

# Measurements of Neutron-Induced Fission Cross Sections via Prompt Neutron Detection at J-PARC MLF ANNRI

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## Acknowledgment

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# Introduction

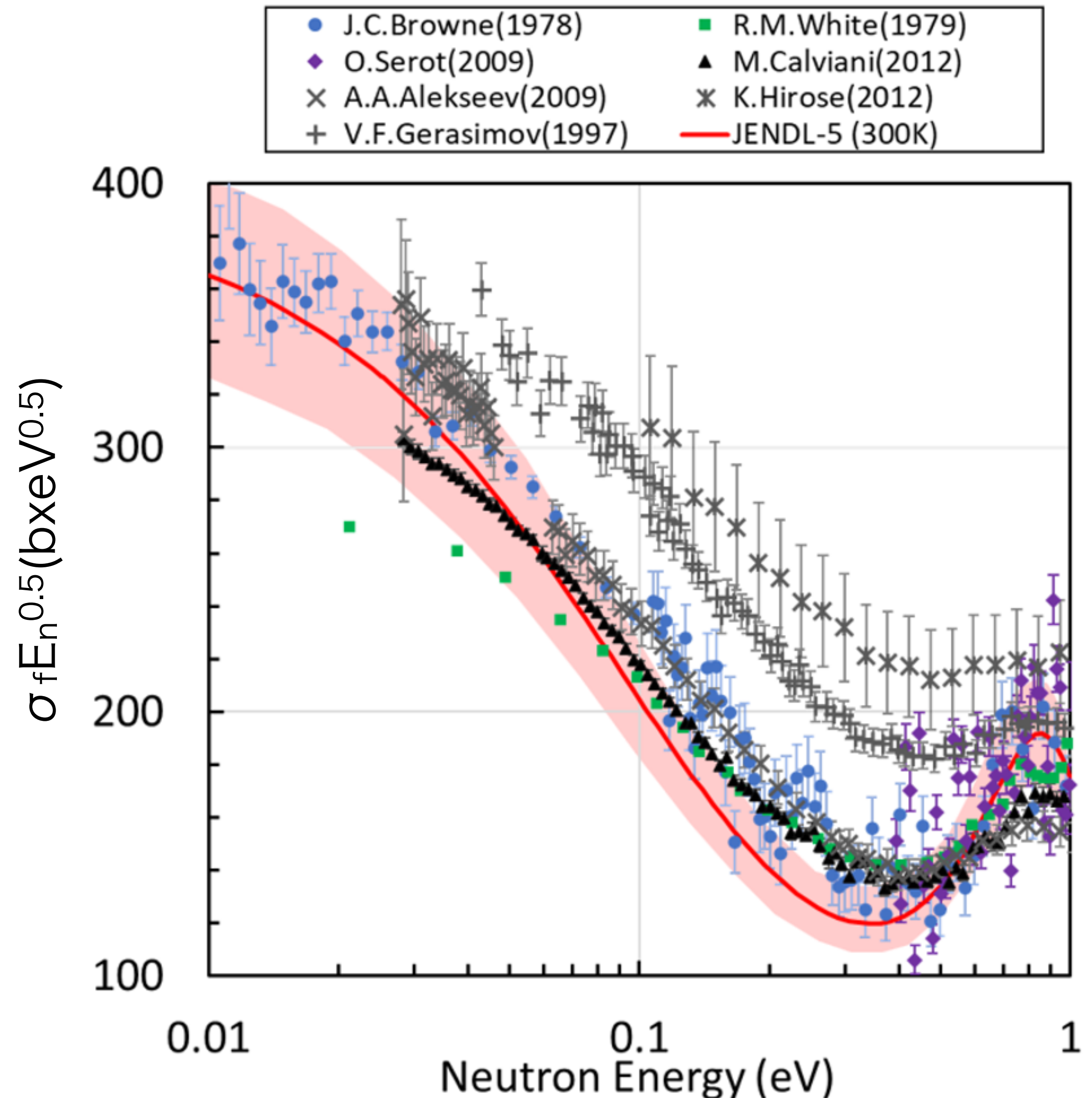
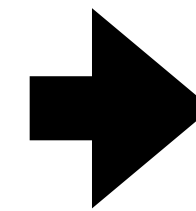
The accuracy of the neutron-induced fission reaction data for minor actinides (MA) is insufficient for the design of reactors with MA-containing fuel or very high burn-up fuel.

Comparison of measured and estimated values of the **fission cross section of  $^{245}\text{Cm}$**  around thermal neutron energy.

→ Discrepancies of **over 40% are presented** even among relatively recent measurements.

**New Measurements are required.**

Listed in high-priority request list (NEA)

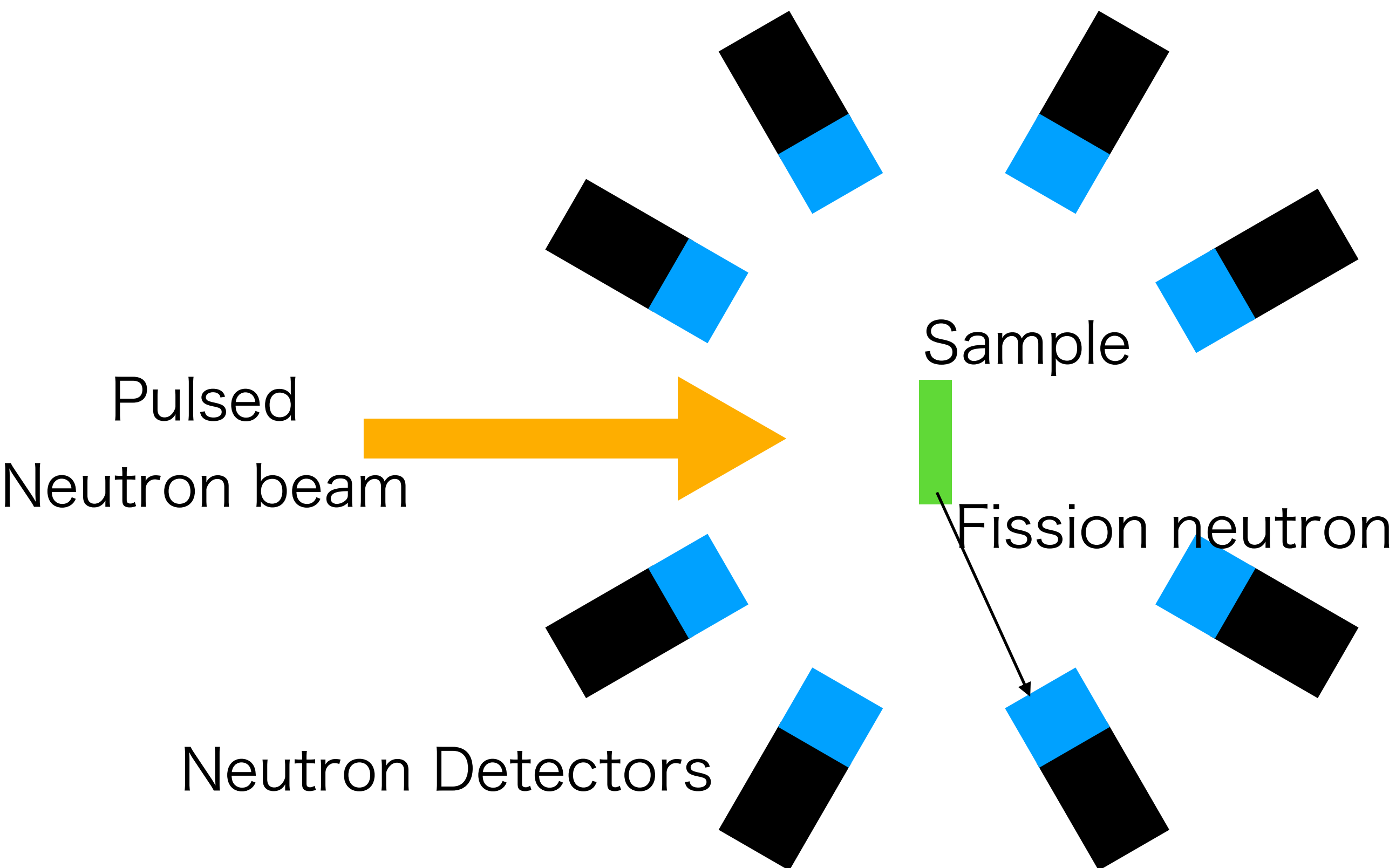


# Experiments

Prompt fission neutrons are detected using a plastic scintillation detector, EJ276D.

A total of 8 detectors were placed around the sample : **test setup (Oct. 2025)**

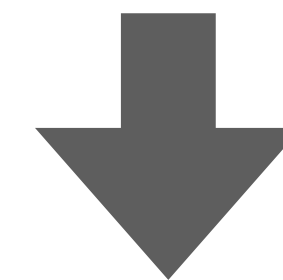
→ Final setup will involve **up to 35** detectors.



**EJ276D** manufactured by Eljen

Neutron detection via recoil protons

Sensitivity >1 MeV



**Background separation**

**Gamma-ray**

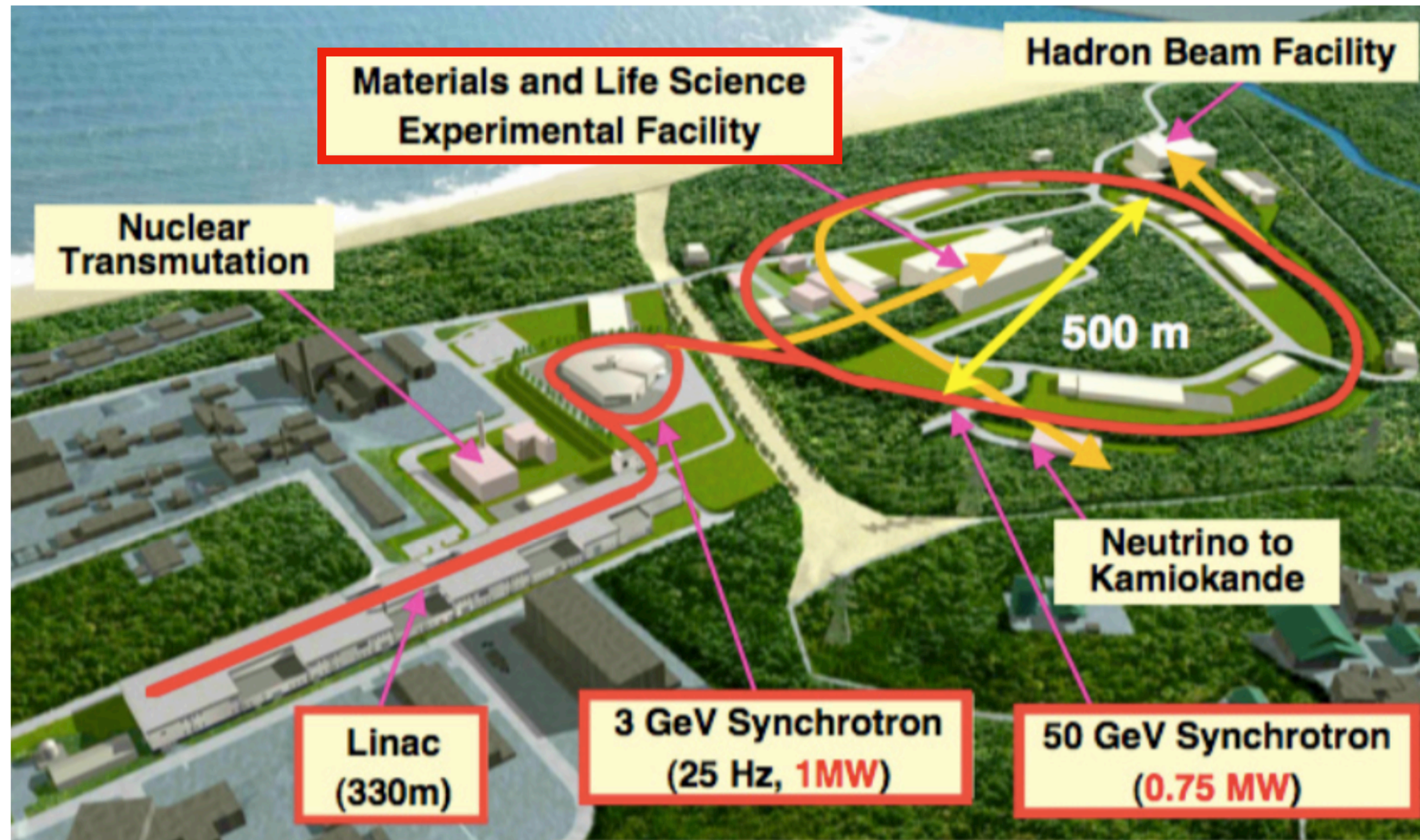
Pulse shape discrimination (PSD) technique

**Scattered neutron**

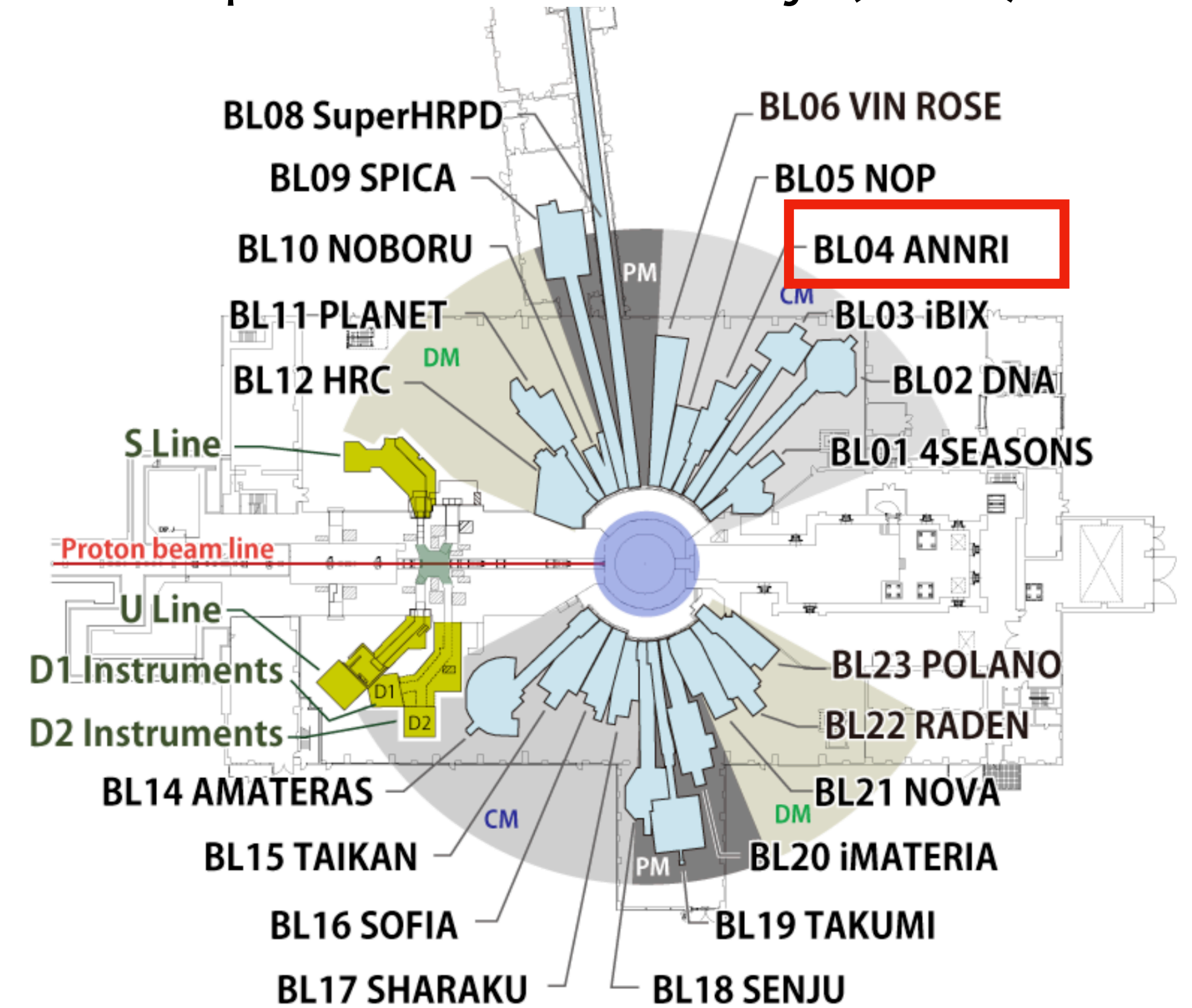
Not sensitive to low energy (<1 MeV) neutron

# J-PARC MLF

Japan Proton Accelerator Research Complex (J-PARC)



Material and Life Science Experimental Facility (MLF)

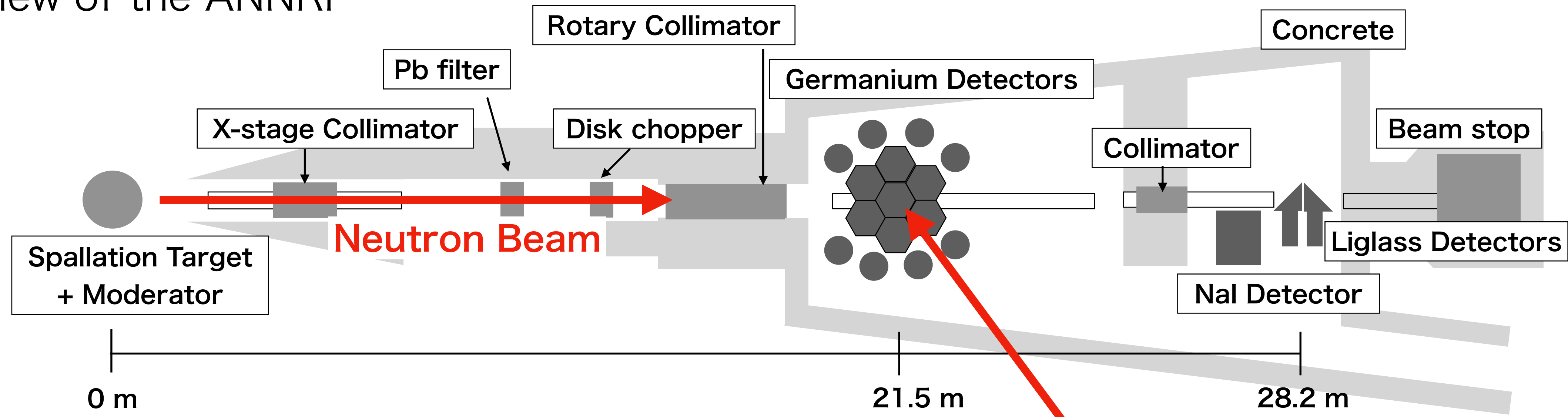


The pulsed neutron beam enables precise energy determination using the time-of-flight method.

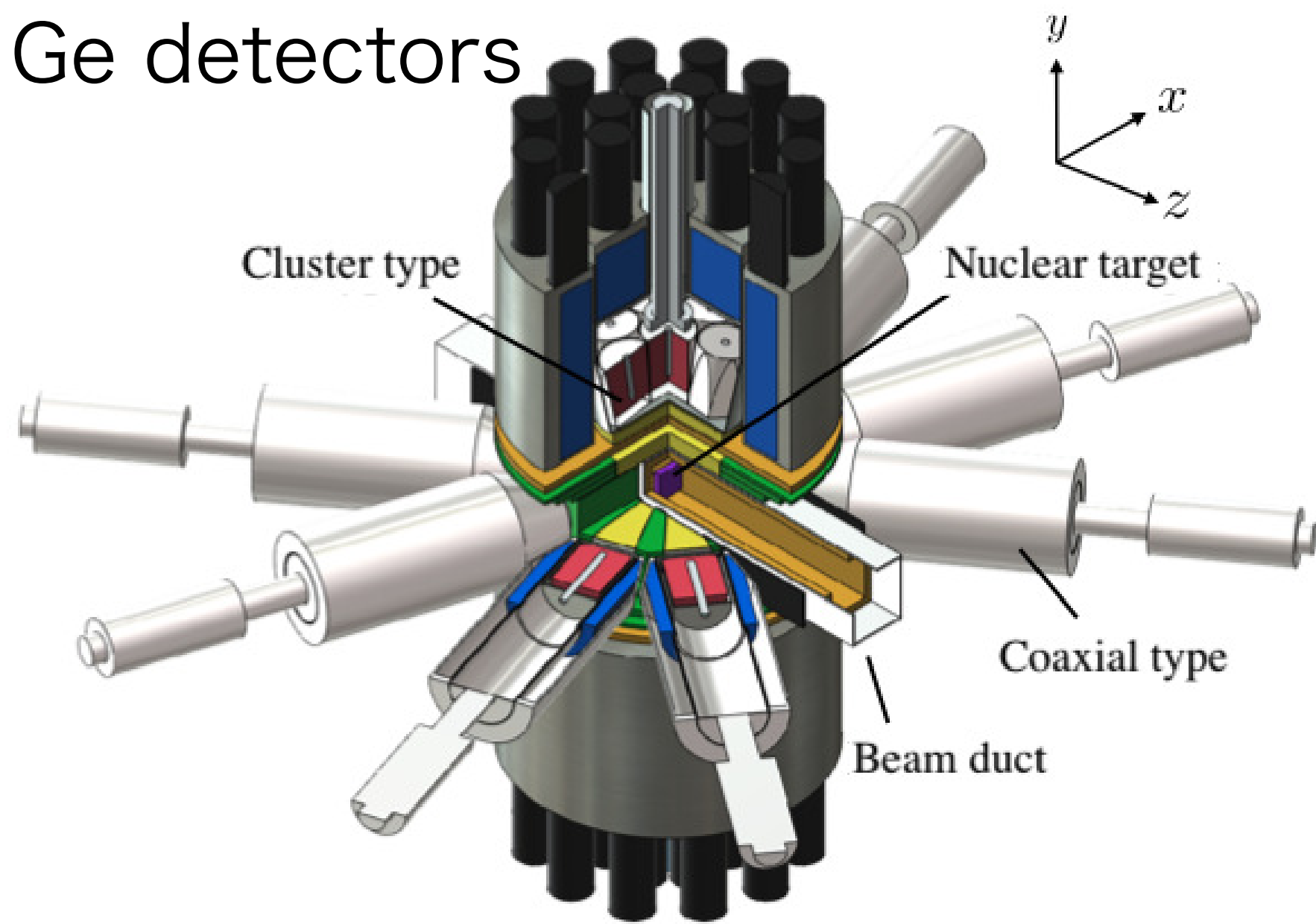
Detector system was installed at Beamline No.4 (ANNRI)

# ANNRI (Accurate Neutron-Nucleus Reaction Measurement Instrument)

Top view of the ANNRI



Ge detectors



Sample Position

In this test experiment, the coaxial-type Ge detectors **were removed and replaced** with neutron detectors.

# Measurements

Samples	Measurement time
Am-241	8.5 h
Cm-245	33.6 h
Am dummy	5.0 h
Cm dummy	5.6 h
Boron	4.7 h
Carbon	13.1 h
Blank	17.0 h

## Am-241 measurements :

Validation of the experimental method

>99% Am-241 (957MBq)

Sample :  $(2.37 \pm 0.03) \times 10^{-5}$  at/b

7.47 mg, 10mm diam.

## Cm-245 measurements :

Main target of this project

2.4% Cm-245 (1.8 GBq)

Sample :  $(3.38 \pm 0.07) \times 10^{-7}$  at/b

0.6 mg, 5mm diam.

Cm-244	42.3%
Cm-245	2.4%
Cm-246	6.4%
Pu-240	49.0%

## Boron measurement :

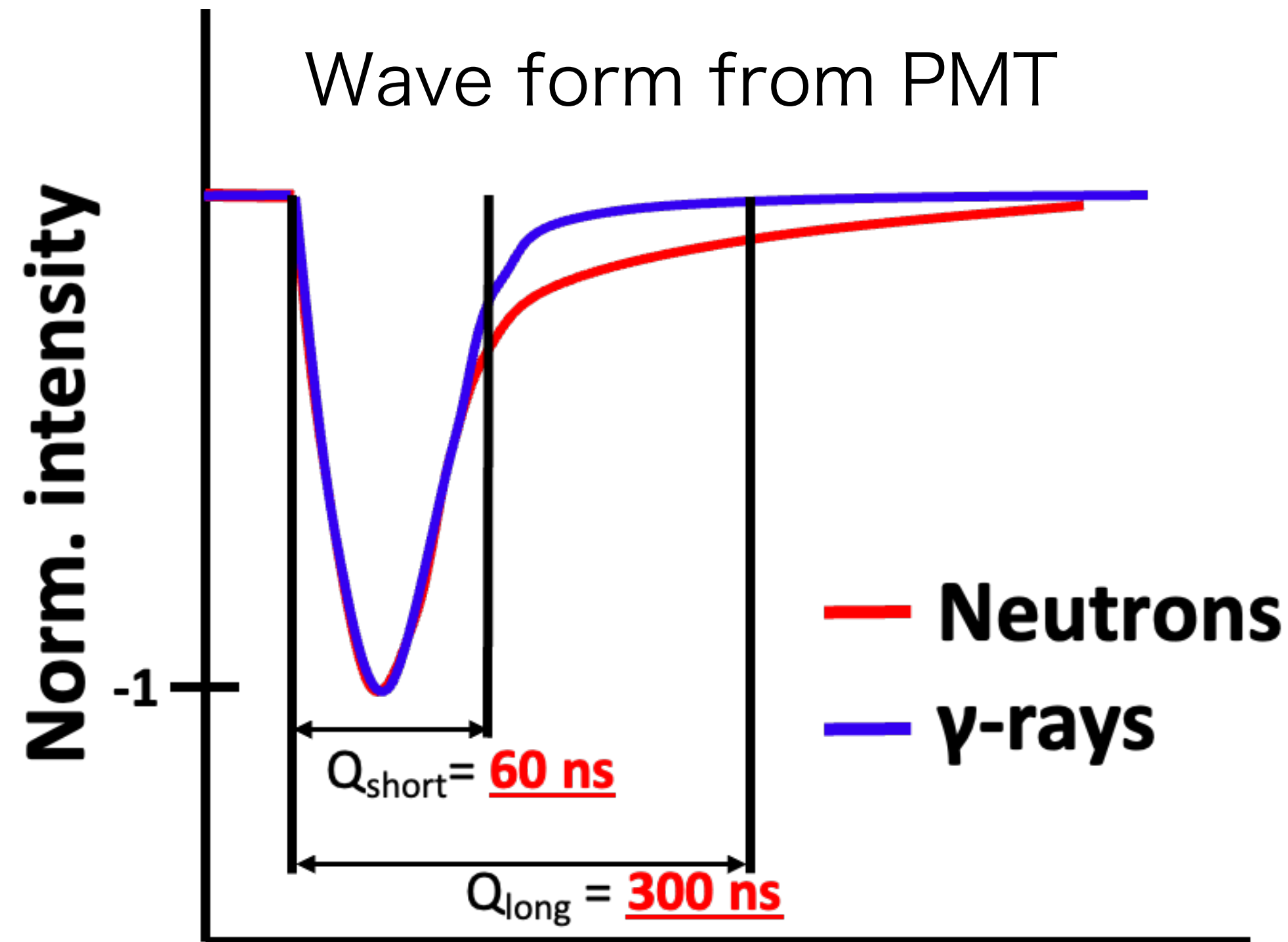
Determination of the beam intensity

## Carbon and Blank measurements :

Background subtraction for the boron measurement

# Analysis: Pulse Shape Discrimination

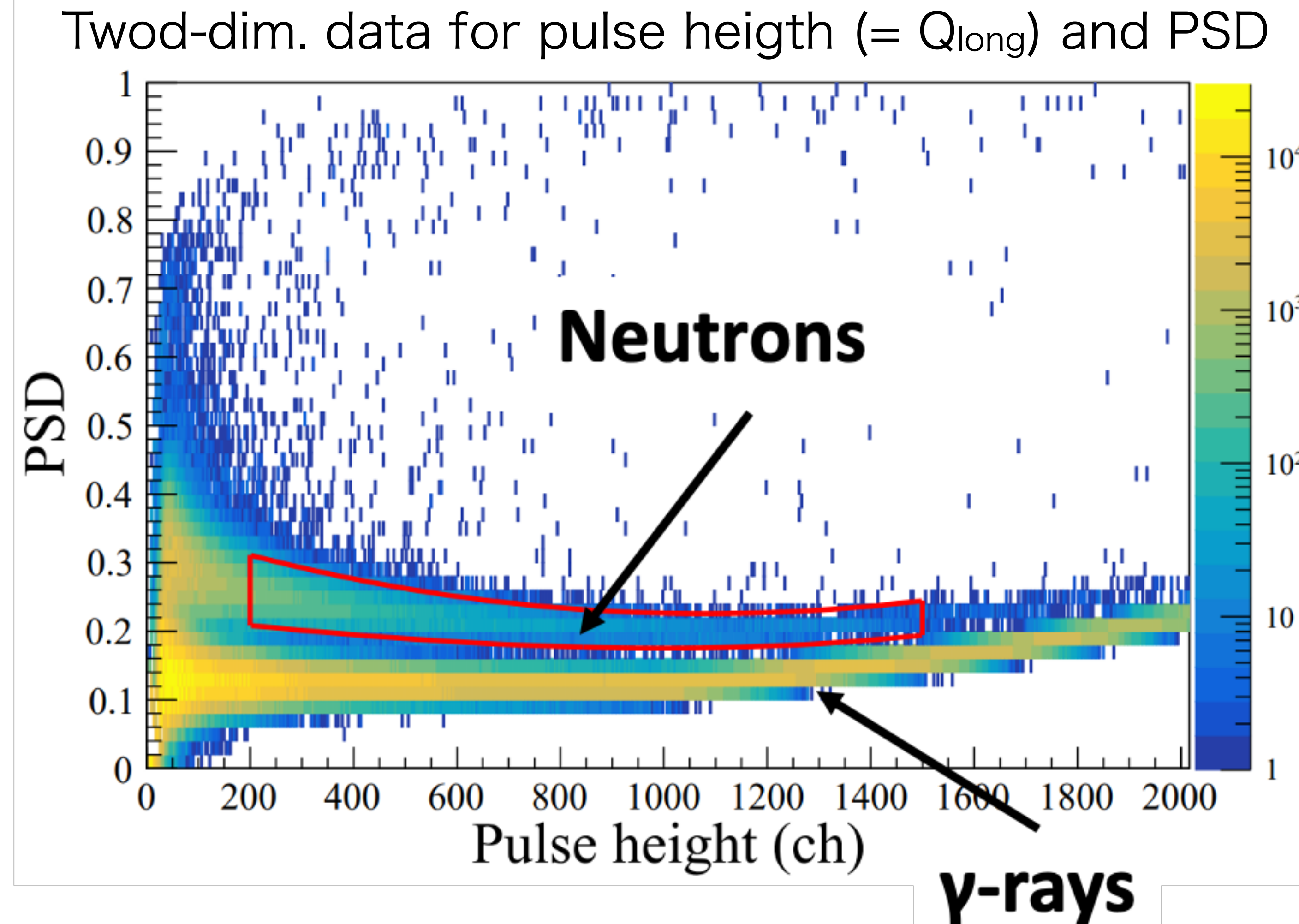
Neutrons and  $\gamma$ -rays can be separated based on the detector signal using PSD.



Peak area :  $Q_{\text{short}}$

Total area :  $Q_{\text{long}}$

$$\text{PSD} = \frac{Q_{\text{long}} - Q_{\text{short}}}{Q_{\text{long}}}$$

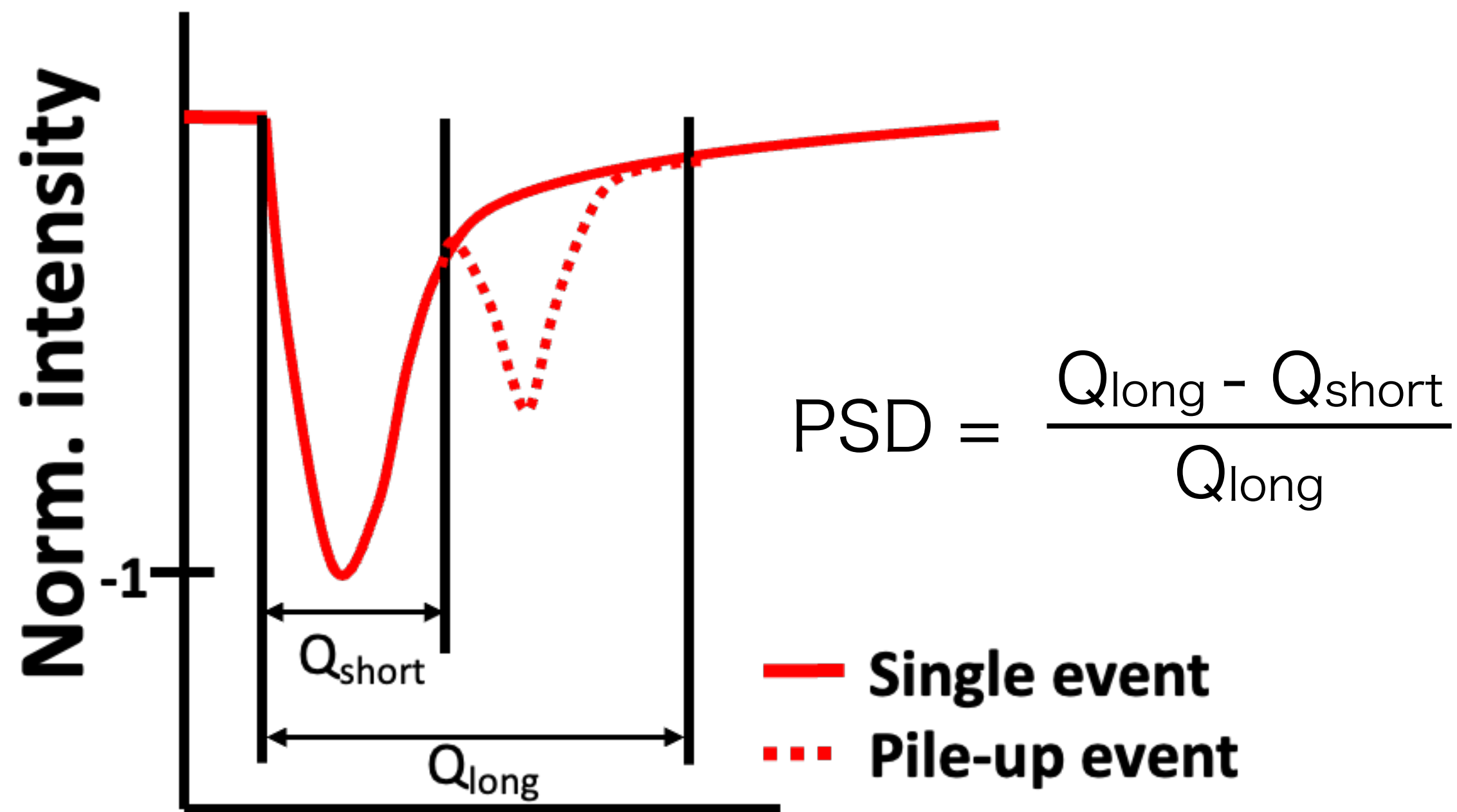


# Analysis: Gamma-ray background by pile up <sup>8</sup>

At high event rates, **pile-up effects become important.**

When pile-up events occur,  $Q_{\text{long}}$  value increases,  $\rightarrow$  PSD value also increases.

$\rightarrow$   $\gamma$ -ray background events **contaminate the neutron region in PSD.**



At resonances, intense gamma-ray emission from the  $(n, \gamma)$  reaction increases the event rate and consequently **the pile-up probability.**

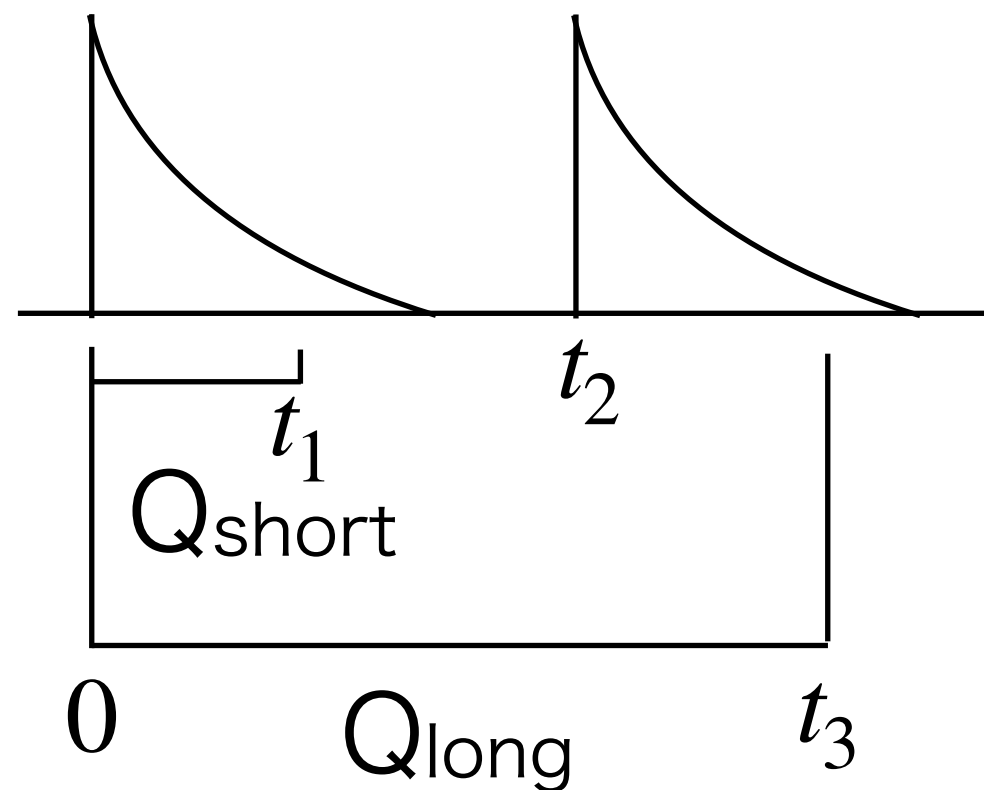
$\rightarrow$  **The pile-up correction is crucial for suppressing gamma-ray contamination and isolating fission events.**

**Monte Carlo (MC) simulations** were conducted **to estimate the contribution** from  $\gamma$ -rays in the neutron PSD region.

# Analysis: MC for pile-up subtraction

The detector waveform was modeled **using exponential functions**.

$$a \exp(-t/\tau) \quad b \exp(-(t - t_2)/\tau)$$



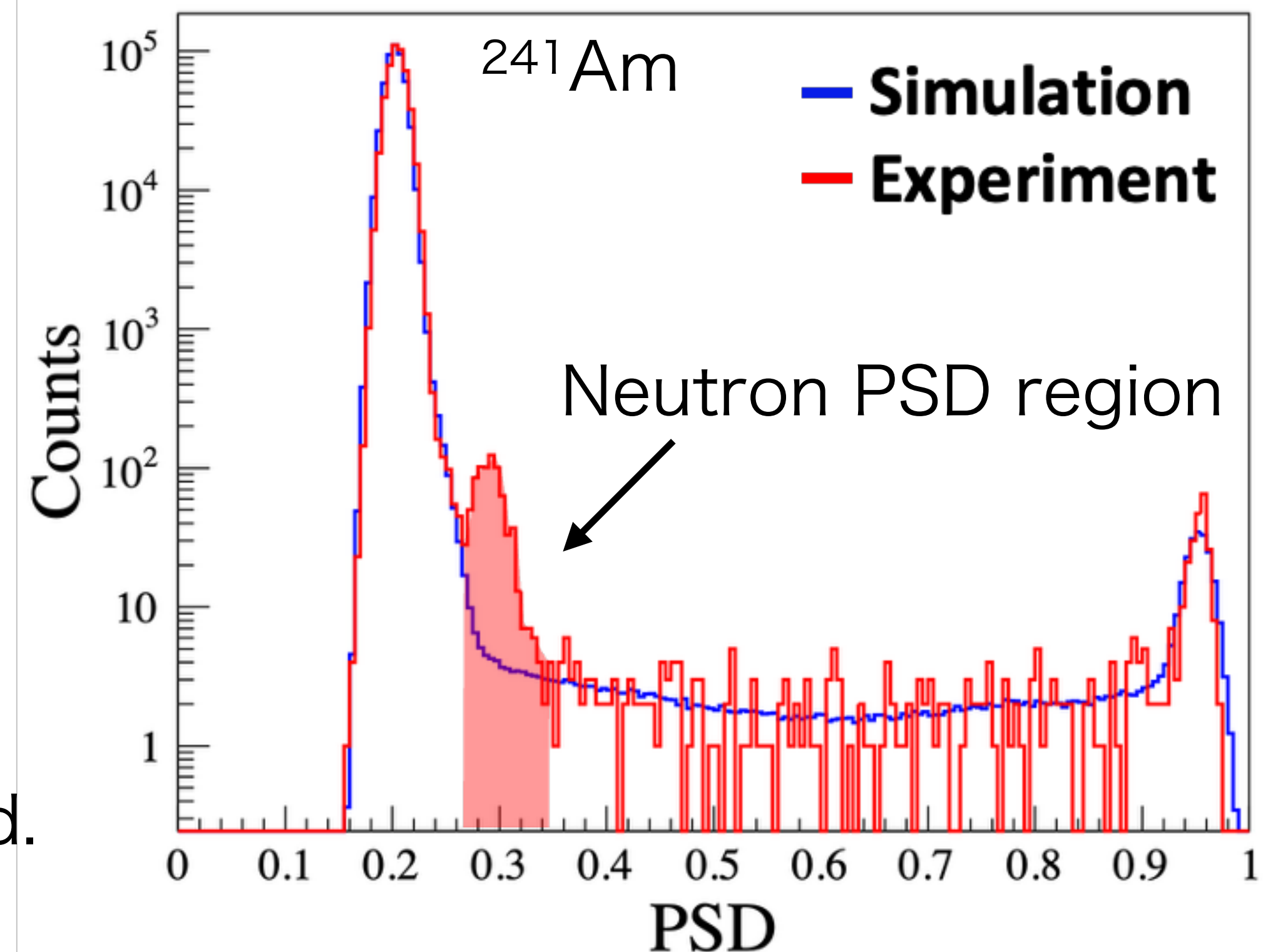
- $t_2$  was randomly sampled from a Poisson distribution based on an event rate.
- The pulse amplitudes,  $a$  and  $b$ , were randomly sampled according to the measured gamma-ray energy spectrum.

$$\tau = 37.3 \text{ ns}, \quad t_1 = 60 \text{ ns}, \quad t_3 = 300 \text{ ns (fix)}$$

$Q_{\text{long}}$  and  $Q_{\text{short}}$  were calculated by integrating the simulated waveform generated from the randomly sampled parameters.

→ **PSD values were calculated for each MC event.**

Gamma-ray leakage background can be estimated.



# Analysis: Gamma-ray background subtraction <sup>10</sup>

The Monte Carlo simulation provides the probability of gamma-ray events,  $R_{th}$ , leaking into the neutron PSD region for an event rate,  $\lambda_{th}$ .

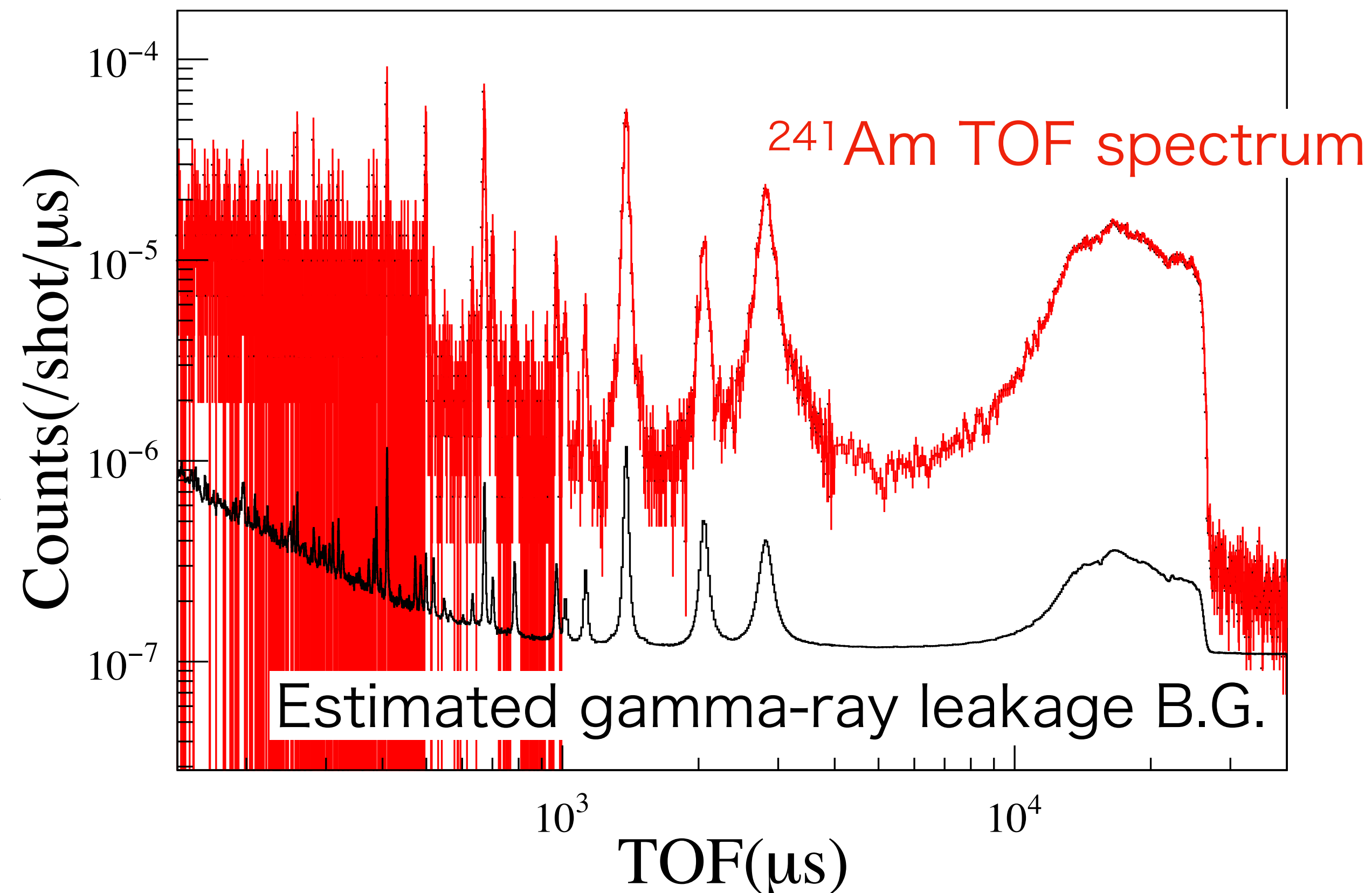
Assuming that the leakage is proportional to the event rate, the leakage contribution,  $Y_n^{BG}(tof)$ , and the gamma-ray count,  $Y_\gamma(tof)$ , satisfy the following relationship:

$$Y_n^{BG}(tof) = Y_\gamma^2(tof) \frac{1}{\Delta t} \frac{R_{th}}{\lambda_{th}}$$

$\Delta t$  : bin width

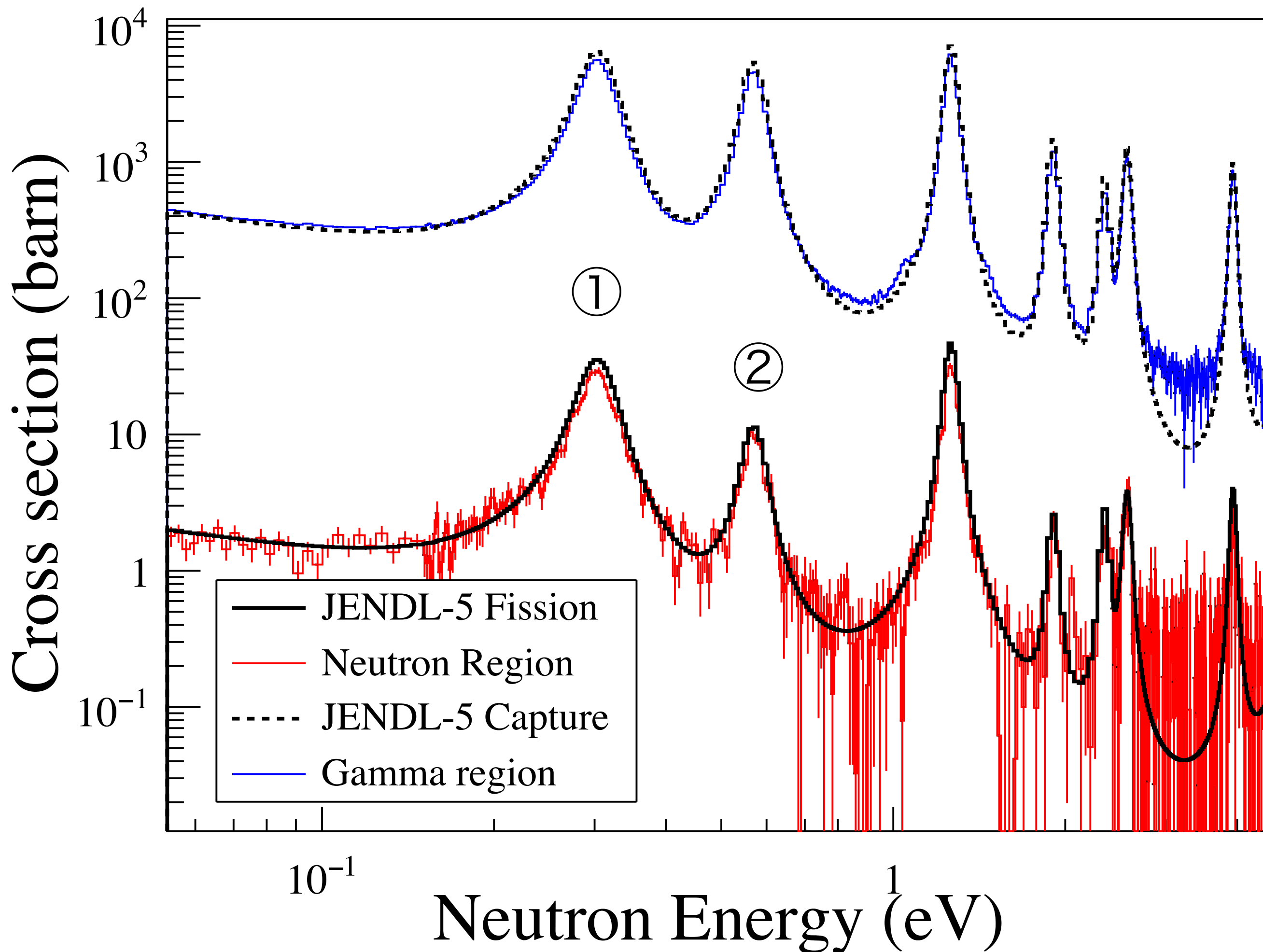
The gamma-ray leakage calculated for each TOF bin using the above equation is shown. 

In  $^{241}\text{Am}$  case, the background effect is up to about 5% even in the resonance region.



# Results: Capture and Fission cross section of $^{241}\text{Am}^{11}$

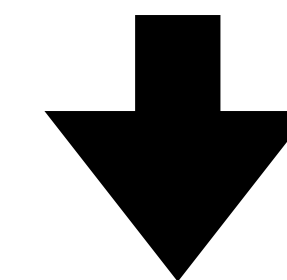
Yields were extracted separately from the **neutron PSD region** and the  **$\gamma$ -ray PSD region**. The two spectra were normalized in the thermal-neutron region with JENDL-5 for comparison.



Neutron region yield = Fission events  
Gamma region yield\* = Capture events

\*PHWT was not applied.

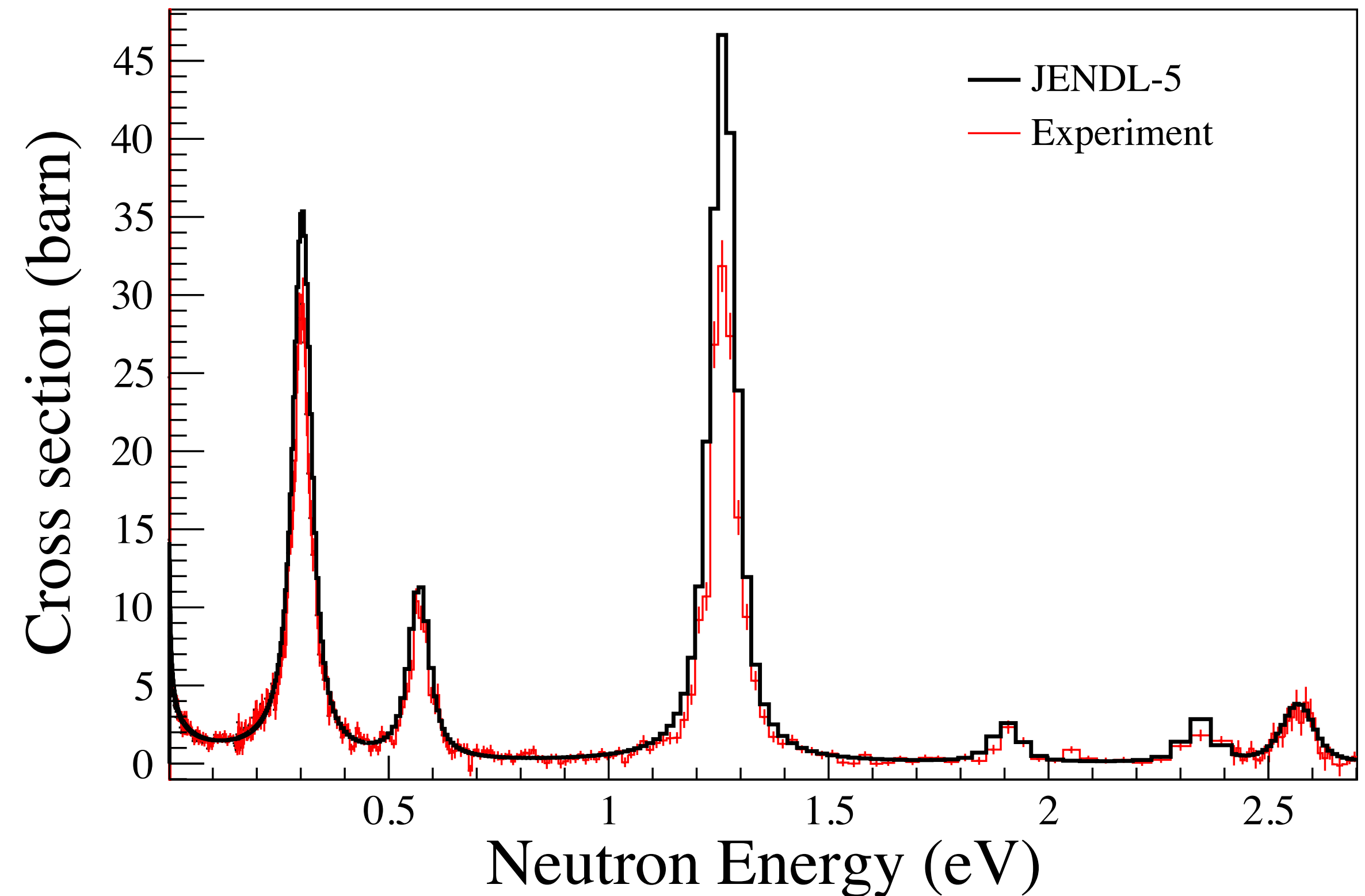
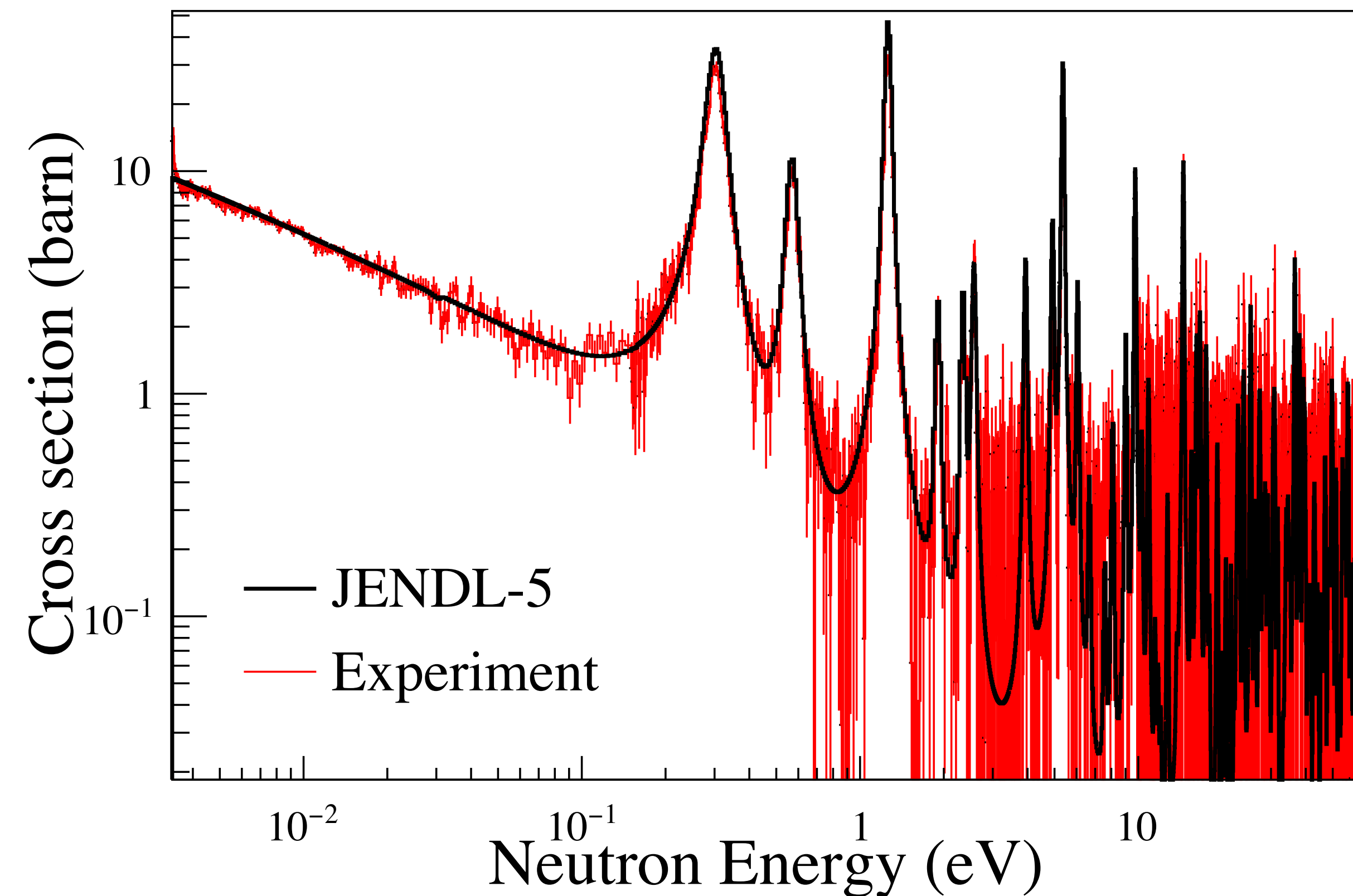
The relative heights of the two resonances (① and ②) are **consistent** with those expected from the JENDL cross sections.



**This demonstrates that PSD analysis can successfully isolate the fission contribution from the measured data.**

# Results: $^{241}\text{Am}$ fission cross section

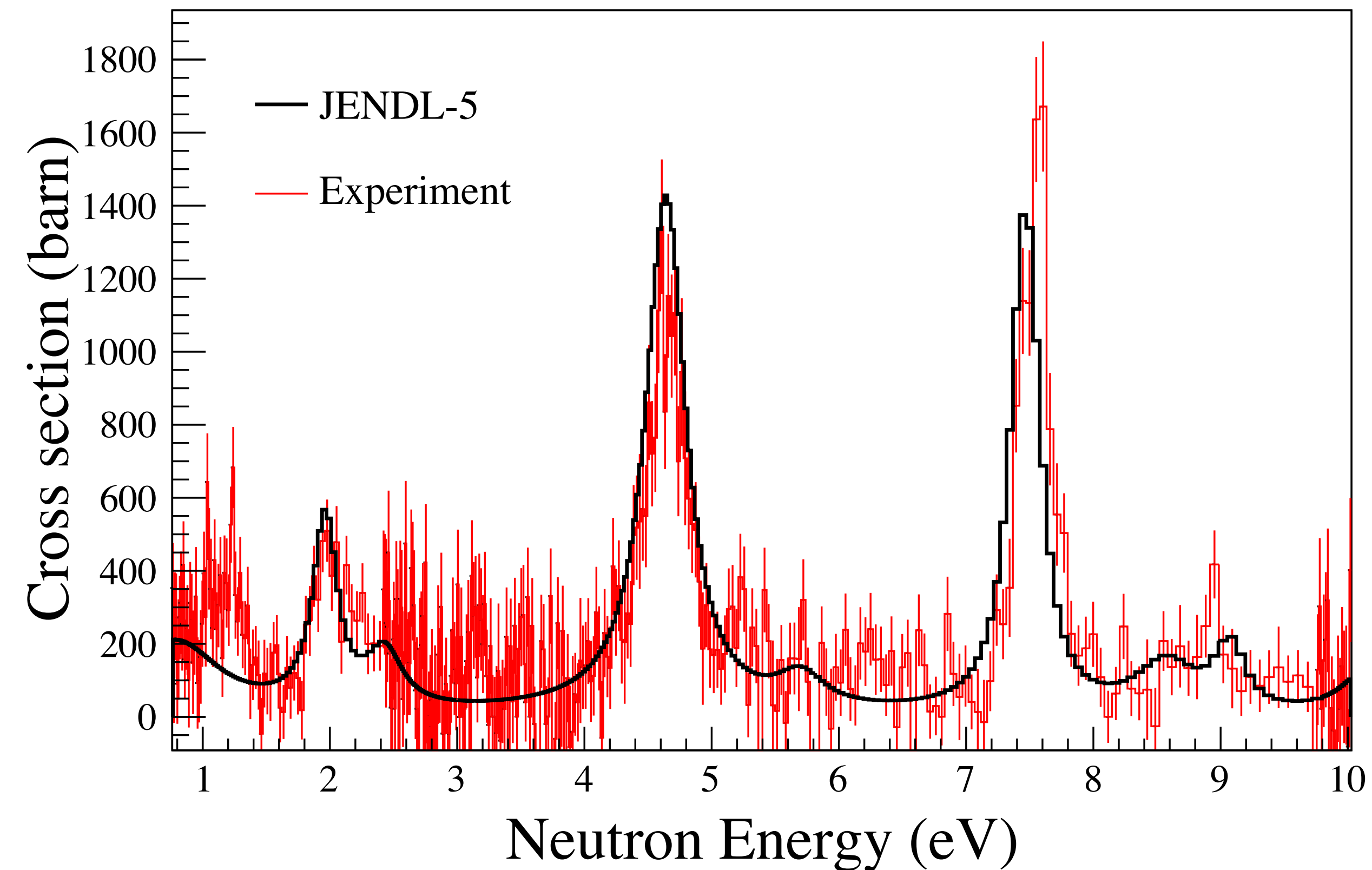
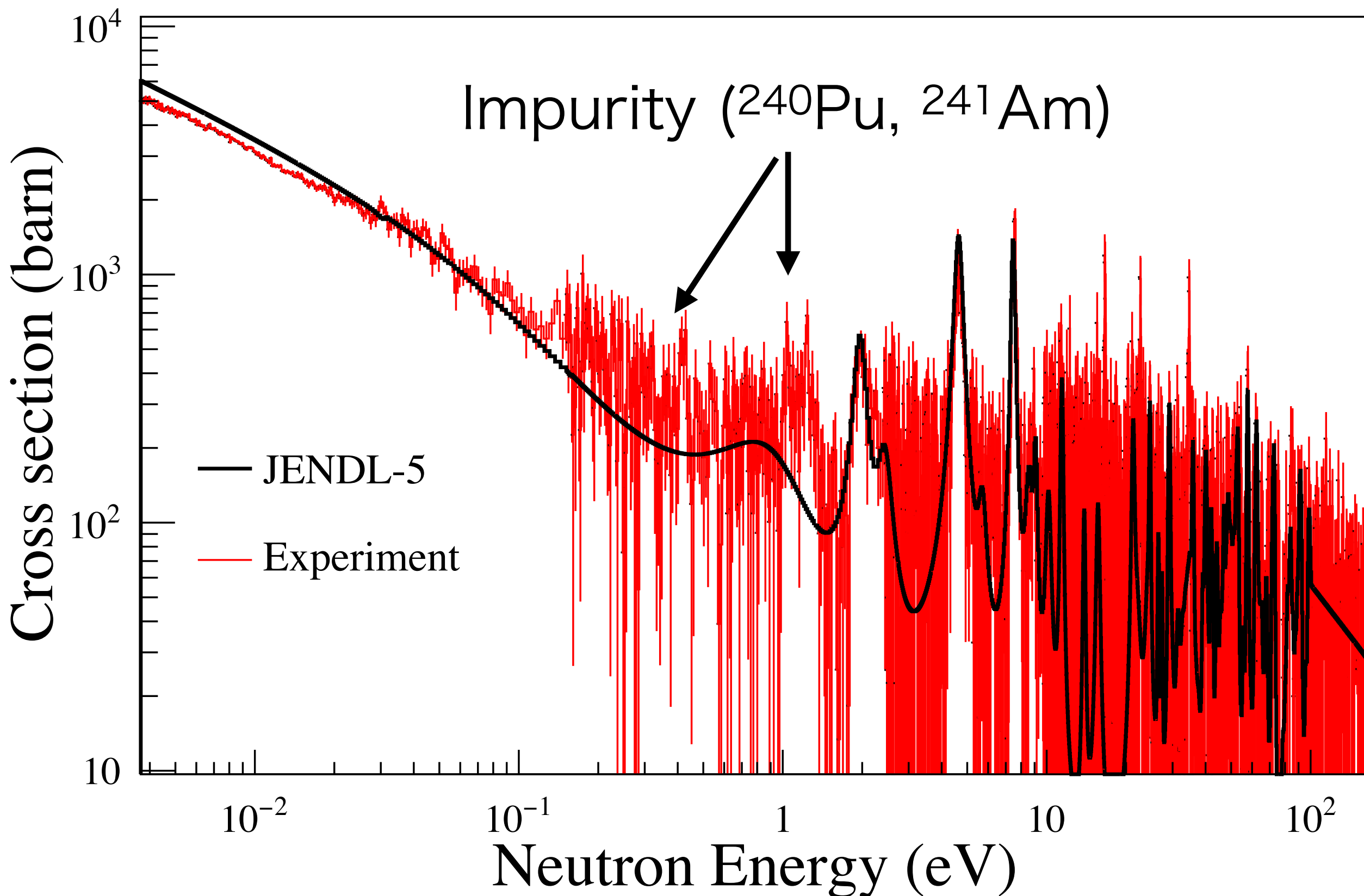
The experimental data were normalized to reproduce the JENDL-5 cross section in the thermal-neutron region.



- Overall, good agreement is observed in the energy dependence.
- In the resonance region, differences in resonance heights are observed, such as 1.25 eV.  
→ The origin of this discrepancy is currently under investigation. (Maybe dead time?)

# Results: $^{245}\text{Cm}$ fission cross section~

The  $^{245}\text{Cm}$  fission cross section was determined using the normalization factor obtained from the  $^{241}\text{Am}$  measurements.

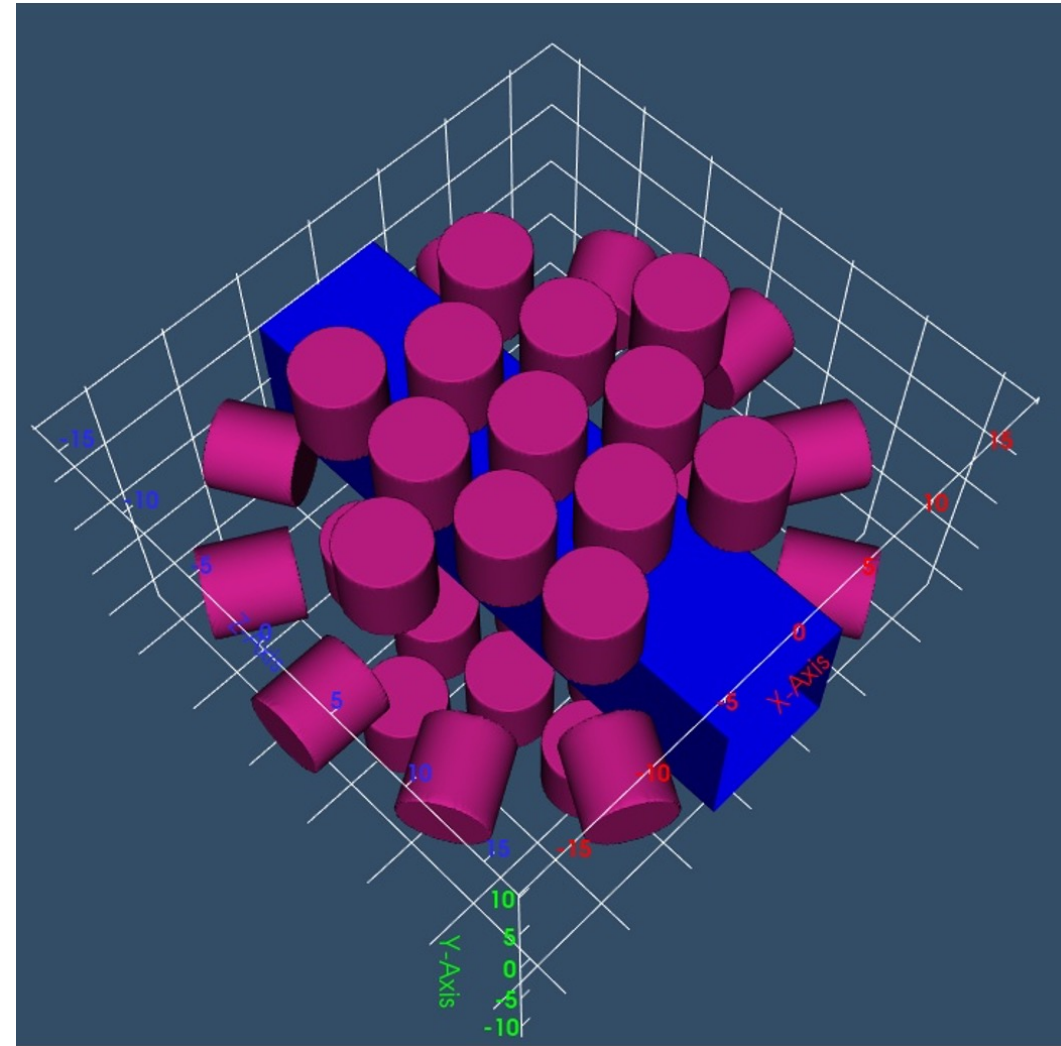


- A **slight discrepancy is observed** in the spectral shape in the thermal-neutron region.
- The current measurement precision is still limited to draw a definitive conclusion.
- A significant **improvement in the S/N ratio is expected** with the full 35-detector array.

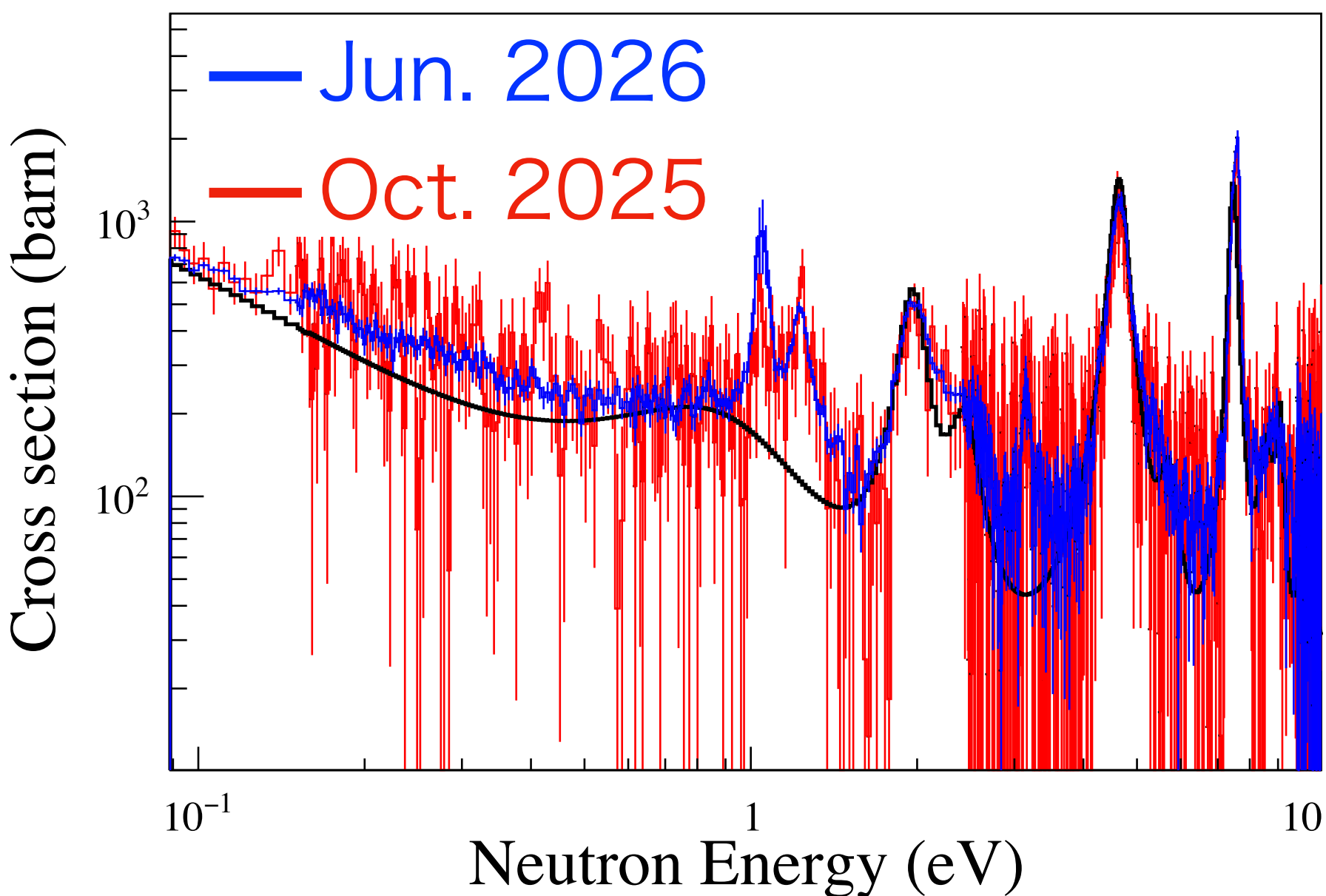
# Future Plan

To improve S/N ratio, many detectors will be placed in ANNRI.

Final setup (total 35 detectors)→



Latest preliminary results of  $^{245}\text{Cm}$  with **20** detectors (June 2026)



The statistical **uncertainty** is significantly smaller than that of previous results.

Frame for detectors



- To improve the fission cross section of MAs, **fission cross section measurements using prompt neutron detection were conducted at J-PARC MLF ANNRI.**
- PSD analysis enabled clear separation of capture and fission components.
- To estimate the gamma-ray background caused by pile-up, MC simulation was performed.
- **Preliminary results for the  $^{241}\text{Am}$  and  $^{245}\text{Cm}$  fission cross sections were obtained** from the experiment performed with the 8-detector configuration in October 2025.
- The full 35-detector system will further improve the S/N ratio and allow more precise investigation of resonance structures.

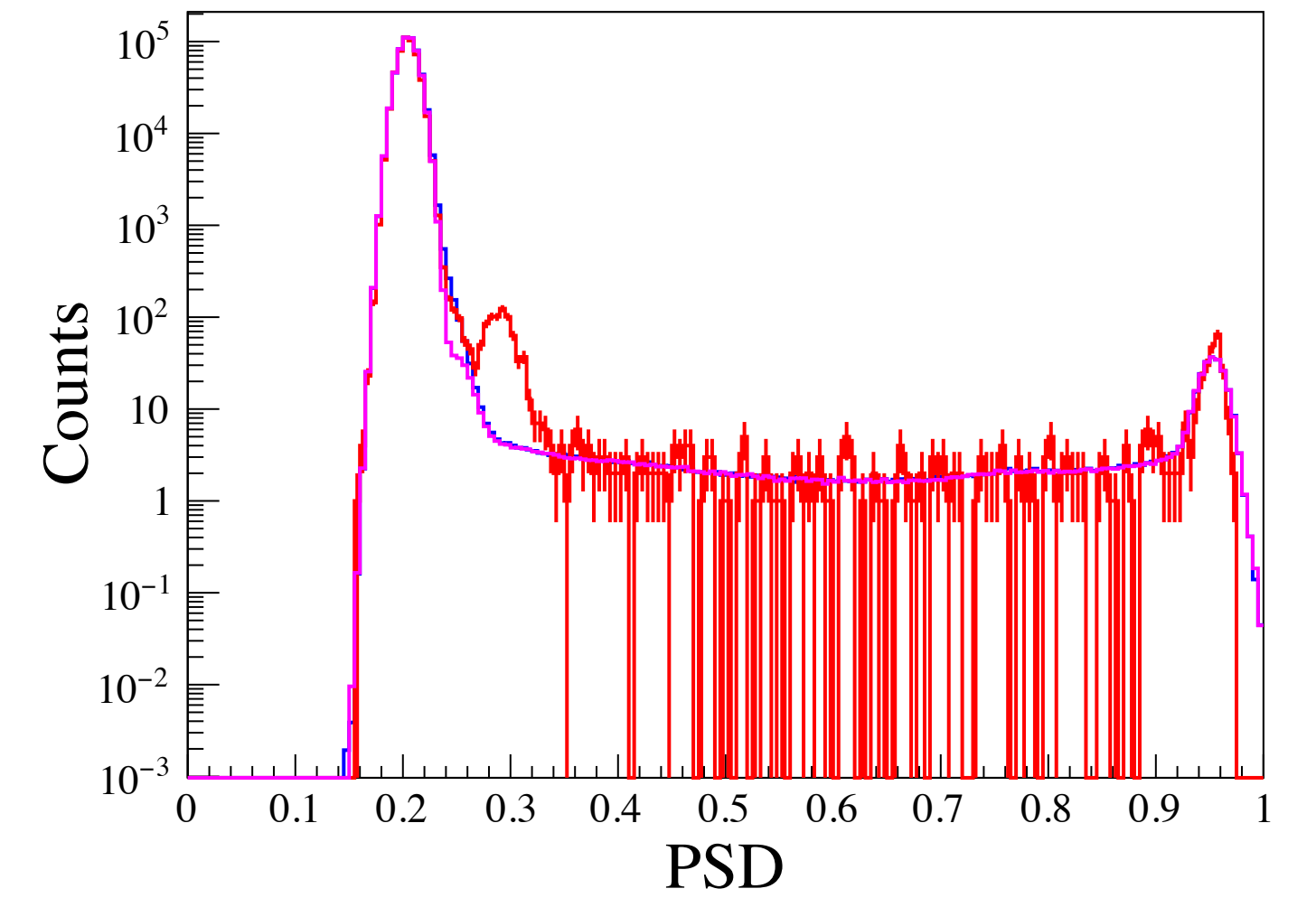
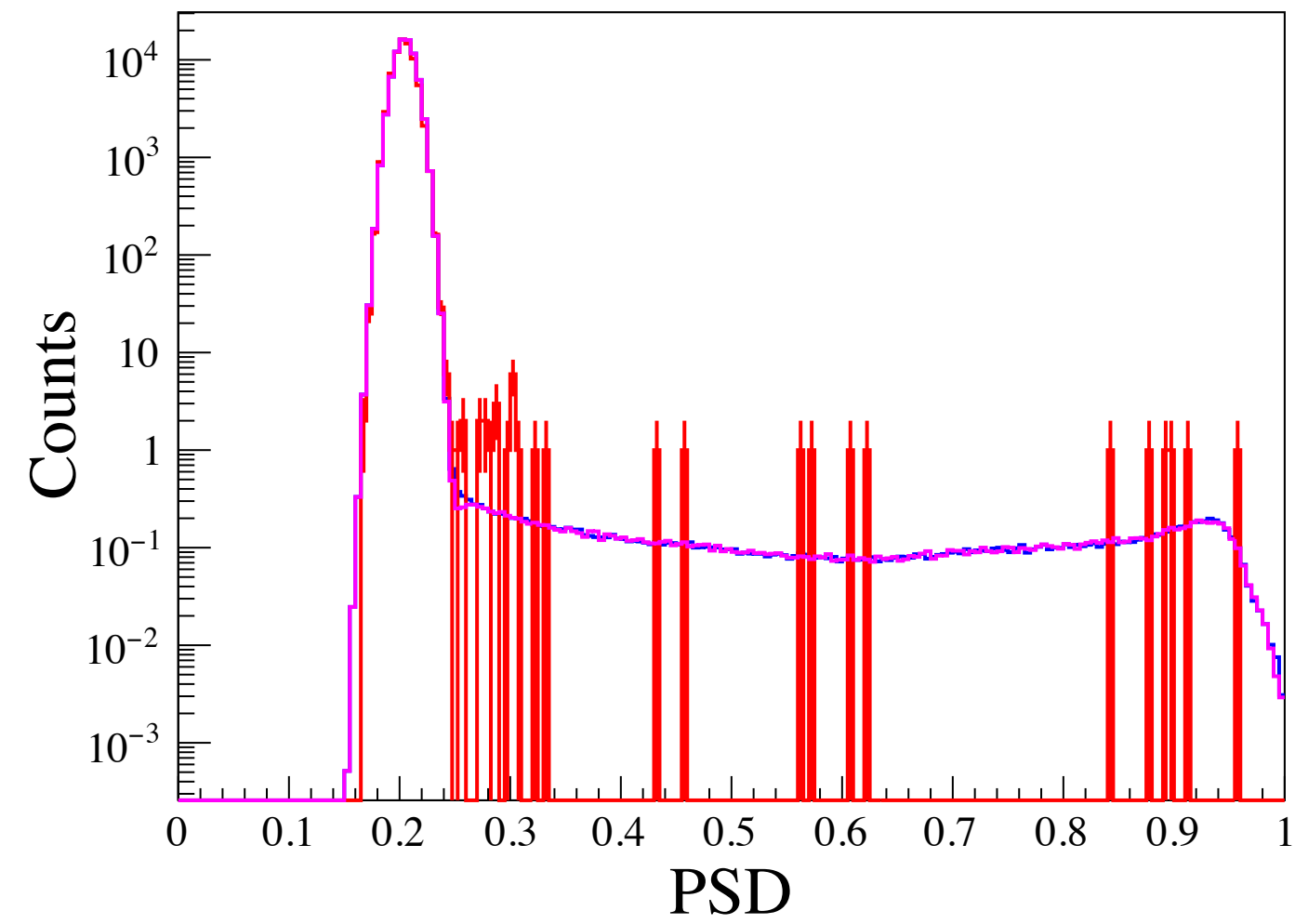
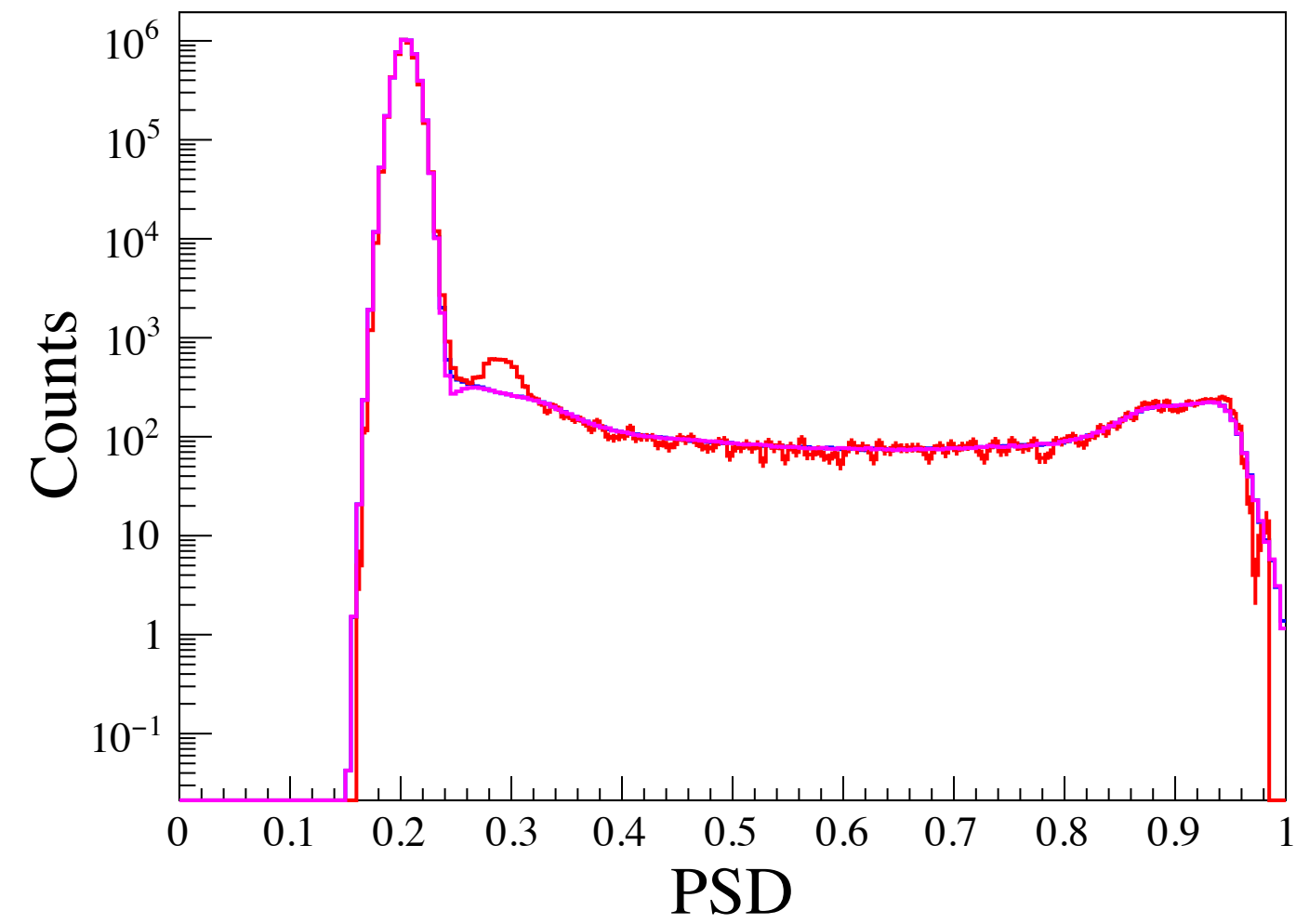
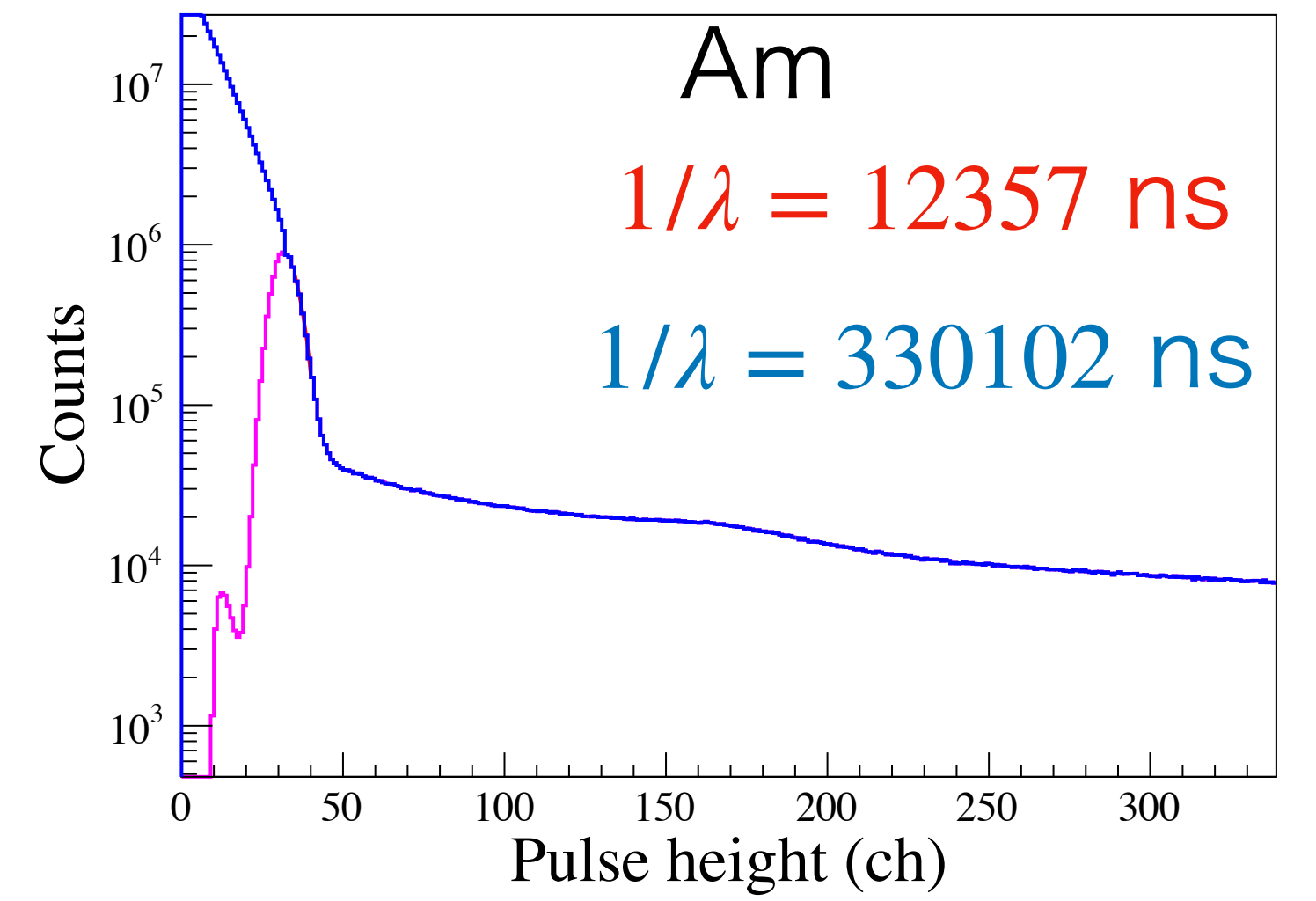
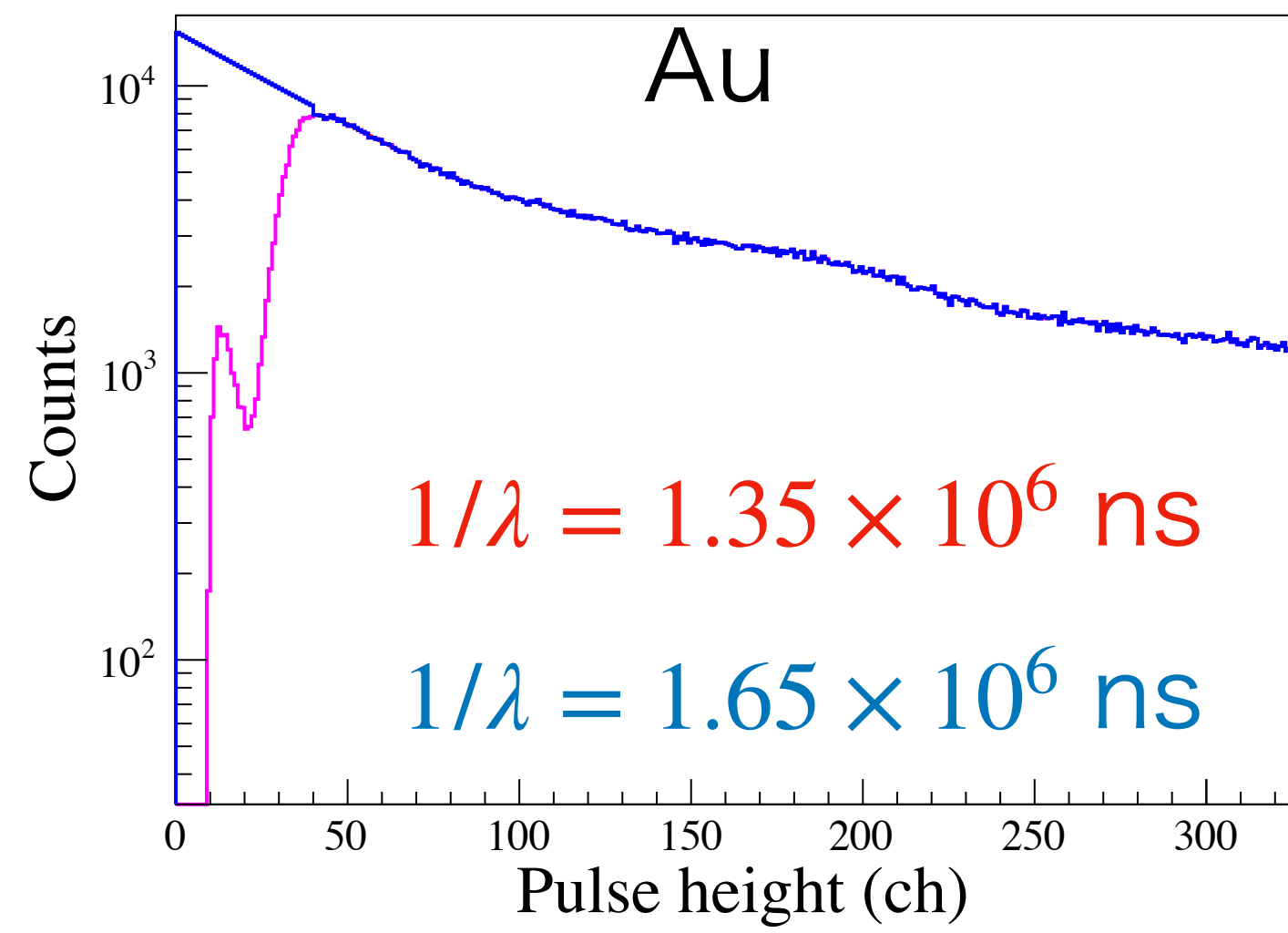
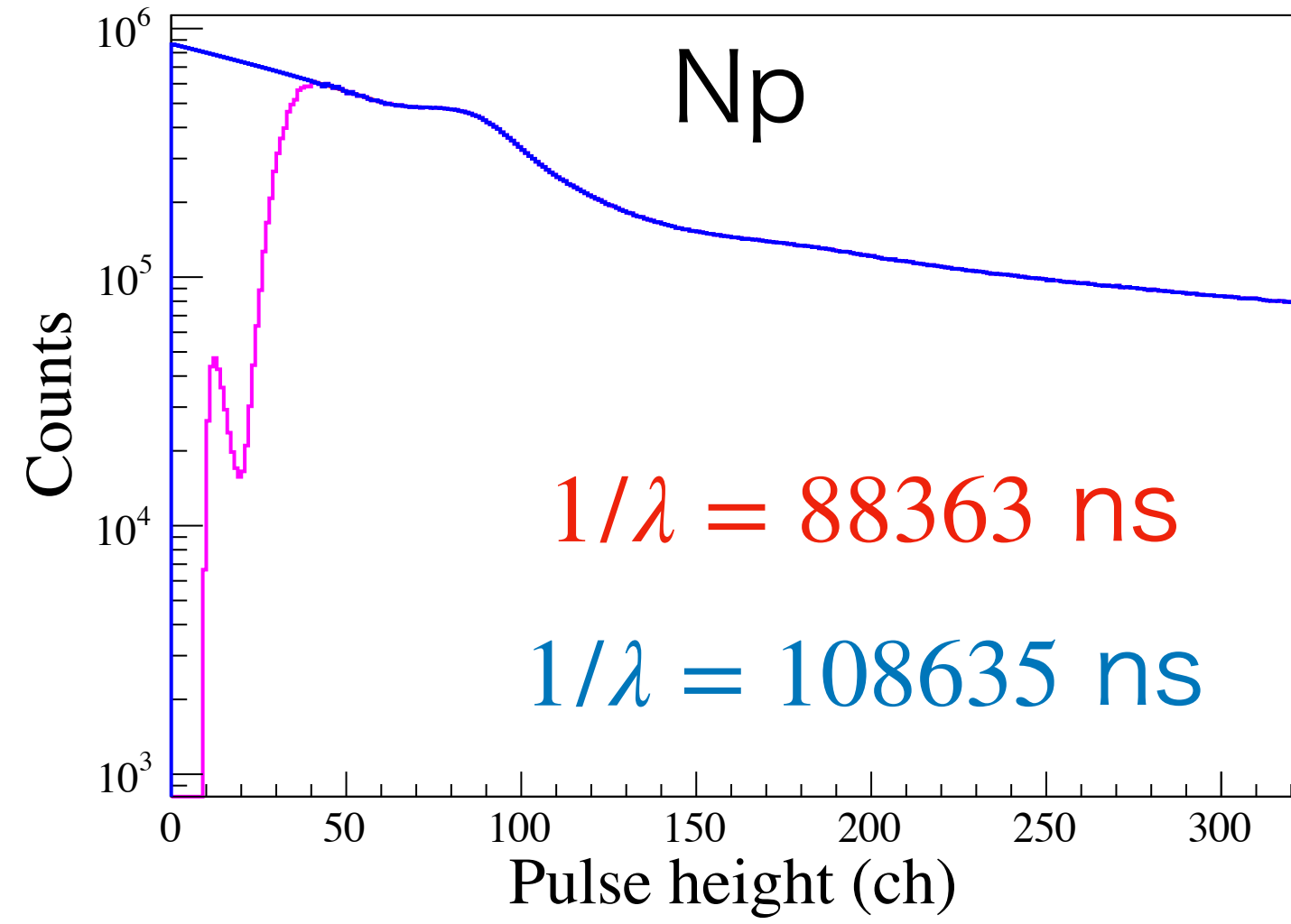
## Acknowledgment

This work was supported by MEXT Innovative Nuclear Research and Development Program Grant Number JPMXD0224020564.

# Back up

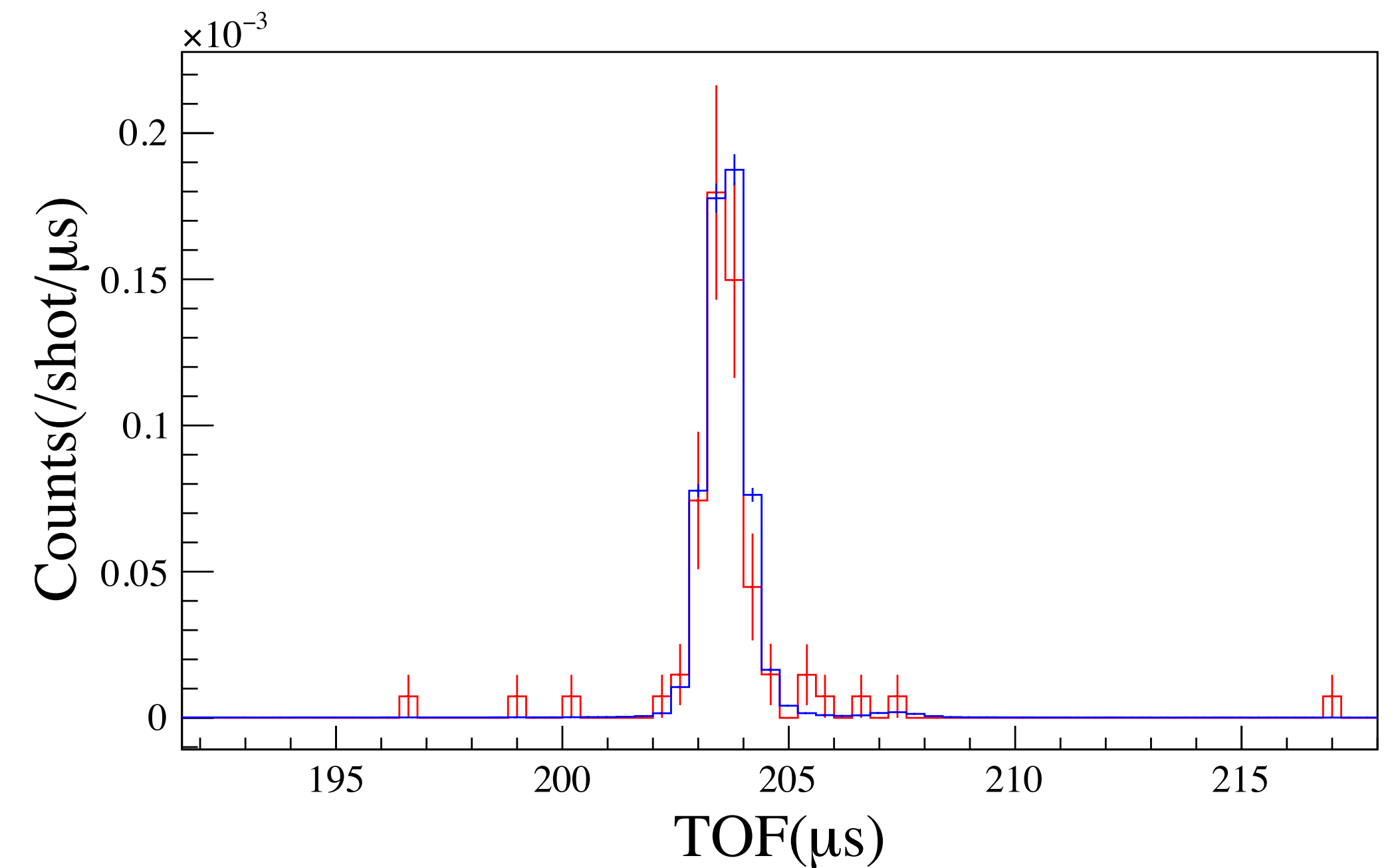
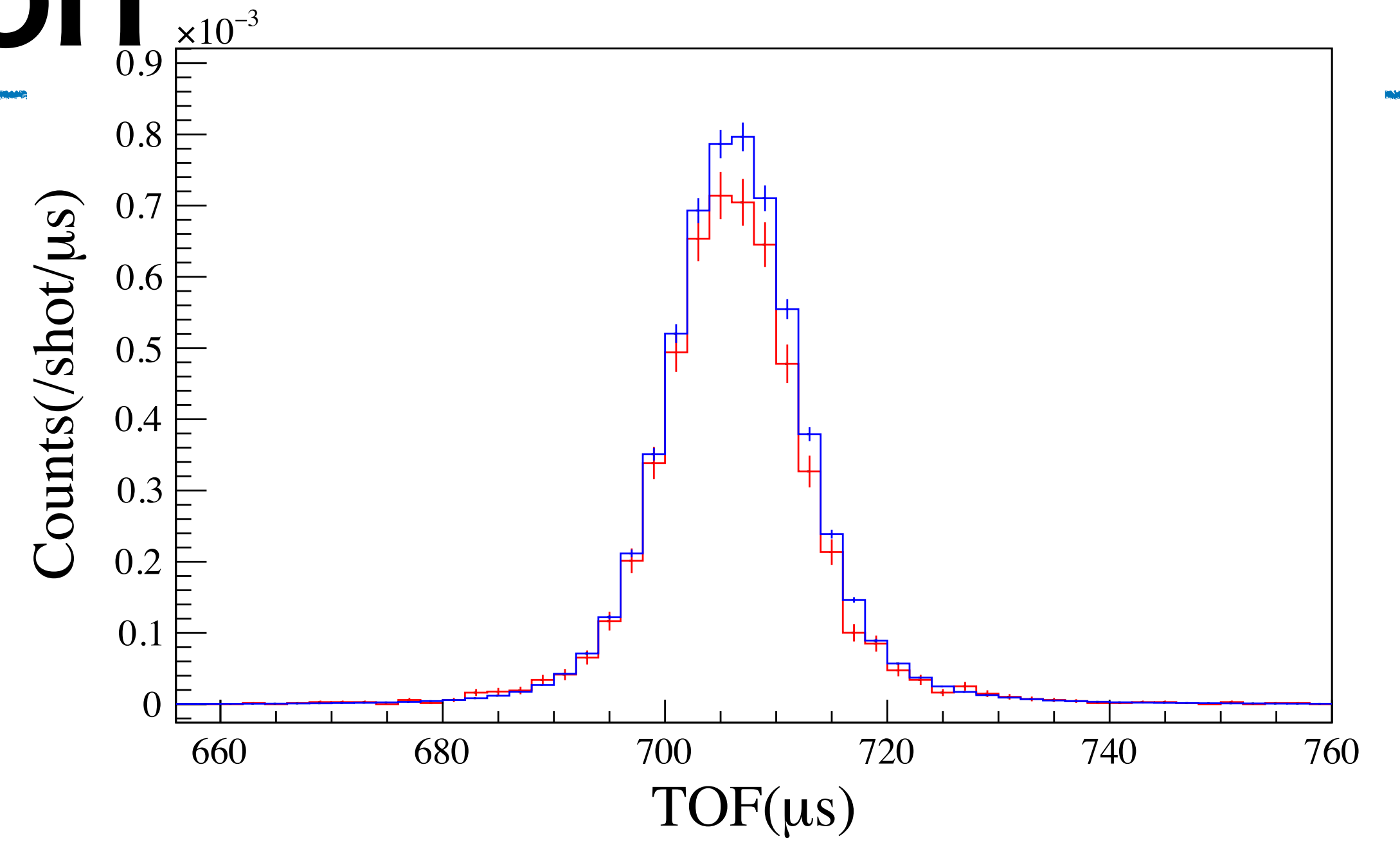
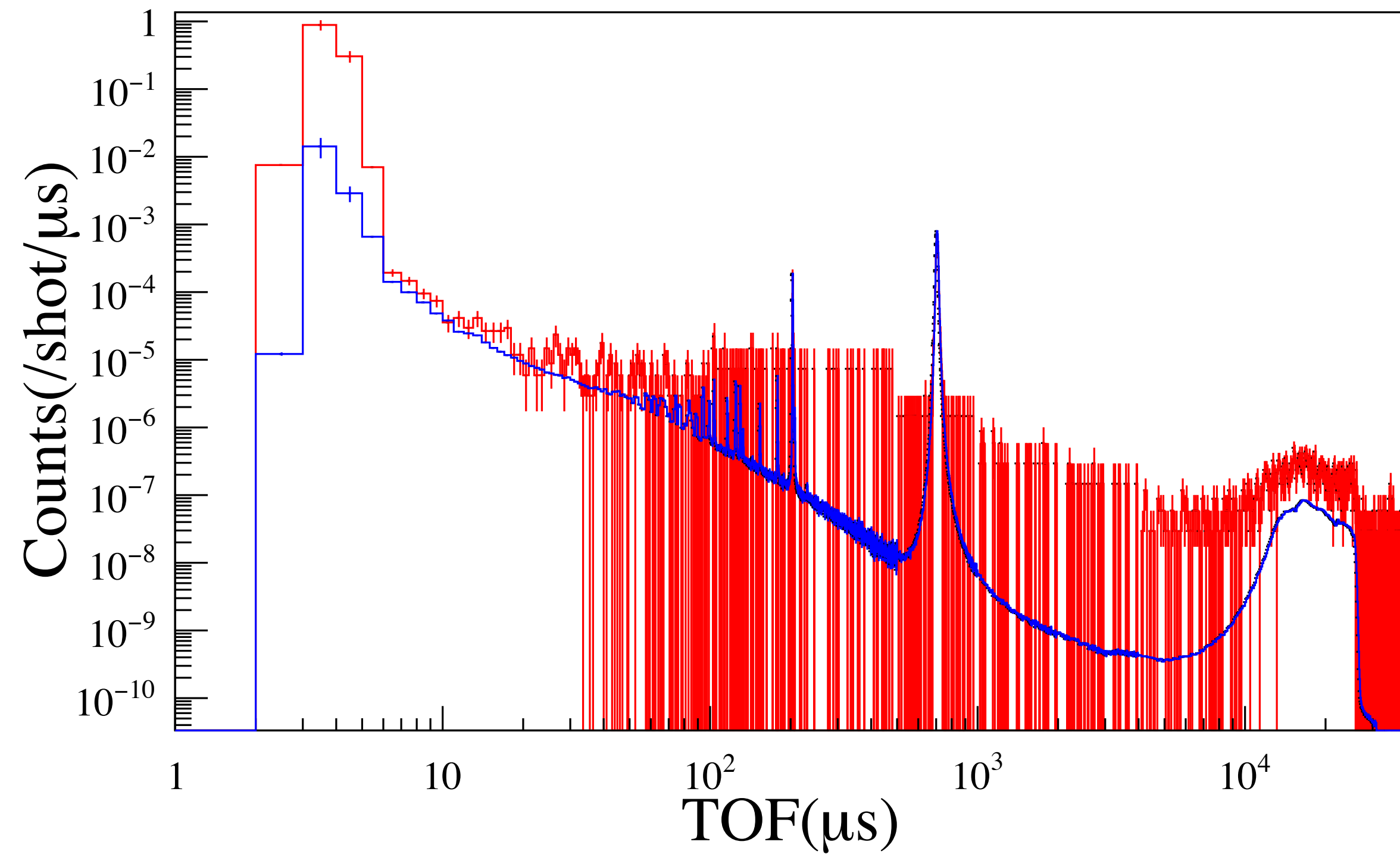
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# Gamma-ray background correction



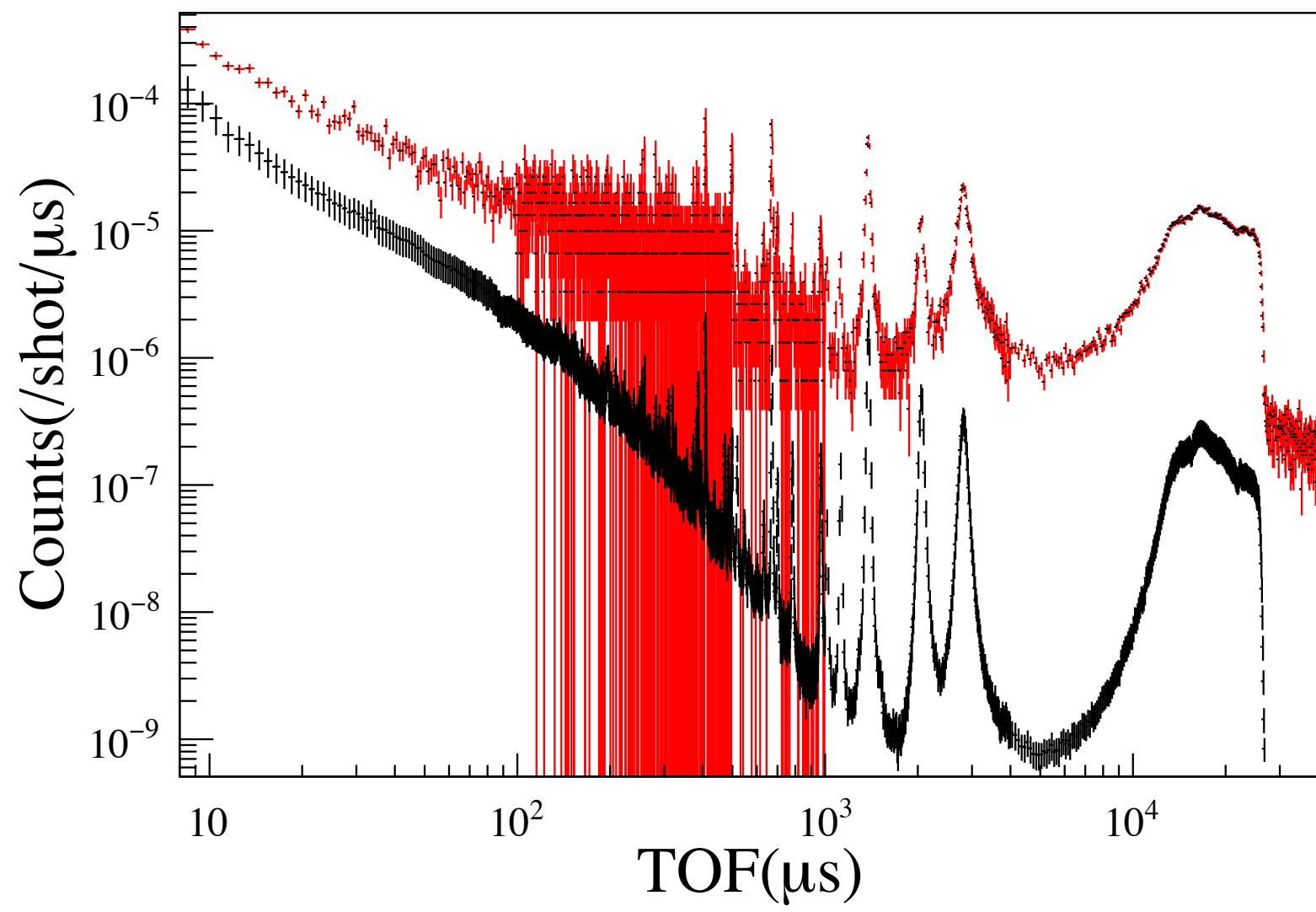
# Background correction

検出器3~8それぞれで求めた補正パラ  
メータで補正して足し算した結果(Au)

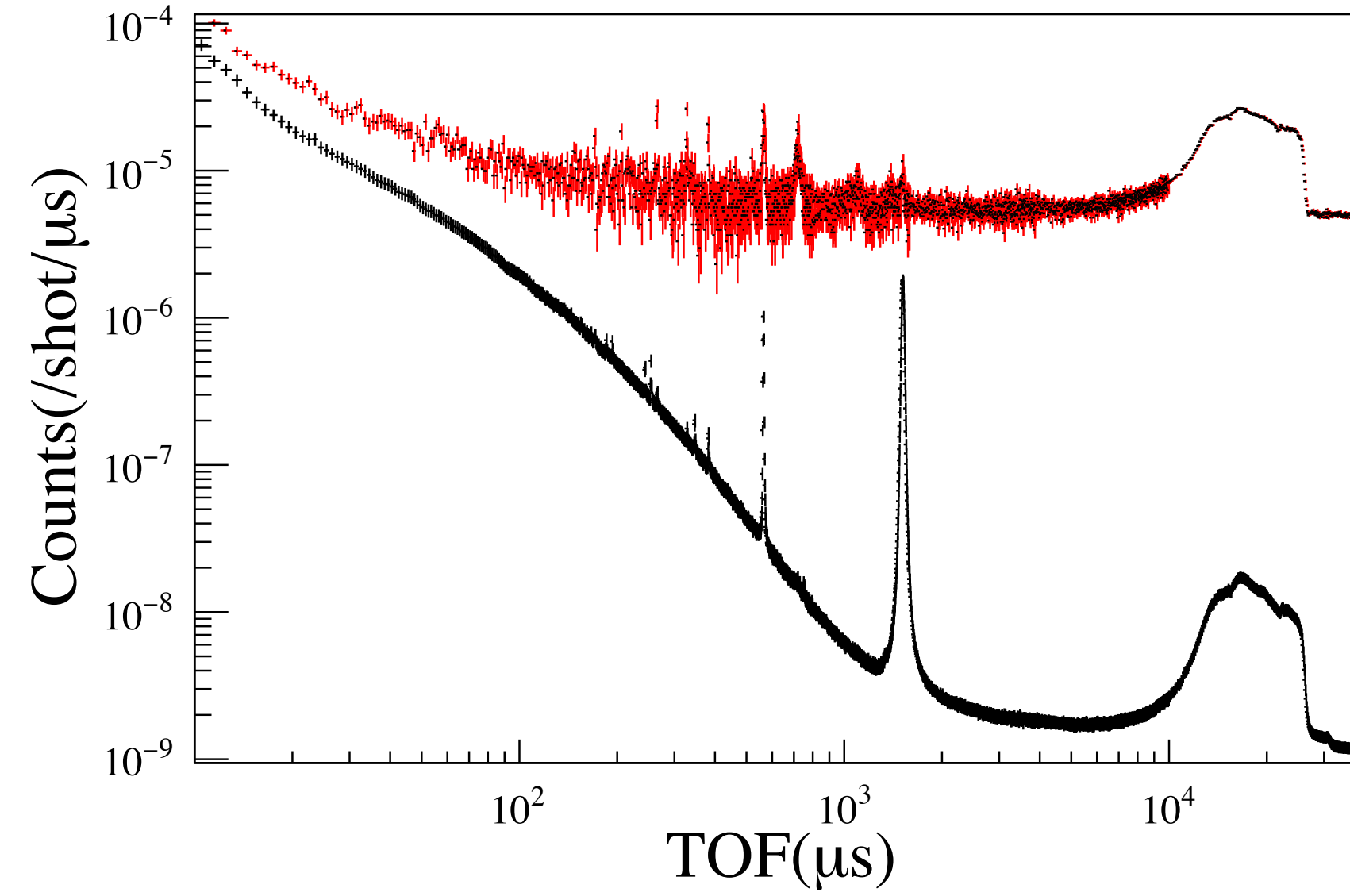


# Gamma-ray background correction

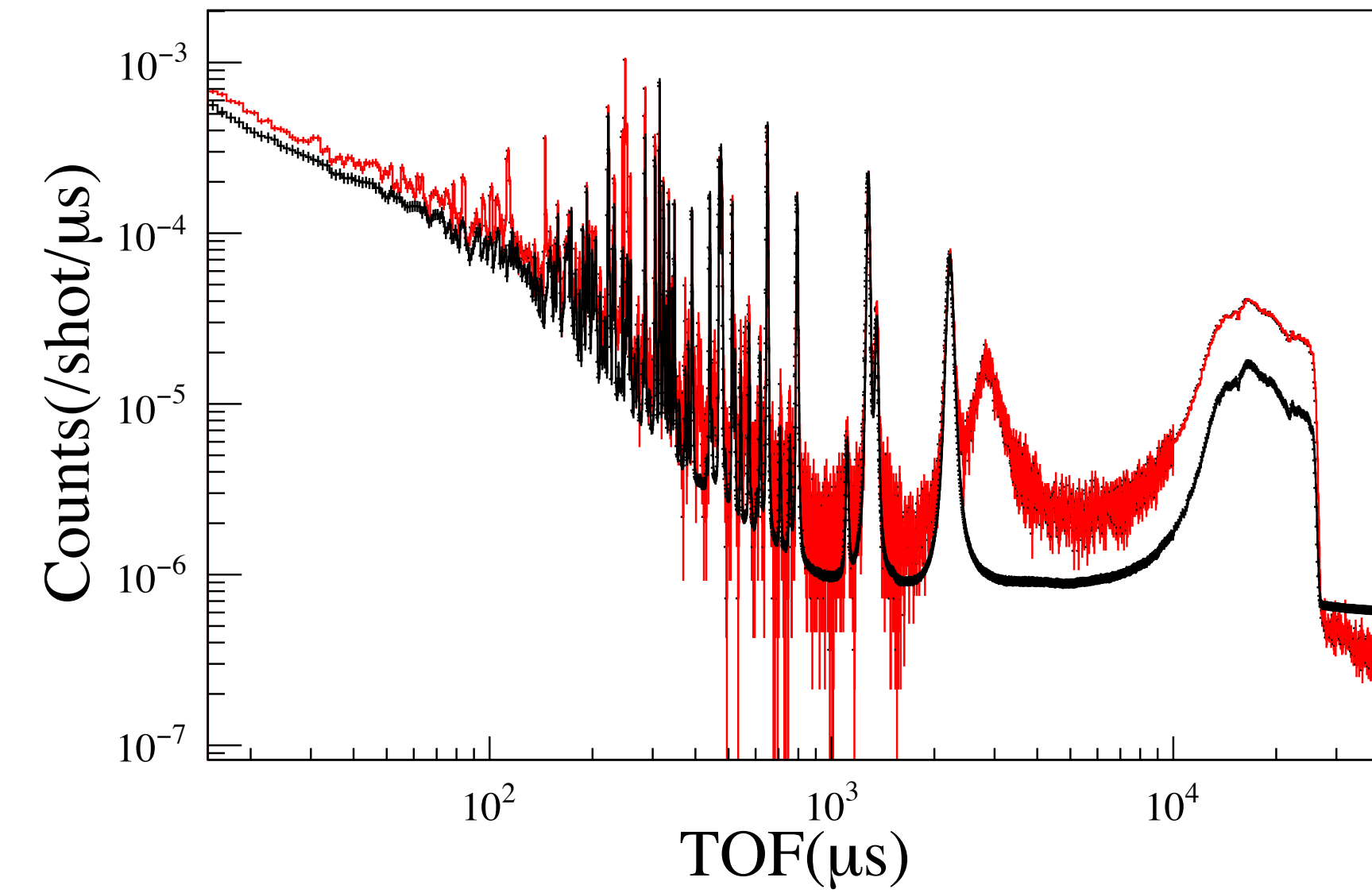
Am



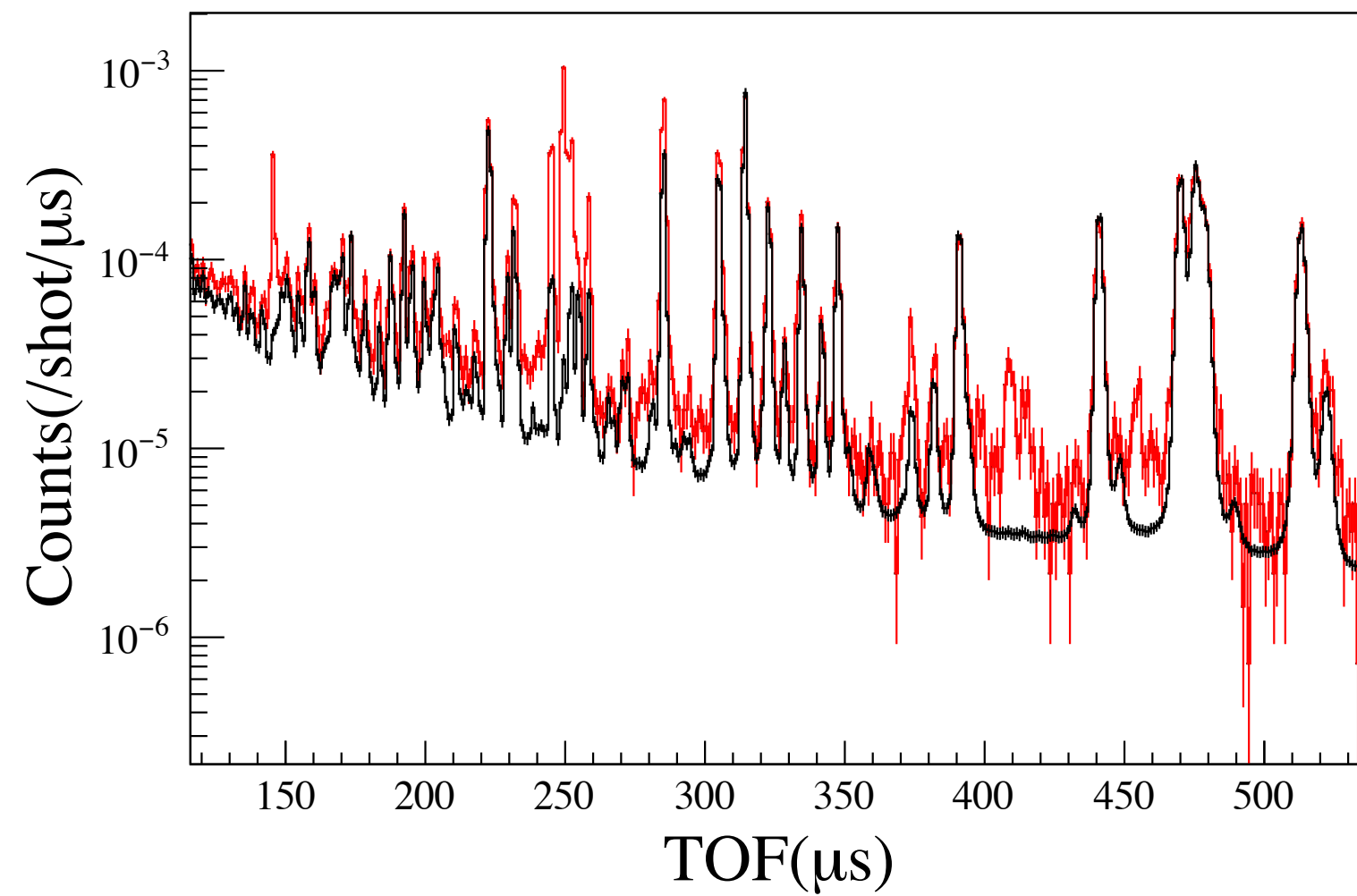
Cm



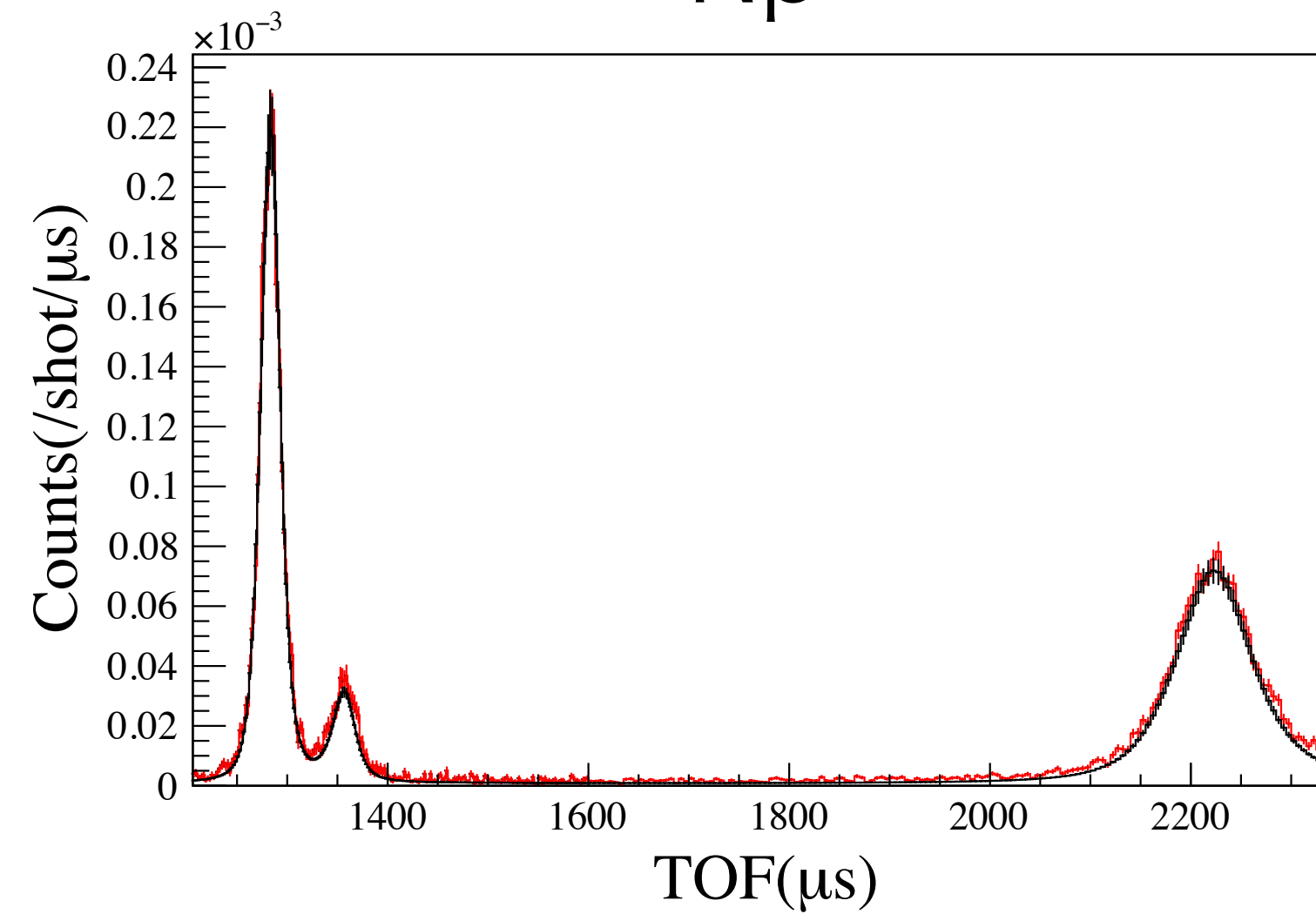
Np



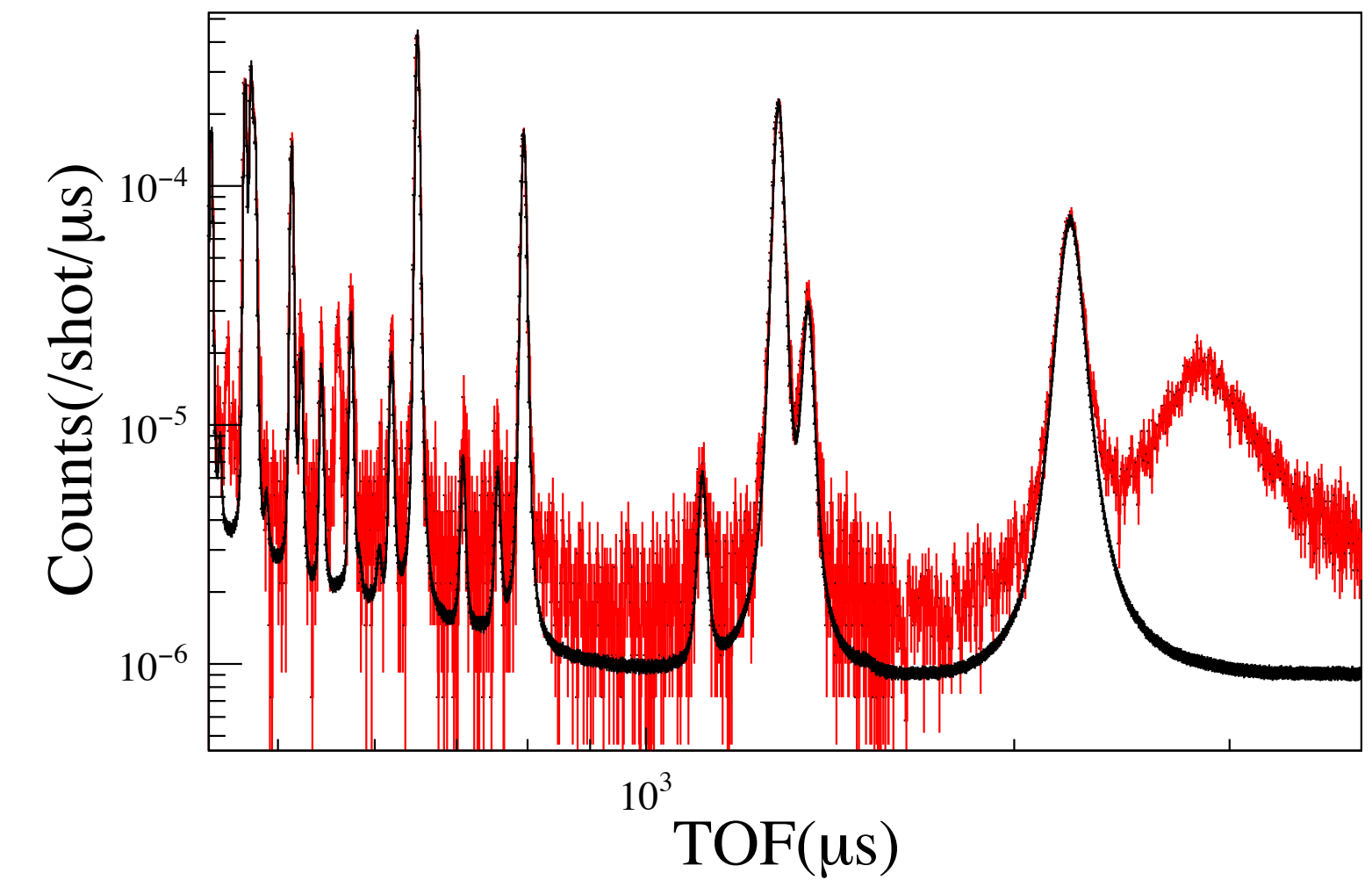
Np



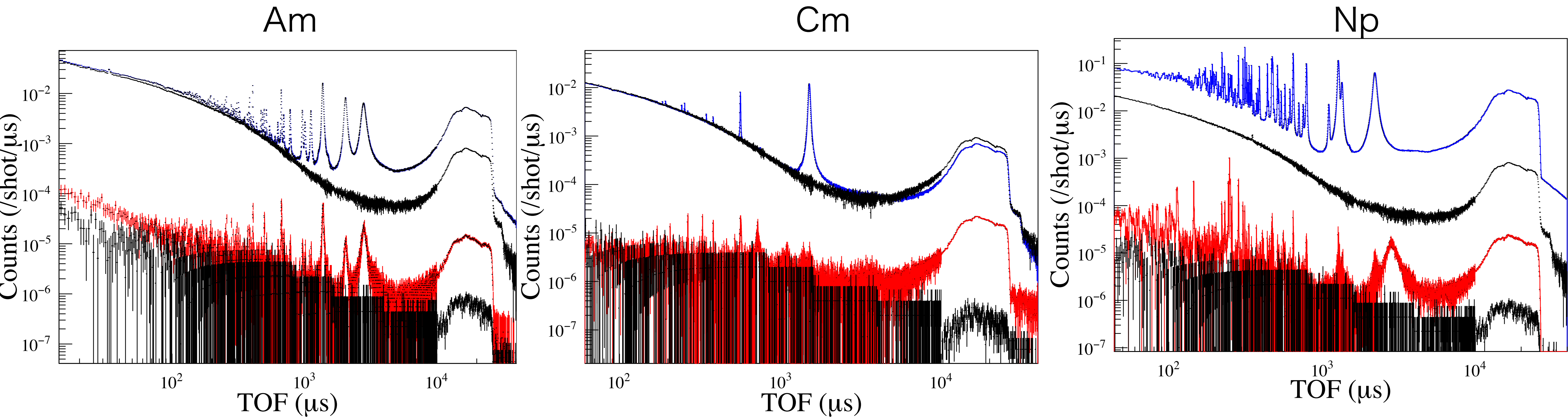
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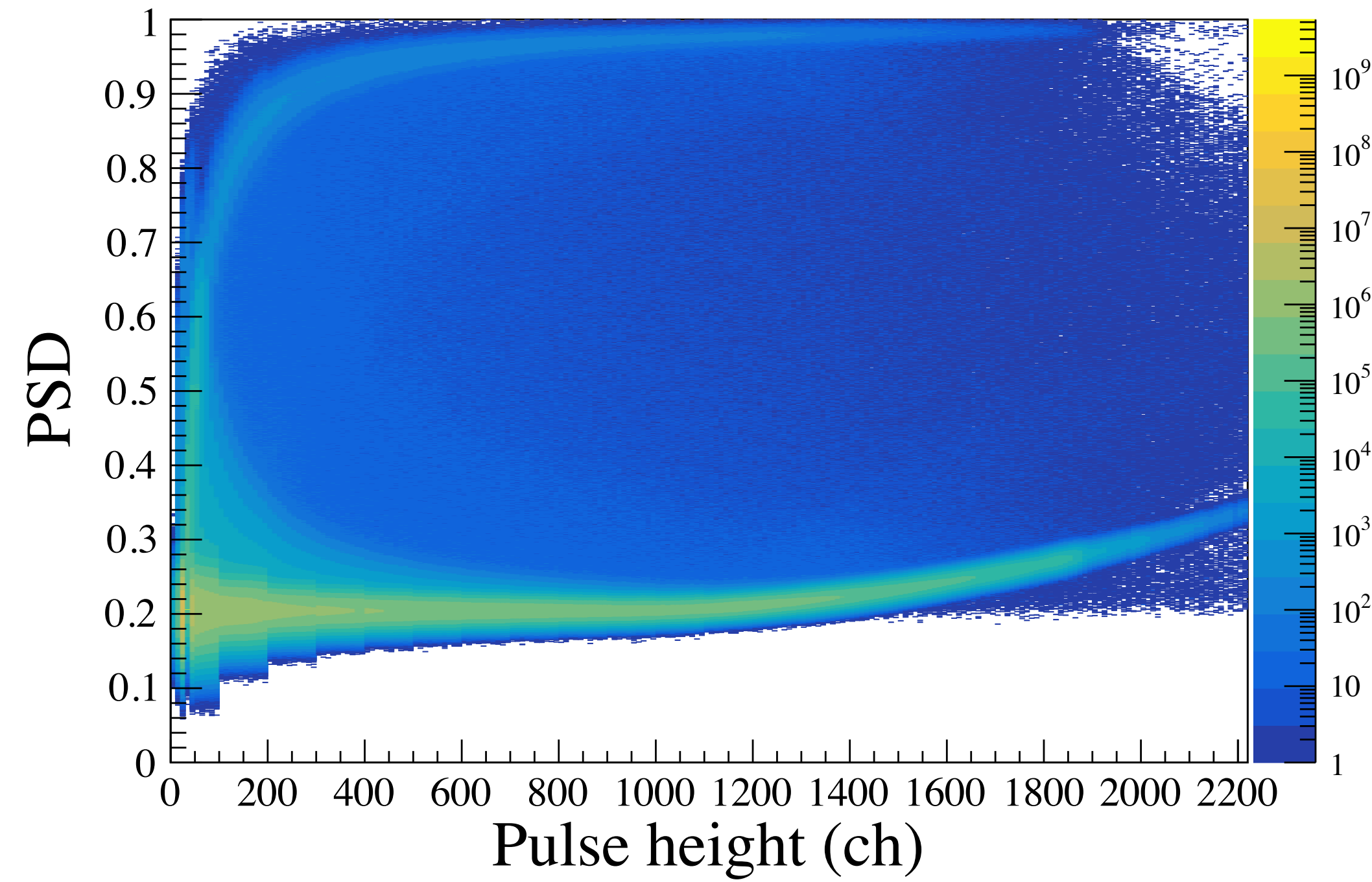
Np



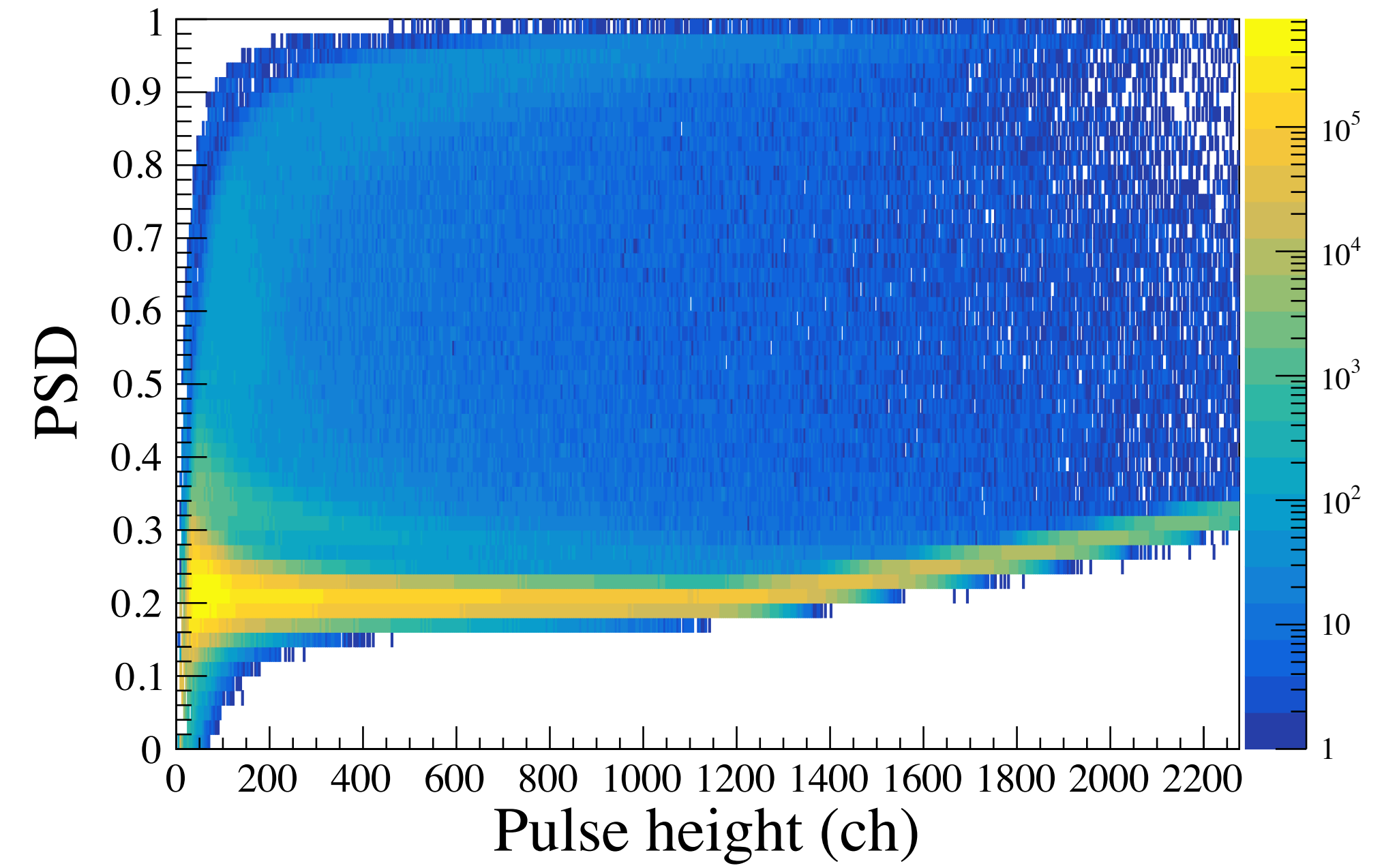
# Dummy correction



## Simulation



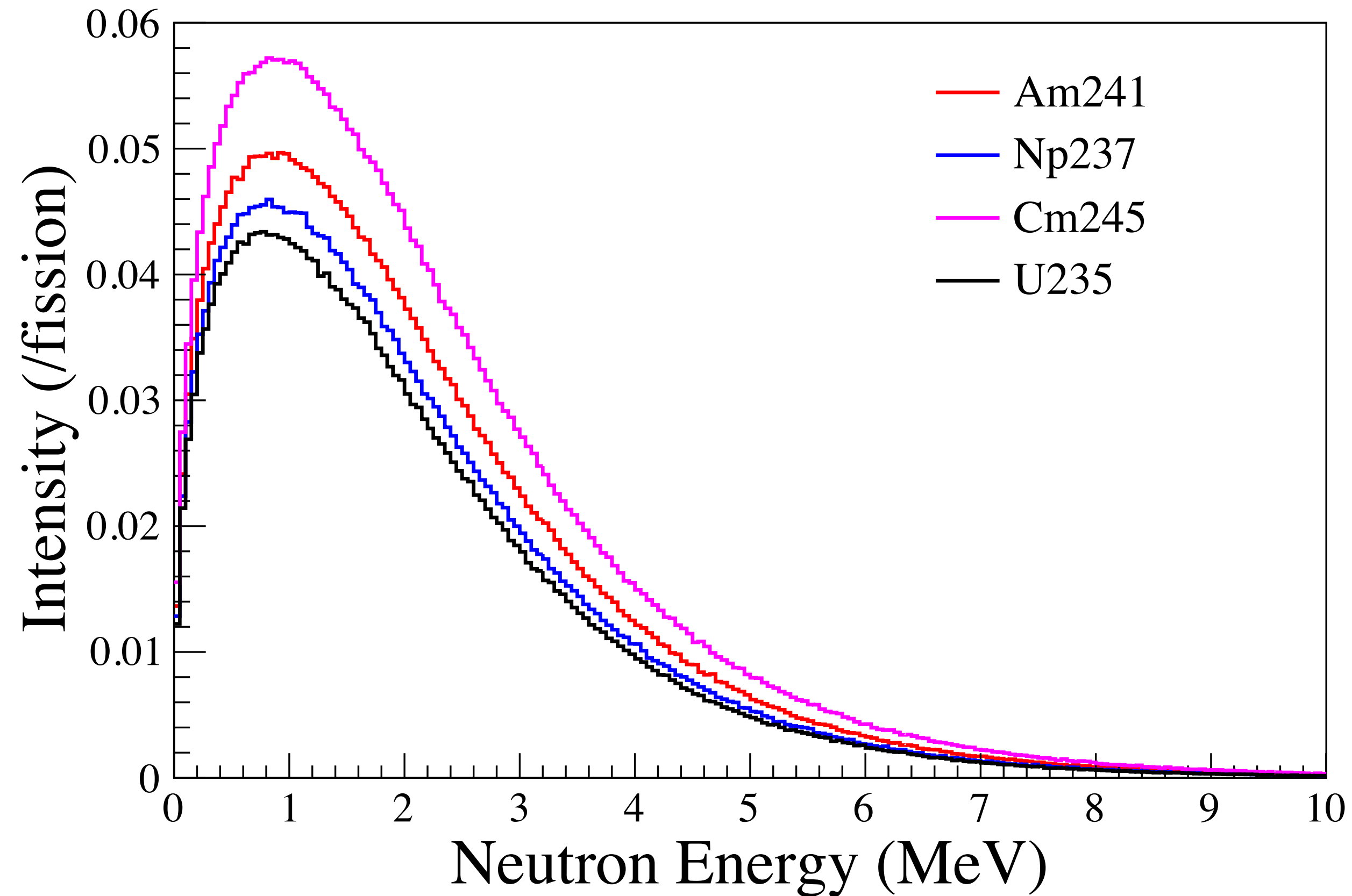
## Experiment



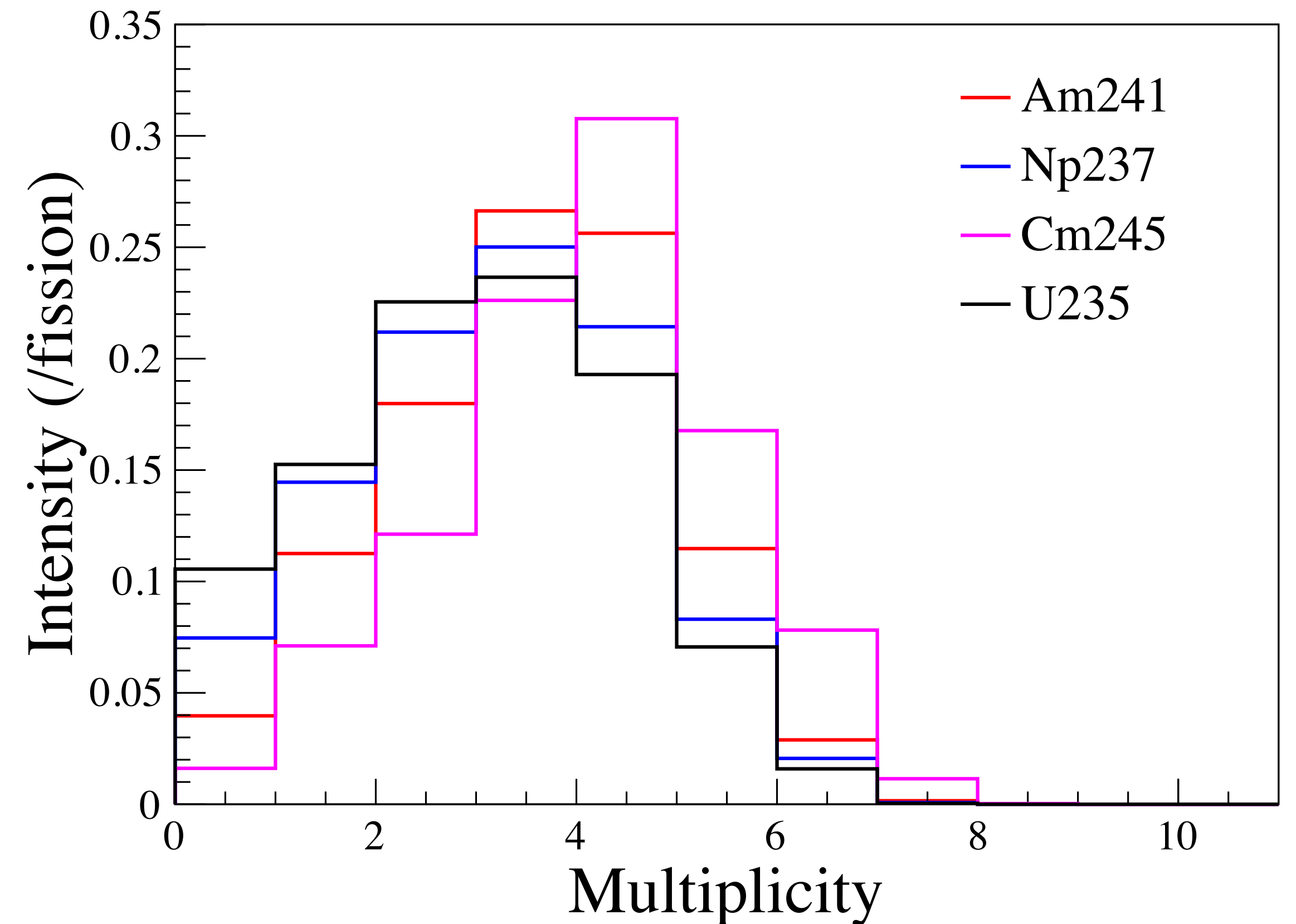
# Neutron energy spectrum and Multiplicity

修さんのデータから確認のため各スペクトルを作成

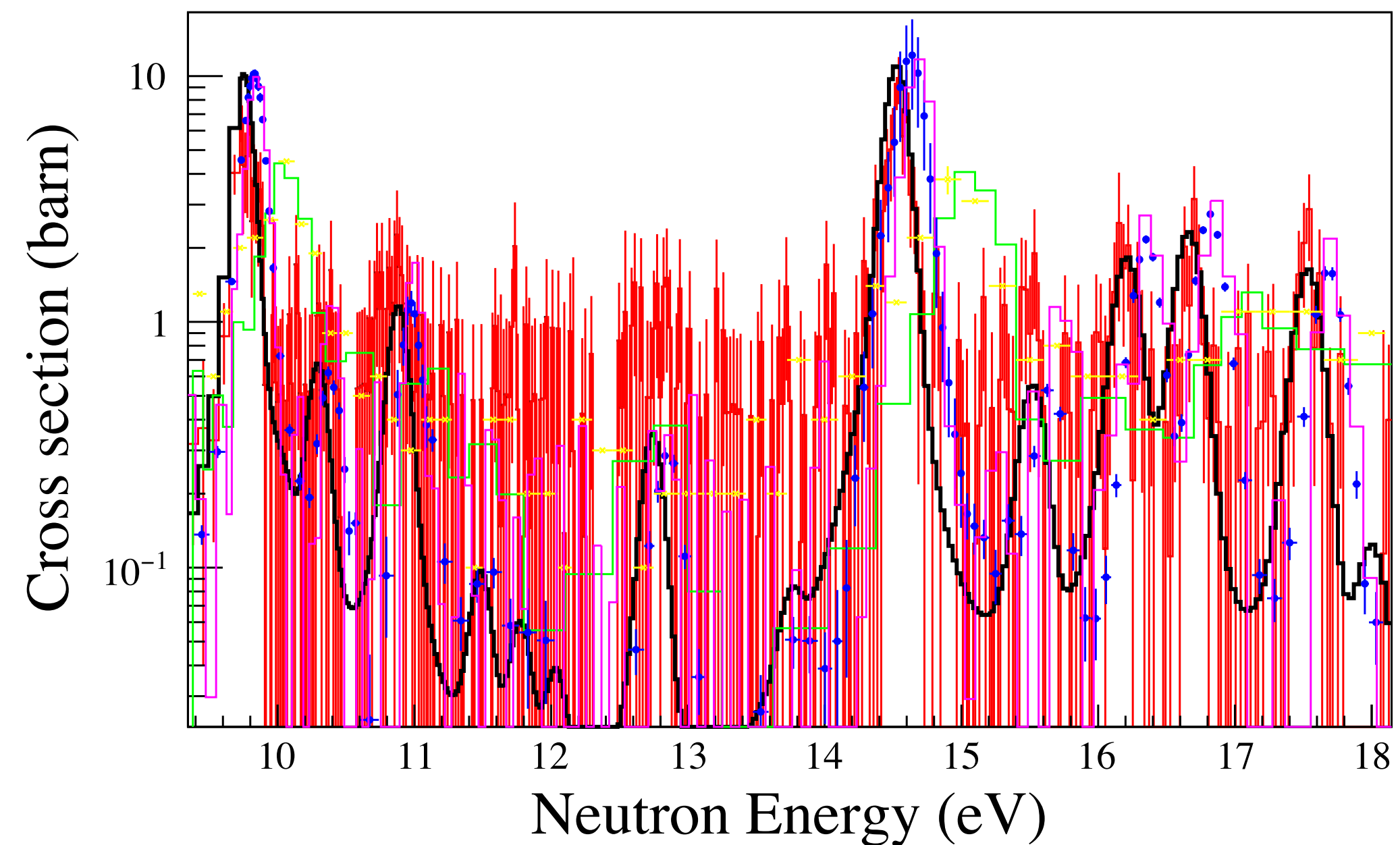
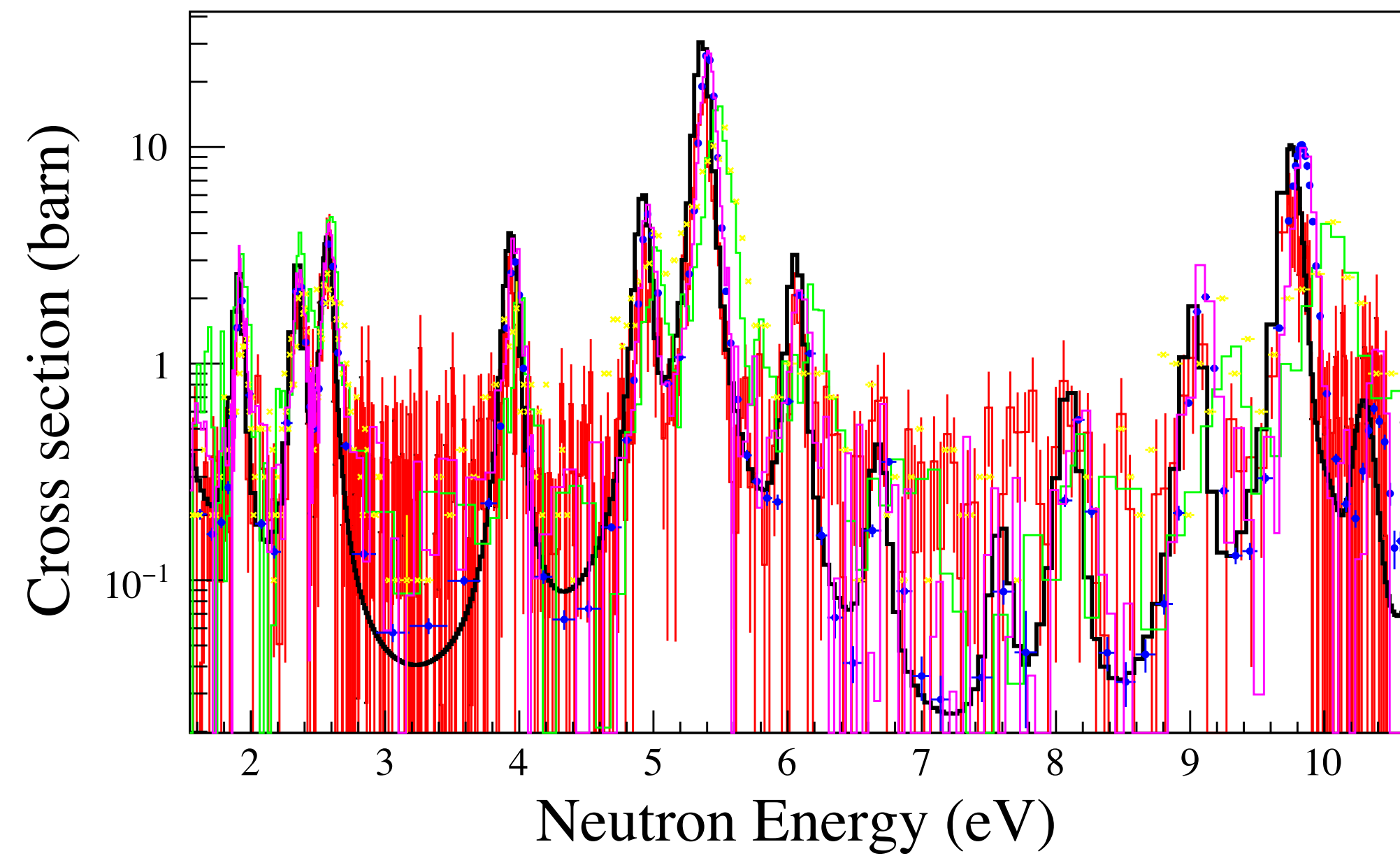
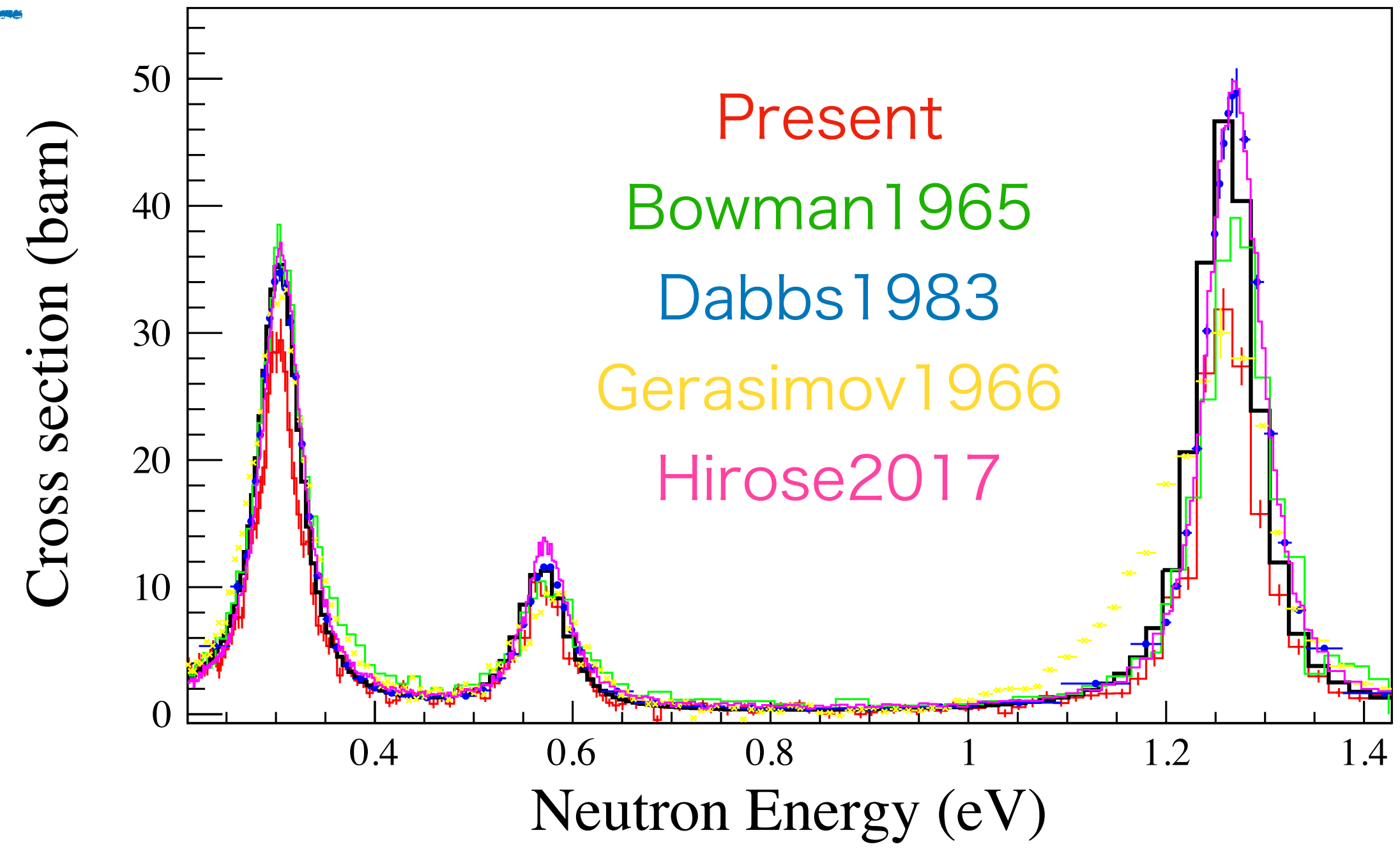
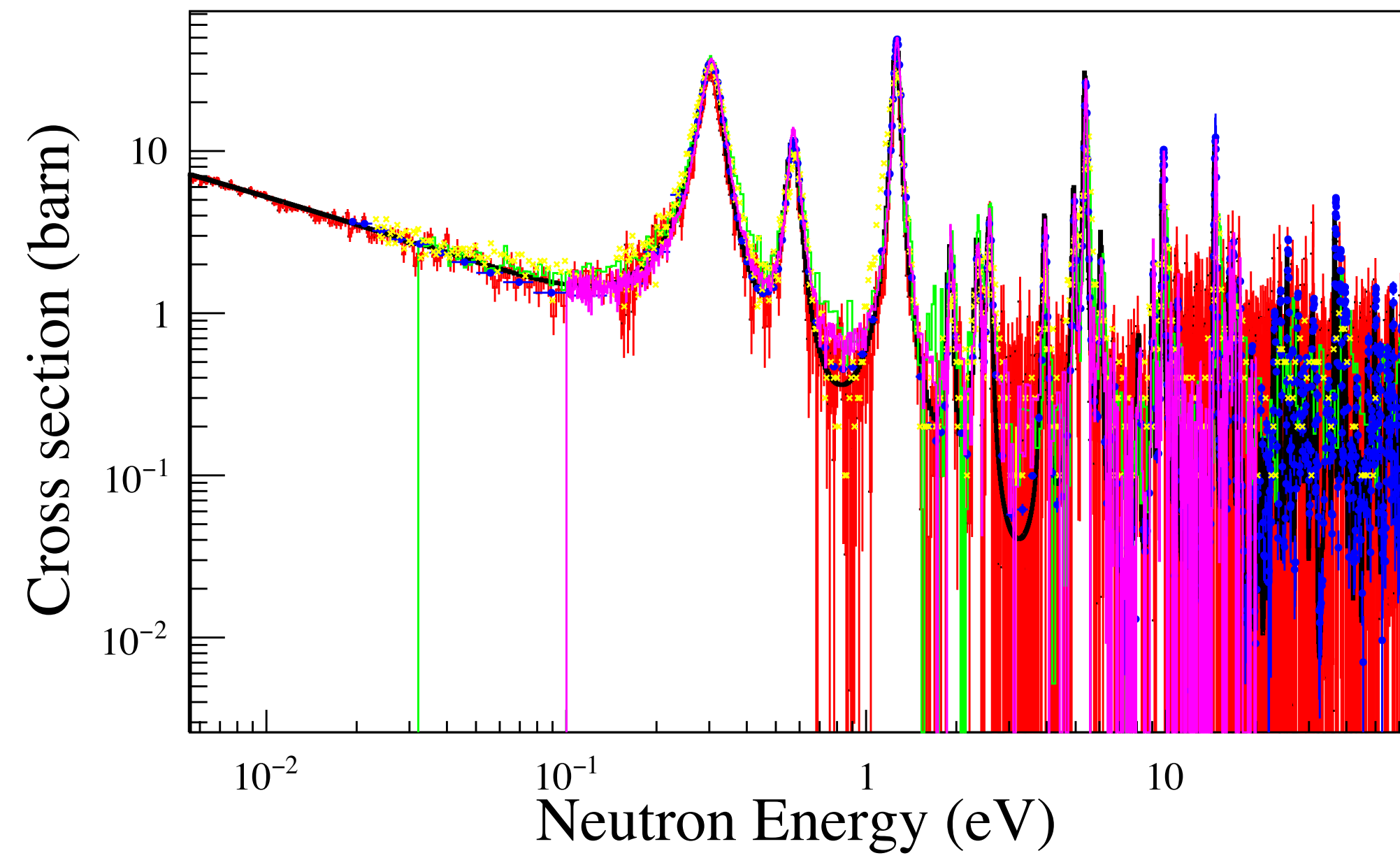
核分裂中性子エネルギー分布



中性子多重度分布



# $^{241}\text{Am}$



# ガンマ線漏れ込み評価

ガンマのイベントレートから漏れ込み量を評価する

- あるイベントレート(とりあえず熱中性子)でのPSDスペクトルを計算(PH領域ごと)
- 中性子cut領域/ガンマ線領域(PHcutなし)のイベント比(=  $R_{th}$ )を導出
- ガンマ線領域(PHcutなし)のカウント数のTOF依存性(=  $Y_\gamma(t)$ )を導出
- イベントレートから中性子cut領域へのガンマの漏れ込みを評価

漏れ込み量

イベントレートと漏れ込み比は比例

カウント数とイベントレートの関係

$$Y_n^{BG}(t) = R(t)Y_\gamma(t)$$

$$\lambda(t) : R(t) = \lambda_{th} : R_{th}$$

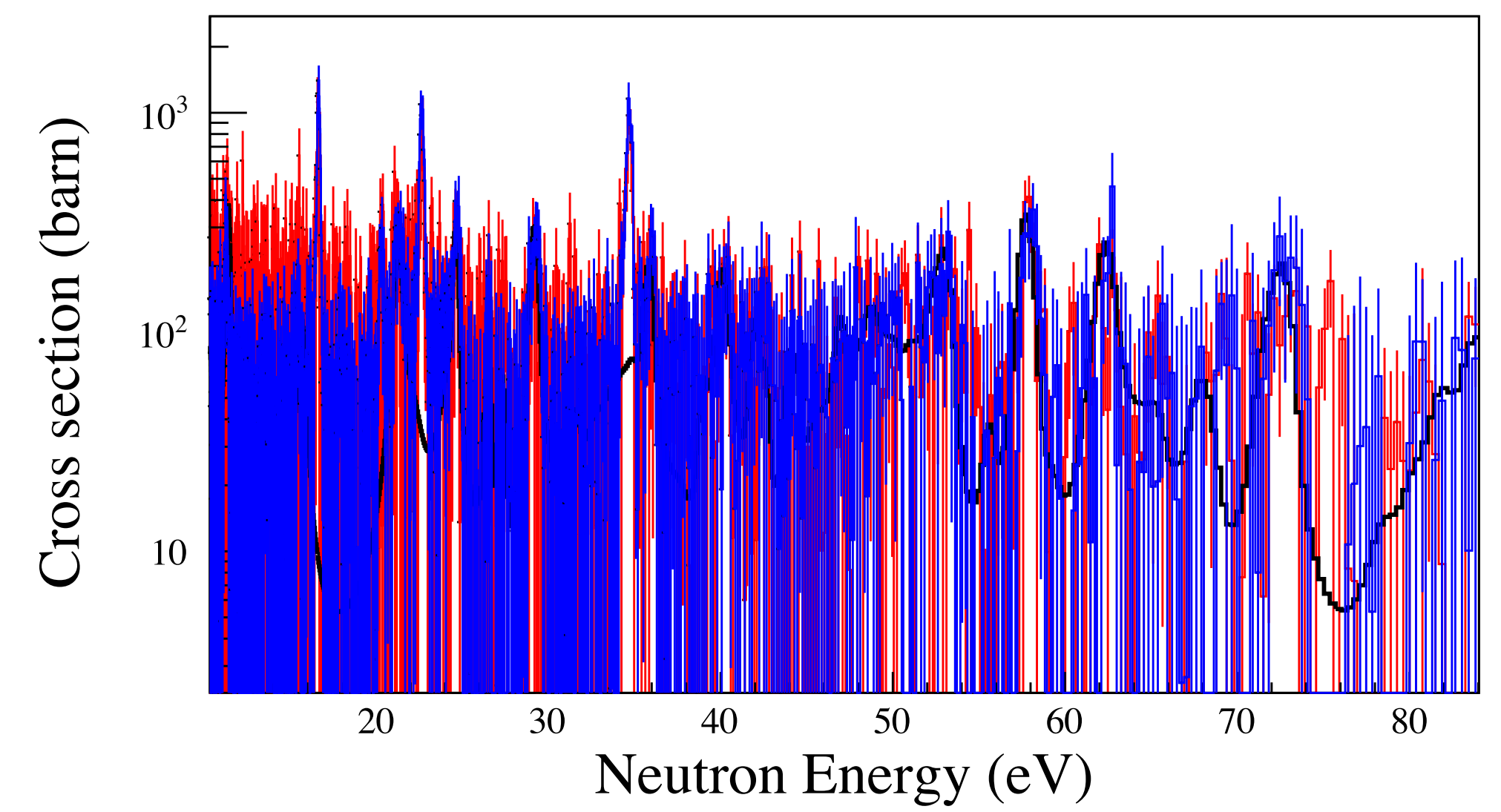
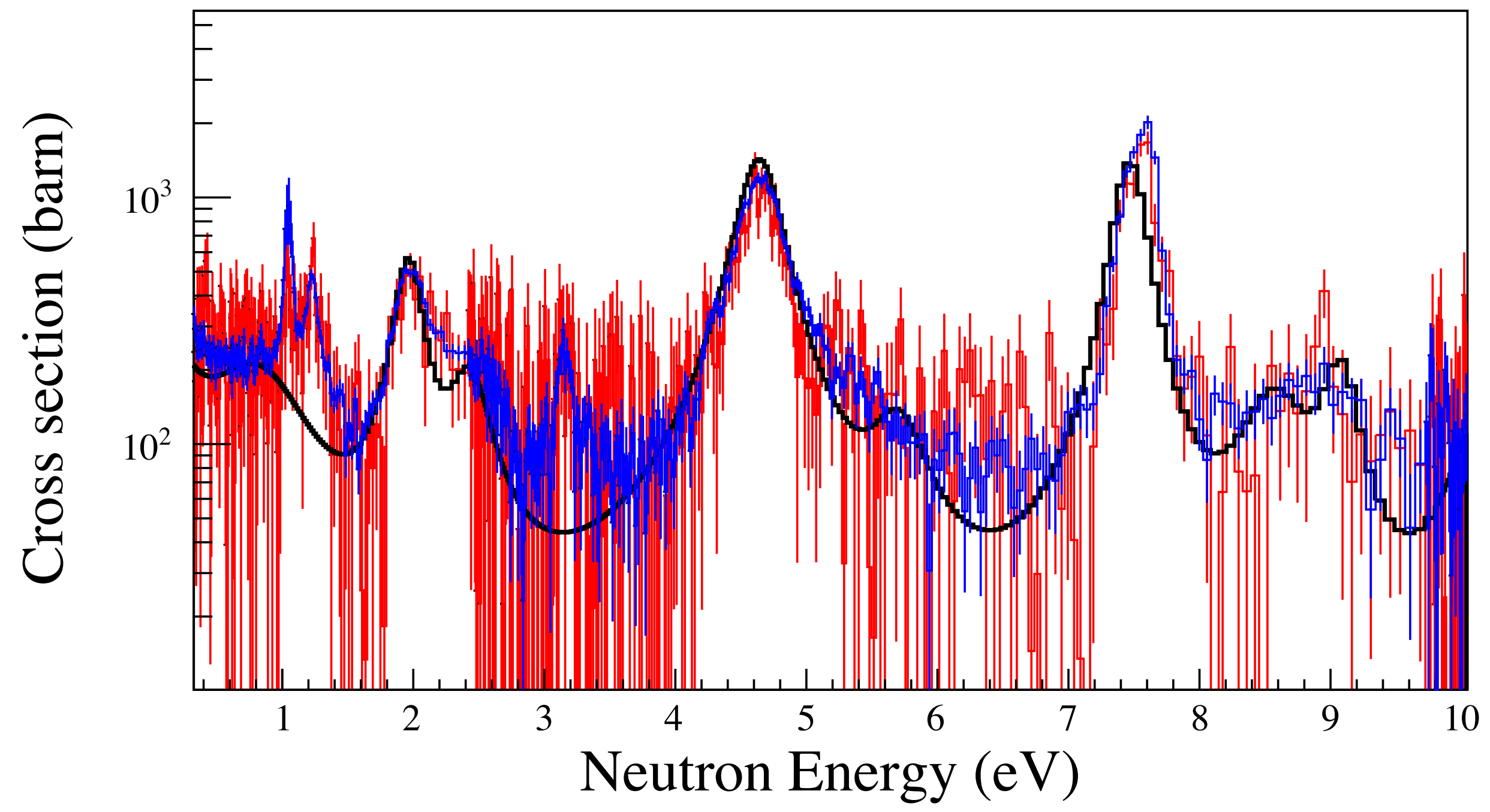
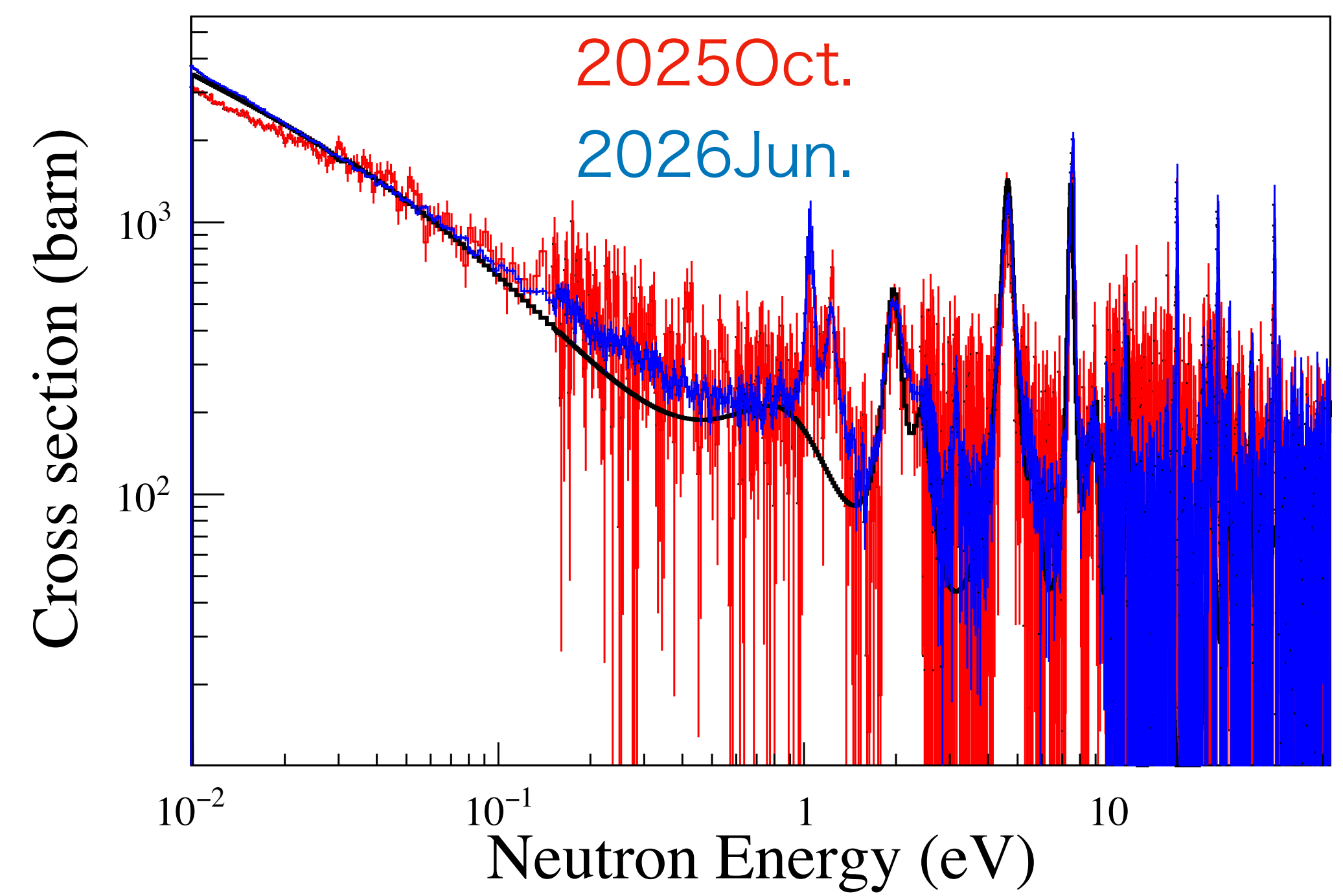
$$\lambda(t) = Y_\gamma(t)/\Delta t$$

$\Delta t$  : bin幅

以上の関係式から漏れ込み量は

$$Y_n^{BG}(t) = Y_\gamma^2(t) \frac{1}{\Delta t} \frac{R_{th}}{\lambda_{th}}$$

バックグラウンドはカウント数 $Y_\gamma(t)$ の2乗に比例



# Cm-245 sample

Cm-244	42.3%
Cm-245	2.4%
Cm-246	6.4%
Pu-240	49.0%

