Pixel chamber: a silicon heavy-flavour imager with monolithic active pixel sensors for measurements of charm and beauty with unprecedented precision

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REGIONE AUTÒNOMA DE SARDIGNA
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INFN
Istituto Nazionale di Fisica Nucleare

Summary

- Introduction
- Geant4 simulation
- Track and vertex finding and fitting
- Future developments

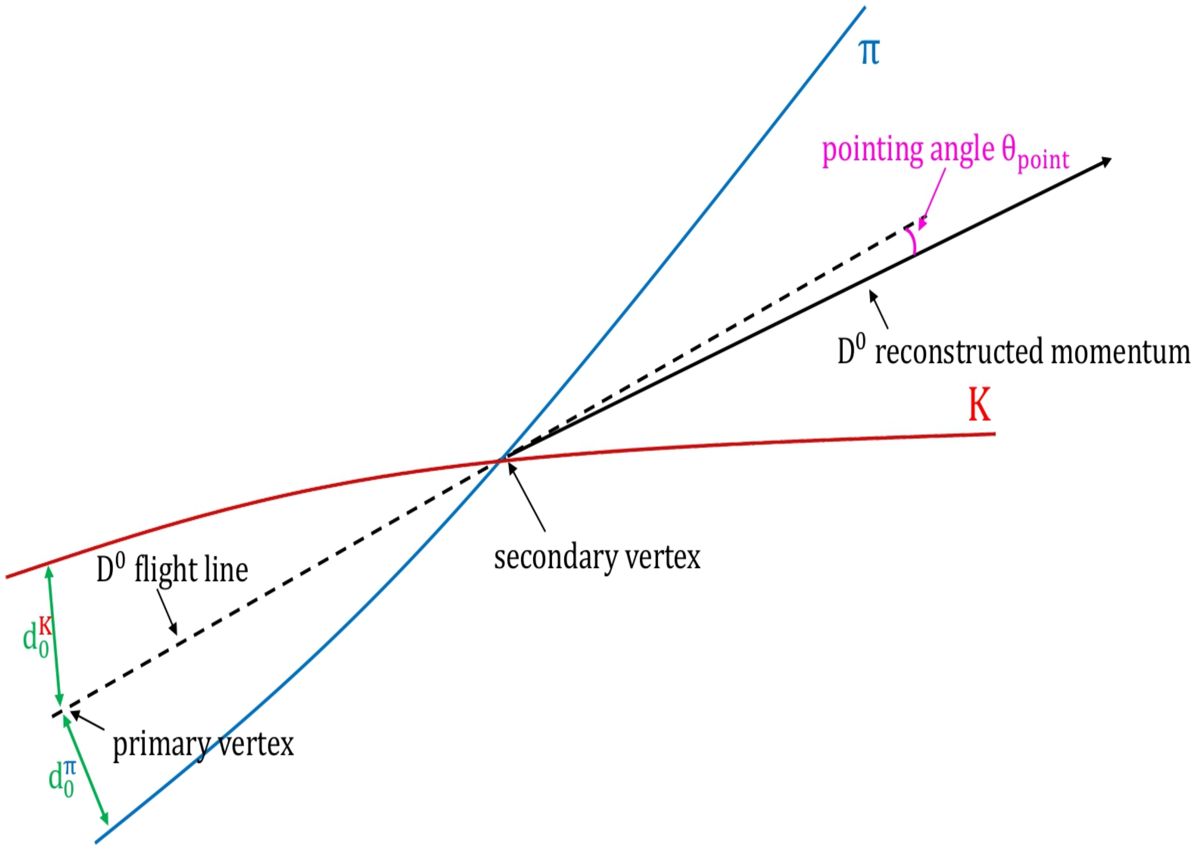
Charm and beauty

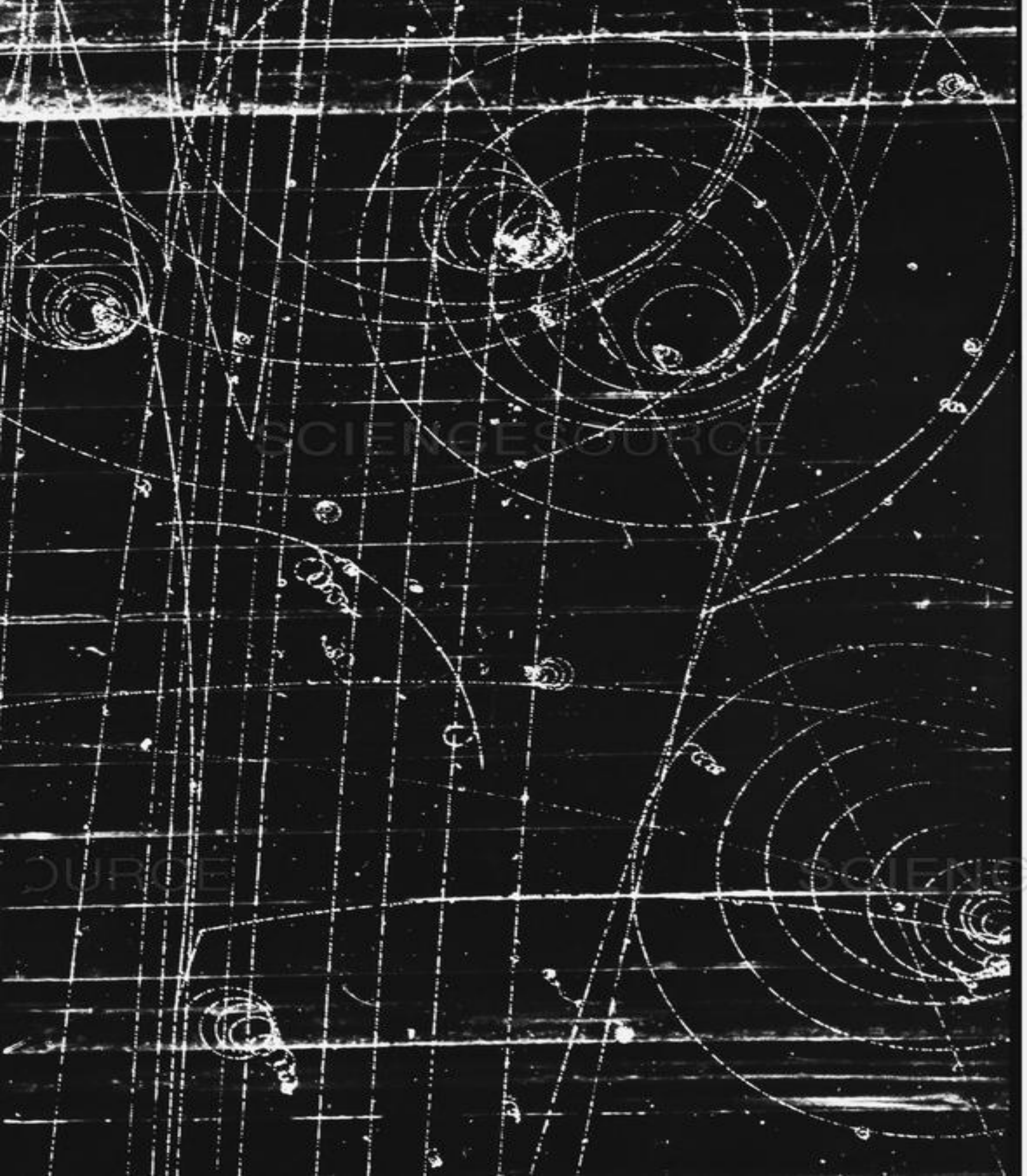
- Long lifetime→can travel distances from O(10-100 μm) up to mm before decay

Ideal Detectors

- As close as possible to production point
- Precision tracking: great spatial resolution to separate primary from secondary vertices

$$D^0 \rightarrow K^- + \pi^+$$
$$c\tau\,(D^0) = 122.9\ \mu m$$



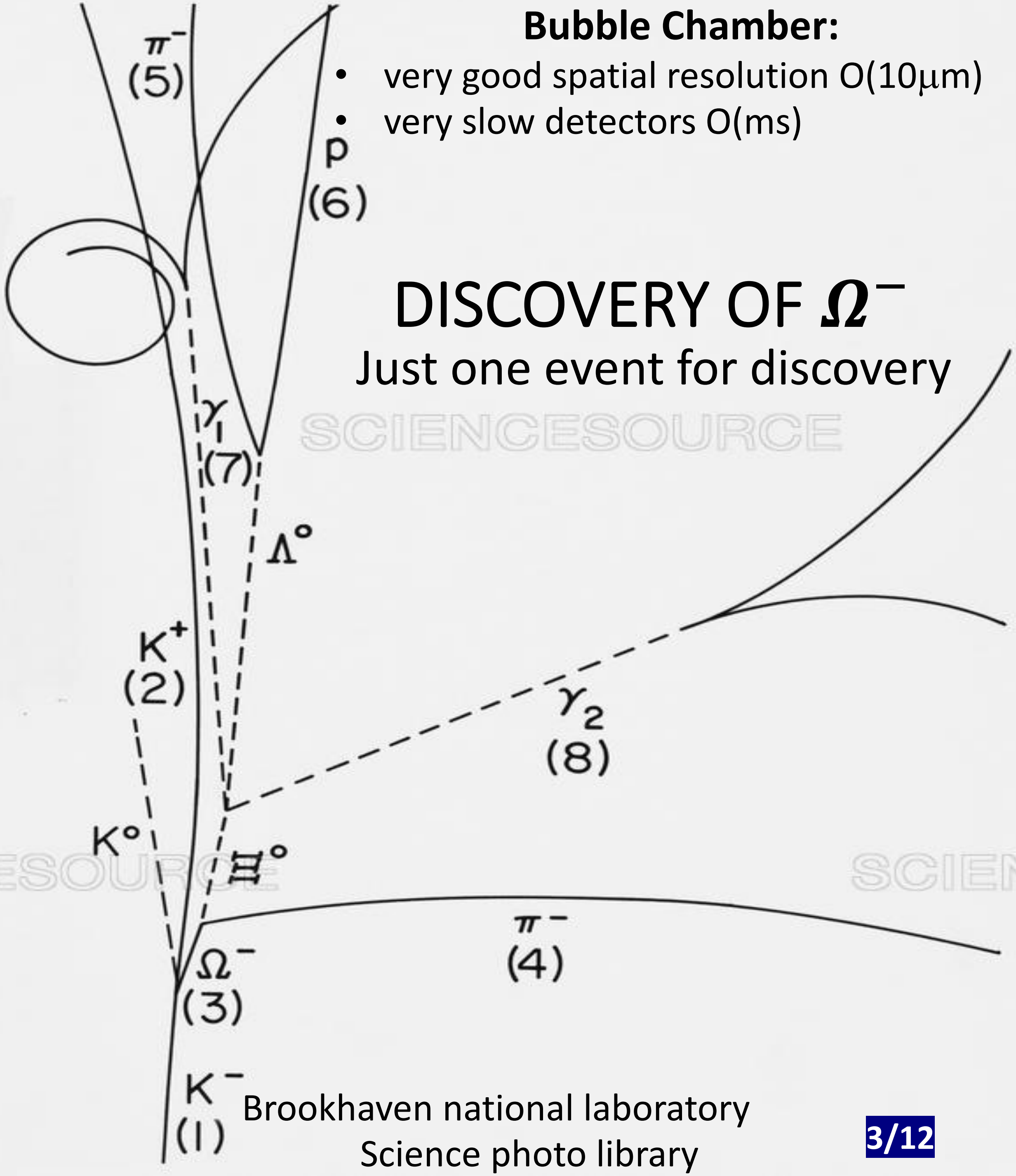


Bubble Chamber:

- very good spatial resolution O(10μm)
- very slow detectors O(ms)

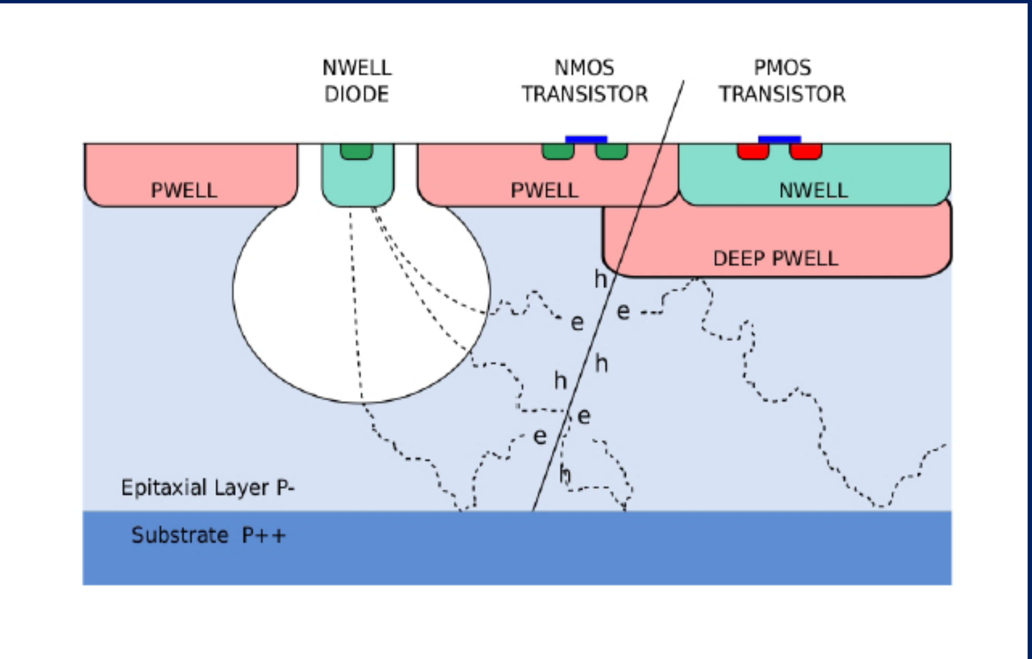
DISCOVERY OF Ω^{-}

Just one event for discovery



Brookhaven national laboratory
Science photo library

Very high resolution silicon pixel detectors: Monolithic sensors



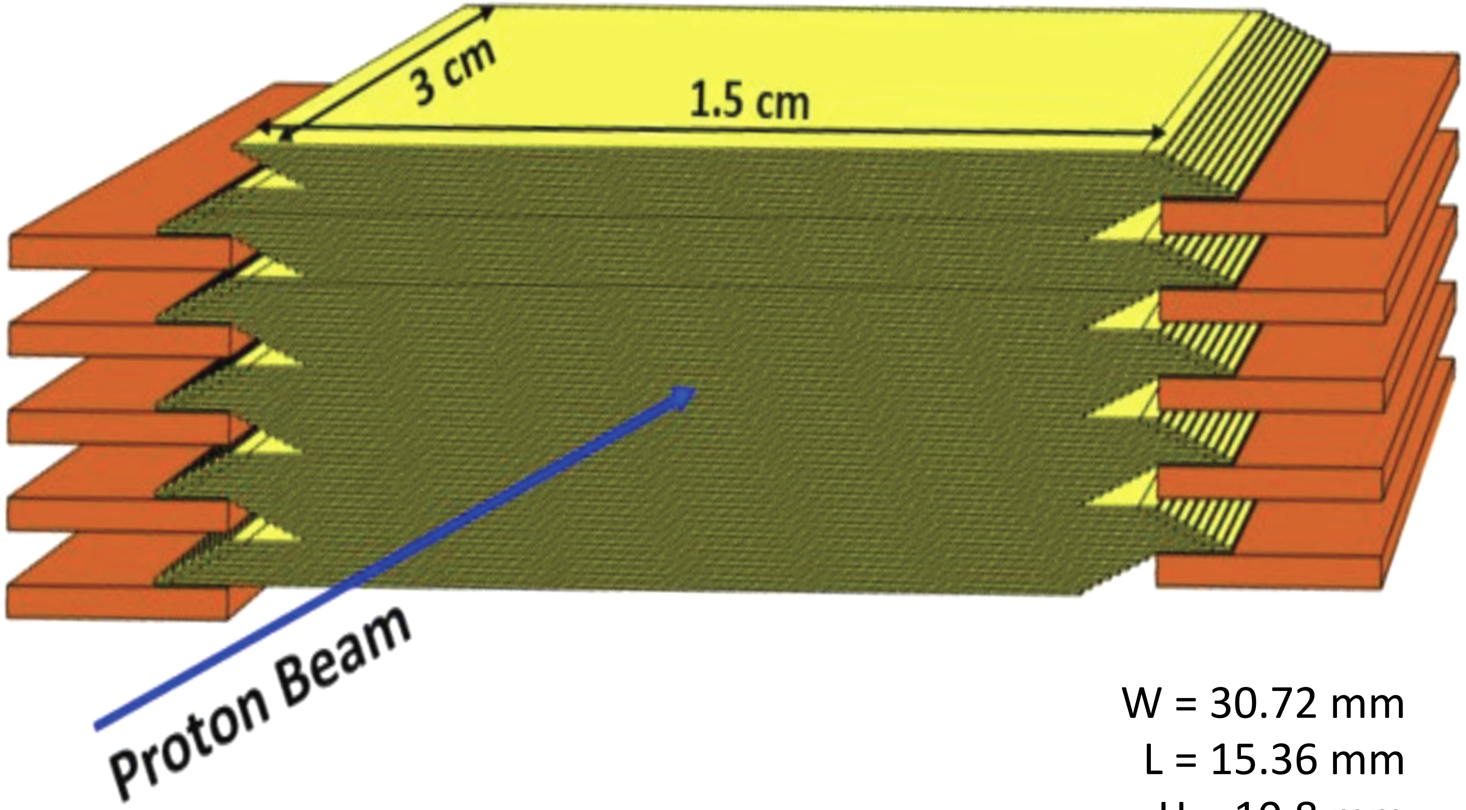
Silicon pixel detectors:

- Reverse biased used to detect a charge particle
- In monolithic pixels the readout electronic is implemented inside the pixel itself

The ALPIDE monolithic sensor (ALICE experiment):

- Most granular and high resolution sensor ever done for high energy physics experiments
- Pixel area 30x30 μm^2
- Matrix of 1024x512 pixels (3x1.5 cm^2)
- Material budget: 50 μm silicon

Interaction inside the chamber



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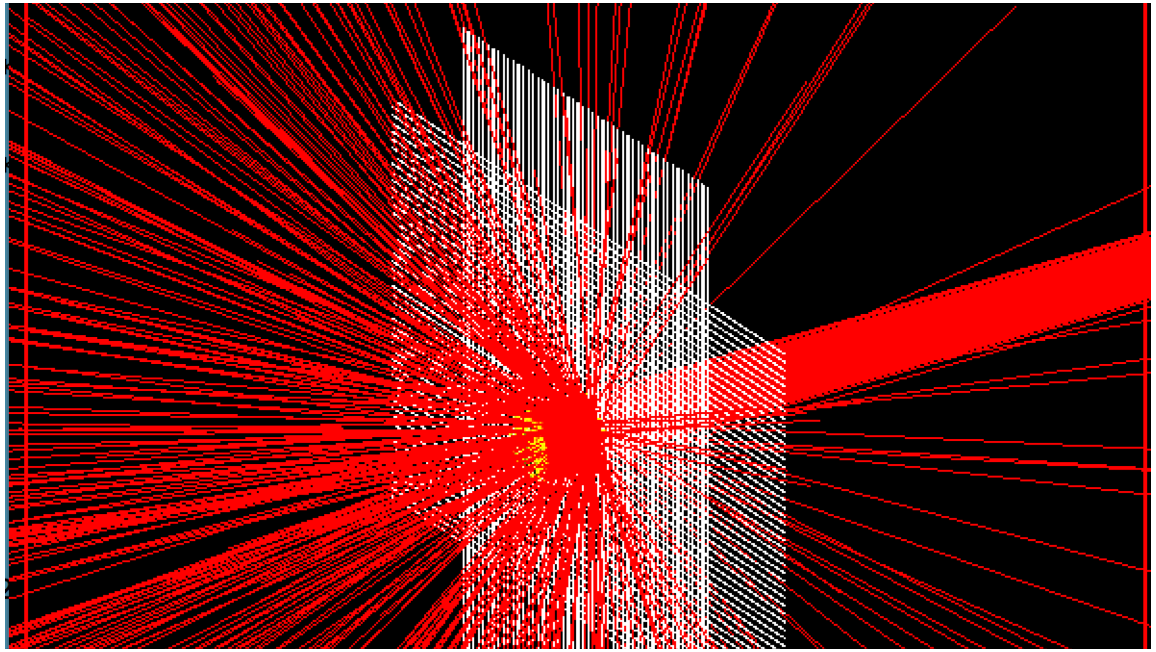
G. Usai, P. Bhattacharya, S. Siddhanta, D. Marras, E. Casula, M. Arba, M. Tuveri, A. Masoni, A. Mulliri

Pixel Chamber

Idea:

- stack of several ALPIDE chips
- 3D volume of pixels
- solid state bubble chamber
  - ➢ active target
  - ➢ performs continuous tracking with very high precision ~5µm spatial resolution

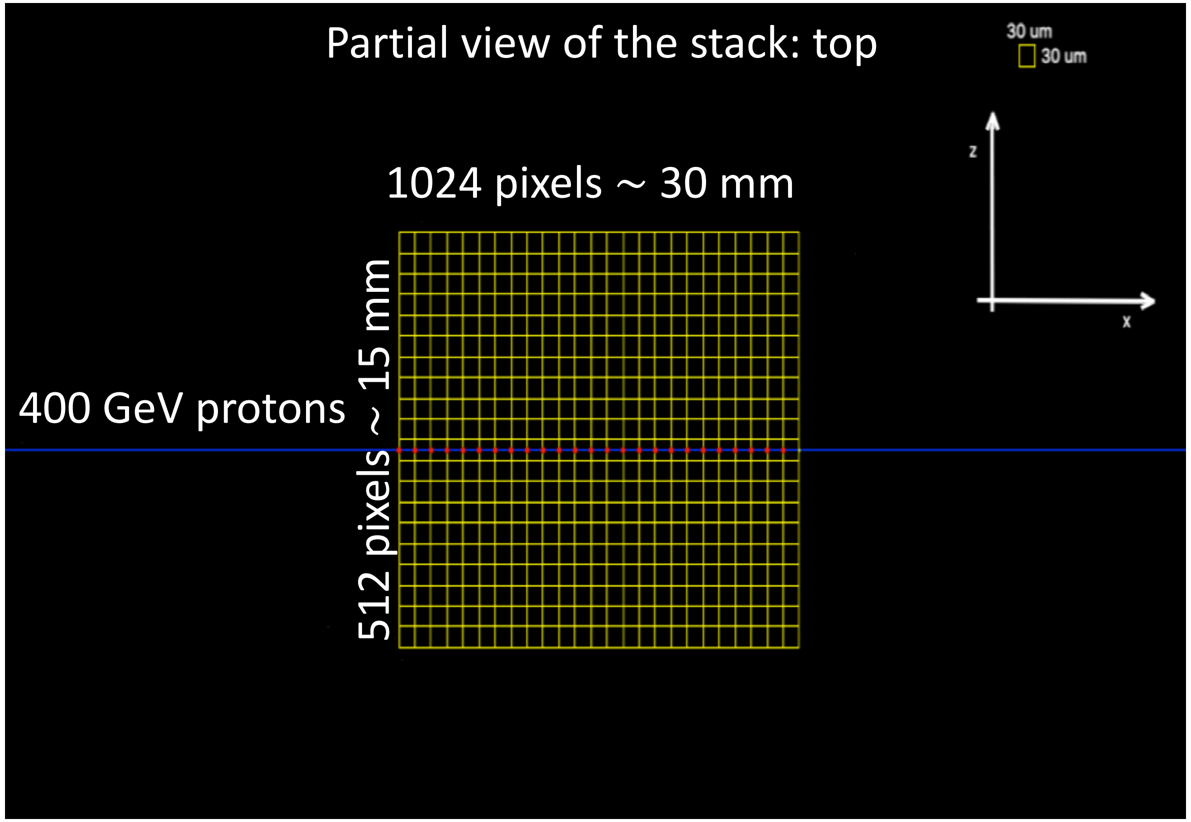
Step1: simulation

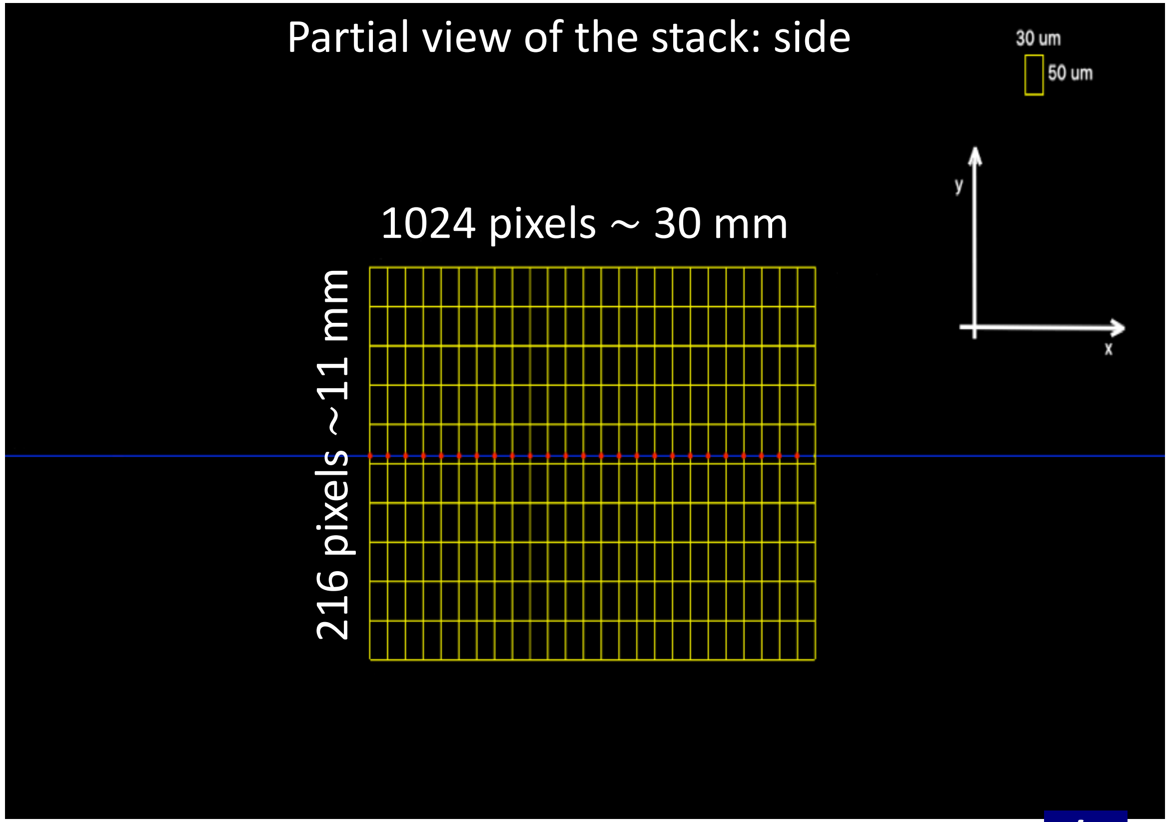


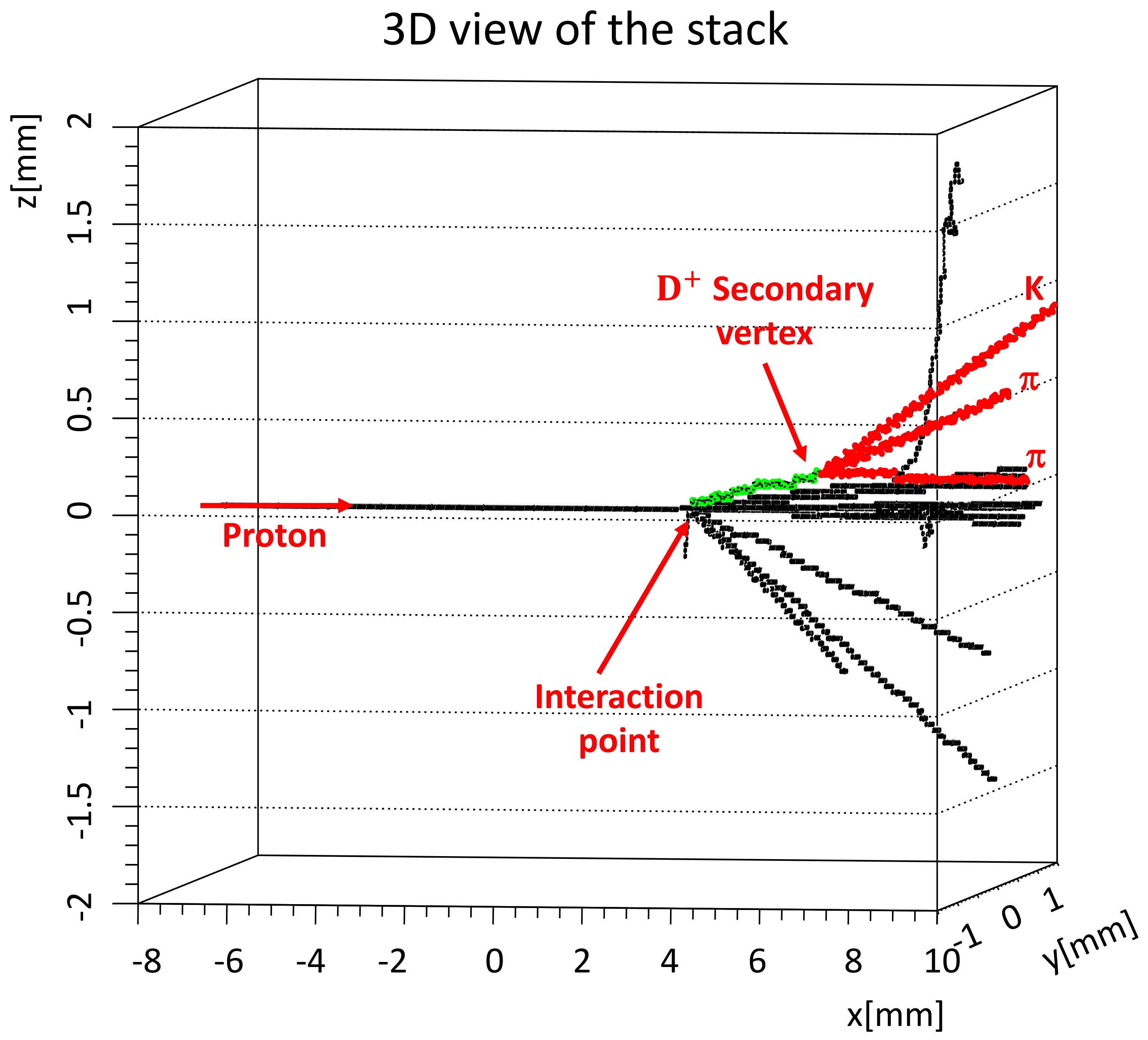
Pixel chamber in Geant4

- Simulation of a protype made of 216 ALPIDE sensors
- Each sensor is a matrix of 1024x512 pixels
- Each pixel is ~30x30x50 μm^3

→ 3D Matrix of ~ 10^8 Pixels!







Pixel chamber: Geant4 simulation

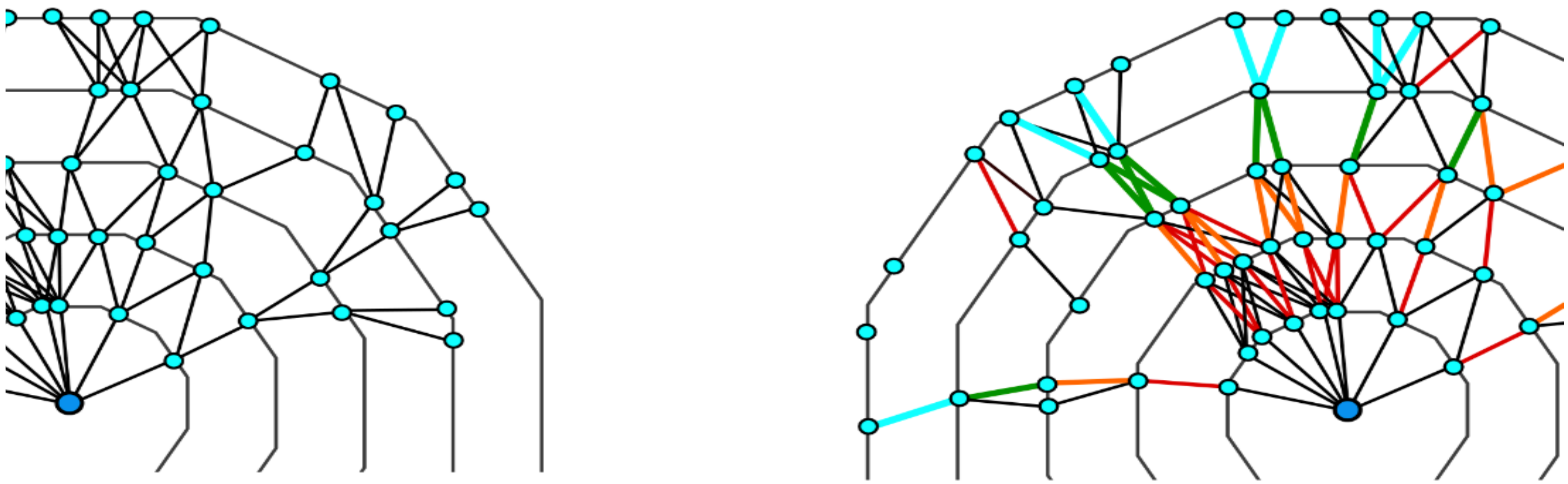
- 400 GeV p-Si interactions
- 3D visualization of p-Si inelastic collision with a D^{+} meson

Dataset produced:

- Digit: center coordinates of the hit pixel
- Data for Monte Carlo truth:
  - Particle momenta
  - PDG code

Step 2: track and vertices finding and fitting

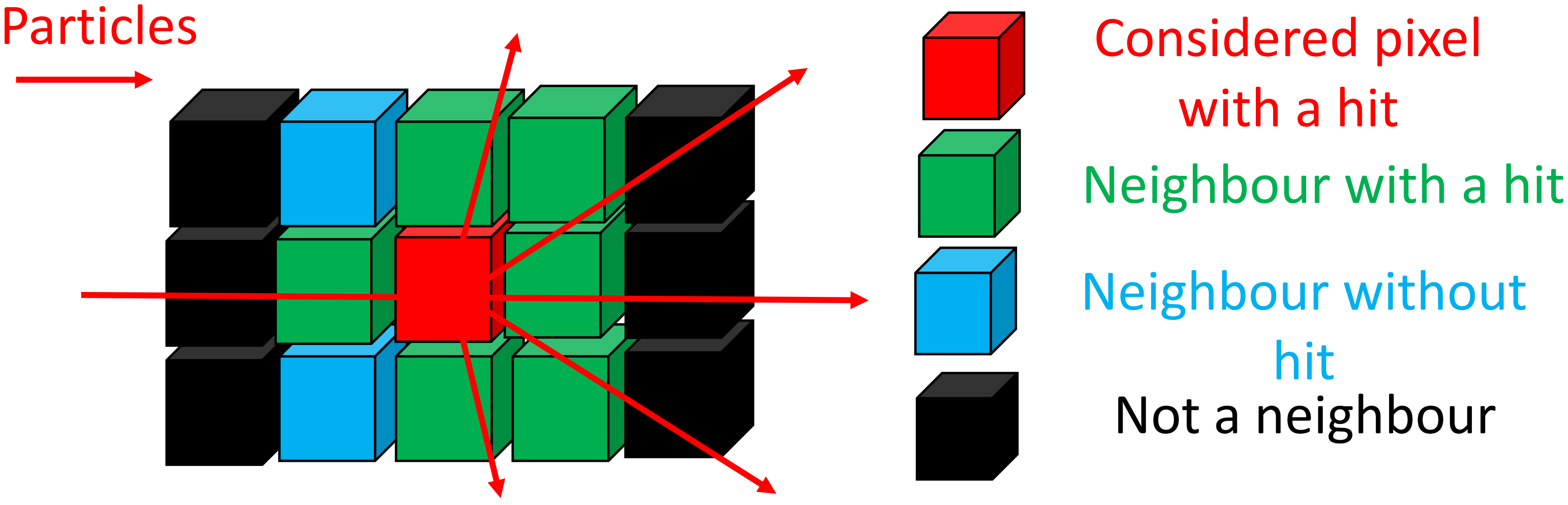
Track finding: group hits into clusters



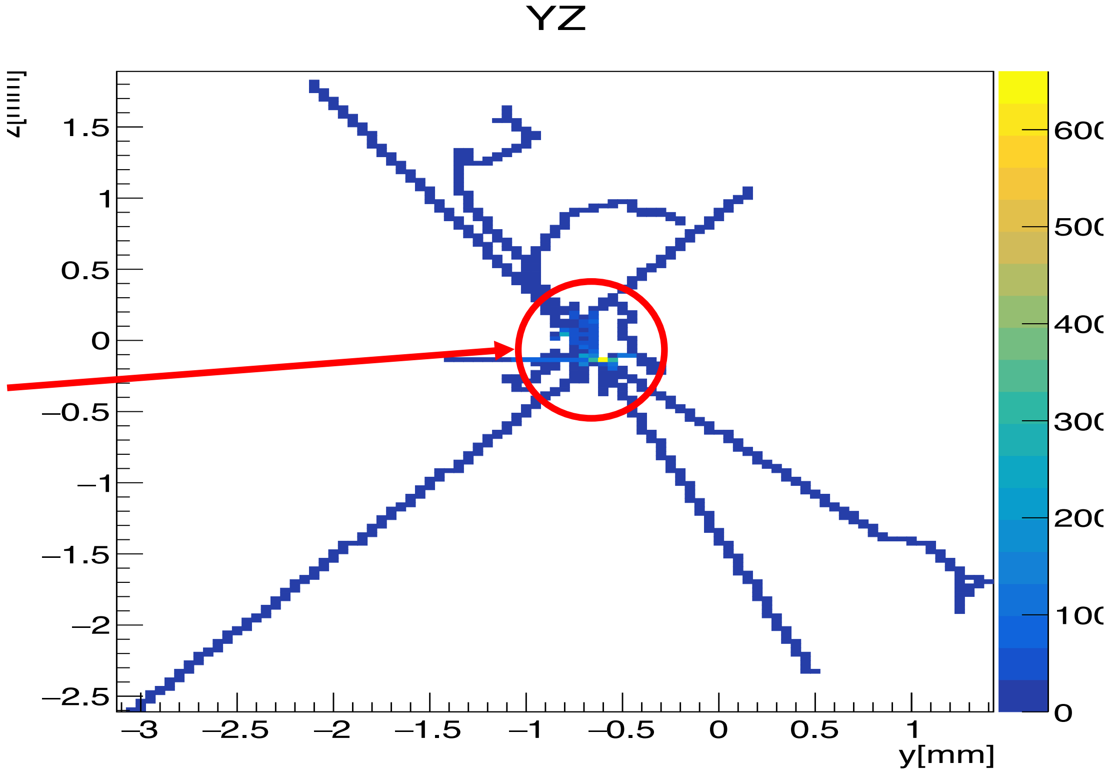
Algorithm

First step:

- Look for pixels' neighbors
- Check which neighbors have a hit
- Consider a point as noise if:
  - Number of neighbors < 2
  - Number of neighbors > 3 required to break clusters belonging to different tracks in regions with high density of hits (example figure right)



Interaction vertex point with large number of hit neighbors

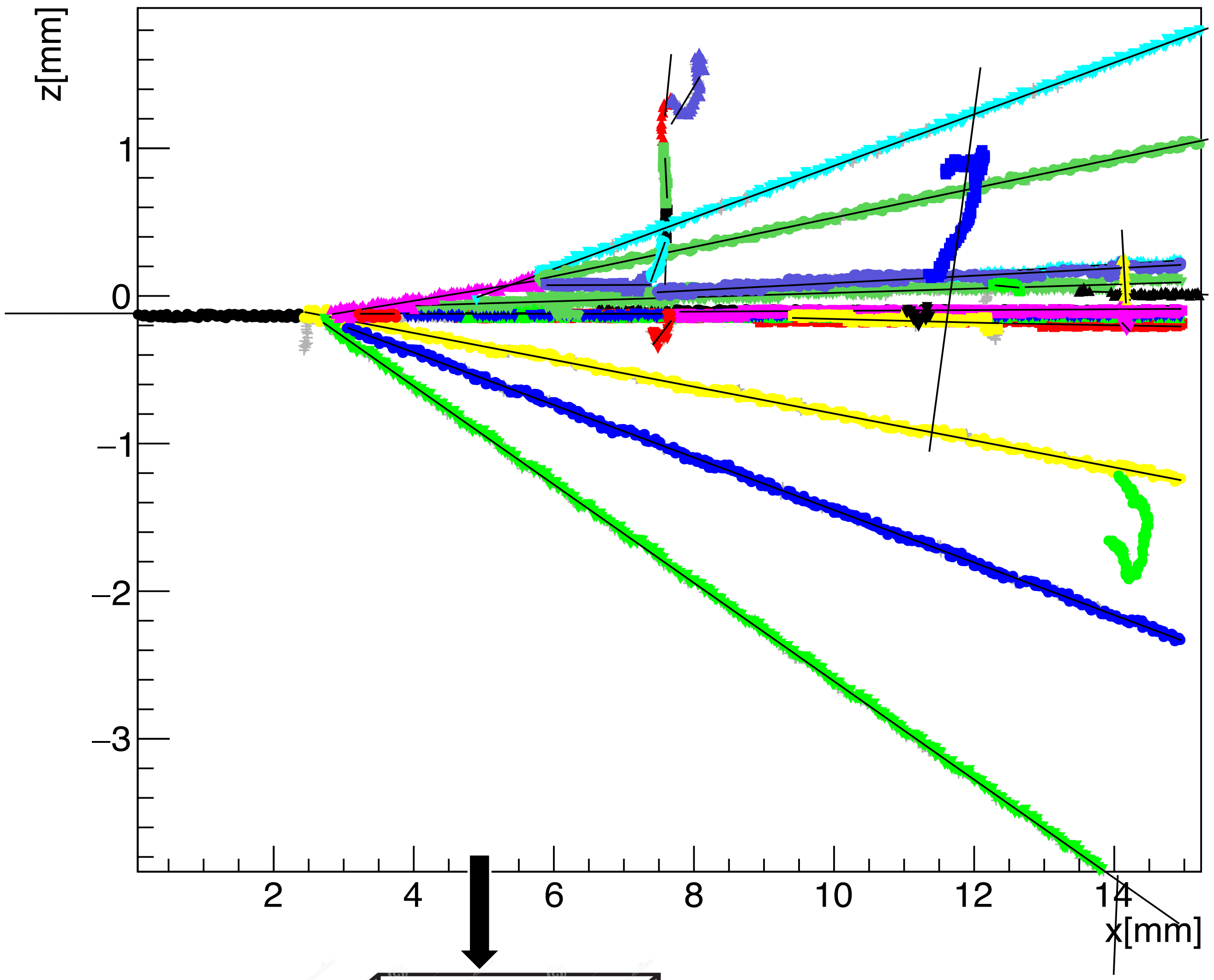


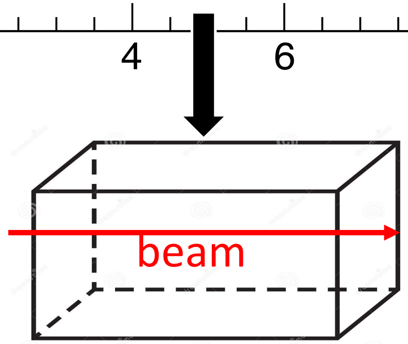
Algorithm

Further steps:

- Fit all reconstructed tracks with straight lines
- Look for compatible straight lines
- Merge compatible linear clusters
- Look if noise points are compatibles with some linear cluster
- New clusterization for residual noise points
- New fit to find vertices (under study):
  - New fit lines have to cross the same point

Reconstructed tracks:
Satisfactory reconstruction of most of the tracks





Summary and outlook

✓ Optimize track finder algorithm:
- ➢Secondary vertices reconstruction
- ➢Introduce machine learning

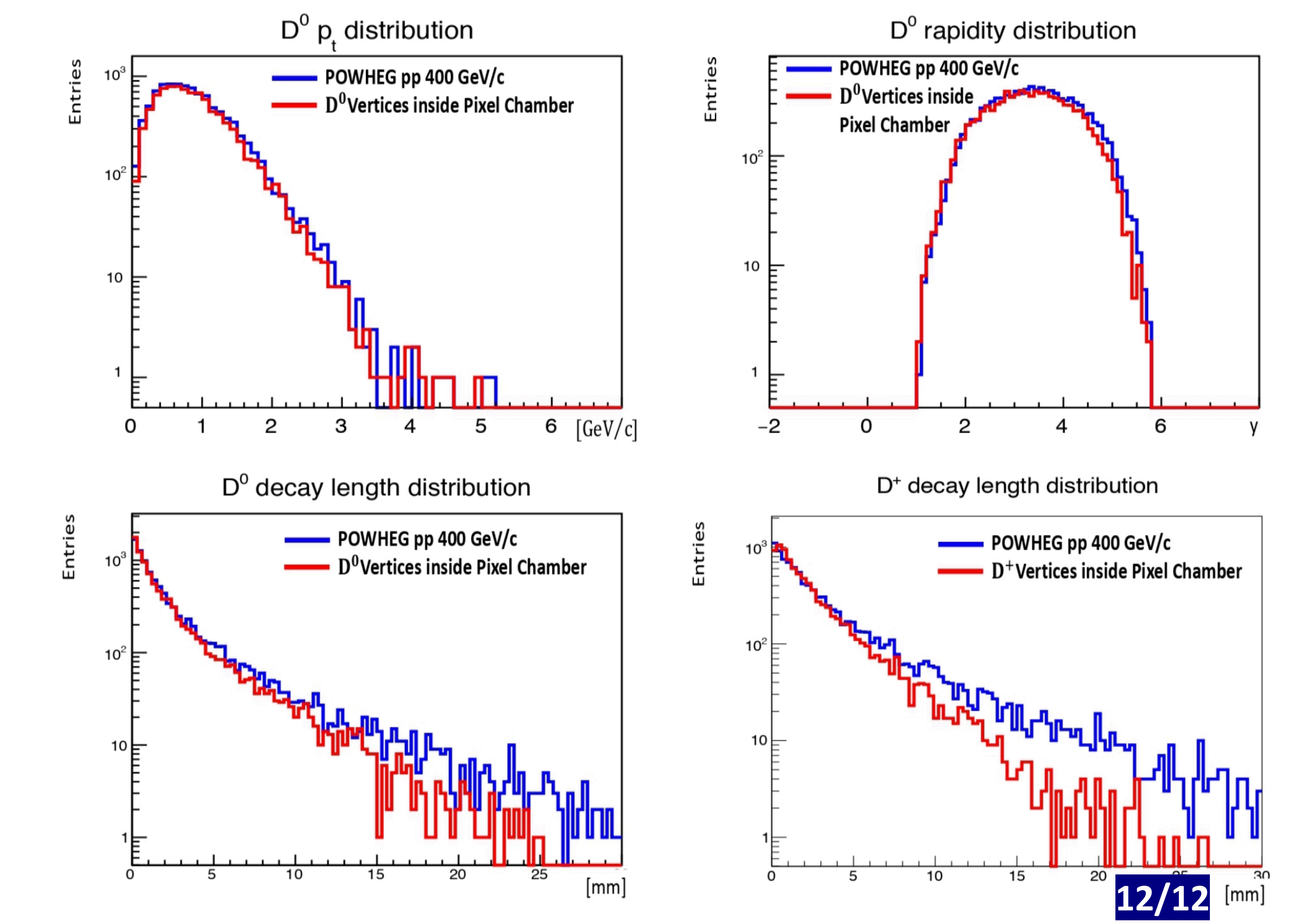
✓ Reconstruction of charmed particles:
- ➢Secondary vertex selection
- ➢Momentum measurements of decay products with additional silicon telescope
- ➢Performance study of reconstruction of other charm and beauty states
- ➢Example of physics measurements: detailed performance study of very high precision charm production at CERN SPS

✓ Construction of a detector prototype

✓ Laboratory test with radioactive sources

✓ Beam tests

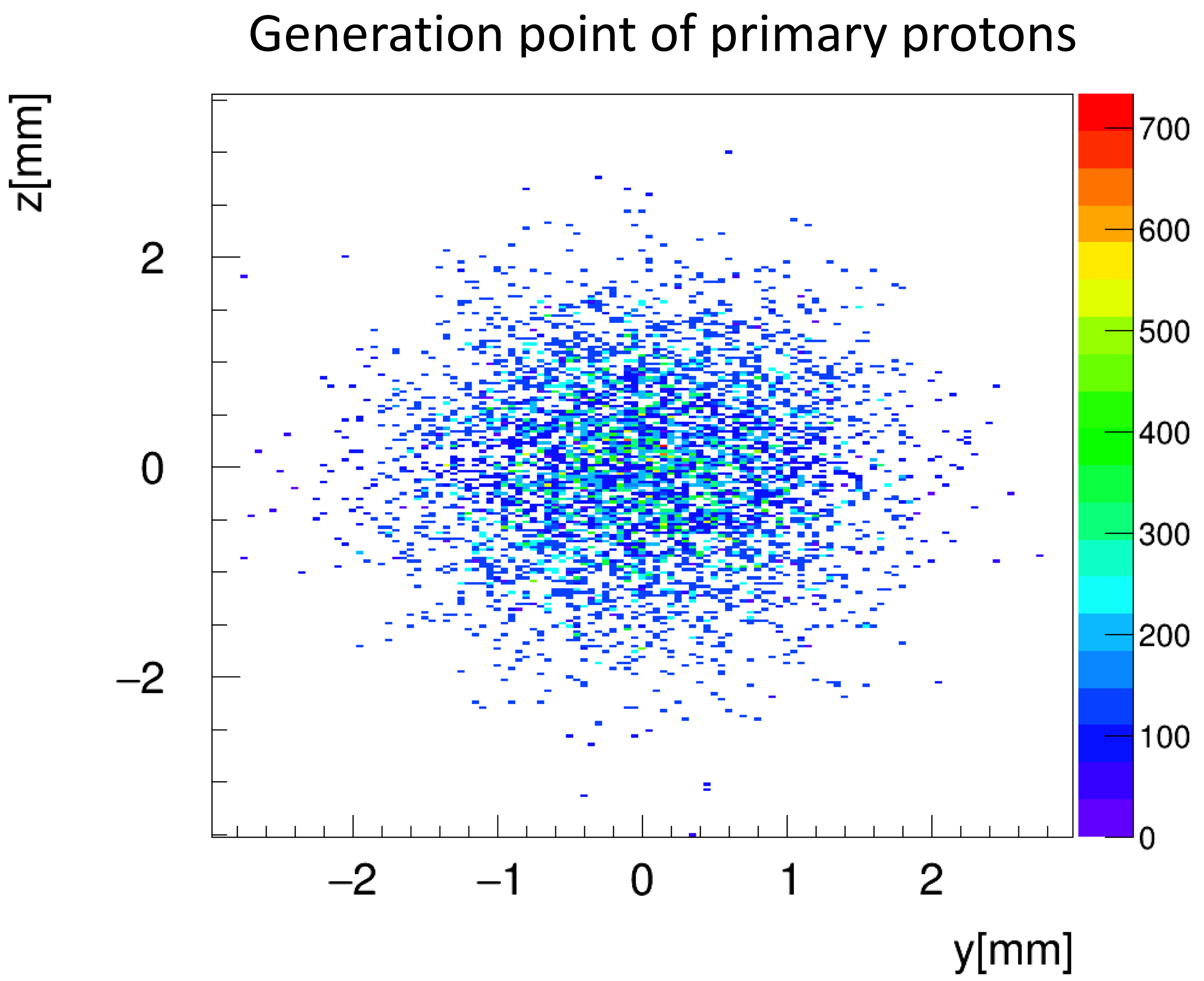
✓ Reasonable fraction of charmed particles decays inside the detector
- ➢ Possibility to identify particles without momentum???

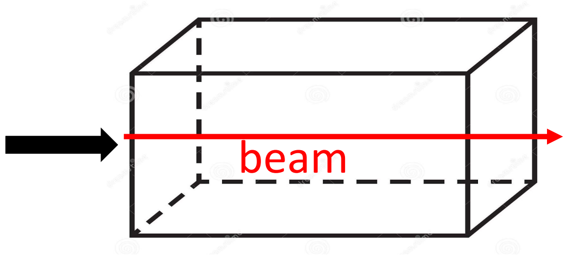


Thanks
for your attention

Backup slides

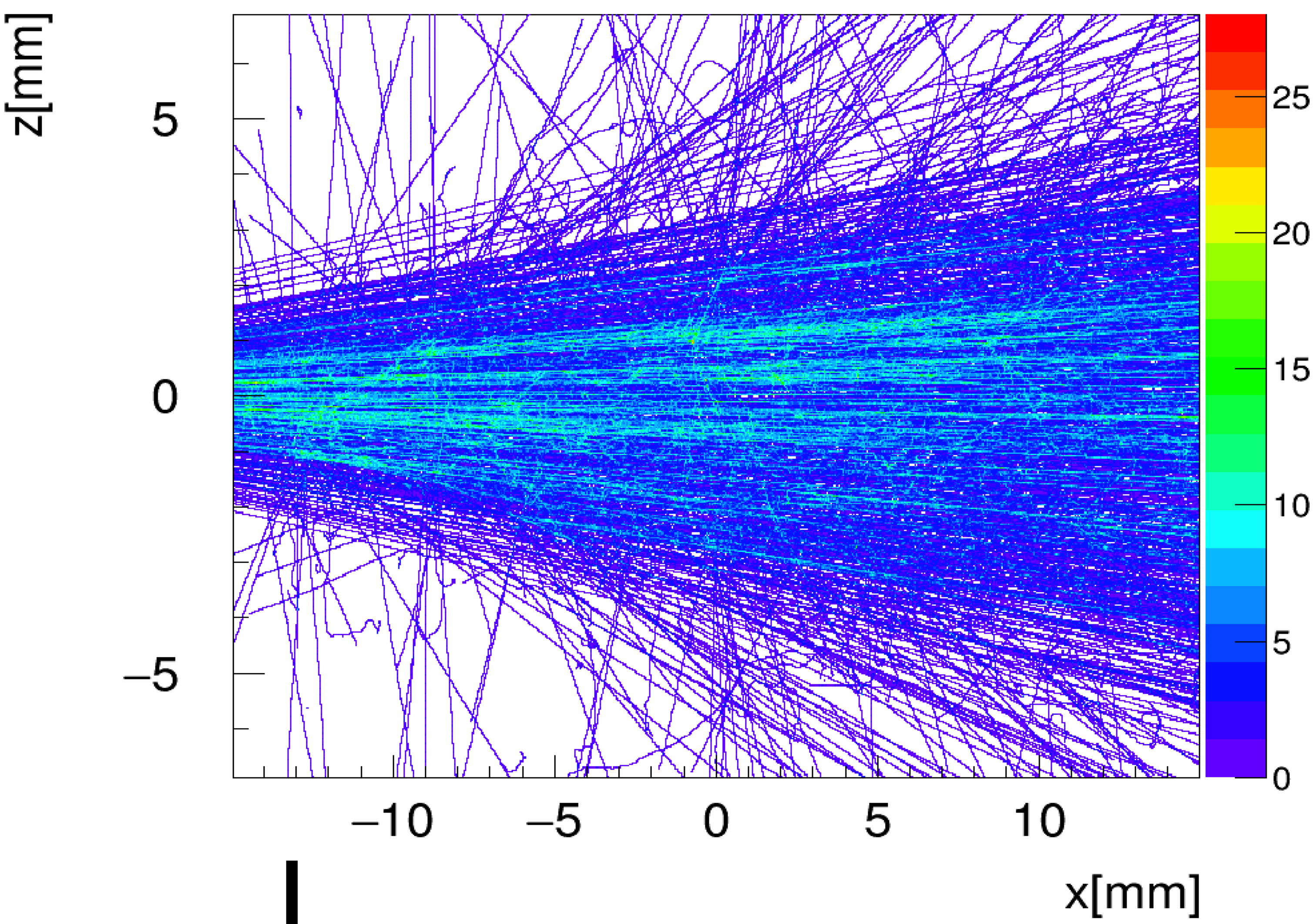
Pixel chamber: Geant4 simulation

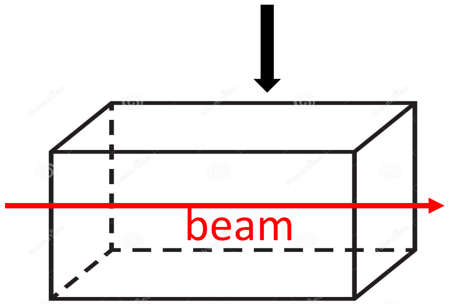




- 400 GeV protons:
  - Production coordinates generated with a gaussian distributions with μ=0 and σ=0.8 mm

Top view of the stack





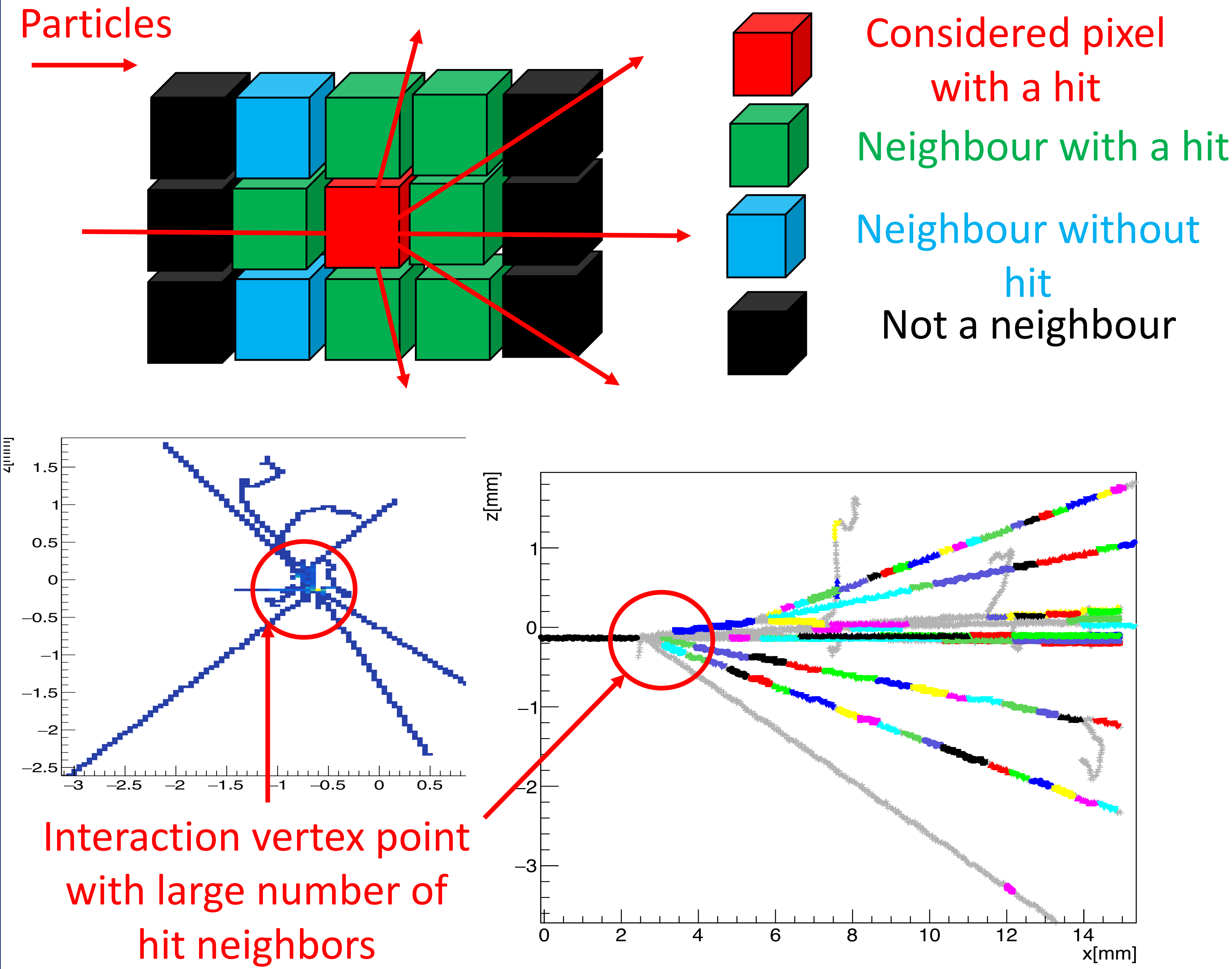
Pixel chamber: Geant4 simulation

- 400 GeV protons:
  - Momentum direction components generated with a gaussian distribution with center in the production point and σ=0.2

Algorithm: track finding

First passes:

- Look for pixels' neighbors
- Check which neighbors have a hit
- Consider a point as noise if:
  - ➢ Number of neighbors < 2
  - ➢ Number of neighbors > 3 required to break clusters belonging to different tracks in regions with high density of hits (example figure right)

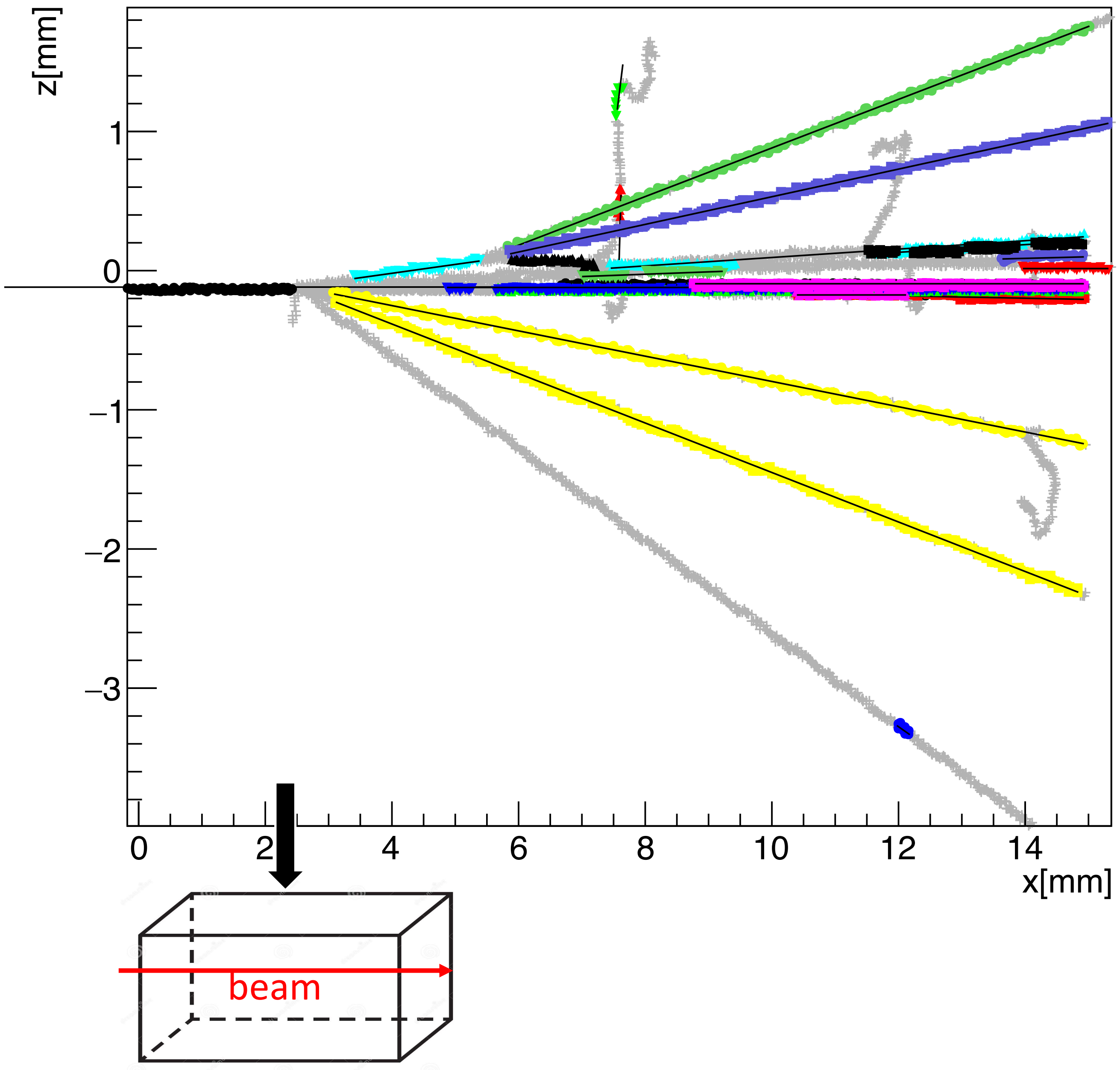


Algorithm: track finding

Fit and merge

- Fit all reconstructed tracks with straight lines
- Look for compatible straight lines
- Merge compatible linear clusters

Reconstructed tracks:
Fit and merge

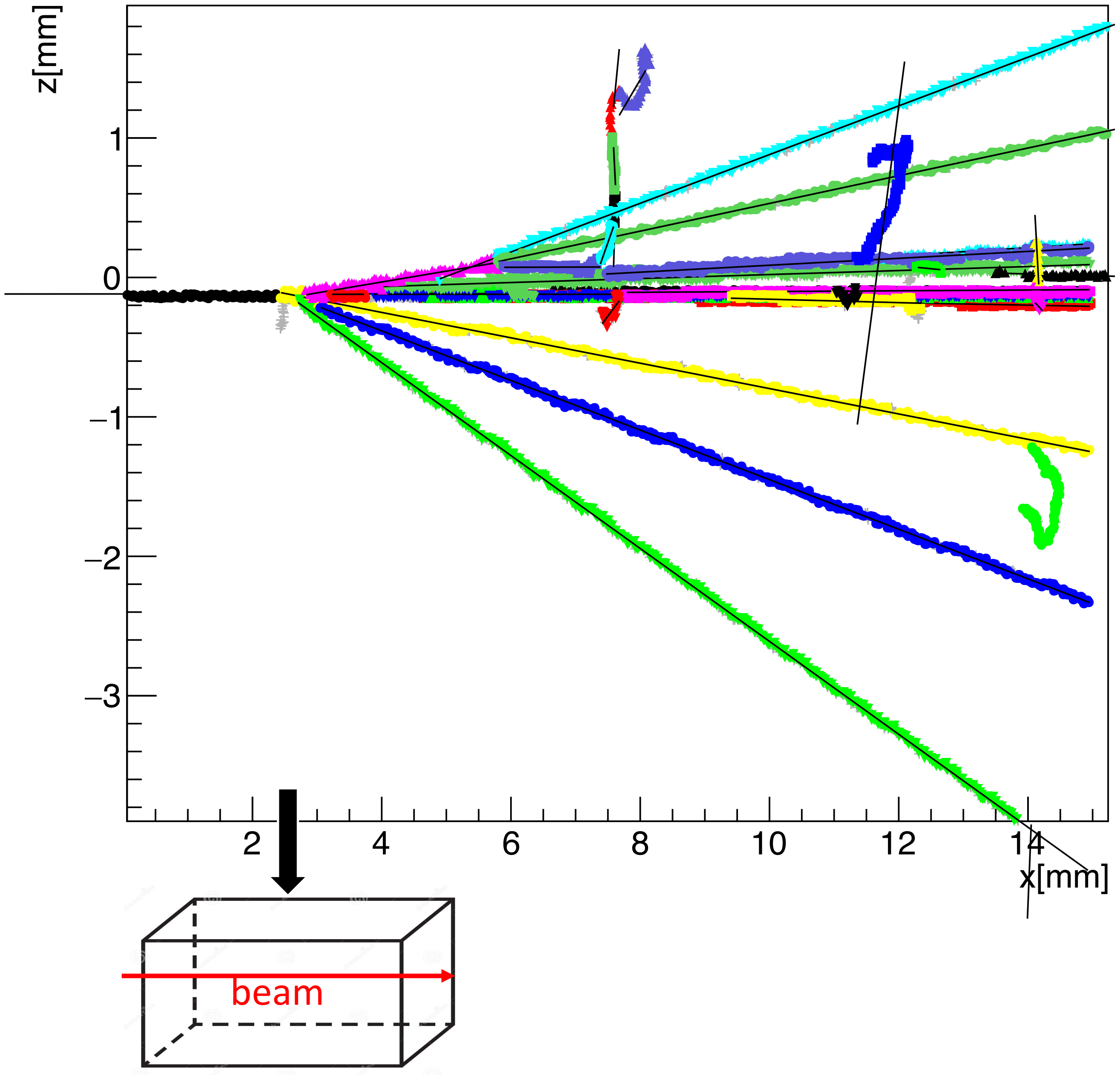


Algorithm: track finding

Noise check

- Look if noise points are compatibles with some linear cluster
- New clusterization for residual noise points
- Last fit

Reconstructed tracks:
Satisfactory reconstruction of most of the tracks



Algorithm: vertex finding

Vertex reconstruction

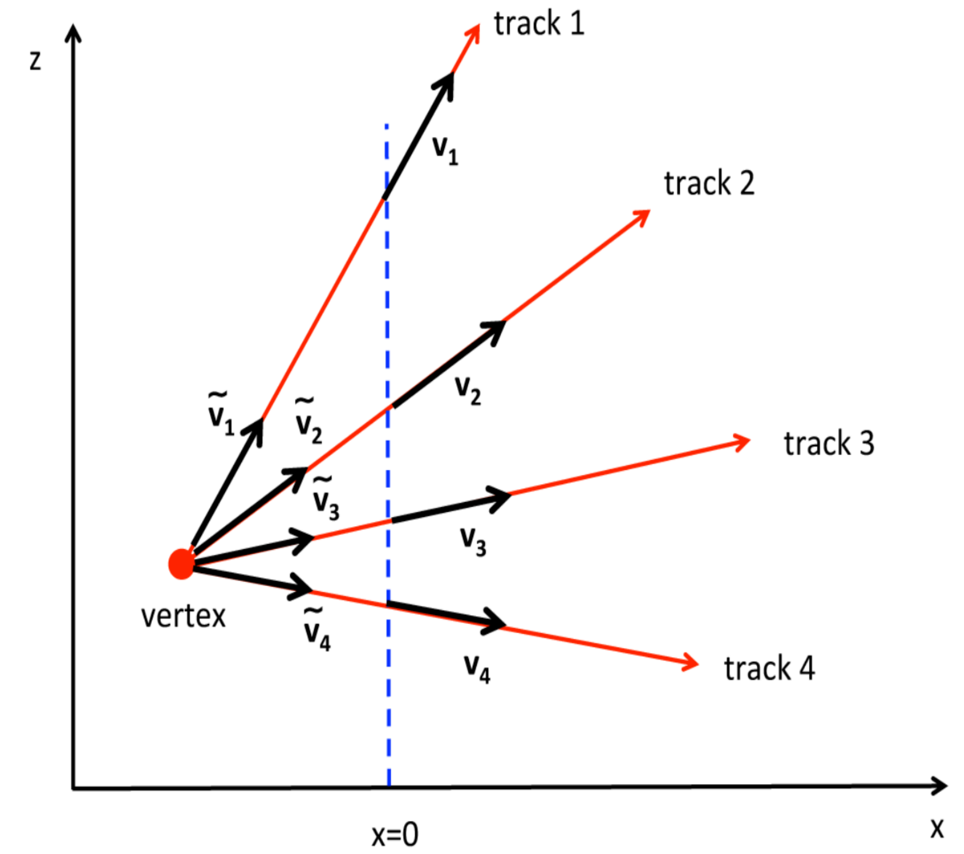
- New fit to find vertices (under study):
  - Fitted tracks are fitted again with new model:
    - ➢ New fit lines have to cross the same point
  - Starting from the proton track, tracks are used for the new fit
  - If the fit with a new track has $\chi^2 > 2$ the track is rejected

Track fit

$$x_p = p[0]$$
$$v_x = p[1]$$
$$y_p = p[2]$$
$$v_y = p[3]$$
$$z_p = p[4]$$
$$v_z = p[5]$$

Model

$$x_v = p[0]$$
$$y_v = p[1]$$
$$z_v = p[2]$$
$$t_{xm} = v_x = p[3]$$
$$t_{ym} = \frac{v_y}{v_x} = p[4]$$
$$t_{zm} = \frac{v_z}{v_x} = p[5]$$



$$\chi^2 = \Sigma_{tracks} \frac{(y_{0p} - y_{0mod})^2}{\sigma_{y0}^2} + \frac{(z_{0p} - z_{0mod})^2}{\sigma_{z0}^2} + \frac{(t_x - t_{xmod})^2}{\sigma_{tx}^2} + \frac{(t_y - t_{ymod})^2}{\sigma_{ty}^2} + \frac{(t_z - t_{zmod})^2}{\sigma_{tz}^2}$$