Overview Of
Experimental Nuclear Data Capabilities at RPI

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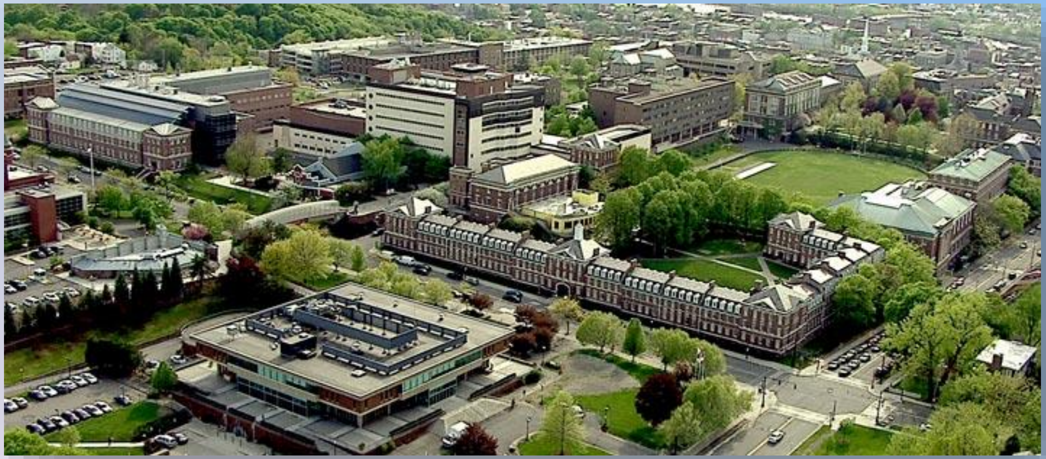

Workshop for Applied Nuclear Data Activities (WANDA), January 22-24, 2019
Elliott School of International affairs at the George Washington University

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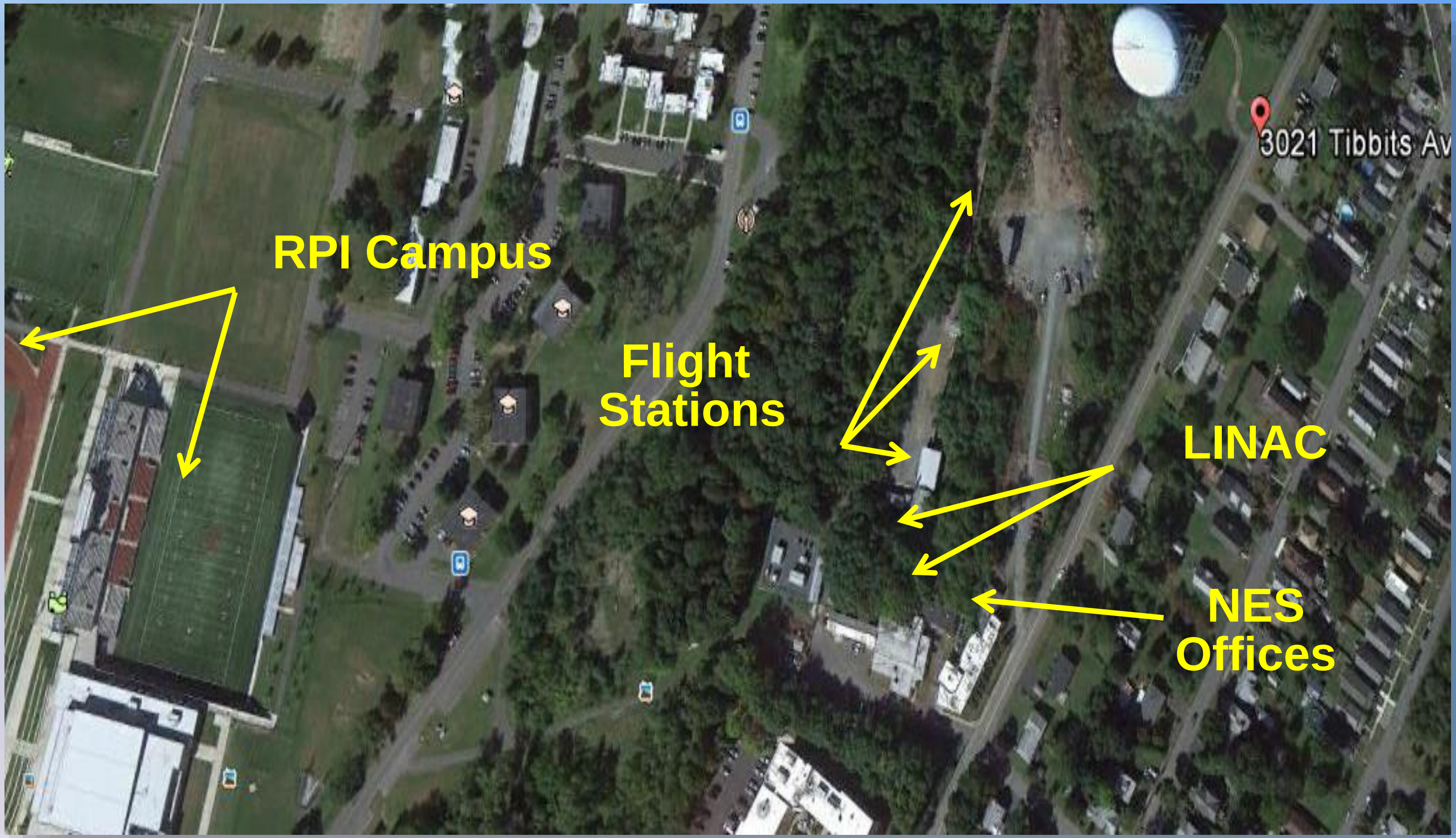
Outline

- The RPI Gaerttner LINAC Center
  - Capabilities
- Examples
  - U-235 fission and Capture
  - Fe-56 and Fe-nat capture
  - H_2O transmission
  - U-238, Be, Fe, scattering

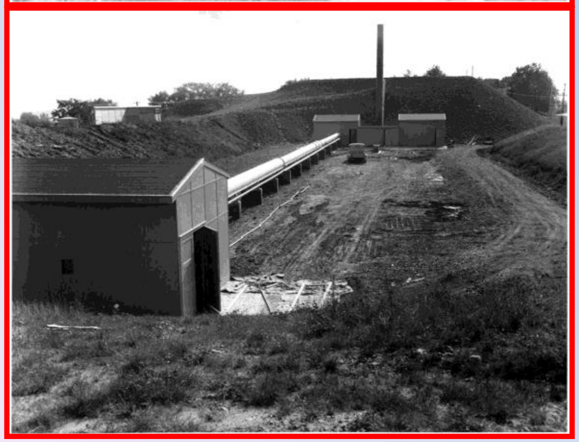
Where is the RPI LINAC ?

- It is on the highest point in Troy, NY

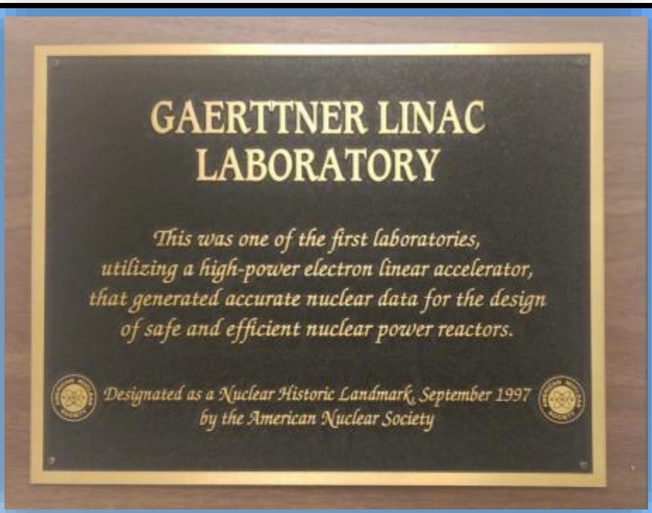


RPI LINAC History

- The RPI LINAC started operation in December 1961.
- Working "continuously" since.



September 1997- LINAC was designated as Nuclear Historic Landmark by the American Nuclear Society

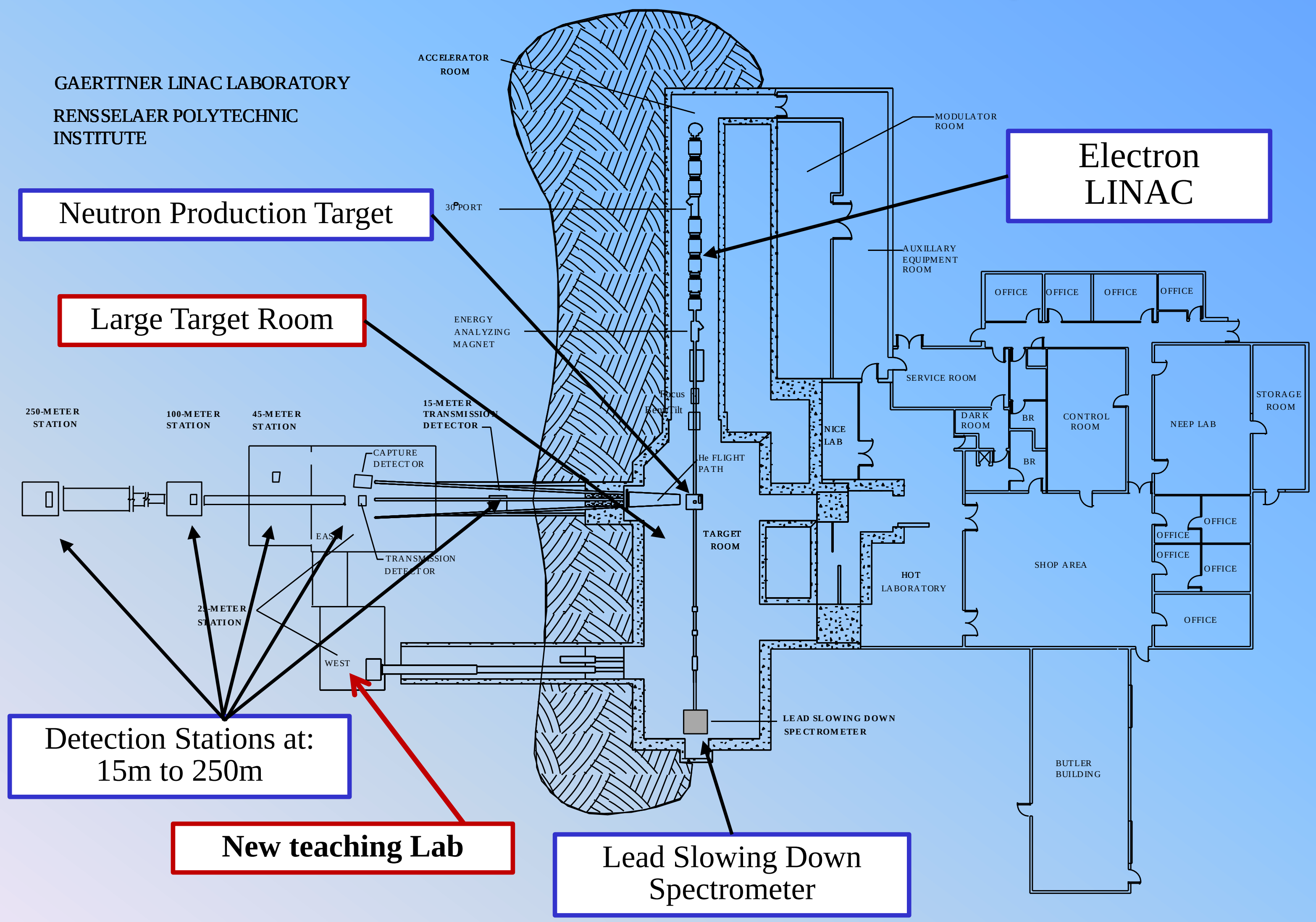


Graduated over 180 students who utilized the LINAC as part of their graduate thesis research

Many years of accumulated experience

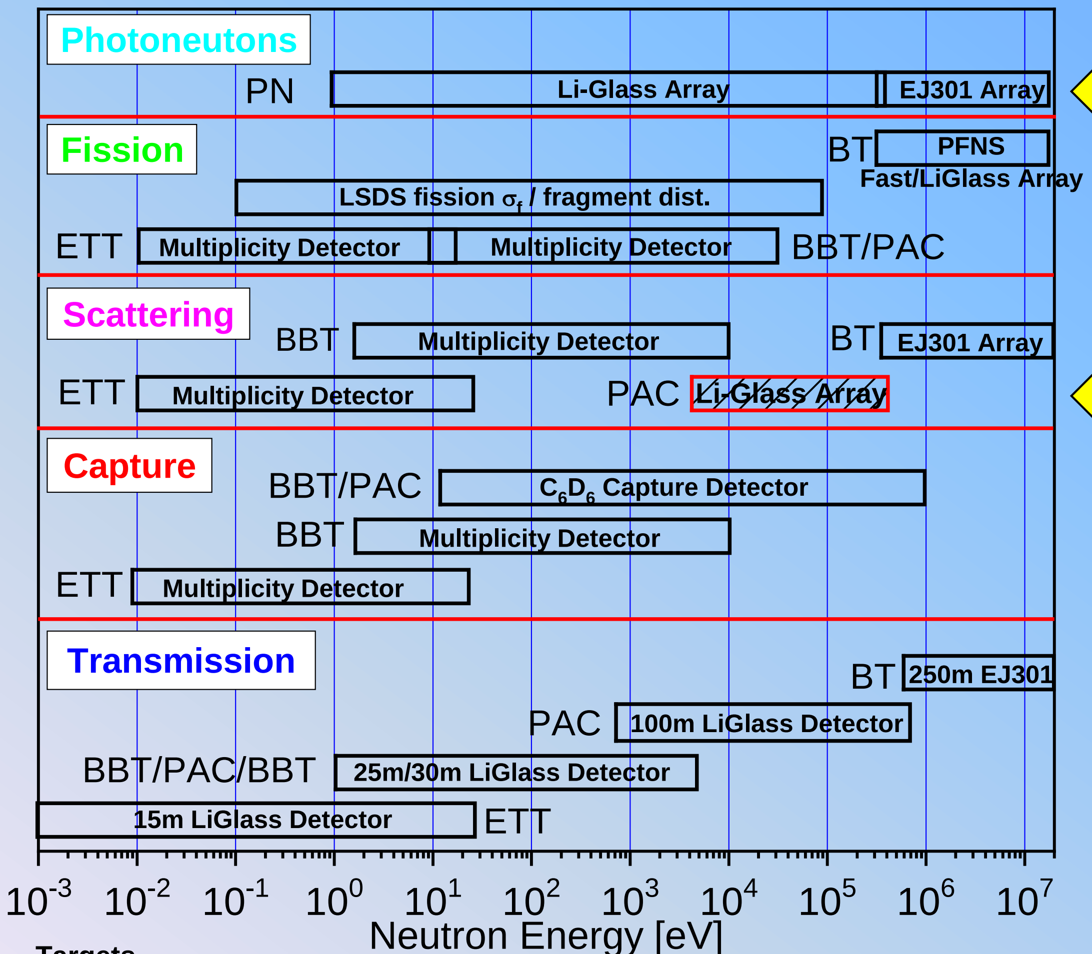
2014 - Started a major refurbishment and upgrade project

The RPI LINAC Facility



Capability Matrix

RPI LINAC - Nuclear Data Measurement Capabilities 2019



In development

Photoneutron target

KeV Neutron Scattering

Targets

ETT- Enhanced Thermal Target
BBT - Bare Bounce Target
BT- Bare Target on Axis

PAC - PacMan Target
PN - Photoneutron target

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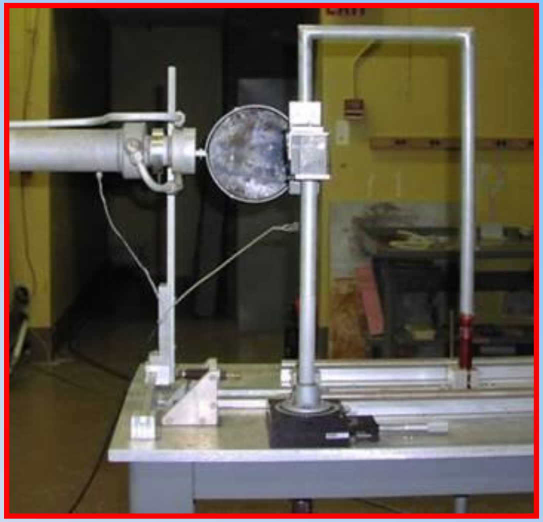
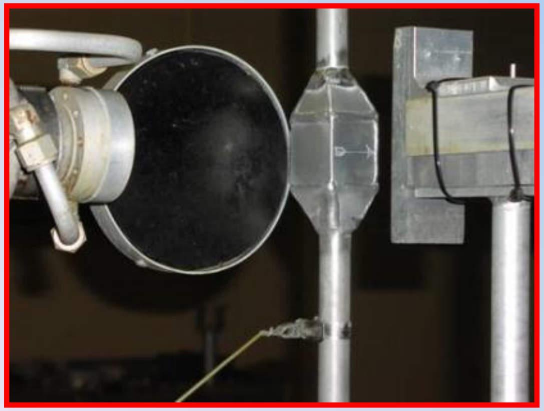
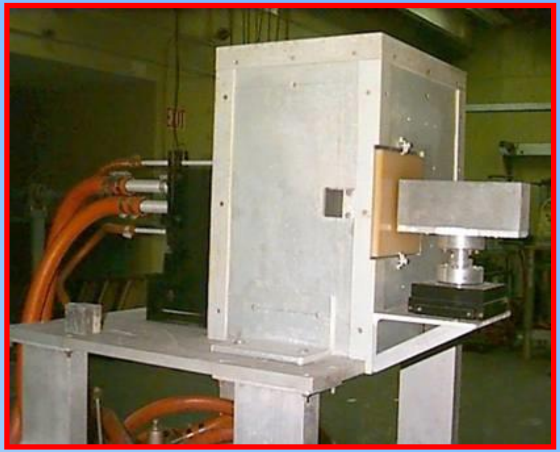
Neutron Production Targets

Bare Bounce Target (BBT)

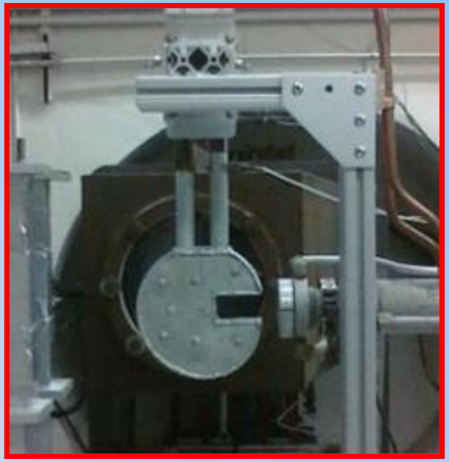




Enhanced Thermal Target (ETT)



C-Shaped target



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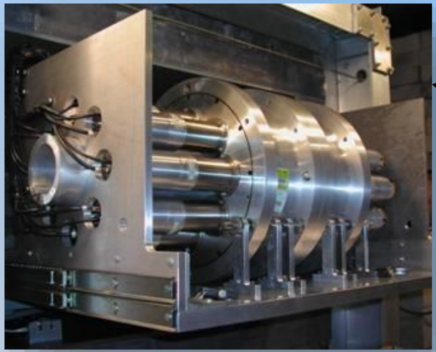
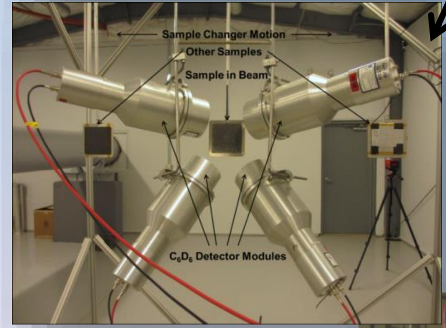
Detectors



25m

Capture/multiplicity

45m



Scattering

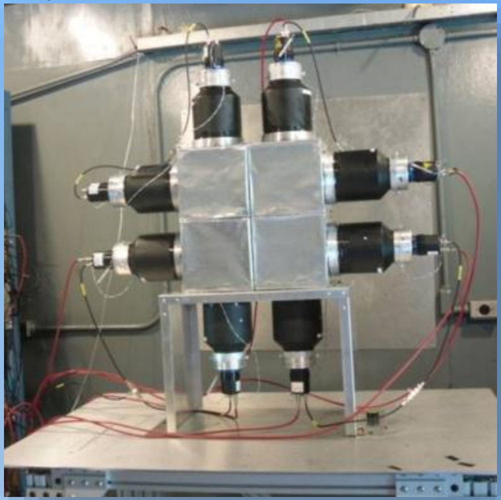
PFNS @ 30m

Transmission

15m- 30m

100m

250m



Current Activity

- **Time of flight measurements**
  - Resonance Region
    - Capture (0.01 eV – 2 keV)
    - Transmission (0.001 eV – 100 keV)
    - Capture to fission ratio (alpha)
    - keV capture detector
    - Neutron scattering (E<0.5 MeV)
  - High energy (0.4-20 MeV)
    - Scattering (30 m flight path)
    - Transmission (100 m and 250 m flight path)
    - Prompt Fission Neutron Spectra
    - Photoneutron spectra
  - High accuracy total cross section measurements using a filtered beam
- **Lead Slowing Down Spectrometer**
  - Simultaneous measurement of fission cross sections and fission fragment mass and energy distributions using the RPI lead slowing down spectrometer
  - Measurements of energy dependent (n,p) and (n,α) cross sections of nanogram quantities of short-lived isotopes. (collaboration with LANL).
  - Capture cross section measurements
- **Other**
  - Research on medical isotope production
  - Thermal scattering ($S(\alpha,\beta)$) measurements (at SNS in ORNL)

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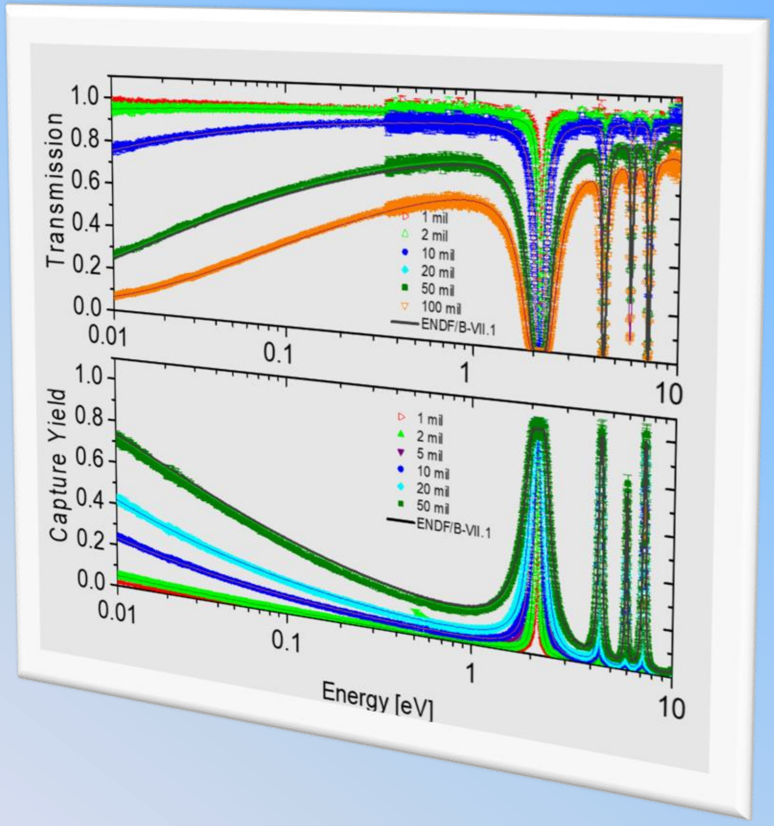
Resonance Region



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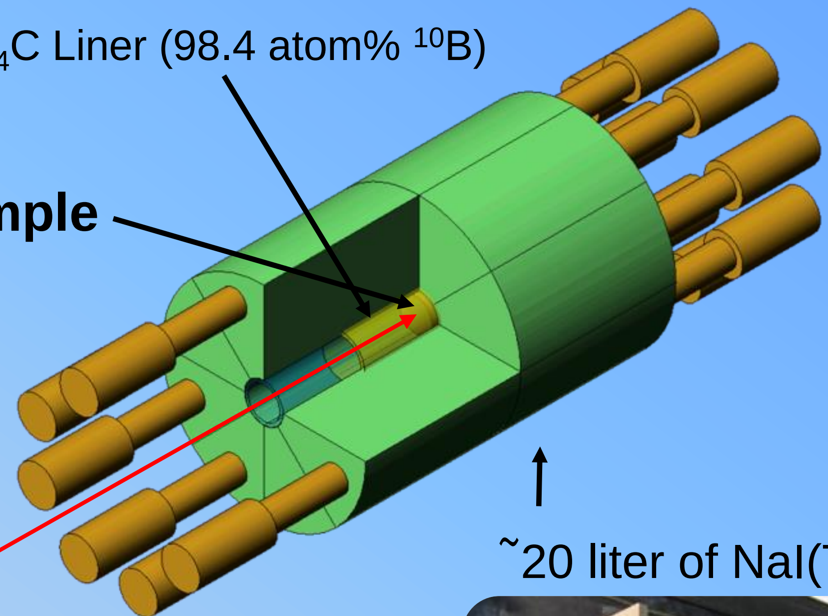
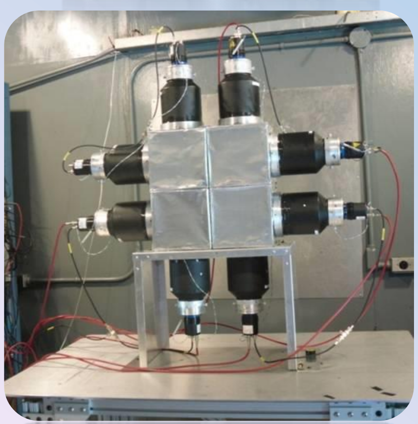
Resonance Region Detectors

2 cm B_4C Liner (98.4 atom% ^{10}B)

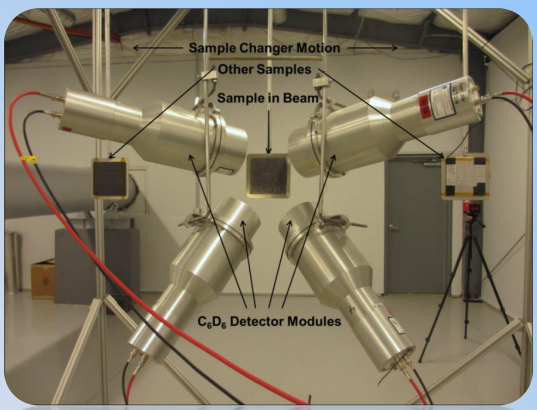


Li-Glass Detector at 25m

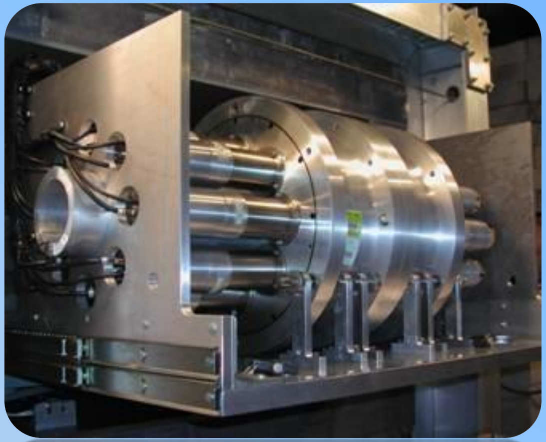
Li-Glass Detector at 100m



C_6D_6 Detector at 45m



~20 liter of NaI(Tl)



^{235}U Capture & Fission Yield Data

- **Challenges:**
  - Normalization
  - False capture due to neutron scattering
- ➢ **Normalize experimental fission yield to a resonance**

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

- ➢ **Use two equations for predominantly capture and fission resonances**

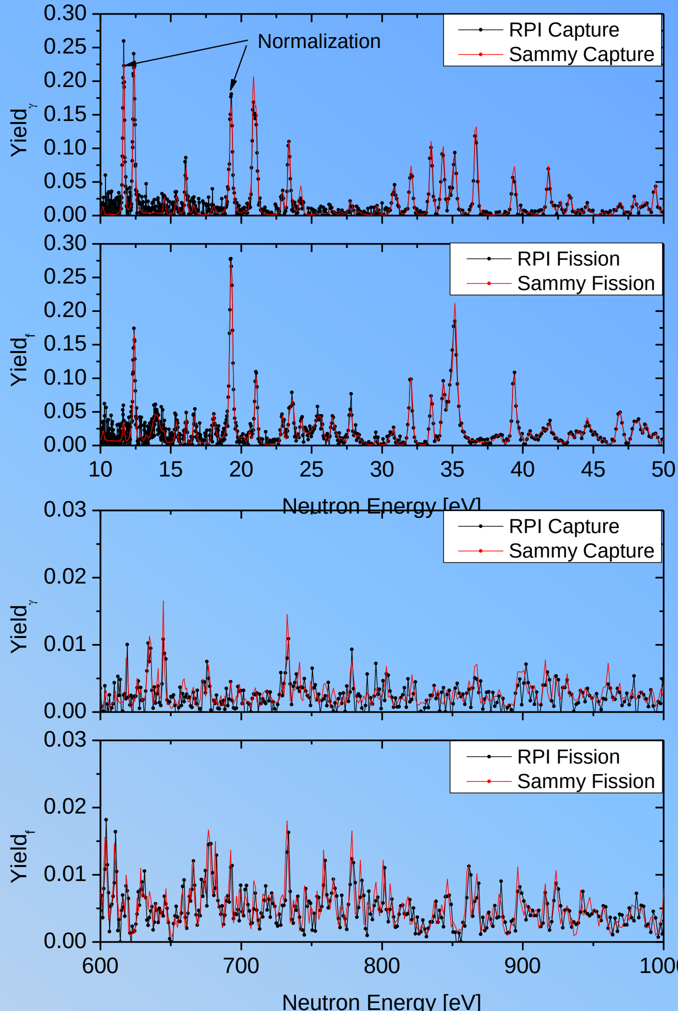
$$\text{@ 11.7 eV res} \quad \left(\frac{\Gamma_\gamma}{\Gamma} = 0.86\right) \qquad \text{@ 19.3 eV res} \quad \left(\frac{\Gamma_f}{\Gamma} = 0.63\right)$$

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

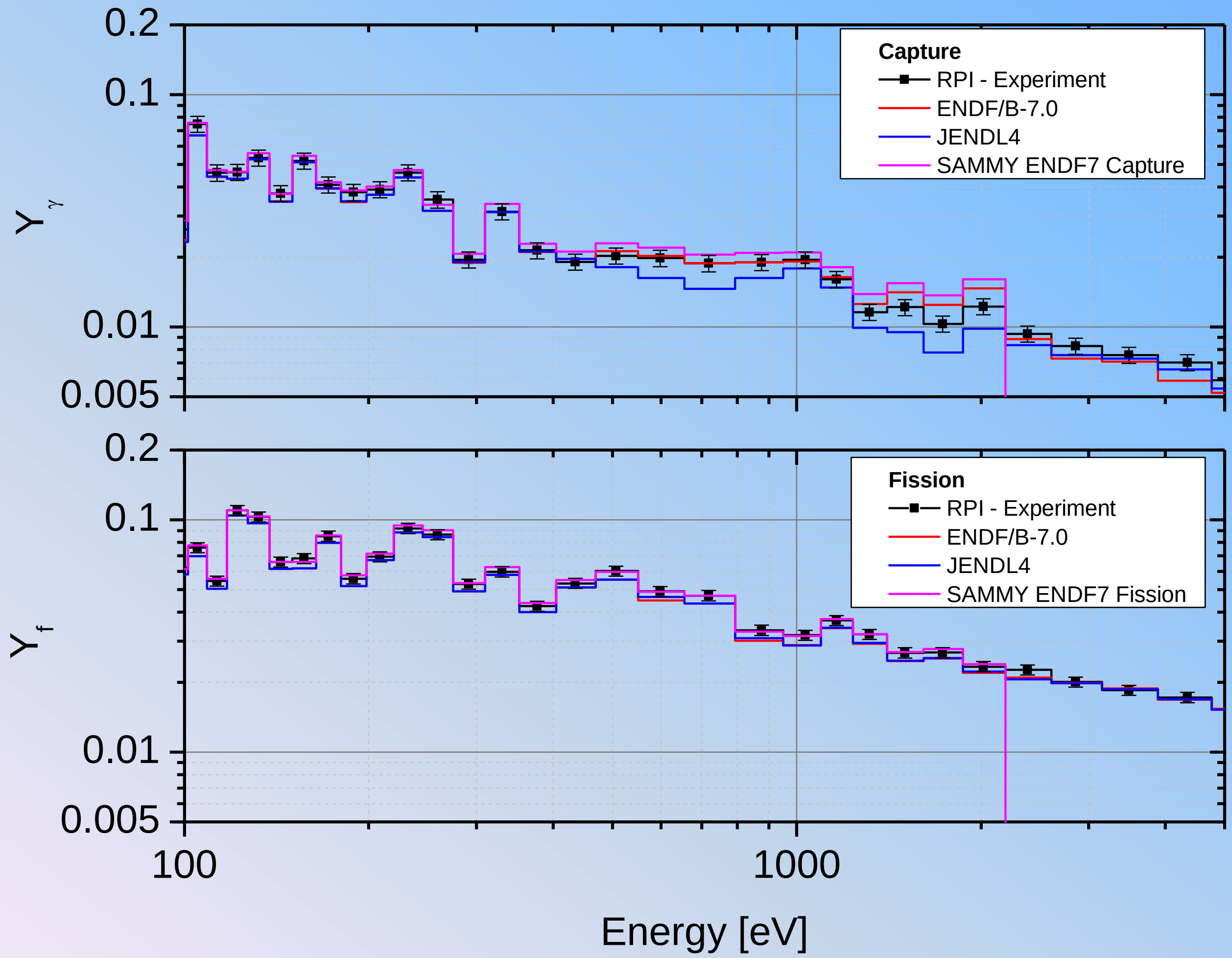
- ➢ **Solve the two equations for k_2 and k_3**

► Need 2 resonances with known parameters ◄

- **Provided data to address WPEC subgroup 29 report "Uranium-235 Capture Cross-section in the keV to MeV Energy Region"**
- **The data were used in the U-235 CIELO evaluation which was adopted to ENDF-8.0**



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

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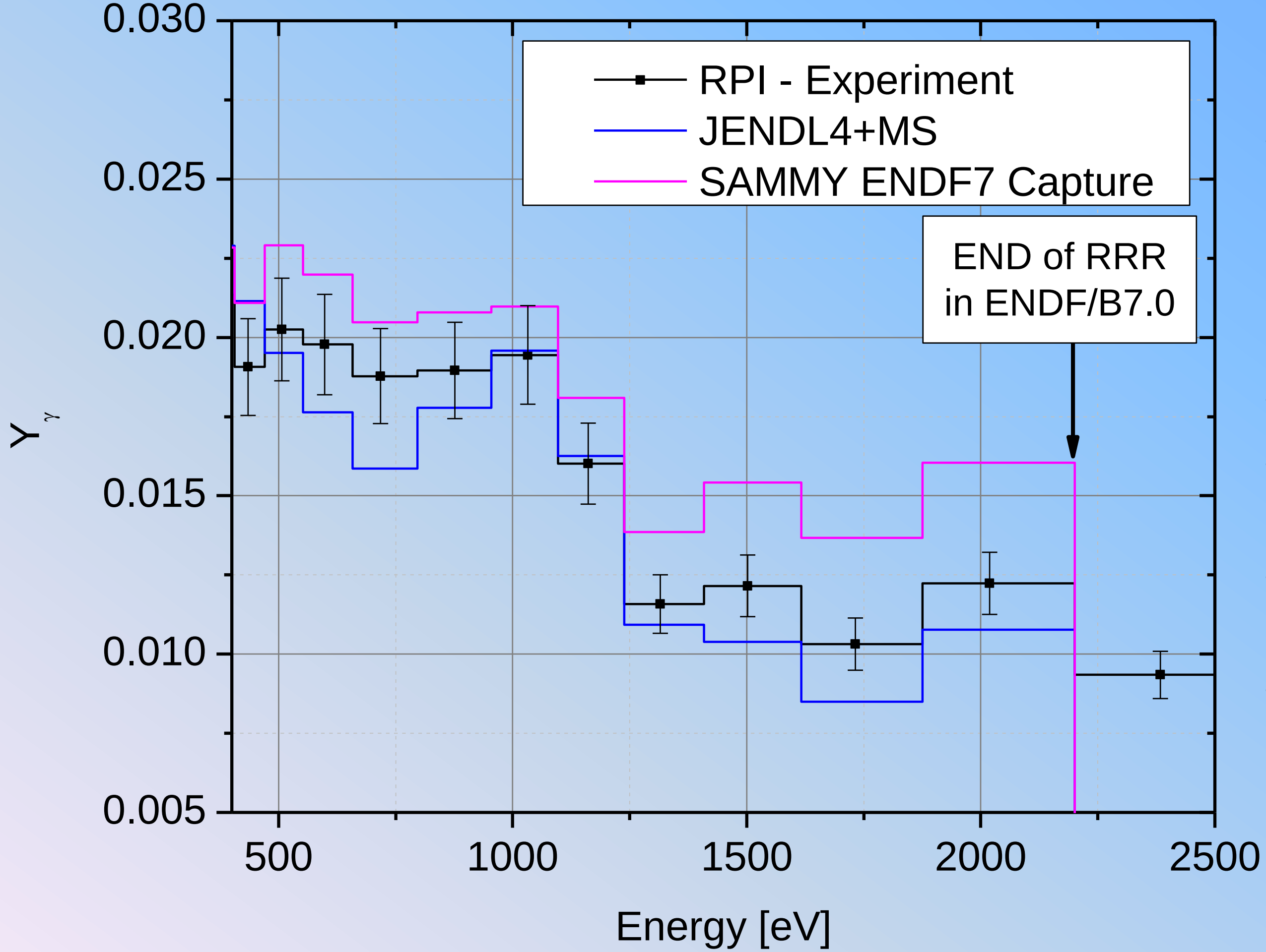

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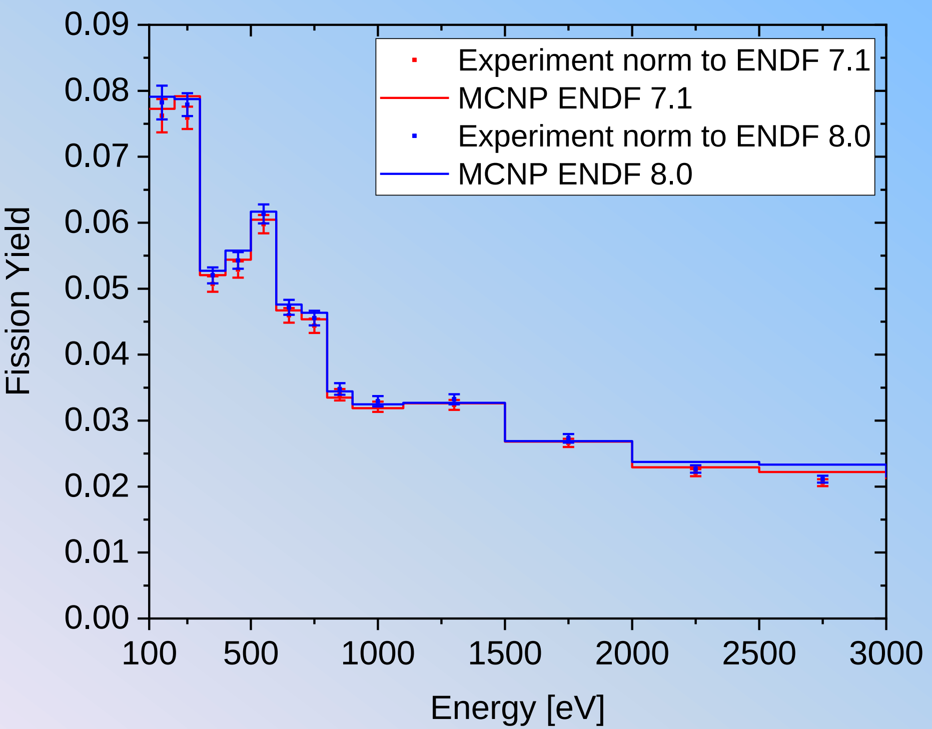
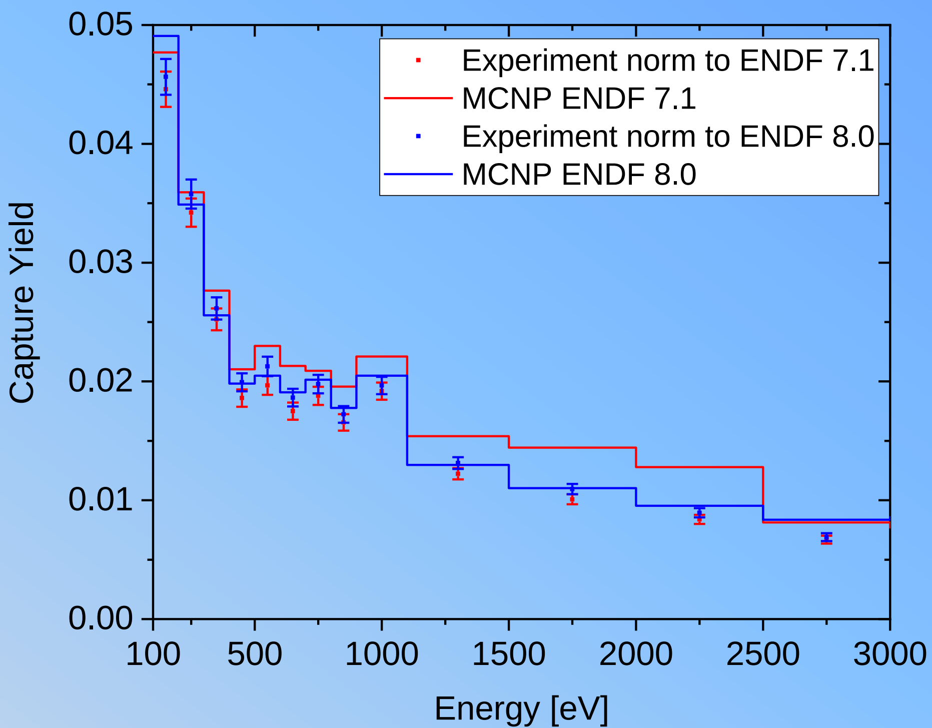
- E>1 keV data is slightly higher than evaluations but within errors

Comparing ^{235}U Fission and Capture with ENDF-8.0

- ENDF 8.0 is a great improvement from ENDF 7.1



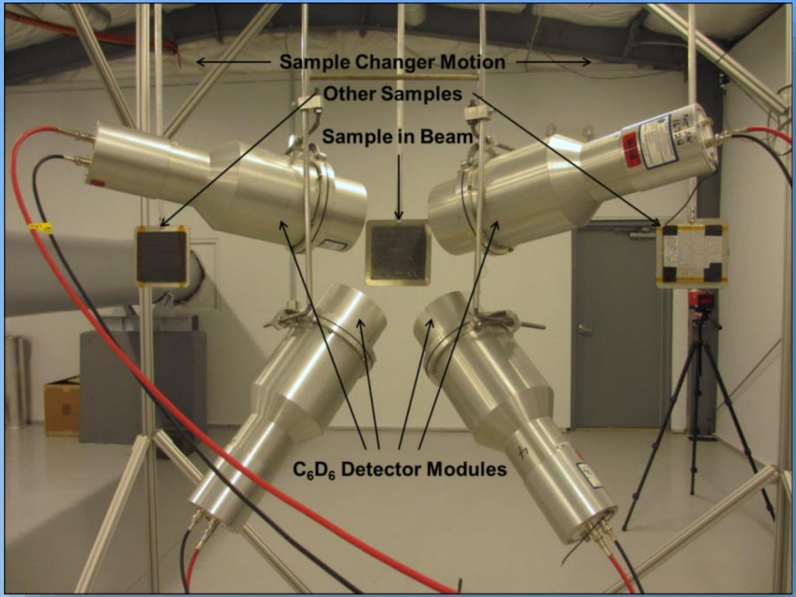


Y. Danon, D. Williams, R. Bahran, E. Blain, B. McDermott, D. Barry, G. Leinweber, R. Block and M. Rapp, "**Simultaneous Measurement of ^{235}U Fission and Capture Cross Sections From 0.01 eV to 3 keV Using a Gamma Multiplicity Detector**", Nuclear Science and Engineering, vol. 187, no. 3, pp. 291-301, 2017.

Fe and Fe-nat KeV Neutron Capture

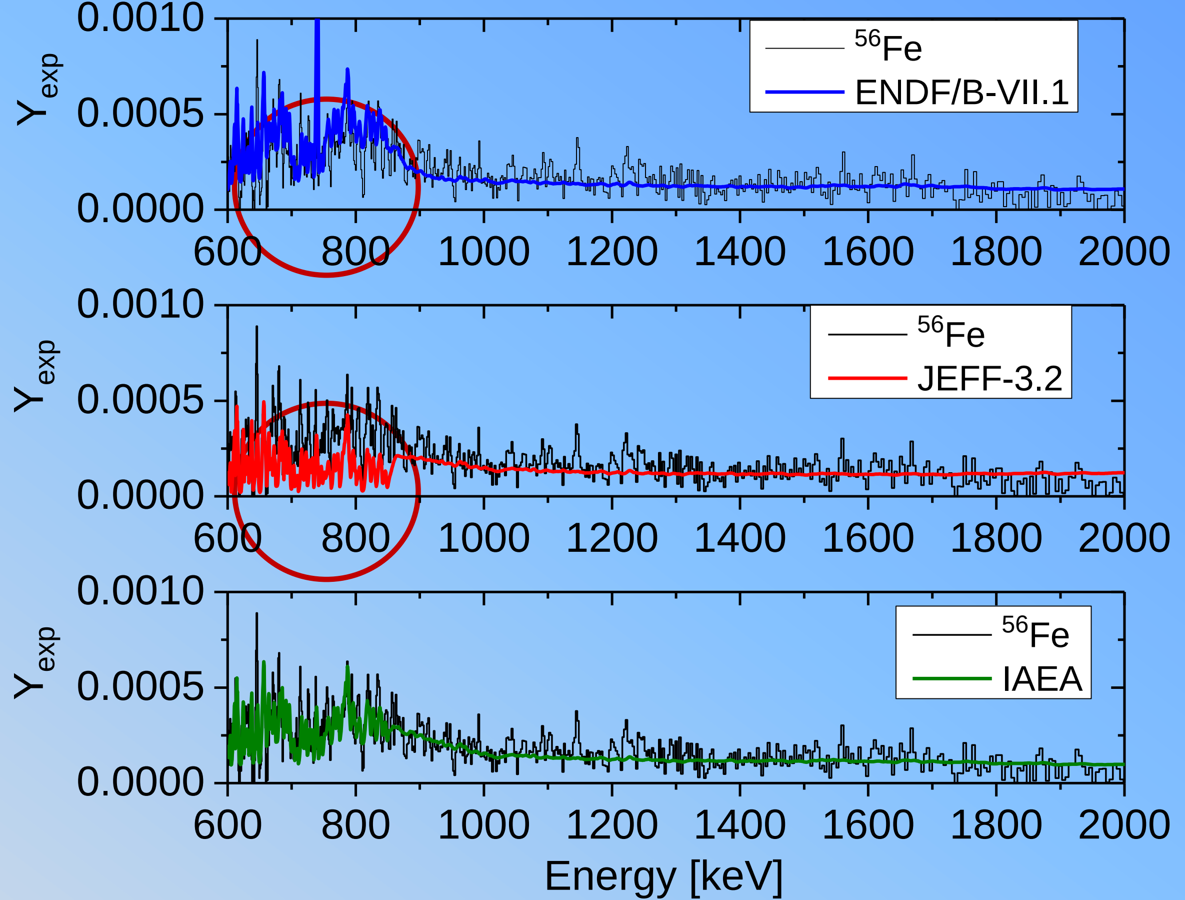
mid-energy capture detector system overview

- 4 C_6D_6 detector modules manufactured by Eljen Technology
- **Low mass, low neutron sensitivity design**
- Located at 45m flight path in newly constructed flight station
- Measurements made from 1 eV to 1 MeV
- Requires a weighting function



^{56}Fe Results – MCNP Comparison

- Possible unresolved or intermediate structure may account for higher data yields from 600-850 keV (self-shielding)
- ENDF/B VII.1 overcompensates with its background treatment, JEFF has no background treatment.
- Above 850 keV, the data agree with the 3 evaluations presented.
- ENDF 8.0 follows uses the IAEA evaluation for Fe-56



McDermott, Brian, Blain, Ezekiel, Thompson, Nicholas, Weltz, Adam, Youmans, Amanda, Danon, Yaron, Barry, Devin, Block, Robert, Daskalakis, Adam, Epping, Brian, Leinweber, Gregory and Rapp, Michael, "**^{56}Fe capture cross section experiments at the RPI LINAC Center**", *EPJ Web Conf.*, vol. 146, pp. 11038, 2017.

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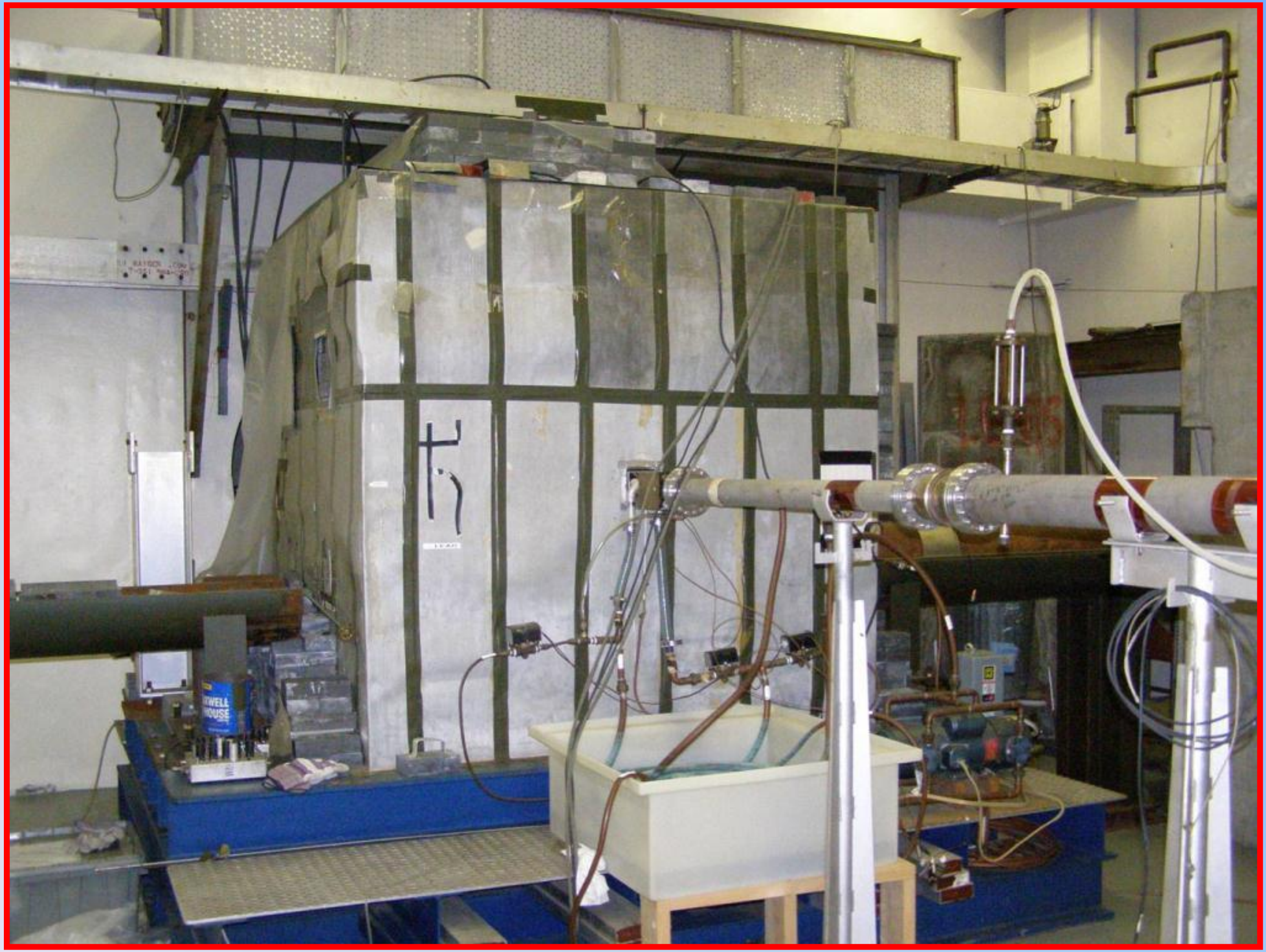
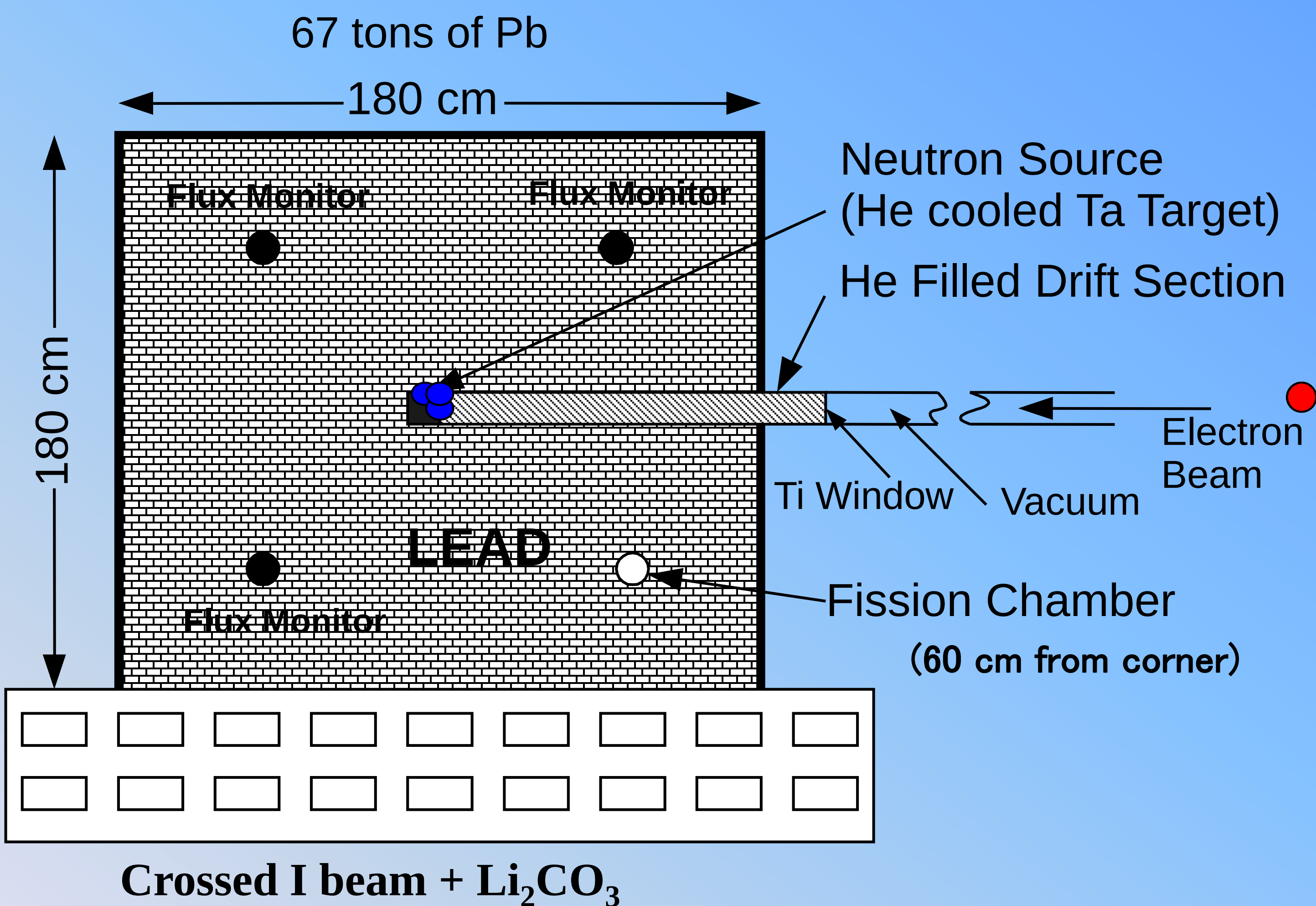
Lead Slowing Down Spectrometer



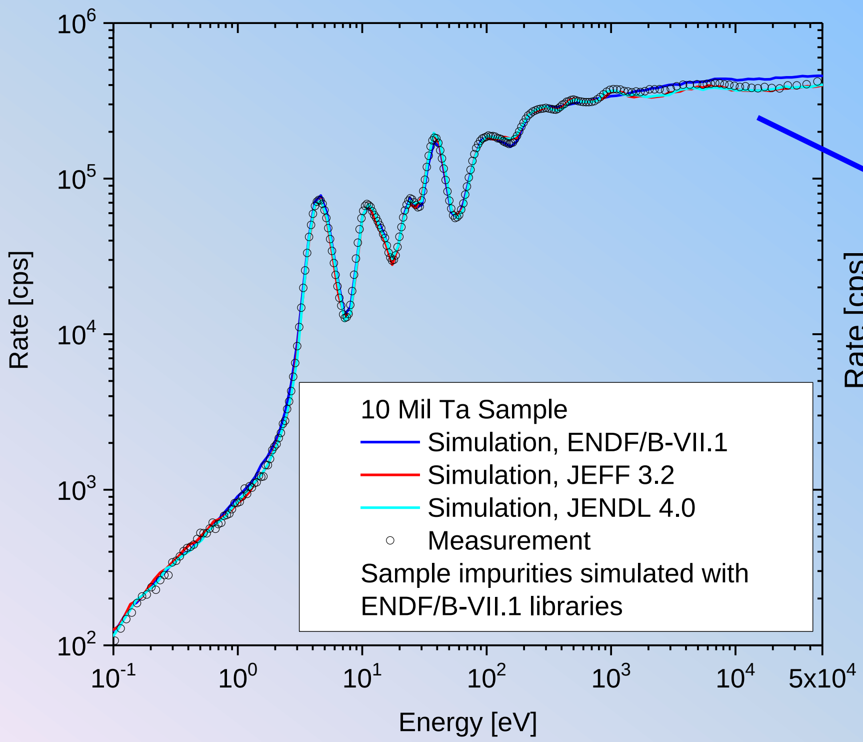
Lead Slowing-down Spectrometer at RPI

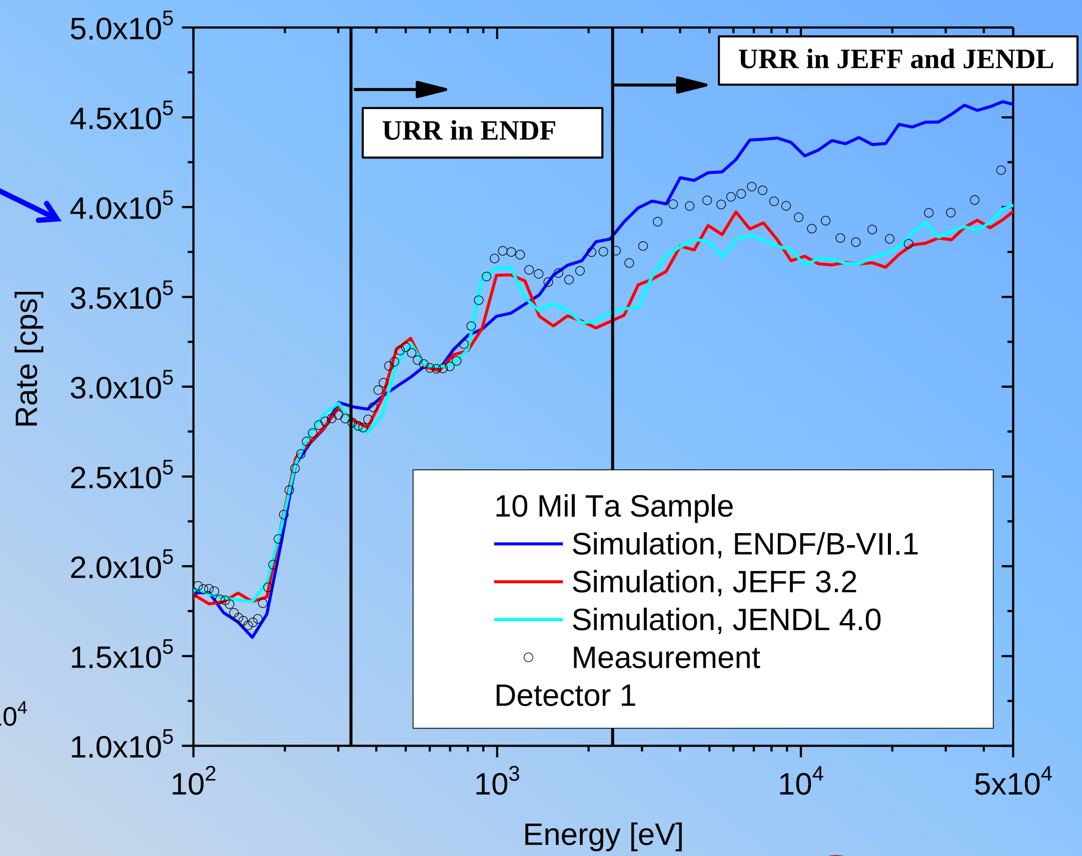
- Tantalum target in the center produces neutrons.
- Neutrons scatter elastically with the Pb.
- Neutrons can pass through the same position several times.
- About 10^3-10^4 times higher flux than an equivalent flight path TOF experiment (5.6m).



Results – Ta Capture

- Good agreement up to 300 eV
  - Some disagreement in the ENDF/B-VII unresolved resonance region
  - RPI is Working on improving Ta RRR cross section in a project funded by NCSP





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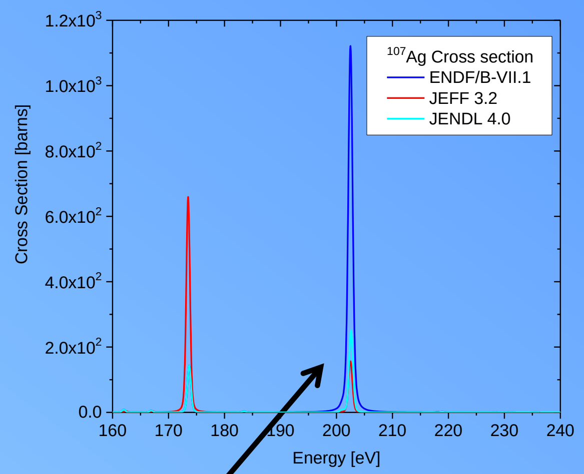
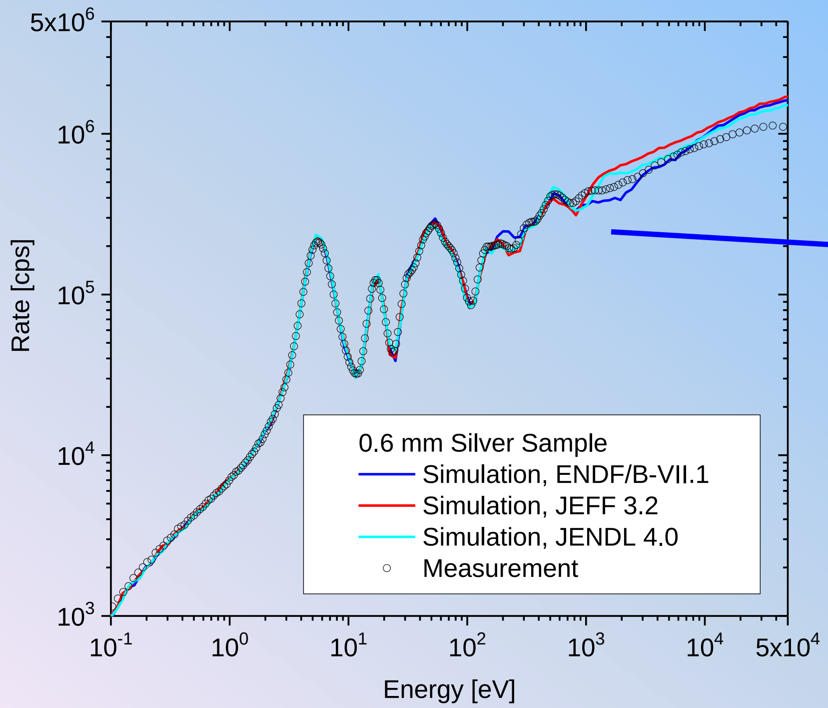
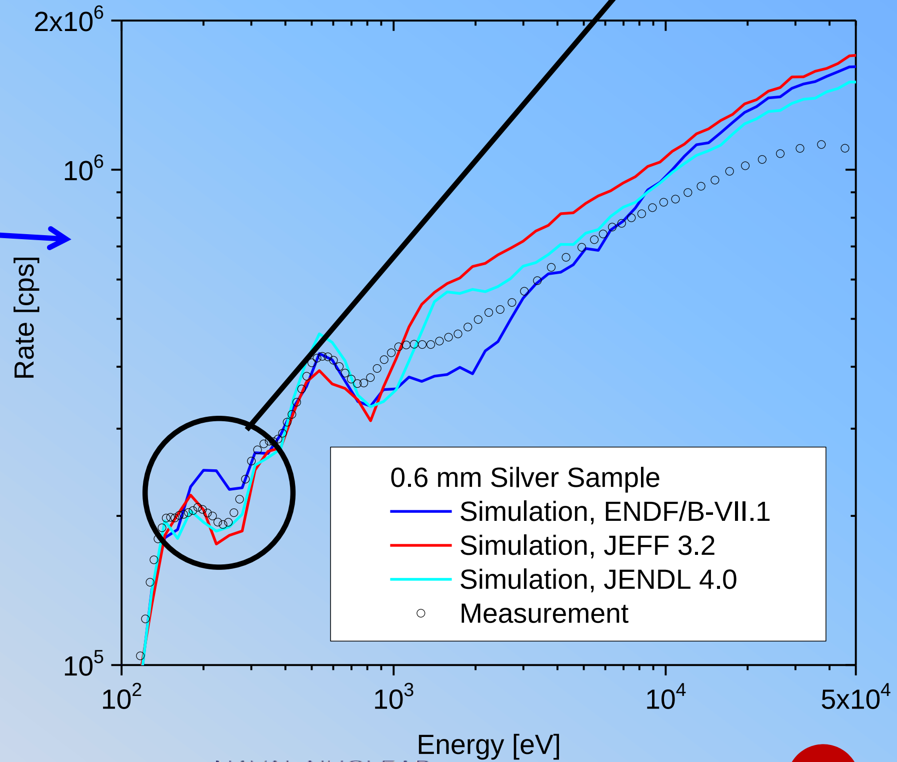
Results – Ag Capture

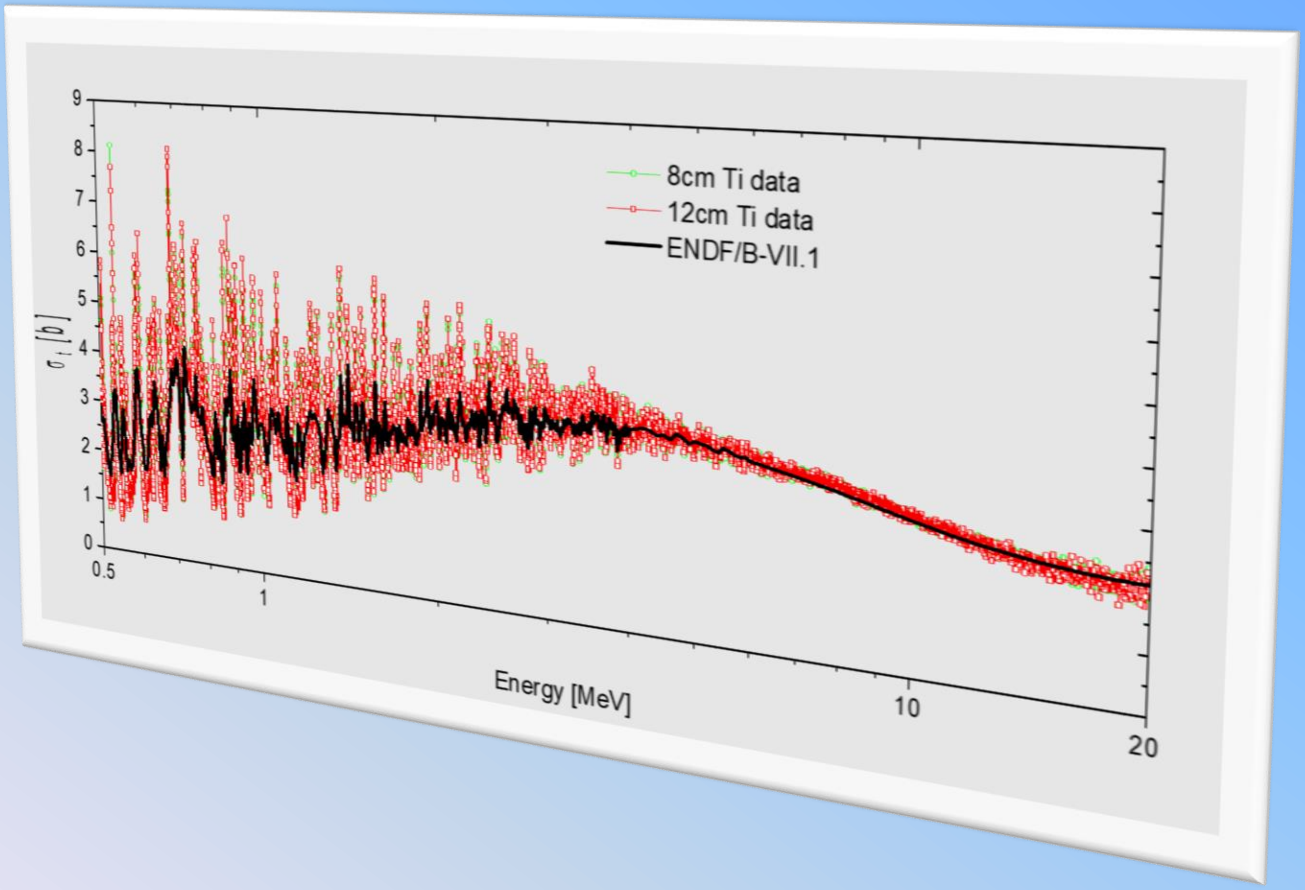
- Large differences between libraries above 1 keV







Fast Region



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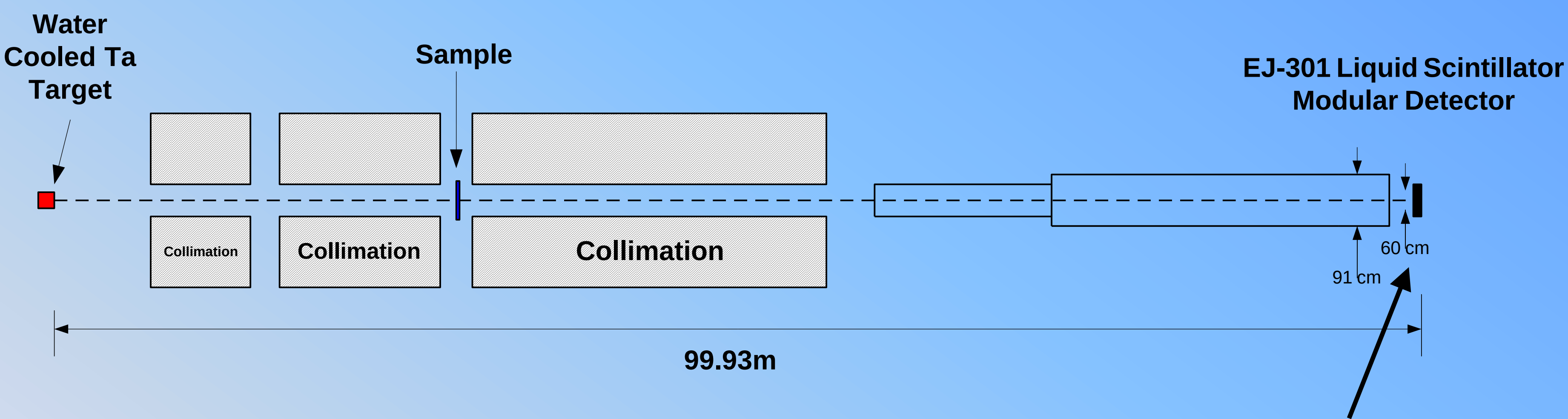
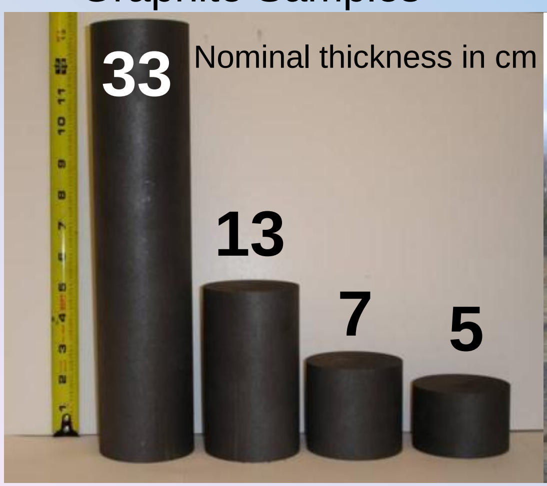
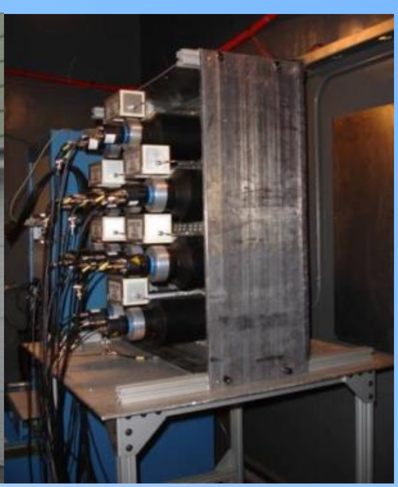
High Energy Transmission Experimental Setup

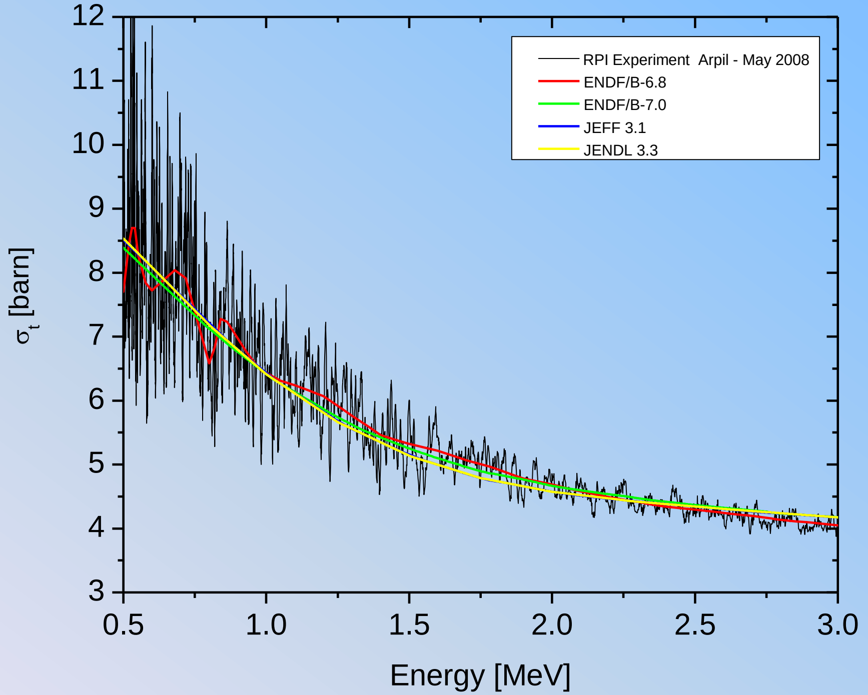


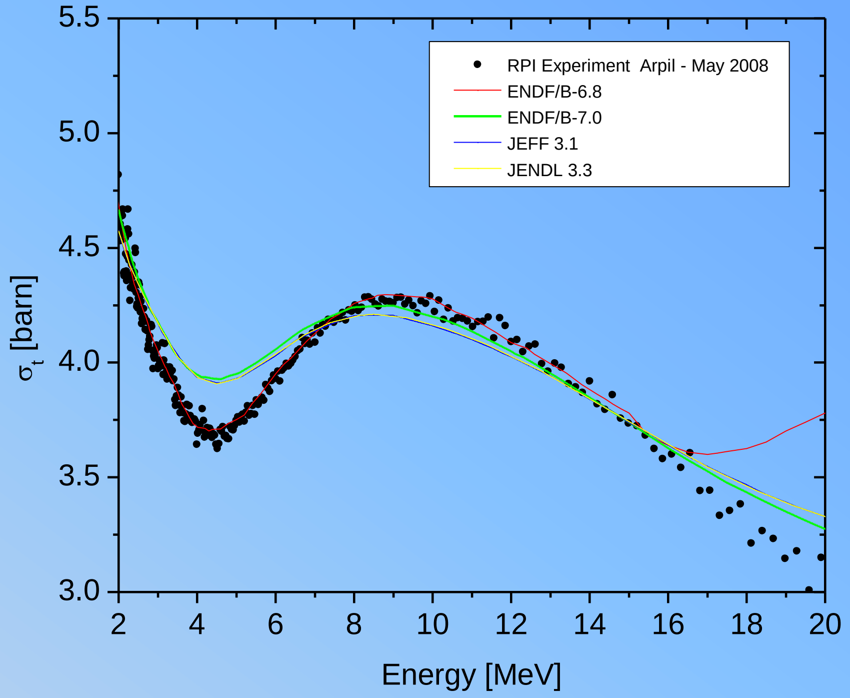
Graphite Samples





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.

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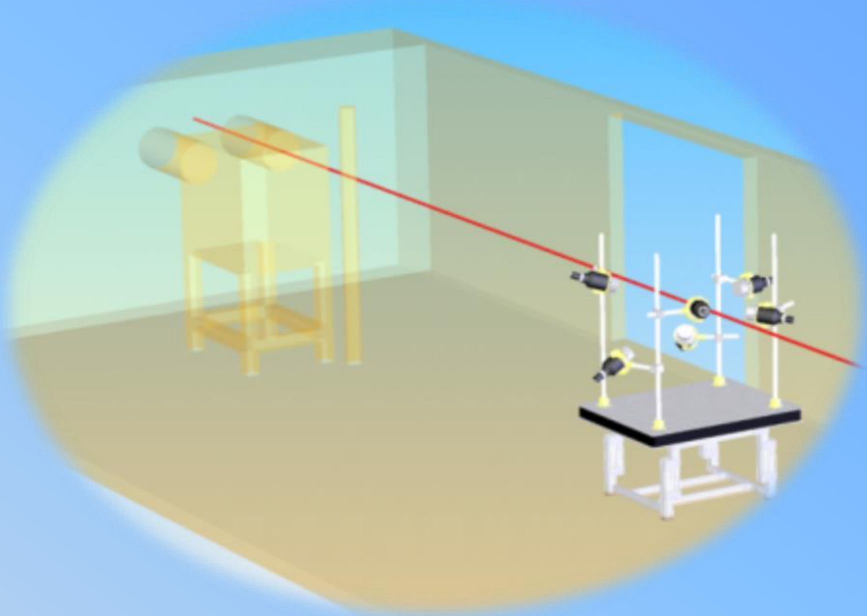


U-238, Fe, Be scattering

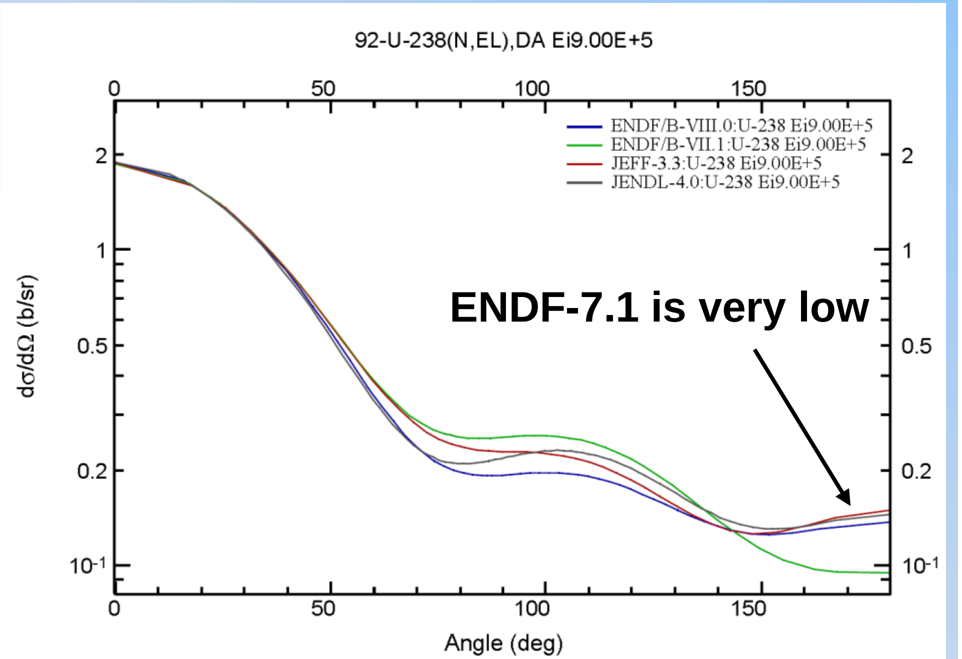
Elastic / Inelastic Neutron Scattering

- **Important for neutron (and gamma) transport calculations**
  - Applications: criticality, reactors, shielding, oil well logging, SNM detection, others…
- **Quantities of interest**
  - Neutron cross section and angular distribution
  - Gamma production from inelastic scattering and its angular distribution
  - Neutron energy transfer (requires inelastic levels)
- **Energy range of interest - from URR to fast**
  - In the RRR, resonance parameters can be used to calculate both cross sections and angular distribution.
  - URR sometimes difficult for model calculations experimental data is needed.

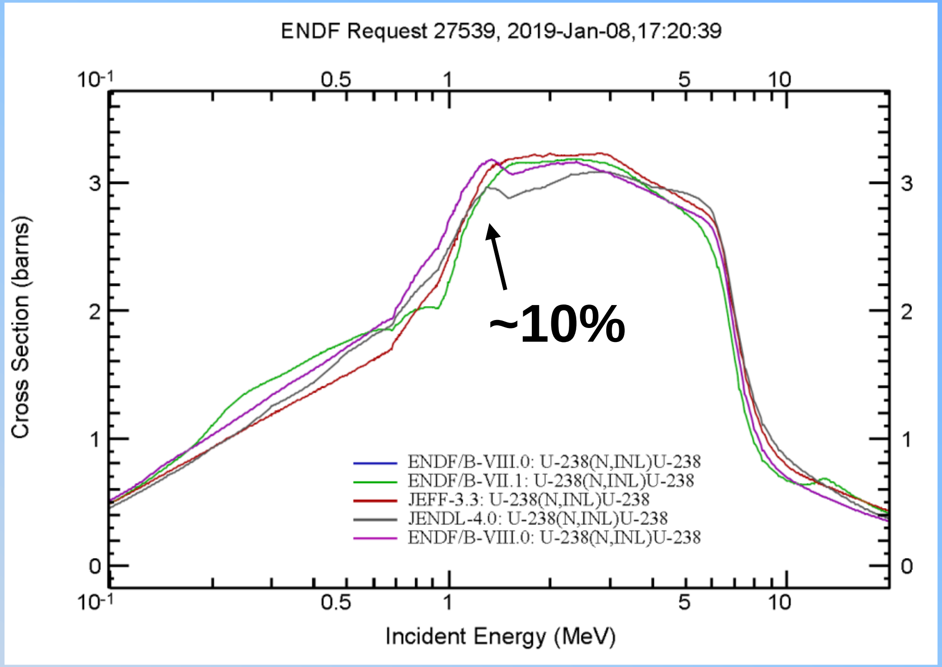
Current Evaluated Scattering Data

- **Hard to measure thus evaluate**
  - Large uncertainties
- **Example: “well known” U-238**

Elastic angular distribution E_n=0.9 MeV
Notice ENDF-7.1 at back angles



(n,inl) cross section



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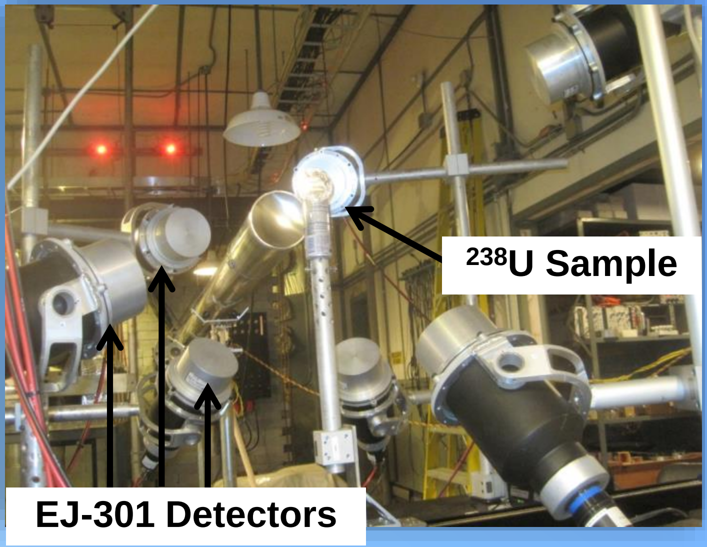
Scattering Detection System: Experimental Setup

- **Detector Array**
  - Eight EJ301 Liquid Scintillation Detectors
  - Eight 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

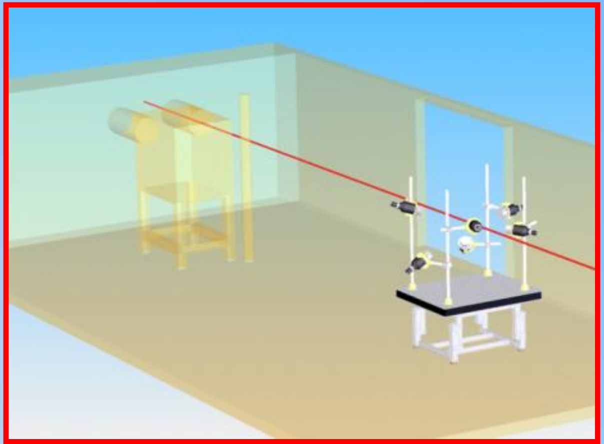


A. M. Daskalakis, E. J. Blain, B. J. McDermott, R. M. Bahran, Y. Danon, D. P. Barry, R. C. Block, M. J. Rapp, B. E. Epping and G. Leinweber, "**Quasi-differential elastic and inelastic neutron scattering from iron in the MeV energy range**", *Annals of Nuclear Energy*, vol. 110, pp. 603 - 612, 2017.

A.M. Daskalakis, R.M. Bahran, E.J. Blain, B.J. McDermott, S. Piela, Y. Danon, D.P. Barry, G. Leinweber, R.C. Block, M.J. Rapp, R. Capote, A. Trkov, "**Quasi-differential neutron scattering from ^{238}U from 0.5 to 20 MeV**", Annals of Nuclear Energy, Volume 73, Pages 455-464, November 2014.

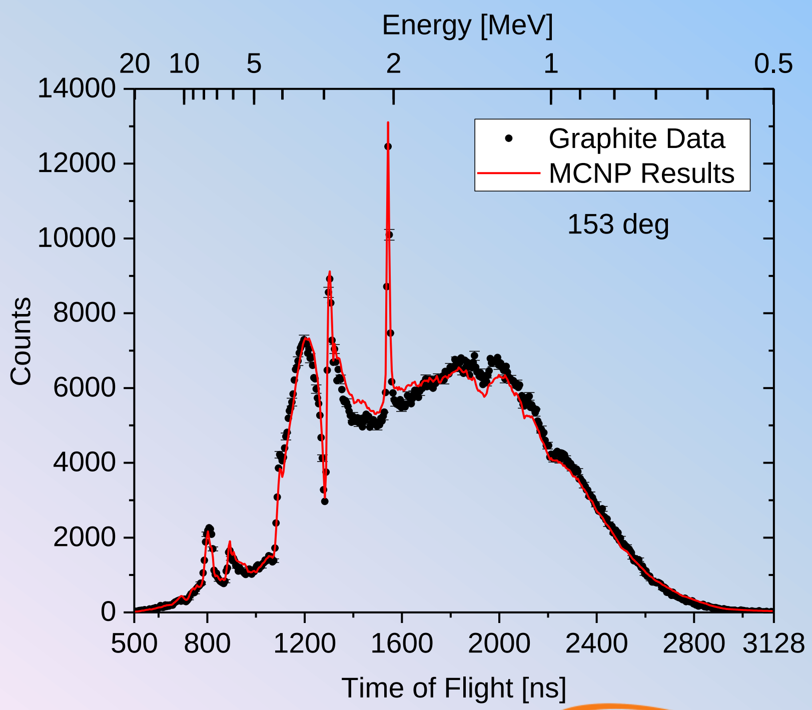
D. P. Barry, G. Leinweber, R. C. Block, and T. J. Donovan, Y. Danon, F. J. Saglime, A. M. Daskalakis, M. J. Rapp, and R. M. Bahran, "**Quasi-differential Neutron Scattering in Zirconium from 0.5 MeV to 20 MeV**", Nuclear Science and Engineering, 174, 188–201, (2013).

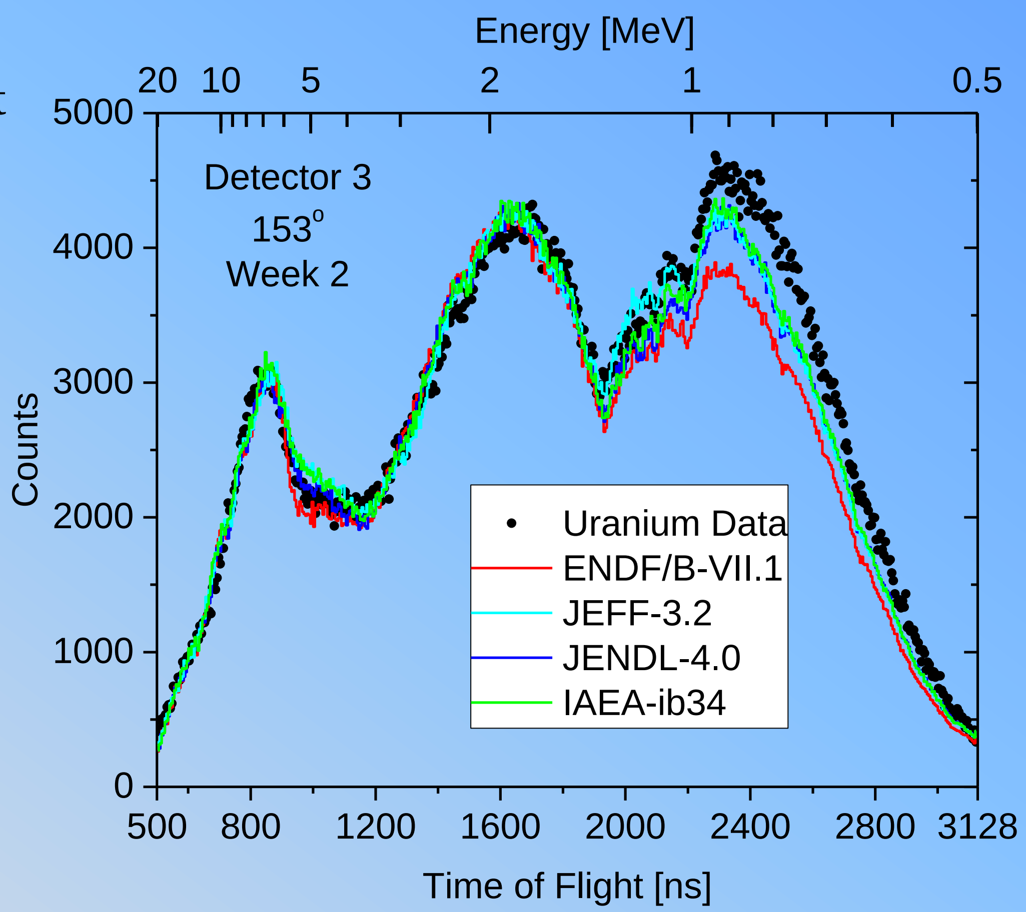
F.J. Saglime, Y. Danon, R.C. Block, M.J. Rapp, R.M. Bahran, G. Leinweber, D.P. Barry and N.J. Drindak, "**A system for differential neutron scattering experiments in the energy range from 0.5 to 20 MeV**", Nuclear Instruments and Methods in Physics Research Section A, 620, Issues 2-3, Pages 401-409, (2010)



^{238}U Scattering at 153 deg

- Graphite experiment shows good agreement with the simulations,
- ^{238}U shows differences near 1 MeV
- Newer IAEA evaluation provides the best fit
- ENDF/B-VII.1 needs improvement





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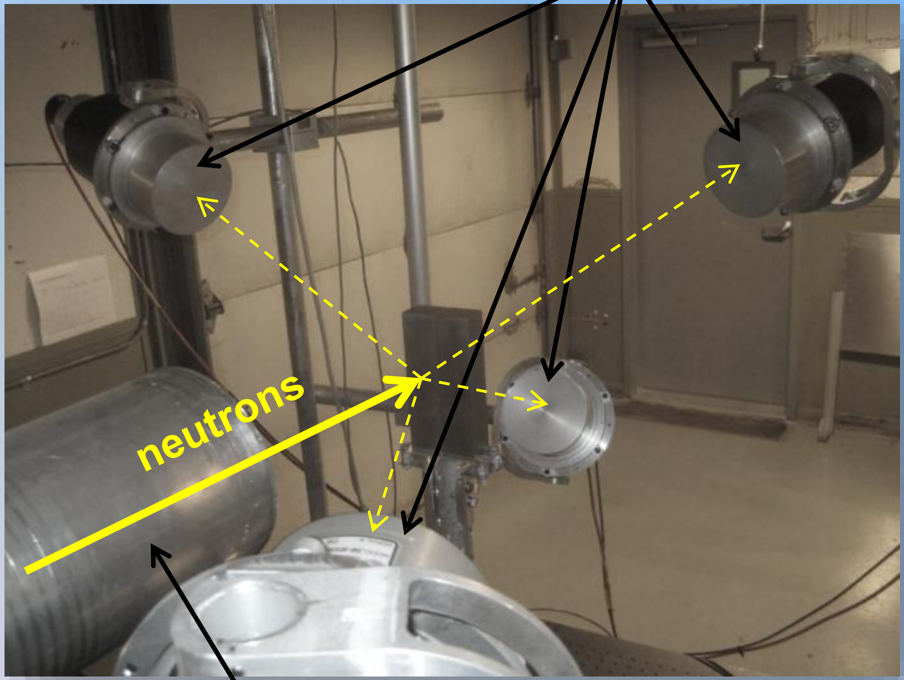
Fe Scattering Measurement - Setup

EJ-301 Liquid Scintillator Neutron Detectors



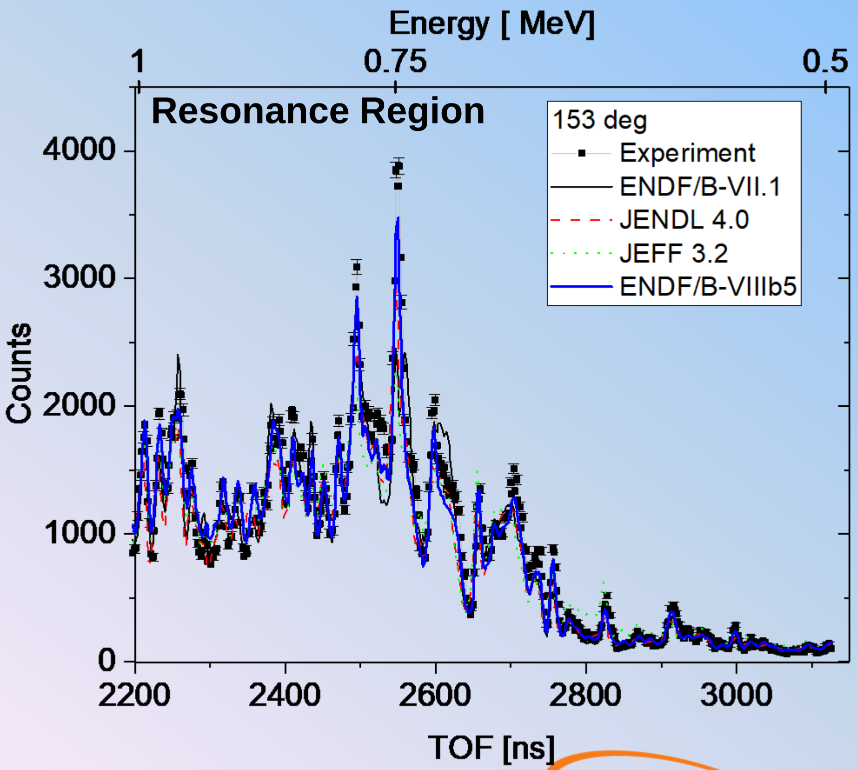
Evacuated Flight Tube

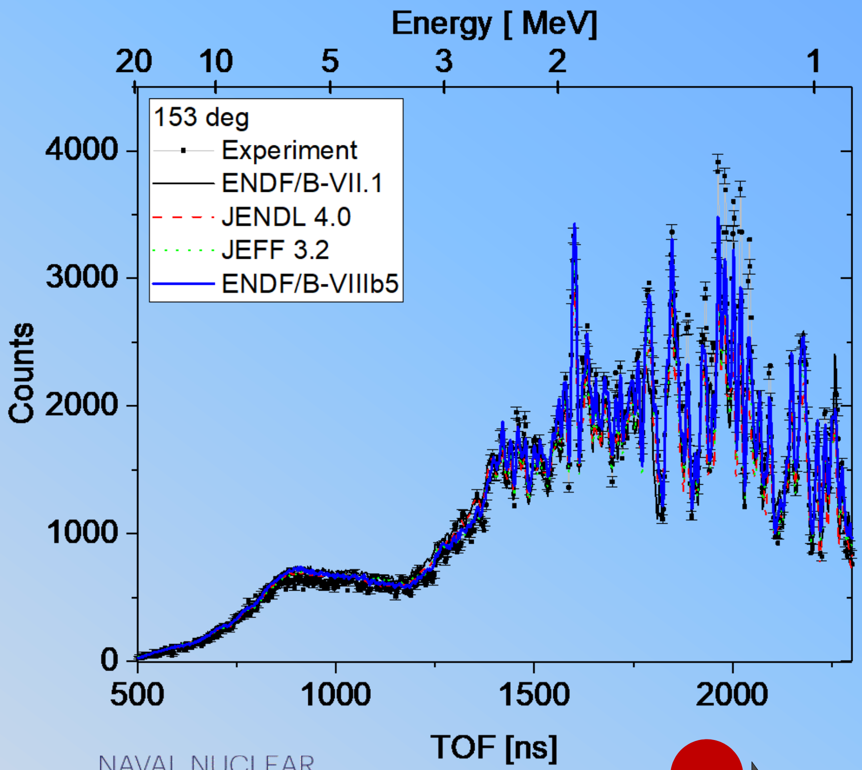
Fe Sample
Dimensions 77.0 x 152.6 x 32.2 mm

The neutron beam diameter is smaller than the sample size.

Iron Scattering

- Measured the total scattering and compared with detailed simulation
- Method was verified with graphite





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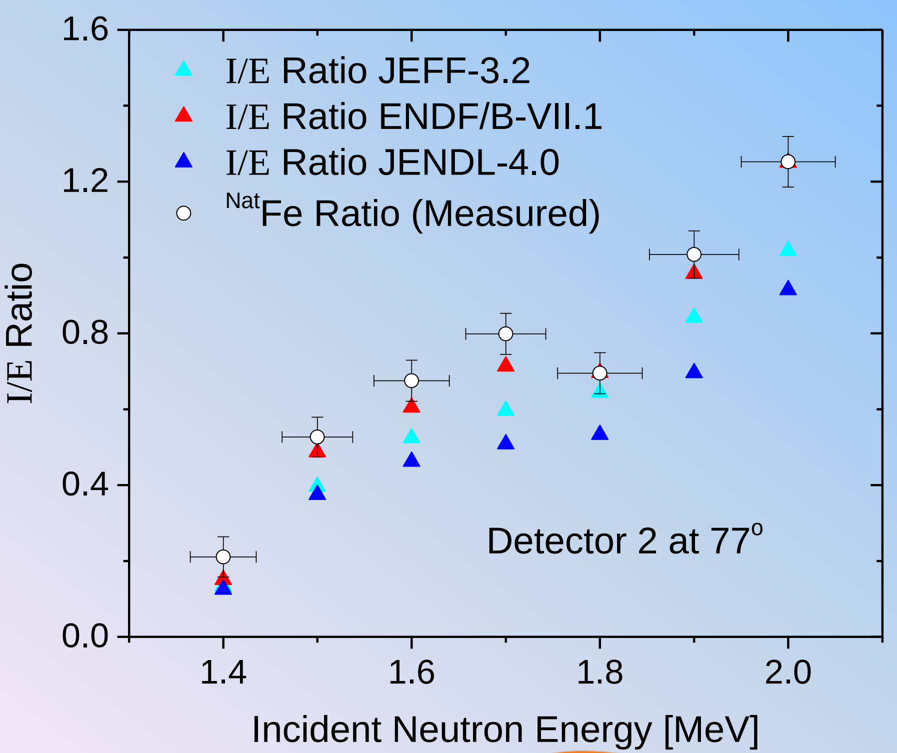
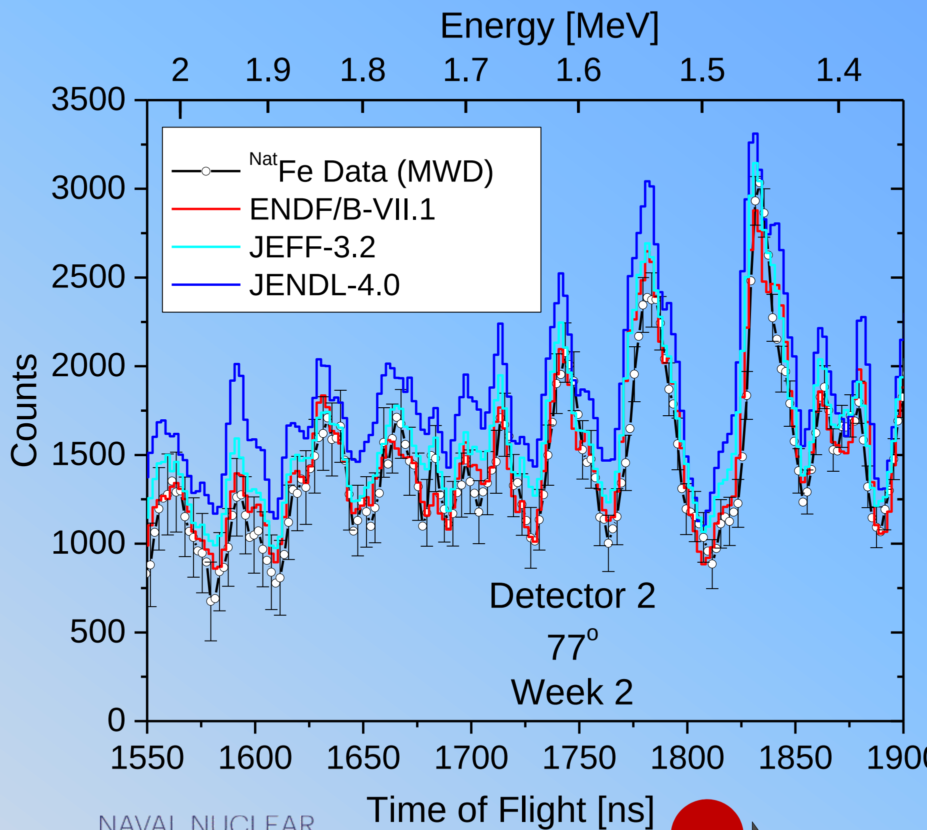
^{Nat}Fe Elastic/Inelastic Scattering – example data

- The JENDL-4.0 evaluation overestimated the elastic signal at 77°
- It seems that the I/E ratio for JENDL is low because the elastic scattering is too high.

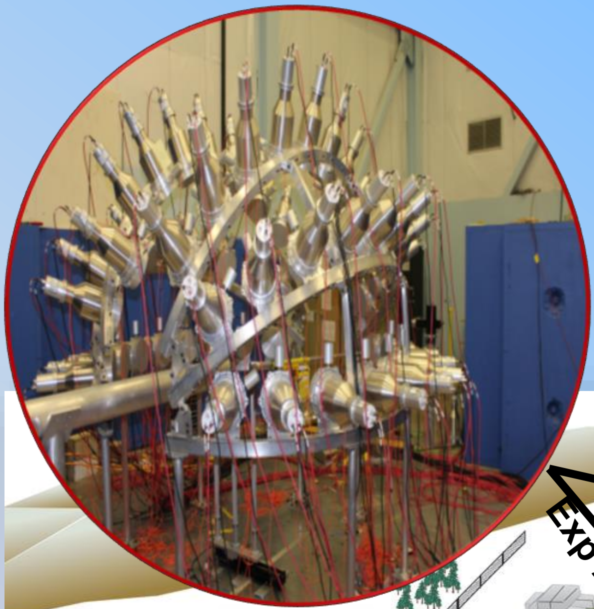


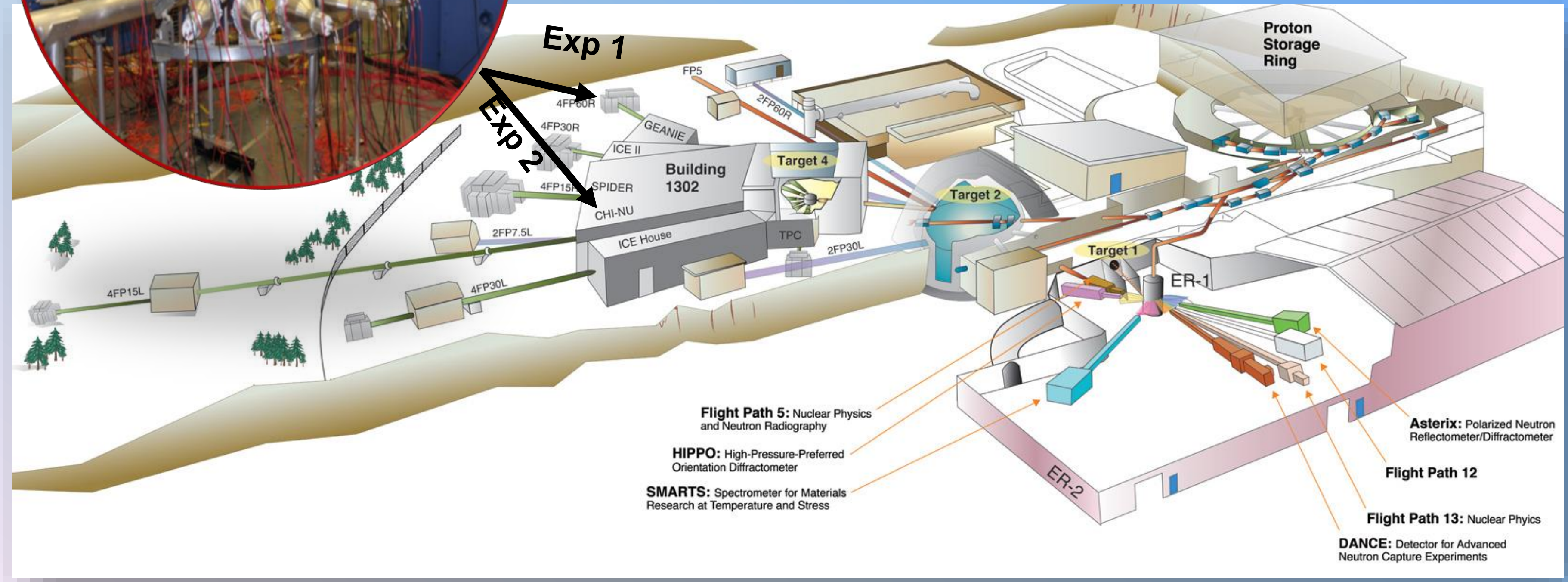
Elastic Scattering



Experimental Setup at LANL

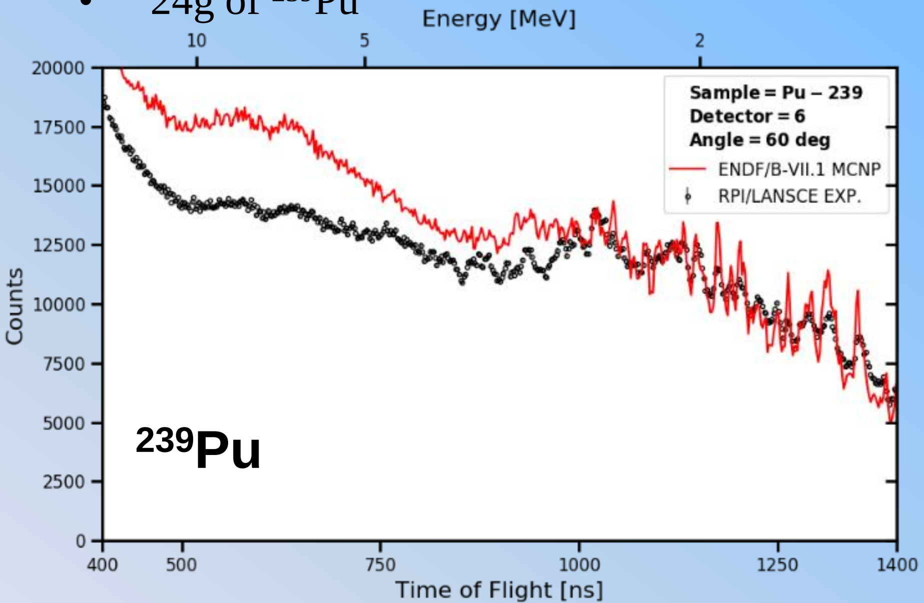
- Motivation U-235 and Pu-239
- Relatively simple experiments
- **Benchmark the simulation physics and nuclear data.**

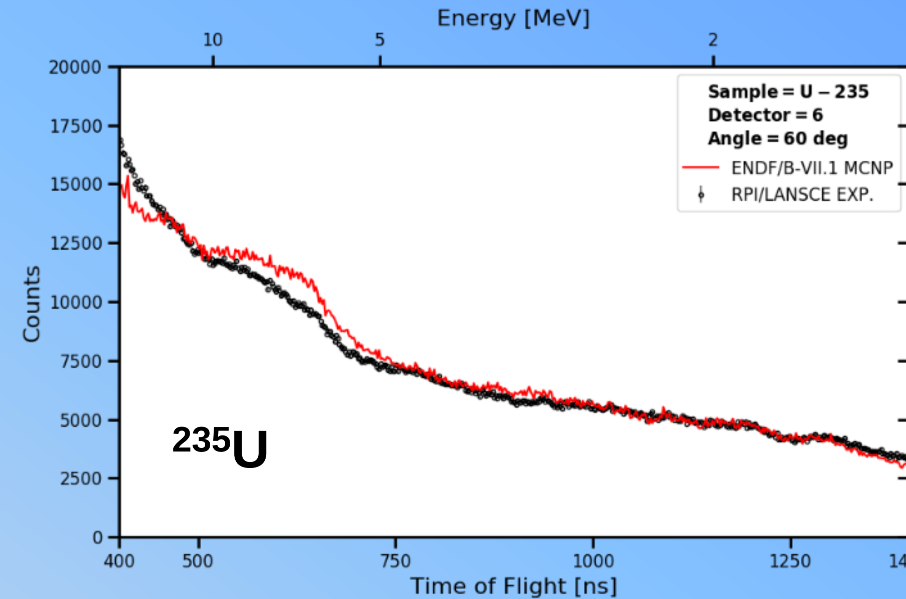


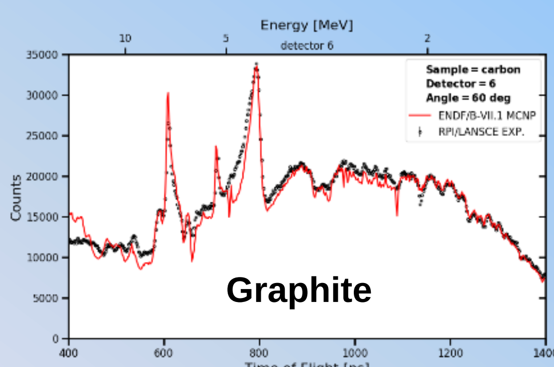


Preliminary Results – ^{235}U and ^{239}Pu at 60 deg

- 49.5 g of U enriched to 93% ^{235}U,
- 24g of ^{239}Pu

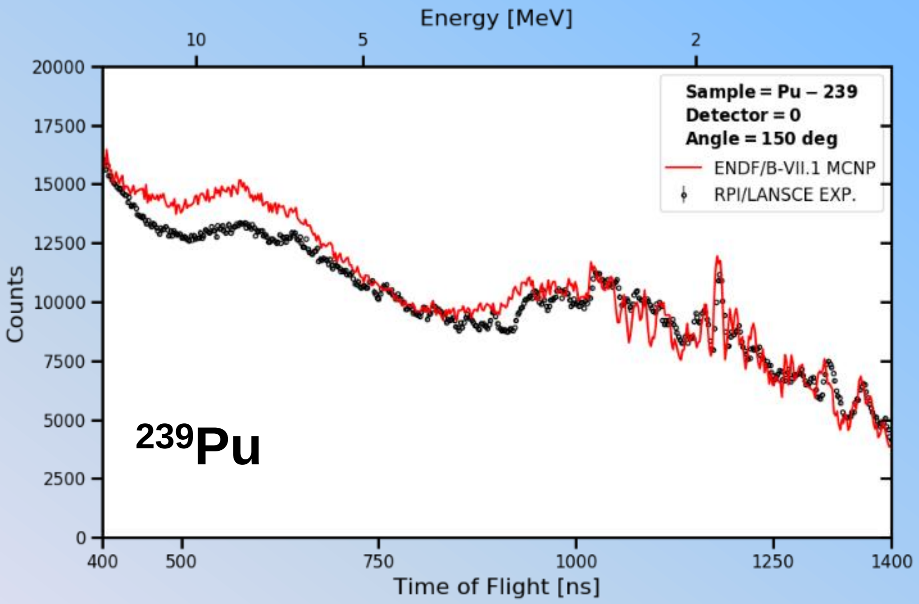


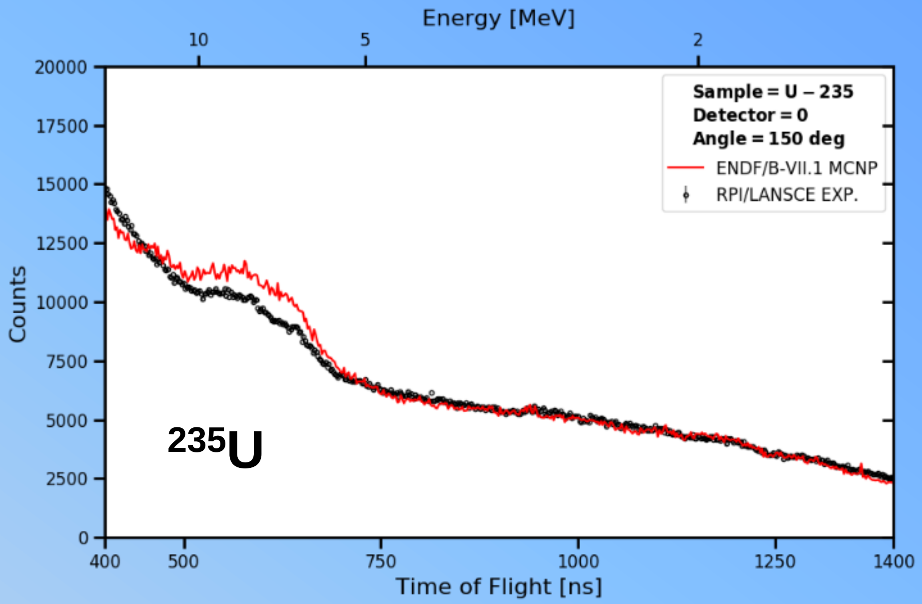


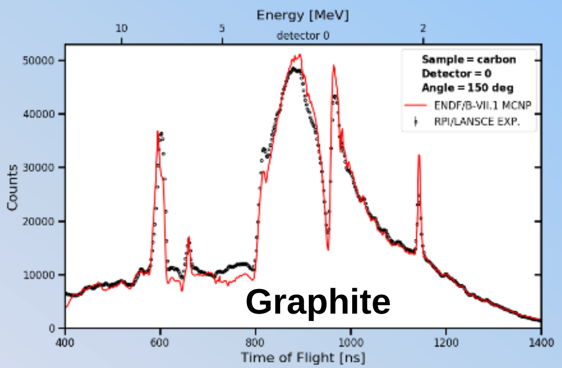


Preliminary Results – ^{235}U and ^{239}Pu at 150 deg

- Similar results at back scattering angles, possible issues with both ^{235}U and ^{239}Pu







Thank you for your attention

For a full list of publications visit: http://www.rpi.edu/~danony

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