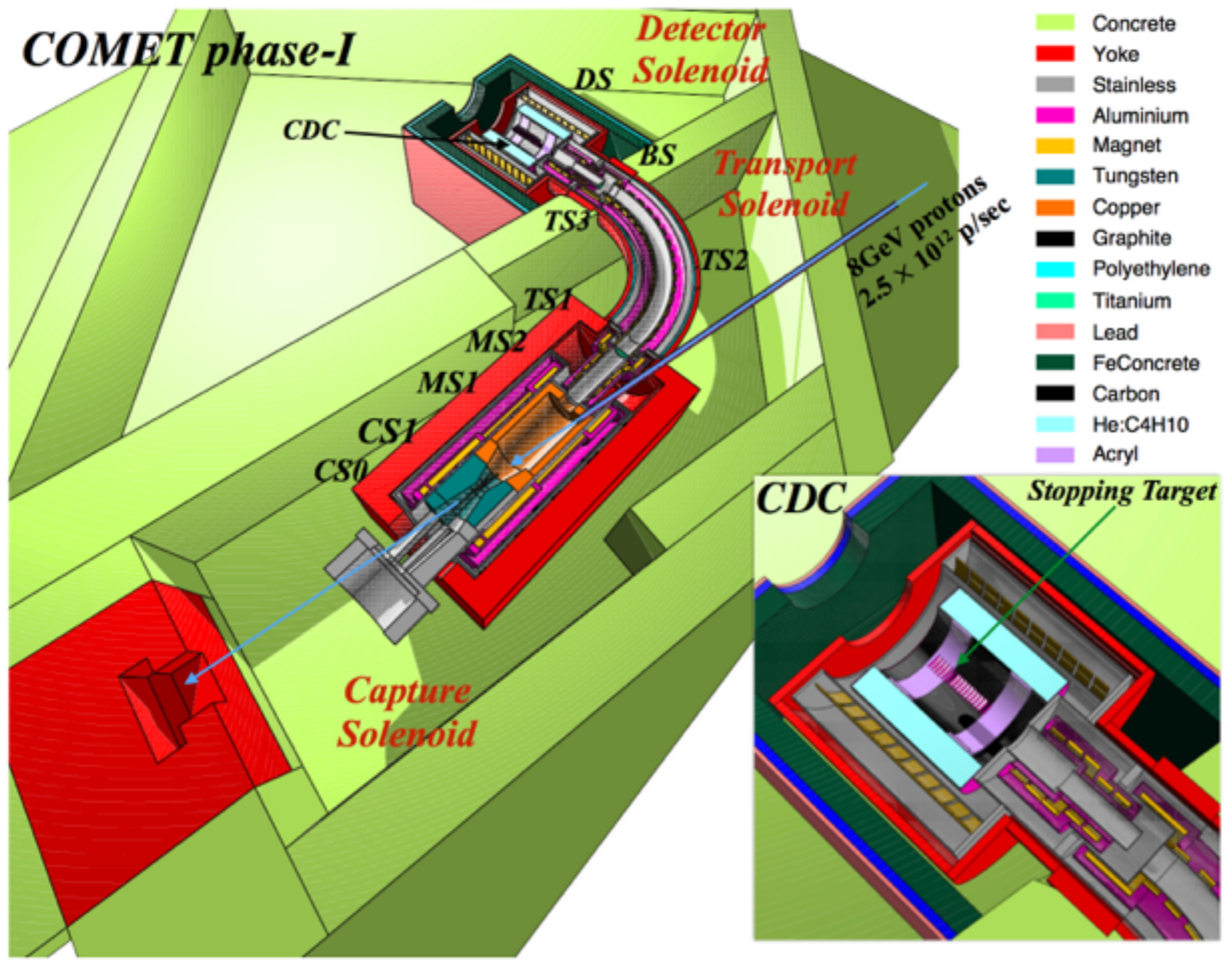
Studies of Cylindrical Drift Chamber for COMET Phase-I



Speaker: TingSam Wong

大阪大学 OSAKA UNIVERSITY

ICEPP 東京大学 素粒子物理国際研究センター International Center for Elementary Particle Physics

Outline

- Introduction
- Studies related to CDC
- Software studies — Track reconstruction
- Future prospect
- Summary

COMET Physics motivation

Physics — charged Lepton Flavour Violation

Signal:

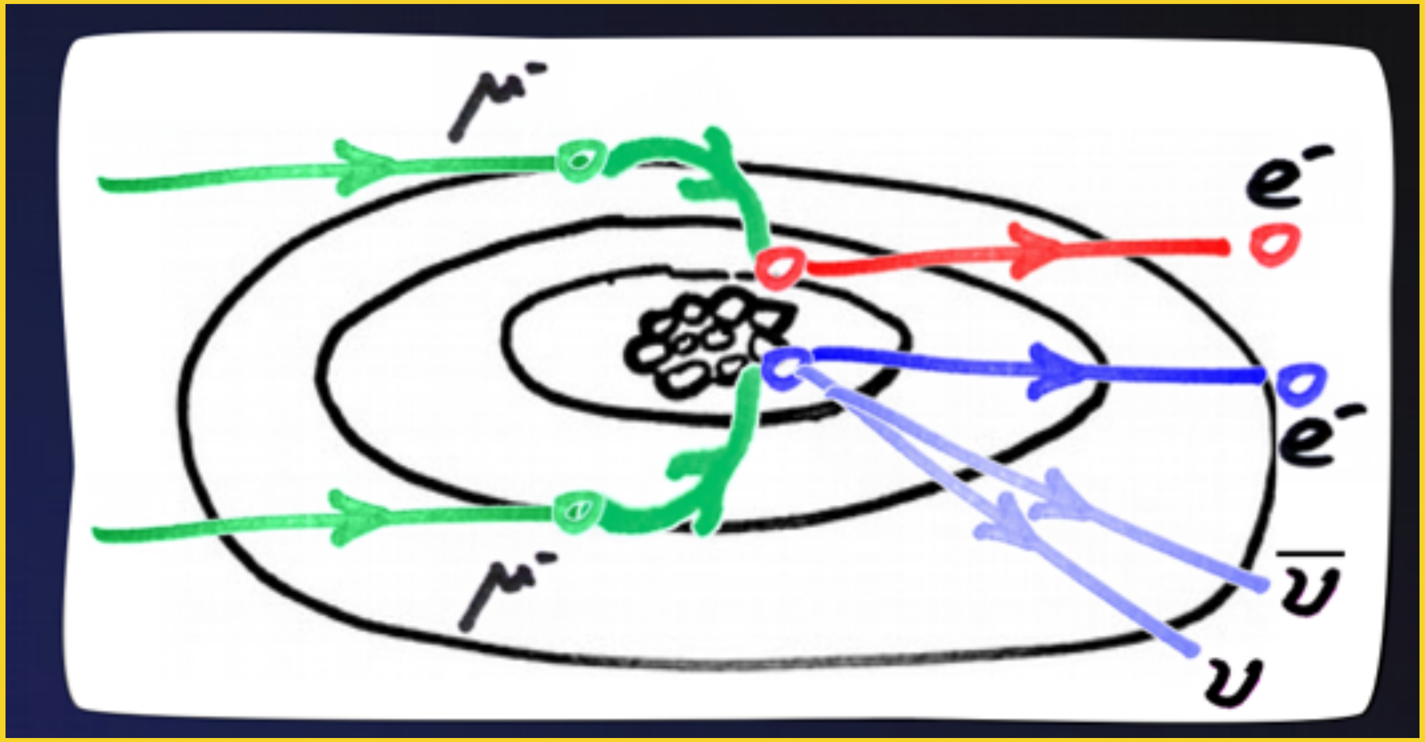
$\mu^- + Al \rightarrow e^- + Al$ (μ-e conversion in Al)

$$E_e = m_\mu - B_\mu - E_{recoil}$$

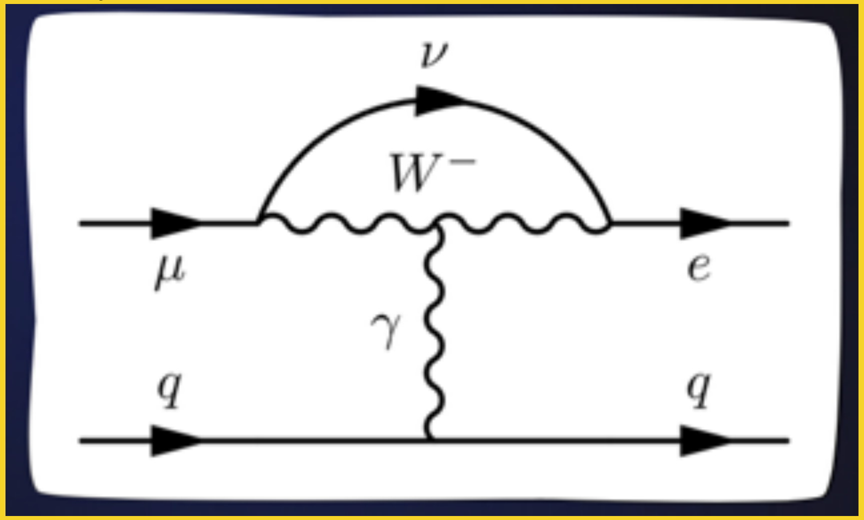
- **With Al target → 105MeV Mono-enegetic**

Background:

$\mu^- + Al \rightarrow e^- + \nu_\mu + \overline{\nu}_e + Al$ (Decay-In-Orbit)

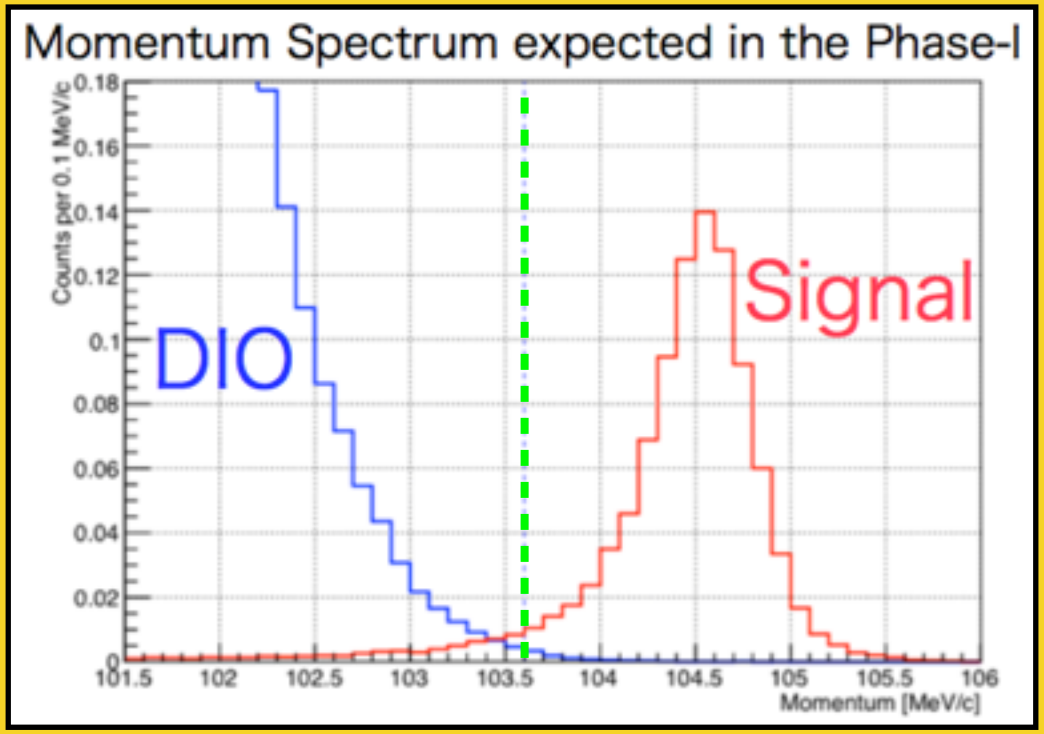


μ - e conversion

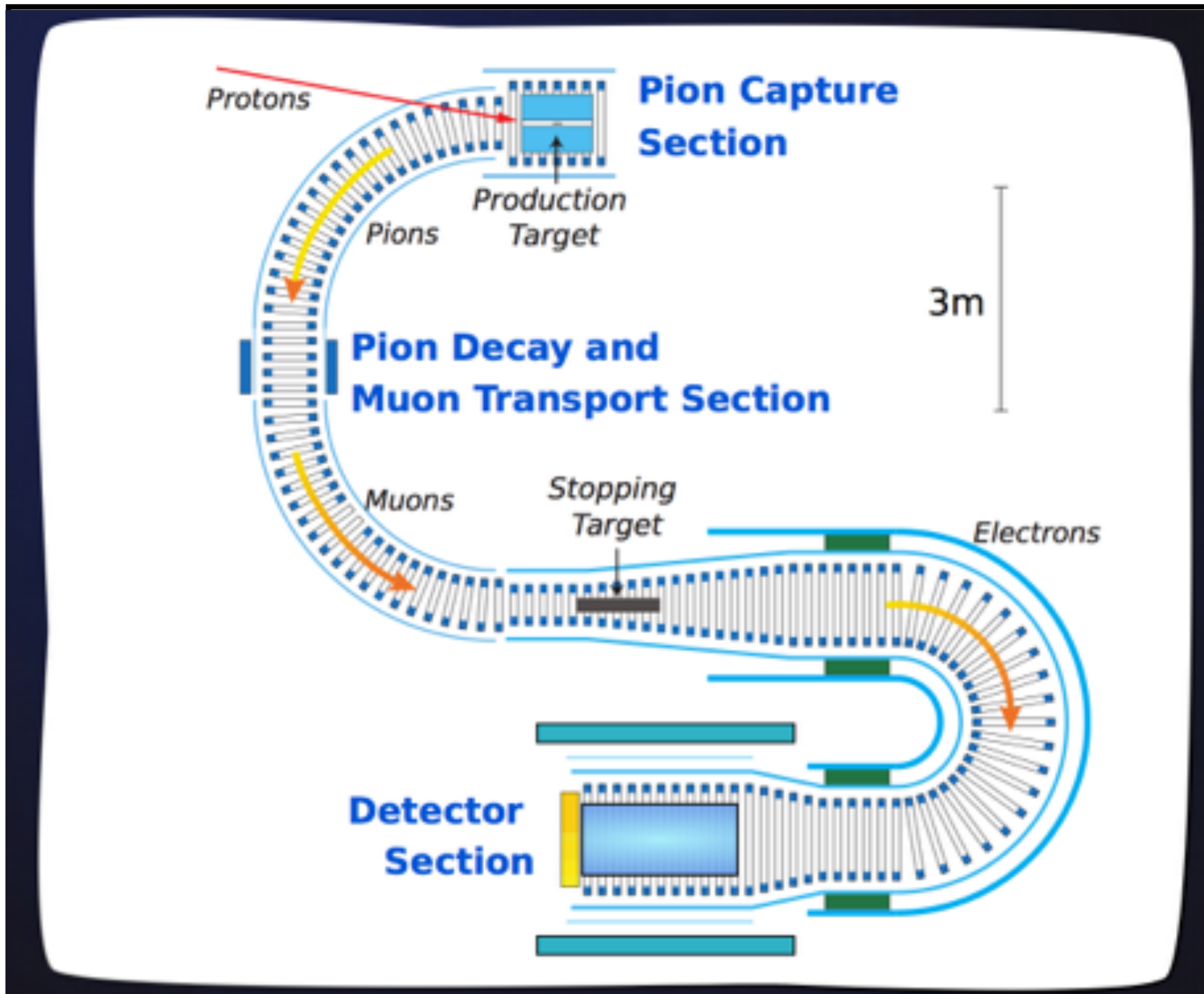


R < O(10^{-15})

Simulation studies



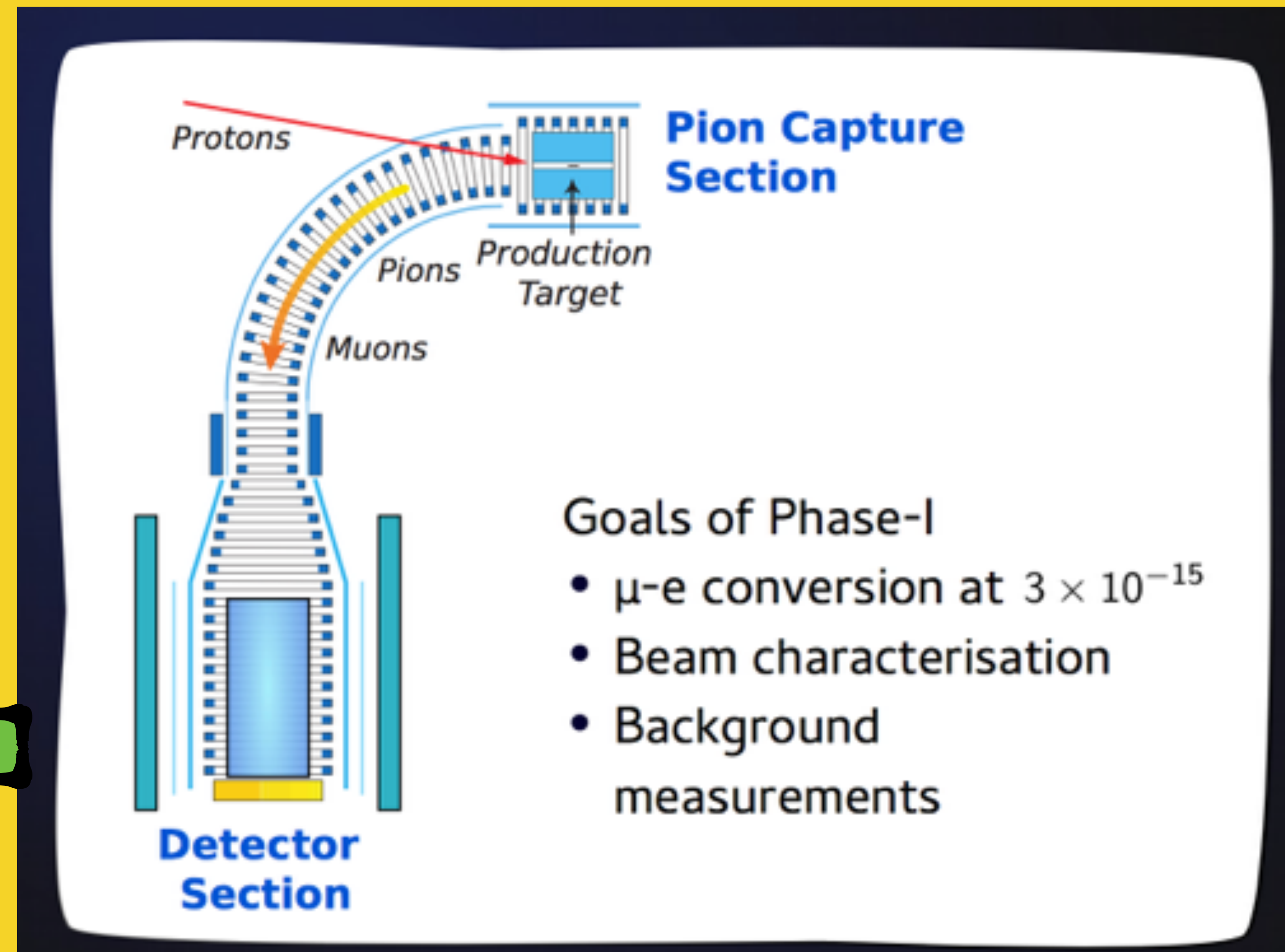
COMET



Staged approach

Phase-II

Sensitivity: 2.6 x 10^{-17}

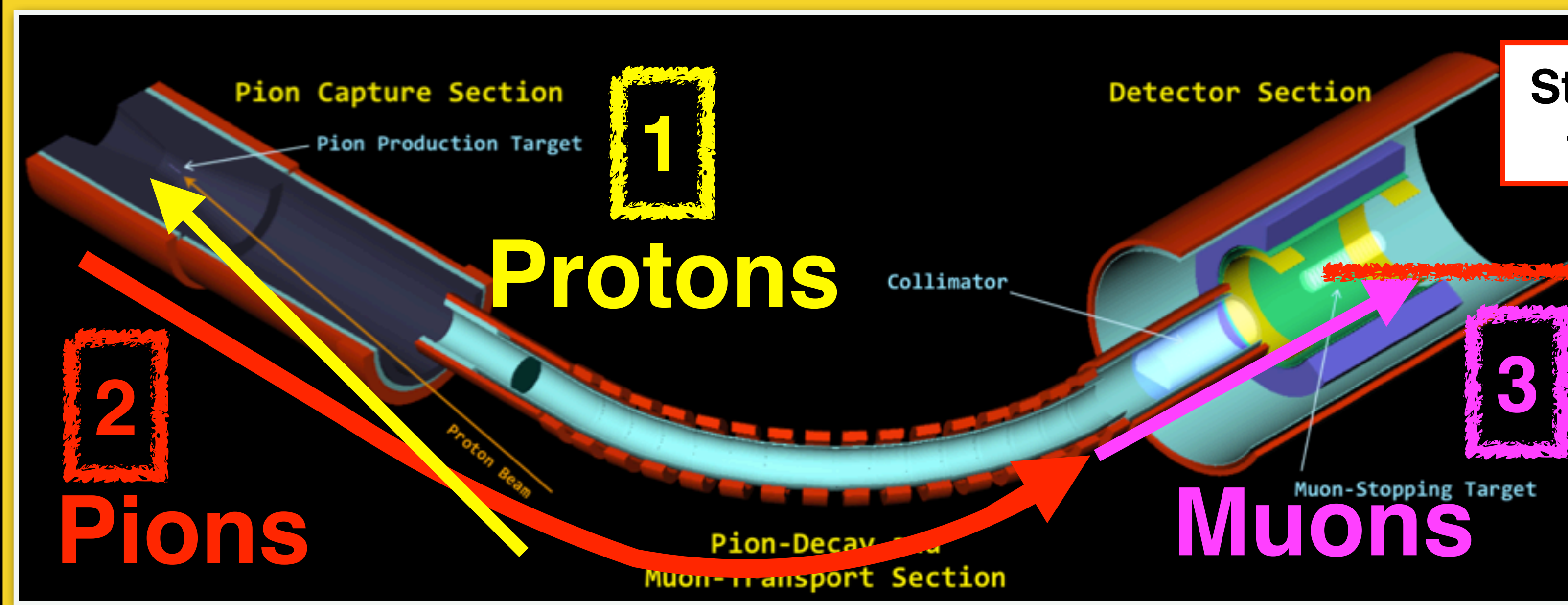


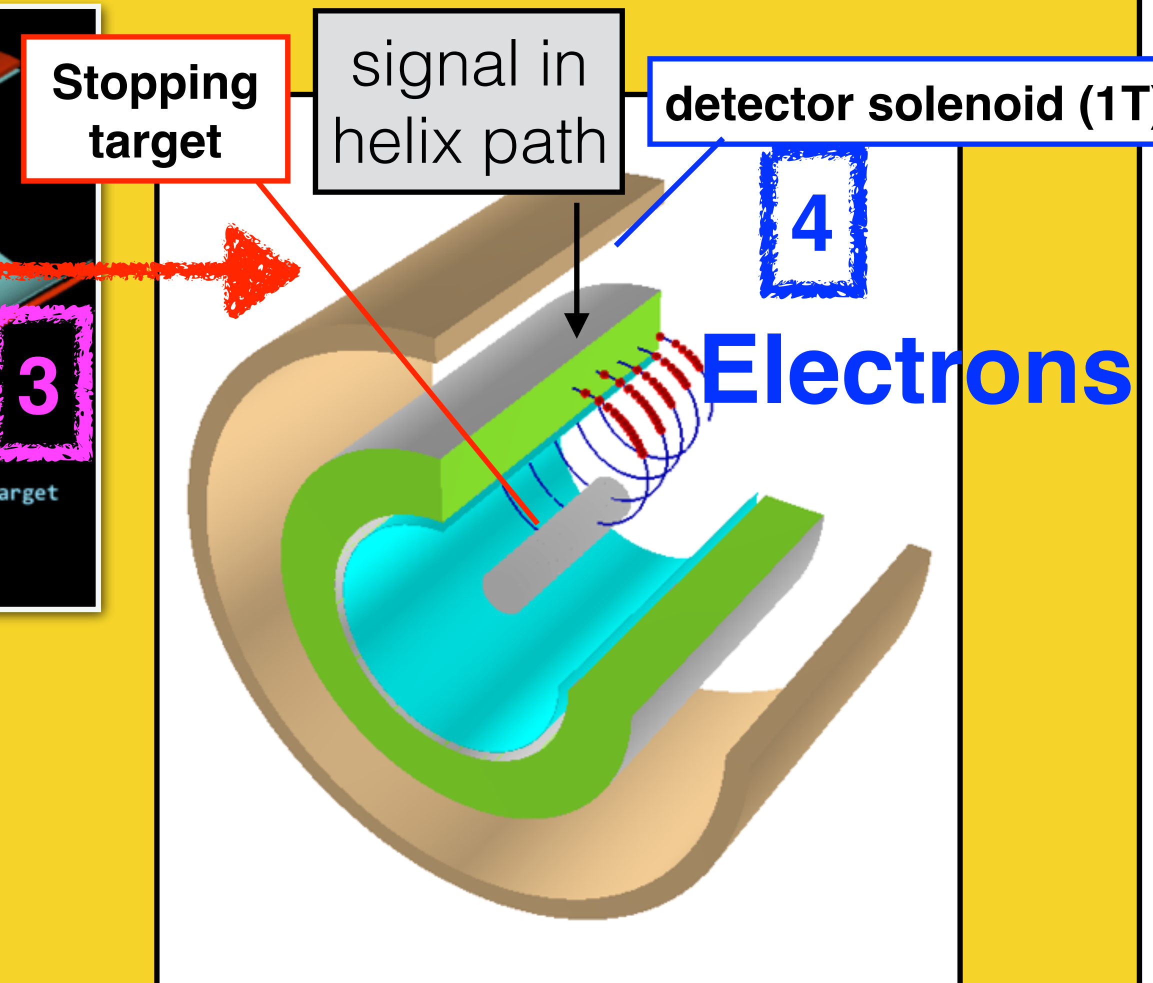
Staged approach

Phase-I

Sensitivity: 3.1 x 10^{-15}

COMET Phase-I





Cylindrical Detector (CyDet) system

1. **Protons hit target**
2. **Pions are captured**
3. **Pions decay to muons**
4. **Muons stopped in Al**
5. **Conversion happens (Hopefully)**
6. **Detect signal electron**

COMET Phase-I

How can we detect the rare events ?!

Ans: We have got lots of muons ! 1.2 x 10^9 stopping muons/second

What can survive in some such a high intensity of muons?

Ans: No, but we can avoid it!

— Drift chamber in COMET

We need to have :

-> Good performance

-> Good resolution

-> Good tracking algorithm

COMET Phase-I

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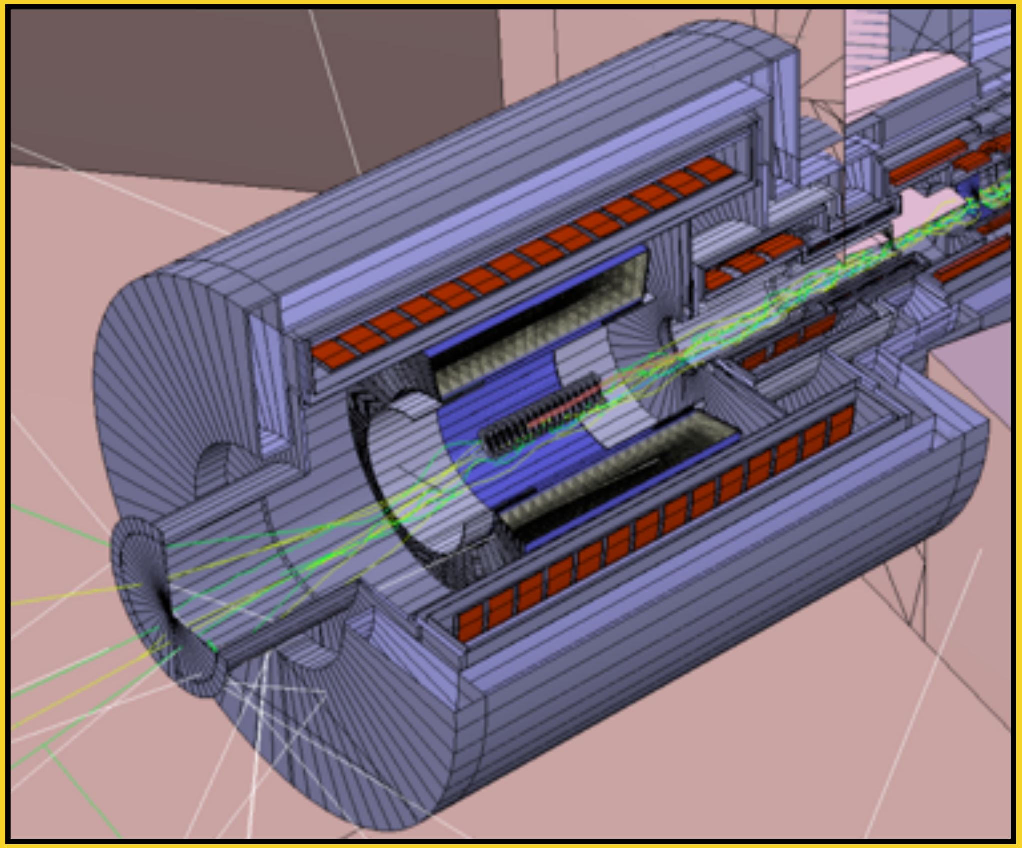
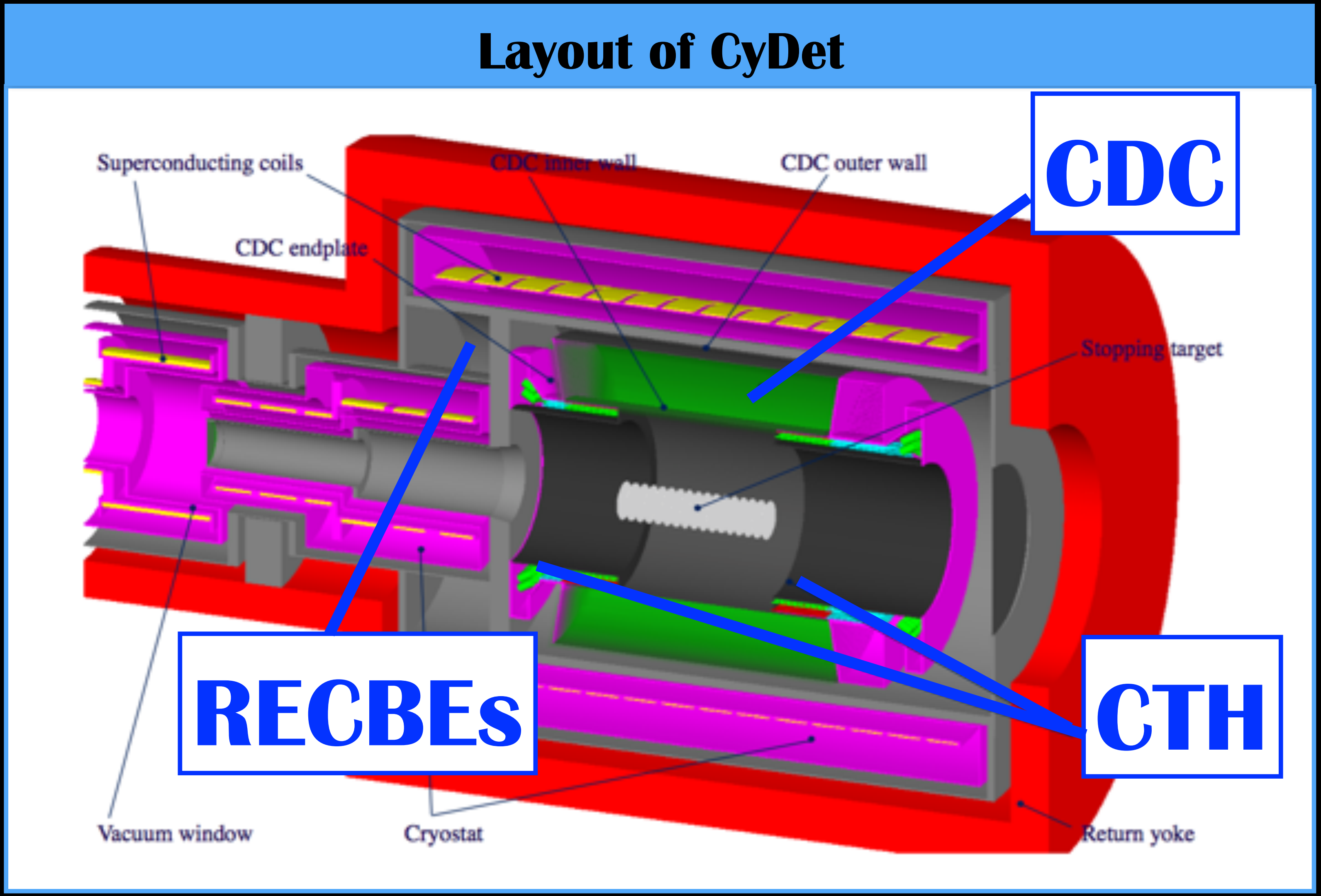


CyDet — Cylindrical Drift Chamber (CDC)

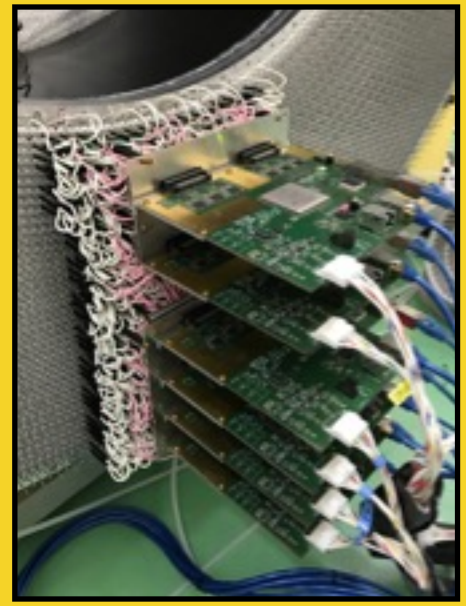


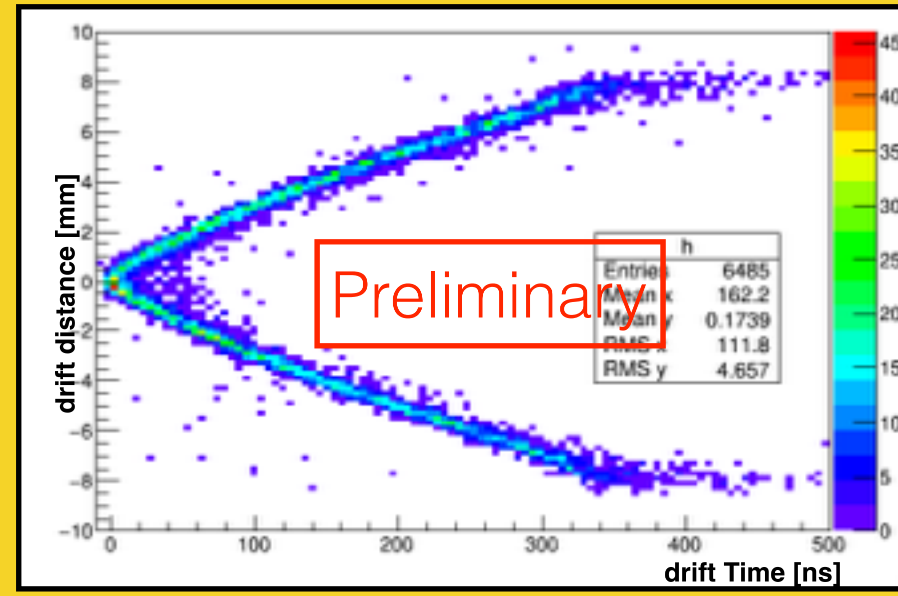
CDC has been constructed successfully in 2016

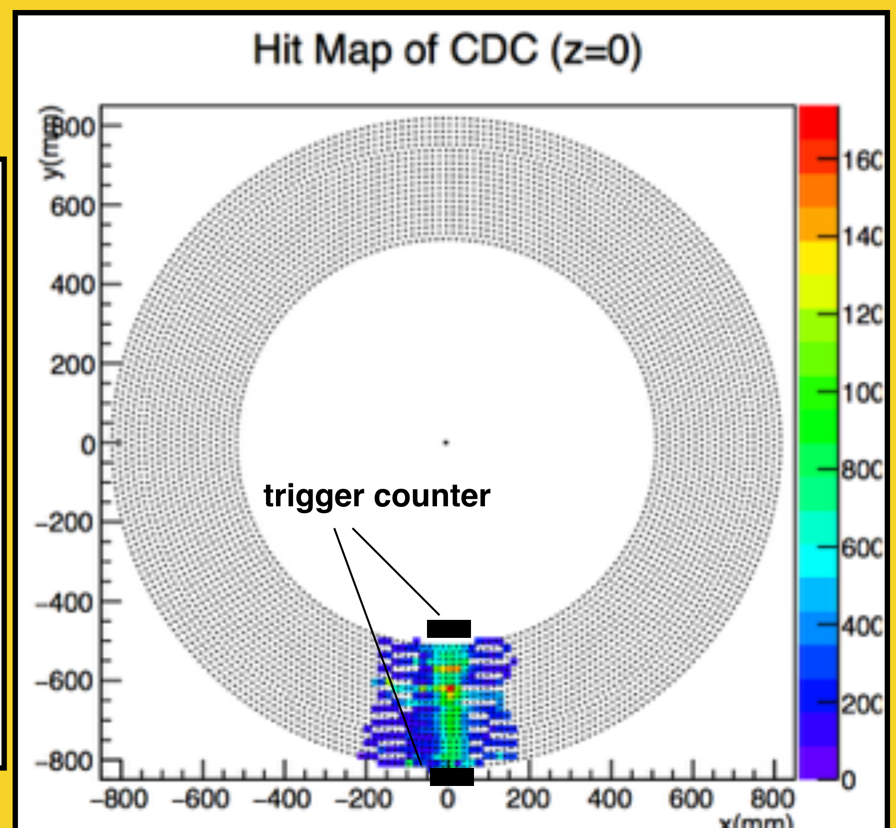
- Radius of CDC : Roughly 496 mm to 835 mm
- Helium based gas mixture (Isobutane, Ethane or Methane)
- All stereo layer with alternating stereo angle for each layer
- Sense wire : ϕ25μm (Au-W) && field wire : ϕ126μm (Al)
- Number of Layer : 20 (sensitive layers + 2 guard layers)
- Cell : about (16 x 16) mm^2
- Readout System : 104 RECBE Boards (one side)

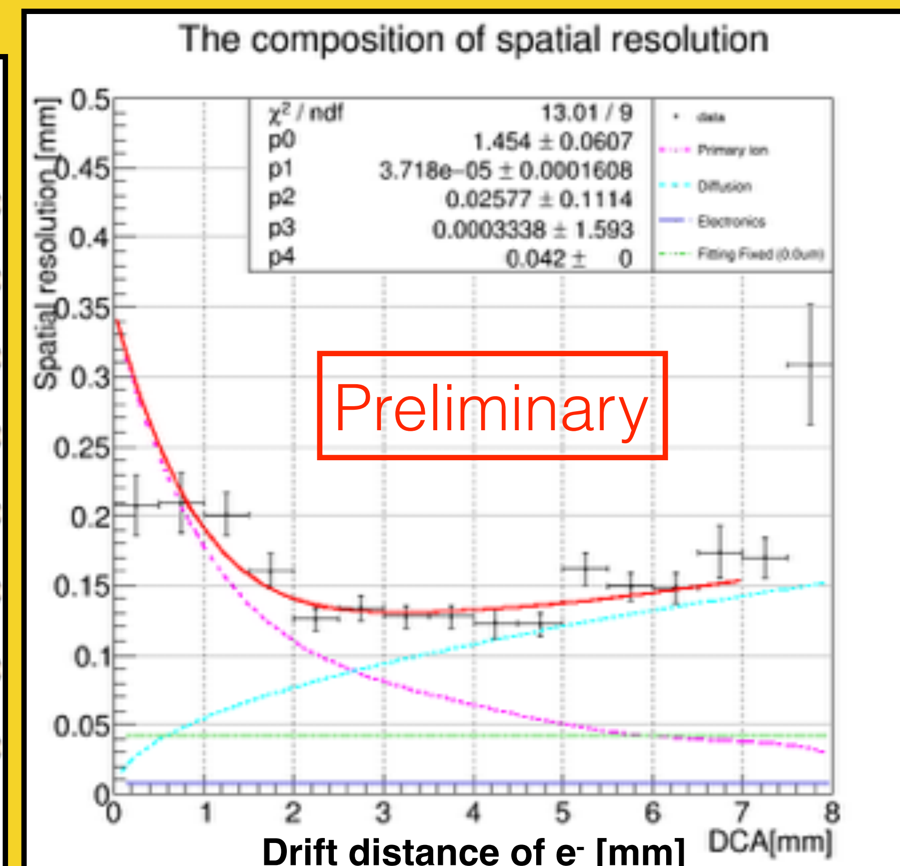
Performance of CDC Cosmic ray tests

- Cosmic ray test @ KEK Fuji building since last August
- Gas mixture : He—iC_4H_{10}(90/10) @ 1850V
- Tracks has been observed
- Position Resolution : >150μm (middle)
- Details of independent studies of CRT analysis will be presented by K. Okinka (next next talk)









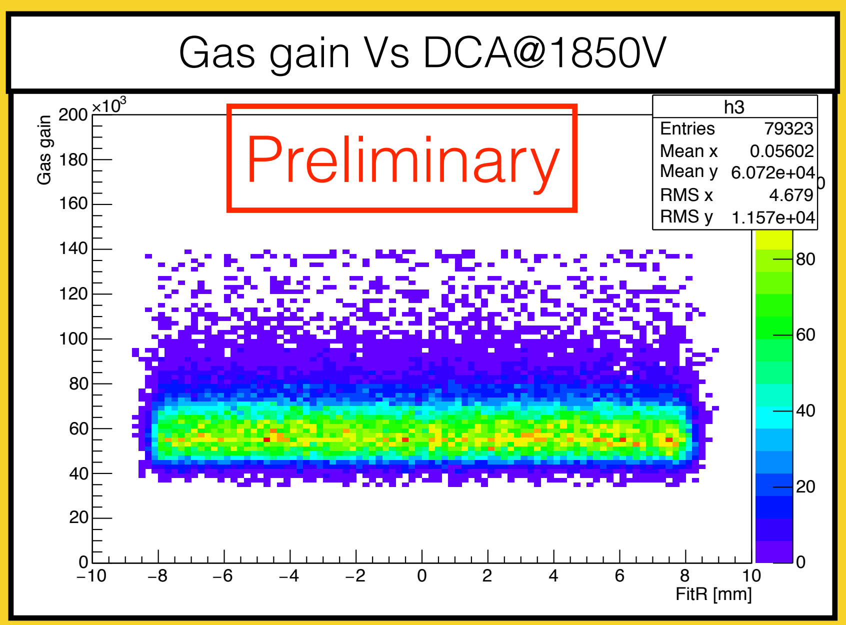
Gas gain studies of CDC

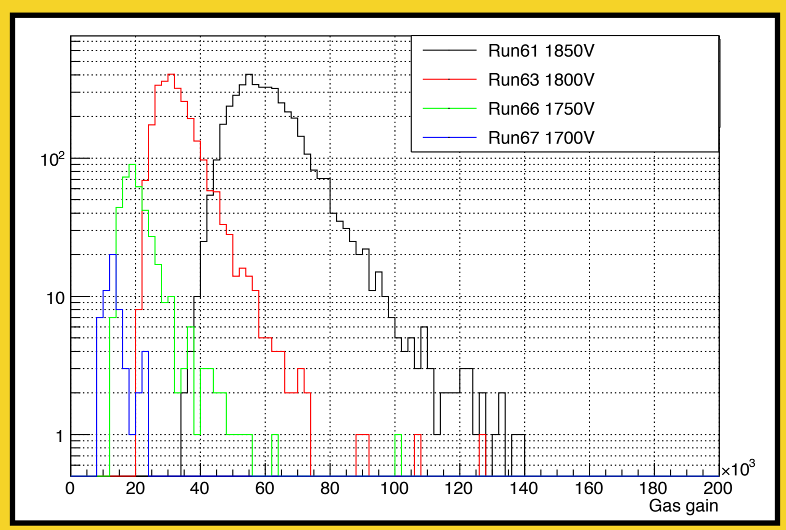
- The gas gain drops when the high voltage decreases.
- Gas gain is independent on drift distance

HighVoltage[V]	# events	Gas gain
1850	24915	~5.5×10^4
1800	24197	~3.0×10^4
1750	55726	~1.8×10^4
1700	24914	~1.3×10^4

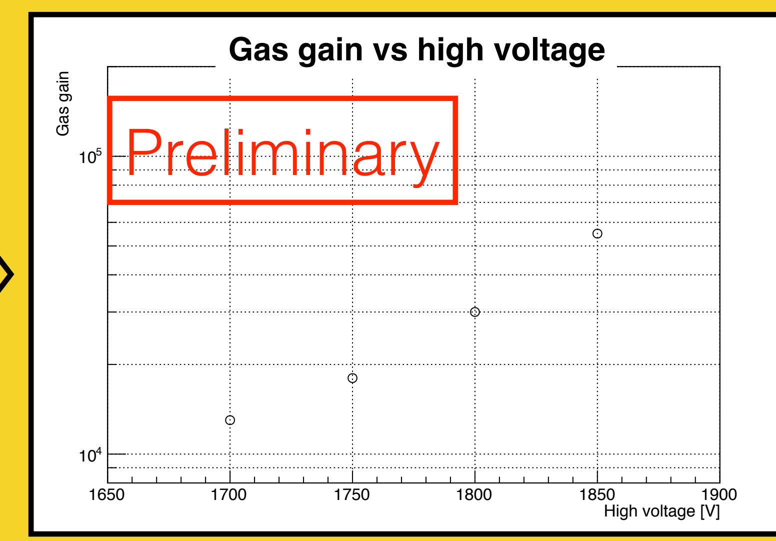
Preliminary

KLOE paper at 1850V gas gain: [1]: $(6.9 \pm 0.7)10^4$





Fitting this with Landau distribution



[1] E De LuciaMisure di ionizzazione sp ecica in prototipi della camera a deriva dellesp erimento KLOEthesis at the University La Sapienza Roma unpublished

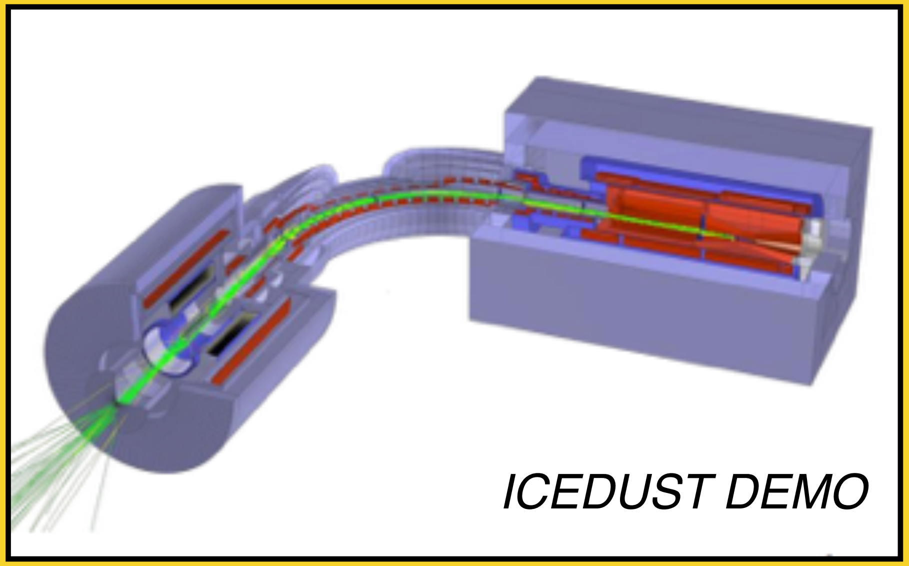
Progress of other related studies of CDC

- **Tension measurement of COMET CDC**
  - **1st Tension measurement — During wire stringing (May-Nov, 2016)**
  - **2nd Tension measurement — Before installation of inner wall (Feb,2016)**
  - **Within safety region**
- **Leak tests of COMET CDC**
  - **Below safety level — Almost every week manually by gas monitor**
- **Ageing test of wires in COMET CDC (Still at preparation stage)**
  - **Details can be seen at Y. Nakamura's talk**
- **Radiation tests of RECBE readout board for CDC and CTH**
  - **Gamma ray and neutron tests (Tested with prototype boards)**
  - **Details can be seen at Y. Nakazawa's talk.**
- **Software studies**
  - **CDC Calibration framework (In progress)**
  - **Track reconstruction (From next page)**

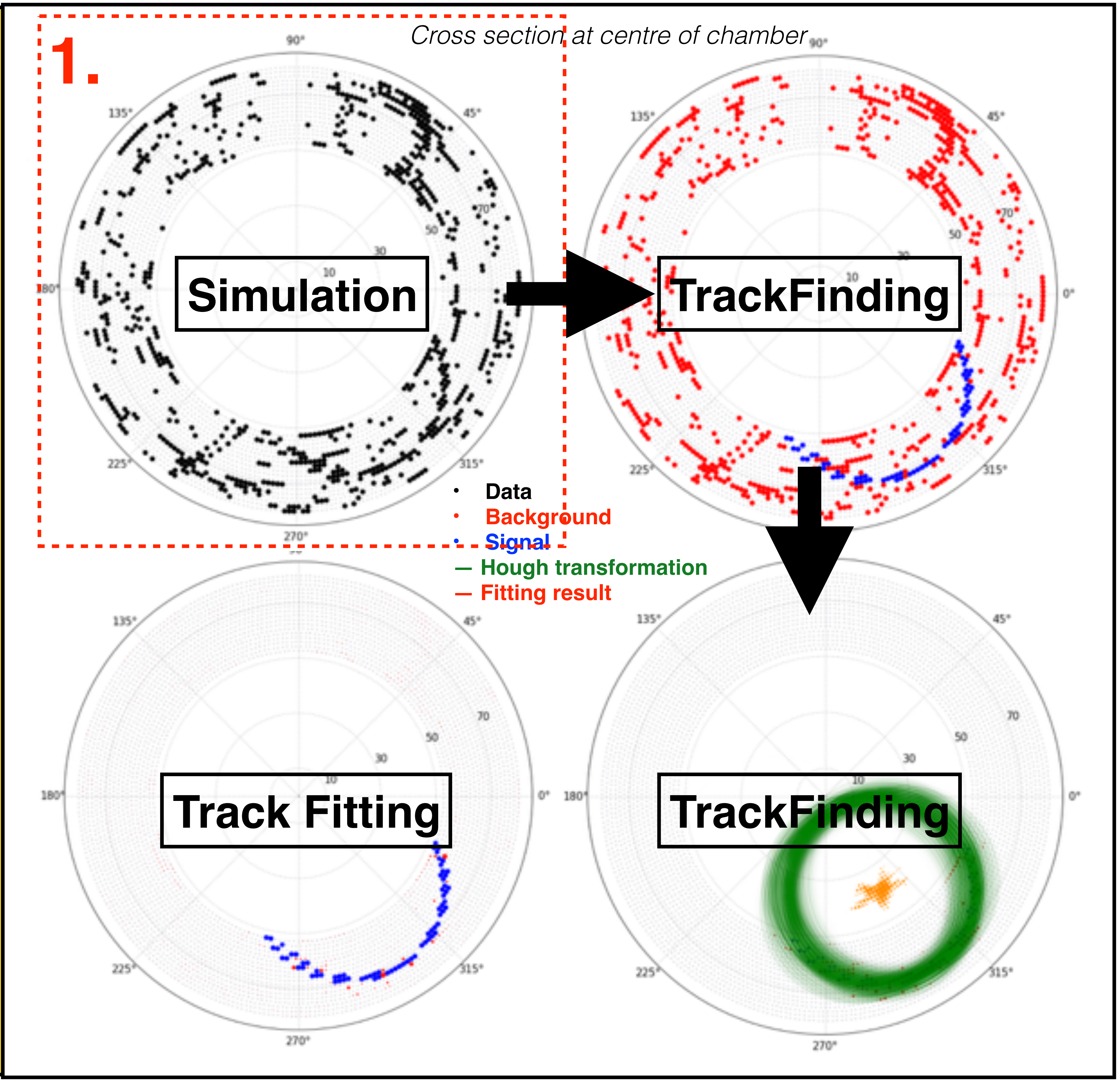
Tracking procedure in COMET

1. **Geant4 based MC simulation at production target (ICEDUST):**

   — **Signal track + beam simulation + hit merging (10^4 bunches)**
   — **Detector response: x-t relation by Garfield simulation and a resolution assumption of 200 μm**



ICEDUST: Official framework for COMET



Tracking procedure in COMET Phase-I

2-3. Track Finding

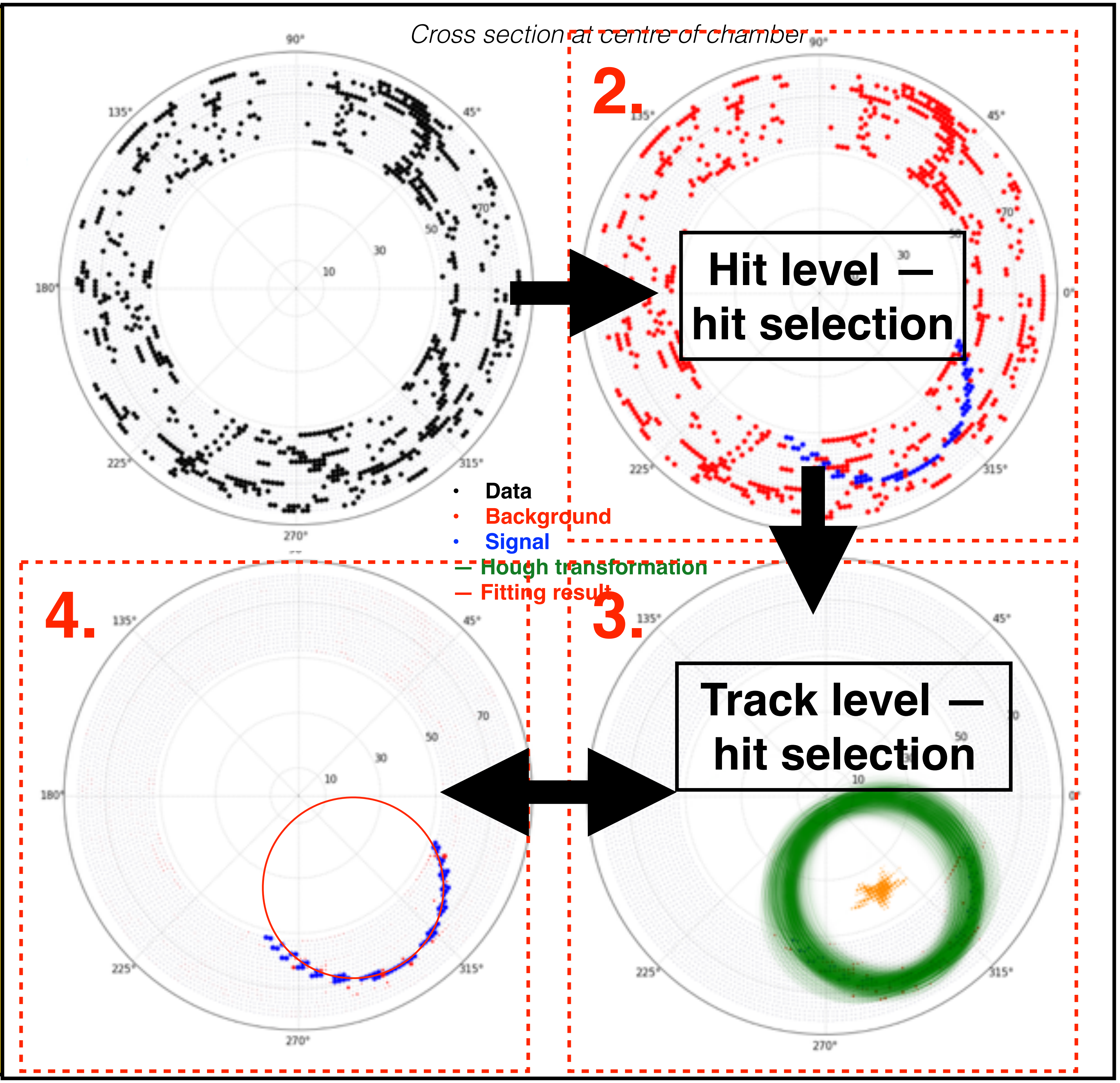
<u>Python based standalone program</u>

- **Machine learning — Gradient Boosted Decision Tree (GBDT) classifiers —> weight each hit**
- **Weight each hit again according to the tracks found by hough transform**
- **Gives initial value for track fitting**

4. Track fitting

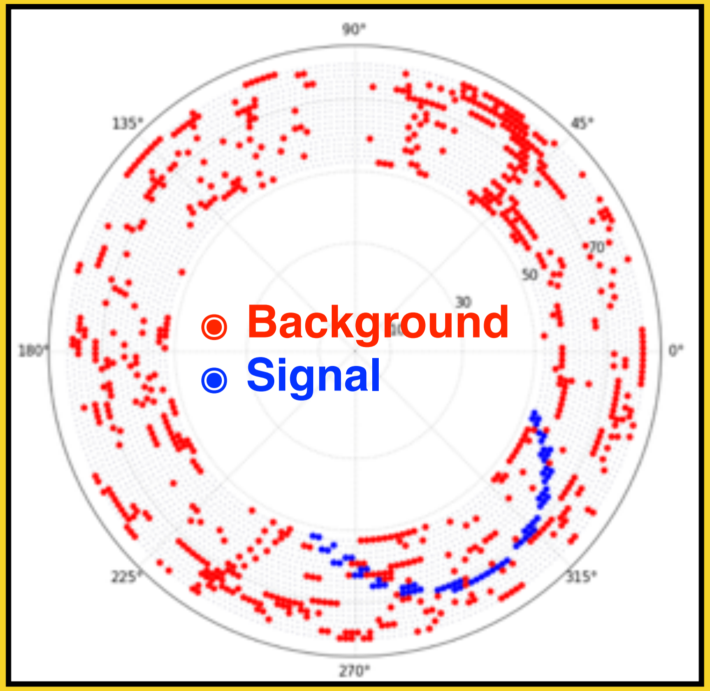
<u>GenFit-2.0 based standalone program</u>

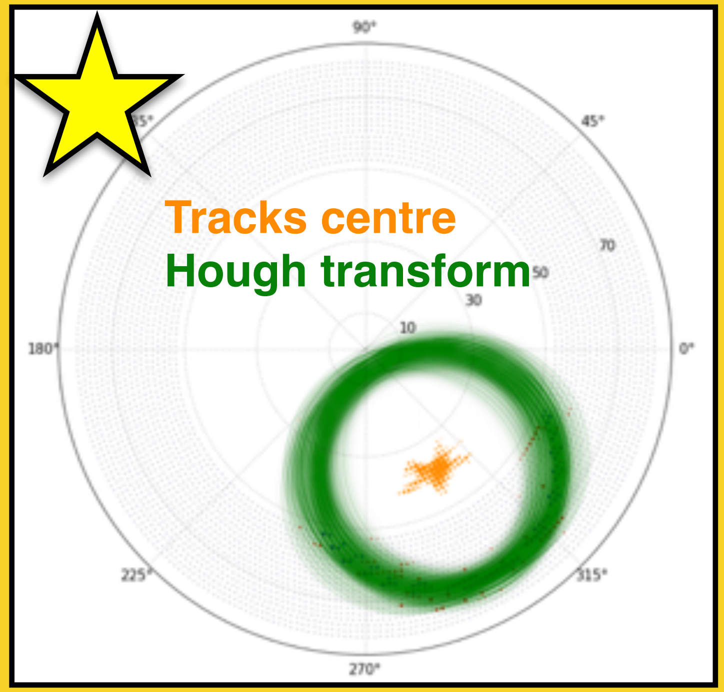
- **Kalman filter**
- **RANdom SAmple Consensus (RANSAC) —> remove noise**
- **Single turn and multiple turns**

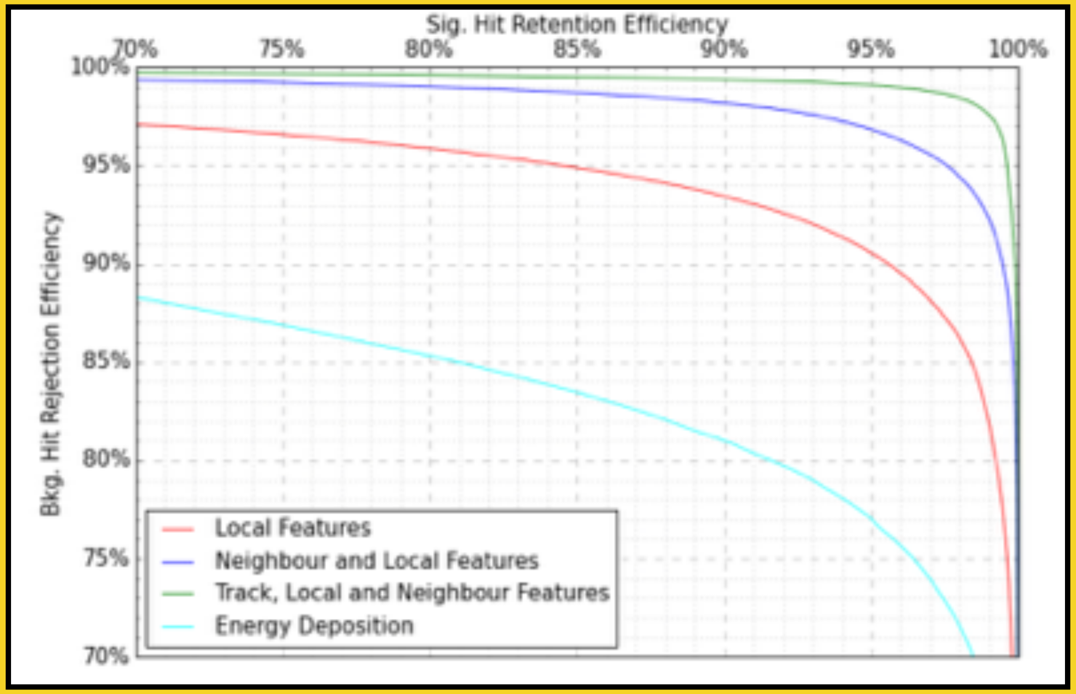


Track Finding — Hit selection

Cross section at centre of chamber

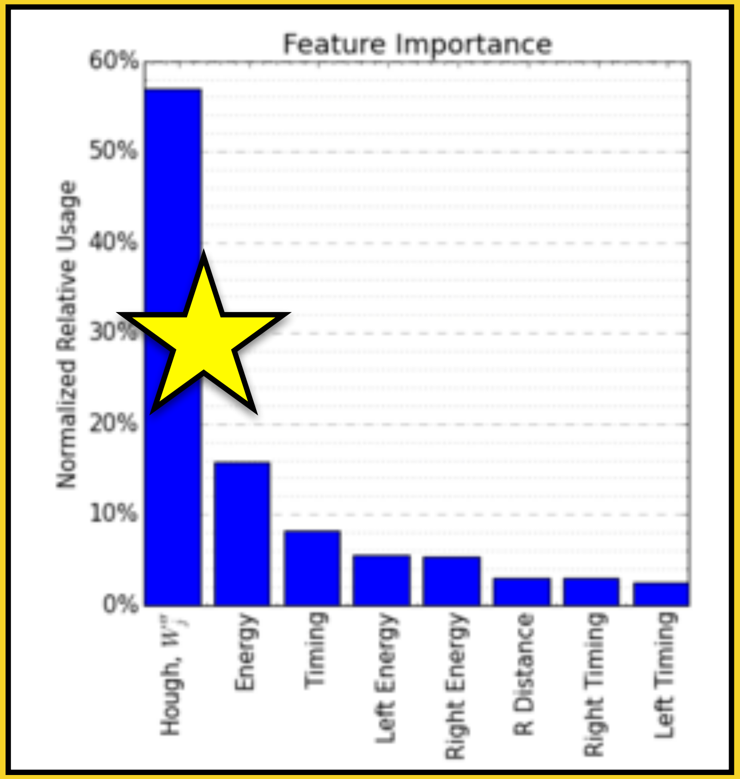






Track finding in COMET provides us a very clean event for track fitting
99 % of background can be rejected while keeping 99% of the signals.

★ **Very important feature**



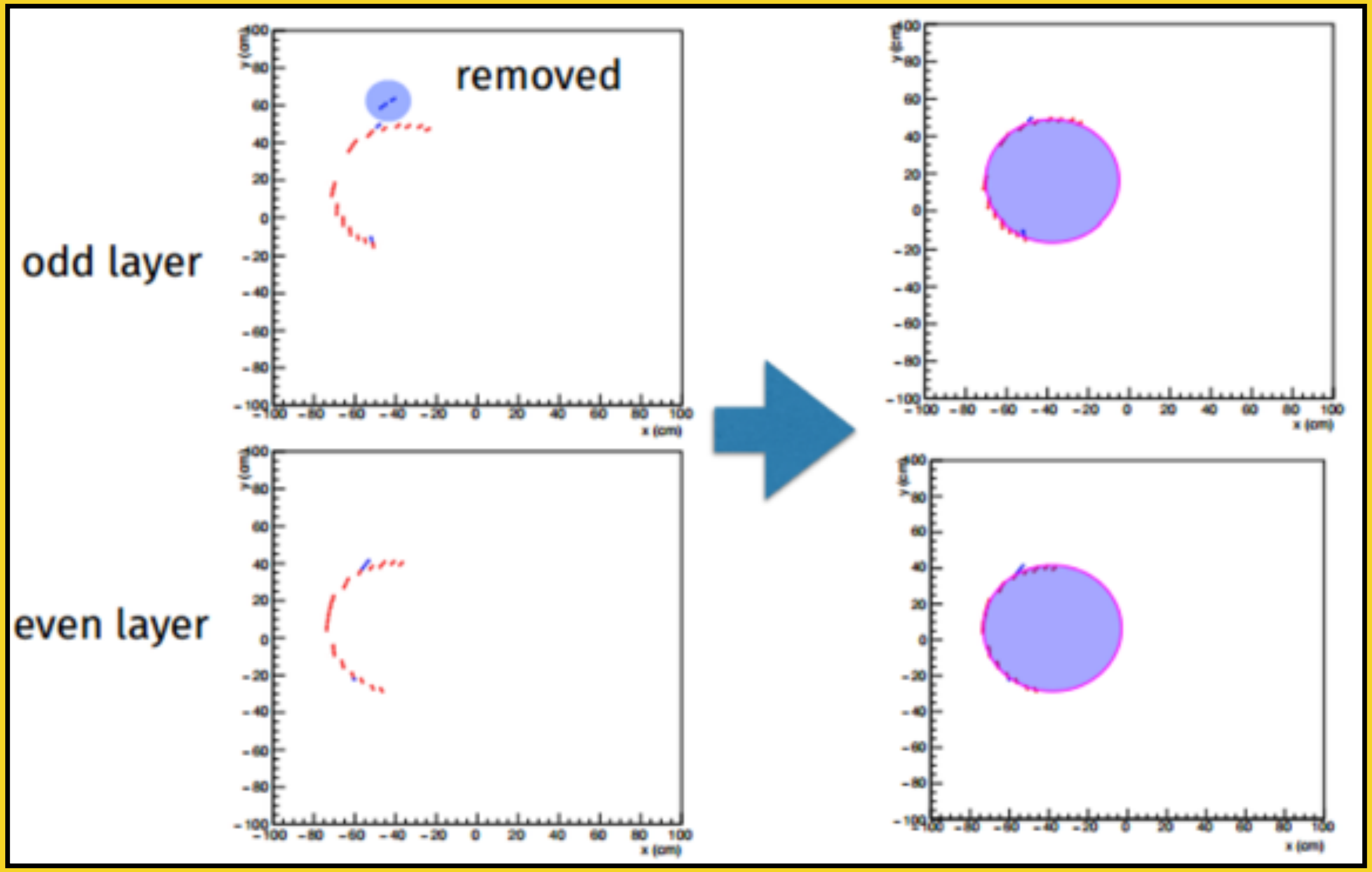
Track Fitting — RANSAC

RANdom SAmpling Consensus (RANSAC)

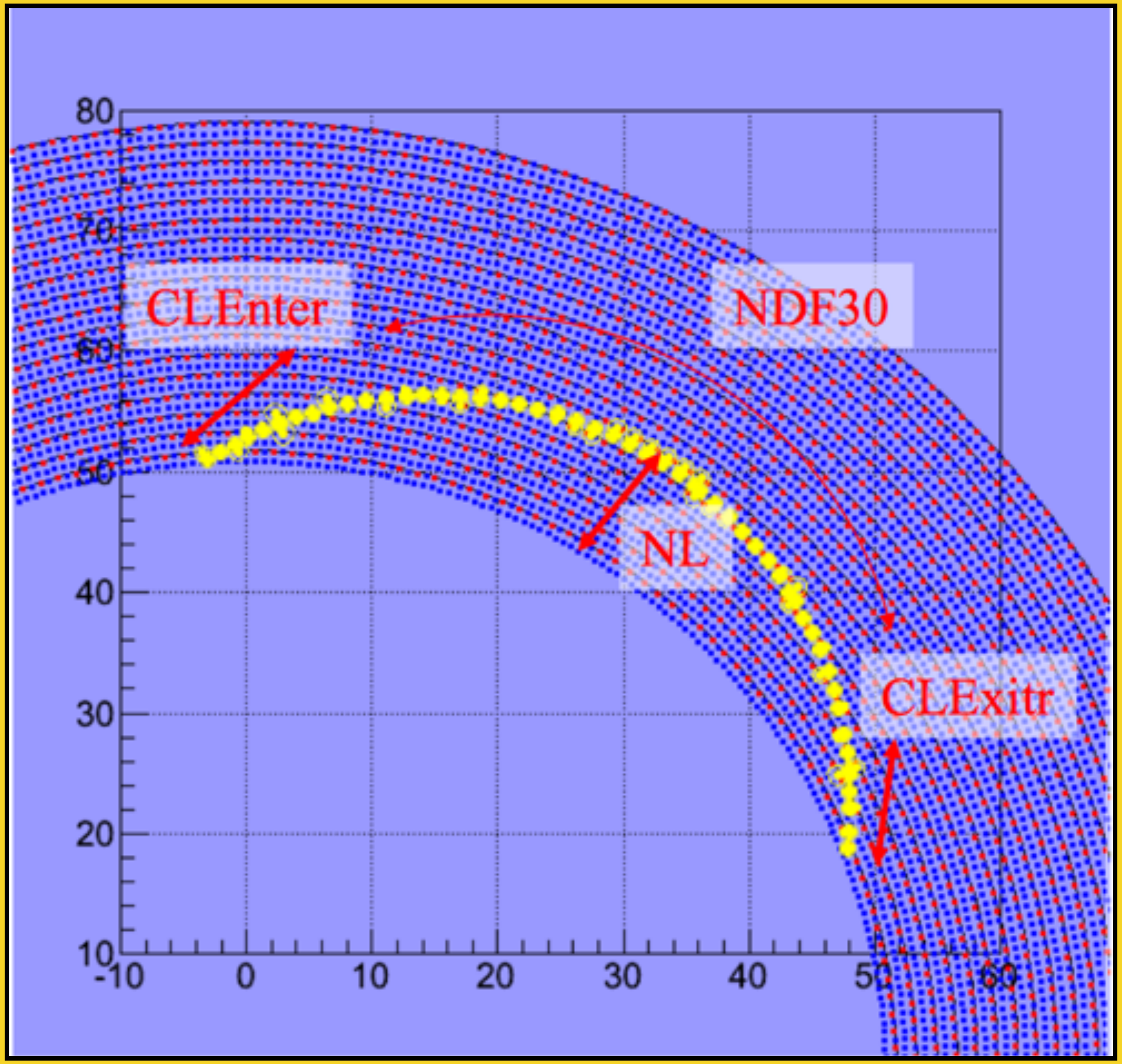
1. Take 3 points from the selected hits
2. Make circles in both odd and even layers
3. Find out the best circle!
4. Remove the point for GenFit

- Signal
- Background

— Fitting result



Track Fitting — quality cut



Event display in CDC

<u>NL5</u> : To ensure enough hits and z position information, tracks must reach 5th sense layer

<u>NFit</u> : At least one whole turn in CDC should be fitted successfully

<u>NDF30</u> : To ensure the reliability of fitting, degree of freedom > 30

<u>X^2</u> : To ensure the reconstruction quality, reduced $X^2 < 2$

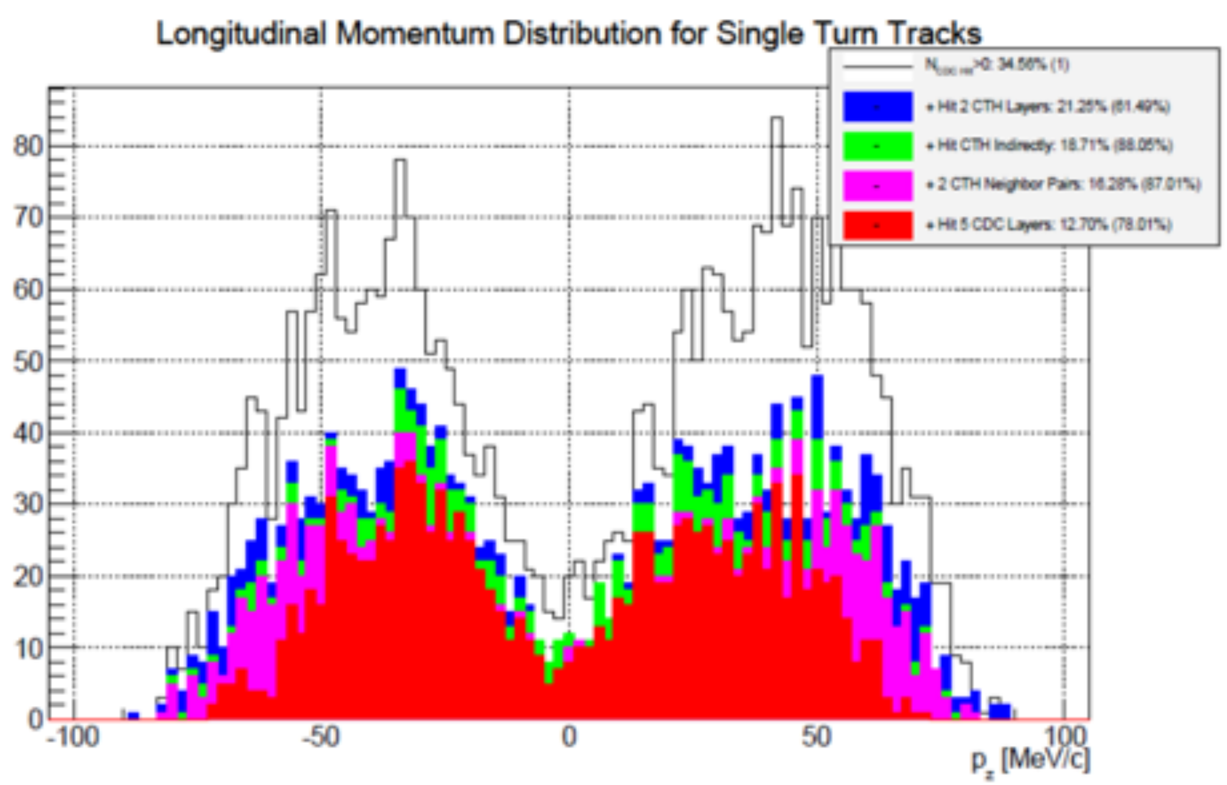
<u>CL3</u> : To suppress the tail, at least 3 consecutive hit layers at both entrance and exit of the CDC is needed

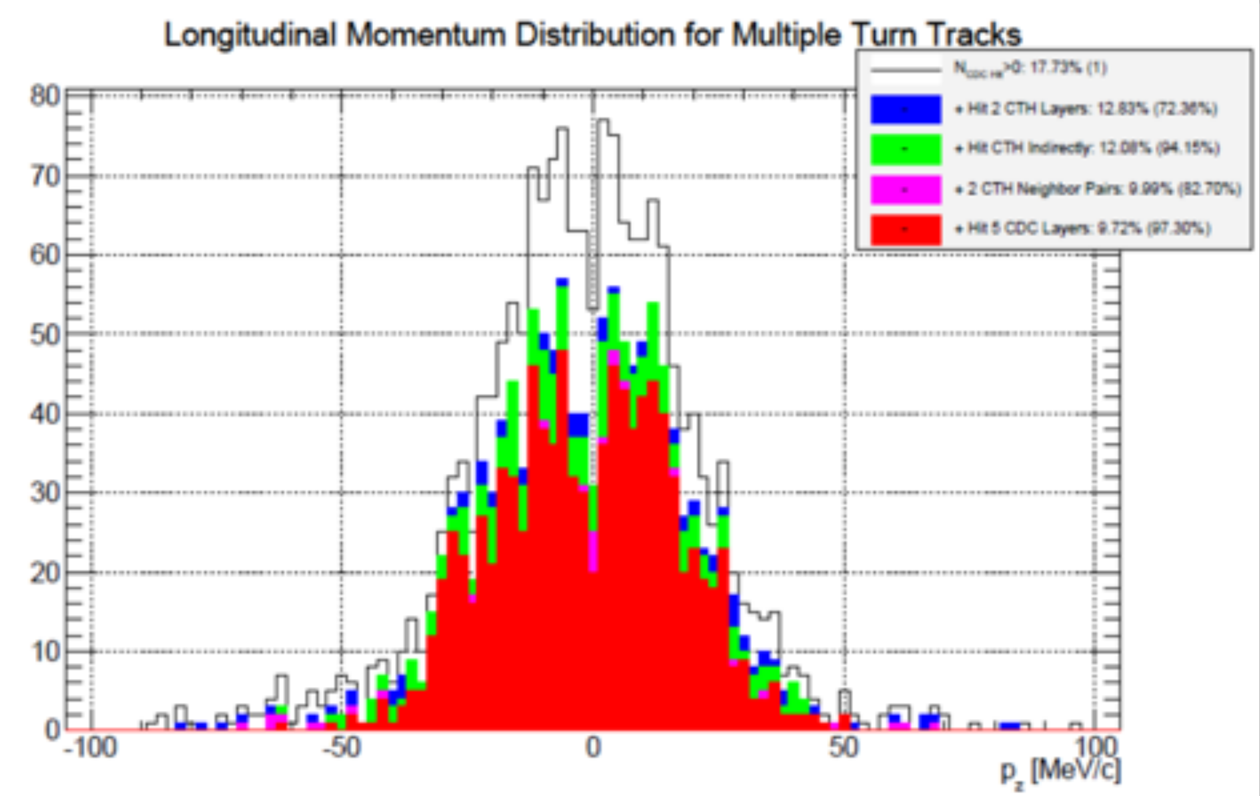
<u>Dpz20</u>: For 2-turn-fit tracks, the rescontruction of momentum p_z can be controlled by requiring Dp_z smaller than 200MeV/c

Track fitting : Acceptance of signal tracks

- Geometrical acceptance is different for multiple turn and single turn as shown below.
- Combining with quality cuts for two cases separately, the total efficiency is estimated as 18%.

	Single-turn	Multi-turn	Total
Geometrical	0.16	0.1	0.26
Quality Cuts	0.71	0.73	
Total	0.11	0.072	0.18



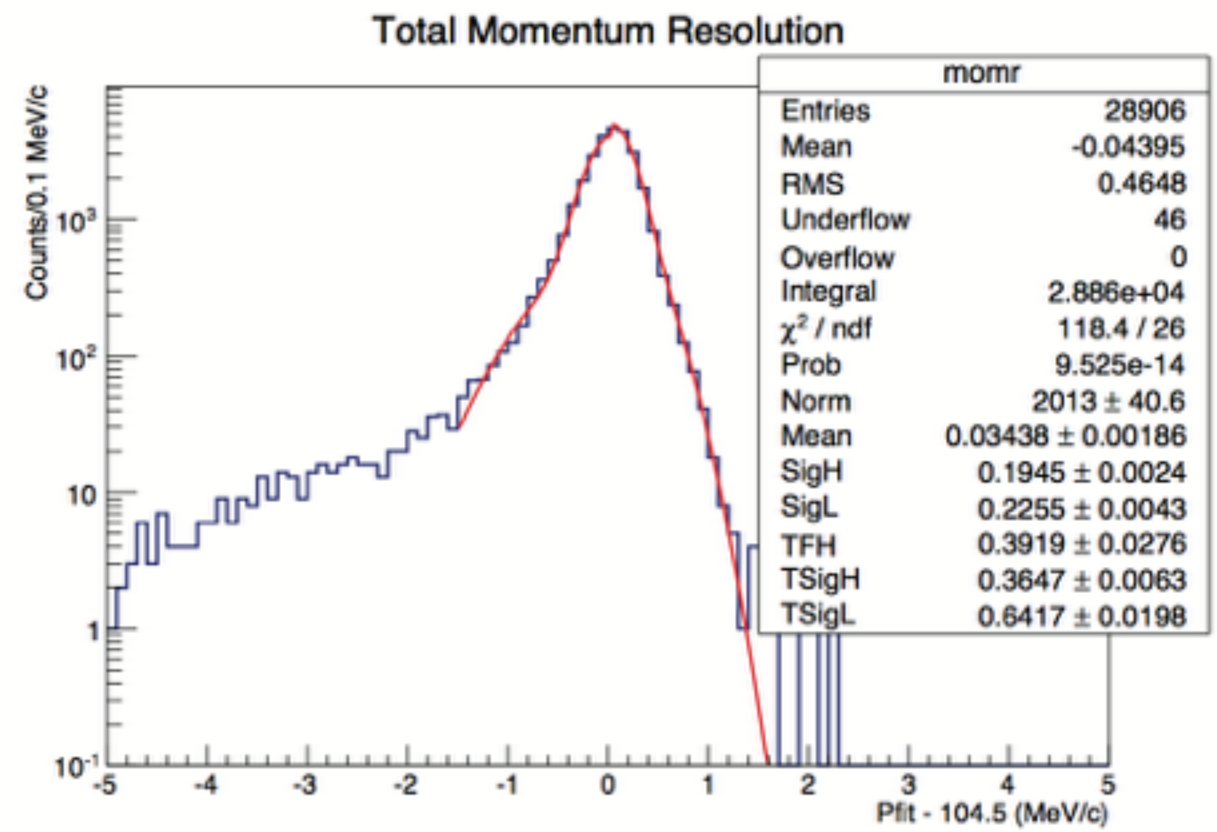


Track Fitting in COMET

With all quality cuts being applied, the momentum resolution achieved the COMET requirement.

The core gaussian of total momentum resolution at high momentum side and tail part of the gaussian are 195 keV/c and 226 keV/c, respectively.

None Gaussian tail is also studied with high static size sample



Core	σ of high-momentum half-Gaussian (SigH)	195 keV/c
	σ of low-momentum half-Gaussian (SigL)	226 keV/c
Fraction in tail distribution (TFH)		39%
Tail	σ of high-momentum half-Gaussian (TSigH)	365 keV/c
	σ of low-momentum half-Gaussian (TSigL)	642 keV/c

Future prospect

1. Upgrade of Cosmic ray test of CDC with integration of setup for COMET Phase-I, including the detector solenoid.

2. Ageing tests for CDC and Radiation tests for readout boards.

3. Track finding, offline tracking should be studied with more noise. In the mean time, trigger rate in COMET is very high, advanced online track finding is now being developed for selecting events.

4. Track fitting with more realistic samples should be carried out for estimating the momentum resolution.

5. Calibration of CDC (Wire, x-t relation, momentum)

Summary

1. COMET CDC has been introduced
2. Some studies in COMET are shown
3. Track procedure in CDC for COMET Phase-I is realised
4. Track finding and track fitting in COMET are introduced

Acknowledge

The studies of CDC are contributed by many collaborators in COMET experiment. Thank you for all the figures and results.

Back up

Sensitivity and DIO BG
#/hits>=34

He:$_{i}C_4H_{10}$(90:10)
30μmΦ(sense)/80μmΦ(field)

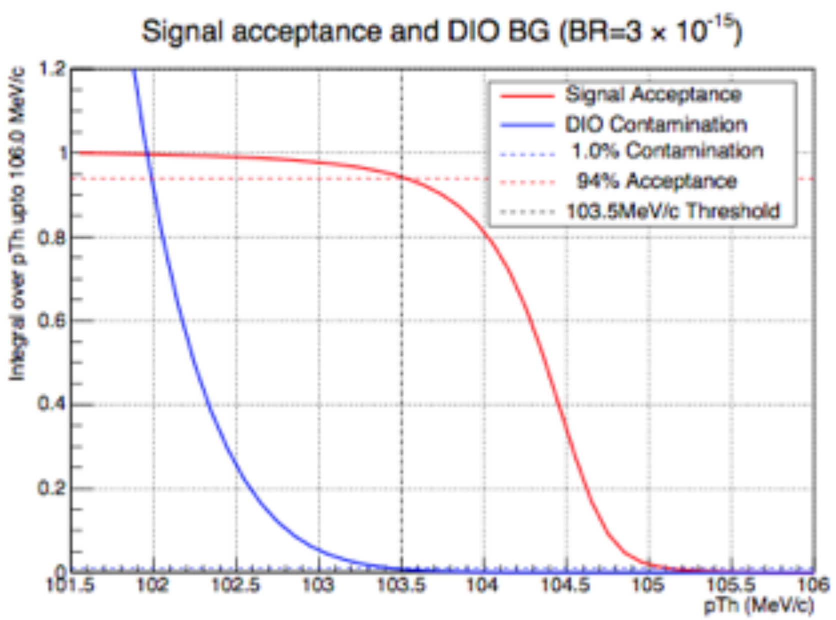
92%→94%

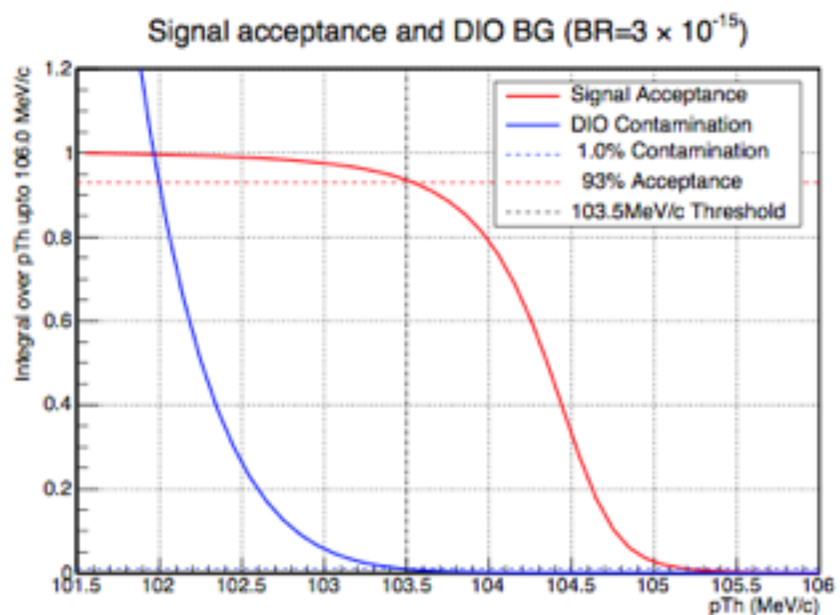
He:$_{i}C_4H_{10}$(90:10)
30μmΦ(sense)/126μmΦ(field)

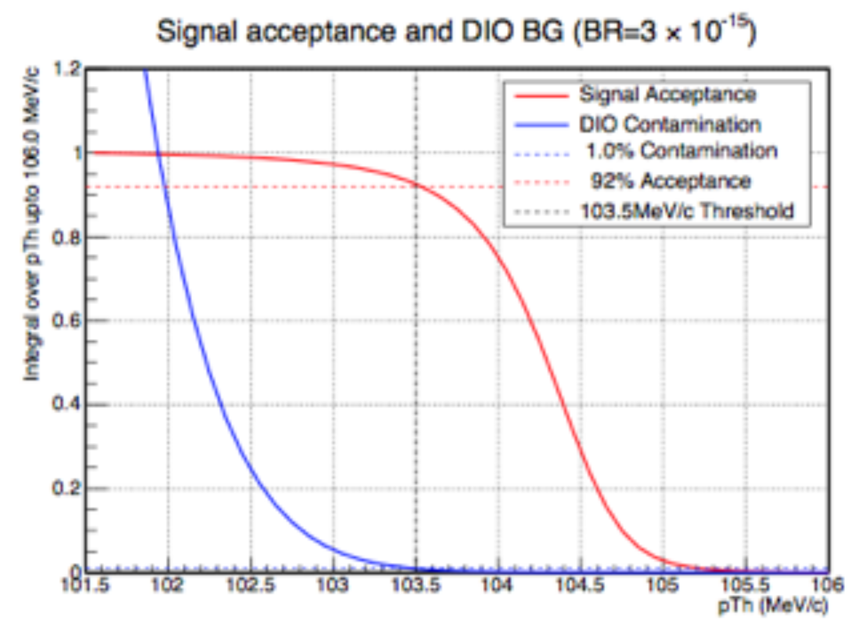
92%→93%

He:C_2H_6(50:50)
30μmΦ(sense)/126μmΦ(field)

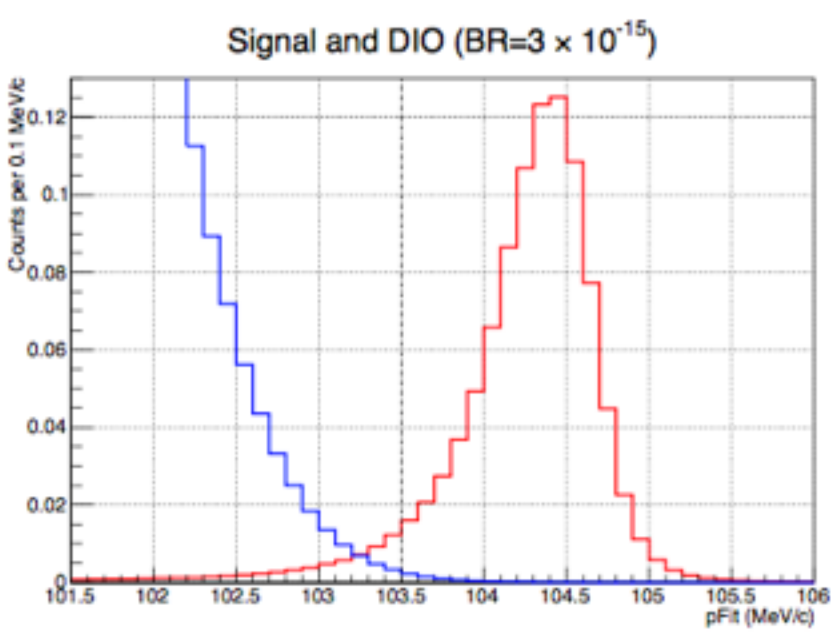
90%→92%

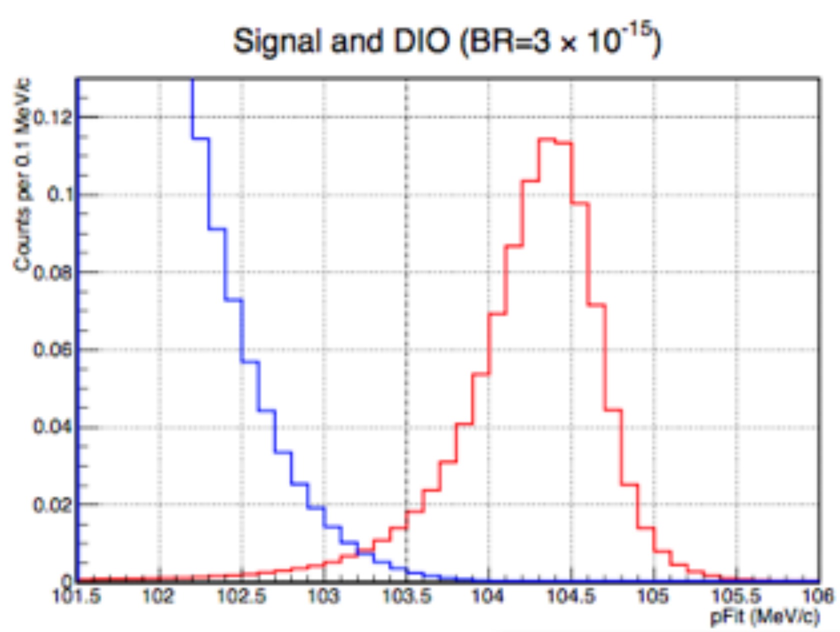


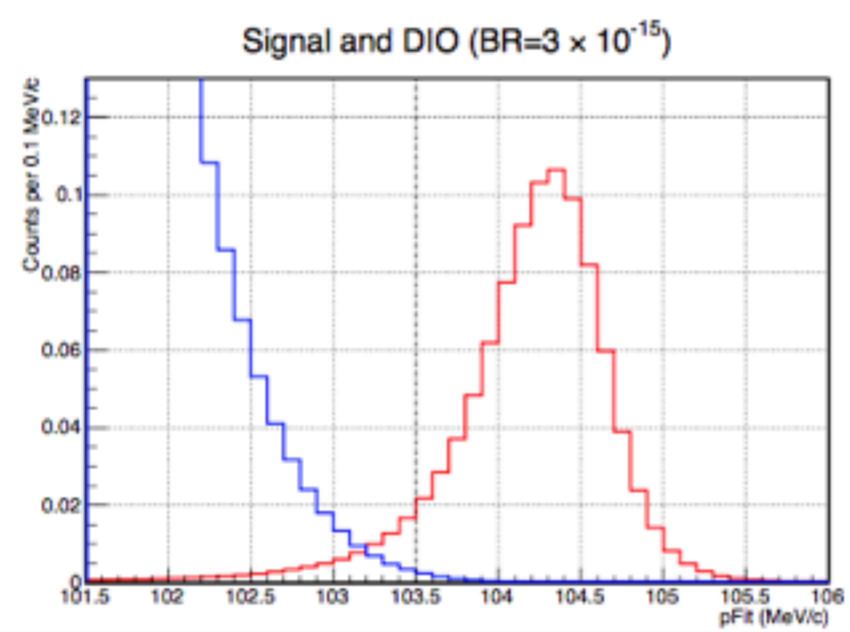




0.01 DIO events







Momentum-window: 103.5–106.0 MeV/c

#/hits cuts does not help -> try to find better cut

Summary

Momentum resolutions and sensitivity checked

- Genfit2/DAF(w/reference track)
- Closest approach only from 1st-turn track (ideal case)
- Statistics: 20M
- Cuts

Geom. : CDC Hit && Indirect Hit@TriggerCounter

Tracking : ndf >=30 && Max_LayerNo>=6 && chi2/ndf<2 && |res_r| < 0.08 cm

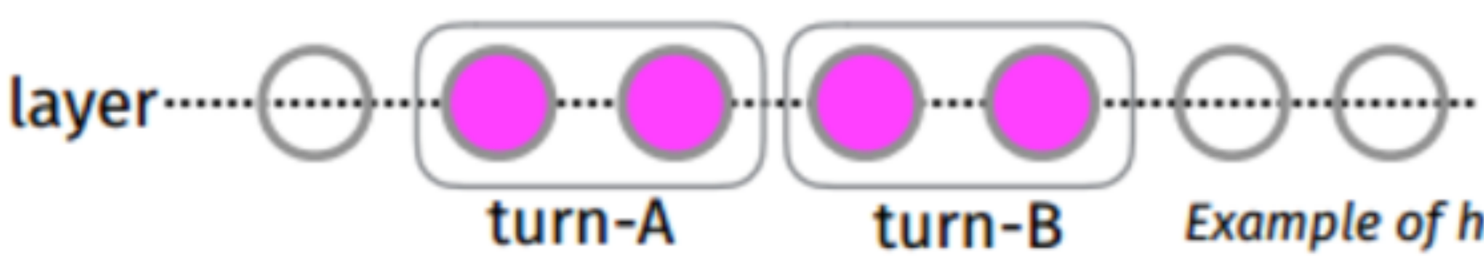
Gas	Wire	σ_{core} @dbl-gaus	σ_{core} @quad-gaus	Sensitivity*
He:iC_4H_{10} (90:10)	30μmΦ(sense)/ 80μmΦ(field)	160 keV/c	130 keV/c	92%
He:iC_4H_{10} (90:10)	30μmΦ(sense)/ 126μmΦ(field)	180 keV/c	140 keV/c	92%
He:C_2H_6 (50:50)	30μmΦ(sense)/ 126μmΦ(field)	220 keV/c	170 keV/c	90%

*momentum-window: 103.6-106.0 MeV/c

Tracking for Multi-turn tracks

- Tracks of small pz have multiple turns in CDC.
- It makes neighboring hits or pile-up hits.
- In tracking (Kalman-filter), all hits should be assigned in correct order.
- Due to neighboring hits, it's difficult for track finding to separate hits.
- First trial method was implemented/tested.
  - "Divide" sequential hits in same layer, odd/even, first/last 90 deg turn.
  - Make ~50 different sets of hit candidates.
  - Fit for each set and keep if fit result is "good" (NDF>20).
  - Using remaining hits, repeat this procedure by 3 times at most.
  - Choose 1st and 2nd maximum momentum tracks and compare each pz.
  - If difference of pz is smaller than 20 MeV/c, finish.

Track-A, Track-B, Track-C → Compare pz of 1st/2nd turn track



Example of how to divide neighboring hits

Boosted decision tree

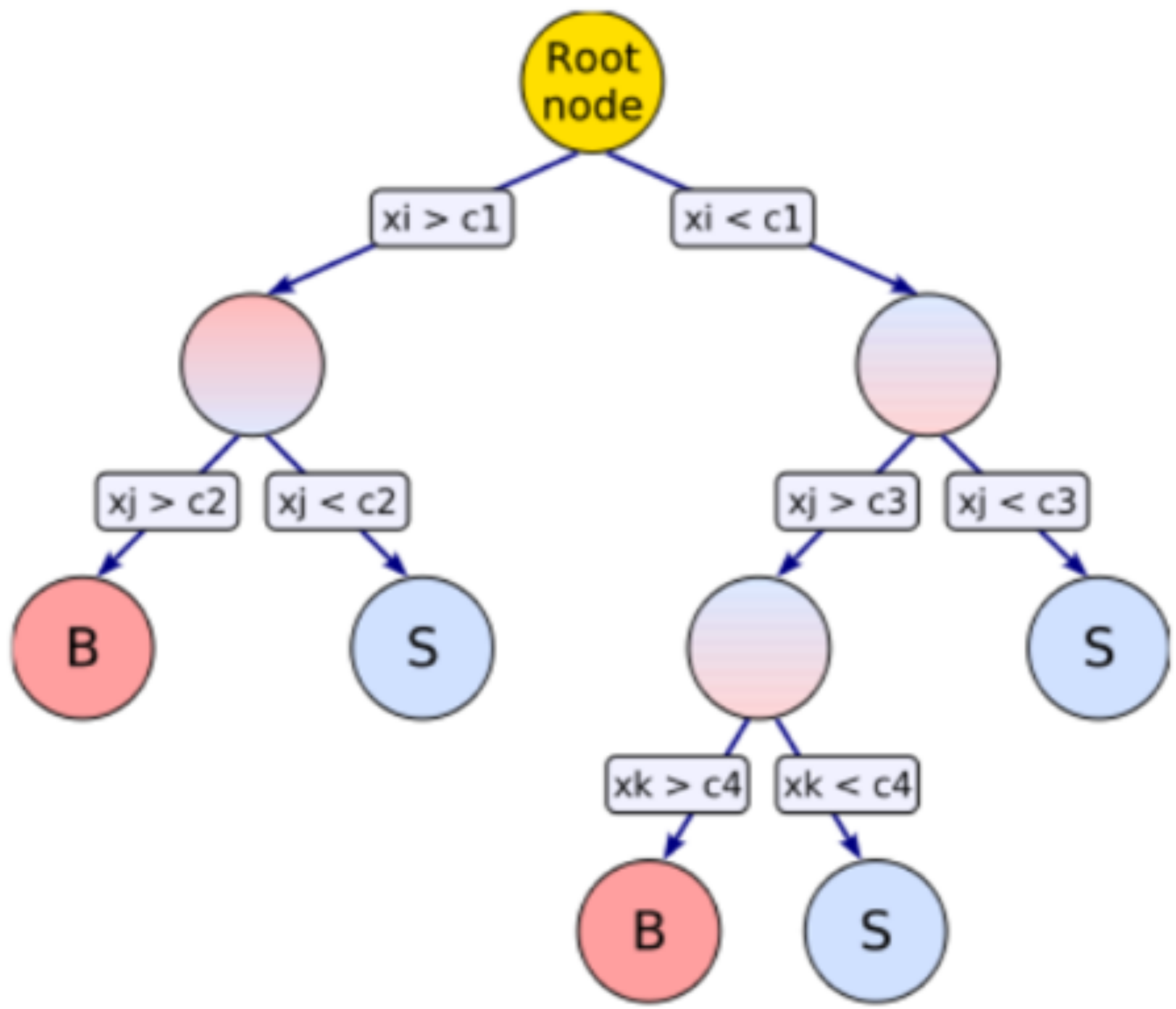
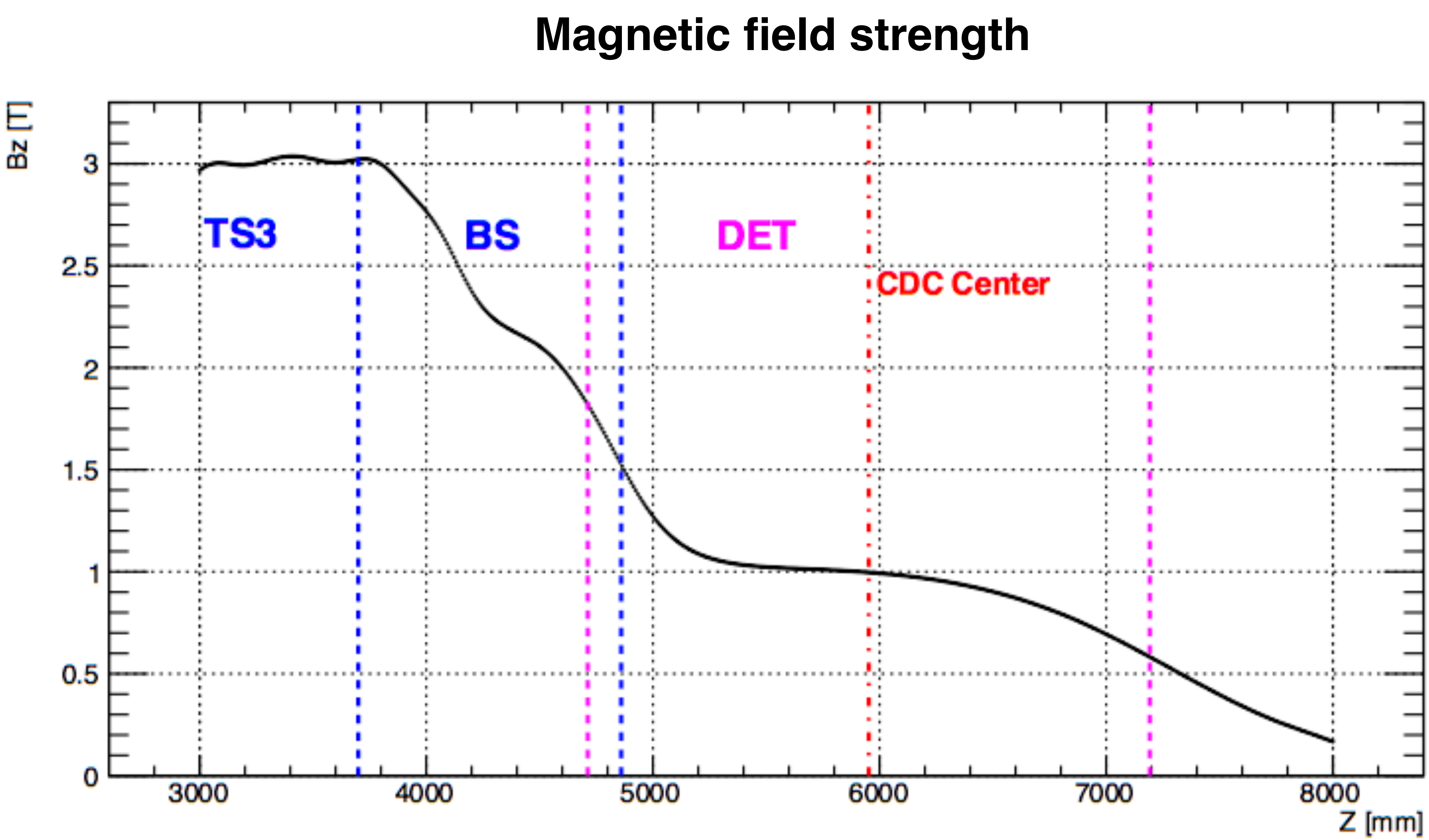


Figure 13.59: A decision tree, where the features are labelled as $\{x_i, x_j, x_k\}$. The first cut is on x_i at value $x_i = c_1$. This cut creates two daughter nodes, the first of which is cut at $x_j = c_2$, while the second is cut on $x_j = c_3$. This process is continued until some stopping criteria is reached. The leaf nodes are labelled as background, B, or signal, S.

COMET— Detector Solenoid

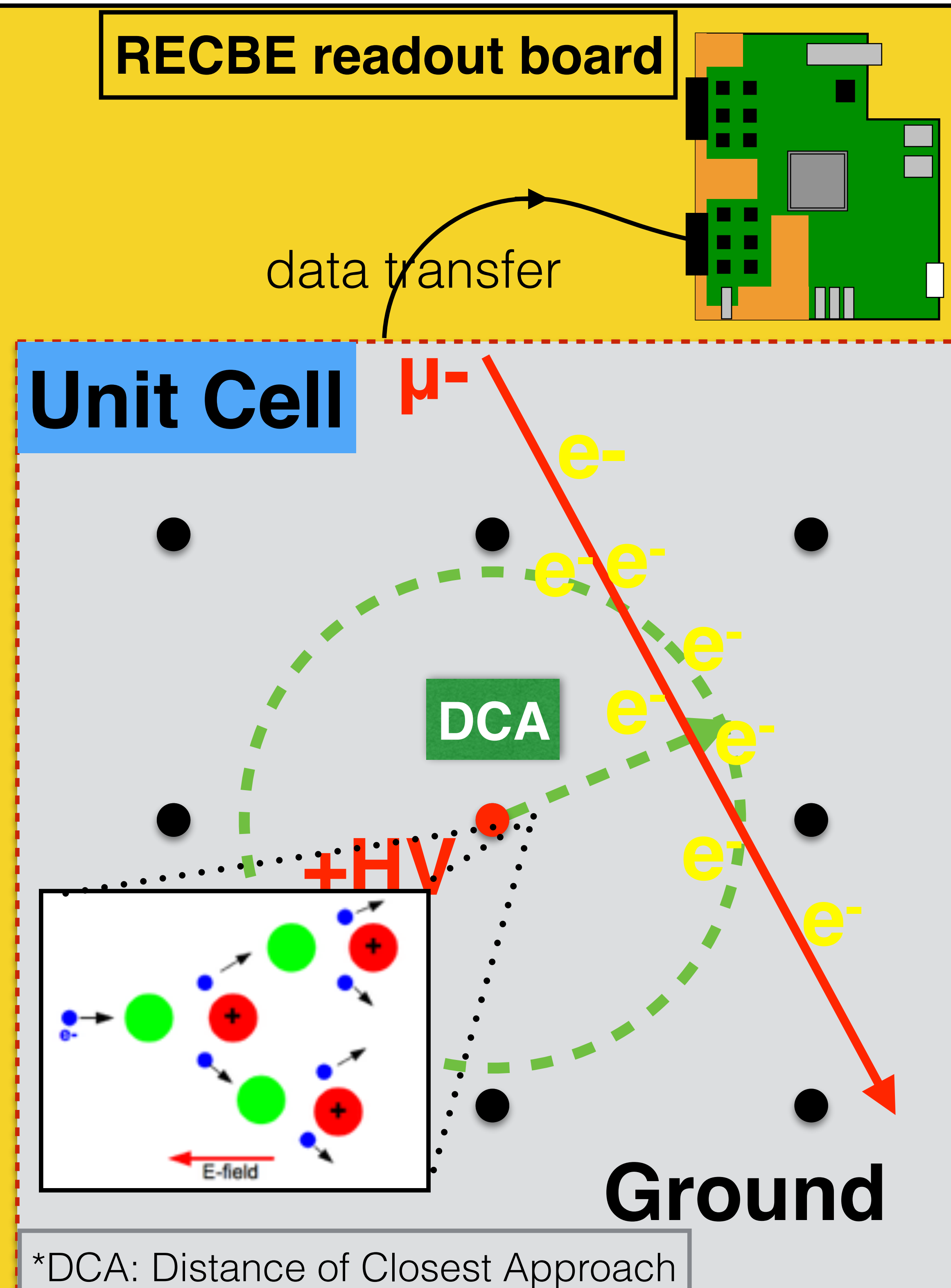


COMET TDR 2016 april

How does drift chamber work?

Different types of wire-chamber

1. **Stereo - type**
2. **Axial - type**
3. **Mix of both type**



1. **Helium-based gas mixture is inside the chamber**
2. **Electrons drift to anode wire.**
3. **Avalanche occurs to induce current on anode wire.**
4. **Gas multiplication occurs due to strong electric field**

RECBE COMET is based on design of Belle-II

Momentum resolution and spatial resolution of CDC

$$\left(\frac{\sigma P_t}{P_t}\right)^2 = (aP_t)^2 + (b)^2$$ [1]

B: Magnetic field strength
σ: Position resolution
N: Number of measurement points
P_t: Transverse momentum
b: Multiple scattering

$$a = \frac{\sigma}{0.3BL^2}\sqrt{\frac{720}{N+5}}$$

Spatial resolution

- **Comparing σ=200 and 300μm, estimated momentum resolution change only 1%**

Assuming X_0 = 507 m, N = 70 , L=1m, P_t=103MeV/*c* and B is uniform at 1T

- **Estimation shows that 300μm is acceptable**

[1] reference from PDG

Rough estimation of σ and σ_{Pt}

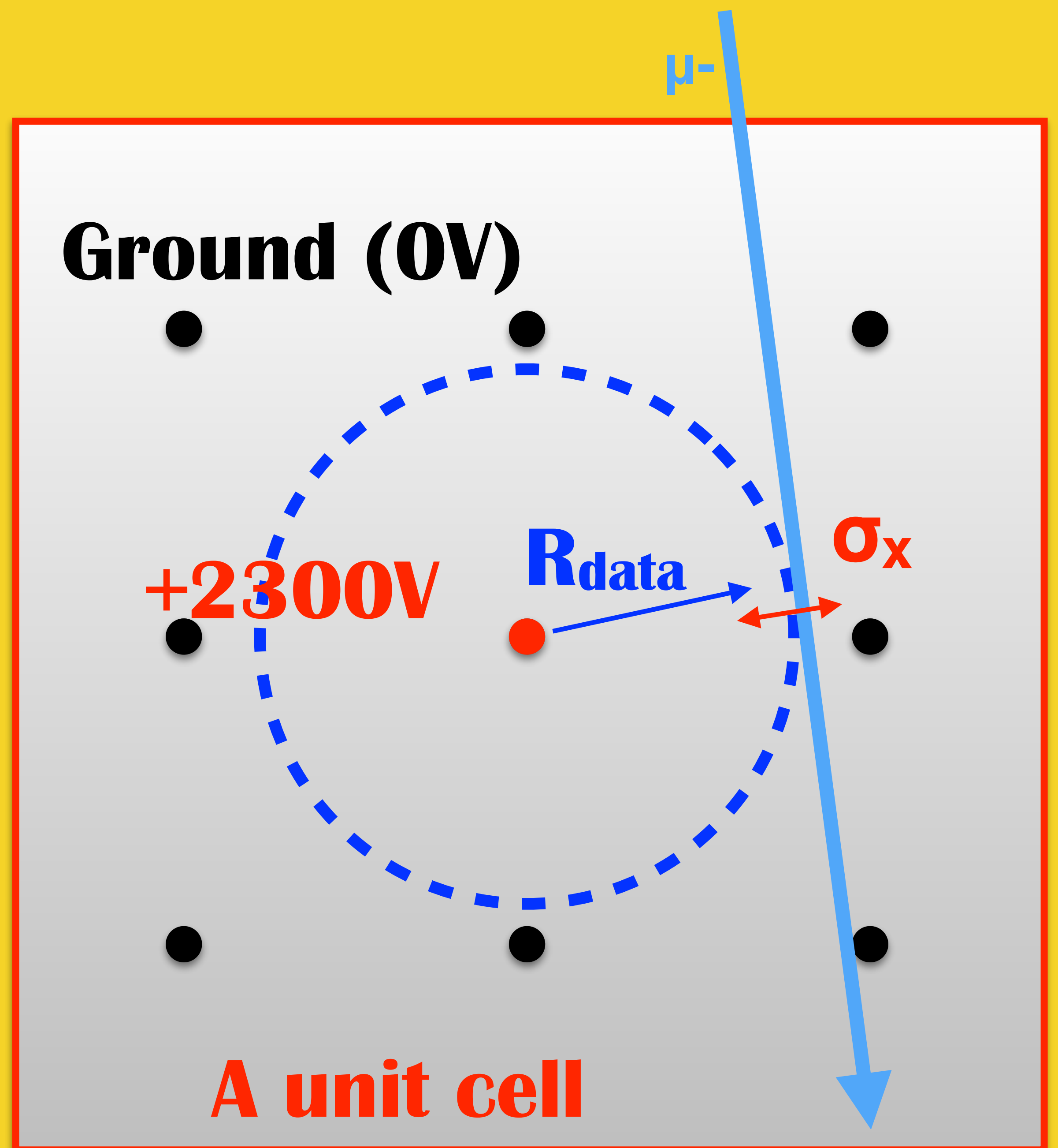
- $$(\frac{\sigma_{P_t}}{P_t})^2 = (aP_t)^2 + (b)^2$$

Assuming X0 = 507 m, N = 70 , L=1 and Pt=103MeV B is uniform at 1T

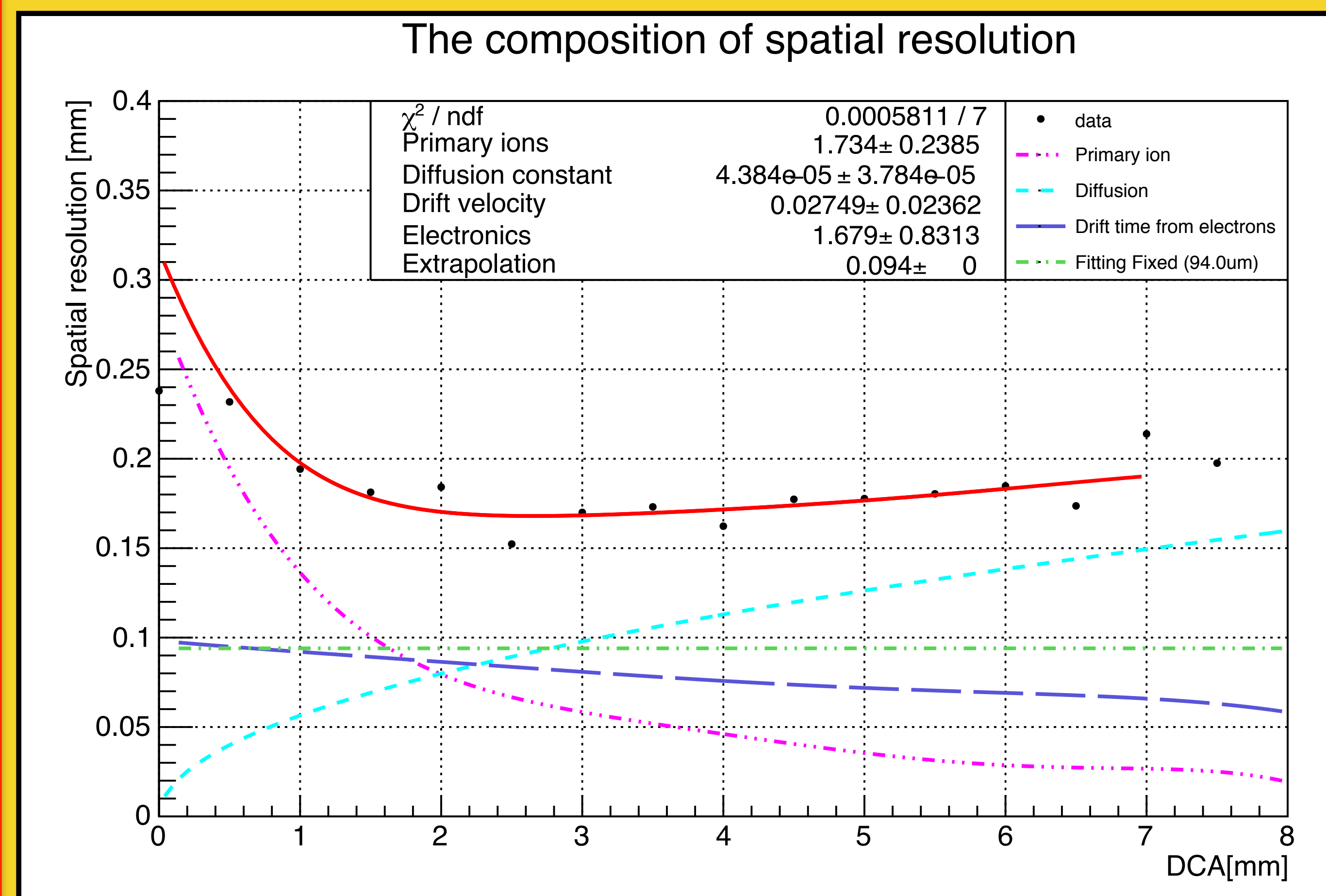
- He—iC_4H_{10}(90/10) 215+-14μm
- **Comparing 200 and 300um**
- **Estimated momentum resolution change only 1% and at 190 keV/c**

Still have to confirm the spatial resolution

How to measure spatial resolution ?



1. Measured Time or drift time → DAQ
2. Drift distance (R_{data}) = drift velocity x drift time
3. Error of measurement of R_{data}



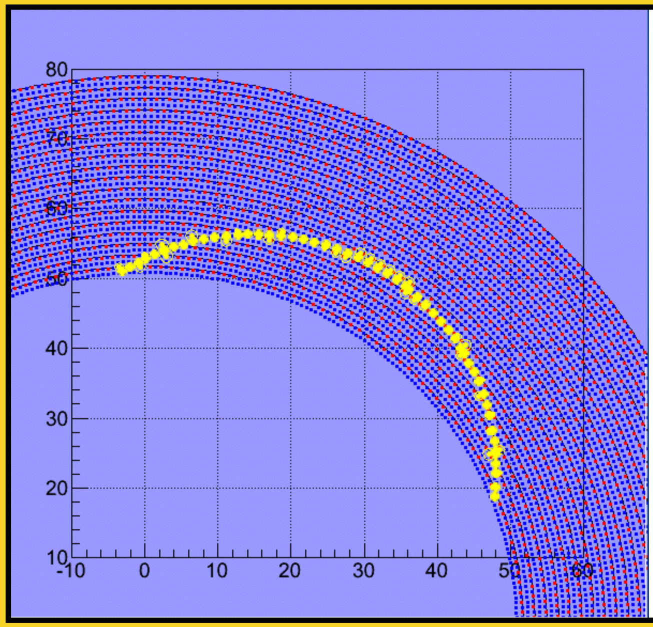
R_{data} : Measured drift distance

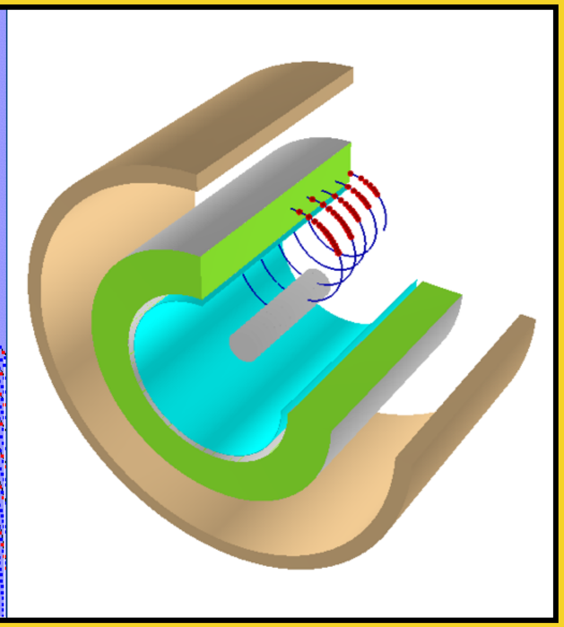
Uncertainty (σ_x) is due to

1. **Primary ions and diffusion**
2. **Electronics**

Cylindrical Drift Chamber

- ➡ 20 sensitive layers with alternating stereo angles of +- 4 degrees
  - ➡ Stereo wire to recover Z information
- ➡ Sense wires: Gold plated tungsten 25 μm
  Field wires: Aluminium 126 μm





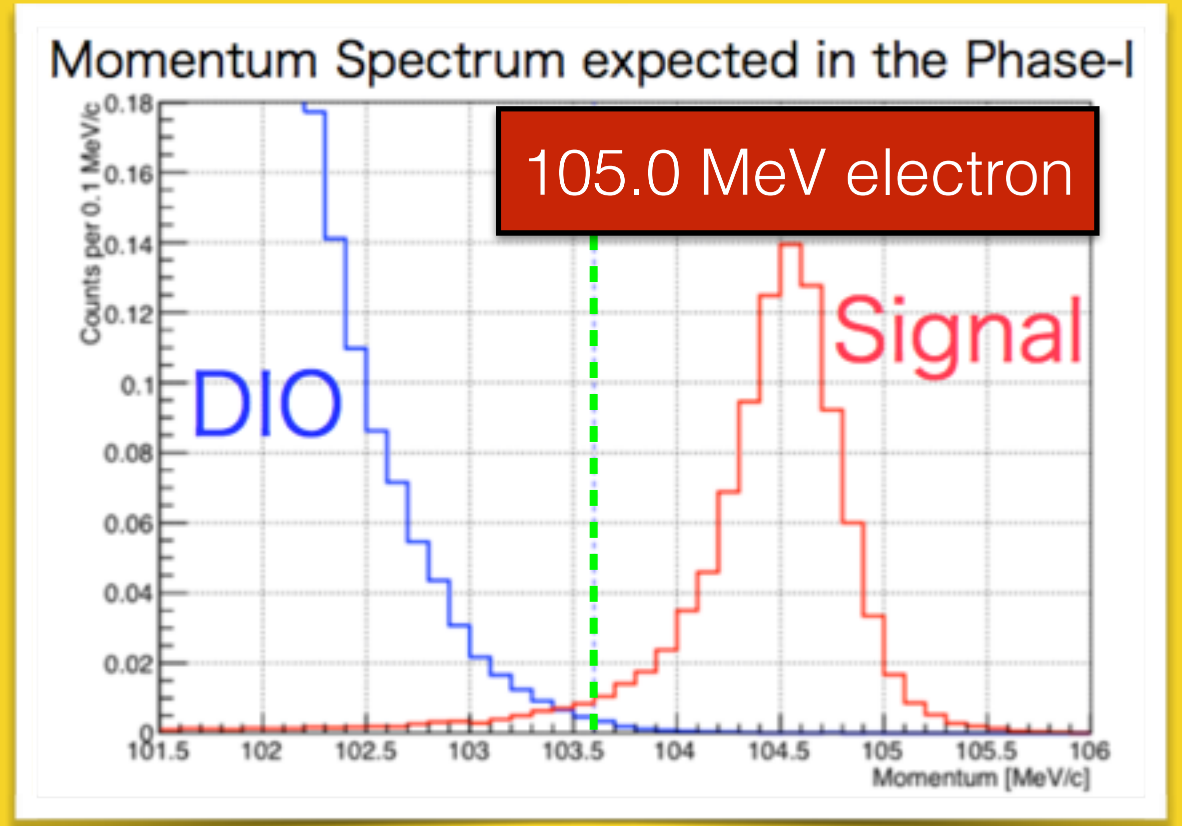
Signal and background

- **Momentum resolution: 200 keV/*c***

$$\left(\frac{\sigma_{Pt}}{Pt}\right)^2 = (aPt)^2 + (b)^2$$

$$a = \frac{\sigma}{0.3BL^2}\sqrt{\frac{720}{N+5}}$$

Position resolution



$$b = \frac{0.054}{LB}\sqrt{\frac{L}{X_0}}\left[1 + 0.038 ln\frac{L}{X_0}\right]$$

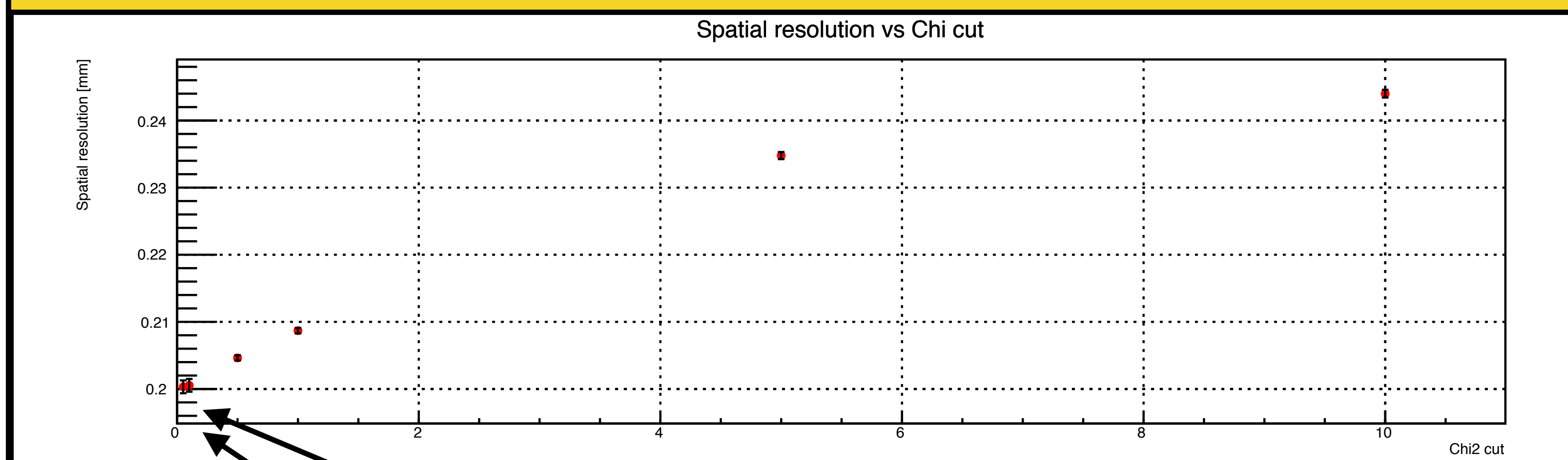
B: Magnetic field strength
L: Size of the chamber
σ: Position resolution
N: Number of measurement points
X0: Radiation length in gas volume
Pt: Transverse momentum

[1] reference from PDG

Curved tracks

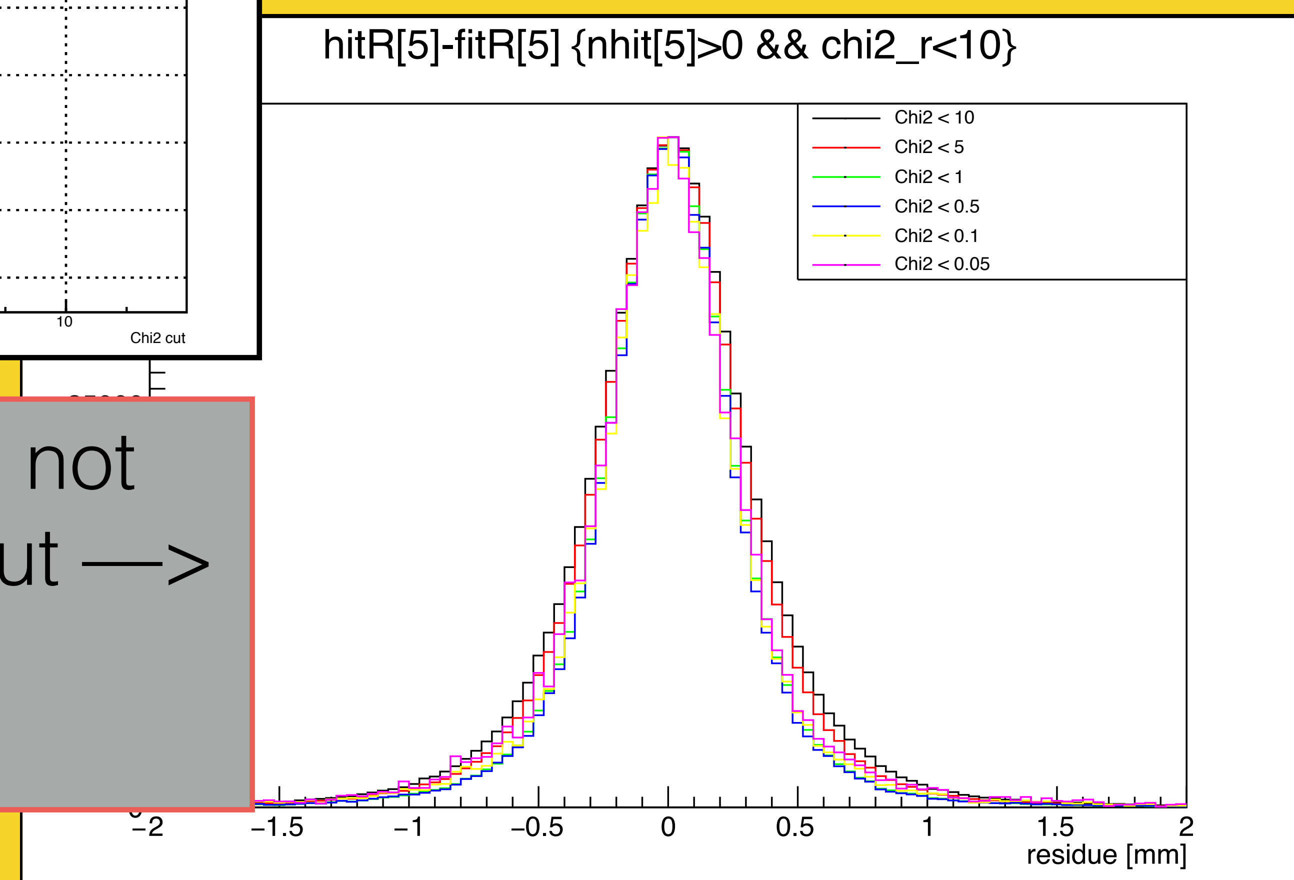
In 1T magnetic field, straight line fitting approximation

- **It consist of straight and curved tracks**
- **High energy particle are selected by X^2**

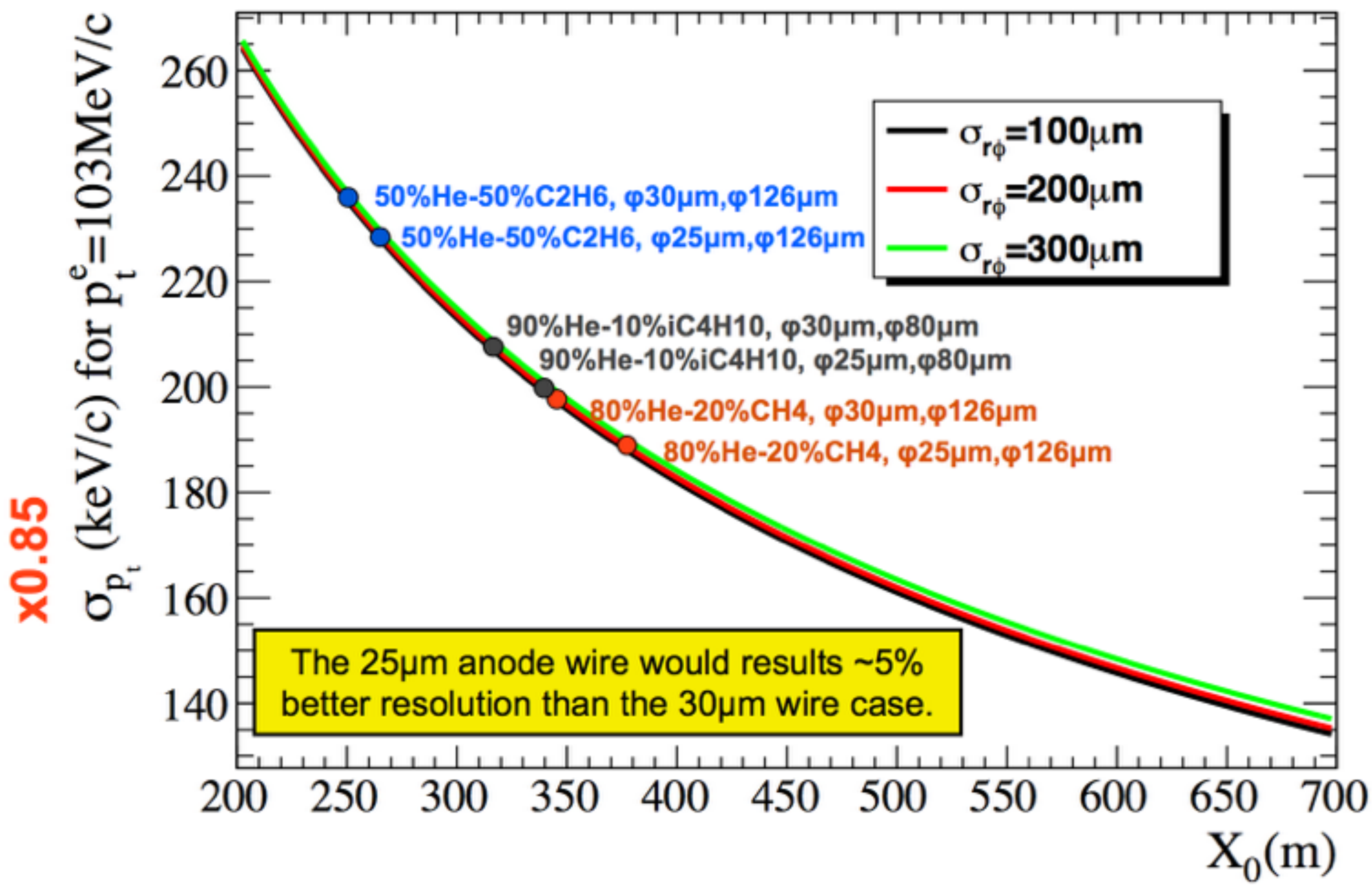


Two points of spatial resolution does not change much with even tighter X2 cut —>

Almost all of them are straight lines



σ_p vs X_0 for 30μm and 25μm



Rough estimation of σ_p

Accuracy on momentum measurement

$$\left(\frac{\sigma_{Pt}}{Pt}\right)^2 = (aPt)^2 + b^2$$

$$a = \frac{\sigma_{r\phi}}{0.3BL^2}\sqrt{\frac{720}{N+5}} \qquad b = \frac{0.054}{LB}\sqrt{\frac{L}{X_0}}\left[1 + 0.038\ln\frac{L}{X_0}\right]$$

Spacial resolution **Multiple scattering**

B : Magnetic field strength (Tesla)
L : Measurement lever ar (m) m (Size of chamber)
$\sigma_{r\phi}$: Measurement error for each point (m)
N : Number of measurement points
X_0 : Radiation length in gas volume (m) (material)
Pt : Transverse momentum (GeV/c)

Slide from Prof. Uno (BelleII CDC, KEK)

- The multiple scattering term is dominant for 100MeV/c electrons in the COMET-CDC.