Track Finding in COMET CDC

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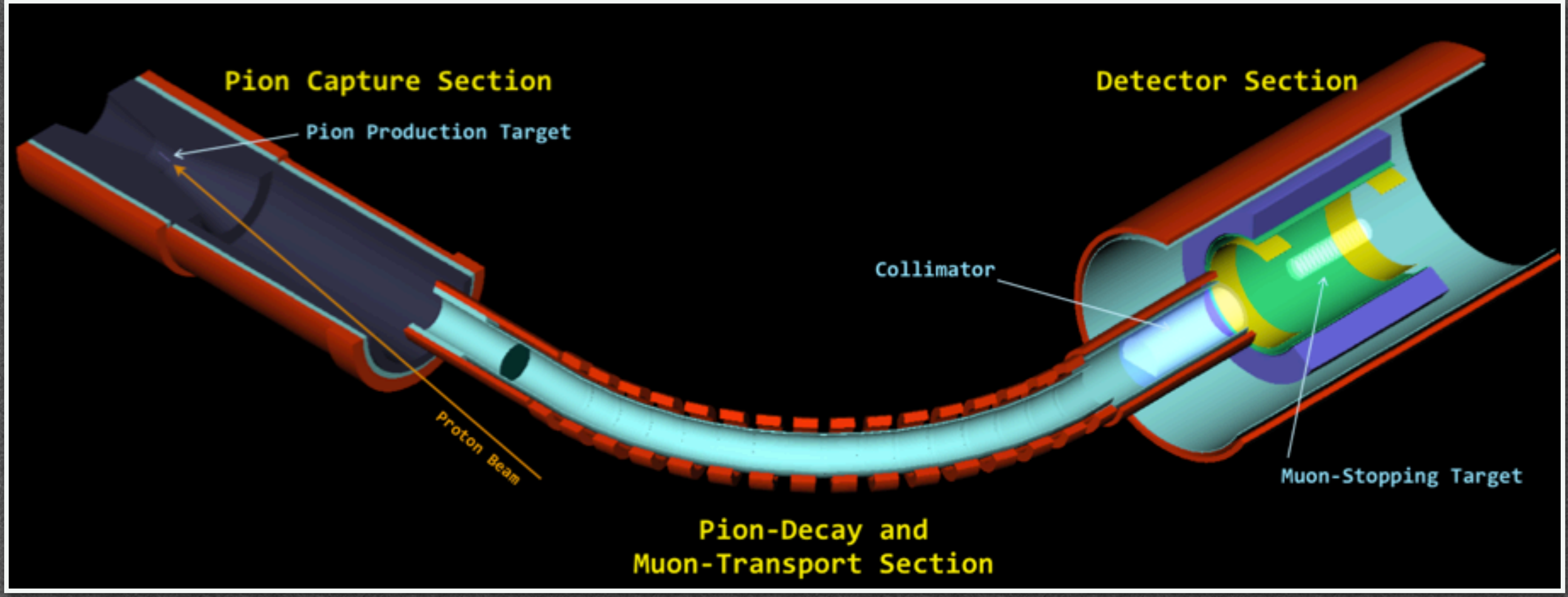
Outline

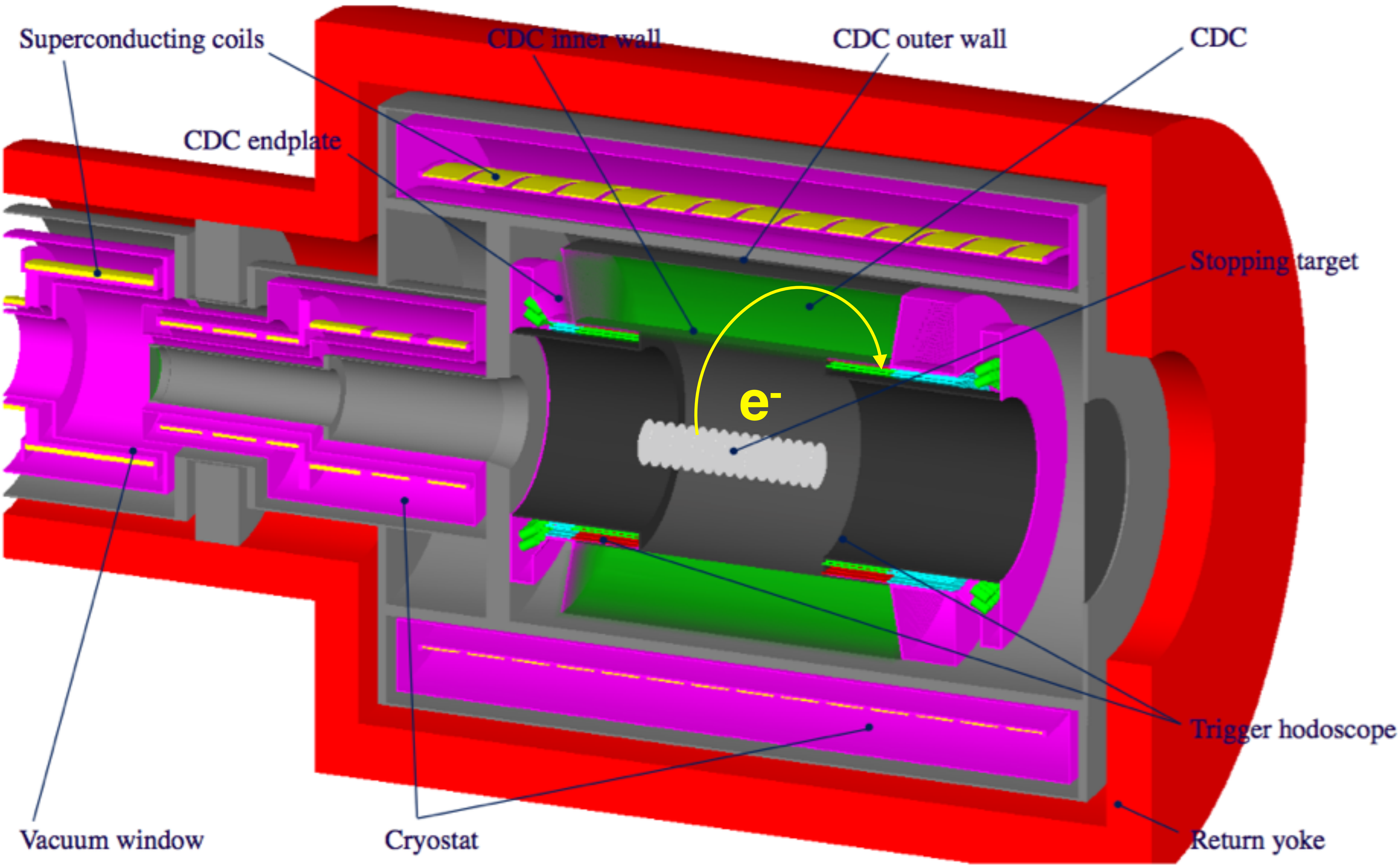
- Introduction to COMET experiment
- Cylindrical Detector System (CyDet)
- Track finding
  - Conformal mapping
  - Hough transformation
  - RANSAC algorithm
- Prospective
- To do list

Introduction to COMET Phase-I

- Location: J-PARC, Tokai, Ibaraki
- Goal: To search for a electron (105MeV) converted from a muon *without neutrino* in muonic aluminium atom via a Charged Lepton Flavour Violation (CLFV) process
- Sensitivity : 3×10^{-15} in 200 days of physics run, which is 100 times better than the current limit
- Two sets of detector systems
  - CyDet : Cylindrical drift chamber + Cylindrical Trigger Hodoscope
  - StrECal: Straw tracker + EM calorimeter



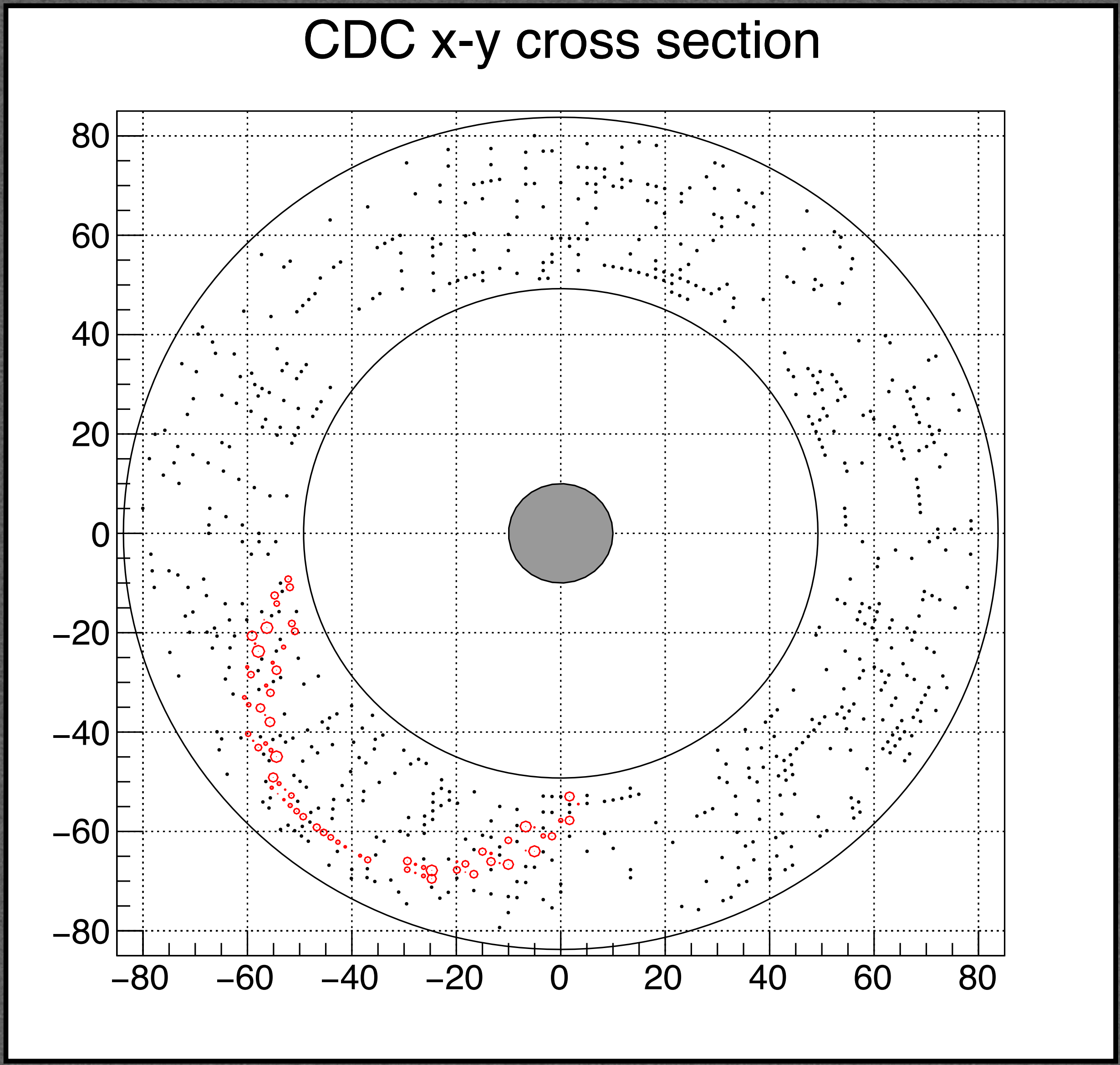
Cylindrical Detector system (CyDet)



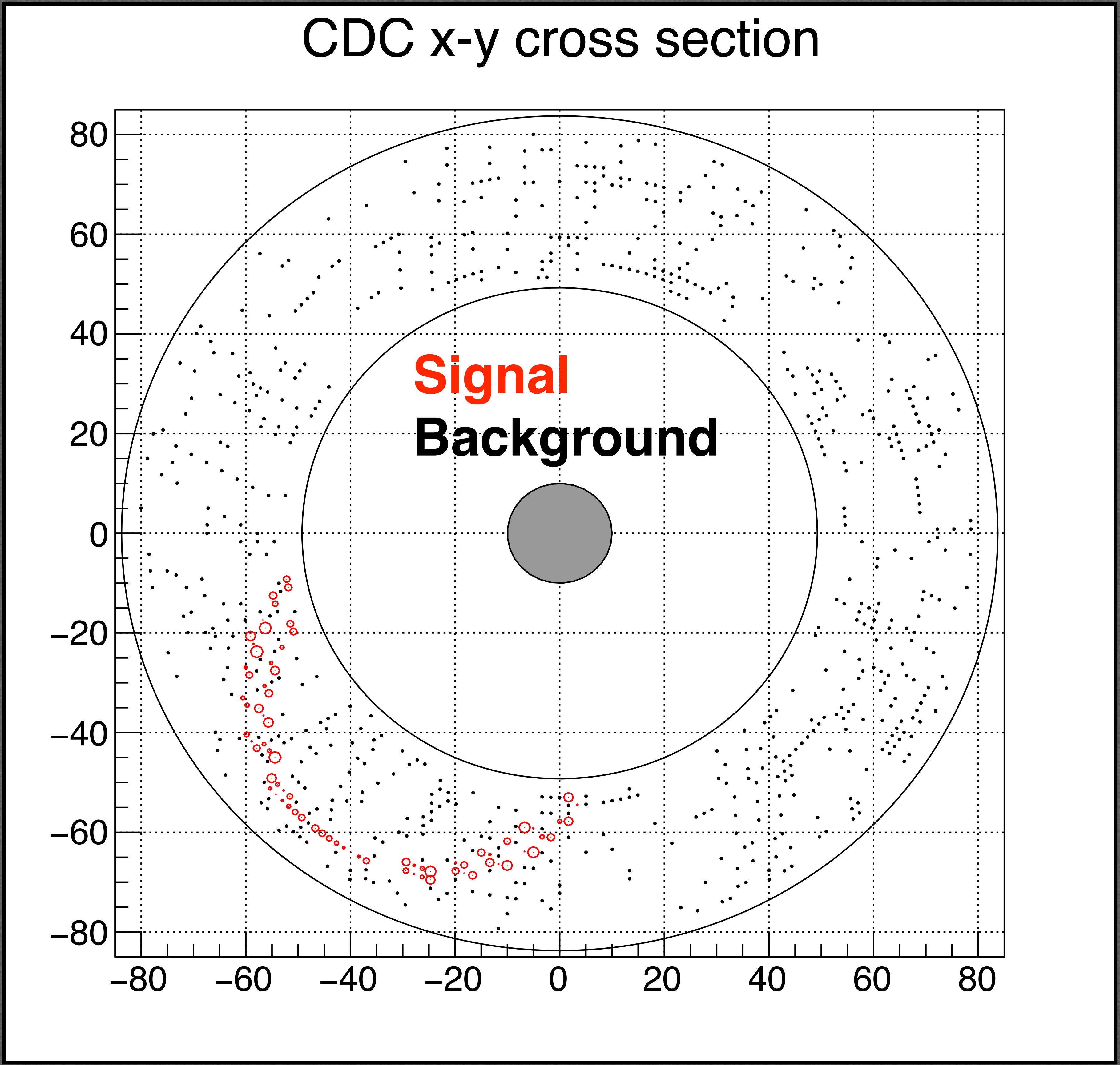
Event generation

- Simlutaion tool kit: Geant4
- Root format: signal. 160513.root, produced by one of our member
- Simulated events 1.0 x 10^4 signal events + noises from beam flash

$E_{\mu^- e^-}$ = 104.97 MeV



Cylindrical Detector system (CyDet)



- # of tracks?
- Charge?
- Momentum?
- Turn?
- Noise/Signal?
- Should we trigger this event?

Track finding — Motivation and goal

- Development of a online/offline track finding algorithm for COMET CyDet system.
- Goal on track finding
    - Hit filtering and signal classification using TMVA
    - Identification of track parameters
        - Momentum (P_T, P_L)
        - Charge (e^+? e^-?)
        - Number of turns
        - Initial value for track fitting using Hough + TMVA

* Framework dedicated for COMET simulation and data analysis

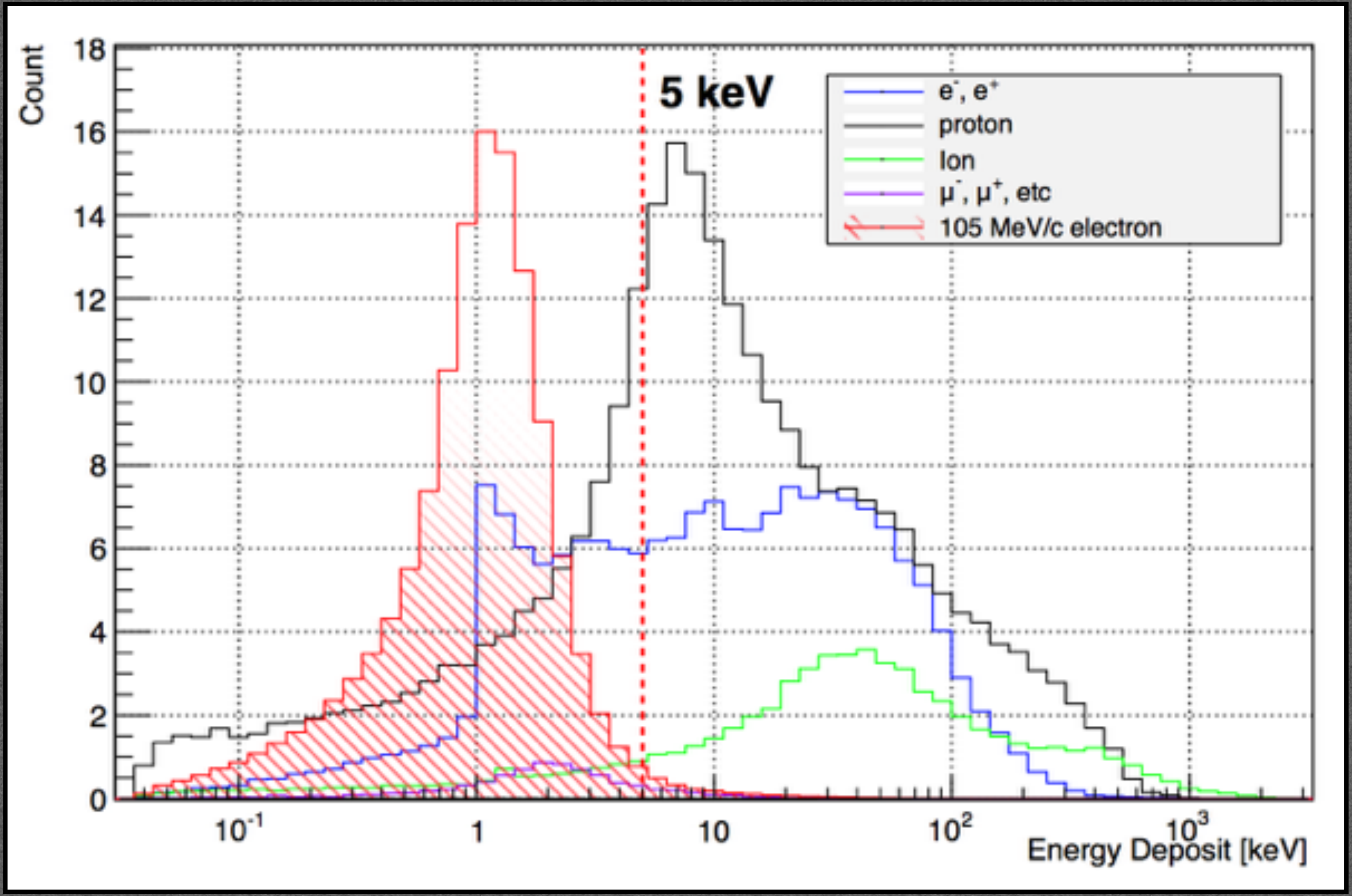
Track finding — Procedure

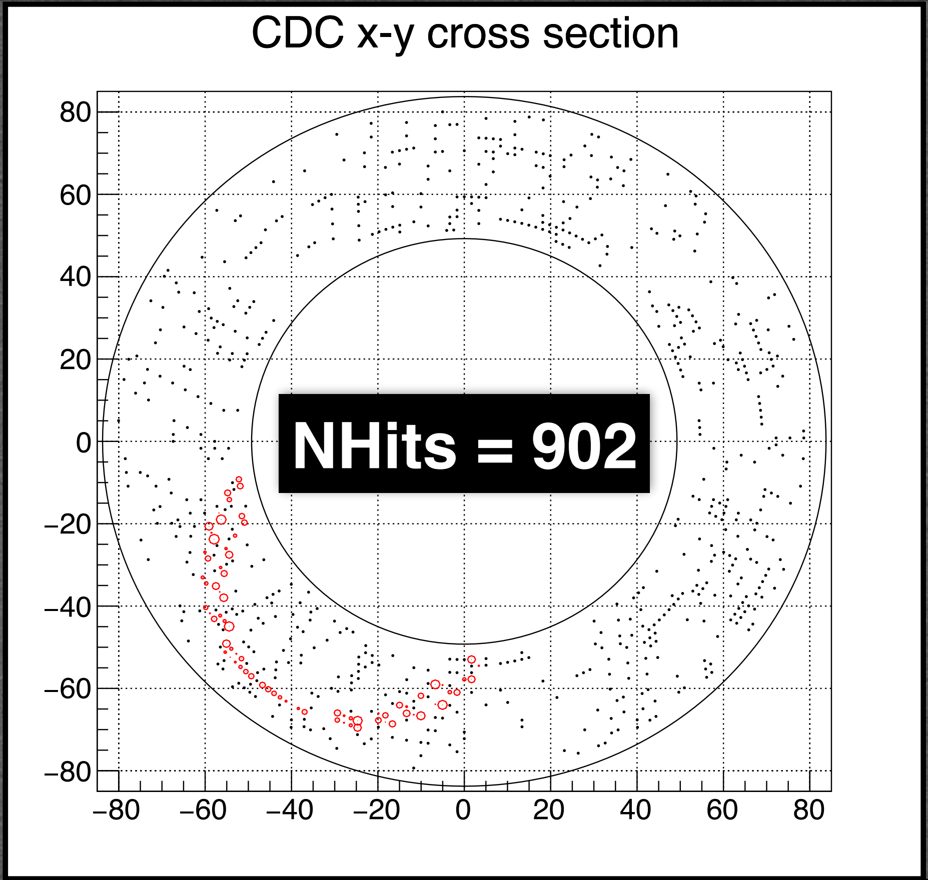
Completeness

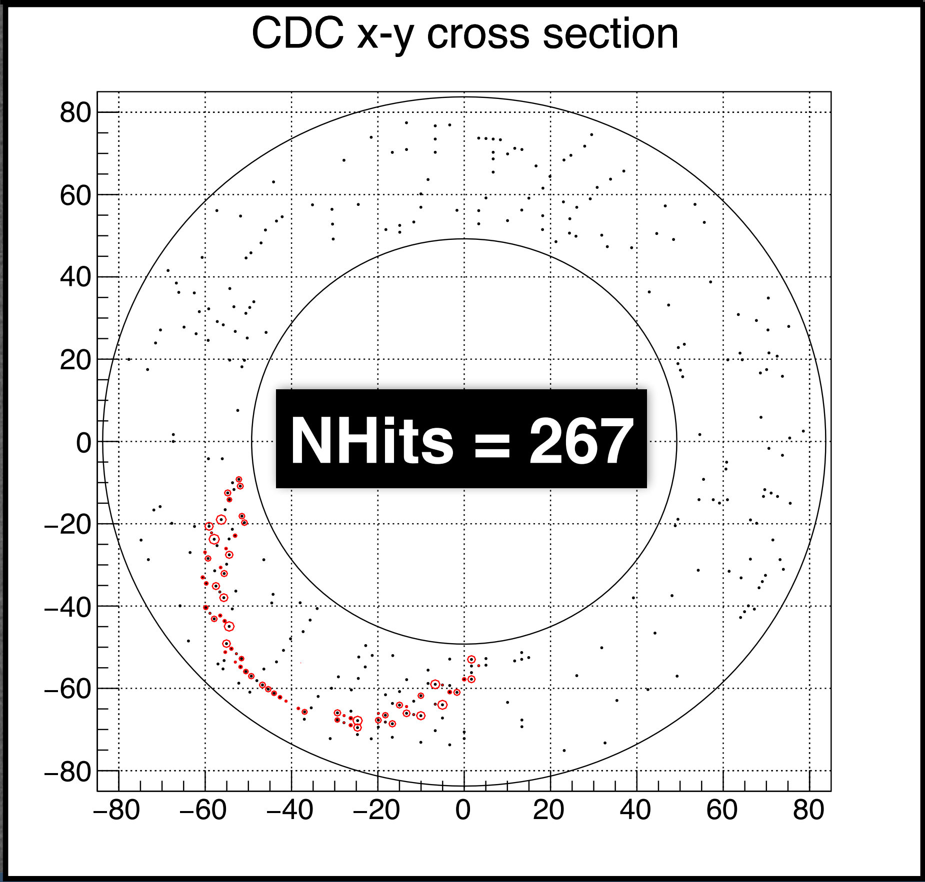
- Read raw hits
- Energy-deposition + trigger timing cut
- Collect cross point of 2 hit stereo-wires
- Conformal mapping
- 2D Hough transformation
- 2D circle Refinement
- 2D Refinement with DriftD information
- RANSAC algorithm
- Helix refinement
- Make tracks with all predictions

Track finding — ED + Timing

- **Energy deposition** on CDC **cut** was set at **5keV**, basically most of the proton, ions and pair production hits are cut out
- Timing cut is after trigger having hits







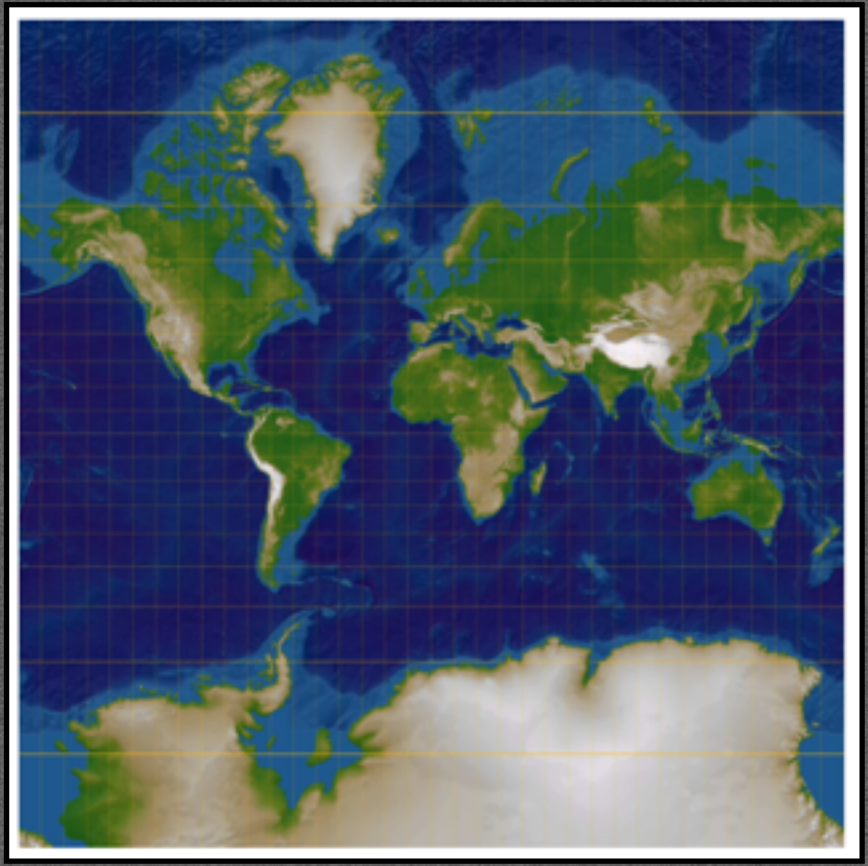
Track finding — Conformal mapping

- We can take the frame at centre of CDC, and assume the track always comes out from the centre

$$(\boldsymbol{x}-\boldsymbol{a})^2+(\boldsymbol{y}-\boldsymbol{b})^2=\boldsymbol{a}^2+\boldsymbol{b}^2$$

- Conformal transformation changes the axis like this

$$\left(u=\frac{x}{x^2+y^2}, v=\frac{y}{x^2+y^2}\right)$$

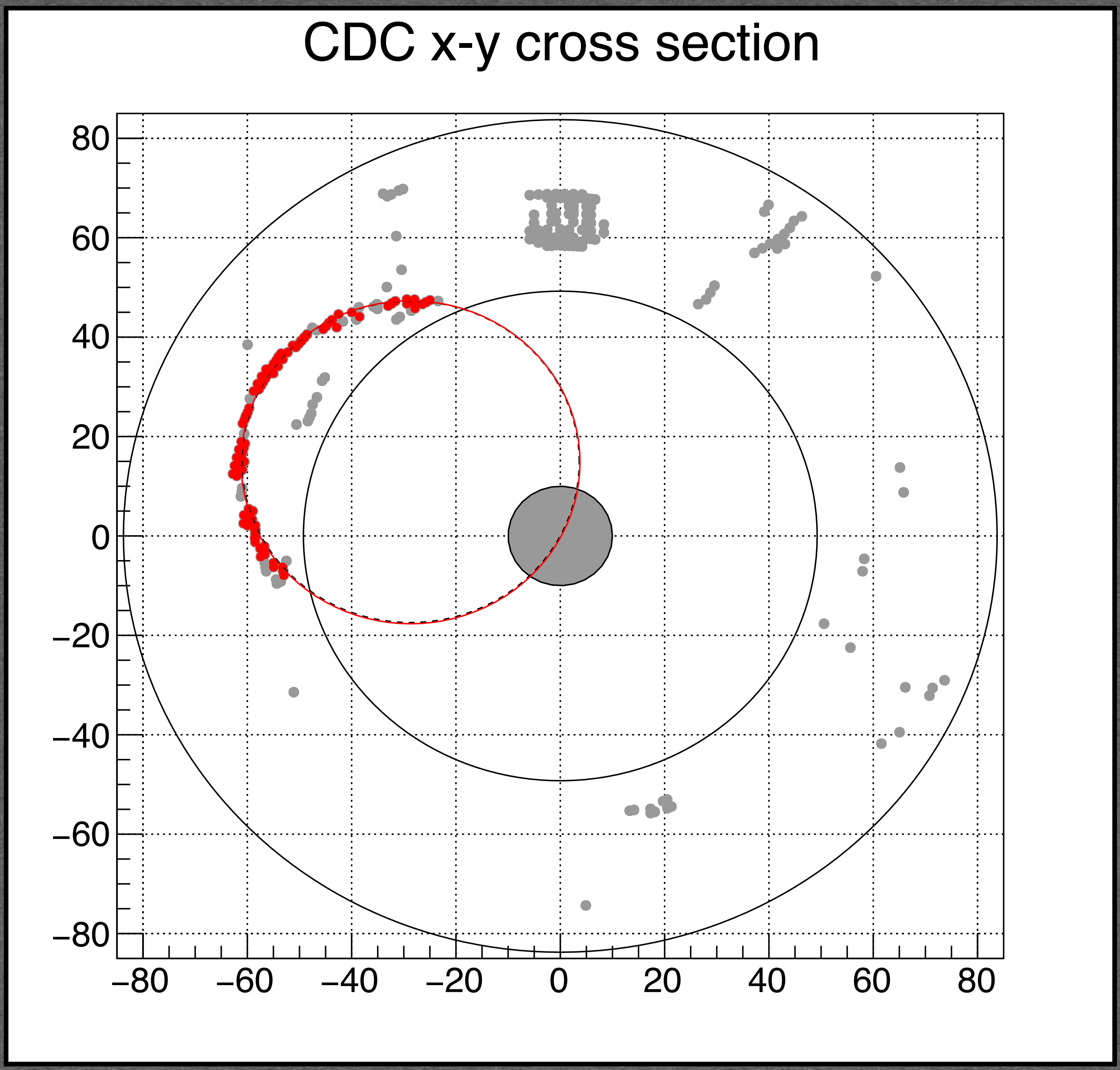


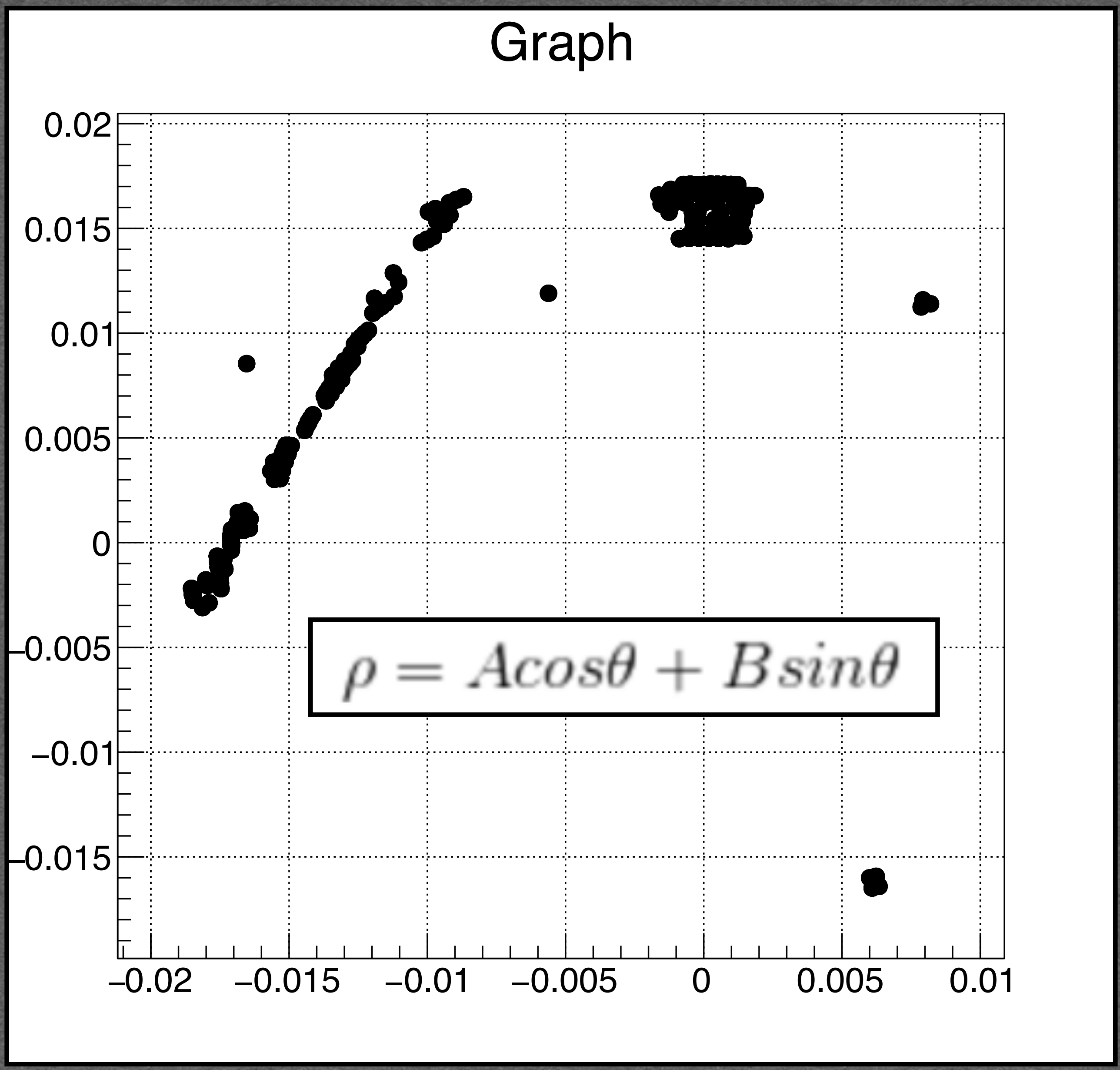
- Mapping a circular object (passing through origin) → Straight line!
- Very useful techniques for Hough transformation

$$(x-a)^2+(y-b)^2=a^2+b^2 \rightarrow \boldsymbol{v}=-\frac{\boldsymbol{a}}{\boldsymbol{b}}\boldsymbol{u}-\frac{\boldsymbol{1}}{\boldsymbol{2b}}$$

Track finding — Conformal mapping (cont.)

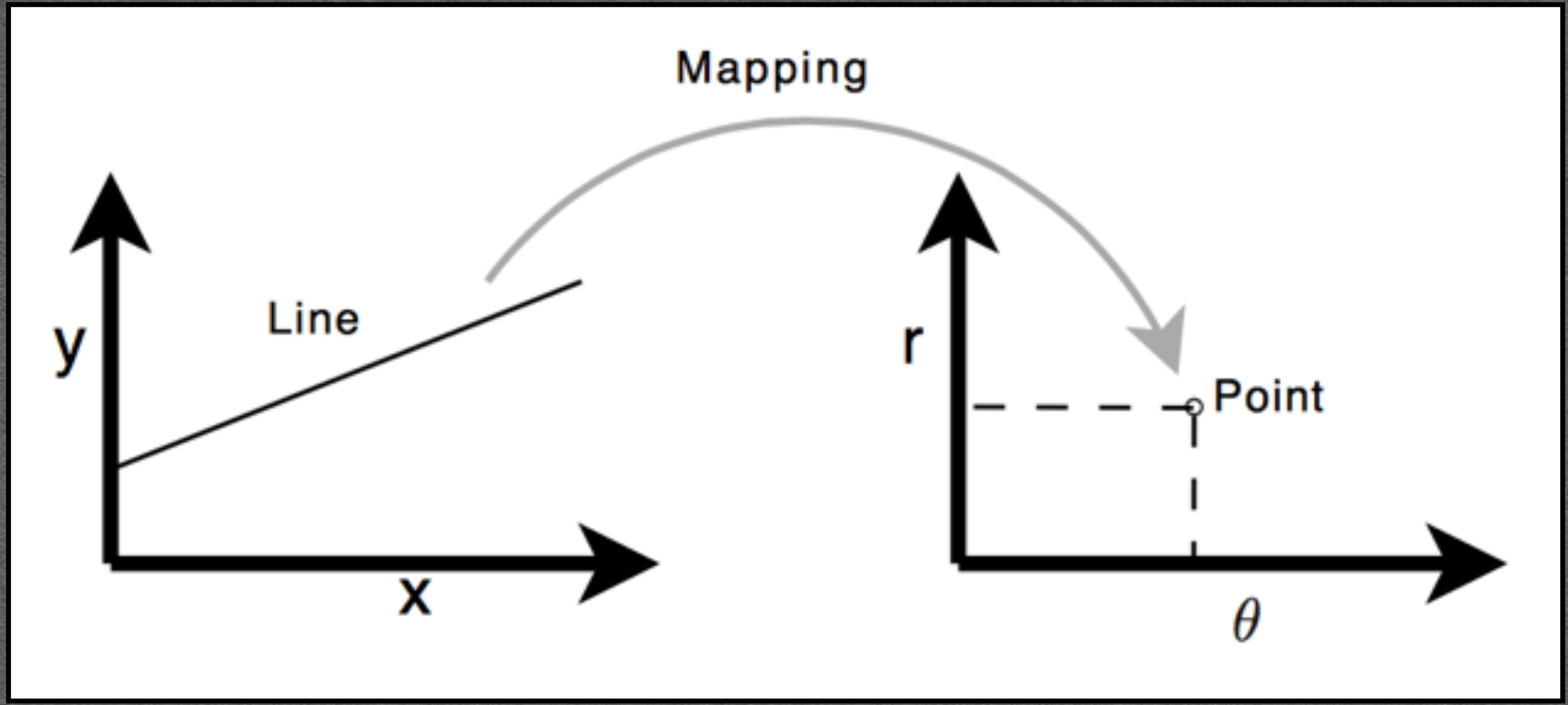
- With the help of conformal mapping, we are able to do hough transformation in a straight line !

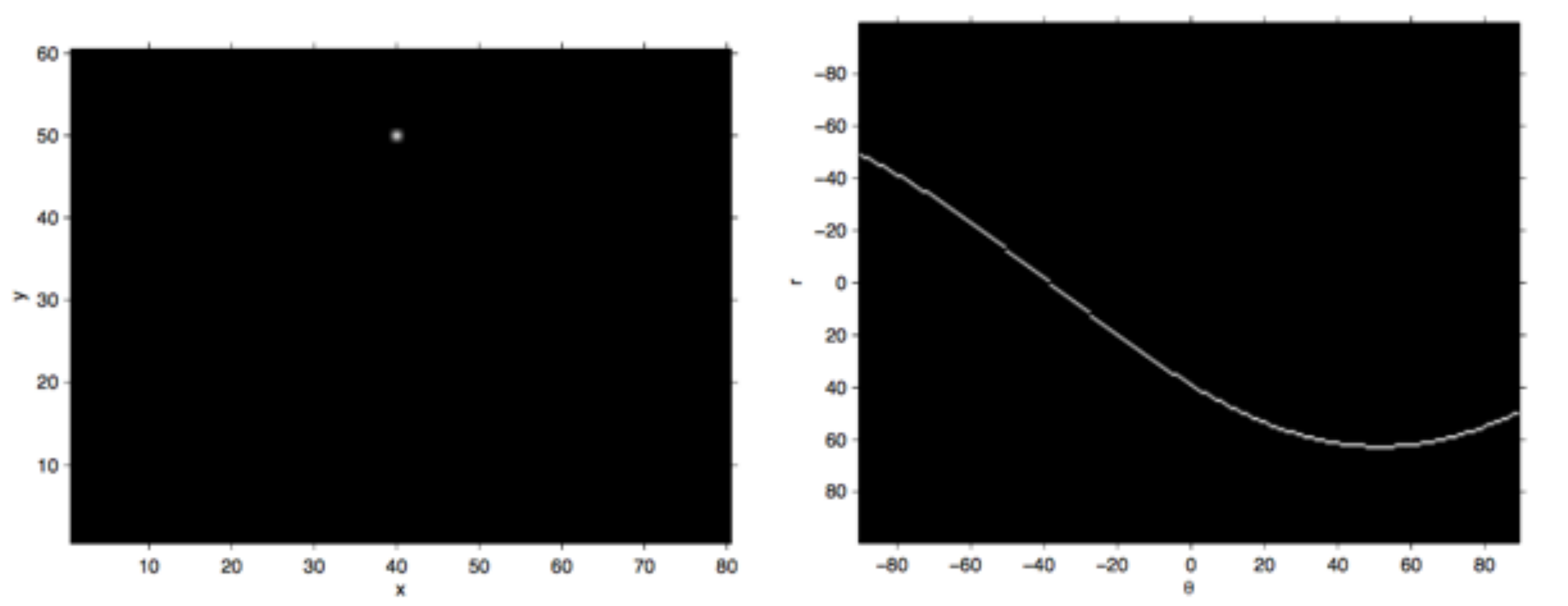




→ **Mapping!!**

Track finding — Hough transformation

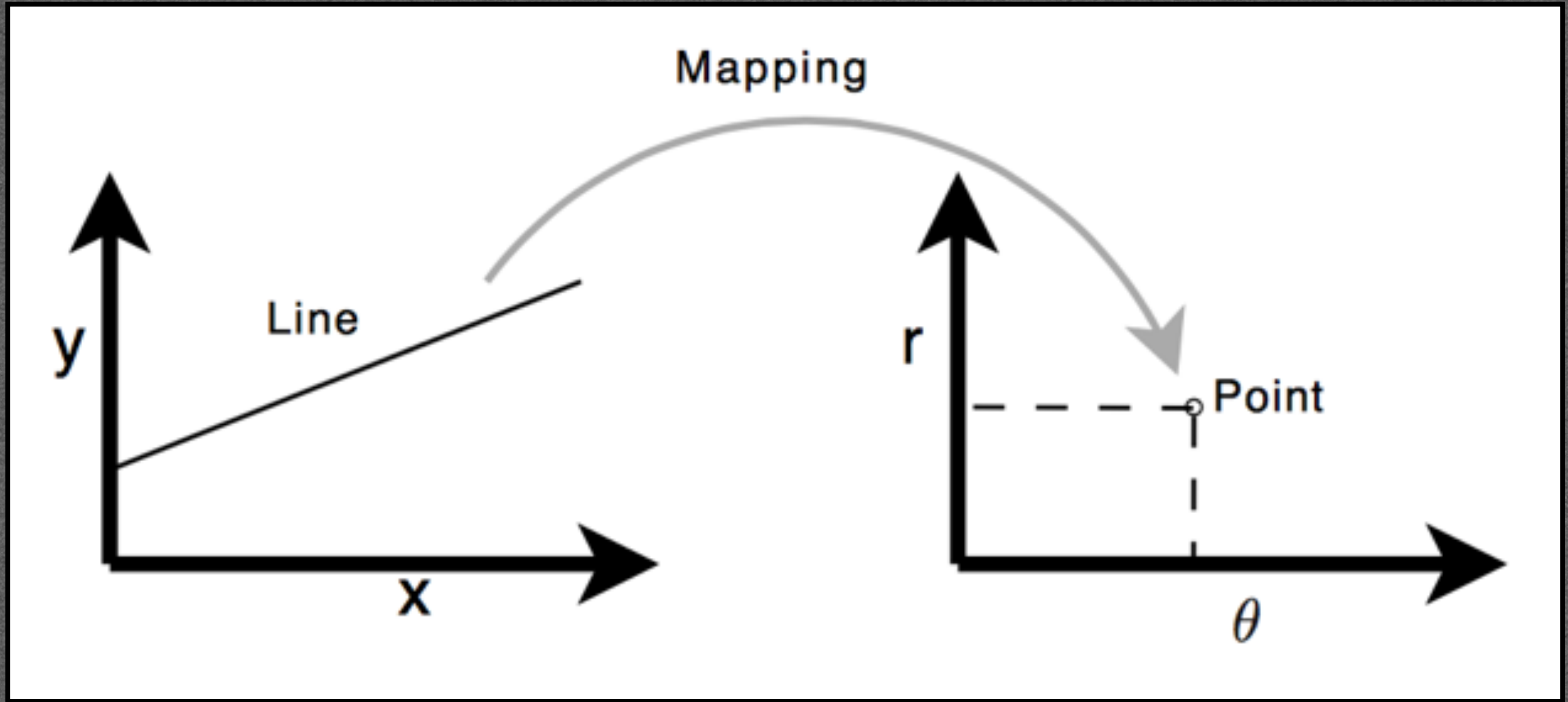


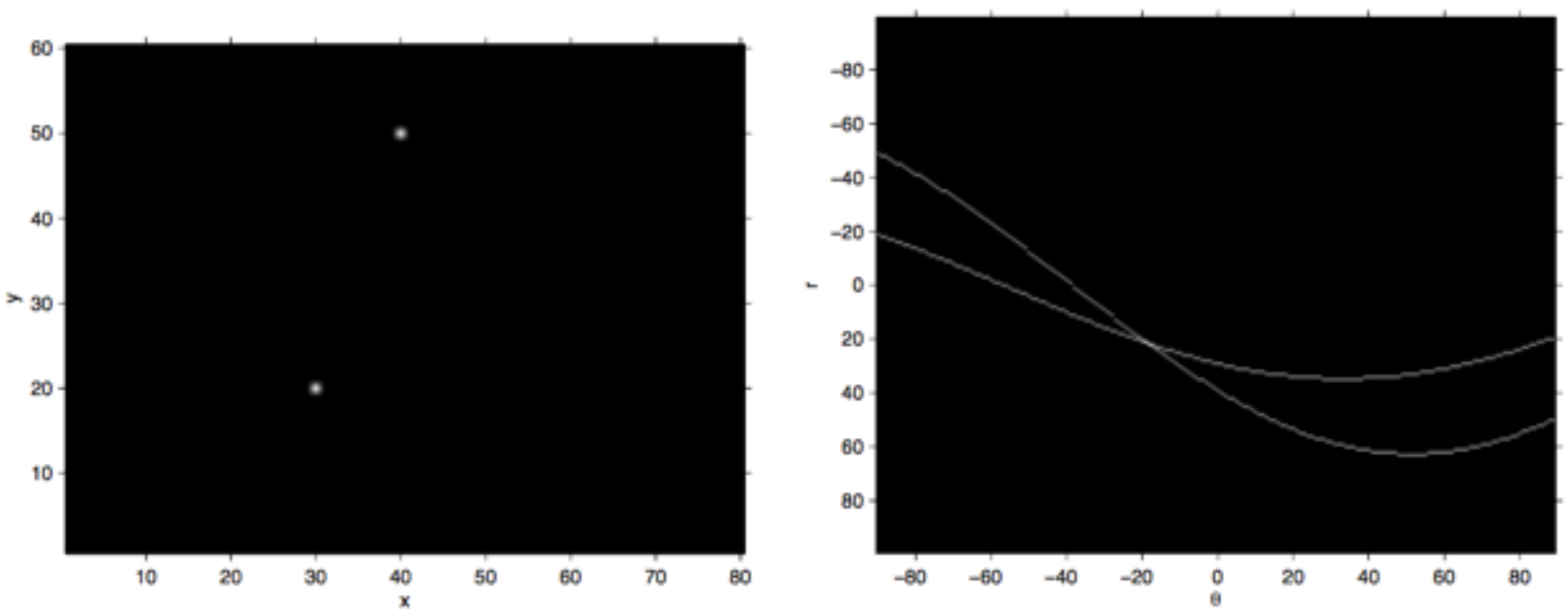


(a) Point p_0.

(b) All possible lines through p_0 represented in the Hough space.

Track finding — Hough transformation





(a) Points p_0 and p_1.

(b) All possible lines through p_0 and/or p_1 represented in the Hough space.

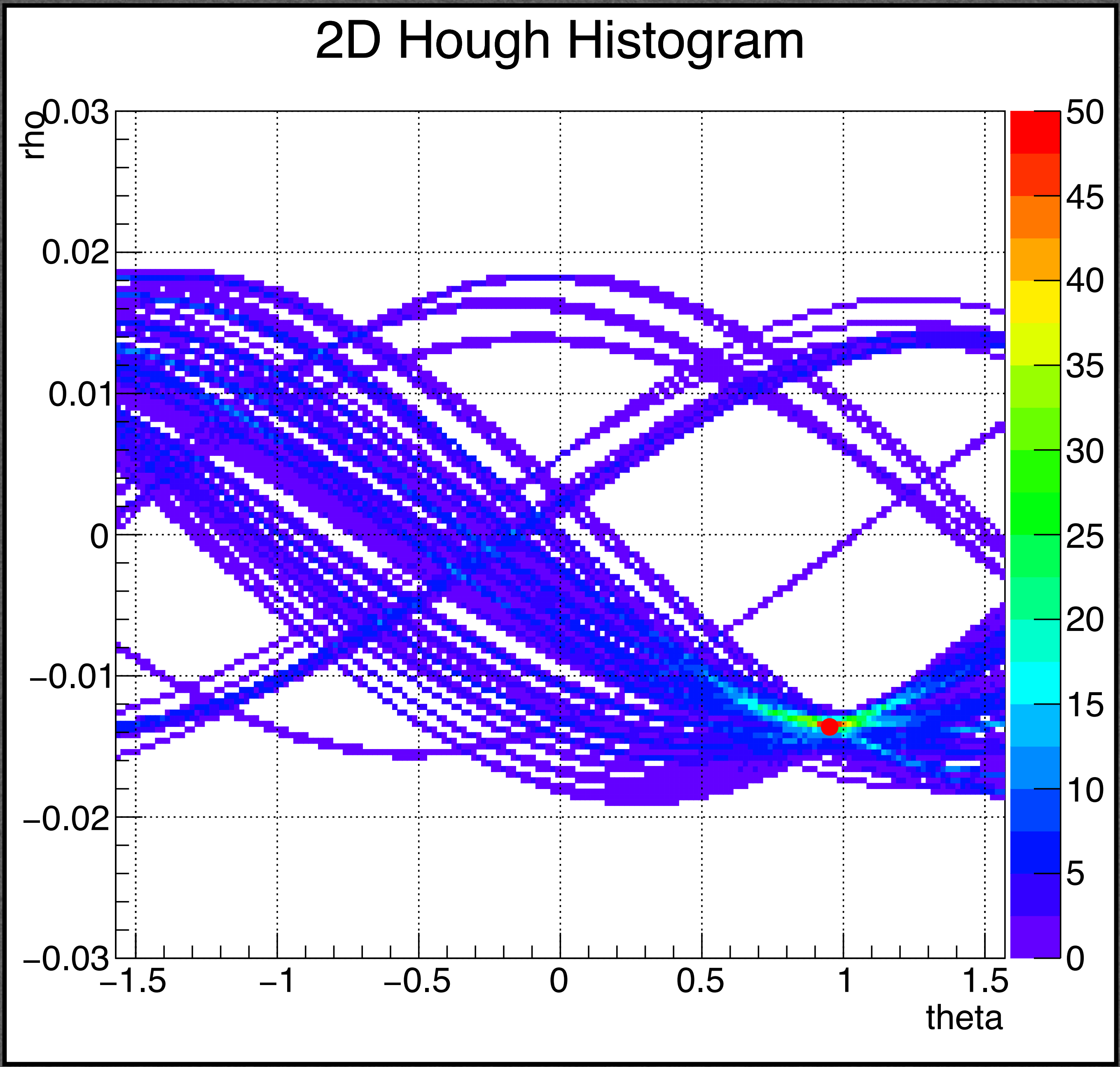
Track finding — Hough transformation

- With the help of conformal mapping, we are able to do hough transformation in a straight line !

$$v_i = -\frac{a}{b}u_i - \frac{1}{2b} \rightarrow \boldsymbol{\rho} = \boldsymbol{u_i}\cos(\boldsymbol{\theta}) + \boldsymbol{v_i}\sin(\boldsymbol{\theta}) \;\; for\ i = 1, \dots, N$$

- But in reality, the track may not be completely circular (Depending on magnetic field line)

- Peak search algorithm should be improved, for now I am choosing the hough peaks which are higher than 80% of the highest peak

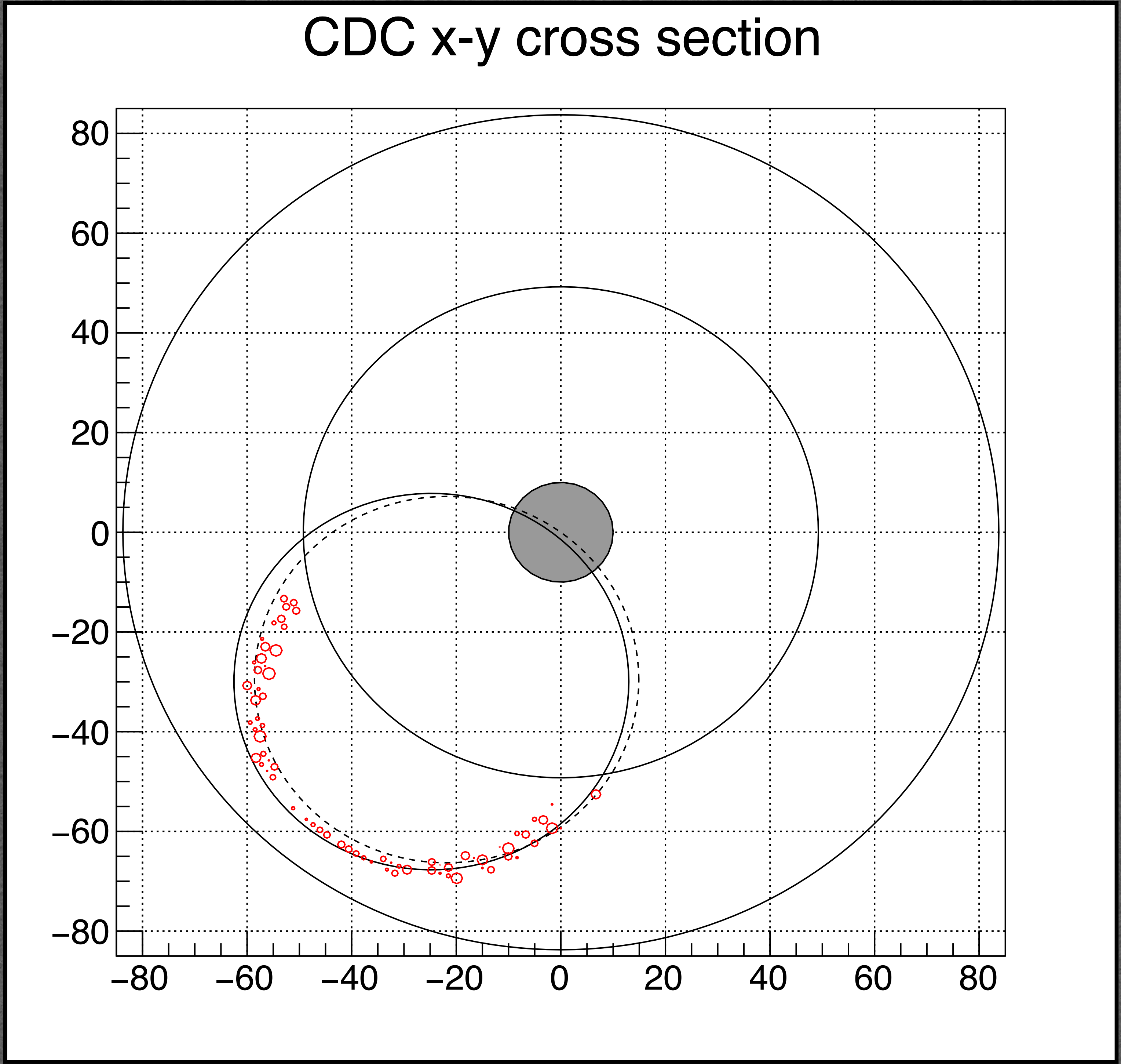


Track finding — Refinement of circles

- Assumption : Not always at the centre, because our Al stopping target disks is 10 cm

- Refinement is first performed by calculating the shortest distance between the wire projected in x-y plane and hough circle.

- This is just a rough estimation of circle. But this is not correct….apparently the result is bad…

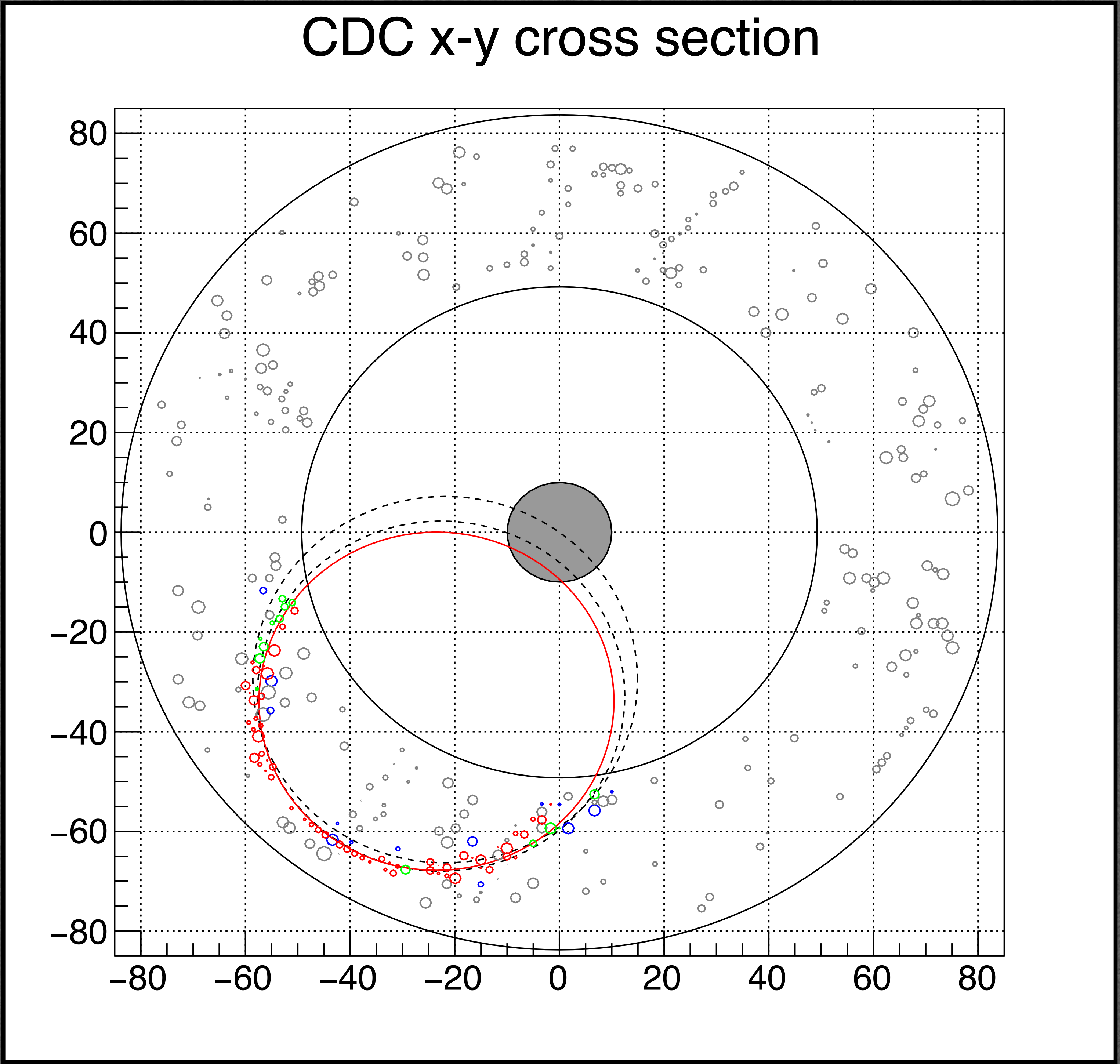


Track finding — Refinement using TMinuit

- Calculating the distance directly using drift distance and minimise it iteratively
- Around 3 times, the "Chi2" does not change anymore
- There are many hits miss recognised, but this is okay!
- This is just a rough estimation.

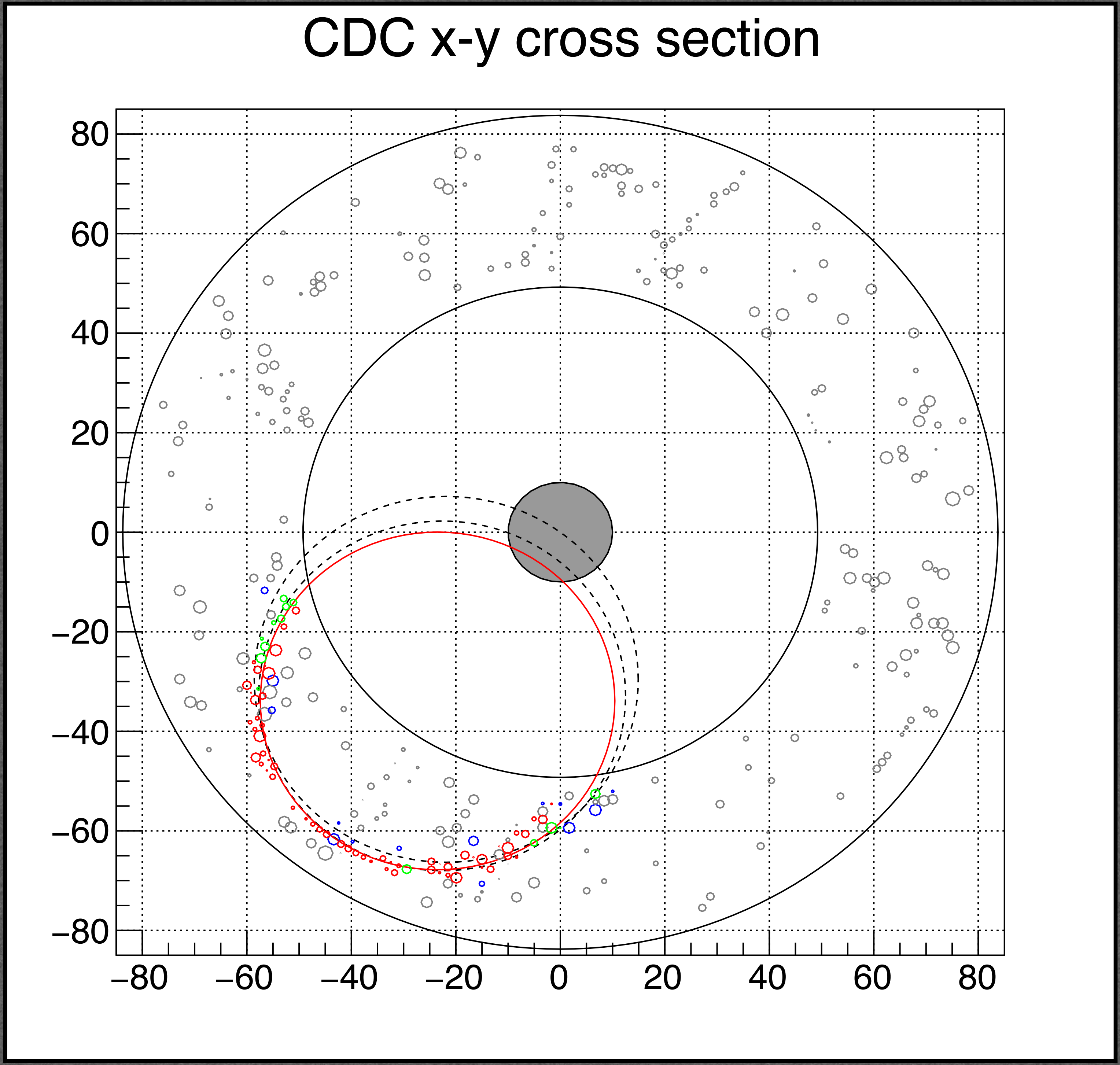
Convention

- not selected but signal (green)
- selected but not signal (blue)
- selected signal (red)
- noise (grey)



Track finding — Consideration of band

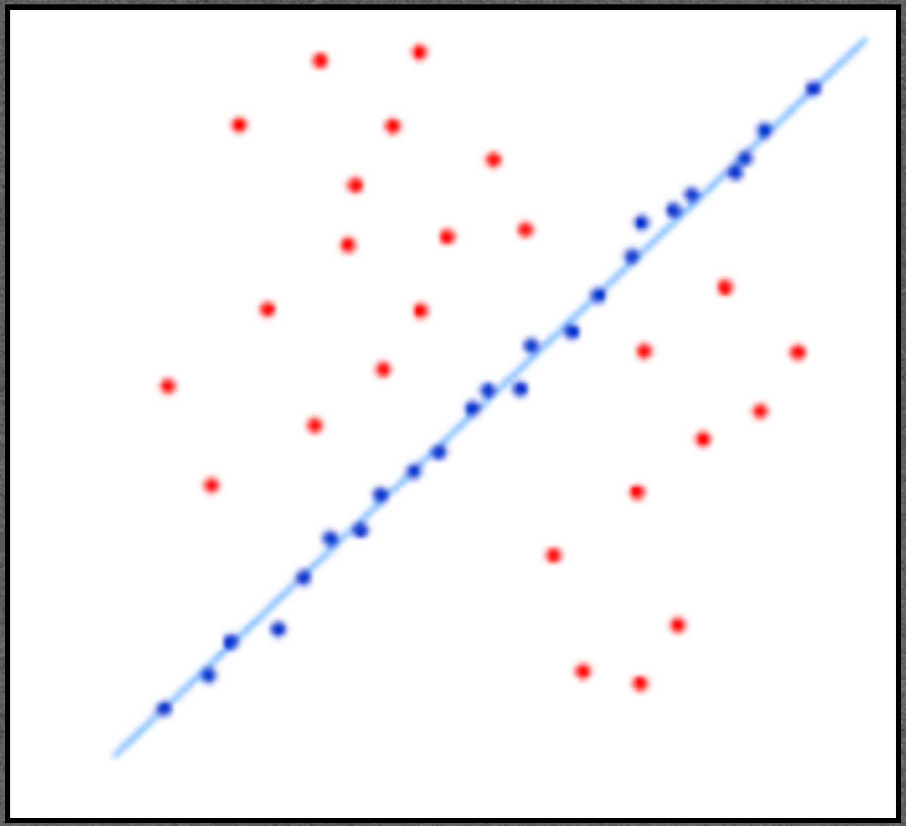
- For now I considered hits with in 2 cm is left, but we cannot consider too big band width, since noise will be included



Track finding — RANSAC

- **RAN**dom **SA**mple Consensus (**RANSAC**) is an iterative method to estimate parameters of a mathematical model from a set of observed data that contains outliers, when outliers are to be accorded no influence on the values of the estimates.

- Idea summarise:
  - ➡ Pick up data points (Minimum required DOF)
  - ➡ Minimising the χ^2 of those picked up data points by fitting
  - ➡ Find out number of points (N_{true}) that is closed to the sample
  - ➡ Maximise N_{true}
  - ➡ Iterate certain times (can be dynamics) to obtained the minimum chi2
  - ➡ Pick up the minimum χ^2 with maximum N_{true}

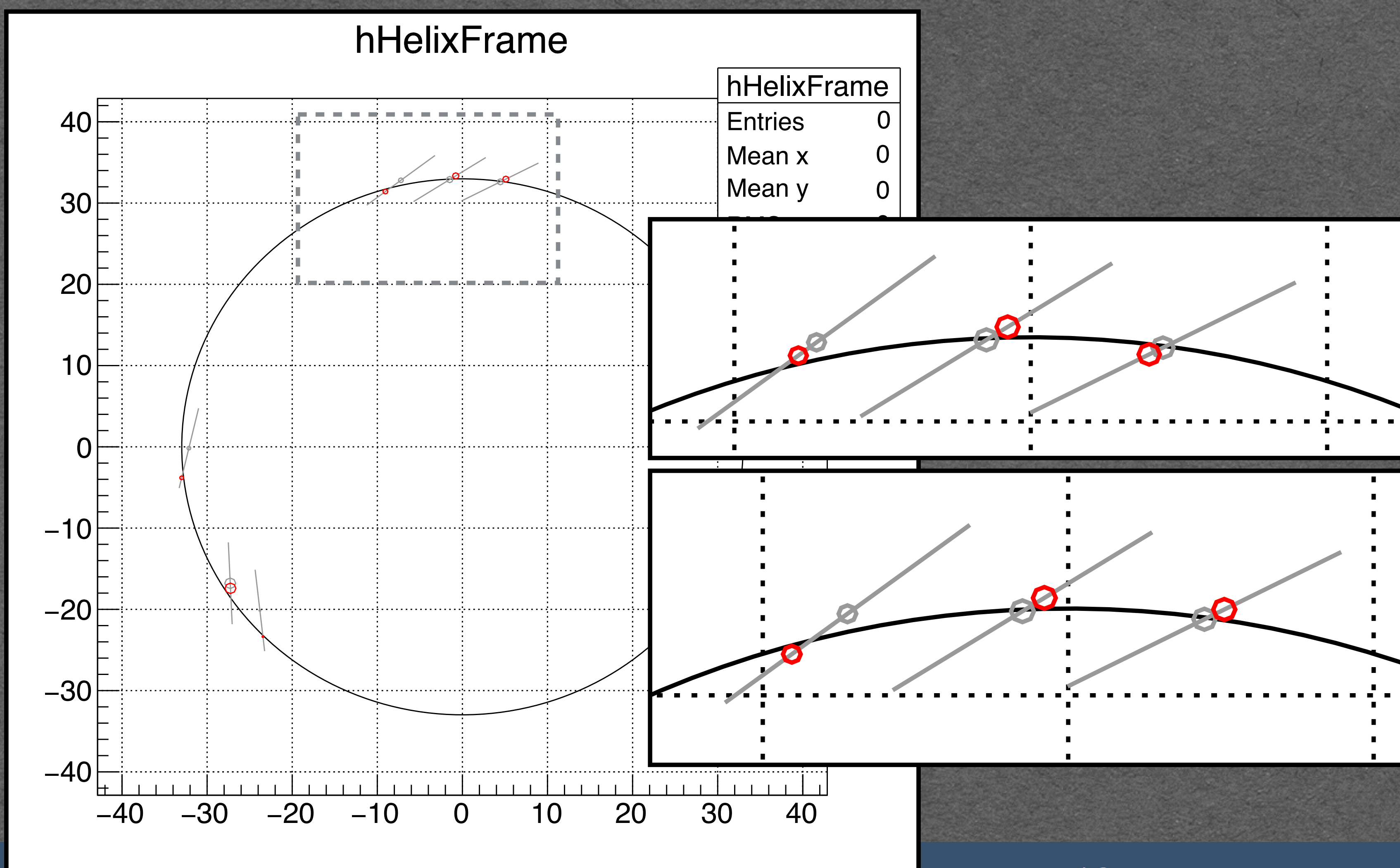


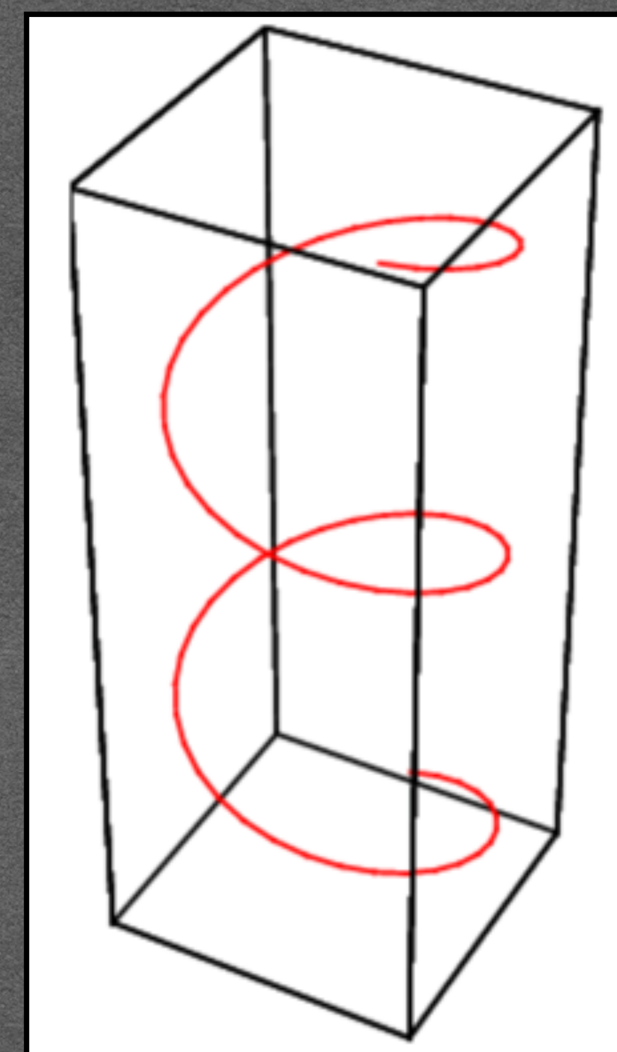
Track finding — RANSAC in CDC

- In CDC similar things can be done
- One should consider the left right ambiguity carefully, since you only limited hits
- In total you can have 2^N, where N is number sampling
- Helix fitting → DOF = 5

- Helix equation:

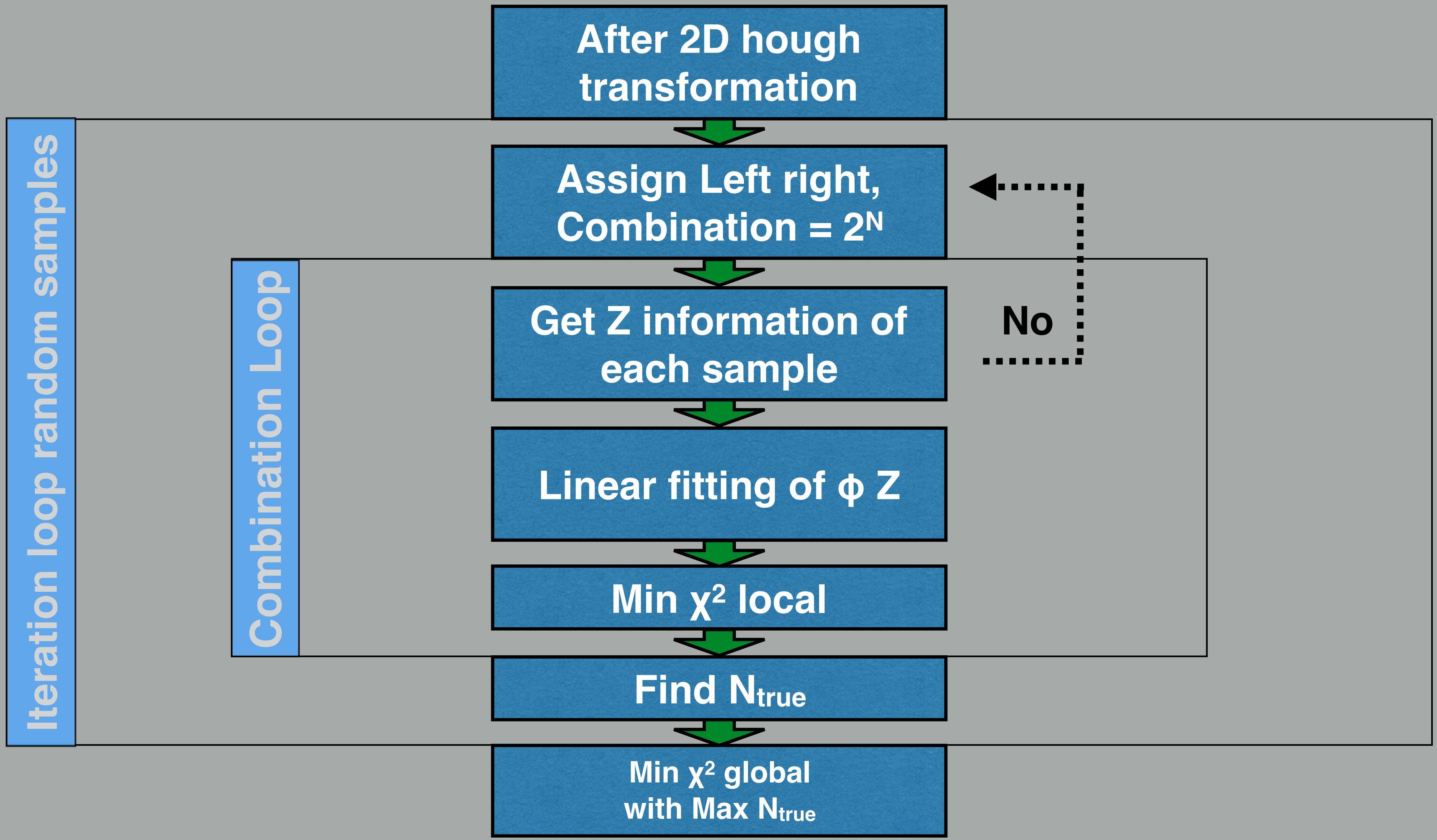
$$x - x_0 = r cos(\phi - \phi_0);$$
$$y - y_0 = r sin(\phi - \phi_0);$$
$$z - z_0 = slope * (\phi - \phi_0);$$





Track finding — RANSAC in CDC

RANSAC algorithm in CDC



To dos

- Optimized RANSAC
- Single and multiple track finding
- Prediction of charge
- Prediction of turns
- Prediction of momentum (direction)
- Prediction of initial helix track parameters for track fitting

Questions
Comments

Backup

Track finding — Neural network

- Developed by one of our M2 student, he's graduated already
- Basic idea is to minimise a Energy function

$$E = -\frac{1}{2}\left[\sum_{kln} T_{kln} V_{kl} V_{ln} - \alpha \left(\sum_{kln(n \neq l)} V_{kl} V_{kn} + \sum_{klm(m \neq k)} V_{kl} V_{ml} \right)\right]$$

$$T_{kln} = \frac{\cos^{\lambda}(|\theta| - \theta_T)}{d_{kl} + d_{ln}}$$