Measurements and Standards Work at NIST and Standards Work at Other Facilities

The Impact of the Standards Measurements on the New Standards Evaluation

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H(n,n)H Angular Distribution Measurements

- Previously, measurements were made at 14.9 MeV and 10 MeV to resolve problems with the hydrogen database. Measurements were made by detecting recoil protons at laboratory angles between 0 and 60 degrees at the Ohio University accelerator facility. An analysis of that data suggests differences near zero degrees in the CMS compared with evaluations.

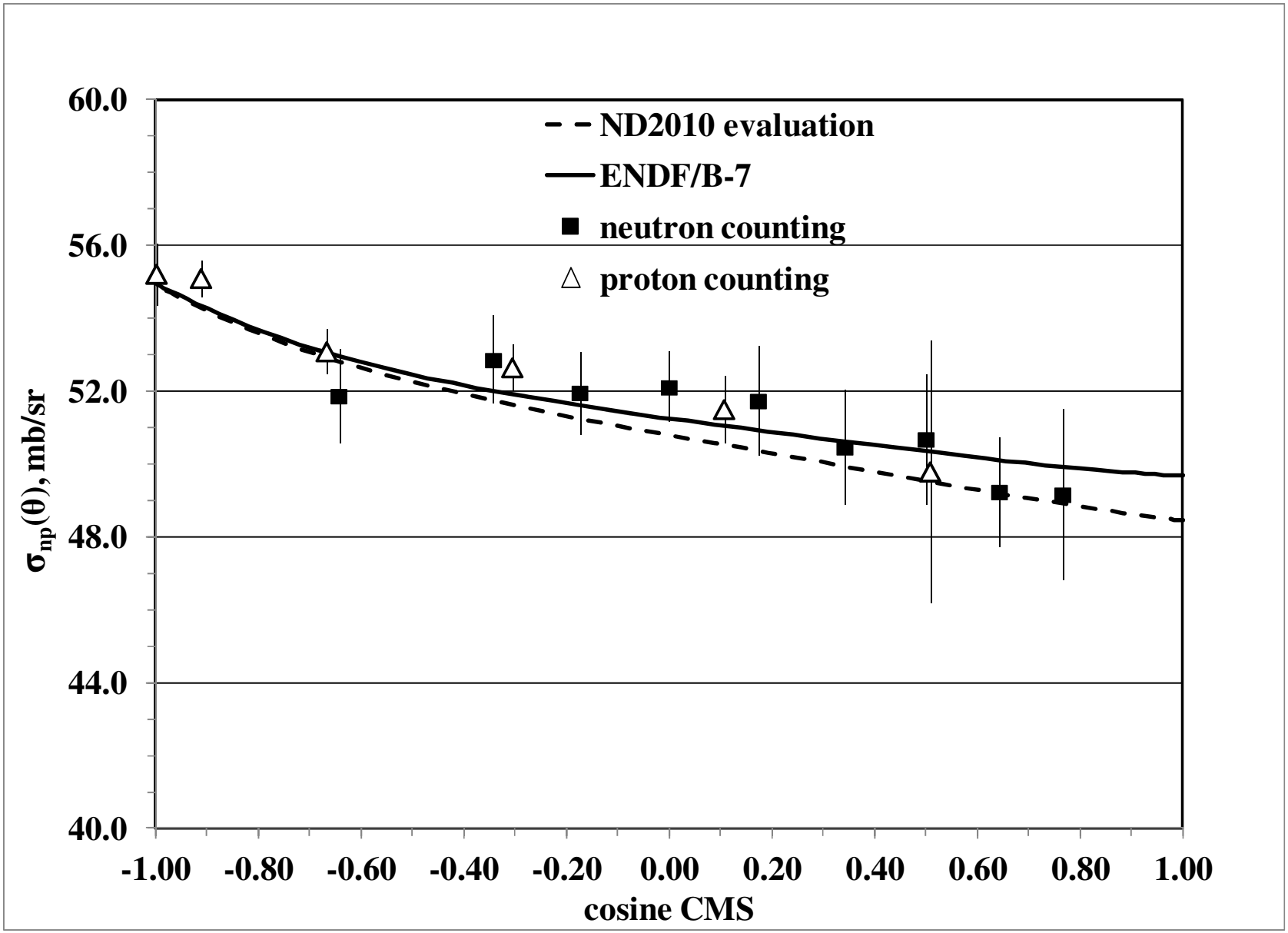
- To obtain data at smaller CMS angles, new measurements have been made at 14.9 MeV By detecting recoil neutrons. Time-of-flight was used between the detection of the associated proton and the neutron with a flight path of about 4 m.

- The efficiency of the neutron detector was measured relative to the ^{252}Cf spontaneous fission neutron spectrum using the time-of-flight between a ^{252}Cf fission fragment and neutron. These measurements used the same flight path as was used for the angular distribution work.

- Also improvements were made to the earlier measurements at 10 MeV. This included providing the mean angles since the central angles were given in the publication and also the normalization was converted to the ENDF/B-VII total elastic cross section.

(collaboration of Ohio University, NIST, LANL and the University of Guelma)

Ohio University Collaboration Results at 14.9 MeV compared with Evaluations



^{6}Li(n,t) Measurements

- At the NIST Neutron Center for Neutron Research a measurement was made of the ^{6}Li(n,t) cross section standard with a 0.3% uncertainty at 3.3255 meV.

- This is the first direct and absolute measurements of this cross section in this neutron energy range using monoenergetic neutrons.

- A primary effort was focused on measuring the neutron fluence accurately. It was determined with an uncertainty of 0.06%.

- Work continues on trying to determine the mass uncertainty of the ^{6}Li target. The original mass yielded a cross section in excellent agreement with the standards evaluation. The deposits were made at IRMM, however IRMM recently found an error so the mass changed by about 1%. This leads to a cross section lower than the standard by about 1%.

- To check the IRMM mass determination, a new measurement using Isotope Dilution Mass Spectrometry is planned at NIST if funding can be obtained.

(collaboration of NIST with the University of Tennessee and Tulane University)

Fluence Determination Work

- Improvements in the determination of the source strength for NBS-I, the U.S. national fast-neutron source standard continue. This work will have an impact on cross section measurements that have used this source as a standard and any future measurements made using this source.

- One method relies on an absolute determination of the fission rate of a bare ^{252}Cf source using a well-defined solid angle for detection. That rate is converted to neutron fluence using the very accurately known nu-bar of ^{252}Cf. Then the absolute neutron rate from that source can be compared with that of NBS-I by measurements of the activation produced in a $MnSO_4$ bath by the two sources. The is in principle only limited in accuracy by the uncertainty in nu-bar of ^{252}Cf, 0.12%. Preliminary results with a 0.9 % uncertainty have been obtained. Additional work is underway.

- Another method is planned in which NBS-I will be absolutely calibrated using a technique employing an α-γ coincidence with the $^{10}B(n,\alpha_1\gamma)$ reaction. Again NBS-I and the absolute source will be inter-compared using $MnSO_4$ baths. This method is expected to produce a result with a smaller uncertainty that that of the other method.

^{3}He(n,p) Measurements

➢Progress continues on an experiment to measure the n-^{3}H coherent scattering length. This measurement is complementary to the n-^{3}He work. This measurement would constrain the fundamental nucleon-nucleon interaction models that underlie all of our cross section work. This work could elucidate the issues with Hale's R-matrix evaluation of the ^{3}He(n,p) standard cross section.

(collaboration of NIST with Indiana University and the University of North Carolina)

The Impact of Measurements

- Selected measurements made after the last evaluation of the standards will be shown.

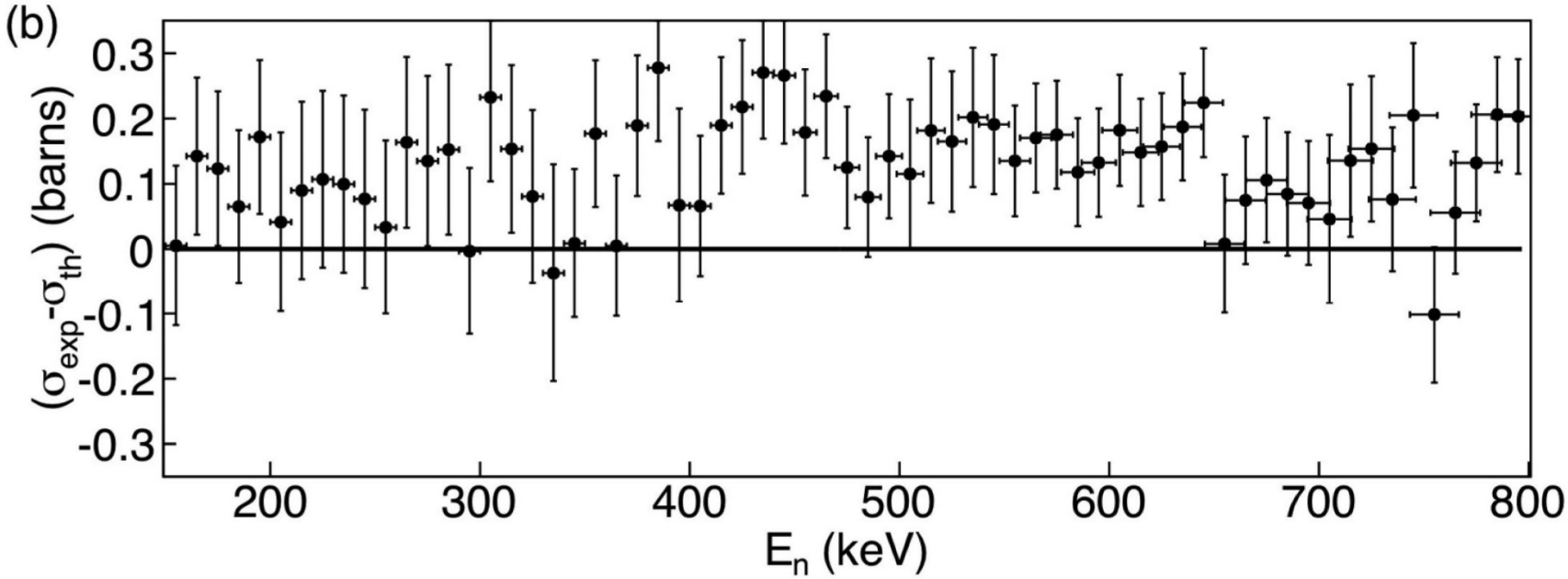
- The impact of new measurements on the new evaluations will be given in specific cases

Recent H(n,n)H Standard Measurements

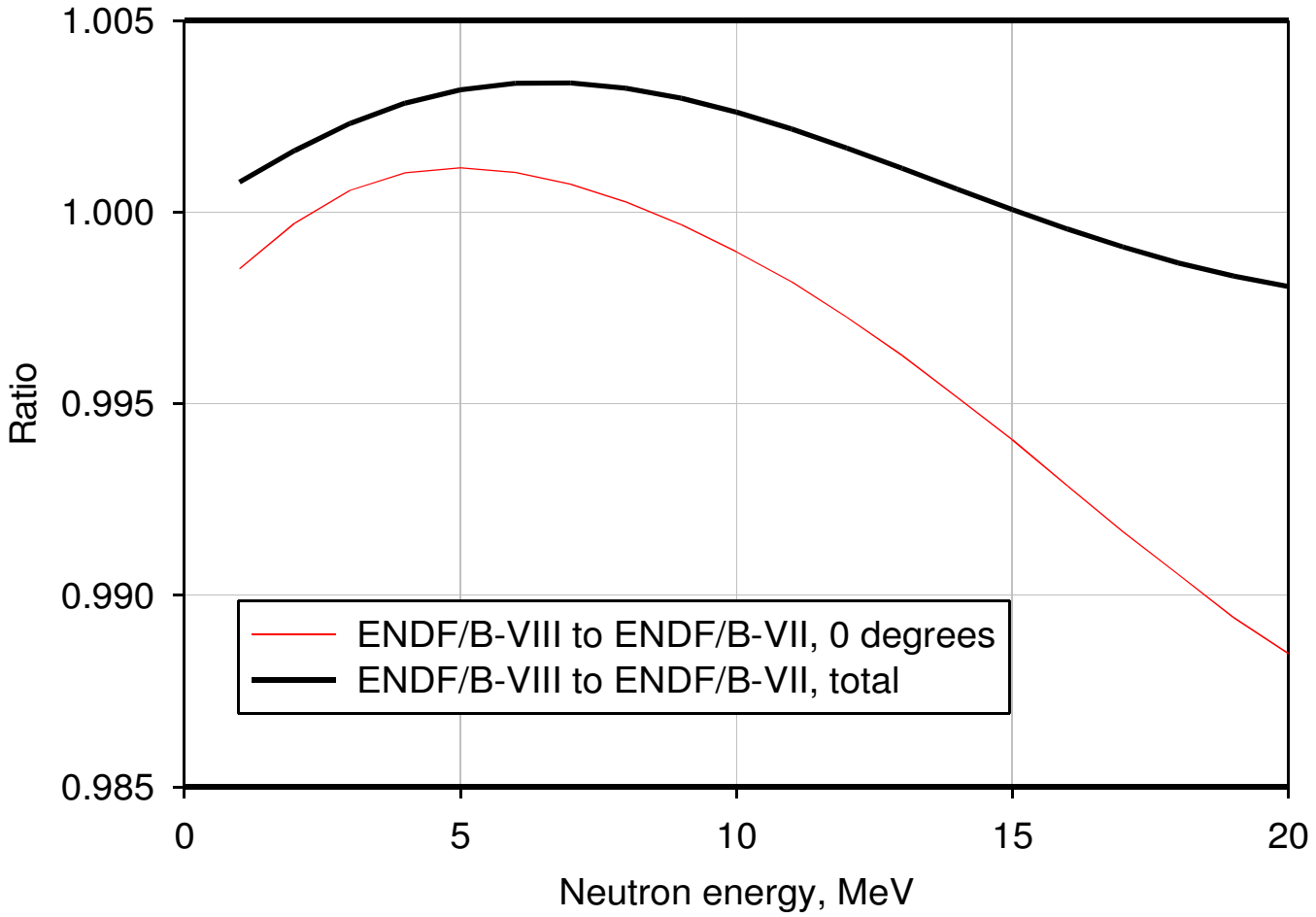
- Concerns about the hydrogen total scattering cross section at low neutron energies led to University of Kentucky Van de Graaff work by Daub *et al.* from 150 keV to 800 keV. The results are systematically slightly larger than the ENDF/B-VII values but generally within their uncertainties of 1.1 to 2%. (Phys Rev C87, 014005 (2013)). Including these data in the new hydrogen being done by Hale and Paris will cause a slight increase in the evaluated cross section. This would then lead to a somewhat better agreement with the Arndt evaluation. The Arndt evaluation is larger than ENDF/B-VII by about 0.1% at low energies and about 1% at about 12 MeV. Gerry however has found EDA normalizes these data down about 2%.

- Additional total cross section work at Kentucky has been done by Yang. The focus was on lower neutron energies than those obtained by Daub *et al*. Data were obtained from 90 keV to 1.8 MeV with uncertainties of 1-2%.

Daub *et al.* Hydrogen Total Cross Section-ENDF/B-VII Evaluation



H(n,n) R-Matrix Evaluation by Hale and Paris (ENDF/B-VIII Standard) compared with the ENDF/B-VII Standards Evaluation



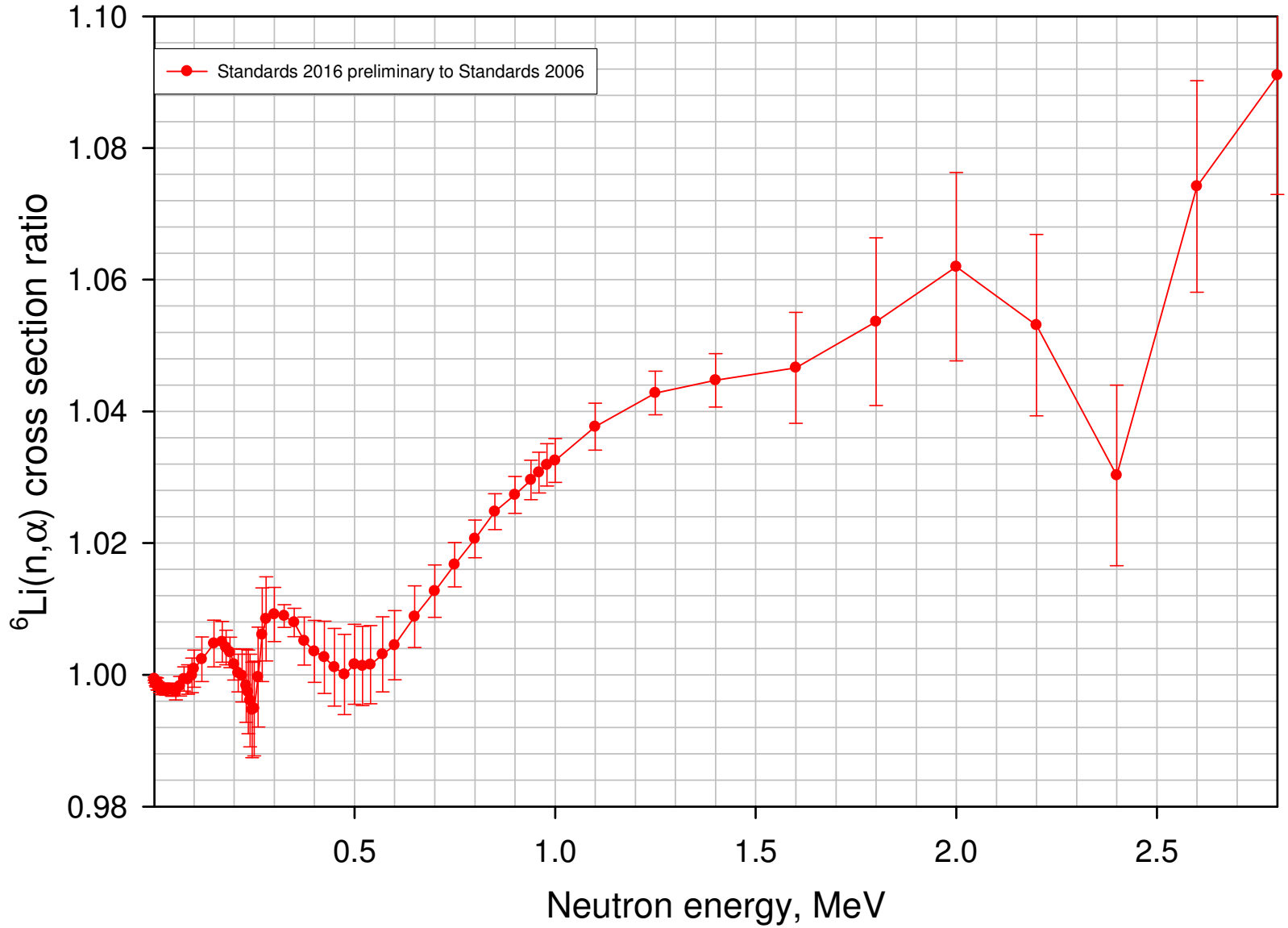
Recent ^{6}Li(n,t) Measurements

➢Measurements have been made of the ^{6}Li(n,t) cross section by Devlin et al. at LANL. This work includes angular distribution data obtained from 0.2 to 10 MeV at eight laboratory angles using four E-ΔE telescopes. These data are absolute ratios to the ^{235}U(n,f) cross section and also the hydrogen scattering cross section. An R-matrix analysis using these data led to larger cross sections particularly about 1 MeV and above.

➢Measurements by Giorginis and Bencardino at IRMM were made in the 2 MeV energy region. The data agreed with the ENDF/B-VII standards evaluation at 1.9 MeV but was 2.6% higher at 2.0 MeV and 1.8% higher at 2.1 MeV

➢ Zhang at Peking University made angular distribution measurements at 1.05 MeV and 1.54 MeV relative to the ^{10}B(n,α) standard; and at 1.85, 2.25, and 2.67 relative to the ^{238}U(n,f) standard.

Comparison of the ^{6}Li(n,t) Standards Evaluations

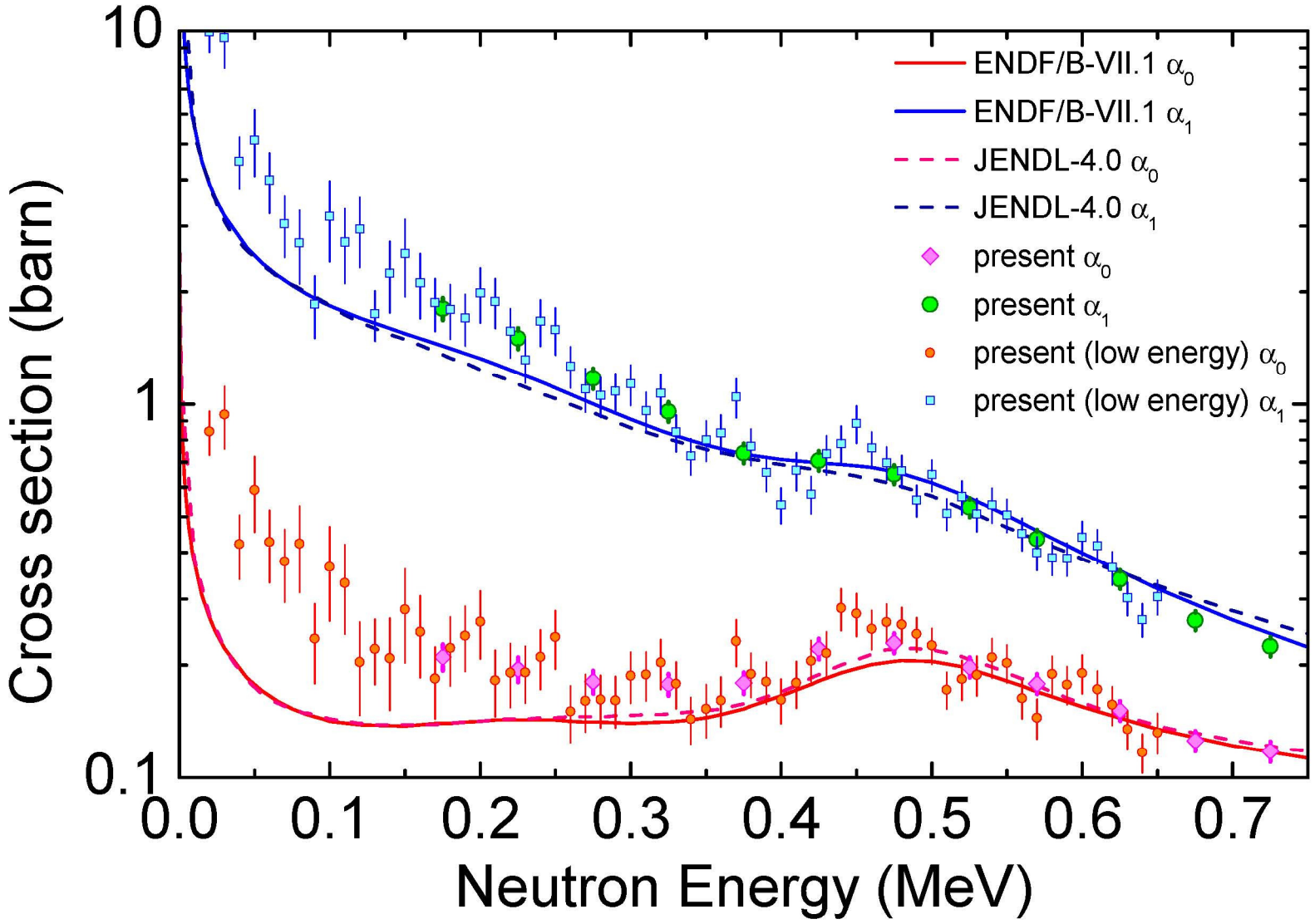


$^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ Measurements

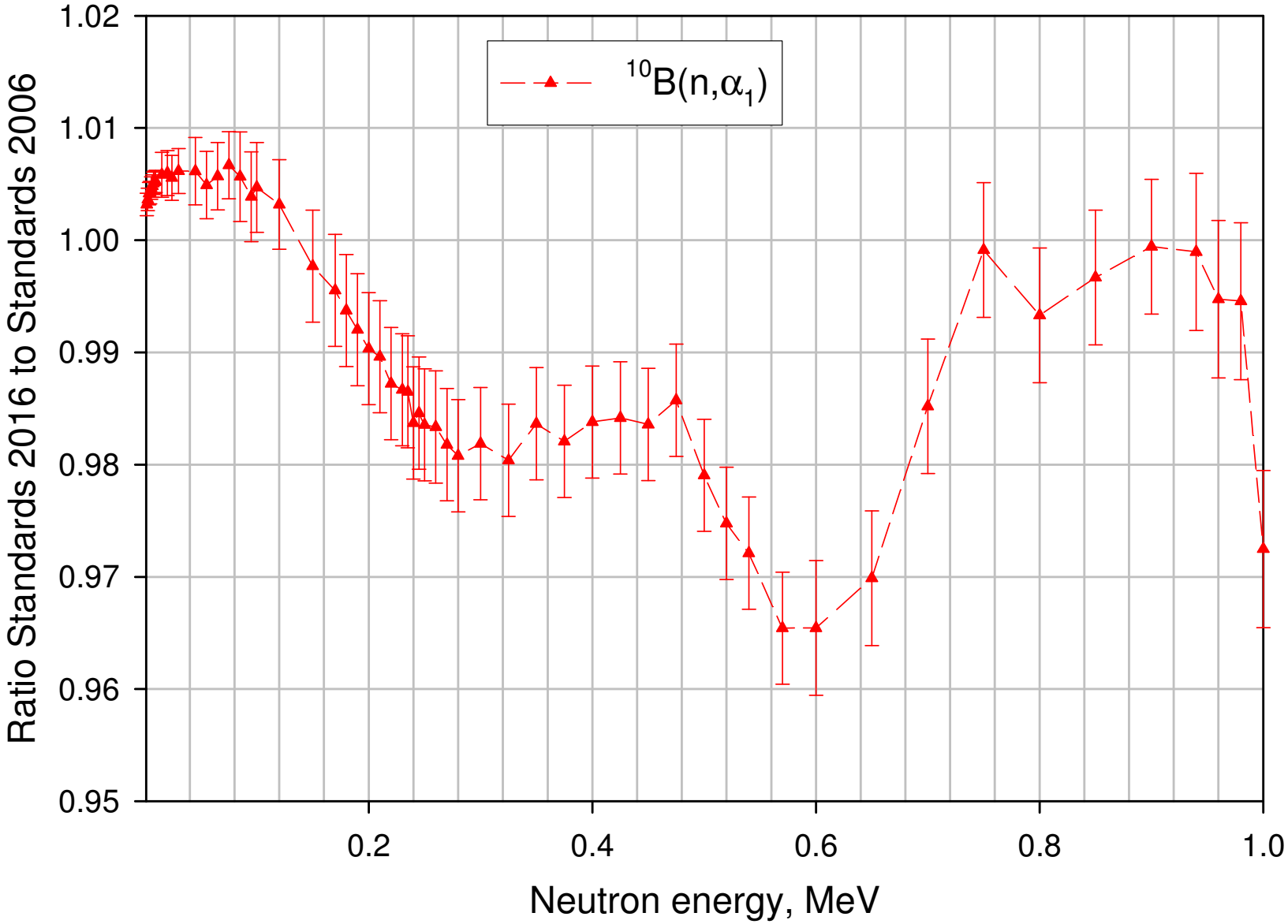
- Hambsch has measurements of the branching ratio, the angular distribution and the $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections relative to the $^{235}U(n,f)$ standard up to 1 MeV. The data were obtained at the 60m station of GELINA at IRMM. They have good statistics but there appear to be some systematic problems. The branching ratio measurements look high at the highest energies and the $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections used to make that ratio are high below about 0.5 MeV. It could something in common such as the fluence determination.

- Zhang et al. made measurements with a Frisch gridded ionization chamber of the $^{10}B(n,\alpha)$ angular distribution relative to the $^{238}U(n,f)$ standard at 4 and 5 MeV . These data are in very good agreement with the 2006 data of Giorginis and Khryachkov.

IRMM Preliminary Measurements of the $^{10}B(n,\alpha_0)$ & $^{10}B(n,\alpha_1)$ Cross Sections



Comparison of $^{10}B(n,\alpha_1\gamma)$ Standards Evaluations



C(n,n) Data

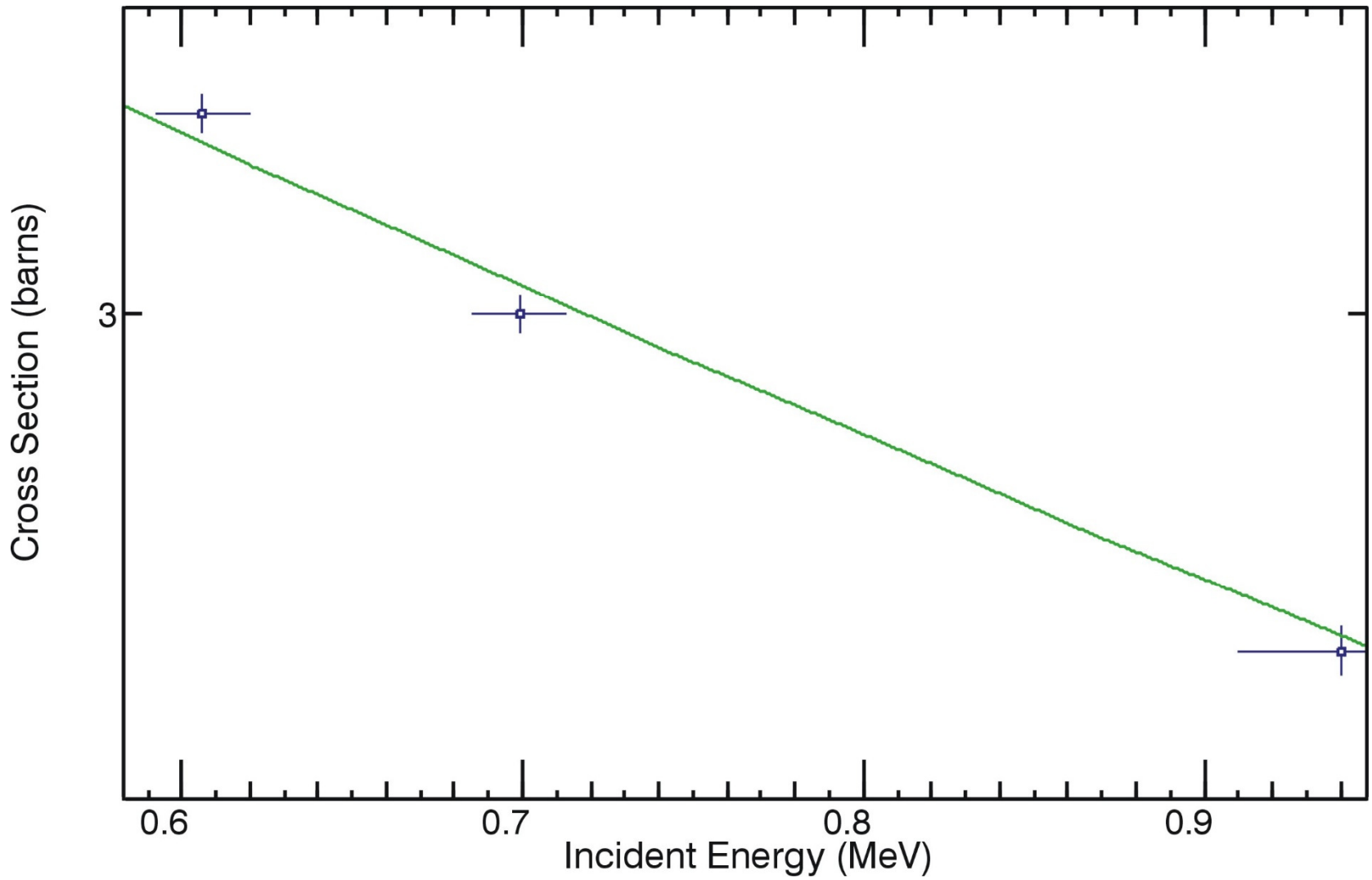
- Daub *et al.* also made very accurate measurements of the carbon total cross section from 150 keV to 800 keV. The results were systematically very slightly lower than the ENDF/B-VII evaluation values but generally within their uncertainties of 1.1 to 2%.

- In addition to the n-p total cross section work, Yang *et al.* also made carbon total cross section measurements since a polyethylene sample was used in the experiment. The focus was on lower neutron energies.

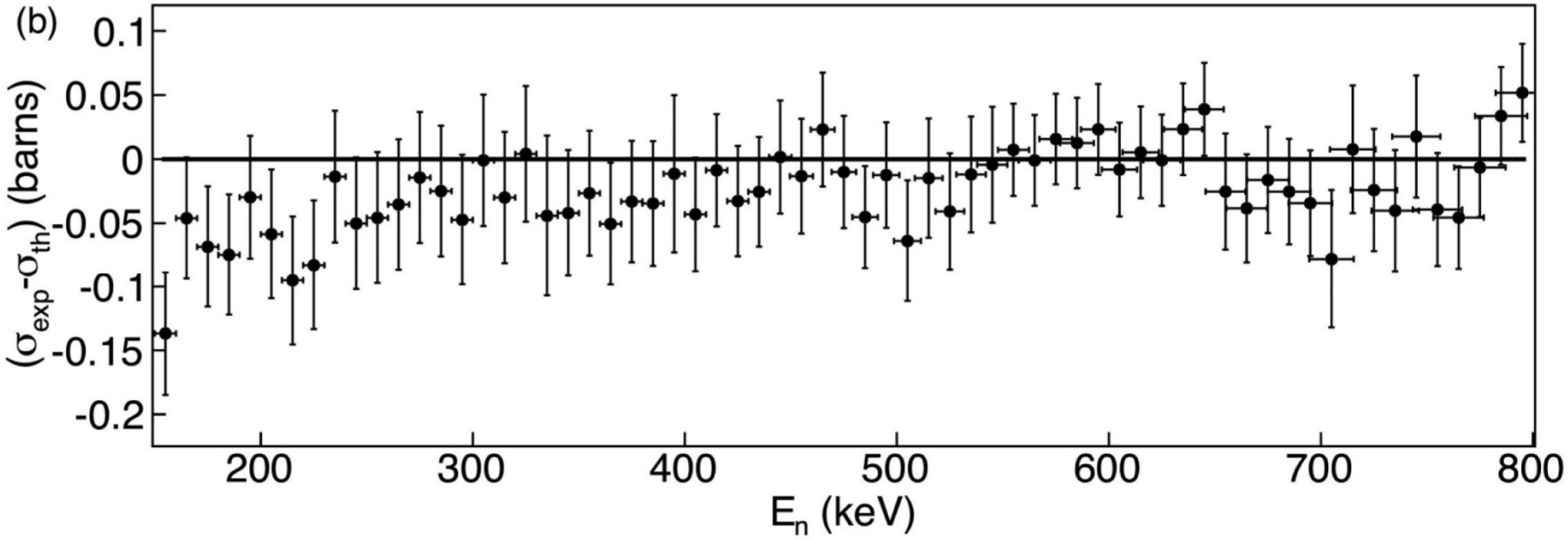
- Danon *et al.* made very accurate measurements of the carbon total cross section using an iron filtered linac neutron beam. The data were obtained for 19 peaks from 24.3 to 945 keV. This method provided very low backgrounds. The results obtained with an accuracy of better than 1% were in excellent agreement with the ENDF/B-VII evaluation.

- Gritzay *et al.* reported at the ND2007 conference carbon total cross section data taken at the Kyiv reactor using filtered beams with energies of 2, 3.5, 12, 24, 55, 59, 133 and 148 keV. They are generally in good agreement with the ENDF/B-VII evaluation. However, with 1-2% uncertainties, at the lower energies their results are somewhat low and at 148 keV their result is about 5 standard deviations higher. However these data are considered preliminary

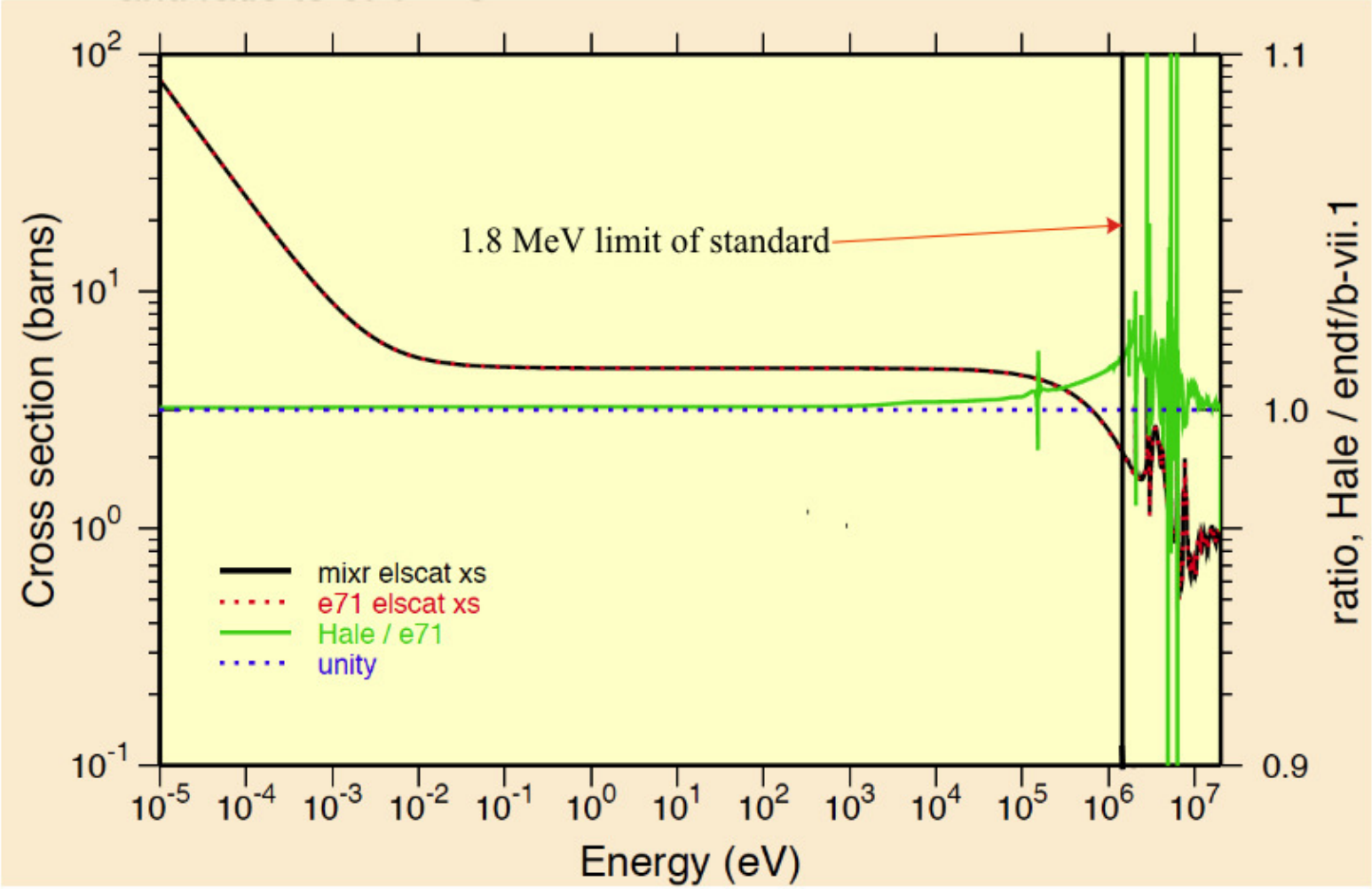
Danon *et al.* Carbon Total Cross Section Compared with ENDF/B-VII



Daub *et al.* Carbon Total Cross Section-ENDF/B-VII



Comparison of Natural Carbon Total Cross Section Standards Evaluations - Preliminary Results



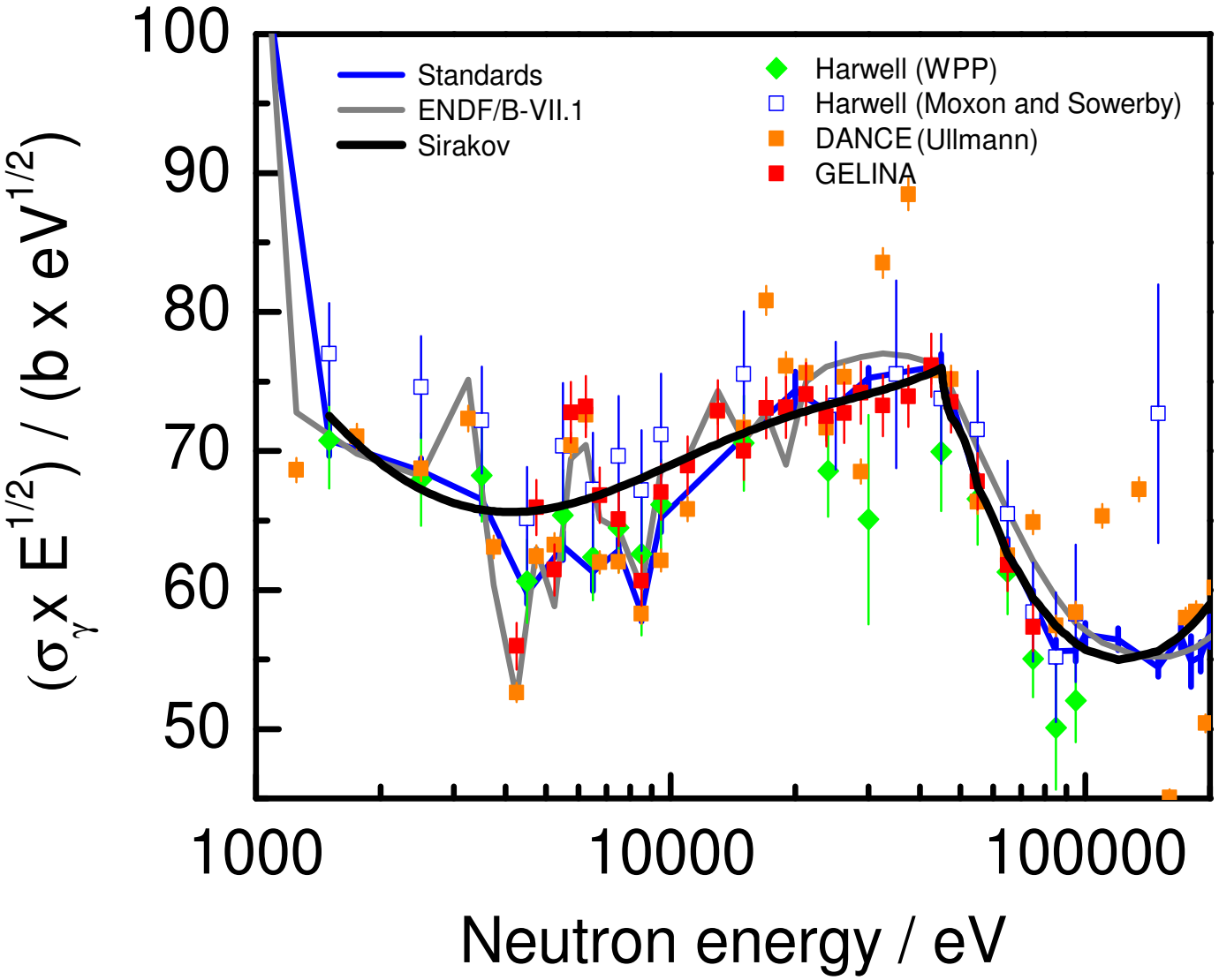
Au(n,γ) and ^{238}U(n,γ) Measurements

➢Wallner (U. of Vienna) made measurements of the ^{238}U(n,γ)/^{197}Au(n,γ) cross section ratio at 426 keV. Accelerator mass spectrometry was used to measure the ^{239}Pu resulting from the ^{239}U. Activation was used for the gold measurements. The measurement has a large (150 - 200 keV FWHM) energy spread. That ratio, 0.99± 0.04, compared with the standards evaluation is in excellent agreement.

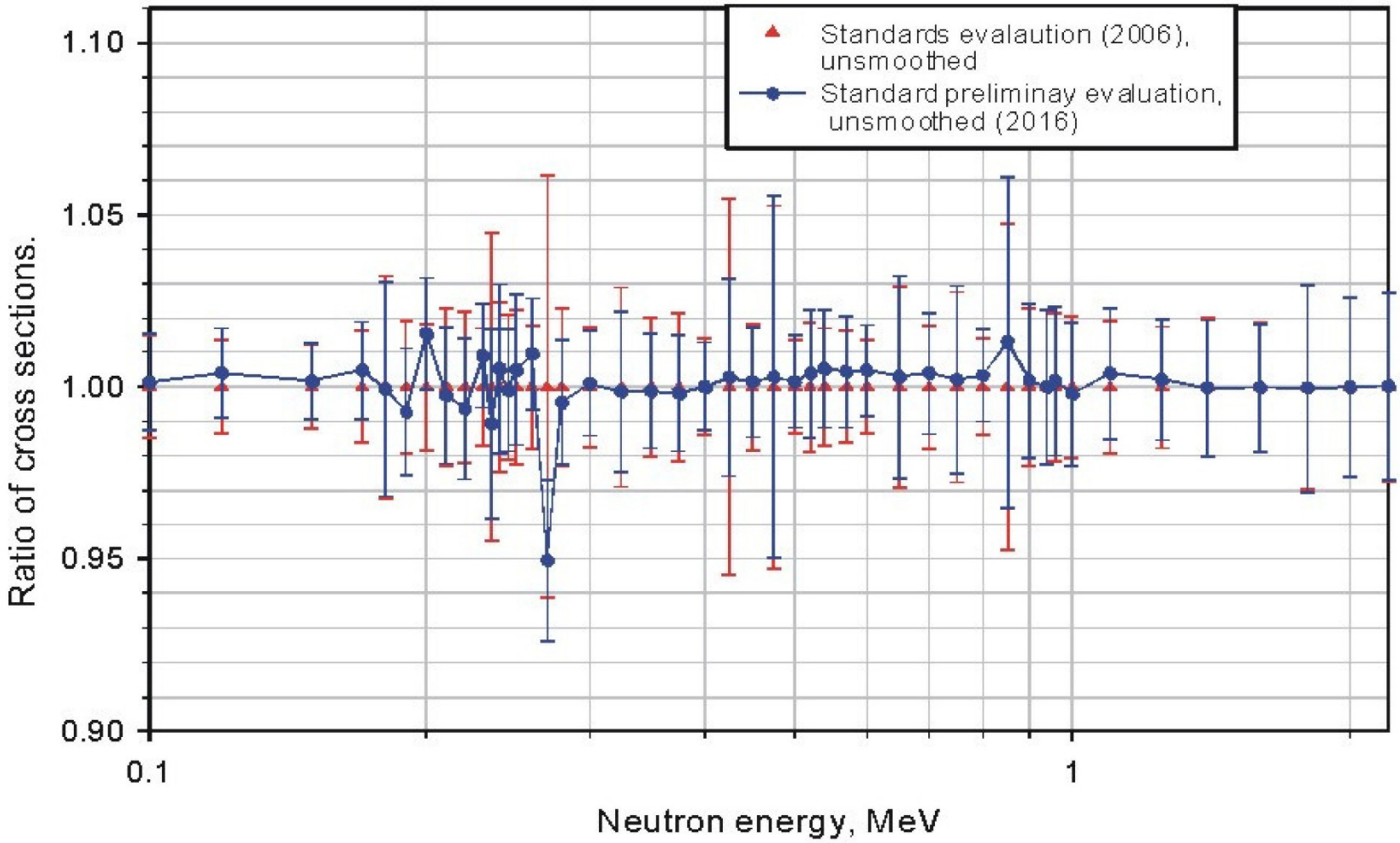
➢ Ullmann *et al.* made measurements of the ^{238}U(n,γ) cross sections using the DANCE. Though the data could be made absolute, they are now normalized to capture in the 80 and 145 eV resonances. They associate a 2 percent uncertainty to this normalization. They state there is generally good agreement with the ENDF/B-VII evaluation. For the evaluation, it was decided that the data from 150 keV to 500 keV could be used in the evaluation, but the data from 10 keV to 150 keV could not be included due to structure in the data.

At GELINA ^{238}U(n,γ) cross sections measurements were made by Kim *et al.* using a C_6D_6 detector with very high accuracy. They agree very well with the ENDF/B-VII data

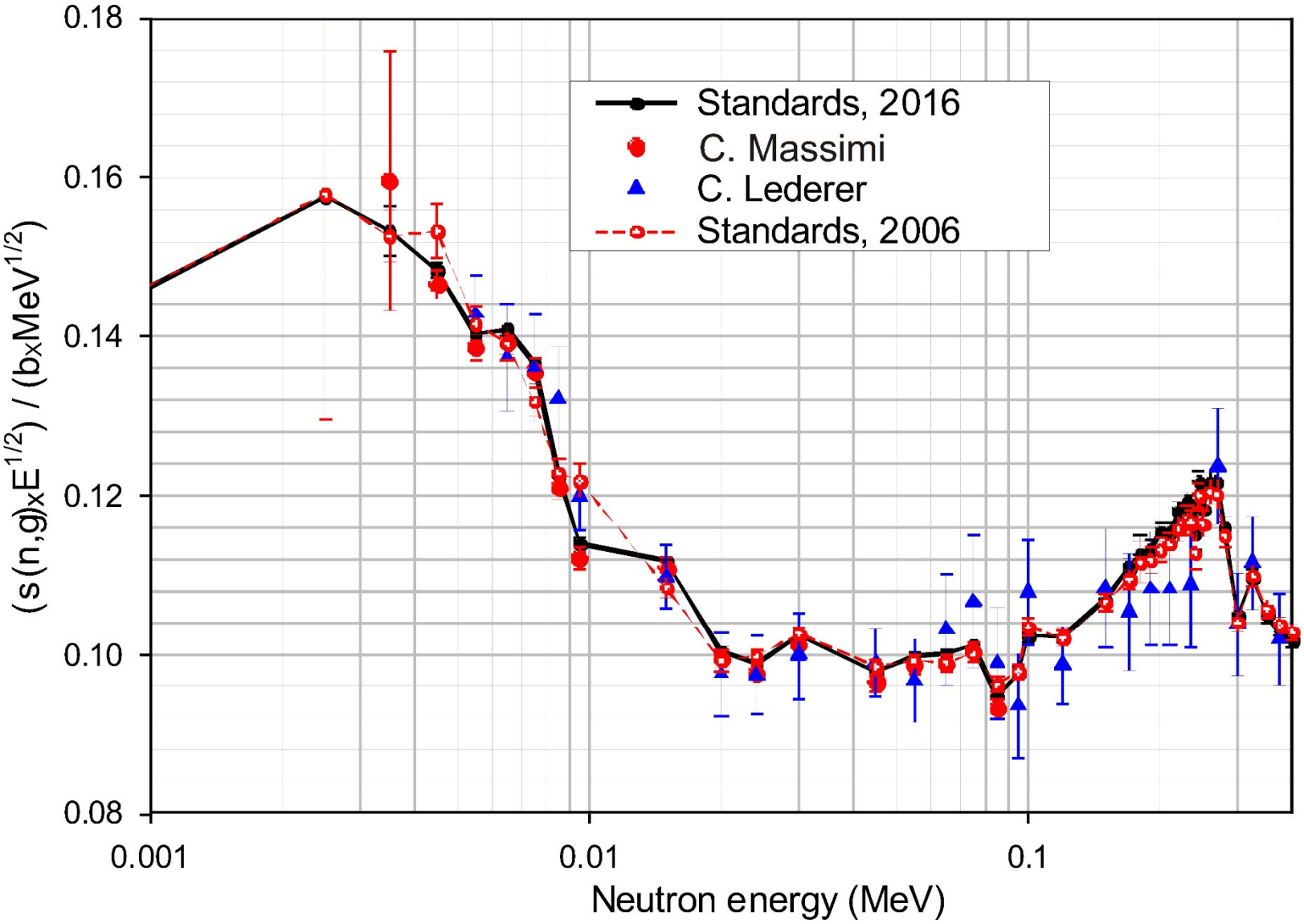
Measurements and Evaluations of the $^{238}U(n,\gamma)$ Cross Section



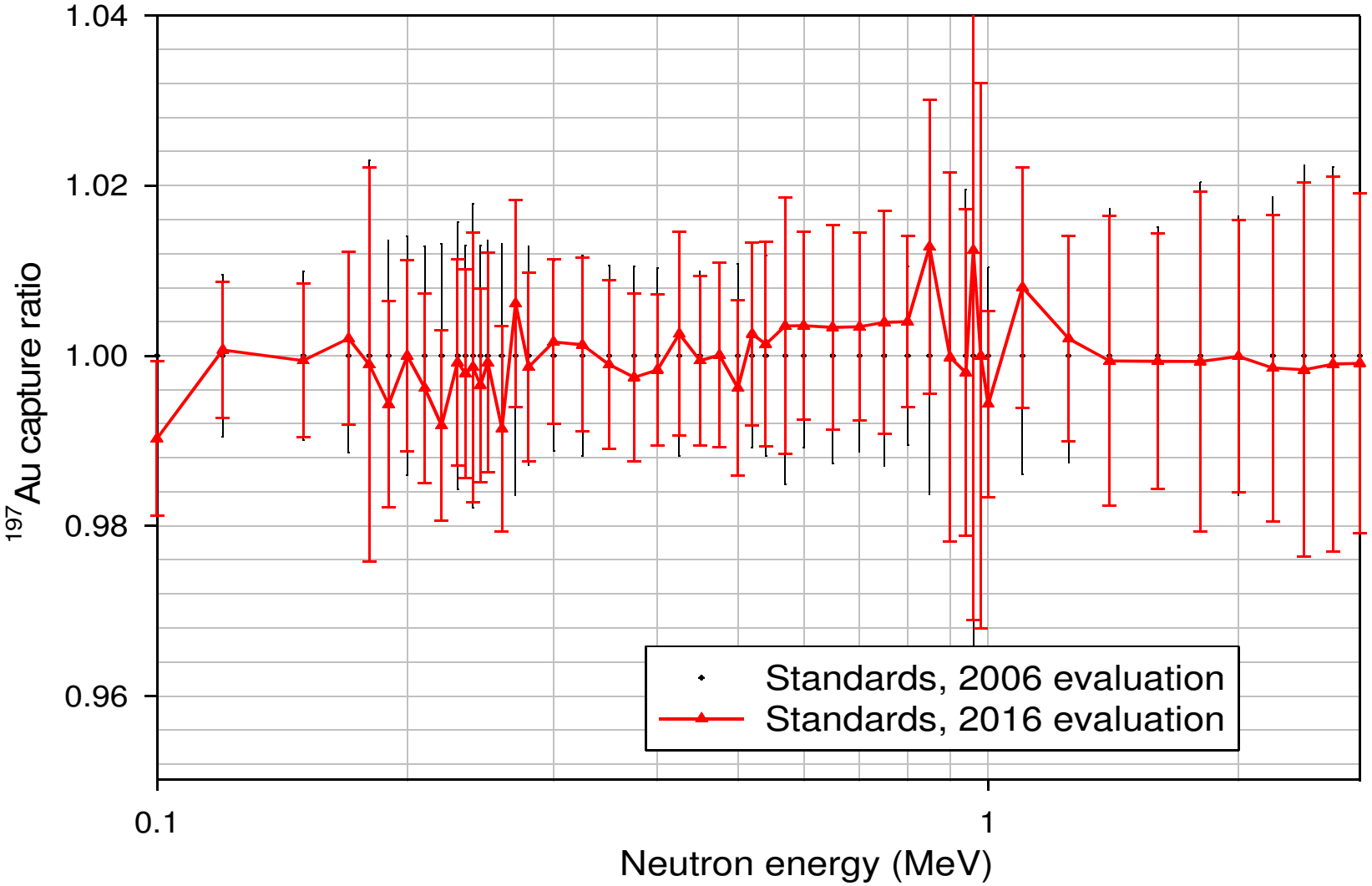
Comparison of $^{238}U(n,\gamma)$ Evaluations



Au(n,γ) Cross Section Measurements and Evaluations



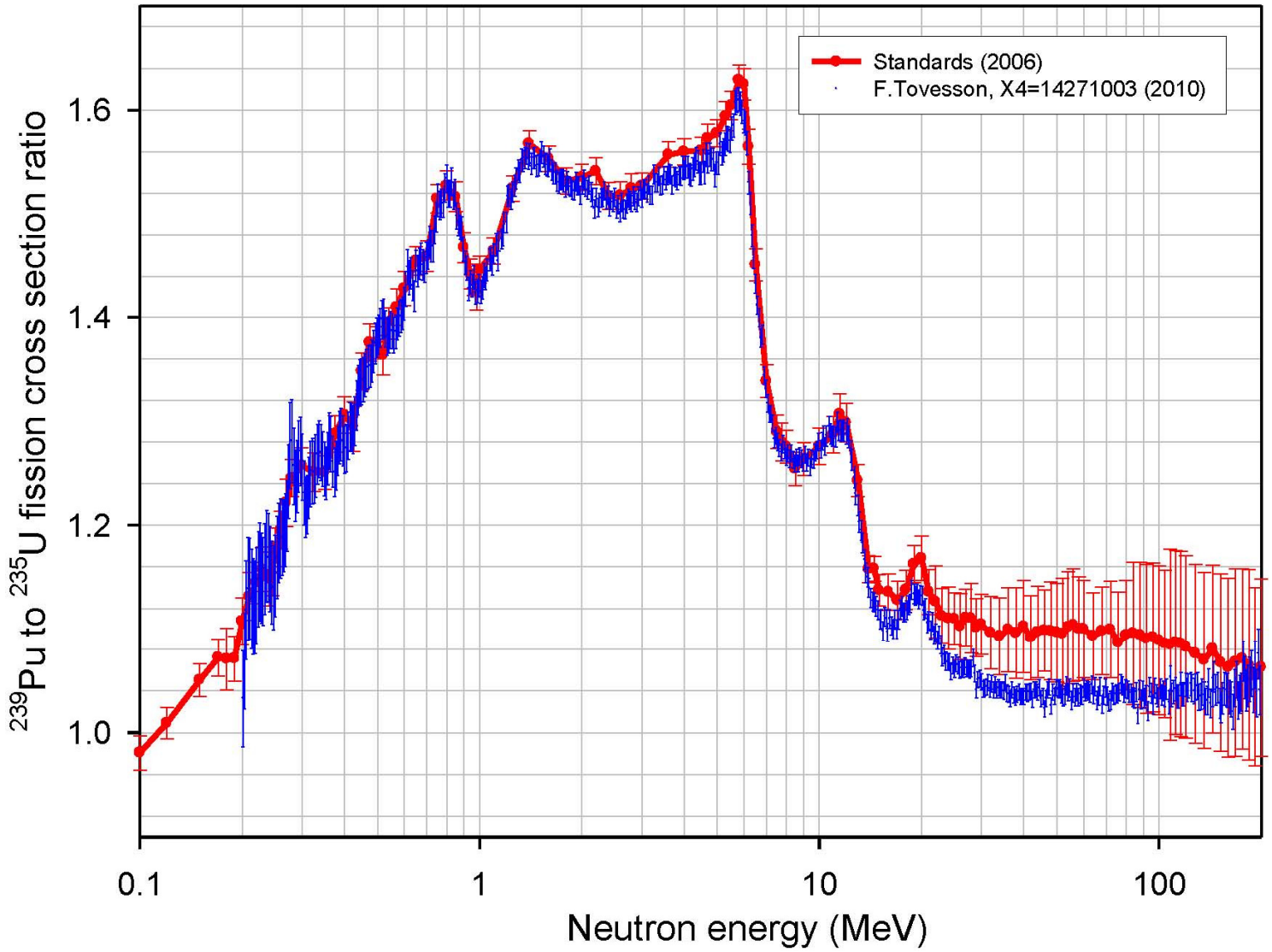
Comparison of Au(n, γ) Standards Evaluations



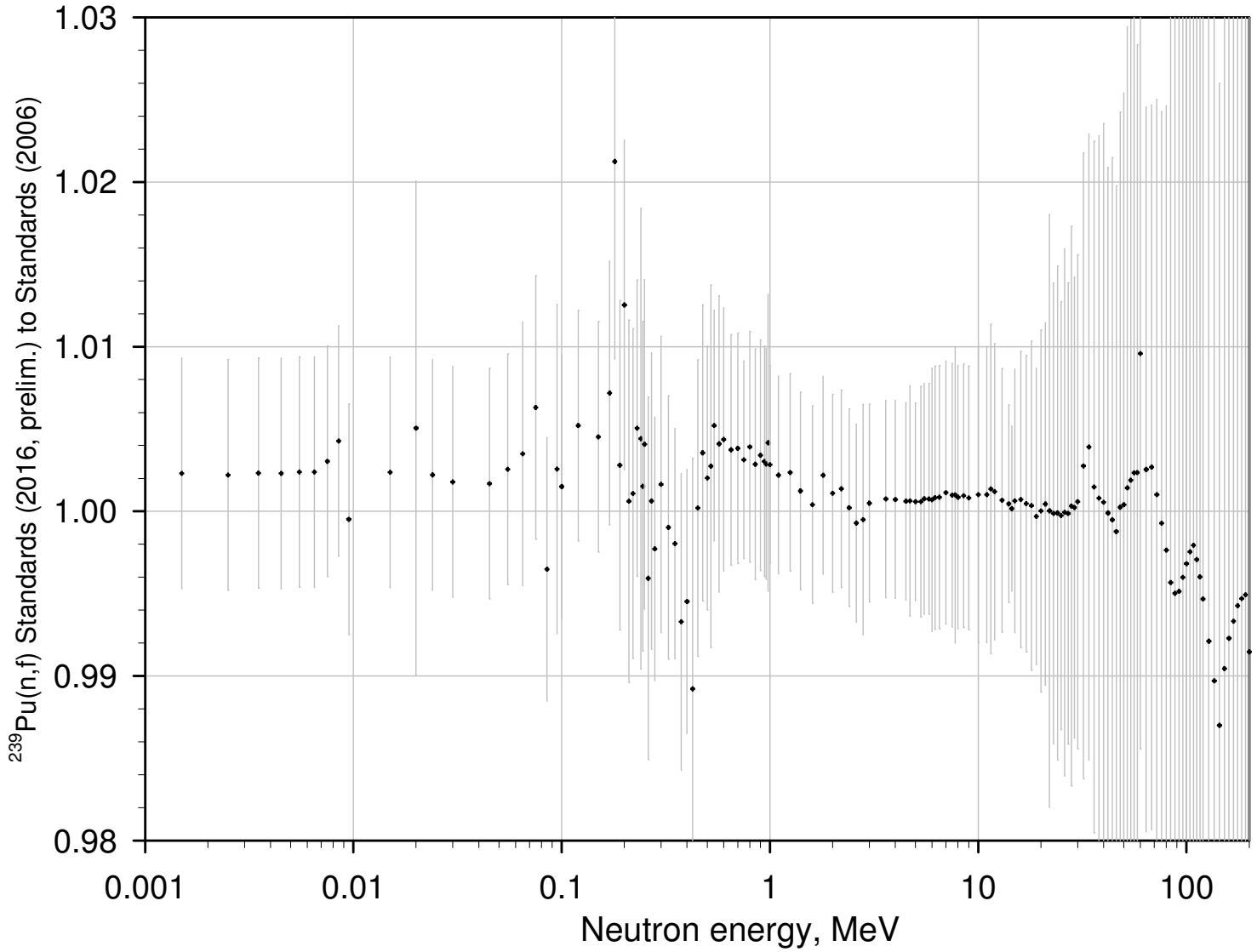
^{239}Pu(n,f) Measurements

- The most recent ^{239}Pu(n,f) cross section measurements were made by Tovesson and Hill at WNR-LANL. They agree reasonably well with the ENDF/B-VII standards evaluation and the Lisowski *et al.* and Shcherbakov *et al.* measurements up to about 10 MeV. The new measurements have somewhat smaller uncertainties than these other two data Sets. Above 10 MeV these new measurements fall somewhat lower than the ENDF/B-VII evaluation and the Lisowski et al. and Shcherbakov *et al.* measurements except above about 100 MeV where they agree with the Lisowski et al. data.

Measurements of the ^{239}Pu(n,f)/ ^{235}U(n,f) Cross Section by Tovesson and Hill Compared with the Standards



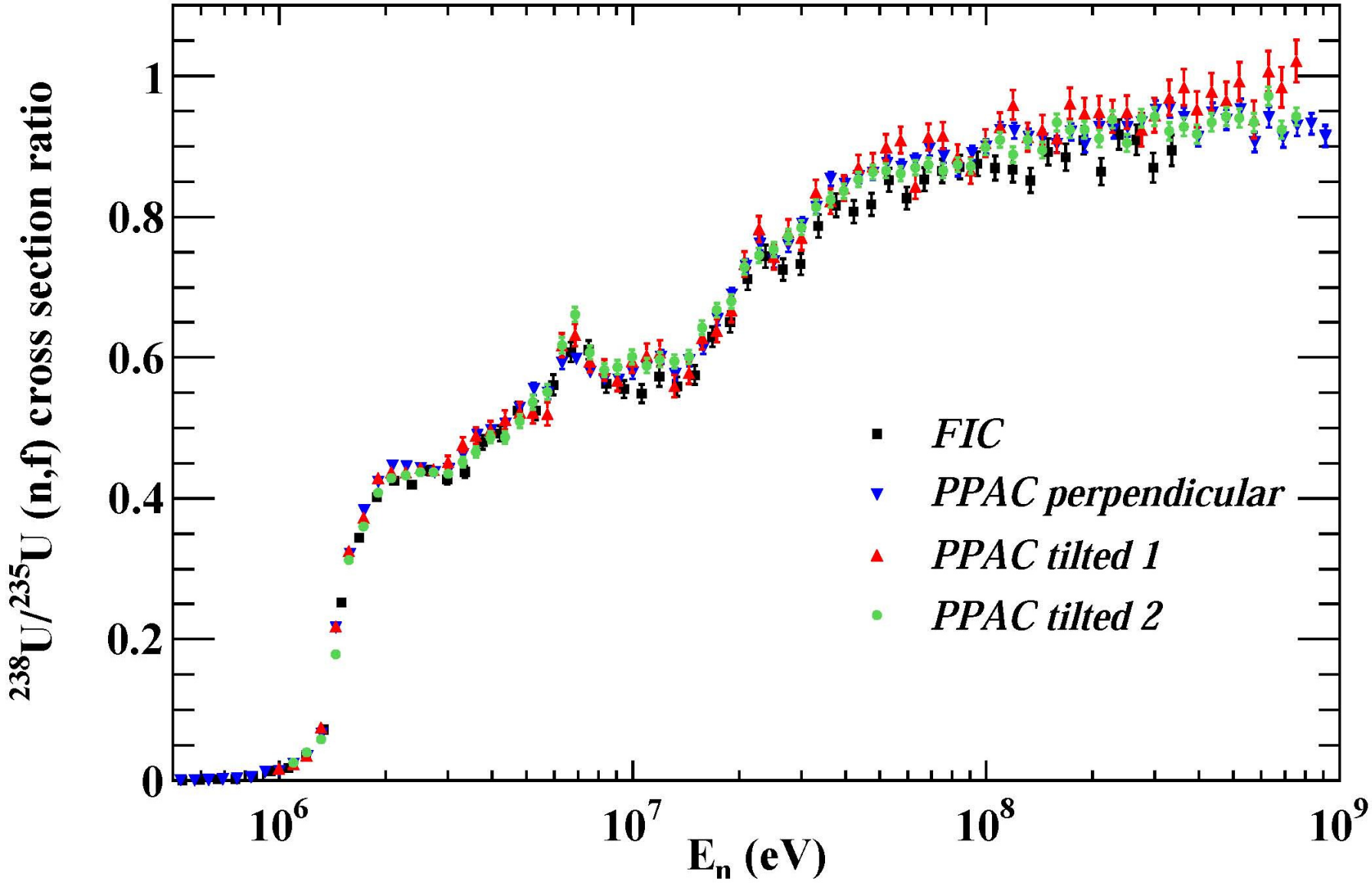
Comparison of ^{239}Pu(n,f) Evaluations



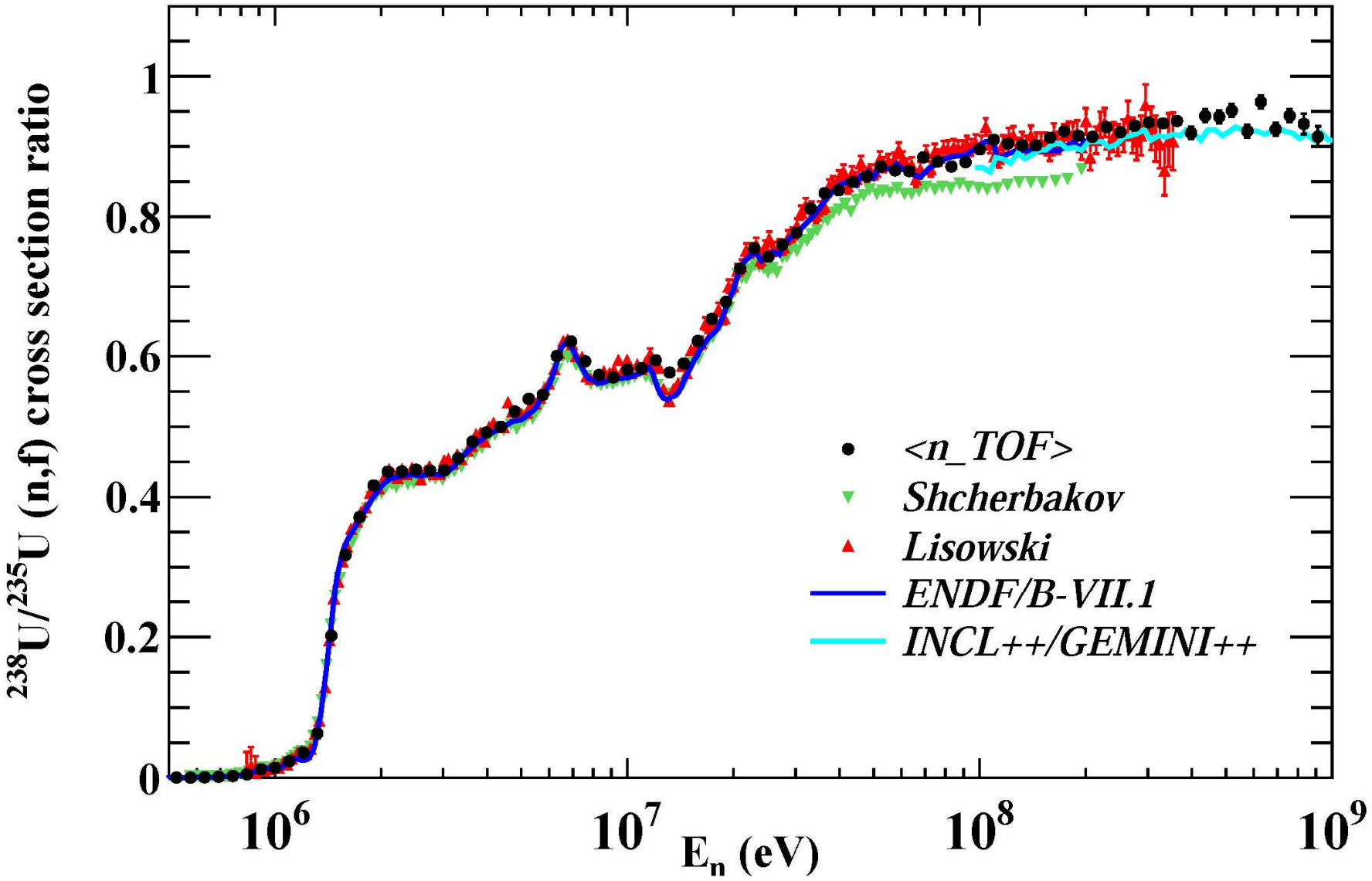
$^{235,\,238}$U(n,f) Measurements

- Four measurements of the ^{238}U(n,f)/^{235}U(n,f) cross section ratio were made at the n_TOF facility.
  - Fission chamber measurements were made (by Calviani).
  - Parallel plate avalanche counters were used for 3 sets of measurements (all formerly associated with Audouin).
    - The same deposits were used for both the PPAC perpendicular (by Paradela) and the PPAC tilted 1 (by Tarrio) measurements. The difference was that the perpendicular measurements were made with the deposits perpendicular to the beam direction whereas the tilted 1 measurements were made with the deposits at 45° to the beam direction.
    - The third setup for the PPAC detectors, PPAC tilted 2 (by leal-chidoncha), again were made with the deposits at 45° to the beam direction, were not as well characterized as the other deposits so they were normalized to ENDF/B-VII.1 between 3 and 5 MeV.
- The PPAC sets are slightly higher than the fission chamber data but they agree within their uncertainties. They all agree reasonably well with the standards evaluation.

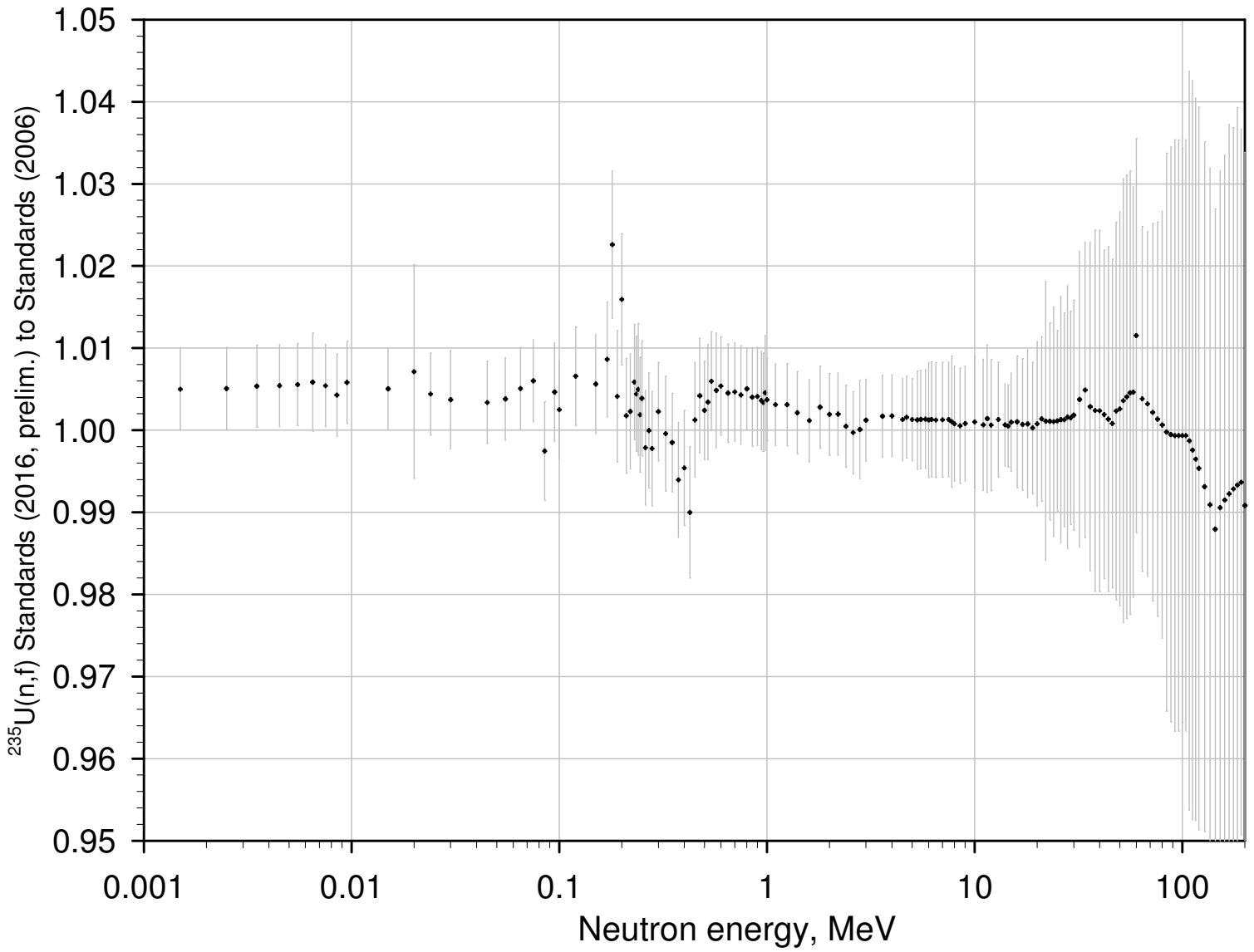
$^{235,\,238}$U(n,f) n_TOF Measurements



$^{235,\,238}$U(n,f) Measurements and Evaluations



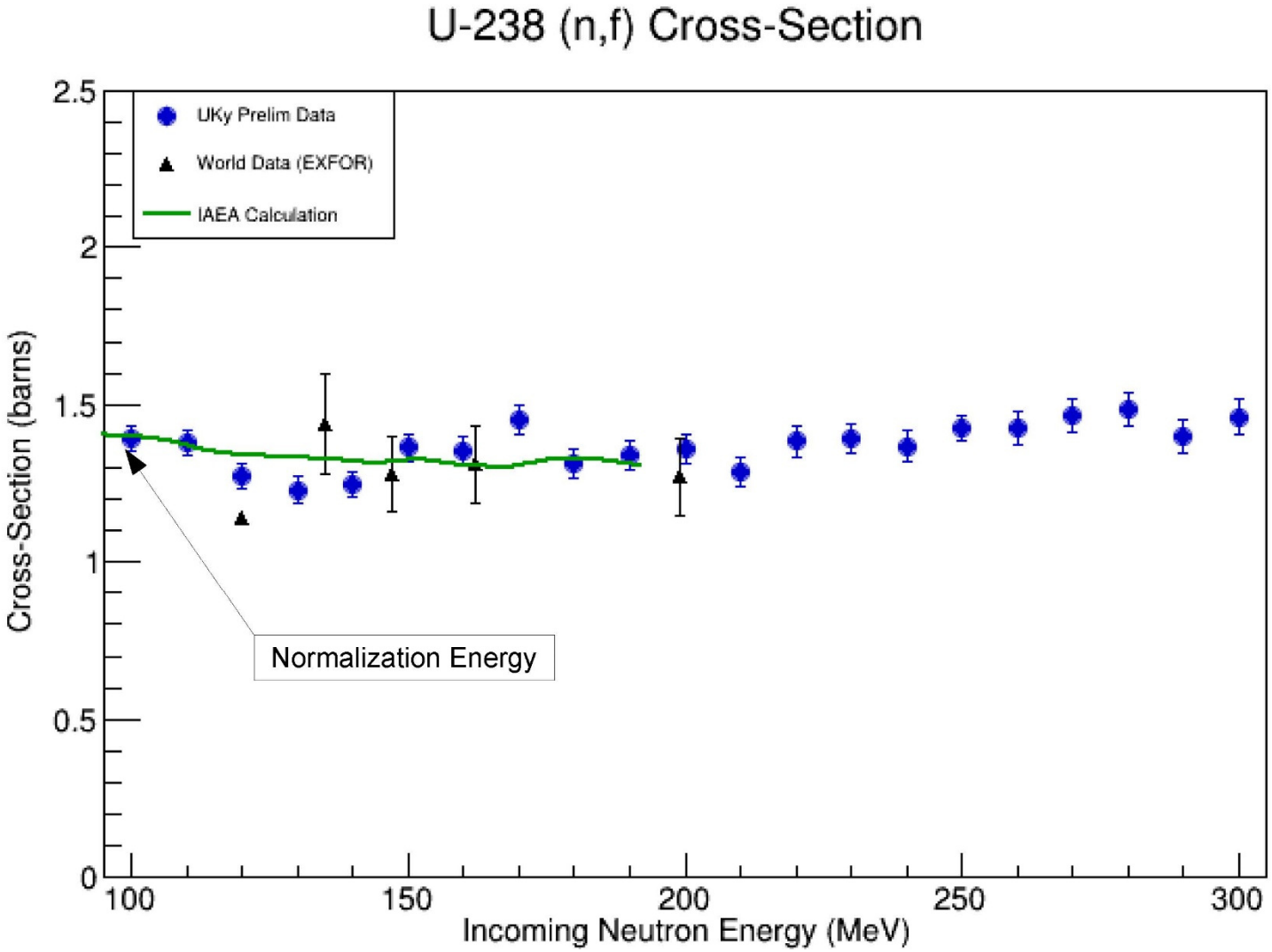
Comparison of ^{235}U(n, f) Standards Evaluations



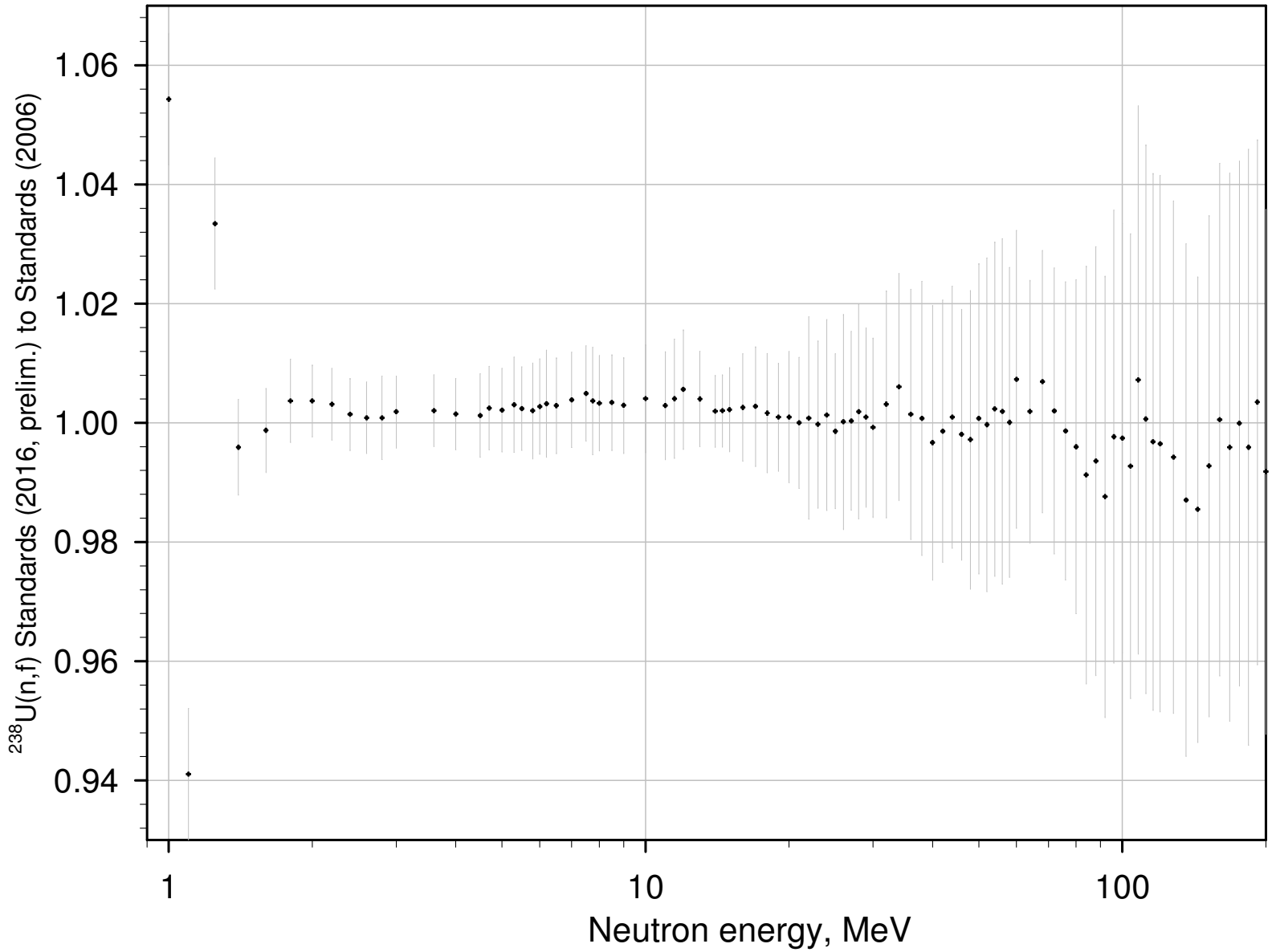
^{238}U(n,f) Measurements

- Measurements were made by Miller from the University of Kentucky of the ^{238}U(n,f) cross section relative to hydrogen scattering. The data are shape measurements extending from 100 to 300 MeV. The data were obtained at the LANL WNR facility.

Very Preliminary Results



Comparison of ^{238}U(n, f) Standards Evaluations



Thermal Constants

- An evaluation of the thermal constants has been completed.
- Due to concerns about how well temperatures are understood for Maxwellian data, only microscopic data were used.
- The GMA code was used for the evaluation.
- An improved evaluation was possible with additional measurements that include the ratio of capture to fission cross sections for ^{235}U at 0.0253 eV by Adamchuck with 2.1% uncertainty, and three results of measurements of the ratios of ^{233}U, ^{239}Pu and ^{241}Pu to ^{235}U at 0.0253 eV done at LANL and n_TOF with estimated uncertainties between 2 and 3%.
- The data from this evaluation are v-bar, the cross sections for fission, capture and scattering for ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu.

Thermal Neutron Constants (GMA fit)

		Standards 2006 (+Maxwellian)	ENDF/B-VII.1	Standards 2016 (2200 m/s)	ENDF/B-VIII.0.β3
$^{233}U(n_{th},f)$	σ_s	12.1±0.7	12.17	12.2±0.7	= ?
	σ_f	531.2±1.3	531.3	534.5±2.4	= ?
	σ_γ	45.6±0.7	45.3	41.9±1.7	= ?
	ν_t	2.4968±0.0035	2.4968	2.4853±0.0054	= ?
$^{235}U(n_{th},f)$	σ_s	14.09±0.22	**15.11**	14.09±0.22	✓ 14.10
	σ_f	584.3±1.0	584.99	587.2±1.4	✓ 586.6
	σ_γ	99.4±0.7	98.69	99.3±2.0	✓ 99.4
	ν_t	2.4355(.0023)	2.4367(.0005)	2.4250(.0045)	✓ 2.4298
$^{239}Pu(n_{th},f)$	σ_s	7.8±1.0	7.99	7.8±1.0	✓ 8.1
	σ_f	750.0±1.8	**747.91**	752.1±2.2	**X 747.4**
	σ_γ	271.5±2.1	270.7	270.4±3.1	✓ 270.1
	ν_t	2.8836±0.0047	2.8807	2.877±0.006	✓ 2.8769
$^{241}Pu(n_{th},f)$	σ_s	12.1±2.6	11.2	11.9±2.6	= ?
	σ_f	1014±7	1012	1024±11	= ?
	σ_γ	361.8±5.0	363.0	361.8±6.2	= ?
	ν_t	2.9479±0.0054	2.9453	2.9400±0.0064	= ?
$^{252}Cf(sf)$	ν_t	3.7692±0.0047	3.7676	3.7635±0.0049	=

Other Changes Made to Standards Files Before Putting Them Into ENDF/B

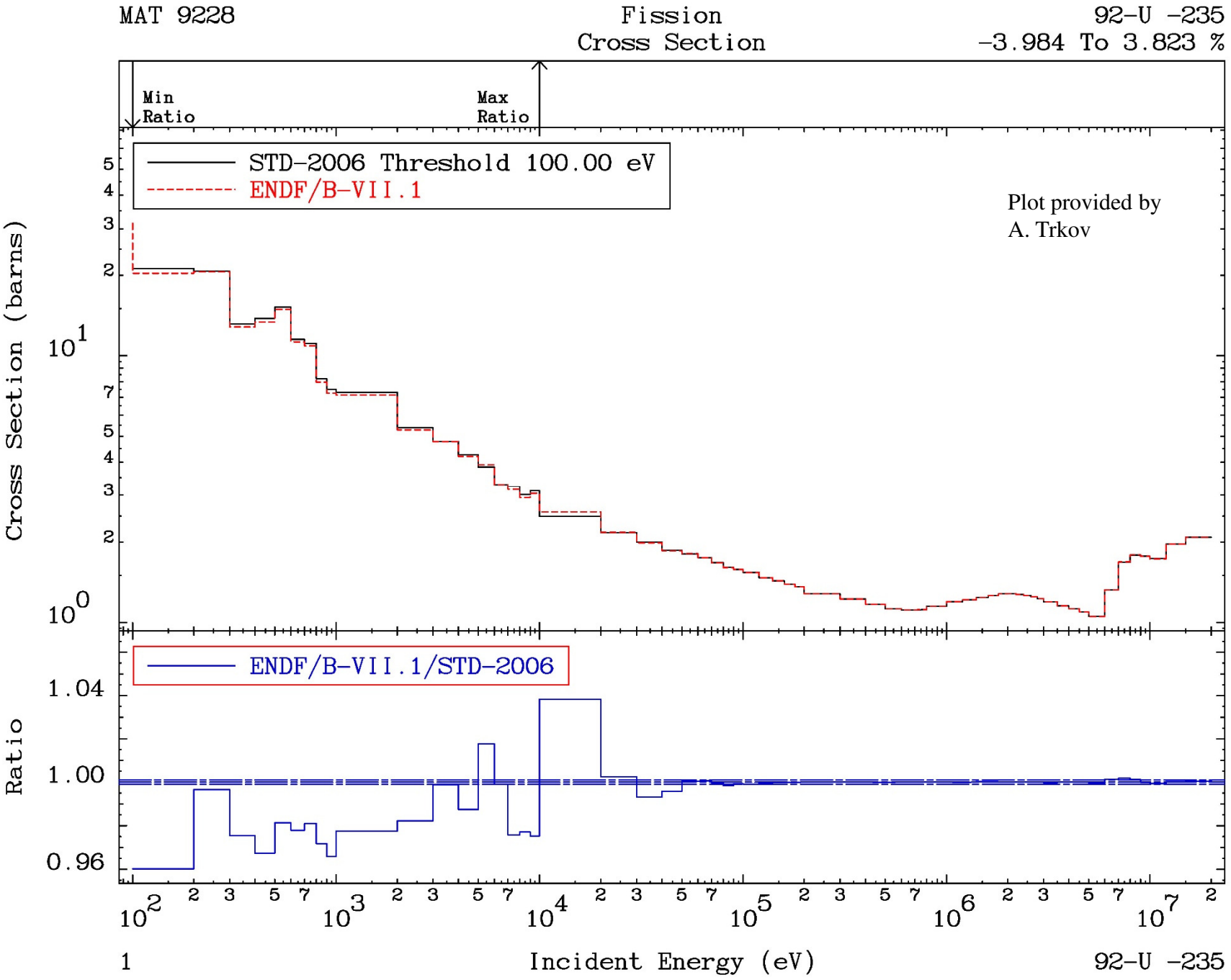
- 7.8-11 eV Integral for ^{235}U(n,f)

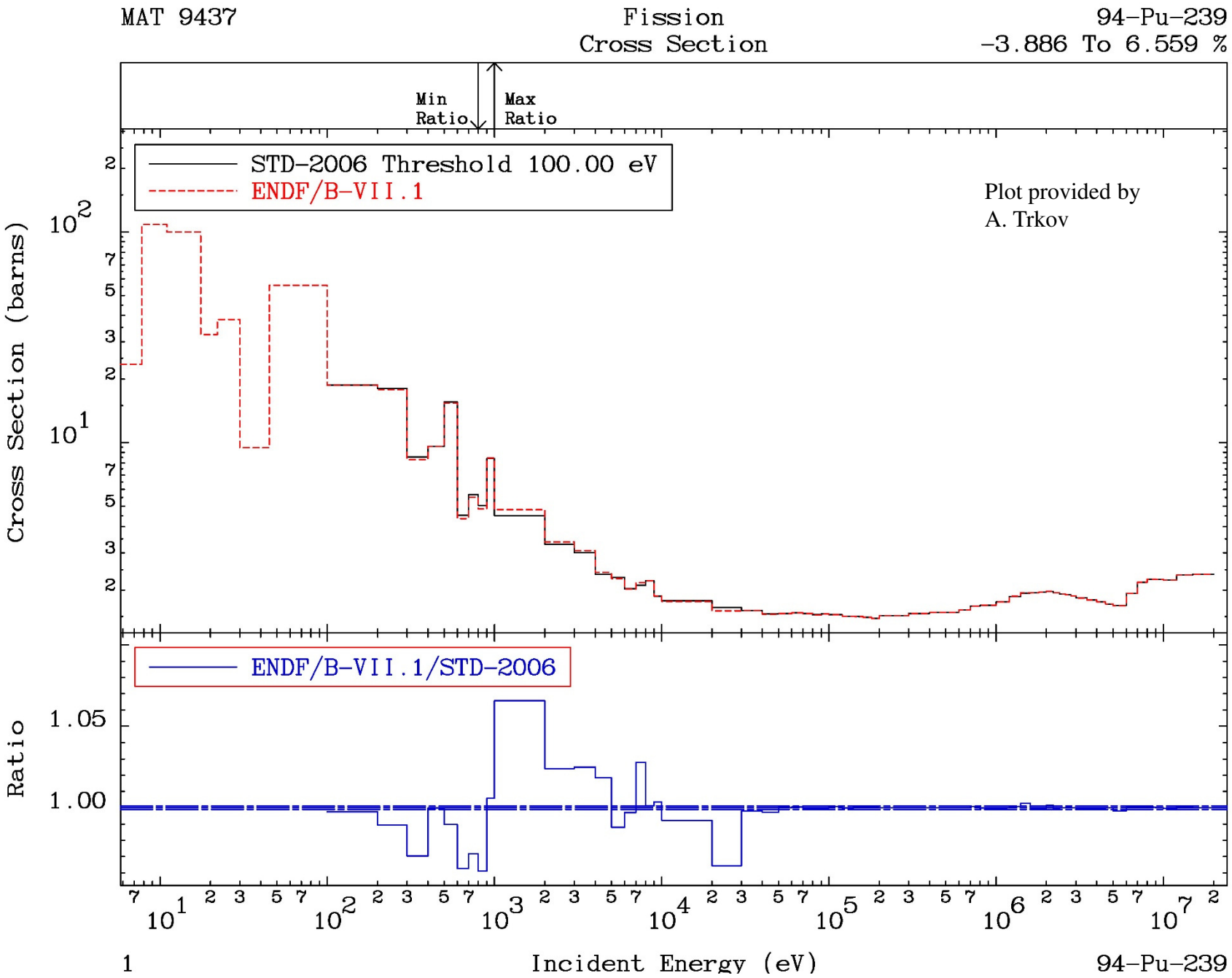
- For the standards produced for the ENDF/B-VI and ENDF/B-VII libraries, cross sections integrated over low energy intervals from 150 eV to 15 keV, in addition to the 7.8 to 11 eV interval, have been provided for the ^{235}U(n,f) cross section.

- These integrals can be obtained since some standards measurements cover these energy regions. Thus these integrals are not constants but are used in the evaluation process so they change due to the introduction of new data. The 7.8 to 11 eV integral was 246.5 beV for the ENDF/B-VI standards evaluation and 246.6 beV for the ENDF/B-VII standards evaluation.

- The 7.8 to 11 eV integral for the ^{235}U(n,f) cross section is very important since It has been used to normalize many cross section data sets.

- The value of that 7.8 to 11 eV interval for both the ENDF/B-VI and ENDF/VII ^{235}U files is **2% lower** than the standard value.


MAT 9228
Fission
Cross Section
92-U -235
-3.984 To 3.823 %
Min Ratio
Max Ratio
STD-2006 Threshold 100.00 eV
ENDF/B-VII.1
Plot provided by
A. Trkov
Cross Section (barns)
ENDF/B-VII.1/STD-2006
Ratio
Incident Energy (eV)
92-U -235


MAT 9437
Fission
Cross Section
94-Pu-239
-3.886 To 6.559 %
Min Ratio
Max Ratio
STD-2006 Threshold 100.00 eV
ENDF/B-VII.1
Plot provided by
A. Trkov
Cross Section (barns)
ENDF/B-VII.1/STD-2006
Ratio
Incident Energy (eV)
94-Pu-239

Conclusions and Recommendations

- The new international standards evaluation is an improvement over previous evaluations of the standards in terms of the scope of the work and the quality of the data.

- The standards evaluation has not been completed, there are still important activities that need to be continued.
  - Extension of the H(n,n) standard to 200 MeV.
    - Re-evaluation of the standards based on the new hydrogen standard since so many standards have been measured relative to it.
    - Possible completion of the ^{3}He(n,p) cross section evaluation.

- These activities could be done under an approved IAEA nuclear data development project. This project will continually update the standards so they are available for new versions of a library. New experiments will be encouraged and experimental results will be investigated for use in new evaluations. Also standards evaluation codes will be maintained and improved.