Drift Chamber for CEPC the 4th Conceptual Detector

Shuiting Xin

For CEPC the 4th conceptual drift chamber working group

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Outline

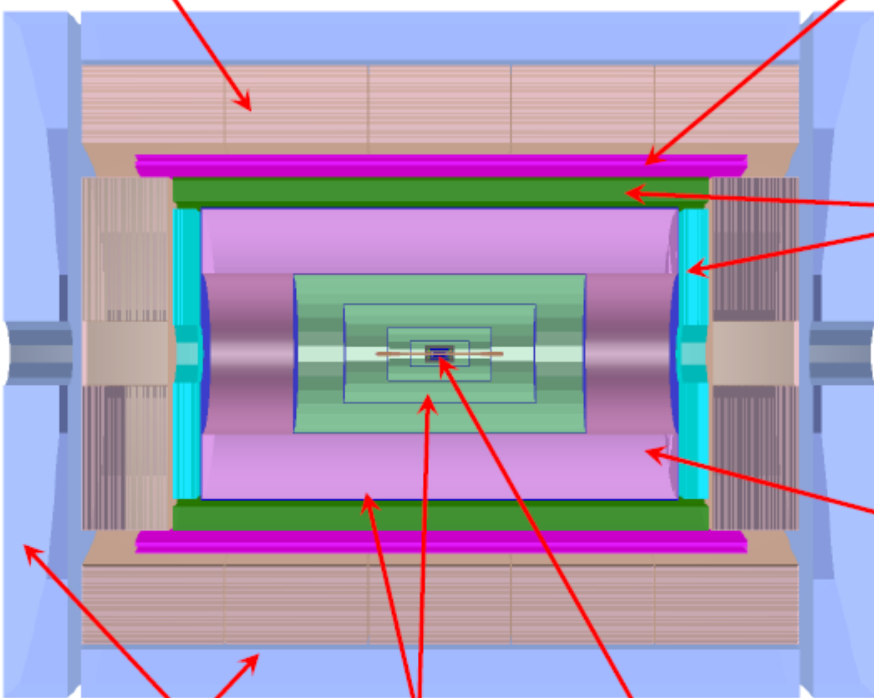
- Introduction
- PID study with simulation
- Prototype test
- Estimation of mechanical parameters
- Summary

Introduction

The 4th conceptual detector design

Scint Glass PFA HCAL

Advantage: Cost efficient, high density
Challenges: Light yield, transparency, massive production.



Solenoid Magnet (3T / 2T)
Between HCAL & ECAL

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

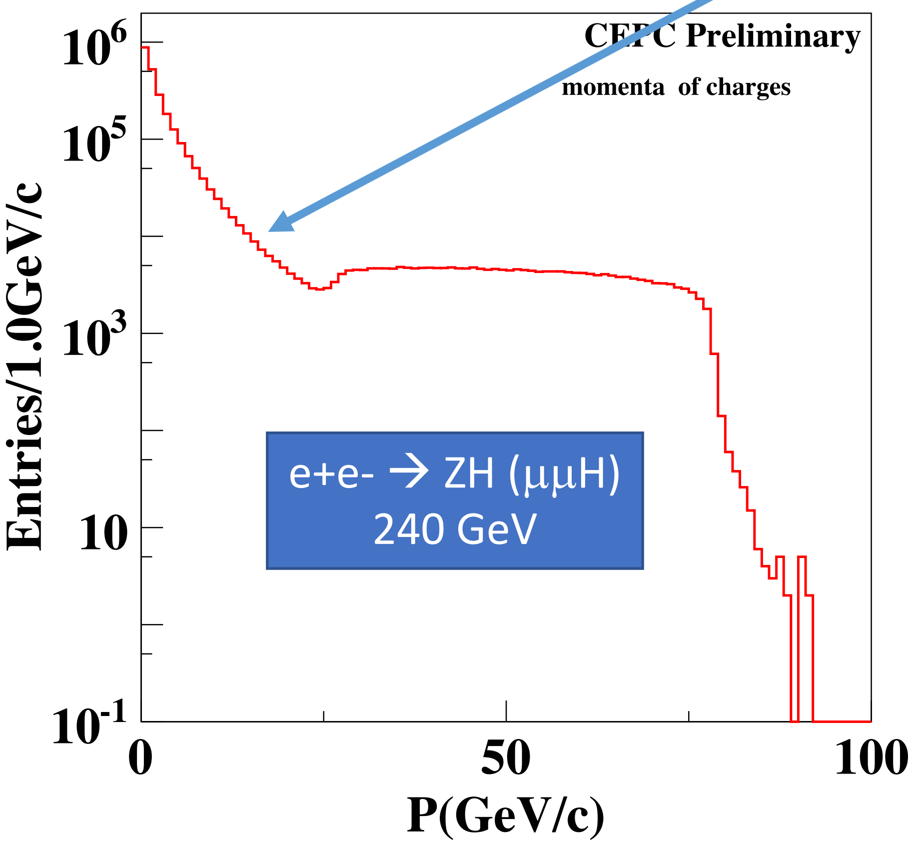
Advantage: better π^0/γ reconstruction.
Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

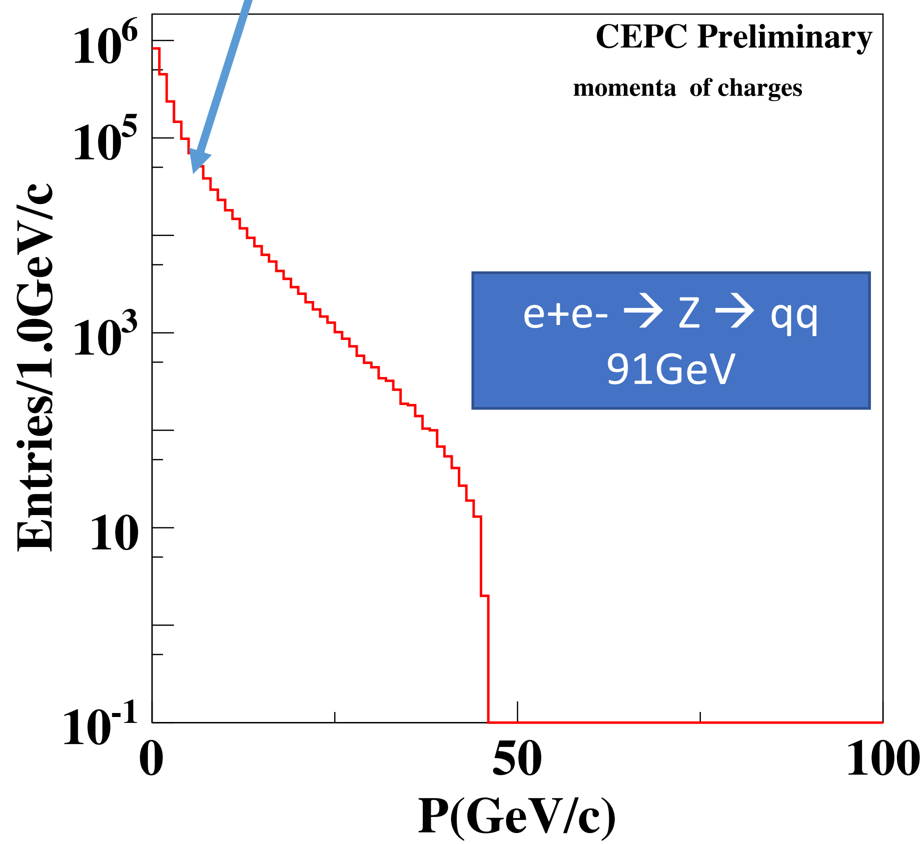
A Drift chamber
that is optimized for PID

Advantage: Work at high luminosity Z runs
Challenges: sufficient PID power; thin enough not to affect the moment resolution.

Momenta of tracks @ 240 & 91 GeV

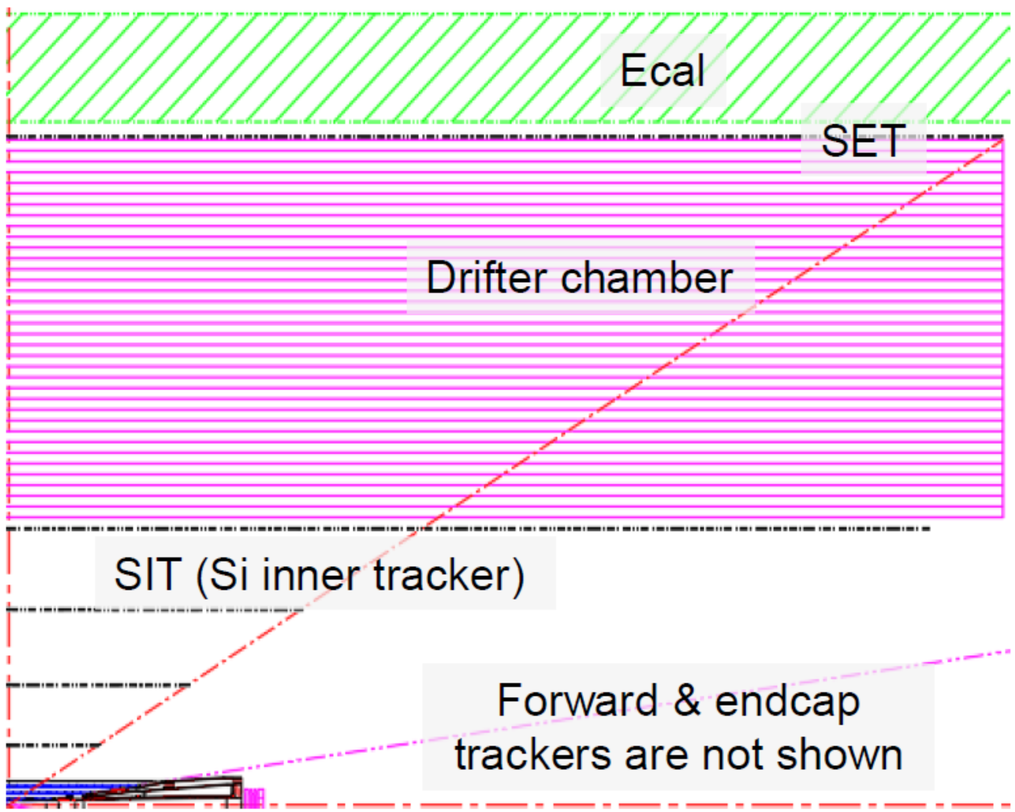
Hadrons: most of them < 20 GeV





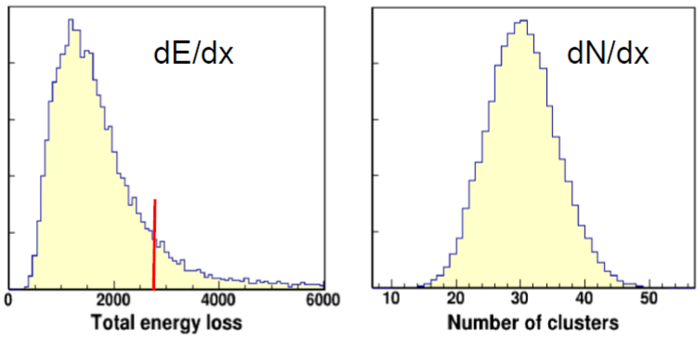
A drift chamber for PID

- A drift chamber (DC) between the Full Silicon Tracker (FST) layers for PID
- To be optimized for PID (better than 2σ K/π separation for P < 20GeV/c)

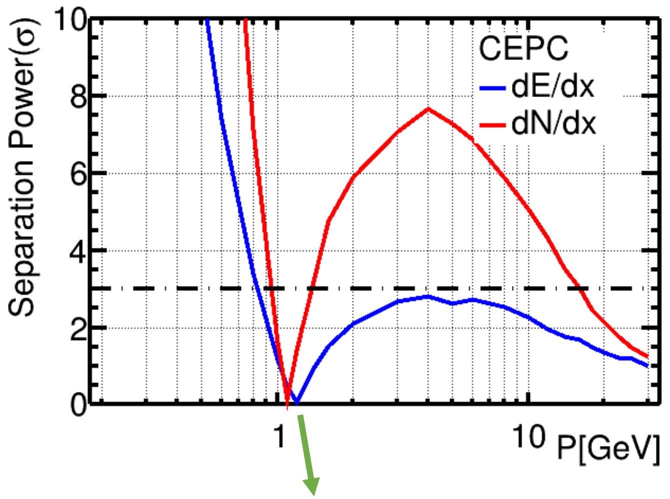


PID with dE/dx vs dN/dx

- Conventionally, dE/dx method is used for PID by measuring energy loss over the track length
  - Usually limited to < 10 GeV
  - One limiting factor is the Landau tail
  - Truncated mean leads to a loss of part of the measured information



- Cluster counting method, or dN/dx, measures the number of primary ionizations, which follow Poisson distribution
  - Less sensitive to Landau tails
  - Significantly improve the separation power



Need a supplementary PID ~ 1 GeV

Key parameters that affects PID

- dN/dx resolution:

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

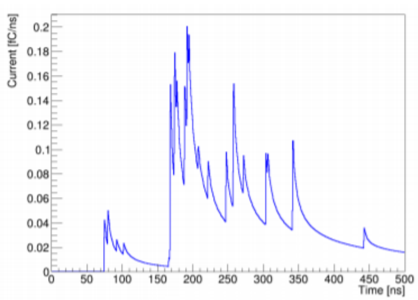
- PID optimization requirement:
  - Low sampling track length L (Sufficient thickness of DC)
  - Large primary ionization density ρ_{cl} (Suitable gas mixture)
  - High cluster counting efficiency ε (Fast front-end electronics and low noise)

- Other concerns
  - Low material budget X/X_0 (minimize the impact of multiple scattering)
  - Location (Inner/Outer radius) (benefit tracking and momentum measurement)

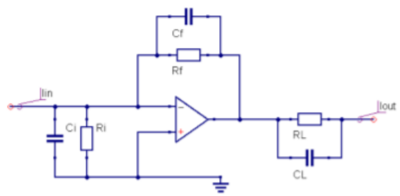
PID study with full simulation

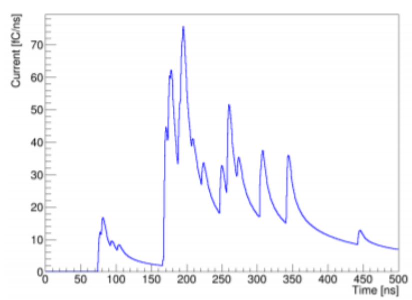
Induced current from Garfield++

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



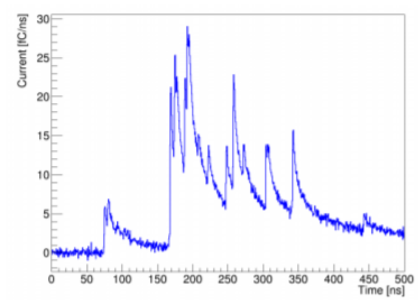
Simulation of preamplifier





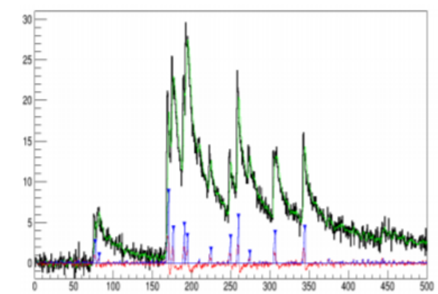
Simulation of noises

- Add white noises to the raw current signal



Peak finding analysis

- <u>Moving average (MA) filter:</u>
  $\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} S[i-k]$ (smoothing)
- <u>First difference (D1) filter:</u>
  D1[i] = MA[i] – MA[i – 1]



Take into account the impact on cluster counting efficiency ε and try to optimize ε

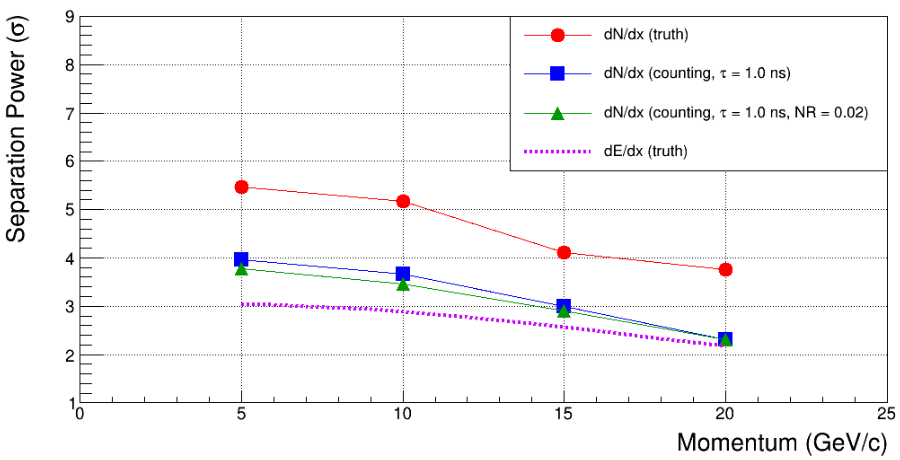
- Sampling rate
- Rise time of electronics
- Noise
- Peak finding algorithm

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

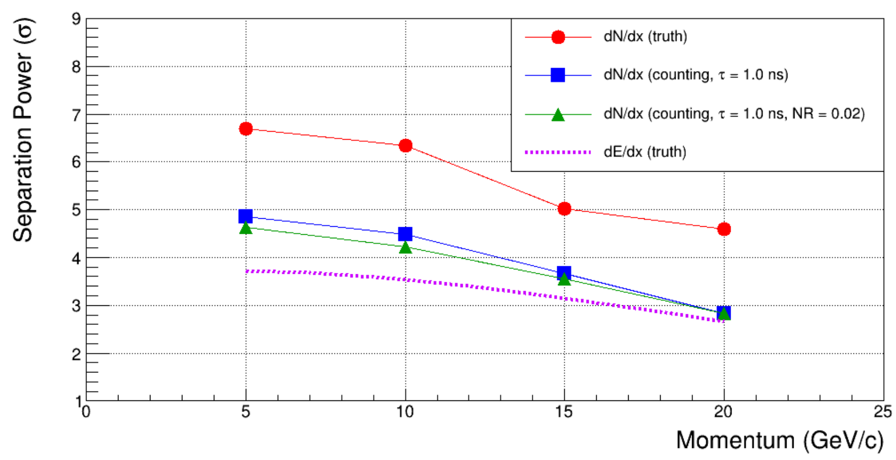
A joint effort with the IDEA group

Preliminary 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% iC_4H_{10}
Sampling frequency : 2GHz

Separation power

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

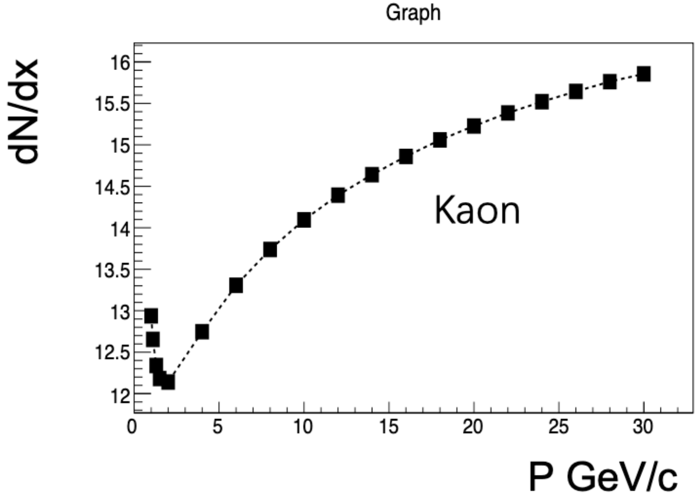
K/π separation up to 20 GeV/c :

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

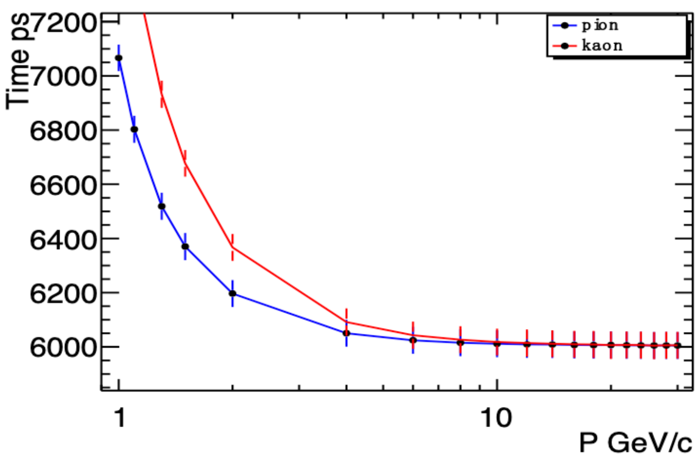
PID study with fast simulation

- **Main objective**: Speeding up the simulation to enable the study of PID performance
- **Method**: Sampling dN/dx (truth) by a certain track length using Garfield
- **Two models are considered.**
  - **dN/dx model :** assuming a counting inefficiency with corresponding uncertainties
  - **TOF model :** assuming a time resolution 50 ps

dN/dx model



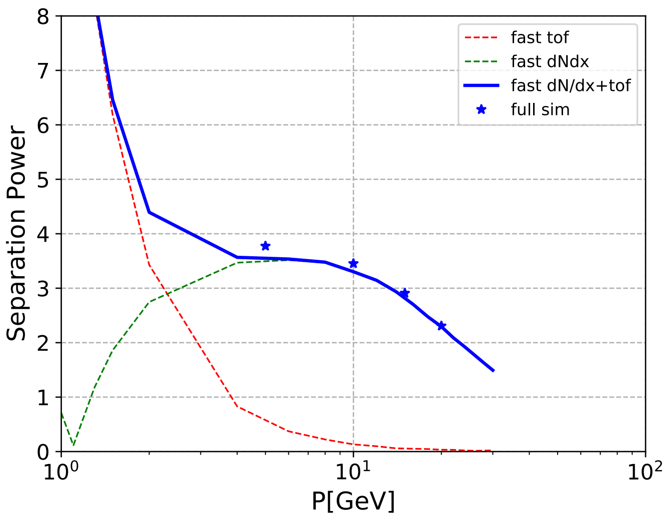
TOF model



Preliminary PID performance

K/π Separation power

(R_{DC} from 0.8 to 1.8m)

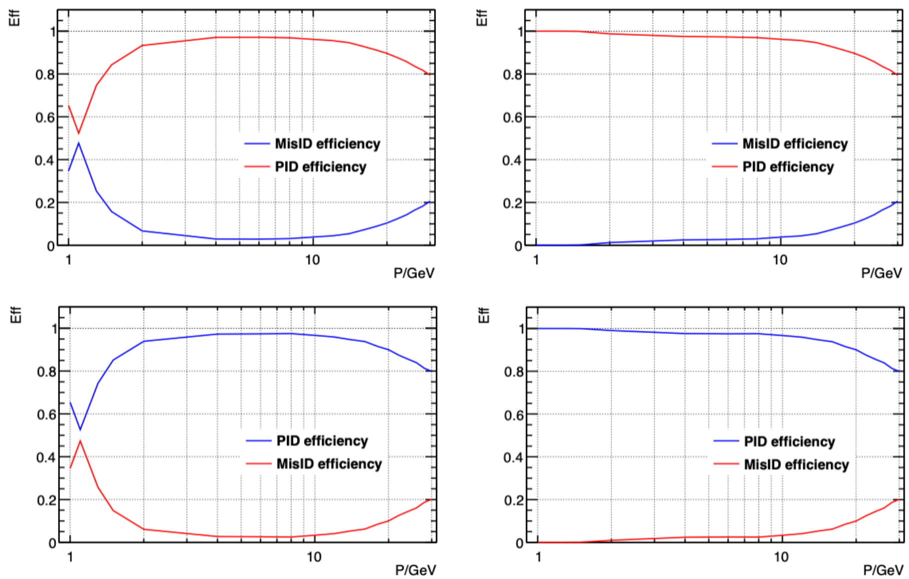


PID efficiency

(R_{DC} from 0.8 to 1.8m)

dn/dx only

dn/dx + tof



For K and π up to 20 GeV/c

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

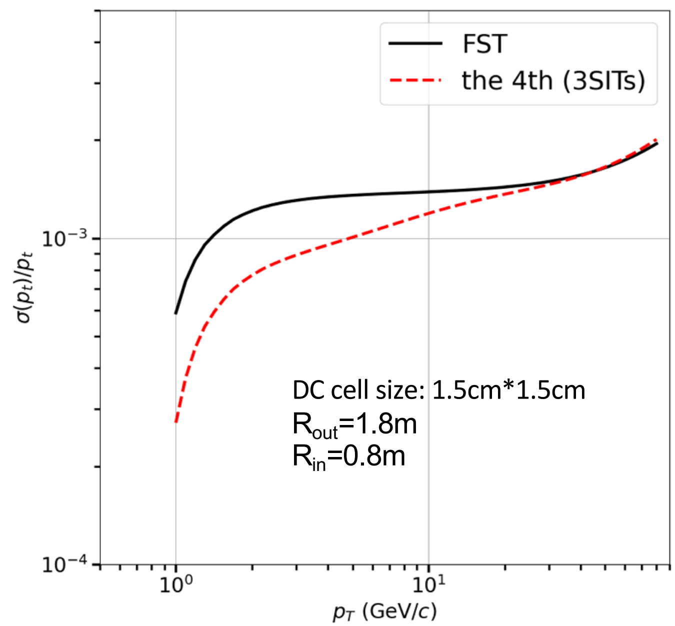
Impact on momentum measurement

- Compared with full silicon tracker (FST), P_T resolution of the hybrid system with drift chamber
  - Improved significantly in momentum range of 0-20 GeV/c
  - Almost no degradation with momentum up to 80 GeV/c
- Software tool for fast tracking simulation: LDT

Parameters for tracking fast simulation

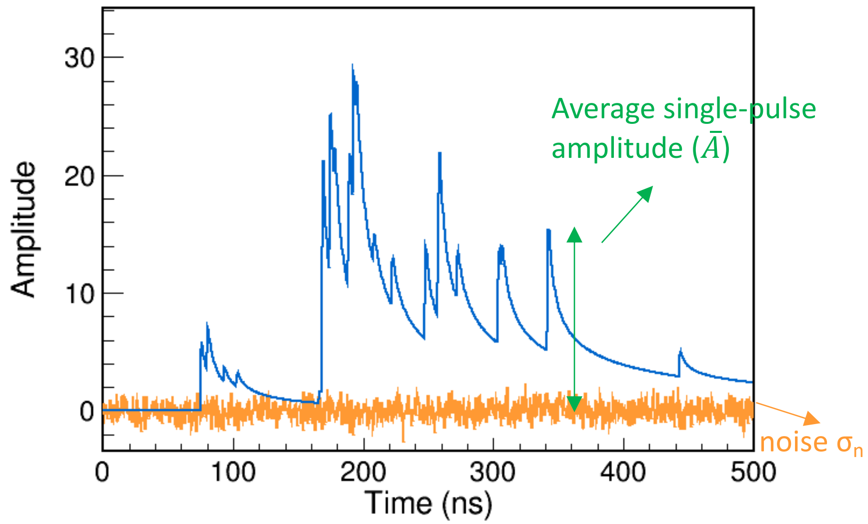
Sub detector	R (mm)	Resolustion (μm)		Materia (%X_0)
		r-φ	z	
Beam pipe	14(10)	---	---	0.15
VXD		2.8/6/4/4/4/4	2.8/6/4/4/4/4	0.15/layer
VXD shell	65	---	---	0.15
SIT	Uniformly	7.2	86.6	0.65/layer
DC inner wall	800	---	---	0.104
DC sense layer	---	100	2000	0.0116/layer
DC outer wall	1800	--	---	1.346
SET	1810	7.2	86.6	0.65

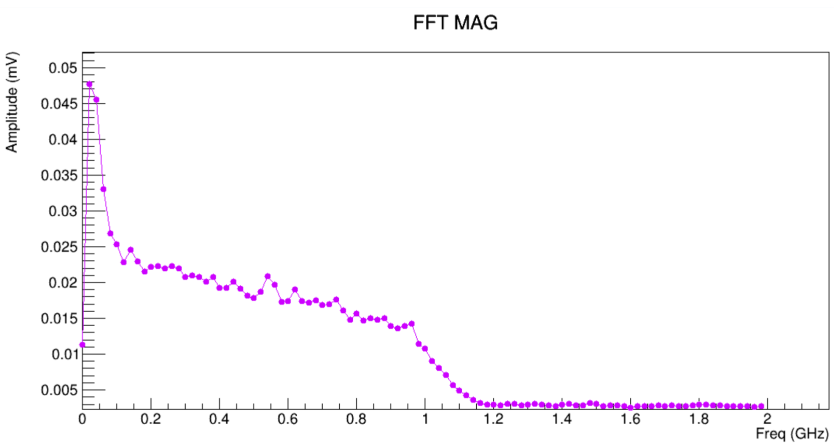
p_T resolution vs p_T



Ongoing efforts – Noise generation

- Noise amplitude related to single-pulse amplitude
  - Noise level definition: $\frac{\sigma_{Noise}}{\bar{A}_{signal}}$
- Noise frequency from experiment measurement
  - Frequency spectrum from FFT analysis

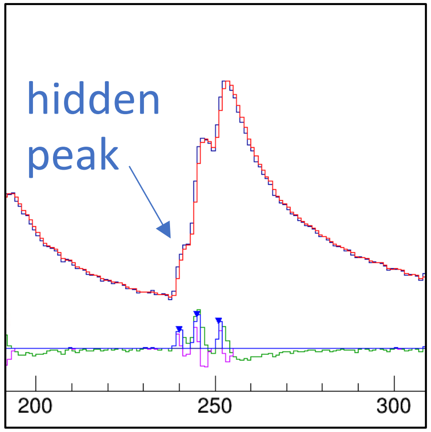




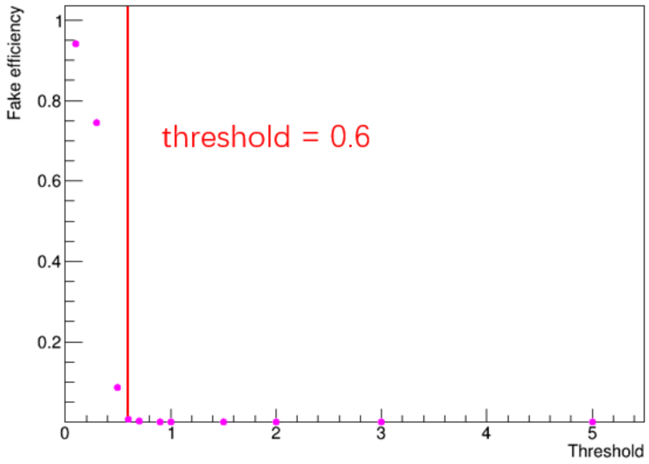
Ongoing efforts – Peak finding algorithm

- Using the second derivative (D2) for "hidden peaks" detection
- Parameter optimization: Detection threshold & Moving average size

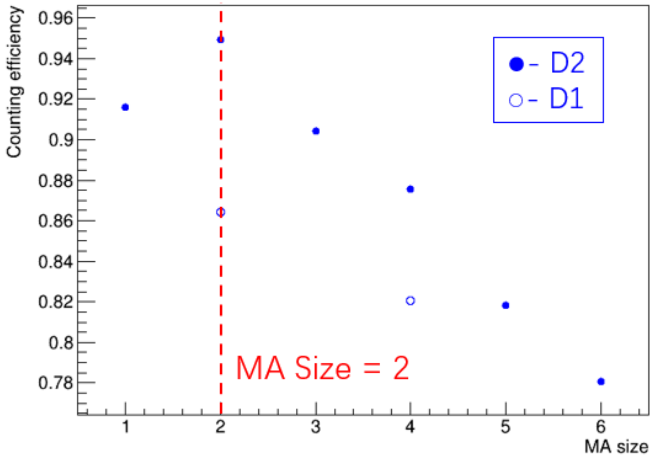
D2 Peak Finding



Fake Efficiency vs. Threshold



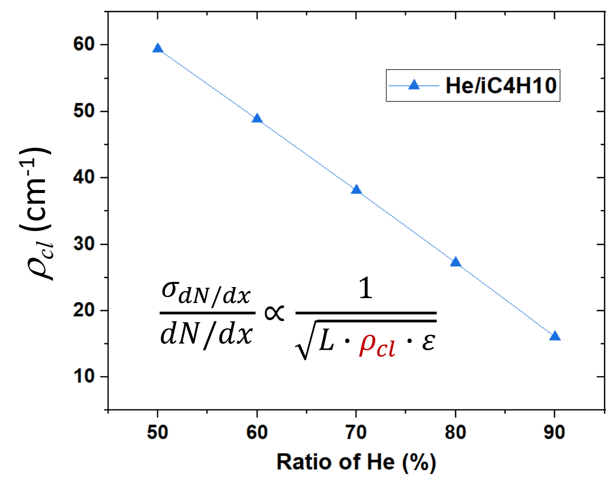
Counting Efficiency vs. MA Size



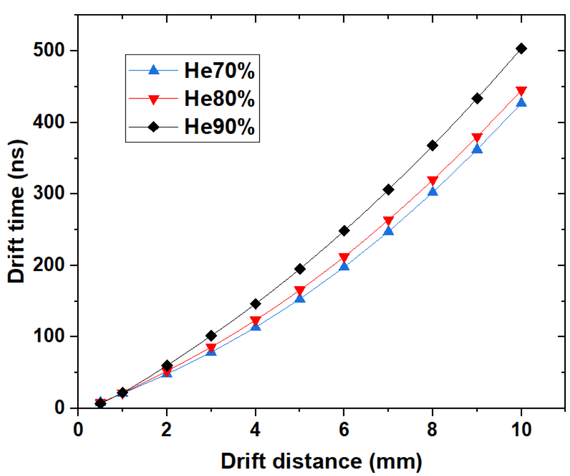
Ongoing efforts – Gas mixtures study

- 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

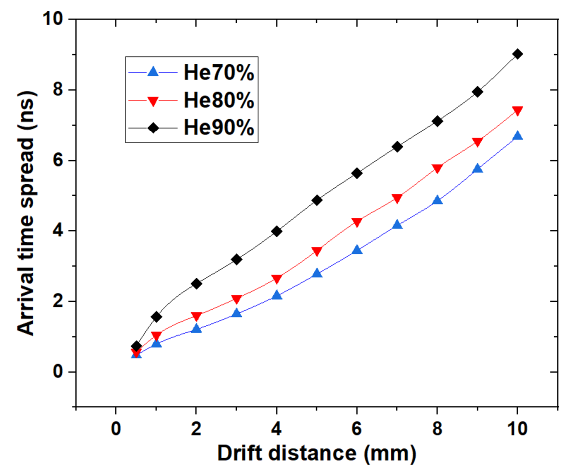
Cluster density vs ratio of He



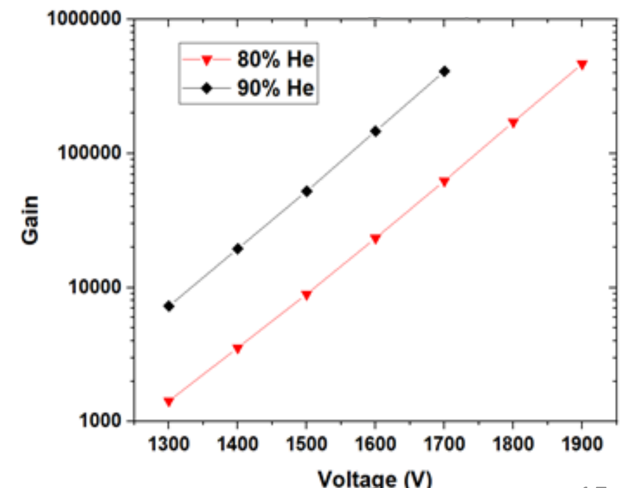
Drift time vs drift distance



Diffusion effect vs drift distance

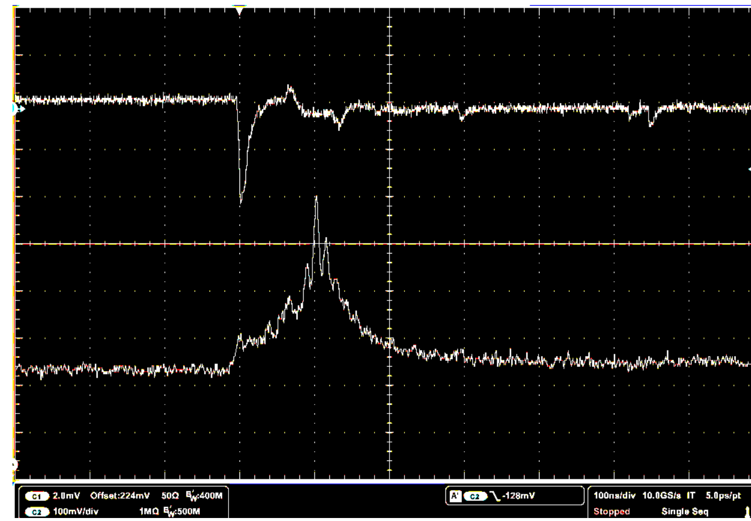


Gain vs H.V.

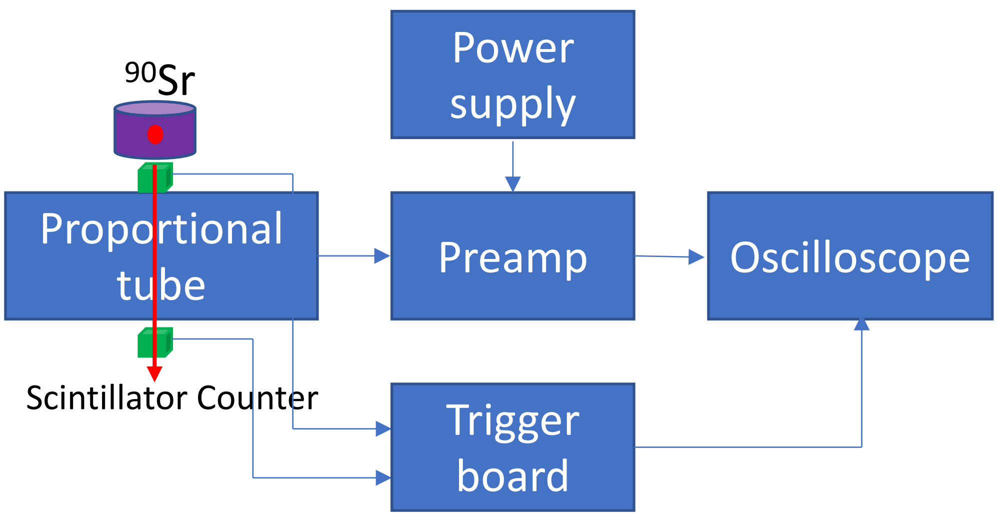


Prototype test

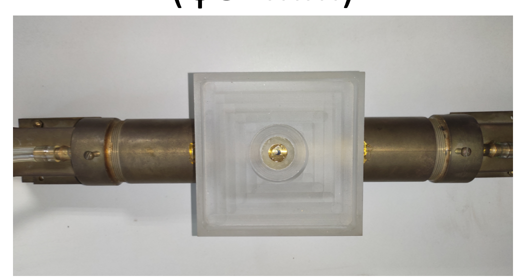
- Prototype test to validate and optimize simulation parameters (ongoing)
- Coincidence of scintillator counters provides trigger and constraint of incident track angle



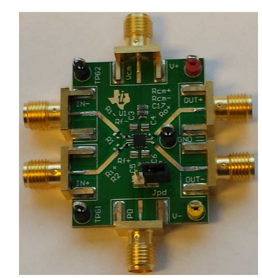
  - Gas: 80% He + 20% iC_4H_{10}
  - **Preamplifier: LMH5401 evaluation module**
    - Gain bandwidth product (GBP): 8 GHz
    - Gain : 12 dB (4 V-V), R_f: 127 Ω



Proportional tube (ϕ32mm)



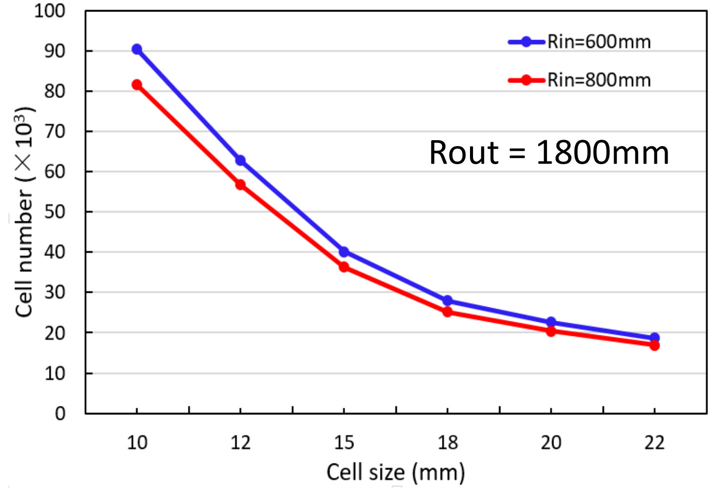
Preamplifier



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

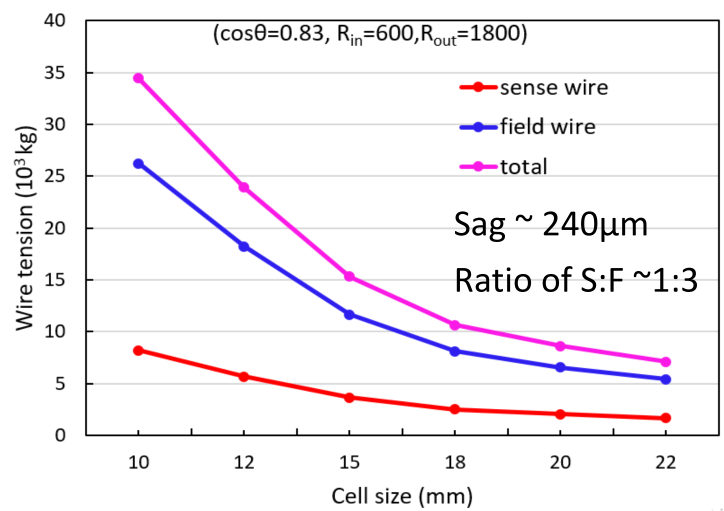


Length of wire vs coverage of barrel section

(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



Summary

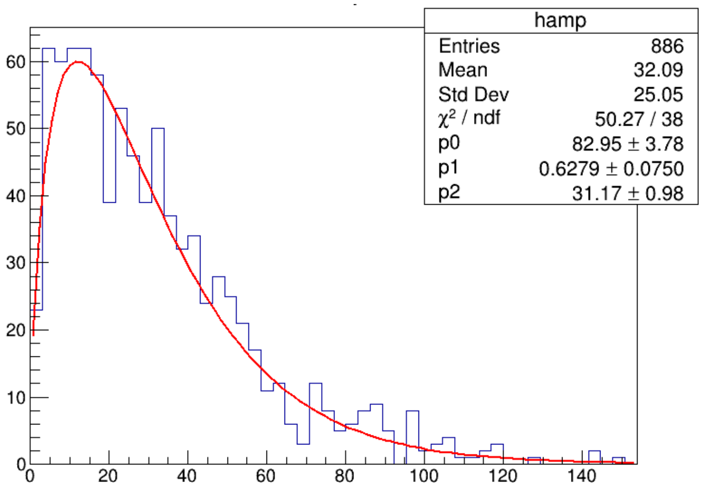
- Preliminary PID performance with simulation (DC thickness = 1m)
  - K/π separation up to 20 GeV/c
  - PID efficiency > 90% For K and π up to 20 GeV/c

- Many studies ongoing
  - Noise generation
  - Peak finding algorithm
  - Gas mixture
  - Prototype test

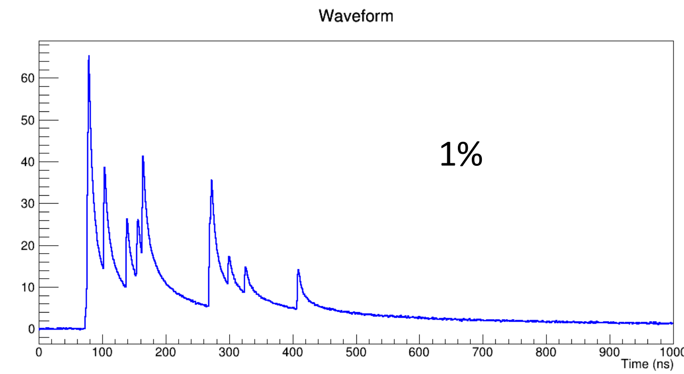
Thanks!

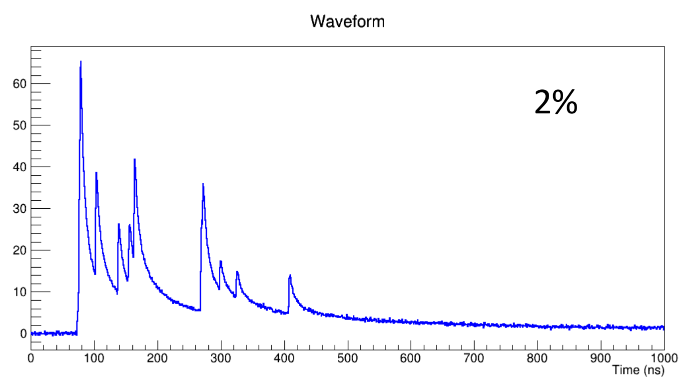
Backup

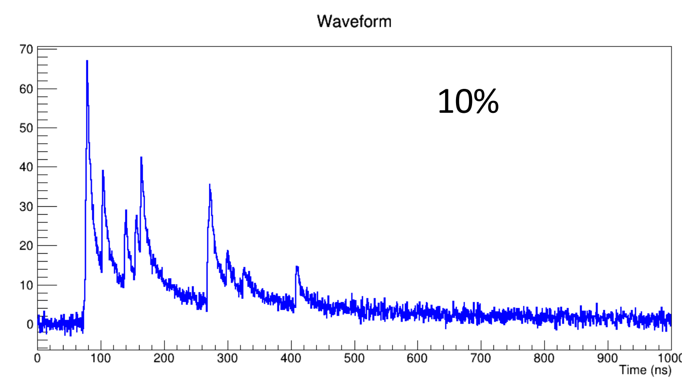
Single pulse amplitude



Noise level = $\dfrac{\textit{Noise R.M.S}}{\textit{Single pulse amplitude}}$

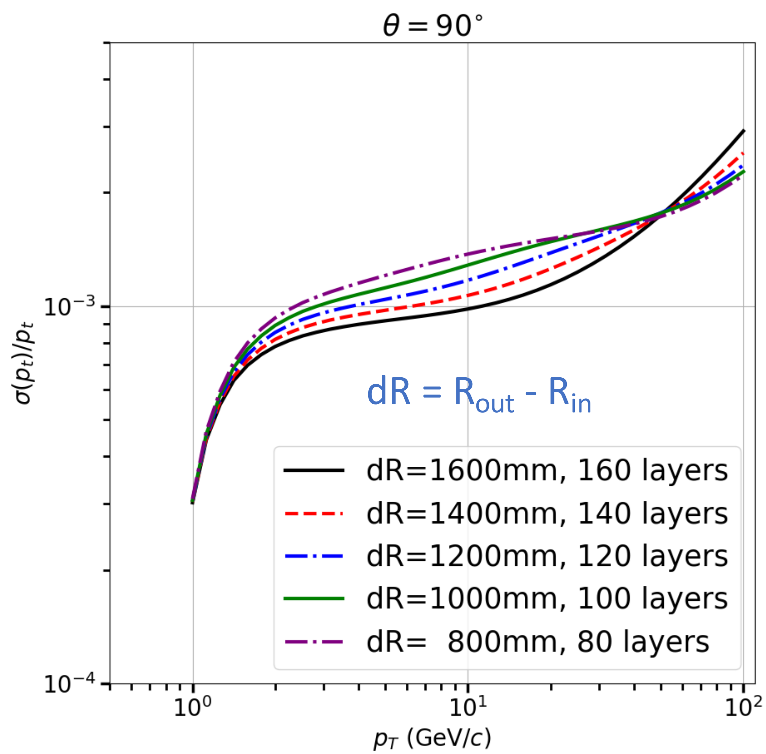


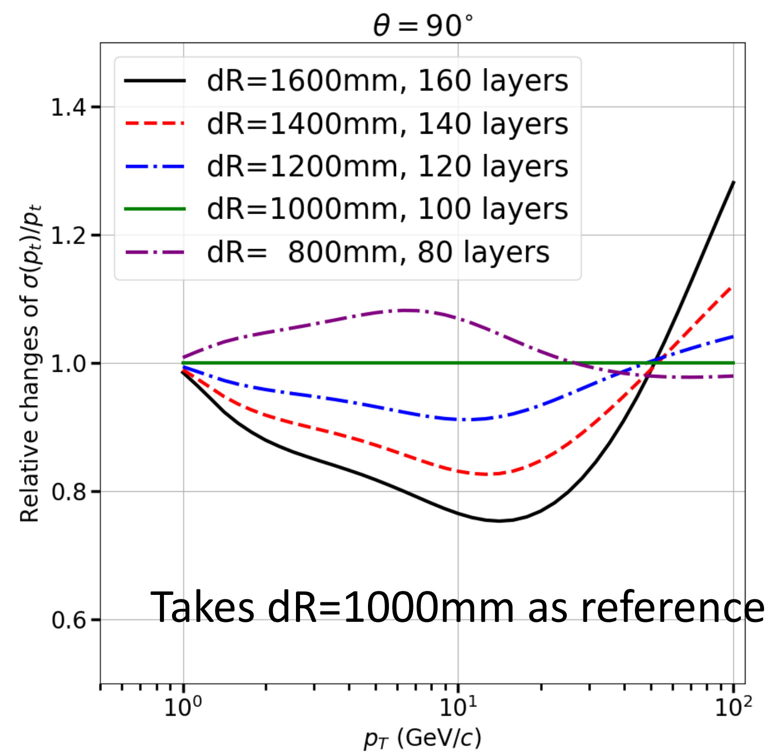




Scanning of DC dimension

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

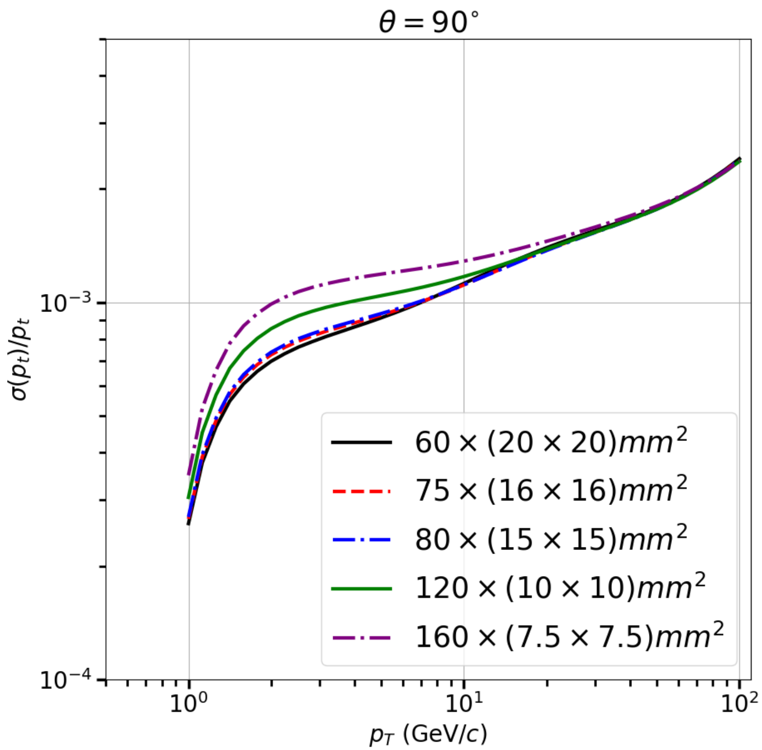


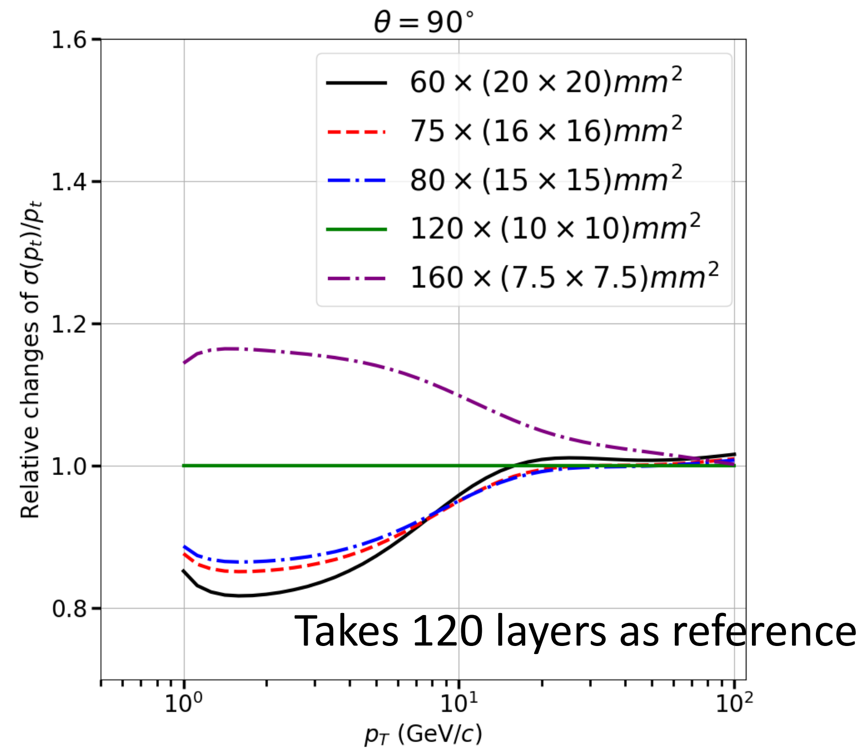


- Larger DC volumes achieve better momentum measurement in low pt region (critical point ~ 40 GeV)
- dR=1200mm (600 ~ 1800 mm) might be a good choice with consideration of PID and P_T resolution

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

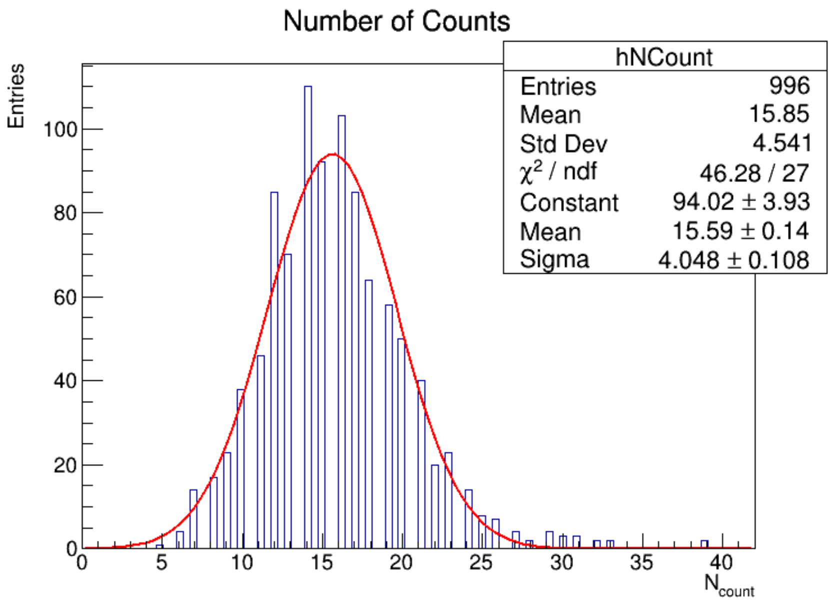




- Less layers achieve better momentum measurement
- Optimization of cell size ongoing with consideration of diffusion effect and mechanical design

dN/dx distribution from counting

# of detected pulses



Numbers:

- # of primary peaks (truth): 16.42
- # of detected peaks: 15.59
- # of detected peaks that match to truth: 13.86

Note:

- dN/dx is very Gaussian-like
- Primary peaks are dominant