Update on angular resolution of low energy electron tracks in CYGNO

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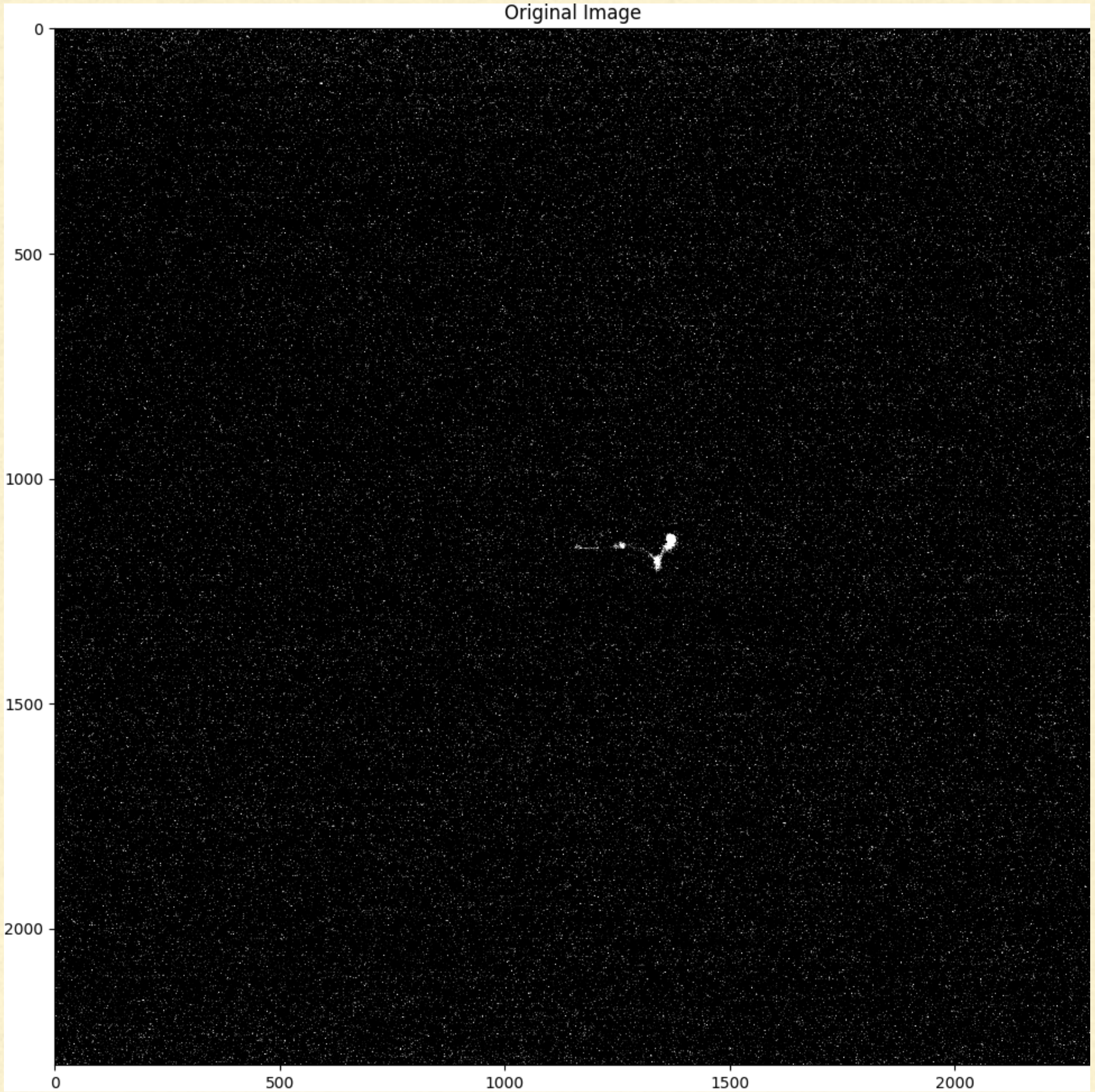
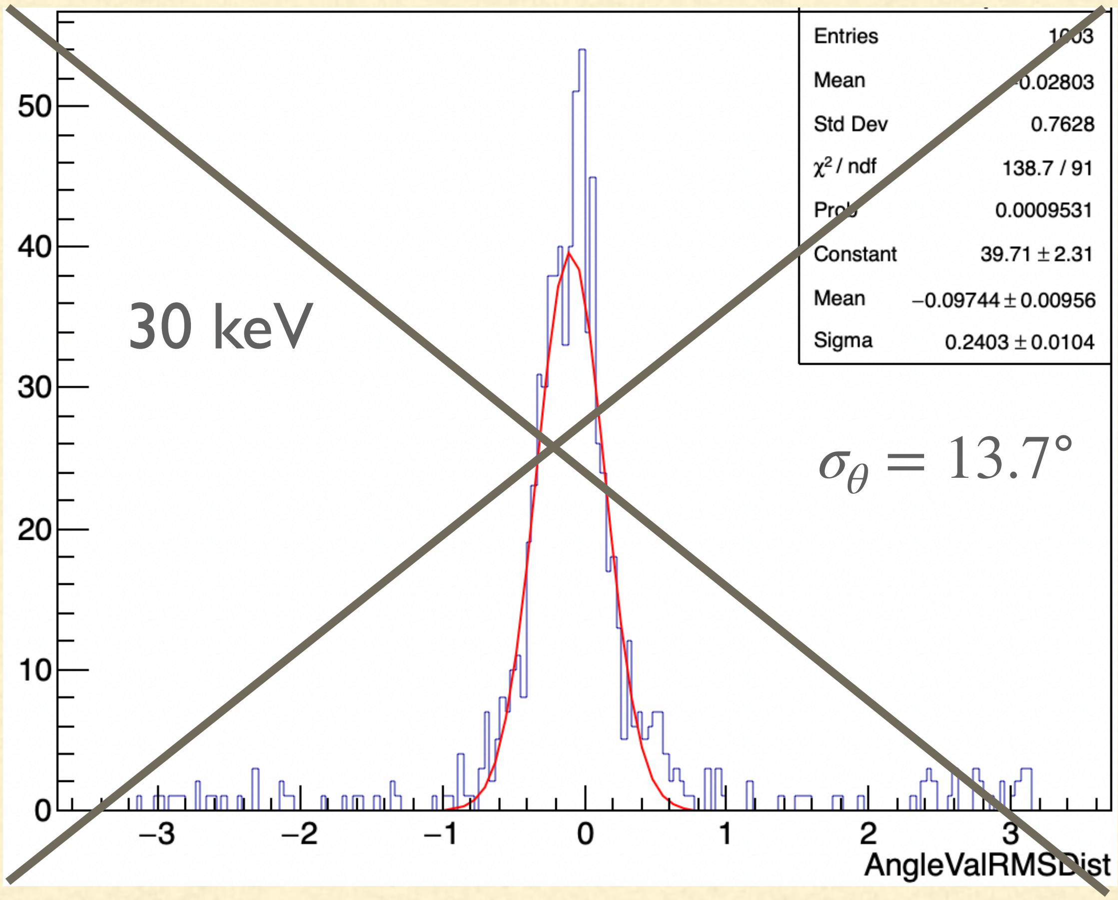
Dataset

Working on on electrons from MC:

- Electron generated at the center of the image
- Electron shot along the x-axis,
  in the positive direction
- Energy of 20 keV, 30 keV, 60 keV, and 100 keV
- Distance from the GEM of 20cm (to simulate diffusion)
- 1 Track per event



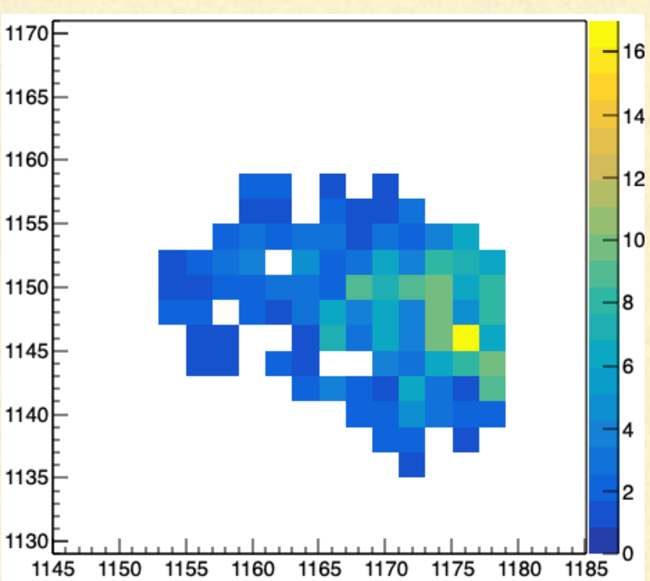
Bug found in previous analysis code

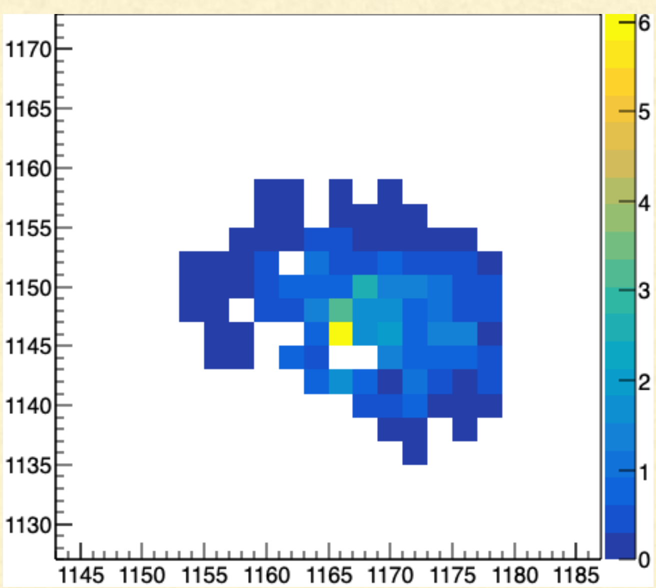


- Bug was found in the re-weight of the bins close to the interaction point (subsequently used to fit to track direction), that was forcing track direction along X-axis
- Simulated tracks were shooted along X-axis, this resulted in a incorrect estimate of the angular resolution
- The bug was fixed and I further worked to improve the algorithm performance

$$W(d_{ip}) = \exp(-d_{ip} / w)$$

Distance from IP — Constant from MC





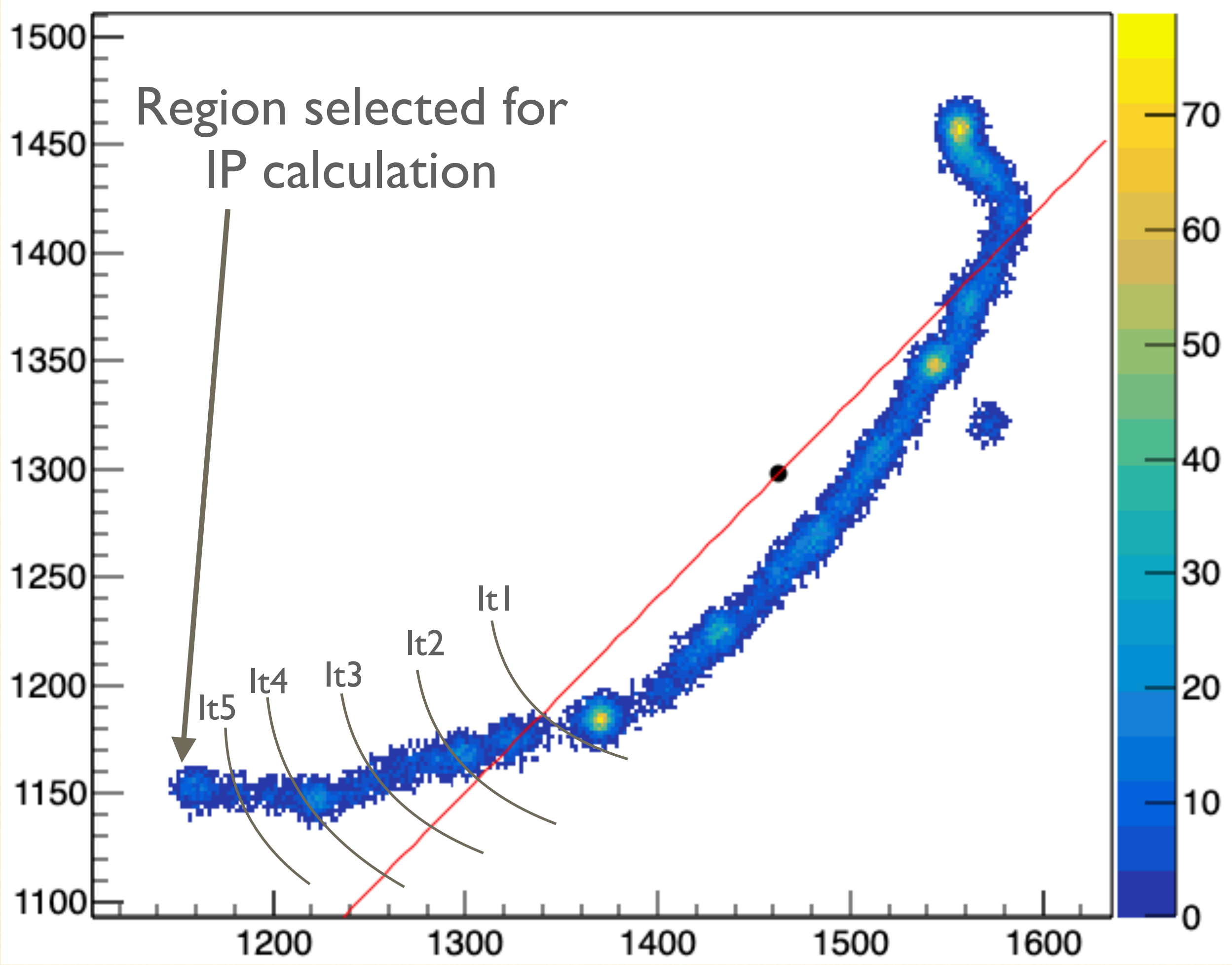
Changes in the analysis

1) Iterative interaction point region selection:

Parameter r_{min} increased iteratively until a fixed number of points is selected (number of point now is a parameter)

Needed for higher energetic track due to higher variability

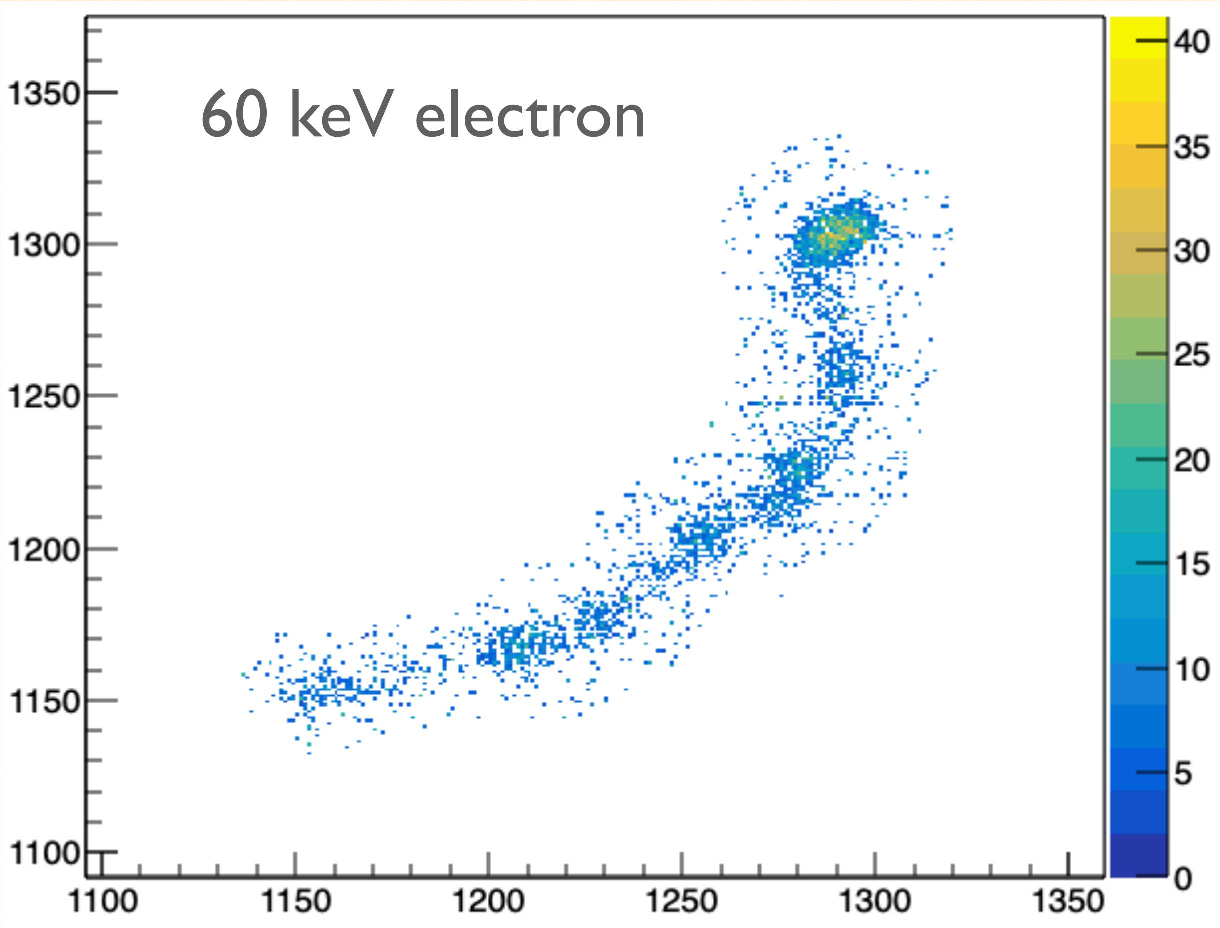
Lead to an improvement of the IP

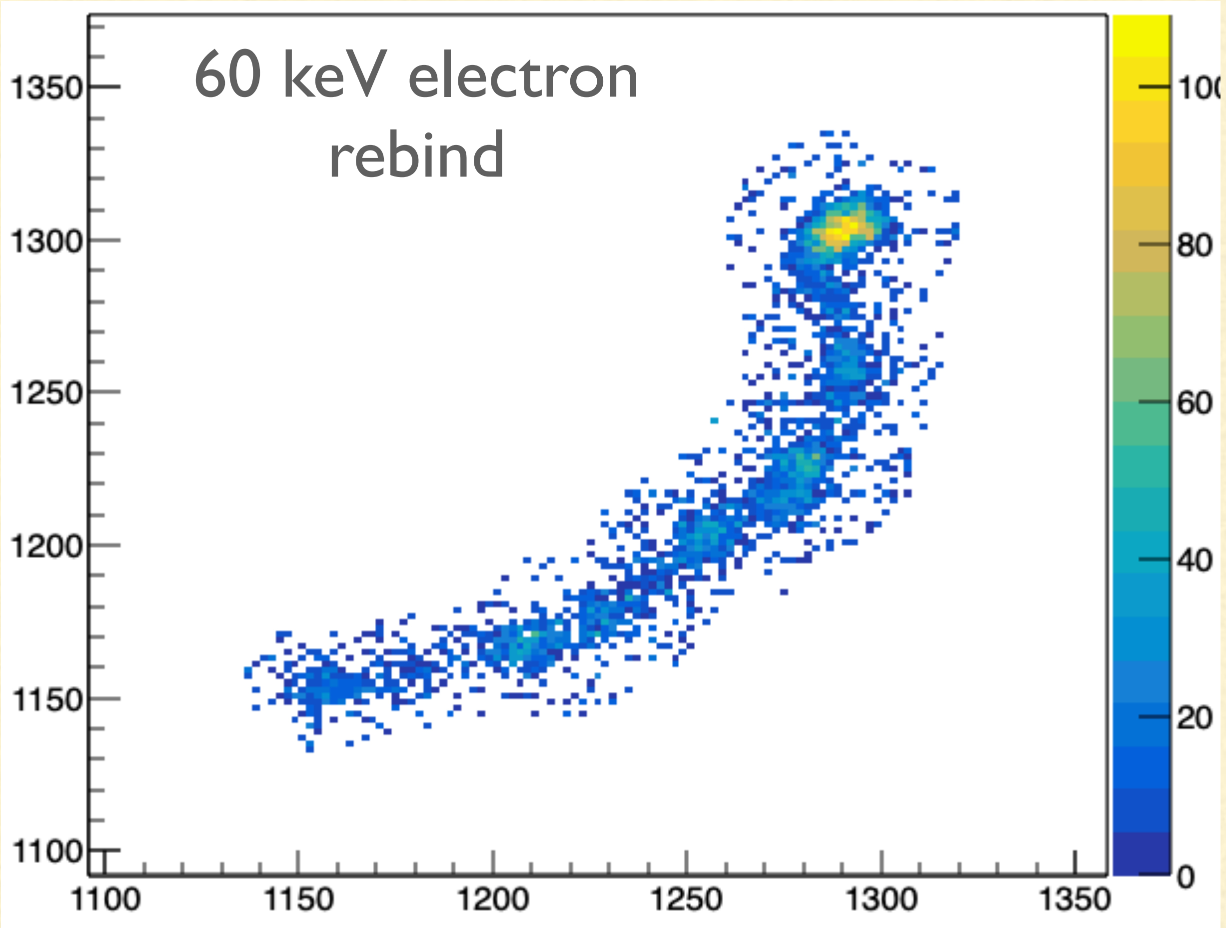


Changes in the analysis

2) Analysis on rebind tracks

Clearer identification of the track

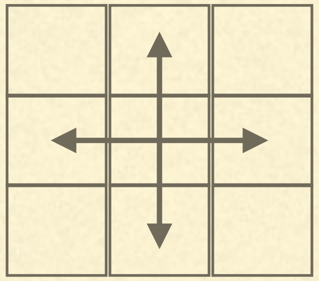




Changes in the analysis

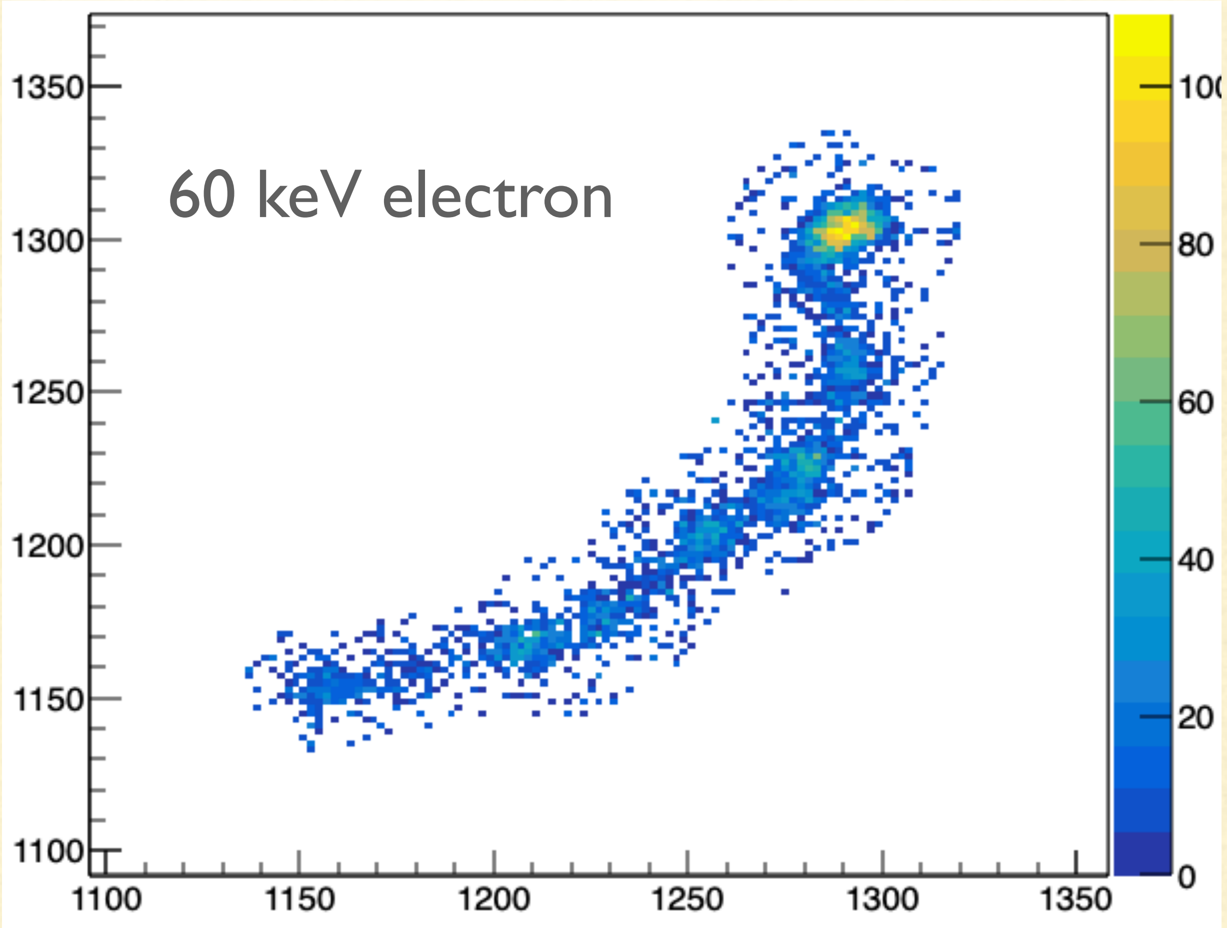
3) Simple filter to remove noise applied

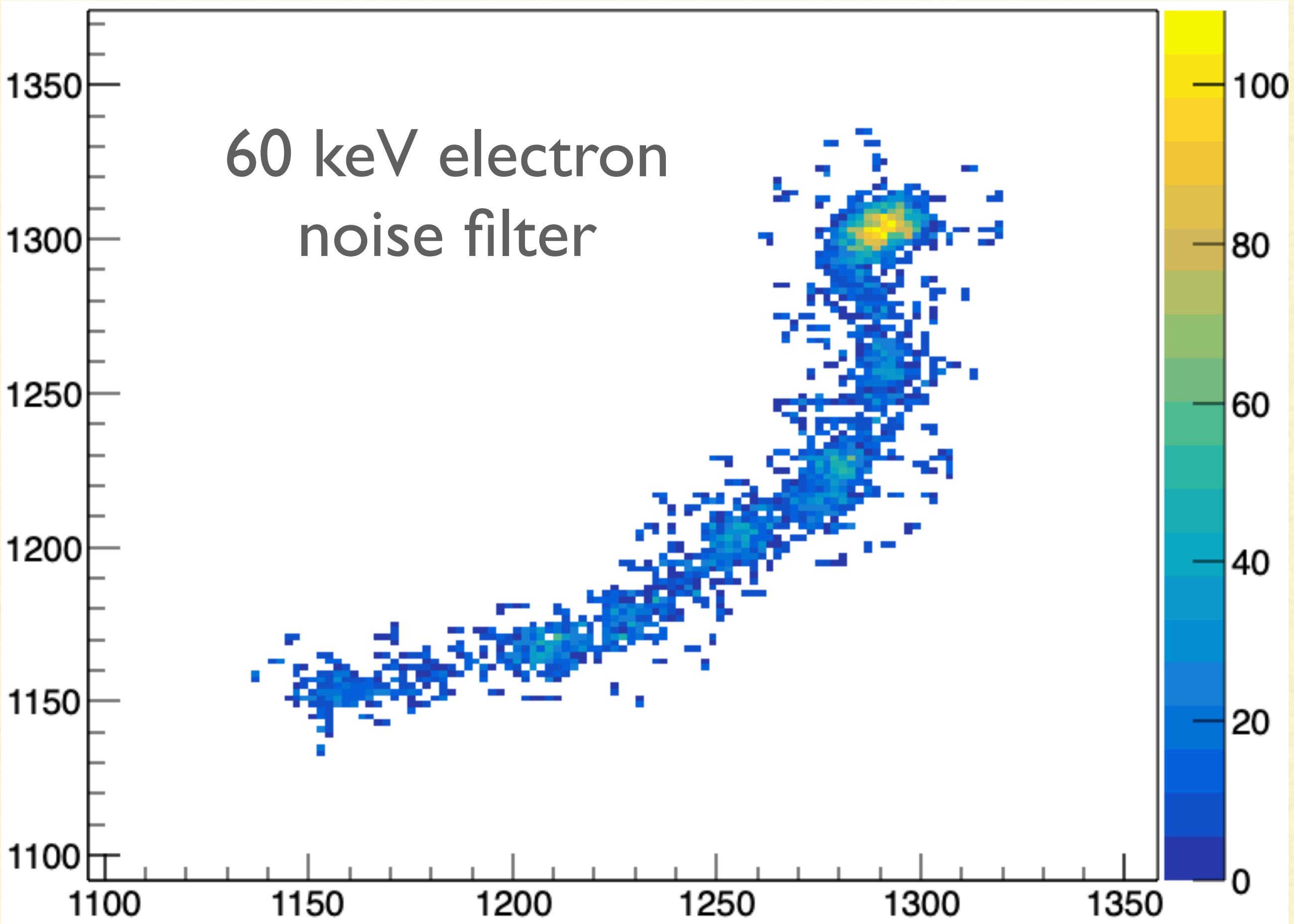
Point removed from the track if it doesn't have at least 1 neighbour
(Check on top, bottom, right, left neighbour)



Noise can affect the IP calculation so the resolution

Very basic→ can be improved

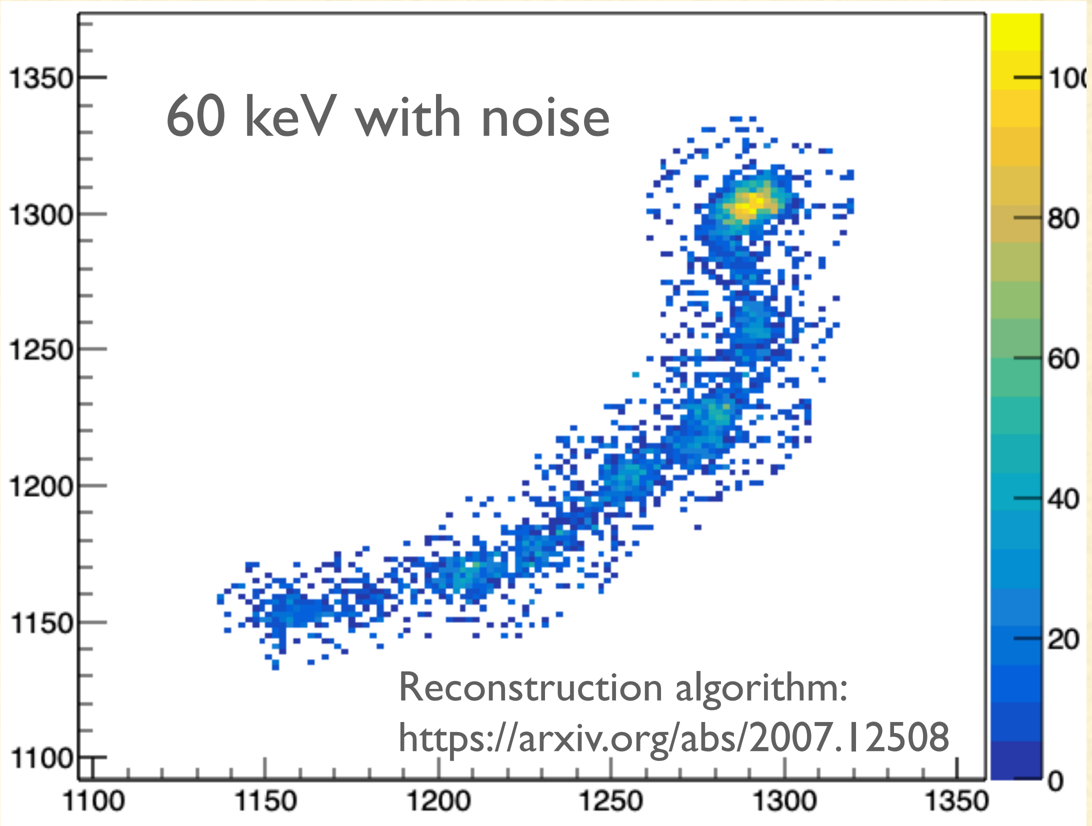


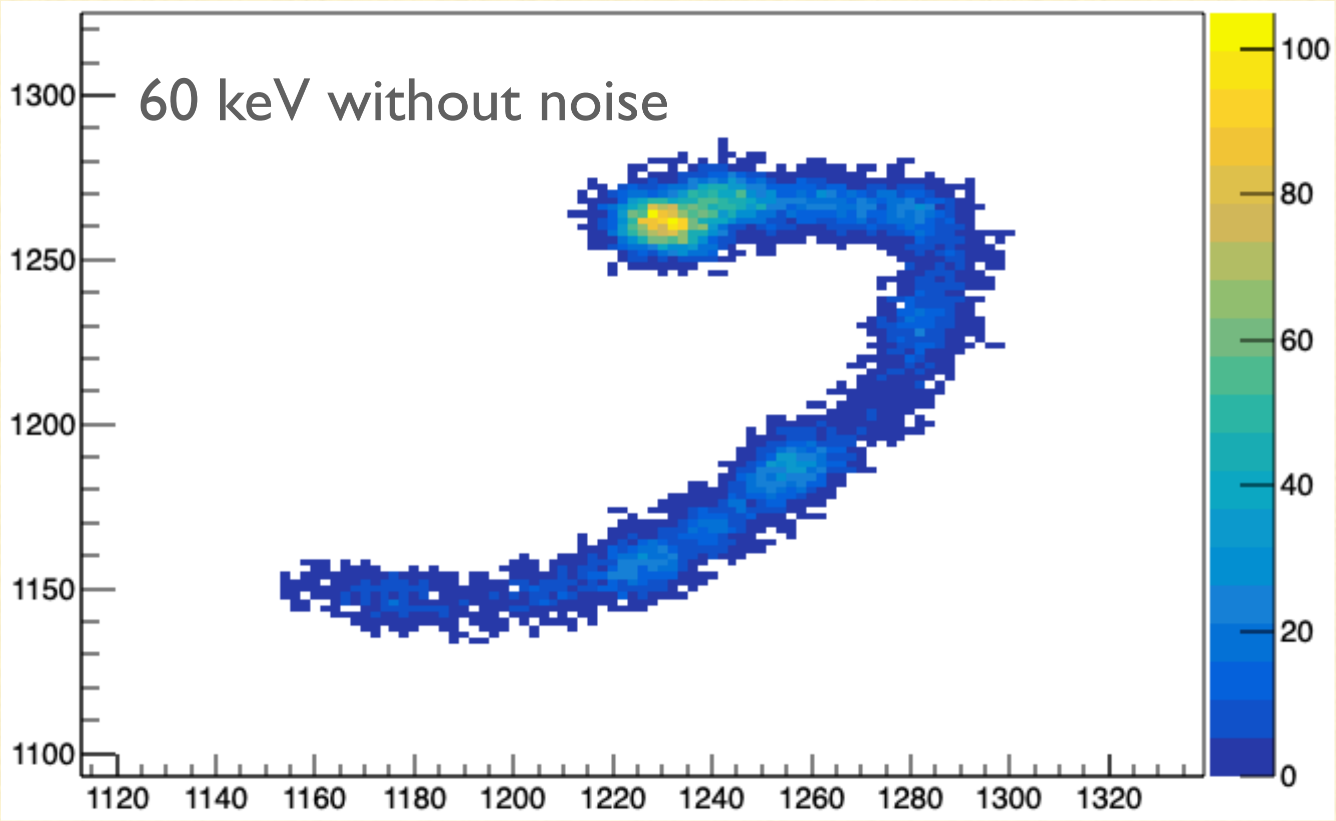


Background vs no background data

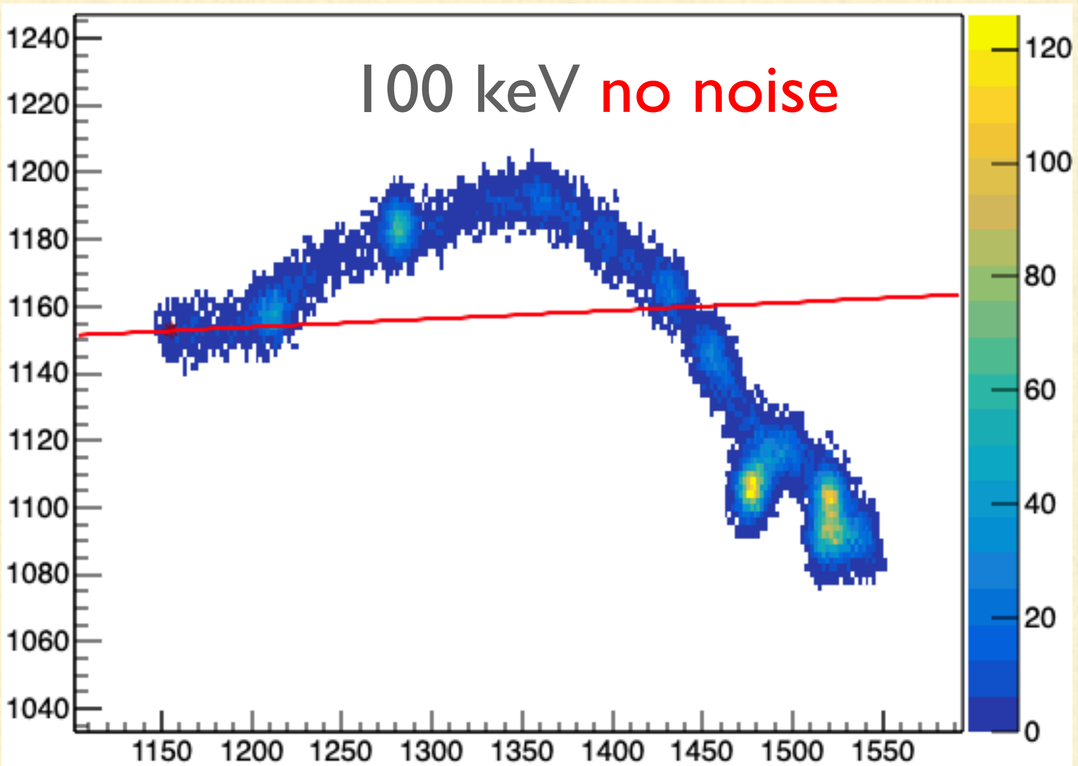
More info: see the talk from F. Di Giambattista https://indico.fnal.gov/event/46746/contributions/210387

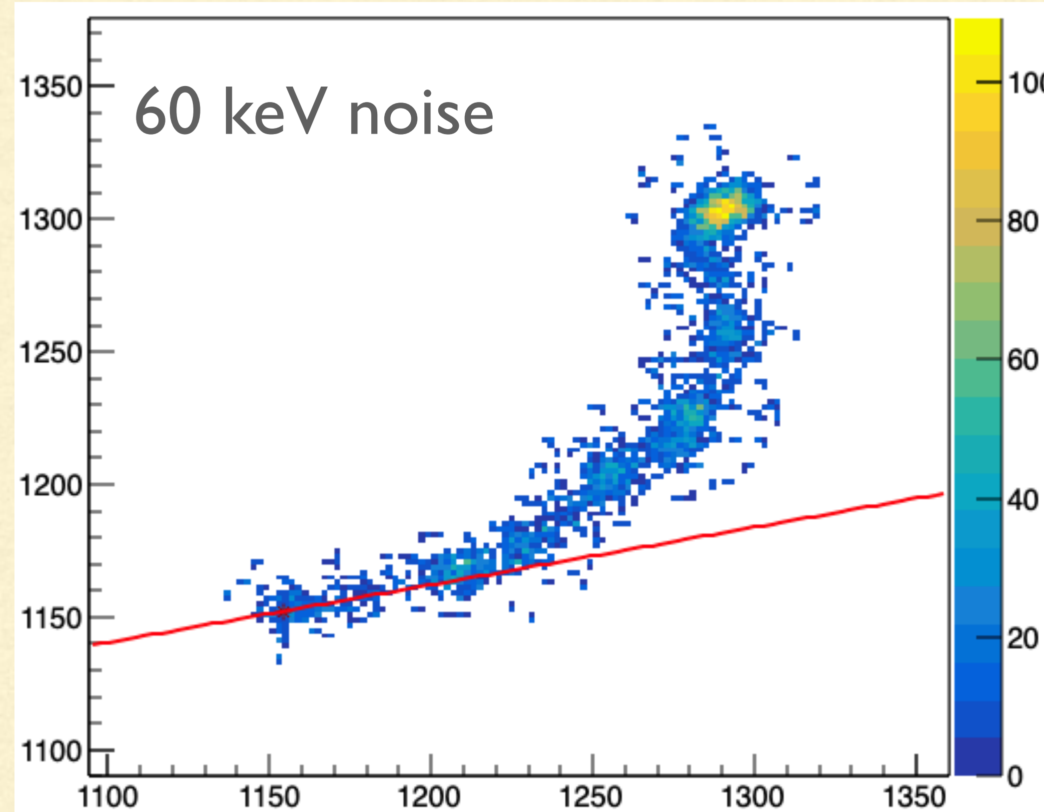
- Simulated track are built:
  - Simulating the e^- track in GEANT4
  - Applying diffusion and amplification according to our model
  - Constructing the CMOS image with or without CMOS noise
- Track without CMOS noise studied as benchmark to understand different contributions to the resolution
- In the track with noise the directionality algorithm is influenced from the track reconstruction algorithm:
  - capability of distinguish signal pixels from noise pixels
- Reconstruction algorithm perfectly working in track without noise

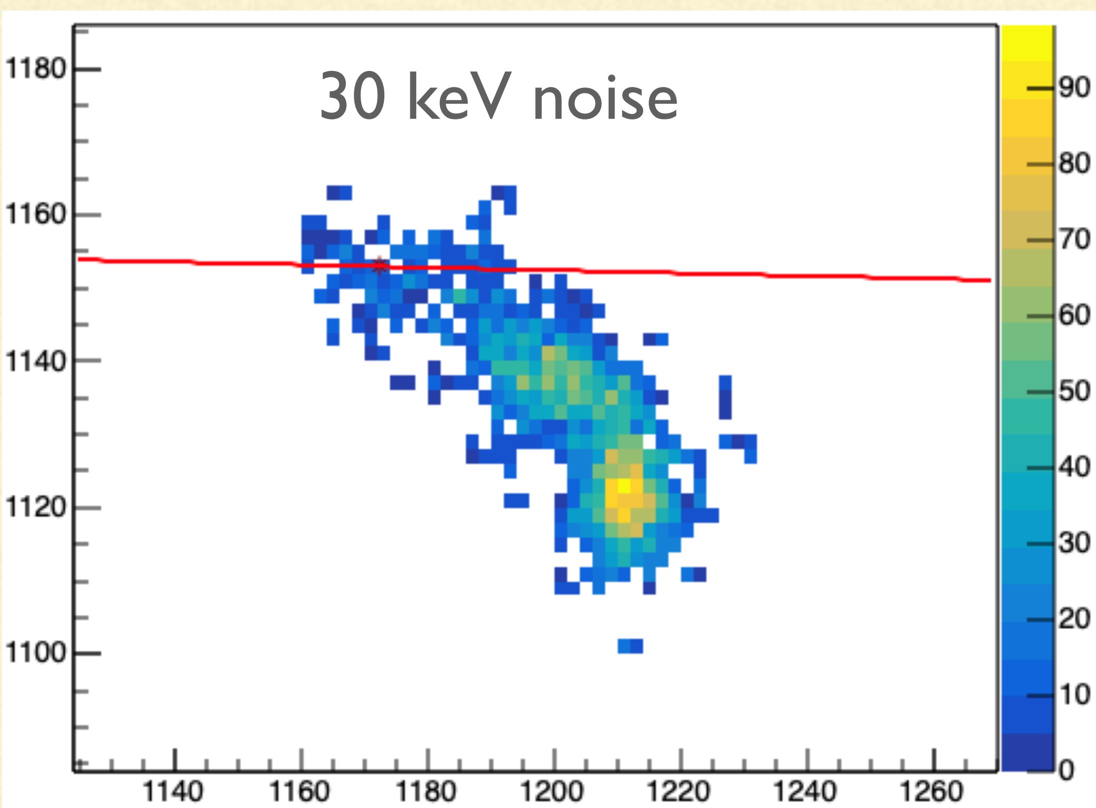


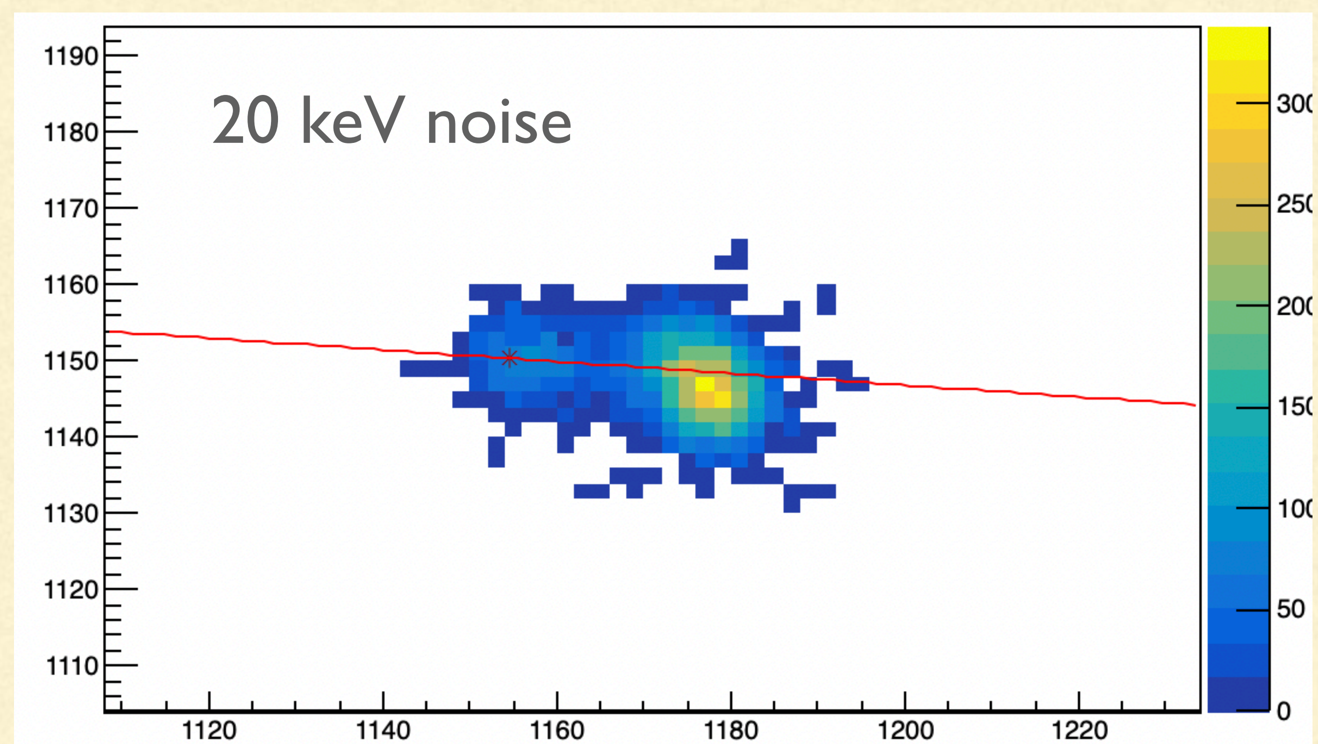


Some reconstructed track









Angular resolution on data

Parameters in the algorithm:

- Number of points in the interaction region
- Radius for the circular selection around the IP
- Factor for the point rescaling with the distance form IP

A dense scan of this parameters have been done

From the parameters combination for which the best angular resolution is found it is obtained:

	Data with background	Data without background
$20\ keV$	$\sigma_\theta = 23.2 \pm 1.7°$	
$30\ keV$	$\sigma_\theta = 19.0 \pm 1.5°$	$\sigma_\theta = 18.5 \pm 0.9°$
$60\ keV$	$\sigma_\theta = 20.1 \pm 1.6°$	$\sigma_\theta = 12.1 \pm 0.6°$
$100\ keV$		$\sigma_\theta = 11.4 \pm 0.7°$

At 60 keV:
Lower energy release at the beginning of the track: problem of signal to noise ratio?

Studies of the correlations and dependences of this parameters in progress

Impact point resolution

- Resolution on impact point determination seems to be very good
- Higher on x coordinate due to the symmetry of the system
- Better in data without noise

	Data with background	Data without background
$20\ keV$	$\sigma_x = (0.377 \pm 0.021)mm$ $\sigma_y = (0.277 \pm 0.016)mm$	
$30\ keV$	$\sigma_x = (0.79 \pm 0.04)mm$ $\sigma_y = (0.422 \pm 0.030)mm$	$\sigma_x = (0.350 \pm 0.020)mm$ $\sigma_y = (0.308 \pm 0.017)mm$
$60\ keV$	$\sigma_x = (1.45 \pm 0.09)mm$ $\sigma_y = (0.74 \pm 0.05)mm$	$\sigma_x = (0.55 \pm 0.04)mm$ $\sigma_y = (0.217 \pm 0.012)mm$
$100\ keV$		$\sigma_x = (0.69 \pm 0.05)mm$ $\sigma_y = (0.247 \pm 0.017)mm$

- Not verified yet if: Best angular resolution $\Longrightarrow$ Best impact point resolution

Conclusions

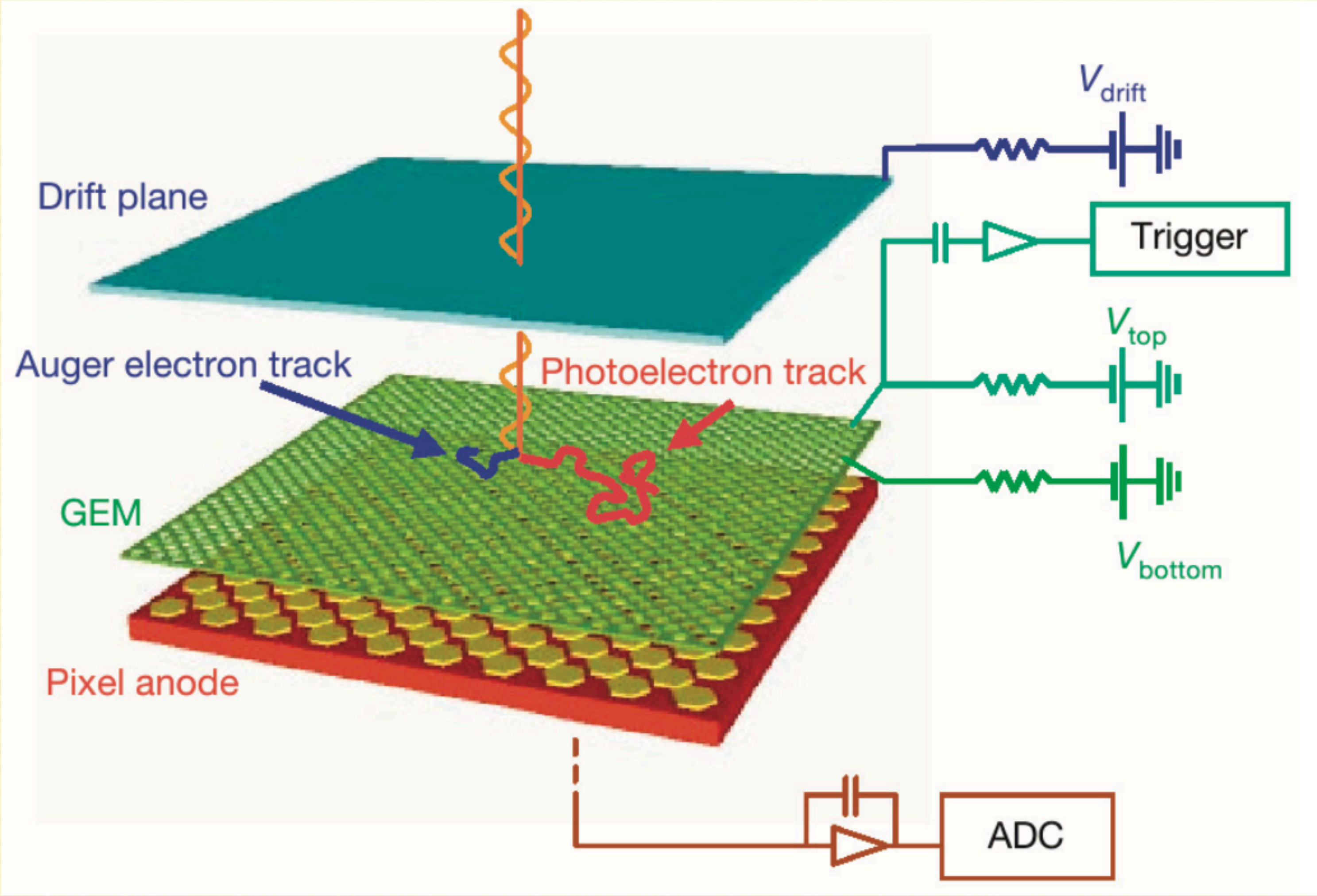
- Bug found, results shown at last meeting not reliable. Bug fixed, current angular resolution not so far from before (19° vs 13°)
- The changes in the analysis algorithm lead to a better angular resolution and IP identification
- The angular resolution trend of no bgk data seems to be consistent with what we expect
- The angular resolution of no bgk data should be studied more in deep
- We plan now to study the parameters of the algorithm more in deep and to think how to improve the angular resolution

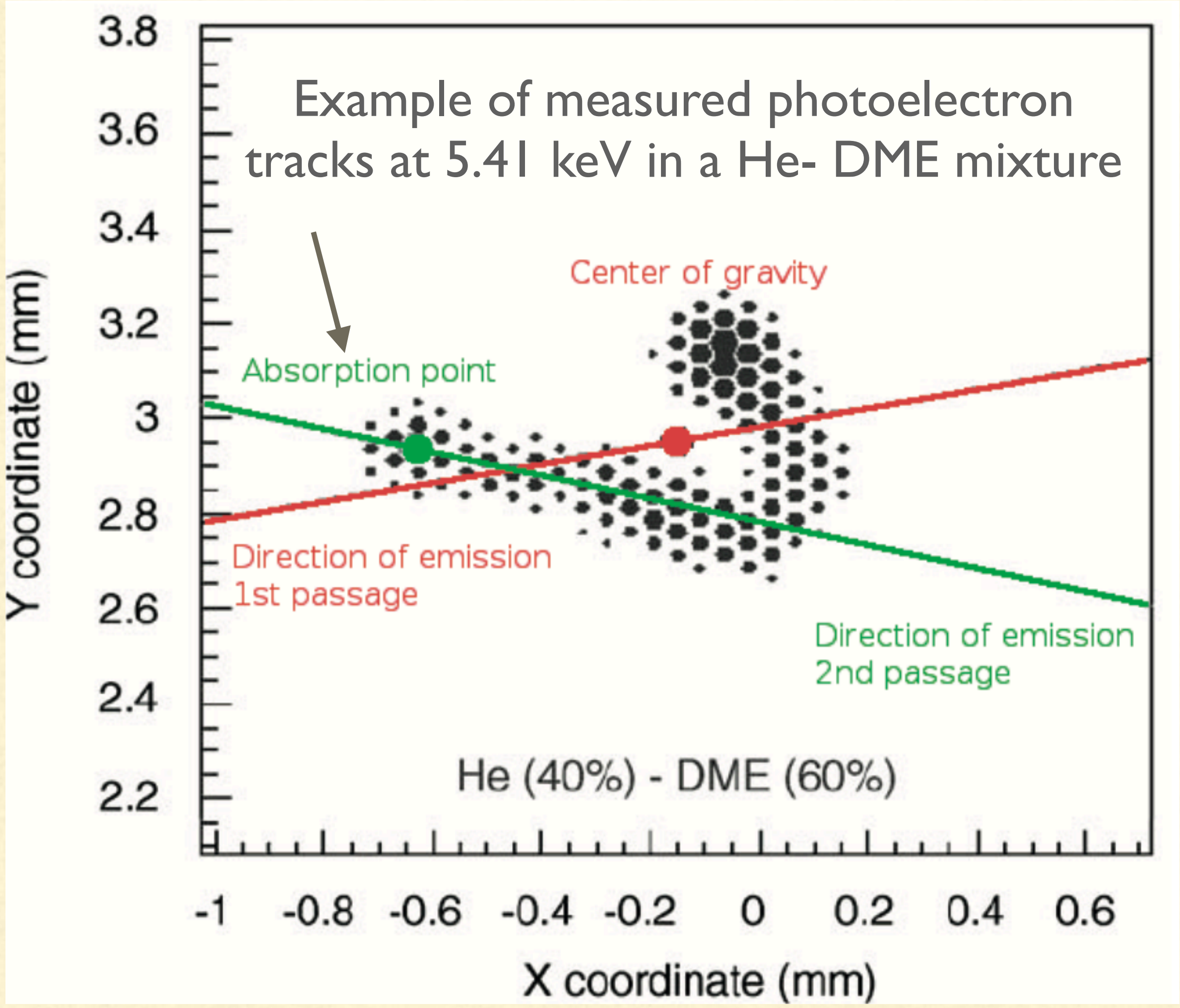
Backup: how the algorithm works

Gas Pixel Detector

X-Ray Polarimetry: https://inspirehep.net/literature/762410
Algorithm: Astronomical X–Ray Polarimetry - pag. 130

Directionality algorithm used for X-Ray polarimetry in Gas Pixel Detector





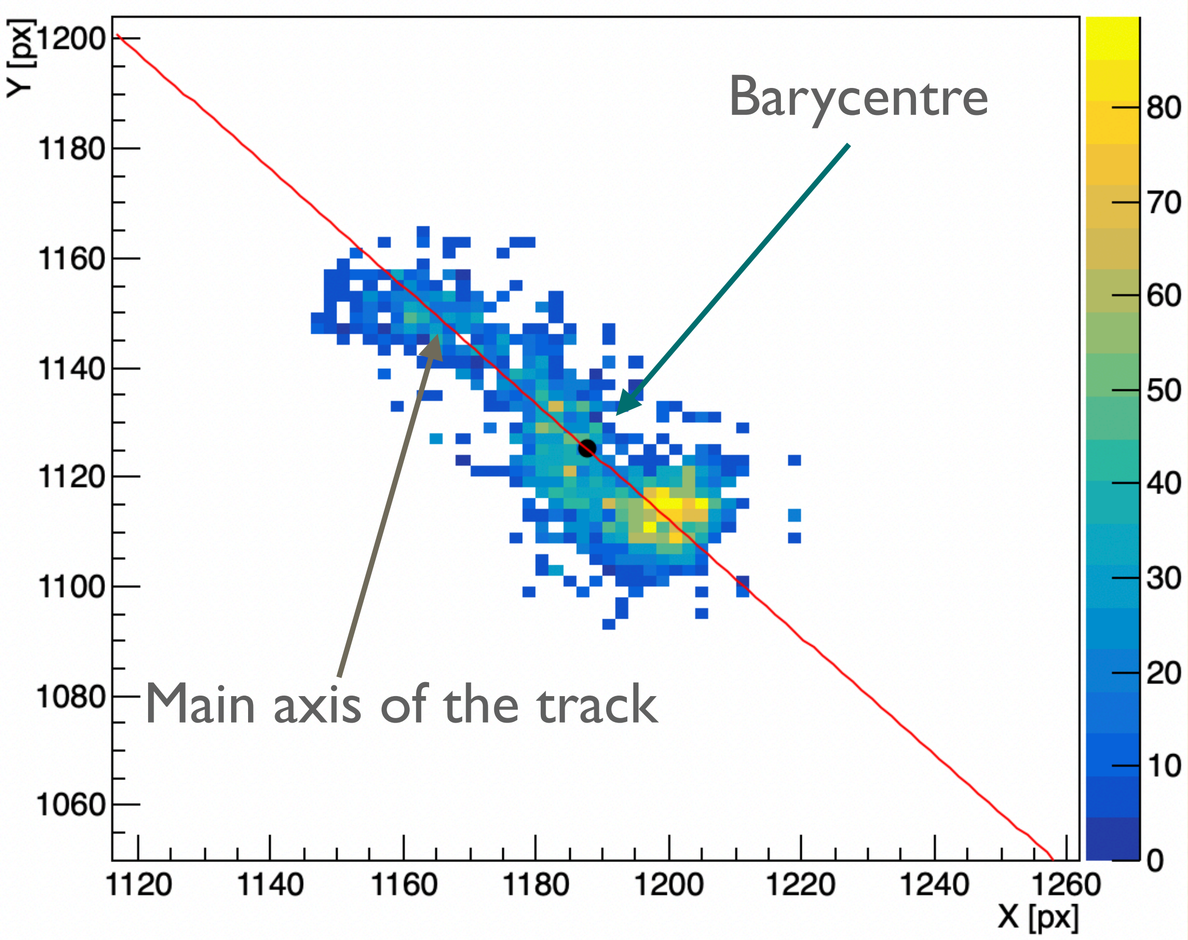
They are able to calculate the direction of a 3-4 keV e- in gas

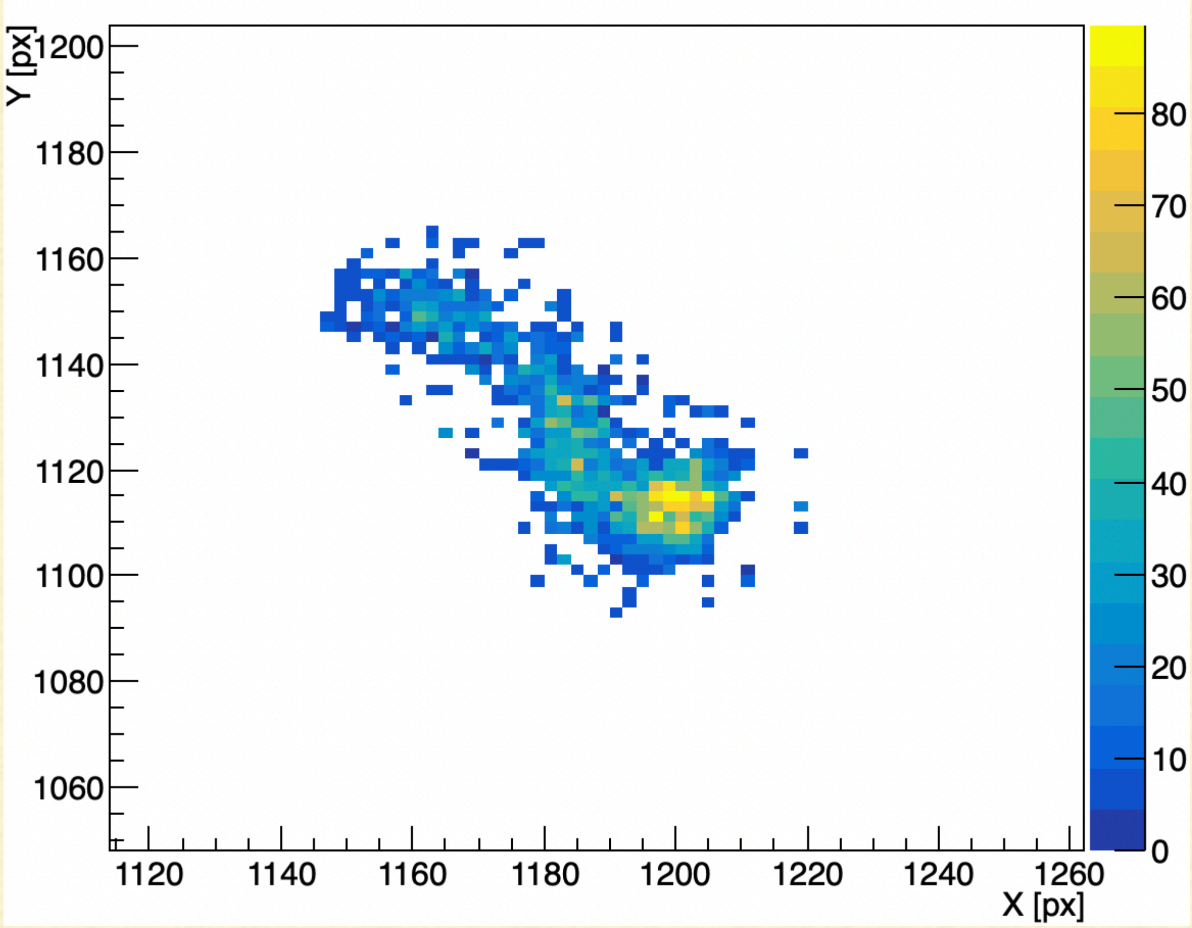
Similar to our detector → same strategy can be applied to our detector

How the algorithm works

- 30 keV electron track
- All pixels over threshold within the supercluster are taken
- Calculation of the barycentre of the pixel weighted with the charge

$$x_c = \frac{\sum_i Q_i \, x_i}{\sum_i Q_i} \qquad y_c = \frac{\sum_i Q_i \, y_i}{\sum_i Q_i}$$





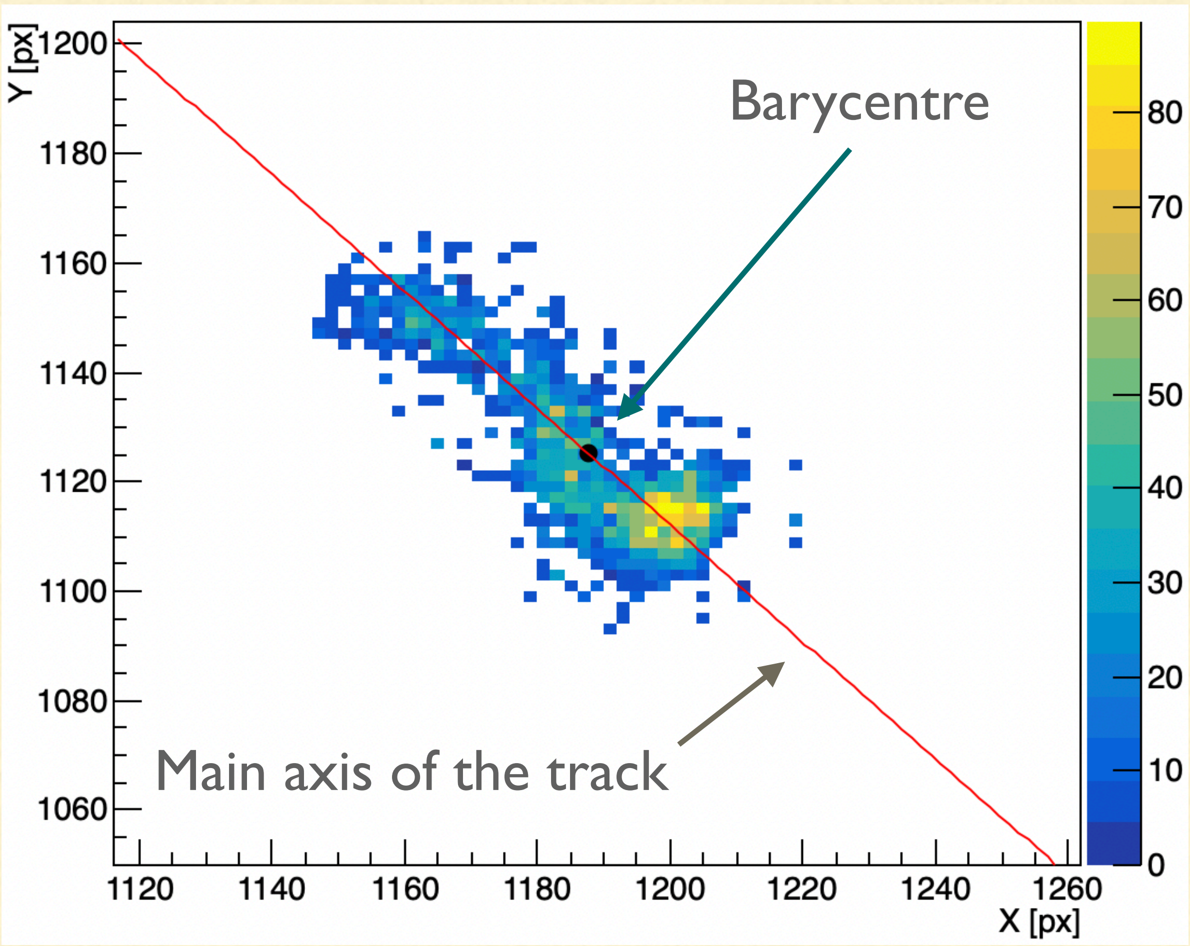
- Calculation of the main axis of the track:
  - Line passing from the barycenter such that the RMS of the histogram resulting from the projection of the track points on the line is maximum

$$M_2(\Phi) = \frac{\sum_i Q_i \, {x'_i}^2}{\sum_i Q_i} = \frac{\sum_i Q_i \left[(x_i - x_c)\cos\Phi + (y_i - y_c)\sin\Phi\right]^2}{\sum_i Q_i}$$

$$\frac{dM_2(\Phi)}{d\Phi} = 0 \implies \Phi_0 = -\frac{1}{2}\arctan\frac{2\sum_i Q_i \, (x_i - x_b)(y_i - y_b)}{\sum_i Q_i \left[(y_i - y_b)^2 - (x_i - x_b)^2\right]}$$

Φ angle of the line respect to the x-axis

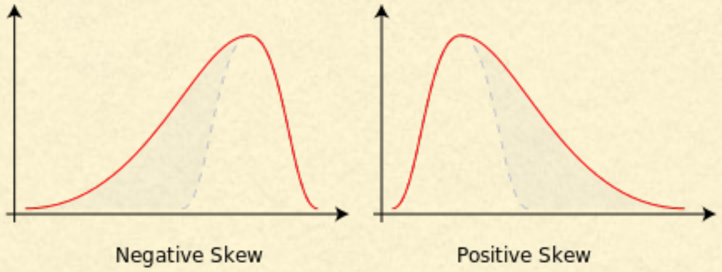
How the algorithm works



- Calculation of the skewness of the track along the main axis respect to the barycenter

$$M_3 = \frac{\sum_i Q_i\, x_i'^3}{\sum_i Q_i} = \frac{\sum_i Q_i\left[(x_i - x_b)\cos\Phi_{\max} + (y_i - y_b)\sin\Phi_{\max}\right]^3}{\sum_i Q_i}$$

- Third momentum of the distribution contains the information on the Bragg Peak



How the algorithm works

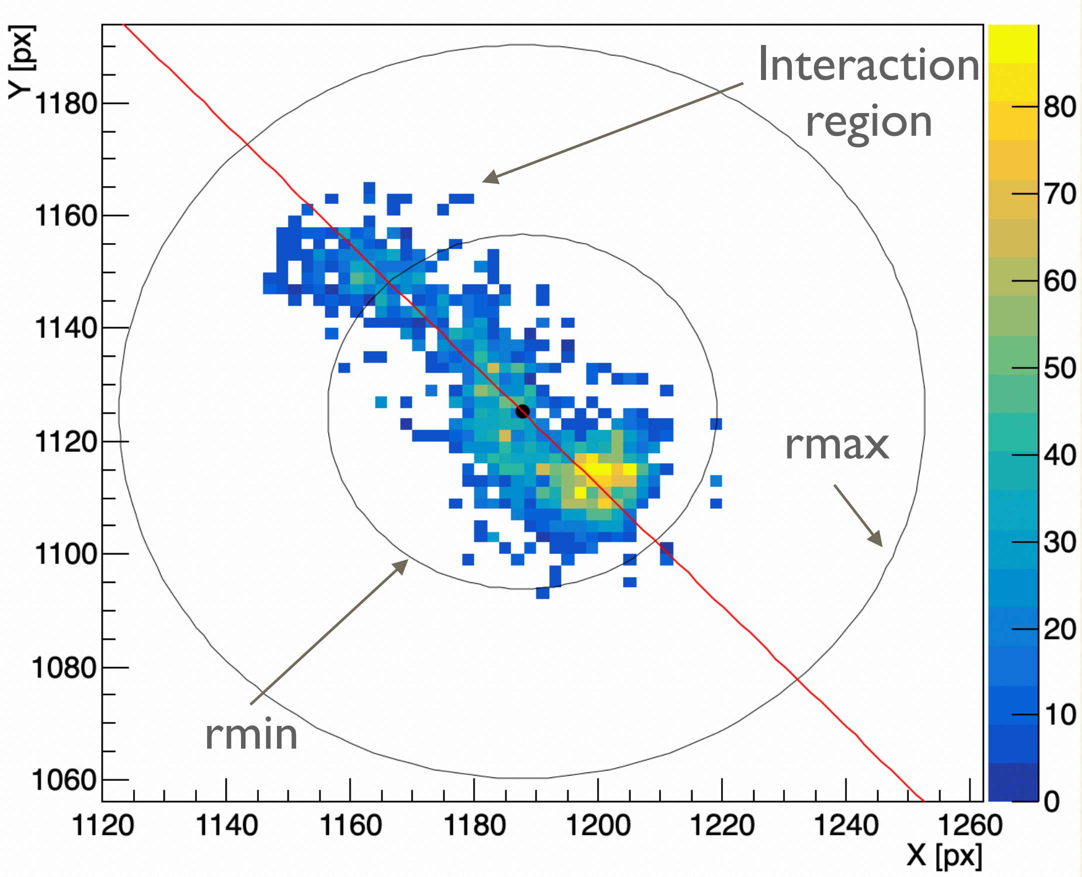
- Calculation of the interaction region as points such that:
  - The point is on the other side of the Bragg peak

$$\frac{x_i'}{M_3} < 0 \implies \frac{(x_i - x_c)\cos\Phi_{\max} + (y_i - y_c)\sin\Phi_{\max}}{M_3} < 0.$$

  - The distance of the point from the barycenter is

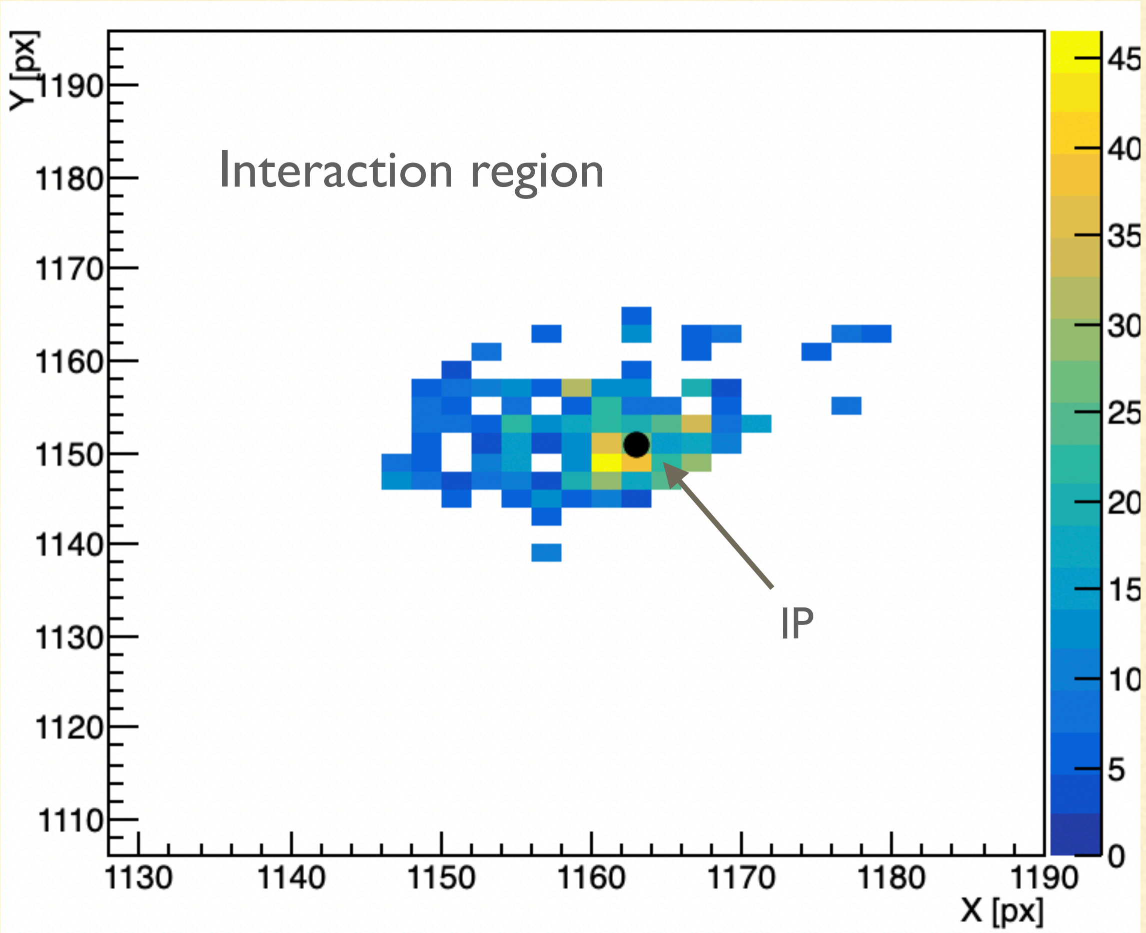
$$r_{\min} < d_{cm} < r_{\max}$$

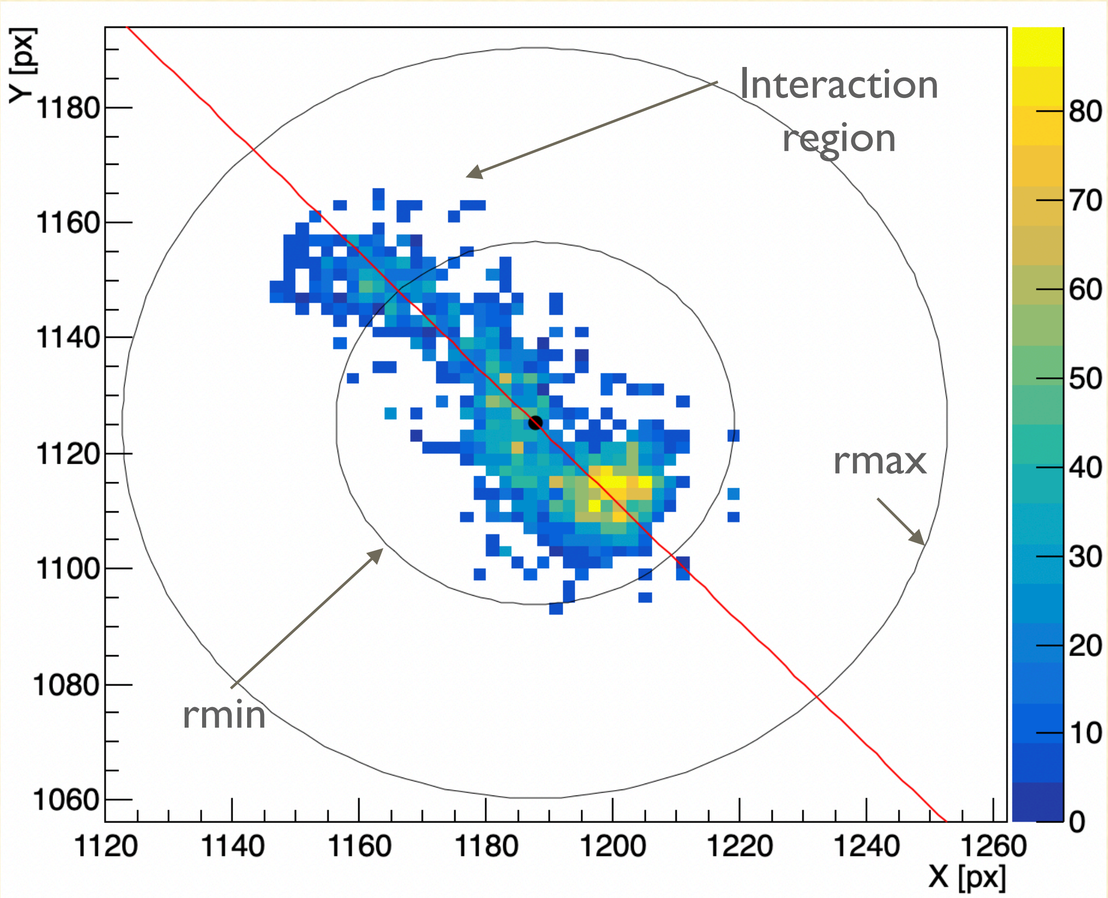
$$d_{cm} = \sqrt{\frac{(x_i - x_c)^2 + (y_i - y_c)^2}{M_2^{\max}}}$$

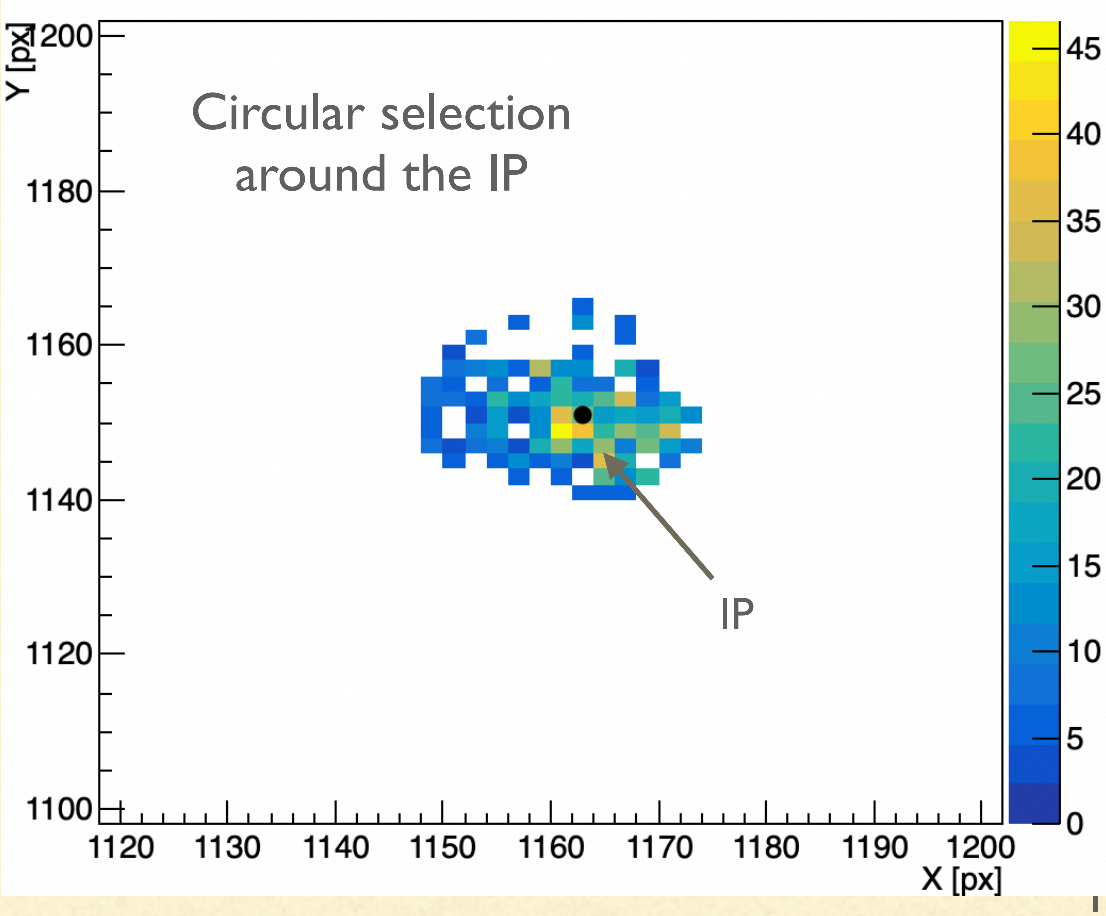


How the algorithm works

- Interaction point (IP) calculated as the barycenter of the interaction region







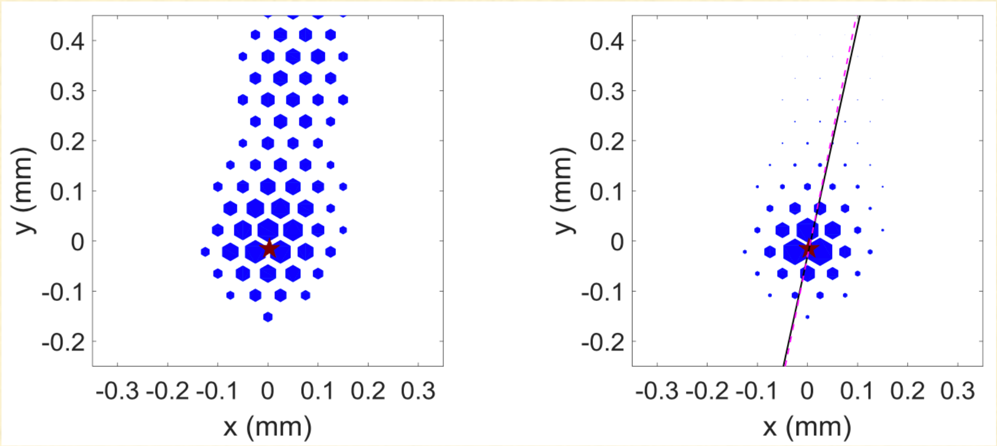
- Due to irregularity of the of the selection an additional circular selection around the IP is performed

Directionality axis determiantion

- Re-weight the intensity of the pixel in the interaction region for the distance from the IP

$$W(d_{ip}) = \exp(-d_{ip} / w)$$

Distance from IP — Constant from MC



- Find the line passing from the IP such that the RMS of the histogram resulting from the projection of the track points on the line is maximum (Red line in the plot below)