

Update on CIELO Related Nuclear Data Measurements at the Gaertner LINAC Center at RPI

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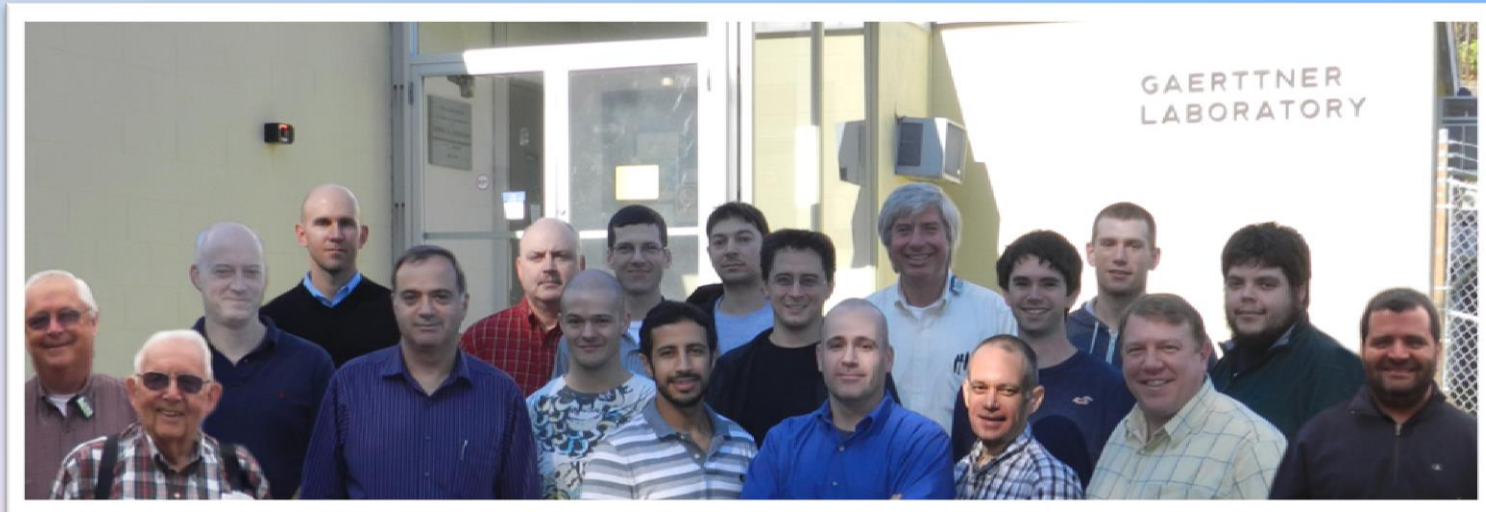
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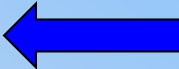
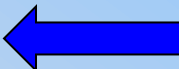
Undergraduate students

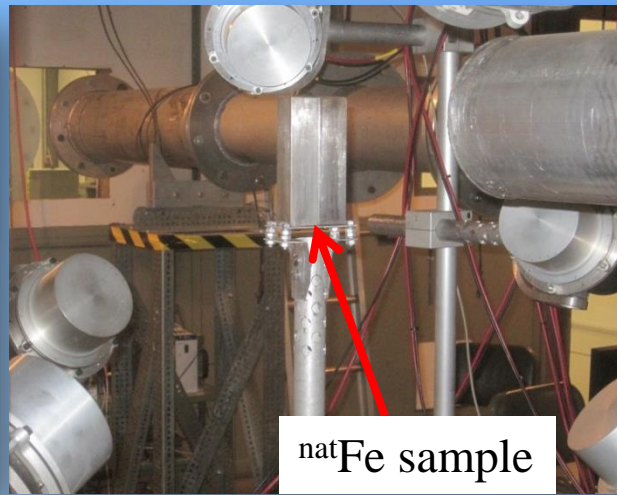
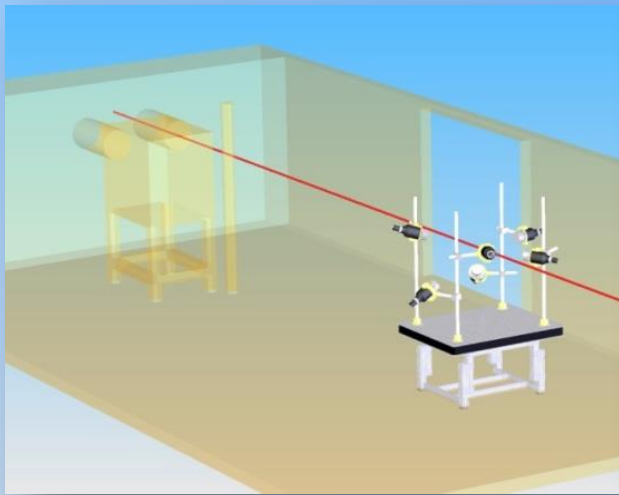
Amanda Lewis
Adam Ney
John Thai
Madison Wyatt



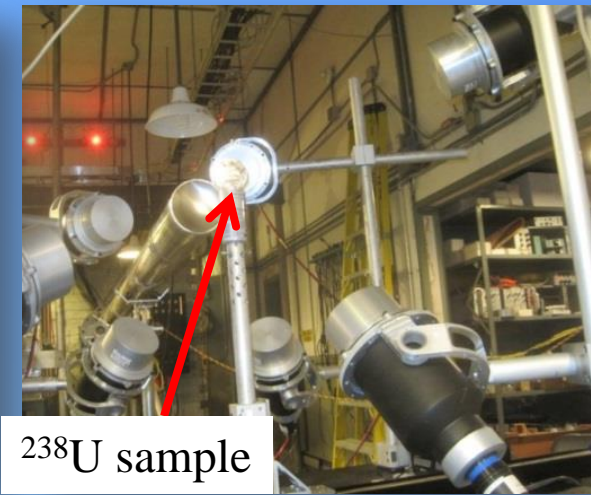
Summary of CIELO Related Activity at RPI

Experimental data to help benchmark and improve new evaluations

- ^{235}U
 - Fission and capture yield up to 2.5 keV
- ^{238}U
 - Neutron Scattering 0.5 – 20 MeV
- ^{56}Fe , $^{\text{nat}}\text{Fe}$  *Update*
 - High resolution transmission, 0.5-20 MeV
 - Neutron capture from 1 keV to 2 MeV
 - Neutron Scattering 0.5 – 20 MeV
- ^{16}O  *Update*
 - High resolution transmission, 0.5-20 MeV
- H_2O thermal scattering  *Update*



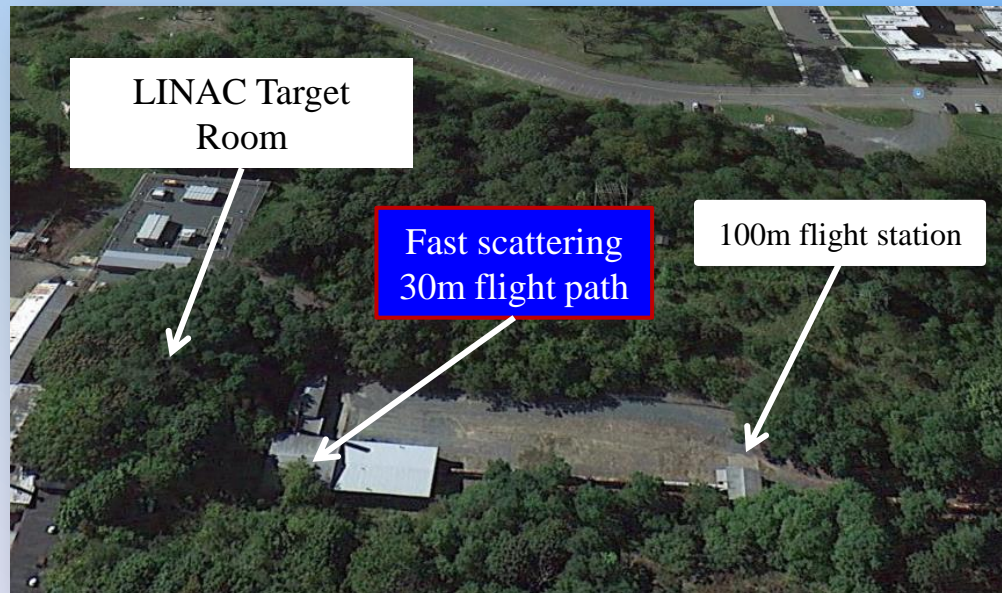
^{nat}Fe sample



^{238}U sample

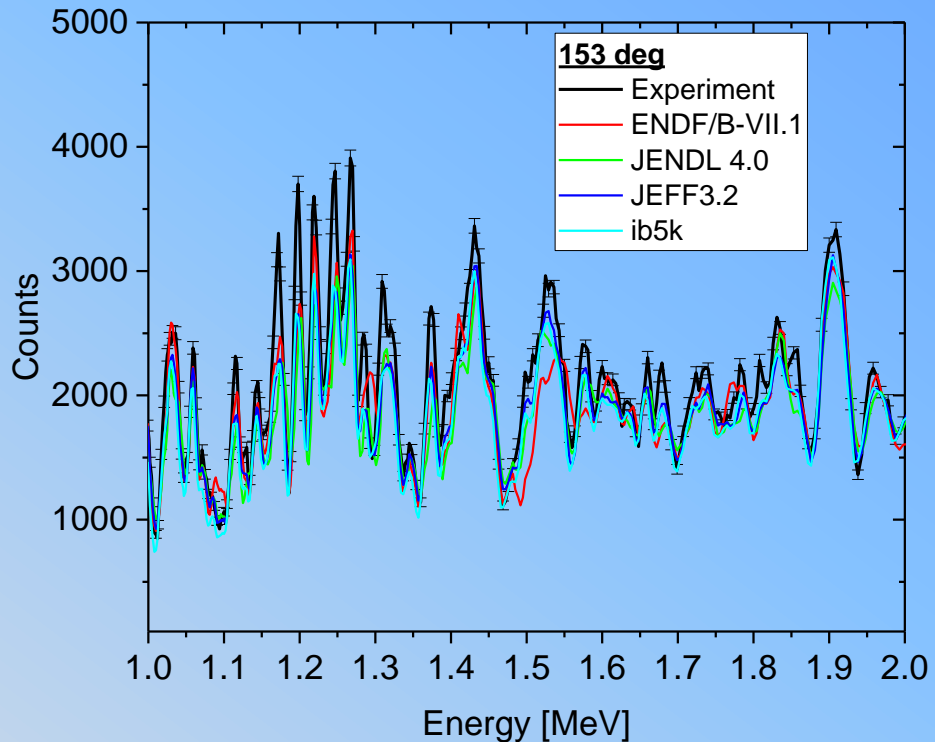
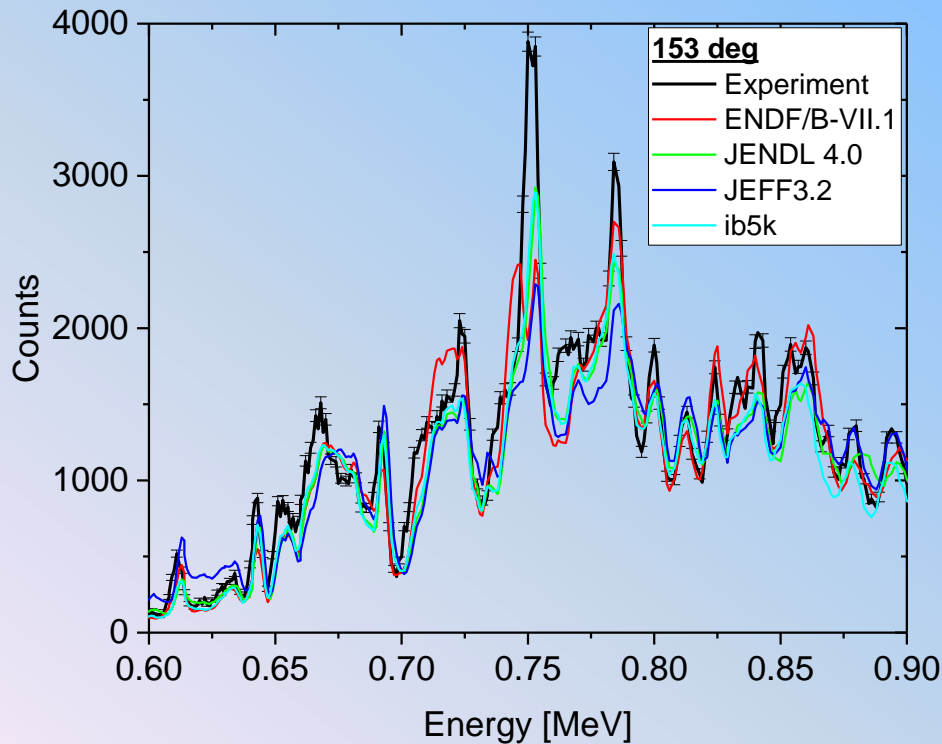
Neutron scattering benchmark of Fe-56 evaluations

Quasi-differential neutron scattering and angular distributions



Example scattering to 153 deg

- Left plot – energies below the 1st inelastic state.
- In order to quantify the differences FOM and C/E metrics were developed (next slides).

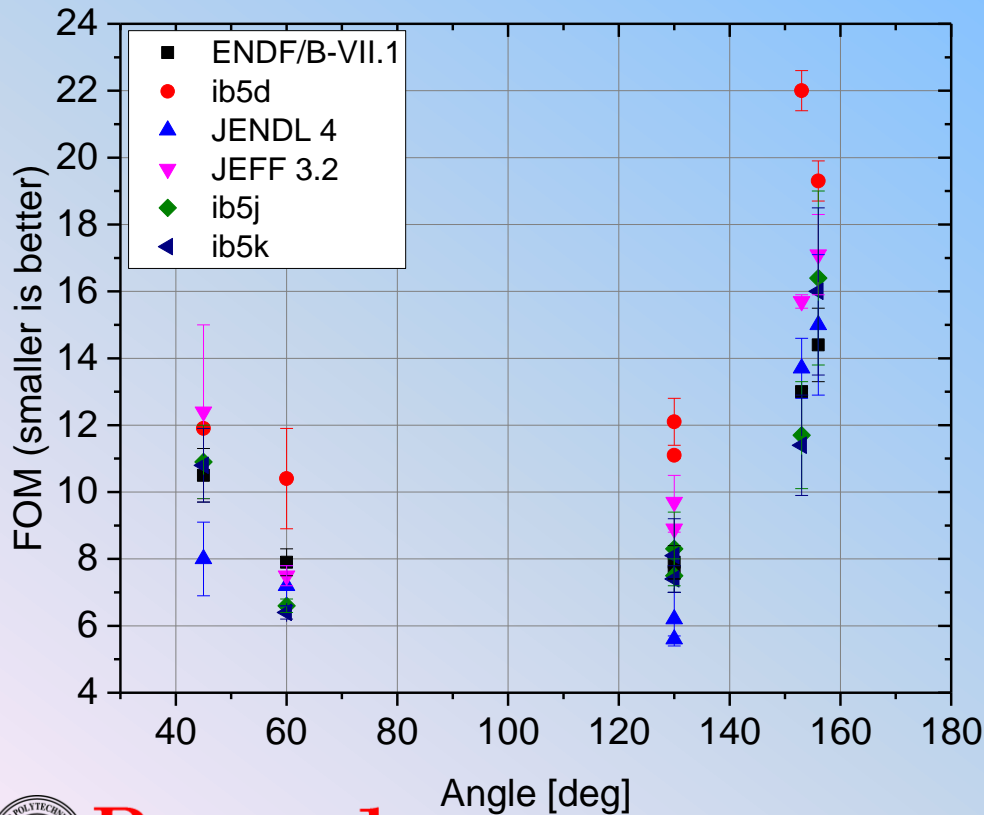


FOM

- For this comparison we define for a given angle FOM as

$$FOM = \frac{1}{n} \sum_{i=1}^n \frac{(Ex_i - Sim_i(1 \pm \epsilon_N))^2}{\Delta Ex_i^2 - (\epsilon_N Ex_i)^2}$$

n – number of TOF channels
 Ex_i, Sim_i – Experimental net counts, and normalized net simulation results
 ϵ_N – fractional normalization uncertainty
 ΔEx_i – uncertainty in the measured net number of counts



ib5k performs reasonably well
JENDL 4 seem to be overall best



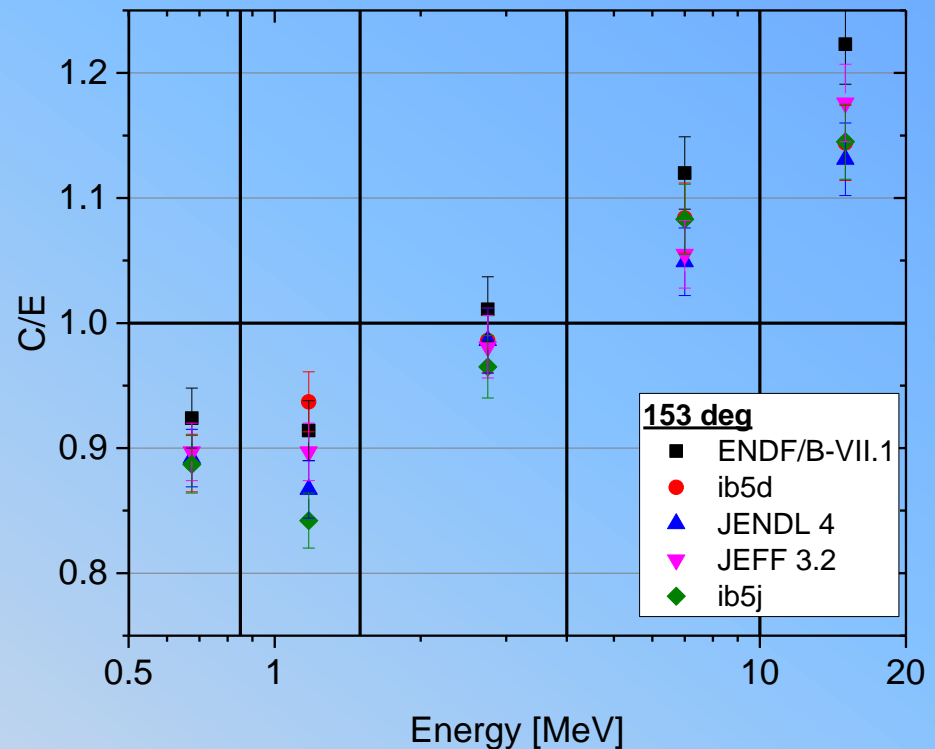
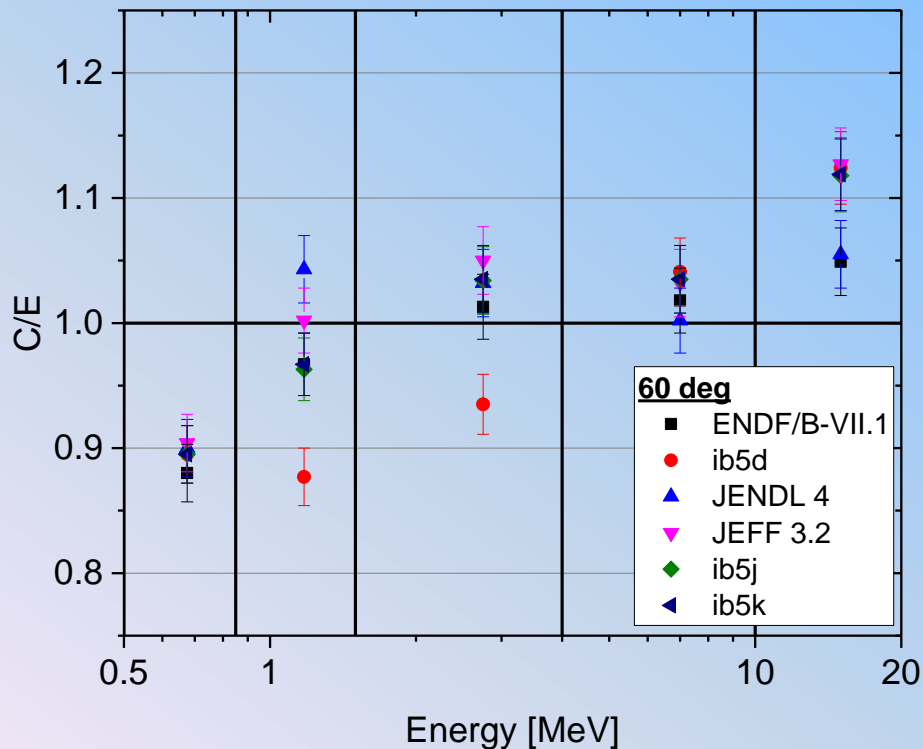
FOM Table

- Lowest FOM was highlighted; however, it could be within uncertainty of neighboring FOM values.
- Note that the 156 deg data should be similar to the 153 deg data; however, the FOMs are much larger, and so is uncertainty due to normalization.

Angle	ENDF /B-VII.1		ib5d		JENDL 4.0		JEFF 3.2		ib5k	
		±		±		±		±		±
60	7.9	0.4	10.4	1.5	7.2	0.6	7.5	0.3	6.4	0.2
153	13.0	0.1	22.0	0.6	13.7	0.9	15.7	0.2	11.4	1.5
156	14.4	1.1	19.3	0.6	15.0	2.1	17.1	1.2	16.0	2.5
130	7.6	0.2	11.1	0.1	5.6	0.1	8.9	0.1	7.4	0.4
130	7.9	0.5	12.1	0.7	6.2	0.8	9.7	0.8	8.1	1.1
45	10.5	0.8	11.9	0	8.0	1.1	12.4	2.6	10.8	1.1

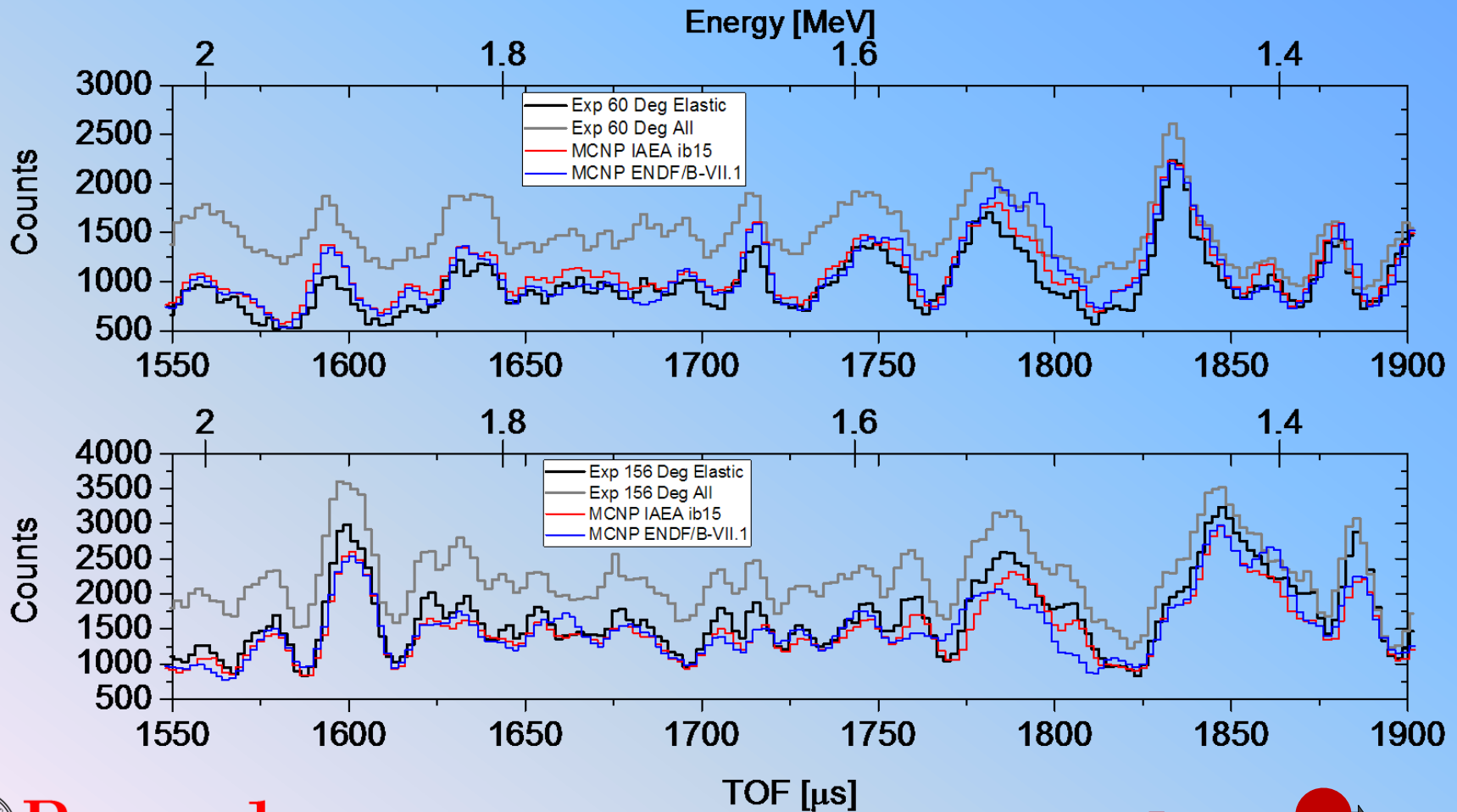
C/E

- C/E was calculated by first grouping the data and calculating the group ratio
- The uncertainty includes only the simulation normalization uncertainty



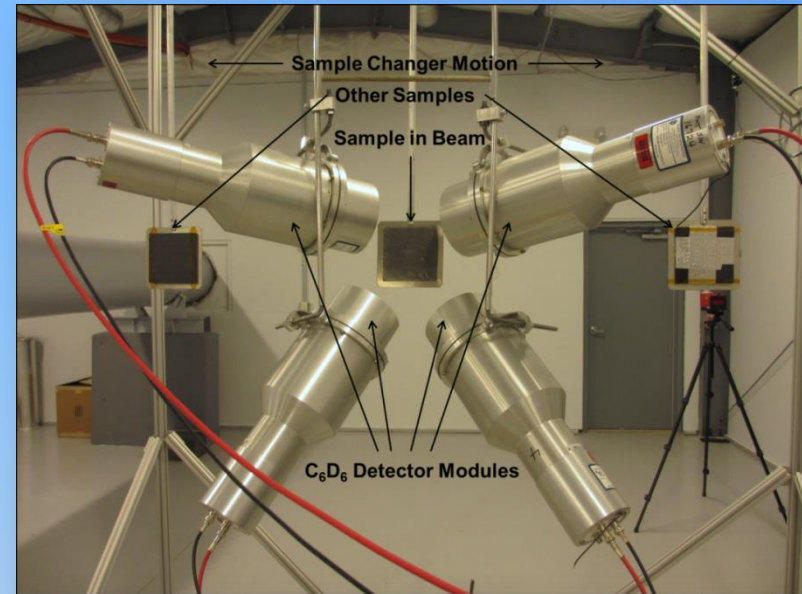
^{nat}Fe Elastic Only

- The new ib15k evaluation agrees slightly better with the experimental data



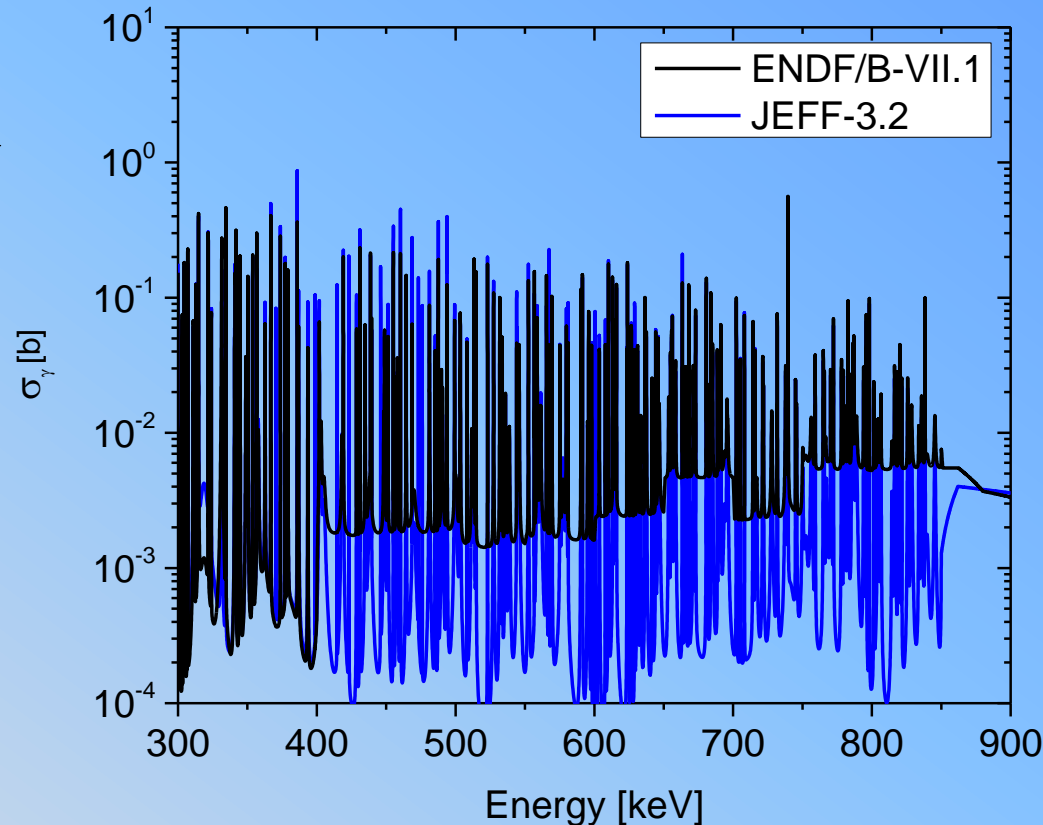
Mid-Energy Capture Detector System Overview

- 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



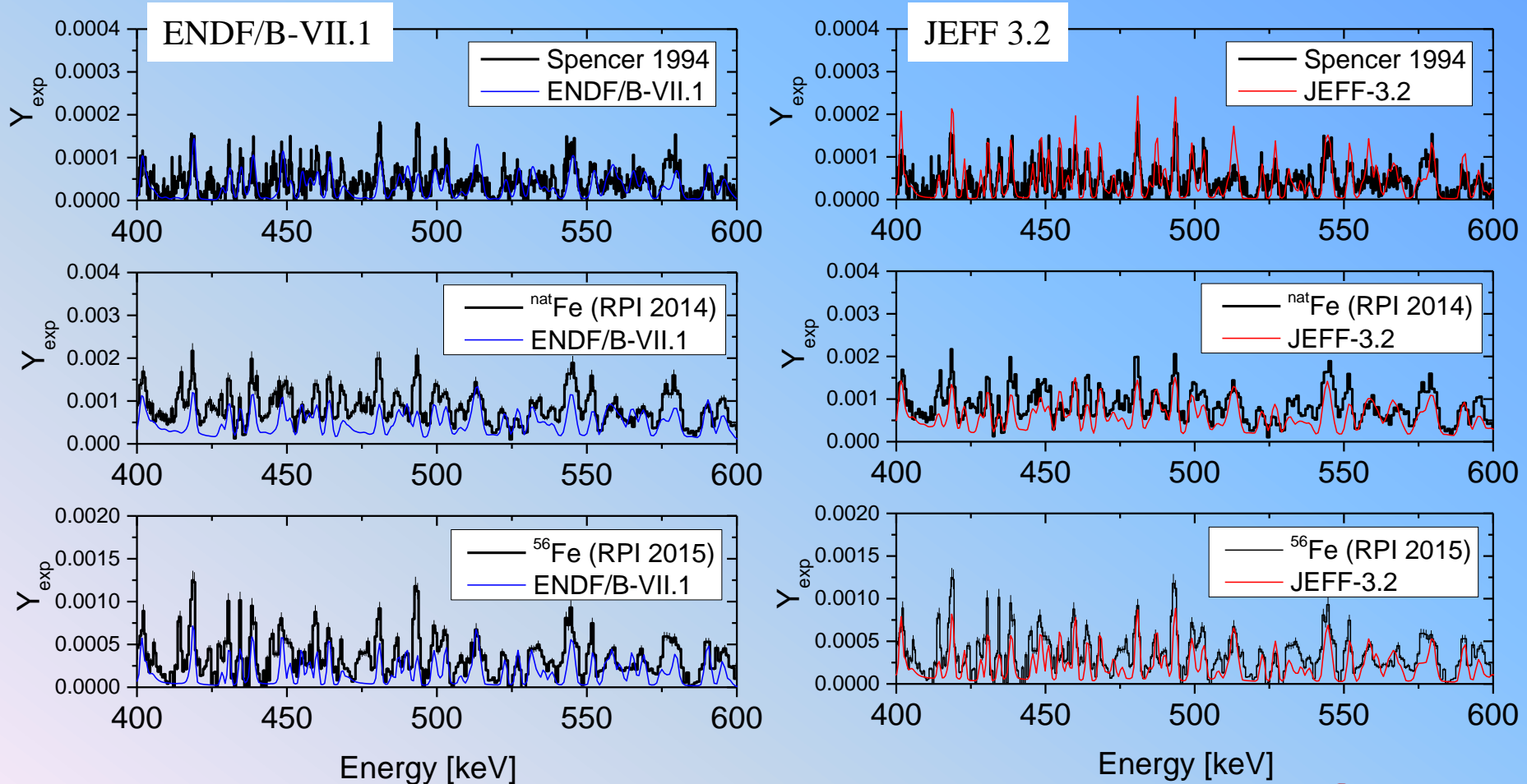
New measurements of ^{nat}Fe and ^{56}Fe capture cross sections up to 2 MeV

- ENDF/B-VII.1 evaluation for ^{56}Fe has artificial background above 400 keV
- Discrepancies are apparent in MCNP calculations



^{nat}Fe , ^{56}Fe Experimental Results vs Evaluations using SAMMY

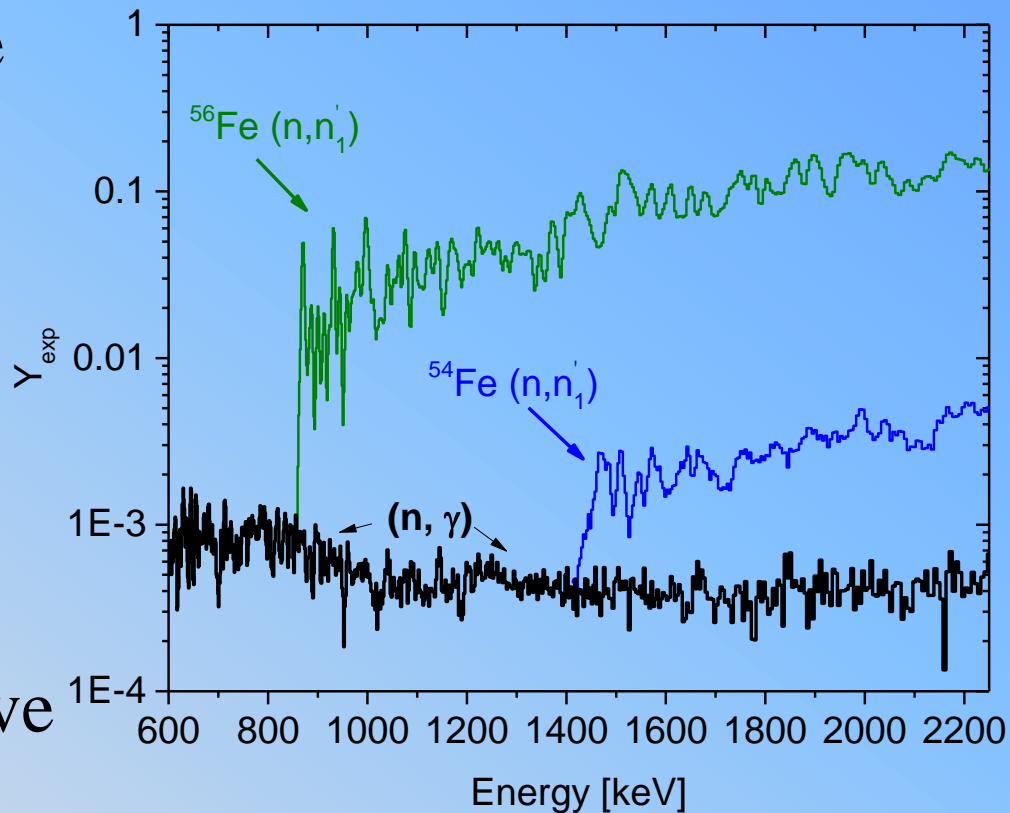
- JEFF 3.2 is matching our experimental data better than ENDF/B-VII.1



^{nat}Fe Capture for $E > 850$ keV

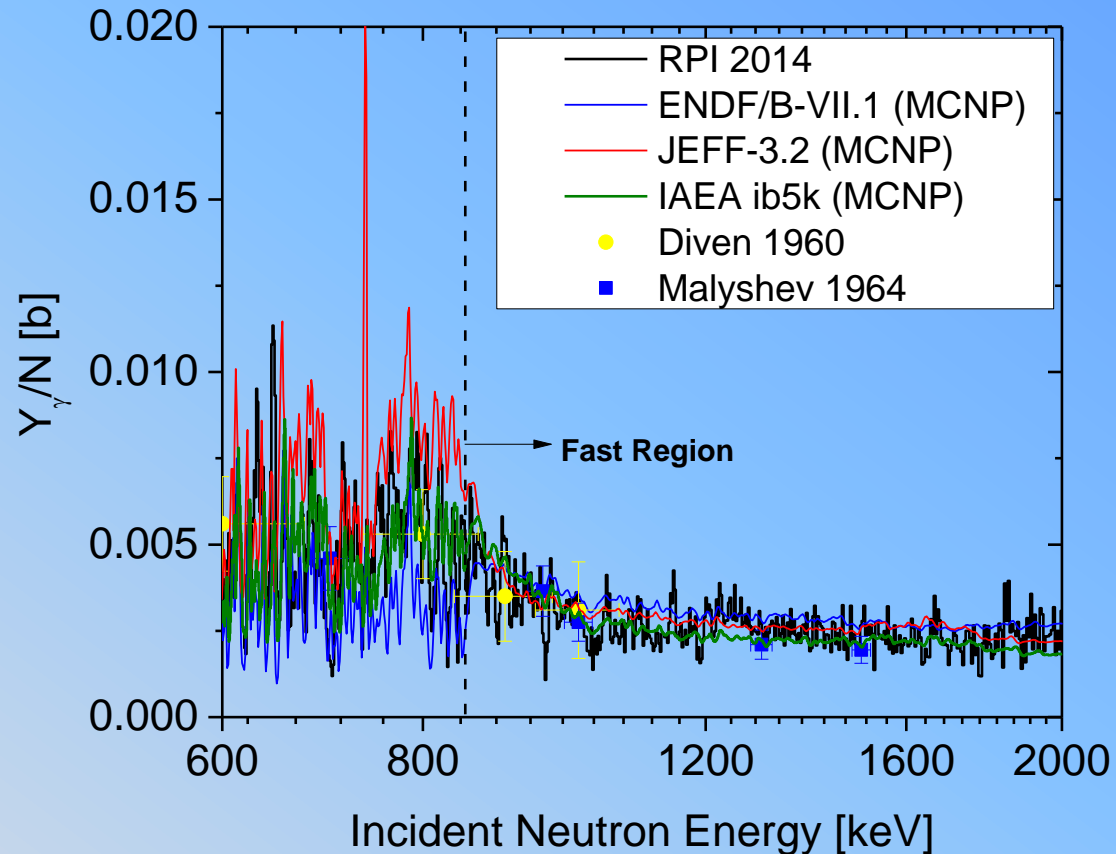
remove gammas from inelastic scattering

- Inelastic states in ^{54}Fe and ^{56}Fe make capture measurements at high energies difficult
- Digital pulse integral discriminator used to remove inelastic scattering signal
- New capture data above 850 keV



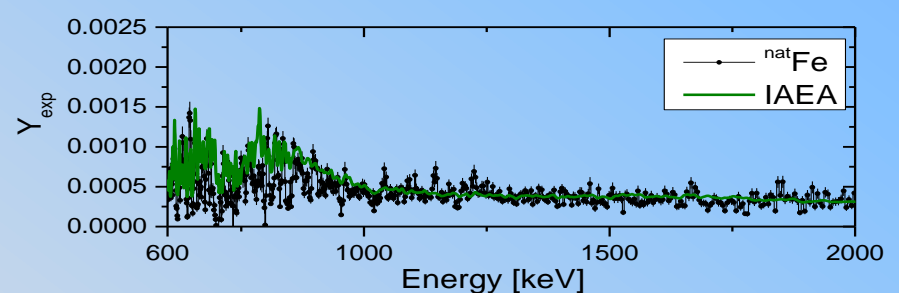
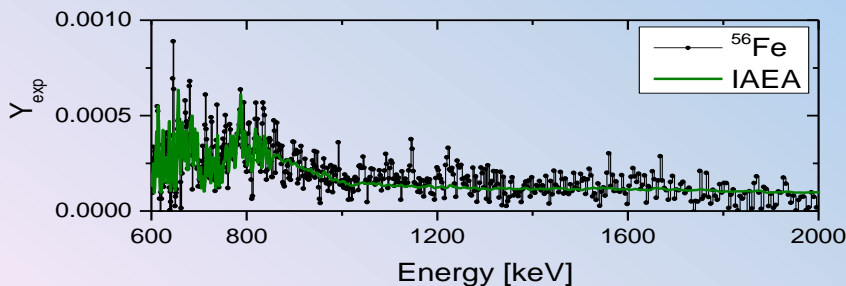
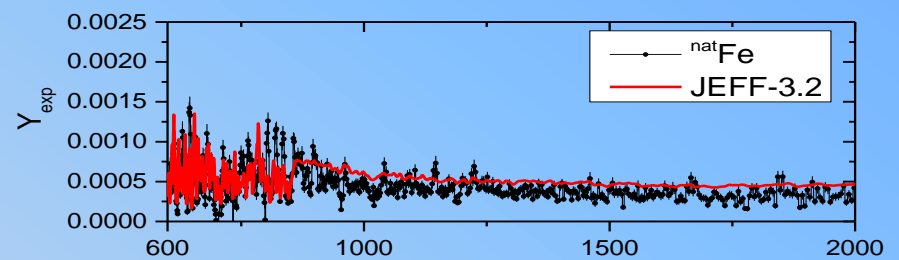
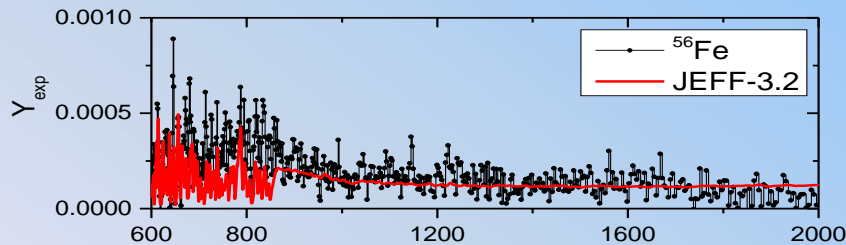
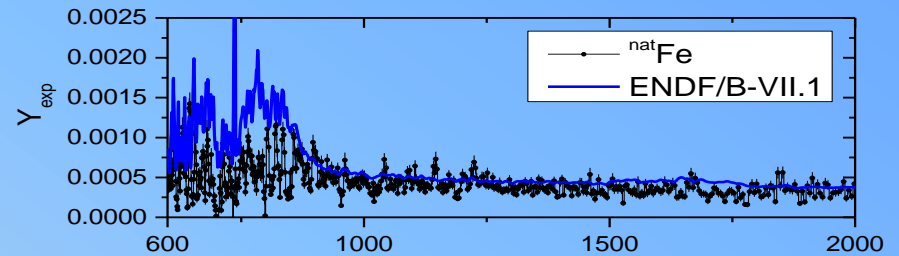
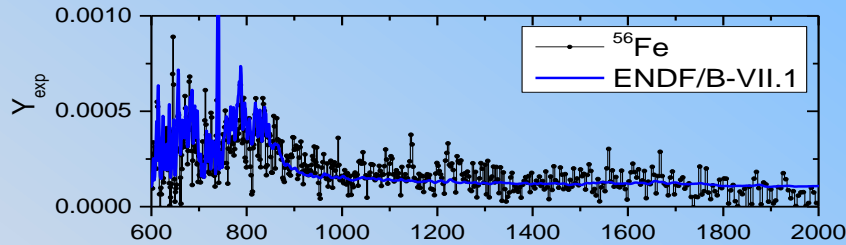
^{nat}Fe Capture above the ^{56}Fe 1st inelastic state

- Experiment shows partially resolved structure
- Used MCNP for this comparison
 - Y-Axis is cross section using thin sample approximation
- IAEA ib5k fits the data in the whole region
- Between 600-800 keV:
 - ENDF/B-VII.1 is lower
 - JEFF 3.2 is higher



Experiment vs evaluations above ^{56}Fe 1st inelastic state

- MCNP calculations of the capture yield above 850 keV agree with experimental data
- Between 600-800 keV the new IAEA ib5k evaluation agrees best with the experimental data.

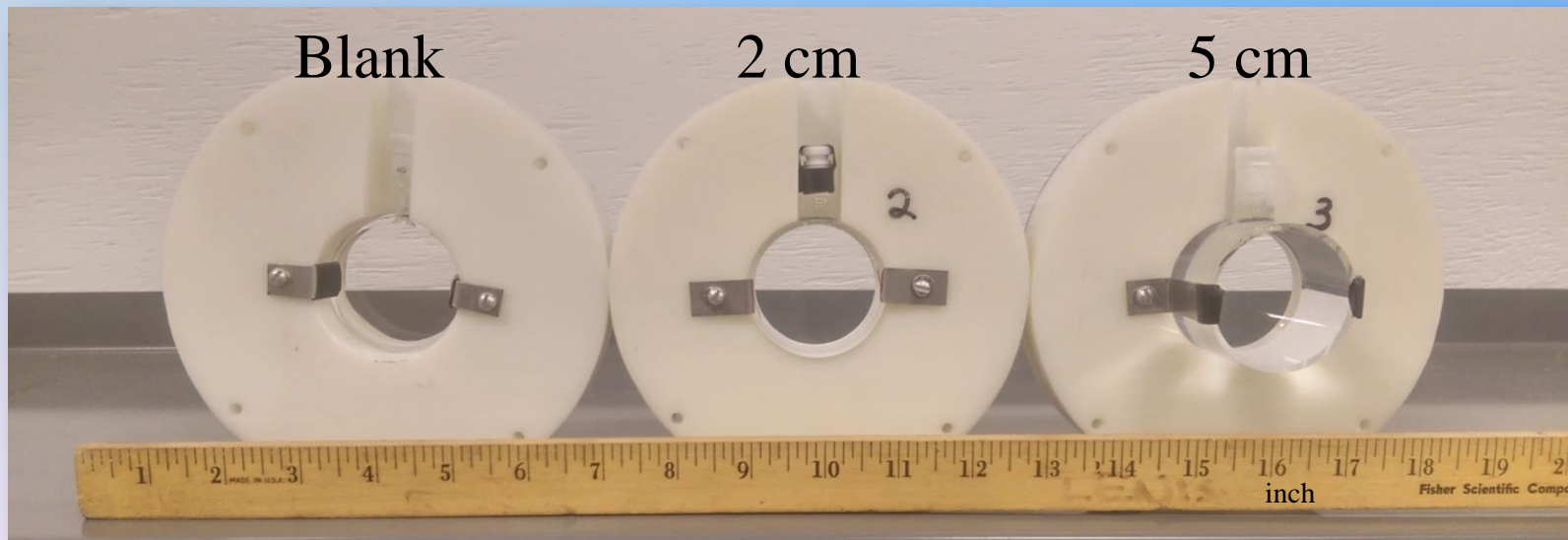


More Oxygen



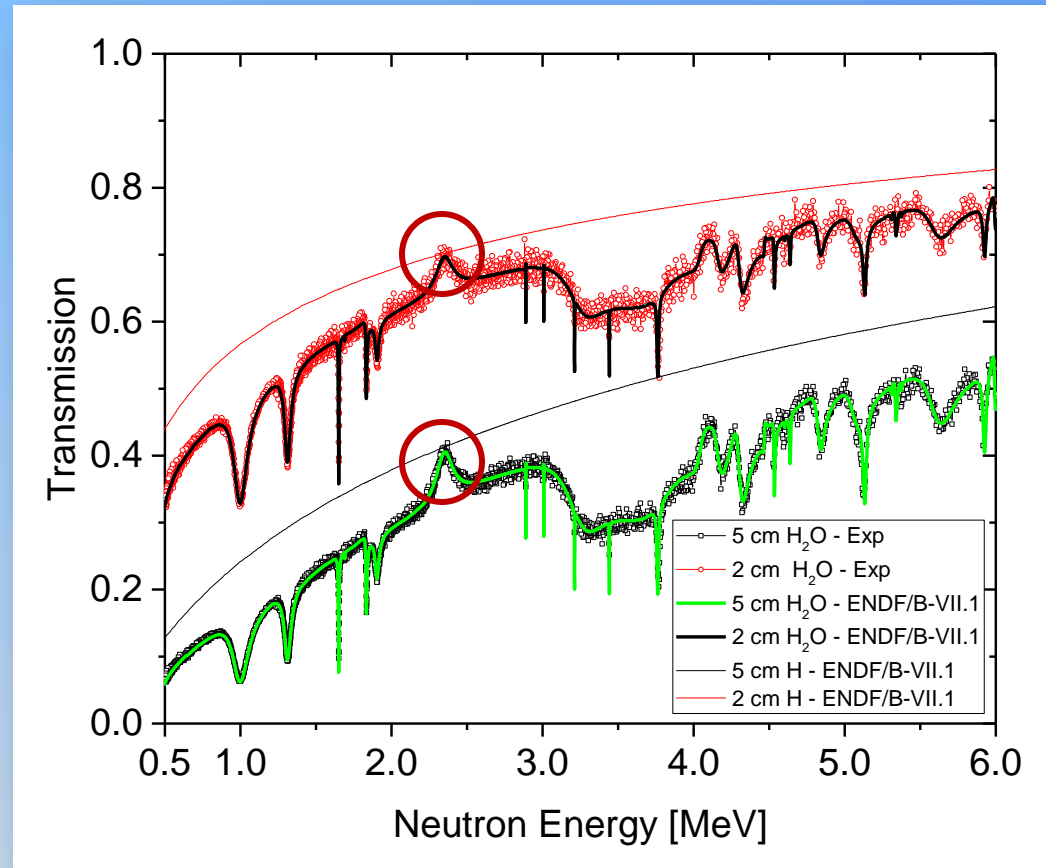
H₂O Samples

- Used a spectroscopic quartz cell to contain research grade water
 - Outgassed the water by drawing vacuum for ~1 minute.
 - Mounted the cells in a polyethylene holder
 - Made sure there was no air bubble in the cell
 - Monitored the sample using a camera to make sure air bubbles were not formed
 - Monitored the room temperature to characterized the variations ($\pm 1.5^\circ\text{C}$)
- Used two cell thicknesses: 2 cm and 5 cm, about 5 cm diameter.
- Measured an empty cell as an open beam
- 13 cm thick graphite sample was used for verification and energy calibration



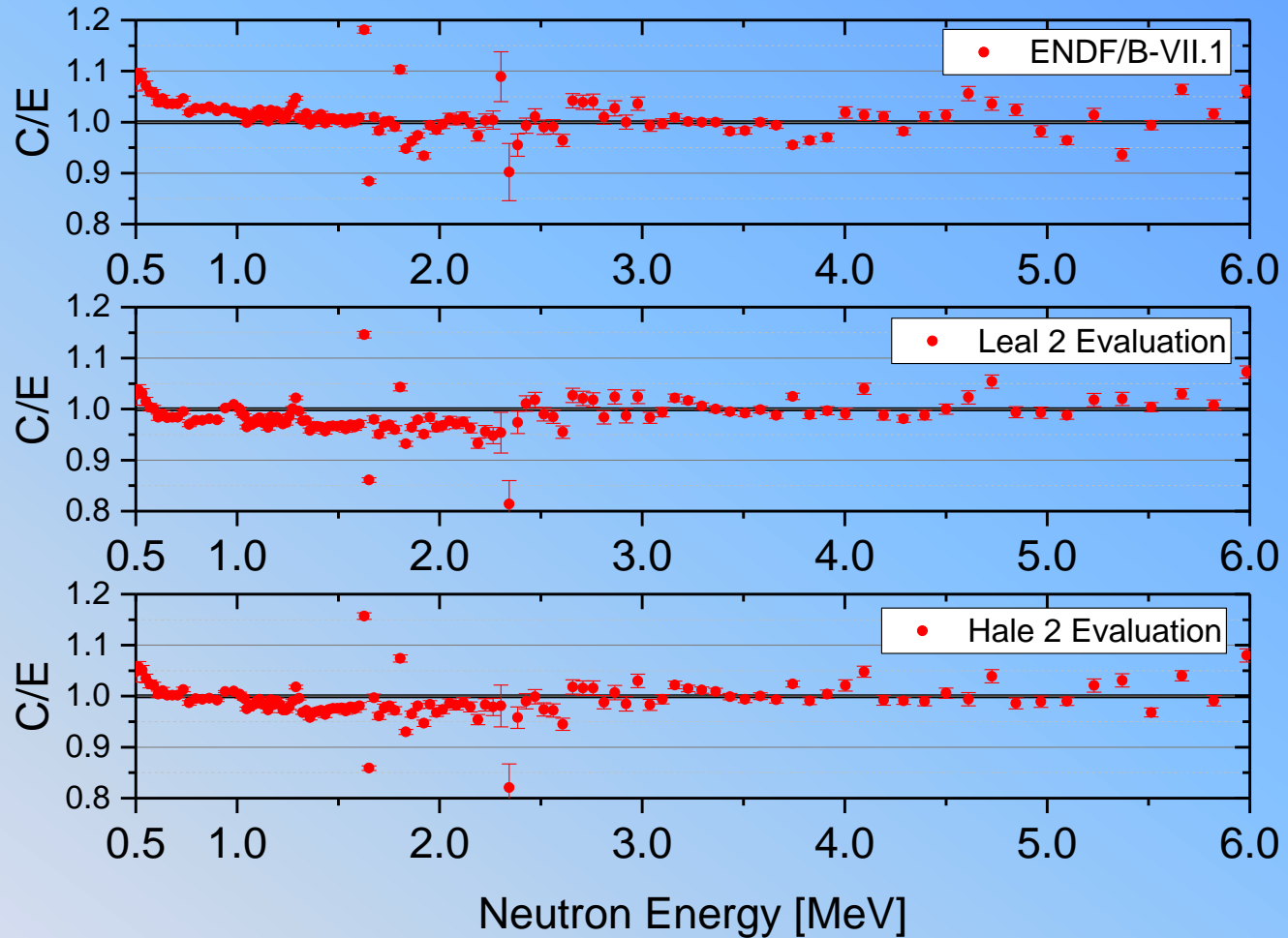
H₂O transmission measurement

- Measurements of 2 cm and 5 cm thick H₂O in thin walled quartz optical cells.
- Used 250 m TOF and 10 ns pulse width.
- Used 3 fission chambers as beam monitors.
 - The experiment requires “good” monitor normalization
- In the ¹⁶O cross section minima at 2.34 MeV mostly H₂ was measured
 - **Provides verification of the normalization**
- Used carbon for energy calibration

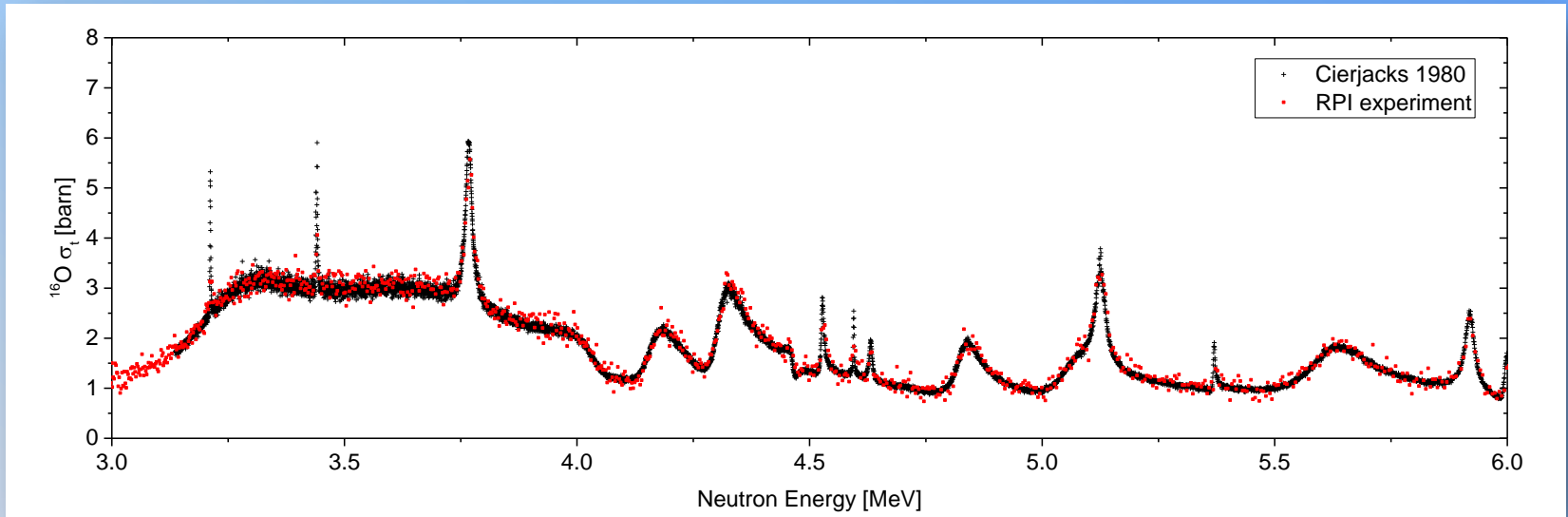


^{16}O – total cross section C/E

- Below 3 MeV the evaluations are lower.
- Below ~ 0.7 MeV there are large differences
 - carbon sample measured at the same time does not have this problem
- Between 3.2 - 6 MeV ENDF/B-VII.1 matches the experiment within $\sim 1.2\%$
- H normalization is better than 1% (next slide)



Comparing Normalization with Other Data Sets



Energy range 3.2 MeV < E < 6 MeV	C/E _{RPI}	C/E _{RPI} Statistics
ENDF/B-VII.1	0.988	±0.002
Leal 1	1.030	±0.002
Leal 2	1.006	±0.002
Hale 1	1.012	±0.002
Hale 2	1.005	±0.002
Cierjacks 80	0.968	±0.002
Cierjacks 68	1.009	±0.002
Johnson 74	0.996	±0.002

Normalization uncertainty:

$$\frac{\sigma_{\text{exp}}^H}{\sigma_{\text{ENDF}}^H} = 0.996 \pm 0.003^*$$

*Statistical

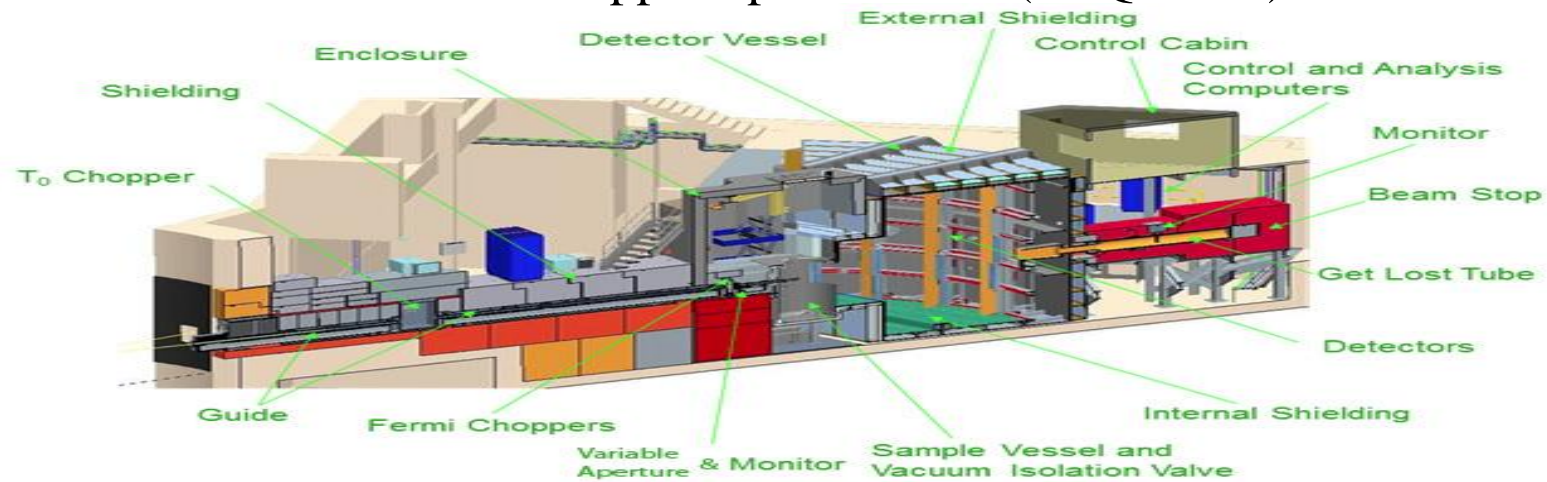


Thermal Scattering in H₂O



SNS Spectrometers

Fine Resolution Fermi Chopper Spectrometer (SEQUOIA)

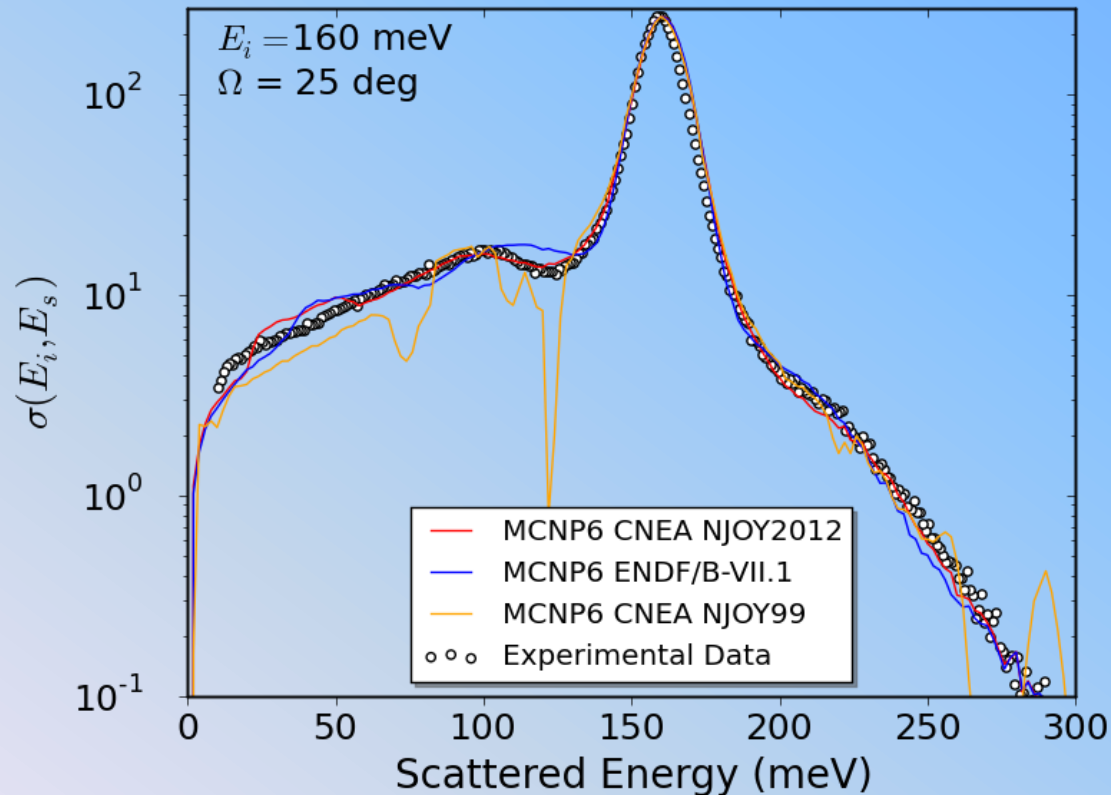


Wide-Angular Range Chopper Spectrometer (ARCS)



NJOY 2012 vs NJOY 99 and CNEA Evaluation

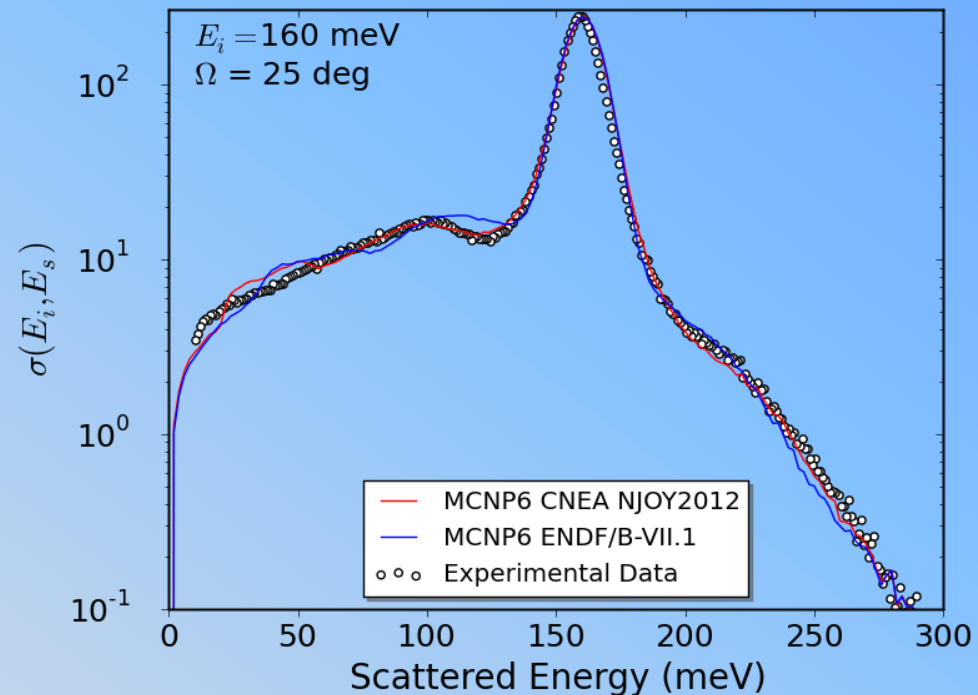
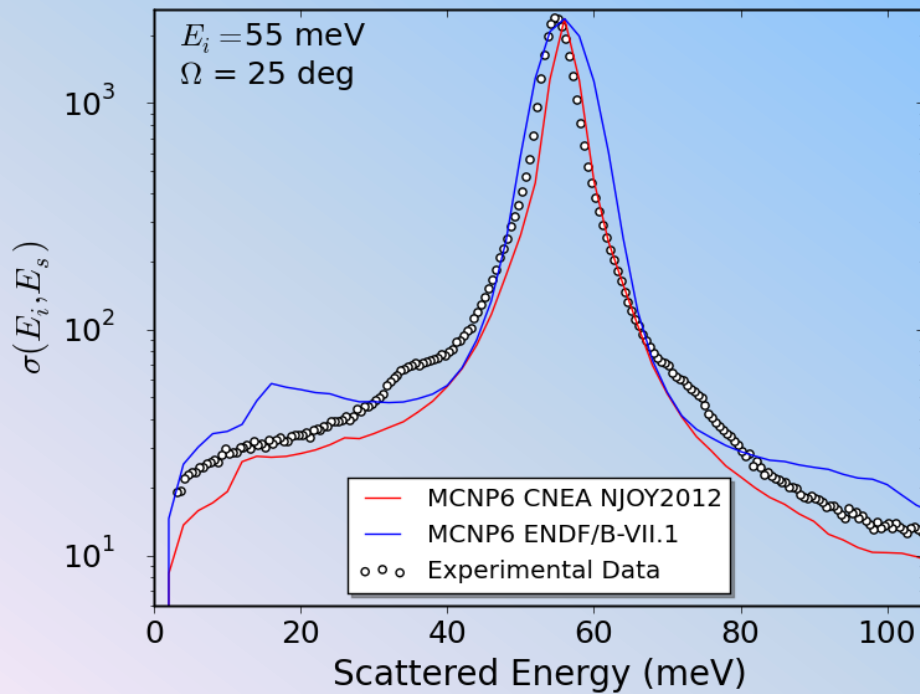
- ACE files were generated with NJOY 2012
 - Used tabulated weighting option
- Processing with NJOY 99 resulted in discontinuities
 - File plotted as NJOY 99 was taken directly from the CNEA CAB web page



Compare ENDF/B-VII.1 and CNEA Evaluations

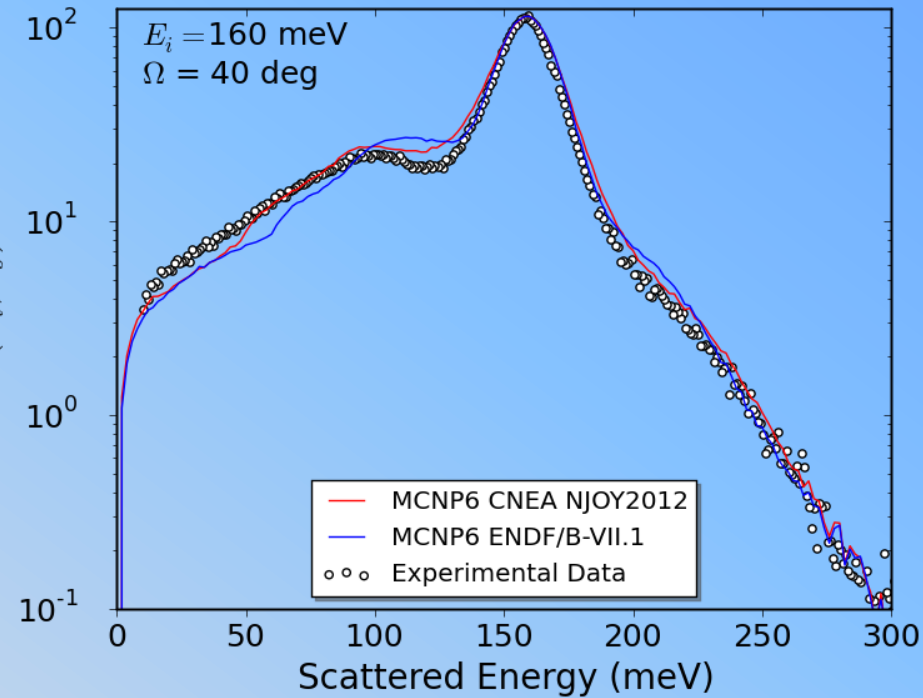
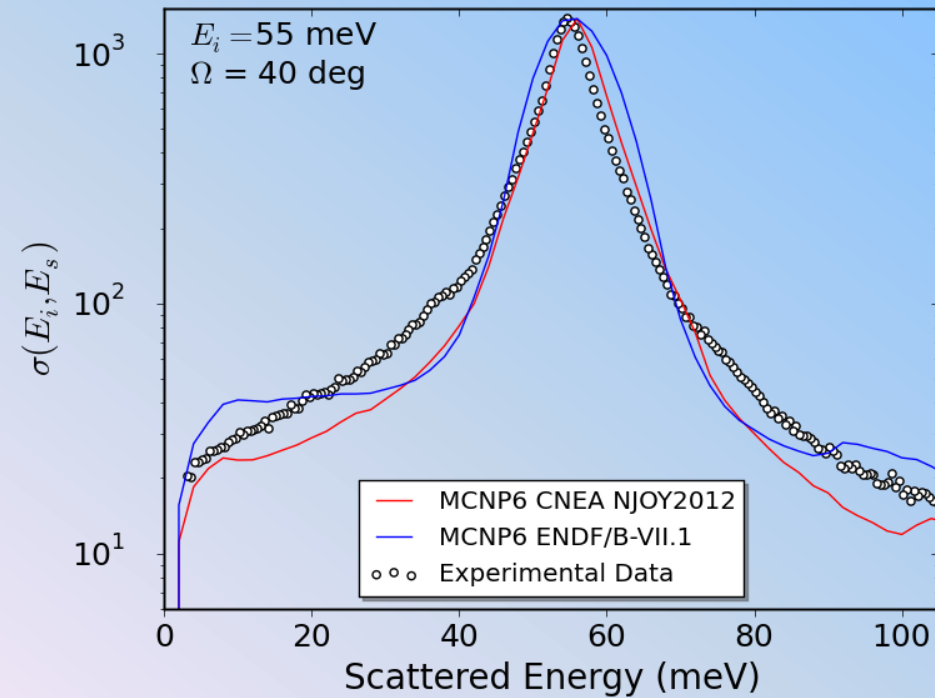
25 deg

- Test only double differential shape
 - Did not measure total cross section
- The CNEA evaluation agrees better with the experimental data



Compare ENDF/B-VII.1 and CNEA Evaluations 40 deg

- The CNEA evaluation agrees slightly better with the experimental data



Conclusions

- The new experimental data help improve and benchmark the new CIELO evaluations
 - Contributions include different measurements on O, ^{56}Fe , $^{\text{nat}}\text{Fe}$, $^{235,238}\text{U}$ and thermal scattering of H_2O .
- New Fe CIELO evaluation agrees better (than other evaluations) with the RPI scattering and capture data
- CNEA thermal scattering kernel agrees with the double differential data better than the ENDF/B-VII.1 kernel