Final results of the ^{239}Pu capture and fission cross section measurements at n_TOF (CERN)

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Contents

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Overview of the ^{239}Pu measurement at n_TOF

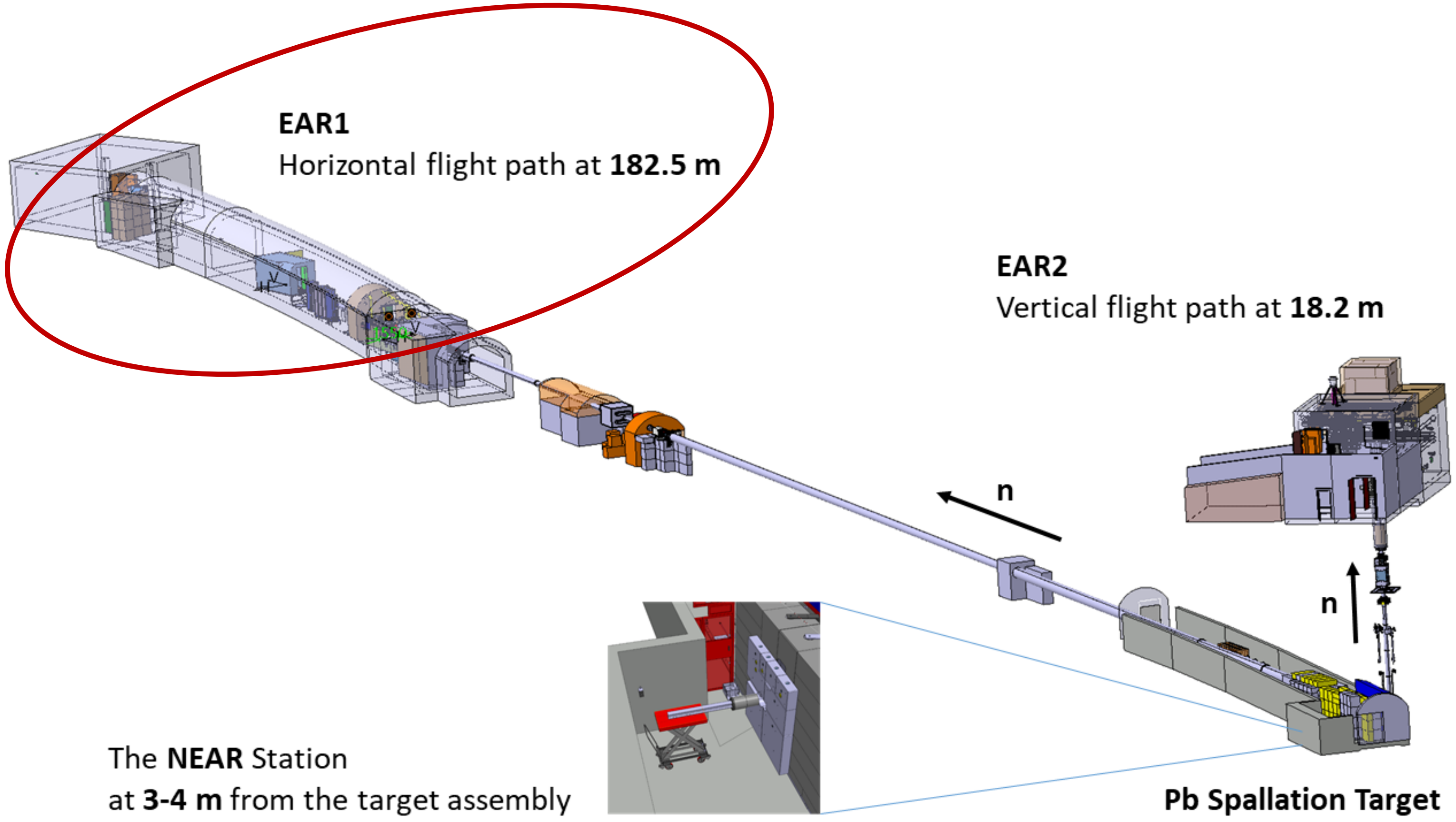
Experimental setup

1.1 n_TOF: neutron time-of-flight at CERN

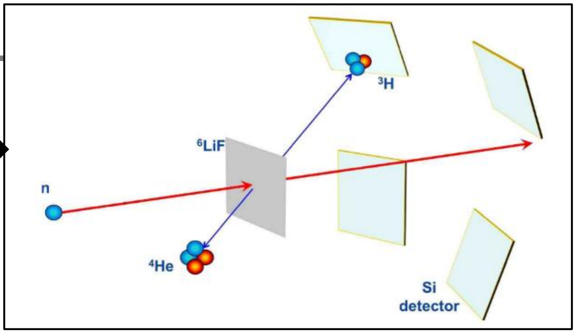
- Experiment performed at n_TOF EAR1 (~185 m flight path) in Sep-Nov 2022.
- Around 8 times larger flight path than in previous ^{239}Pu measurements, which enables higher energy resolution.

n_TOF features

- 25 years operation, with relevant measurements for nuclear technology, nuclear astrophysics, medical science and basic research.
- Neutron beam by **spallation** of 20 GeV protons into a lead target.
- Pulses of about 1 Hz repetition rate → no overlapping pulses.
- $8 \cdot 10^{12}$ protons per pulse, 7 ns RMS, with option for lower intensities.
- **Three experimental areas** for different purposes (EAR1, EAR2 and NEAR).
- EAR1: moderated neutrons with a layer of borated water.



1.2 Detectors



Proton Beam Monitors

- Wall Current Monitor (WCM).
- Beam Current Transformer (BCT).

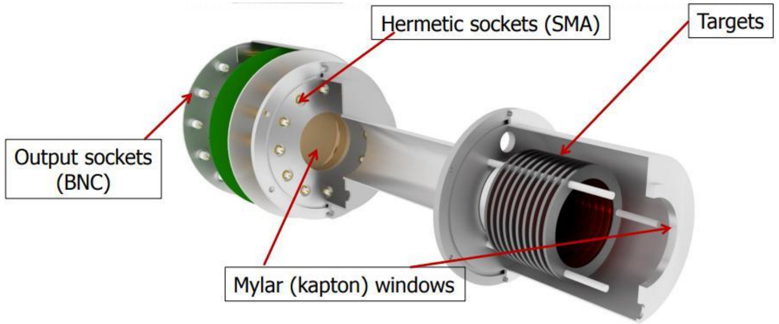
Neutron Beam Monitor (SiMon)

- Four silicon detectors to monitor neutron beam intensity using ^{6}Li(n,α)^{3}H standard reaction.

^{239}Pu-specific detectors at EAR1

FFD[1]

Fission **F**ragment **D**etector

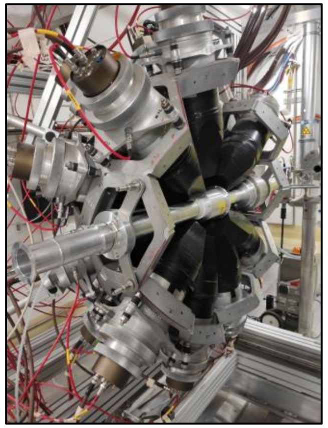


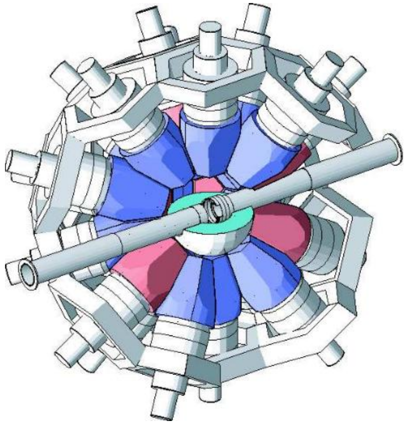
[1] Perkowski et al., Nucl. Instrum. Methods Phys. Res. A 1067, 169649 (2024)

- Detection of charged particles.
- Fast pre-amplifiers.
- Filled with Ar + (10%)CF_4 gas.

TAC[2]

Total **A**bsorption **C**alorimeter



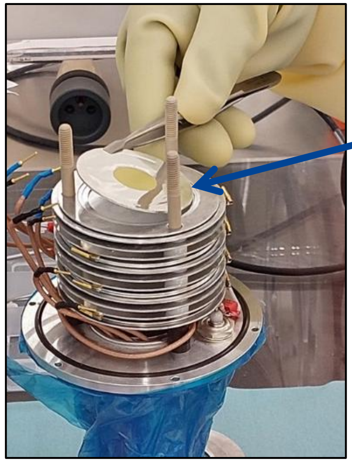


[2] Guerrero et al., Nucl. Instrum. Methods Phys. Res. A 608(3), 424 (2009)

- To detect capture and fission *γ*-rays.
- Composed of 40 BaF_2 crystals operated in coincidence.
- Events characterized by E_{sum} (total deposited energy from contributing crystals) and m_{cr} (crystal multiplicity).

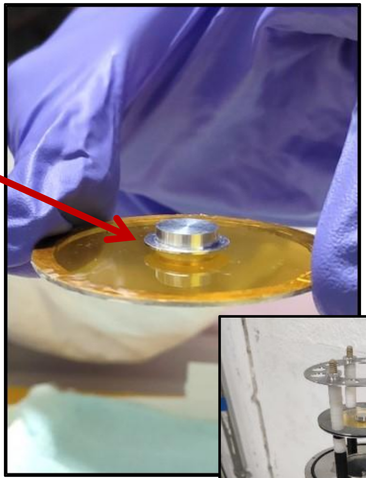
1.3 Experimental configurations and samples

- Experimental campaign **divided into two different configurations**:

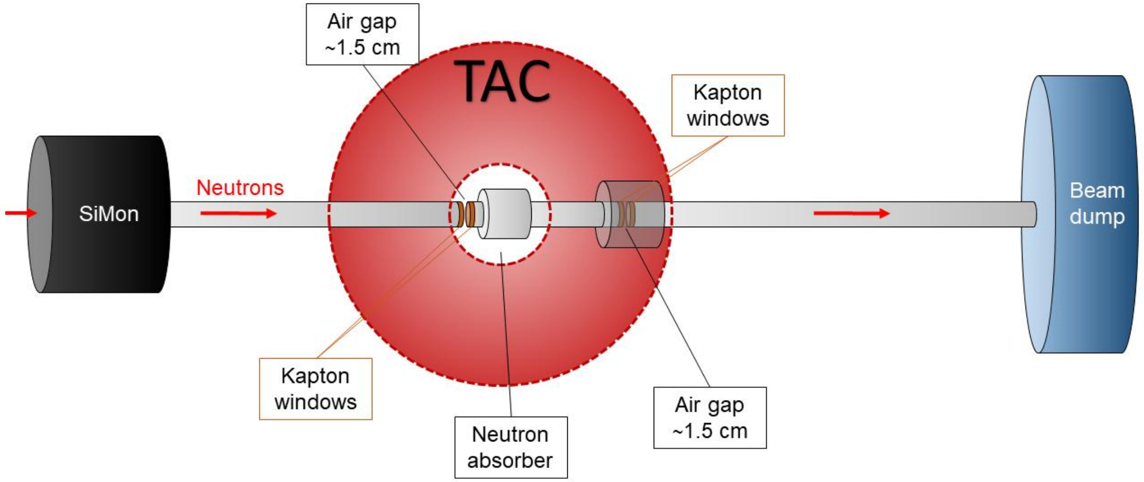


1. FC config.
- **10 thin Pu samples** (<10 mg total mass) within fission chamber.
- Use FFD + TAC simultaneously.
- Measure fission and capture (up to ~1 keV), and the α-ratio.

2. TS config.
- 1 **thick sample** (~100 mg).
- Use only TAC.
- Measure capture above 1 keV.
- Sample inside dummy chamber to have similar bkgds.



Both setups share similar beam line configuration:



Plutonium base material

- Produced by JRC-Geel and SCK CEN.
- Plutonium dioxide PuO_2.
- 99.9% purity of ^{239}Pu.
- From the same base material, <u>two different type of samples</u> were prepared.

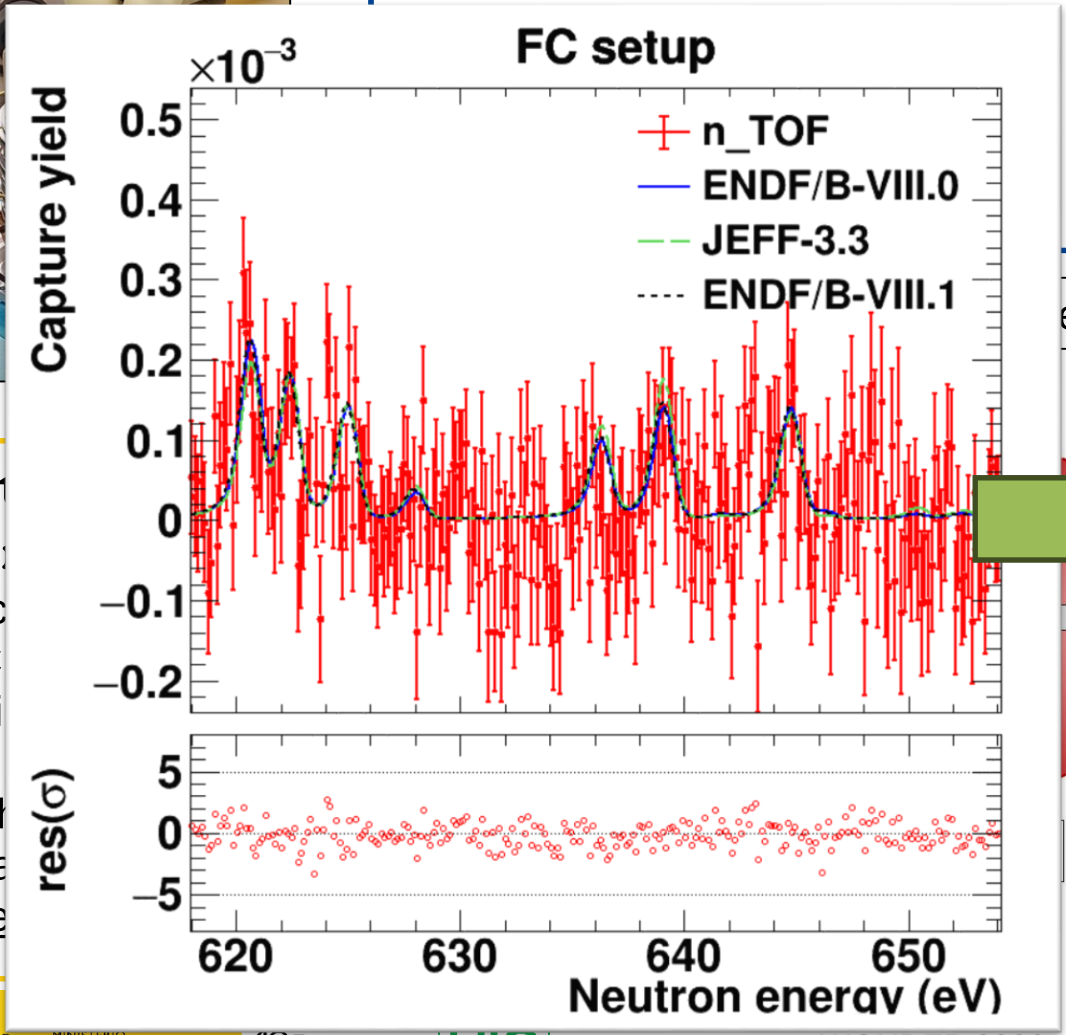
Isotopes	Abundance (%)
^{239}Pu	**99.90**
^{240}Pu	0.06
^{241}Pu	0.02
^{242}Pu	0.01

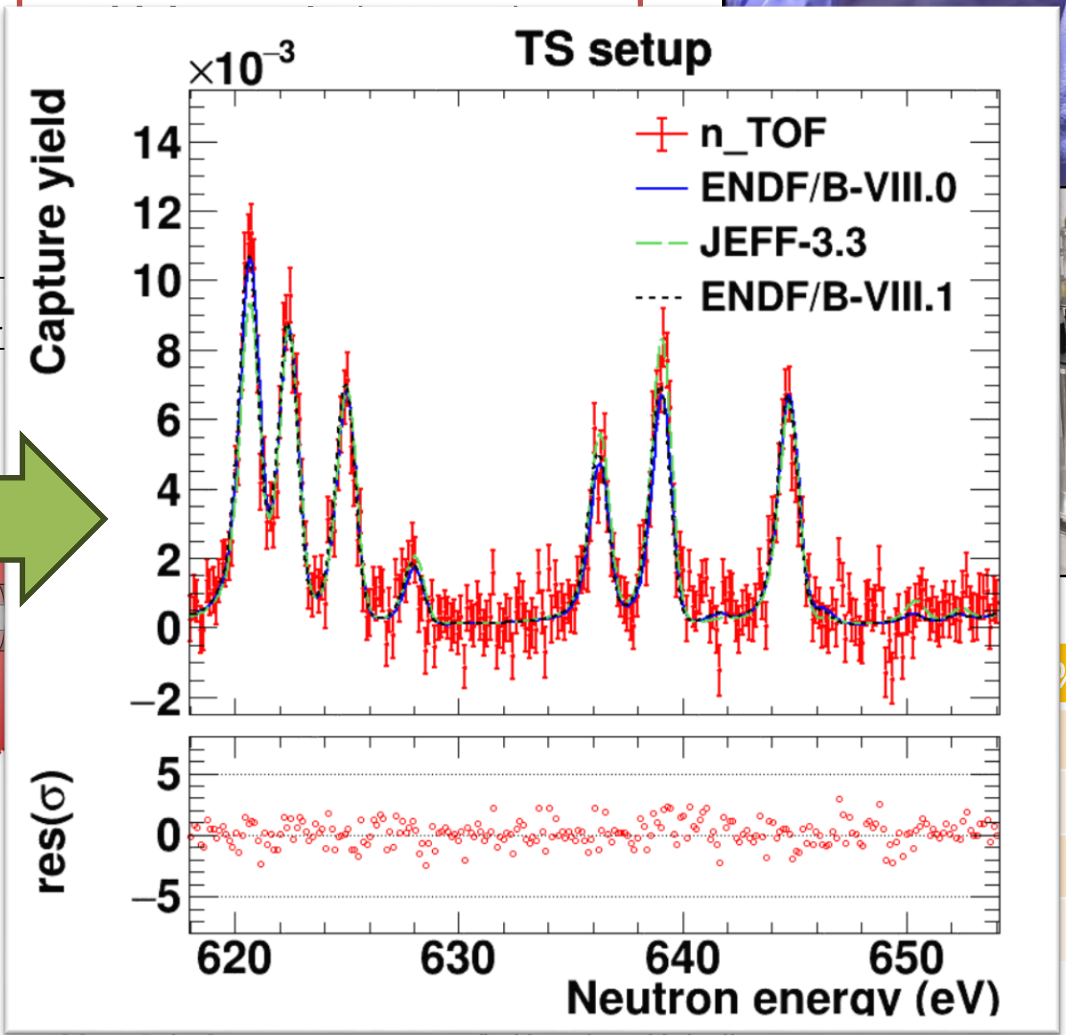
1.3 Experimental configurations and samples

- Experimental campaign **divided into two different configurations**:

1. FC config.

2. TS config.





ea

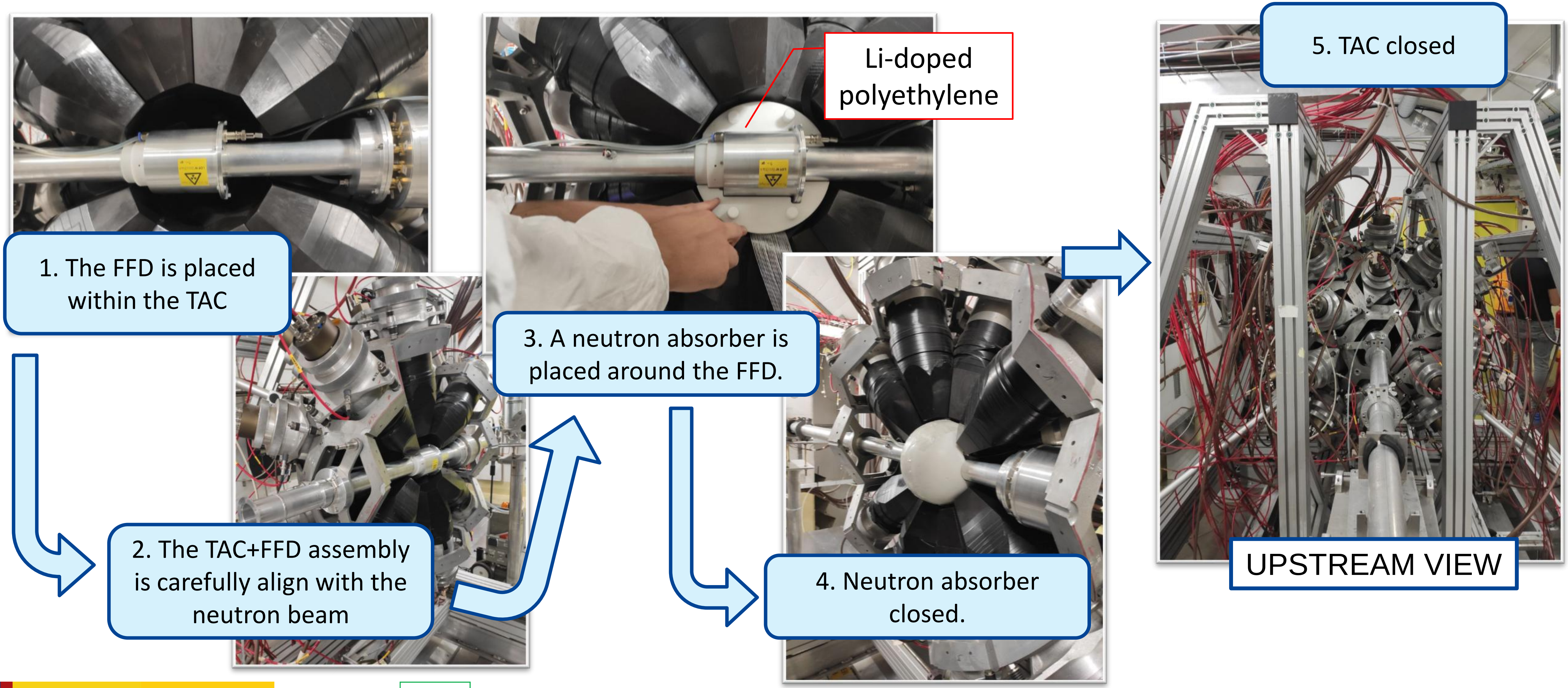
Plut

- Produc SCK C
- Plutoni
- 99.9%
- From th materia sample

%)

1.3 Experimental configurations (mounting)

Pictures of the mounting procedure at n_TOF EAR1 during the experimental campaign in 2022.



2

Summary of the Data Analysis

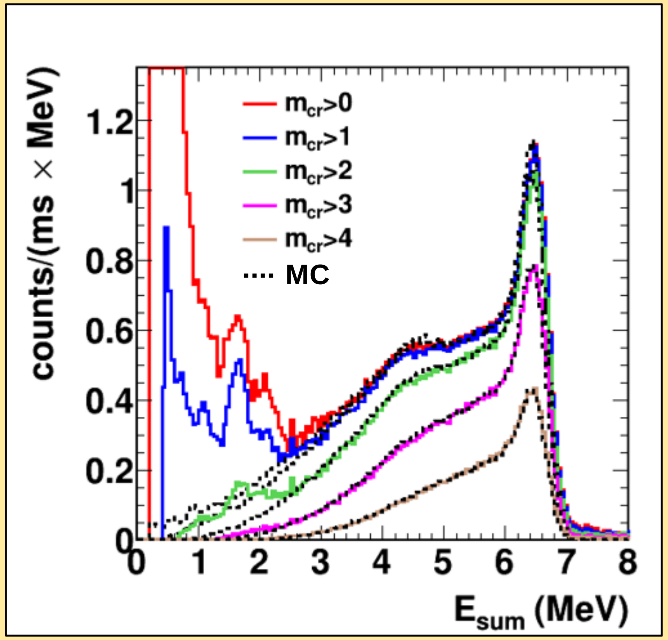
2.1 Fundamentals of the data analysis

$$Y_x^{exp}(E_n) = \frac{C_{tot}(E_n) - C_b(E_n)}{\varepsilon_x(E_n)\,\phi(E_n)}$$

Detection efficiency

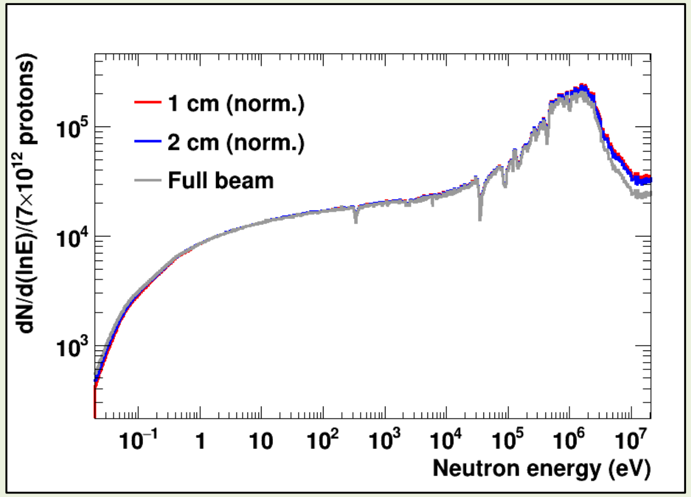
- Can be determined experimentally or by simulations.
- Only required for ^{239}Pu(n,γ).

Comparison of TAC E_{sum} spectra between experimental and MC simulations.



Neutron fluence crossing the sample

- Depends on sample diameter.
- Common for the same setup.

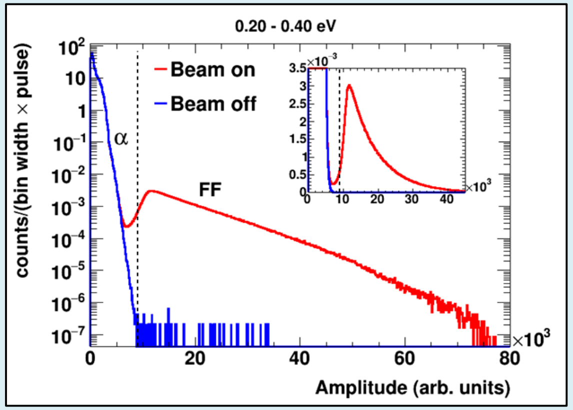


Count rate due to background events

- Measured through dedicated background measurements…
- or by simulations.

Data reduction (thresholds)

- FFD: α-FF discrimination using amplitude threshold in the FFD signals.



- TAC: energy and multiplicity thresholds to improve signal-to-background ratio.

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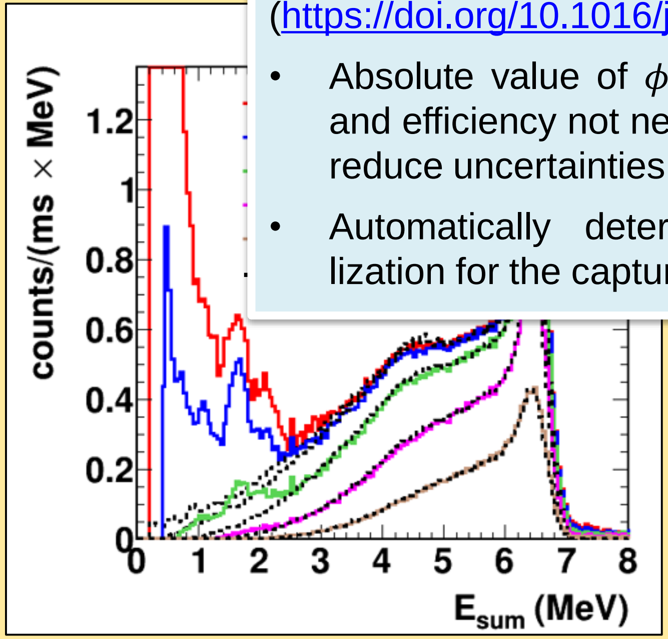


Normalization

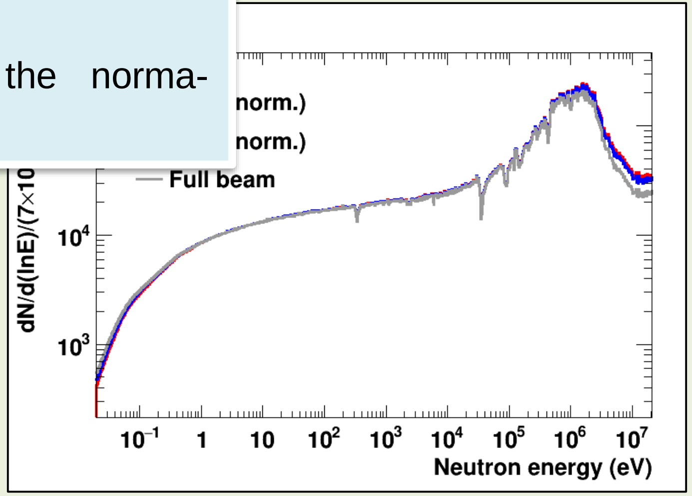
The fission yield was normalized to the recommended evaluated $^{239}Pu(n,f)$ cross section integral (9-20 eV) by I. Durán et al. (https://doi.org/10.1016/j.nds.2024.01.004).

- Absolute value of $\phi(E_n)$, sample mass, and efficiency not needed → significantly reduce uncertainties.
- Automatically determines the normalization for the capture yield.

…utron fluence …ing the sample

…n sample diameter.

…or the same setup.



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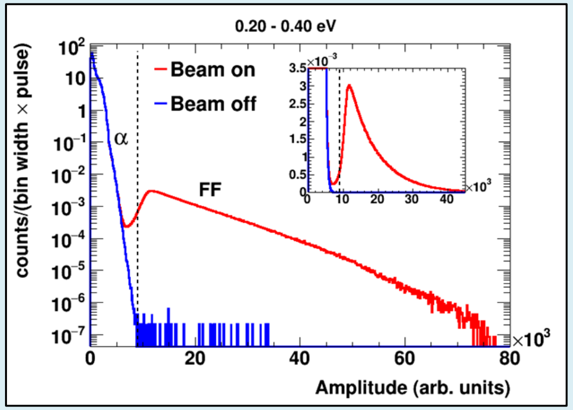
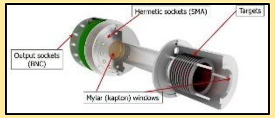


- TAC: energy and multiplicity thresholds to improve signal-to-background ratio.

2.2 Summary of backgrounds for capture

FC setup (FFD + TAC)



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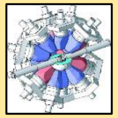
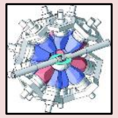
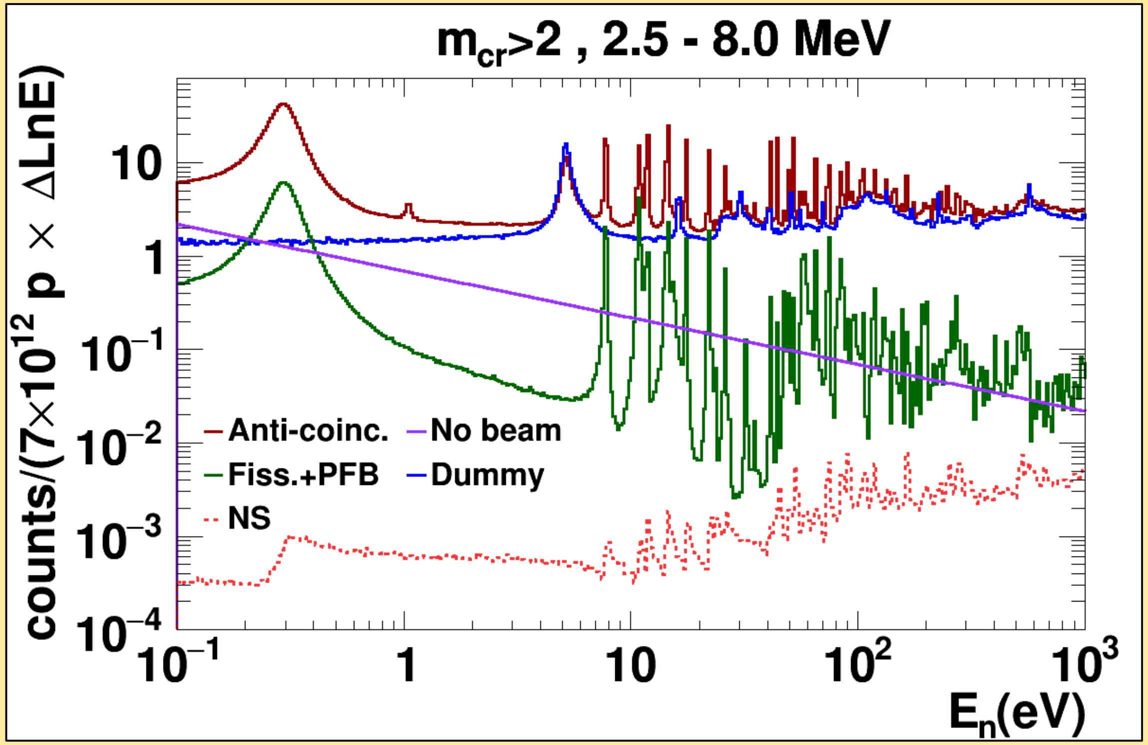


TS setup (TAC)

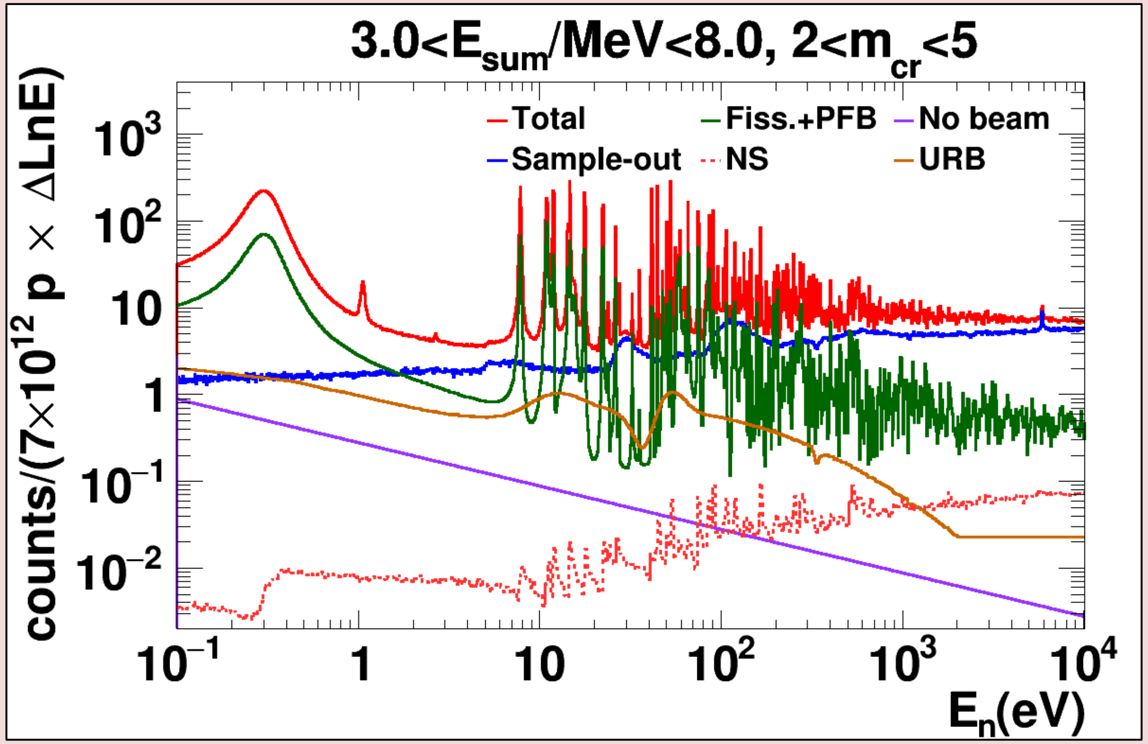


Background contributions in both setups: some components share similar approaches but others (fission) required completely different procedures.

TAC count rates as a function of neutron energy

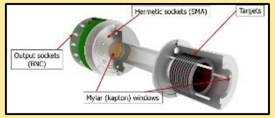


TAC count rates as a function of neutron energy



2.2 Summary of backgrounds for capture

FC setup (FFD + TAC)



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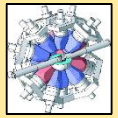
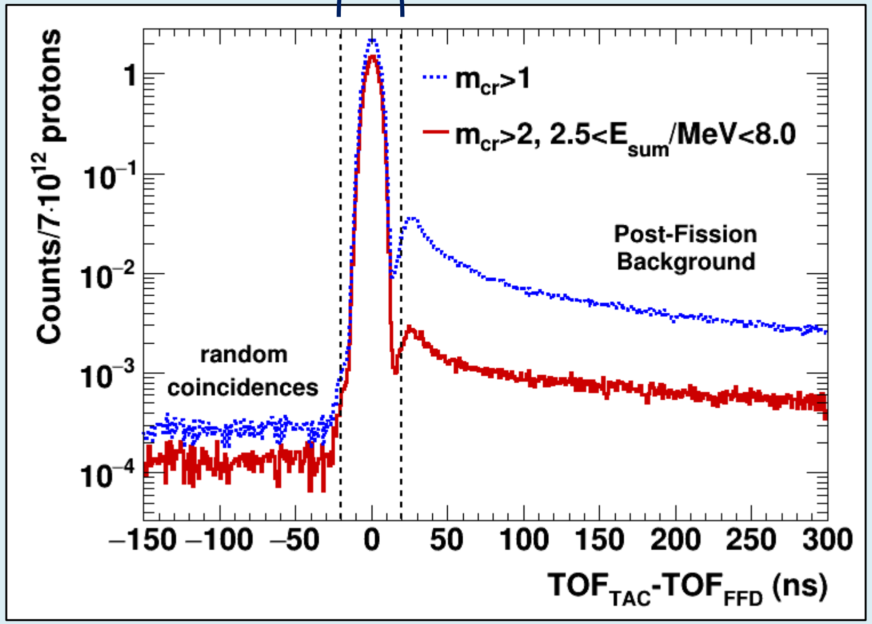


Fission subtraction: Fission Tagging[1,2,3]

FFD+TAC event coincidences used as veto to suppress fission background.

coincidence window



[1] C. Guerrero et al., Eur. Phys. J. A 48, 29 (2012).
[2] J. Balibrea-Correa et al., Phys. Rev. C 102, 044615 (2020).
[3] M. Bacak et al., EPJ Web of Conferences 211, 03007 (2019).

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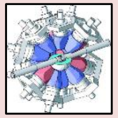
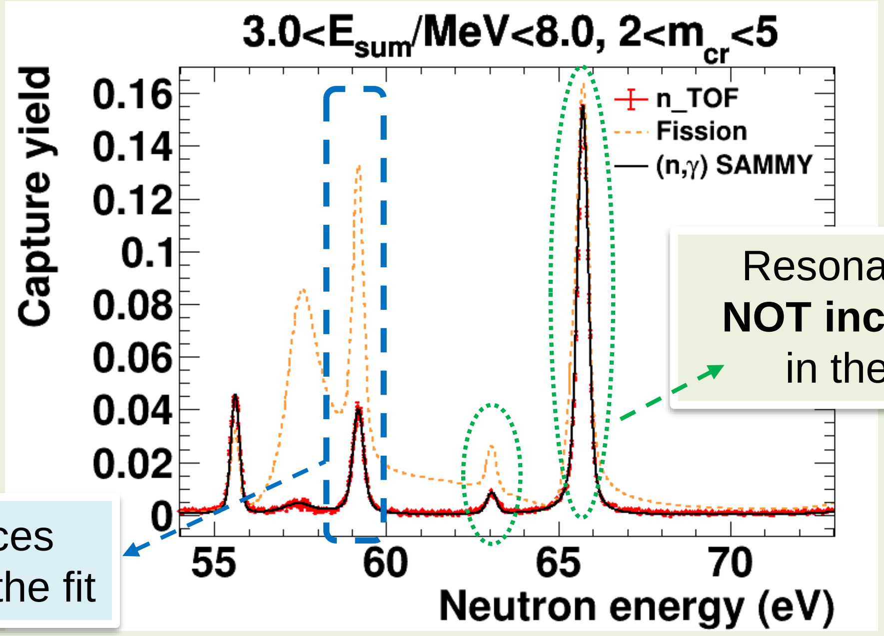
TS setup (TAC)



Fission subtraction in the TS setup

- Use the results from the FC setup.
- FC-TS overlap region below 200 eV → fit of capture and fission yields on selected resonances (resonance parameters from SAMMY fit).



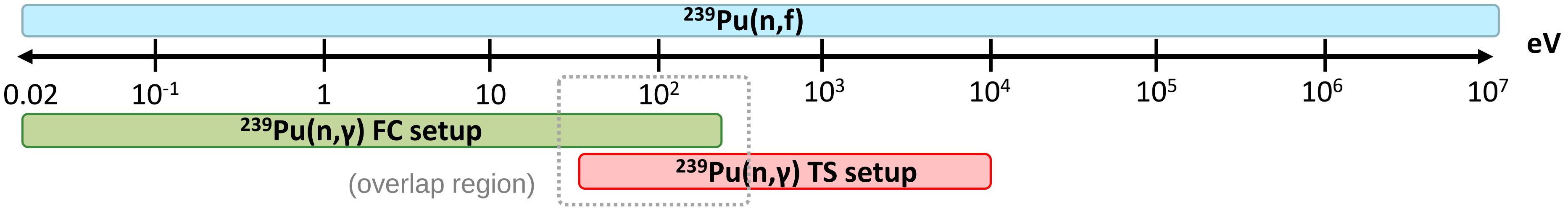
Resonances **NOT included** in the fit

Resonances included in the fit

2.3 Resonance parameters: SAMMY fit

To obtain a final set of resonance parameters (RPs) **combining the three measured datasets**:

- **Fission yield (FC setup).**
- **Capture yield (FC setup).**
- **Capture yield (TS setup).**

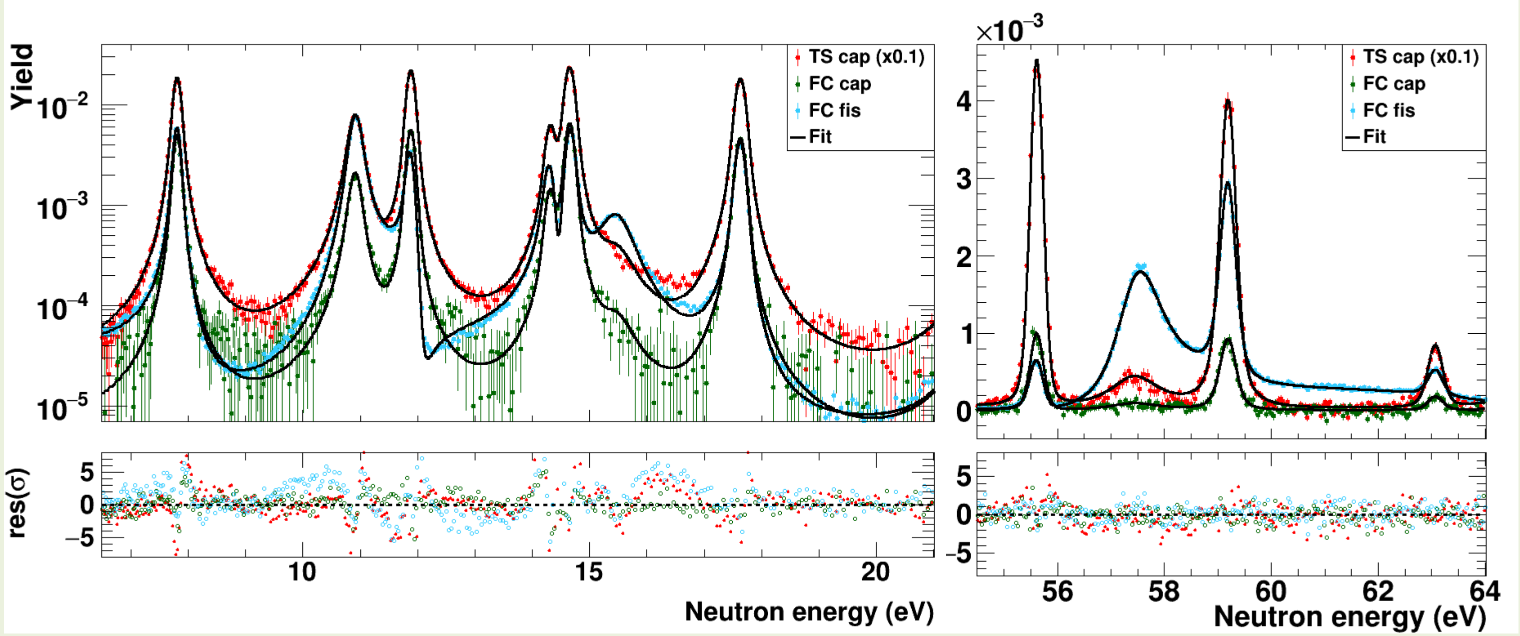


Combine capture data from both setups:

- FC data for $E_n < 200$ eV.
- TS data for $E_n > 200$ eV and some low-statistics resonances below 200 eV (overlap region).

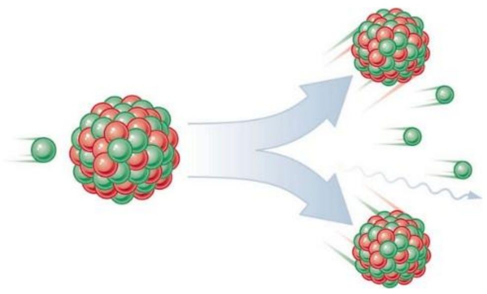
The resonance analysis obtained the resonance parameters for **1000 resonances up to 2.5 keV**:

- Neutron energy E_n, neutron width Γ_n, capture width Γ_g, and fission width Γ_f.



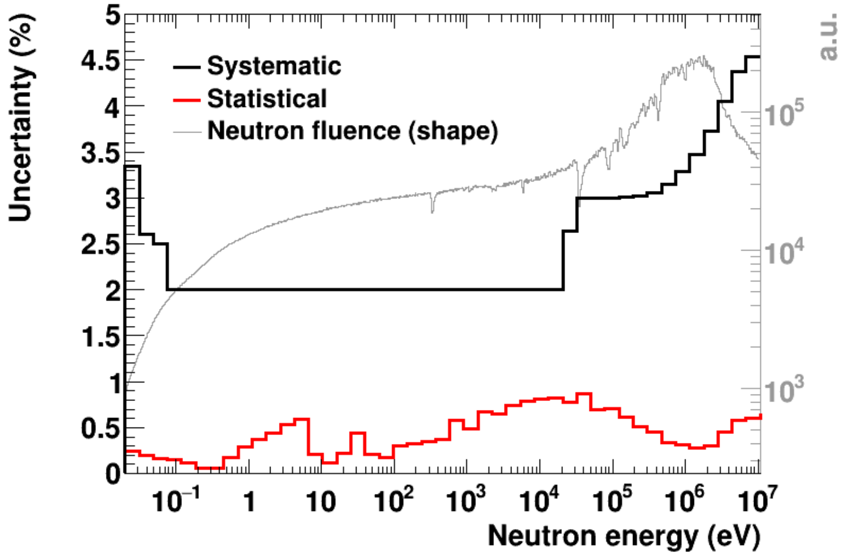
3

Fission results

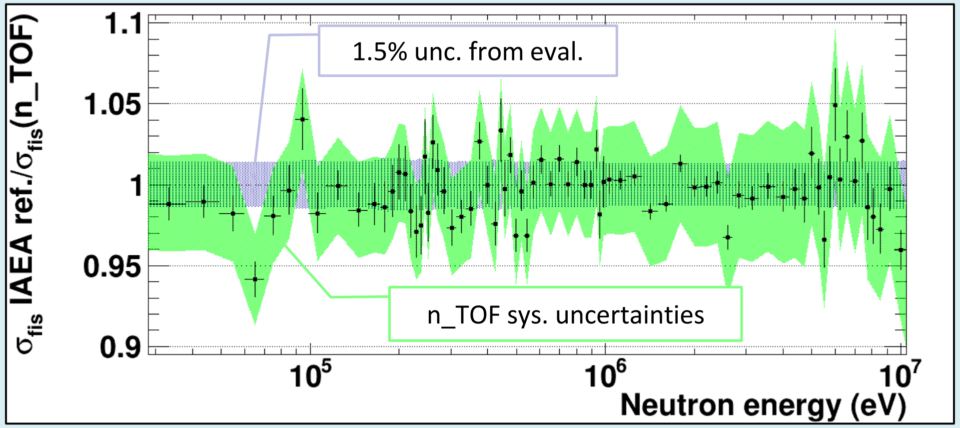


3.1 Fission results: uncertainties and integrals

Low-uncertainties were achieved due to the **excellent properties of samples and fission chamber**, which did not require additional corrections apart from neutron fluence shape.



Our results are compatible with the ^{239}Pu(n,f) cross section **reference (0.15-200 MeV) from the 2017 IAEA's** Neutron Data Standards (NDS).



Excellent compatibility with well-known ^{239}Pu(n,f) cross section integrals, from thermal to fast energy regimes.

statistical (red) systematic (blue)

	I_1 (0.02-0.06 eV)	I_3 (9-20 eV)	I_3/I_1	I_{HE} (8-10 MeV)
n_TOF / I. Durán et al.	1.011(1)(29)	**1.0**	0.989(2)(20)	1.014(8)(46)
n_TOF / ENDF/B-VIII.1	1.014(1)(29)	1.010(1)(20)	0.995(2)(20)	1.007(8)(46)
n_TOF / ENDF/B-VIII.0	1.013(1)(29)	1.007(1)(20)	0.994(2)(20)	1.016(8)(46)
n_TOF / JEFF-3.3	1.015(1)(29)	1.010(1)(20)	0.995(2)(20)	1.011(8)(46)

^{239}**Pu(n,f) spectrum-averaged cross section (SACS)** in the ^{252}Cf(sf) reference neutron field. Total SACS uncertainties are reported.

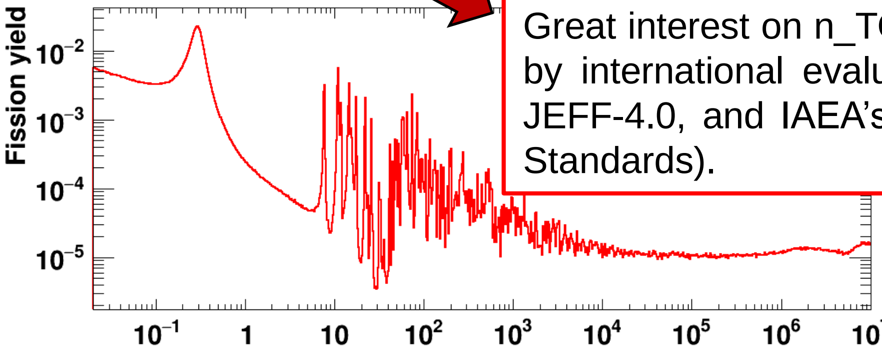
Data	SACS
Derived, this work	**1802±65 (3.6%)**
Derived, IAEA standard 2017[1]	1798±23 (1.3%)
Mannhart evaluation[2]	1812±25 (1.4%)
Capote et al. evaluation[3]	1826±19 (1.0%)

Excellent agreement with evaluations in the regions where the cross section is very well known → confidence in our data to improve regions where it is not so well-known.

[1] Carlson et al., Nucl. Data Sheets 148, 143–188 (2018).
[2] Bersillon et al., IAEA TRS 452 (2006).
[3] Capote et al., EPJ Web Conf. 281, 00027 (2023)

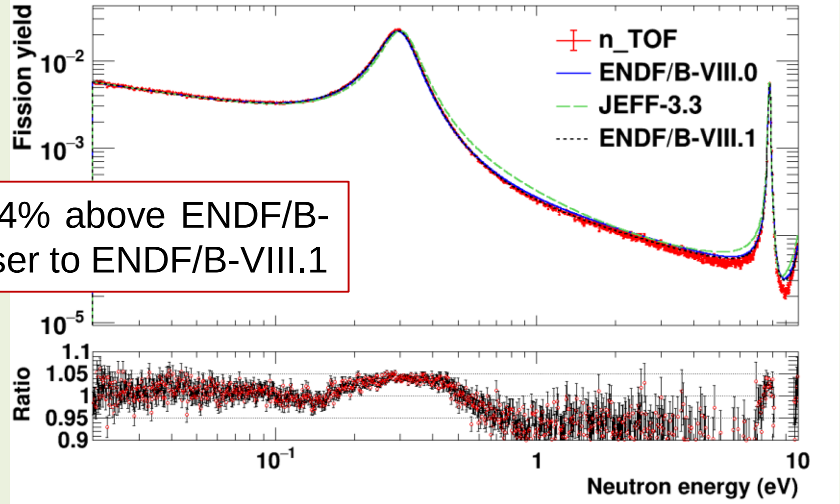
3.2 Fission results: comparison with evaluations

^{239}Pu fission dataset with the broadest neutron energy range to date, covering almost 9 orders of magnitude, from thermal to fast region.



Great interest on n_TOF data shown by international evaluators (INDEN, JEFF-4.0, and IAEA's Neutron Data Standards).

First ^{239}Pu resonance at 0.3 eV, of relevance for nuclear reactor technology.

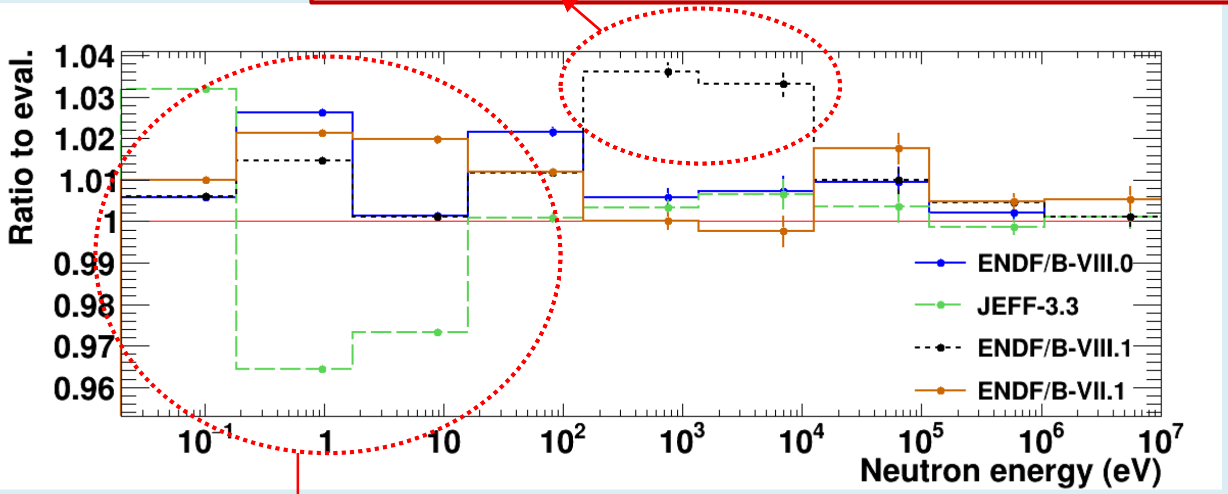


n_TOF about 4% above ENDF/B-VIII.0, and closer to ENDF/B-VIII.1

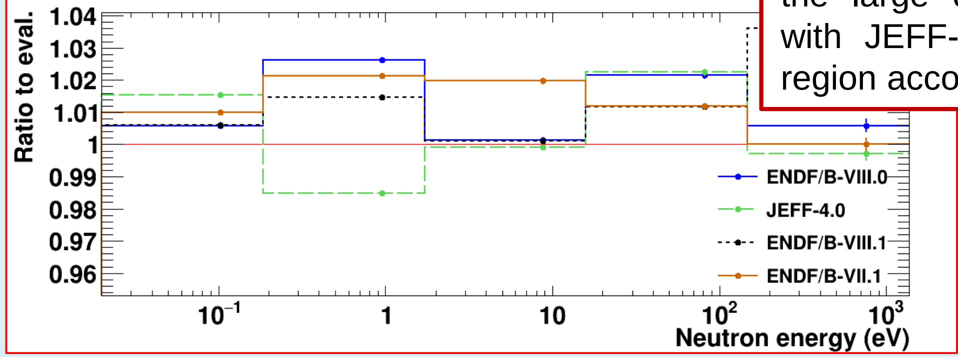
Ratios calculated relative to ENDF/B-VIII.0

Ratios of our data to different ^{239}Pu(n,f) evaluations from major libraries. With broader bins, differences are not larger than 3% (within uncertainties).

ENDF/B-VIII.1 evaluation taken from INDEN, with an increase around 1 keV not compatible with n_TOF data.



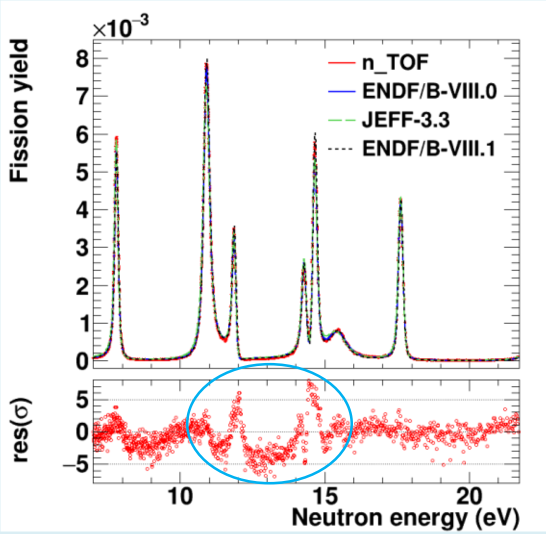
JEFF-3.3 ↔ JEFF-4.0

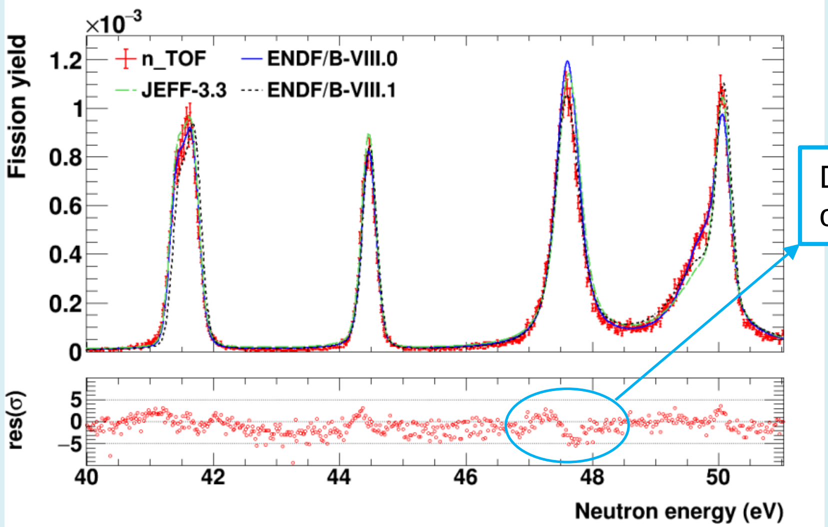


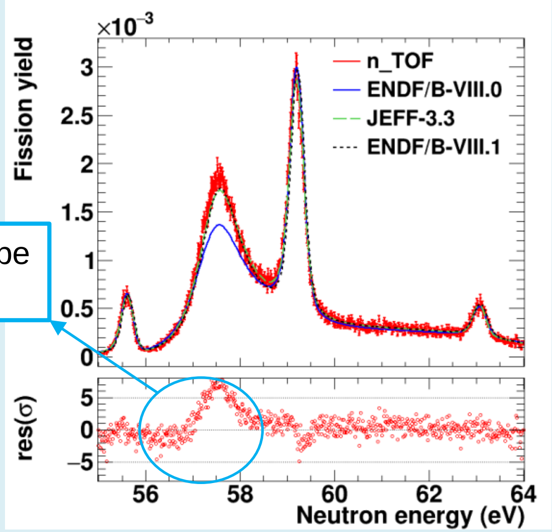
New JEFF-4.0 evaluation improves the large discrepancies observed with JEFF-3.3 in the low energy region according to n_TOF data.

3.2 Fission results: comparison with evaluations

Some examples of fission yield resonances

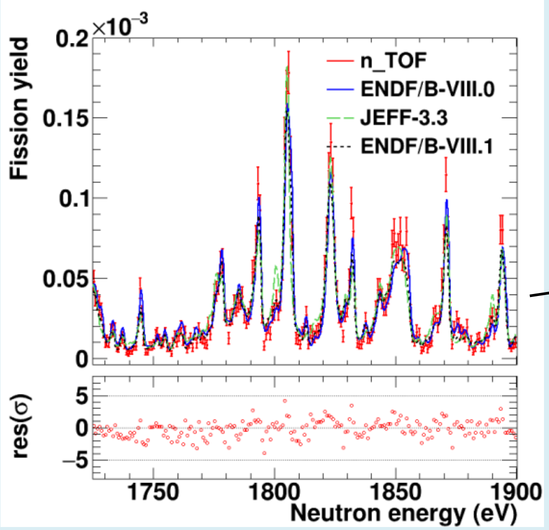




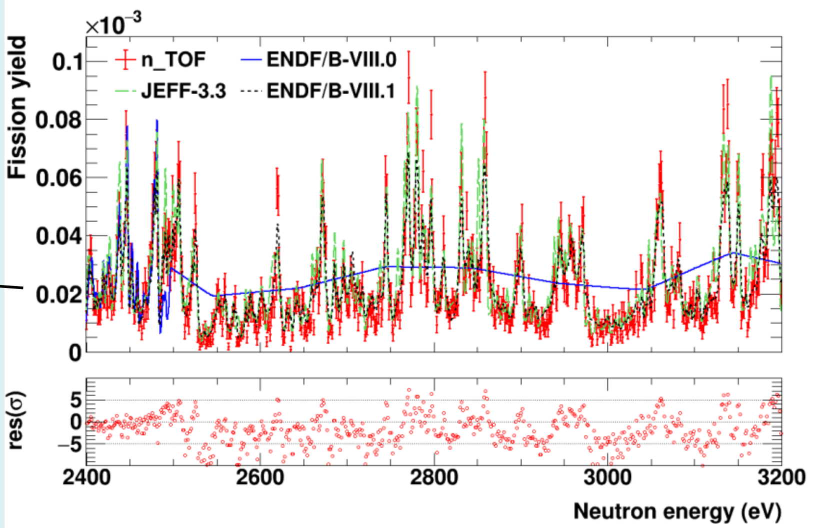


Discrepancies in the shape of some resonances

Residuals calculated relative to ENDF/B-VIII.0



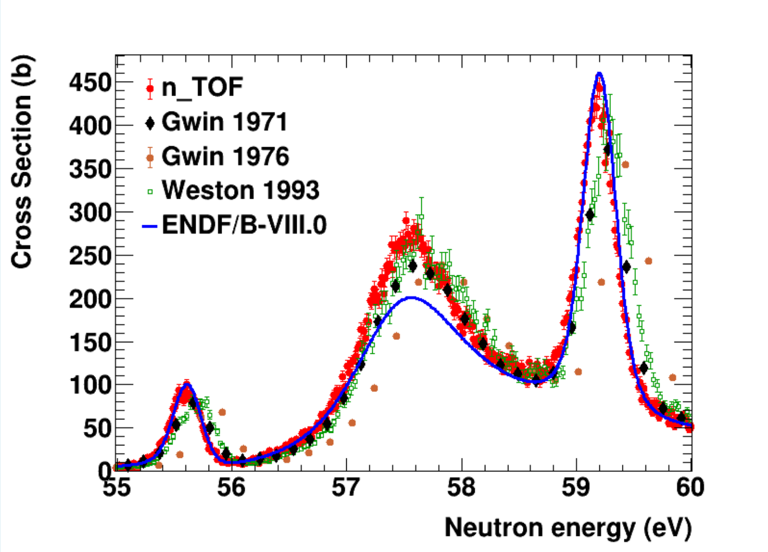
Resonances and structures are observed even at relatively high neutron energies, surpassing the limit of the resolved resonance region of some libraries (up to 2.5 keV).



3.3 Fission results: comparison with experimental data

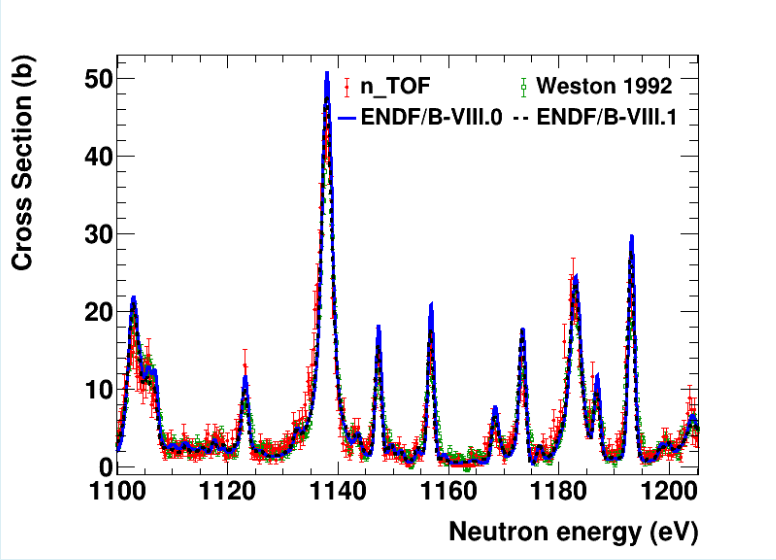
Energy resolution

The longer flight path of n_TOF (185.6 m) allows obtaining a higher neutron energy resolution, which is visible in the shape of some resonances.



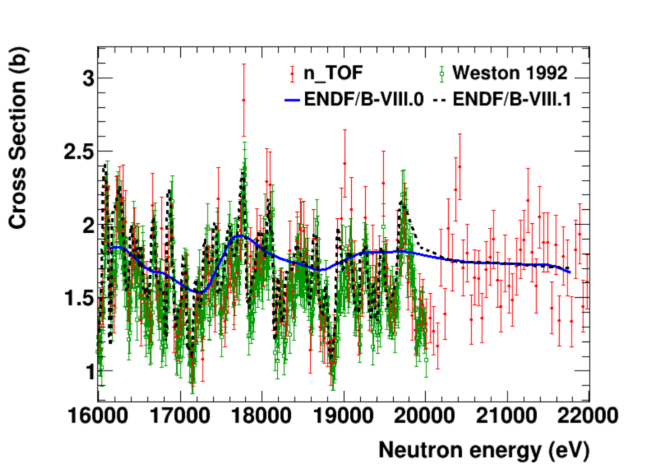
Weston 1992 data

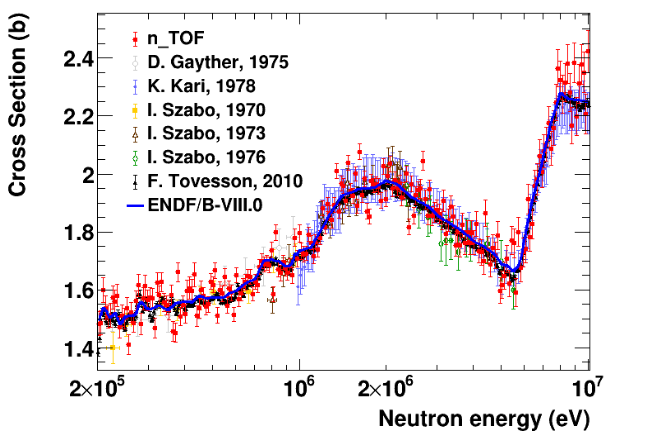
Good compatibility with Weston 1992 data in intermediate energy range resonances, with similar energy resolution.



High energies

Our data may help extend physical fluctuations in evaluations above 20 keV (limit of Weston 1992 data).

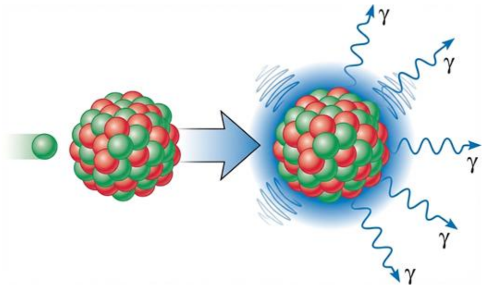


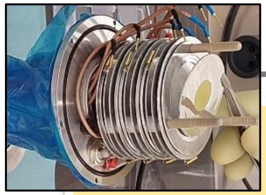


n_TOF data provides the broadest dataset in neutron energy with high resolution and contained uncertainties, providing valuable information in low, intermediate and high energy regions up to 10 MeV.

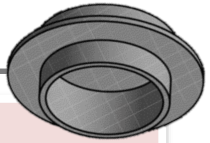
4

Capture results

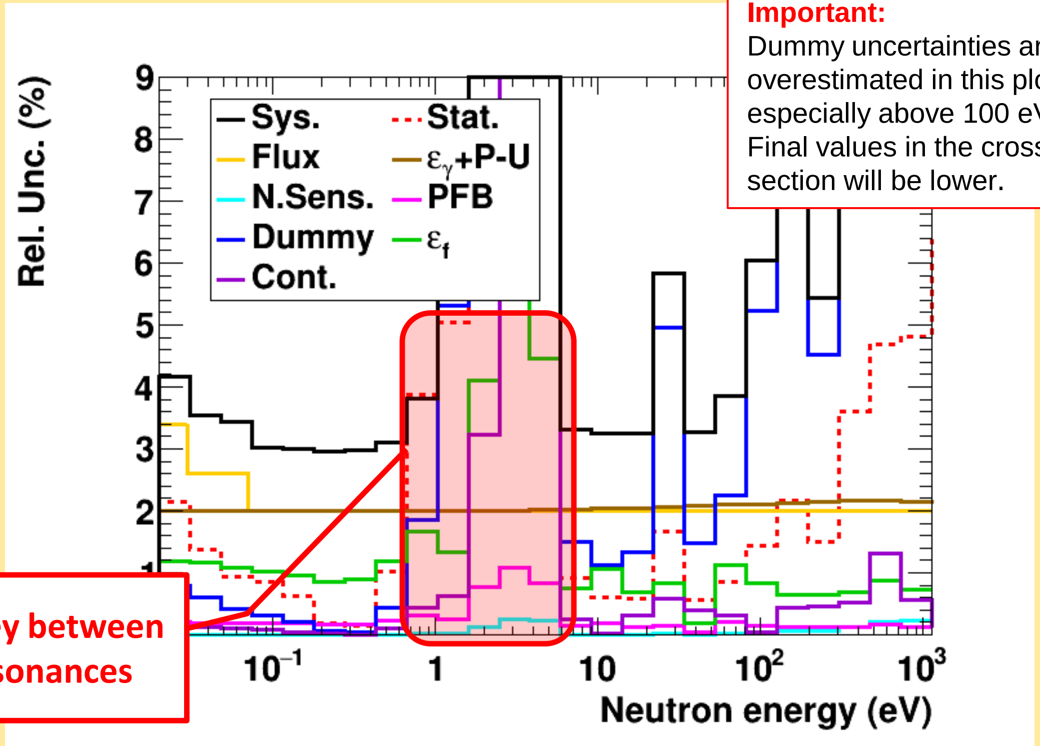




4.1 Capture results: uncertainties



FC setup



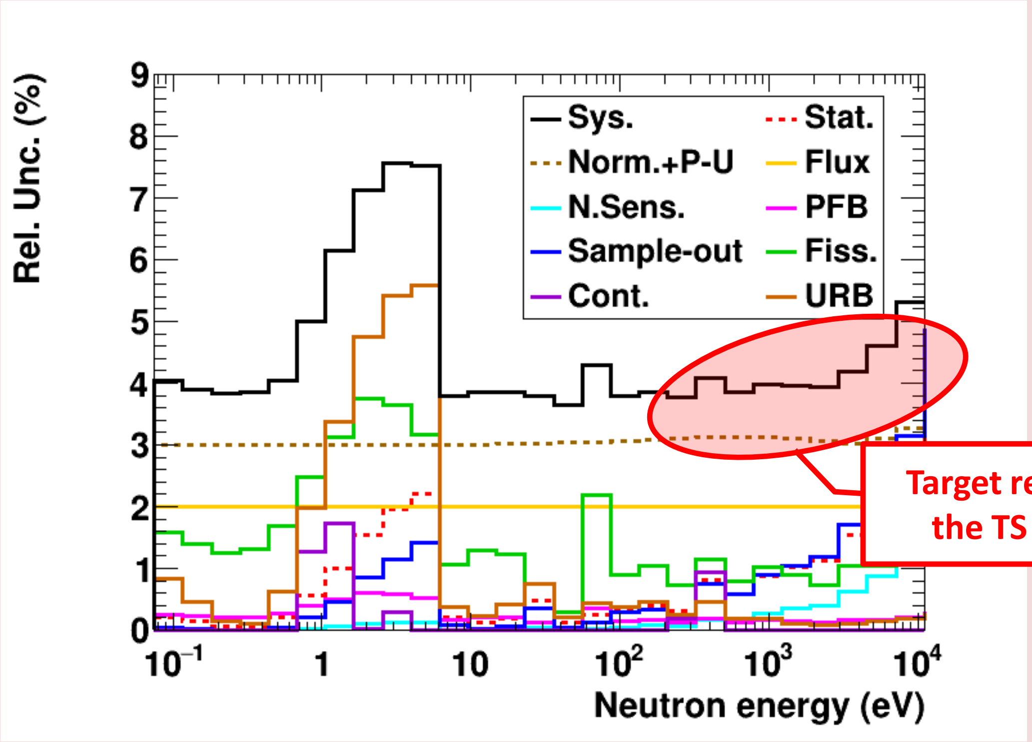
Important:
Dummy uncertainties are overestimated in this plot, especially above 100 eV. Final values in the cross-section will be lower.

Valley between resonances

5 bins per decade

Overall uncertainty between 3-4%

TS setup

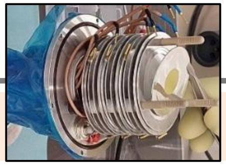


Target region of the TS setup

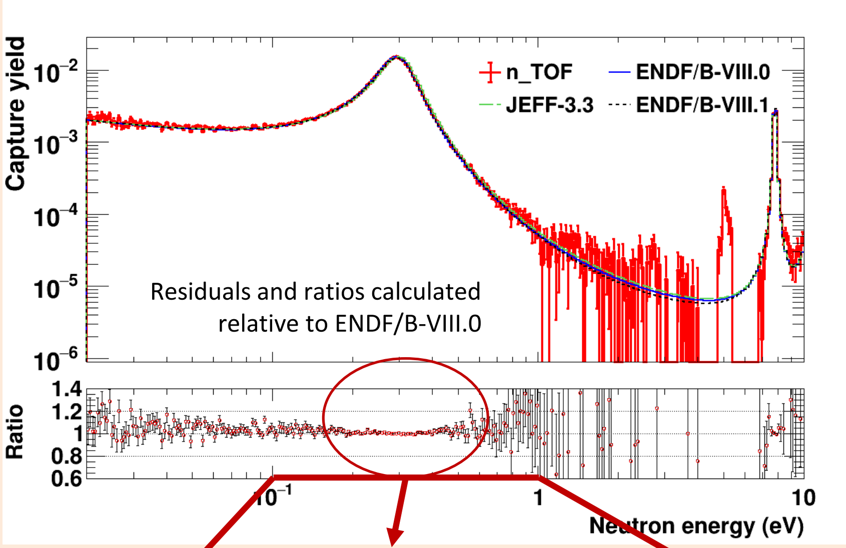
5 bins per decade

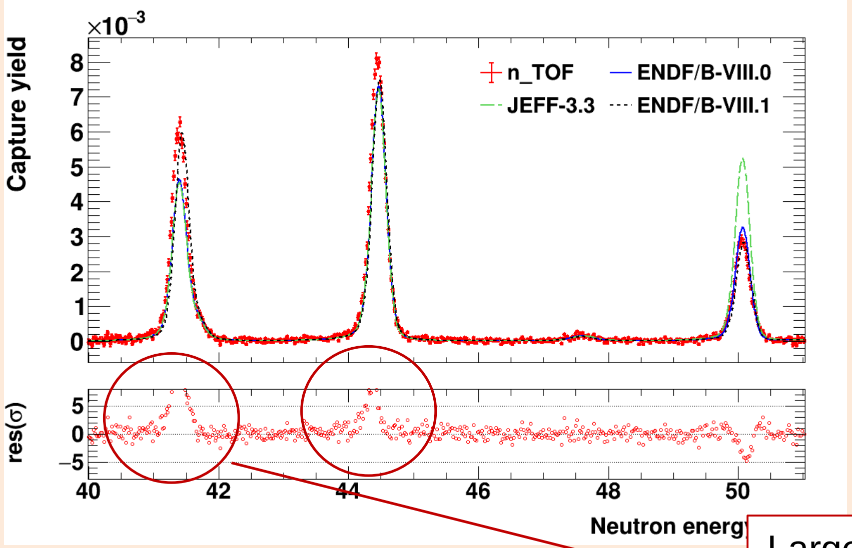
Overall uncertainty between 4-5%

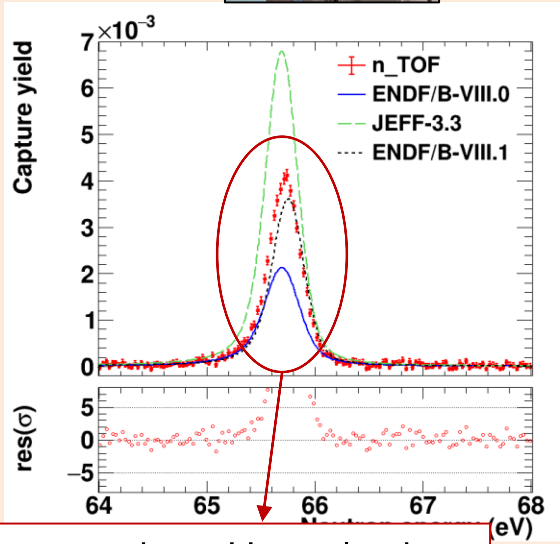
4.2 Capture results: comparison with evaluations



Some examples of capture yield resonances (FC setup)

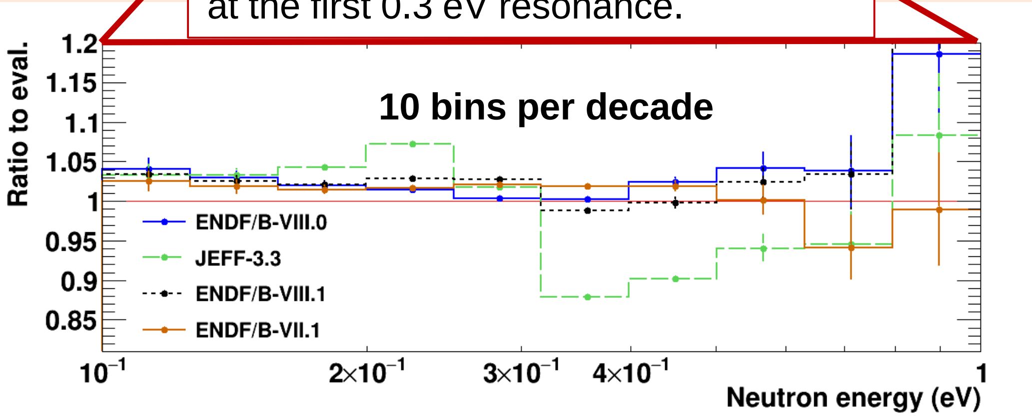




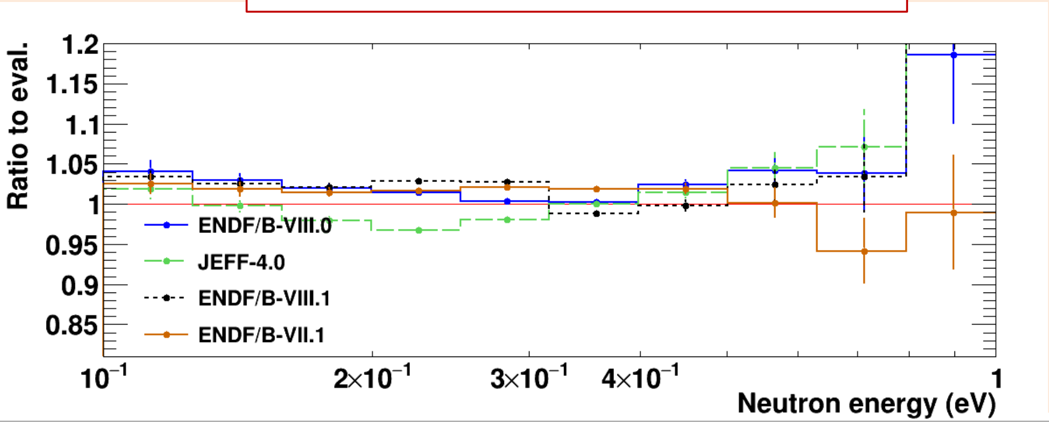


Large discrepancies with evaluations (and among themselves) in the shape of some resonances.

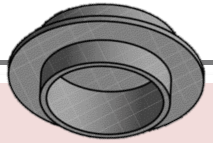
Great compatibility with ENDF/B-VIII.0 at the first 0.3 eV resonance.



JEFF-3.3 ↔ JEFF-4.0

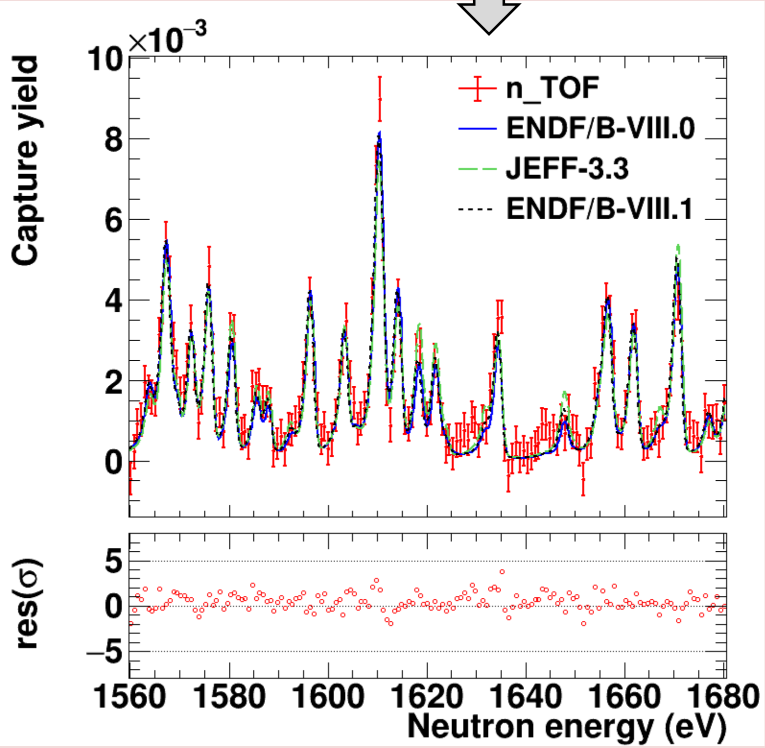


4.2 Capture results: comparison with evaluations

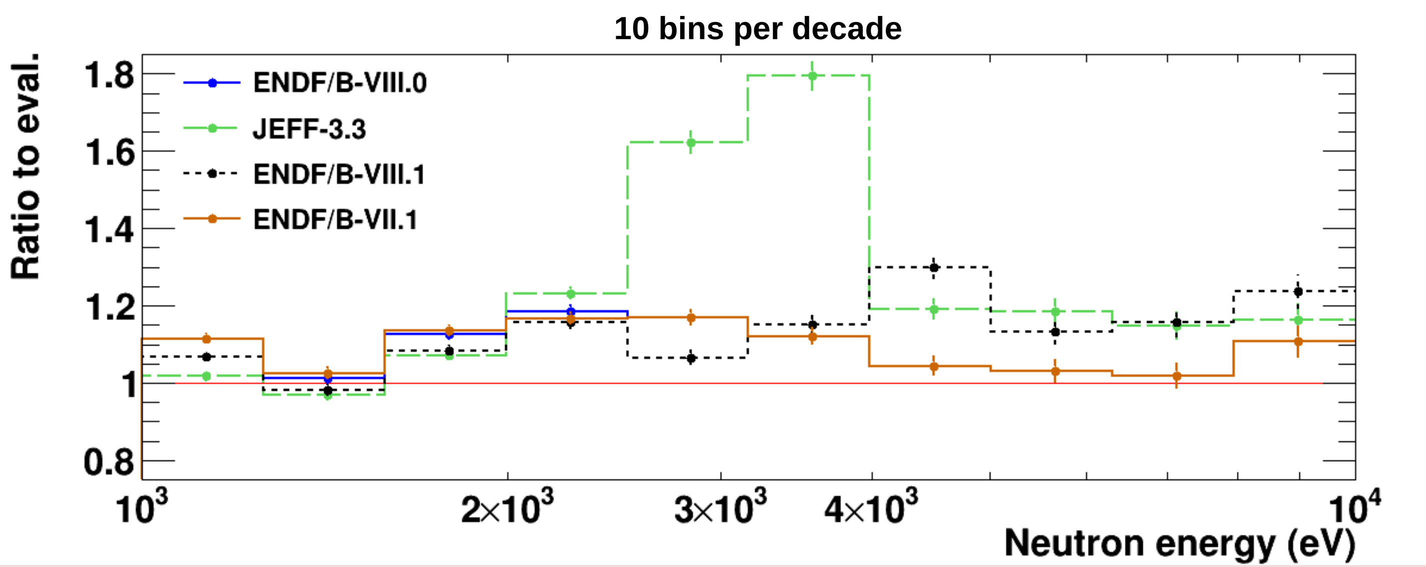


TS setup data at high energies

The capture yield from the data with the larger mass sample enables preforming **SAMMY analysis up to higher neutron energies** with reasonable energy resolution and statistics.



Ratio of integrated yield from TS data above 1 keV: n_TOF data remains 5-10% systematically above evaluations with best agreement to the ENDF/B-VII.1 evaluation.



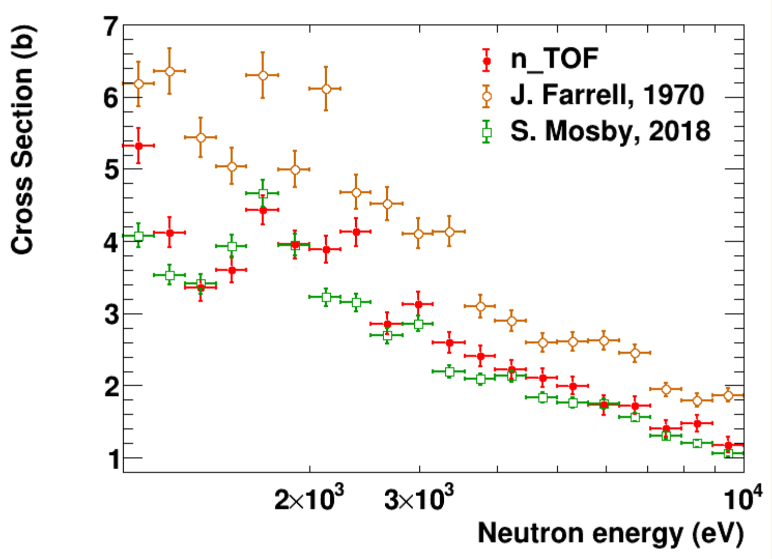
ENDF/B-VIII.0 and VIII.1 may be influenced by Mosby 2018 data for this region.

4.3 Capture results: comparison with experimental data

Scarcity of high-resolution ^{239}Pu(n,γ) cross-section measurements. Two datasets in EXFOR (Gwin 1971, Mosby 2014/2018) mainly used for all evaluations.

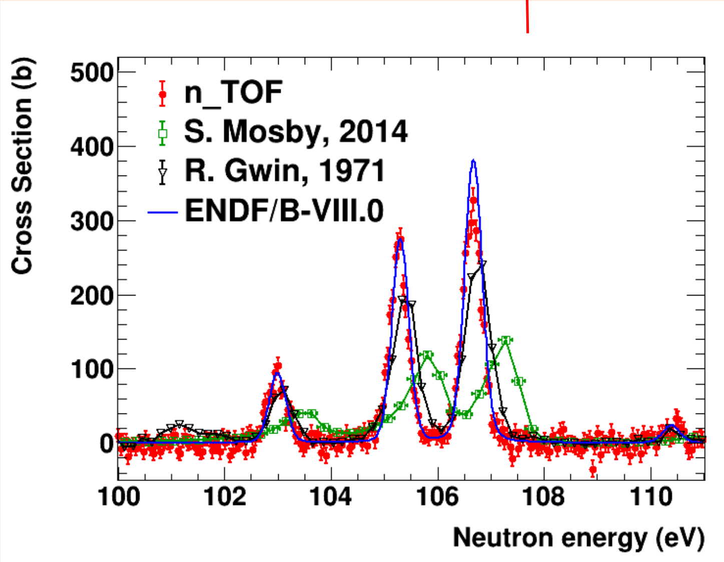
High neutron energies

At higher neutron energies, from 1 keV to 10 keV (TS setup), the n_TOF cross section integrals generally stays slightly above Mosby 2018 data.



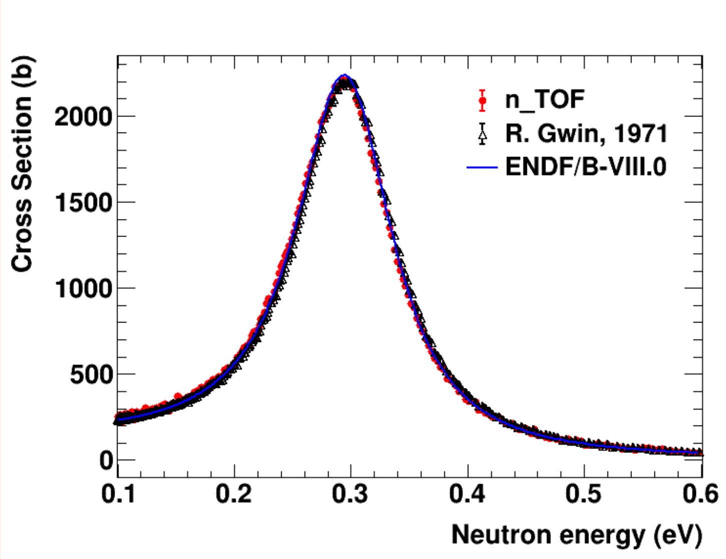
Energy resolution

Our capture data exhibit **the highest neutron energy resolution** among the existing experimental data.



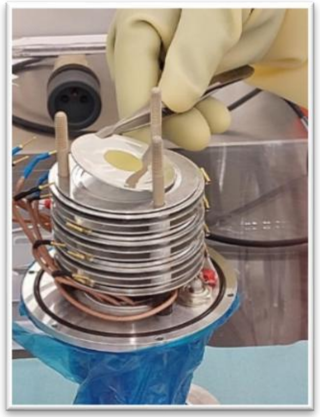
First resonance @ 0.3 eV

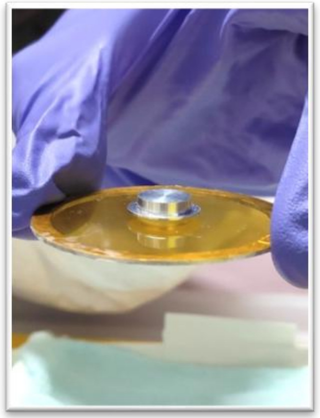
Good compatibility within uncertainties with Gwin 1971 dataset in the shape and size of the first, large resonance at 0.3 eV. Both slightly below evaluation at peak.



5. Summary and Conclusions

Successfully accomplished the ^{239}Pu measurement of fission and capture cross sections (and α-ratio) for the first time at n_TOF (CERN), through a collaboration between CIEMAT, JRC-Geel, SCK CEN and University of Lodz. The excellent properties of the facility, samples, and the detection systems, along with the experienced acquired through previous n_TOF fission-tagging measurements, have resulted in new high-quality experimental data for ^{239}Pu, providing valuable input for future evaluations.





Fission

- Broad energy coverage (20 meV to 10 MeV) and low-uncertainties.
- Data submitted to EXFOR data bank at the end of 2025.
- Publication in Physics Letters B: 10.1016/j.physletb.2025.140070
- Good candidate to become a reference dataset for future evaluations.

Capture

- Successful combination of thin and thick sample measurements to cover a wider energy range from 0.1 eV to 10 keV.
- High-resolution dataset to contribute to the scarcity of measurements for evaluations.
- Draft paper will be submitted this year.
- All details in my PhD Thesis: 10.17181/179rm-jc146

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

European Research Council

- **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

- This work was supported by the European Union NextGenerationEU/PRTR project C17.I02.P02 – SGI_GICS, subproject C17.I02.P02.S01 CIEMAT_CERN.
- **Spanish national projects** PGC2018-096717-B-C21, PID2021-123100NB-I00 and PDC2021-120828-I00.
- This work has been supported by the ENRESA-CIEMAT agreement 2023-2026 “Tecnologías Disponibles para la Transmutación de Radionucleidos de Vida Larga”.

THANK YOU!

Backup slides

2.3 ^{239}Pu samples

Samples were produced in the Target Preparation laboratory at JRC-Geel in collaboration with SCK CEN institute.

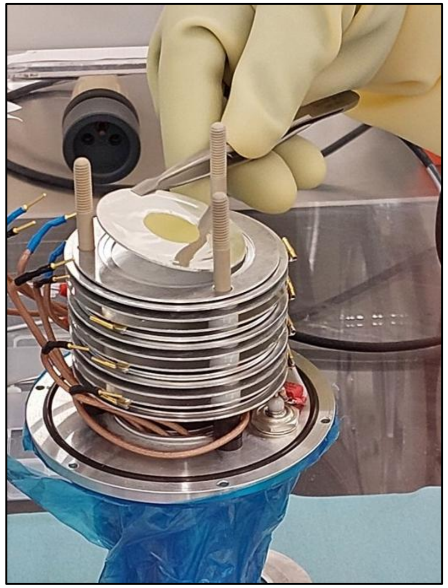
Plutonium base material

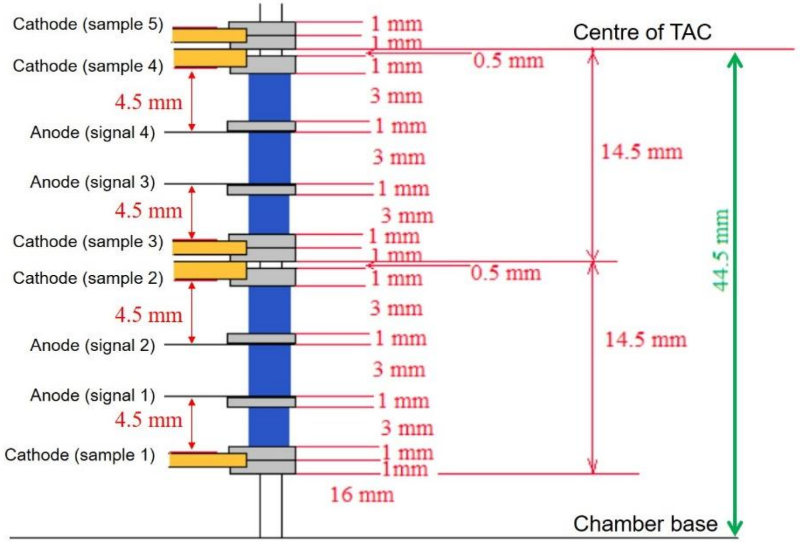
- Plutonium dioxide PuO_2.
- Purified from ^{241}Am.
- 99.9% purity of ^{239}Pu.
- From the same base material, two different type of samples were prepared.

Isotopes	Abundance (%)
^{239}Pu	**99.90**
^{240}Pu	0.06
^{241}Pu	0.02
^{242}Pu	0.01

Thin samples

- 10 samples deposited by molecular plating on 10 µm thickness aluminum foils.
- 20 mm diameter.
- 2 MBq and 950 µg each, expect for a ~10 times thinner sample with 0.3 MBq and 120 µg.
- Placed inside the FFD chamber, parallel and opposite-oriented (facing up- and down-stream).
- High homogeneity.





3.1 Neutron fluence

The Neutron fluence (shape) for the full beam **is known** from the SiMon monitoring data and the n_TOF evaluated flux. However, **corrections** are required to take into account the **smaller sizes of the samples** (Beam Interception Factor, BIF).

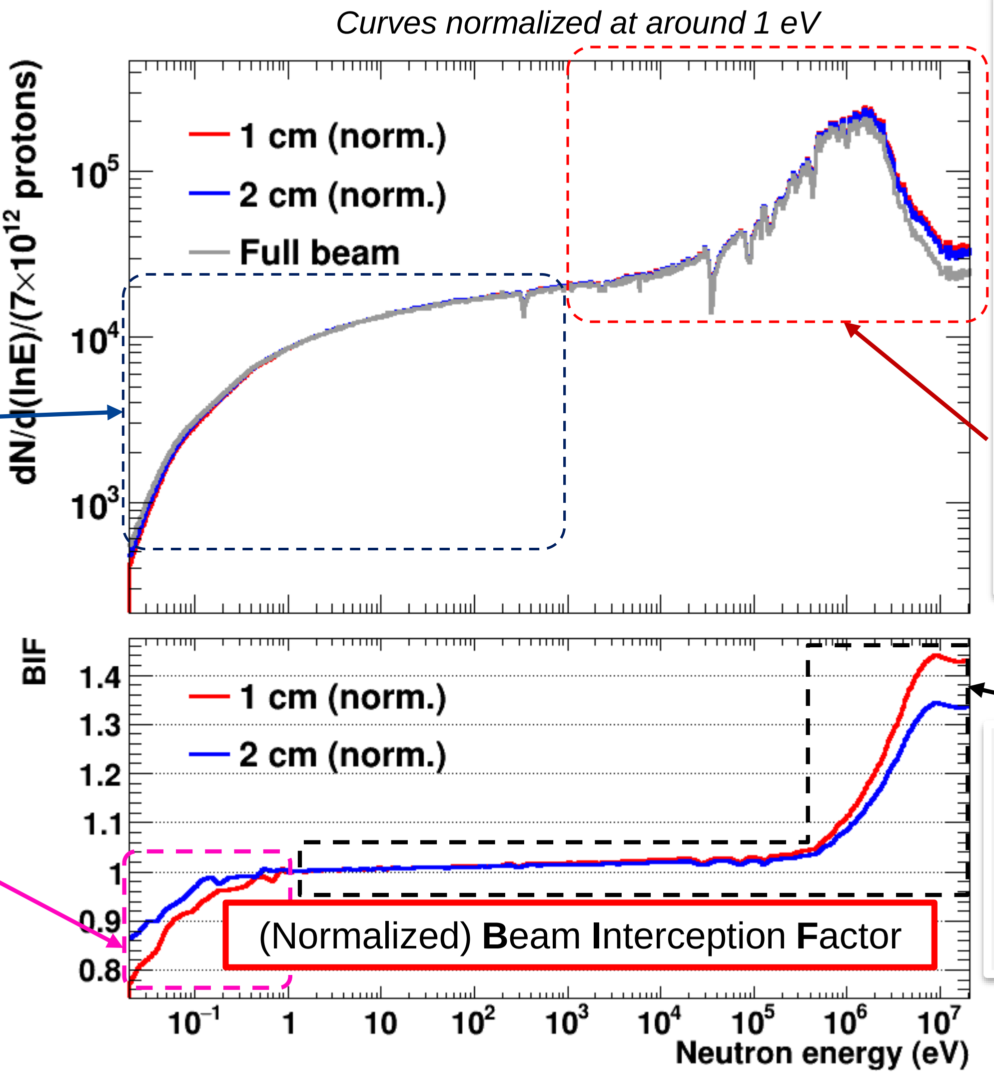
SiMon for 0.02 eV < E_n < 1 keV

The transmission through different dead-materials (aluminum, mylar) and the LiF foil of SiMon was taken into account (effect of about 1%), using FLUKA simulations.

BIF correction from ^{197}Au(n,γ)

The correction for the sample diameters **below 1 eV** was performed using ancillary measurements with gold samples of the same diameter.

^{197}Au(n,γ) cross section is smooth and well-known in this region.



EAR1 evaluated neutron fluence for E_n > 1 keV

Shape taken from the neutron beam commissioning at EAR1, using several detectors based on standard reactions:

- ^{6}Li(n,t)^{4}He
- ^{10}B(n,α)^{7}Li
- ^{235}U(n,f)

BIF from simulations

For E_n>1 eV, the BIF was determined from simulations with FLUKA.

3.2 Extraction of fission yield

Once the energy dependence of the neutron fluence for 2 cm samples, $\varphi_{2\text{cm}}$, is known, and the detectors are characterized (thresholds, calibrations…) the extraction of the fission reaction yield Y_f(En) is straightforward.

Fission Fragment count rate

$$Y_f(E_n) = \frac{C_{\text{FF}}(E_n) - C_b(E_n)}{\varepsilon_{FF}(E_n)\,\phi(E_n)}$$

$C_b(E_n) \to 0$

$\varepsilon_{FF}(E_n) \to N_f$

$\phi(E_n) \to \varphi_{2\text{cm}}(E_n)$ (previous slide)

Zero background

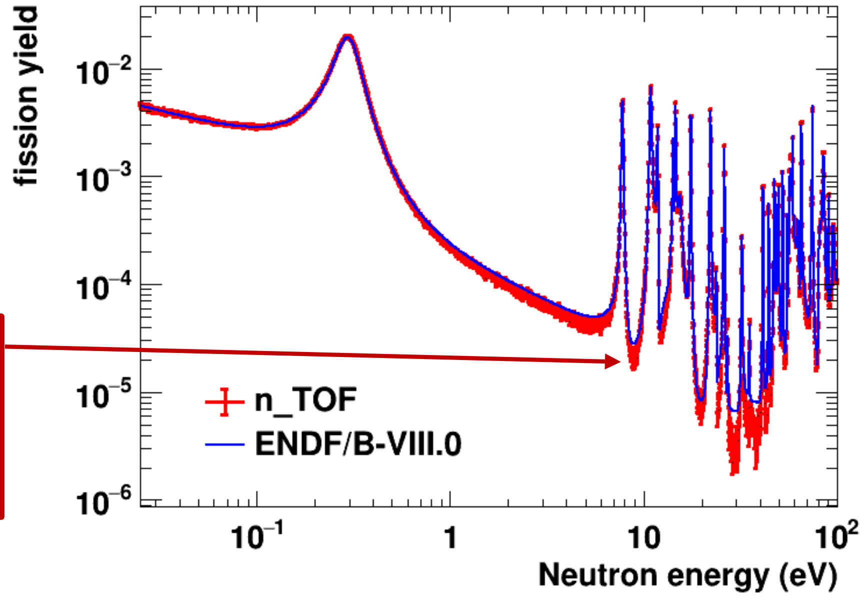
No background in the fission yield was observed after the α-FF separation.

Normalization constant N_f

The fission yield was normalized to the recommended evaluated ^{239}Pu(n,f) cross section integral (9-20 eV) by I. Durán et al. (https://doi.org/10.1016/j.nds.2024.01.004).

- ε_{FF} replaced by normalization factor N_f.
- Absolute value of $\phi(E_n)$, sample mass, and efficiency not needed → significantly reduce uncertainties.
- No dependence on E_n.
- Automatically determines the normalization for the capture yield.

Obtained yield compared with evaluation (ENDF/B-VIII.0)

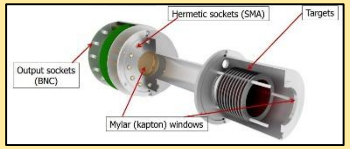


n_TOF data below evaluations in the valleys between resonances

↓

Indication of no residual background

3.3 TAC background subtraction: fission (FC)



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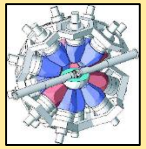


Fission subtraction in the FC setup

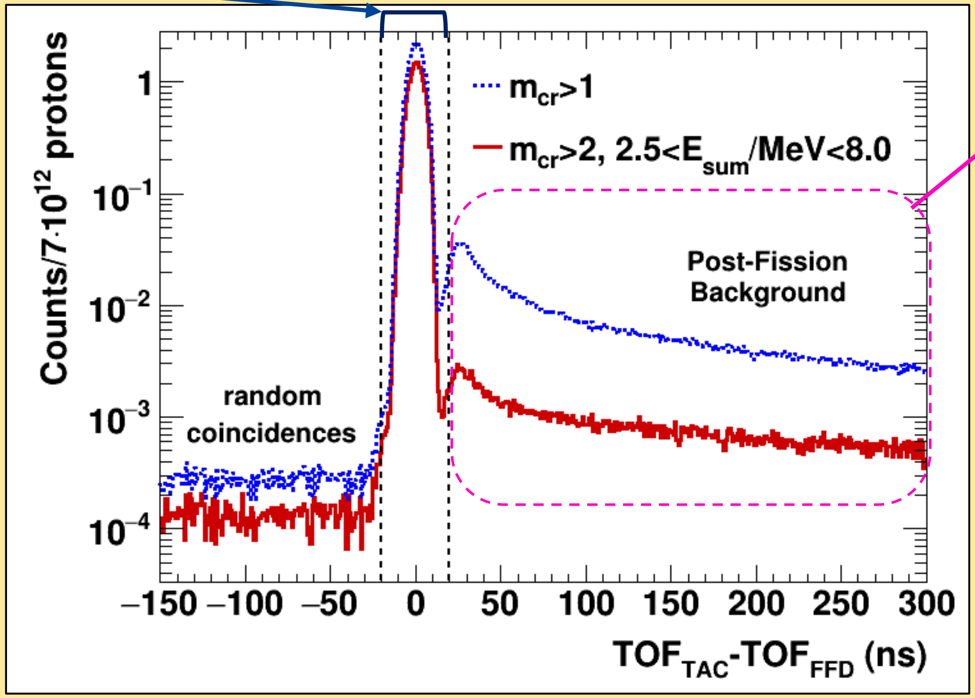
Fission tagging

Coincidences between FFD and TAC

Prompt Fission Coincidence window:

±20 ns

It covers practically the full prompt-fission peak while minimizing the probability of tagging non-fission events (<<1%). Consistent with previous fission tagging measurements.

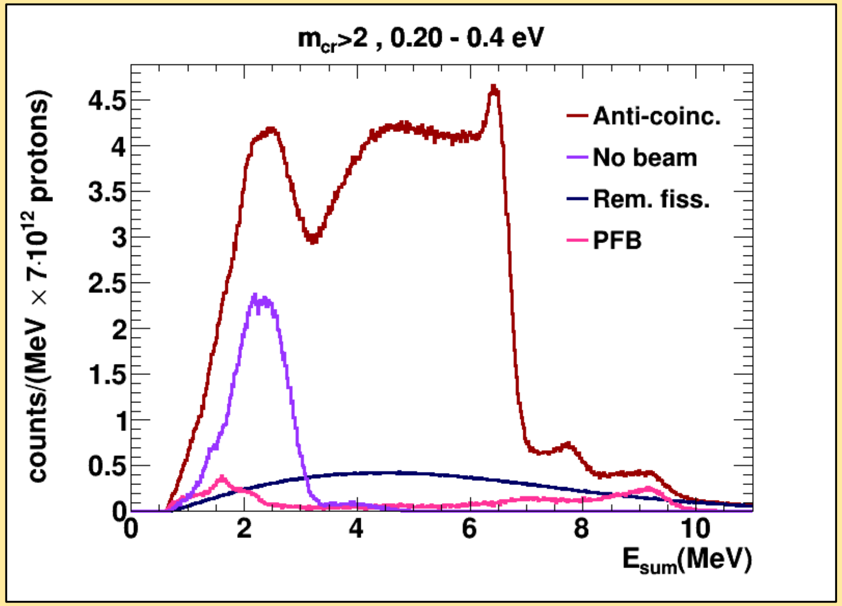


PFB

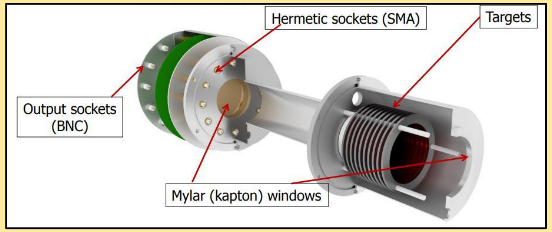
Post-**F**ission **B**ackground

Fission-related counts with ΔT>20 ns up to 3 us.

Attributed primarily to fission neutrons.



Fission subtraction in the FC setup



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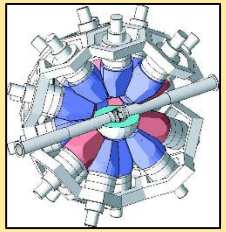
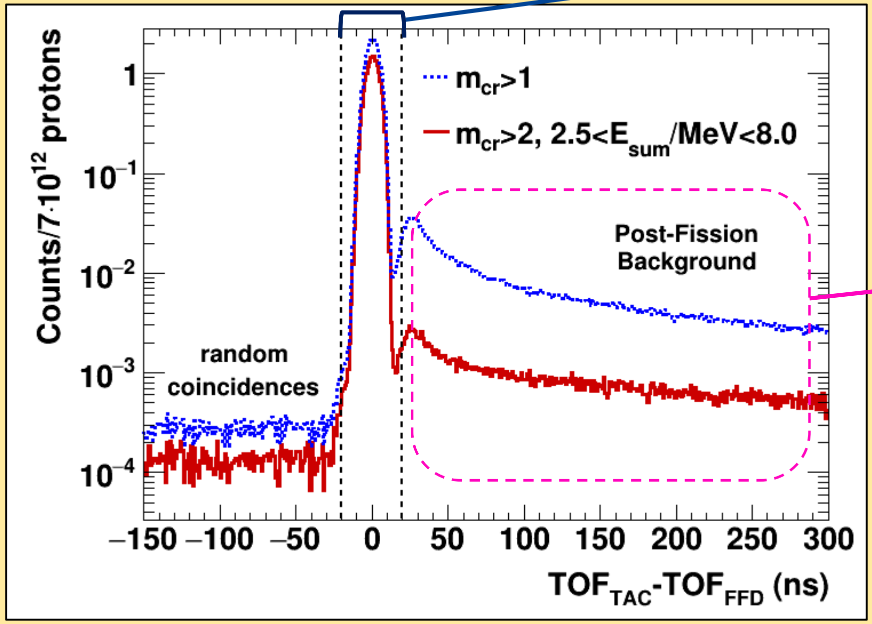


Fission tagging

Coincidences between FFD and TAC

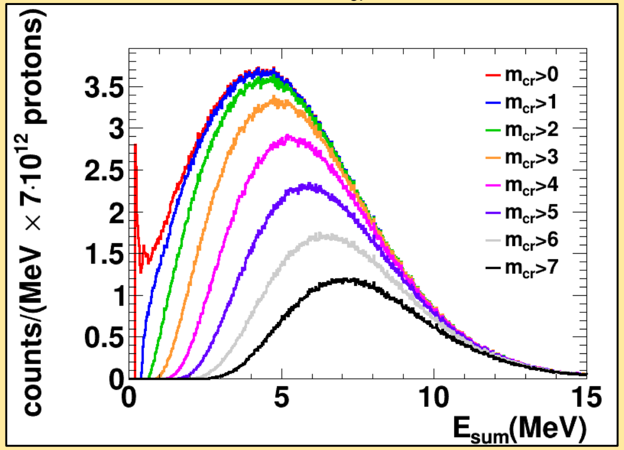


Fission tagging coincidence window

±20 ns

It covers practically the full prompt-fission peak while minimizing the probability of tagging non-fission events ($\ll$1%). Consistent with previous fission tagging measurements.

E_{sum} prompt fission spectrum under different m_{cr} cuts



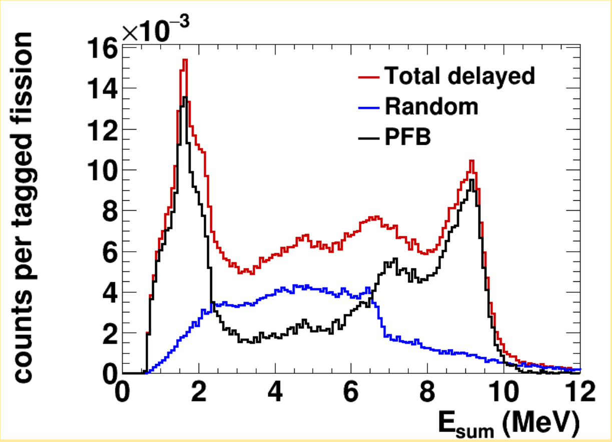
PFB

Post-**F**ission **B**ackground

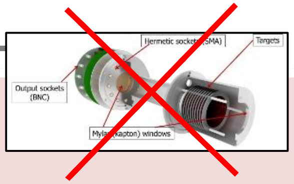
Fission-related counts with ΔT>20 ns up to 3 us.

Fission tagging enables the extraction of the PFB E_{sum} and count rate distribution.

Attributed primarily to fission neutrons.



3.3 TAC background subtraction: fission (TS)



Fission subtraction in the TS setup

General idea: to use the results of fission and capture that were accurately measured in the FC setup below 200 eV.

Followed approach:

1. Subtract all known non-fission backgrounds (excluding also PFB) and divide by the neutron fluence to obtain a *quasi-yield Y**.
2. This quasi-yield can be reasonably interpreted by a linear combination of the capture and fission yields:

We know ✓ — Measured in the TS setup

We want to know

$$Y^*(E_n) = \hat{\lambda}_{\gamma,TS} Y_{\gamma,TS}(E_n) + \hat{\lambda}_{F,TS} Y_{F,TS}(E_n)$$

Coefficients related with capture and fission detection efficiencies

Extrapolate to the rest of neutron energies using the found $\hat{\lambda}_{\gamma,TS}$ and $\hat{\lambda}_{F,TS}$ (constant) values.
$Y_{F,TS}(E_n)$ is taken from the FC setup:

- Derived from the RPs for the resonance region.
- Directly from the measured yield with the FFD above 2.5 keV.

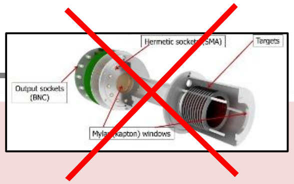
Restricted below 200 eV at selected resonances

$$Y^*(E_n) = \hat{\lambda}_{\gamma,TS} Y_{\gamma,TS}(E_n) + \hat{\lambda}_{F,TS} Y_{F,TS}(E_n)$$

$\hat{\lambda}_{\gamma,TS}$ and $\hat{\lambda}_{F,TS}$ can be determined by matching the experimental and expected capture yields in these resonances.

Yields derived with SAMMY using RPs from the FC setup

3.3 TAC background subtraction: fission (TS)



Fission subtraction in the TS setup

Results for the optimal coefficients

$$\lambda_{\gamma}^{min} = 1.038(31)$$

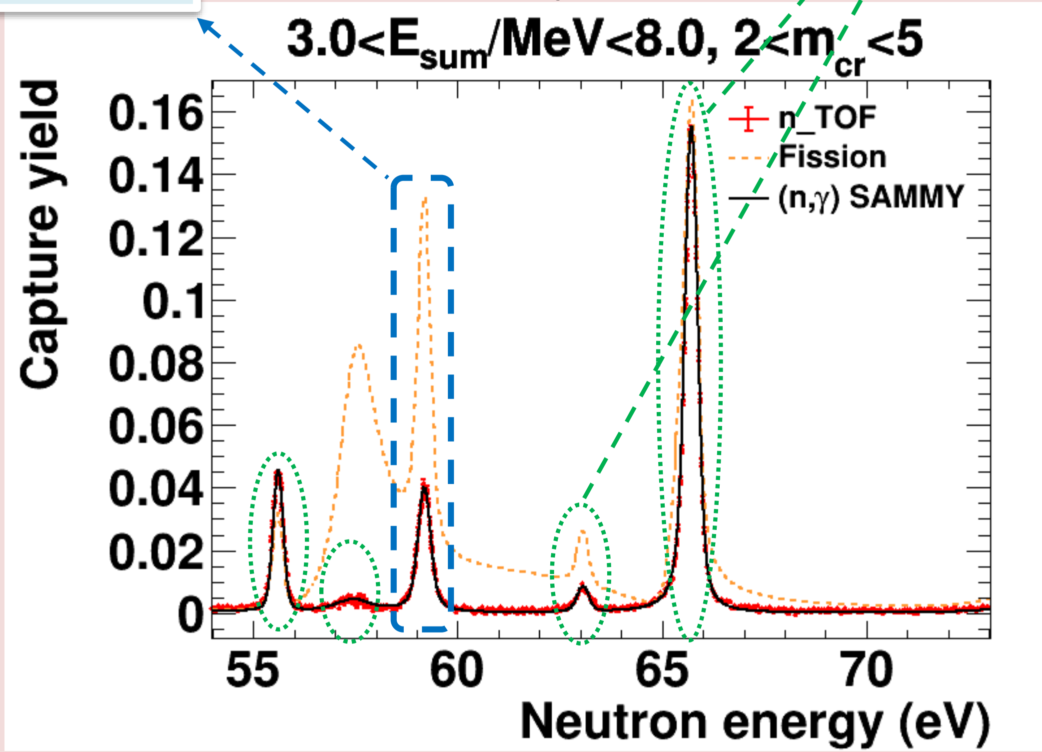
$$\lambda_{F}^{min} = 1.038(31)$$

Resonances included in the fit

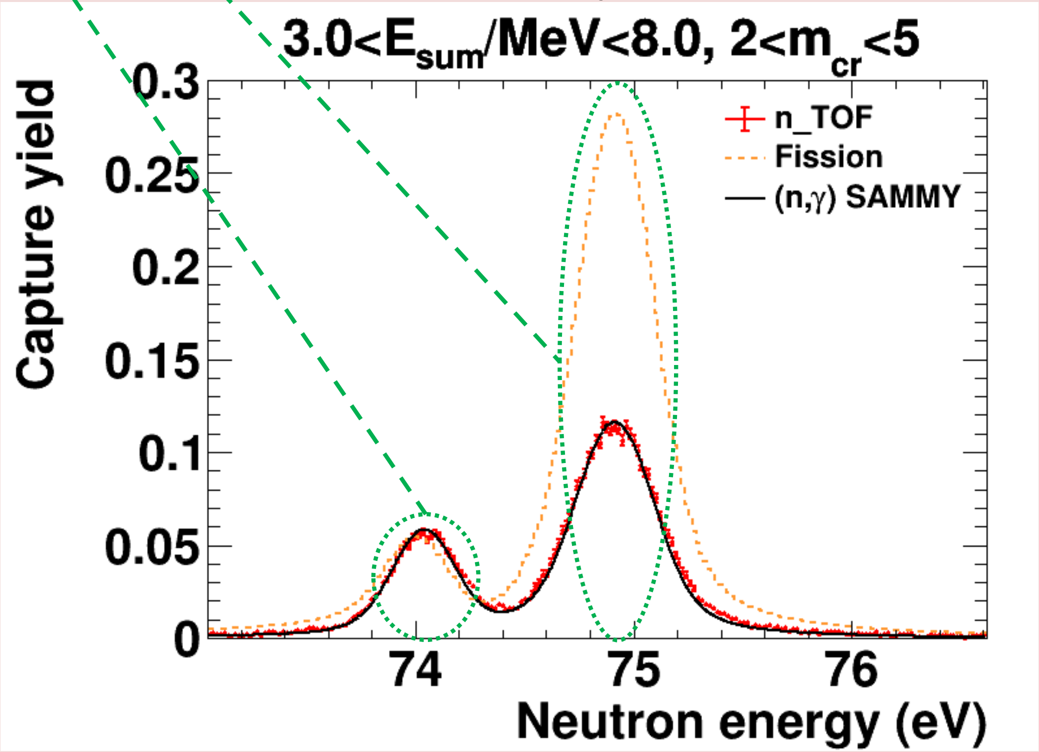
Resonances **NOT included** in the fit

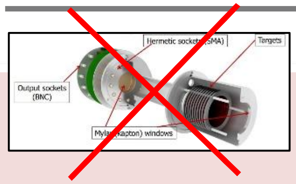
Excellent compatibility between TS and FC capture yield even in resonances not used for the optimization problem with large fission → obtained fission bkgd. for higher energies.

Result on the fitted yield resonances



Result on the fitted yield resonances





Fission subtraction in the TS setup

- Obtained fitted scaling factors (change from the expected values for the efficiencies taken from simulations and FC data):

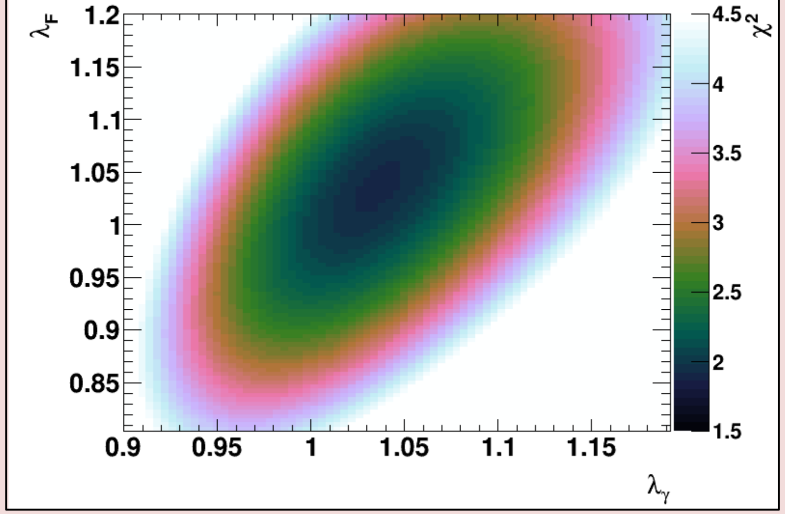
$$\varepsilon_\gamma = \frac{1}{\lambda_\gamma}\hat{\varepsilon}_\gamma$$

$$\varepsilon_F = \lambda_F \hat{\varepsilon}_F$$

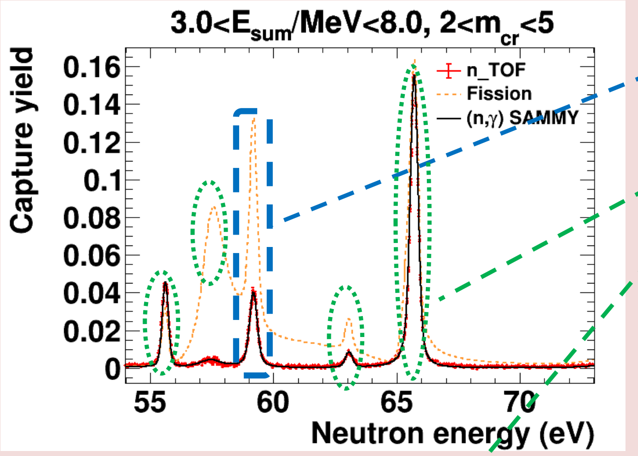
$$\lambda_\gamma^{min} = 1.038(31)$$

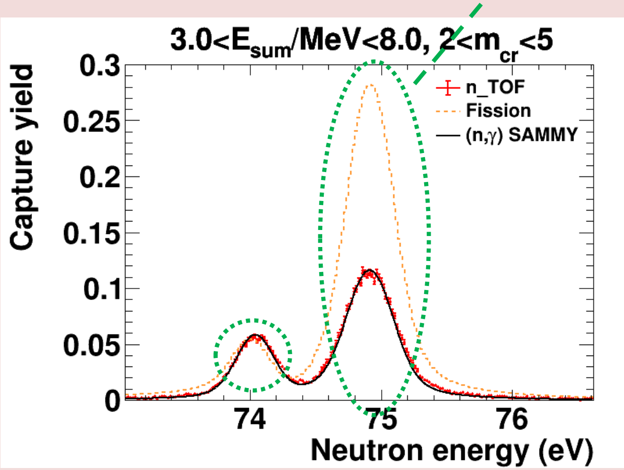
$$\lambda_F^{min} = 1.038(31)$$

Results for the X^2 function (to be minimized)



Result on the fitted yield resonances





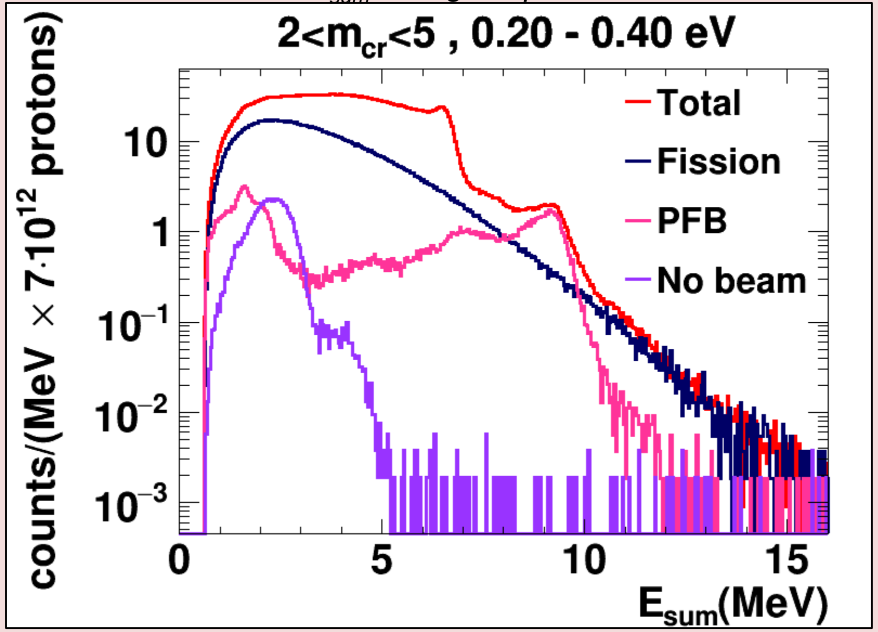
Resonances included in the fit

Resonances included in the fit

Fission count rate

Obtained scaling the fission shape from FC setup (SAMMY). The PFB is then determined from the obtained prompt-fission using the FC results.

Result in E_{sum}, using shapes from FC data



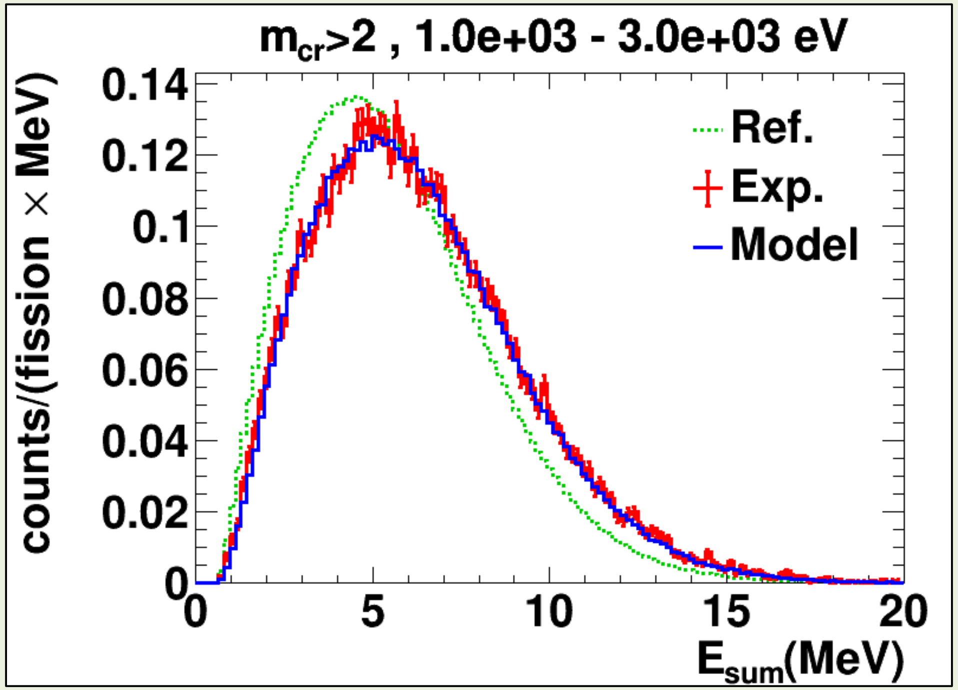
3.5 Pile-up correction

Observed pile-up effects that depend on the time-of-flight (neutron energy) within the same pulse, reproducible with artificial data buffers with sample signals. Same method as in previous measurements with the TAC[1].

Validation with experimental data

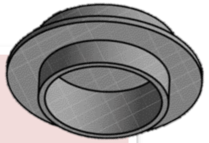
Able to reproduce gain shifts and data losses.

Comparison of E_{sum} prompt-fission spectra between experimental data and pile-up model at 1-3 keV.



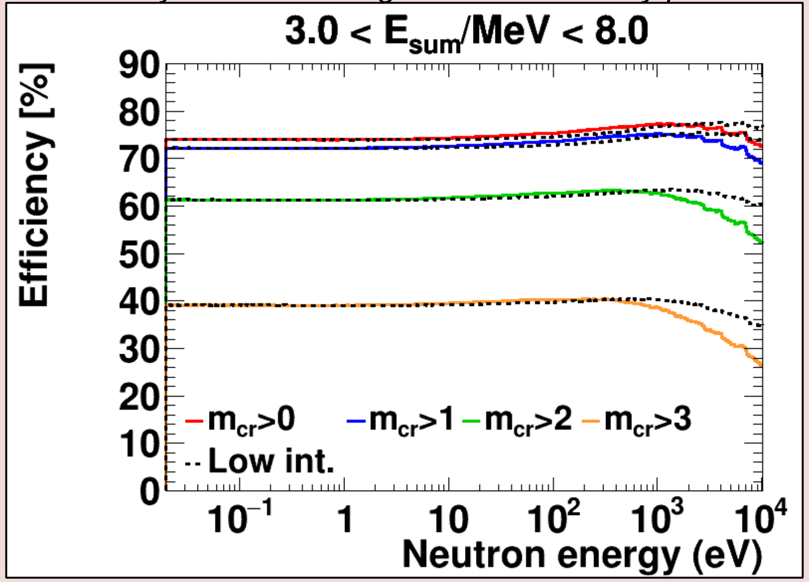
[1] E. Mendoza et al. Nucl. Instrum. Methods Phys. Res. A 768, 55 (2014).

TS setup



- Significantly larger corrections than in the FC setup, especially for E_n>2 keV (up to 15%).
- Low intensity pulses: corrections below 2.5% up to 10 keV.

Efficiency curves with high and low intensity pulses.



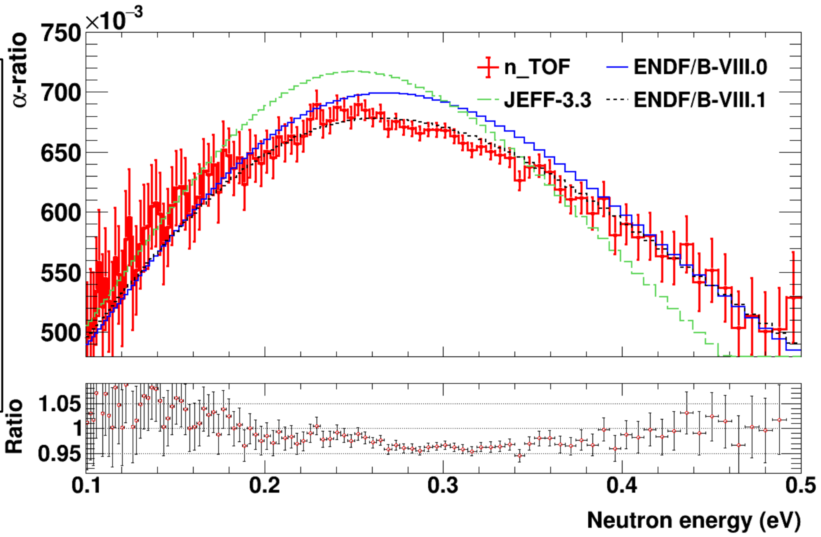
TS capture yield was measured using only low-intensity pulses to minimize pile-up corrections.

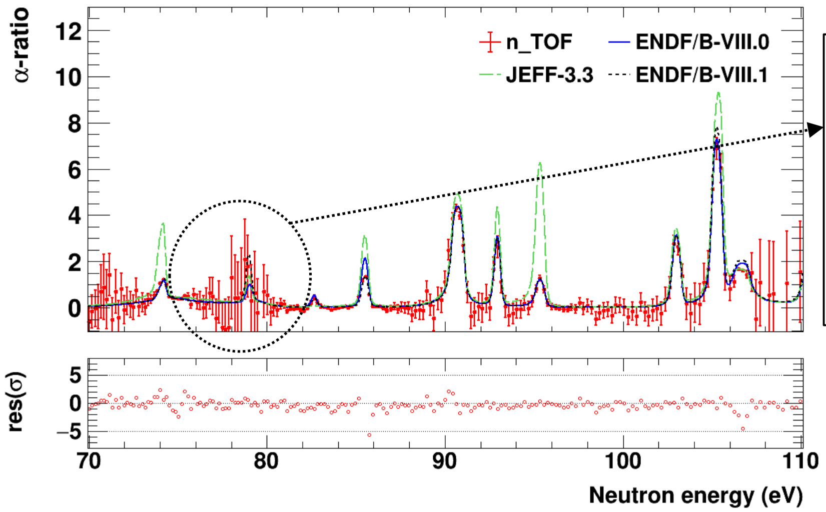
4.4 α-ratio: comparison with evaluations (and exp. data)

Better agreement with ENDF/B-VIII.1 at 0.3 eV, and 3-4% below the other libraries.

This deviation is driven by the difference in the fission cross section.

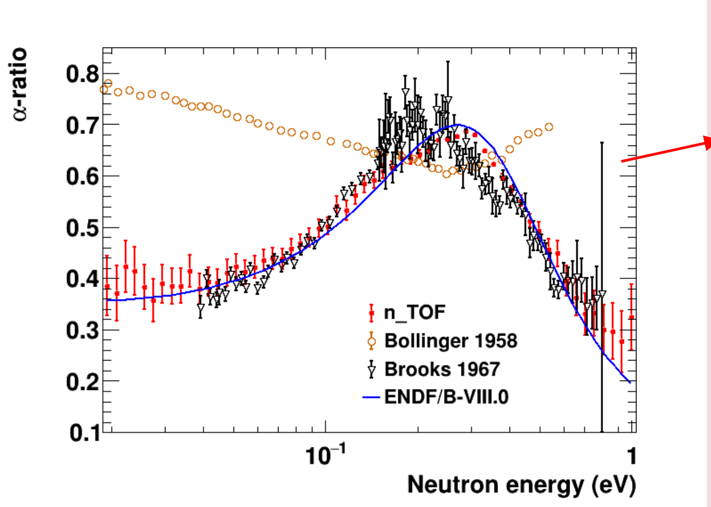
Residuals and ratios calculated relative to ENDF/B-VIII.0





Regions with large errors due to counting statistics (valleys in fission and/or capture). No valuable information there.

Comparison with experimental data



First resonance @ 0.3 eV

New dataset for α-ratio with smaller uncertainties for the 0.3 eV resonance. Compatible with Brooks 1967 data in the tails but with more precision.

Energy resolution and discrepancies

Where the comparison is possible, n_TOF data show slightly higher energy resolution than Mosby 2014 data (starting at 10 eV). There are regions with agreement but also regions with significant discrepancies between both datasets.