

# Nuclear Data Related Activity at RPI

*Report to CSEWG November, 2012*

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# Measurements Completed This Year

- **Scattering**

- $^{56}\text{Fe}$ , Neutron Scattering (7 angles), 0.5-20 MeV, 30m flight path.

- **Transmission**

- $^{92/94}\text{Mo}$ , 5-600 keV, 100m flight path
- Ti, 0.5-20 MeV, 250m flight path
- Cu, 0.5-20 MeV, 250m flight path

# Planned Measurements

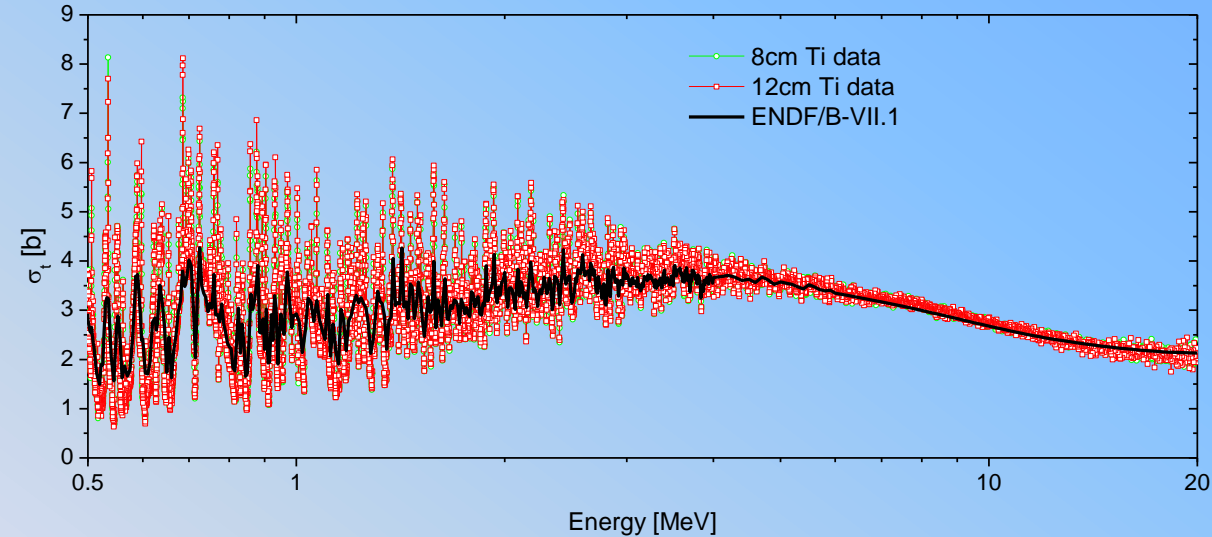
- **Scattering**
  - H<sub>2</sub>O, Thermal Neutron scattering, develop capability
- **Transmission**
  - <sup>92,94</sup>Mo, 10 eV - 600 keV, 100m and 30m flight paths (improve statistical accuracy)
  - <sup>236</sup>U, 15m flight path, concentrate on the 5.45 eV resonance
  - Fission neutrons spectrum for <sup>252</sup>Cf and <sup>235</sup>U
- **Capture**
  - Develop capability for KeV measurements

# Data Analysis

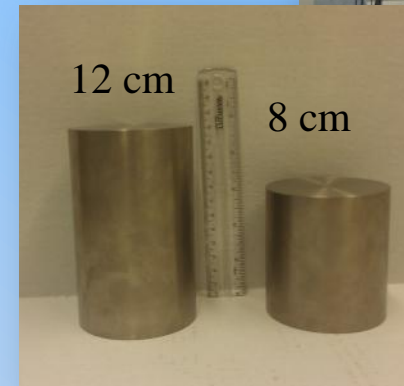
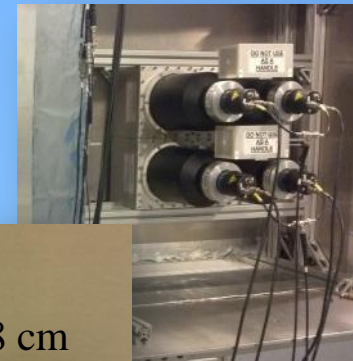
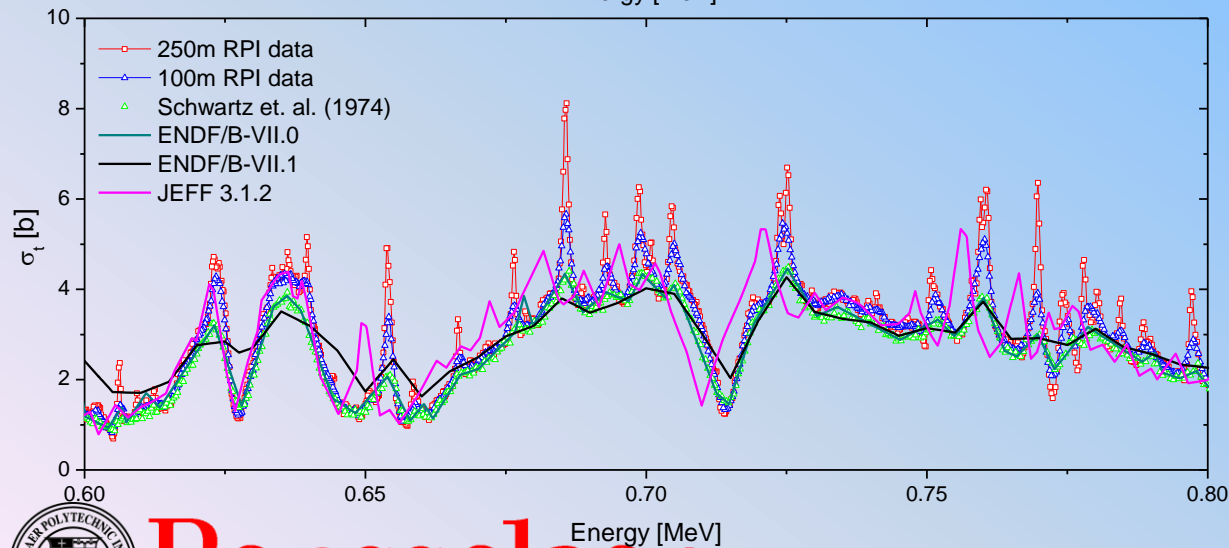
Sample	Status
Be, C	High energy (0.5-20MeV) transmission, <b>Accepted for publication (NS&amp;E)</b>
Zr	High energy (0.5-20MeV) scattering, <b>Accepted for publication (NS&amp;E)</b>
$^{147,149}\text{Sm}$ (n, $\alpha$ )	Cross section measurements with the LSDS, <b>Published</b> <i>J.T. Thompson, T. Kelley, E. Blain, R.C. Haight, J.M. O'Donnell, Y. Danon, "Measurement of (n,<math>\alpha</math>) reactions on <math>^{147}\text{Sm}</math> and <math>^{149}\text{Sm}</math> using a lead slowing-down spectrometer", Nuclear Instruments and Methods in Physics Research Section A, Volume 673, Pages 16-21, 1 May (2012)</i>
Ti, Ta, Zr, 92/94,95,96,98,100,natMo	High energy (0.5-20MeV) publication in preparation
$^{235}\text{U}$	Capture and fission in the energy range thermal to 5 keV (thesis in progress), keV data analyzed by ORNL
92/94,95,96,98,100,natMo, $^{153}\text{natEu}$ , $^{161,162,163,164}\text{Dy}$ $^{155,156,157,158,160}\text{Gd}$ ,	Gd publication in preparation Resonance parameters analysis in progress (Dy, Eu)



# Ti Total Cross Section Measurements 0.5 – 20 MeV



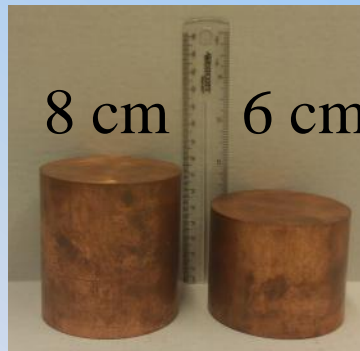
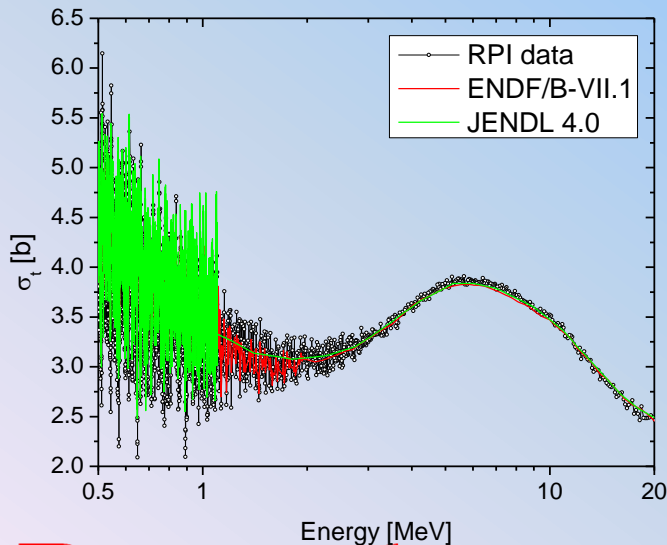
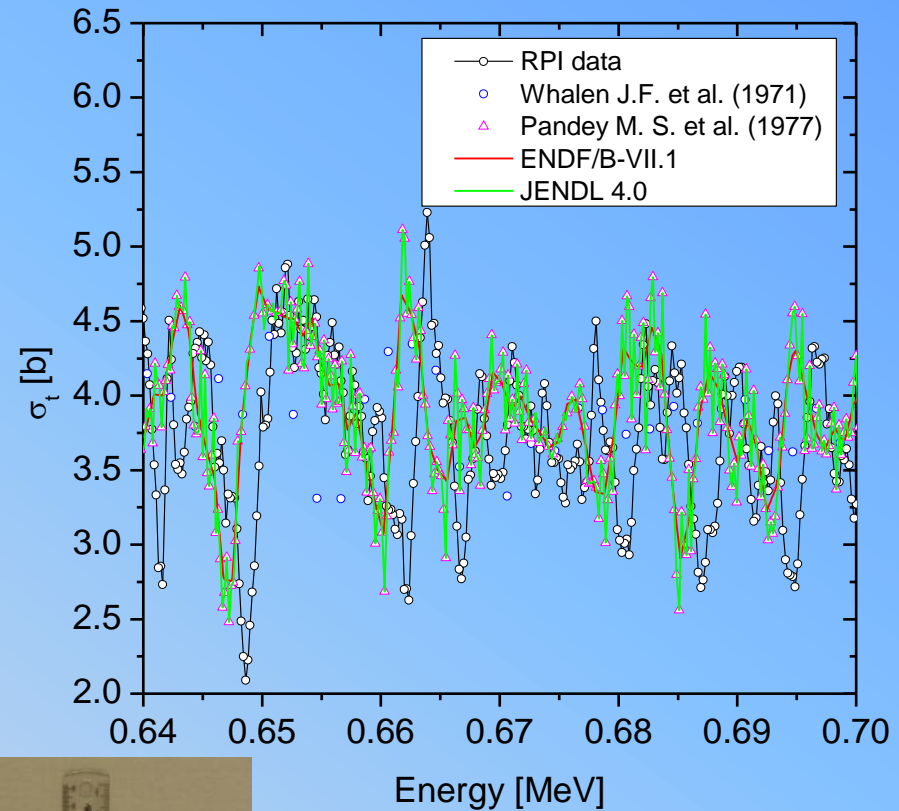
- 250m flight path measurement shows structure that was not resolved in prior measurements
- JEFF 3.1.2 shows an energy shift
- ENDF/B-VII.1 lower resolution than JEFF 3.1.2 and ENDF/B-VII.0



# Cu Total Cross Section Measurements

## 0.5 – 20 MeV

- All Evaluations similar with the exception of JENDL 4.0
  - Follows the isotopic measurements by Pandey et al.
  - JENDL shows more structure below 1.1 MeV, but smoothes to average value prior to other libraries (1.1 MeV vs. 2.0 MeV)
- Shift in energy seen in evaluations



# $^{151,153}\text{Eu}$ Measurements - Samples

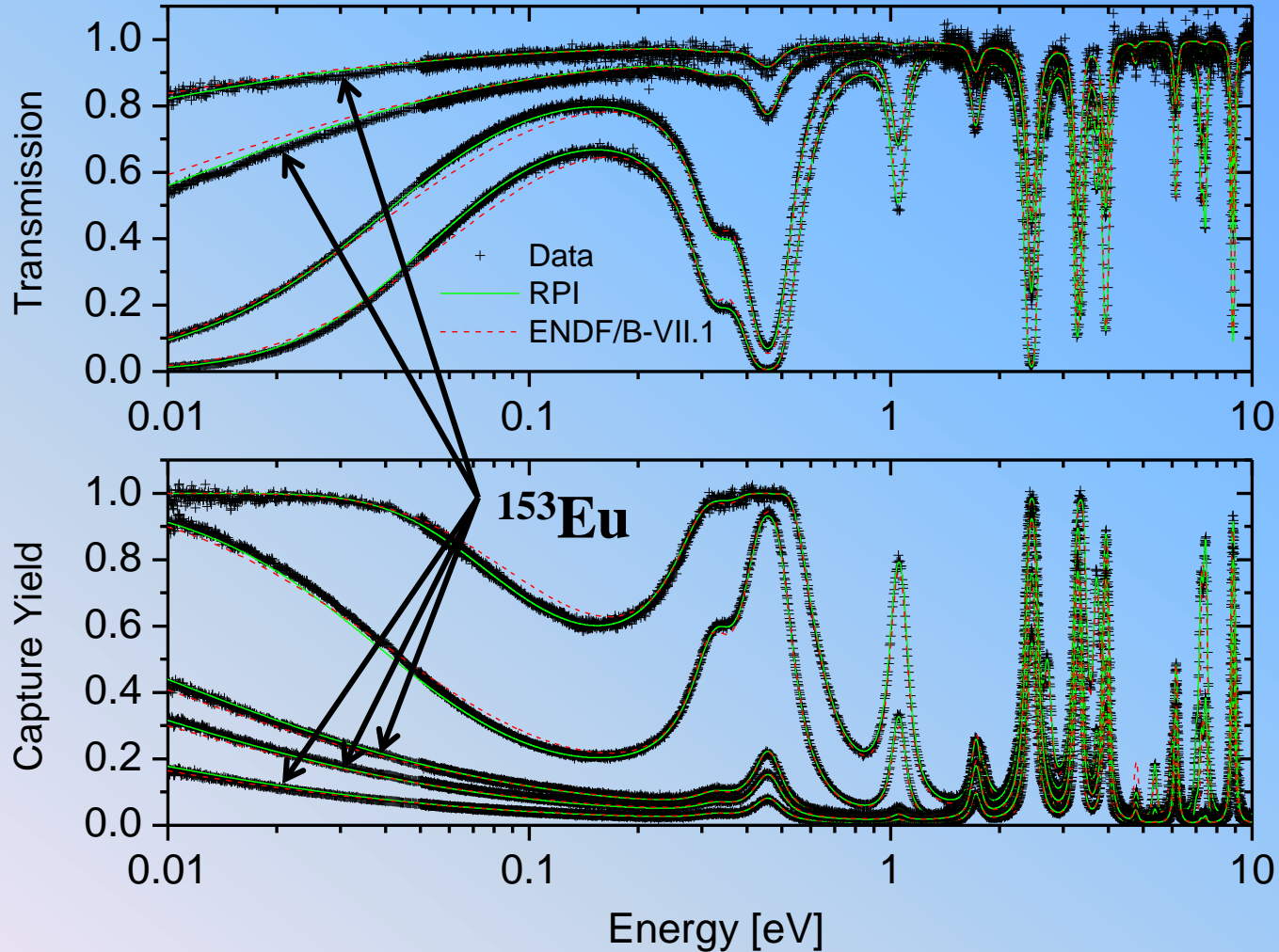
- Stable samples of volatile metals
- Natural and enriched metal samples
- Sample thickness details verified by X-ray imaging.\*

	Natural Samples [at frac.]	Enriched [at frac.]
$^{151}\text{Eu}$	0.478	0.0123
$^{153}\text{Eu}$	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”, submitted to Journal of X-Ray Science and Technology, 2012.



# $^{153}\text{natEu}$ Thermal/Epithermal Region Fit





# Eu Thermal Total Cross Sections (barns) from SAMMY fits

- Results in significant changes to negative energy resonances

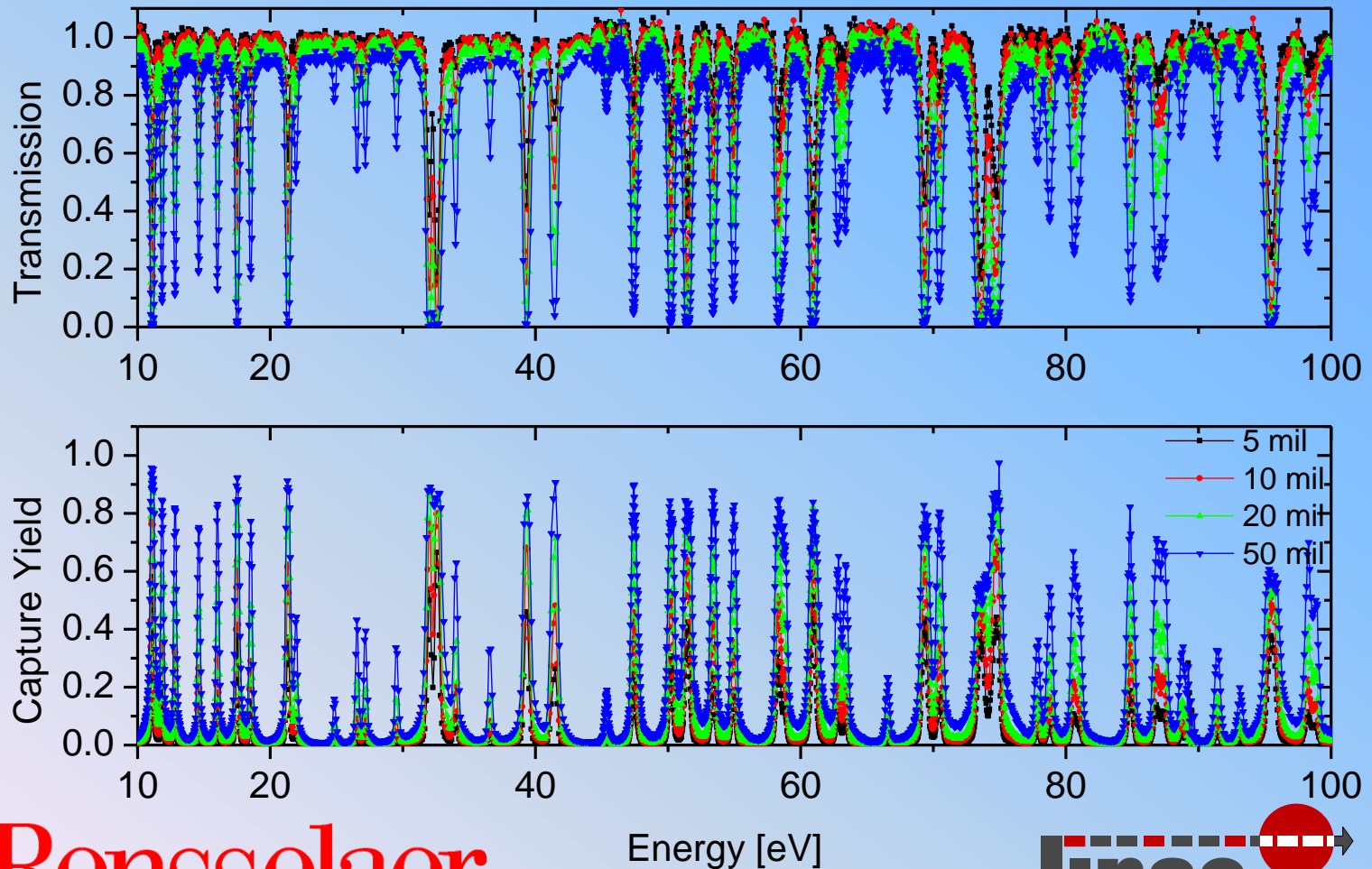
Isotope	ENDF error from atlas [b]	RPI [b]	Dean et al. Reactivity Worth [b]	Mughabghab [b]
$^{151}\text{Eu}$	$9187 \pm 100$	$9700 \pm 200$		
$^{153}\text{Eu}$	$321 \pm 8$	$350 \pm 20$	$382^*$	$358^*$

(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.

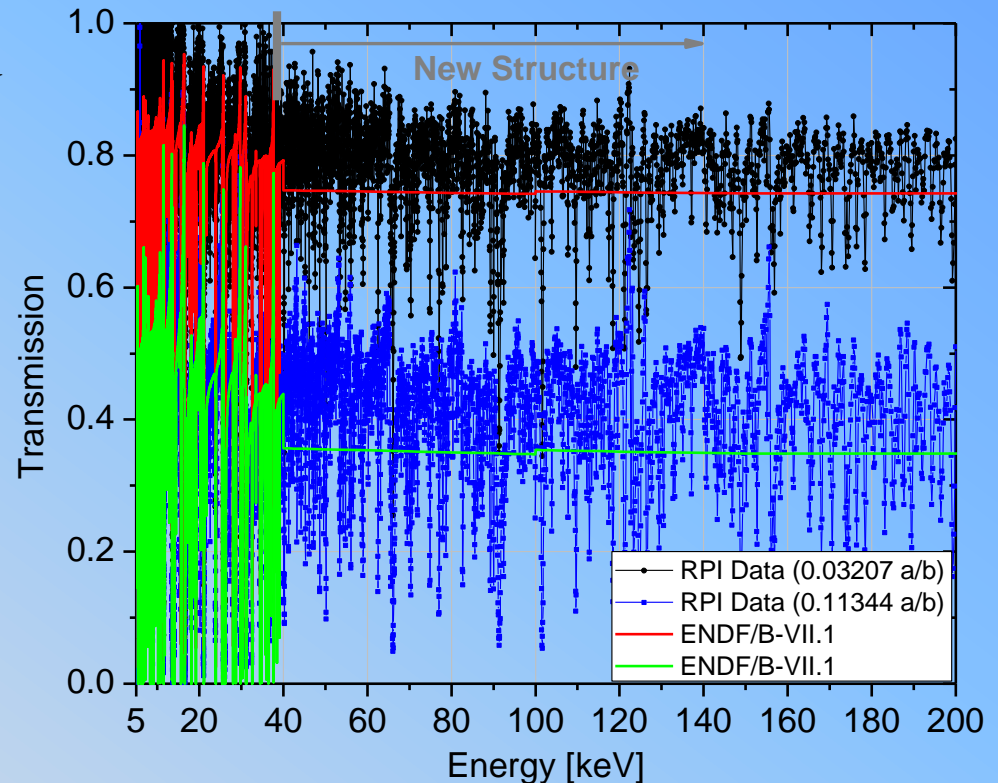
# Re Epithermal Measurements

- Capture corrected for gamma attenuation (2<sup>nd</sup> densest element)
- Higher and lower energy transmission and capture data taken; analysis underway



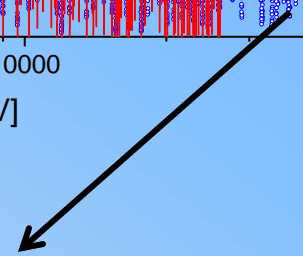
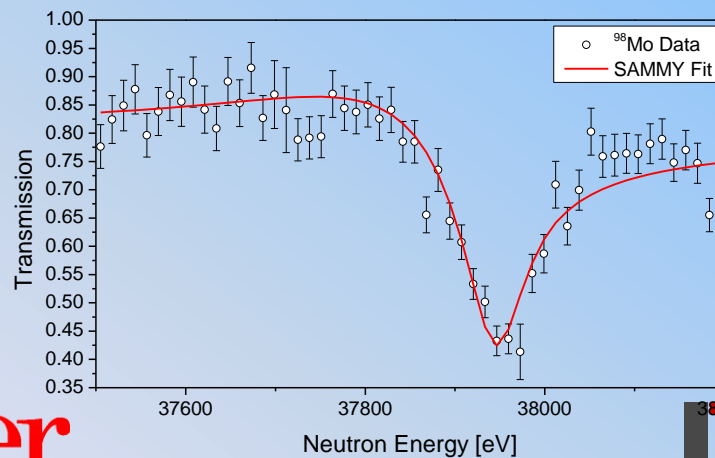
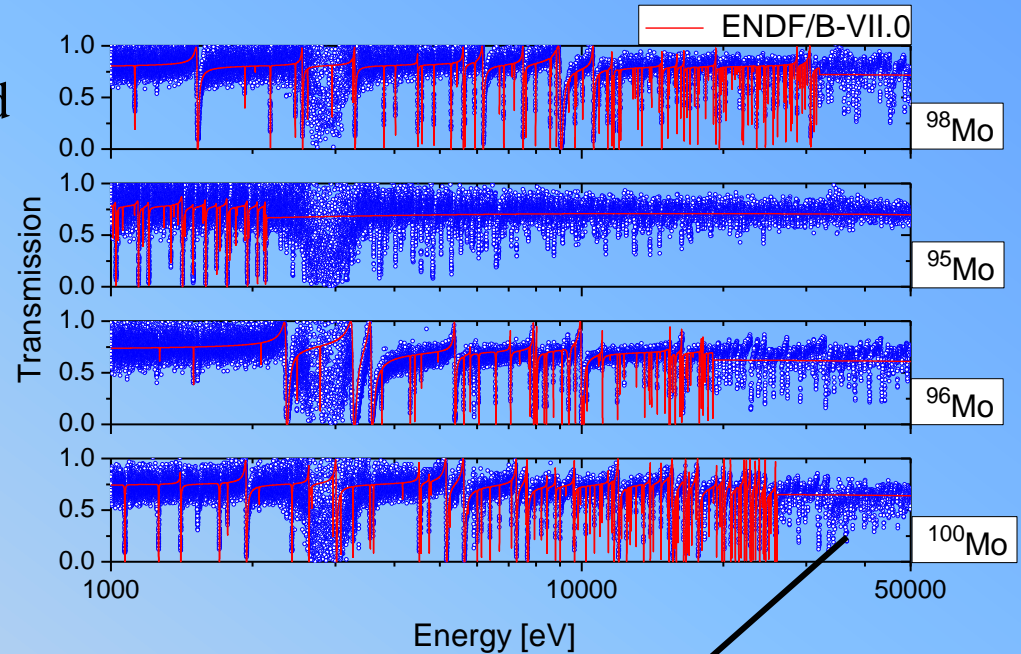
# Measurements of $^{92/94}\text{Mo}$ Transmission at 100m Flight Path

- High resolution Mo transmission data was measured from 5 keV to 200 keV
- Enriched Mo samples were prepared by Bettis (75.57%  $^{92}\text{Mo}$ , 23.77%  $^{94}\text{Mo}$ )
- The data show (possibly resolved) structure within the current URR
- Additional experiments are planned for next year to improve statistics
- Data analysis started.



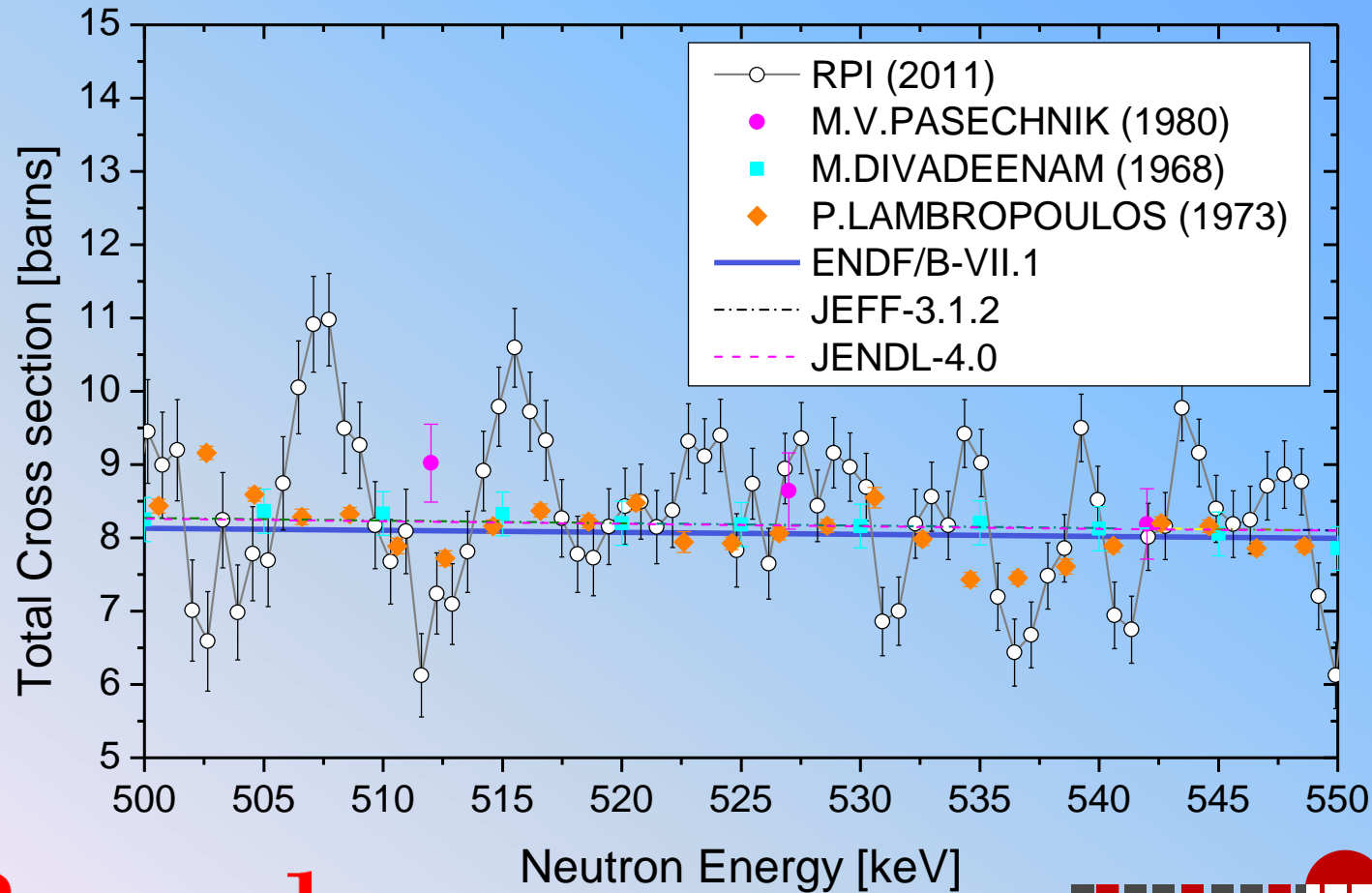
# Isotopic Mo Measurements in the Energy Range 1 – 620 keV

- $^{95,96,98,100}\text{Mo}$  data in the resolved region shows good agreement with ENDF in the RRR.
- The new high resolution data include newly resolved resonances extending the RRR for each isotope.
- A treatment for data analysis in the URR is currently under development.



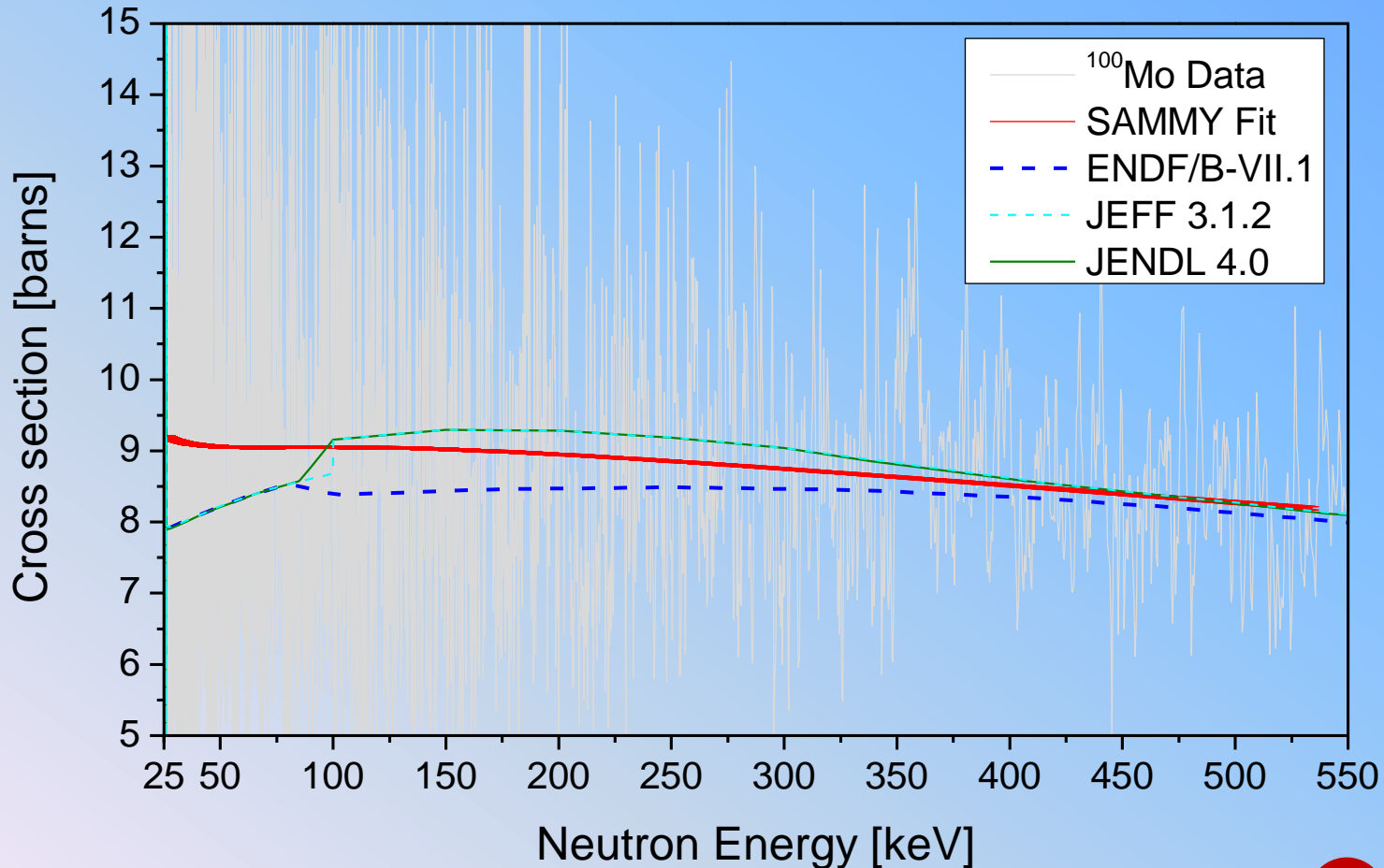
# Isotopic Mo Experimental Data in the URR

- New  $^{100}\text{Mo}$  experimental data is compared to previous data.
- Partially resolved structure can clearly be seen due in the higher resolution of the RPI experiment.



# Isotopic Mo Data Analysis and Evaluation in the URR

- The fit to the high-resolution  $^{100}\text{Mo}$  experimental data deviates from the current ENDF evaluations by 2-15% – and is in closer agreement with the JEFF/JENDL evaluation.



# Isotopic Mo Measurement and Evaluation in the URR

- Average resonance parameters / covariances extracted from SAMMY fit in URR.
- Comparisons were made to JENDL-4 (ENDF/B-VII.1 has average parameters only up to 100 keV and they were obtained from the JENDL-3.3).

<sup>100</sup> Mo Varied Parameter	Atlas Value	SAMMY
R' (fm)	$6.9 \pm 0.2$	$6.81 \pm 0.02$
$S_{l=0}$	$0.8 \pm 0.22$	← Kept
$S_{l=1}$	$5.14 \pm 0.71$	$4.66 \pm 0.05$
$S_{l=2}$	N/A	$2.00 \pm 0.01$
$\Gamma_{\gamma l=0}$ (eV)	$0.064 \pm 0.004$	$0.064 \pm 0.004$
$\Gamma_{\gamma l=1}$ (eV)	$0.093 \pm 0.012$	$0.093 \pm 0.012$

<sup>100</sup>Mo:  $S_{l=0}$ ,  $J^\pi = +1/2$

SAMMY			JENDL-4		
E (keV)	D (eV)	$g\Gamma_n^0$ (meV)	E (keV)	D (eV)	$g\Gamma_n^0$ (meV)
100	521.58	0.0417	100	617	0.039488
200	441.52	0.0353	200	435.63	0.02788
300	374.26	0.0299	300	322.16	0.020619
400	317.65	0.0254	400	247.08	0.015813
500	270	0.0216	500	195.52	0.012513

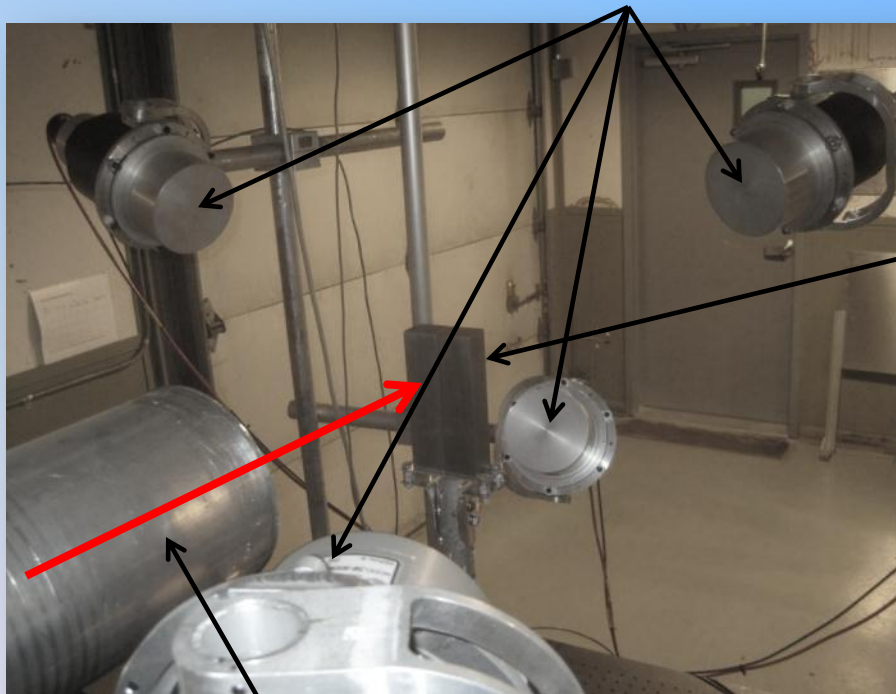
<sup>100</sup>Mo:  $S_{l=1}$ ,  $J^\pi = +1/2$

SAMMY			JENDL-4		
E (keV)	D (eV)	$g\Gamma_n^0$ (meV)	E (keV)	D (eV)	$g\Gamma_n^0$ (meV)
100	521.58	0.244	100	617	0.31714
200	441.52	0.207	200	435.63	0.22391
300	374.26	0.175	300	322.16	0.16559
400	317.65	0.149	400	247.08	0.127
500	270	0.126	500	195.52	0.1005



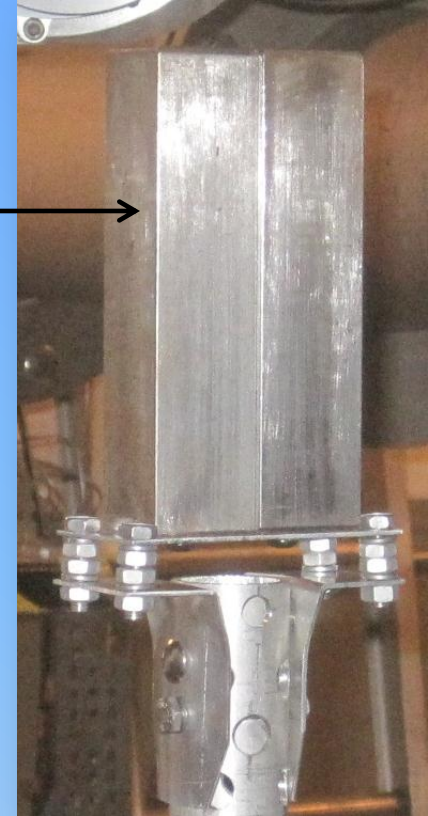
# $^{56}\text{Fe}$ Scattering Measurement - Setup

EJ-301 Liquid Scintillator Neutron Detectors



Evacuated Flight Tube

- $^{56}\text{Fe}$  Sample
- 99.87% metallic  $^{56}\text{Fe}$
- Dimensions 77.0 x 152.6 x 32.2 mm

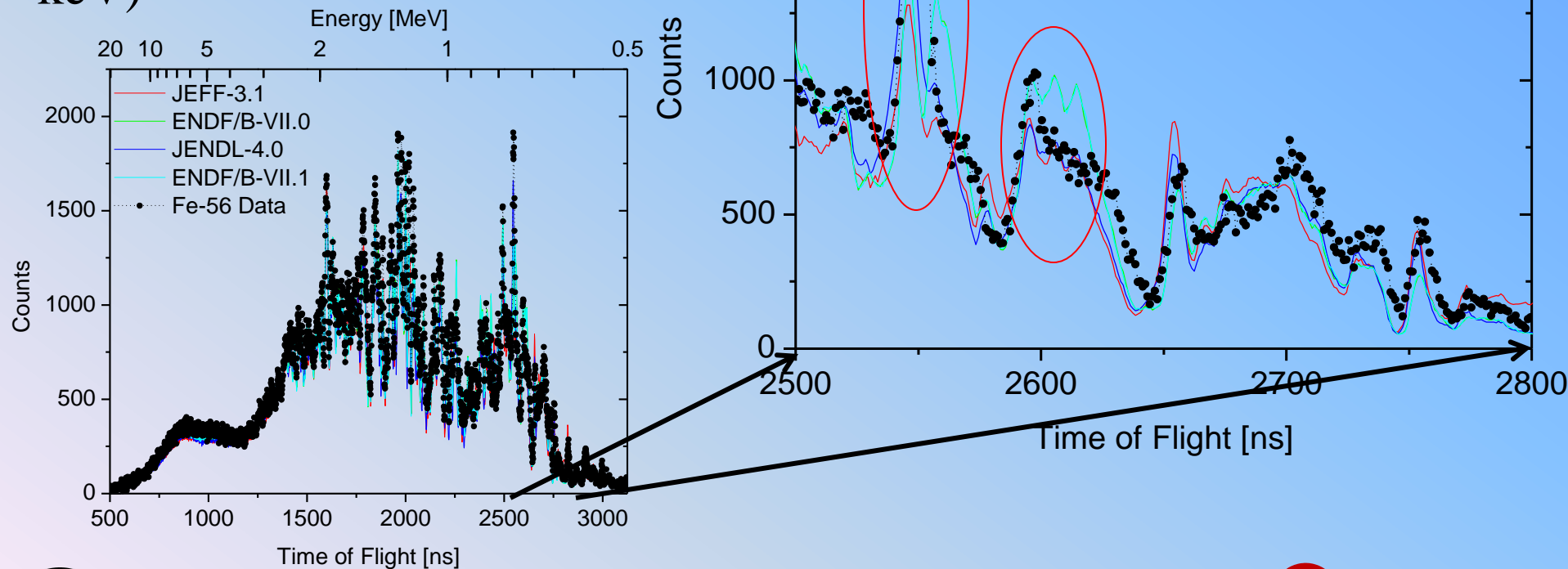


The neutron beam size is smaller than the sample.



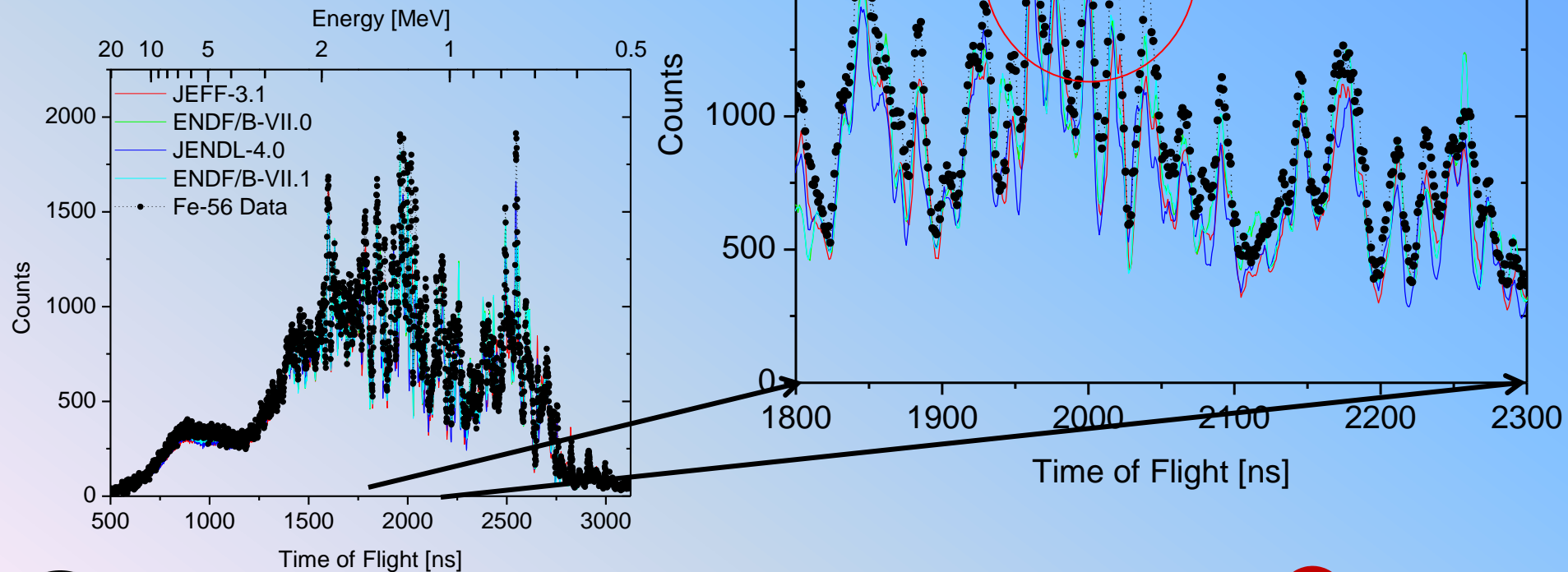
# $^{56}\text{Fe}$ Scattering Measurement – Results $155^\circ$

The energy resolution is sufficient to show some discrepancies in the resonance region ( $E < 850$  keV)



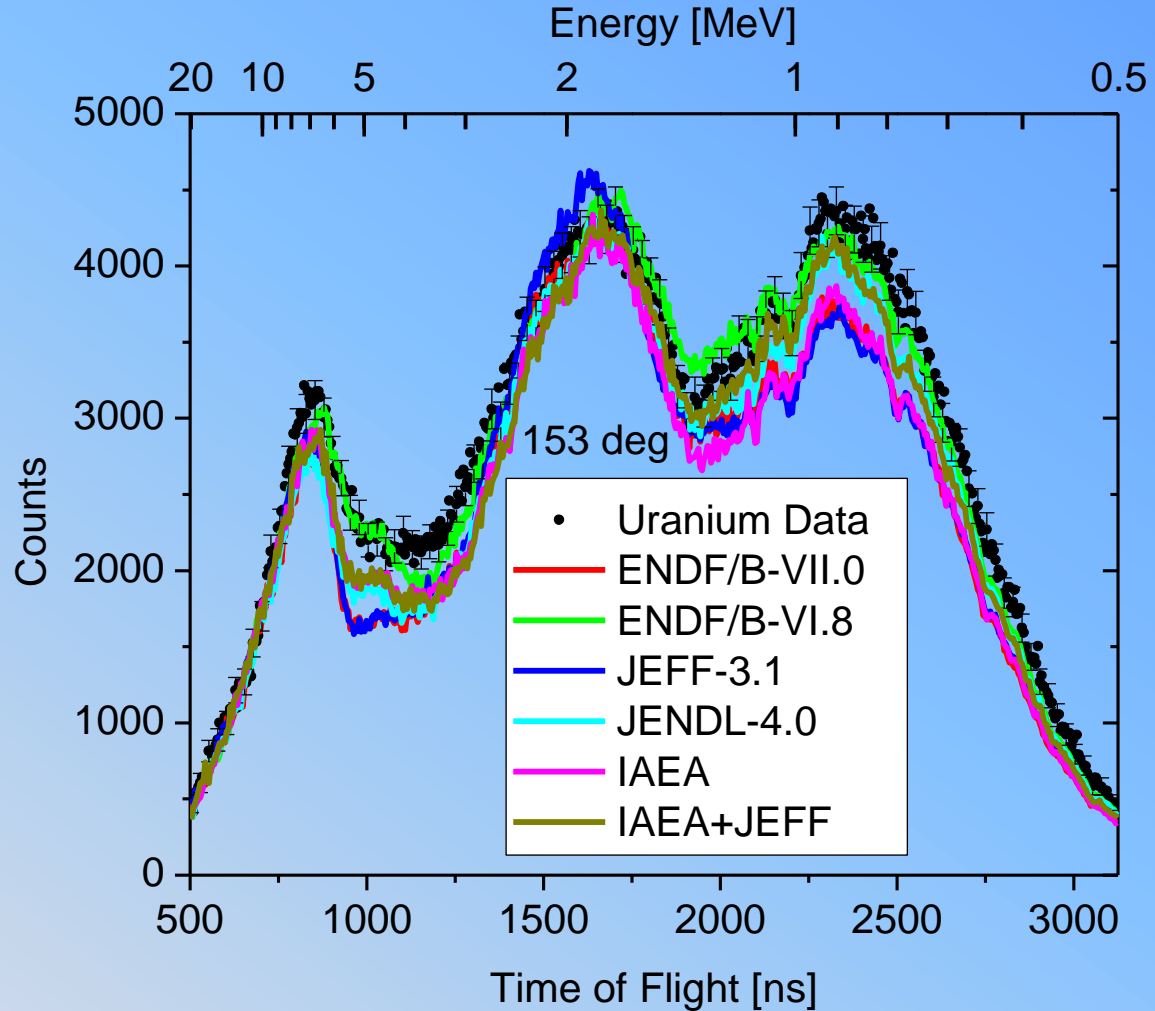
# Fe-56 Scattering Measurement – Results 155°

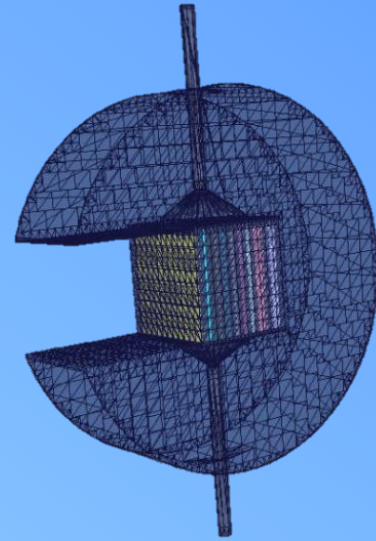
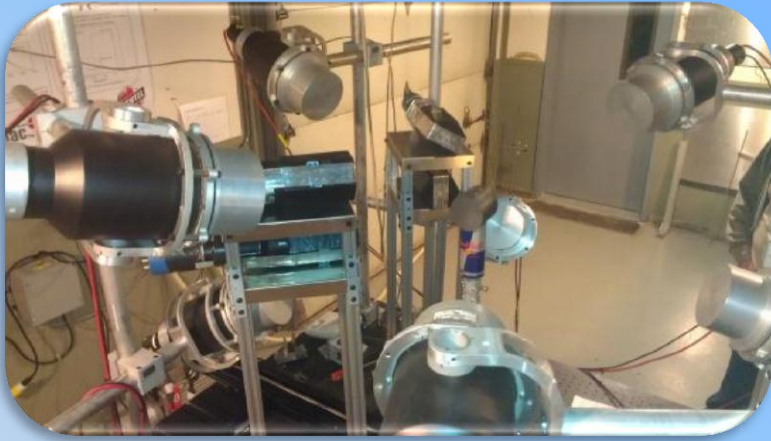
- Above the first inelastic state ( $E > 847$  keV) there are some differences with the evaluations
- We are exploring the possibility to extract double differential cross section data from these experiments.



# $^{238}\text{U}$ Scattering Revisited

- Following the WINS meeting we interacted with Trkov Andrej and Roberto Capote from IAEA to help improve new  $^{238}\text{U}$  evaluation
- The new evaluation performed well at forward angles
- At back angles the IAEA evaluations with JEFF angular distributions performed better than JEFF3.1 and ENDF/B-VII.1 but for  $E > 2$  MeV still lower than the experimental data (ENDF/B-VI.8 performs better).





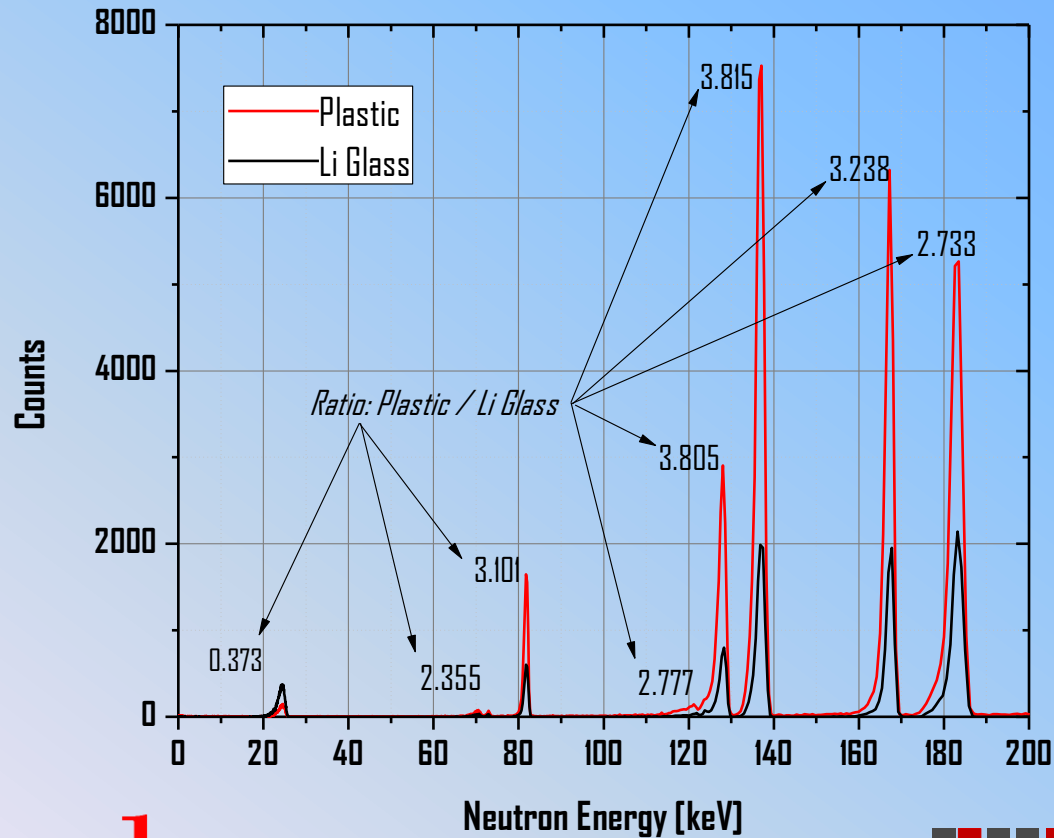
# Development of New Capabilities



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# Consider the use of Plastic Scintillator

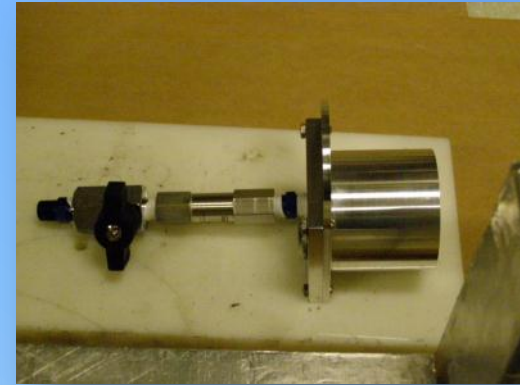
- Fe filtered beam experiment show possible improvement in efficiency when using 1.27 cm plastic scintillator to replace 1.27 cm Li-Glass
- Need to determine effect on background due to gamma sensitivity



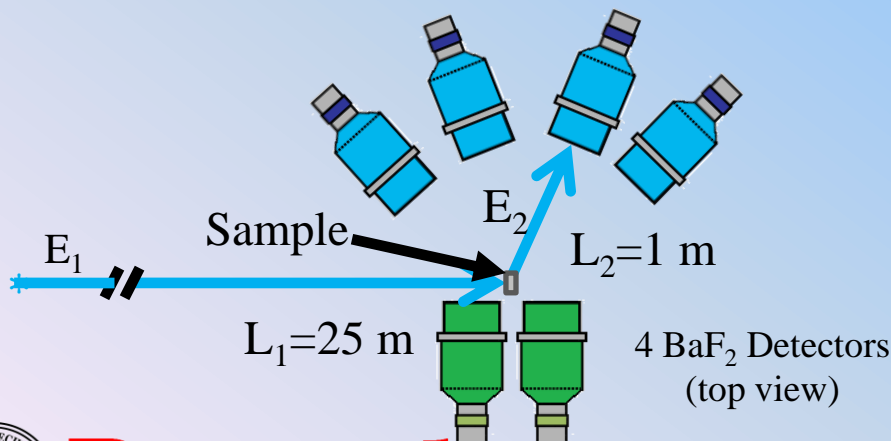
# Nu-bar and Fission Spectrum Measurements (SSAA)

- A system under development 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
- Initial tests with  $^{252}\text{Cf}$  fission are ongoing

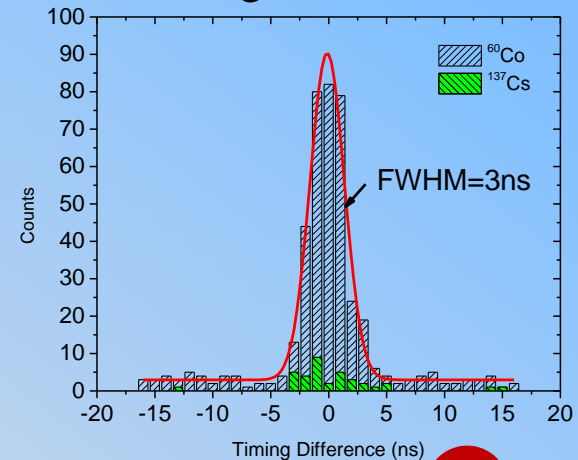
RPI designed and fabricated  $^{252}\text{Cf}$  (~18ng) fission chamber



## Experimental Setup



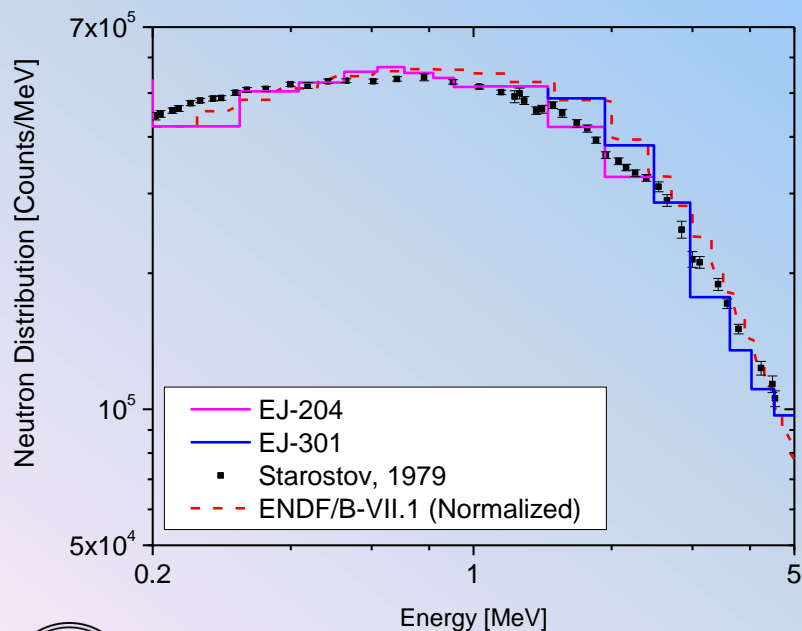
## Timing Resolution



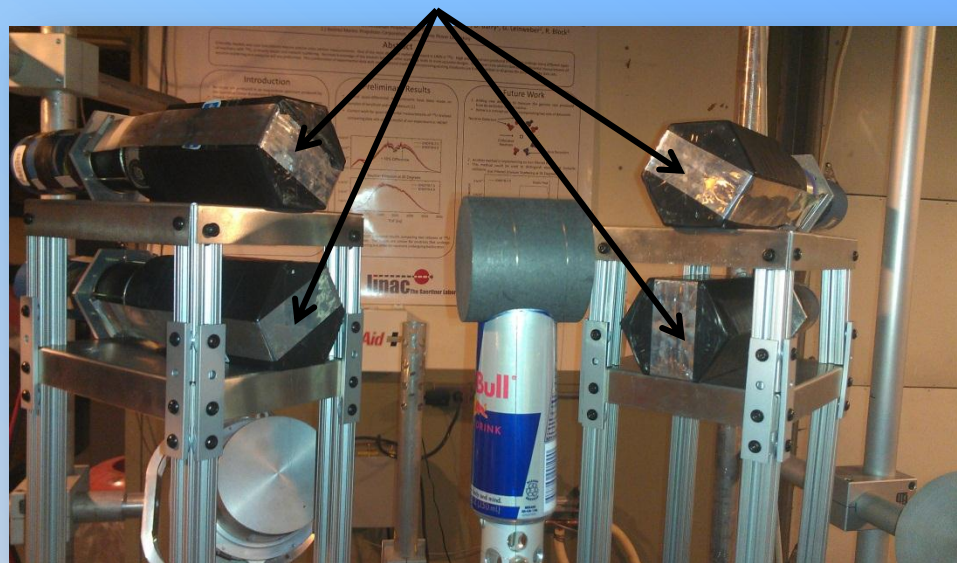
# Measurement of $^{252}\text{Cf}$ Prompt Fission Neutron Spectrum

- A preliminary step  $^{252}\text{Cf}$  was measured using the fission chamber as a fission tag.
- This kind of data will be compared with measurements using the gamma tag.
- EJ-301 measurements agree with ENDF/B-VII.1 from 5 MeV to 1 MeV while EJ-204 measurements extend the agreement down to 0.2 MeV

$^{252}\text{Cf}$  Prompt fission neutron spectrum

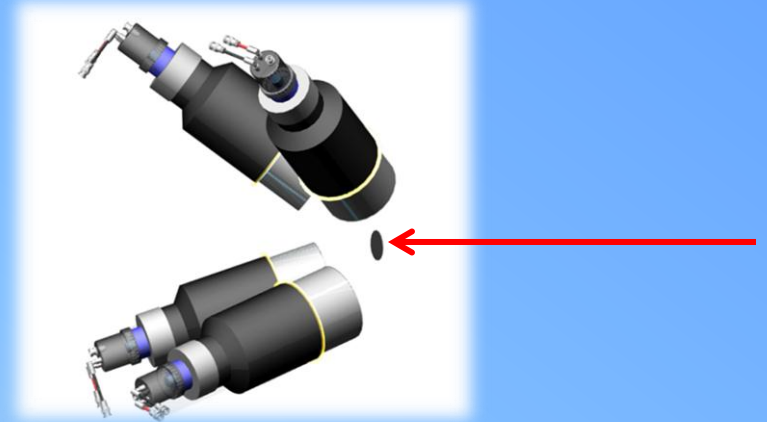


$\text{BaF}_2$  detector array

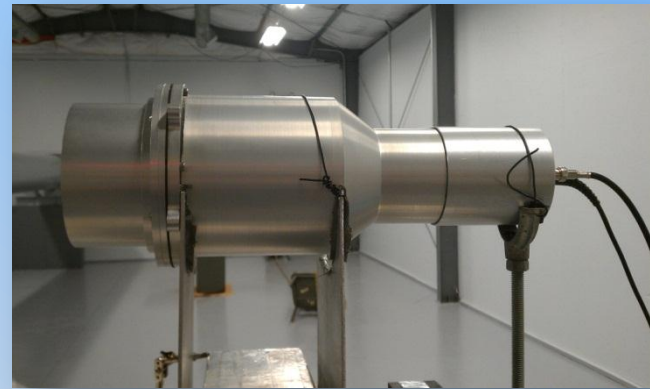


# Mid-Energy Capture Detector

- 4 deuterated benzene ( $C_6D_6$ ) liquid scintillators with low neutron sensitivity
- Located at newly constructed 40m flight station
- 10-bit, 8 channel Struck Systems SIS3305 digital data acquisition system allows for low dead time operation
- Low mass design to minimize background contributions from neutrons captured in detector and surrounding structural materials



CAD model of the detector array and sample



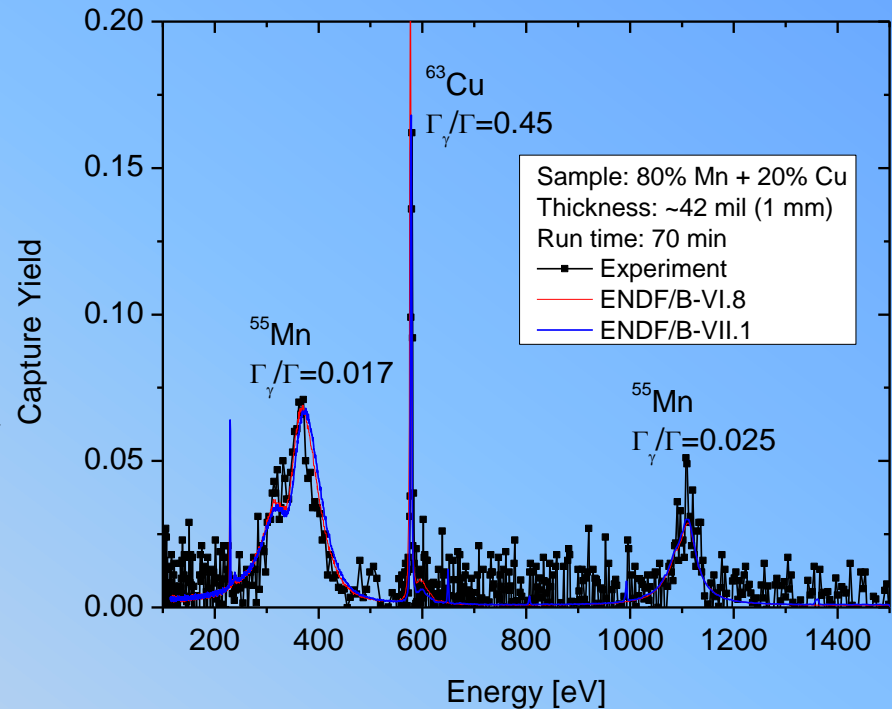
A picture of the prototype detector





# Mid-Energy Capture Detector First Test

- Capture measurements performed on Mn/Cu sample using existing analog TOF setup
- Experimental results show consistency with ENDF/B-VI.8 and VII.1 data libraries
- Low contribution from scattered neutrons is apparent
- Future experiments will incorporate a digital DAQ system



# Summary

- **Publications in 2012**

- $^{147,149}\text{Sm}$  (n, $\alpha$ ) cross section measurements with the LSDS (Published, Nuc. Inst Meth. A)
- Eu sample x-ray characterization (submitted to Journal of X-Ray Science and Technology)
- High energy scattering from Zr (accepted to NS&E)
- High energy transmission for Be and C (accepted to NS&E Nov. 2012)

- **Analysis in progress**

- Ti, Ta, Zr and  $^{92/94,95,96,98,100,\text{nat}}\text{Mo}$  high energy (0.5-20 MeV) transmission
- Eu,  $^{153}\text{Eu}$ ,  $^{161,162,163,164}\text{Dy}$ ,  $^{155,156,157,158,160}\text{Gd}$ ,  $^{236}\text{U}$ – Resonance parameter analysis
- $^{92/94,95,96,98,100}\text{Mo}$  resonance region (10 eV - 600 keV) transmission measurements
- $^{238}\text{U}$ ,  $^{56}\text{Fe}$  neutron scattering

- **Planned measurements**

- $^{92/94}\text{Mo}$ , Transmission, 10 eV - 600 keV, 100m and 30m flight paths
- $^{236}\text{U}$ , Transmission, 15m flight path, concentrate on the 5.45 eV resonance
- Fission neutron spectra and nubar from  $^{252}\text{Cf}$  and  $^{235}\text{U}$
- $\text{H}_2\text{O}$ , Thermal neutron scattering
- Continue development of mid energy capture detector

