



# Preliminary results on the $^{233}\text{U}$ ( $n, \gamma/f$ ) cross section measured @ n\_TOF (CERN) with the fission tagging technique

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<sup>5</sup> CEA, DAM, DIF, F-91297 Arpajon (FR),

<sup>6</sup> CEA, DEN, Cadarache (FR),

<sup>7</sup> EC-JRC Geel (BE)

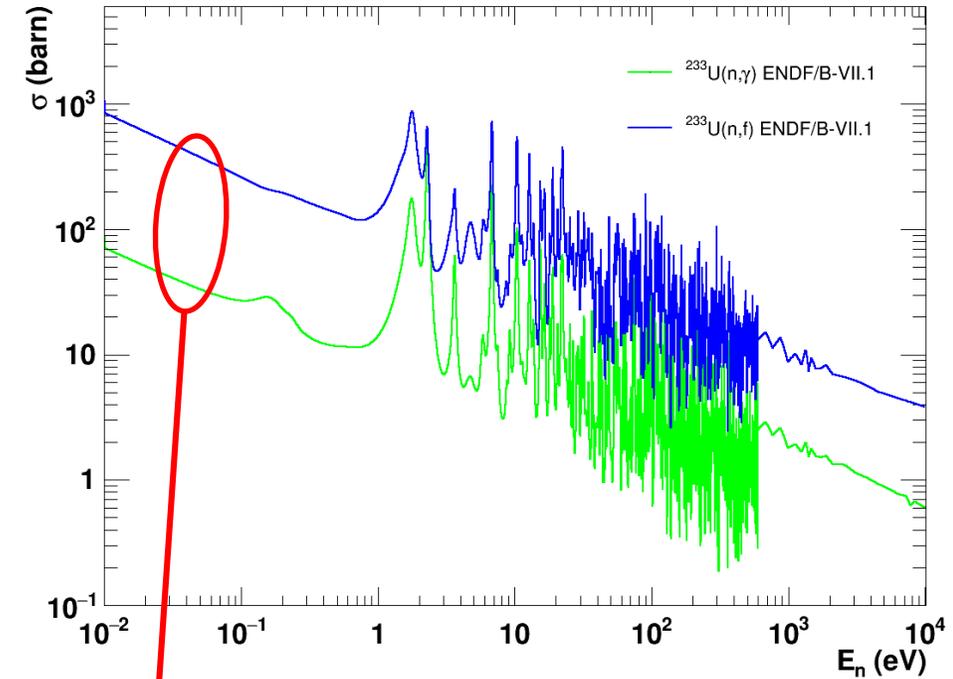
# Motivation – Why $^{233}\text{U}$ ?

- Key nuclide in the Th-U fuel cycle governing:
  - Neutronics performance
  - Economics
  - Nuclear safety
  - Proliferation resistance properties



- NEA Nuclear Data High Priority Request List

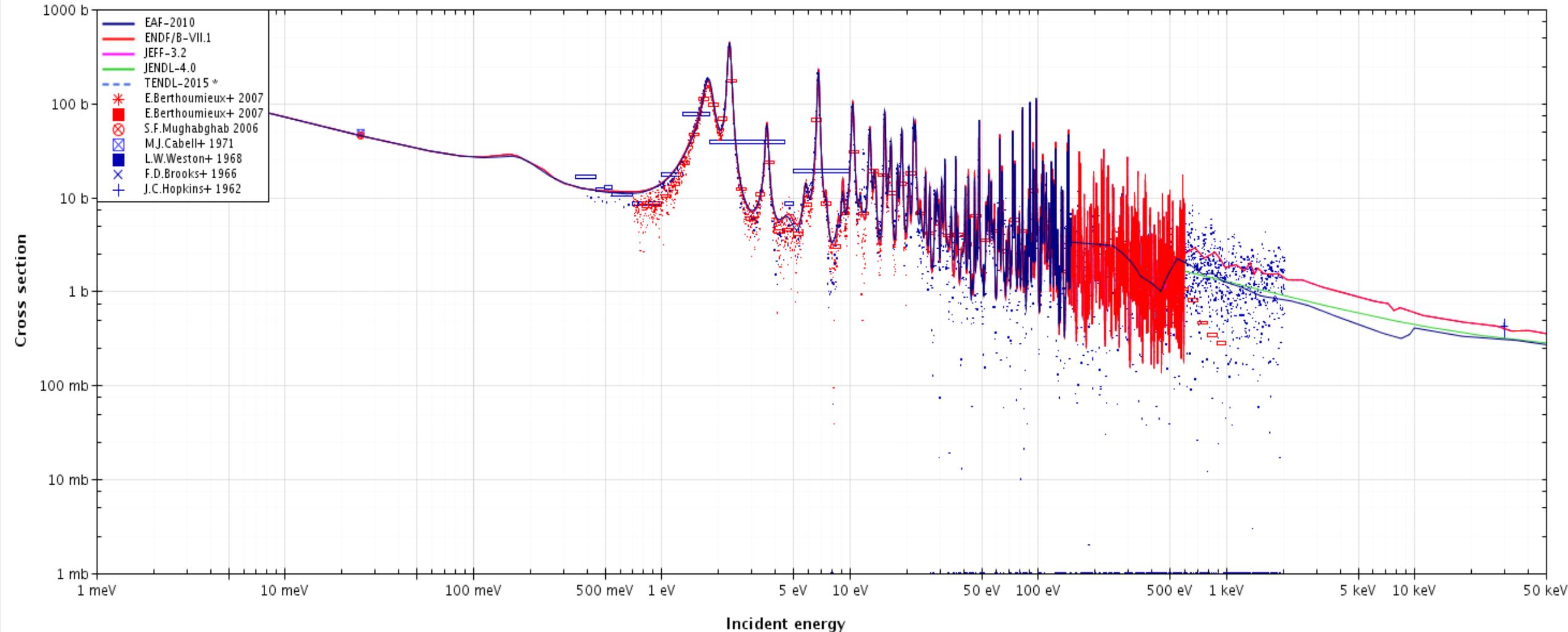
$^{233}\text{U}(n,\gamma)$	$\sigma_\gamma$	$\sigma_\gamma$
$E_n$	Thermal - 10 keV	10 keV - 1 MeV
Target accuracy	5%	9%



$$\frac{\sigma_f}{\sigma_\gamma} \sim 10 \rightarrow \text{Fission Tagging}$$

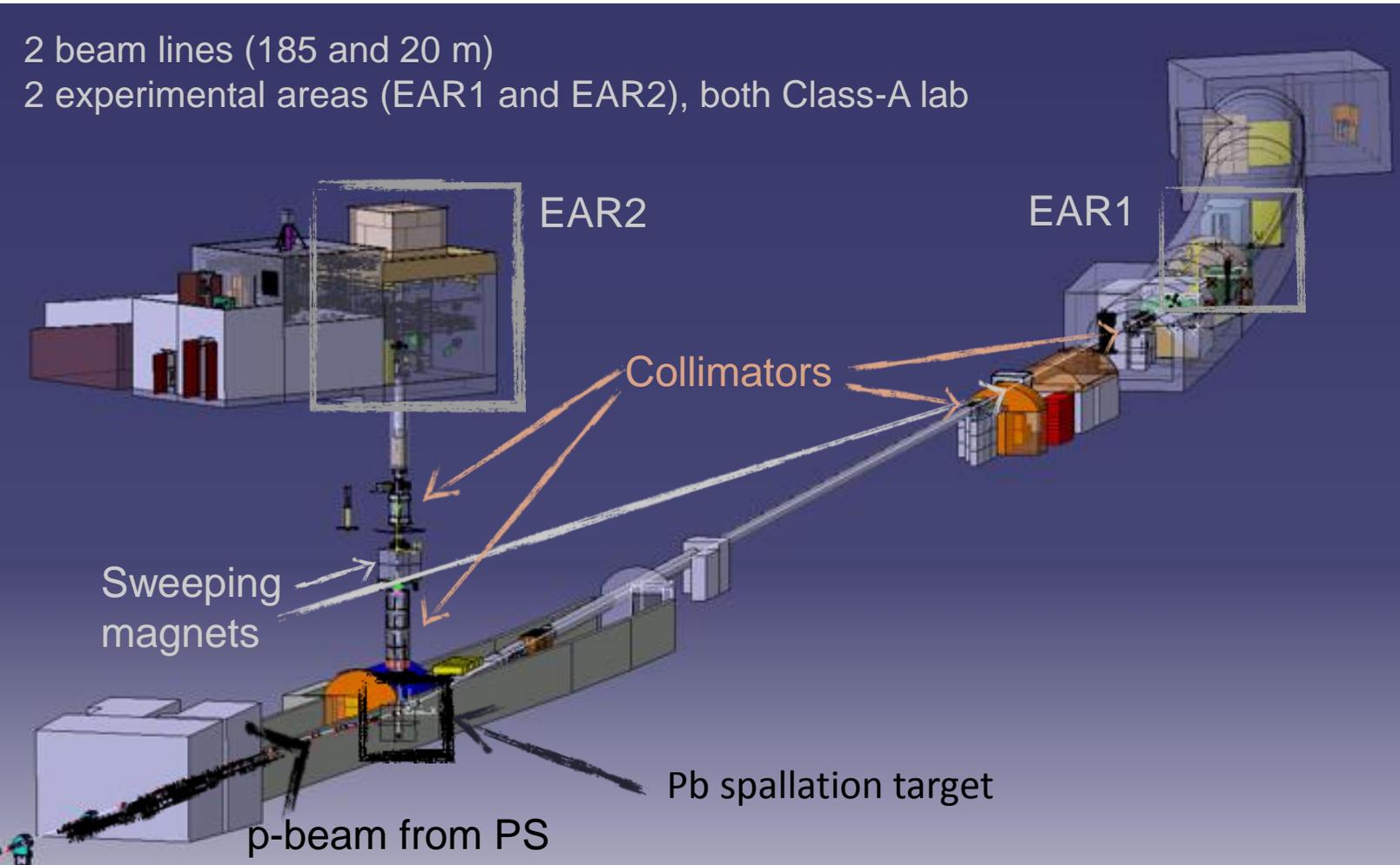
# Motivation – Looking at existing data

U233 (n, $\gamma$ )



# n\_TOF in a nutshell

2 beam lines (185 and 20 m)  
2 experimental areas (EAR1 and EAR2), both Class-A lab

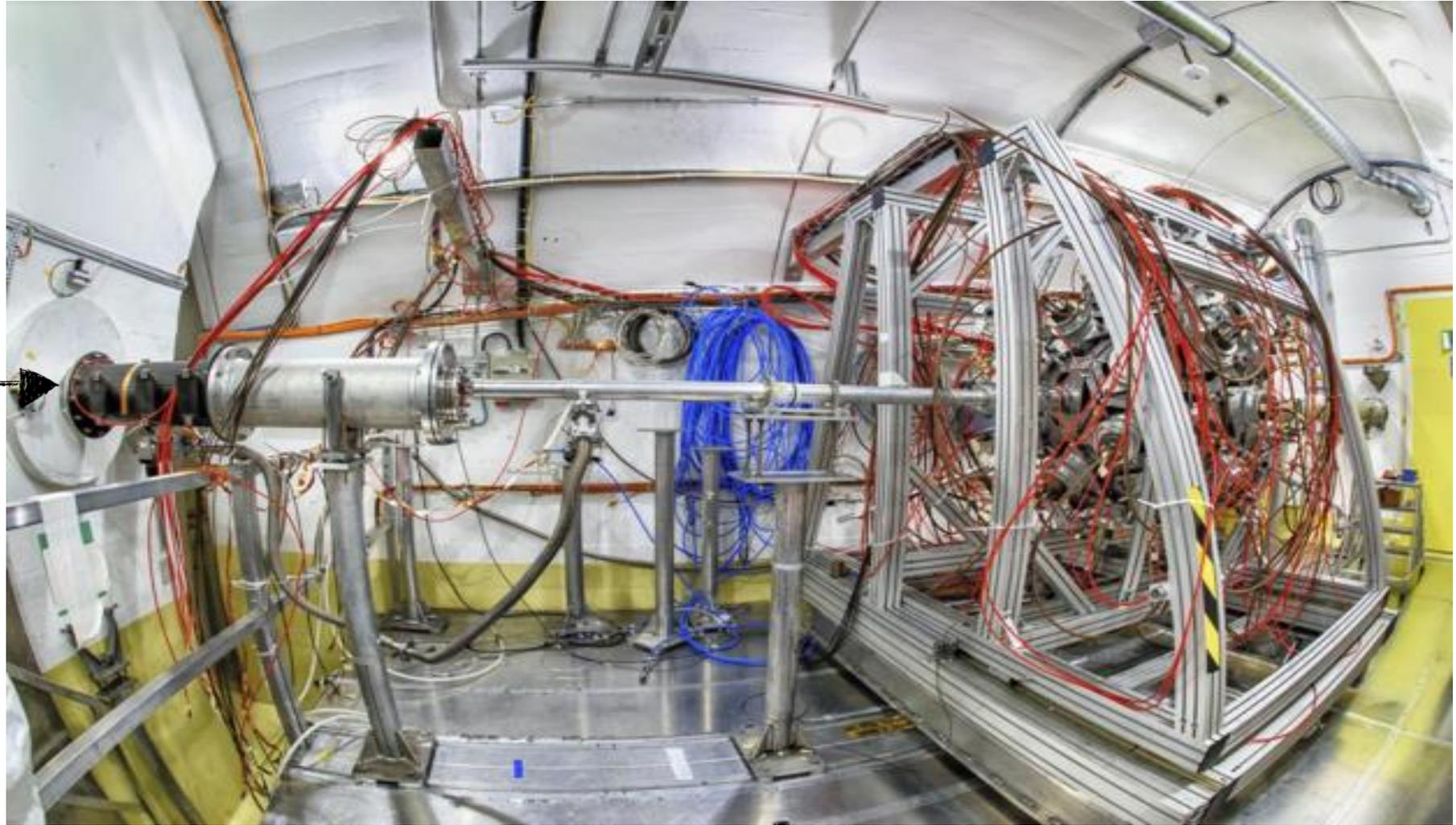


## Some numbers

	EAR1	EAR2
Wide energy range	thermal to 1 GeV	thermal to 300 MeV
High instantaneous neutron flux	$10^5$ n/cm <sup>2</sup> /pulse	$10^6$ n/cm <sup>2</sup> /pulse
Low repetition rate	< 0.8 Hz (1 pulse/1.2 s max)	
High energy resolution	$\Delta E/E=10^{-4}$ (@10 eV)	$\Delta E/E=10^{-2}$ (@10 eV)

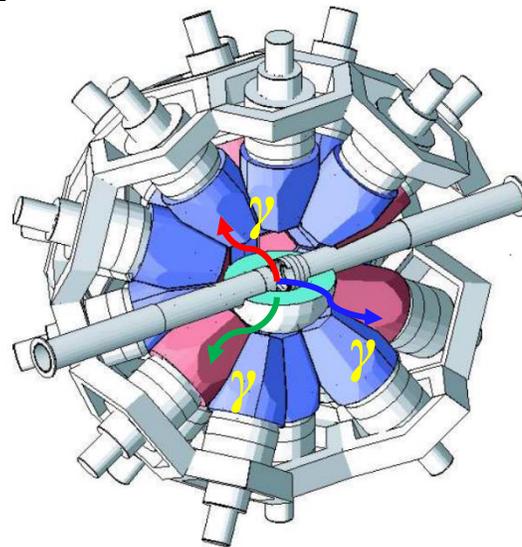
# n\_TOF: Peeking into EAR1

neutron  
beam



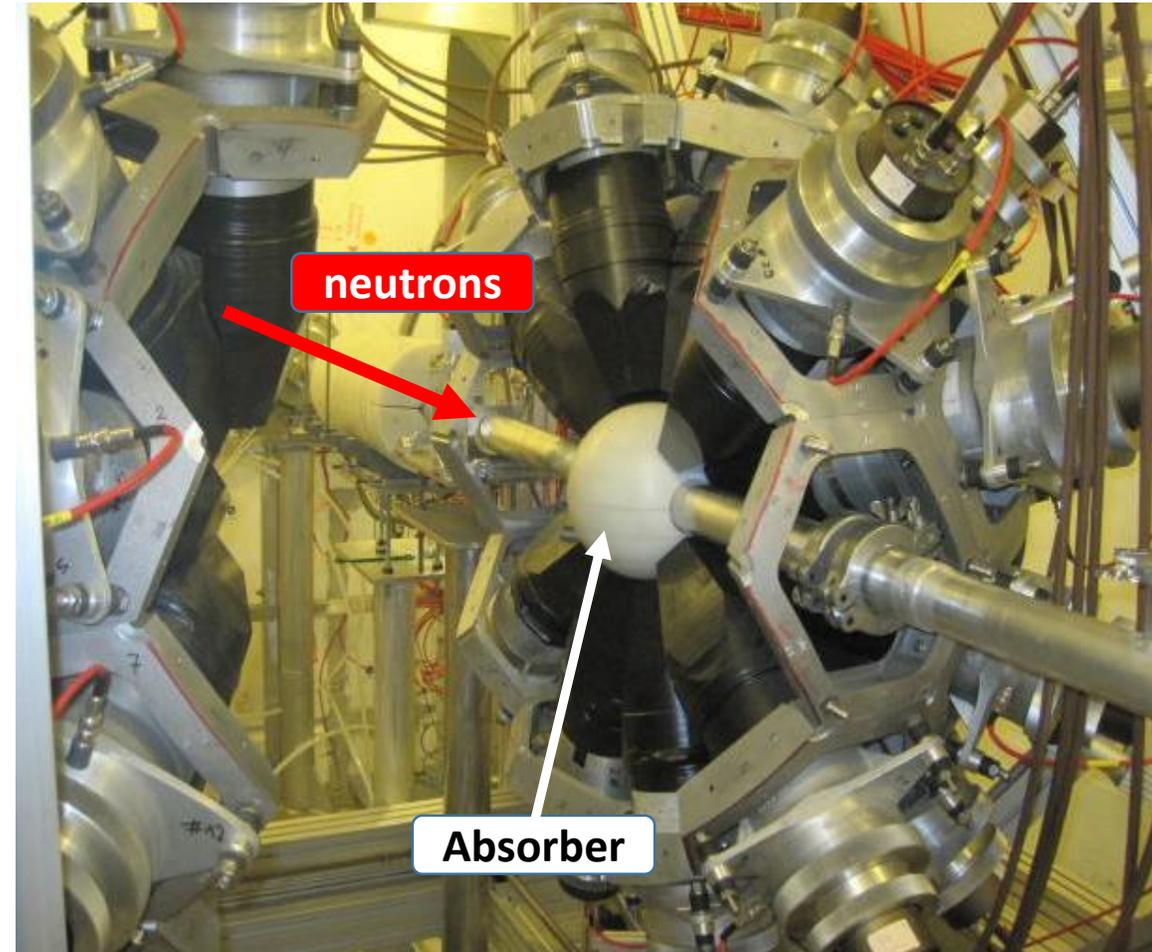
# Experimental Setup – Gamma Detector

- n\_TOF's Total Absorption Calorimeter (TAC)
- Almost  $4\pi$  spherical array of 40 BaF<sub>2</sub> crystals
- Absorber (polyethylene + 7.5% Li) to reduce neutron scattering into the BaF<sub>2</sub>
- Inner diameter:
  - TAC: 20 cm
  - Absorber: 10 cm (!)
- Sum energy  $E_{Sum}$  and crystal multiplicity  $m_{cr}$



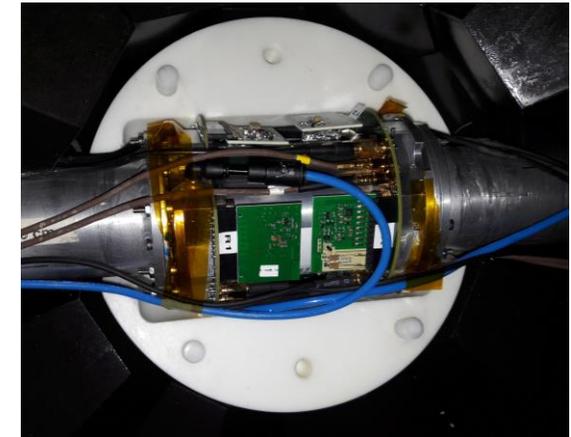
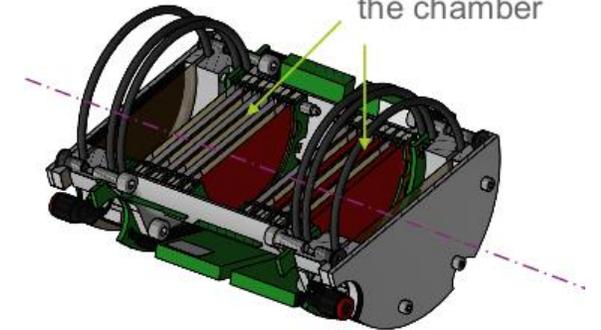
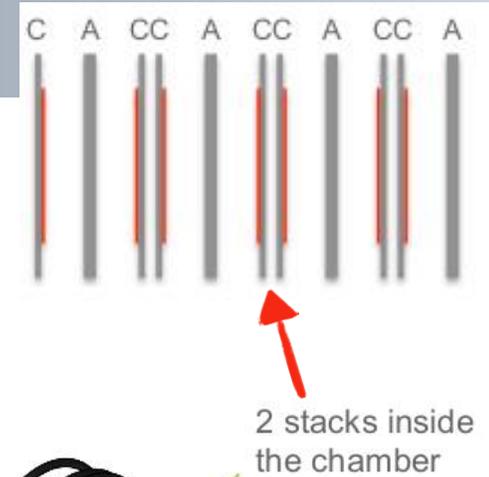
$$E_{Sum} = E_1 + E_2 + E_3$$

$$m_{cr} = 1 + 1 + 1$$



# Experimental Setup – Fission Detector

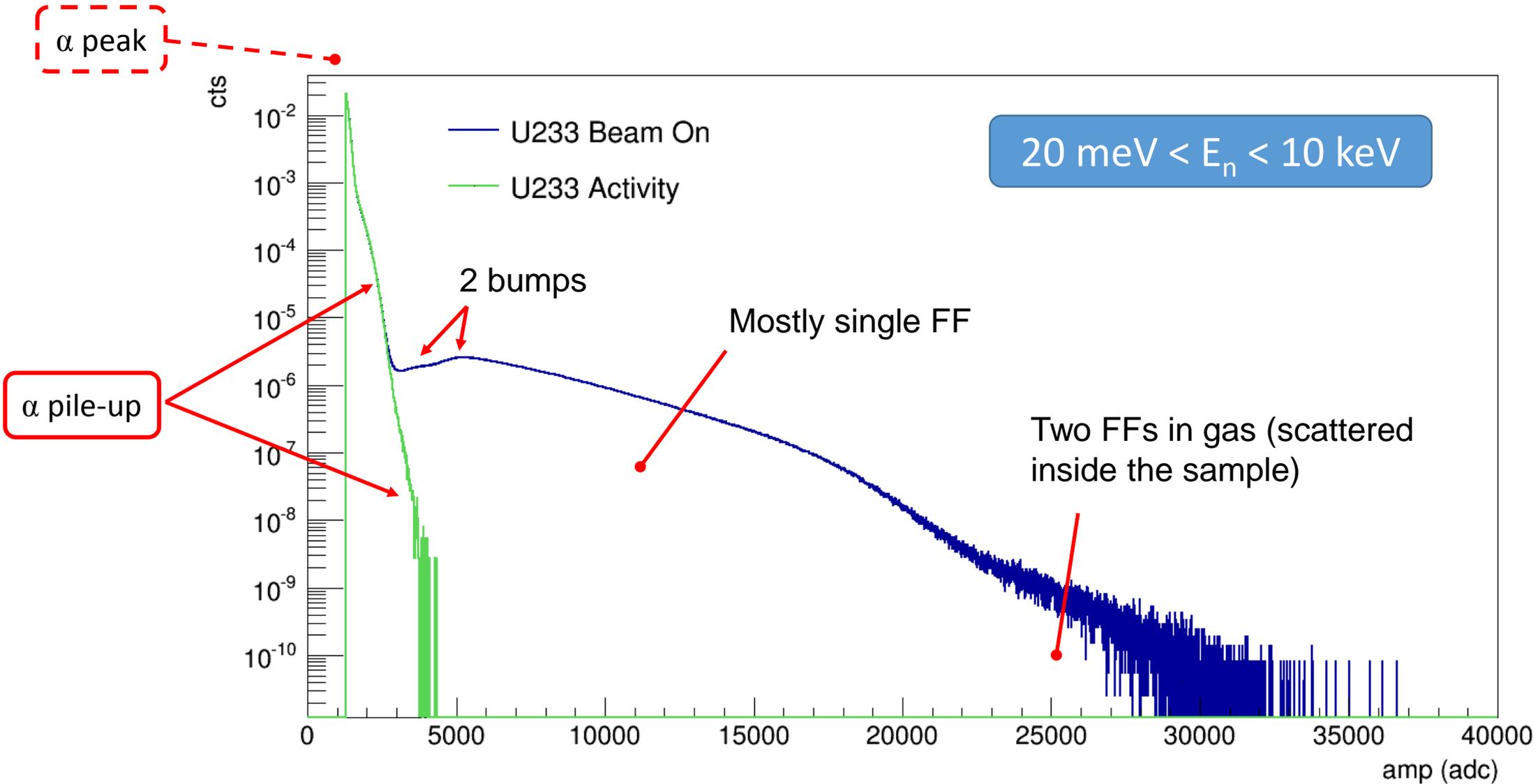
- Novel **F**ission **C**hamber (**FICH**)
- Compact – cylindrical chamber  $\varnothing 9\text{ cm} \times 12\text{ cm}$
- Simple ionization cells
  - 14 cathodes/deposits ( $10\ \mu\text{m Al}$  each)
  - Readout from 8 anodes ( $20\ \mu\text{m Al}$  each)
- Fast signals (34 ns FWHM) for high  $\alpha$ -count rates ( $>1\ \text{MBq}$  per anode) :
  - Fast ionizing gas  $\text{CF}_4$  @ 1.1 bar
  - Dedicated electronics (CEA/DAM/DIF)
  - Gap width: 3 mm @ 1.4 kV/cm
- 14 unsealed  $^{233}\text{U}$  deposits molecular plated by JRC-Geel:
  - 4 cm diameter
  - 46.5 mg  $^{233}\text{U}$  total



Isotope	w%
$^{233}\text{U}$	99.936
$^{234}\text{U}$	0.0496
$^{235}\text{U}$	0.0012
$^{236}\text{U}$	0.0002
$^{238}\text{U}$	0.0128

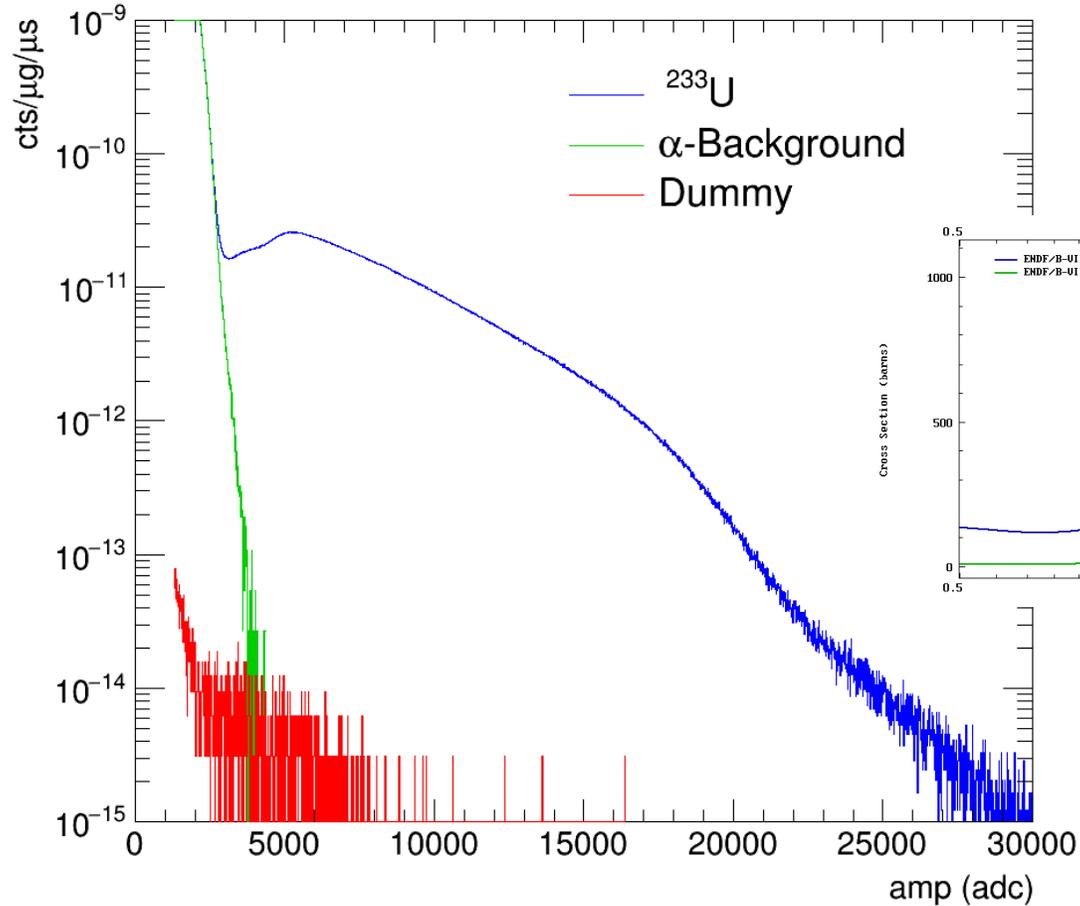
Fission

# FICH – Amplitude spectra

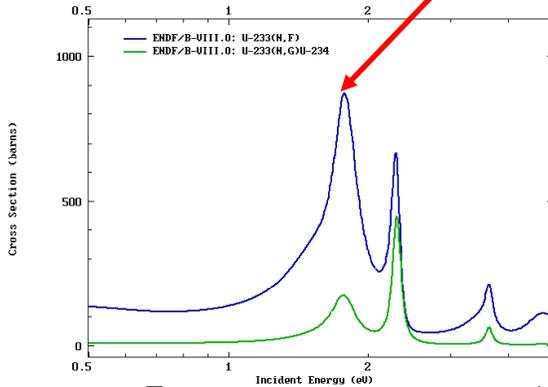
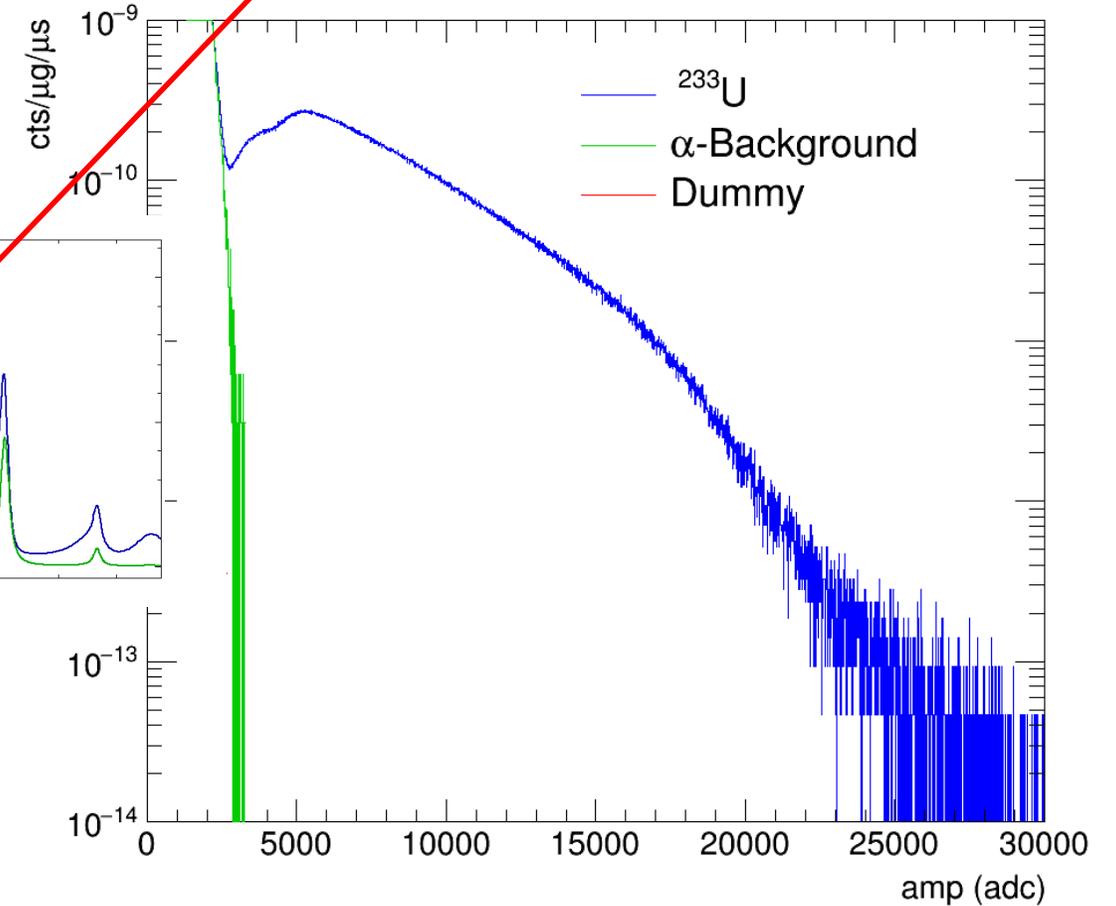


# FICH – Amplitude spectra

$20 \text{ meV} < E_n < 10 \text{ keV}$

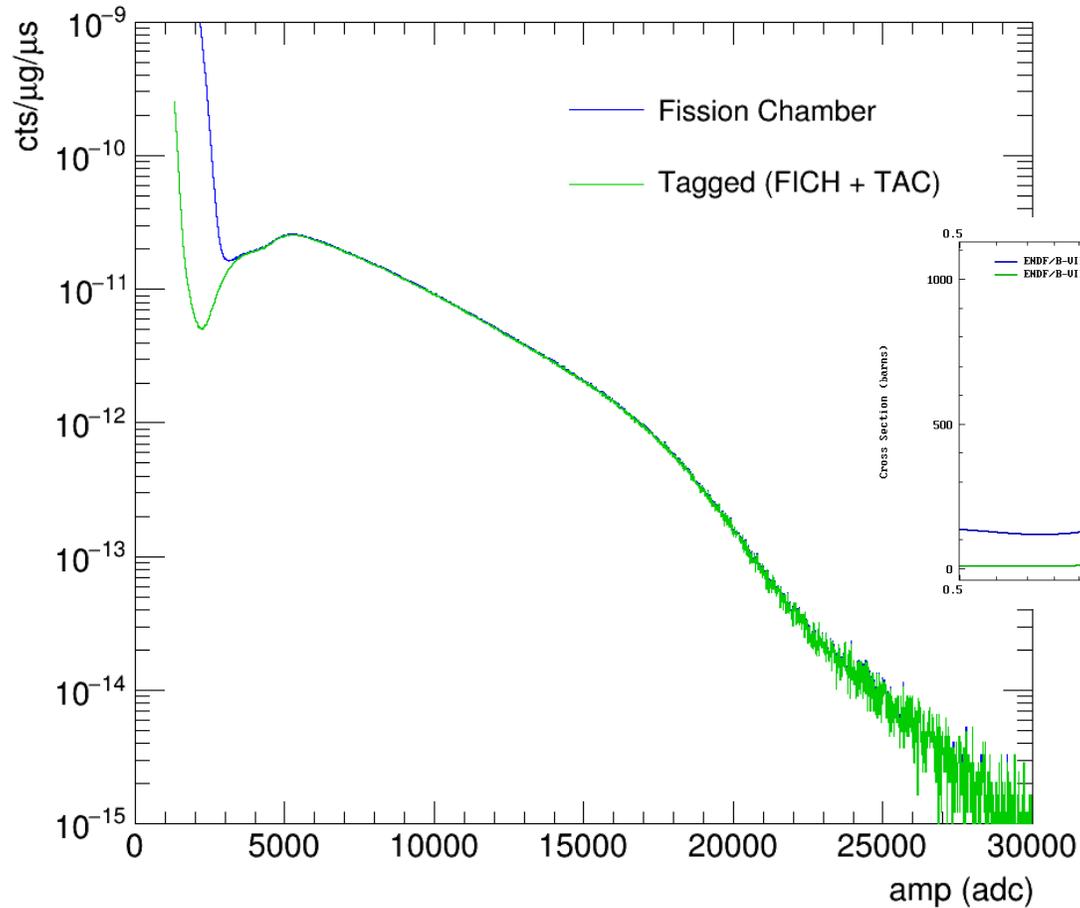


$1.6 \text{ eV} < E_n < 1.9 \text{ eV}$

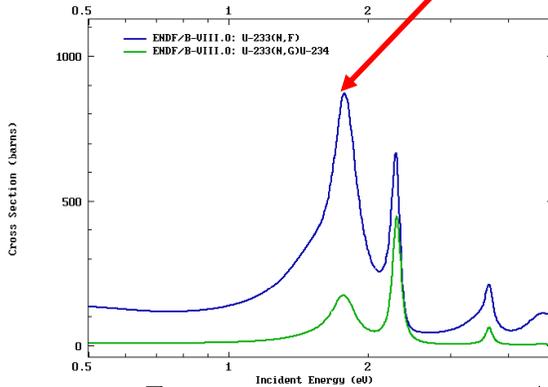
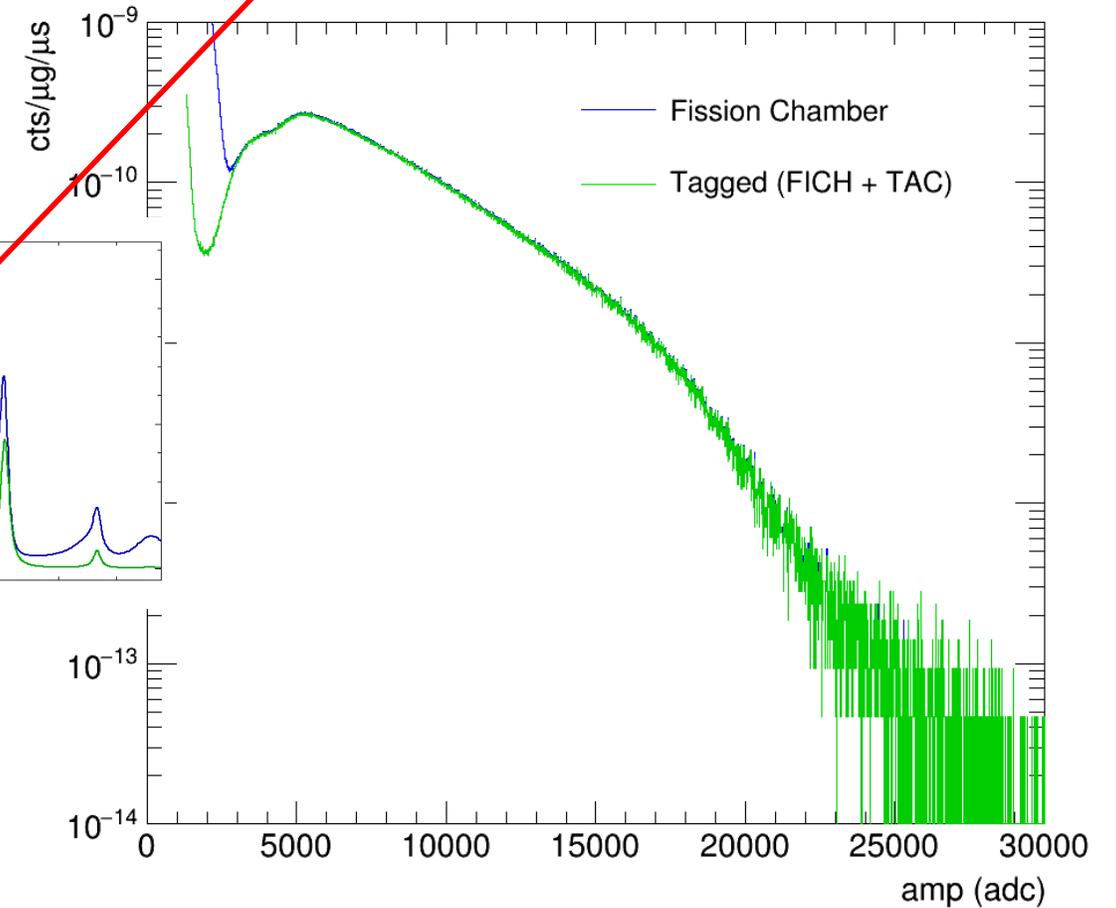


# FICH vs. Tagged – Amplitude spectra

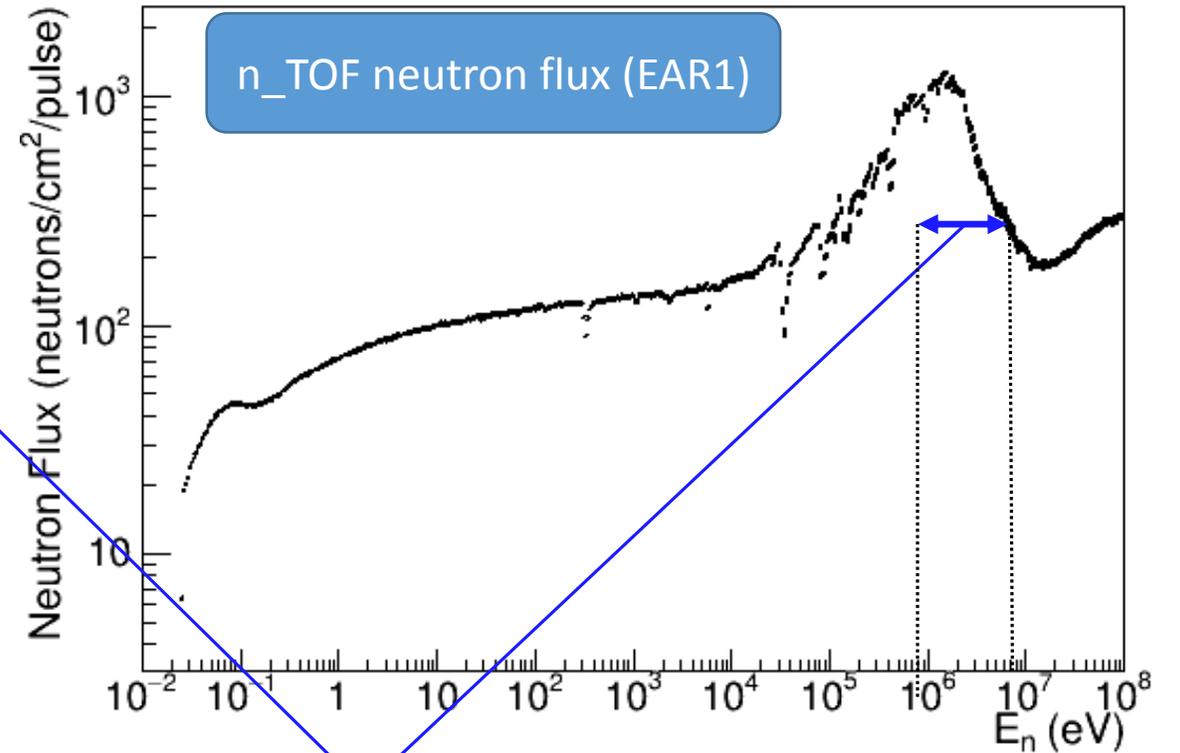
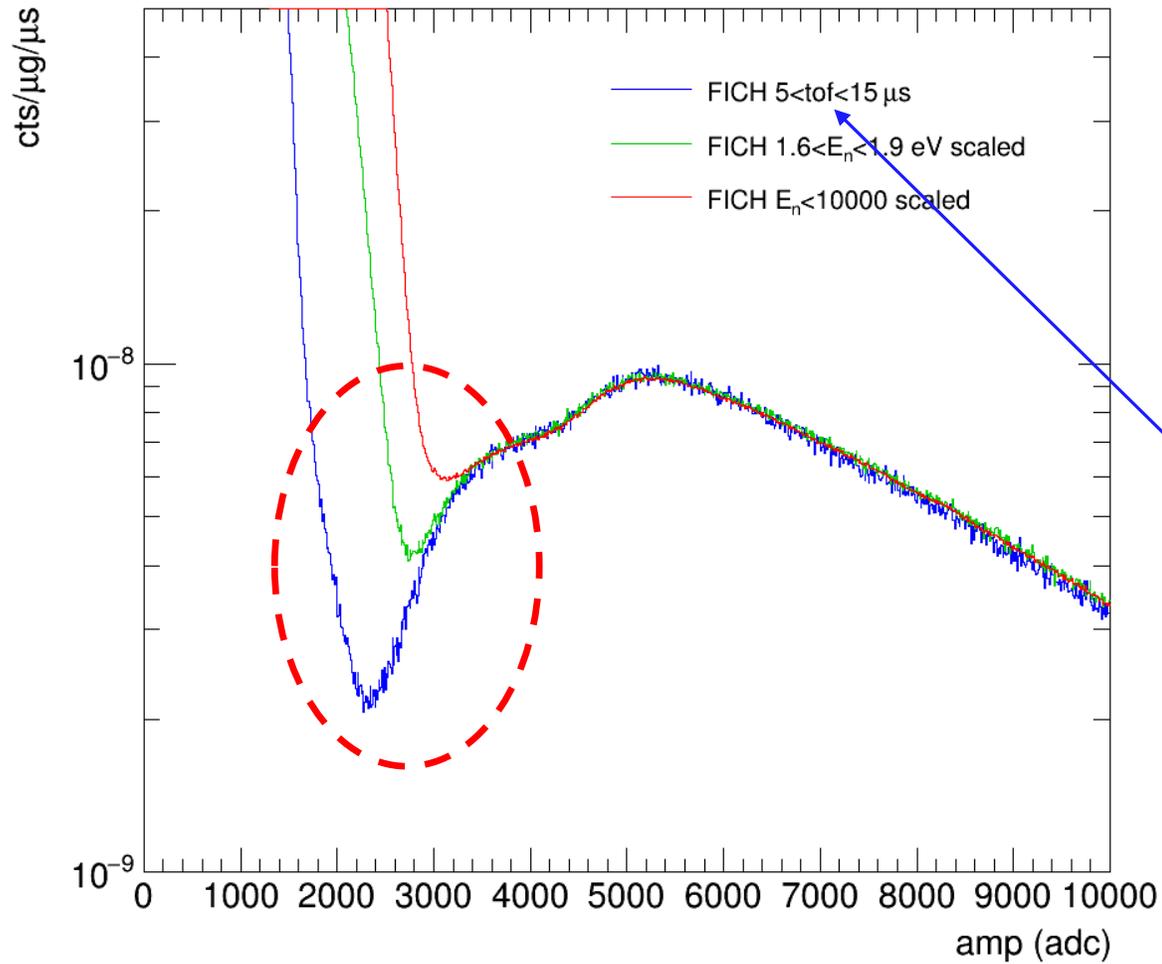
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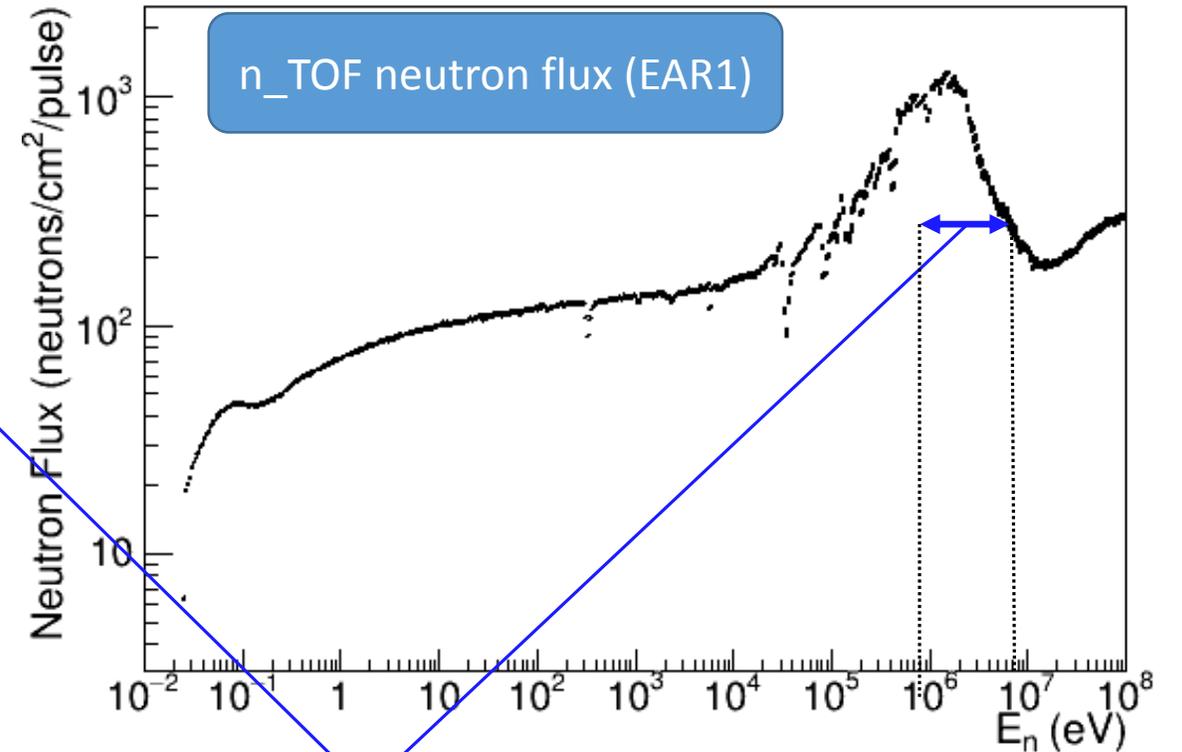
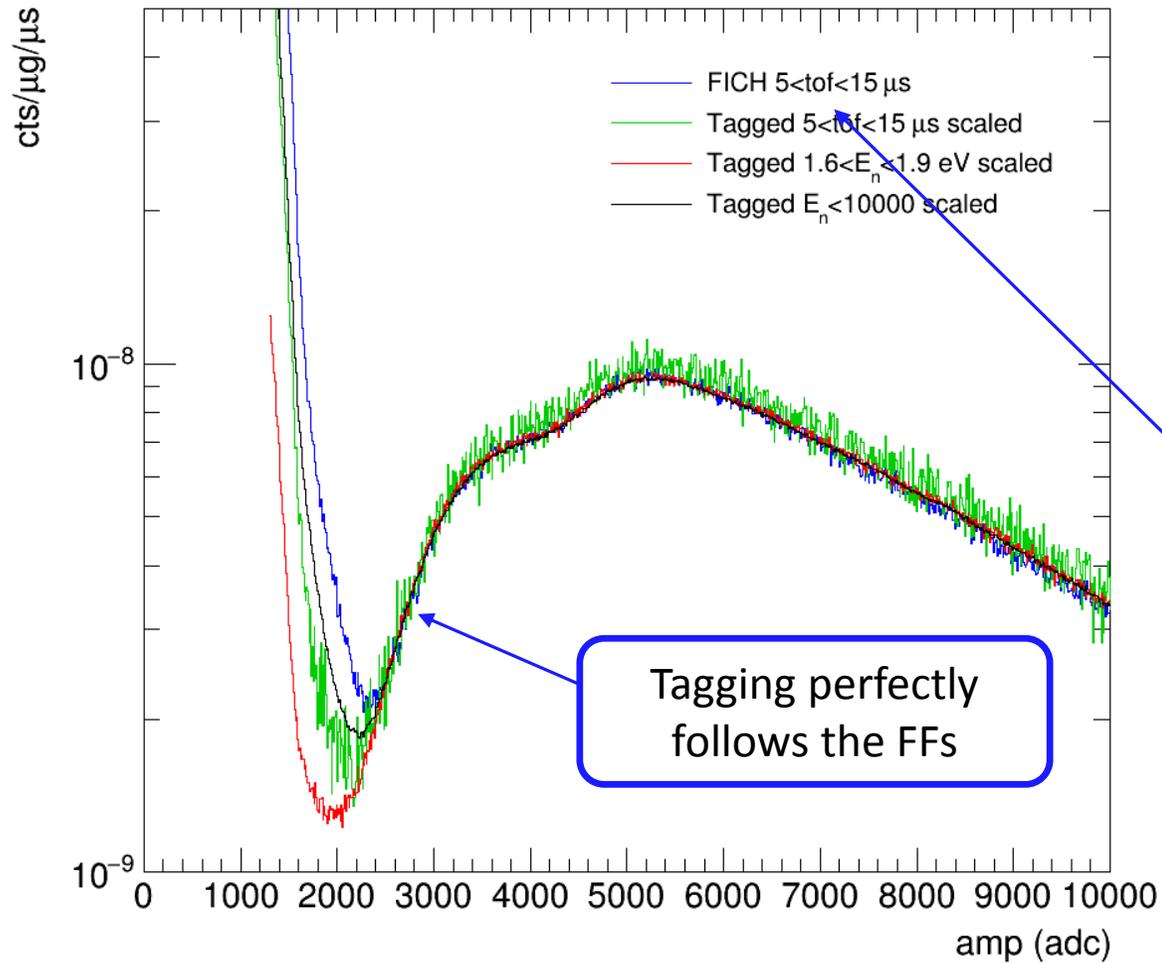


# FICH – $\alpha$ -FF separation



$5 < \text{tof} < 15 \mu\text{s} \Leftrightarrow 800 \text{ keV} < E_n < 7 \text{ MeV}$   
 $\rightarrow$  increased Fission/alpha ratio

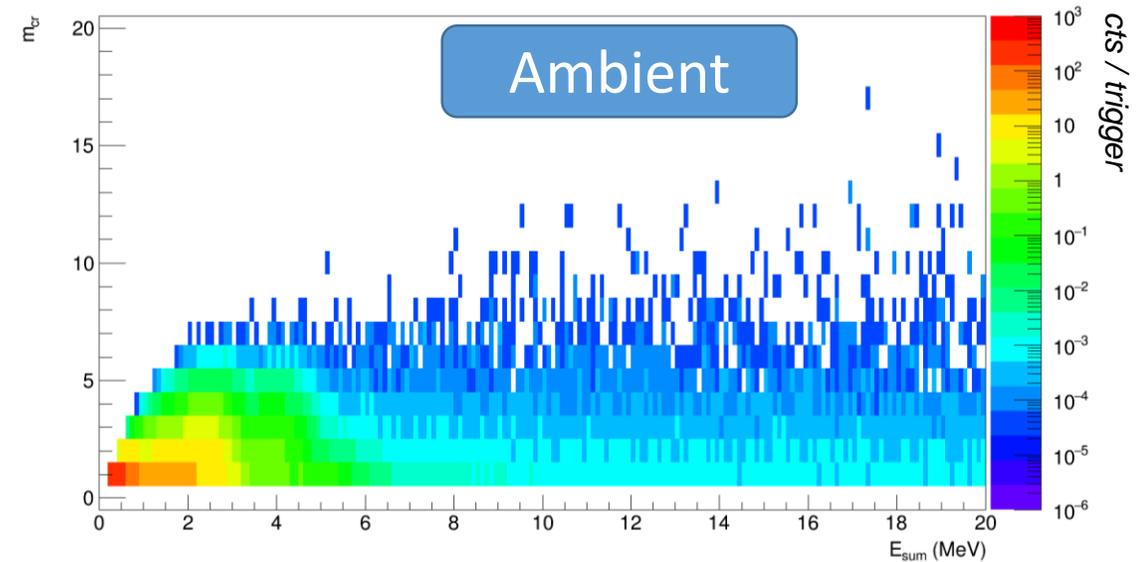
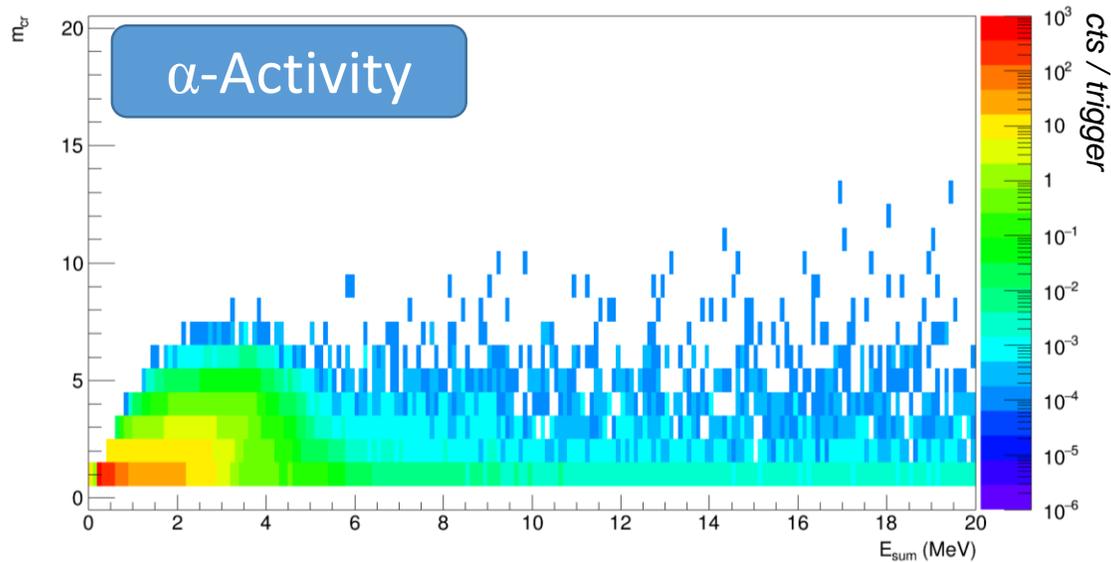
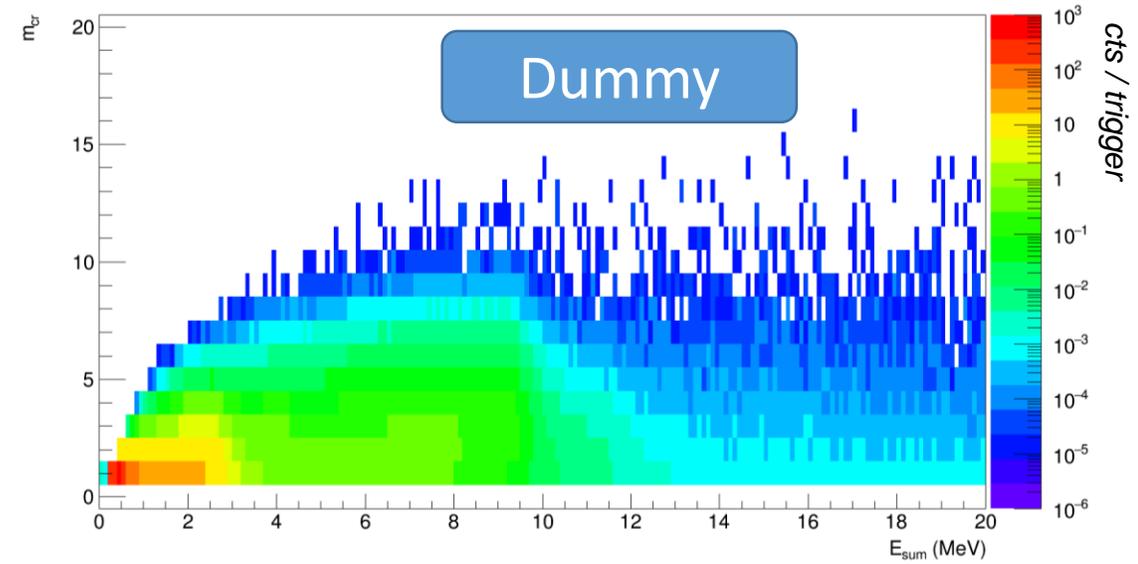
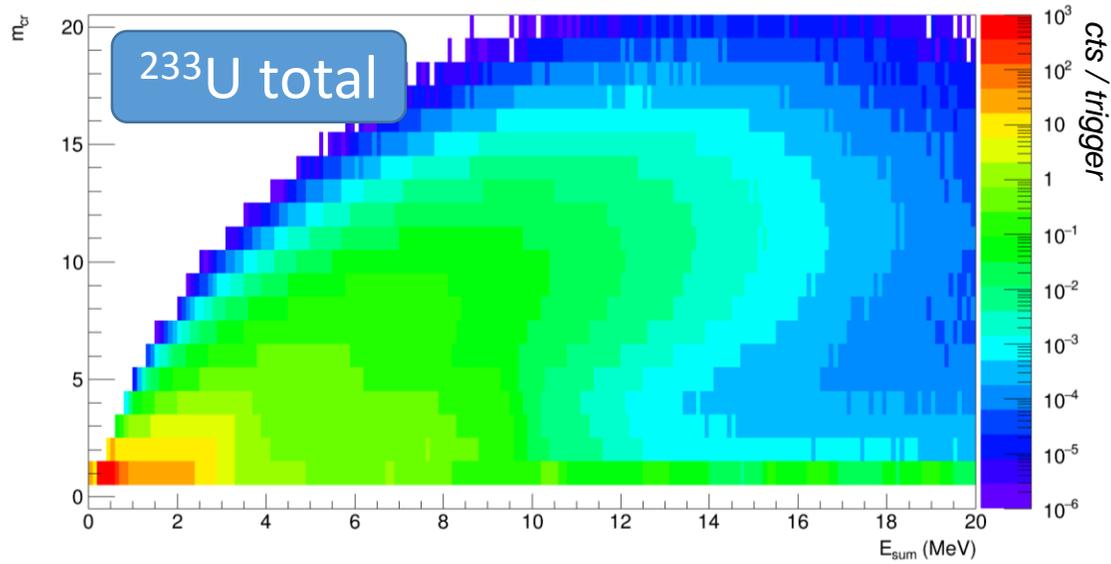
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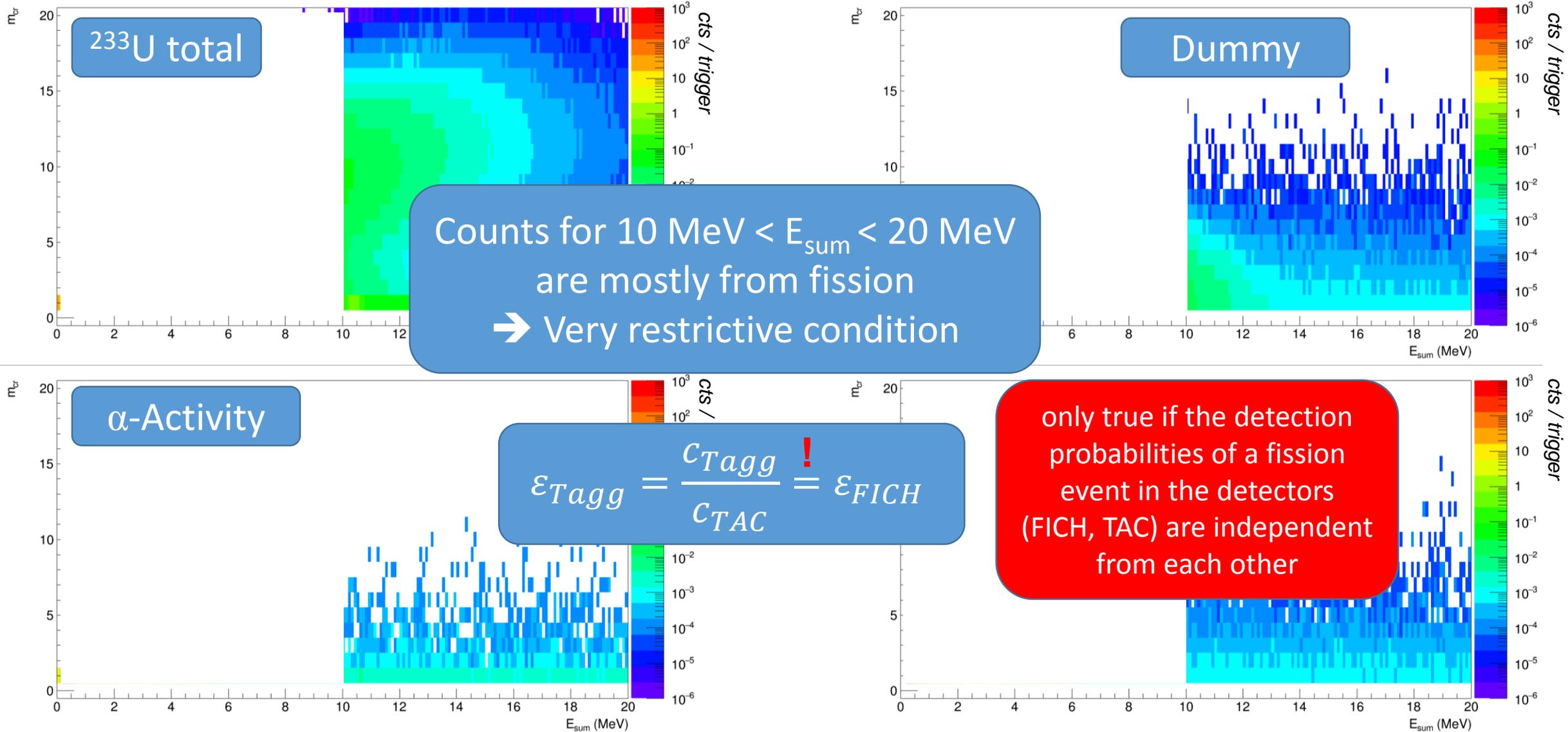
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FICH Efficiency

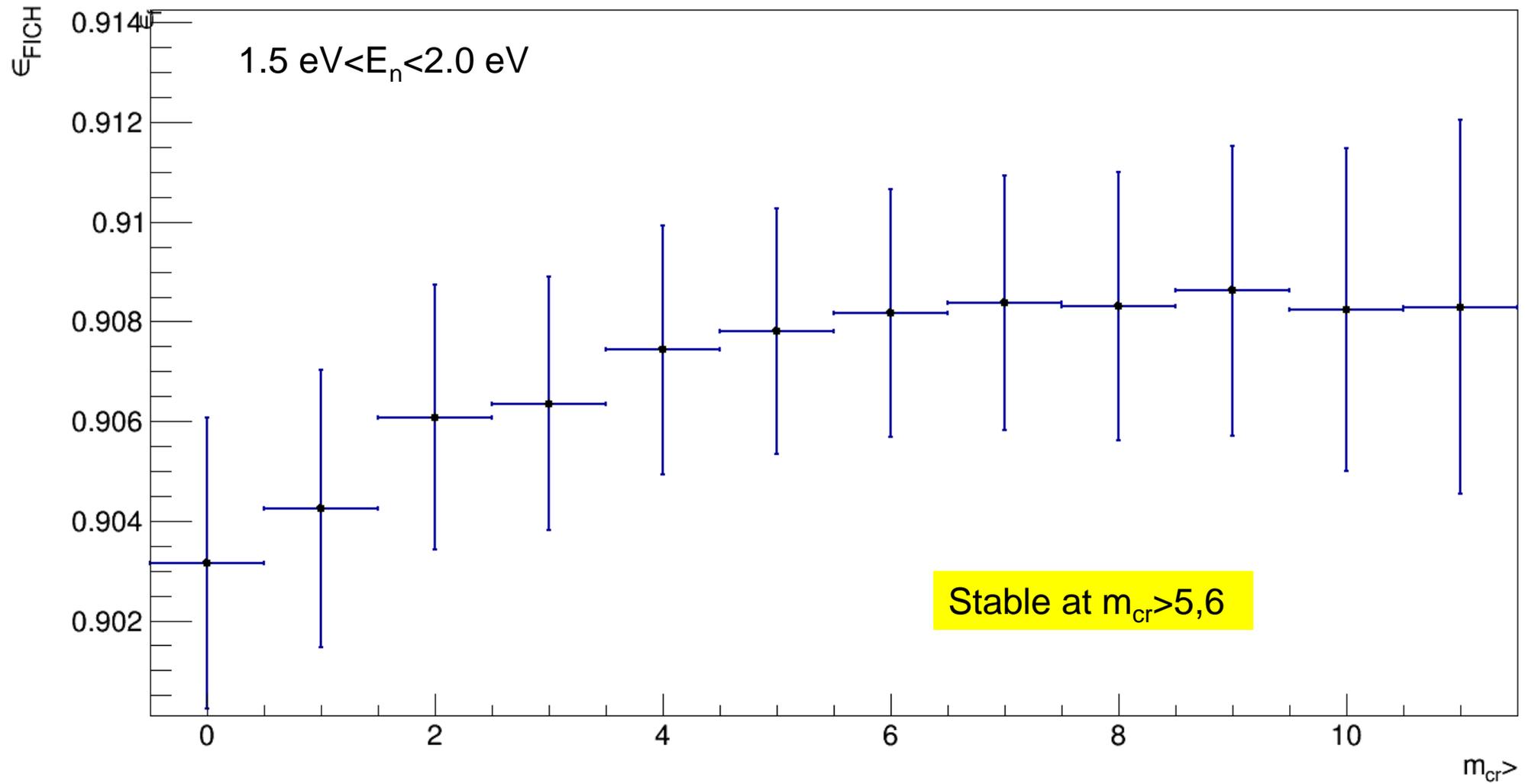
# FICH Efficiency – Method



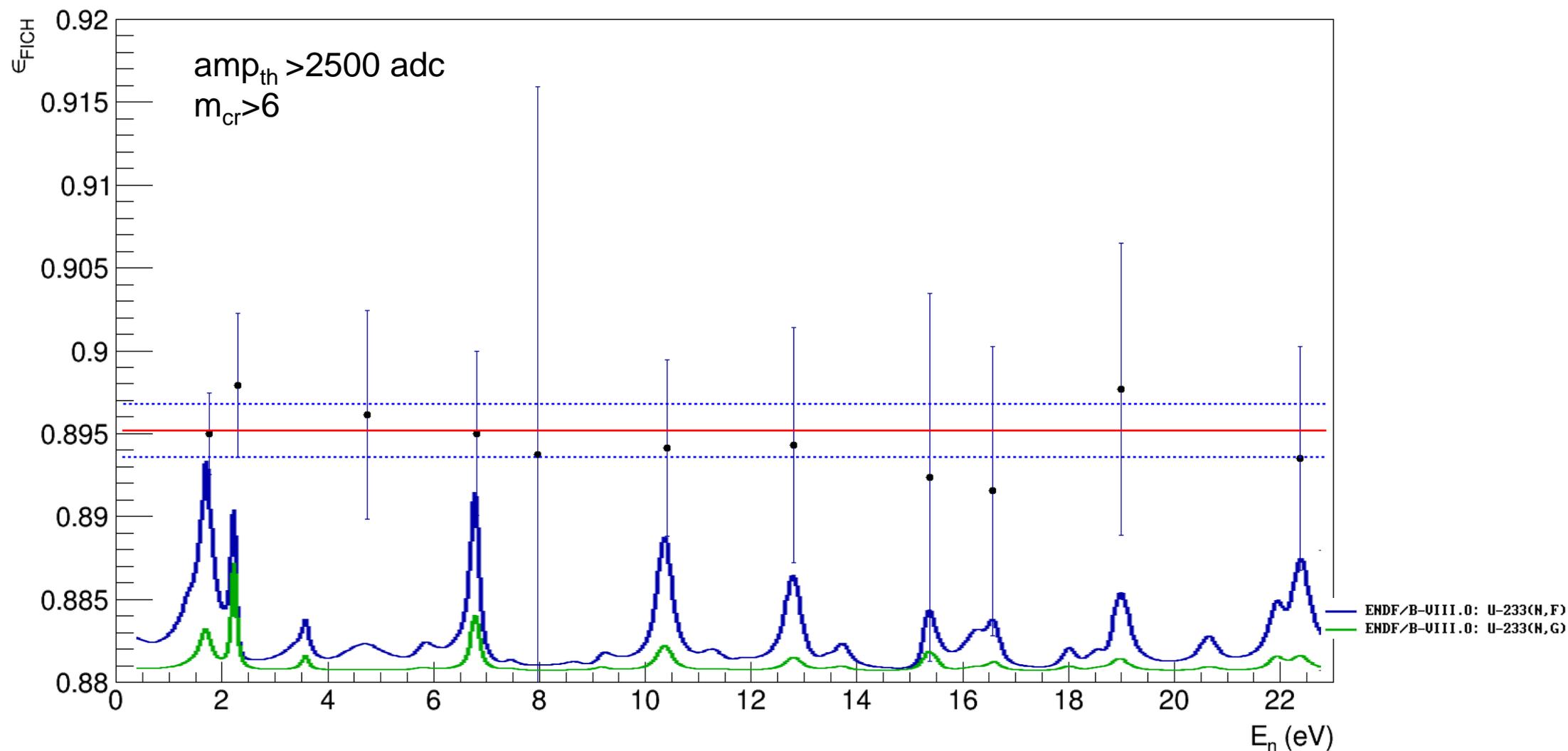
# FICH Efficiency – Method



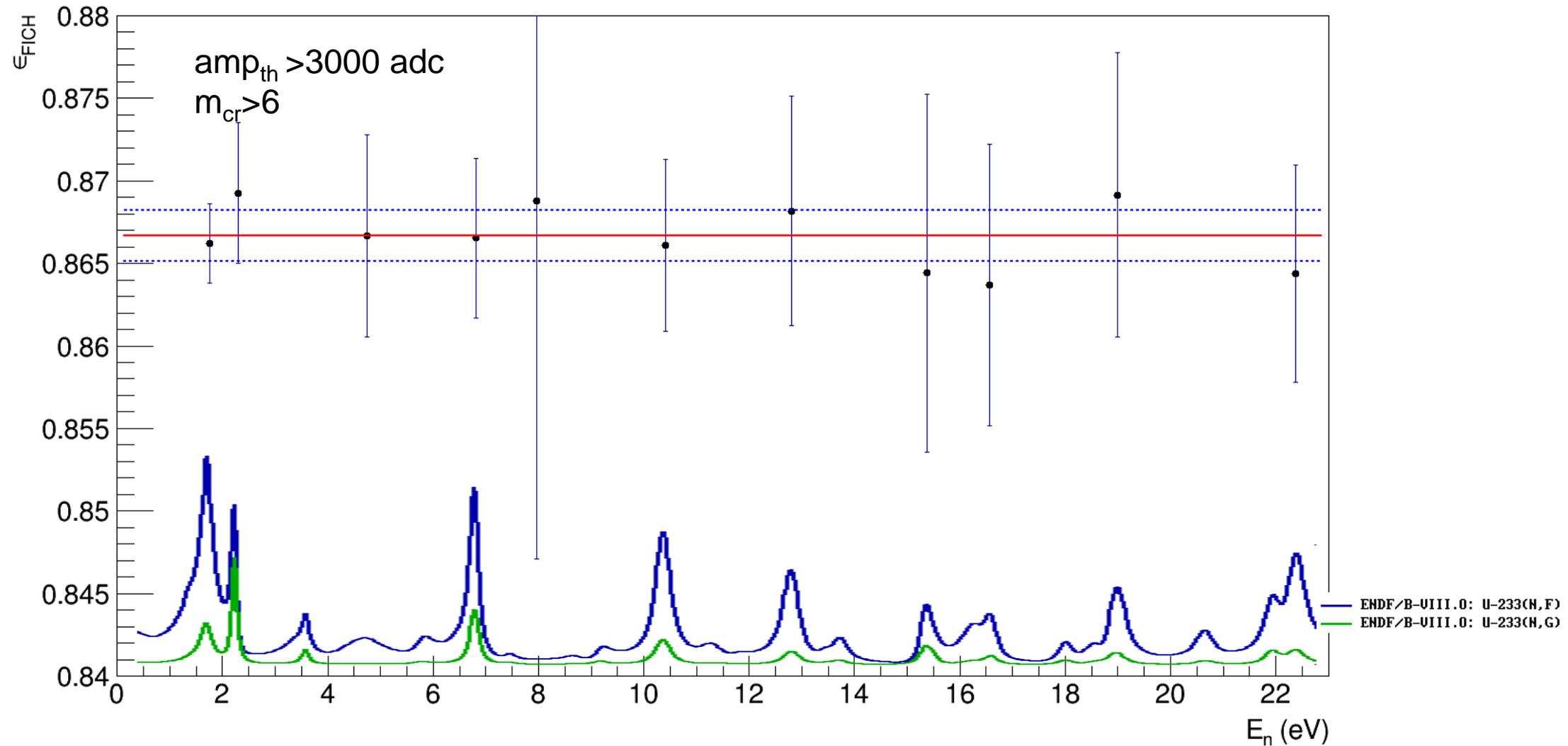
# FICH Efficiency



# FICH Efficiency – amplitude thresholds



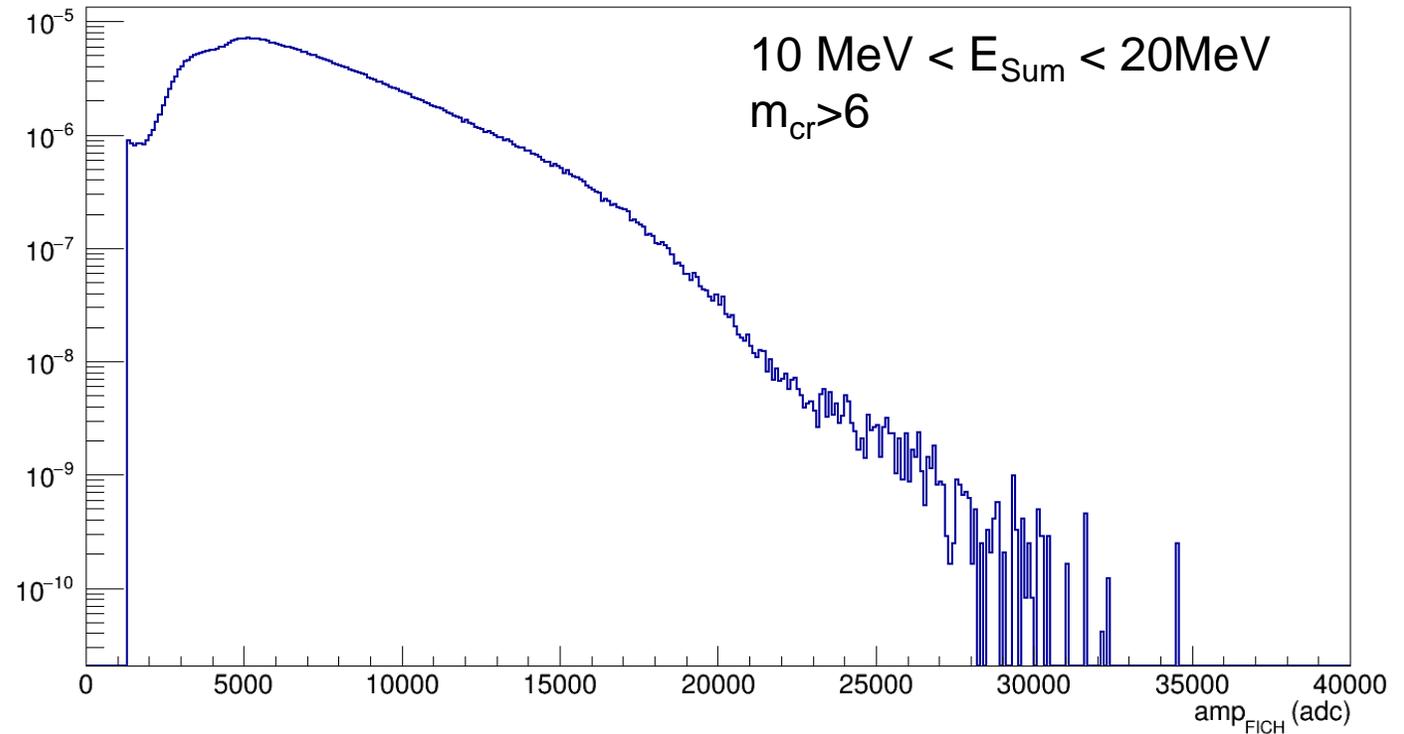
# FICH Efficiency – amplitude thresholds



# Efficiency - Correction

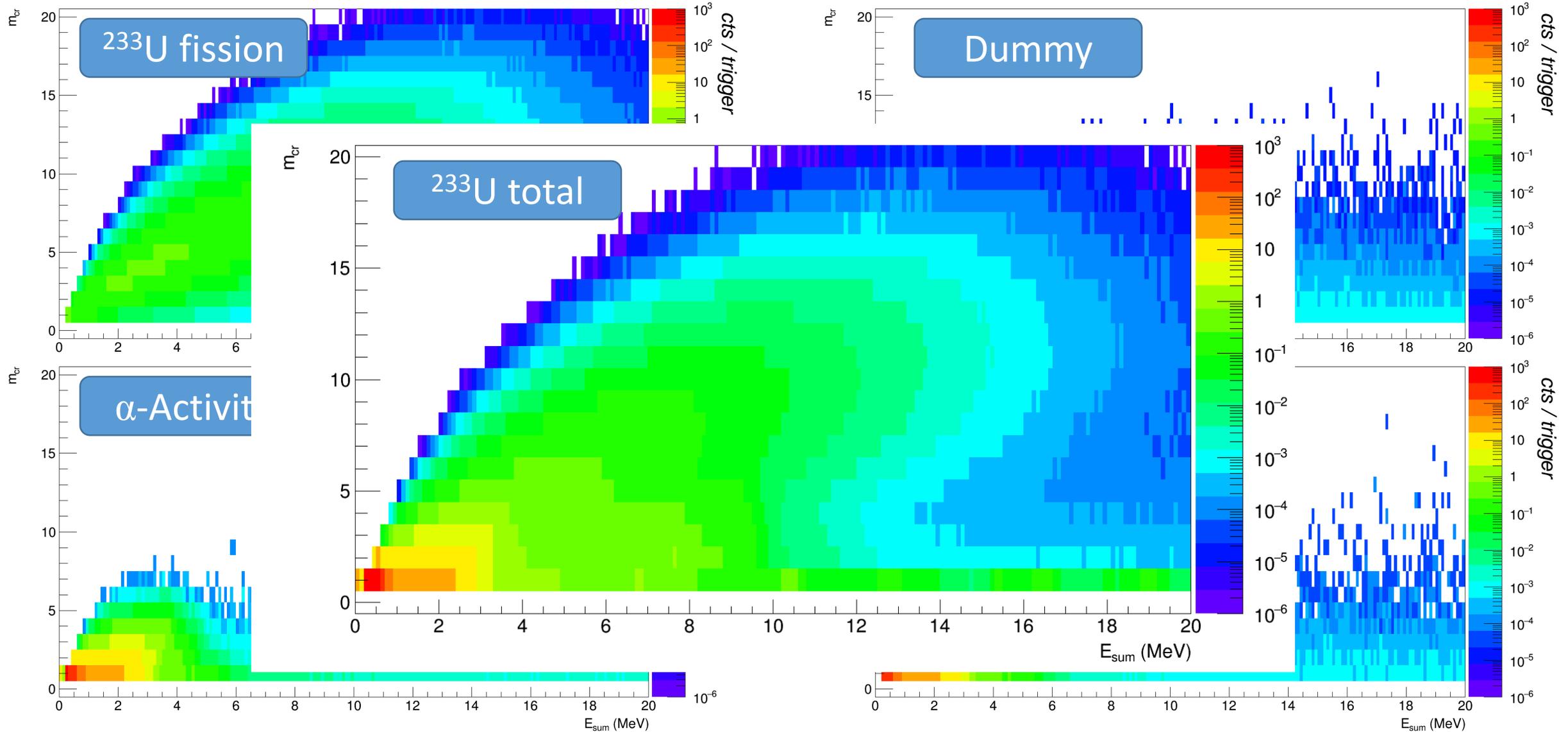
- Experimental fission efficiency for various amplitude thresholds  $\text{amp}_{\text{th}}$

	mcr>			
	5		6	
$\text{amp}_{\text{th}} >$	mean	uncertainty	mean	uncertainty
1300	0.9195	0.0016	0.9200	0.0016
2000	0.9078	0.0016	0.9082	0.0016
2500	0.8948	0.0016	0.8952	0.0016
3000	0.8665	0.0015	0.8667	0.0015
3500	0.8215	0.0015	0.8215	0.0015
4000	0.7676	0.0014	0.7674	0.0014

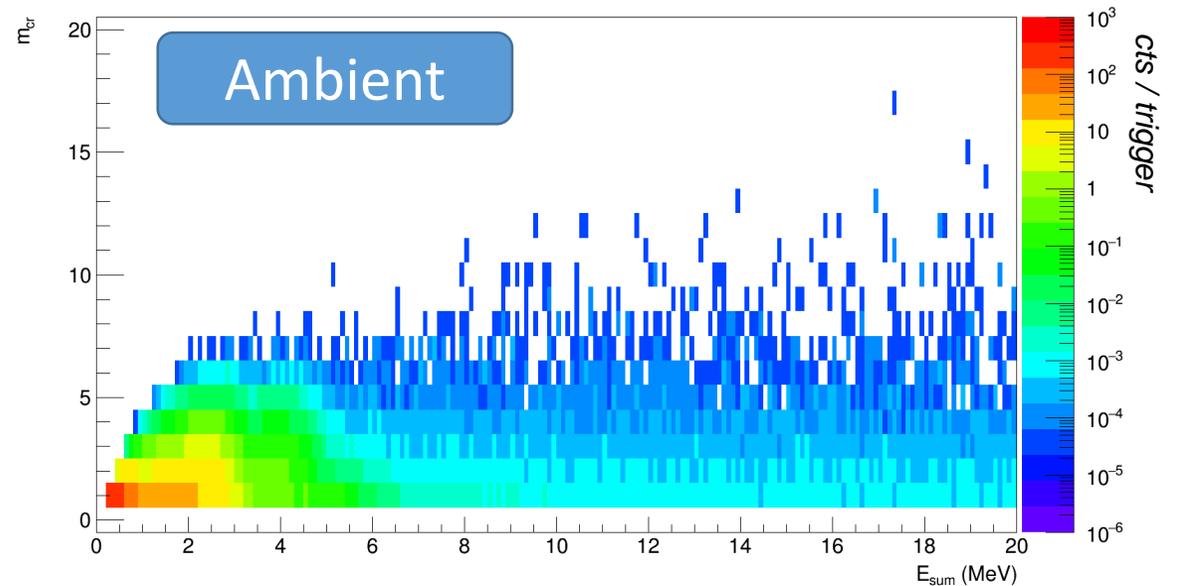
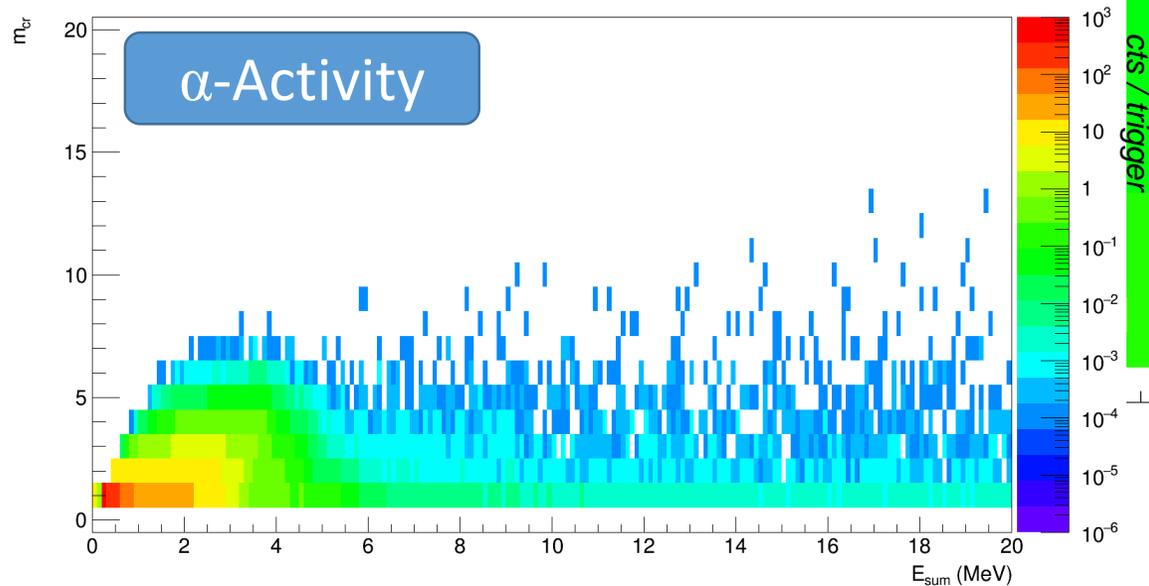
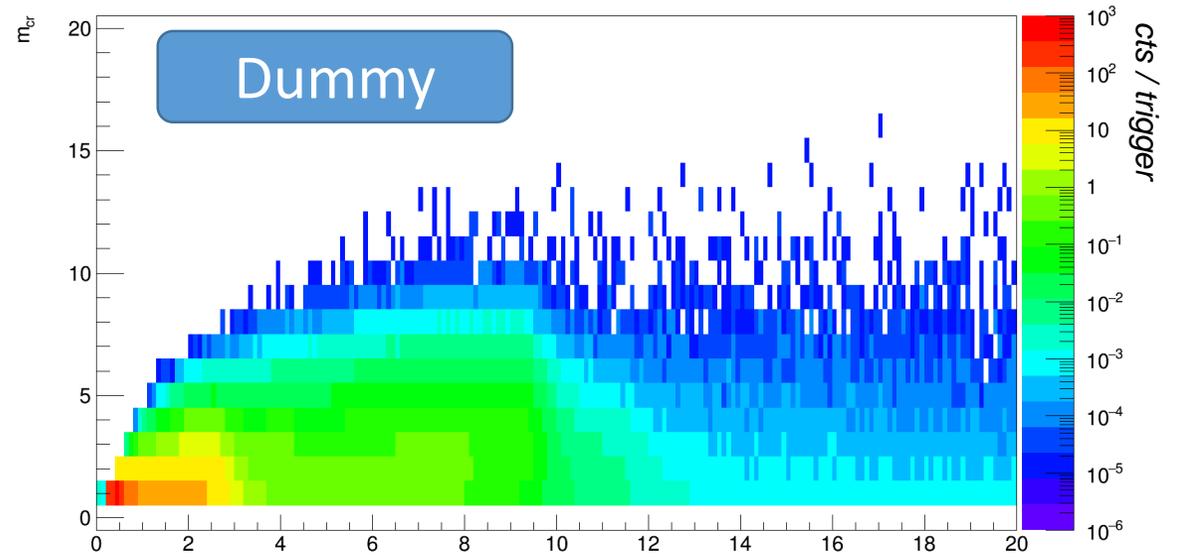
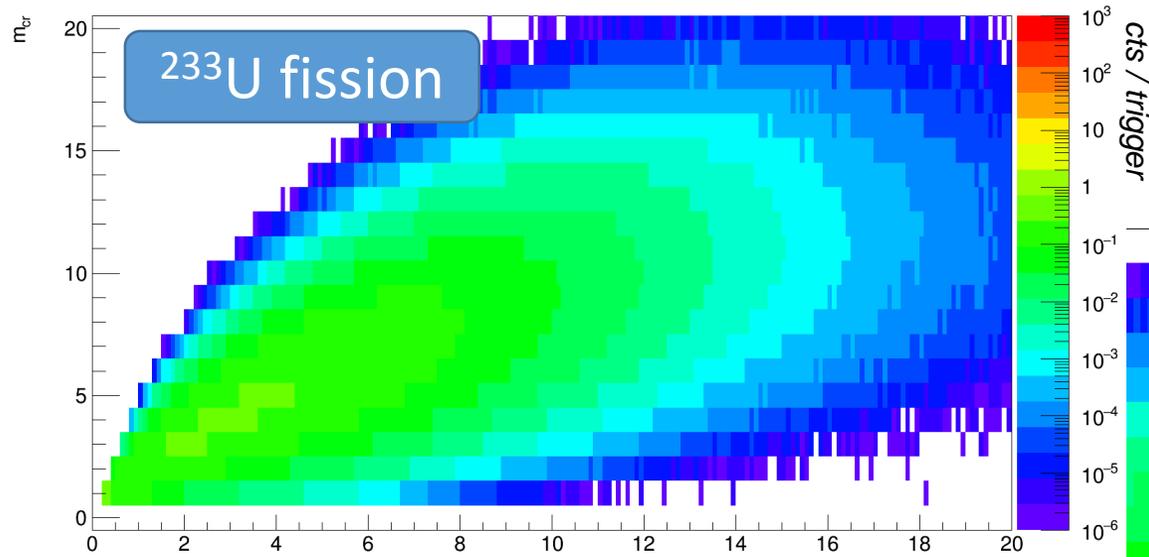


Capture Preliminary

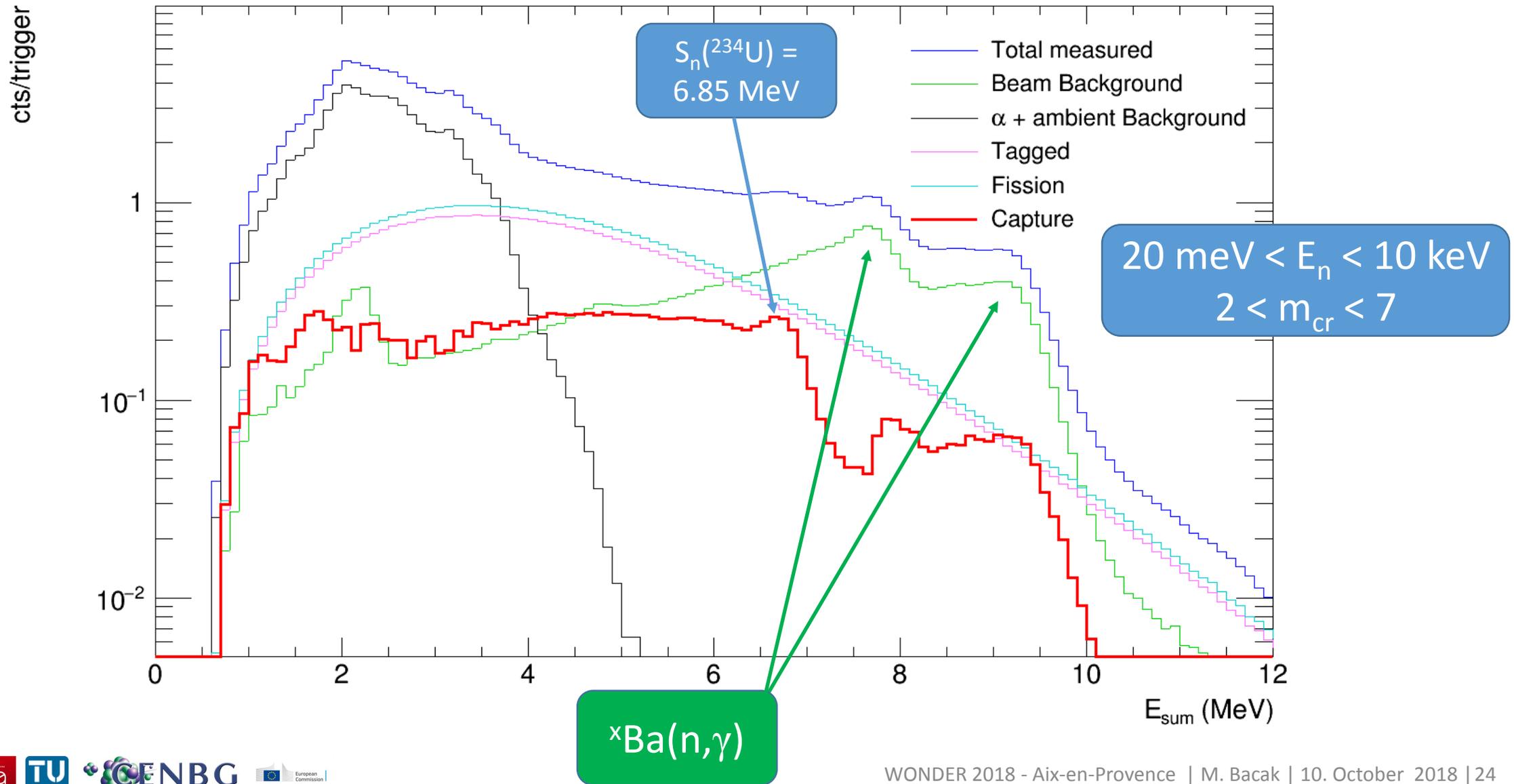
# Capture – Sources of background



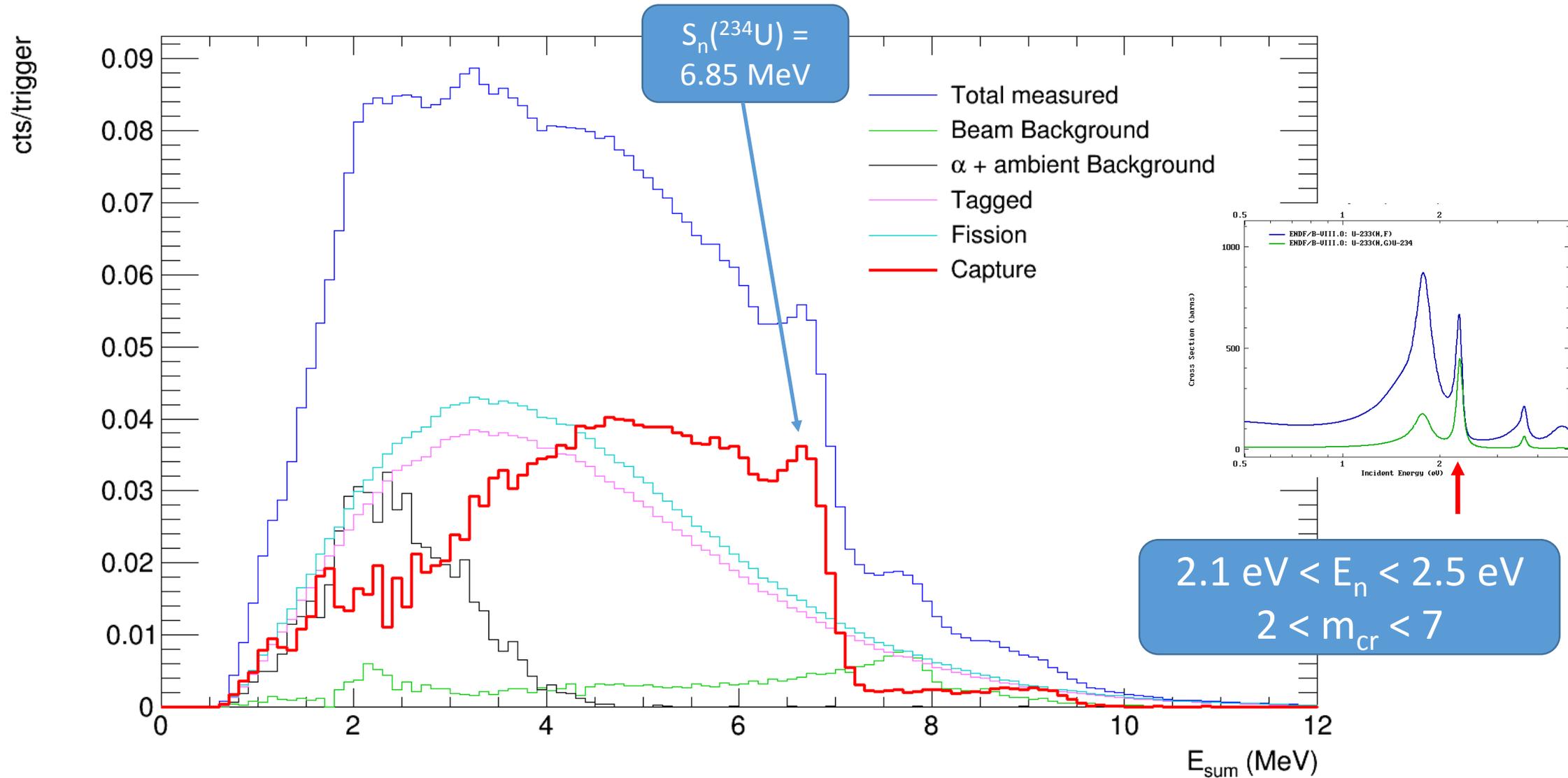
# Capture – Sources of background



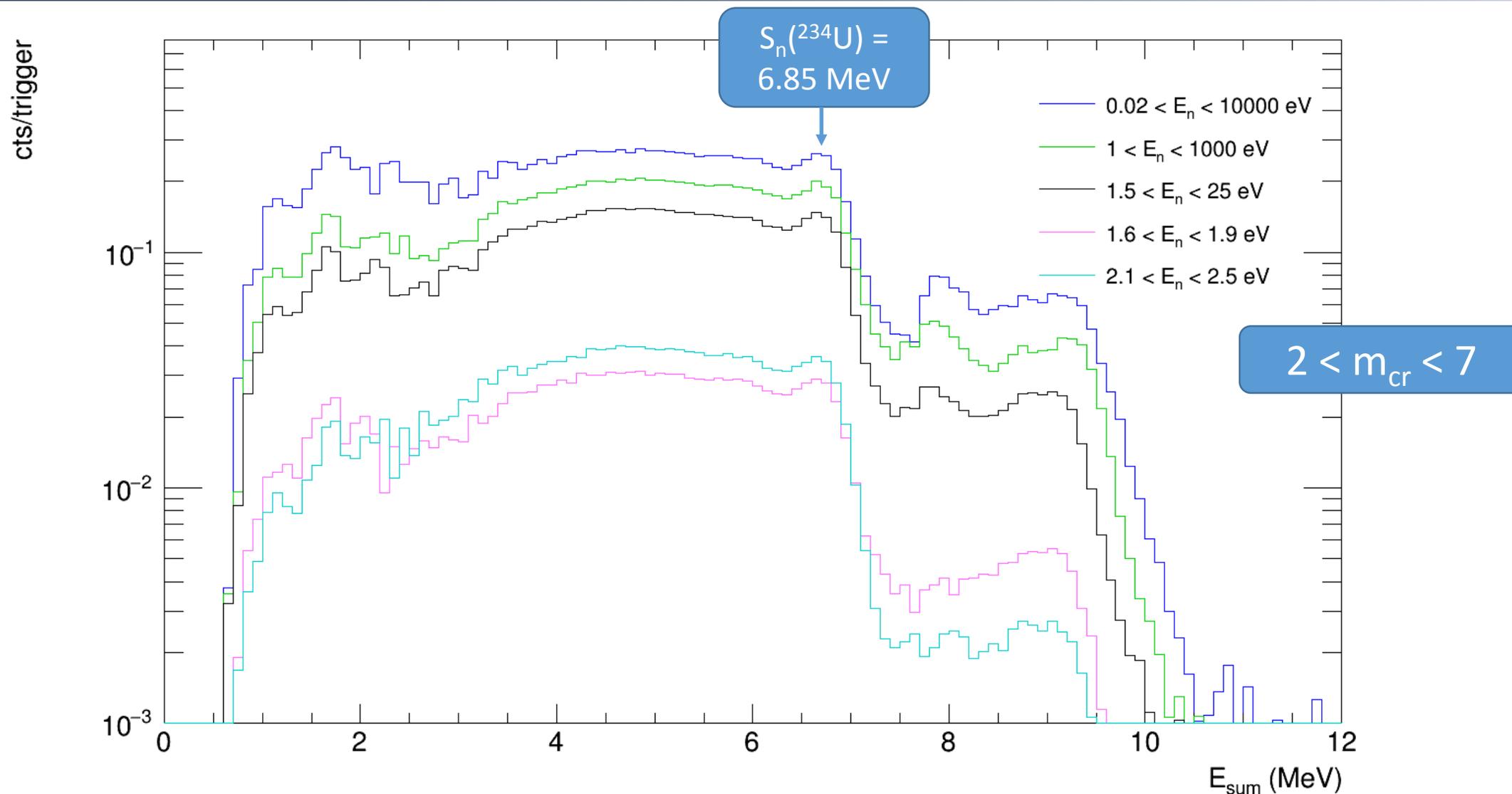
# Capture – TAC response



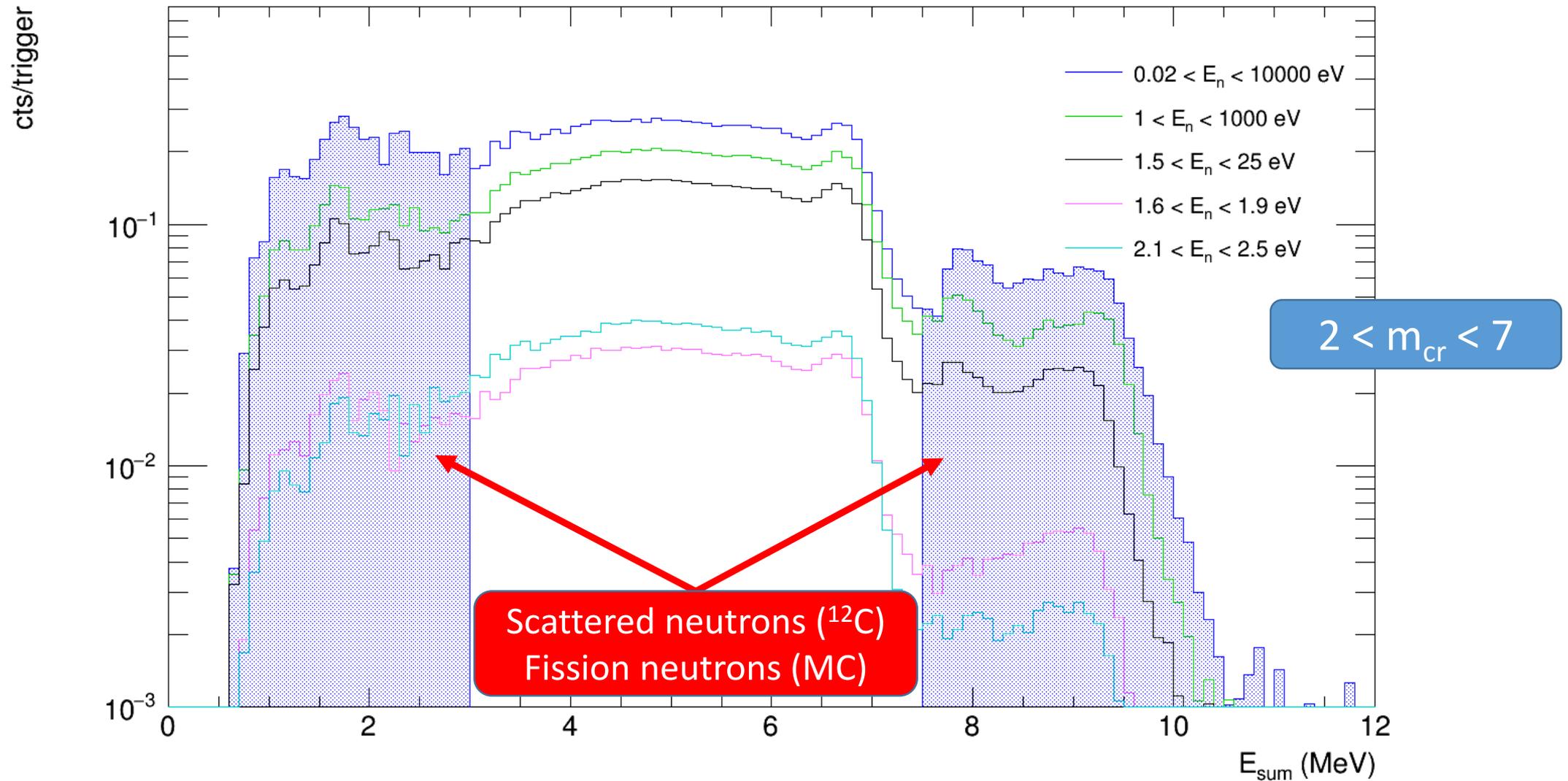
# Capture – TAC response



# TAC Capture response – various $E_n$

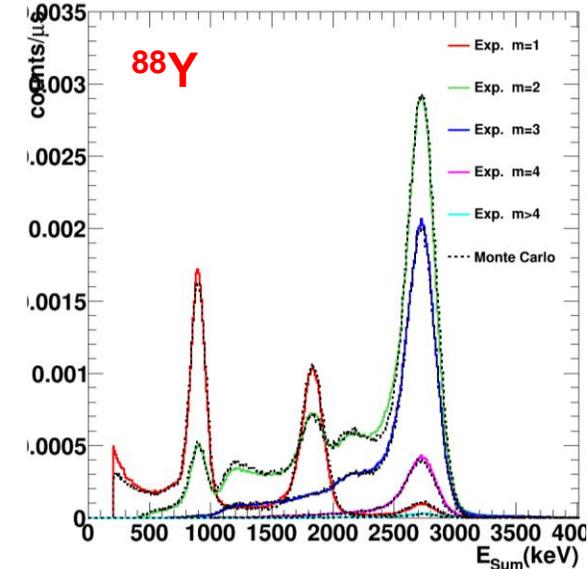
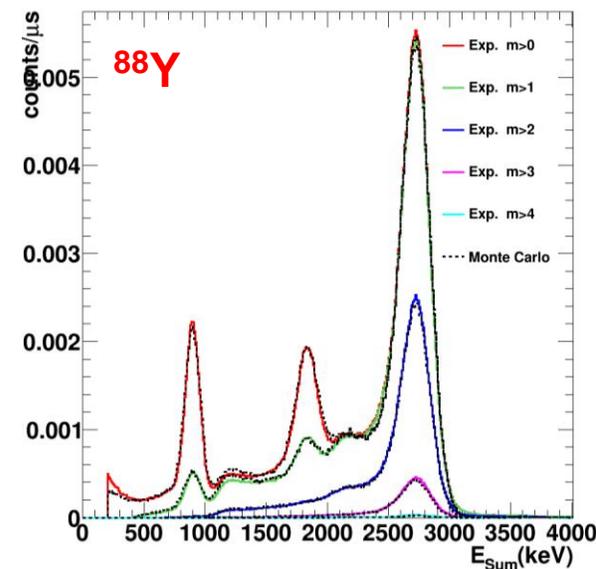
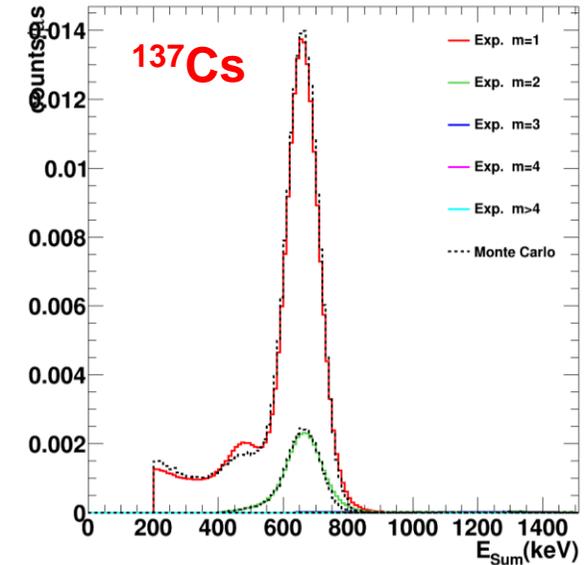
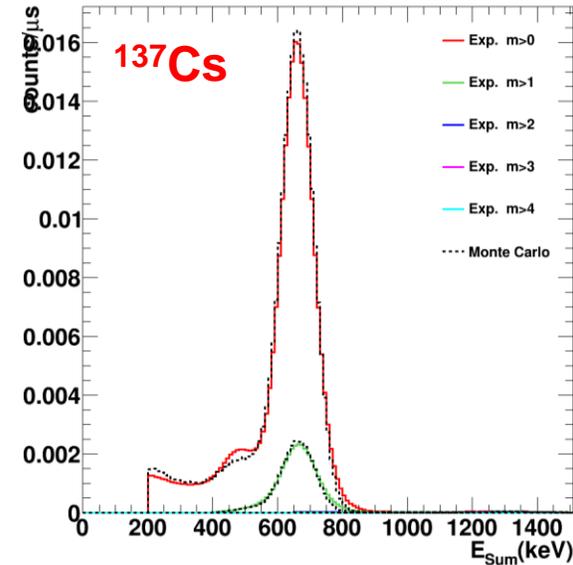


# Capture – TAC response background leftovers



# Corrections – Simulations

- Full geometry implemented in geant4
- Verify MC with experimental data of  $\gamma$ -sources ( $^{137}\text{Cs}$ ,  $^{88}\text{Y}$ )
- Fission and capture cascades from DiceBox
- Fission neutron response
- Calculate detection efficiencies
- Calculate corrections (dead time, ...)



# Summary

- Data reduction successfully performed
- MC studies for corrections
- Final  $\alpha$ -ratio in 2019
- Resonance analysis (including statistical analysis of resonances)
- Publication & EXFOR

Thank you



# Topics

## I. Motivation

## I. Experimental Setup

- n\_TOF
- Detectors

## II. Tagging Technique

## IV. Fission

- Amplitude Spectra
- Efficiency correction

## V. Capture

- Sources of background
- TAC response to capture

## VI. Summary & next steps

# Tagging Technique

# Tagging – Coincidence & Event Selection

- TimeWindow in TAC: 12 ns
- TimeWindow FICH-TAC  $\geq$  TimeWindow TAC
- Choose a time window where as little as possible FF are lost while a reasonable coincidence time is assumed

# Tagging – Coincidence & Event Selection

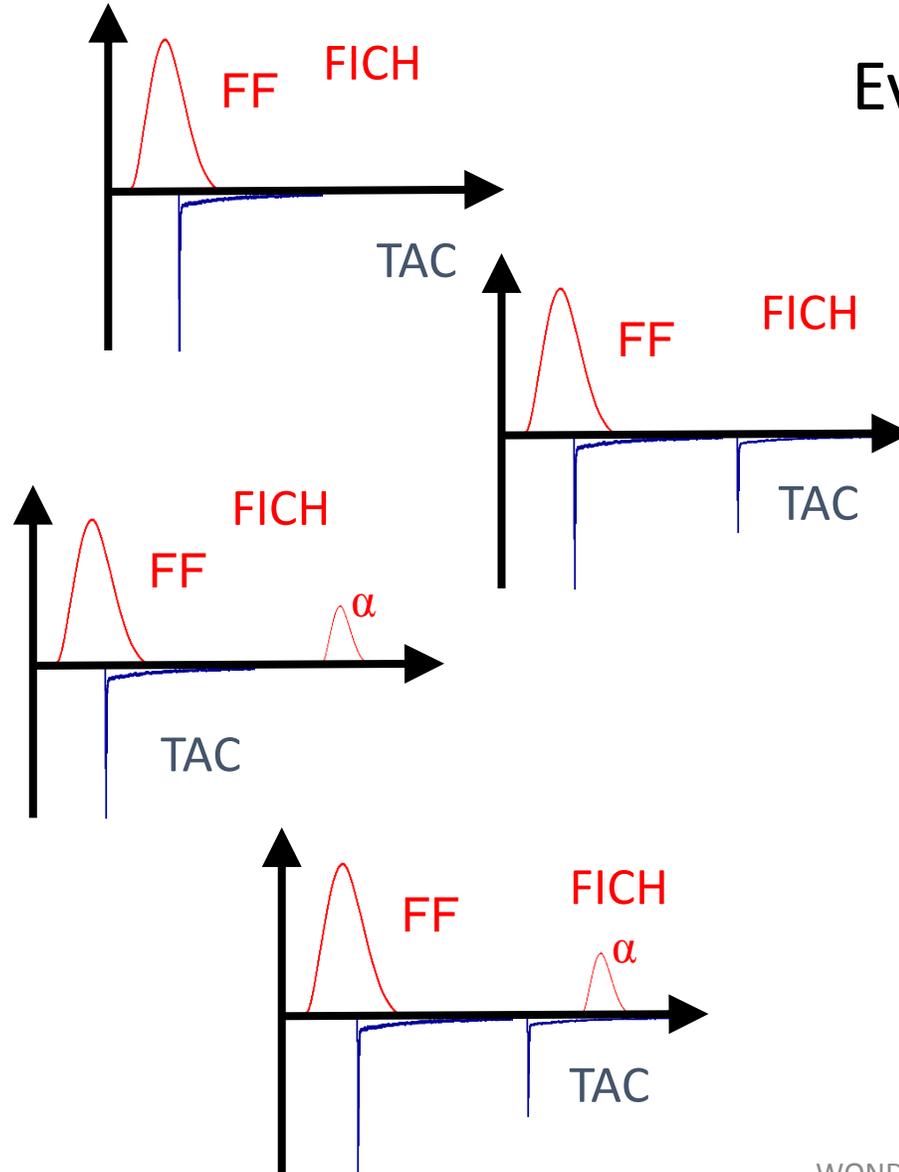
## 4 Types of Events:

a. 1 FICH for 1 TAC

b. 1 FICH for 2 TAC

c. 2 FICH for 1 TAC

d. n FICH for m TAC



## Event Selection, choose:

a. Easy (75%)

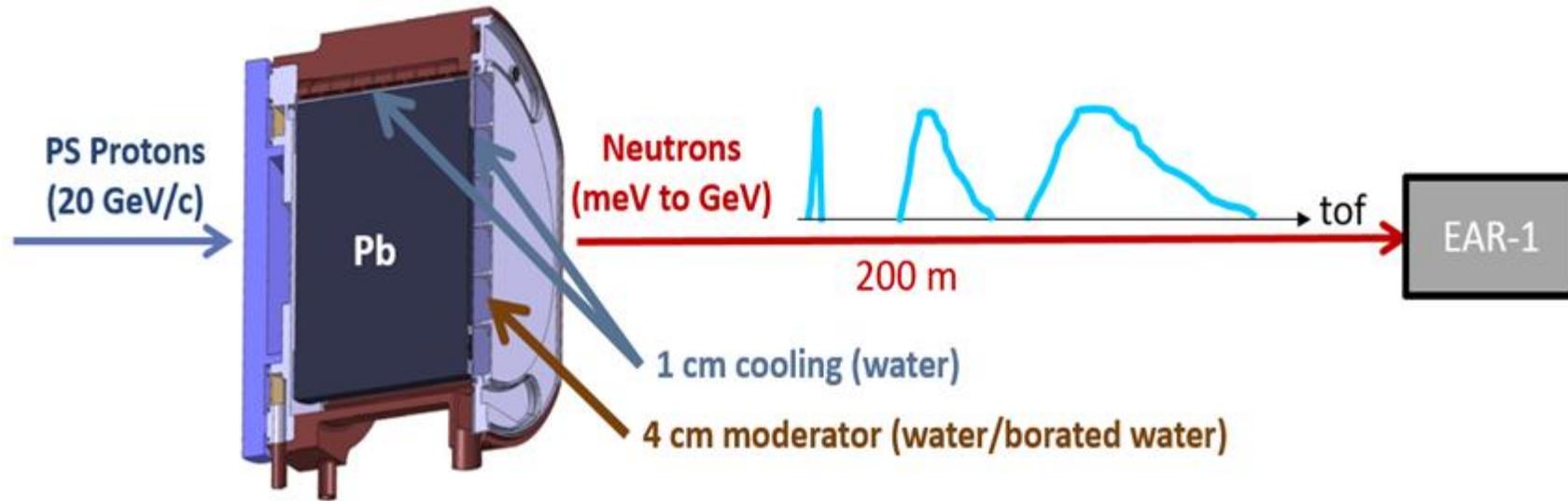
b. Larger  $m_{cr}$  then  $E_{Sum}$  (24%)

c. Larger amplitude  
(loss of FICH signal!)

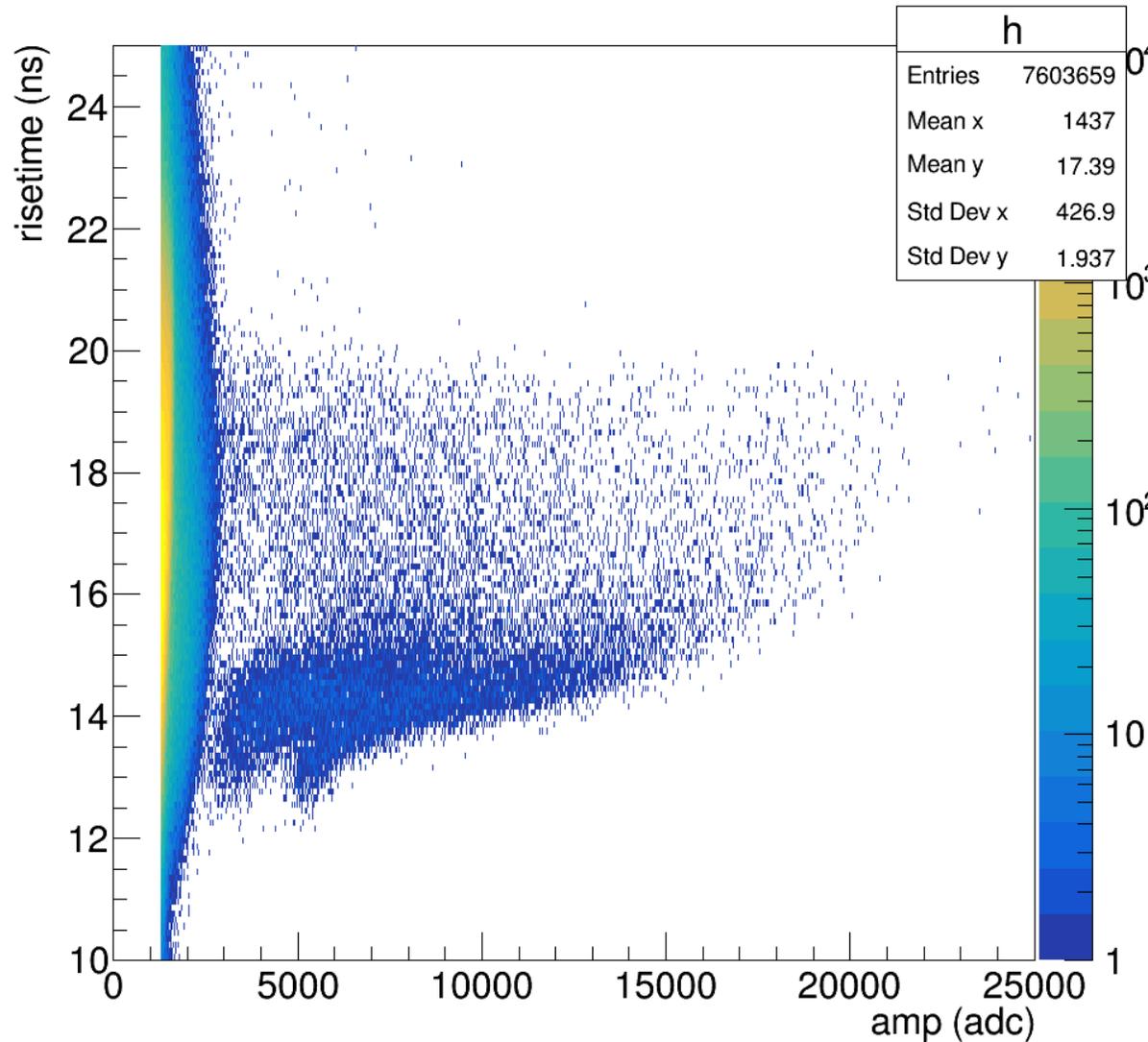
d. FICH - larger amplitude  
(loss of FICH signal!)  
TAC - Larger  $m_{cr}$  then  $E_{Sum}$

# Experimental Setup

# n\_TOF at CERN



# PSA - FICH performance

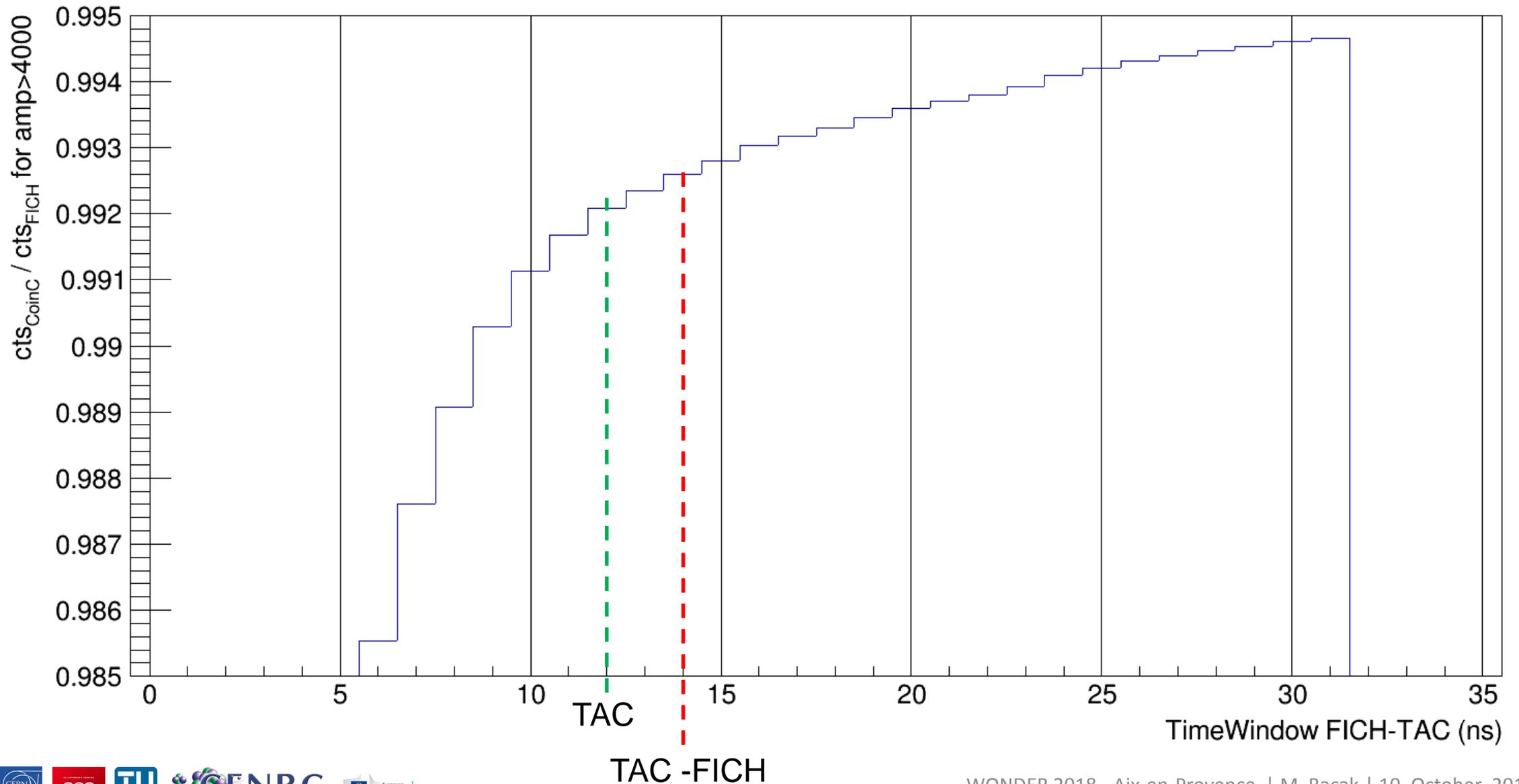


- Two Bananas → Light & Heavy
- Large spread due to emission angle dependence

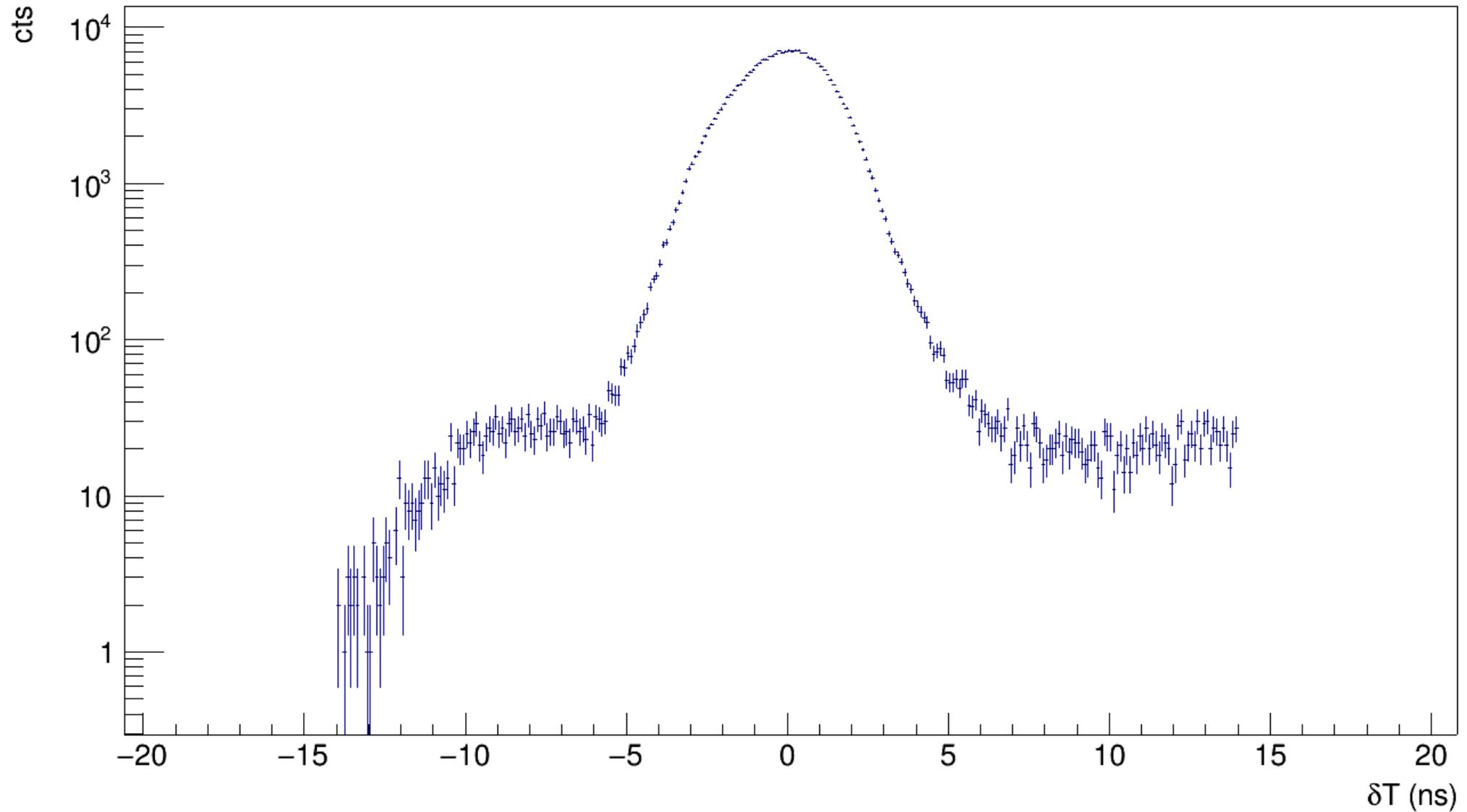
# Tagging – Coincidence & Event Selection

- TimeWindow in TAC: 12 ns
- TimeWindow FICH-TAC  $\geq$  TimeWindow TAC
- Choose a time window where as little as possible FF are lost while a reasonable coincidence time is assumed
  - $c_{\text{Tagg}} / c_{\text{FICH}} > 99\%$  for FFs

# Tagging – Coincidence & Event Selection

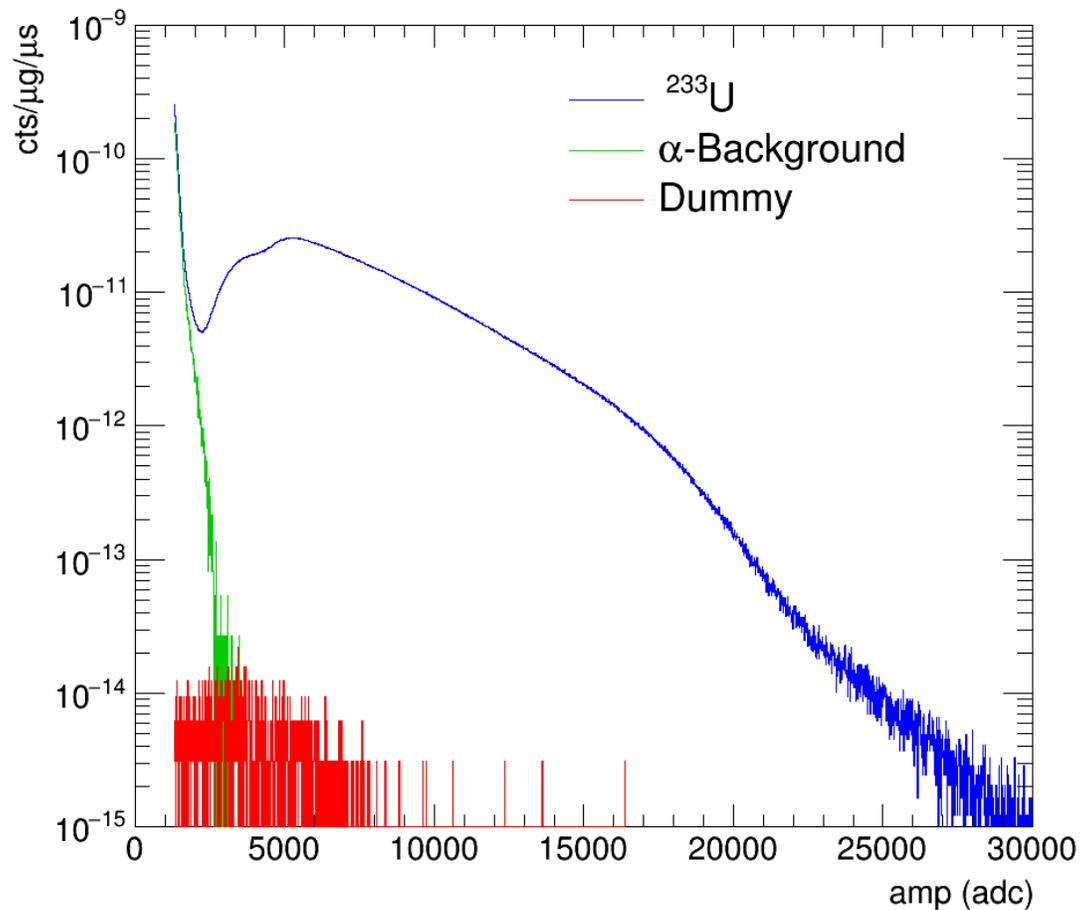


# Tagging – Coincidence & Event Selection

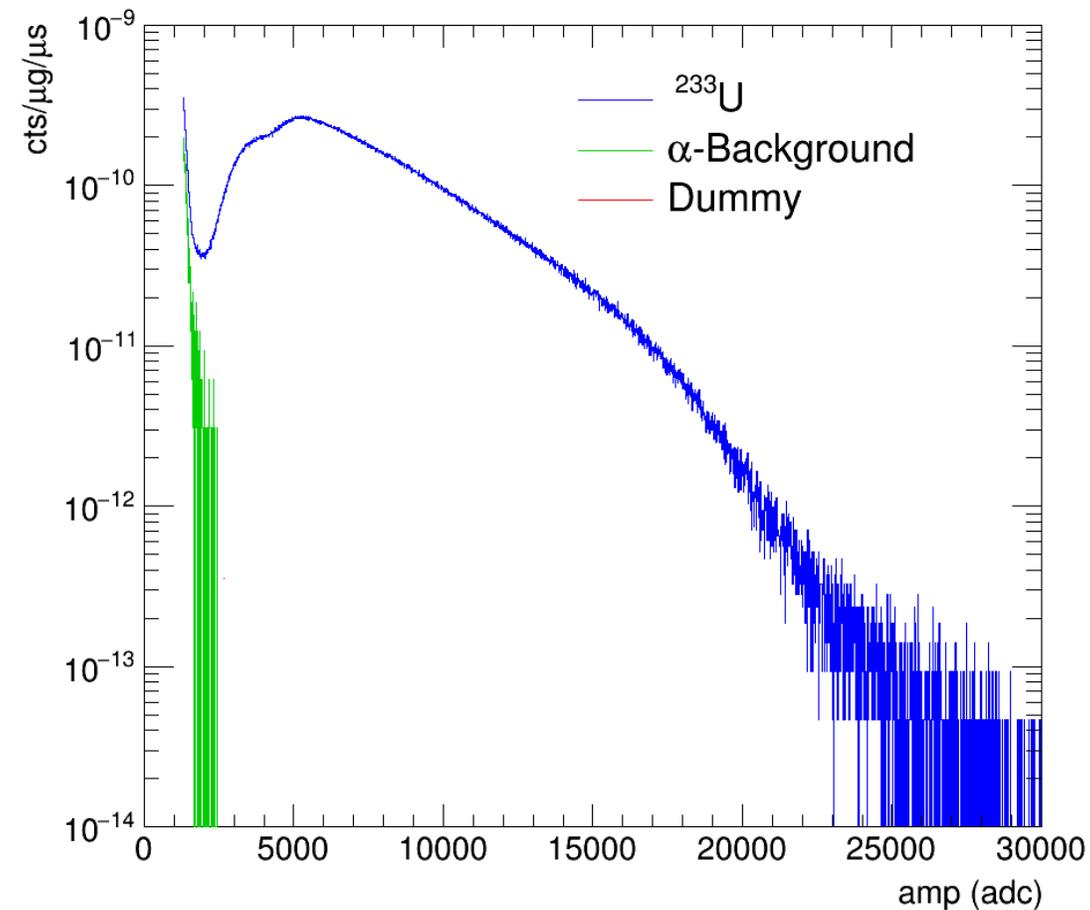


# Tagged – Amplitude spectra

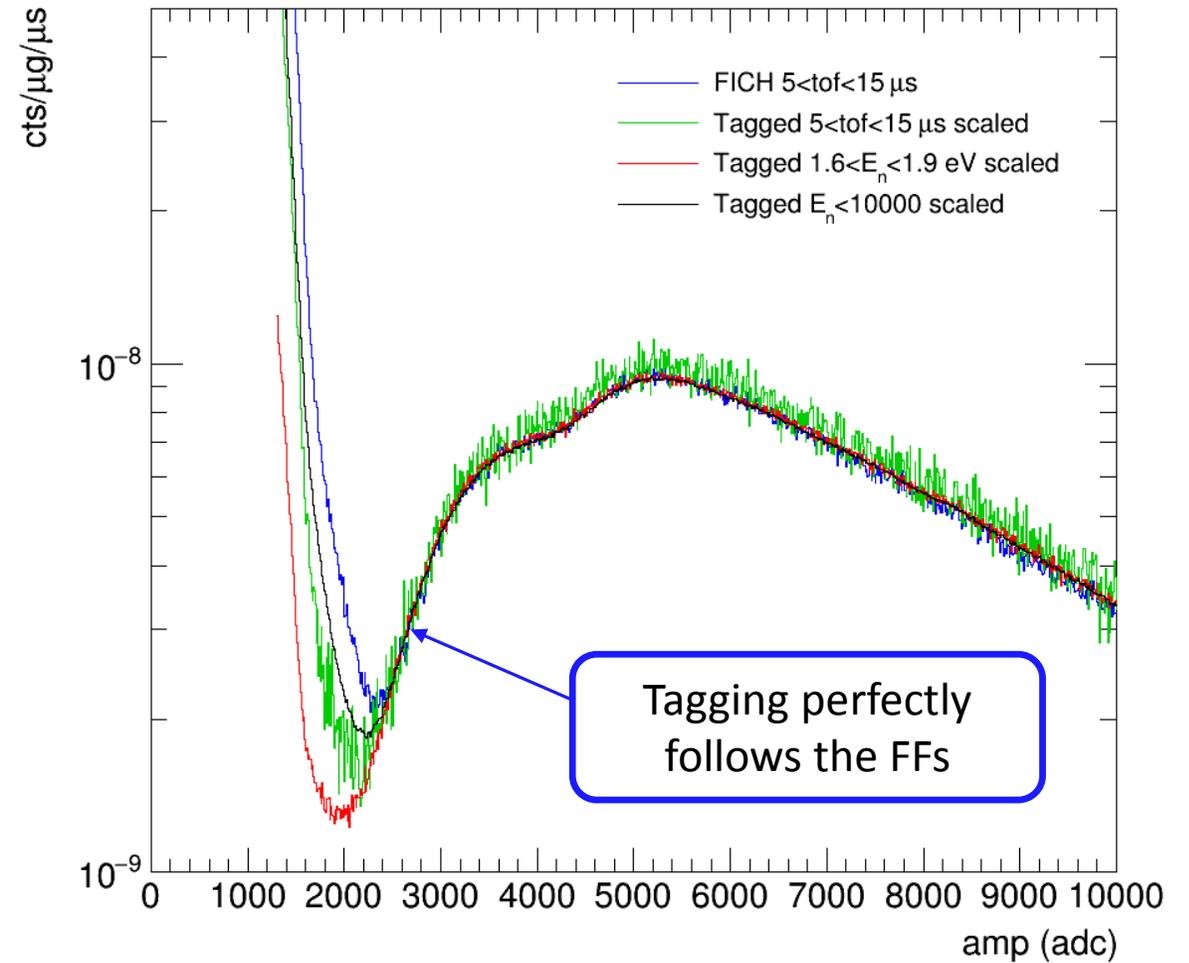
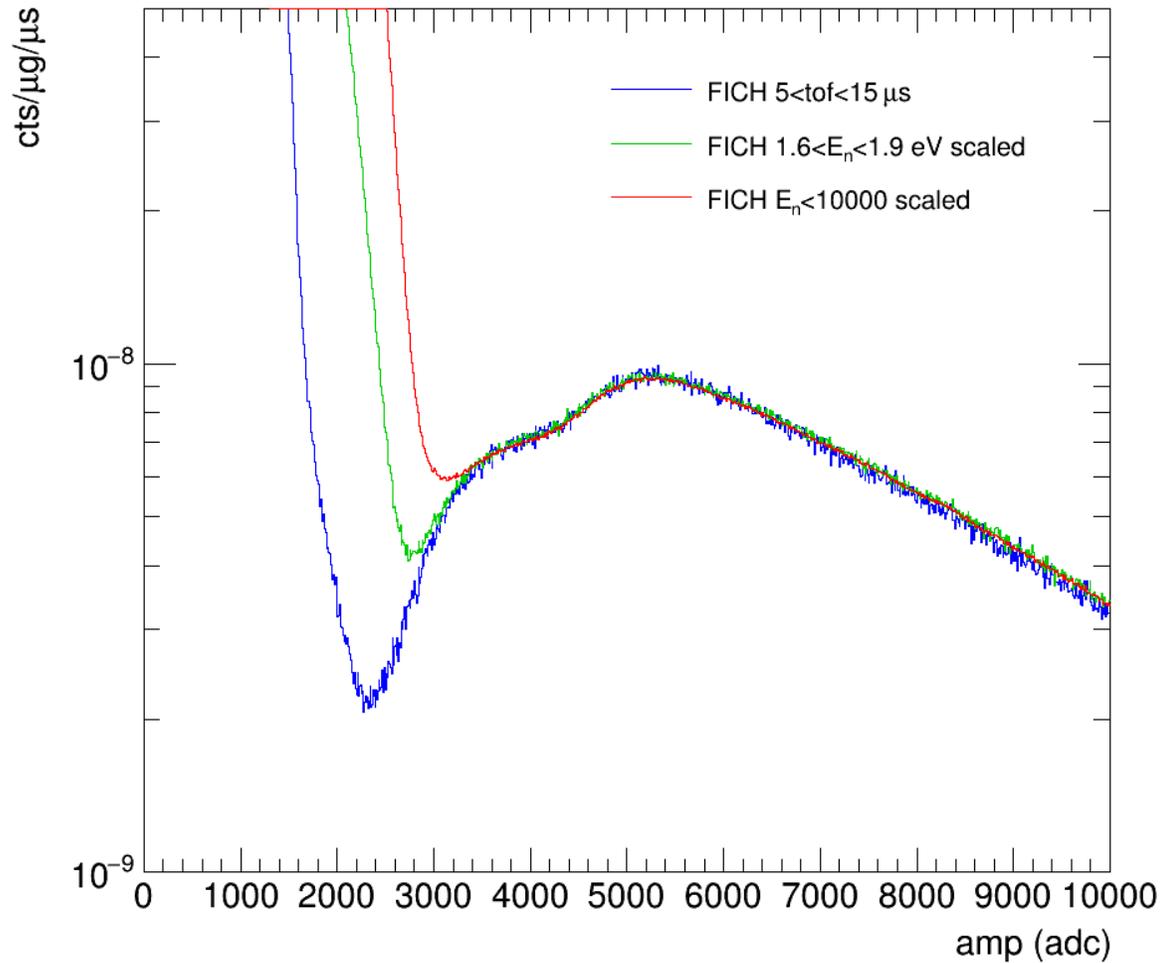
$20 \text{ meV} < E_n < 10 \text{ keV}$



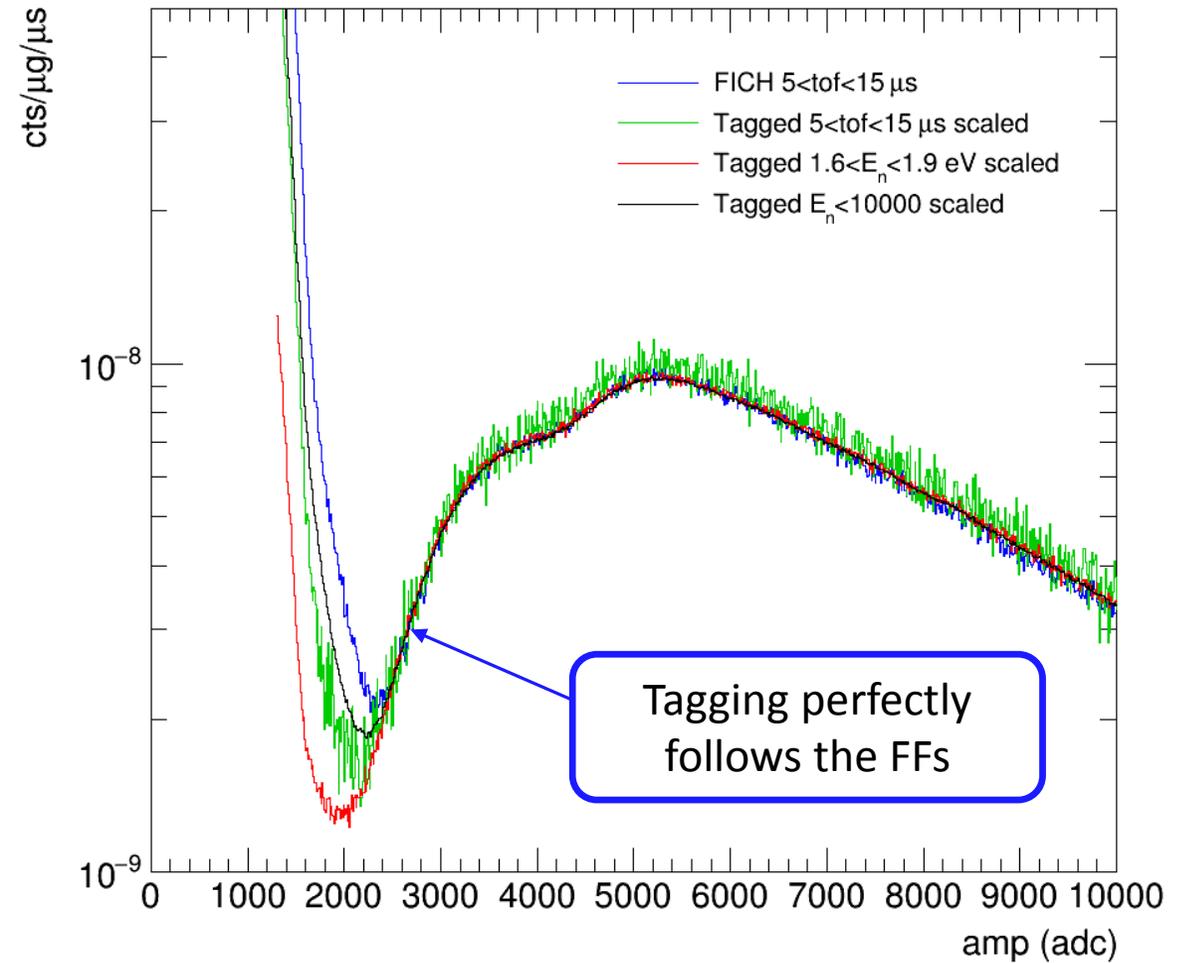
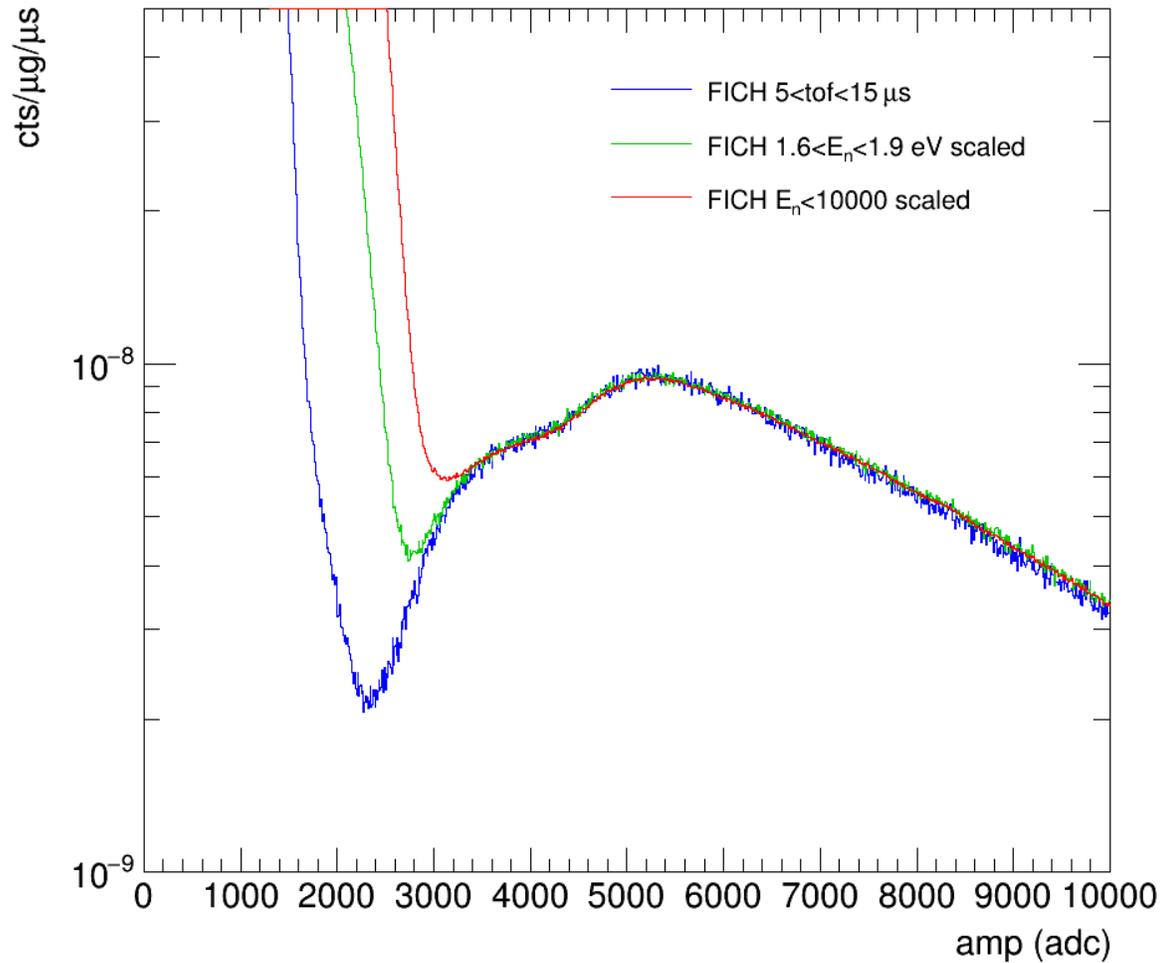
$1.6 \text{ eV} < E_n < 1.9 \text{ eV}$



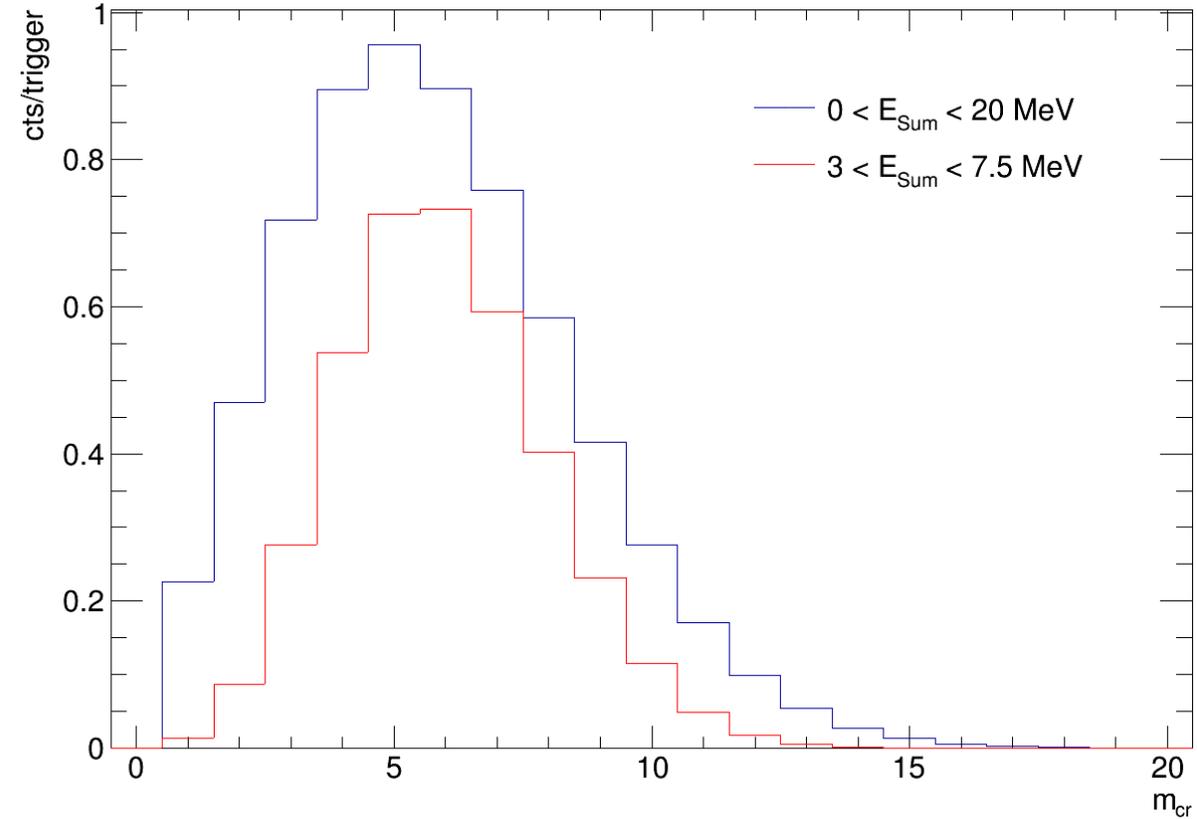
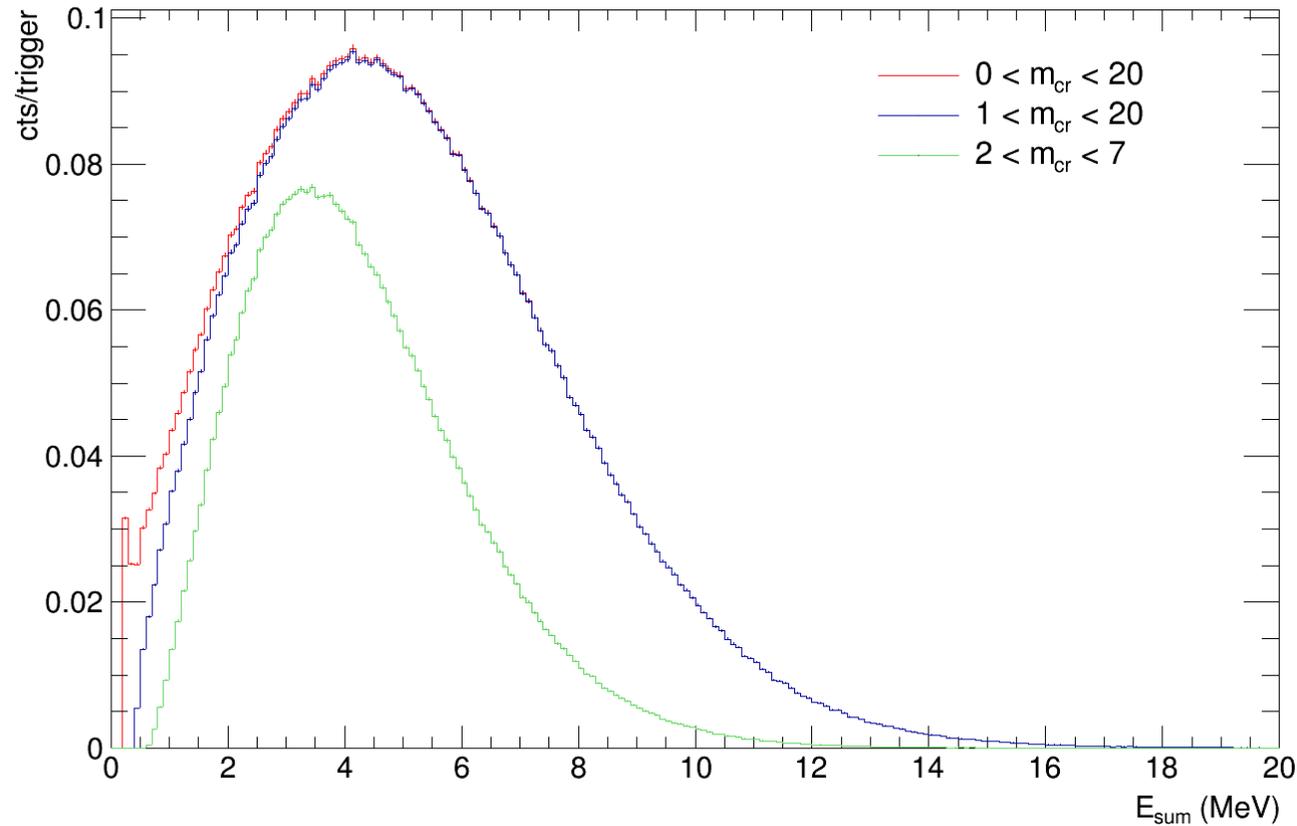
# FICH vs. Tagged – $\alpha$ -FF separation



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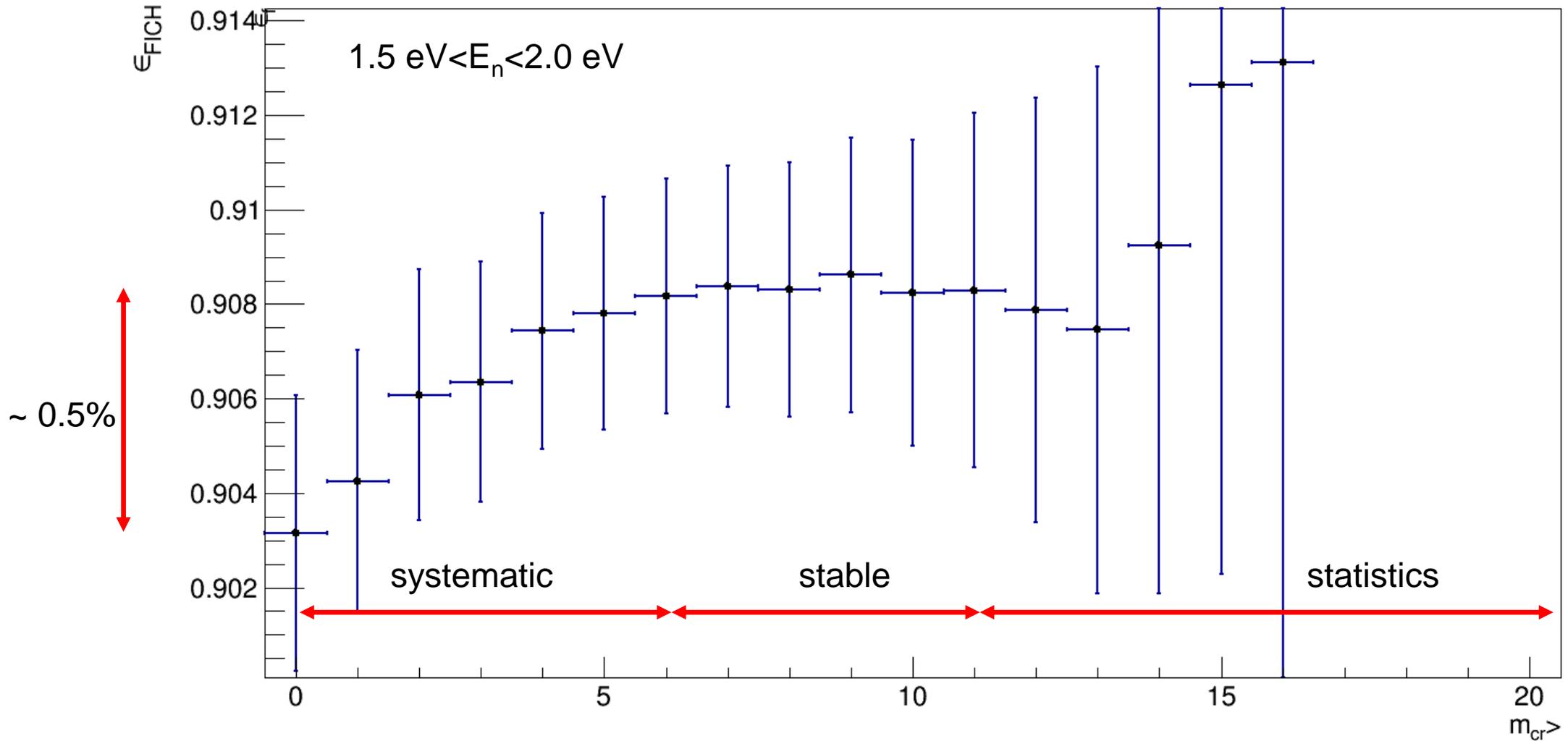


# Fission $\gamma$ -rays – $E_{\text{Sum}}$ and $m_{\text{cr}}$

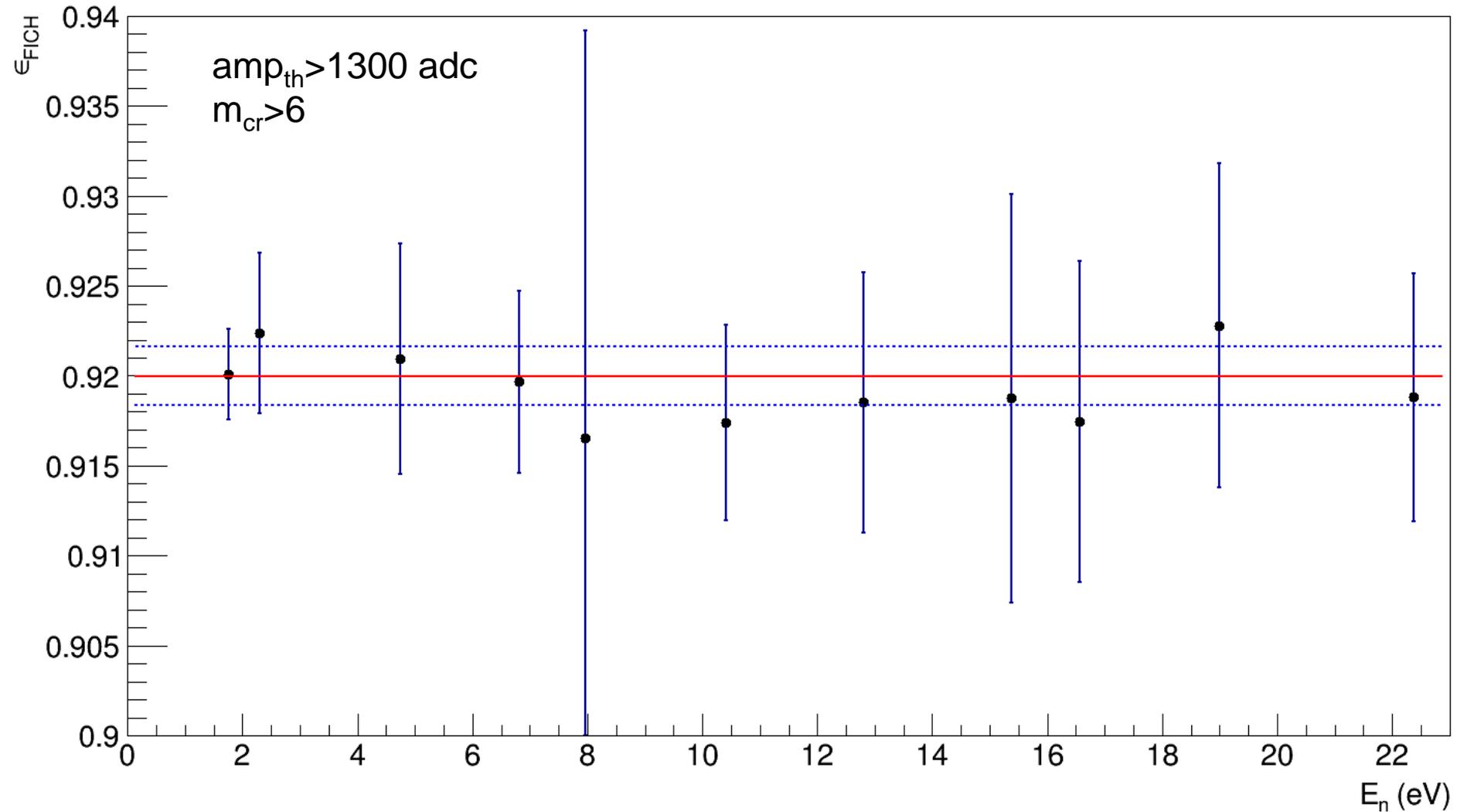


20 meV <  $E_n$  < 10 keV

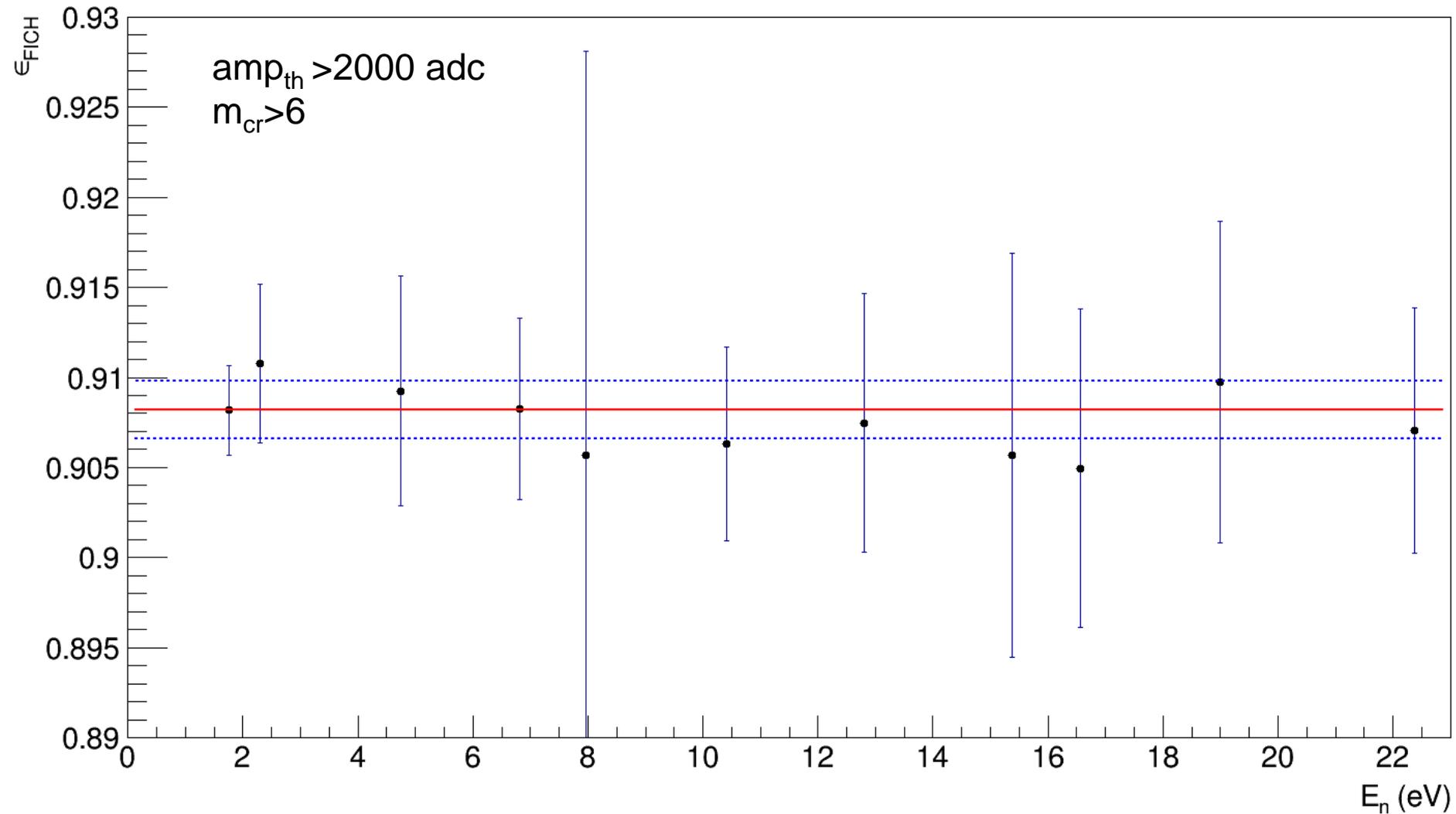
# FICH Efficiency



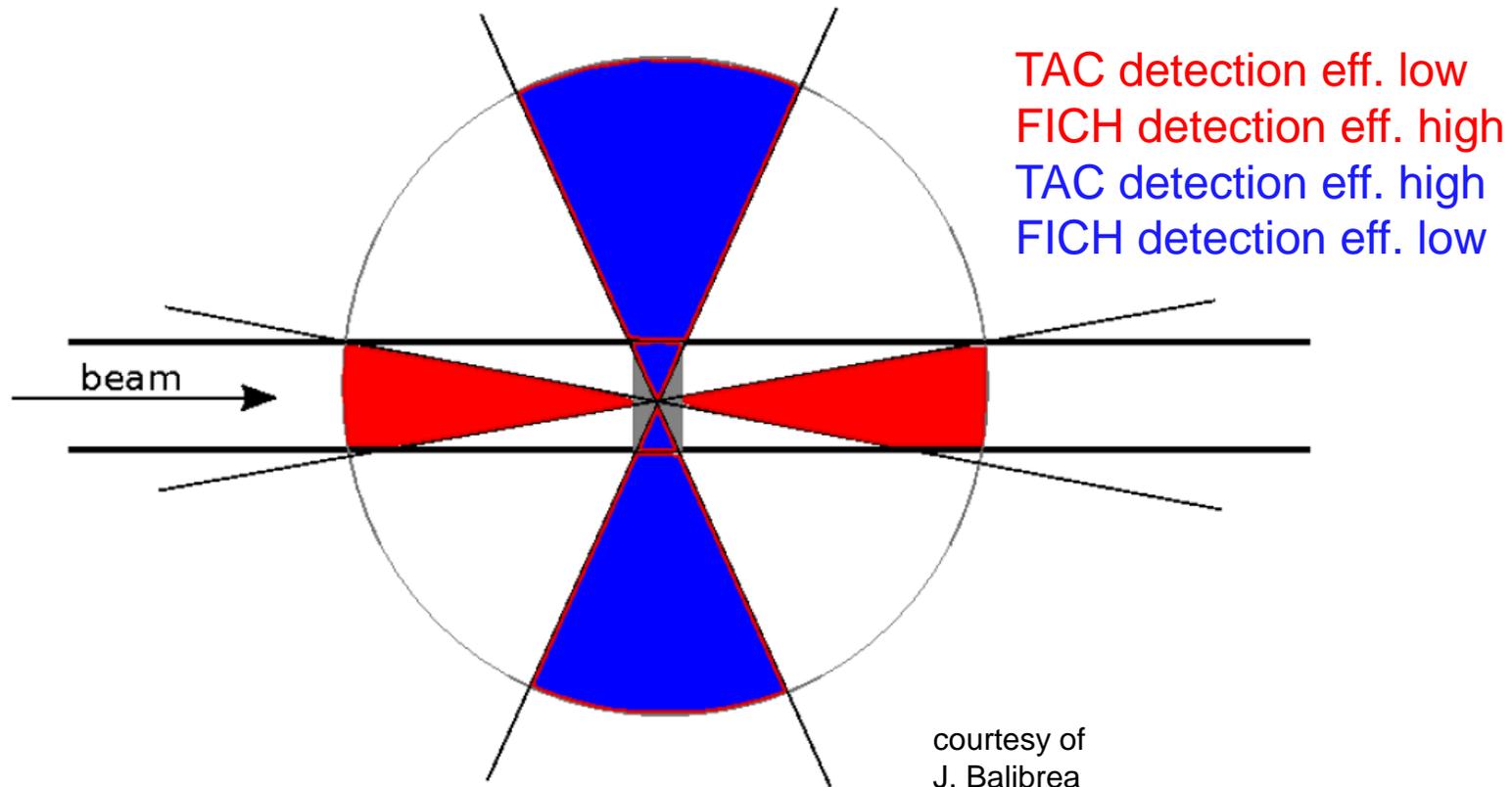
# FICH Efficiency – amplitude thresholds



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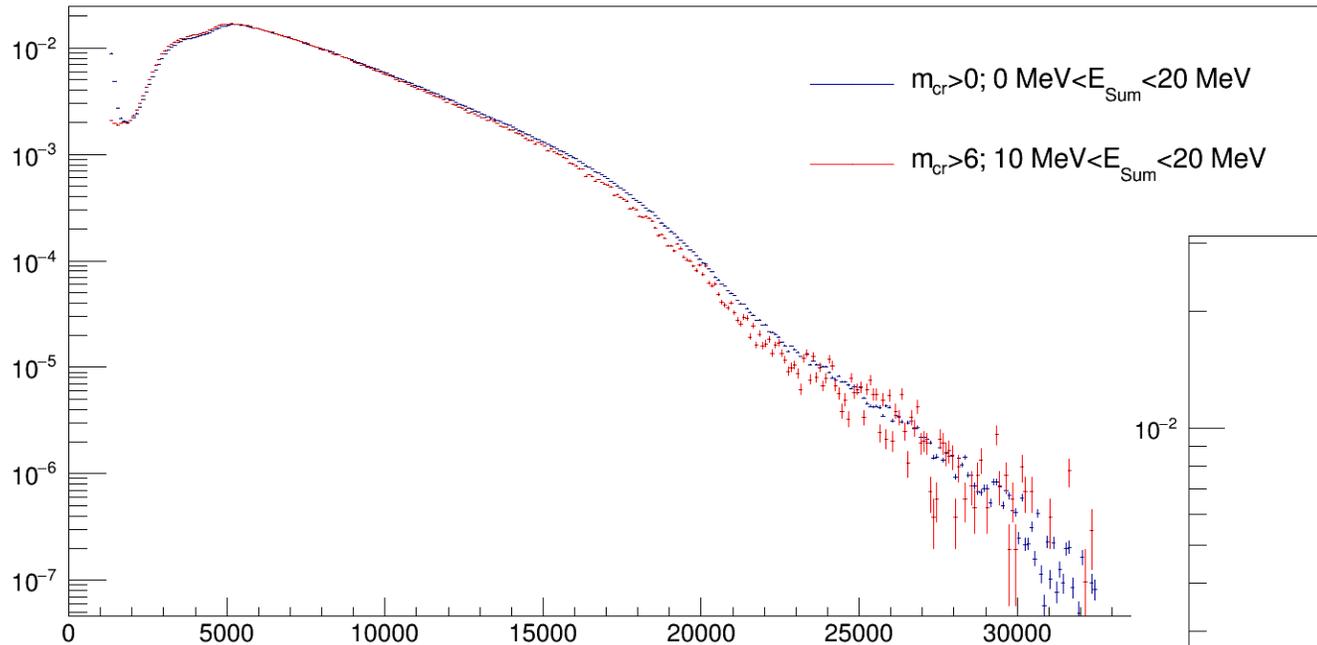


# Efficiency – Open Question

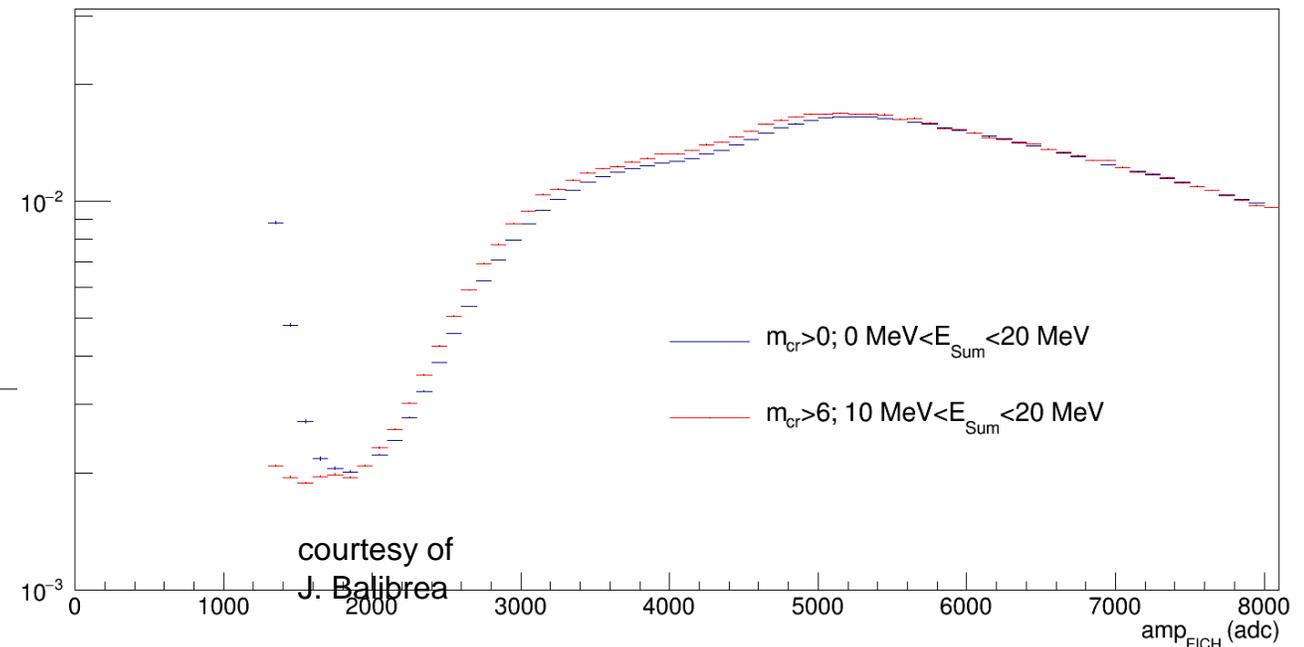


# Efficiency – Open Question

- Investigate how the amplitude spectrum changes applying different cuts in  $m_{cr}$  and  $E_{Sum}$

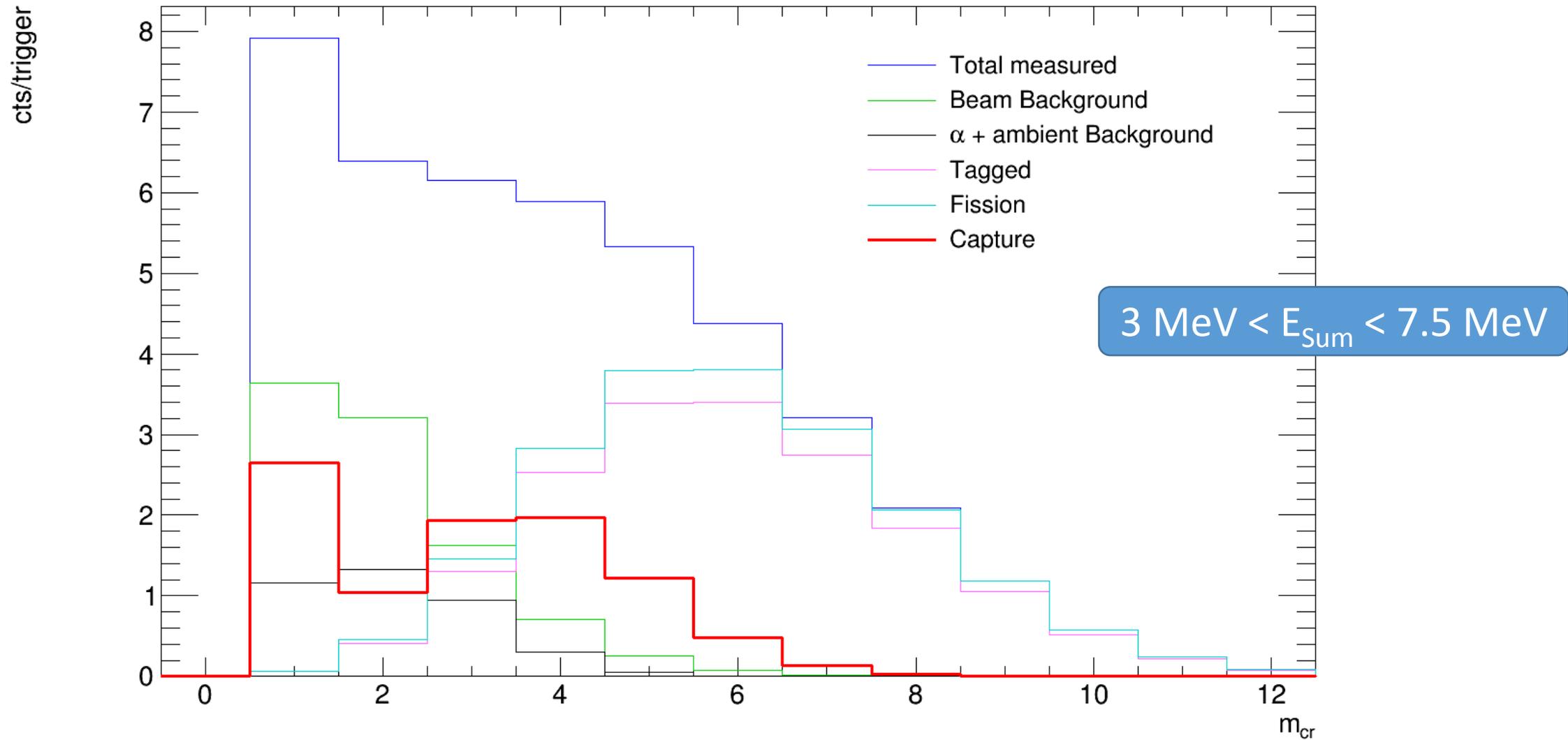


Spectra are scaled to each other

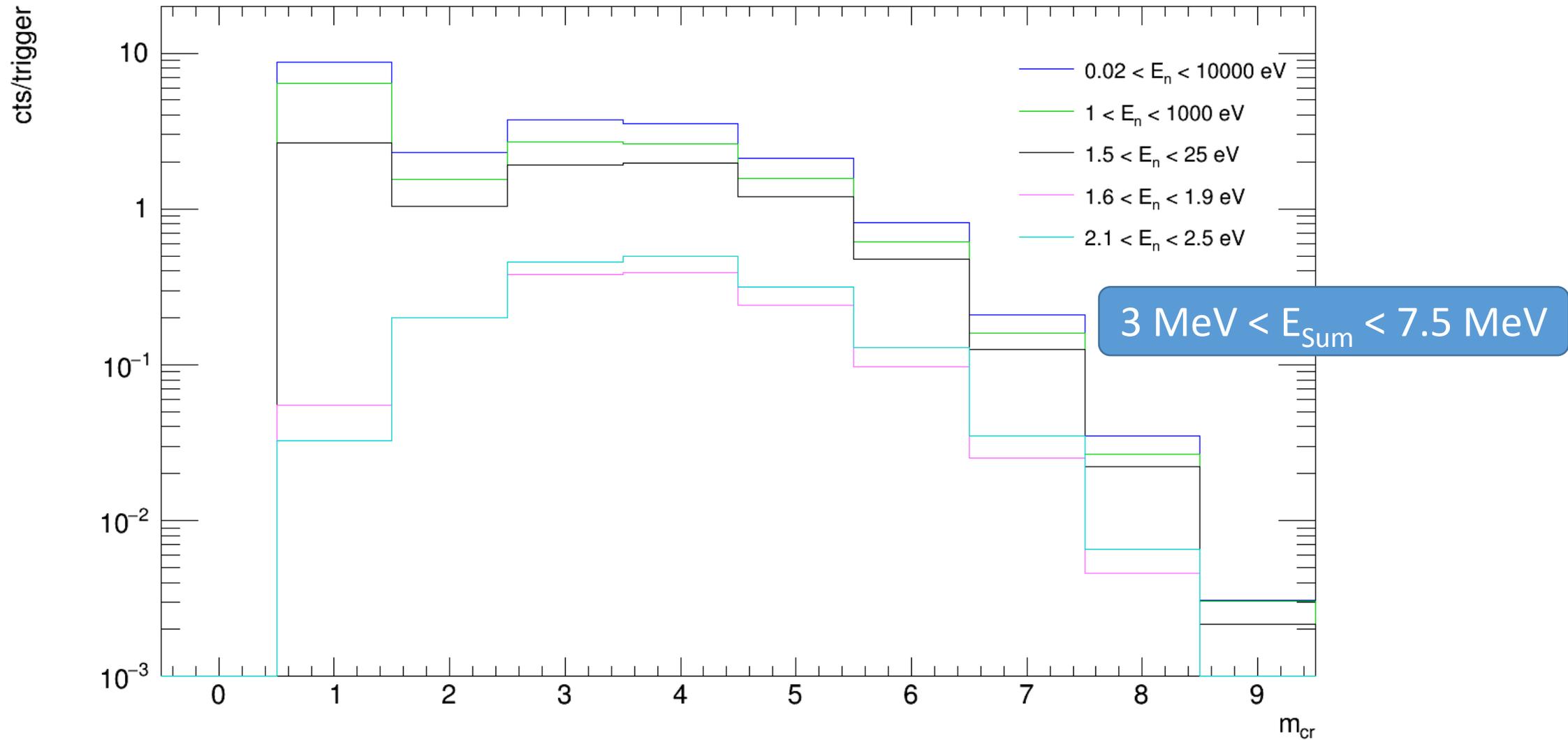


courtesy of  
J. Balibrea

# Capture – TAC response for $m_{cr}$



# Capture – TAC response for $m_{cr}$



# FICH – Cross Section

