Analysis of low energy Nuclear Recoils' from AmBe neutron source

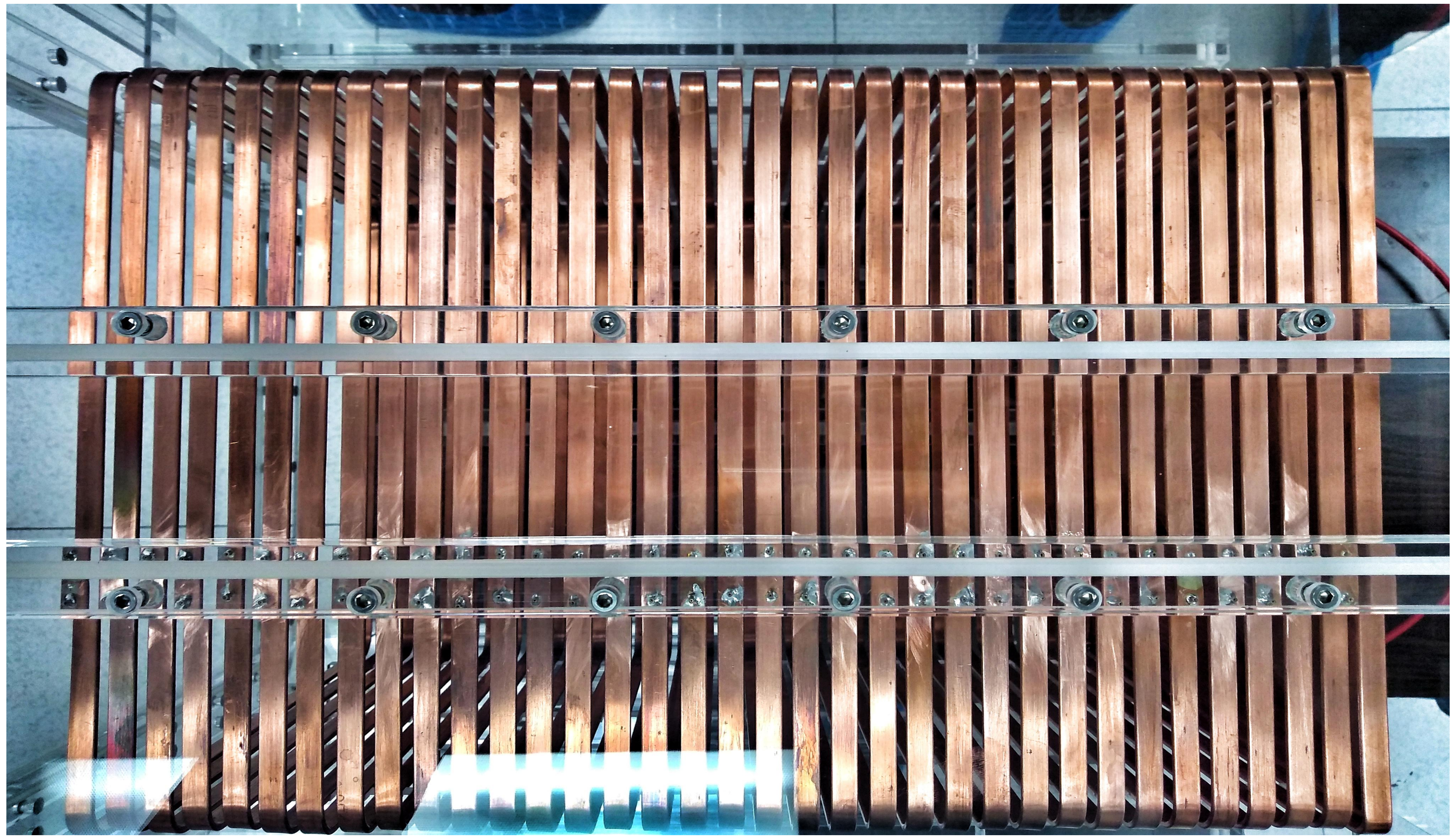
Luca Zappaterra Master Thesis

CYGNO Experiment

LIME: Large Imaging module

50 litres sensitive volume:

- 33 x 33 ~ 1000 cm^2 GEM surface;
- 50 cm drift path;



A 50 l Cygno prototype overground characterization

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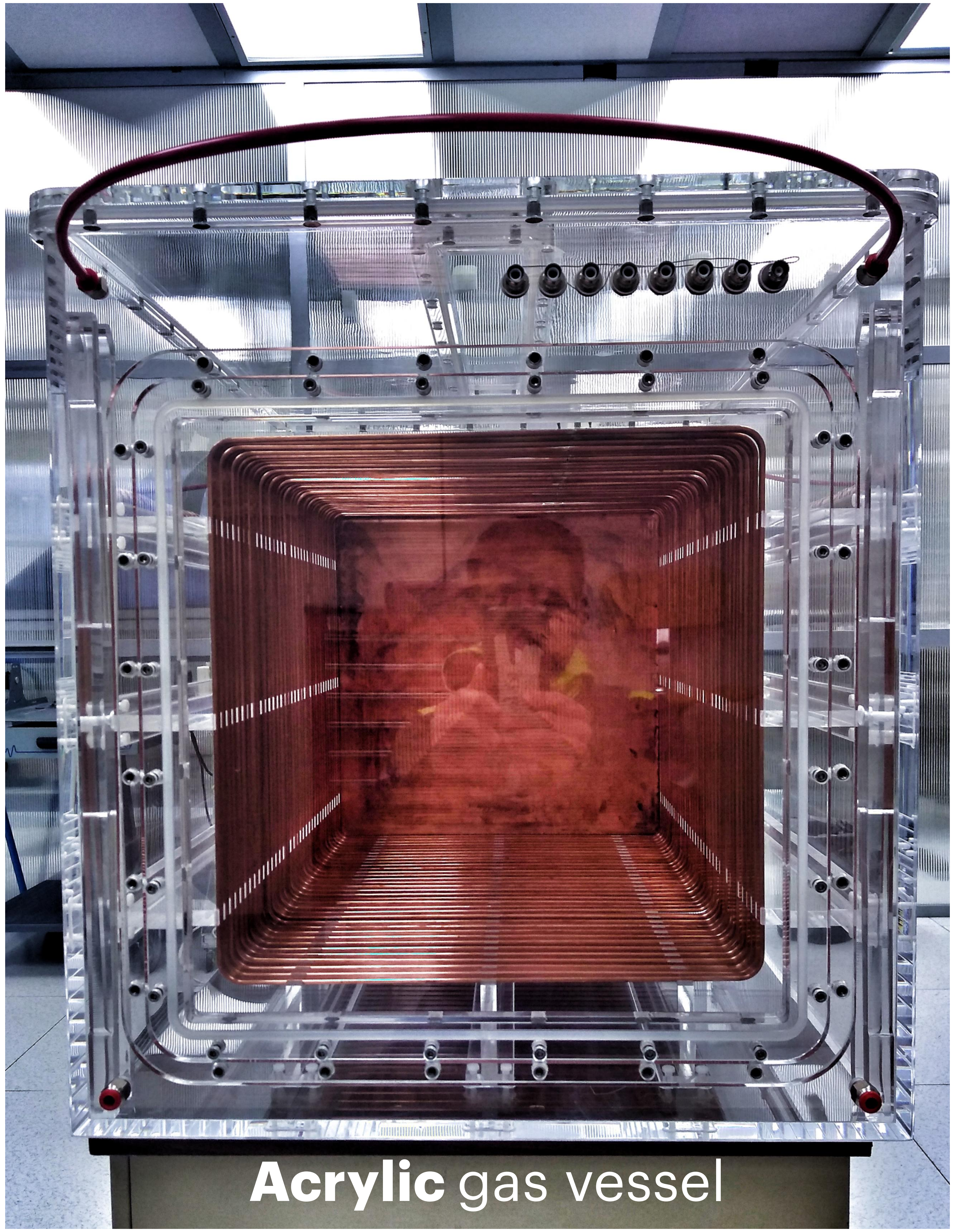
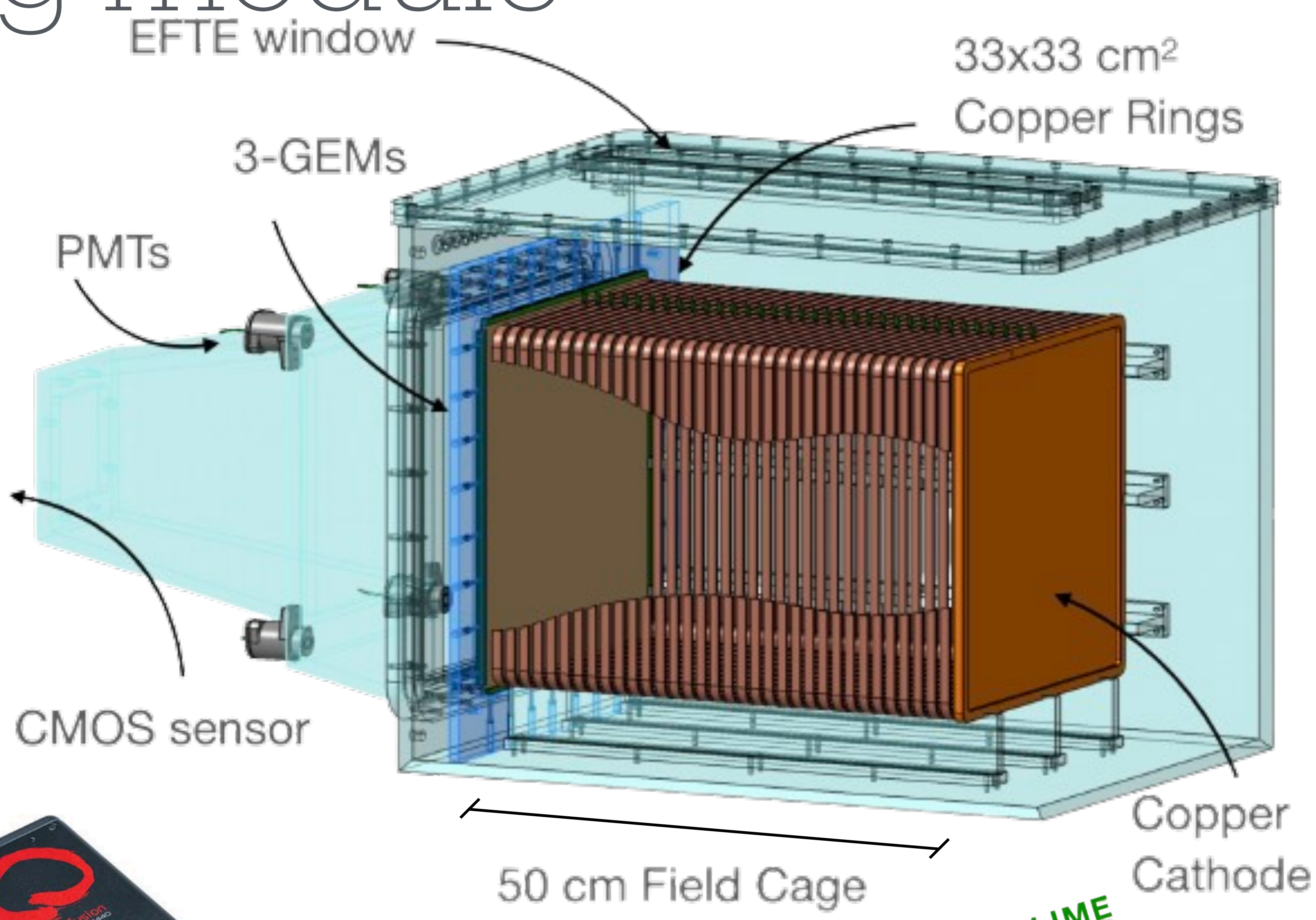


LIME: Large Imaging module

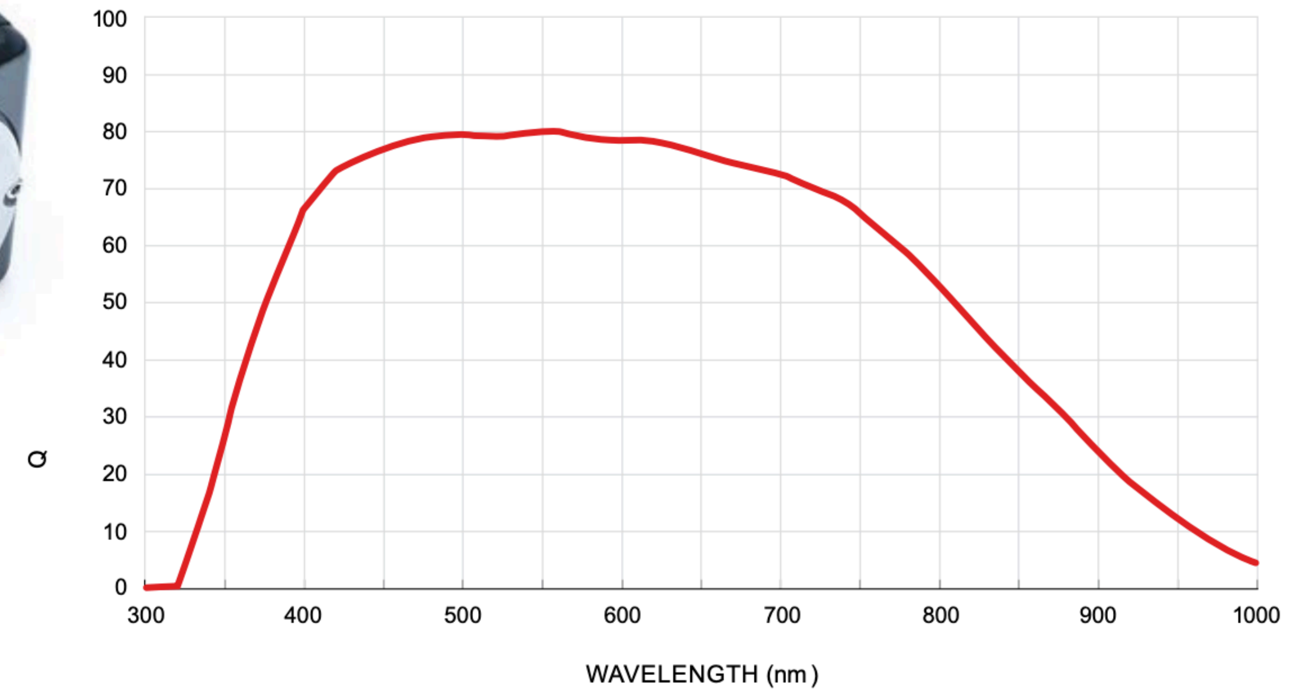
- It is a 50 L TPC with:
  - Gas Mixture: **He:CF_4 (60:40)**
  - 3 stacked Gas Electron Multipliers (**GEMs**) for the amplification stage.
  - 1 **APS** (CMOS) camera to acquire photons produced during the GEM stage.
  - 4 **PMTs** to obtain information about the ionisation electrons time of arrival.



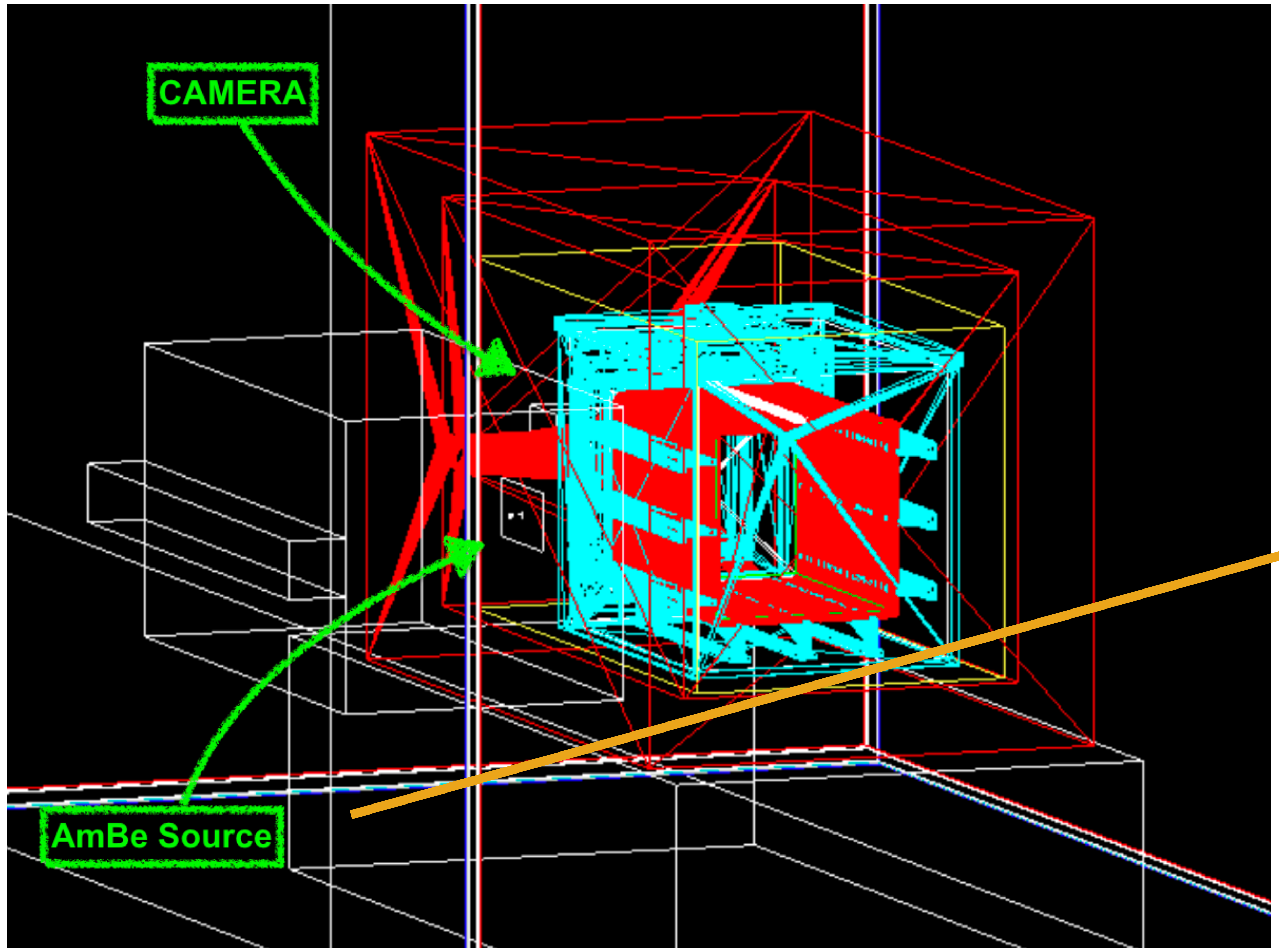
ORCA-Fusion

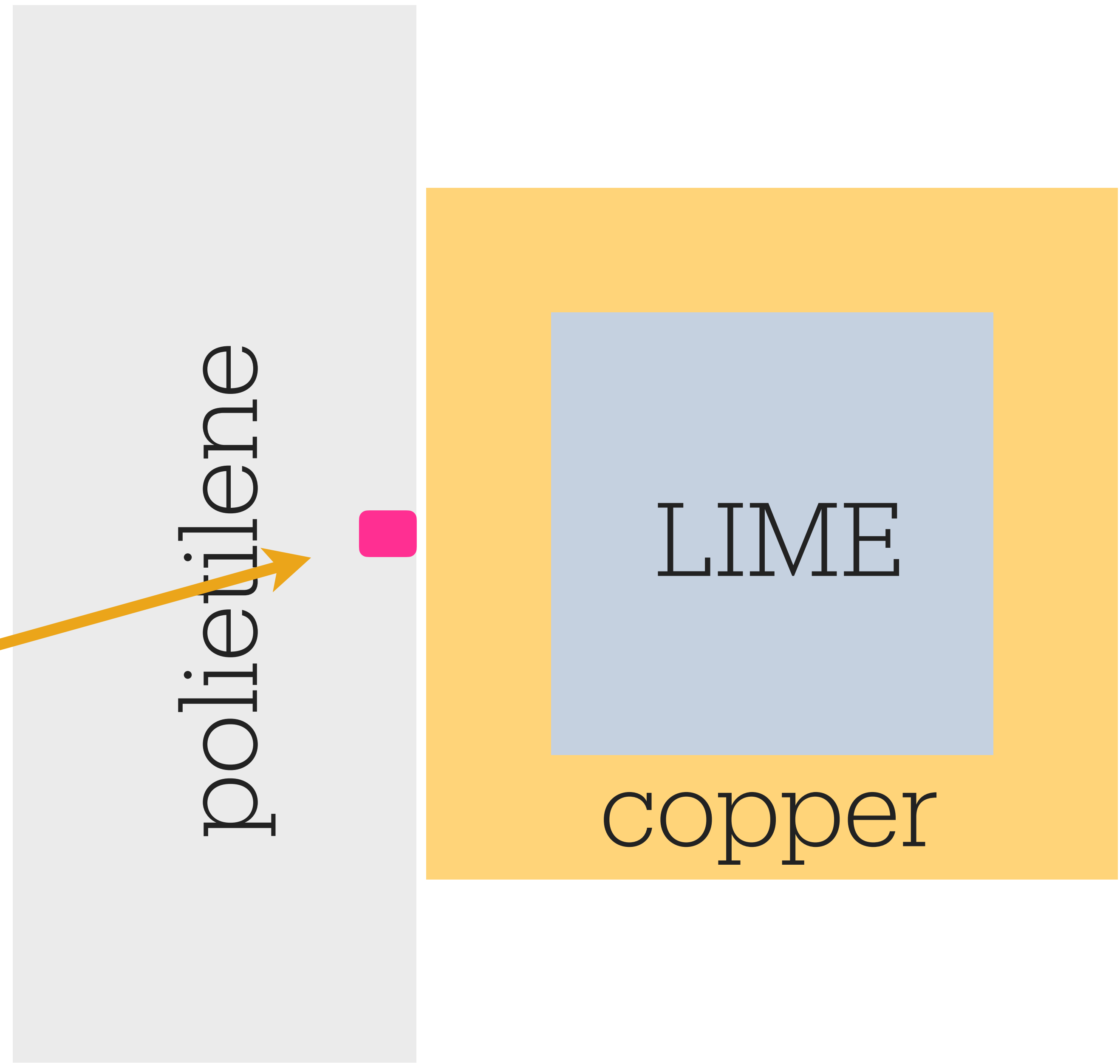
HIGH RESOLUTION
2304 × 2304
5.3 Megapixels

READOUT NOISE
0.7 electrons rms
Ultra-quiet Scan



Data taking setup





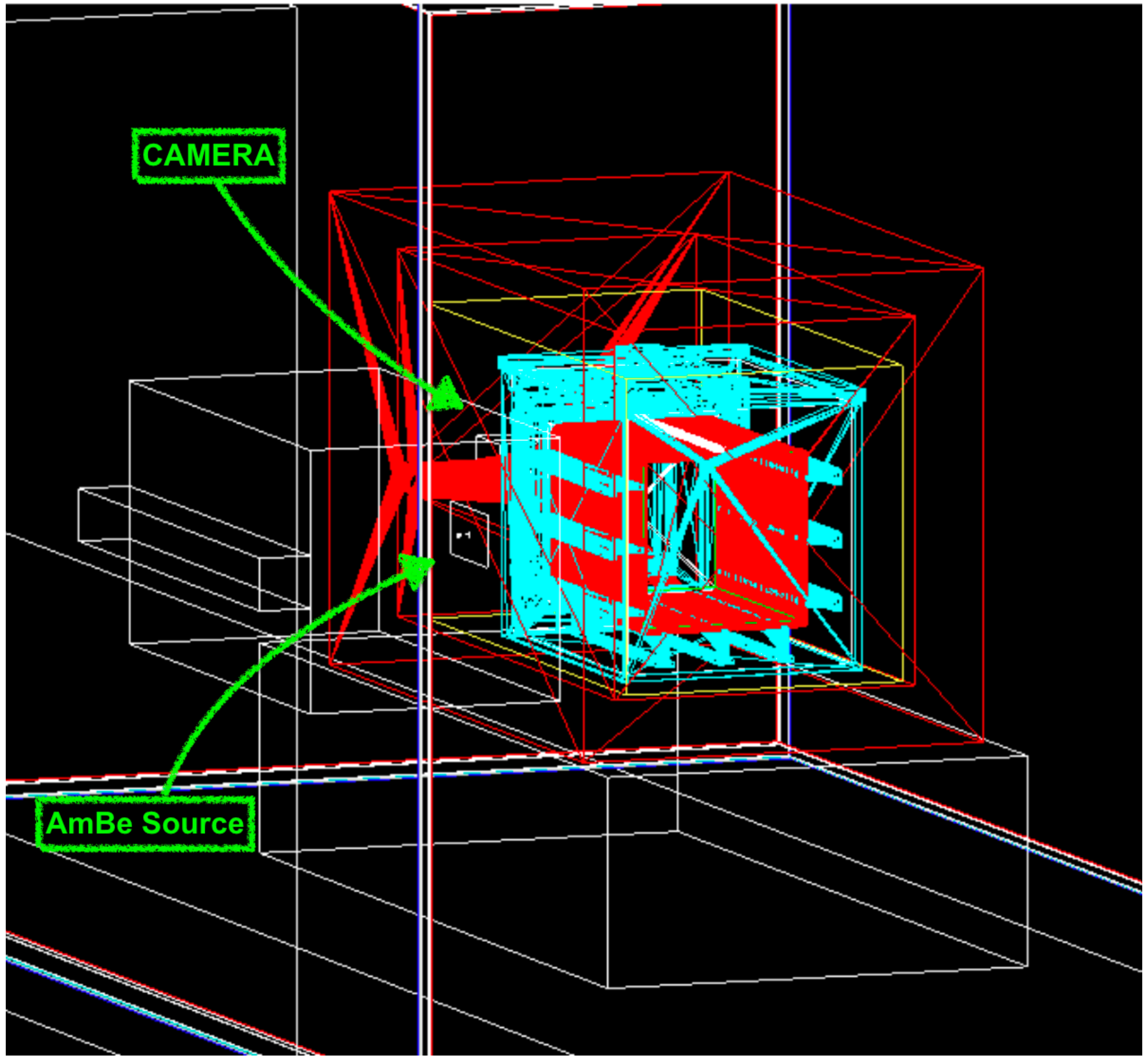
- The detector was shielded in a 10 cm thick copper box in the Gran Sasso underground labs;
- A 50 cm thick polietilene wall was placed to screen the external part of the lab

Data taking setup

- Two different periods used:

Alias	Runs range	Date range [mm/dd]	Eff. Exposure [h]
AmBe_p1	23820 ÷ 23984	08/02 ÷ 08/03	16.9
AmBe + Fe	23988 ÷ 24022	08/03 ÷ 08/03	2.1
AmBe_p2	24023 ÷ 24328	08/03 ÷ 08/04	31.0

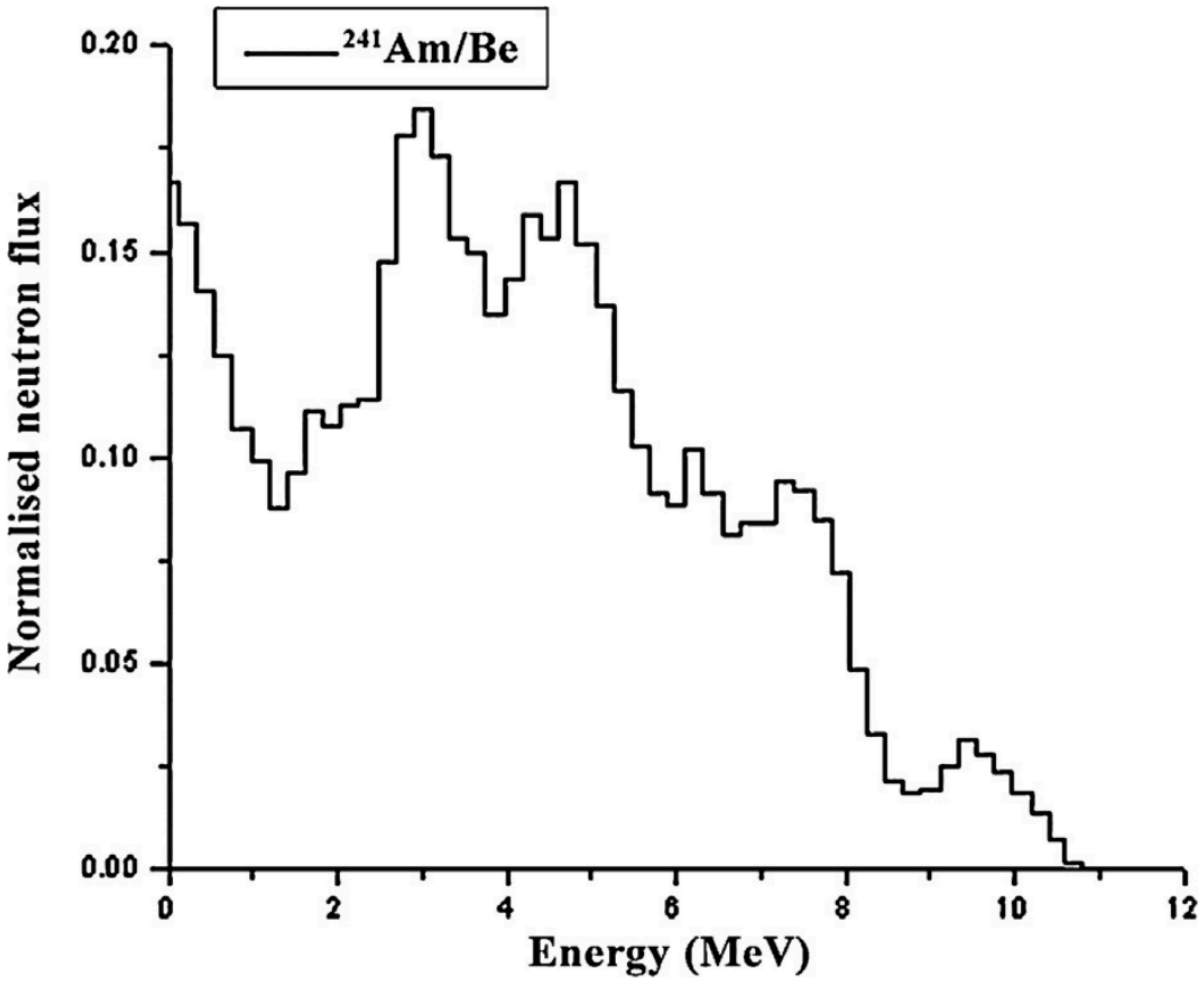
Alias	Runs range	Date range [mm/dd]	Eff. Exposure [h]
Bkg	25735 ÷ 27844	29/09 ÷ 10/10	226.9



- 47.9 h (172440 sec) with AmBe
- 226.9 h (816840 sec) without AmBe

Data taking setup

- Most of neutrons produced in the MeV range
- Detailed MC under development
- We expect **NR with hundreds of keV** energies



- From previous tests we expect **NR** to produce very **"dense" tracks** with large losses per unit area (i.e. lot of light per pixel)

- We defined a variable δ that indicates the **ratio between the total light and the area** of each **reconstructed cluster**

AmBe excess selection

Disclaimer: because of the "gain saturation", NR scale still to be evaluated

AmBe excess selection

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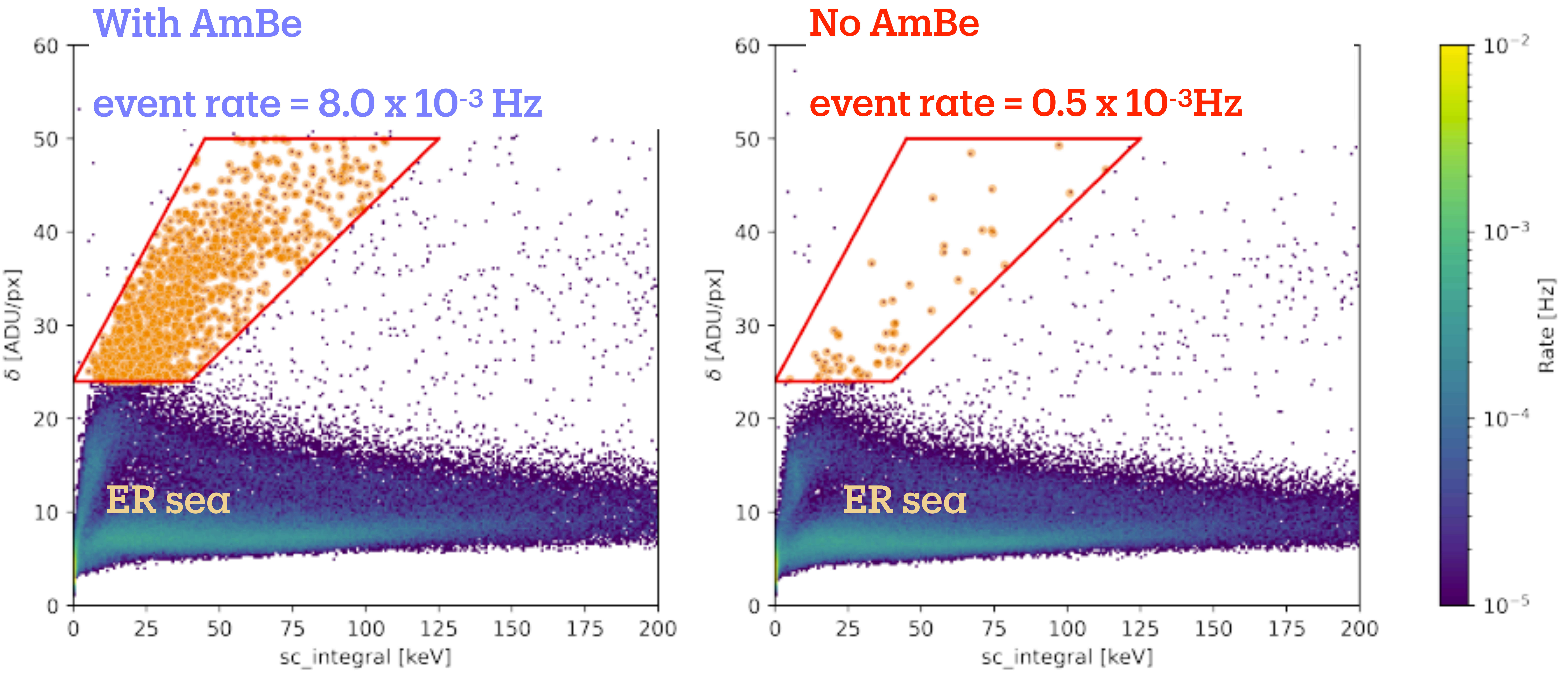
AmBe excess selection (zoom)



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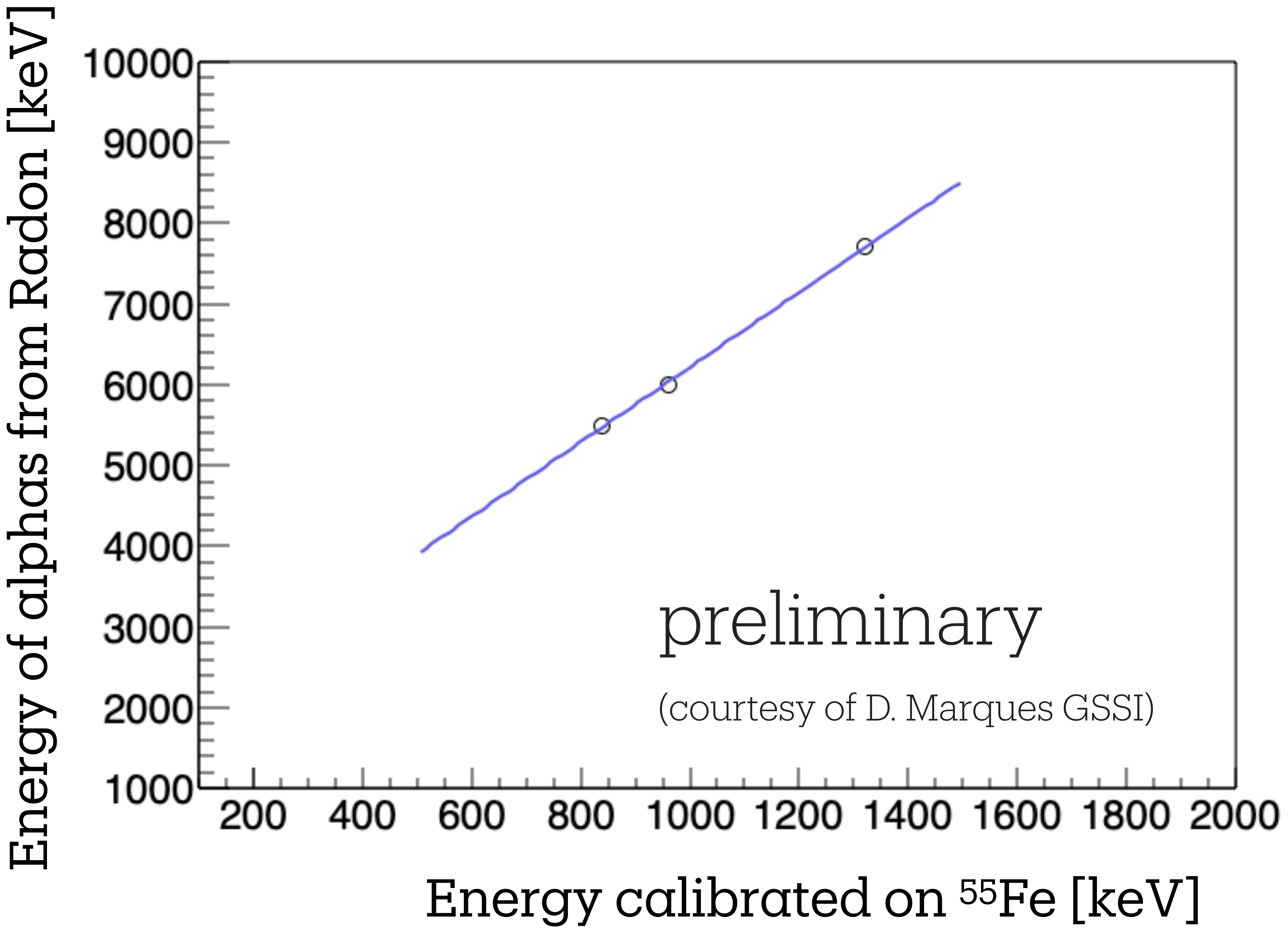
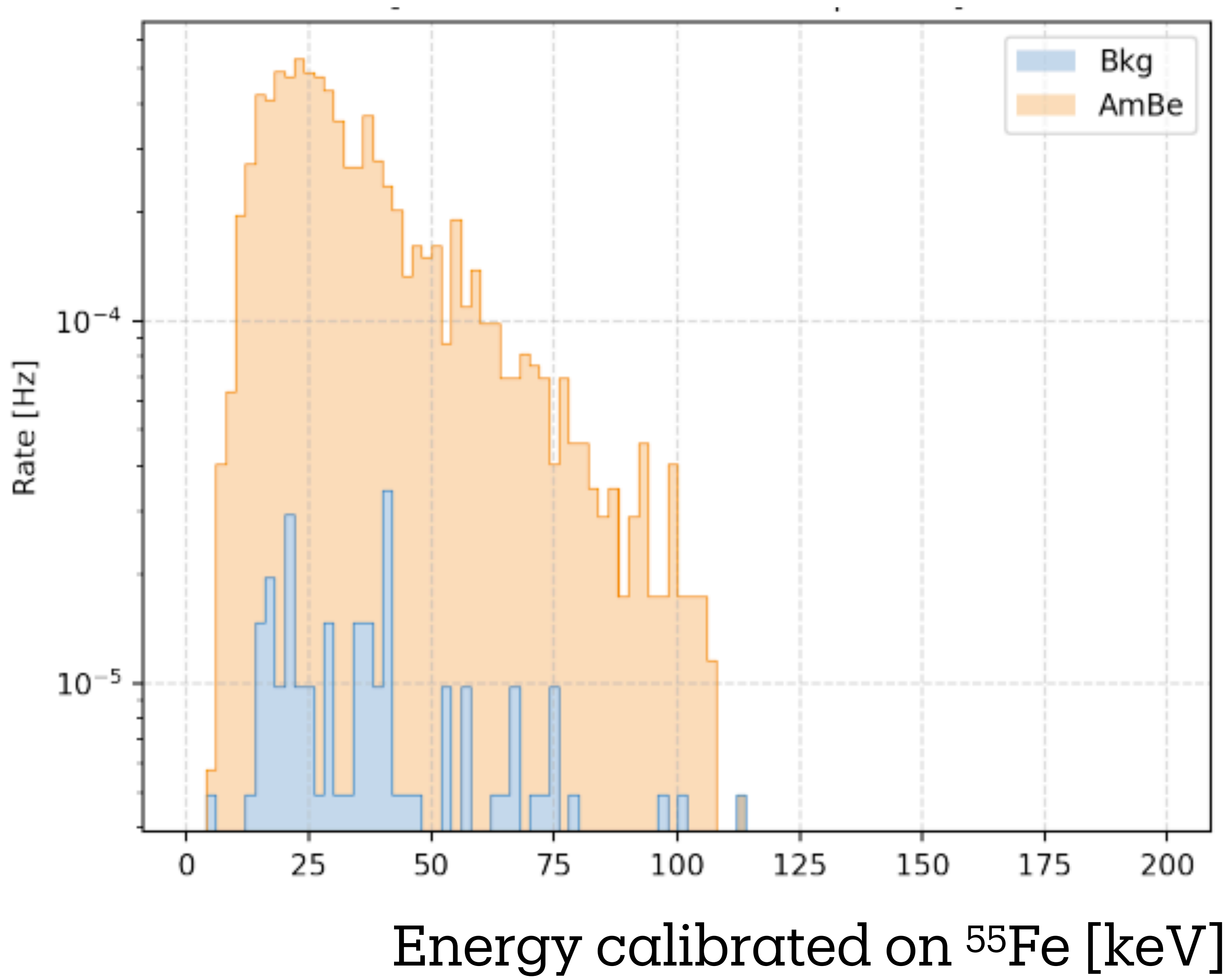
AmBe excess selection



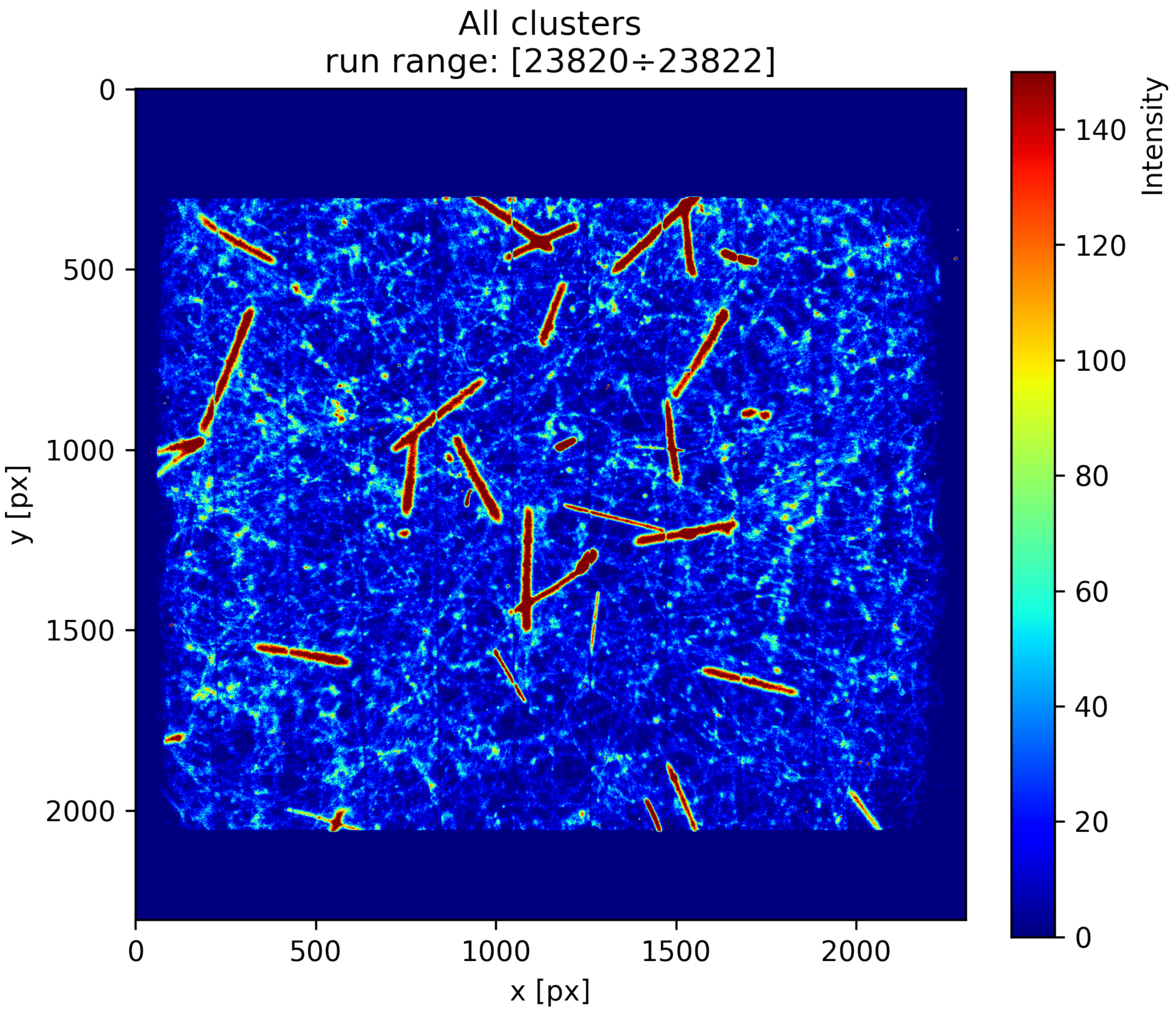


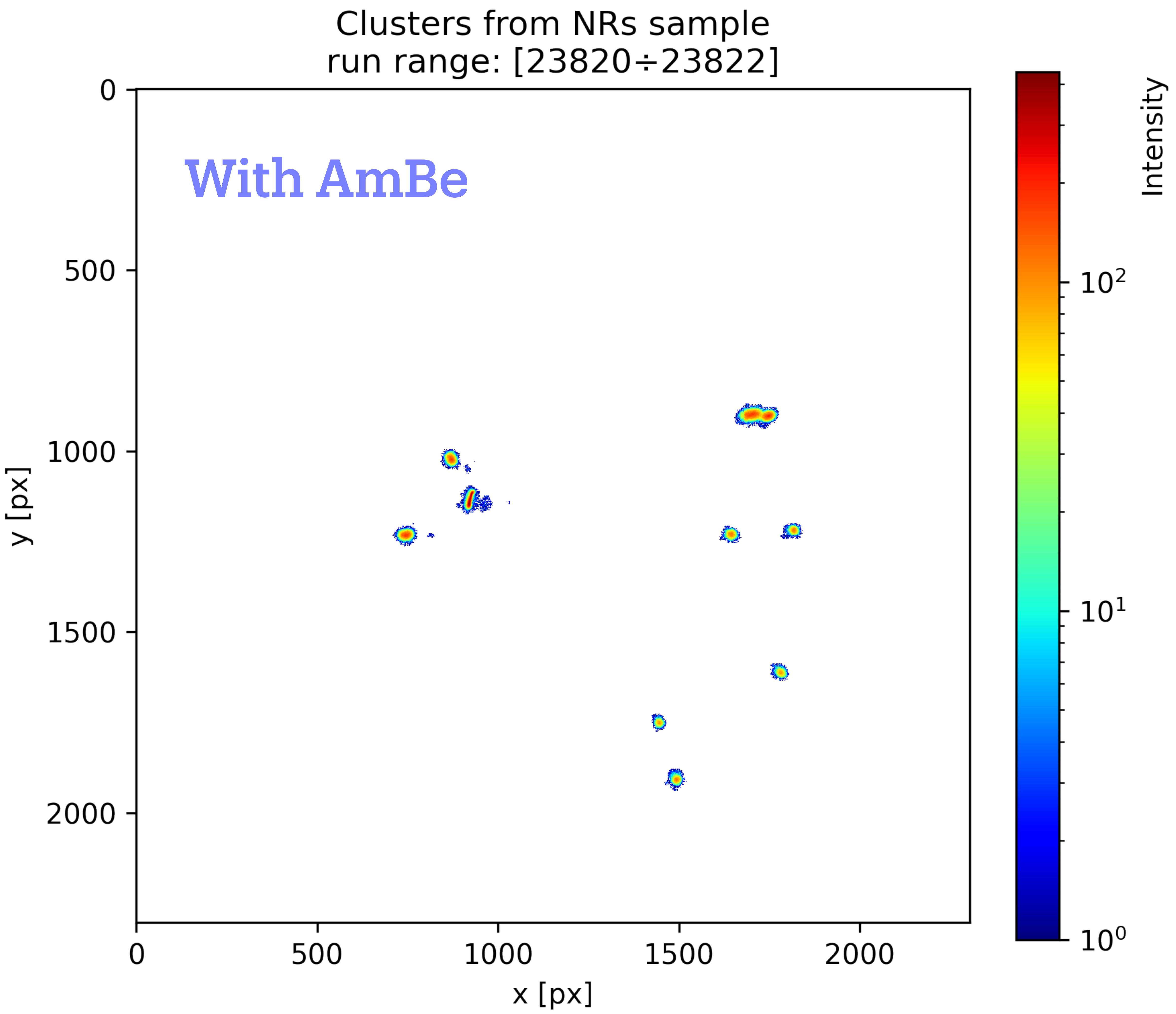
Because of the saturation, **alpha energies** appear 6-10 times lower the the real ones

Most of **NR** selected in this analysis are expected to have an **energy of few hundreds of keV**

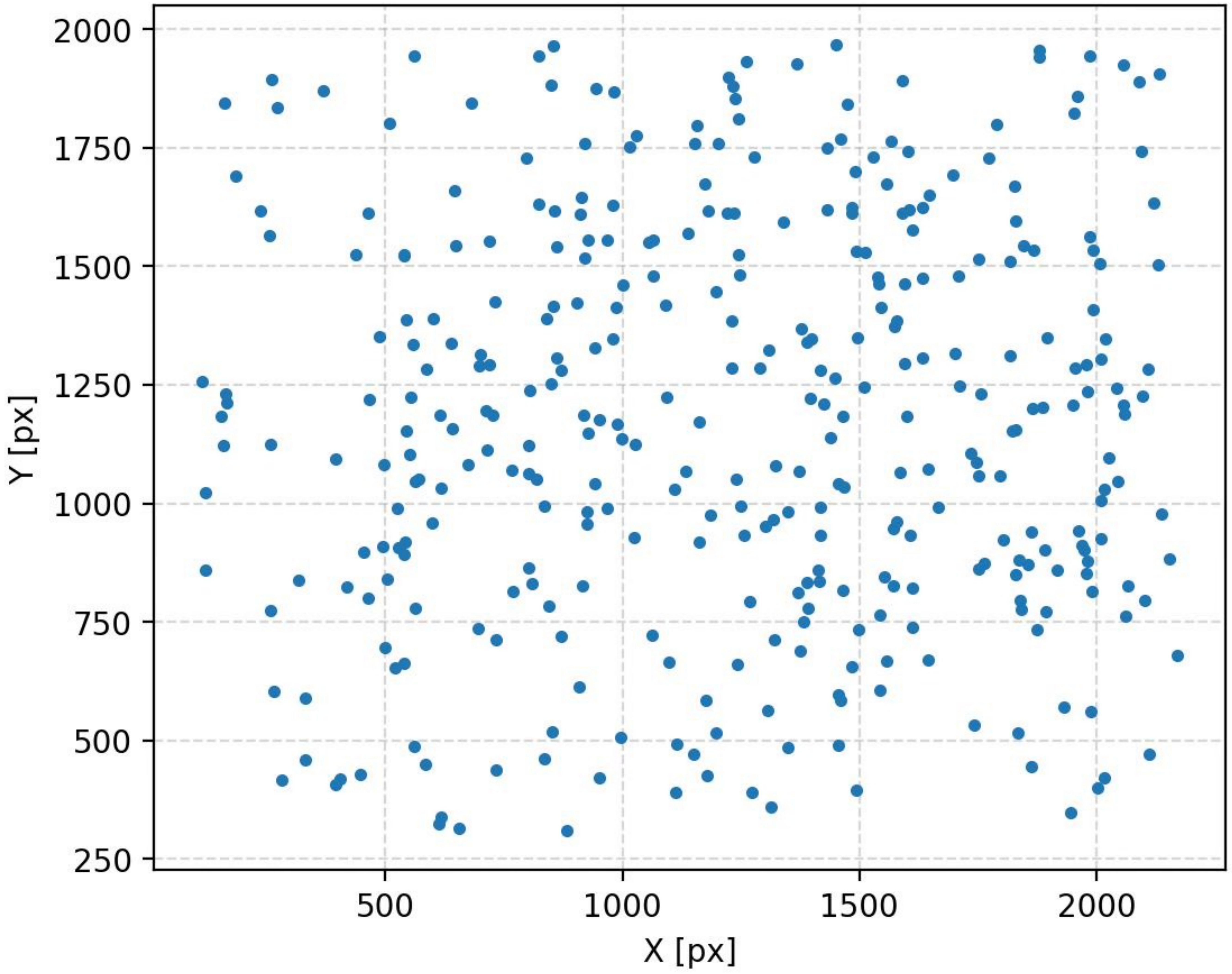
Simulation needed to properly evaluate these values

AmBe excess selection - Some samples





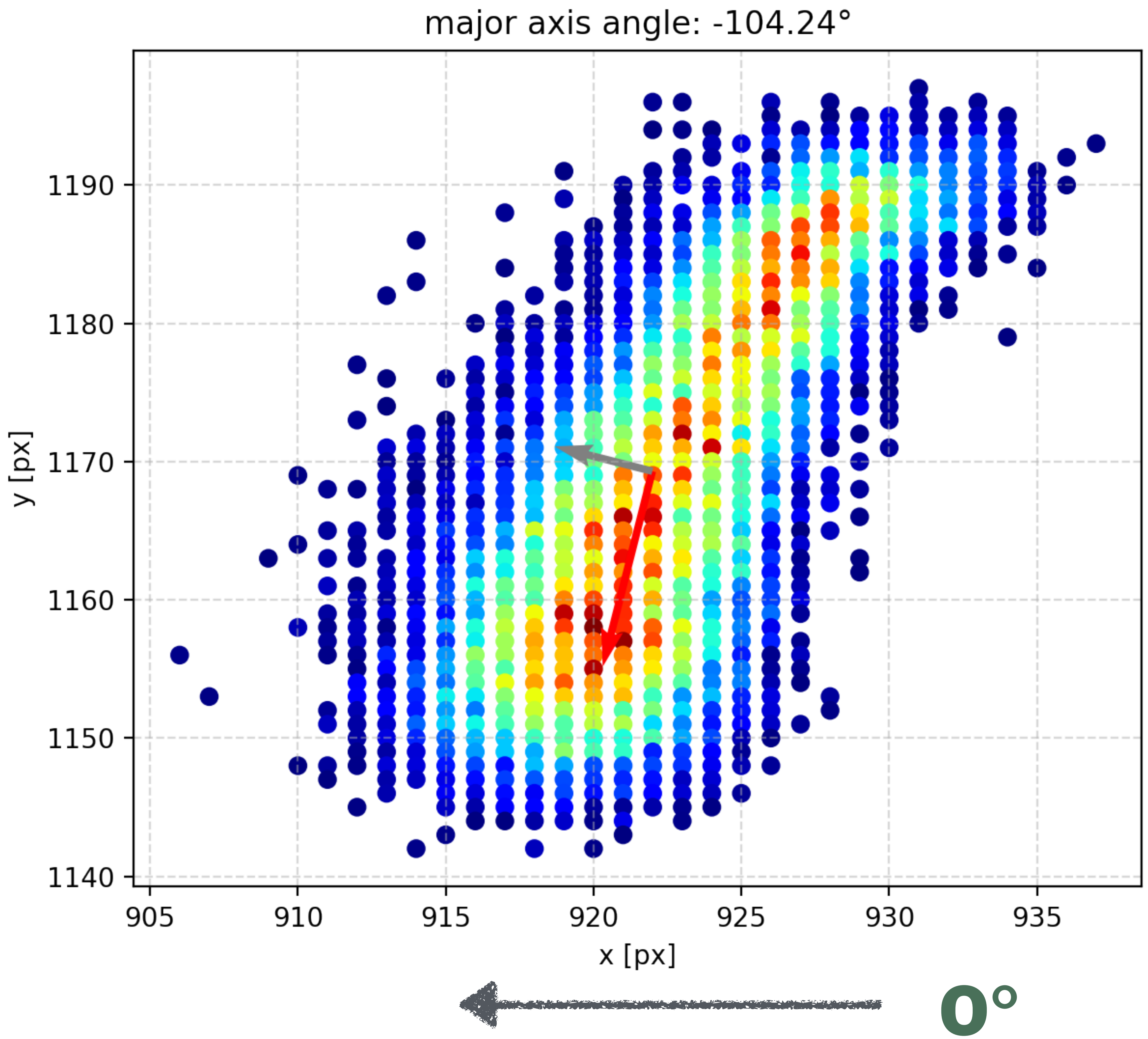
Map of AmBe Nuclear Recoils



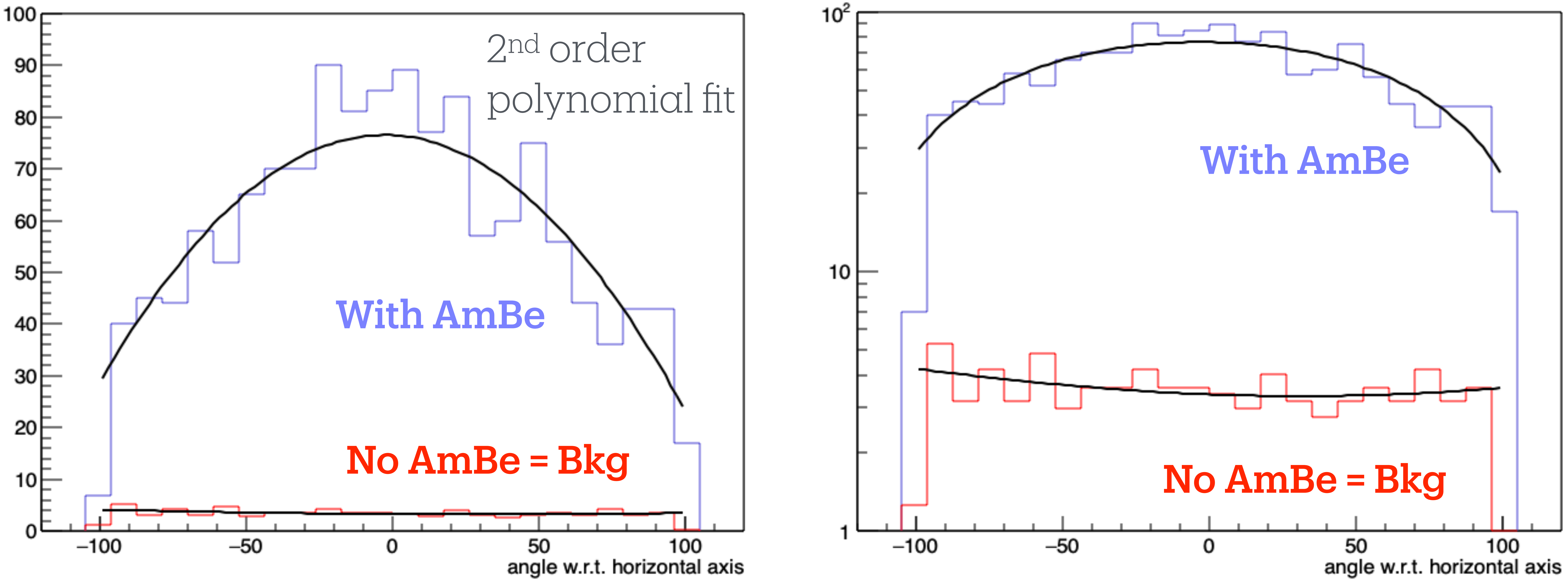
AmBe

Directionality evaluation

- Principal Component Analysis (**PCA**) with 2 parameters on the most intense part of the clusters to **extract the clusters' axes**.
- Use always the **biggest eigenvector** to compute the **angle with respect to the $\hat{x}$ direction**.
- A **better algorithm** was developed for ER and should be used on NR to take into account possible lateral straggling
- **Impose the head-tail**, since we know this excess comes from the AmBe source.
- Do the **same on the Background dataset and compare** to see if there are differences.



Directionality evaluation - AmBe vs. Bkg



The presence of AmBe source produces an excess of **Nuclear Recoil candidates**;

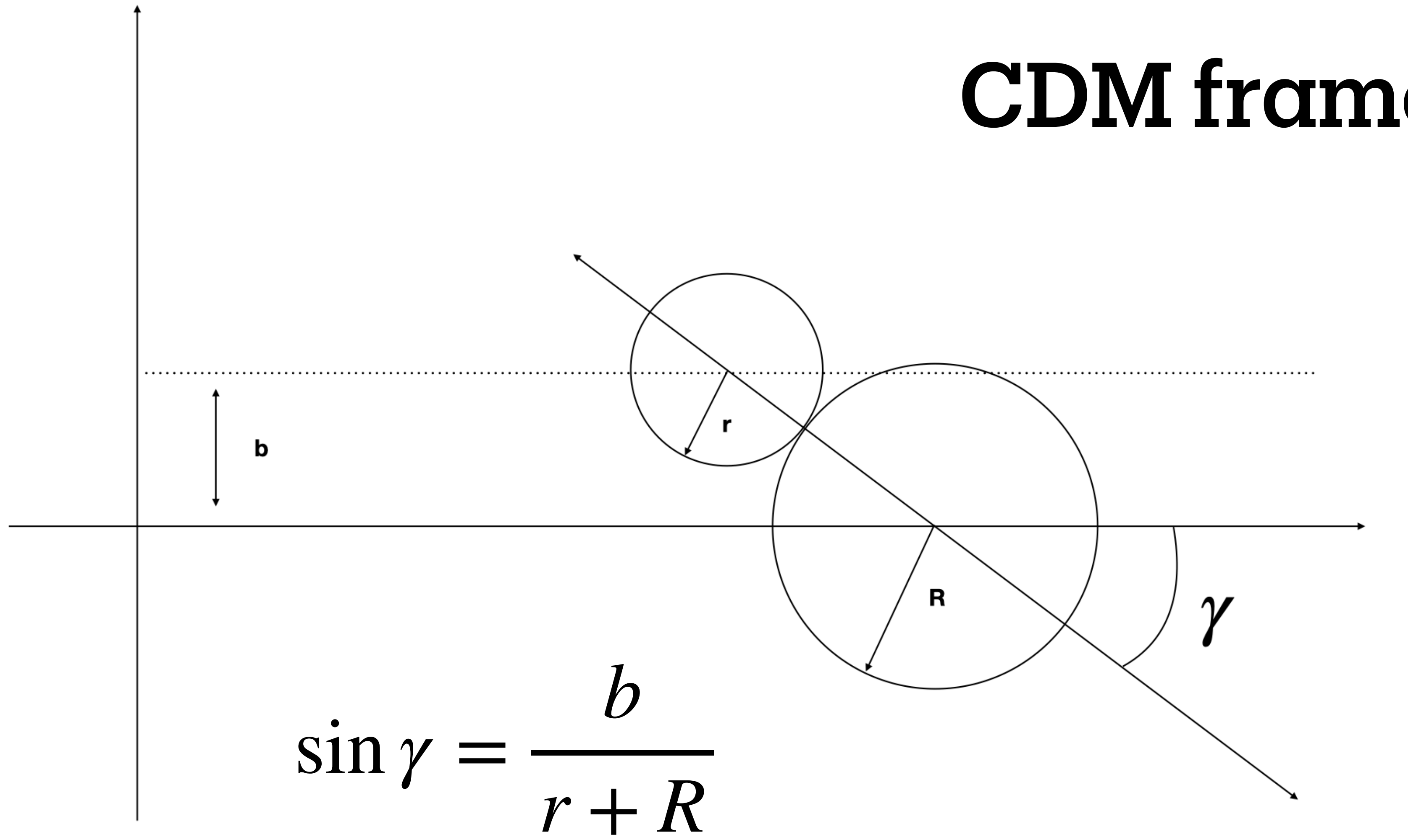
A simple 2^{nd} order polynomial fit shows that **background** is compatible with **flat distribution** while the presence of **AmBe** produces a **peaked distribution**;

Monte Carlo validation

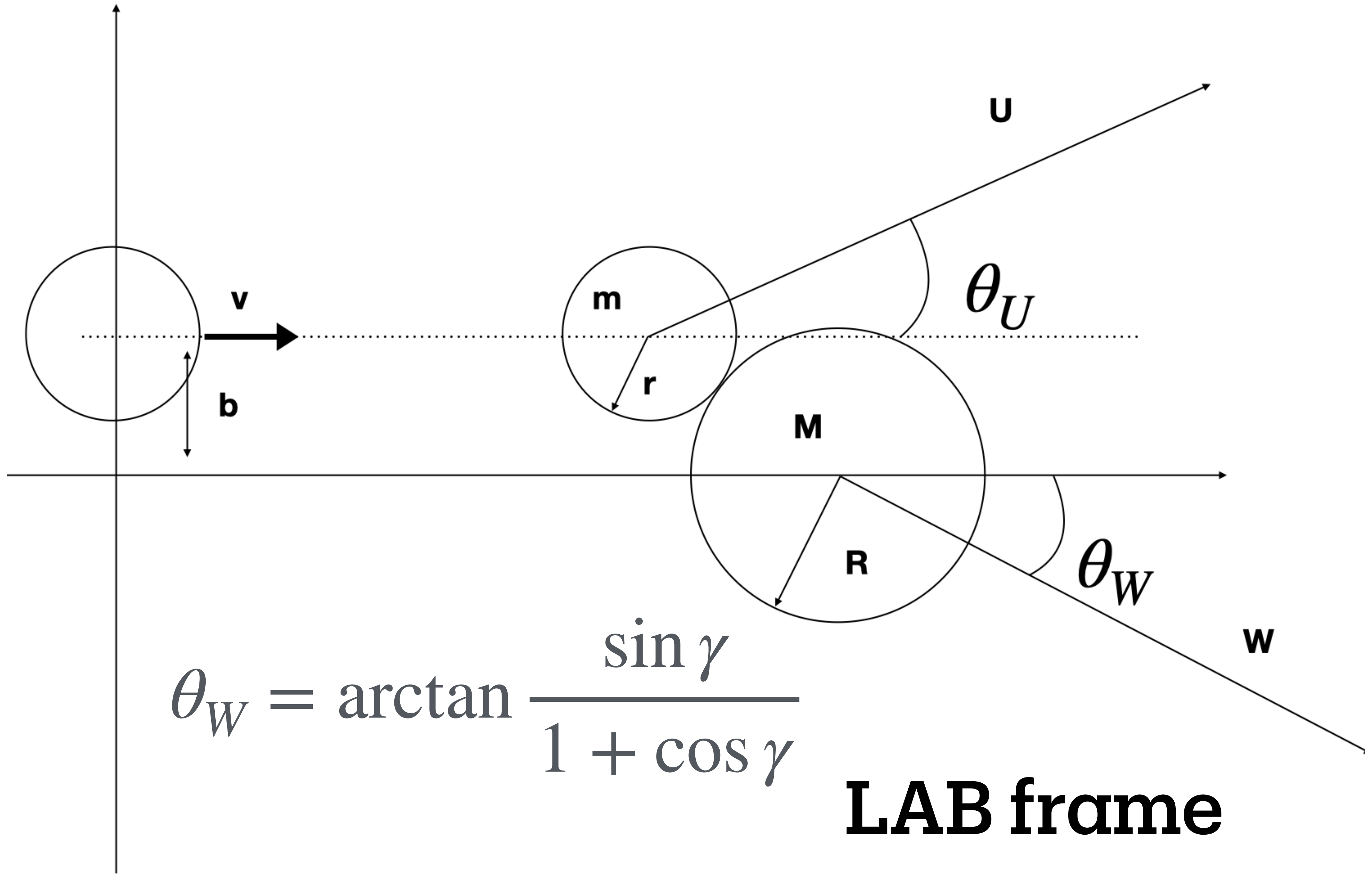
To evaluate the expected 1D angle distribution for NR induced by the neutron scattering, a simple kinematic MC was developed

- Model the interaction as a **simple elastic scattering**.
- **Simulate nuclear recoil** inside the detector frame.
- Project the angle on the GEM plane and **compare with the observed distribution**.
- Add an experimental **resolution on the angle reconstruction**

CDM frame



$$\sin\gamma = \frac{b}{r+R}$$



$$\theta_W = \arctan\frac{\sin\gamma}{1+\cos\gamma}$$

LAB frame

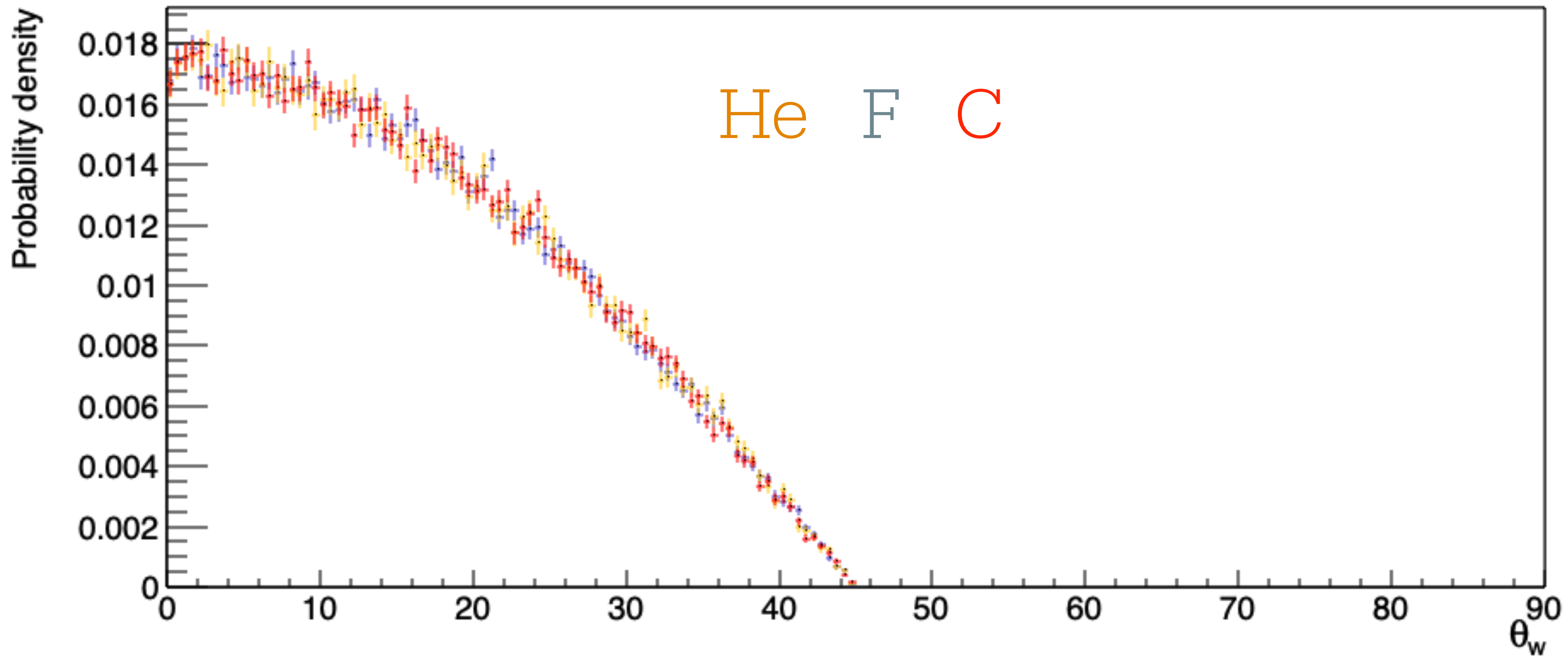
Monte Carlo validation

The scattering angle in the Lab frame is $\theta_W = \arctan \dfrac{\sin\gamma}{1+\cos\gamma}$

Where $\sin\gamma = \dfrac{b}{r+R}$ depends on the impact parameter and the sum of the radii;

By assuming an uniform distribution for b it is possible to evaluate the distributions for θ_W for the different nuclei, assuming $r = 1$ and $R = \sqrt[3]{A}$

The PDF of the θ_W for the different species **do not depend on the nucleus radius** (while, the cross section and the transferred momentum do)



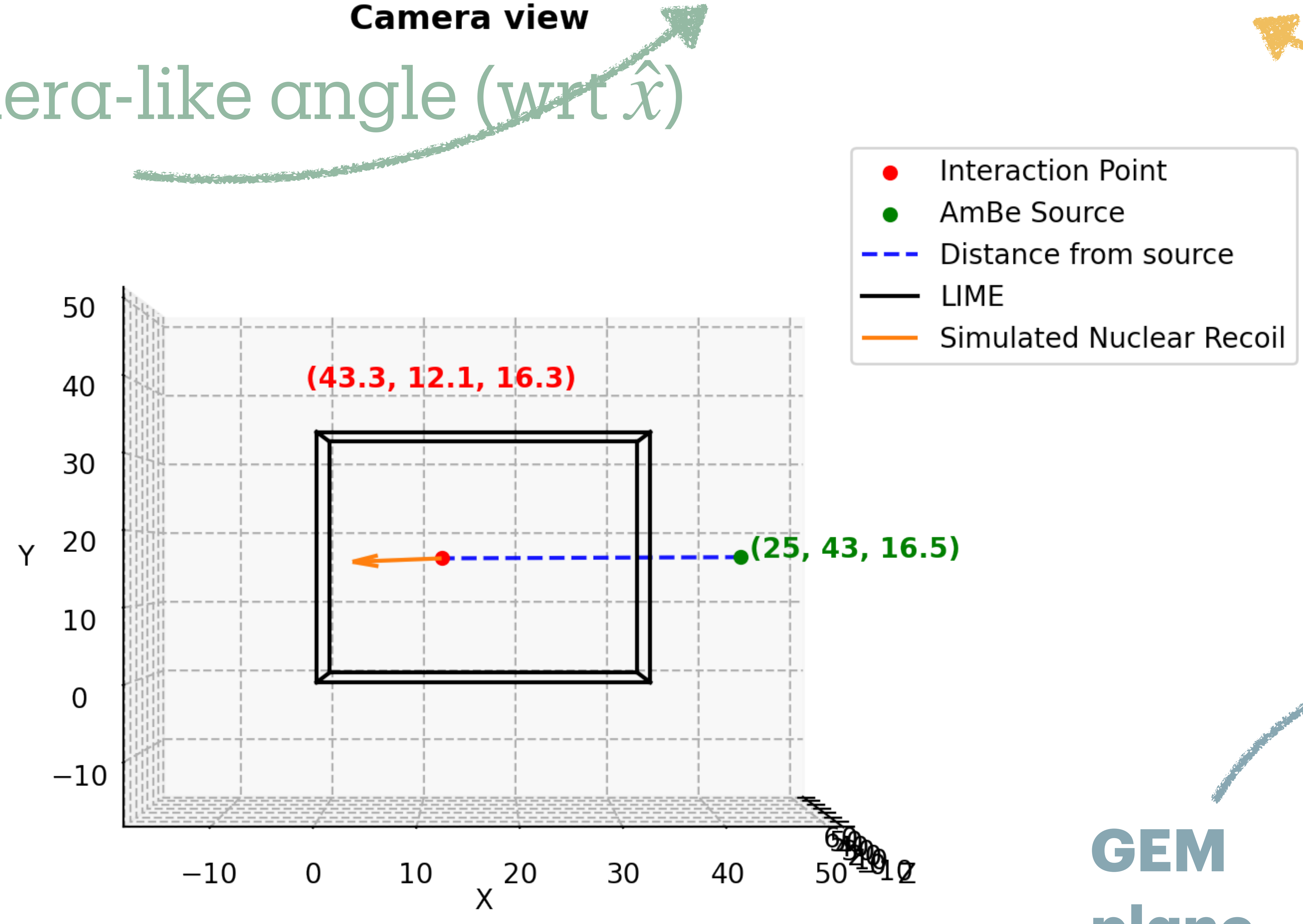
MC validation - 3D simulation

$\varphi \in [0, 2\pi]$ flat

Simulated nuclear recoil with θ = -13.5° and φ = 191.2°
Angles: XY: -177.00°, ZX: -72.68°, ZY: -9.53°

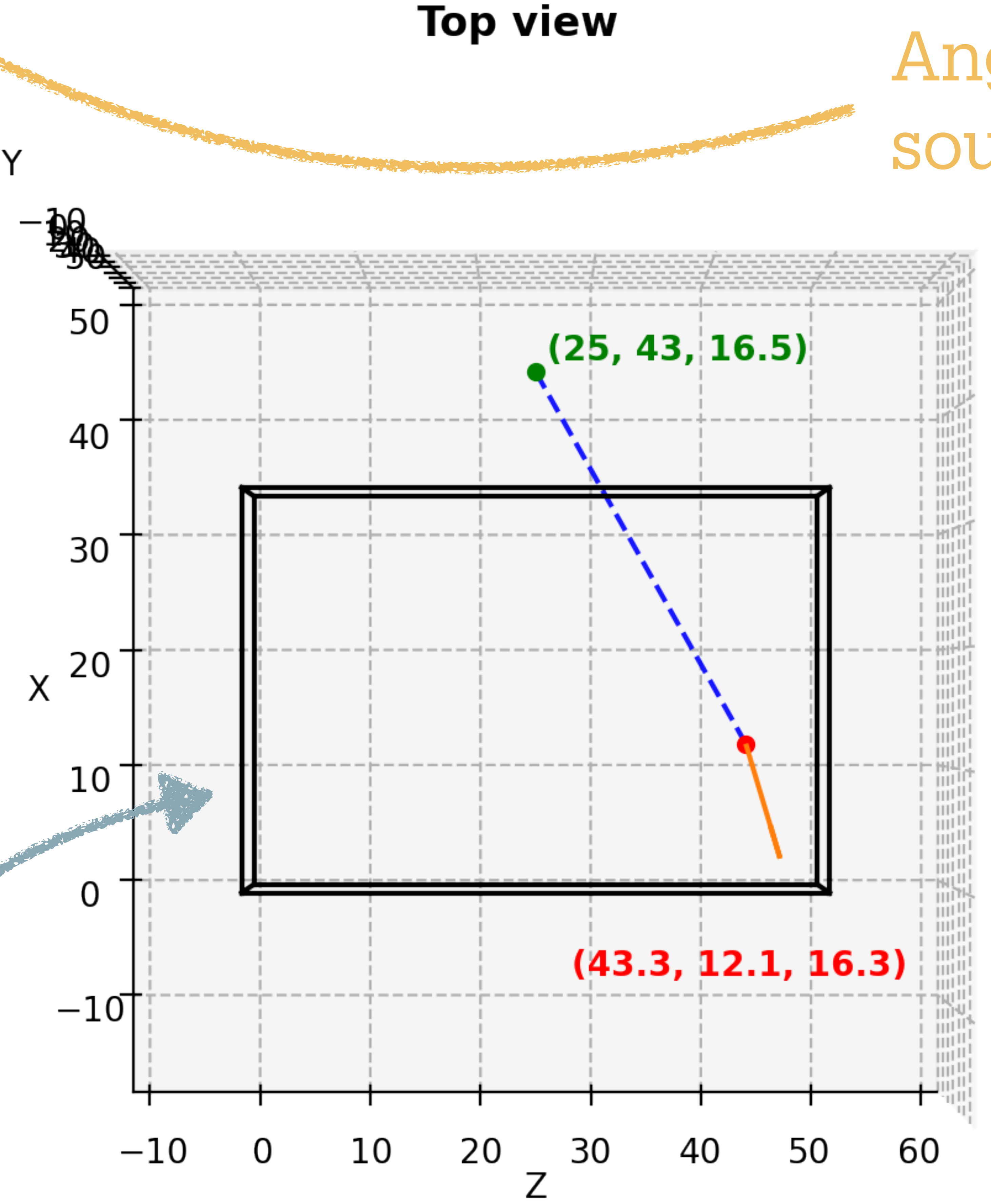
Camera-like angle (wrt $\hat{x}$)

Angle wrt source wall



lateral view

GEM plane

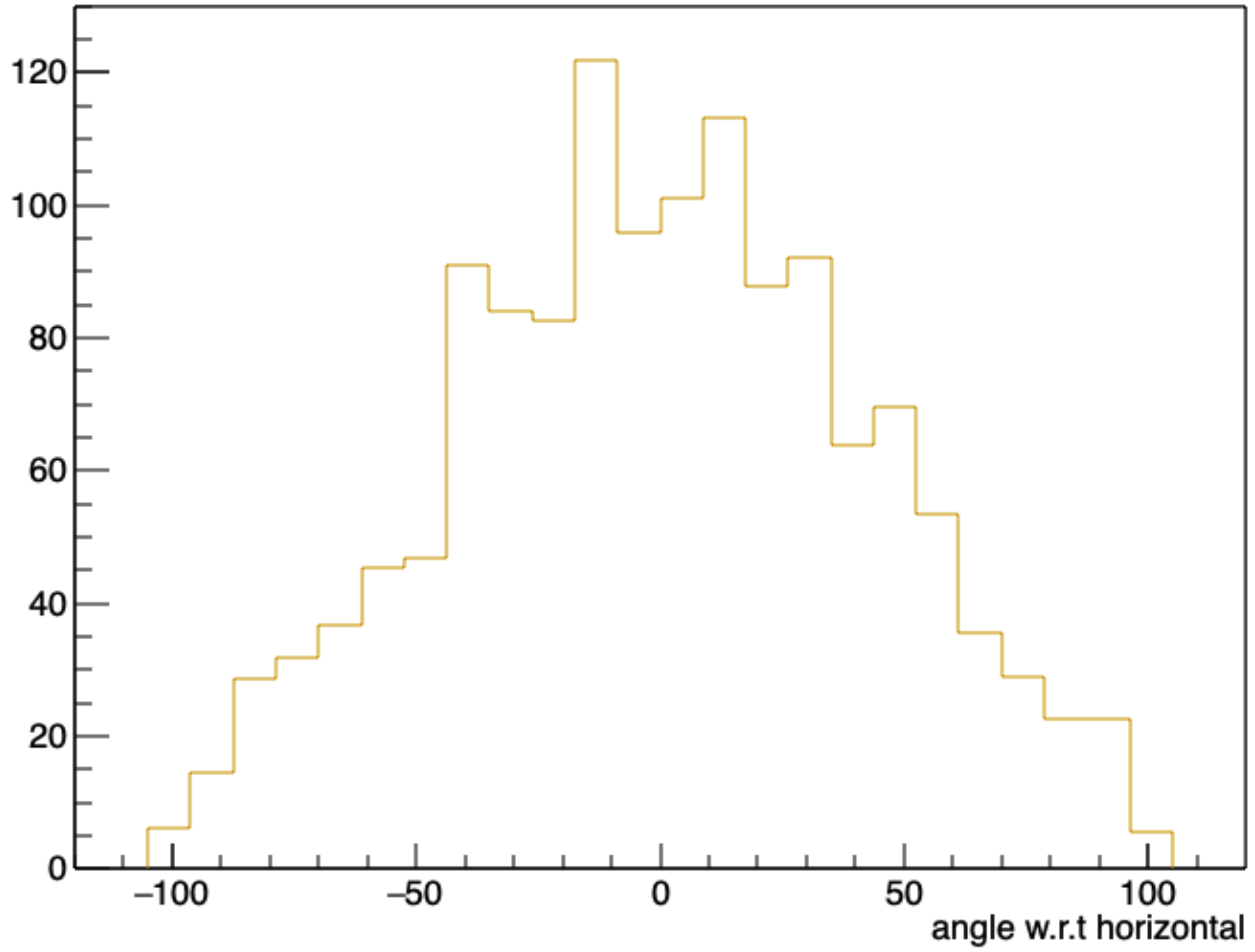


from below

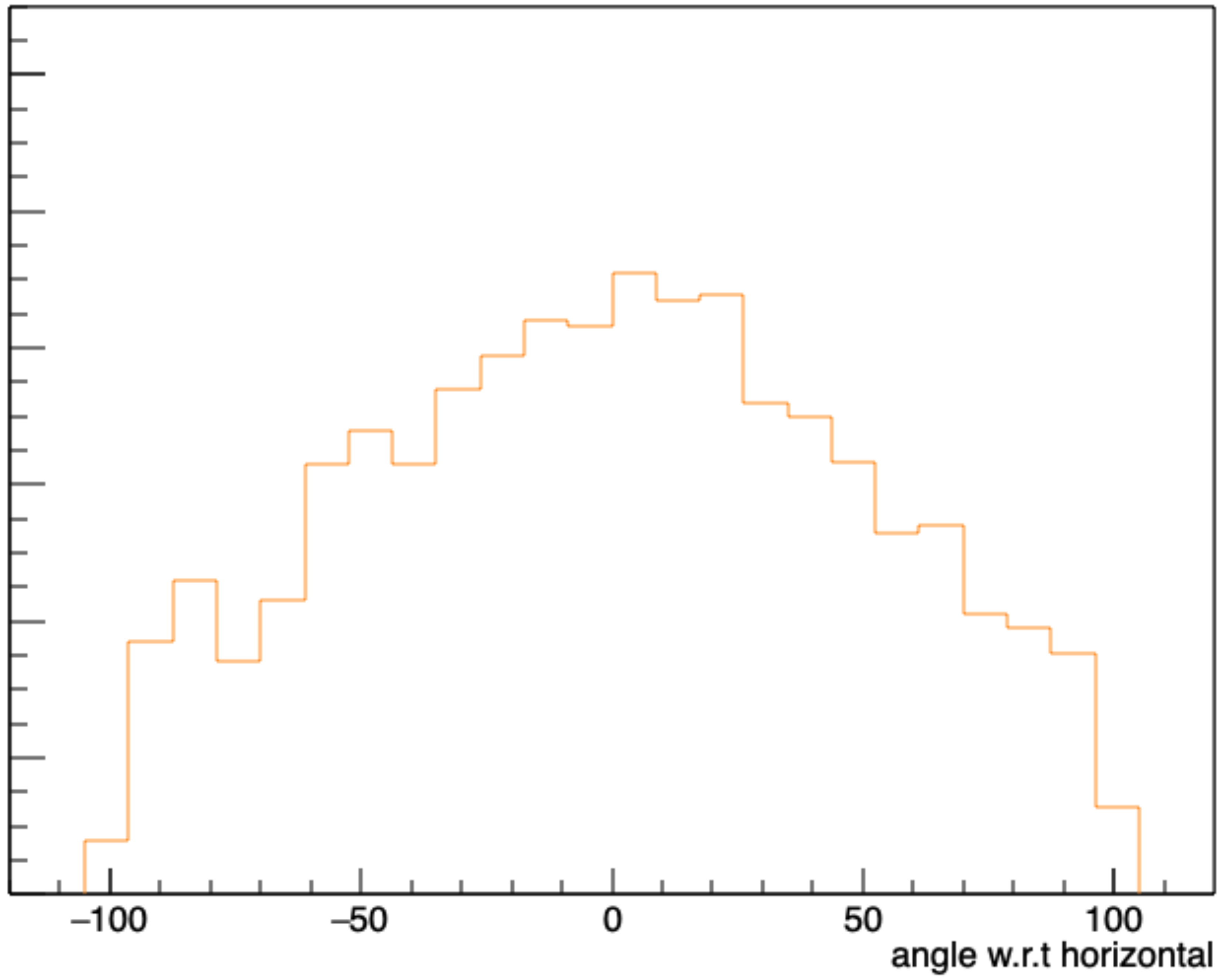
Monte Carlo validation

With an simulated **resolution on the angle reconstruction of 30°, 45° and 60°** we found the distributions below

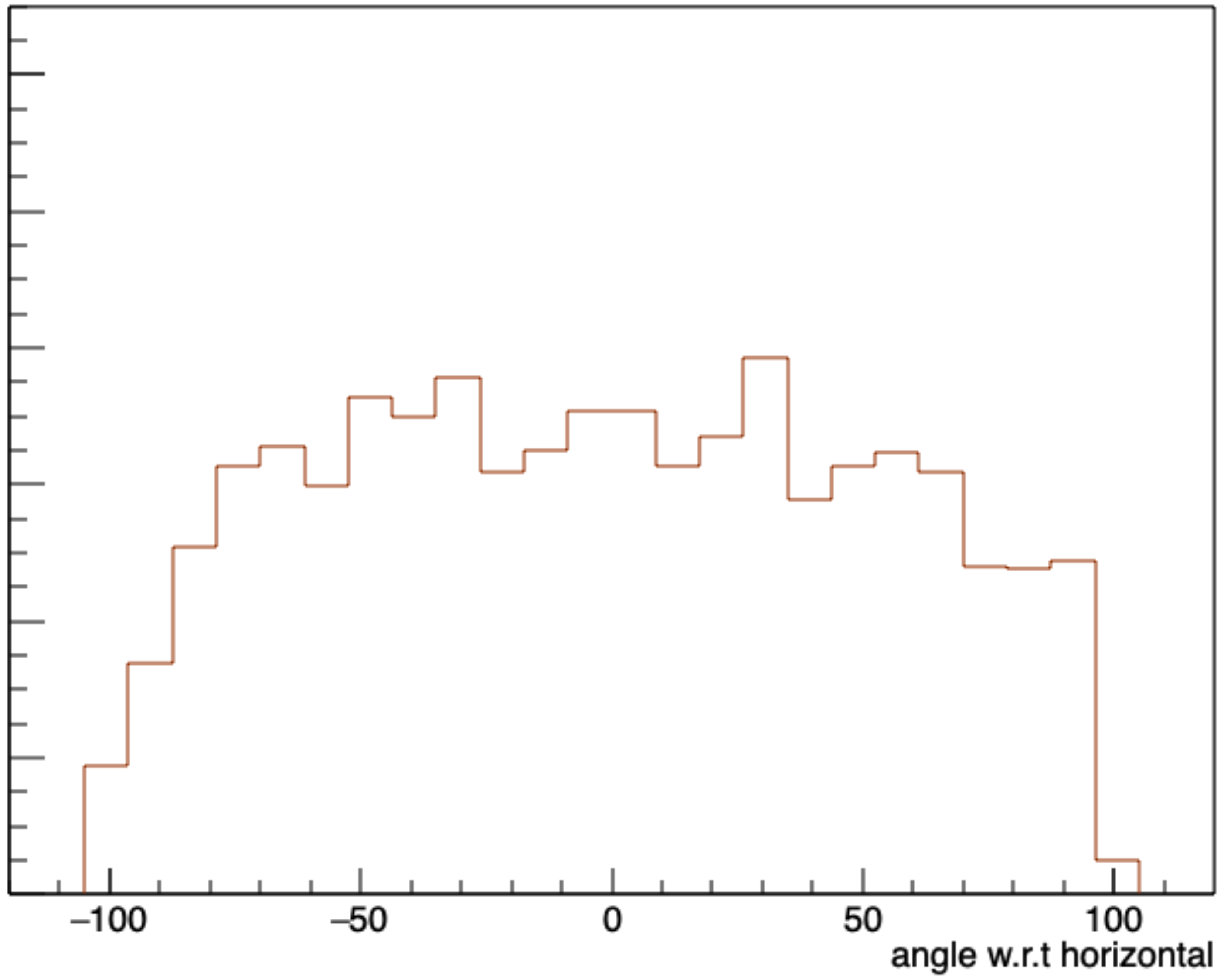
MC AmBe (30°)



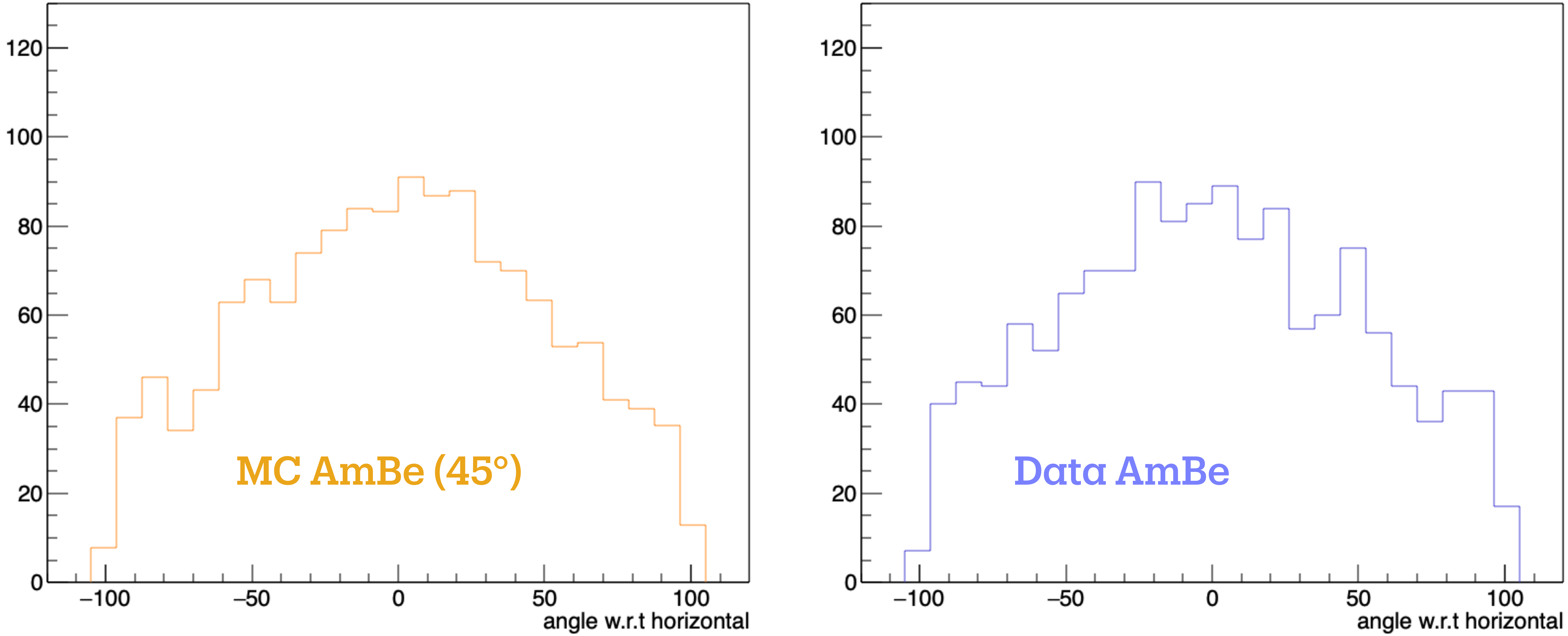
MC AmBe (45°)



MC AmBe (60°)



Monte Carlo validation



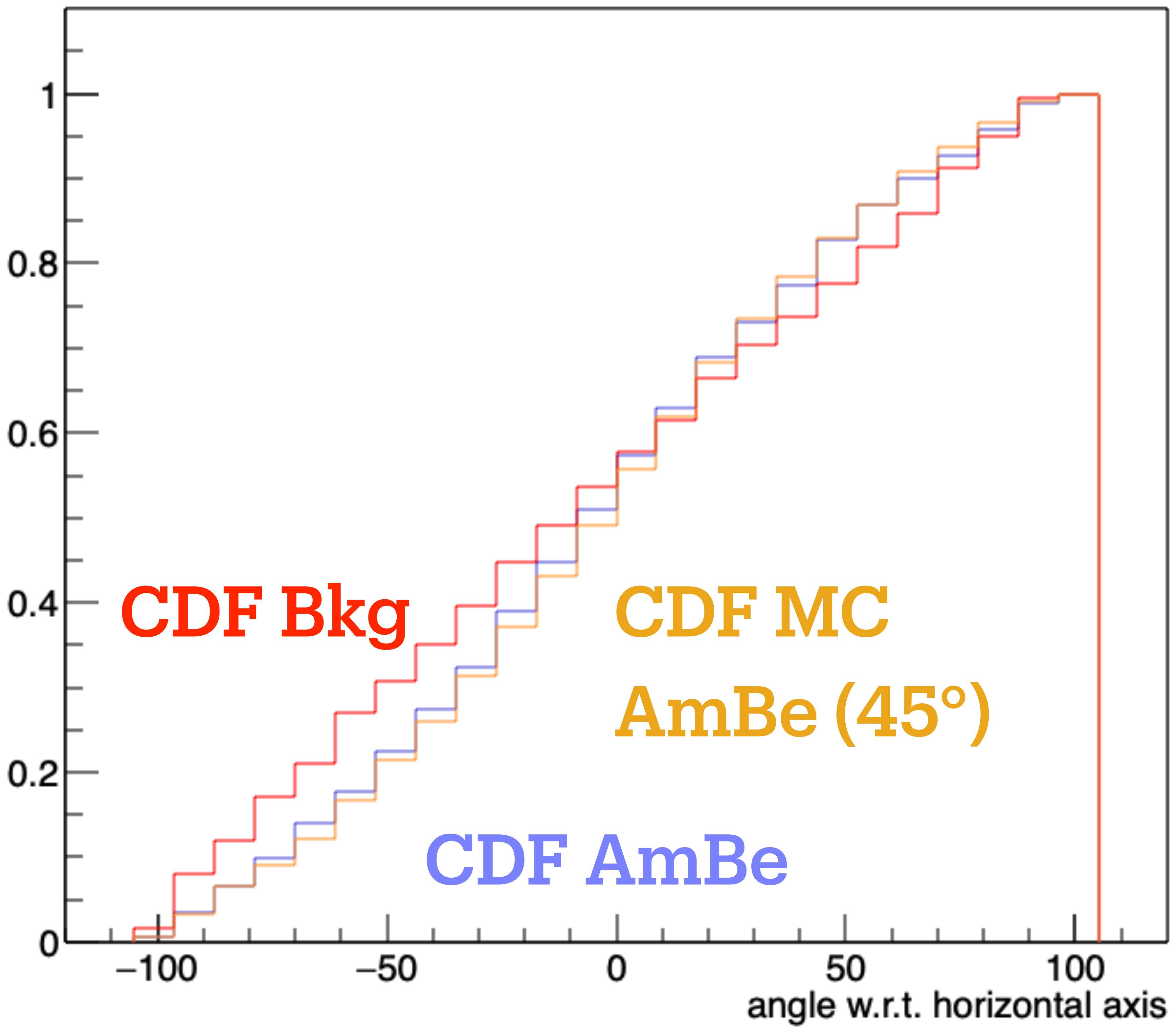
With an experimental **resolution on the angle reconstruction of 45°** a reasonable agreement was found

Directionality evaluation - KS test

- To study the compatibility between the two samples, the **Kolmogorov-Smirnov Test** was used;

- Based on the **maximum distance** between the **cumulative distribution functions (CDF)**, it returns a pValue indicating the **probability that the two samples are extracted from the same PDF**;

Samples	pValue
AmBe - Bkg	0.010
AmBe - MC(30)	0.001
AmBe - MC(45)	0.964
AmBe - MC(60)	0.138
Bkg - MC(45)	0.003



Conclusions

First RUN with **AmBe** (Aug 2023) lasted about **48 hours**: **1388 NR candidates** were identified, to be compared with **384 in a longer data-taking without source**;

The distribution of their **angles reconstructed** with a **simple PCA** performed on the saved clusters is:

- different for the AmBe and bkg neutron, indicating a **clear sensitivity to the NR direction**;
- a **direction resolution** of about **45°**;

A new longer run is undergoing:

- **increase statistics** (2 weeks of data taking);
- upgrade the **selection** to go deeper in energy (in the ER see);
- exploit more sensitive algorithms for **original direction reconstruction** ;
- perform a **complete MC of the setup** for data comparison;