DE LA RECHERCHE À L'INDUSTRIE

cea den

Integral data assimilation on U235 and U238 nuclear data and impact on FCA-IX spectral indices.

V. Huy
G. Rimpault, G. Noguère

CEA/DER/SPRC/LEPh

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OUTLINE

I-Context and strategy

- C/Es of Integral experiments using JEFF libraries

II-Integral Data Assimilation on U235&U238 nuclear data

- Choice of prior nuclear data
- Nuclear Data trends and comparison with differential measurements and recent evaluations.

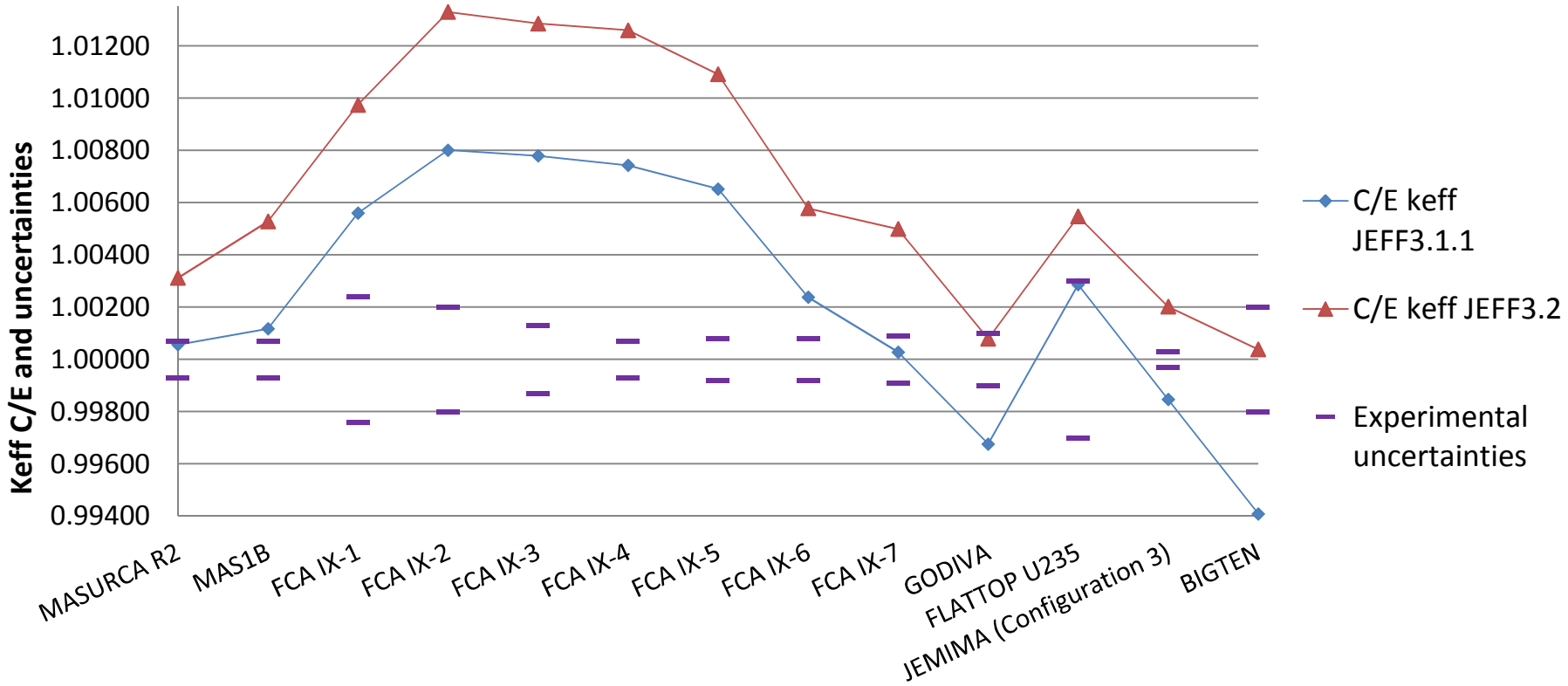
III-Impact on FCA-IX spectral indices

Conclusion

CONTEXT AND STRATEGY

CONTEXT (URANIUM CONFIGURATIONS)

- It is acknowledged that critical mass' C/Es calculated for different configurations can display great dispersion in results depending on the ND library used.



Critical mass C/E and uncertainties for Uranium configurations (JEFF libraries)

→ Use of integral experiments to identify which reaction and isotopes are responsible for this dispersion (assimilation using Bayesian Inference with CONRAD)

STRATEGY

- Make the most of the useful information provided by integral C/E to identify possible improvement on nuclear data **for fast reactor application**. Critical mass provide **a great variety of sensitivity profiles to U235 capture and U238 capture and inelastic cross sections**.

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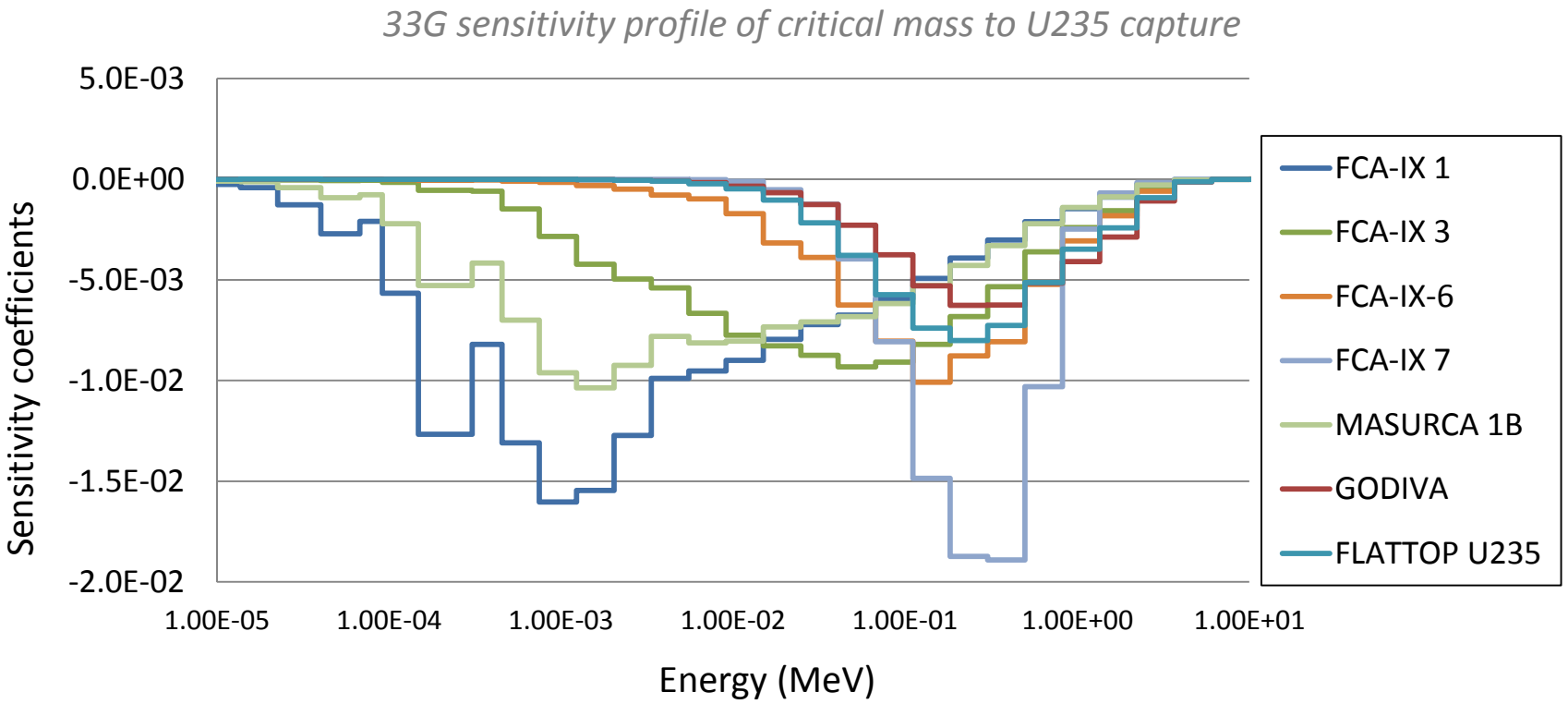
- For now, we have avoided using critical mass sensitive to Pu isotopes and Na.

- PROFIL irradiation experiment adds **specific constraints on capture cross sections**.

- Compare trends suggested by the assimilation work to **recent differential measurements** and **evaluations** in order to look for converging results.

U235 CAPTURE

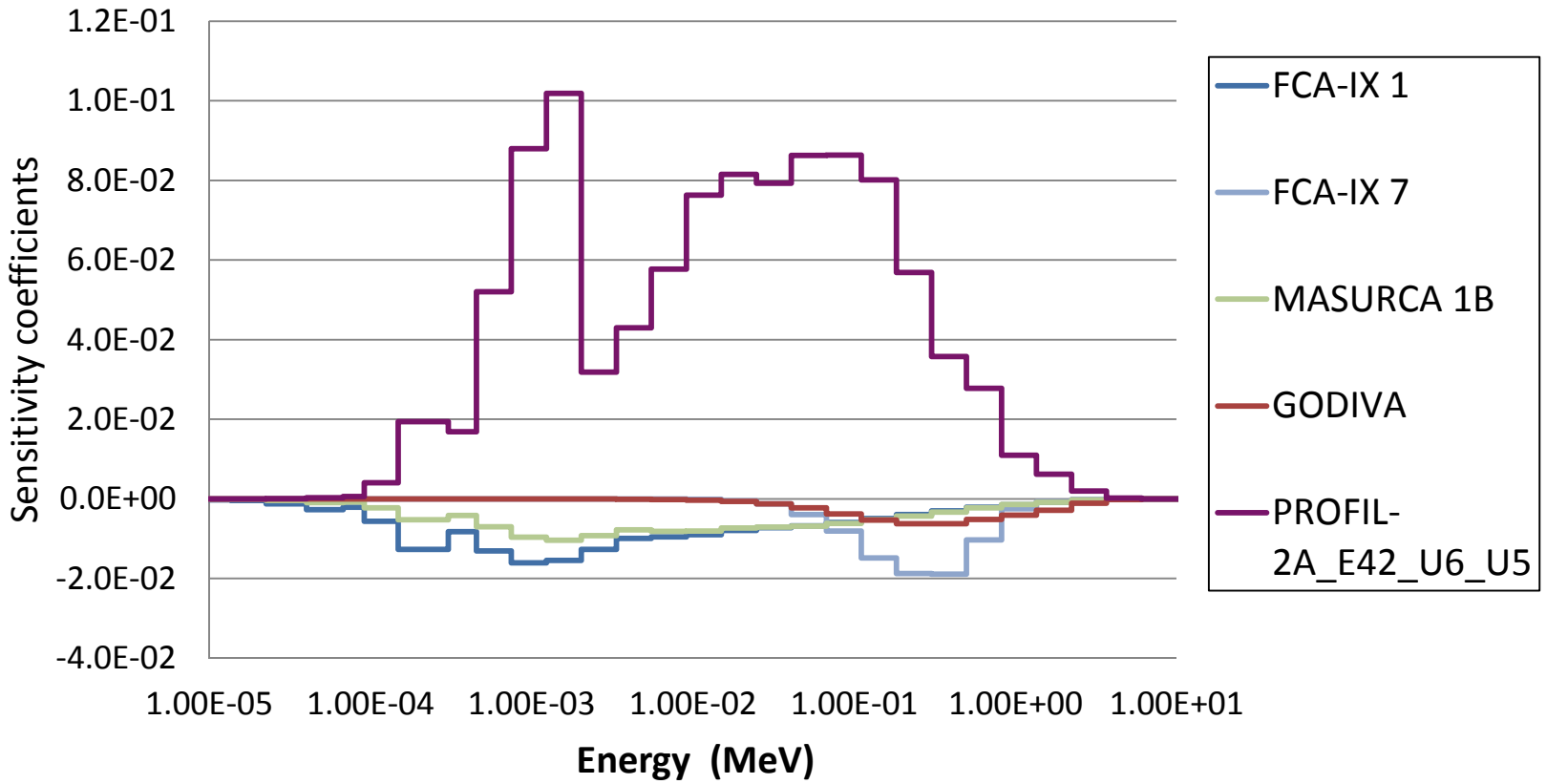
- **WPEC SG 29** (2011) raised concerns about U235 capture evaluations pointing out integral C/E for fast reactors with high sensitivity to this reaction were not satisfying.
- Current evaluations are still resulting in large C/E for some configurations. They have large sensitivity to U235 capture :



U235 CAPTURE

- PROFIL irradiation experiment add constraints on capture cross sections ($\frac{U_{236}}{U_{235}}$ ratio variation is mainly sensitive to U235 capture).
  However, for PROFIL we have **prior C/E~1 (when using JEFF-3.1.1).**

33G sensitivity profile of critical mass and PROFIL to U235 capture



INTEGRAL EXPERIMENTS ASSIMILATION ON U235 & U238

HYPOTHESIS AND CHOICE OF A PRIOR

- For assimilation on U235&U238 nuclear data, we choose **JEFF3.1.1 and COMACV1 covariance matrix as a prior**. This is the JEFF library that gives the most satisfying results on Uranium configurations (awaiting JEFF3.3T4).

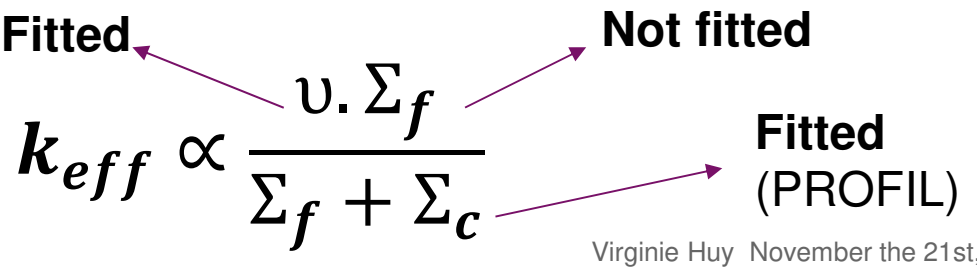
  → **All trends are given compared to the *a priori* JEFF-3.1.1**

- U235(n,f) and U238(n,f) from JEFF3.1.1 are in reasonable agreement with IAEA standard recommendations over the fast energy range.

- Reactions that are fitted through assimilation procedure :
  -Nu, fission spectrum, inelastic, elastic, capture of U235 and U238

- Approximation : **we don't take into account sensitivity to anisotropy of heavy nuclides scattering**.

- **Integral Data Assimilation is subject to compensating errors :**



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- Approximation : **we don't take into account sensitivity to anisotropy of heavy nuclides scattering**.

- **Integral Data Assimilation is subject to compensating errors :**

Fitted **Not fitted**

$$k_{eff} \propto \frac{\upsilon . \Sigma_f}{\Sigma_f + \Sigma_c} + \chi \; ?$$

Fitted (PROFIL)

CHOICE OF RELEVANT INTEGRAL EXPERIMENTS

- 20 C/Es were used :
  -**Critical mass C/E** calculated with Monte-Carlo code TRIPOLI-4 (with “as-built” model or correction factor for **modeling bias**).

	MASURCA 1B	FCA-IX-1	FCA-IX-2	FCA-IX-3	FCA-IX-4	FCA-IX-5	FCA-IX-6	FCA-IX-7	FLATTOP U235	GODIVA
U235 Enrichment	30%	93%	93%	93%	93%	93%	93%	20%	93% (Unat reflector)	94%
Dilutant	Graphite	Graphite	Graphite	Graphite	Stainless steel	Stainless steel	Stainless steel	-	-	-

-**PROFIL-2A** $\frac{U_{235}+U_{236}}{U_{238}}$ and $\frac{U_{236}}{U_{235}}$ variation of concentrations ratio (sensitive to U235 and U238 capture).

→ Few C/Es used but a particular care was taken for modeling and calculating bias.

DIFFERENT OPTIONS

- Alternative options have been considered :

1/Fission spectrum for U235 and U238 have been **either constrained (set to JEFF- 3.1.1) or fitted**.

2/For graphite : we considered **either the evaluation from JEFF3.1.1 or JENDL4.0.**

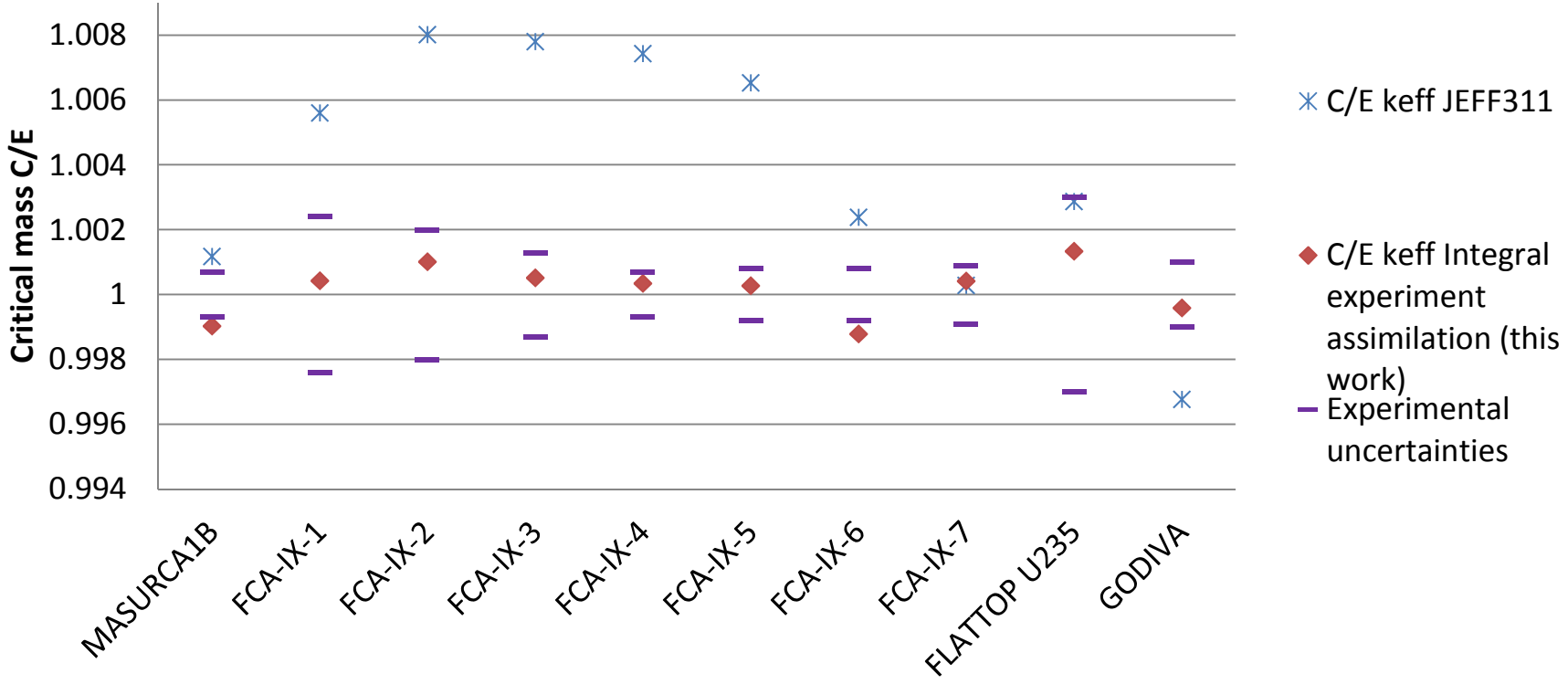
	MASURCA1B	FCA-IX-1	FCA-IX-2	FCA-IX-3
Impact on critical mass when using graphite from JENDL4.0	**-260 pcm**	**-420 pcm**	**-280 pcm**	**-230pcm**

INTEGRAL EXPERIMENTS ASSIMILATION ON U235 & U238 NUCLEAR DATA : RESULTS

COMPARING C/E POST-ASSIMILATION

- Comparing C/E post-assimilation (provided by CONRAD) with prior JEFF-3.1.1.

C/E for different Uranium configuration : comparison between JEFF-3.1.1 and assimilation results



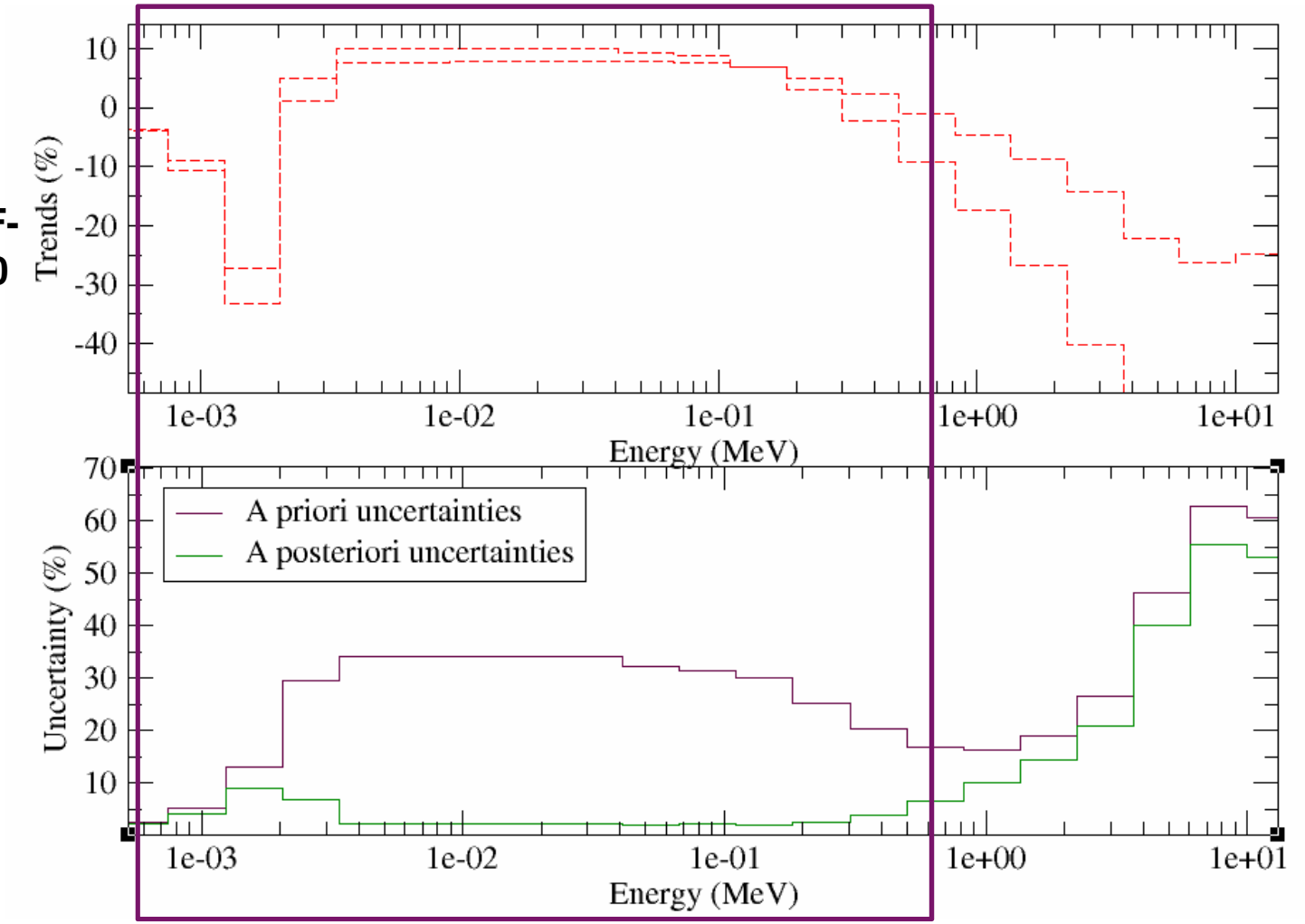
- PROFIL posterior C/E $(\frac{U_{235}+U_{236}}{U_{238}}) \approx 0{,}9993 \pm 2\%$ and C/E$(\frac{U_{236}}{U_{235}}) \approx 1{,}005 \pm 1{,}7\%$

U235 CAPTURE

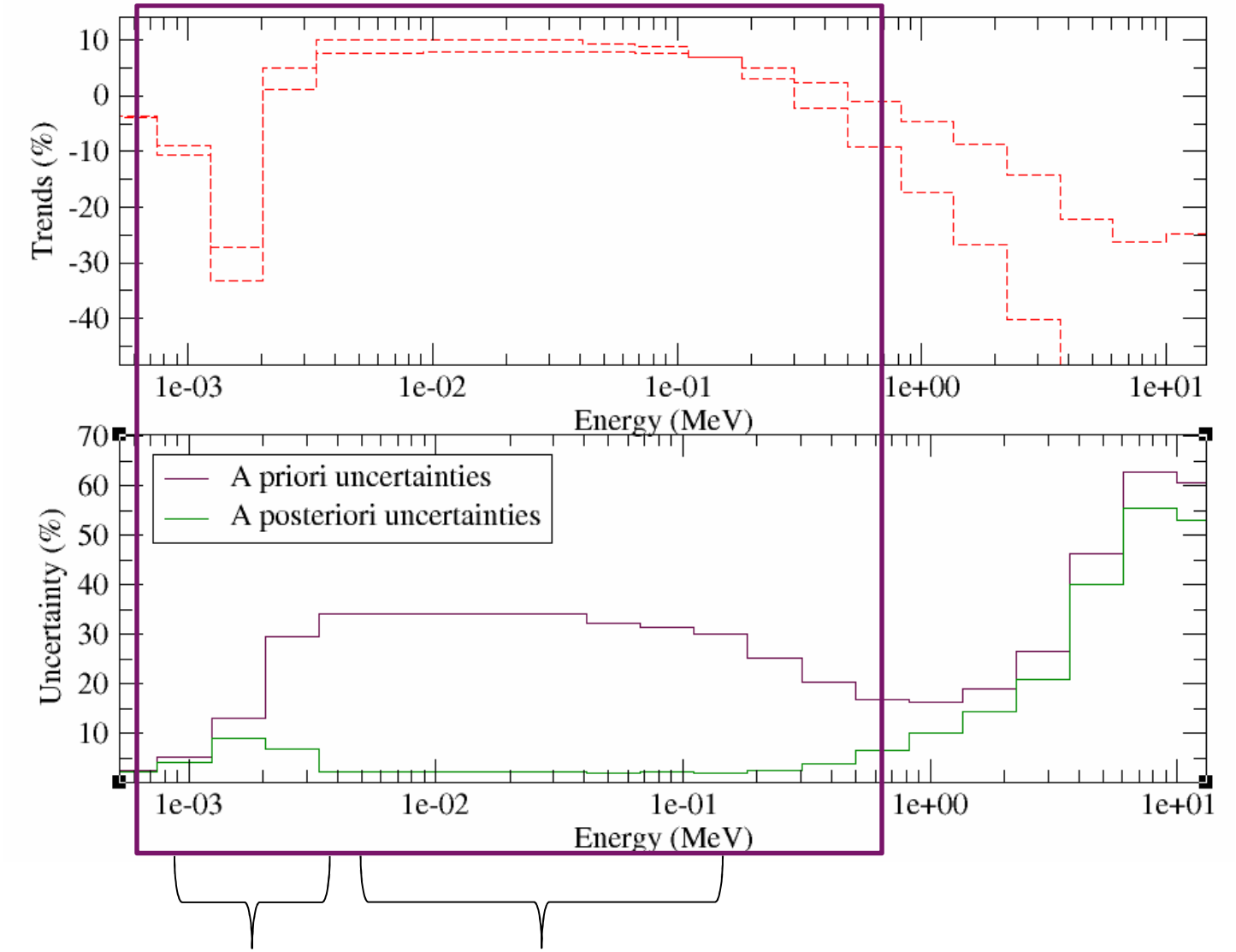
ASSIMILATION RESULTS : TRENDS FOR U235 CAPTURE

- We define an envelope gathering all trends possibilities : **Carbon from JEFF-3.1.1 or JENDL-4.0** and **fission spectrum either constrained or fitted**.

- From **1 keV up to 500 keV, a posteriori uncertainties are sufficiently low** to consider trends as possible recommendations.



ASSIMILATION RESULTS : TRENDS FOR U235 CAPTURE



-27 to -33 % decrease at 1-2 keV (end of RRR)

+8 to +10% increase in the 10-100keV region (URR)

U235 CAPTURE AT 1-2 KEV

- Recent U235 capture **measurements at RPI are consistent with assimilation results** :

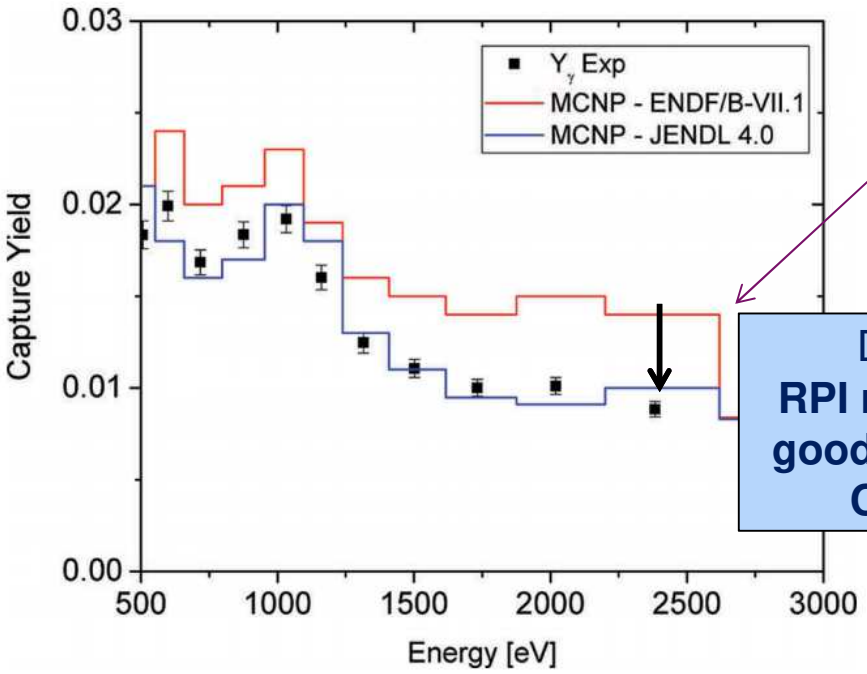


Fig. 11. A zoomed view of the capture yield illustrates the differences between the experiment and evaluations in the energy range from 0.5 to 3 keV.

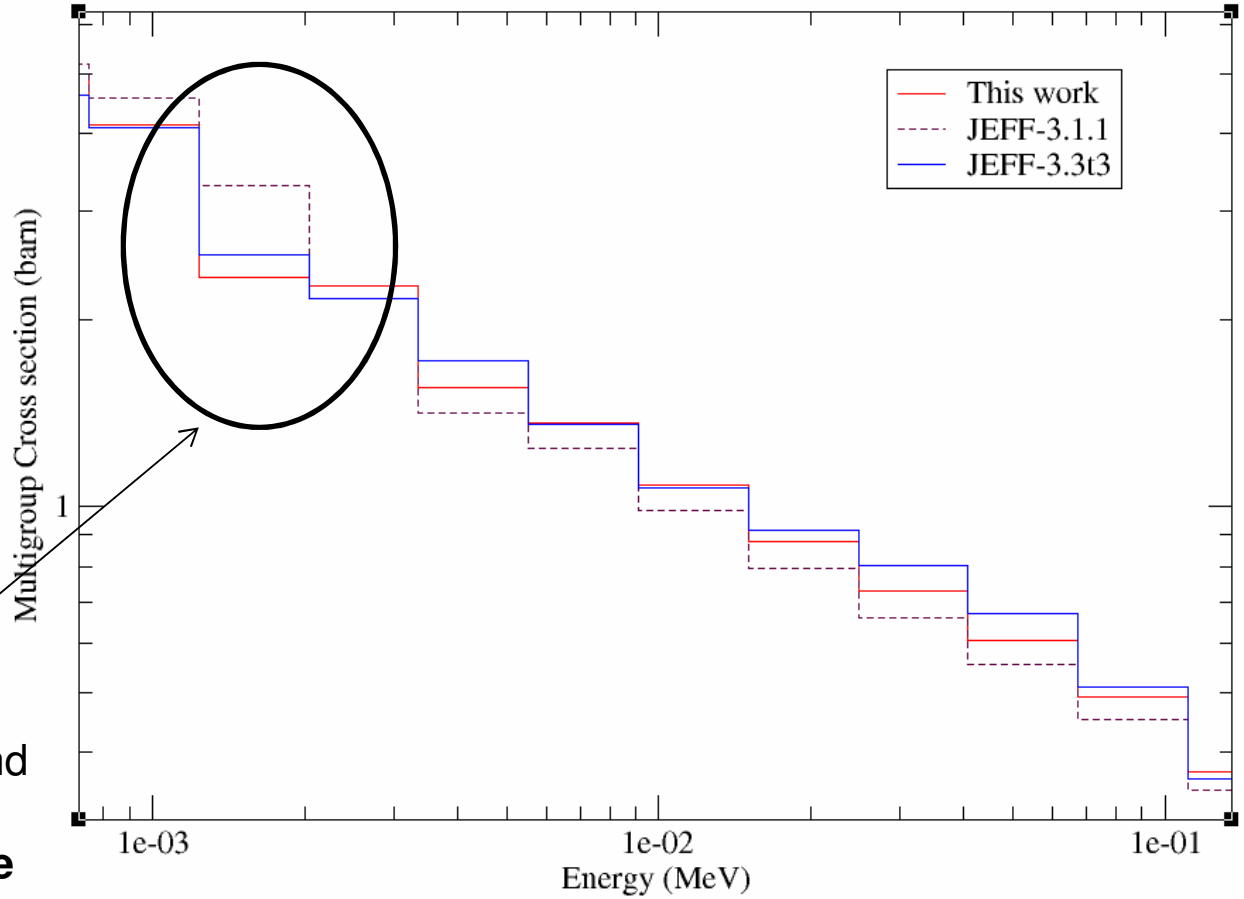
For U235 capture,
ENDF/B-VII.1=JEFF-3.1.1

Decrease of ~33%
RPI measurements are in good agreement with our CONRAD analysis

From "Simultaneous Measurement of 235U Fission and Capture Cross Sections From 0.01 eV to 3 keV Using a Gamma Multiplicity Detector" (Danon et al, NSE, september 2017)

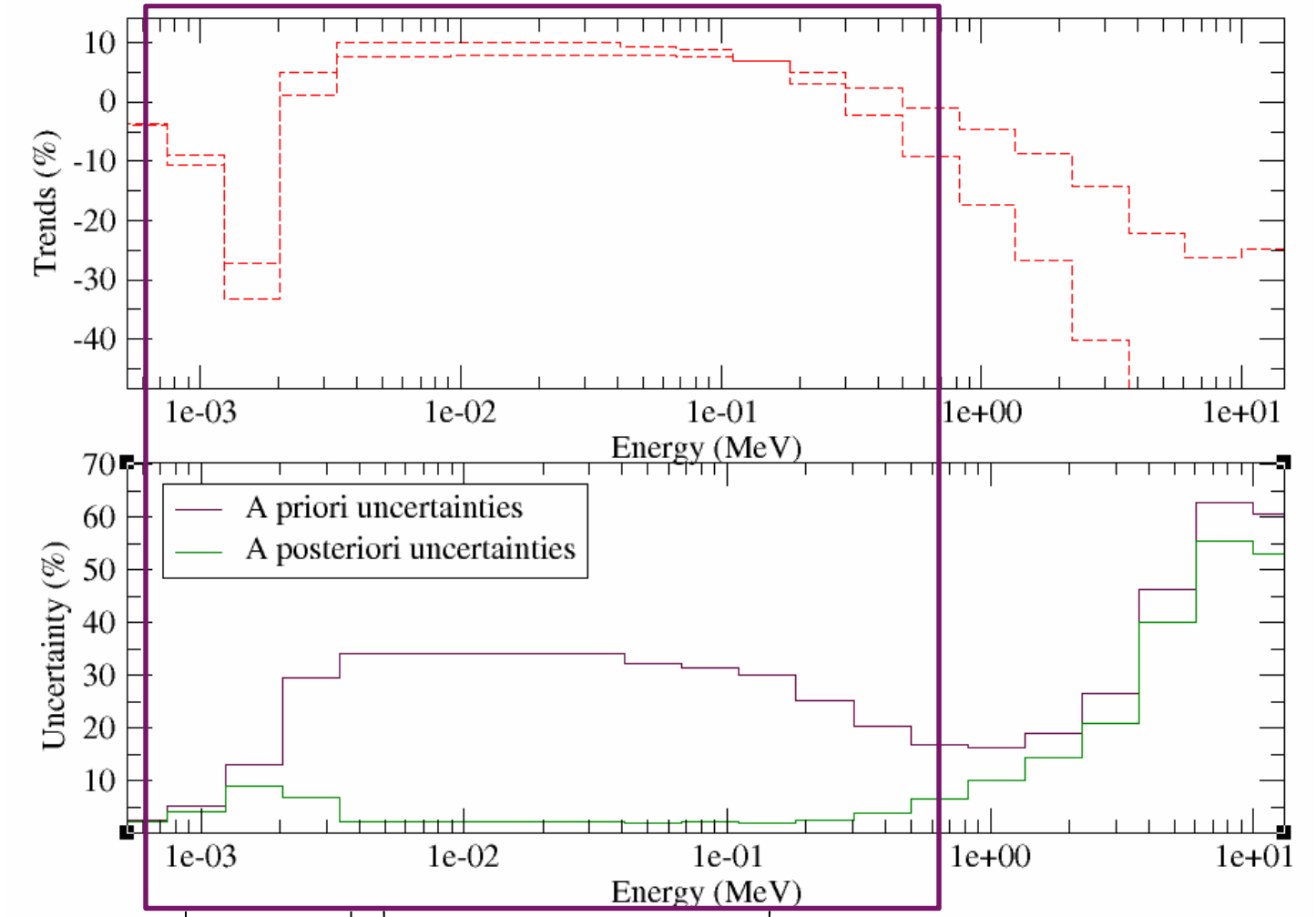
U235 CAPTURE : COMPARISON WITH CURRENT EVALUATIONS

- Comparing assimilation results with JEFF-3.3t3 :



Between 1 keV and 2 keV, the **resonance range** of JEFF-3.3t3 is in good agreement with our assimilation results

ASSIMILATION RESULTS : TRENDS FOR U235 CAPTURE

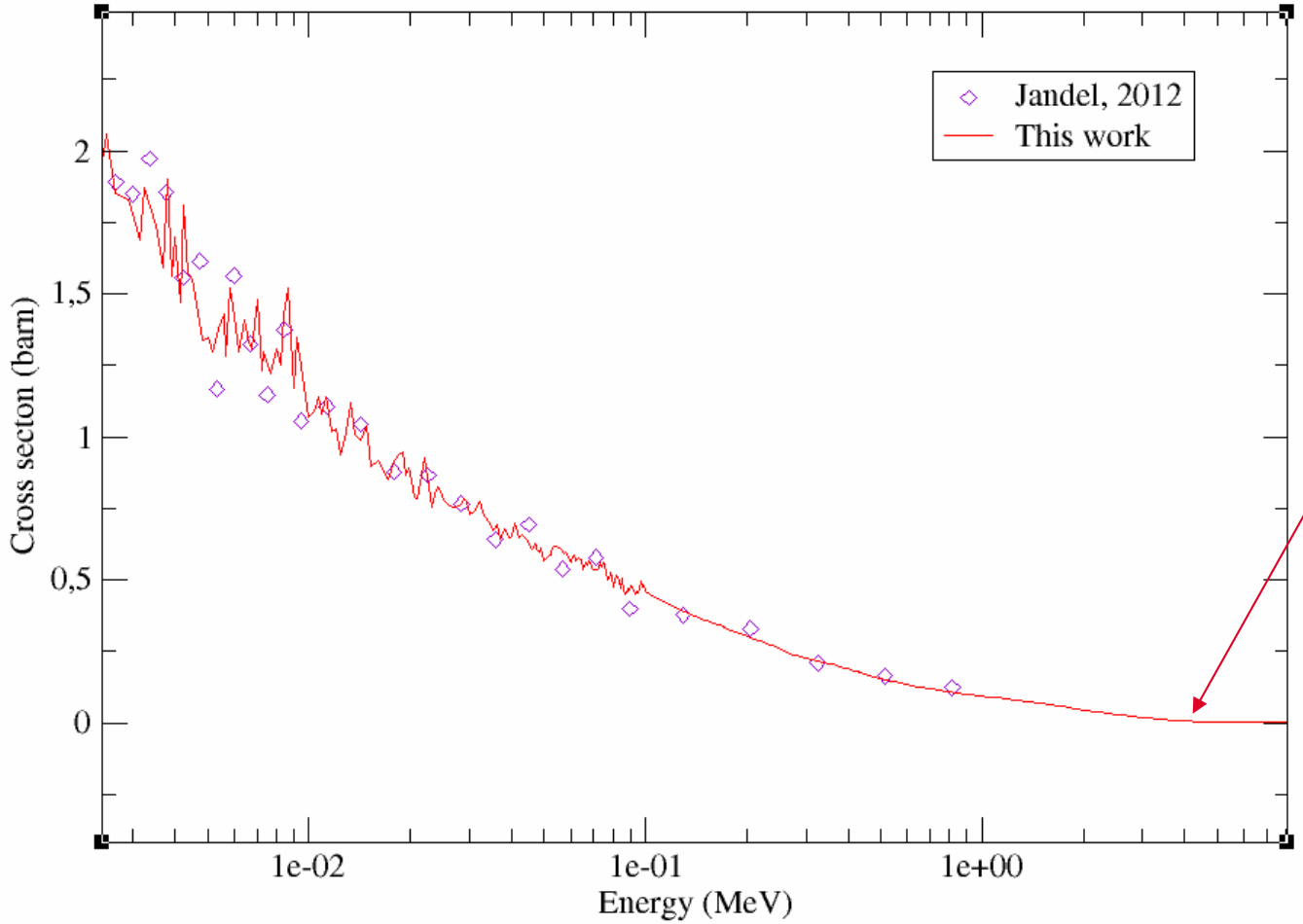


-27 to -33 % decrease at 1-2 keV (end of RRR)

+8 to +10% increase in the 10-100keV region (URR)

U235 CAPTURE AT 10-100 KEV

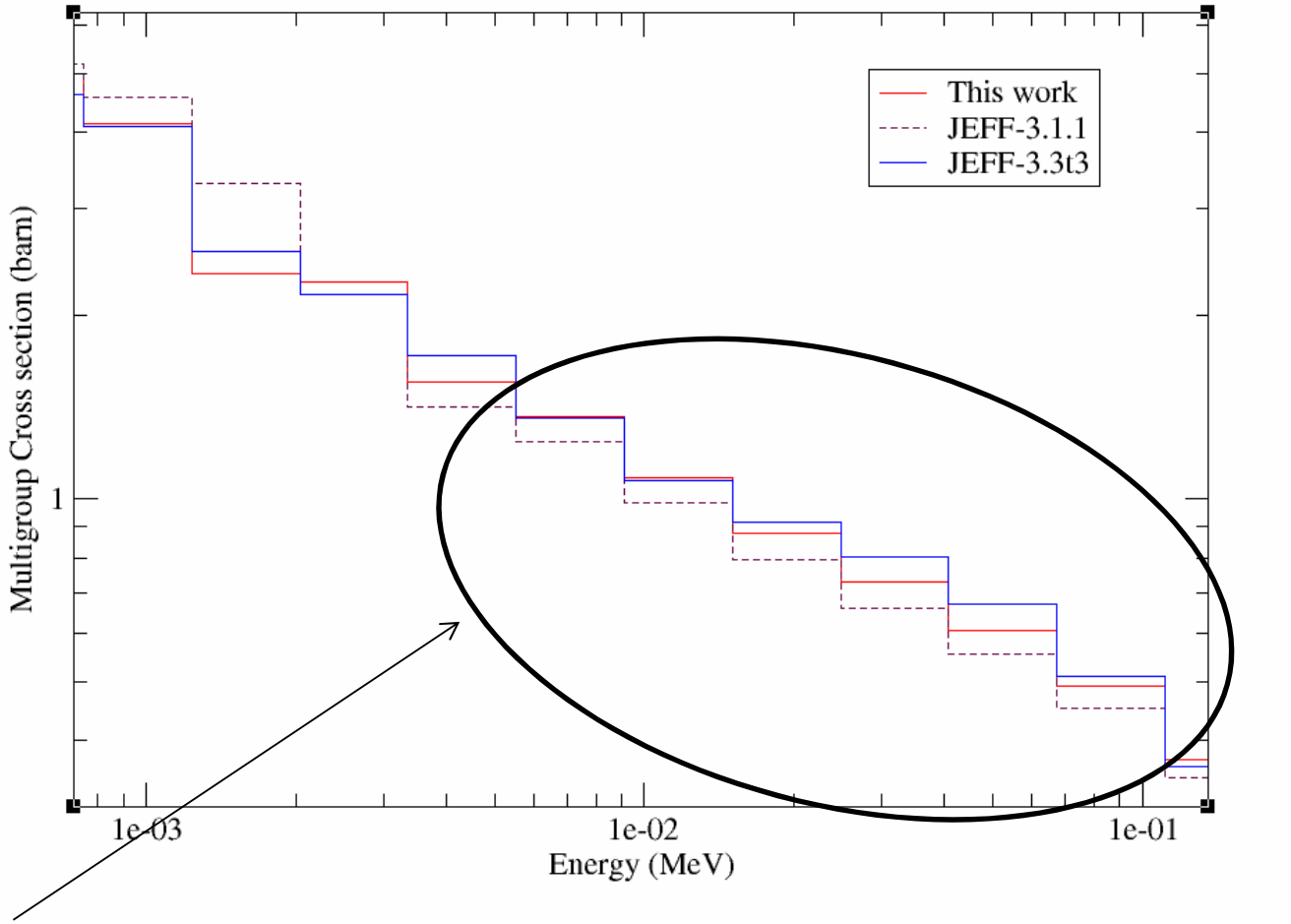
- Assimilation results on U235 capture **are consistent with recent differential measurements done in the DANCE detector at LANSCE by (Jandel et al, 2012)**



In red, we applied our assimilation work's trends on JEFF-3.1.1 continuous evaluation

U235 CAPTURE : COMPARISON WITH CURRENT EVALUATIONS

- Comparing assimilation results with JEFF-3.3t3 :



Above 20 keV, JEFF-3.3t3 is higher than our assimilation results. (+20% compared with JEFF-3.1.1)

U235 CAPTURE : SUMMARY

- Results on U235 capture were obtained using critical mass and also PROFIL irradiation experiments.

- At 1-2keV, our assimilation results agrees with recent measurement at RPI (**-30% when compared to JEFF-3.1.1**) $\Rightarrow$ confirm the conclusions of WPEC/SG-29

- From 10keV to 100keV, assimilation results are consistent with DANCE measurements (**+10% from JEFF-3.1.1**) $\Rightarrow$ JEFF-3.3t3 is higher (+20%)

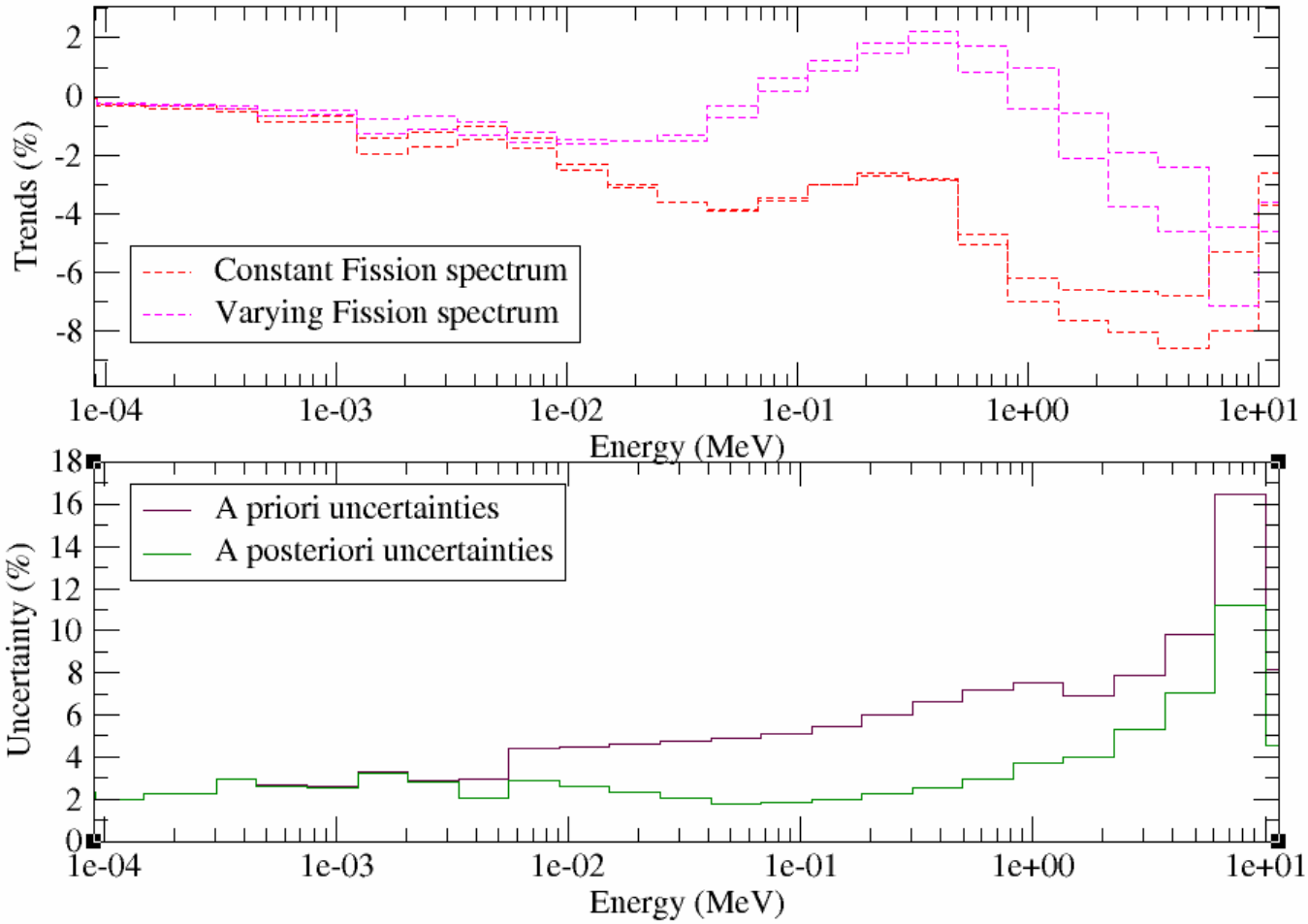
U238 CAPTURE

ASSIMILATION RESULTS : TRENDS FOR U238 CAPTURE

- Trends **noticeably differ depending on whether fission spectrum is fitted or not.**

- In the case where fission spectra are fitted, proposed changes are compatible with posterior uncertainties.

- In the case fission spectrum is constrained to JEFF-3.1.1, a **3-4% decrease from 10keV to 600keV** is suggested by the assimilation.



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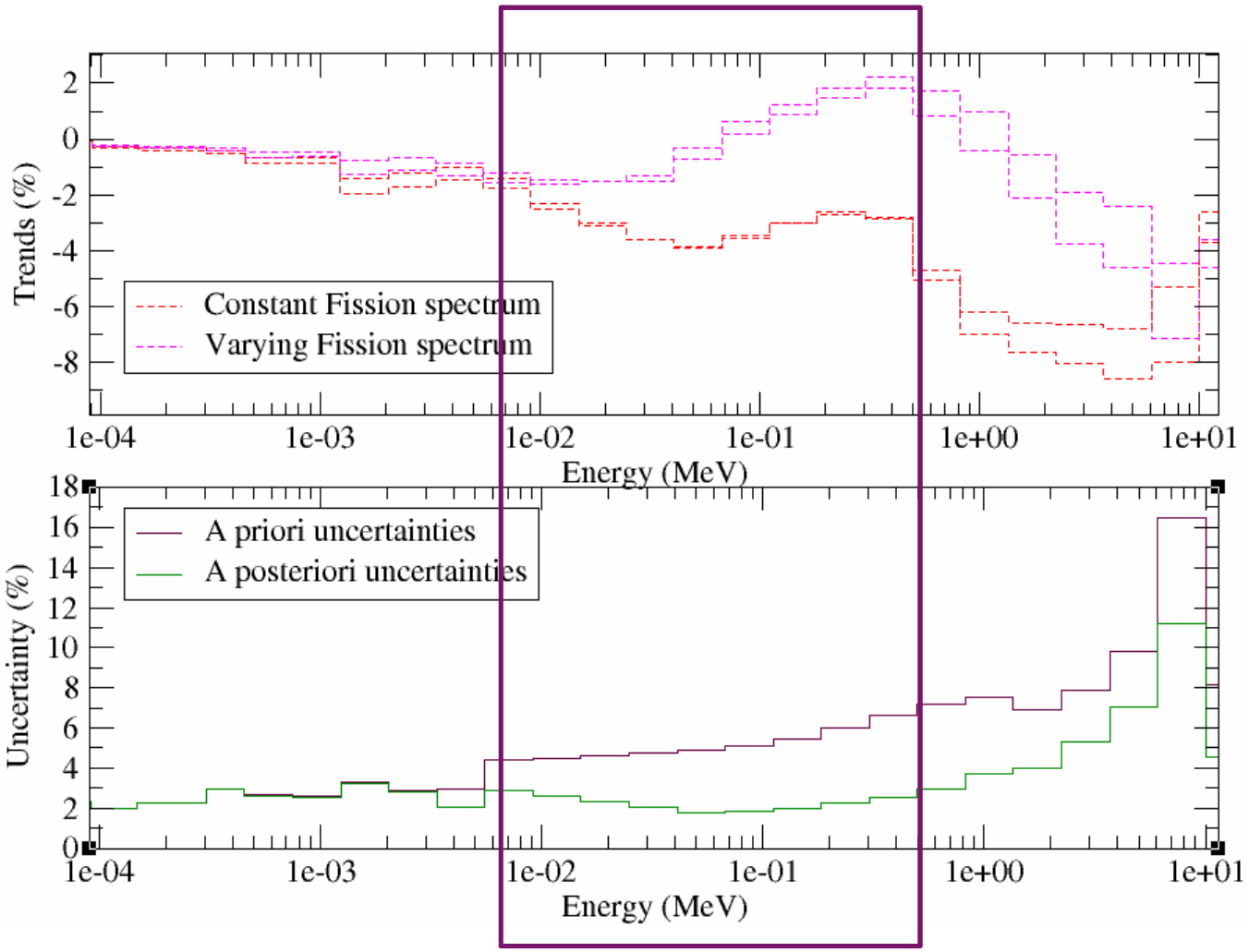
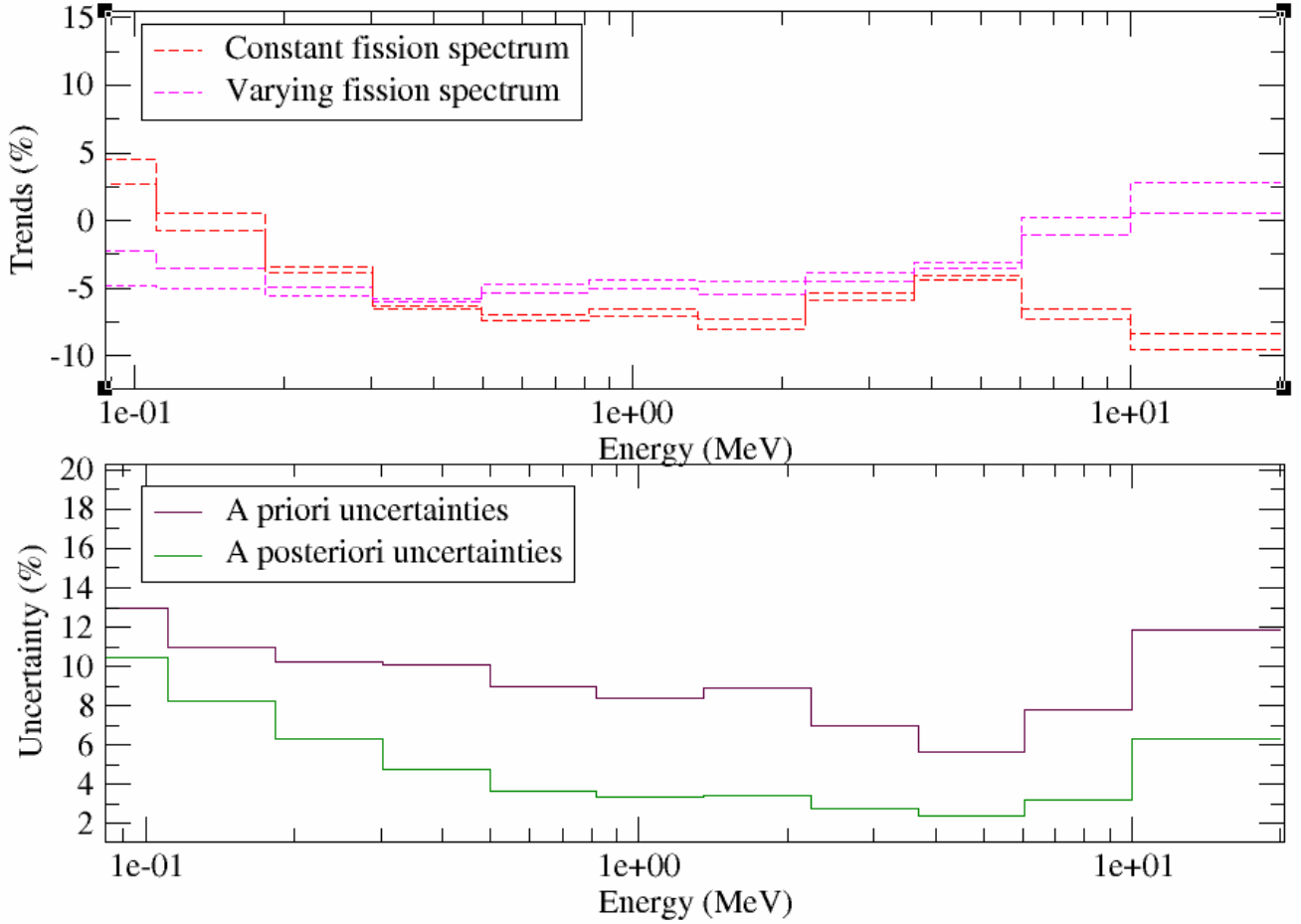


U238 INELASTIC

ASSIMILATION RESULTS : TRENDS FOR U238 INELASTIC

- In the **plateau region (1MeV to 6MeV), assimilation result suggest a ~4% to 8% decrease for U238 inelastic.** Outside this range, posterior uncertainties are too high to make recommendations.



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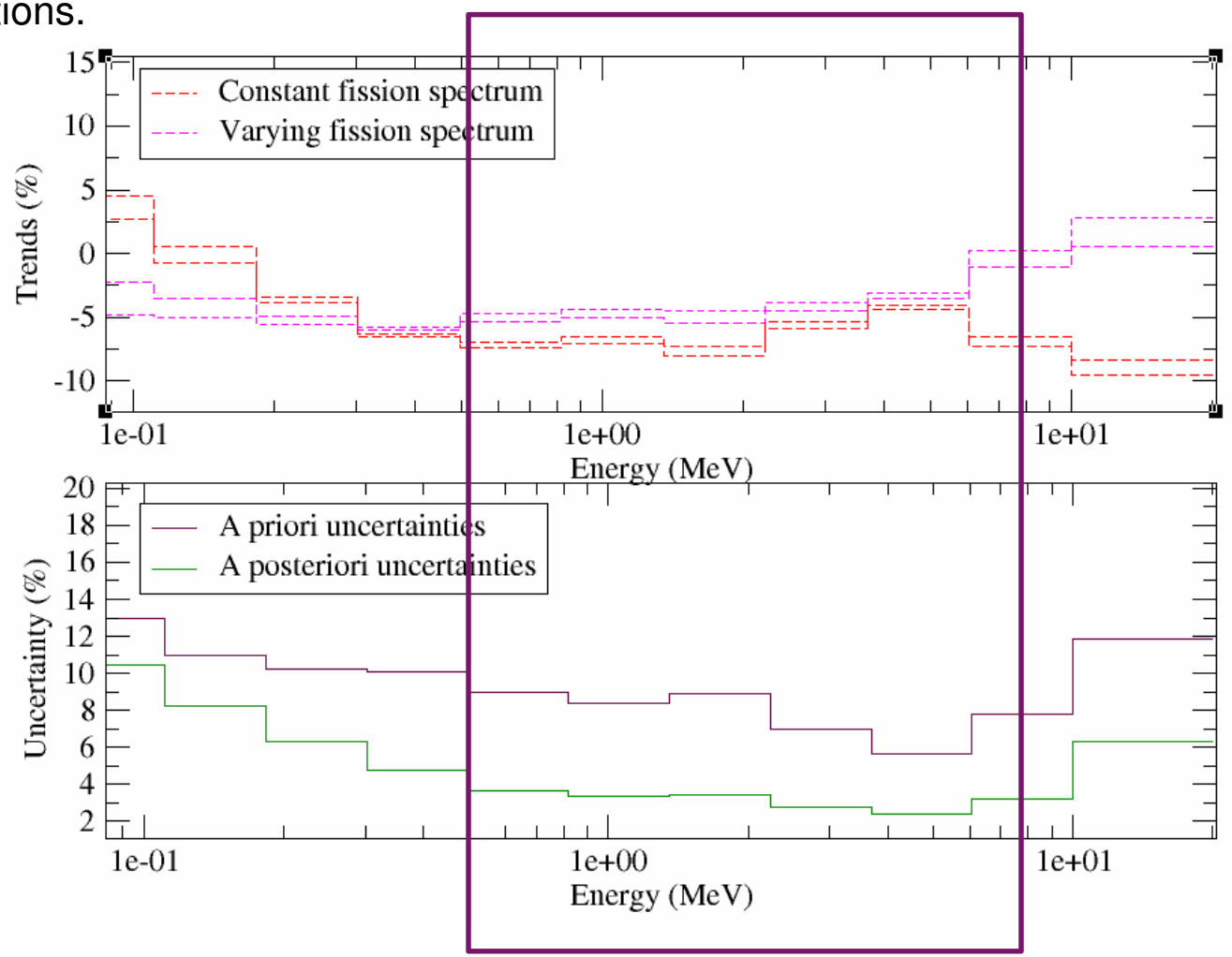
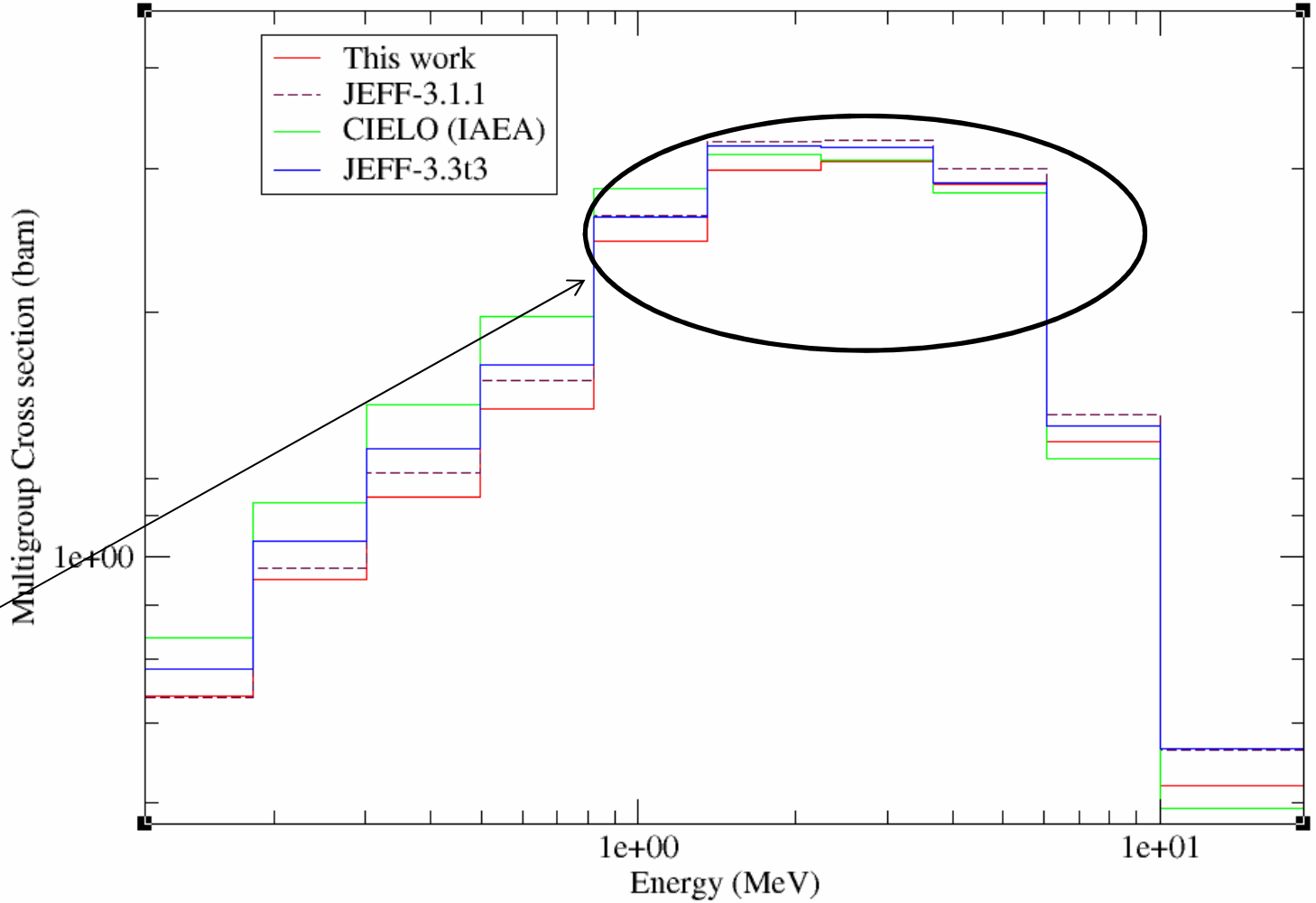


U238 INELASTIC : COMPARISON WITH CURRENT EVALUATIONS

- Comparing assimilation results *(fission spectra set to JEFF-3.1.1)* with CIELO (september 2017) and JEFF-3.3t3 :

In the plateau region, CIELO is consistent with our assimilation results (6-7% decrease from JEFF-3.1.1).



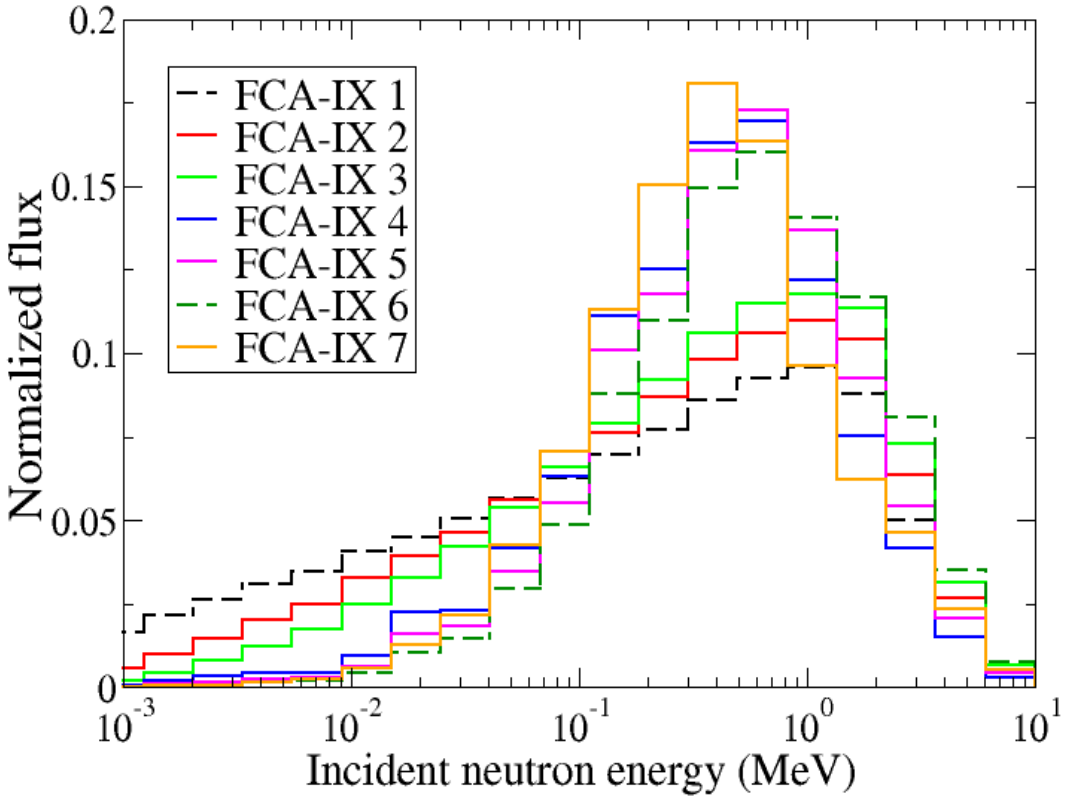
IMPACT ON FCA-IX SPECTRAL INDICES

FCA-IX CORES

	FCA-IX 1	FCA-IX 2	FCA-IX 3	FCA-IX 4	FCA-IX 5	FCA-IX 6	FCA-IX 7
Combustible	HEU 93%	HEU 93%	HEU 93%	HEU 93%	HEU 93%	HEU 93%	LEU 20%
Diluant	Graphite	Graphite	Graphite	Stainless Steel	Stainless Steel	Stainless Steel	-

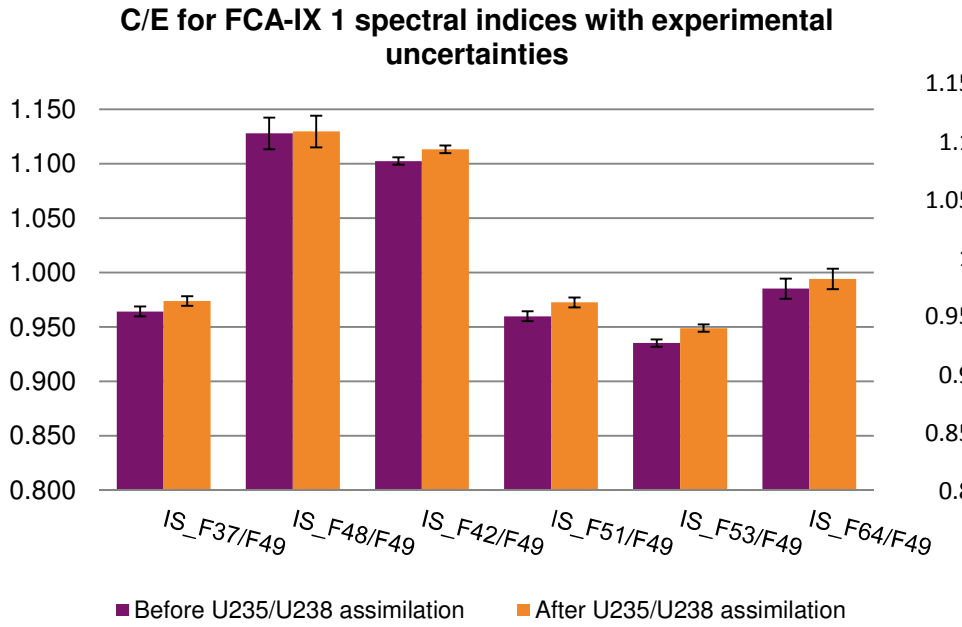
- 33 group spectra :

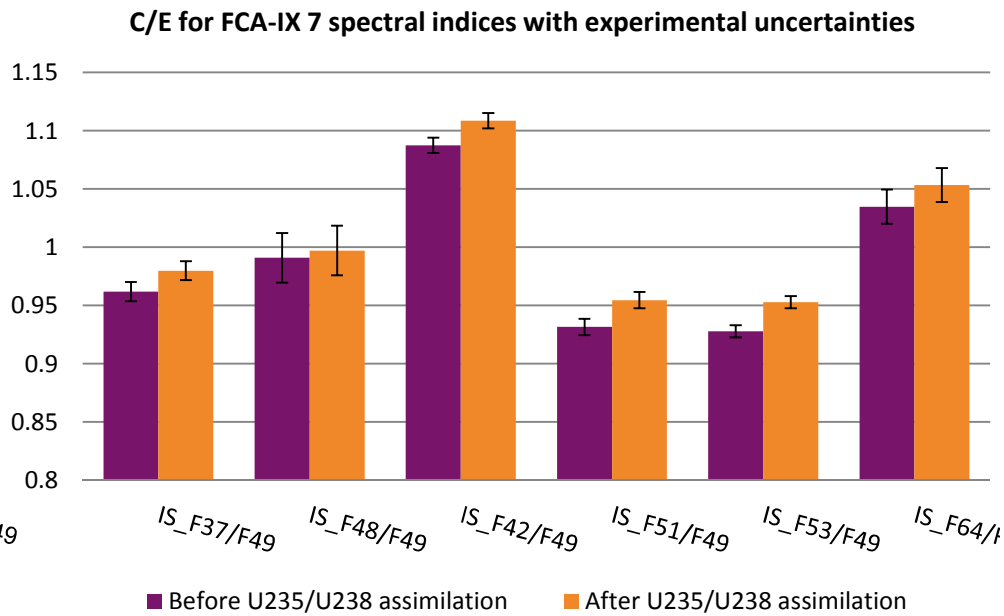
-



IMPACT OF U5/U8 ASSIMILATION ON SPECTRAL INDICES

- Major change proposal for capture cross section, nu and fission spectrum distribution for U235 -> **Impact on Spectral Indices calculation ?**



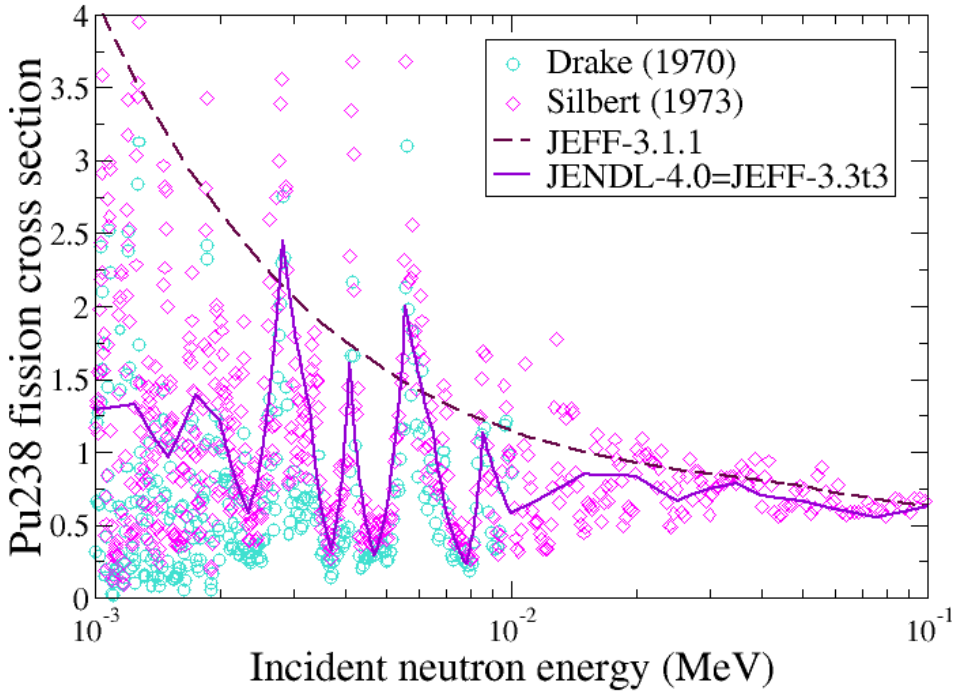


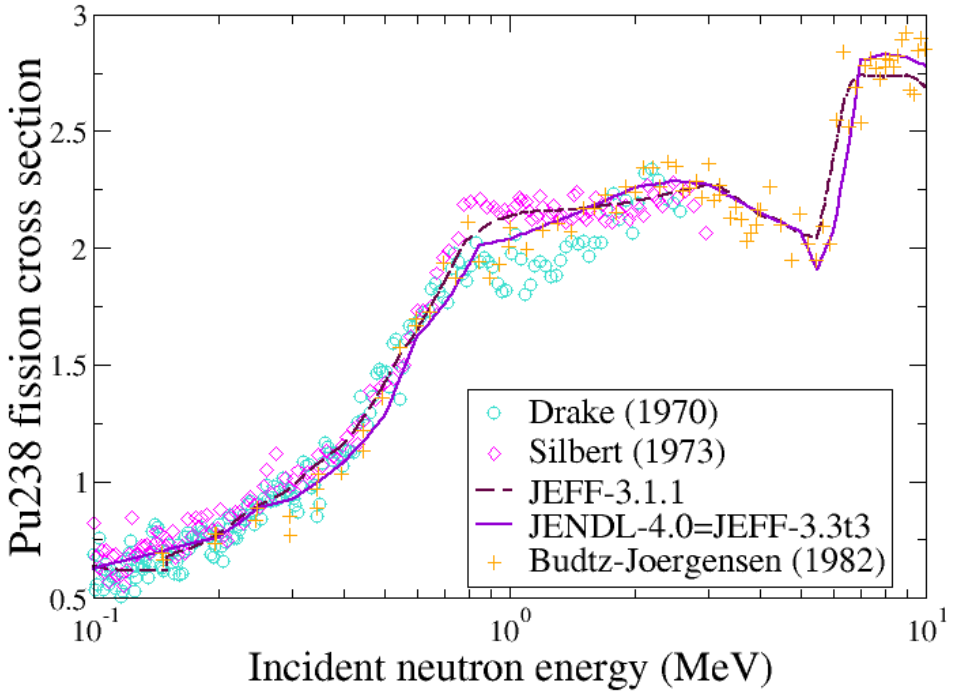
- Slight increase in most C/Es values when U235/U238 assimilation is taken into account.
- Same trends before and after U235/U238 assimilation for all configurations, soft or hard spectrum.

FCA-IX SPECTRAL INDICES : THE EXAMPLE OF PU238 FISSION

- According to FCA-IX spectral indices, Pu238 fission is overestimated below the threshold in JEFF-3.1.1. This was taken into account in JEFF-3.3t3.

- Above the threshold, JEFF-3.1.1 gives satisfying results for FCA-IX spectral indices. However, high experimental uncertainties are associated to Drake, Silbert and Budtz-Joergensen measurements (Pu-238 is an alpha emitter with a 87,7 years half life).





CONCLUSION

- Integral experiments provide a complementary point of view on nuclear data.
  → Comparison with recent differential measurements should allow us to have confidence in or criticize assimilation results.

- Assimilation using critical mass + PROFIL C/Es gave interesting results for **U235 capture : -30% trend at 1-2keV and +10% trend from 10 to 100 keV are confirmed when comparing this to recent differential experiments** (at RPI and LANSCE).

- **Results on U238 cross sections are highly dependent on fission spectra** (for which we have high uncertainties).

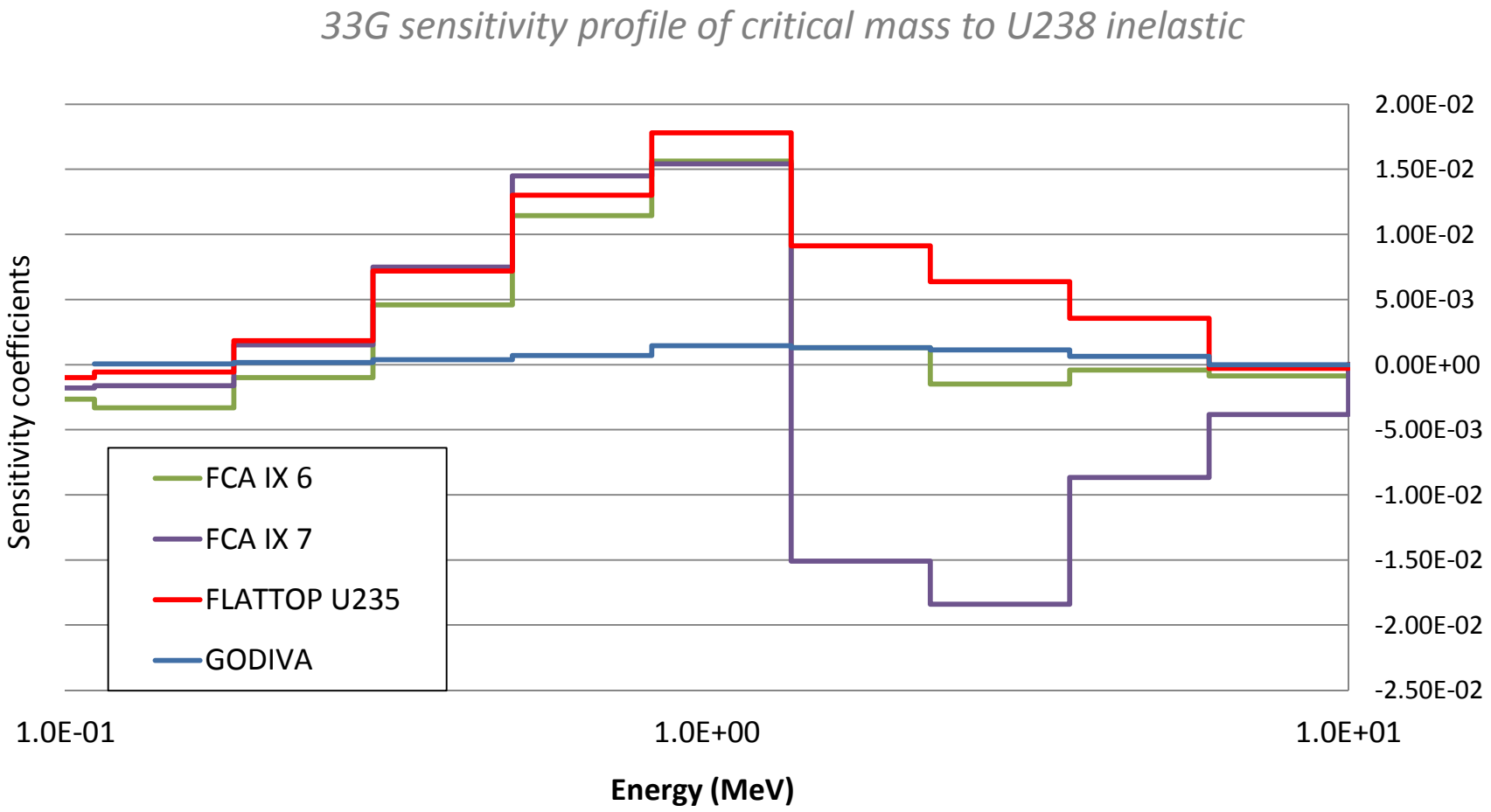
- Nevertheless, for **U238 inelastic in the plateau region**, assimilation suggest **JEFF-3.1.1 is overestimated (from 4% to 8%).**

- The impact on FCA-IX spectral indices is small (compared to experimental uncertainties) and thus we can use those to make recommendations on Minor Actinides fission cross sections.

- Forthcoming work : assimilation including Pu-fueled benchmarks. Will the trends on U238 cross sections remain the same ?

U238 INELASTIC : SENSITIVITY PROFILES

- ICSBEP benchmarks : the presence of Unat reflector in FLATTOP-U235 allows us to discriminate U238 contribution to C/E bias in the fast energy range.

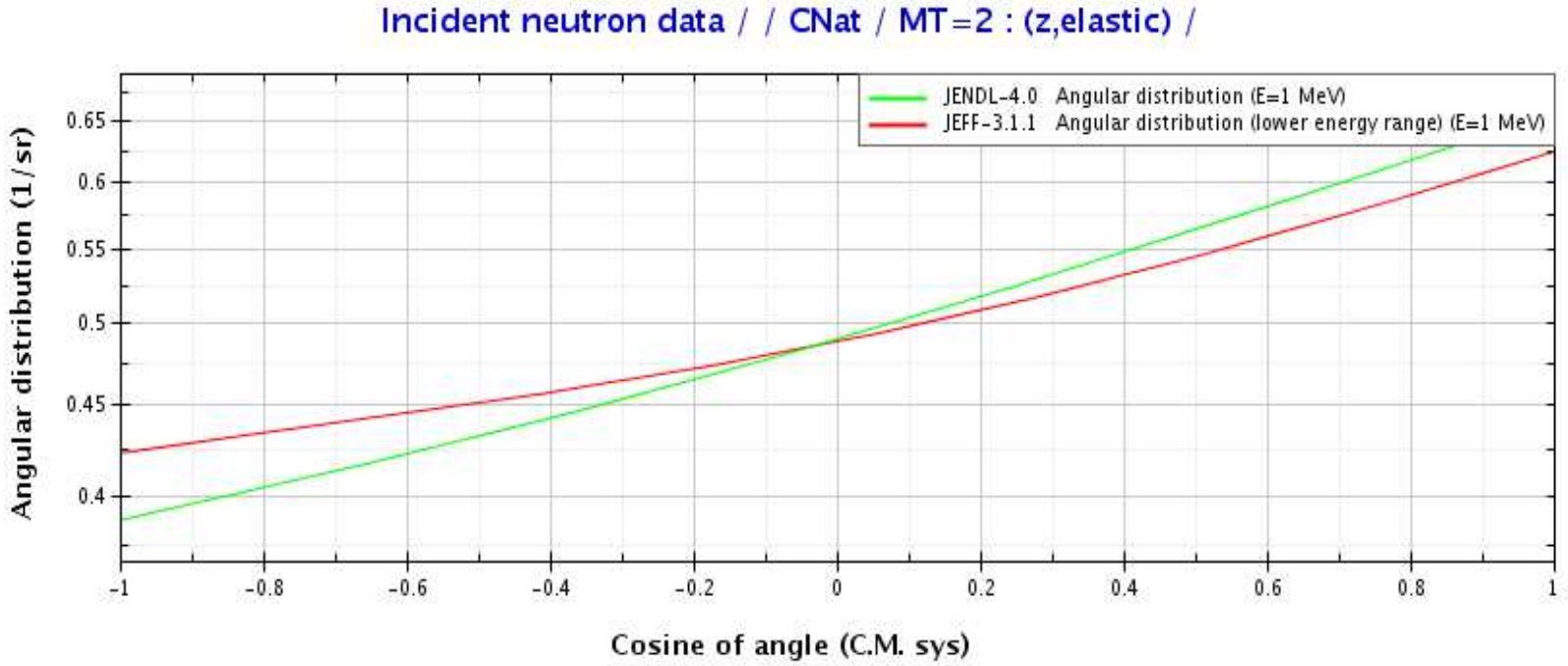


DIFFERENT OPTIONS

- Alternative options have been considered :

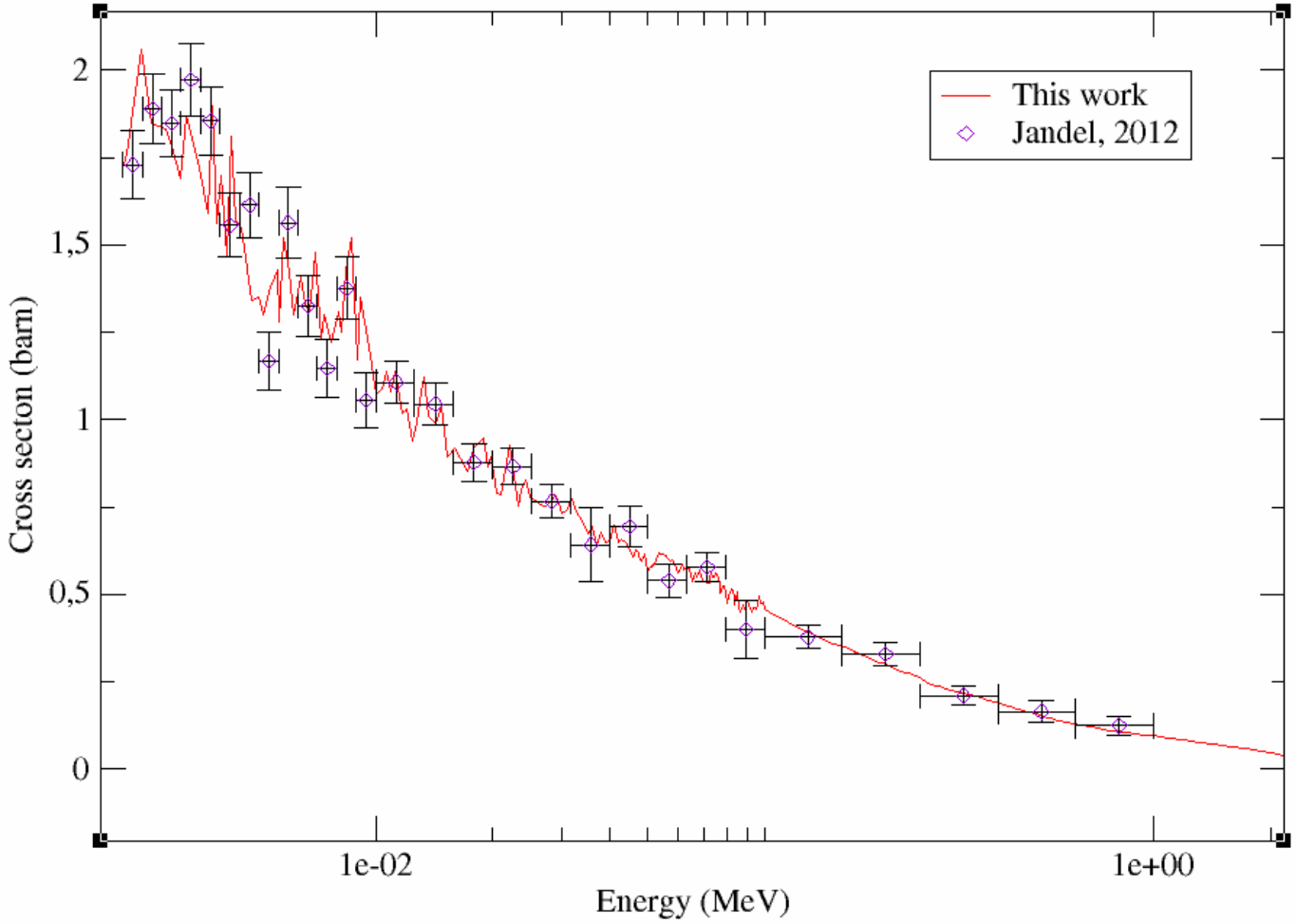
1/Fission spectrum for U235 and U238 have been **either constrained (set to JEFF- 3.1.1) or fitted**.

2/For graphite : we considered **either the evaluation from JEFF3.1.1 or JENDL4.0.**

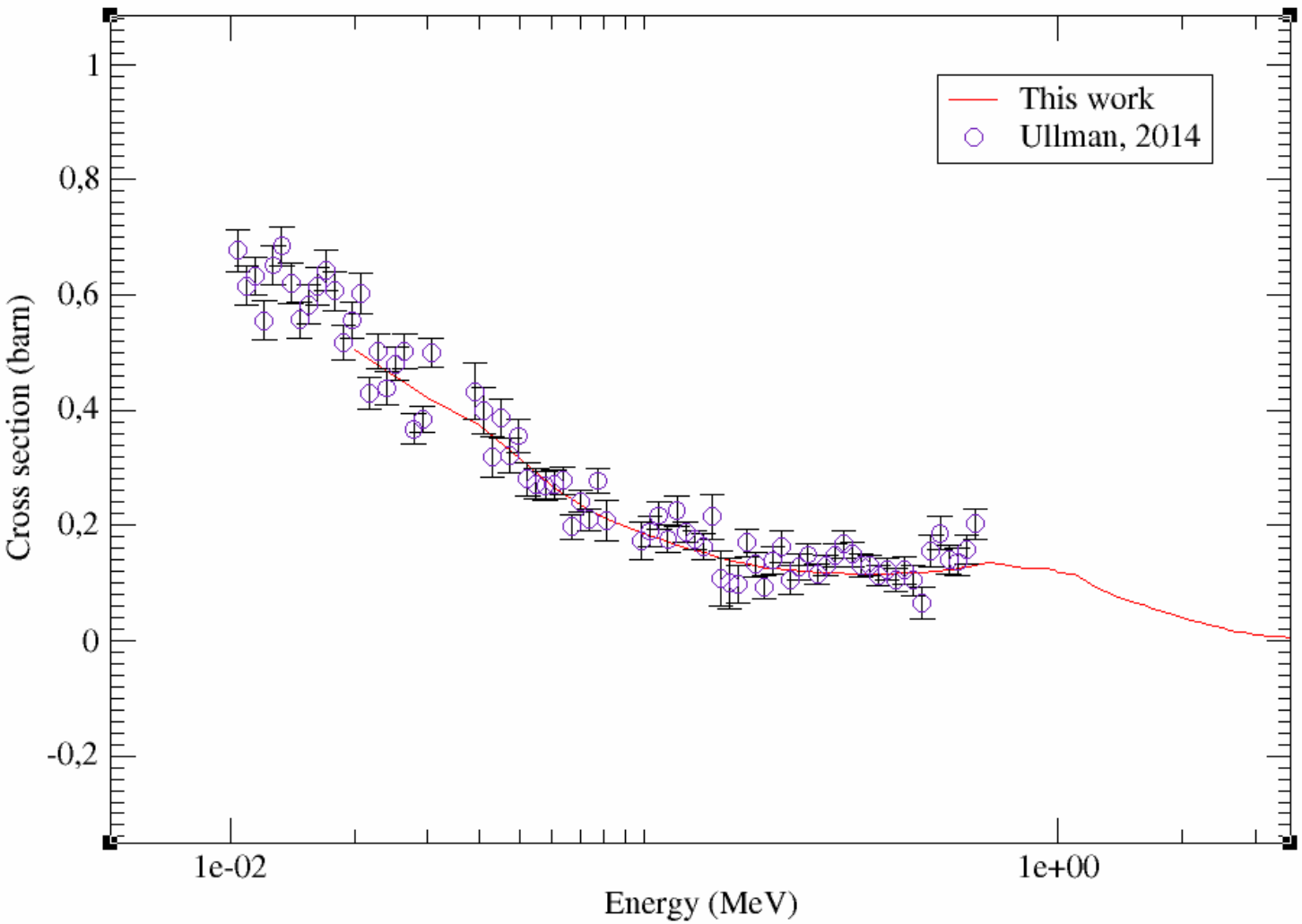


JEFF3.1.1 & JENDL-4.0 Angular Distributions for Carbon elastic XS (E=1MeV)

U235 CAPTURE : COMPARING WITH DIFFERENTIAL MEASUREMENTS



U238 CAPTURE : COMPARING WITH DIFFERENTIAL MEASUREMENTS



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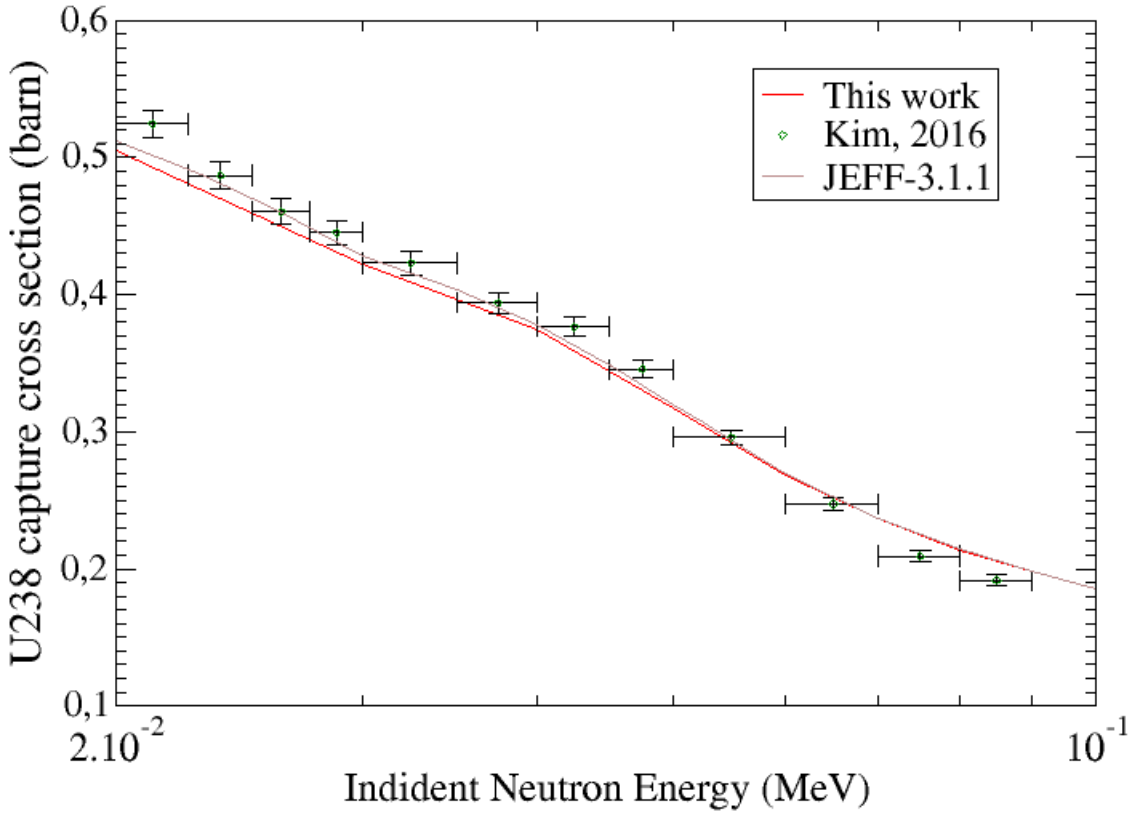


U238 CAPTURE : SUMMARY

- Results on U238 are **highly dependent on fission spectra** :
  -when fission spectra varies through assimilation, trends are included in posterior uncertainties (JEFF-3.1.1 is ok).
  -when fission spectra are constrained**, a -3% to -6% decrease is suggested from 15 keV to 1MeV.**

- Such modifications (decrease from 3 to 6 % from) can have a significant impact on critical mass of fast reactor ! For instance, **modifications suggested by assimilation (fission spectra fixed) results in +500pcm on k_{eff} of a SFR core such as ASTRID.**
  → Further investigation is needed.

U238 INELASTIC : SUMMARY

- Assimilation results on U238 are highly dependent on fission spectra : **inelastic trends goes from -4% to -8%** (depending on whether fission spectra are varying or not) **in the plateau region**.

- Overall, CIELO and JEFF-3.3t3 both agree with this trend of decreasing U238 inelastic in the plateau region.

IMPACT OF U5/U8 ASSIMILATION ON SPECTRAL INDICES

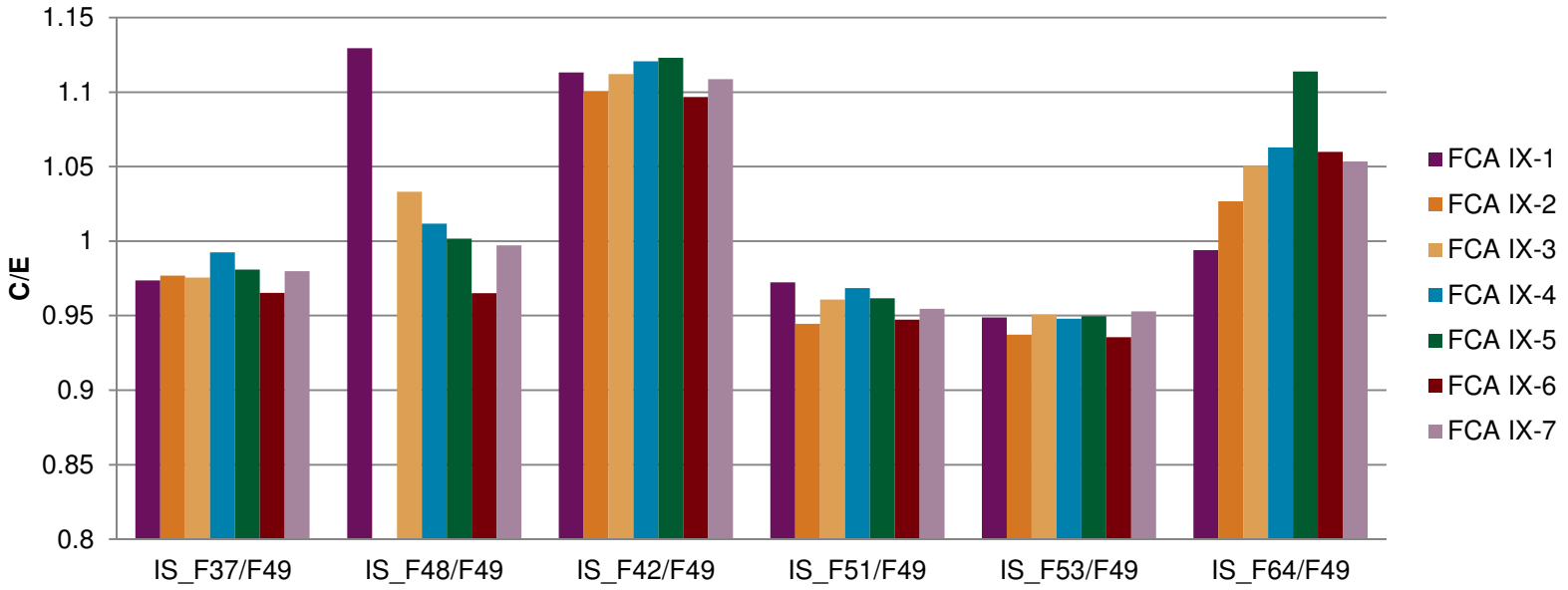
- FCA-IX spectral indices give **information on Minor Actinides cross sections in the whole fast energy range**.

- Assimilation on U235 and U238 nuclear data using FCA-IX critical masses allows us to reduce indirect uncertainties on spectral indices values.

- Impact on spectral indices of FCA-IX was quantified. For most C/Es, trends before and after assimilation on U235/U238 are unchanged. Nevertheless**, indirect contributions on nuclear data uncertainties are noticeably reduced** and ND **uncertainties are still higher than experimental uncertainties**.

FCA-IX SPECTRAL INDICES : C/E AFTER U5/U8 ASSIMILATION

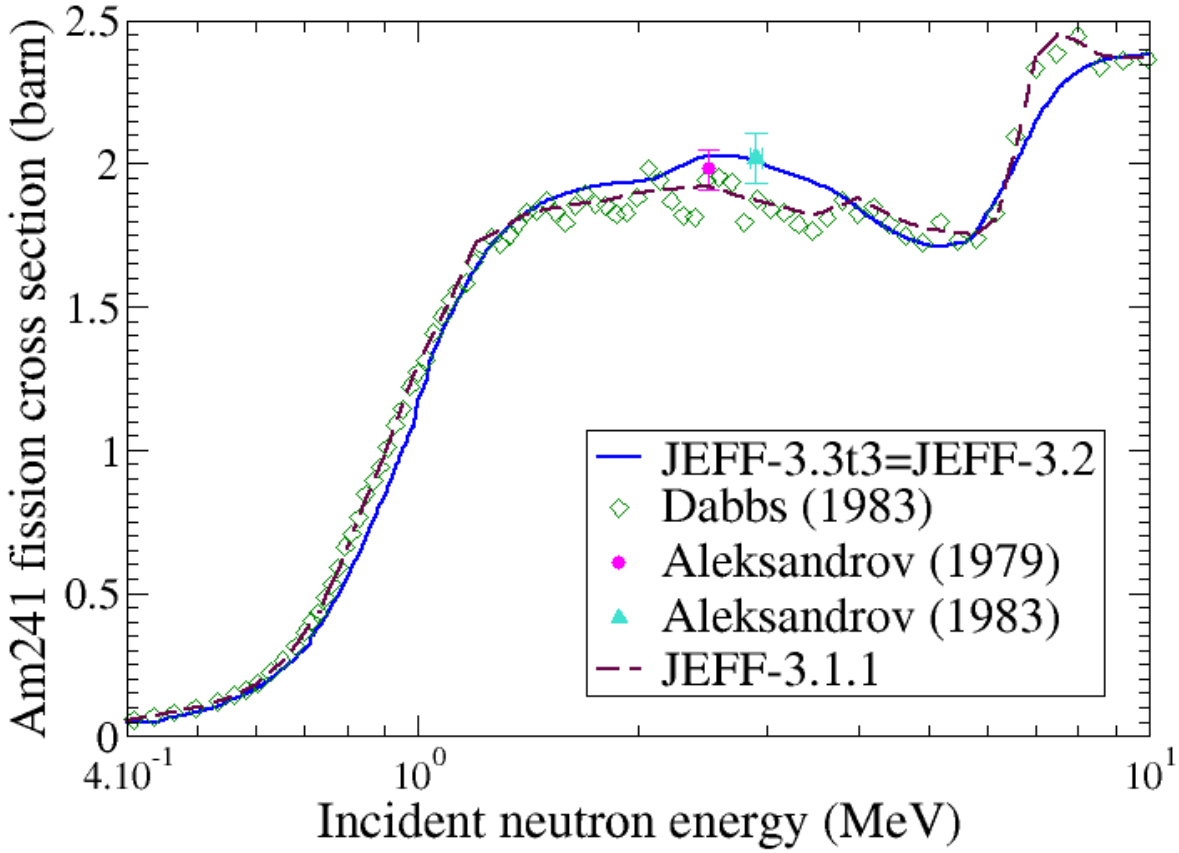
FCA-IX spectral indices C/Es (JEFF-3.1.1+results from U235/U238 assimilation)



- FCA-IX spectral indices suggest an overestimation of Pu242 fission (~10%).
- Possible underestimation for fission of Np237 (3-4%), Am241 and Am243 (~5%)
- Spectrum effect is observed for Pu238 and Cm244 spectral indices :
  -High overestimation of Pu248 fission (~13%) in the softest spectrum
  -Overestimation of Cm244 fission (5-10%) in the hardest spectra

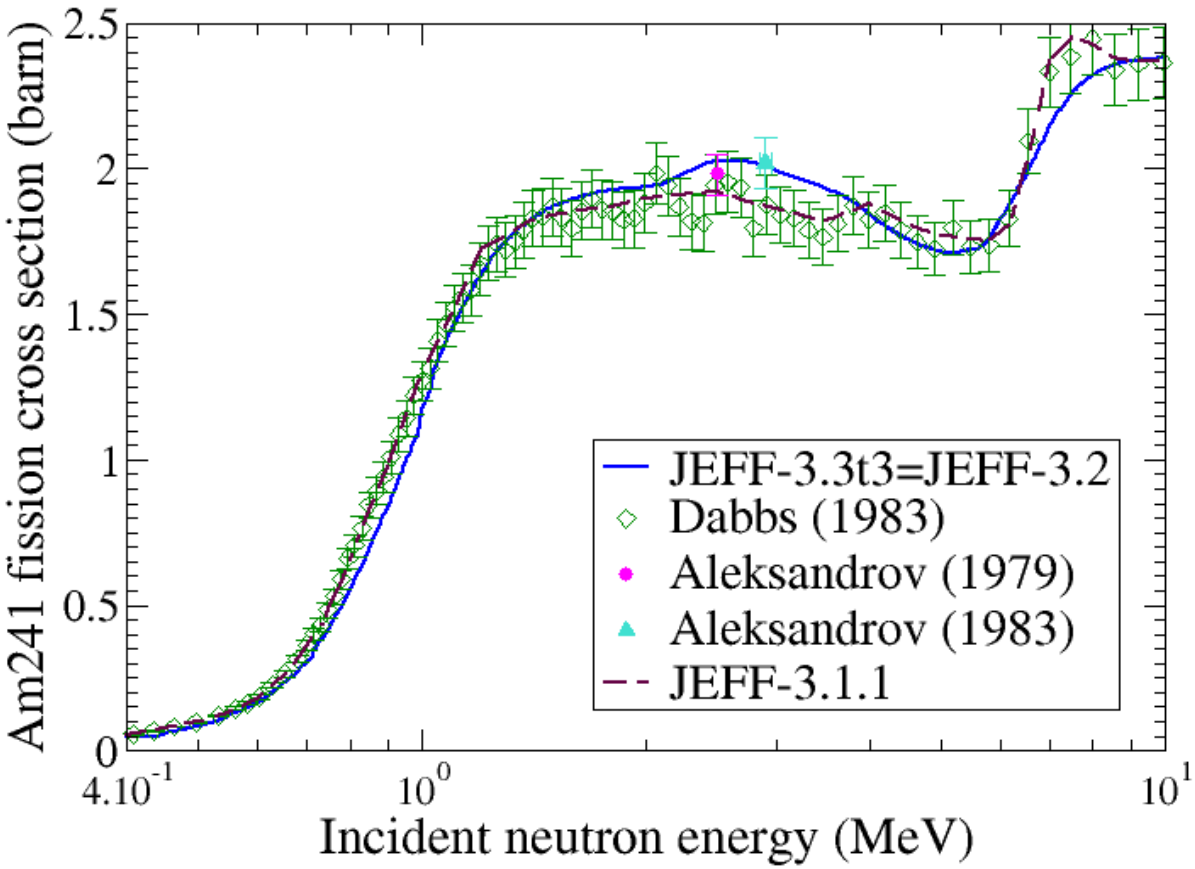
FCA-IX SPECTRAL INDICES : AM241 FISSION

- According to FCA-IX spectral indices**, Am241 fission should be increased of ~5%.** This is in agreement with Aleksandrov measurements (1983). New differential measurements would help to conclude on this matter.



FCA-IX SPECTRAL INDICES : AM241 FISSION

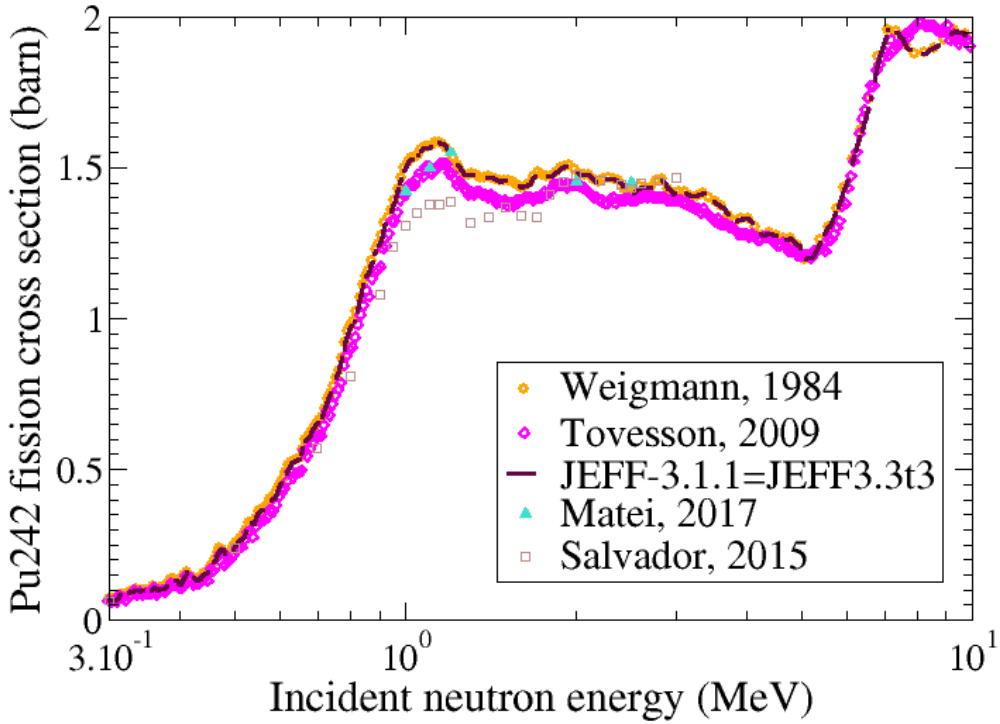
- JEFF-3.3t3 (equal to JEFF3.2 for this energy range) is in agreement with Aleksandrov measurements in the plateau region.
- However, in the threshold, Am241 fission might be underestimated in JEFF-3.3t3 (out of Dabbs experimental uncertainties for this energy range). Am241 spectal indices are slightly more underestimated with JEFF3.2 than with JEFF3.1.



FCA-IX SPECTRAL INDICES : PU242 FISSION

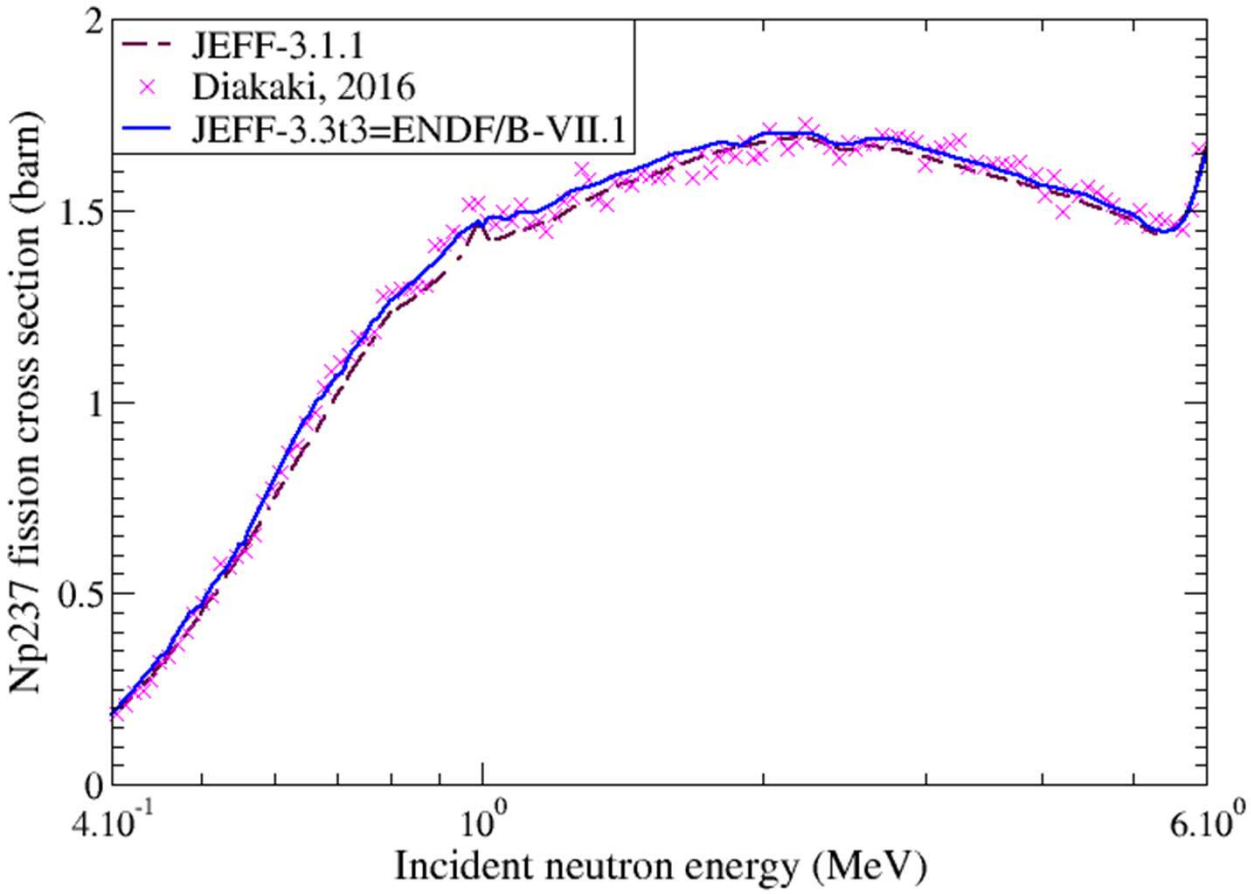
- According to FCA-IX spectral indices, Pu242 fission should be lowered of ~10%. This go in the same direction as Tovesson measurements (2009) around 1-2 MeV.

- Tovesson, Staples and Weigmann measurements agree on the profile of the cross section in the plateau region. There might be a normalization issue.



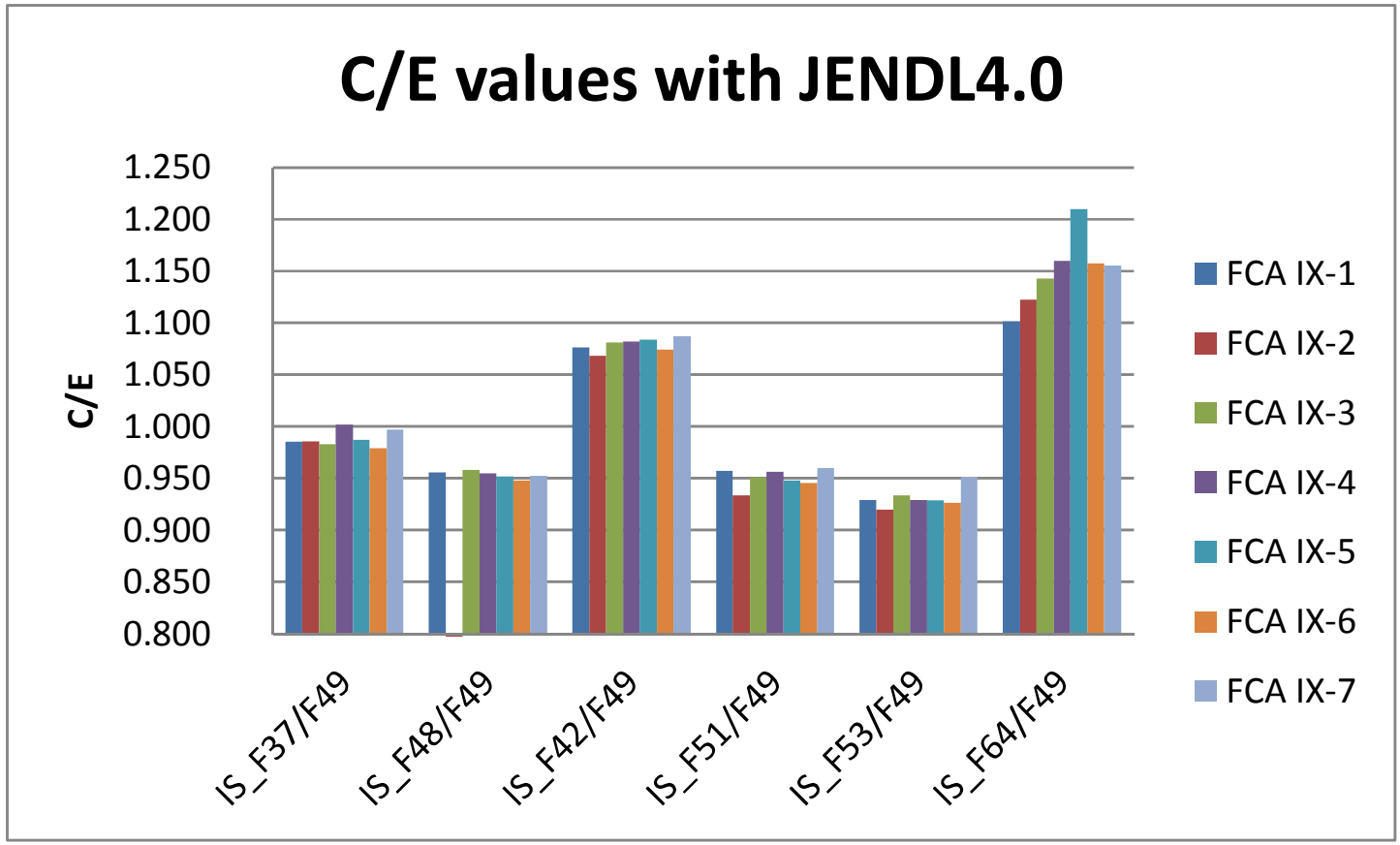
FCA-IX SPECTRAL INDICES : NP237 FISSION

- According to FCA-IX spectral indices, Np237 fission should be increased of ~4%. This is in agreement with Diakaki (2016) around 1 MeV. JEFF-3.3t3 is in agreement with Diakaki measurements. However, the bump at around 1MeV is not present in the evaluation.

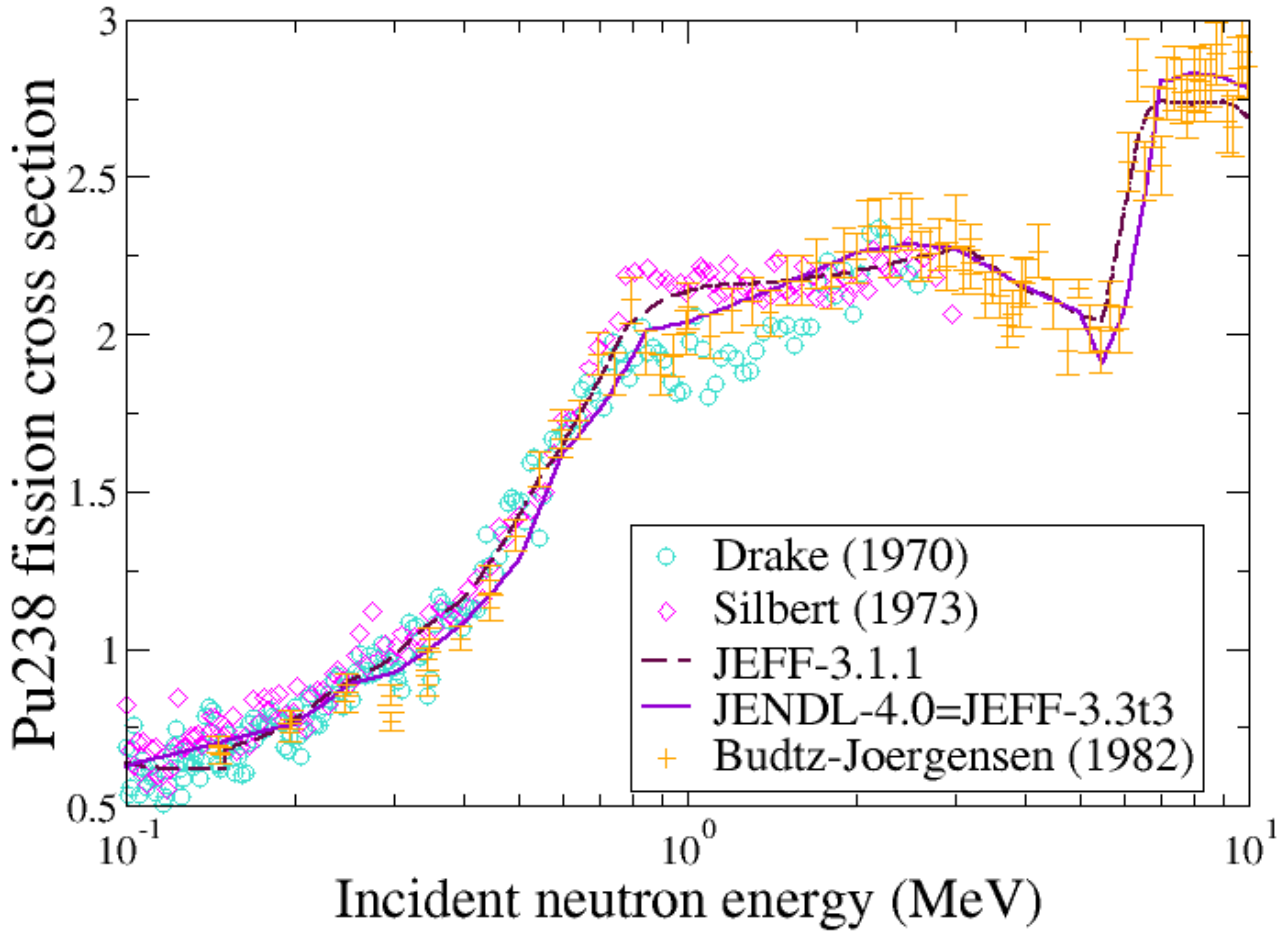


FCA-IX SPECTRAL INDICES : PU238 FISSION

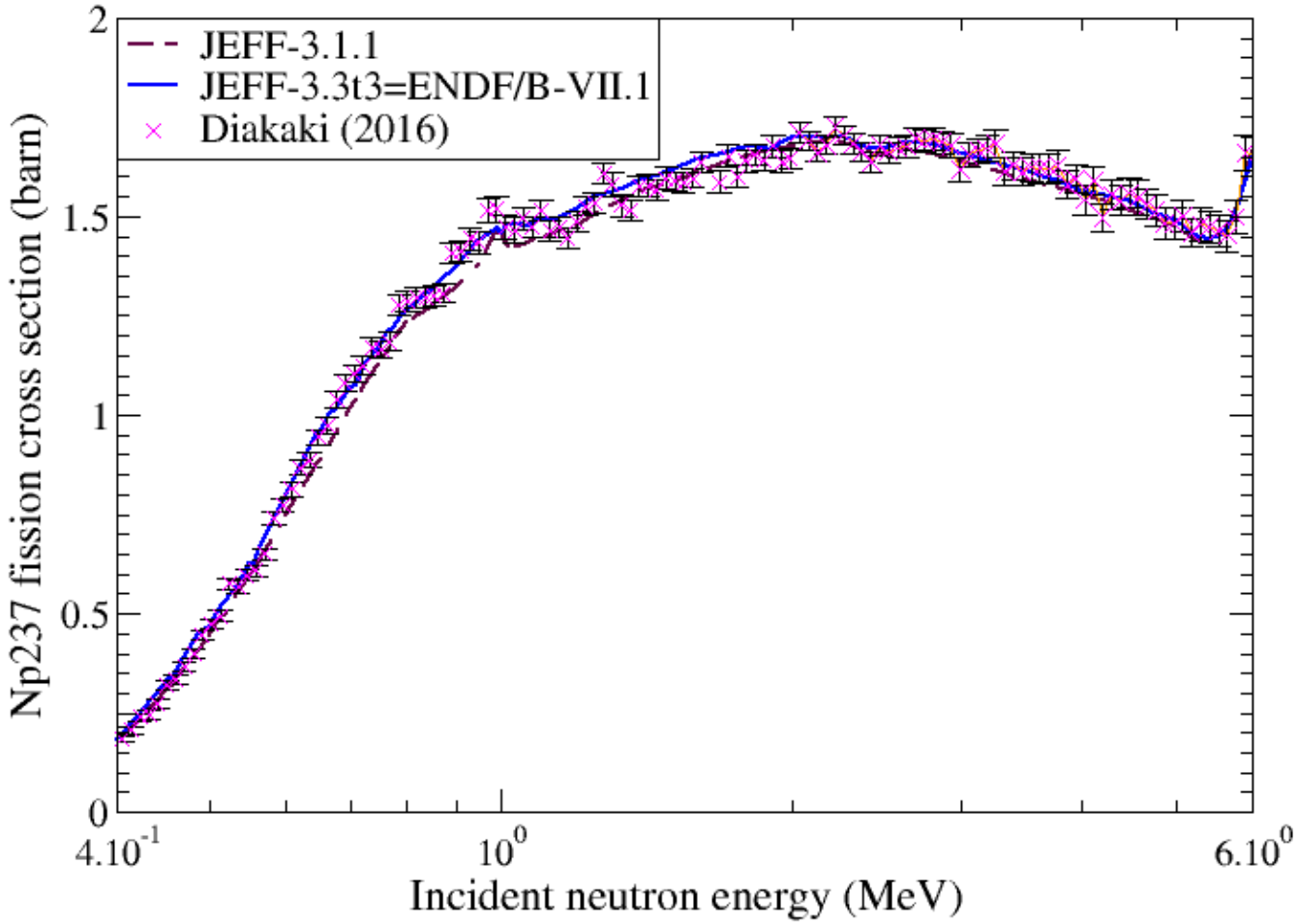
- For the FCA-IX experimental program, Pu238 spectral index from JENDL-4.0 is underestimated of around 5%.



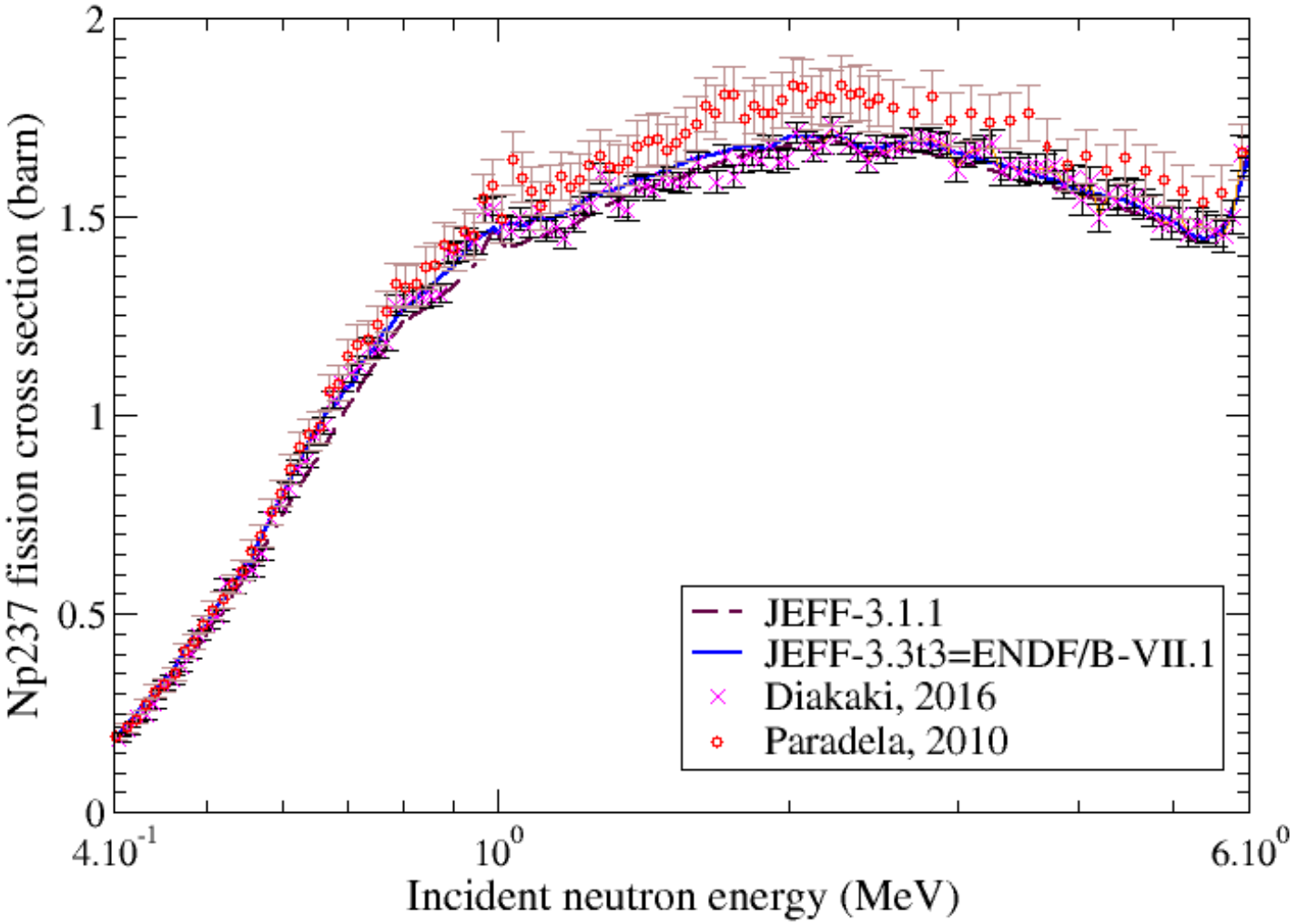
FCA-IX SPECTRAL INDICES : PU238 FISSION



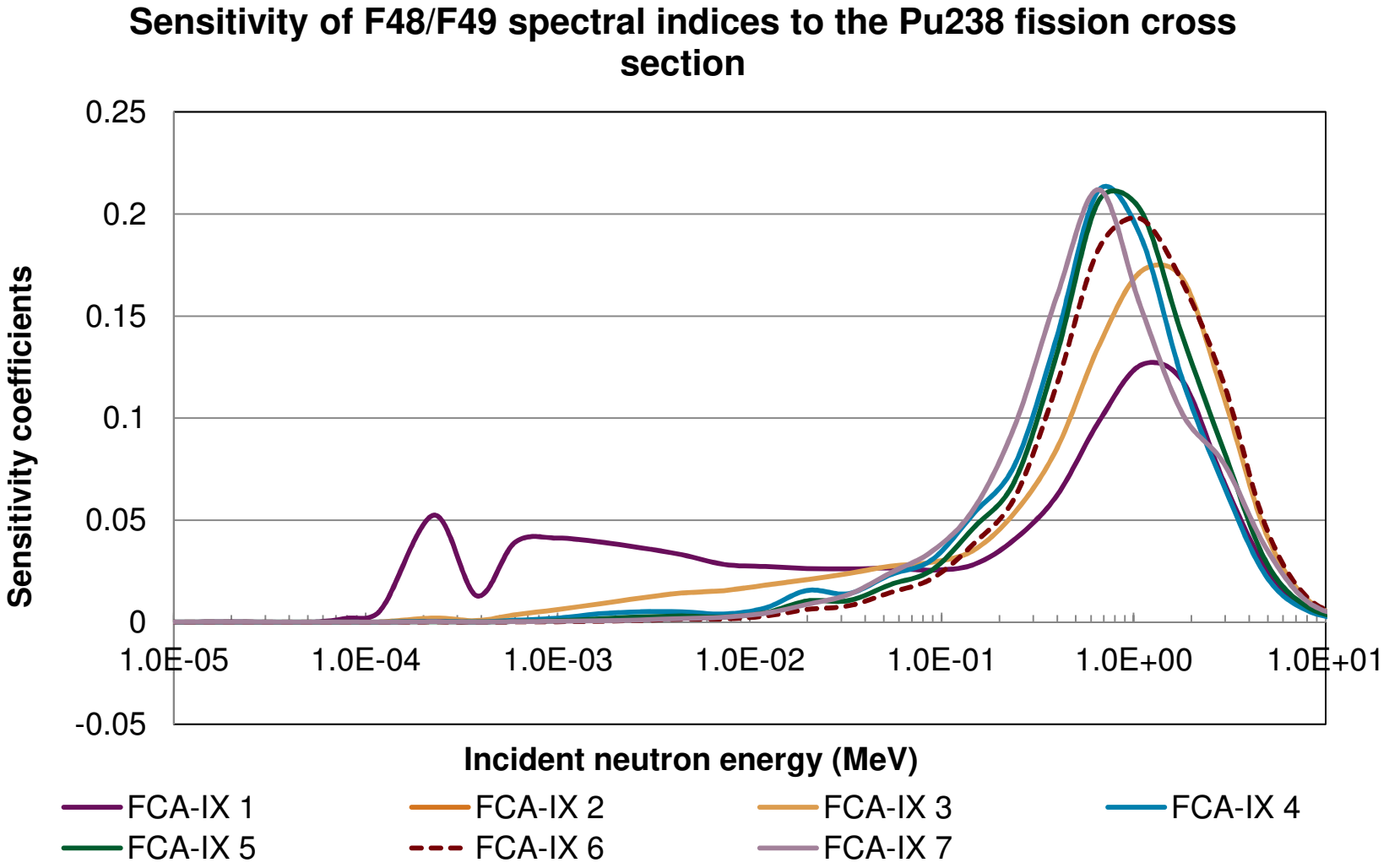
FCA-IX SPECTRAL INDICES : NP237 FISSION



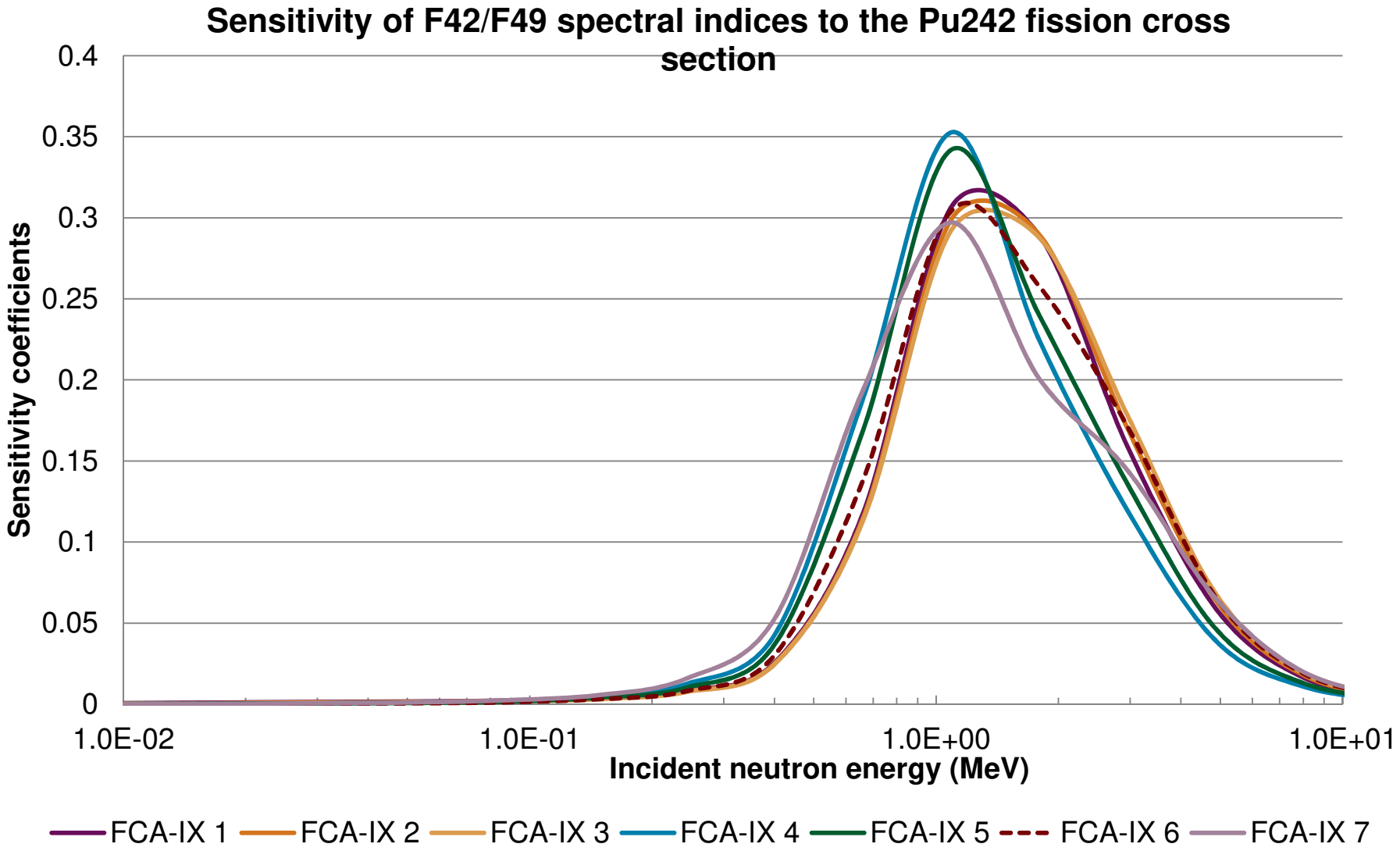
FCA-IX SPECTRAL INDICES : NP237 FISSION



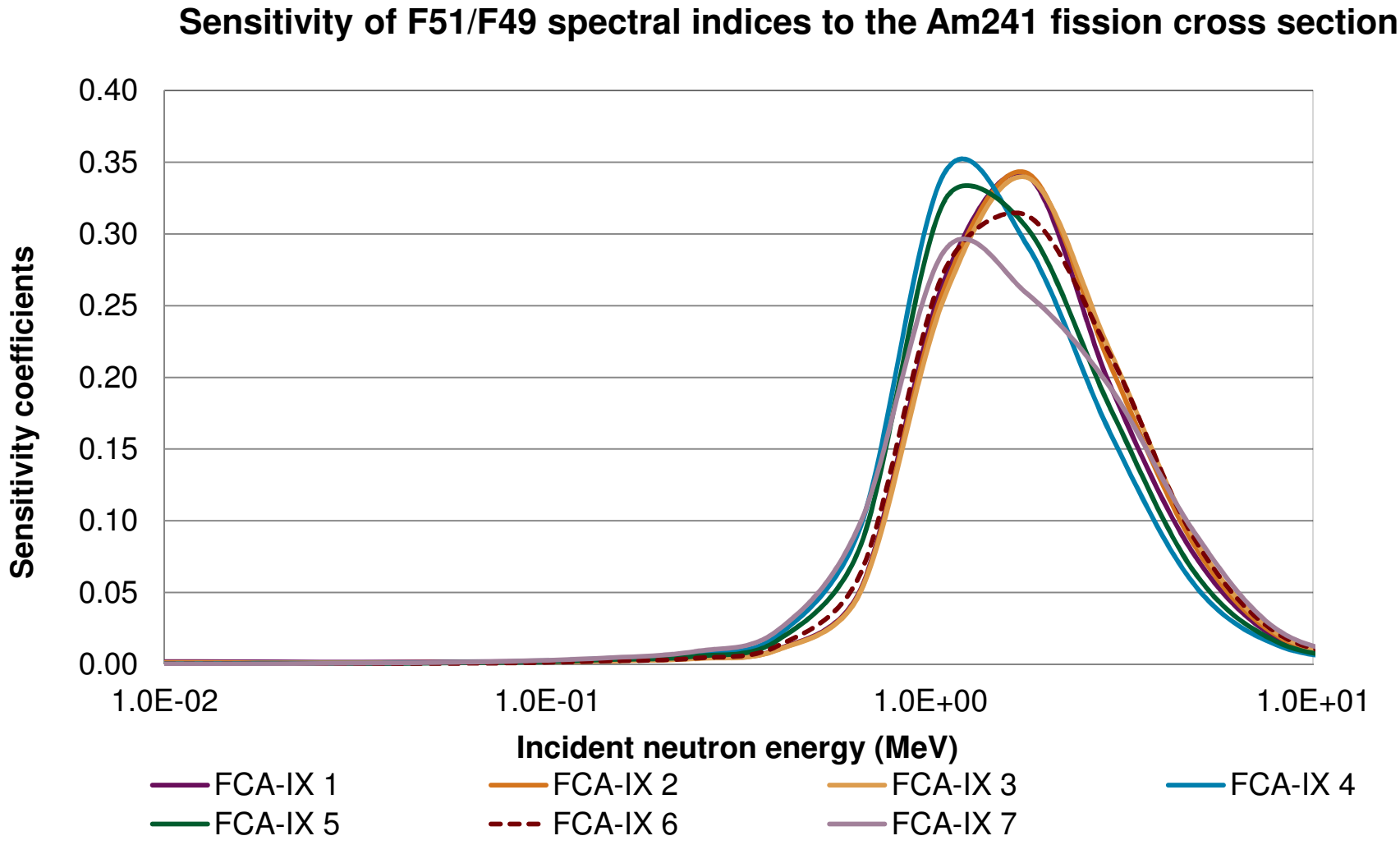
FCA-IX SPECTRAL INDICES SENSITIVITY STUDY : PU238 FISSION



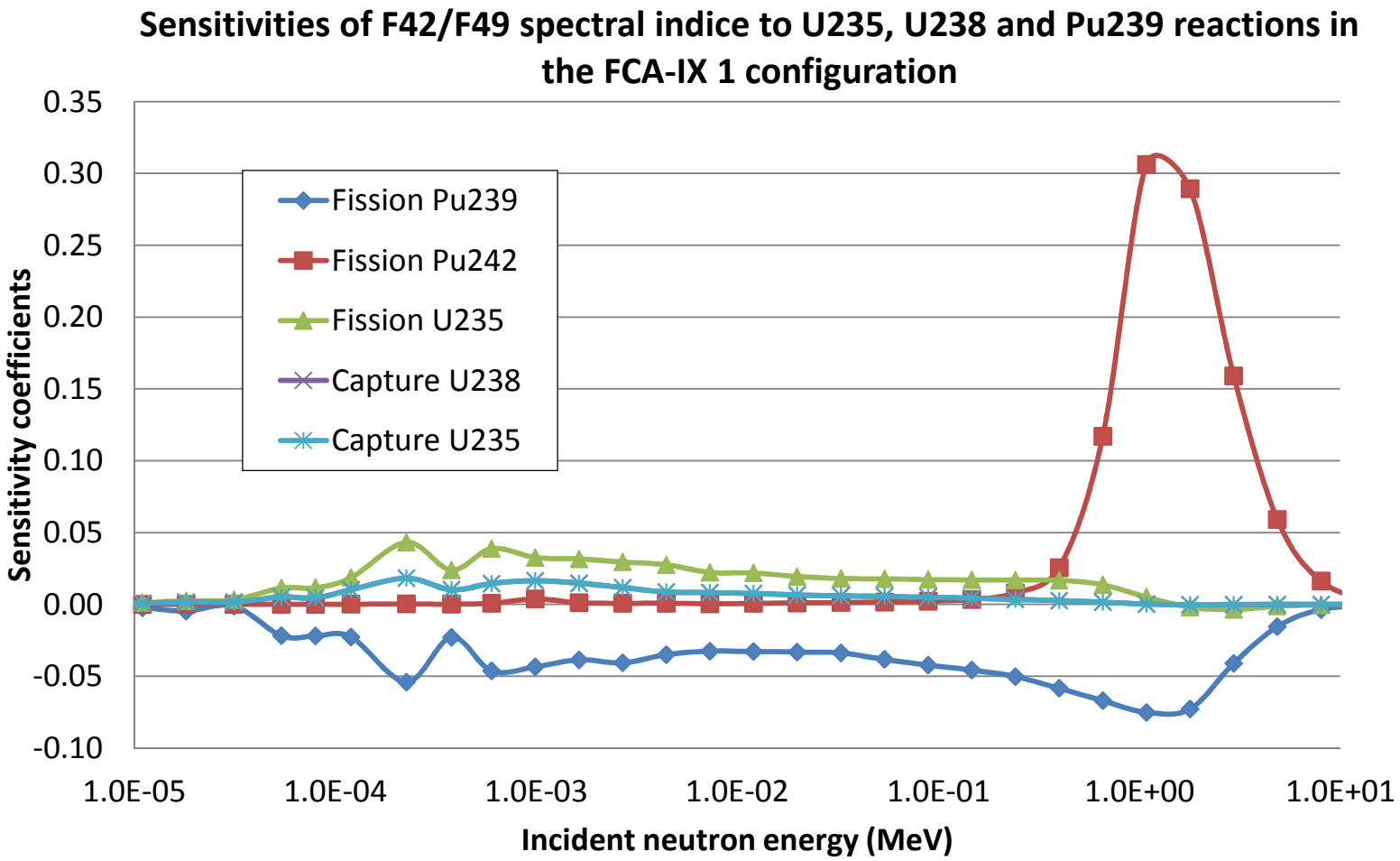
FCA-IX SPECTRAL INDICES SENSITIVITY STUDY : PU242 FISSION



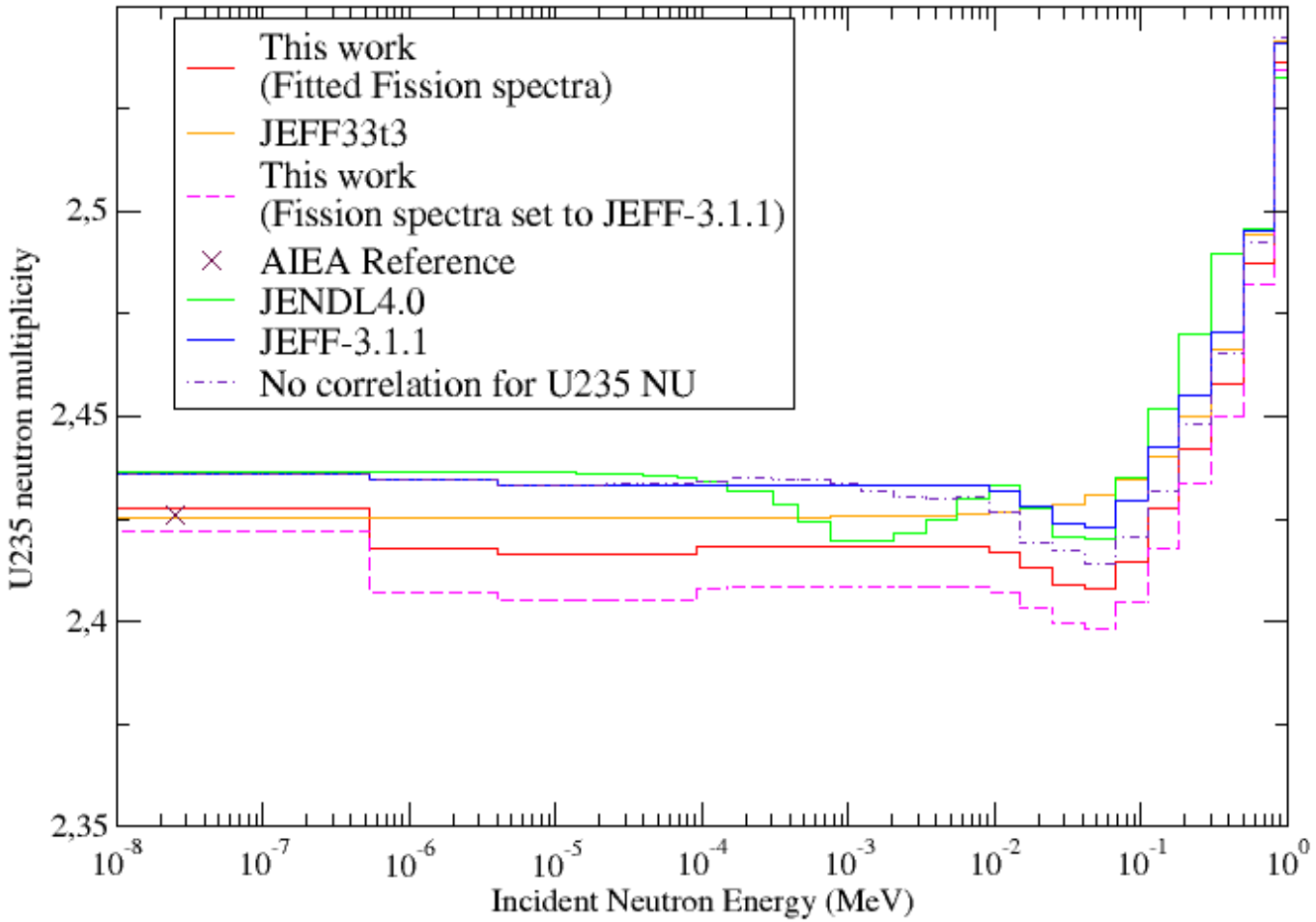
FCA-IX SPECTRAL INDICES SENSITIVITY STUDY : AM241 FISSION



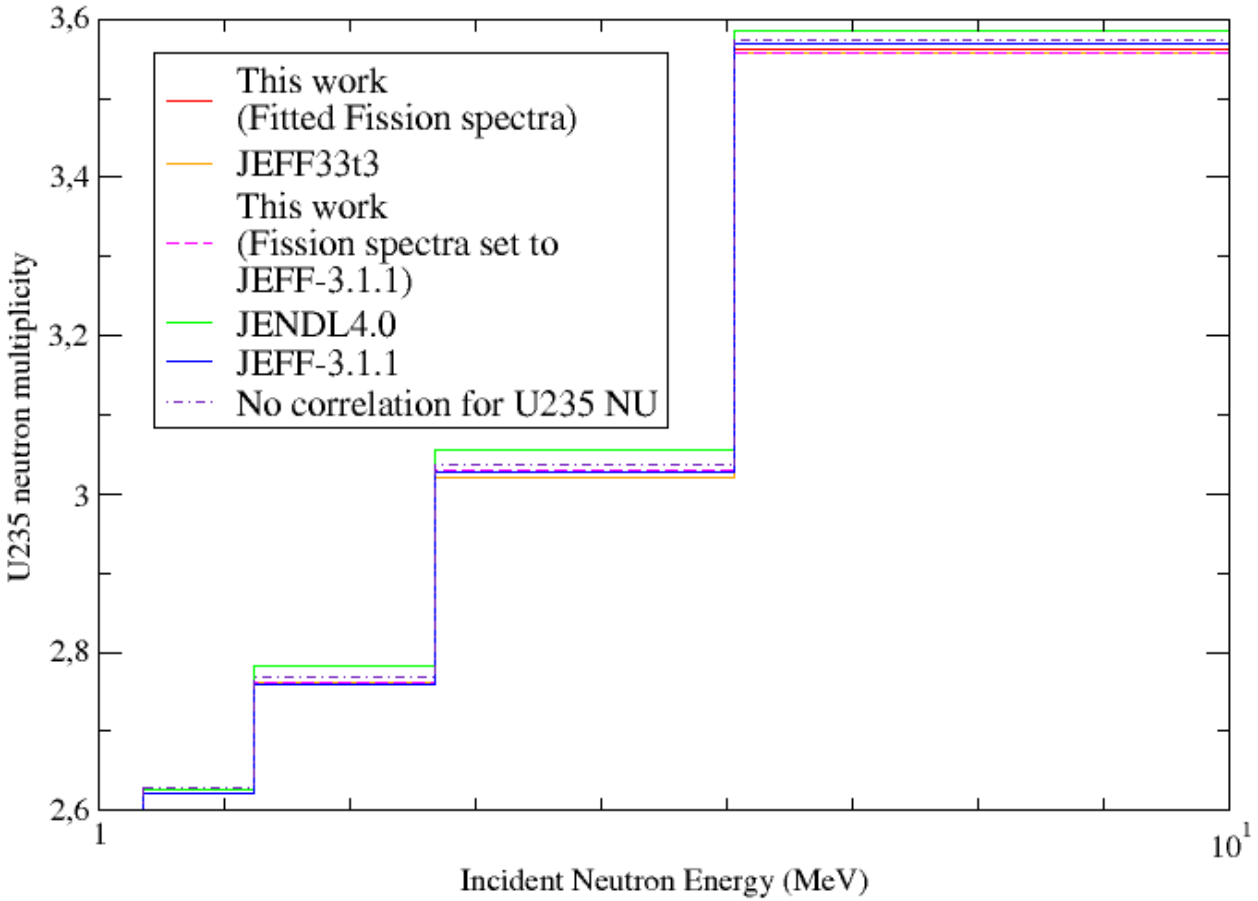
FCA-IX SPECTRAL INDICES SENSITIVITY STUDY : PU242 FISSION



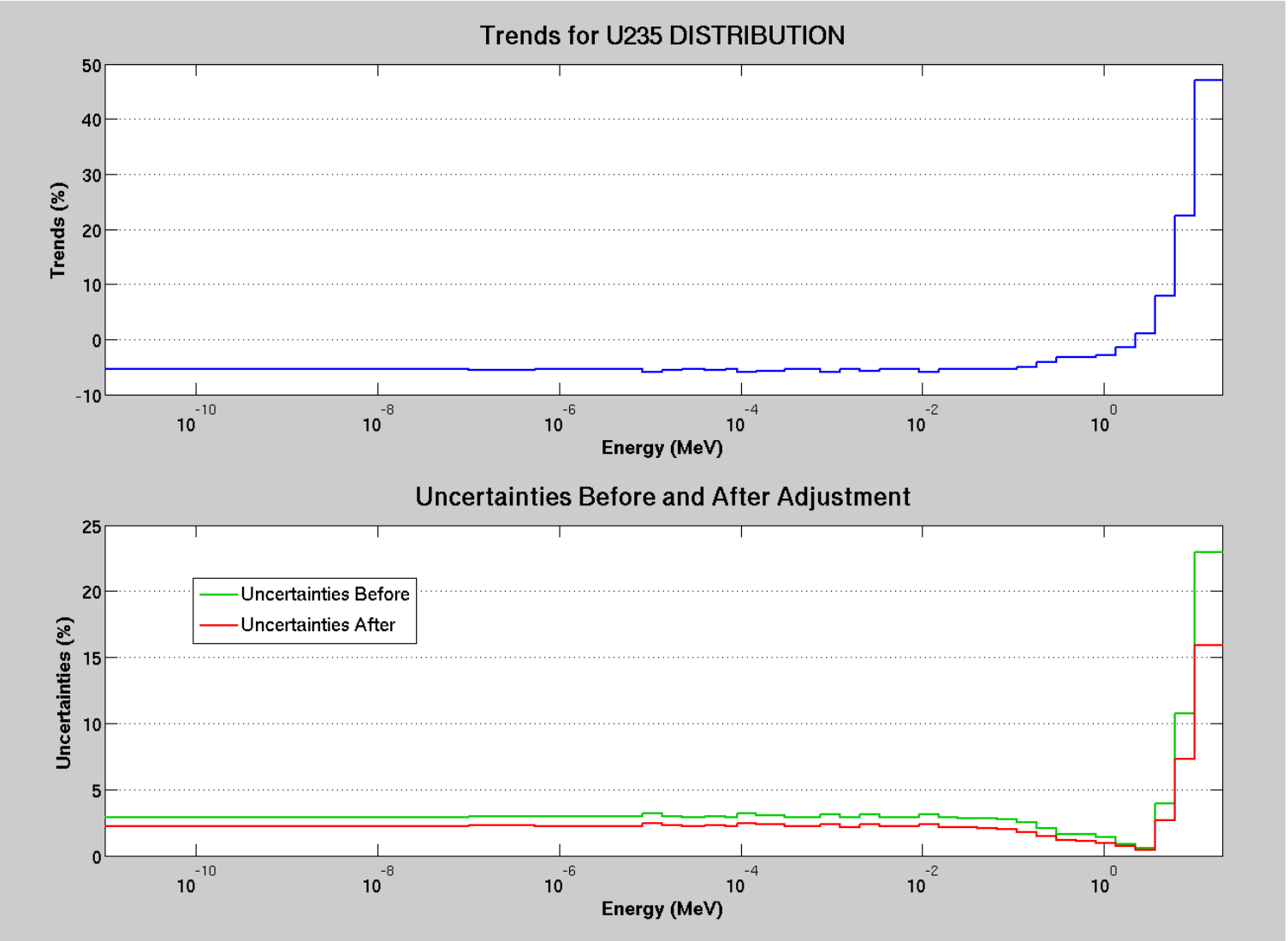
U235 NU


This work
(Fitted Fission spectra)
JEFF33t3
This work
(Fission spectra set to JEFF-3.1.1)
AIEA Reference
JENDL4.0
JEFF-3.1.1
No correlation for U235 NU
U235 neutron multiplicity
2,5
2,45
2,4
2,35
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
Incident Neutron Energy (MeV)

U235 NU


3,6
3,4
3,2
3
2,8
2,6
1
10^1
U235 neutron multiplicity
Incident Neutron Energy (MeV)
This work
(Fitted Fission spectra)
JEFF33t3
This work
(Fission spectra set to
JEFF-3.1.1)
JENDL4.0
JEFF-3.1.1
No correlation for U235 NU

U235 PFNS


Trends for U235 DISTRIBUTION
Trends (%)
50
40
30
20
10
0
-10
10^-10
10^-8
10^-6
10^-4
10^-2
10^0
Energy (MeV)
Uncertainties Before and After Adjustment
Uncertainties (%)
25
20
15
10
5
0
Uncertainties Before
Uncertainties After
10^-10
10^-8
10^-6
10^-4
10^-2
10^0
Energy (MeV)