Measurements of Neutron Induced Reactions Relevant to NCSP

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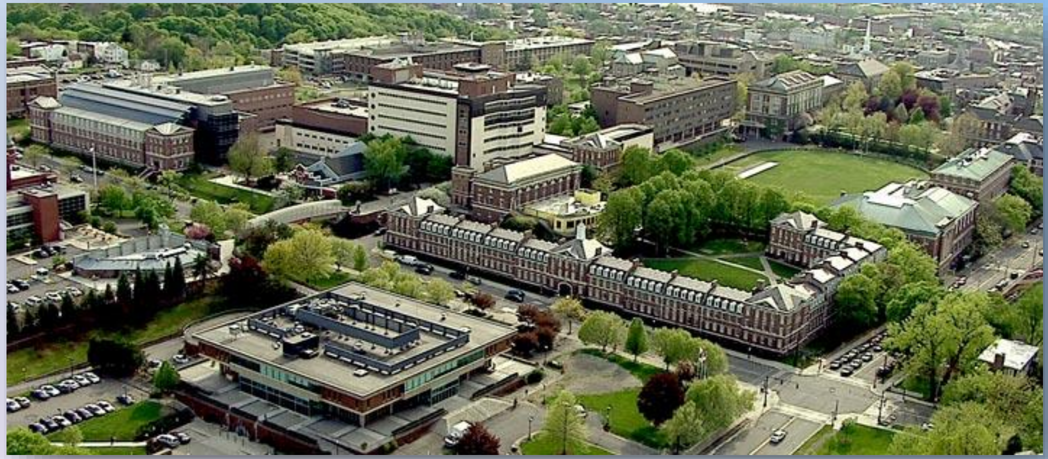

NCSP Meeting, ORNL, March 27-28, 2018

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NCSP Activity Overview

- **ND-1 Resonance Region Nuclear Data Measurement**
  - Tantalum in the RRR and URR
    - Performed measurements of neutron transmission at 100m flight path
    - Performed measurements of neutron capture at 45m flight path
    - Performed thick sample transmission measurements to benchmark resonance self shielding in the URR.
- **ND-2 Thermal Neutron Scattering Measurements**
  - Measurement of thermal neutron scattering
    - Final analysis of previous measurements of: polyethylene, Lucite, quartz, and concrete.
- **ND-3 LINAC 2020 Refurbishment and Upgrade Plan**
  - Five klystrons were fabricated and passed factory acceptance tests.
  - Klystron #6 construction in progress.
  - Modulators fabrication in progress.
  - Accelerator section fabrication in progress.
  - RPI started construction of a modulator building

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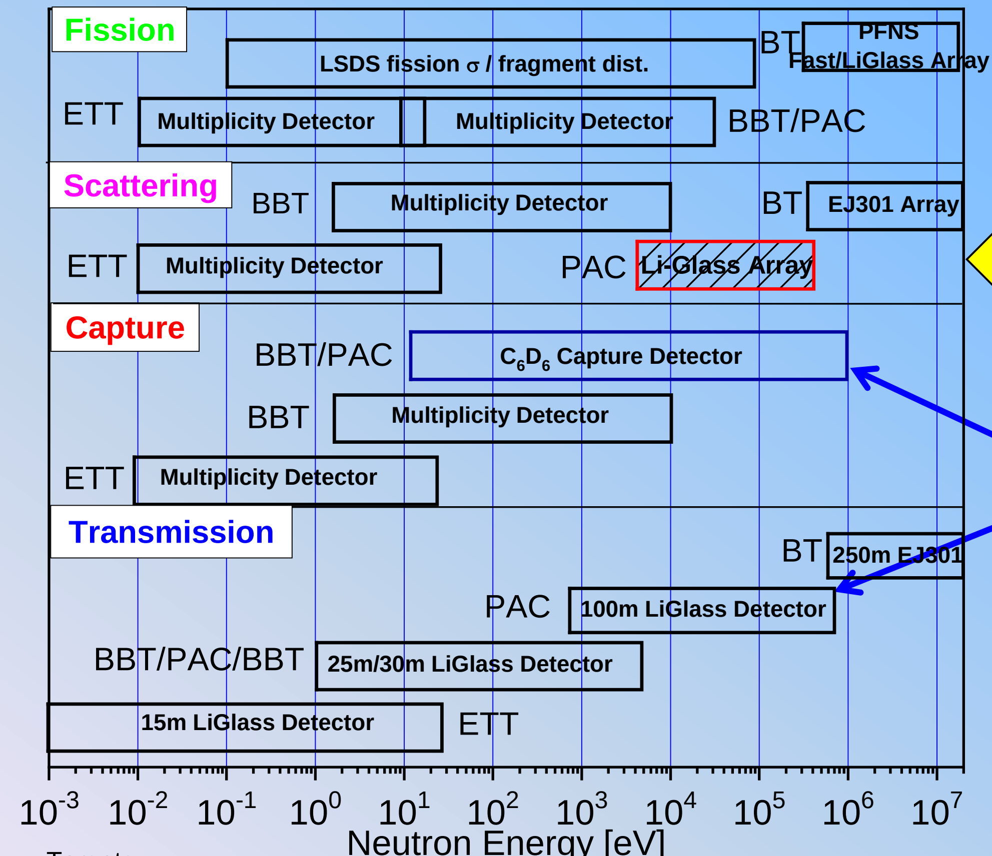
ND 1 – Cross Section Measurements

Capability Matrix

- RPI capability matrix for Nuclear Data Measurements

RPI LINAC - Nuclear Data Measurement Capabilities 2018



In development

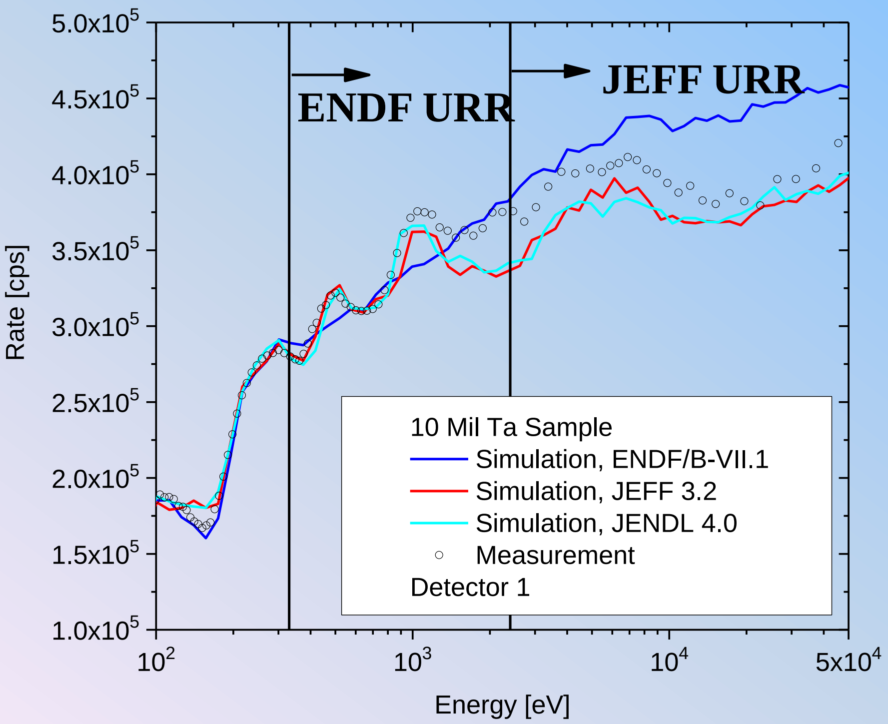
KeV Neutron Scattering

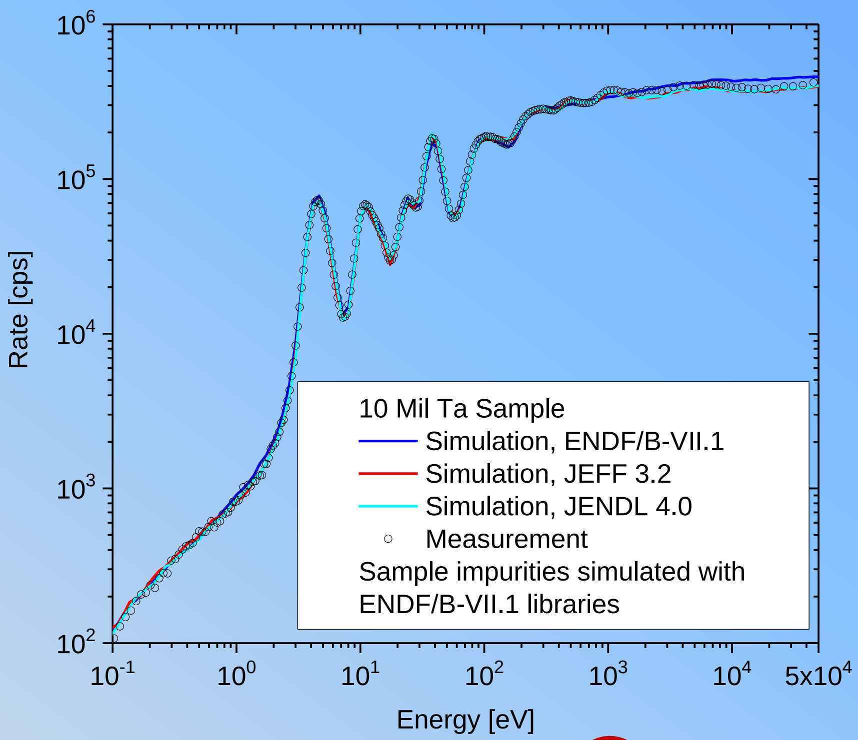
Used for this work

Targets
ETT- Enhanced Thermal Target
BBT - Bare Bounce Target
BT- Bare Target on Axis
PAC - PacMan Target

Motivation – Lead Slowing Down

- NDAG prioritized the Ta measurement
- LSDS study: Discrepancies between libraries in simulated capture rate





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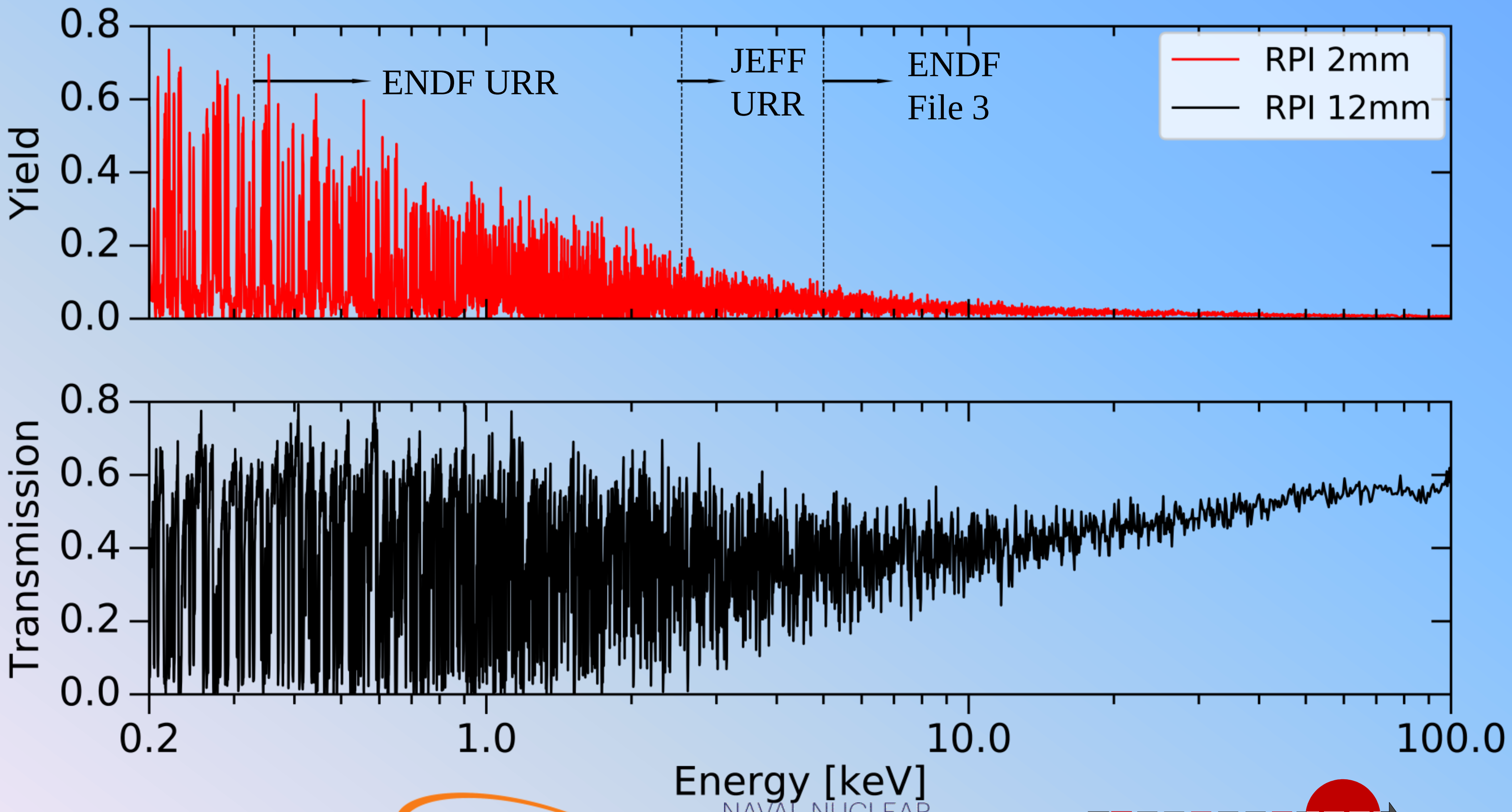
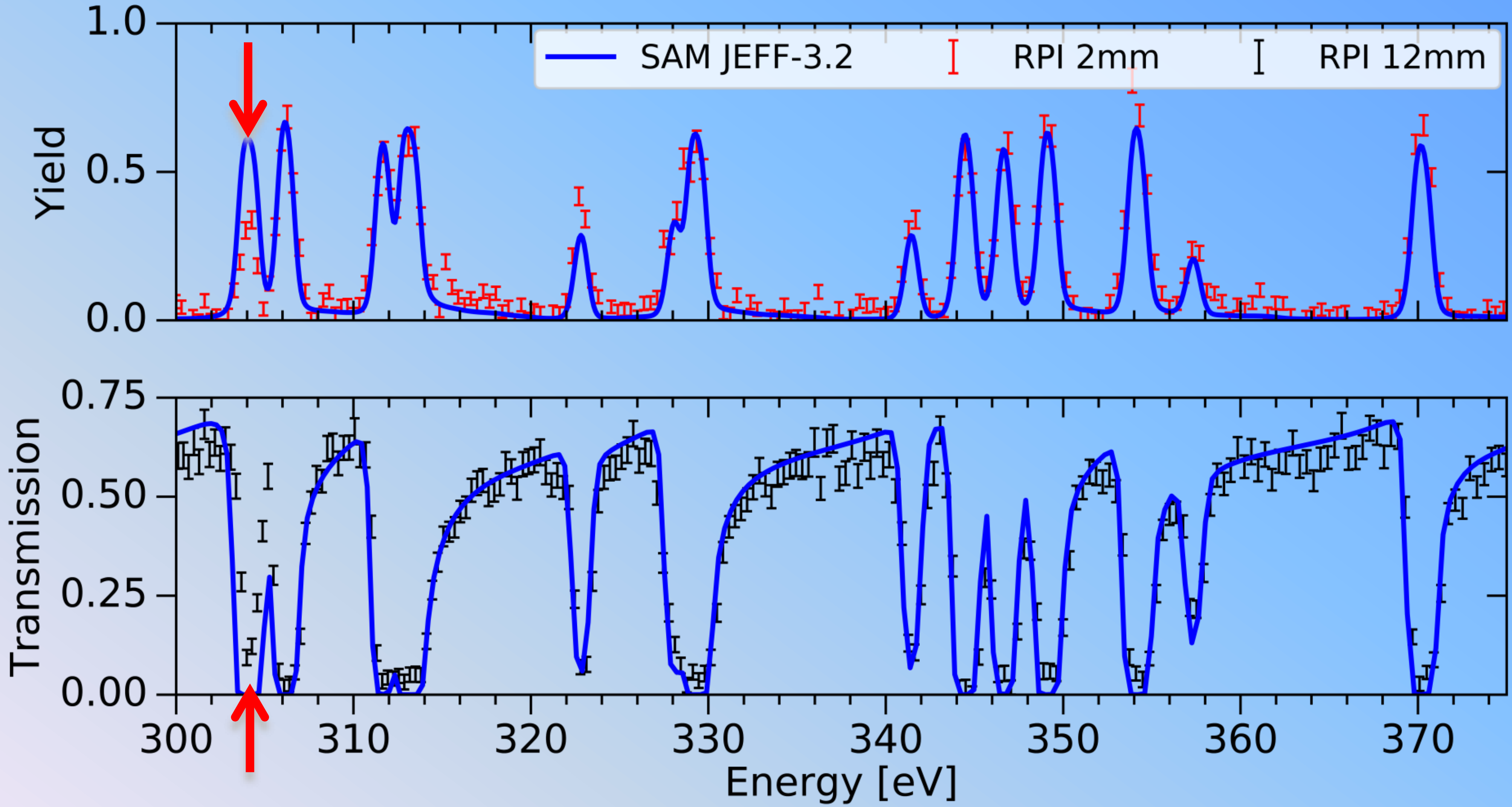
Ta Transmission and Capture Measurements

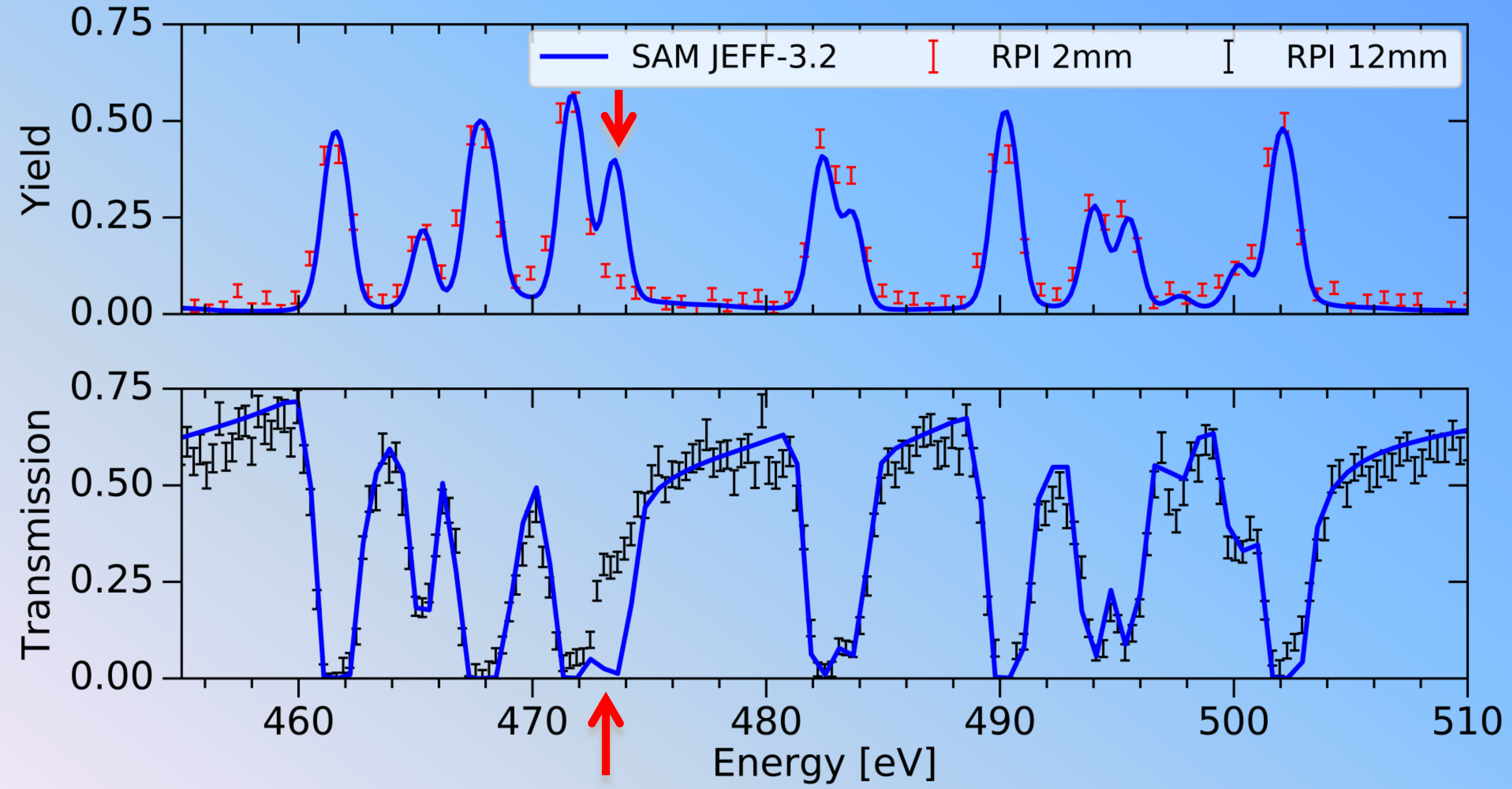
- Used 100m flight station for transmission and 45m for capture
- High resolution data resolving resonance structure up to 10 keV.
- URR self-shielding test using transmission through thick samples



Ta RRR: Minor discrepancies



Ta RRR: Minor discrepancies



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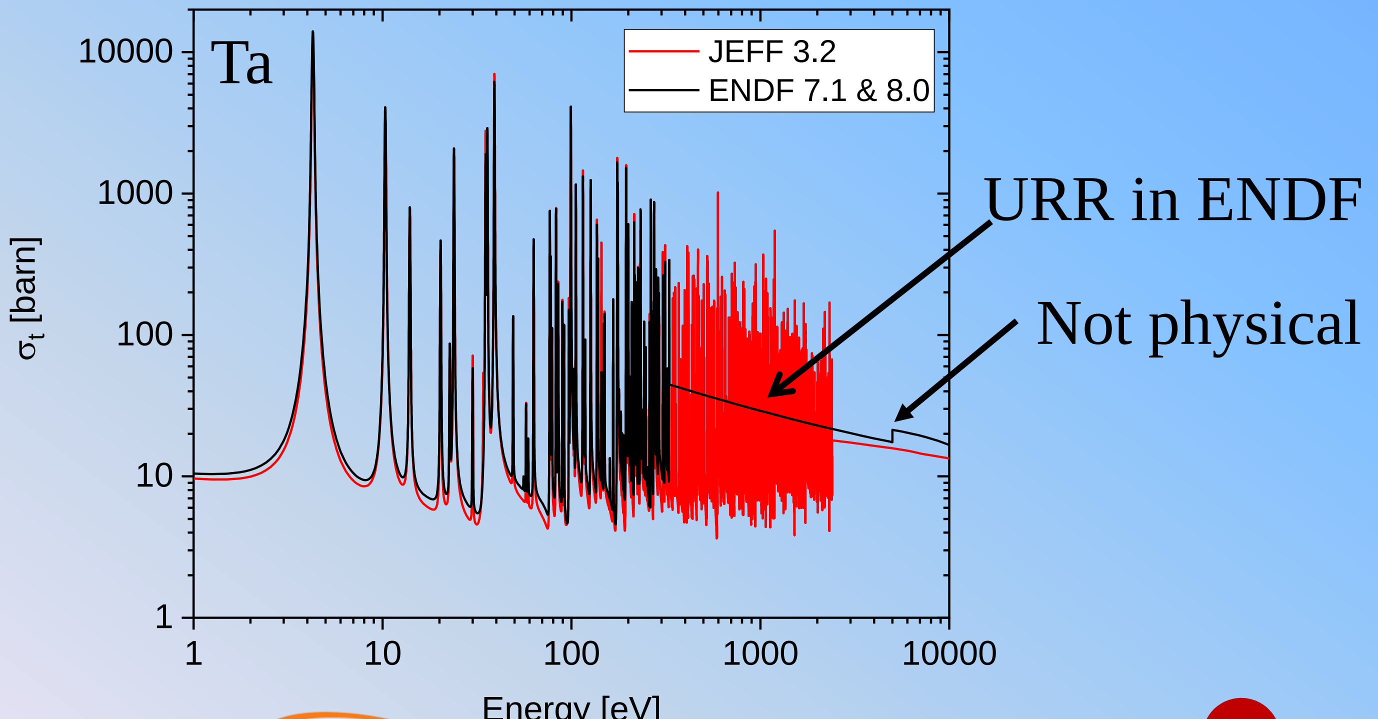
Unresolved Resonance Region (URR)

- The URR starts where resonances can not be resolved in a measurement (they overlap each other).
- In URR (for different reactions) current evaluations include:
  - Average cross sections
  - Average resonance parameters that are important for accurate calculations (will be explained).



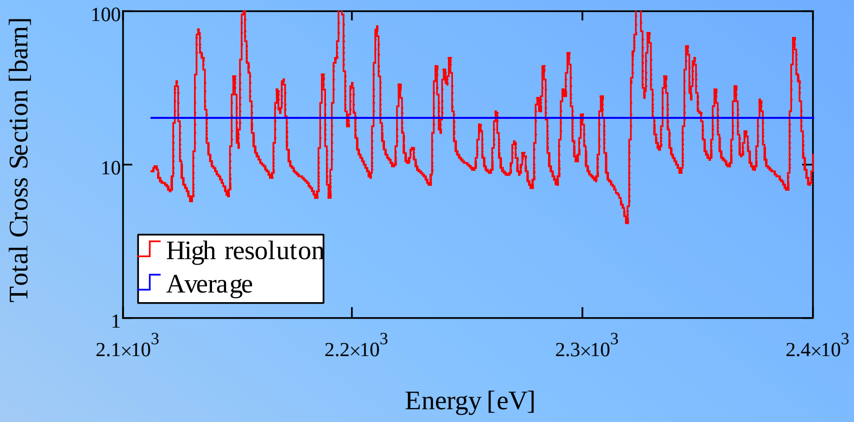
URR Self Shielding

- Example calculating neutron transmission through a 6mm Ta sample
- If the cross section was known in high energy resolution:

$$\langle T \rangle = \frac{1}{E_2 - E_1} \int_{E_1}^{E_2} e^{-N \cdot \sigma_t(E)} = 0.59$$

- If we use only the cross section average:

$$\bar{T} = \frac{1}{E_2 - E_1} \int_{E_1}^{E_2} e^{-N \cdot \langle \sigma_t \rangle} = e^{-N \cdot \langle \sigma_t \rangle} = 0.51$$



- Thus the fluctuation must be taken into account in applications
- When measuring the total cross section with a thick sample a correction for the self shielding is needed.
  - Can use two sample thicknesses →
  - Can use a model based approach → SESH

Froehner, et al, “Cross-section fluctuations and self-shielding effects in the unresolved resonance region “, International Evaluation Co-operation volume 15 (NEA-WPEC--15), Nuclear Energy Agency of the OECD, NEA, (1995).

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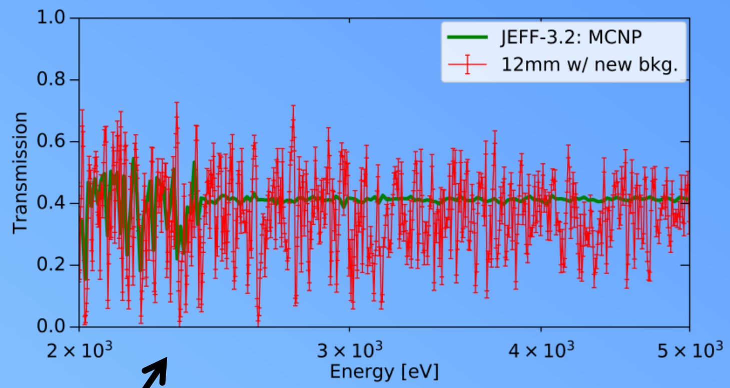
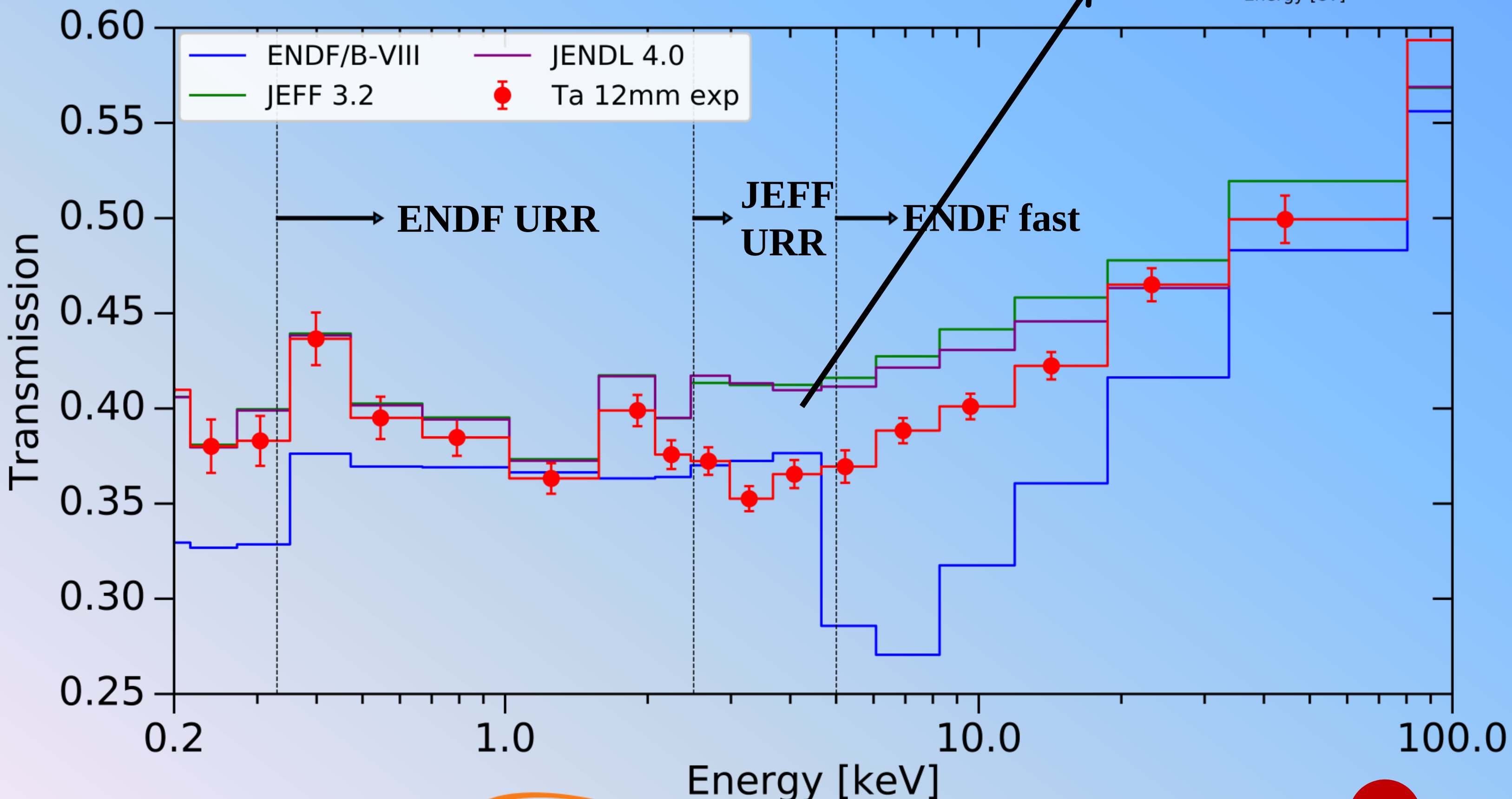
Thick sample transmission

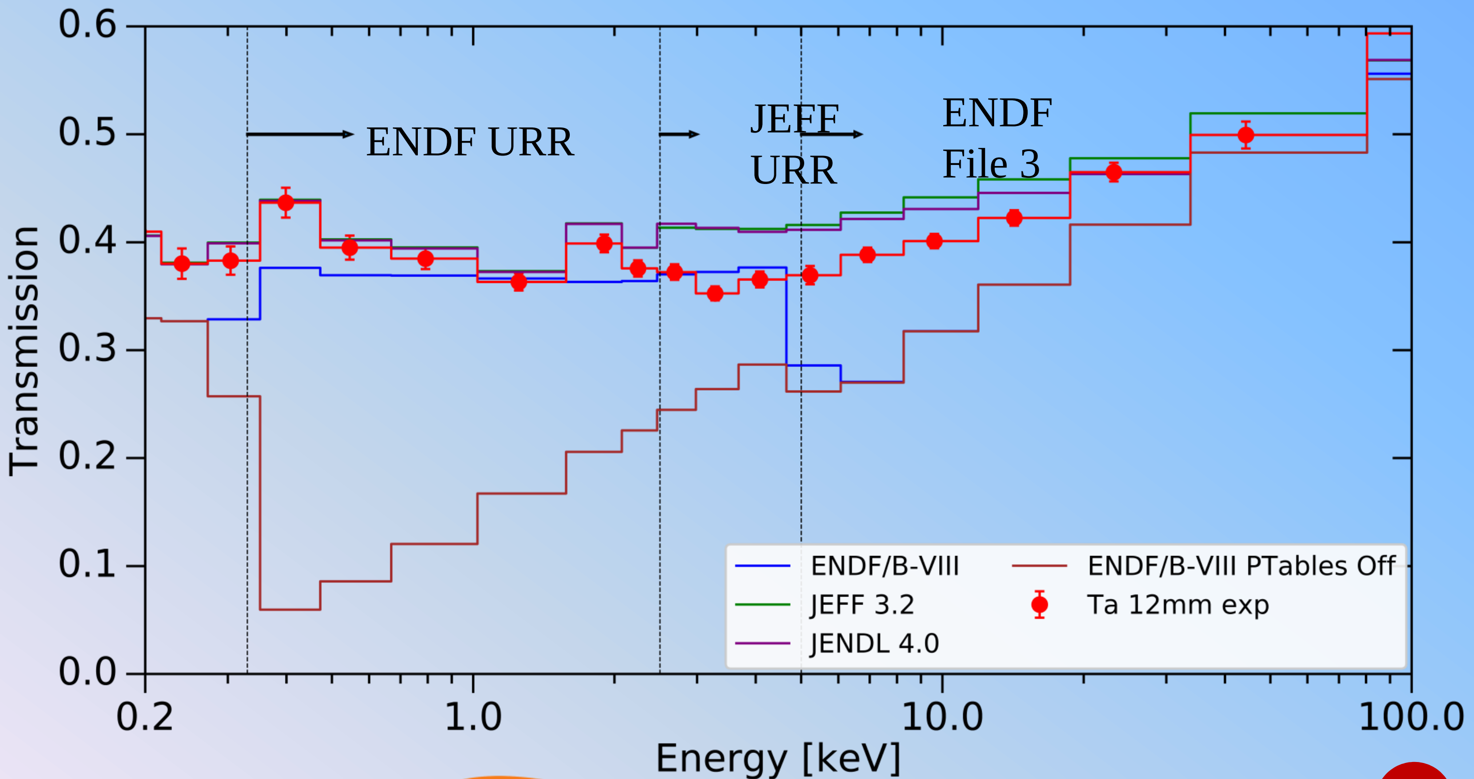
- Test URR treatment
- ENDF is performing poorly





Resonance Self-Shielding

- The effect of self shielding is shown by turning off the URR treatment in MCNP
- Near 300 eV self-shielding reduces the transmission by a factor of about 6. Considering such large effect, the evaluations are reasonable but the new data will help improve.



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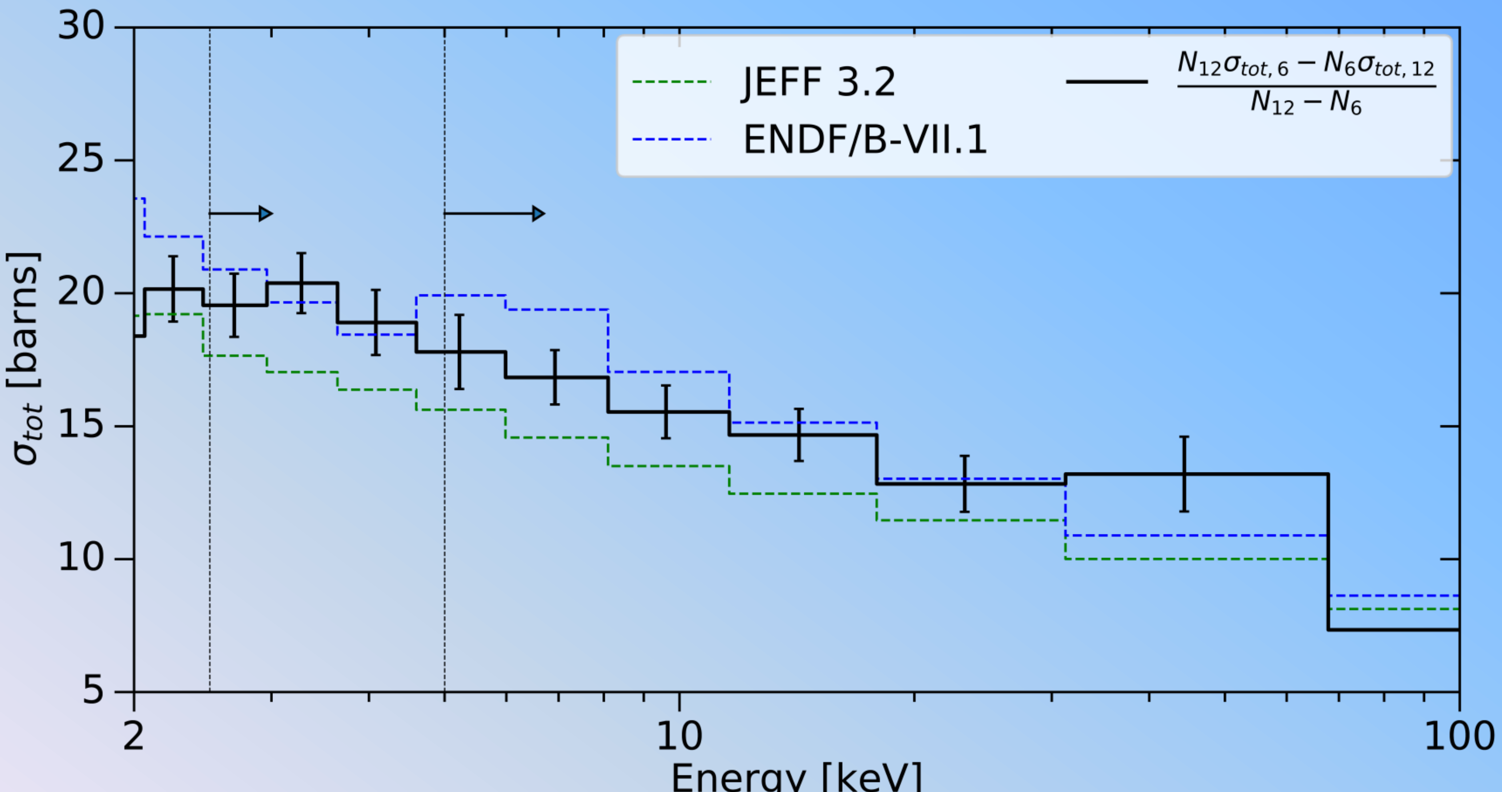
The “true” average cross section

- Use two sample thicknesses and the Froehner method to get the “true” average cross section
- The experiment is between the two current evaluations



ND 2 - Thermal Scattering

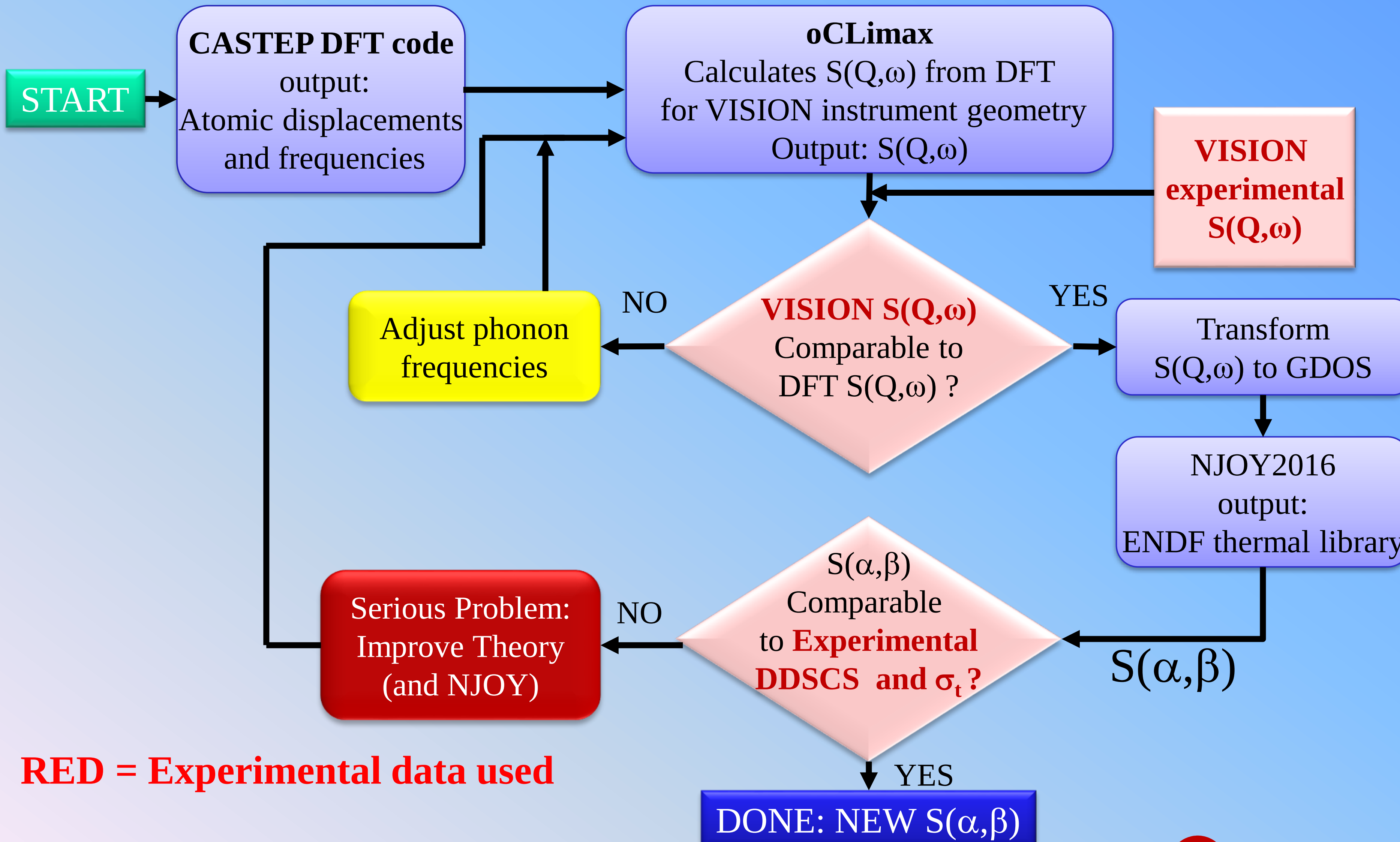
Thermal Scattering Overview

- Overall objectives:
  - **Use double differential thermal scattering and vibrational spectroscopy measurements to benchmark and improve thermal scattering evaluations.**

- Preform measurement at SNS (ORNL):
  - Use ARCS and SEQUOIA for double differential scattering.
  - Use VISION for phonon spectrum measurements.
    - Key collaborators at ORNL: Goran Arbanas, (Mike Dunn).
    - Scientists at SNS: Alexander Kolesnikov, Doug Abernathy, Luke Daemen,

- Advantages:
  - New measurements have much better energy and angle resolution compared to old data.
  - Can measure different type of samples (liquid, solid, mixtures, compounds).
  - Measurements can be done at variety of temperatures starting from 5K
  - **Tremendous amount of different experimental information helps constrain and overcome modeling deficiencies.**

Thermal scattering – evaluation methodology



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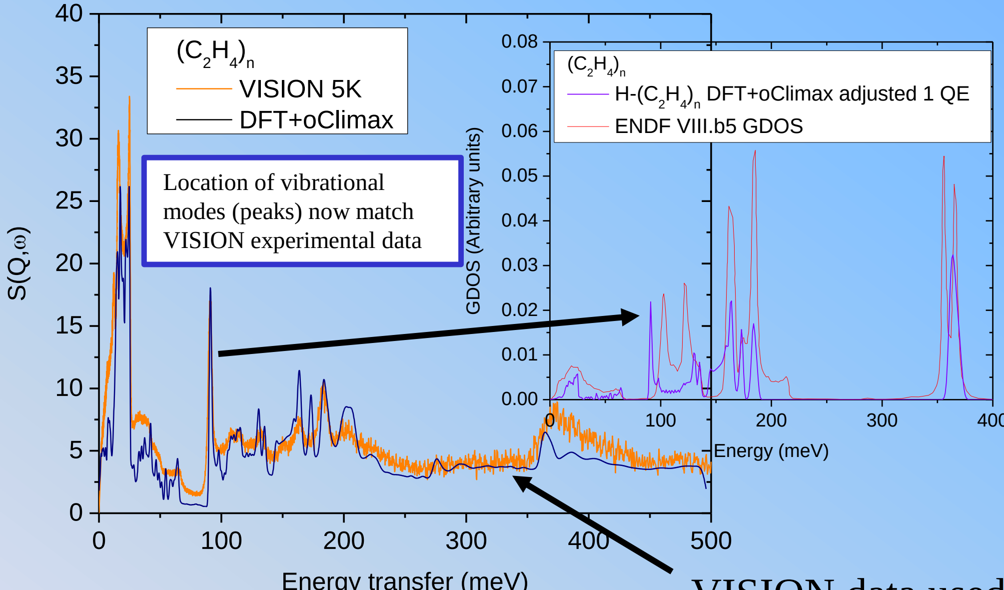
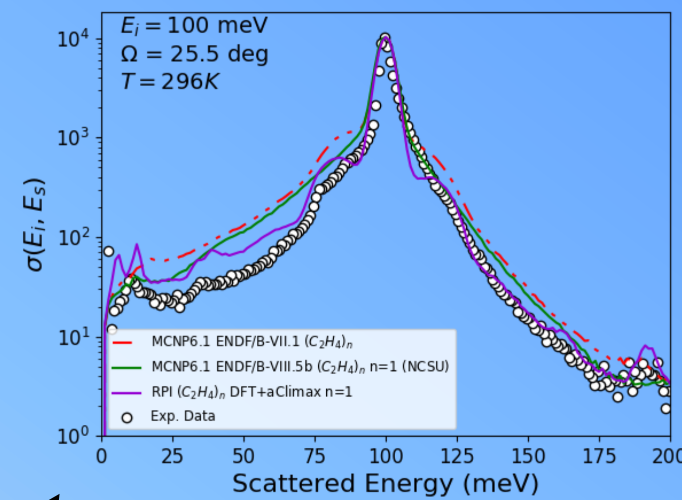
Completed Experiments

Moderators	SEQUOIA (Ω: 3-58º in 1º increments)	ARCS (Ω: 3-125º in 1º increments)	VISION (at 5 K)
Light Water (H_2O)	E_I: 55, 160, 250, 600, 1000, 3000, 5000 meV Temp: 300 K		YES
Polyethylene (CH_2)	E_I: 55, 160, 250, 600, 1000, 3000, 5000 meV Temp: 300 K	E_I: 50, 100, 250, 700 meV Temp: 5, 295 K	YES
Quartz (SiO2)		E_I: 50, 100, 250, 700 meV Temp: 5, 295, 573, 823, 873 K Thickness: 3.175, 6.35 mm	YES
Teflon ($(C_2F_4)_n$)		E_I: 50, 100, 250, 700 meV Temp: 5, 300, 500 K	NO
Lucite ($C_5O_2H_8$)		Ei: 50, 100, 250, 700 meV Temp: 5, 300, 400 K	YES
Concrete (mixture)		Ei: 50, 100, 250, 700 meV Temp: 5, 300 K	NO

Polyethylene Experimental Data and Evaluation

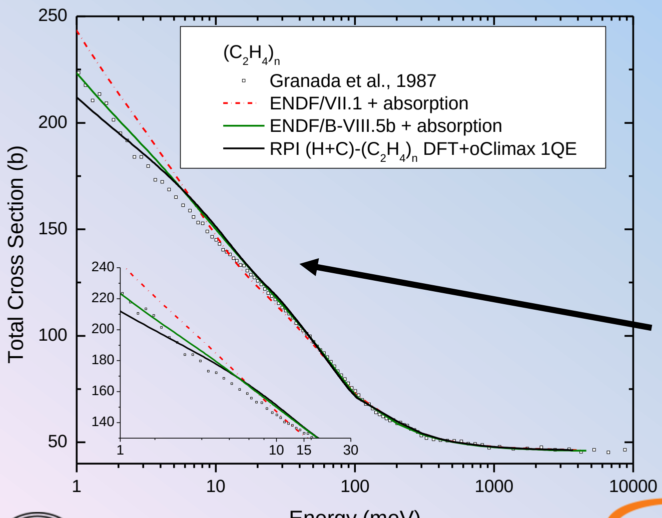


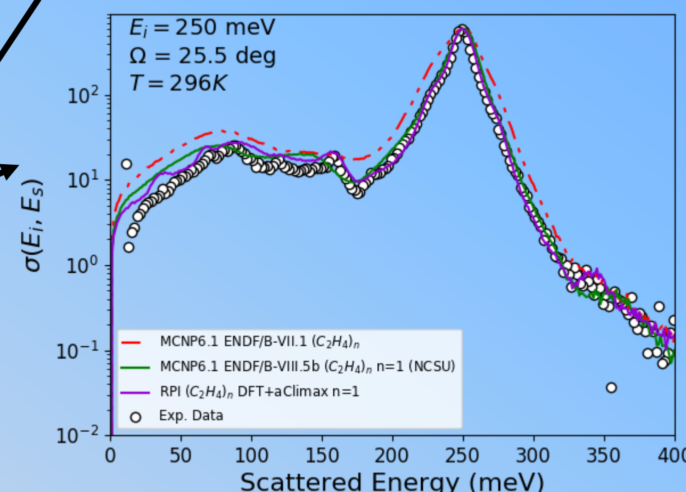


VISION data used to validate and adjust the evaluation

Experimental data used for validation:

- Double differential scattering
- Total cross section from the literature





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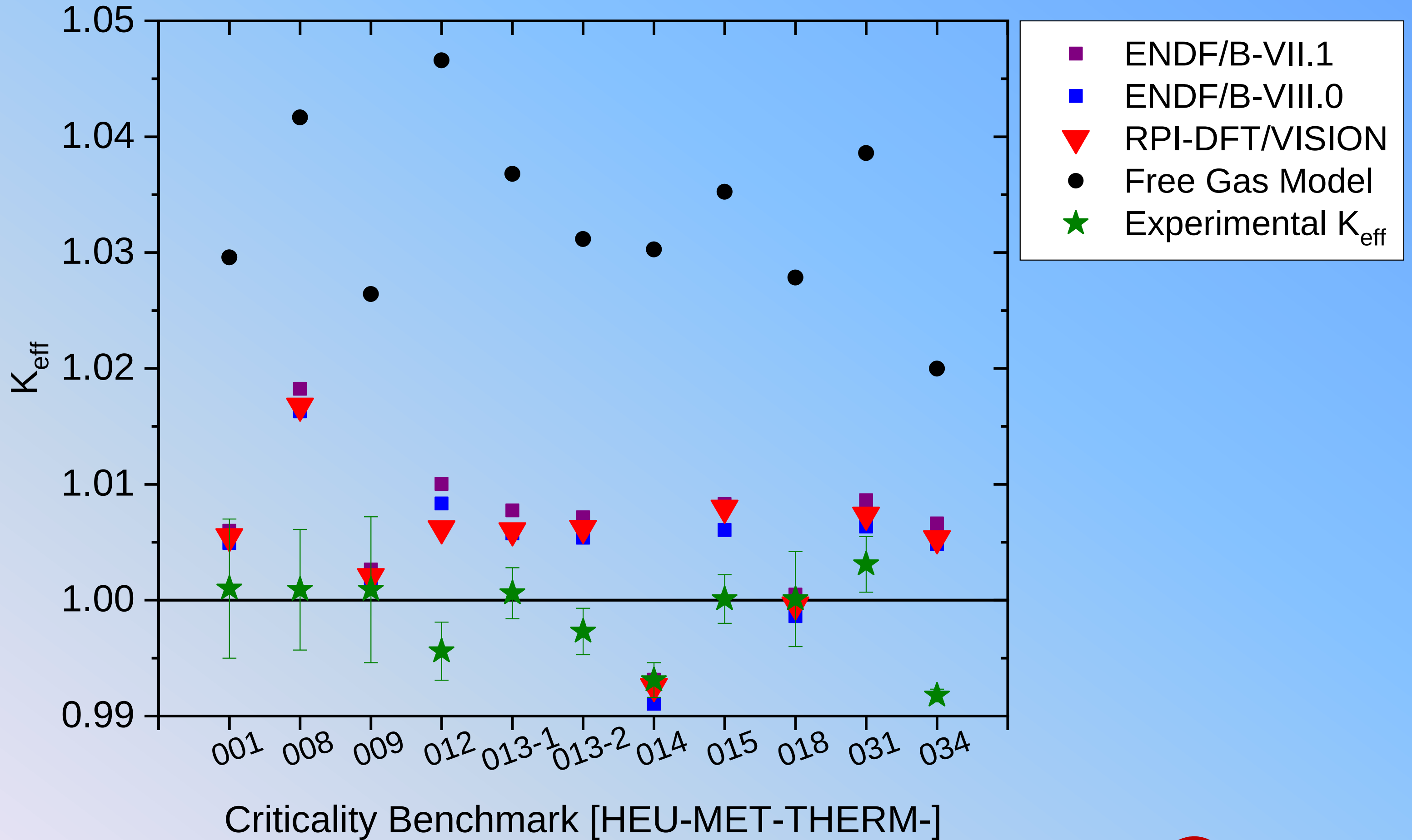
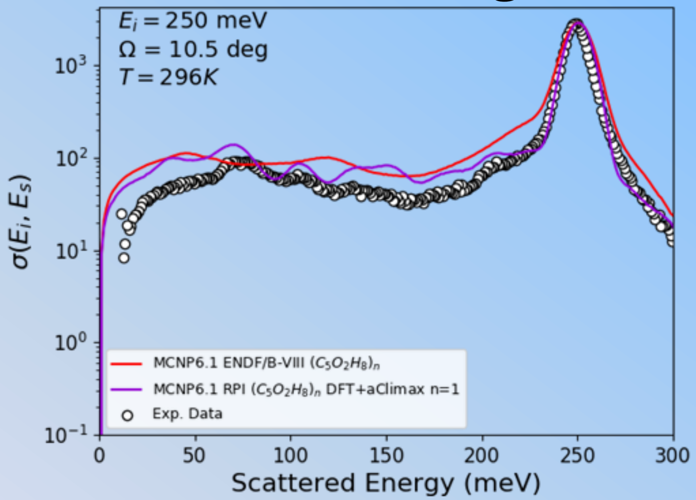
Polyethylene Criticality Benchmarks

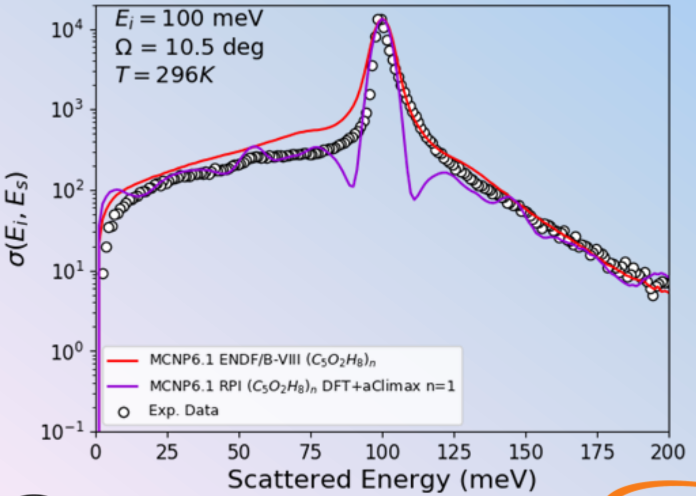
- The new RPI evaluation and the ENDF/B-VIII.0 give similar results.
- There are some discrepancies between the benchmarks and simulation.

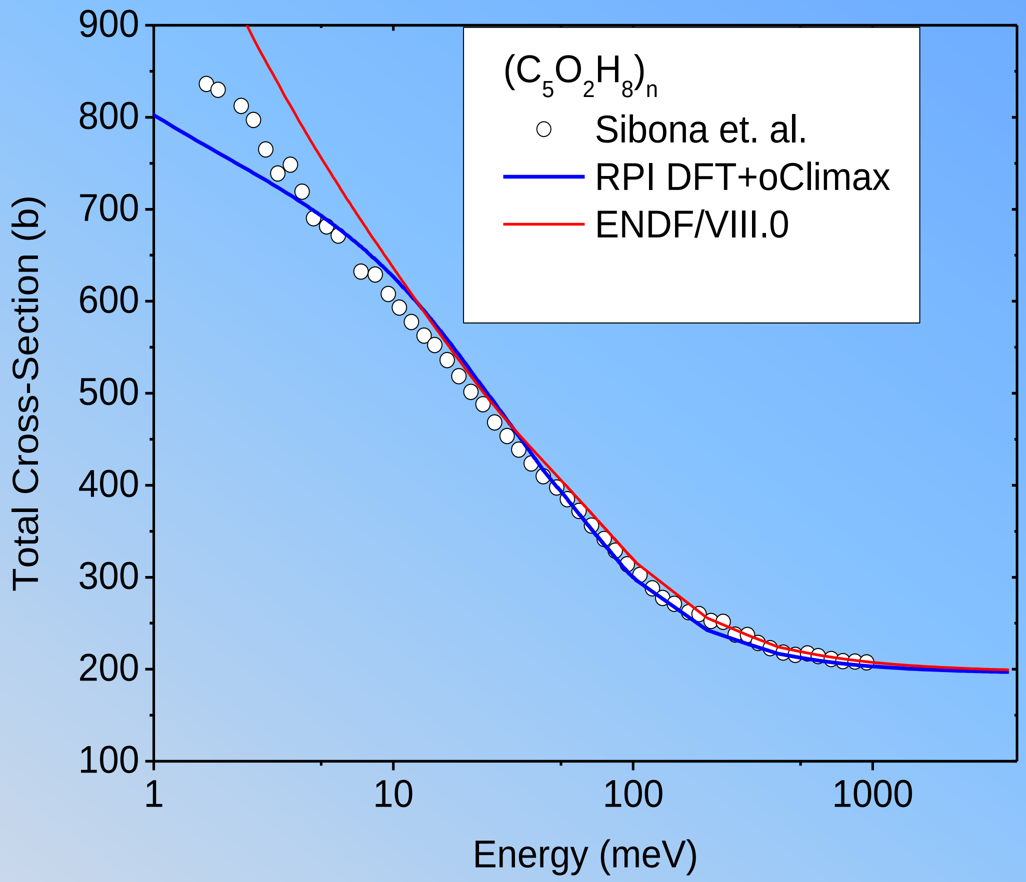


Lucite ($C_5O_2H_8$) DDSCS

- ENDF/B-VIII.0 gives better representation of inelastic region







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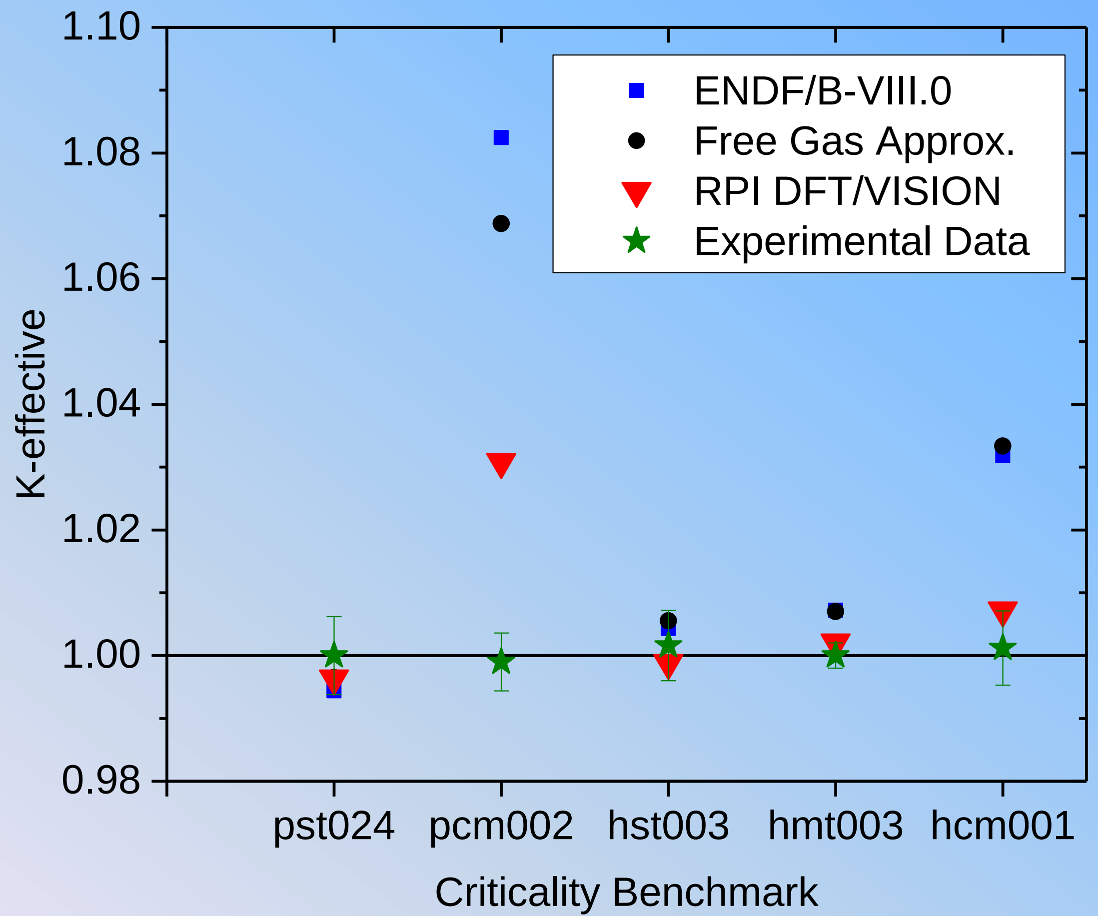
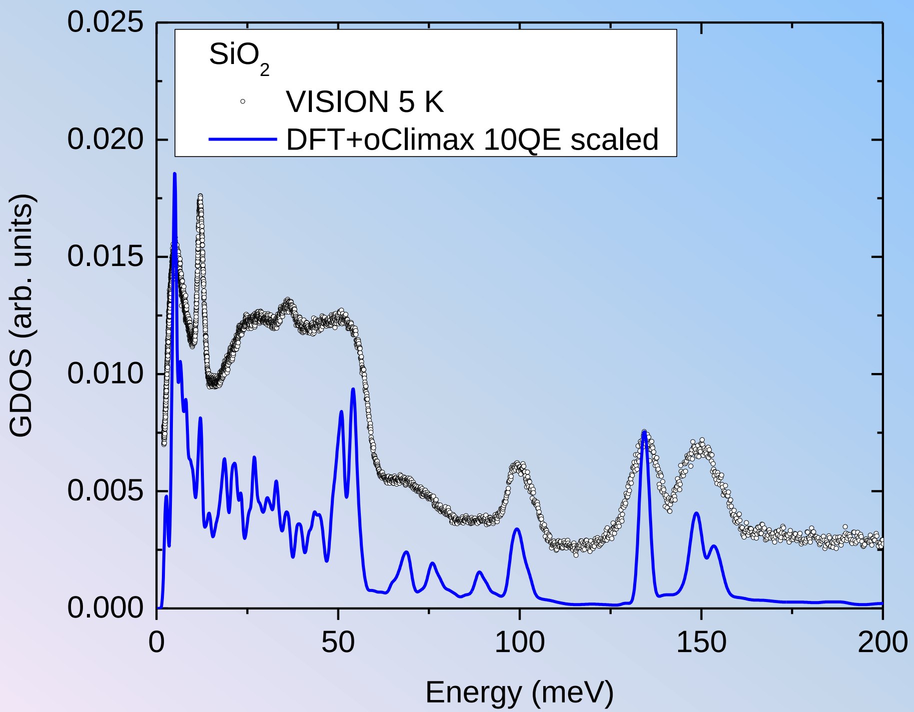
Lucite Criticality Benchmarks

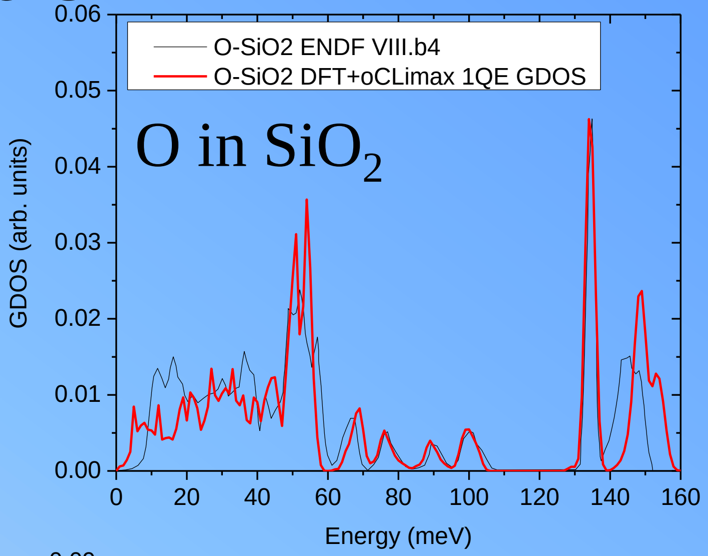
- RPI TSL file represents a clear improvement to K-effective
- ENDF/B-VIII.0 is similar to free gas treatment

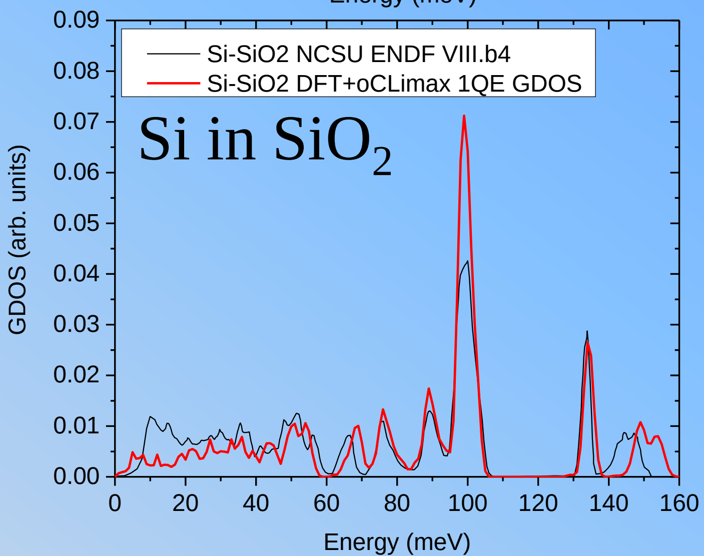


Quartz Evaluation

- Use VISION data to fine tune mode locations.
- Separate files for Si and O







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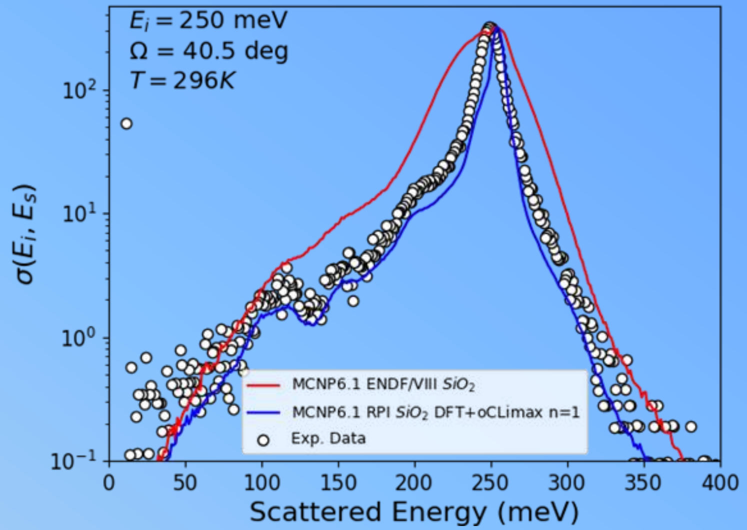
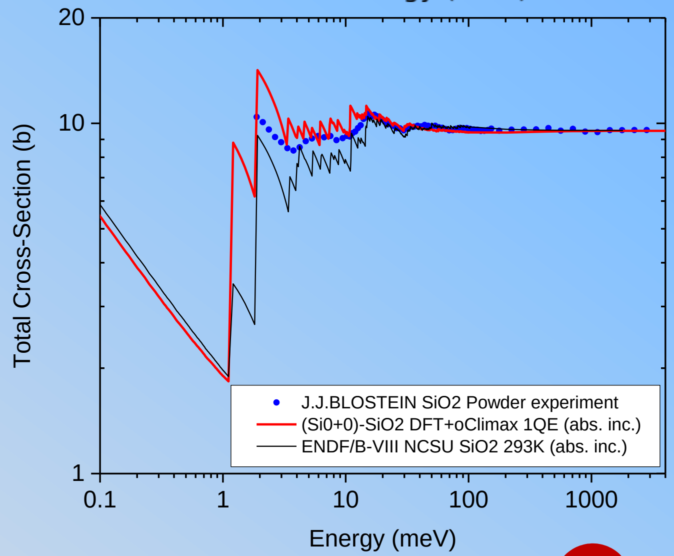
Quartz Evaluation

- The RPI evaluation is in better agreement with the differential scattering experiment

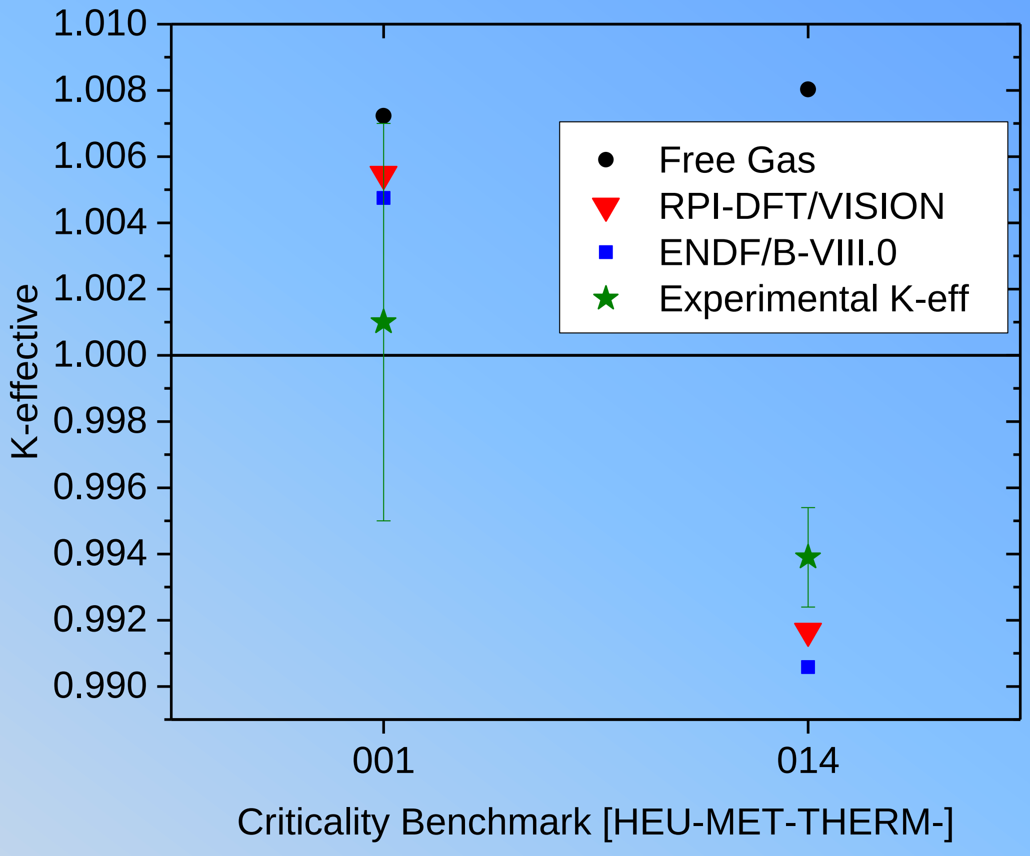


- Better agreement with the literature total cross section below 15 meV



Quartz Criticality Benchmarks

- Found only two sensitive benchmarks
- ENDF/B-VIII.0 and the RPI evaluation show similar performance for HEU-MET-THERM-001 which is close to free gas (low sensitivity to s(α,β))
- The RPI evaluation is slightly better when there is high sensitivity to thermal scattering (HEU-MET-THERM-014)



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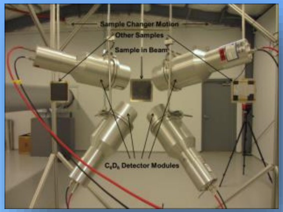
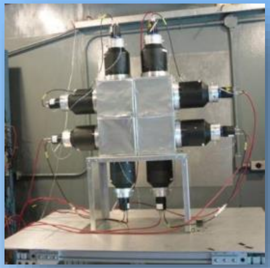
ND 3 - LINAC 2020 Refurbishment and Upgrade Plan

LINAC 2020 – Capabilities Improvement

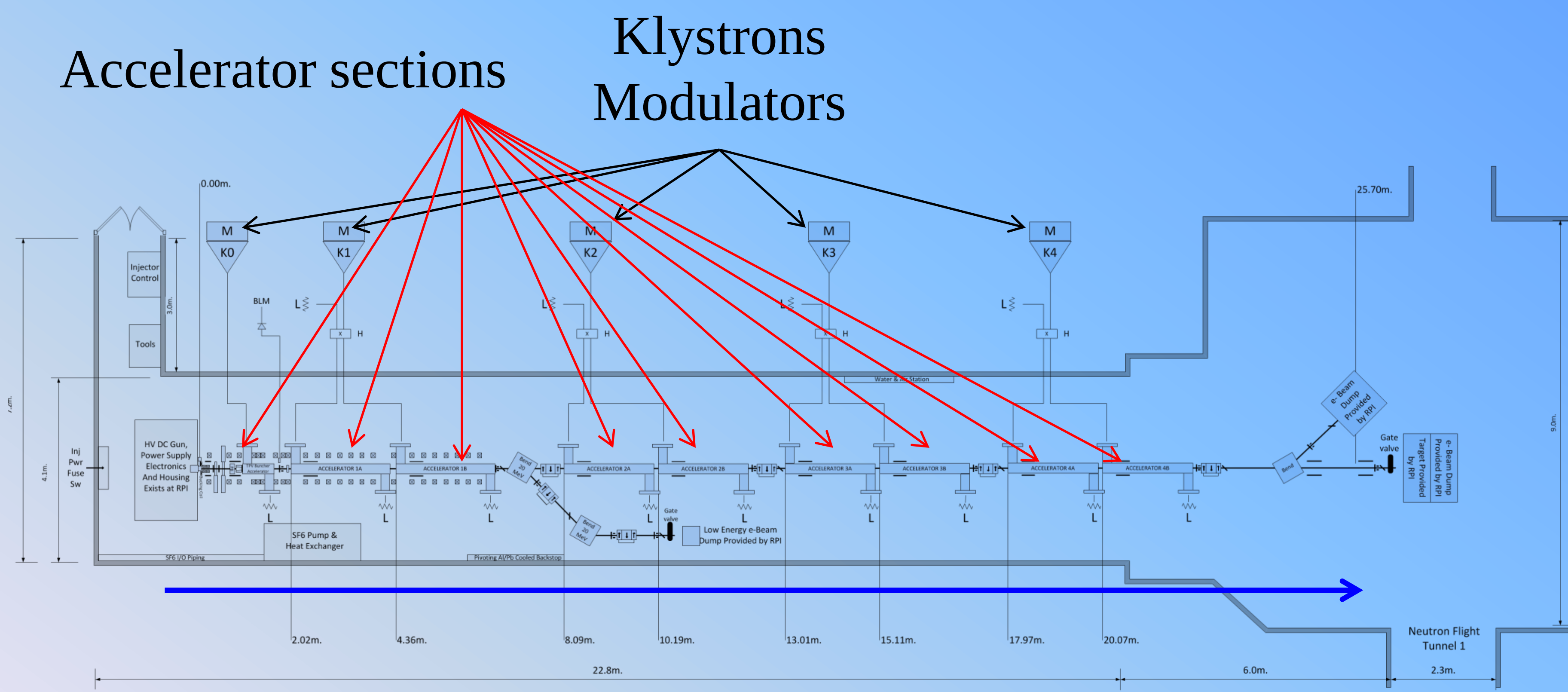
- Improvement in short pulse operation:
  - **Currently**: pulse width: 6 ns, power: 500 W
  - **Future**: pulse width: 5 ns, power: 5 kW (specs 7 kW)



- Improvement to current experimental setups:
  - **keV Capture**
    - Improve S/N ratio and thus improve accuracy of measured capture yield
    - Enable measurements on smaller enriched (expensive) isotopic samples
    - Reduce multiple scattering and self-shielding by using smaller samples
    - Study gamma coincidence and angular distribution for resonance spin assignment
  - **keV Transmission**
    - Improve S/N ratio by better filtering of the gammas in the beam
    - Enable measurements on smaller enriched (expensive) isotopic samples



Conceptual Design RPI L-Band LINAC



Modulator
Klystron
Gun Assembly w/Pump
Current Monitor
Pepper Pot & Aperatures
Cathode View Mirror & Phospher Screen (Three-Way Cross)
1.3GHz Prebuncher
TPV Collimator
Bunch Length Monitor
Stripline Monitor
Faraday Cup
Profile Monitor *(used in short bunch low rep rate for tuning)*
Steering Coil
Quadrupole Triplet
Focusing Solenoid
Accelerator Output Load

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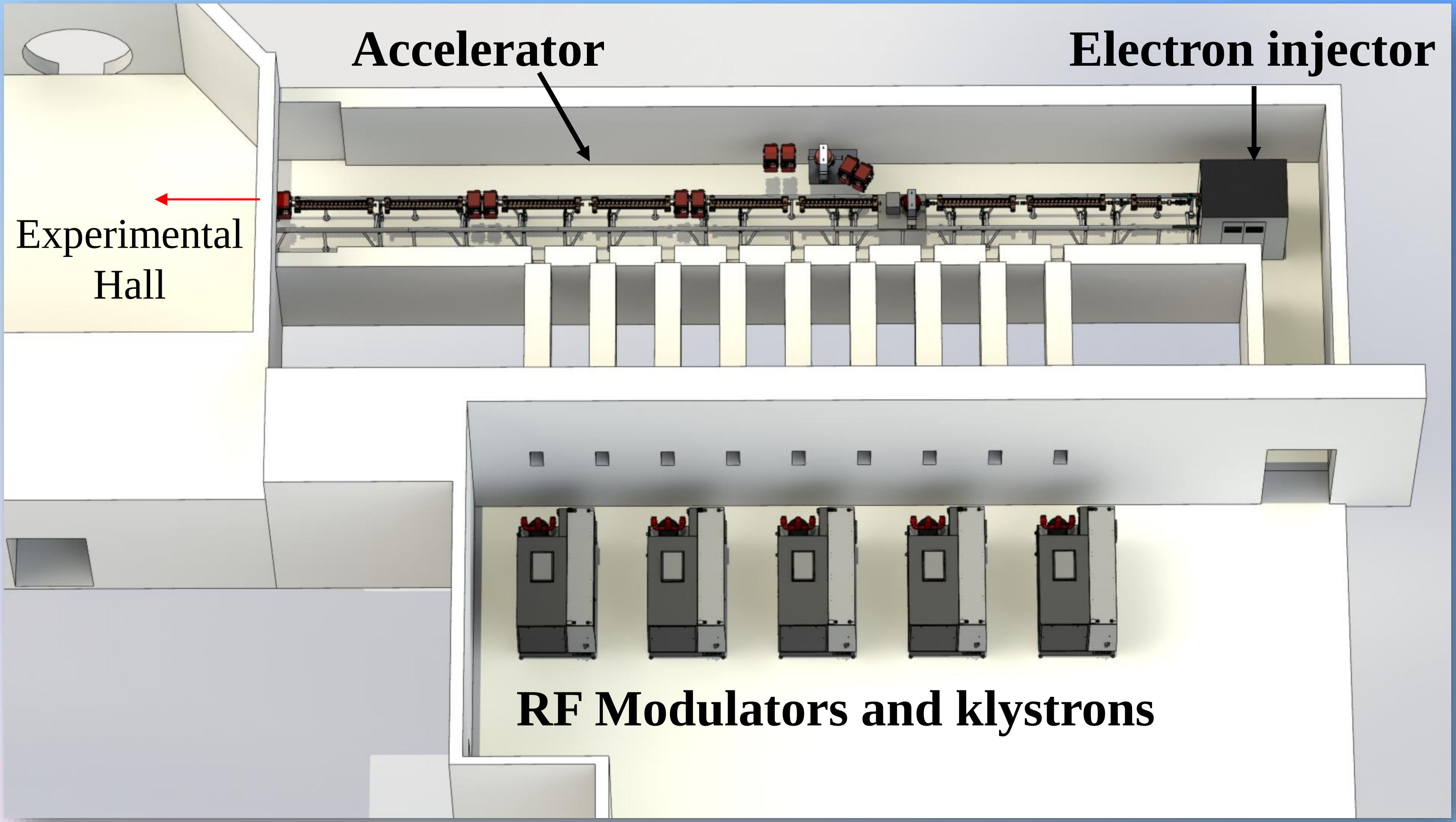
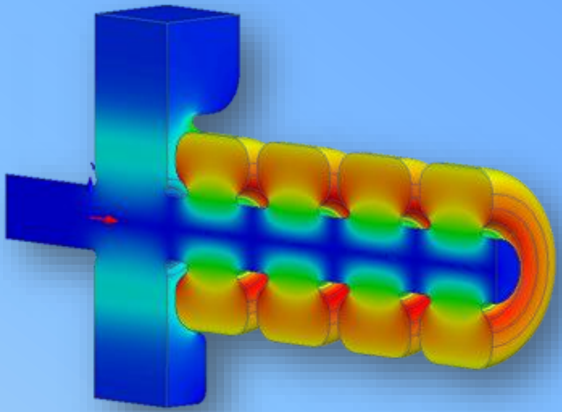
3D CAD Model

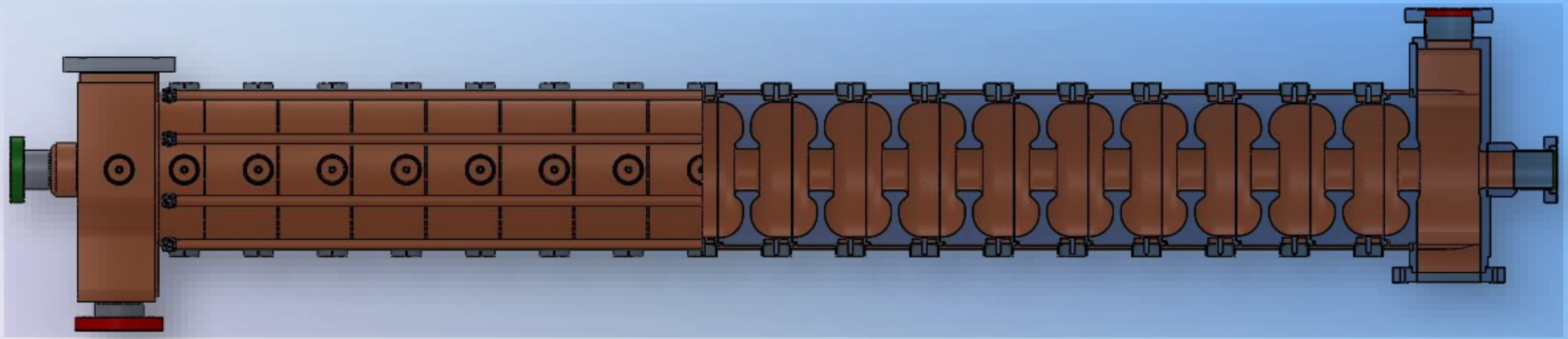

Accelerator
Electron injector
Experimental
Hall
RF Modulators and klystrons

New Accelerating Structure Design

- Order process in progress for 9 traveling-wave accelerating structures
  - One tapered-phase-velocity(TPV):

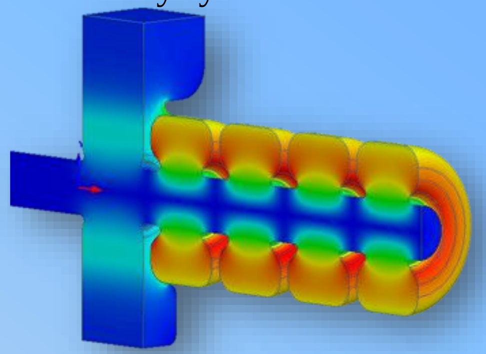


  - Eight speed-of-light(SOL)



LINAC 2020 Refurbishment and Upgrade Plan I

- **SLAC**
  - Delivered
    - Detailed designs for Tapered Phase Velocity (TPV) & Speed of Light (SoL) accelerating structures.
  - Working on
    - RPI LINAC simulation tools and training to cognizant RPI personnel.
      - Peter Brand will visit SLAC for training in April 2018.
    - Designs for magnetic optics elements, beamline instrumentation, RF components, and mechanical supports directly related to the accelerator structure designs. This is expected to be completed by the end of the summer.
    - Design & build an electron gun (higher peak current) and design of a beam delivery system.
      - This is being funded in phases.
      - Phase 1: Technical work associated with electron gun design to begin soon.
- **Klystrons**
  - Five klystrons passed their factory acceptance test (FAT).
  - Sixth in production; FAT expected within 4-6 weeks.



Rendering of Magnetic field in a part of an accelerator section

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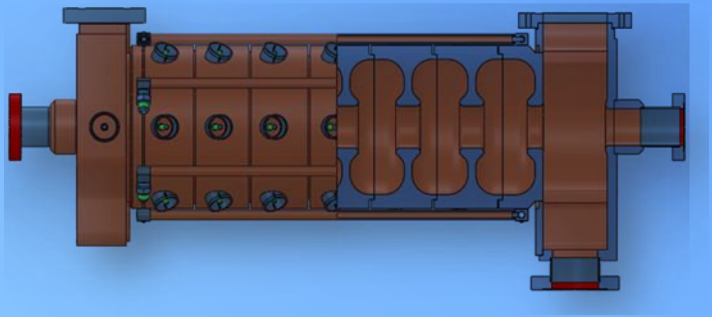
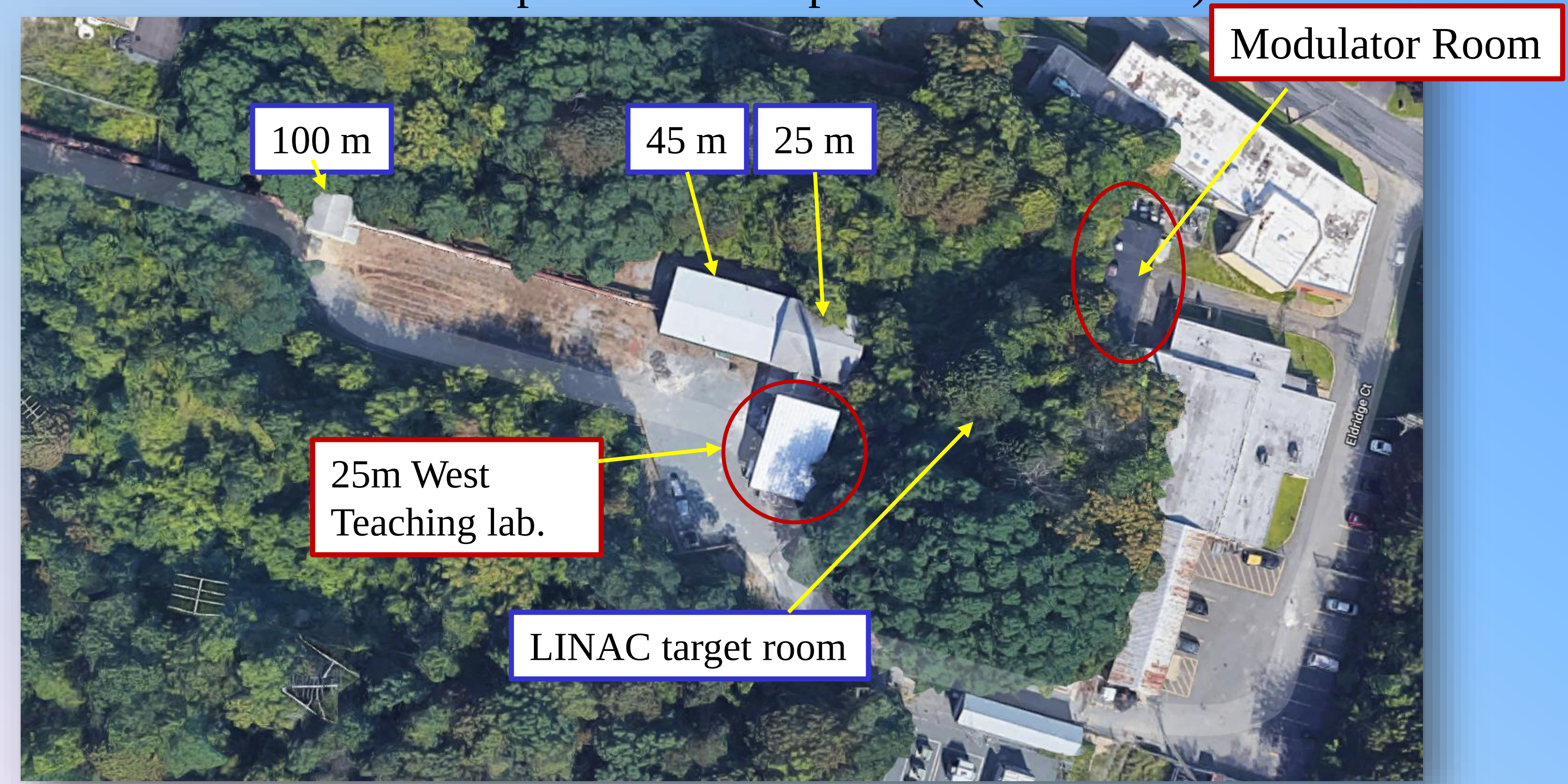
LINAC 2020 Refurbishment and Upgrade Plan II



- **Modulators**
  - First modulator system FAT rescheduled for June 2018.
  - FAT of modulators 2 & 3 planned for October 2018.
  - FAT of modulators 4 & 5 planned for December 2018.
- **Accelerator Sections**
  - Fabrication of Structures contract was awarded.
  - One SoL and TPV structures to be completed and FAT by 2nd quarter 2019.
    - High power RF conditioning and site acceptance test (SAT) of structures to be done at RPI.
- **Modulator Building**
  - Expansion of modulator building is in-progress.
  - Major plumbing changes and foundation complete.
  - Metal Building is on-order; Deployment of 'shell' should be completed by April 2018.
  - Next major phase will be after present accelerator is removed (late 2019).
- **High Power RF Conditioning Setup**
  - Used to condition accelerating structures and perform SAT.
  - Electrical, cooling water, and heat exchanger infrastructure to be completed by 10/1/2018.
  - Modulator installation and preliminary RF testing to be completed by 1/1/2019.
  - First accelerating structure conditioning and SAT by mid-2019.

Infrastructure upgrades

- Completed construction of a new teaching/research laboratory
- Construction of new large modulator room is in progress
- Beamline to 250m was rust proofed and repainted (not shown)



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2017 related group publications

Journal

1. Y. Danon, D. Williams, R. Bahran, E. Blain, B. McDermott, D. Barry, G. Leinweber, R. Block and M. Rapp, “Simultaneous Measurement of ^{235}U Fission and Capture Cross Sections From 0.01 eV to 3 keV Using a Gamma Multiplicity Detector”, Nuclear Science and Engineering, vol. 187, no. 3, pp. 291-301, 2017.
2. A. M. Daskalakis, E. J. Blain, B. J. McDermott, R. M. Bahran, Y. Danon, D. P. Barry, R. C. Block, M. J. Rapp, B. E. Epping and G. Leinweber, “Quasi-differential elastic and inelastic neutron scattering from iron in the MeV energy range”, Annals of Nuclear Energy, vol. 110, pp. 603 - 612, 2017.
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