This project has received funding from the Euratom support safe operation of nuclear systems programme 2014-2018 under grant agreement No 847552 (SANDA)

Task 2.2.1: The ^{239}Pu(n,γ) and (n,f) cross section measurement at CERN

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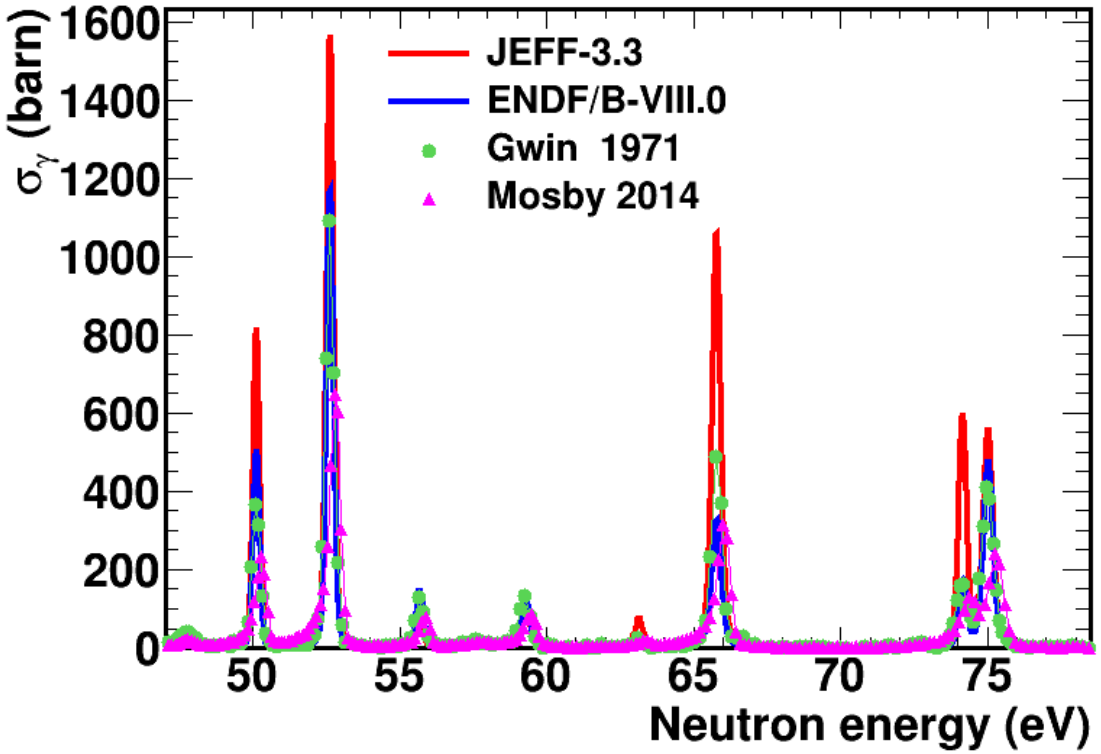
In this talk …

- Motivation
- Experimental setup
- Data analysis
- Results

Previous measurements

Previous ^{239}Pu capture measurements with high energy resolution in EXFOR

- **Gwin et al. (1971)**. For neutron energies between 0.02 eV and 30 keV.
- **Mosby et al. (2014)** at LANSCE (Los Alamos, USA) in the neutron energy range from 10 eV to 1.3 MeV. Only the shape of the cross-section was measured (normalized to ENDF/B-VII.0 cross-section)



Previous measurements

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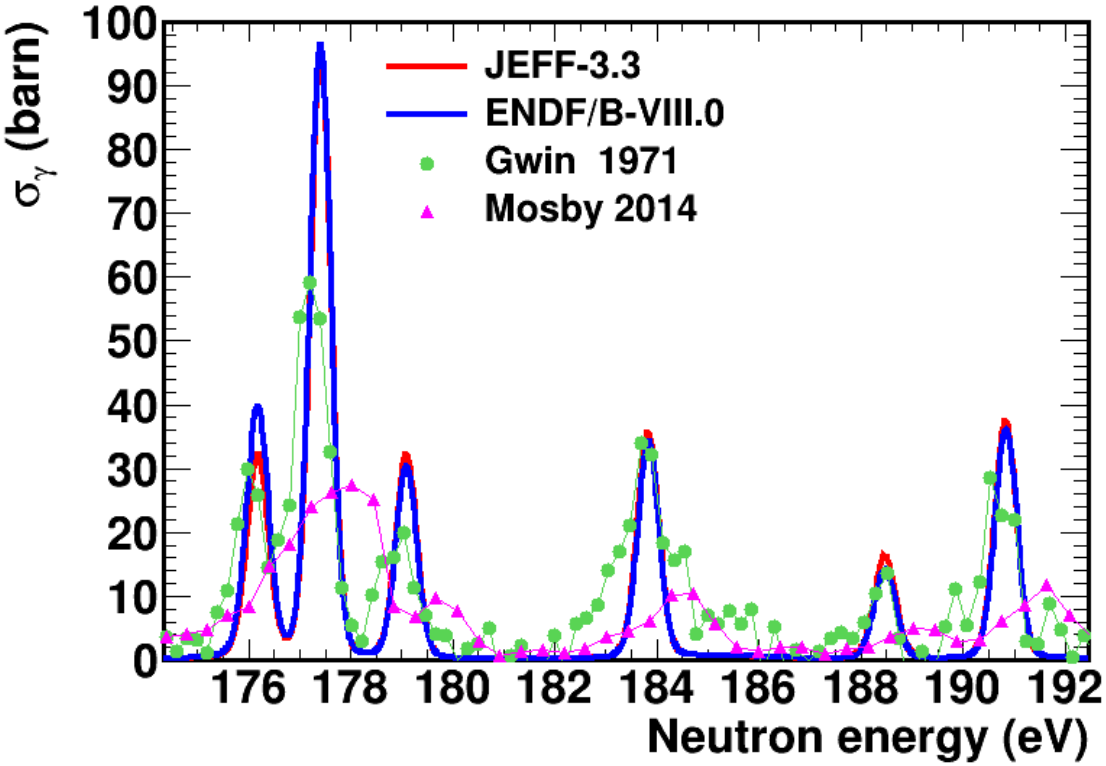
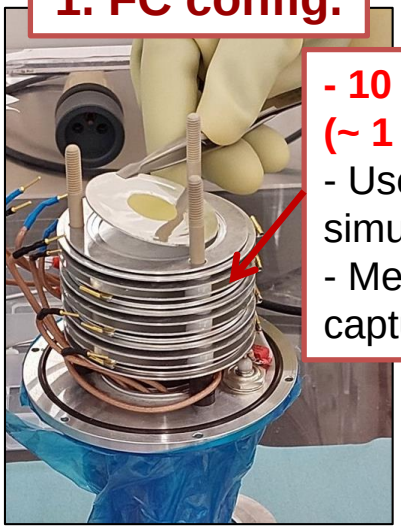


funded by the EU H2020 programme

Experimental setup

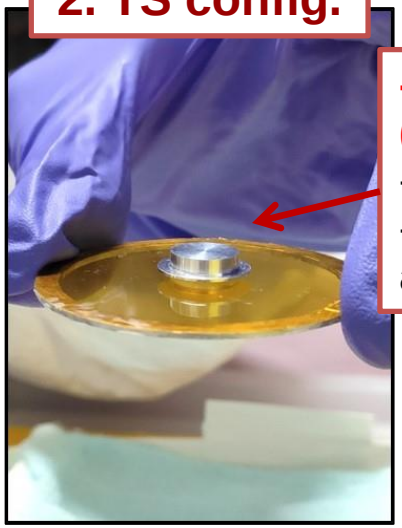
- The experimental campaign took place in the last quarter of 2022, with **2 months of beam time** (~$5 \cdot 10^{18}$ protons).
- The campaign was divided in **two different configurations**:

1. FC config.



- 10 thin Pu samples (~ 1 mg each).
- Use FICH + TAC simultaneously.
- Measure fission and capture (up to 1 keV).

2. TS config.



- 1 thick sample (~100 mg).
- Use only TAC.
- Measure capture above 1 keV.

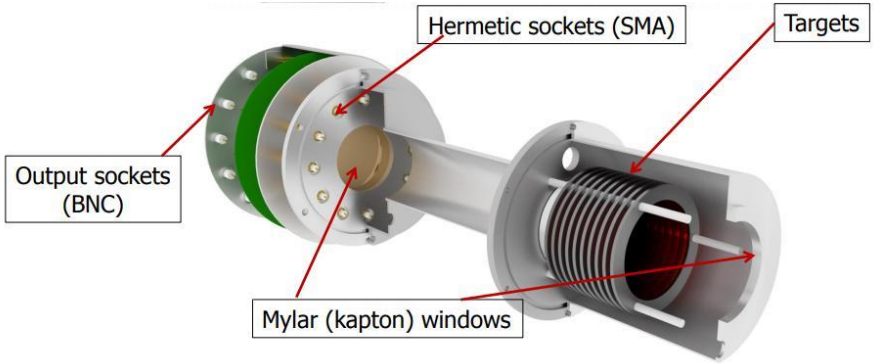
The ^{239}Pu targets

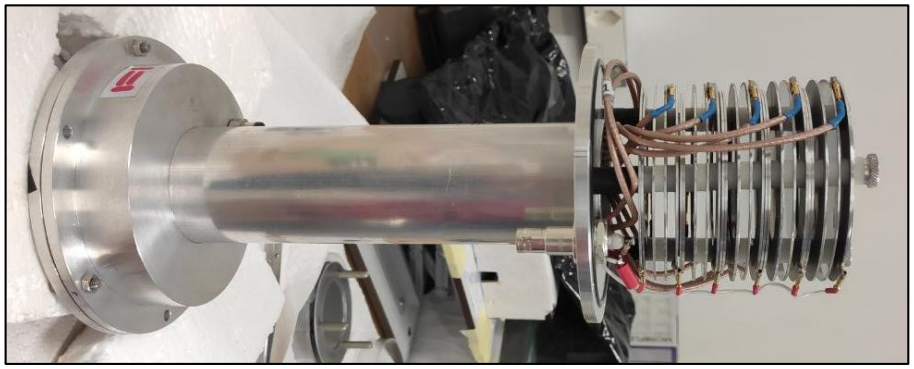
- The **PuO_2 10 thin samples (~1 mg each)** and the **thick sample** (**~100 mg**) were produced, deposited and encapsulated in the JRC-Geel.

Experimental setup

Fast fission detector

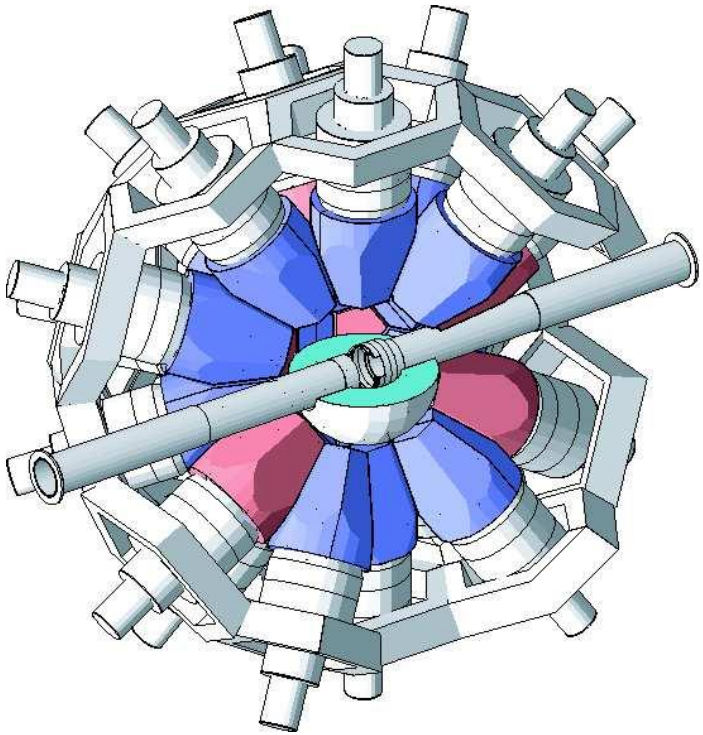
- To perform **fission tagging** with the TAC and to **measure fission** cross-section.
- **Housing of 10 parallel targets of PuO_2** deposited in 10 μm aluminum backing.
- **Fast pre-amplifiers**.
- **Filled with Ar+CF_4 gas**. Efficiency of ~90%.





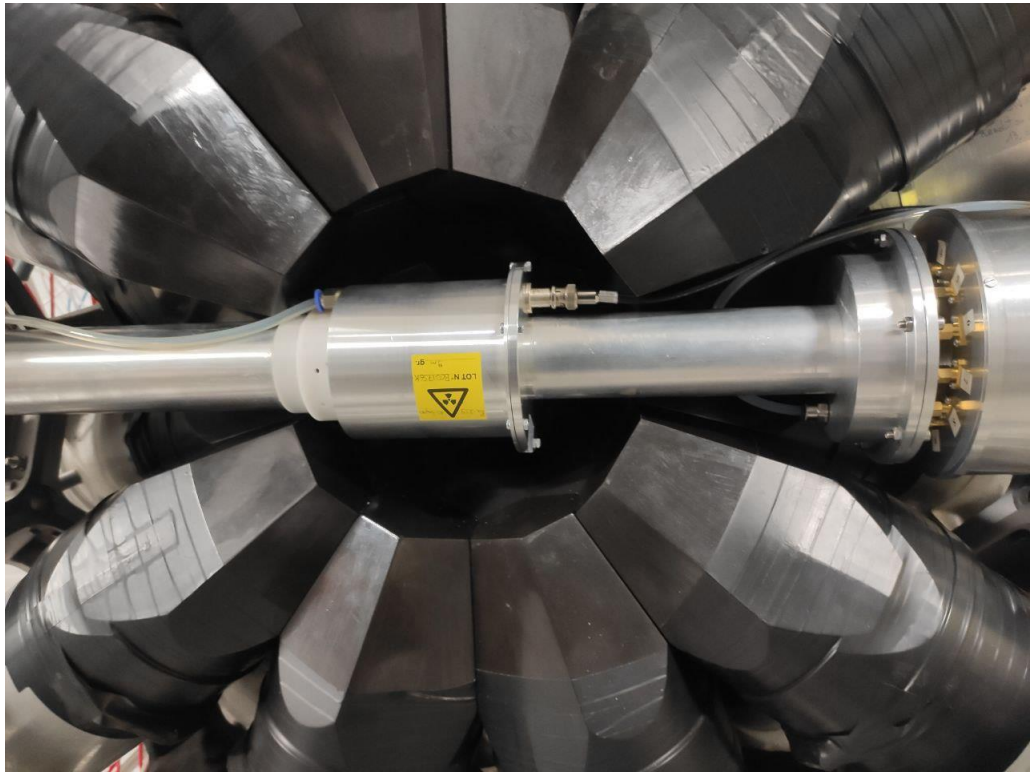
Total Absorption Calorimeter (TAC)

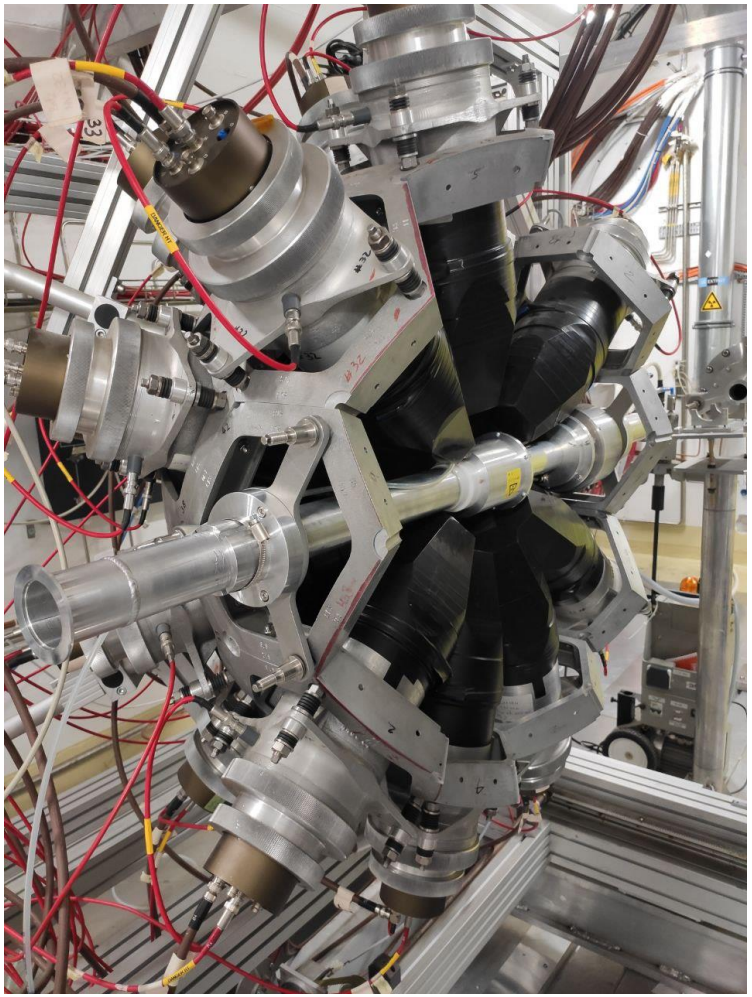
- To detect capture and fission *γ*-rays
- Composed of **40 BaF_2 crystals**.
- **Fast response, high efficiency** and **low neutron sensitivity.**



Experimental setup

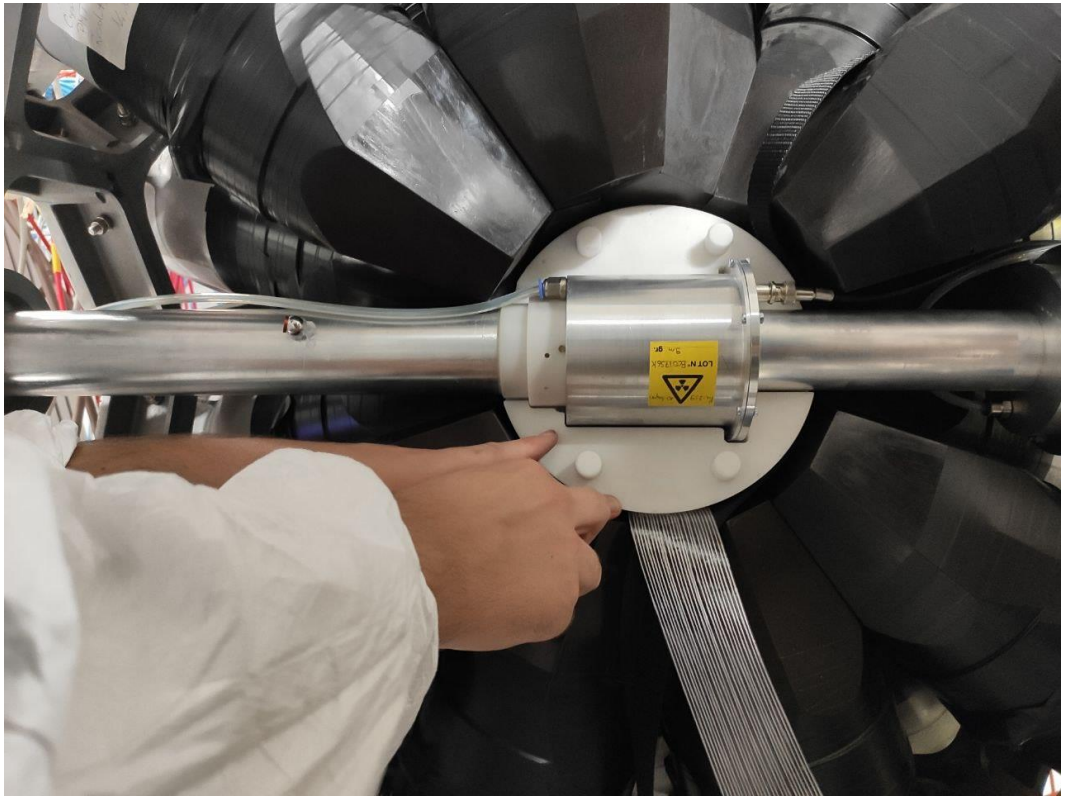
- Mounting of the **fission chamber inside the TAC**. The targets in the chamber are placed around the center of the TAC.





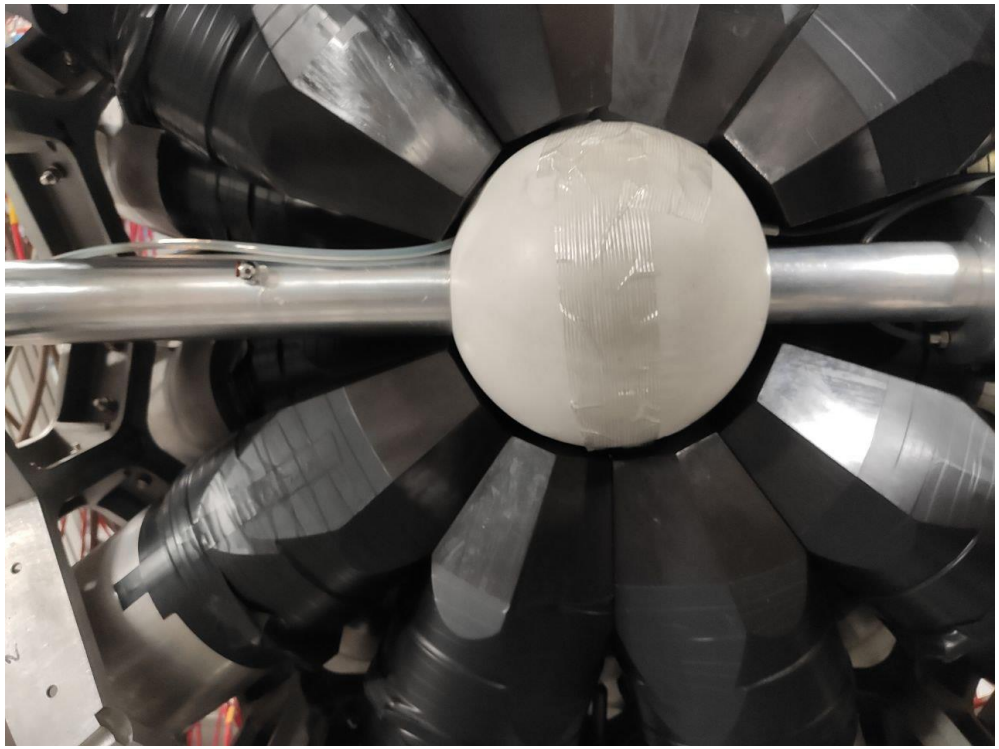
Experimental setup

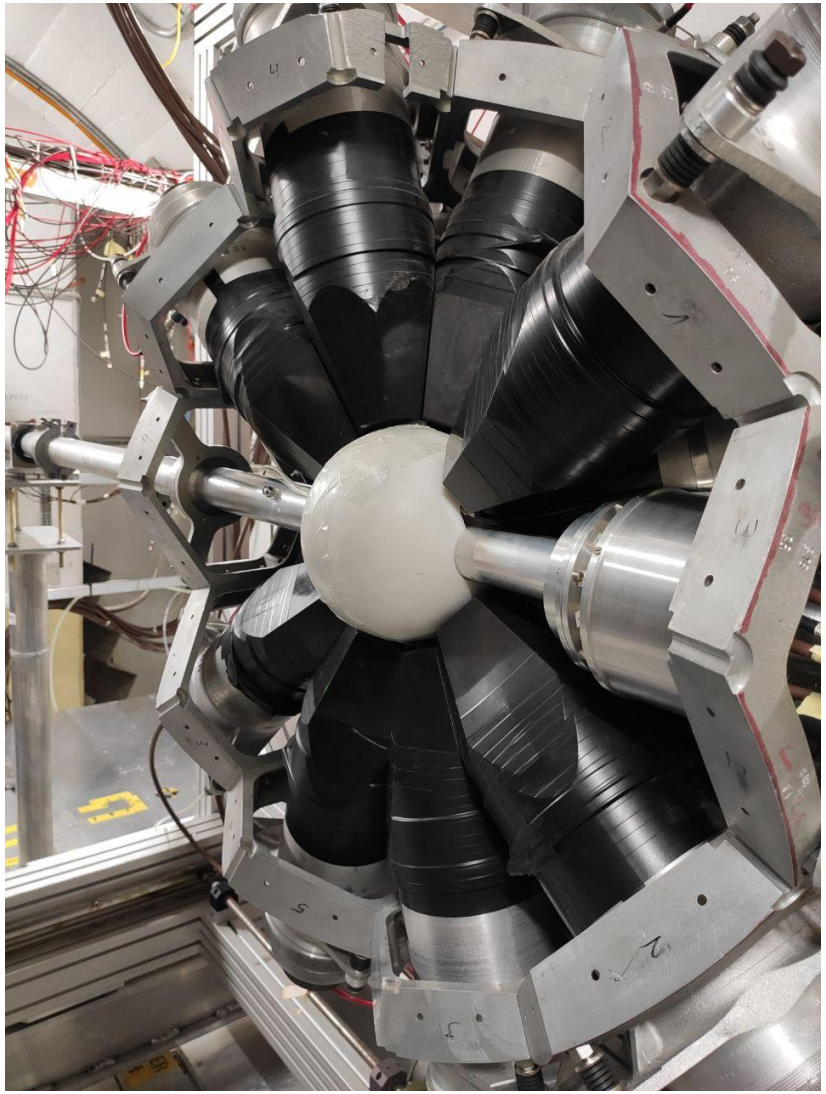
- Placement of **the Li-doped polyethylene neutron absorber** to reduce the number of neutrons reaching the BaF_2 crystals (high neutron sensitivity).



Experimental setup

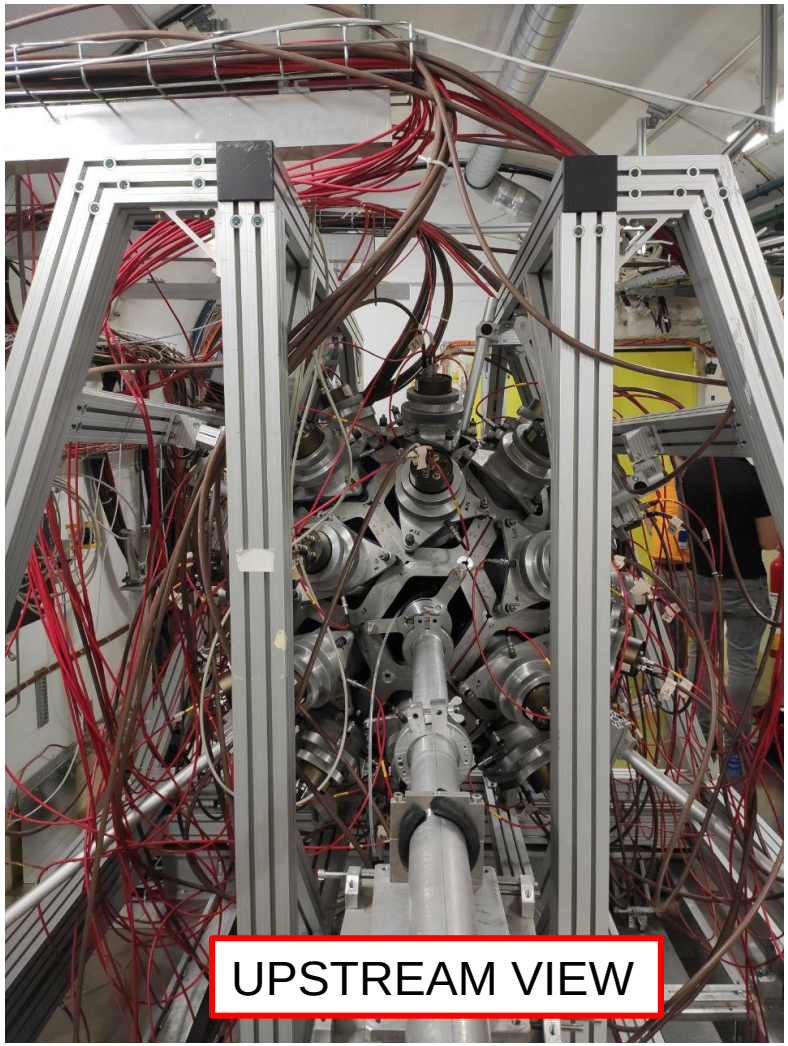
- Final setup after closing the neutron absorber and before closing the TAC.

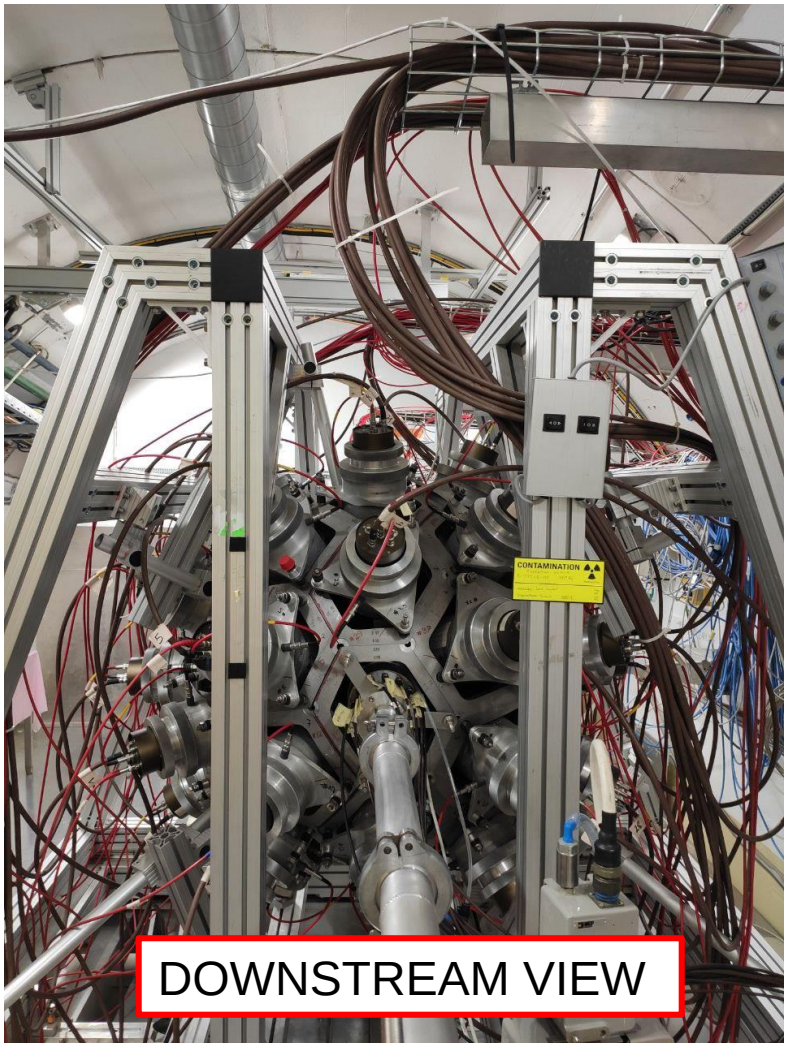




Experimental setup

Experimental setup (TAC closed)



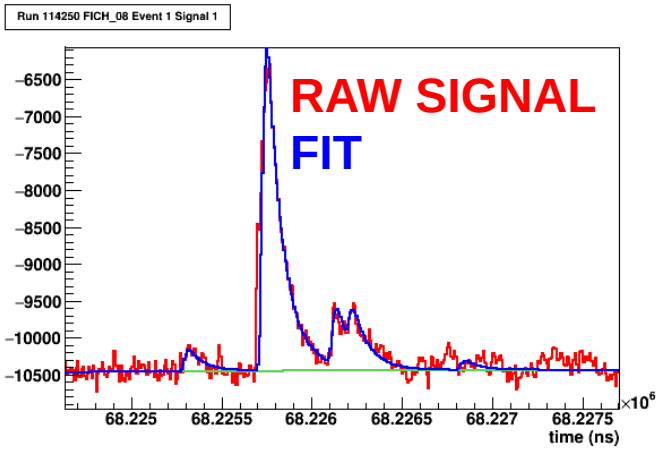


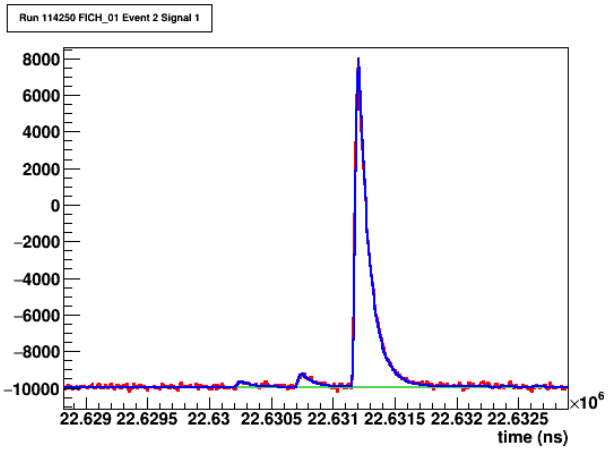
Data analysis

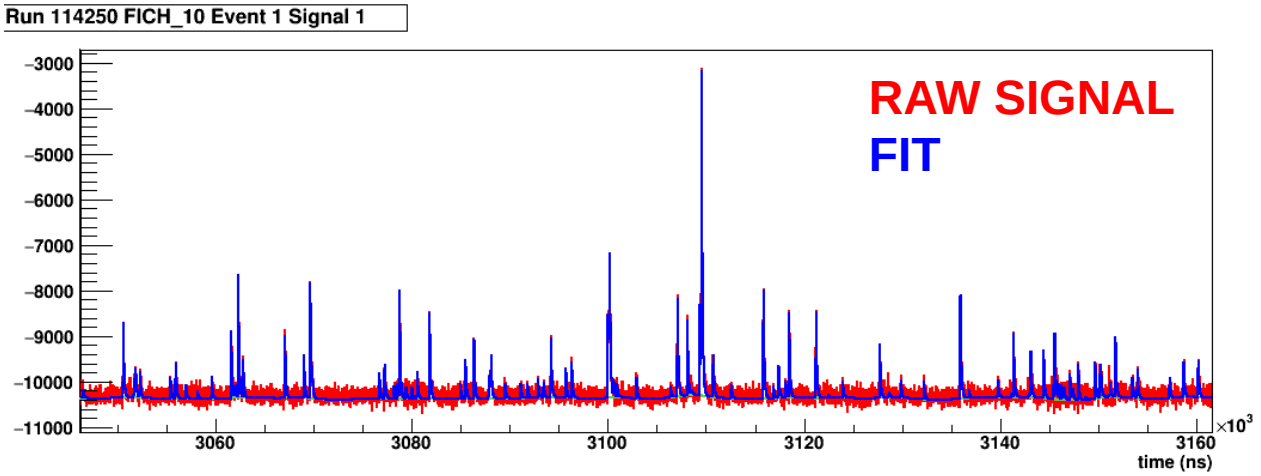
New Pulse Shape Analysis routine

Signal reconstruction examples with the **new dedicated Pulse Shape Analysis routine**.

Fission Chamber



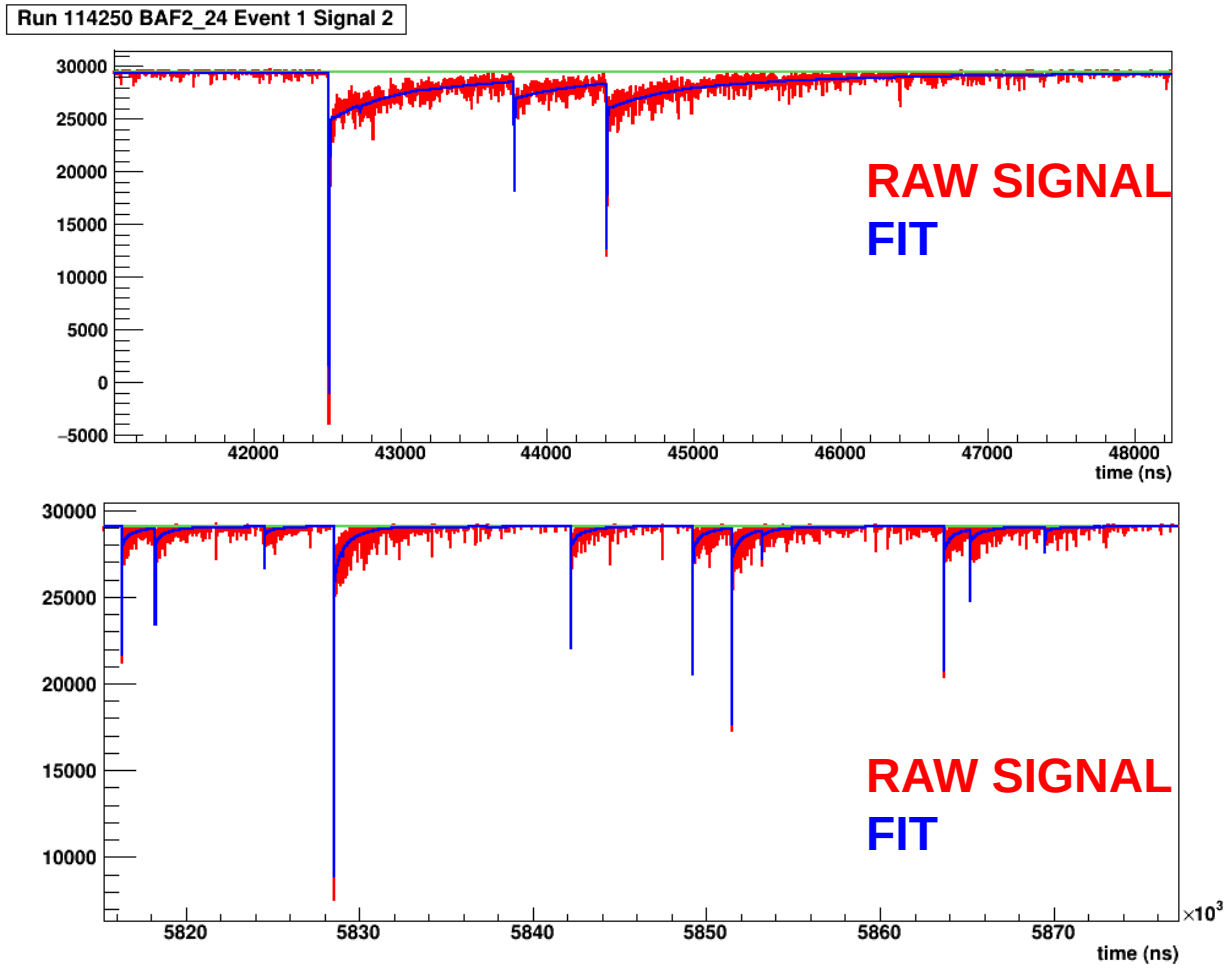




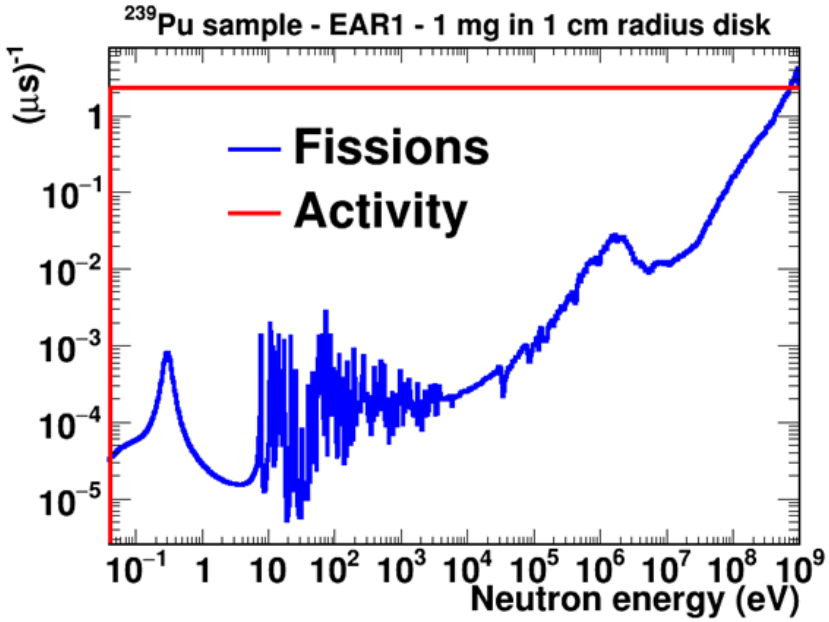
New Pulse Shape Analysis routine

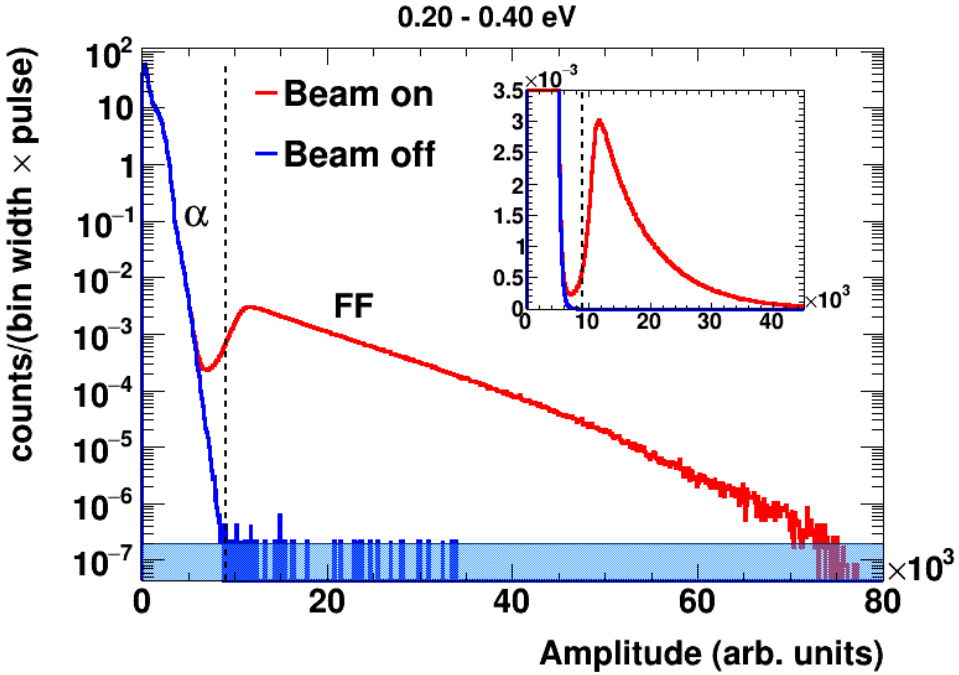
Signal reconstruction examples with the **new dedicated Pulse Shape Analysis routine**.

TAC



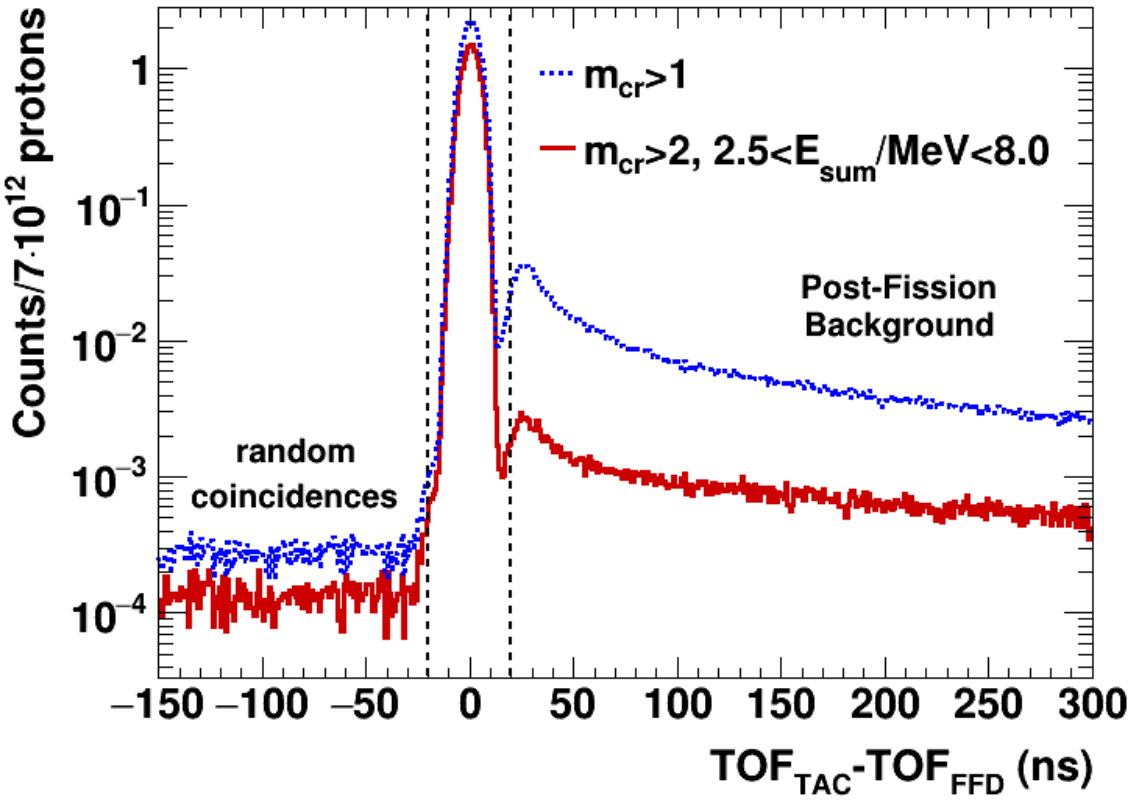
Fission fragment detector





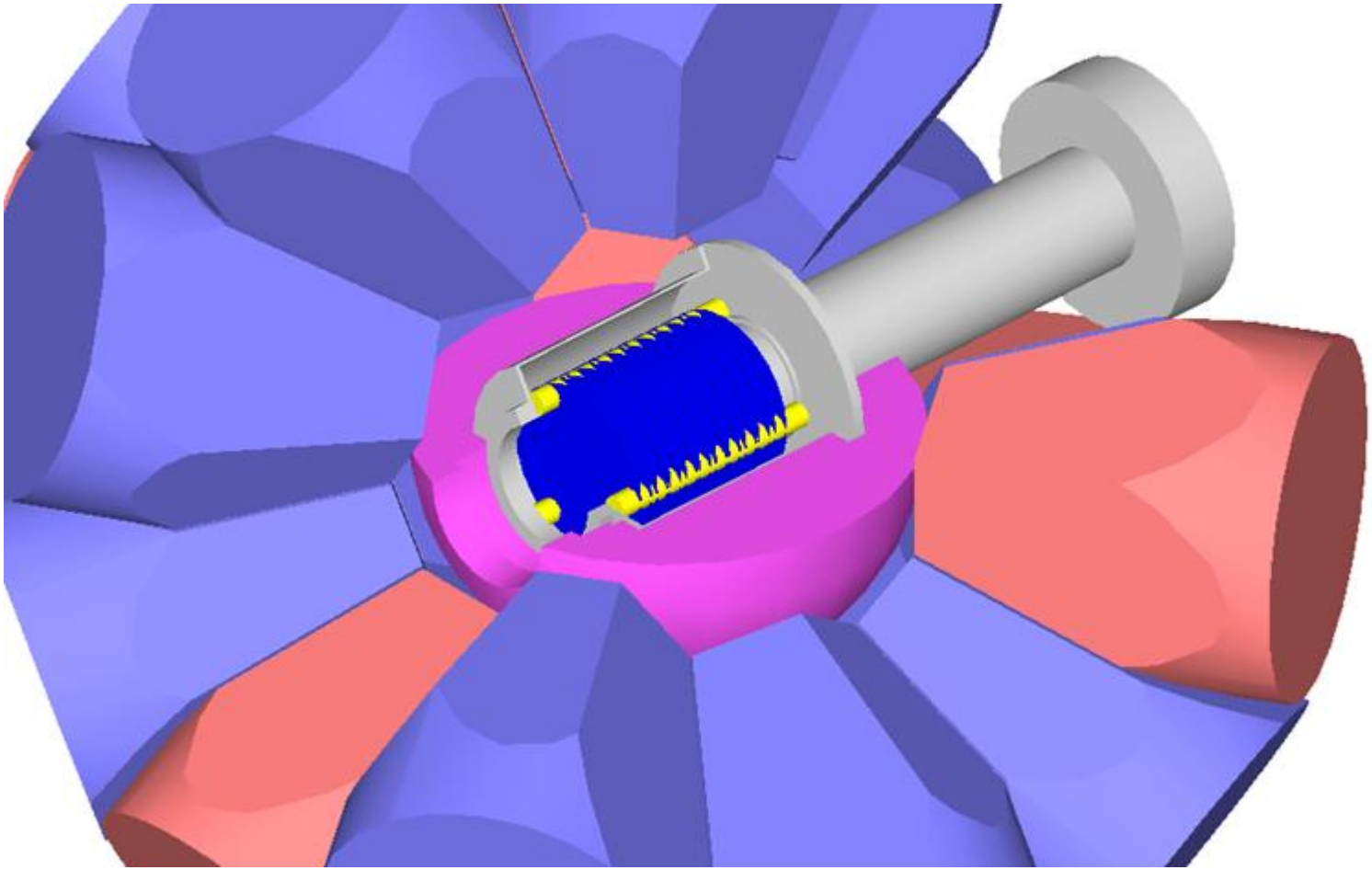
Excellent separation between α-particles and fission fragments (FF)

Coincidence analysis



Distribution of time differences between the TAC and the FICH

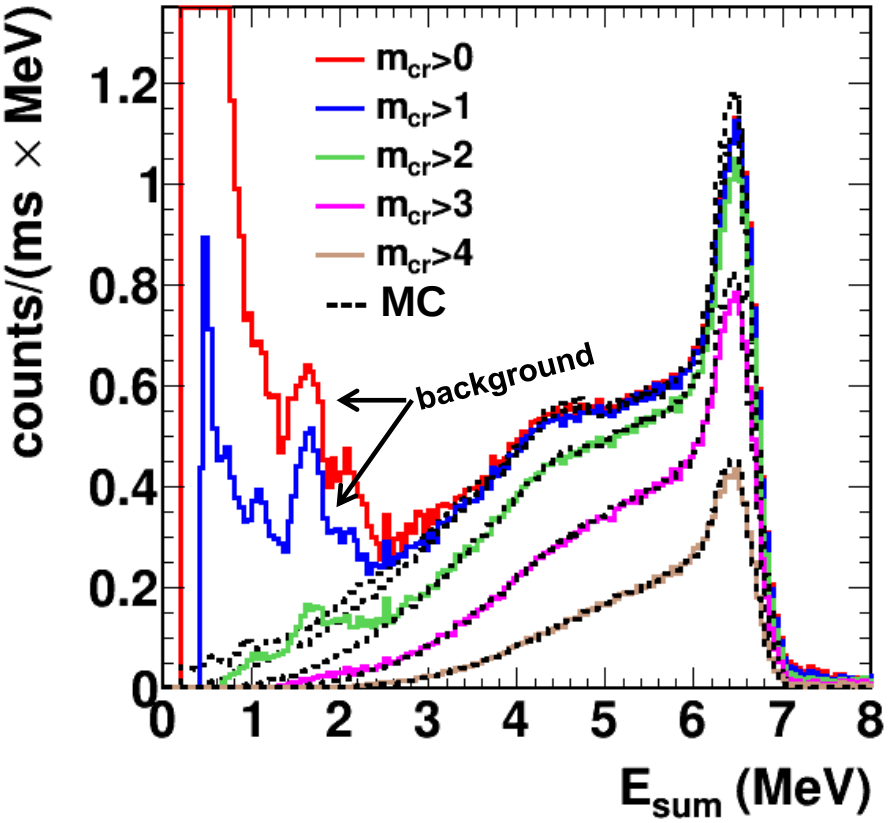
TAC: MC modelling



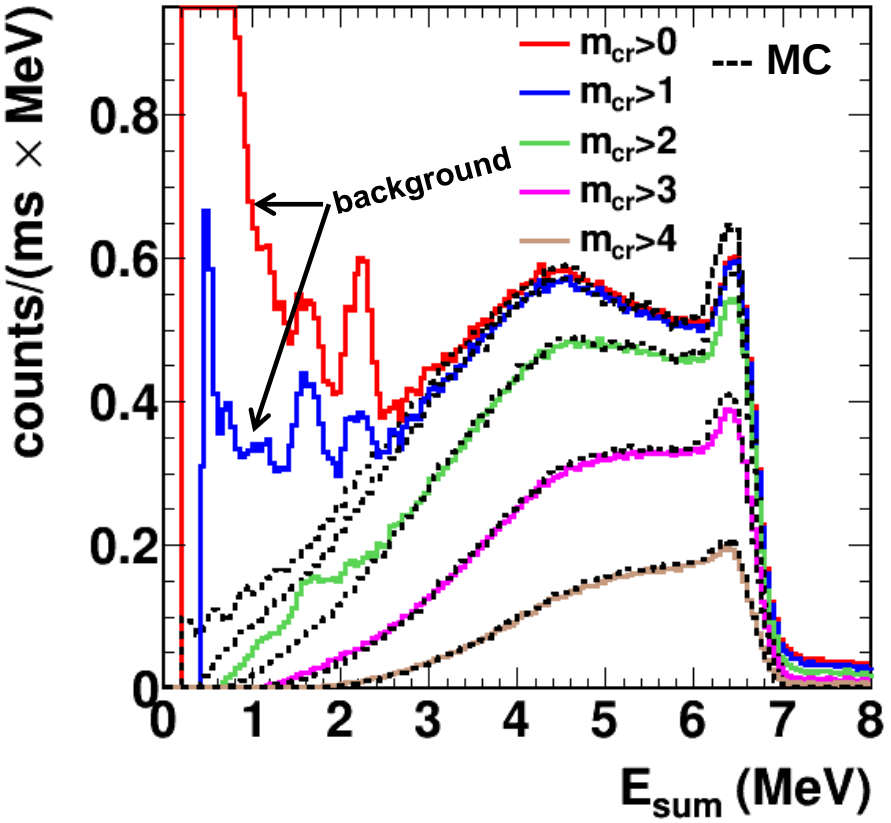
Part of the geometry of the experimental setup implemented in the Geant4 code to perform the Monte Carlo simulations.

TAC: MC modelling

without neutron absorber

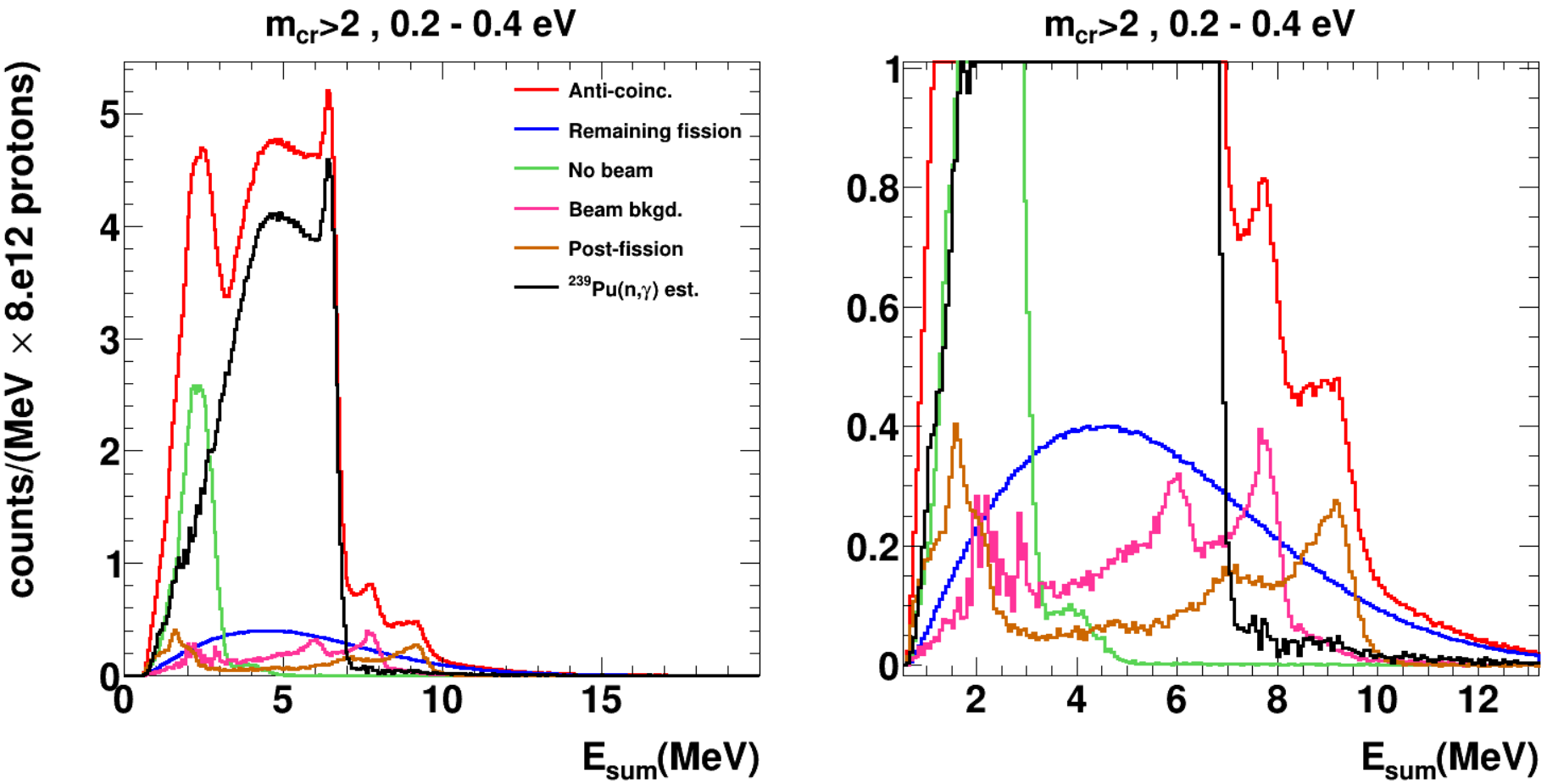


with neutron absorber



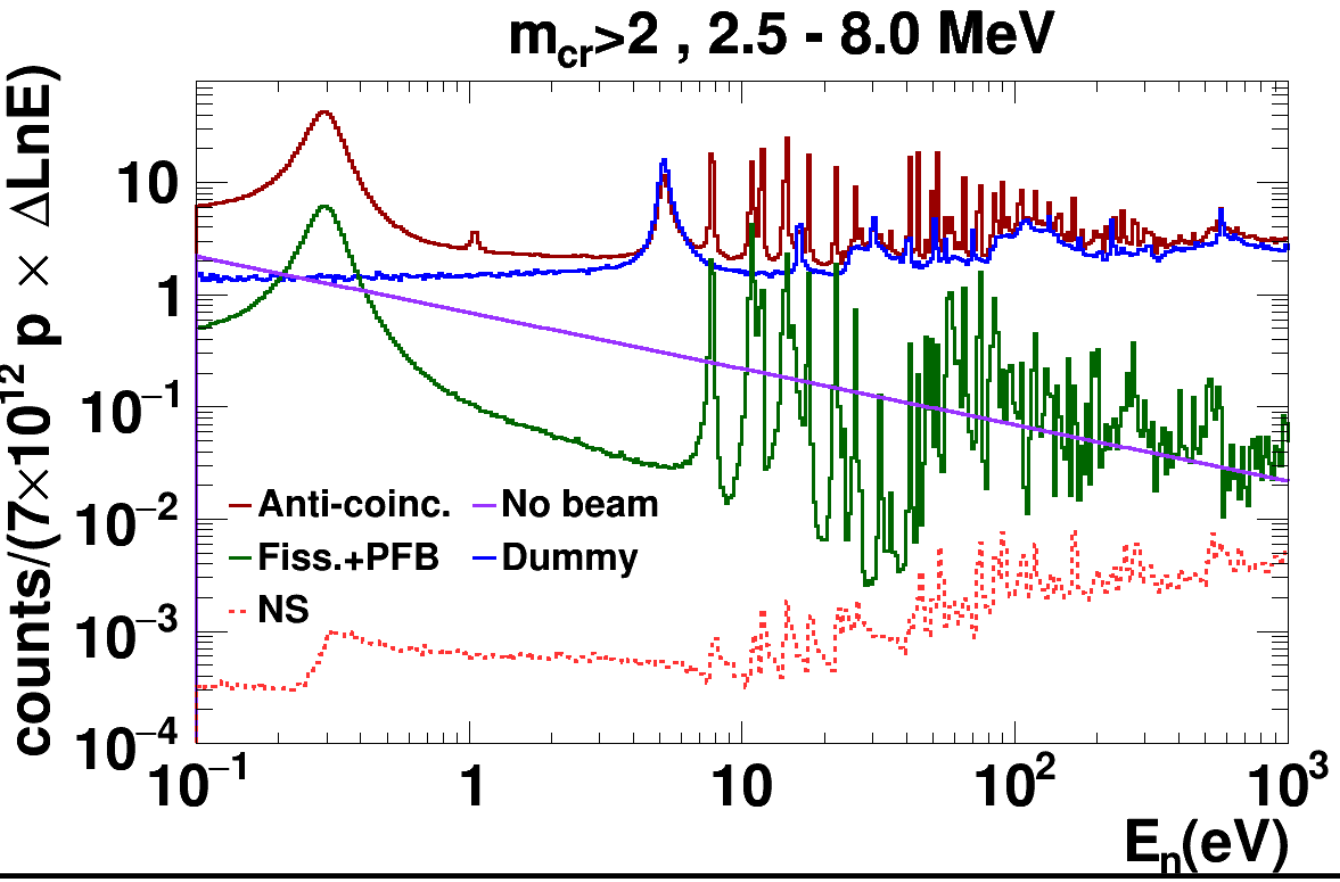
Comparison between experimental and simulated (MC) total energy deposited spectra, for 0.2-0.4 eV neutron energies, with and without neutron absorber.

Deposited energy spectra



Total energy (E_{sum}) spectra in the TAC for neutron energies between 0.2 and 0.4 eV and m_{cr}>2. The total spectrum in anticoincidence with the FICH is presented in red; the different background components in different colors, and the spectrum due to capture in ^{239}Pu in black.

Time of flight spectra

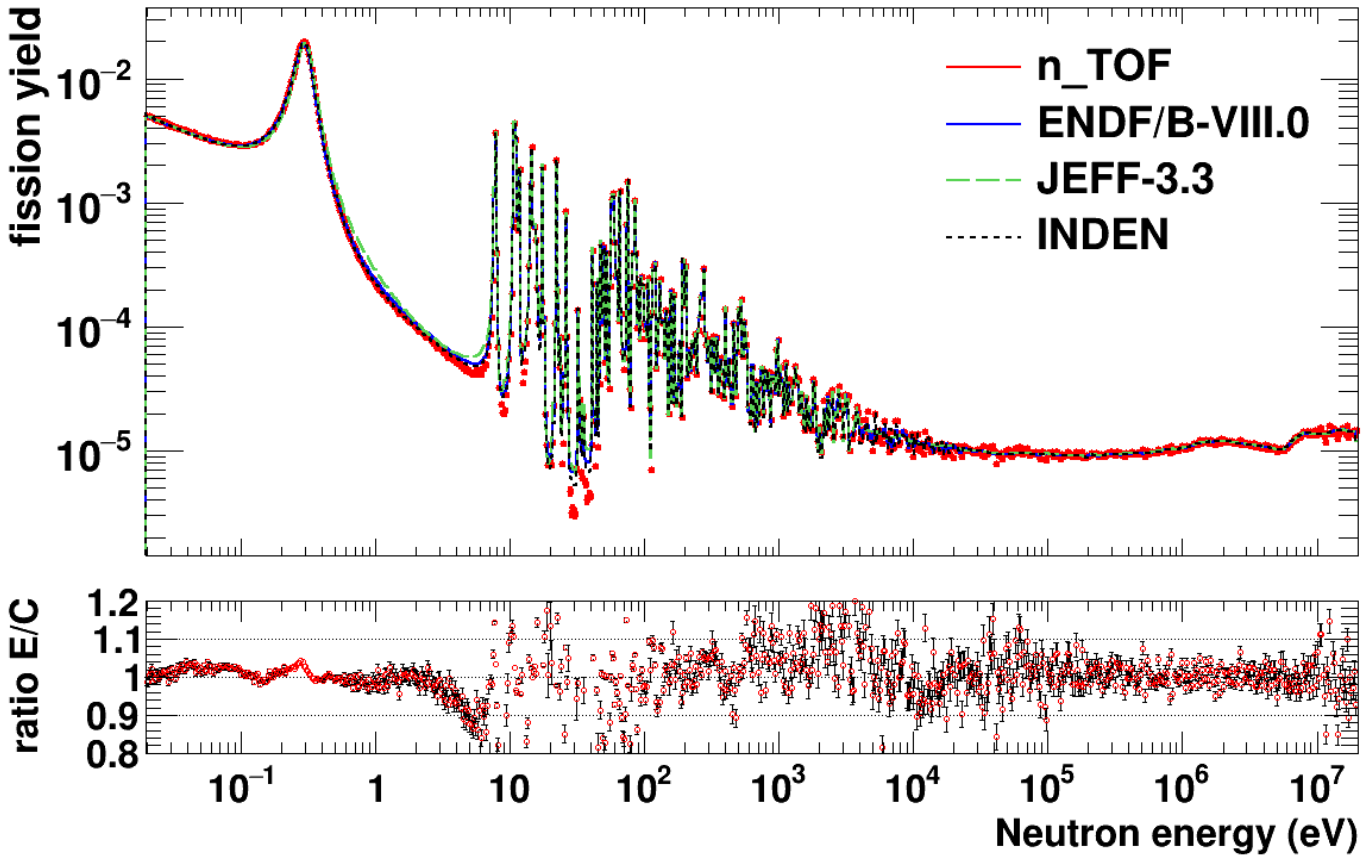


Time of flight spectra ($2.5<E_{sum}<8$ MeV and $m_{cr}>2$) for all the counts in the TAC in anticoincidence with the FICH (Anti-coinc.), together with different background components.

funded by the EU H2020 programme

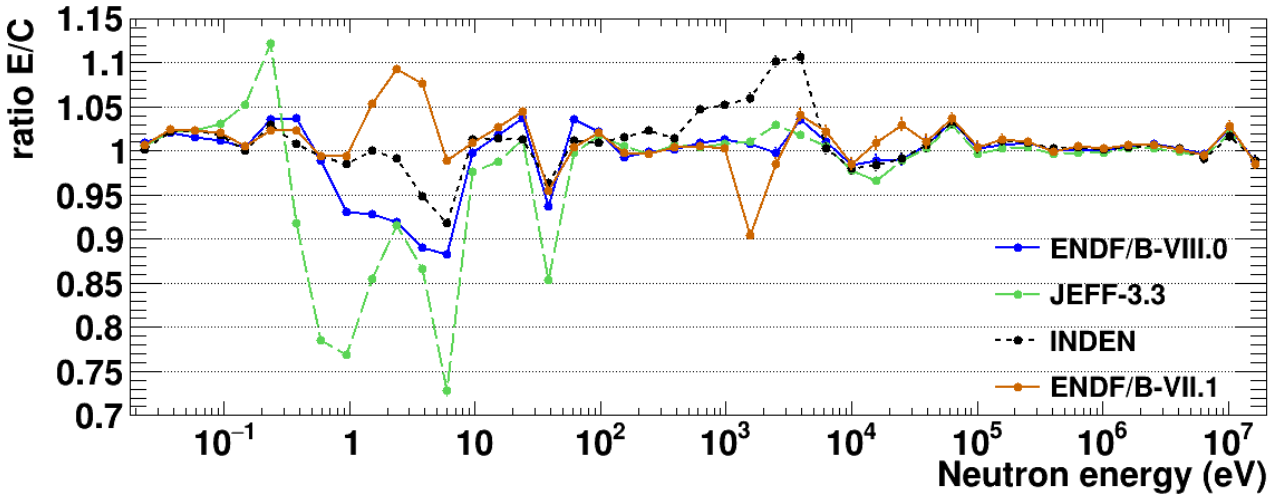
Results

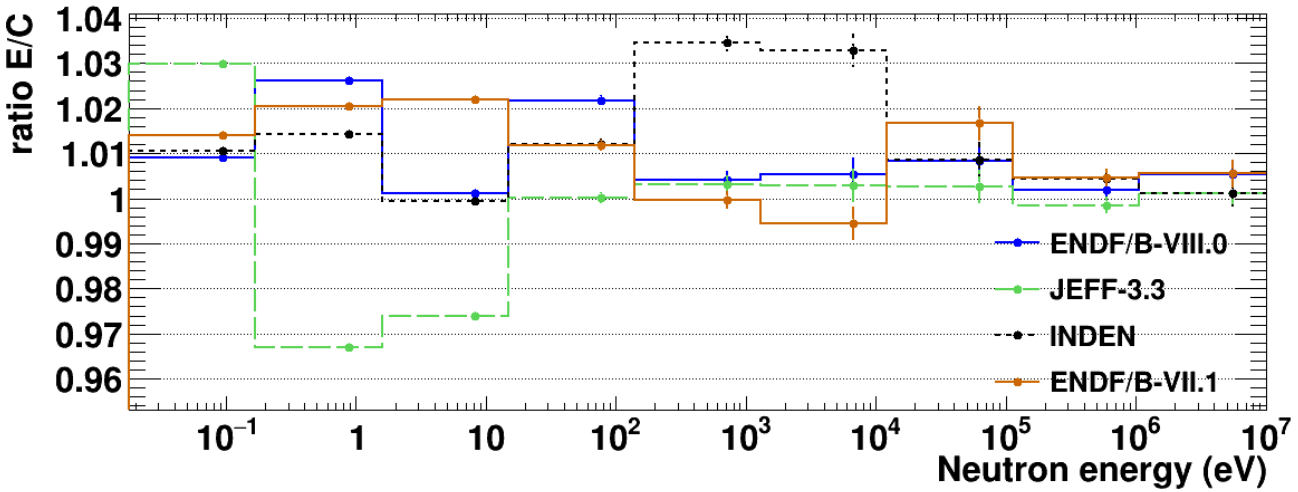
^{239}Pu(n,f) yield compared to evaluations



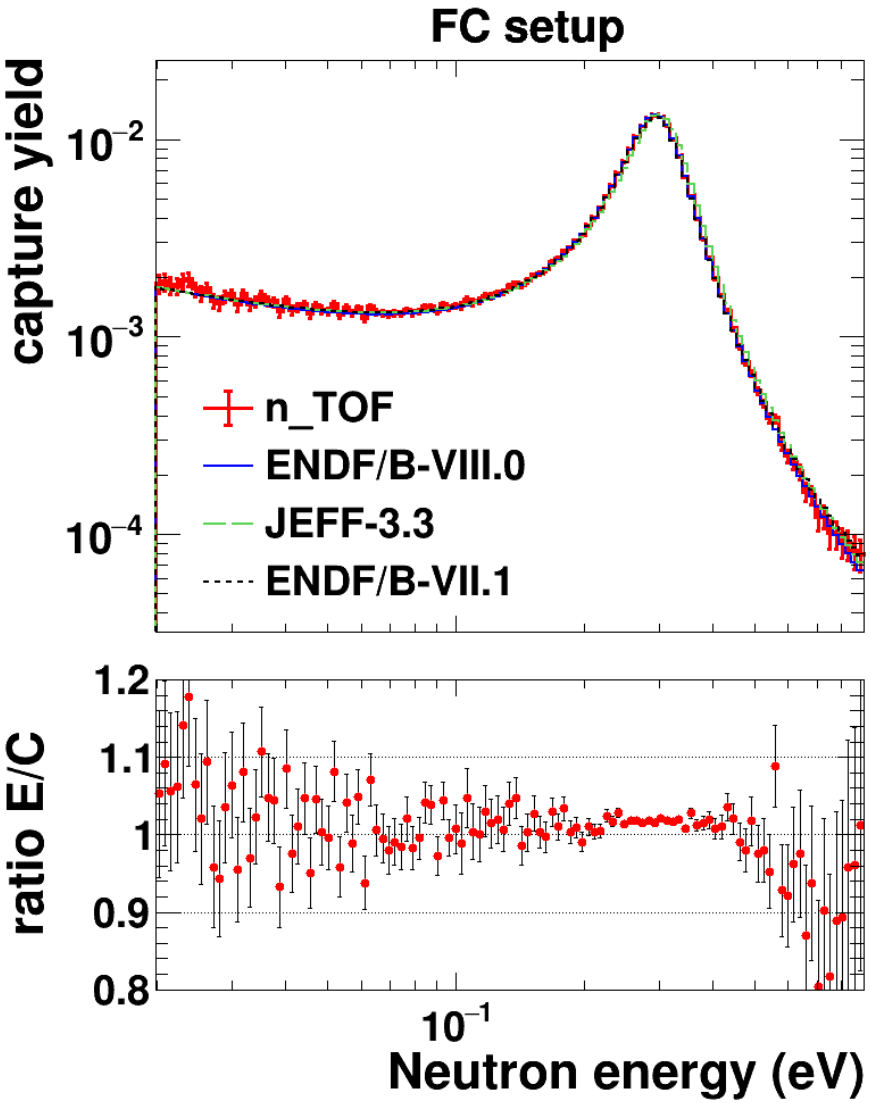
We have measured the ^{239}Pu(n,f) cross section between 0.02 eV and 20 MeV in a single measurement (9 orders of magnitude in neutron energy).
Data normalized to the recommended value for fissile targets in: I. Durán, R. Capote and P. Cabanelas, *Normalization of ToF (n,f) Measurements in Fissile Targets: Microscopic cross-section integrals*. Nuclear Data Sheets, 193, 95-104 (2024).

^{239}Pu(n,f) yield compared to evaluations





^{239}Pu(n,γ) yield compared to evaluations



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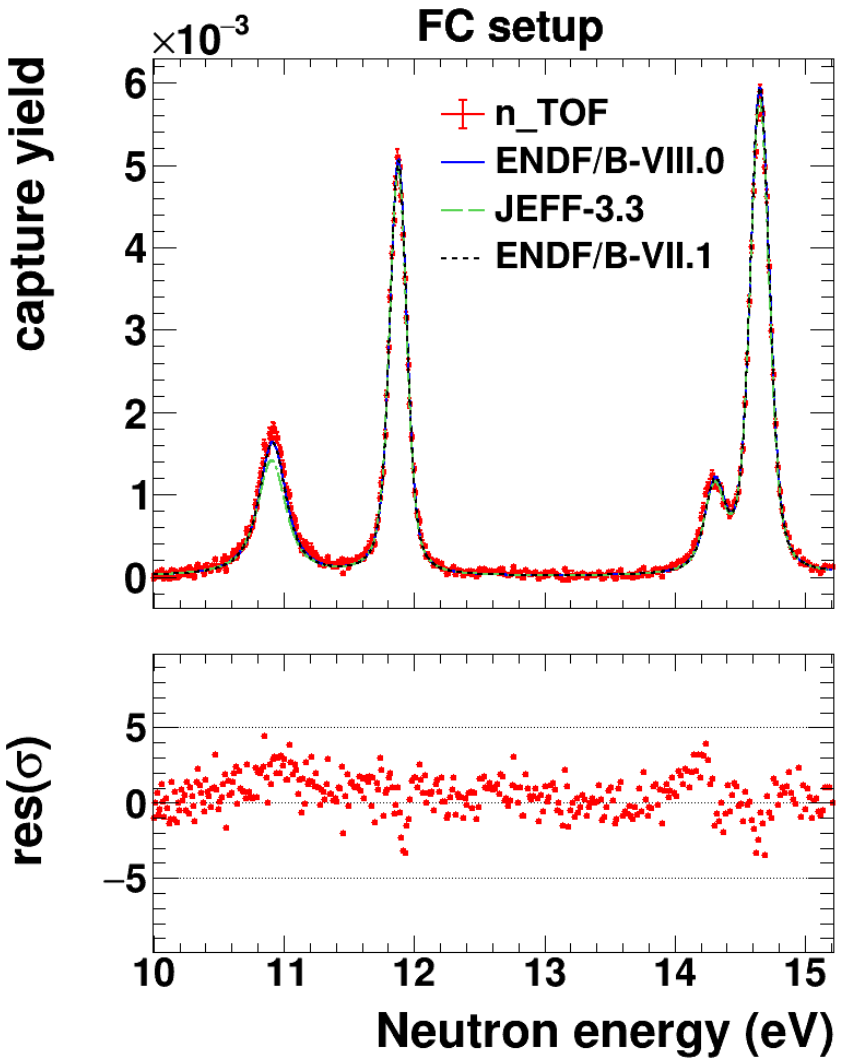
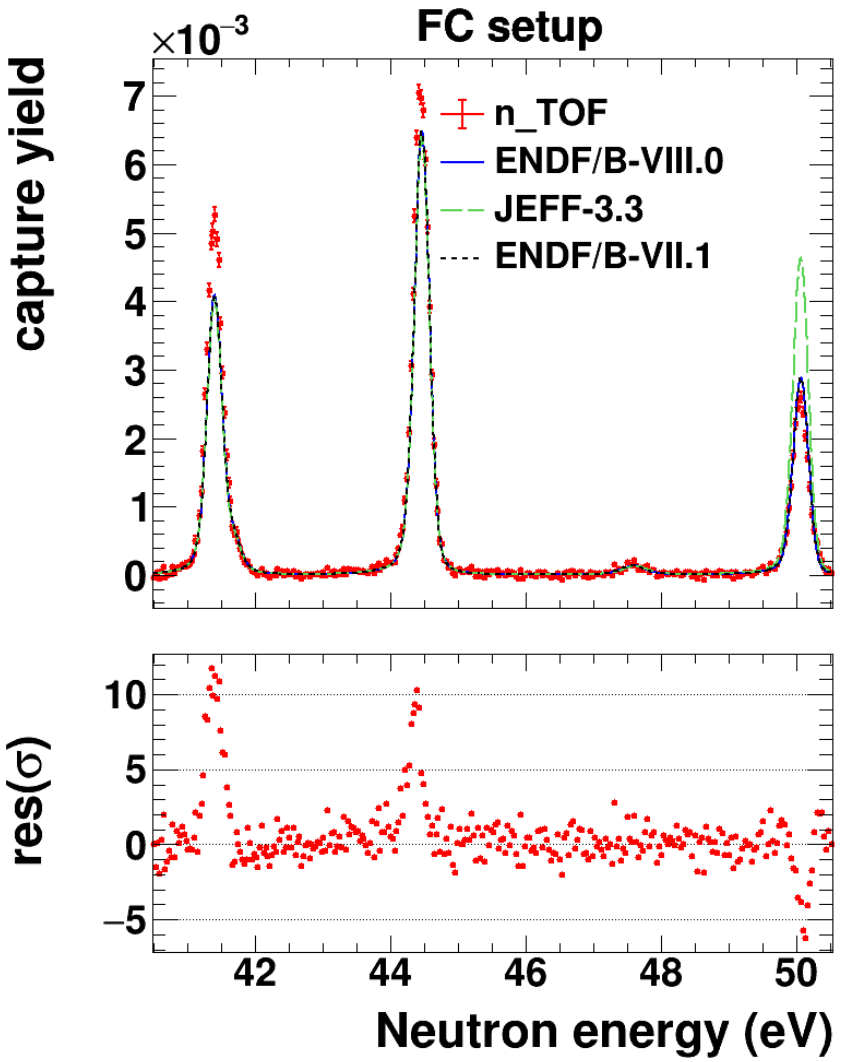
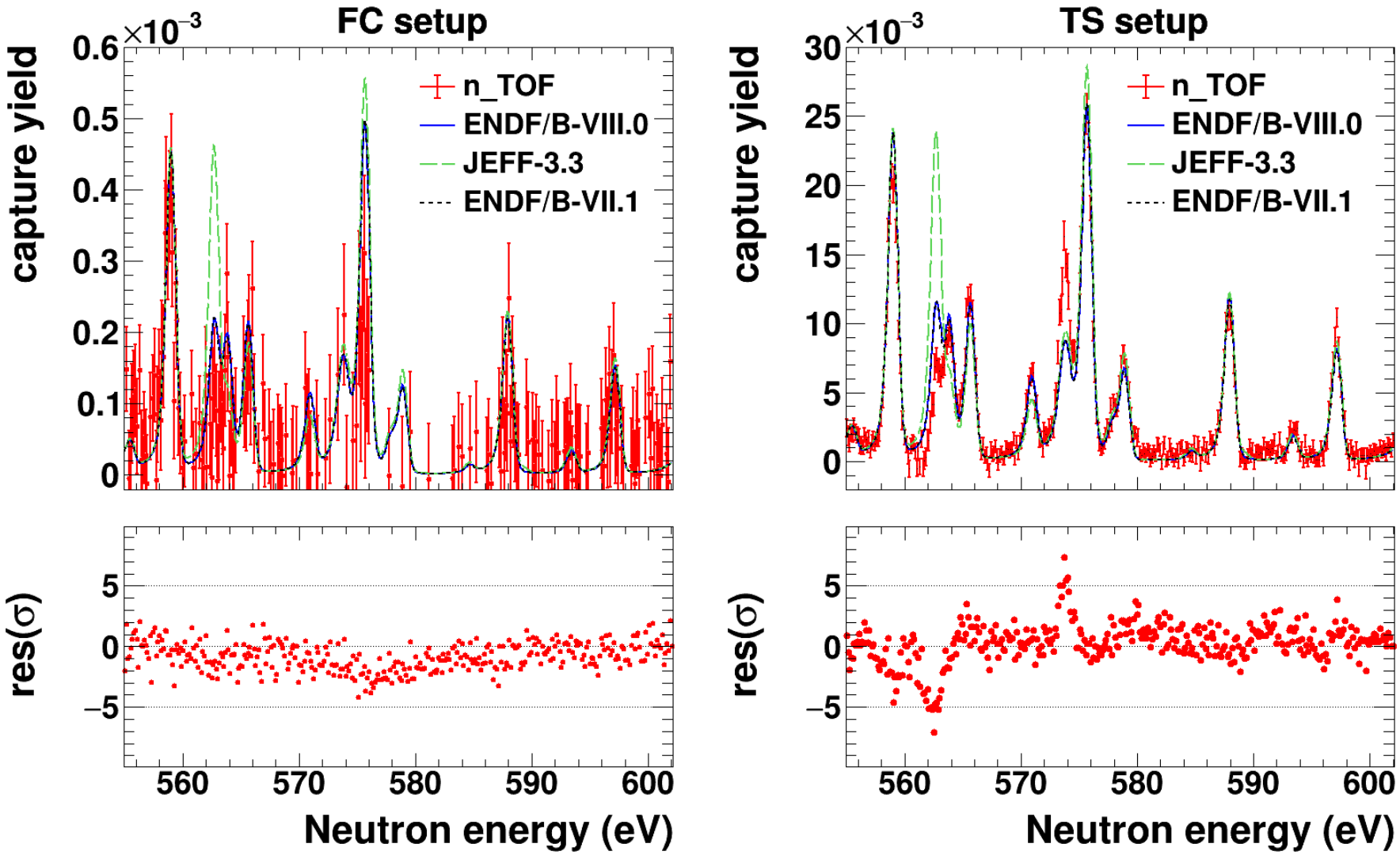




^{239}Pu(n,γ) yield compared to evaluations



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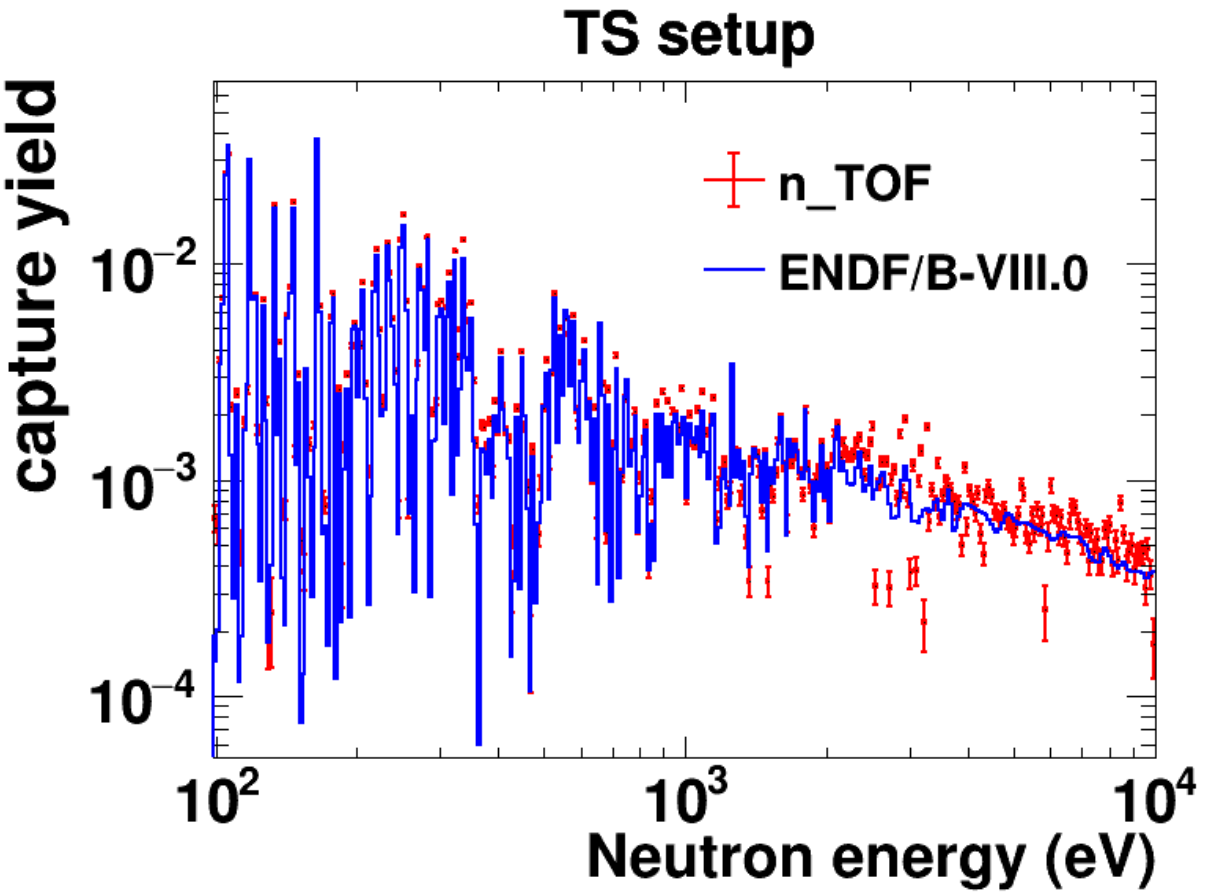

Conclusions

- We have measured the (n,f), (n,γ) and α-ratio of ^{239}Pu at the n_TOF facility at CERN.
- ^{239}Pu(n,f) cross-section measured between 0.02 eV and 20 MeV neutron energies. Excellent agreement with evaluations; differences within a 2% at 1 bin per decade.
- ^{239}Pu(n,γ) and α-ratio between 0.02 eV and 10 keV.
- Data with larger energy resolution than previous experiments.
- Our results will be used to improve the existing evaluations.

- PhD thesis of Adrián Sánchez Caballero → end of 2024
- Paper(s) in progress
- Proceeding:
  - A. Sánchez-Caballero, EPJ Web of Conferences 294, 01003 (2024)

- Deliverable: D2.3- Report on the ^{239}Pu(n,γ), ^{92,94,95}Mo(n,γ) cross section measurements at n_TOF and GELINA.