Status of inelastic scattering cross section measurements for ^{238}U, ^{56}Fe and ^{23}Na

Arjan Plompen

Overview

- *HPRL entries for inelastic scattering*
- *Performed experiments*
- *Ongoing work*

$^{238}U(n,n')$

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www.nea.fr/html/dbdata/hprl/

NEA Nuclear Data High Priority Request List

Req.ID	View	Target	Reaction	Quantity
G 1		14-SI-28	(n,np)	SIG

Request ID	18		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
92-U-238	(n,inl) SIG	65 keV-20 MeV	Emis spec.	See details	Y
Field	Subfiel				
Fission	Fast R EFR,SF				

Requests are divided in t

1. High priority reques
2. General requests

Energy Range	Initial versus target uncertainties (%)					
	Initial	ABTR	SFR	EFR	GFR	LFR
6.07-19.6 MeV	29	12			7	
2.23-6.07 MeV	20	3	5	4	2	3
1.35-2.23 MeV	21	4	5	4	2	2
0.498-1.35 MeV	12	7	6	5	2	2
67.4-183 keV	11	7		9	7	4

			,tot)	SIG
			,tot)	SIG
			(n,f)	n spectrum
			(n,f)	n spectrum
			,inl)	SIG
			(n,f)	SIG
			(n,f)	SIG
			(n,f)	SIG
H	25	96-CM-244	(n,f)	SIG

^{56}Fe(n,n')

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NEA Nuclear Data High Priority Request List

Req.ID	View	Target	Reaction	Quantity
G 1		14-SI-28	(n,np)	SIG

Request ID	34		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
26-FE-56	(n,n') SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y
Field	Subfield	Date Request created	Date Request accepted	Ongoing action	
Fission	ADMAB and SFR	04-APR-08	12-SEP-08	Y	

Energy Range	Initial versus target uncertainties (%)												
	Initial	ABTR			SFR			EFR		LFR		ADMAB	
		λ=1	λ≠1,a	λ≠1,b	λ=1	λ≠1,a	λ≠1,b	λ=1	λ≠1,a	λ=1	λ≠1,a	λ=1	λ≠1,a
6.07 - 19.6 MeV	13				9	11	13						
2.23 - 6.07 MeV	7				4	5	7					3	3
1.35 - 2.23 MeV	25	6	7	10	3	4	7	7	7	4	6	2	2
0.498 - 1.35 MeV	16	8	9	13	3	4	6	8	9	4	5	2	2

^{23}Na(n,n')

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www.nea.fr/html/dbdata/hprl/

NEA Nuclear Data High Priority R

Request ID	29		Status of the request	High Priority request	
Target	Reaction and process	Incident Energy	Secondary energy or angle	Target uncertainty	Covariance
11-NA-23	(n,inl) SIG	0.5 MeV-1.3 MeV	Emis spec.	See details	Y
Field	Subfield	Date Request created	Date Request accepted	Ongoing action	
Fission	Fast Reactors (SFR)	04-APR-08	12-SEP-08		

1. High priority r
2. General reque

Energy Range	Target versus initial uncertainties (%)			
	Initial	ABTR	SFR	EFR
1.35 - 2.23 MeV	13		9	
0.498 - 1.35 MeV	28	10	4	8

HPRL summary

- *U-238: 2-6%, 0.5-6 MeV, k-eff*
- *Fe-56: 2-6%, 0.5-6 MeV, k-eff*
- *Na-23: 4-8%, 0.6-6 MeV, Na-void reactivity eff.*

- *All: advanced fast reactors*

- *Cross sections*
- *Angular distribution*
- *Energy spectra*

^{238}U status
NDS, ENDF/B-VII, P. Young, 2007

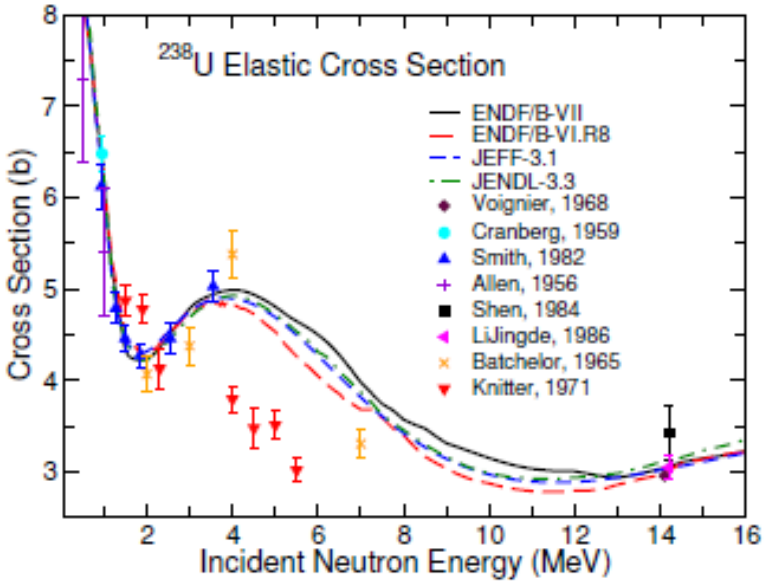


FIG. 79: Measured and evaluated cross section for elastic scattering from 0 to 16 MeV. The inelastic cross section for states up to E_x=0.5 MeV are included.

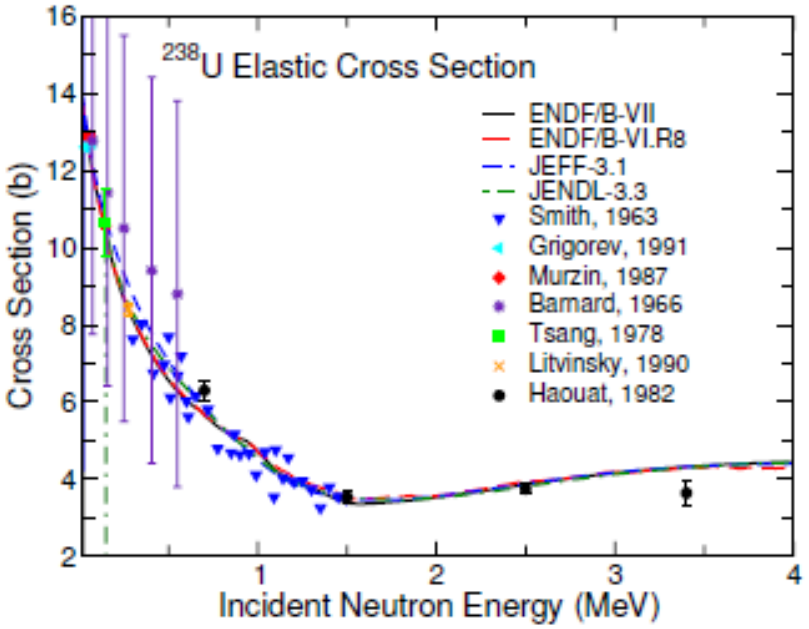
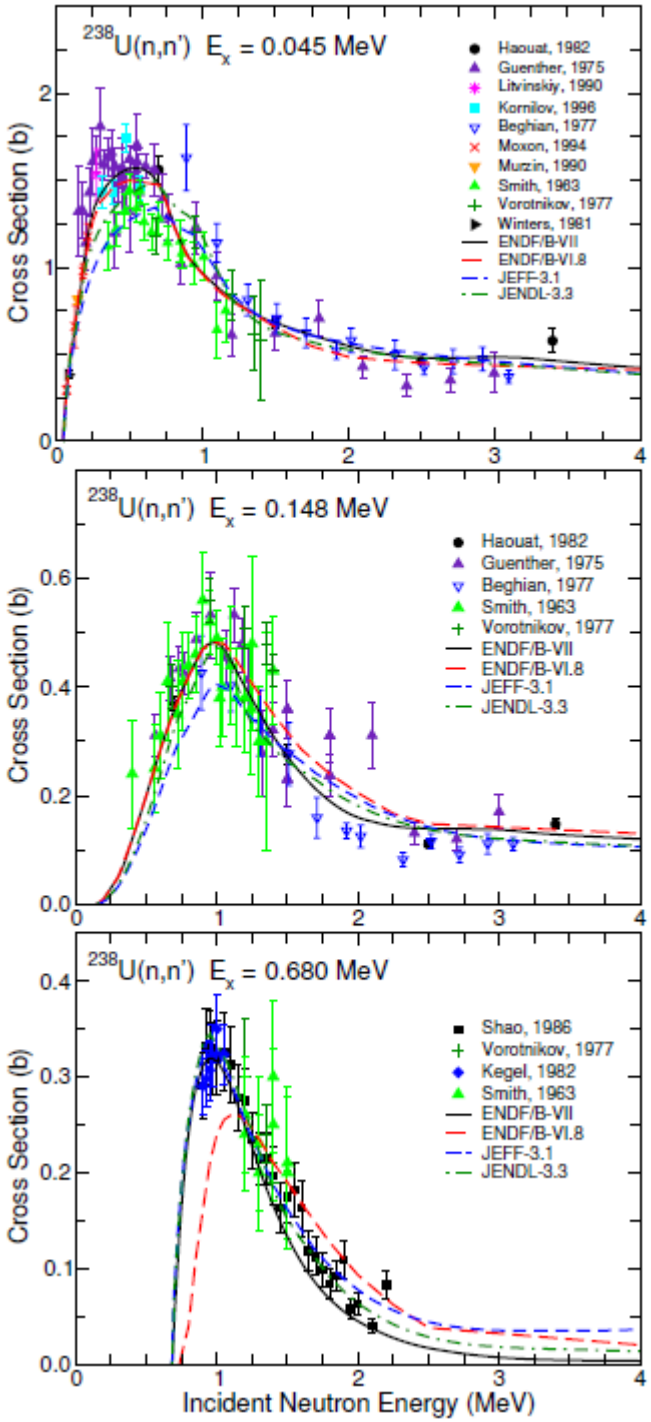


FIG. 78: Measured and evaluated cross section for elastic scattering from 0 to 4 MeV.



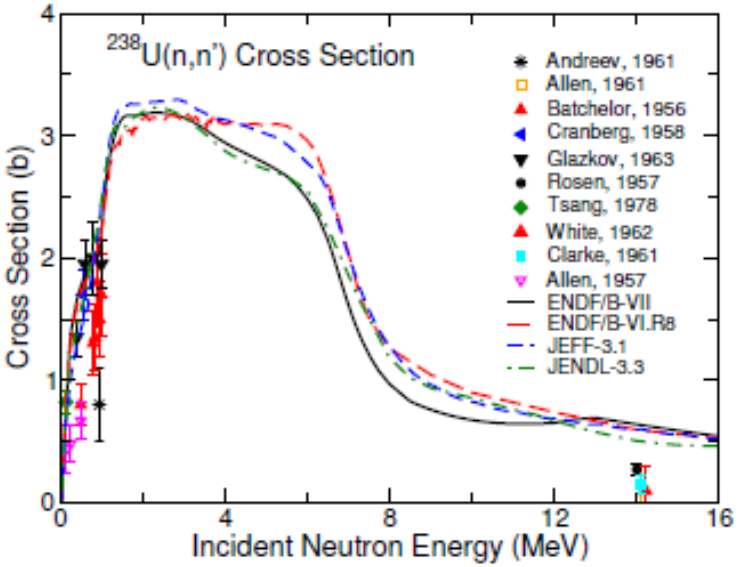


FIG. 83: Evaluated and measured cross sections for the ^{238}U(n,n') reaction for E_n=0-16 MeV.

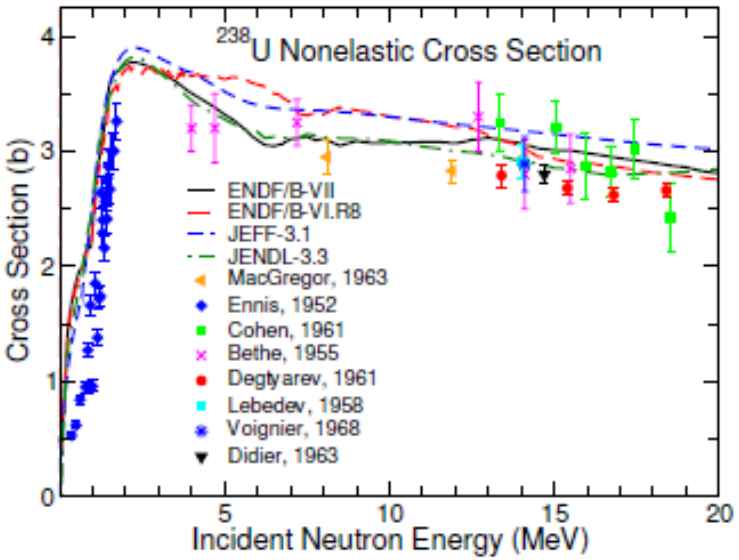
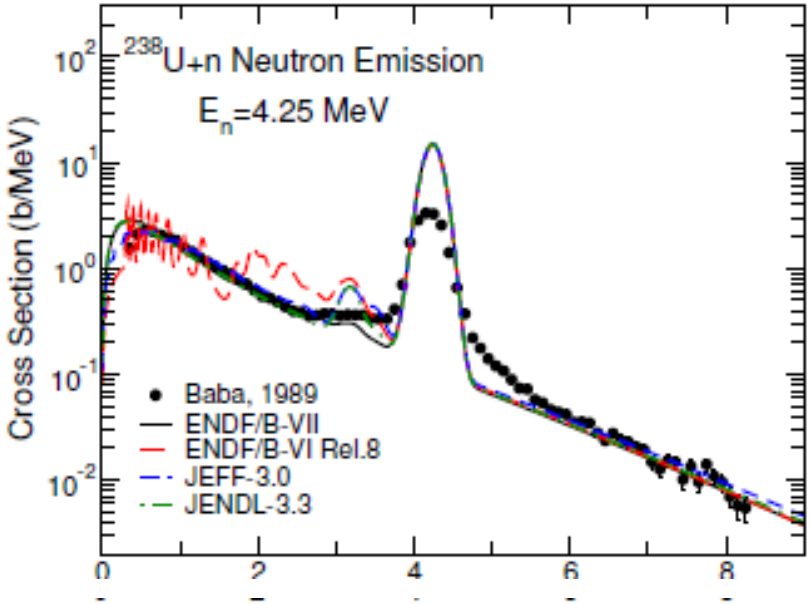


FIG. 84: Evaluated and measured ^{238}U+n nonelastic cross sections for E_n=0-20 MeV.



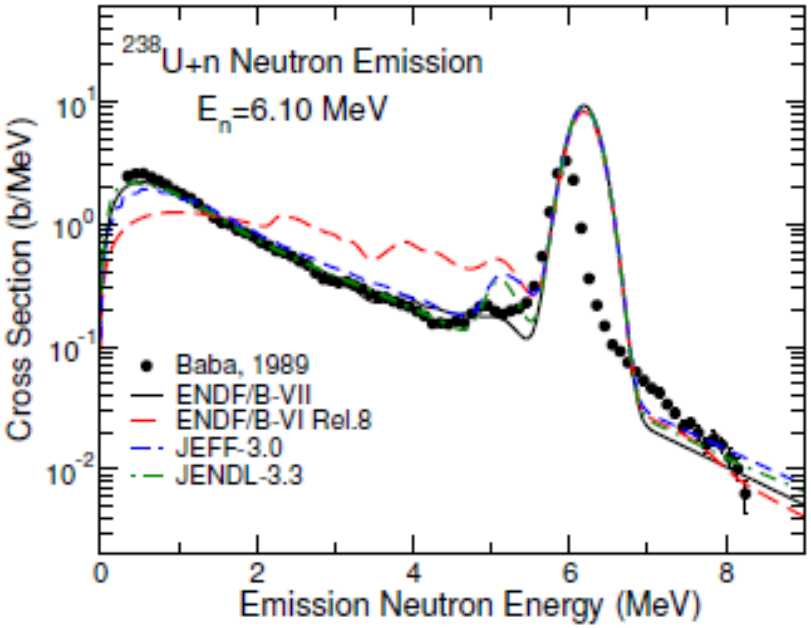
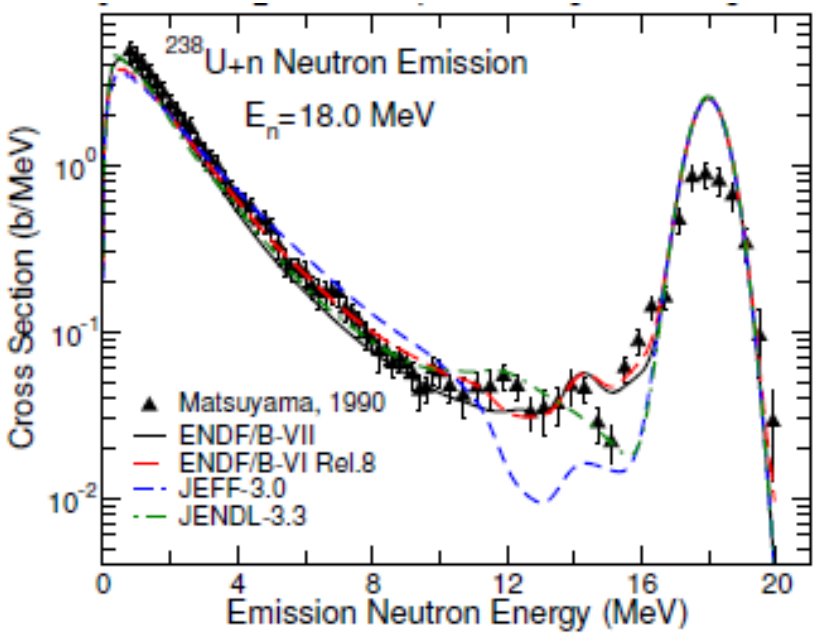
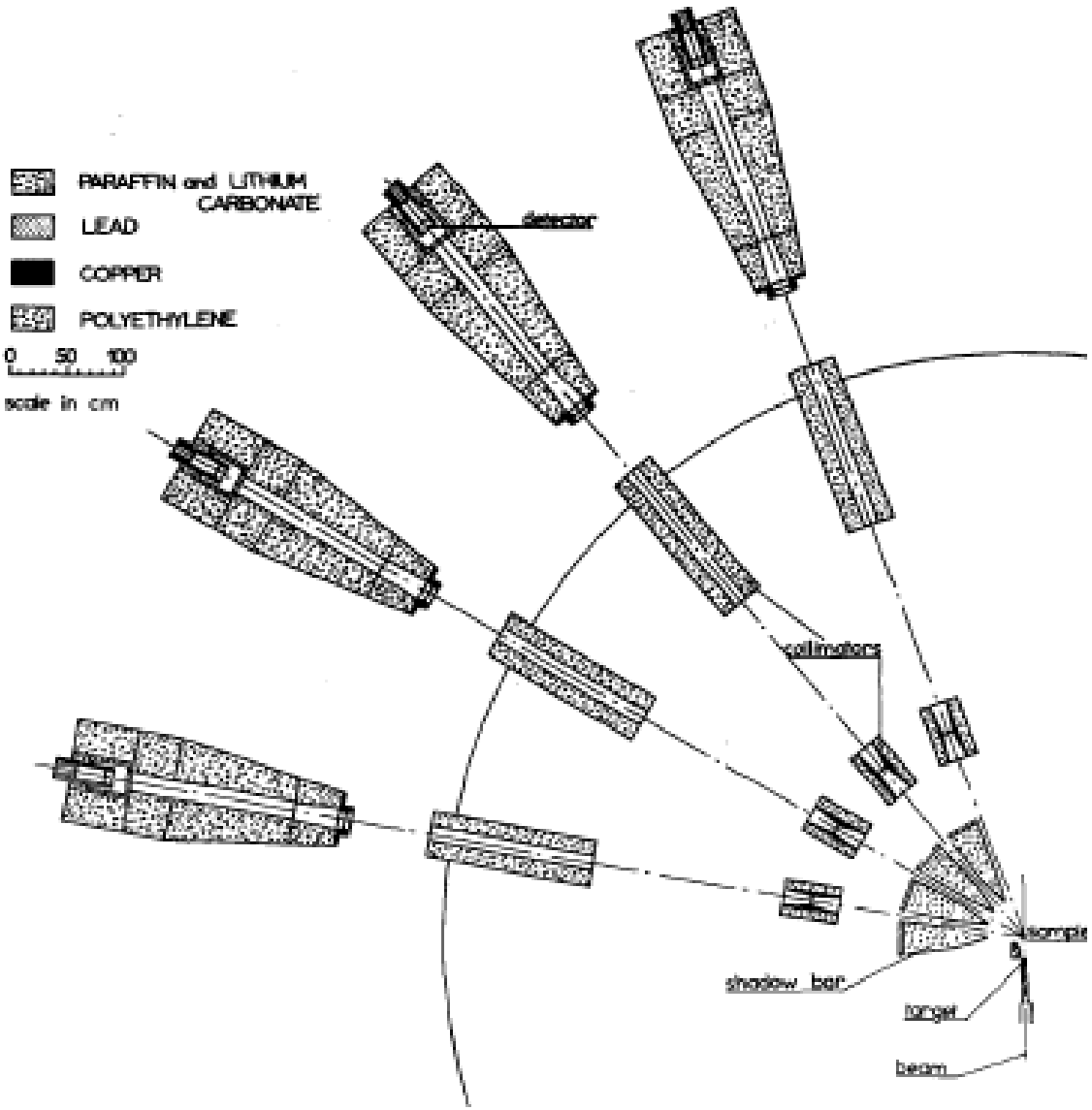


FIG. 85: Comparison of angle-integrated neutron emission spectra calculated from evaluations with measurements of Baba *et al.* and Matsuyama *et al.* at E_n=4.25, 6.10, 18.0 MeV.



Best (n,n') measurement

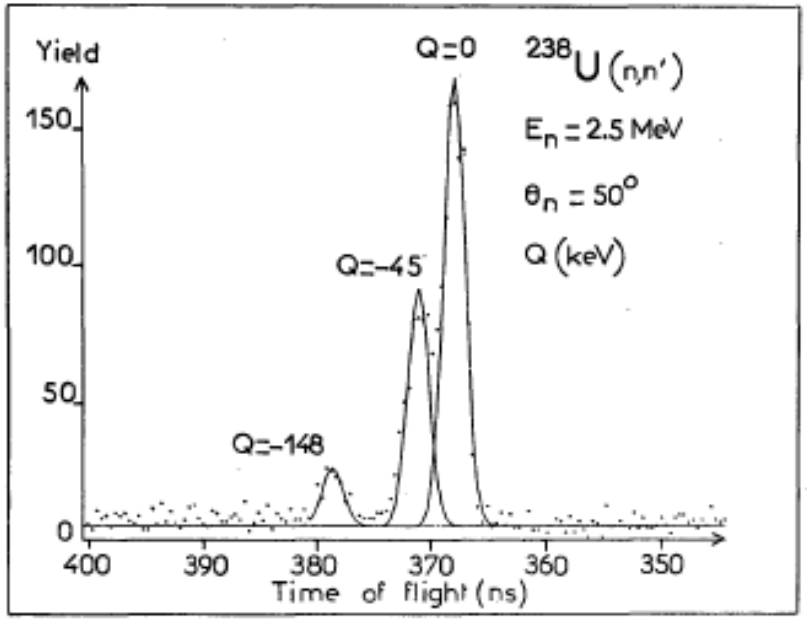


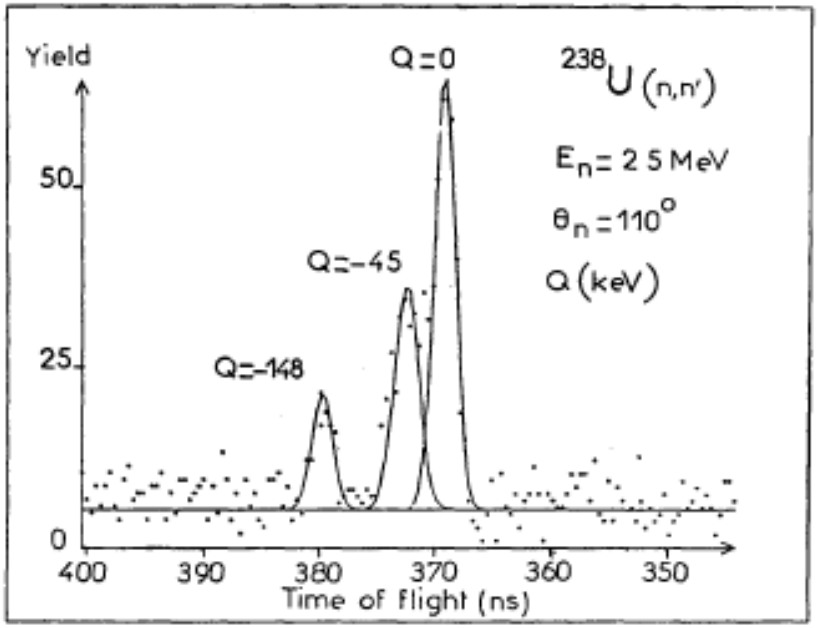
Haouat et al. 1982

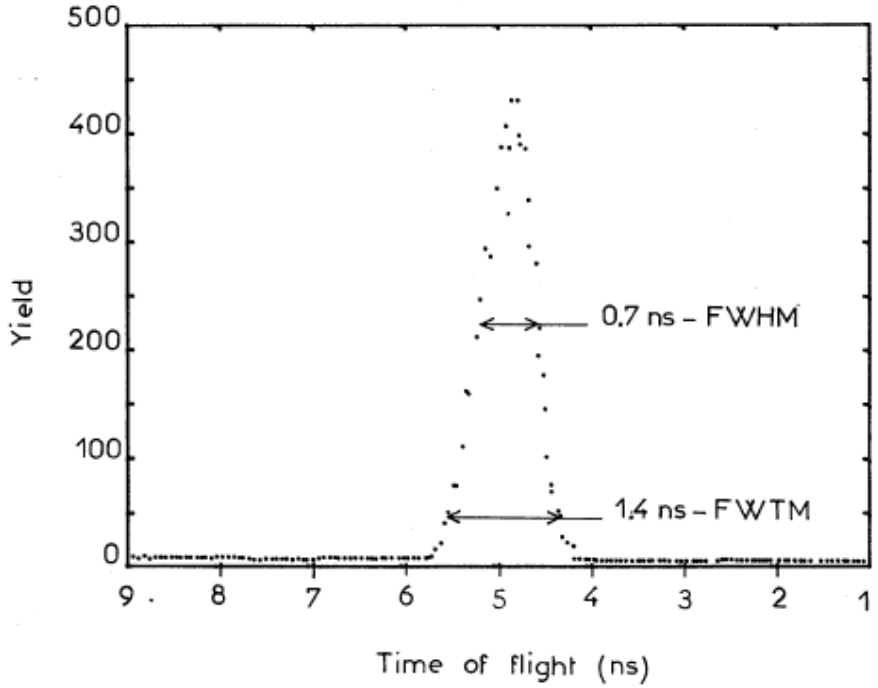
Best E-res. 28 keV
^{7}Li(p,n0), 2.5 MHz
10.3 cm target-sample
1.5 cm ø, 60 g.
NE213 2.5 x 10ø cm^2
10 m flight path
Normalisation by zero degree yield (no sample)
Angle dependence
Li(p,n0) and Li(p,n1) vs.
Evaluation for E-dep. Eff.

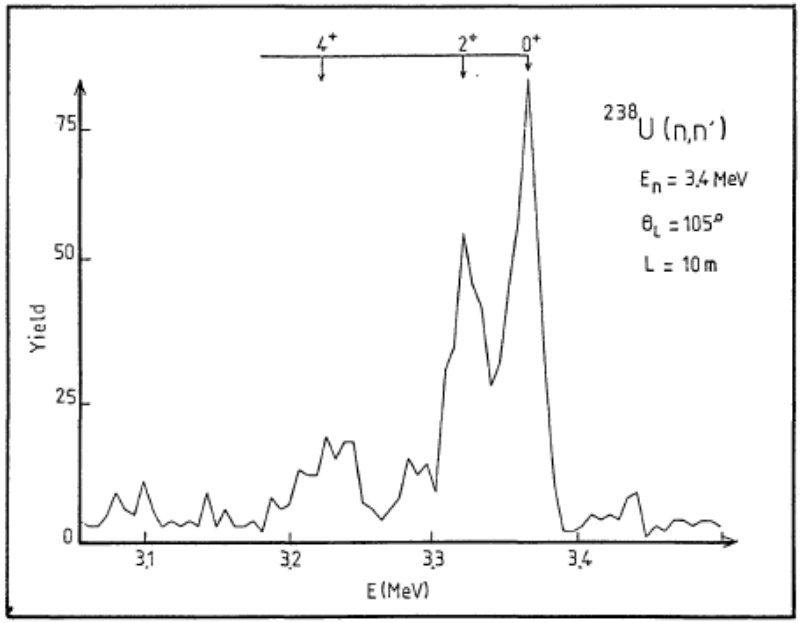
Related by monitors
Self-normalised

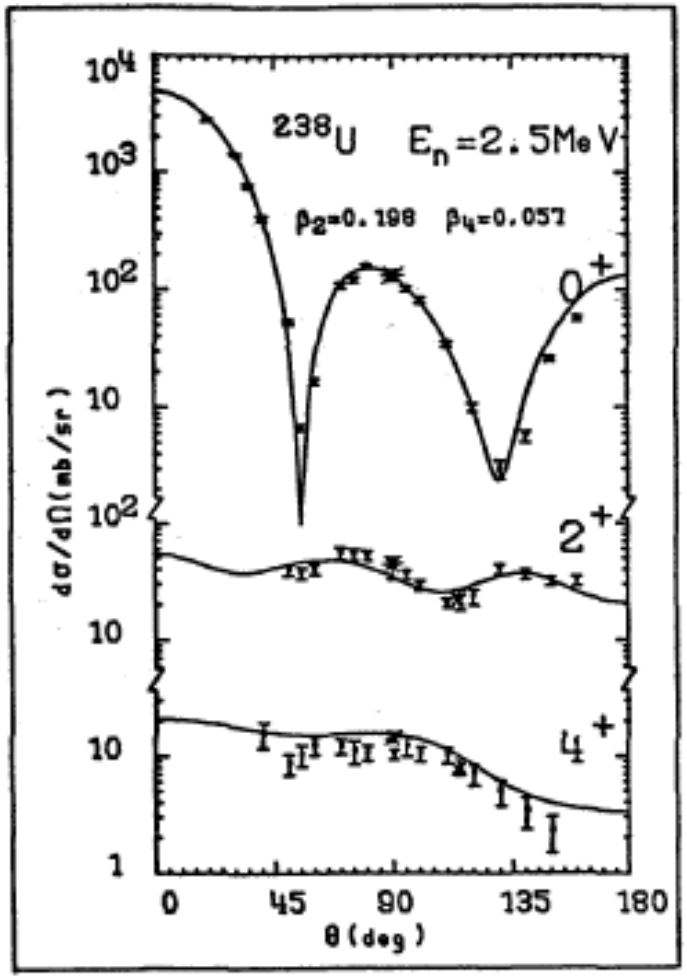
Source anisotropy, multiple scattering, attenuation, finite size corrections, background subtraction (sample out)

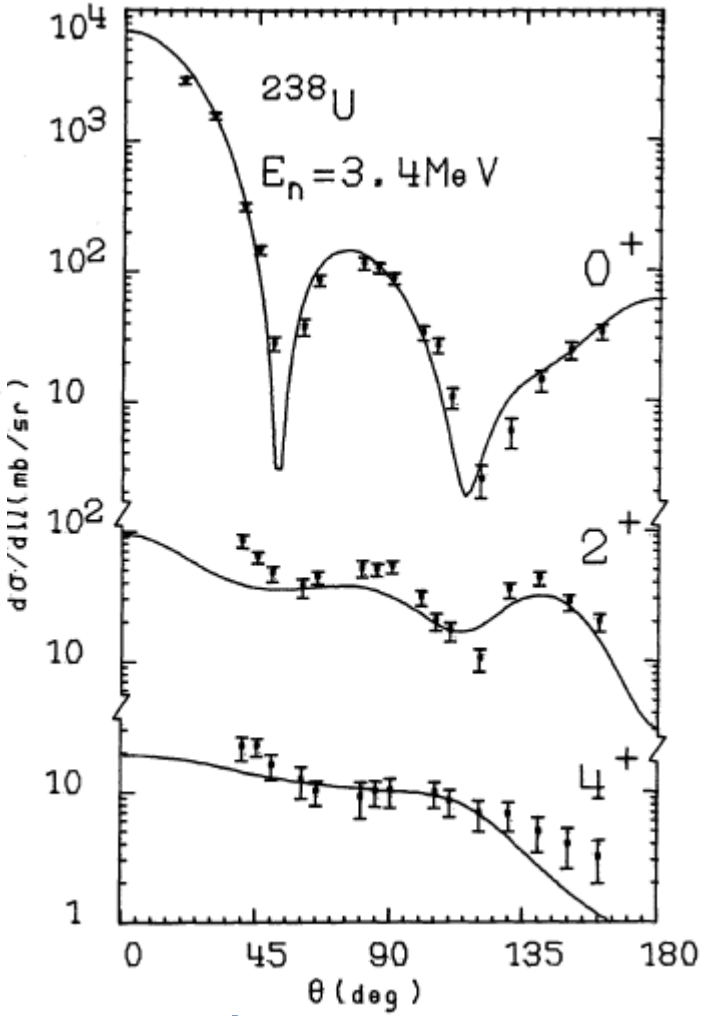

Yield
Q=0
238U (n,n')
En = 2.5 MeV
θn = 50°
Q (keV)
Q=-45
Q=-148
150
100
50
0
400
390
380
370
360
350
Time of flight (ns)

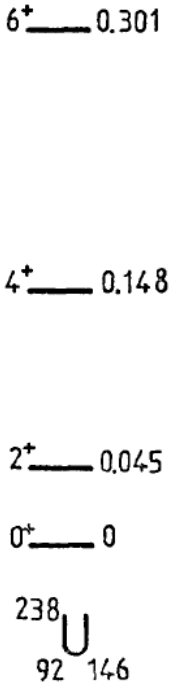

Yield
Q=0
238U (n,n')
En = 2.5 MeV
θn = 110°
Q (keV)
Q=-45
Q=-148
50
25
0
400
390
380
370
360
350
Time of flight (ns)


Yield
500
400
300
200
100
0
0.7 ns - FWHM
1.4 ns - FWTM
9
8
7
6
5
4
3
2
1
Time of flight (ns)

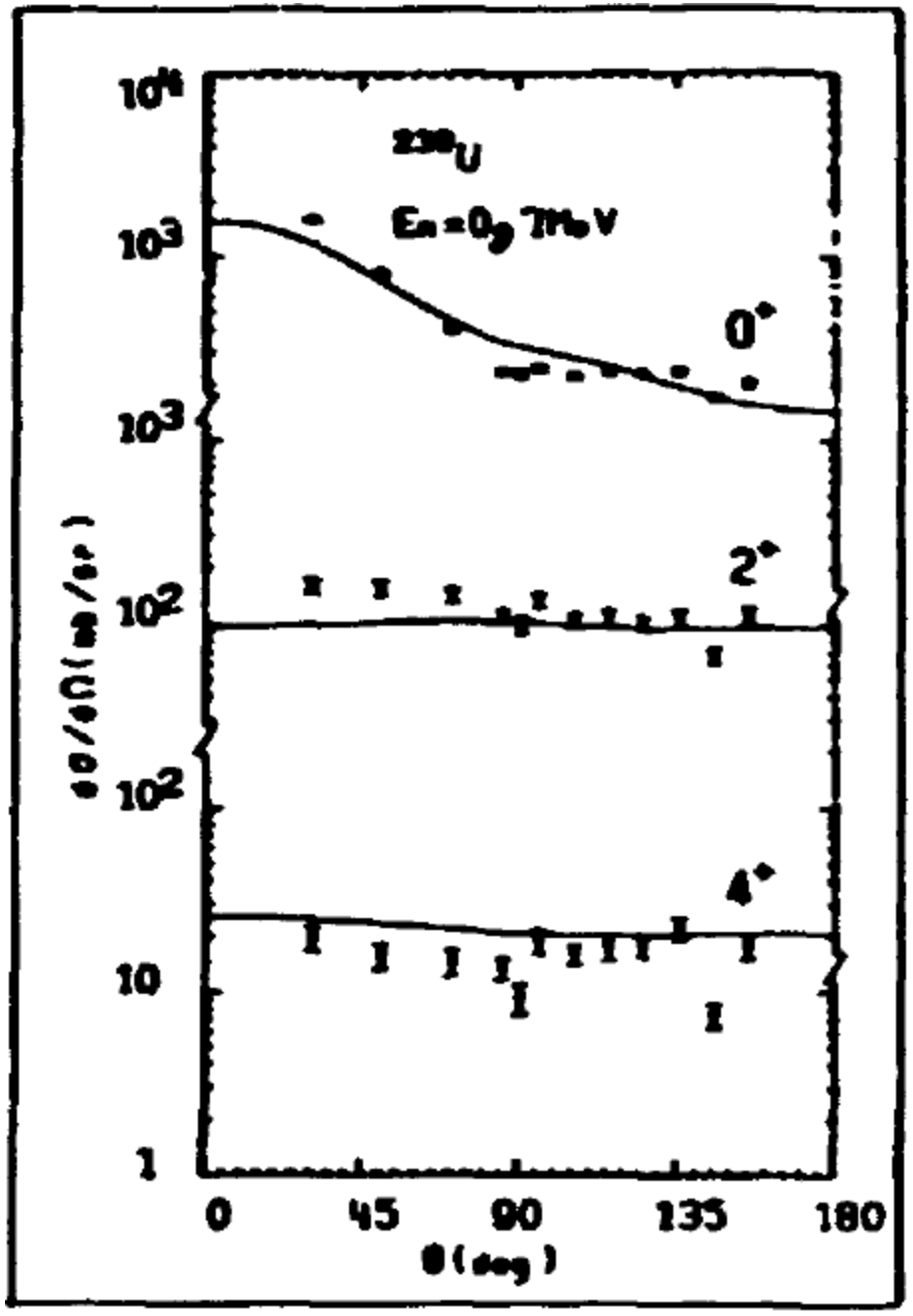

4+
2+
0+
238U (n,n')
En = 3.4 MeV
θL = 105°
L = 10 m
Yield
75
50
25
0
3.1
3.2
3.3
3.4
E (MeV)

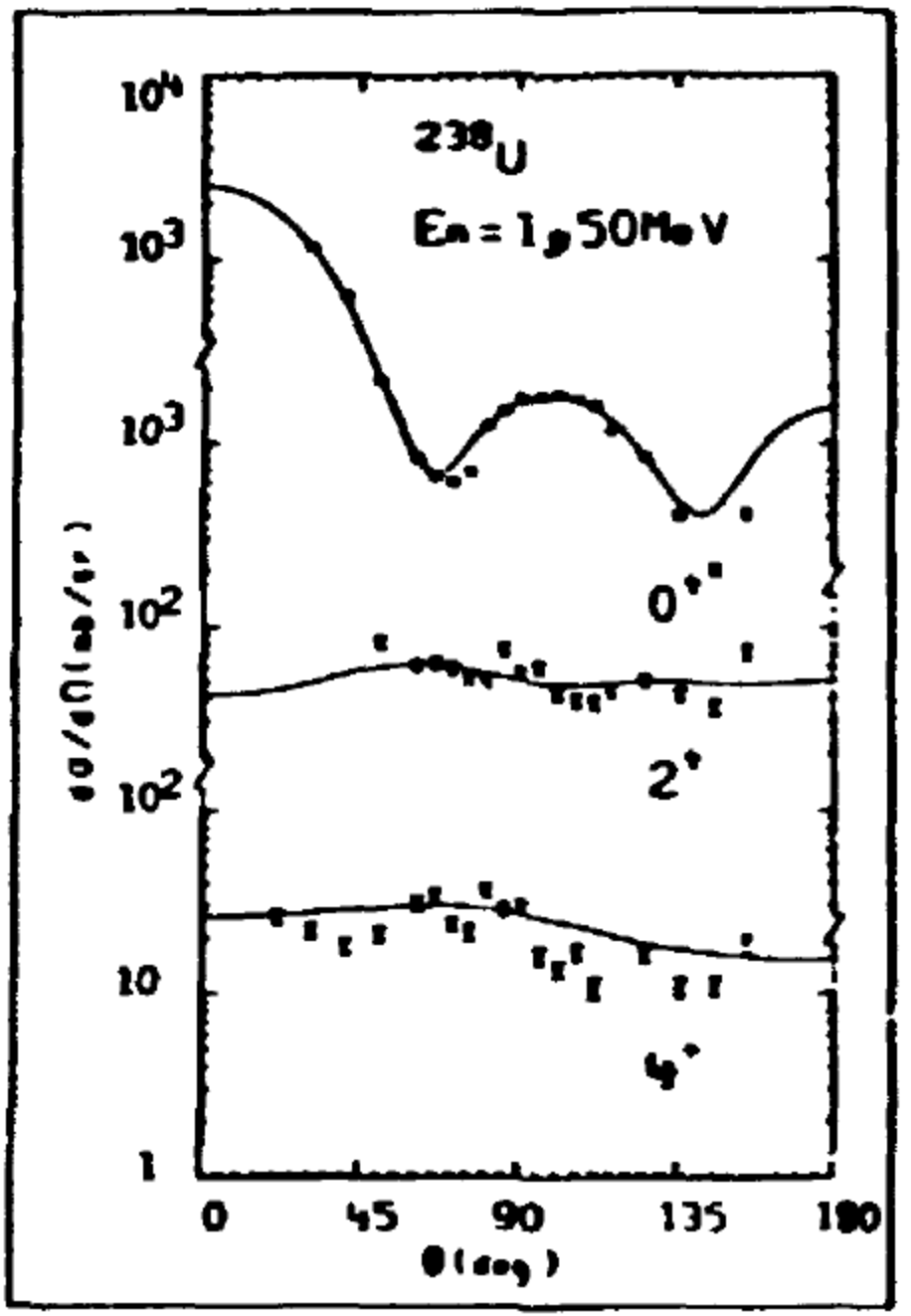






Uncertainty angle integrated cross section: 7%


238U
En=0.7MeV
0+
2+
4+
dσ/dΩ(mb/sr)
θ(deg)


238U
En=1.50MeV
0+
2+
4+
dσ/dΩ(mb/sr)
θ(deg)

^{238}U(n,n'g) ongoing work

- *ANDES-JEFF meeting*

BacquiasWPEC.pdf

^{56}Fe inelastic scattering

Nicely reviewed by Luiz Leal for SG-35, 22-5-2012

$^{56}Fe(n,n'\gamma)^{56}Fe$

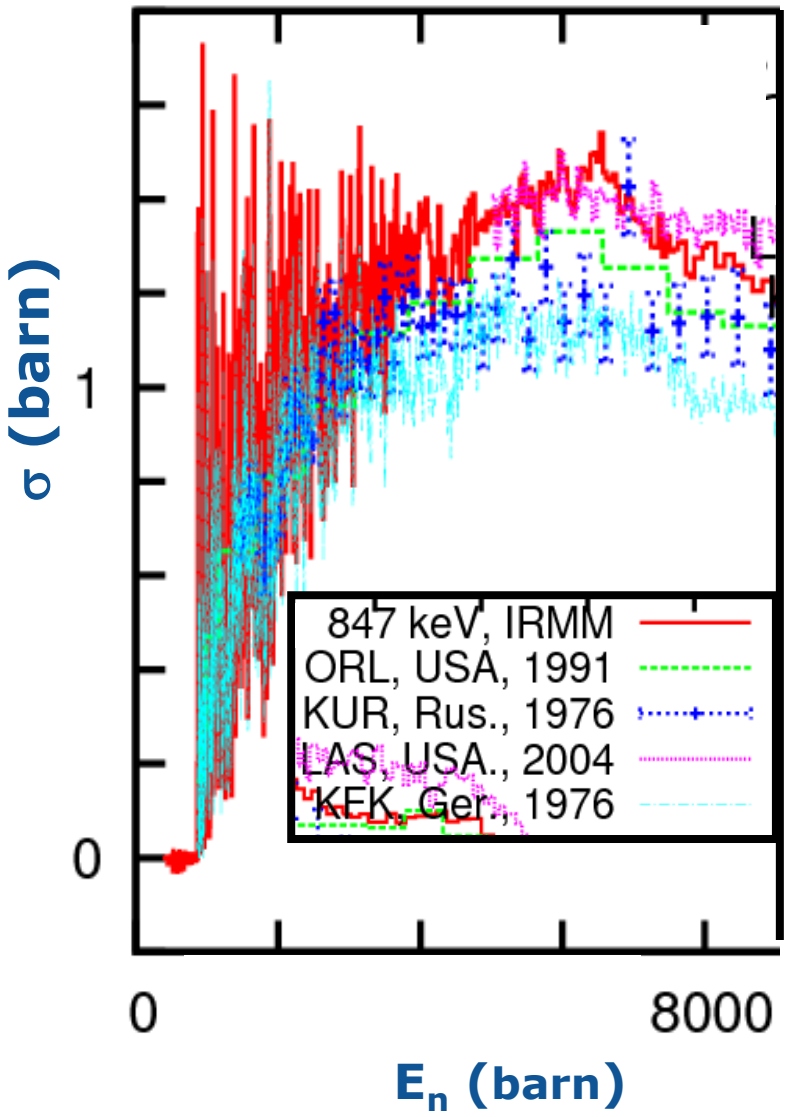
Improved data were sent to CEA for benchmark testing in the PERLE experiment. First feedback was received.

Recommendation is to consider the data only up to 3.5 MeV

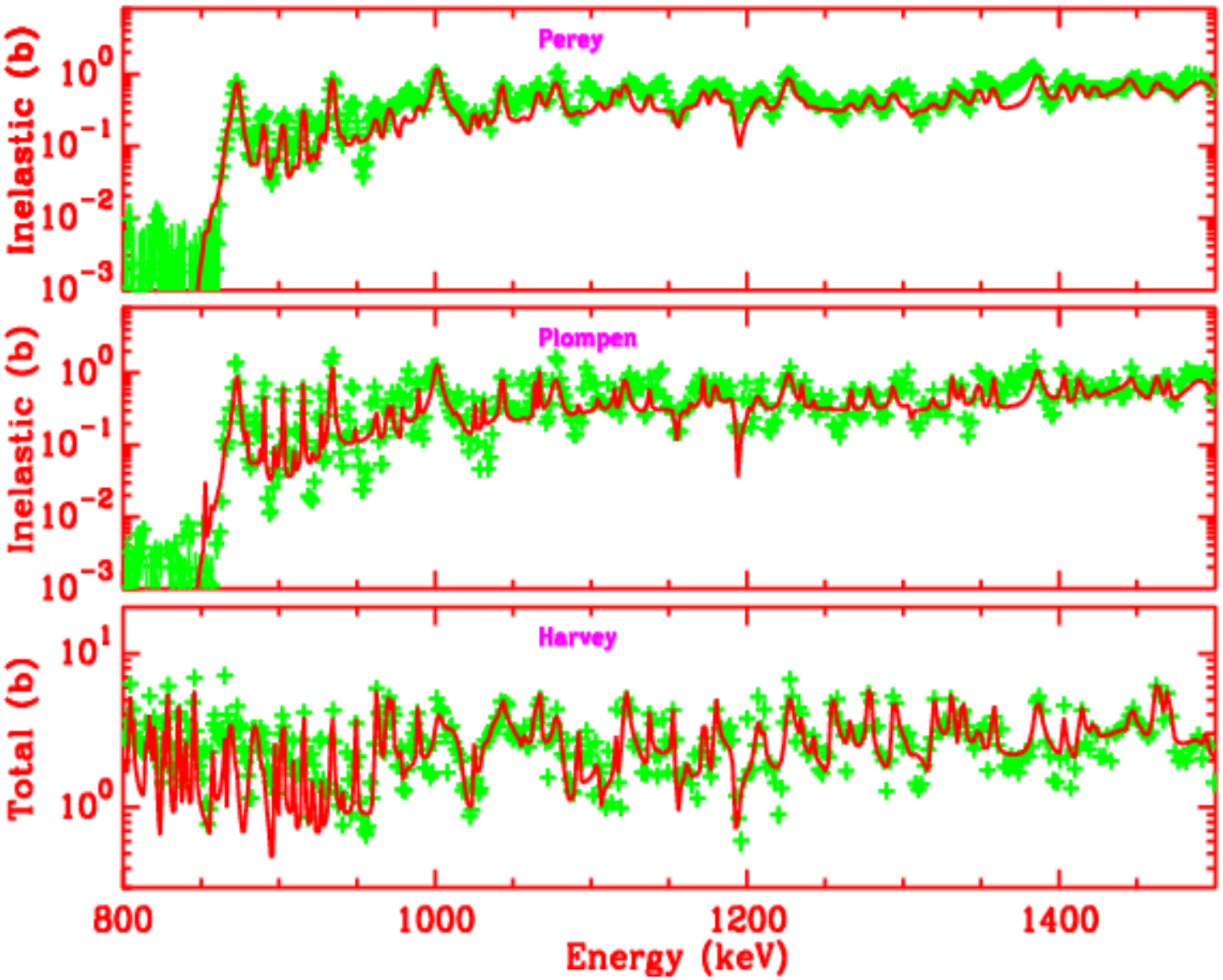
Feedback indicates data above 3.5 MeV are too low, in agreement with the principle of the measurement

Data were sent to ORNL to help extend the resolved resonance range analysis

Collaboration between
Negret, Plompen, Vaglio-Gaudard, Noguere, de Saint-Jean, Leal et al.



Leal, RM analysis, status



^{23}Na(n,n'), recent work and status

- *Na inelastic scattering with GAINS*

  C. Rouki et al., Nucl. Instrum. Meth. A 672 (2012) 82

- *Na elastic and inelastic scattering with eight liquid scintillators*

  S. Kopecky and A. Plompen "R-matrix analysis of the total and inelastic scattering cross sections" EUR 25067 EN (LANA-25067-EN-N.pdf)

GAINS @ FP3/200m

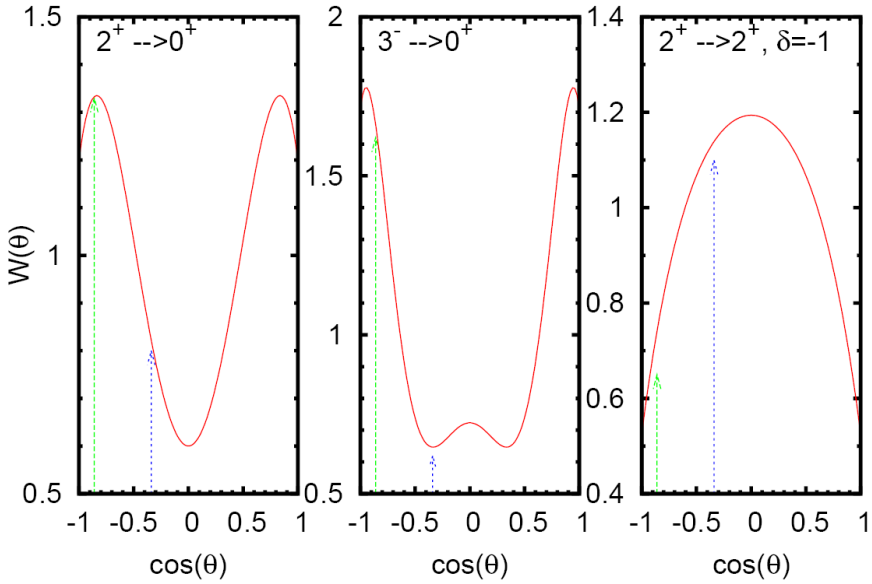
GELINA

Angle integration

Exact angle integration $1 \leq L \leq 3$

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{\sigma}{4\pi} W(\theta) = \frac{\sigma}{4\pi} \sum_{k=0}^{k_{max}} c_{2k} P_{2k}(\cos(\theta))$$

$$\sigma = 2\pi \int_{-1}^{1} \frac{d\sigma}{d\Omega}(x)dx = 2\pi \sum_{i=1}^{2} w_i \frac{d\sigma}{d\Omega}(x_i)$$



$$x_i = \cos(\theta_i)$$

θ_1=110°, 70° → w_1=1.30429
θ_2=150°, 30° → w_2=1.69571

Gamma efficiency determination

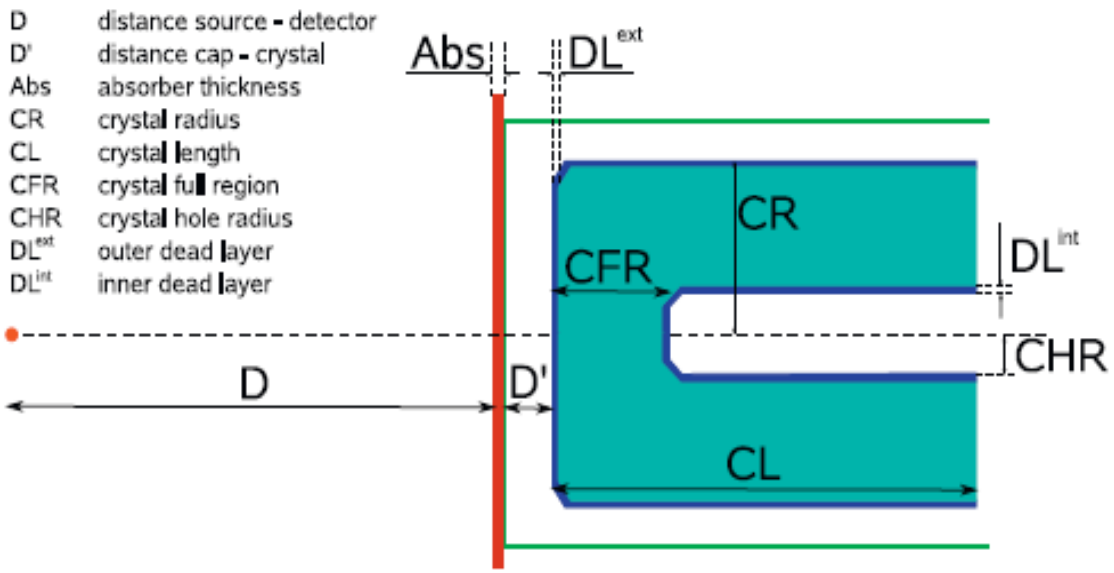


Fig. 2. Schematic drawing of a HPGe detector. The most important parameters are emphasized.

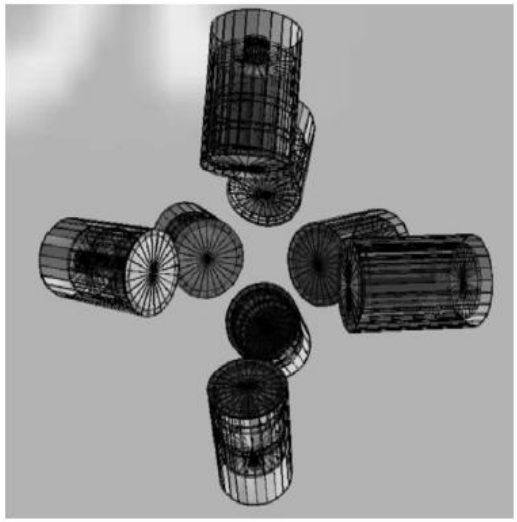


Fig. 1. GAINS. Drawing of the simulated geometry.

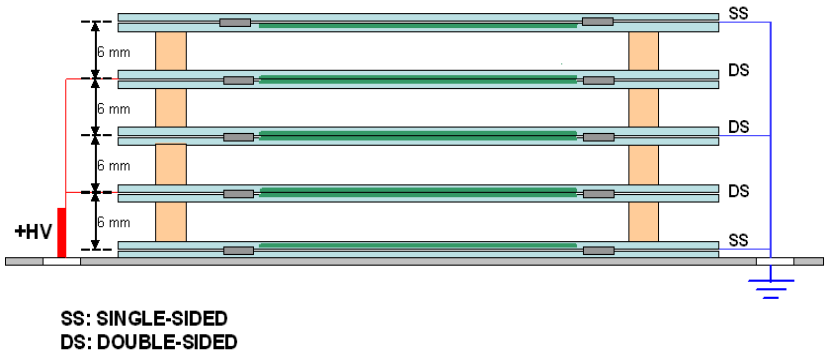
Large dependence on MC simulation
Point source calibration to model detector
Calculation for extended self-attenuating sample
Comparison of MCNP5 versus GEANT4

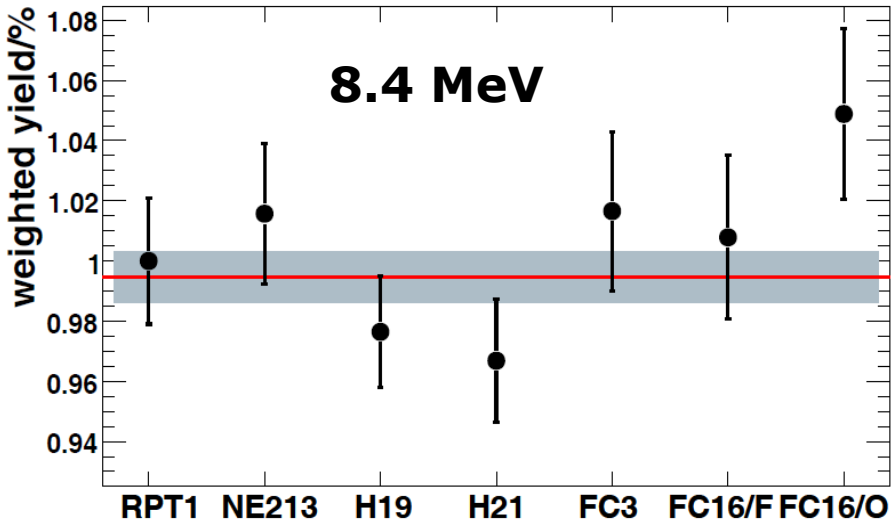
Neutron fluence determination

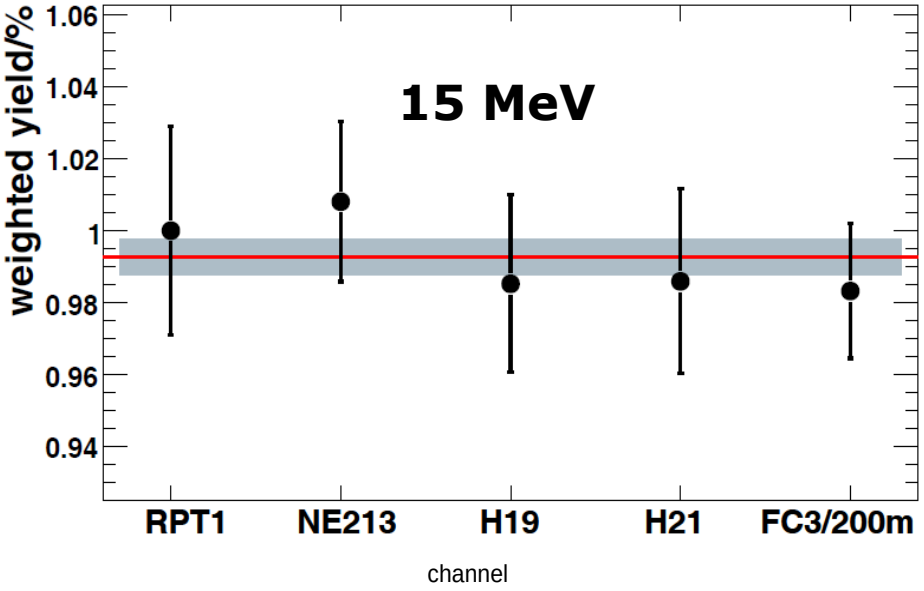
Neutron fluence monitoring: ^{235}U fission chamber

Revisiting of the fluence measurement

- Mass verified by alpha-counting
- Study of efficiency
- Control measurement at PTB (intercomparison)





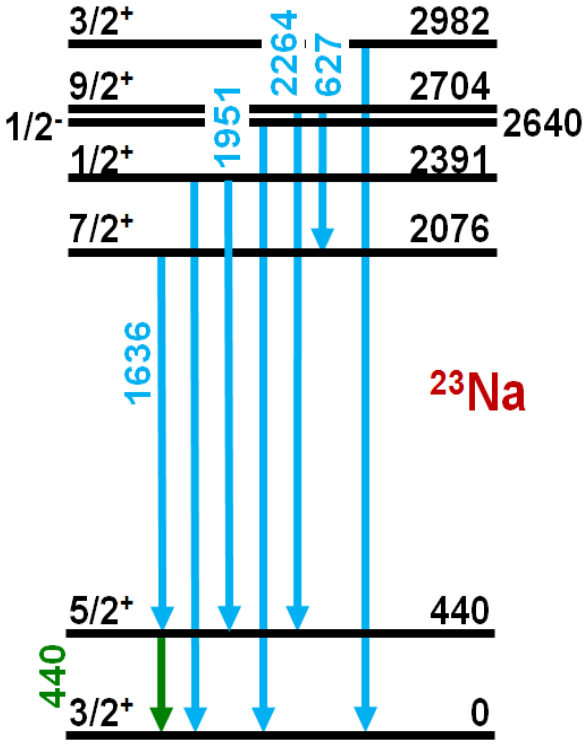


Observed transitions

- *Upper limit of energy 3.84 MeV*
- *Total inelastic and level inelastic*
- *(relies on decay data)*

- *All statistics analysed*
- *Careful efficiency check gamma-ray detectors*

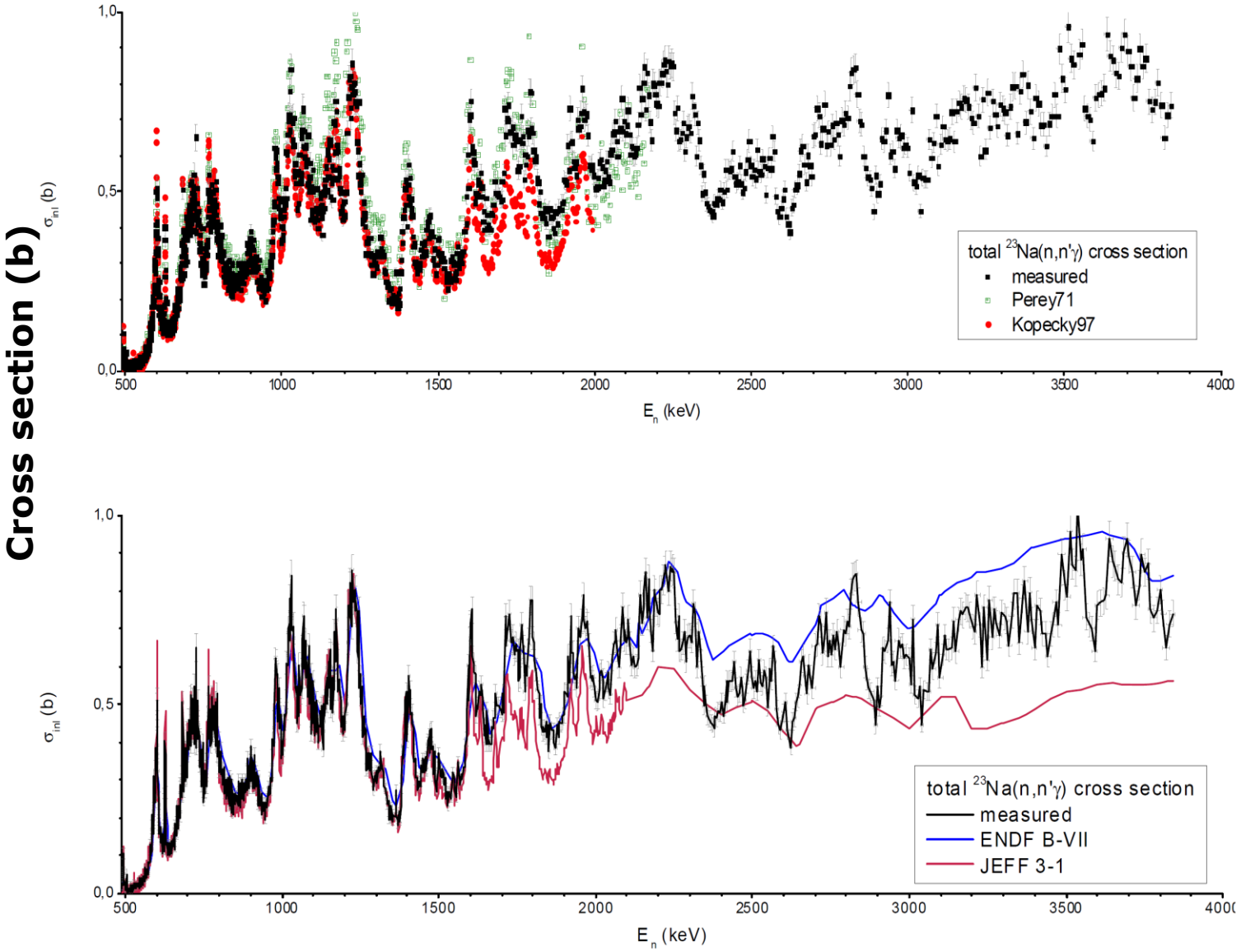
- *Final data delivered to CEA for benchmark testing*
- *Report EUR 24871 EN.*
- *Group cross section < 2.5 %!*



E_γ (keV)	E_{level1} (keV)	$J_{\pi 1}$	$T_{1/2}$	E_{level2} (keV)	$J_{\pi 2}$	I_γ	γ mult.
439.986(10)	439.990(9)	5/2+	1.24(8) ps	0	3/2+	100	M1+E2
1635.96(3)	2076.011(22)	7/2+	24(2) fs	439.990(9)	5/2+	100.00(14)	M1+E2
1950.652(21)	2390.732(13)	1/2+	594(81) fs	439.990(9)	5/2+	52.1(8)	E2
2390.599(18)	2390.732(13)	1/2+	594(81) fs	0	3/2+	100.0(6)	
2639.70(5)	2639.85(4)	1/2-	58(11) fs	0	3/2+	100	
2263.39(3)	2703.500(25)	9/2+	95(4) fs	439.990(9)	5/2+	100.0(9)	E2 (+M3)
2541.92(4)	2982.060(19)	3/2+	2.5(4) fs	439.990(9)	5/2+	70.1(3)	M1+E2

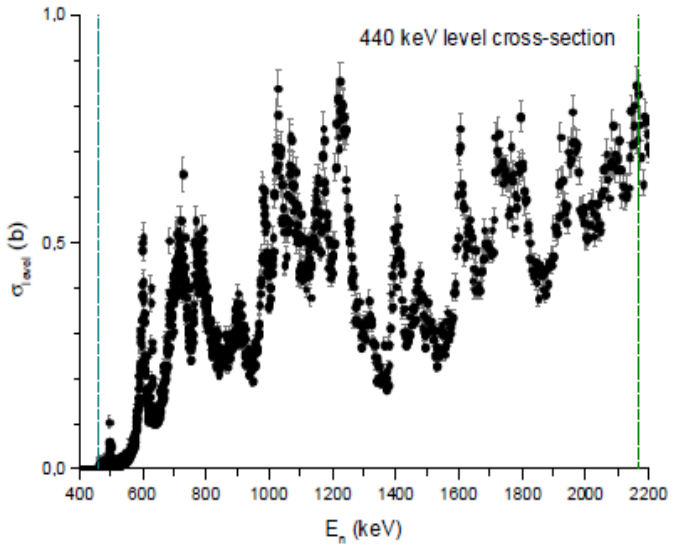
Table 1: Observed gammas from ^{23}Na(n,n'γ) and associated initial (1) and final (2) levels [10].

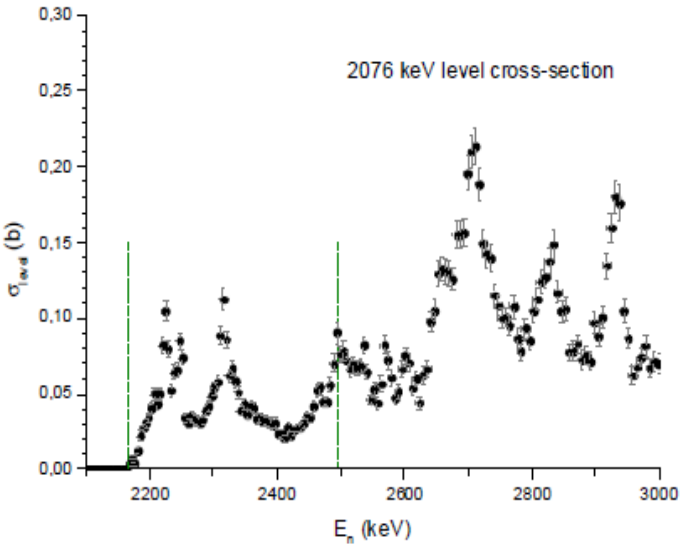
Inelastic versus other data and evaluations



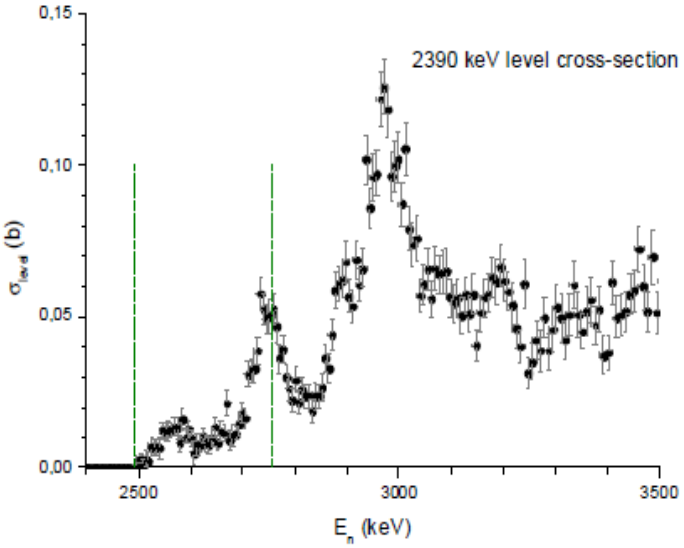
European Commission

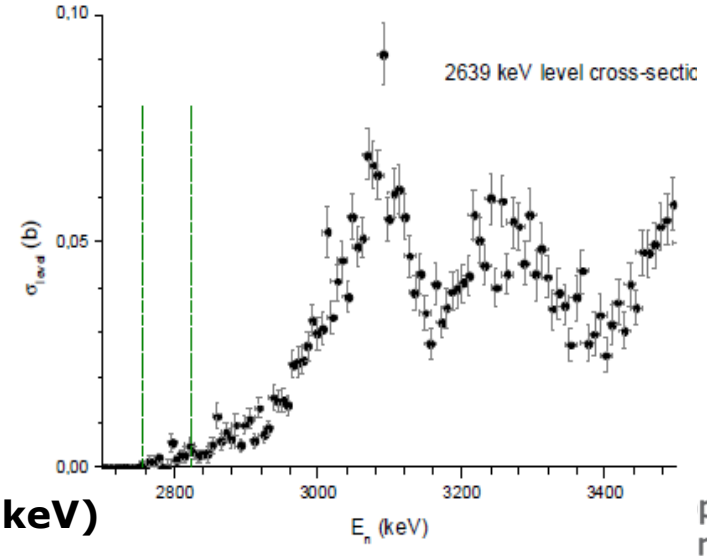
Level cross sections





Cross section (b)





E_n (keV)

pean mission

Conclusion
GAINS inelastic scattering

- *The GAINS measurements meet the HPRL target uncertainties derived from SG-26.*
- *GAINS data are not yet part of a new evaluation*
- C. Rouki et al.,

  Nucl. Instrum. Meth. A 672 (2012) 82
- *Phys. Rev. C does not appreciate a good measurement*

Na elastic and inelastic scattering with eight liquid scintillators

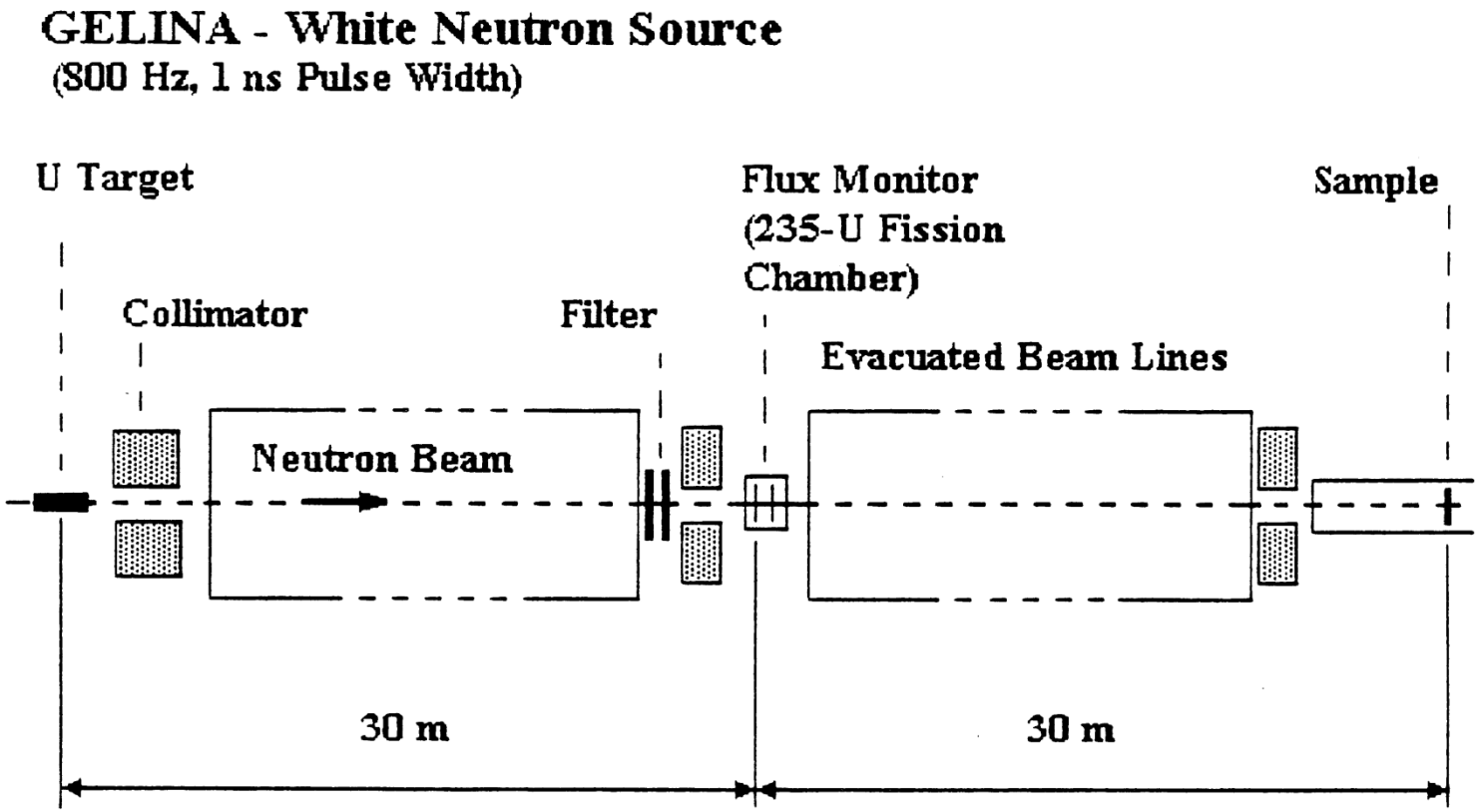
- *H. Märten, J. Wartena and H. Weigmann, Simultaneous high resolution measurement of the differential elastic and inelastic neutron scattering cross secftion on selected light nuclei, GE/R/ND/02/1994 (1994), unpublished*
- *S. Kopecky, H. Märten, J. Wartena and H. Weigmann NDST, Triëste and EXFOR entry (1997), unpublished*
- *S. Kopecky and A. Plompen "R-matrix analysis of the total and inelastic scattering cross sections" EUR 25067 EN, LANA-25067-EN-N.pdf (2011)*

Overview

- *Measurements at GELINA in 1994, C, Na, Al, Fe*
- *Analysis using Blatt-Biedenharn and Multi-code*
- *Re-analysis S. Kopecky in 1994-1997 using SAMMY and compilation in EXFOR*
- *Provision of R-matrix parameters to CEA (2011)*
- *Analysis of the consistency of the combined elastic differential and inelastic data sets*

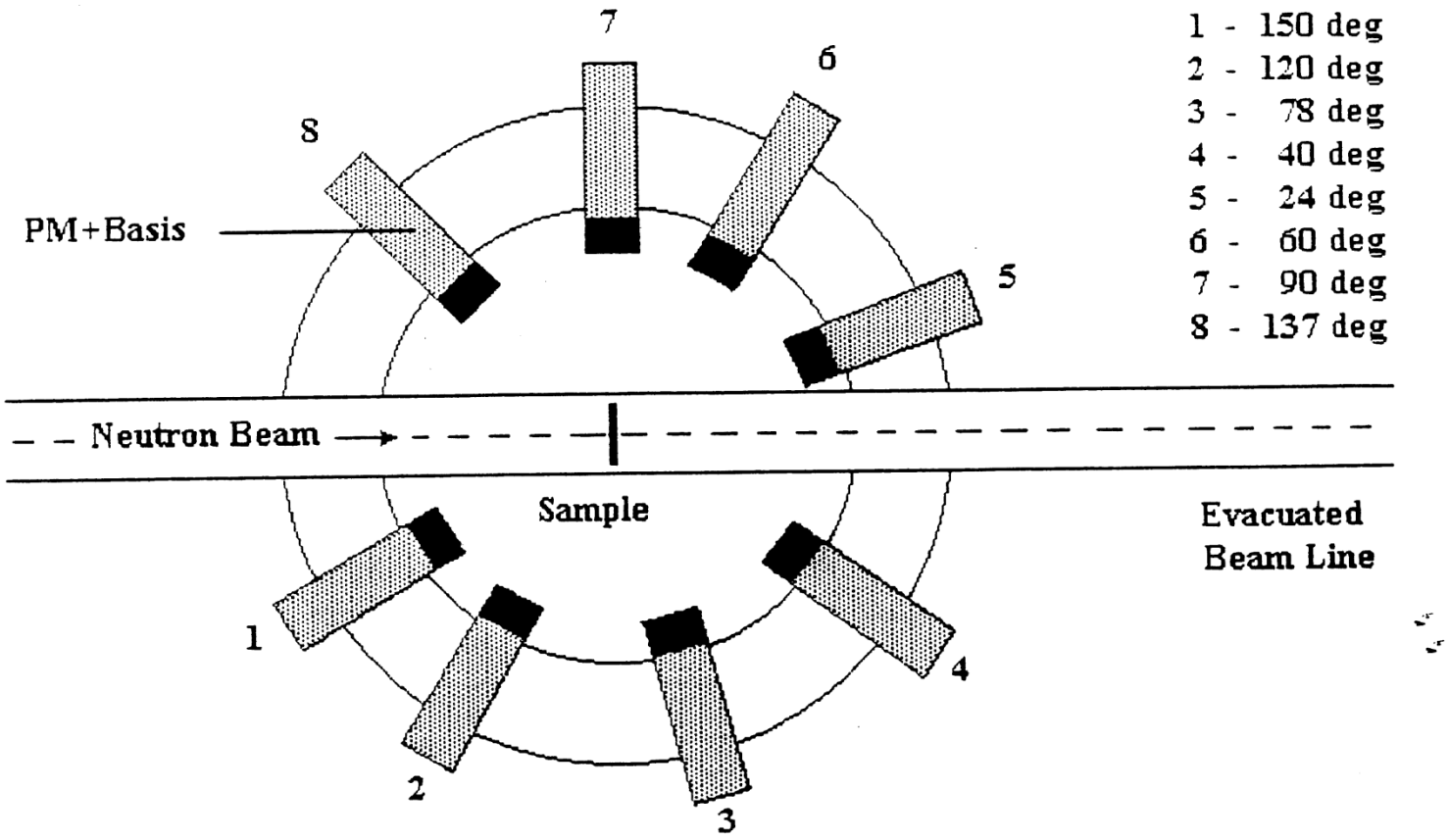
  Angle integration and comparison with total xs (2011)

Setup

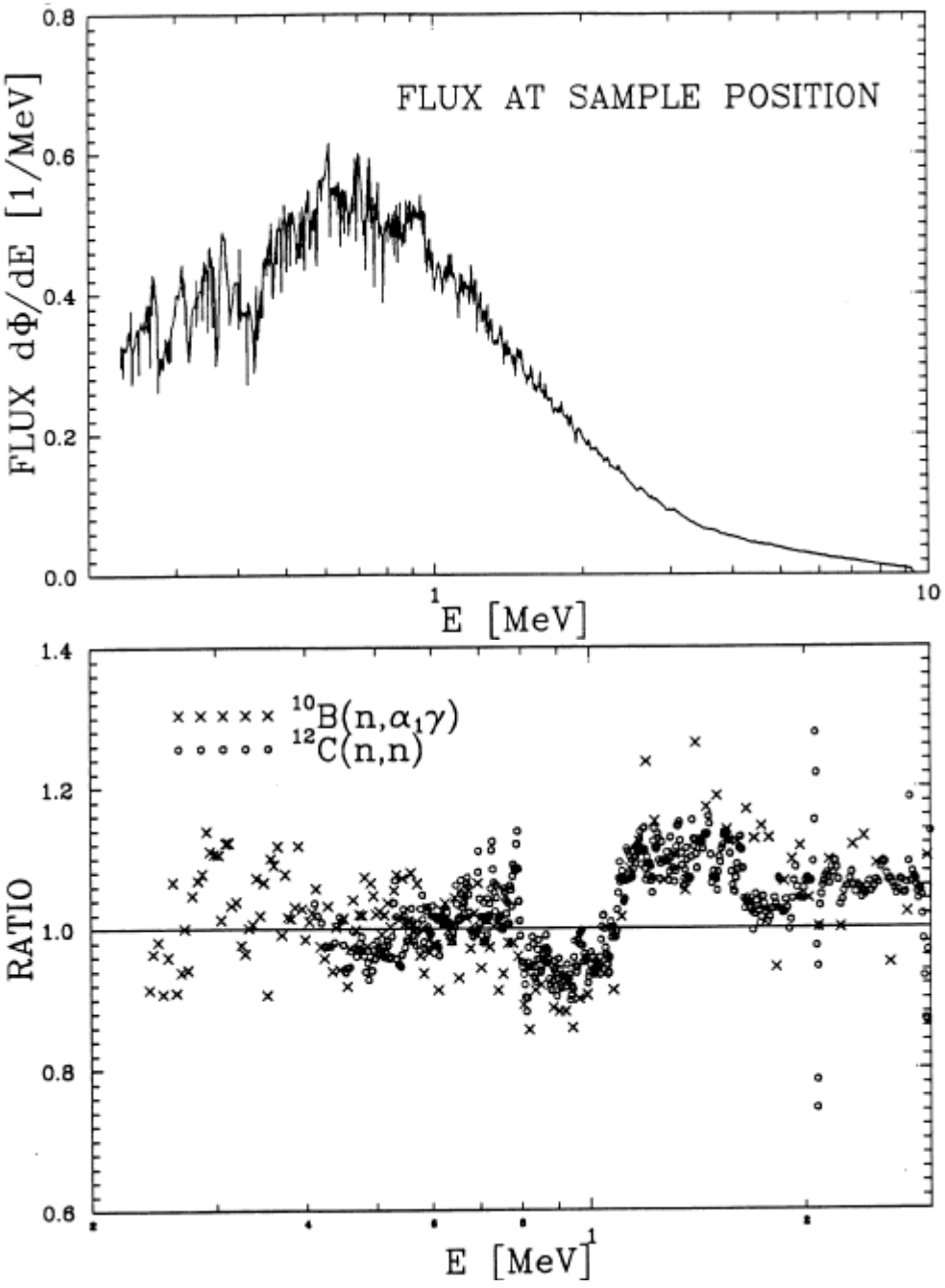

GELINA - White Neutron Source
(800 Hz, 1 ns Pulse Width)
U Target
Flux Monitor
(235-U Fission
Chamber)
Sample
Collimator
Filter
Evacuated Beam Lines
Neutron Beam
30 m
30 m

Setup

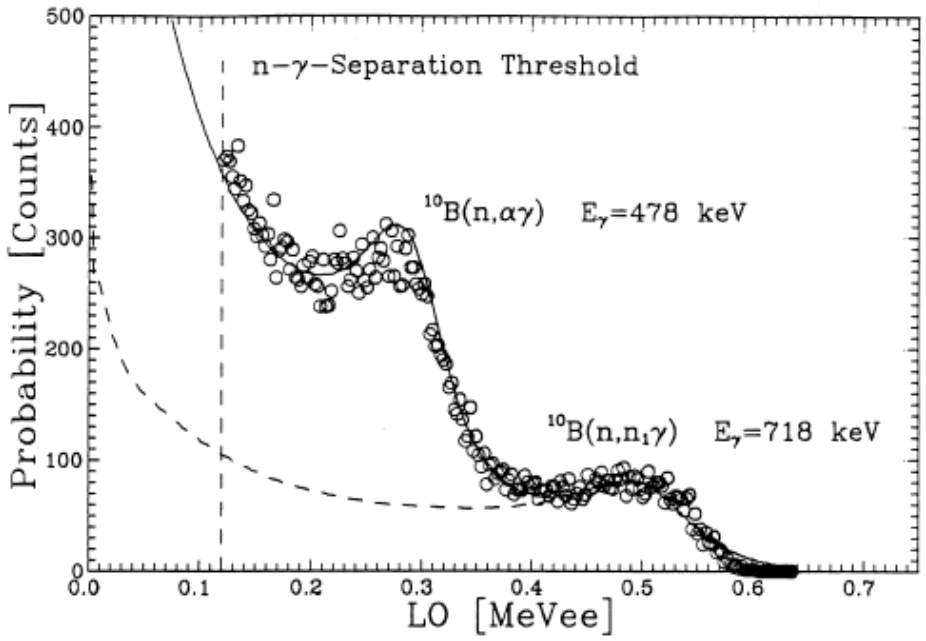
- *8x NE213*
- *2”x2”ø*
- *Metal. Na*
- *v.s. $^{10}B(n,ag)$*

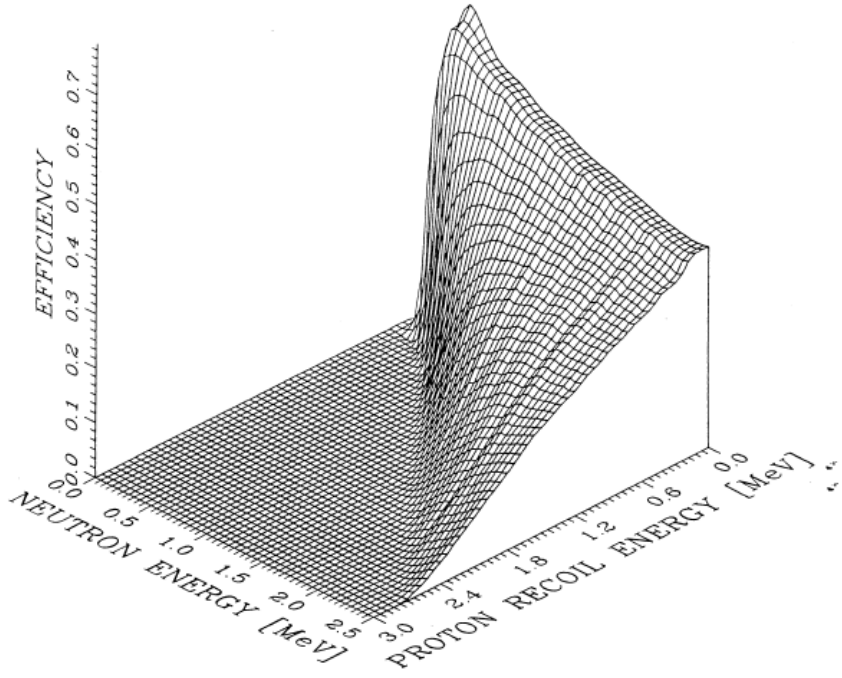


Flux


FLUX AT SAMPLE POSITION
FLUX dΦ/dE [1/MeV]
0.0
0.2
0.4
0.6
0.8
1
10
E [MeV]
RATIO
0.6
0.8
1.0
1.2
1.4
$^{10}B(n,\alpha_1\gamma)$
$^{12}C(n,n)$
E [MeV]

Response modeling required: n and g

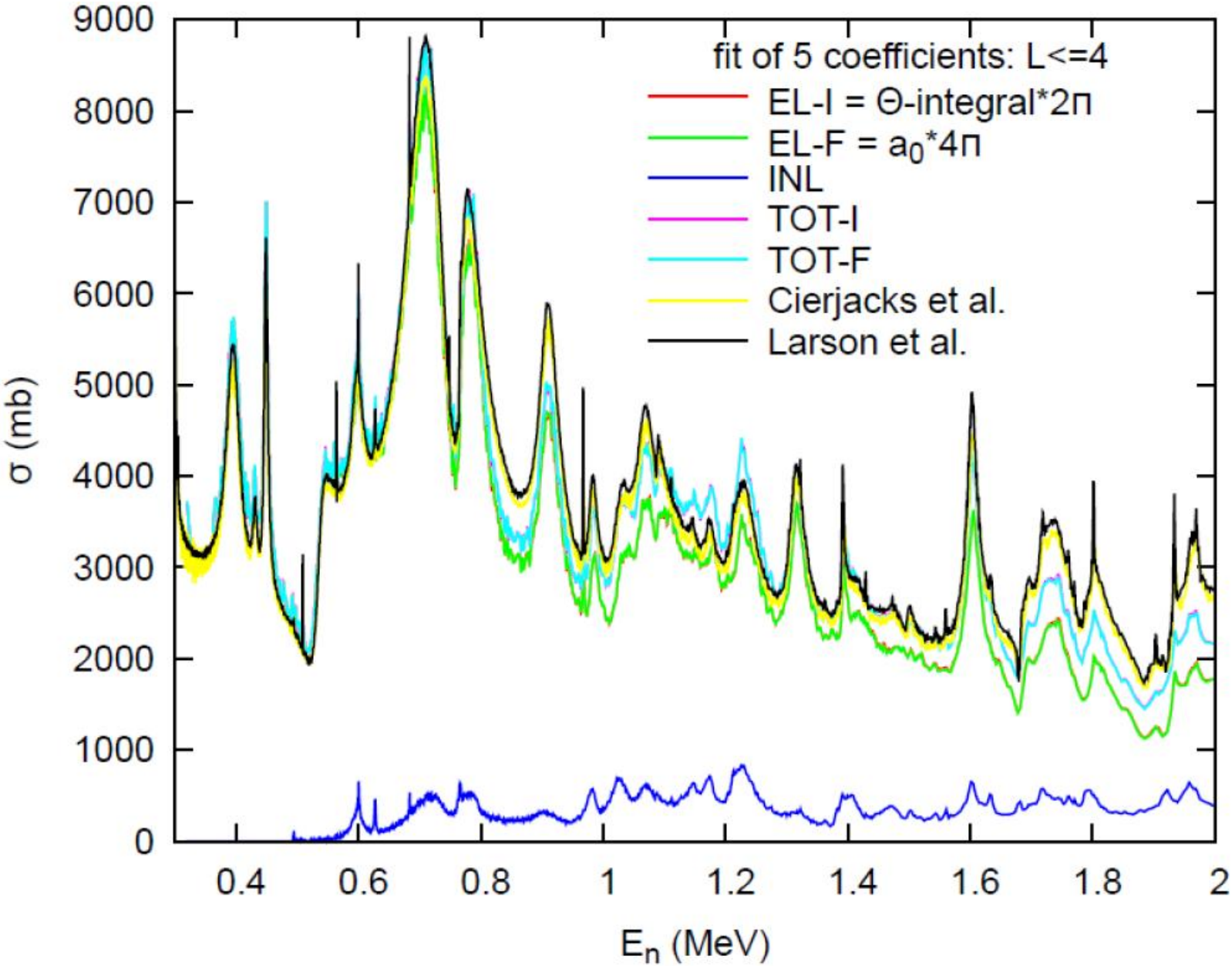




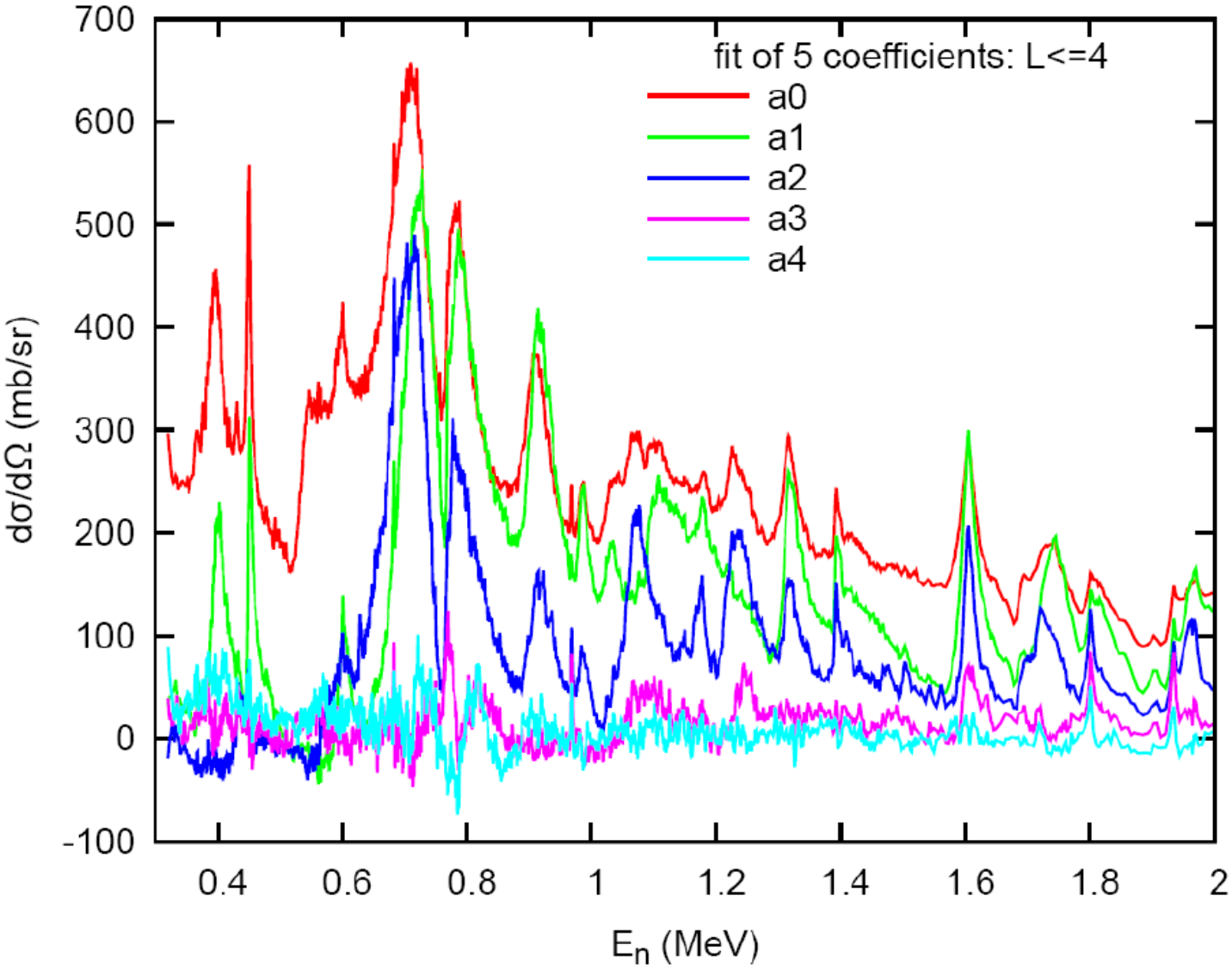
Further

- *Multiple scattering corrections*
- *Background subtraction*

Consistency check



Legendre-fit to diff. xs.



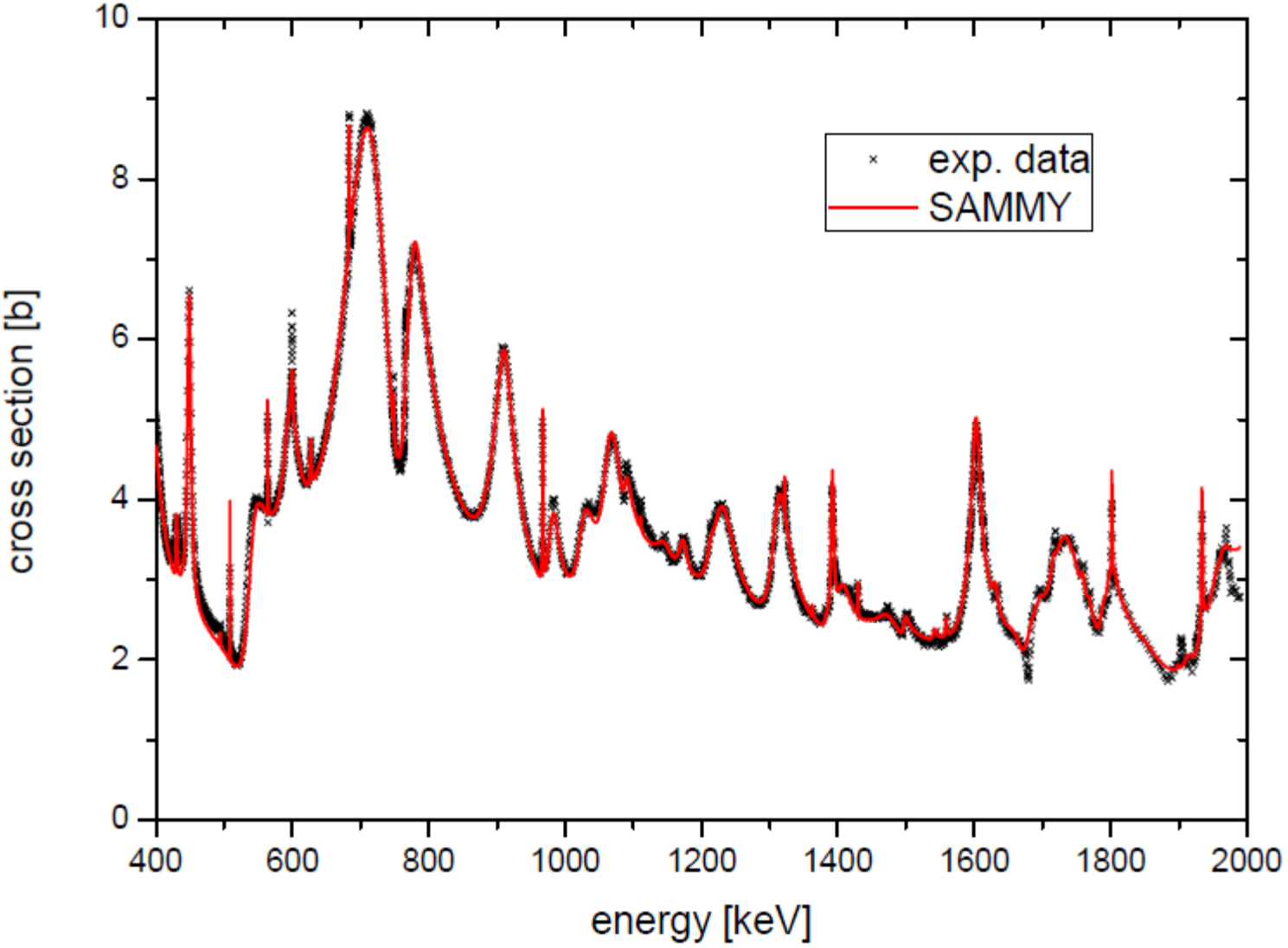


Fig 3: Comparison of experimental total cross section data of Larson et al. with calculation

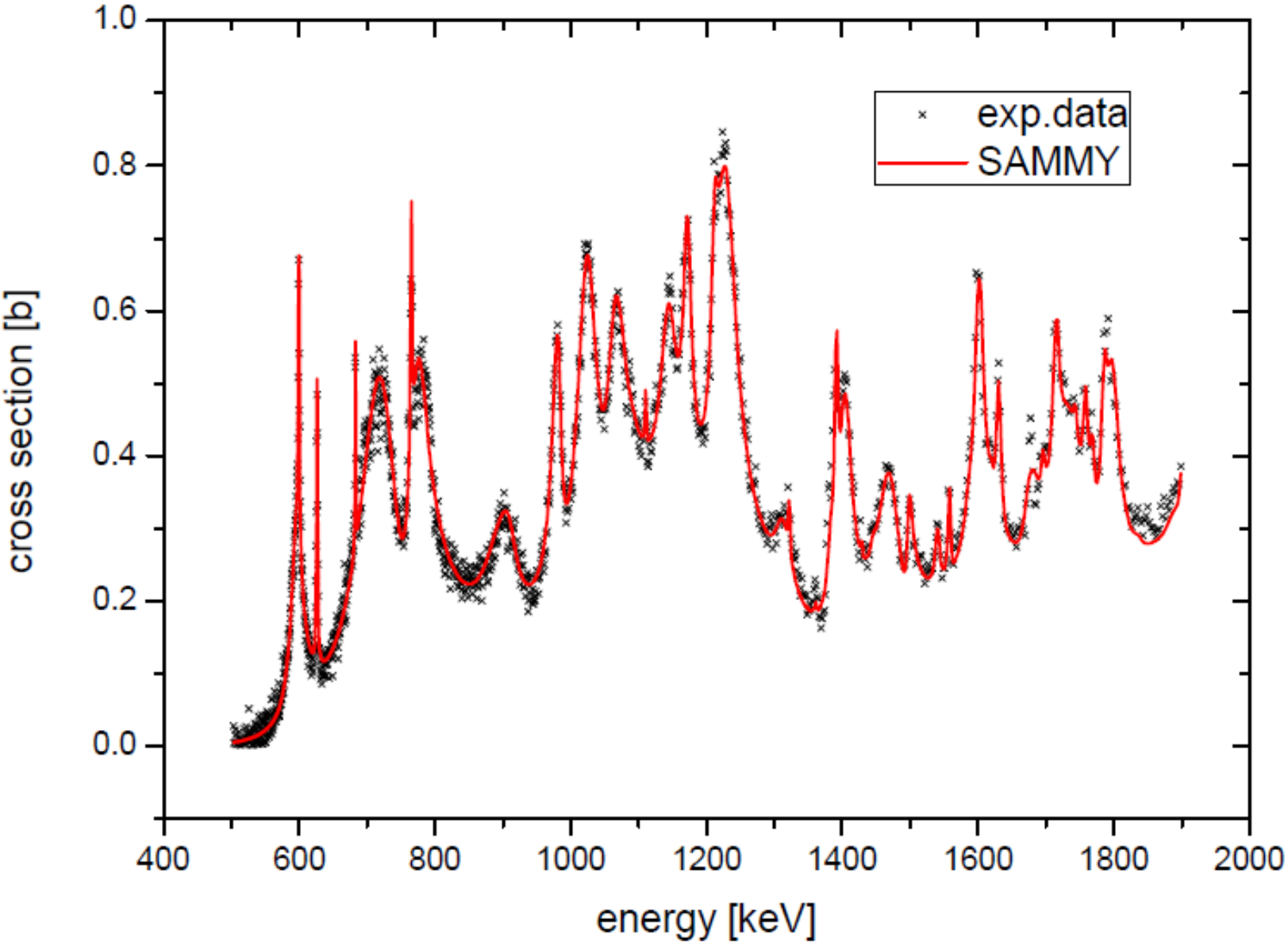


Fig 4: Comparison of experimental inelastic cross section data with calculation

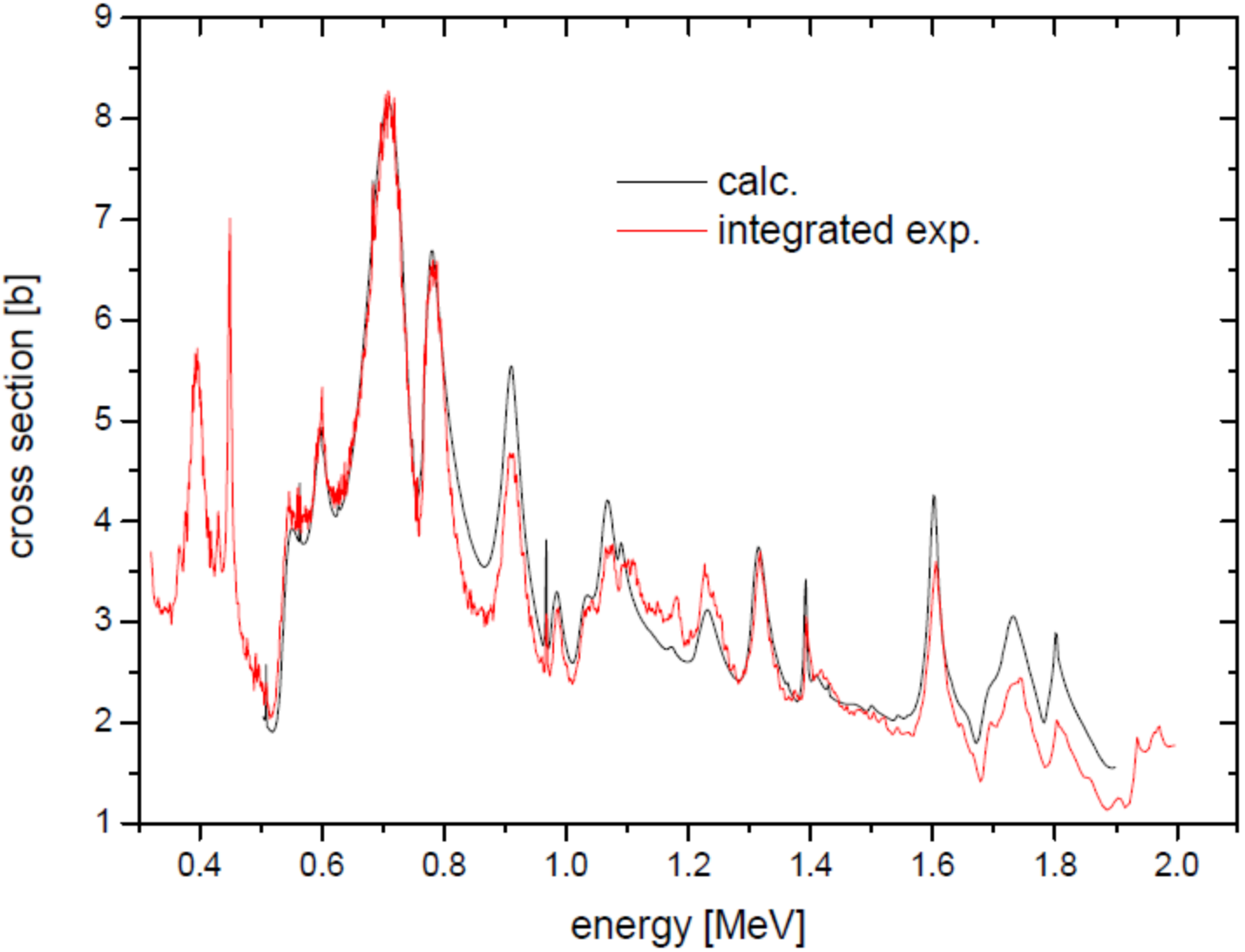


Fig 13: The elastic scattering cross section from the R-matrix calculation (calc.) and the Legendre fit to the experimental data (Integrated exp.).

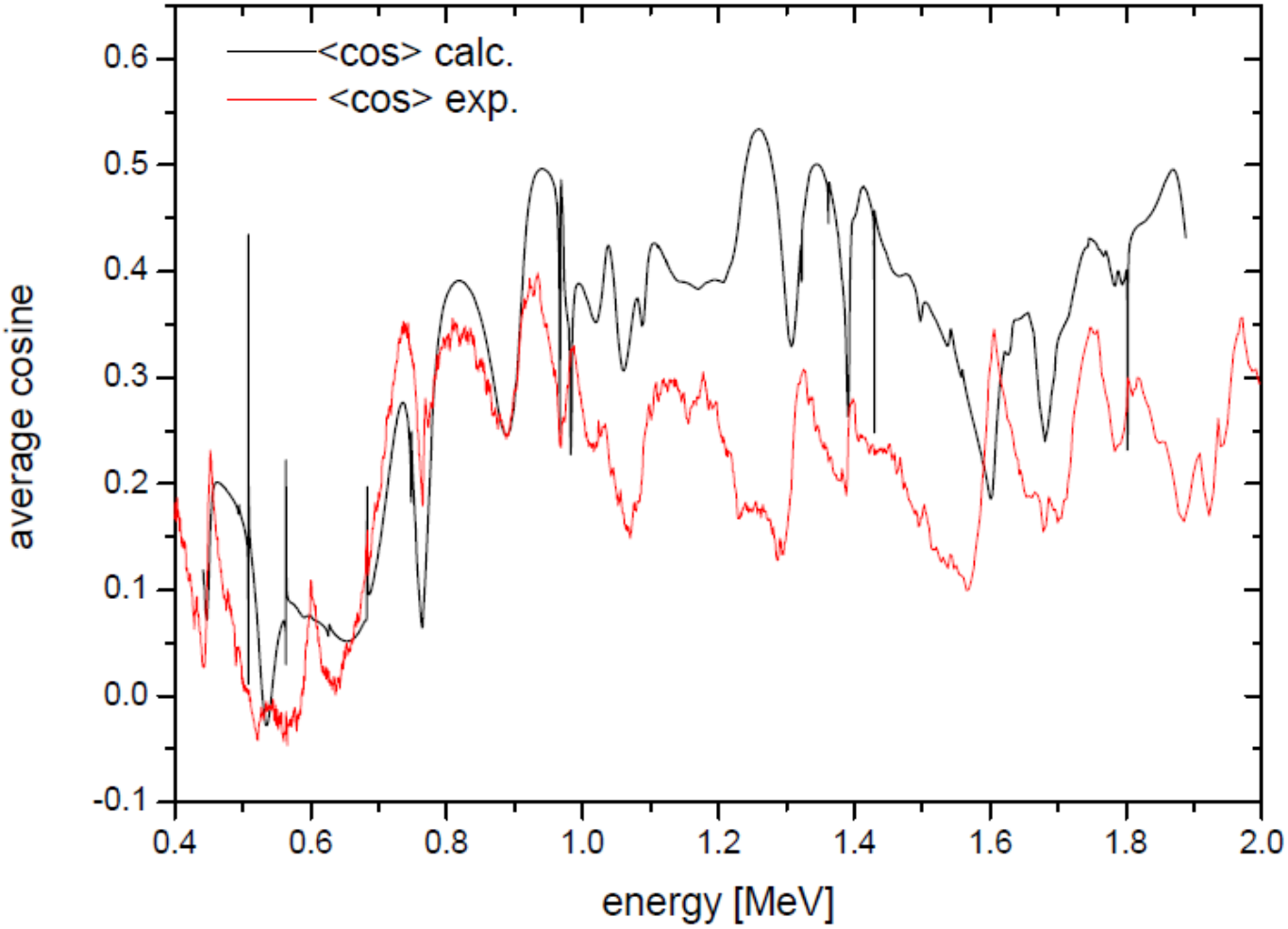


Fig 14: The centre of mass average cosine from the R-matrix calculation (calc.) and the Legendre fit to the experimental data (exp.).

Summary liq.scint.meas. Na

- *R-matrix describes total and inelastic*
- *Parameters available (report, CEA)*
- *Elastic data not well described*
- *Expt. elastic+inelastic does not equal total of Larson and Cierjacks*
- *May be due to response modeling of detectors and the very low thresholds for some energies and angles*

Summary

^{23}Na cross section needs are met

- **Remaining points: angular distribution, in particular for elastic scattering. Impacts shown in SG35**

^{56}Fe cross section needs still not met

- **Remaining discrepancies not fully understood**
- **10-15% between measurements**

^{238}U

- **cross section: long way to go (15% currently)**
- **Differential data: partial but sometimes accurate (7%)**
- **Promising new (n,n'g) data (ANDES/Strasbourg/ Geel)**
- **Technique to improve further?**
- **Encourage new work**