The mystery of the errors in the GMA evaluation of the PFNS of U-235

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Preface

- **The available ratio data (Cf-252/U-235) suggest performing a simultaneous evaluation of both spectra.**

- **However, a meaningful simultaneous evaluation also requires the existence of ‘absolute’ measurements of both spectra (covering a wide energy range). Is this requirement really fulfilled?**

- **The common least-squares evaluation codes cannot handle correlations between input data and parameters (final result).**

- Due to the normalization of the spectral distribution to unity, the covariance matrix of the spectrum is **positive semi-definite**. I.e., the matrix is singular and one of the eigenvalues of the matrix is exactly zero (inversion problem).

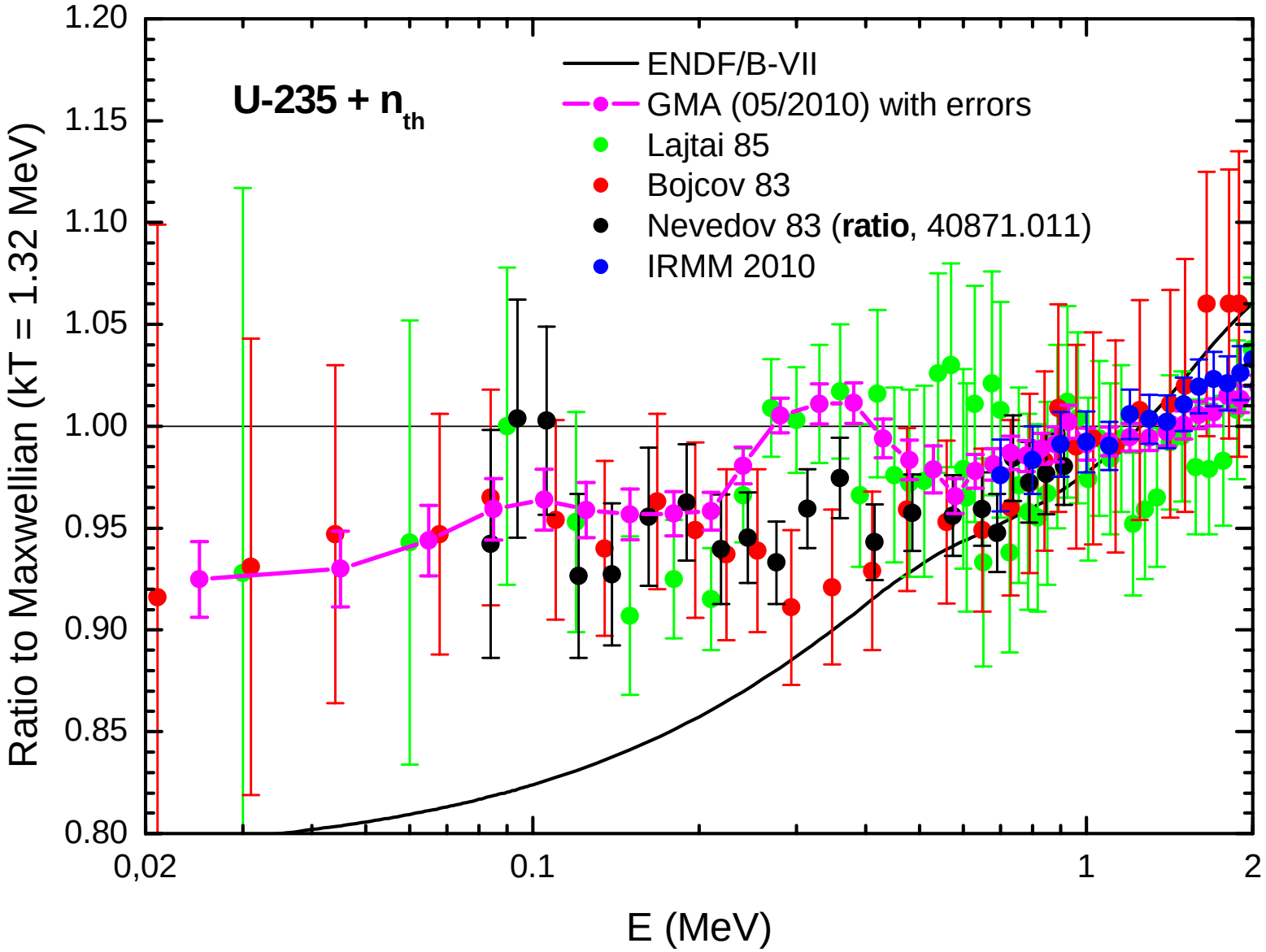
Comparison of representative errors between 25 keV and 12.8 MeV

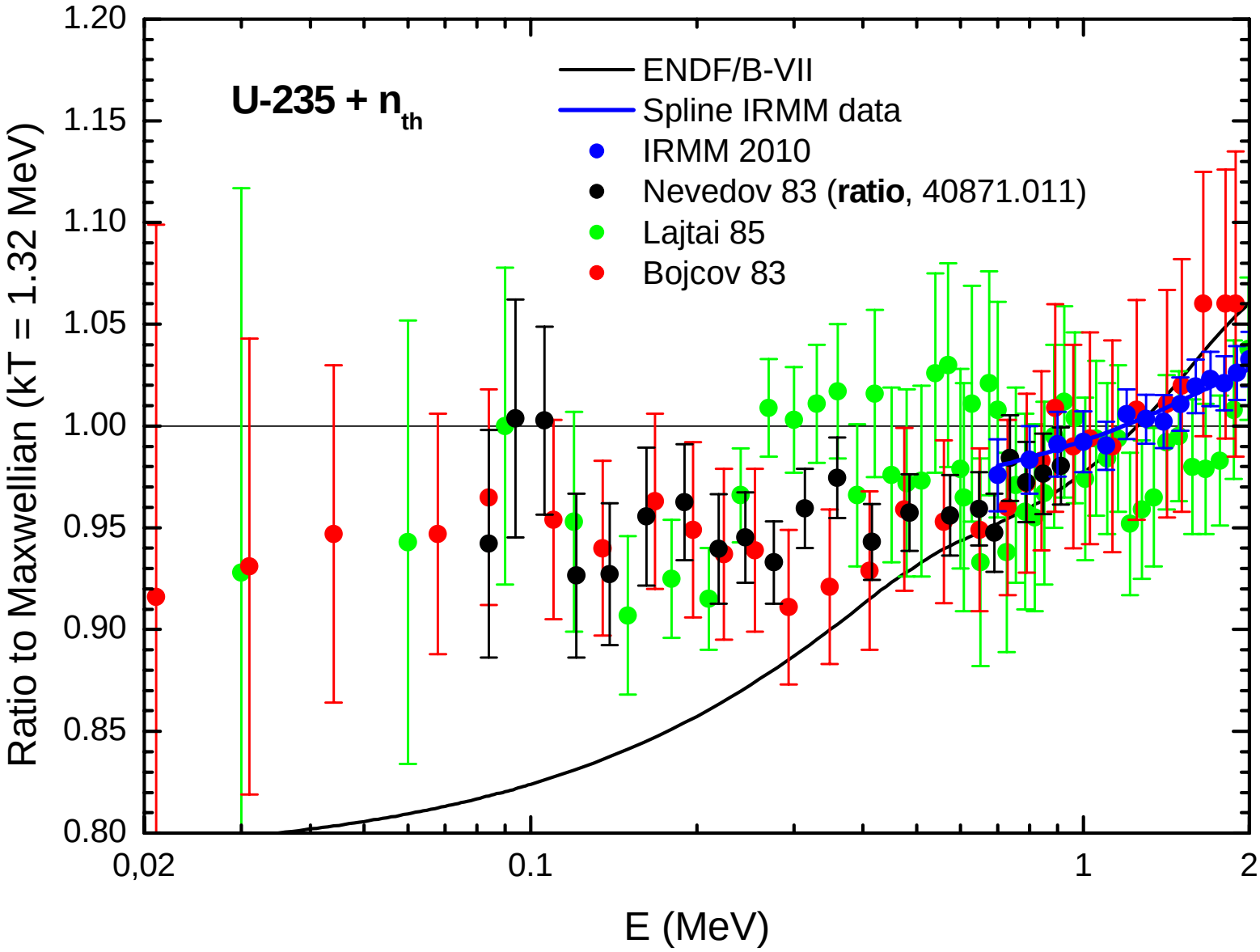
	U-235	Cf-252
Neutron energy	GMA	EVAL
E(MeV)	error in %	error in %
0.025	2.0 (max)	10.4 (max)
0.125	1.4	3.4
1.0	0.8	1.6
2.25	0.5 (min)	1.1 (min)
10.0	1.4	2.5
12.8	1.8	5.0
in the range		
1.0 – 6.3	≤ 0.8	≤ 1.6

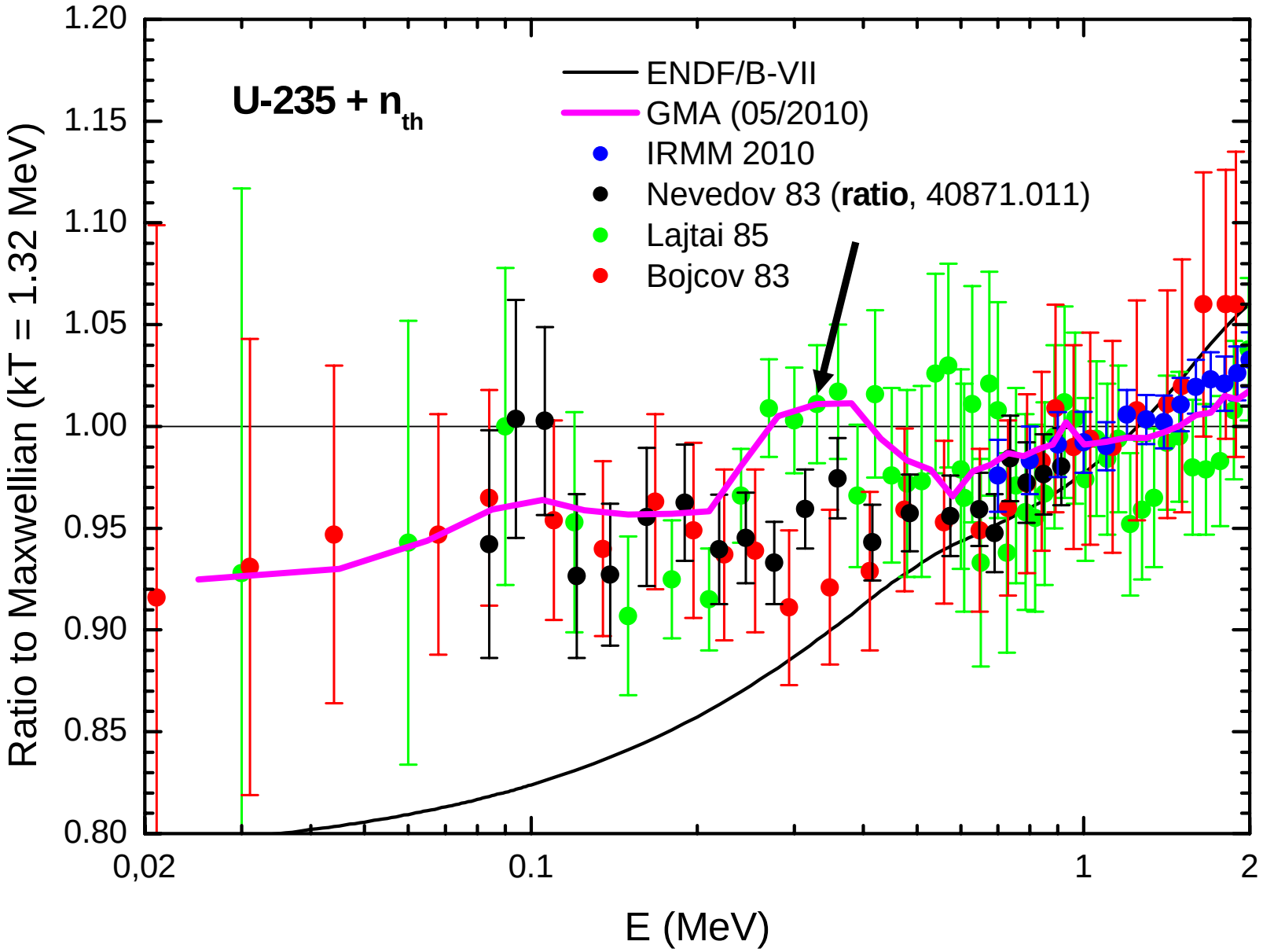
- **Firstly the question arises: Are the U-235 spectrum measurements really so much better than that of Cf-252?**

- **Secondly, the extremely low uncertainties obtained between 1 MeV and 6 MeV suggest a serious problem in the error propagation process.**

- **It seems that some of the systematic error components have been handled similar to statistical components.**

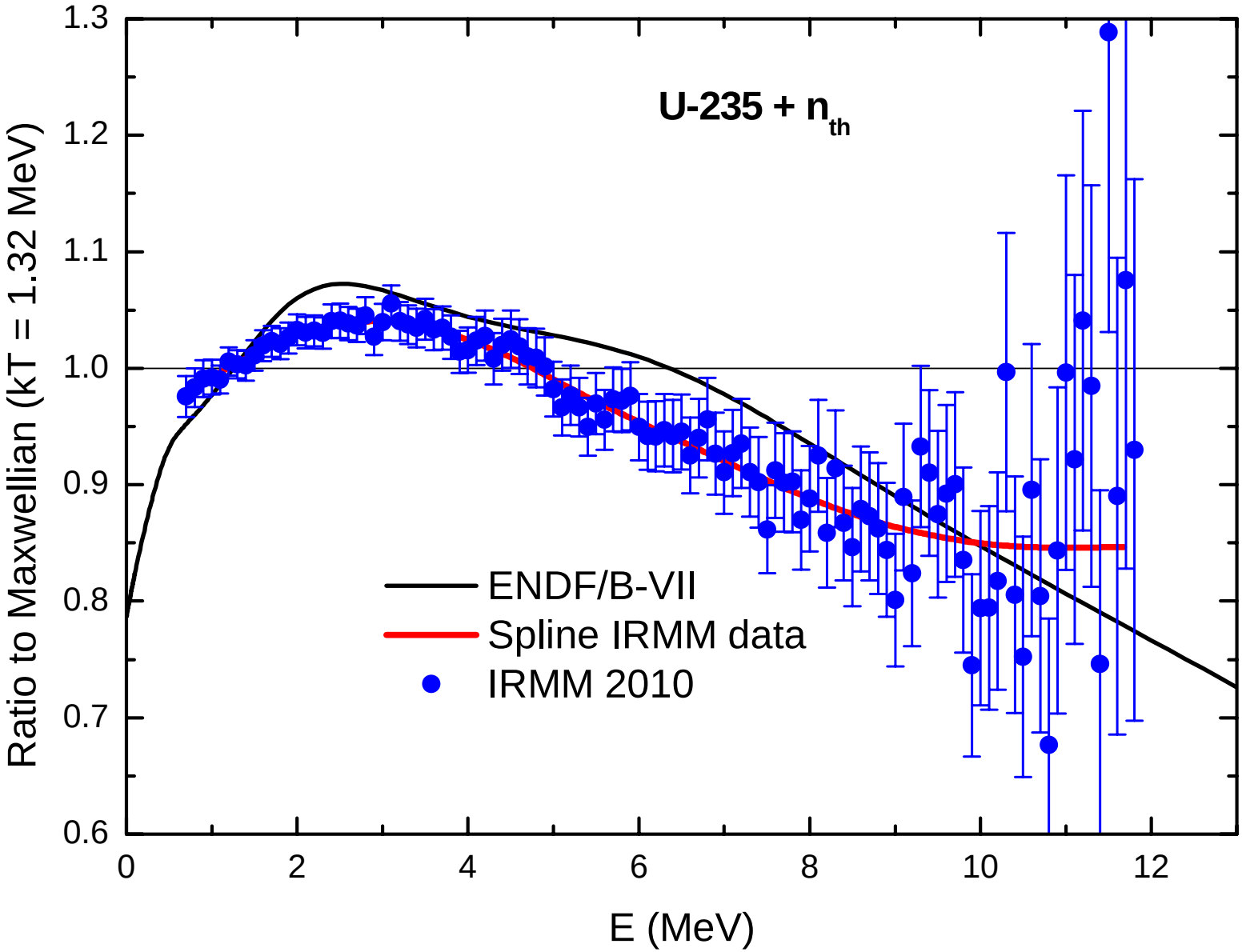

U-235 + n th
ENDF/B-VII
GMA (05/2010) with errors
Lajtai 85
Bojcov 83
Nevedov 83 (ratio, 40871.011)
IRMM 2010
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0,02
0.1
1
2

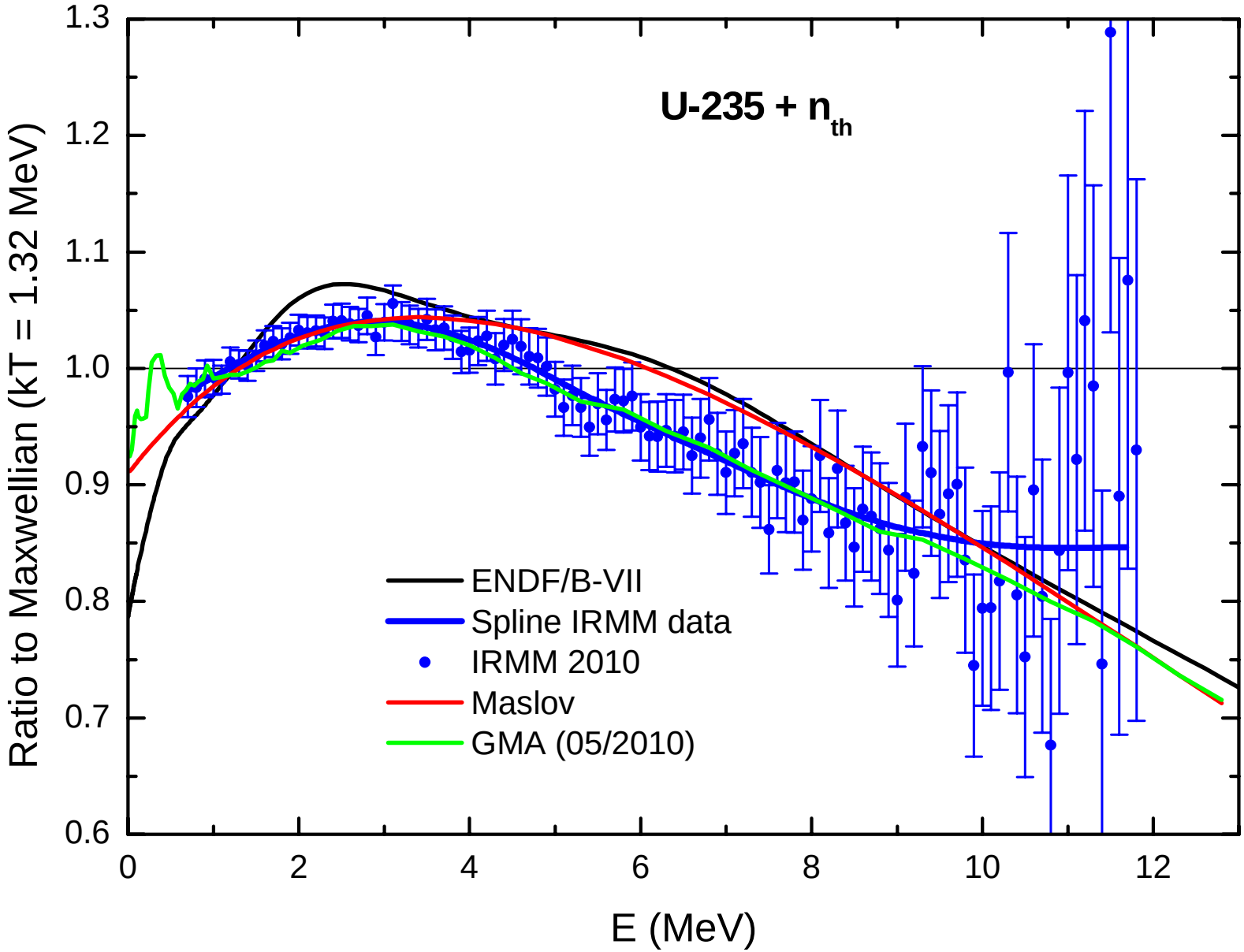

U-235 + n th
ENDF/B-VII
Spline IRMM data
IRMM 2010
Nevedov 83 (ratio, 40871.011)
Lajtai 85
Bojcov 83
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0,02
0.1
1
2

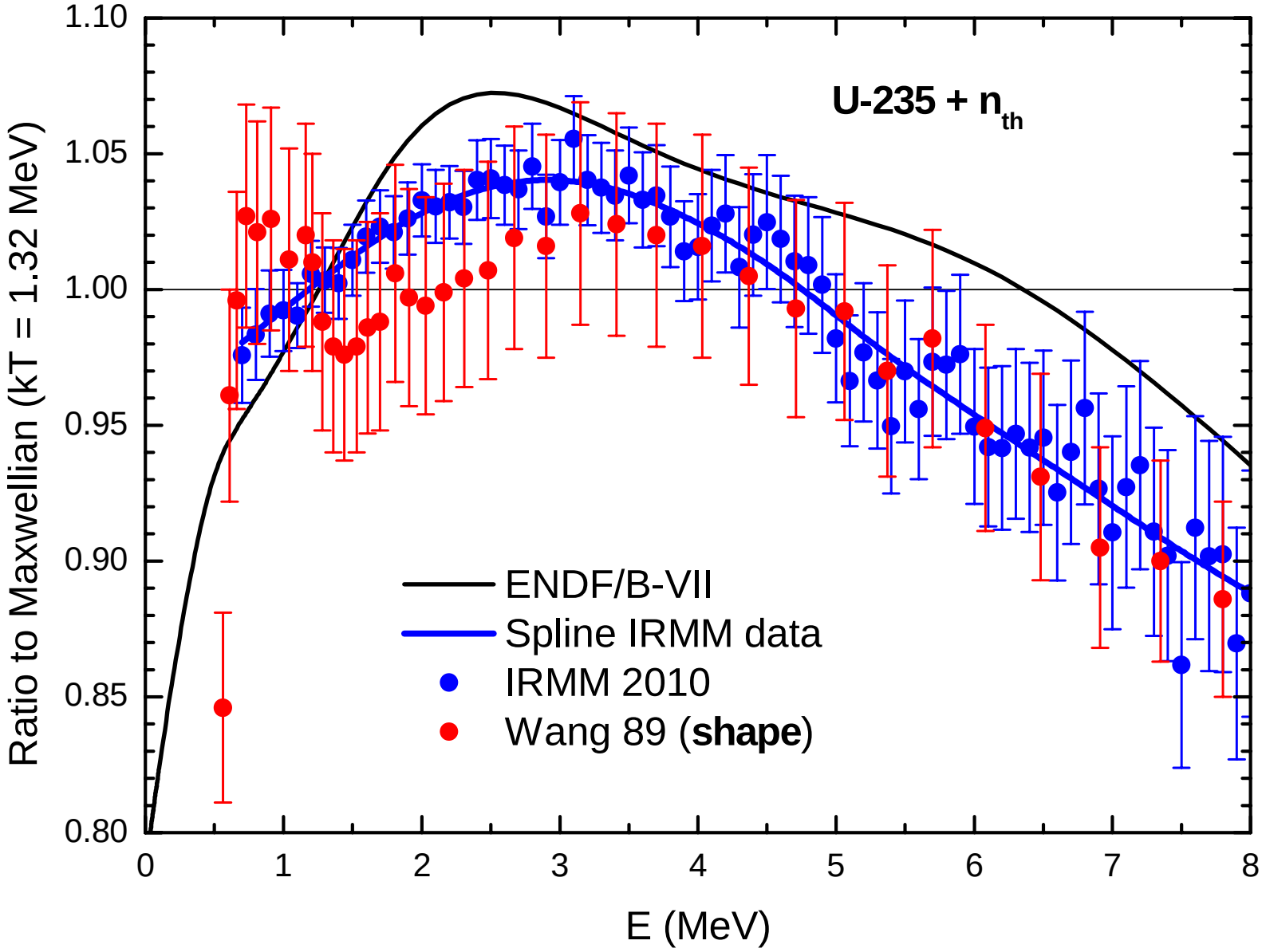

U-235 + n th
ENDF/B-VII
GMA (05/2010)
IRMM 2010
Nevedov 83 (ratio, 40871.011)
Lajtai 85
Bojcov 83
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0,02
0.1
1
2

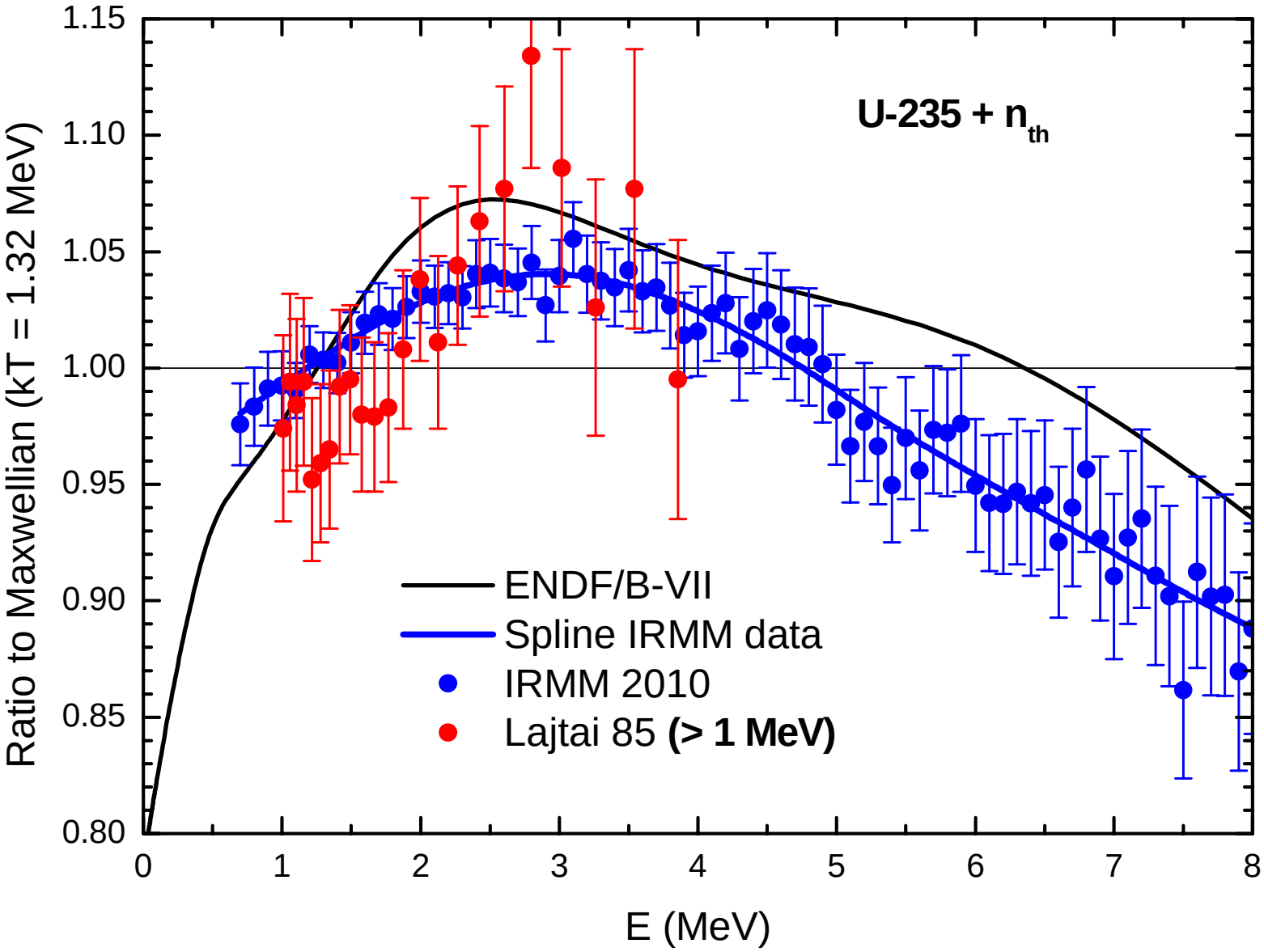
Experimental data sets

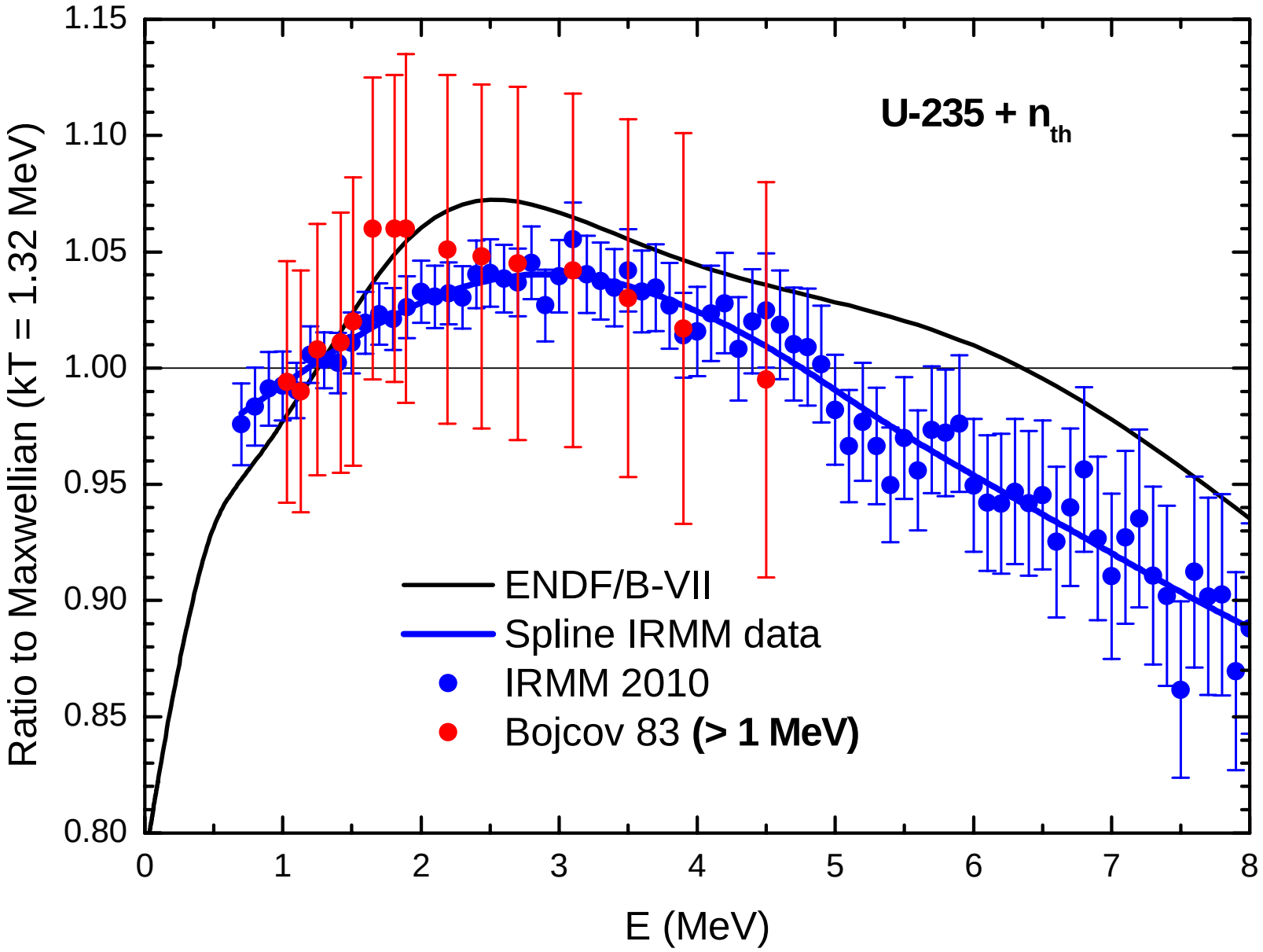
Experiment/ EXFOR	TOF (cm)	E-Range in MeV	Neutron detector	Data given	Reference	Reference used	Errors given
Bojcov 83 40873.004	≤ 40	0.012 – **2.0**(4.5)	U-235(n,f)	**relative to kT=1.296**	**Cf-252**	kT=1.418	total
Lajtai 85 30704.003	30	0.030 – **2.0**(3.9)	Li-glass	**n(E)**	**Cf-252**	kT=1.42	total **not ε_n(E)**
IRMM 2010	300	0.7 – 11.8	NE213 equiv.	**n(E)**	**Cf-252**	Eval.	total
Wang 89 32587.002	317	0.6 – 13.8(15.4)	liquid scint.	**shape**	-----	-----	only stat.
Nevedov 83 40871.011	51	0.084 – 0.91	antracen	**ratio Cf-252/U-235**	-----	-----	only stat.
Nevedov 83 40871.012	231	1.01 – 7.84	stilbene	**ratio Cf-252/U-235**	-----	-----	only stat.
Starostov 83 40872.007	611	4.12 – 12.1	plastic detector	**ratio Cf-252/U-235**	-----	-----	only stat.
Vorobyev 2010 data ???	50	0.2 – **2.0**(13.5)	stilbene	**ratio Cf-252/U-235**	-----	-----	only stat.


U-235 + n th
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
ENDF/B-VII
Spline IRMM data
IRMM 2010
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0
2
4
6
8
10
12


U-235 + n th
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
ENDF/B-VII
Spline IRMM data
IRMM 2010
Maslov
GMA (05/2010)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0
2
4
6
8
10
12


U-235 + n_th
ENDF/B-VII
Spline IRMM data
IRMM 2010
Wang 89 (shape)
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0
1
2
3
4
5
6
7
8

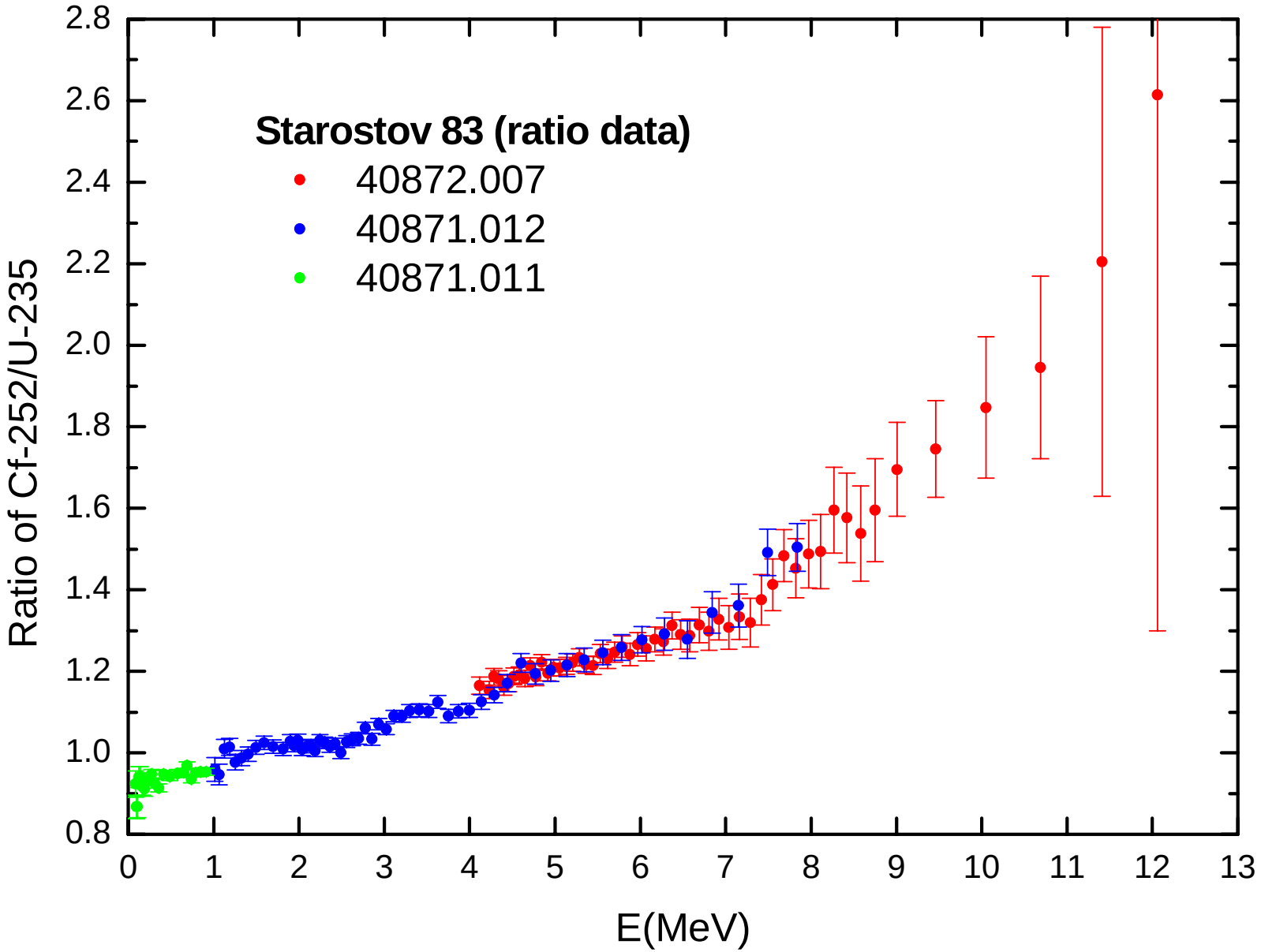

U-235 + n th
ENDF/B-VII
Spline IRMM data
IRMM 2010
Lajtai 85 (> 1 MeV)
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0
1
2
3
4
5
6
7
8

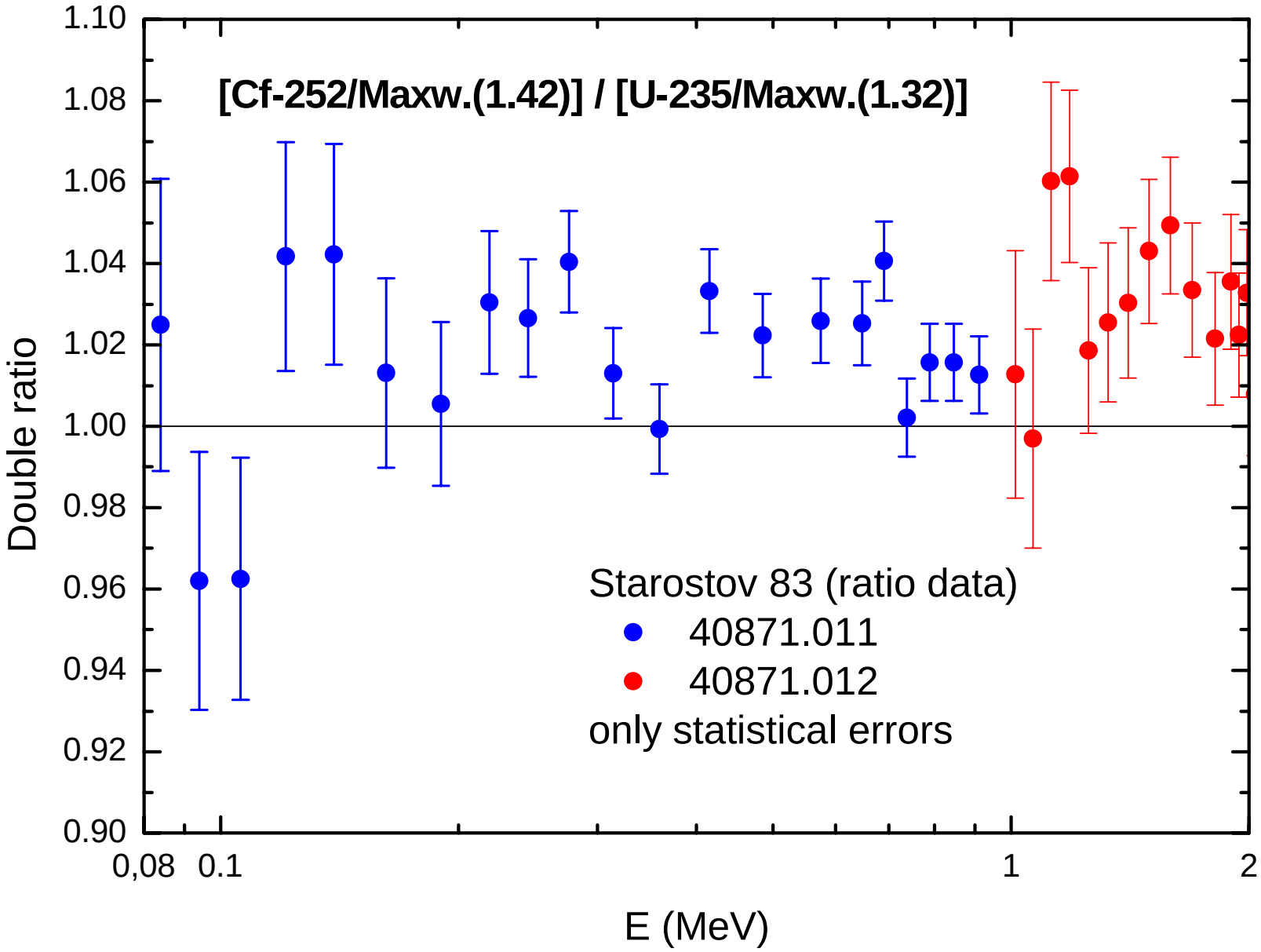

U-235 + n th
ENDF/B-VII
Spline IRMM data
IRMM 2010
Bojcov 83 (> 1 MeV)
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0
1
2
3
4
5
6
7
8

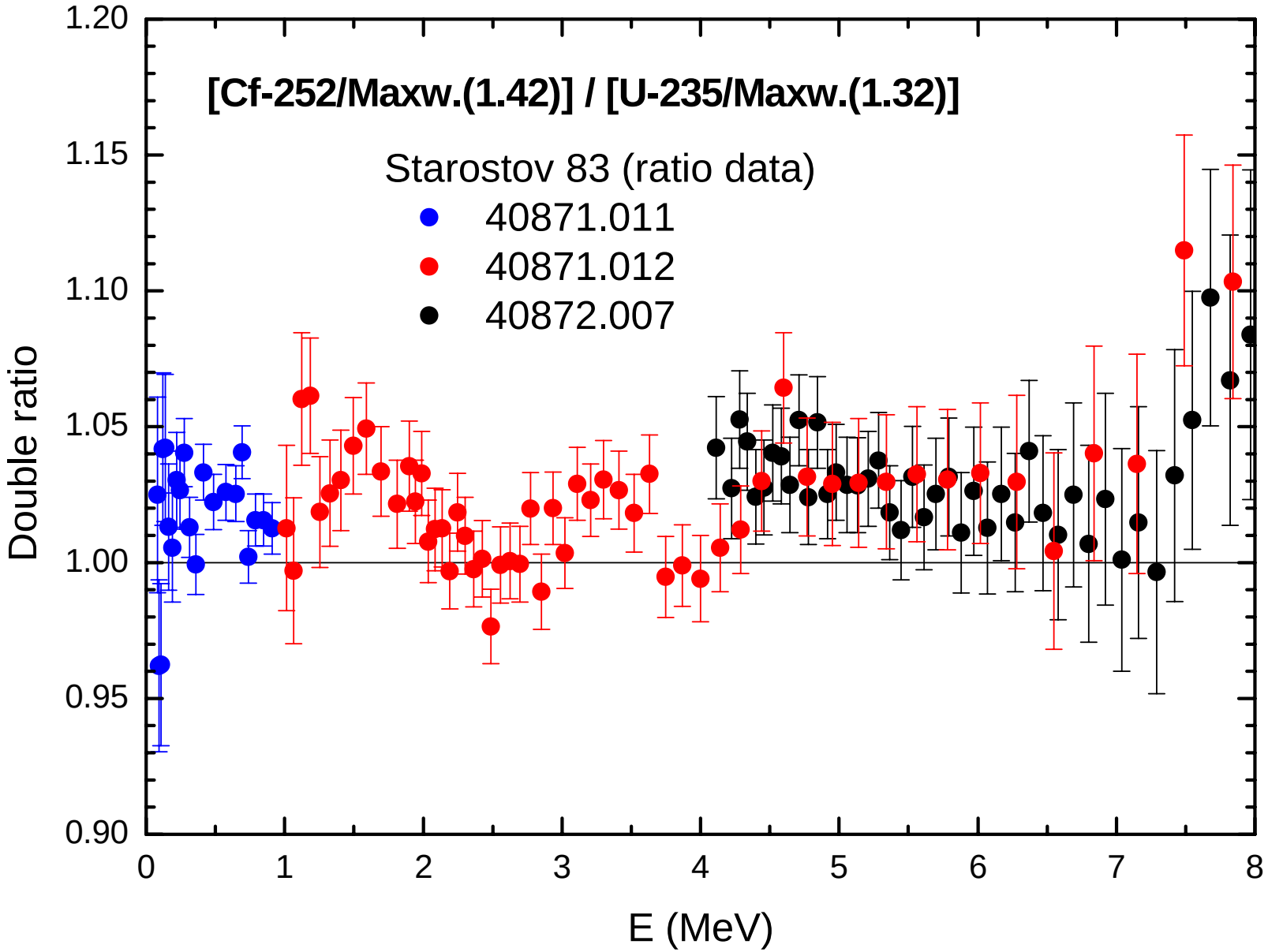
Details of the ratio measurements

and the question:

Do we really have an absolute measurement of the U-235 spectrum?


Starostov 83 (ratio data)
40872.007
40871.012
40871.011
Ratio of Cf-252/U-235
E(MeV)
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0
1
2
3
4
5
6
7
8
9
10
11
12
13


[Cf-252/Maxw.(1.42)] / [U-235/Maxw.(1.32)]
Double ratio
E (MeV)
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
0,08
0.1
1
2
Starostov 83 (ratio data)
40871.011
40871.012
only statistical errors


[Cf-252/Maxw.(1.42)] / [U-235/Maxw.(1.32)]
Starostov 83 (ratio data)
40871.011
40871.012
40872.007
Double ratio
E (MeV)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0
1
2
3
4
5
6
7
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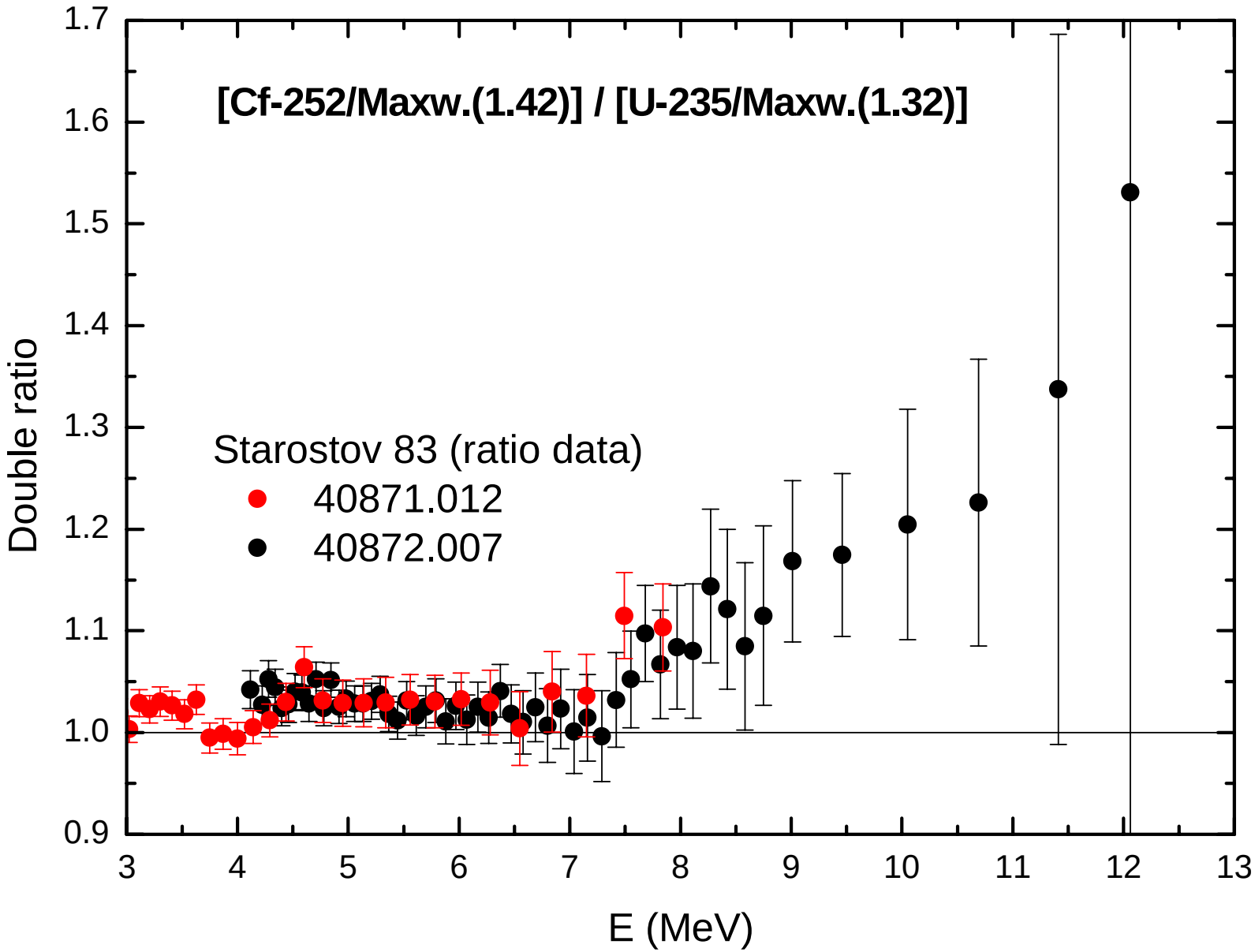
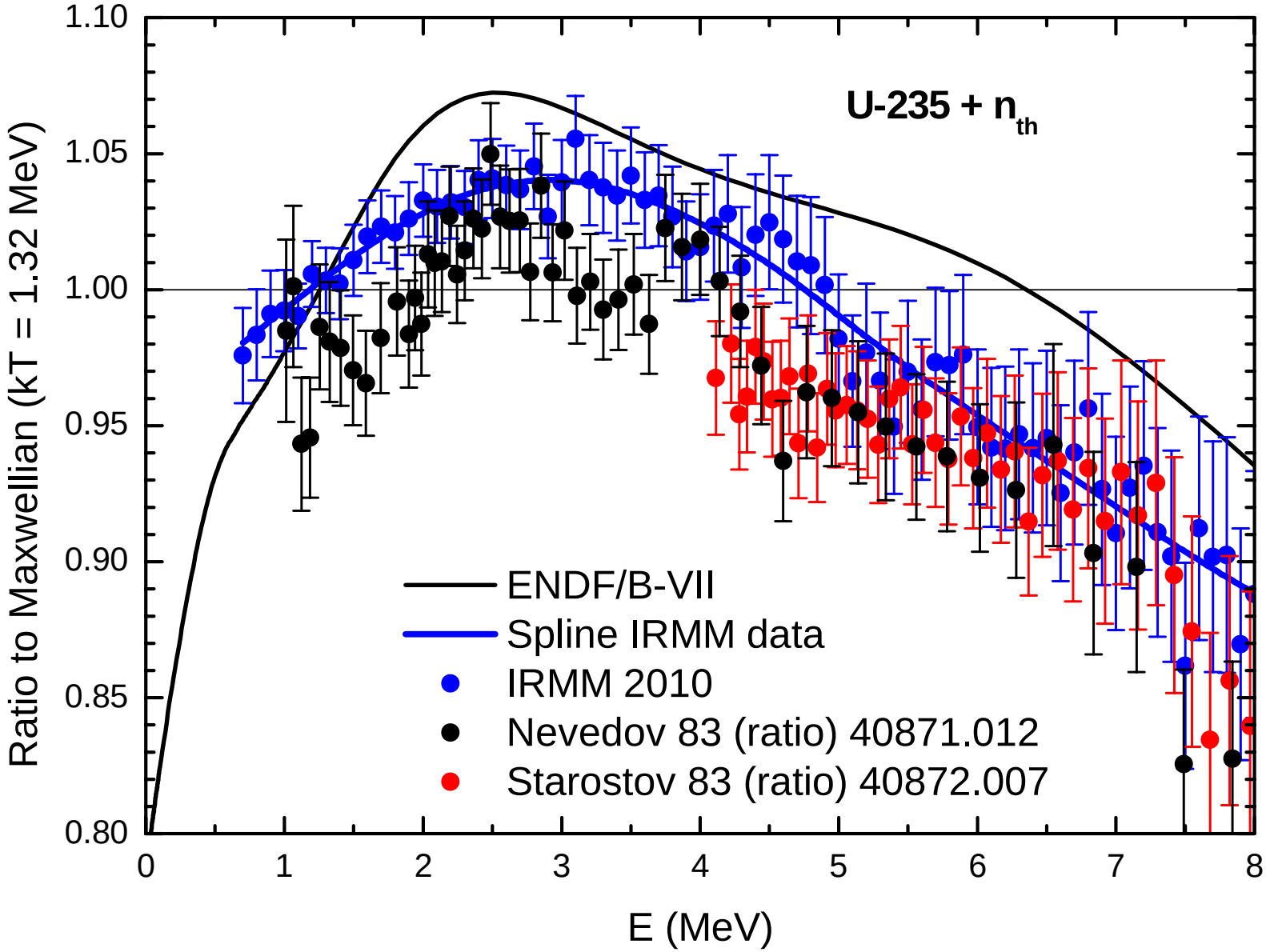
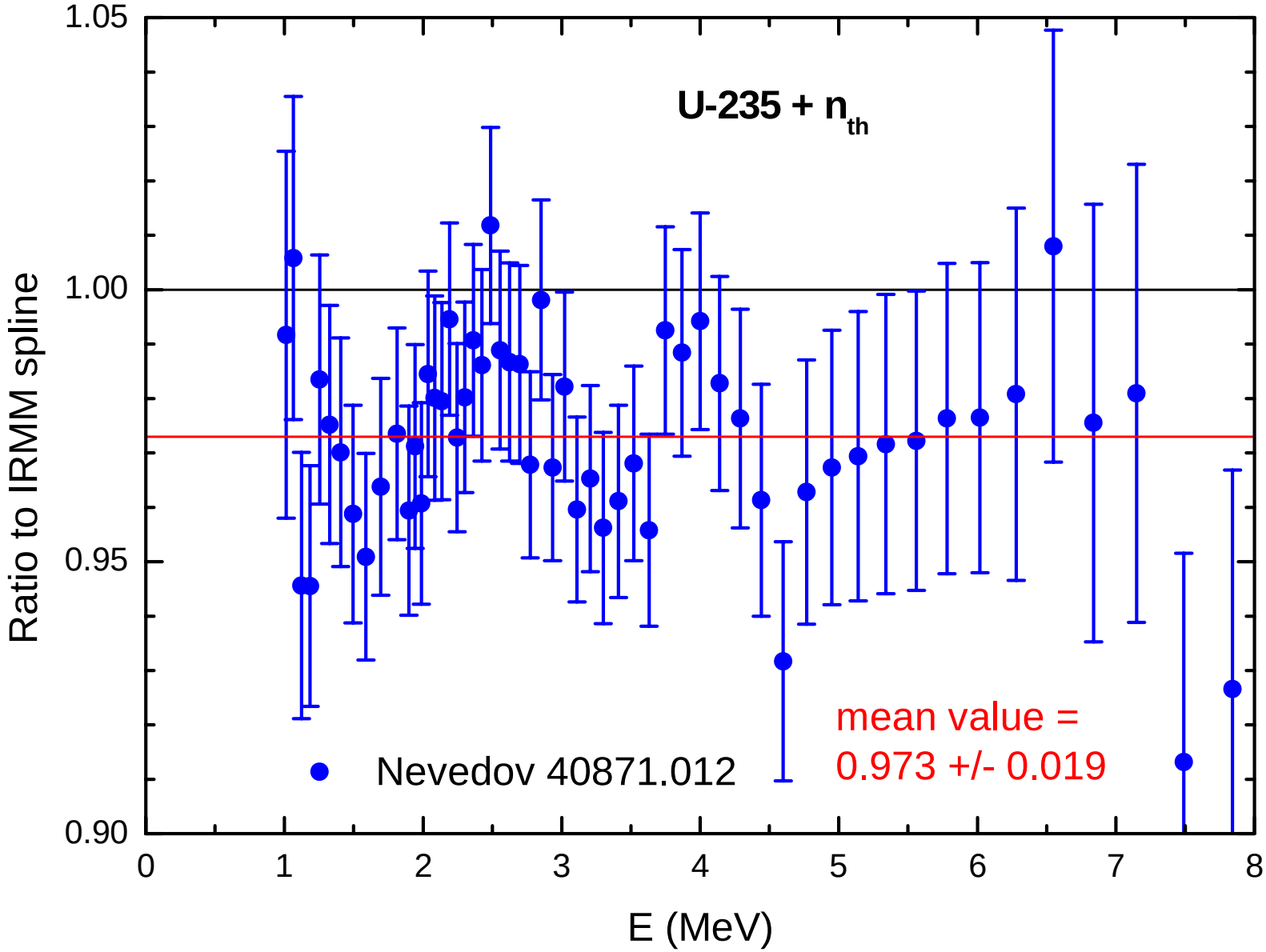
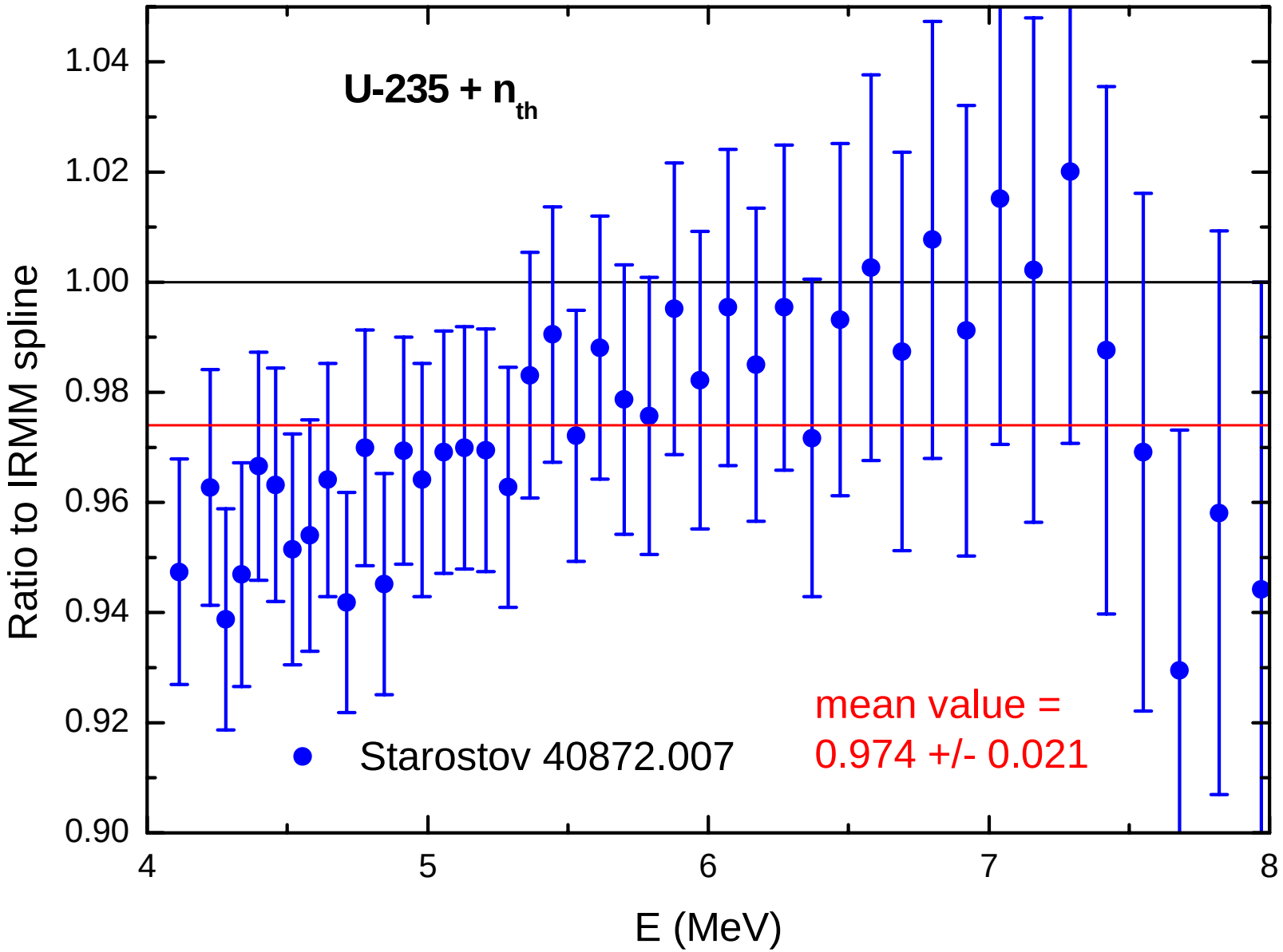

[Cf-252/Maxw.(1.42)] / [U-235/Maxw.(1.32)]
Starostov 83 (ratio data)
40871.012
40872.007
Double ratio
E (MeV)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
3
4
5
6
7
8
9
10
11
12
13


U-235 + n th
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0
1
2
3
4
5
6
7
8
ENDF/B-VII
Spline IRMM data
IRMM 2010
Nevedov 83 (ratio) 40871.012
Starostov 83 (ratio) 40872.007


U-235 + n th
Ratio to IRMM spline
E (MeV)
1.05
1.00
0.95
0.90
0
1
2
3
4
5
6
7
8
Nevedov 40871.012
mean value =
0.973 +/- 0.019


U-235 + n th
Ratio to IRMM spline
E (MeV)
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
4
5
6
7
8
Starostov 40872.007
mean value =
0.974 +/- 0.021

Coincidence between neutrons and fission fragments

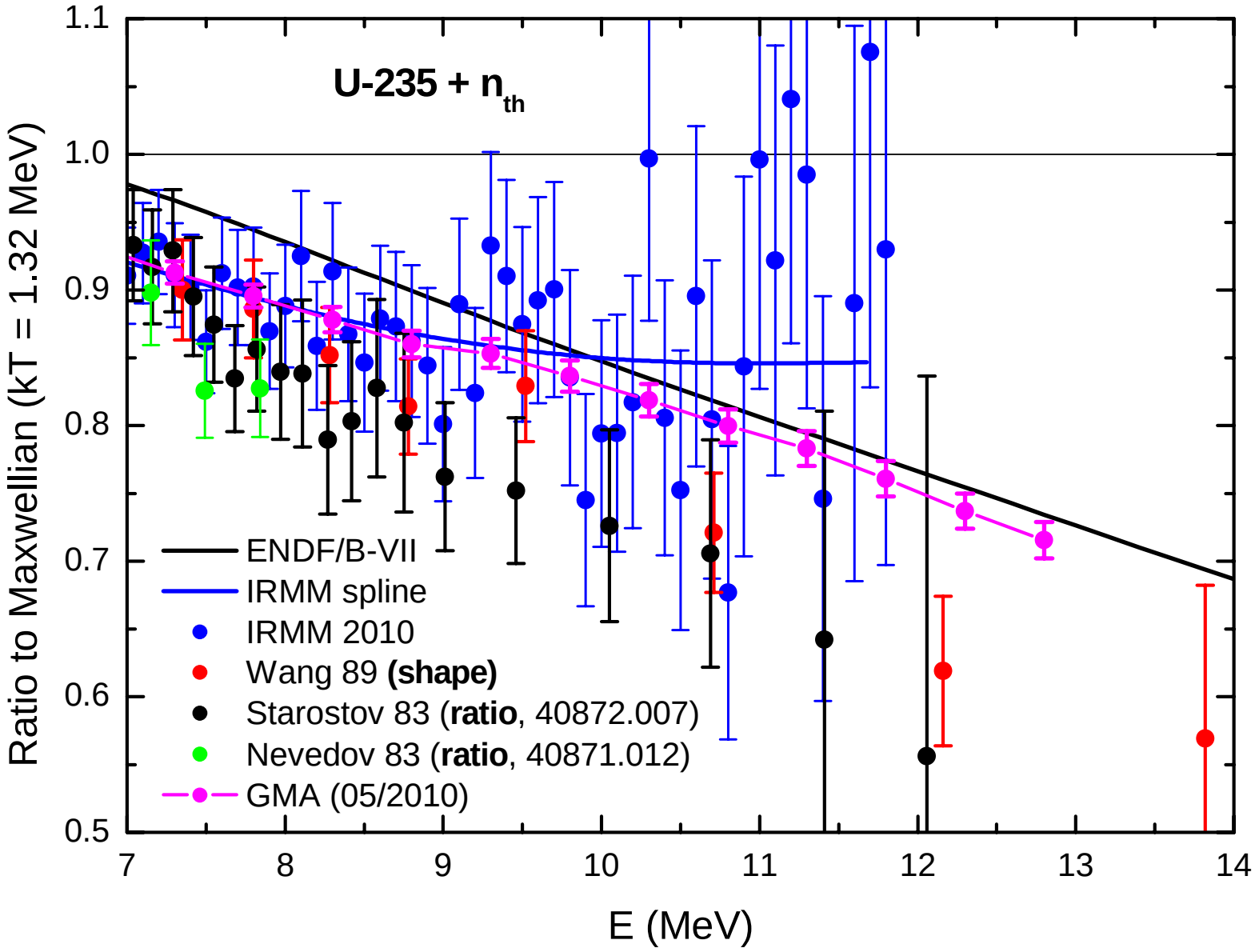
$$n(E) = \frac{|\partial t / \partial E|\, n(t)\, C(E,\Omega)}{\bar{\nu}\,(N_f / \varepsilon_f)\,(\Omega / 4\pi)\,\varepsilon_n(E)}$$

- **Due to the coincidence between the measured fission fragments and the time distribution of the neutrons the measured data of n(E) are already normalized quantities. Deviations from a perfect normalization originate from the accuracy of the efficiency values and the corrections used in the experiment. Realistic errors of the experimental data reflect such deviations.**

- **The fact that the result (the parameters) of the evaluation is normalized does not justify the (hidden) normalization of the individual data sets. Such normalization is identical with the assumption that the experimental data only correspond to shape measurements.**

Efficiency of the fission fragment detector (ε_f)

Experiment	U-235	Cf-252	Reference
	ε_f	ε_f	
Bojcov 83	**~ 0.95**	**~ 0.95**	Kiev 83, Vol.2 (1983) p.294
Lajtai 85	**?**	**?**	Santa Fe 85, Vol.1 (1985) p.613
IRMM 2010	**0.98**	**0.98 ± 0.01**	NSE 165 (2010) p.117
Wang 89	**?**	**?**	CNP 11 (1989) p.47
Nevedov 83	**0.95 ± 0.02**	**0.98 ± 0.02**	Kiev 83, Vol.2 (1983) p.285
Starostov 83	**0.95 ± 0.02**	**0.98 ± 0.02**	Kiev 83, Vol.2 (1983) p.290
Starostov 85	**0.98**	**0.99**	**YK 1985, no.3 (1985) p.16** numerical data only given for Cf-252
Vorobyev 2010	**?**	**?**	???


U-235 + n th
Ratio to Maxwellian (kT = 1.32 MeV)
E (MeV)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
7
8
9
10
11
12
13
14
ENDF/B-VII
IRMM spline
IRMM 2010
Wang 89 (shape)
Starostov 83 (ratio, 40872.007)
Nevedov 83 (ratio, 40871.012)
GMA (05/2010)

Bojcov 83 as a possible absolute measurement ?

positive **Use of the well-known cross section of U-235(n,f)**

negative **TOF of ≤ 40 cm limits the upper neutron energy to about 2 MeV (accuracy of the energy scale)**

Facts: **The experiment is a new analysis of an old experiment performed in 1978**

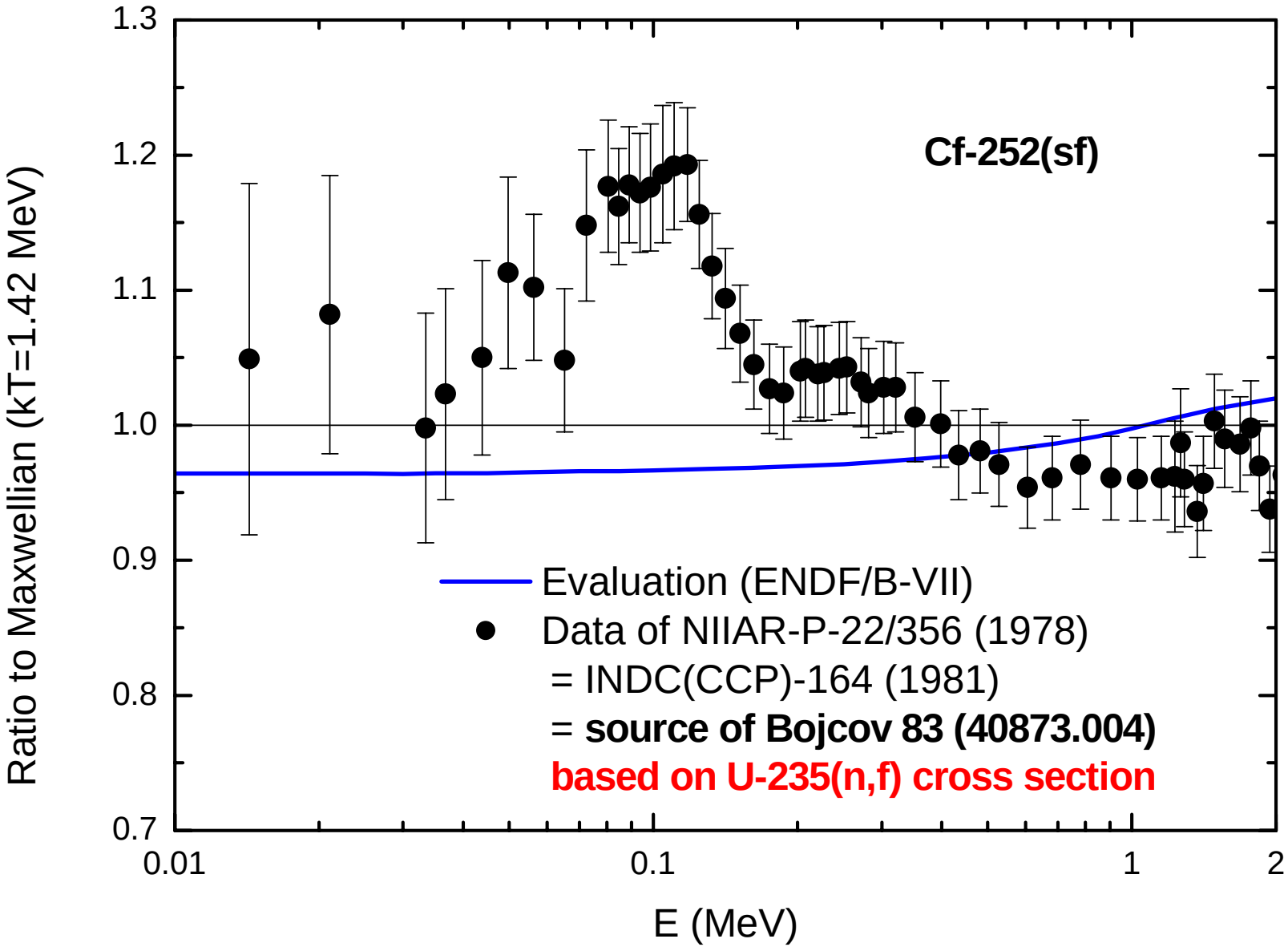
The original data are given in the report NIIAR-P-22/356 (1978)

A translation of NIIAR-P-22/356 (1978) is given in the report INDC(CCP)-164 (1981)

critical **The status of the U-235(n,f) cross section used is that of the year 1975.**

The errors of Bojcov 83 are:

E(MeV)	Error in %
0.021	20.0
0.35	4.1 (min)
2.0	7.1
4.5	8.5


Cf-252(sf)
Ratio to Maxwellian (kT=1.42 MeV)
E (MeV)
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.01
0.1
1
2
Evaluation (ENDF/B-VII)
Data of NIIAR-P-22/356 (1978)
= INDC(CCP)-164 (1981)
= source of Bojcov 83 (40873.004)
based on U-235(n,f) cross section

- **The experiment Bojcov 83 is based on data given in the report NIIAR-P-22/356 (1978). The data were measured by using the U-235(n,f) cross section as neutron monitor. The original data of the measured spectral distributions of Cf-252 and U-235 show a quite unexpected structural behavior which can only originate from the numerical data used for the monitor cross section. It is questionable if the data can be renormalized to the present knowledge of the U-235(n,f) cross section.**

- **If the experiment of Bojcov 83 cannot be used as an absolute measurement of the U-235 neutron spectrum, the remaining database of the U-235 neutron spectrum comprises only ratio data (Cf-252/U-235) and a single shape measurement. In this case the new U-235 evaluation completely relates to the existing Cf-252 evaluation (probably the most realistic result).**

GMA result of the Cf-252 neutron spectrum

- **The GMA evaluation comprises the simultaneous evaluation of the Cf-252 neutron spectrum.**

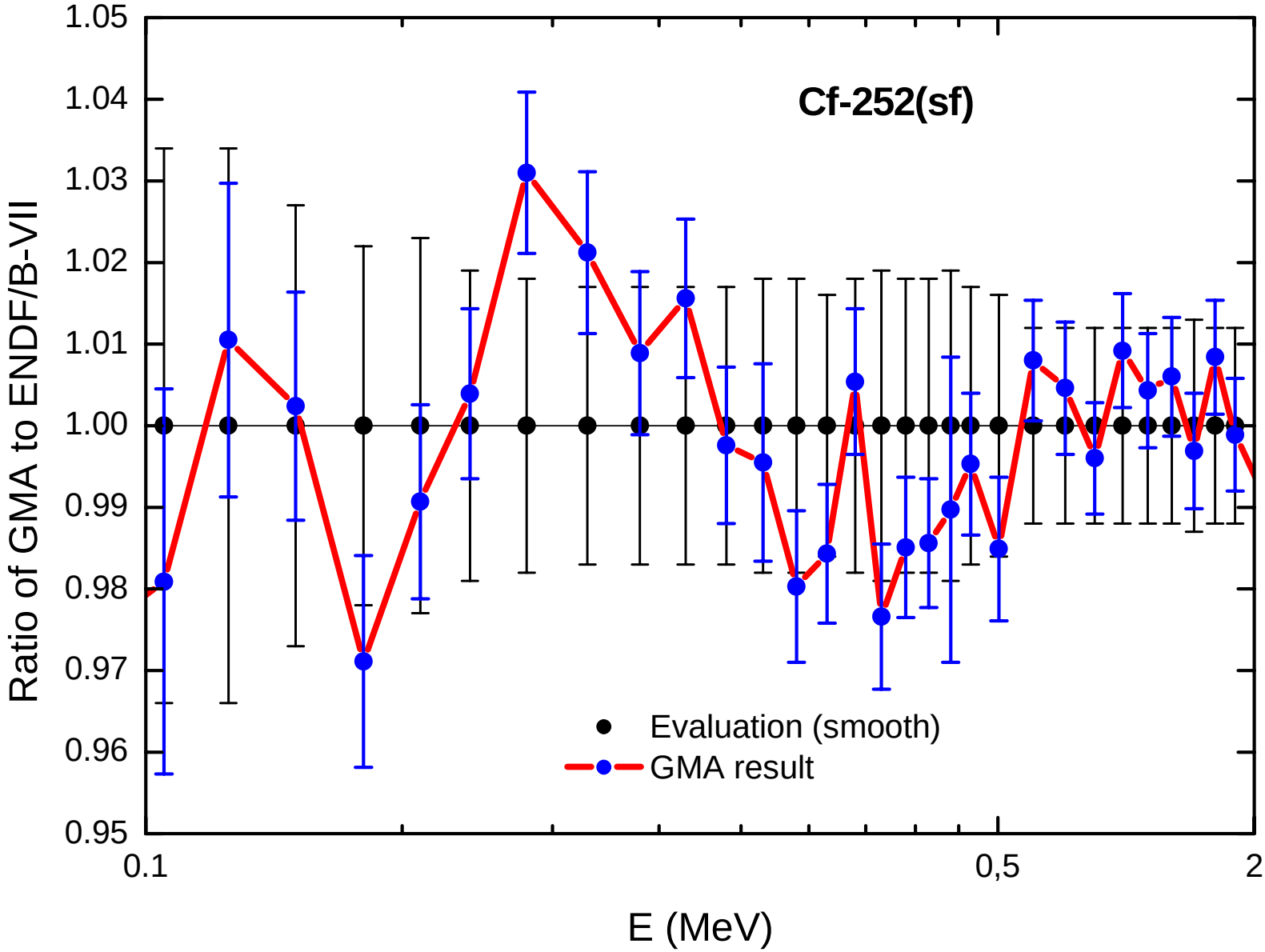
- **The result of the GMA evaluation of the Cf-252 neutron spectrum and especially the given errors are a joke.**

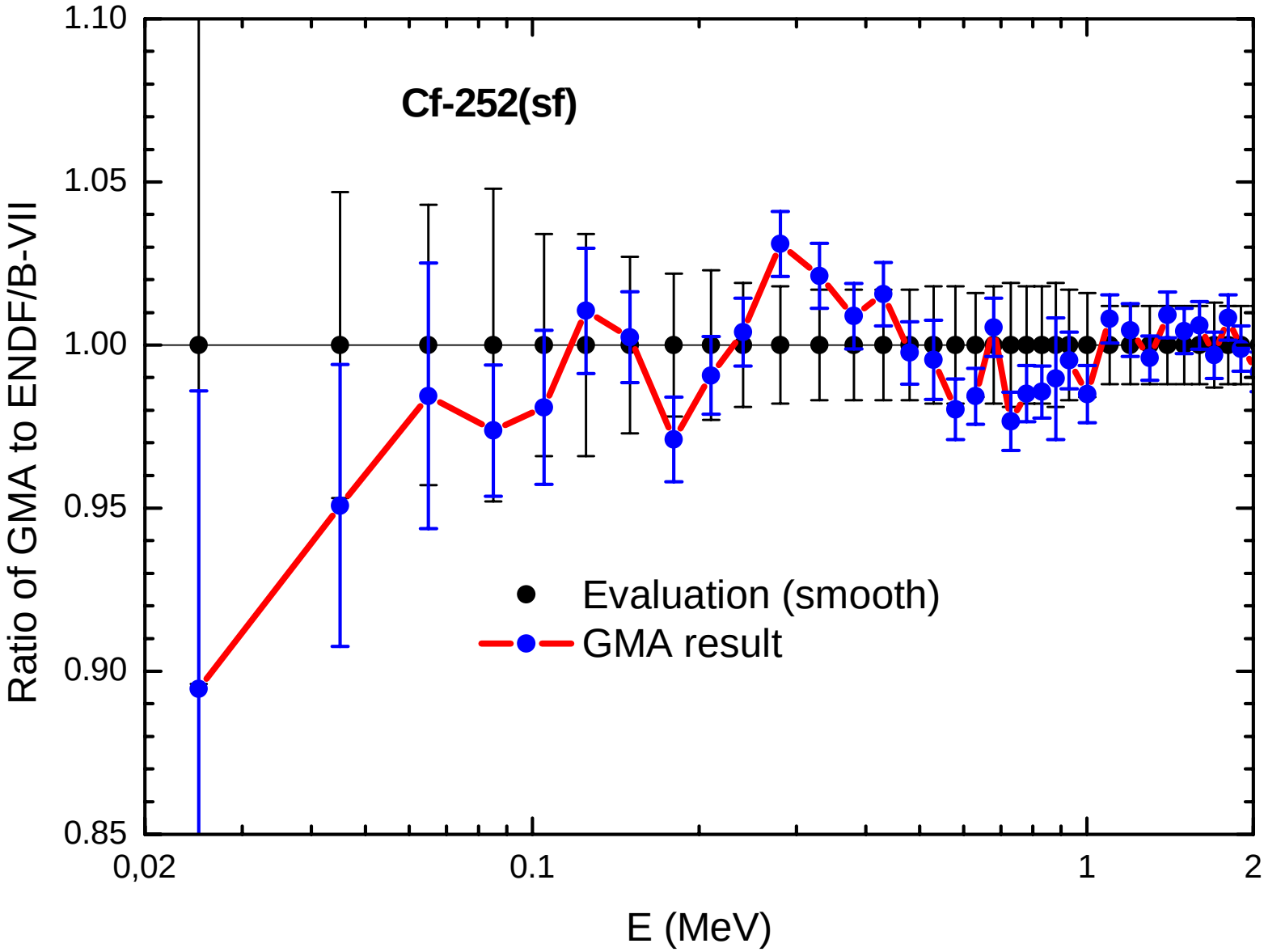
- **Based on a questionable ‘absolute’ evaluation of the U-235 spectrum, the ratio measurements were exclusively used to adjust the Cf-252 neutron spectrum.**

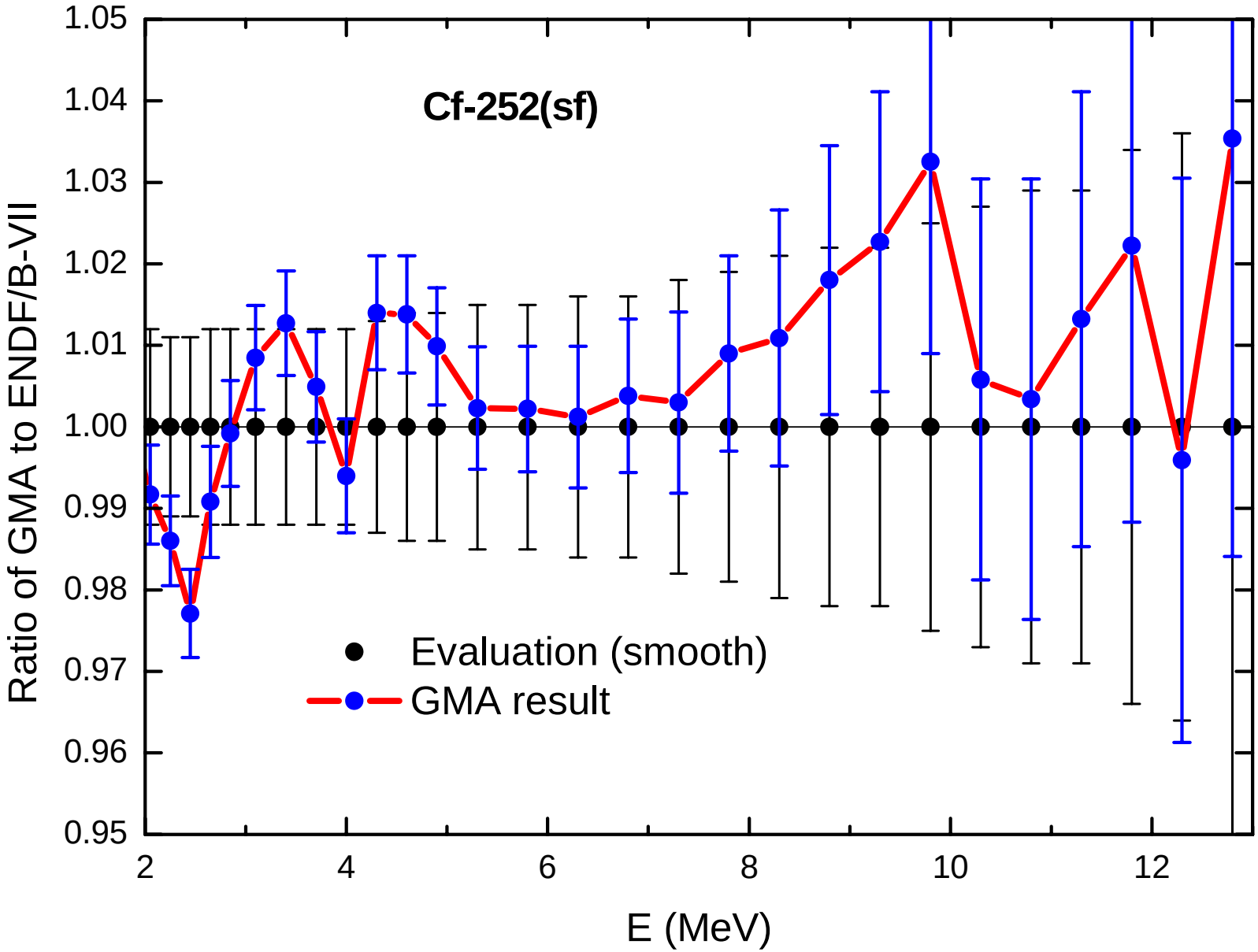
- **A careful analysis of the database shows that all available measurements of the U-235 neutron spectrum were performed relative to the Cf-252 neutron spectrum. Any modification of the Cf-252 standard, used in the experiments as reference, is therefore highly speculative.**

Comparison of representative errors between 25 keV and 12.8 MeV

	U-235	Cf-252	Cf-252
Neutron energy	GMA	EVAL	GMA
E(MeV)	error in %	error in %	error in %
0.025	2.0 (max)	10.4 (max)	10.2 (max)
0.125	1.4	3.4	1.9
1.0	0.8	1.6	0.9
2.25	0.5 (min)	1.1 (min)	0.6 (min)
10.0	1.4	2.5	2.4
12.8	1.8	5.0	5.0
in the range			
1.0 – 6.3	≤ 0.8	≤ 1.6	≤ 0.9


Cf-252(sf)
Ratio of GMA to ENDF/B-VII
E (MeV)
Evaluation (smooth)
GMA result
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.95
0.1
0,5
2


Cf-252(sf)
Ratio of GMA to ENDF/B-VII
E (MeV)
1.10
1.05
1.00
0.95
0.90
0.85
0,02
0.1
1
2
Evaluation (smooth)
GMA result


Cf-252(sf)
Ratio of GMA to ENDF/B-VII
E (MeV)
Evaluation (smooth)
GMA result
1.05
1.04
1.03
1.02
1.01
1.00
0.99
0.98
0.97
0.96
0.95
2
4
6
8
10
12

Summary

- **The EXFOR entries comprise besides the numerical data also details of the measurement process. In the input of the present GMA evaluation the experimental procedure was partially ignored and the data were classified in a wrong way (absolute or ratio measurements?).**
- **It is inconsistent to use the data errors in the least-squares process and to ignore the errors at the same time in the spectrum normalization.**
- **The reduction of the data errors by a factor of two, compared with previous evaluations, is a drastic step and needs urgently a careful verification.**
- **It seems that even thirty years after the introduction of the covariance concept into the nuclear data business the general understanding of the data covariances remained underdeveloped.**
- **The mentioned inconsistencies in the GMA evaluation will also influence the result of the simultaneously evaluated spectra of U-233 and Pu-239.**