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Nuclear Data at Rensselaer

Report to CSEWG November, 2010

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and

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KAPL
Neutron Spectroscopy Group

Measurements Completed This Year

- ^{235}U – Epithermal (10 eV - 6 keV) capture and fission cross measurement to support development of an α (capture to fission ratio) measurement technique.

- ^{155,156,157,158,160}Gd – Completed Epi thermal (2-2000 eV) capture measurements

Planned Measurements

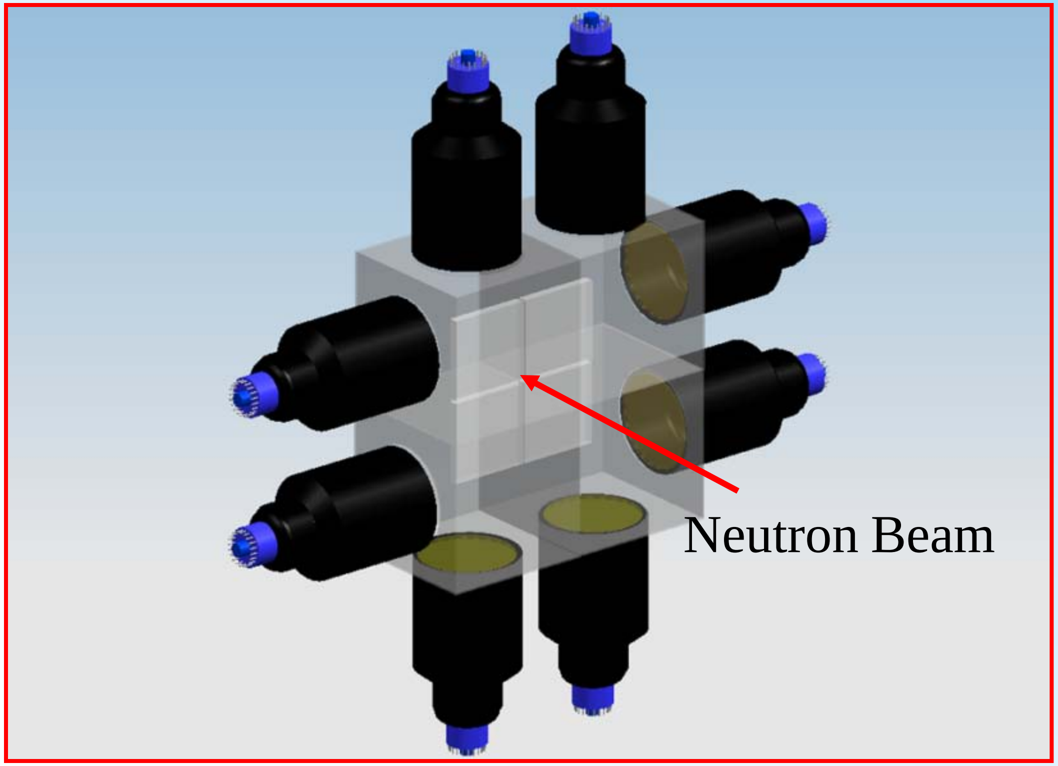
- Complete resonance region (1 eV- 400 keV) transmission measurements for $^{95,96,98,100}Mo$ isotopes
- Complete ^{235}U capture to fission ratio measurements (thermal – 6 keV)
- High energy (0.5-20 MeV) neutron scattering from ^{238}U (new PhD student started to work on this project)
- High energy (0.5-20 MeV) transmission of ^{56}Fe
- Fission neutron spectra and nubar from ^{252}Cf and ^{235}U
- $^{50}V(n,\alpha)$ cross section measurements at the RPI and LANL LSDS

Data Analysis

Sample	Status
Be, Mo	High energy (0.5-20MeV) transmission, publication is in internal review
Ti, Ta, Zr	High energy (0.5-20MeV) transmission in progress
Zr	High energy (0.5-20MeV) scattering, publication is in internal review process
Mo, C	F.J. Saglime, Y. Danon, R.C. Block, M.J. Rapp, R.M. Bahran, G. Leinweber, D.P. Barry and N.J. Drindak, "A system for differential neutron scattering experiments in the energy range from 0.5 to 20 MeV", Nuclear Instruments and Methods in Physics Research Section A, 620, Issues 2-3, Pages 401-409, (2010)
Mo	G Leinweber, DP Barry, JA Burke, NJ Drindak, RC Block, Y Danon, BE Moretti, "Resonance Parameters and Their Uncertainties Derived from Epithermal Neutron Capture and Transmission Measurements of Elemental Molybdenum", Nuclear Science And Engineering, 164, 287-303, (2010)
Rh, Eu, ^{153}Eu, Cd, ^{161,162,163,164}Dy ^{155,156,157,158,160}Gd,	Resonance parameters analysis in progress
^{147,149}Sm (n,α)	Cross section measurements with the LSDS, publication in internal review
^{235}U fission fragment distributions	C. Romano, Y. Danon, R. Block, J. Thompson, E. Blain, E. Bond, "Fission Fragment Mass And Energy Distributions As A Function of Neutron Energy Measured In A Lead Slowing Down Spectrometer", Phys. Rev. C 81, 014607 (2010).

High Resolution Transmission Detector

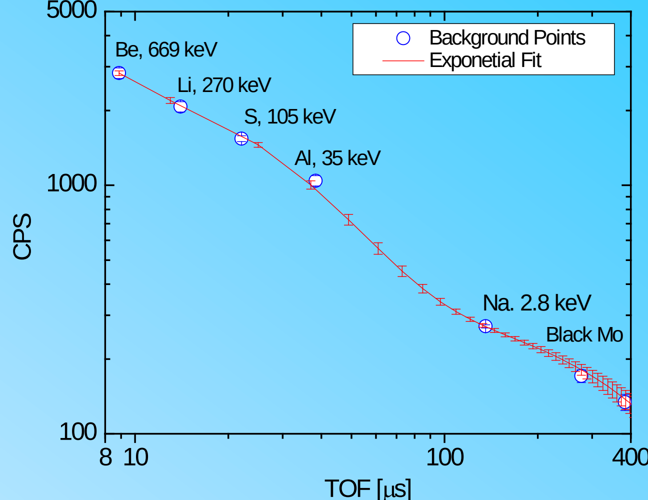
- Modular Li-Glass detector at 100m flight path
  - Extends our capabilities to the unresolved resonance region
  - Qualification measurements in progress.

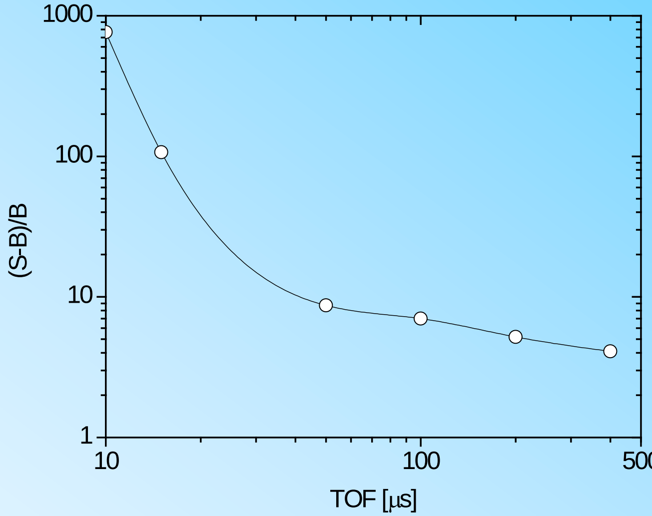


^{6}Li-Glass

Background During ^{95}Mo measurement

- First production measurements indicated a high gamma background component
- This results in a low signal (S) to background (B) ratio
- Simulation indicated the source is 2.2 MeV gammas from H(n,γ) reaction in the moderator
- Lead can reduce it but will also reduce the neutron flux





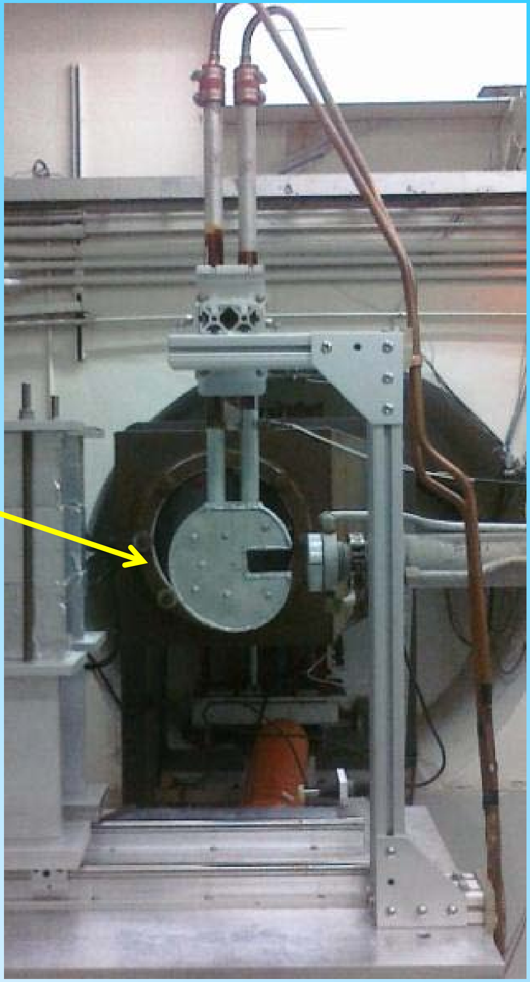
New D_2O Moderated Target

- Modified “Pacman” target with D_2O moderator and coolant.

- Reduce gamma background by eliminating capture in H

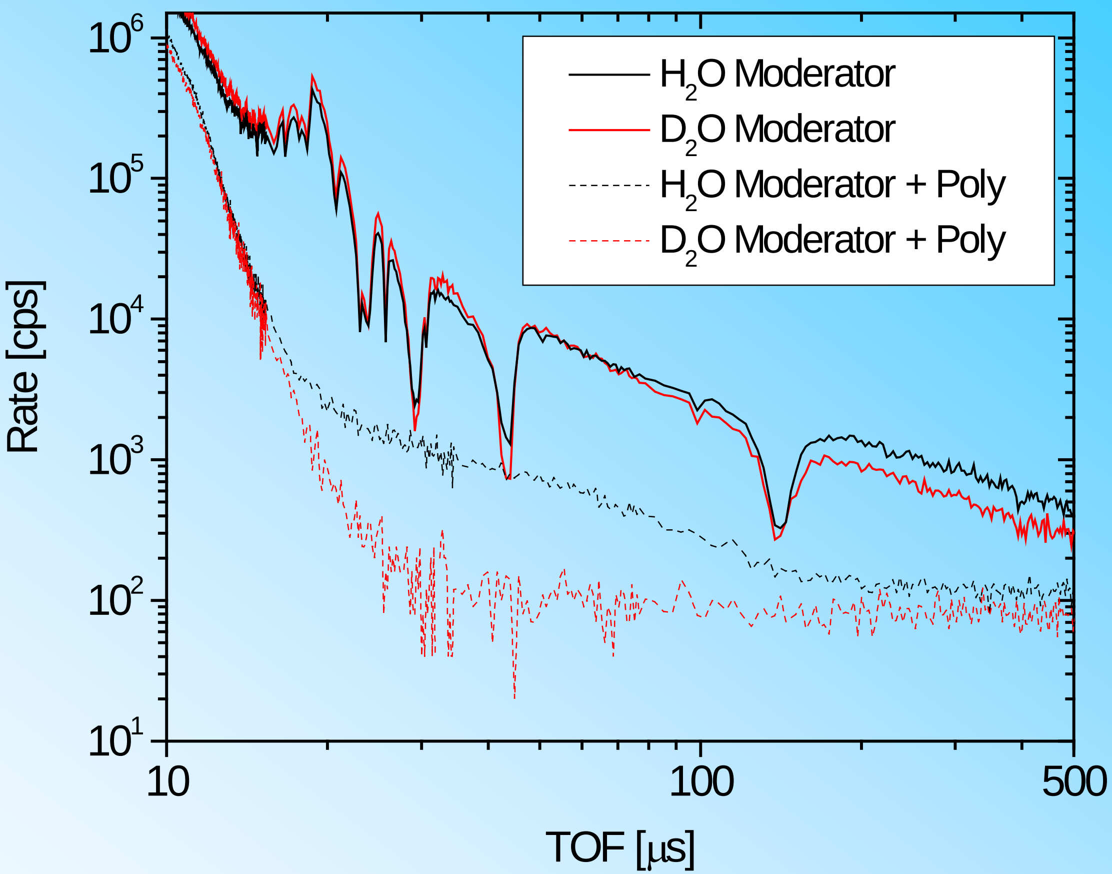
- MCNP calculations indicate flux should also increase in the keV energy range.

Pacman Target



Results - New D_2O moderator

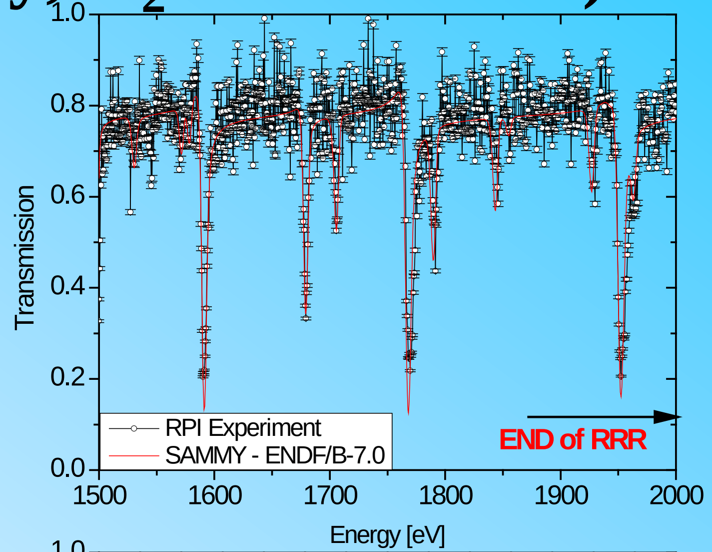
- Modified "Pacman" target with D_2O moderator and coolant.
- Large reduction in the 2.2-MeV hydrogen capture γ–ray.

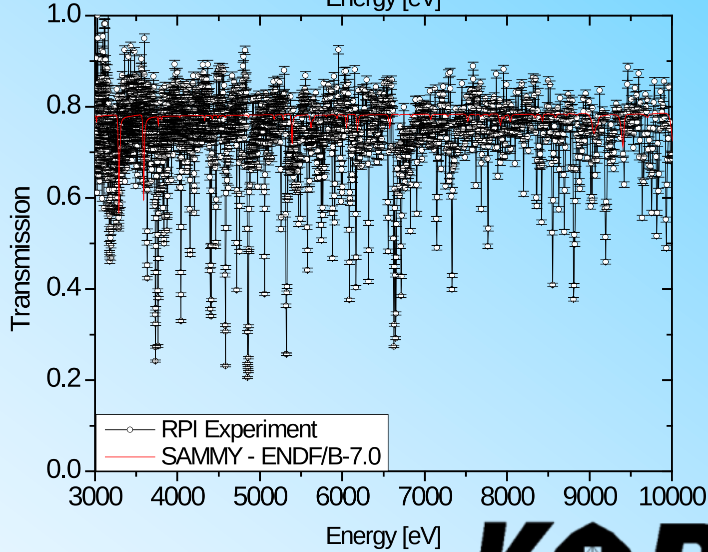


Results Mo-95 (Preliminary, H_2O moderator)

- Below 2 keV end of Resolve Resonance Range (RRR) the new data is in agreement with ENDF/B-7.0

- Above 2 keV there are many new resonances





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Eu Resolved Resonance Parameters

- Natural and enriched (153) metal samples
  - Used stable samples of volatile metals
- Combined Transmission and Capture thermal and epithermal data (0.01-300 eV)
- Extended resonance region from 100 eV to 300 eV
  - Identified isotope (151 or 153) of each resonance

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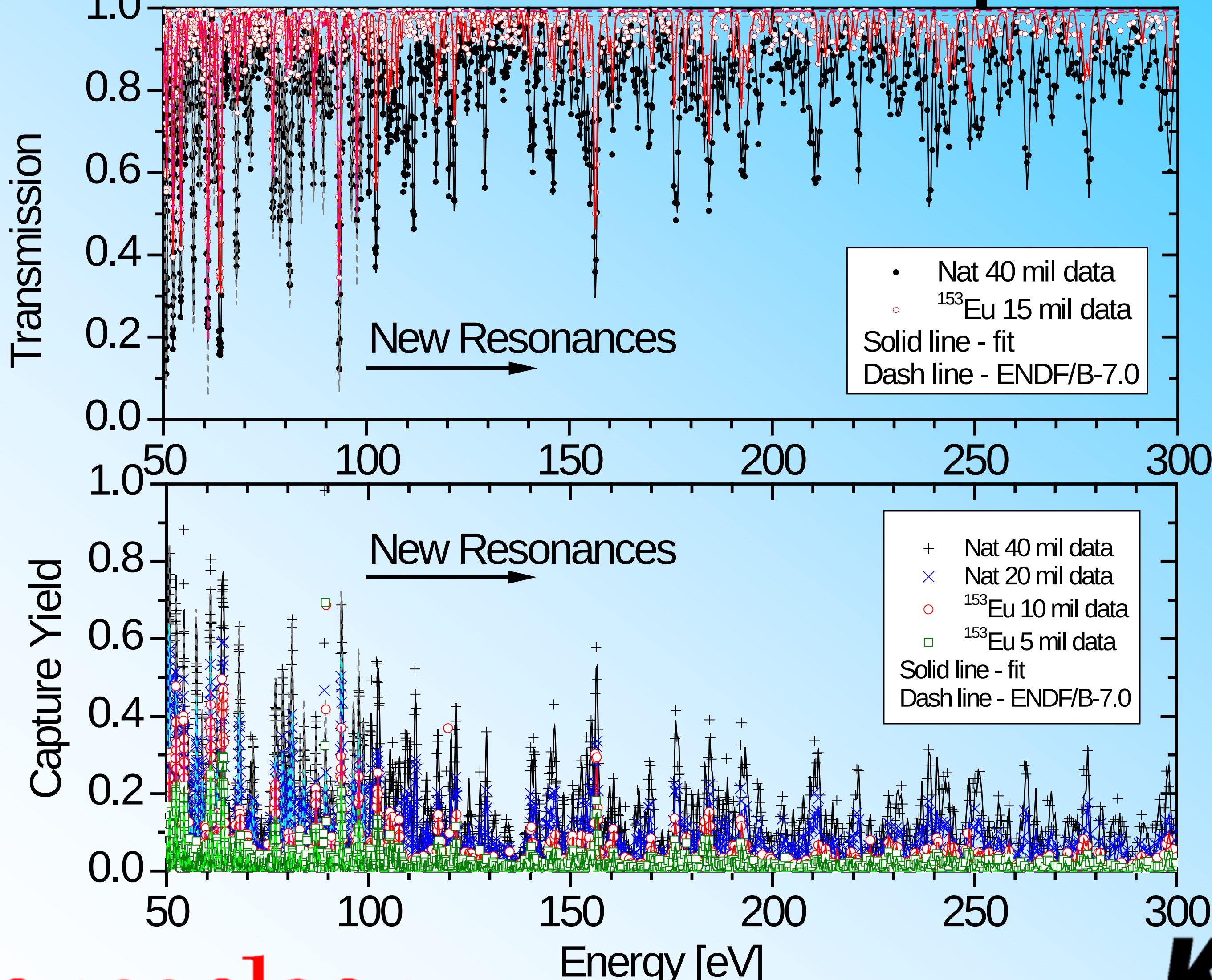
Fits to Eu Transmission and Capture Data



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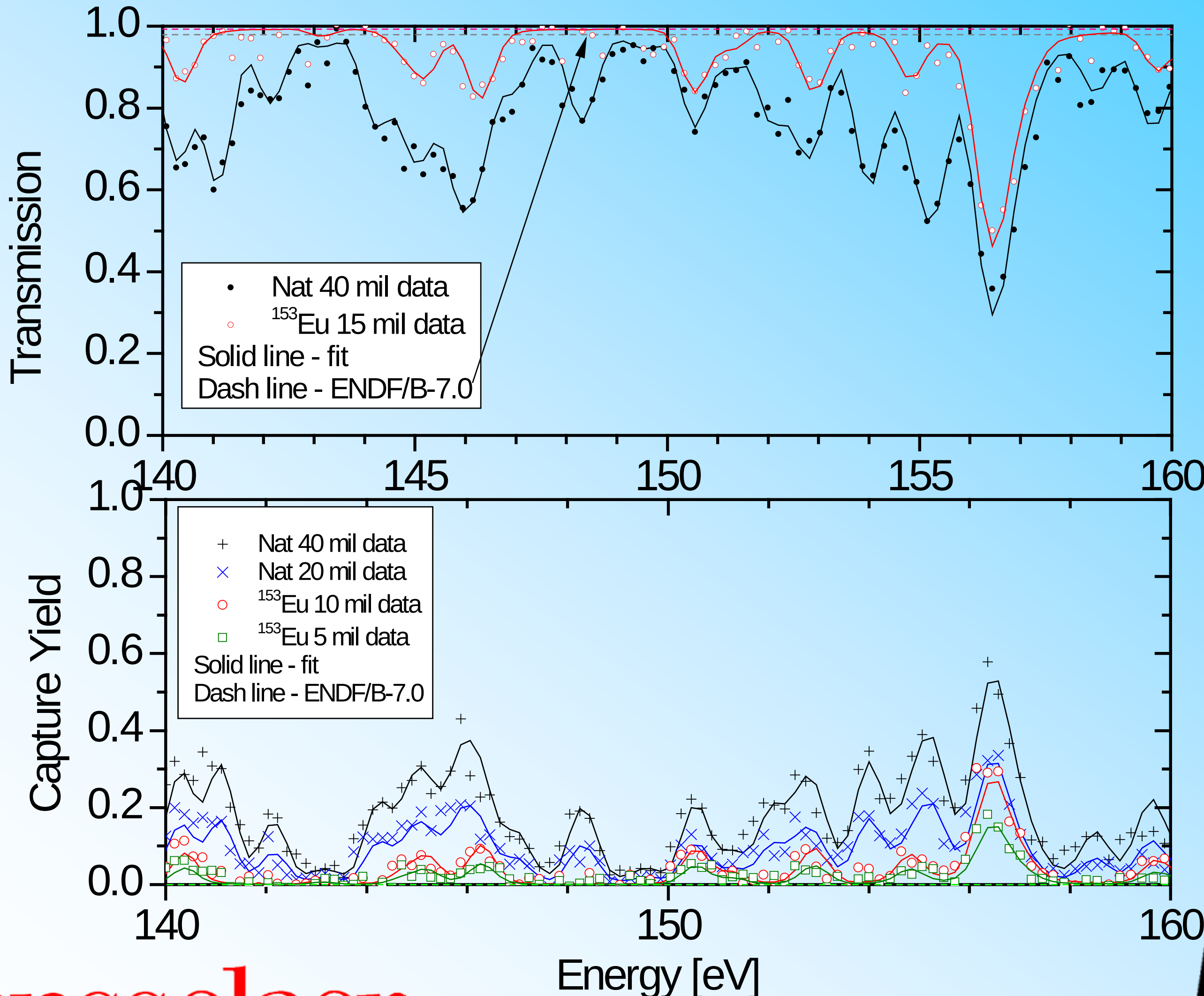
Eu extended the Resolved Resonance Region from 100 eV to 300 eV



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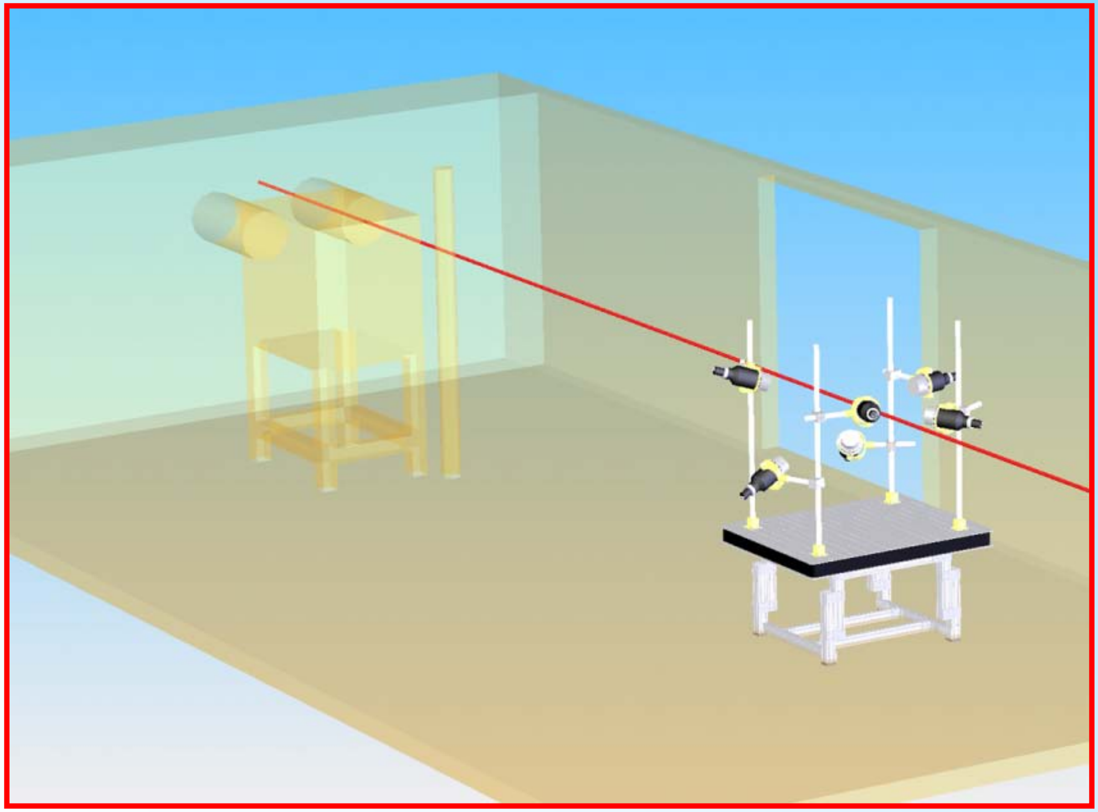
Fast Neutron Scattering Detector Array



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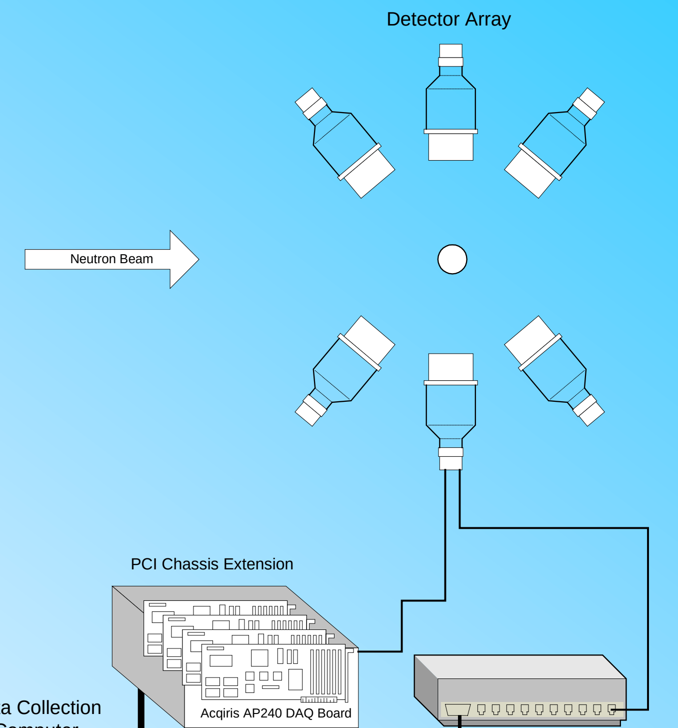
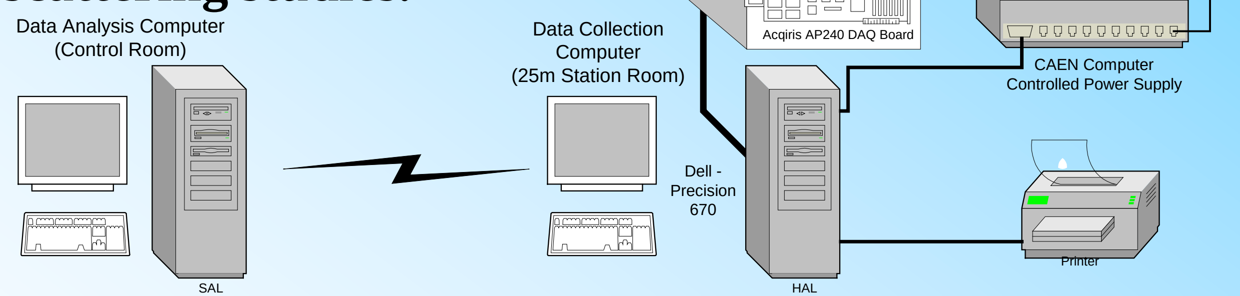
Scattering Detection System: Experimental Setup

- 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
- **The system can now handle fast coincidence for fission and inelastic scattering studies.**





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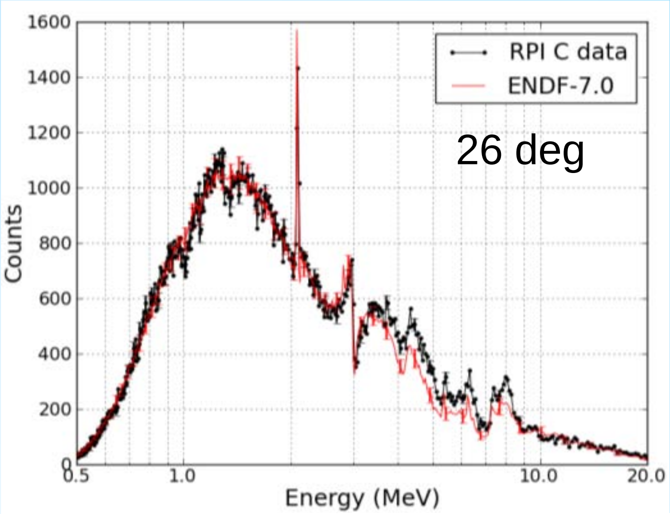
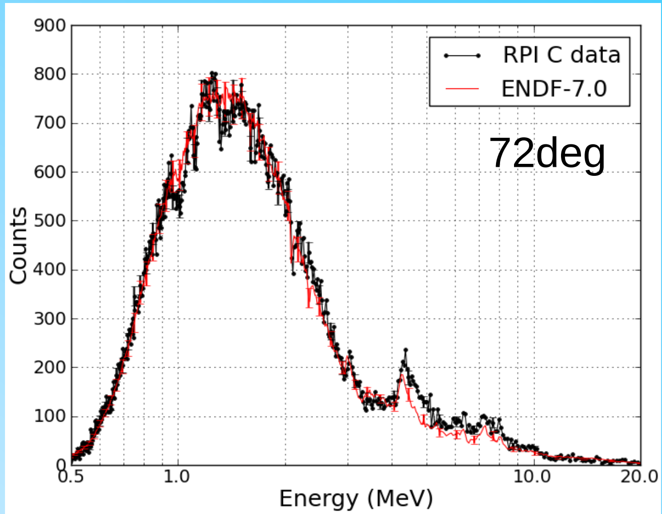
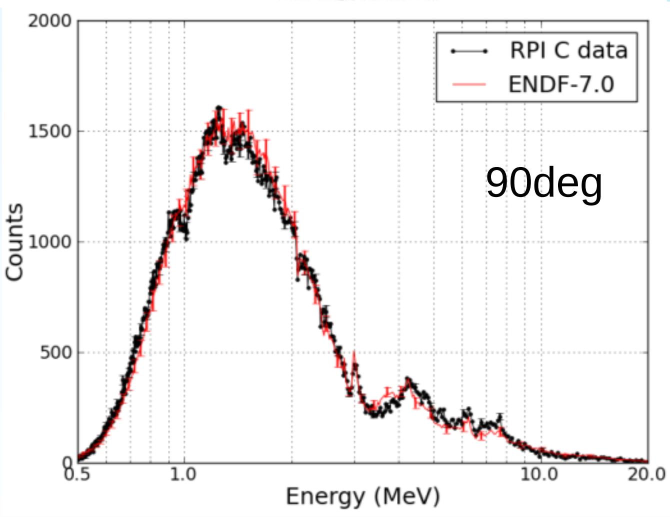
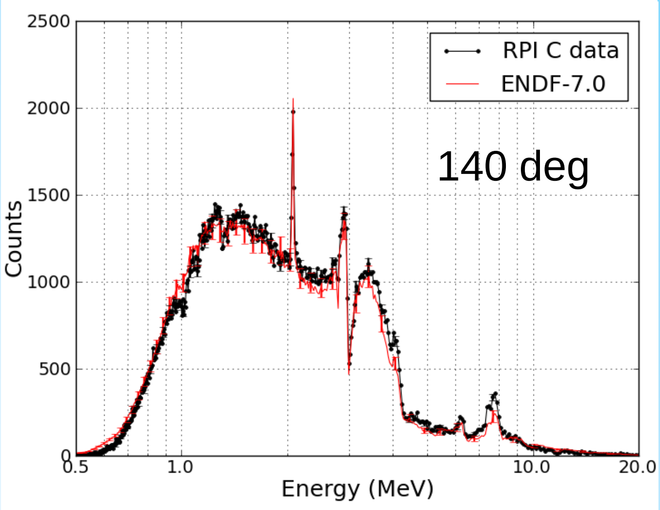
Carbon Standard









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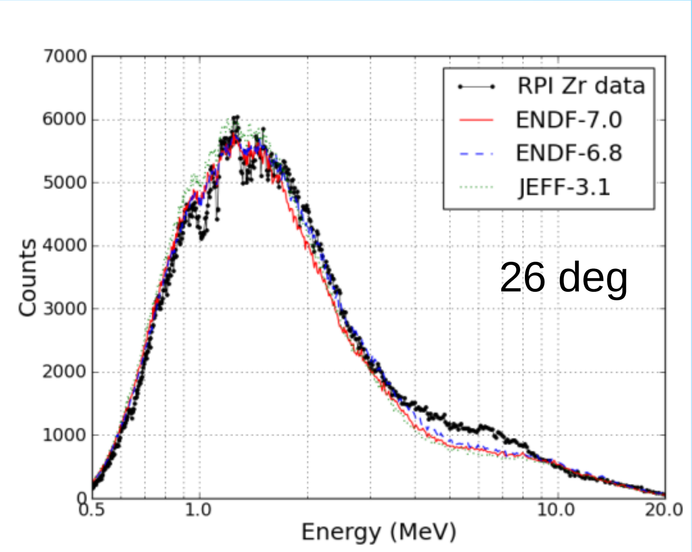
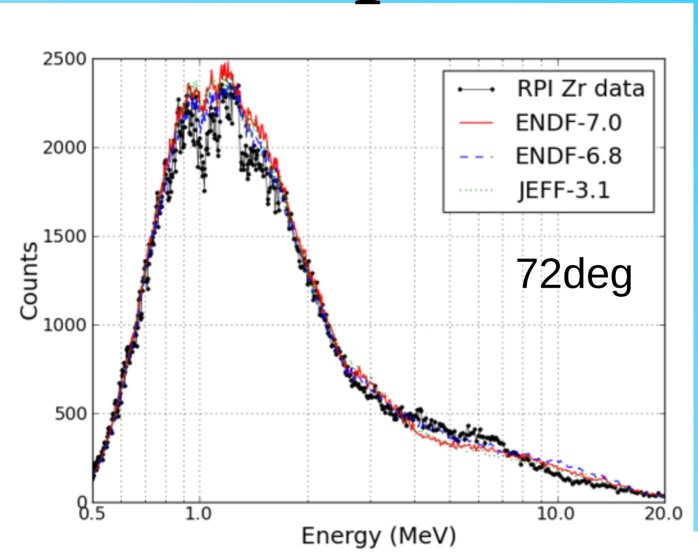
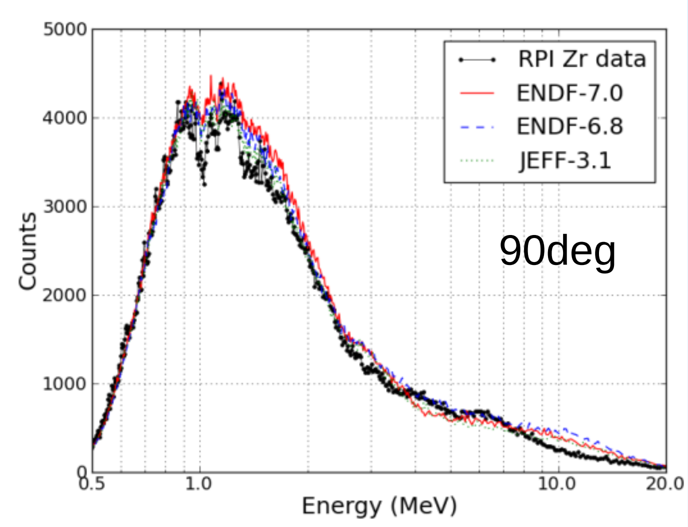
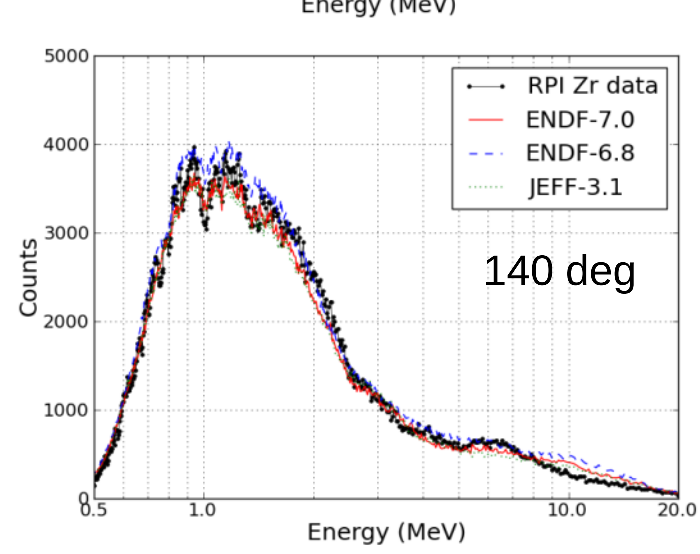
Zr – 6 cm Thick Sample









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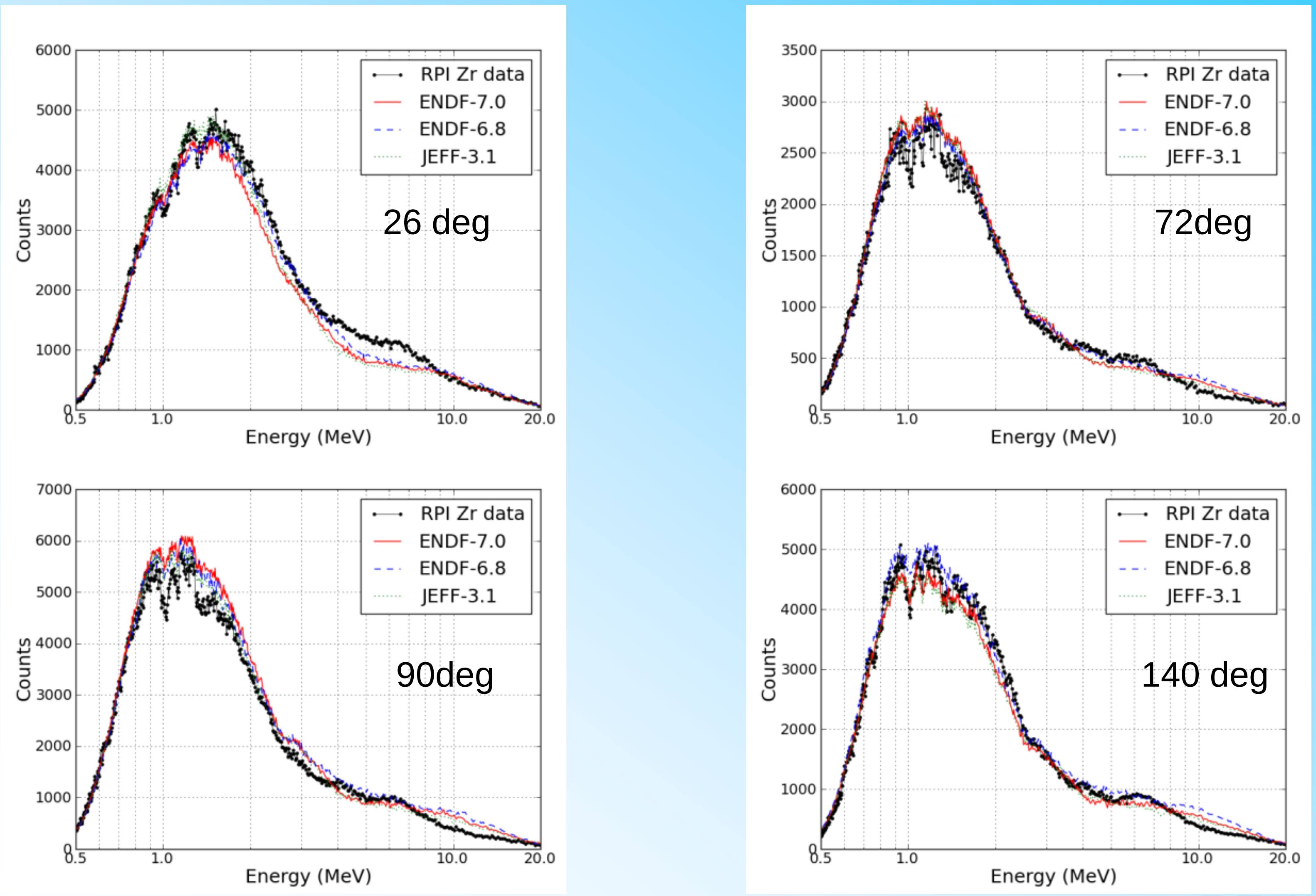
Zr – 10 cm Thick Sample



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Comparing Experiments and Evaluations

- The MCNP calculations and experimental data were used to calculate *C/E* values in several different scattering angles and energy regions between 0.5 MeV and 20 MeV.
- Differences between MCNP simulations of the carbon standard and the experiment were treated as systematic errors

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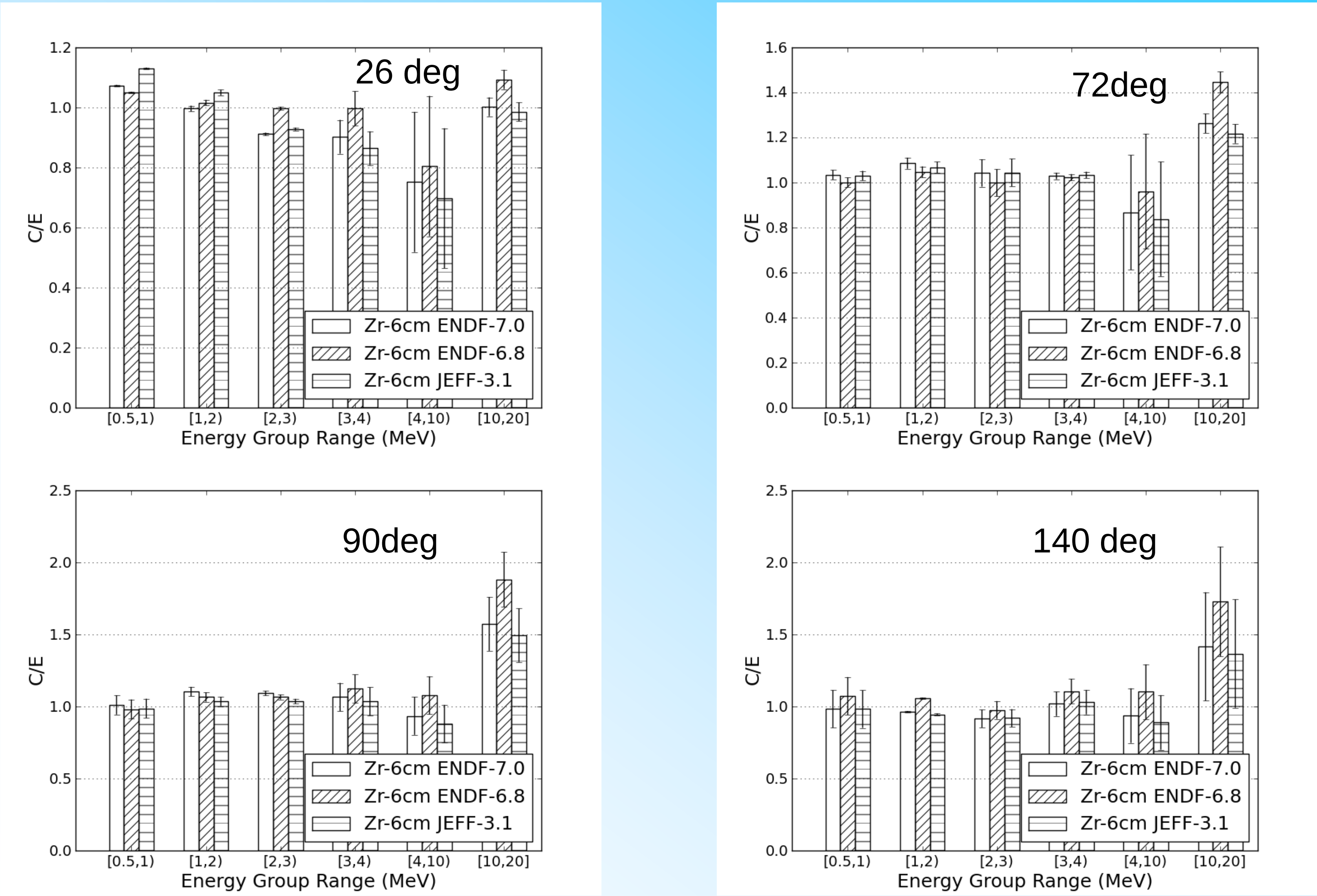
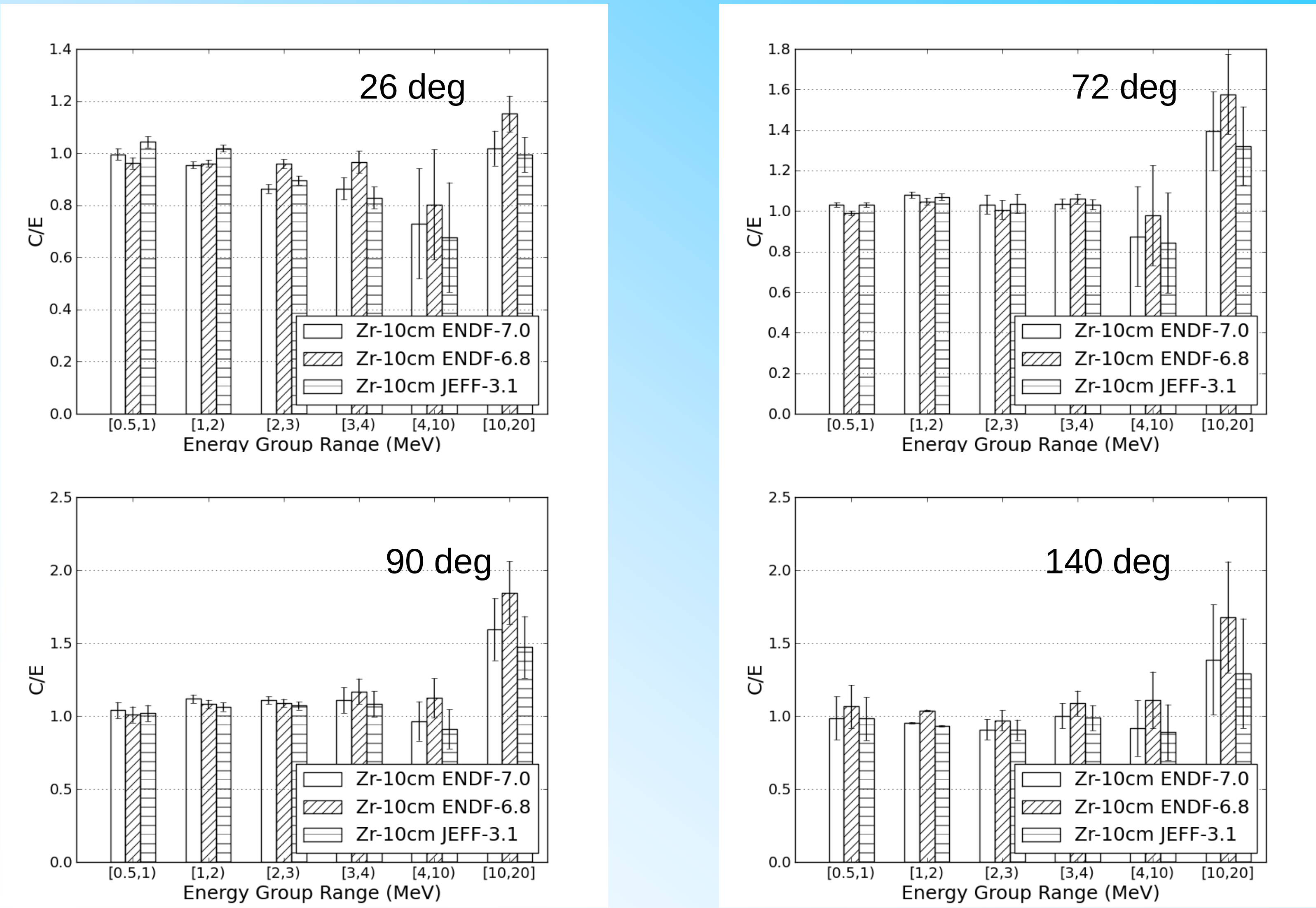
C/E for 6 cm Zr sample



C/E for 10 cm Zr sample

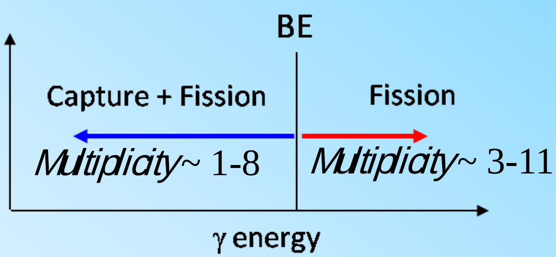


Observations

- Overall there is good agreement between the experiments and calculations.
- For the energy group of 10 MeV to 20 MeV the C/E values for all libraries were significantly greater than unity, indicating that the experimentally observed differential scattering cross section is less than the one used in the evaluated library.

Measurements of ^{235}U Capture & Fission Yields

- **Thermal** measurement with enriched ^{235}U sample
- 16 Segment Multiplicity Detector with 4 E_γ groups
- Good agreement with SAMMY calculations
- Extracting Capture Yield from data with mixture of capture and fission events



- Challenges: **Normalization**

➢ Normalize experimental fission yield to thermal point

$$Y_f^{ENDF} = k_1 \cdot Y_f$$ Solve for k_1 @ 0.0253 eV

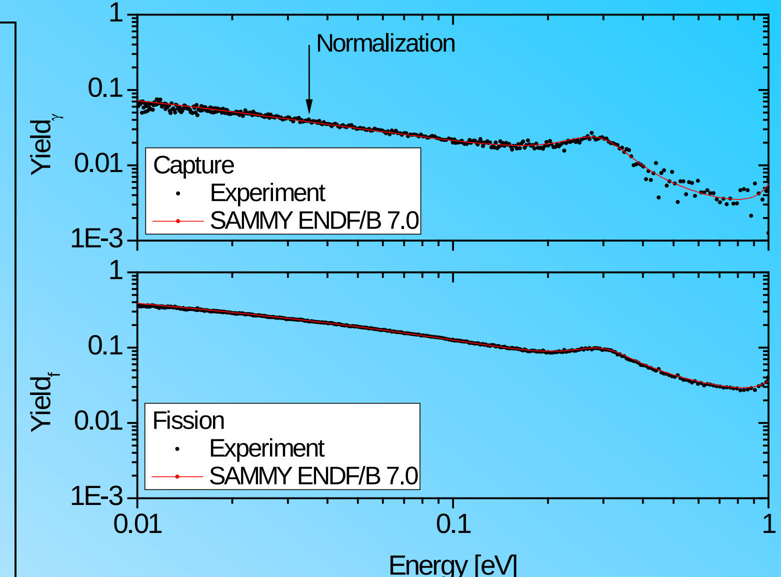
➢ Use two equations for a predominantly capture resonance and predominantly fission region (thermal)

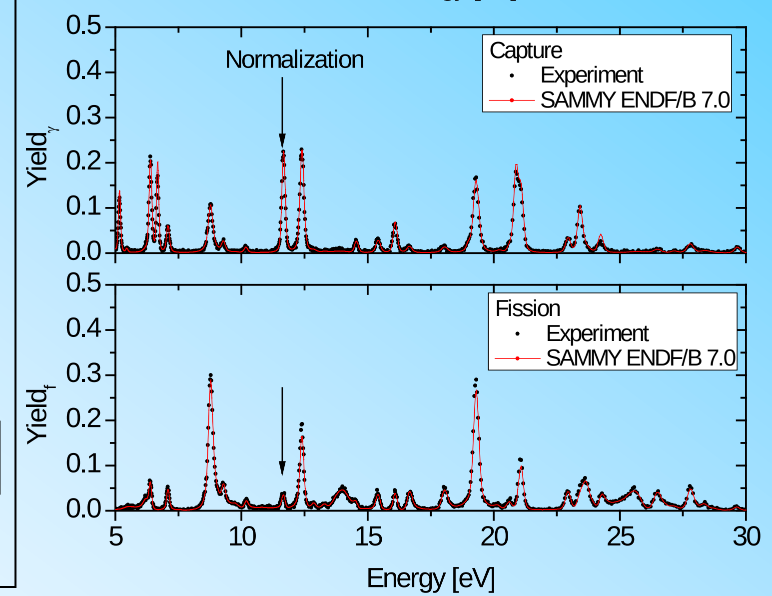
@ 11.7 eV res $\left(\frac{\Gamma_\gamma}{\Gamma} = 0.86\right)$ @ 0.0253 eV

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

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

➢ Solve the two equations for k_2 and k_3





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

- Challenges:
  - Normalization
  - False Capture due to neuron scattering

➢ Normalize experimental fission yield to resonance

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

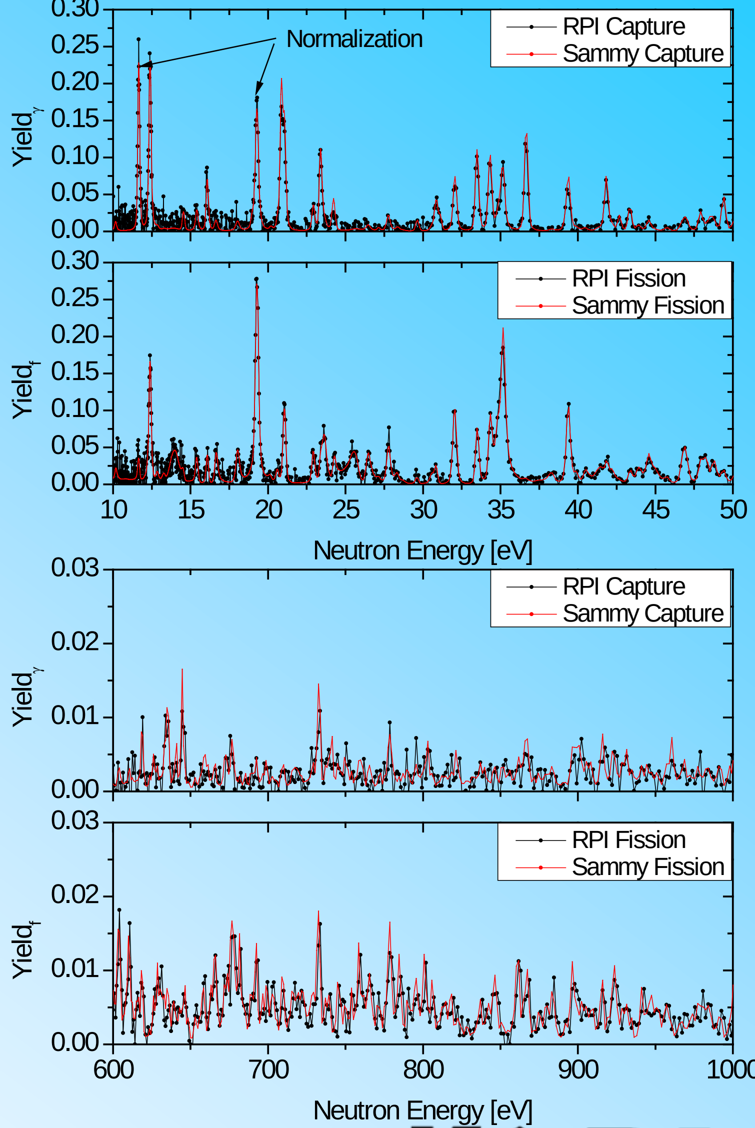
➢ Use two equations for predominantly capture and fission resonance

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

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

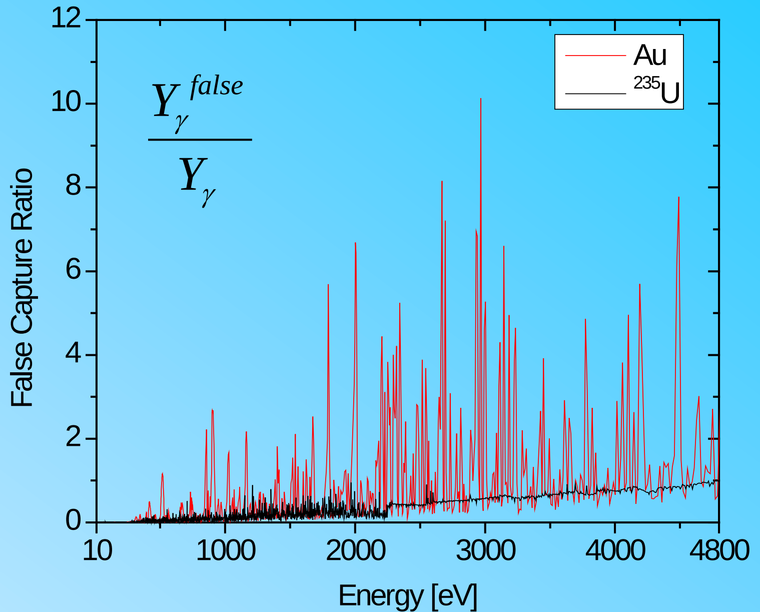
➢ Solve the two equations for k_2 and k_3

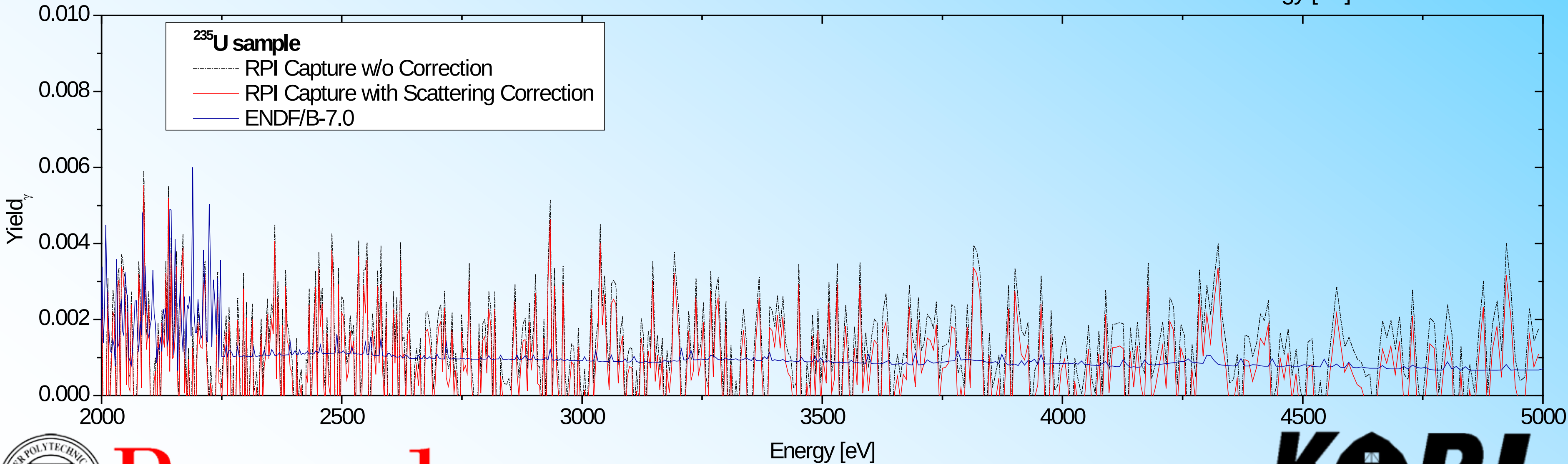
► **Need 2 resonances with known parameters**



False Capture Correction

- Use gold to develop the method:
  - For Au Y_{false}/Y_{γ} is up to a factor of 10
  - For U-235 Y_{false}/Y_{γ} is less than 1
- **Au**: demonstrated false capture correction to 10% error in Yγ relative to Yγ calculated using ENDF/B-7.0
- Error due to false capture correction in ^{235}U Yγ expected to be less than 2%





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New Gd Resonance Region Measurements

- Obtained enriched isotopes of $^{155,156,157,158,160}Gd$ from Korea
- Measurements were funded by NCSP.
- SAMMY analysis is in progress by students of Profs. Guinyun Kim and Tae-Ik Ro.

Gd enriched samples

- Small samples
  - Round samples dimensions: ~ 18 mm diam x 0.1 mm thick
  - Square samples dimensions: ~ 15 mm x 15 mm x 0.2 mm thick
- Measured for ~90 hours

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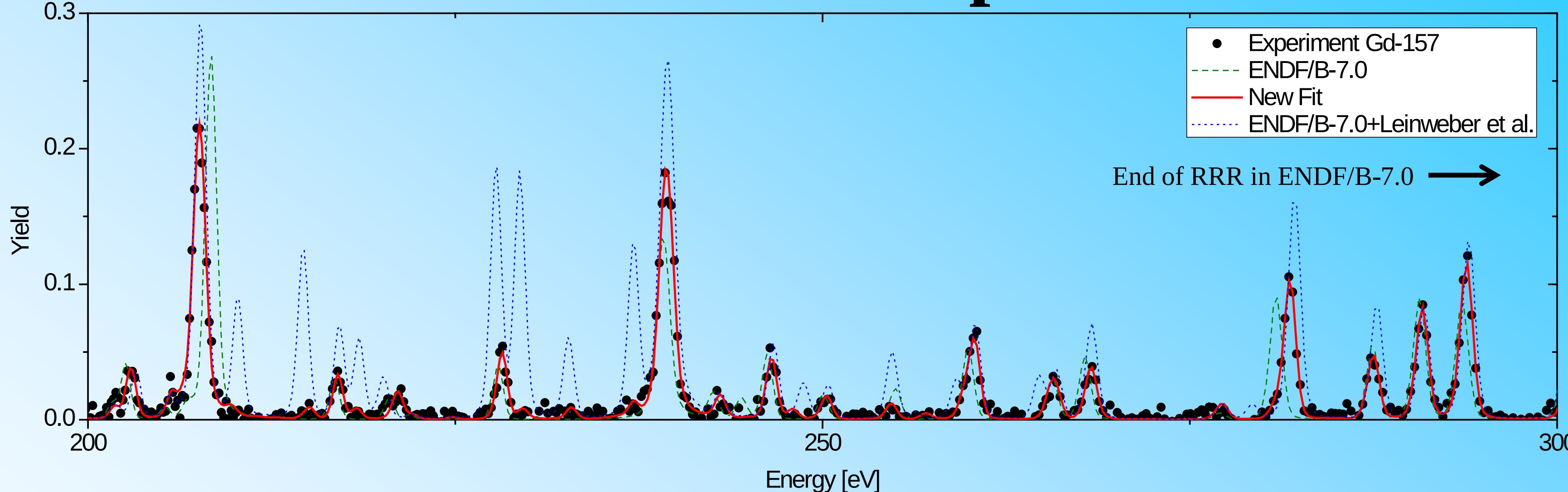
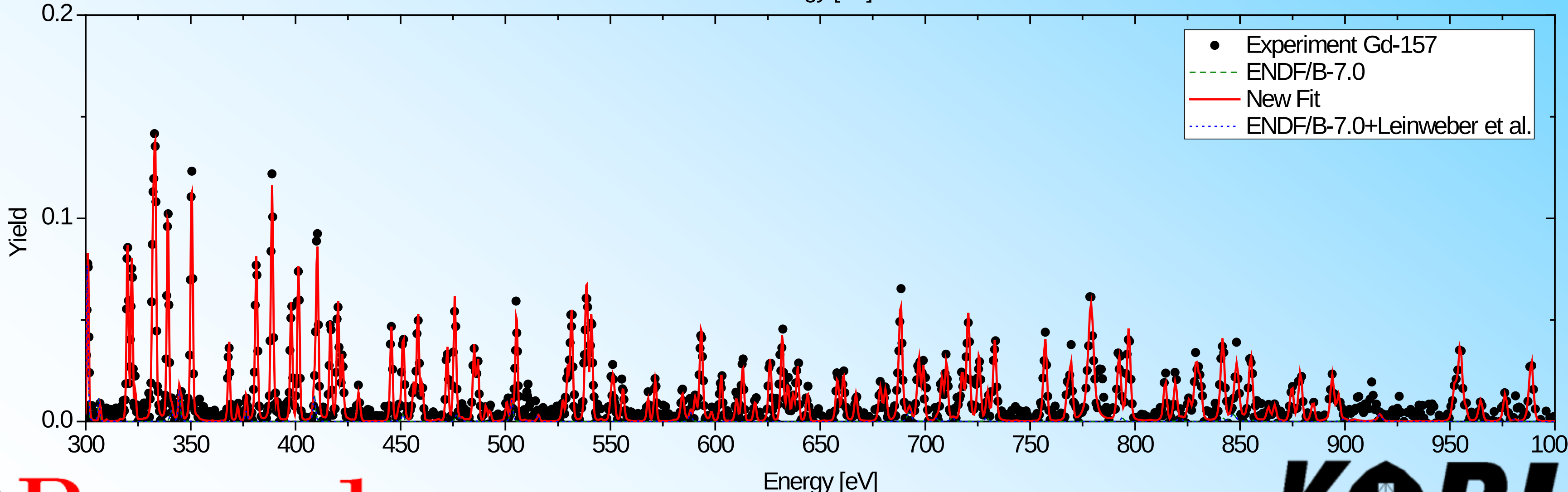
SAMMY fits to ^{157}Gd Capture Yield





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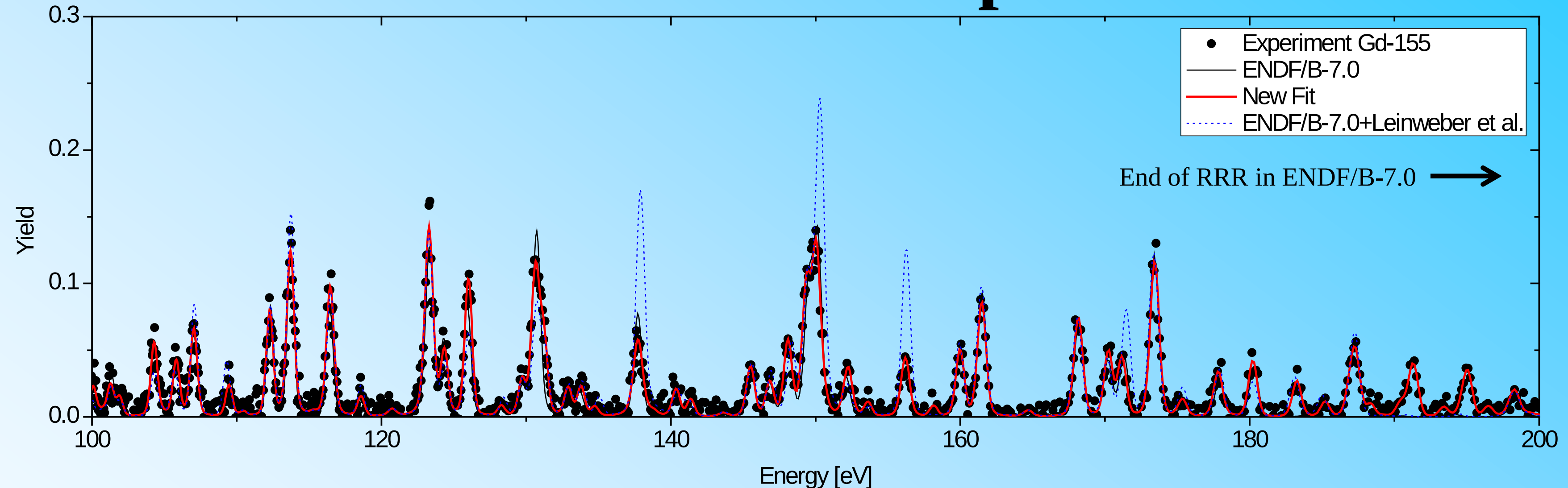
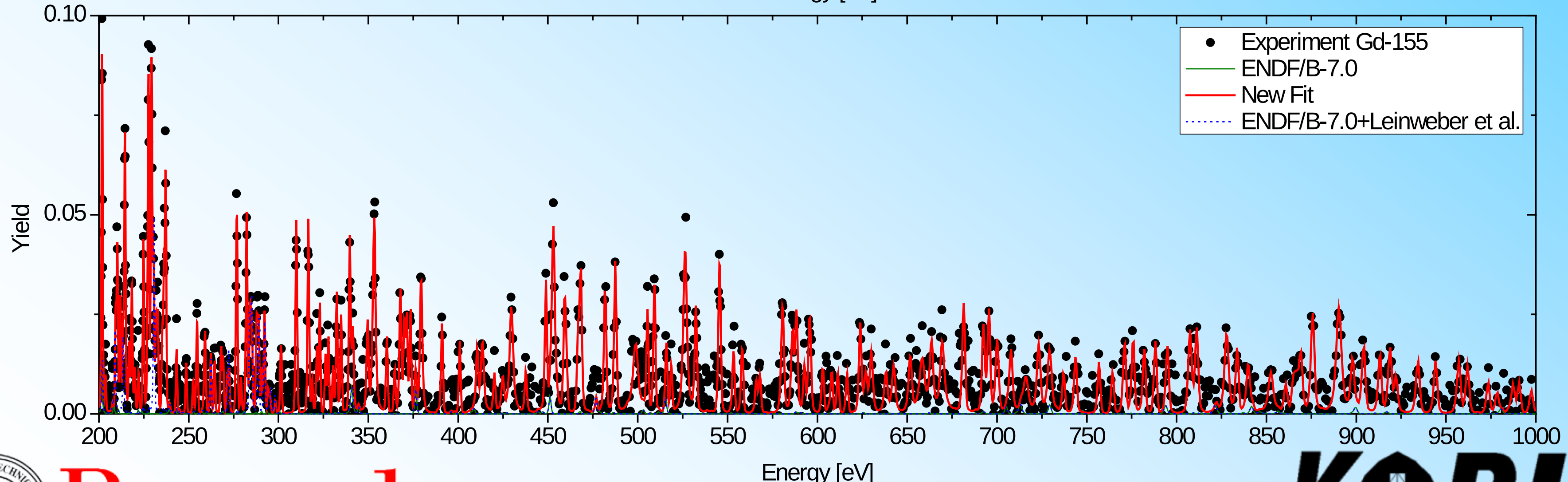
SAMMY fits to ^{155}Gd Capture Yield





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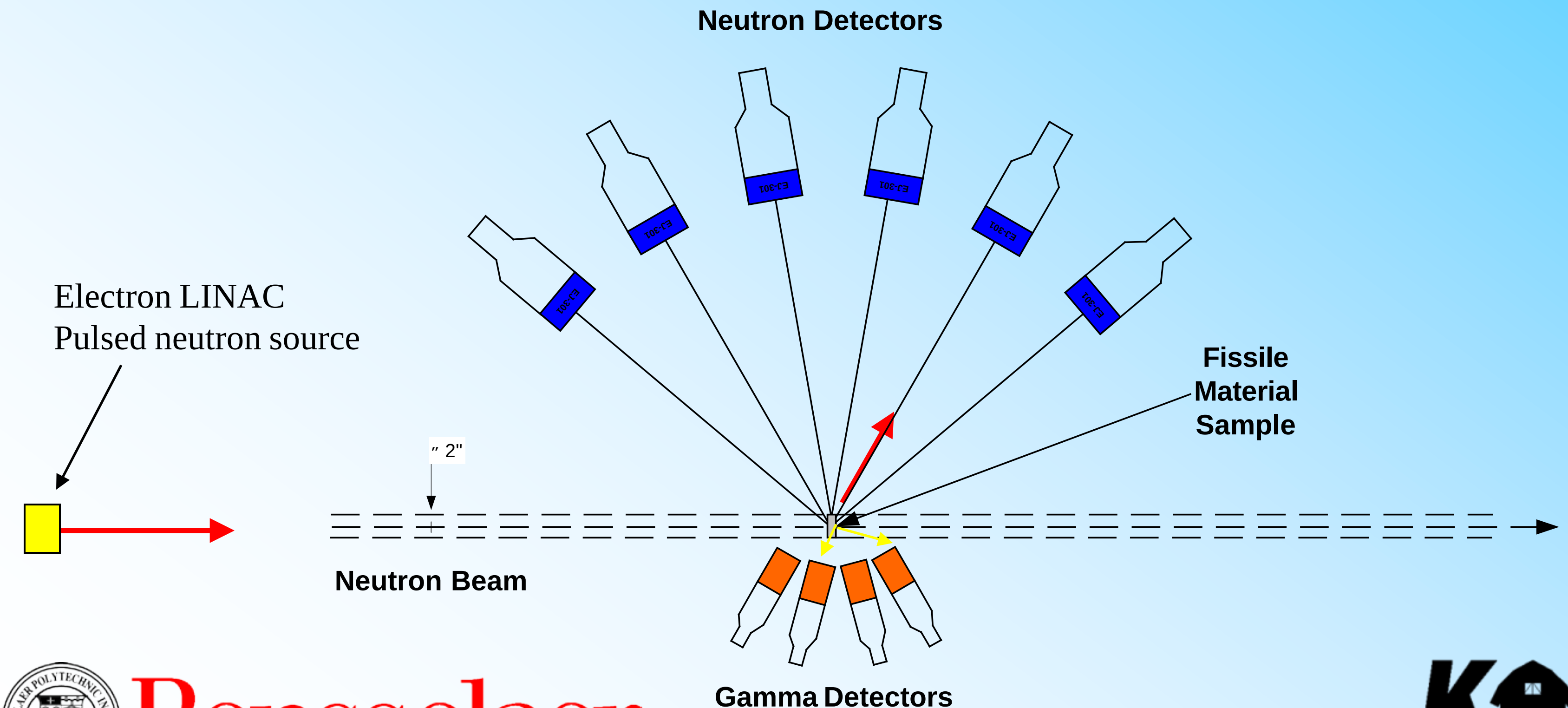
Development -Fission Spectrum Measurement

- Use the double TOF method
- Use a gamma tag for fission
- Use a combination of Liquid Scintillators and Li-Glass neutron detectors
- Same system will be used for inelastic scattering measurement



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Lead Slowing Down Spectrometer

- (n,α) and (n,p) measurements are under development
  - Compensated PIPS detectors
  - Compensated diamond detectors
- Run for V-50 new Passivated, Implanted, Planar Silicon (PIPS) detector did not perform
- Planning to use a compensated diamond detector on the next run

Working hard with the LANL LSDS

2010 Publications

Journal Publications

- F.J. Saglime, Y. Danon, R.C. Block, M.J. Rapp, R.M. Bahran, G. Leinweber, D.P. Barry and N.J. Drindak, “A System for Differential Neutron Scattering Experiments in the Energy Range from 0.5 to 20 MeV”, Nuclear Instruments and Methods in Physics Research Section A, 620, Issues 2-3, Pages 401-409, (2010).
- G Leinweber, DP Barry, JA Burke, NJ Drindak, RC Block, Y Danon, BE Moretti, “Resonance Parameters and Their Uncertainties Derived from Epithermal Neutron Capture and Transmission Measurements of Elemental Molybdenum”, Nuclear Science And Engineering, 164, 287-303, (2010).
- C. Romano, Y. Danon, R. Block, J. Thompson, E. Blain, E. Bond, “Fission Fragment Mass And Energy Distributions As A Function of Neutron Energy Measured In A Lead Slowing Down Spectrometer”, Phys. Rev. C 81, 014607 (2010).

Conferences Publications

- Y. Danon, R. Block (emeritus), C. Romano, J. Thompson, “Fission Physics and Cross Section Measurements with a Lead Slowing Down Spectrometer”, Invited, International Conference on Nuclear Data for Science and Technology (ND2010), Korea, 26-30 April, (2010).
- M. Rapp, Y. Danon, F. Saglime, Rian Bahran, Robert Block, Greg Leinweber, Devin Barry, Jeff Hoole, “Molybdenum and Zirconium Neutron Total Cross Section Measurements in the Energy Range of 0.5 to 20 MeV”, International Conference on Nuclear Data for Science and Technology (ND2010), Korea, 26-30 April, (2010).
- Yeong-Rok Kang, Tae-TK Ro, Taofeng Wang, Sung-shul Yang, Manwoo Lee, Guinyun Kim, Jong-Hwan Lee, Robert Block, Devin Barry and Yaron Danon, “Neutron Capture Measurements and Parameters of Gadolinium”, International Conference on Nuclear Data for Science and Technology (ND2010), Korea, 26-30 April, (2010).

Invited talks

- Y. Danon, “The Nuclear Data Program at Rensselaer”, Measurements and Models of Nuclear Reactions 2010 (EFNUDAT 2010) Workshop, Paris, May 25-27, Paris, France (2010).
- Y. Danon, “Report on U.S.A. Experimental Activities”, Working Party on International Nuclear Data Evaluation Co-operation (WPEC) meeting 2010, June 3-4, NEA Headquarters, Issy-les-Moulineaux, France, (2010).
- Y. Danon, “Nuclear Data Research at the RPI Gearttner LINAC laboratory”, Chalk River Laboratories, Atomic Energy of Canada Limited (AECL) Canada, 9-11 April (2010).

Summary – FY2010 and planned 2011 activity

- Data publications (published and in preparation)
  - Mo resonance parameters (published)
  - High energy total cross section for Mo and Be
  - High energy scattering from Zr
  - ^{147,149}Sm (n,α) cross section measurements with the LSDS
- Analysis in progress
  - Ti, Ta, Zr high energy (0.5-20 MeV) transmission
  - Rh, Cd, Eu, ^{153}Eu, ^{161,162,163,164}Dy, ^{155,156,157,158,160}Gd – Resonance parameter analysis
- Planned measurements
  - ^{95,96,98,100}Mo resonance region (1 eV- 400 keV) transmission measurements
  - ^{235}U capture to fission ratio measurements (thermal – 6 keV)
  - High energy (0.5-20 MeV) neutron scattering from ^{238}U
  - High energy (0.5-20 MeV) transmission of ^{56}Fe
  - Fission neutron spectra and nubar from ^{252}Cf and ^{235}U
  - ^{50}V(n,α) cross section measurements with a LSDS