# Drift Chamber for CEPC the 4th Conceptual Detector

Linghui Wu

For CEPC the 4th conceptual drift chamber working group

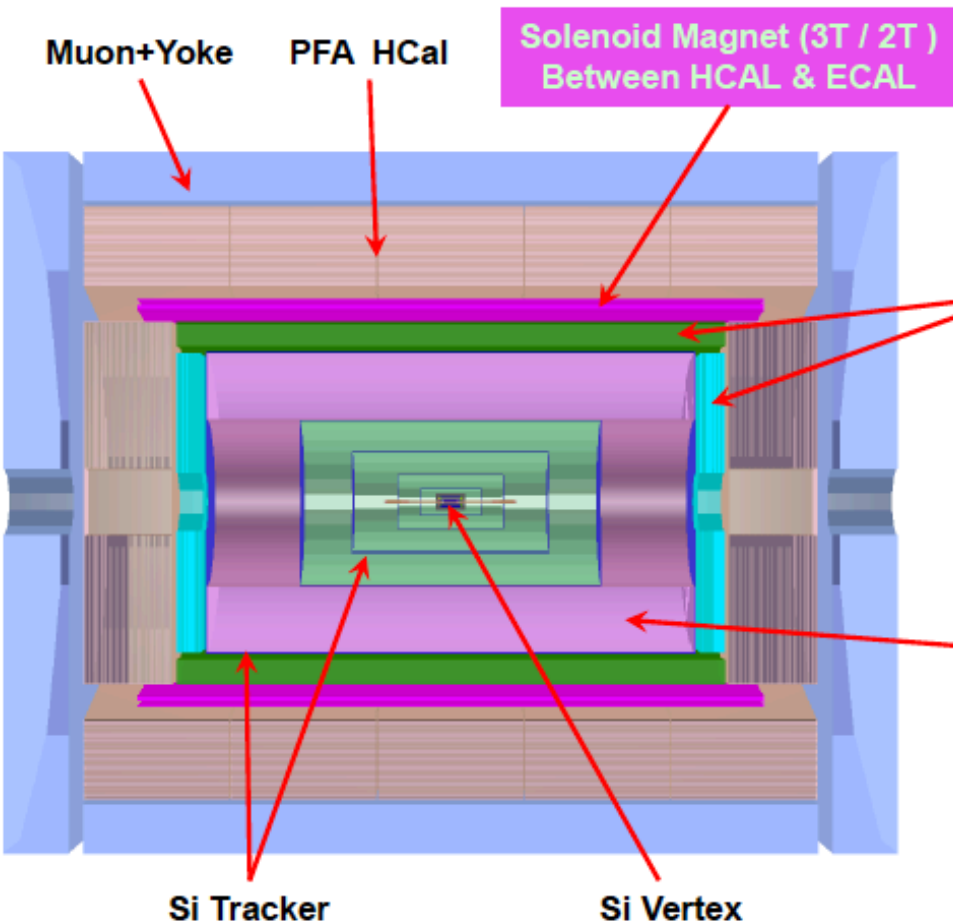
CEPC Day,  Oct 28, 2021

# Outline

- Introduction
- Study of PID
- Fast simulation of momentum resolution
- Estimation of mechanical parameters
- Software development in CEPCSW
- Summary

# Introduction

## The 4th conceptual detector design




**Advantage:** the HCAL absorbers act as part of the magnet return yoke.

**Challenges**: thin enough not to affect the jet resolution (e.g. BMR); stability.

**Transverse Crystal bar ECAL**

**Advantage:** better $\pi^0/\gamma$ reconstruction.

**Challenges**: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

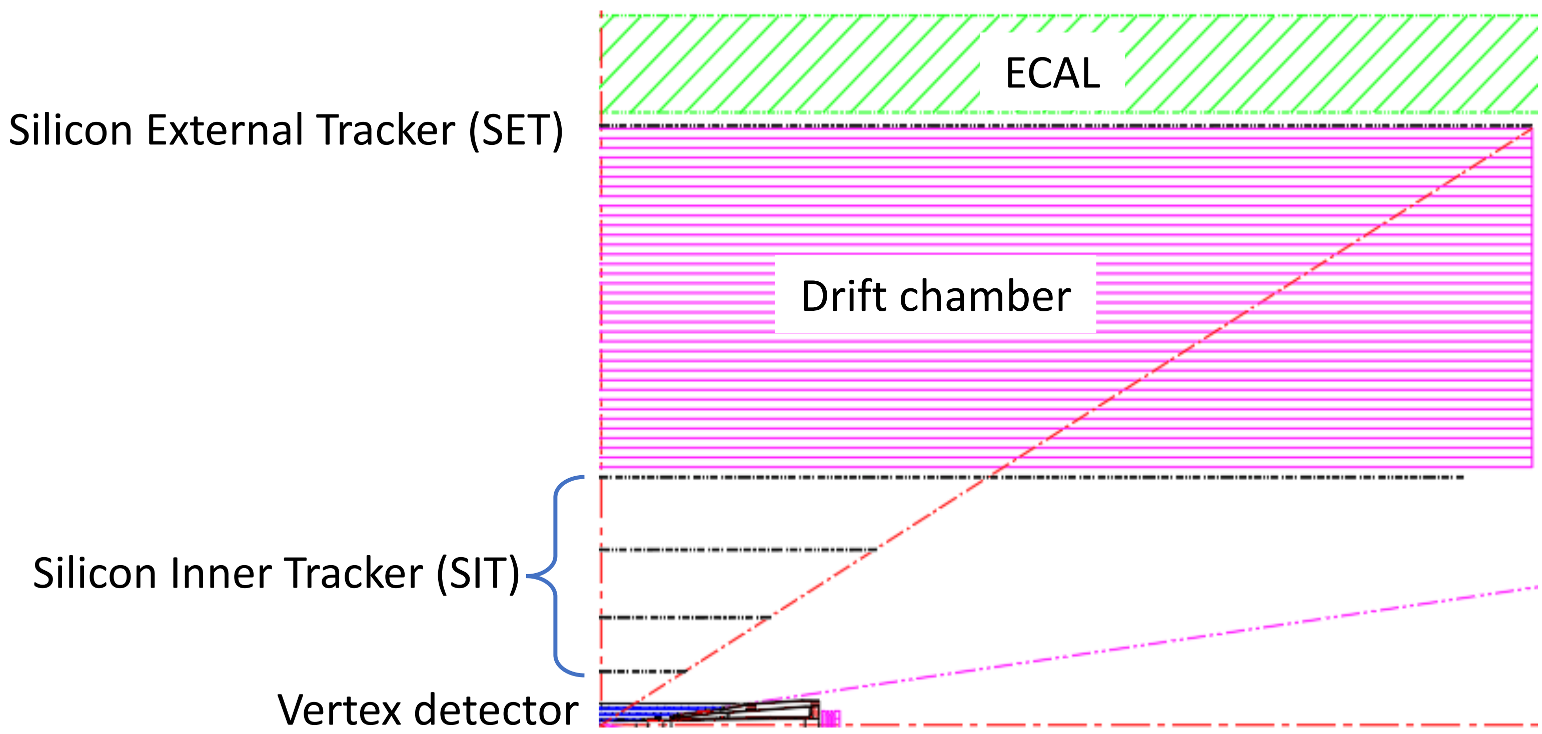
**Drift chamber that is optimized for PID**

**Advantage:** Work at high luminosity Z runs

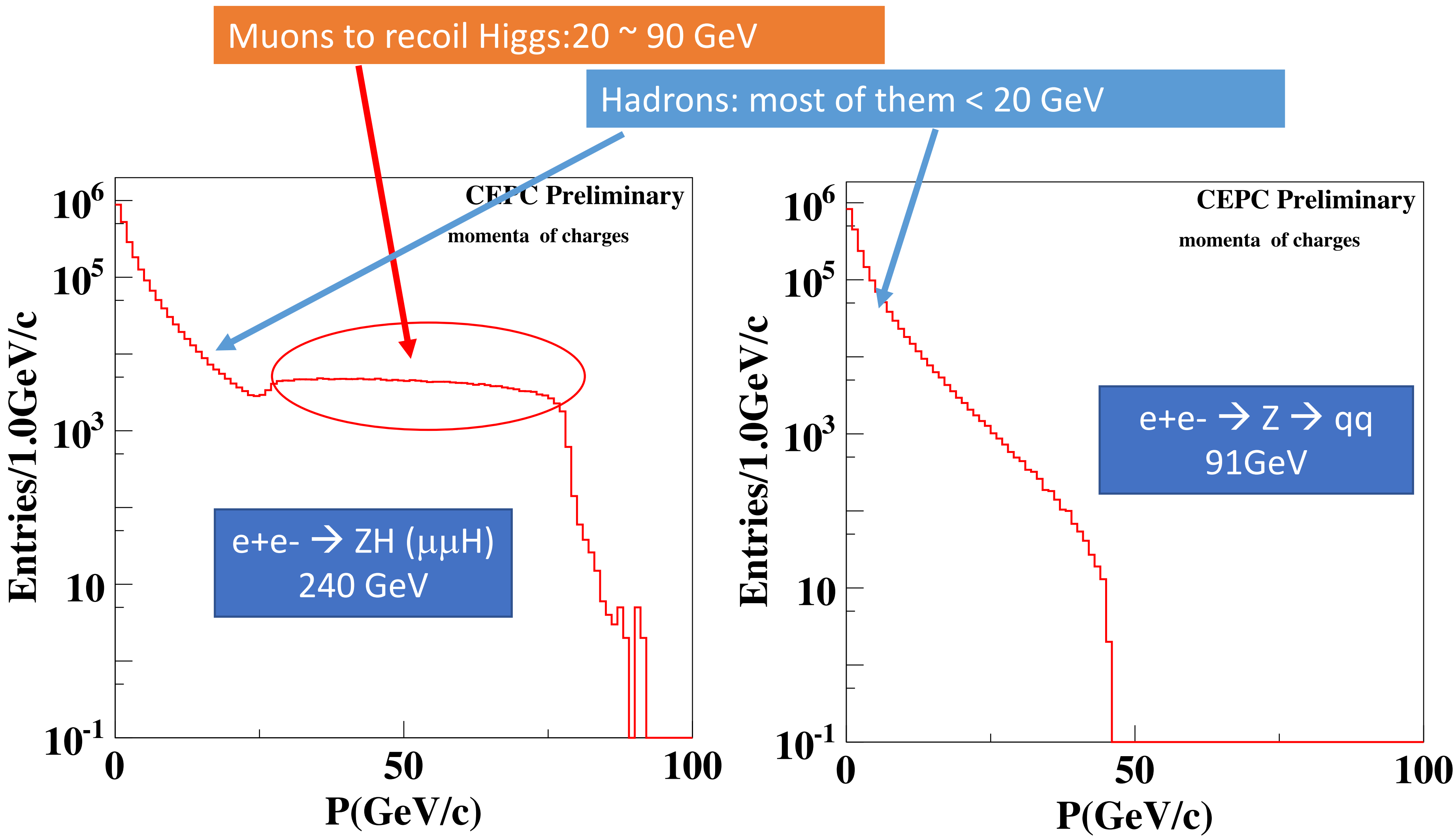
**Challenges**: sufficient PID power; thin enough not to affect the moment resolution.

# Tracking system

- A design of tracker combined with silicon tracker and drift chamber
- Applying cluster counting technology in the drift chamber to provide excellent PID
  - Better than 2$\sigma$ separation of K/$\pi$ at momentum up to ~20 GeV/c



# Momenta of tracks @ 240 & 91 GeV



# Requirements of drift chamber

dN/dx resolution: $\frac{\sigma_{dN/dx}}{dN/dx} \propto \frac{1}{\sqrt{L \cdot \rho_{cl} \cdot \varepsilon}}$

$P_T$ resolution: $\frac{\sigma P_T}{P_T} = a \cdot P_T \oplus \frac{b}{sin^{1/2}\theta}$

$\frac{\sigma P_T}{P_T}|_{Res.} = \frac{\sigma_{r\phi} P_T}{0.3BL^2}\sqrt{\frac{720}{N+5}}$ $\frac{\sigma P_T}{P_T}|_{MS} = \frac{0.0136\,(GeV/c)}{0.3\beta BL}\sqrt{\frac{X}{X_0 \sin\theta}}$

- Sufficient sampling track length $L$ for PID and tracking
- High primary ionization density $\rho_{cl}$ taking into account cluster counting efficiency $\varepsilon$
- Low material budget $X/X_0$ to minimize the impact of multiple scattering to momentum and impact parameter resolutions

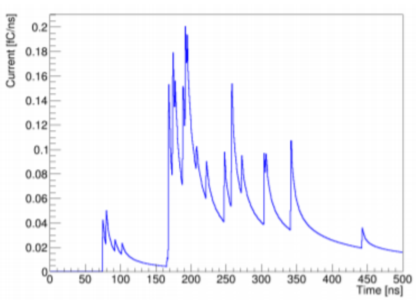
# Study of PID

- Performance study with full simulation
- Fast simulation for PID efficiency
- Simulation study of gas mixtures
- Prototype test

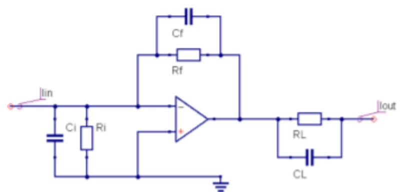
# Performance study with full simulation

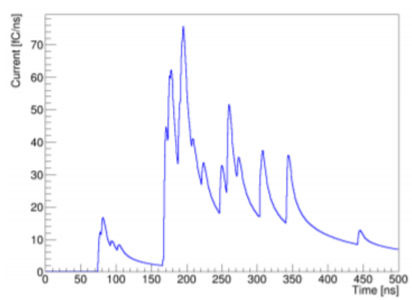
## Induced current from Garfield++

<u>Gas composition:</u> He 90% + $iC_4H_{10}$ 10%
<u>Cell size:</u> 1x1 cm
<u>Particle:</u> 10 GeV/c pions, $\theta$ = 90 deg
<u>Average $N_{cl}$:</u> ~16.5



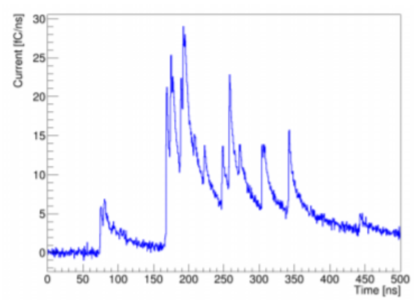

## Simulation of preamplifier




## Simulation of noises

- Add white noises to the raw current signal



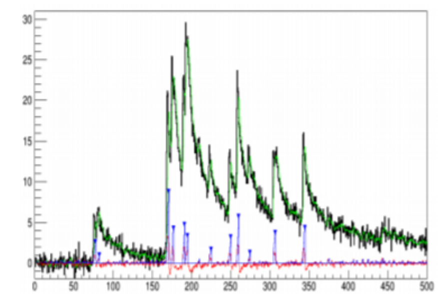

## Peak finding analysis

- <u>Moving average (MA) filter:</u>

$$\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} S[i-k] \text{ (smoothing)}$$

- <u>First difference (D1) filter:</u>

D1[i] = MA[i] – MA[i – 1]



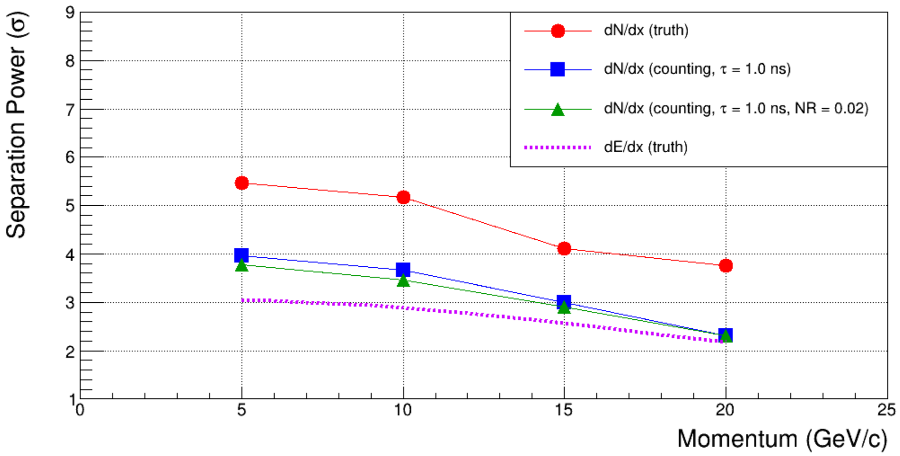
Take into account the impact on cluster counting efficiency $\varepsilon$ and try to optimize $\varepsilon$

- Sampling rate
- Rise time of electronics
- Noise
- Peak finding algorithm

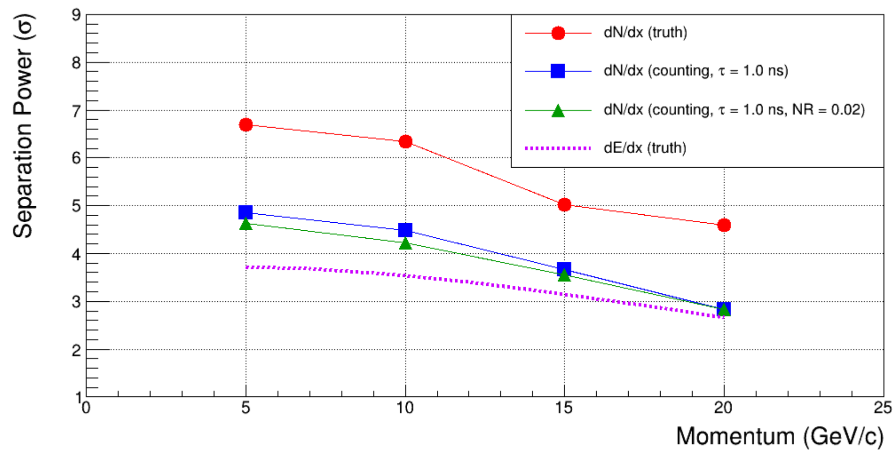
$$\frac{\sigma_{dN/dx}}{dN/dx} \propto \frac{1}{\sqrt{L \cdot \rho_{cl} \cdot \varepsilon}}$$

# Preliminary results of K/π separation power

## 100 layers ($R_{DC}$ from 0.8 to 1.8m)




## 150 layers ($R_{DC}$ from 0.3 to 1.8m)




Cell size: 1cm ×1cm,
Gas mixture: 90% He + 10% iC4H10
Sampling frequency : 2GHz

Separation power

$$S = \frac{\left|\left(\frac{dN}{dx}\right)_\pi - \left(\frac{dN}{dx}\right)_K\right|}{(\sigma_\pi + \sigma_K)/2}$$

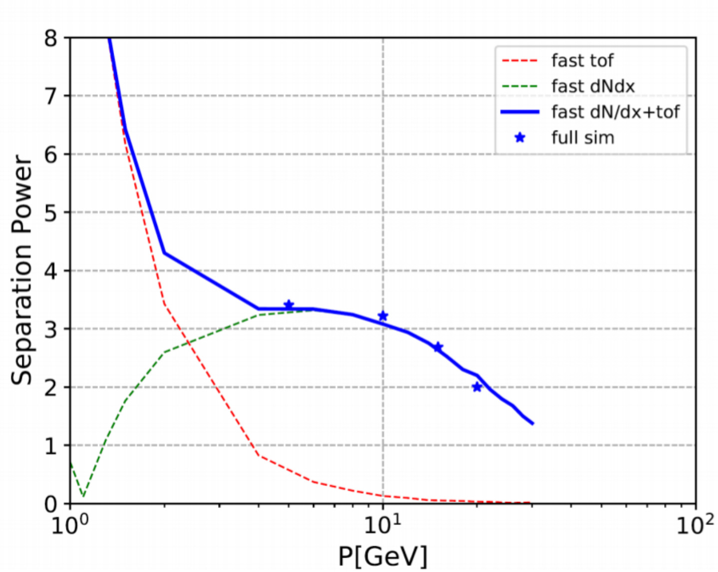
K/π separation up to 20 GeV/c :

- better than 2σ with 100 layers
- better than 3σ with 150 layers

# Fast simulation of PID performance

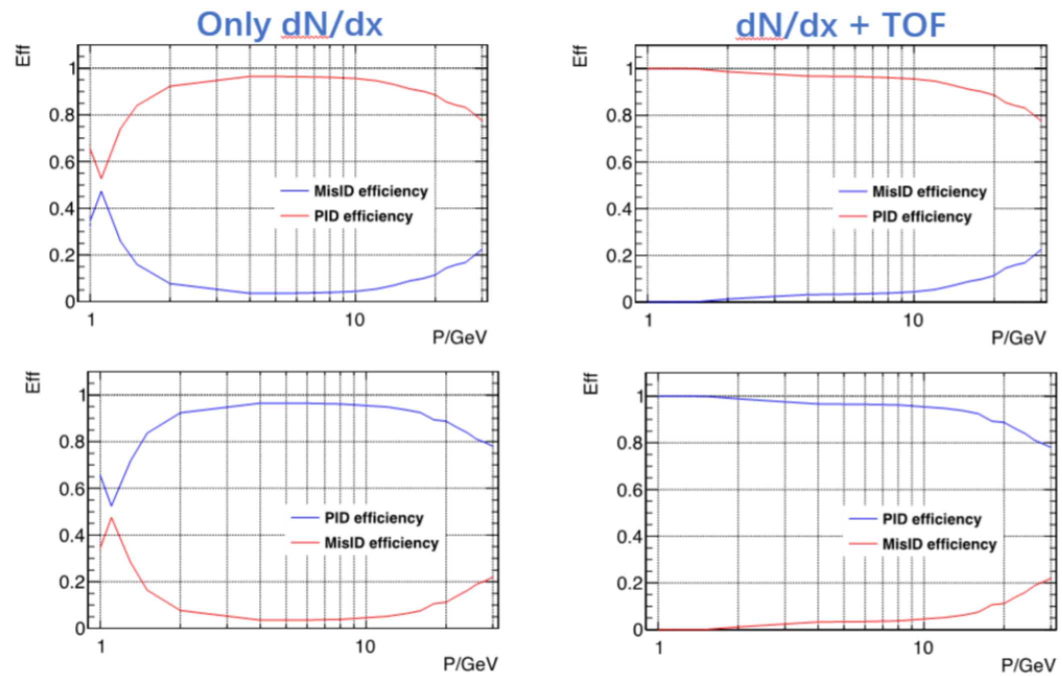
## K/π Separation power

($R_{DC}$ from 0.8 to 1.8m)




## PID efficiency

($R_{DC}$ from 0.8 to 1.8m)



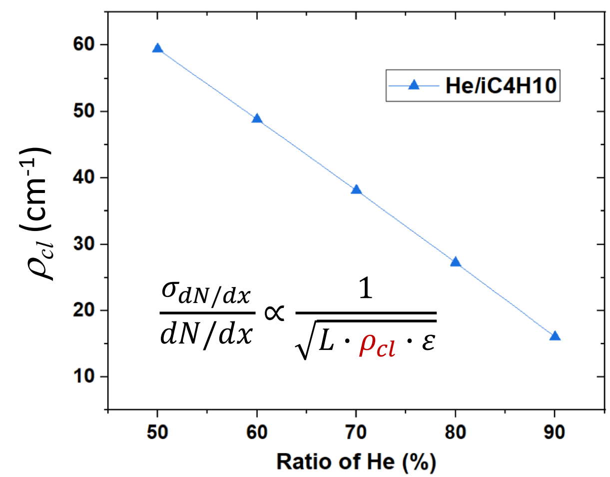

For K and π up to 20 GeV/c

- PID efficiency > 90%
- Misidentification rate < 10%

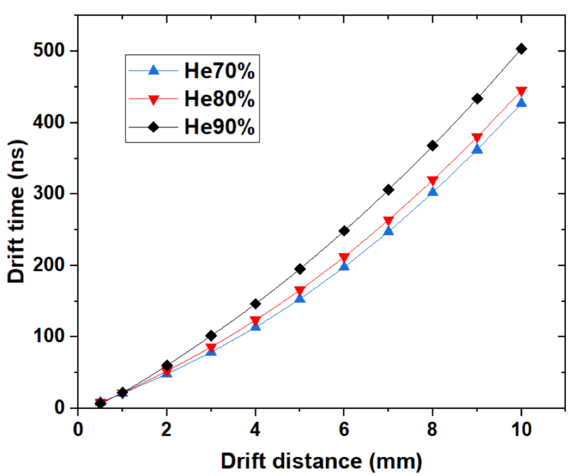
# Simulation of gas mixtures

- choice of the gas mixture is essential
    - High cluster density compatibly with cluster counting efficiency
    - Low drift velocity helps to identify clusters in time
    - Small longitudinal diffusion is beneficial to both spatial resolution and dN/dx measurement
- Simulation of gas mixture performed to understand the gas property and optimize the working point

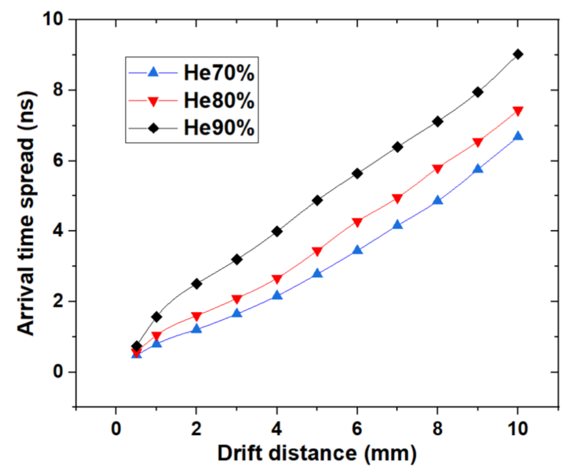
Cluster density vs ratio of He



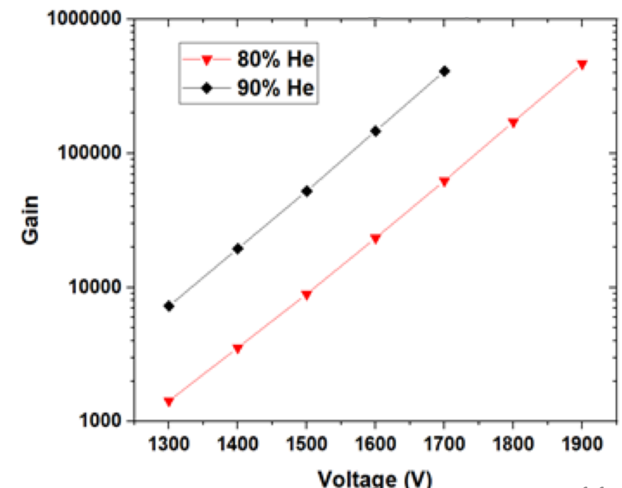

Drift time vs drift distance




Diffusion effect vs drift distance

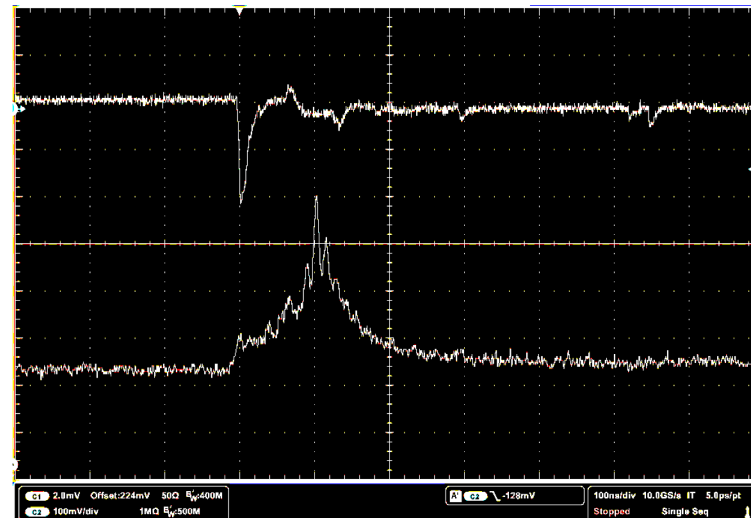



Gain vs H.V.

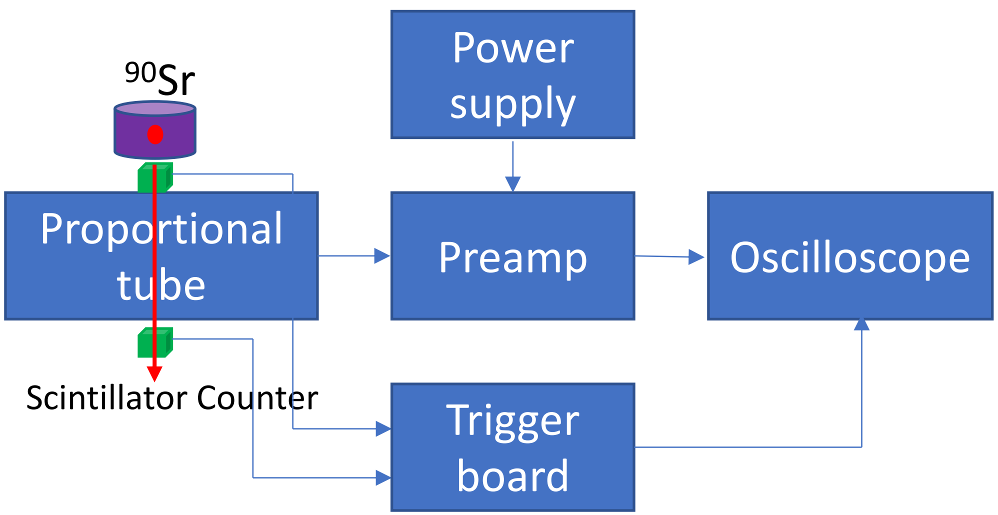


# Prototype test

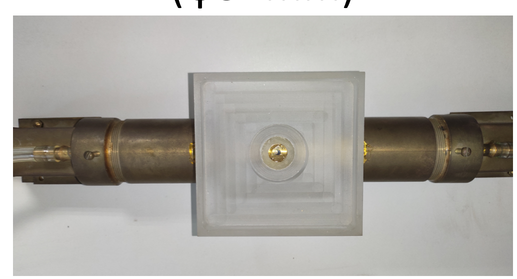
- Prototype test to validate and optimize simulation parameters (ongoing)
- Coincidence of scintillator counters provides trigger and constraint of incident track angle



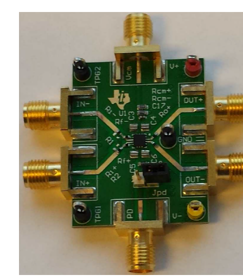
  - Gas: 80% He + 20% $iC_4H_{10}$
  - **Preamplifier: LMH5401 evaluation module**
    - Gain bandwidth product (GBP): 8 GHz
    - Gain : 12 dB (4 V-V), $R_f$: 127 Ω




Proportional tube (ϕ32mm)



Preamplifier



# Fast simulation of momentum resolution

- Software tool : LDT (LiC Detector Toy) arXiv:0901.4183v1

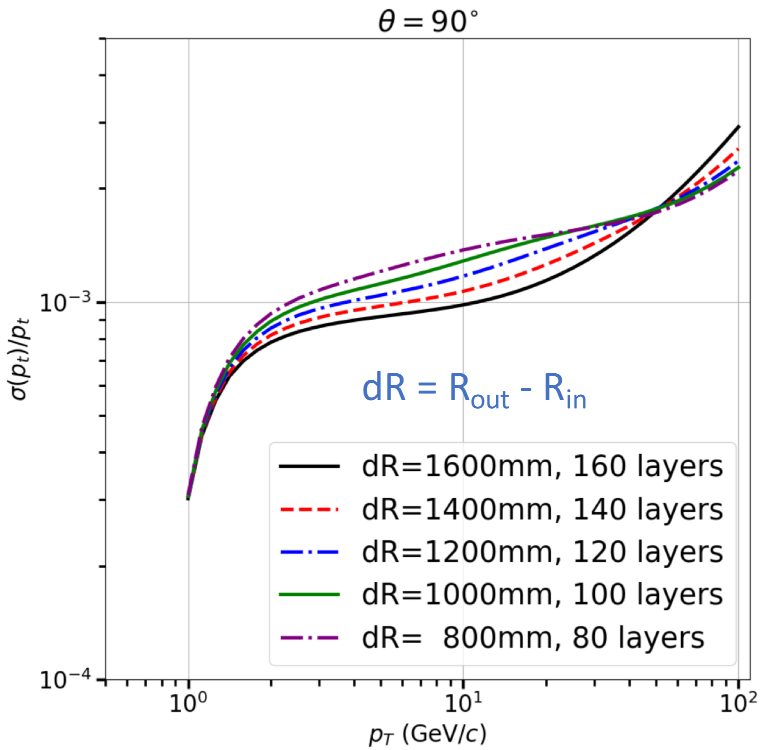
## Parameters for fast simulation

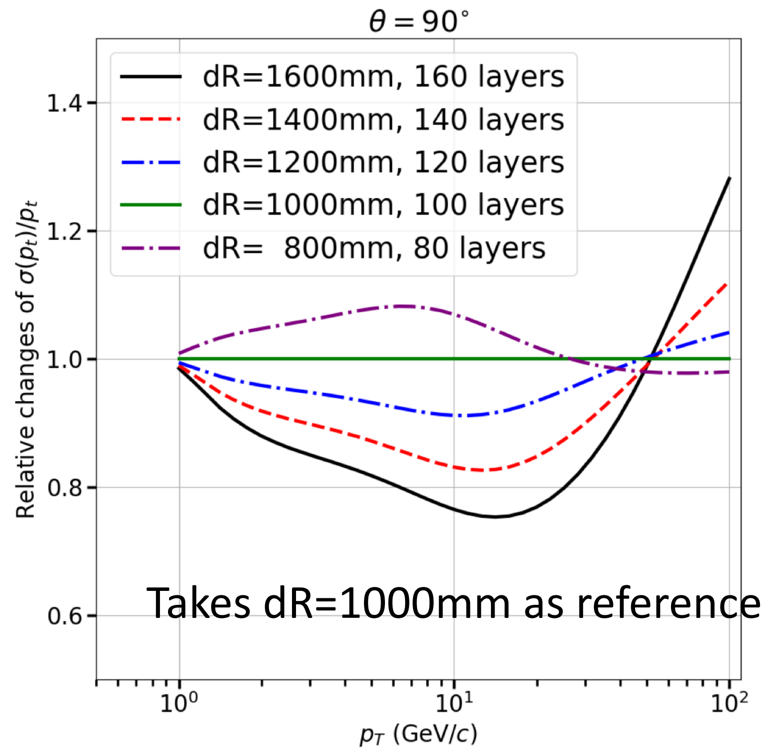
| Sub detector | # layers | R (mm) | Resolustion (μm) | | Material (%$X_0$) |
|---|---|---|---|---|---|
| | | | r-φ | z | |
| Beam pipe | 1 | 14(10) | --- | --- | 0.15 |
| VXD | 6 | | 2.8/6/4/4/4/4 | 2.8/6/4/4/4/4 | 0.15/layer |
| VXD shell | 1 | 65 | --- | --- | 0.15 |
| SIT | 3 or 4 | | 7.2 | 86.6 | 0.65/layer |
| DC inner wall | 1 | --- | --- | --- | 0.104 |
| DC sense layer | --- | --- | 100 | 2000 | 0.0116/layer |
| DC outer wall | 1 | 1800 | -- | --- | 1.346 |
| SET | 1 | 1810 | 7.2 | 86.6 | 0.65 |

Total X/X0 ~ 7% for 100 DC layers

# Scanning of DC dimension

- Cell size fixed (10mm * 10mm)
- Larger DC volume means more layers
- Sensitive to p<40 GeV

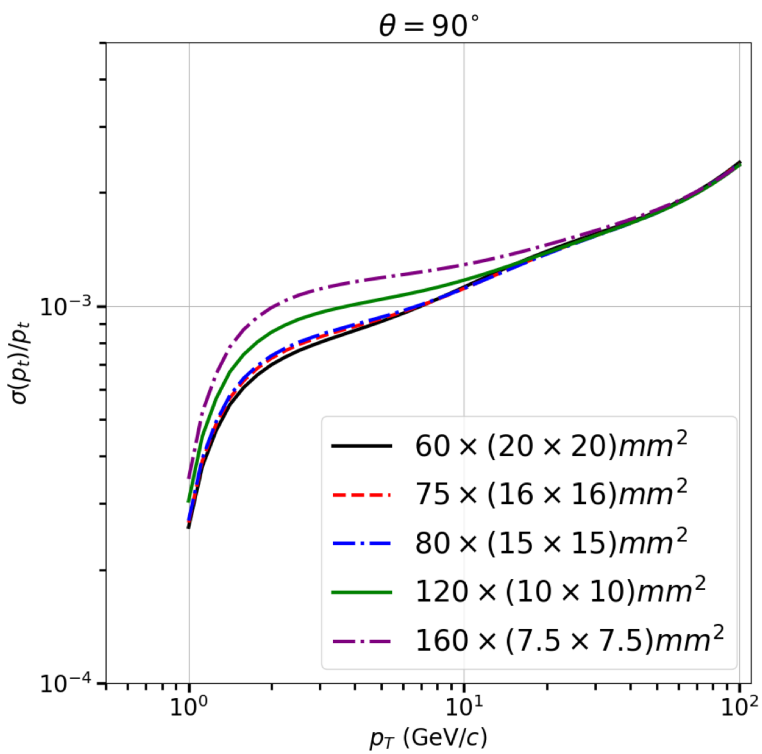


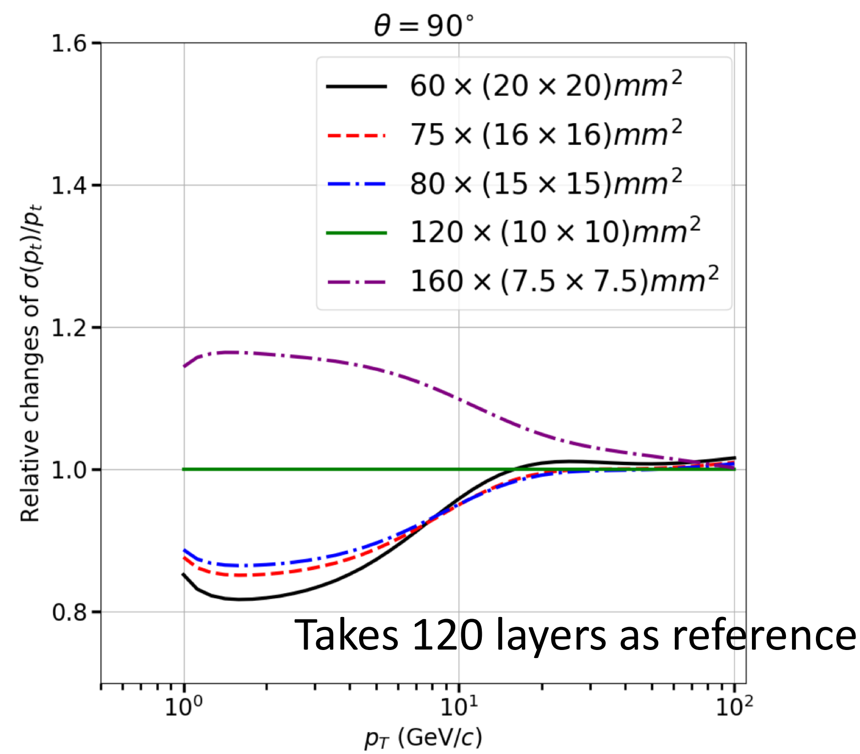




- Larger DC volumes achieve better momentum measurement in low pt region (critical point ~ 40 GeV)
- dR=1200mm (600 ~ 1800 mm) might be a good choice with consideration of PID and $P_T$ resolution

# Scanning of number of DC layers

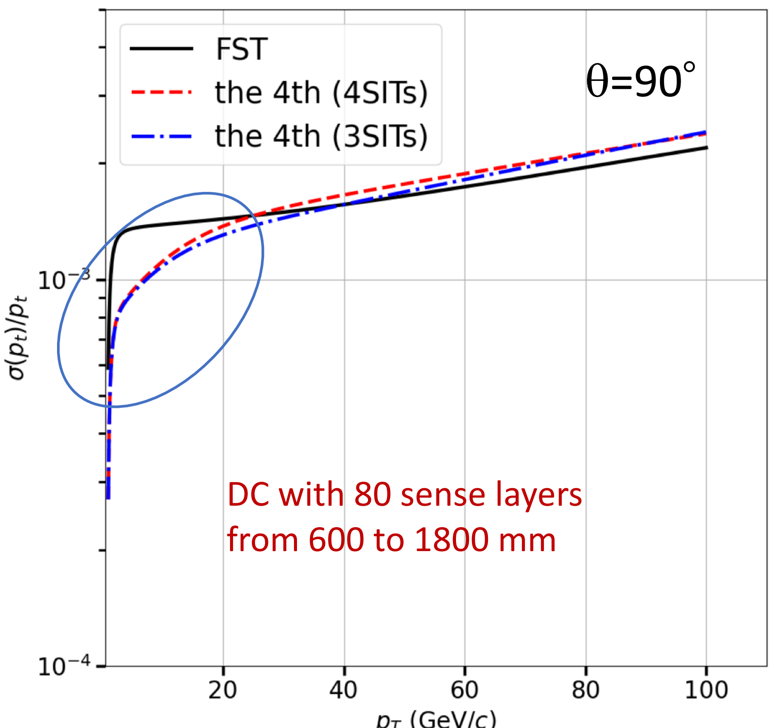
- DC dimension fixed (600 ~ 1800 mm)
- Less DC layers means larger cell
- Affects $P_T$ resolution ~ 10% in [0-10] GeV range

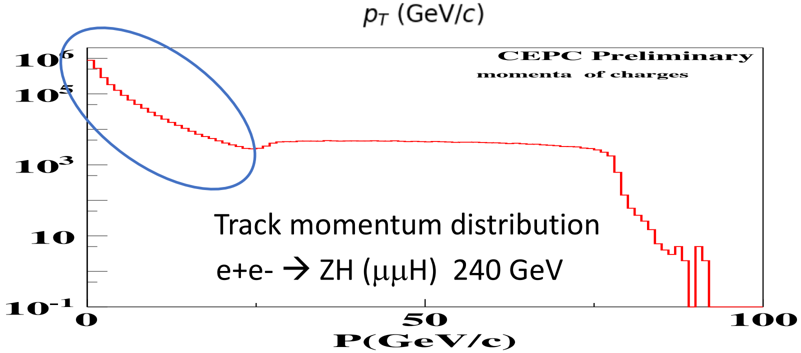



- Less layers achieve better momentum measurement
- Optimization of cell size ongoing with consideration of diffusion effect and mechanical design

# Comparison with FST design in CDR




$$\frac{\sigma P_T}{P_T} = a \cdot P_T \oplus \frac{b}{\sin^{1/2}\theta}$$

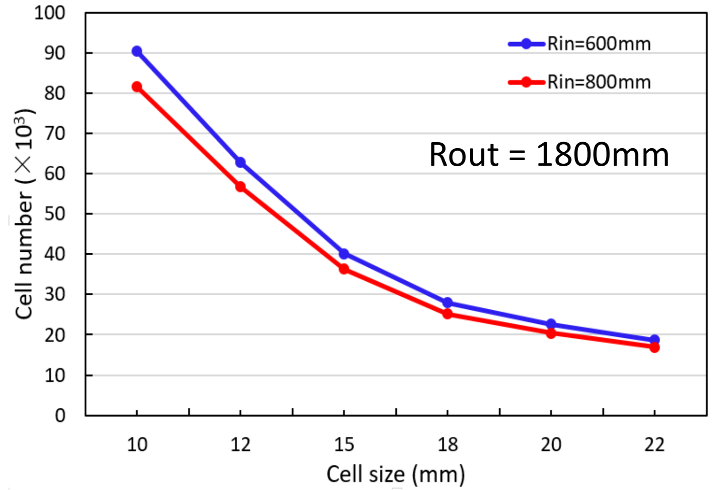
| Tracker design | X/X0 (%) | $P_T$ resolution | |
|---|---|---|---|
| | | a ( x $10^{-5}$) | b ( x $10^{-3}$) |
| FST | 5.11 | 1.67 | 1.37 |
| The 4th with 4 SITs | 8.22 | 1.96 | 0.80 |
| The 4th with 3 SITs | 7.57 | 1.80 | 0.81 |

- Compared with FST, $P_T$ resolution
  - improved significantly in low momentum range
  - degraded slightly (~8%) in high momentum range
- 3 SITs design is slightly better than 4 SITs design

# Estimation of mechanical parameters

- Rough estimation of mechanical parameters performed
- Further optimization of DC parameters should take into account mechanical design
- More work ongoing

Number of cells vs cell size

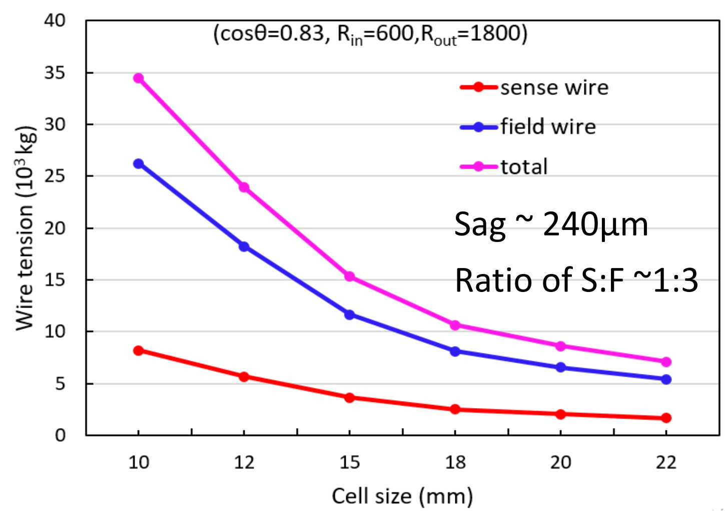



Length of wire vs coverage of barrel section

(Rout = 1800 mm)

| cosθ | 0.80 | 0.81 | 0.83 | 0.85 |
|---|---|---|---|---|
| Length of wire (mm) | 4800 | 4972 | 5357 | 5809 |

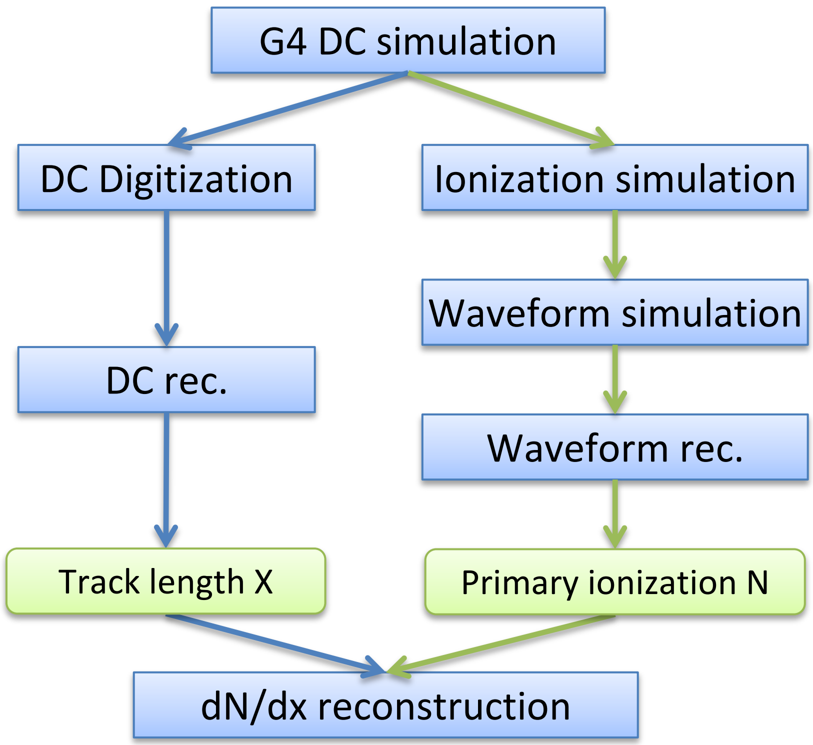
Wire tension vs cell size



# Software development in CEPCSW

- ➢ The drift chamber software has been developed from scratch
- ➢ dN/dx simulation is in progress

- CEPCSW
  - Gaudi based framework
  - External libraries and tools
- Geometry and field map
  - DD4hep
  - Non-uniform magnetic field: **done**
- Data model
  - EDM4hep and FWCore
  - dN/dx event model: in progress
- Drift chamber
  - DC Simulation: **done**
  - DC Digitization: **done**
  - dN/dx simulation: in progress
  - dN/dx reconstruction: in progress
  - Track fitting with measurement: **done**



# Collaboration & Regular meetings

## Cluster counting regular meeting

Called by Franco & Linghui

Physics and Detector Meetings » Tracker » Drift Chamber

### Drift Chamber

October 2021

- 15 Oct Meeting on cluster counting in drift chambers

September 2021

- 30 Sep Meeting on cluster counting in drift chambers
- 16 Sep Meeting on cluster counting in drift chambers

**Participants from:**

- IHEP
- INFN
- Shandong University
- Jilin University
- BINP

## Tracker layout optimization discussion

Called by Gang & Linghui

CEPC » Physics and Detector Meetings » Physics and Simulations » Tracking

### Tracking

October 2021

- 15 Oct Tracker Discussion

September 2021

- 24 Sep Tracker Discussion
- 17 Sep Tracker Discussion

**Participants from:**

- IHEP
- Lancaster University
- Jilin University
- Shandong University
- Nanjing University

# Paper

**Paper in writing**

### 6.3 Charge Particle Identification

4p by Mingyi, Xin, Guang

PID Introduction and requirements:

Good hadron separation is essential for momentum up to 10 GeV/c, extremely useful in the 10-20 GeV/c range.

#### 6.3.1 General design

Drift chamber mainly provides PID capability, could also benefit track and momentum measurement.

Physics design and structure design. Key parameters:

(1)Thickness (layers): good dN/dx resolution and sufficient PID power

(2)Location and dimension (Inner/outer radius, length): not to affect tracker performance

(3)Low material budget

Cluster counting technique will be adopted for energy loss measurement, measuring the number of primary ionization (Poisson distribution) over the track. It is less sensitive to Landau tails. Resolution and separation power with dN/dx will be significantly improved.

### 6.4 Optimization of The Tracking System

3p by Linghui, Gang

Simulation study is performed to optimize the layout of the tracker system, including the locations and size of each sub-detector, the number of layers, the cell size of the drift chamber, and so on. Fast simulation is useful to achieve a quick evaluate the impact of each parameter to the tracking performances.

#### 6.4.1 Fast simulation for tracker layout

The simulation of PID performance shows that the thickness of the drift chamber should be at least 1 meter to provide sufficient particle identification power. In this study, the baseline value of the DC thickness is assumed to be at least 1 m, the cell size is chosen as a larger one, i.e, $2 \times 2$ $cm^2$, since the to the PID performance is not sensitive to the cell size in the cluster-counting method. Table 6.2 shows the spatial resolutions and the material budgets of the tracking system which are uses in the simulation, where the total material budget at $\theta = 90°$ is about 7%.

# Summary

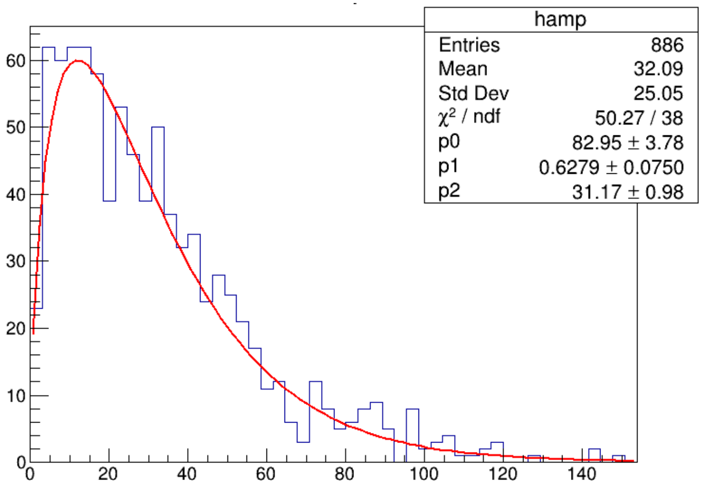
- Simulation study for PID shows with DC thickness more than 1m
  - K/π separation up to 20 GeV/c
  - PID efficiency > 90% For K and π up to 20 GeV/c
- Protype test ongoing
- Fast simulation of tracking shows
  - DC from 0.6 to 1.8m with 3 SITS is a favorable choice
- Further optimization ongoing
  - Cell size, gas mixture …
- Software development going well

***Thanks!***

***Comments and suggestions are welcome!***

# Backup

Single pulse amplitude




$$\text{Noise level} = \frac{\boldsymbol{Noise\ R.M.S}}{\boldsymbol{Single\ pulse\ amplitude}}$$