Nuclear Data Measurements at RPI

Report to CSEWG November, 2011

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Measurements Completed This Year

- **Scattering**
  - ^{238}U, Neutron Scattering (4/7 angles), 0.5-20 MeV, 30m flight path.
- **Transmission**
  - ^{95}Mo, Fe-filtered transmission, 100m flight path
  - ^{95,96,98,100}Mo, 10 eV - 600 keV, 100m and 30m flight path
  - ^{95,96,98,100}Mo, 0.5-20 MeV, 250m flight path
  - ^{56}Fe, 0.5-20 MeV, 250m flight path

Planned Measurements

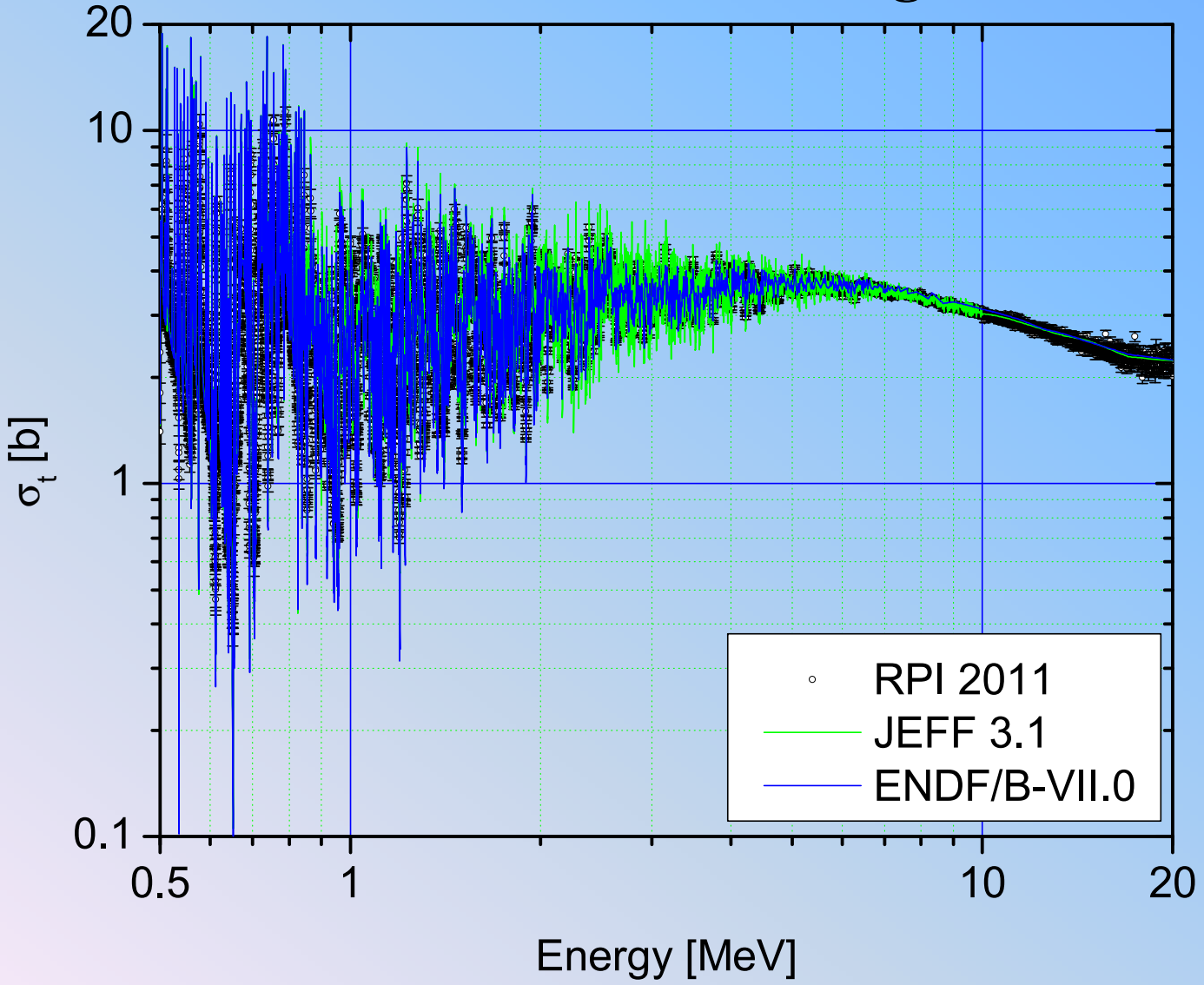
- **Scattering**
  - Complete ^{238}U, Neutron Scattering, 0.5-20 MeV, 30m flight path.
- **Transmission**
  - Fe-filtered ^{56}Fe, 100m flight path
  - ^{92,94}Mo, 10 eV - 600 keV, 100m and 30m flight path
  - Ti, Zr, Mo 0.5-20 MeV, 250m flight path
  - Fission neutrons spectrum for ^{252}Cf and ^{235}U

Data Analysis

Sample	Status
Be, C	High energy (0.5-20MeV) transmission, submitted for publication
Zr	High energy (0.5-20MeV) scattering, submitted for publication
^{147,149}Sm (n,α)	Cross section measurements with the LSDS, submitted for publication
Ti, Ta, Zr, Mo	High energy (0.5-20MeV) transmission analysis in progress
^{235}U	Capture and fission in the energy range thermal to 5 keV (in progress)
^{95,96,98,100}Mo, Rh, Eu, ^{153}Eu, Cd, ^{236}U, ^{161,162,163,164}Dy ^{155,156,157,158,160}Gd,	Resonance parameters analysis in progress

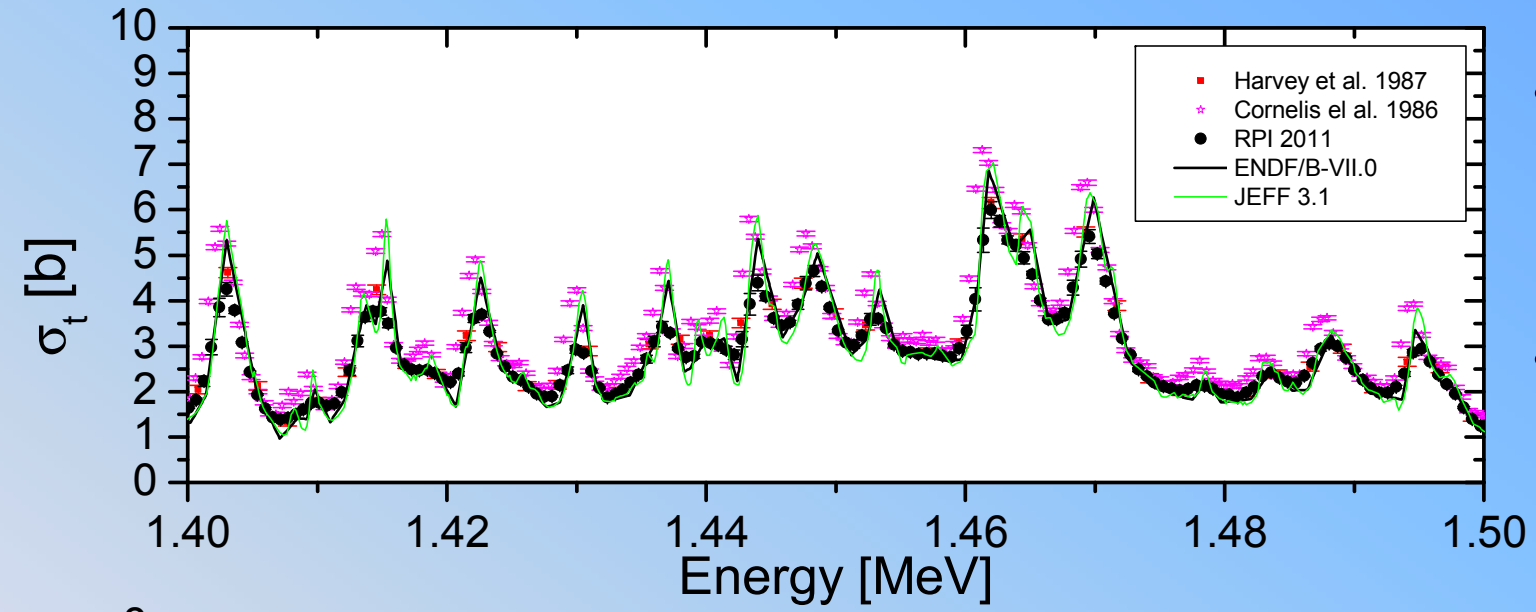
^{56}Fe Total Cross Section Measurements (NCSP)

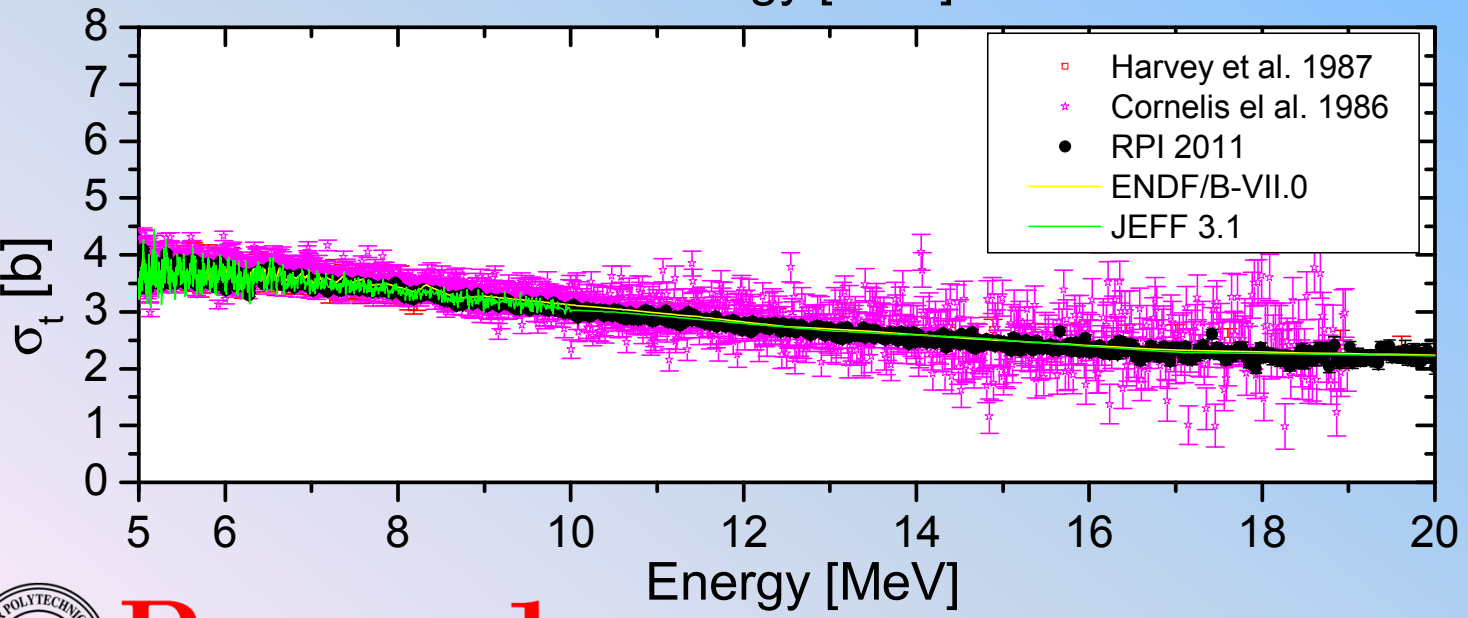
250m Flight Path



- Measured at 250m flight station with 8ns pulse width.
- Two sample thicknesses were used 0.271767 a/barn (3.22 cm) and 0.649742 a/barn (7.69 cm)
- Sample is 99.87% metallic ^{56}Fe
- Can help extend the resolved resonance region above 892 keV
- Only two other data sets available on EXFOR above 900 keV (Harvey et al. and Cornelis et al.)
- The JEFF 3.1 evaluation follows the Cornelis et al. data

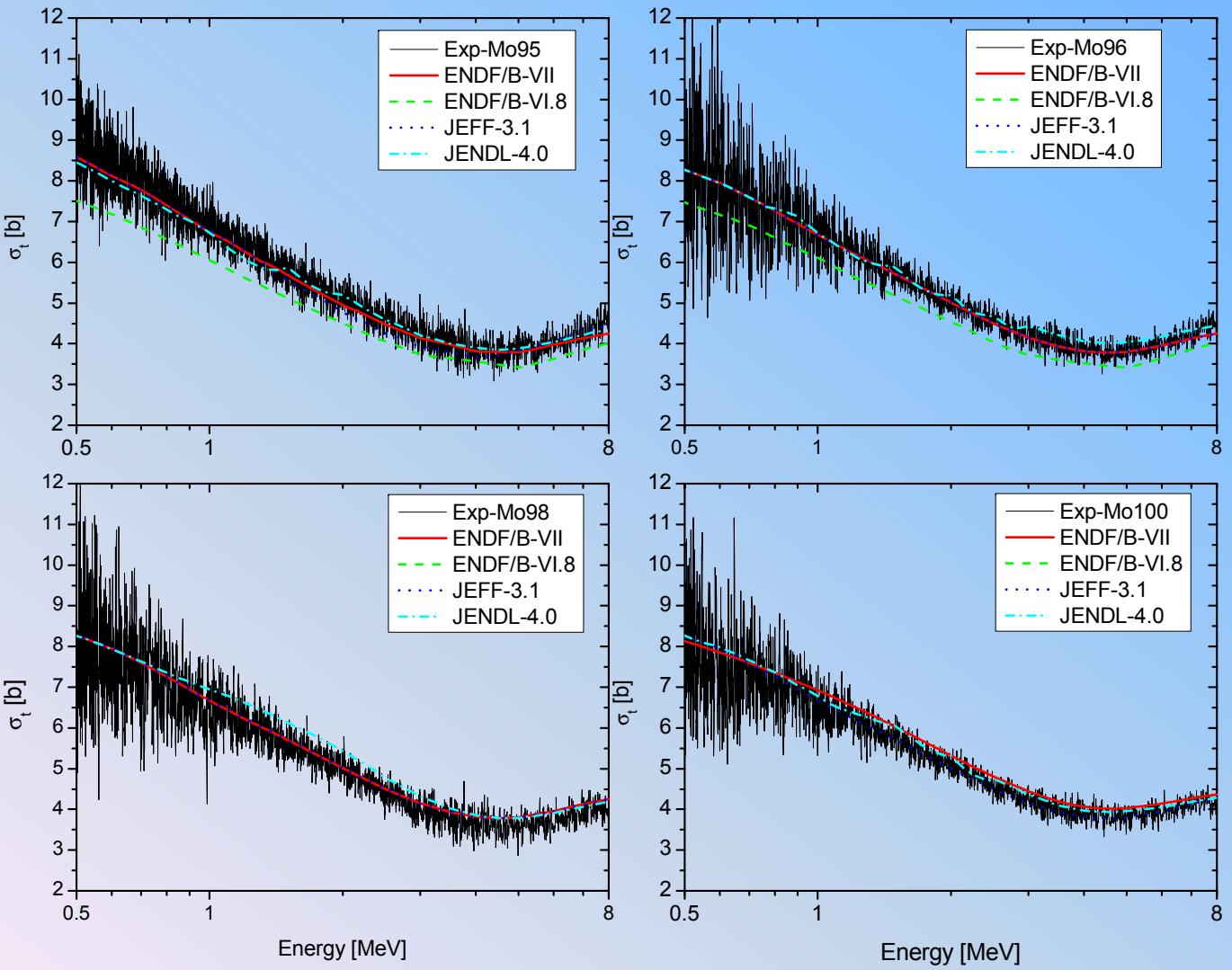
^{56}Fe Total Cross Section Measurements





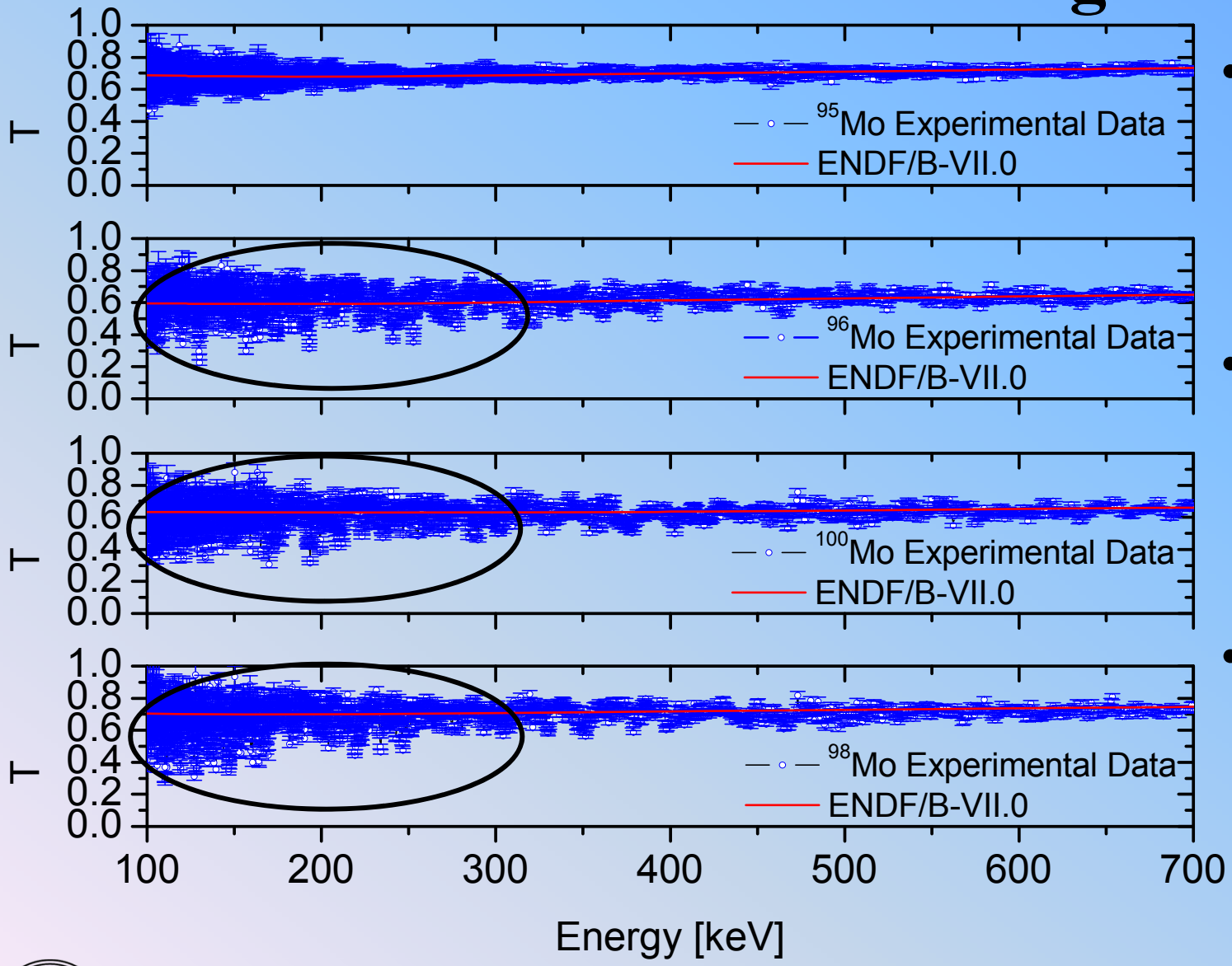
- New data has good energy resolution but lower then Cornelis et al.
- The Cornelis et al. data is based on an oxide sample Fe_2O_3 (need to correct for O_3)
- Above 10 MeV the data has low errors and is in good agreement with both ENDF/B-VII.0 and JEFF 3.1

High Energy Total Cross Section of Mo Isotopes 250m Time of Flight



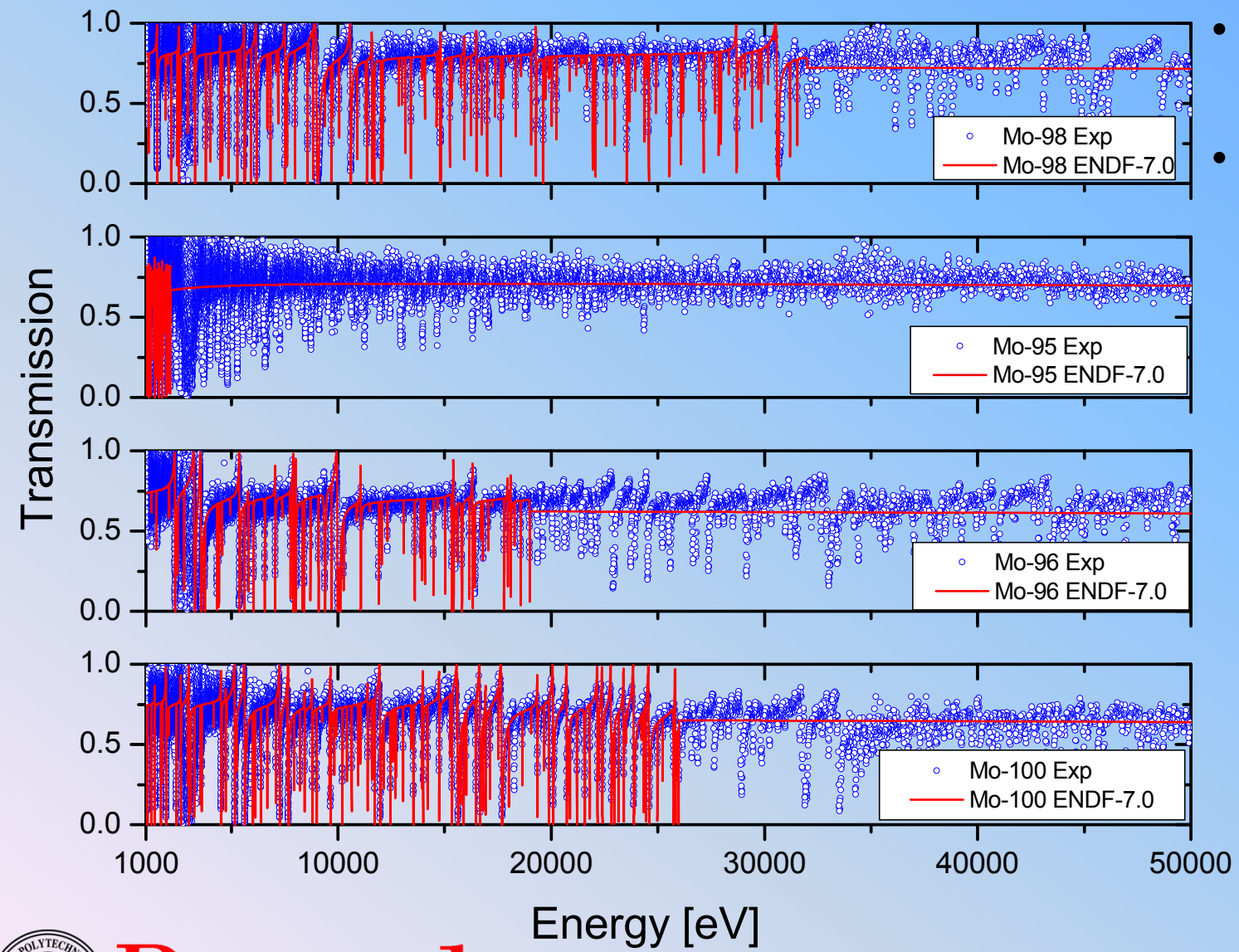
- Data show structure below 2 MeV
- General good agreement with evaluations

^{95,96,98,100}Mo Transmission 100to 700 keV 100m Time of Flight



- Experiments with ^{6}Li-Glass detector at 100m flight distance
- Detector counts were grouped but still data show structure
- Good agreement with ENDF//B-7.0

Mo Isotopes in the Resonance Region
100m Flight Path



- Resonance parameters analysis in progress
- Data provide information to extend the resolved resonance region of several isotopes

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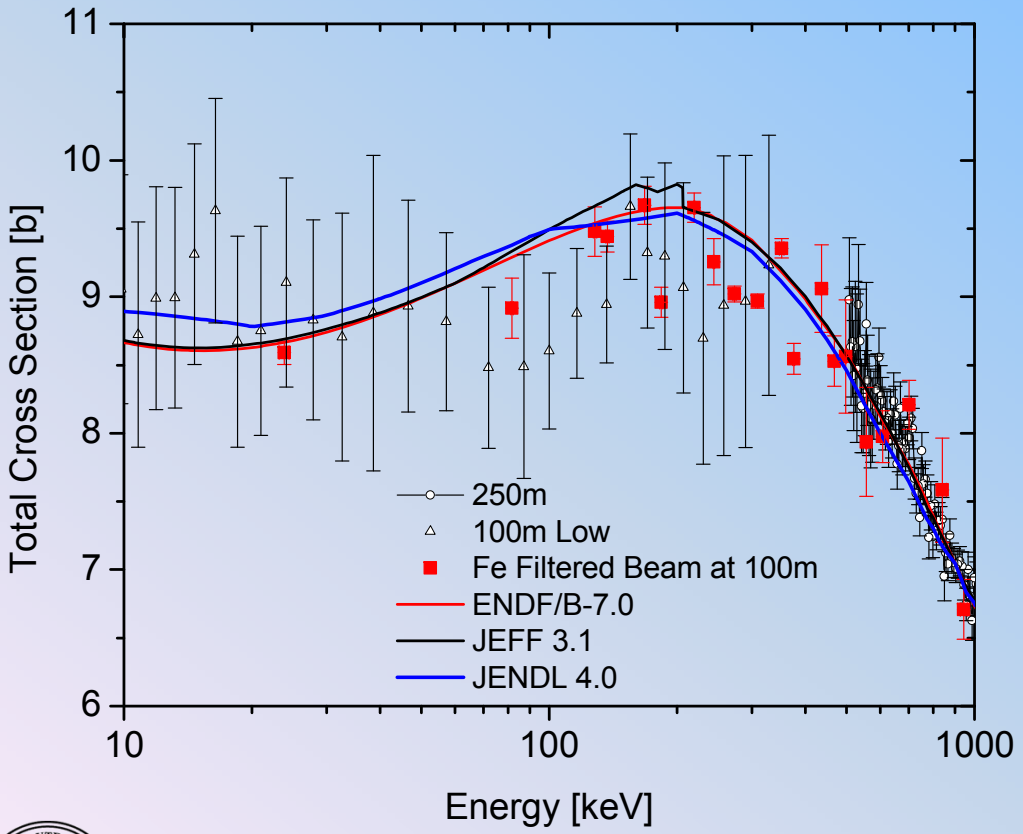
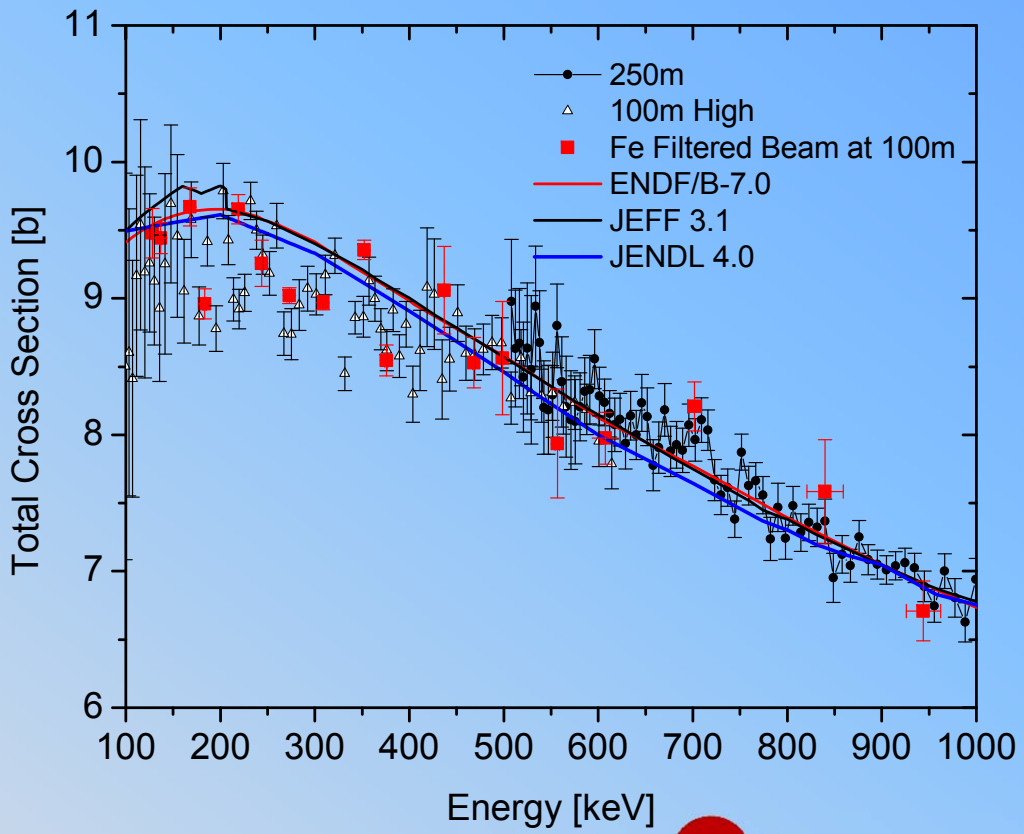
Iron Filtered beam Mo-95 total cross section

- There is general good agreement in the shape of all experimental data sets and evaluations.
- Above 10 keV Mo-95 the filtered beam, 100m, and 250m transmission experiments suggest structure in total cross section.
- Near 200 keV the data are~4% lower than the evaluations.

Configurations

- 100m Detector
  - low energy – 10 keV-200 keV
  - high energy – 100-600 keV
  - Iron Filtered beam 24-960 keV
- 250m detector
  - 0.5-20 MeV





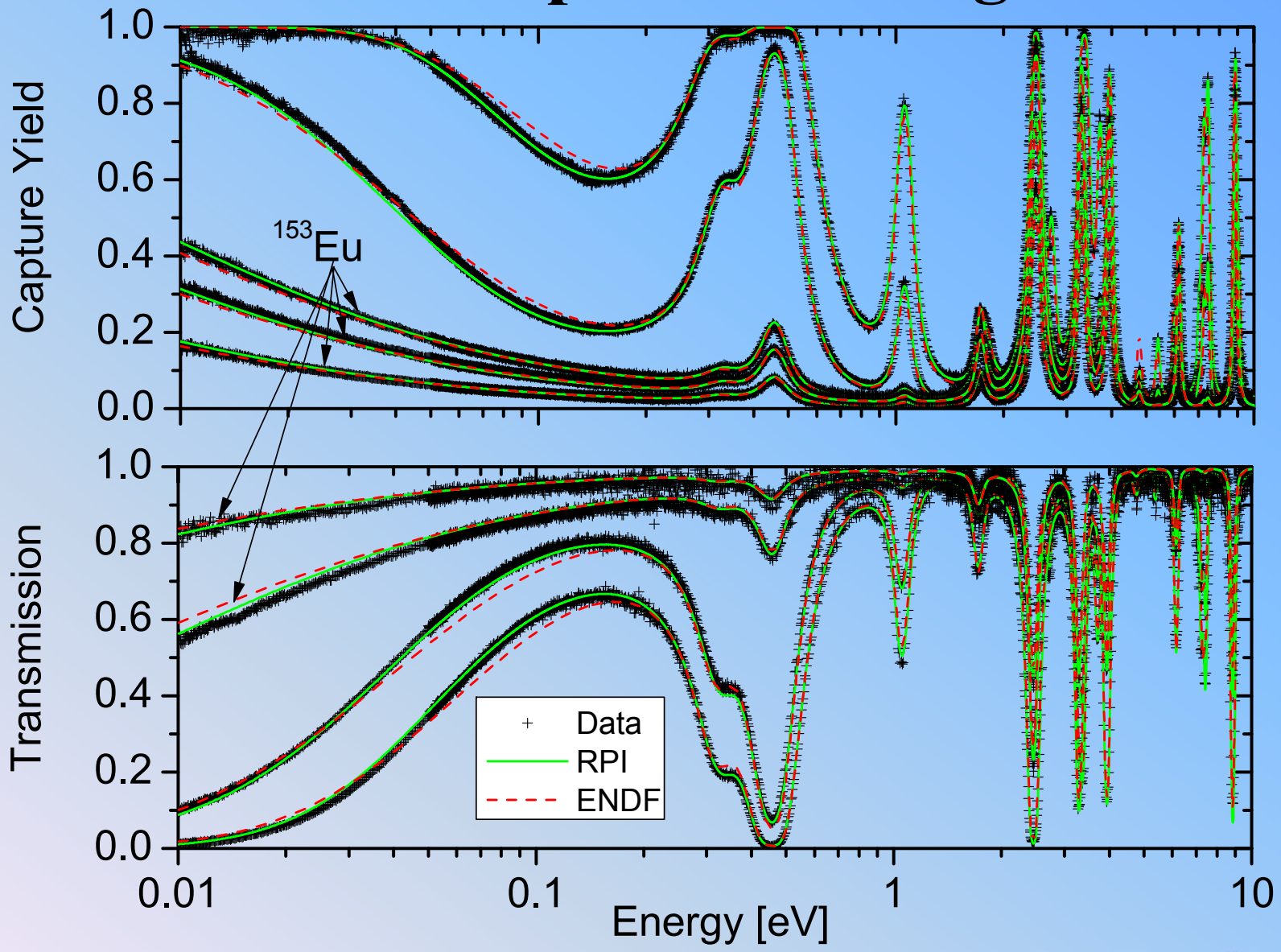
^{151,153}Eu measurements - Samples

- Stable samples of volatile metals
- Natural and enriched metal samples
- Sample thickness distribution verified by X-ray imaging*

	Natural Samples [at frac.]	Enriched [at frac.]
^{151}Eu	0.478	0.0123
^{153}Eu	0.522	0.9877

*Jeffrey A. Geuther, Robert C. Block, Brian Methe, Devin P. Barry, Gregory Leinweber, "X-ray Determination of the Thickness of Thin Metal Foils" to be submitted to NIM A, 2011.

Eu Thermal/Epithermal Region Fit



Eu Thermal Total Cross Sections (barns)

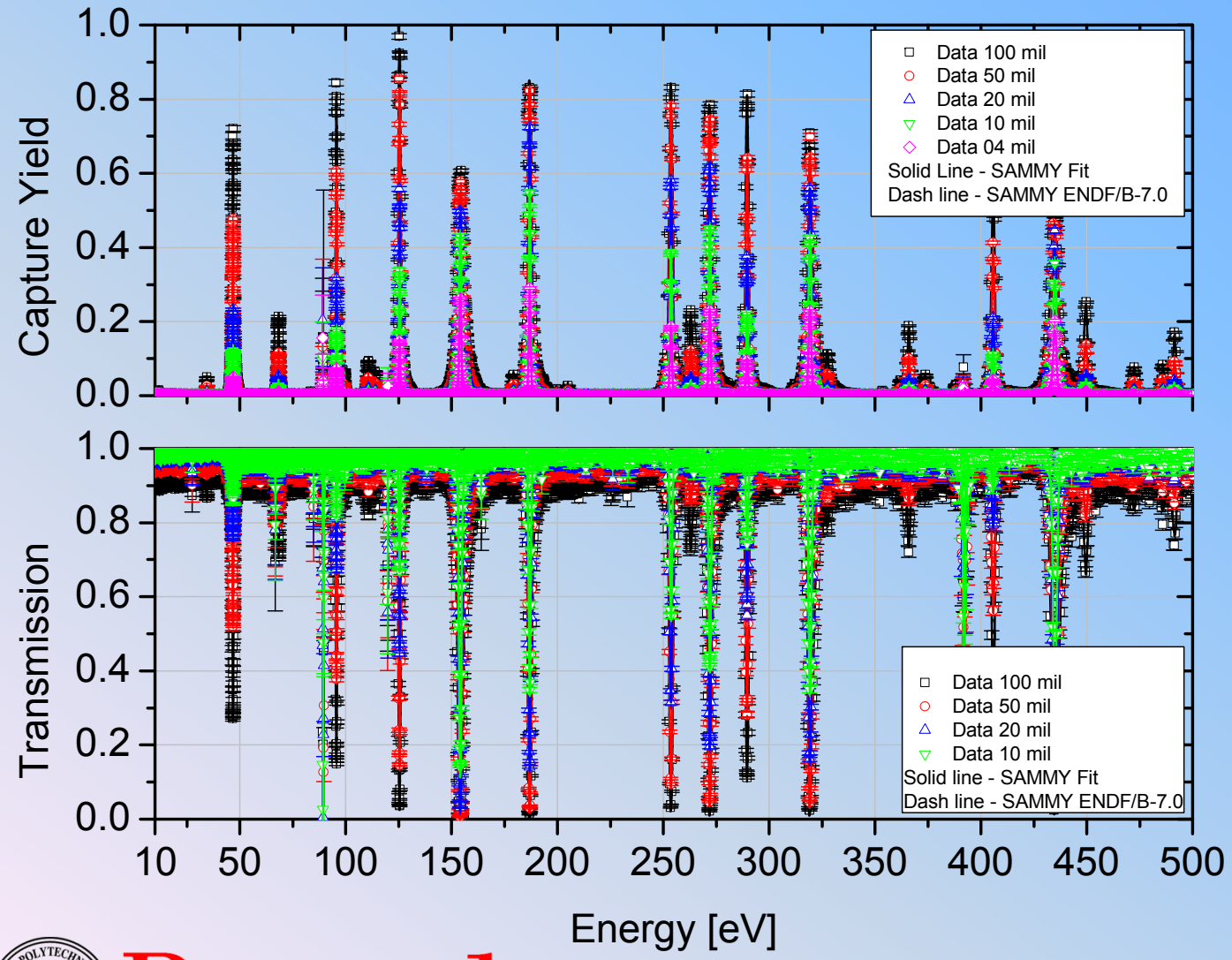
- RPI thermal values obtained from the measured data itself.
- Results in significant changes to negative energy resonances

Isotope	ENDF error from atlas [b]	RPI [b]	Dean et al. Reactivity Worth [b]	Mughabghab [b]
^{151}Eu	9187±100	9700±200		
^{153}Eu	321±8	360±20	382*	358*

(Uncertainties provided at the one sigma level)

** Said Mughabghab, "Analysis of Measurements in the Unresolved Resonance Region for ENDF Evaluations", PI Nuclear Data (RND) 2011 Symposium for Criticality Safety and Reactor Applications.*

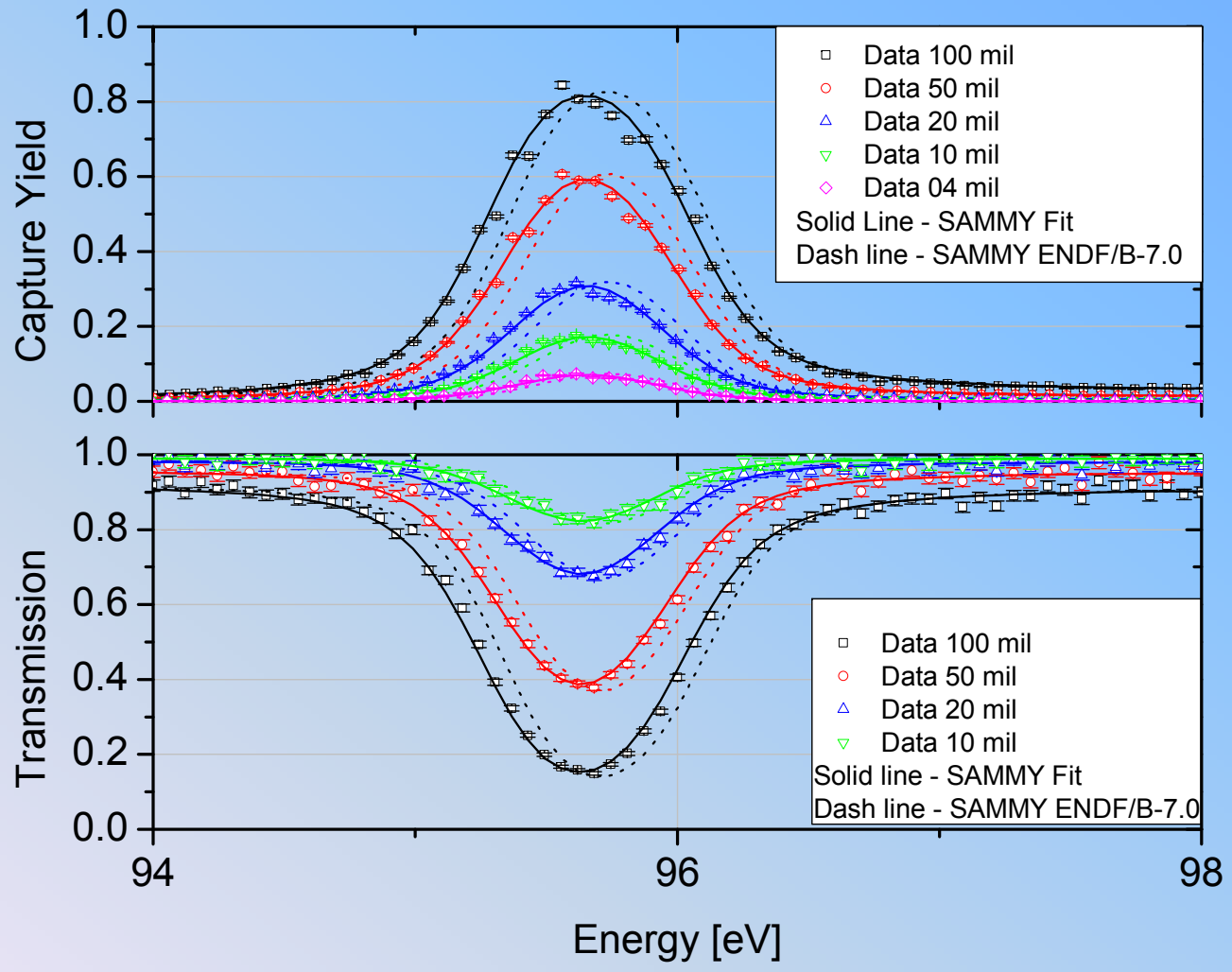
Rh Transmission and Capture Measurements



- Data analysis from thermal to 500 eV
- Generally the data agree well with ENDF/B-7.0
- Thermal data analysis in progress

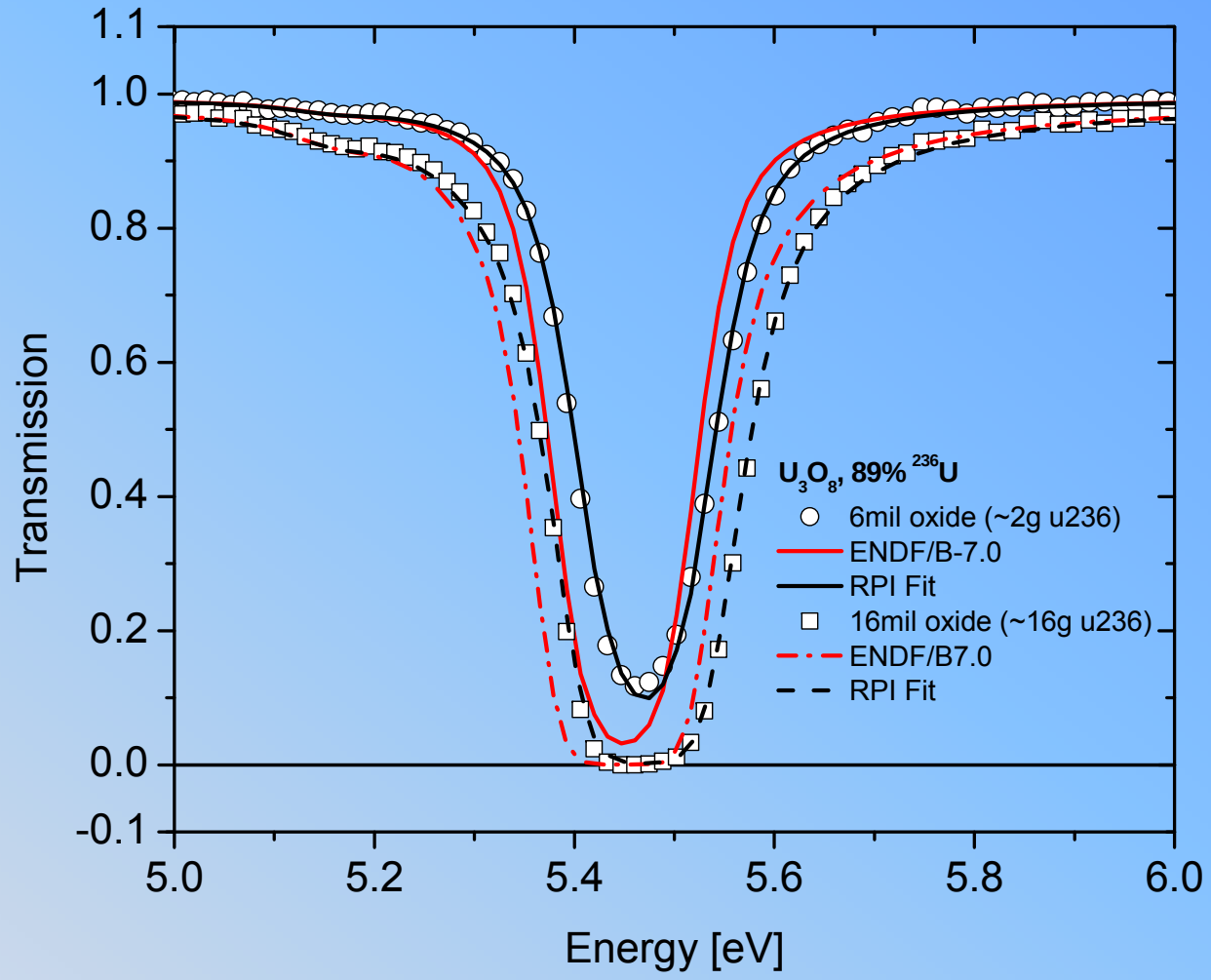
Rh Resonance Analysis

- Showing improvements to ENDF/B 7.0 parameters



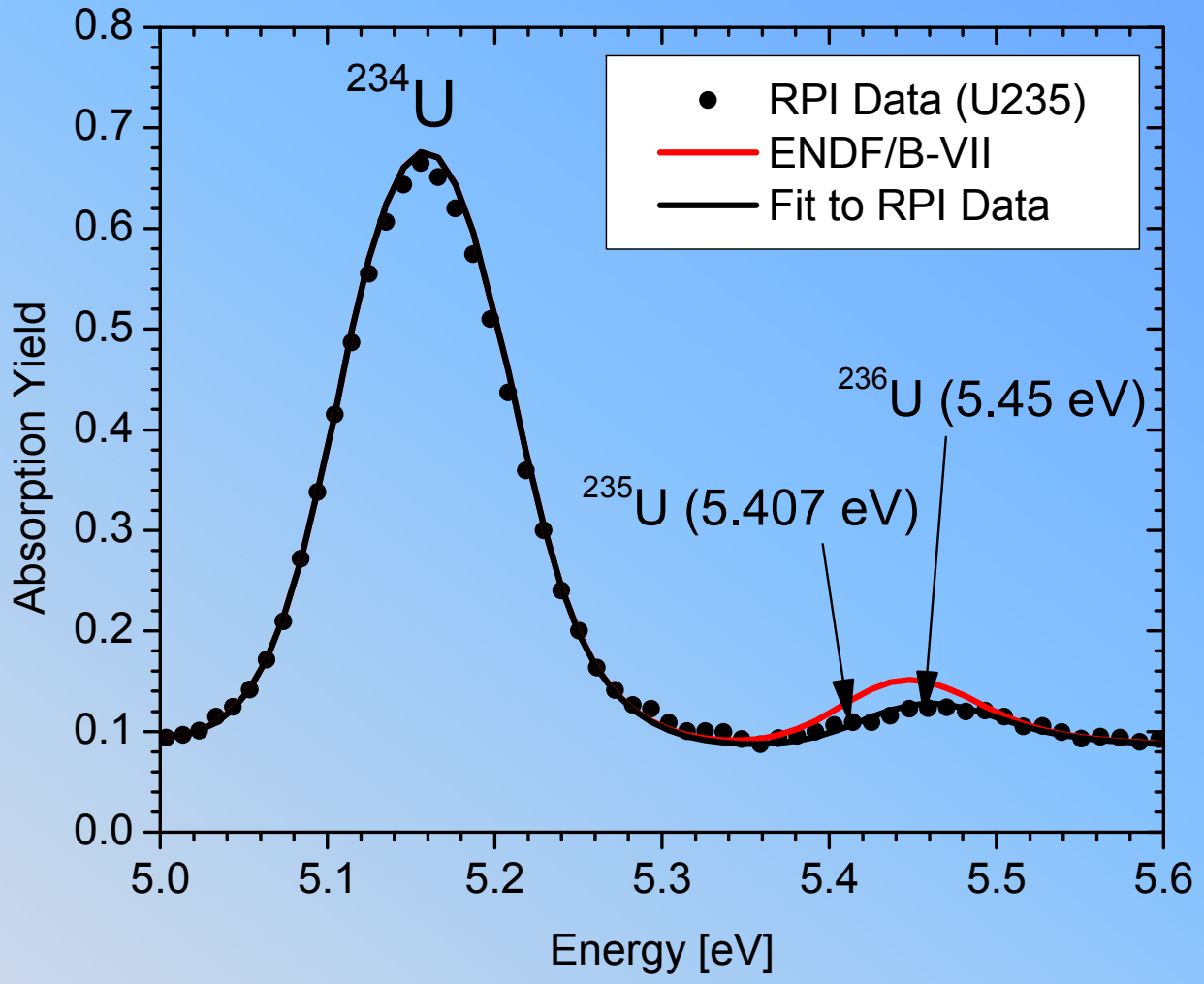
^{236}U Resonance At 5.45 eV

- Fitted several thicknesses of U_3O_8 samples, 89% ^{236}U, thinnest two shown
- RPI data have higher transmission
- Peak cross section for RPI is about 30% less than ENDF-7.0
- Could be explained by possible voids in the sample
- Use of liquid samples in new measurements is being evaluated.



^{235}U Measurement Supports Lower ^{236}U Cross Section @ 5.45 eV

- 40 mil thick Sample
- 93.399± 0.016% enriched in ^{235}U
- 0.1264±0.0012% ^{236}U



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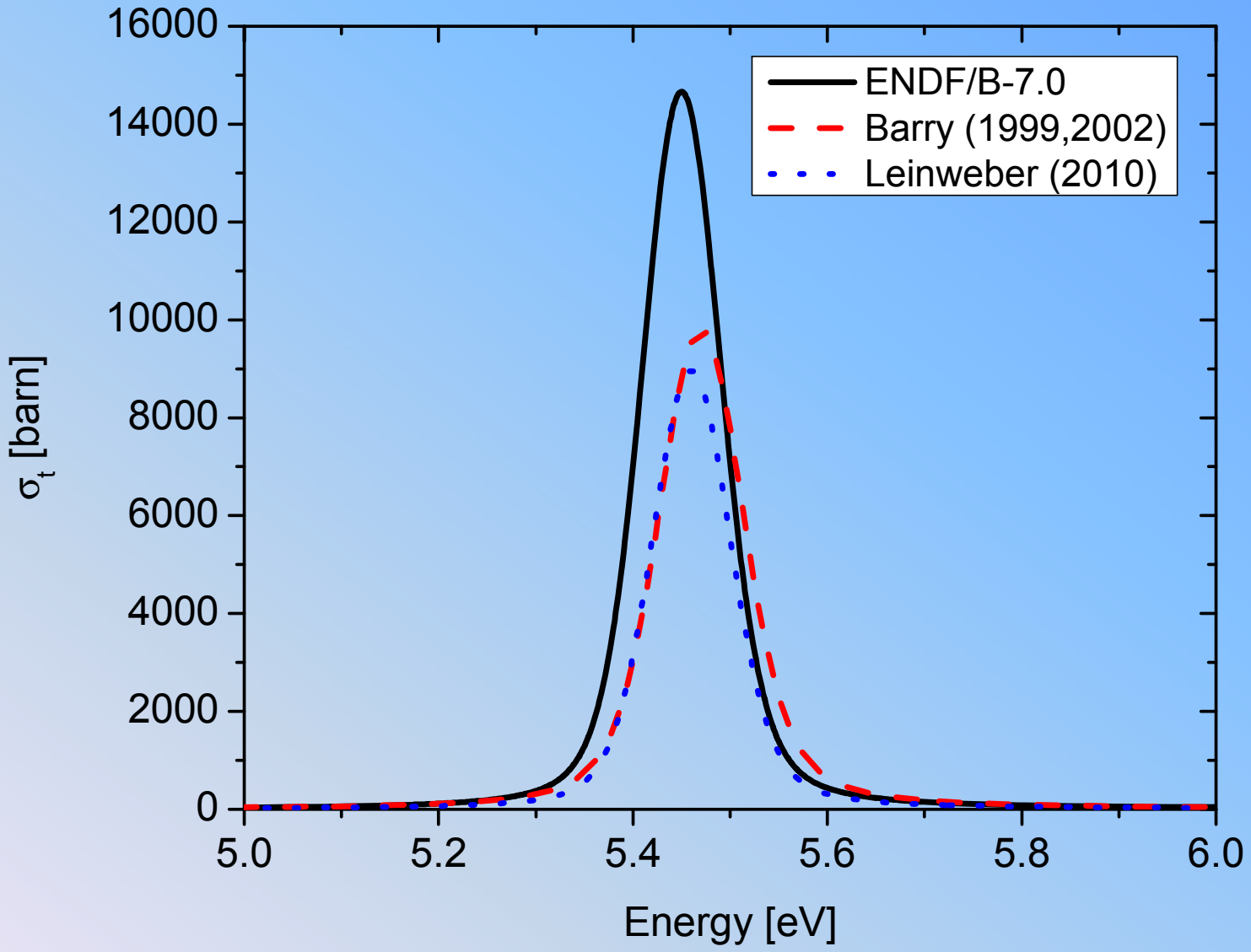
^{236}U Conclusions



Both Barry and Leinweber measurements indicate ~ 33% reduction in Γ_n

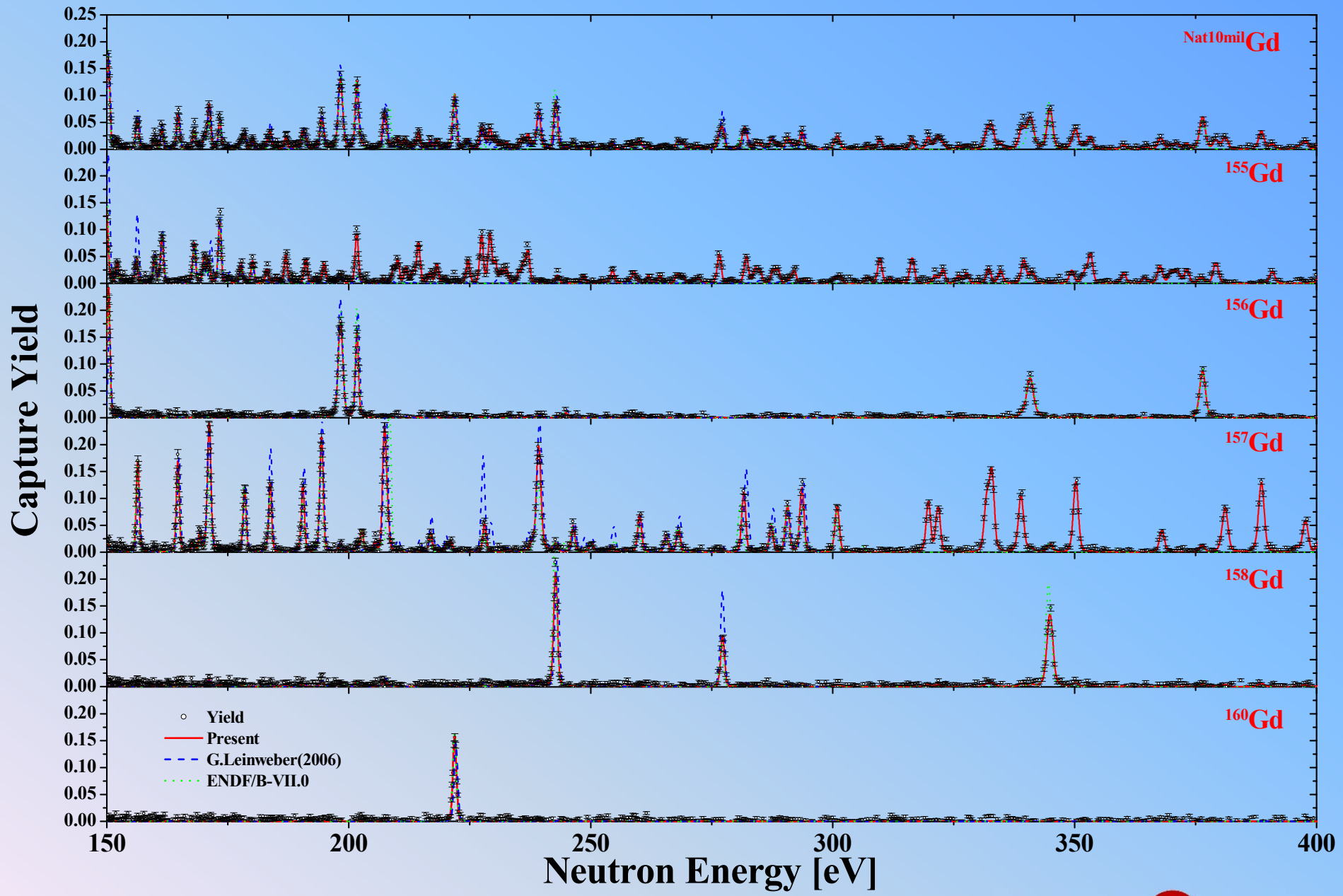
Analysis of Capture Measurements of Gd and Dy Isotopes (NSCP/RPI)

- Resonance parameter analysis of $^{155, 156,157,158,160}$Gd nearly complete.
  - ^{155,157}Gd resonance region was extended to 1000 eV
  - Used transmission data from previous RPI measurements to test data below 300 keV
- Resonance parameter analysis of ^{161,162,163,164}Dy data started
  - Plan to include older RPI measurements in the analysis
- **Demonstrates good collaboration with Korean universities**

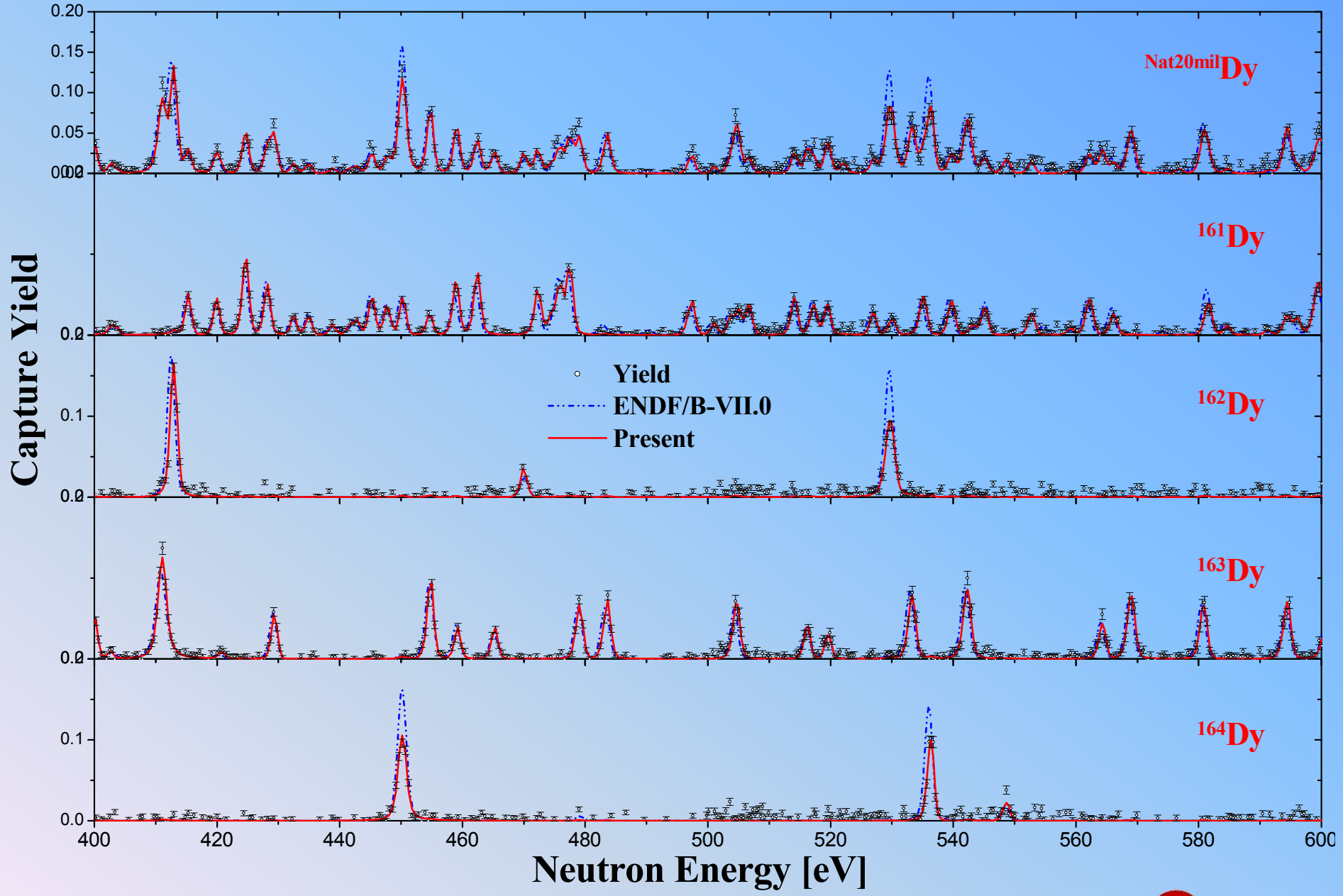
Gd enriched samples

Dy enriched samples

SAMMY fits to ^{155,156,157,158,160}Gd Capture Yield



SAMMY fits to ^{161,162,163,164}Dy Capture Yield



^{235}U Capture & Fission Yield Data - Epithermal Measurement

- Challenges:
  - Normalization
  - False capture due to neutron scattering

➢ Normalize experimental fission yield to resonance

$Y_f^{ENDF} = k_1 \cdot Y_f$ Solve for k_1 @ 19.3 eV res $\left(\frac{\Gamma_f}{\Gamma} = 0.63\right)$

➢ Use two equations for predominantly capture and fission resonances

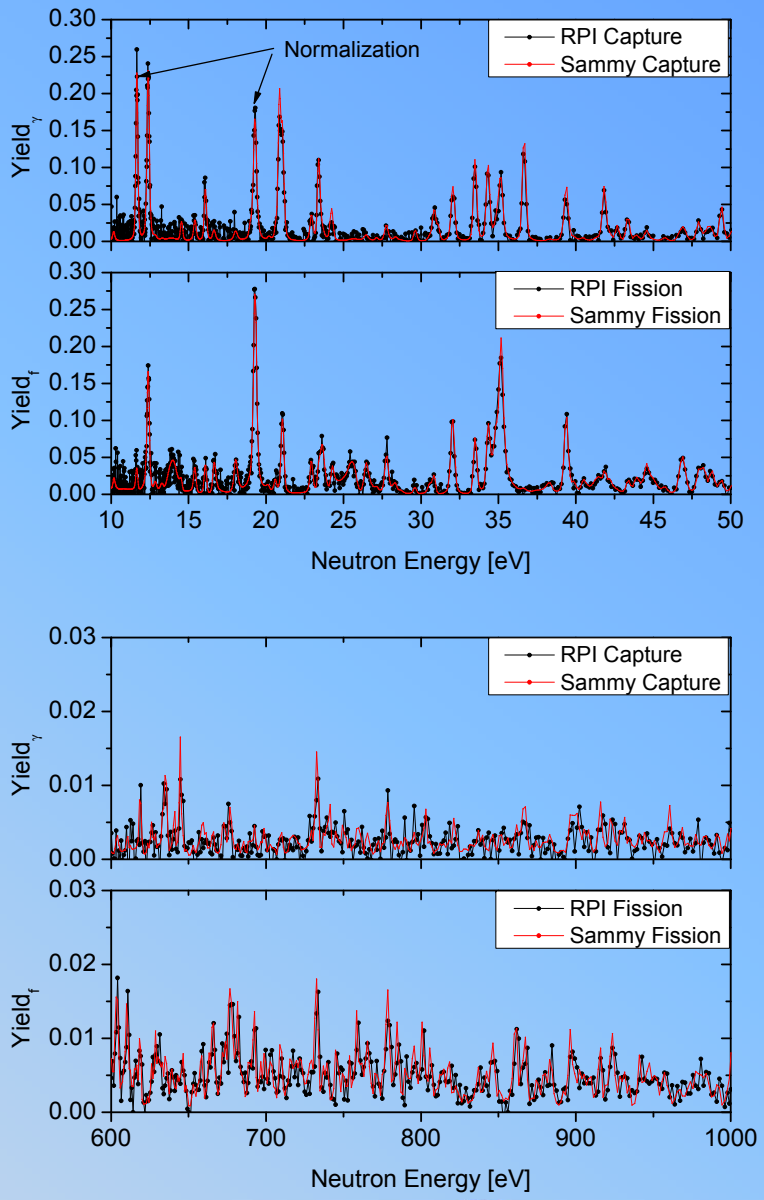
@ 11.7 eV res $\left(\frac{\Gamma_\gamma}{\Gamma} = 0.86\right)$ @ 19.3 eV res $\left(\frac{\Gamma_f}{\Gamma} = 0.63\right)$

$Y1_\gamma^{ENDF} = k_2 \cdot Y1_\gamma - k_3 \cdot k_1 \cdot Y1_f$ $Y2_\gamma^{ENDF} = k_2 \cdot Y2_\gamma - k_3 \cdot k_1 \cdot Y2_f$

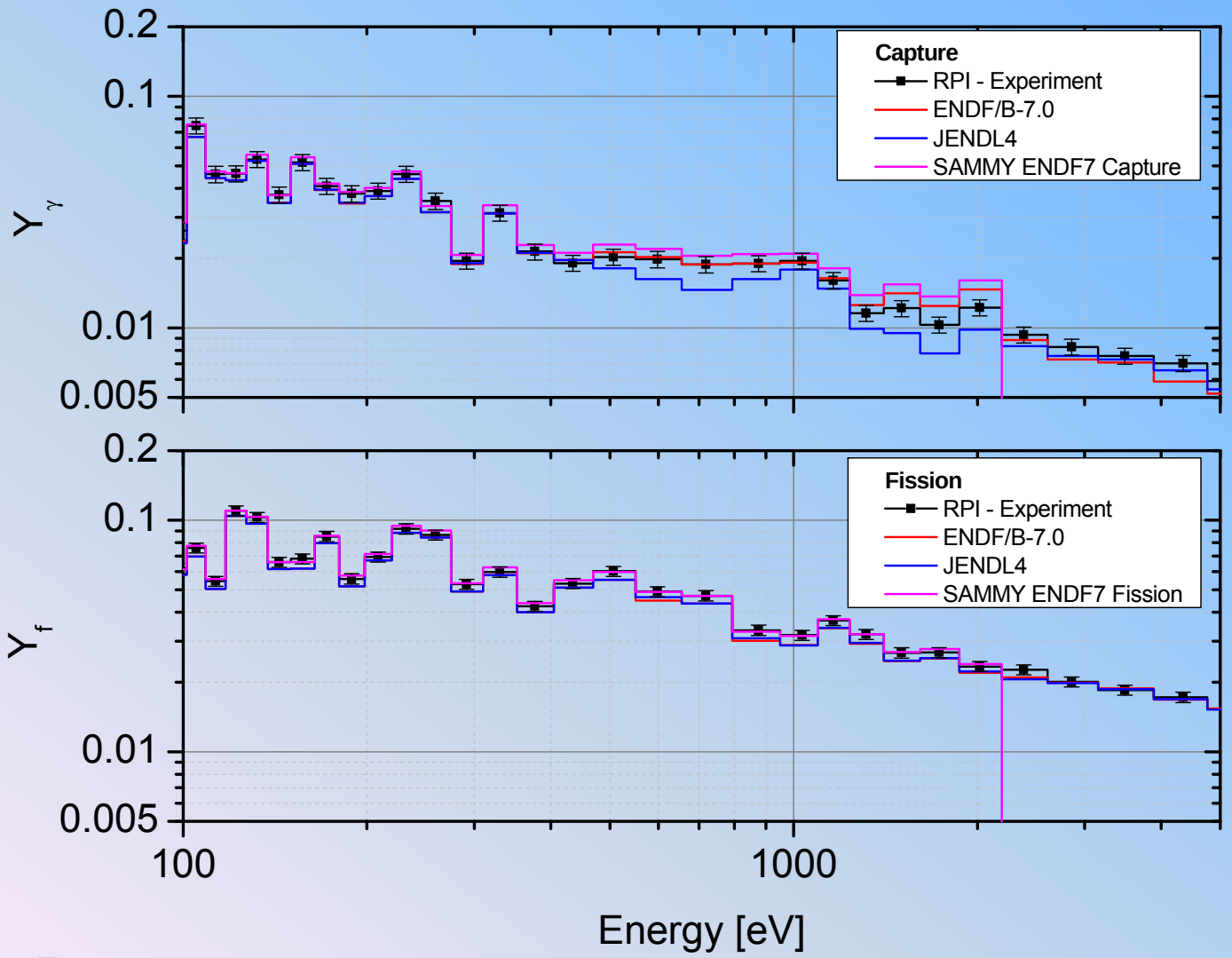
➢ Solve the two equations for k_2 and k_3

► **Need 2 resonances with known parameters** ◄

Provides data to address WPEC subgroup 29 report
"Uranium-235 Capture Cross-section in the keV to MeV Energy Region"



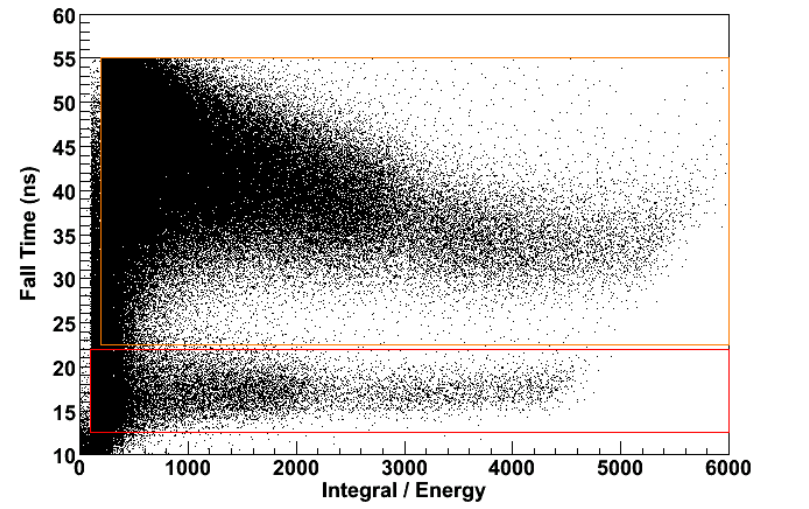
Comparing ^{235}U Fission and Capture with Evaluations

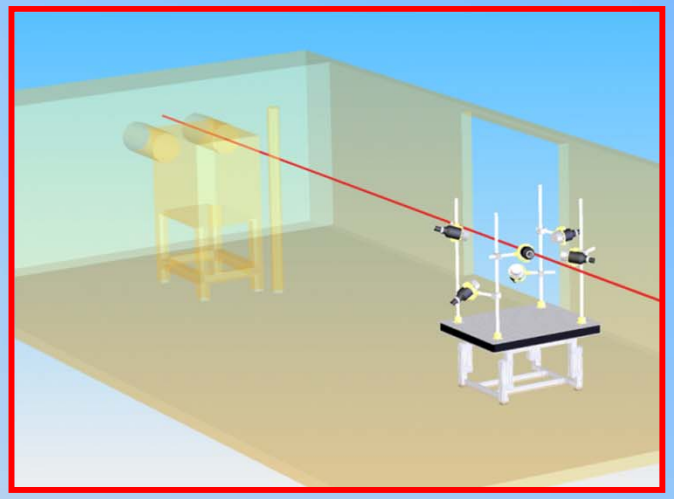


- Fission is in excellent agreement with evaluations
- Capture data has up to 8% multiple scattering that must be taken into account during the analysis
- Capture error is about 8%
- **0.4-1 keV capture data is closer to ENDF/B-7.0**
- **1-2 keV ENDF/B7.0 too high JENDL 4.0 too low.**
- **E>1 keV data is slightly higher than evaluations but within errors.**

Scattering Detection System: Experimental Setup

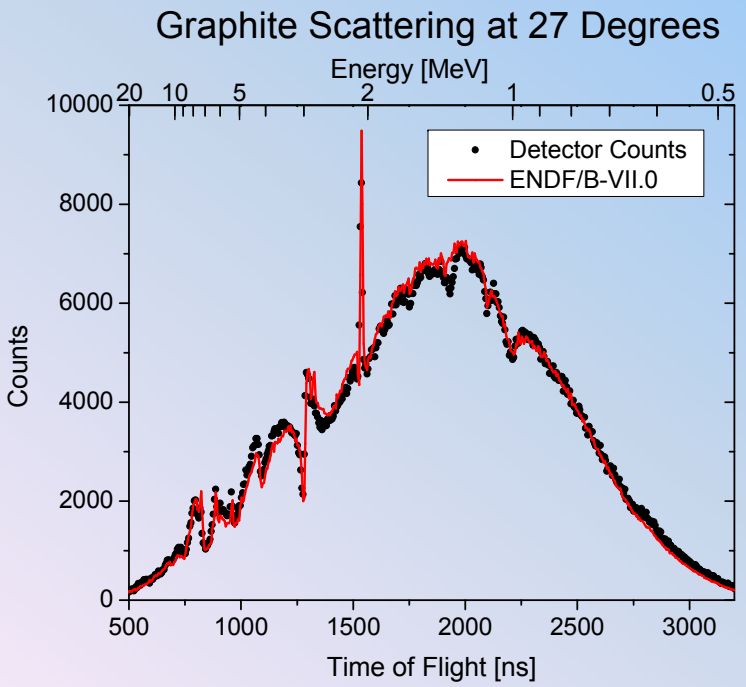
- Detector Array
  - 8 EJ301 Liquid Scintillation Detectors
  - 8 A/D channels
  - Pulse Shape discrimination in TOF
- Measures neutrons scattered from the sample at different angles
- Measured scattered neutron energy 0.5 MeV - 20 MeV
- Results are compared with a Monte Carlo simulation of the system

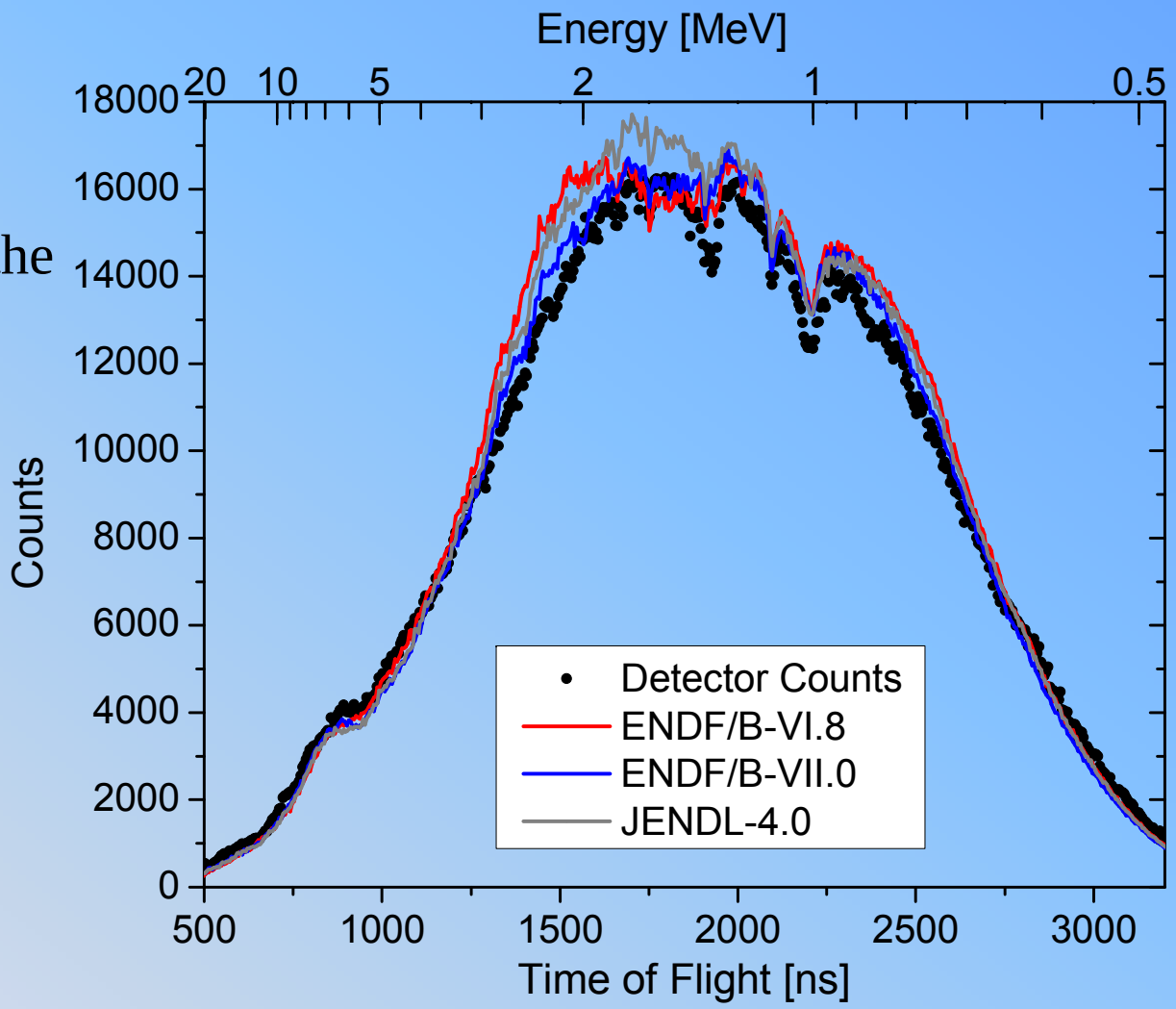




^{238}U Scattering at 27 Degrees

- Measured in September 2011.
- Compare measured data to MCNP simulations
- Use Carbon for verification of system and methodology
- ENDF/B 7.0 has the best fit to the data





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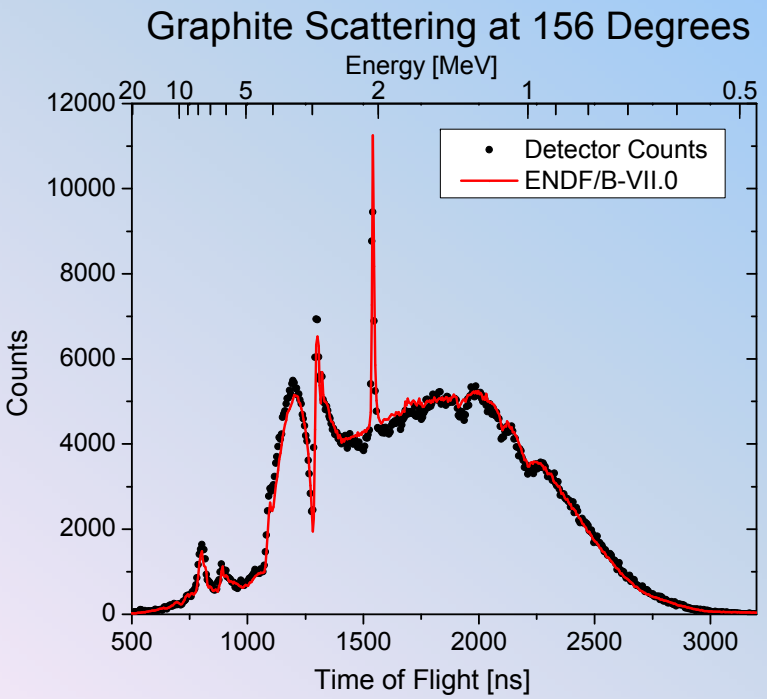
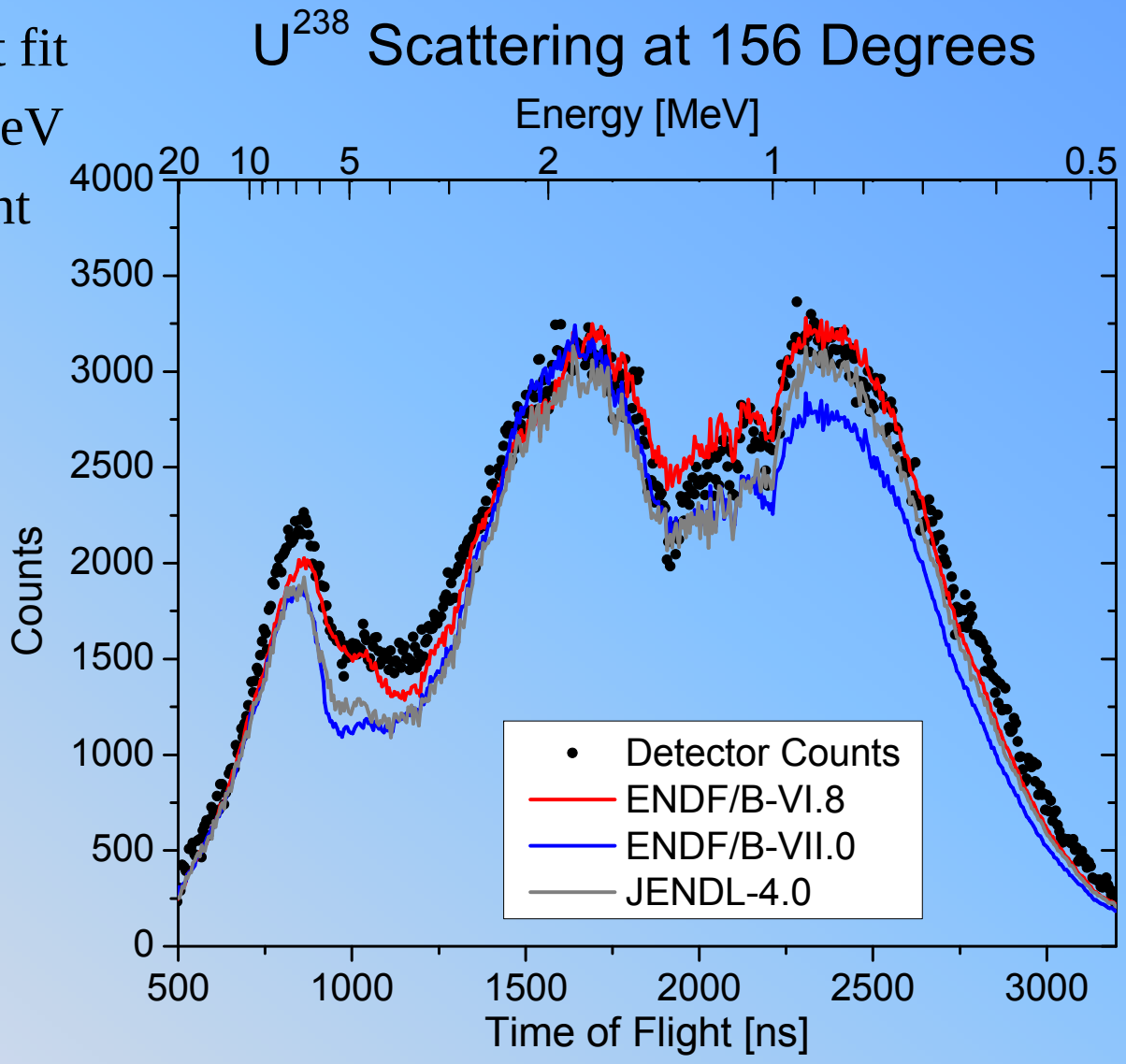
^{238}U Scattering at 156 Degrees

- ENDF/B-VI.8 provides the best fit
- JENDL-4.0 fits well for E<3 MeV
- ENDF/B 7.0 needs improvement





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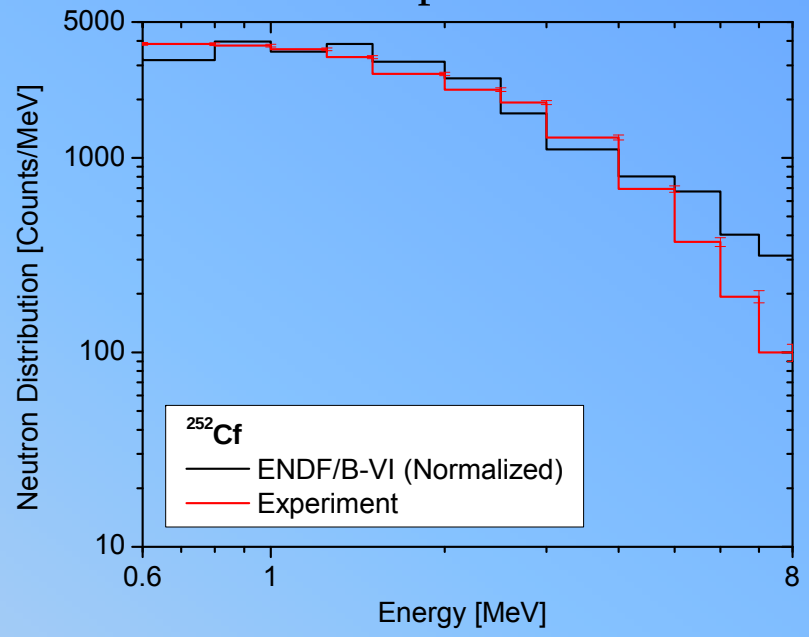
Nu-bar and Fission Spectrum Measurements (SSAA)

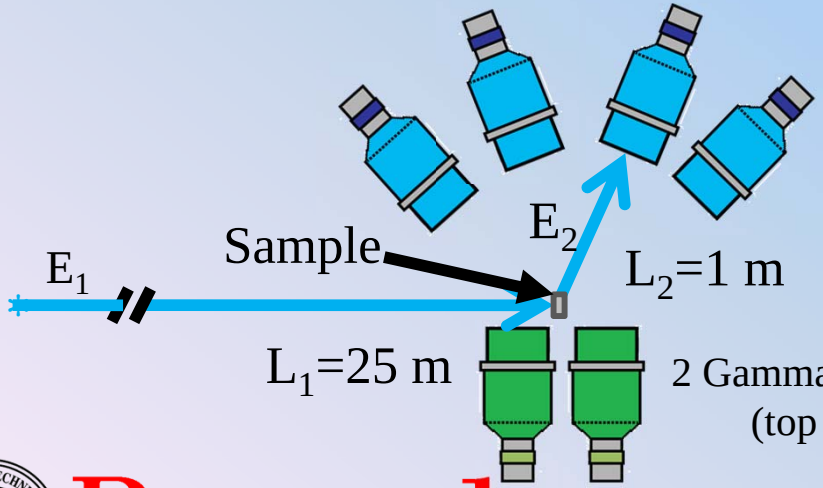
- A system is developed for the simultaneous measurement of nu-bar and fission spectrum.
- This system utilizes a coincidence requirement on an array of gamma detectors to tag fission events.
- This allows for much larger samples to be used than with conventional fission chambers

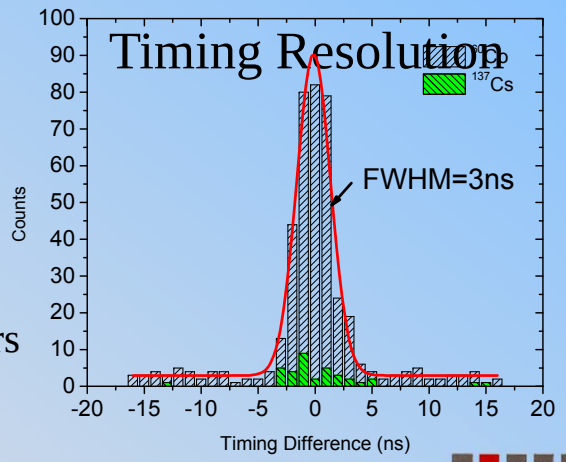
Preliminary ^{252}Cf prompt fission neutron spectrum



Experimental Setup

Neutron Detectors





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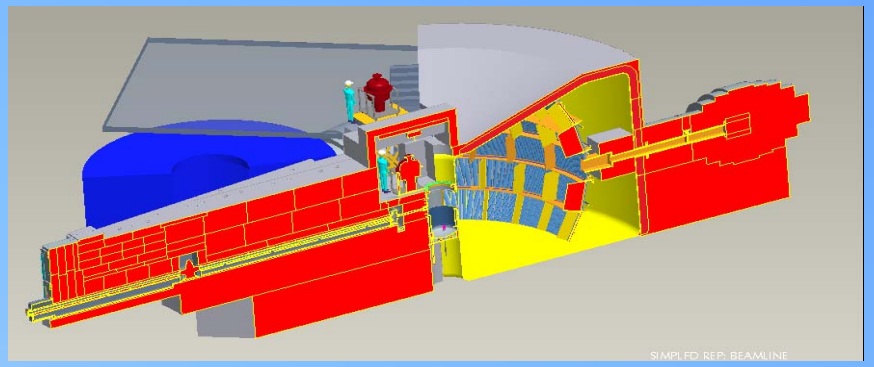
Thermal Scattering Experiment at SEQUOIA (SNS)

- SEQUOIA:
  - Fine-Resolution Fermi Chopper Spectrometer at SNS
  - E_i = 10 to 2000 meV
  - 900 ^{3}He detector tubes
  - Scattering angles: -30° to -3° horizontal and 3° to 60° vertical
  - Flux: > 1×10^5 neutrons/cm^2/s
  - Resolution: $\Delta E/E_i \sim 1\%$



- Double differential scattering cross section for inelastic scattering:

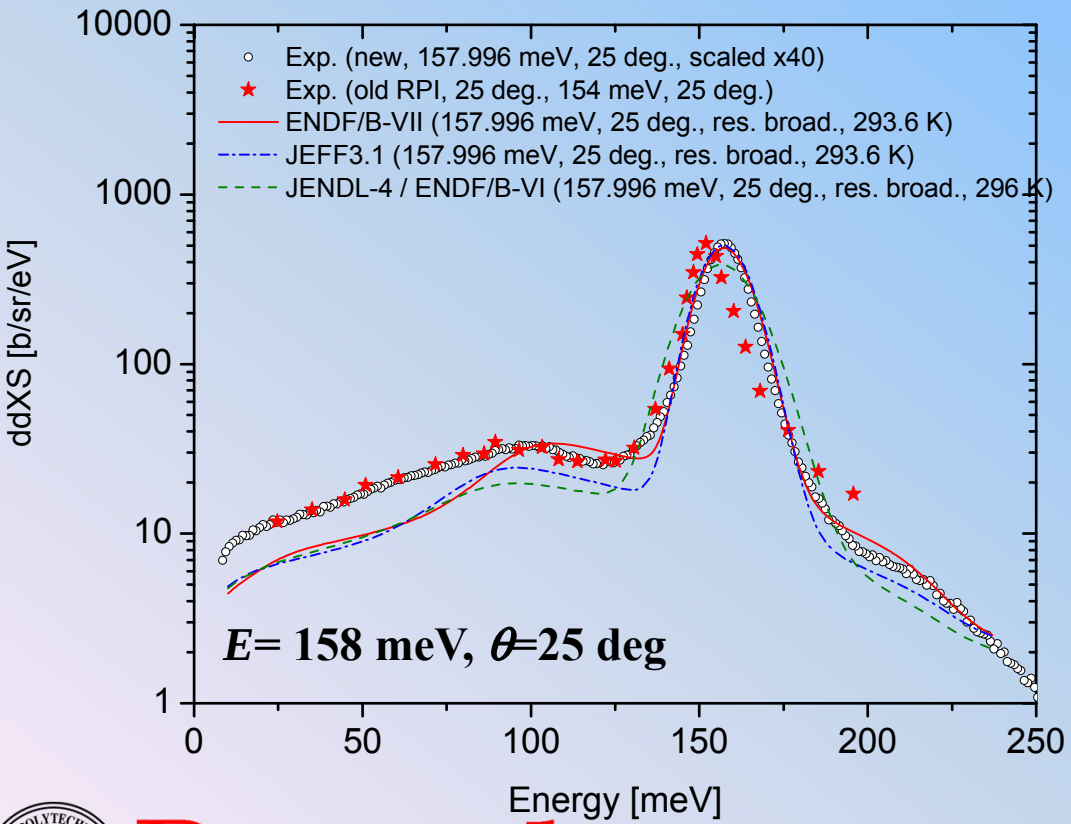
$$\frac{d^2\sigma}{d\Omega dE'}\left(E\to E',\Omega\to\Omega'\right)=\frac{\sigma_b}{4\pi kT}\sqrt{\frac{E'}{E}}e^{-\frac{\beta}{2}}S(\alpha,\beta)$$

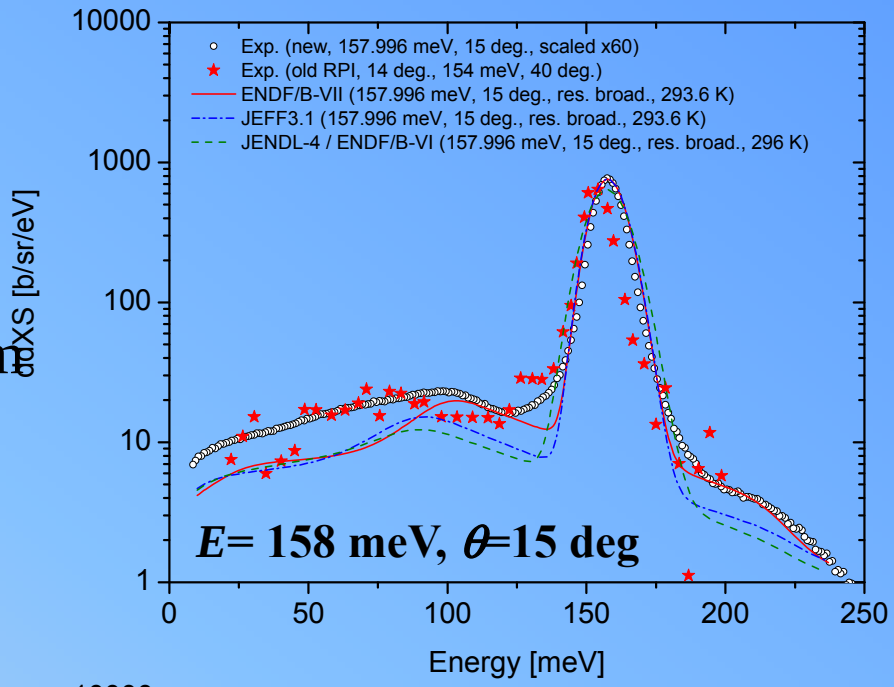
$$\alpha=\frac{E'+E-2\sqrt{E'E}\cos\theta}{AkT}=\frac{\hbar^2\kappa^2}{2MkT}\qquad\beta=\frac{E'-E}{kT}=\frac{\varepsilon}{kT}$$

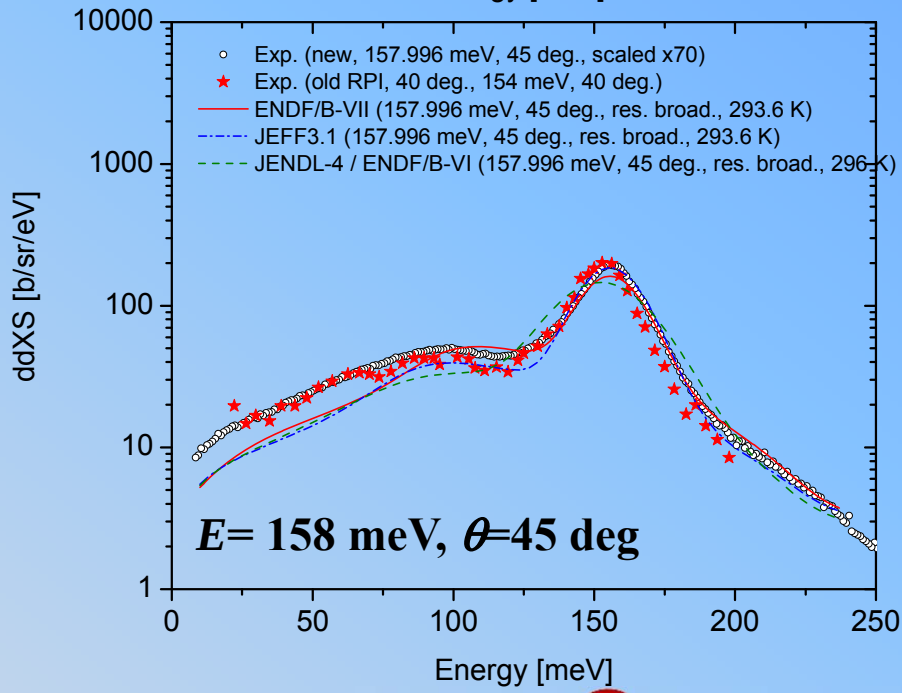
Thermal Scattering Measurements

Emily Liu(RPI), Alexander Kolesnikov(ORNL/SNS)

- Samples: **H_2O**, Poly, Empty Can, Vanadium
- E_i (eV): 0.055, 0.16, 0.25, 0.6, 1, 3, 5
- Working on absolute normalization







Summary – FY2011 and planned 2012 activity

- Data publications (published and in preparation)
  - High energy total cross section for C and Be
  - High energy scattering from Zr
  - ^{147,149} Sm (n,α) cross section measurements with the LSDS
  - Eu sample x-ray characterization
  - Michael Rapp PhD thesis – "Design and construction of a large area detector system and neutron total cross section measurements in the energy range 0.4 to 20 Mev", included transmission results on C, Be, Mo, Zr, Ta, Ti
- Analysis in progress
  - Ti, Ta, Zr and Mo high energy (0.5-20 MeV) transmission
  - Rh, Cd, Eu,^{153}Eu, ^{161,162,163,164}Dy, ^{155,156,157,158,160}Gd, ^{236}U– Resonance parameter analysis
  - ^{95,96,98,100}Mo resonance region (10 eV - 600 keV) transmission measurements
  - ^{238}U neutron scattering
- Planned measurements
  - Fe-filtered ^{56}Fe, 100m flight path
  - ^{92,94}Mo, 10 eV - 600 keV, 100m and 30m flight path
  - Ti, Zr, Mo 0.5-20 MeV, 250m flight path
  - Fission neutron spectra and nubar from ^{252}Cf and ^{235}U
  - ^{50}V(n,α) cross section measurements with a LSDS