Potential impact of new evaluated data files on the FENDL Library

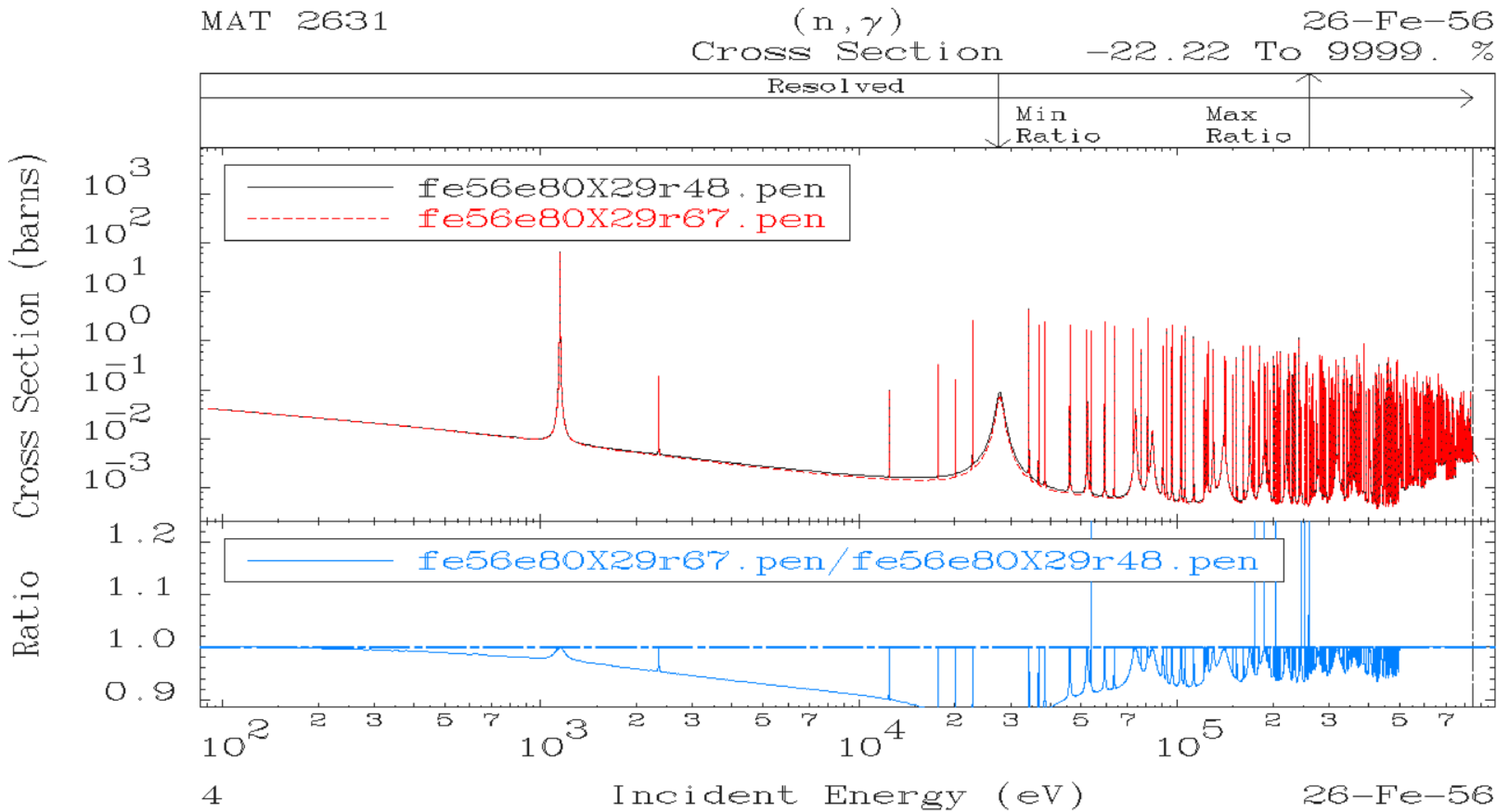
Andrej Trkov and R. Capote (on behalf of the INDEN Collaboration)
Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia
International Atomic Energy Agency, Vienna, Austria

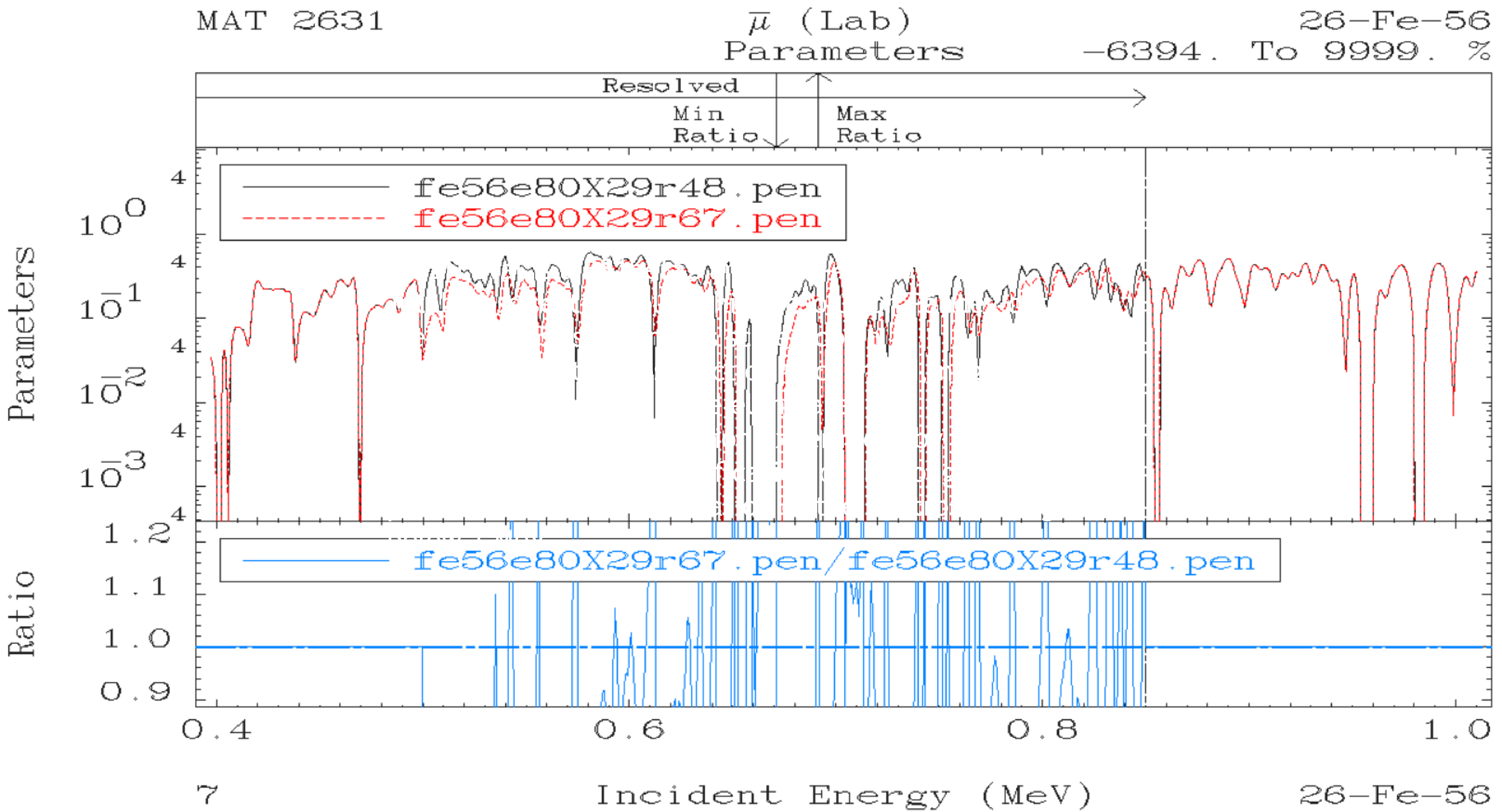
Uranium isotopes

- U-235, U-238 in FENDL are from ENDF/B-VII.1, extended to 60 MeV from JENDL-HE
- Many improvements were made to the INDEN evaluations to improve the performance in criticality problems
- Unfortunately the new evaluations extend only up to 30 MeV.
- If the new evaluations are to be adopted, the exercise of extending them to 60 MeV would need to be repeated.

Fe-56

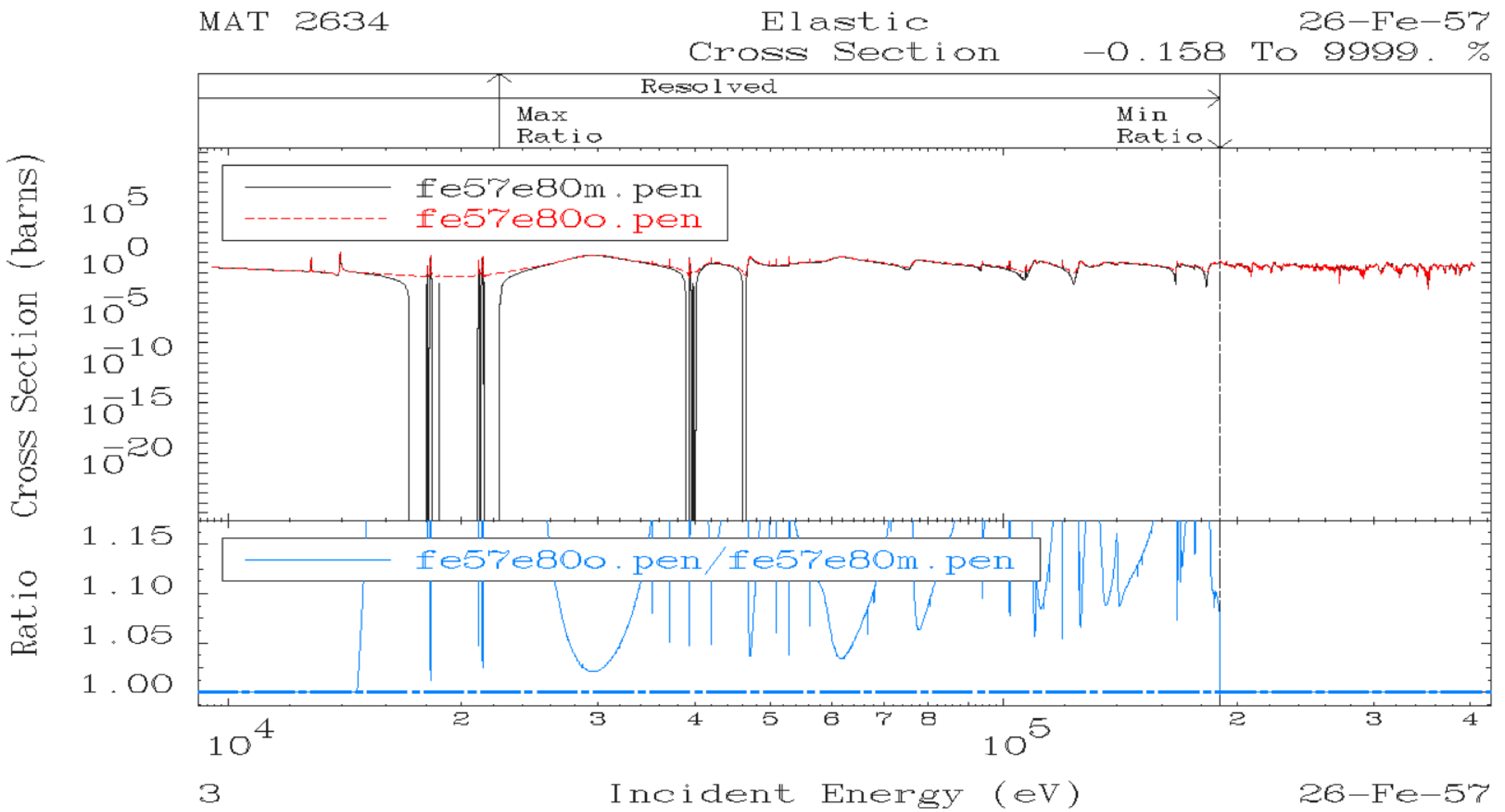
- Currend FENDL evaluation is “fe56e80X29r48”, featuring RRR from INDEN, thermal capture from Firestone (unsupported by validation)
- Current INDEN version is “fe56e80X29r67”, featuring RRR from JEFF-3.3, angular distributions from measured data, fine-tuned capture background, thermal capture corrected (B81beta2 and JEFF-4T3 candidate)
- Excellent validation up to 20 MeV both at RPI and Rez
- Replacement would require several benchmark cases to be repeated


MAT 2631
(n,γ)
26-Fe-56
Cross Section -22.22 To 9999. %
Resolved
Min Ratio
Max Ratio
fe56e80X29r48.pen
fe56e80X29r67.pen
Cross Section (barns)
fe56e80X29r67.pen/fe56e80X29r48.pen
Ratio
Incident Energy (eV)
4
26-Fe-56

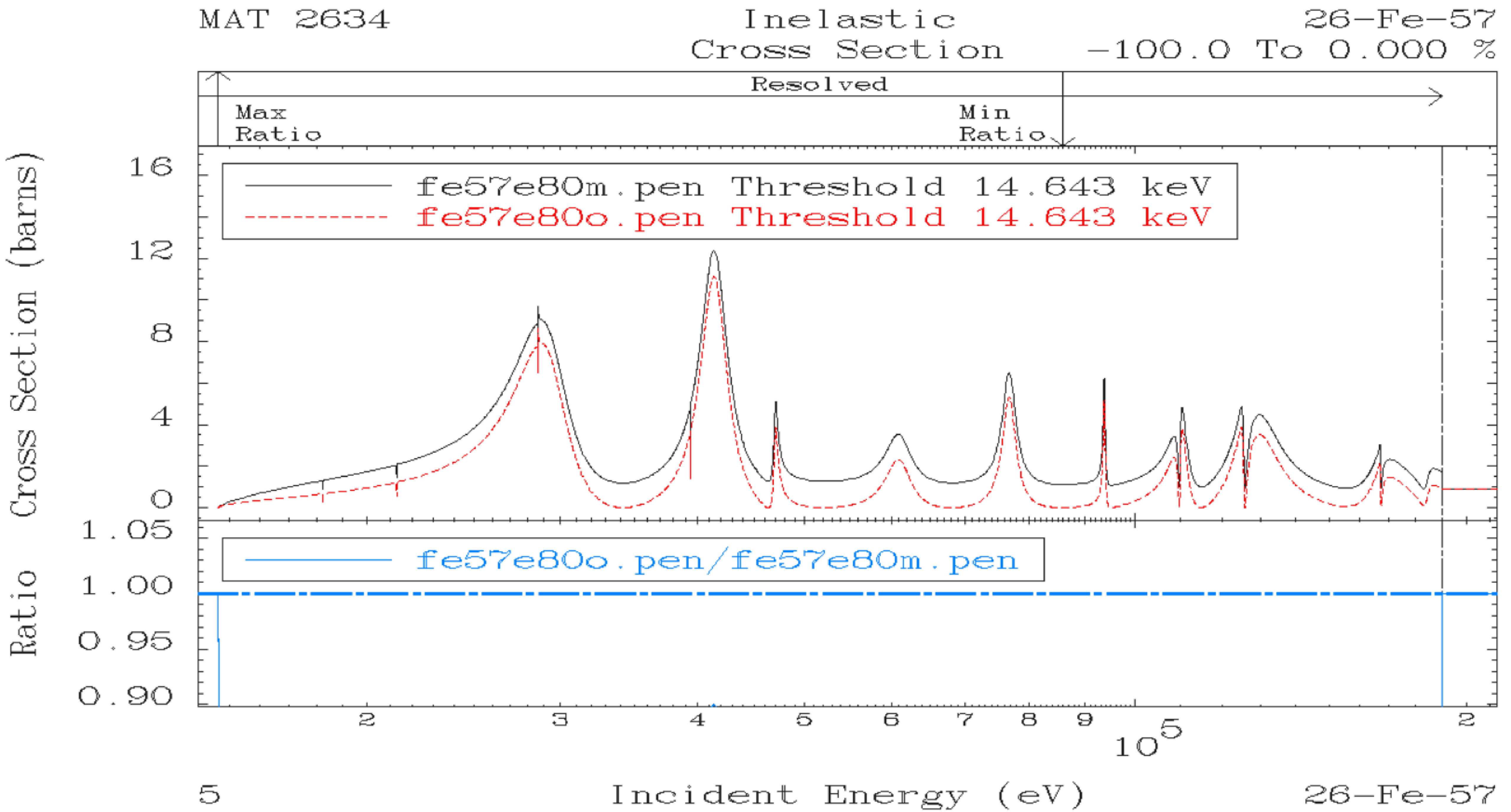

MAT 2631
$\bar{\mu}$ (Lab)
Parameters
26-Fe-56
-6394. To 9999. %
Resolved
Min Ratio
Max Ratio
fe56e80X29r48.pen
fe56e80X29r67.pen
fe56e80X29r67.pen/fe56e80X29r48.pen
Parameters
Ratio
0.4
0.6
0.8
1.0
7
Incident Energy (MeV)
26-Fe-56

Fe-57

- INDEN eval is a B81beta2 and JEFF-4T3 candidate
- Total cross sections follow high resolution Pandey data
- Inelastic cross section was scaled down
- Keeping the total cross section unchanged, negative elastic cross sections were eliminated
- Key nELBE thick transmission experiment by Junghans, Beyer et al allowed identification of the long standing problem of the overestimation of the neutron leakage below 1 MeV



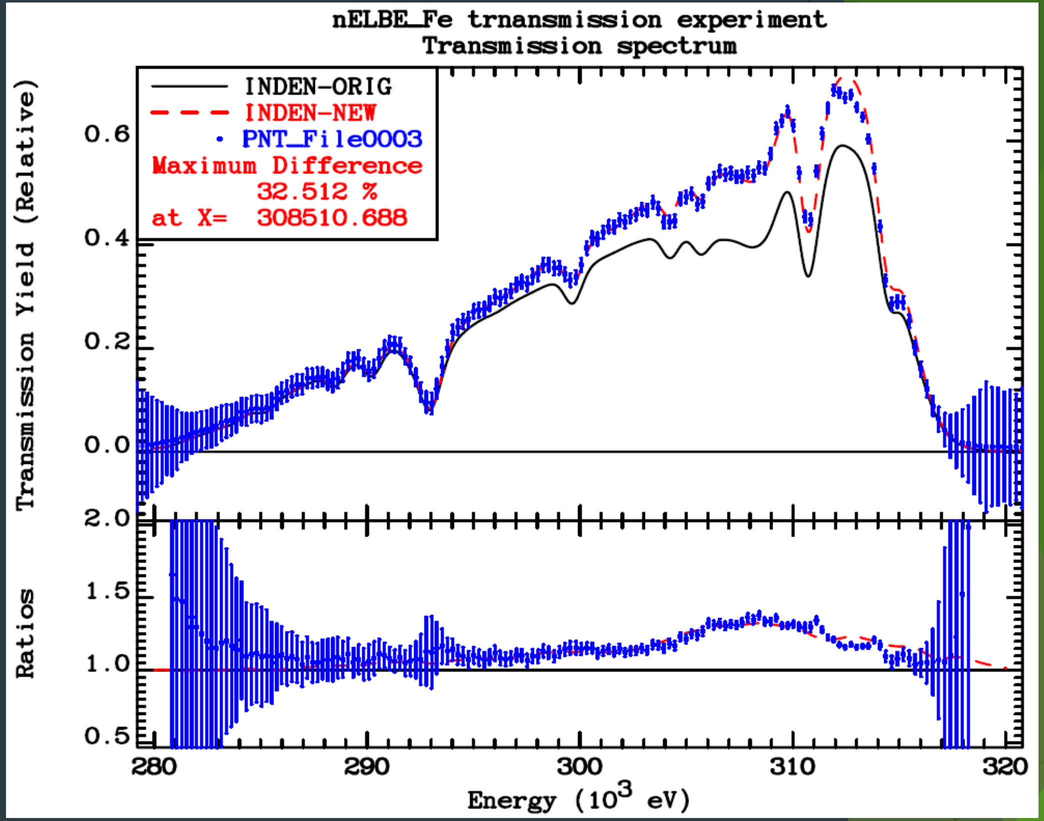
MAT 2634
Elastic
Cross Section -0.158 To 9999. %
26-Fe-57
Resolved
Max Ratio
Min Ratio
fe57e80m.pen
fe57e80o.pen
fe57e80o.pen/fe57e80m.pen
Cross Section (barns)
Ratio
Incident Energy (eV)
3
26-Fe-57



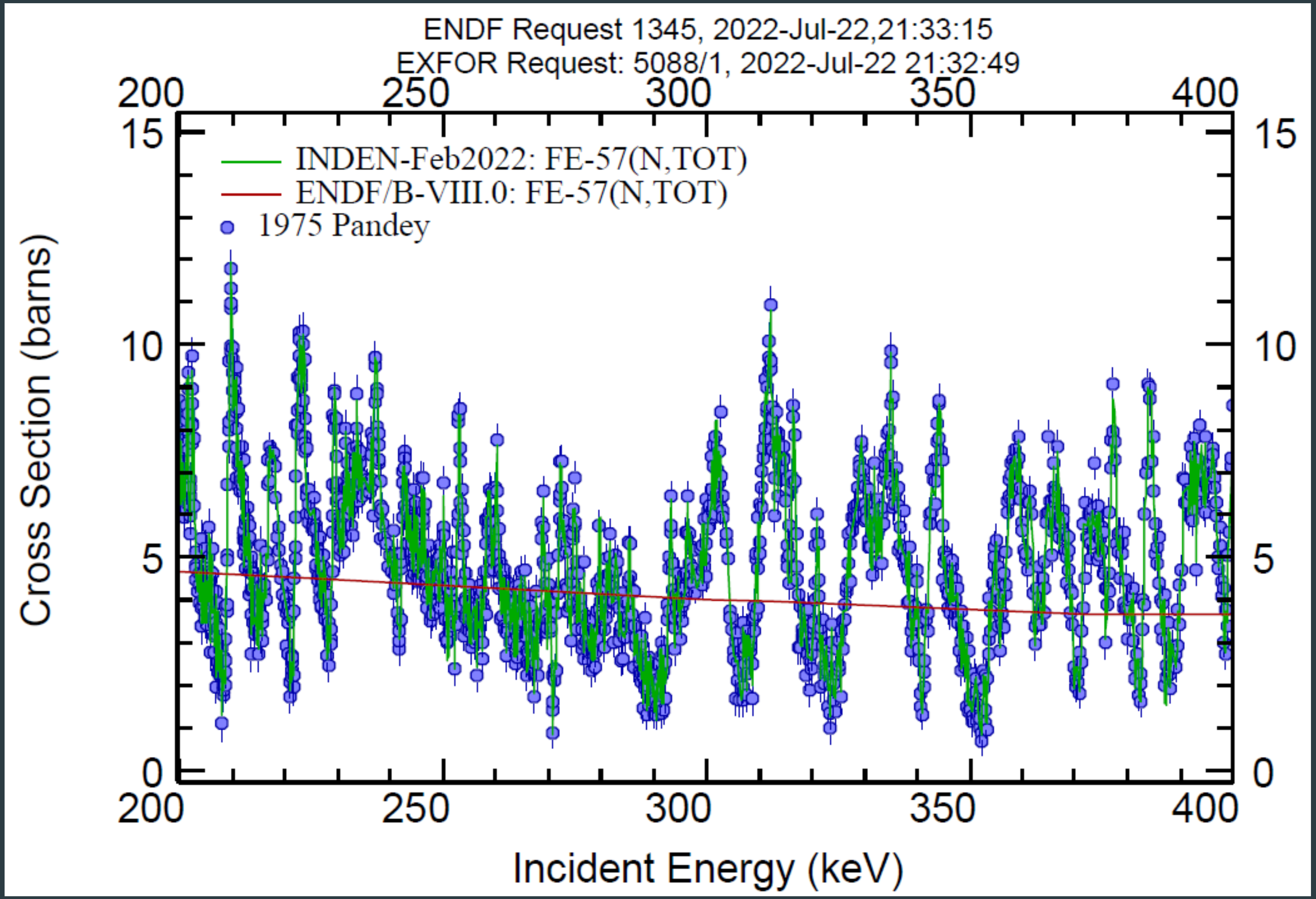
MAT 2634
Inelastic
Cross Section
26-Fe-57
-100.0 To 0.000 %
Resolved
Max
Ratio
Min
Ratio
fe57e80m.pen Threshold 14.643 keV
fe57e80o.pen Threshold 14.643 keV
fe57e80o.pen/fe57e80m.pen
Cross Section (barns)
Ratio
16
12
8
4
0
1.05
1.00
0.95
0.90
2
3
4
5
6
7
8
9
10^5
2
5
Incident Energy (eV)
26-Fe-57

New transmission measurement at nELBE

- A dedicated transmission measurement on very thick target by Arnd Junghans and Roland Beyer at the nELBE facility was performed.
- The assumption about the cross-section minima in Fe-56 is not supported (**black line**).
- An alternative solution was sought: a deficiency in the Fe-57 cross sections was identified as the major cause of the problem (**dashed-red line**).
- Very good agreement with n-ELBE data was achieved.



Fe-57 evaluation does not describe Pandey (n,tot) data having fluctuations up to 7 barn



INDEN updated "structural" evaluations: see nds.iaea.org/INDEN/ - Validation

- ✓ Fe isotopes (IAEA/JSI), fe57e80m, fe56e80X29r41, fe54e80o
- ✓ Cr isotopes, BNL/ORNL/IAEA/JSI/CEA, v2.3.2

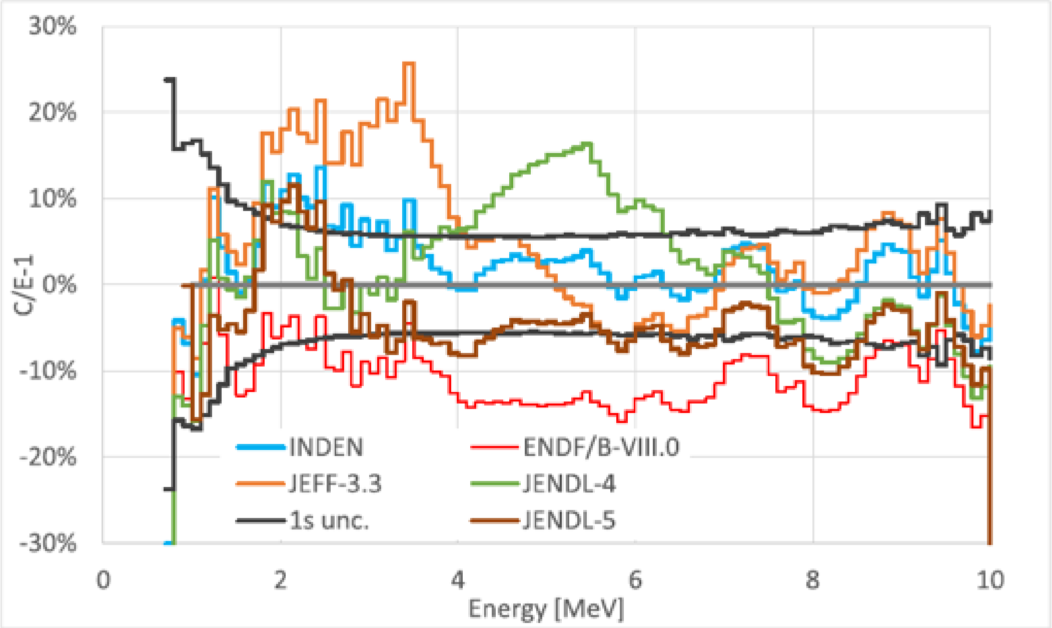


Fig. 12. C/E-1 for different stainless steel neutron transport libraries. One sigma uncertainty is displayed as a bold black curve.

ALARM-CF-STAINLESS-STEEL-321-SHIELD-001

Figure 4. Photo of Stainless steel Block with Shielding Cone and Stilbene Detector.

SS neutron leakage (Rez, CZ, 11/2021)

M. Schulc et al, Ann. Nucl. En. **179**(2022) 109433

https://nds.iaea.org/INDEN/data/ALARM-CF-steel-SHIELD-001-final.pdf

Examination of C, Be, Mo, ^{238}U, Fe, and Zr using the RPI HES Data with Current ENDF, JEFF, and JENDL Evaluations

Naval Nuclear Laboratory
Adam Daskalakis, Michael Rapp, Devin Barry

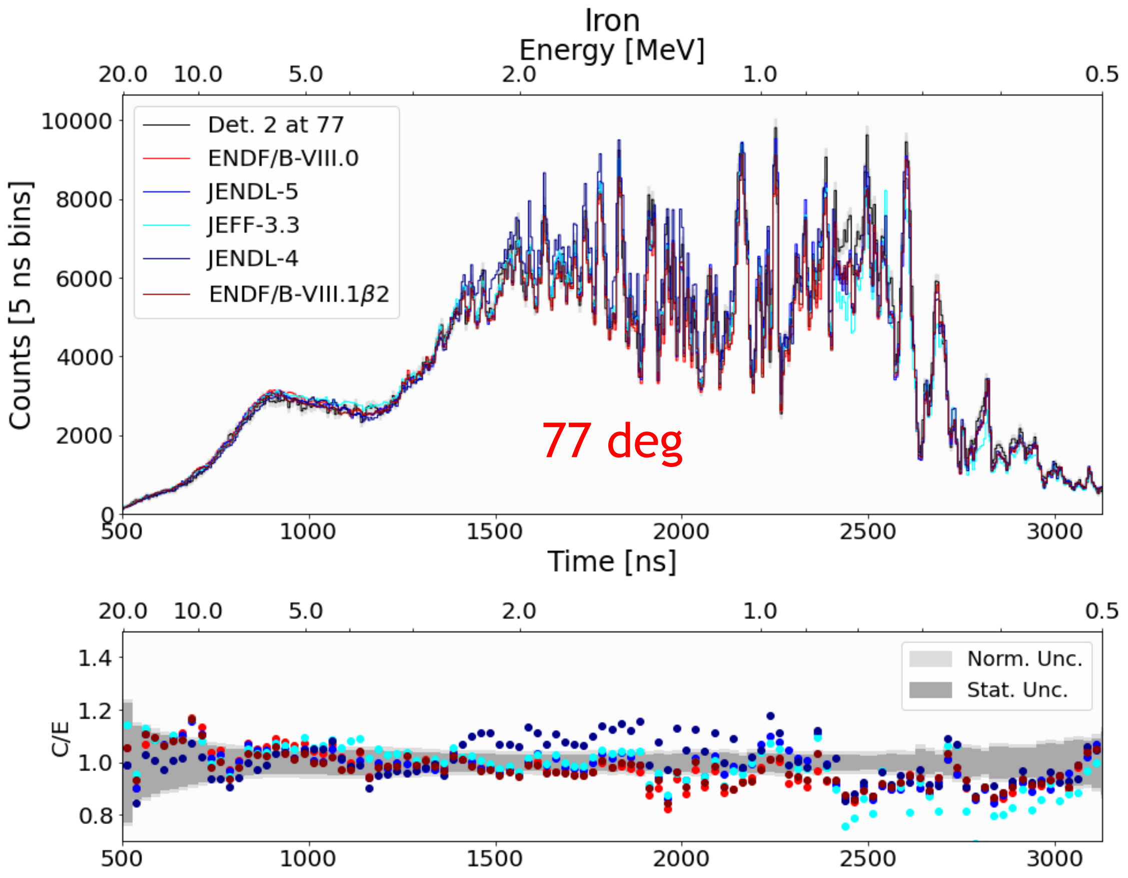
Rensselaer Polytechnic Institute
Peter Brain, Hunter Belanger, and Yaron Danon

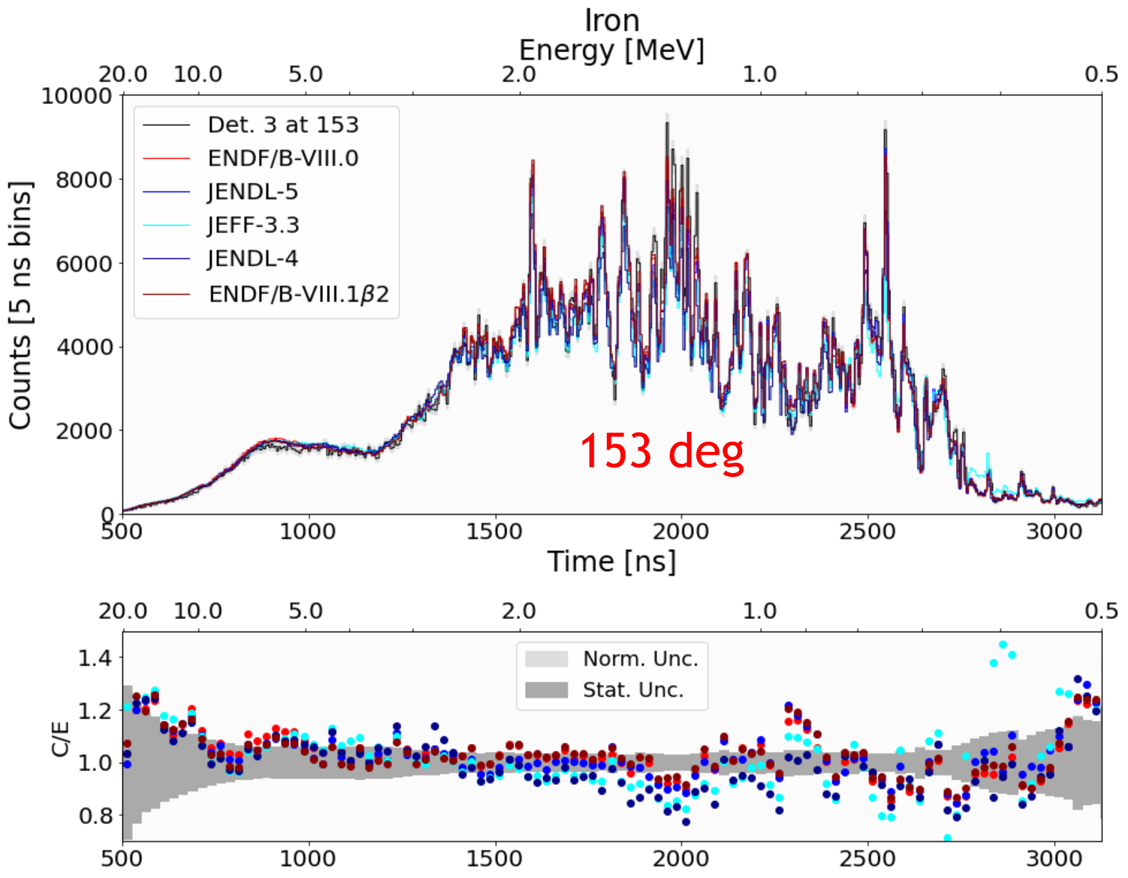
Presented at WINS-2023
October 2023, RPI

Iron

Presented at WINS-2023
October 2023, RPI

- Measured in 2012.
  - Total quasi-differential, inelastic-to-elastic ratios, and elastic-only
- Results first presented in Dresden at WINS2014
- Additional iron data, poor JEFF performance below 1 MeV, INDEN (B81beta2 is good)

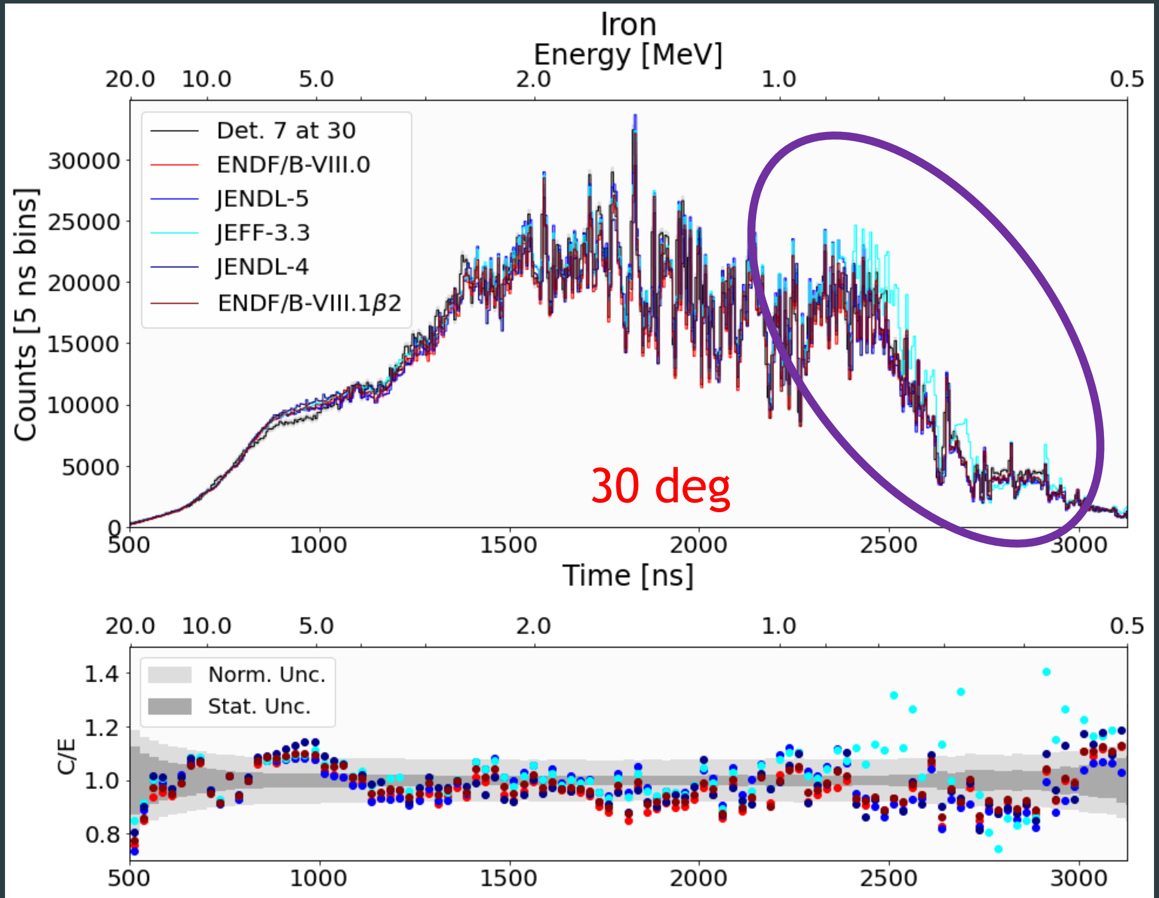


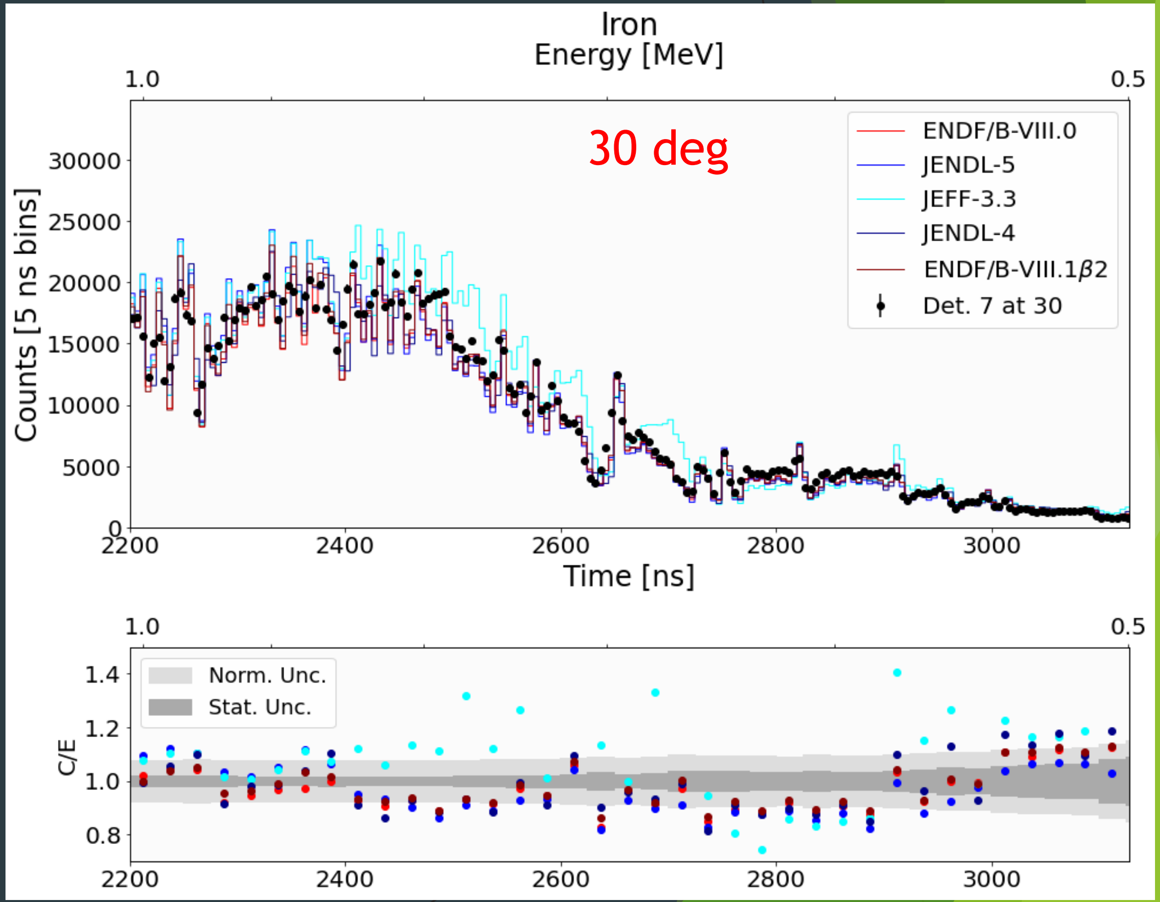


Iron – Continued

Presented at WINS-2023
October 2023, RPI

- Additional iron data, poor JEFF performance below 1 MeV, INDEN (B81beta2 is good)

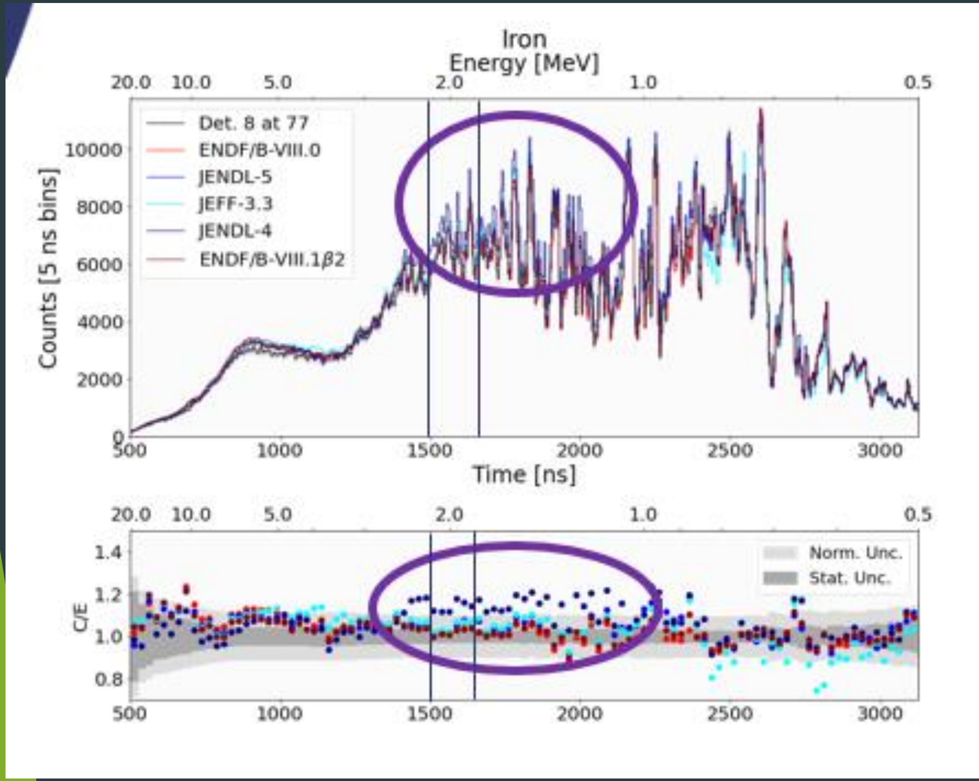


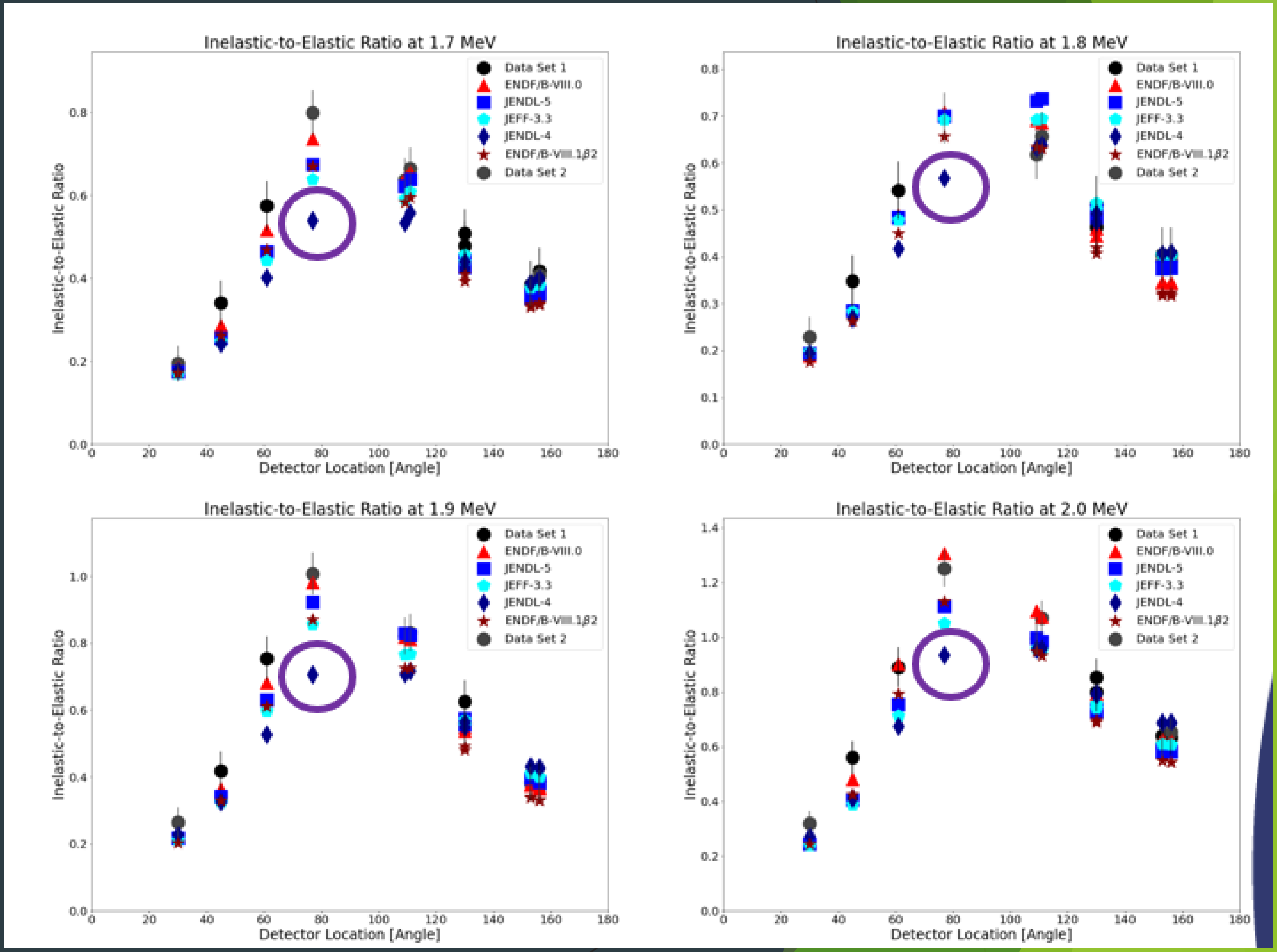


Presented at WINS-2023
October 2023, RPI

Iron – Continued

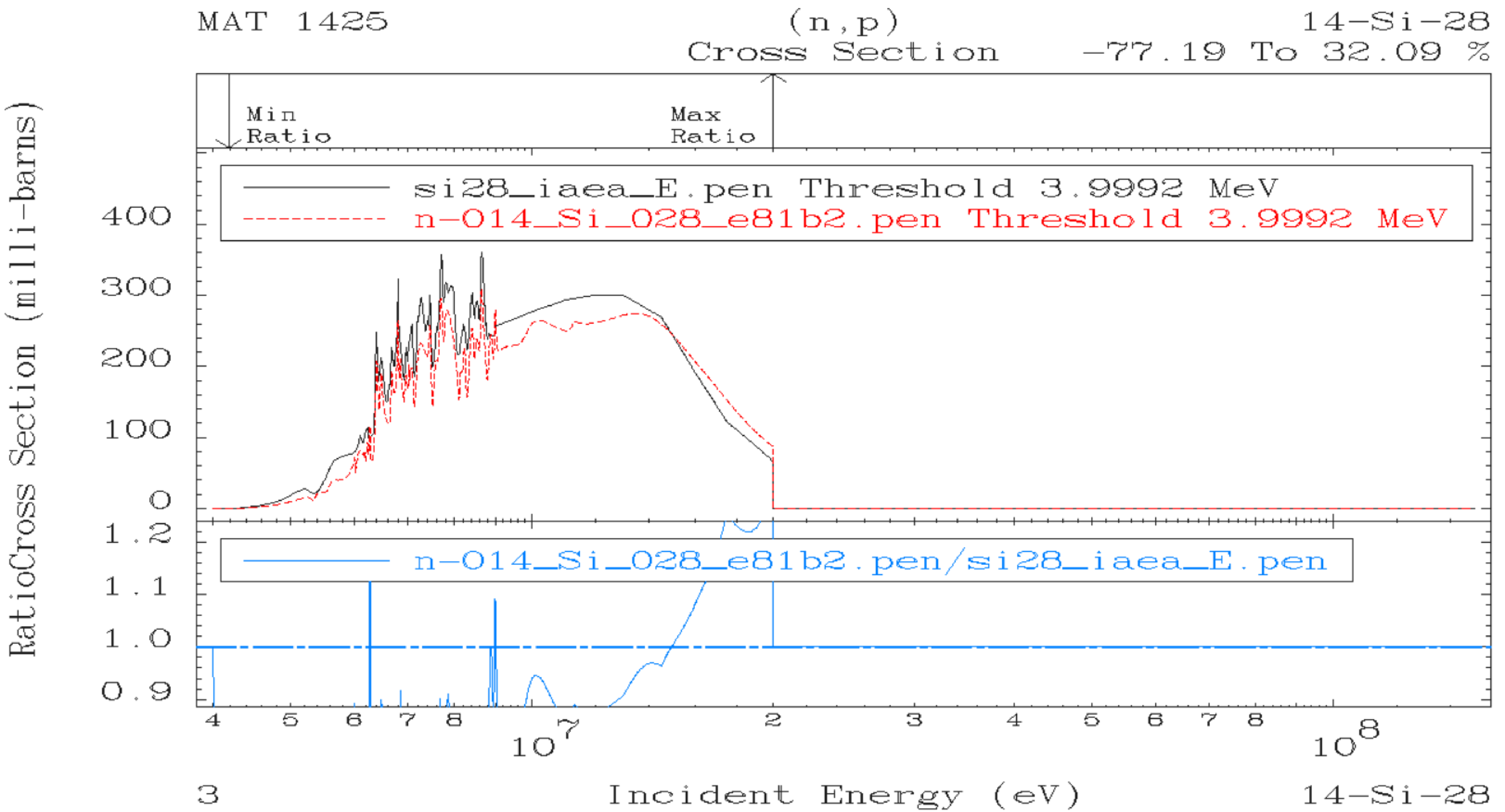
- Isolate narrow time bin approximating a monoenergetic neutron beam
- Inelastic-to-elastic ratios





Si-28,29,30

- Current FENDL evaluations are from ENDF/B-VII.1 with extensions to 60 MeV from JENDL-4/HE
- Major re-evaluation of RRR for Si-28,29,30 including direct capture component
- Evaluations extend to 150 MeV.
- Reaction (n,p) renormalized to IRDFF-II
- Some additional information on missing particle distributions was added for ENDF/B-VIII.1



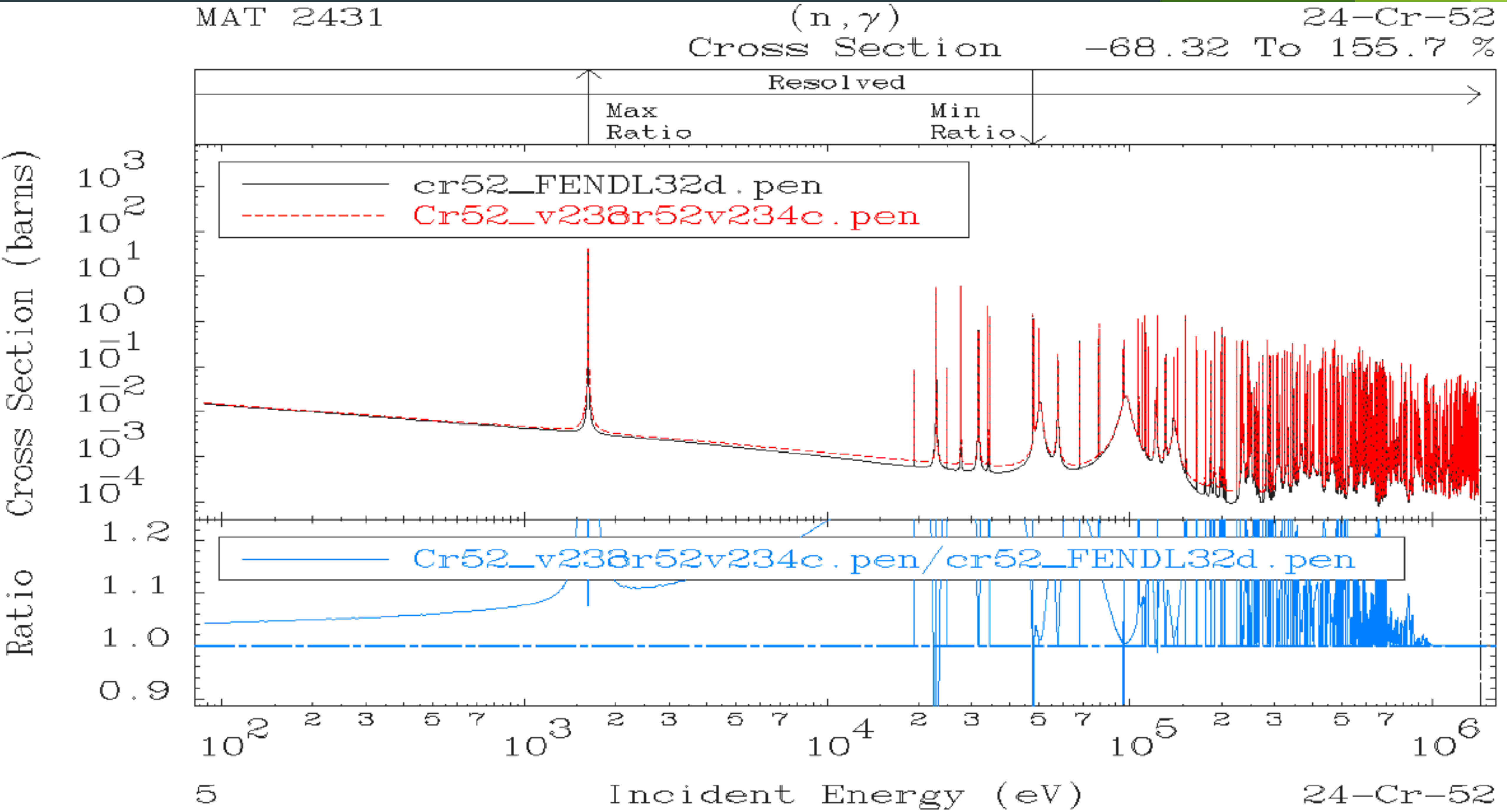
MAT 1425
(n,p)
Cross Section
14-Si-28
-77.19 To 32.09 %
Min Ratio
Max Ratio
si28_iaea_E.pen Threshold 3.9992 MeV
n-014_Si_028_e81b2.pen Threshold 3.9992 MeV
n-014_Si_028_e81b2.pen/si28_iaea_E.pen
Cross Section (milli-barns)
Ratio
400
300
200
100
0
1.2
1.1
1.0
0.9
4
5
6
7
8
10^7
2
3
4
5
6
7
8
10^8
3
Incident Energy (eV)
14-Si-28

Mn-55

- Current evaluation from INDEN (2011)
- In the INDEN file major improvement to capture gamma production from EGAF was made
- Evaluation extends to 60 MeV, no impact on neutronics benchmarks

Cr-50,52,53,54

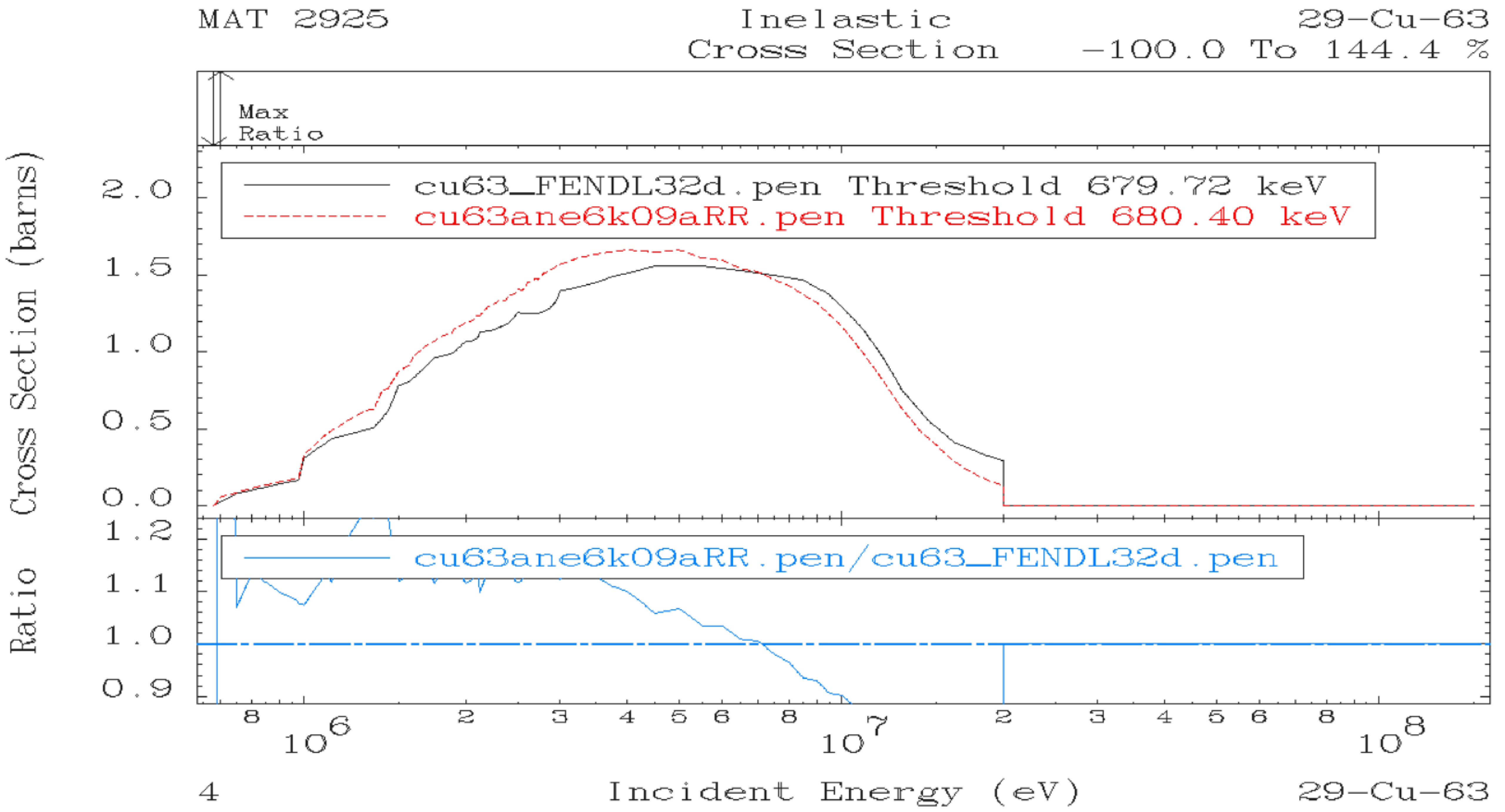
- Current files are from INDEN (2020)
- Refinements to the RRR were made for all isotopes (version "v2.3.2", 2021)
- Additional RRR refinement to Cr-52 (version 2.3.4c, 2022), taking selected widths from BROND-3.1



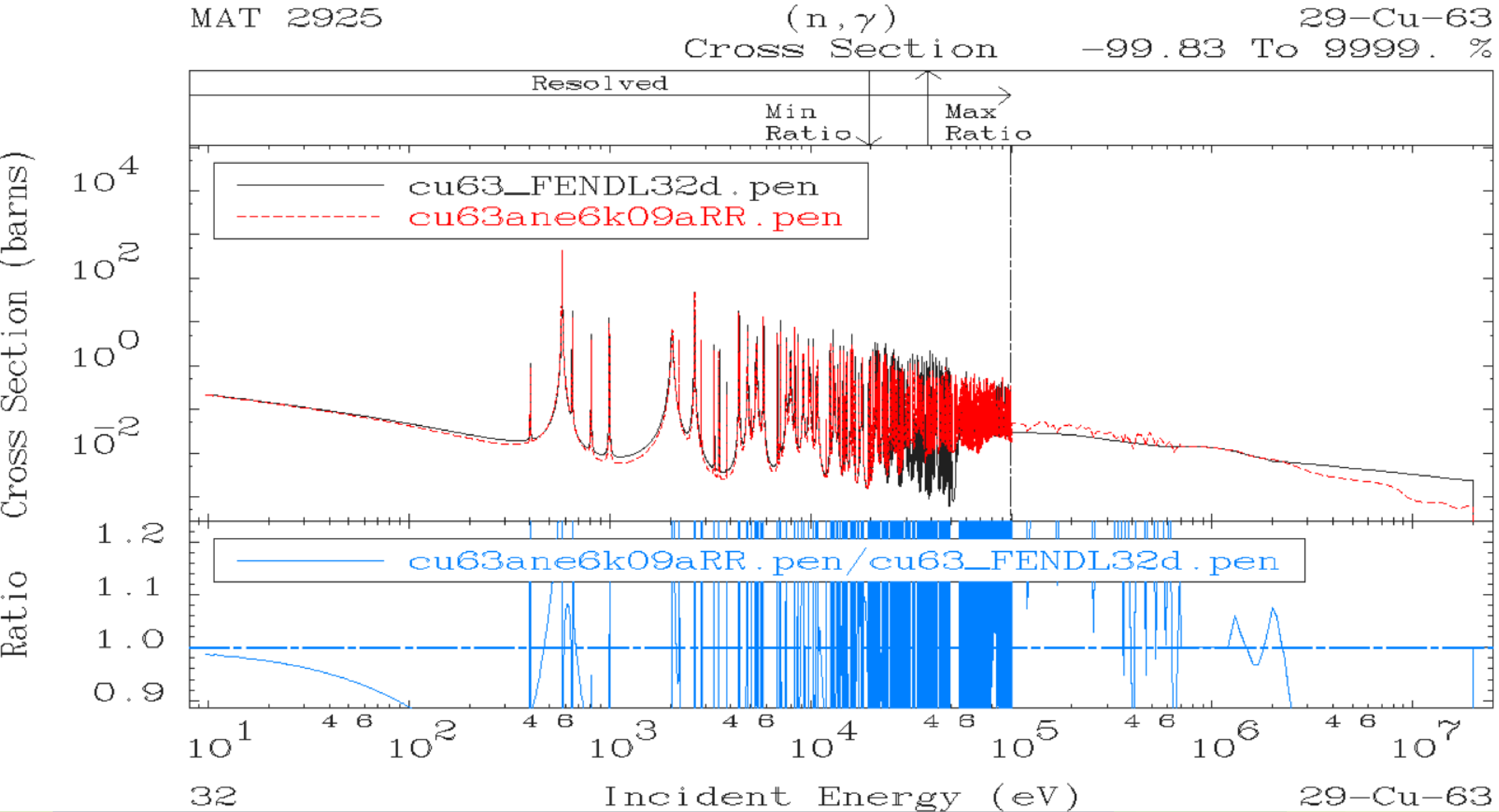
MAT 2431
(n,γ)
24-Cr-52
Cross Section
-68.32 To 155.7 %
Resolved
Max Ratio
Min Ratio
cr52_FENDL32d.pen
Cr52_v238r52v234c.pen
Cross Section (barns)
Cr52_v238r52v234c.pen/cr52_FENDL32d.pen
Ratio
5
Incident Energy (eV)
24-Cr-52

Cu-63,65

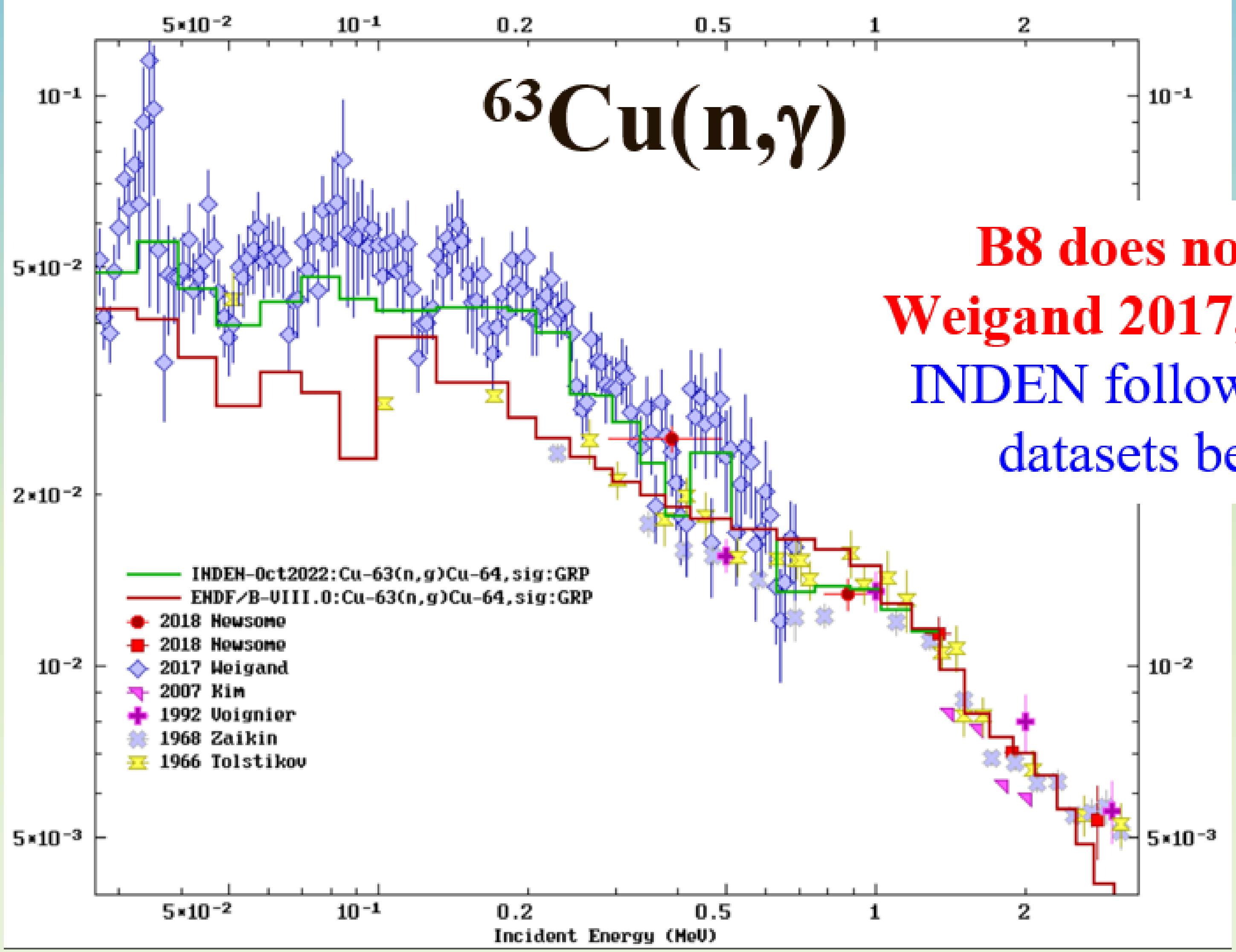
- Current FENDL evaluations are from ENDF/B-VII.1 with extensions to 60 MeV from JENDL-4/HE
- Cu-63 Version “ane6k09aRR” is a new INDEN evaluation, RRR from IAEA/JSI/ORNL (updated capture), fast updated by IAEA/JSI
- Cu-65 Version “ane5k05” is a new INDEN evaluation with updated capture, fast region updated by IAEA/JSI.
- Reactions (n,p) and (n,a) are consistent with IRDFF-II
- The energy range extends to 150 MeV
- INDEN evaluation validated in Rez Cf-252(sf) neutron leakage experiment
- The new evaluations lead to significantly improved performance in criticality and leakage benchmarks.



MAT 2925
Inelastic
Cross Section
29-Cu-63
-100.0 To 144.4 %
Max
Ratio
cu63_FENDL32d.pen Threshold 679.72 keV
cu63ane6k09aRR.pen Threshold 680.40 keV
Cross Section (barns)
2.0
1.5
1.0
0.5
0.0
cu63ane6k09aRR.pen/cu63_FENDL32d.pen
Ratio
1.2
1.1
1.0
0.9
8
10^6
2
3
4
5
6
8
10^7
2
3
4
5
6
8
10^8
4
Incident Energy (eV)
29-Cu-63


MAT 2925
(n,γ)
29-Cu-63
Cross Section
-99.83 To 9999. %
Resolved
Min Ratio
Max Ratio
cu63_FENDL32d.pen
cu63ane6k09aRR.pen
Cross Section (barns)
Ratio
cu63ane6k09aRR.pen/cu63_FENDL32d.pen
Incident Energy (eV)
32
29-Cu-63

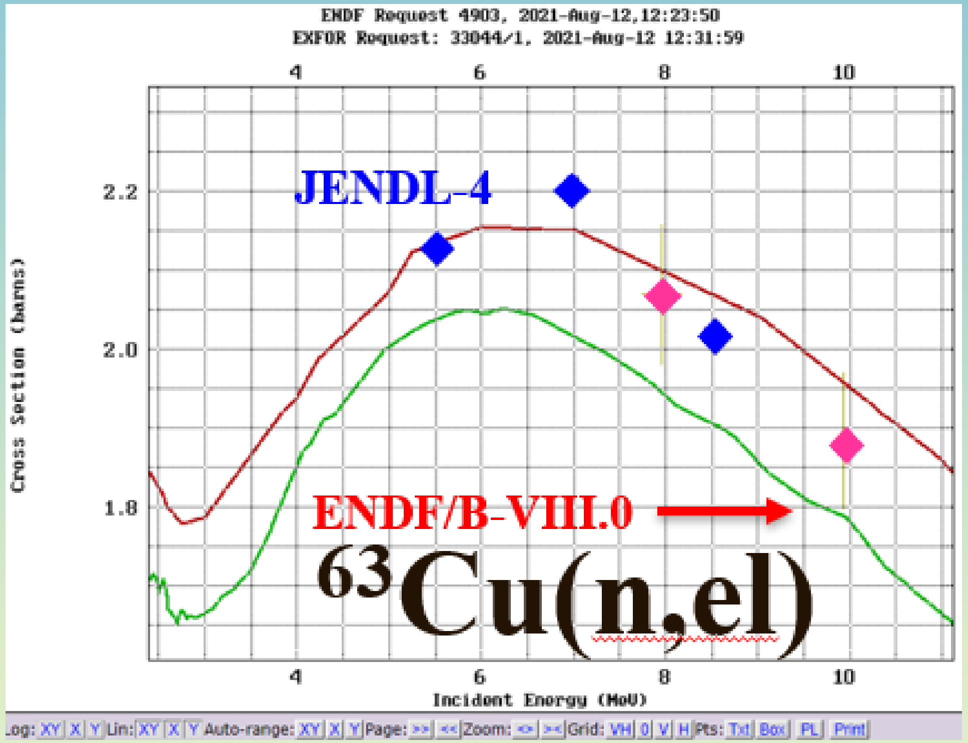
Capture on Cu-63: New exp. data

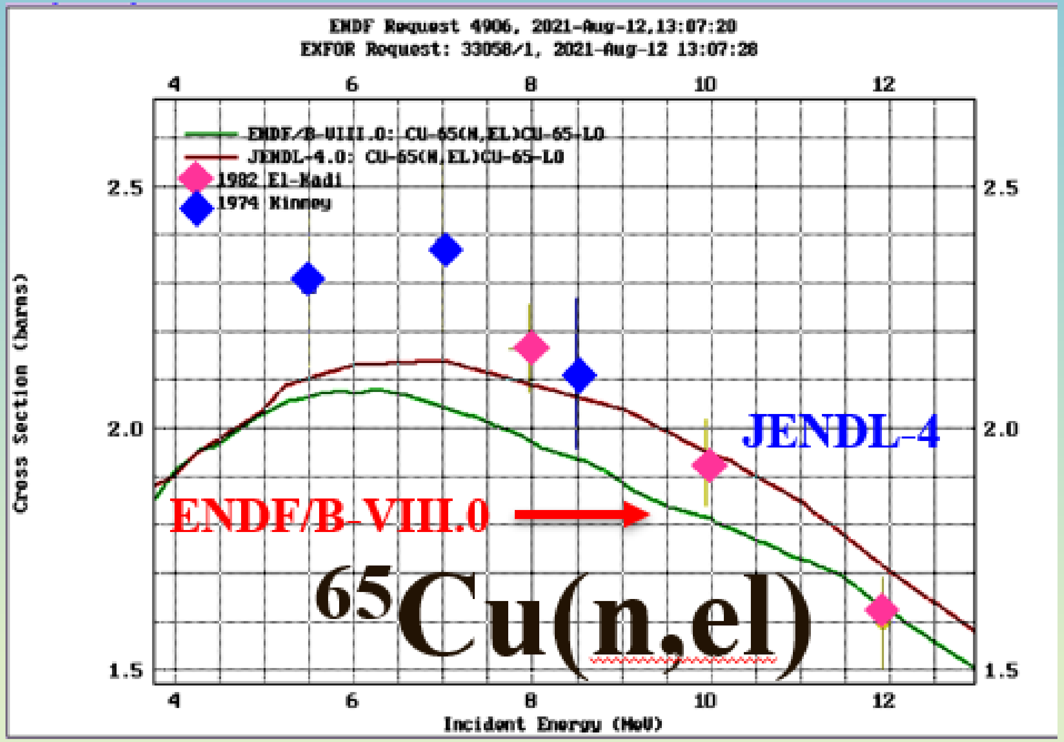


B8 does not agree with Weigand 2017, Newsome 2018

INDEN followed those newer datasets below 1 MeV

Cu: Differential elastic cross-section data

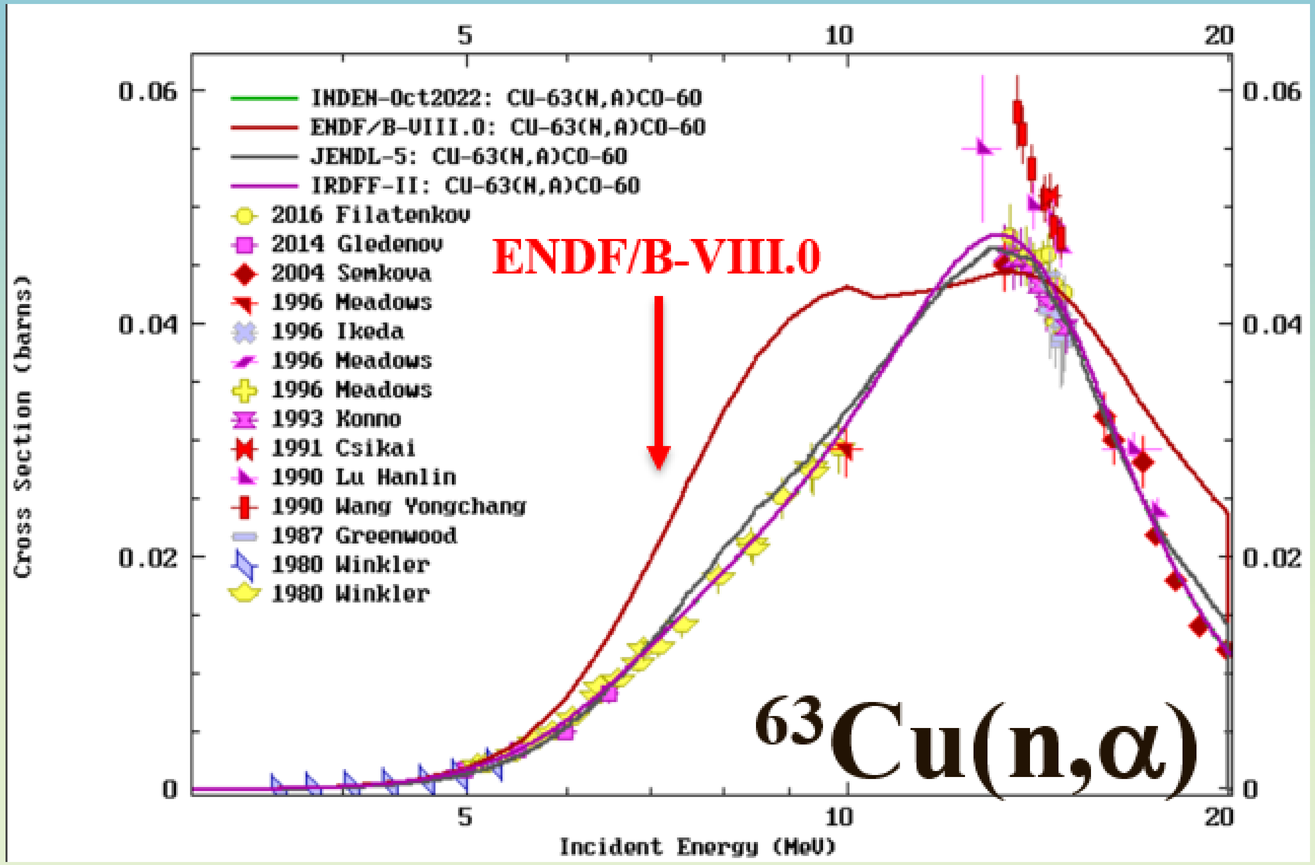




B8 does not agree with elastic EXP data above ~4 MeV

JENDL-4 much better but not perfect !

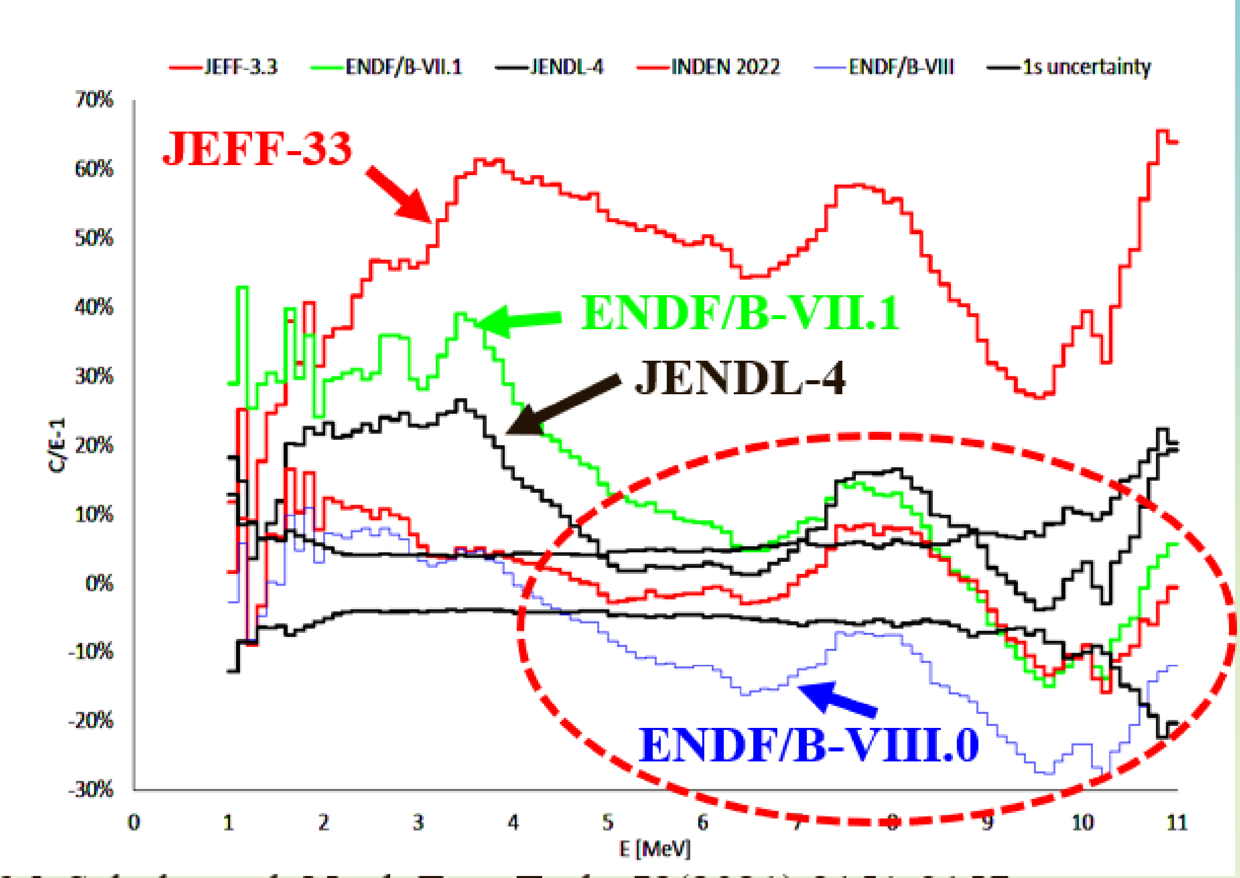
Alpha emission from Cu-63: IRDFF-II



B8 disagrees with (n,α) – probably a model calc.

INDEN adopted the IRDFF-II evaluation (GLSQ fit)

^{252}Cf(sf) neutron leakage of a Cu cube



50x50x50 cm^3 Cu cube
Cf-252(sf) source,
neutron leakage, Rez, CZ

B8 low, JENDL-5
ok above 4 MeV
JEFF-33 bad

M. Schulc et al, Nucl. Eng. Tech. **53**(2021) 3151-3157

https://nds.iaea.org/INDEN/data/ALARM-CF-CU-SHIELD-001-FINAL.pdf

Integral data hinted at data problems

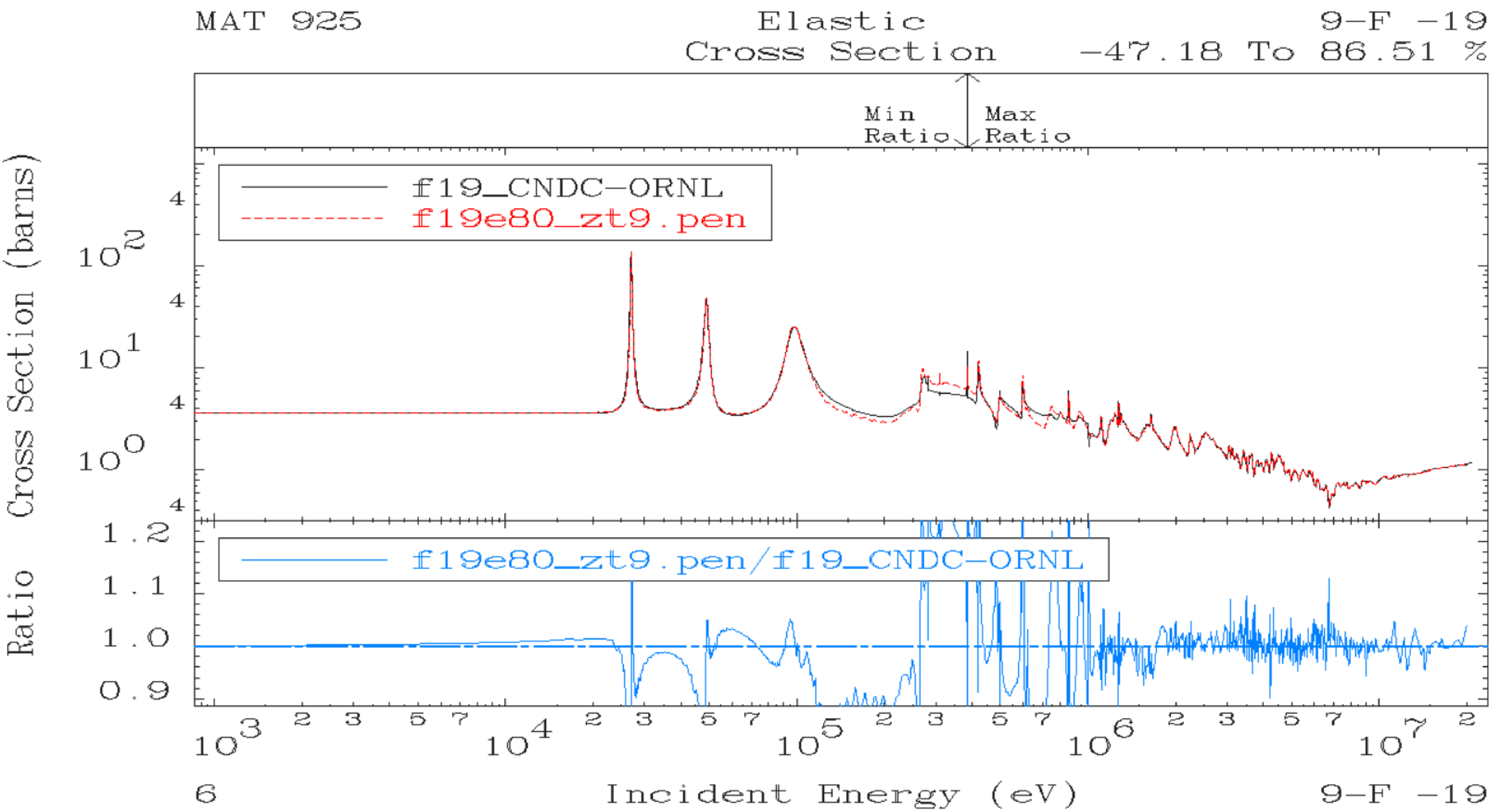
Leakage sensitive to elastic XS and AD/inl/total

B-10,11

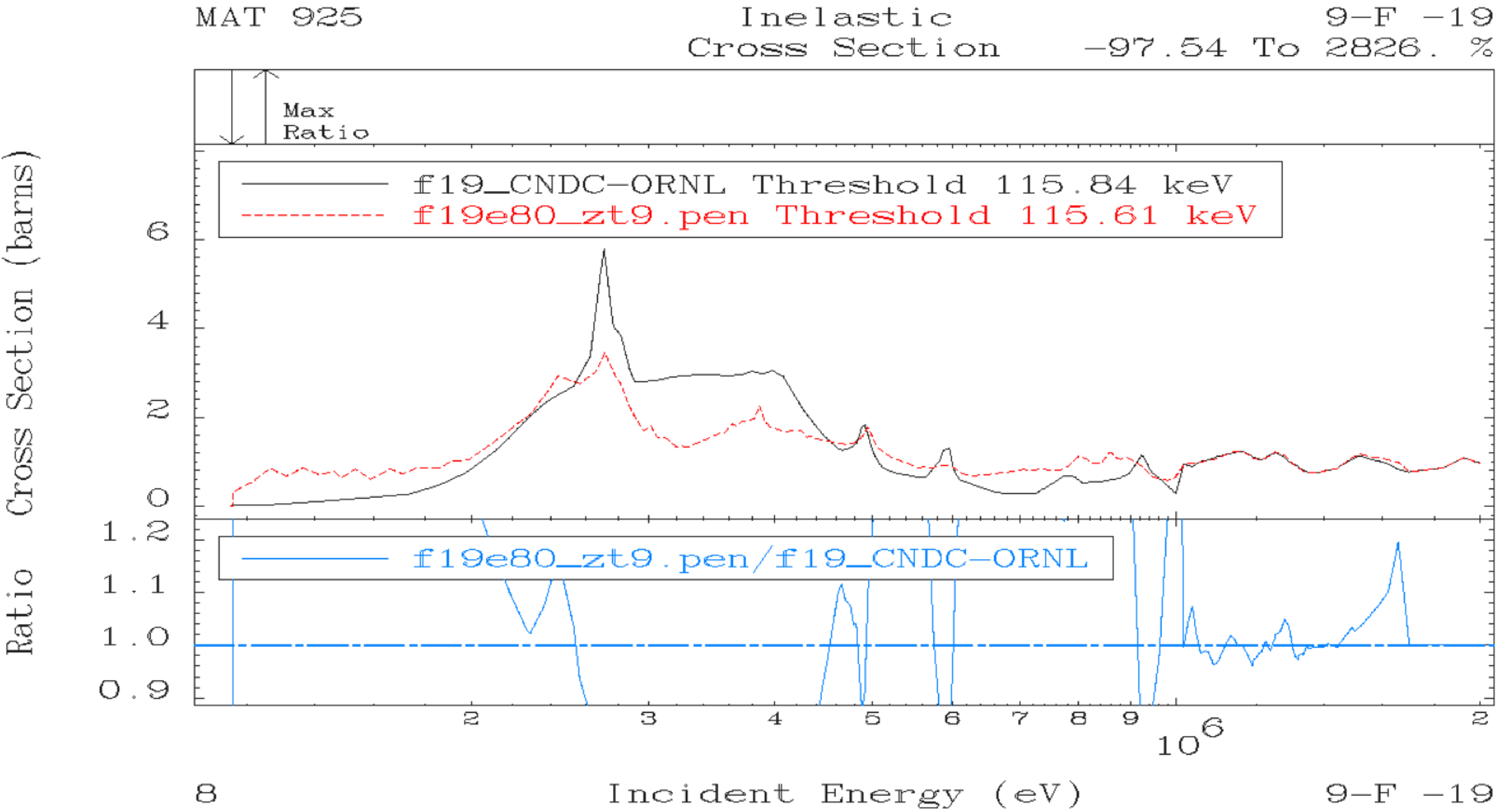
- Current B-10 evaluation is from LANL, 2017
- Current B-11 evaluation is from LANL, 1989
- INDEN recommendation for both isotopes is to use ENDF/B-VIII.0 with patches for consistency with IRDFF-II (= Standards)

F-19

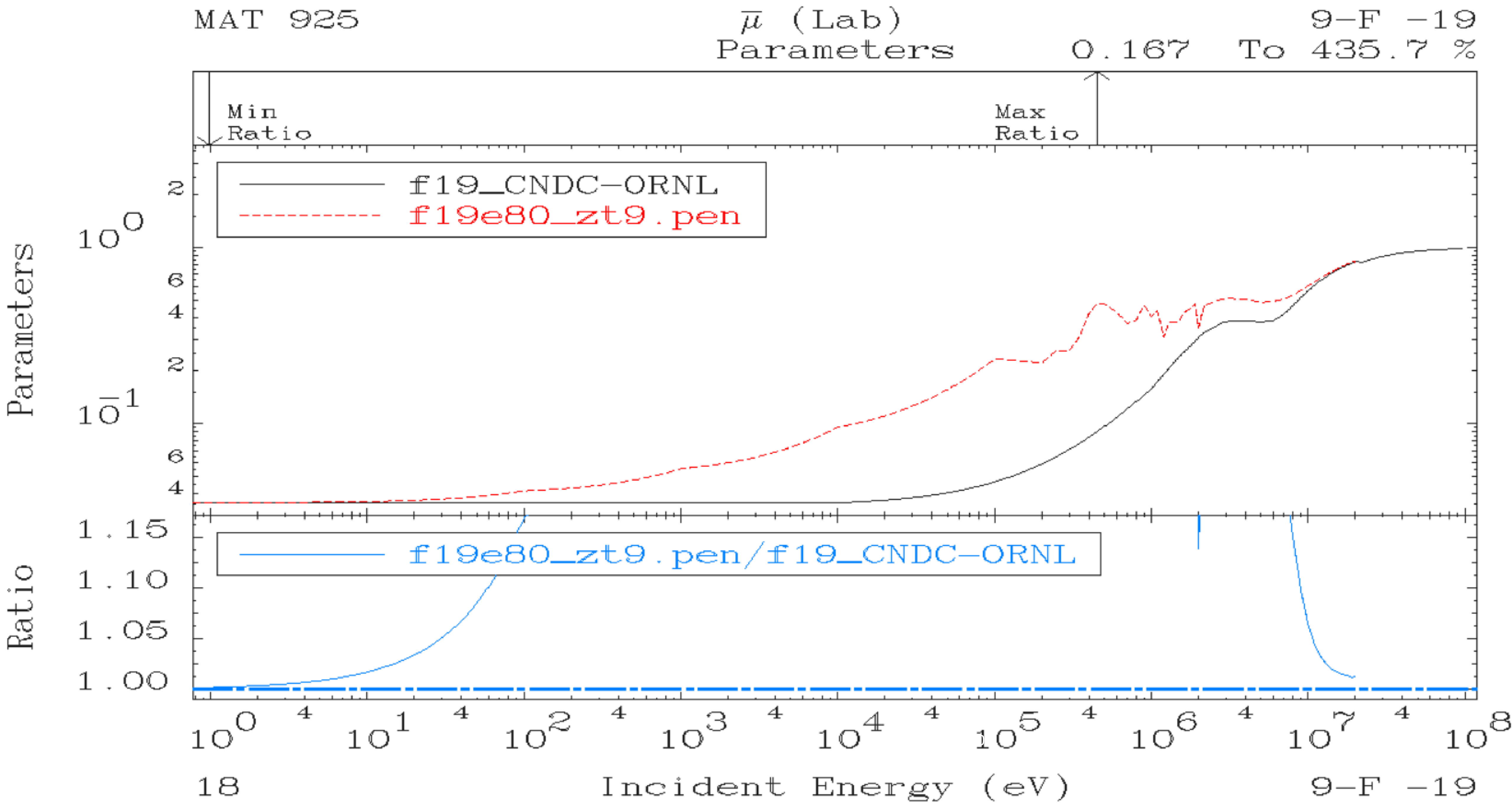
- Current file is a CNDC/ORNL evaluation from 2003.
- INDEN evaluation uses ENDF/B-VIII.0 as the basis to preserve the gamma emission and includes:
  - Elwyn angular distributions
  - Morgan inelastic for the first two levels
- Huge impact on criticality benchmarks
- Validated by new RPI experiments
- Evaluation extends only up to 20 MeV



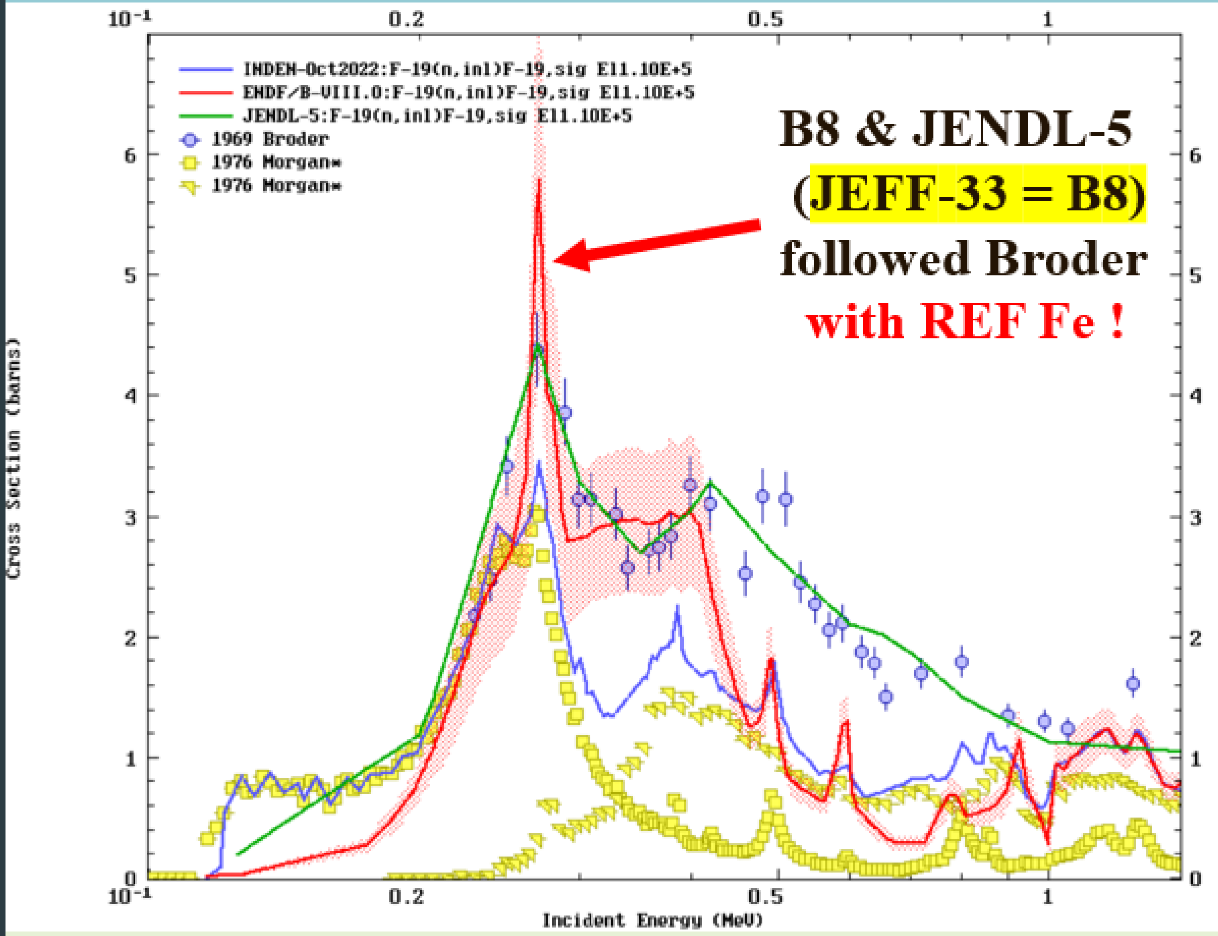
MAT 925
Elastic
Cross Section
9-F -19
-47.18 To 86.51 %
Min Ratio
Max Ratio
f19_CNDC-ORNL
f19e80_zt9.pen
f19e80_zt9.pen/f19_CNDC-ORNL
Cross Section (barns)
Ratio
Incident Energy (eV)
6
9-F -19

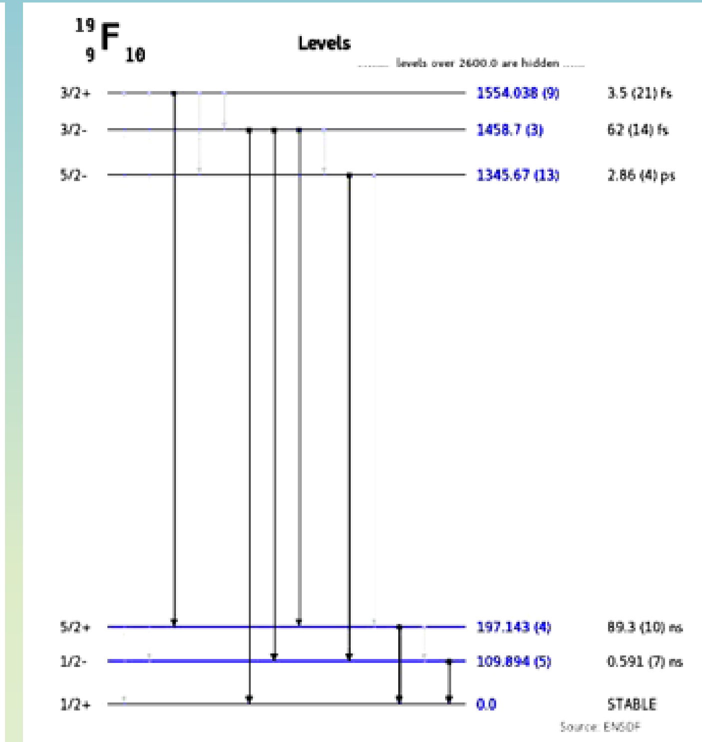


MAT 925
Inelastic
Cross Section
9-F -19
-97.54 To 2826. %
Max
Ratio
f19_CNDC-ORNL Threshold 115.84 keV
f19e80_zt9.pen Threshold 115.61 keV
Cross Section (barns)
6
4
2
0
Ratio
1.2
1.1
1.0
0.9
f19e80_zt9.pen/f19_CNDC-ORNL
2
3
4
5
6
7
8
9
10^6
2
8
Incident Energy (eV)
9-F -19


MAT 925
$\bar{\mu}$ (Lab)
9-F -19
Parameters 0.167 To 435.7 %
Min Ratio
Max Ratio
f19_CNDC-ORNL
f19e80_zt9.pen
f19e80_zt9.pen/f19_CNDC-ORNL
Parameters
Ratio
18
Incident Energy (eV)
9-F -19

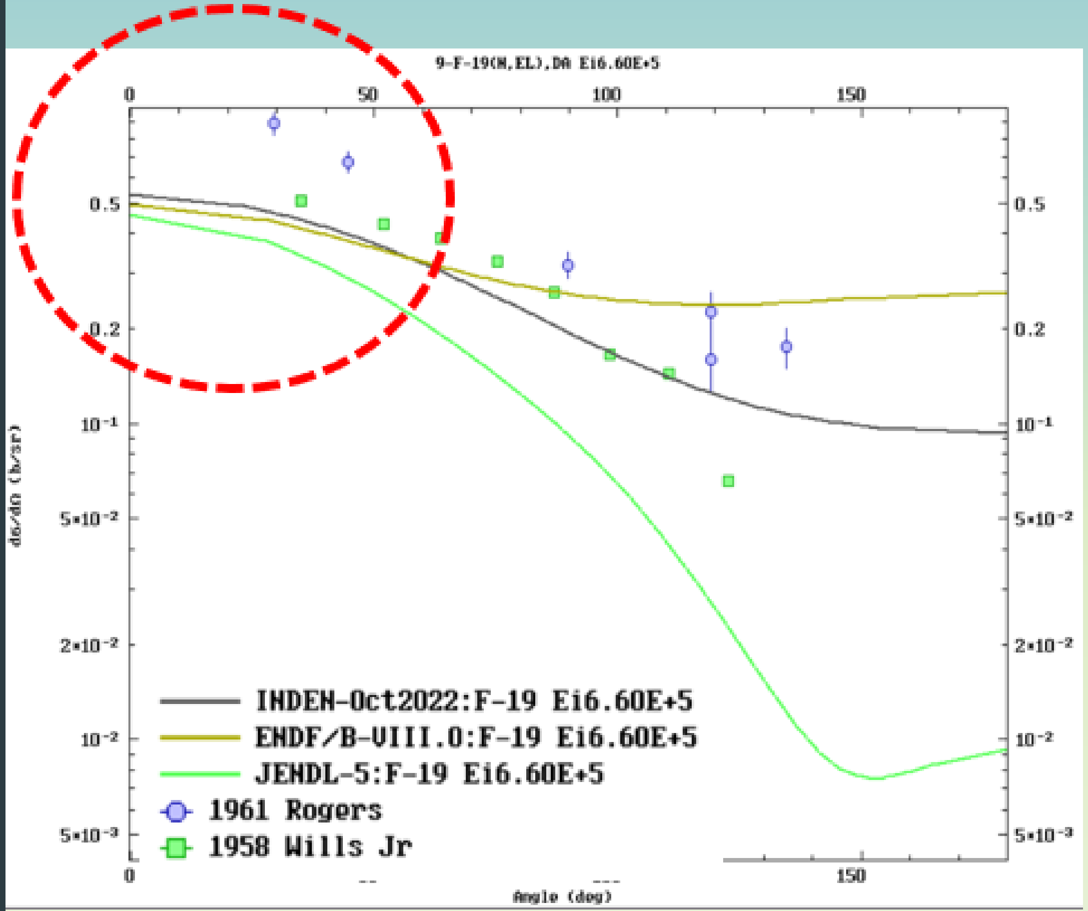
Morgan 76 data adopted << Broder data

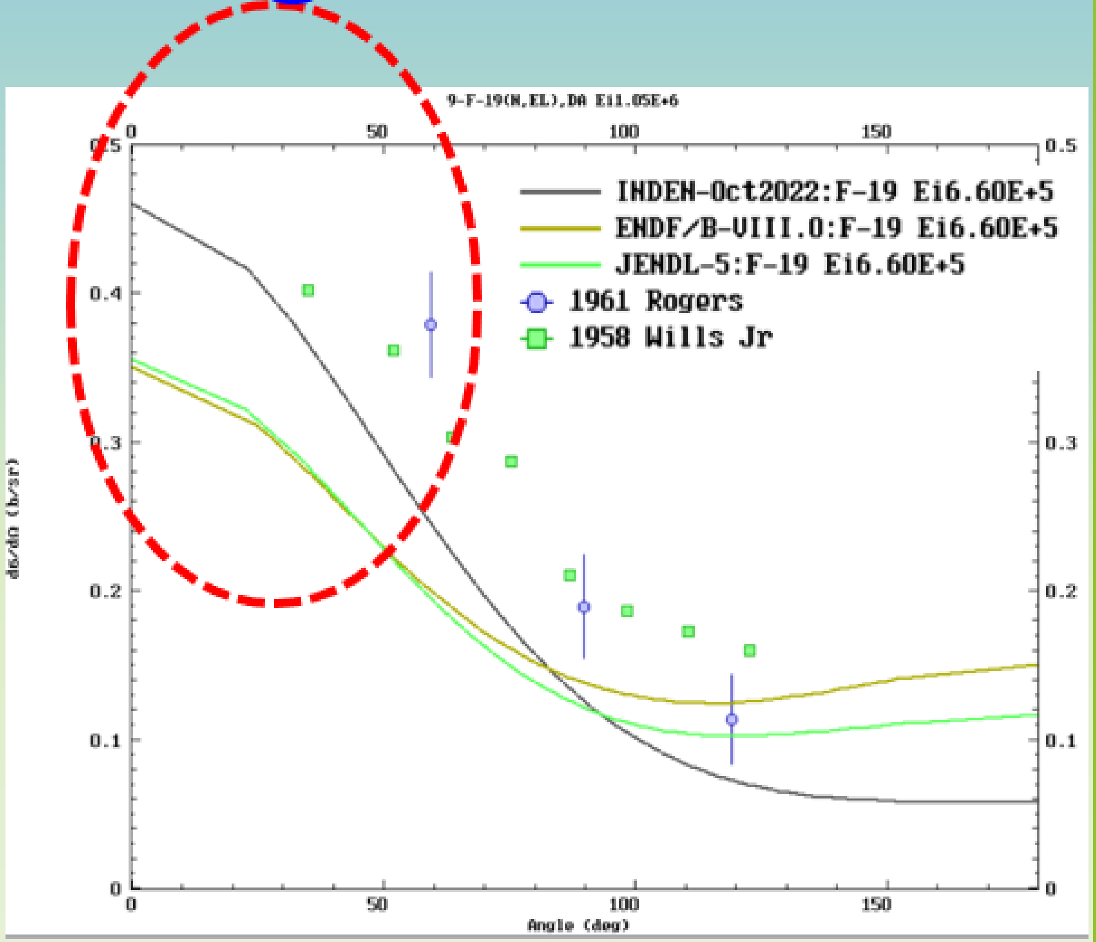




By using Morgan derived INL data (nng x 4pi)
F-19(n,inl) reduced by ~40% from 300 keV

Issues in ^{19}F(n,el) AD below 1 MeV at forward angles



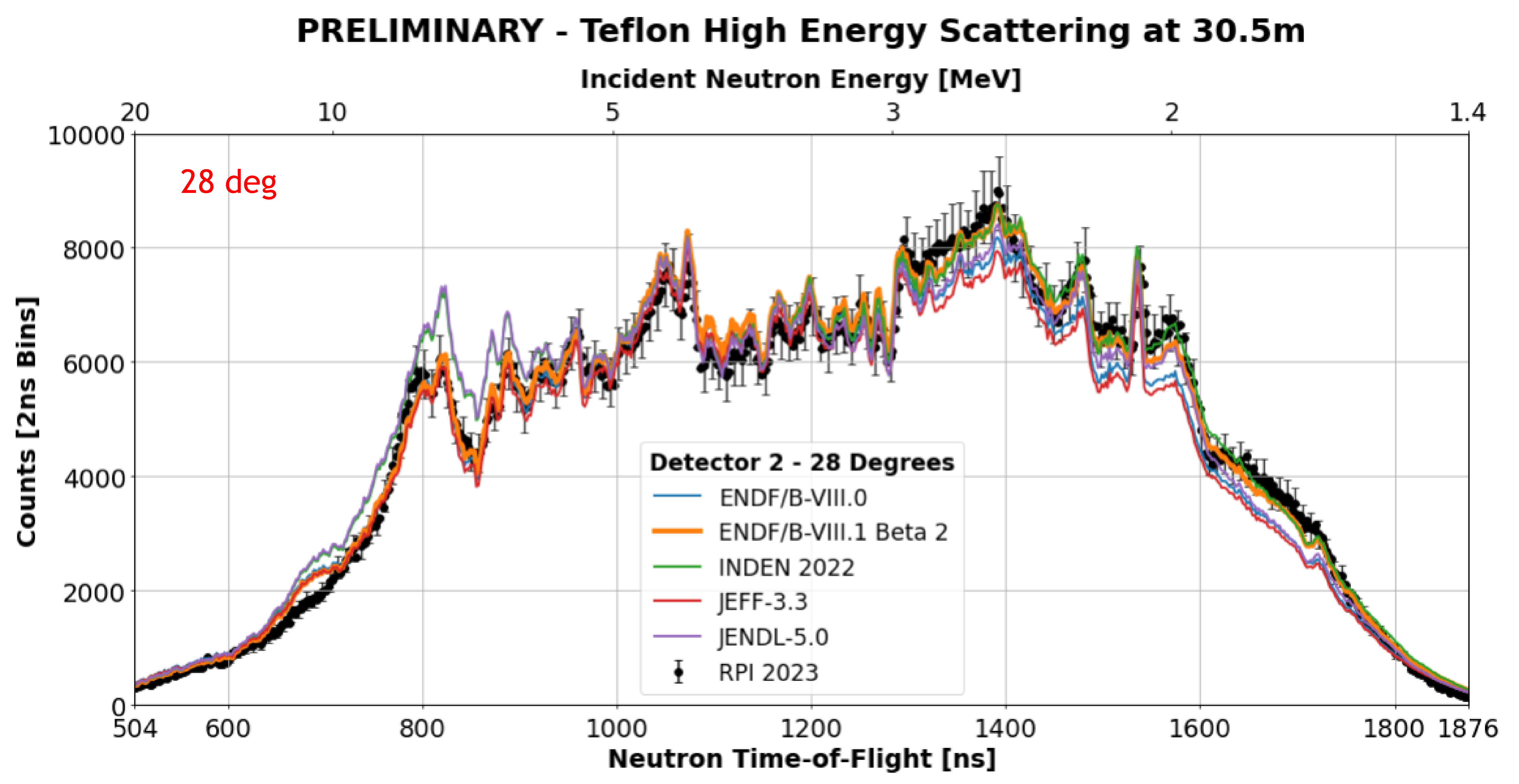


Quasi-Differential Neutron Scattering Measurements of ^{181}Ta and Teflon from 1.5 to 20 MeV

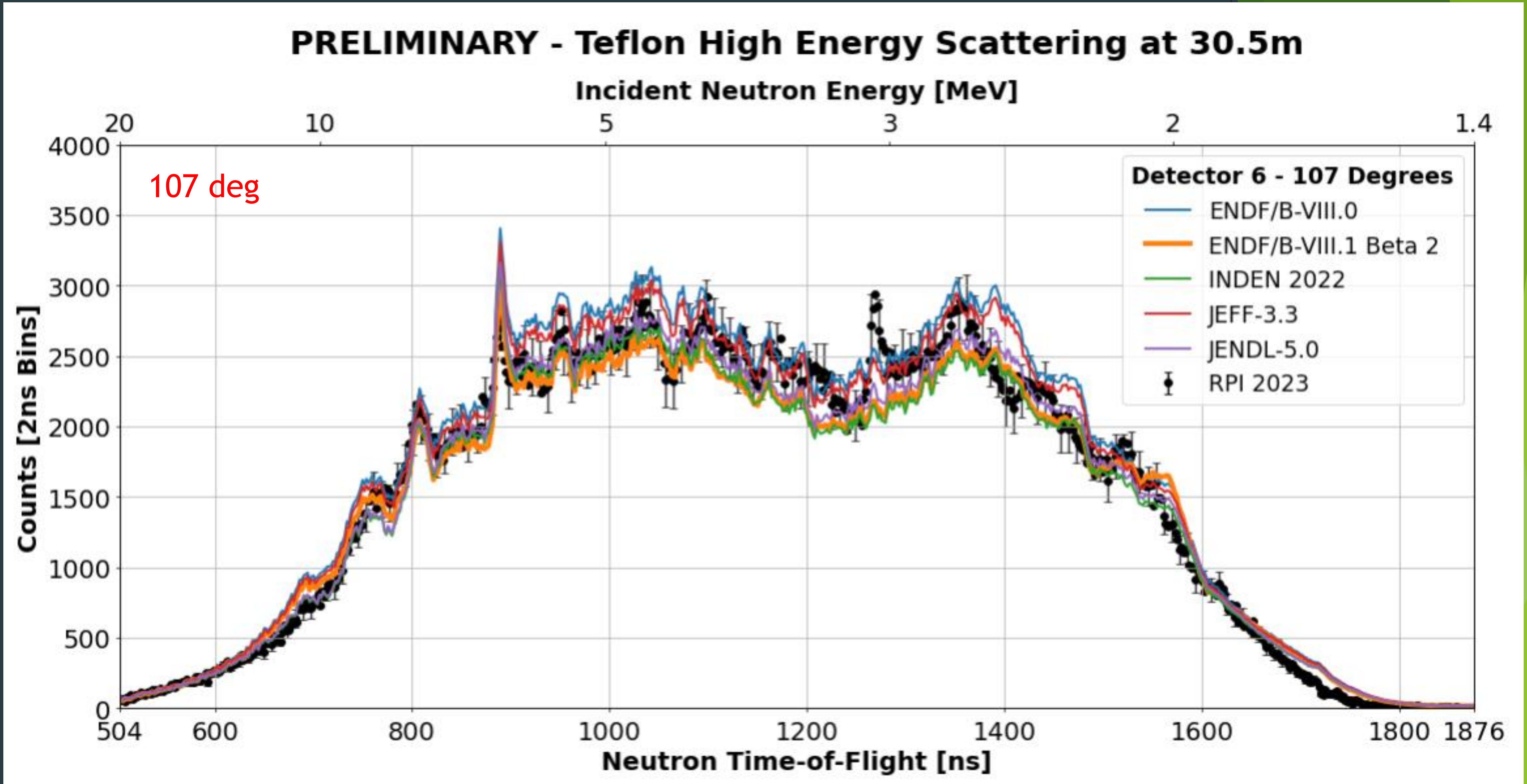
Gregory Siemers[1,3], S. Singh[1], Y. Danon[1], A. Daskalakis[2], K. Cook[1,2], B. Wang[1], P. Brain[1,3], M. Rapp[3]

1. Rensselaer Polytechnic Institute – Troy, NY 12180
2. Naval Nuclear Laboratory – Niskayuna, NY 12309
3. Los Alamos National Laboratory – Los Alamos, NM 87545

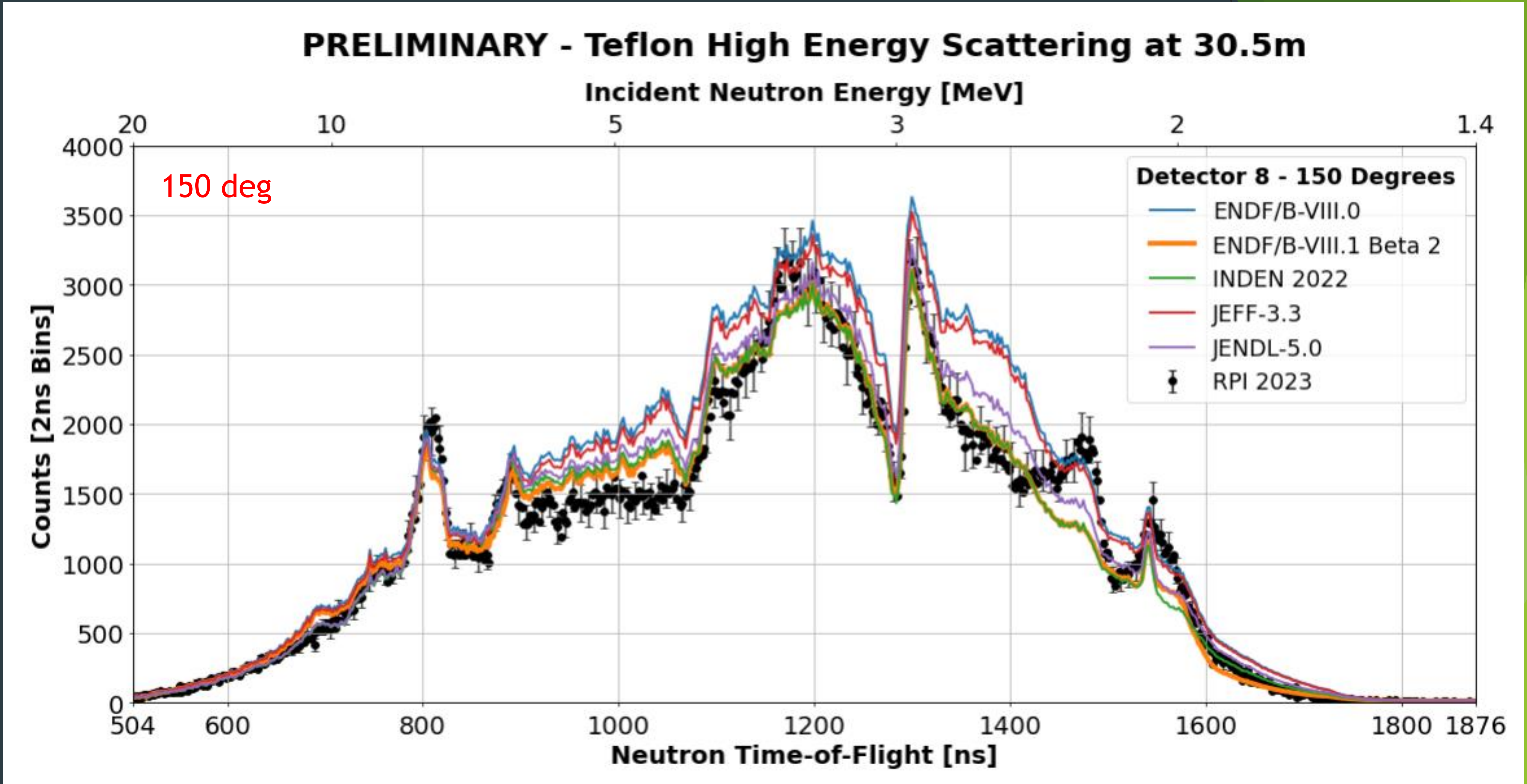
Rensselaer NAVAL NUCLEAR LABORATORY NCSP



Presented at WINS-2023
October 2023, RPI



Presented at WINS-2023
October 2023, RPI



Presented at WINS-2023
October 2023, RPI

Conclusions

- Several new evaluations are available
- Fe, Cr, Cu, F-19, Si show significant improvement in shielding and criticality
- Some of them might have a significant impact
  - The need to redo benchmarks
- Some of them extend to 20 MeV only
  - If adopted, (formal) extension to 60 MeV would be mandatory of older evaluation can remain above 20 MeV (very scarce validation available)

Summary

New evaluations to consider for FENDL-3.*	
U-235	Improved performance for criticality, but limited to 30 MeV
U-238	Improved performance for criticality, but limited to 30 MeV
Fe-56	Several improvements (JEFF-3.3 RRR), requires re-running benchmarks
Fe-57	Versione80m --> e80o (reduced inelastic, non-negative elastic)
Si-28,29,30	RRR re-evaluation
Mn-55	Capture gamma from EGAF
Cr-50,52,53,54	Refined RRR, might require re-running benchmarks
Cu-63,65	Re-evaluated RRR, monitor xs IRDFF, might require re-running benchmarks
B-10,11	Consistency with Standards
F-19	Elwyn angular, distributions, Morgan inelastic (limited to 20 Mev)

Additional general items to be discussed

- If ITER will be water-cooled, TSL should be included in FENDL (perhaps for other materials as well)
- How can we validate heating and radiation damage?
  - Dpa depends on the processing options
- There is no consensus on the oxygen data yet; they impact many benchmarks
- Considering an extensive use of tungsten in ITER and other tokamaks, should we revisit the tungsten evaluations?