Update on the status of the ^{239}Pu data analysis (part 2)

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1. **Fully characterization of background.**
2. **Dead time and pile-up corrections.**
3. **Determination of the neutron flux in the ^{239}Pu measurement.**

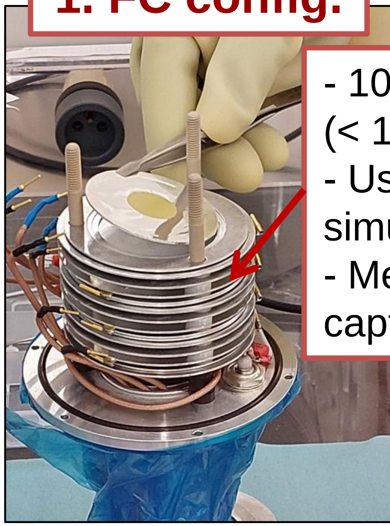
0

Previously on ^{239}Pu talks…

0.1 Quick reminder (1/2)

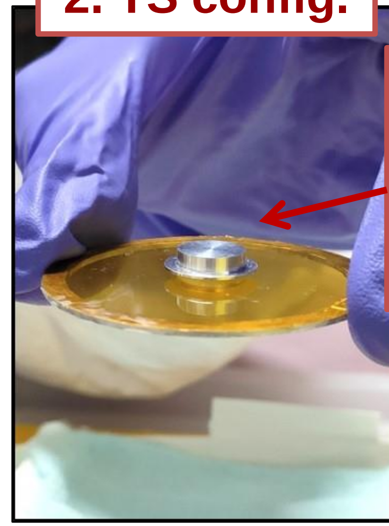
- Last year we **measured** the ^{239}**Pu(n,g)** and ^{239}**Pu(n,f) (α-ratio) cross-sections in EAR1**. The experiment consisted in **two different setups**: Fission Chamber configuration (thin samples) and Thick Sample configuration.

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.

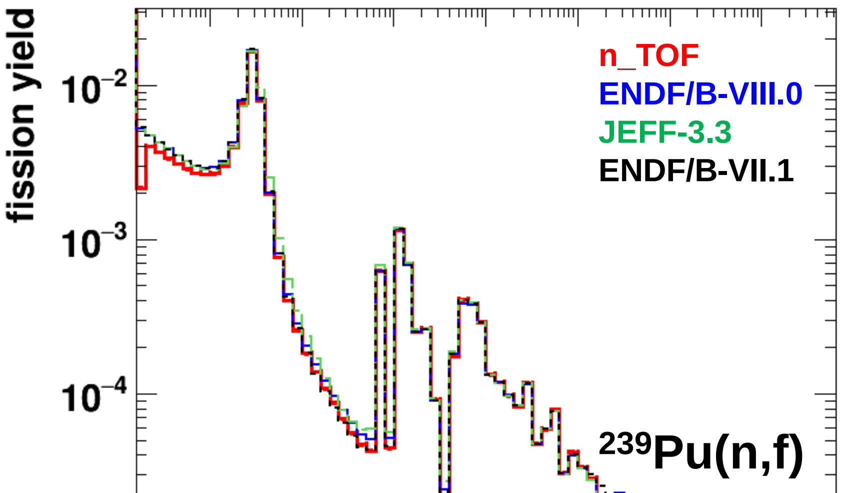
- **Re-processed** of the entire exp. dataset with a refined version of the new Pulse Shape Analysis routine was performed at the beginning of 2023 (see ^{239}Pu presentation in n_TOF Collab. meeting in May2023). Some improvements in the preliminary results.

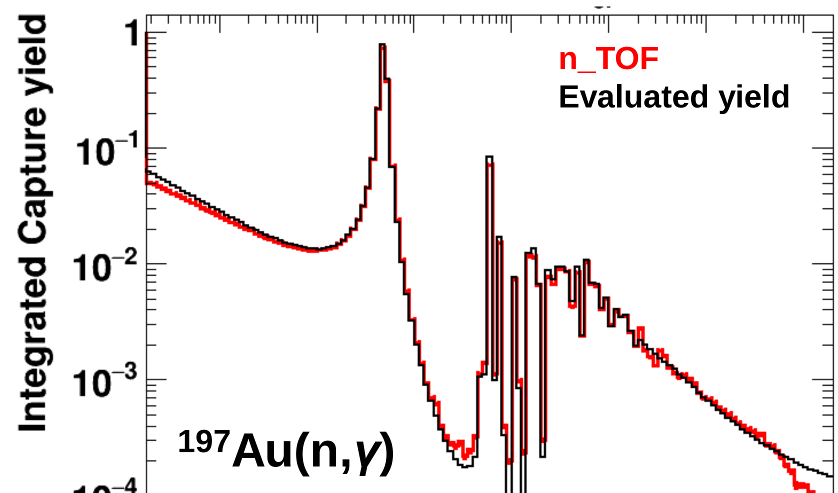
- **BaF_2 time and energy calibrations** were performed, and validated with Monte Carlo simulations.

- Pileup/Dead-time analysis started.

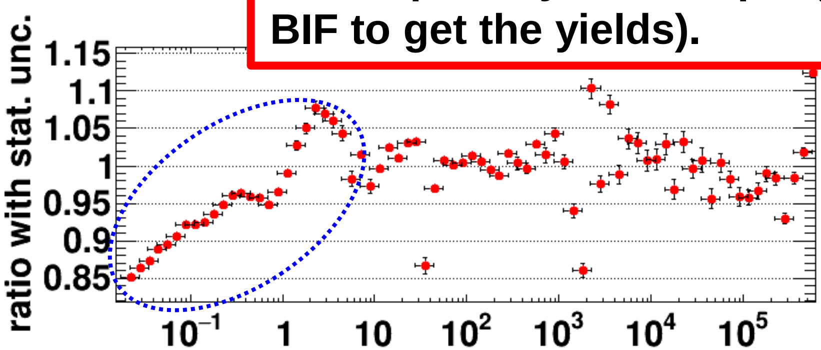
0.1 Quick reminder (2/2)

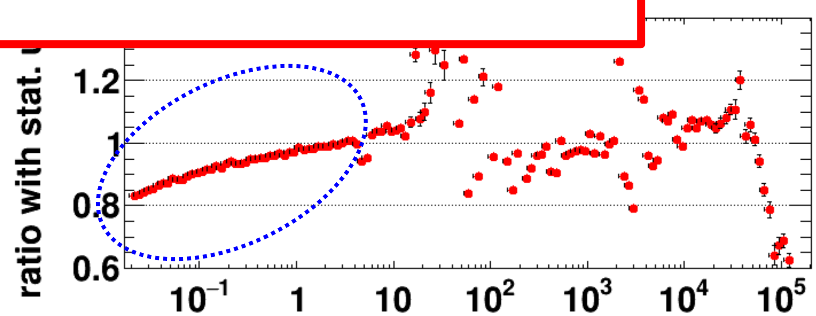
20 bins per decade





Below 1 eV the obtained yields (^{197}Au(n,g), ^{239}Pu(n,g) and ^{239}Pu(n,f)) deviates from the evaluations.
We attribute this effect to changes in the fraction of neutrons intercepted by the sample (BIF) below 1 eV (we used a constant BIF to get the yields).



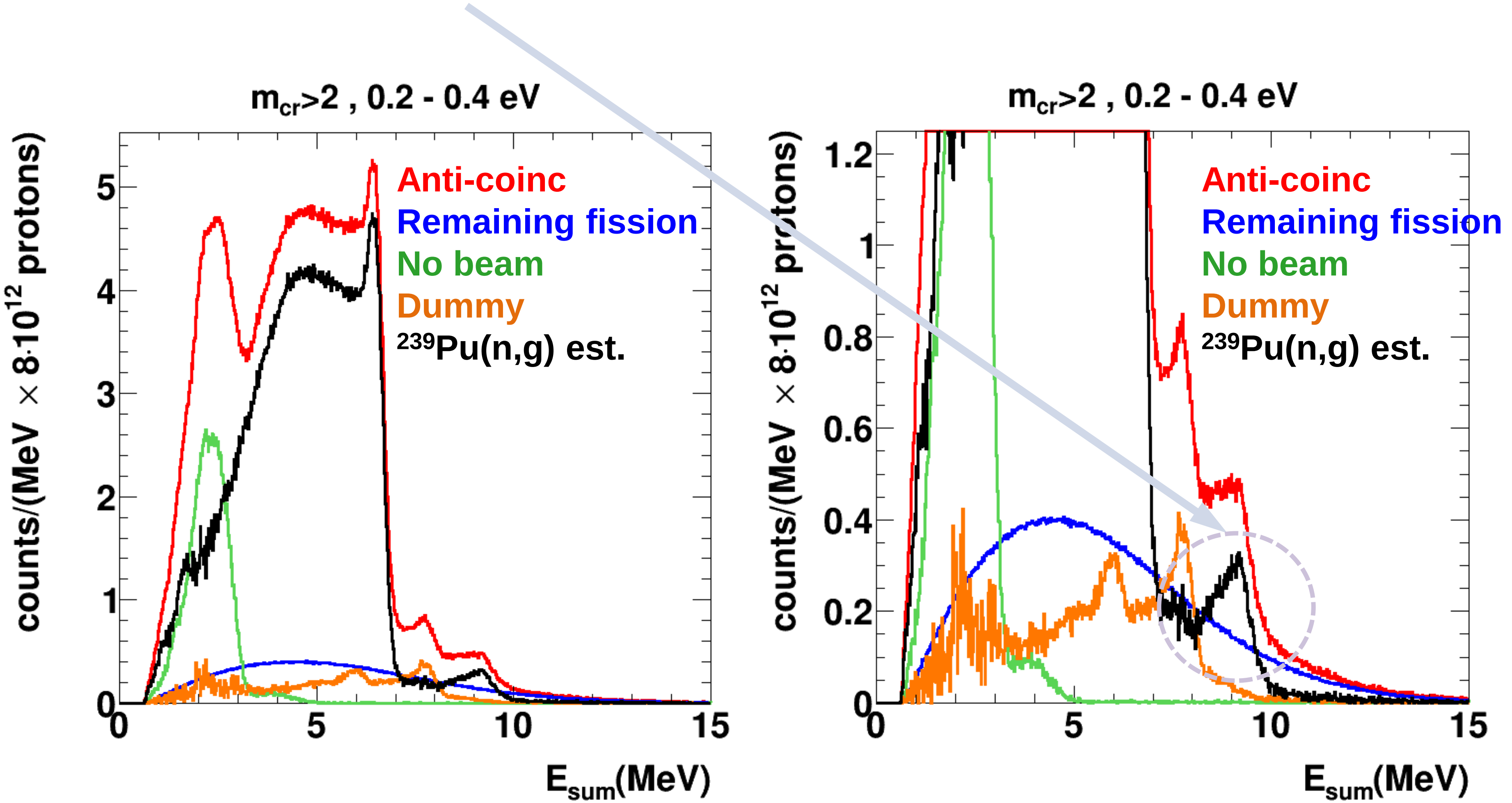


1

Fully characterization of background

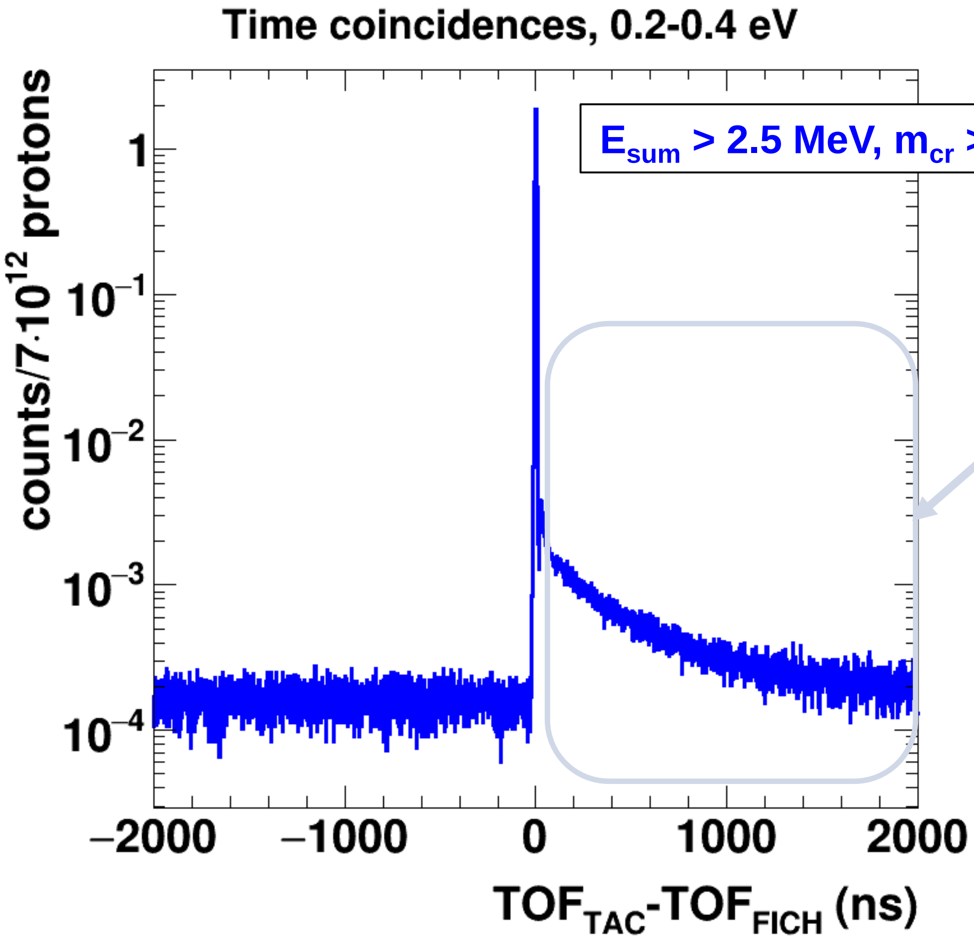
1.1 Previous situation

Previously, the subtraction of the known background contributions in the sum energy spectra of the TAC indicated the presence of some background that was not taken into account in the form of **a peak around 9 MeV**.



1.2 The *Post-Fission* Background

As observed in the coincidences between TAC and FICH, the fission gamma-ray cascades (peak around dT=0 ns) are follow by an exponential tail of events in the TAC, that may include fission neutrons, decay of fission products, etc.

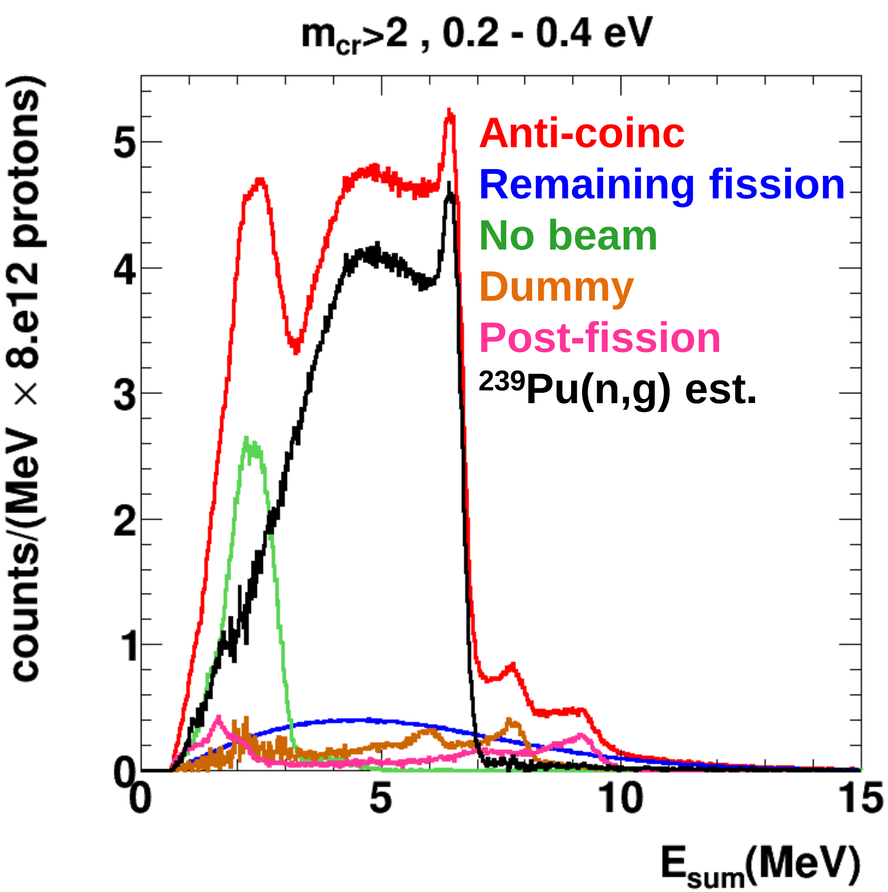


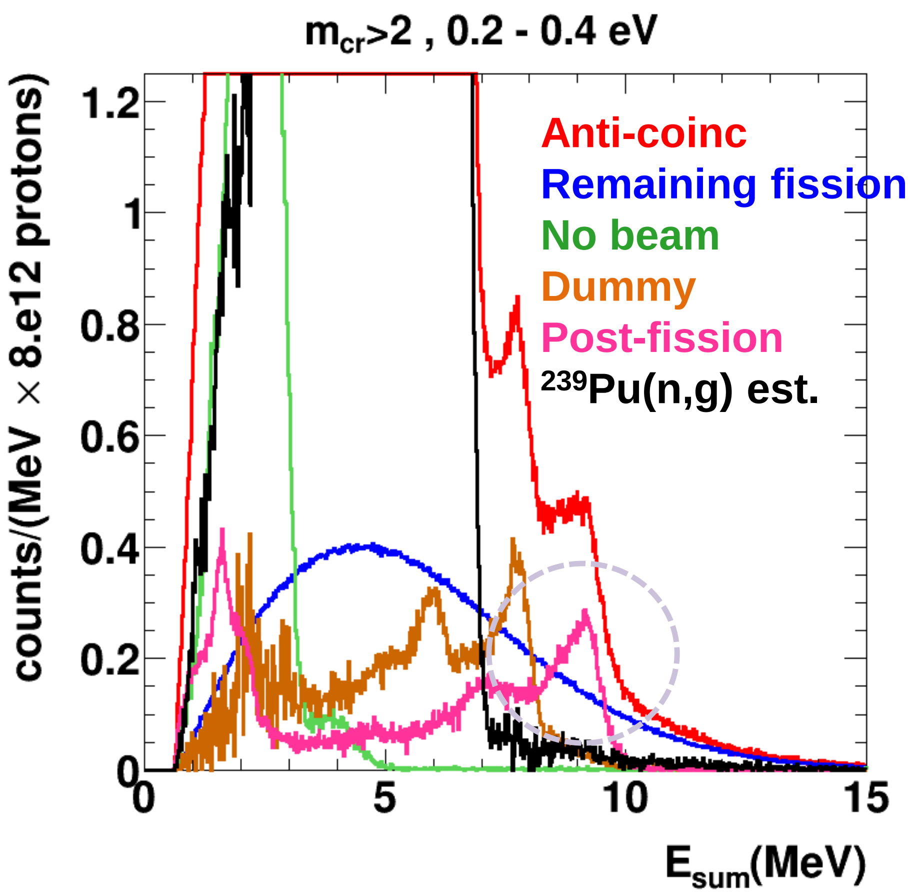
These extra counts with an exponential shape observed after a fission were not taken into account in the preliminary analysis.

1.2 The *Post-Fission* Background

By taking the TAC counts in the region of the exponential tail of previous slide, we can obtain the **deposited energy spectrum** of this post-fission counts.

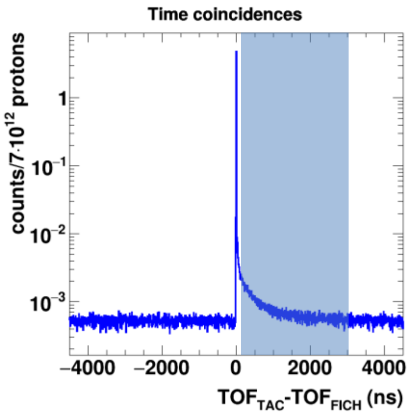
The subtraction of this background should have a small effect in the capture yield inside the usual analysis conditions (2.5 < E_{sum}/MeV < 7).

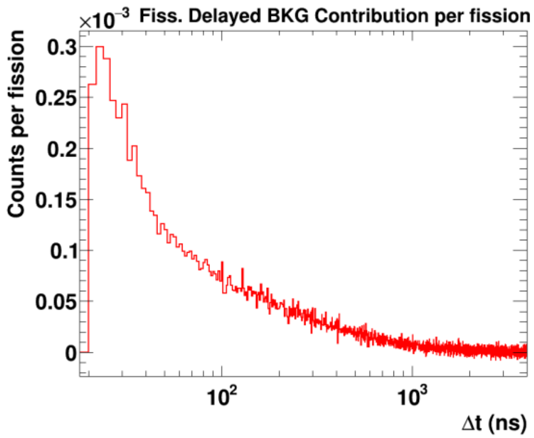


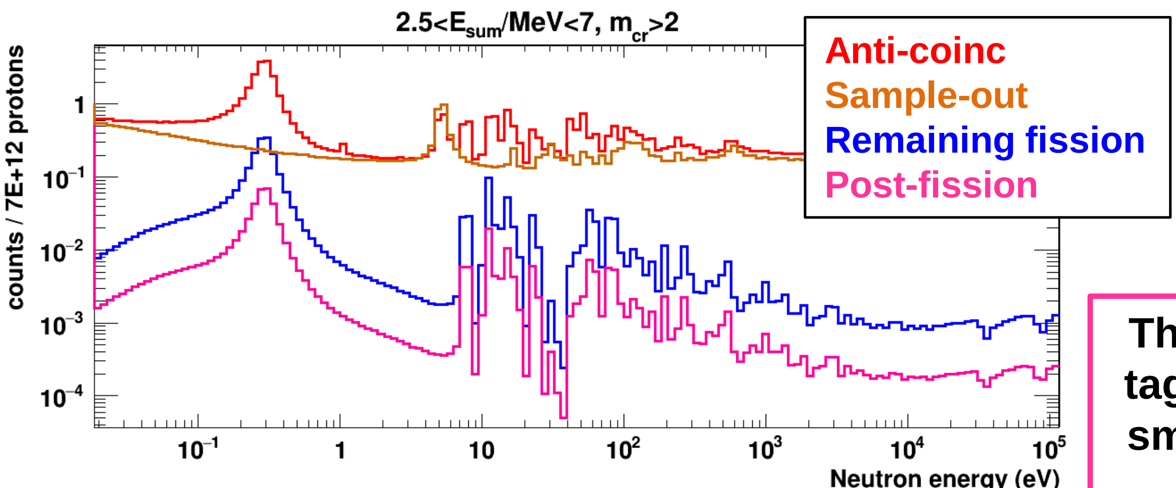


1.3 The *Post-Fission* Background in the En spectrum

To obtain this background contribution in terms of time-of-flight or neutron energy, we use the TAC-FICH Time Coincidences spectrum to obtain the **post-fission counts per fission unit**, and then **combine** this **with the tagged fission** E_n spectrum.





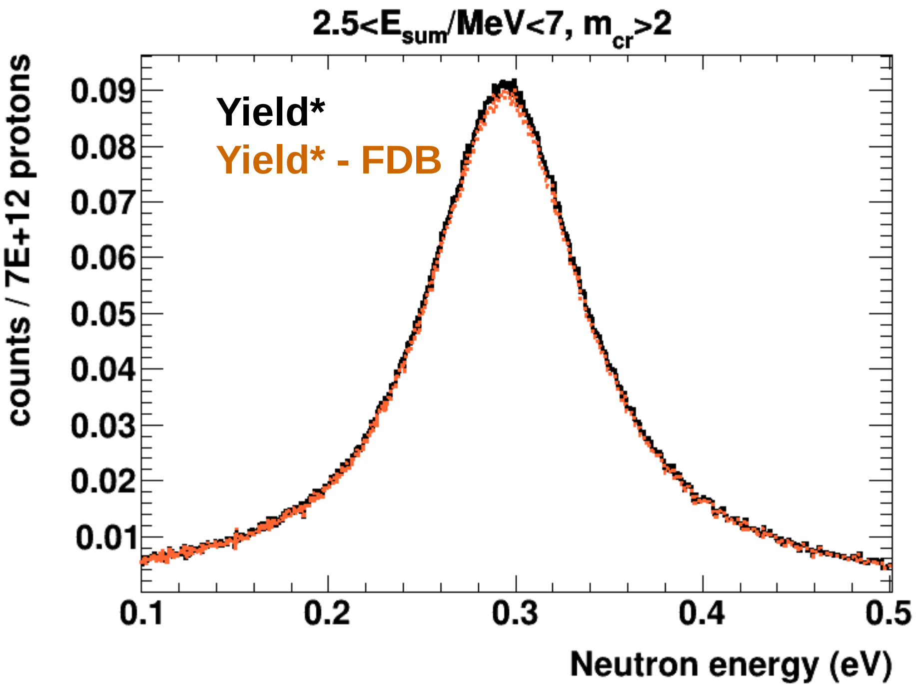


The PFB is practically a scaled tagged-fission, with a relatively small effect in the final capture yield.

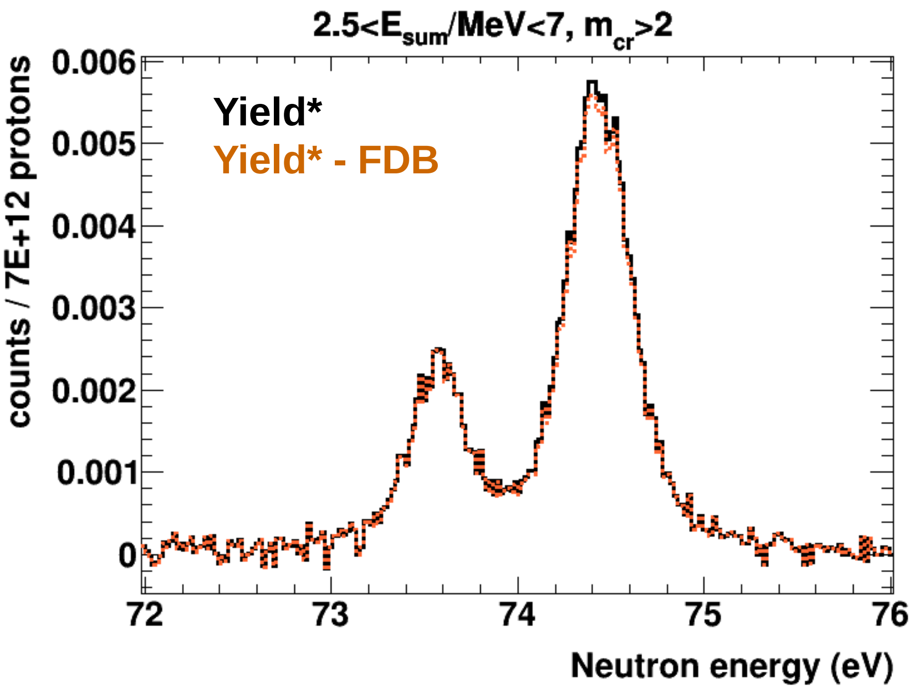
1.4 The *PFB.* Effect in the final capture yield.

Comparing the yield* (before dividing by neutron flux) with and without the post-fission background for the TAC event conditions of the analysis. In general the effect is small, reaching up to ~3% change in some resonances.

In the thermal resonance, the effect of subtracting this background is of 2.2%



Here, about a 2.7%



2

Dead Time / Pile-Up corrections

2.1 Dead Time due to Time-of-flight

Pile-up corrections in the TAC

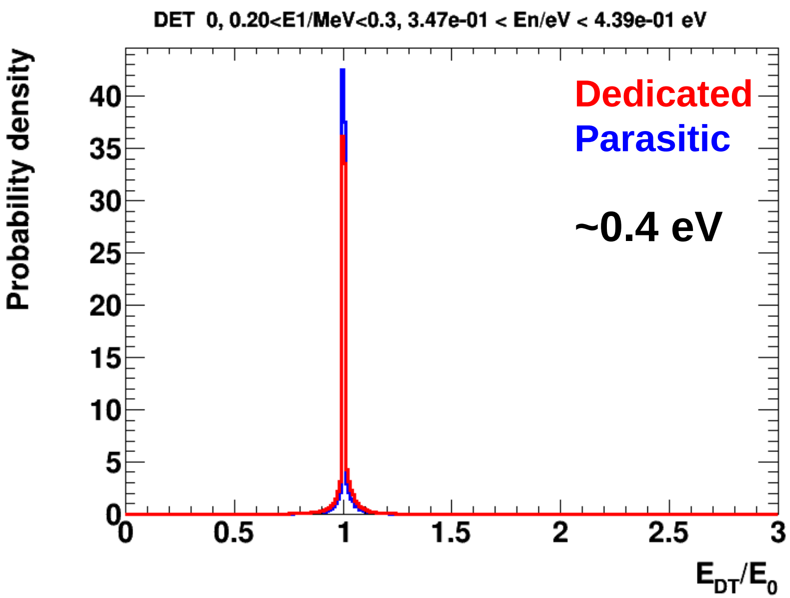
To study the response of the analysis routine in terms of the fitted energy of a signal under **two different scenarios or effects** [E. Mendoza, et al., Nucl. Inst. Meth. A 768 (2014) 55-61]:

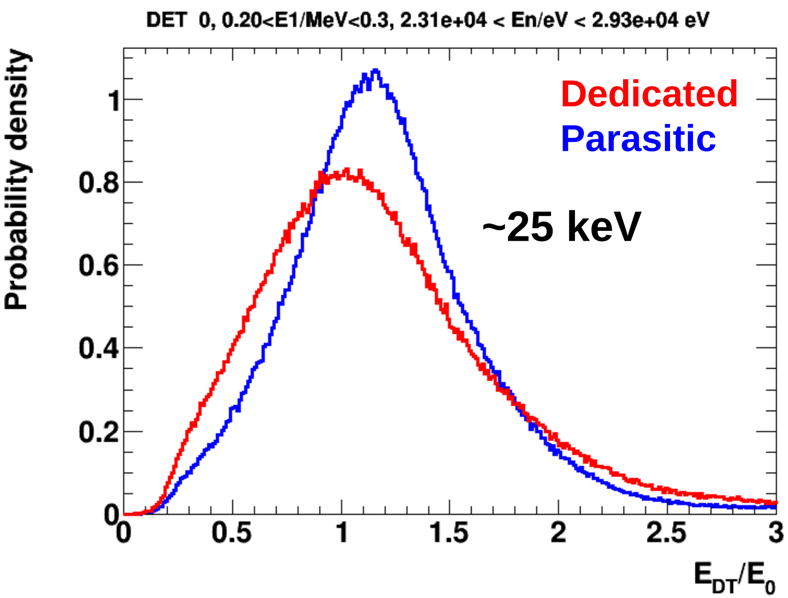
1. Due to **different position in the data buffer (different time-of-flight)**.
2. Due to **high reaction rate** (as in the saturated ^{197}Au resonance). Not expected to be significant in ^{239}Pu.

2.1 Dead Time due to Time-of-flight

For every BaF_2 individually, and **different neutron energy intervals** and **signal amplitudes**, we characterized:

- Prob. distribution of the change in the signal energy.



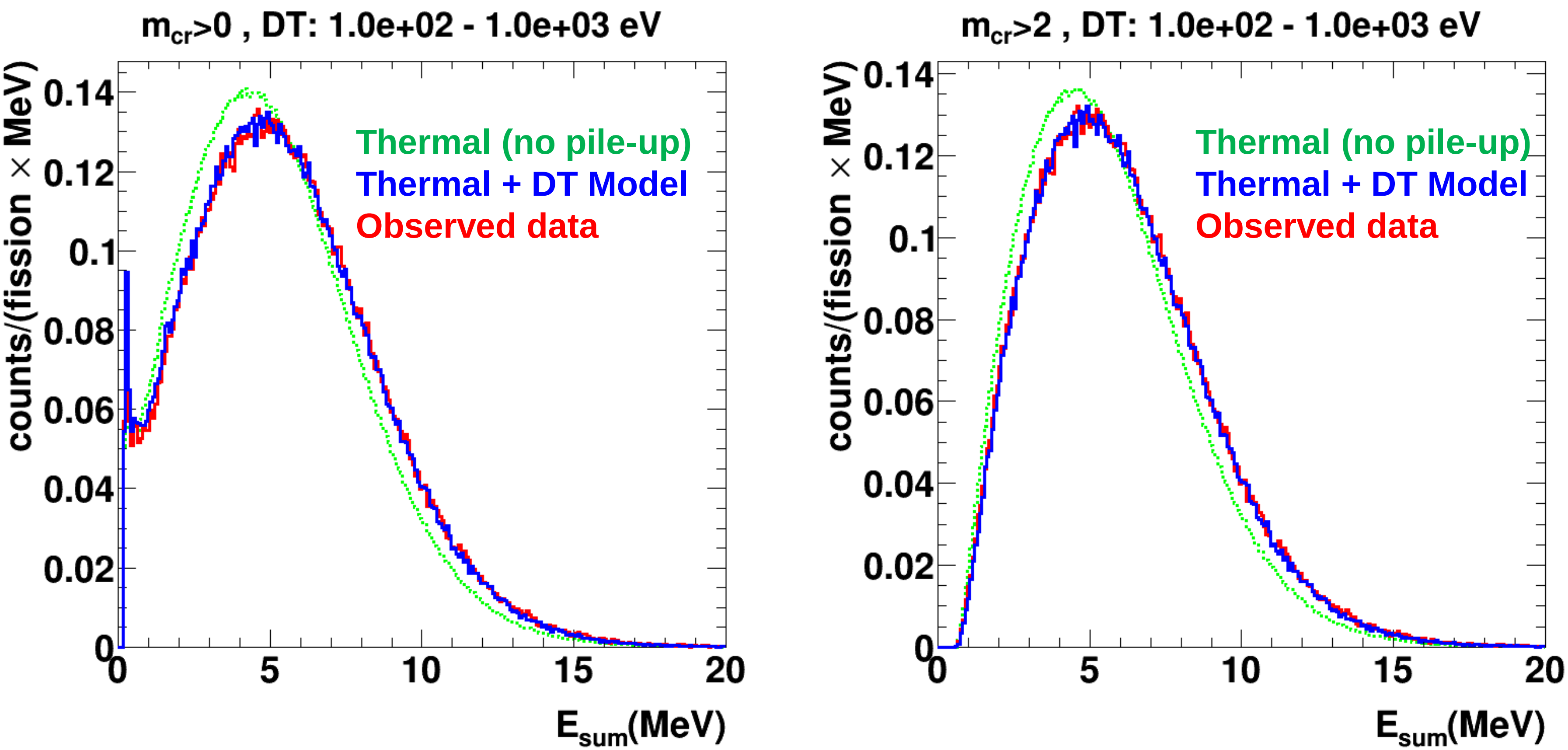


- The non-detection probability.
- The time shift in nanoseconds of the fitted signal.

2.1 Evaluation of TOF DT model

We can **validate** this Dead Time model using the **experimental data**.

The fission tagged E_{sum} spectrum



The pile-up is reproduced by the model perfectly for all m_{cr} cuts.

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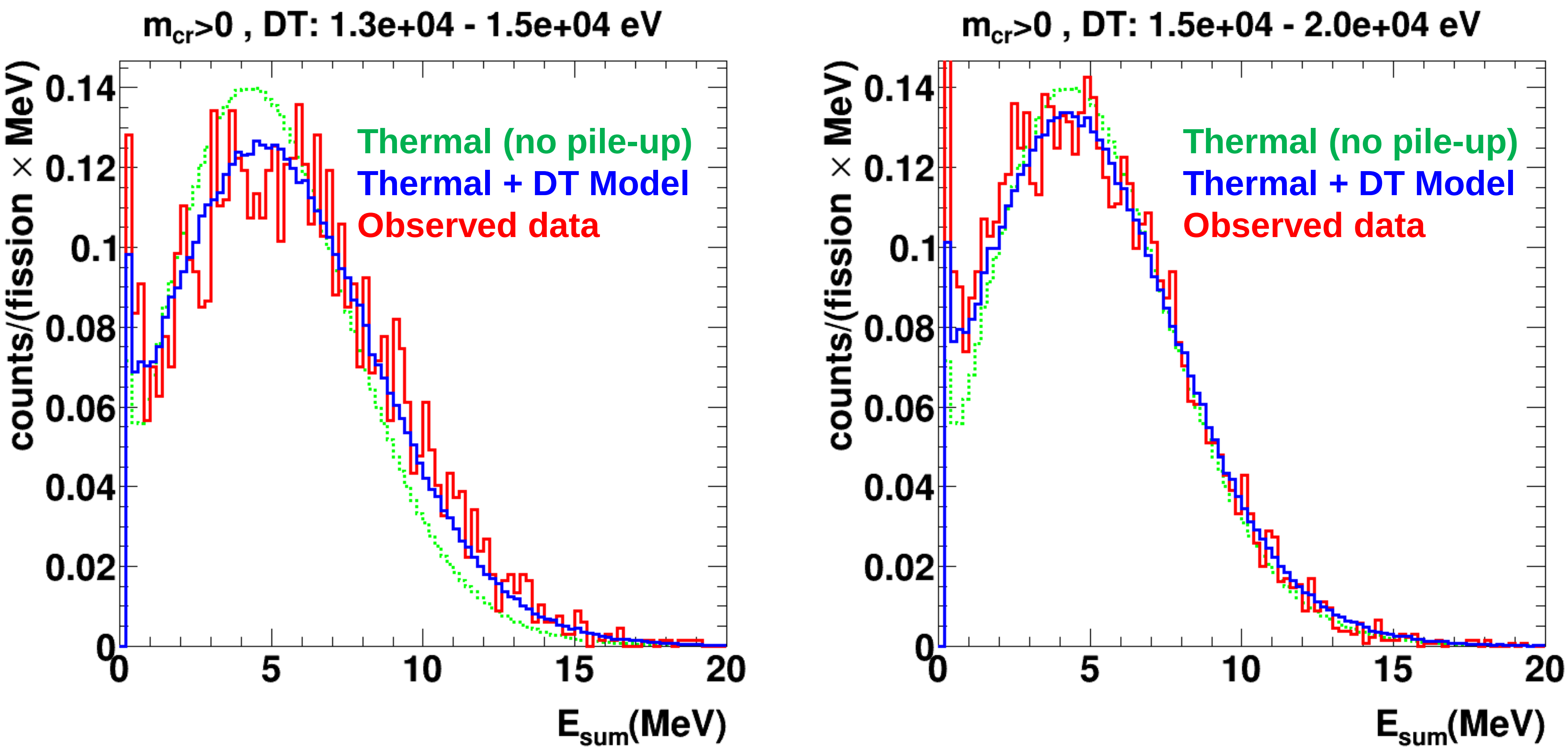
We can **validate** this Dead Time model using the **experimental data**.

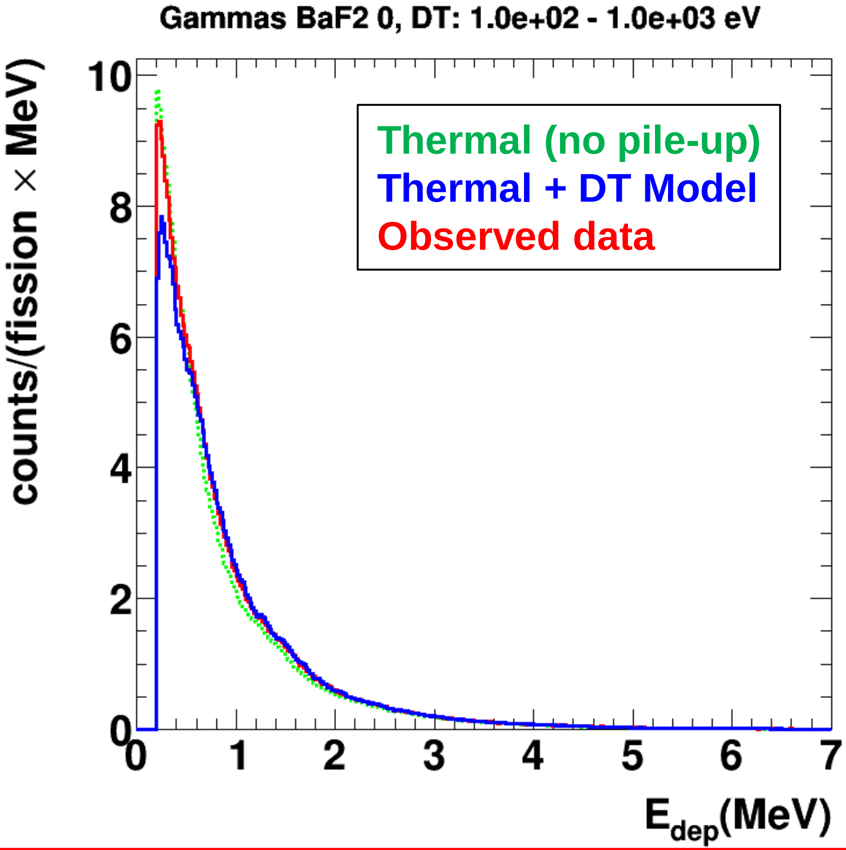
The fission tagged E_{sum} spectrum

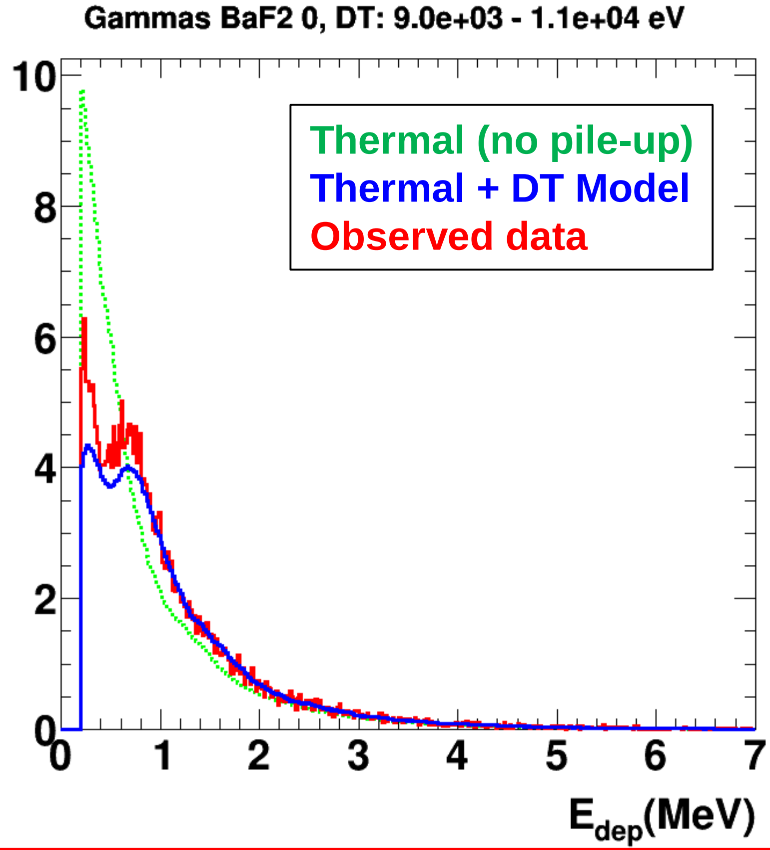


The prediction of the DT model agrees with observed data even for high neutron energies

2.1 Evaluation of TOF DT model

Another check for the Dead Time or pile-up effects is to monitor the **fission spectra** in the **individual BaF_2 crystals** (in coincidence with the FICH).



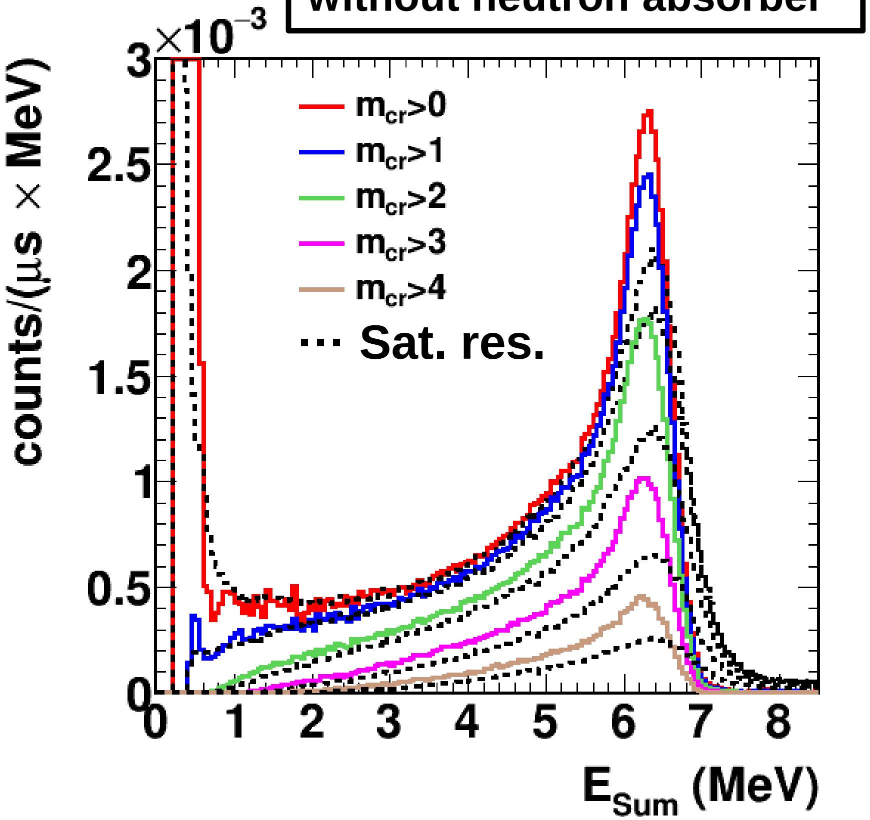


The gain shift is well reproduced, but the DT model underestimates the counts below 1 MeV.

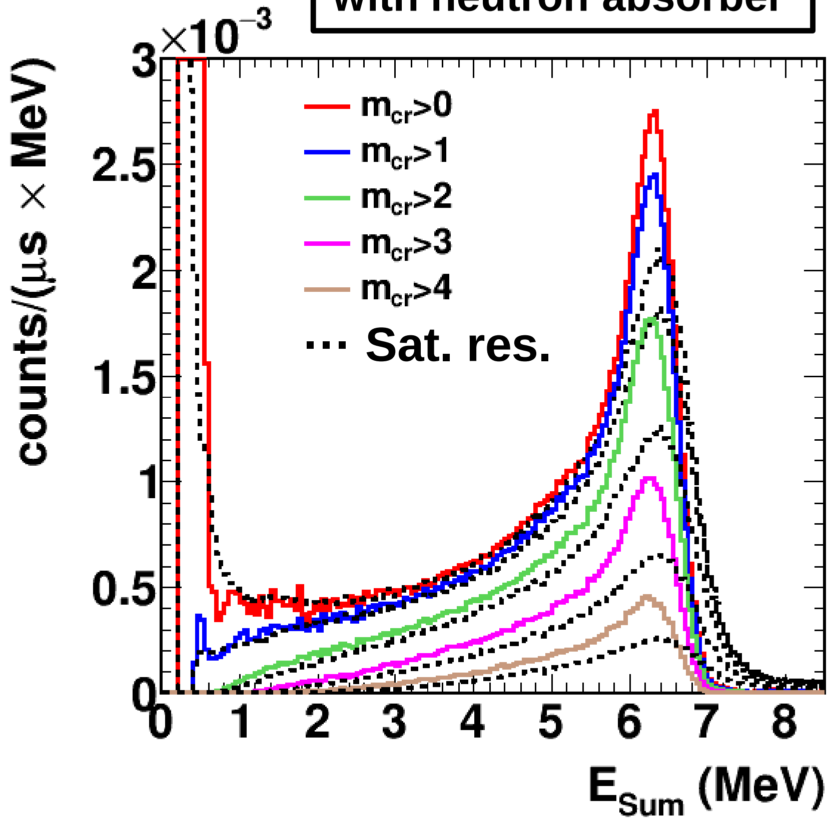
2.2 Dead time due to Counting Rate

We can see there is an effect in the total deposited energy spectra in the TAC due to high CR, as shown for the case of **^{197}Au(n,g)**, comparing thermal (0.1-1.0 eV) to the **saturated resonance** region (4.8-5.0 eV).

without neutron absorber



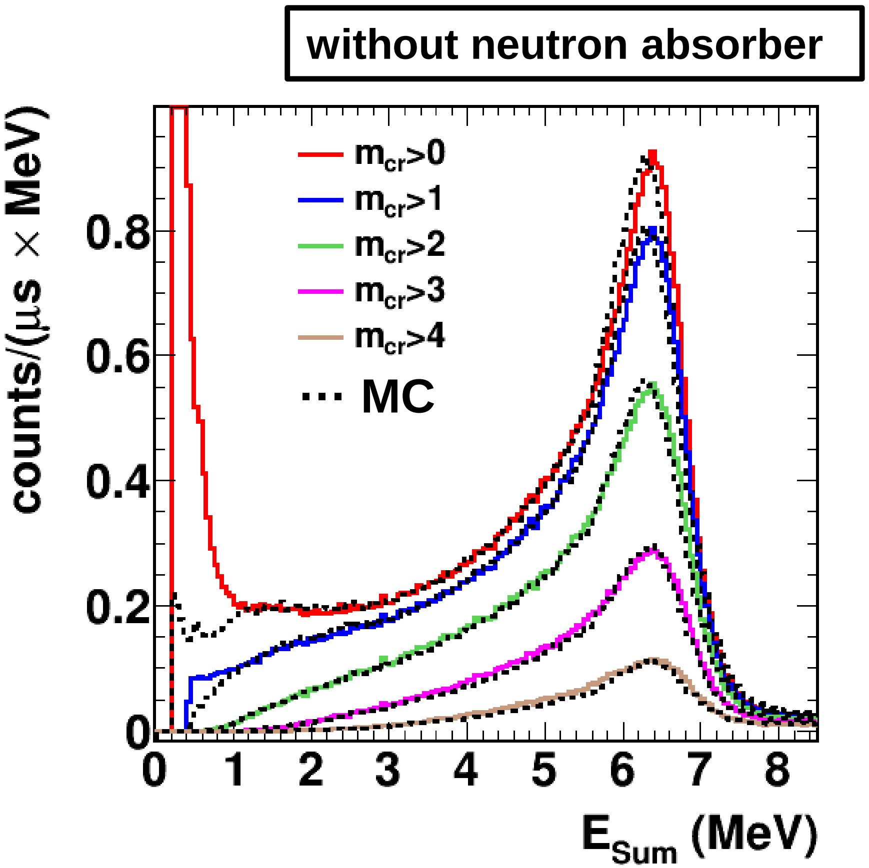
with neutron absorber

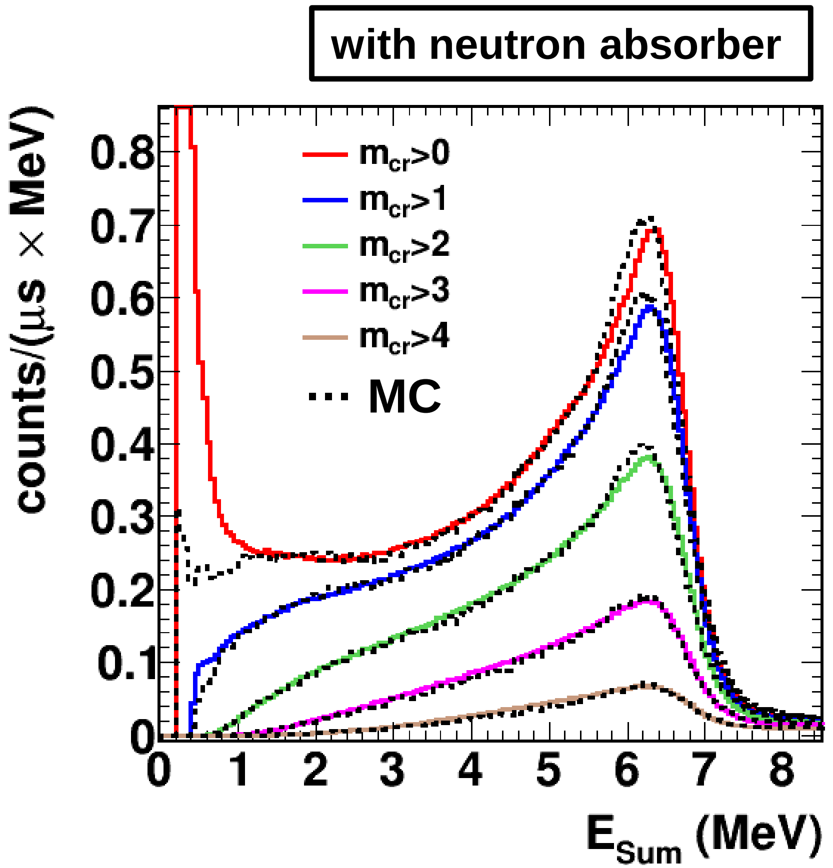


Data for dedicated pulses. The black spectra were normalized to the colored ones.

2.2 Dead time due to Counting Rate

The geometry of the experimental setup and the ^{197}Au(n,g) cascades have been modelled to obtain **Monte Carlo simulations** including the **Dead Time model**.





Data for dedicated pulses, with a reaction rate of ~2.7 (n,γ)-cascades/μs.

3

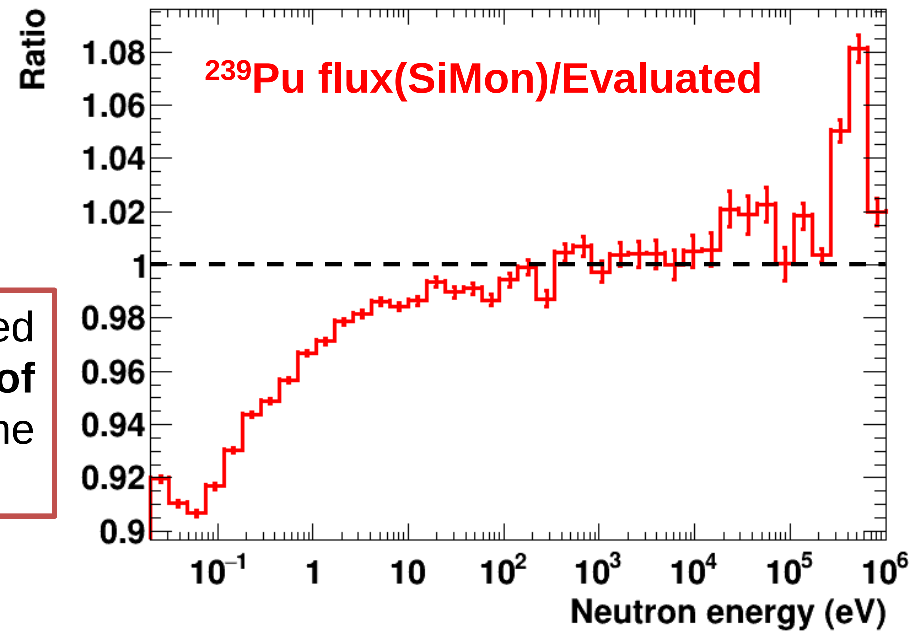
Determination of the ^{239}Pu measurement neutron flux

3.1 Full beam neutron flux

As the preliminary results showed, a better determination of the neutron flux was needed to understand the observed discrepancies.

The **full beam neutron flux** has been obtained in the following way:

- From the flux measured by the **SiMon** detector **during the ^{239}Pu measurement**, for energies **below 1 keV**.
- **Above 1 keV** from the **evaluated flux** during the Commissioning 2021 (SiMon, uMegas, PPAC, PTB detectors). <u>Thanks to the Commissioning and Neutron Flux evaluation team!)</u>
- A minor correction (<1%) to take into account the **transmission** of the in-beam dead material.



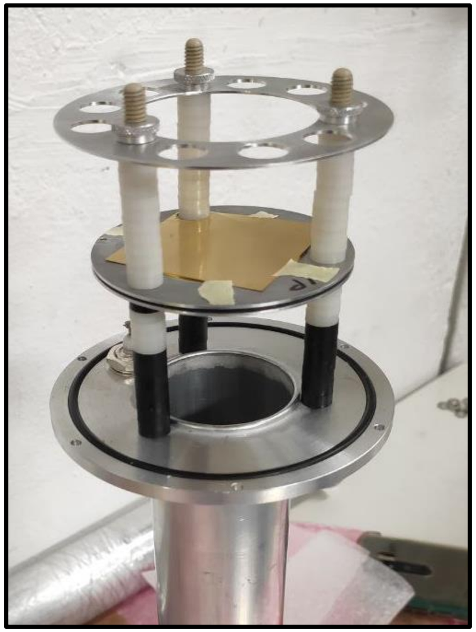
The differences below 10 eV are attributed to **changes in the concentration of boron** in the moderator close to the spallation target.

3.2 FC config. neutron flux

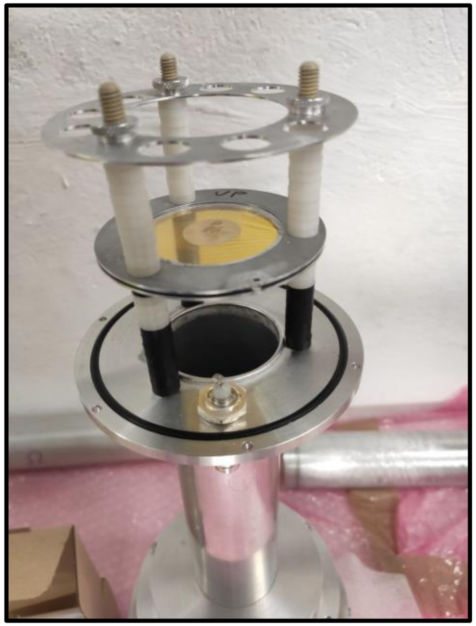
But the **neutron flux intercepted by the ^{239}Pu targets** in the Fission Chamber (FC) setup, of **2 cm diameter**, is different from the full-beam neutron flux (~5 cm diameter). This change in the neutron flux shape has been obtained by 2 methods:

1. **Below 1 eV**: comparing two measurements of ^{197}Au, one with a big sample covering the full beam and another one with a 2 cm diam. sample.

5x5 cm Au in TS config.



2 cm Au in TS config.



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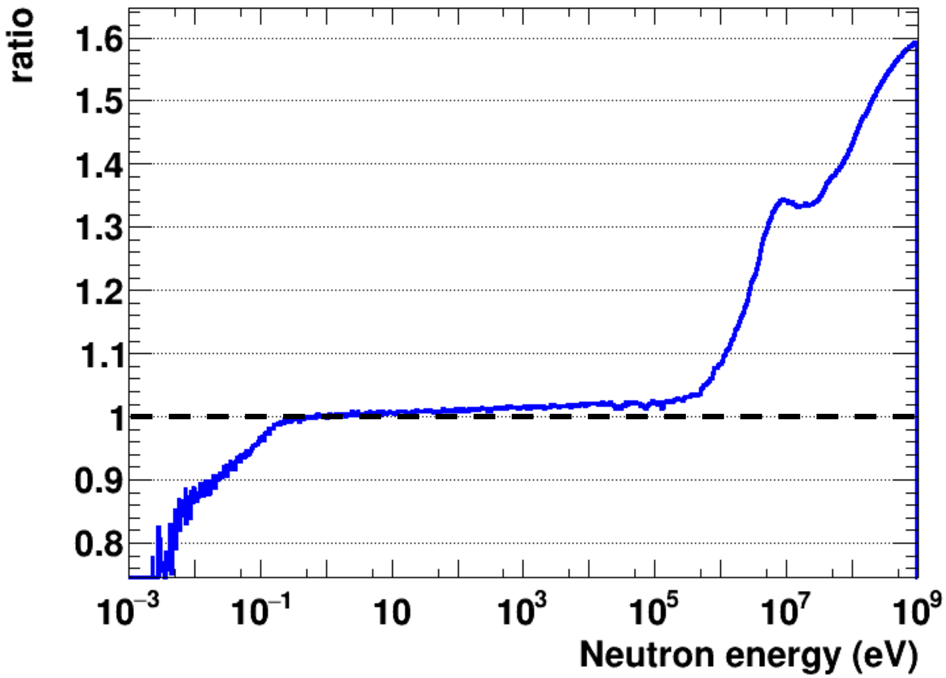
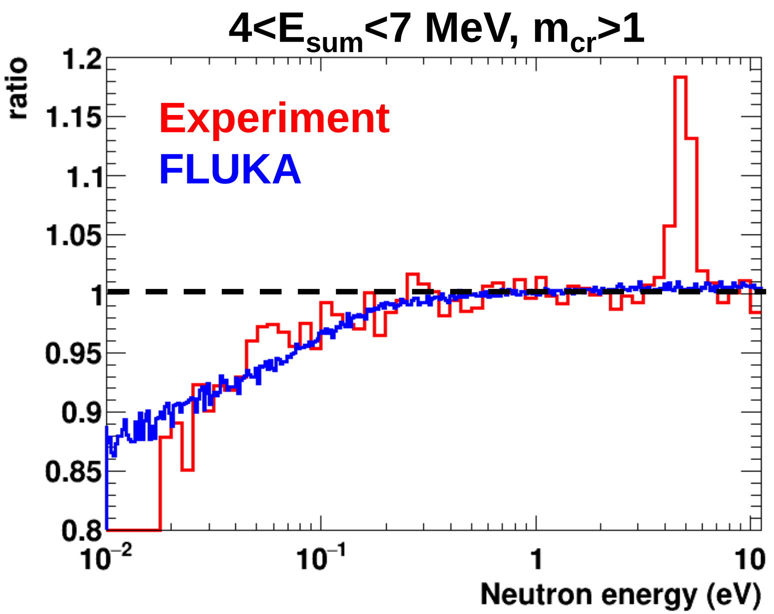
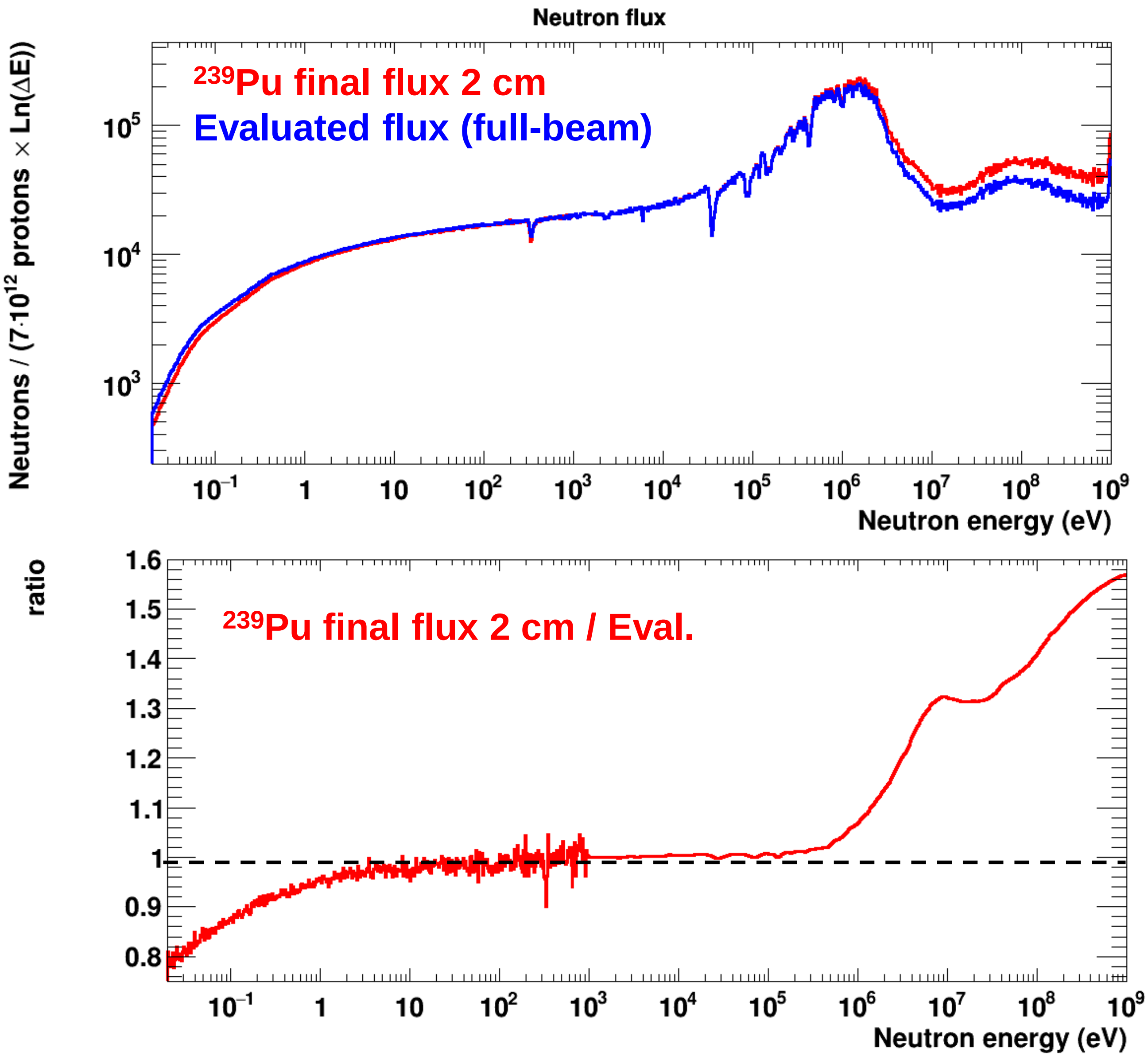
1. **Below 1 eV**: comparing two measurements of ^{197}Au, one with a big sample covering the full beam and another one with a 2 cm diam. sample.
2. **Above 1 eV**: using the FLUKA+transport-code calculations (thanks to the n_TOF FLUKA team!).





3.2 FC config. neutron flux

The final flux shape to be used for the capture and fission of ^{239}Pu measurement, in the thin samples configuration. Fluxes **normalized to ~1keV** region. ACORTAR PLOT



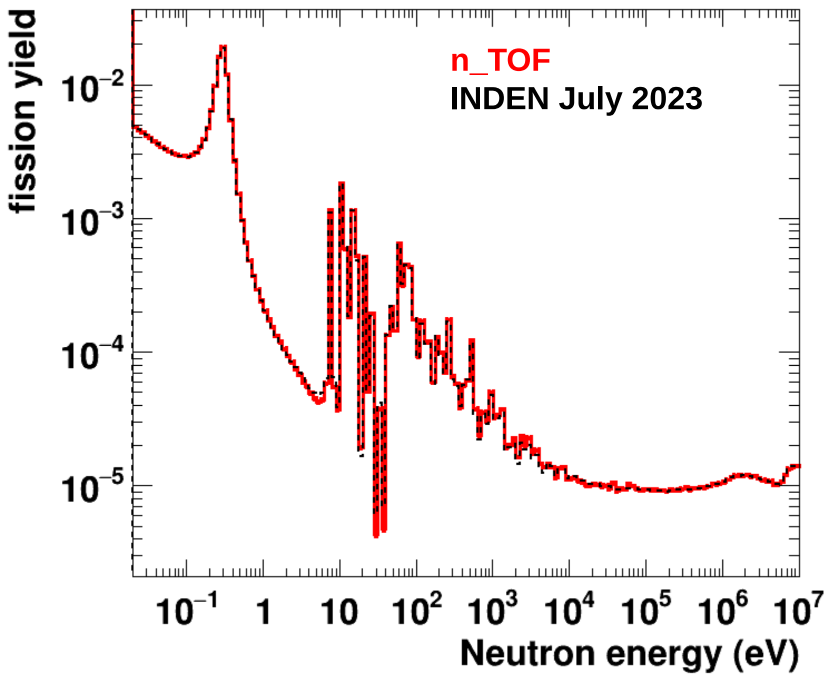
3.3 The fission yield

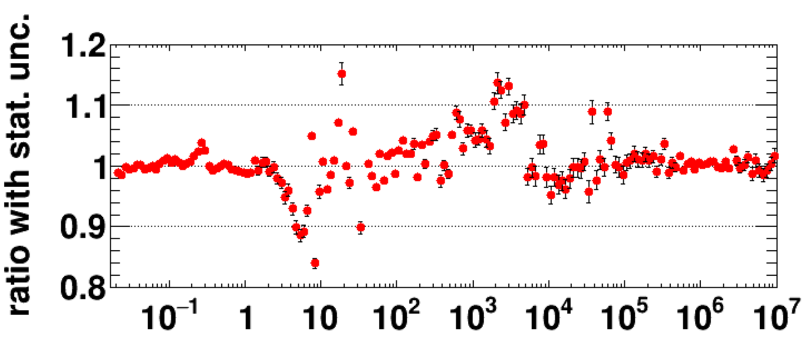
Now, obtaining the fission yield with this new neutron flux should improve the results of the comparisons with the evaluated libraries. n_TOF data normalized to the integral value between 9-20 eV as recommended by I. Durán, R. Capote and P. Cabanelas.

A new $^{239}Pu(n,f)$ cross-section evaluation from INDEN have been published recently.

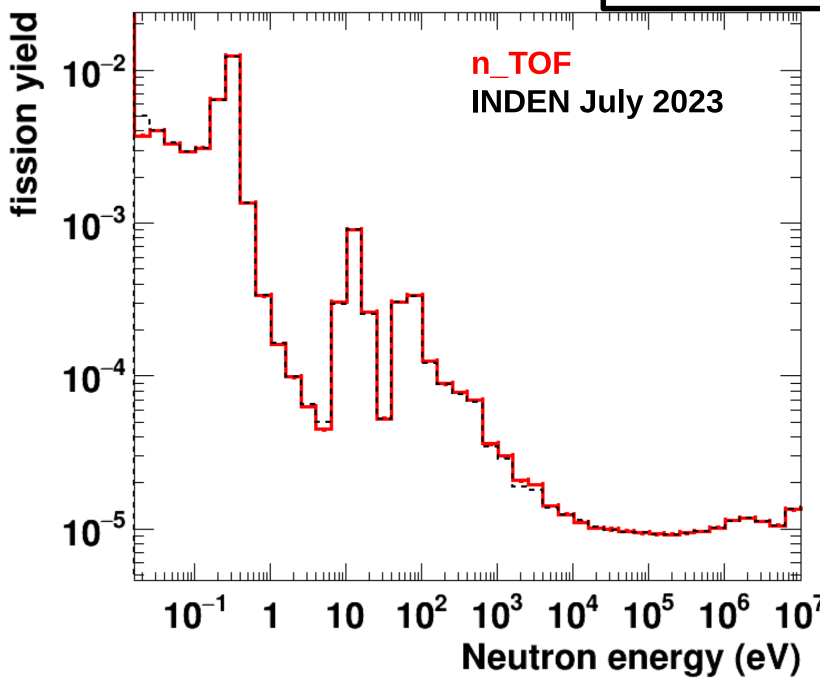
$$\text{ratio} = \frac{\text{n\_TOF}}{\{\text{eval}\}}$$

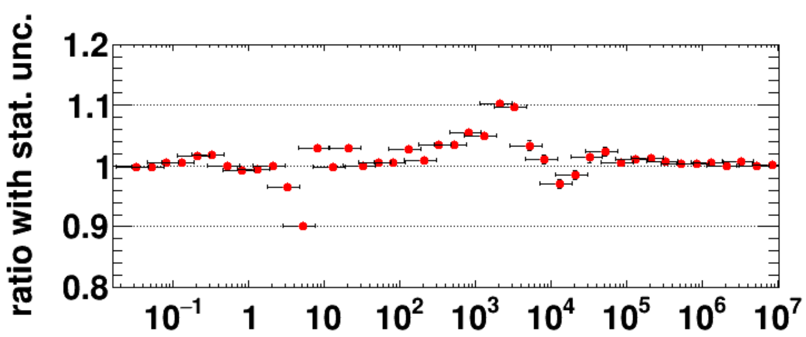
20 BPD





5 BPD





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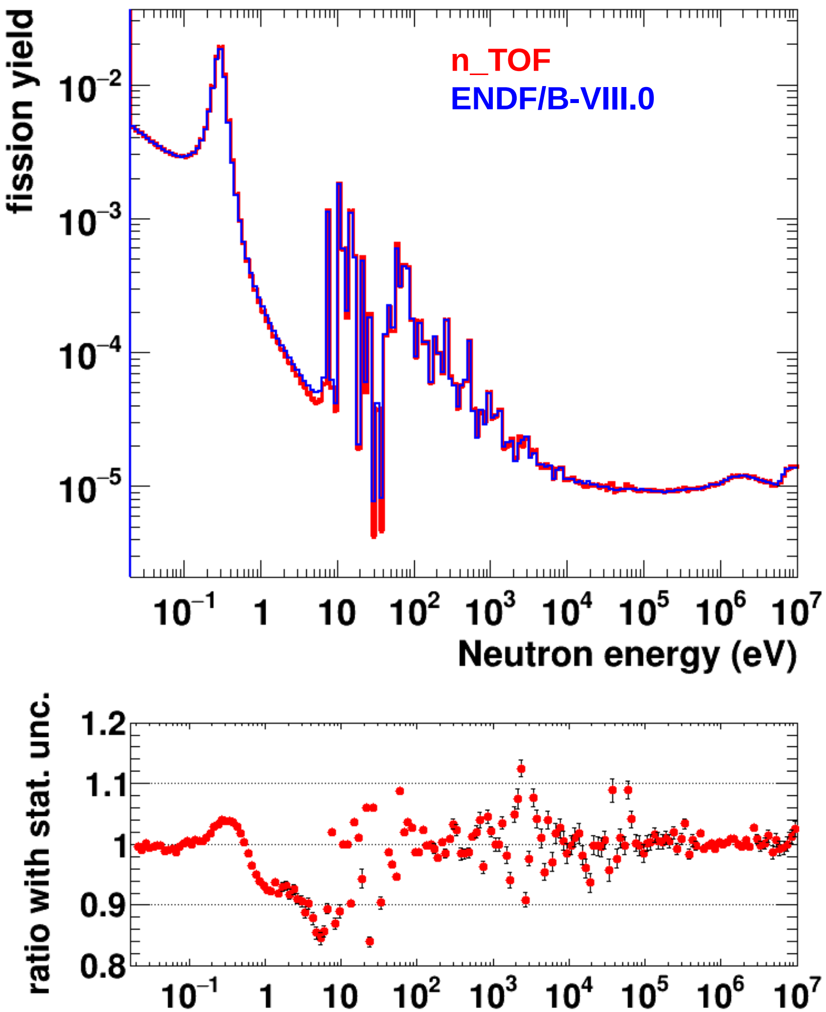
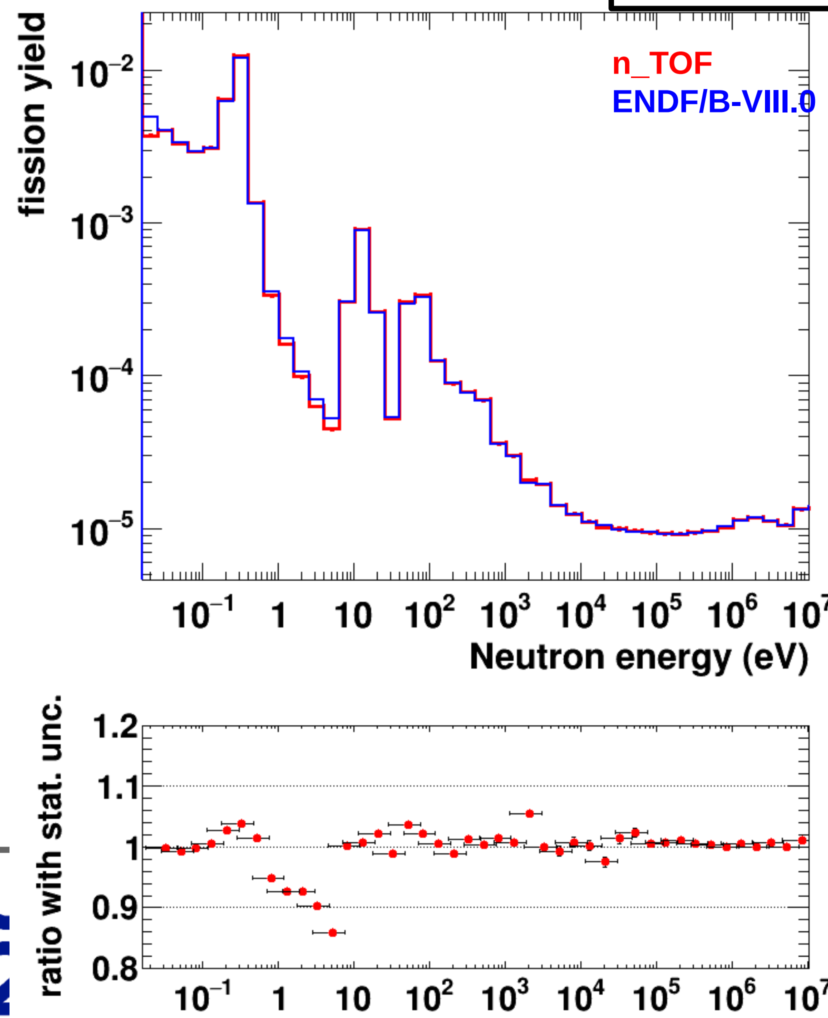


5 BPD



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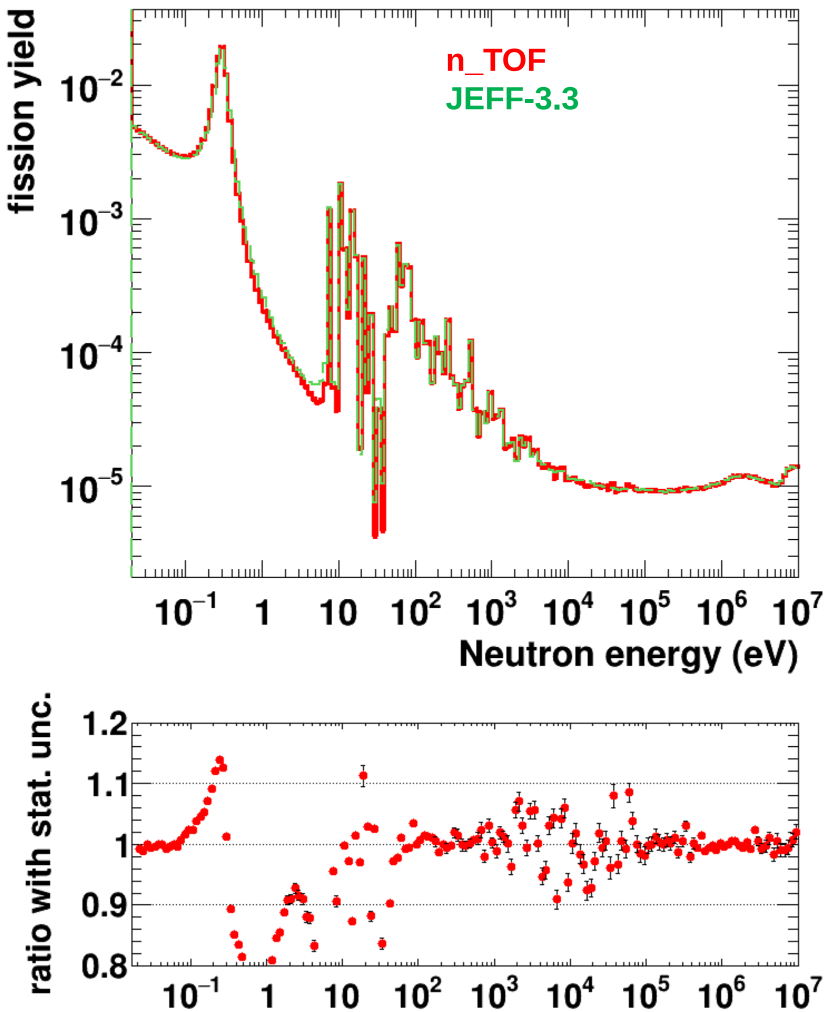
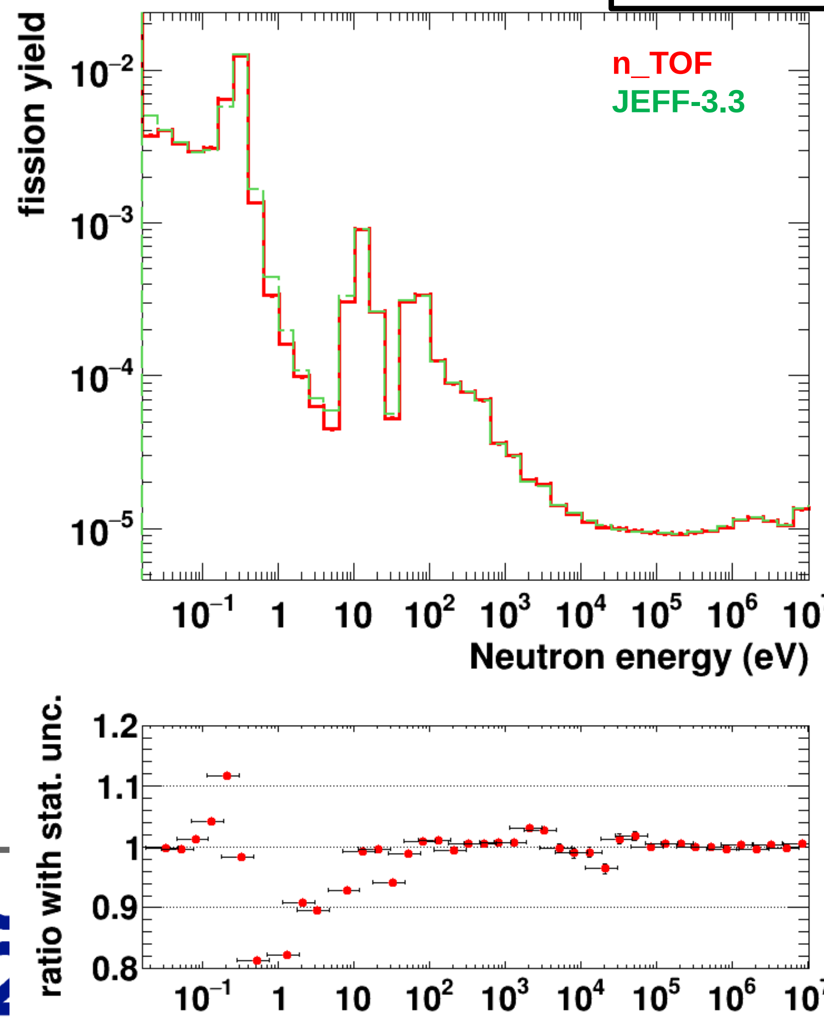
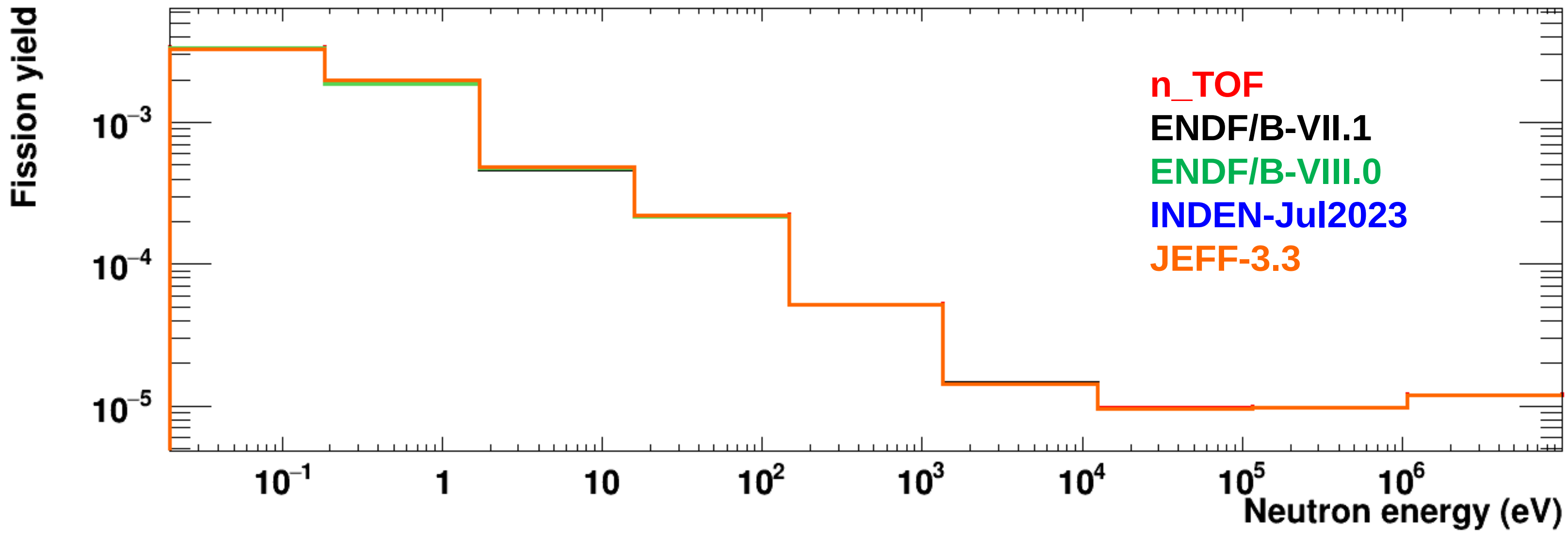
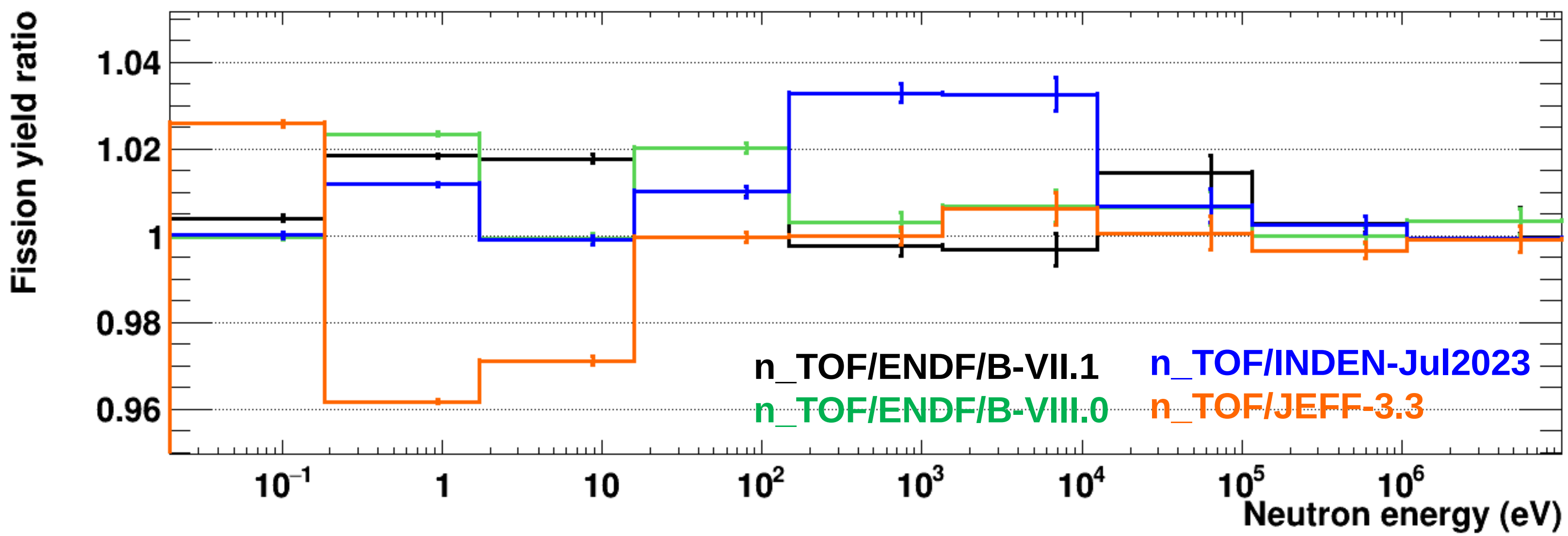


5 BPD



Comparison with evaluations (1 BPD)





Conclusions

- Big progress in the ^{239}Pu data analysis have been done in the last months, including a better understanding and characterization of the backgrounds for the capture measurement, determination and validation of dead-time and pile-up models, etc.
- Determination of the neutron flux for the ^{239}Pu measurement, including the boron concentration correction and the beam intersection factor calculation for a wide neutron energy range.
- These improvements allow us to provide a **^{239}Pu(n,f) yield** that agrees with evaluations within ~2% (integrating in 1 bin per decade) **from 0.02 eV to 10 MeV in one single measurement**.
- The fission yield is ready to start the paper preparation.
- The analysis of ^{239}Pu(n,g) data is still on progress.

Acknowledgments

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

Accelerator and Research reactor Infrastructures for Education and Learning — ARIEL

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SANDA

erc European Research Council
Established by the European Commission

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EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

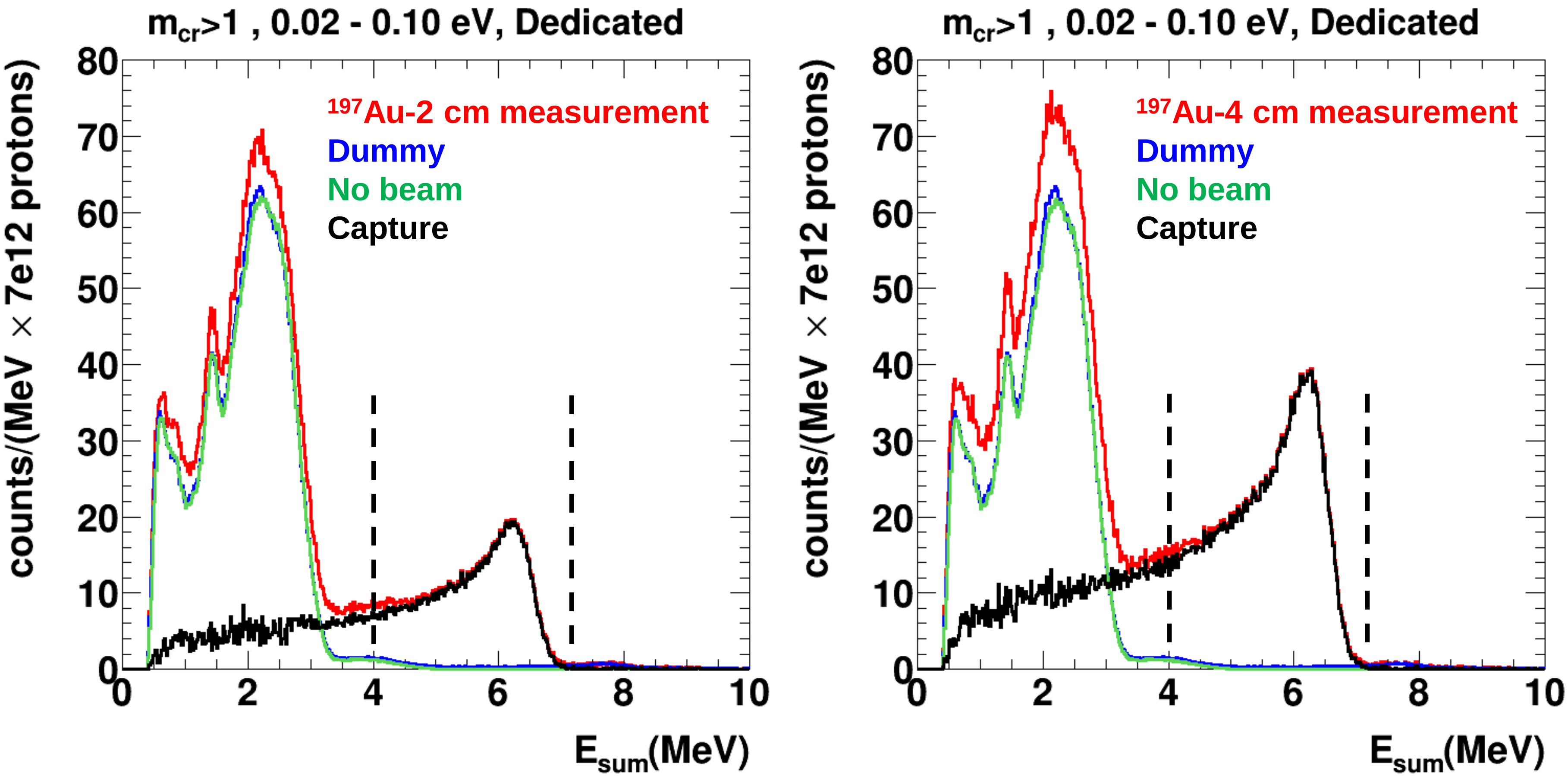
Directorate G - Nuclear Safety and Security
Standards for Nuclear Safety, Security and Safeguards

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


THANK YOU!

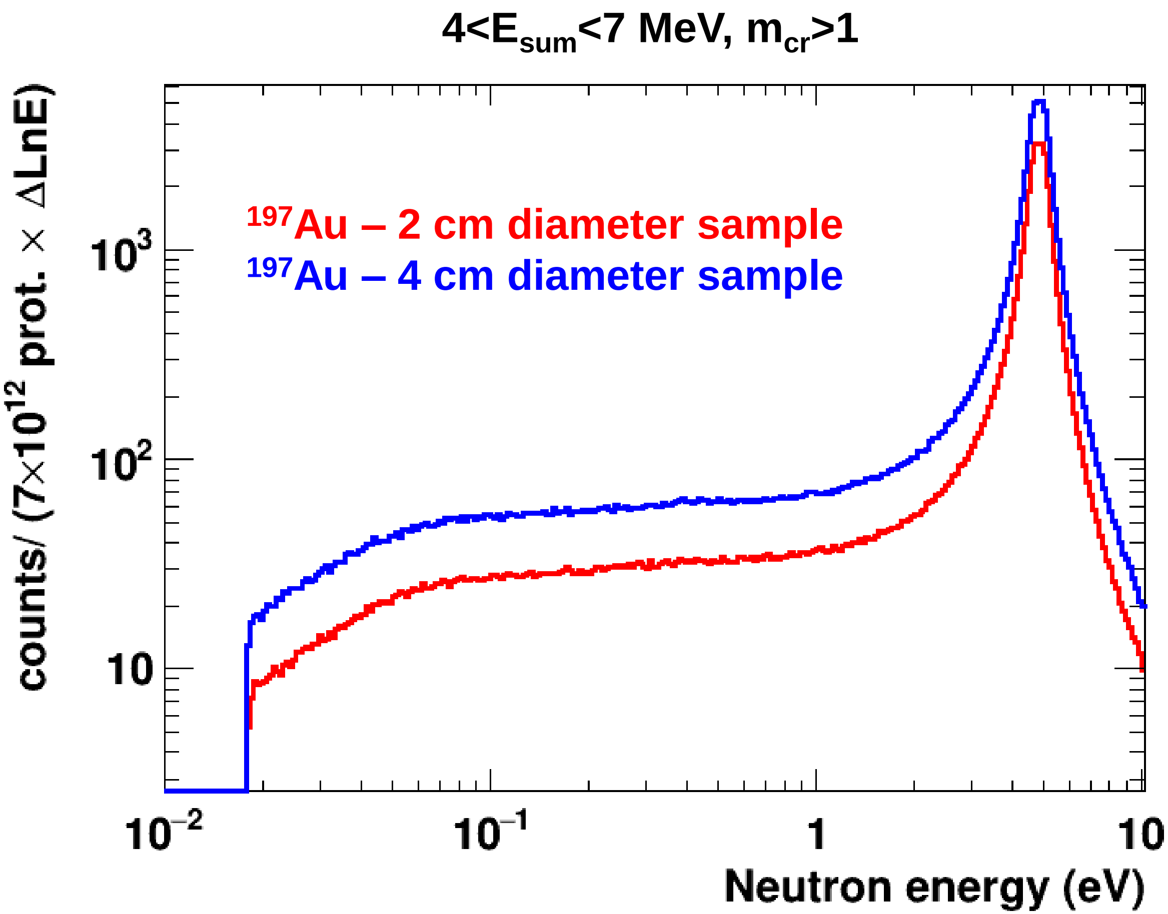
Extra slides

Variations in the flux with the sample radius



Deposited energy spectra for the 2 cm ^{197}Au sample (left) and the 4 cm ^{197}Au sample (right), both in the thick sample configuration.

Variations in the flux with the sample radius

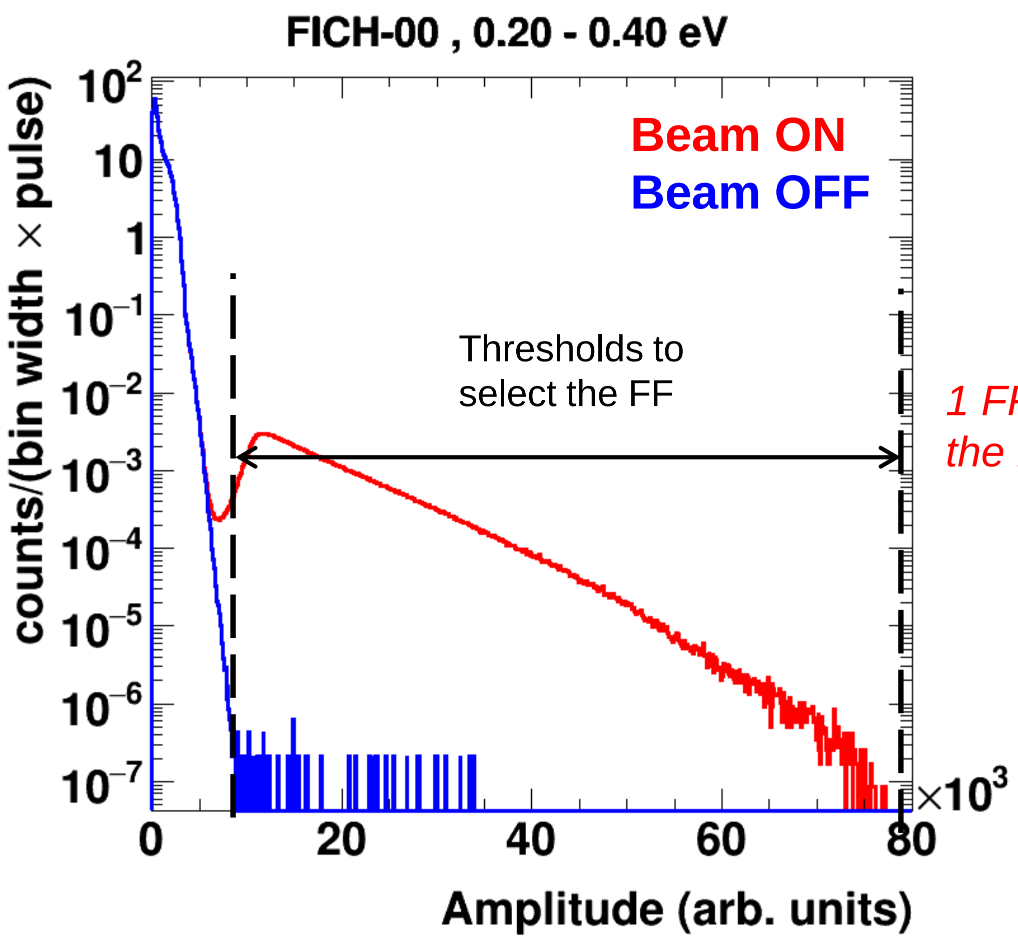


Time of flight spectra for the 2 cm ^{197}Au sample (red) and the 4 cm ^{197}Au sample (blue), both in the thick sample configuration.

1.1 Fixing observed artifacts of the routine

Amplitude spectra of the Fission Chamber

- In addition, the **complete alpha spectrum** from the Pu activity has been obtained.

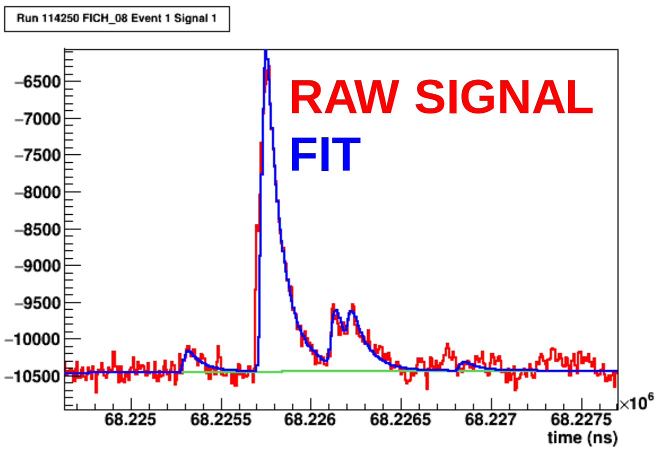


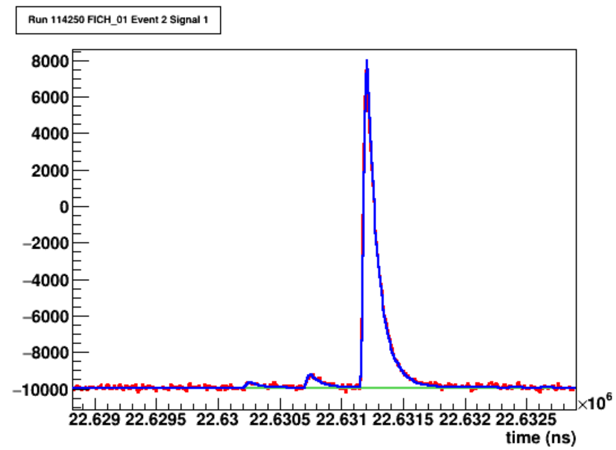
1 FF per >2000 alphas in the biggest resonance

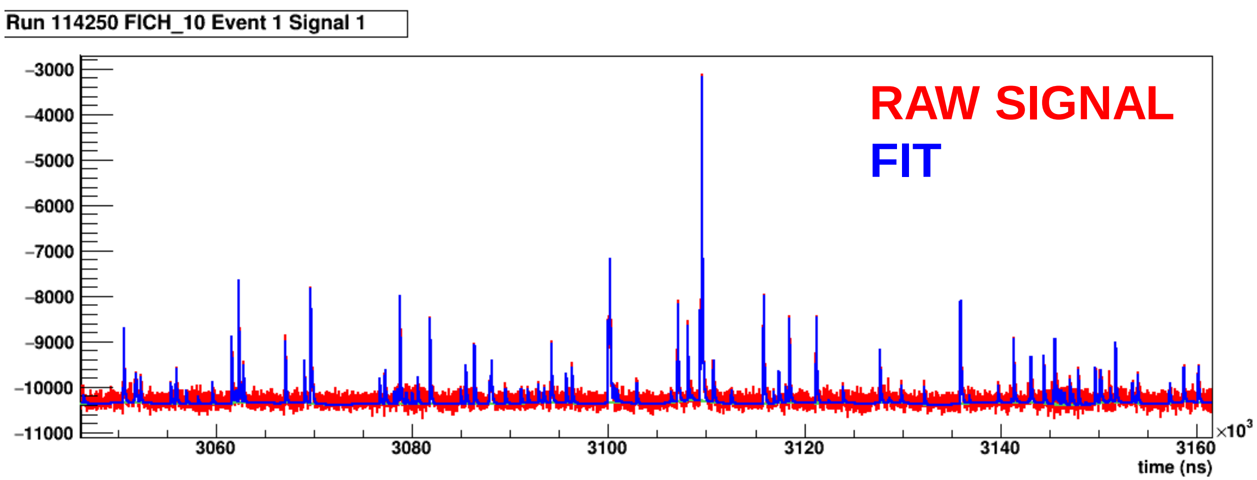
Fission Chamber configuration

Preliminary results

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



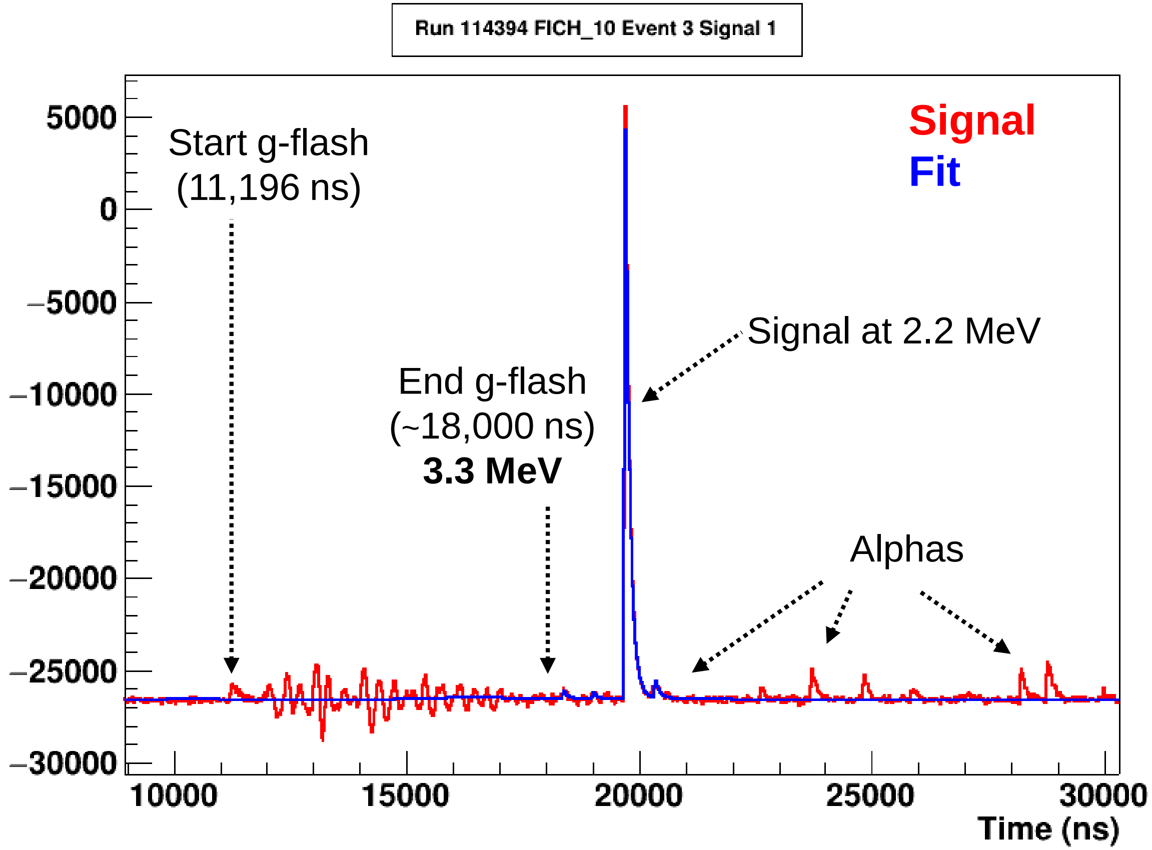




Max. E_n in fission yield

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**.

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

NEUTRON BEAM

Target position-10

Target position-9
Target position-8

Target position-7
Target position-6

Target position-5
Target position-4

Target position-3
Target position-2

Target position-1