fe capture and transmission implicit data covariances (IDC) were generated.
  - Fitting was compared w/ and w/o IDCs in SAMMY.
- $^{54}$Fe RRR evaluation near completion using RPI differential data and other experiments from EXFOR.
  - Resonance parameters w/ SAMMY determined.
  - Evaluated covariances currently under investigation.
- Neutron beam imaging system in development to improve future RPI TOF measurements.
  - TOF measurements conducted to confirm beam position can be predicted accurately.

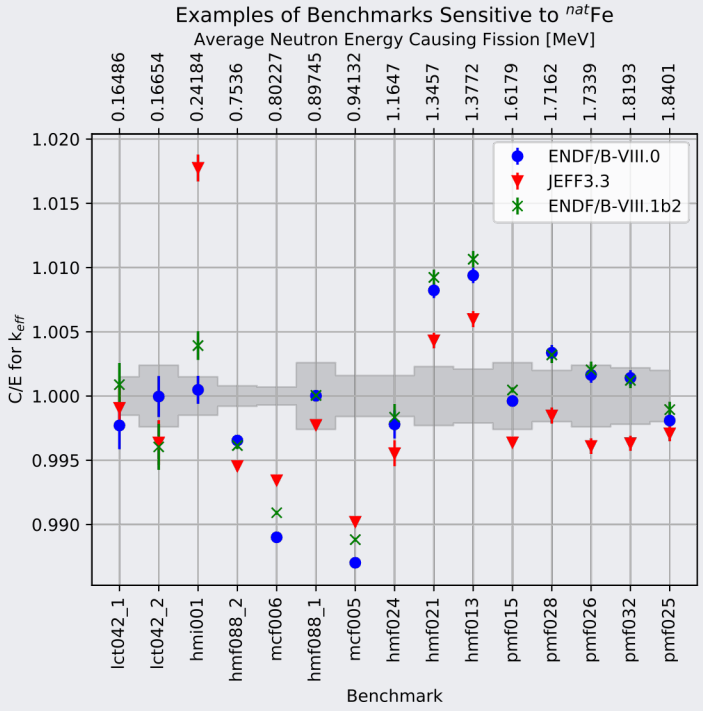
# Project Overview

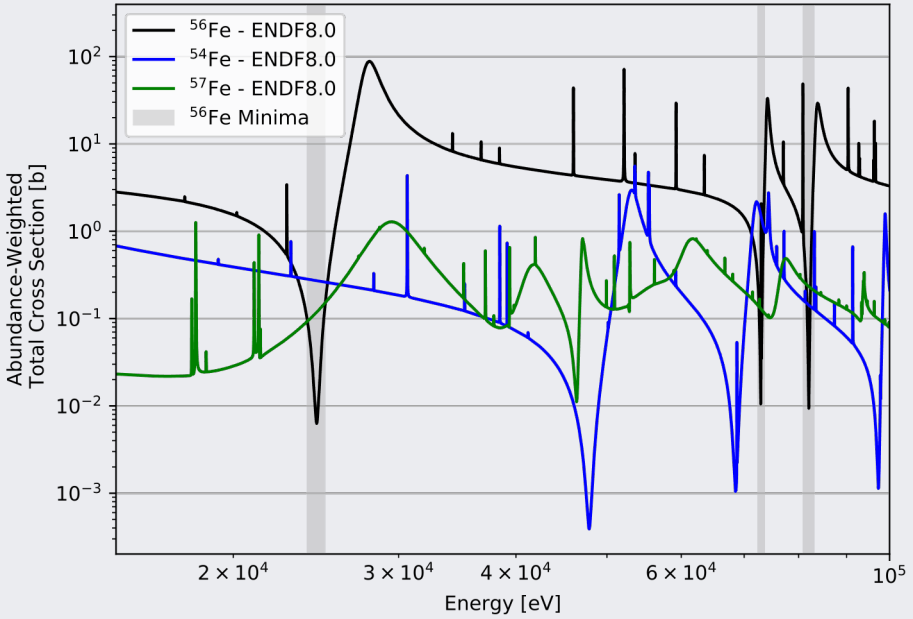
- Motivation:
  - Criticality safety calculations require high accuracy nuclear data to reduce uncertainties
  - $^{54}$Fe neutron cross sections have not been well-studied relative to $^{56}$Fe.
    - Iron is important in shielding, criticality safety, and stellar nucleosynthesis
- Project Goals:
  - Perform new RRR evaluation for $^{54}$Fe cross section in the keV region using RPI and EXFOR nuclear data.
    - Evaluation will include covariances along w/ consideration of measurement covariances from RPI experiments.
  - Perform radiative capture and transmission measurements of $^{54}$Fe in the keV energy region



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

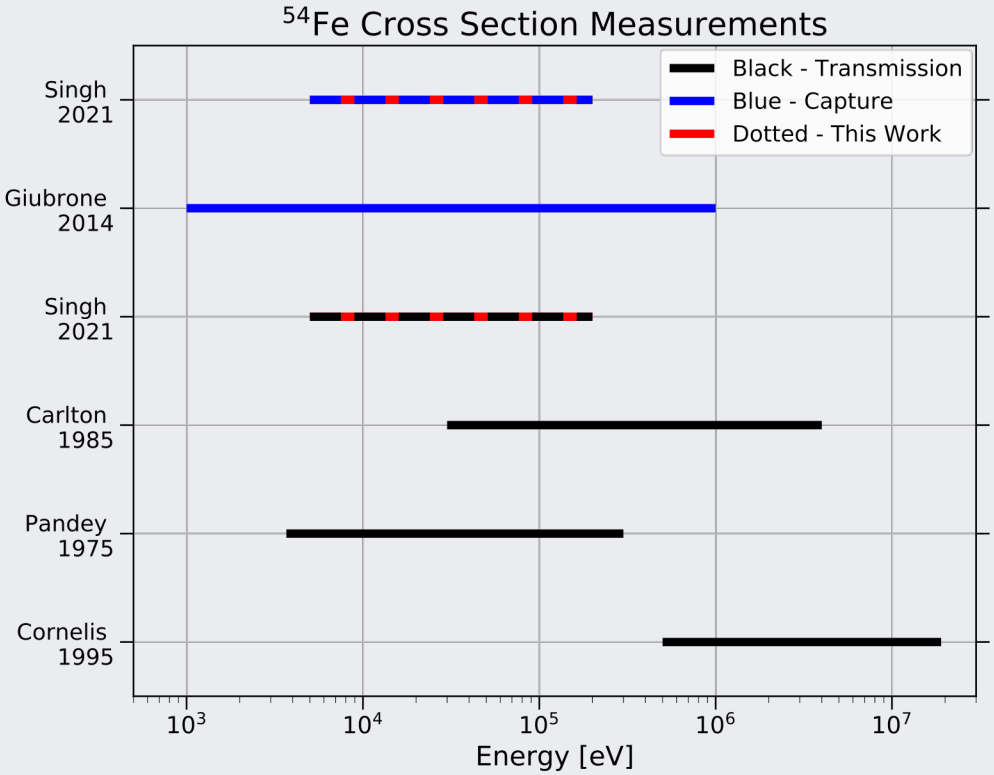
- Iron is very important to study with respect to radiation shielding, criticality safety, and stellar nucleosynthesis.
- Since Iron is an important structural material in nuclear reactors, benchmarks can be shown to have sensitivity to $^{nat}Fe$ cross sections.
- In the minima of $^{56}Fe$ cross sections,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



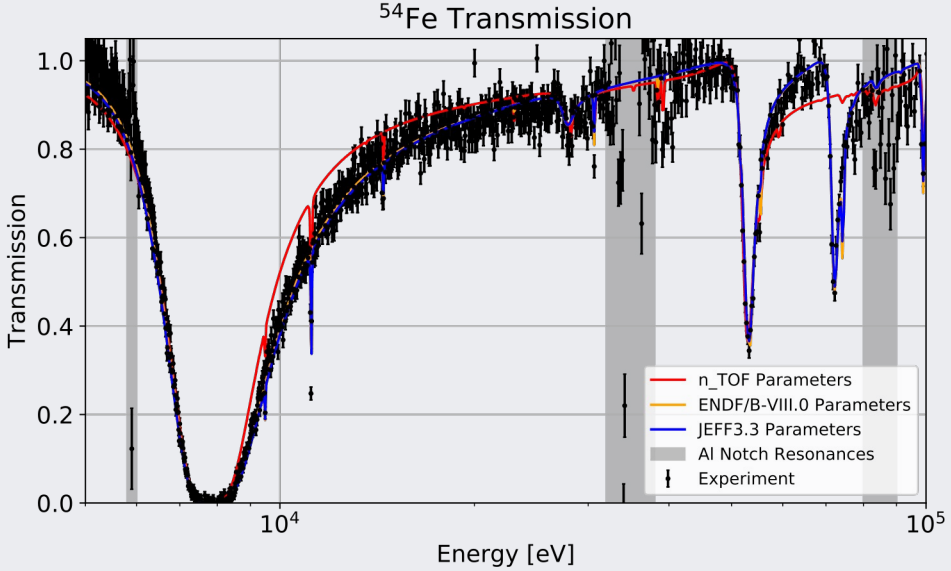
# RPI $^{54}$Fe Measurement Campaign Overview

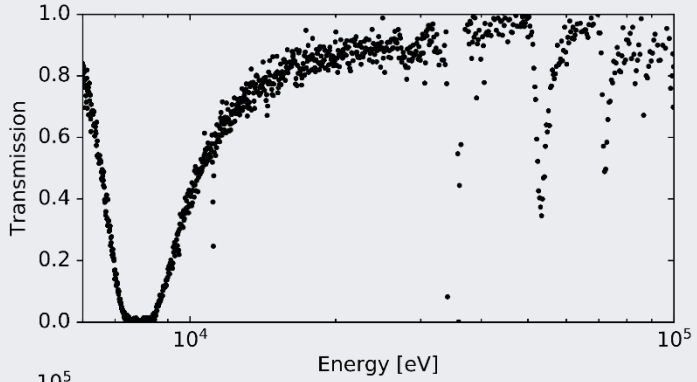
- The RPI capture and transmission measurements both provide valuable insight and address deficiencies in EXFOR.
- RPI capture measurement provides additional data for evaluation work and comparison to the n_TOF experiment.
- RPI transmission measurement provides valuable data below 30 keV, a region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

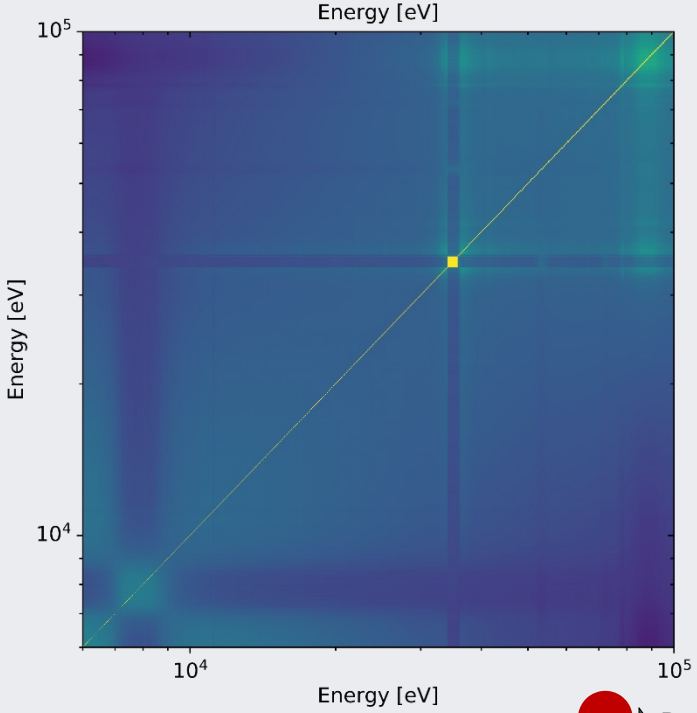


# Overview of RPI Transmission Results

- Transmission is less sensitive to changes in evaluations.
  - Covariance passes all mathematical checks.
- Small correlations are present in the transmission experiment.

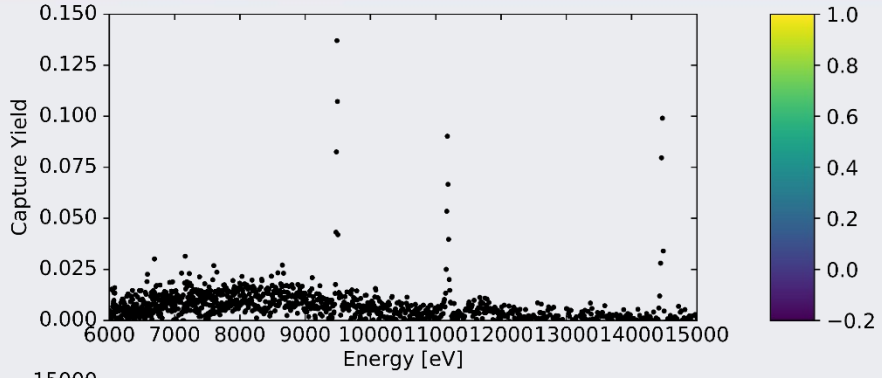


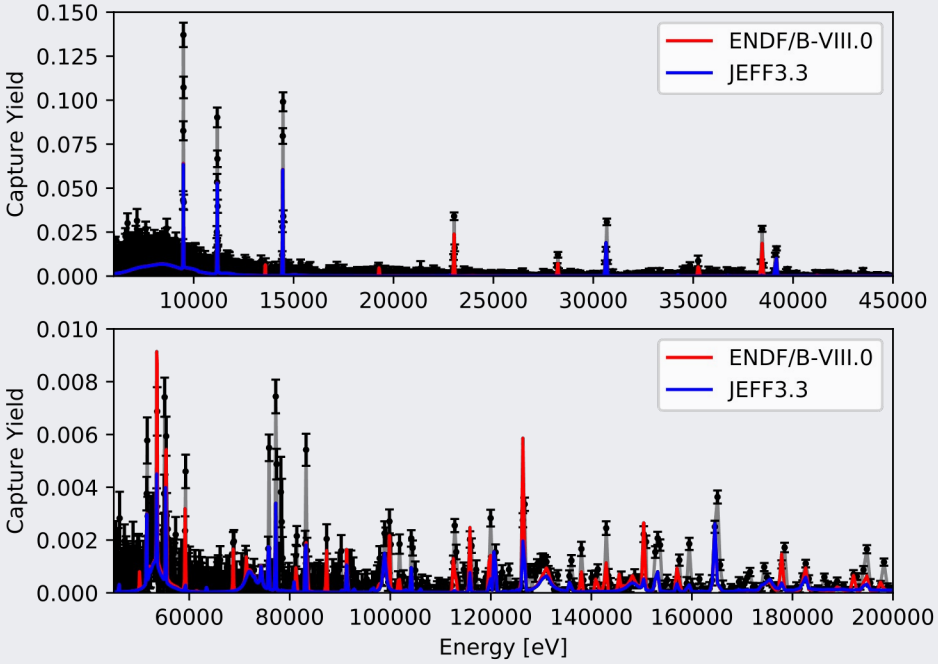



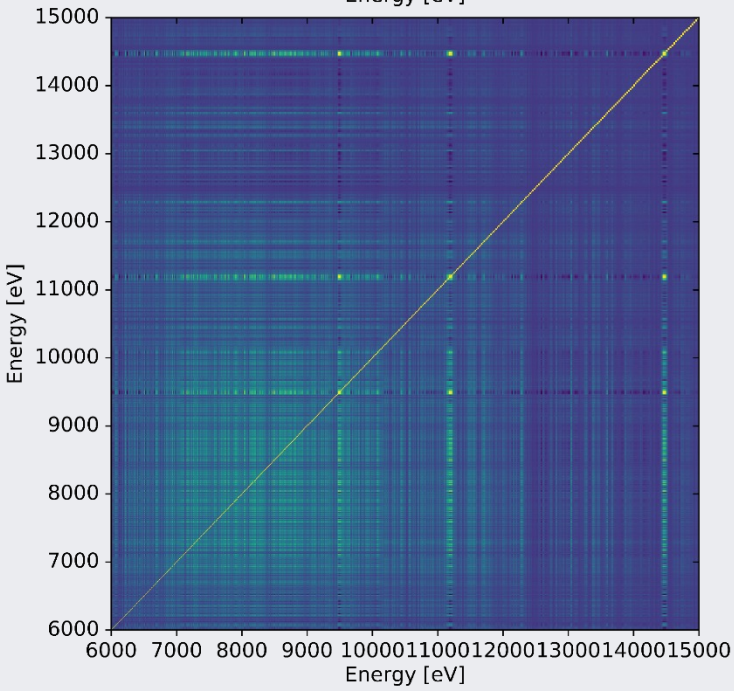



# Overview of RPI Capture Results

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



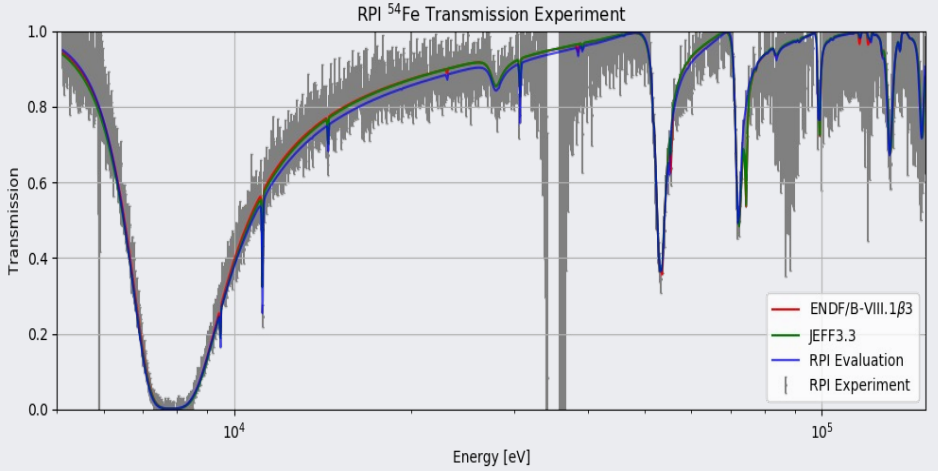



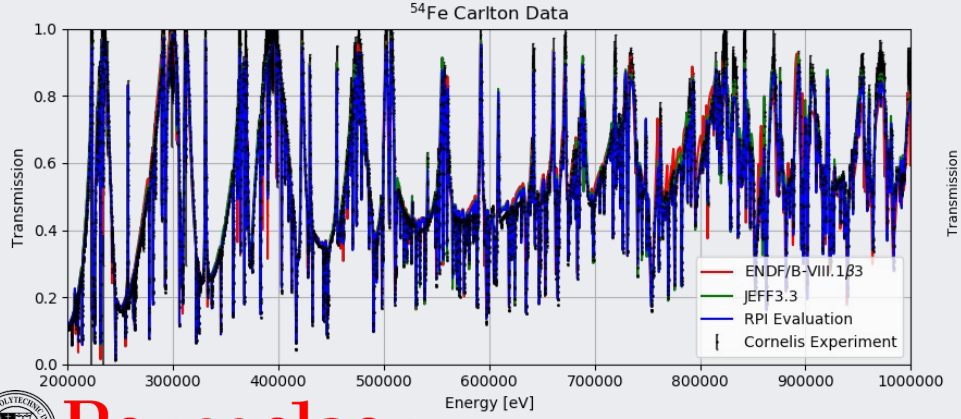
# Overview of RPI $^{54}$Fe Evaluation Work

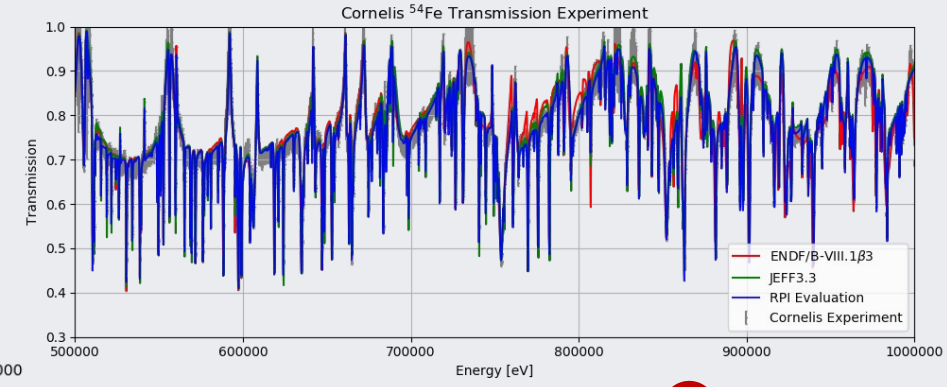
- SAMMY is being used to fit new RRR parameters up to 1.036 MeV
  - RRR not being extended due to lack of high-resolution measurements at higher energies
- Measurements are fit sequentially w/ the inclusion of IDCs for RPI data.
  - Fitting w/ or w/o IDCs does not significantly impact the fits potentially due to lower correlations in the data.
  - Covariance of fitted parameters is updated after each fit.
- Current evaluations have no MF-32, will be included in the RPI evaluation.
  - Work on evaluated covariances is still underway – very preliminary analysis has been performed.

# Transmission Fitting

- Multiple transmission experiments fitted
  - RPI: 0.021 a/b enriched metallic sample, ~35m FP
  - Cornelis: 0.06 a/b enriched oxide sample, ~400 m FP GEEL.
  - Carlton: 0.166 a/b enriched metallic sample, ~200m ORELA
  - Pandey: (not pictured) 0.019 a/b, 78m FP ORELA

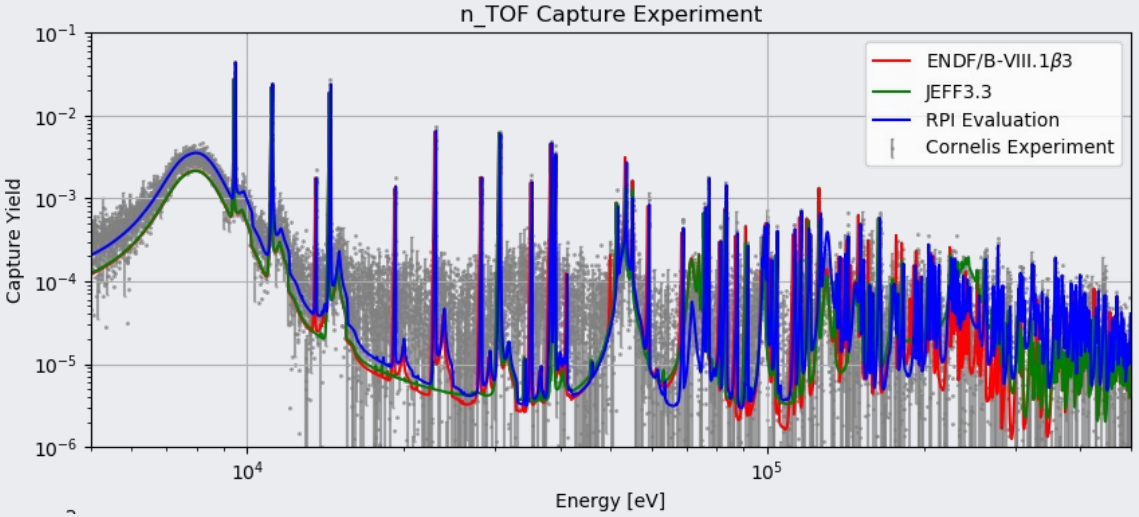


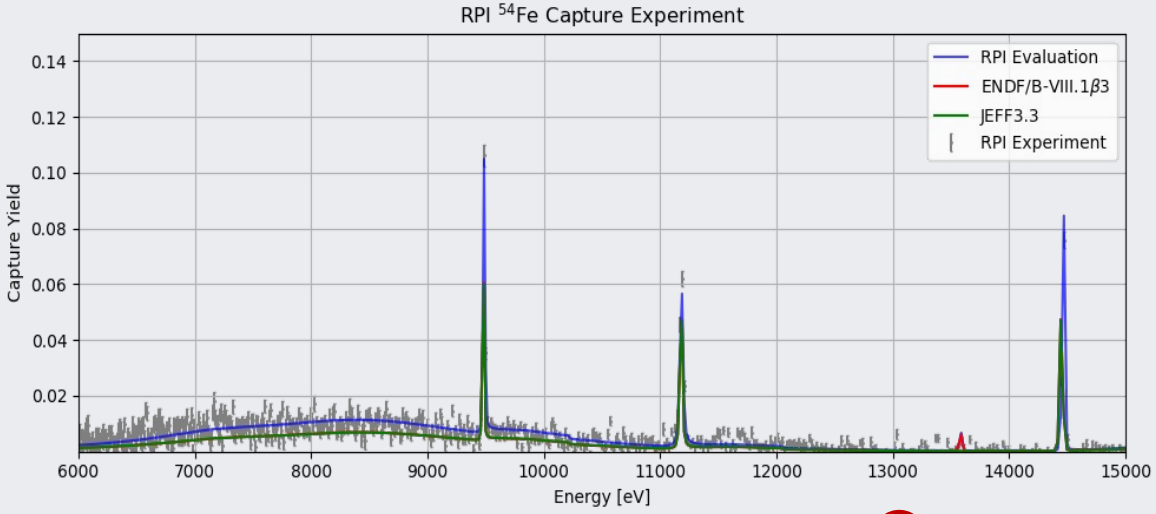



# Capture Fitting

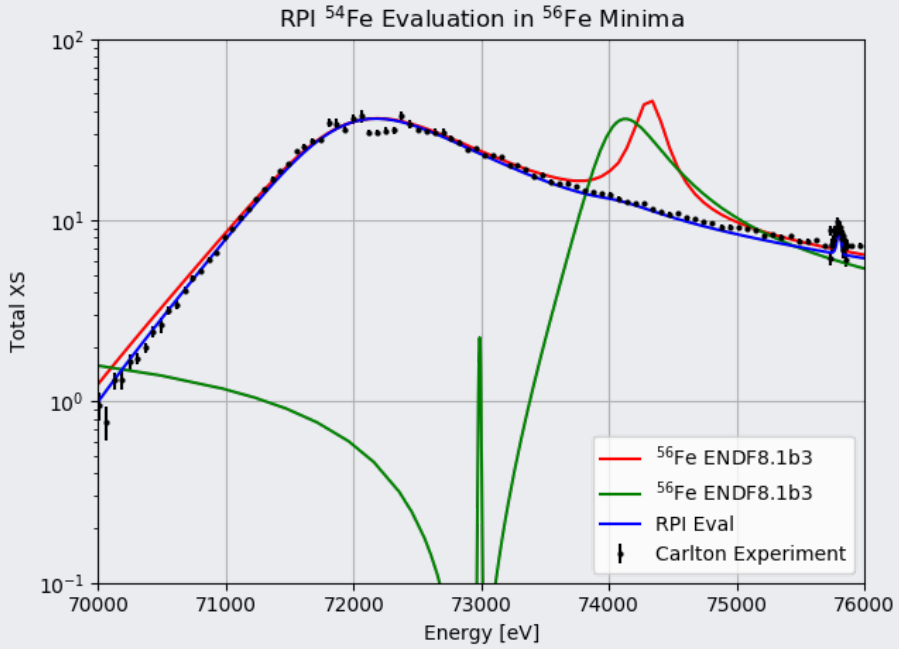
- Limited high-resolution capture data are available on EXFOR.
- Capture is increased relative to existing evaluations, resonance structure seen in experiments is better fit w/ RPI evaluation
- Direct capture was considered in evaluation but currently opting for inclusion of bound levels over direct capture background

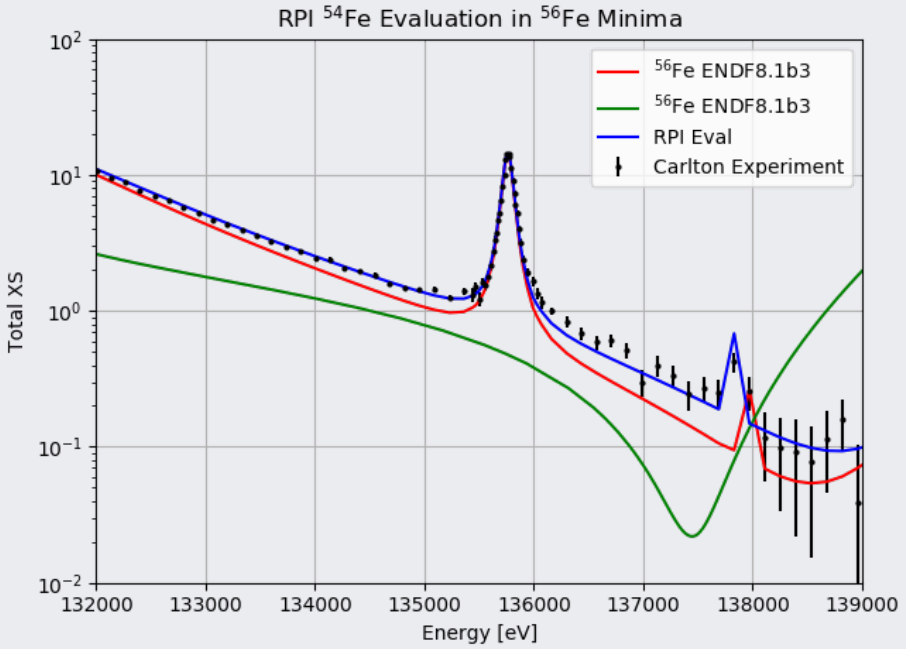


# Examples of Changes in $^{56}$Fe XS Minima

- Changes to $^{54}$Fe XS in the region of $^{56}$Fe XS minima may have implications on different applications including shielding.
- Some examples of changes made are shown below:
  - False resonance removed at about 74 keV
  - Better fit obtained to differential data at 137 keV
- Validation studies are underway – need to study impact on shielding experiments.



# MACS and Thermal Values

| Source | $\sigma_\gamma$ [barns] at 0.0253 eV |
|---|---|
| RPI Evaluation | 2.27 |
| ENDF/B-VIII.0 | 2.25 |
| JEFF-3.3 | 2.25 |
| Litvinskij Capture | 2.28 |
| Wallner Capture | 2.26 ± 0.15 |
| NIST | 2.25 |
| Atlas (2018) | 2.30 ± 0.07 |

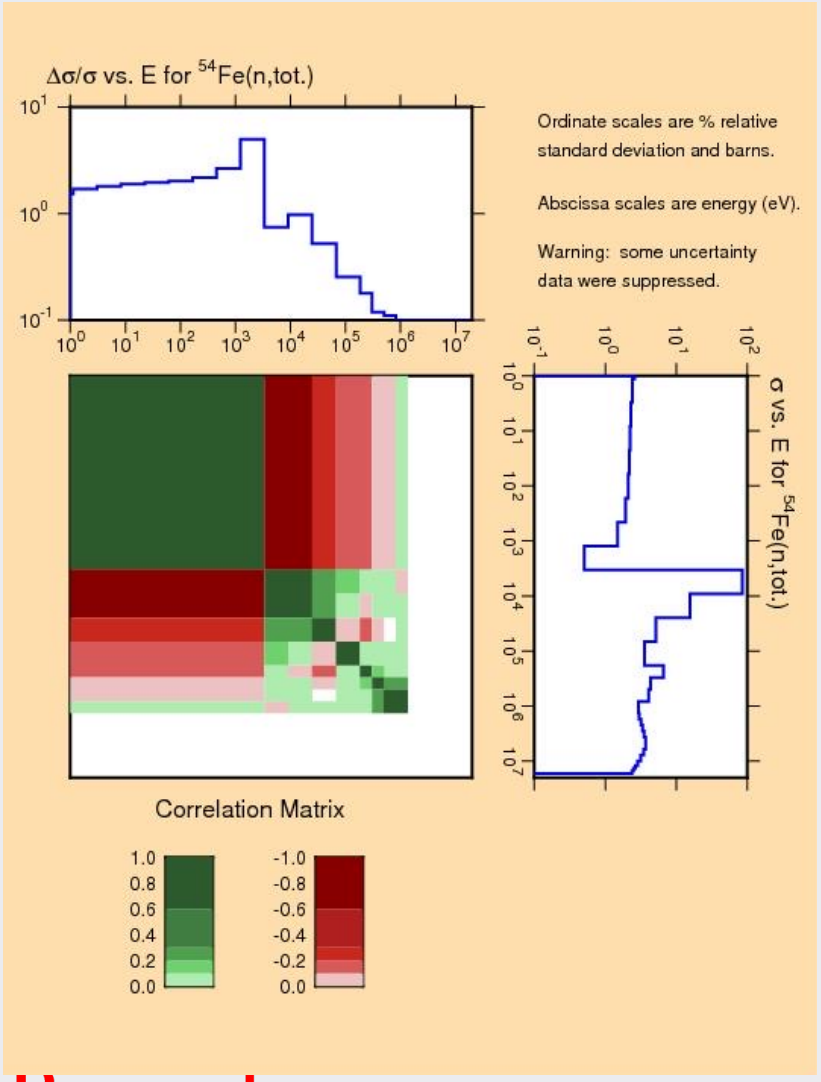
| Source | $\sigma_t$ [barns] at 0.0253 eV |
|---|---|
| RPI Evaluation | 4.46 |
| ENDF/B-VIII.0 | 4.43 |
| JEFF-3.3 | 4.45 |
| NIST | 4.45 |
| Atlas | 4.47 ± 0.12 |

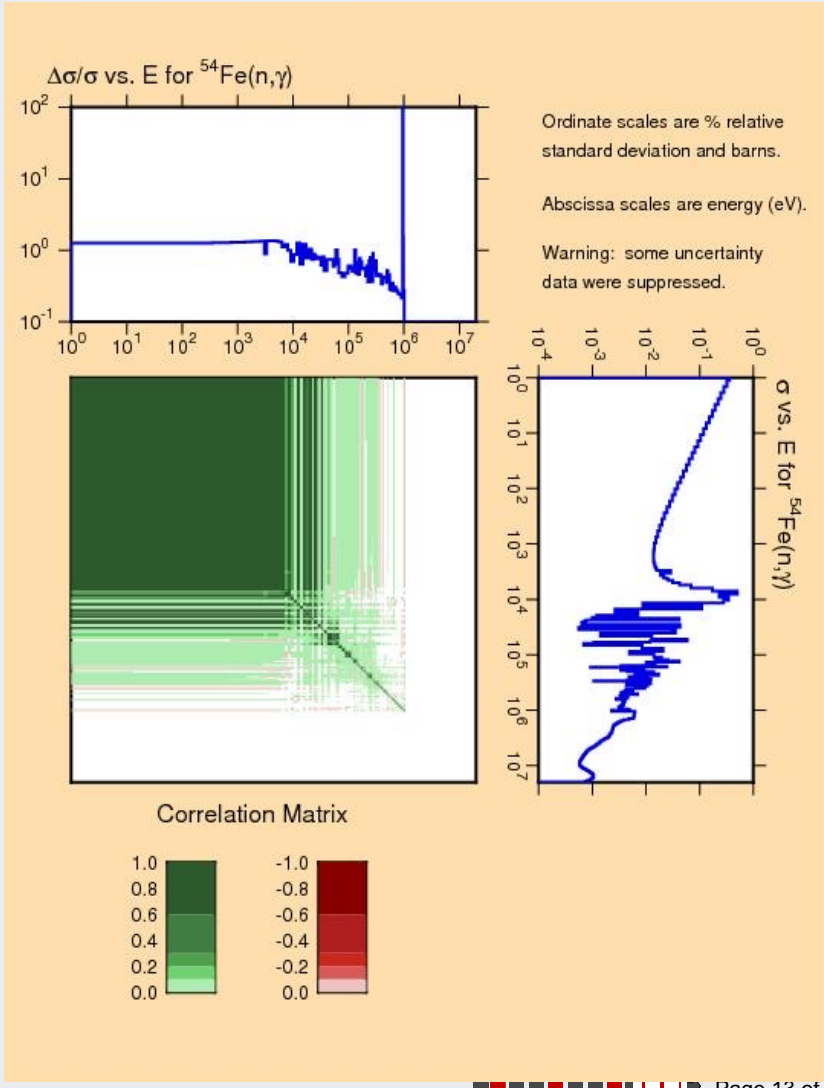
| Experiment or Evaluation | Value [mb] @ 30 keV |
|---|---|
| ENDF/B-VIII.0 | 27.13 |
| RPI Eval | 29.8 |
| KADoNiS-0.3 | 29.6 ± 1.3 |
| n_TOF Exp | 30.8 ± 1.6 |
| Allen Exp | 33.6 ± 2.7 |

| Experiment | Value @ 481 keV |
|---|---|
| Wallner | 6.01 ± 0.28 [mb] |
| n_TOF Exp | 6.04 [mb] |
| RPI Eval | 6.10 [mb] |

- Evaluated uncertainty quantification is underway.

# Preliminary Evaluated Covariances



# Validation Testing Plan

- Impact of new RPI $^{54}$Fe evaluation needs to be studied in tandem with candidate files for ENDF/B-VIII.1.
- A suite of critical experiments sensitive to Natural Fe has been compiled and is currently being studied.
  - Current benchmark suite consists of ~15 critical experiments and growing.
- $^{nat}$Fe differential experiments will be used as another validation – new RPI evaluation should not break
  - Compensating changes may be attributed to other minor isotopes w/ enough evidence.
- Shielding experiments may show sensitivity to changes in Fe streaming windows
  - $^{252}$Cf leakage experiments, D-T source measurements, “Broomstick” measurements

**“Do no harm”**

# Conclusions and Future Work

- $^{54}$Fe measurement campaign has concluded with IDCs fully developed for capture and transmission experiments.
- $^{54}$Fe RRR evaluation campaign at RPI is near its conclusion, covariance matrix generation is needed for evaluation.
  - Evaluation is not currently planned for ENDF/B-VIII.1
- A new evaluation will offer improvements in crit safety, shielding, and stellar applications.
- Measurement + Evaluation paper will be completed by June 2024.
  - Experimental data will be available on EXFOR.
- RPI graduate school commitments to be completed by August 2024.