Improving nuclear data for iron: results and outlook from GELINA experiments

G. Gkatis[1], A. Coman[2], P. Dessagne[3], M. Diakaki[4], G. Henning[3], M. Kerveno[3], S. Kopecky[1], A. Negret[2], G. Noguere[5], M. Nyman[6], A. Oprea[1], C. Paradela[1], E. Pirovano[7], A. Plompen[1], P. Schillebeeckx[1]

[1]European Commission, Joint Research Centre, Geel, Belgium

[2]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania

[3]Université de Strasbourg, CNRS, IPHC, Strasbourg, France

[4]Department of Physics, National Technical University of Athens, Athens, Greece

[5]CEA/DES/IRESNE/DER/SPRC/LEPh, Cadarache, Saint Paul Lez Durance, France

[6]Department of Chemistry, University of Helsinki, Helsinki, Finland

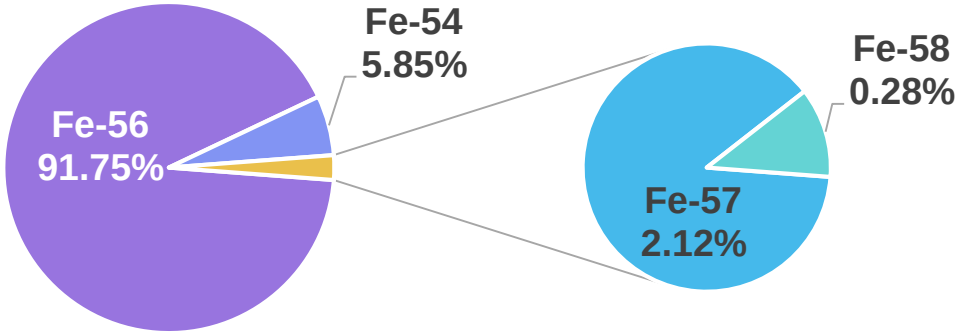
[7]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Motivation

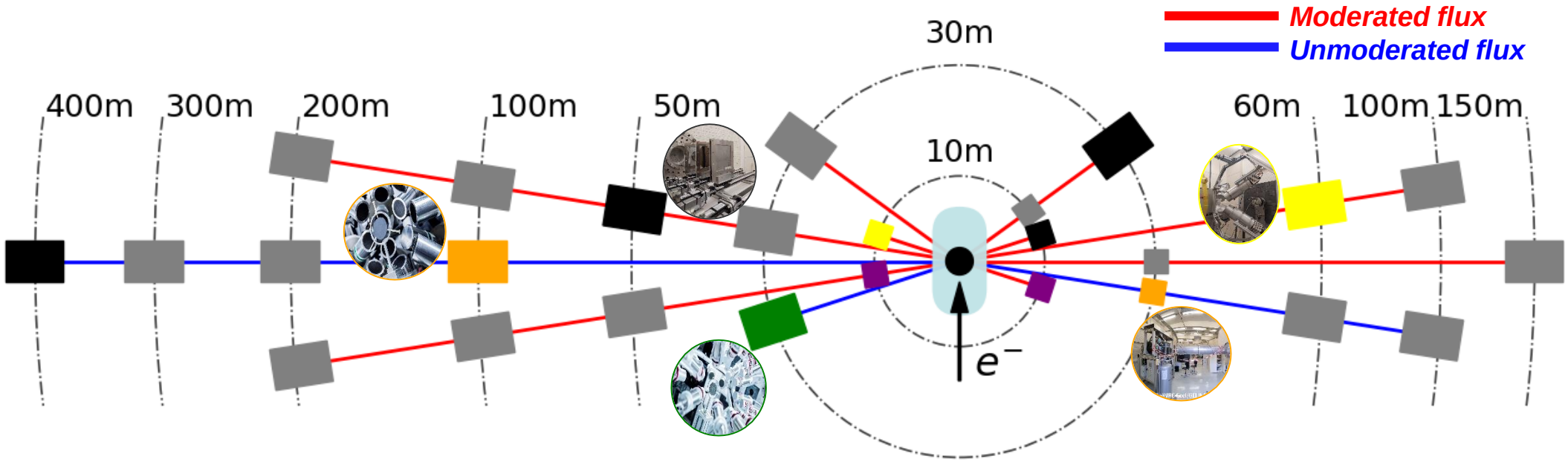
- **Iron** is a **major structural material** with a plethora of uses in **nuclear reactors**
- **Accurate** evaluated neutron cross section data on iron are indispensable for the **design**, **safe operation,** and **development** of advanced reactor systems
- Iron is **difficult** to **evaluate** :

  1. Lack of experimental data (majority of measurements done with ^{nat}**Fe**)
  2. Theoretical models **difficult** to describe the cross sections in some regions
  3. ^{56}Fe most **abundant**, **BUT** benchmarks **sensitive** to the **minor isotopes**

Heavy stainless steel PWR reflector



Iron measurements at GELINA

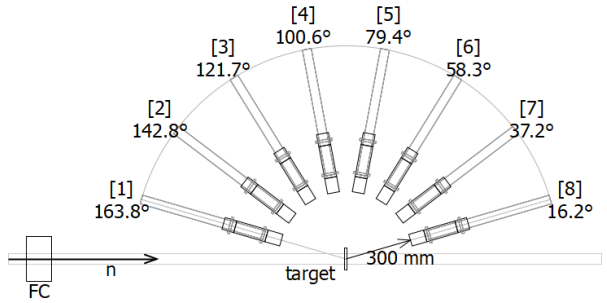


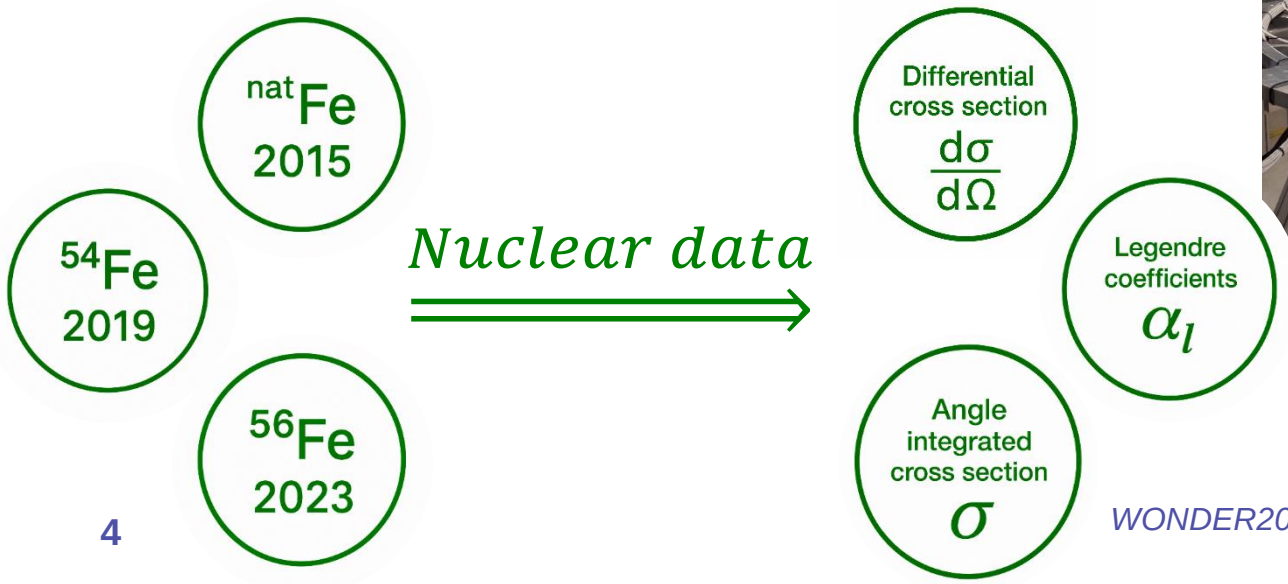
(n,n) - Elastic (30m)
(n,n´γ) - Inelastic (30m, 100m)
(n,γ) - Capture (10m, 60m)
(n,tot) - Transmission (10m, 30m, 50m, 400m)
(n,f) - Fission (10m)
Rest

Isotope	Elastic scattering	Inelastic scattering	Transmission (total)	Capture
^{nat}Fe	✓	–	✓	✓
^{54}Fe	✓	✓	–	–
^{56}Fe	✓	✓	✓	✓
^{57}Fe	–	✓	–	–

The ELISA setup

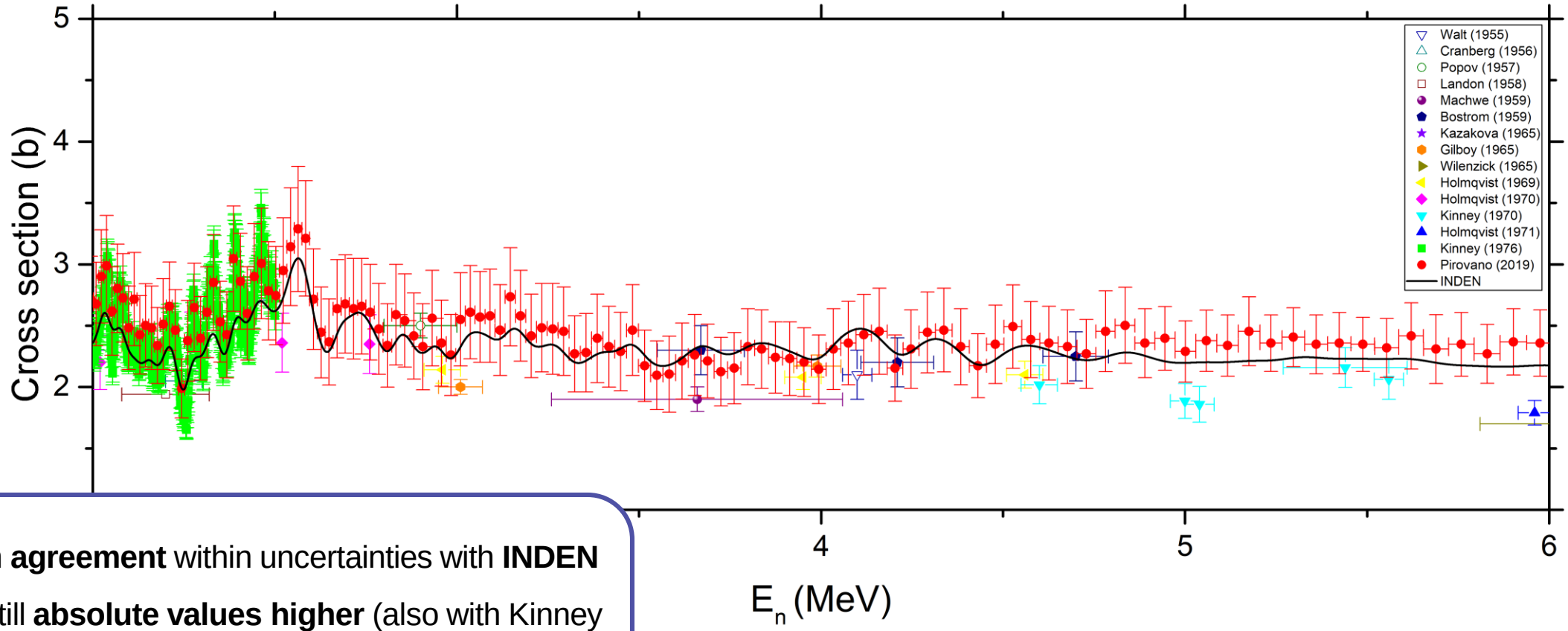
- ELISA (ELastic and Inelastic Scattering Array)
  - **^{235}U fission chamber** (neutron flux)
  - **32 liquid organic scintillators** (scattered neutrons)





See presentations of J. Knijpstra & A. Karakaxi

Results of the ^{nat}Fe(n,n)

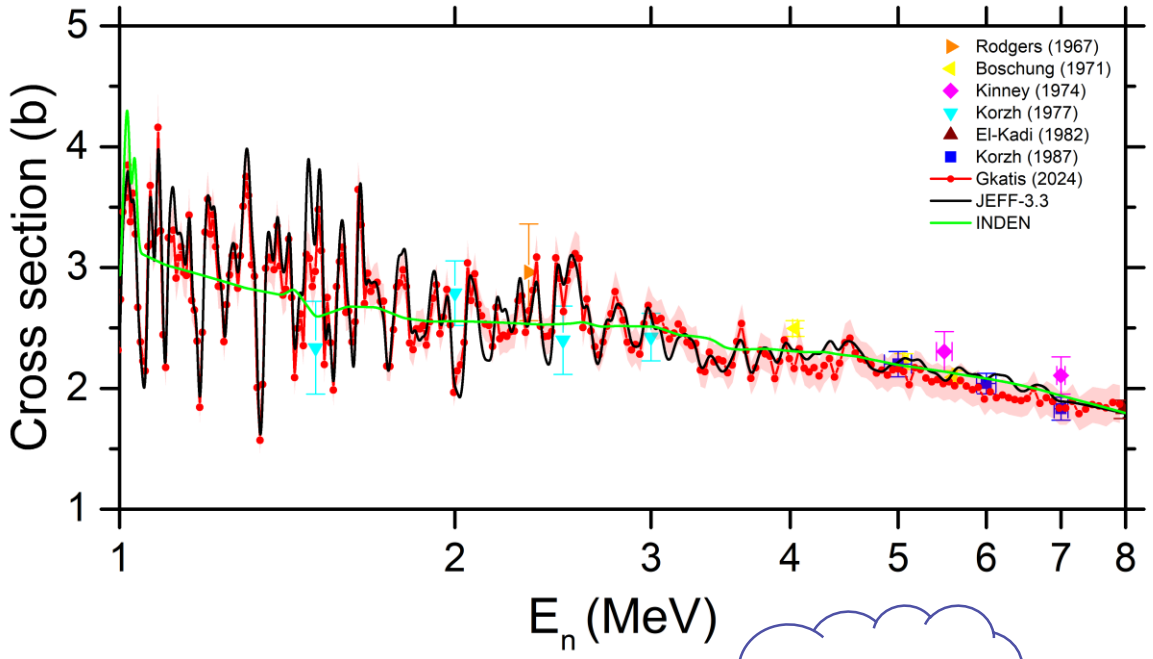


- In **agreement** within uncertainties with **INDEN**
- Still **absolute values higher** (also with Kinney data)
- **Experiment lacked statistics**

E. Pirovano et al., PRC 99, 024601 (2019)

Results of the ^{54,56}Fe(n,n)

^{54}Fe

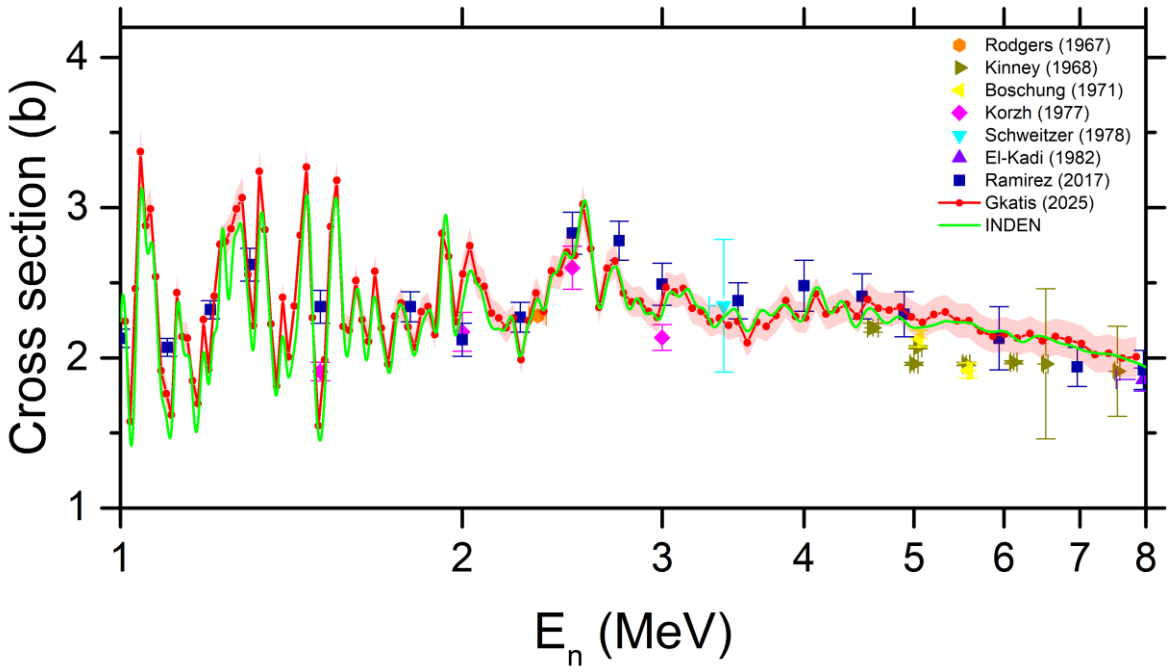


- JEFF-3.3 = Total – non.elastic
- INDEN = OMP calculations

Maybe revisit the JEFF-3.3 approach?

G. Gkatis et al., PRC 109, 034612 (2024)

^{56}Fe

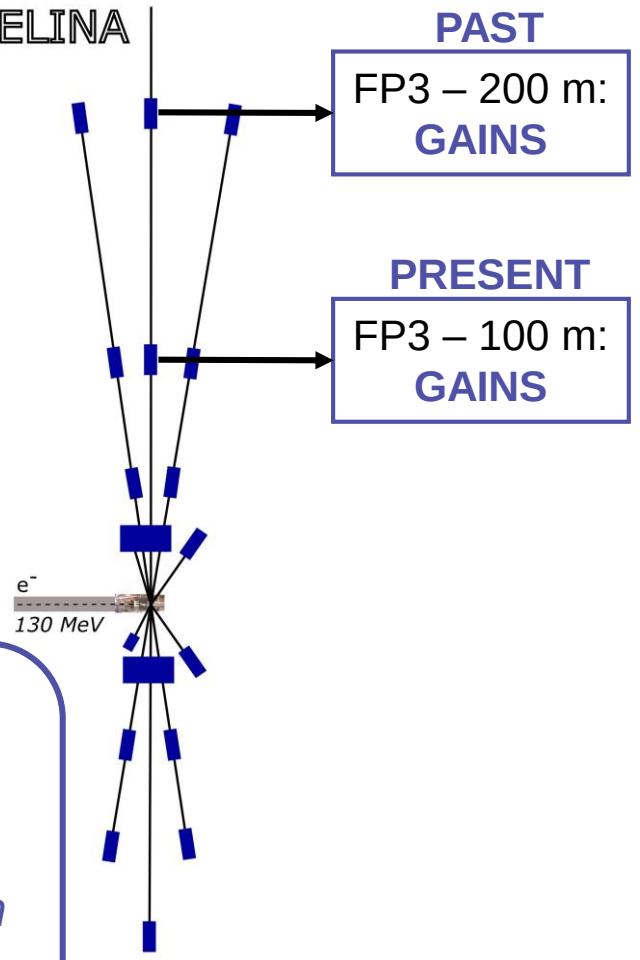


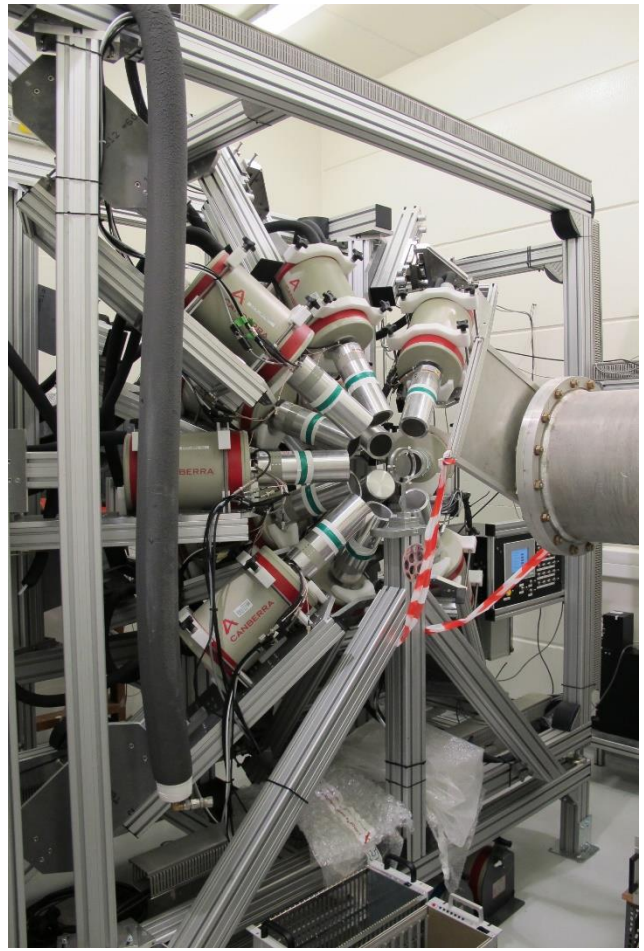
- INDEN = Total – non.elastic

G. Gkatis et al., PRC 112, 044603 (2025)

The GAINS setup

- GAINS (Gamma Array for Inelastic Neutron Scatter
  - **^{235}U fission chamber** (neutron flux)
  - **12 HPGE** (emitted gamma rays)



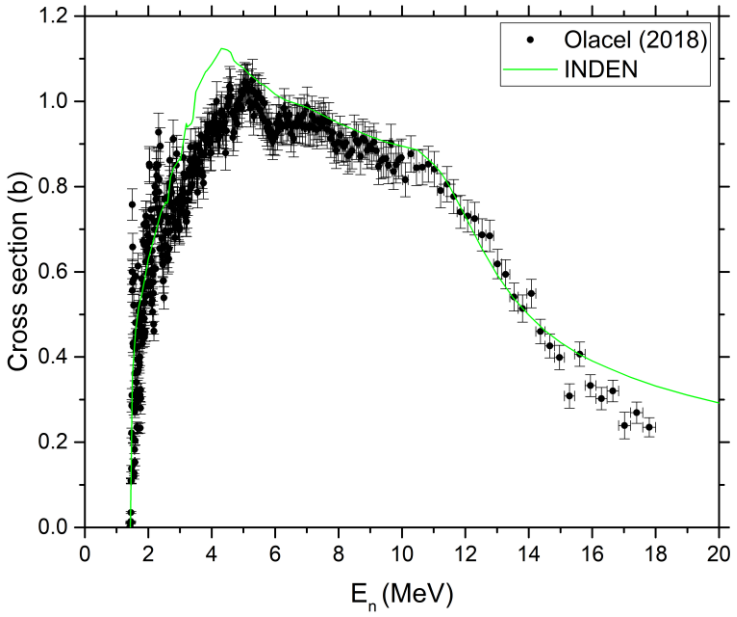


Extensive work for iron isotopes by IFIN-HH:

- *^{54}Fe: A. Olacel et al., EPJA 54, 183 (2018) – 100m*
- *^{56}Fe: A. Negret et al., PRC 88, 027601 (2013) – 200m*
- *^{57}Fe: A. Negret et al., PRC 96, 024620 (2017) – 200m*

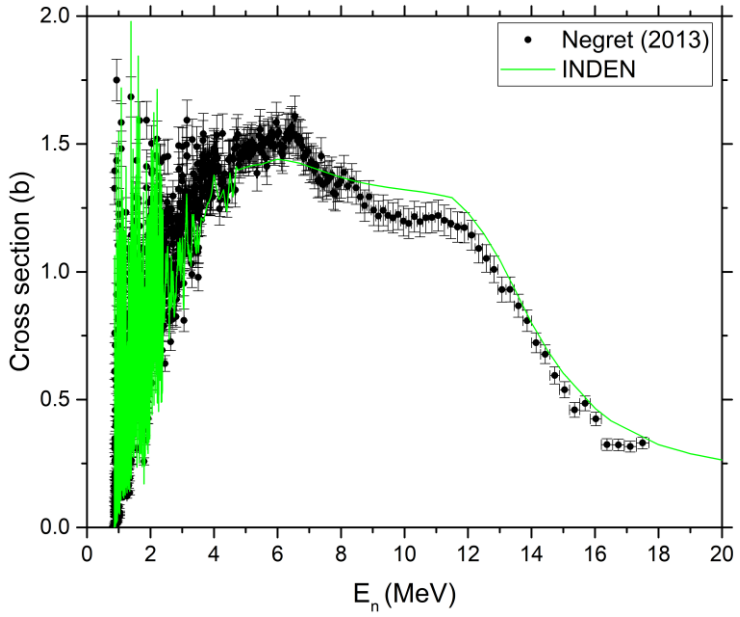
GAINS results

^{54}Fe



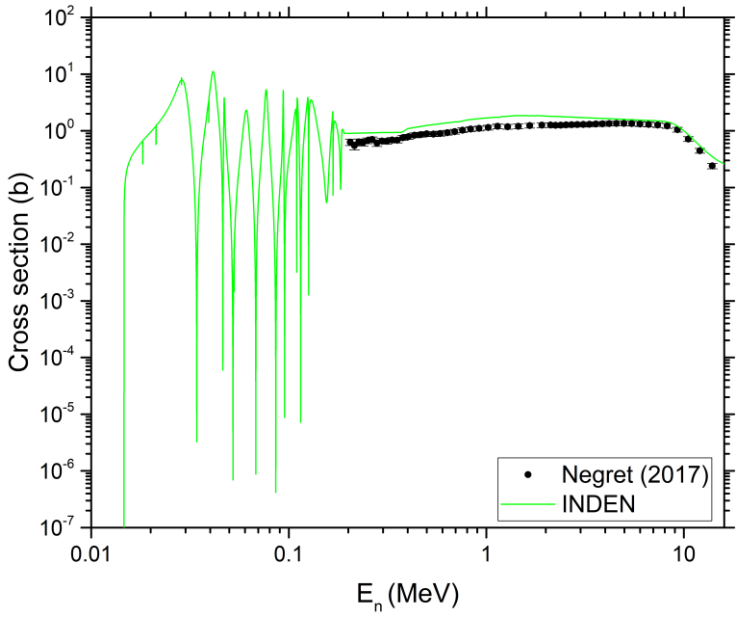
- Highly enriched sample
- First and only high-resolution measurement
- Data >4MeV: lower limit (due to unobserved γ-ray transitions)

^{56}Fe



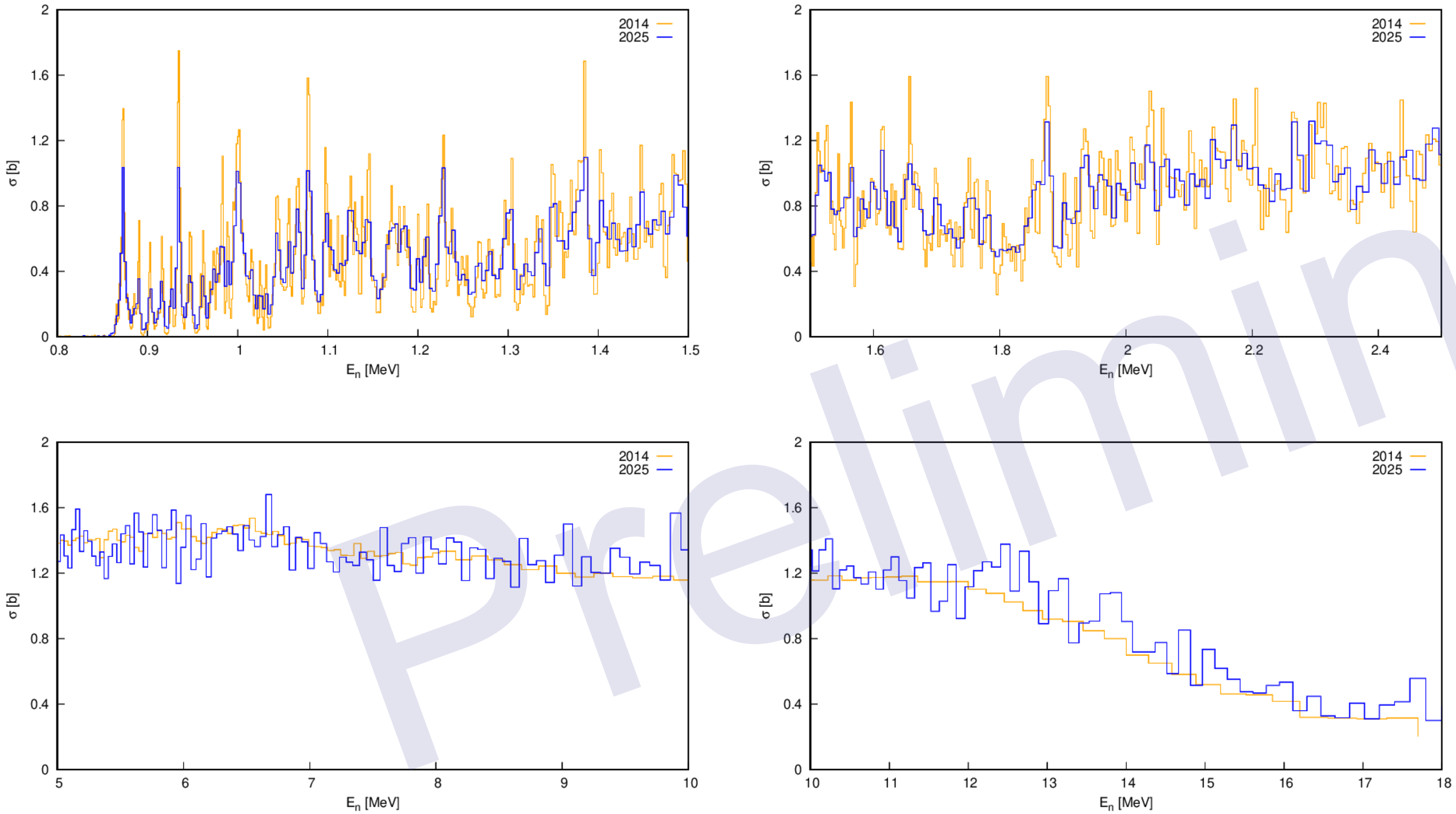
- Natural iron sample used
- Accurate total inelastic scattering cross section up to ~4.5MeV
- >4.5MeV slightly underestimated (simmilar to ^{54}Fe)

^{57}Fe



- Tricky to evaluate – inelastic threshold lies in the RRR
- GAINS data are missing the contribution of the first state

New ^{56}Fe measurement at GAINS



2014

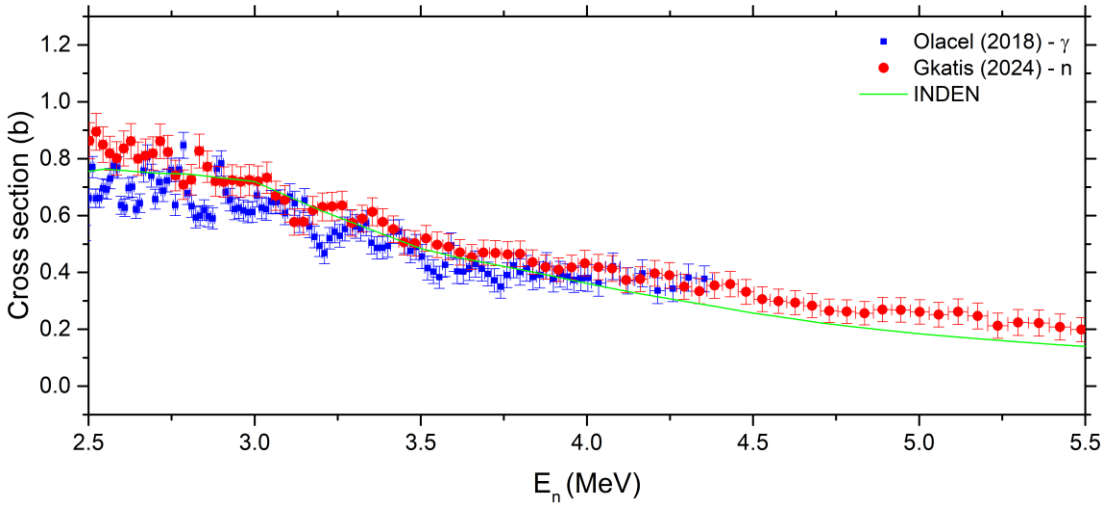
- FP3_200m
- 8 HPGE
- Natural sample

2025

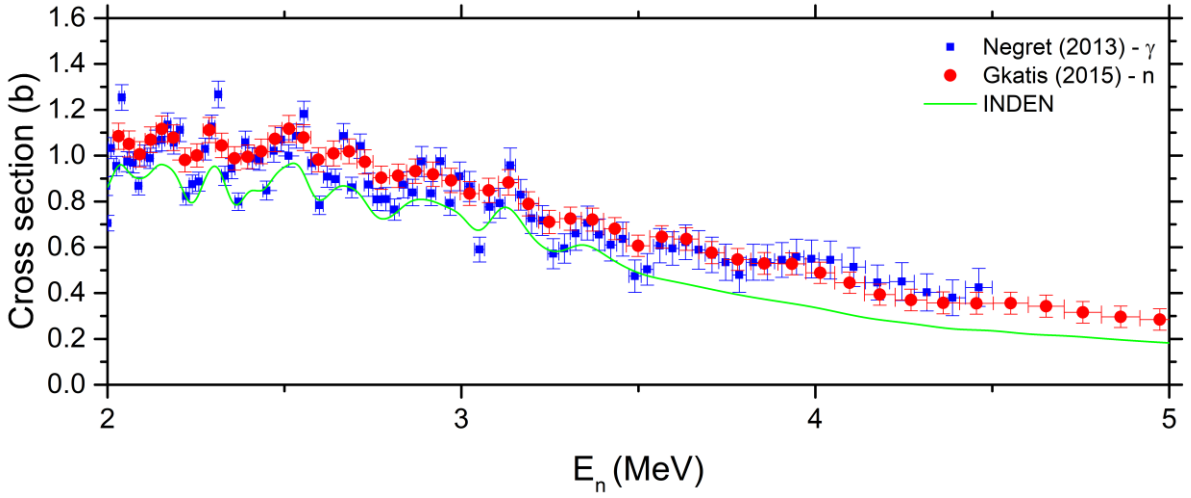
- FP3_100m
- 10 HPGE + 2 $LaBr_3$
- New DAQ
- Enriched sample

$^{54,56}Fe(n,n_1´)$ results from ELISA

^{54}Fe



^{56}Fe

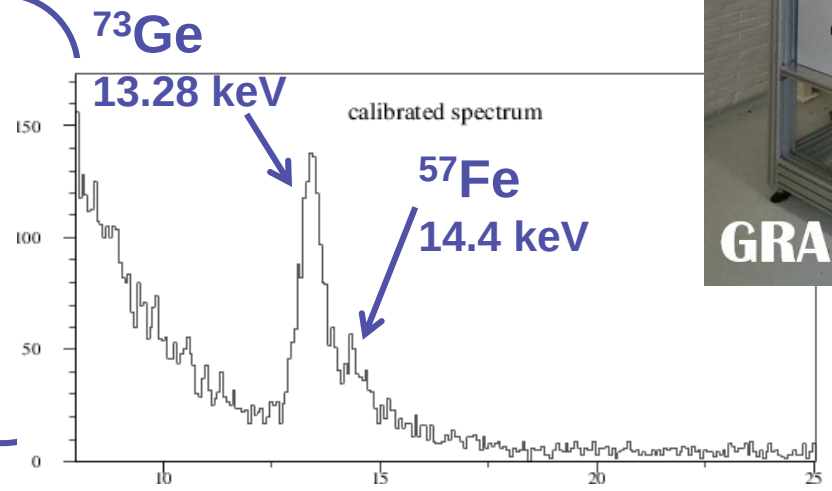


Excellent agreement between **ELISA (n)** and **GAINS (γ)** data!!!

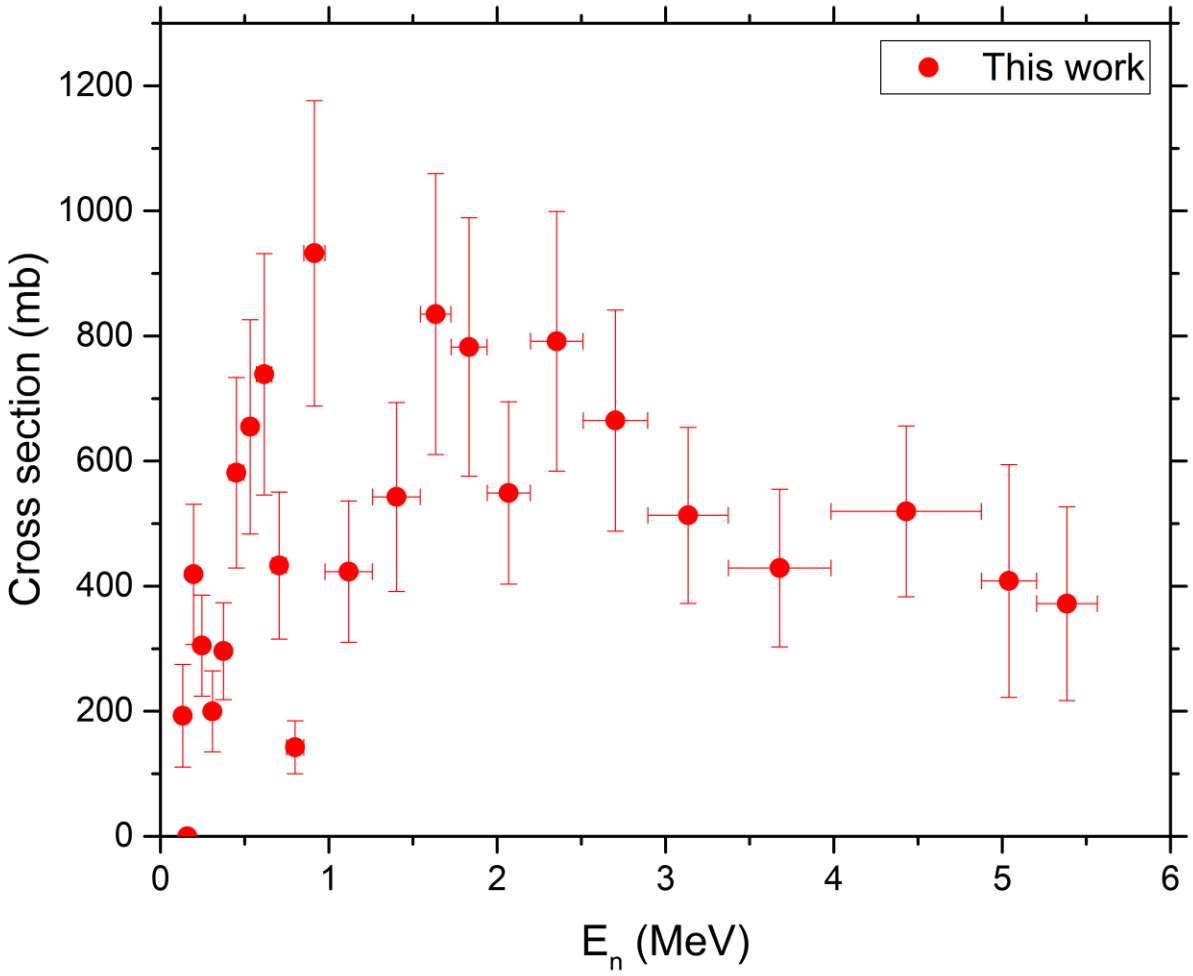
The GRAPhEME setup

- GRAPhEME (GeRmanium array for Actinides PrEcise MEasurements)
  - **^{235}U fission chamber** (neutron flux)
  - **6 HPGE** (emitted gamma rays)

- **^{57}Fe** measured in 2018
- The first state (14.4 keV) measured successfully
- Tricky analysis…



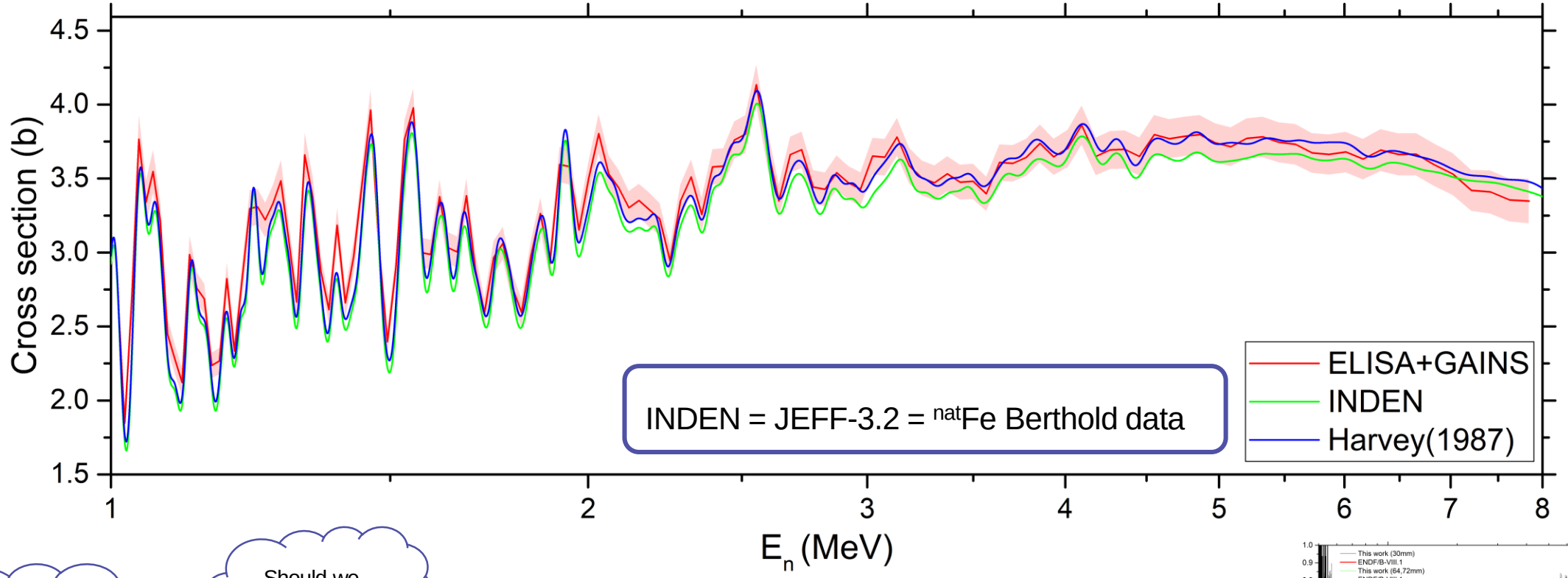
Results on ^{57}Fe



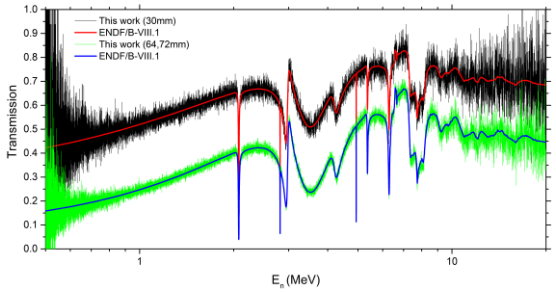
14-keV transition of ^{57}Fe

- $T_{1/2}$ = 98.3 ns
- Measured yield **corrected** for **delayed emission**
  - Time-window dependent correction
- Cross section extracted up to ~**5 MeV**
- >5 MeV → poor statistics
- No other measurements reported in **EXFOR**

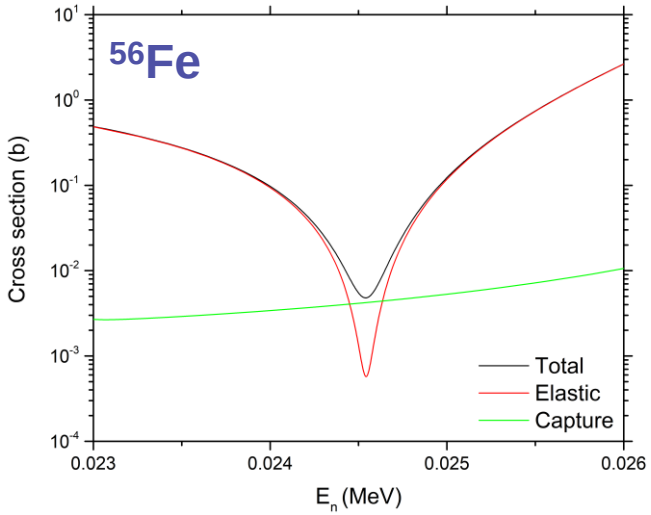
Results of the ^{56}Fe(n,tot) – ELISA + GAINS



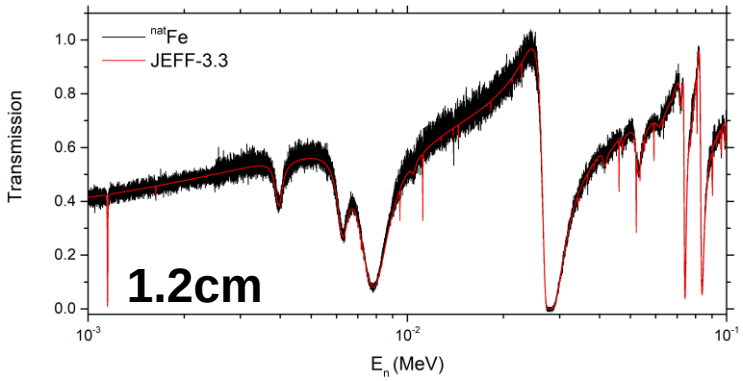
- **New transmission station at 400m**
- **Ultra high-resolution 2ns@400m**

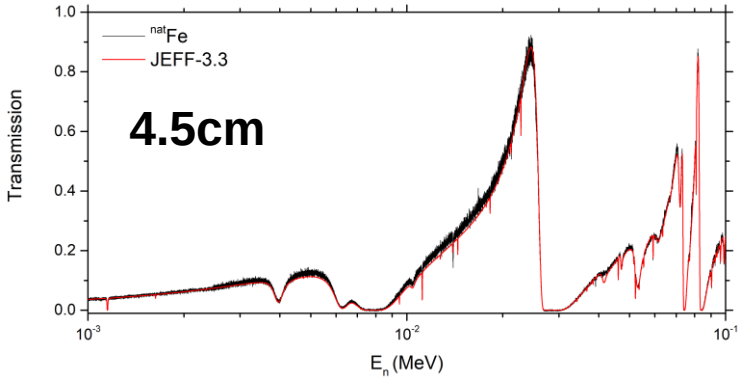


Measurements of ^{nat}Fe(n,tot)



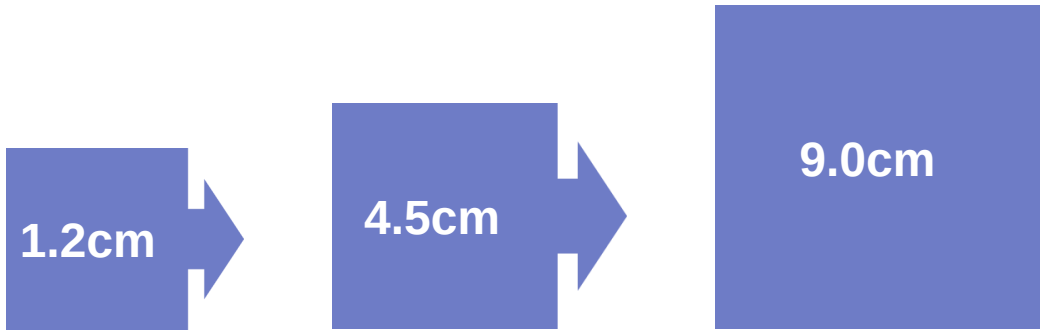
- Measurements at **FP4_50m**
- **E_n = 1 – 100 keV**
- 9.0 cm (18 weeks)
  - Analysis ongoing

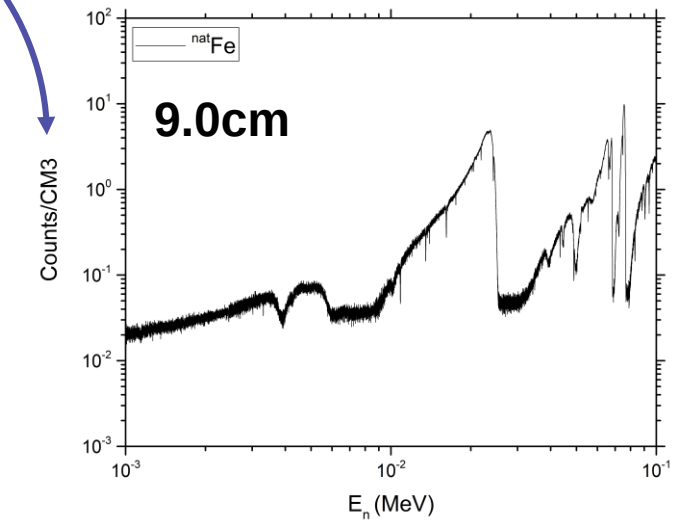




At **24.5keV** elastic scattering drops drastically!

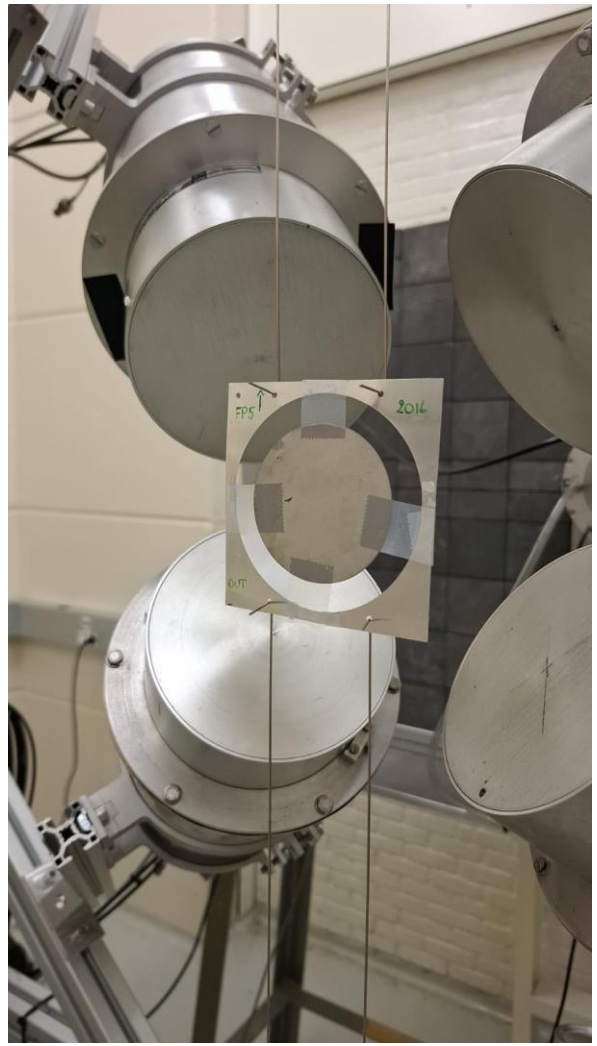
$$Total \approx Capture$$





Capture on ^{56}Fe and ^{nat}Fe

- Enriched **^{56}Fe** sample measured recently at **n_TOF** (presentation by Aparna Basavaraja Allannavar)
- A measurement at **GELINA** is also **planned**
- A lot of **^{nat}Fe(n,γ)** data accumulated over the years – used for **normalization** via the **1.15 keV** resonance
- An in-depth study of these data might be worthy…



Summary

^{nat,54,56}Fe(n,n)

- **Elastic scattering cross sections** and **neutron angular distributions** produced for **1-8 MeV**
- **First high-resolution** experimental data for elastic scattering in this range
- **Legendre coefficients** also extracted
- Data submitted in **EXFOR**

^{54,56,57}Fe(n,n´γ) + (n,n´)

- Extensive work done by **IFIN-HH** for **^{54,56,57}Fe** with the **GAINS** setup
- **New measurement of ^{56}Fe at GAINS** – Campaign finished recently – Data analysis ongoing
- Partial **inelastic scattering cross sections** and **angular distributions** for first excited states of **^{54,56}Fe** from **ELISA** in excellent agreement with **GAINS**
- **^{57}Fe** measured also at **GRAPhEME** by **CNRS** – **14 keV** transitions measured for the **first time**

^{nat,54,56}Fe(n,tot)

- Combination of **ELISA** and **GAINS** data to describe **^{54,56}Fe(n,tot)** in the **fast energy region**
- **New transmission** measurements at **FP3_400m** are planned
- **3 natural iron** samples measured at **FP4_50m** – **9cm** sample analysis ongoing – Results between **1 – 100 keV**

^{nat,56}Fe(n,γ)

- Recent **^{56}Fe** measurement at **n_TOF –** Measurement to take place also at **GELINA**
- **^{nat}Fe data** accumulated over the years to be investigated

How about a new evaluation of iron?

Thank you