# Status of low energy ER directionality in the CYGNO/INITIUM experiment

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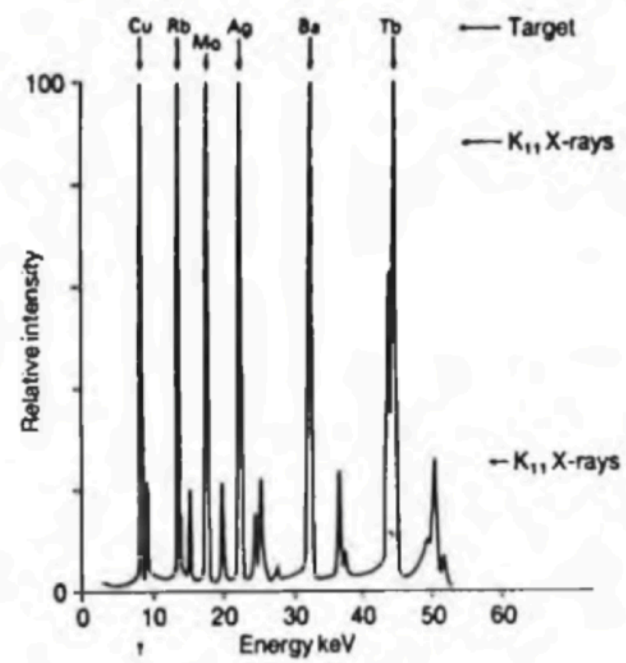
# Energy response and resolution on data

- Study of linearity and energy resolution performed overground with low energy electron recoils from X-Rays with LIME

- Source documentation with both $k_\alpha$ and $k_\beta$ Shell gamma energy reported

- Information about:
  - Absolute peak position
  - Relative peak intesity




$K_\alpha$ X-ray peak heights normalized to the same relative intensity

**X-ray emission**

| target selected | energy (keV)[1] Kα | Kβ | photon yield[2] (photons/sec per steradian) |
|---|---|---|---|
| Cu | 8·04 | 8·91 | $2{\cdot}5 \times 10^3$ |
| Rb | 13·37 | 14·97 | $8{\cdot}8 \times 10^3$ |
| Mo | 17·44 | 19·63 | $2{\cdot}43 \times 10^4$ |
| Ag | 22·10 | 24·99 | $3{\cdot}85 \times 10^4$ |
| Ba | 32·06 | 36·55 | $4{\cdot}65 \times 10^4$ |
| Tb | 44·23 | 50·65 | $7{\cdot}6 \times 10^4$ |

**Notes**
**(1)** Weighted mean energies
**(2)** The photon output is highly collimated limiting emission to ~0·5 steradians.

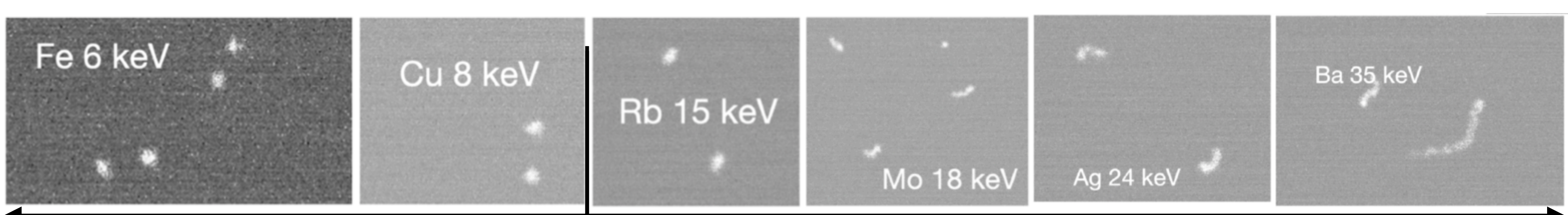
**Primary source**
A 10mCi, 370MBq americium-241 source*, consisting of a ceramic active component in a welded stainless steel capsule, with integral tungsten alloy rear shielding.

*activity tolerance −0, +25%

These sources are also available with an iron-55 primary source for lower energy spectrometry.

**Recommended working life** 15 years

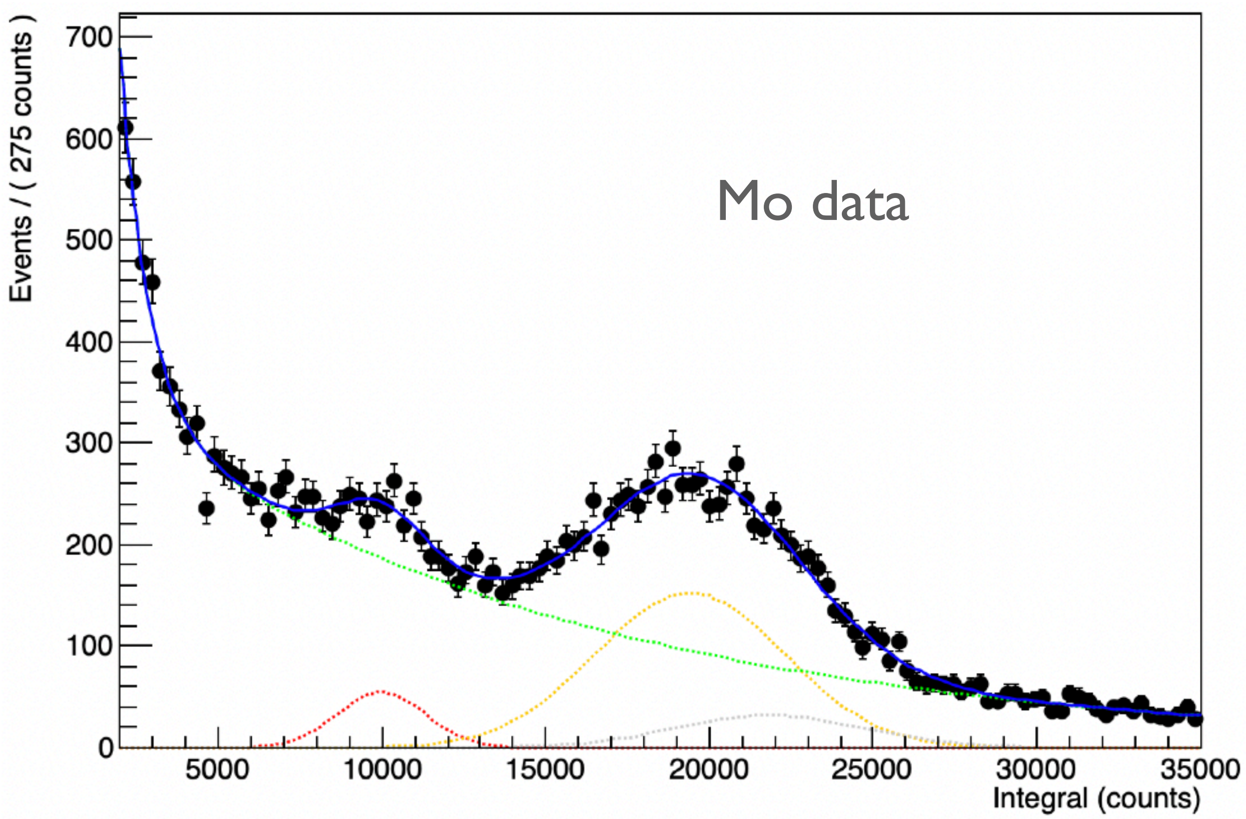
- How tracks appear:

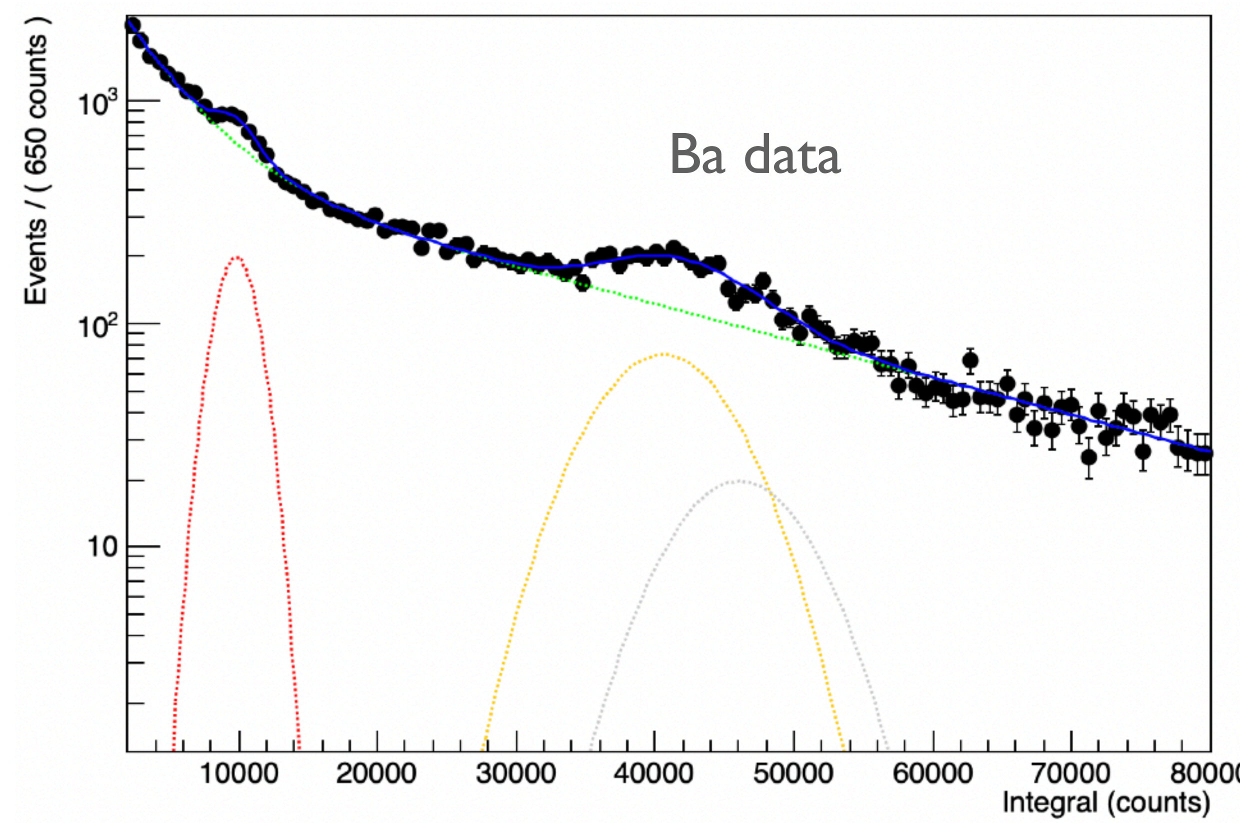



Spot like tracks — Extended tracks

# Data fit model

- Fit done with:
  - 2 exponential to model the background (fake cluster + physics)
  - 2 gaussians for the $k_\alpha$ and $k_\beta$ peaks

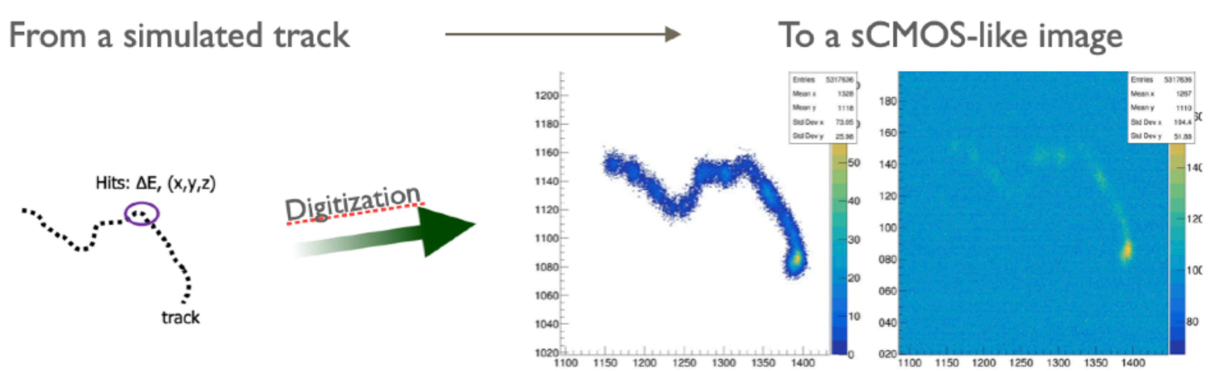


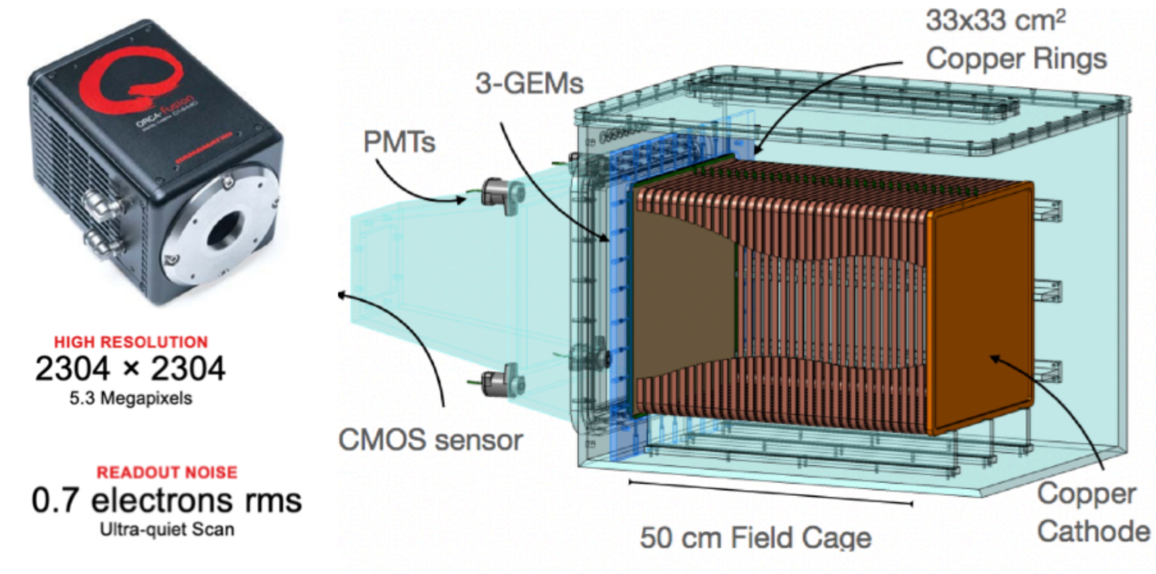




- Constrains applied on $k_\alpha$ and $k_\beta$ peak relative yield and relative position
- Same sigma used for the two peaks (very similar energies)
- Copper peak present at energies higher than 8 keV

# Digitization code

- Digitization of simulated tracks into sCMOS pictures

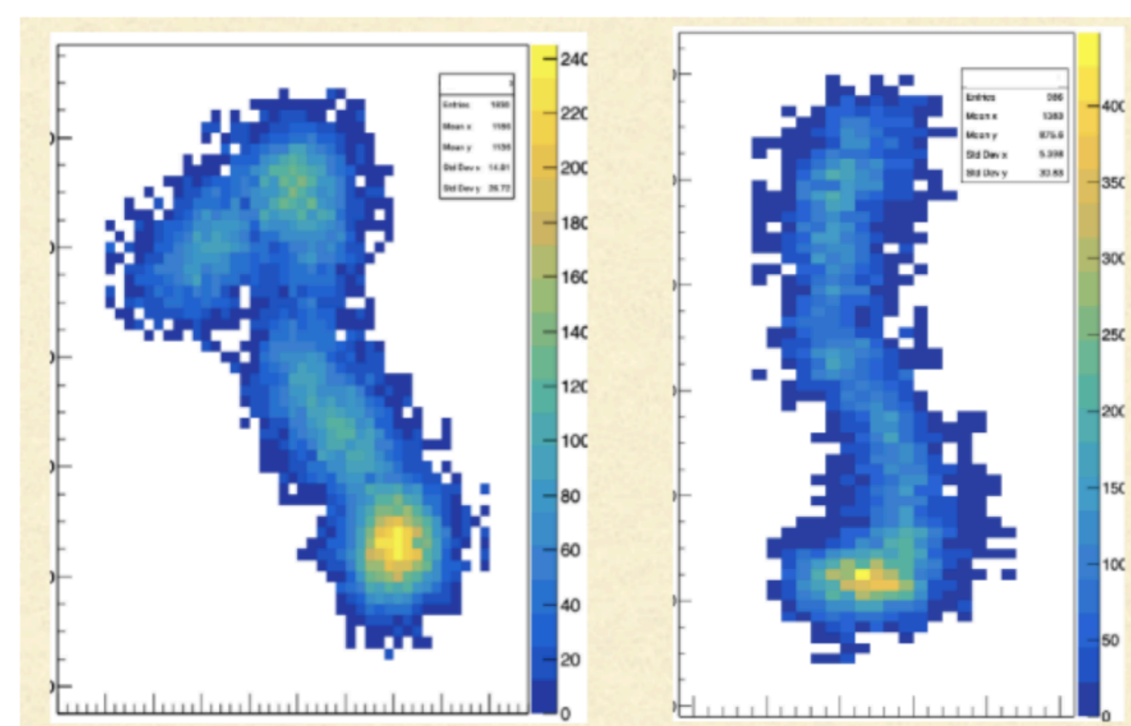



Developed taking into account detector effect:

- Fluctuation in primary electrons production (poiss.)
- GEM gain fluctuation (expo.)
- Gain dependence on electron density
- Electron diffusion from measured coefficients
- Fluctuation in photon production (poiss.)
- Light collection efficiency
- Vignetting effect with track produced in different x-y
- Addition of noise from a real sCMOS picture

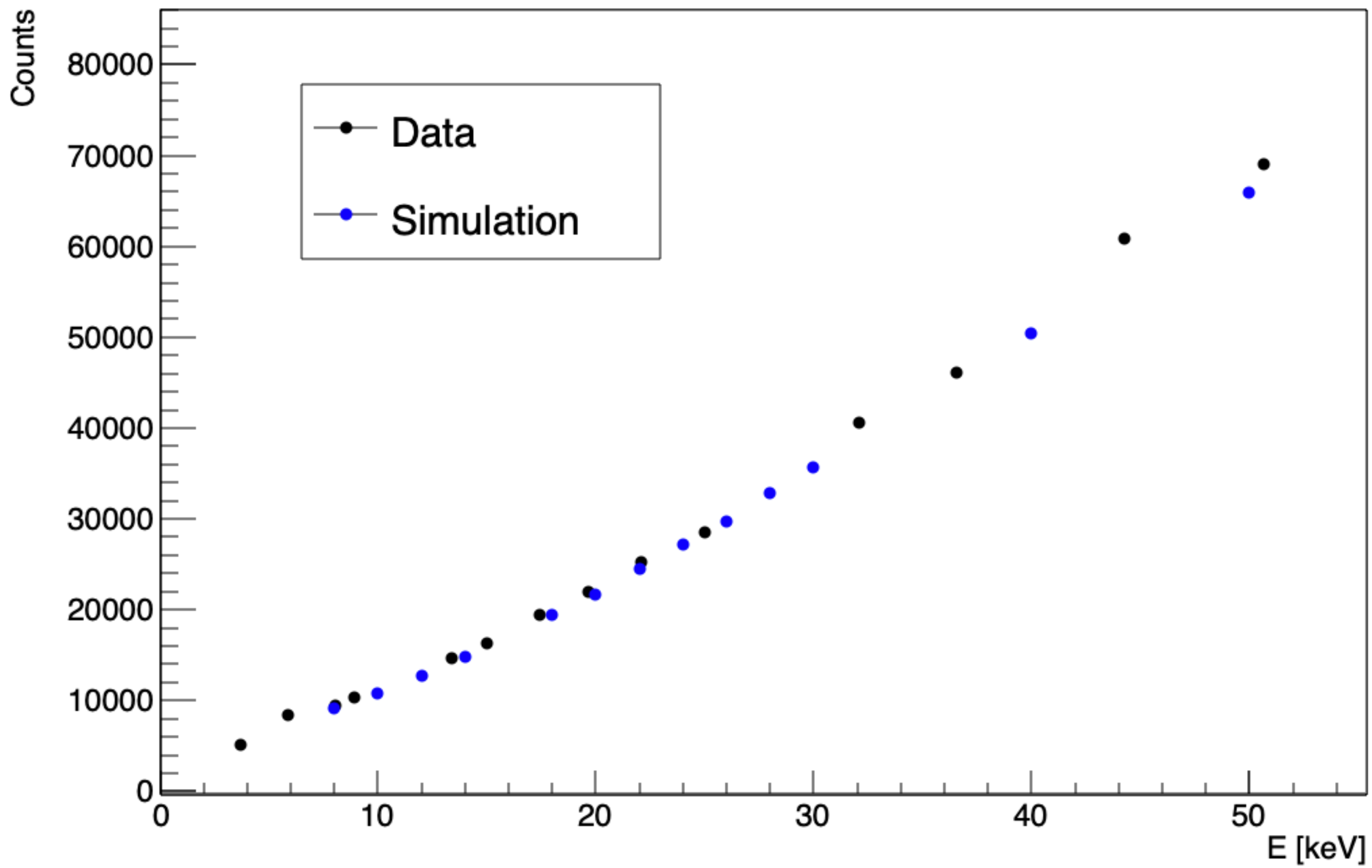
**30 keV electron**



**Simulation** **Data**

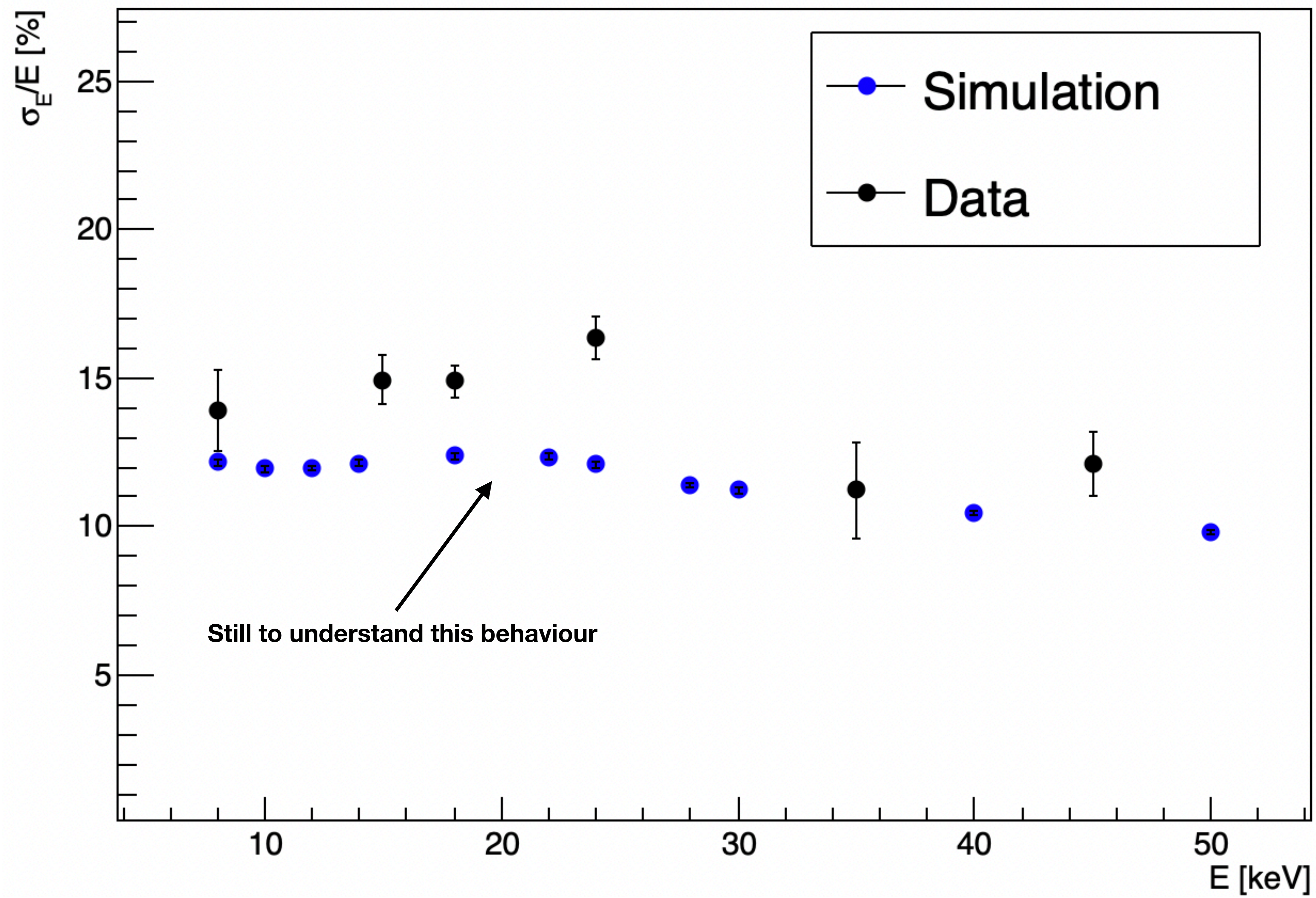
# Linearity data-MC comparison

- Both $k_\alpha$ and $k_\beta$ energy shown in the plot for data
- High statistic simulation at different energies



# E Resolution data-MC comparison

- Only $k_\alpha$ energy resolution shown in the plot for data (same sigma for both peaks)
- Gaussian energy distribution for data



# sPlots: a statistical tool to unfold data distributions

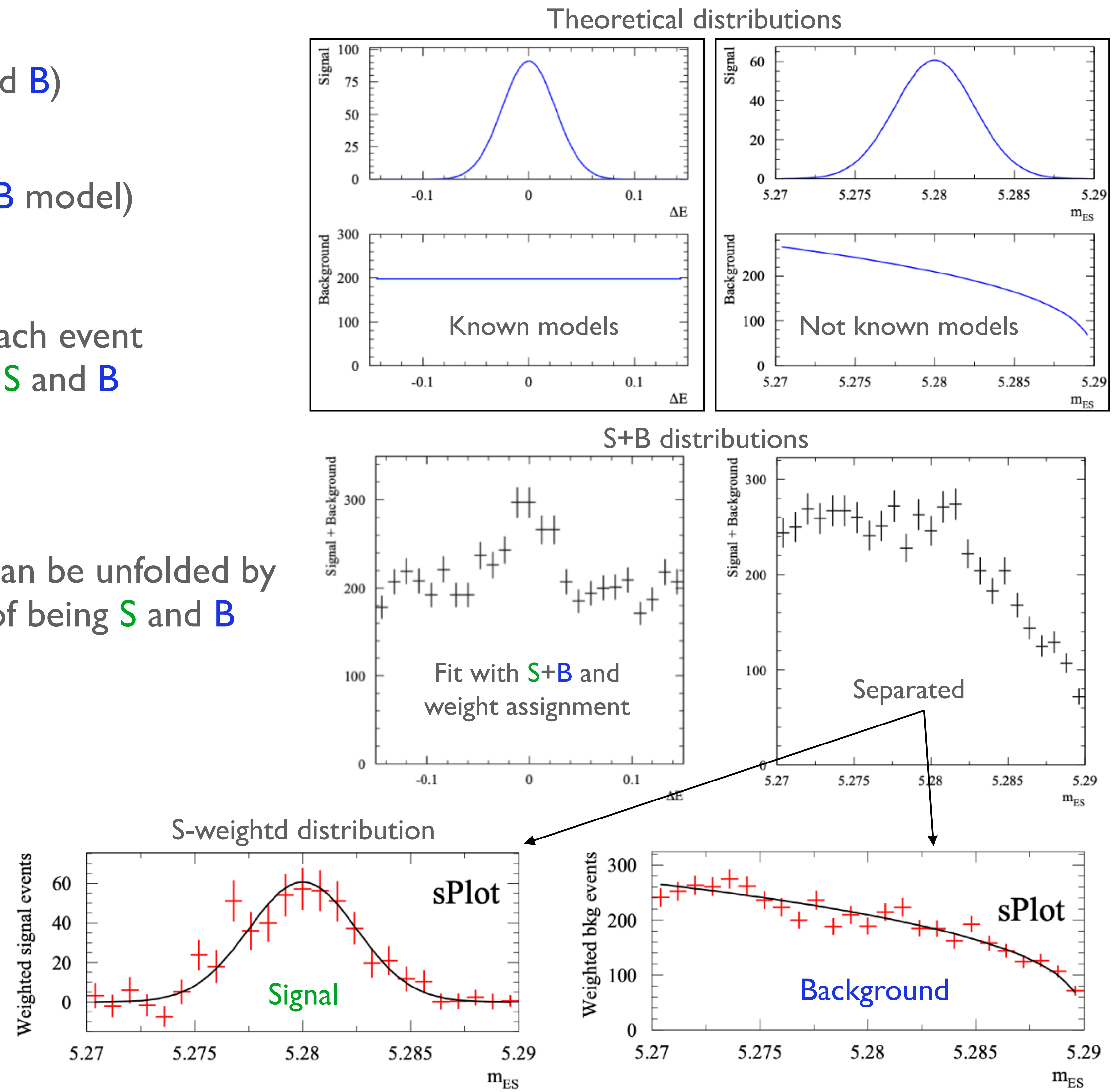
- Dataset containing two variables (consisting of signal S and background B)
- By fitting one distribution (with S + B model)

  ↓

  S weight and B weight assigned to each event proportional to probability of being S and B

- The pure S and pure B distribution can be unfolded by weighting each event by the weight of being S and B
- Since the weight can be positive or negative plotting the pure signal distribution the negative weight cancels the background part

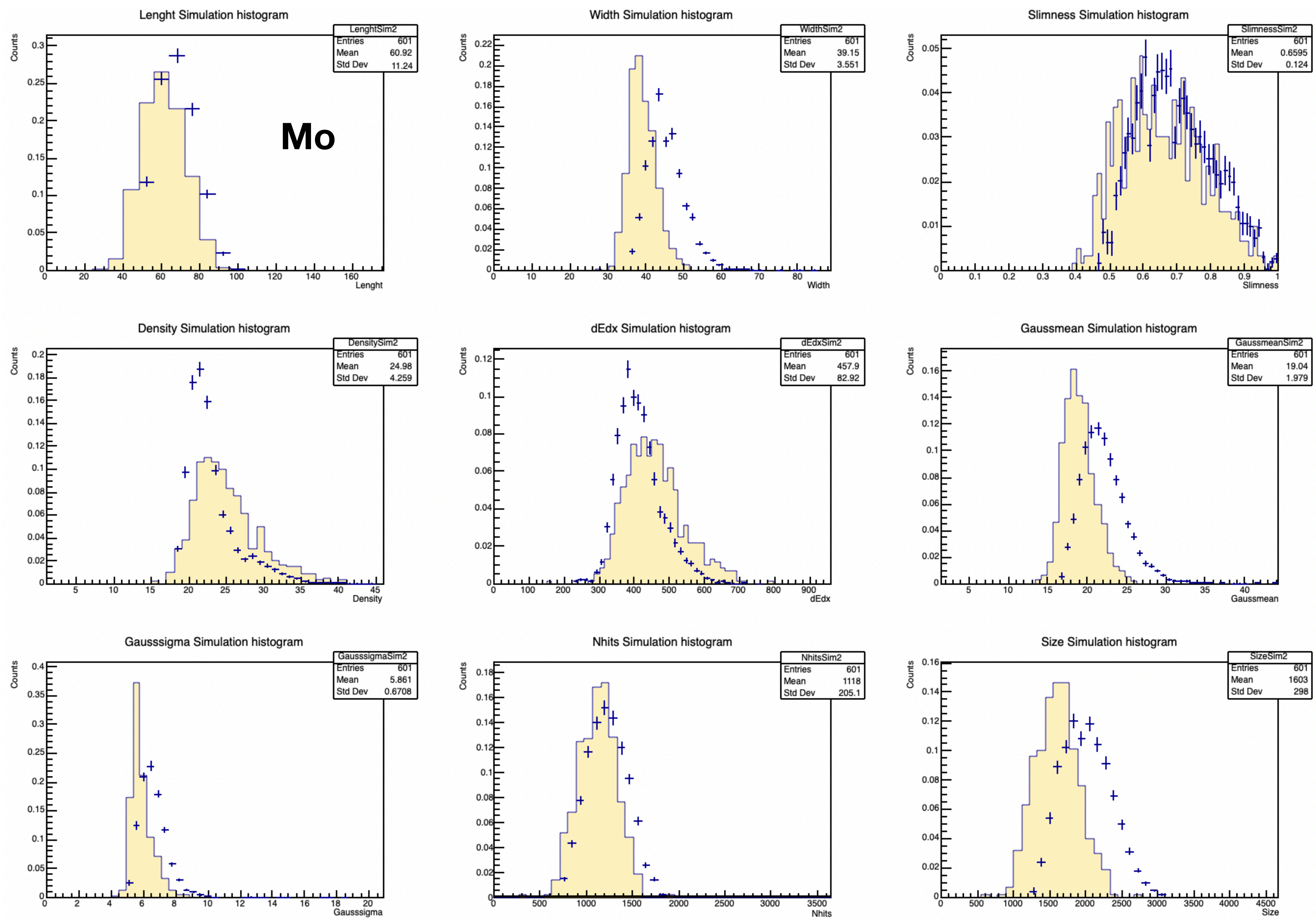
*Nucl.Instrum.Meth.A 555 (2005), 356-369*



# Track shape comparison

Simulation | Data unfolded

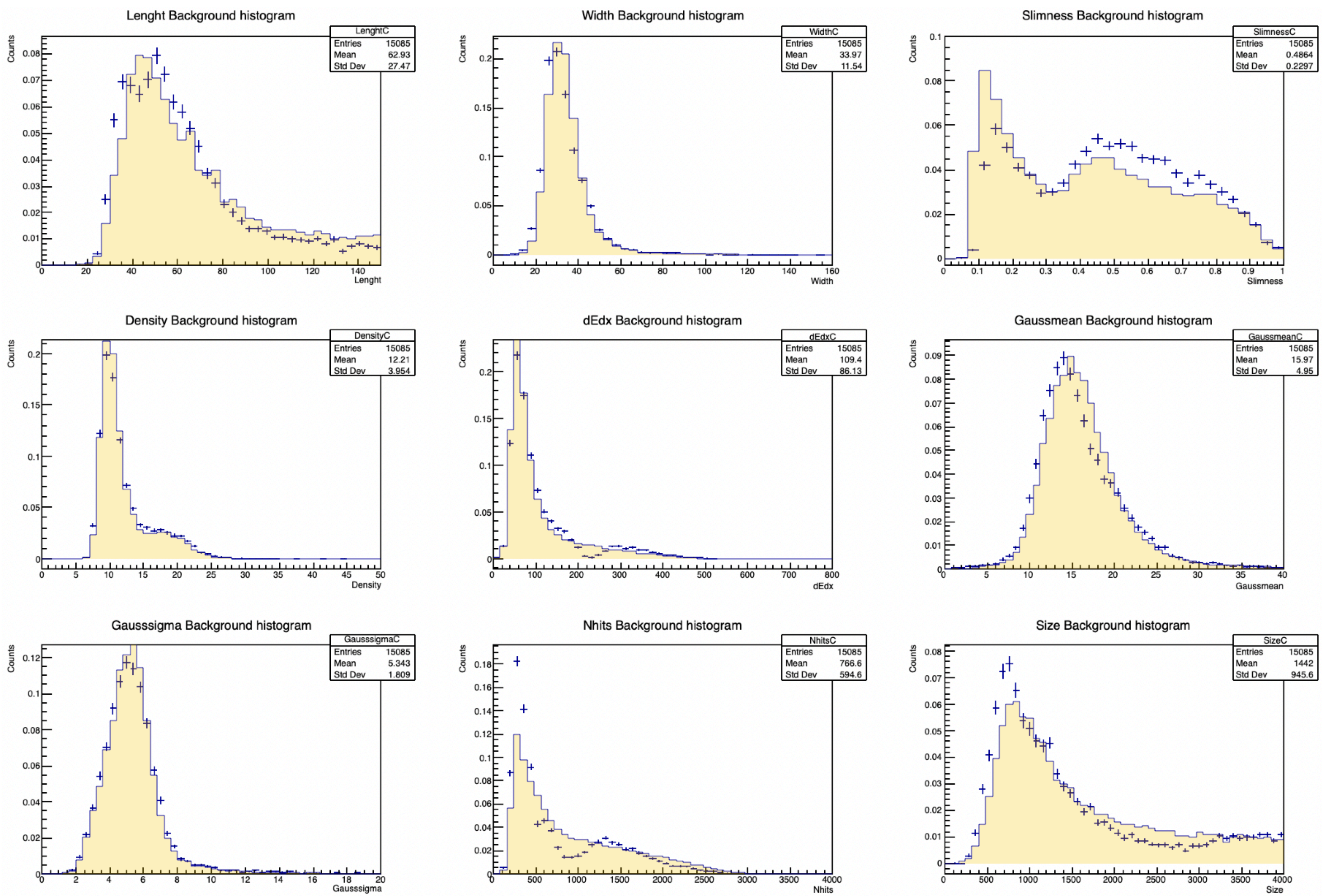
- Using sPlot we can unfold the distributions of variables for pure signal



# Track shape comparison

Cosmic run — Pure bkg extracted distrib.

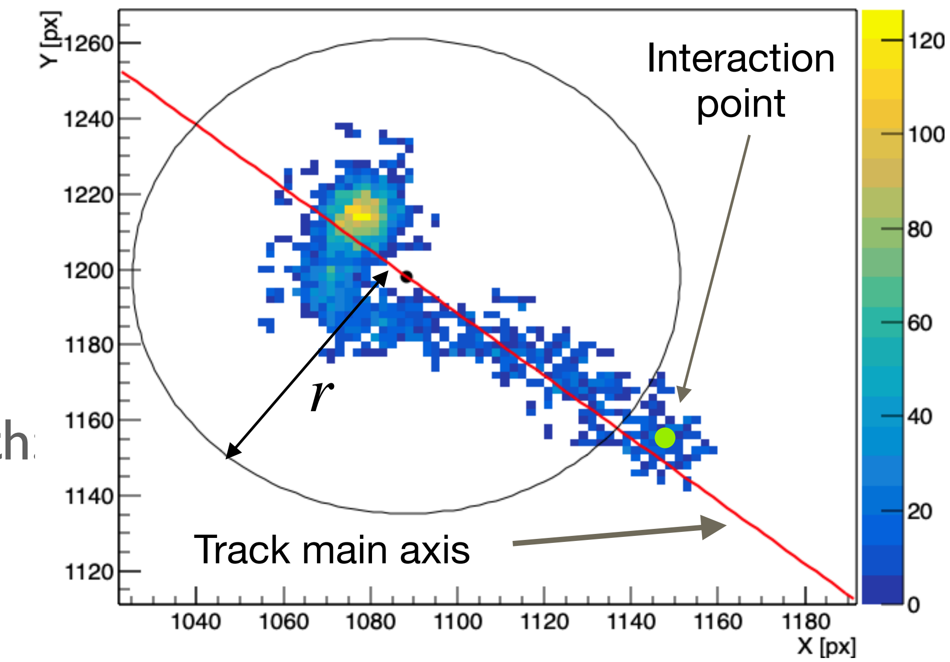
- Using sPlot we can unfold the distributions



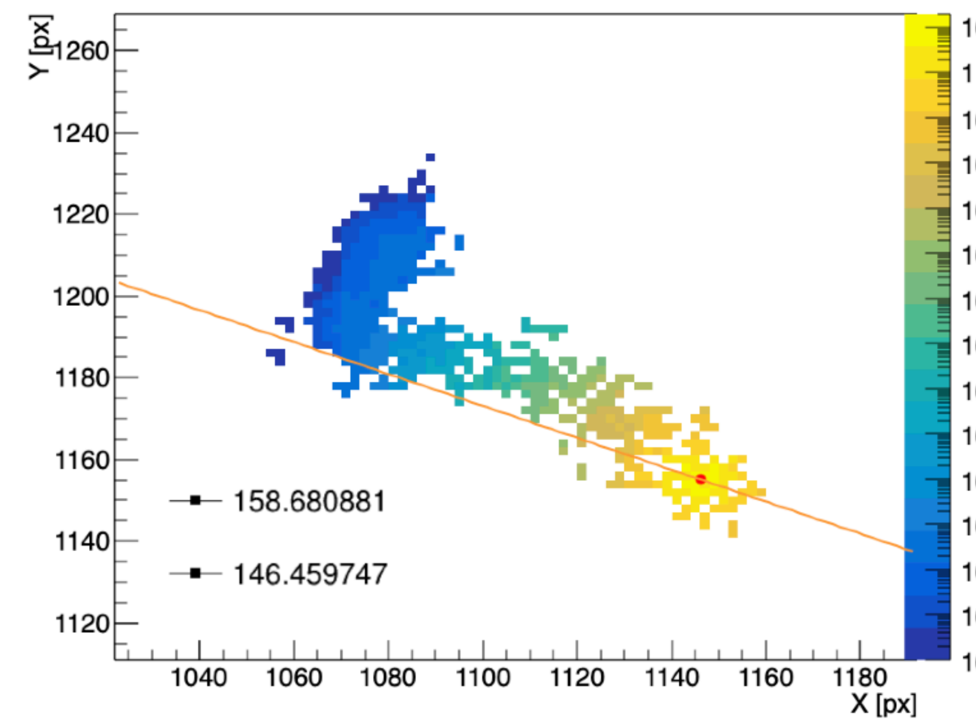
# Directionality algorithm in a nutshell

- Algorithm adapted from X-ray polarimetry:

"Measurement of the position resolution of the Gas Pixel Detector"
Nuclear Instruments and Methods in Physics Research Section A, Volume 700, 1 February 2013, Pages 99-105




- First part of the algorithm: searching for the beginning of the track with:
  - Skewness
  - Distance of pixels from barycenter (farthest pixels)
  - Selection of a region with fixed number of points $N_{pt}$

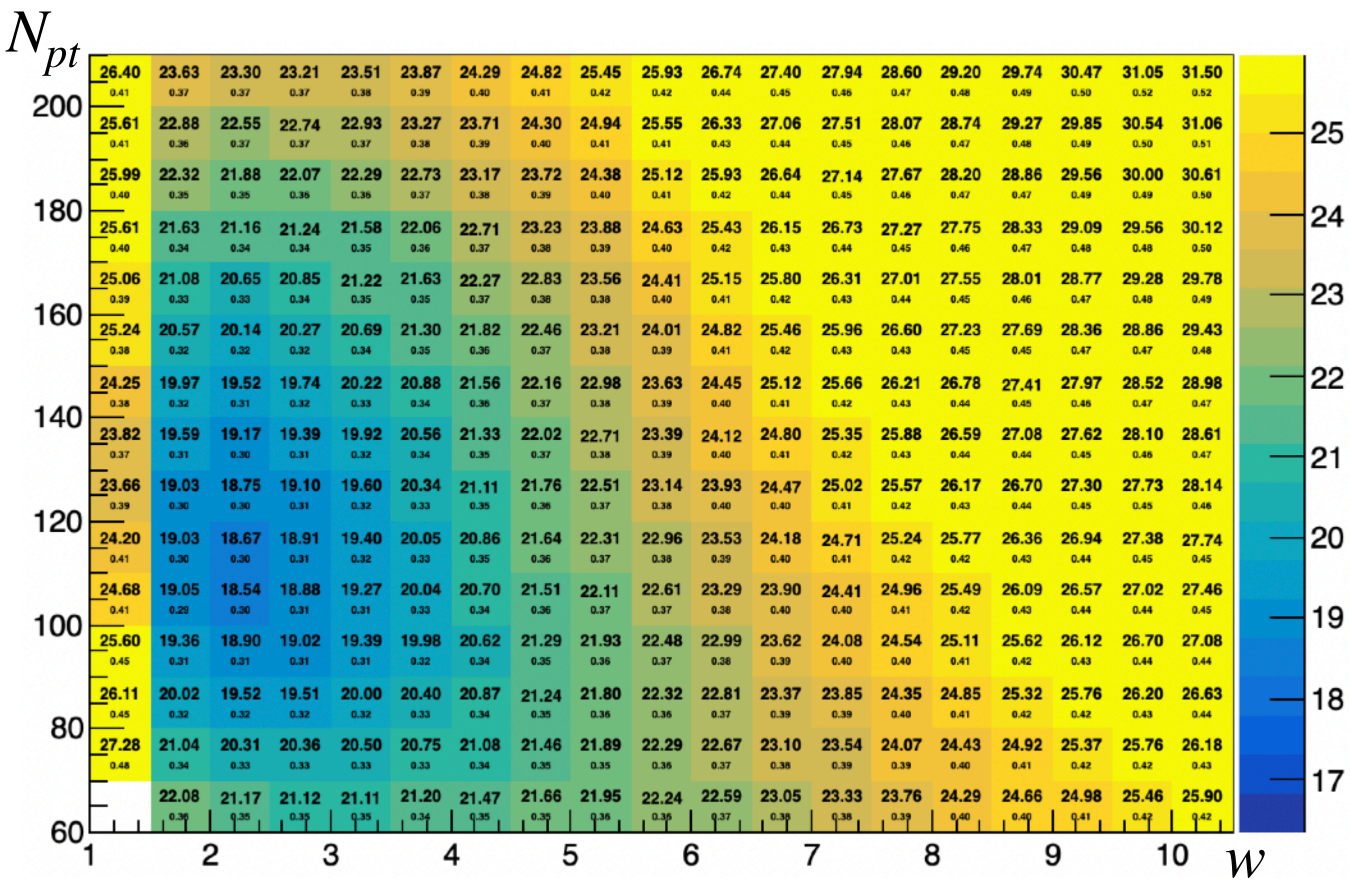


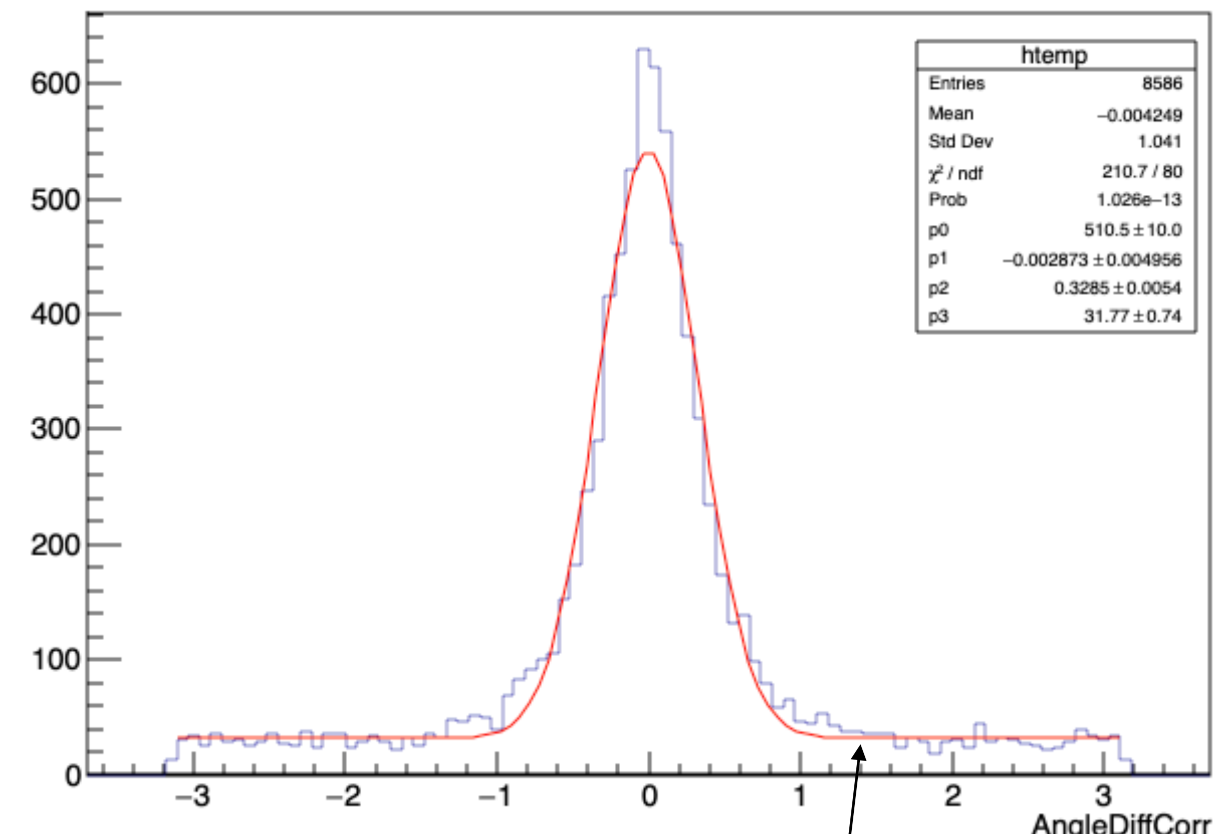

- Second part of the algorithm aims to find the direction:
  - Track point intensity rescaled with the distance from the interaction point: $W(d_{ip}) = exp(-d_{ip}/w)$
  - Direction taken as the main axis of the rescaled track passing from the interaction Point
  - Orientation given following the light in the Pixels

- Two parameters of the algorithm: $N_{pt}$ and $w$

# Parameters optimization

- Optimization of the parameter from a scan of angular resolution vs $N_{pt}$ and $w$



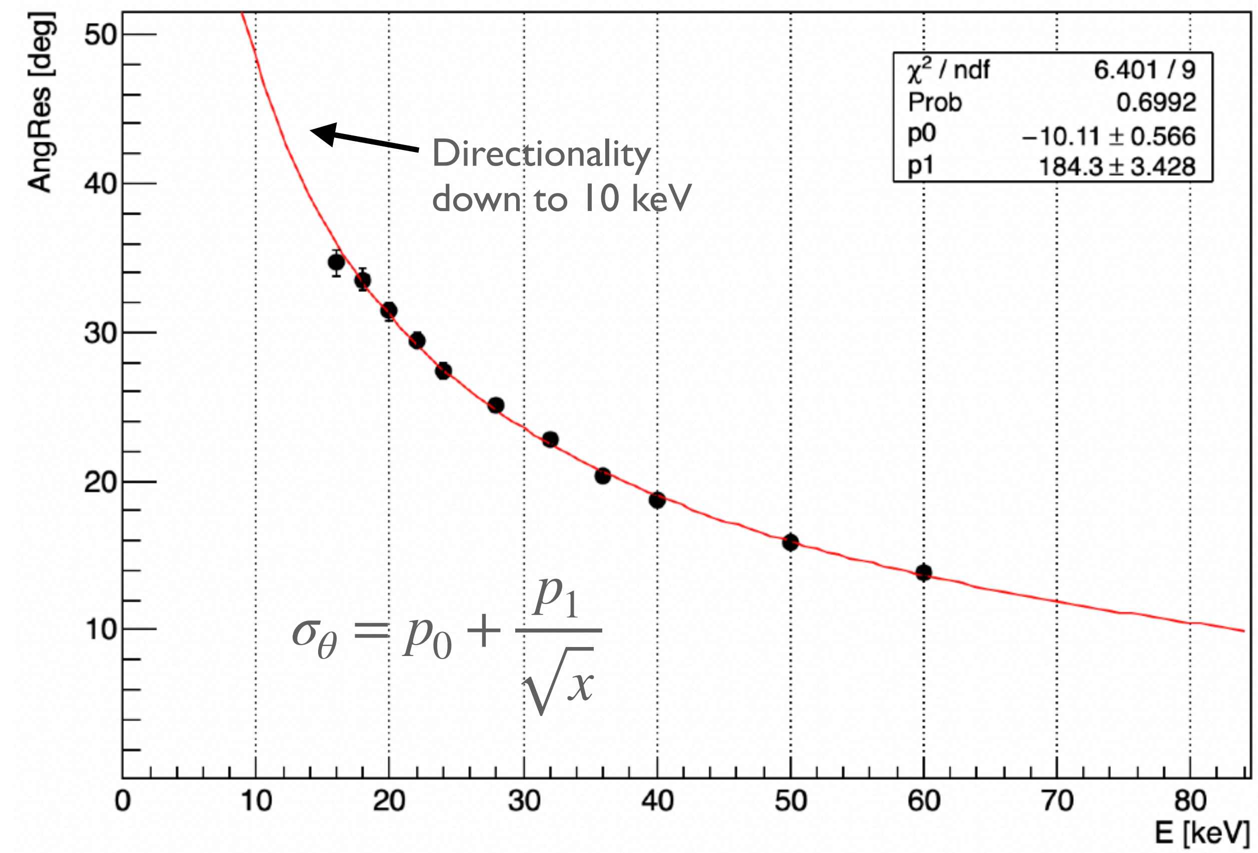

- Values which provide the best angular resolution chosen

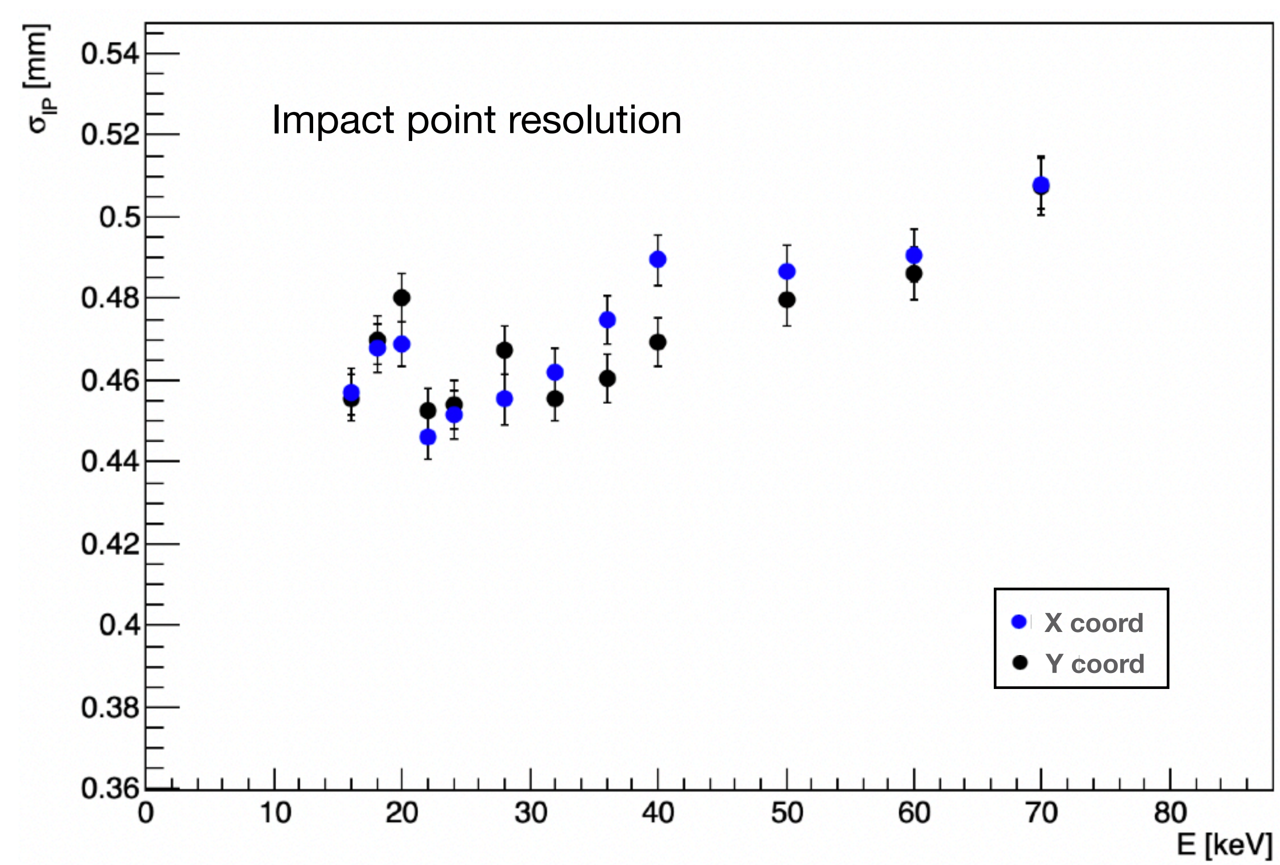
Constant term in the fit due to lack of 3rd coordinate ($e^-$ towards the GEM)

- All the values are in the same region for every energy

# Results on angular resolution

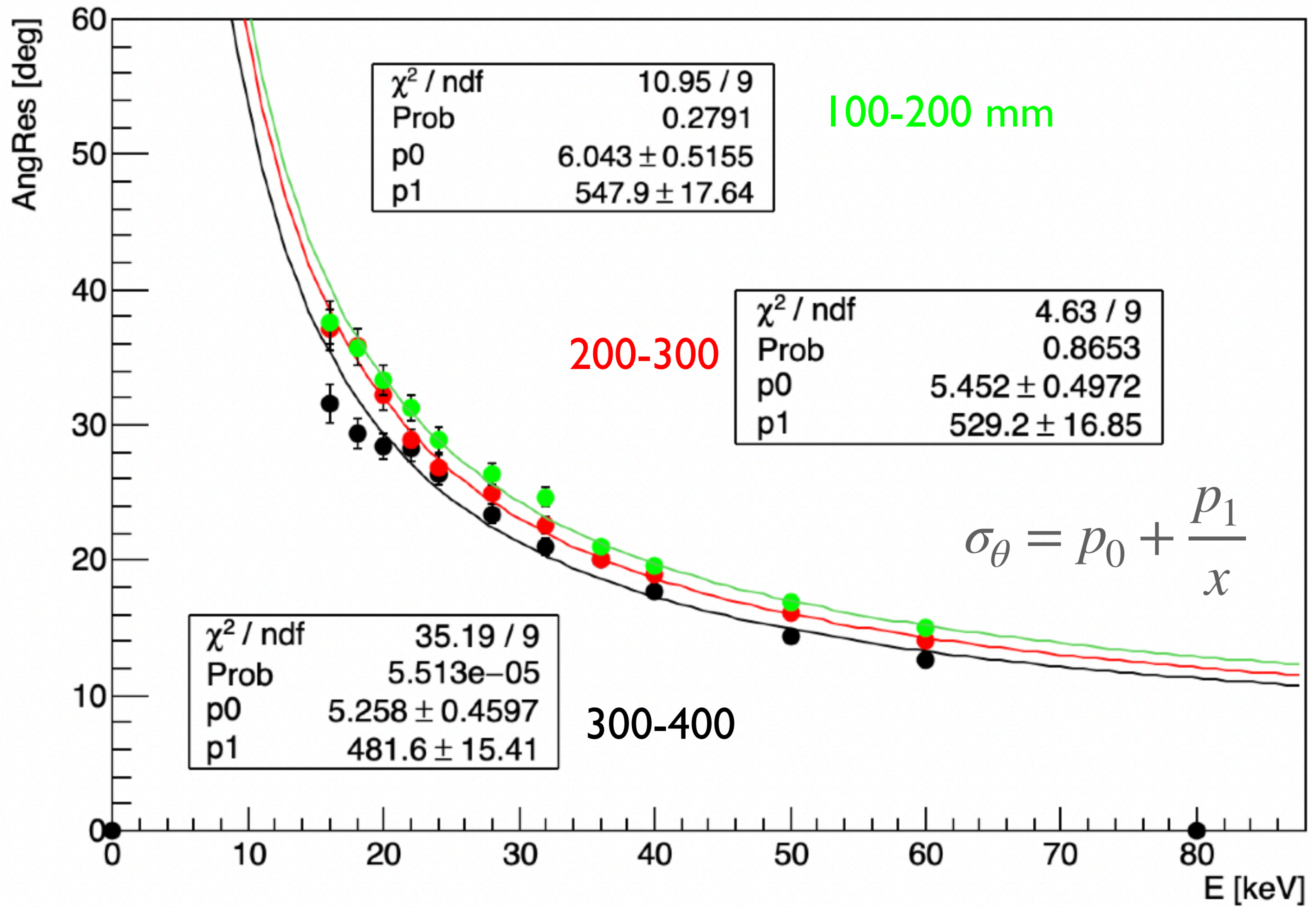
- Results of directionality resolution on low energy electron recoils
- Tracks simulated isotropically in angle
- Drift distance uniform from 10 to 40 cm
- Random x-y position with vignetting included
- Resolution as the sigma of $\theta_{meas} - \theta_{true}$ distrib.
- Same for impact point distribution



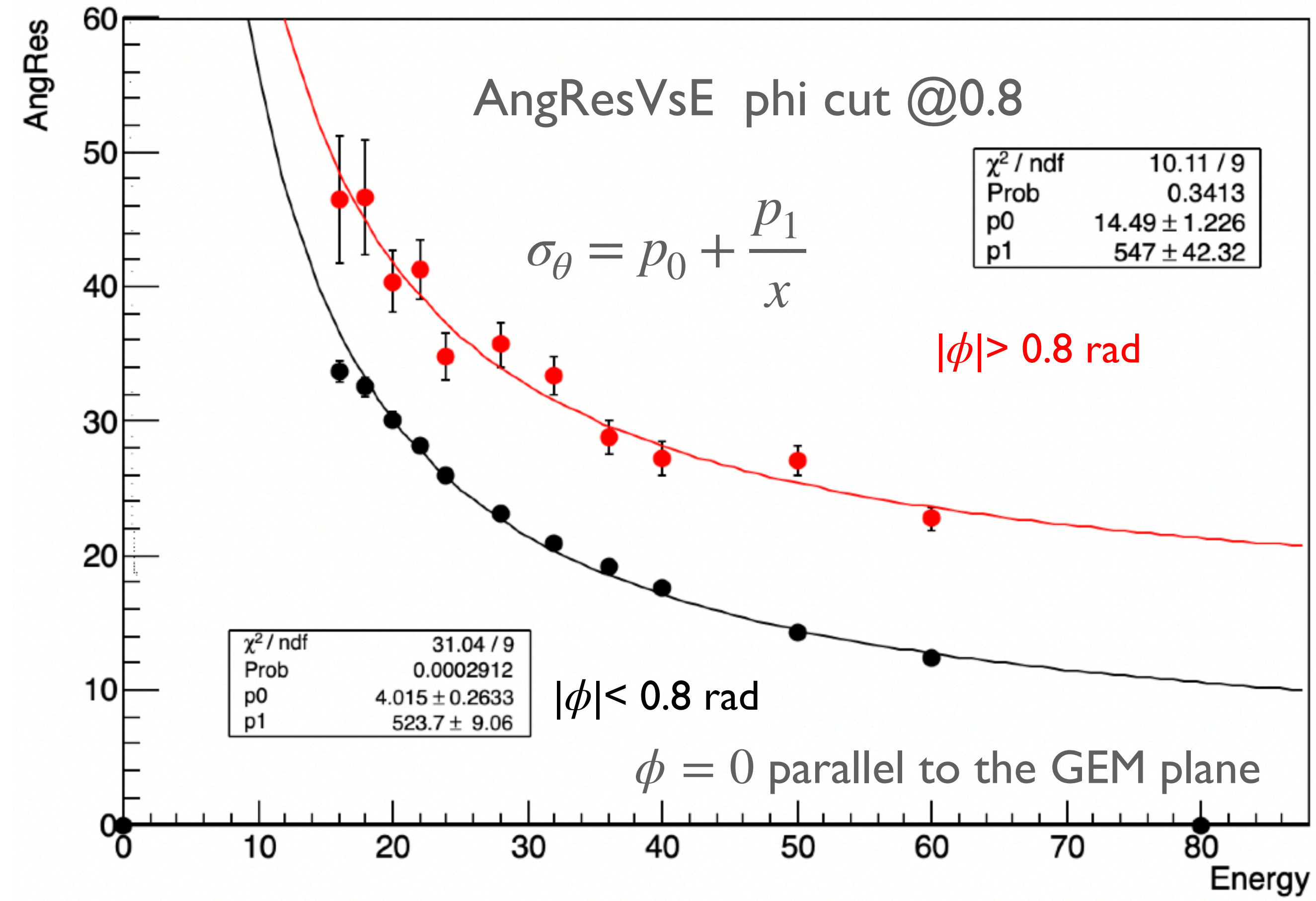
# Further considerations on angular resolution

## Effect of the diffusion on ang res




- Diffusion can affect directionality at lower energies

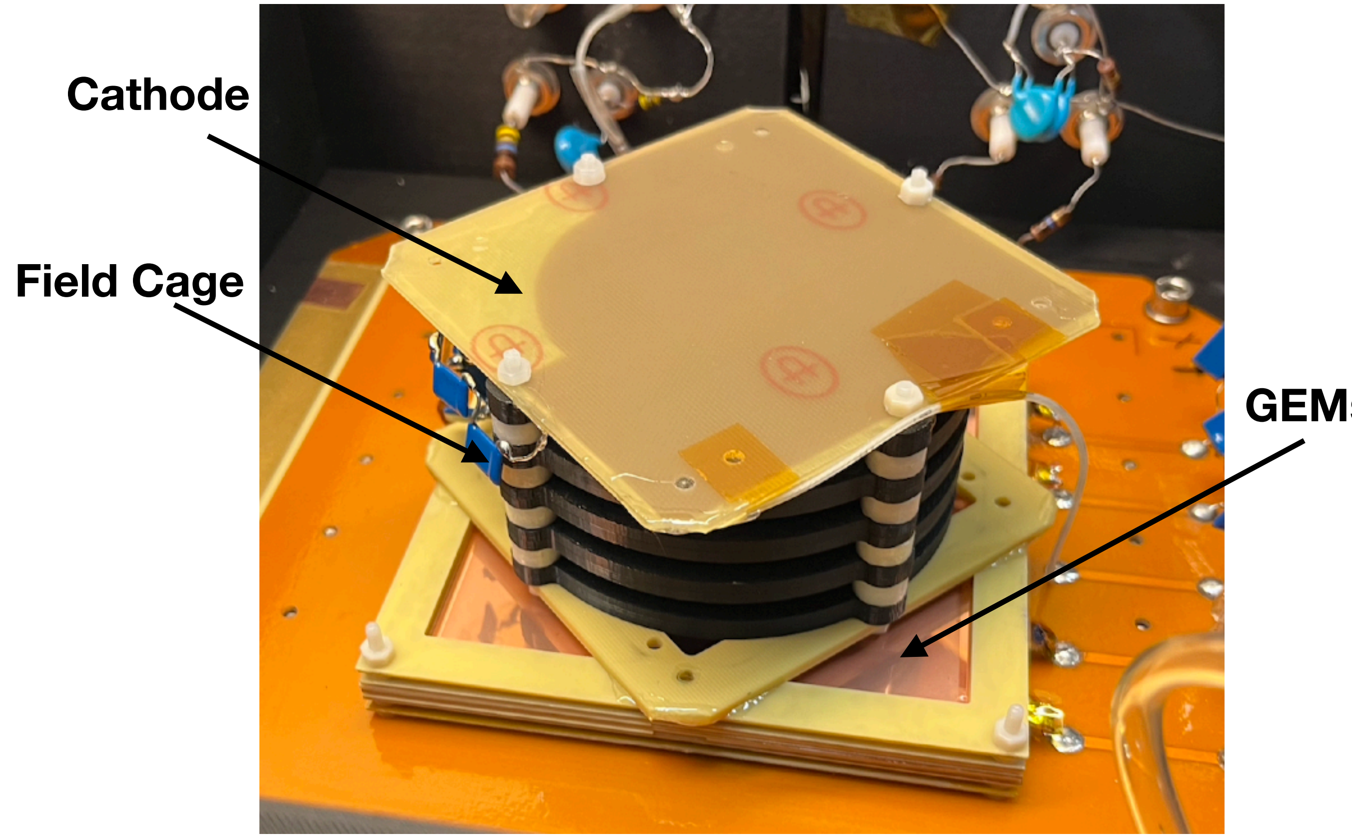
## Effect of the lack of 3D on ang res

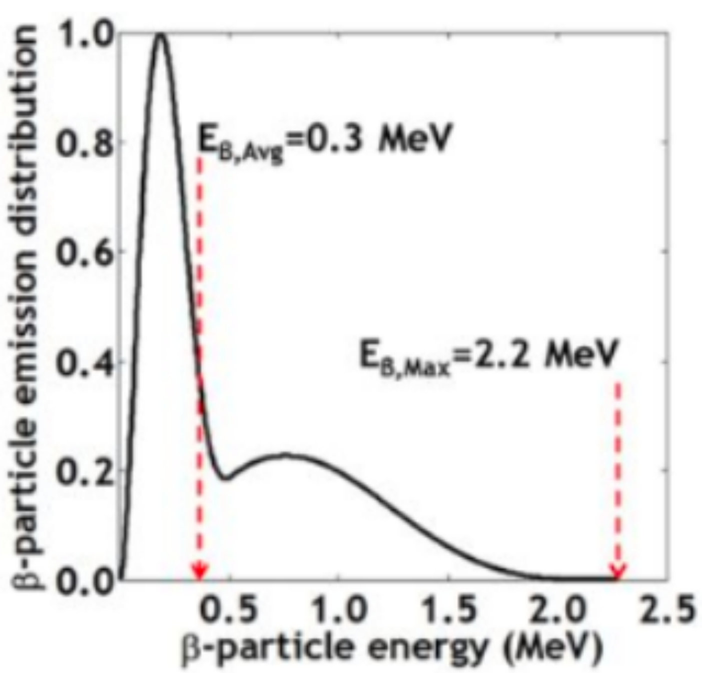



- Worsening with tracks parallel to the GEM plane

# Directionality measurement with MANGO

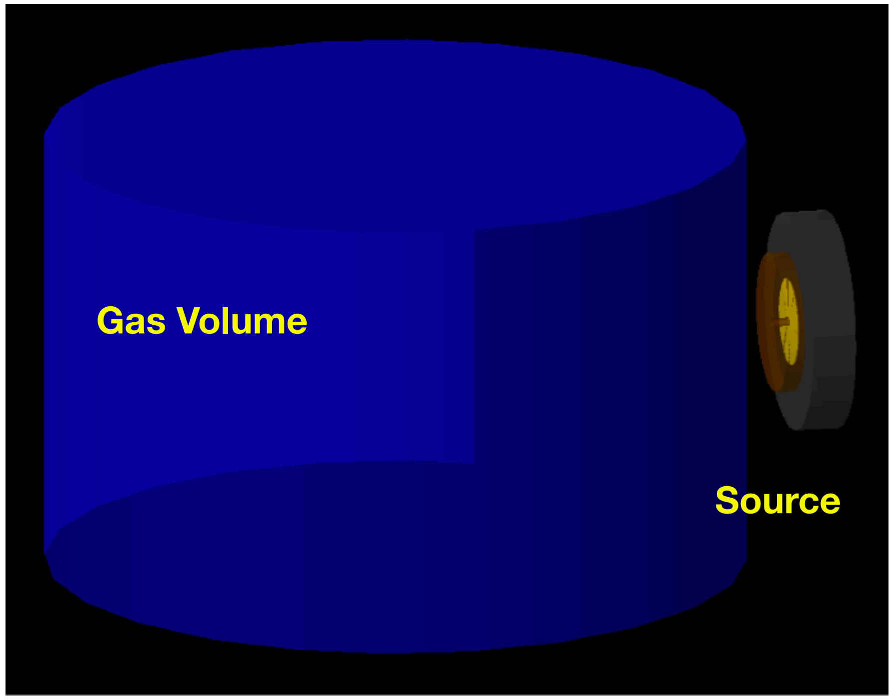
- Data taking for directionality measurement with done with MANGO @ INAF Roma
- Triple GEM configuration with 5 cm field cage
- Sn-90 source, collimated with tungsten rings of 2 mm thikness with 2 mm hole
- Source placed outside the field cage



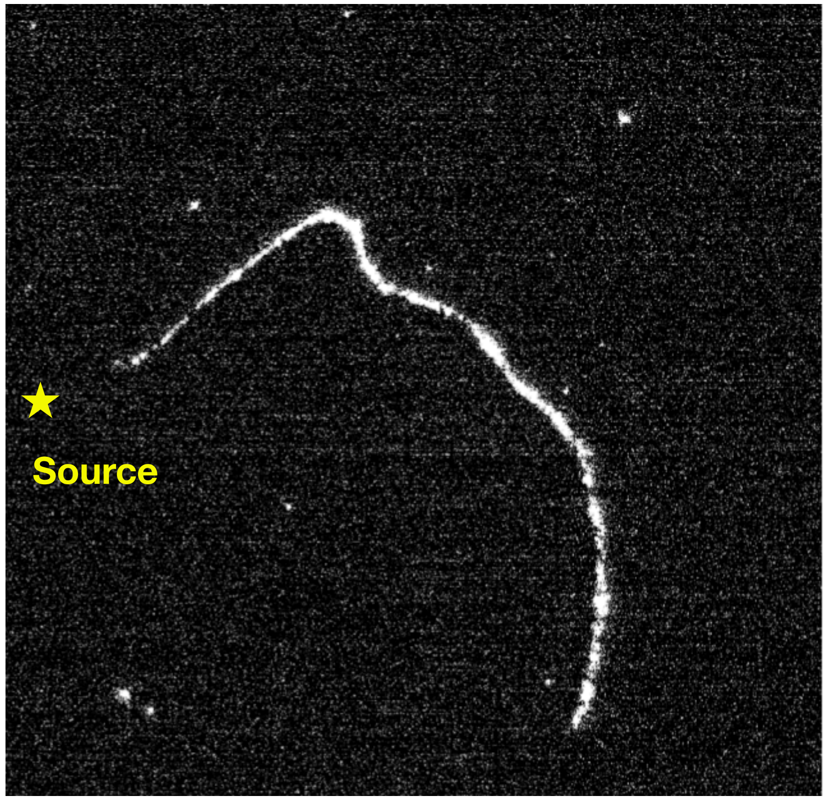




# Concept of the measurement

- From the GEANT4 simulation we expect:
  - Maximum contained energy ~80 keV
  - Fully containment percentage ~20%
  - Intrinsic trac angular spread:
    - 30° with 2 mm hole collimator
    - Less ~20° with 2x 2 mm hole collimator

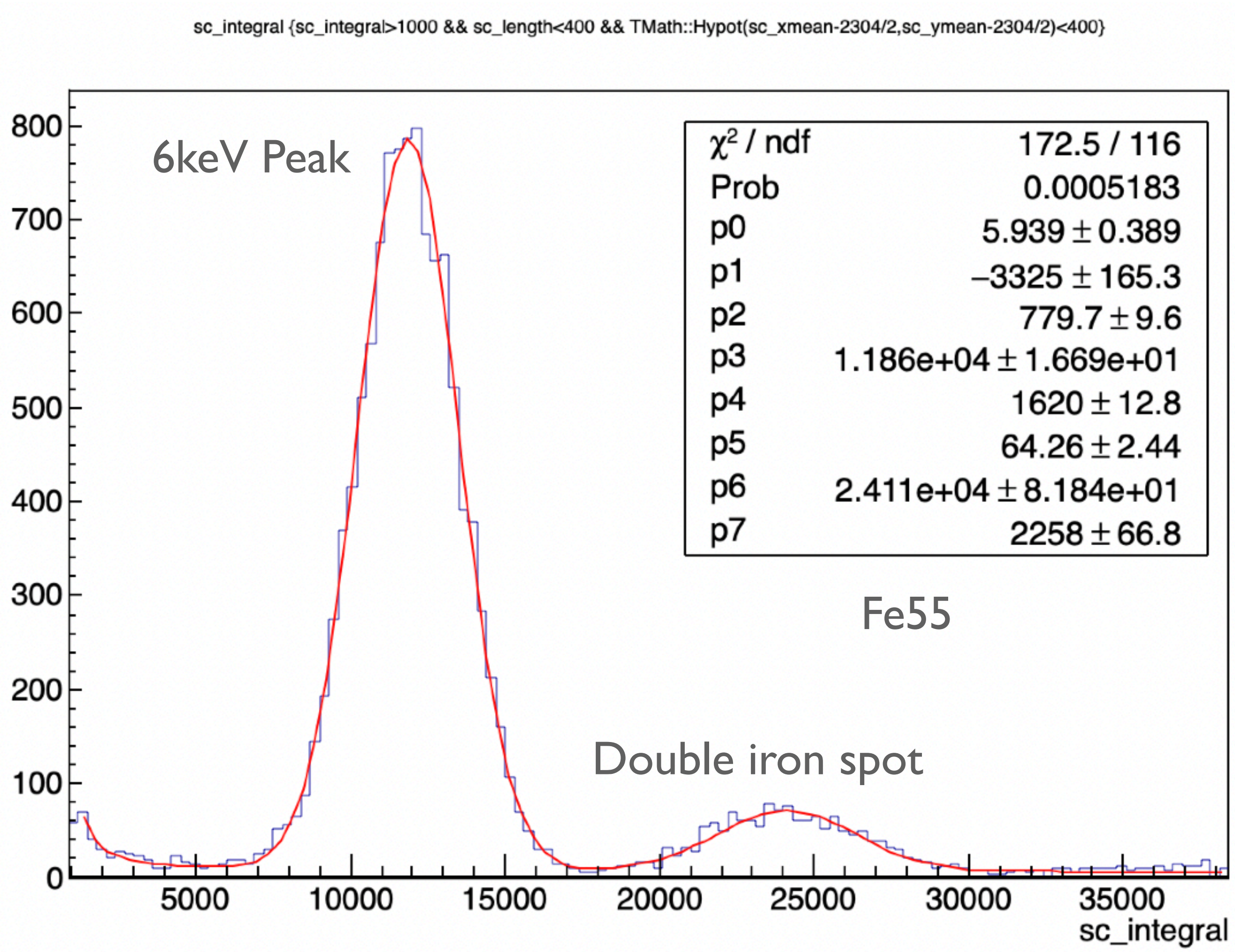


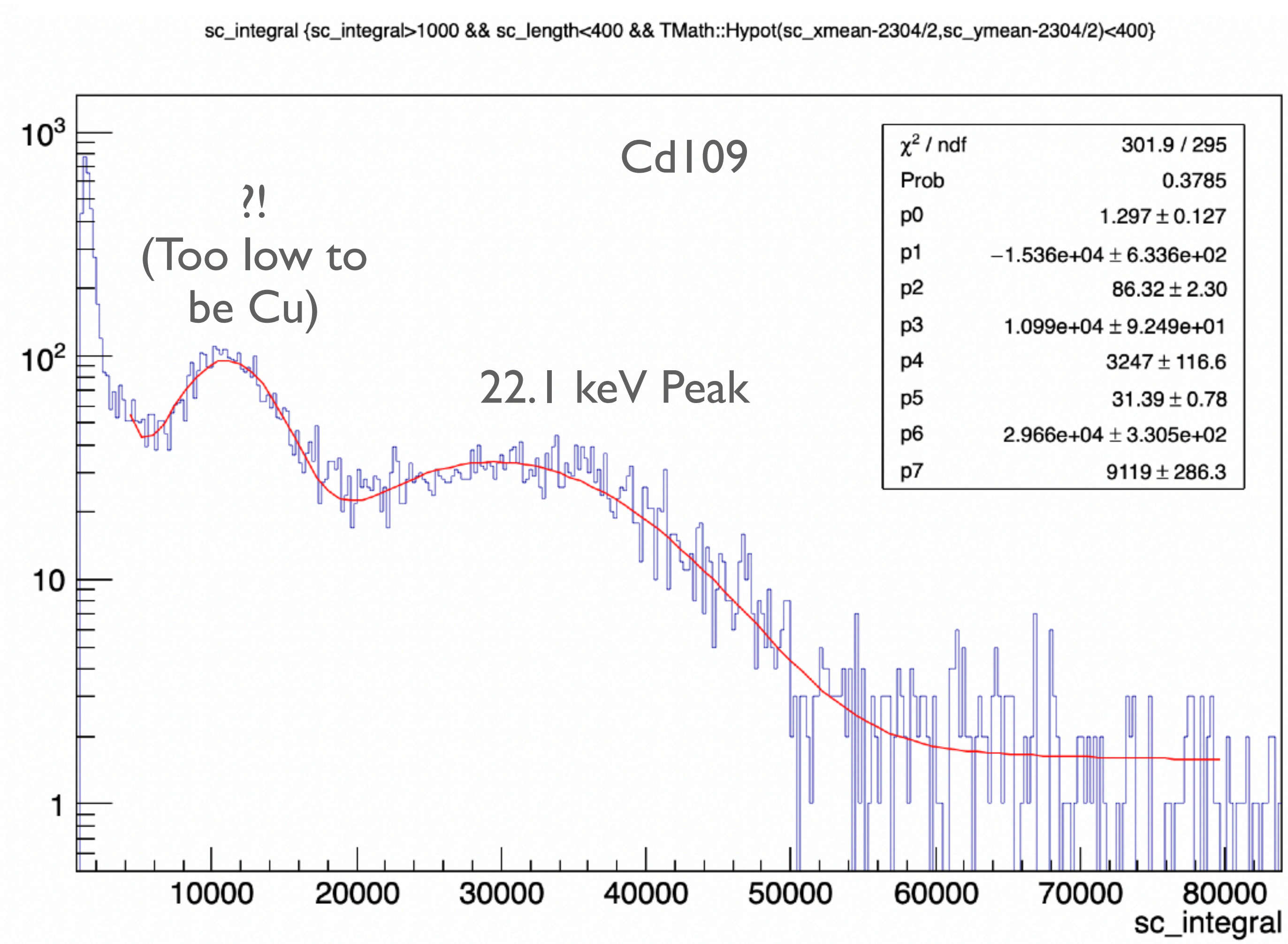

- Strategy of the analysis:
  - Selection of a pure sample of fully contained track
  - Directionality analysis of fully contained track with impact point compatible with the position of the source
  - Real angular resolution obtainable by subtracting in quadrature the intrinsec spread to the angular distrib.



# Preliminary spectra

- Preliminary spectra of monochromatic gamma sources for calibration purpose
- Fe55 ad Cd109 used (very intense sources O(MBq) )

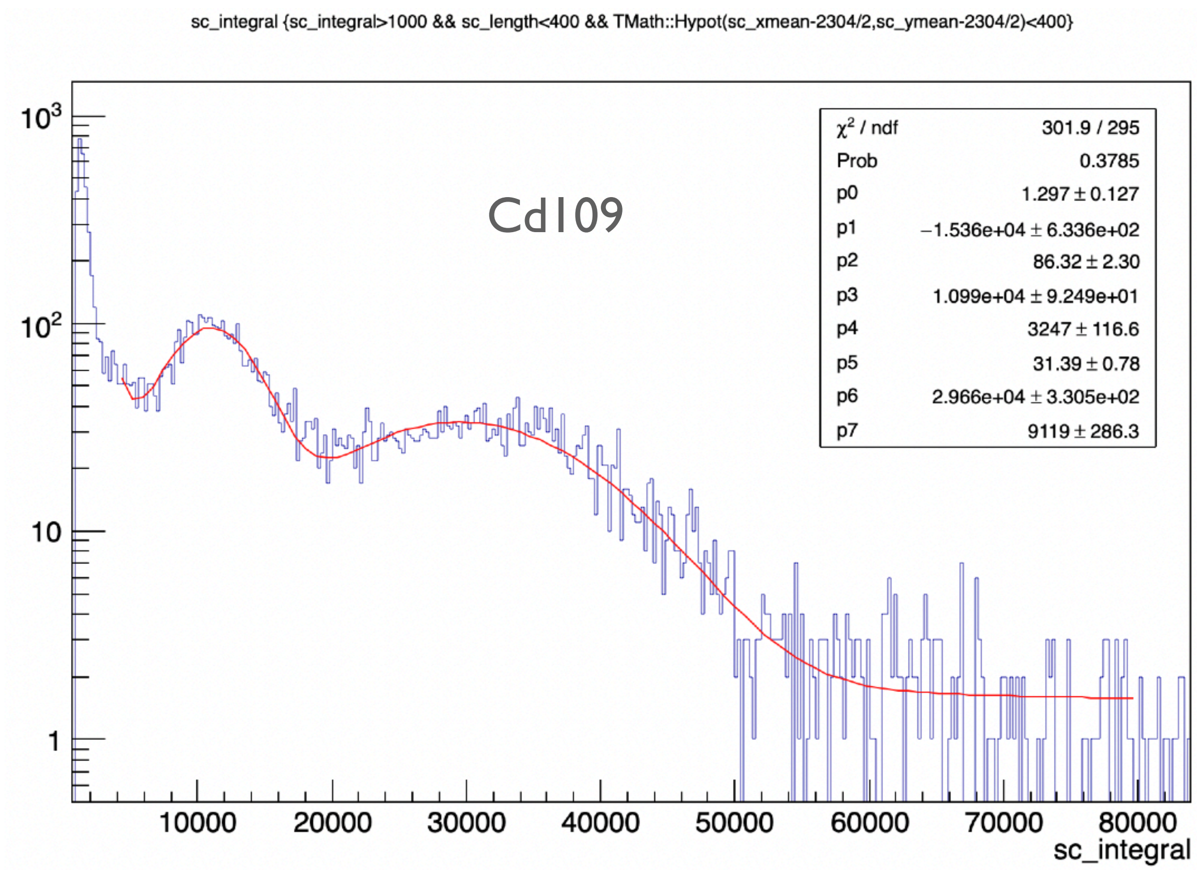


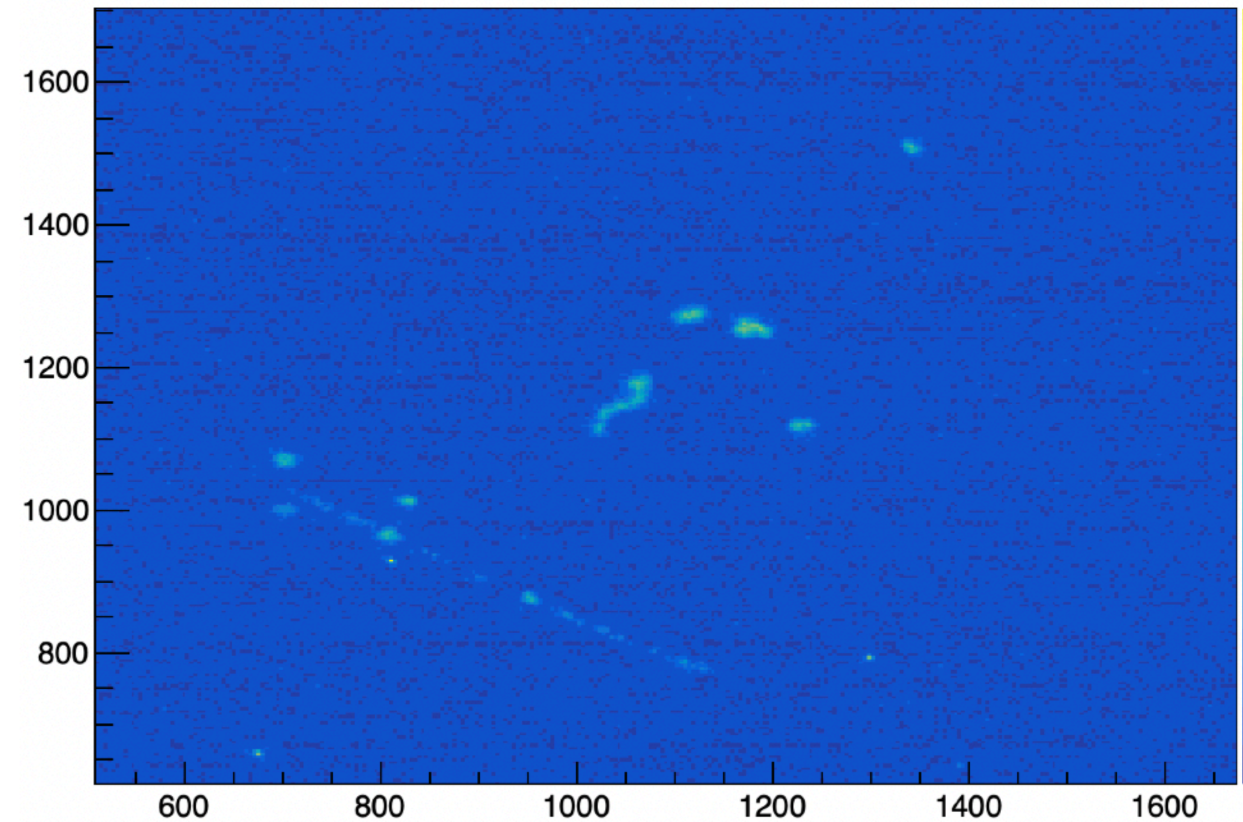



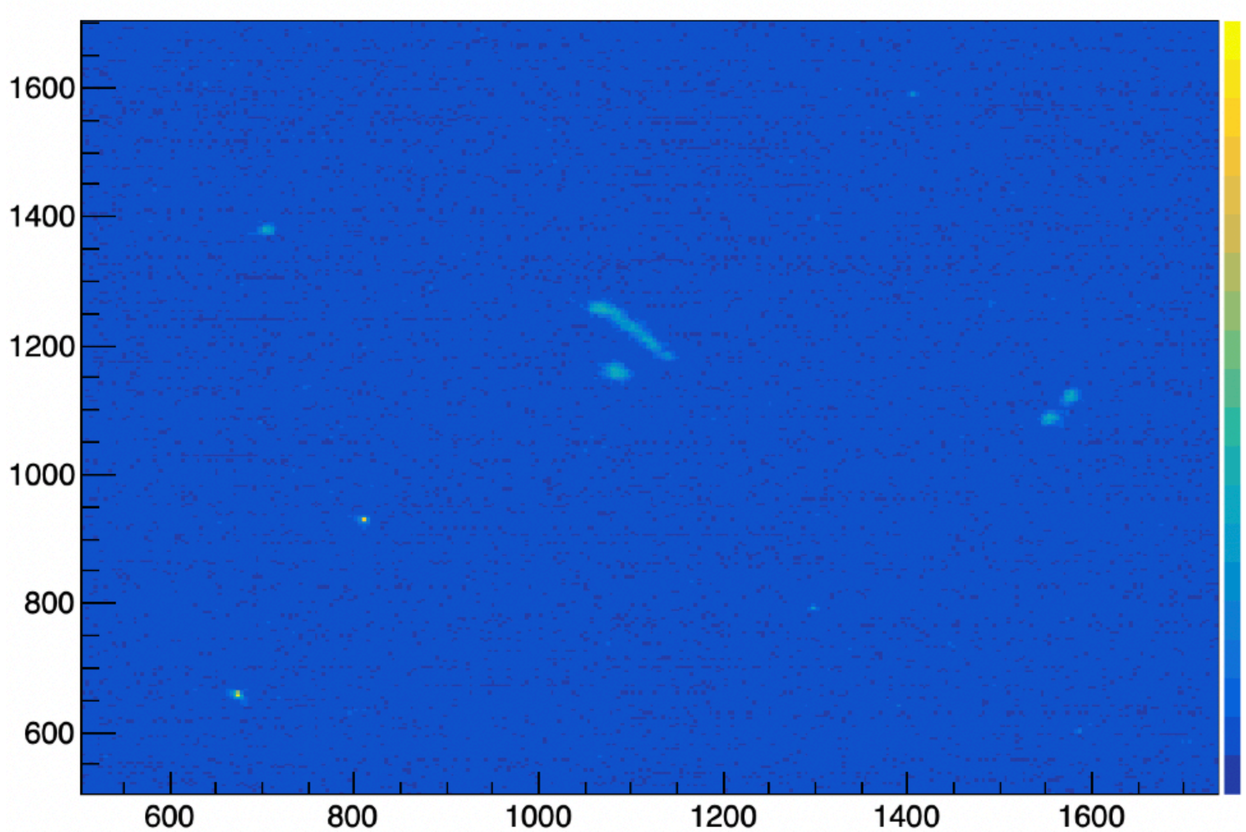

- 13% energy resolution @ 6 keV, while 30% energy resolution @ 22 keV
- Response of 2010 ph/keV from Fe55 and only 1350 ph/keV from Cd109

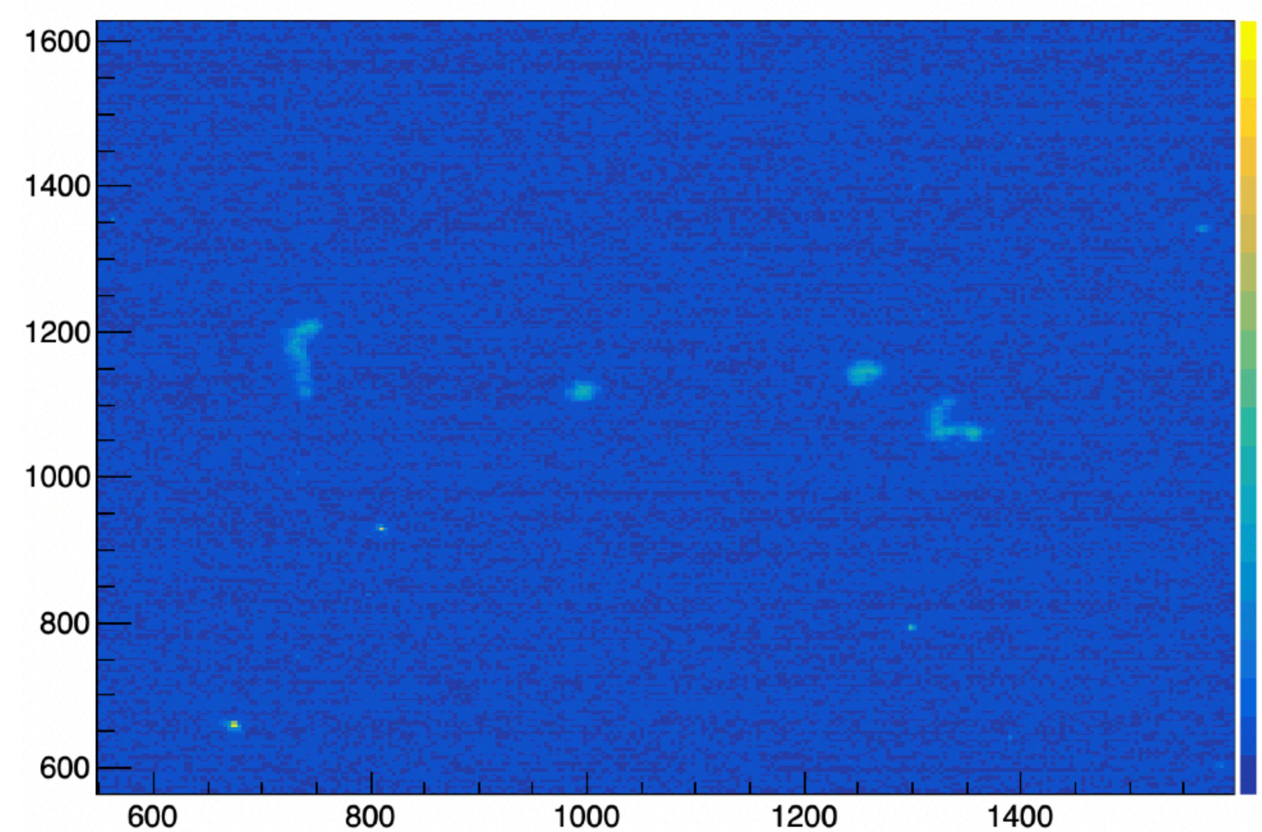
GEMs at 450V (high saturation) + thick plexiglass window

# Low energy spots in Cd109







# Conclusions

- The analysis of low energy electron recoils allowed use to study the linearity response and energy resolution of LIME
- The digitization code after a process of parameter optimization is able to generate ER tracks as they appear in the data
- With the simulated tracks an algorithm to measure the directionality of low energy ER has been developed and optimized
- A measure of angular resolution on real data is in progress with the data acquired with MANGO at INAF