



The evaluation of experimental data in fast range for ^{56}Fe

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Three parts of the work were done



- **Experimental data evaluation**
- **Theoretical calculation(code UNF)**
- **Preliminary work for consistent joint evaluation of all cross sections**
- **The work in the future**



List of the experimental information for ^{56}Fe was submitted to M.Herman last fall. The original data, corrected data, reference articles and figures were included.



List of the experimental information for ^{56}Fe

Three evaluated documents of EFF from H.Vonach and V.Pronyaev in 1992 and 1995, they gave a detail experimental data evaluation of the fast neutron cross sections of ^{56}Fe , even including complete covariance information.

The report of 1995 was based on a few new experimental data including the total cross section and (n,a) cross section.

It was the updated of the ^{56}Fe evaluation.

After 1995, there are very few experimental data in EXFOR for natural iron and iron 56, so we take these three documents as the reference of our experimental data evaluation.

REF: Evaluated by [vonach91/effdoc-085](#) [vonach92/effdoc-184](#) [pronyaev95/effdoc-378](#)

Evaluated data:

[ENDF/B-VII.1](#) [JENEL-4.0](#) [ROSFOND](#) [JEFF-3.1](#) [JEFF-3.2](#) [CNEDL-2.1](#) [CENDL-3.1](#) [Theoretical calculation UNF EAF](#)

Total Cross section

(Because the isotopical dependence of the total cross section for the non-resonance region is rather weak, we used the data of natural iron for the evaluation of the ^{56}Fe total cross section.)

Data come recommend: ENDF/B-VII.1

Figure shows the evaluated result from different libraries (B71 C31 F31 J40 ROSFOND) and a new theoretical calculated result from CNDC, which used UNF series codes. We can see that the evaluated result from different libraries are consistent in the fast neutron region (above 10MeV). The total cross section in general known with an accuracy of about 1-3%.

Selected	ExpFigure/	
ENDF FILE	ExpData	
ENDF/B-VII.1	EXPData	Exp+EvalFigure
Sheet	(uncorrected)	
(Vonach92)		

Nonelastic cross section (According to Energy and Resource)

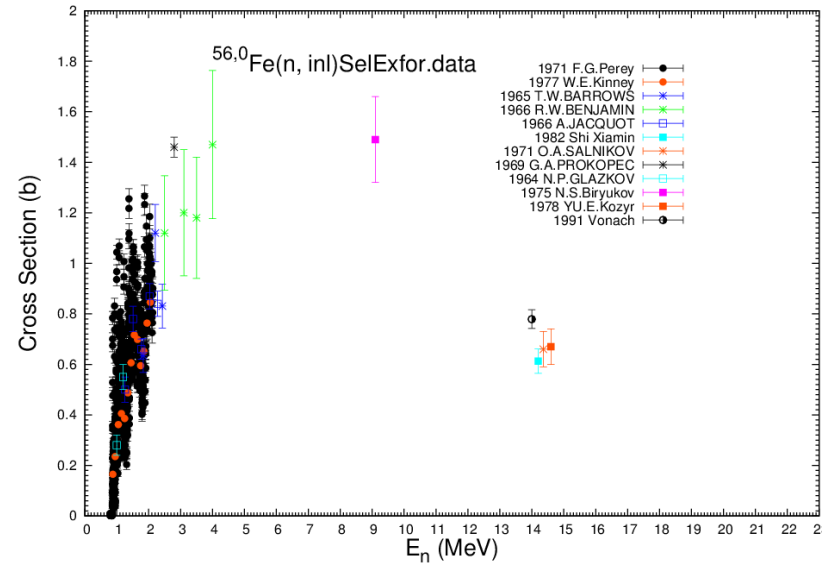
The other important reaction is nonelastic cross sections.

1. The nonelastic cross section for fast neutron energies ($E > 4\text{MeV}$ in ^{56}Fe) is measured with a higher accuracy than the elastic scattering cross section;
2. As the capture cross section is less than a few mb and the effective thresholds of the (n,p) and (n,a) reactions are higher than 5MeV, the total inelastic cross section for 0.85-5MeV is with a high accuracy (<0.1%) equal to the nonelastic one;
3. The results from direct measurements of the nonelastic cross sections by means of the spere transmission method. The experimenters claim a high accuracy for these absolute measurements. But the missing partial cross sections should be added in order to obtain the total nonelastic cross section.
4. A sets of data from the book (FAST NEUTRON PHYSICS 1963 PART II: Experiments and Theory P1429 Neutron Nonelastic Collision Cross Section) were collected and corrected (including the missing partial cross sections) in our figure.



Experimental data for inelastic cross section

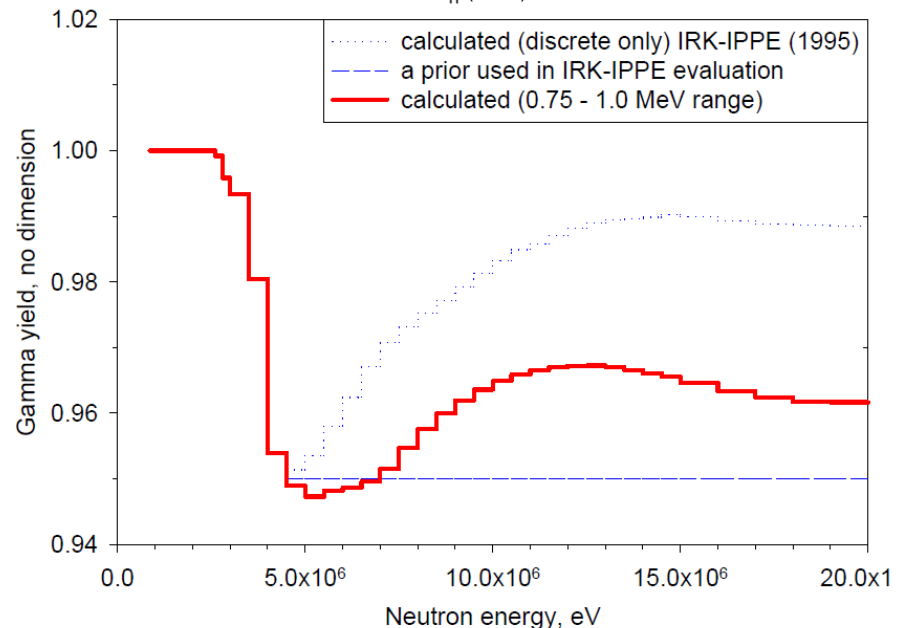
~14MeV



Experimental data for γ -ray production(847keV)

three sets of exp. data $\xrightarrow{\text{Convert to}}$ Inelastic cross section

$$\frac{\sigma(n, inl)_{exp}}{\sigma(n, inl)_{th}} = \frac{\sigma(n, inl\gamma)_i}{\sigma(n, inl\gamma)_{L=1 \rightarrow 0 th}}$$



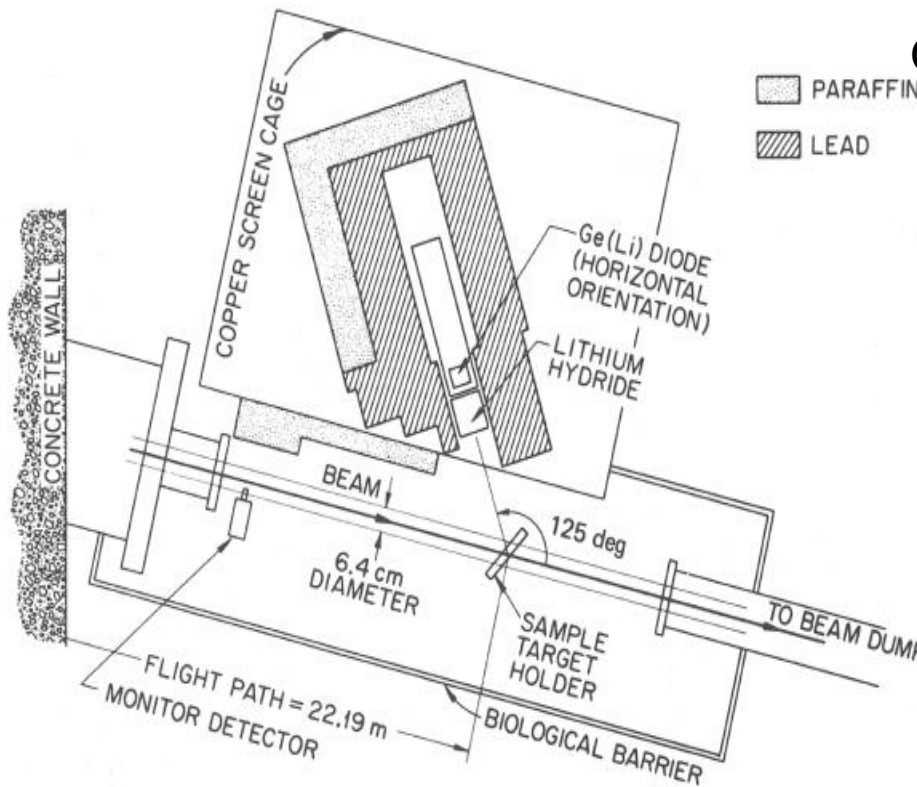


1

ORNL(Oak Ridge National Laboratory) J.K.Dickens 1991

Method:

The experimental approach is based the detection of the gamma rays emitted following the inelastic scattering of neutrons on the target.

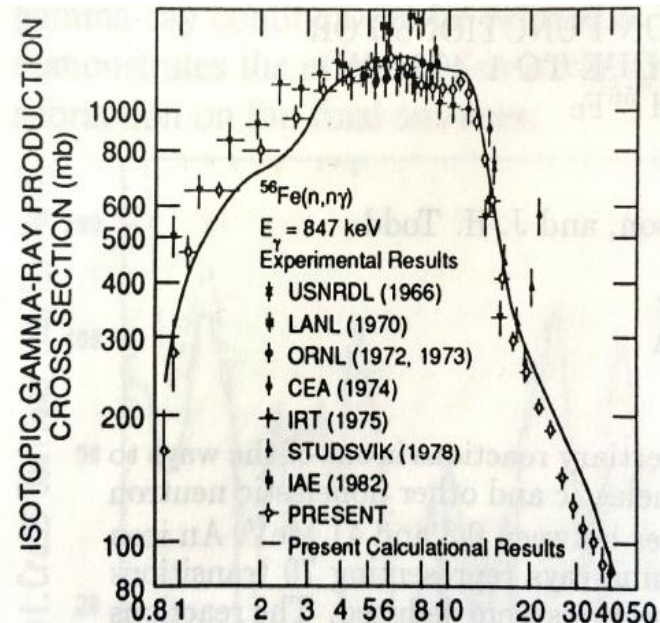


■ PARAFFIN
▨ LEAD

OREAL(0.8~41MeV)

Measured σ ($E_\gamma, \theta_\gamma=125\text{deg}$)

Position of the sample: 22.19m



Experimental arrangement for $(n, x\gamma)$ measurements. The sample is 22.19 m from the tantalum target



Neutron Source: LANSCE/WNR Detector: GEANIE

LANL LANSCE

Spallation neutrons
travel 20.34m to GEANIE
sample

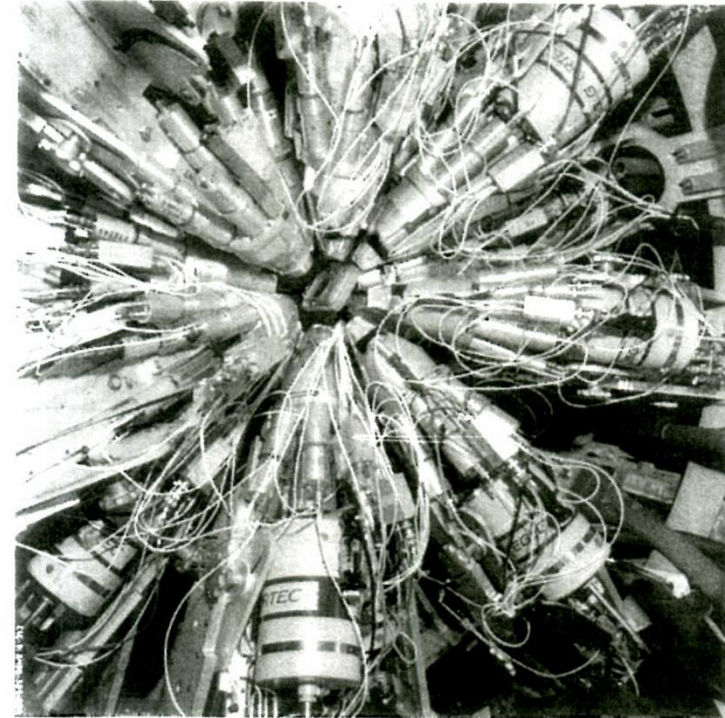


Figure 2. Top view of the GEANIE array showing the detectors with a mockup of an encapsulated Pu sample at the center.

The best available accuracy for r-ray cross section standards is typically 5% to 10%.
But two evaluations (Simakov98 - Savin00) differ by 26%.

In order to discuss discrepancies, R.O.Nelson performed

- (1) Absolute cross-section measurements
- (2) Relative cross-section measurements using the $\text{Cr}(n, n' \gamma)$ reaction
- (3) Use accurately measured neutron total cross-section and elastic-scattering data to further validate their results

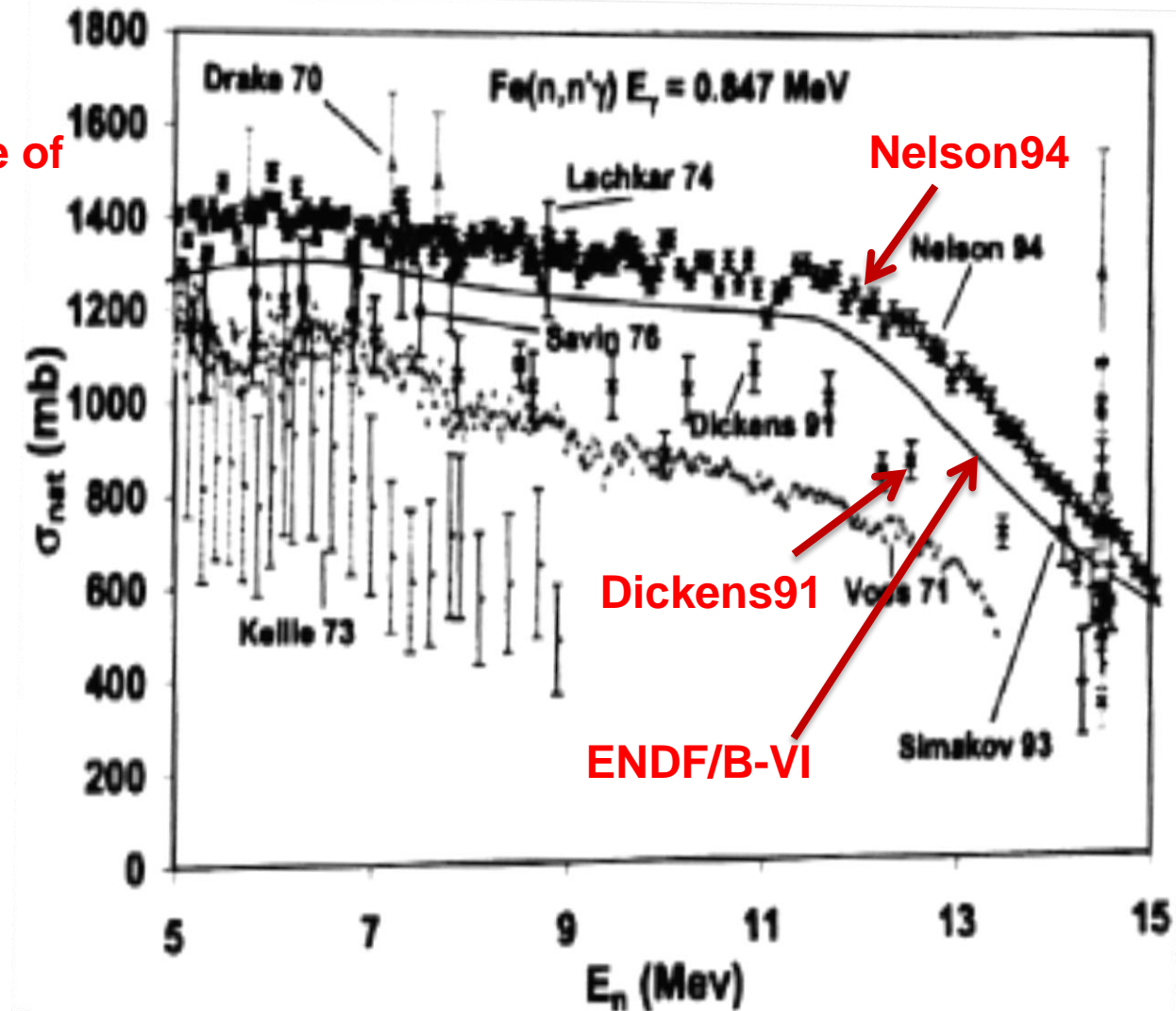


(1) Absolute cross-section measurements

Nelson:

This is not true for some of the previous measurements

Results agree well with the excitation function shape of Dickens that was used in the ENDF evaluation, but are about 20% larger than those of Dickens





(3) Use accurately measured neutron total cross-section and elastic-scattering data to further validate their results

TABLE 2. Cross sections for the Fe 847-keV γ ray at $E_n = 14.5$ MeV.

Data Set	$\sigma(^{\text{nat}}\text{Fe})$ (mb)	$\sigma(^{\text{nat}}\text{Fe})$ (mb)	$\sigma(^{56}\text{Fe})$ (mb)
	$^{56}\text{Fe}(n,n'\gamma) + ^{57}\text{Fe}(n,2n\gamma)$	$^{56}\text{Fe}(n,n'\gamma)$ natural	$^{56}\text{Fe}(n,n'\gamma)$ isotopic
This Work - Absolute	705 ± 56	683 ± 57	744 ± 62
This Work - Relative	684 ± 45	669 ± 46	730 ± 50
Simakov <i>et al.</i> Evaluation	785 ± 48		
Savin <i>et al.</i> Evaluation	621 ± 62		
ENDF/B-VI Inelastic Channel			681

The cross section result of $^{56}\text{Fe}(n,n\gamma)$ is shown in the last row of the table. The data of ENDF/B-VI are not accurate, lower by 7%.



3 GEEL 2014

Neutron source: GELINA (Geel Electron LINear Accelerator)
L=198.68m $\Delta T < 1\text{ns}$ $E_n = 0.1\text{-}18\text{MeV}$ High energy resolution

Detector: GAINS (Germanium Array for Inelastic Neutron Scattering)

110deg 150deg
position of sample: 154mm 119mm

Data given:

Each excited level cross section

Using the evaluated level scheme

To deduce the total inelastic cross section and various level cross sections

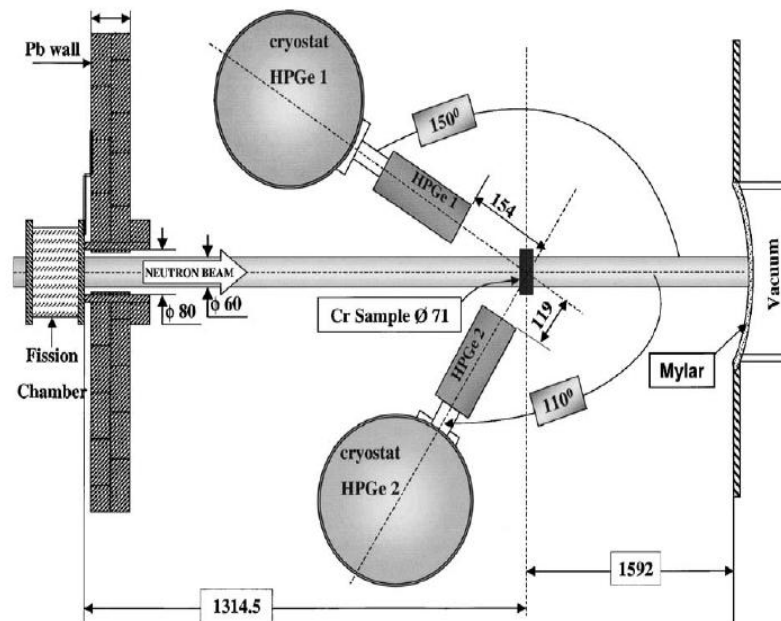
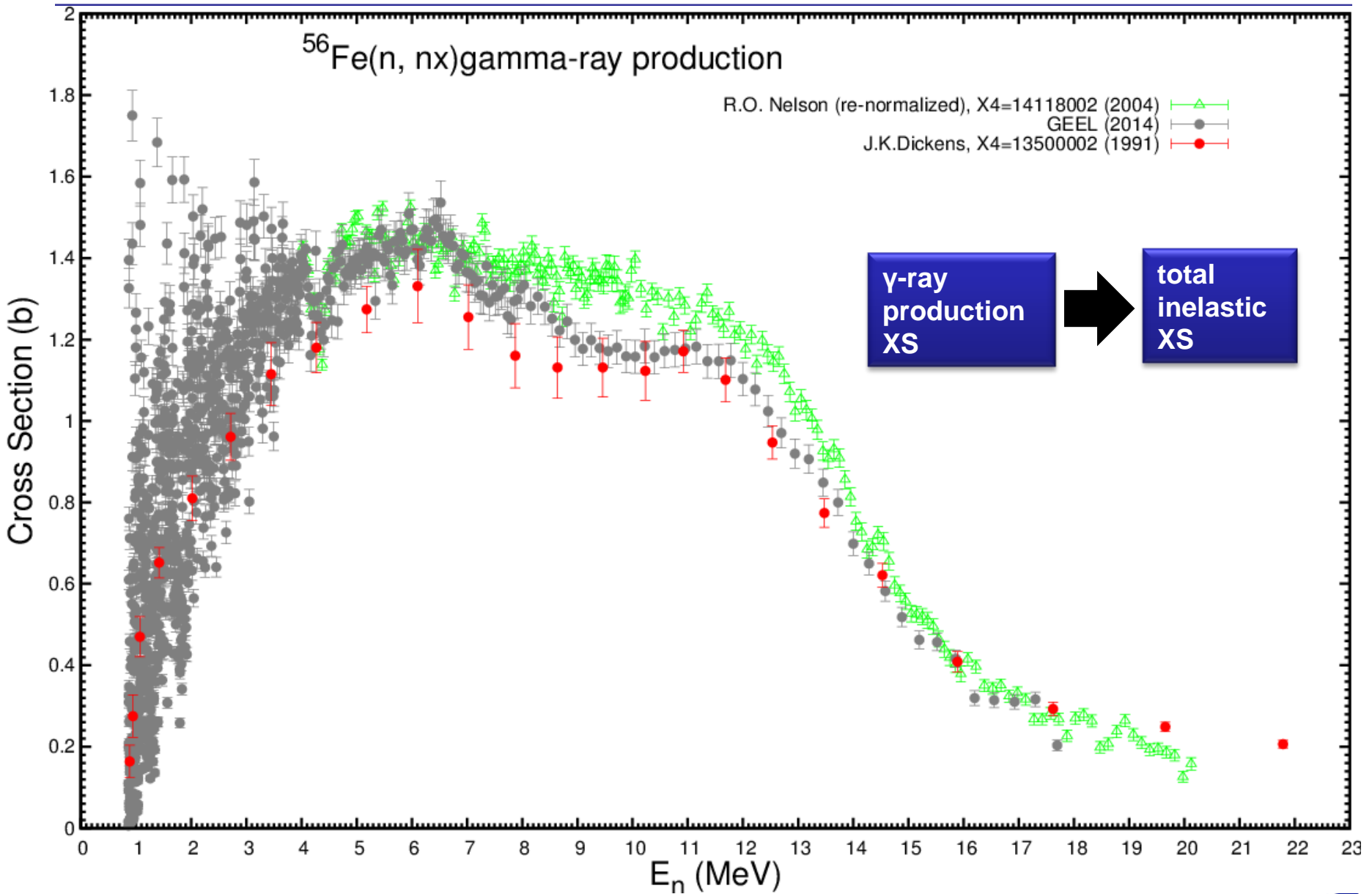
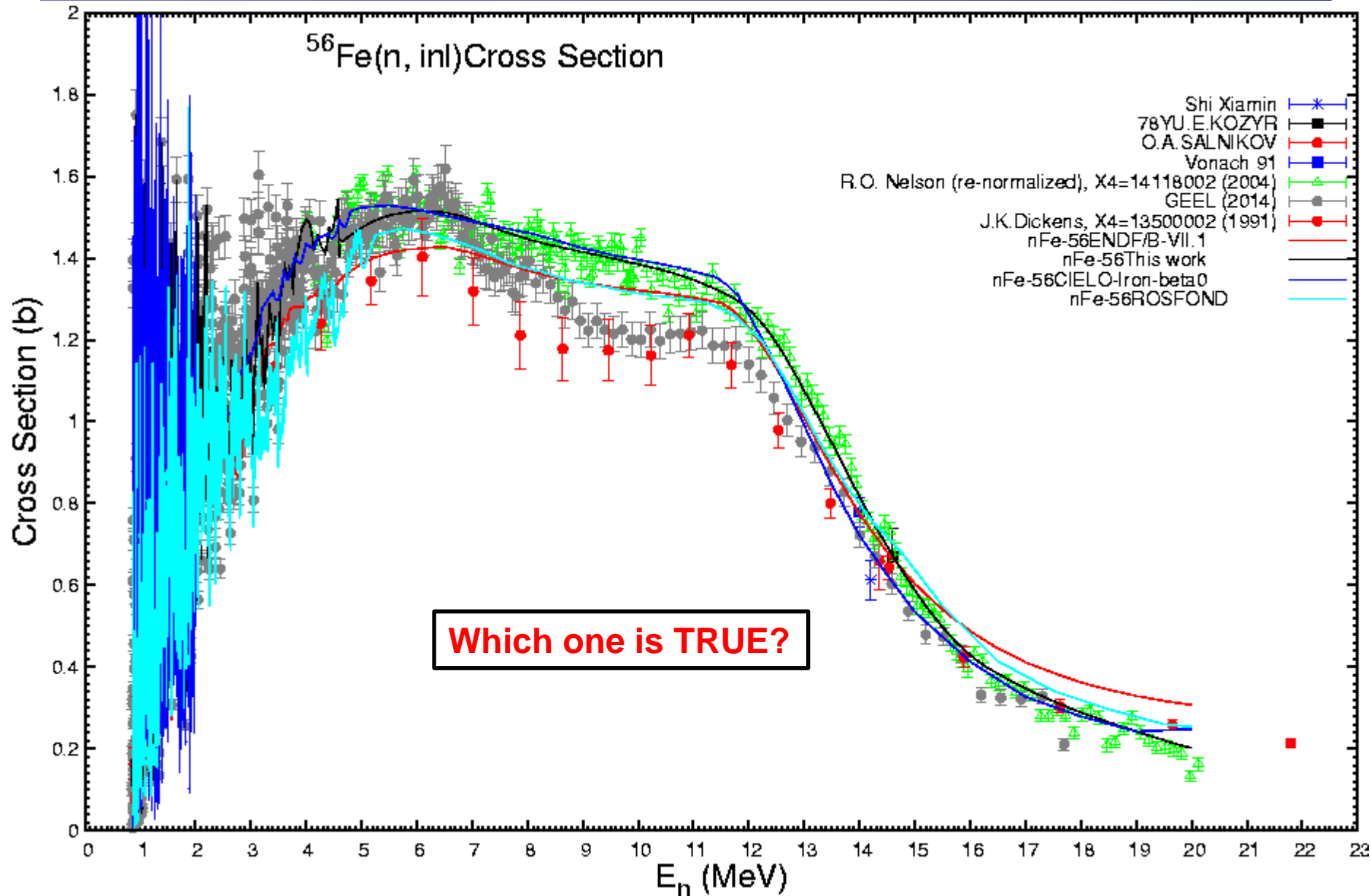


Fig. 2. Configuration of the detectors in Gelina flight path number 3 at the 200 m measurement station. The germanium detectors are placed at 150° and at 110° with respect to the beam axis. The fission chamber for the fluence normalization and a lead shielding wall are shown as well. Dimensions in mm.



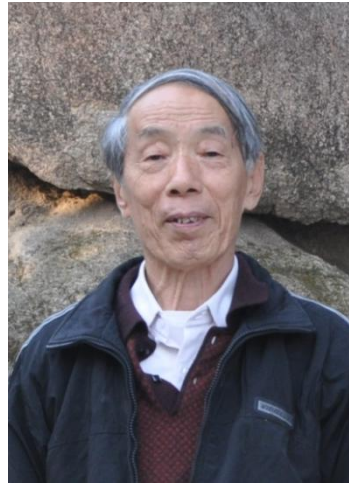


How to clarify the discrepancy?

Presentation for the CIELO Meeting of the NEA
18-20 May 2015 Paris, France



Hanlin LU



Tingjin LIU

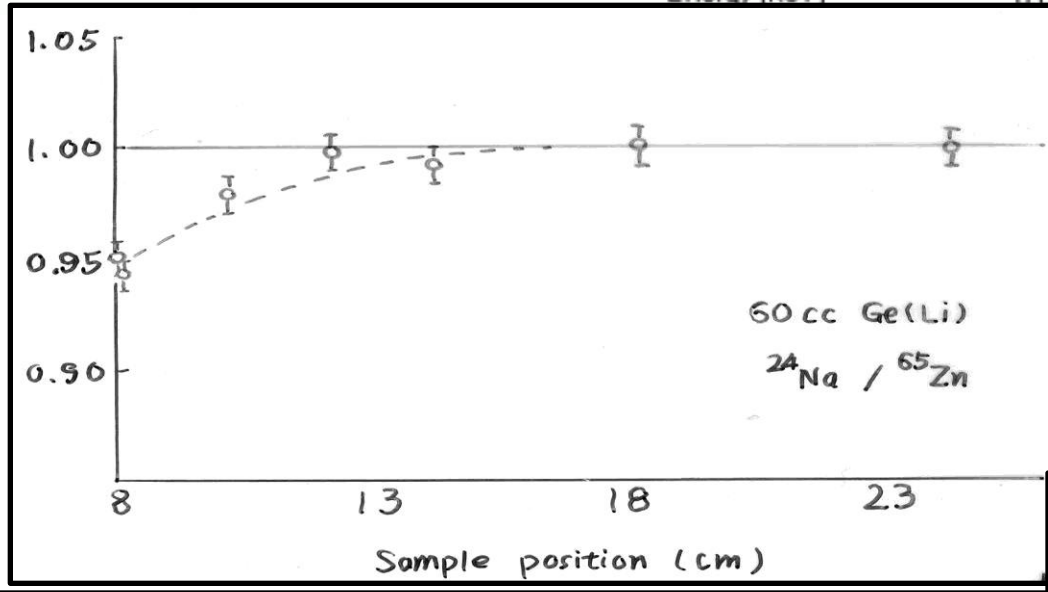
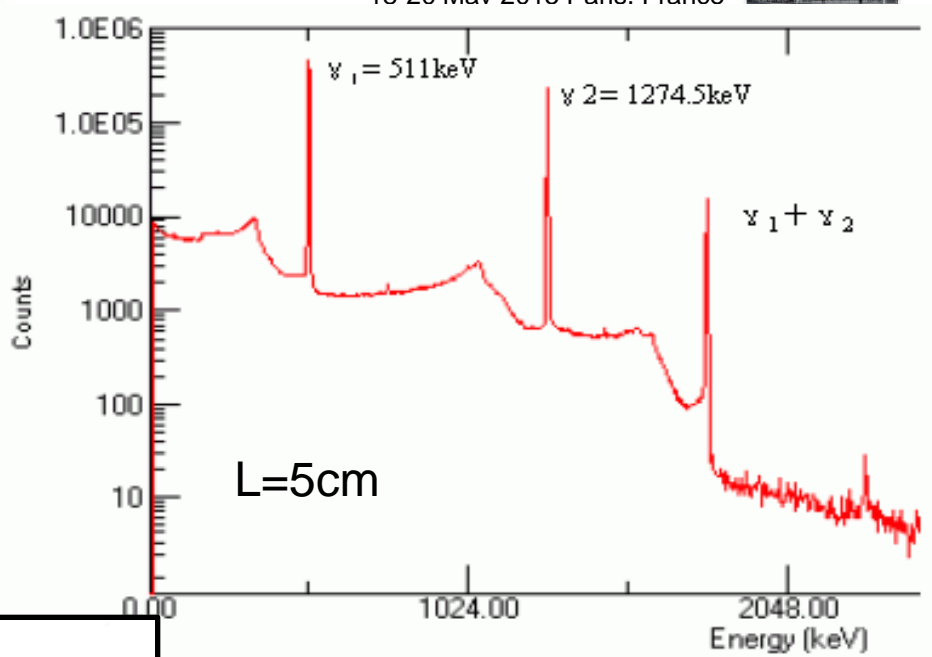
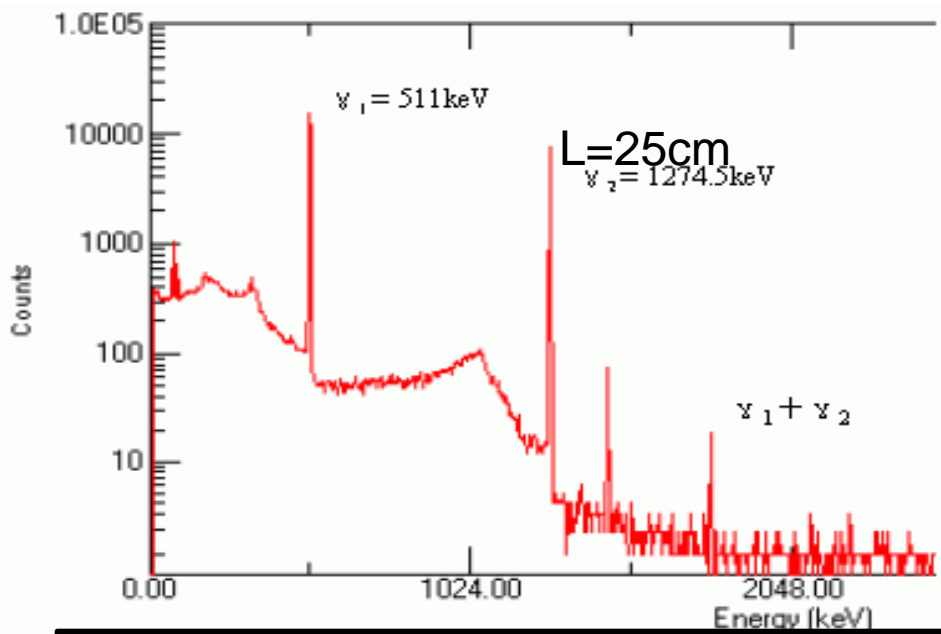


Jingshang ZHANG

■ Cascade problem?

■ Angle-integrated problem?

■ Cascade problem?



The cascade decay can affect the detection efficiency seriously when the distance between sample and detector is short.
measured in CIAE earlier with a combined source

the detection efficiency decrease fast when the distance is less than 15 cm.

the ratio of source intensity of ^{24}Na to ^{65}Zn as a function of distance

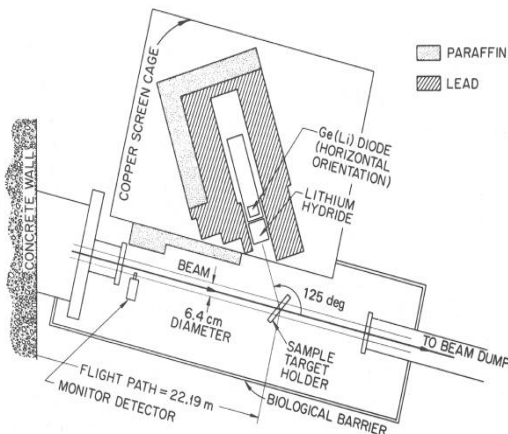


■ Cascade problem?

Suggested a new measurement, using a ^{137}Cs source as a reference, to find the efficiency correction factor due to cascade decay as a function of distance between sample and detector.

■ Angle-integrated problem?

Gamma emission is anisotropic. Integrated value by simply multiplying them with a factor 4π can cause uncertainty.



Experimental arrangement for $(n, x\gamma)$ measurements. The sample is 22.19 m from the tantalum target of the ORELA.

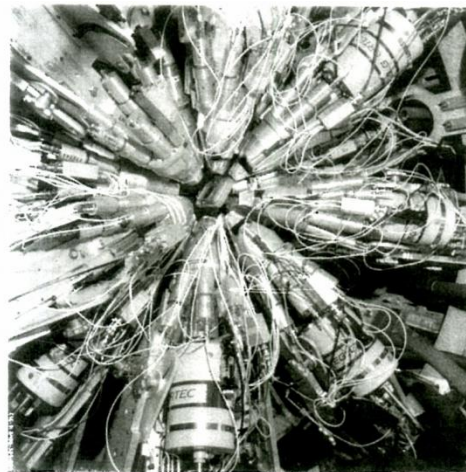


Figure 2. Top view of the GEANIE array showing the detectors with a mockup of an encapsulated Pu sample at the center.

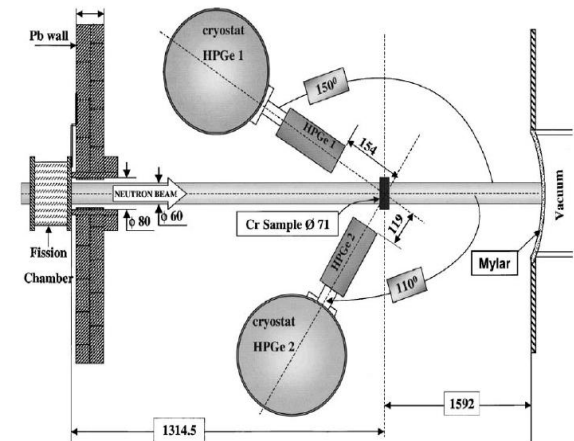


Fig. 2. Configuration of the detectors in Gelina flight path number 3 at the 200 m measurement station. The germanium detectors are placed at 150° and at 110° with respect to the beam axis. The fission chamber for the fluence normalization and a lead shielding wall are shown as well. Dimensions in mm.

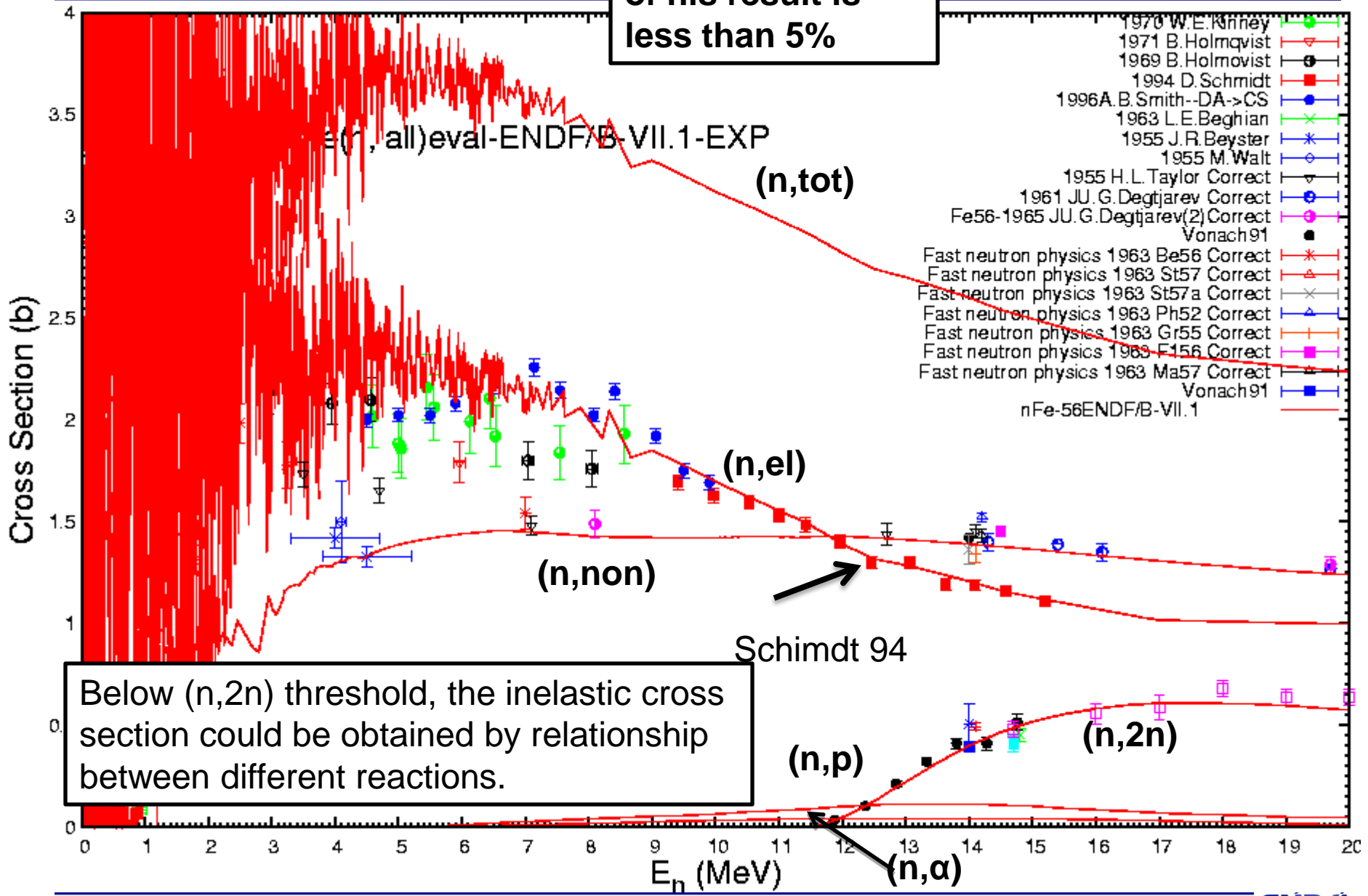


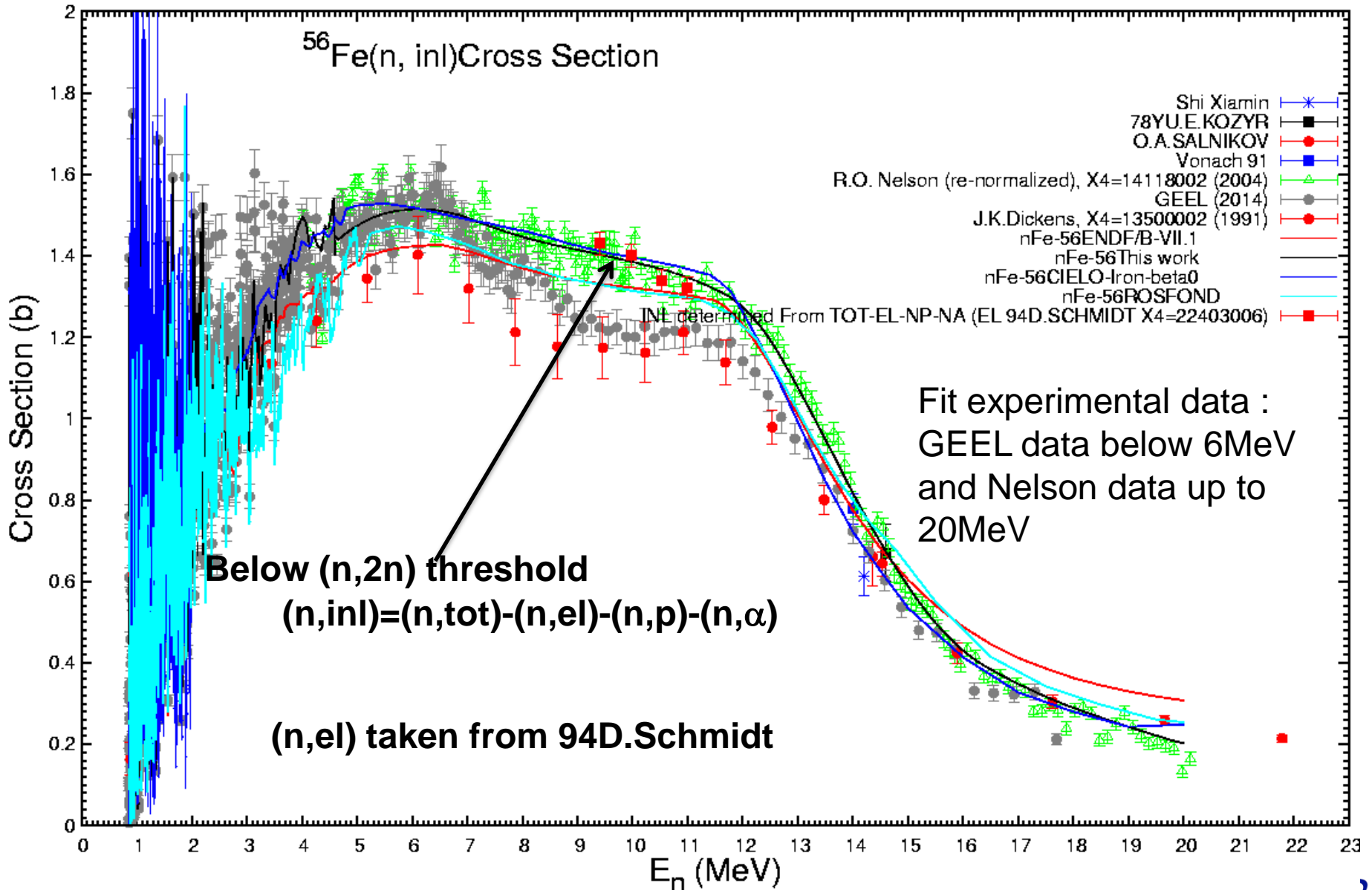
**One important experimental data can
be used in our evaluation for inelastic
scattering cross section.**



**Experimental data of
(n,el) reaction measured
by Schimdt in 1994 at
PTB**

The uncertainty of his result is less than 5%







Integral measurements and evaluated data libraries

NUCLEAR SCIENCE AND ENGINEERING: 170, 207-233 (2012)

Novel Investigation of Iron Cross Sections via Spherical Shell
Transmission Measurements and Particle Transport
Calculations for Material Embrittlement Studies

Michael T. Wenner*† and Alireza Haghghat‡
University of Florida, Gainesville, Florida 32611

James M. Adams§ and Allan D. Carlson

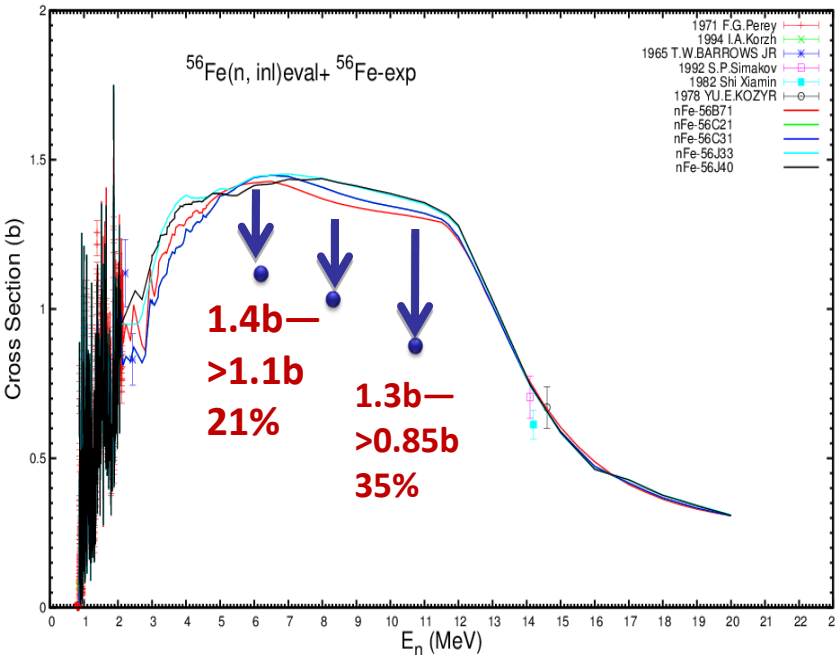
Author suggest that the inelastic cross section of B7 should be adjusted, decreasing by 21%, 29% and 35% in energy ranges of 6.18 to 6.20, 8.16 to 8.21, and 10.76 to 10.81 MeV.

INTEGRAL MEASUREMENTS AND EVALUATED DATA LIBRARIES

R. O. Nelson*, N. Fotiades*

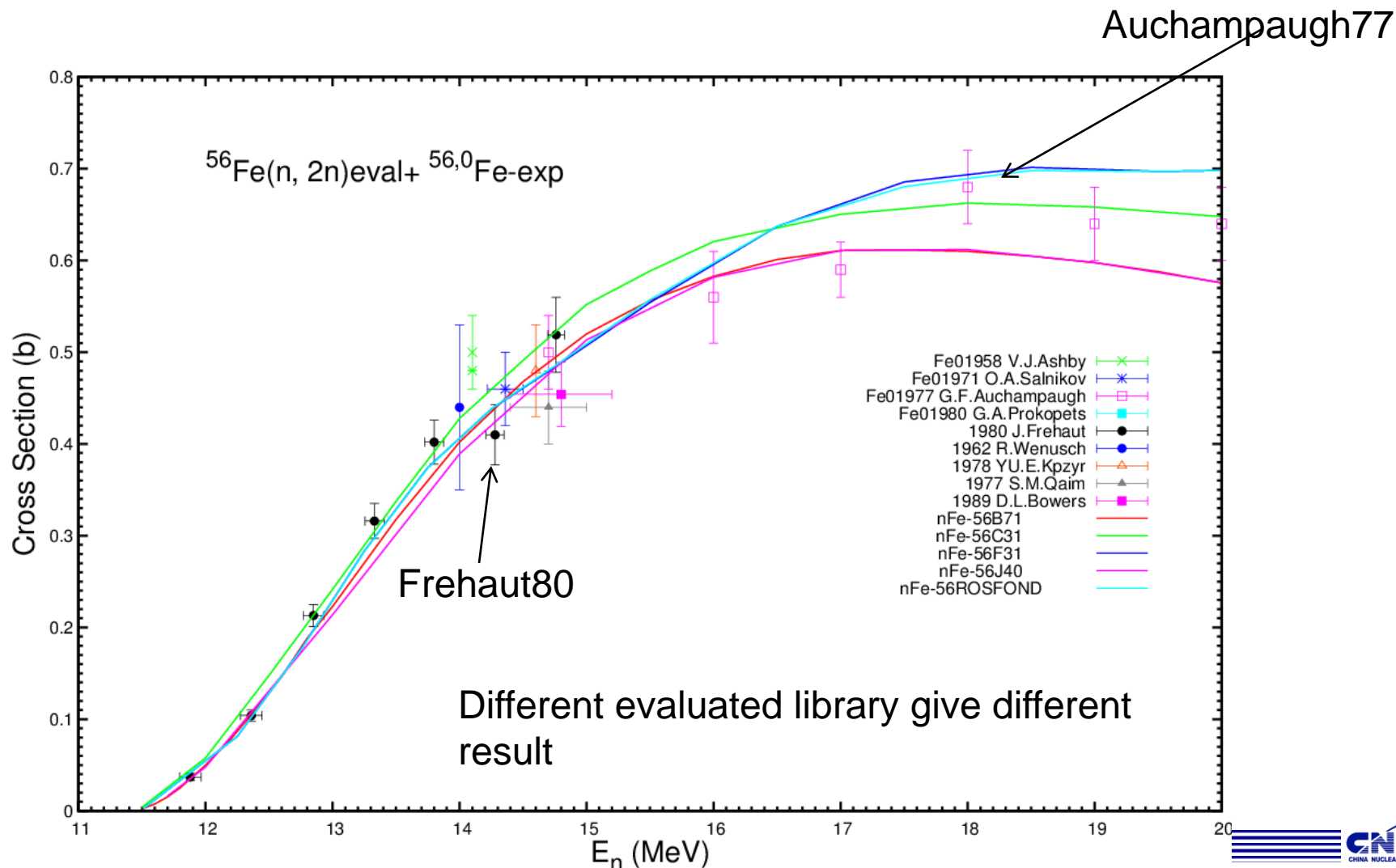
Integral neutron spectral measurements with pulsed spheres and for nuclear reactor pressure vessels, in the past, have often shown more high-energy neutrons than calculated using the data libraries, and hence appear to **contradict our result of a larger inelastic cross section.** A solution to this problem may lie in adjusting the angular distributions of the neutron elastic and inelastic scattering. New higher accuracy

pulsed-sphere data such as those of Massey *et al.* [11] may aid in resolving these questions. Recent measurements of Christodoulou *et al.* [12] of the angular distributions of the elastic and inelastic scattering of neutrons from Fe do show some discrepancies. It is noted that at the very forward angles the experiment underestimates the elastic cross section due to the variation with angle of the incident neutron energy.





focuses on two experimental data which measured by the large gadolinium loaded liquid scintillator method ,a direct measurement method



STATUS OF (n,2n) CROSS SECTION MEASUREMENTS
AT BRUYERES-LE-CHATEL

J.FREHAUT, A.BERTIN, R.BOIS and J.JARY

Service de Physique Neutronique et Nucléaire
Centre d'Etudes de Bruyères-le-Châtel
B.P. 561
92542 MONTRouGE CEDEX, France

$D(d,n)3He \rightarrow 6\sim 15\text{MeV}$
neutron

7MV VDG

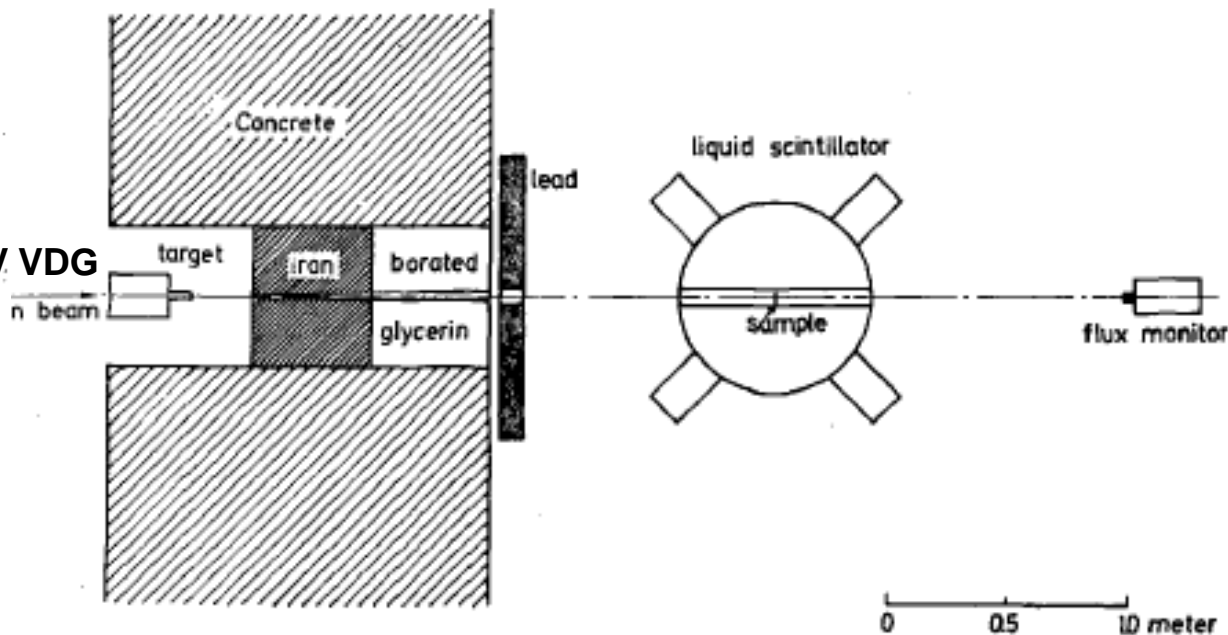


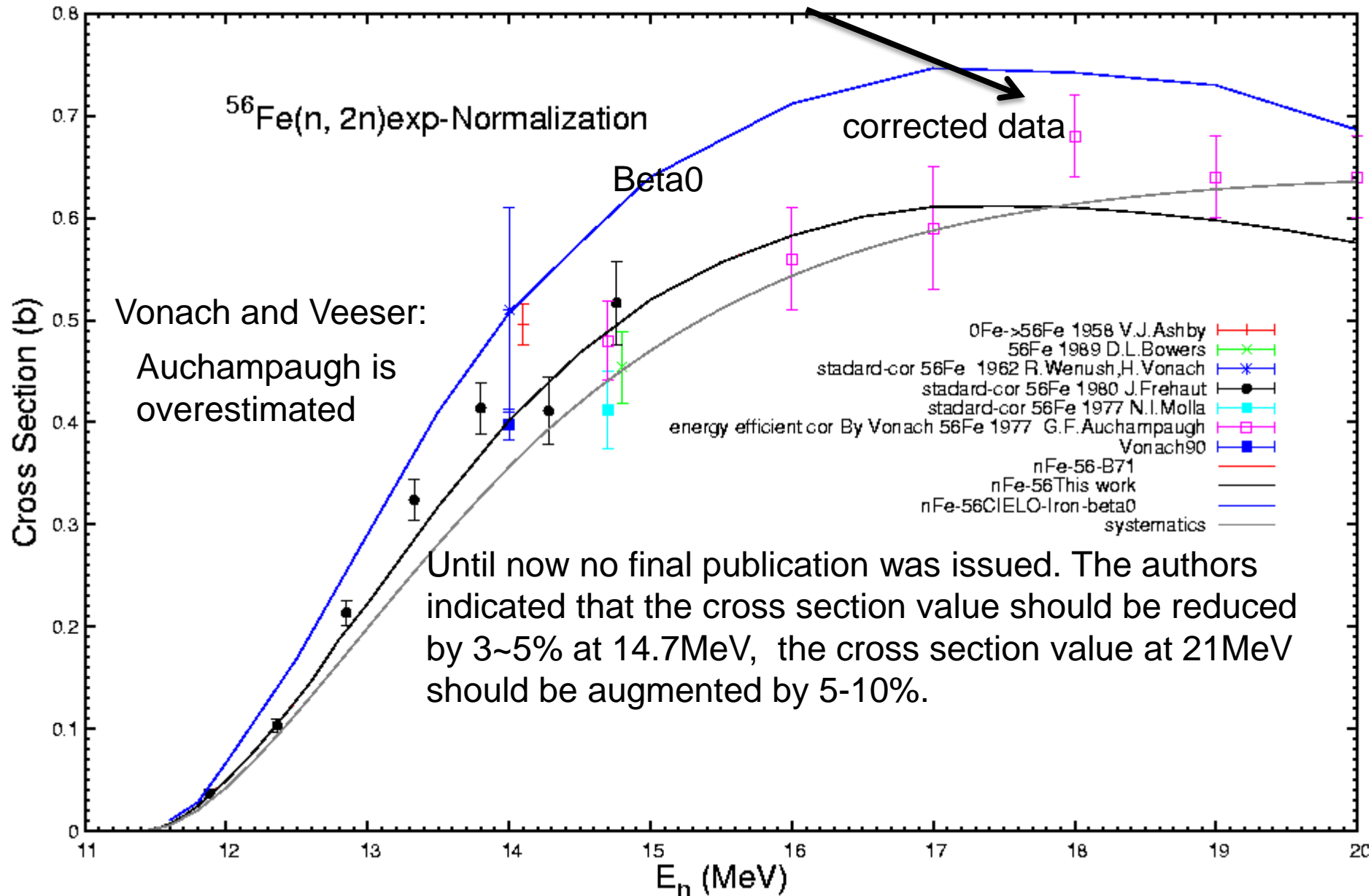
Fig. 1 - Experimental set-up.

Corrections were applied to obtain the multiplicities of neutrons emitted by the sample

DATA REDUCTION

- 1、 Subtraction of the detector background
- 2、 Correction for the detection dead time losses (dead time 120 ns)
- 3、 Backgrounds from 2 scattered neutrons in a single burst were corrected
- 4、 The detection efficiency (~75%) was measured with a ^{252}Cf

The (n,2n) cross sections are obtained with a relative accuracy of 4% to 10%.



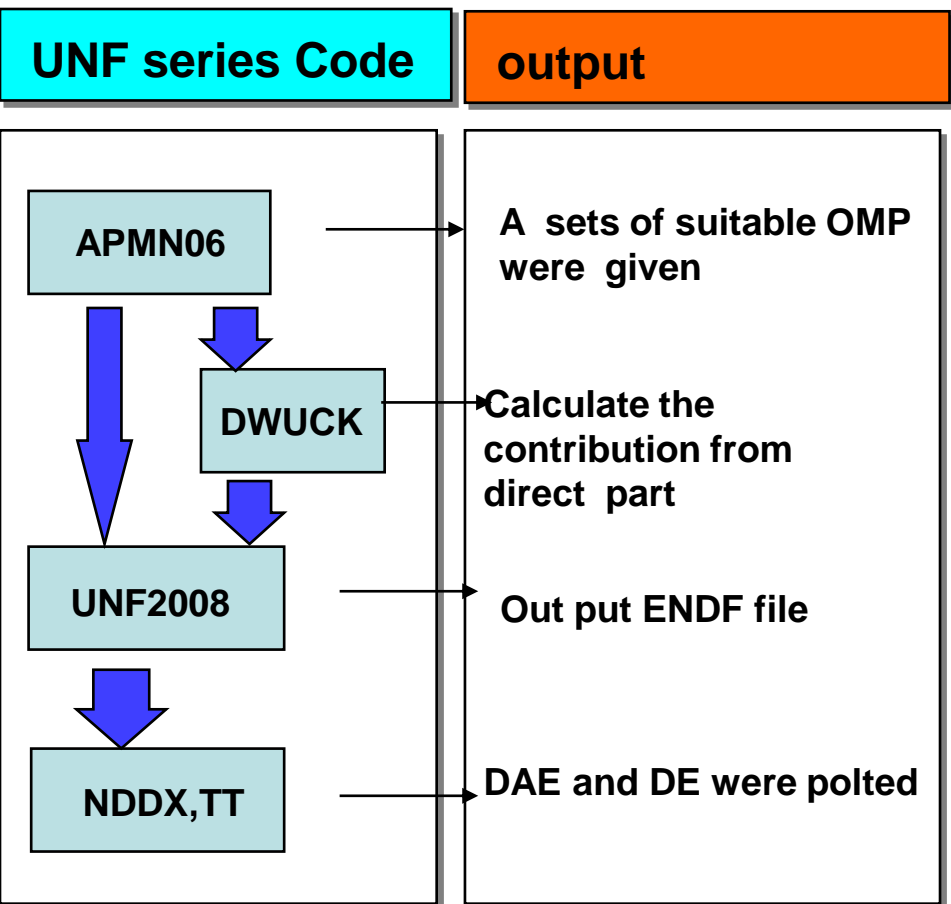


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Theoretical calculation result by code UNF



OMP			
V_0	54.52155685	U_2	-0.00040197
V_1	-0.23792717	r_r	1.09132423
V_2	-0.00590990	r_s	1.27747381
V_3	-24.87143517	r_v	1.49487329
V_4	-0.00619497	α_r	0.65029401
W_0	10.84276485	α_s	0.50812095
W_1	-0.25981072	α_v	0.44999999
W_2	-12.94733429	U_{SO}	6.23620844
U_0	-1.39829016	r_{so}	1.08222973
U_1	-0.19923522	a_{so}	0.62750721

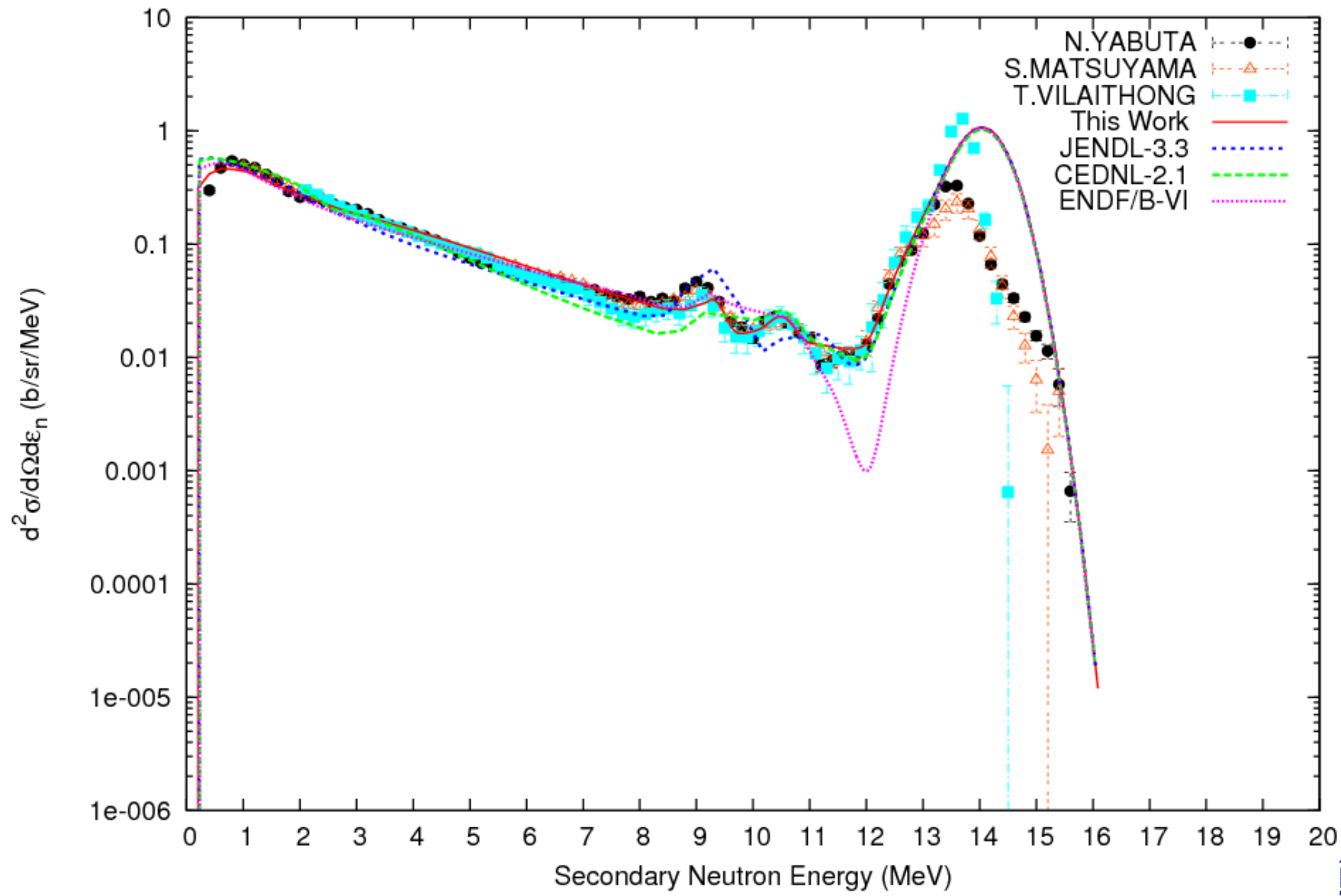
	level	Energy	$J\pi$	β
β parameters	1	0.4868	2+	0.260
	2	2.0851	4+	0.44
	3	2.6576	2+	0.06
	5	2.9599	2+	0.08
	8	3.3698	2+	0.12
	11	3.4453	3+	0.03
	20	3.8564	3+	0.03
	24	4.1199	3+	0.05
	29	4.3948	3+	0.01
	30	4.4014	2+	0.05
	38	4.6583	3+	0.12

Level density parameters and pair correction:

	(n, γ)	(n,n')	(n,p)	(n, α)	(n, ^3He)	(n,d)	(n,t)	(n,2n)	(n,n α)	(n,np)	(n,3n)
Level density parameters	7.650	5.152	6.395	5.680	6.076	6.334	6.337	5.261	5.416	7.157	5.577
Pair correction	0.100	0.25	-0.75	0.40	0.35	0.15	0.00	0.50	0.40	0.20	0.50

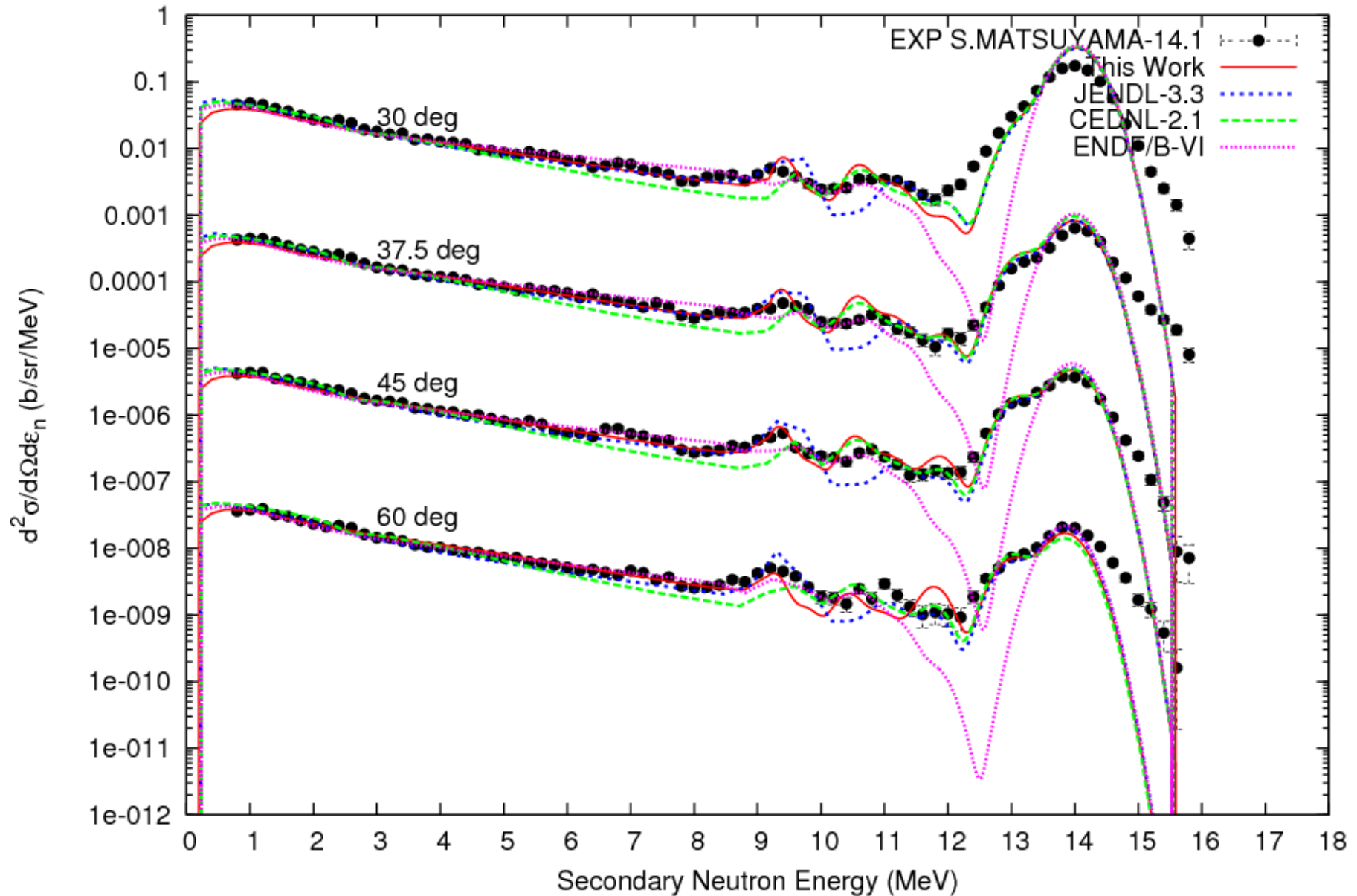


$^{0}\text{Fe}(n, xn)$ 1-N.YABUTA 2-S.MATSUYAMA 3-T.VILAITHONG-14.1





$^{56}\text{Fe}(n, xn)$ DAE S.MATSUYAMA-14.1





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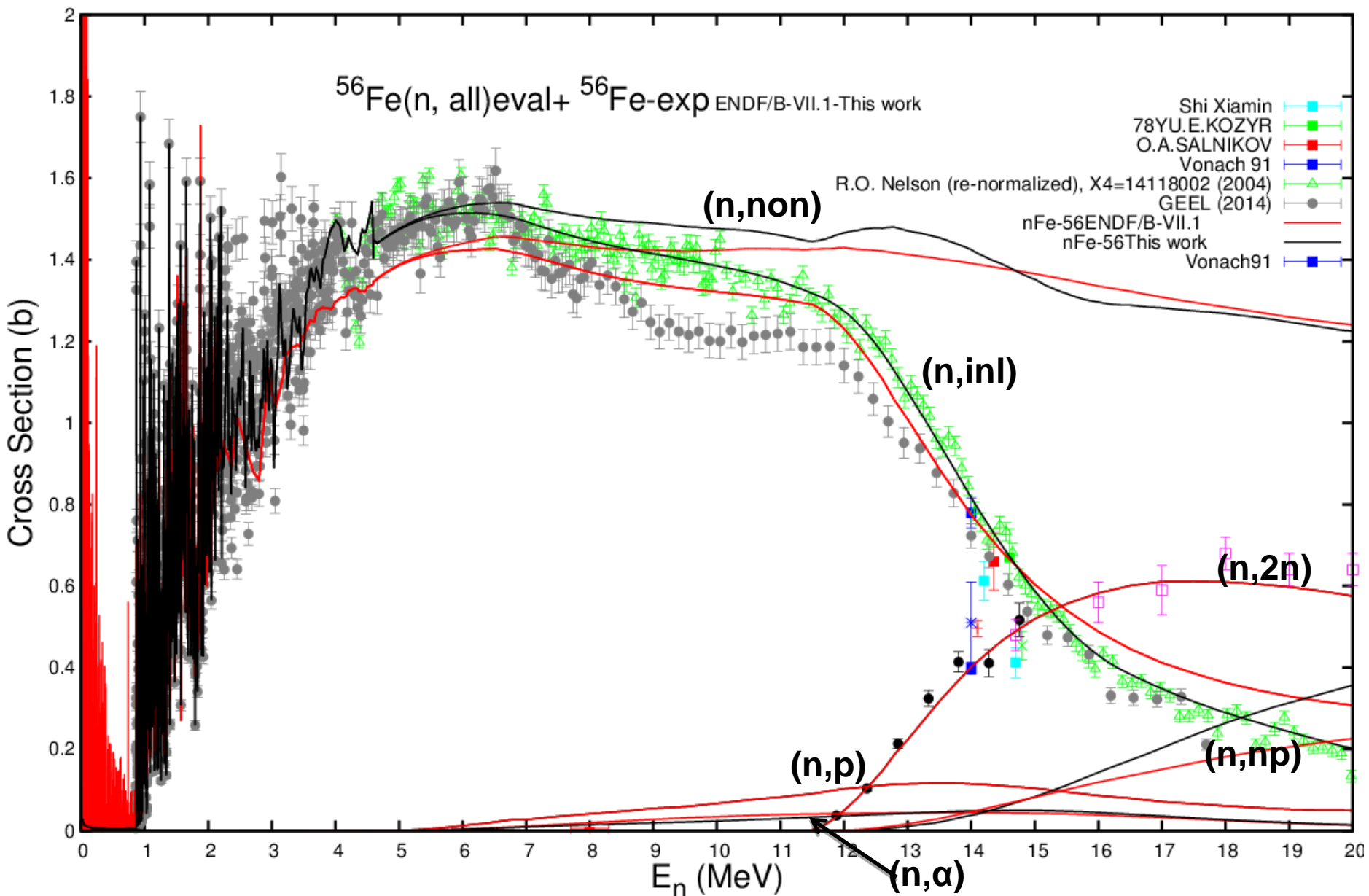


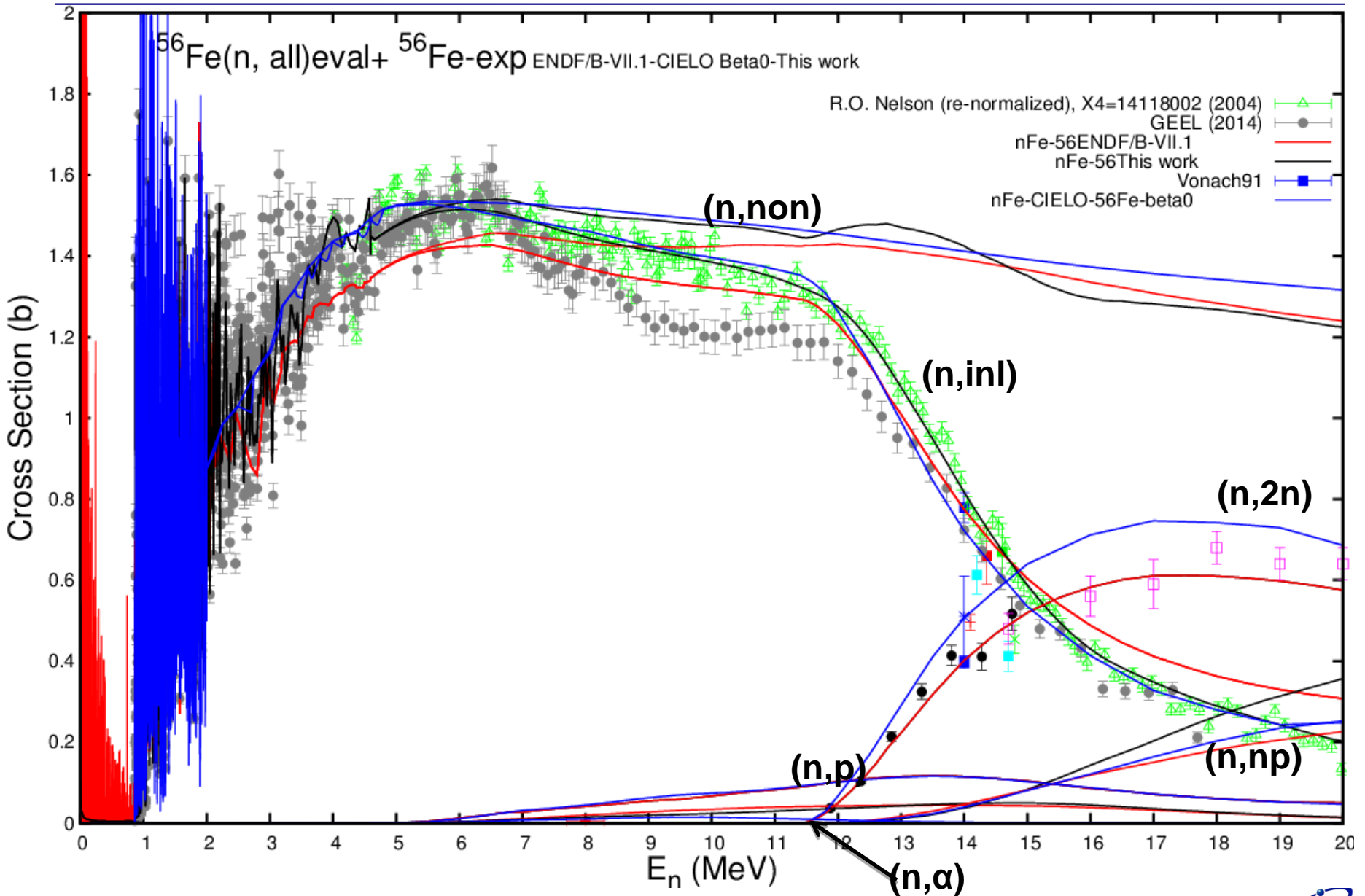
Preliminary work

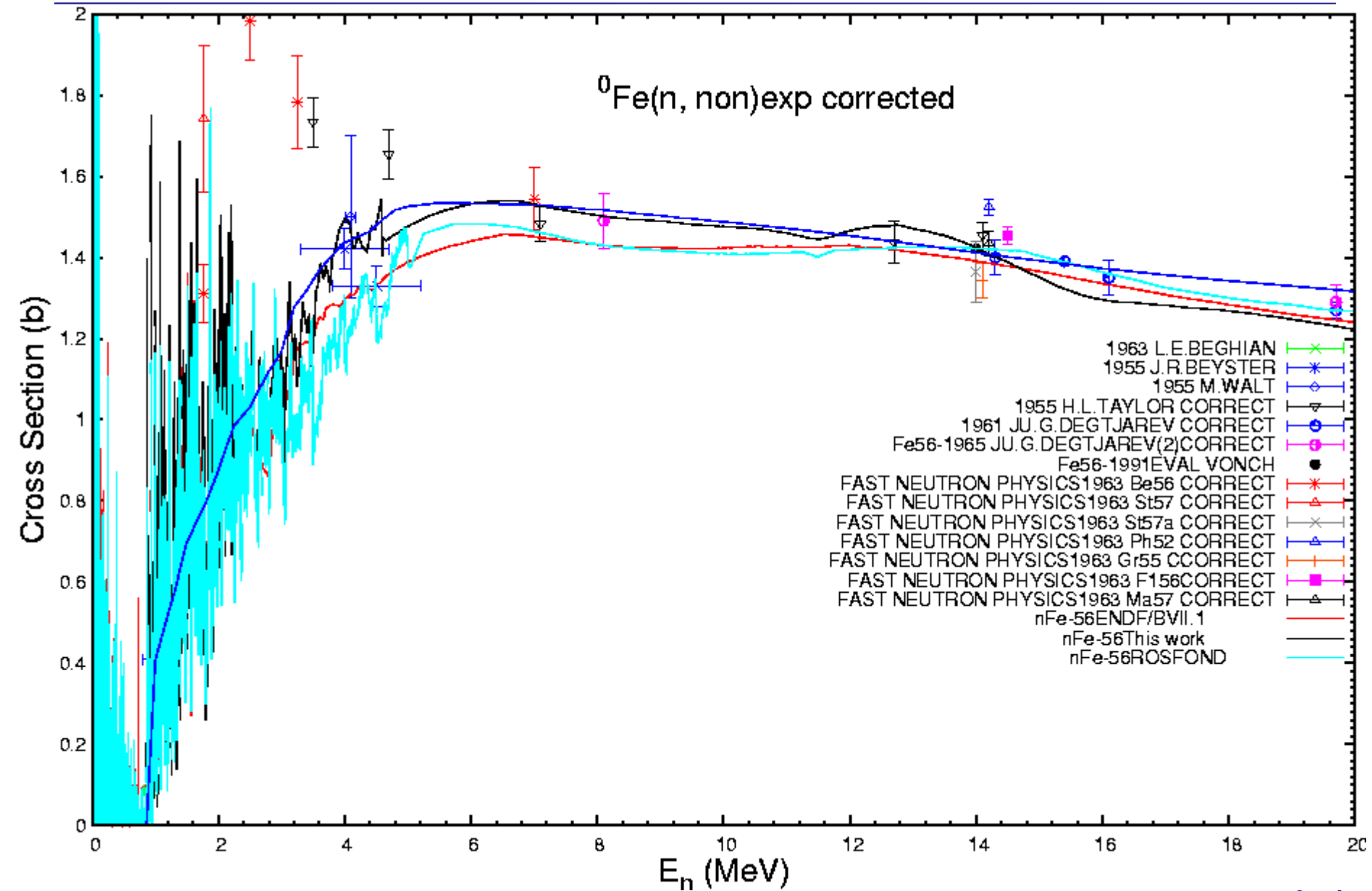
Data: theoretical calculation result by UNF
Evaluated result of Experimental data

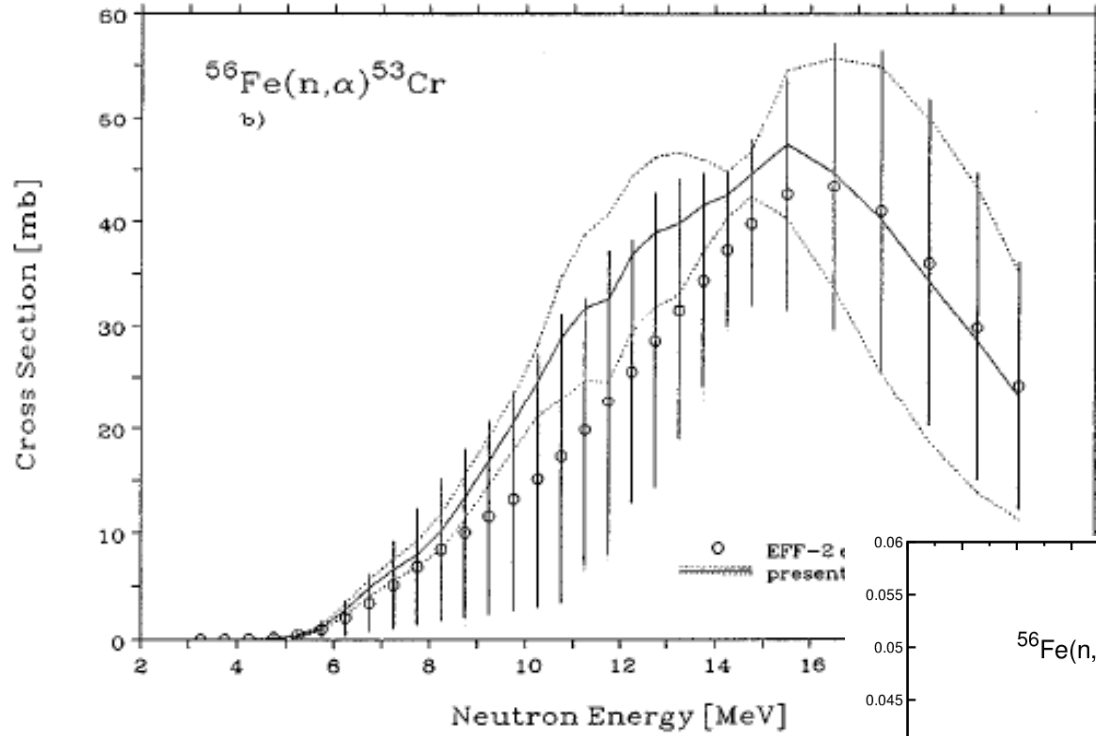
MF	MT	Data Source	
3	1	ENDF/B-VII.1	
3	4	Fit GEEL2014 Exp Data(~6MeV)+Nelson2004Exp Data(6~20MeV)	
		51	Fit GEEL2014 Exp Data
		52~88	Theoretical calculated result(UNF)
		91	(3,4)-(3,51:88)
3	16	Fit Exp Data	
3	103	ENDF/B-VII.1	
3	102, 104,105, 106,107	Theoretical calculated result(UNF)	
3	3	(3,3)=(3,102)+(3,4)+(3,16)+(3,103)+(3,104)+(3,105)+(3,106)+(3,107)	
3	2	(3,2)=(3,1)-(3,3)	

$$(3,3) = (3,102) + (3,4) + (3,16) + (3,103) + (3,104) + (3,105) + (3,106) + (3,107)$$



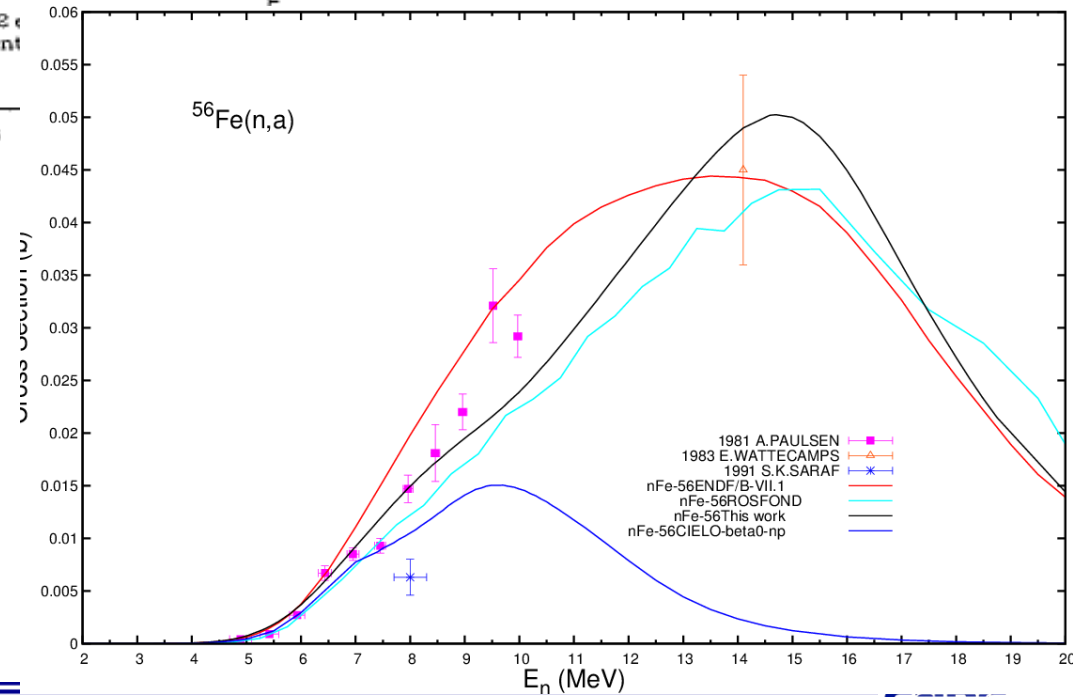


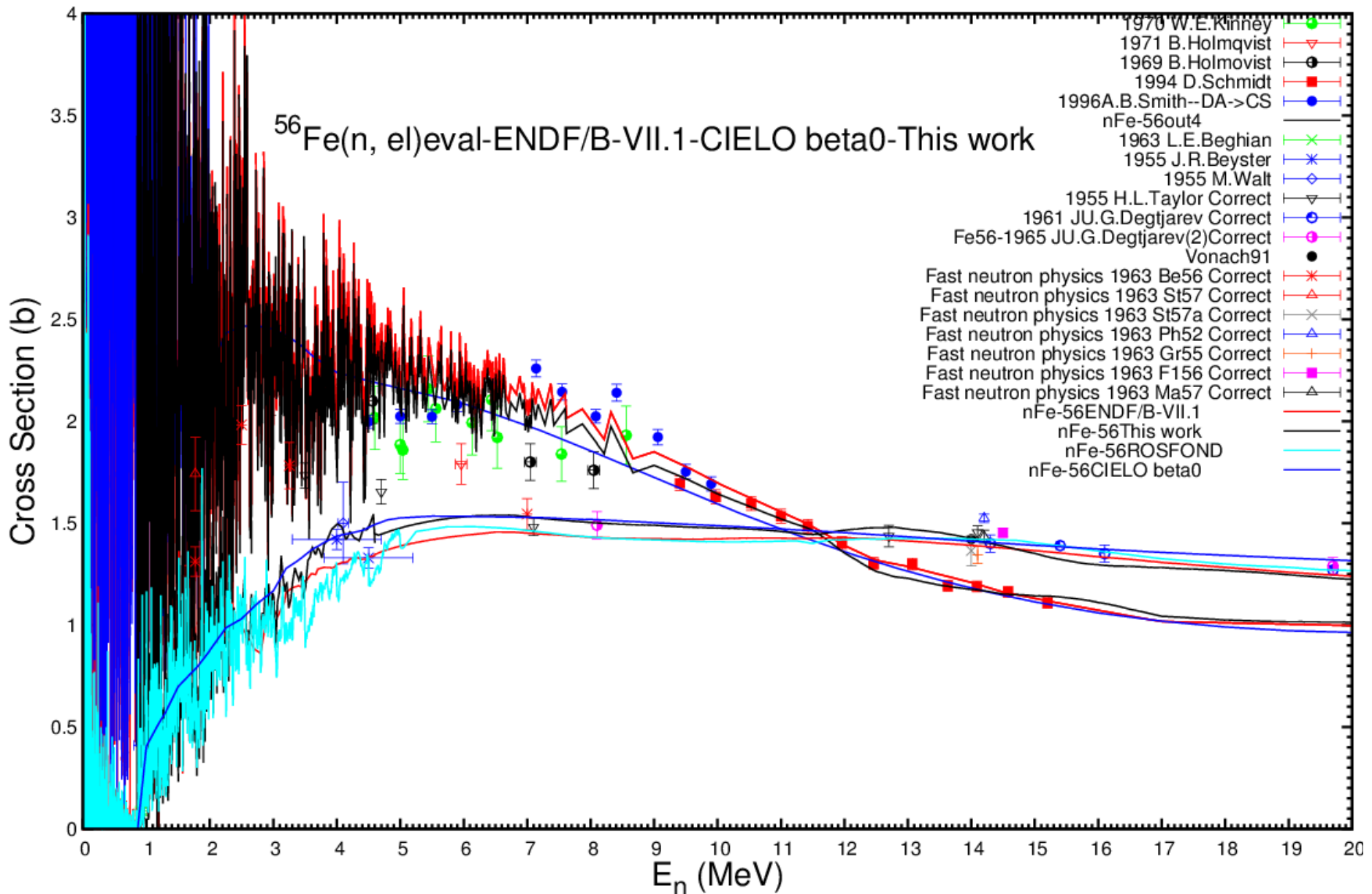




EFFdoc-184 By Vonach 92

Beta0 is the lowest one







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The work in the future

- The discrepancy of **the γ production data** and the inelastic cross section obtained from these data between Nelson and GEEL **need to be investigated further.**
- In order to find the discrepancy of integral measurements and evaluated data libraries, the **data of angular distribution should be paid more attention.**
- **Consistent joint evaluation of all cross sections should to be proceed** based on the experimental data and theoretical calculated results.