Thesis work summary

Luca Zappaterra, Davide Pinci, 25th July 2024

Table of contents

1. Data pre-processing

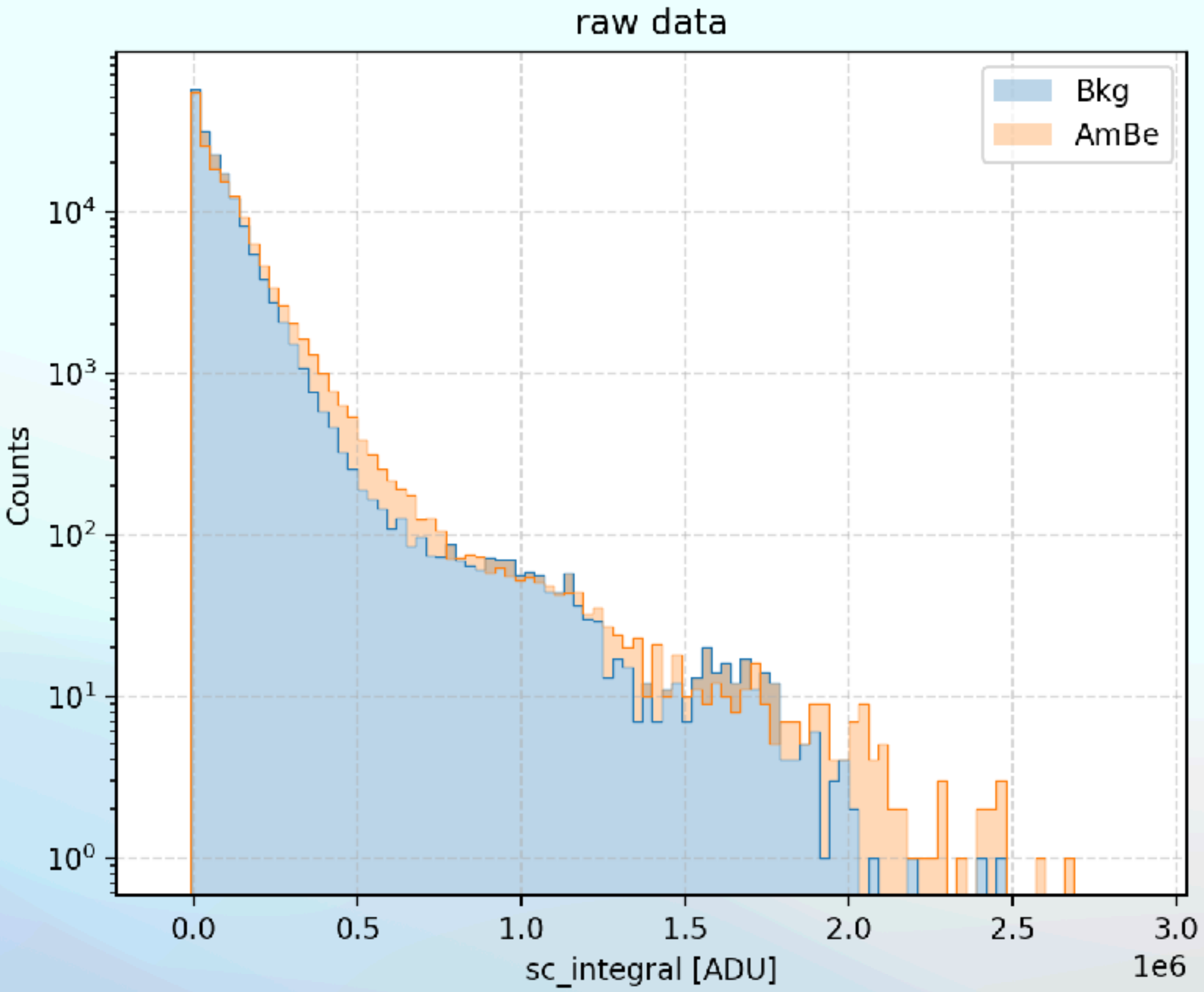
1. Datasets infomation

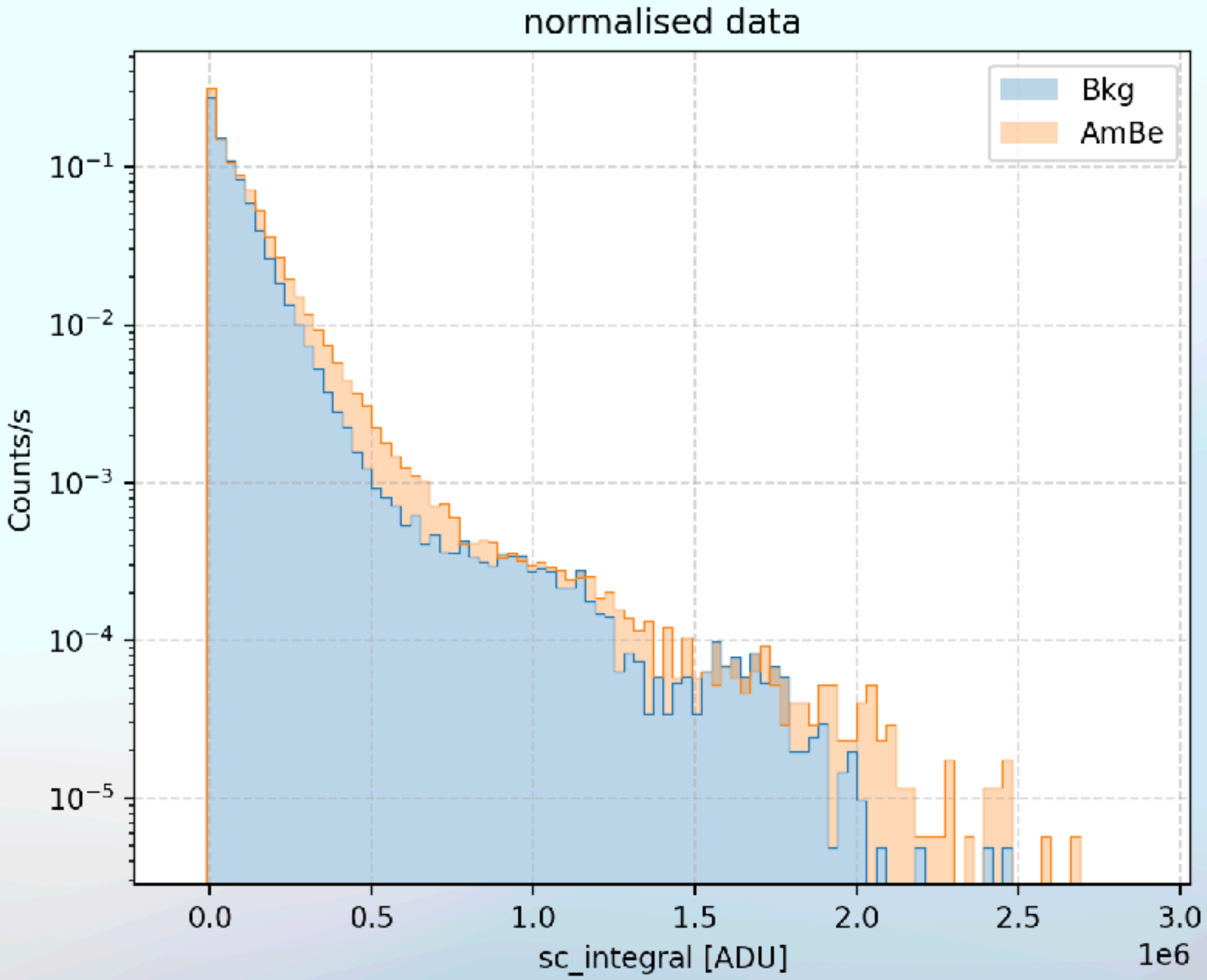
Alias	Runs range	Date range [mm/dd]	Eff. Exposure [h]
AmBe_p1	23820 ÷ 23984	08/02 ÷ 08/03	16.9
AmBe + Fe	23988 ÷ 24022	08/03 ÷ 08/03	2.1
AmBe_p2	24023 ÷ 24328	08/03 ÷ 08/04	31.0
Stability	25486 ÷ 25772	09/26 ÷ 09/29	10.5
Bkg	27322 ÷ 27844	10/07 ÷ 10/10	56.6
Bkg_stability	27512	10/09 ÷ 10/09	–

- **AmBe_p1 + AmBe_p2 = AmBe from now on**

1.1. Normalisation

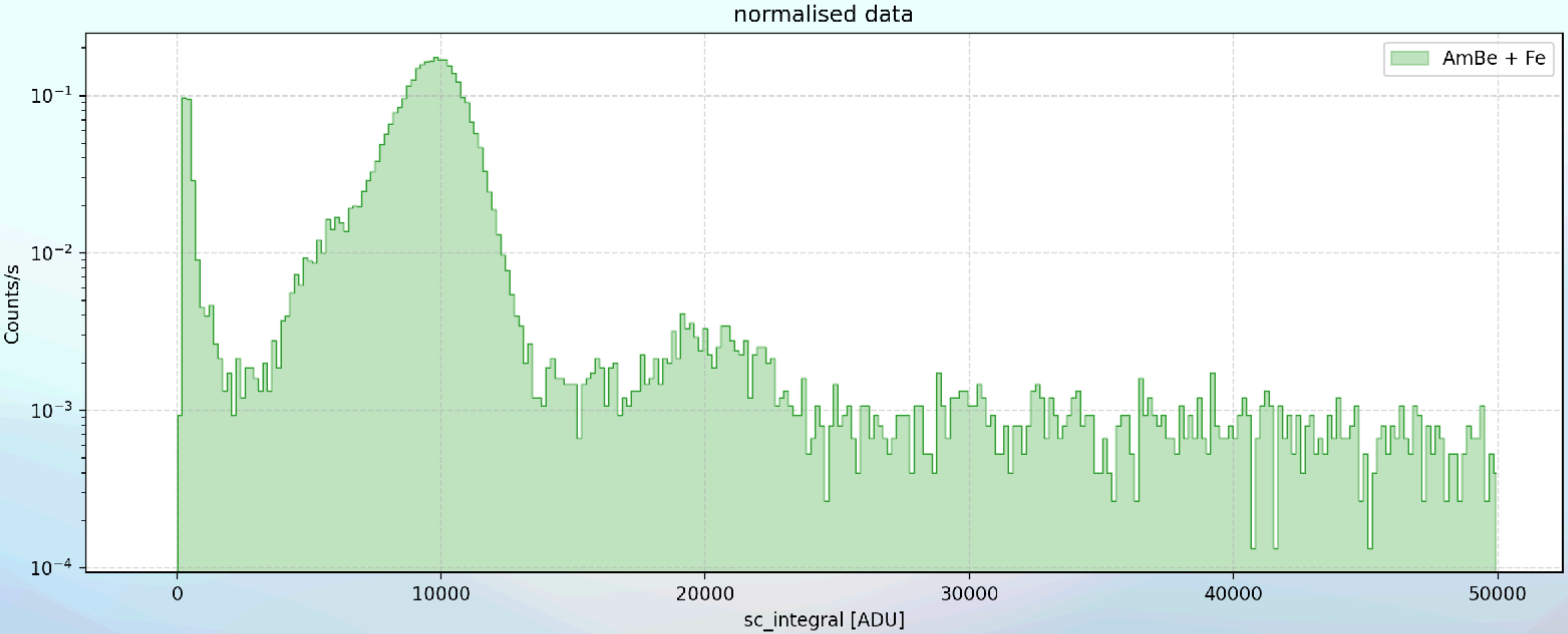
- Normalisation is performed **dividing for the total time of the considered runs**.





1.1. Normalisation

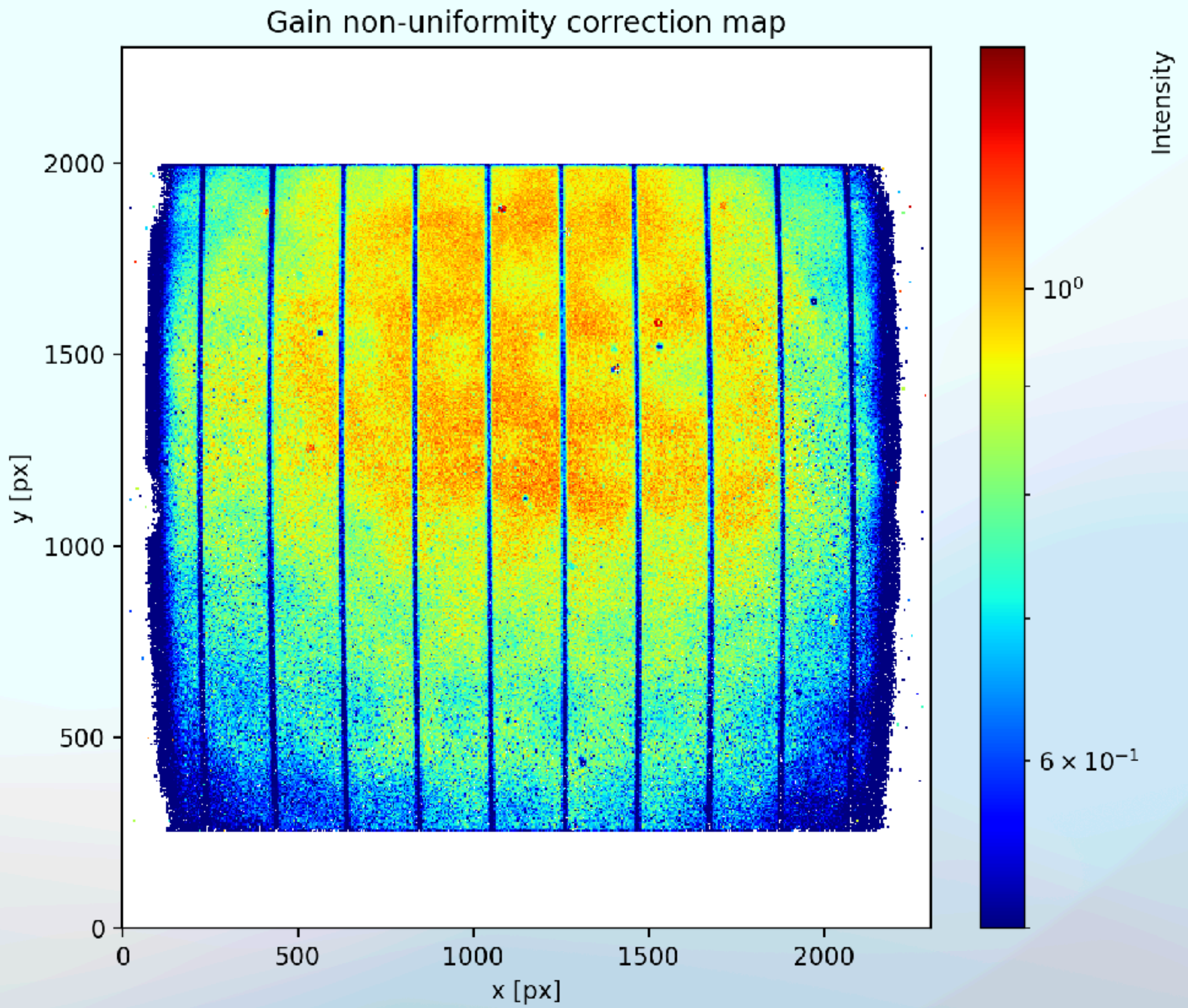
- An idea of the energy scale is given from the AmBe+Fe normalised spectrum



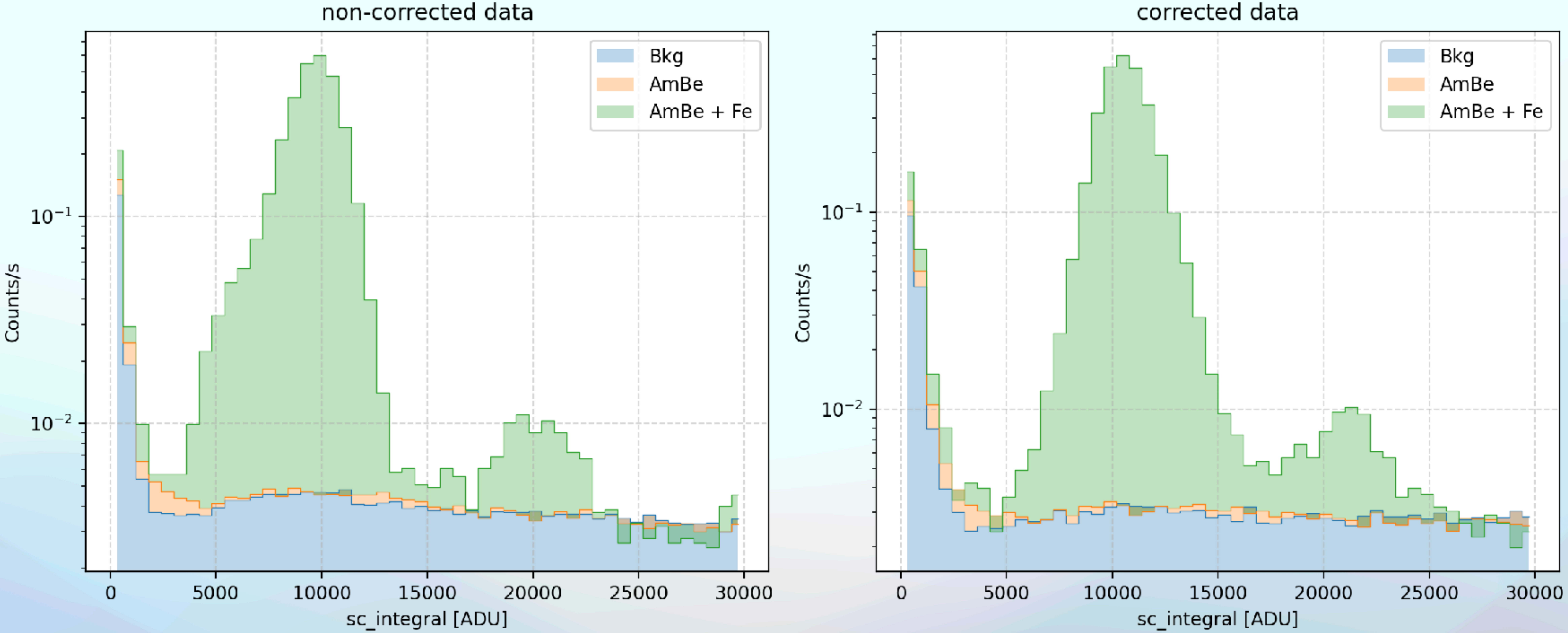
X

1.2. Gain non-uniformity correction

- Since **we experience gain non-uniformity** inside the detector we should correct for this using the correction map provided form Davide.

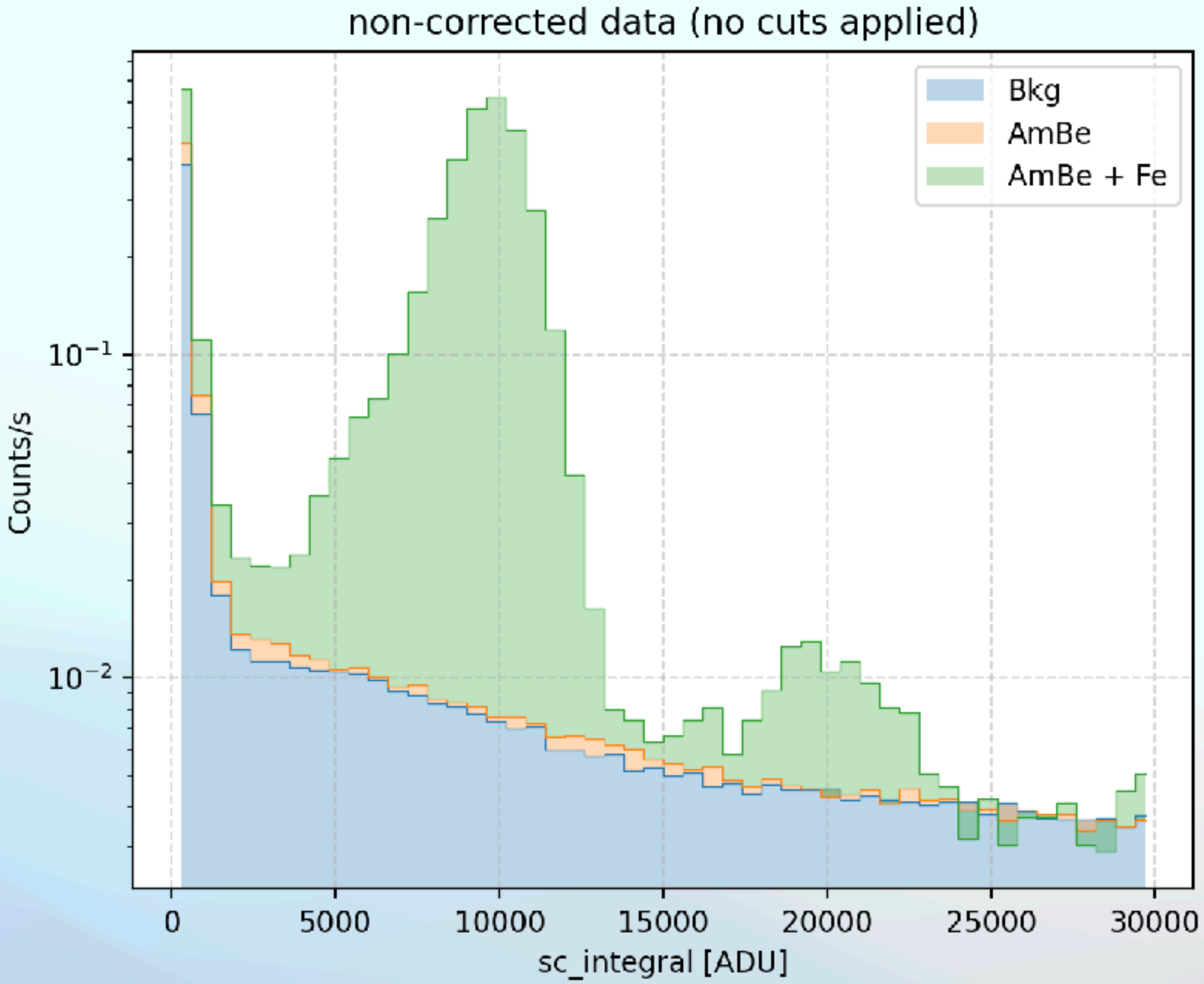


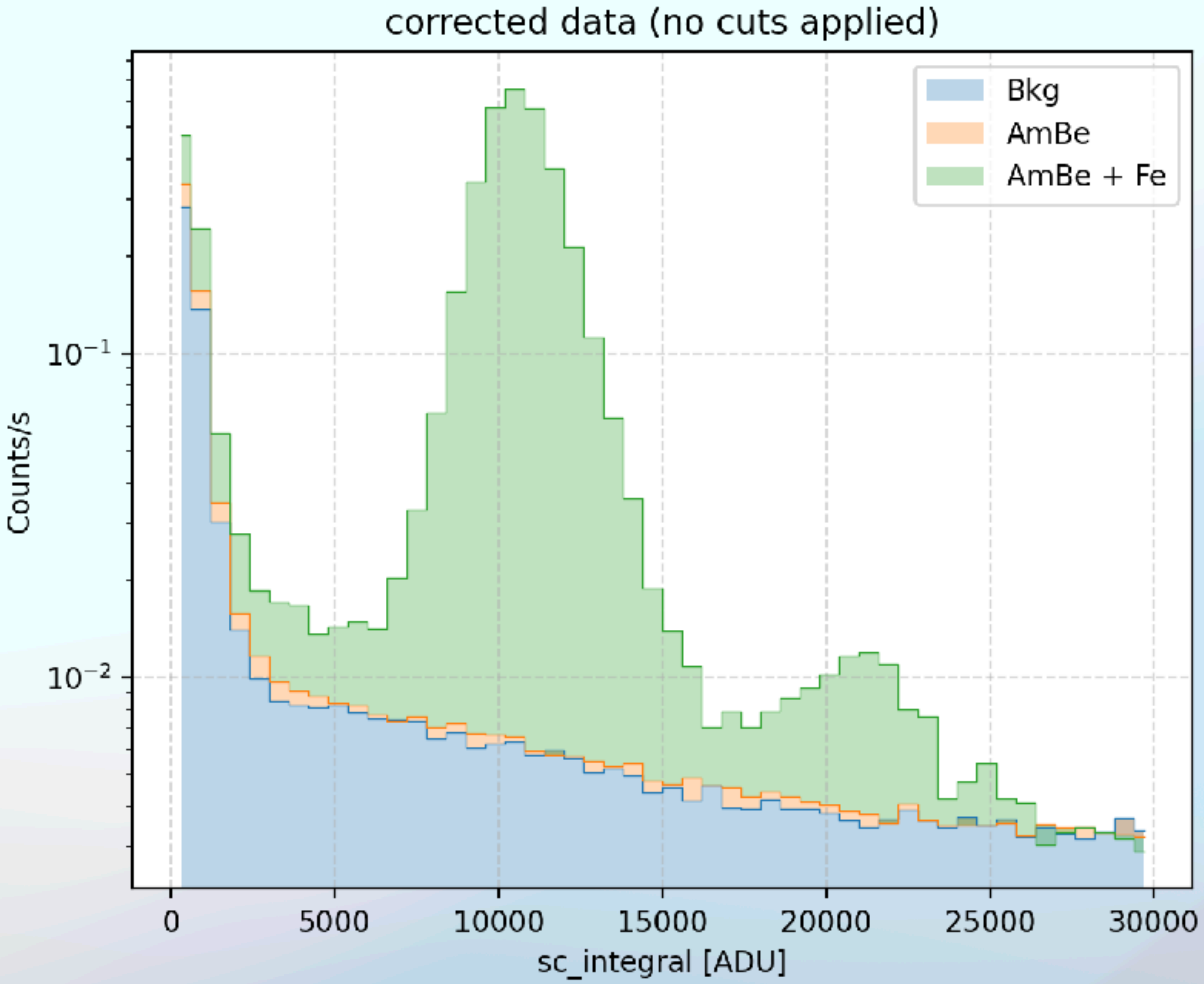
1.2. Gain non-uniformity correction



SIDENOTE: border cuts

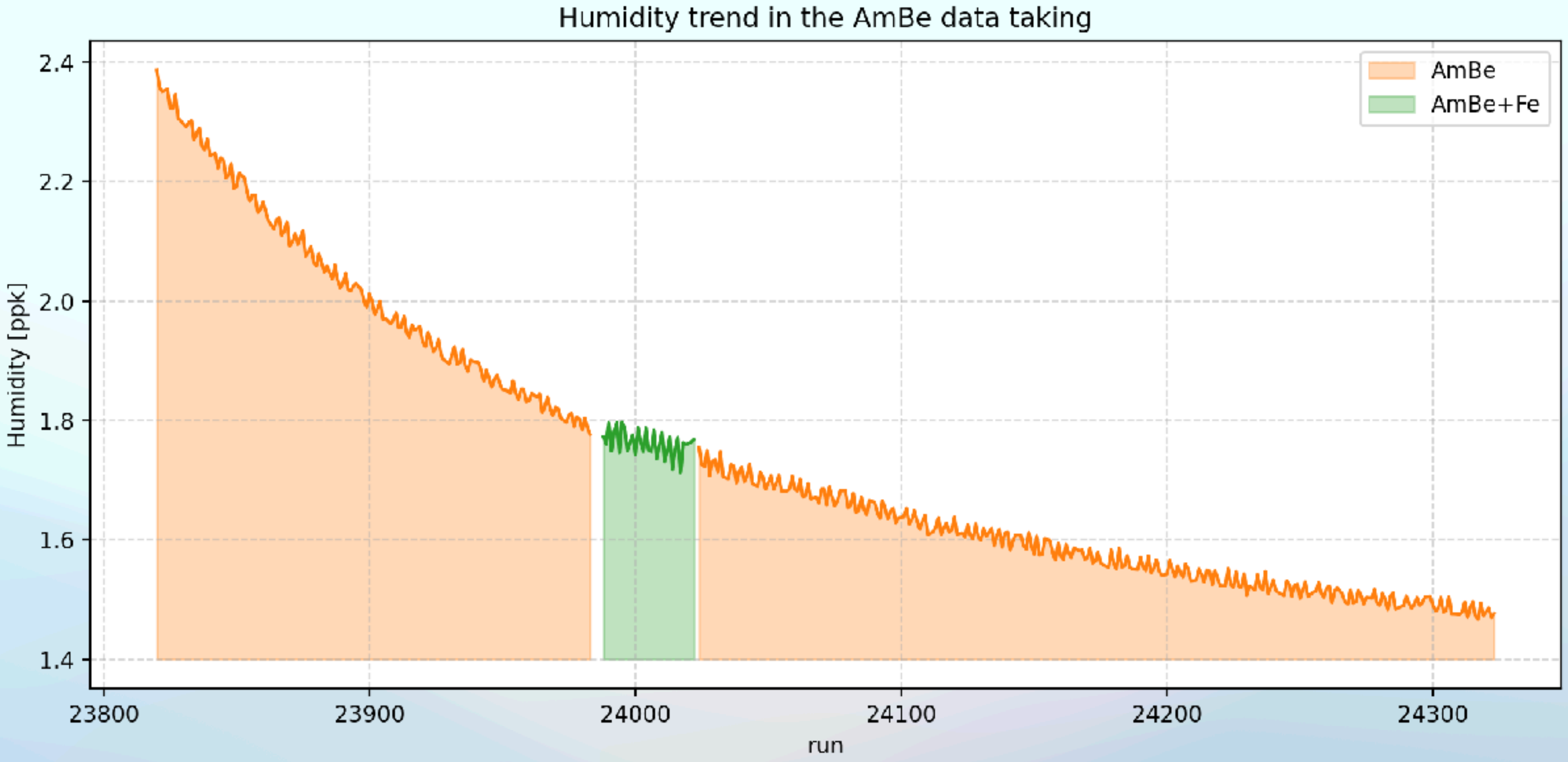
- Removing sufficiently short clusters on borders is imperative, it is particularly evident with Iron source: the cut efficiently removes the excess around 5k ADU.





1.3a. Humidity trend during AmBe

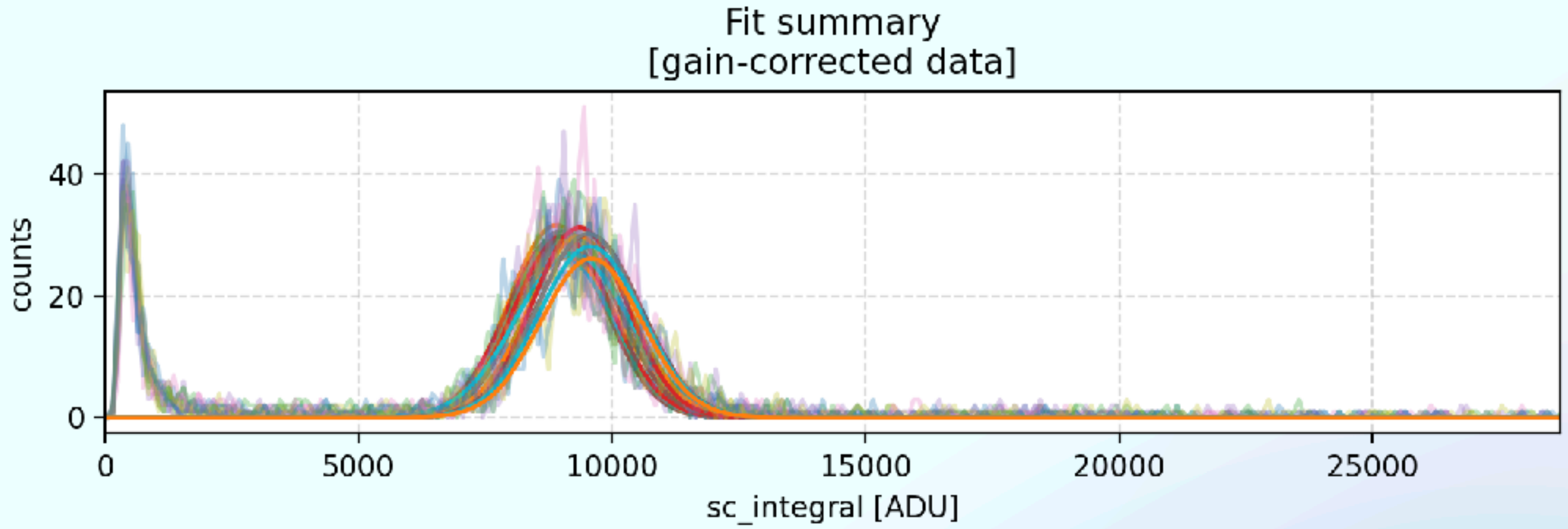
- Humidity was decreasing during the AmBe Data taking and **sc_integral should be linearly related to humidity**, hence **we can exploit this relation to calibrate in energy**.

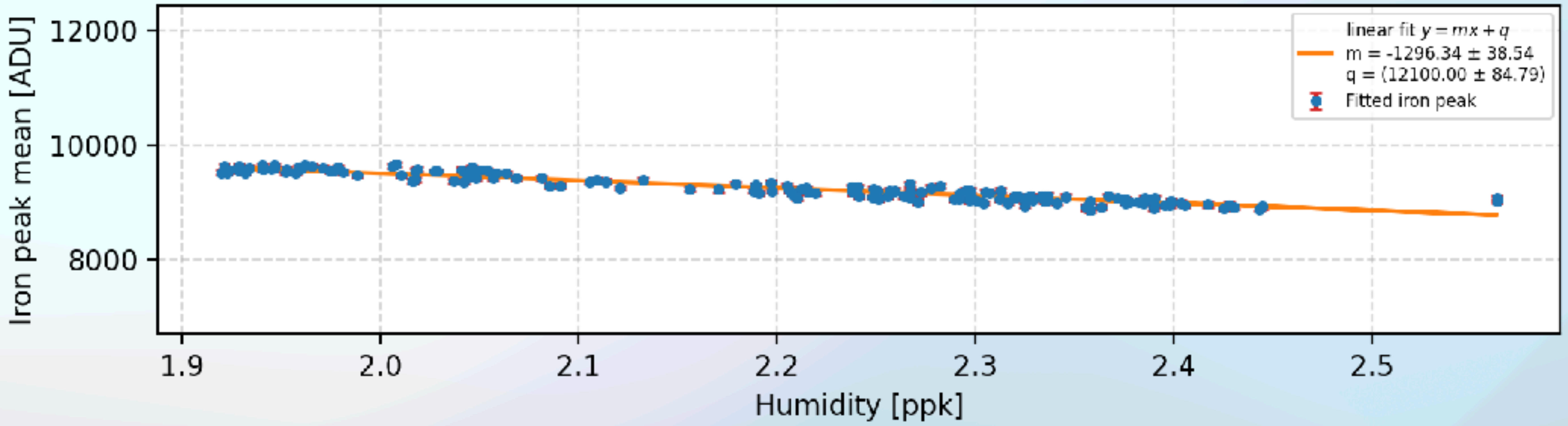


1.3b. Light Yield calibration with humidity

Strategy:

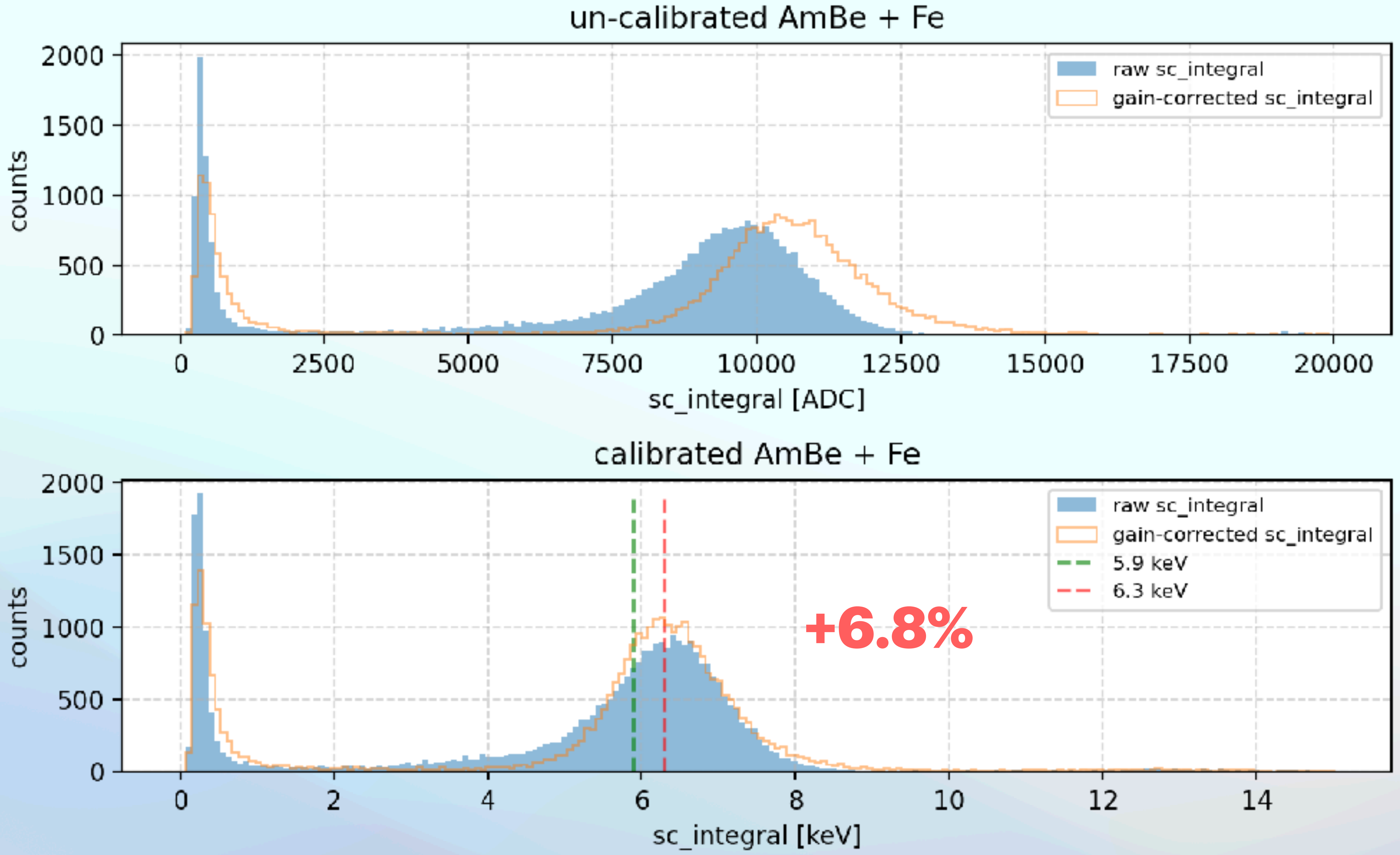
- Fit the iron peak run by run for a stability dataset.
- Plot it vs. Humidity.
- Fit the linear relation to obtain the calibration function at each humidity value.
- Calibrate sc_integral of each using the corresponding humidity value for the current run.

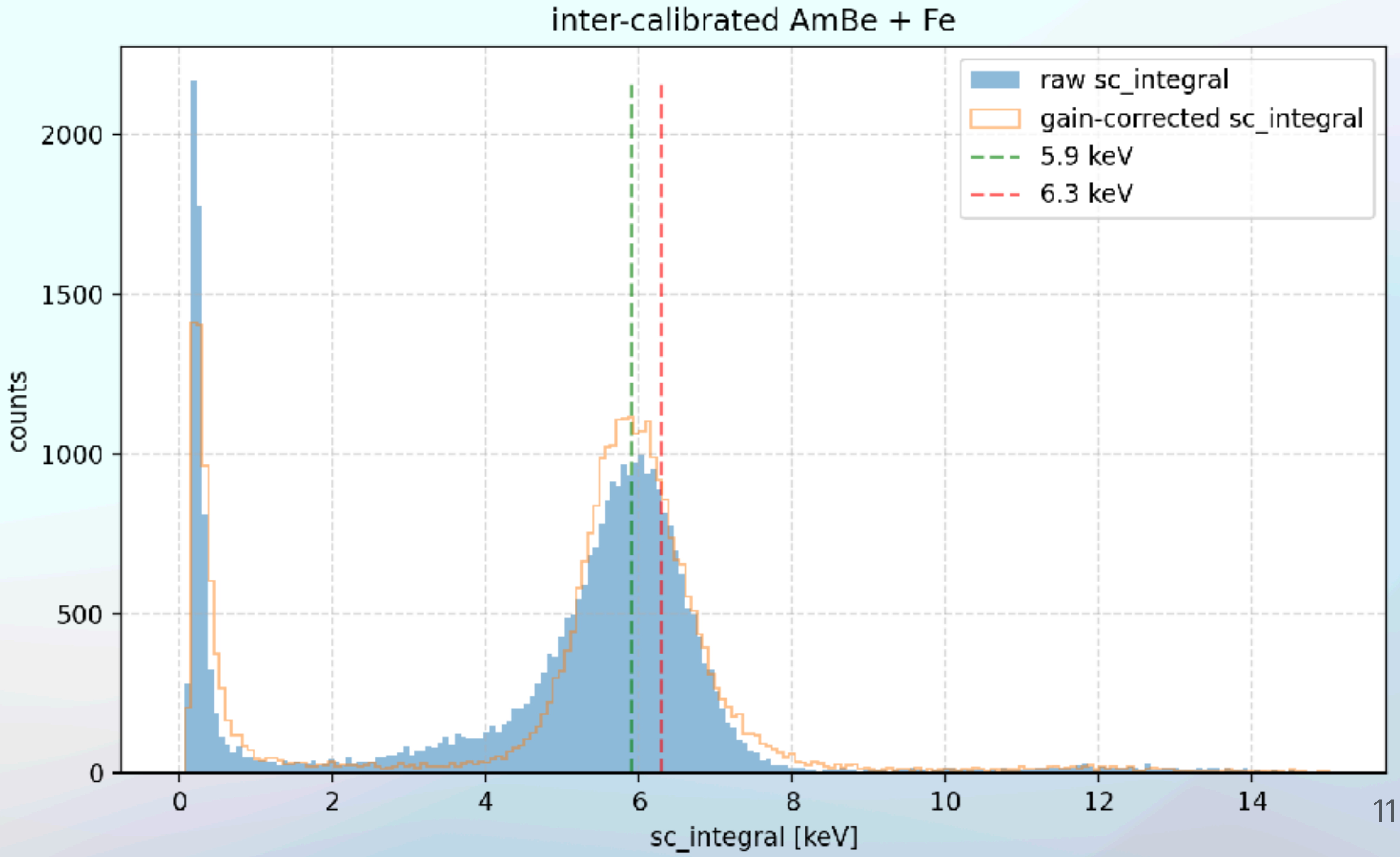




1.3c. Light Yield inter-calibration (AmBe)

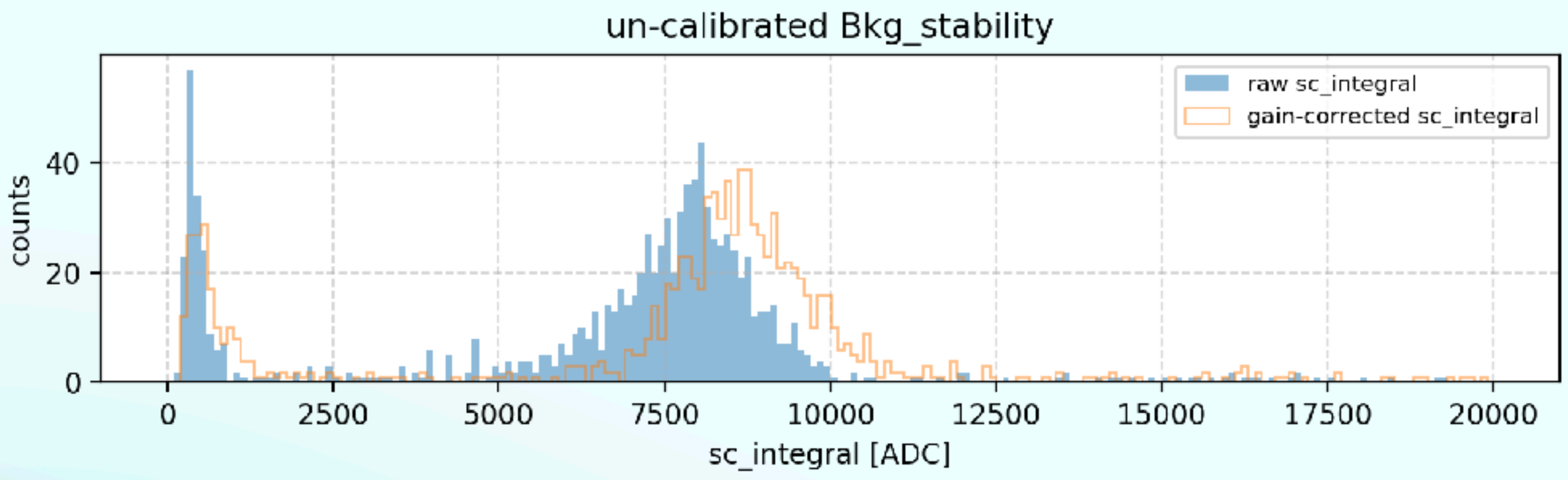
- Applying the calibration function to data taken in different timeframes results in a shifted peak from the expected one, probably related to other parameters of the detector (pressure / Oxygen?). **Physics makes the rules → rescale all to match the correct peak**.

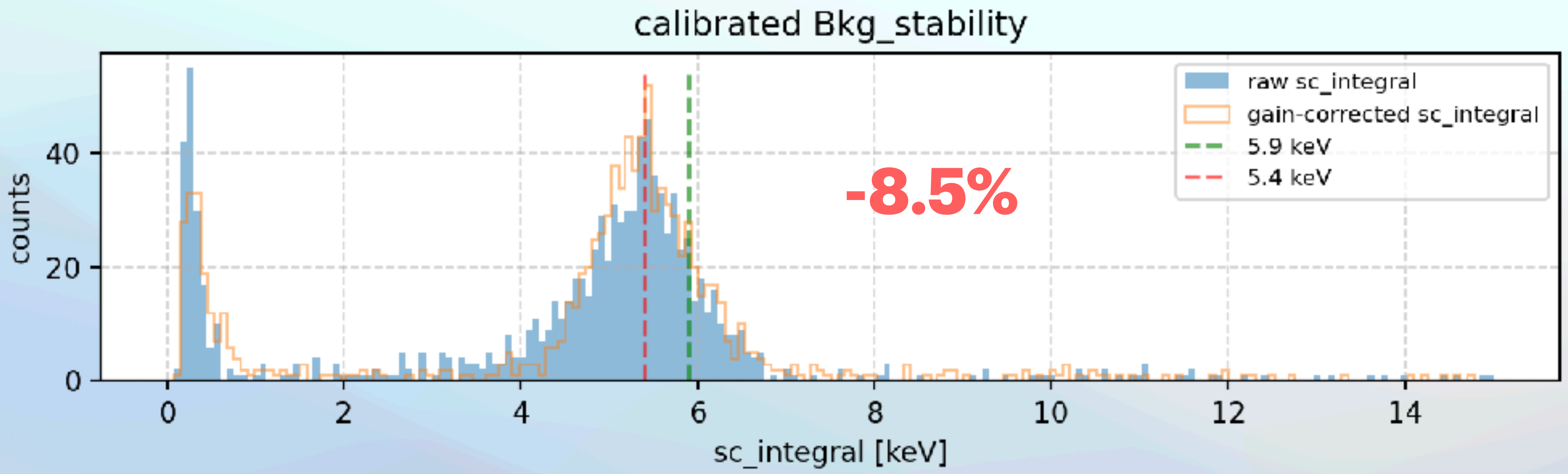


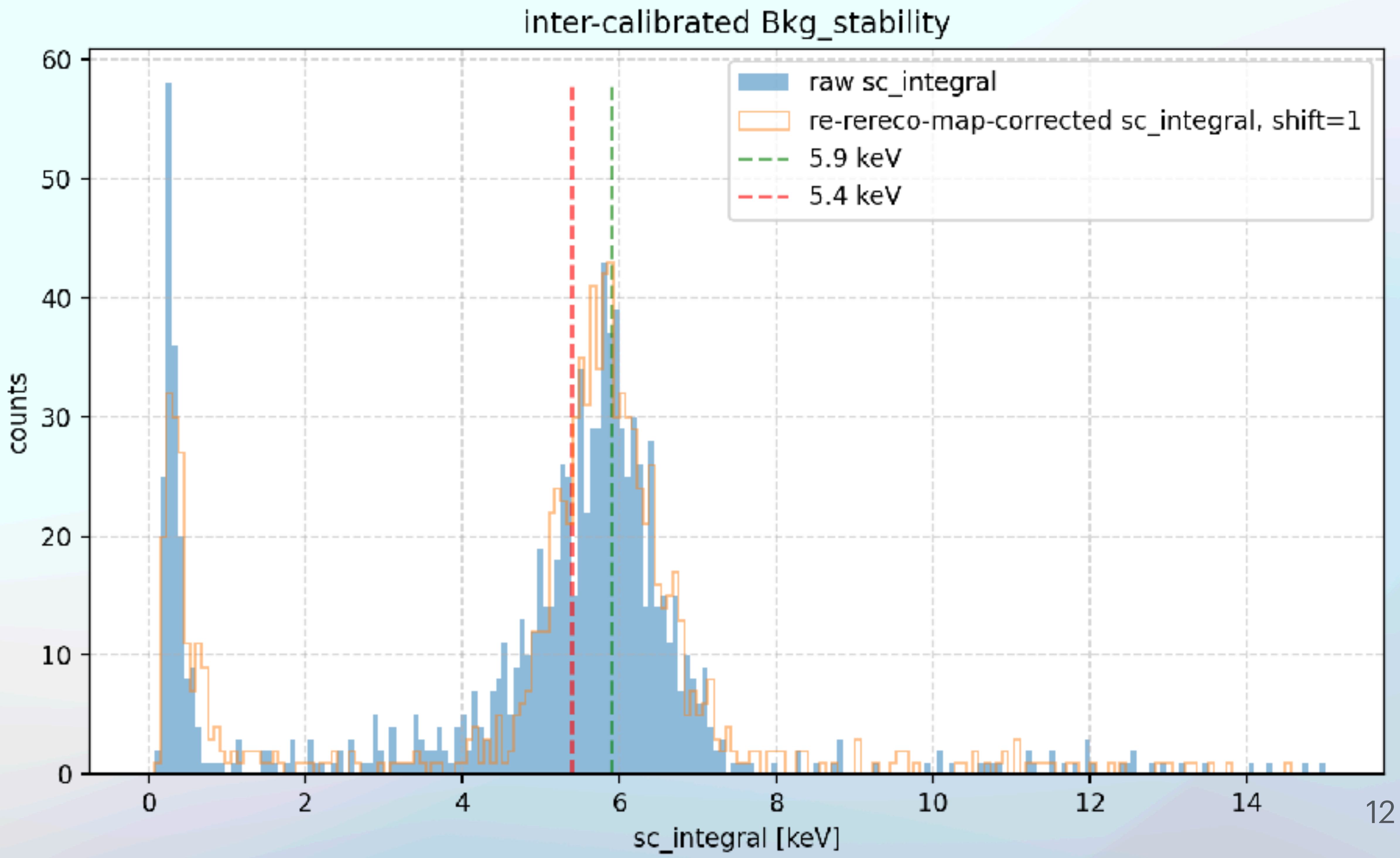


1.3c. Light Yield inter-calibration (Bkg)

- Same concept with background but opposite behaviour

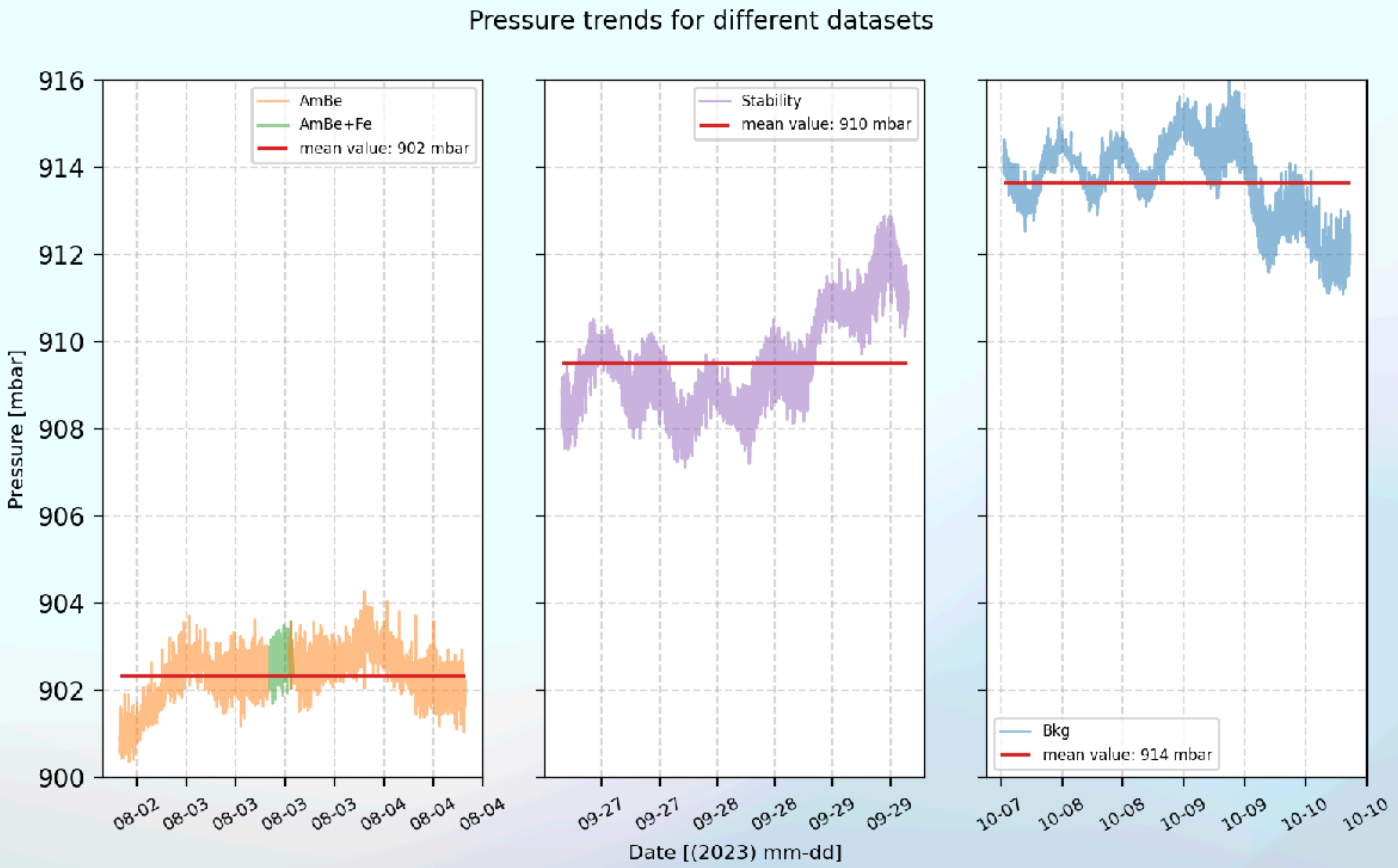




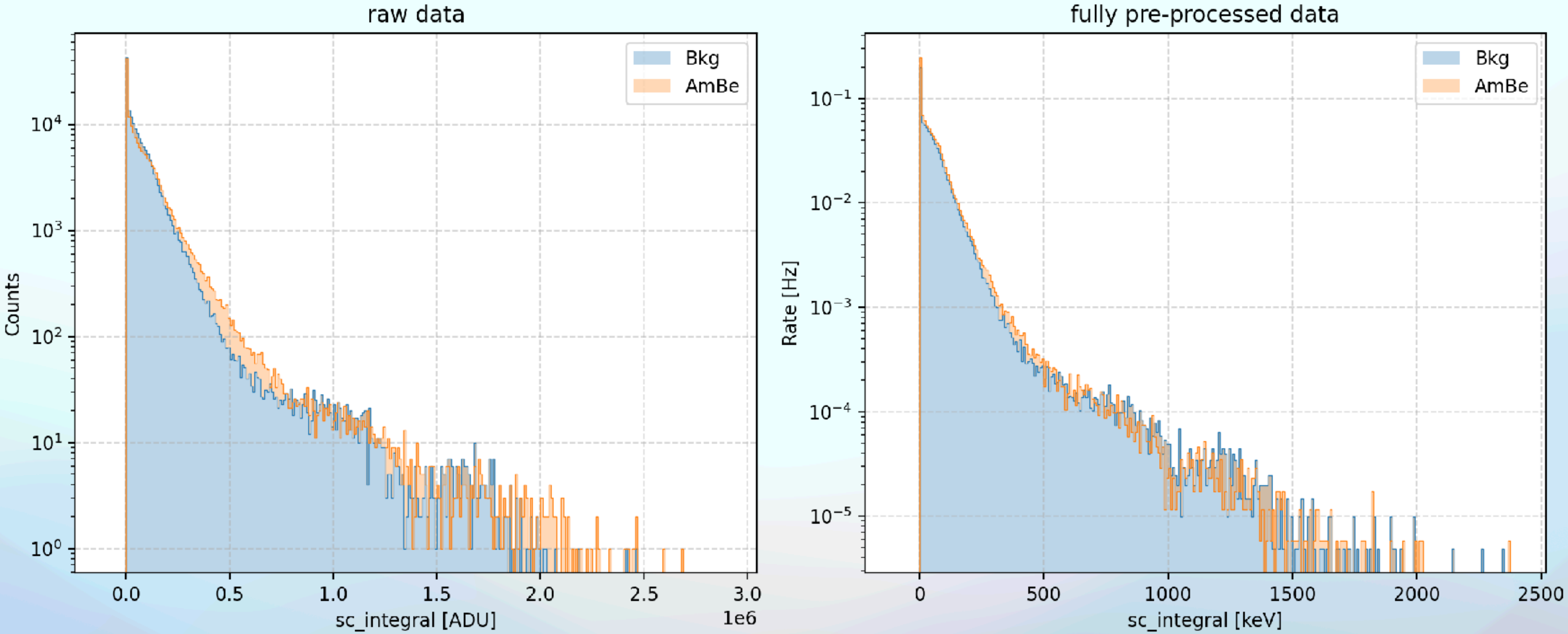


1.3c. Light Yield inter-calibration (pressure hypothesis)

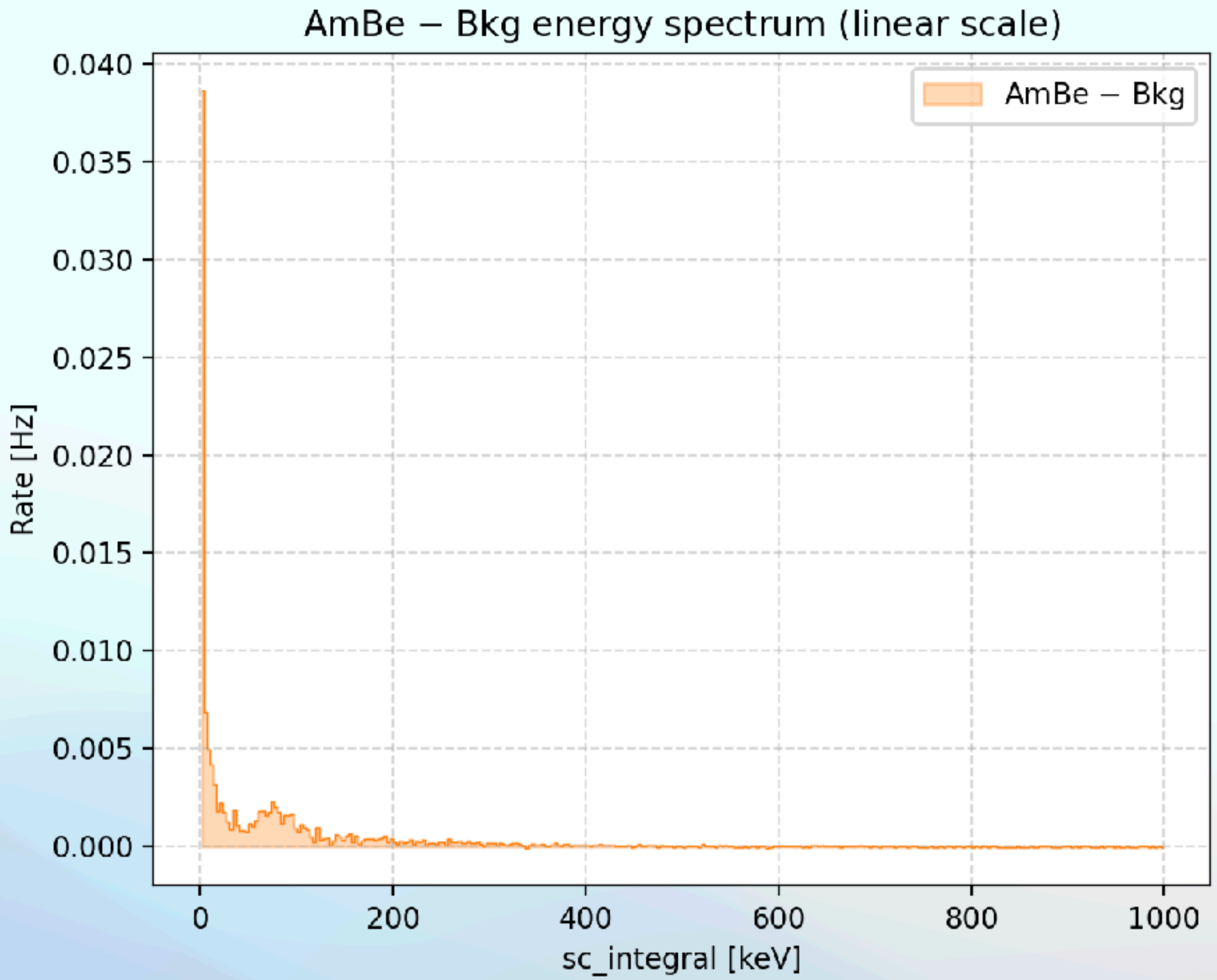
- Opposite pressure trends of AmBe and Bkg wrt Stability.
- Relation between LY and pressure is known from overground studies; **variation of 0.6% LY/mbar**
- Pressure variation could explain:
  - 4.8% of 6.8% (AmBe)
  - 2.4% of 8.5% (Bkg)

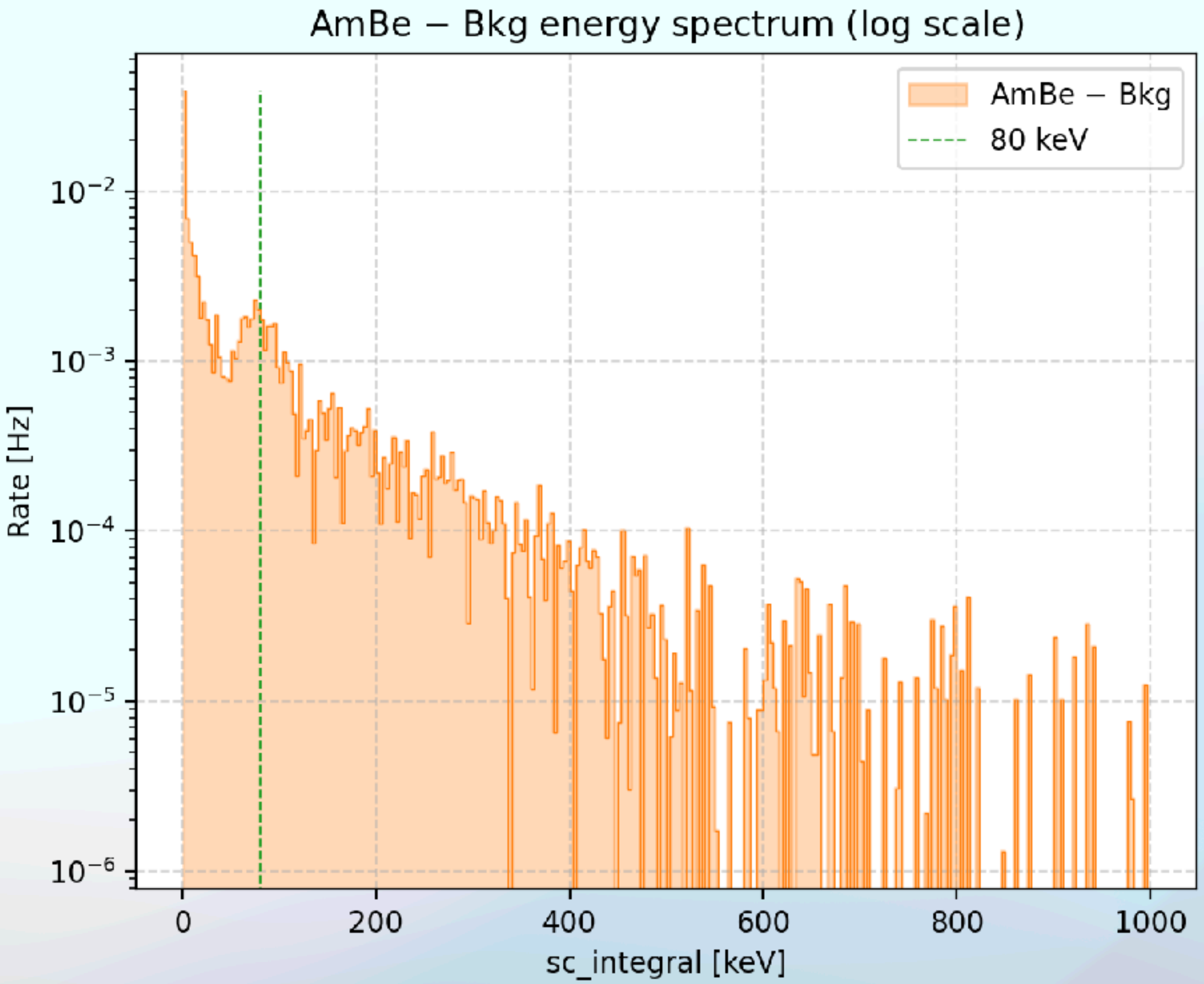


Pre-Processing results: sc_integral spectrum

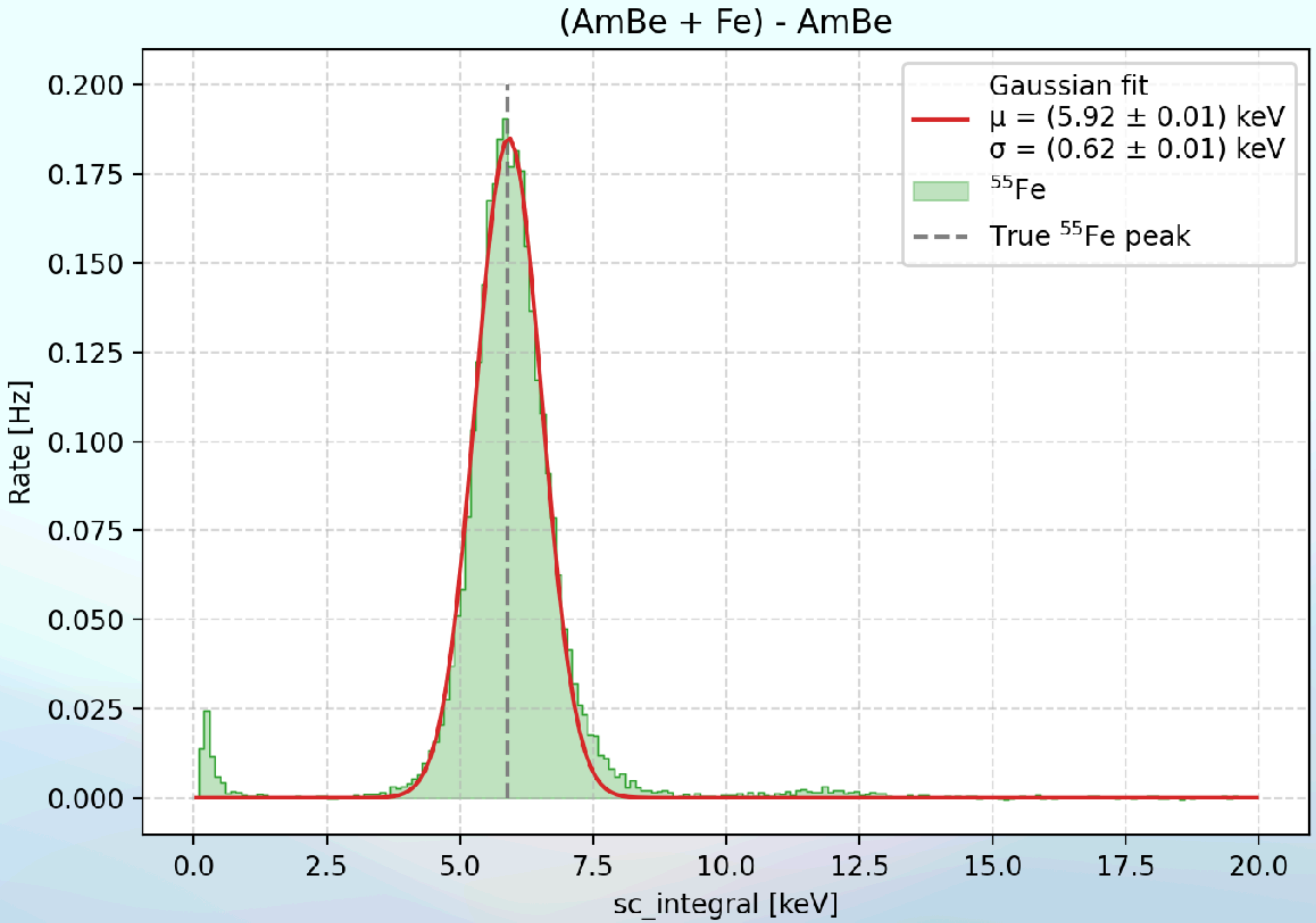


Pre-Processing results: AmBe — Bkg





Pre-Processing results: Iron peak



2. Low energy NRs analysis

2.1. AmBe excess selection

2.1. AmBe excess selection

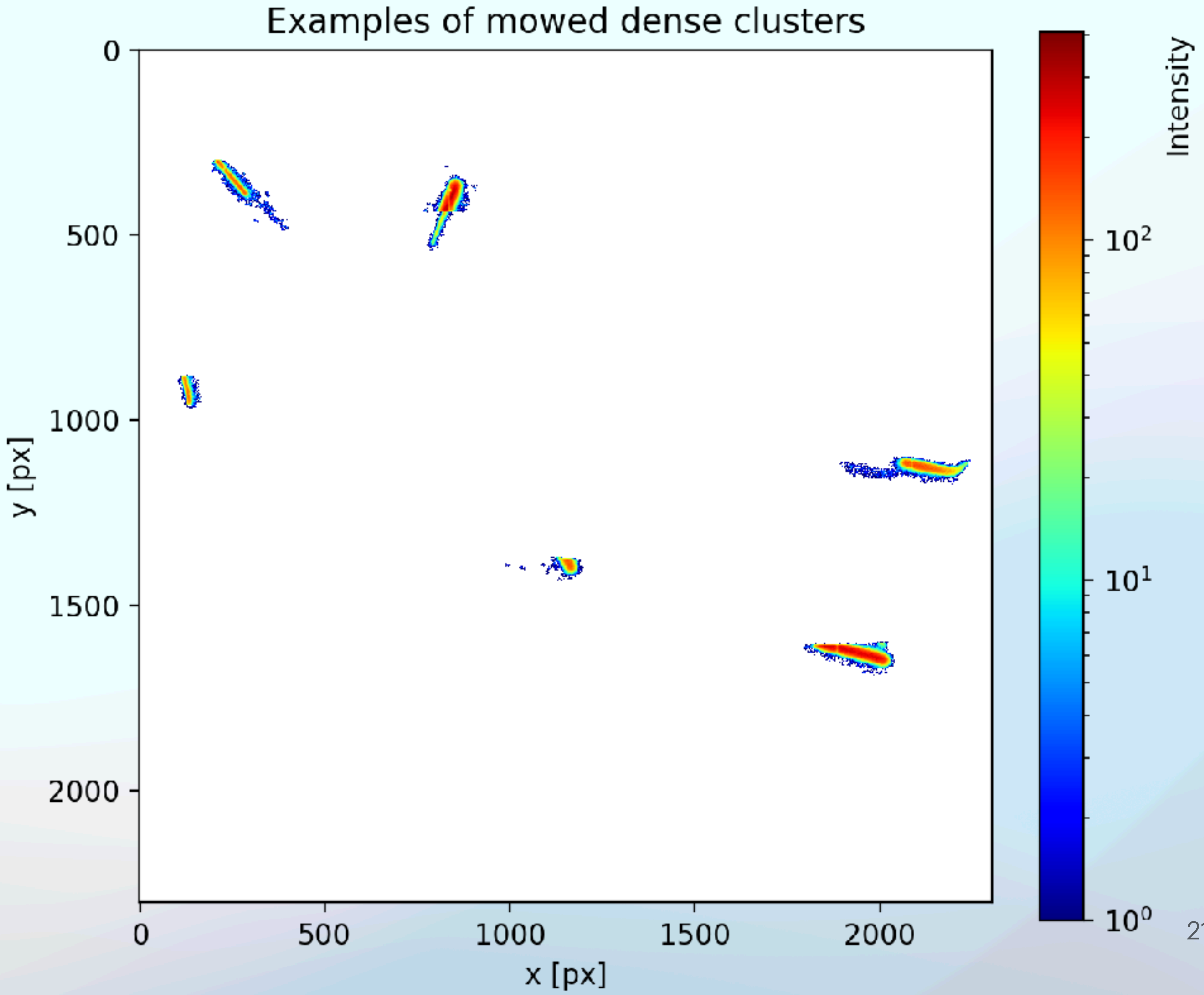
2.1. AmBe excess selection

2.1. AmBe excess selection - Mowed clusters

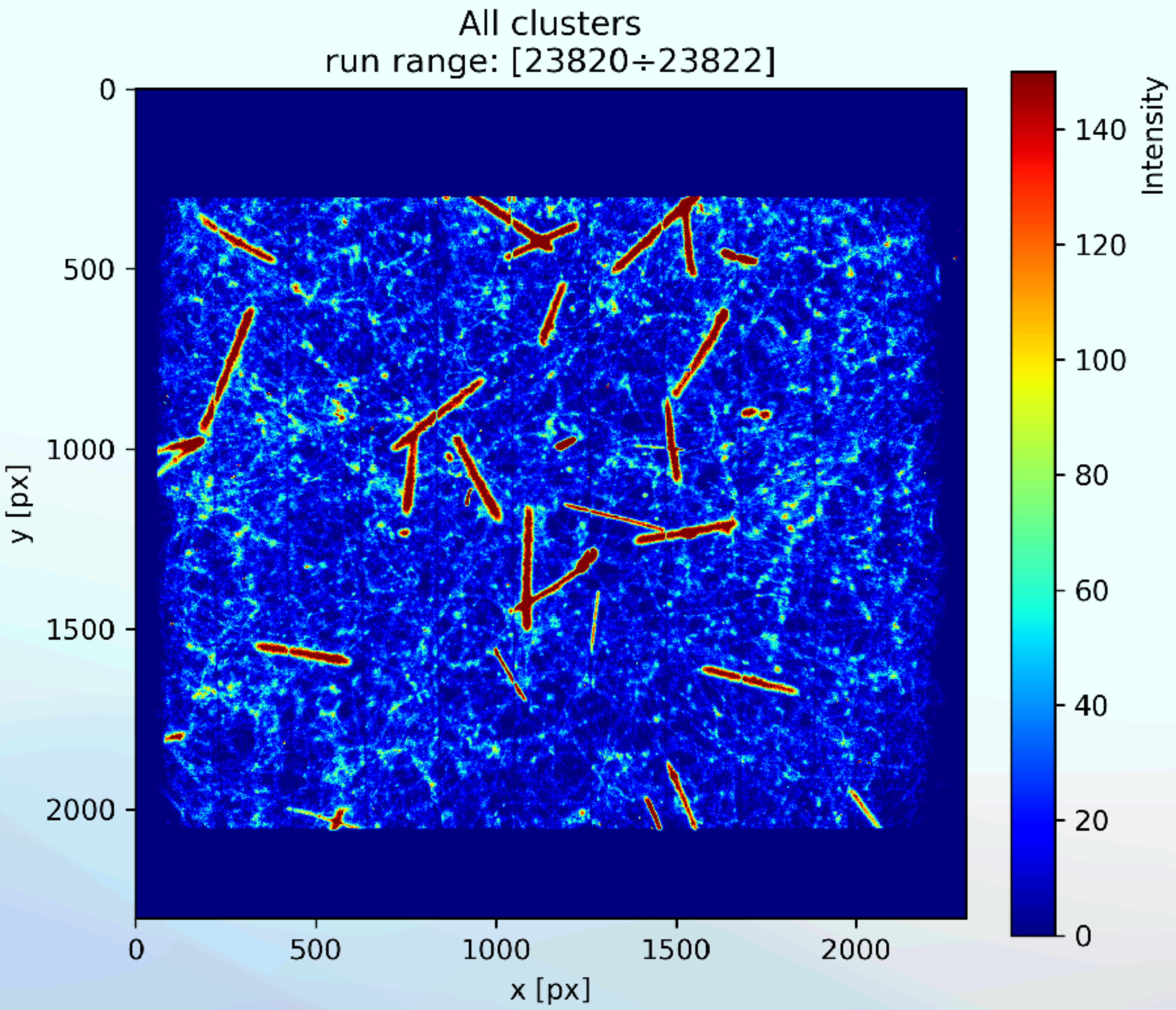
- We can use the Trigger Time Tag (**TTT**) to identify the clusters that were "mowed" from the pixels activation / deactivation.

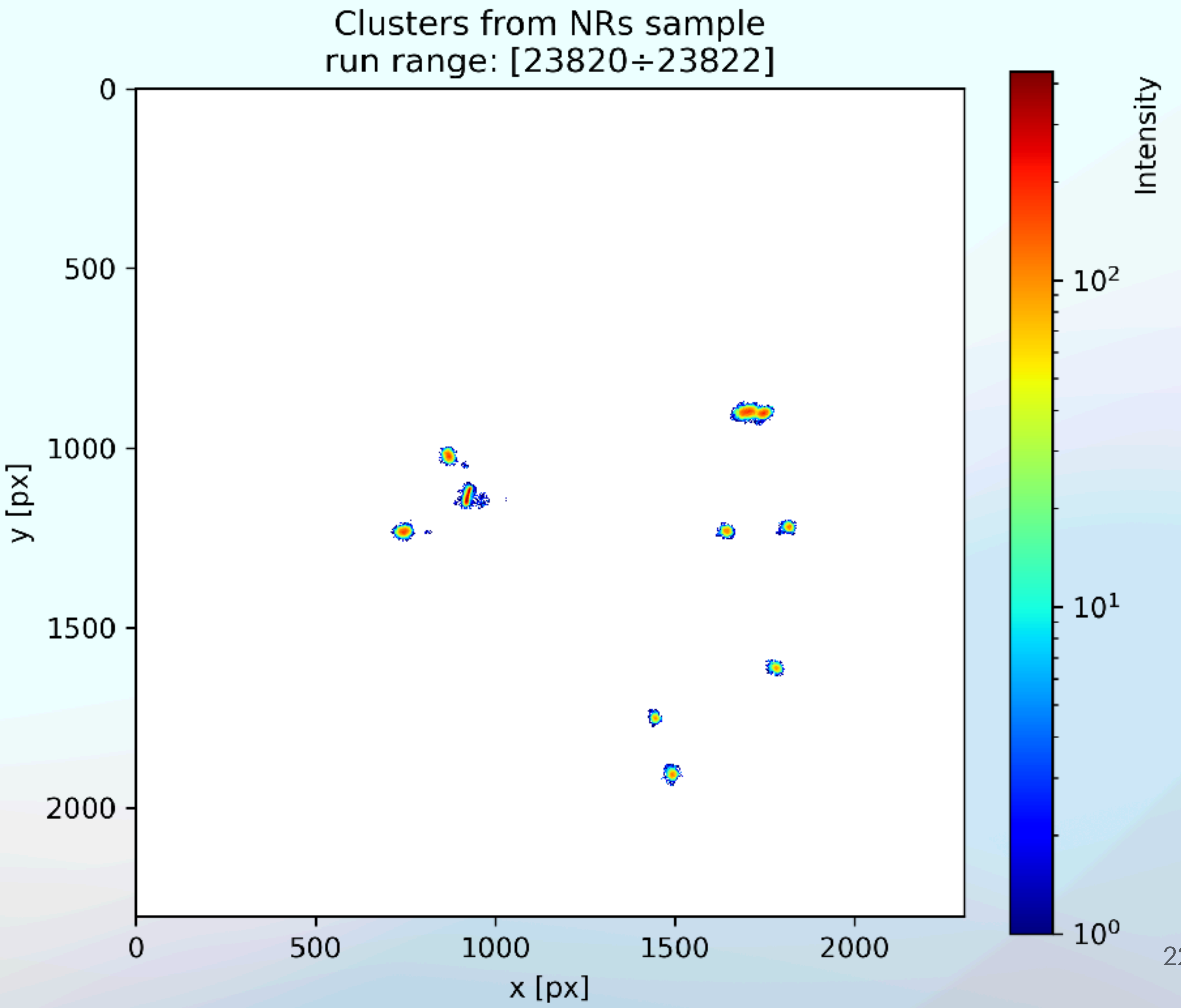
Strategy:

- Convert TTT in the number of active pixels (**$\mathbf{TTT_{eqpx}}$**)
- Retrieve y_{min} and y_{max} for a cluster from the camera data
- Check if $y_{min} < \mathrm{TTT}_{eqpx} < y_{max}$ for at least one TTT_{eqpx} and remove the cluster from the sample in such case.

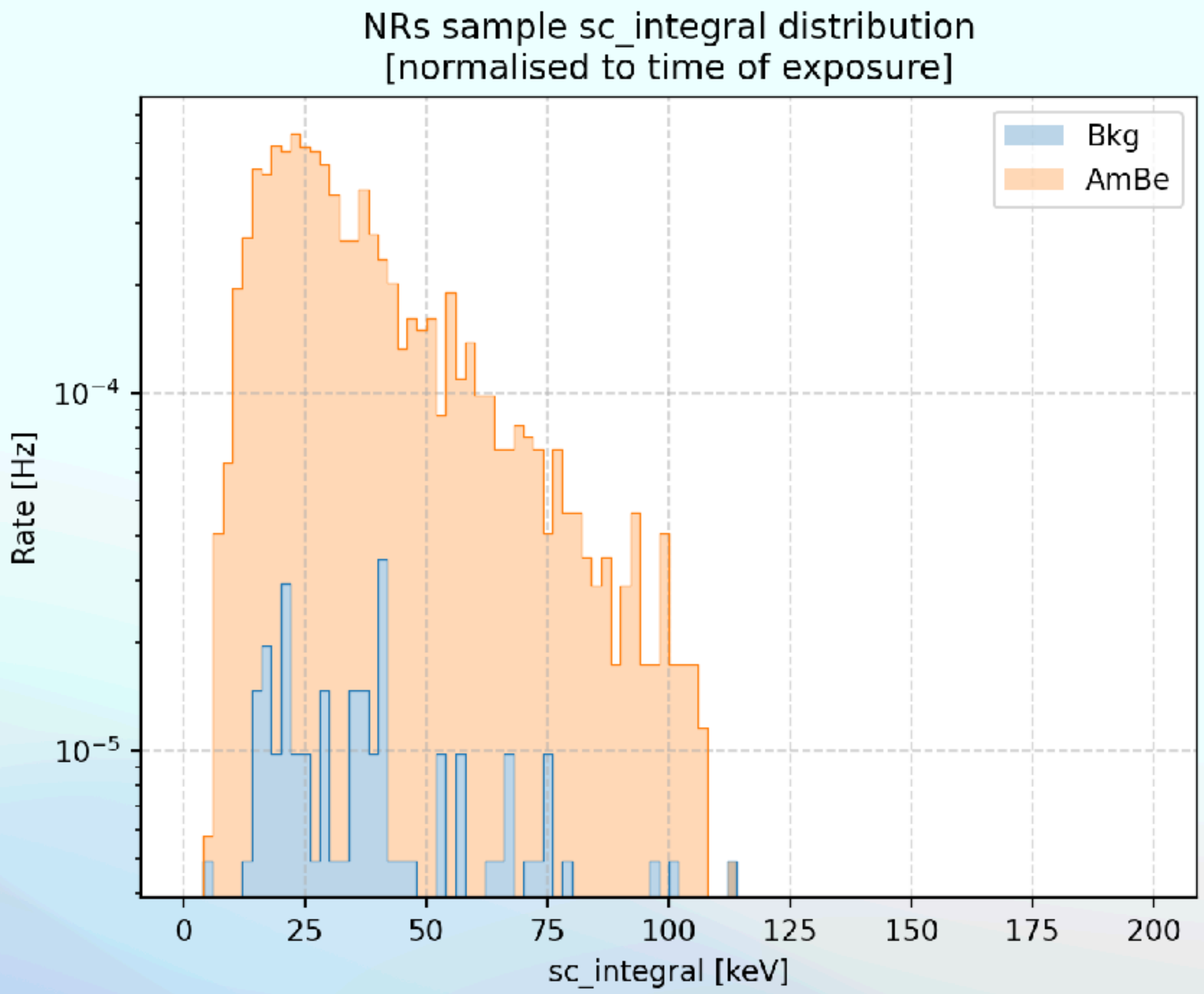


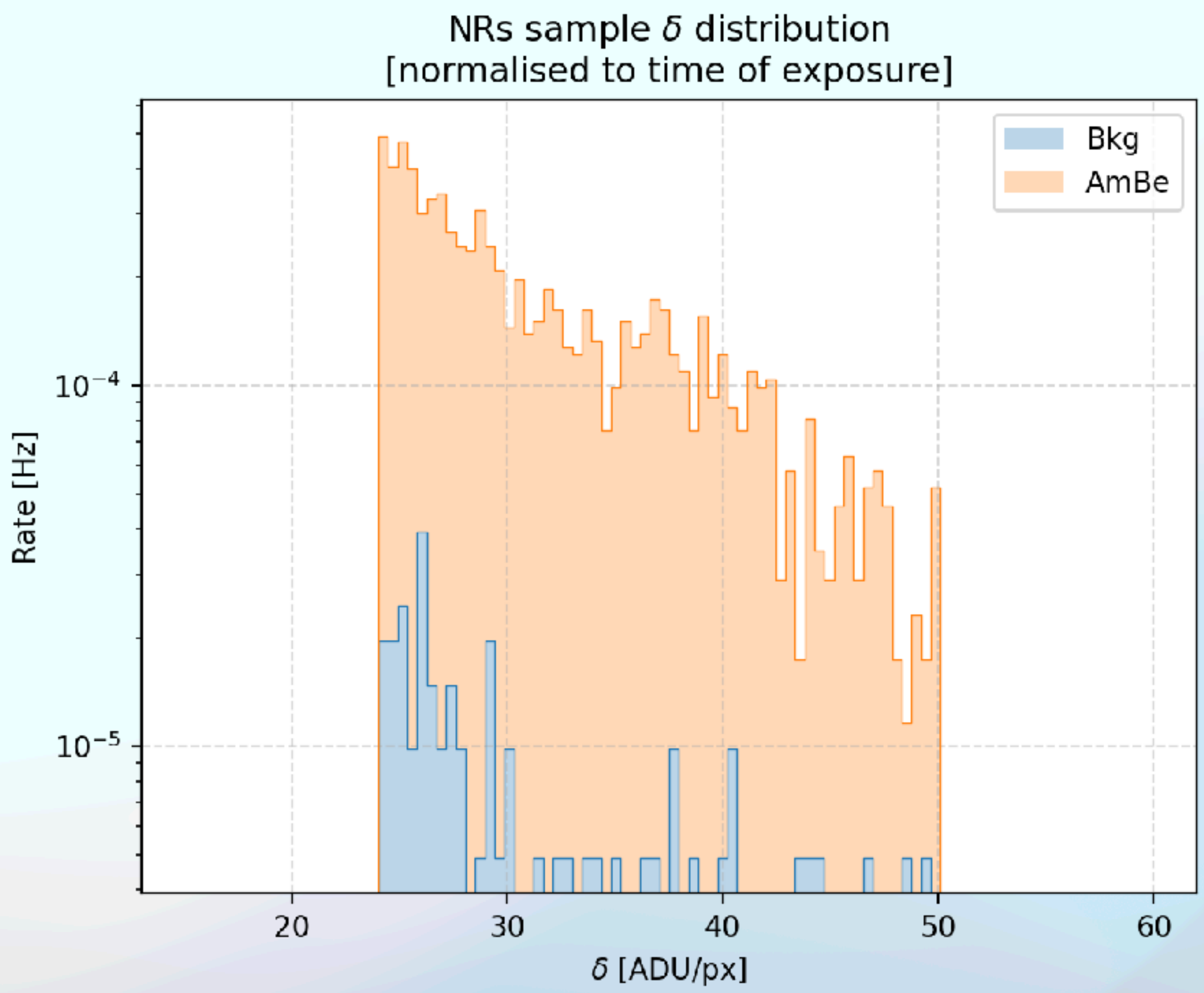
2.1. AmBe excess selection





2.1. AmBe excess selection





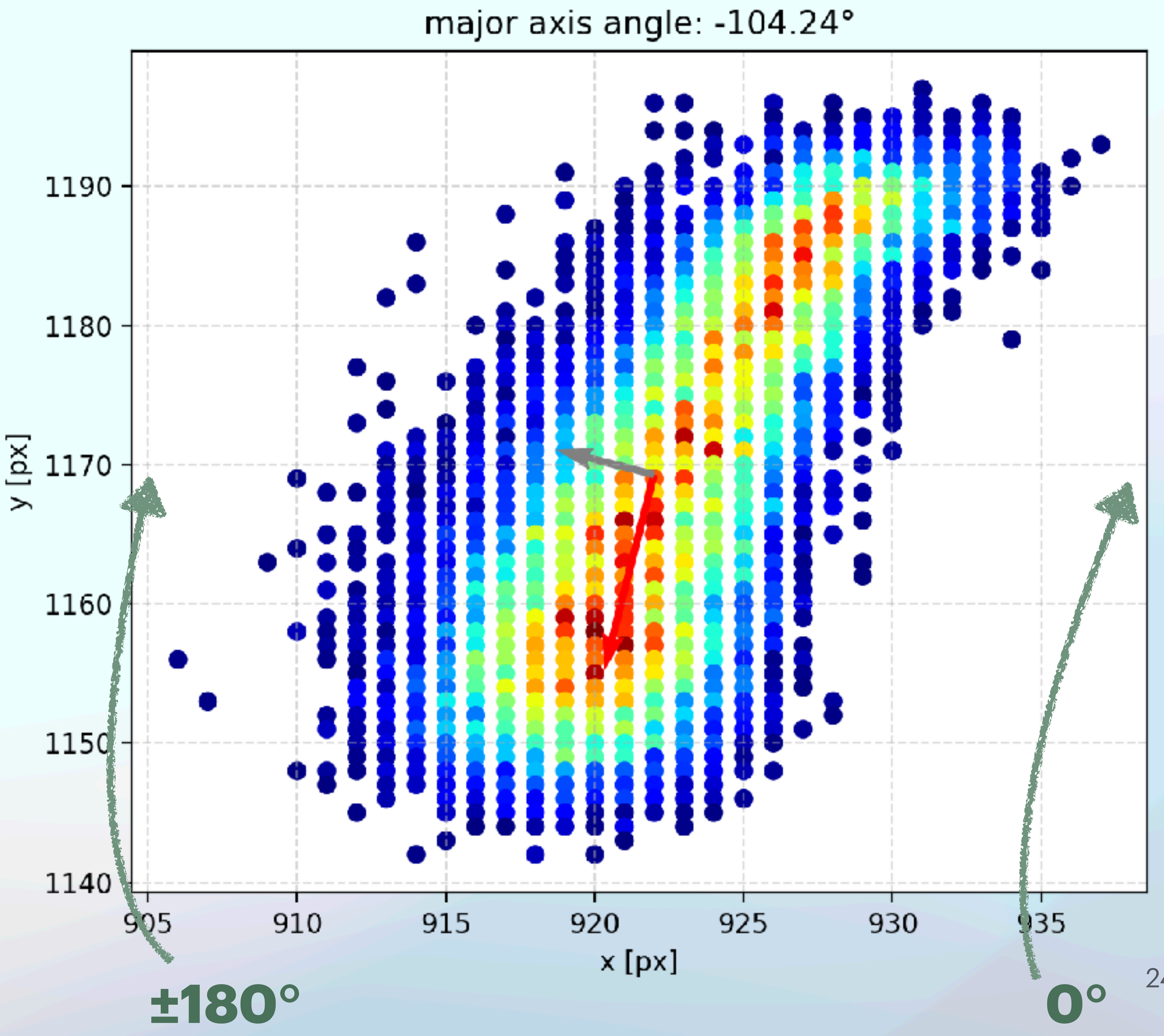
2.2a. Directionality evaluation

- Re-implementation of the Principal Component Analysis (**PCA**) with 2 parameters on the most intense part of the clusters to remove shadow and **extract the clusters' axes**.

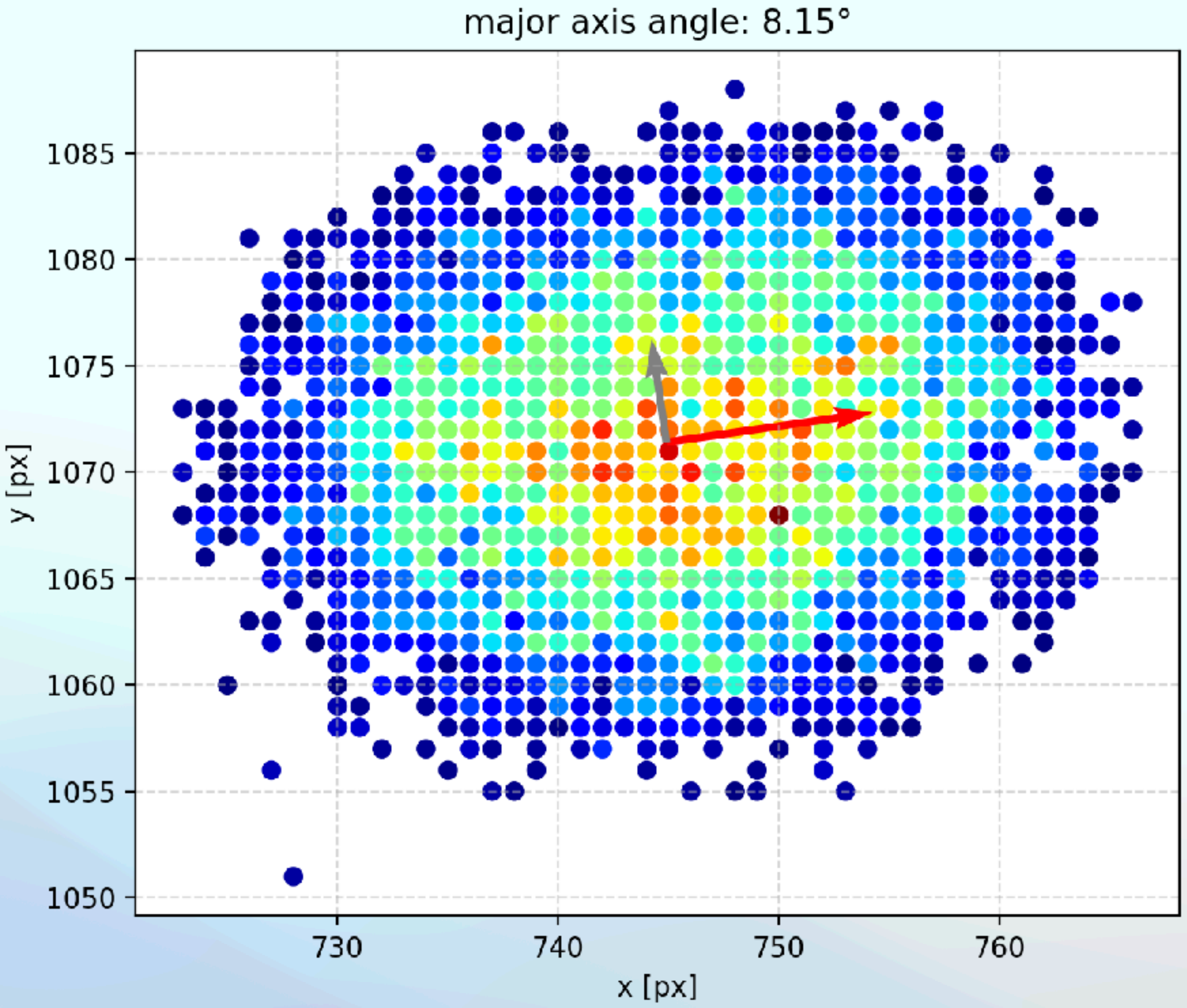
- Use always the **biggest eigenvector** to compute the angle with respect to the $\hat{x}$ direction.

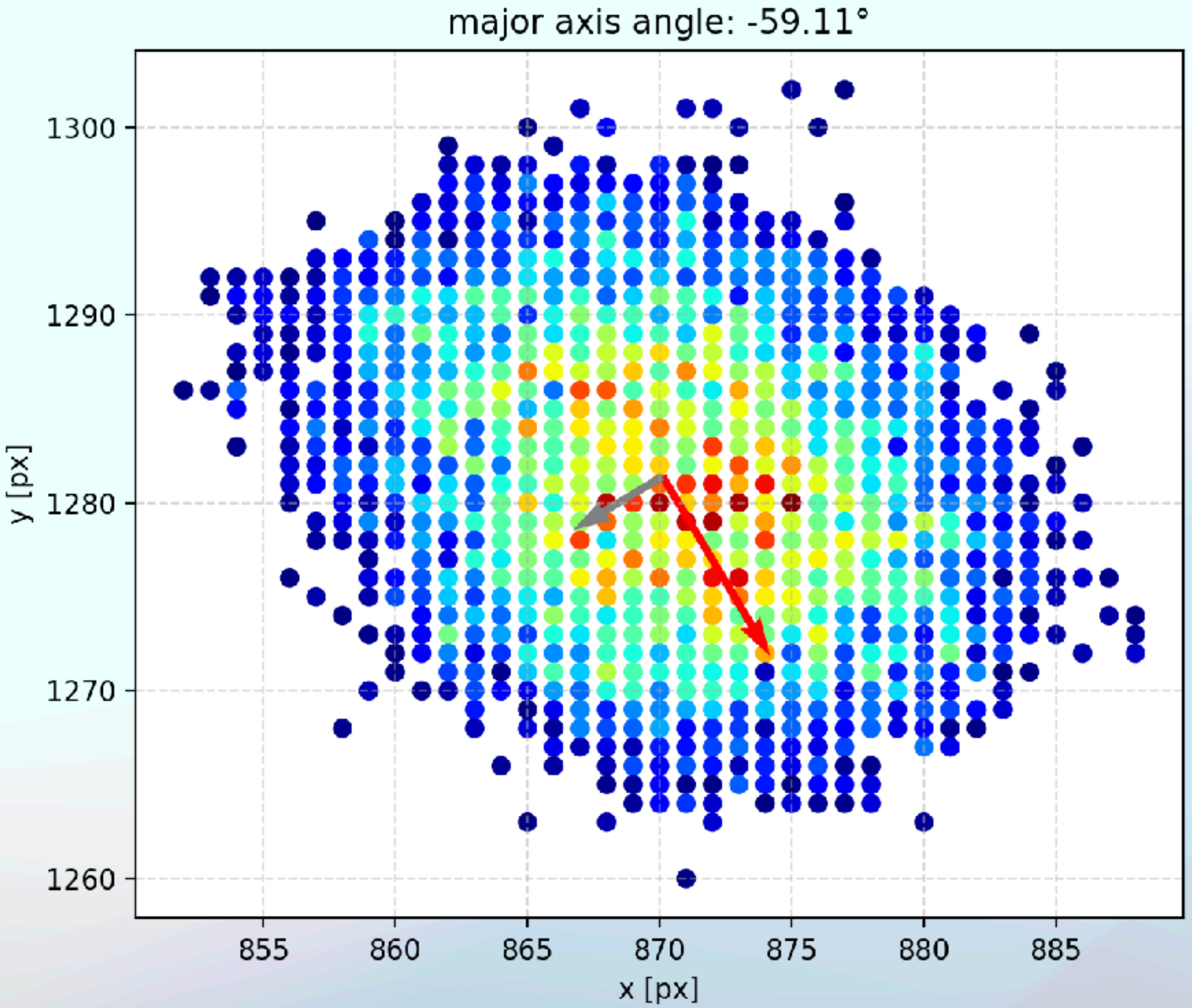
- Then, we can **impose the head-tail**, since we know this excess comes from the AmBe source (right side of the image reference frame), and **flip all the angles between ±90° by 180°**.

- Do the same on the Bkg dataset and compare to see if there are differences.

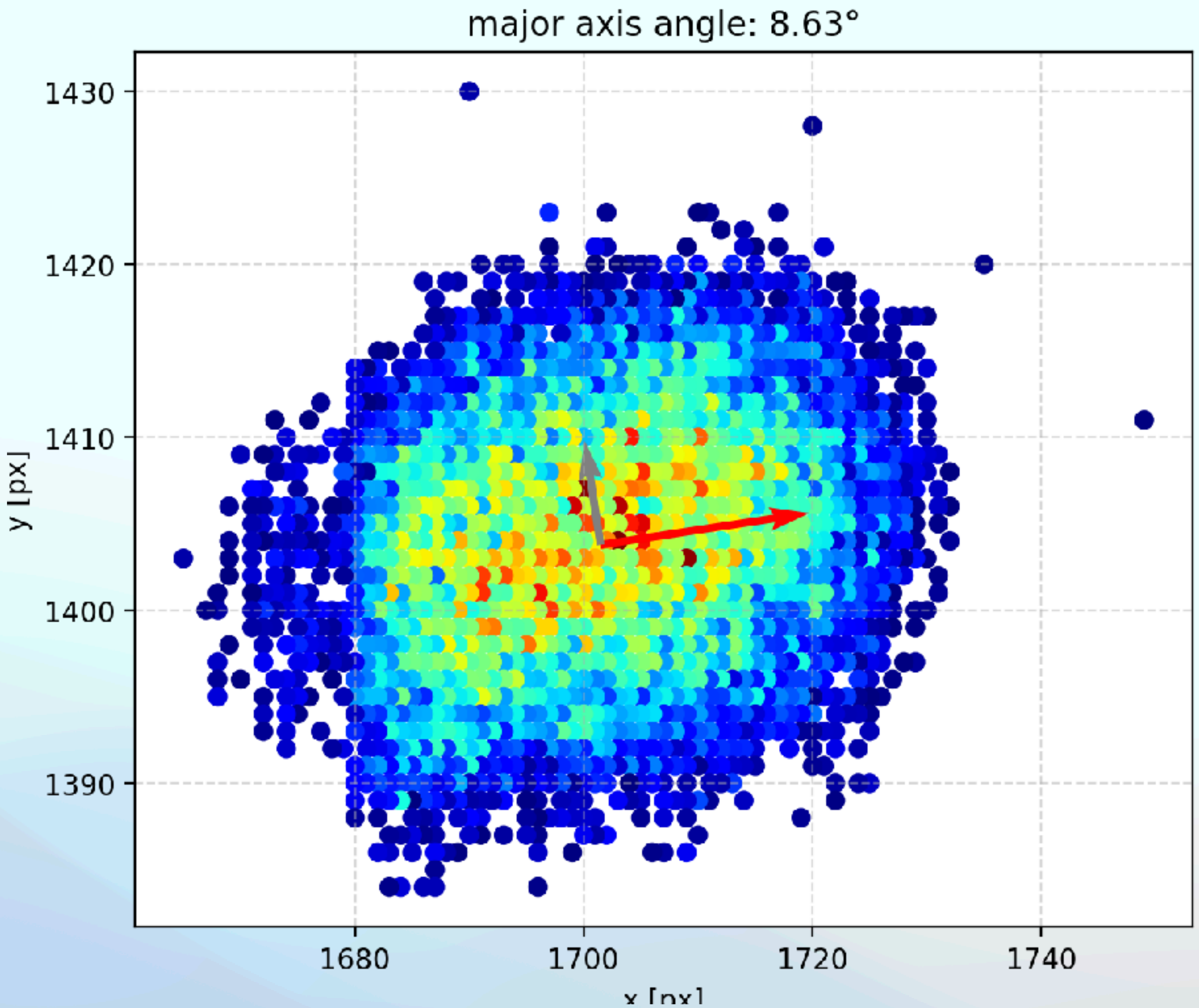


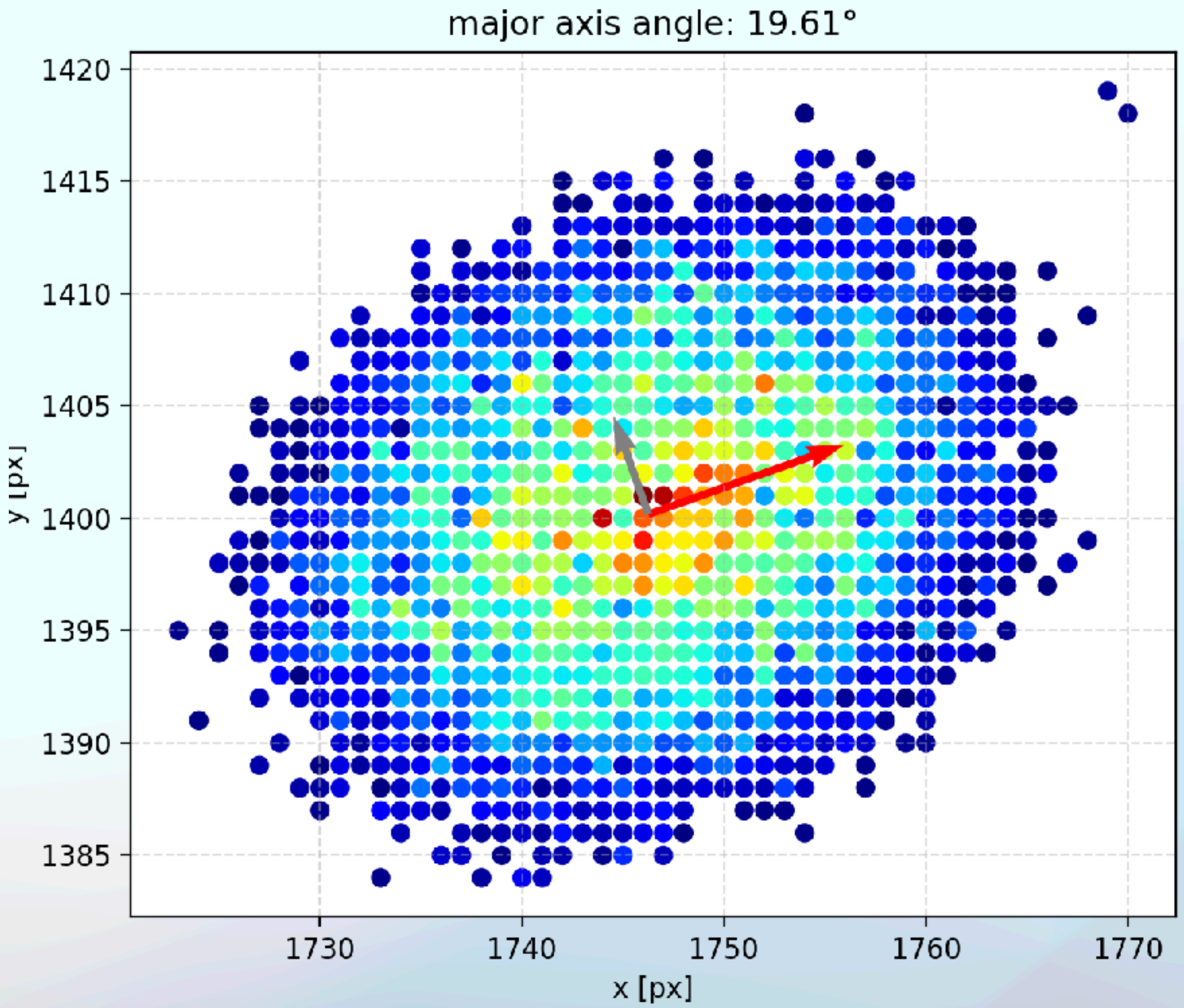
2.2a. Directionality evaluation - Examples





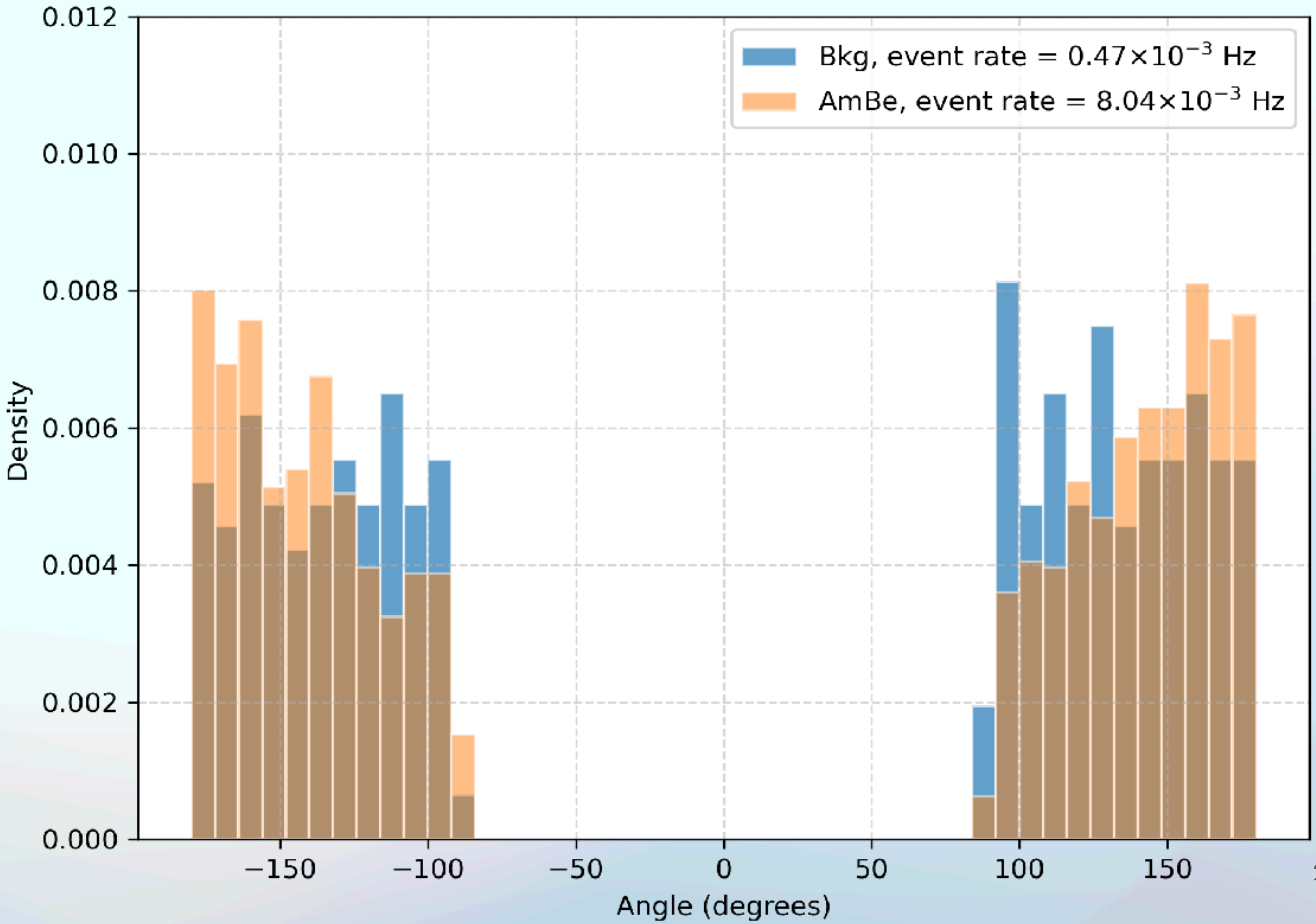
2.2a. Directionality evaluation - Examples





2.2a. Directionality evaluation - AmBe vs. Bkg

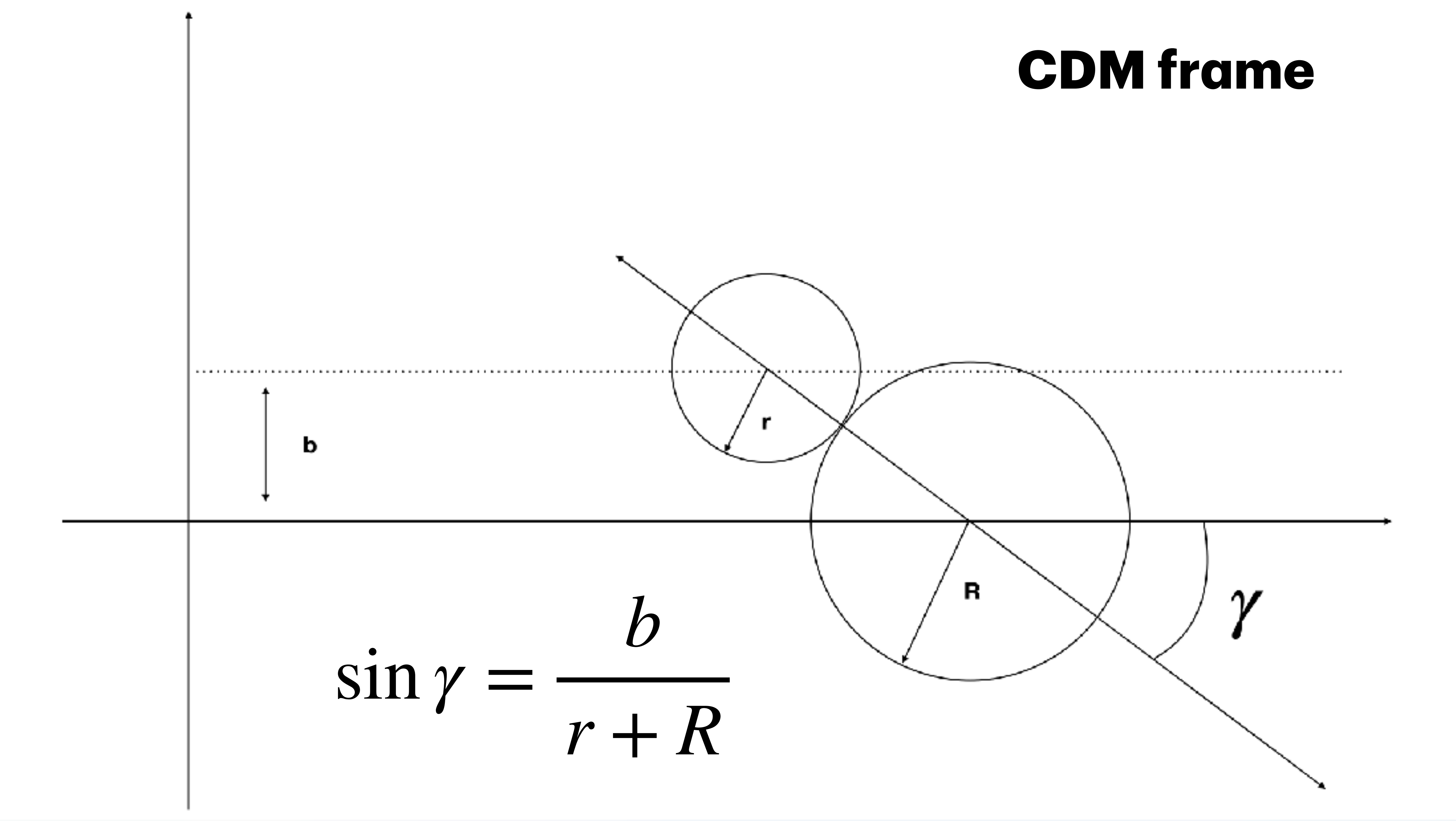
- Apply the same method to clusters in the selected region with and without AmBe source.
- **Excess of vertical clusters in Bkg sample** (here the Bkg Dataset has been expanded to collect more clusters).
- **Excess of horizontal clusters in AmBe sample**.
- **Is this last excess expected?**



2.2b. Monte Carlo validation

Strategy:

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



2.2b. MC validation - LAB kinematics

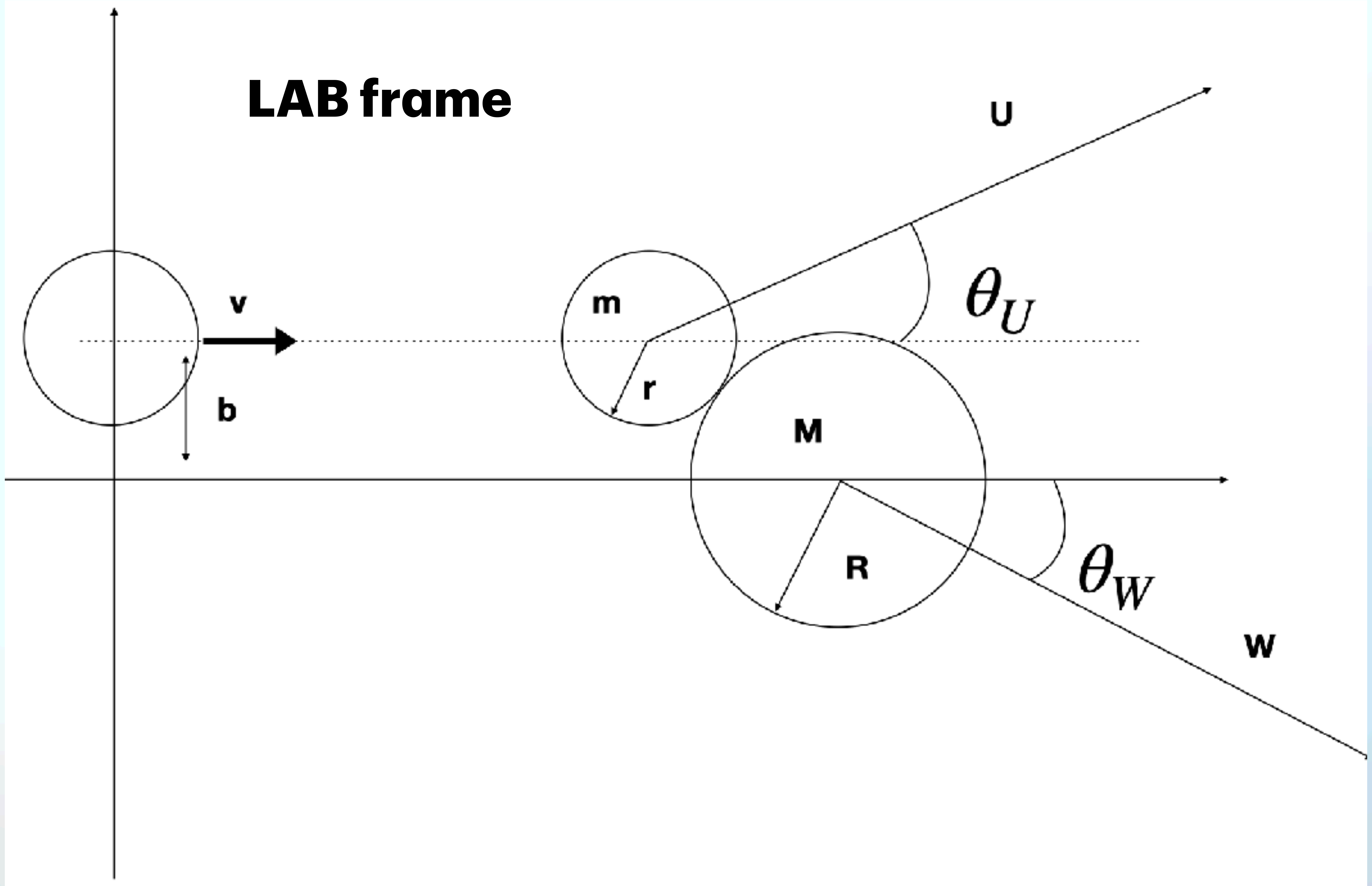
- We are interest in θ_W, to retrieve it:

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

- If **b = ±(r + R)**

$$\sin\gamma = \pm 1 \quad \cos\gamma = 0 \Rightarrow \theta_W = \pm\,\pi/4$$

$\mp\pi$ since the source should be on the left



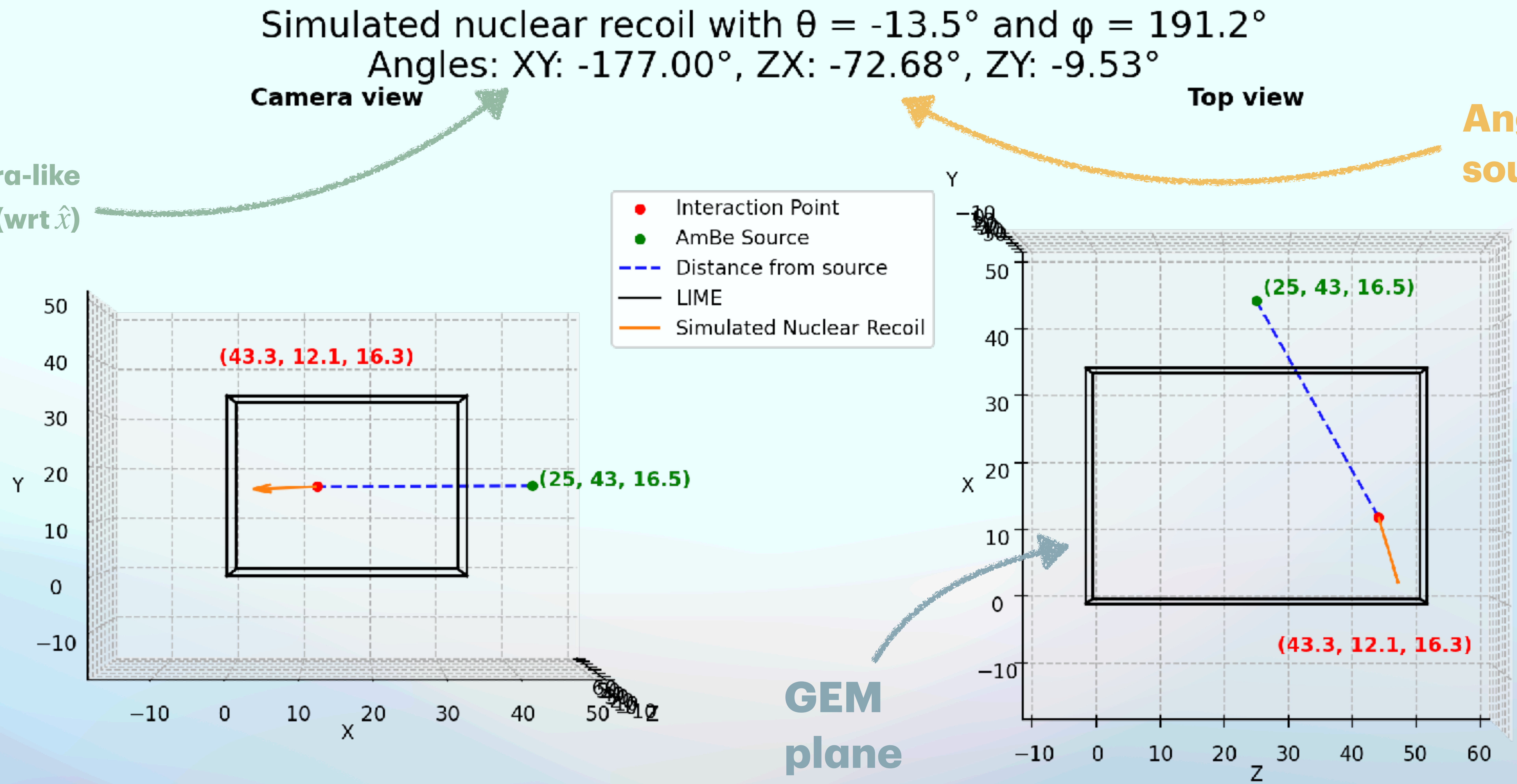
2.2b. MC validation - 3D simulation

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

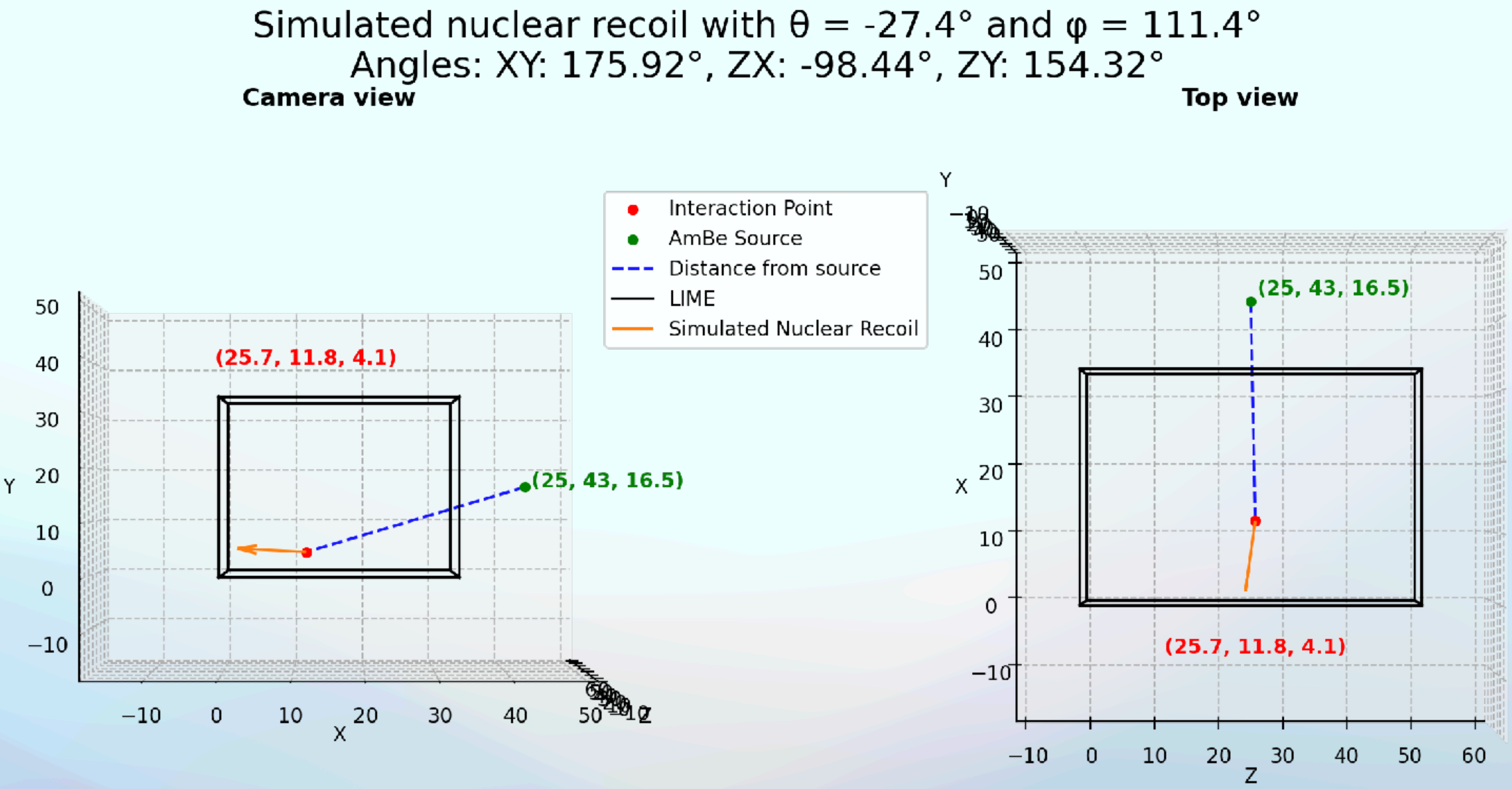
Angle wrt source wall

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

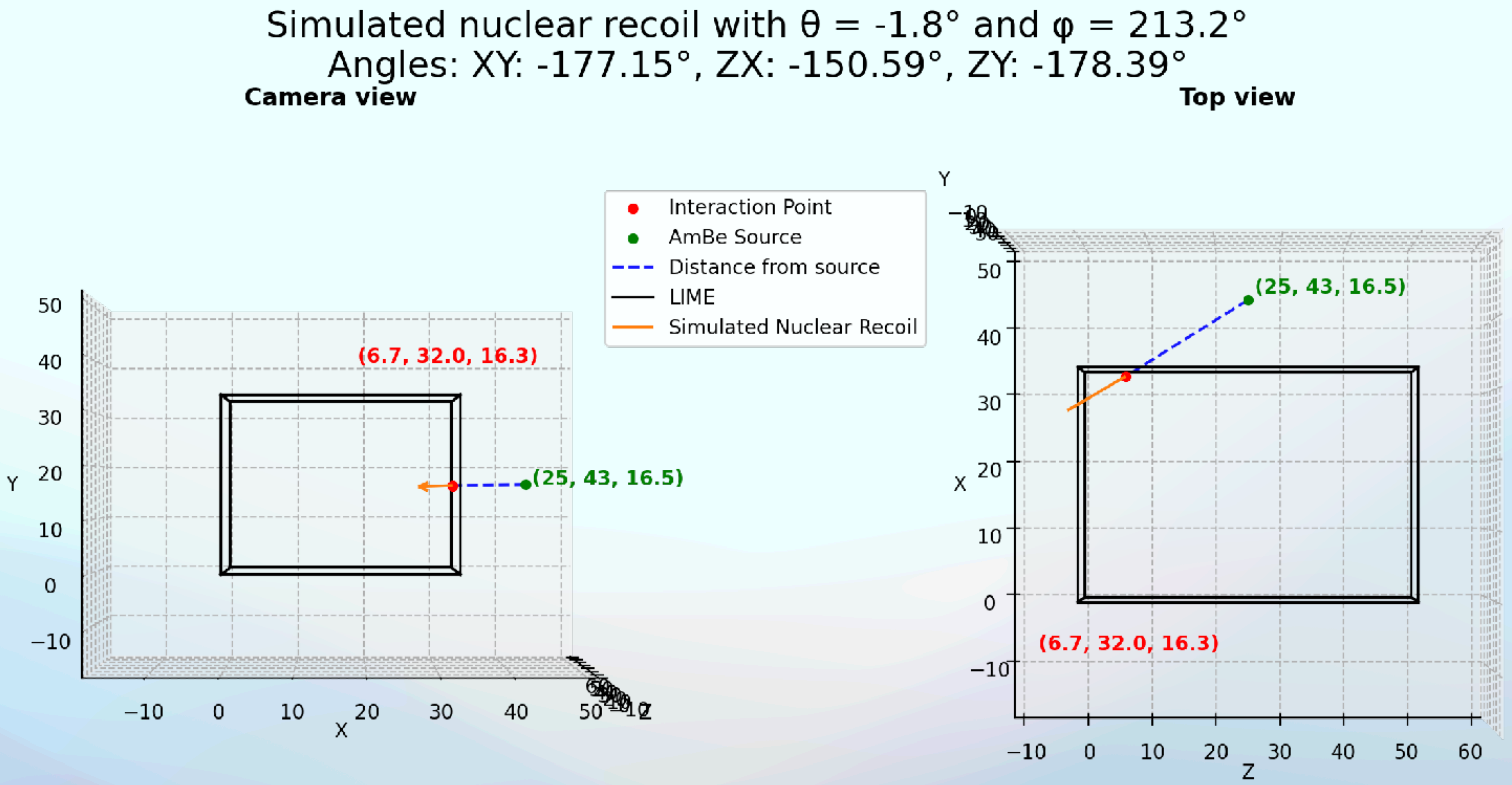
GEM plane



2.2b. MC validation - 3D simulation

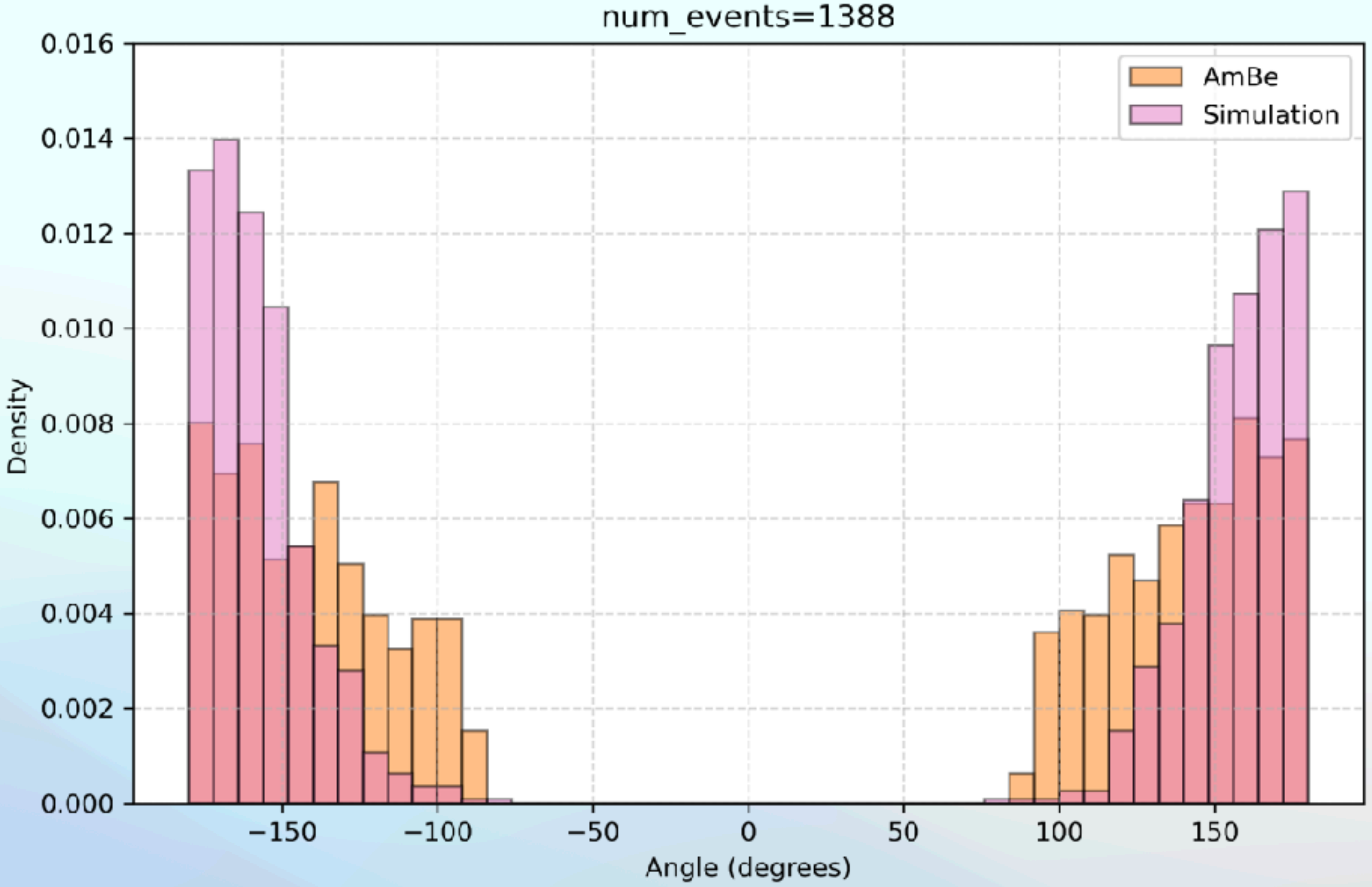


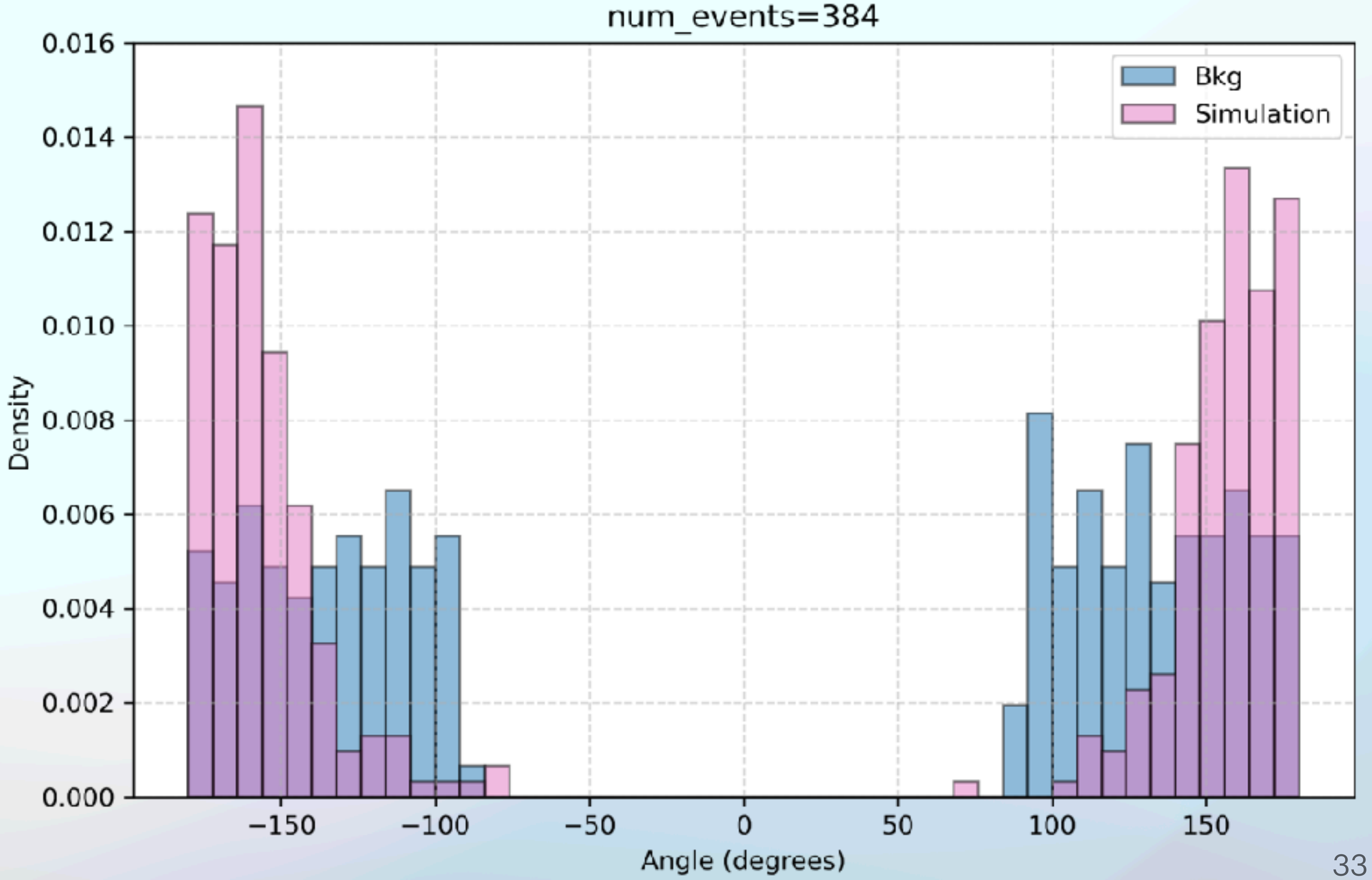
2.2b. MC validation - 3D simulation



2.2c. MC validation - Simulated angle

The vertical region is not perfectly matched by the AmBe sample, but Bkg is for sure flatter.





2.2c. MC validation - Gaussian Smearing

- The differences in the distributions could be due to **our angular resolution**, which is **absent in the simulation**.

- We can simulate it by means of a gaussian smearing, where the angular resolution (**res**) is multiplied times a number (**fact**) drawn with a Gaussian probability distribution between [-1, 1] and added to the simulated value.

$$\theta_{XY}^{(smeared)} = \theta_{XY}^{(sim)} + res \times fact$$

where $fact \in Gauss(0,1)$

2.2c. MC validation - Gaussian Smearing

Angular resolution = 5°:

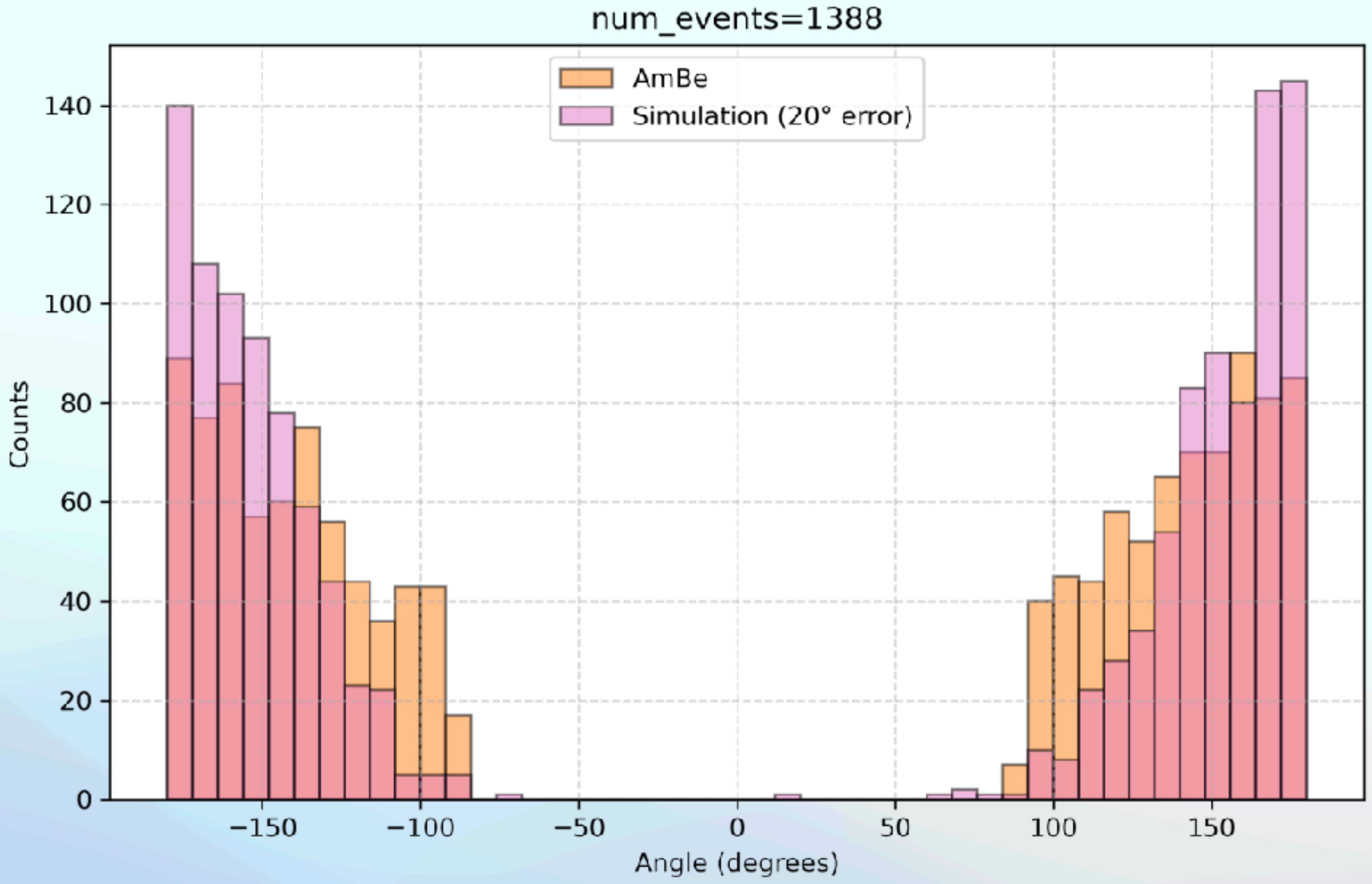
X

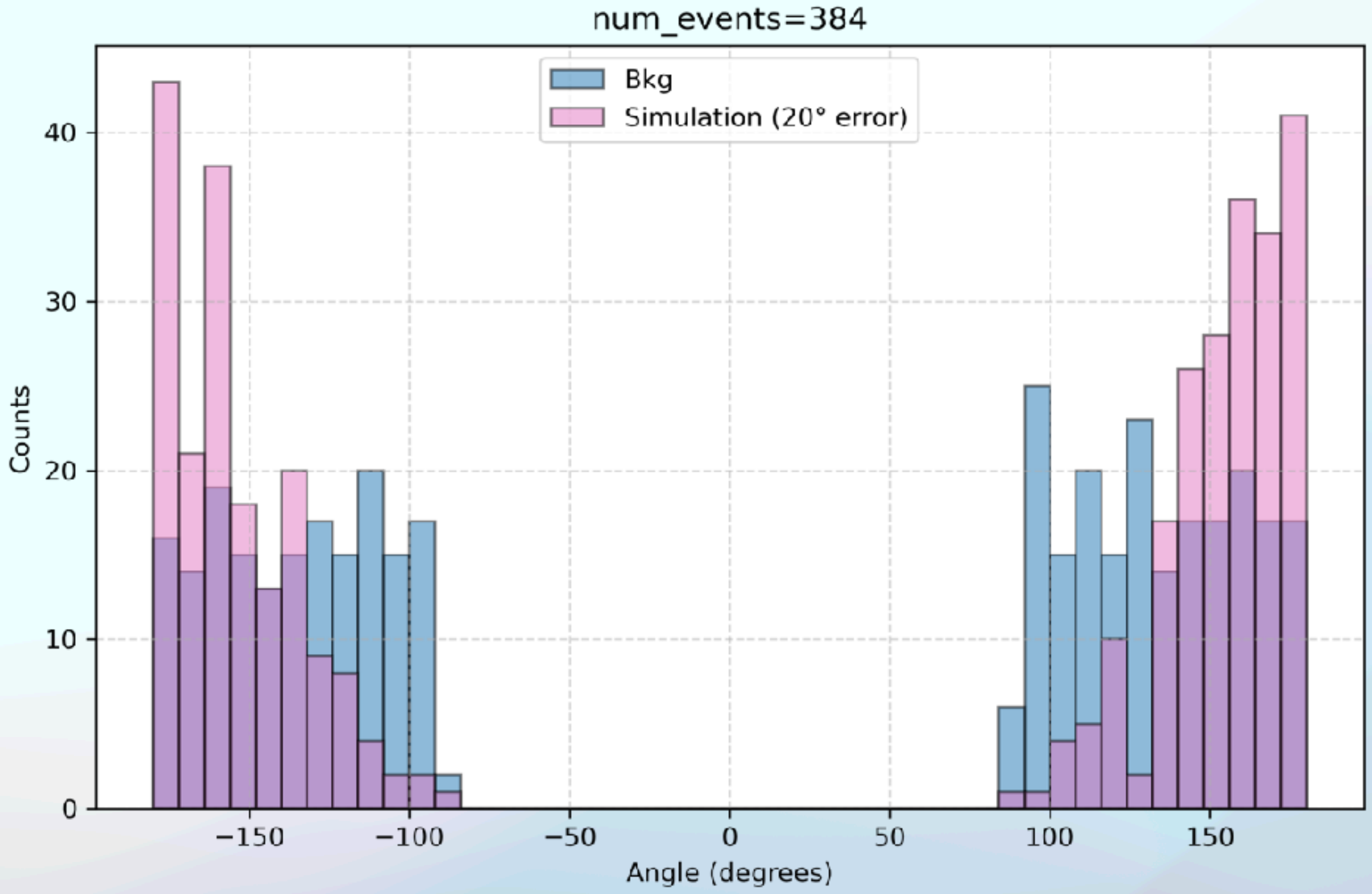
2.2c. MC validation - Gaussian Smearing

Angular resolution = 10°:

2.2c. MC validation - Gaussian Smearing

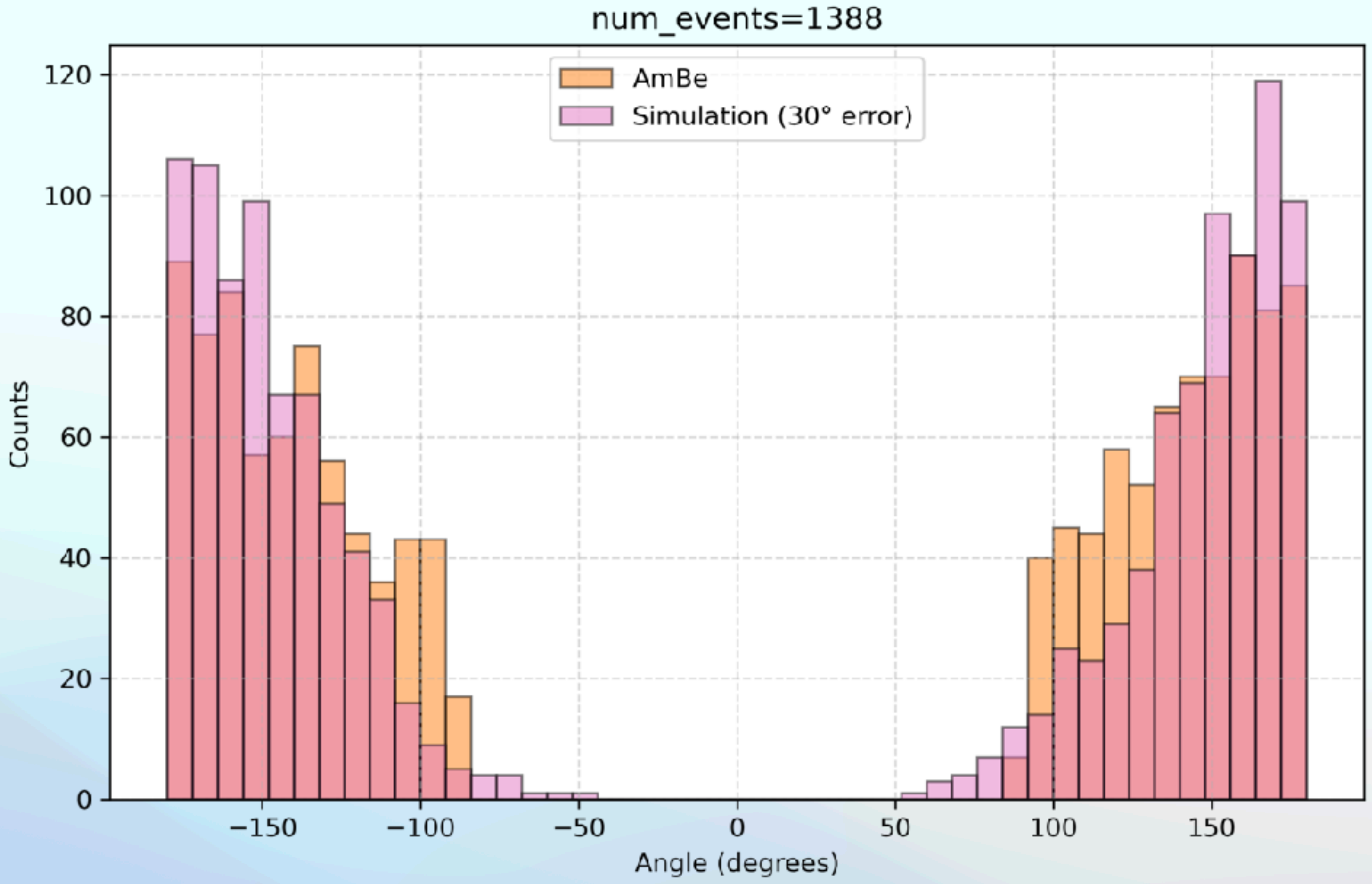
Angular resolution = 20°:

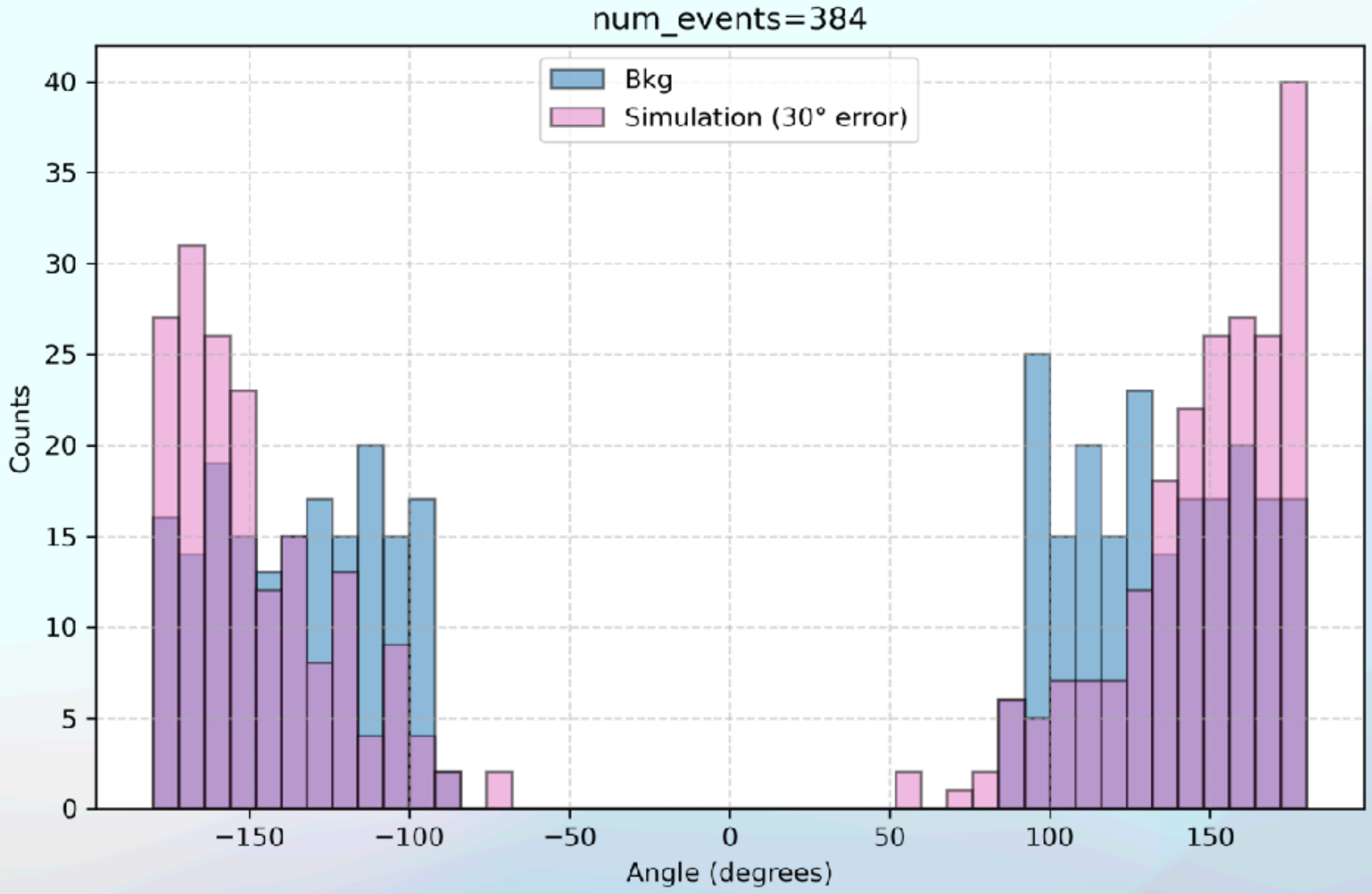




2.2c. MC validation - Gaussian Smearing

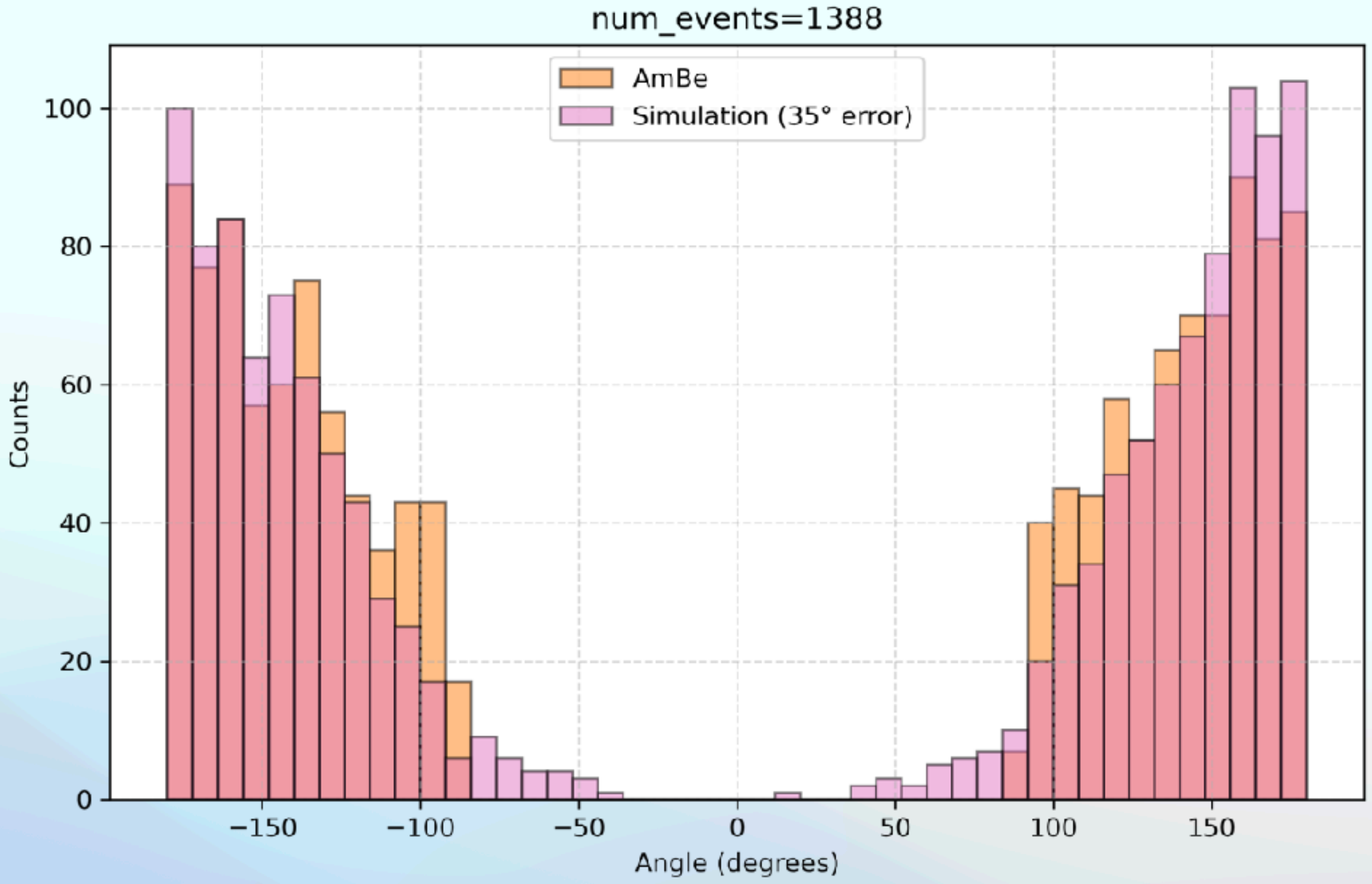
Angular resolution = 30°:

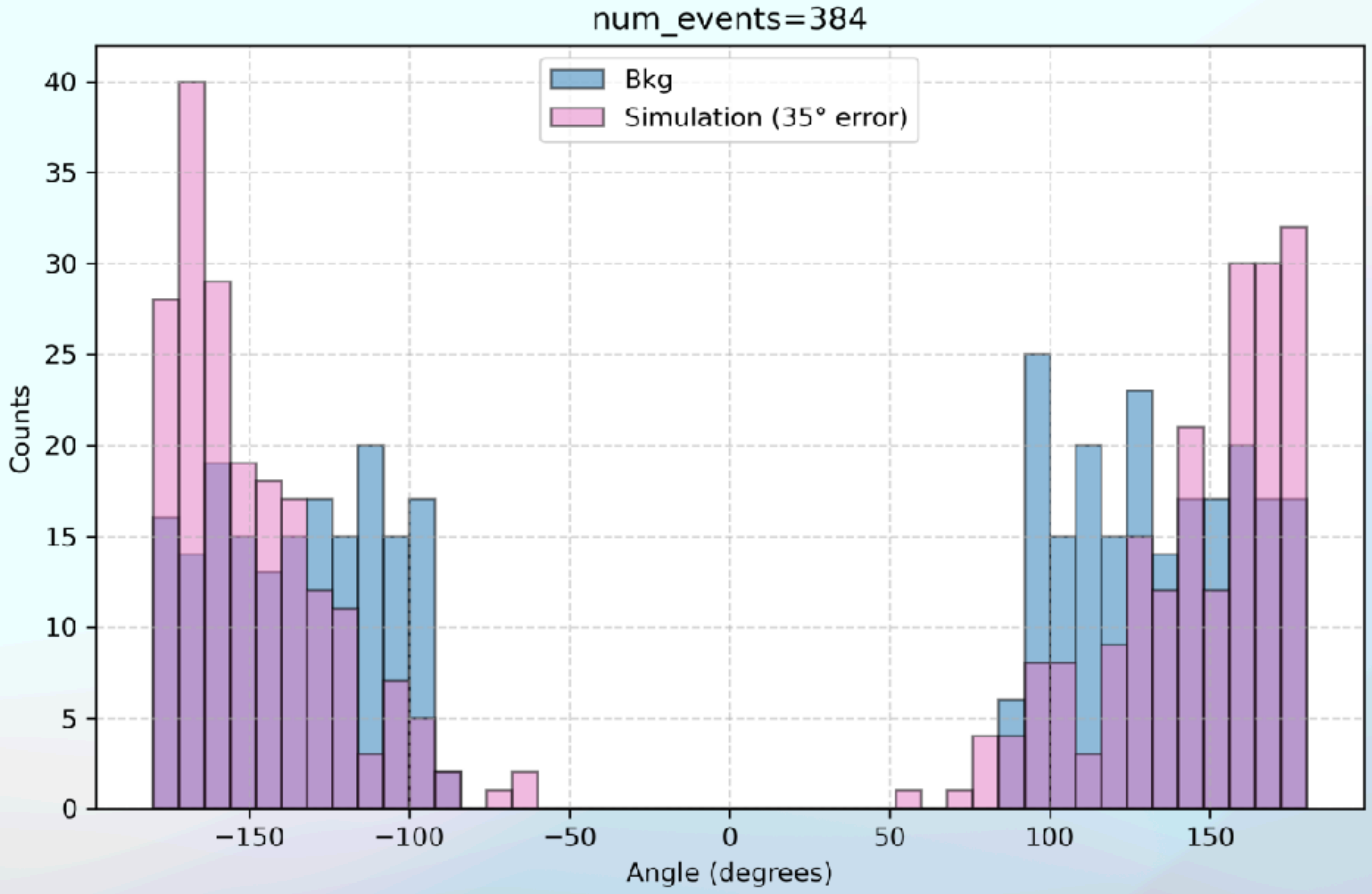




2.2c. MC validation - Gaussian Smearing

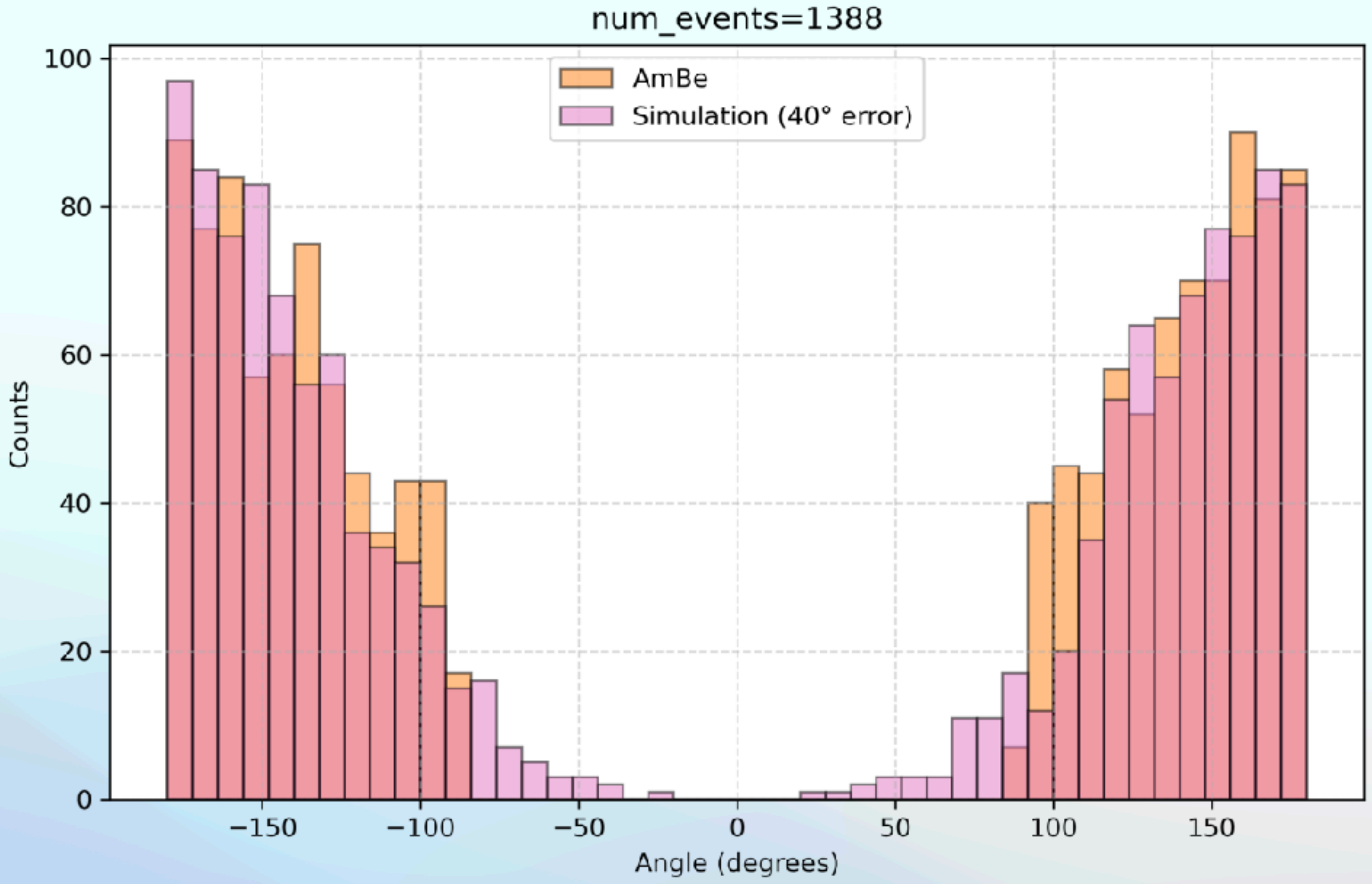
Angular resolution = 35°:

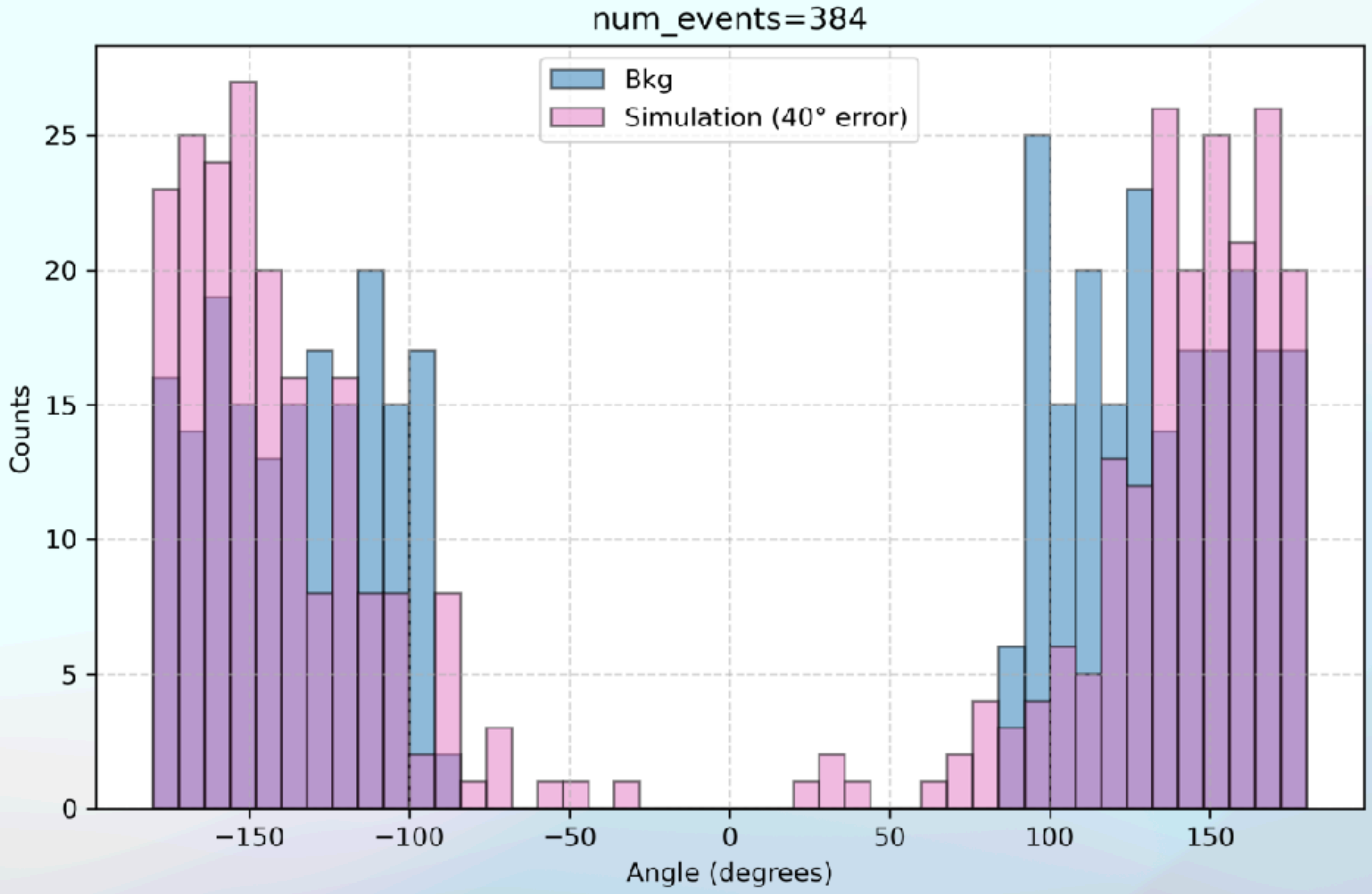




2.2c. MC validation - Gaussian Smearing

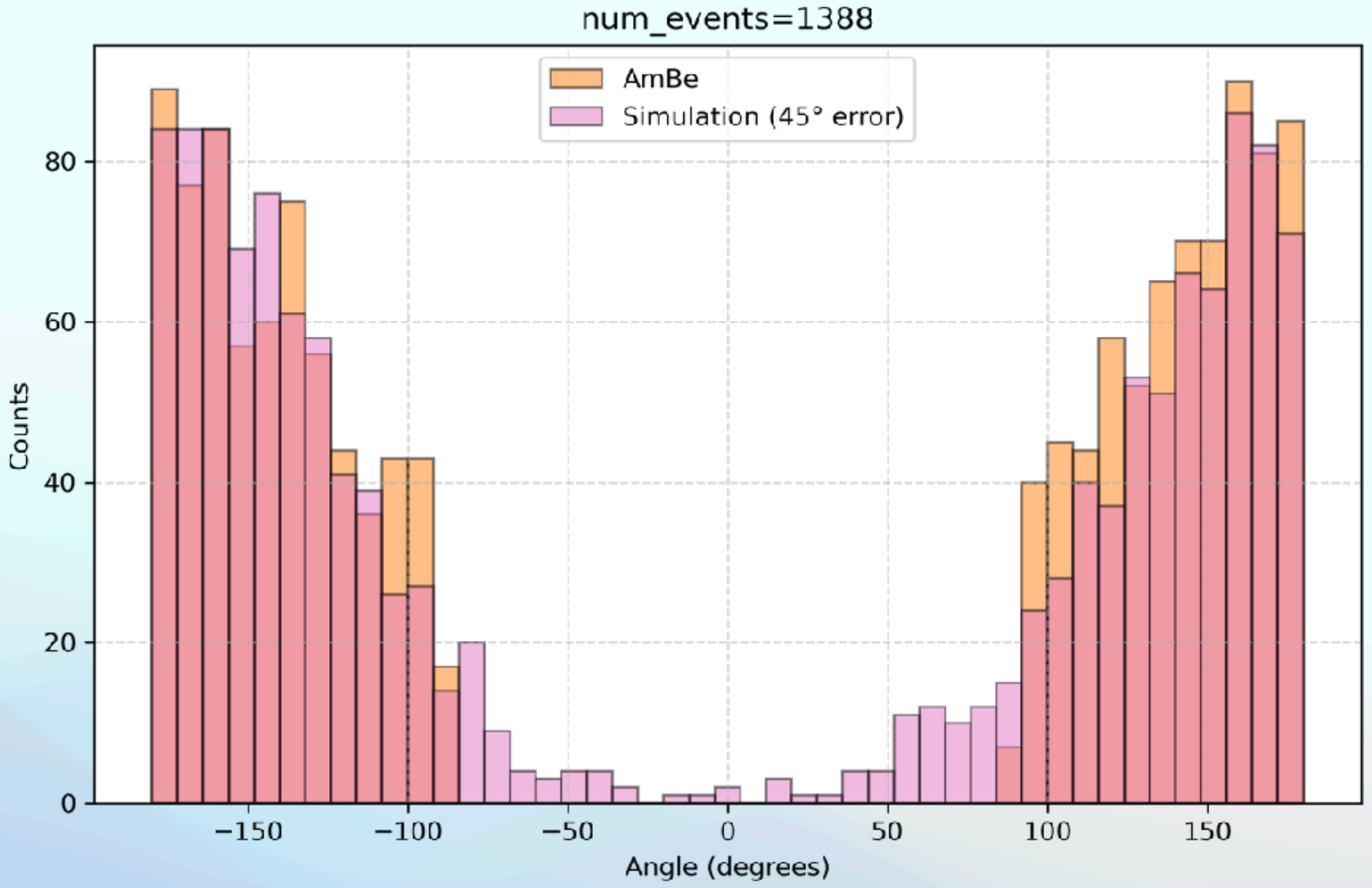
Angular resolution = 40°:

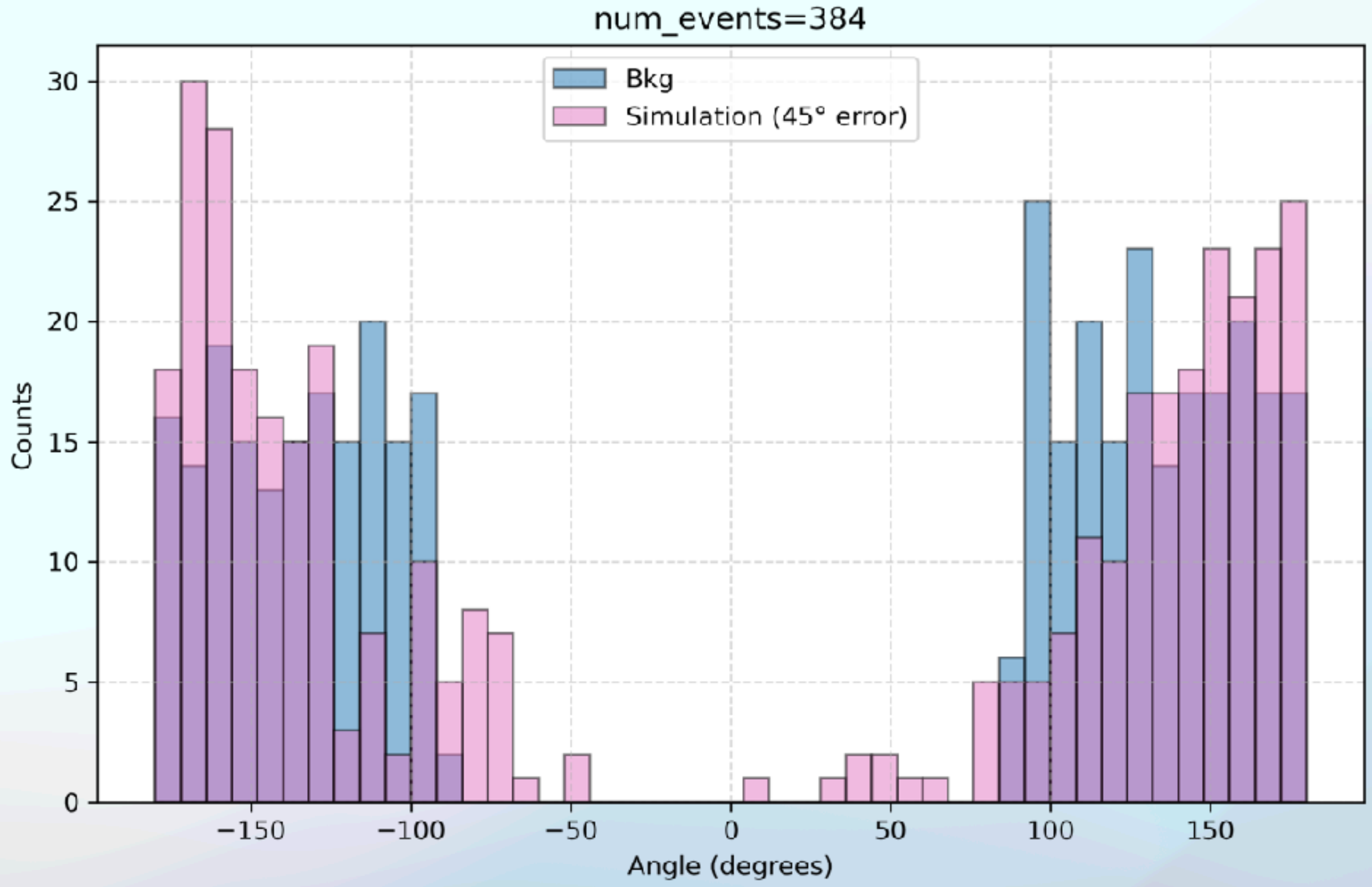




2.2c. MC validation - Gaussian Smearing

Angular resolution = 45°:

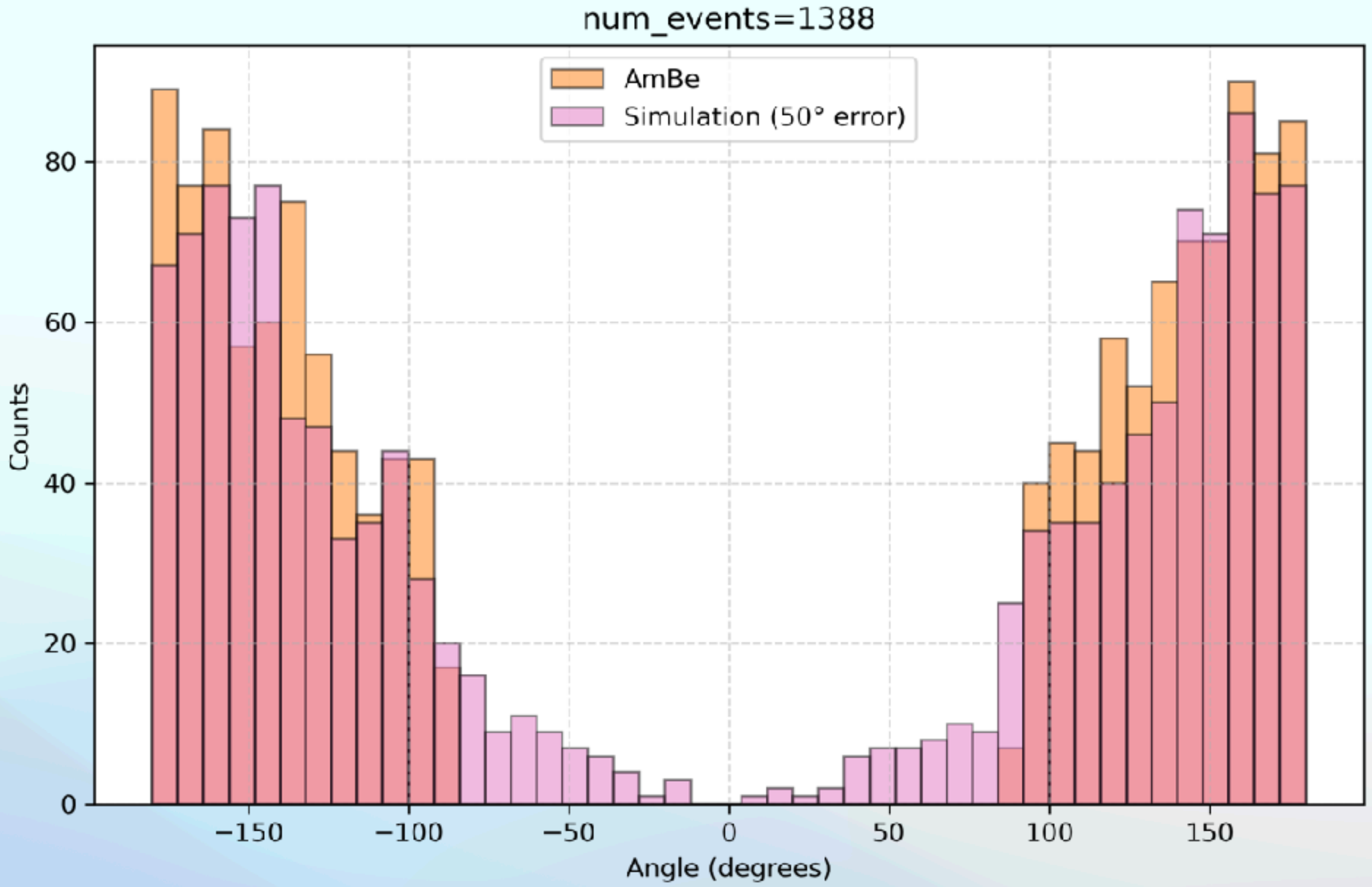


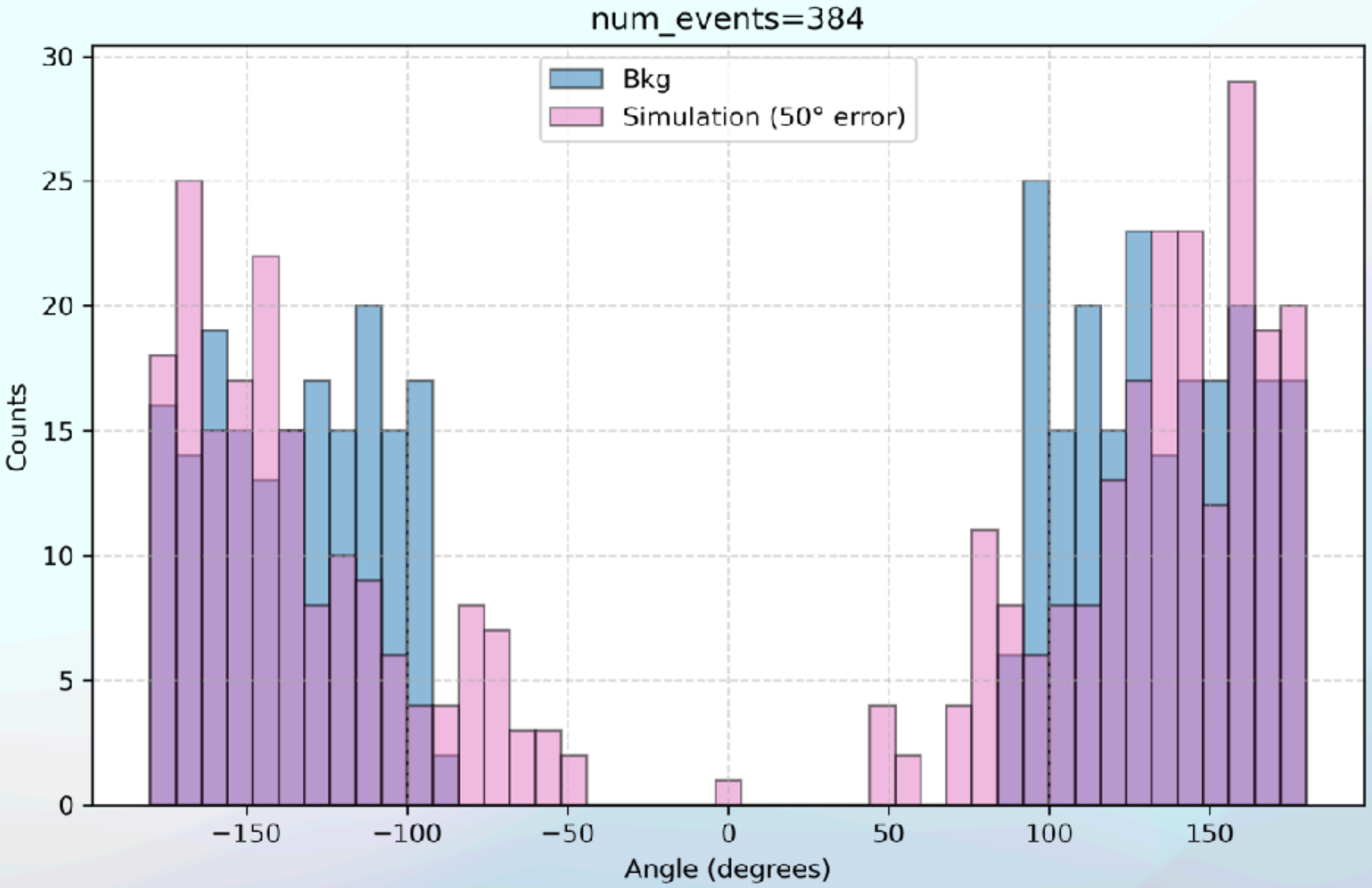


X

2.2c. MC validation - Gaussian Smearing

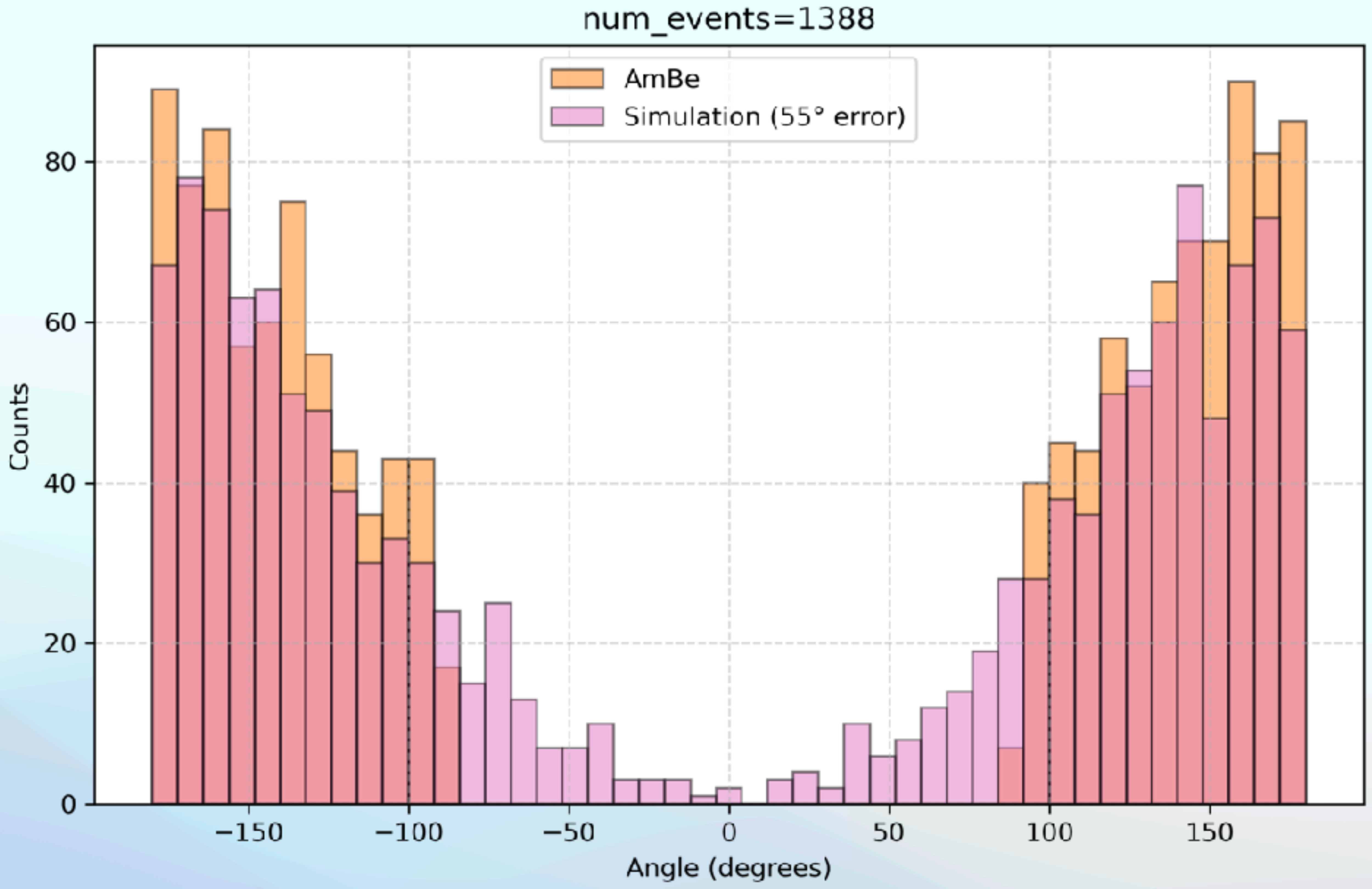
Angular resolution = 50°:

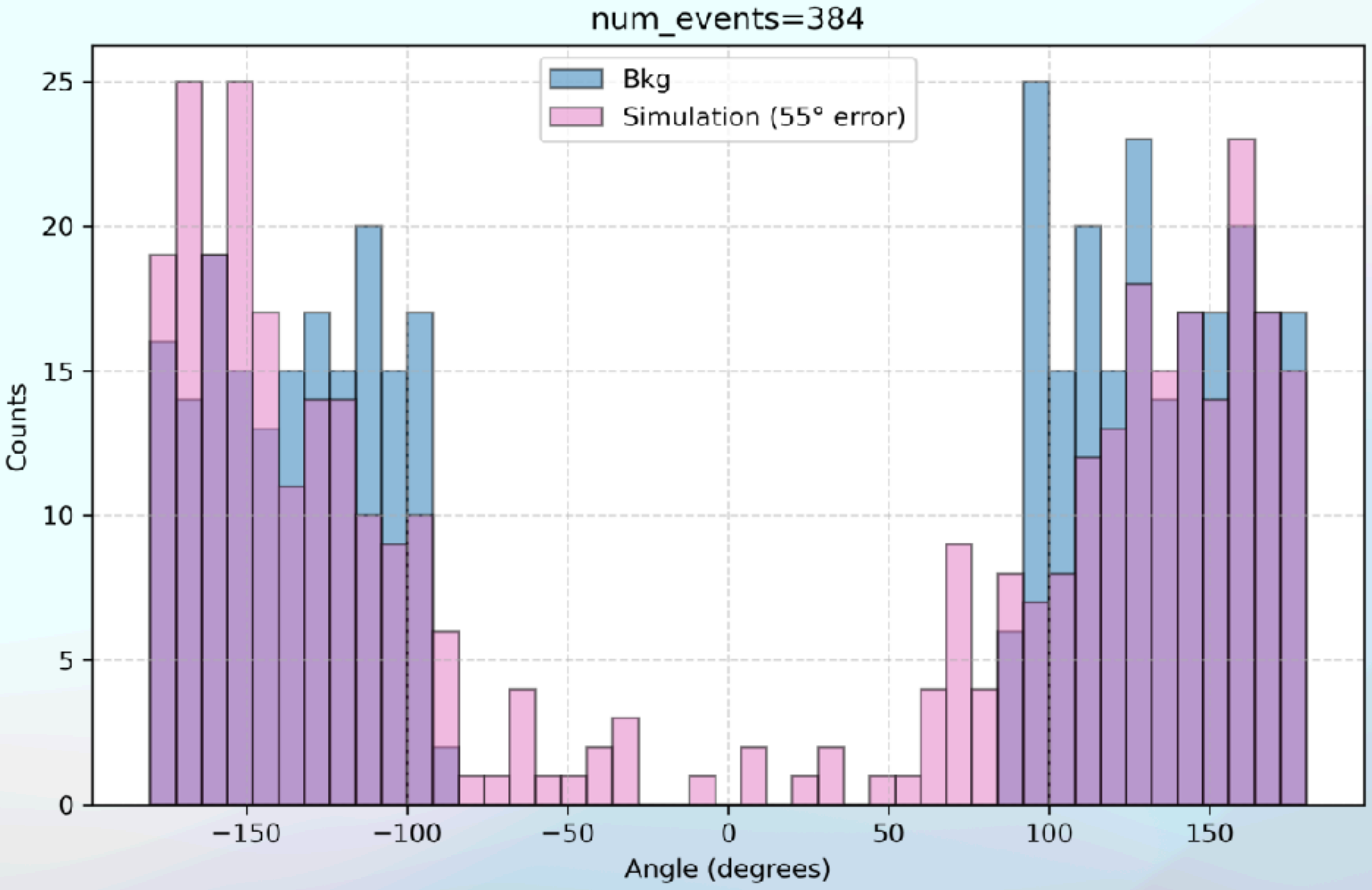




2.2c. MC validation - Gaussian Smearing

Angular resolution = 55°:

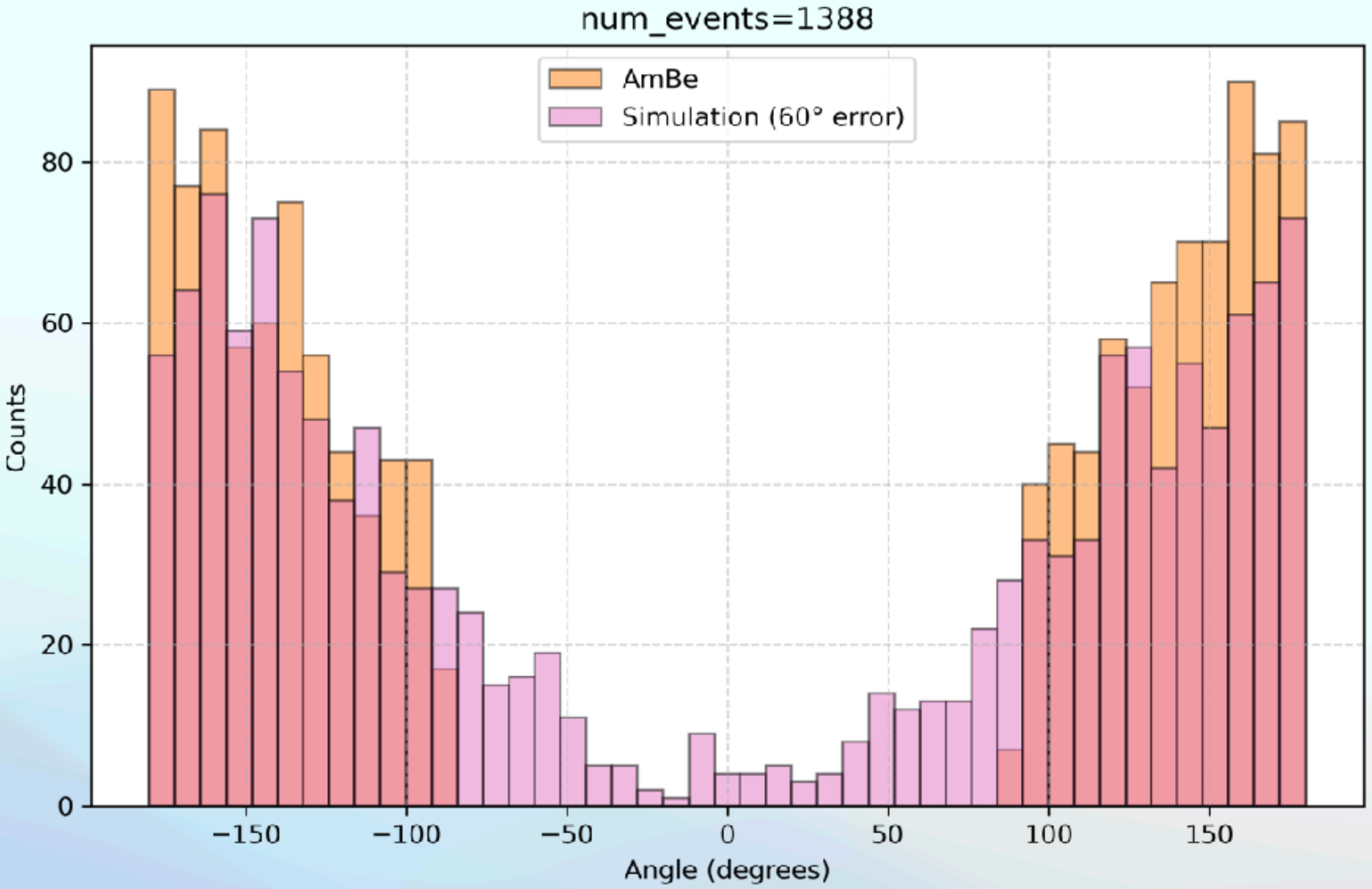


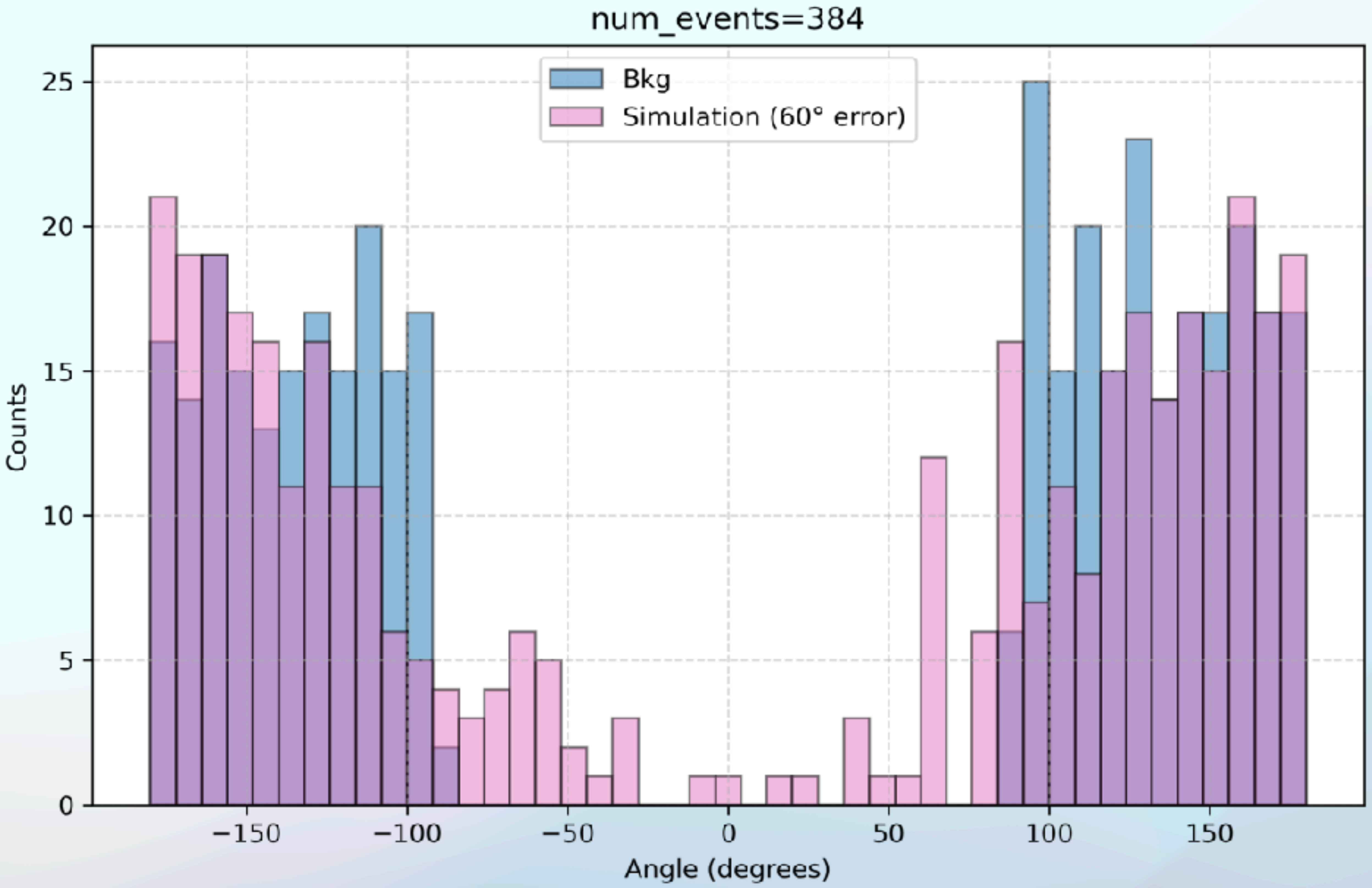


X

2.2c. MC validation - Gaussian Smearing

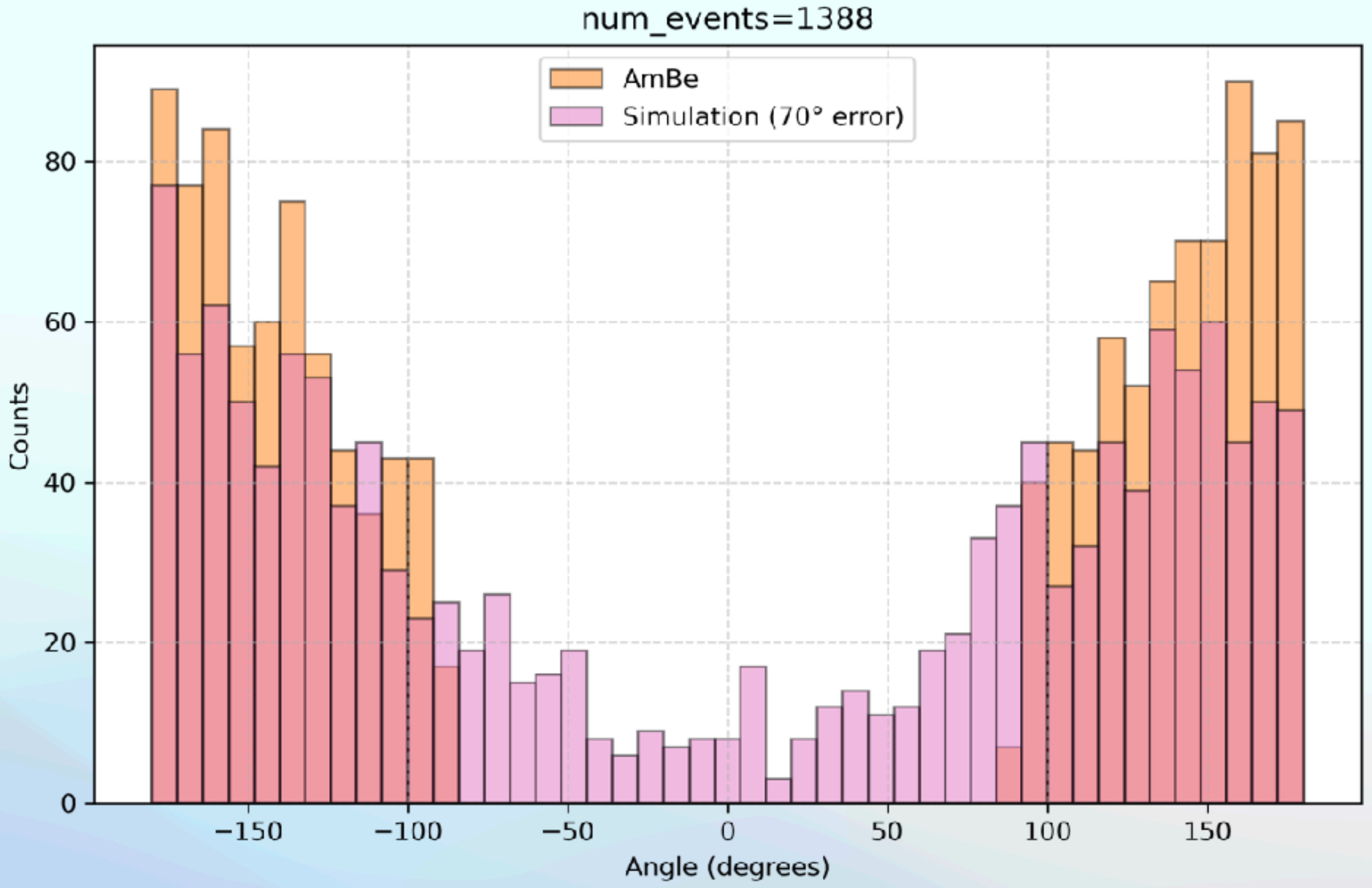
Angular resolution = 60°:

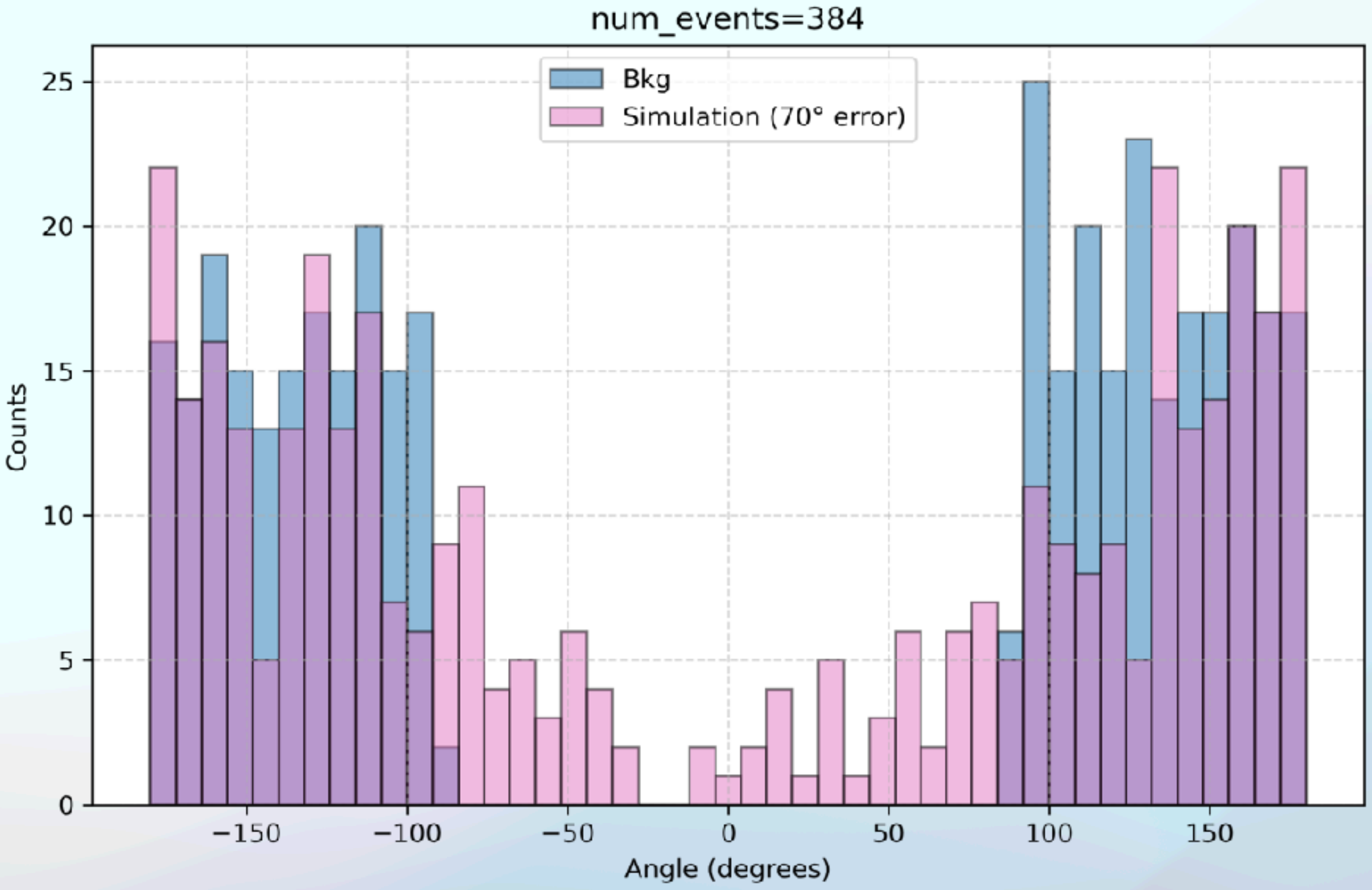




2.2c. MC validation - Gaussian Smearing

Angular resolution = 70°:





X

2.2c. MC validation - Gaussian Smearing

Angular resolution = 80°:

X

2.3. Clusters 3D range reconstruction

- To perform 3D range reconstruction, we should **sum in quadrature** the length we measure from the camera reco (**sc_length**) with the length we can reconstruct from the PMTs (**L_z**).

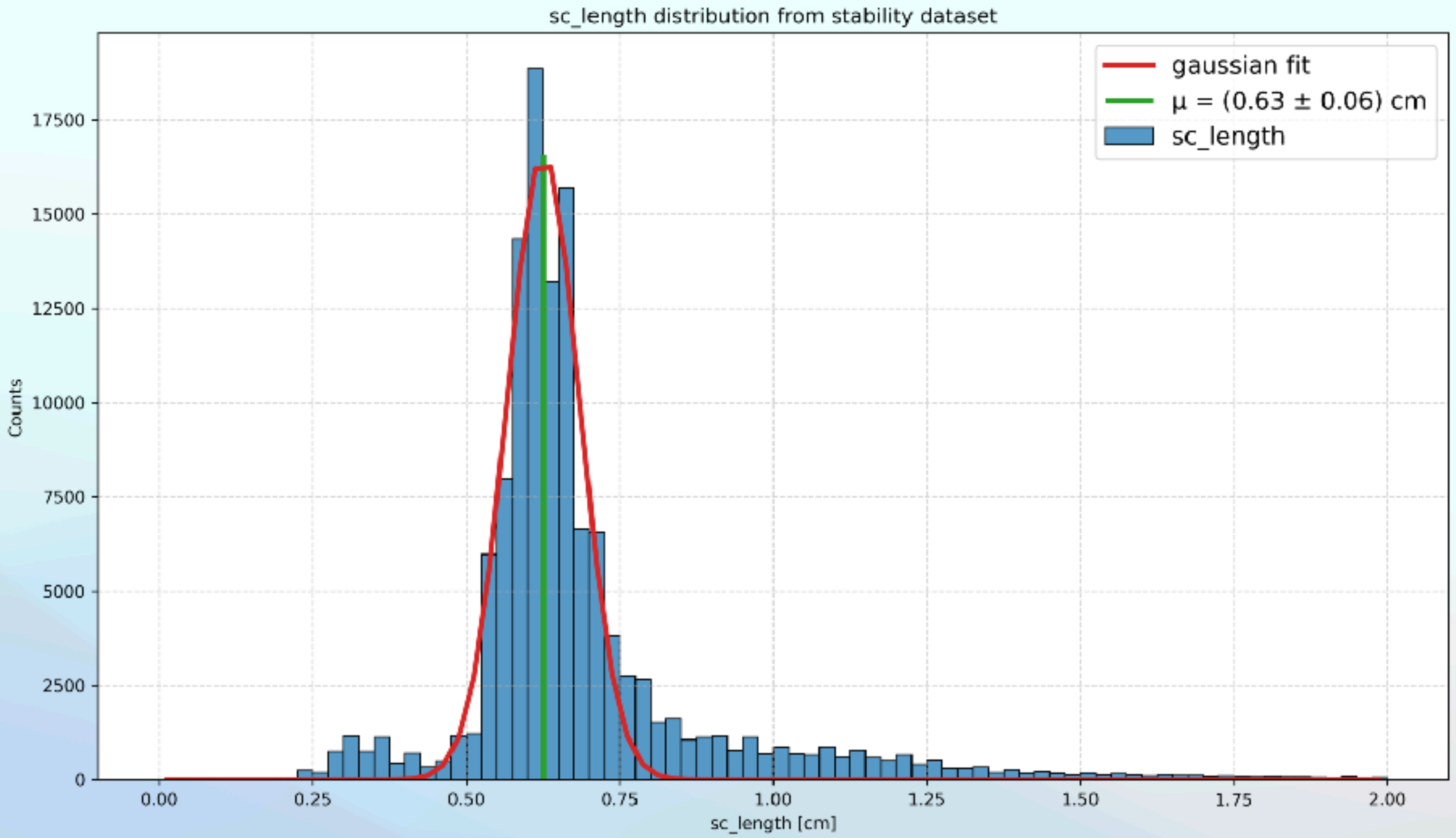
- L_z can be computed by multiplying the drift velocity (**v_{drift}**) to the maximum time over threshold (**ToT**) that we can find in the waveforms associated to a specific cluster.

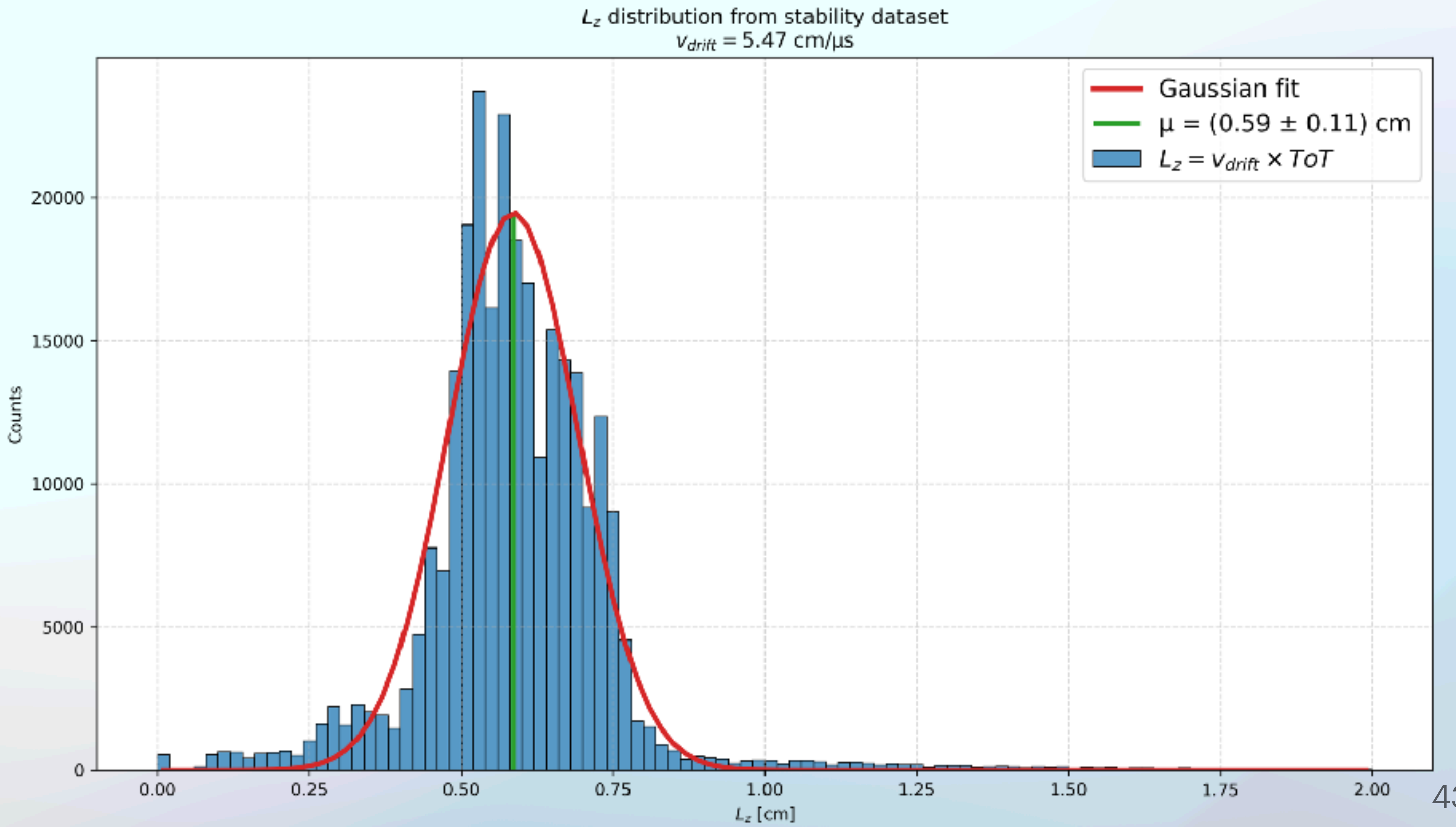
- Namely: 3D range $= \sqrt{\text{sc\_length}^2 + L_z^2}$, with $L_z = v_{drift} \times ToT^{max}$

- To perform an analysis of this kind, **only lonely nuclear recoils are considered**, in order to have a 1:1 cluster-waveforms match, reducing the AmBe NR sample to ~**350 events**.

2.3. Clusters 3D range reconstruction

- Using Stability dataset, we can evaluate the diffusion that we experience on the GEM plane and in the drift direction.
- Their sum in quadrature gives us the effective diffusion that affects ^{55}Fe clusters.



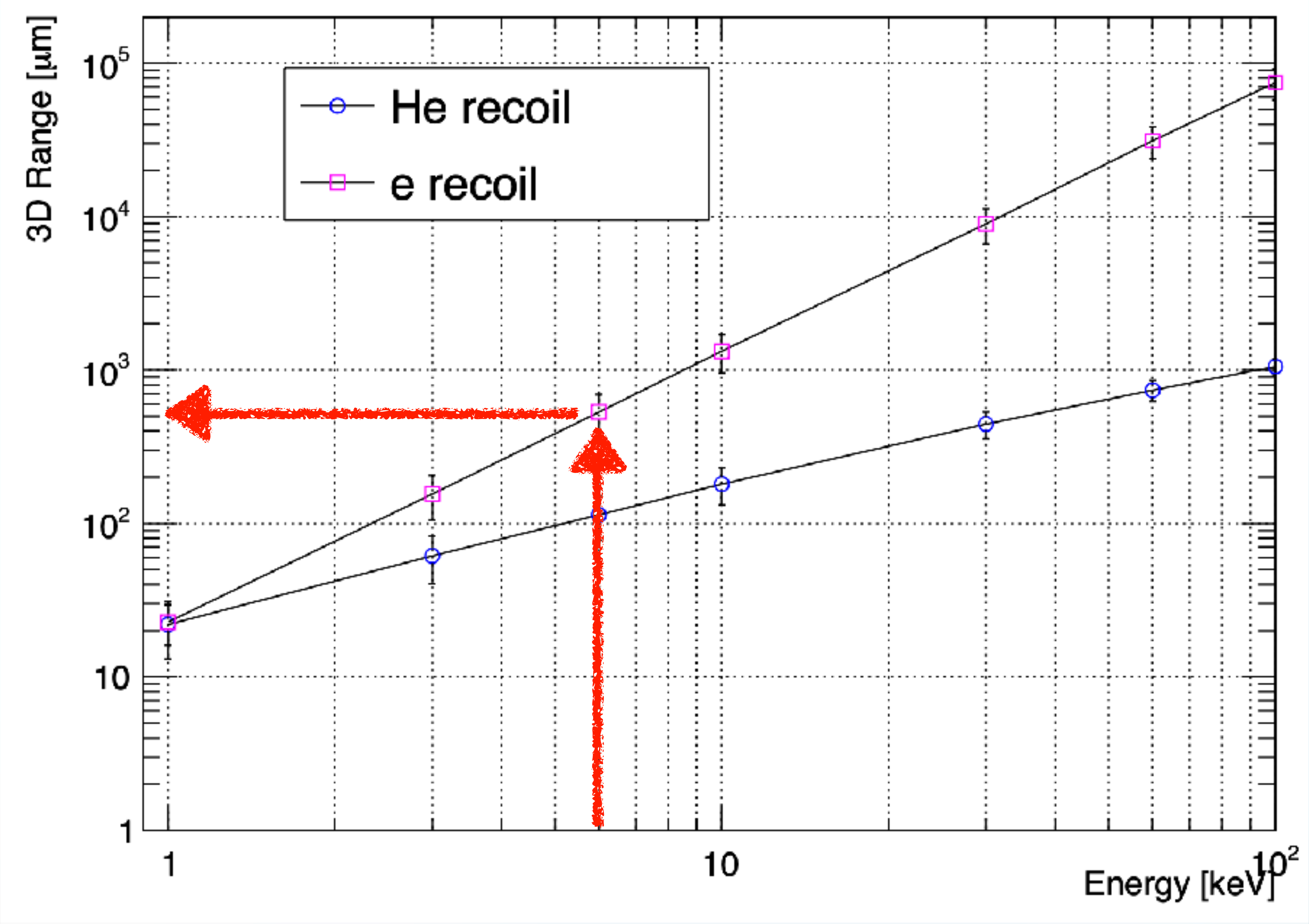


2.3. Clusters 3D range reconstruction

- A 5.9 keV e^- should travel ~0.5 mm in $He:CF_4$.
- From the previous slide we obtain:

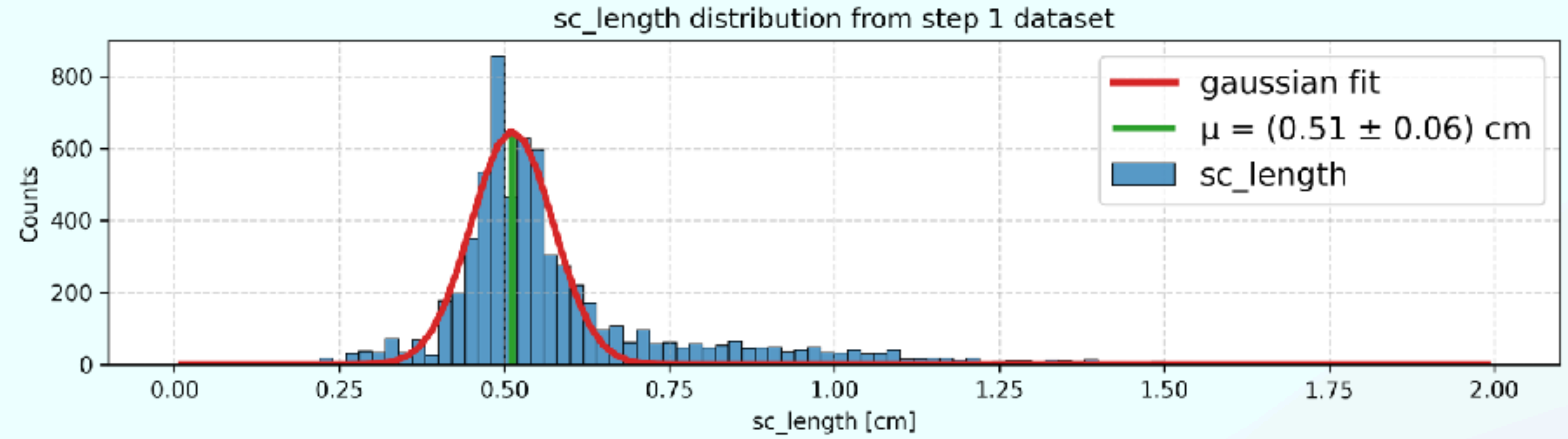
$$8.63 \pm 0.9 \text{ mm}$$

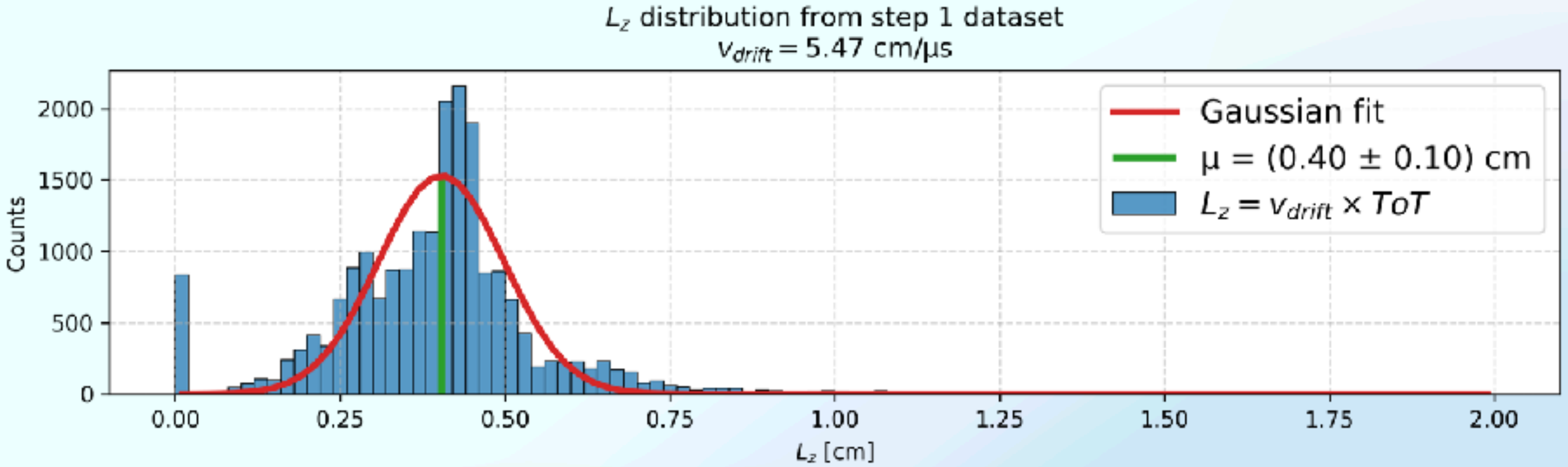
- **1 order of magnitude bigger wrt the true value.**
- We will use this diffusion measurement as offsets to be subtracted to their respective physical quantity.

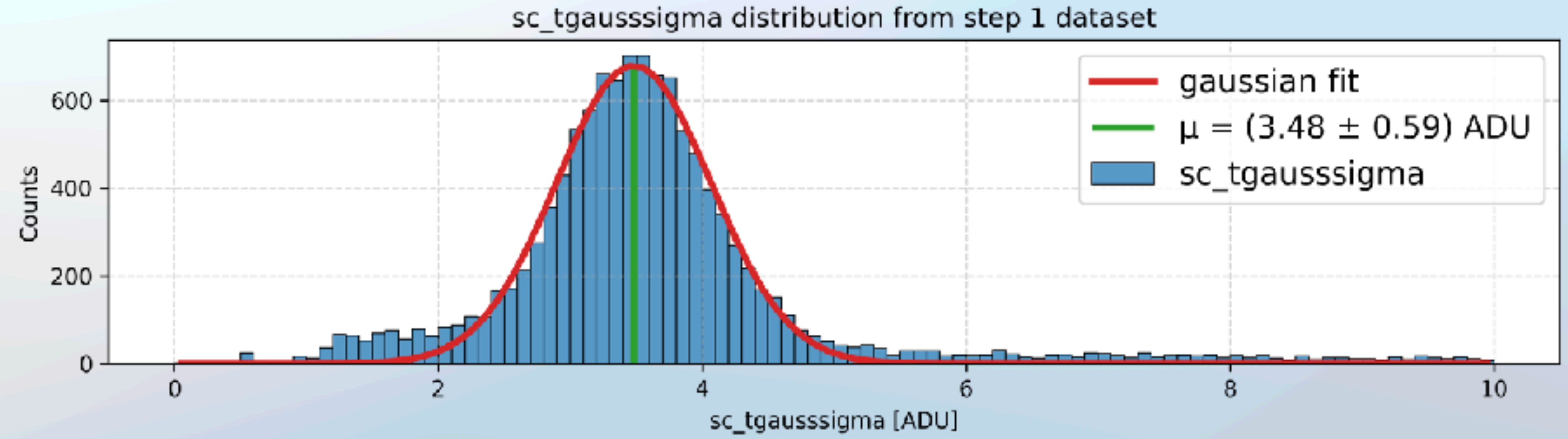


2.3. Clusters 3D range reconstruction

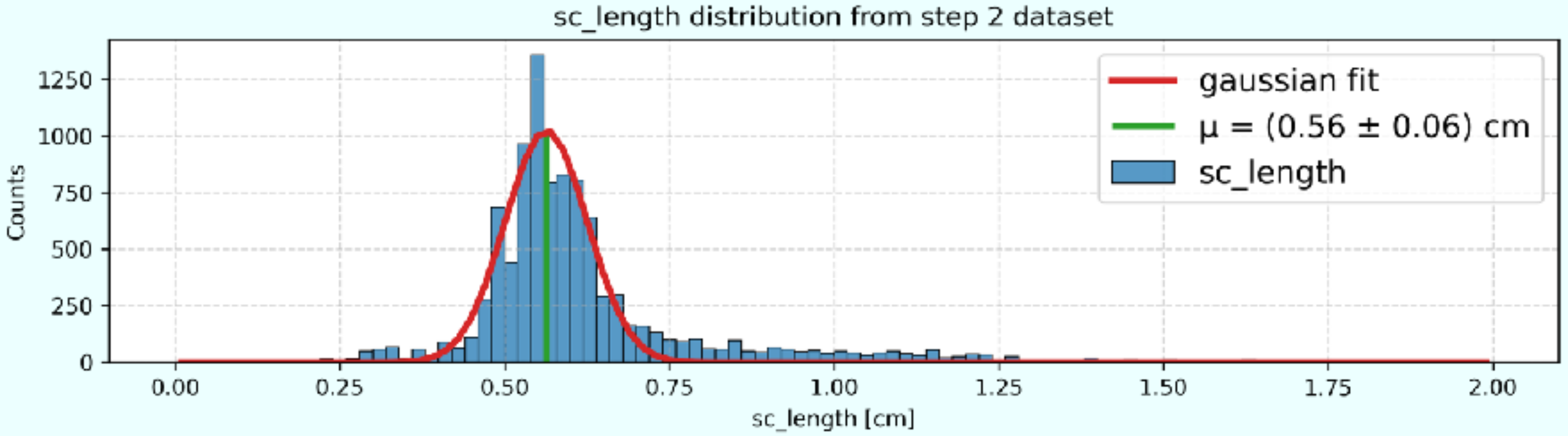
- Actually, we can do better.
- We can use **sc_tgausssigma to track distance from the GEMs**.
- From the daily calibration we can perform the previous analysis at each calibration step to extract the diffusion offsets and associating them to a mean sc_tgausssigma.
- Then, we can subtract the correct offset to each cluster by means of its sc_tgausssigma, exploiting the diffusion dependance on this variable using a square root fit.

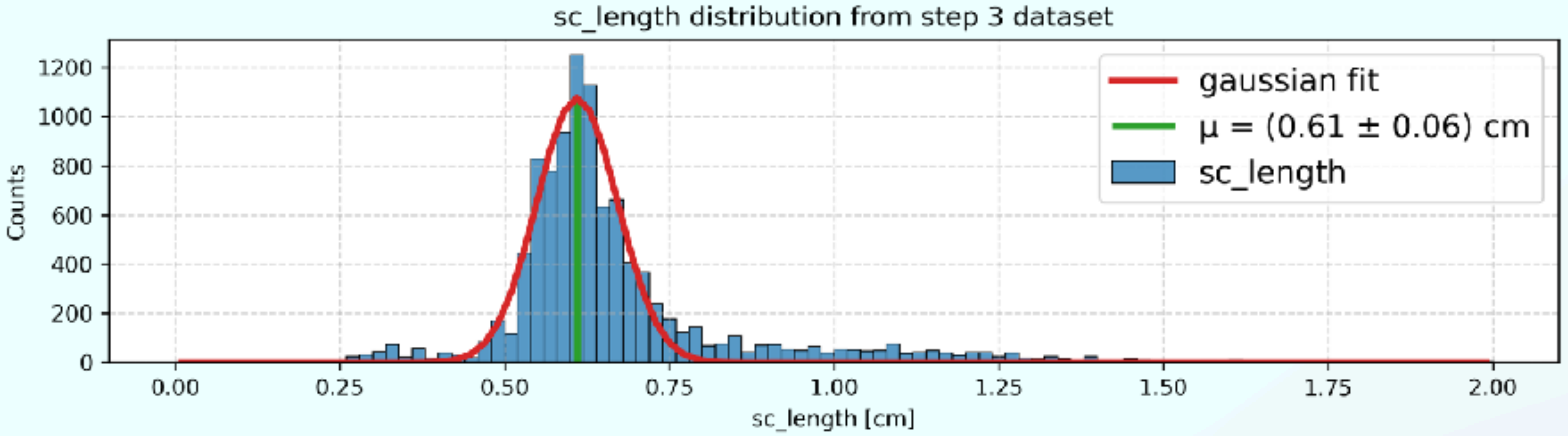


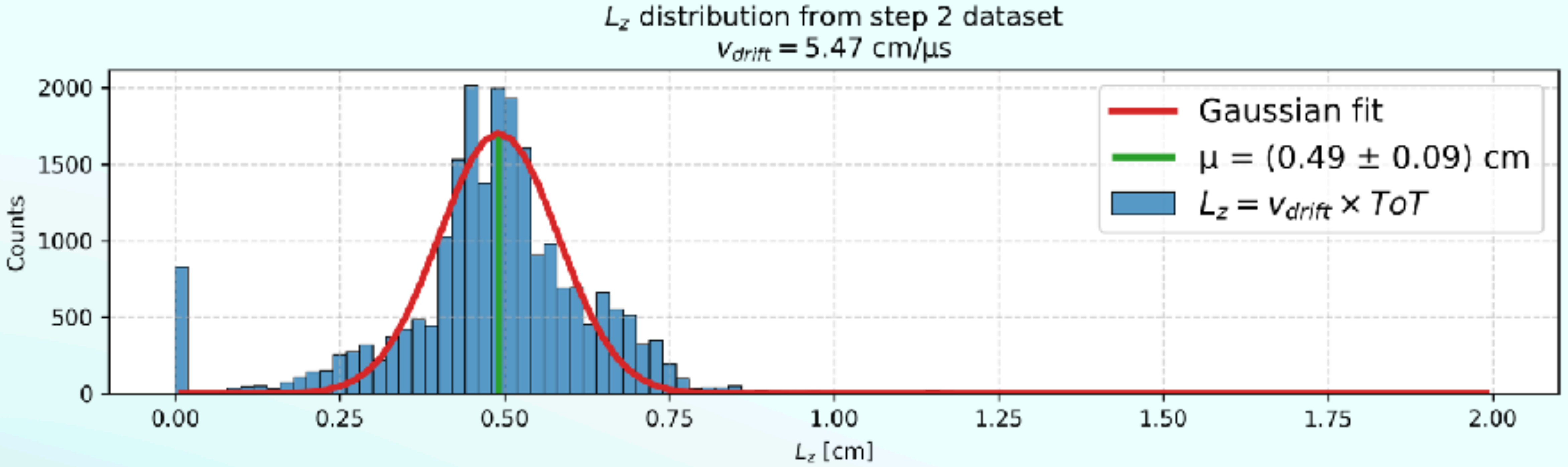


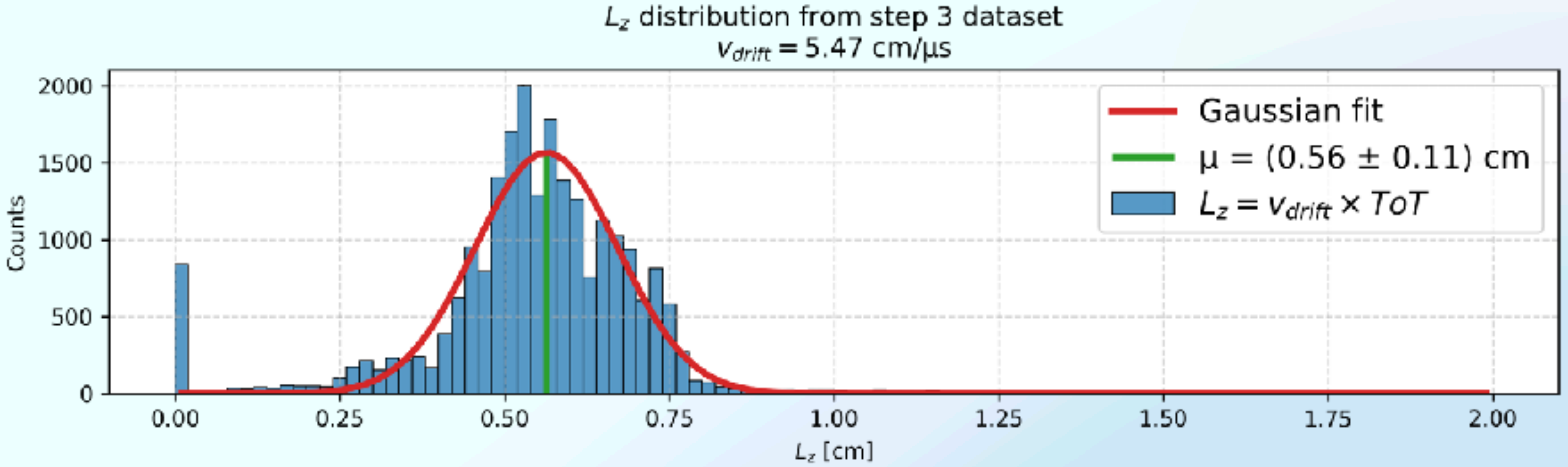


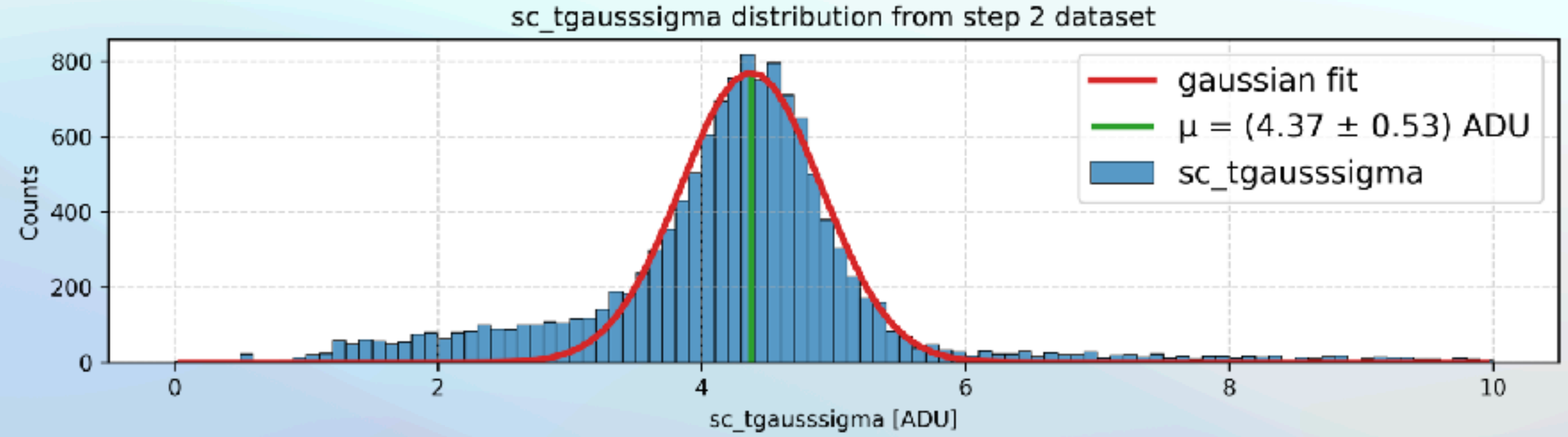
2.3. Clusters 3D range reconstruction

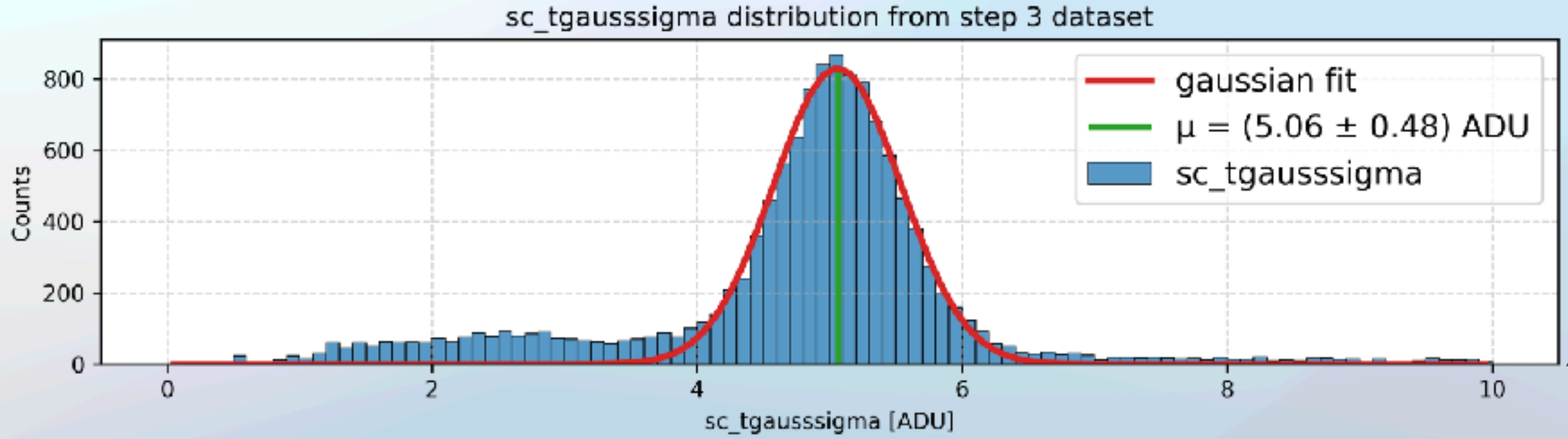




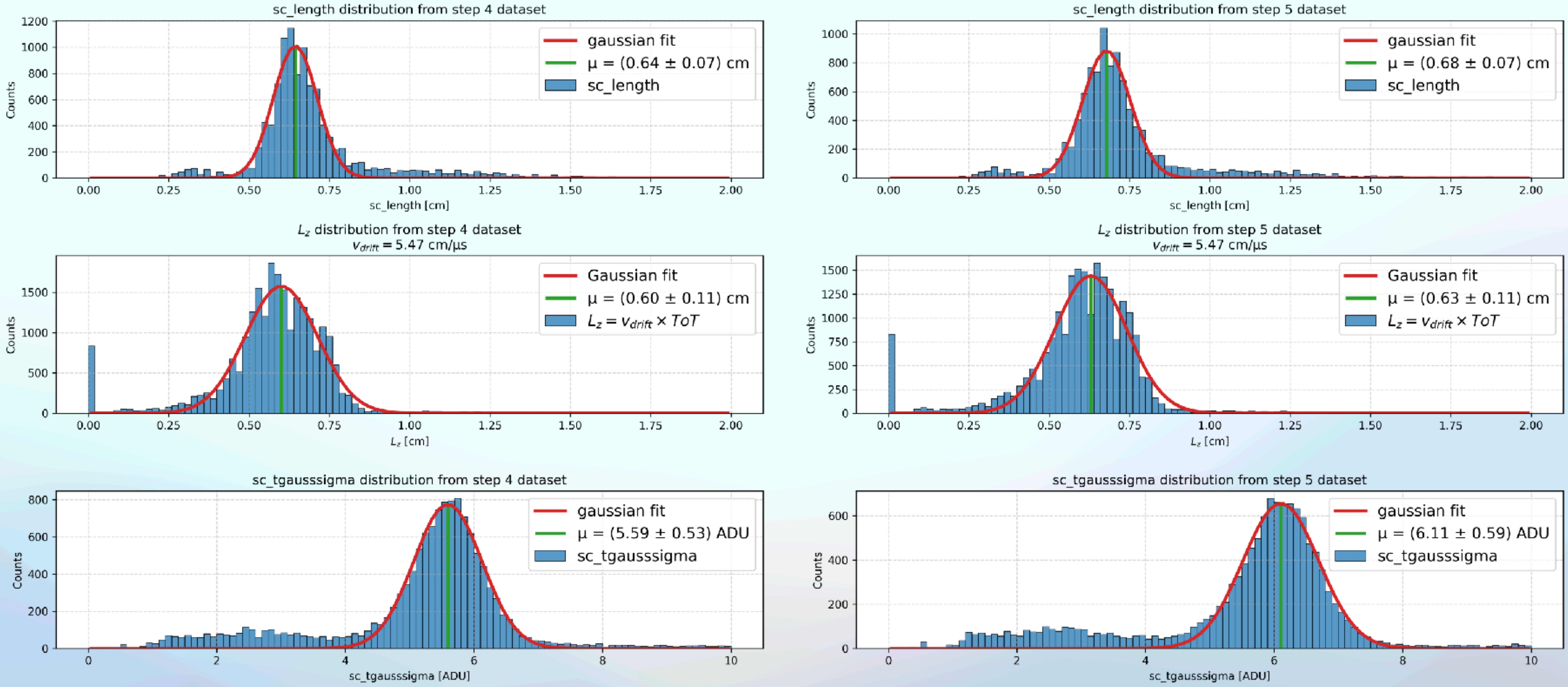






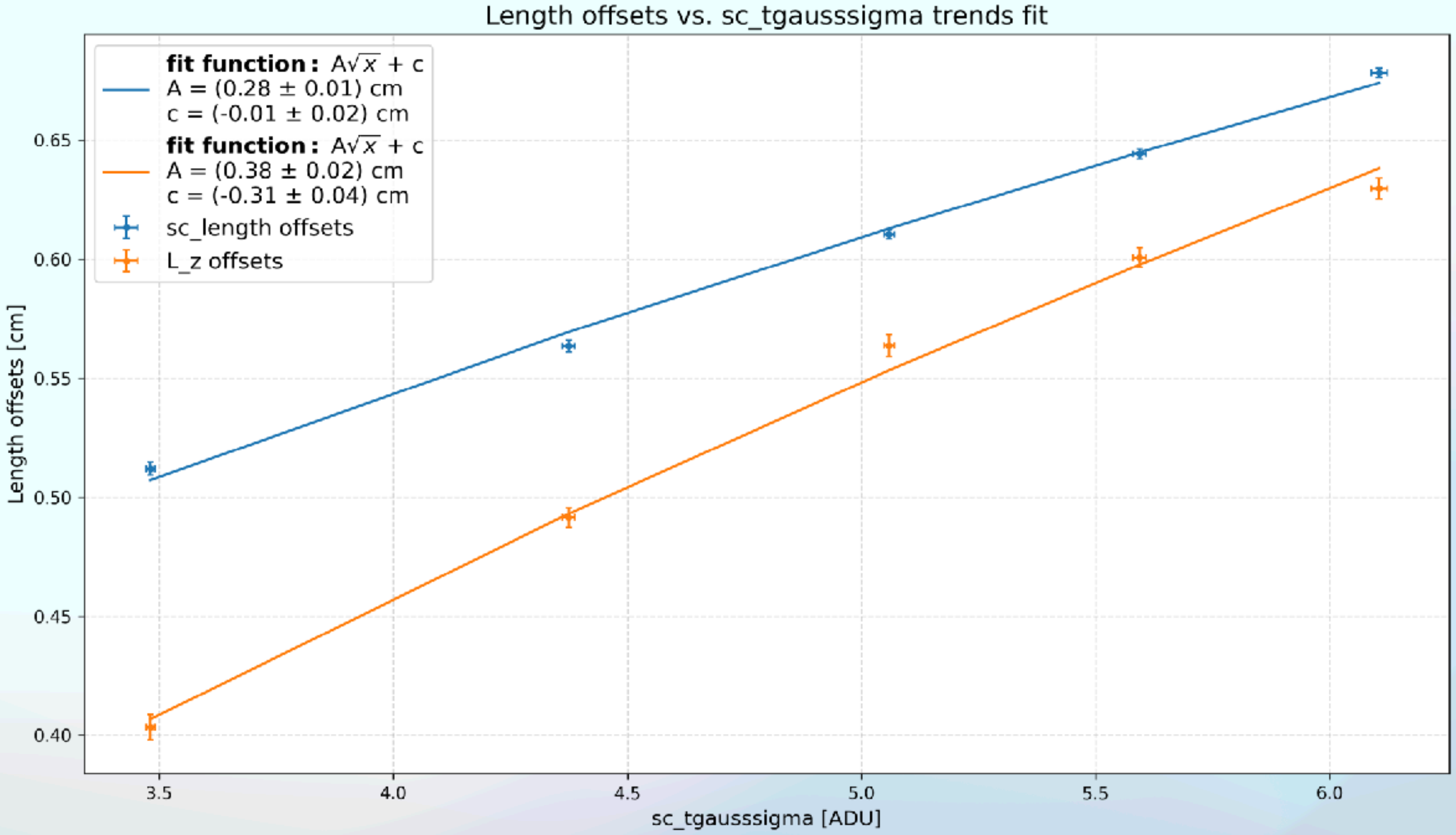


2.3. Clusters 3D range reconstruction



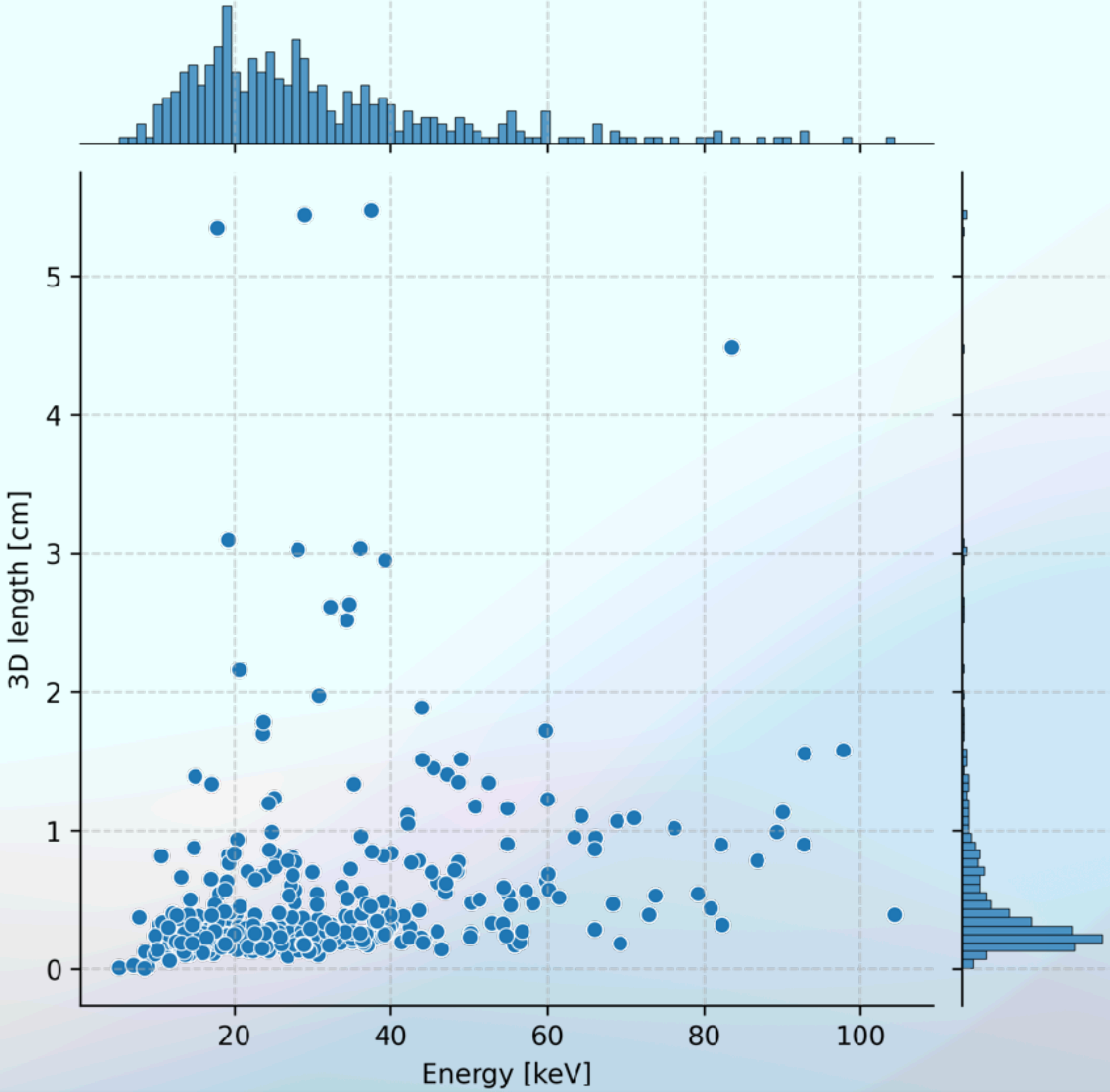
2.3. Clusters 3D range reconstruction

- It is known that **diffusion of ionisation electrons scales with the square root of the distance** (in drift chambers).
- The match between the square root fit and the data points for both sc_length and L_Z vs. sc_tgausssigma is a nice confirmation of the goodness of this approach.



2.3. Clusters 3D range reconstruction

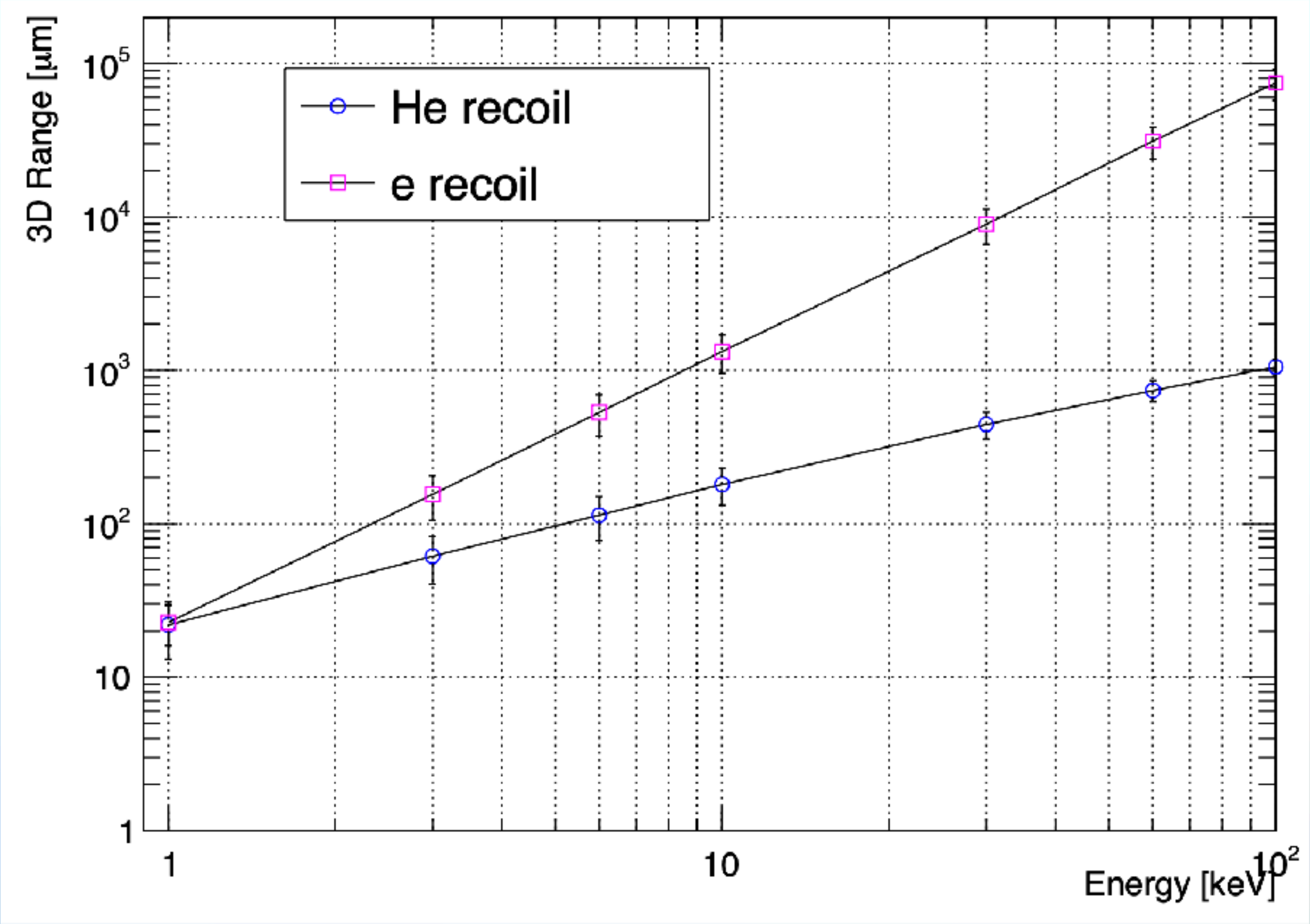
- In He:CF_4, we should see nuclear recoils from He, C or F.
- In principle, this should be reflected in the range vs energy distribution, but **no evident population is visible**.
- This could be due to the well known **gain saturation problem** that manifests when a large number of ionisation electrons reach the GEMs all at once.

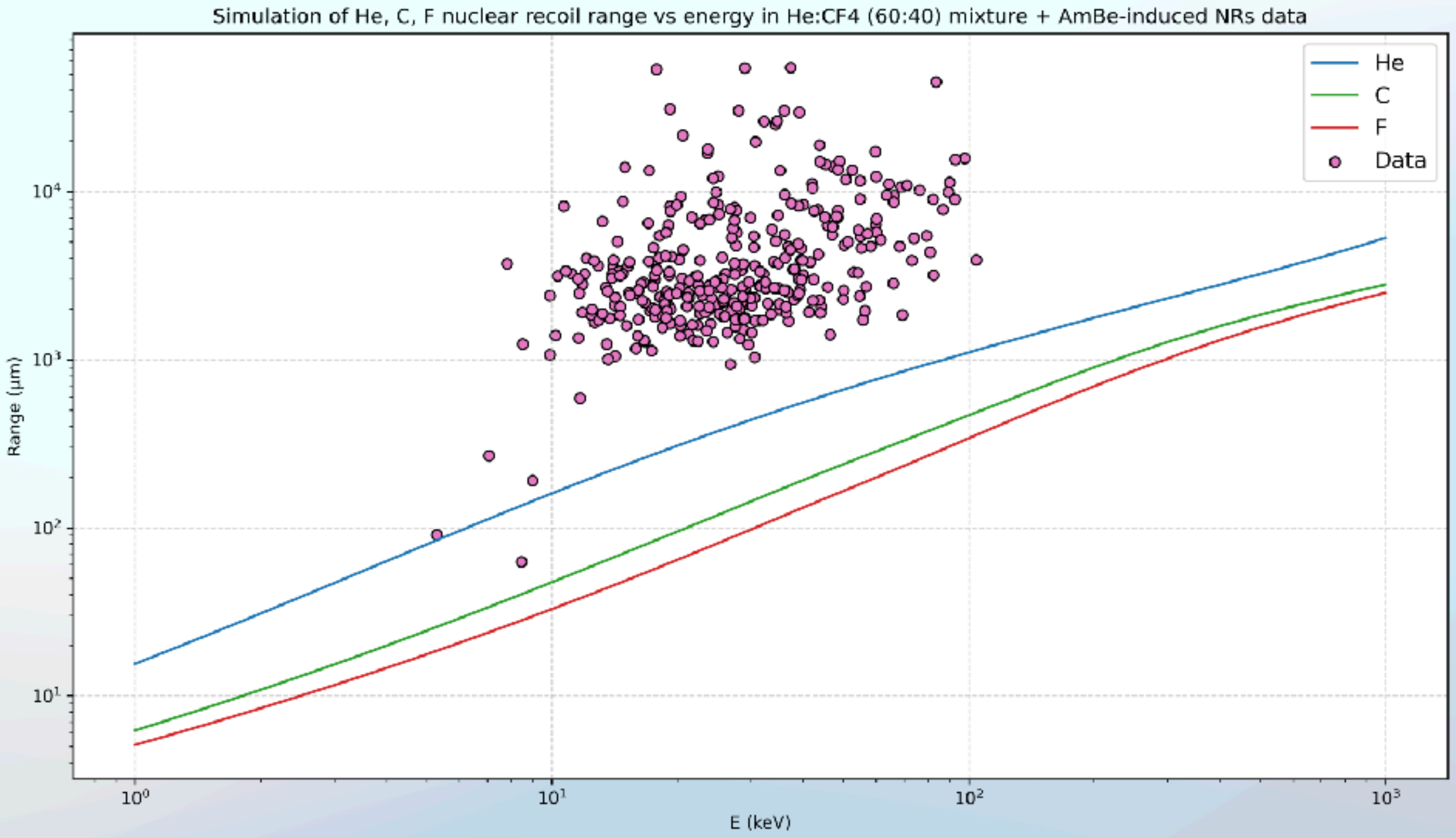


2.3. Clusters 3D range reconstruction

- Expand **Range vs Energy** simulation for He NRs in He:CF_4 plot using E. Marconato data which also include C and F.

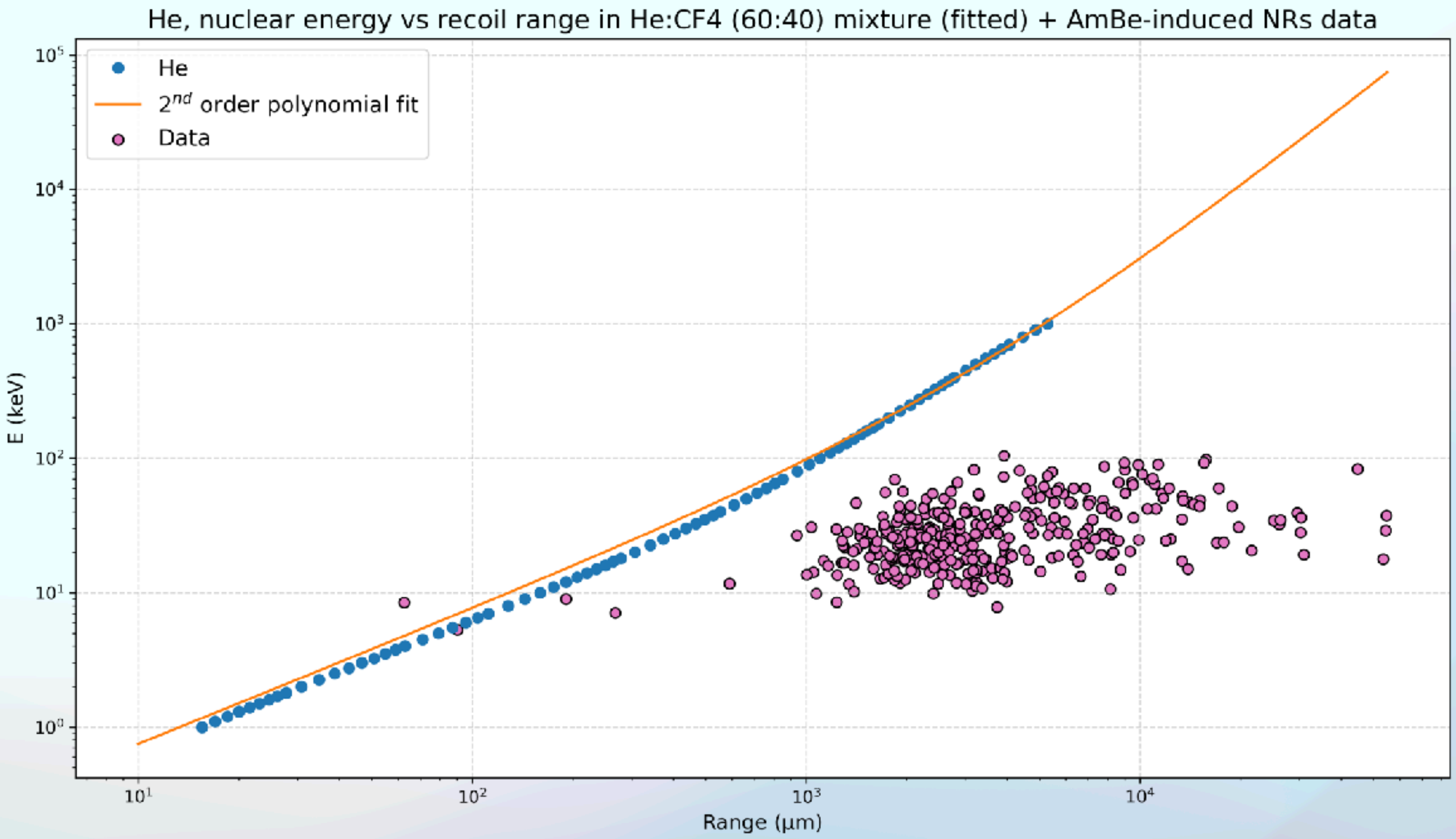
- We see the gain saturation in action.





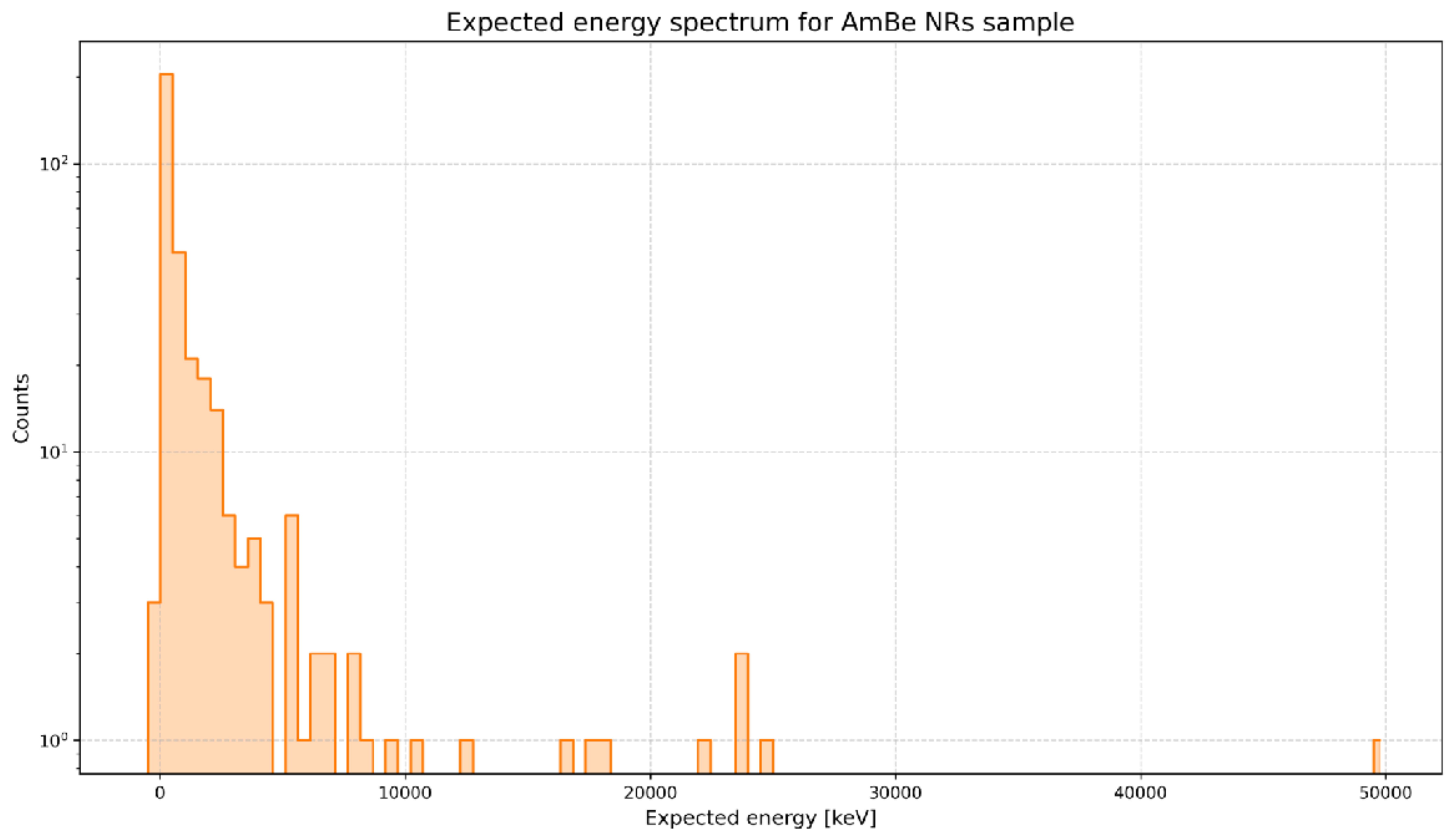
2.3. Clusters 3D range reconstruction

- Assume we have only He recoils.
- Fit the **Energy vs Range** simulation with a 2nd order polynomial function.
- With this we can extrapolate energies outside the simulated range domain and compute the "**expected energy**".



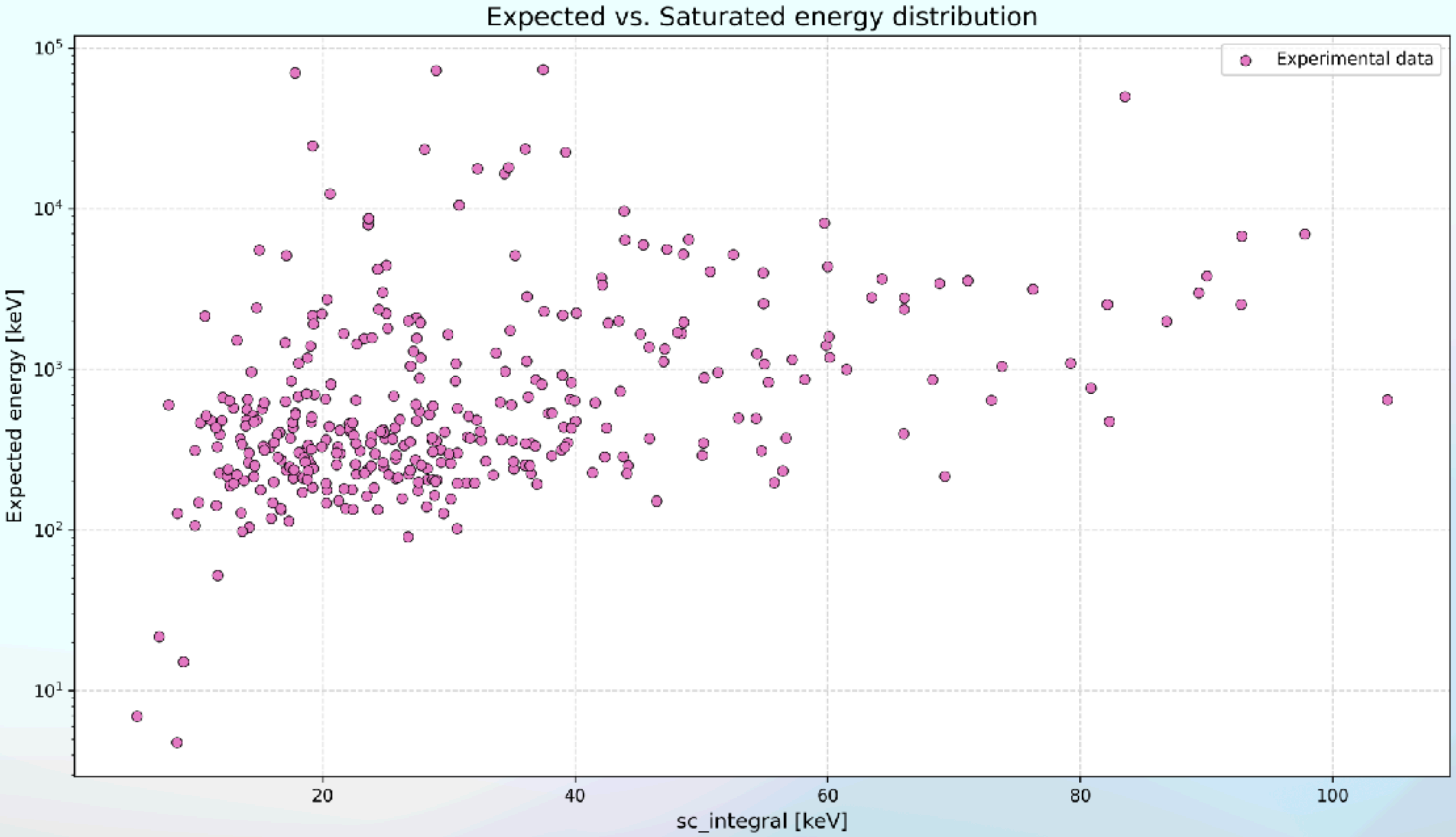
2.3. Clusters 3D range reconstruction

- There are a **small number of outliers** above 10 MeV,
- They are probably due to a wrong extrapolation of the fitted law or to an error in the range reconstruction.



2.3. Clusters 3D range reconstruction

- Expected vs Reco (saturated) energy distribution gives us an idea of **how much each clusters' energy is corrected with this method**.

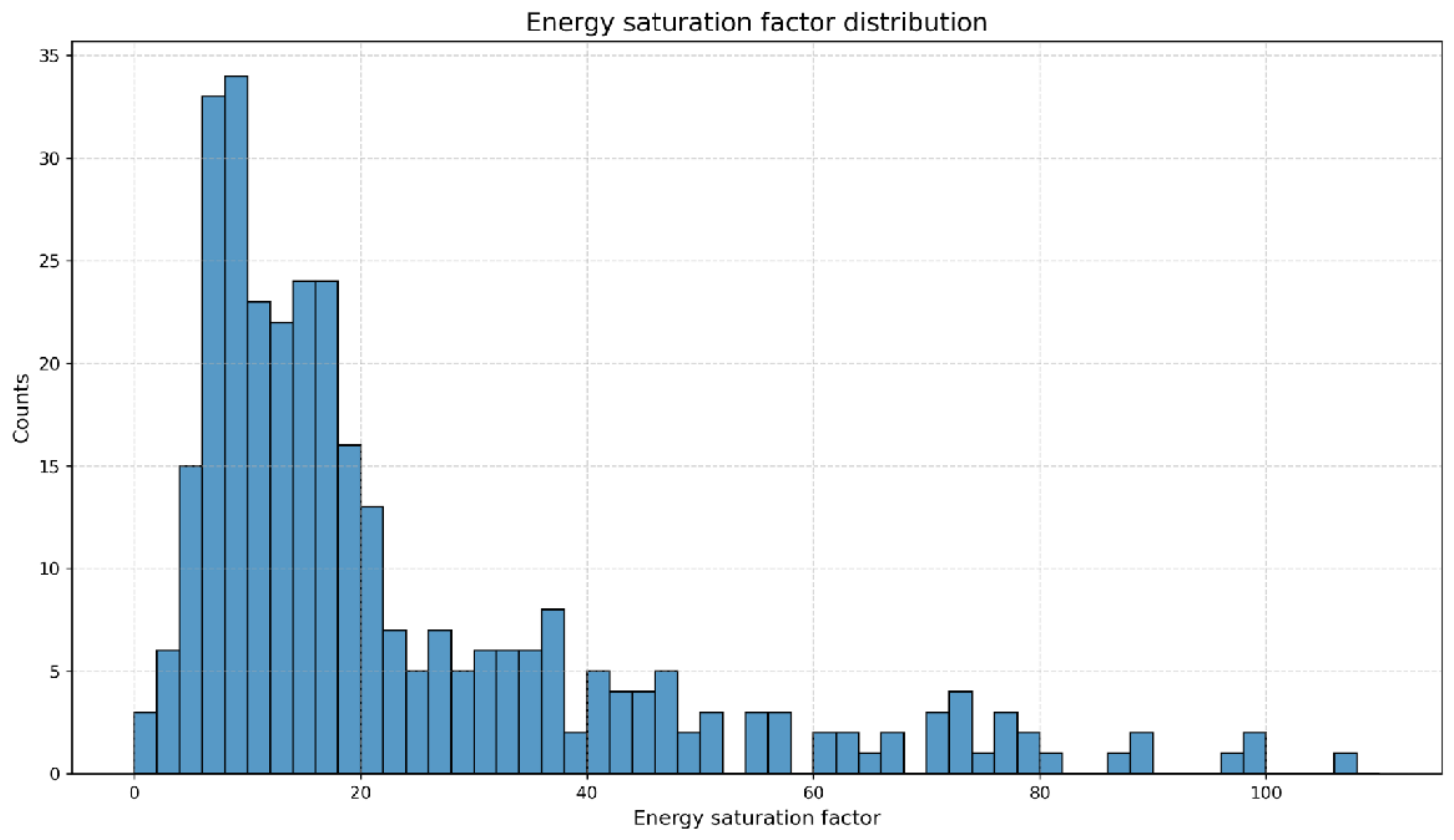


2.3. Clusters 3D range reconstruction

- We can extract:

$$\text{Saturation factor} = \frac{\text{expected energy}}{\text{saturated energy}}$$

- This is mostly distributed around 10-12, which is coherent with Atul claim:
  "**1 MeV** *(expected)* ***energy NR after reconstruction appears to be between 30 - 110 keV*** *depending on the distance from the GEMs*", that correspond to a **saturation factor ranging between 9 and 33**.



Results, Remarks and Conclusions

- **Well defined pre-processing pipeline**
  - ✓ Data normalization
  - ✓ Gain non-uniformity correction
  - ✓ Calibration of the light yield as a function of the detector humidity).
- **Sample of NRs identification in the 100 - 1000 keV expected kinetic energy region**
  - ✦ Angle computed cluster-by-cluster
  - ✓ Toy Monte Carlo validation
  - ✓ Angular resolution evaluated around 35°/40°.
- **Lonely nuclear recoils 3D range reconstruction.**
  - ✓ Critical considerations regarding nuclear recoils energy spectrum.
  - ✓ Gain saturation characterisation, with energy saturation factor coherent with previous preliminary studies and simulations.
  - ➡ More data = better information.

Thank you for your attention!