The ^{239}Pu neutron capture and fission cross-section measurements at n_TOF, CERN

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Contents

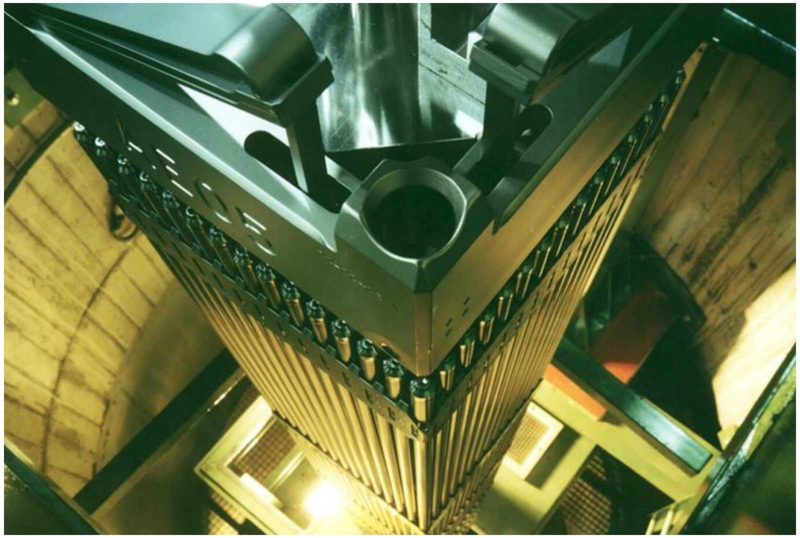
1

Motivation and experimental context

1.1 Motivation and context

More accurate ^{239}Pu capture and **fission** cross-section data are required for:

- Design of advanced nuclear devices (Gen IV reactors).
- Optimization of nuclear waste management strategies of current reactors.
- Operation of fast and thermal reactors that use MOX fuels.



Nuclear data evaluations for ^{239}Pu(n,g) and (n,f)

- Main evaluations for capture cross-sections show **significant discrepancies**.
- **Only two existing measurements** for ^{239}Pu(n,g) cross-section exist, due to the intrinsic complexity of measuring a fissile sample.

^{239}Pu capture and fission cross-sections are included in the **NEA/OECD High Priority Request List.**

2

^{239}Pu measurement at n_TOF

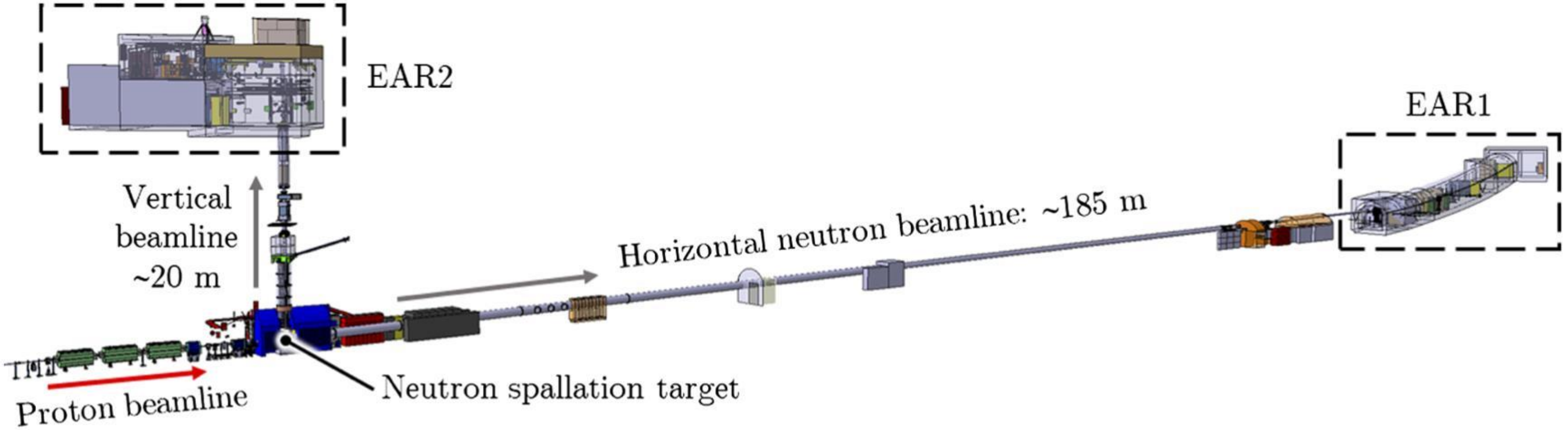
2. ^{239}Pu measurement at n_TOF

Objectives

- **Measuring** the neutron capture-to-fission ratio (**alpha-ratio**), the **fission** and the **capture cross sections of ^{239}Pu** at the n_TOF EAR-1.
- To provide an **overall uncertainty ~3%** in the range from **thermal energies to 10 keV**.
- To provide an **absolute alpha-ratio**, thanks to the accurate determination of the fission and capture detection efficiencies (experience from previous measurements, e.g. ^{235}U(n,g)).

Why at n_TOF?

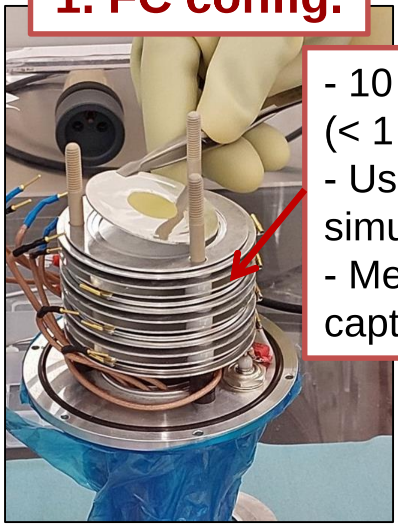
- A **185 m flight path** (**10 times larger** than in previous measurements) will provide **better energy resolution** to improve significantly the resonance analysis.



2.1 Overview of the experiment and samples

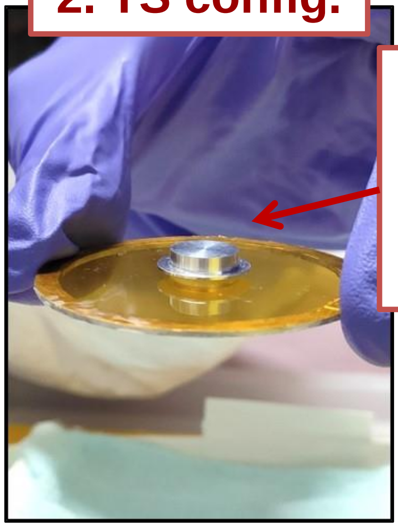
- The experimental campaign took place in the last quarter of 2022, with **2 months of beam time** (~$5 \cdot 10^{18}$ protons).
- The campaign was divided in **two different configurations**:

1. FC config.



- 10 thin Pu samples (< 1 mg).
- 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 (99.90% purity) 10 thin samples (~1 mg each)** and the **thick sample** (**~100 mg**) were produced, deposited and encapsulated by JRC-Geel+SCK·CEN.

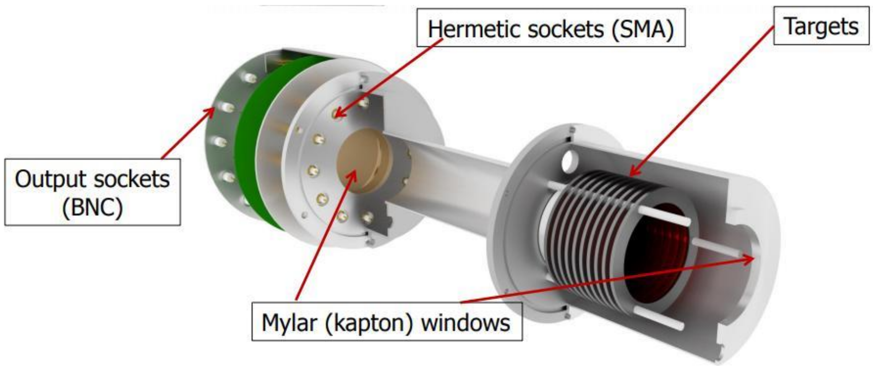
2.2 Main detectors

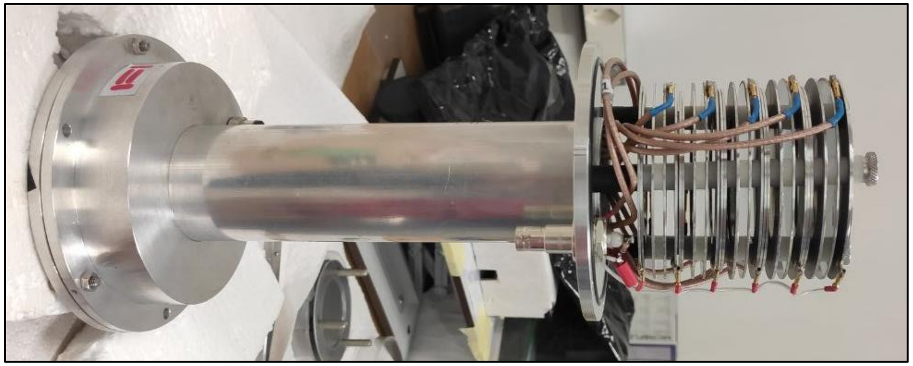
Fast fission detector

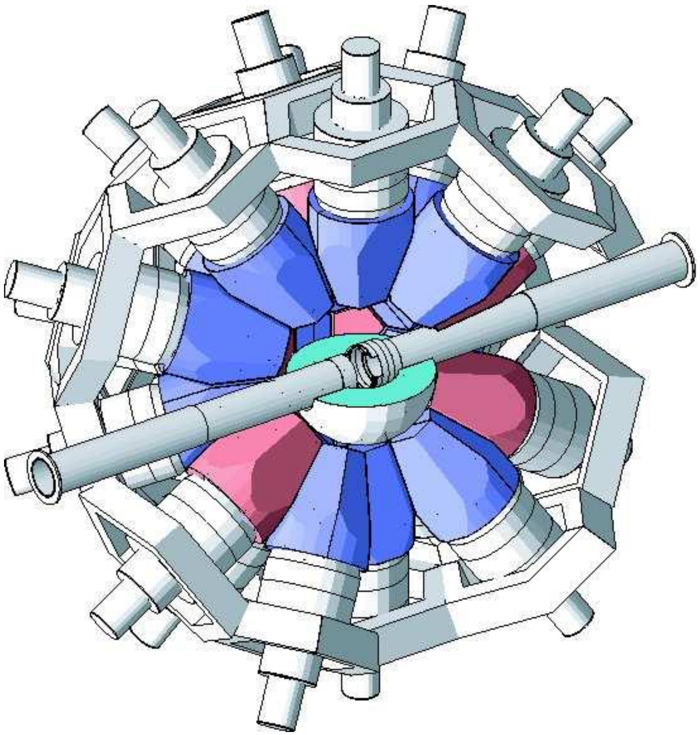
- To perform **fission tagging** with the TAC and to **measure fission** cross-section.
- **Housing of 10 parallel targets of PuO_2** deposited in 10 µm aluminum backing.
- **Fast pre-amplifiers**.
- **Filled with Ar+CF_4 gas**. Efficiency of ~90%.

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.**

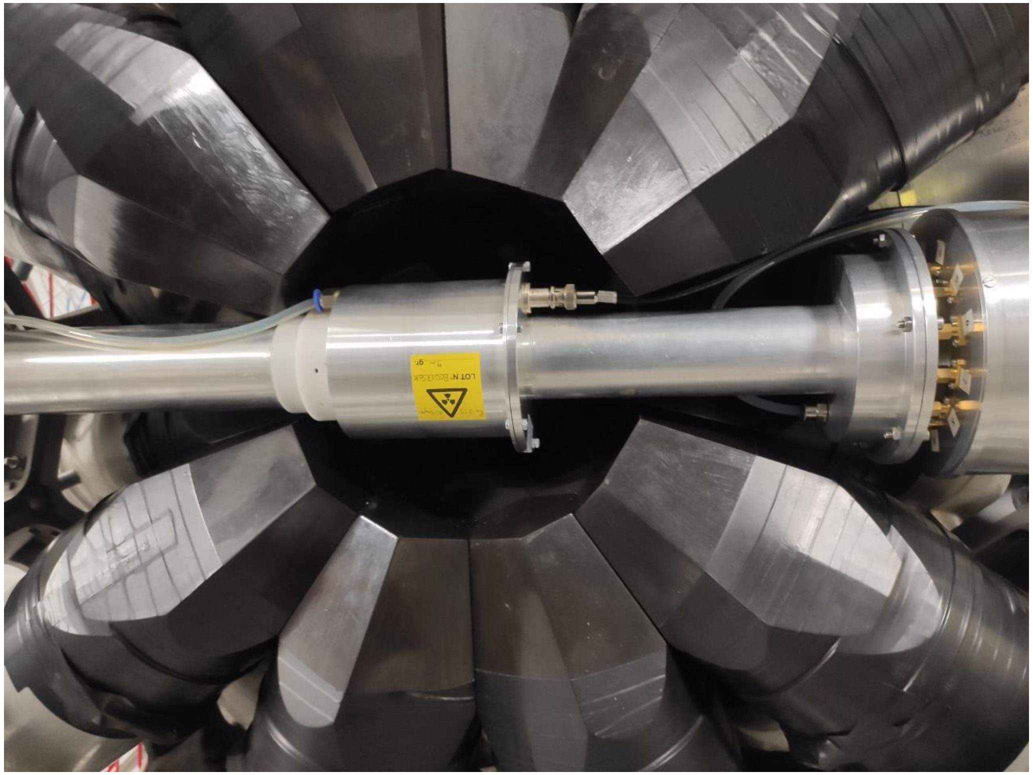


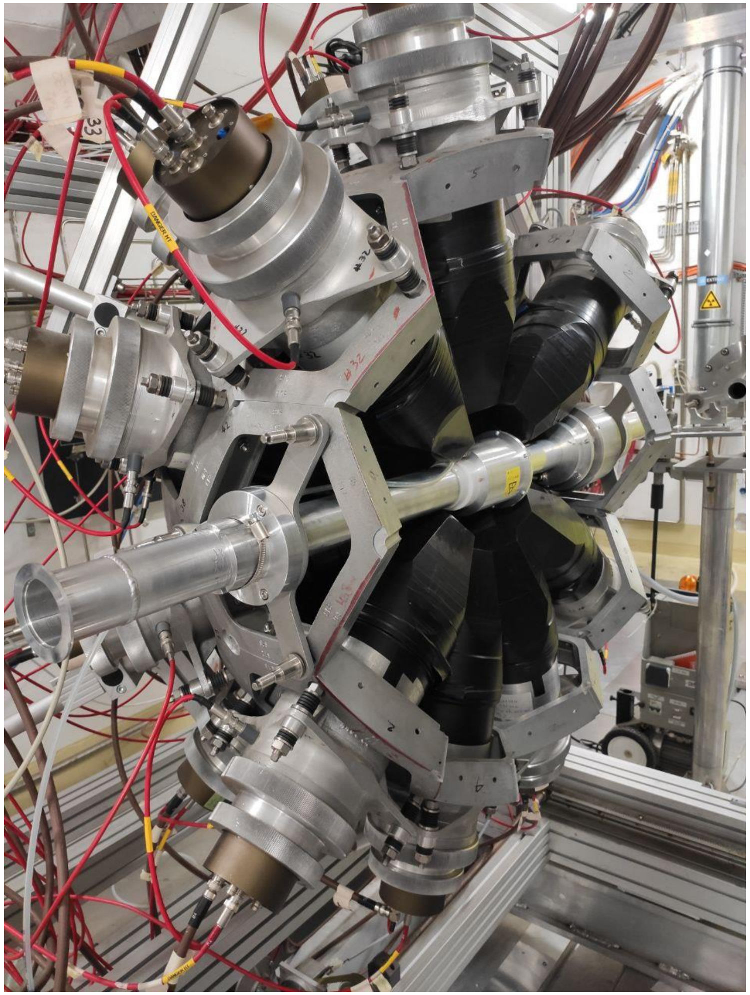




2.3 Experimental setup: mounting

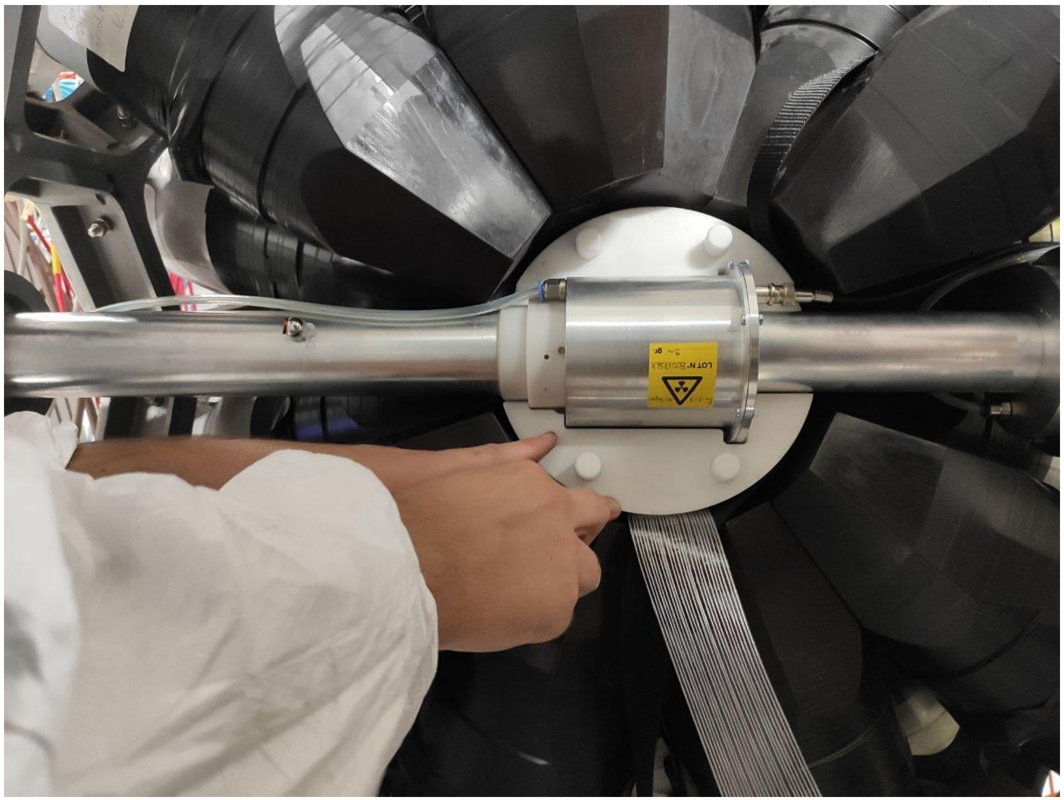
- Mounting of the **fission chamber inside the TAC**. The targets in the chamber are placed around the center of the TAC.





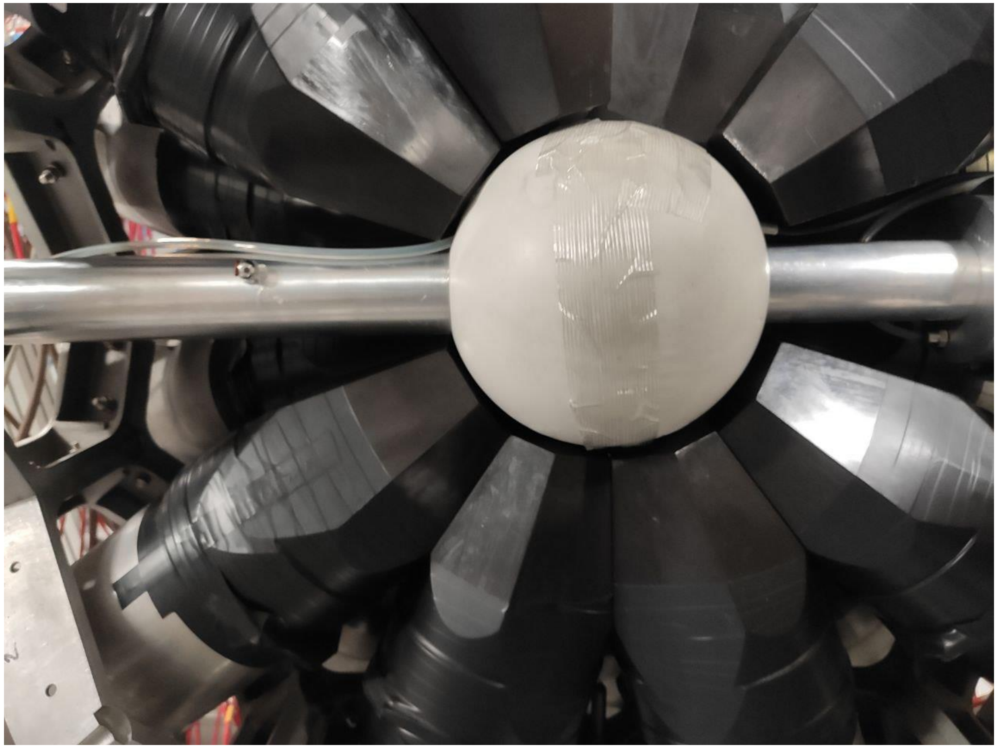
2.3 Experimental setup: mounting

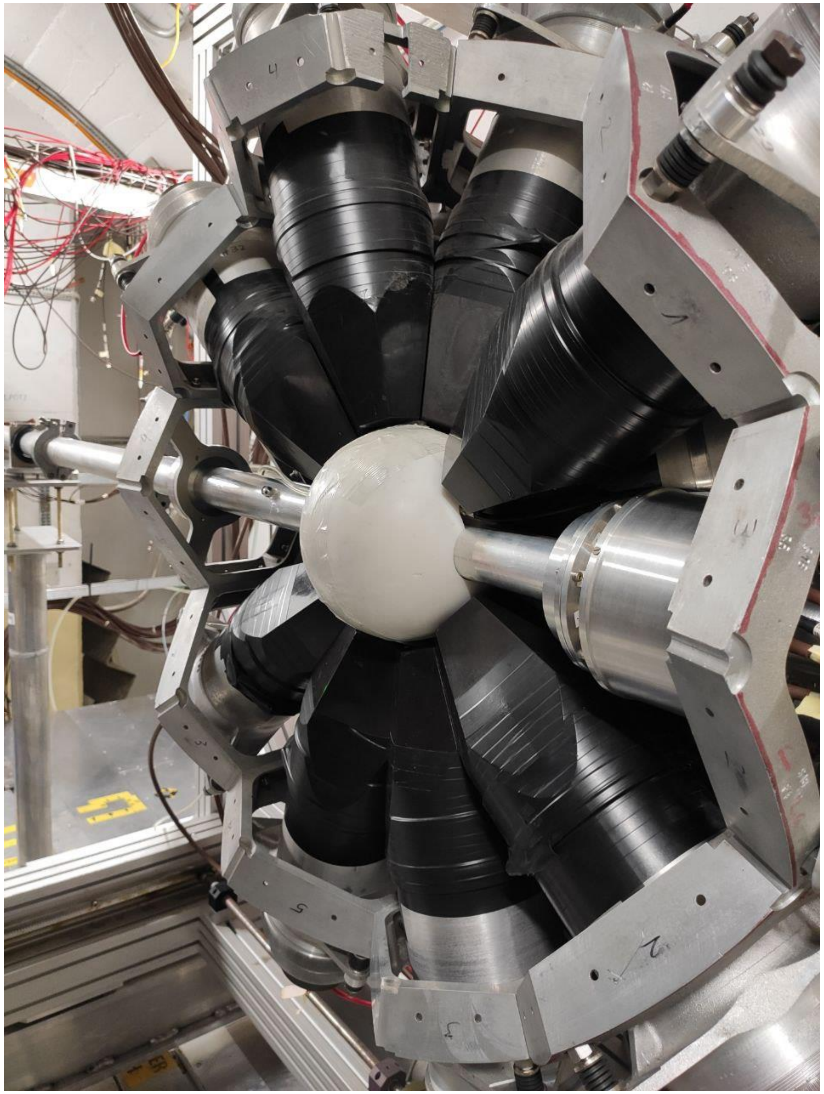
- Placement of **the Li-doped polyethylene neutron absorber** to reduce the number of neutrons reaching the BaF_2 crystals.



2.3 Experimental setup: mounting

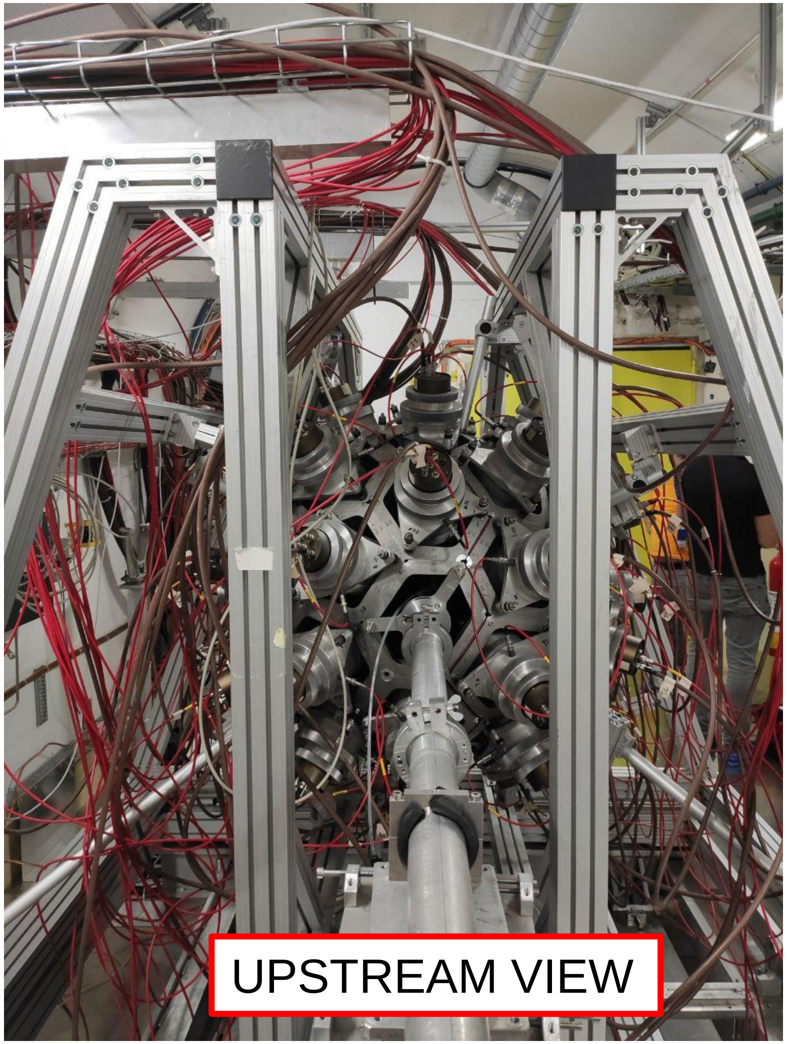
- Final setup after closing the neutron absorber and before closing the TAC.

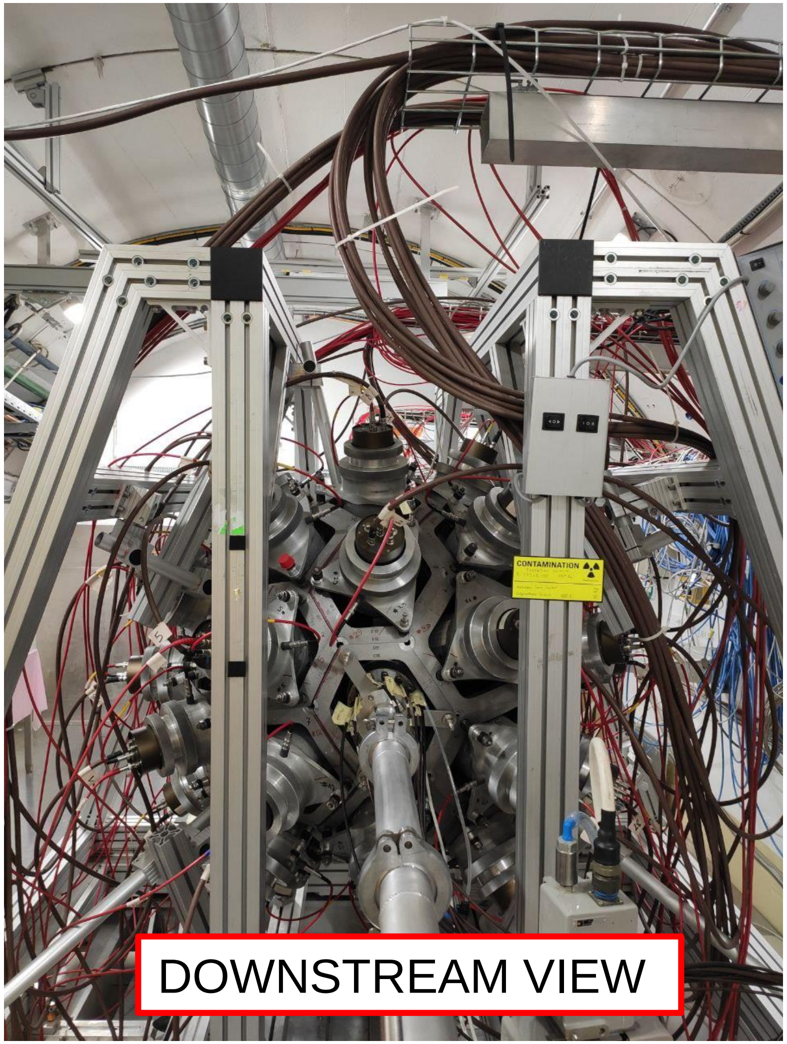




2.3 Experimental setup: mounting

Experimental setup (TAC closed)





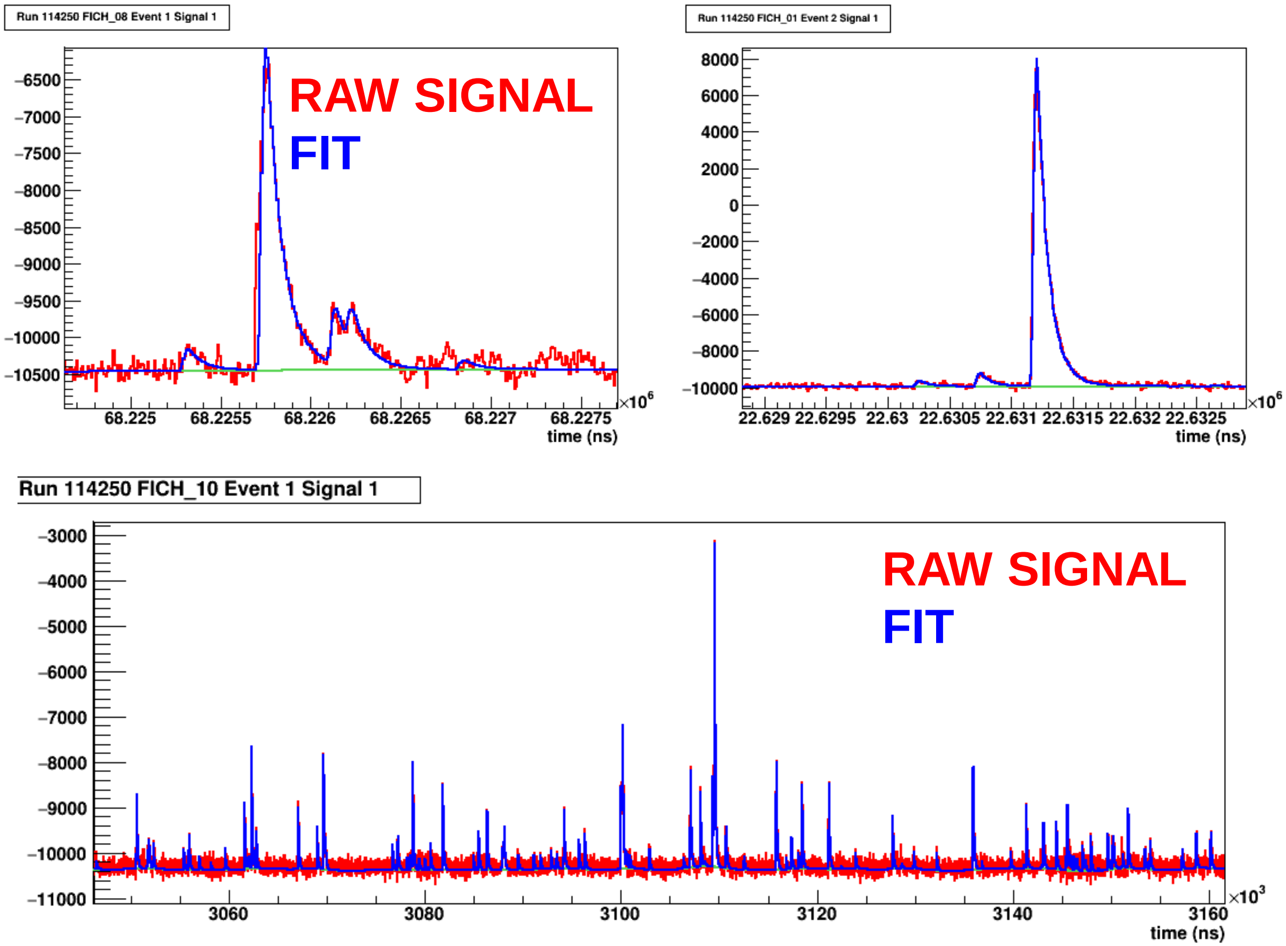
3

Data analysis

3.1 New dedicated Pulse Shape Analysis routine

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

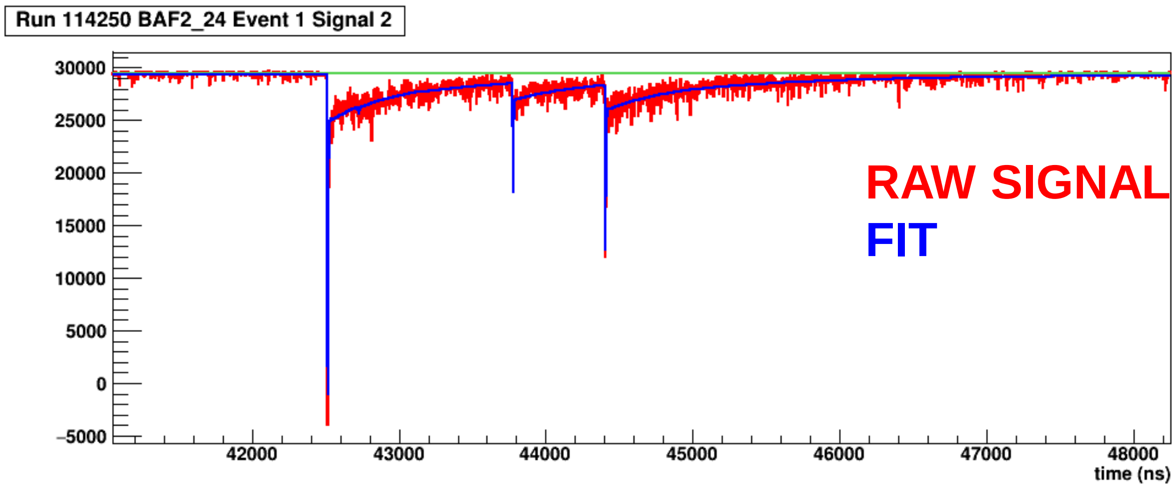
Fission Chamber

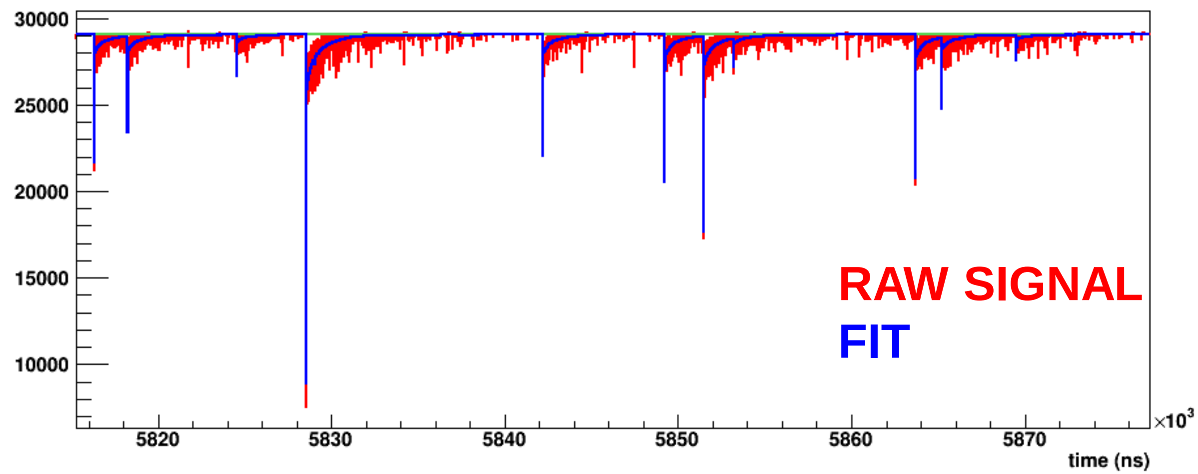


3.1 New dedicated Pulse Shape Analysis routine

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

TAC





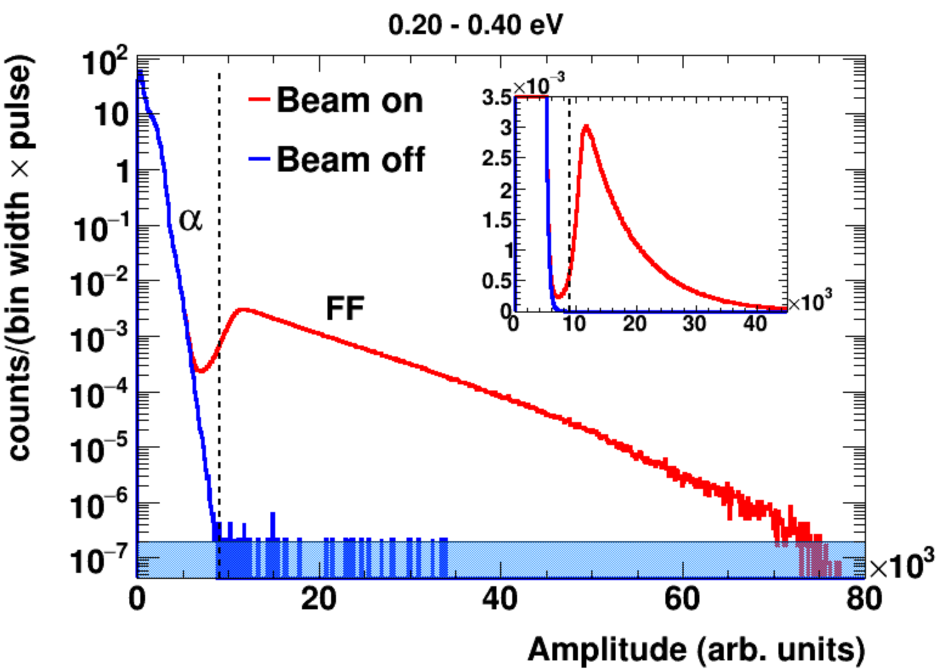
3.2 Amplitude/E_{sum} spectra

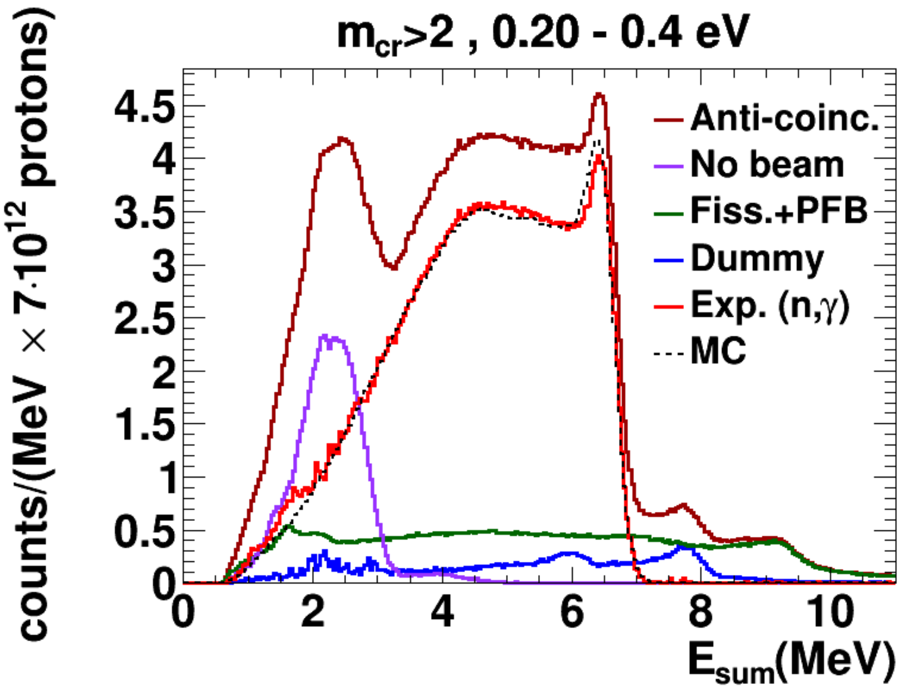
FFD

- Amplitude spectra in the fast fission detector.
- FF = Fission Fragment
- Vertical line: selected α-FF threshold.
- **1 FF per >2000 alphas.**

TAC

- Sum energy spectra with the different **background** components, for the first resonance at 0.3 eV.
- MC = Monte Carlo simulation of $^{239}Pu(n,\gamma)$.



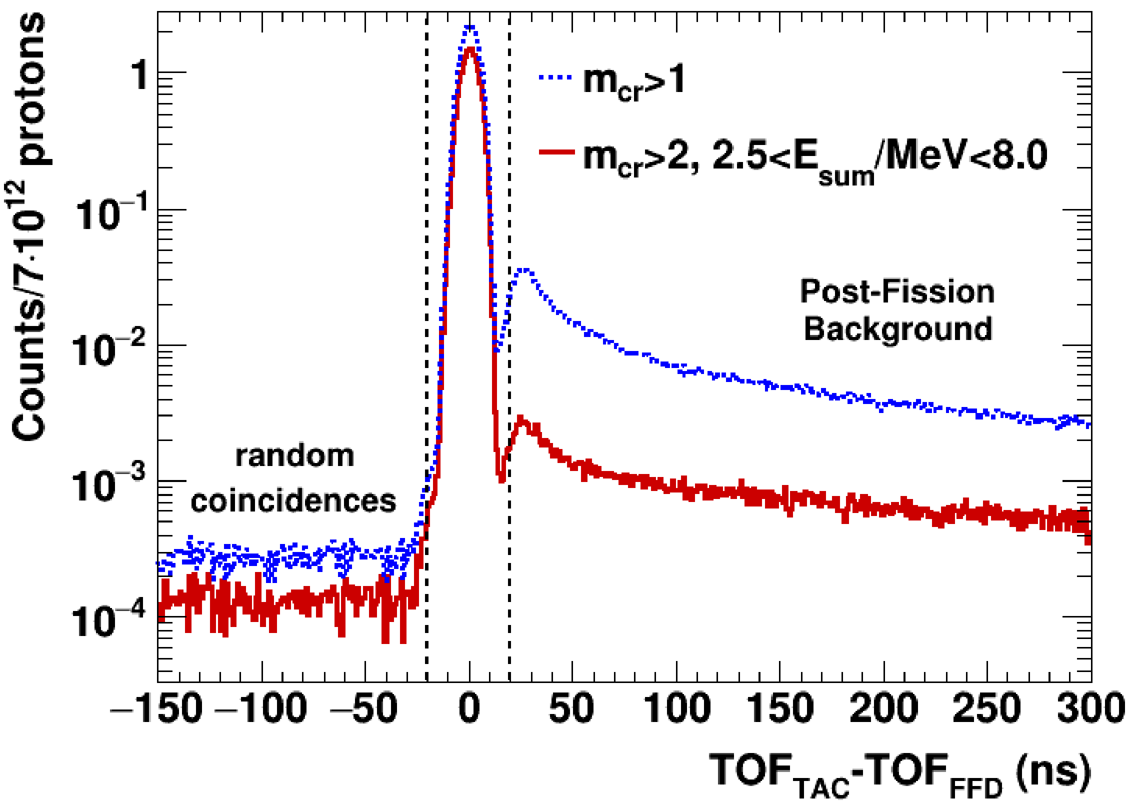


E. Mendoza et al. NuDEX: a new nuclear γ-ray cascade generator. EPJ Web of Conferences 239, 17006 (2020)

E. Mendoza et al. Study of photon strength functions of ^{241}Pu and ^{245}Cm from neutron capture measurements. EPJ Web of Conferences 239, 01015 (2020)

3.3 Coincidence analysis

- **Time coincidences** between **TAC events** and **fission chamber (FICH) signals** in the energy region close to the 0.3 eV ^{239}Pu resonance.
- **Coincidence window (-20,+20) ns.**

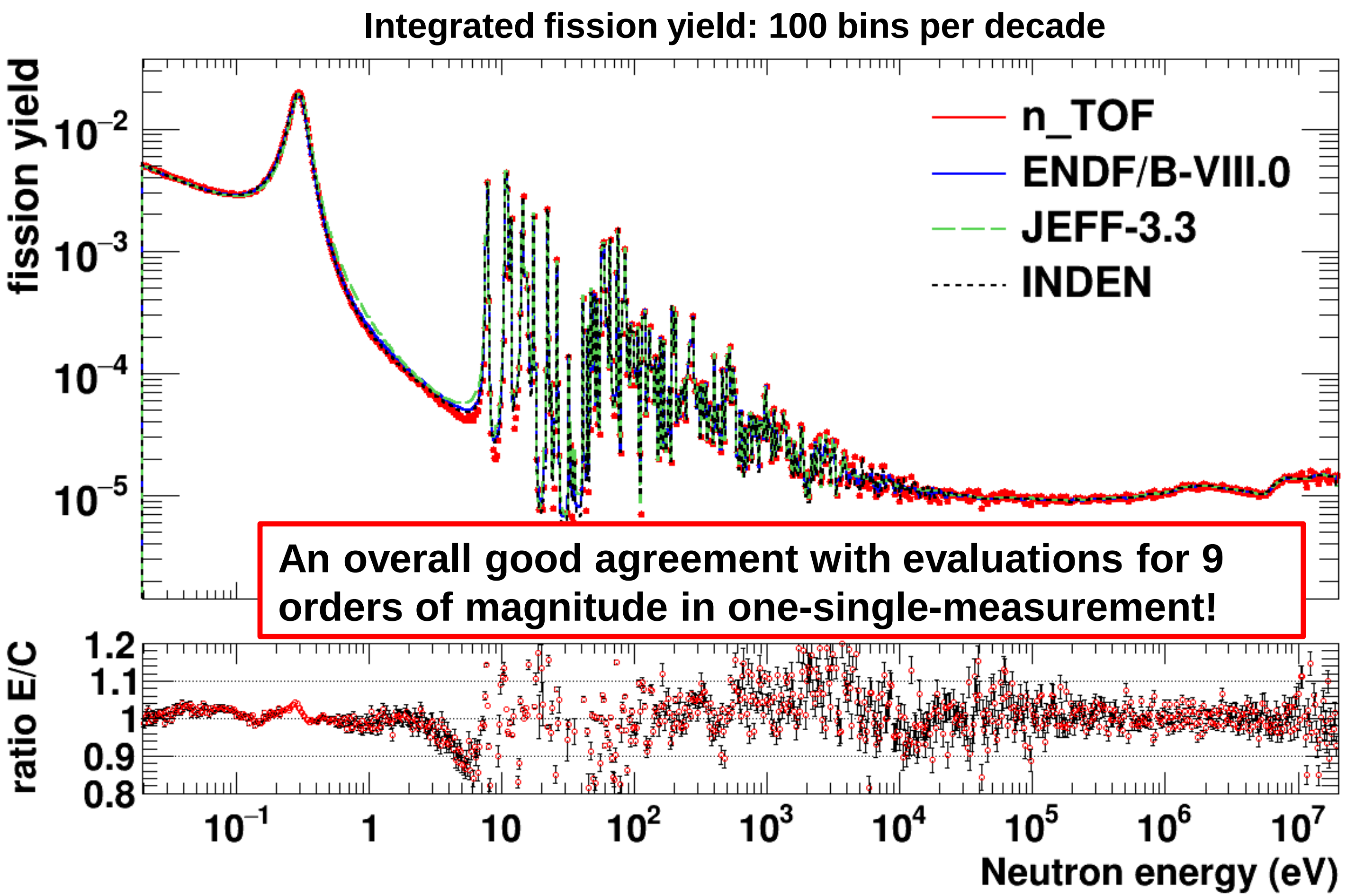


4

Experimental yields

4.1 ^{239}Pu(n,f) yield compared to evaluations

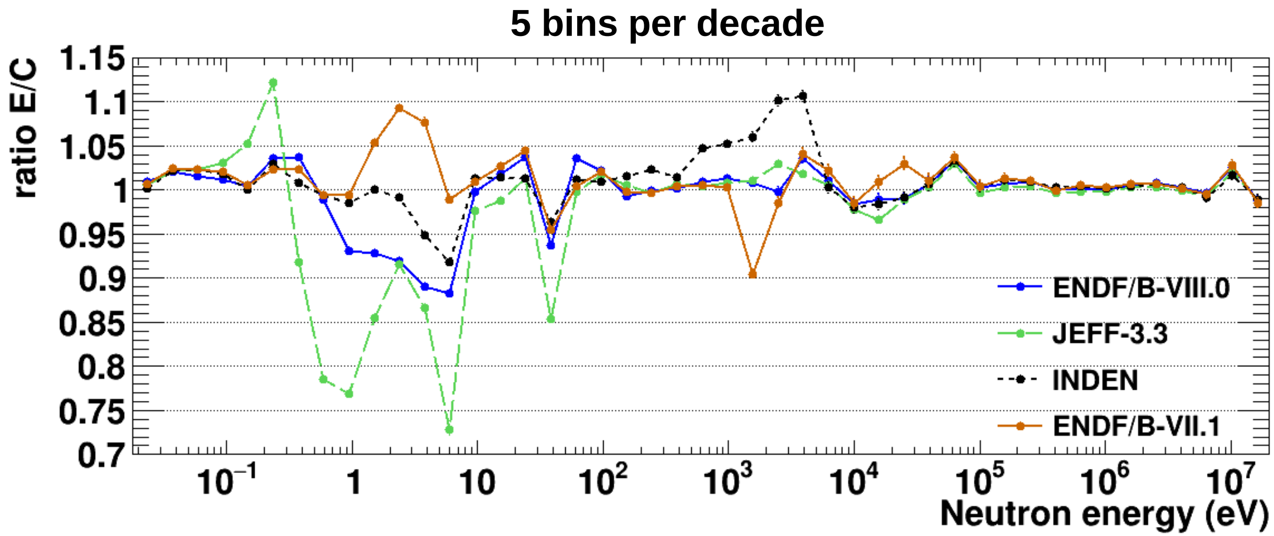
Fission yield **normalized** to the recommended value for fissile targets in: *Durán, I., Capote, R., & Cabanelas, P. (2024).* Normalization of ToF (n, f) Measurements in Fissile Targets: Microscopic cross-section integrals*. Nuclear Data Sheets, 193, 95-104.*

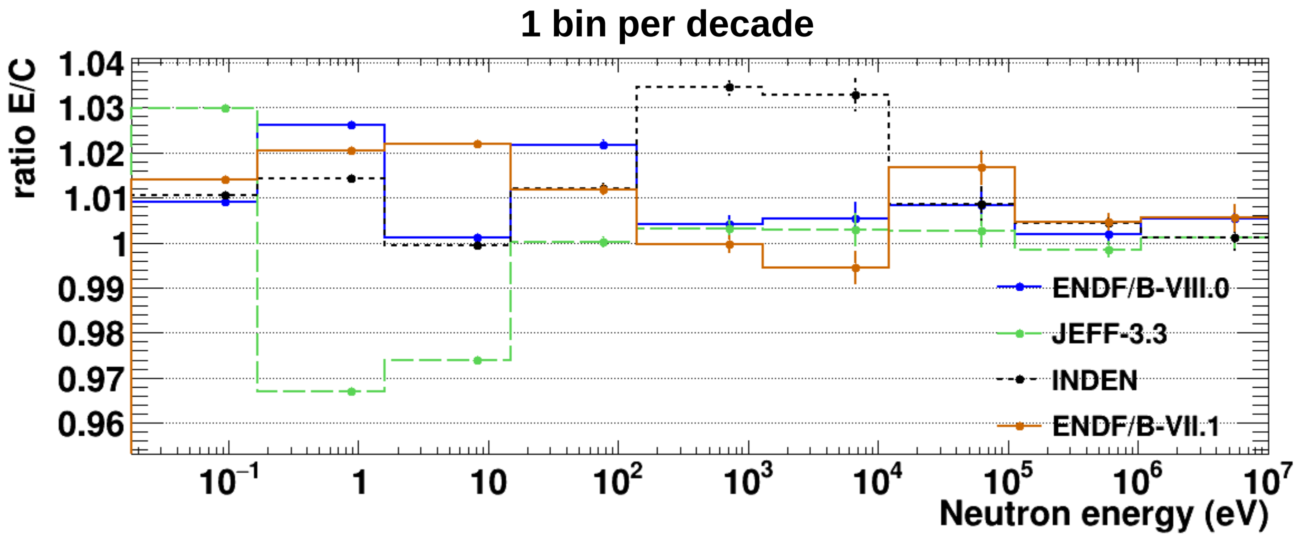


Ratios are calculated using the INDEN evaluation published in July 2023.

https://www-nds.iaea.org/INDEN/

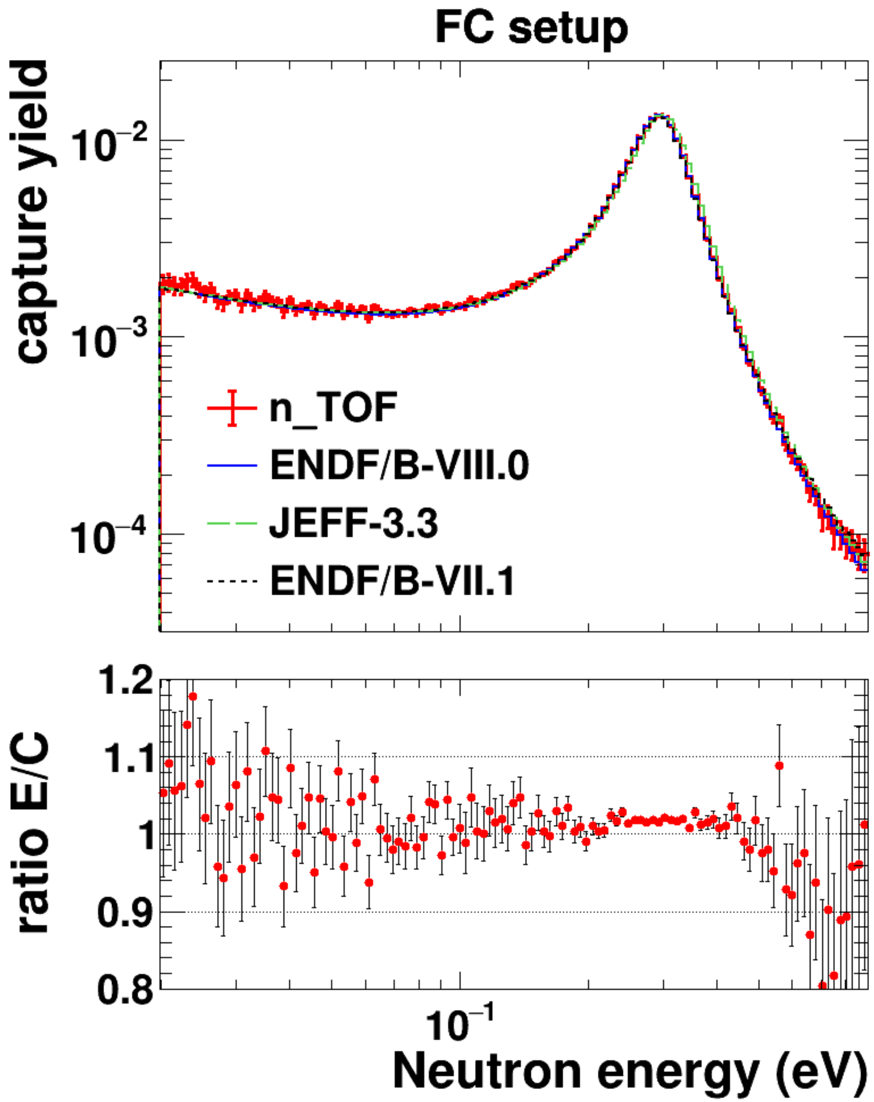
4.1 ^{239}Pu(n,f) yield compared to evaluations





4.3 ^{239}Pu(n,γ) yield compared to evaluations

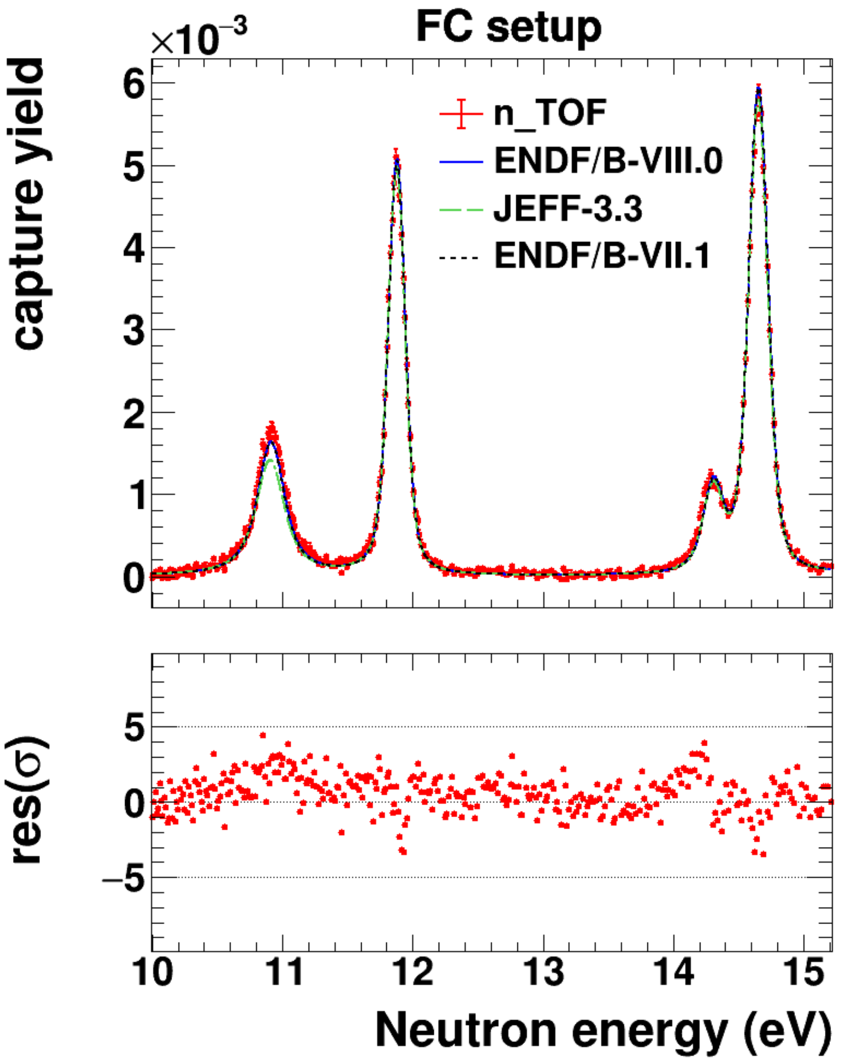
Capture in FC setup has been normalized using the ^{239}Pu(n,f) yield normalization.

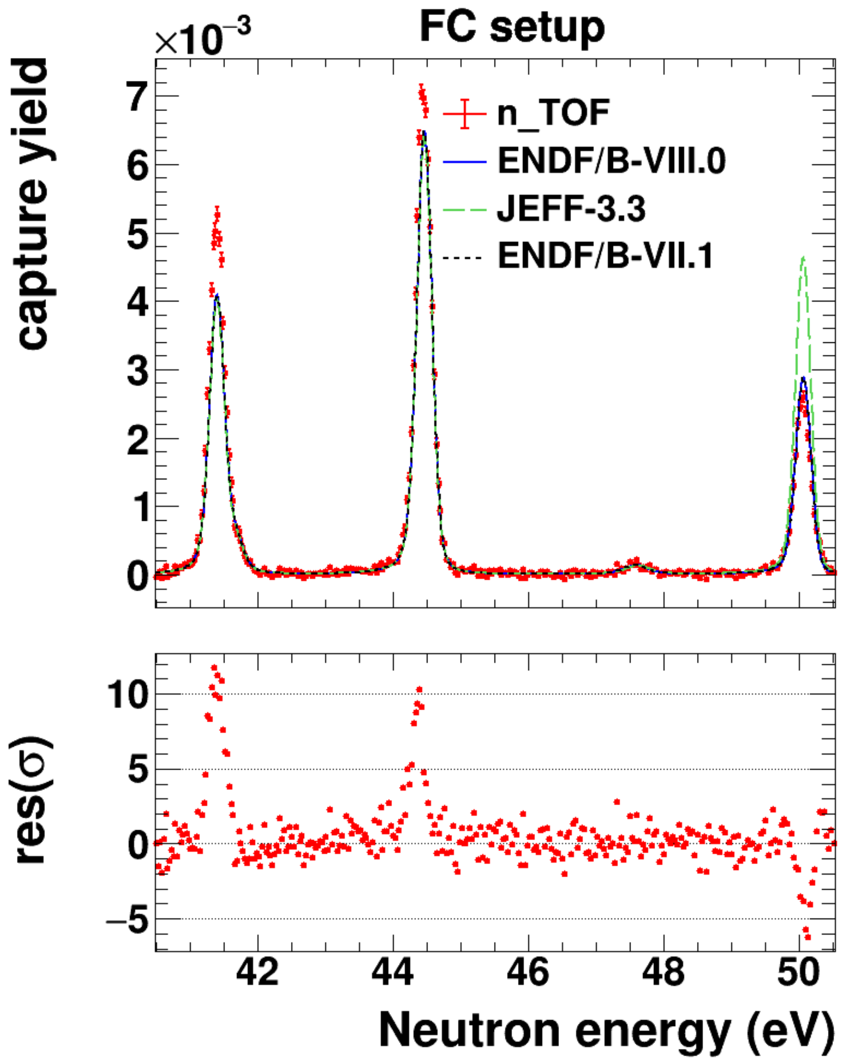


Ratios are calculated relative to ENDF/B-VII.1. Only statistical uncertainties are shown.

4.3 ^{239}Pu(n,γ) yield compared to evaluations

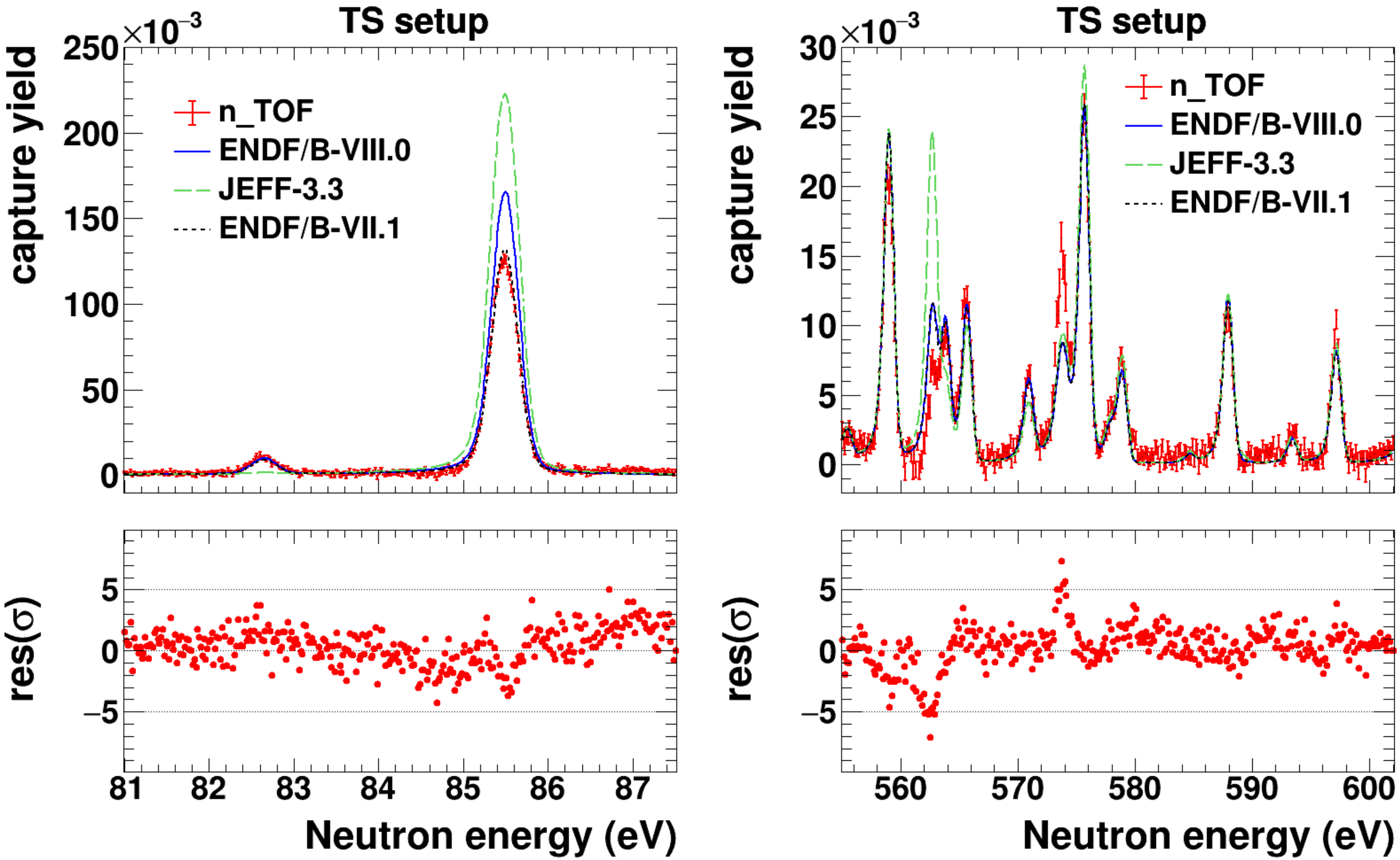
Capture in FC setup has been normalized using the ^{239}Pu(n,f) yield normalization.





4.3 $^{239}Pu(n,\gamma)$ yield compared to evaluations

Capture in TS setup.



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5

Summary

5. Summary

- **^{239}Pu experimental campaign** at n_TOF **successfully accomplished**. Measured neutron **capture** and **fission cross-sections** and other auxiliary measurements.
- Good **performance of the new fission chamber** and **high quality of the produced radioactive samples**.
- **^{239}Pu(n,f) cross-section** measured between **thermal and 20 MeV neutron energies.** Excellent agreement with evaluations; differences within a 2% at 1 bin per decade.
- **$^{239}Pu(n,\gamma)$ cross-section analysis** is quite **advanced**. Final results expected soon.
- A **paper** with the **fission** results is being prepared, and will be **submitted soon**.
- For **capture**, publications are expected for **next year**.
- The **new n_TOF ^{239}Pu data** will be submitted to the **EXFOR database**.

Acknowledgments

- This project has received funding from the **Euratom** research and training programme 2011-2018 under grant agreement No 847595 (**ARIEL**)

Accelerator and Research reactor Infrastructures for Education and Learning
ARIEL

- This activity is part of the scientific program approved by the European Commission *H2020* ***Supplying Accurate Nuclear Data for energy and non-energy Applications* – SANDA** project (WP2, Task 2).

SANDA

erc
European Research Council
Established by the European Commission

- **2021-1-RD EUFRAT-GELINA** project funding for the stay at JRC-Geel.

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Directorate G - Nuclear Safety and Security
Standards for Nuclear Safety, Security and Safeguards

- **Spanish national projects** PGC2018-096717-B-C21, PID2021-123100NB-I00 and PDC2021-120828-I00.

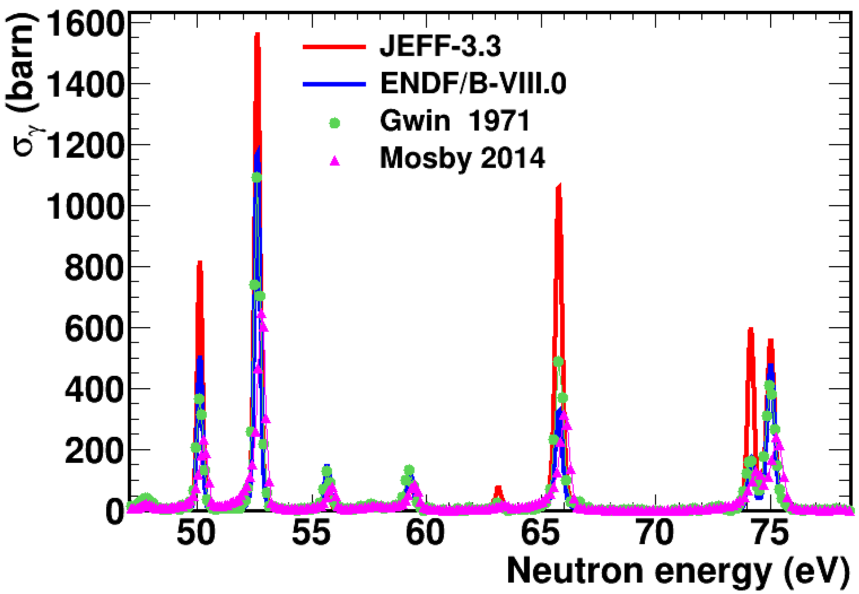

THANK YOU!

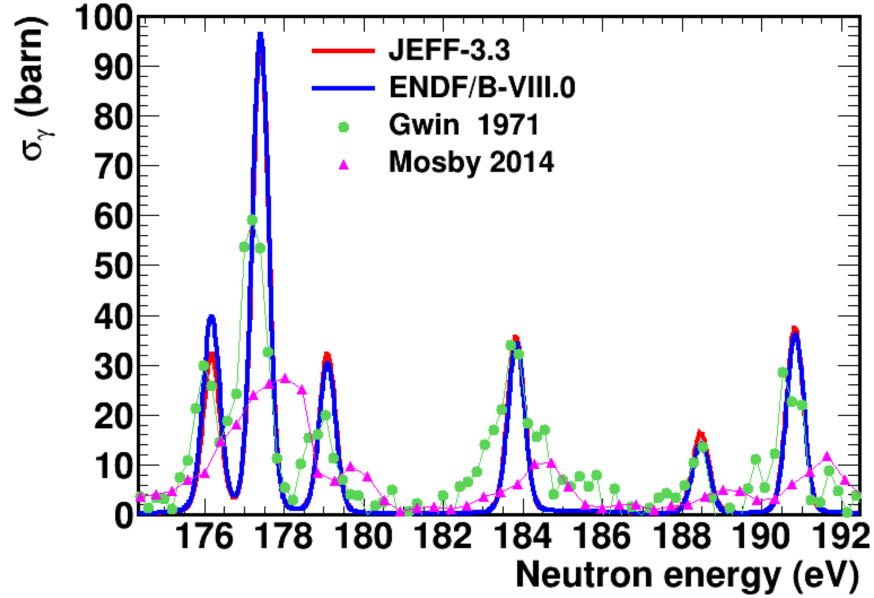
Extra slides

1.2 Previous measurements

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

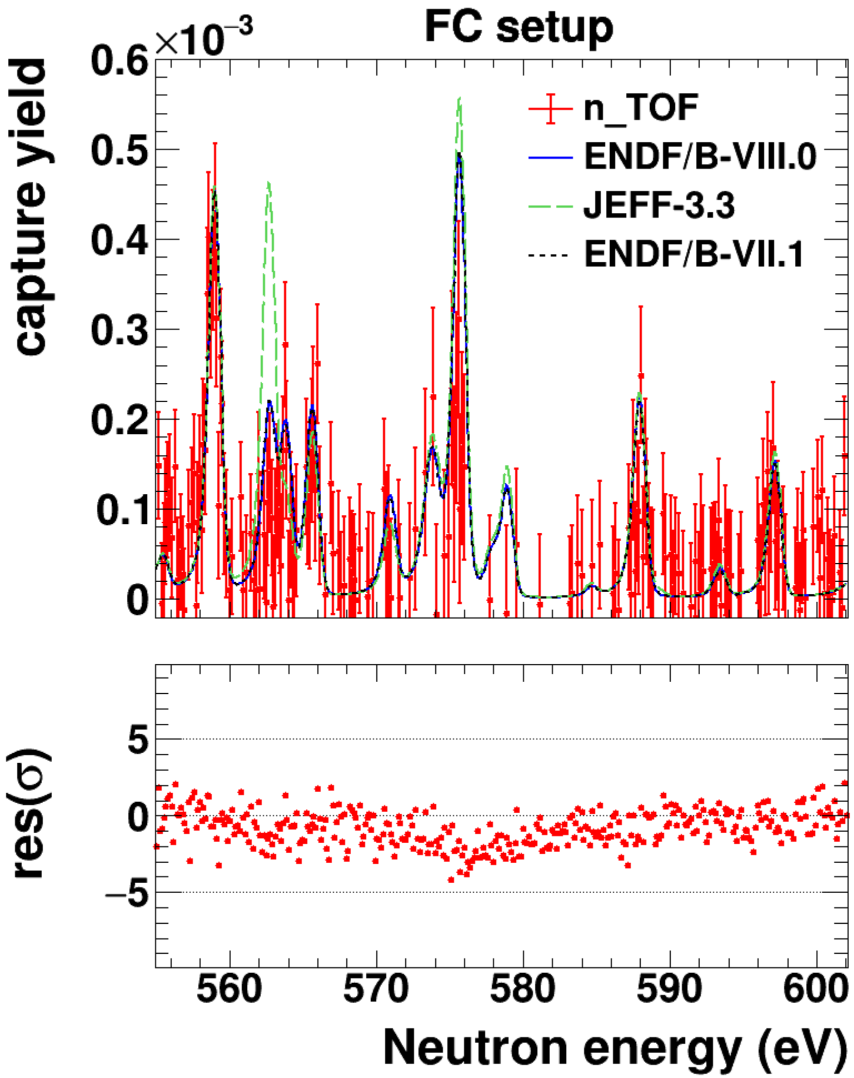
- **Gwin et al. (1971)**. For neutron energies between 0.02 eV and 30 keV.
- **Mosby et al. (2014)** at LANSCE (Los Alamos, USA) in the neutron energy range from 10 eV to 1.3 MeV. Only the shape of the cross-section was measured (normalized to ENDF/B-VII.0 cross-section).

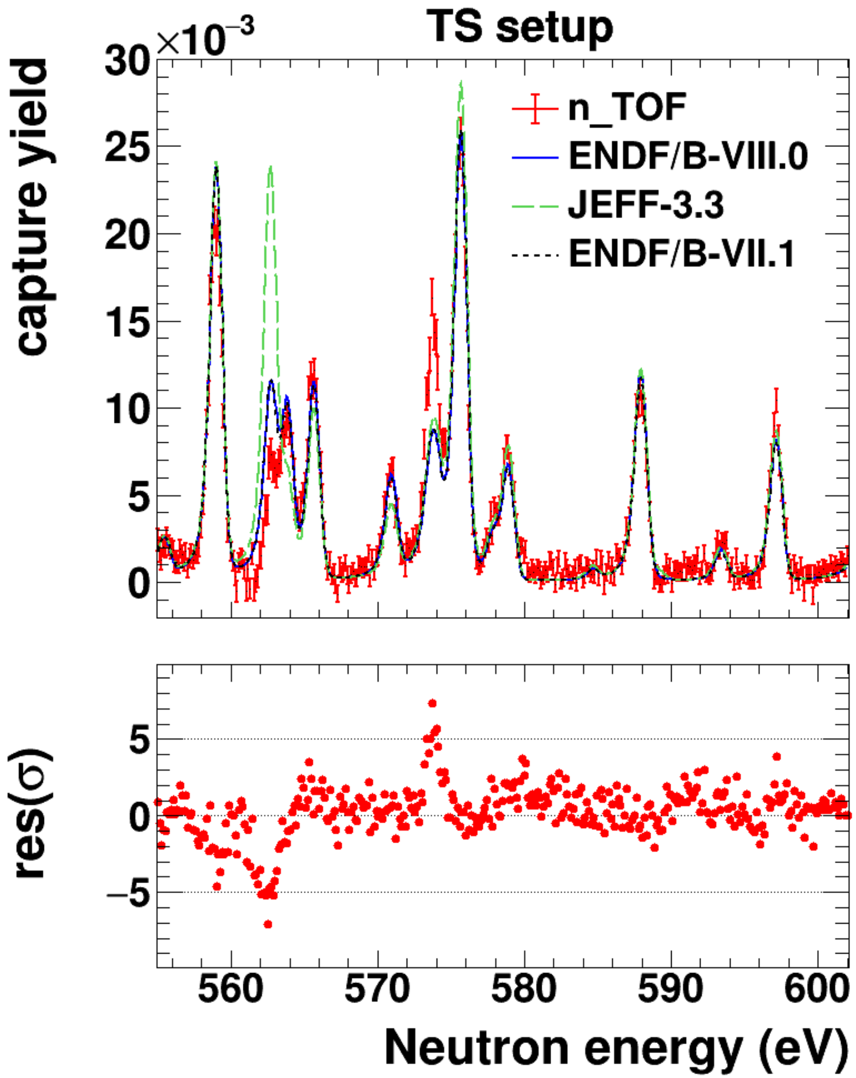




4.3 ^{239}Pu(n,γ) yield compared to evaluations

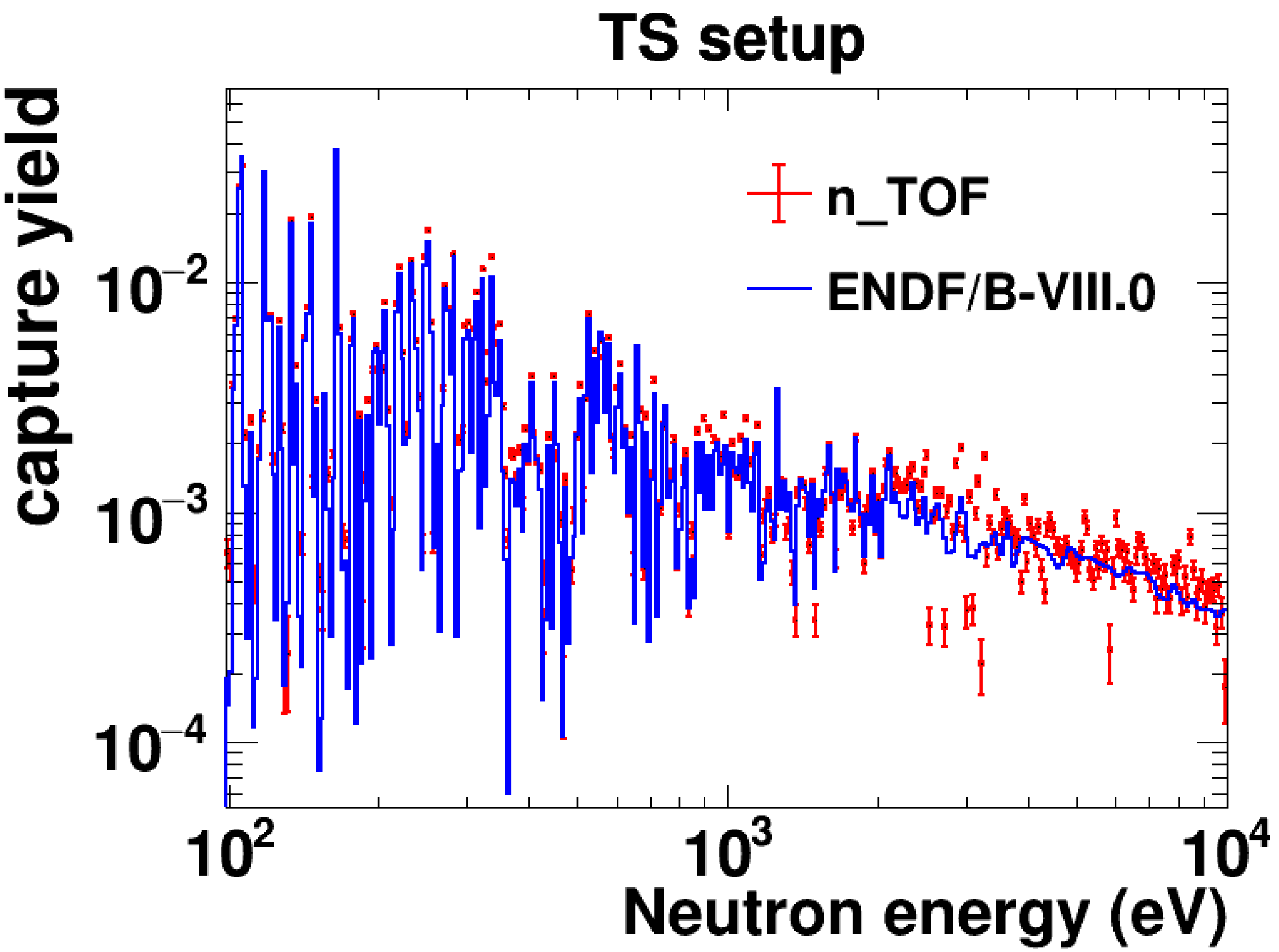
Capture comparison FC vs TS setup.





4.3 ^{239}Pu(n,γ) yield compared to evaluations

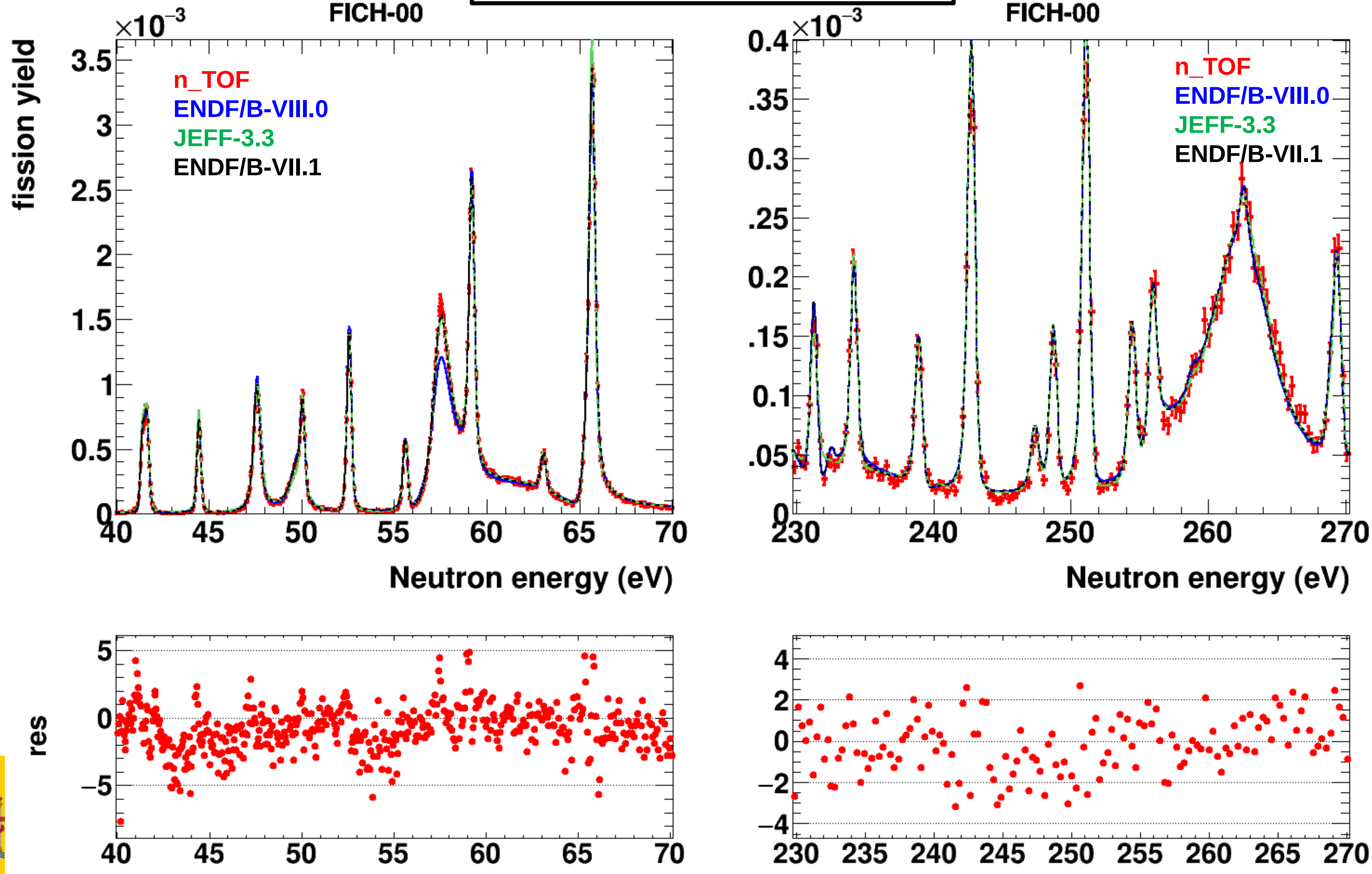
Capture in TS setup.



Fission Chamber configuration

Preliminary results: fission yield compared with evaluated libraries

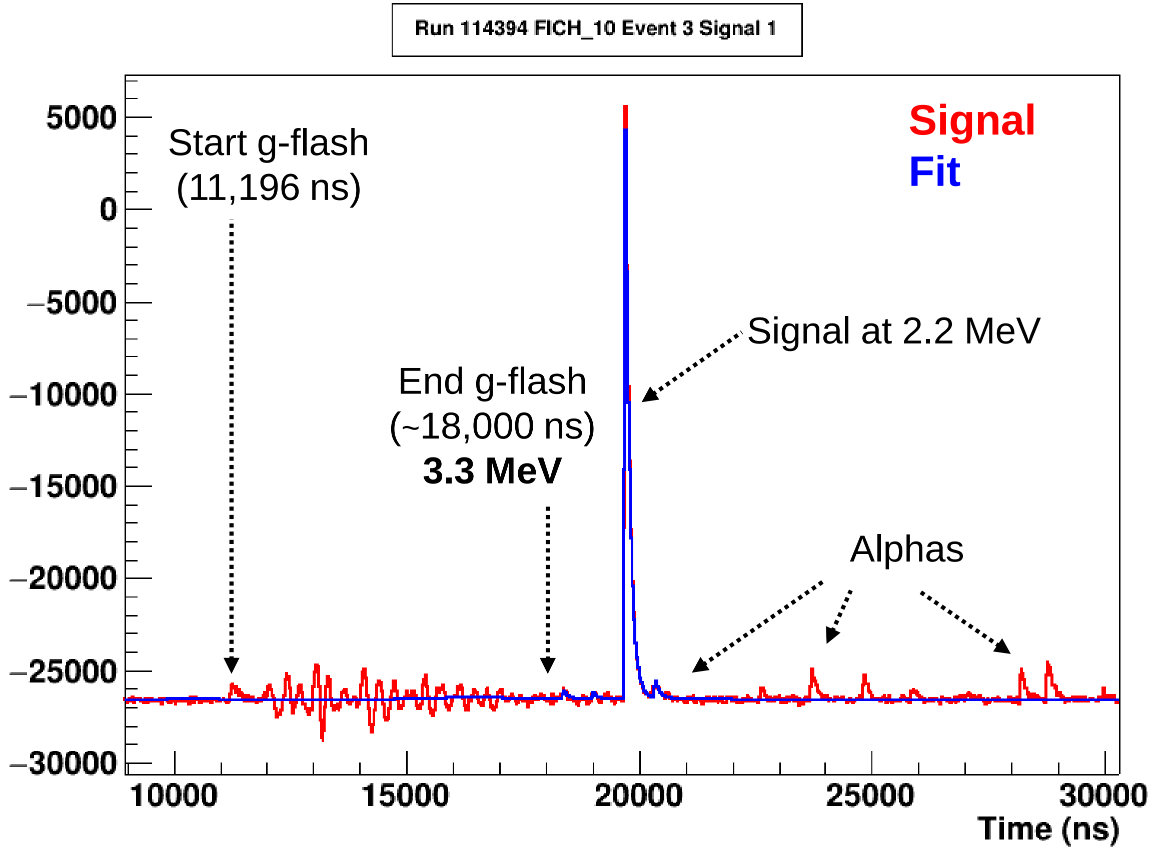
$$\text{res} = \frac{\text{n\_TOF} - \text{ENDF/B-VII.1}}{\{\text{n\_TOF unc.}\}}$$



Max. E_n in fission yield

Inspecting the data buffers, we can estimate the width of the gamma flash, thus obtaining the maximum valid neutron energy for the fission yield that we could potentially reach.

Plot taken from file run114394_0_s1.raw.finished. The Tflash has been obtained from Baf2 #18 from the same pulse. TOFD = 185.59 m.

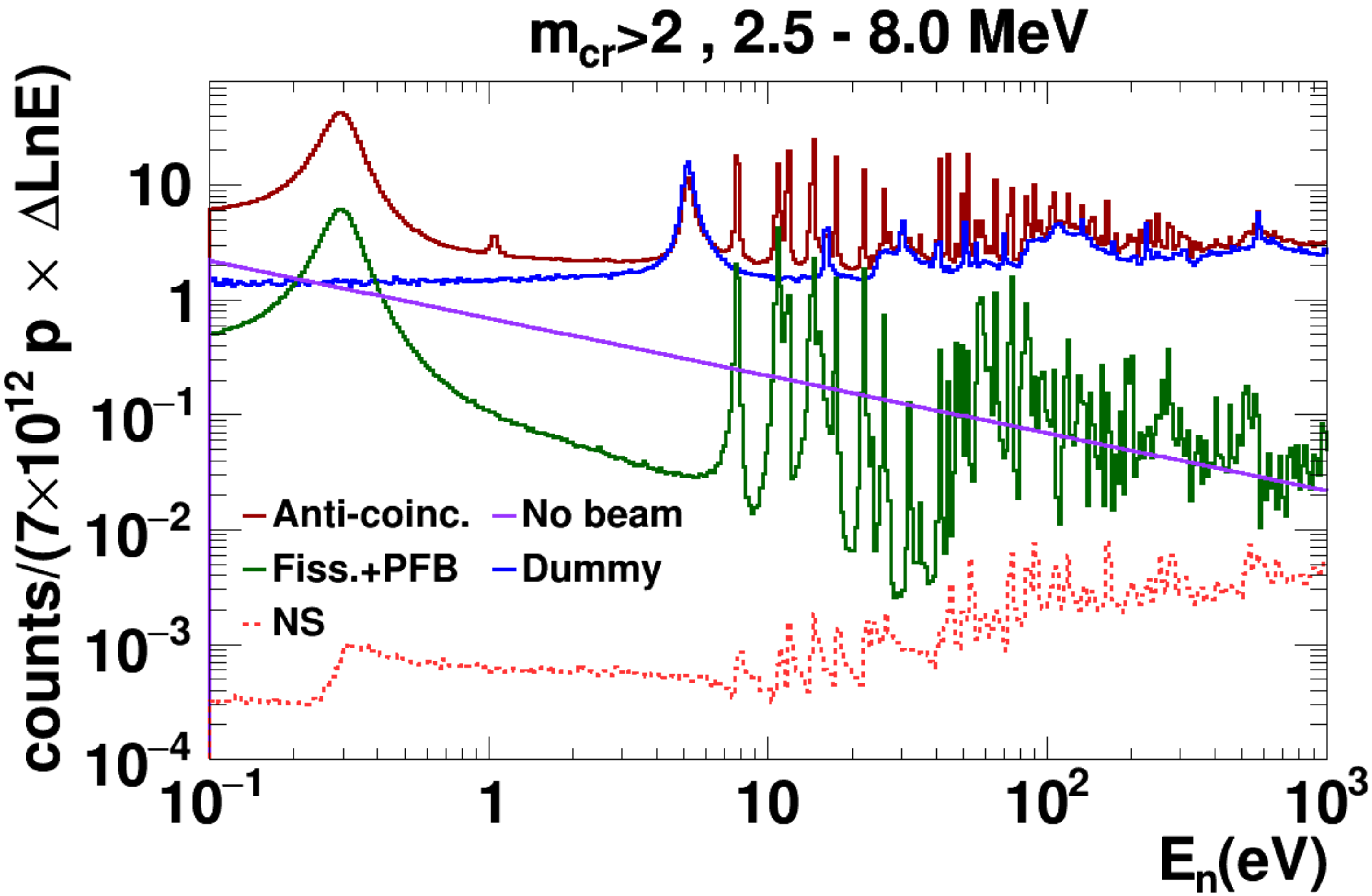


According to this, we could measure fission without being affected by the gamma-flash **up to ~3 MeV**.

Fission Chamber configuration

Preliminary results: background contributions

- TAC neutron energy spectra with the standard cuts for a capture measurements.



Targets description

Number of electronic output from preamplifiers	Target position in the FC chamber	Pu-239 samples			
		TP number	Activity [μg/cm^2]	Mass [μg]	Areal density [μg/cm^2]
6	1	2020-006-15	2.24E+06	975	310
1	2	2020-006-02	2.22E+06	965	307
7	3	2020-006-04	2.20E+06	959	305
2	4	2020-006-06	2.09E+06	911	290
8	5	2020-006-14	2.81E+05	122	39
3	6	2020-006-07	1.94E+06	844	268
9	7	2020-006-08	2.19E+06	953	303
4	8	2020-006-10	2.11E+06	920	293
10	9	2020-006-12	2.09E+06	912	290
5	10	2020-006-13	2.25E+06	982	312

Targets description