New cross section measurements on Fe performed at the GELINA facility

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Accelerator and Research reactor Infrastructures for Education and Learning

ARIEL

Motivation

- Iron is a major structural material widely used in nuclear facilities and nuclear technology applications
- In nuclear power reactors, iron is used to make pressure vessels that contain the coolant, core shroud, and the reactor core
- Accurate neutron cross section data are indispensable for the design and reliable operation of such facilities
- Uncertainties on the current evaluated nuclear data libraries of iron do not meet yet the target requirements for the development of advanced reactor systems
- Discrepancies between evaluated and experimental cross sections have been observed in the fast neutron energy range

Lack of experimental data available in the literature → Need for new measurements!

The GELINA facility

- Pulsed white neutron source

  10 meV < E_n < 20 MeV

- Neutron energy determination using the TOF (Time-Of-Flight) technique

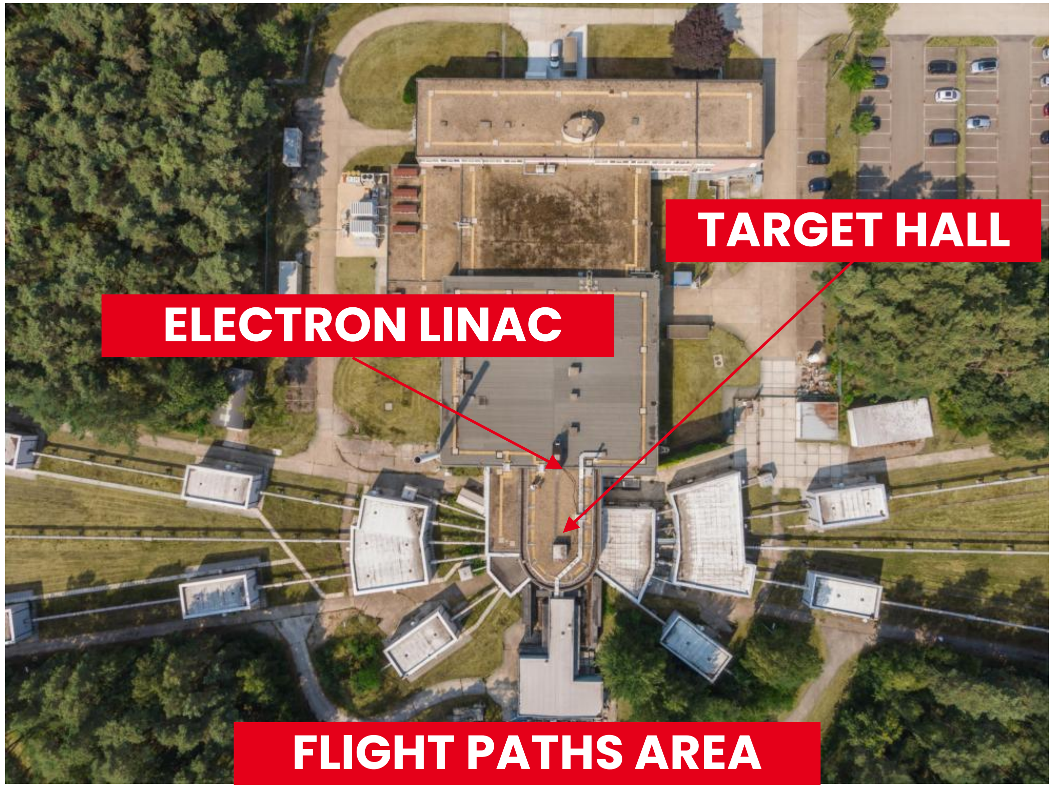
- 10 flight paths

  Flight path length 10 m – 400 m

- Various experimental setups

  (n,tot) – **(n,el)** – **(n,inl)**– (n,γ) –

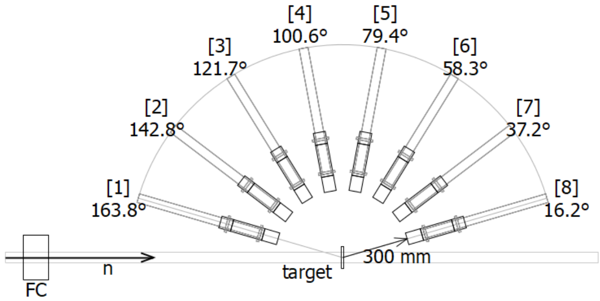
  (n,f) – (n,cp)



Neutron scattering cross section measurements on ^{56}Fe

The ELISA setup

- ELISA (ELastic and Inelastic Scattering Array)
  - ^{235}U **fission chamber** (neutron flux)
  - **32 liquid organic scintillators** (scattered neutrons)
- **27.037 m** distance from the GELINA neutron source (**FP1_30m**)
- **Beam diameter** at sample position: **49 mm**
- Fission chamber (FC) placed **1.37 m** from the sample
- Four sets of **8 detectors** each – mounted at specific angles
- **Digitizer-based** acquisition system + **NIM electronics** for the FC
- The goal is to produce **high-resolution cross section data** of neutron scattering in the fast neutron energy range



Some experimental details

^{nat}C experiment

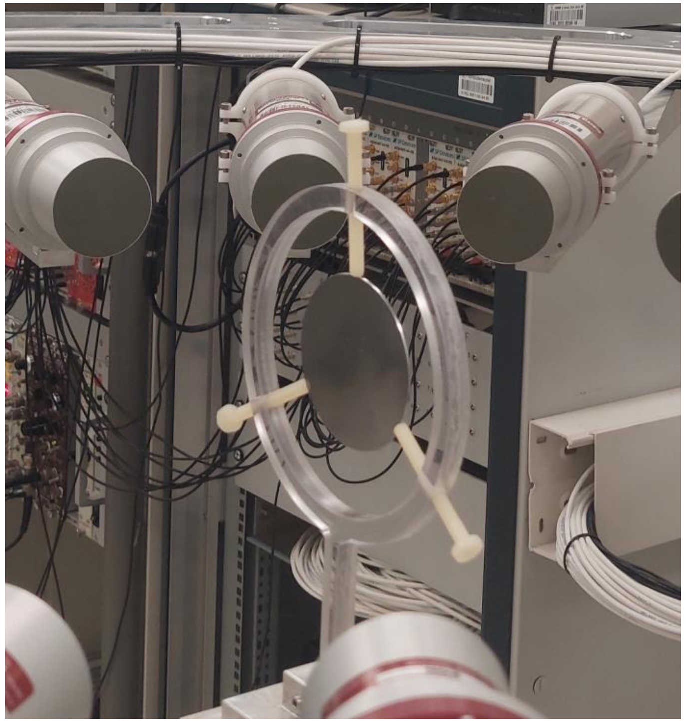
- Date: **2020**
- Duration: ~**600** hours
- Resolution: **5 ns**
- Pure ^{nat}C sample
  - Diameter: 100 mm
  - Thickness: 2.0 mm
  - Mass: 35.7 g

Isotope	Atomic percent
^{12}C	98.94
^{13}C	1.06

^{56}Fe experiment

- Date: **Spring/Summer 2023**
- Duration: ~**850** hours
- Resolution: **10 ns**
- Enriched ^{56}Fe sample
  - Diameter: 70 mm
  - Thickness: 1 mm
  - Mass: 31.396 g

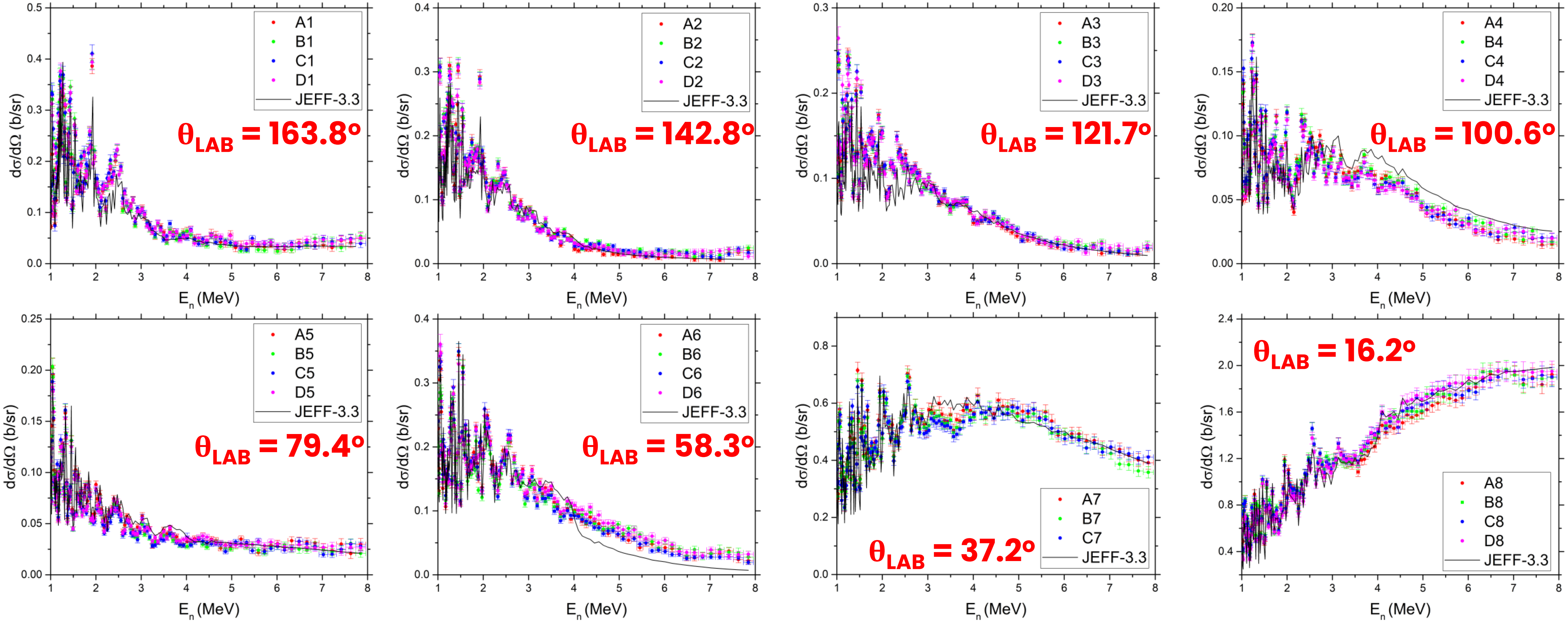
Isotope	Atomic percent
^{54}Fe	0.16
^{56}Fe	**99.77**
^{57}Fe	0.07
^{58}Fe	<0.01



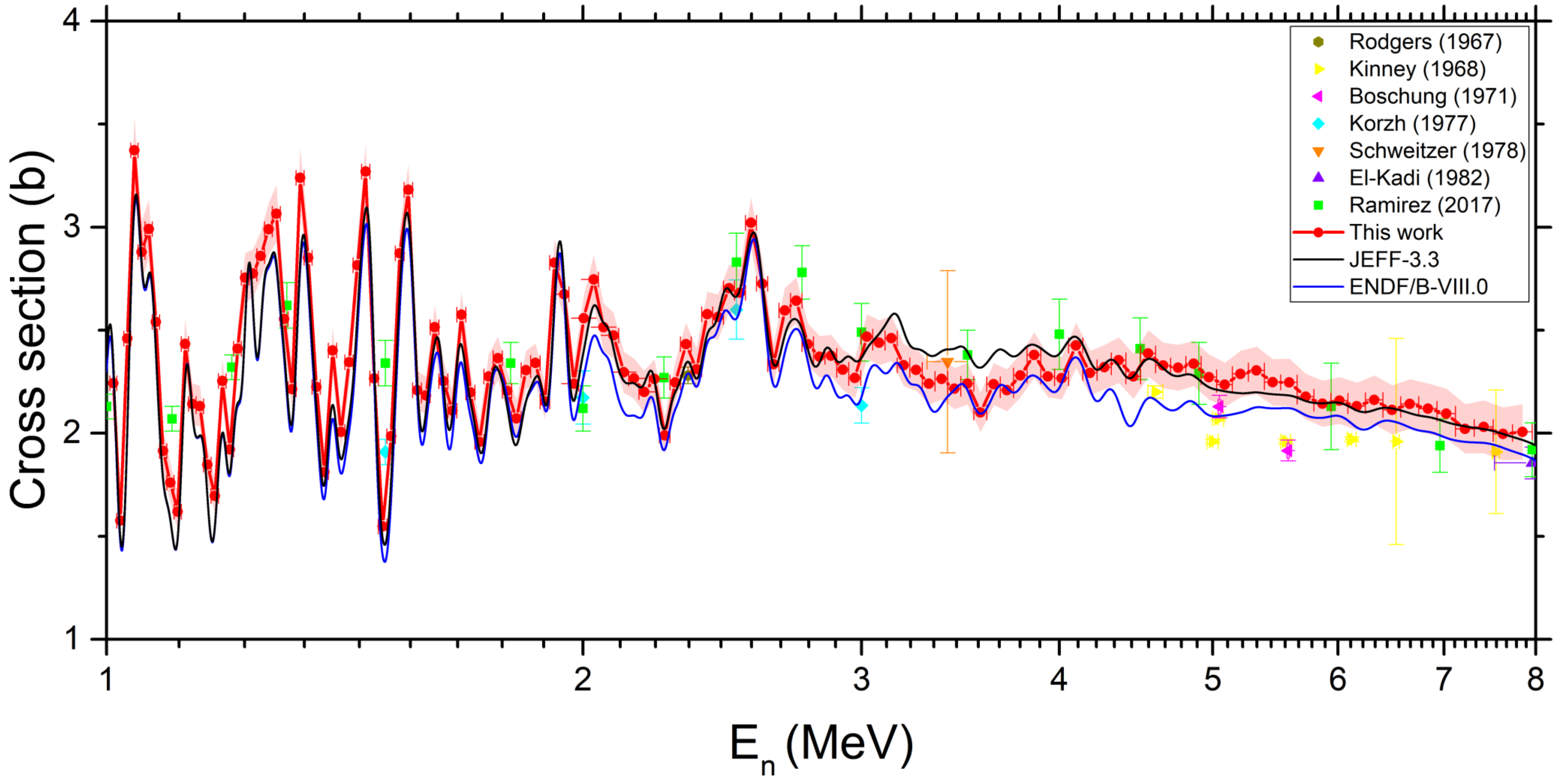
Analysis

- *Step 1:* Characterization of the detectors (determination of the *resolution + response functions*)
- *Step 2:* Separate photon from neutron induced events via pulse shape analysis (*charge integration method*)
- *Step 3:* Background subtraction (*sample-out* measurement)
- *Step 4:* Elastic – Inelastic separation (*kinematics* calculations + deconvolution of the light output distributions)
- *Step 5:* Multiple scattering correction (*Monte Carlo* simulations)
- *Step 6:* Calculation of the neutron fluence (*fission chamber* data analysis)
- *Step 7:* Cross section calculation

Results of the $^{56}Fe(n,n)$ – (JEFF-3.3)

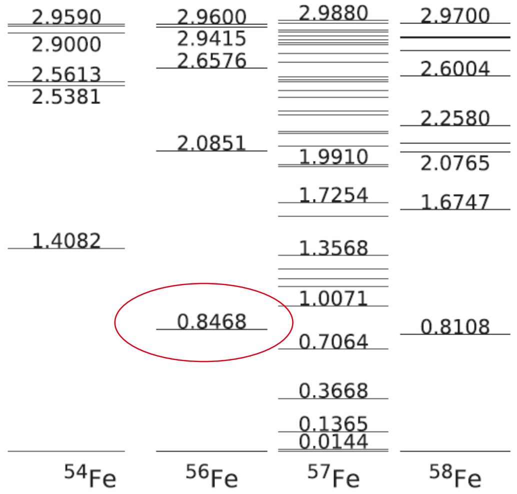


Results of the $^{56}Fe(n,n)$ - (Angle-integrated)



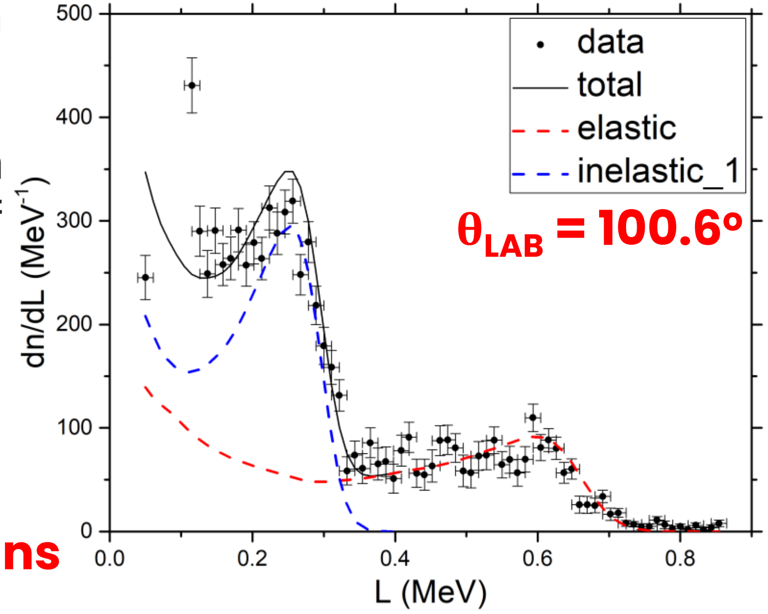
Inelastic scattering with the ELISA setup

- Inelastic scattering can be extracted using the ELISA setup via **neutron spectrometry**
- **^{56}Fe(n,n′γ)** cross section from the first excited state of ^{56}Fe (**E_x = 0.8468 MeV**) was explored



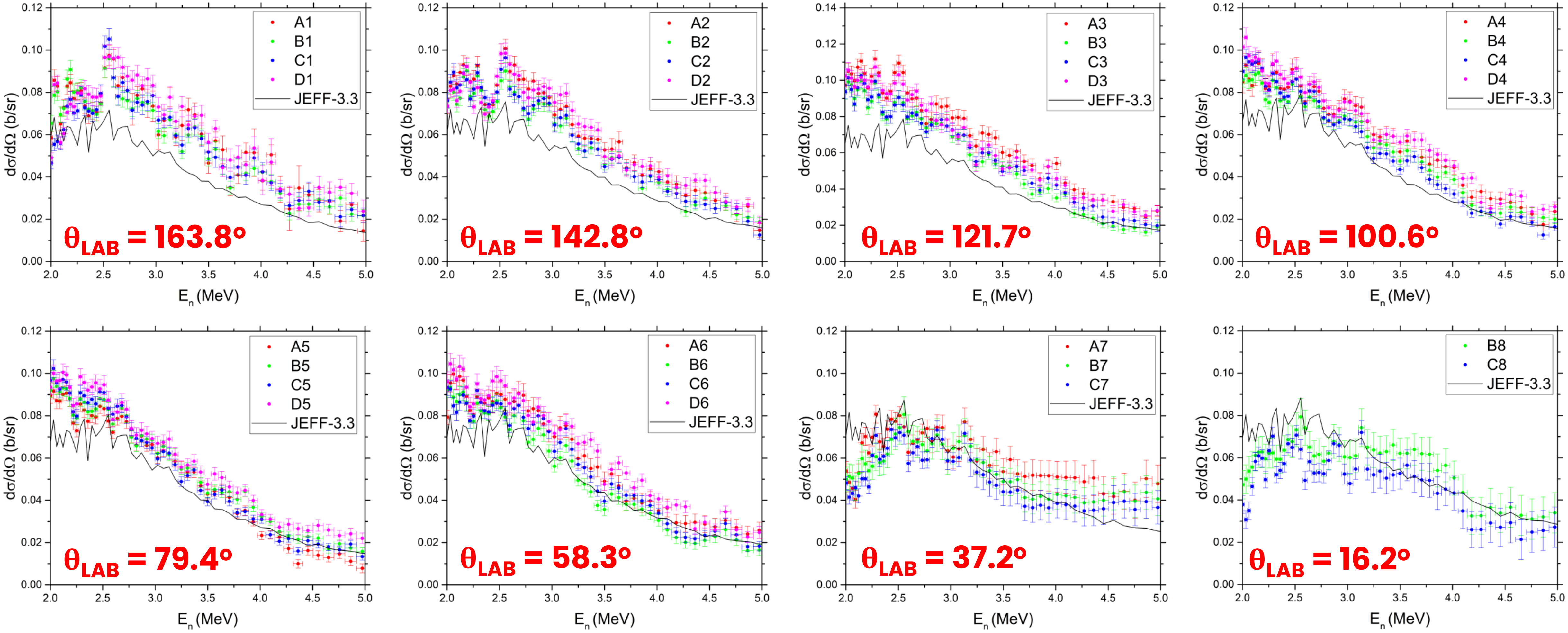
Step 4: Elastic – Inelastic separation

- Split the neutron t.o.f. spectrum in small intervals of **10 ns** each (time resolution of the measurement)
- Knowing the neutron **incident energy** and the **detection angle** – via **kinematics calculation** determine the energy of the neutrons scattered elastically E'_{el} and inelastically E'_{inl}
- **Overlaps** in the light output (L) distribution of these 2 neutron energies – **proper threshold** application

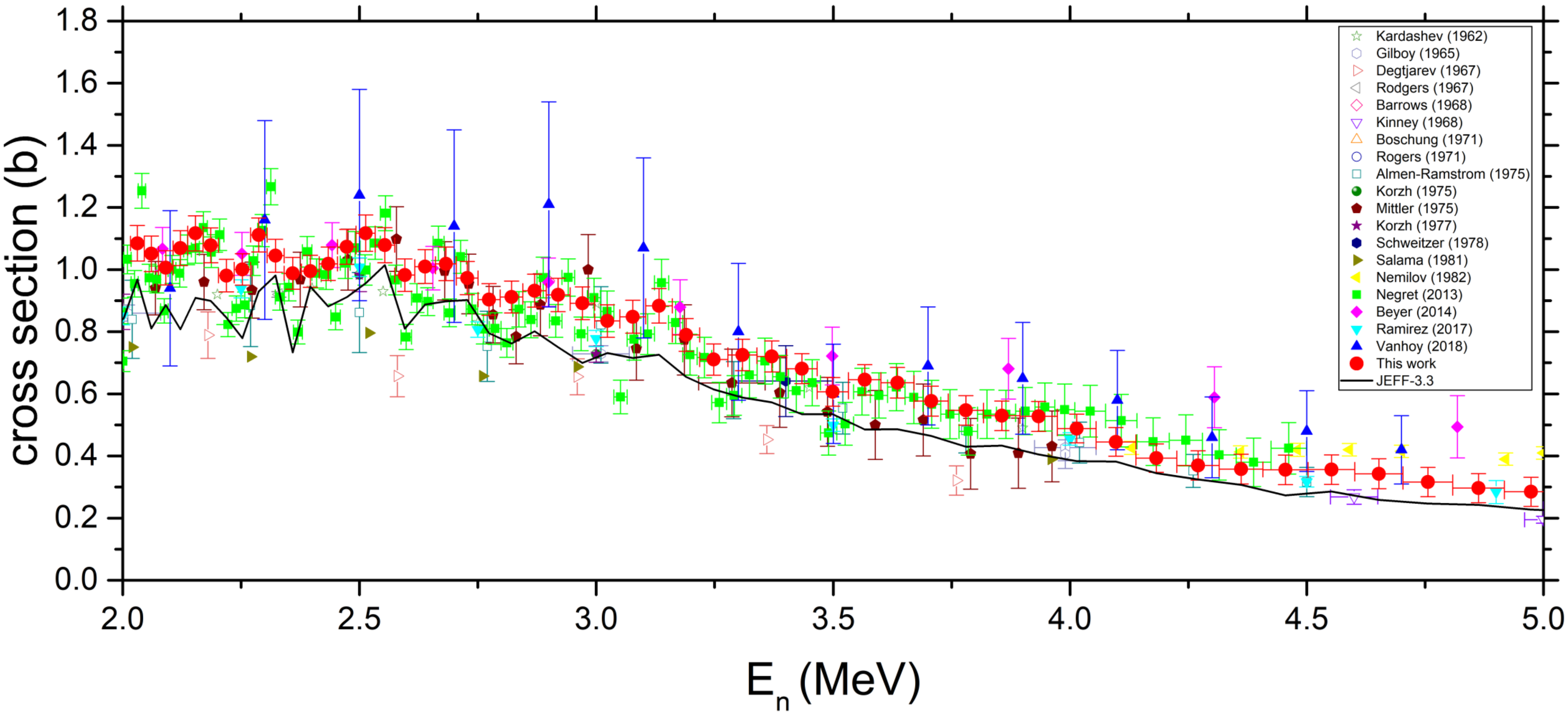


t.o.f. = 1086 – 1096 ns

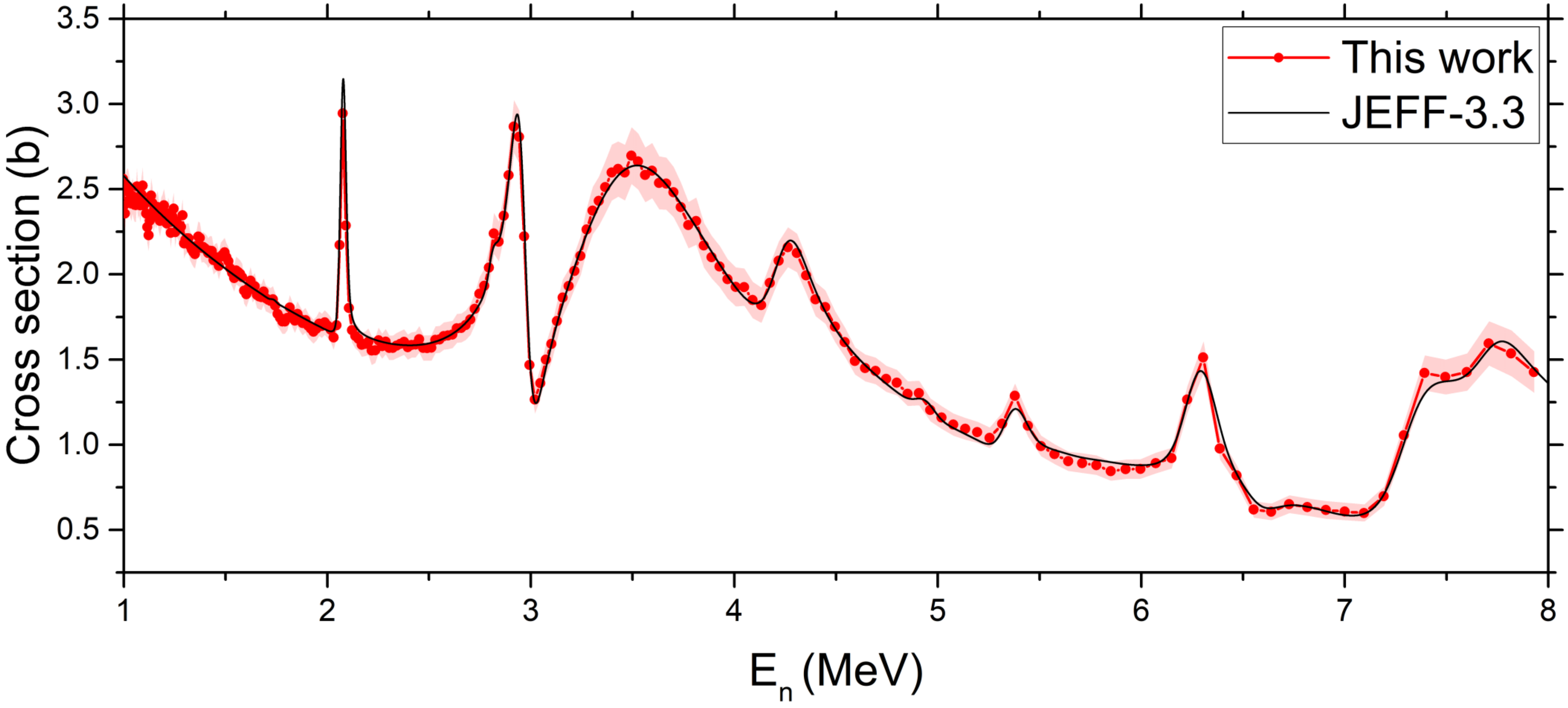
Results of the $^{56}Fe(n,n_1')$ – (E_x=846.8 keV)



Results of the $^{56}Fe(n,n_1')$ – (Angle-integrated)



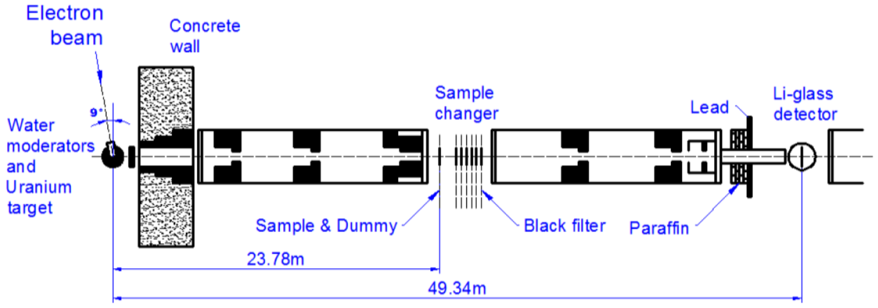
Results of the $^{nat}C(n,n)$ - (Angle-integrated)



Total cross section measurements on ^{nat}Fe

^{nat}Fe measurements at GELINA

- **50 m** distance from the GELINA neutron source (FP4_50m)
- Accelerator operating at **800 Hz repetition rate**
- The **moderated** neutron spectrum was used
- A ^{10}**B overlap filter** was placed to absorb slow neutrons from a previous burst
- A **Pb filter** was placed to reduce the intensity of the γ-flash
- ^{nat}**Fe** sample was placed at **25 m** distance from the neutron source
- The detector was placed at about **47.67 m** from the neutron target



^{nat}Fe measurements at GELINA

- A 6.35 mm thick and 152.4 mm diameter **NE912 Li-glass** scintillator enriched in **^{6}Li**
- **3** natural iron metallic discs were acquired
- The area of the samples was characterized by an optical surface inspection using a microscope system

ID	Thickness (cm)	Mass (g)	Area/mm²	Areal density (at/b)
1	1.1942 (2)	667.00 (5)	7093 (15)	0.1014 (2)
2	4.4864 (6)	2506.40 (5)	7095 (15)	0.381002 (6)
3	4.4876 (6)	2504.00 (5)	7086 (15)	0.3811 (6)

- Samples **#1** and **#2** were measured in **Spring/Summer 2023** (6 weeks), a new measurement **combining samples #2 and #3** is planned to take place as soon as possible!

Analysis – Background determination

The background contribution of the current transmission measurements is described by the following analytical expression:

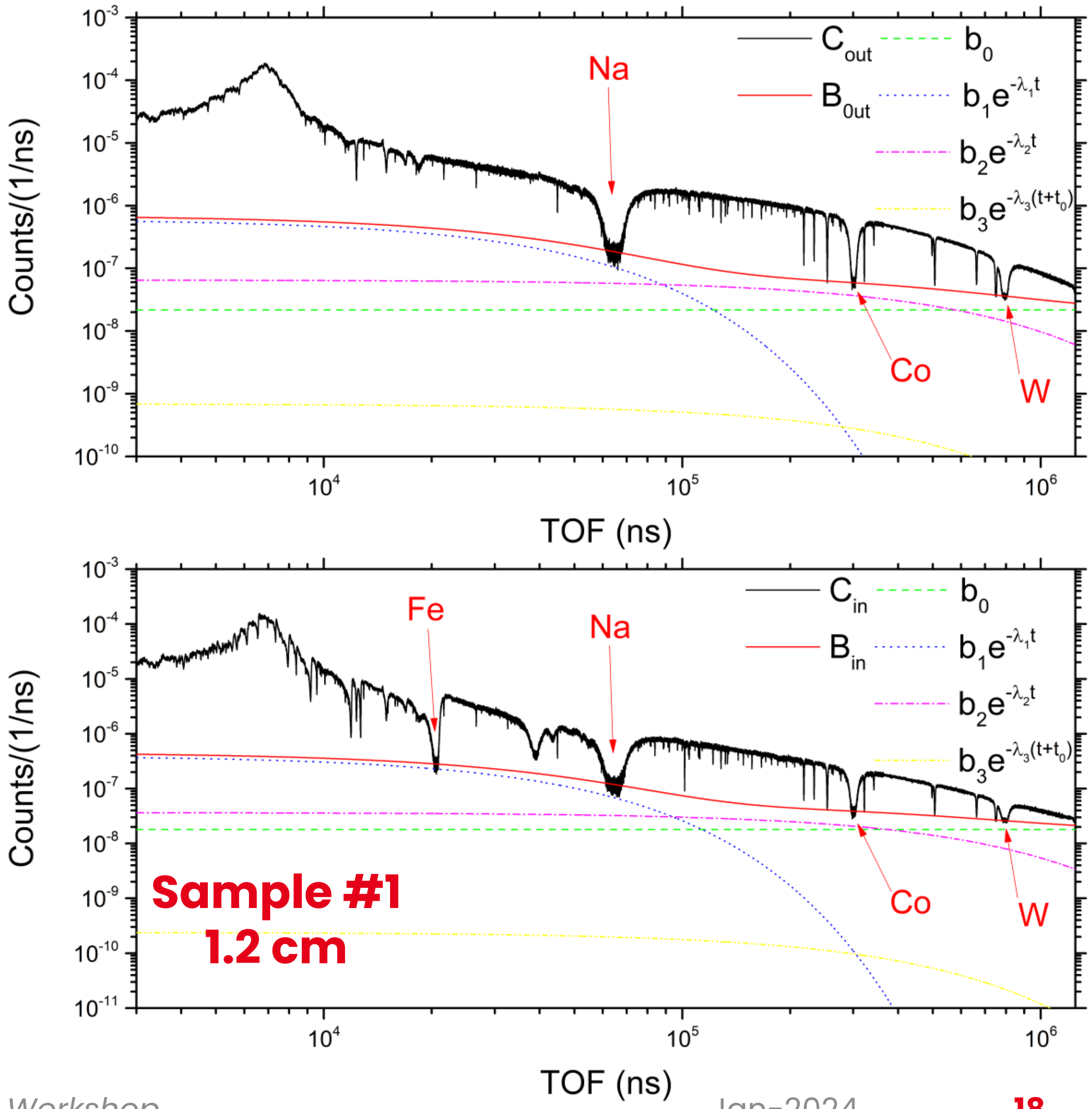
$$B(t) = b_o + b_1 e^{-\lambda_1 t} + b_2 e^{-\lambda_2 t} + b_3 e^{-\lambda_3 (t+t_0)}$$

- b_o: time independent contribution
- $b_1 e^{-\lambda_1 t}$: accounts for the contribution due to the detection of 2.2 MeV γ-rays resulting from neutron capture in hydrogen that is present in the moderator
- $b_2 e^{-\lambda_2 t}$: originates predominantly from neutrons scattered inside the detector station
- $b_3 e^{-\lambda_3 (t+t_0)}$: accounts for the contribution due to slow neutrons from previous accelerator cycles

Analysis – Background determination

- The overlap component $\left(b_3 e^{-\lambda_3(t+t_0)}\right)$ and the independent term (b_o) were obtained by extrapolating the TOF spectra at the end of the cycle
- The rest of the background contributions $\left(b_1 e^{-\lambda_1 t},\, b_2 e^{-\lambda_2 t}\right)$ were determined by using the black resonance technique.
- Black resonance filters used:

Na – Co - W



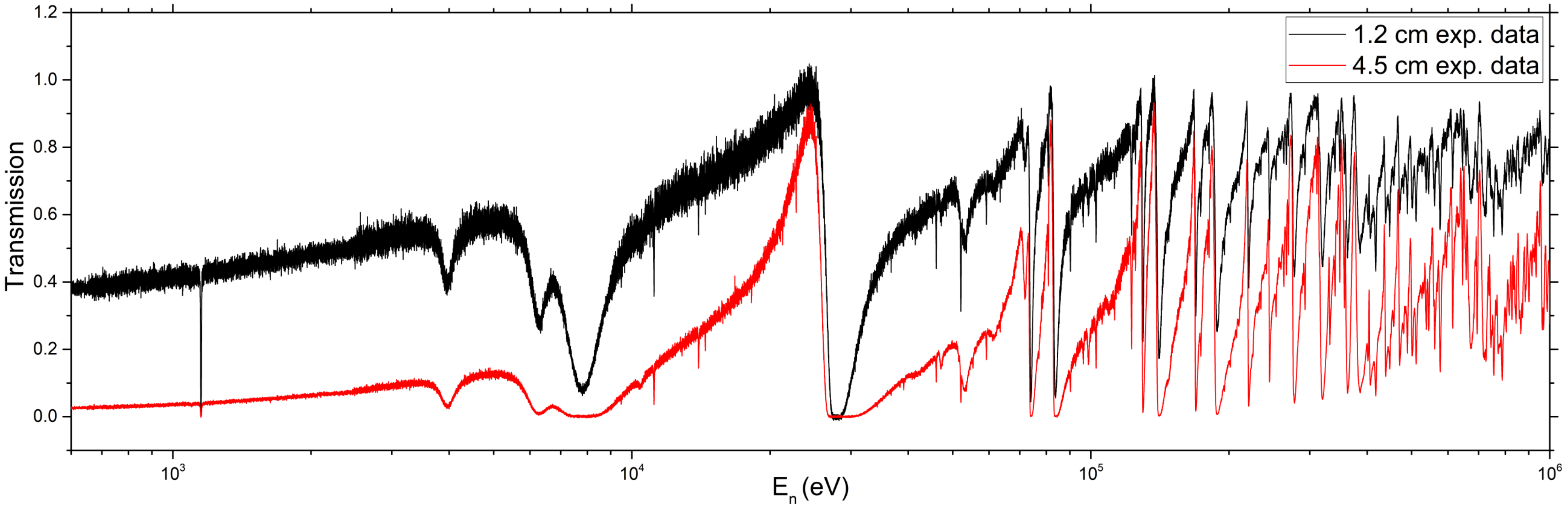
Analysis – Transmission calculation

$$T_{exp}(t_m) = N_T \frac{C_{in}(t_m) - k_T B_{in}(t_m)}{C_{out}(t_m) - k_T B_{out}(t_m)}$$

- C_{in}, C_{out}: counts of the sample-in and the sample-out measurement
- B_{in}, B_{out}: background contributions
- N_T: normalization factor to account for the losses due to dead time in the detector and electronics chain
- k_T: correlated uncertainty component for systematic effects due to the background model
- t_m: time-of-flight (T_0-start signal / T_s-stop signal / t_0-time offset)

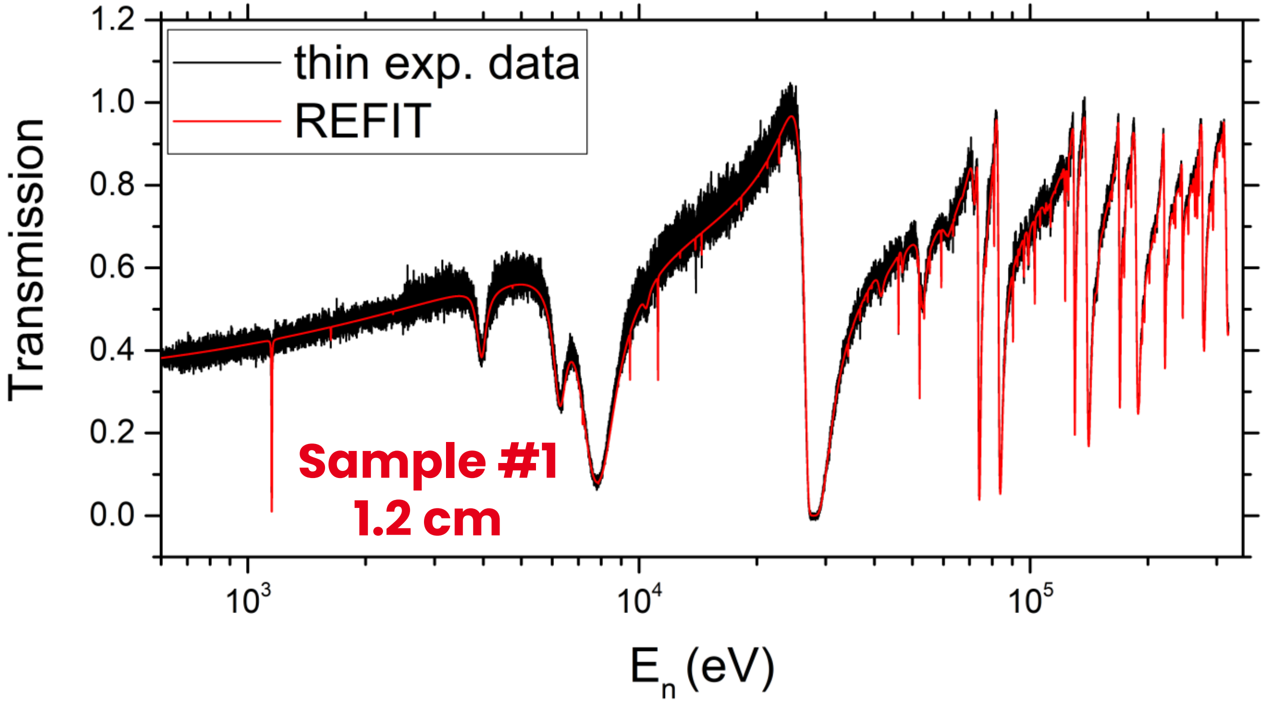
$$t_m = (T_s - T_0) + t_0$$

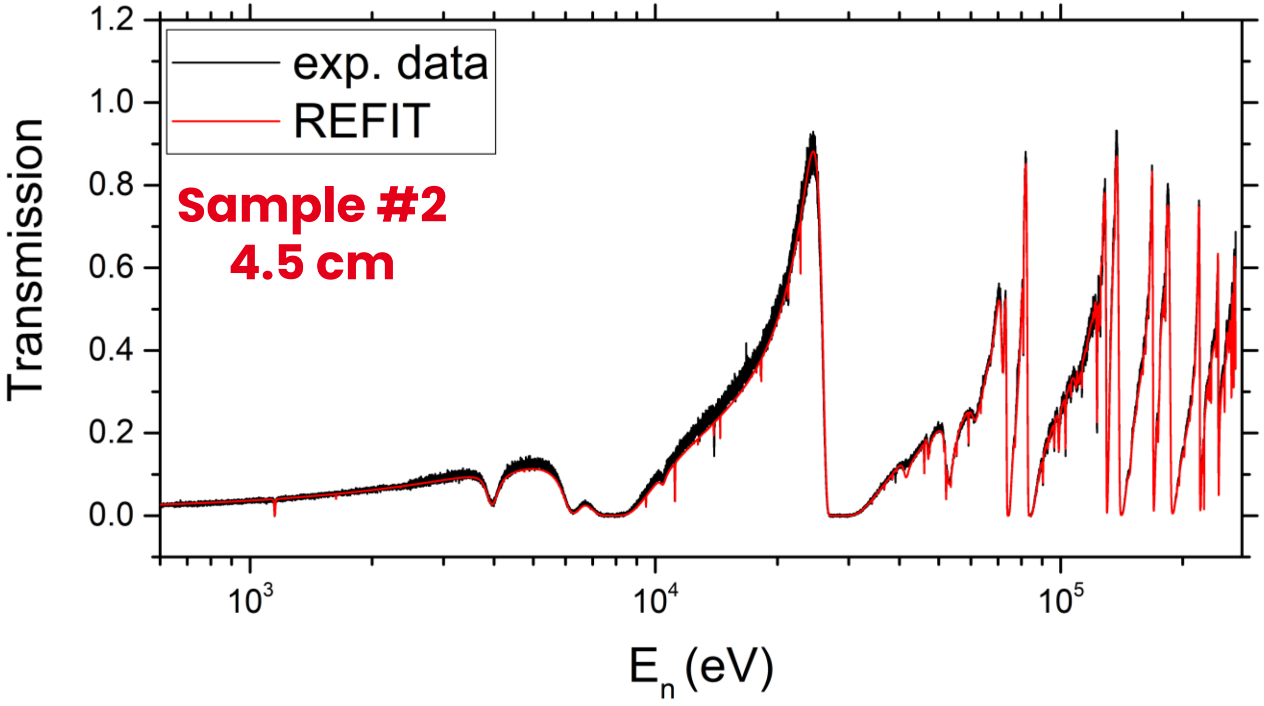
Transmission



Analysis – REFIT (*work in progress…*)

- Fit of the resonance parameters using the REFIT code (R-matrix formalism)
- Resonance parameters taken from JEFF-3.3
- Account for the resolution of the detector and the accelerator





Conclusion

^{56}Fe(n,n) + (n,n$_1$')

- The **angular distributions** of neutron **elastic scattering** by ^{56}Fe were produced in the energy range of **1** to **8 MeV**
- This was the **first experiment** providing **high-resolution** cross section data for elastic scattering in the fast neutron energy region
- The **total uncertainties** of the angular distributions vary from **3%** to **20%**, and for the elastic scattering cross section between **3%** and **6%**
- **Angular distributions** and **partial inelastic scattering cross section** from the first excited state of ^{56}Fe (**E_x = 0.8468 MeV**) were also extracted in the energy range between **2** and **5 MeV**
- The **total uncertainties** of the inelastic angular distributions vary from **5%** to **30%**, and for the partial inelastic scattering cross section between **4%** and **15%**
- All the results were compared with **JEFF-3.3** and other experimental data available in the literature (EXFOR) and there is relatively **good agreement** (within uncertainties)

Conclusion

$^{nat}Fe(n,tot)$

- **Two natural iron** samples of **1.2 cm** and **4.5 cm** thickness were measured at **FP4_50m**
- The **transmission of both measurements** has been extracted
- The resonance analysis using the **REFIT** code and the resonance parameters of **JEFF-3.3** has been initiated – The work is in progress…
- There is a plan to perform a measurement **combining samples #2** and **#3**, to get a sample with a total thickness of ~**9 cm**.
- The new data will be uploaded to the **EXFOR** library soon!

Thank you for your attention!

This project has received funding from the EURATOM research and training programme 2014-2018 under grant agreement No 847594 (ARIEL)