Analysis of low energy Nuclear Recoils' from AmBe neutron source

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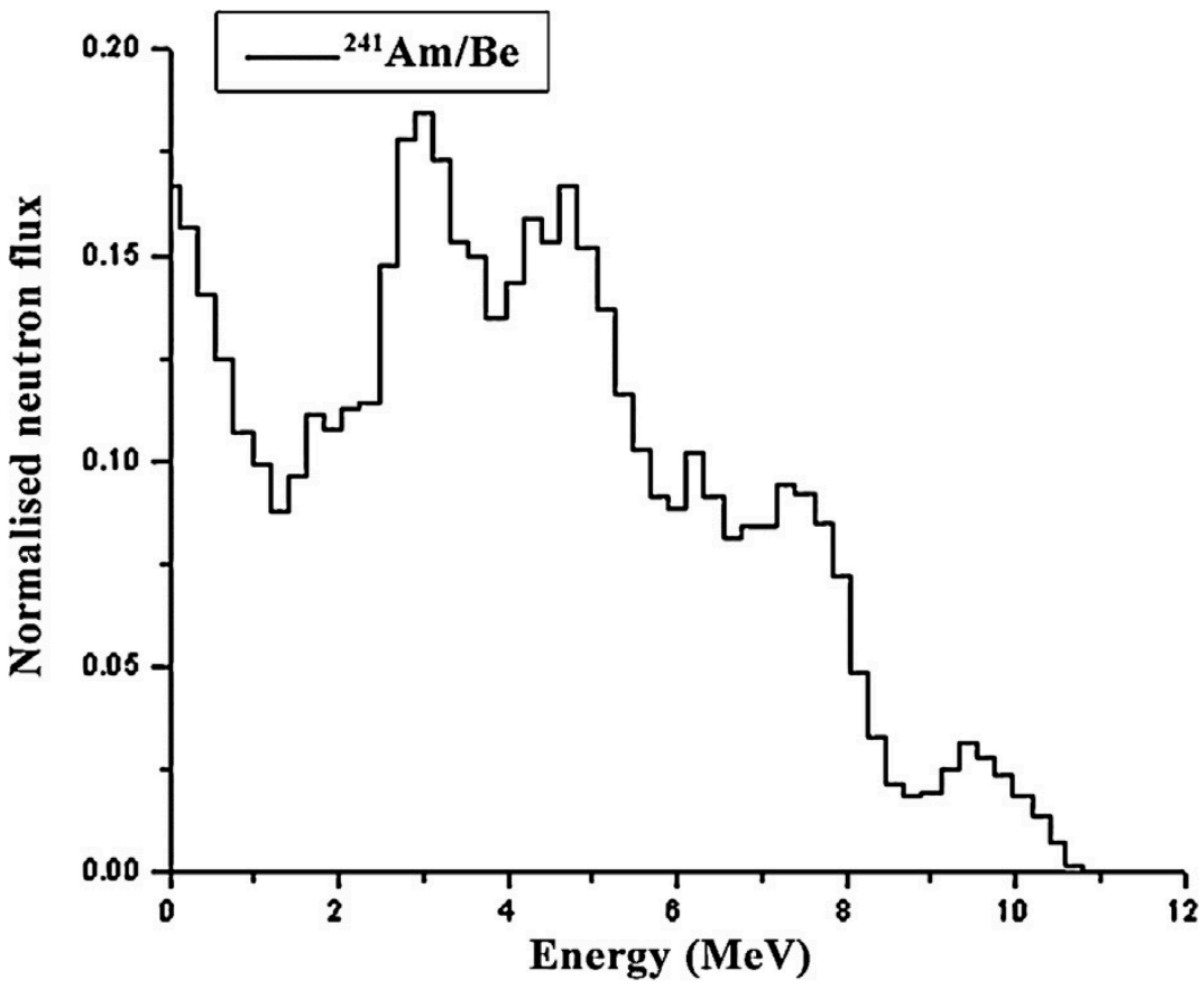
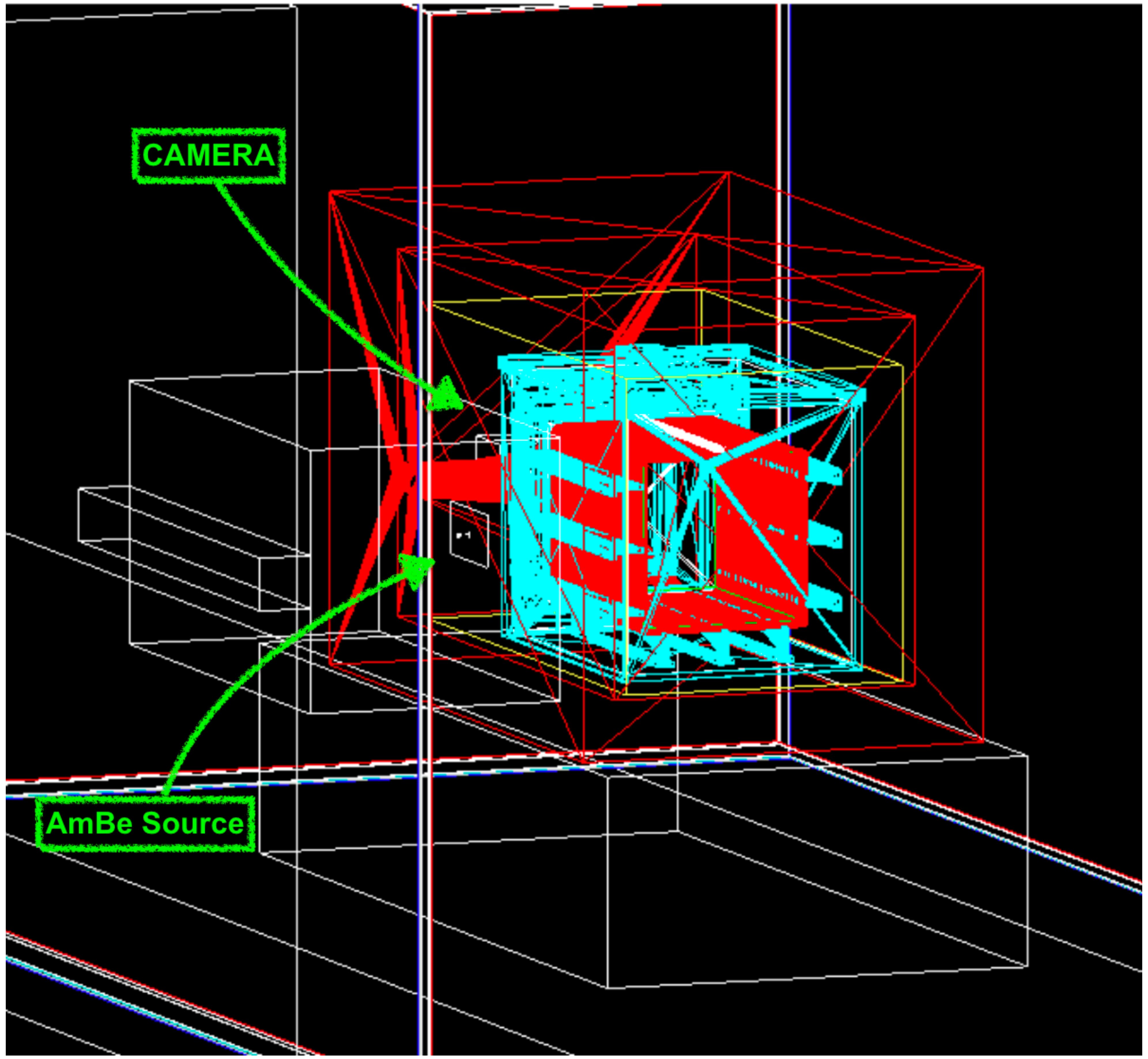
CYGNO Experiment

Data taking setup

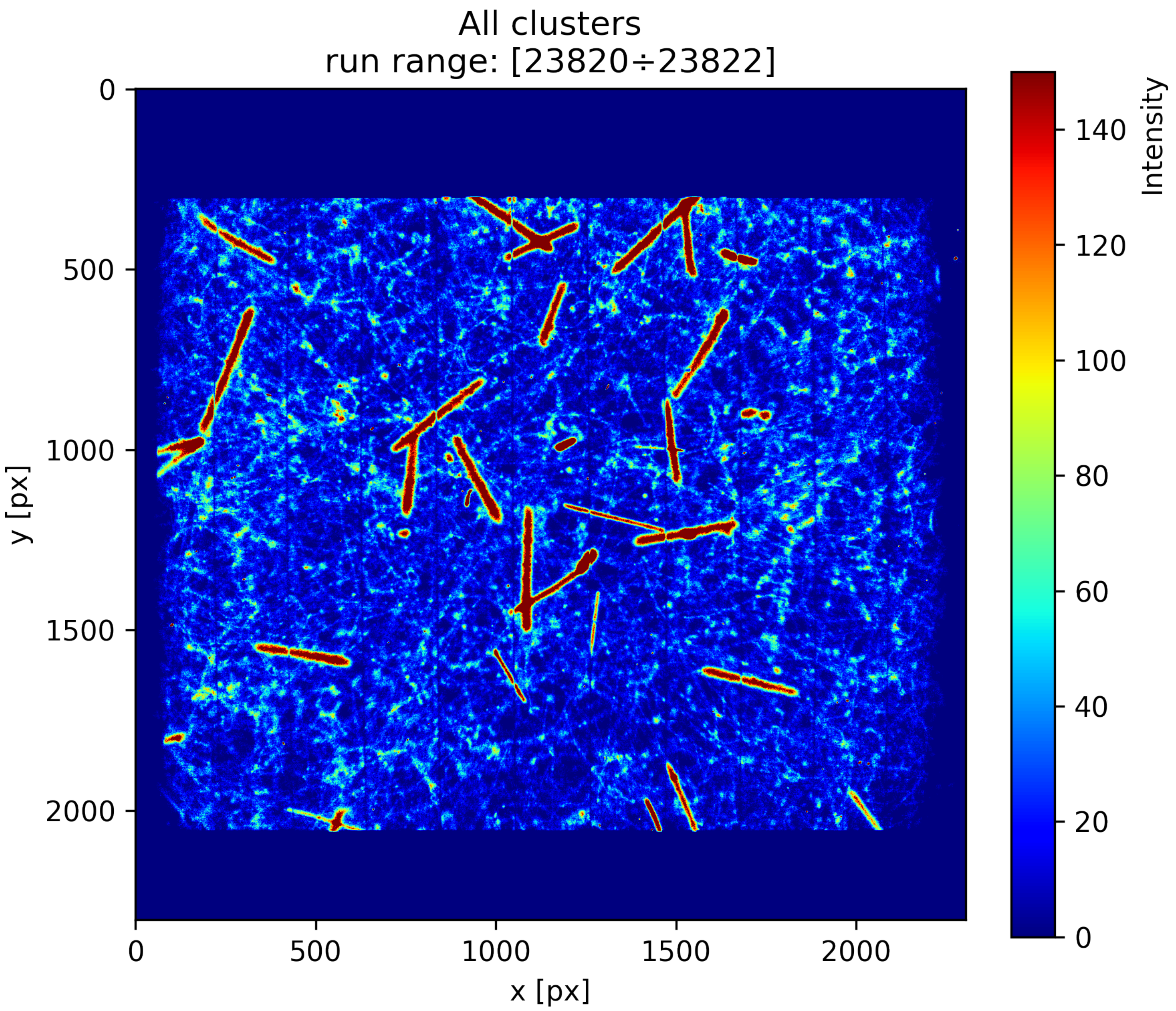


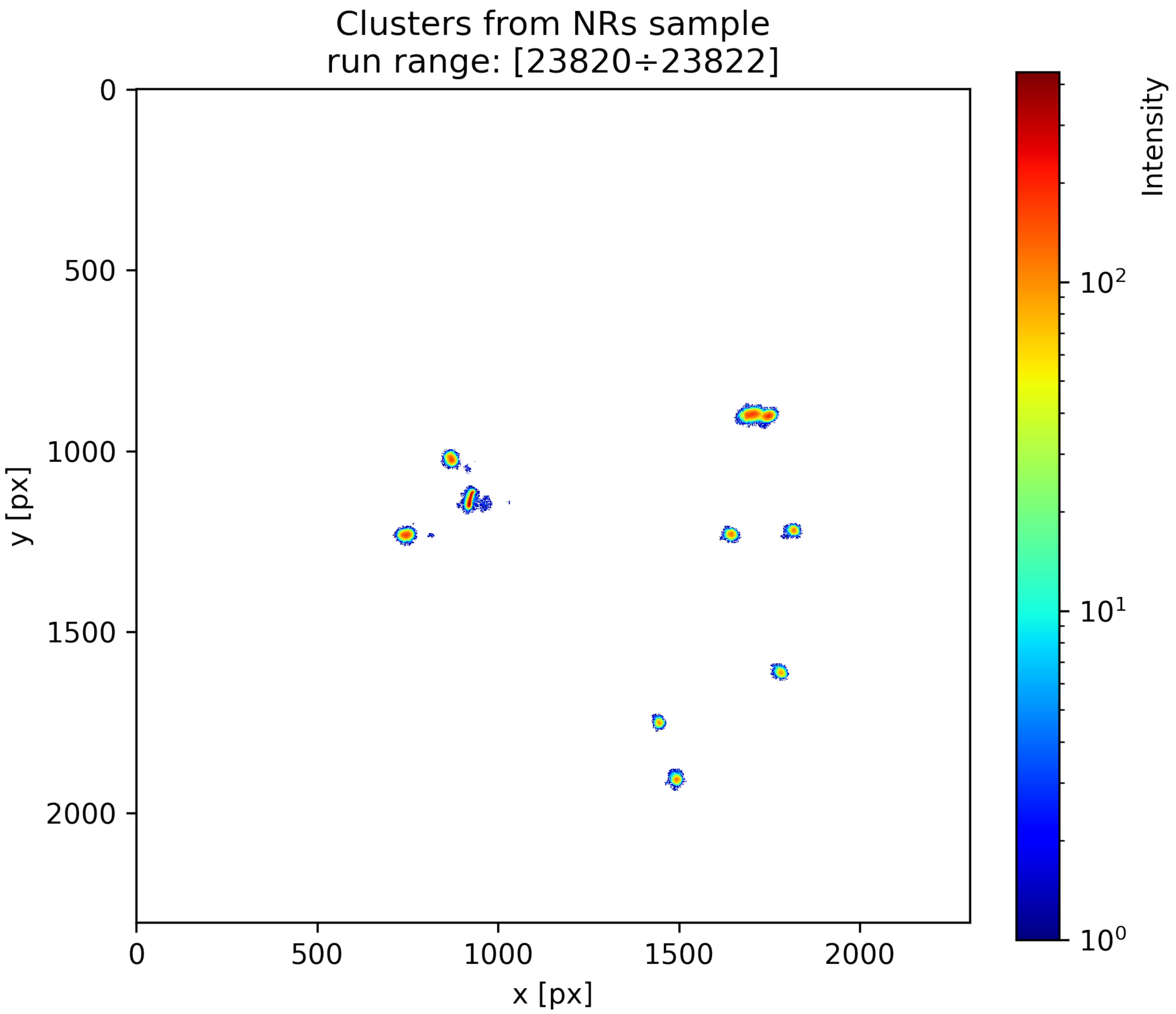


AmBe excess selection

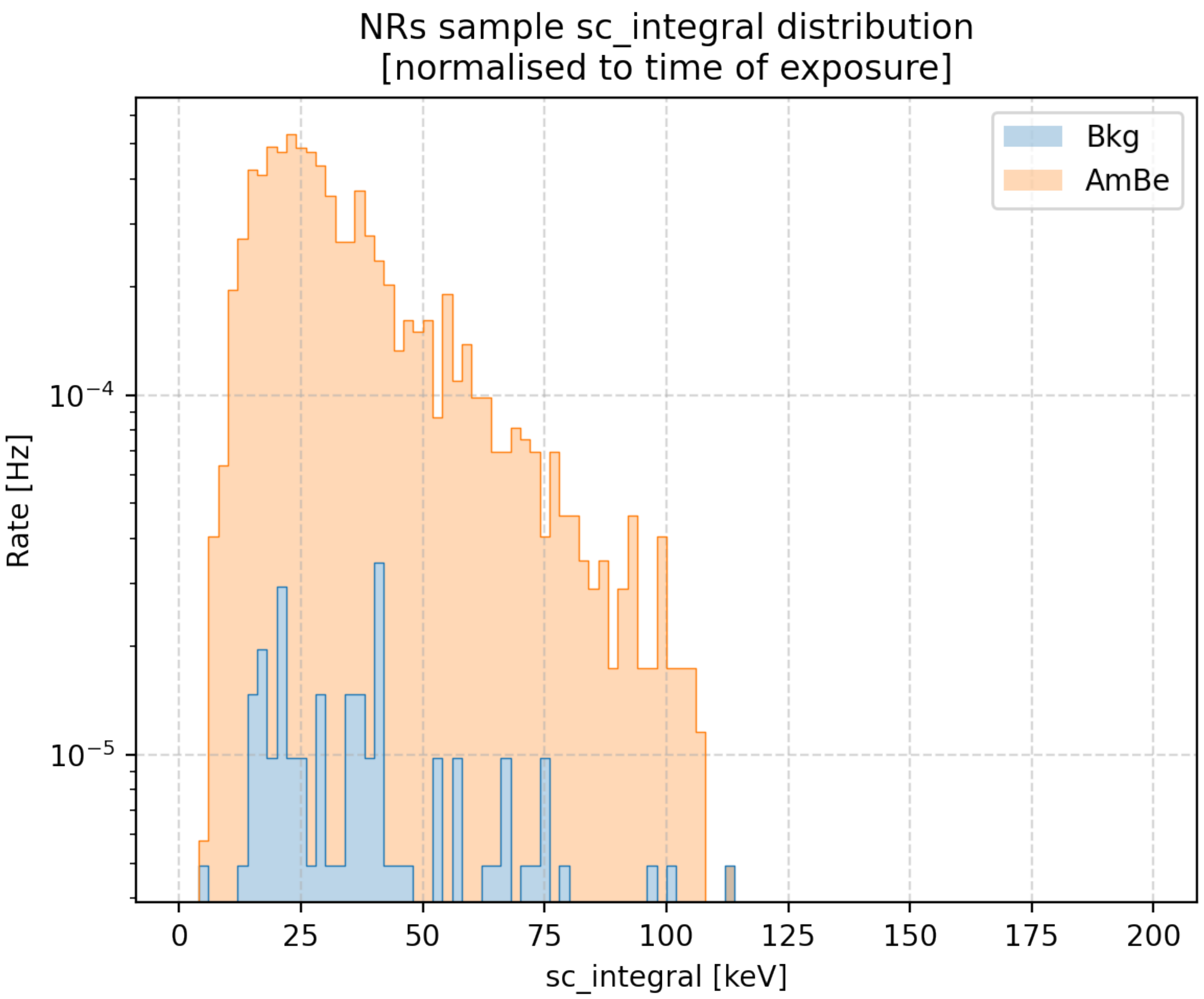
AmBe excess selection (zoom)

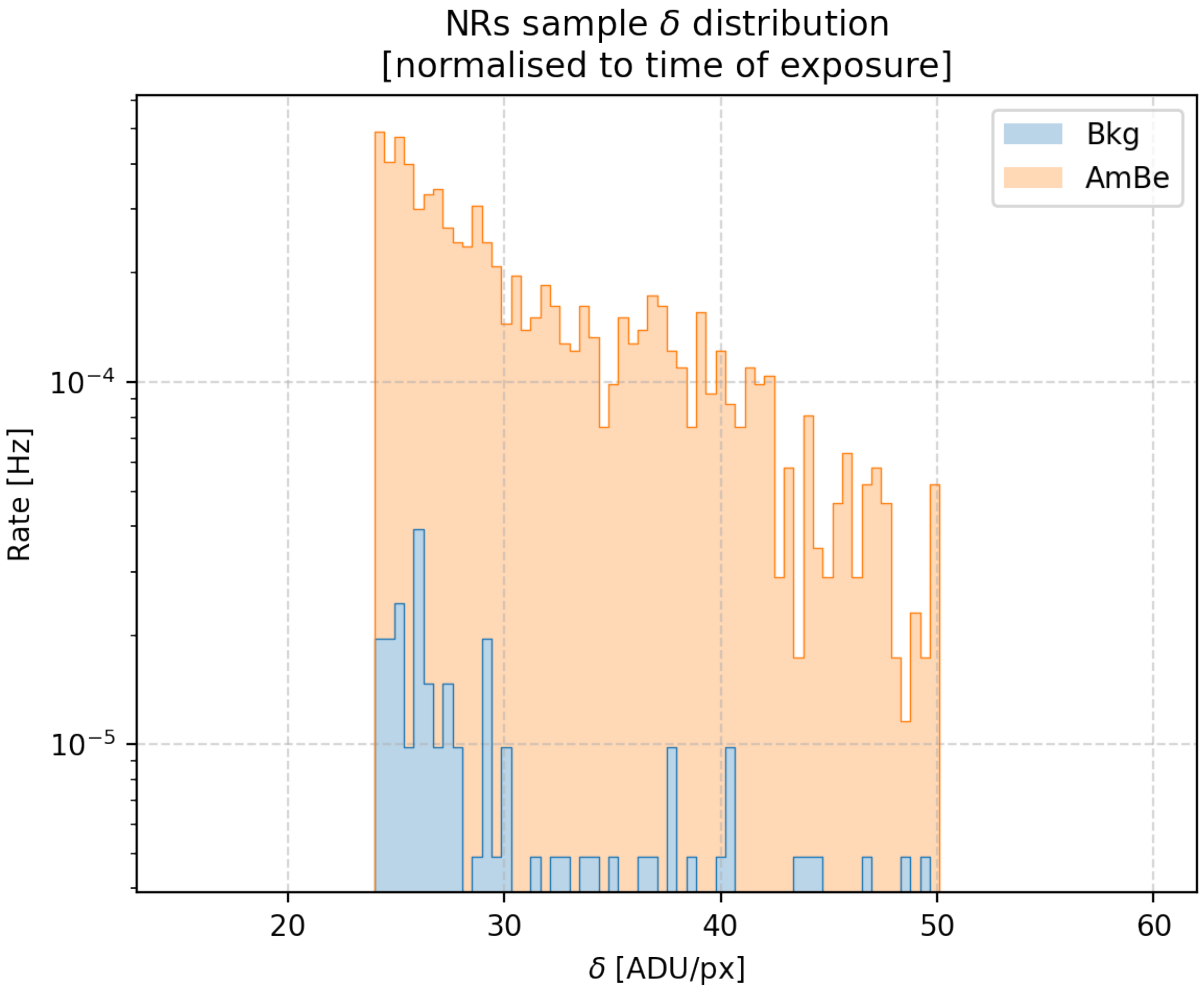
AmBe excess selection - Some samples





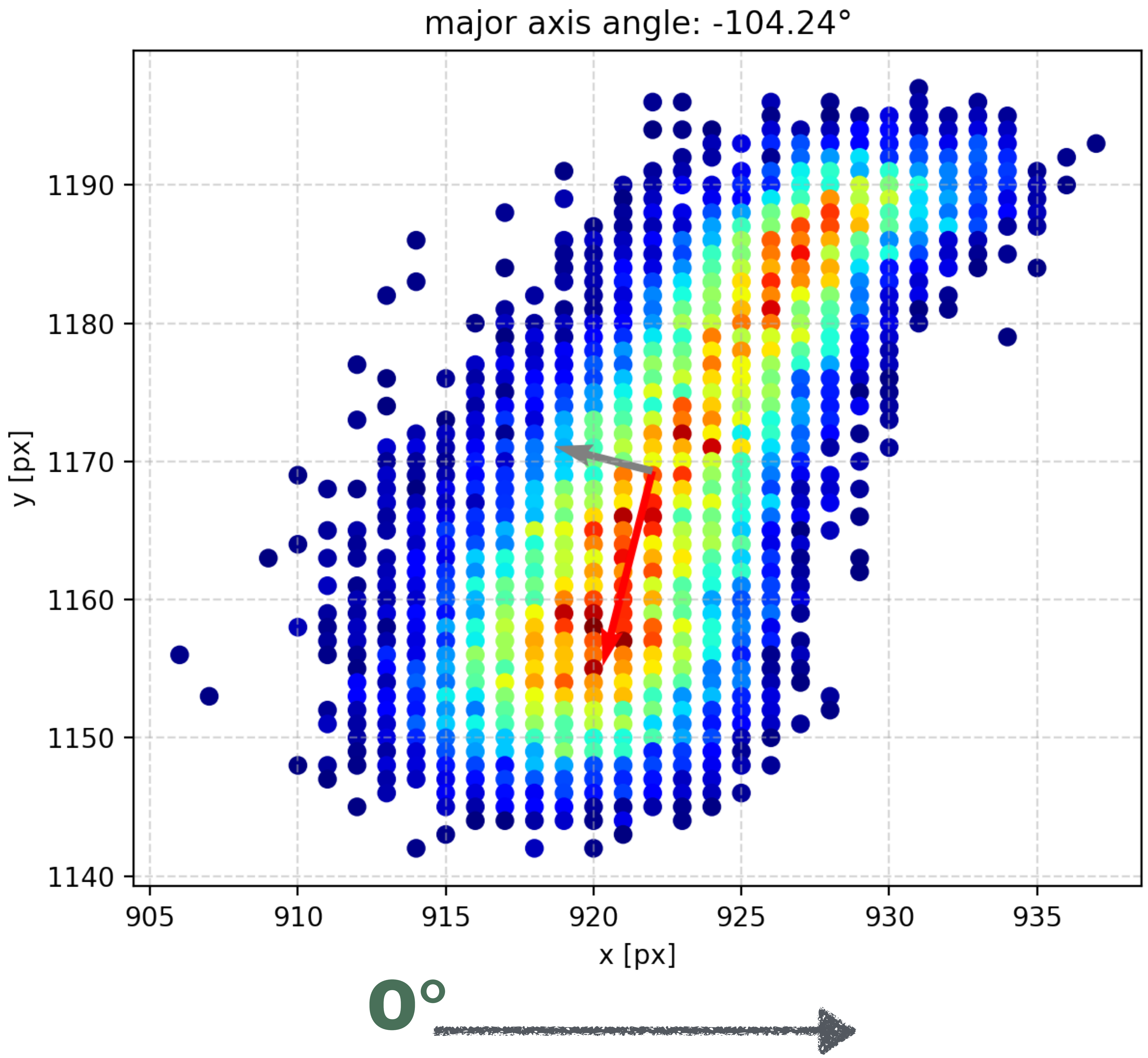
Selected clusters Energy/Density spectra



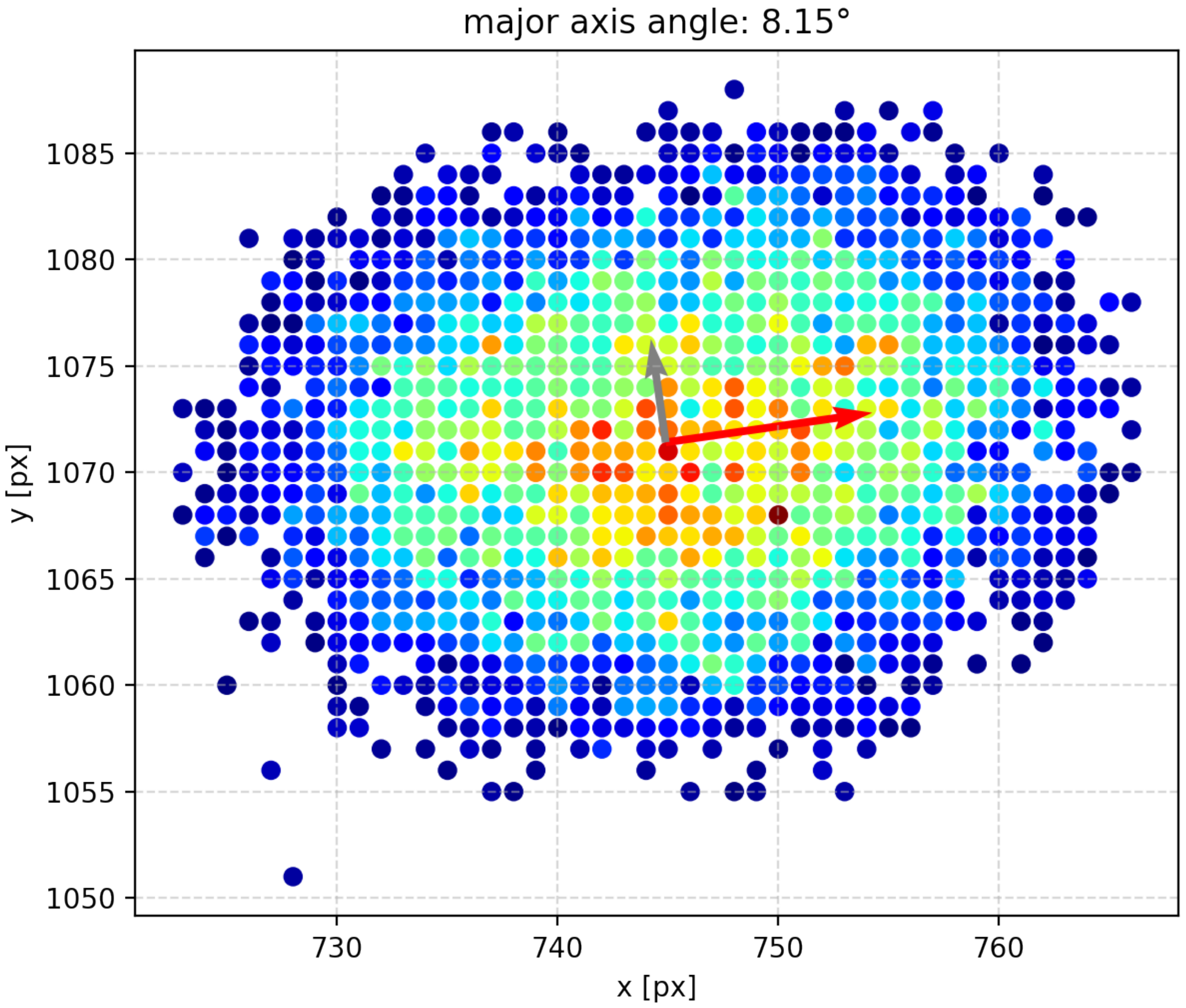


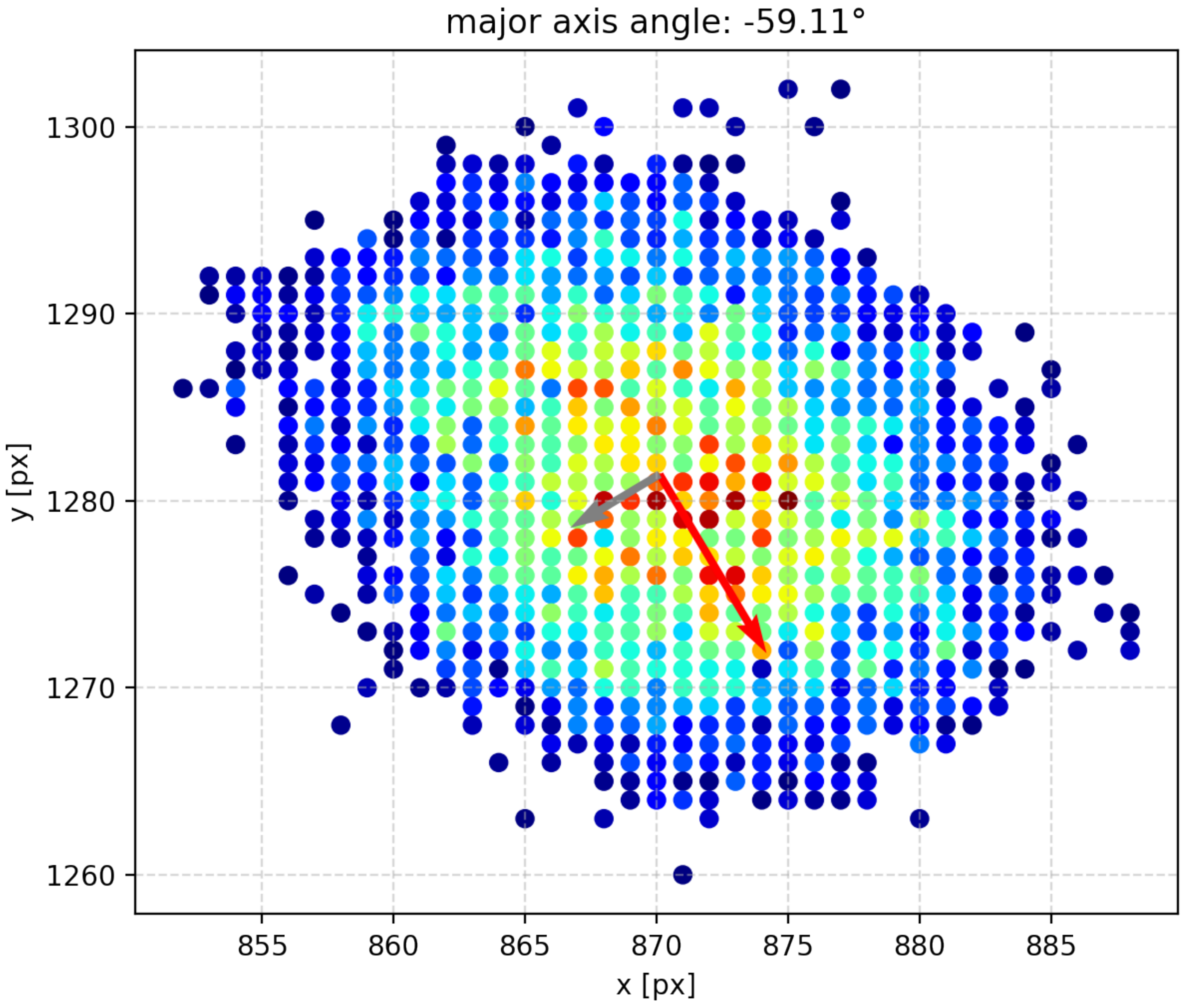
Directionality evaluation

- 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**.
- **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.

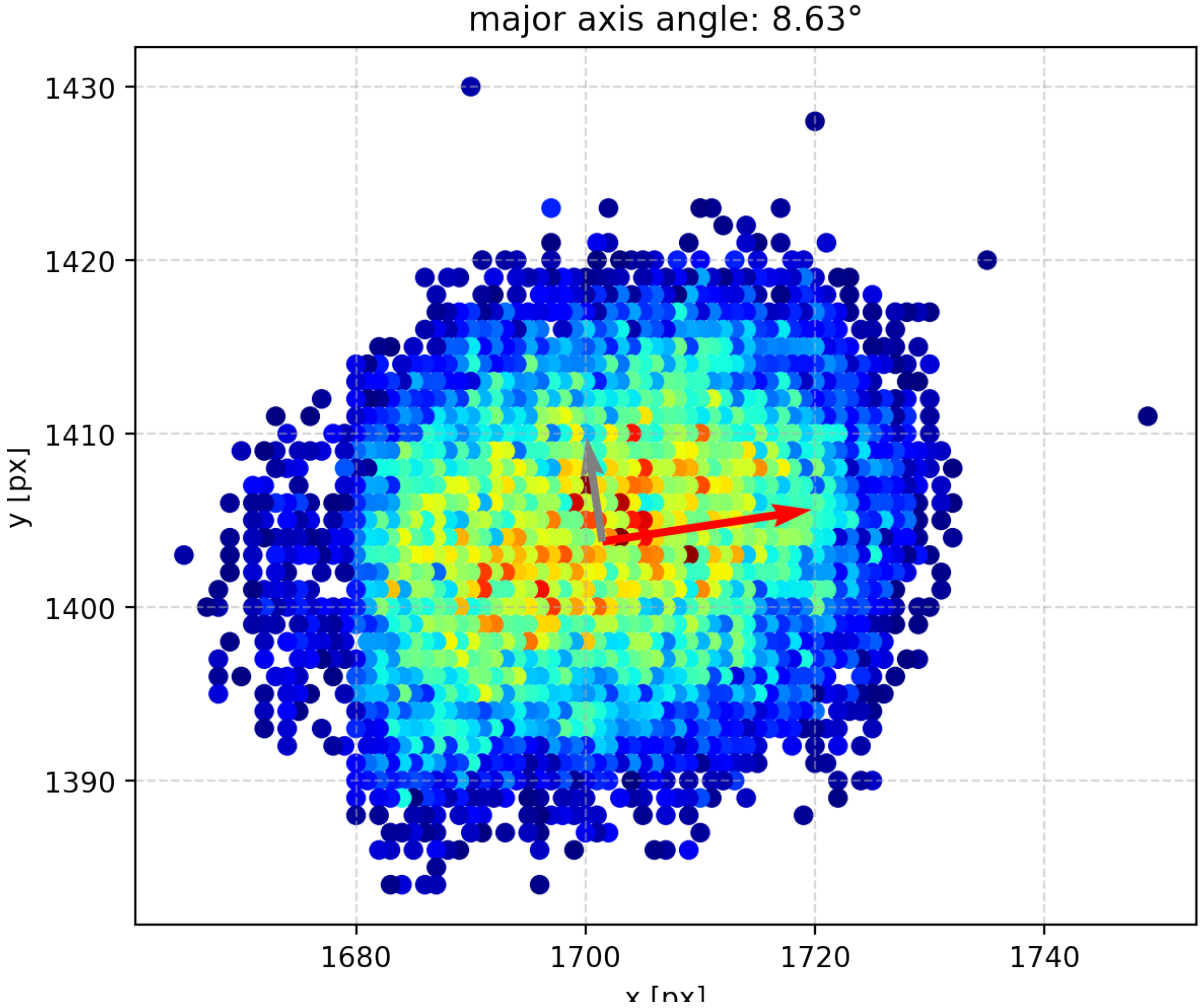


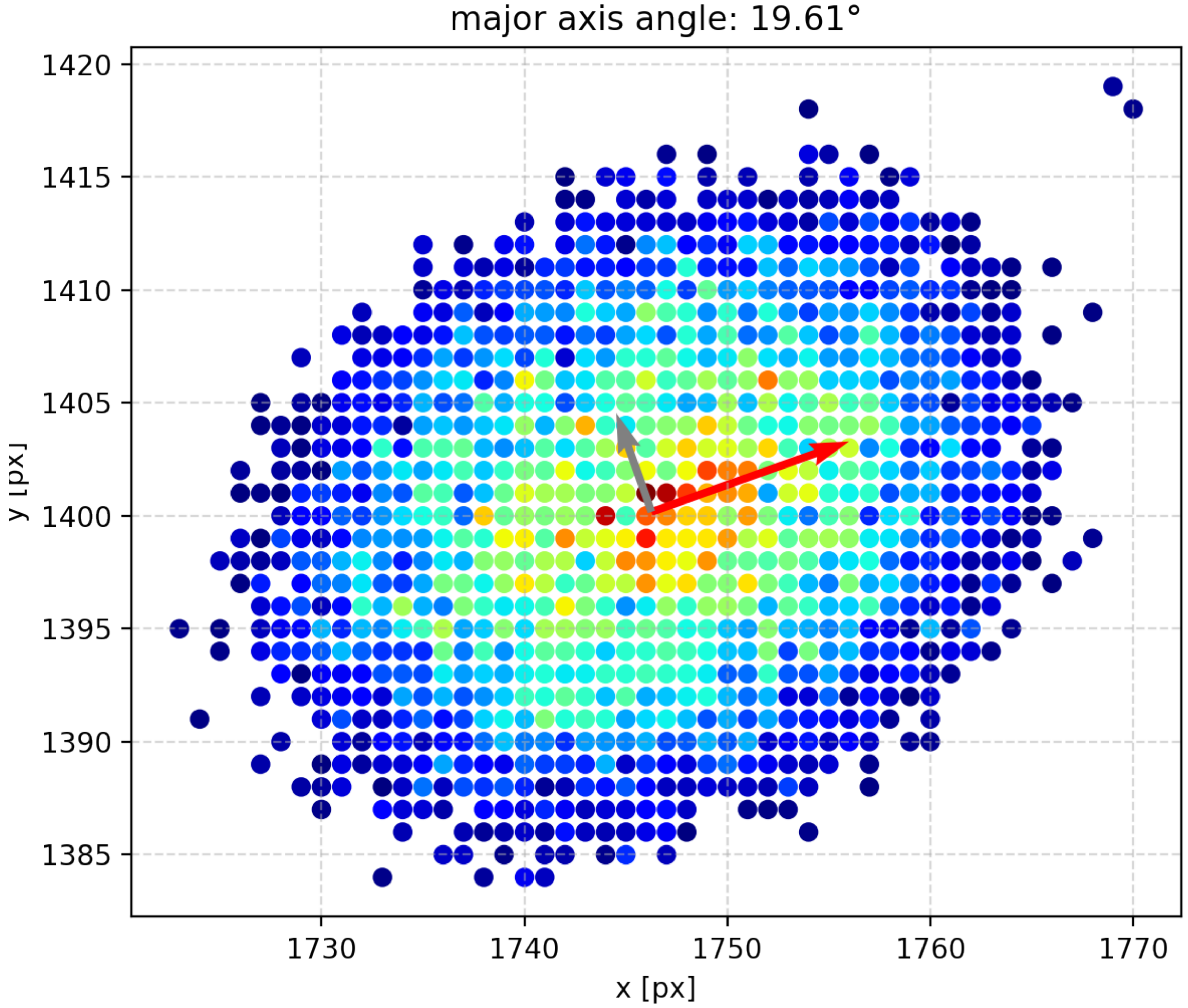
Directionality evaluation - Examples



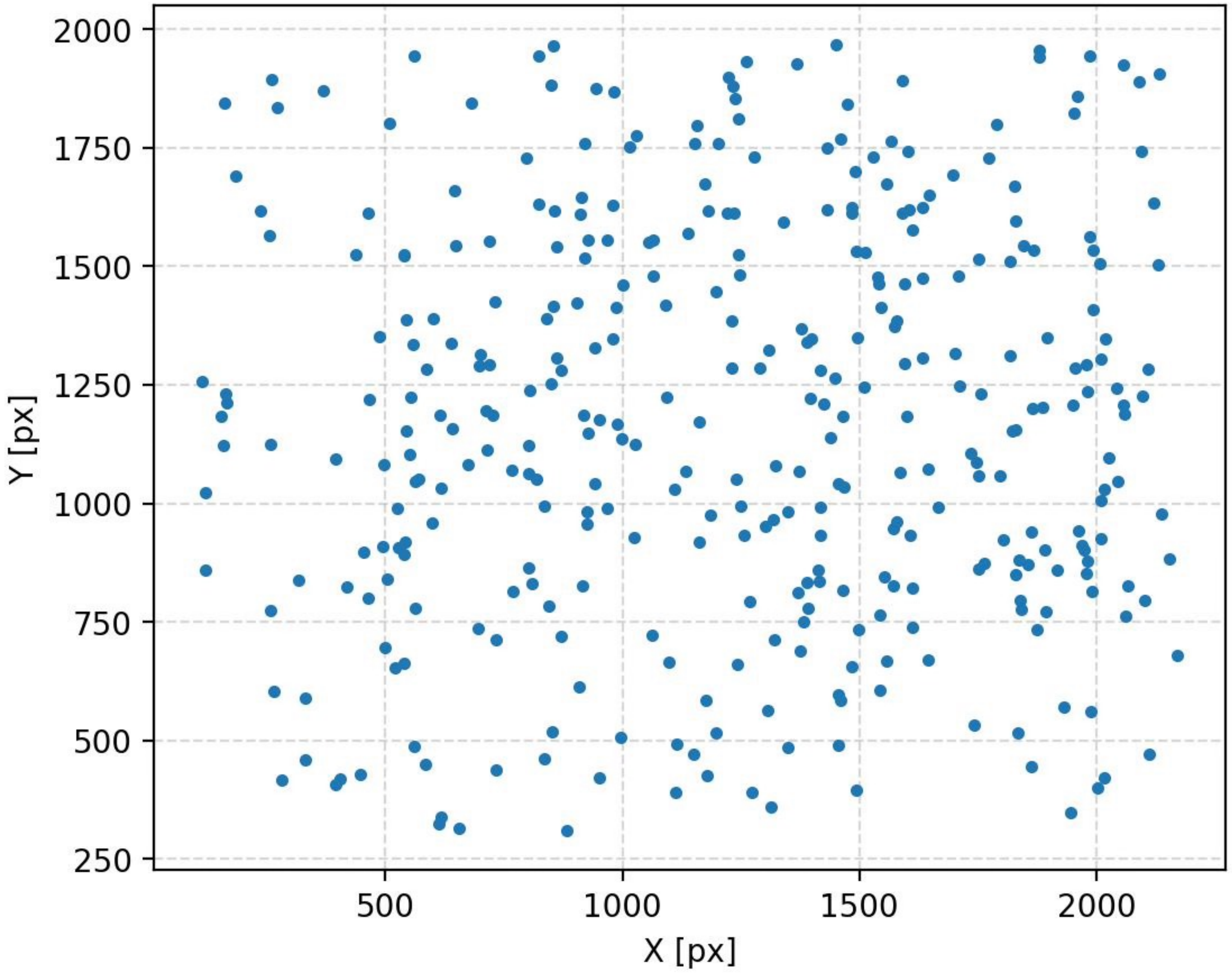


Directionality evaluation - Examples



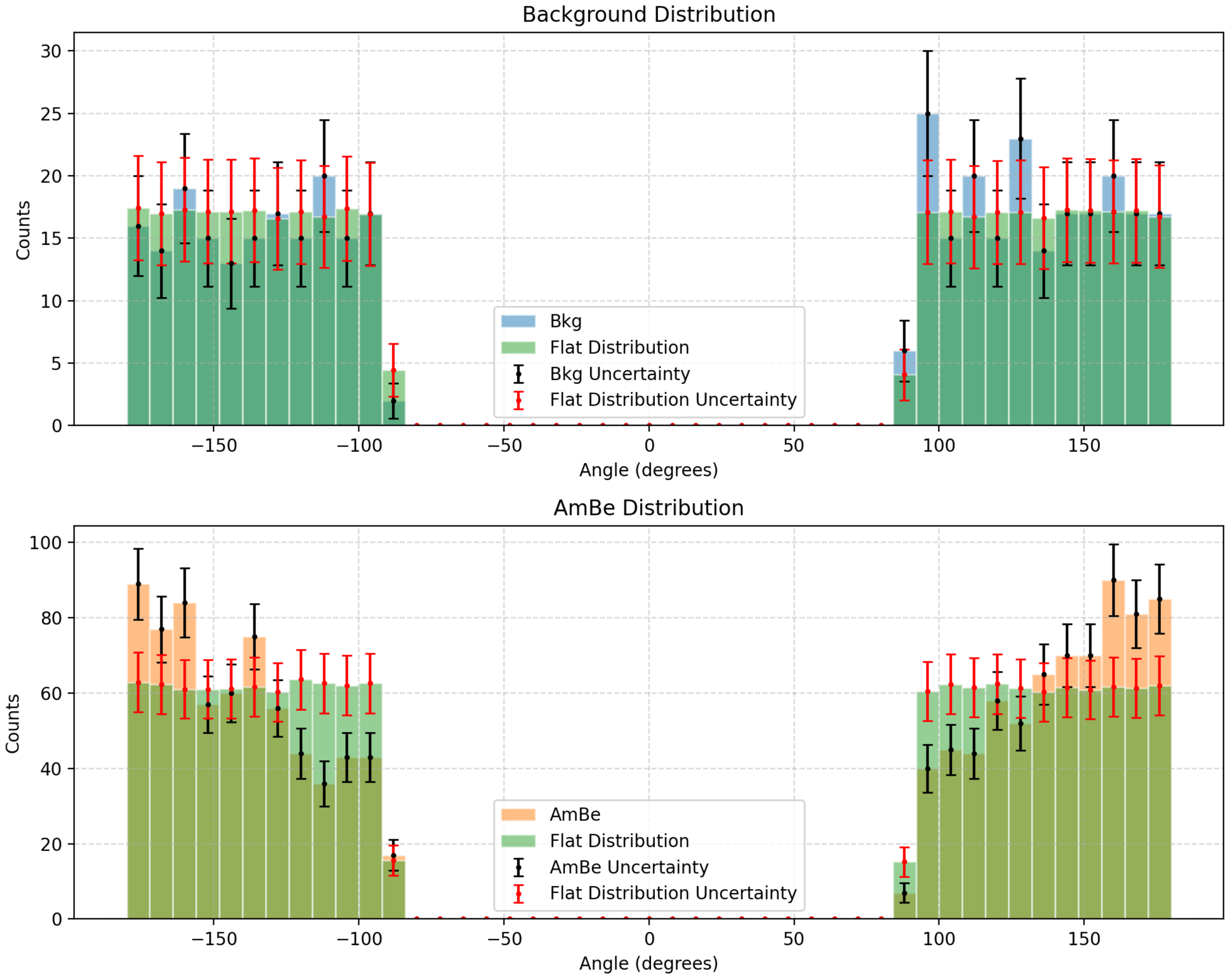


Map of AmBe Nuclear Recoils



Directionality evaluation - AmBe vs. Bkg

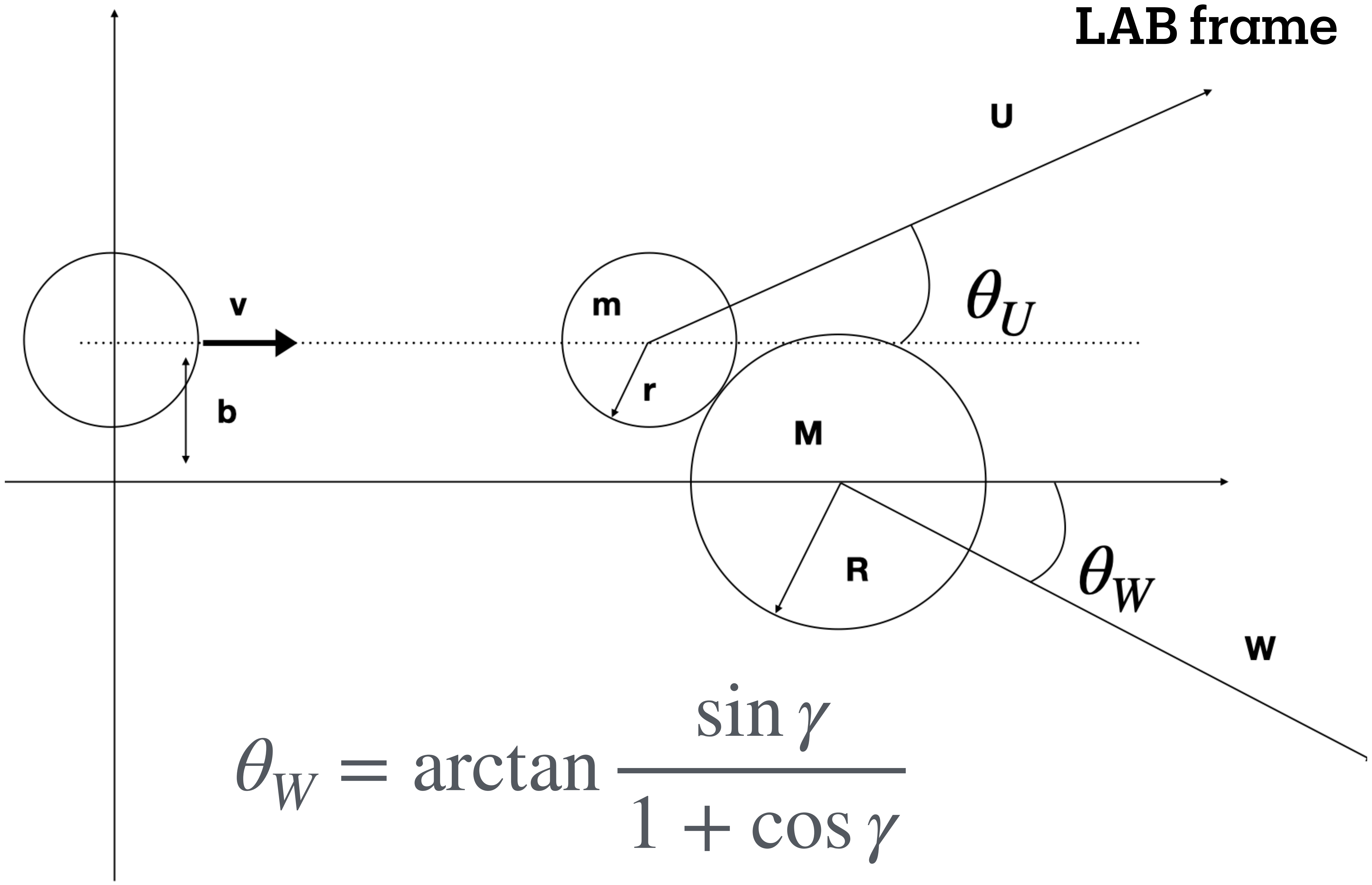
- **Observations:**
  - Excess of vertical clusters in Bkg sample. **Compatible with flat distribution.**
  - Excess of horizontal clusters in AmBe sample. **Not compatible with flat distribution.**
- **Is this expected?**



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**.



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

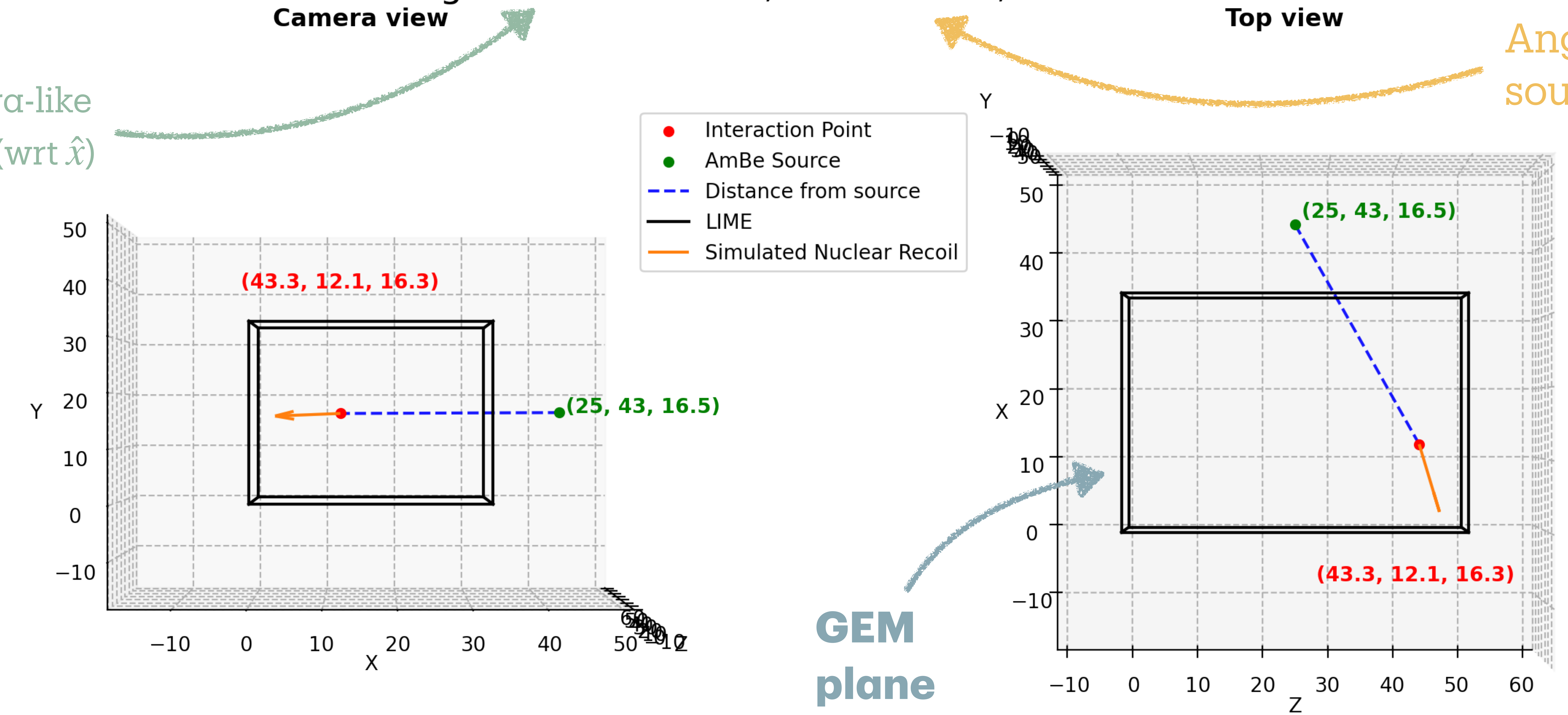
MC validation - 3D simulation

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

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

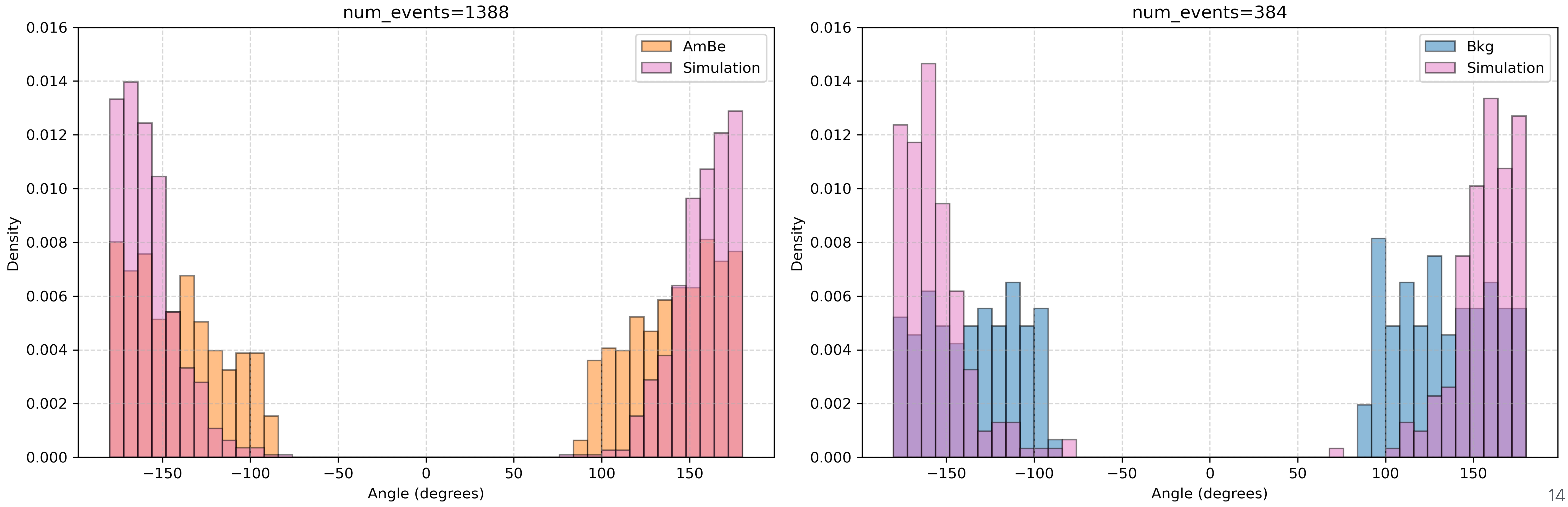
Camera-like angle (wrt $\hat{x}$)

Angle wrt source wall



MC validation - Simulated angle

- Vertical region is not perfectly matched by the AmBe sample, but **Bkg is for sure flatter.**



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**.

- In order to statistically compare the distributions, we can use the reduced χ^2, indicating the measurements with O_i and the simulation with $E_i(\sigma)$.

$$E_i(\sigma) = E_i + error$$

where $$error \in Gauss(0, \sigma)$$

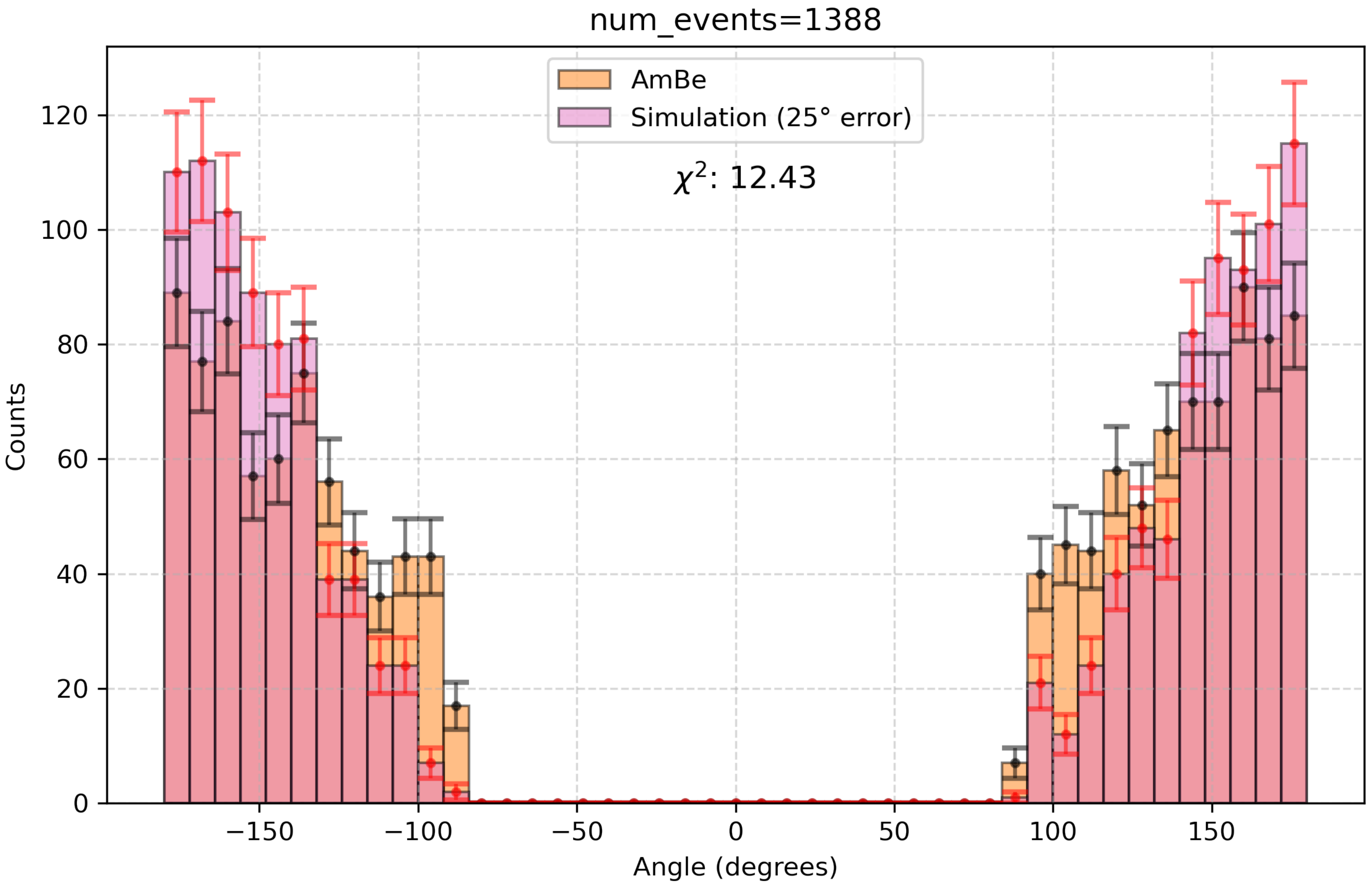
$$\chi^2 = \sum_i \frac{\left[O_i - E_i(\sigma)\right]^2}{E_i(\sigma) \times \nu} \qquad \nu = \text{\# of bins}$$

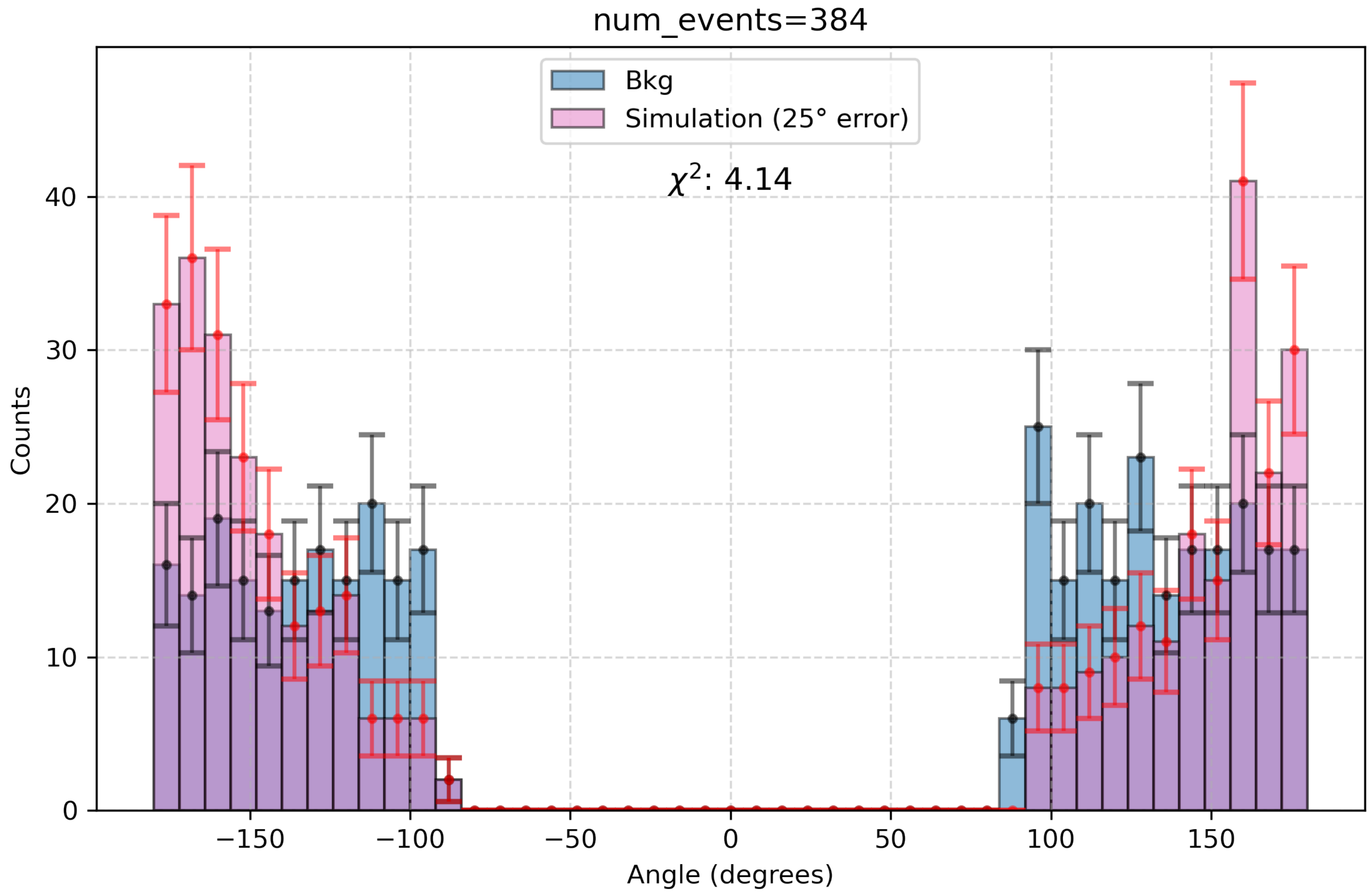
MC validation - Gaussian Smearing

Angular resolution = 5°:

MC validation - Gaussian Smearing

Angular resolution = 25°:



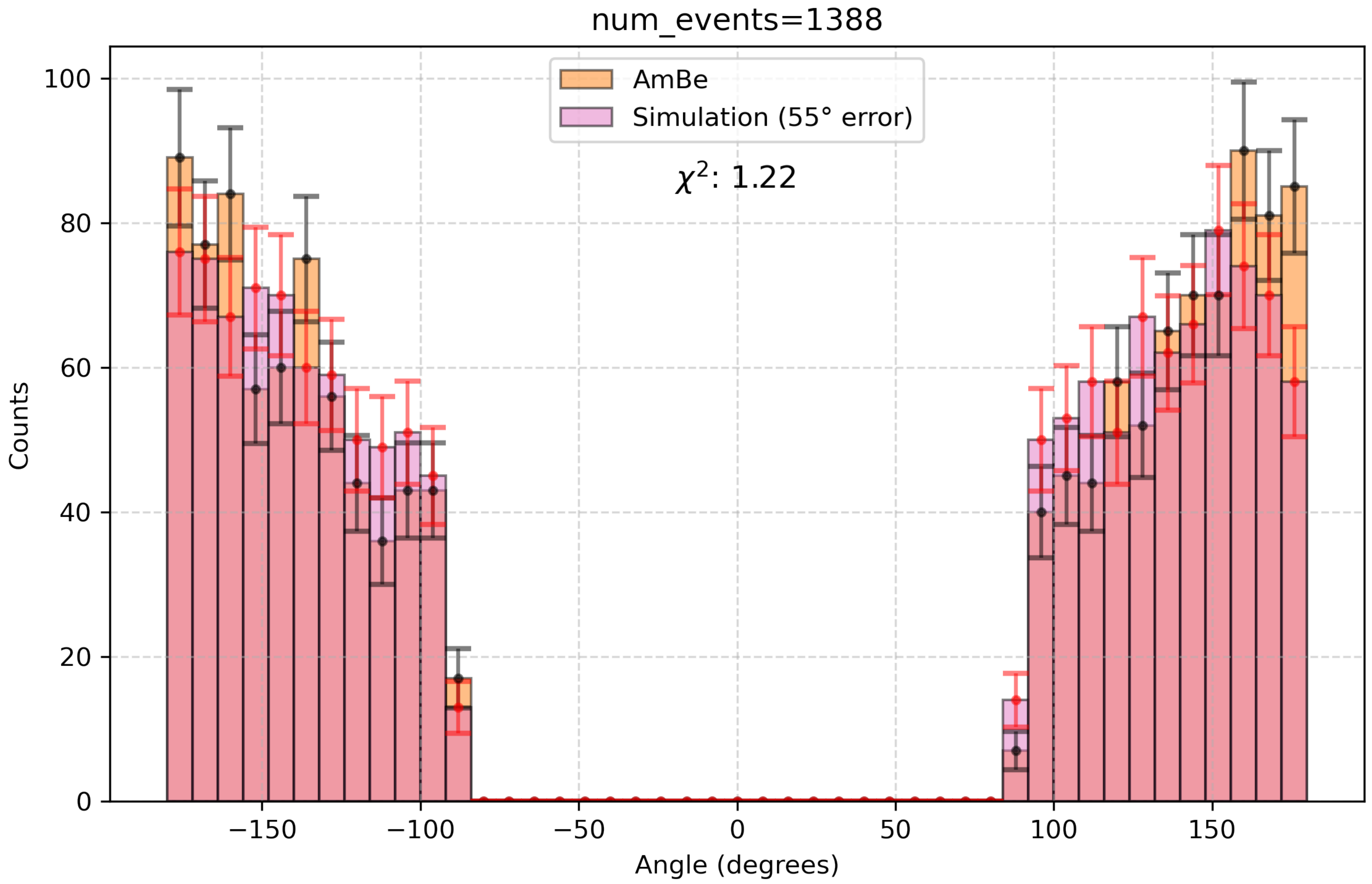


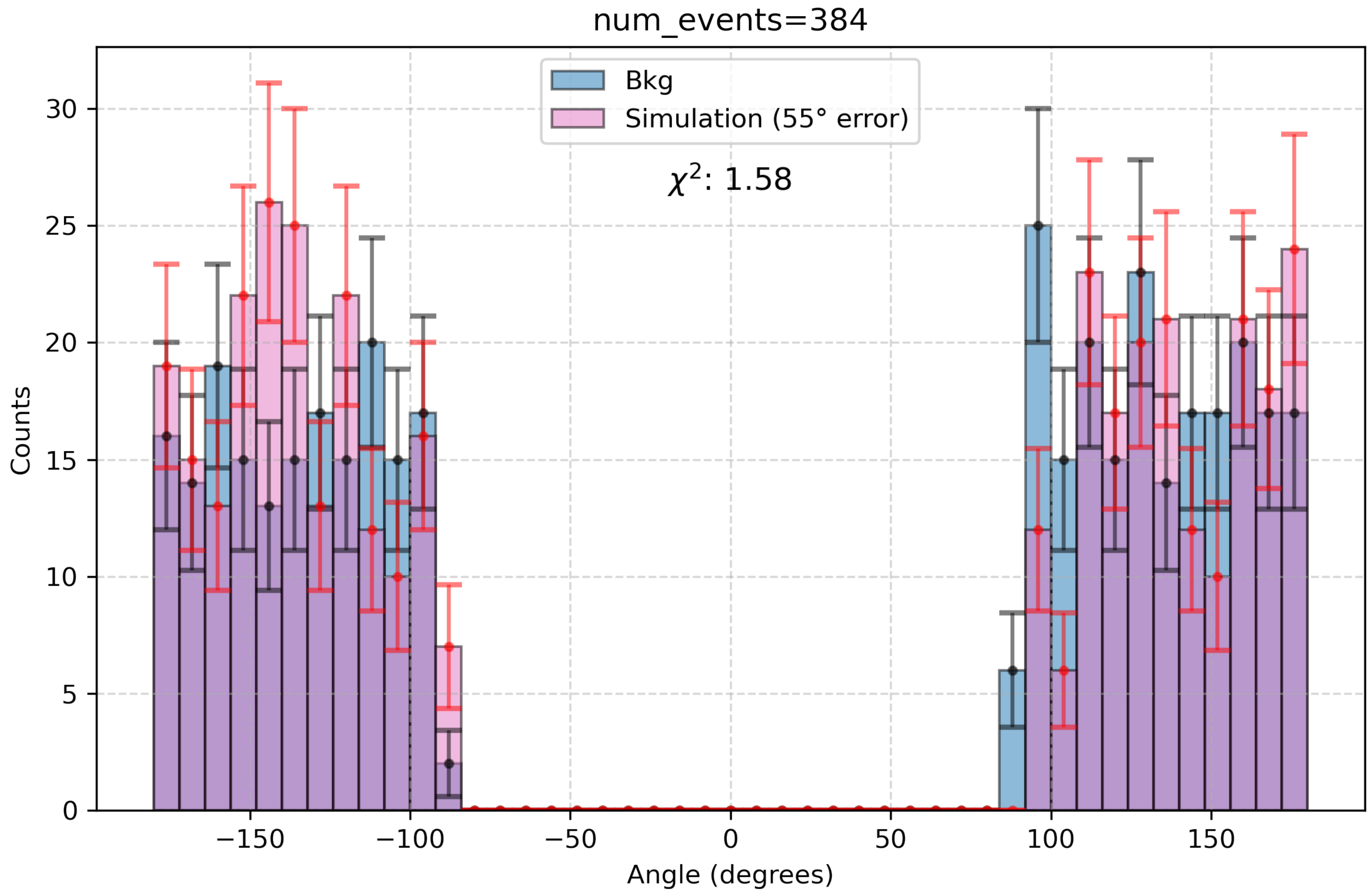
MC validation - Gaussian Smearing

Angular resolution = 40°:

MC validation - Gaussian Smearing

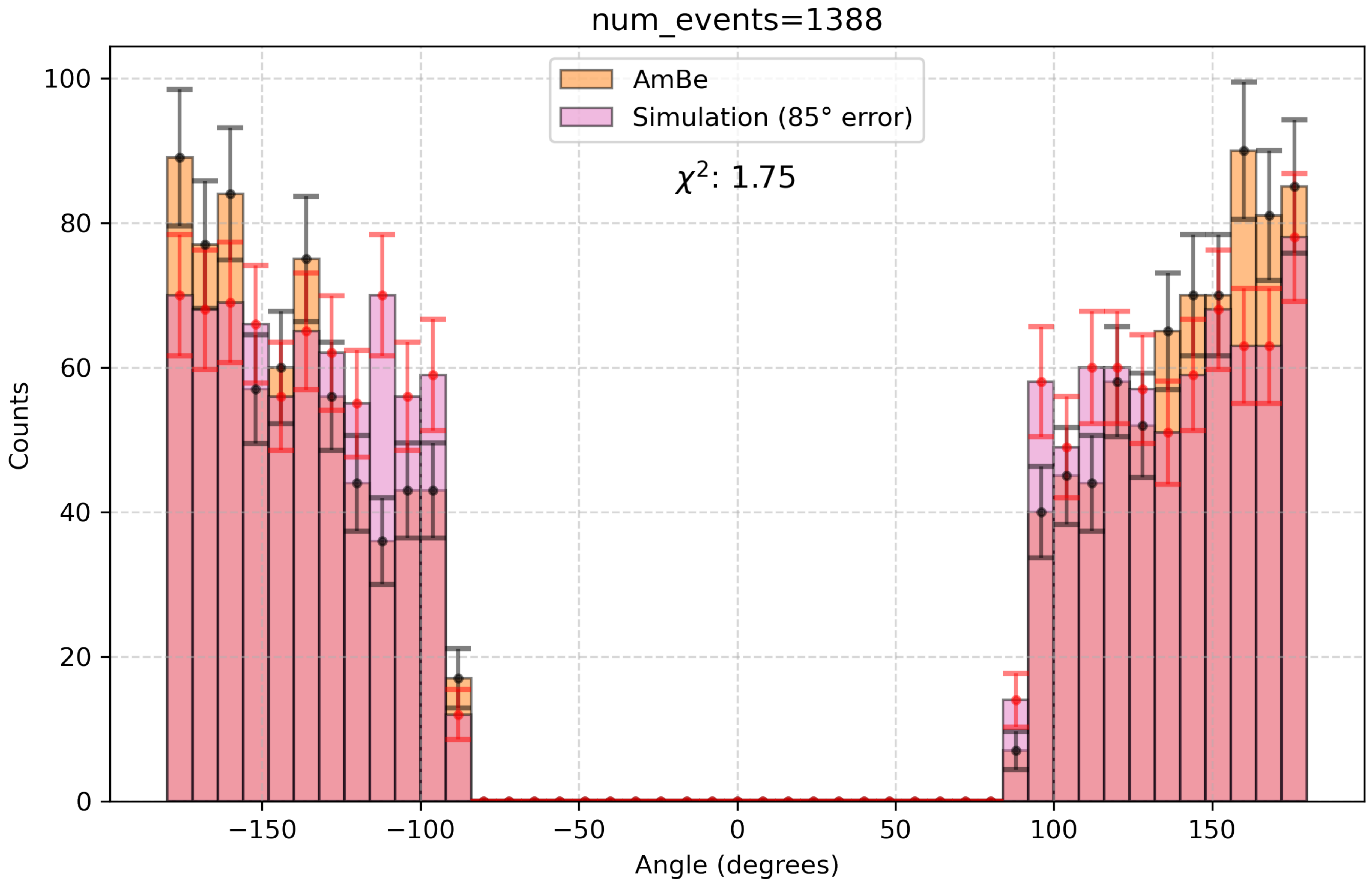
Angular resolution = 55°:

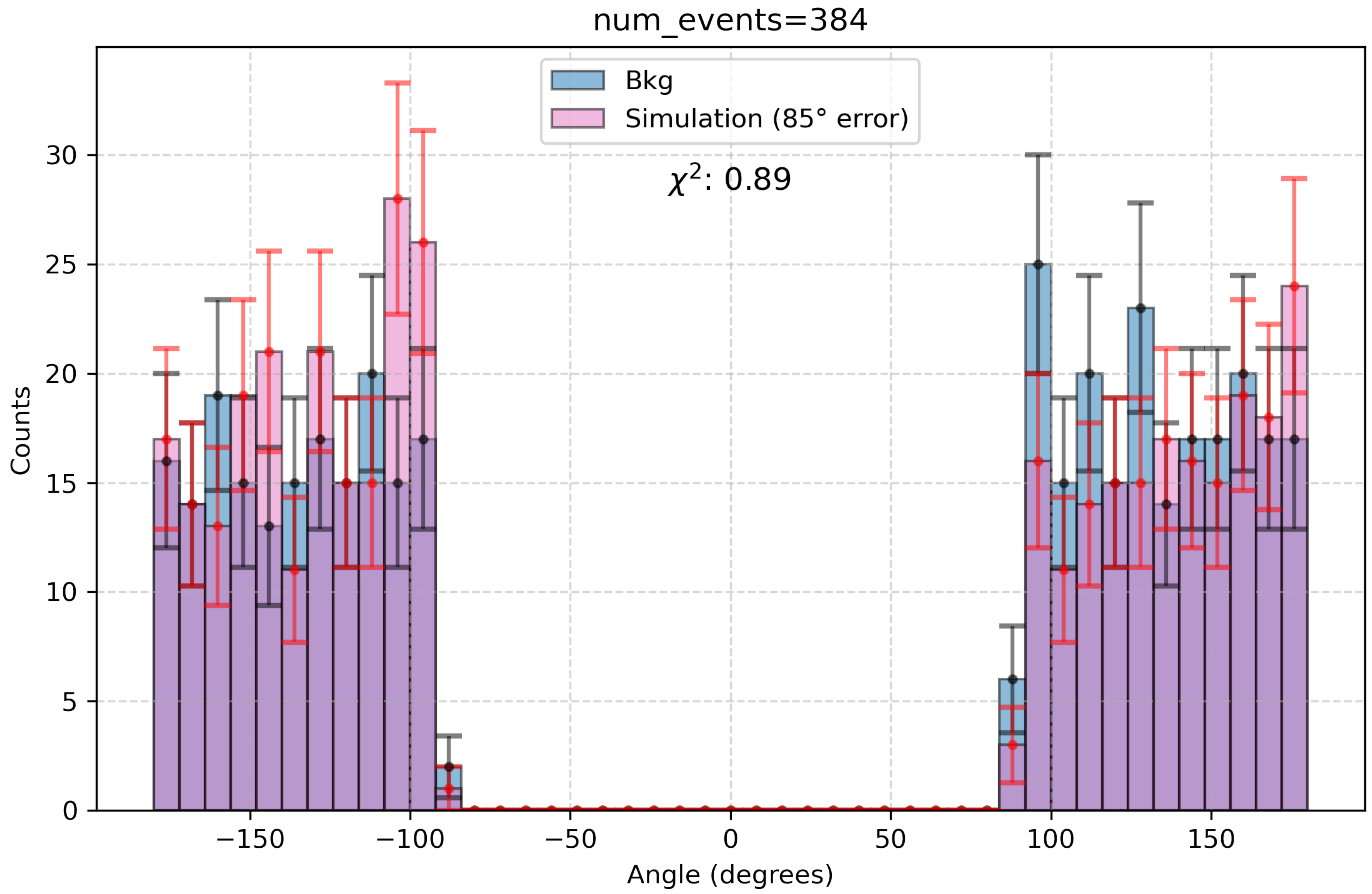




MC validation - Gaussian Smearing

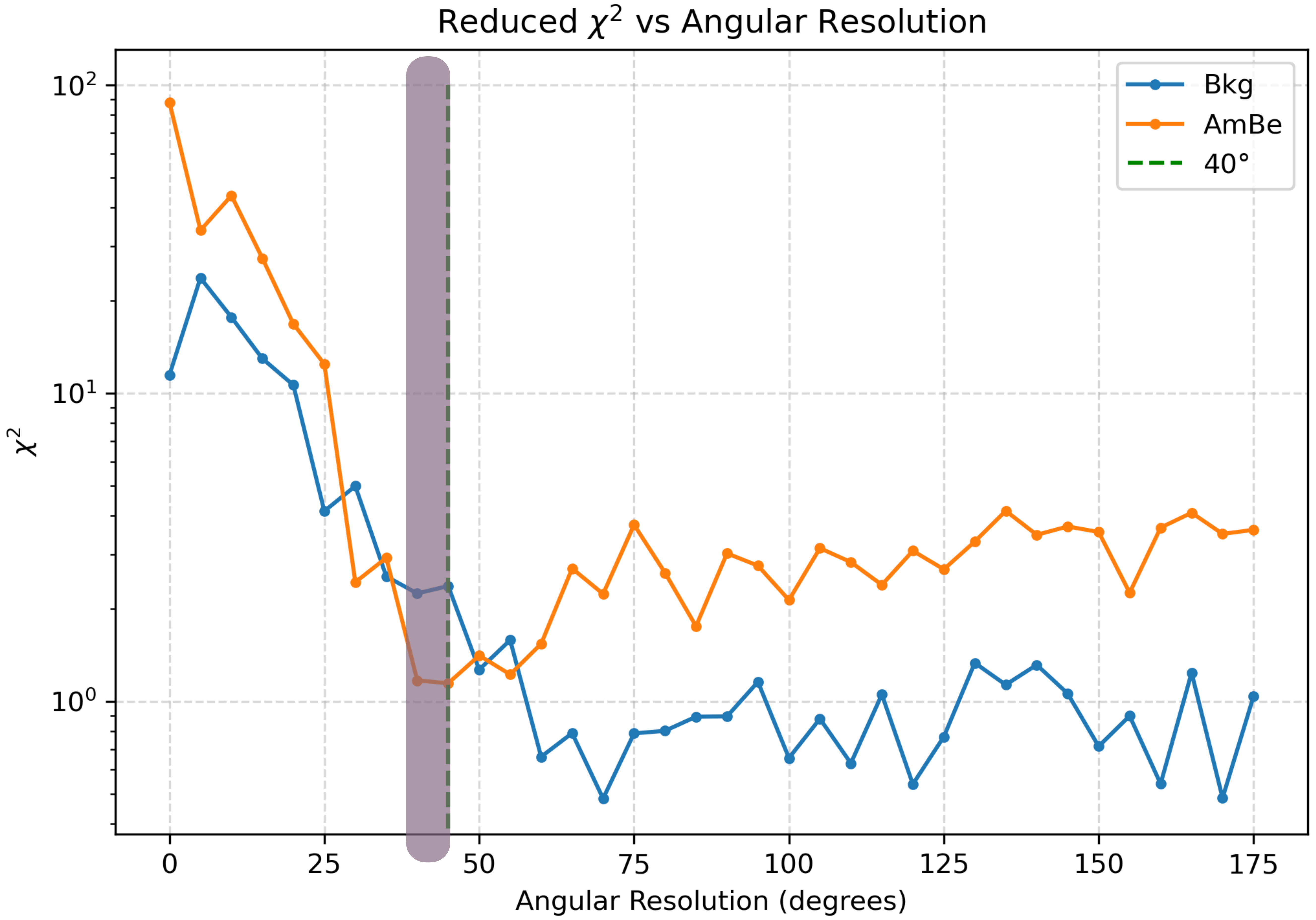
Angular resolution = 85°:





MC validation - χ^2 vs. Resolution

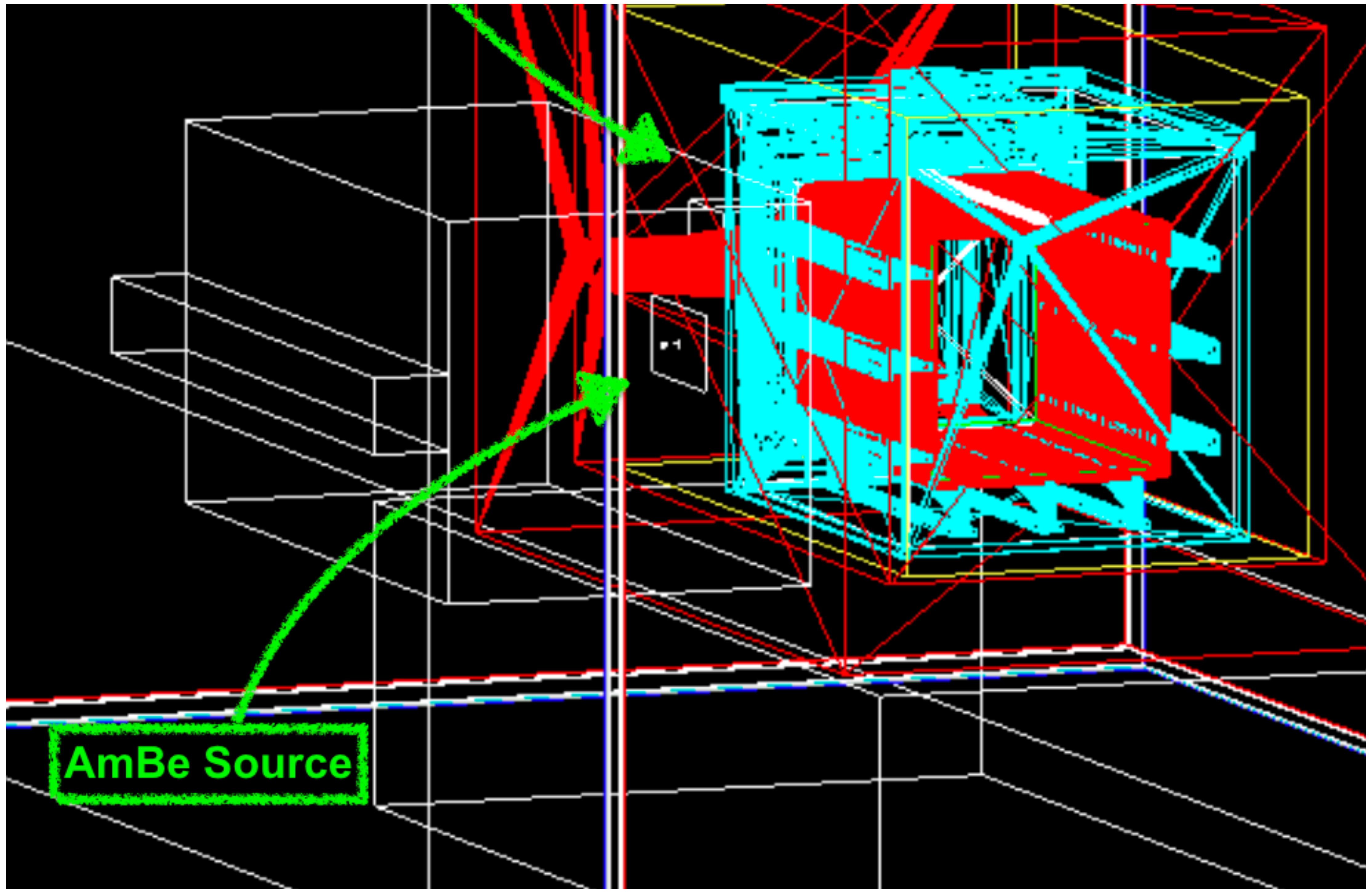
- **Two claims** can be extracted from these tests:
  - Our **measurement resolution** with this method **is around 40-45°.**
  - There is a **preferential direction in the AmBe dataset.**

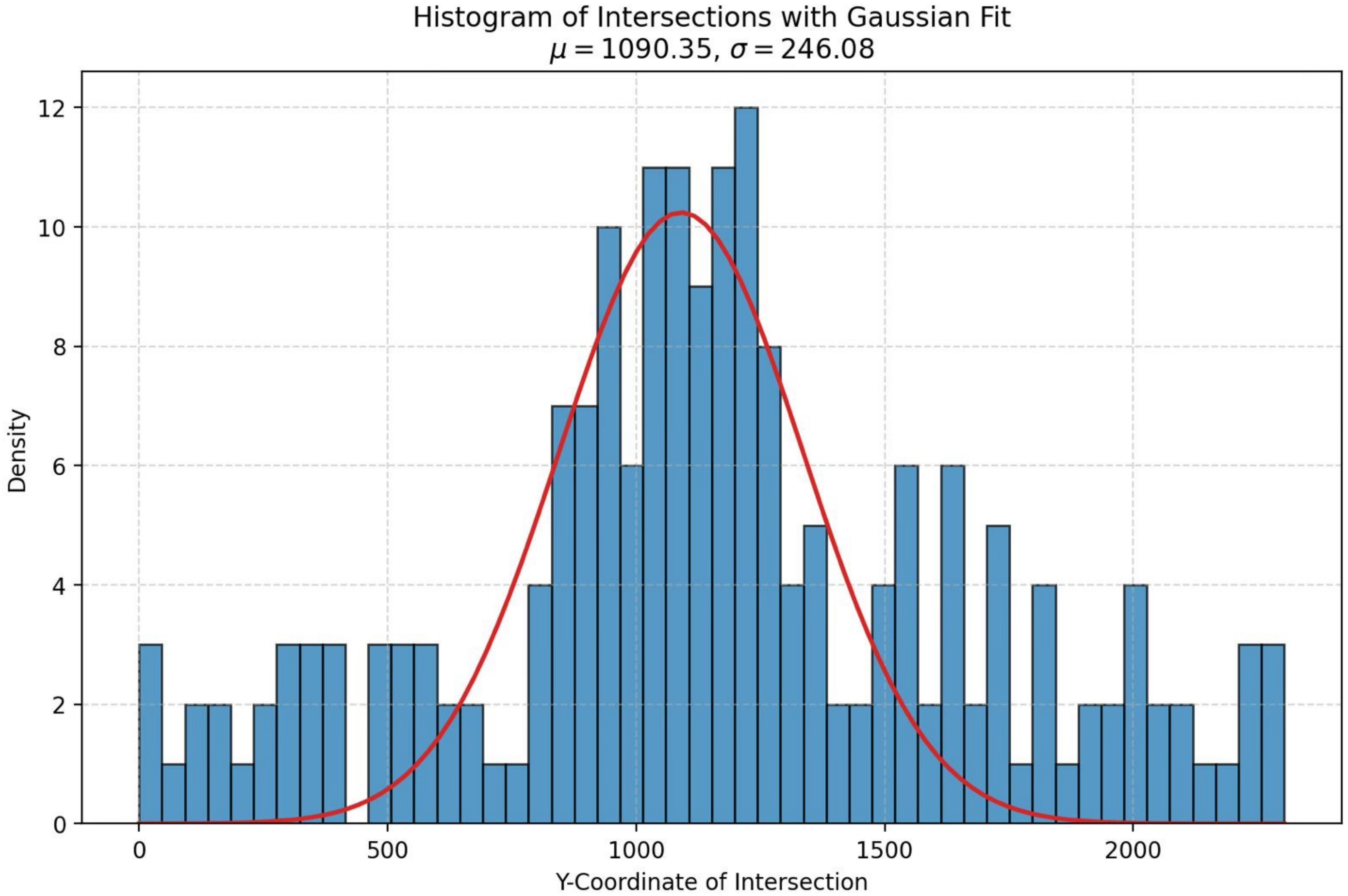


First evidence of the directionality of LIME for Nuclear Recoils

We can reconstruct the source position

- **The AmBe source was placed at half height (Y ~ 1150pixels)**





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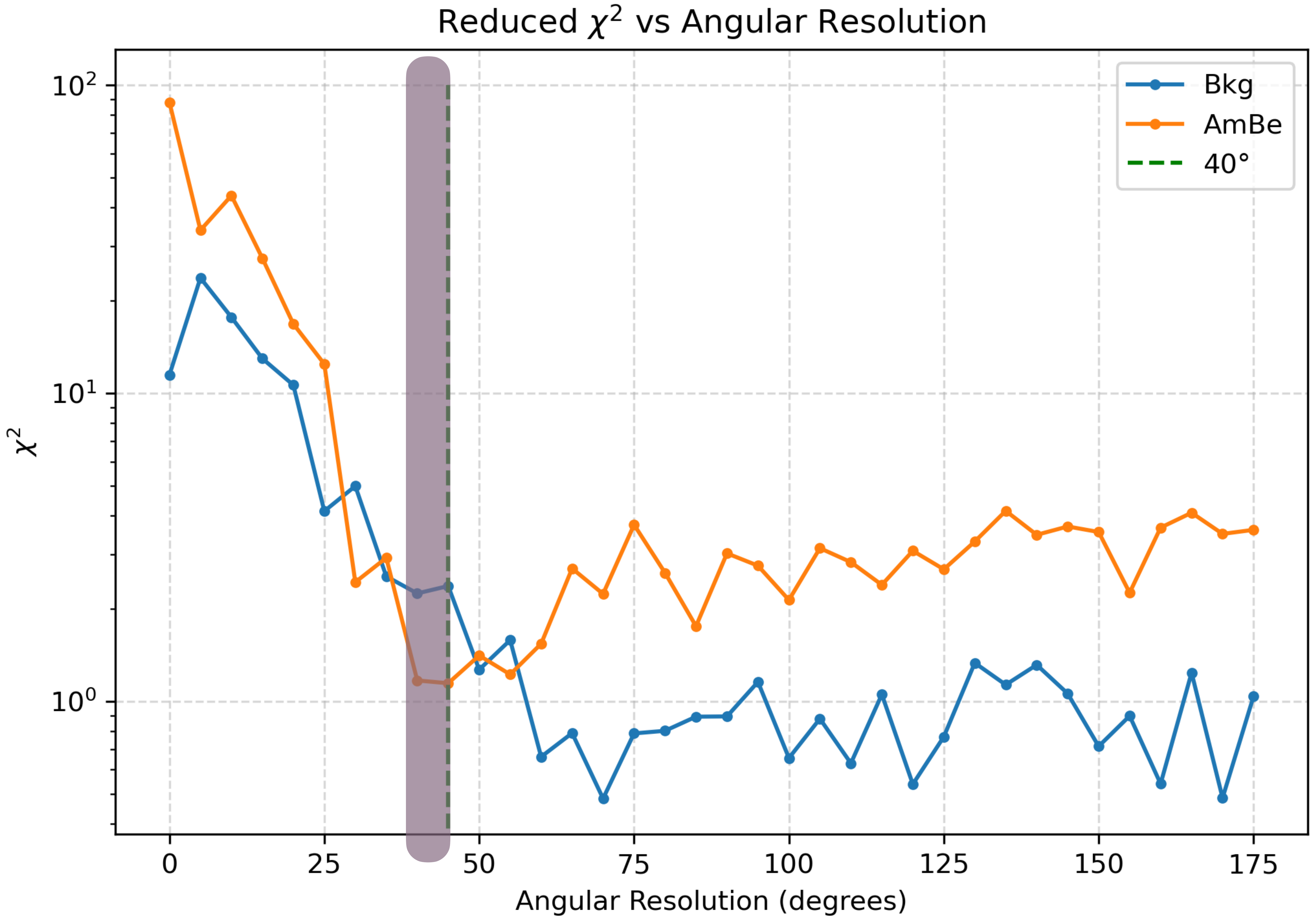
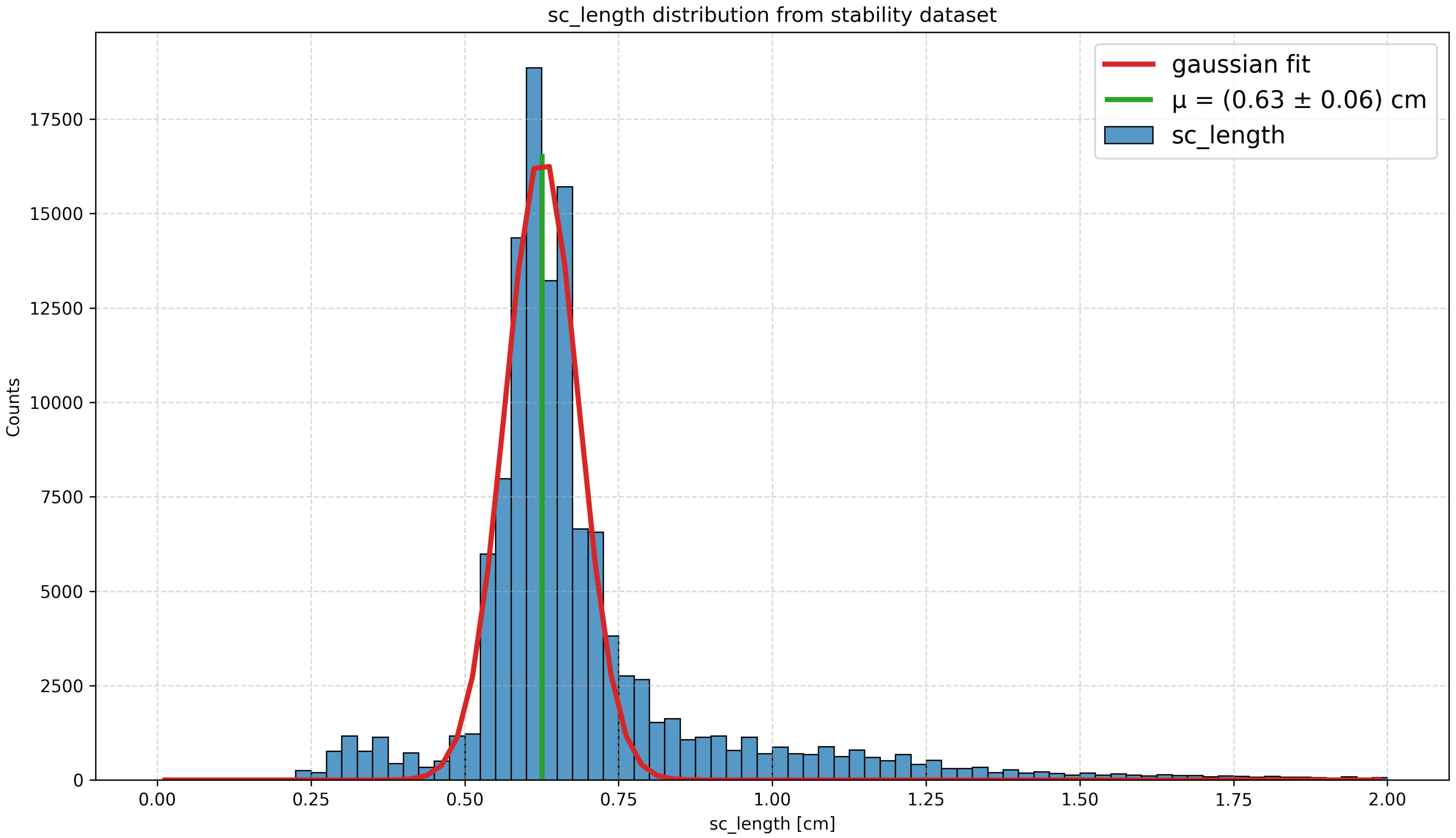
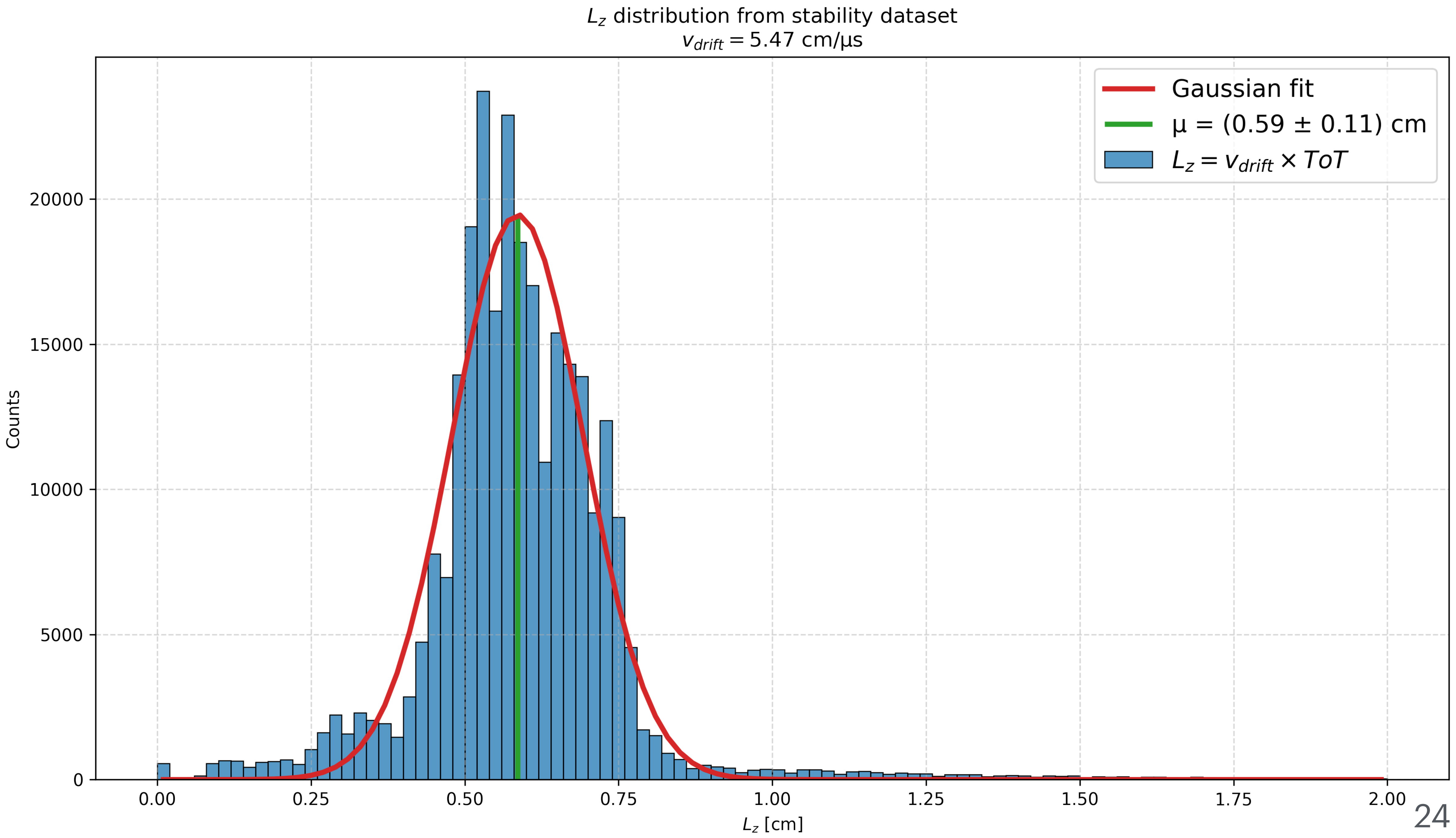


First evidence of the directionality of LIME for Nuclear Recoils

Clusters 3D range reconstruction

- 3D range $= \sqrt{\text{sc\_length}^2 + L_z^2}$, with $L_z = v_{drift} \times ToT^{max}$
- Both lengths should be preprocessed removing the diffusion, evaluated from data taken with ^{55}Fe source half-way in the drift direction.





Clusters 3D range reconstruction

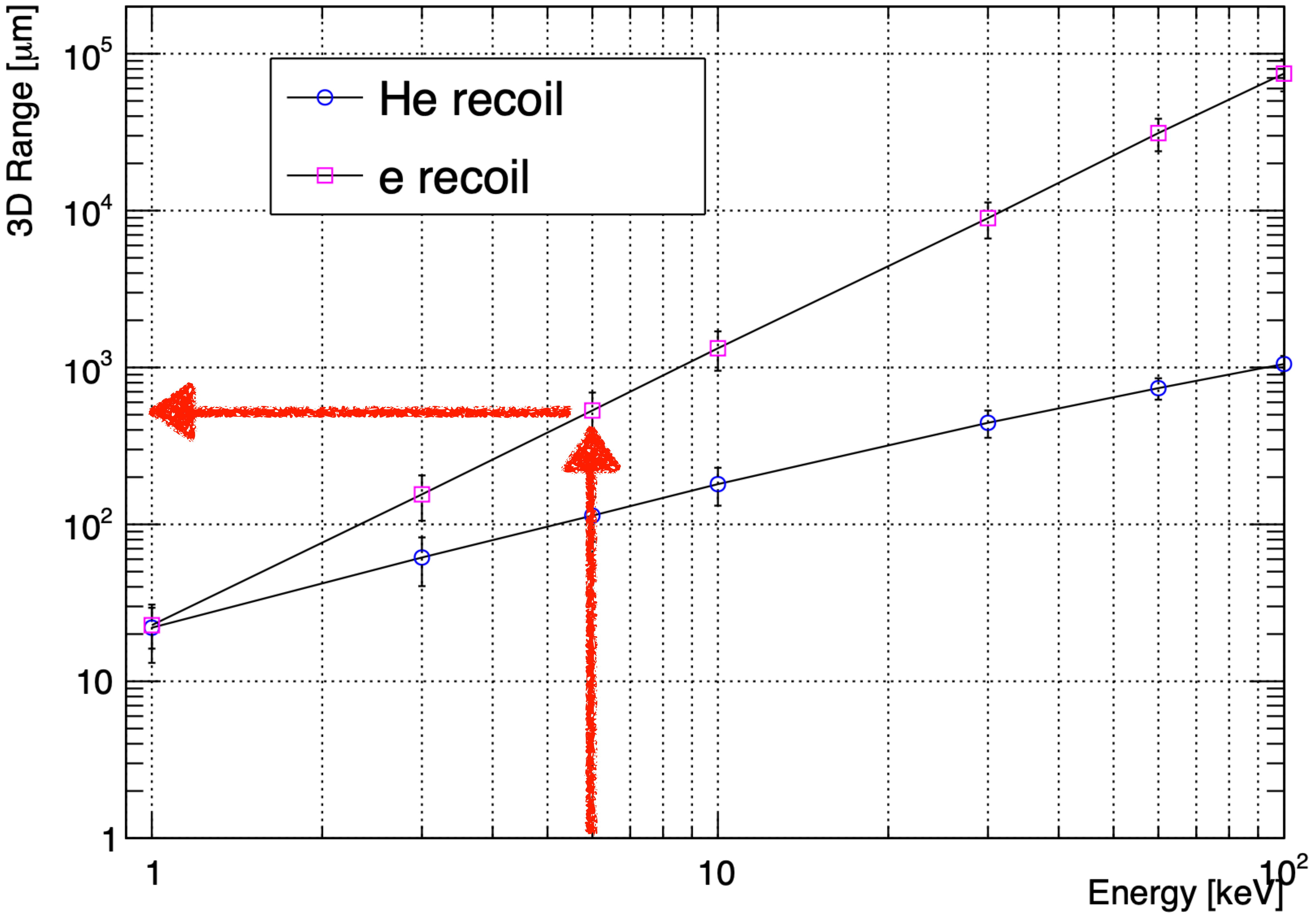
- A **5.9 keV** e^- travel ~**0.5 mm in He:CF$_4$**.

- From the previous slide we obtain:

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

- spot size mainly due to **diffusion only**.

- This measurements can be interpreted as offsets to be subtracted to their relative physical quantities.

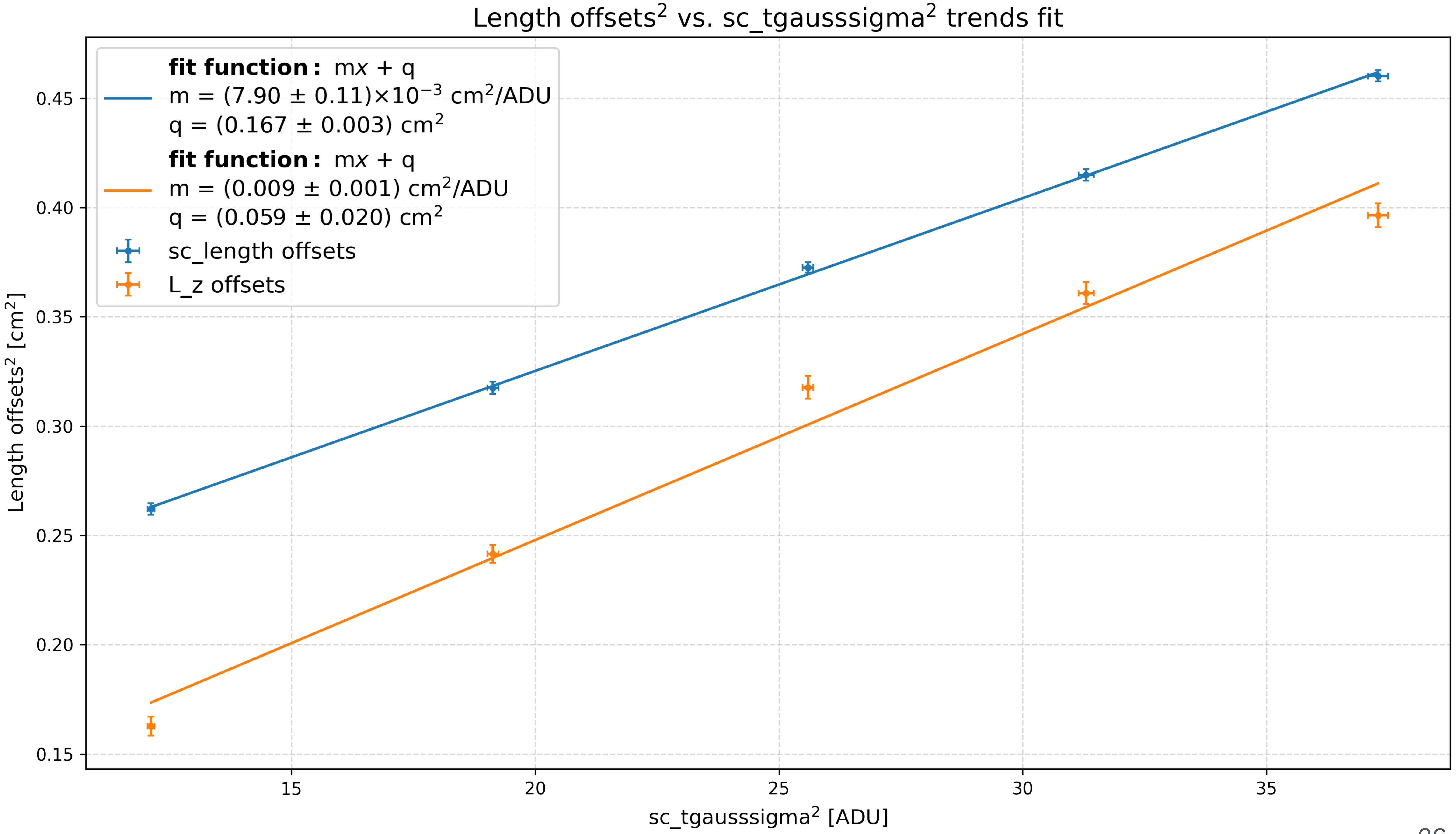


Clusters 3D range reconstruction

- Since the effect of the diffusion increases with the distance, the length offset does it too;

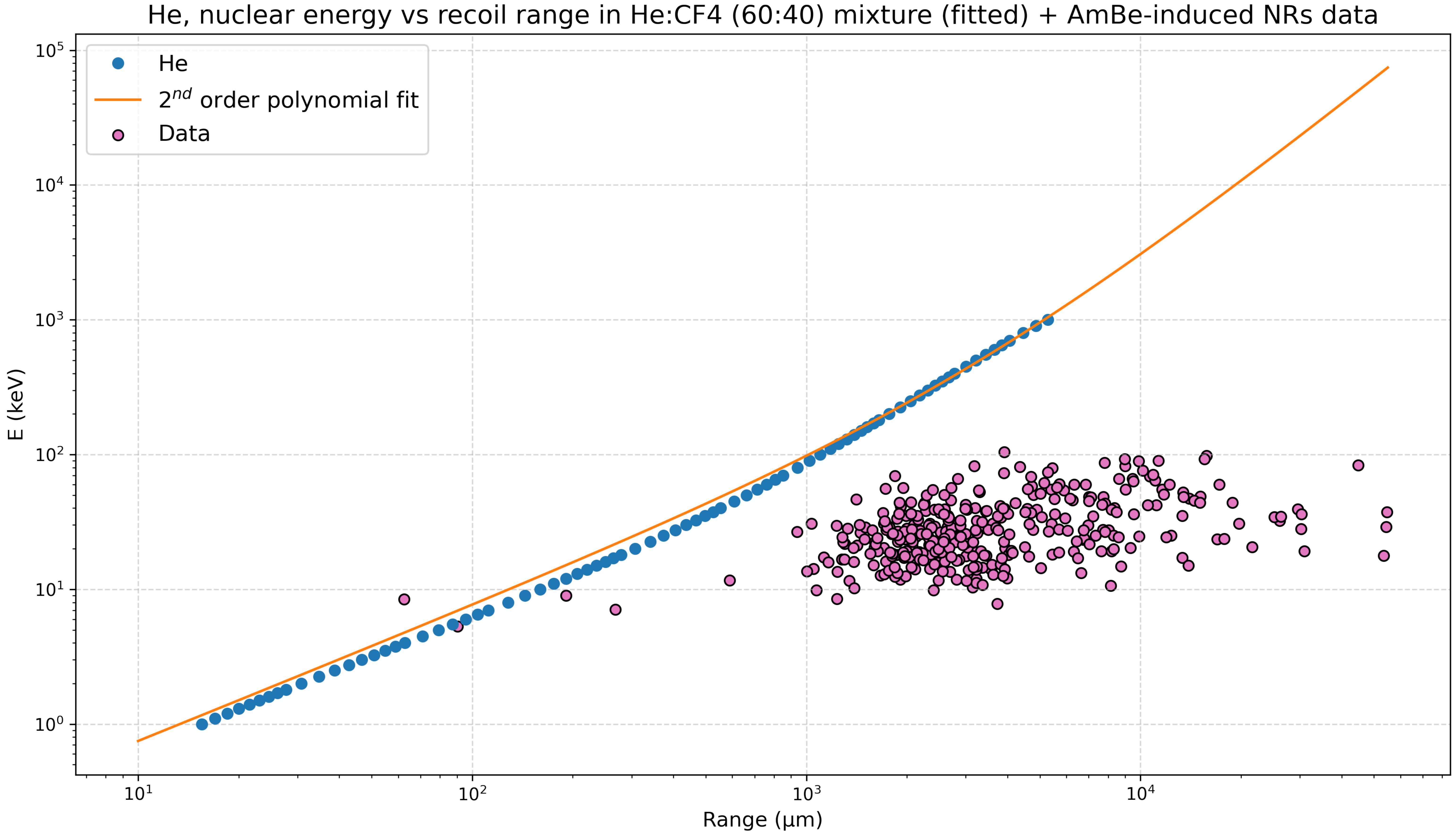
- **Diffusion** of ionisation electrons **scales with the square root of the distance** in drift chambers.

- Transverse profile σ gives a measure of the **position of small clusters in the drift direction**.



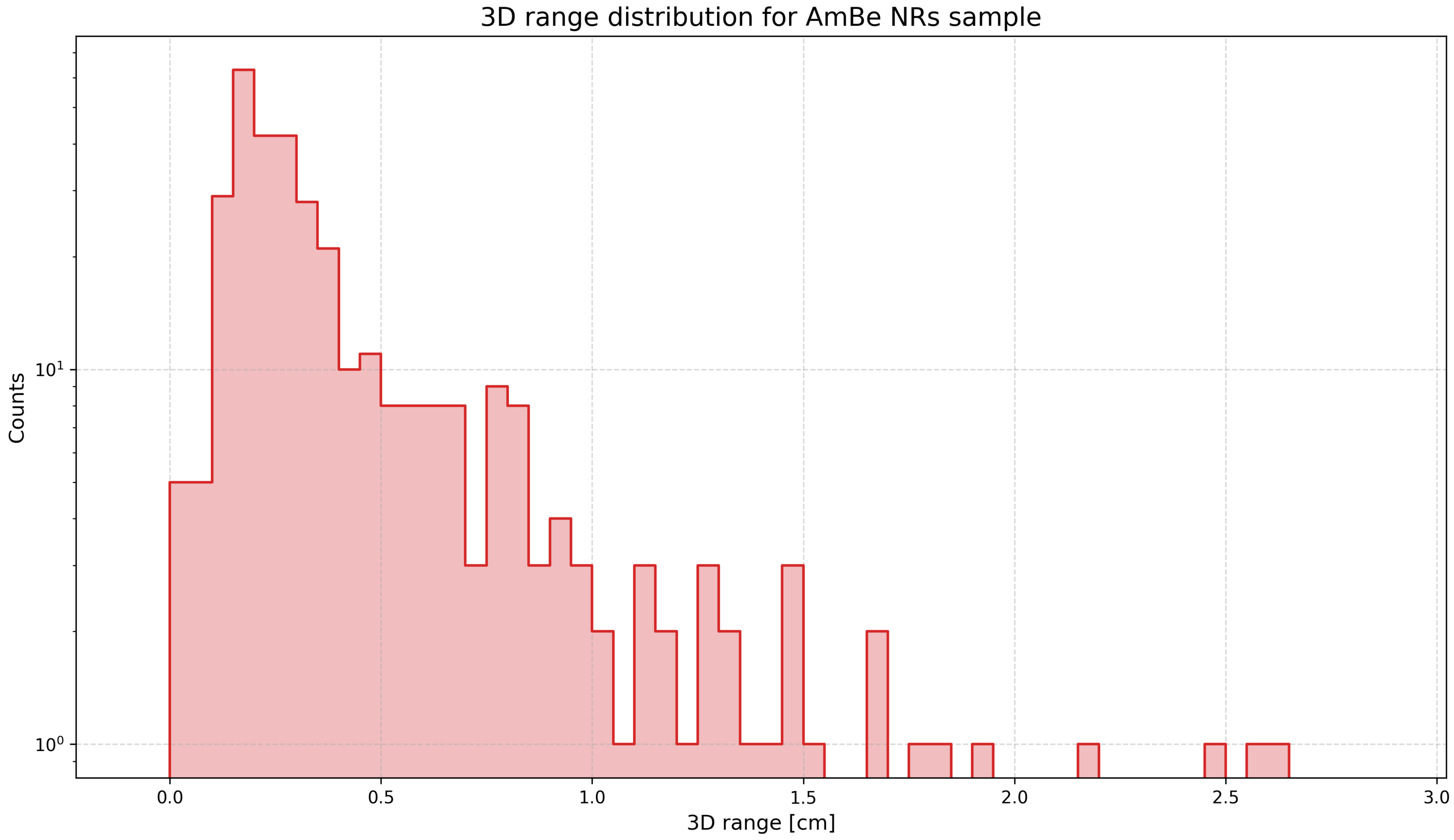
Clusters 3D range reconstruction

- **Fit 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”.



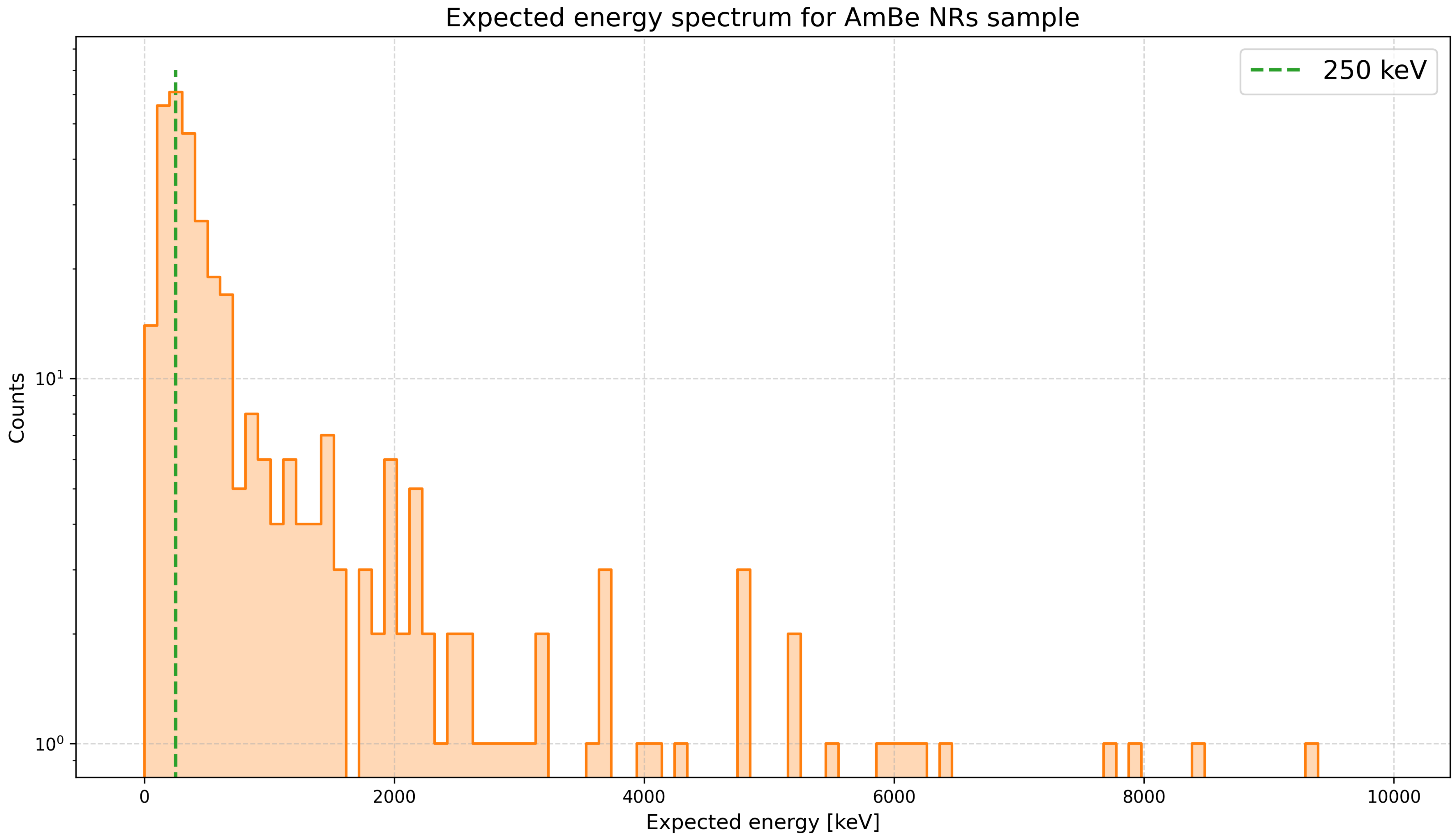
Clusters 3D range reconstruction

- Combining camera and PMTs we can obtain 3D range for each cluster.
- **Most** of the clusters are **shorter than 10 mm**.



True energy spectrum from 3D range

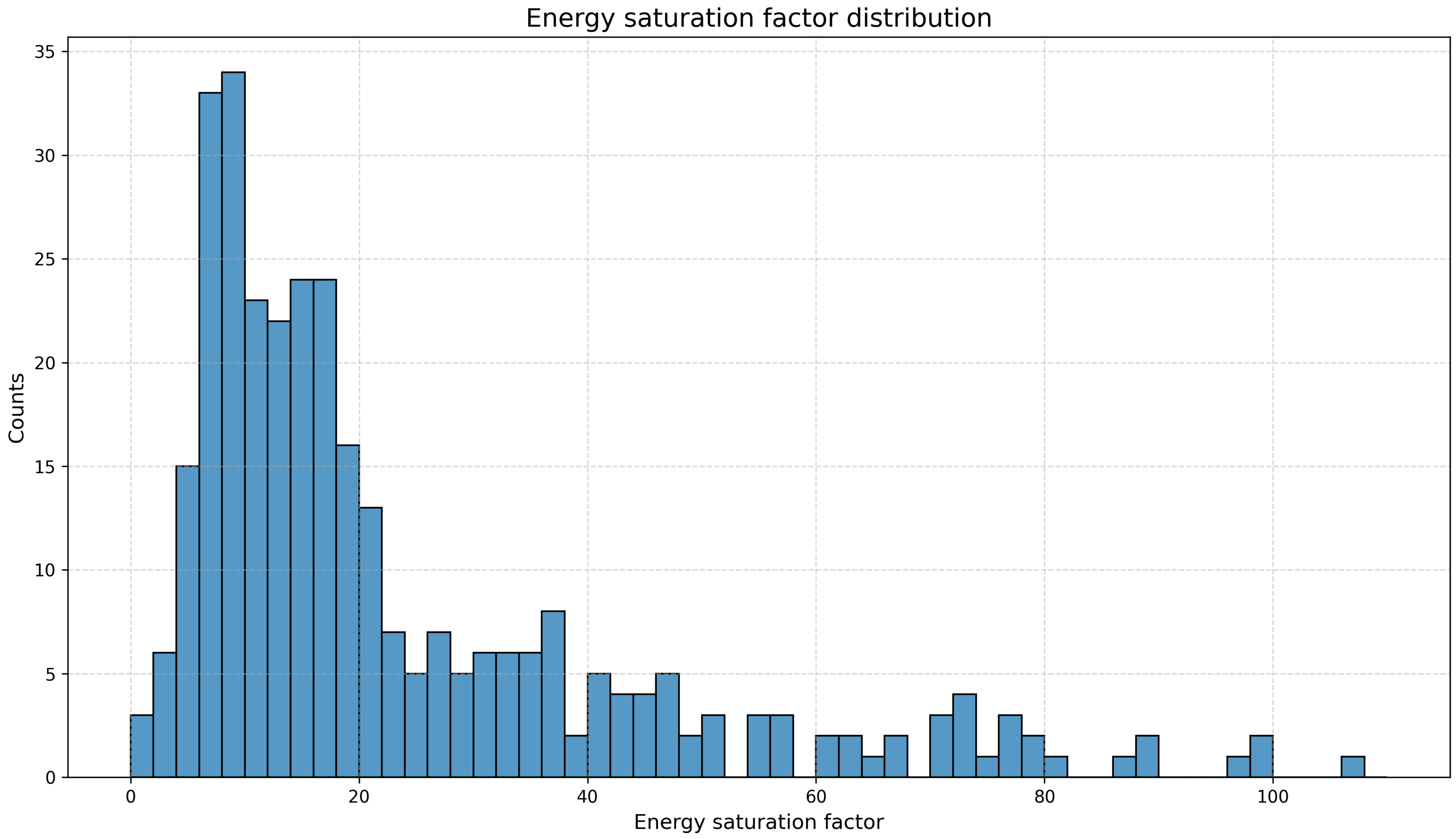
- Known **non-linearity response for very dense tracks**.
- Using previous range vs energy simulations, the **true energy spectrum** is **extracted**.
- Maximum bin for NR with reconstructed energies between 200 and 300 keV



Clusters 3D range reconstruction

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

- Mostly distributed around 10-12
- **Coherent previous studies**.



Conclusions

First RUN with AmBe lasted unfortunately less than 48 hours;

With a very simple selection, 1461 NR were identified, to be compared with 71 in a same data-taking without source;

From an evaluation based on their length, their energy was reconstructed to be mainly below 1 MeV;

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

- different for the AmBe and bkg neutron, indicating a clear sensitivity to the NR preferred direction

- compatible with a direction resolution of about 40-45°