The evaluation of experimental data in fast range for ^{56}Fe (n,inl)

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Iron is one of the five materials (^{1}H, ^{16}O, ^{56}Fe, $^{235,238}U$ and ^{239}Pu) selected for evaluation within the pilot international evaluation project CIELO.

Critical analysis of experimental data for n+^{56}Fe reaction is the basis for constraining theoretical calculations and eventual creation of the evaluated file.

This work:

Make efforts to resolve the discrepancies between the measurements for ^{56}Fe(n,inl) .

Provide recommended results for ^{56}Fe(n,inl) in the fast neutron energy range.

Collections and corrections of experimental data

- The experimental data were taken mainly from the EXFOR library (taken from the original publications) and from the recent new measurements

- Natural iron were used for the reactions

  - the difference between ^{56}Fe and ^{nat}Fe is known to be small

  -conversion from ^{nat}Fe to ^{56}Fe is possible

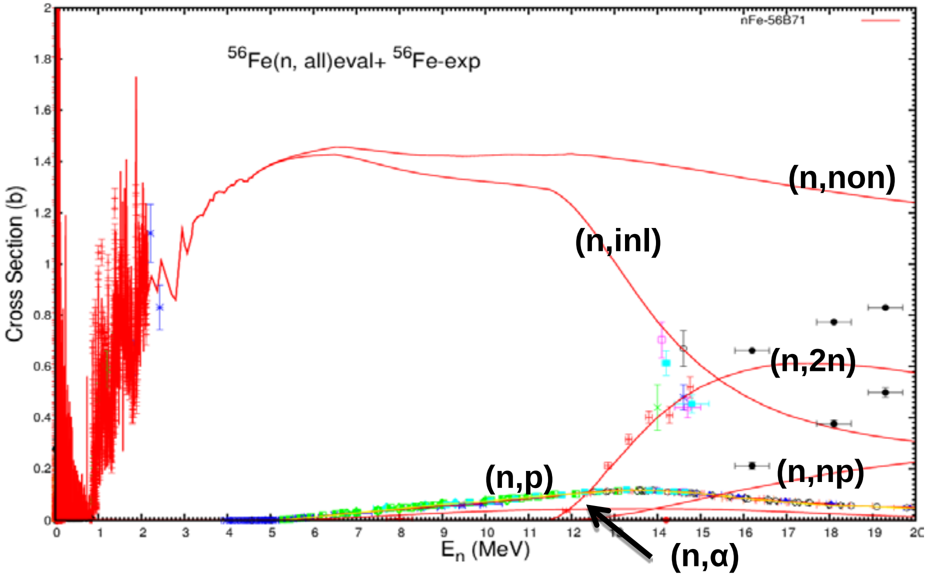
- The Experimental data were critically reviewed and corrected according to the newly recommended standard cross sections for monitor reactions and recommended decay data, if possible.

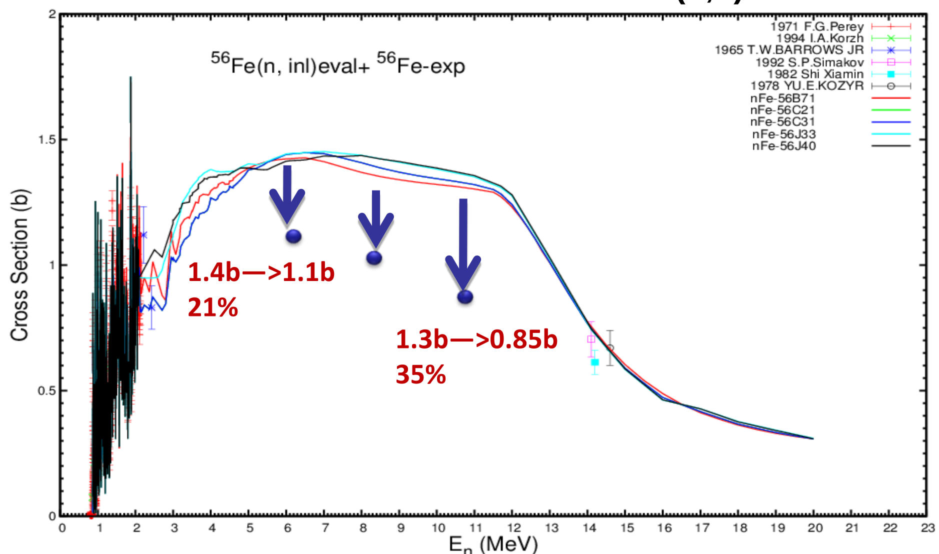
Inelastic scattering cross section

- The inelastic scattering cross section is the major part of the noelastic cross section

- Different evaluated libraries: do not agree well

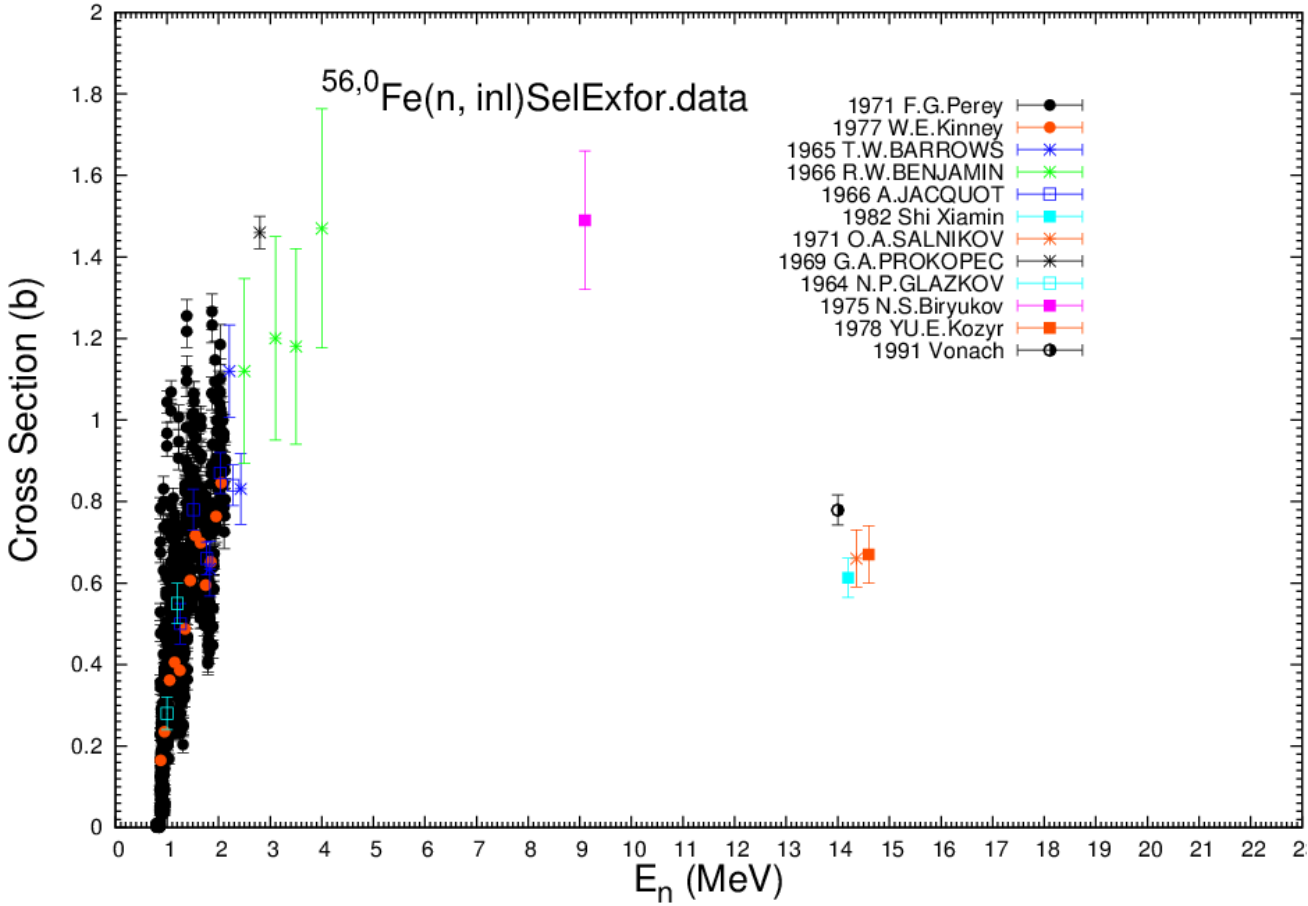
- Recent **measurement of neutron transmission through iron spheres**, for quasi-monoenergetic neutrons ranging from about 6 to 11 MeV, suggested decreases of $^{56}Fe(n,inl)$ cross section by 21%, 29%, and 35% at 6.2, 8.2, and 10.8 MeV respectively.





Status of experimental data of inealstic reaction

Apart from scarce experimental data existing around 14 MeV, there is nothing available that could be used for constraining theoretical calculations in the fast energy region.



Use of the γ-ray production to infer the total inelastic cross section

For ^{56}Fe, the production of the 847-keV γ-ray amounts to **93-100%** of the total inelastic cross section with an energy dependence that can be deduced **from known decay schemes and experimental data of partial γ-ray production.**

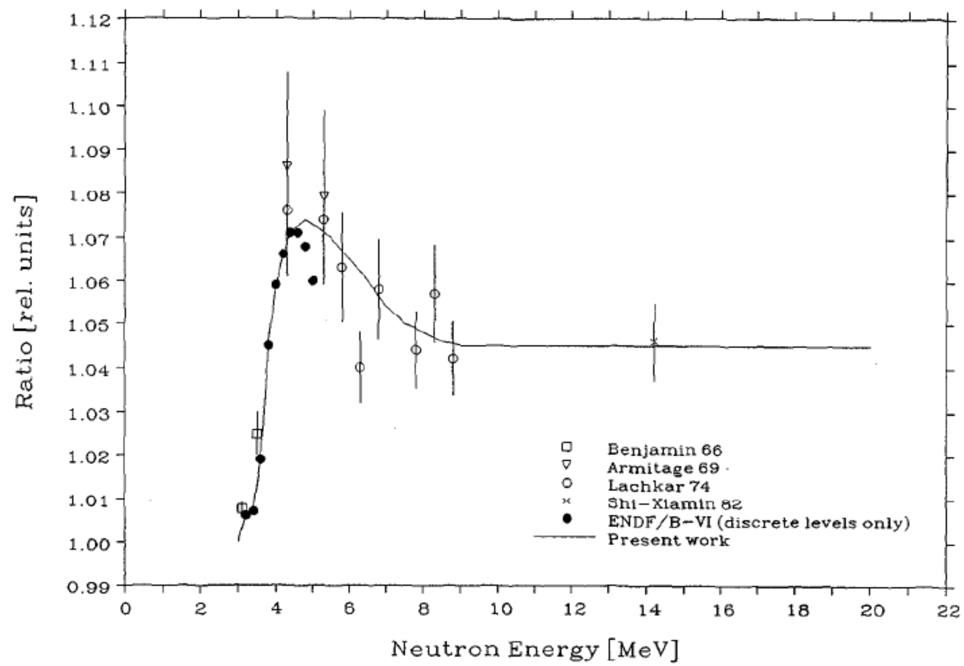


Figure 2: Ratio of the total inelastic scattering cross section to the cross section for production of the 0.847 MeV γ - ray obtained from available experimental and evaluated data. The solid line is drawn as an eye guide and represents the values used in the present work.

Experimental data for γ-ray production(847keV)

↓ Convert to

$$R=\sigma_{total\ inelastic}/\sigma_{847keV}$$

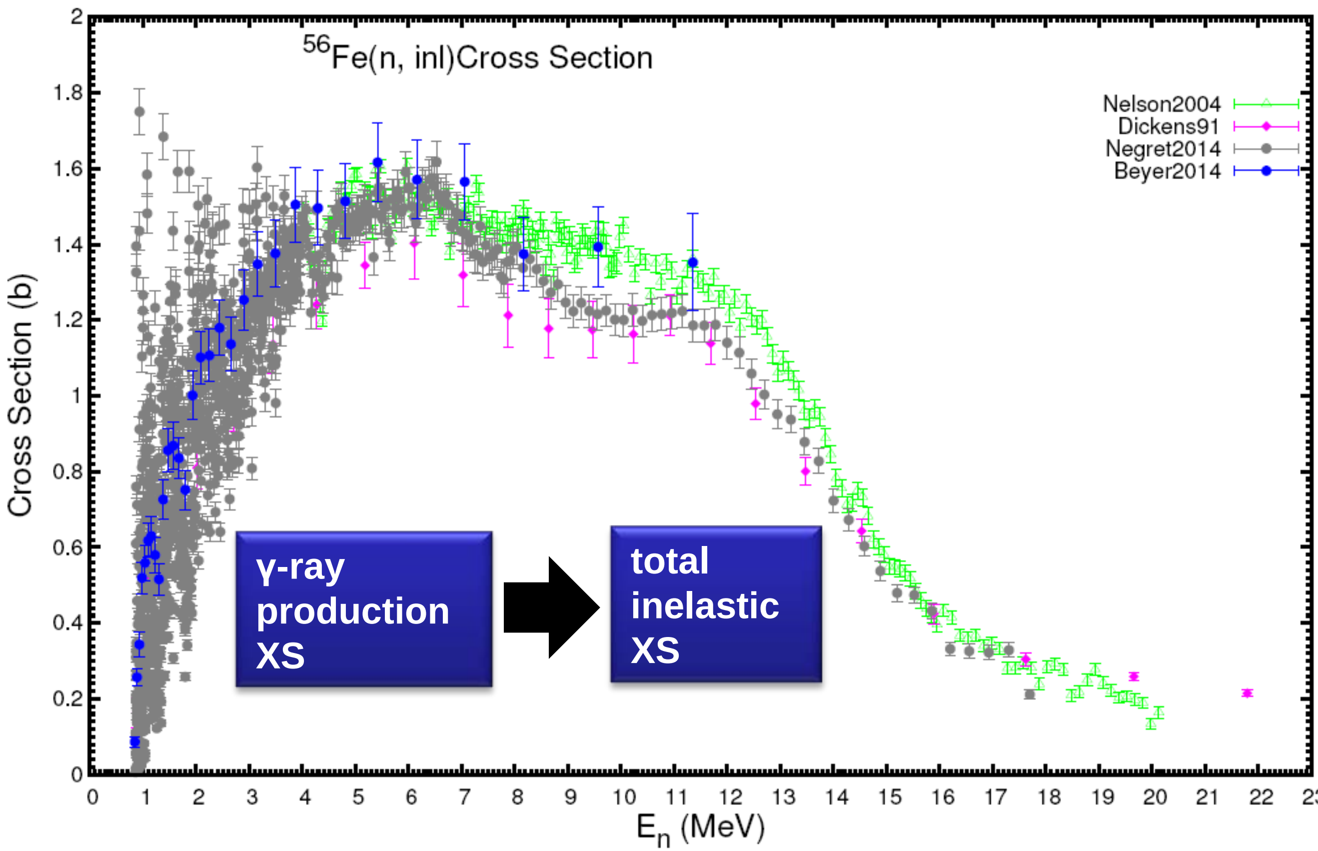
Inelastic cross section

The R value was utilized in this work to convert the high accurate measurements of 847-keV γ-ray production to the total inelastic cross section.

Use of the γ-ray production to infer the total inelastic cross section

More than 40 measurements for the (n,n'γ) cross section at various incident neutron energies have been performed since 1970's but the consistency between these measurements is generally poor.

In 1990's, the neutron energy range was extended. Four measurements were included in this work.



Four sets of data for γ-ray production

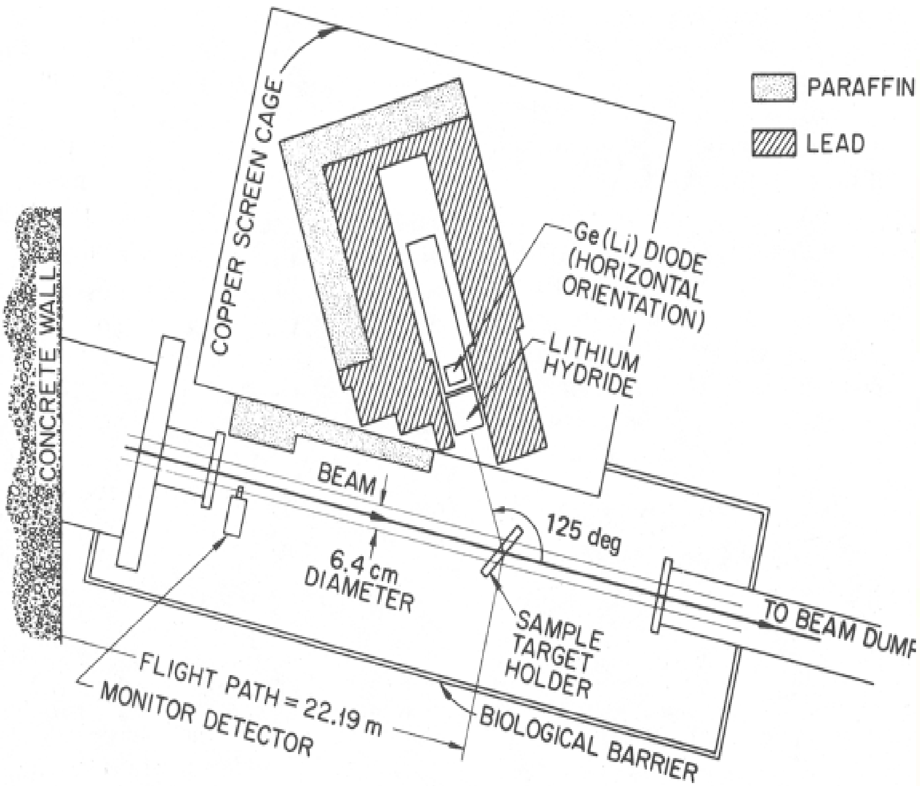
1 J.K.Dickens 1991

ORNL(Oak Ridge National Laboratory)

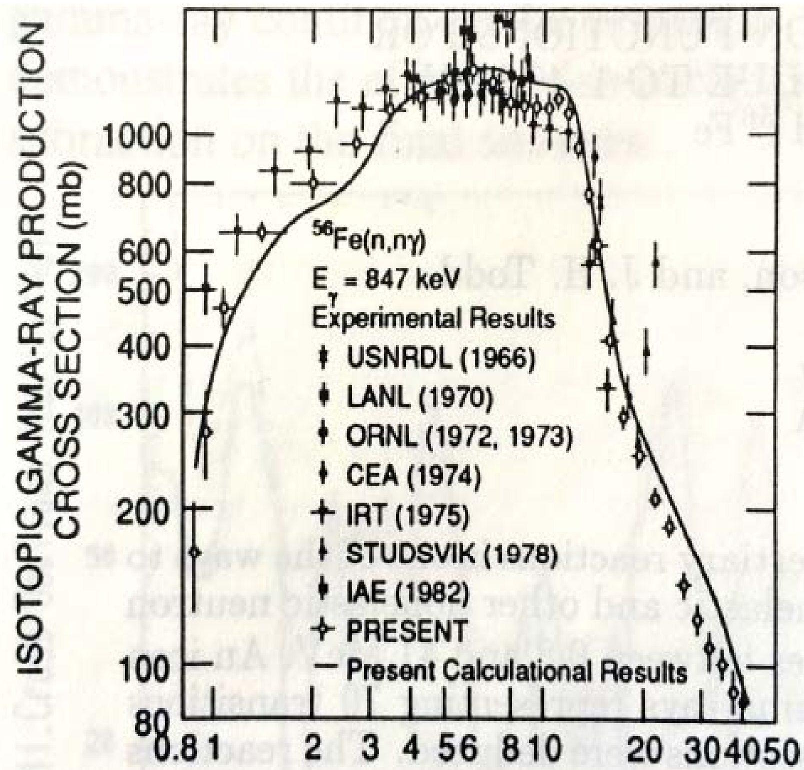
OREAL(0.8~41MeV)

Measured σ（Eγ,θγ=125deg）

Position of the sample：22.19m



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



Four sets of data for γ-ray production

2 **R.O.Nelson 2004** **LANL LANSCE**

Neutron Source:LANSCE/WNR

Spallation neutrons travel 20.34m to GEANIE sample

Detector: GEANIE

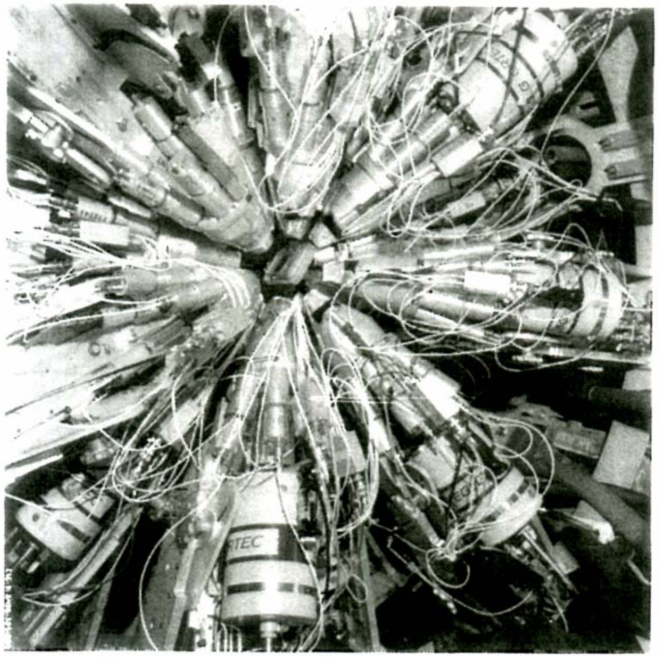


Figure 2. Top view of the GEANIE array showing the detectors with a mockup of an encapsulated Pu sample at the center.

R.O.Nelson performed

(1) Absolute cross-section measurements

(2) Relative cross-section measurements using the Cr(n,n' γ)reaction

Four sets of data for γ-ray production

2 R.O.Nelson 2004

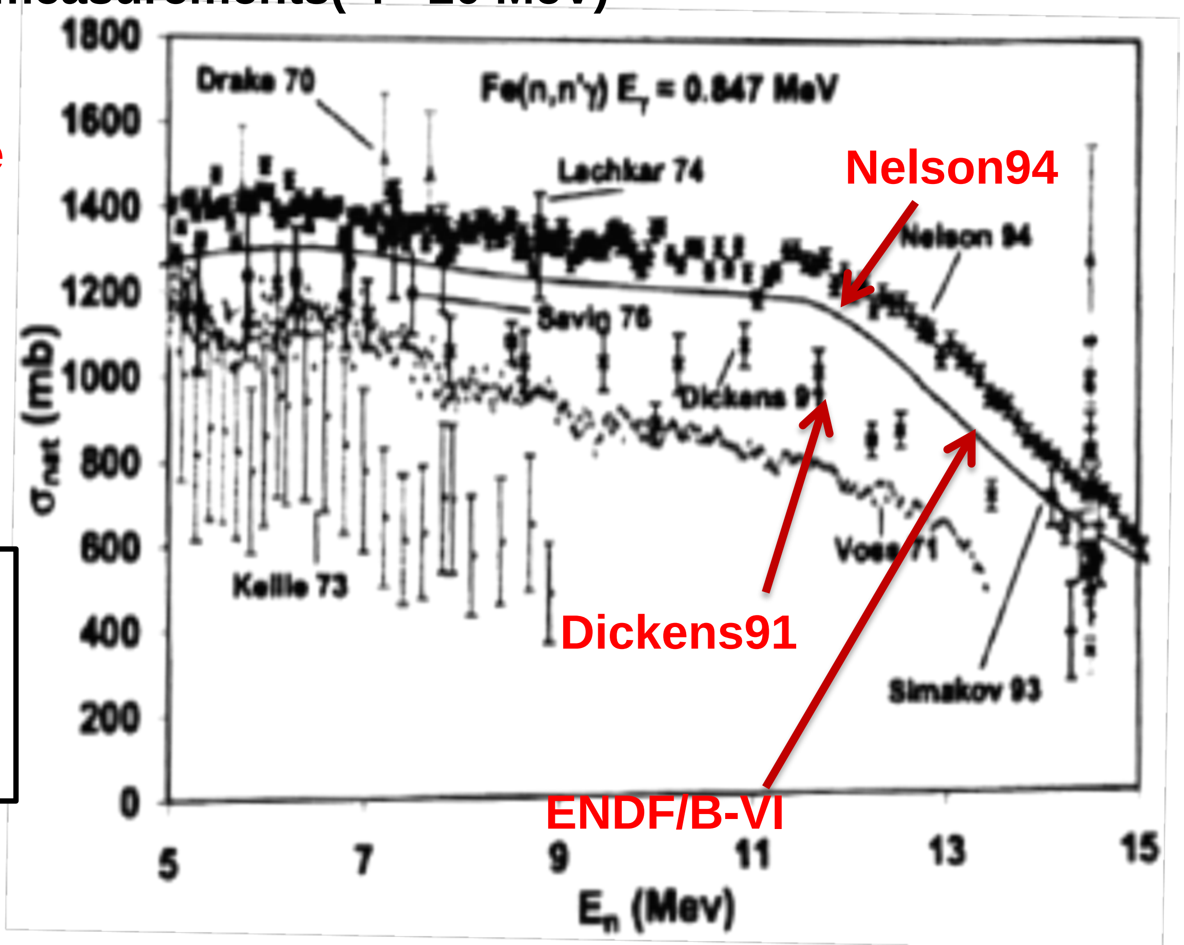
(1) Absolute cross-section measurements(4 - 20 MeV)

Nelson:

This is not true for some of the previous measurements

The best available accuracy for r-ray cross section standards is typically 5% to 10%.

Results agree well with the excitation function shape of Dickens but are about 20% larger than those of Dickens



Four sets of data for γ-ray production

2 **R.O.Nelson 2004** **at 14.5 MeV**

(2) Relative cross-section measurements using the $^{52}Cr(n,n'\gamma)$reaction

Reduce corrections
- **neutron multiple scattering and reactions**
- **γ-ray attenuation in the samples**

$^{52}Cr(n,n'\gamma)$1434keV γ-ray cross-section as standard

Thickness: Cr(338mg/cm^2)
Fe(164mg/cm^2)

They get the result with an accuracy of less than 5%.

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

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

The cross section result of ^{56}Fe(n,n'γ) is shown in the last row of the table. The data of ENDF/B-VI are lower by 7%.

Four sets of data for γ-ray production

3 **Negret 2014 GEEL**

- **Neutron source:**
  GELINA（Geel Electron LINear Accelerator）
  L=198.68m del_T<1ns En=0.1-18MeV **High energy resolution**
- **Detector：GAINS**
  110deg 150deg
  position of sample:154mm 119mm **very short**

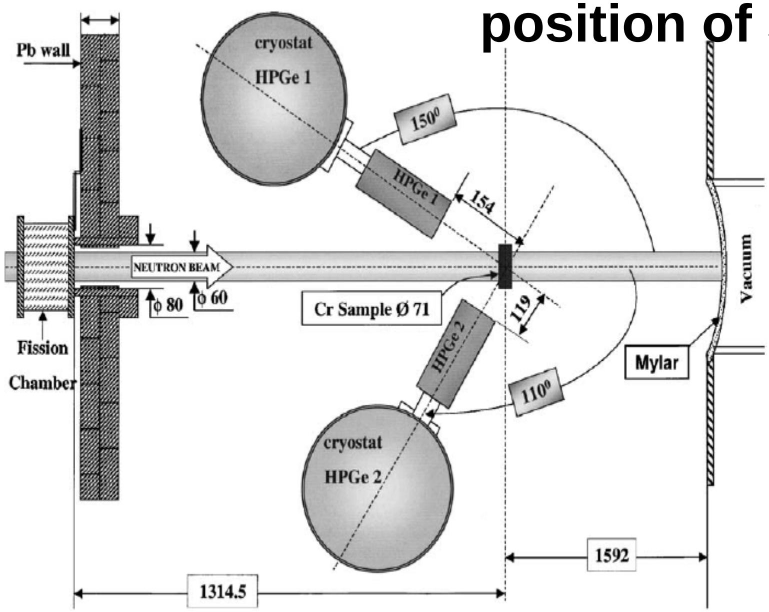


Fig. 2. Configuration of the detectors in Gelina flight path number 3 at the 200 m measurement station. The germanium detectors are placed at 150° and at 110° with respect to the beam axis. The fission chamber for the fluence normalization and a lead shielding wall are shown as well. Dimensions in mm.

- **Data given:**
  Each excited level cross section

Using the evaluated level scheme

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

Four sets of data for γ-ray production

4 Beyer 2014 Germany

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Photoneutron source nELBE at the superconducting electron accelerator ELBE of the Helmholtz-Zentrum Dresden-Rossendorg (HZDR)

A high-purity germanium detector 20cm distance from the target and at an angle of 125°relative to the beam direction.

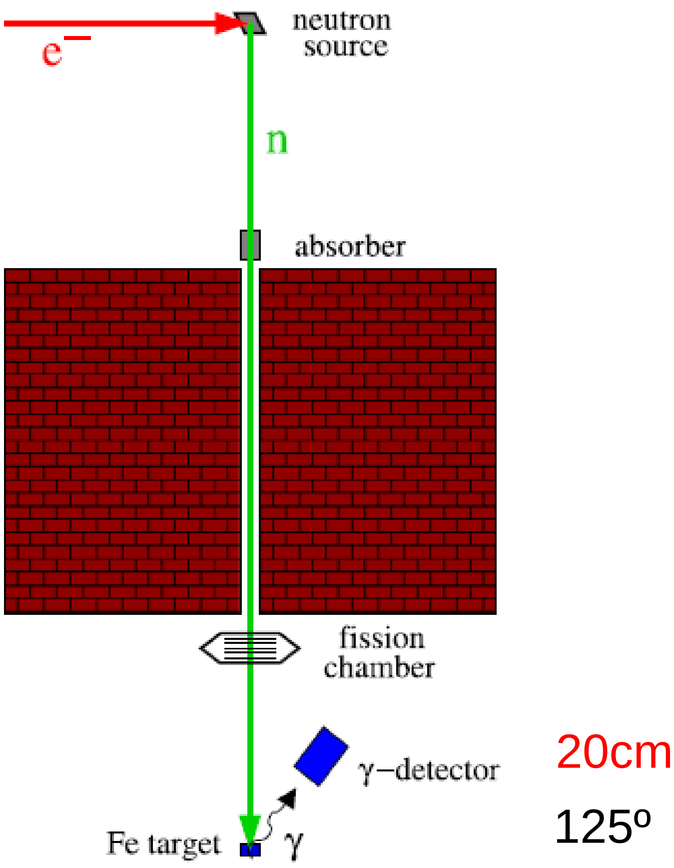
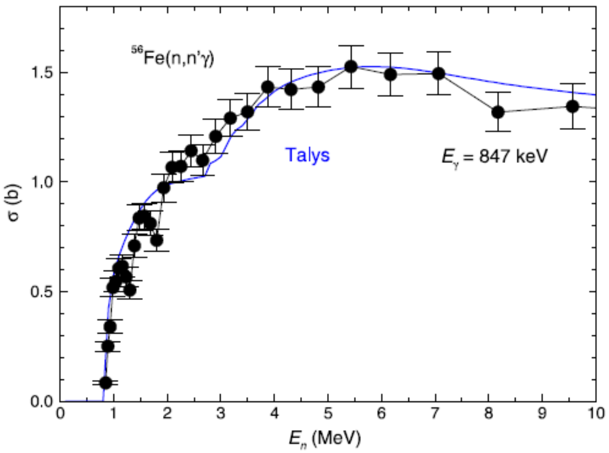
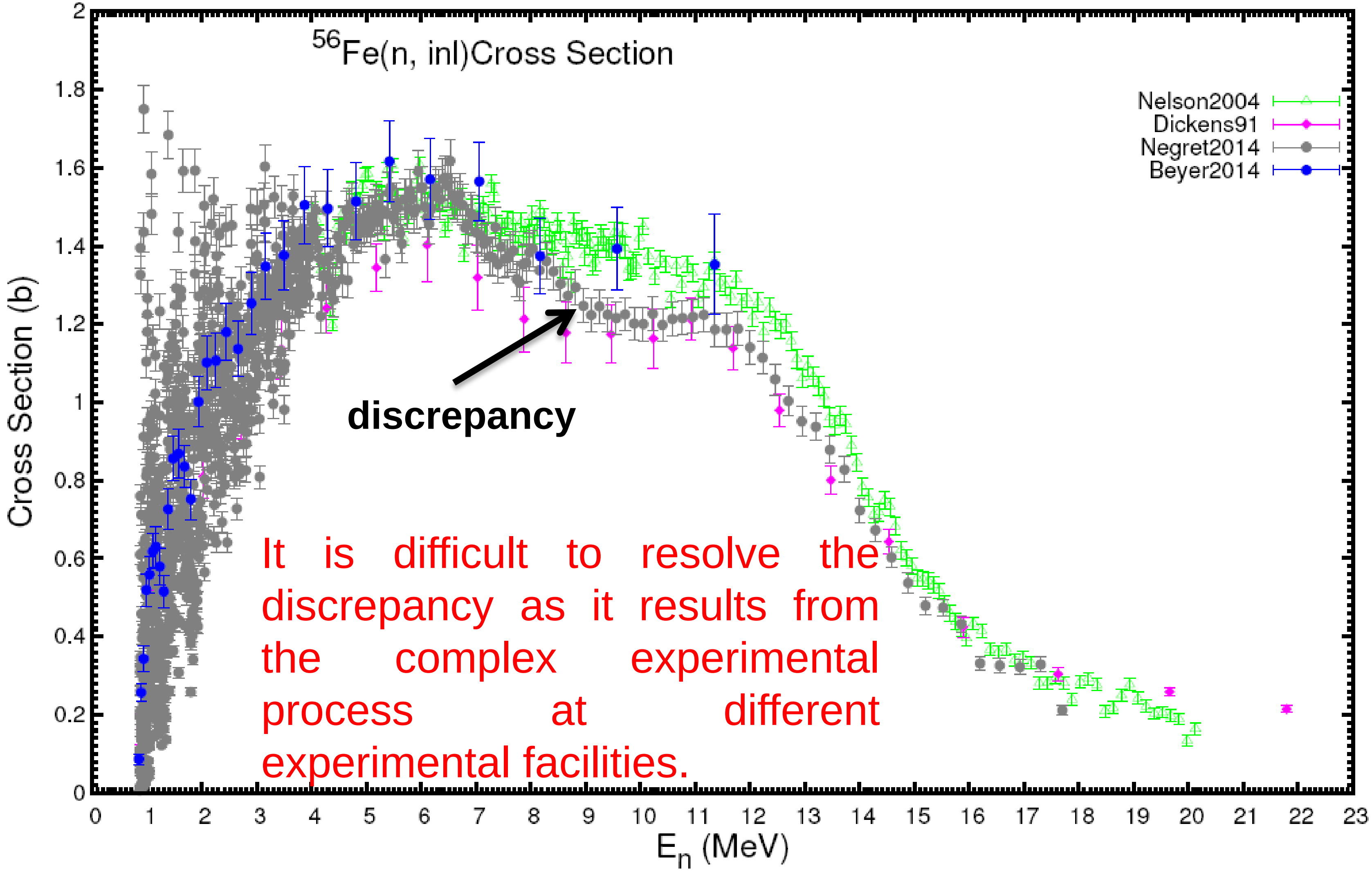


Fig. 1. (Color online.) Time-of-flight setup at the photoneutron source nELBE.



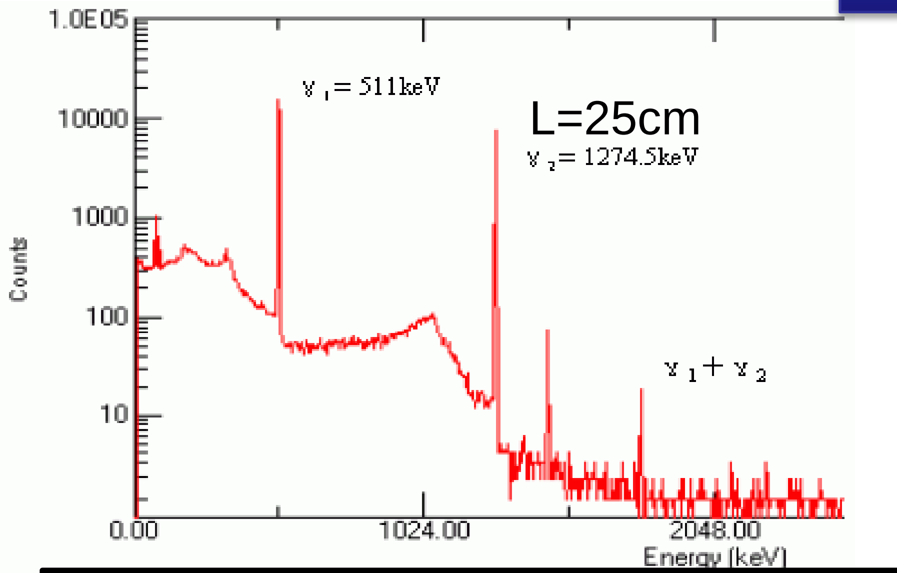
How to clarify the discrepancy?

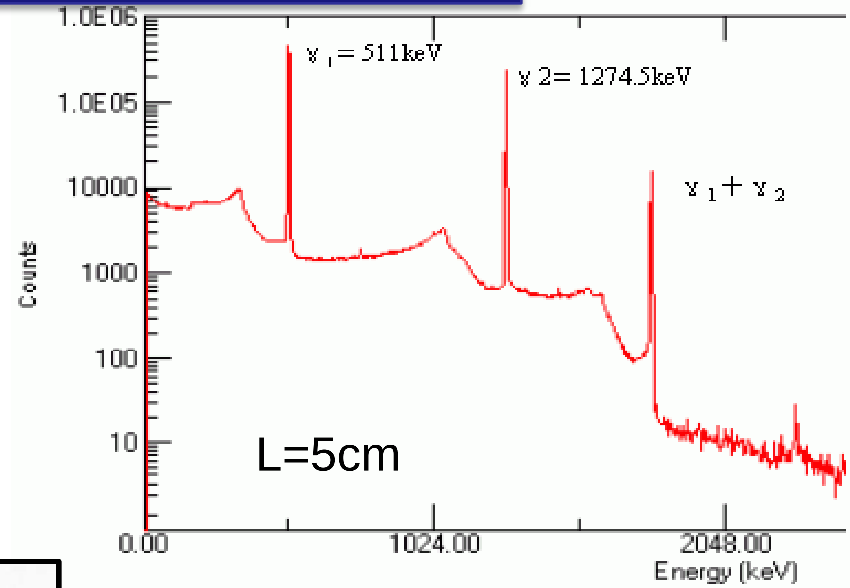


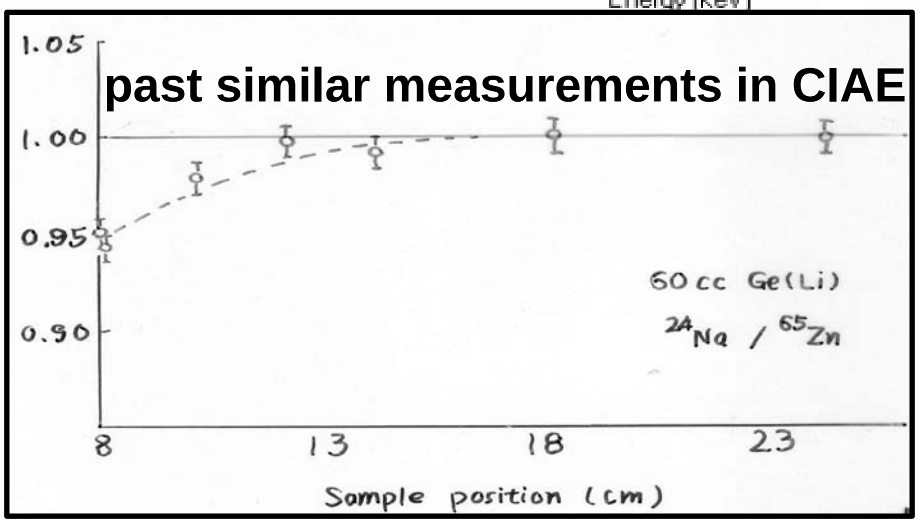
It is difficult to resolve the discrepancy as it results from the complex experimental process at different experimental facilities.

How to clarify the discrepancy?

■Cascade problem?







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

The cascade decay can affect the detection efficiency seriously when the distance between sample and detector is short.

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

How to clarify the discrepancy?

- **Cascade problem?** **Maybe is one of the possible reasons of discrepancy**

Suggestion

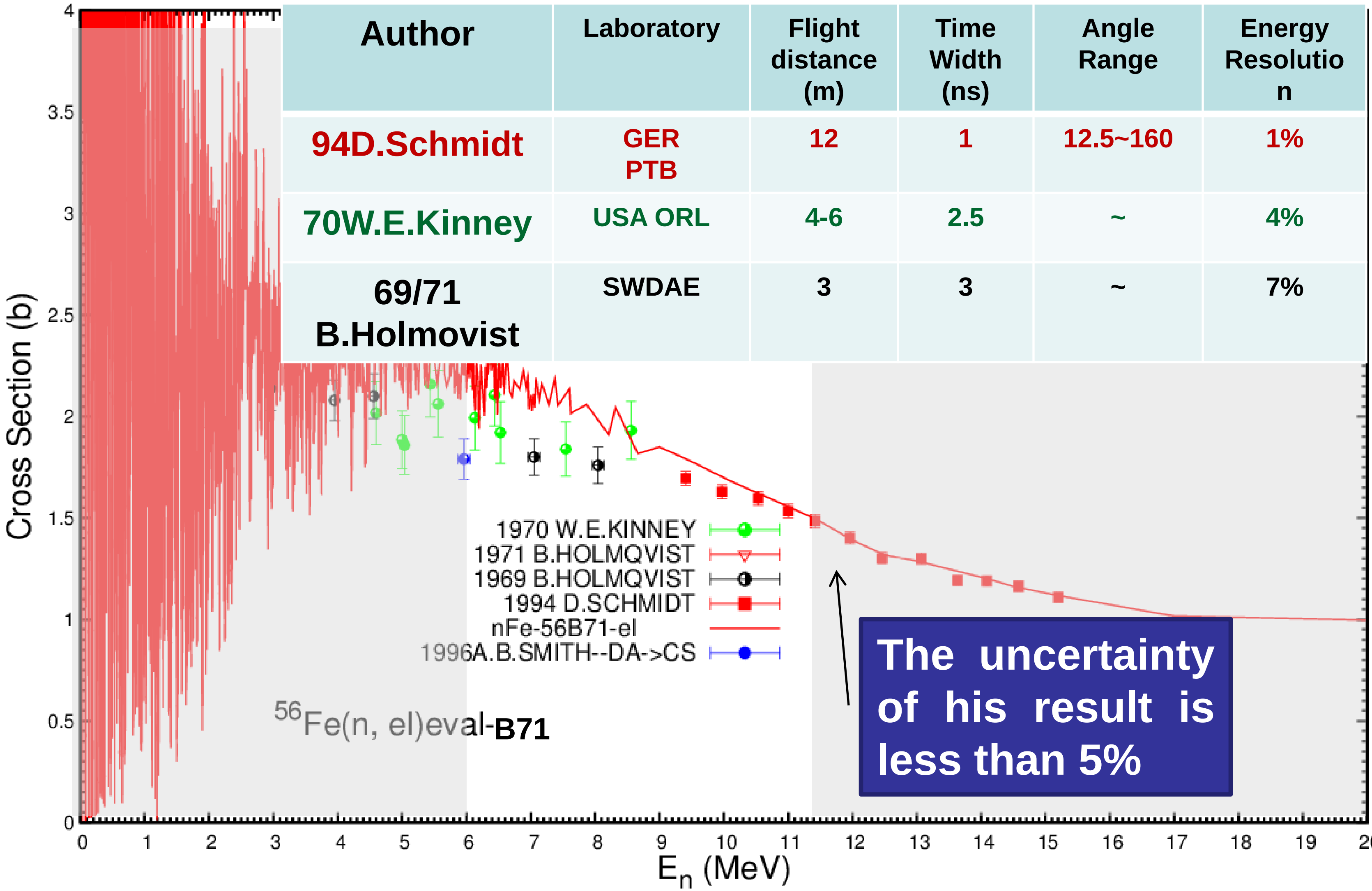
Suggested a new measurement, using a ^{137}Cs source as a reference, to find the efficiency correction factor due to cascade decay as a function of distance between sample and detector.

Clarify the discrepancy

■The unitarity constrain

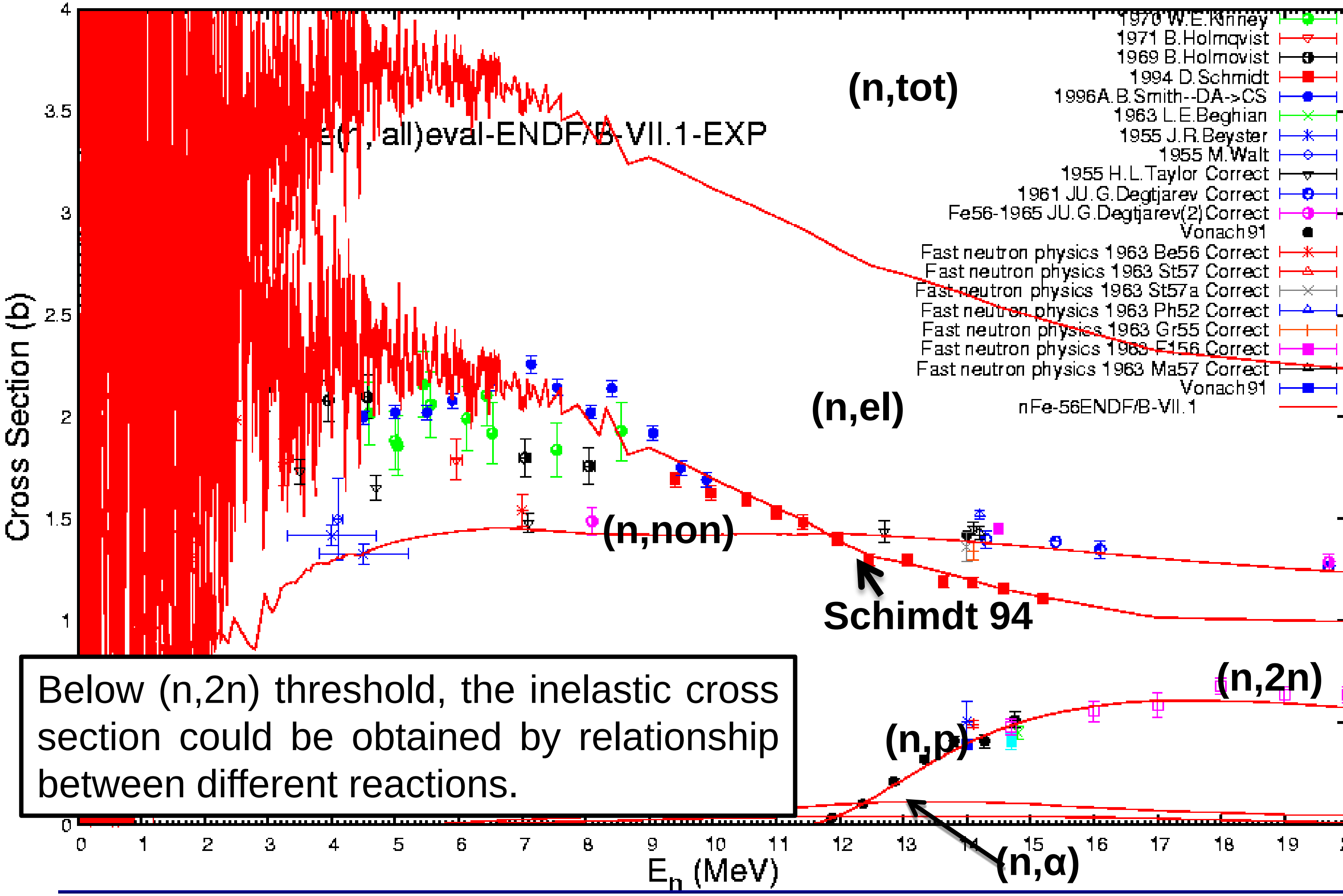
In this energy region (9-11MeV) , there were reliable measurements exist for the competing reactions .

Author	Laboratory	Flight distance (m)	Time Width (ns)	Angle Range	Energy Resolution
94D.Schmidt	GER PTB	12	1	12.5~160	1%
70W.E.Kinney	USA ORL	4-6	2.5	~	4%
69/71 B.Holmovist	SWDAE	3	3	~	7%



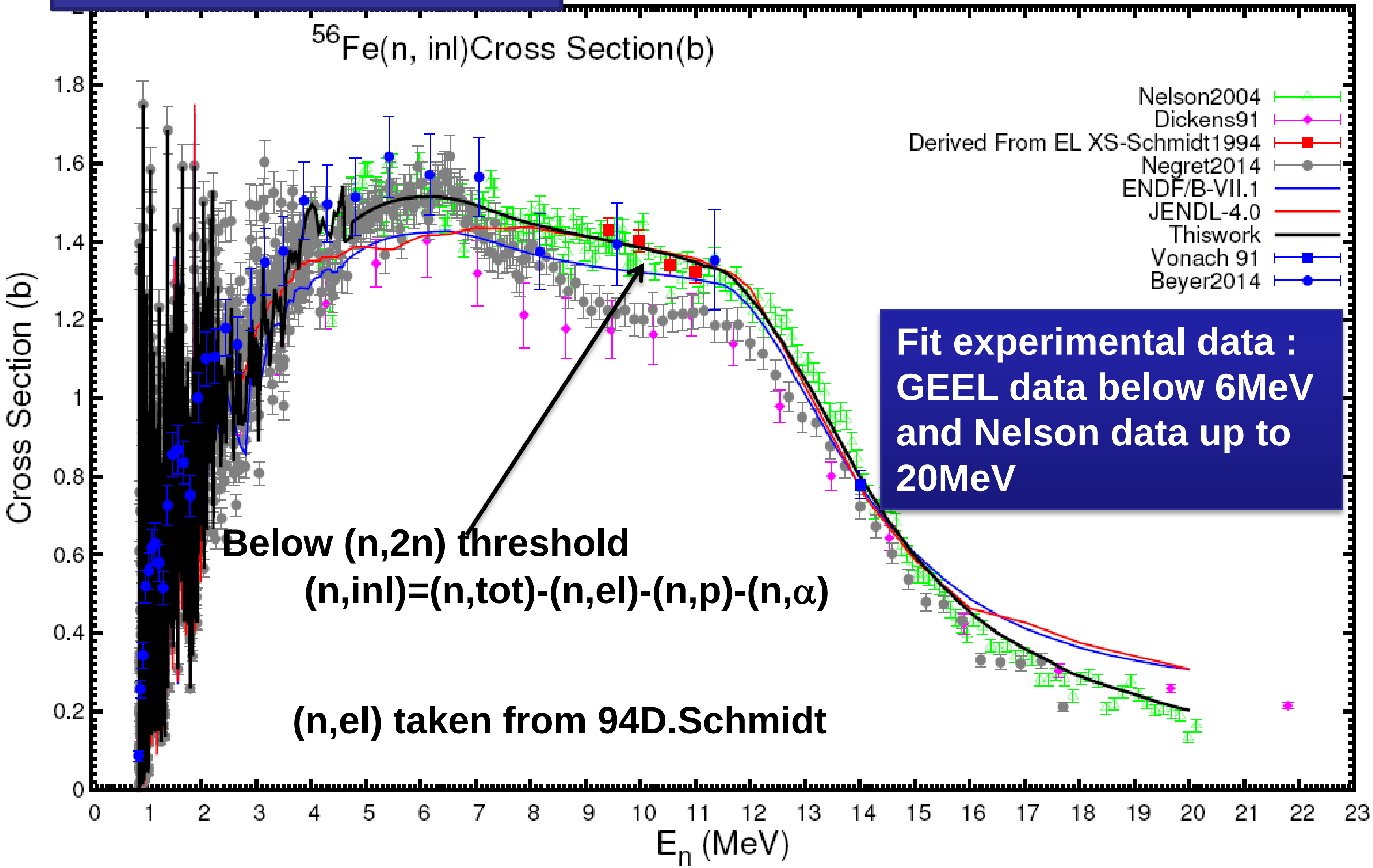
Clarify the discrepancy

$$(n,inl)=(n,tot)-(n,el)-(n,p)-(n,\alpha)$$



Below (n,2n) threshold, the inelastic cross section could be obtained by relationship between different reactions.

Clarify the discrepancy



Fit experimental data : GEEL data below 6MeV and Nelson data up to 20MeV

Conclusion

In order to obtain the more accurate description of the cross section data as much as possible within our present knowledge, the existing old and new experimental data were collected and analyzed carefully. The new evaluated data for inelastic cross sections on ^{56}Fe were performed in the fast neutron energy range.

- **Multiple ways were applied to clarify the discrepancy for the inelastic scattering cross section, especially in the energy range between 9-11 MeV.**

- **These new improved evaluated data will give more effective reference for theoretical calculations of CIELO project.**