

Report and summary of the ^{239}Pu campaign at EAR1 and preliminary results

16th Sep - 16th Nov 2022

A. Sanchez-Caballero¹, V. Alcayne¹, J. Andrzejewski², D. Cano-Ott¹, J. García-Pérez¹, E. González-Romero¹, J. Heyse³, T. Martínez¹, E. Mendoza¹, J. Perkowski², J. Plaza del Olmo¹, A. Plompen³, P. Schillebeeckx³, G. Sibbens³

¹CIEMAT, Spain

²University of Lodz, Poland

³JRC-Geel, Belgium



Accelerator and Research reactor Infrastructures for
Education and Learning

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3. Thick sample configuration.
 - Description of the experimental setup.
 - Preliminary results.
4. Summary

Overview of the experiment

- **Motivation:** needs on ^{239}Pu cross-section data, included in the OCDE/NEA HPRL.
- **Objective:** measuring the ^{239}Pu (n, γ) and (n,f) cross section (and α -ratio).
- **Used protons statistics** (from 16th September to 16th November 2022):
 - *Fission Chamber* configuration: 2.87×10^{18} protons.
 - *Thick Sample* configuration: 2.22×10^{18} protons.
- **1.1 petabytes** of raw data recorded for the whole campaign.

Main new characteristics of the experimental setup

- **NEW fission chamber** (University of Lodz) with **10 x ~1mg ^{239}Pu targets** (JRC-Geel).
- **NEW thick ^{239}Pu (100 mg) encapsulated sample** (JRC-Geel).
- **NEW Li-doped neutron absorber** (designed by CIEMAT and fabricated by CERN).
- **NEW pipes and structure material** for the fission chamber inside the TAC (made by O. Aberle and O. Fjeld).
- **NEW pulse shape analysis routine** for both Fission Chamber and Total Absorption Calorimeter.

Fission Chamber configuration

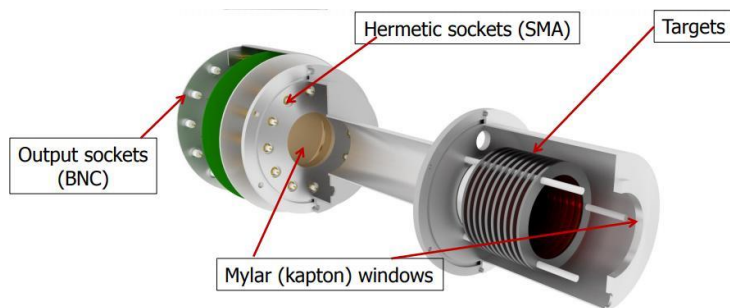
Fission Chamber configuration

Objectives

- To **measure the ^{239}Pu (n, γ)** cross section using the **fission tagging technique** for *low* neutron energies (**up to 1 keV**), without thick-sample-related effects (e.g. self-shielding, multiple scattering).
- To **measure the (n,fission)** cross section using the new fission chamber and electronics (up to higher neutron energies).

Samples and Fission chamber

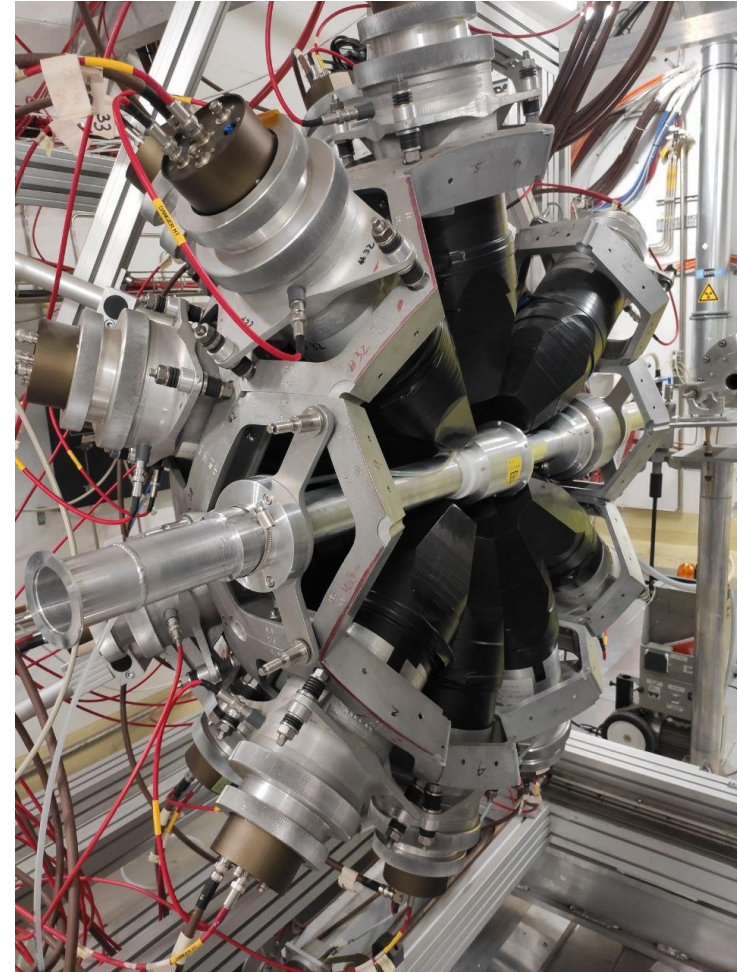
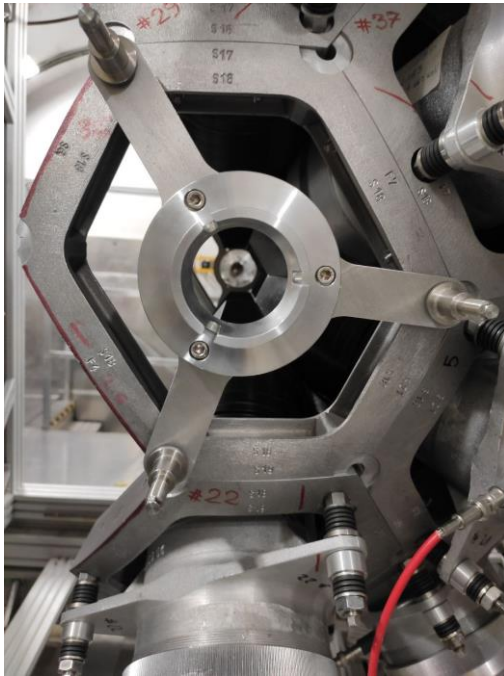
- **10 targets of PuO_2** deposited in 10 μm aluminum backing, inside the fission chamber.
- **Pre-amplifiers** attached to the fission chamber (both inside the Total Absorption Calorimeter).
- Fission chamber **filled with $\text{Ar}+\text{CF}_4$ gas** to detect fission fragments of each target.



Fission Chamber configuration

Experimental setup

- The gamma rays are detected using the **Total Absorption Calorimeter (TAC)**.
- For mounting the fission chamber inside the TAC, **new supporting pieces and pipes** have been designed and made by **O. Aberle and O. Fjeld**.



Fission Chamber configuration

Experimental setup

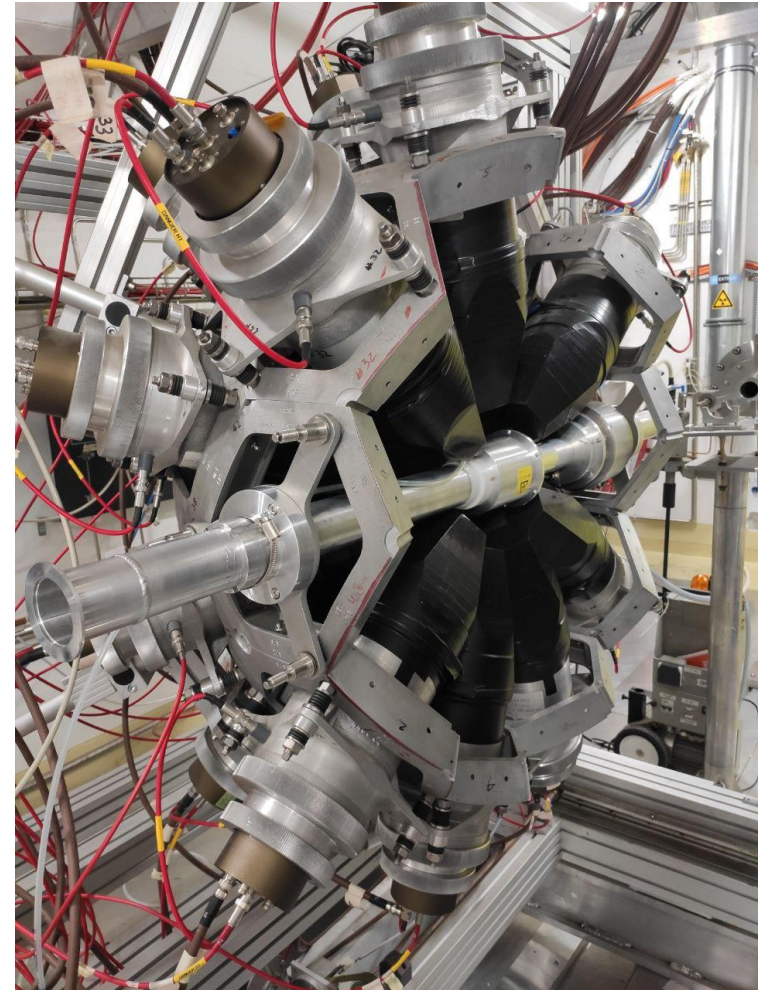
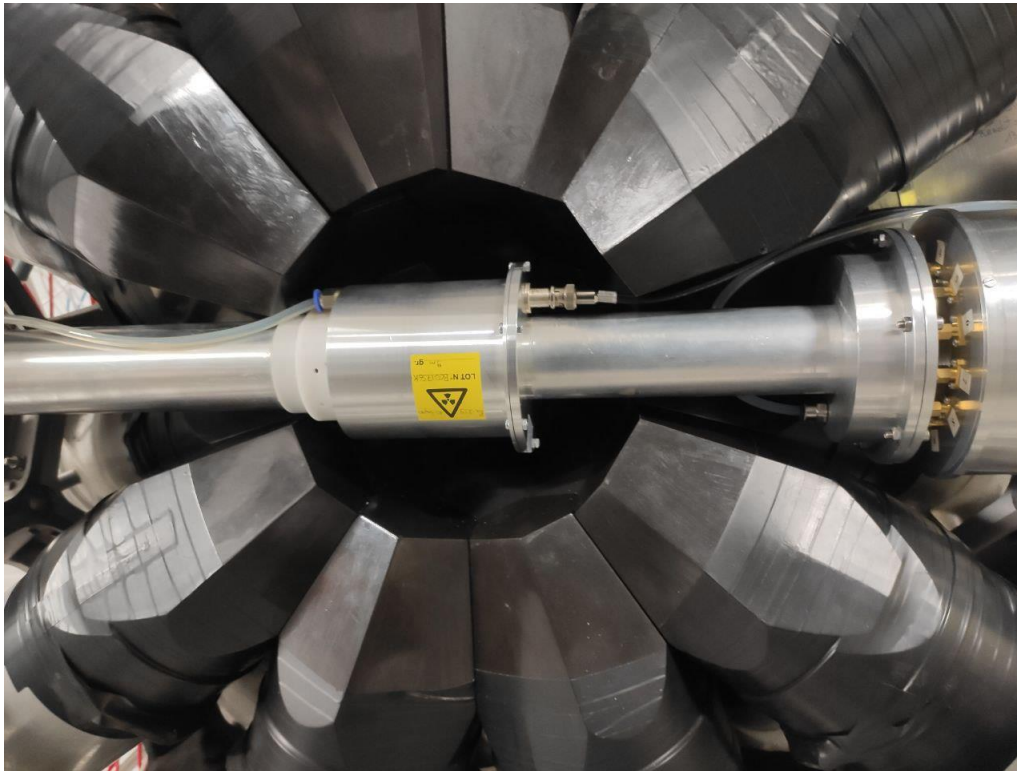
- Due to the small dimensions of the fission chamber and pipes, a **highly accurate alignment** was performed with the help of **CERN Survey Team** (thanks to Dirk Mergelkuhl and colleagues).



Fission Chamber configuration

Experimental setup

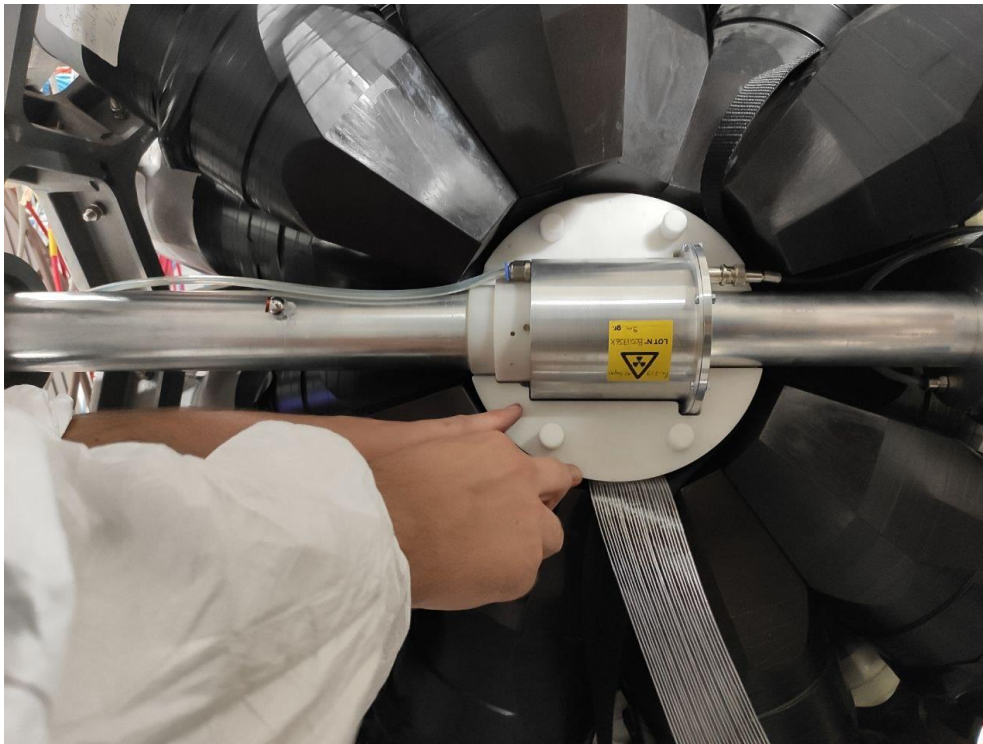
- Mounting of the fission chamber inside the TAC.



Fission Chamber configuration

Experimental setup

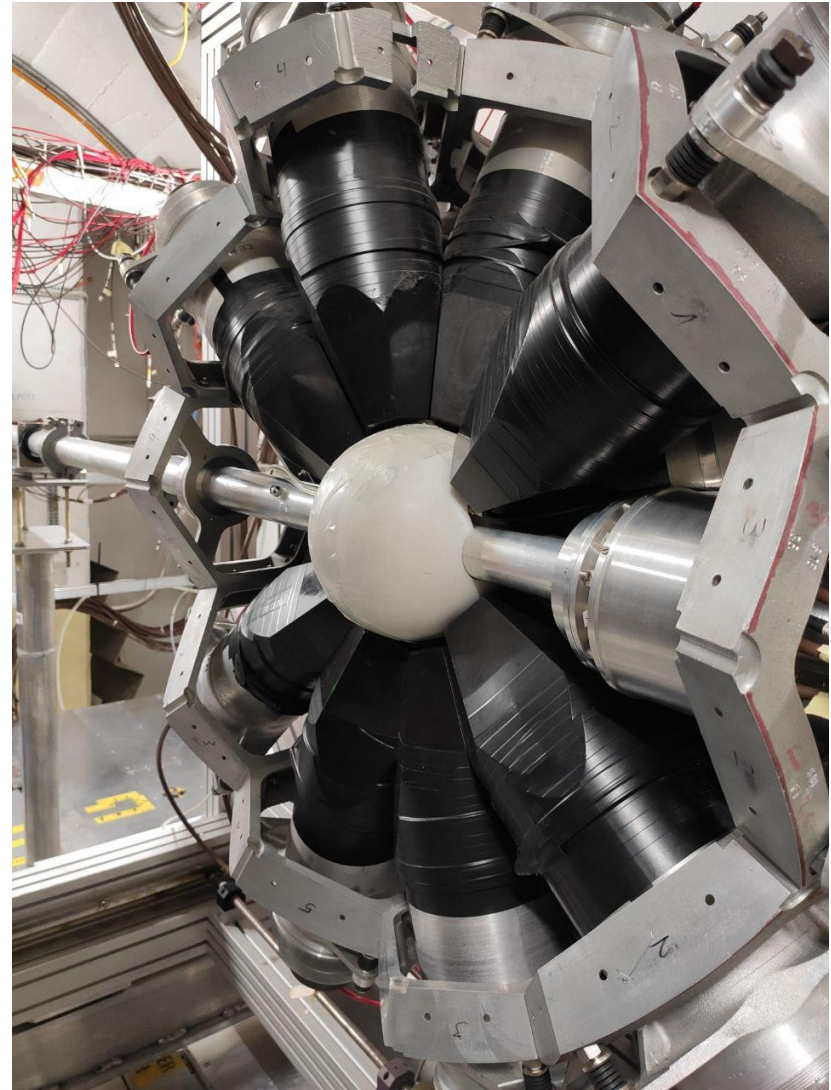
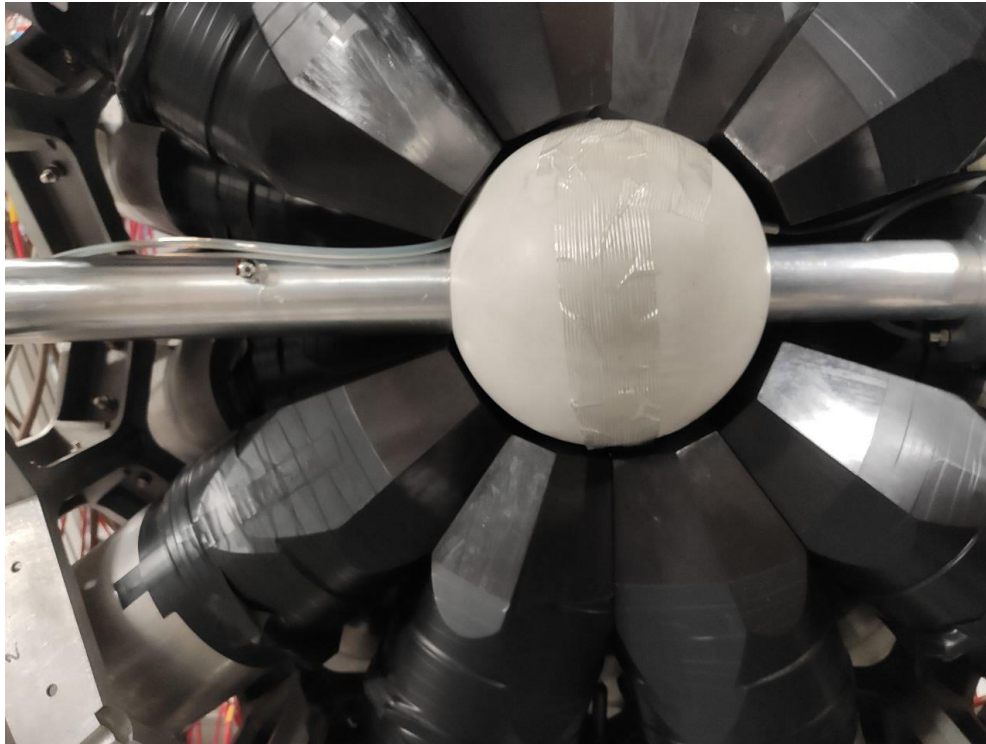
- Placement of the **Li-doped polyethylene neutron absorber** to reduce the number of neutrons reaching the BaF_2 crystals (high neutron sensitivity).



Fission Chamber configuration

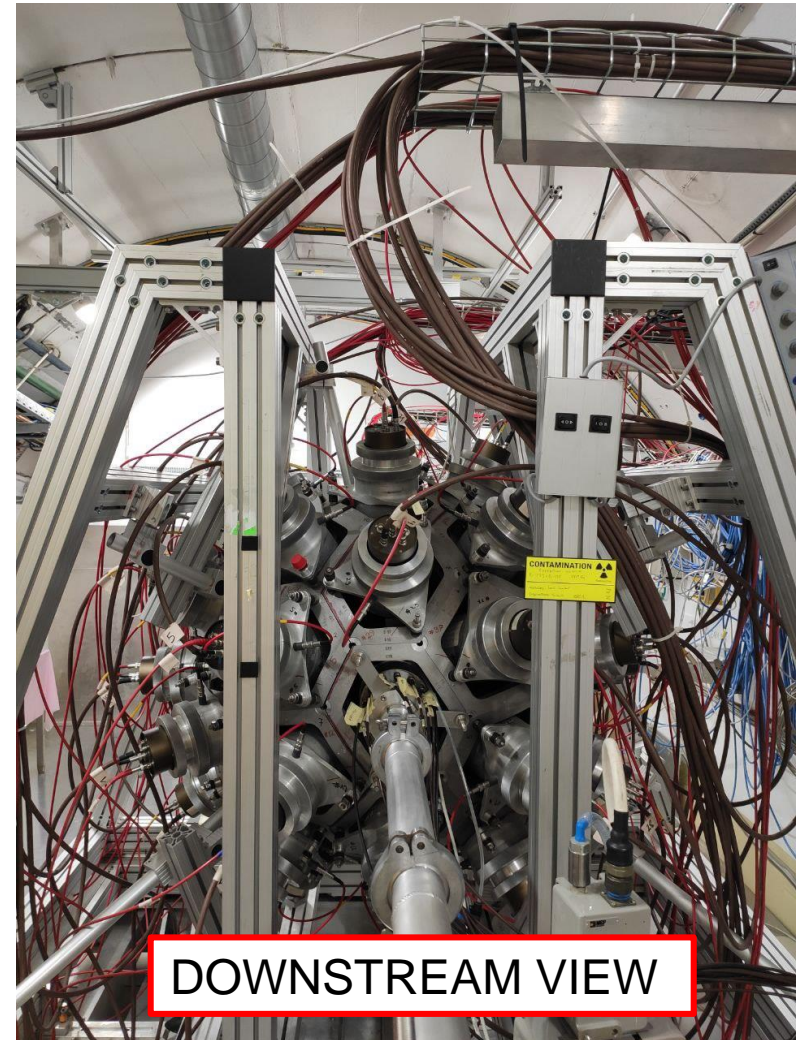
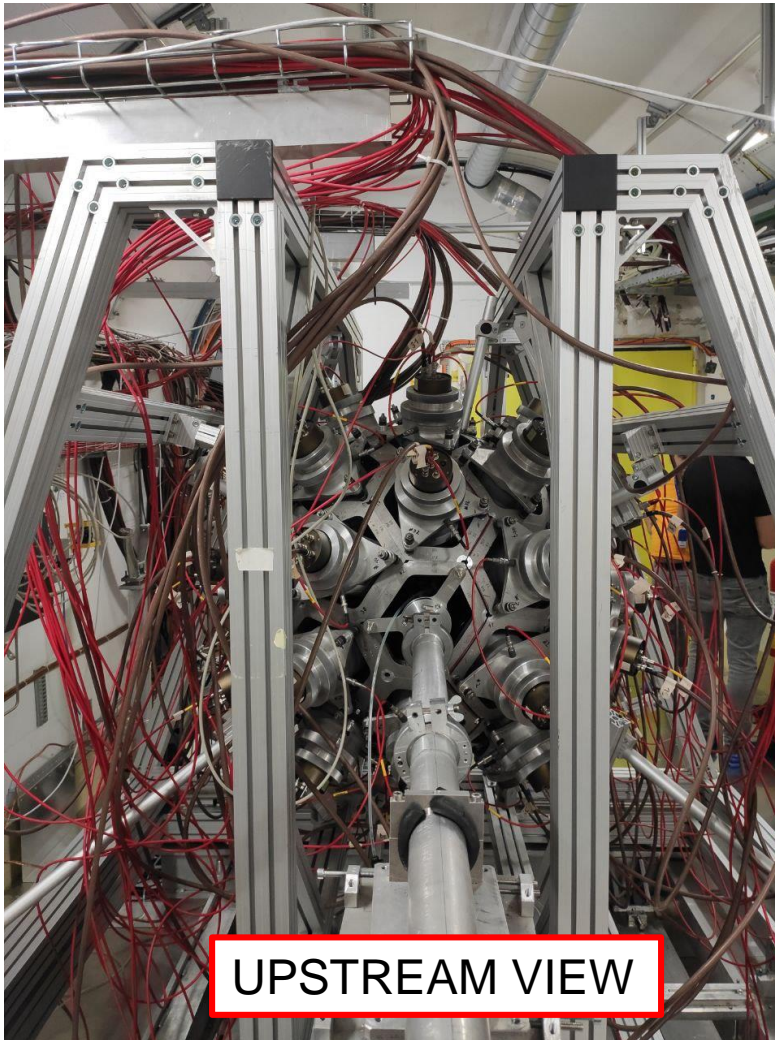
Experimental setup

- Final setup after closing absorber.



Fission Chamber configuration

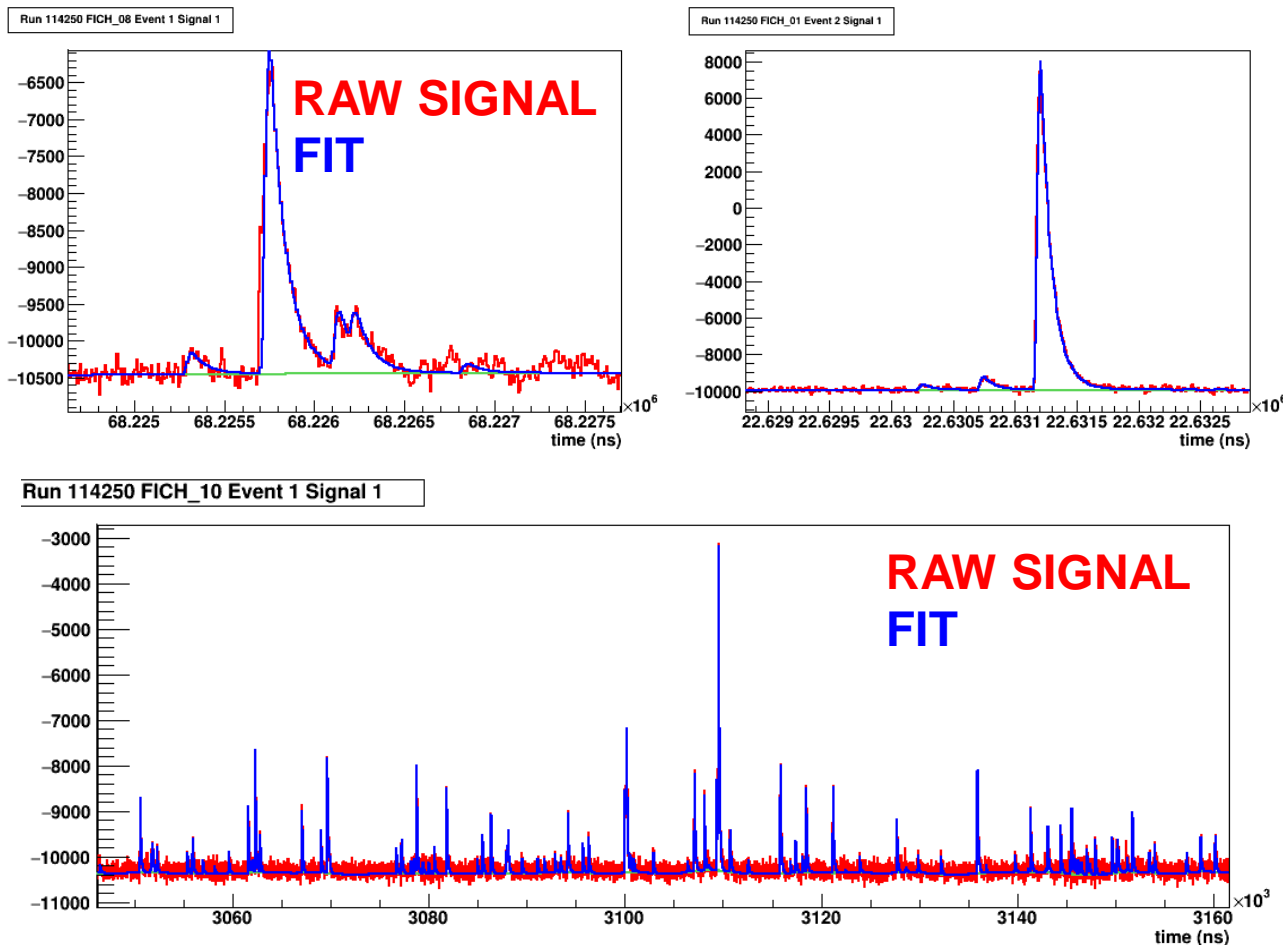
Experimental setup (TAC closed)



Fission Chamber configuration

Preliminary results

- Signal reconstruction examples (Fission Chamber) with the new dedicated Pulse Shape Analysis routine.

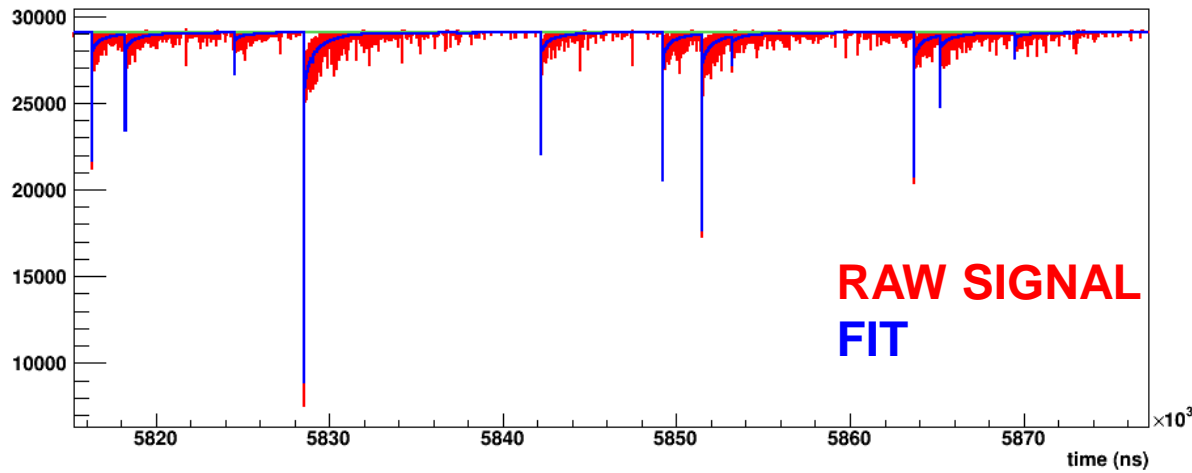
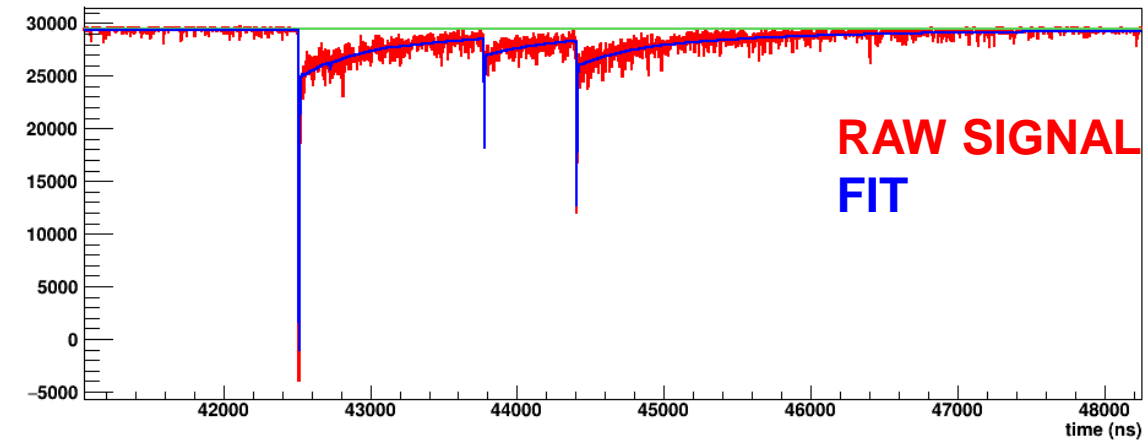


Fission Chamber configuration

Preliminary results

- **Signal reconstruction examples (TAC) with the new dedicated Pulse Shape Analysis routine.**

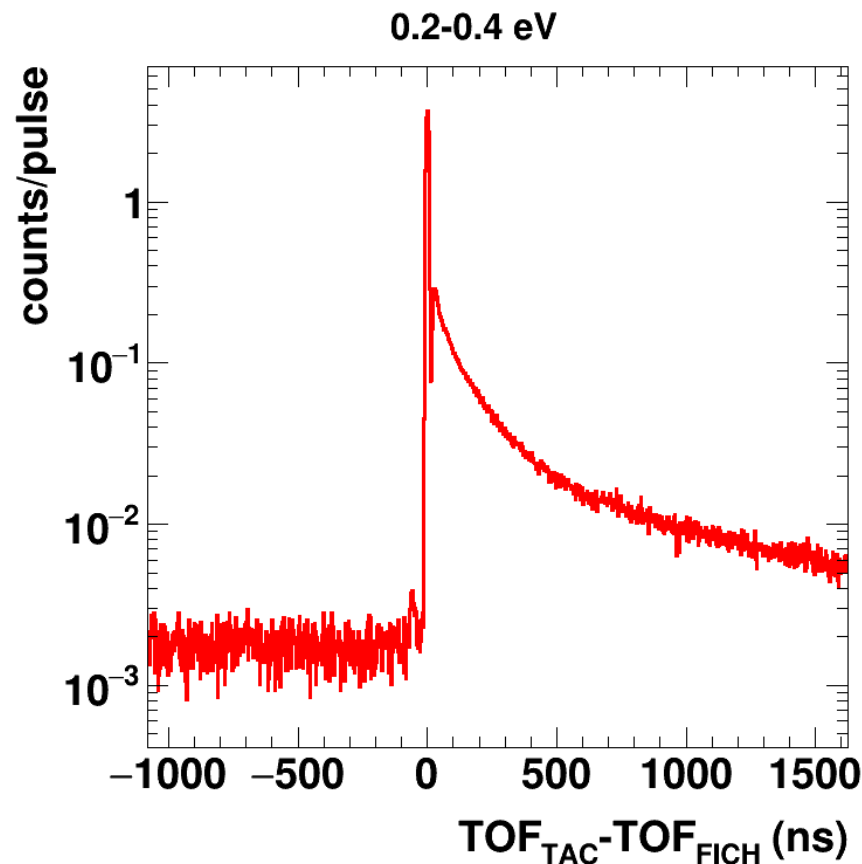
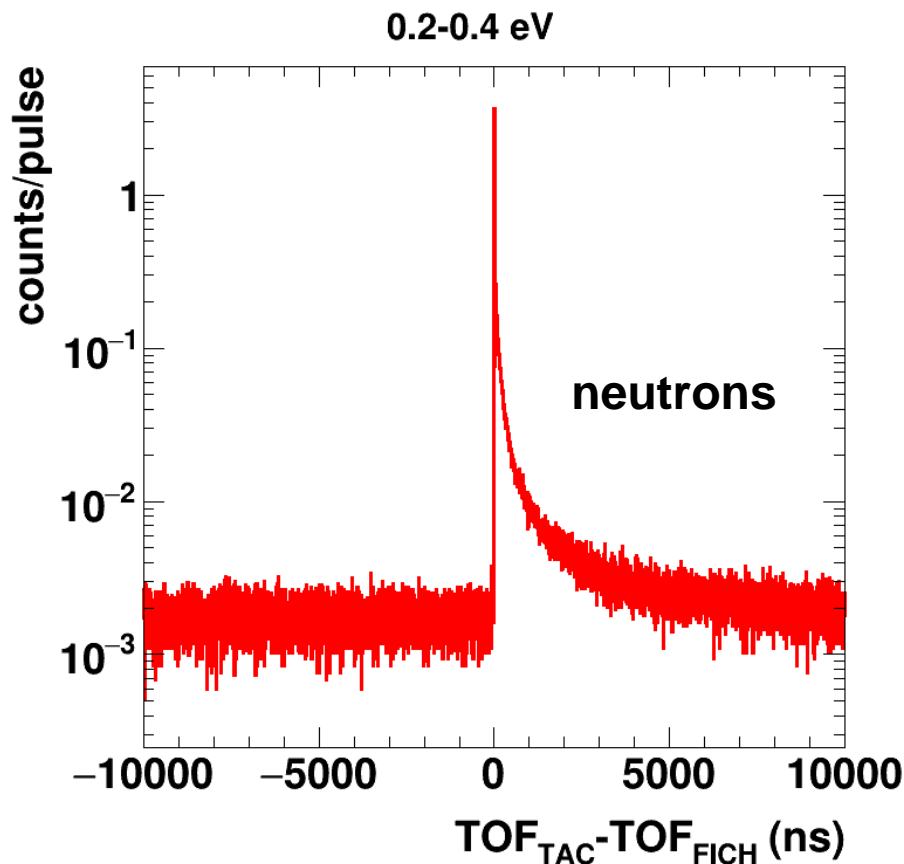
Run 114250 BAF2_24 Event 1 Signal 2



Fission Chamber configuration

Preliminary results: TAC – FICH Time coincidences

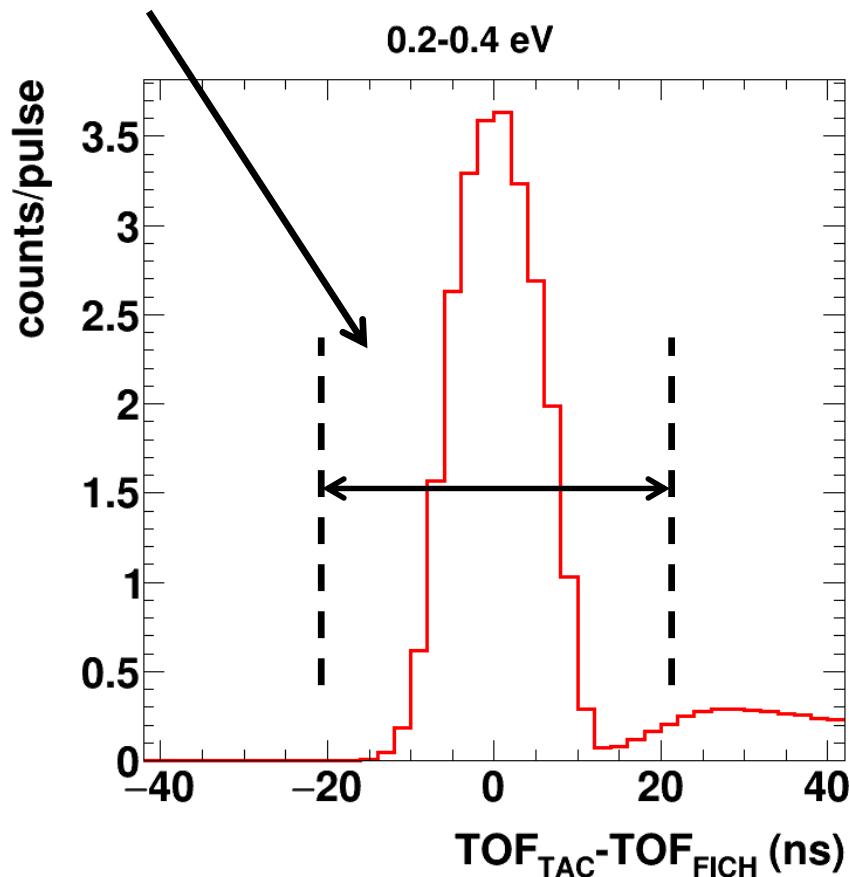
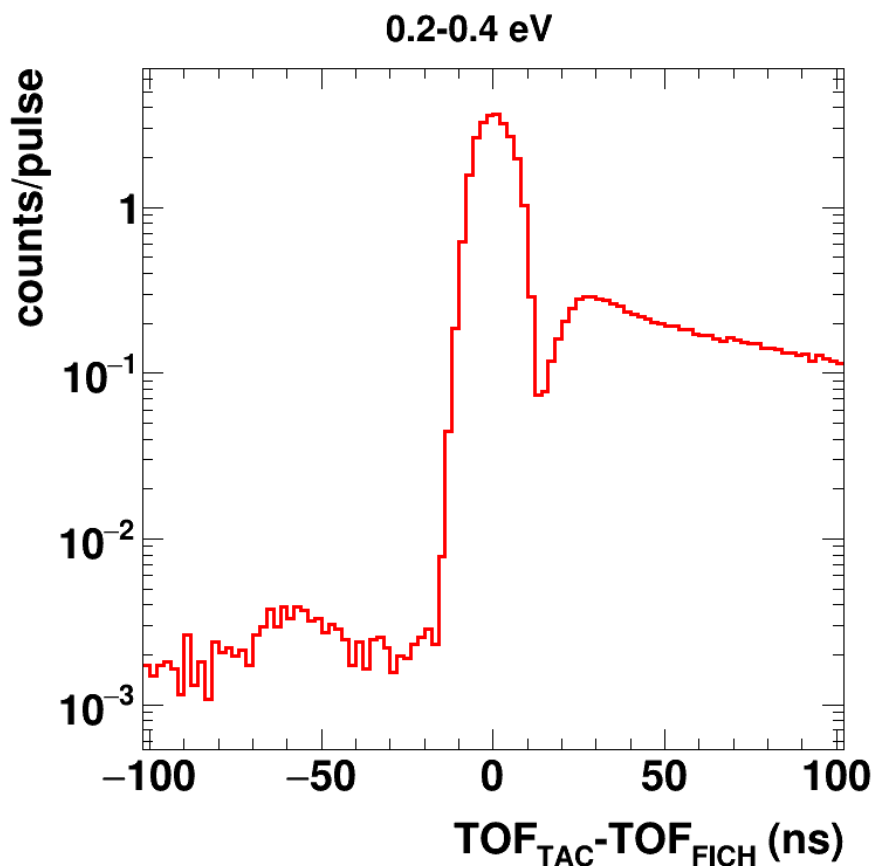
- Time coincidences between TAC events and fission chamber (FICH) signals in the energy region close to the 0.3 eV ^{239}Pu resonance.



Fission Chamber configuration

Preliminary results: TAC – FICH Time coincidences

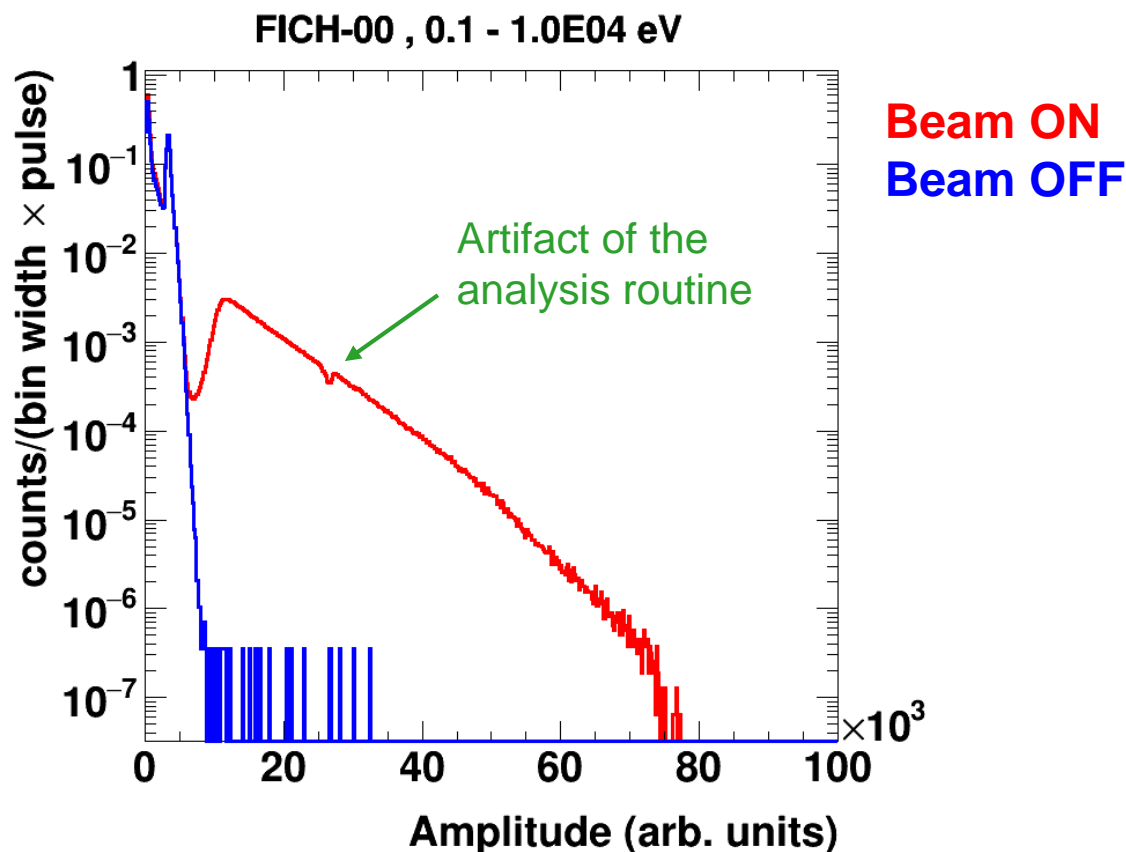
- Time coincidences between TAC events and fission chamber (FICH) signals in the energy region close to the 0.3 eV ^{239}Pu resonance.
- We have set a time a preliminary coincidence window of (-20,+20) ns.



Fission Chamber configuration

Preliminary results: Fission fragments identification

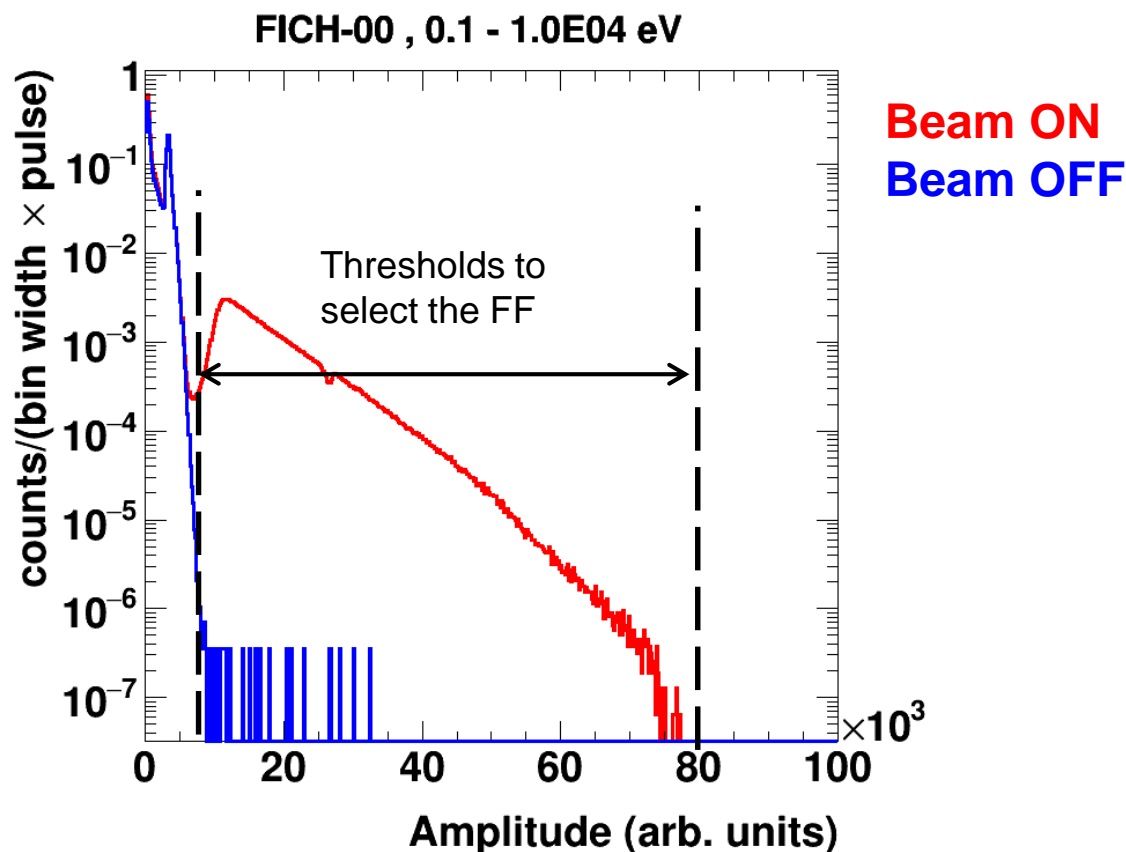
- Good separation in the amplitude signal spectrum between fission fragments (FFs) and alphas from the ^{239}Pu activity.



Fission Chamber configuration

Preliminary results: Fission fragments identification

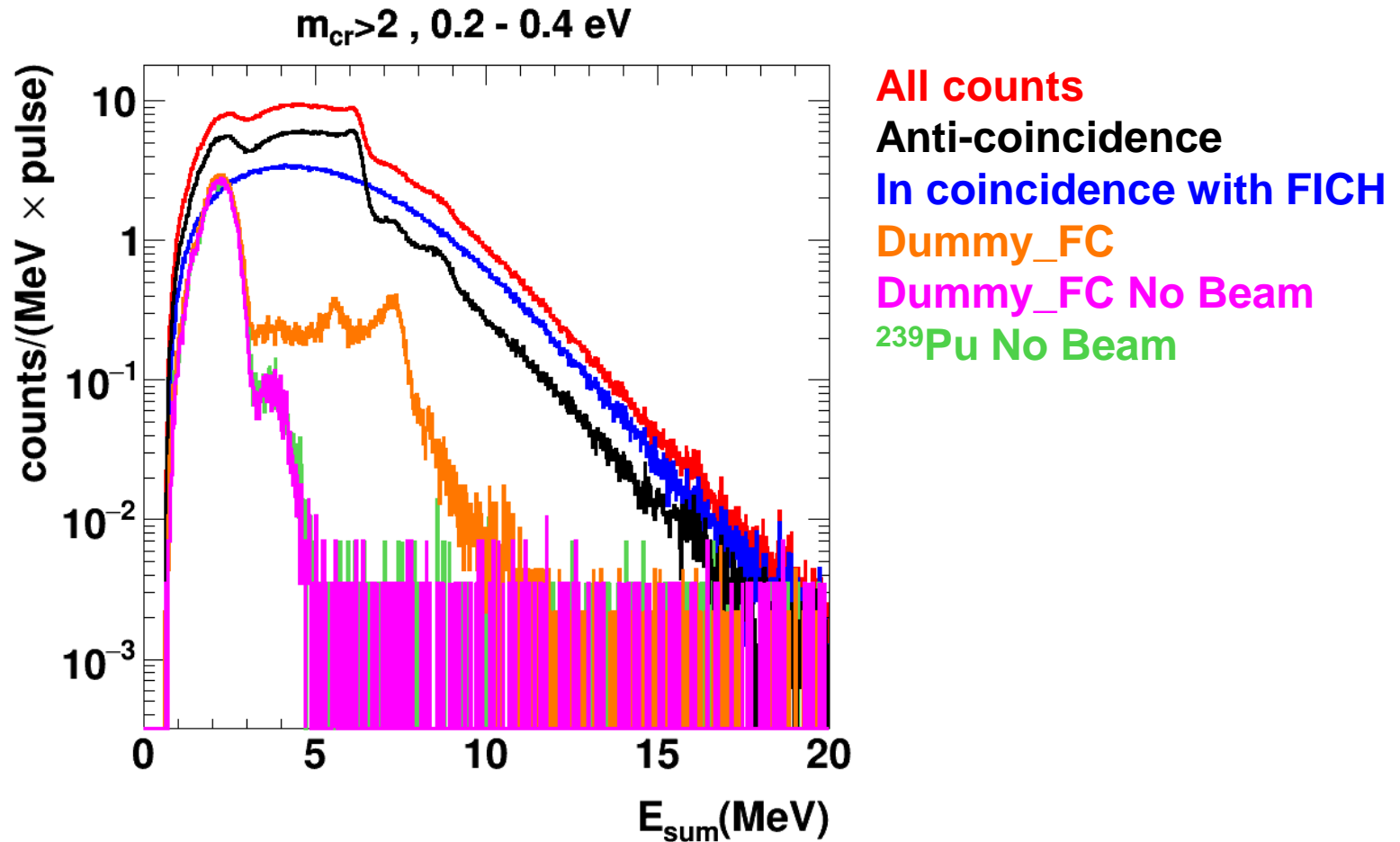
- Good separation in the amplitude signal spectrum between fission fragments (FFs) and alphas from the ^{239}Pu activity.



Fission Chamber configuration

Preliminary results: background contributions

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

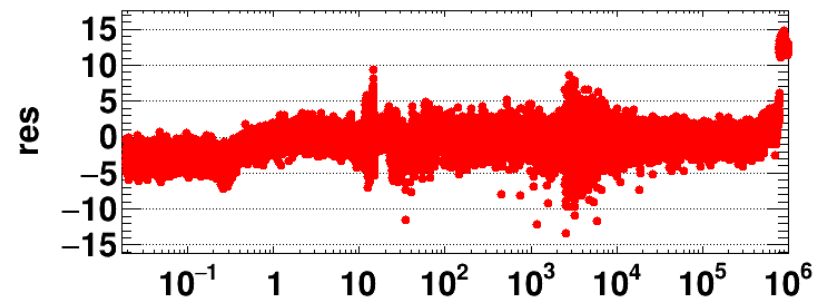
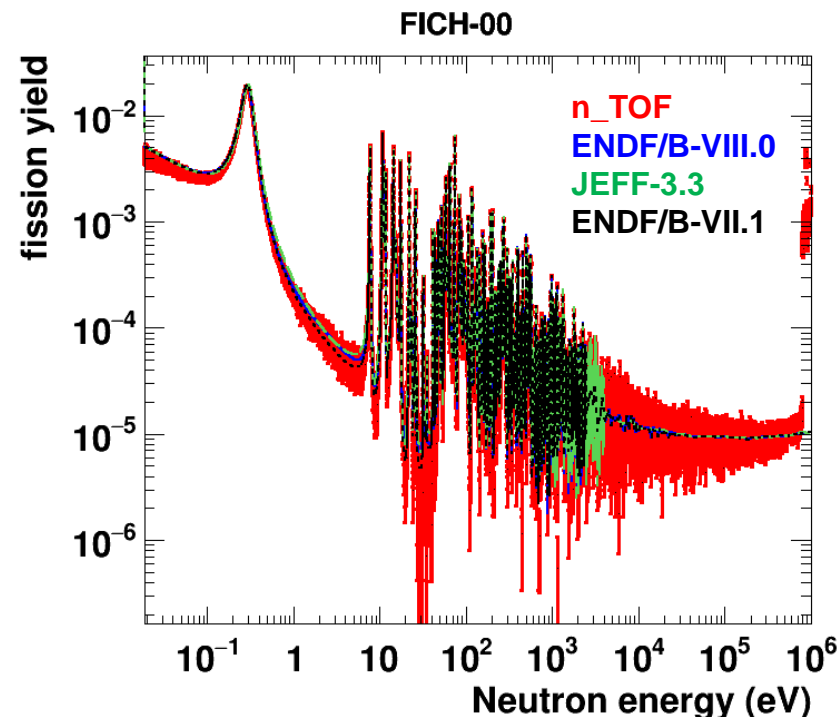


Fission Chamber configuration

Preliminary results: fission yield compared with evaluated libraries

- A **preliminary fission yield** obtained with the data from the Fission Chamber. For this, we used a **preliminary version of the neutron flux** and a **fission efficiency for the FC of 91%** (estimated from the data).
- Error bars show **only statistical errors**.
- In general, a better agreement with ENDF/B-VII.1 is observed.

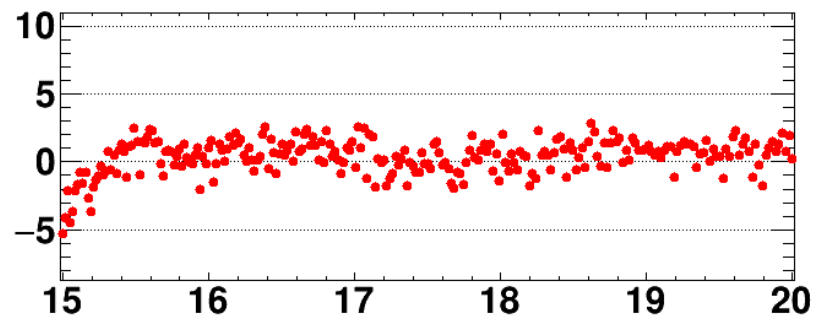
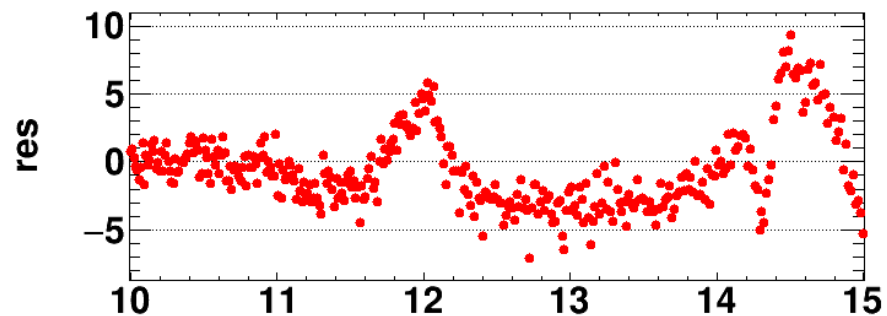
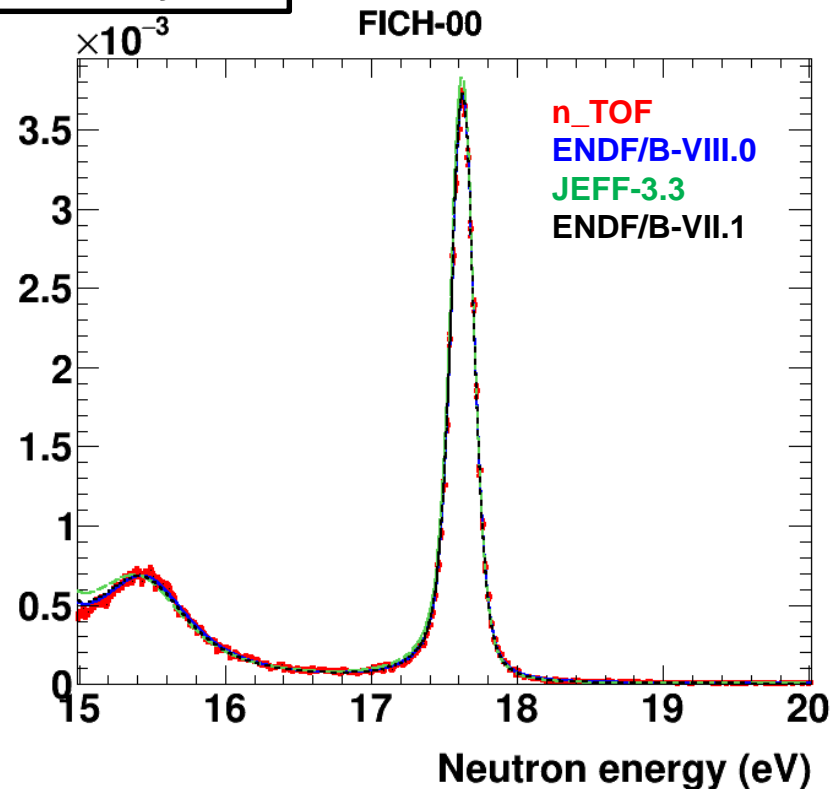
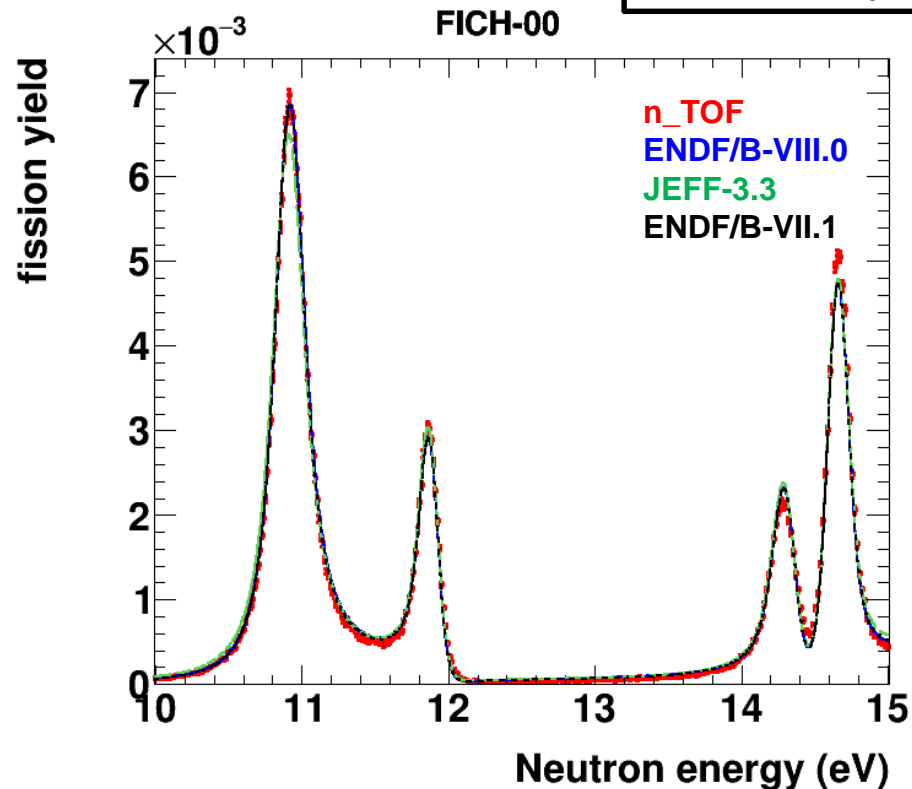
$$\text{res} = \frac{n_TOF - \text{ENDF/B-VII.1}}{\{n_TOF \text{ unc.}\}}$$



Fission Chamber configuration

Preliminary results: fission yield compared with evaluated libraries

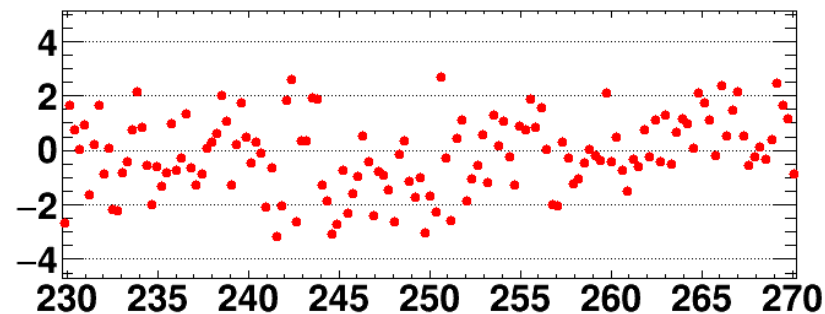
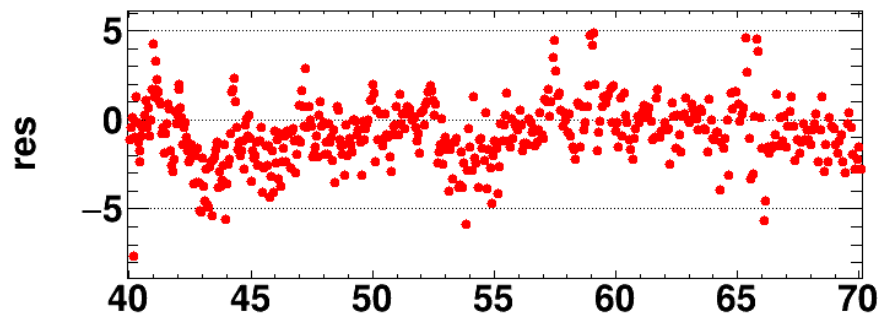
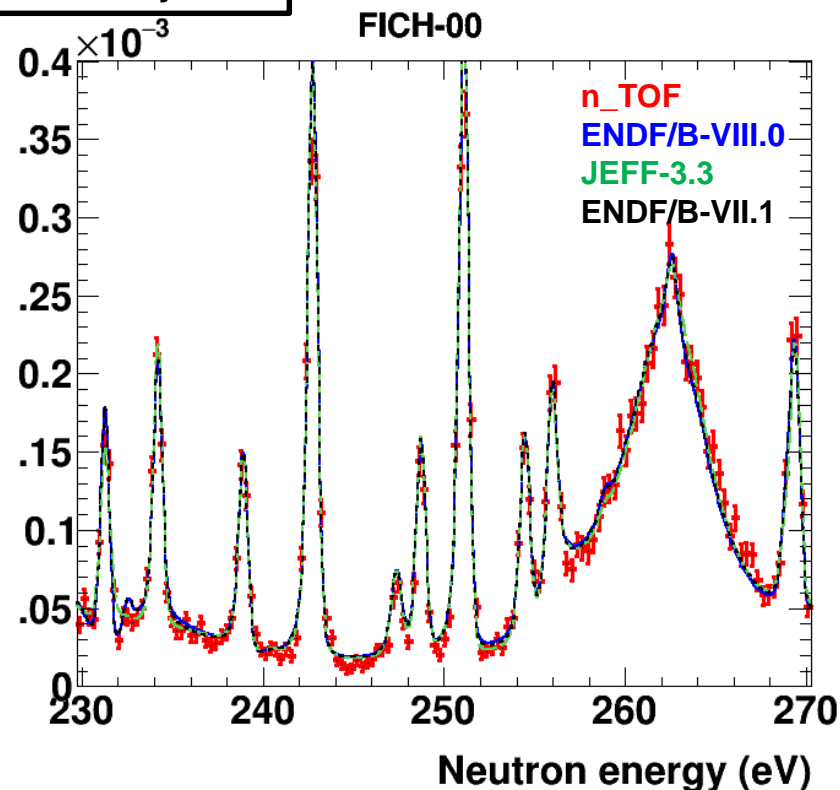
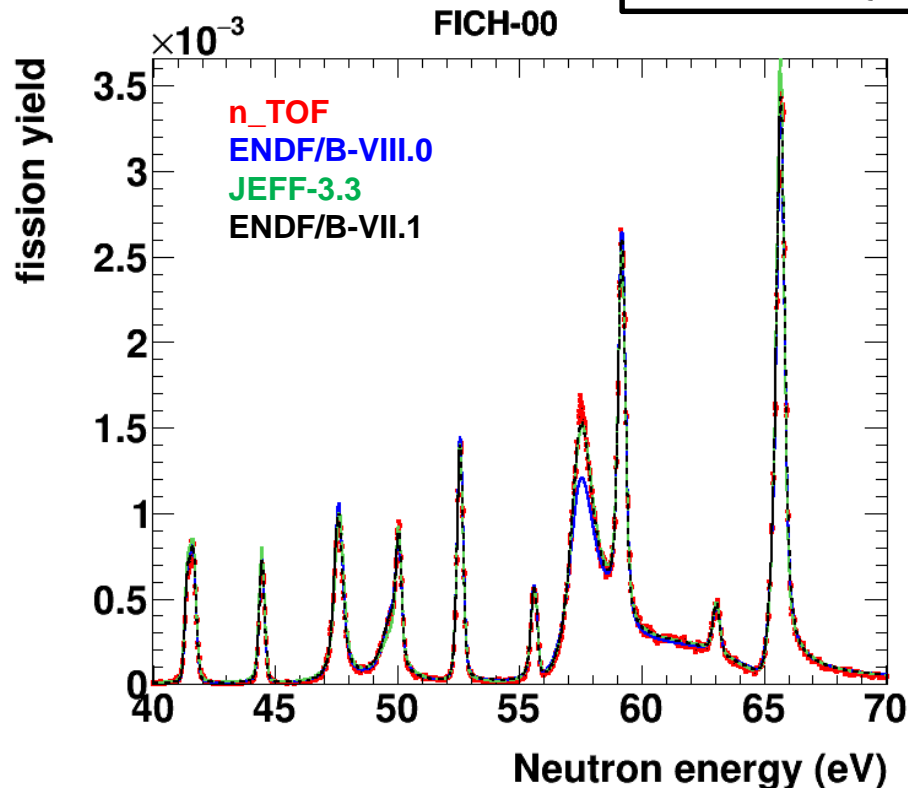
$$\text{res} = \frac{n_{\text{TOF}} - \text{ENDF/B-VII.1}}{\{n_{\text{TOF}} \text{ unc.}\}}$$



Fission Chamber configuration

Preliminary results: fission yield compared with evaluated libraries

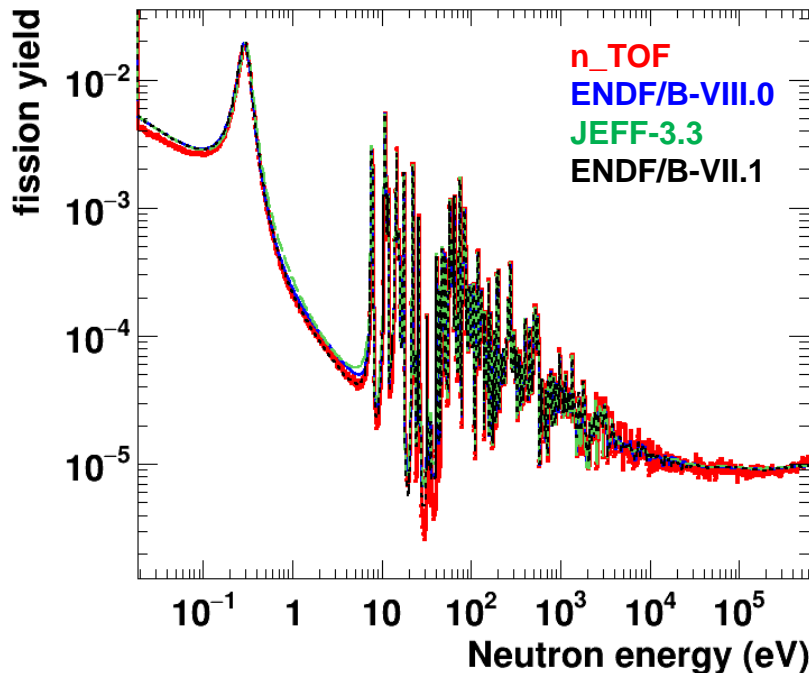
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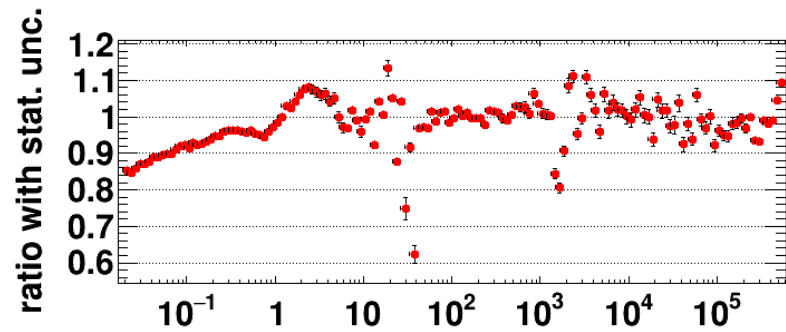
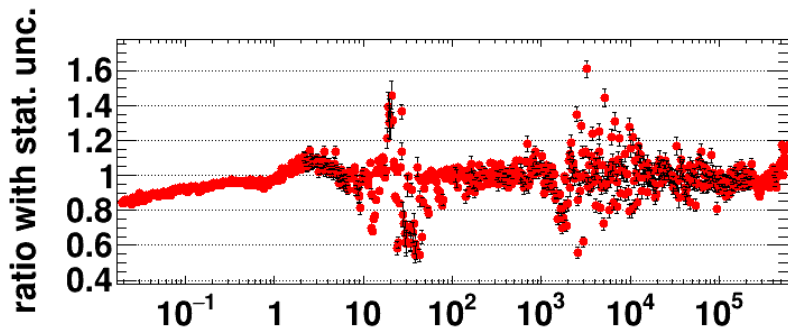
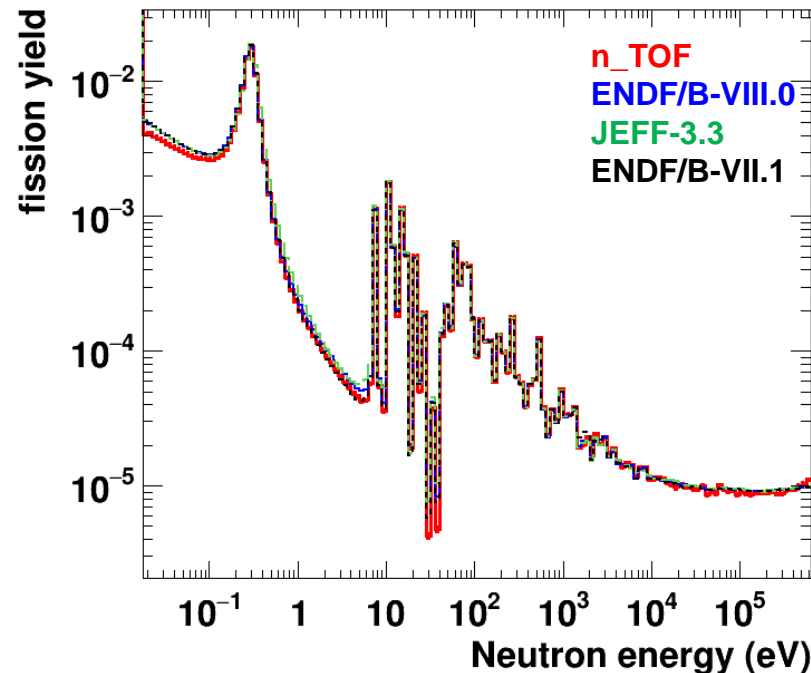
Fission Chamber configuration

Preliminary results: averaged fission yield

100 bins per decade



20 bins per decade

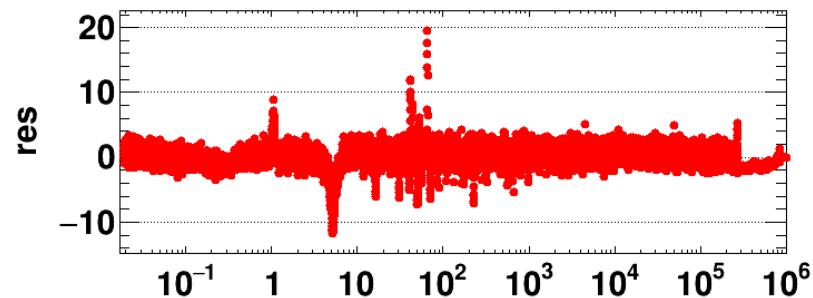
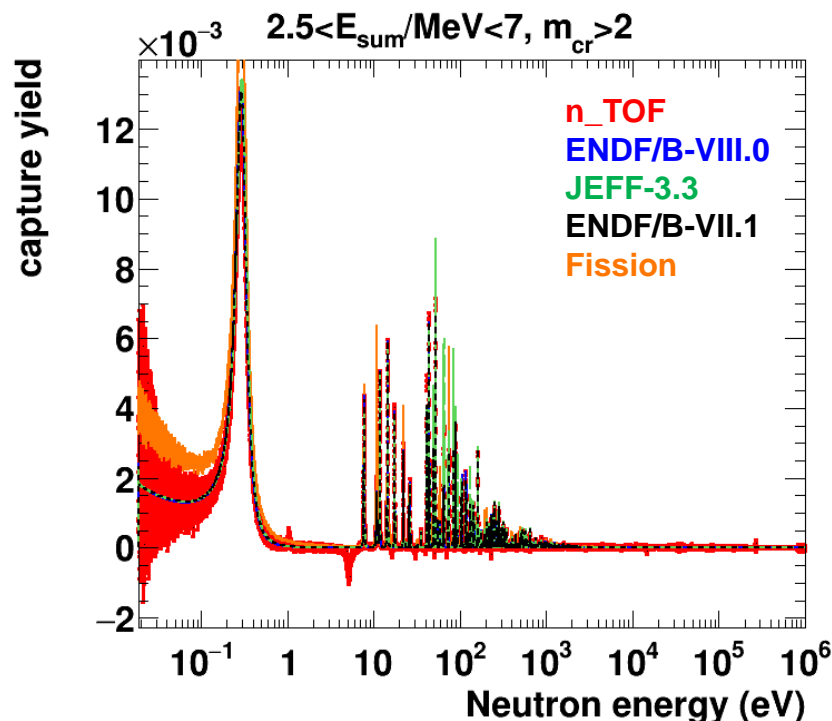


Fission Chamber configuration

Preliminary results: capture yield compared with evaluated libraries

- A **preliminary capture yield** obtained with the data from the TAC and the **fission tagging technique**. For this, the previous estimated 91% fission efficiency was used to subtract all the fission counts.
- Due to a higher **presence of a Ag-nat** contaminant in the dummy fission chamber, some *dips* values appear in the silver resonances (e.g. @ 5 eV).
- Error bars show **only statistical errors**.
- In general, a better agreement with ENDF/B-VII.1 is observed.

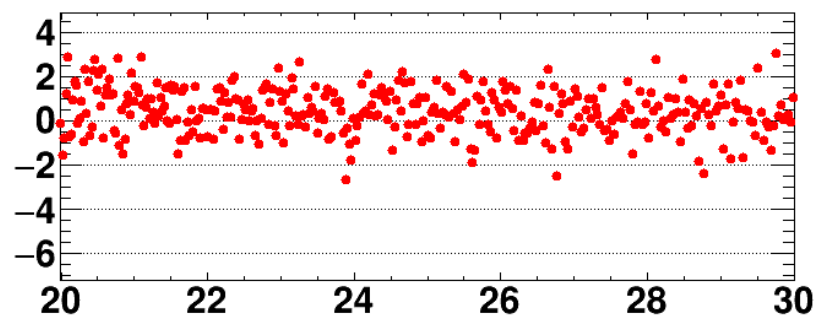
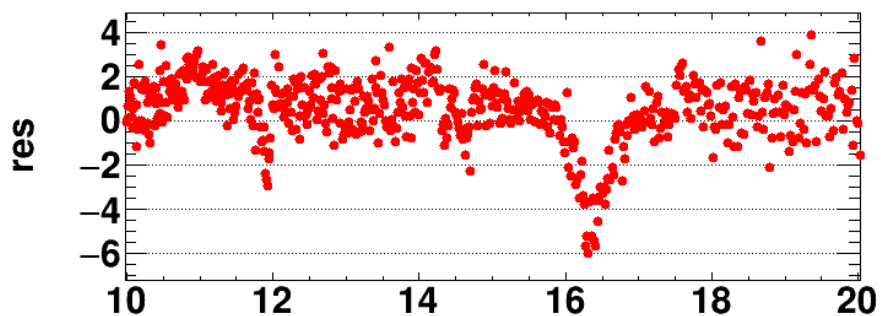
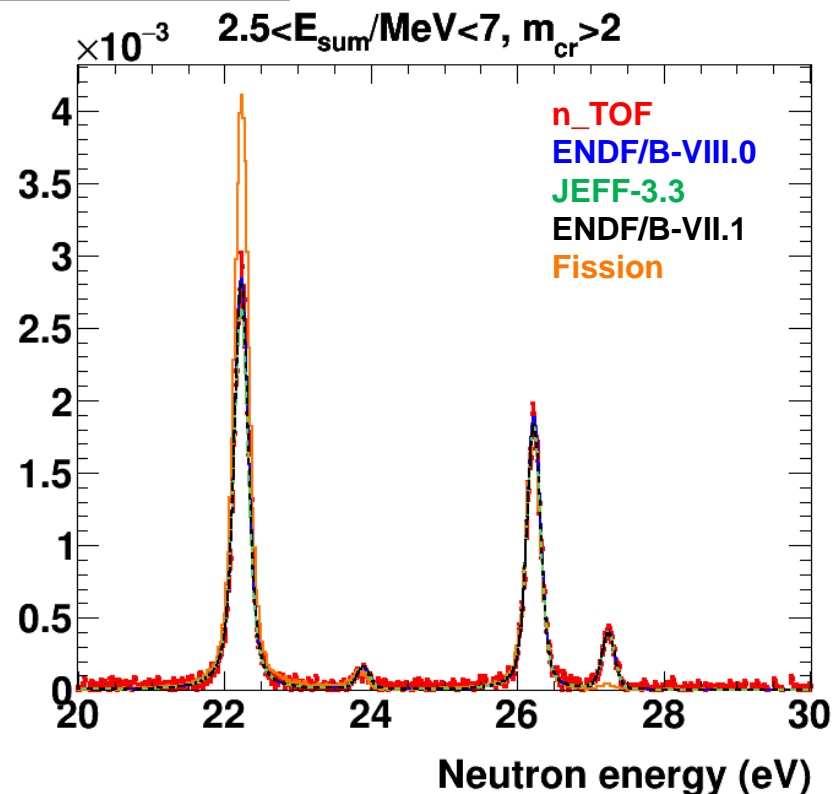
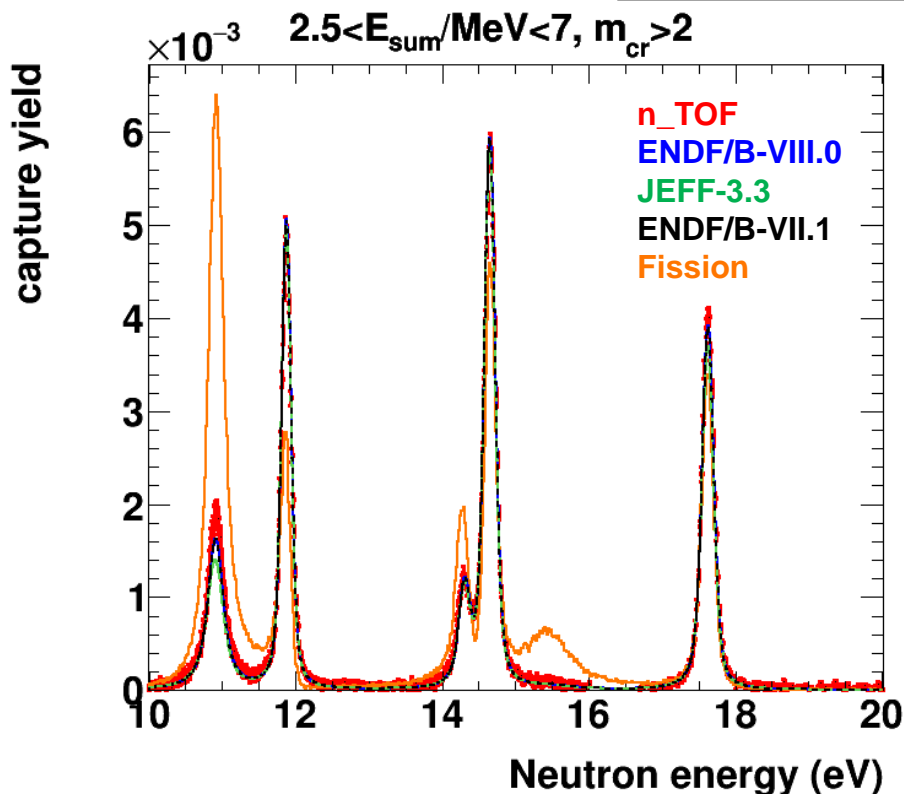
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Fission Chamber configuration

Preliminary results: capture yield compared with evaluated libraries

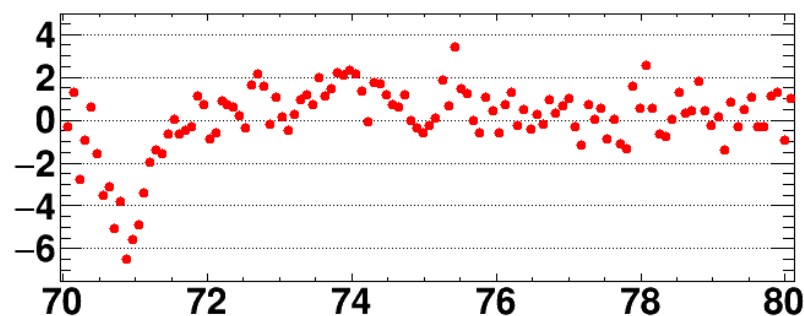
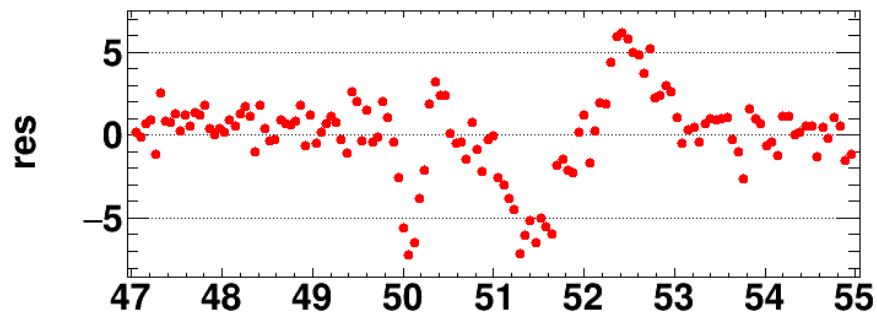
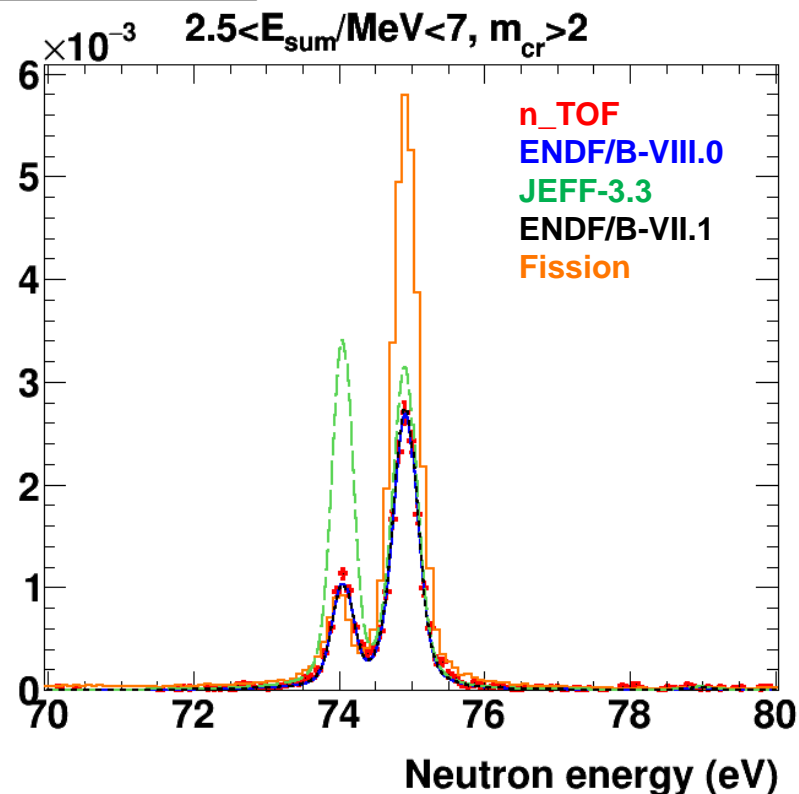
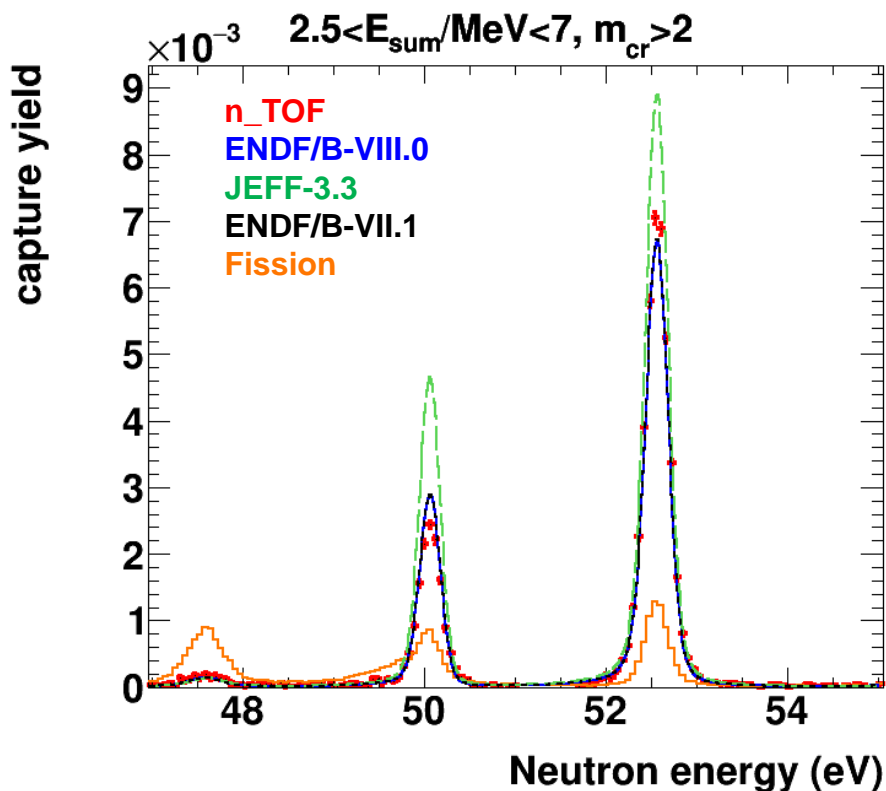
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Fission Chamber configuration

Preliminary results: capture yield compared with evaluated libraries

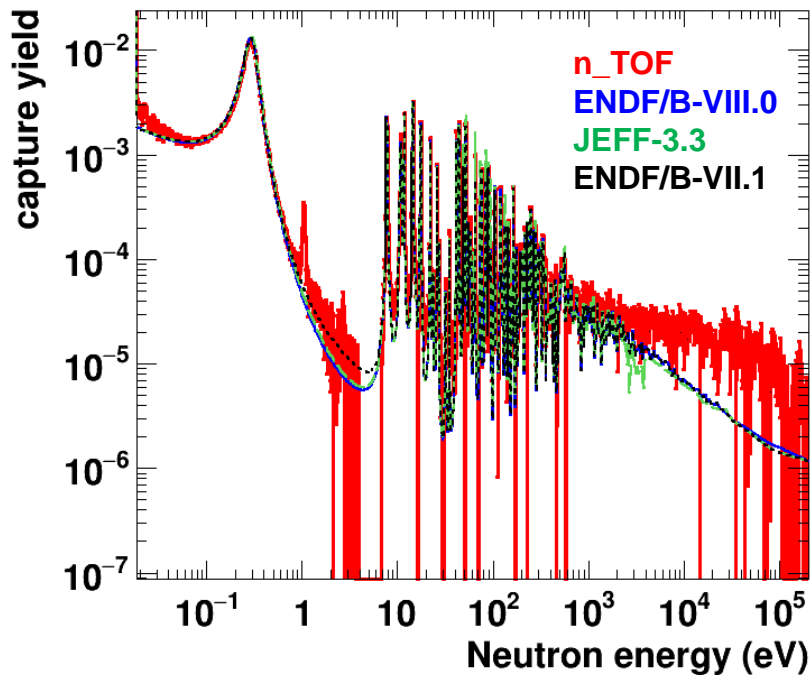
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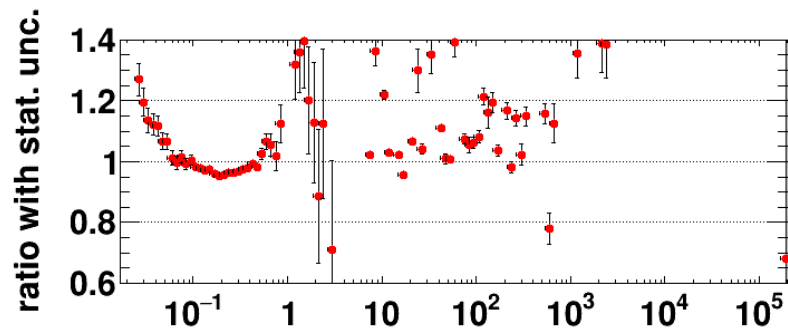
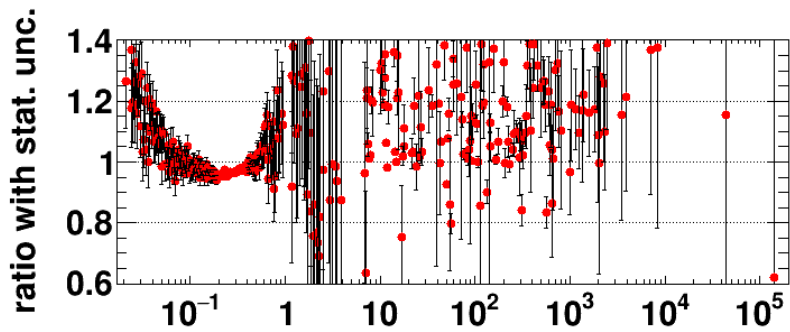
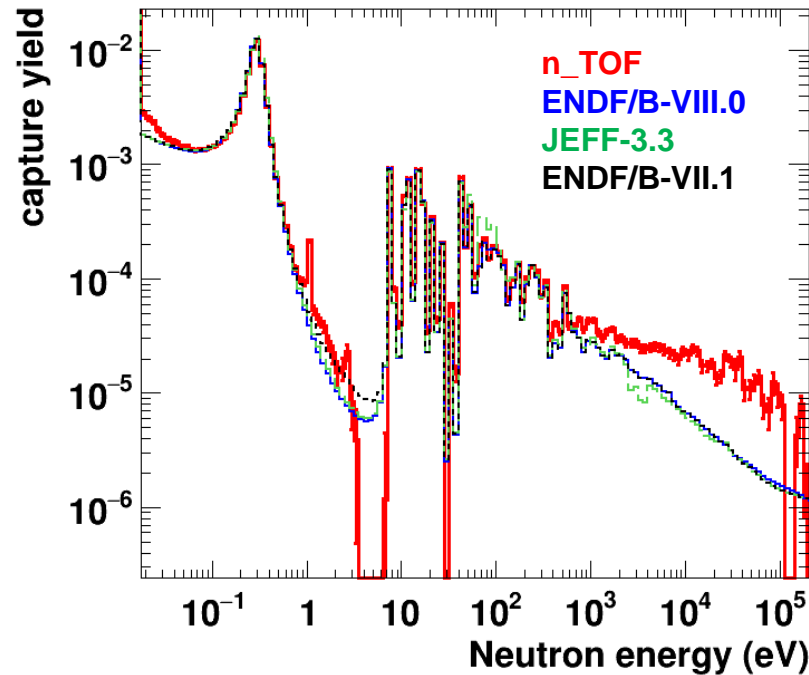
Fission Chamber configuration

Preliminary results: averaged capture yield

100 bins per decade



20 bins per decade



Thick Sample configuration

Thick Sample configuration

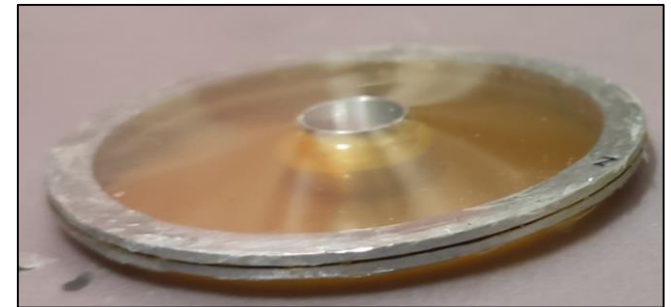
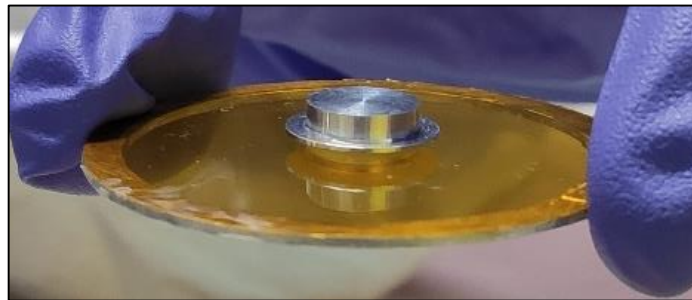
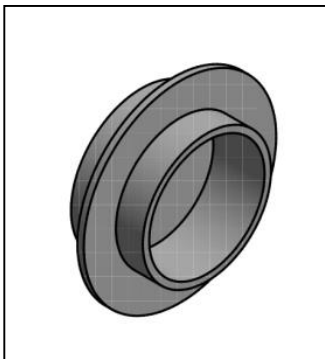
Experimental setup

Objectives

- To measure the ^{239}Pu (n, γ) cross section for **high neutron energies (above 1 keV)** using the higher mass of the thick sample (~100 mg).
 - **Challenges:** subtract the fission counts in the TAC without a tagging system, with much higher counting rate (pile-up), self-shielding effect, etc.

Mounting of the thick PuO_2 capsule

- The 100 mg PuO_2 sample is encapsulated in a glued aluminum capsule with *hat* structure, and is placed inside a **25 μm kapton foil** and between 2 aluminum rings with **mylar** foil.
- The dummy fission chamber was used as holder for the thick sample.

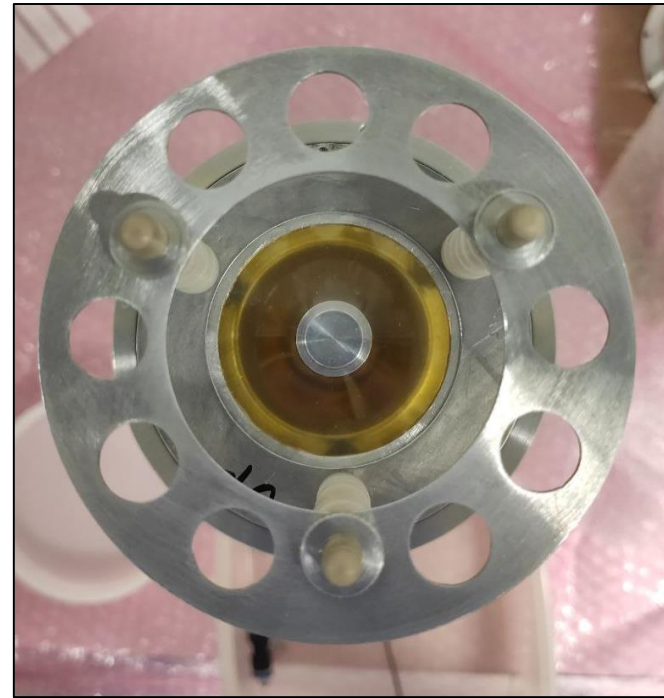


Thick Sample configuration

Experimental setup

Advantages of using the dummy fission chamber as a holder

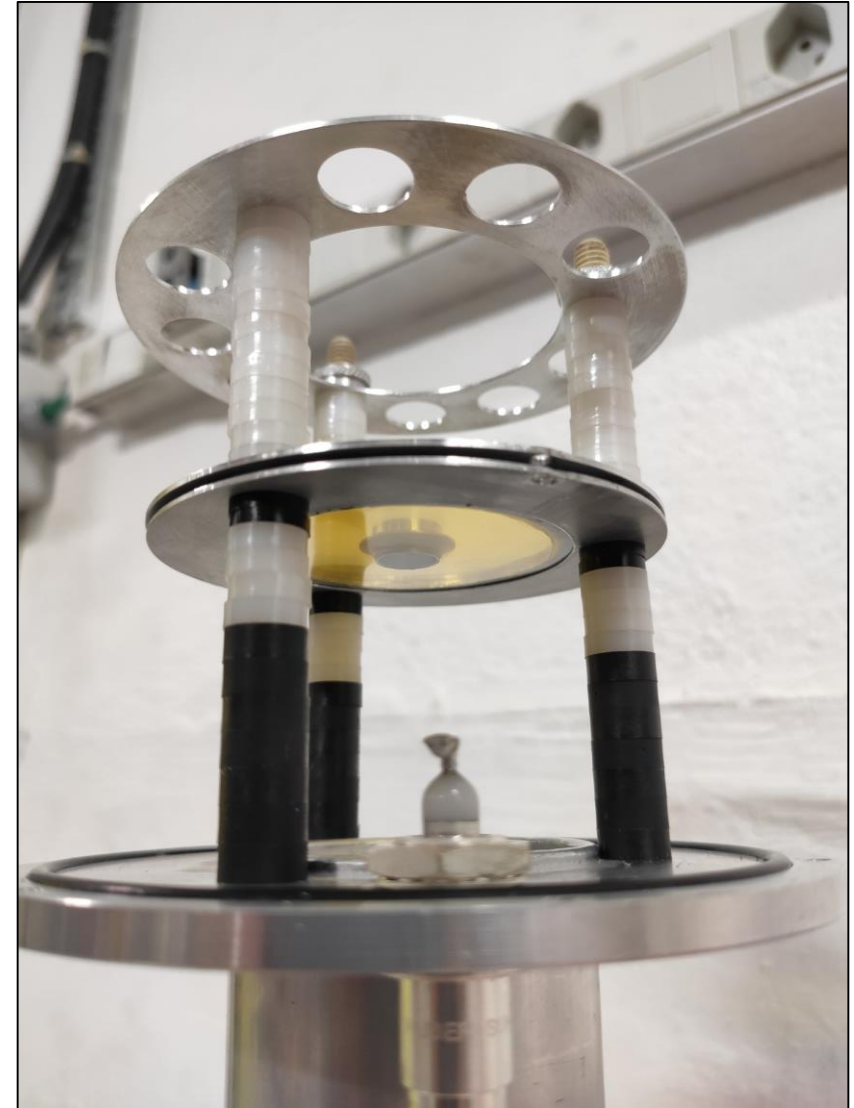
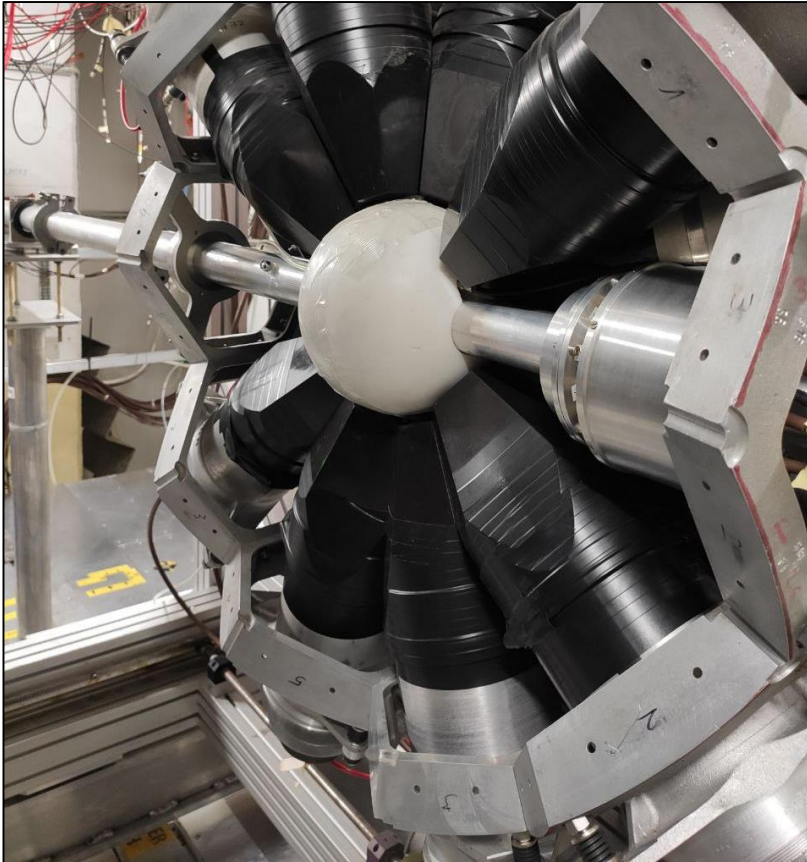
- **No new material** needed to be built, in order to fit inside the neutron absorber geometry.
- Geometry and **mounting** quite similar to the previous configuration.
- Using the validated good **alignment** of the fission chamber + TAC system.



Thick Sample configuration

Experimental setup

- All cables and dummy material removed.
- Air inside the chamber.

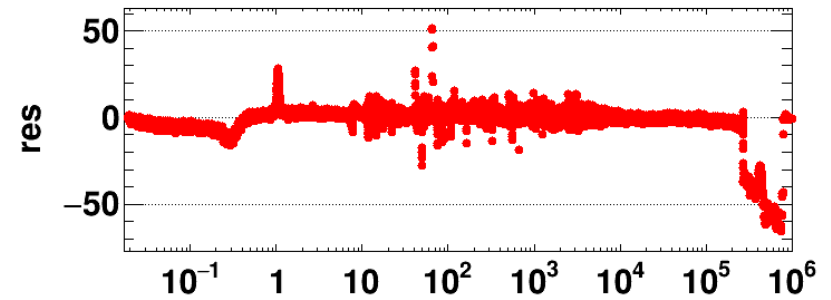
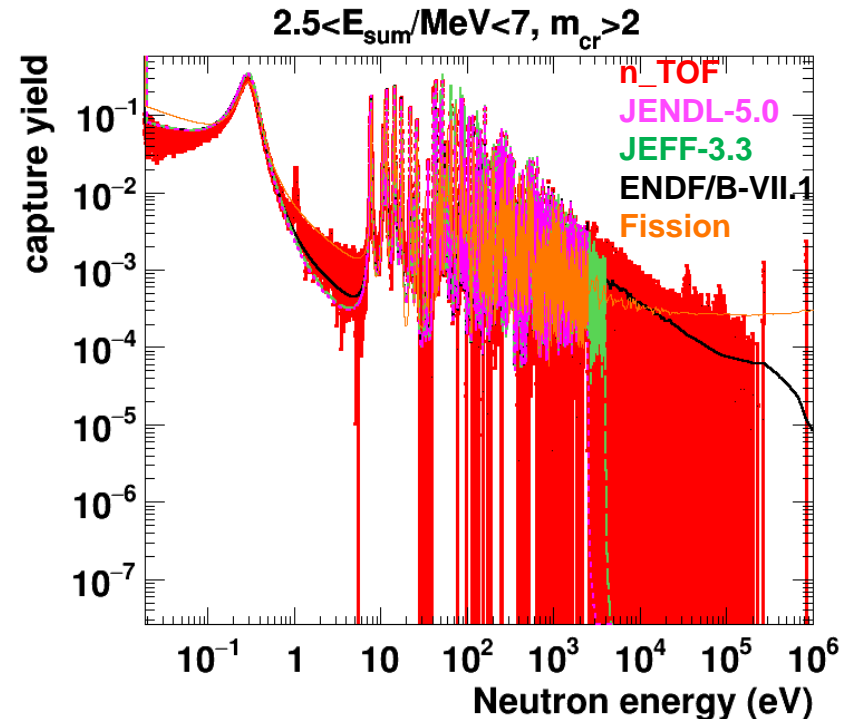


Thick Sample configuration

Preliminary results: capture yield compared with evaluated libraries

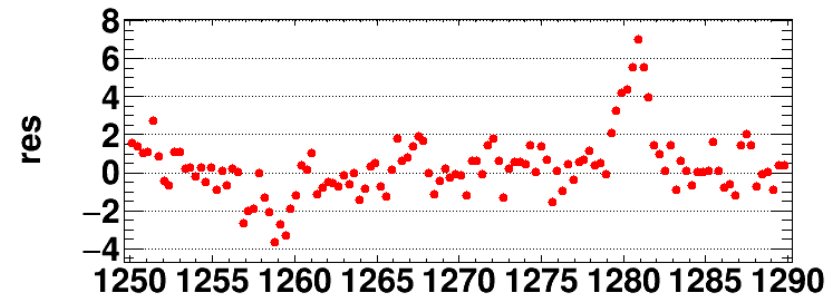
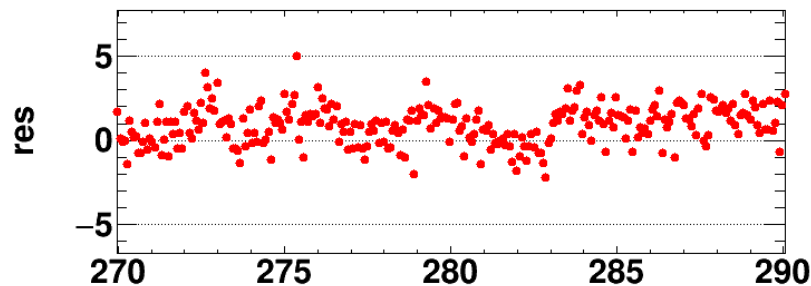
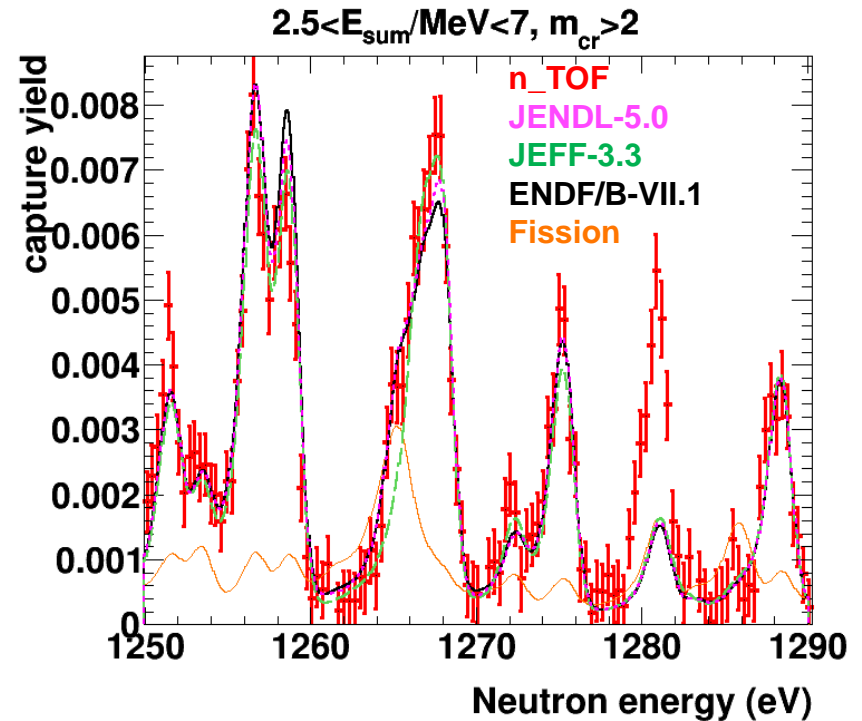
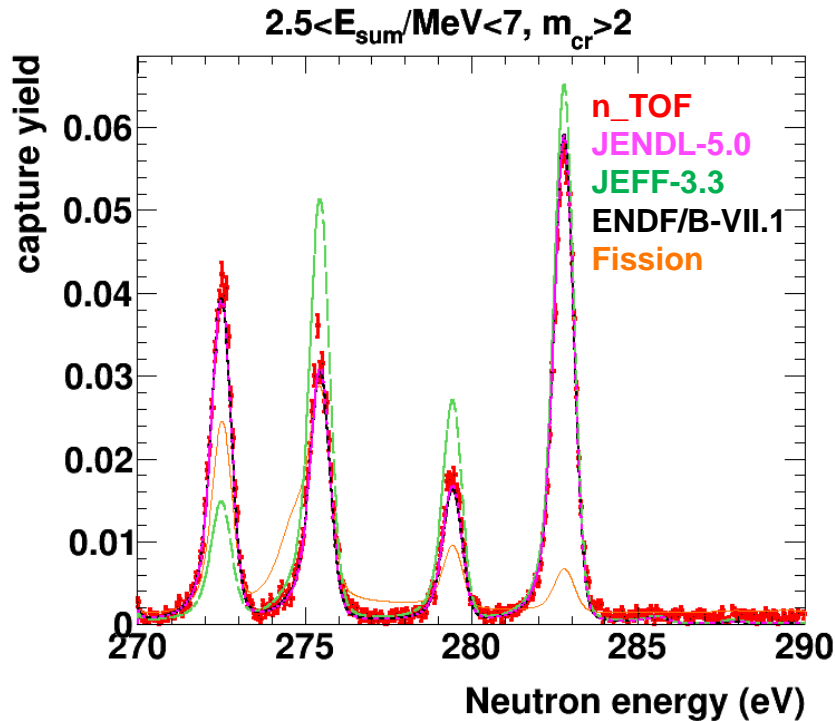
- A preliminary capture yield obtained with the data from the TAC.
- To **subtract the fission** counts we have taken an **evaluated fission yield** and assumed a constant TAC fission **efficiency of 54%**, taken from the measurement with the fission tagging technique.
- The capture efficiency has been adjusted by eye, to match the evaluated yield.

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



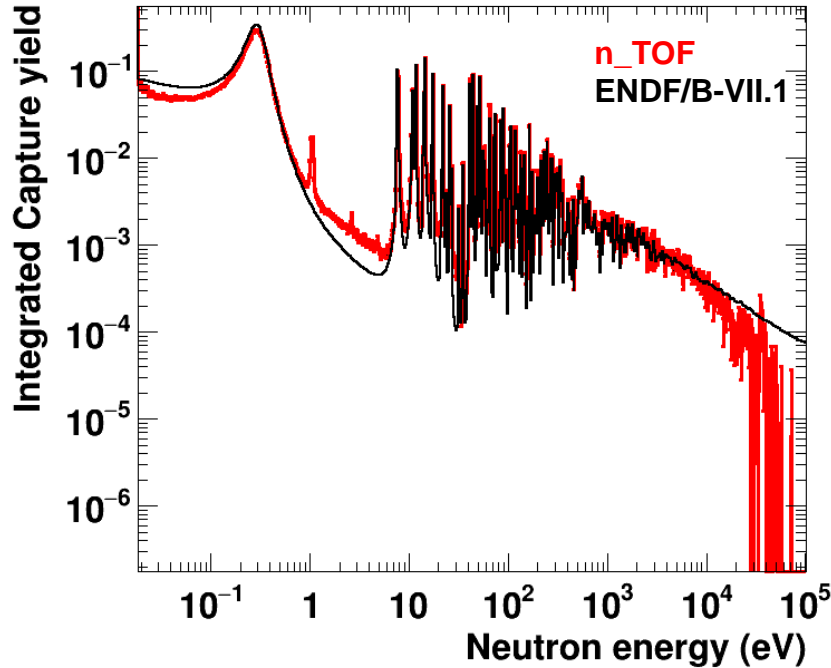
Thick Sample configuration

Preliminary results: capture yield compared with evaluated libraries

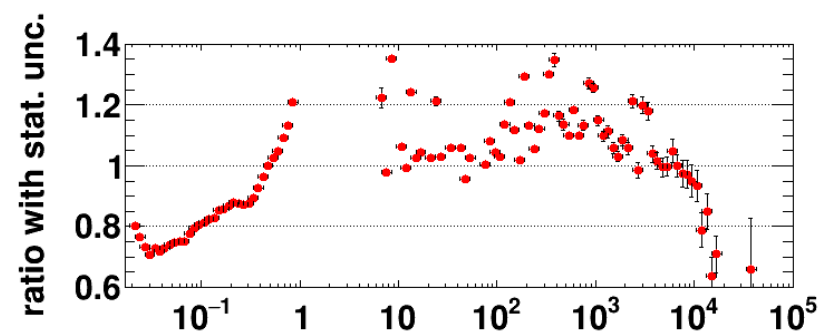
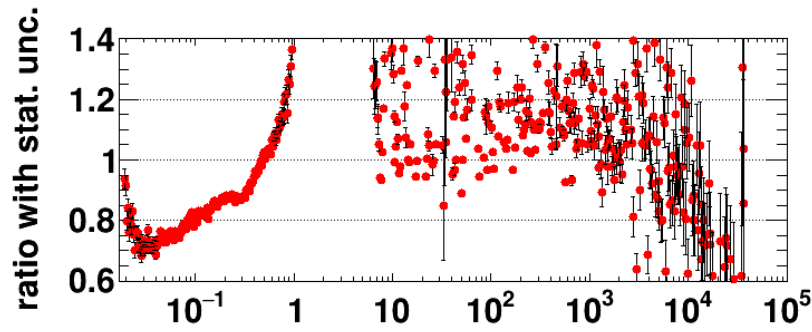
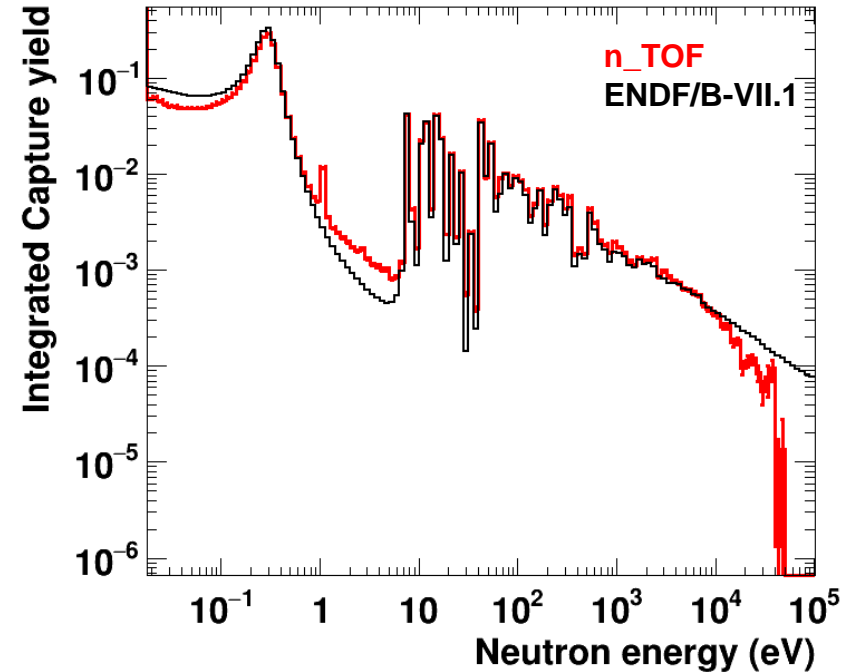


Thick Sample configuration

Preliminary results: averaged capture yield
100 bins per decade



20 bins per decade



Summary

- Despite some technical problems during the run (early beam stop, POPS, etc.), all the **planned statistics and different measurements** (main and auxiliaries) have been **successfully accomplished**.
- We are happy with the **performance of the new fission chamber** and the **good quality of the produced radioactive samples**.
- **Preliminary results** look good so far. The final data analysis (including dead time, pile-up corrections and so on) currently ongoing.

Acknowledgments

- **EURATOM** research and training program (**ARIEL**) funded the stay at CERN.

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- 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).



- **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!

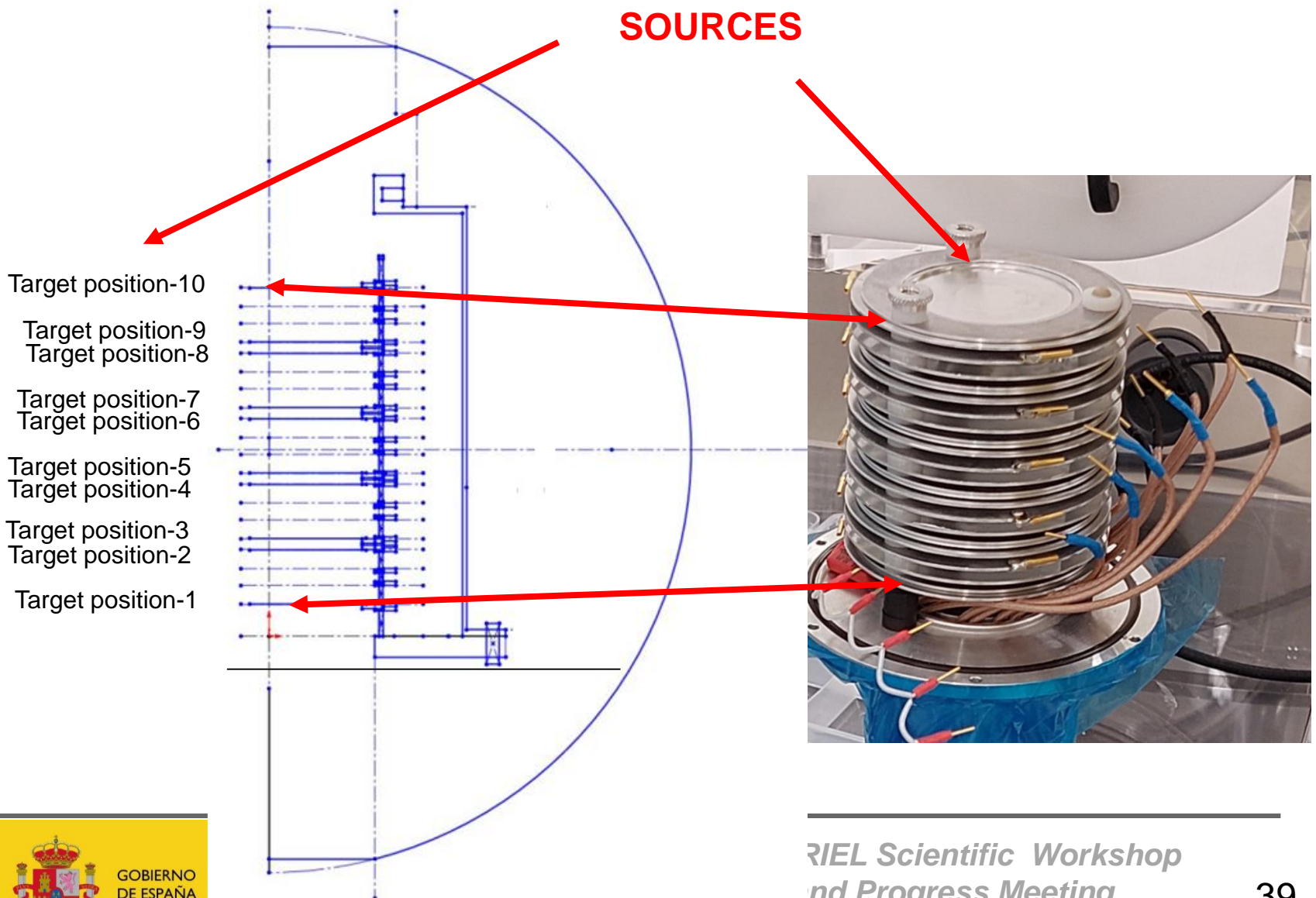
Extra slides

Targets description

Number of electronic output from preamplifiers	Target position in the FC chamber	Pu-239 samples			
		TP number	Activity [$\mu\text{g}/\text{cm}^2$]	Mass [μg]	Areal density [$\mu\text{g}/\text{cm}^2$]
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

**CLOSER TO NEUTRON
SOURCES**



Fission Chamber configuration

Preliminary results: background contributions

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

