



High-resolution neutron scattering cross section measurements with the upgraded ELISA at GELINA

A. Karakaxi^{1,2}, M. Diakaki², G. Gkatis³, G. Noguere¹, C. Paradela³, E. Pirovano⁴ and A. Plompen³

¹CEA/DES/IRESNE/DER/SPRC/LEPh, Cadarache, 13108 Saint Paul Lez Durance, France

²Department of Physics, National Technical University of Athens, 15780 Athens, Greece

³European Commission, Joint Research Centre, 2440 Geel, Belgium

⁴Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany

Presenting author email: Georgia-Anna.KARAKAXI@cea.fr



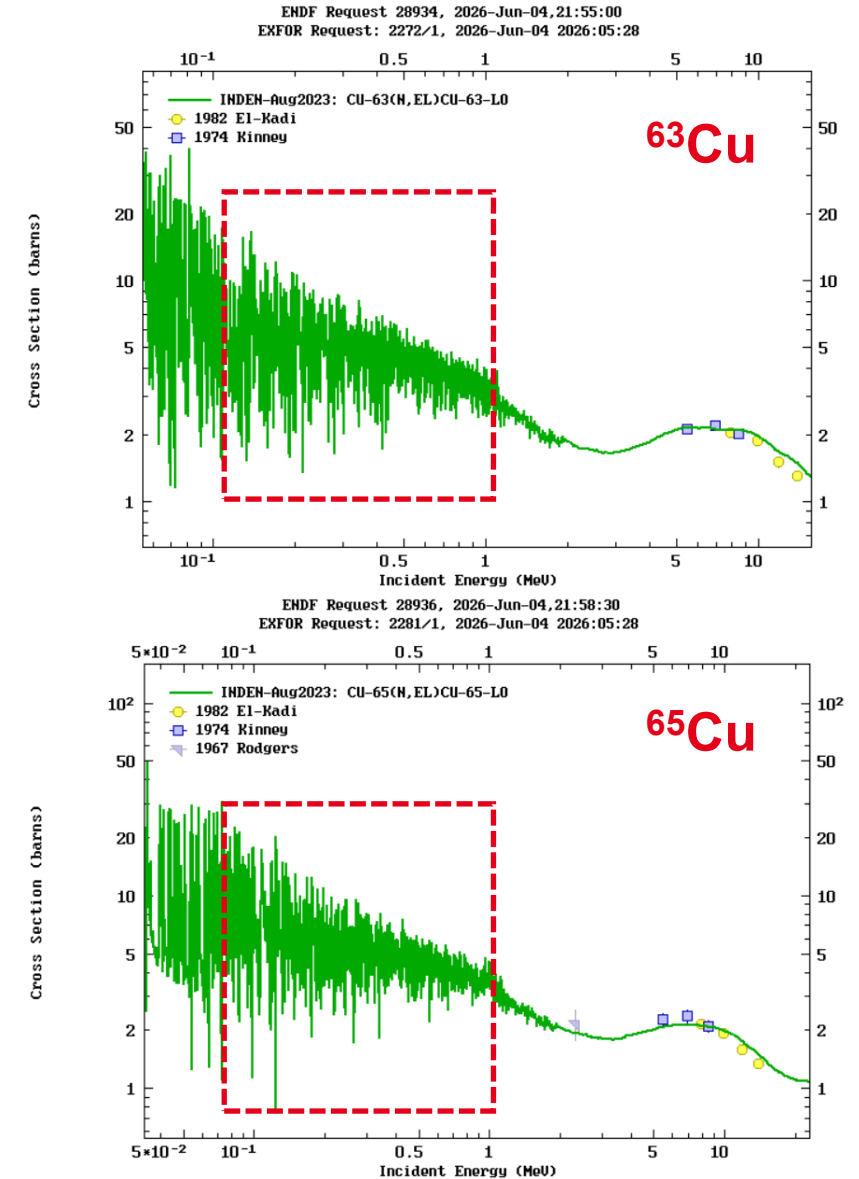
WONDER, 29/06/26 – 03/07/26

Motivation

- Elastic scattering is one of the most dominant and understudied reactions on structural materials
- ELISA setup at the GELINA facility in JRC-Geel
- **Cu** → presents **strong resonance behavior below 1 MeV**
- Not studied
- Characterization of the resonance region
- High impact in applications like fusion reactors and criticality experiments
- Where neutrons in fusion/fission start at higher energies, but they moderate into the < 1 MeV range

Need to extend to sub-MeV neutron detection energies

EXFOR data on Cu(n,e)



The GELINA Facility

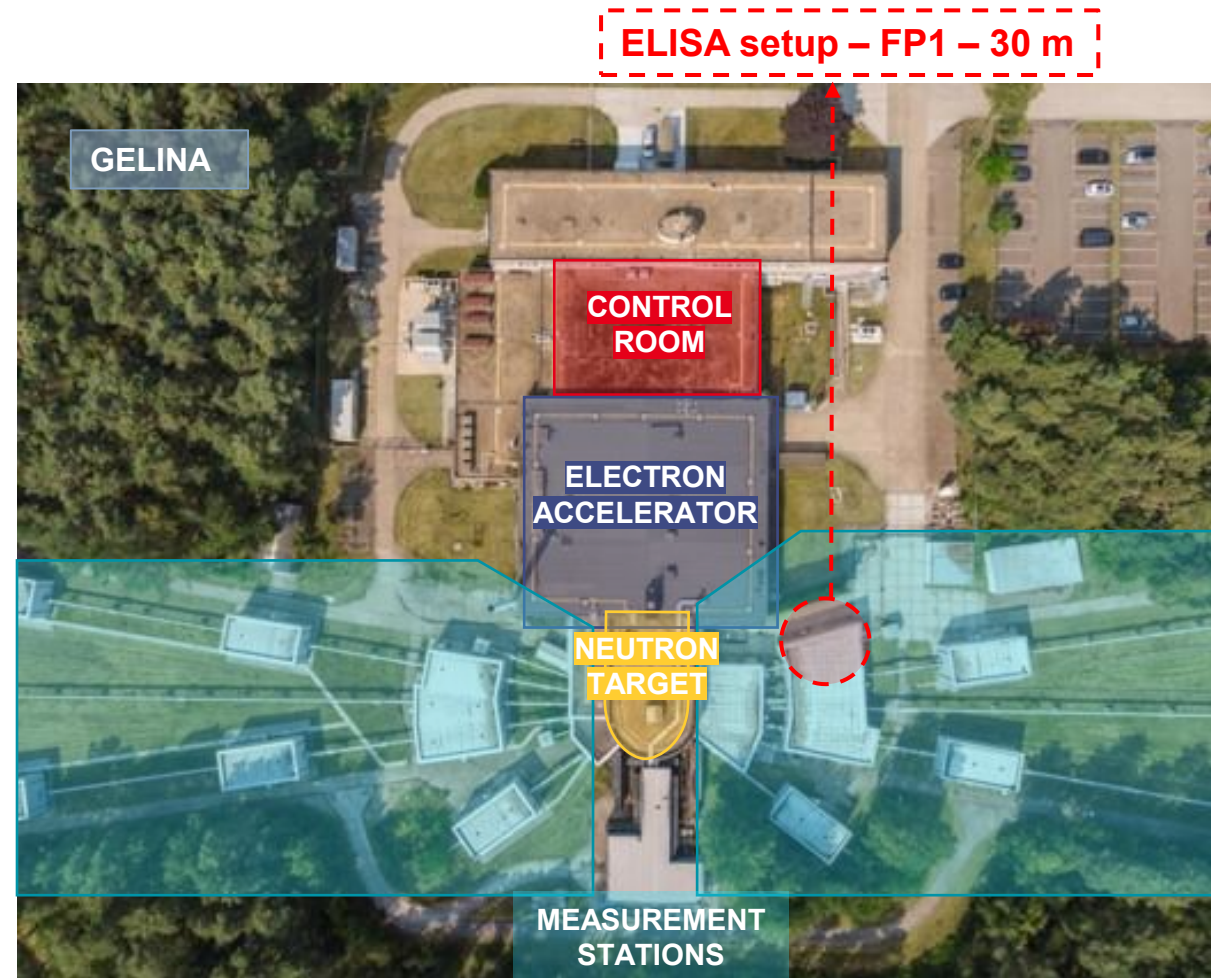
Geel Electron LINear Accelerator

- Pulsed white neutron source

$$E_n = 10 \text{ meV} - 20 \text{ MeV}$$

via bremsstrahlung and consecutive photonuclear reactions

- Neutron energy determination with **time-of-flight (TOF) technique**
- 10 flight paths with distance: 10 m – 400 m
- Various experimental setups:
(n, el) - (n, inl) - (n, γ) - (n, tot) - (n,f) - (n, cp)



ELISA setup

Elastic and Inelastic Scattering Array:

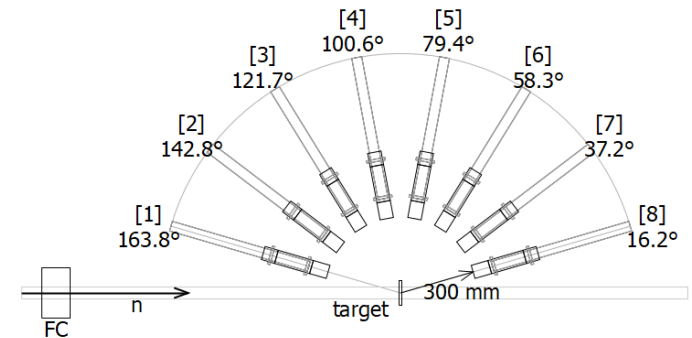
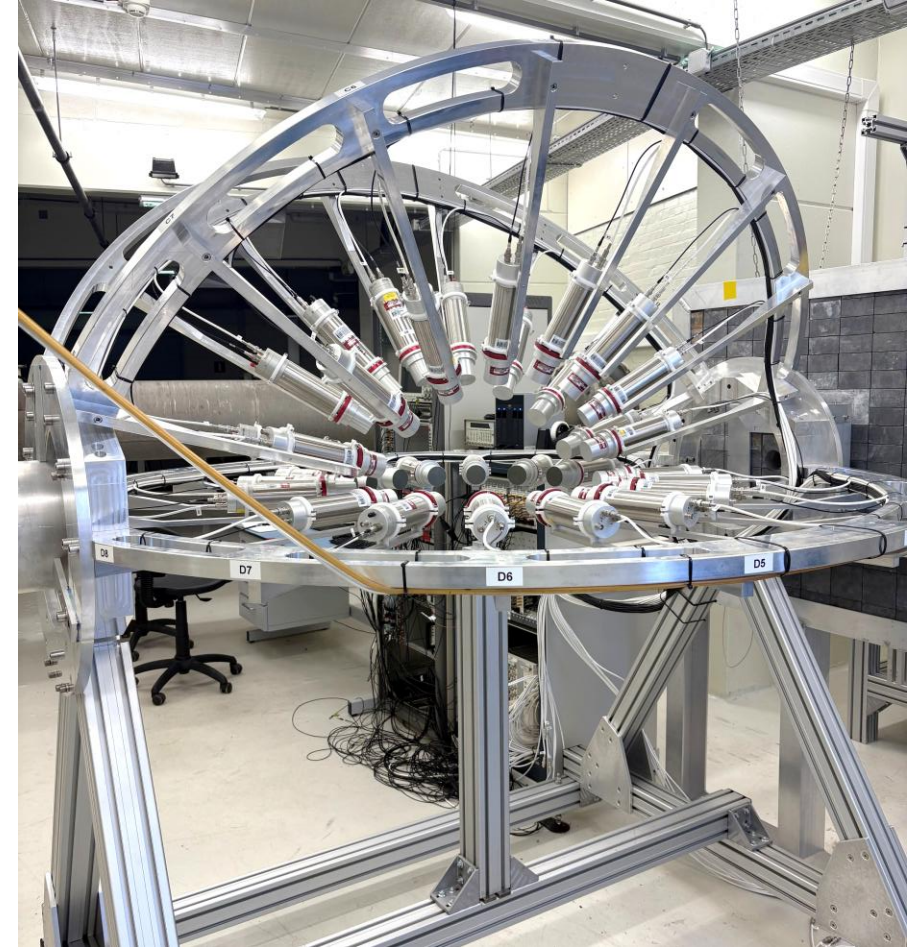
- 32 liquid organic scintillators
4 sets of 8 detectors at different scattering angles
 - 16 EJ301 – xylene (C_8H_{10}) – (n-p)
 - 16 EJ315 – deuterated benzene (C_6D_6) – (n-d)

1. Good n – g discrimination
2. Different neutron response
3. 4 detectors at the same angle

- ^{235}U fission chamber - Beam monitoring
- Measurement of the incoming neutron flux

High resolution double differential cross section data on neutron scattering reactions

^{nat}Fe : E. Pirovano et al., Phys. Rev. C 99, 024601 (2019)
 ^{nat}C : G. Gkatis et al., Phys. Rev. C 110, 034609 (2024)
 ^{54}Fe : G. Gkatis et al., Phys. Rev. C 109, 034612 (2024)
 ^{56}Fe : G. Gkatis et al., Phys. Rev. C 112, 044603 (2025)



ELISA setup

Elastic and Inelastic Scattering Array:

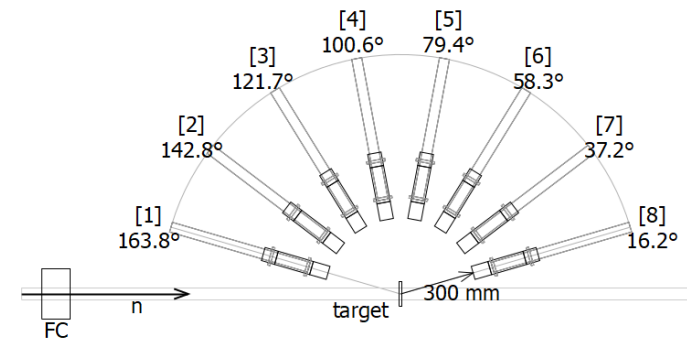
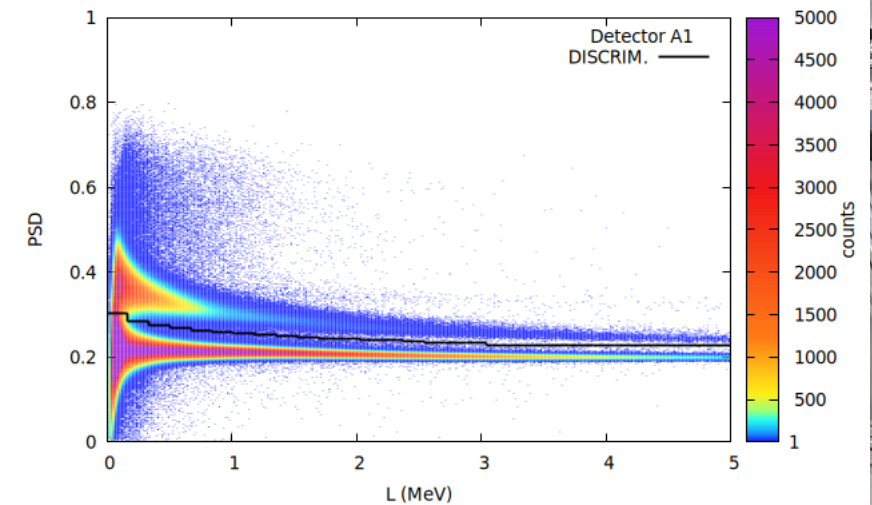
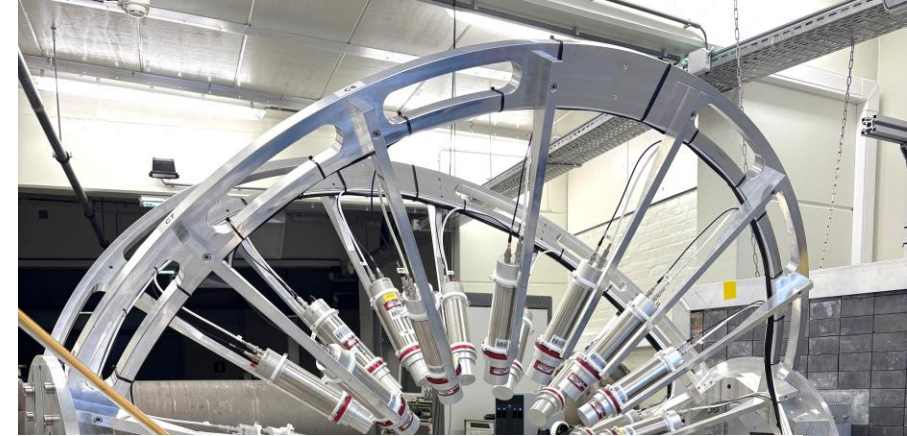
- 32 liquid organic scintillators
 - 4 sets of 8 detectors at different scattering angles
 - 16 EJ301 – xylene (C_8H_{10}) – (n-p)
 - 16 EJ315 – deuterated benzene (C_6D_6) – (n-d)

1. Good n – g discrimination
2. Different neutron response
3. 4 detectors at the same angle

- ^{235}U fission chamber - Beam monitoring
 - Measurement of the incoming neutron flux

High resolution double differential cross section data on neutron scattering reactions

^{nat}Fe : E. Pirovano et al., Phys. Rev. C 99, 024601 (2019)
 ^{nat}C : G. Gkatis et al., Phys. Rev. C 110, 034609 (2024)
 ^{54}Fe : G. Gkatis et al., Phys. Rev. C 109, 034612 (2024)
 ^{56}Fe : G. Gkatis et al., Phys. Rev. C 112, 044603 (2025)



Upgraded ELISA setup

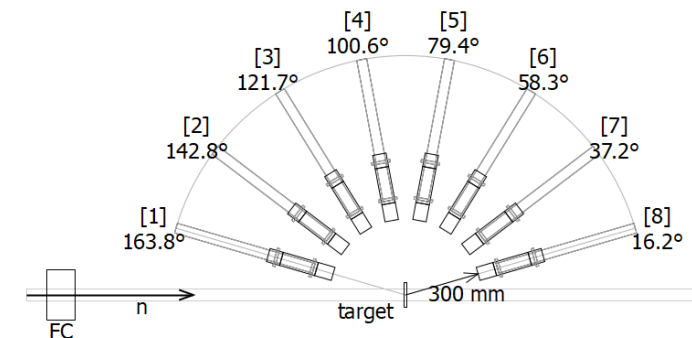
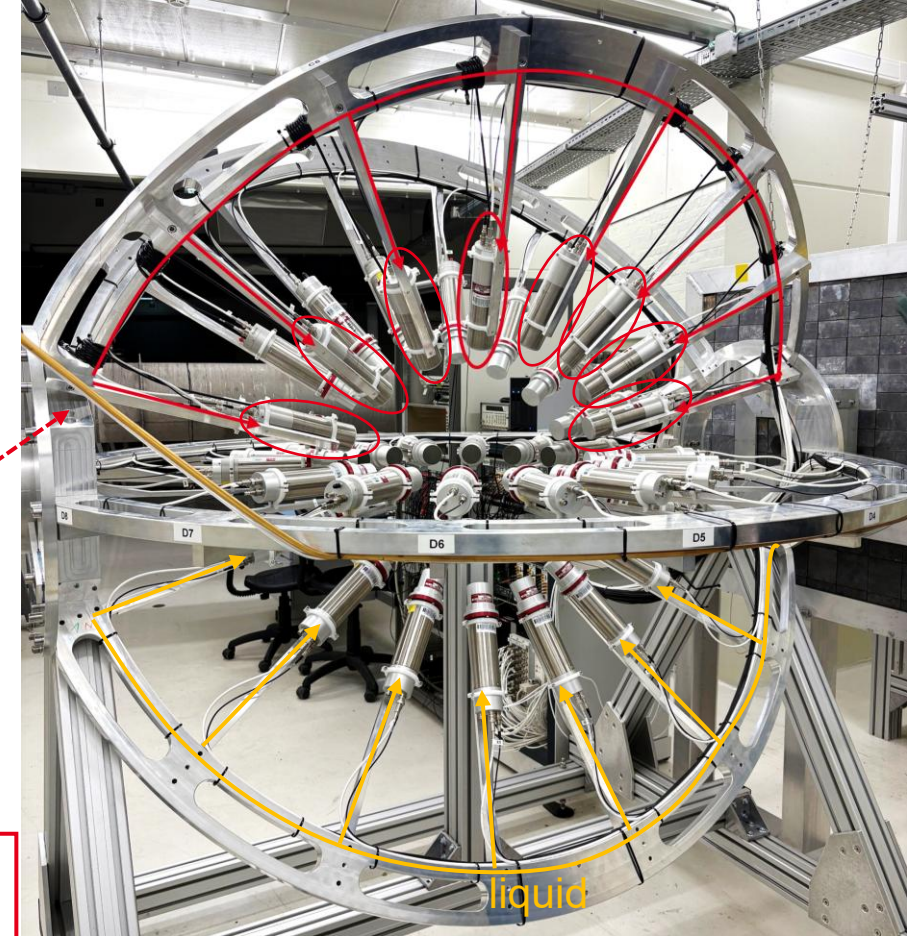
Elastic and Inelastic Scattering Array:

- 32 liquid organic scintillators
4 sets of 8 detectors at different scattering angles
 - 14 EJ301 – xylene (C_8H_{10}) – (n-p)
 - 2 EJ309 – PXE ($C_{16}H_{18}$) – (n-p)
 - 16 EJ315 – deuterated benzene (C_6D_6) – (n-d)
- 1 set of 8 Li-glass detectors enriched in 6Li
- ${}^{235}U$ fission chamber

- Change of mechanical parts
- ABCD data acquisition system [1]

[1] C. Fontana, <https://gitlab.com/cristiano.fontana/abcd>

Attempt to measure elastic scattering in neutron incident energies **lower than 1 MeV**



Experimental Details: $^{nat}\text{C}(n,\text{el})$ & $^{nat}\text{Cu}(n,\text{el})$

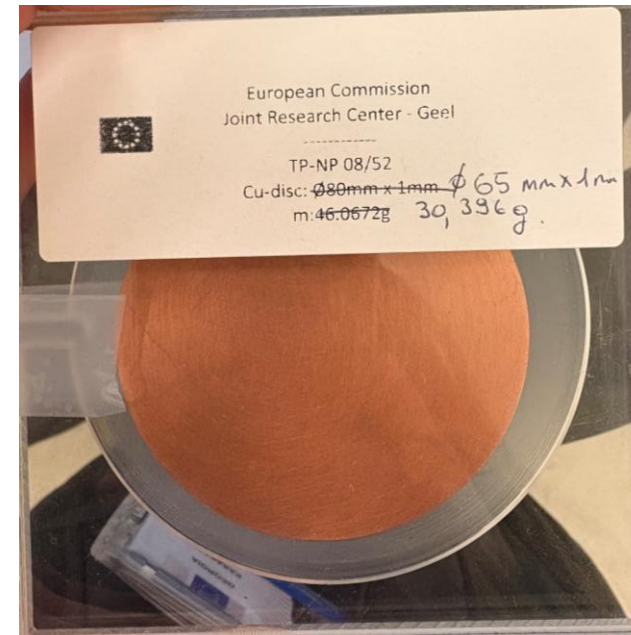
$^{nat}\text{C}(n,\text{el})$

- Diameter: 70 mm
- Thickness: 4 mm
- February 2026 – May 2026
- Duration:
 - ✓ ~ 390h (sample-in)
 - ✓ ~ 123h (sample-out)

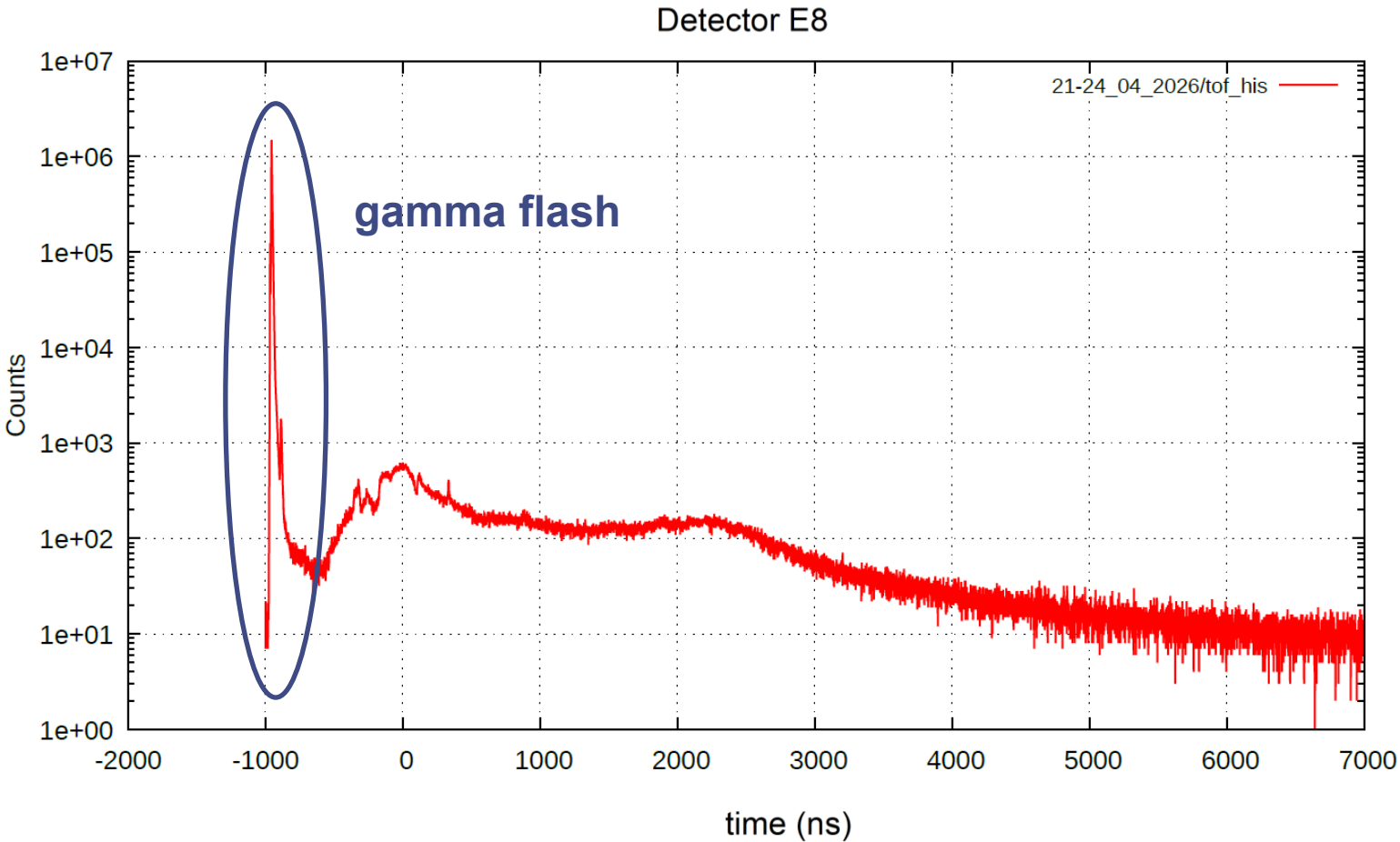


$^{nat}\text{Cu}(n,\text{el})$

- Diameter: 65 mm
- Thickness: 1 mm
- February 2026 - ongoing
- Duration:
 - ✓ ~ 300h (sample-in)
 - ✓ ~ 123h (sample-out)



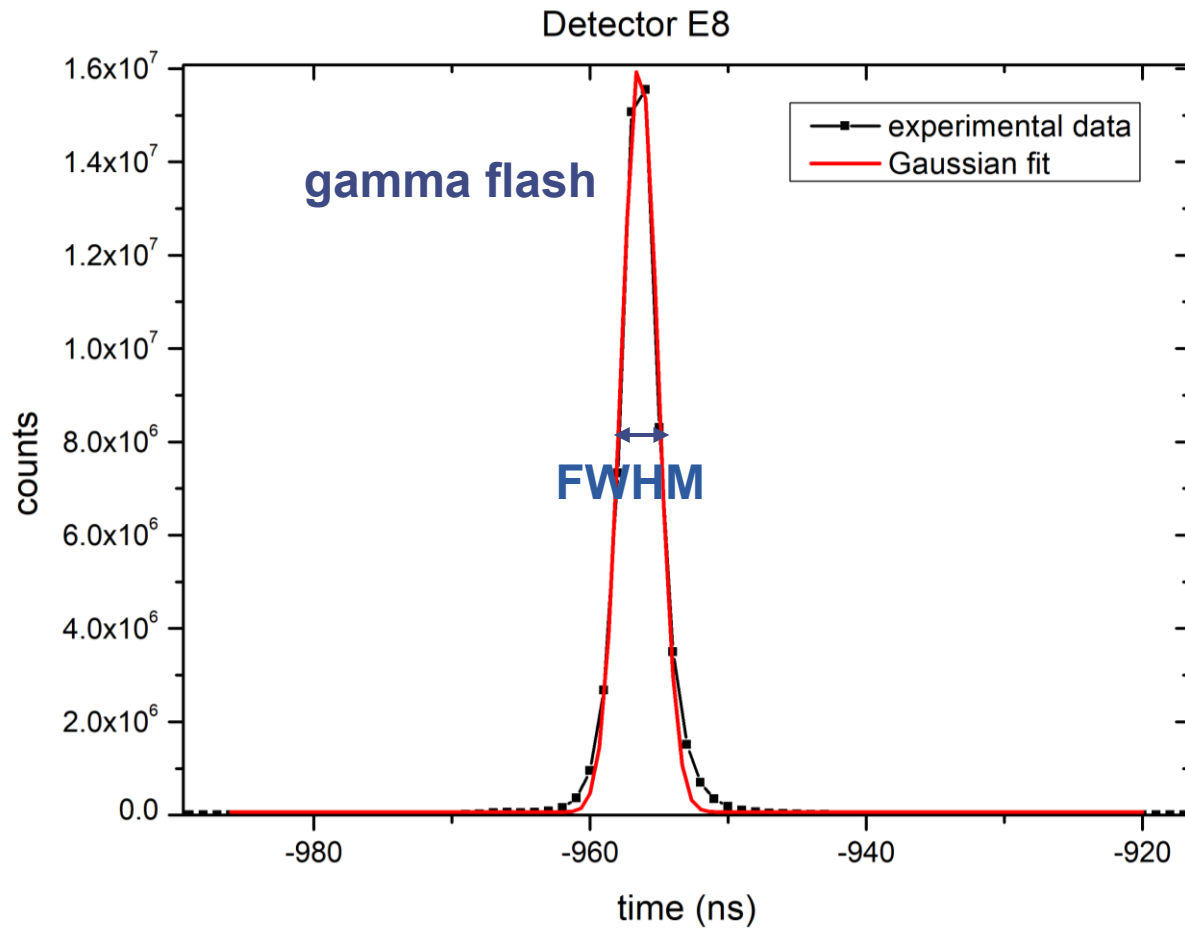
Time resolution of Li-glass scintillators



| | Time resolution (ns) | Uncertainty (ns) |
|----|----------------------|------------------|
| E1 | 5.96 | 0.09 |
| E2 | 8.9 | 0.1 |
| E3 | 8.0 | 0.1 |
| E4 | 7.40 | 0.09 |
| E5 | 6.88 | 0.08 |
| E6 | 5.28 | 0.05 |
| E7 | 4.11 | 0.03 |
| E8 | 3.09 | 0.02 |

The time resolution of **liquid scintillators** is around **3.0 ns**.

Time resolution of Li-glass scintillators



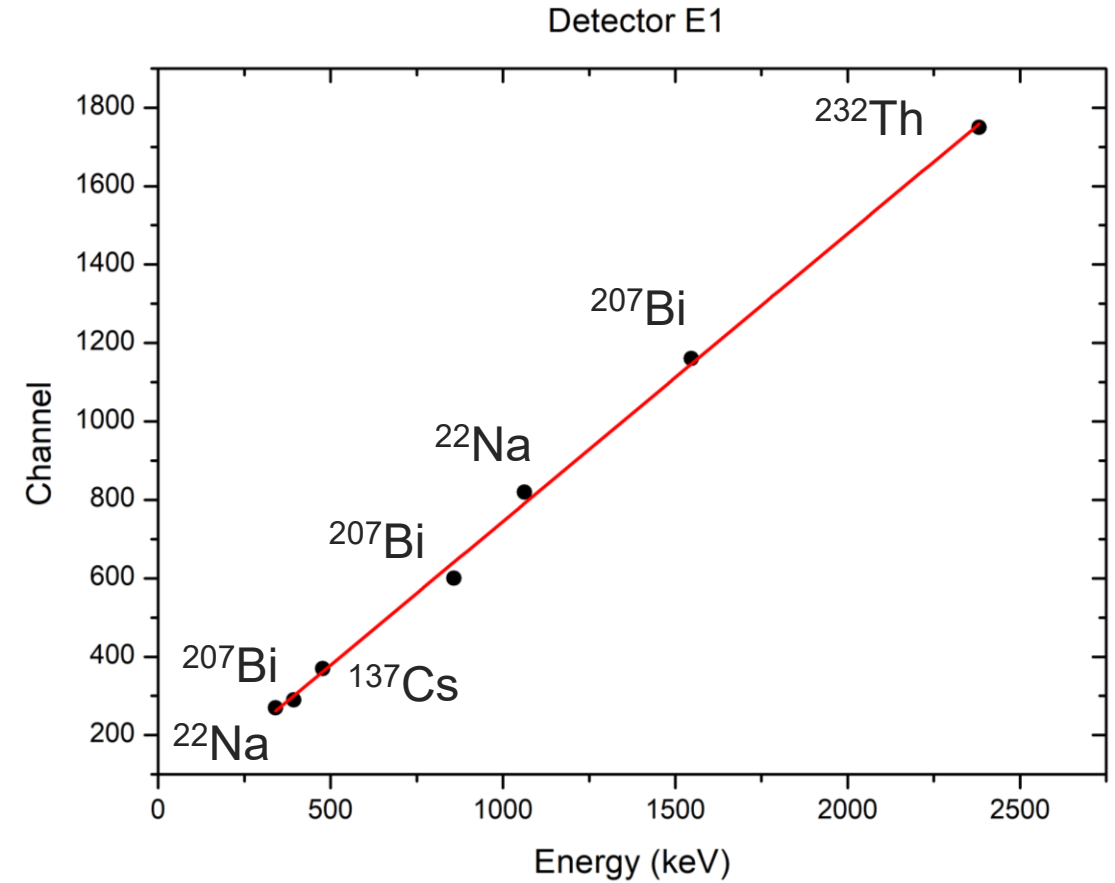
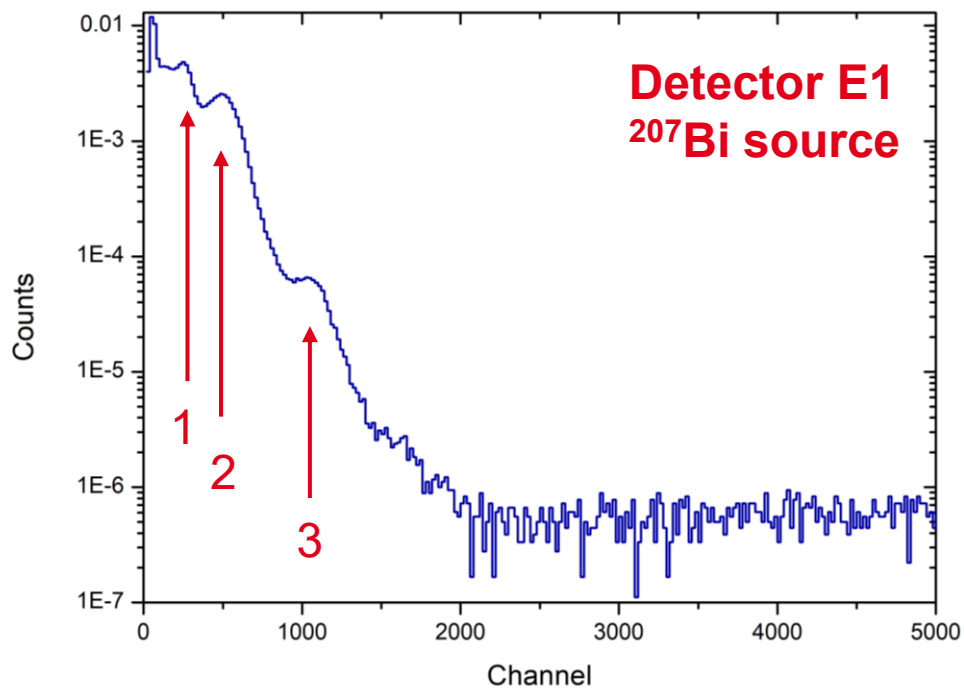
| | Time resolution (ns) | Uncertainty (ns) |
|----|----------------------|------------------|
| E1 | 5.96 | 0.09 |
| E2 | 8.9 | 0.1 |
| E3 | 8.0 | 0.1 |
| E4 | 7.40 | 0.09 |
| E5 | 6.88 | 0.08 |
| E6 | 5.28 | 0.05 |
| E7 | 4.11 | 0.03 |
| E8 | 3.09 | 0.02 |

The time resolution of **liquid scintillators** is around **3.0 ns**.

Calibration with gamma sources



| ^{22}Na | ^{137}Cs | ^{207}Bi | ^{232}Th |
|------------------------|-------------------|---------------------------------|-------------------|
| 511, 1274.54 keV | 662 keV | 569.7, 1063.7, 1770.2 keV | 2614 keV |

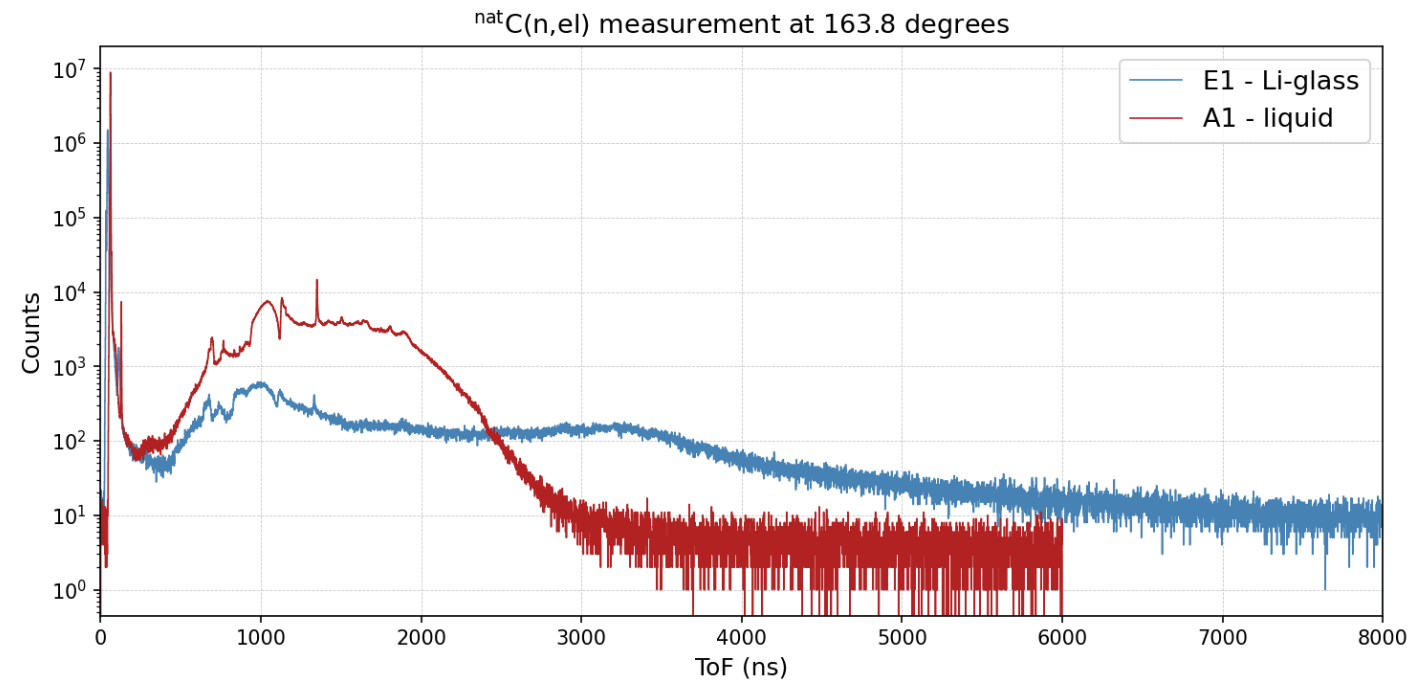
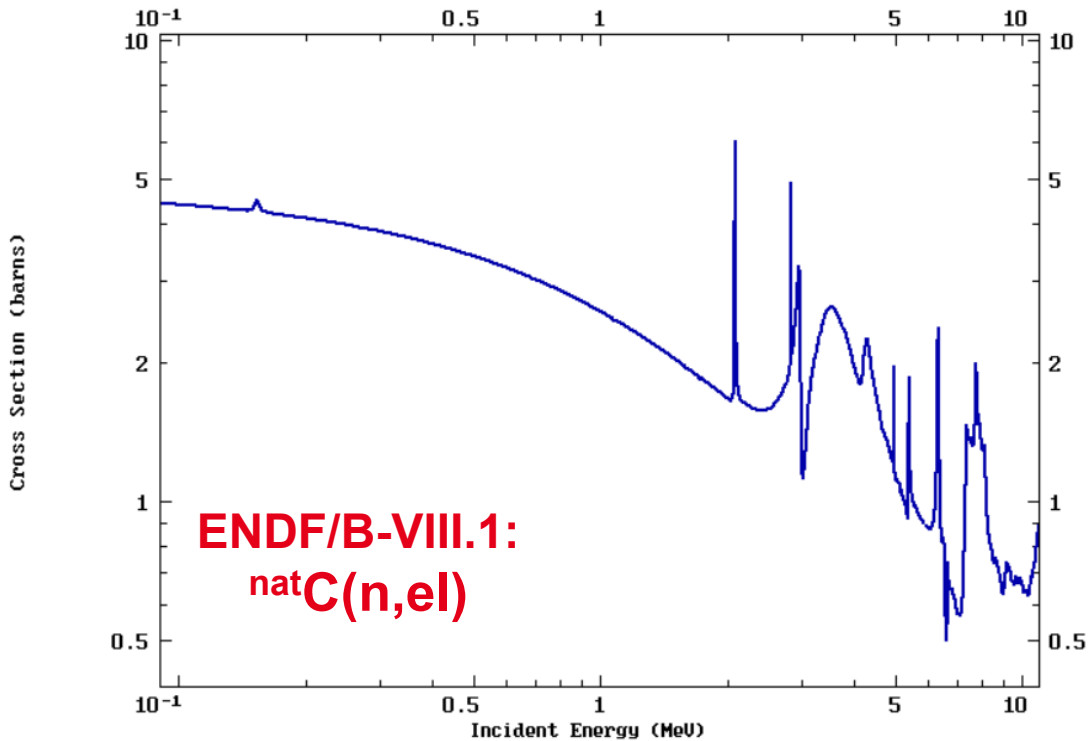


$^{nat}\text{C}(n,\text{el})$ measurements

- Carbon cross section is accurately known with an uncertainty of less than 1% up to 4.8 MeV incident neutron energy
- IAEA indicates the differential cross section as a standard for neutron energies below 1.8 MeV [2]

- Perform time rebinning to improve statistics, worsening time resolution
- Possible improvement – Add more Li-glass detectors (foreseen in fall 2026)

[2] A.D. Carlson et al., Nuclear Data Sheets, 148 (2018), 143-188

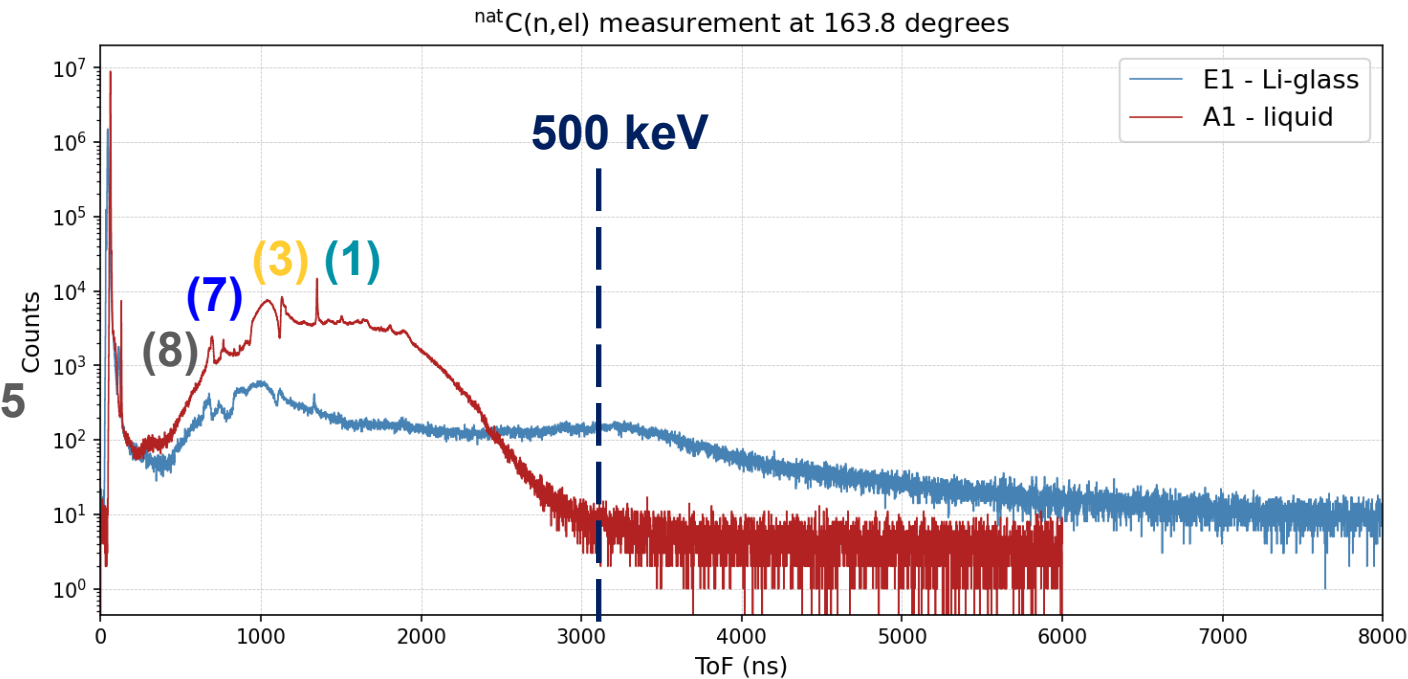
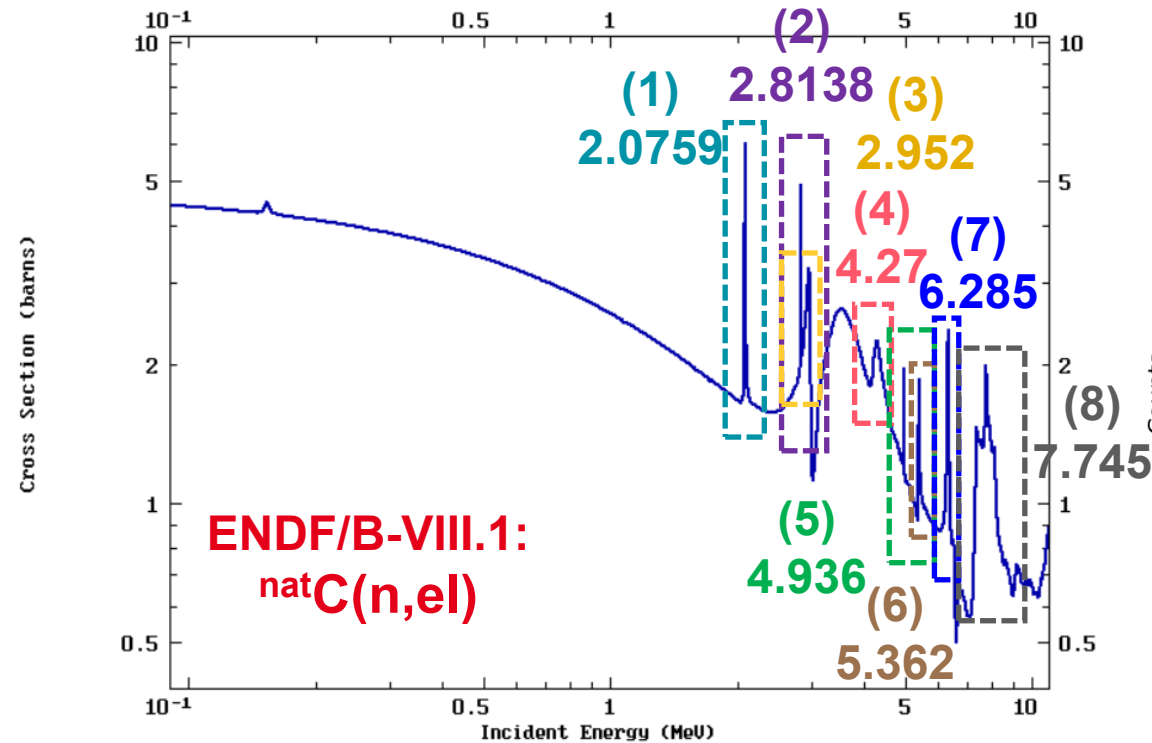


$^{nat}\text{C}(n,e)$ measurements

- Carbon cross section is accurately known with an uncertainty of less than 1% up to 4.8 MeV incident neutron energy
- IAEA indicates the differential cross section as a standard for neutron energies below 1.8 MeV [2]

- Perform time rebinning to improve statistics, worsening time resolution
- Possible improvement – Add more Li-glass detectors (foreseen in fall 2026)

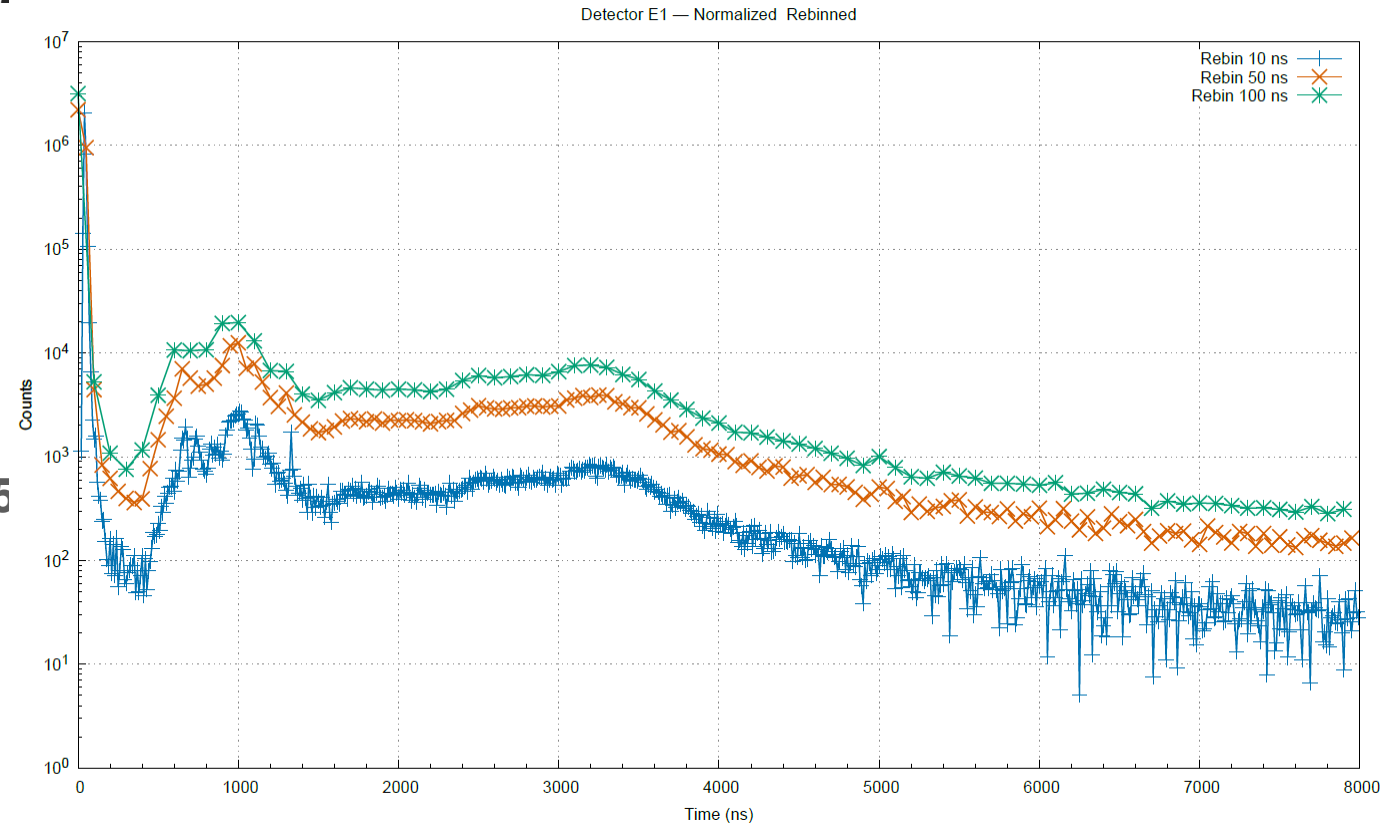
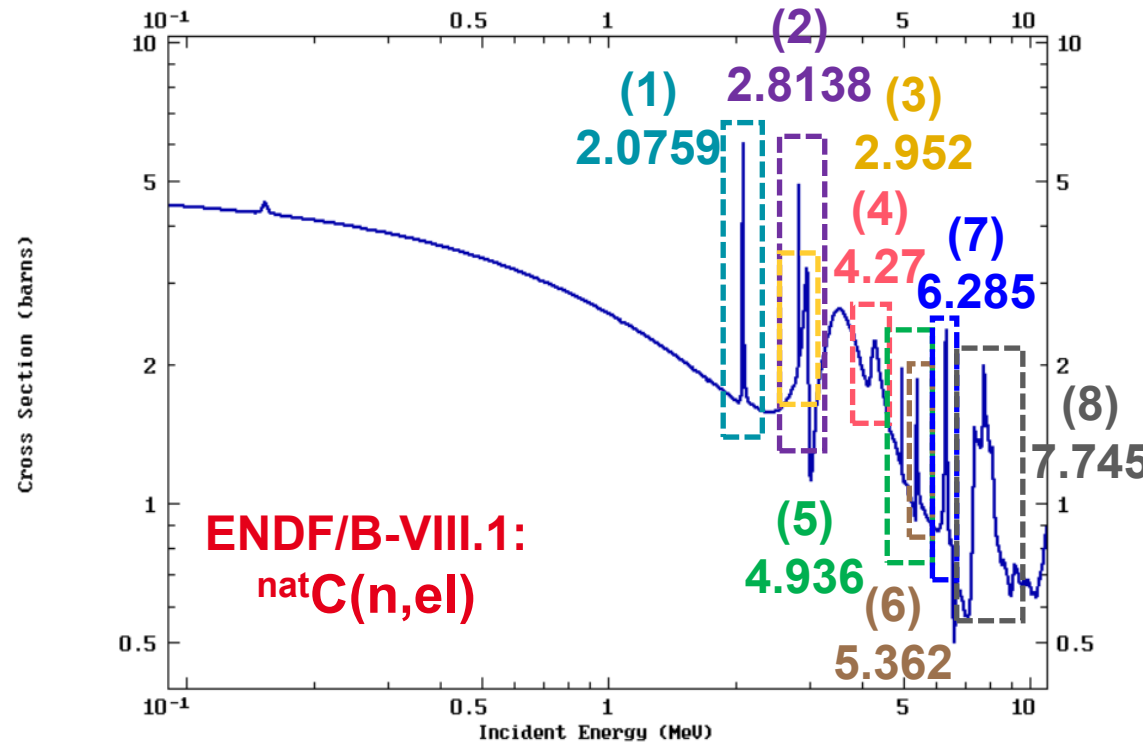
[2] A.D. Carlson et al., Nuclear Data Sheets, 148 (2018), 143-188



$^{nat}\text{C}(n,e)$ measurements

- Carbon cross section is accurately known with an uncertainty of less than 1% up to 4.8 MeV incident neutron energy
- IAEA indicates the differential cross section as a standard for neutron energies below 1.8 MeV [2]¹

- Perform time rebinning to improve statistics, worsening time resolution
- Possible improvement – Add more Li-glass detectors (foreseen in fall 2026)



Analysis for liquid scintillators

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

$$\frac{d\sigma}{d\Omega}(\mathbf{E}, \boldsymbol{\theta}) = \frac{N_{el}(\mathbf{E}, \boldsymbol{\theta})}{\Phi(\mathbf{E}) \cdot \rho_T}$$

$N_{el}(\mathbf{E}, \boldsymbol{\theta})$: is the number of neutron elastic scattering events

$\Phi(\mathbf{E})$: is the incident neutron fluence

ρ_T : is the target areal density (atoms per unit surface)

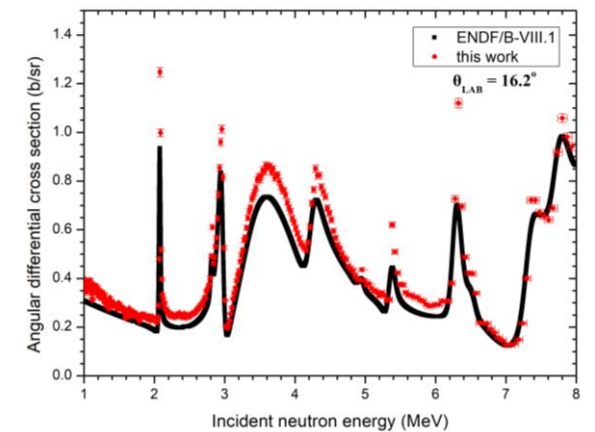
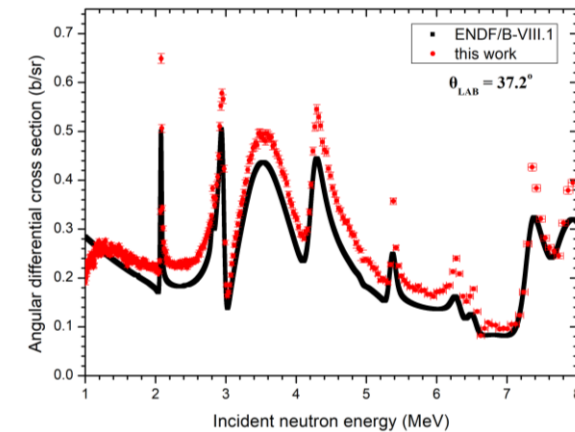
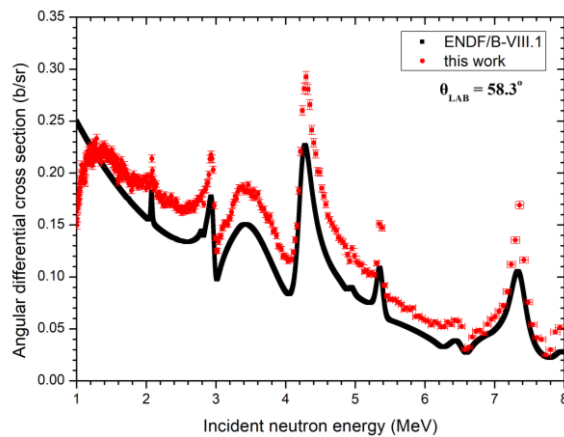
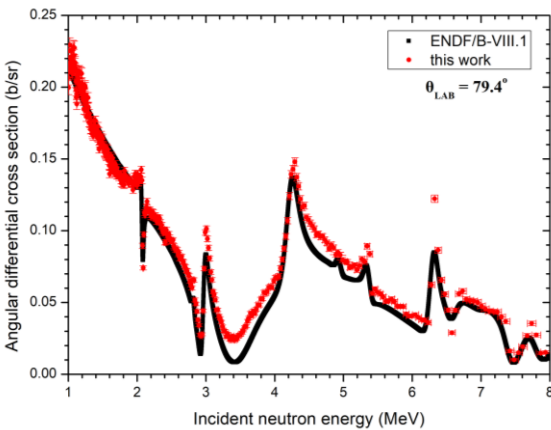
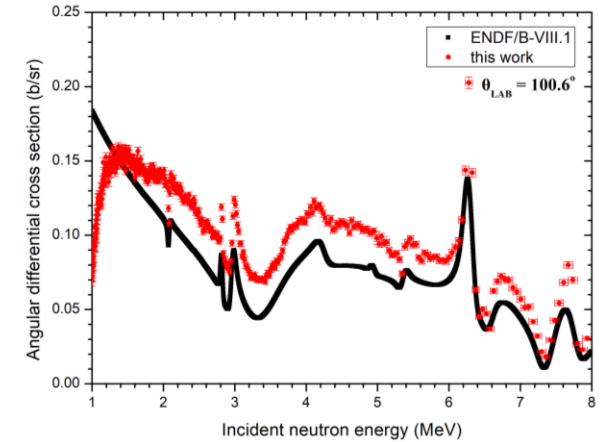
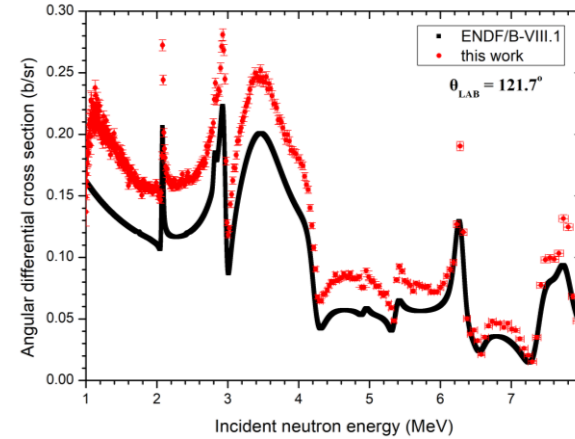
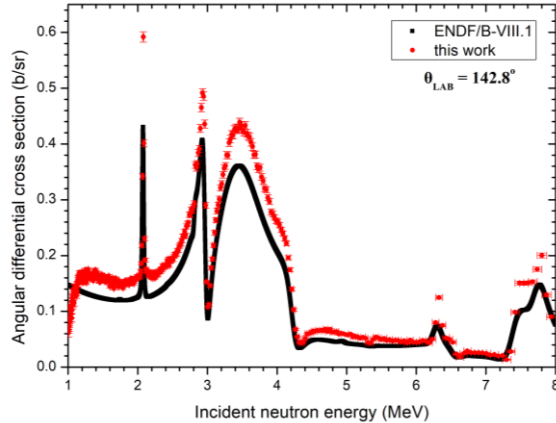
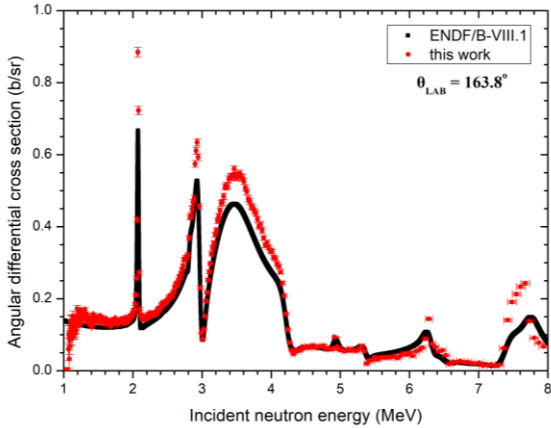
The angle-integrated cross section $\sigma(\mathbf{E})$ can also be calculated by applying the Gauss-Legendre quadrature rule:

$$\sigma = 2\pi \sum_{i=1}^8 w_i \cdot \frac{d\sigma}{d\Omega}(\cos\theta_i)$$

$^{nat}\text{C}(n,e)$ preliminary results



Backward scattering angles



Forward scattering angles

Next steps

Li-glass detectors :

- The project is still in its initial phase
- Neutron – gamma discrimination
- Determine efficiency
- Data analysis methodology

Liquid Scintillators :

- Multiple scattering correction
- Analysis for the remaining 24 detectors
- Checks to finalize results

Future Perspectives

- Measurements of ^{nat}Cu are still ongoing
- Enriched ^{65}Cu measurements (fall 2026)
- Further upgrade with the addition of 8 ^6Li -glass and 1 ^7Li scintillator

Thank you for your attention!

Acknowledgments

- Big thank you to the GELINA & MONNET scientific and technical staff at JRC-Geel
- CuElisa is partially funded by OFFERR, a Euratom project funded by the Horizon Europe programme under grant agreement n°101060008.

