

Cross Section Measurements and Analysis at Rensselaer

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Measurements Completed This Year

- Ti, Zr
 - High energy (0.5-20 MeV) transmission
- Be, Mo
 - High energy (0.5-20 MeV) neutron scattering
- Elemental Eu and ^{153}Eu
 - Epi thermal (2-2000 eV) transmission and capture
 - Thermal (0.01-20 eV) transmission
- ^{238}U
 - Resonance scattering
- ^{239}Pu fission fragment mass and energy distributions with the RPI LSDS
- Elemental Samarium
 - (n, α) cross section measurements with the LANL LSDS

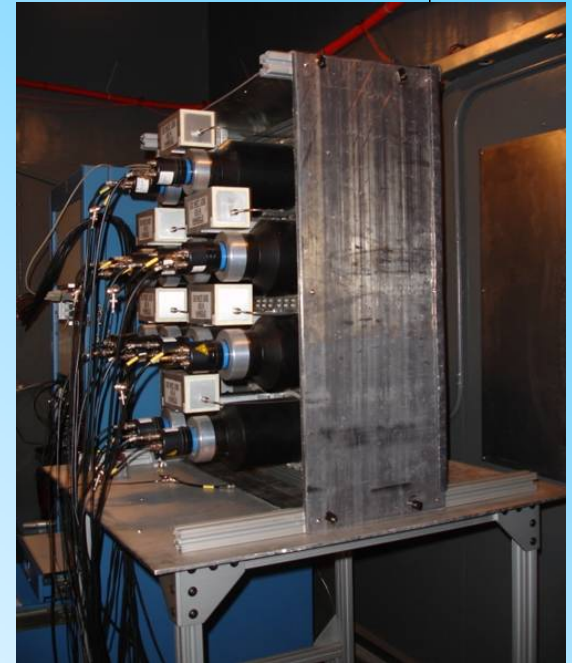
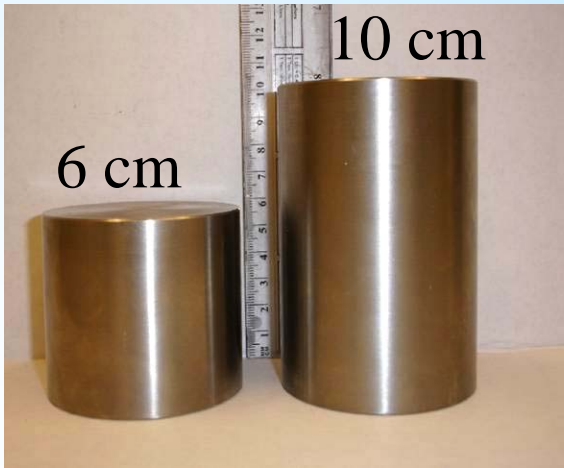
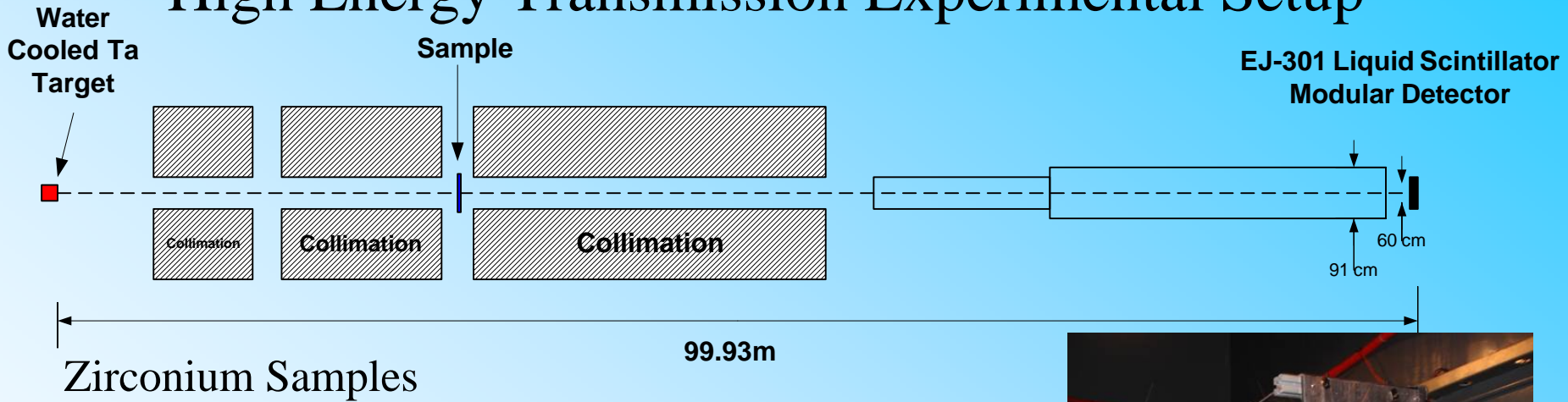
Planned Measurements

- High energy (0.5-20 MeV) neutron scattering from Zr
- Resonance region (1 eV- 400 keV) transmission for Mo
 - ORNL is preparing samples of $^{95,96,98,100}\text{Mo}$.
- Capture measurements of $^{155,156,157,158,160}\text{Gd}$ (NCSP).
- Fission fragment mass and energy distributions of ^{248}Cm
- (n, α) cross section measurements on ^{149}Sm with the LSDS

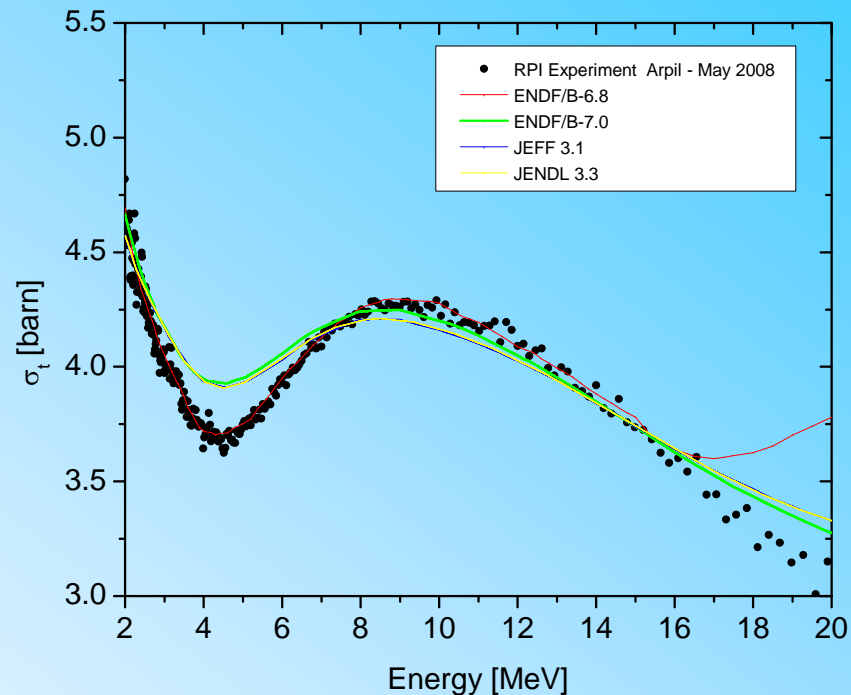
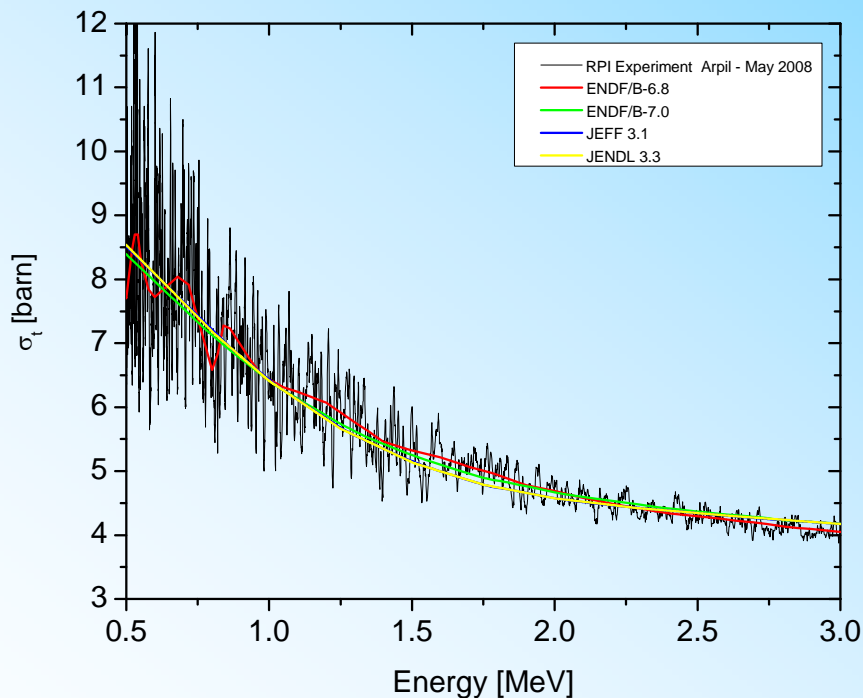
Data Analysis

Sample	Status
Rh	SAMMY analysis pending
Cd	REFIT analysis pending (Moxon has our data)
Re	Data analysis suspended
Eu	Data analysis started
U-236	New samples and a transmission measurement required for completion of this task
^{164}Dy	Data analysis and resonance parameters of the epi-thermal region are in Molly Ernesti's MS Thesis.
Be,Mo,Zr,Ti	High energy (0.5-20MeV) transmission analysis in progress
Be, C, Mo	High energy (0.5-20MeV) scattering data analysis in progress

High Energy Transmission Experimental Setup

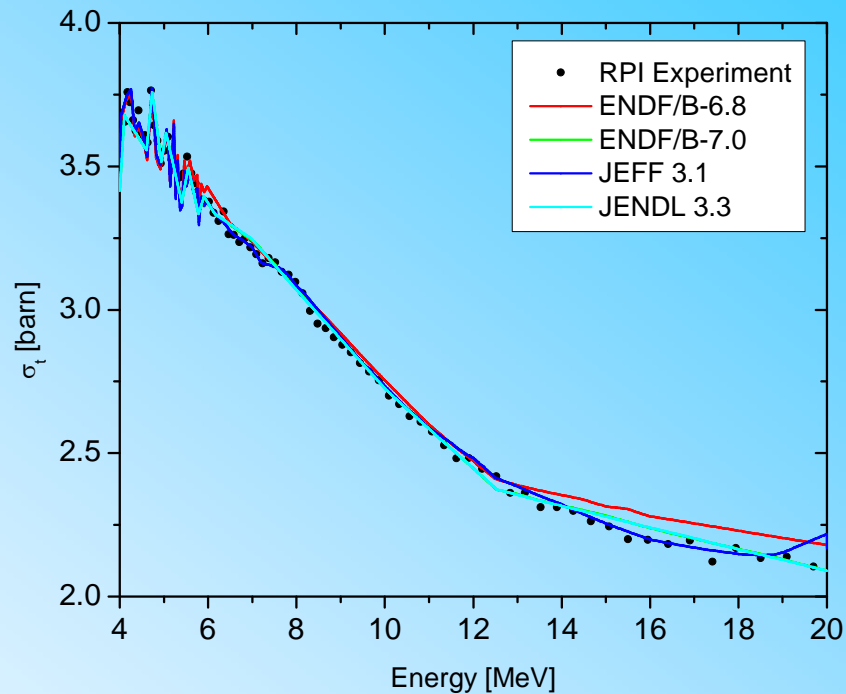
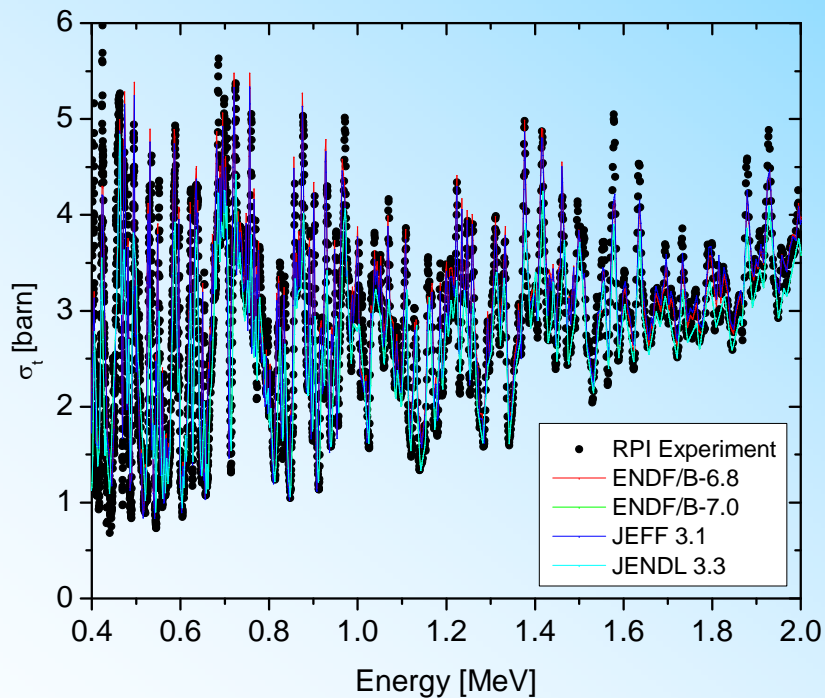


Zr Total Cross Section Measurements (0.5-20 MeV)



- Used low Hf (less than 100 ppm) Zr metal
- ENDF/B 6.8 seems like a better fit for $E < 16$ MeV
- New partially resolved structure below 2.0 MeV
- Data can be used to improve the unresolved resonance region evaluation

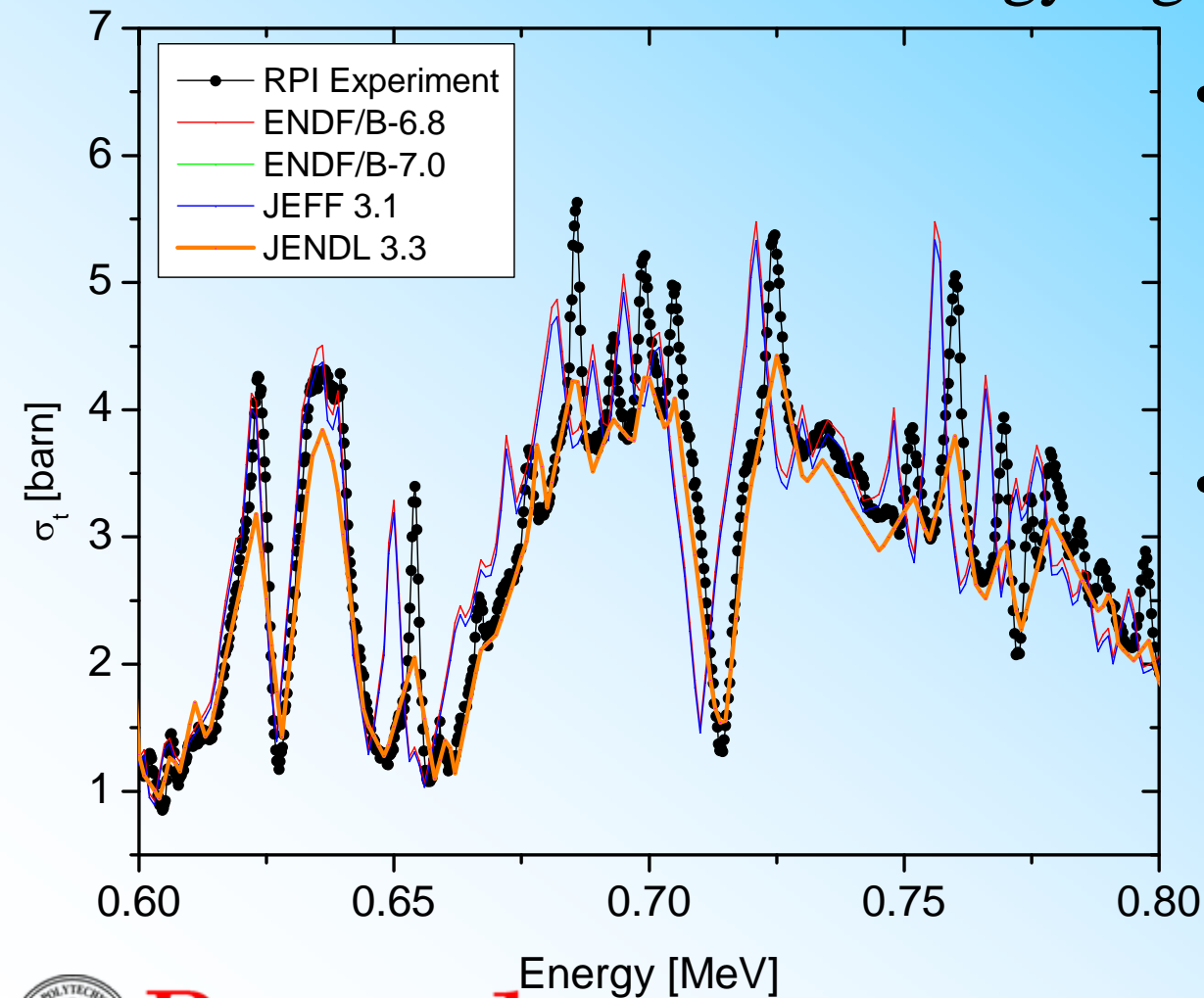
Ti Total Cross Section Measurements (0.5-20 MeV)



- The evaluation are generally in good agreement with the data
- Below 2 MeV the data has better energy resolution than the evaluation

Ti Total Cross Section Measurements

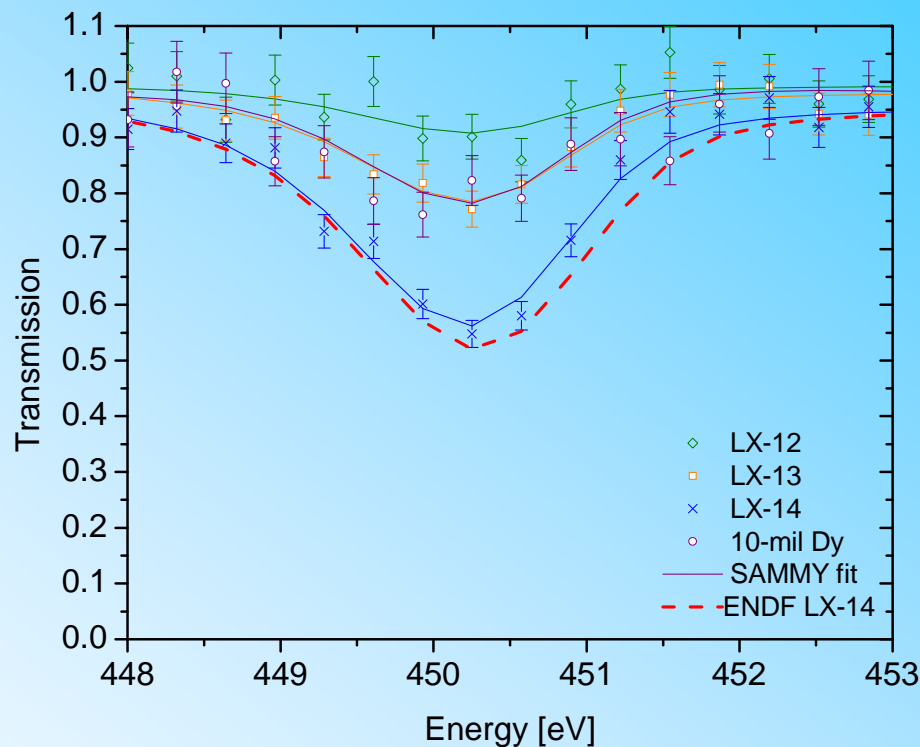
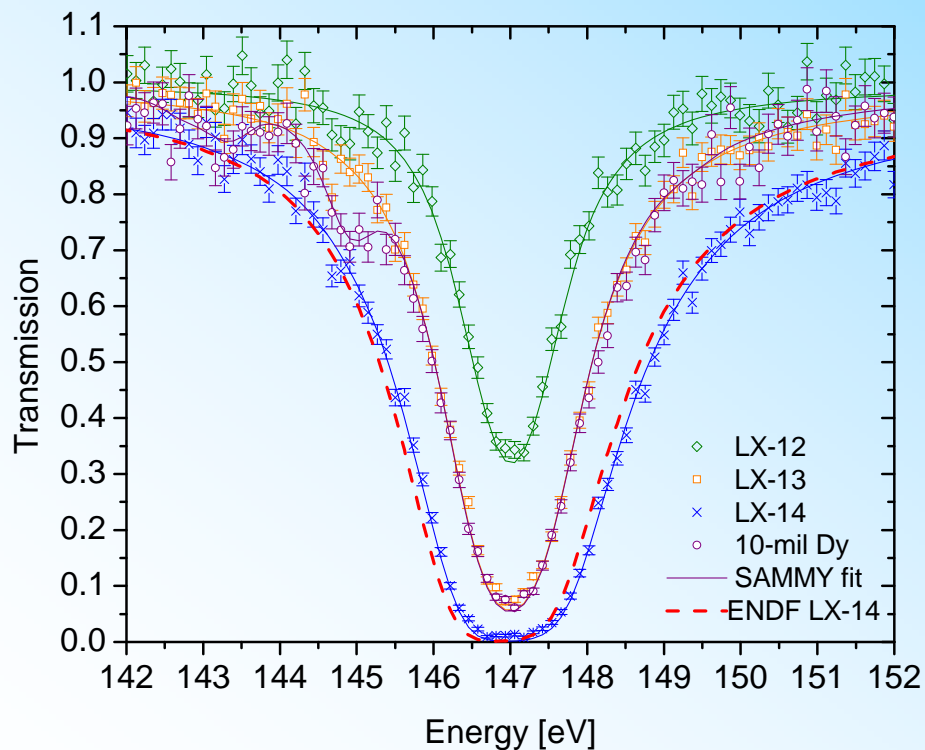
0.5-1 MeV energy region



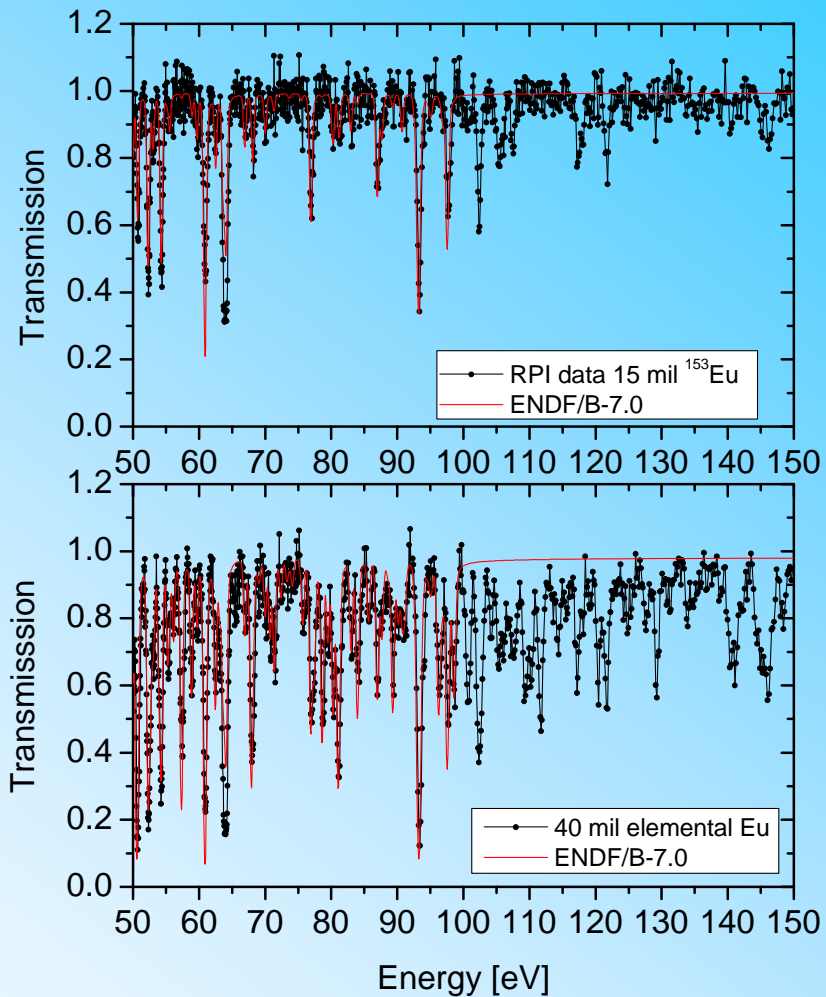
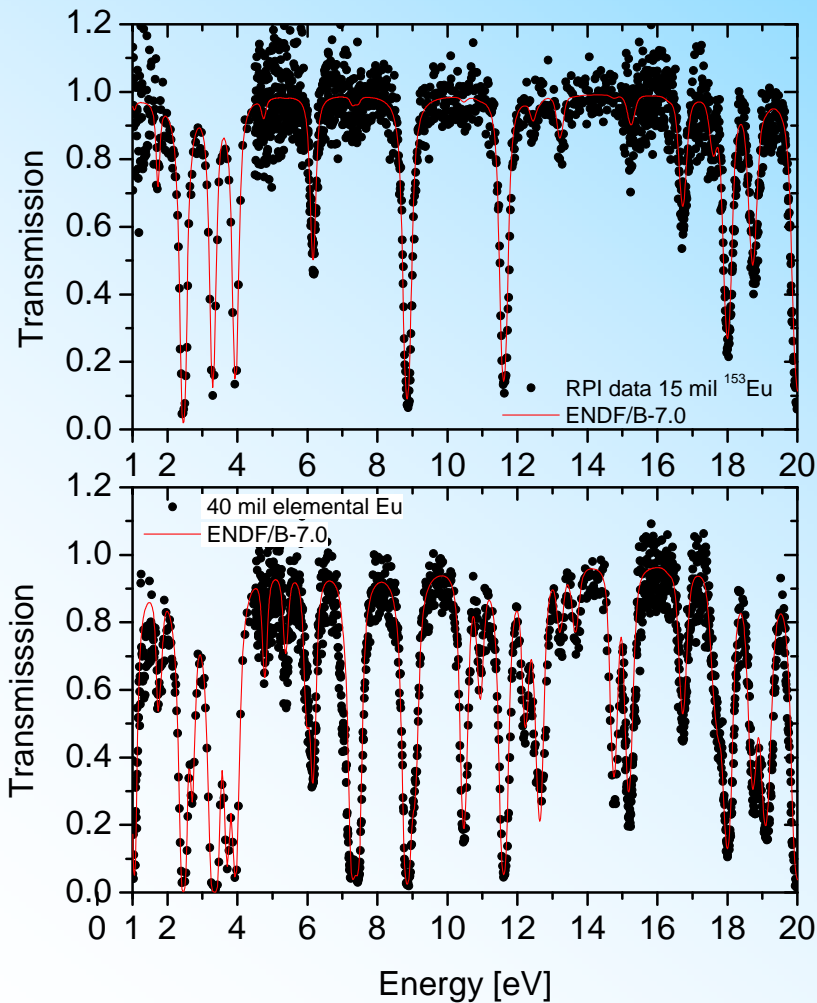
- With the exception of JENDL3.3 and ENDF/B-7.0, all evaluations seem to have an energy shift.
- The JENDL/ENDF evaluation is based on low resolution data.

^{164}Dy Transmission Resonance Analysis

- Samples 98.6% enriched in ^{164}Dy



Eu Transmission compared to ENDF/B-7.0

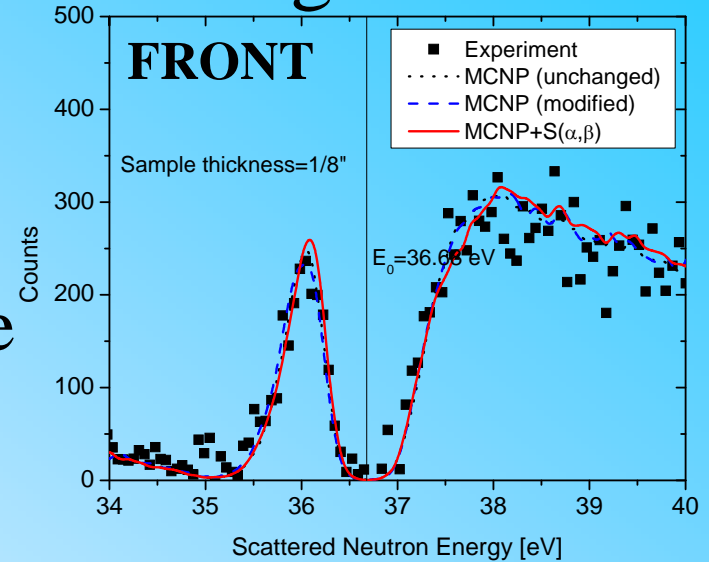
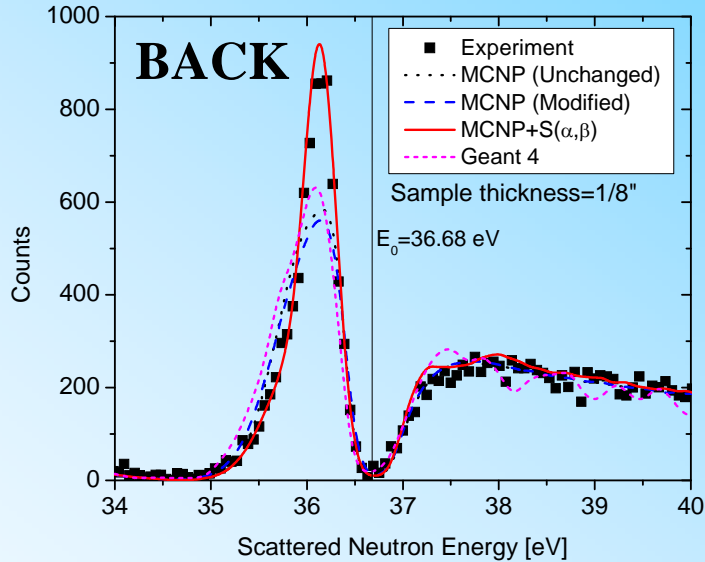


^{238}U Resonance Scattering

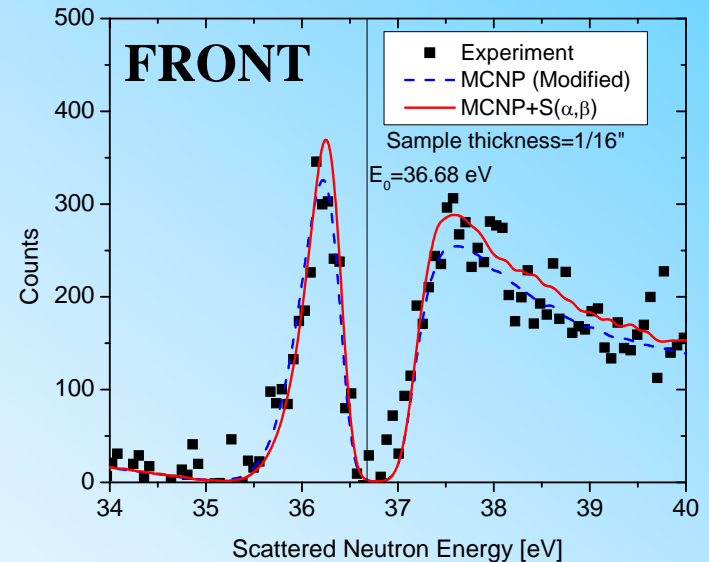
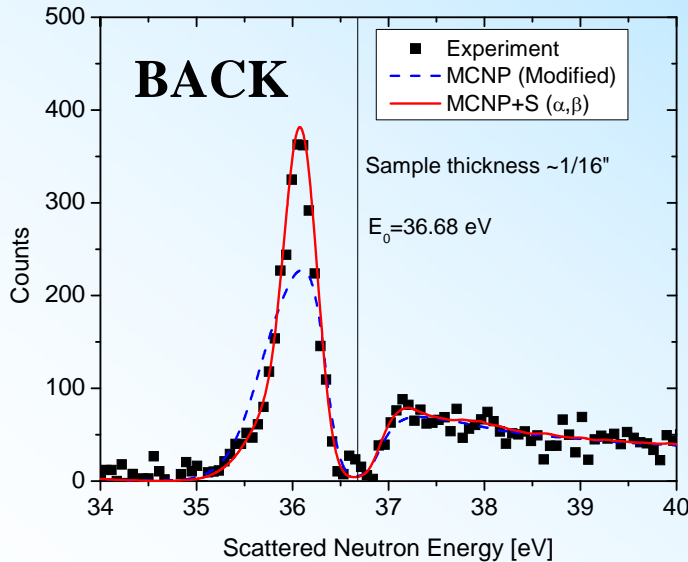
- Neutron scattering kinematics in the resonance region is normally treated as free gas.
- The derivation of the scattering kernel in most (if not all) Monte Carlo (MC) codes assumes a constant cross section
 - OK in the thermal region, but not for the low lying resonances.
- By default MCNP stops its approximated free gas model treatment at 400 kT (~ 10 eV). This can be easily overridden.
- We collaborated with Ron Dagan from Institut für Reaktorsicherheit (IRS) Forschungszentrum Karlsruhe, GmbH
 - Dagan et al. derived the resonance scattering kernel and implemented it in NJOY to create a scattering kernel $S(\alpha, \beta)$ for MCNP
- Together with a visiting scholar, *Dr. Tae-Ik Ro*, we performed experiments to validate this model.

Results - ^{238}U Scattering

Thick Sample

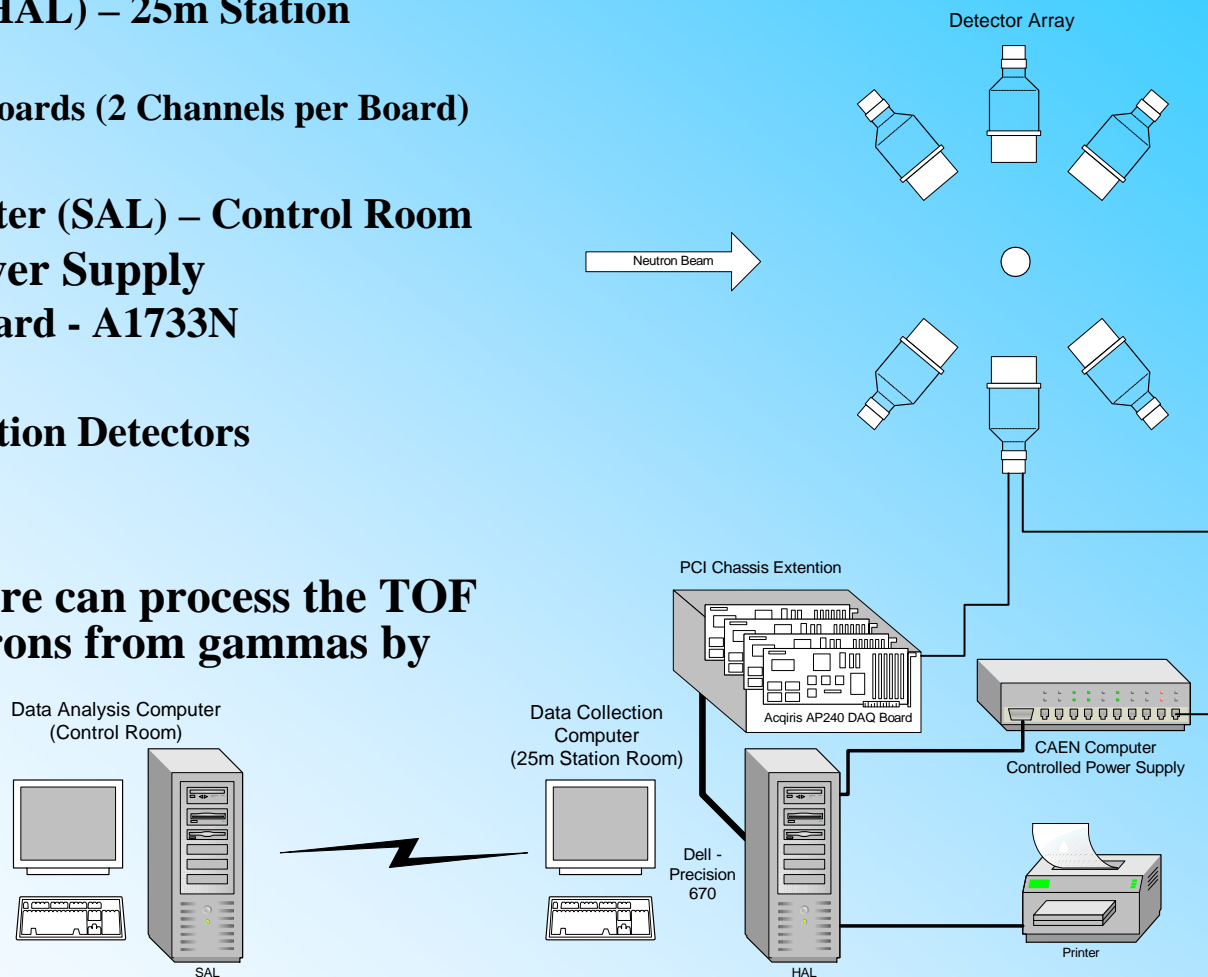


Thin Sample

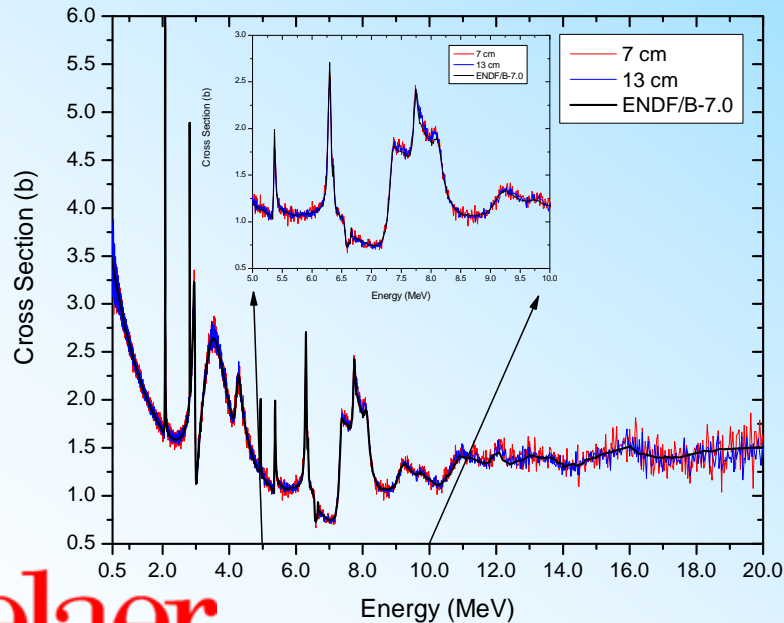
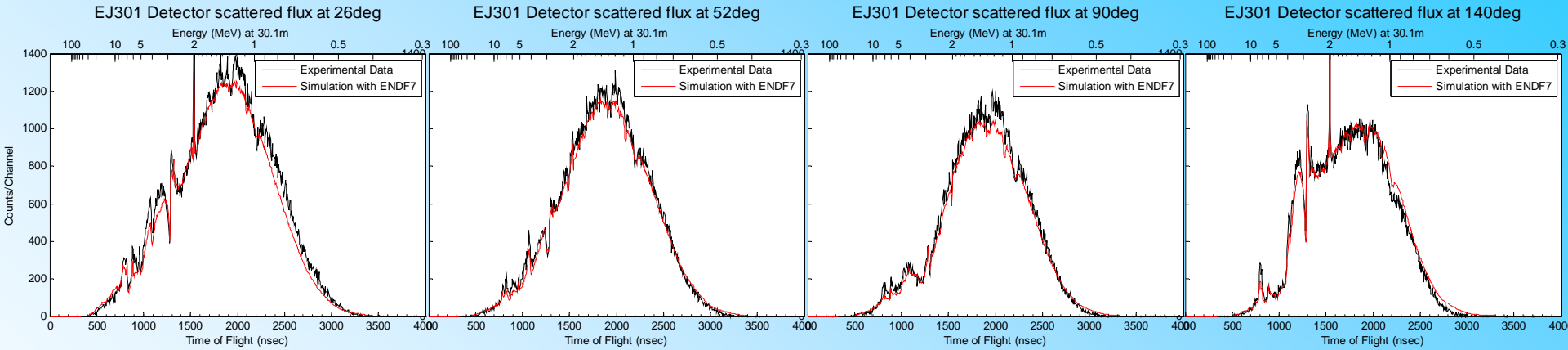


Scattering Detection System: Experimental Setup

- **Data Acquisition System**
 - Main DAQ Computer (HAL) – 25m Station
 - PCI Extension Chassis
 - Acqiris AP240 DAQ Boards (2 Channels per Board)
- **Data Processing System**
 - Data Processing Computer (SAL) – Control Room
- **Computer Controlled Power Supply**
 - Chassis - SY 3527 Board - A1733N
- **Detector Array**
 - 8 EJ301 Liquid Scintillation Detectors
 - Detector Stands
- **Sample Holder / Changer**
- **The RPI developed software can process the TOF data and distinguish neutrons from gammas by pulse shape analysis**



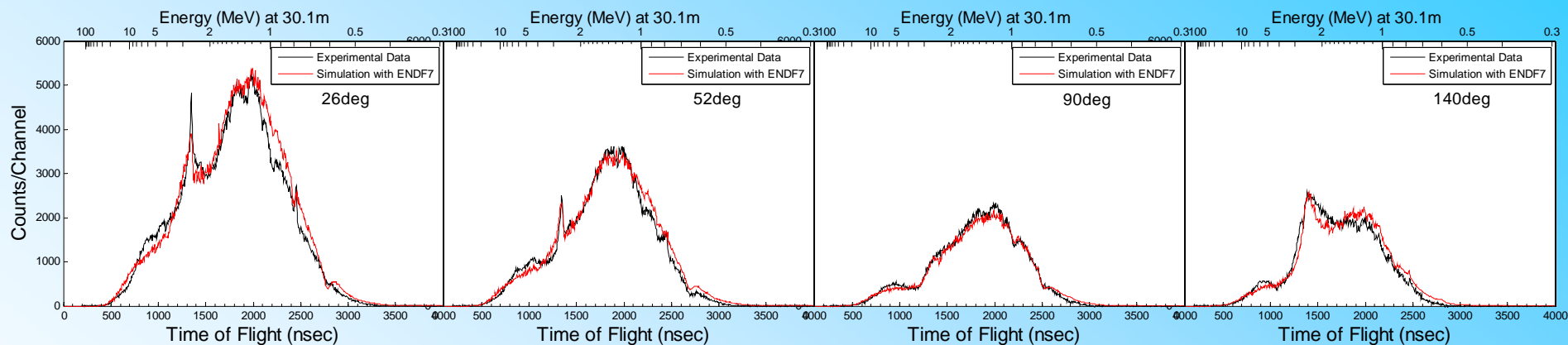
Carbon Experimental Results



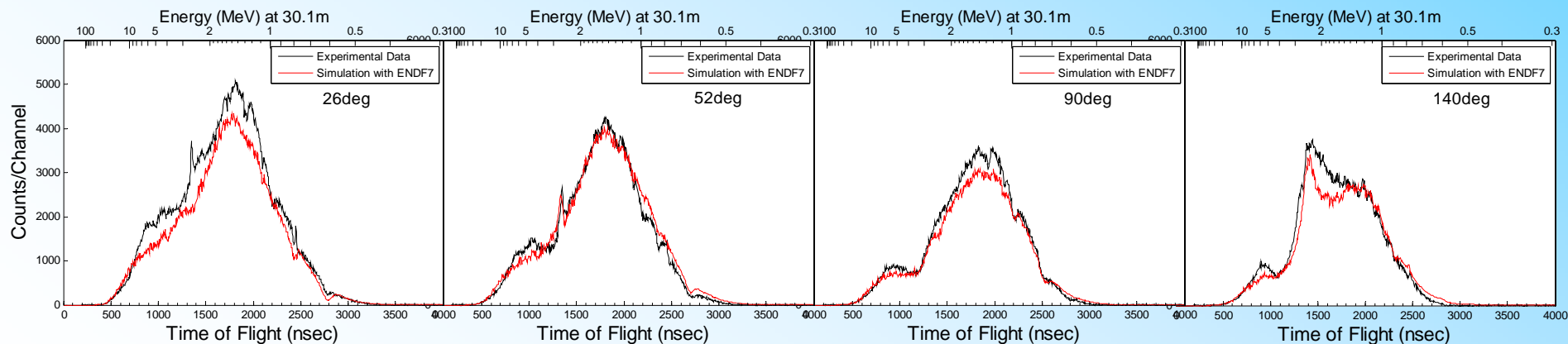
Total cross section

Beryllium Experimental Results

4cm

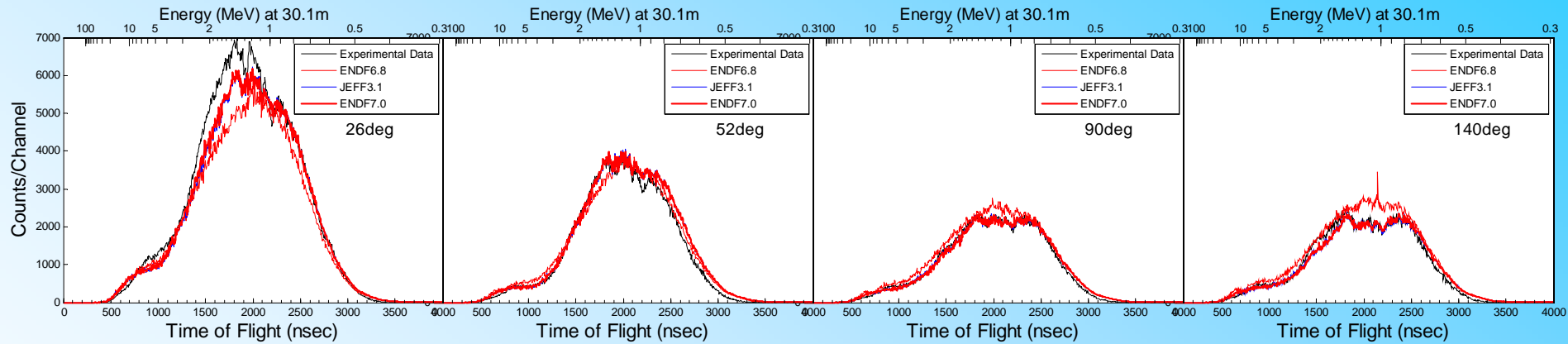


8cm

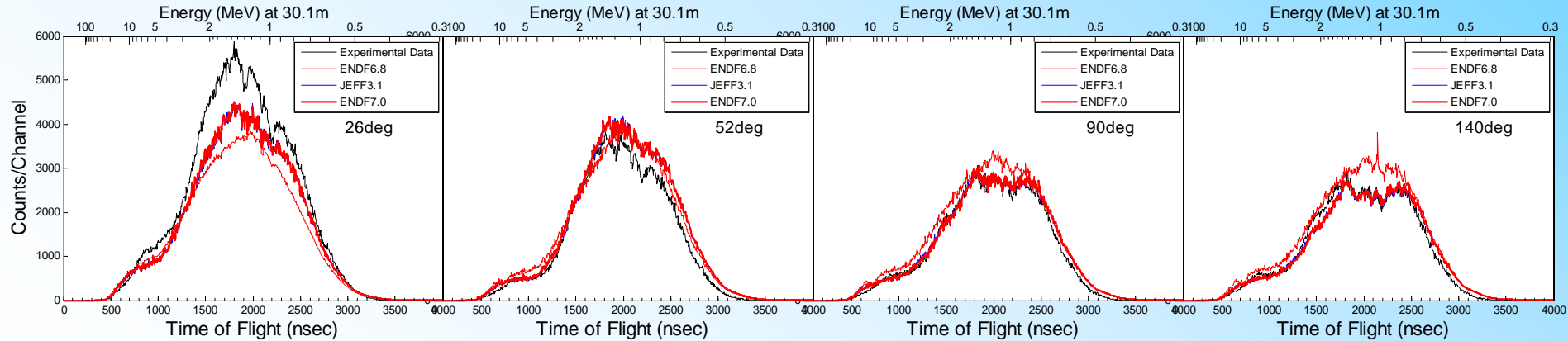


Molybdenum Experimental Results

5cm

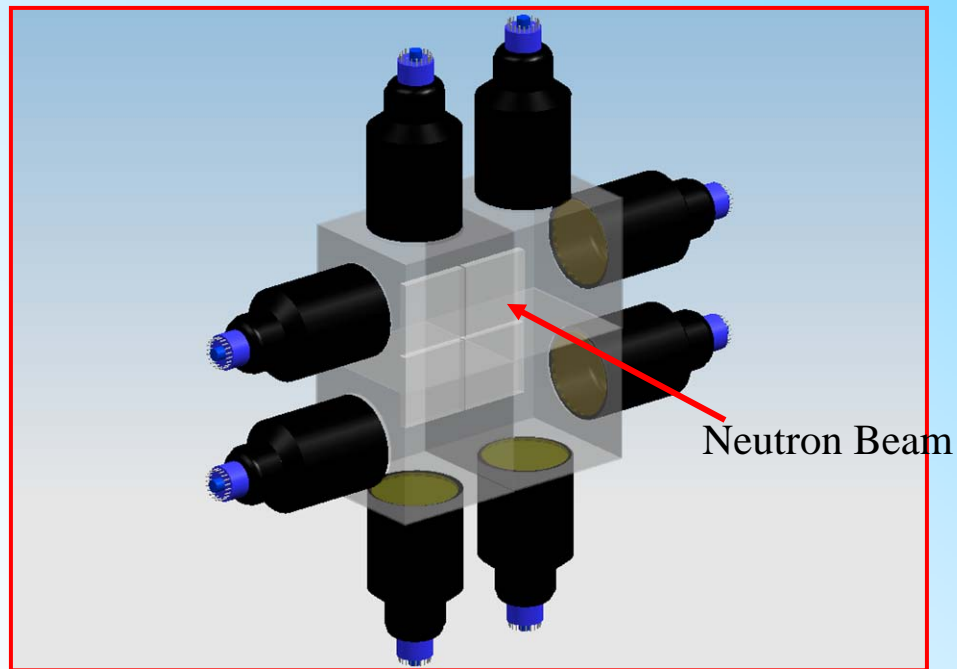


8cm



High Resolution Transmission Detector

- Modular Li-Glass detector will be positioned at 100m flight path
 - Extends our capabilities up to the unresolved resonance region
- Prototype module built and tested.



Lead Slowing Down Spectrometer

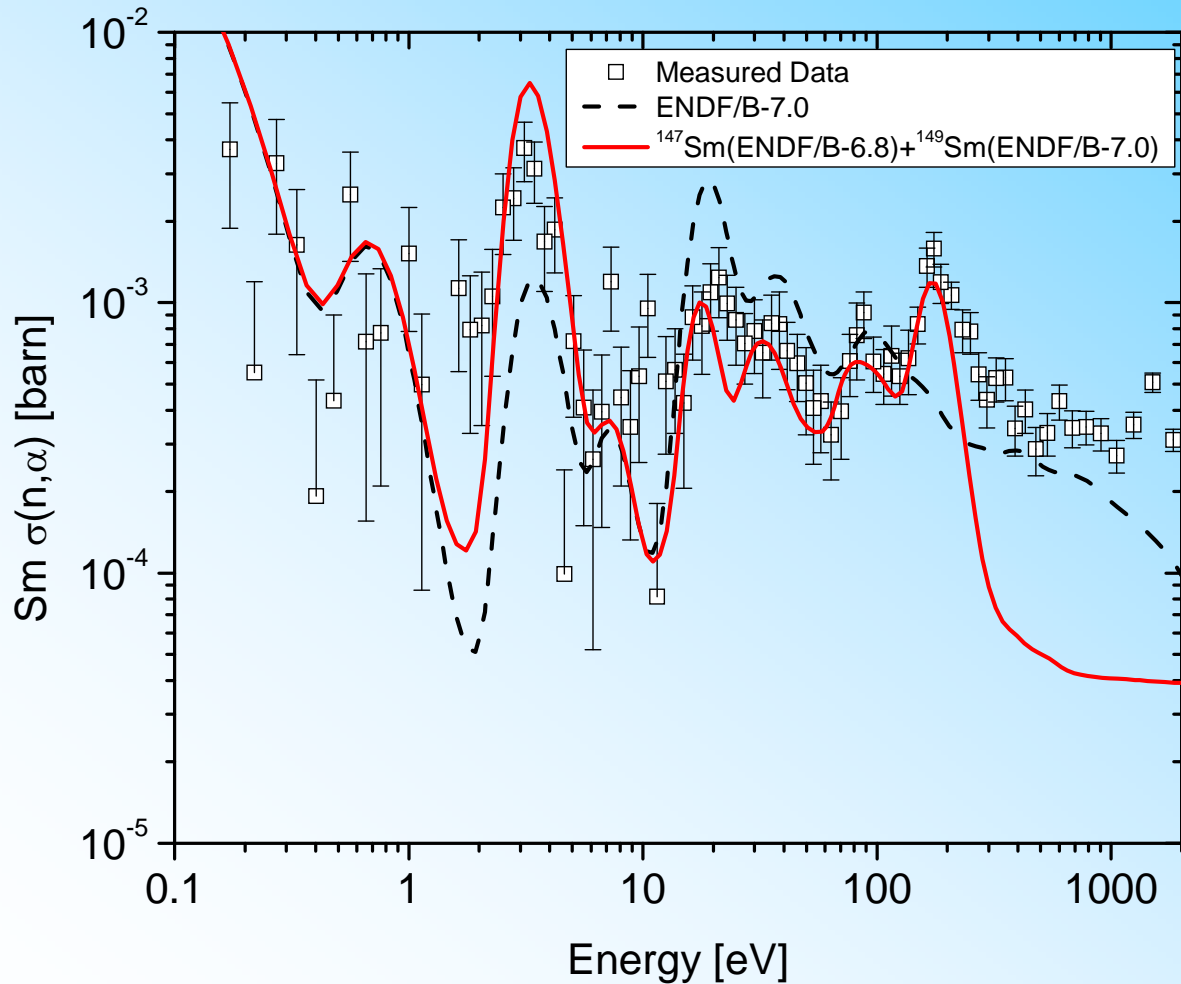
- Fission cross section and fission fragment spectroscopy
 - Measured ^{235}U and ^{239}Pu .
 - ^{248}Cm is planned.
 - Cathy Romano PhD topic.
- Detectors for (n, α) and (n,p) measurements are under development
 - Compensated Solar Cells
 - **Compensated PIPS detectors**
 - Compensated GEM amplified detectors (shown on the right)



Working hard with the LANL LSDS



Measurement of (n,α) cross section of Natural Sm



- The motivation was to demonstrate the ability to measure small cross section of small sample with the LSDS
- Possible contamination from ^{149}Sm (n,γ) was not corrected yet.
- Data were normalized to the evaluations.
- Best fit with ^{147}Sm from ENDF/B 6.8 and ^{149}Sm from ENDF/B-7.0
- The ^{147}Sm ENDF.B 6.8 evaluation is in better agreement with the recent ORNL (n,α) measurement.

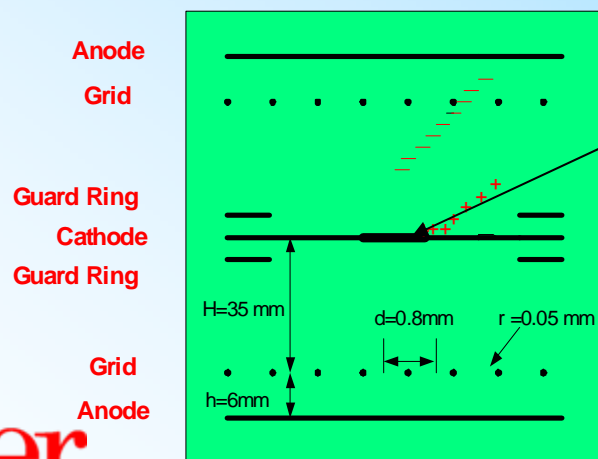
Paul E. Koehler et al. Phys. Rev. C 69,015803,2004

Simultaneous Measurements of Fission Cross Section and Fission Fragment Mass and Energy Distributions of Small Samples

- Use a double gridded fission chamber with the RPI LSDS
- Use kinematics to compute
 - Fragment angle relative to the normal to the sample
 - Fragment energy distribution
 - Fragment mass distribution

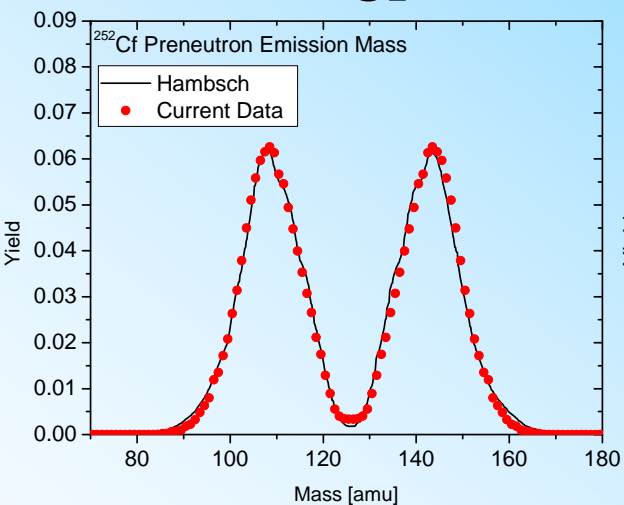


Sample

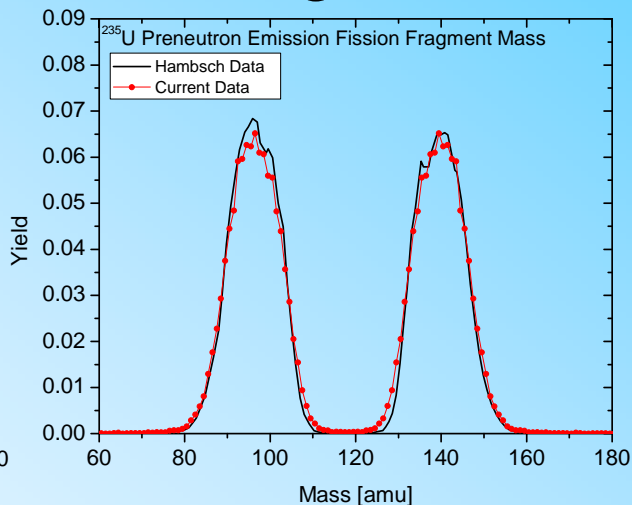


Results – Fission Fragment Mass distribution $E_n < 0.1$ eV

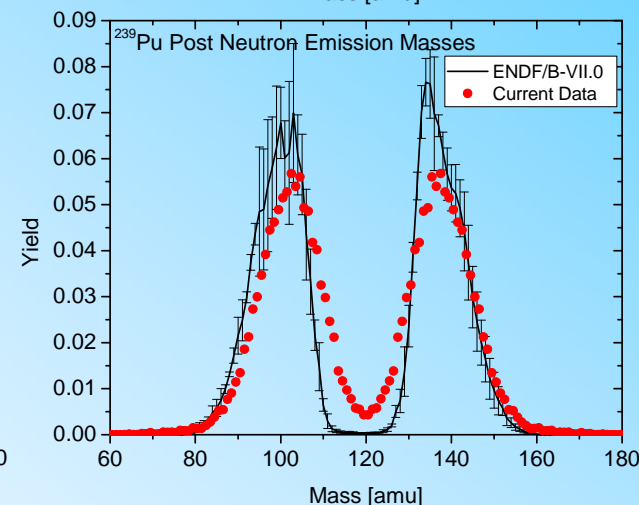
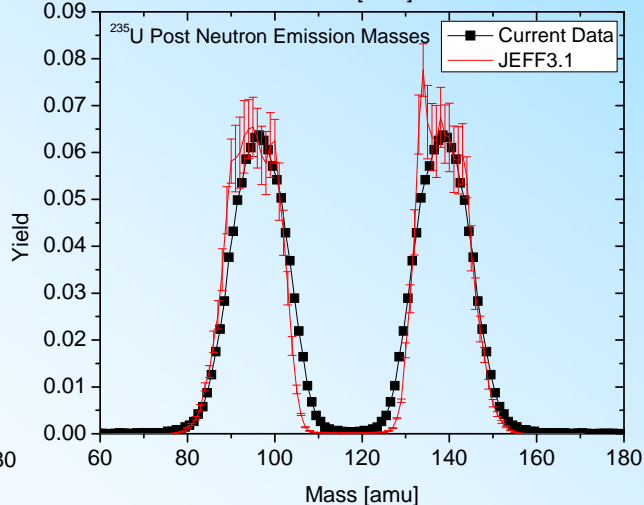
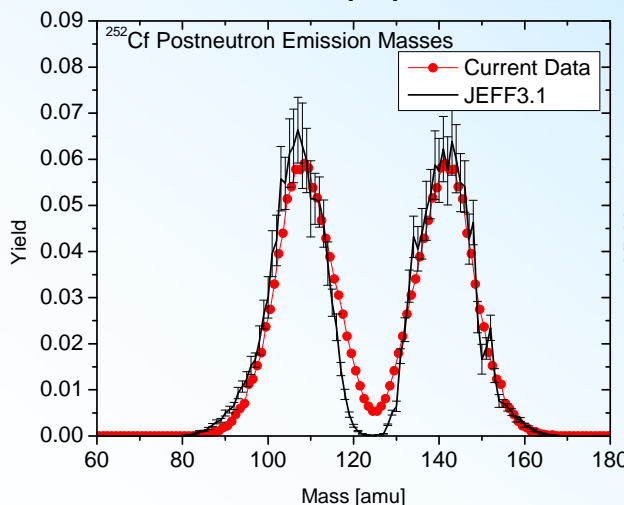
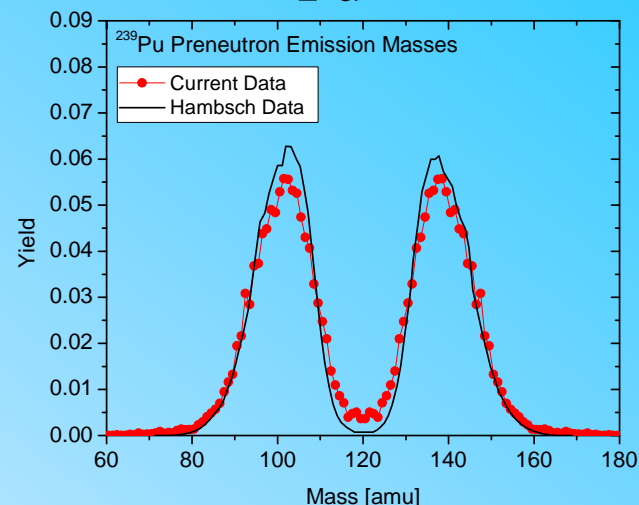
^{252}Cf



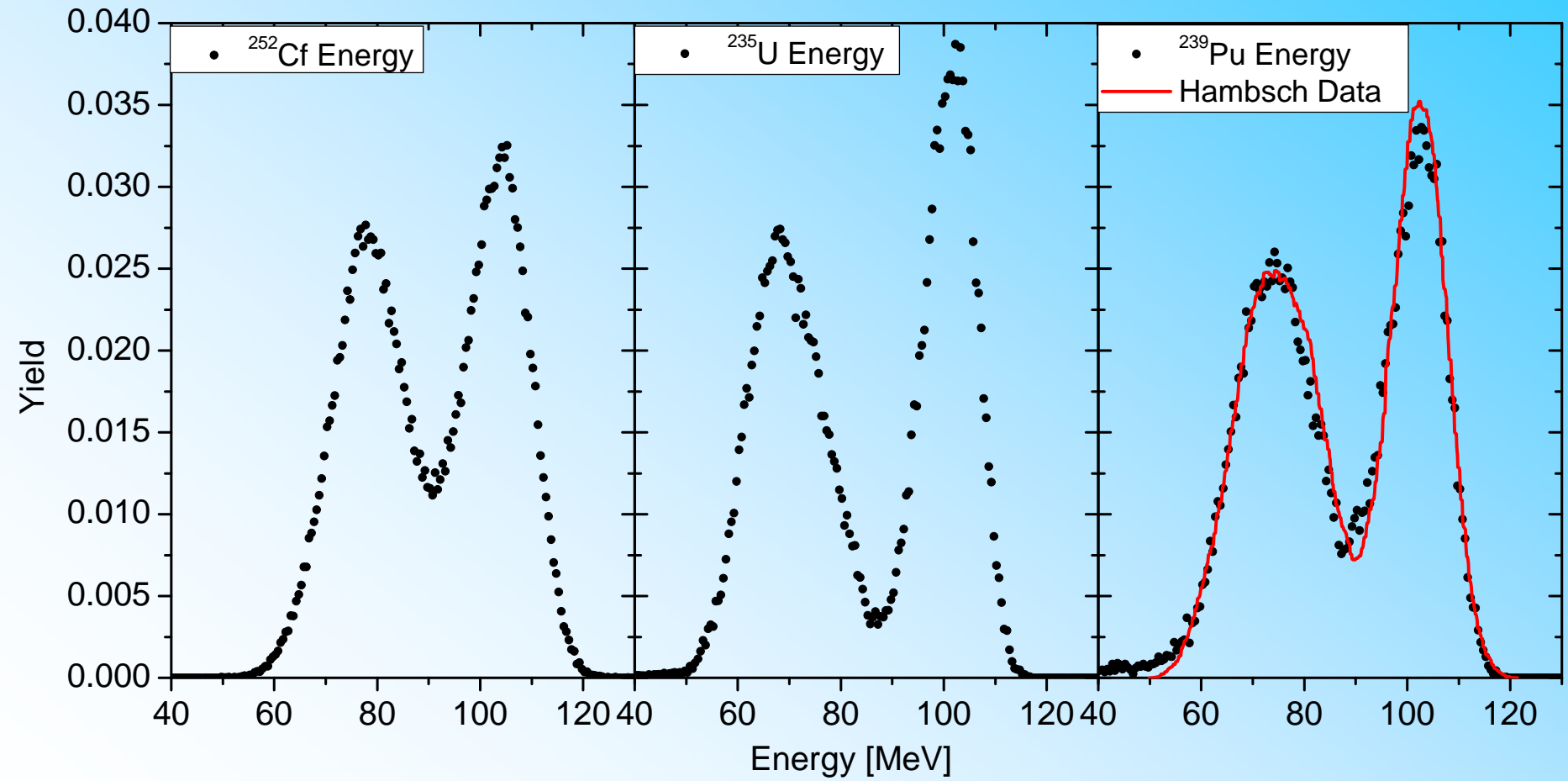
^{235}U



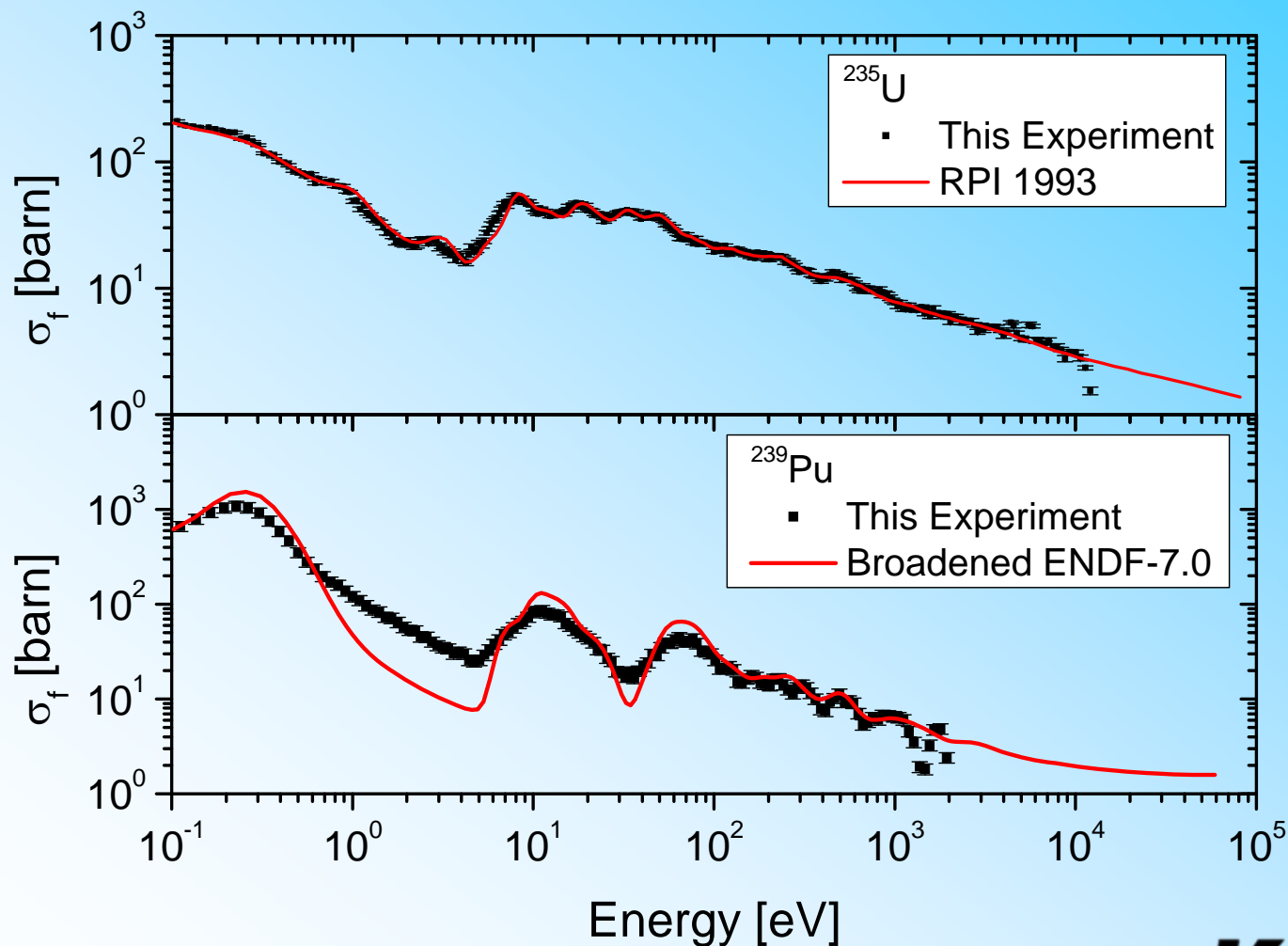
^{239}Pu



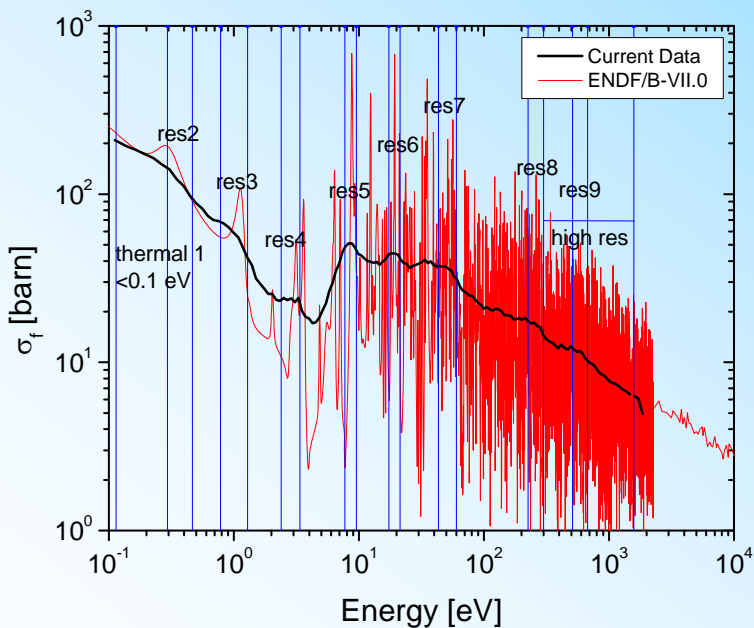
Results – Fission Fragment Energy Distribution $E_n < 0.1$ eV



Results – Measured Fission Cross Section

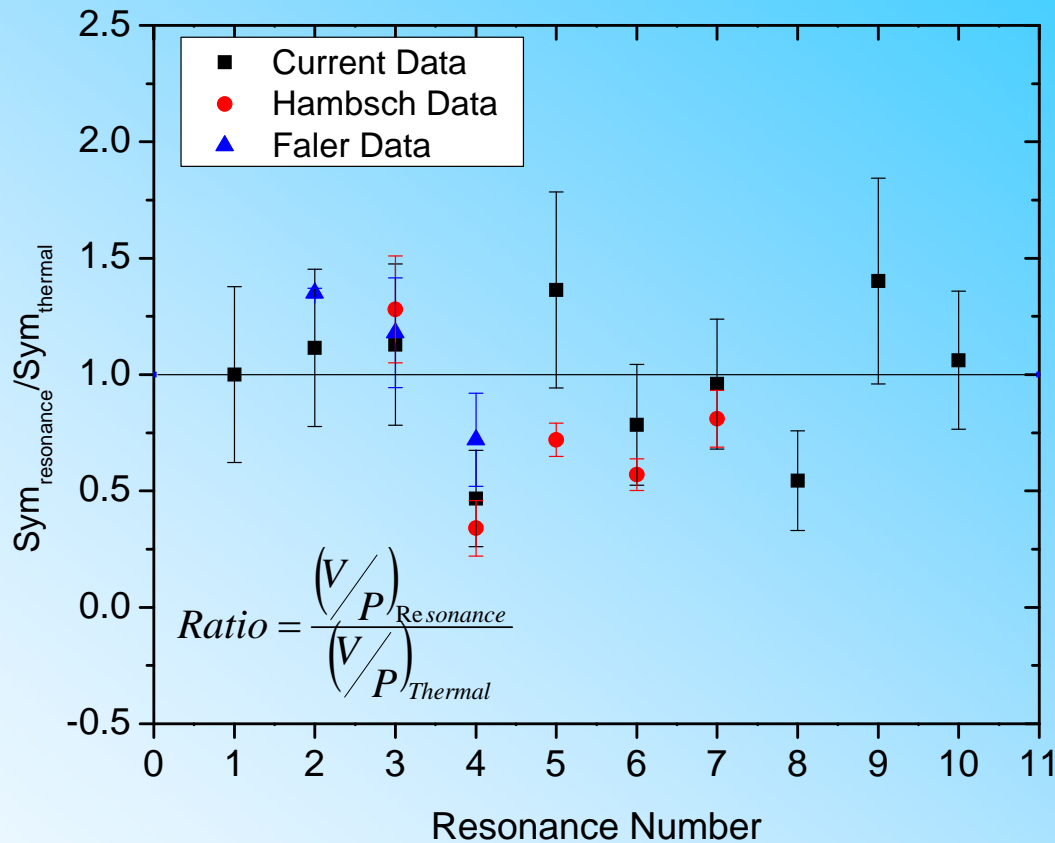


Fission symmetry in resonance clusters



Calculated with the pre neutron emission mass distribution

Symmetric Fission in Resonances Relative to Thermal



Summary

- Total cross section measurements for Zr and Ti from 0.5-20 MeV were completed
- Neutron scattering measurements for Mo and Be from 0.5-20 MeV were completed.
- Measurements of ^{238}U resonance scattering were completed.
- Measurements of ^{239}Pu fission fragment mass and energy distributions were completed.
- Measurement of (n,α) for natural samarium was accomplished at the LANL LSDS
- Analysis of Rh, Cd, Eu, ^{236}U and ^{164}Dy measurements is in progress
- Results for Mo resonance parameters were submitted for publication.
- Iron filtered beam measurement of Be total cross section was accepted for publication (Nuc Sci Eng).
- New transmission detector for high resolution resonance measurements is under construction.