Charged Particle Identification

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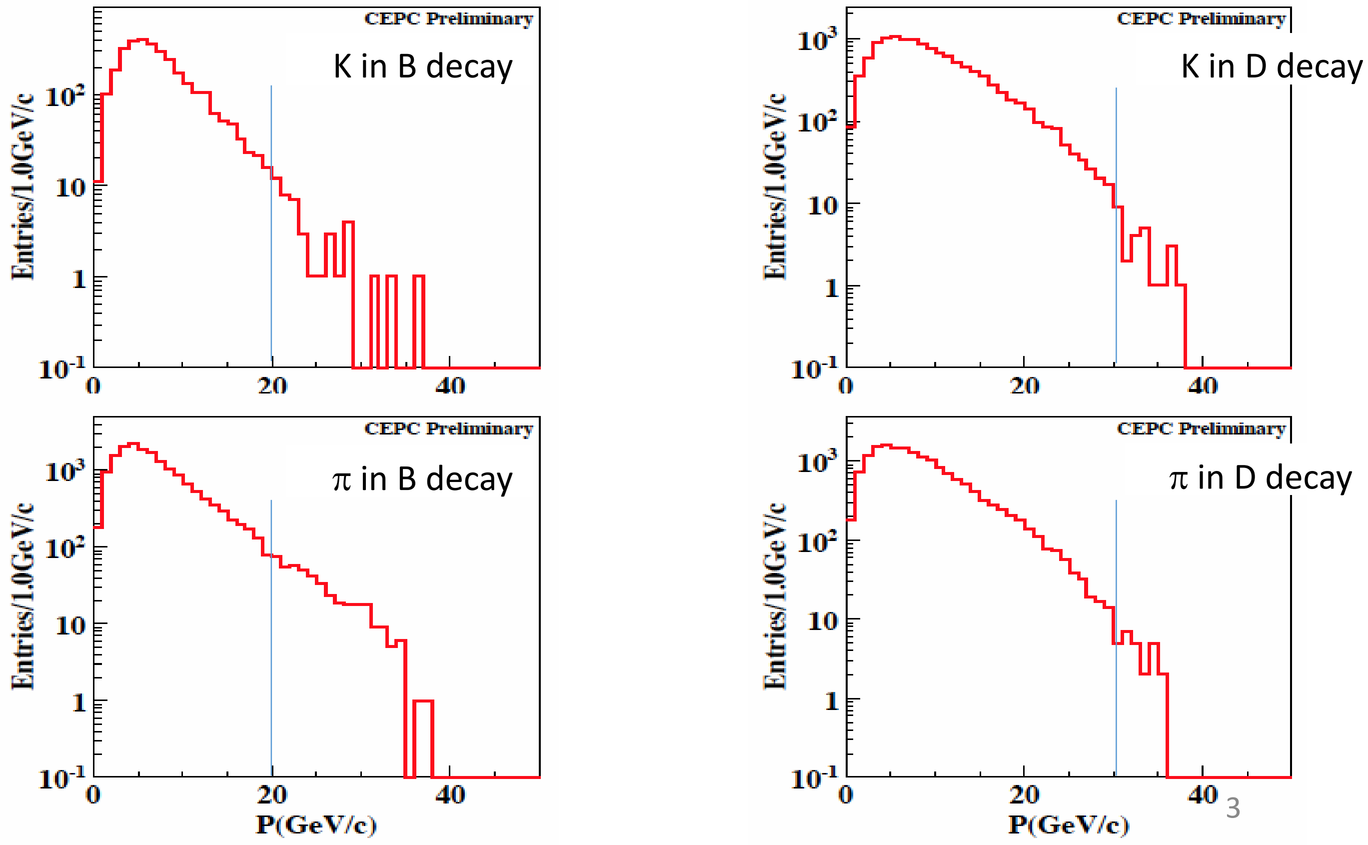
Outline

- Introduction of PID
- Simulation of PID in CEPCSW
- Preliminary R&D
- Summary

Requirement of PID in CEPC

- CEPC will produce 10^{12} Z boson at Z pole → Rich flavor physics program
- Good hadron separation is essential for momentum up to 10 GeV/c, extremely useful in the 10-20 GeV/c range

  - Improve signal to background ratio
  - Improve mass resolution
  - Improve jet energy resolution
  - Benefit flavor tagging



Most of K & π with the momentum less than 20 GeV/c

Charged Particle Identification

- Charge $\longrightarrow$ Test track in magnetic field

- Mass: test mass related Kinematic variables

  (velocity, momentum)

  - Time-of-flight (TOF) measurements
  - Detection of Cherenkov radiation
  - Detection of transition radiation
  - Measurement of the energy deposit by ionization

$$p = \gamma m v \quad \rightarrow \quad m = \frac{p}{c\beta\gamma}$$

$$\left(\frac{\mathrm{d}m}{m}\right)^2 = \left(\frac{\mathrm{d}p}{p}\right)^2 + \left(\gamma^2\frac{\mathrm{d}\beta}{\beta}\right)^2$$

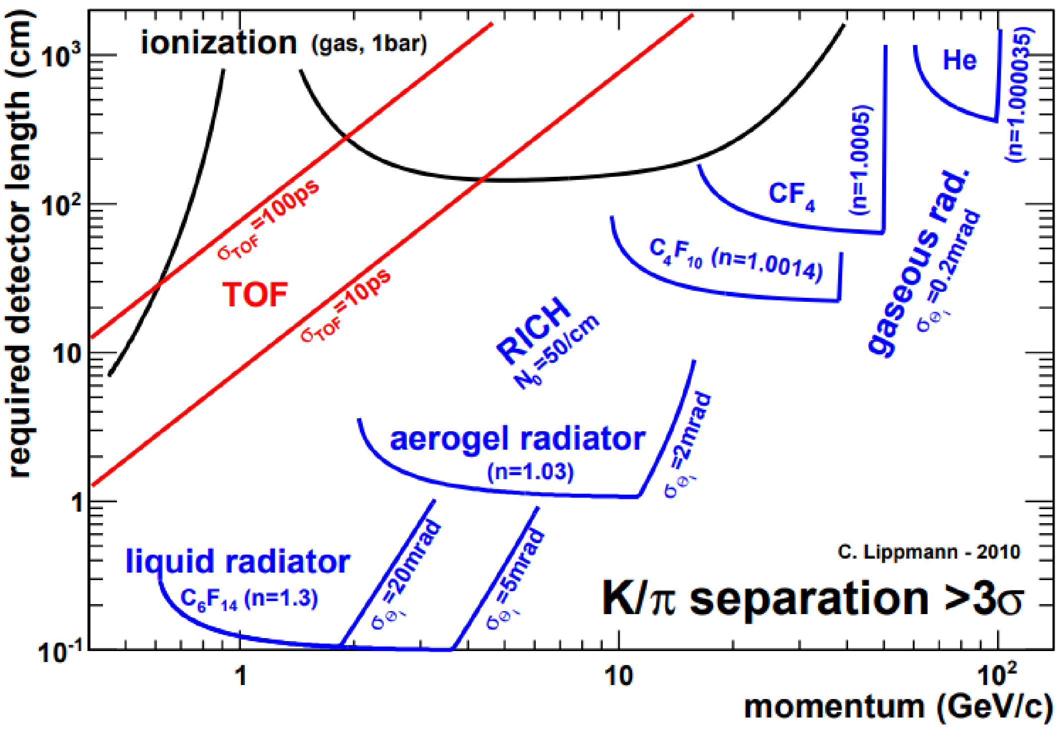
Separation power:

$$S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma_{I_A}^2 + \sigma_{I_B}^2}}$$

Detector options for PID

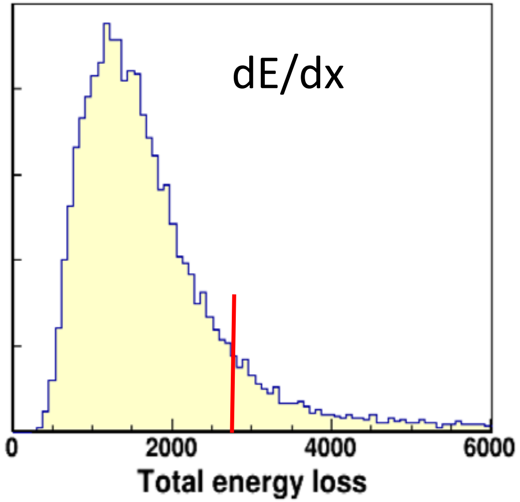
- RICH
  - RICH can provide good PID over a wide momentum range. Space needed is a main challenge
- TOF and Cherenkov based TOF system
  - TOF is a valid solution for low momentum PID
  - An Cherenkov-based approach that takes up much less space, Measuring either Cherenkov angle (DIRC) or time of propagation in radiator (Belle II TOP)
- Ionization energy/yield measurement (dE/dx and dN/dx)

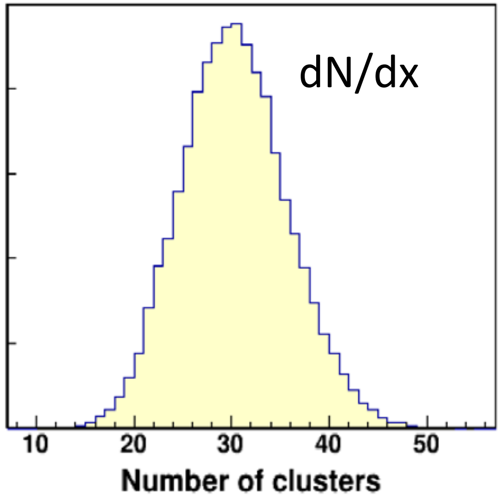
arXiv:1101.3276v4



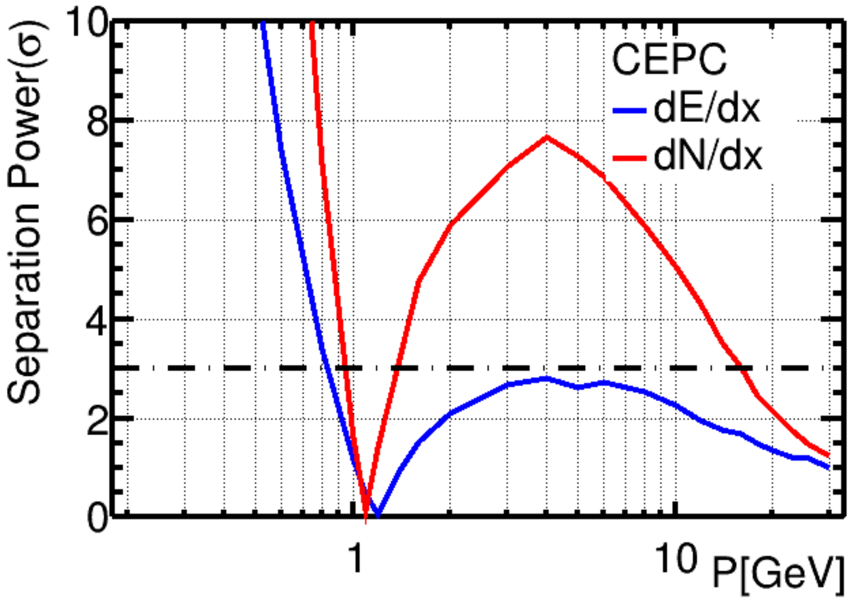
dE/dx vs dN/dx of drift chamber

- dE/dx is well-established PID method in gaseous tracking detector (e.g. drift chamber) by measuring energy loss and track length
- Usually limited to < 10 GeV/c. One limiting factor is Landau tails which necessitates using a truncated mean and loss part of measured information





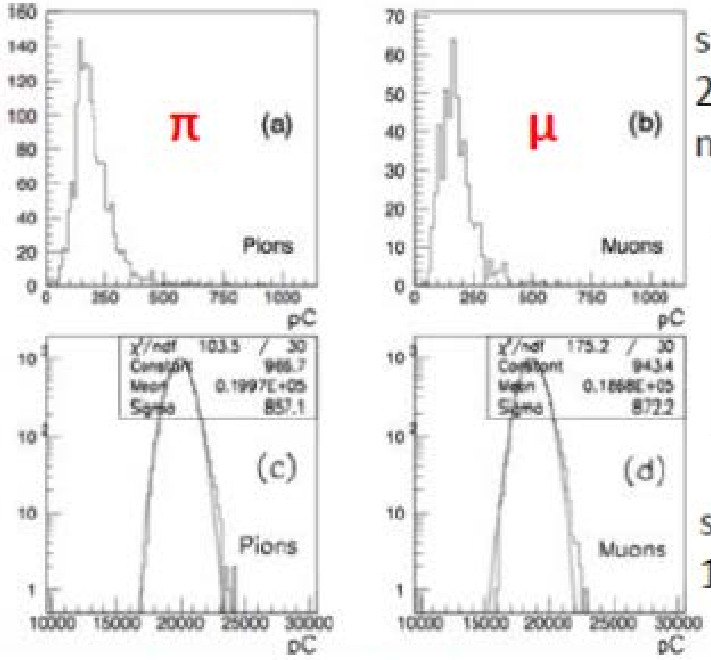
- Alternative method is cluster counting, measuring the number of primary ionization (Poisson distribution) over the track
- It is less sensitive to Landau tails, resolution and separation power with dN/dx will be significantly improved



dE/dx vs dN/dx (test results from Franco's slide)

μ/π separation at 200 MeV/c in He/iC_4H_{10} – 95/5 100 samples 3.7 cm

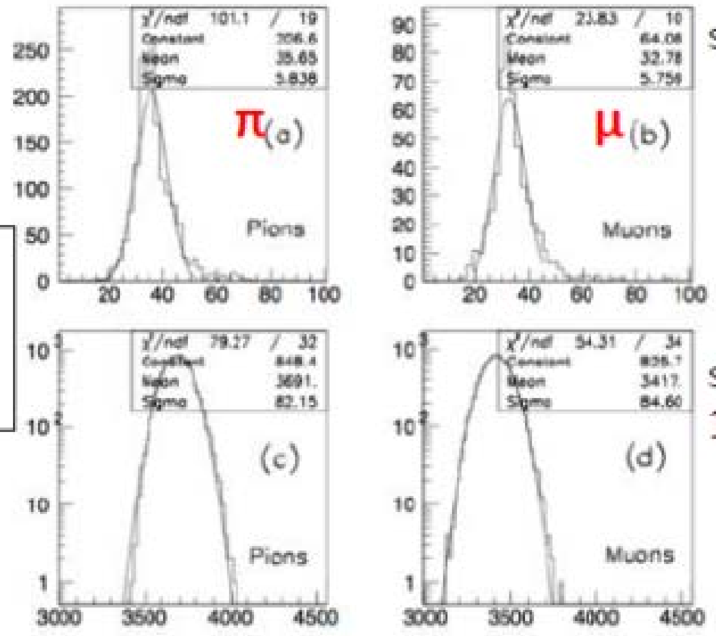
gas gain 2×10^5, 1.7 GHz – gain 10 amplifier, 2GSa/s – 1.1 GHz – 8 bit digitizer



single sample
20% truncated
mean

sum over
100 samples

test beam data



single sample

π: $\sigma/\sqrt{N_{cl}}$=0.978
μ: $\sigma/\sqrt{N_{cl}}$=1.006

sum over
100 samples

π: $\sigma/\sqrt{N_{cl}}$=1.35
μ: $\sigma/\sqrt{N_{cl}}$=1.45

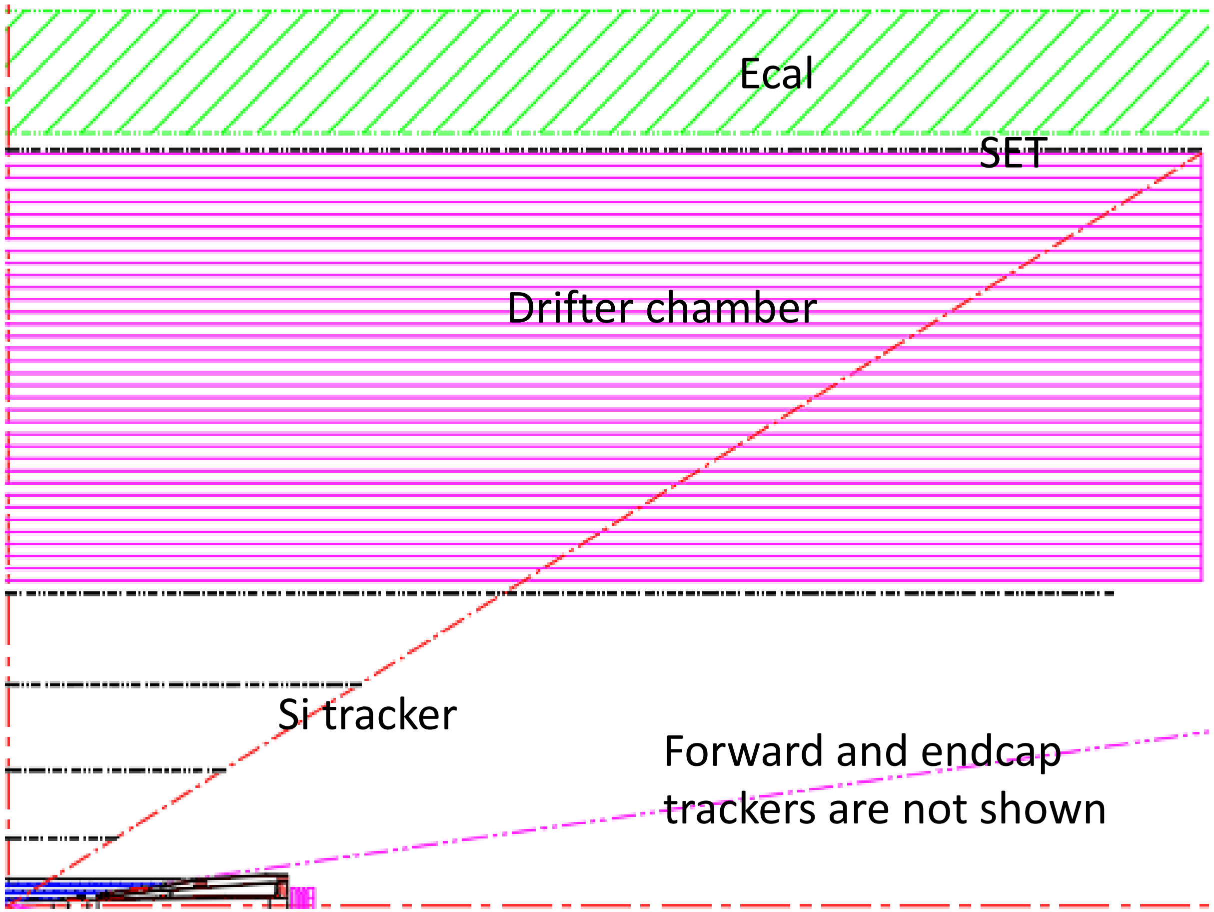
integrated charge	cluster counting
expected 2.0 σ separation	**expected 5.0 σ separation**
measured 1.4 σ separation	**measured 3.2 σ separation**

Slide shown by Franco Grancagnolo at FCC Physics & Experiments Workshop 12/11/2020

Cataldi, Grancagnolo & Spagnolo, NIM A386 (1997) 458

Drift chamber for 4th conceptual detector

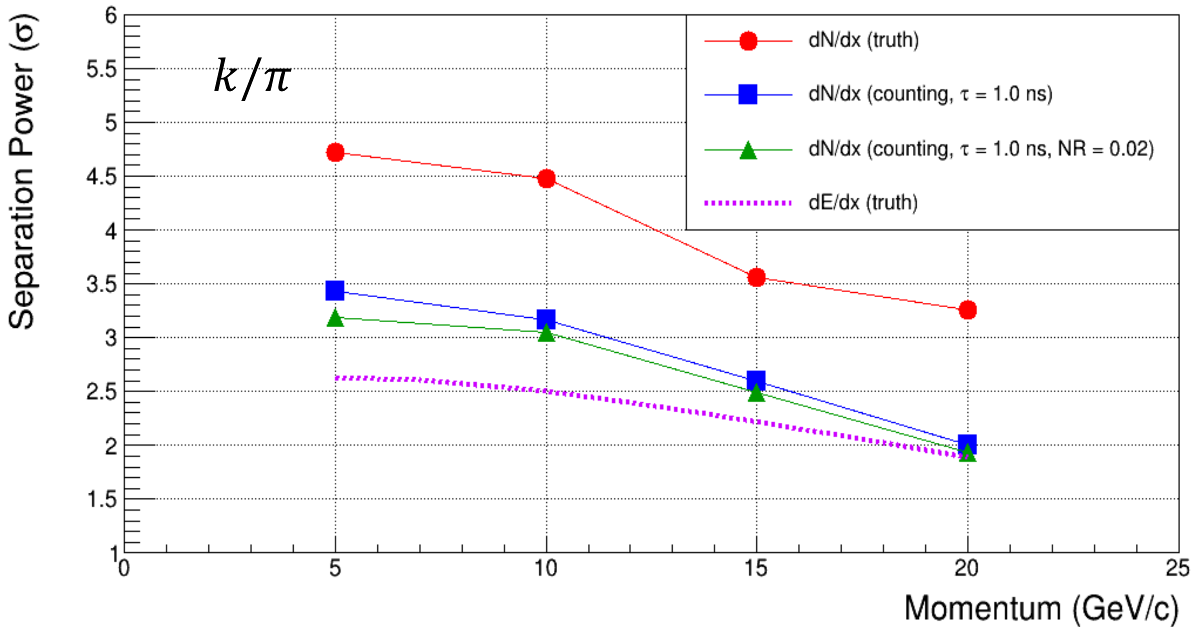
- Drift chamber (DC) mainly provides PID capability, could also benefit track and momentum measurement
- Put between tracker and Silicon External Tracker (SET)
- Key parameters
  - Layers(thickness): good dN/dx resolution and sufficient PID power
  - Location(Inner/outer radius) and thickness: not to affect tracker performance
  - Low material budget



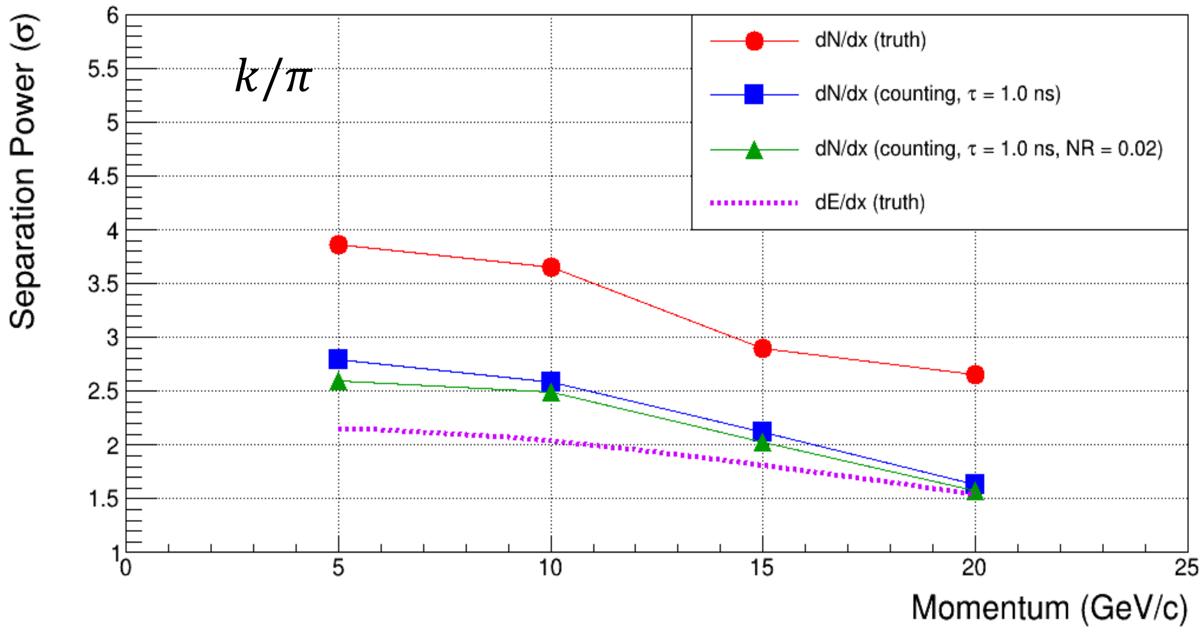
Preliminary results of dN/dx simulation

- A full simulation including signal induction, response of pre-amplifier and white noise is performed
- 2σ separation of K/π up to 20 GeV/c with 150 layers and up to 15 GeV/c with 100 layers

150 layer (R_O=1.8m, R_i=0.3m)



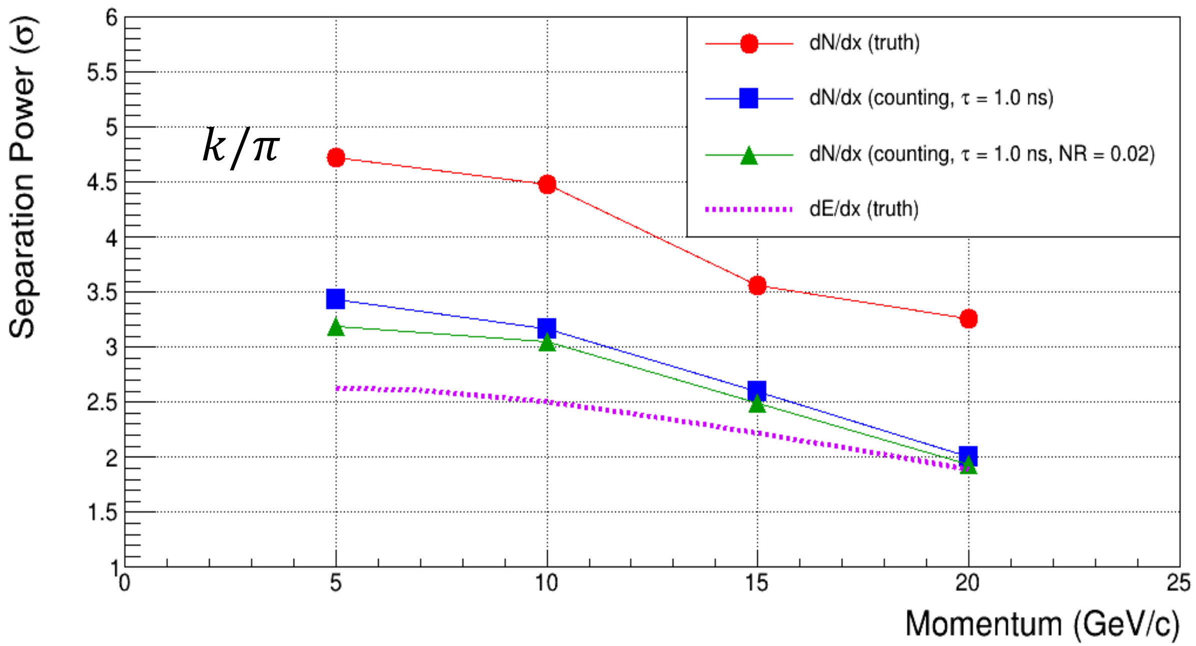
100 layers (R_O=1.8m, R_i=0.8m)

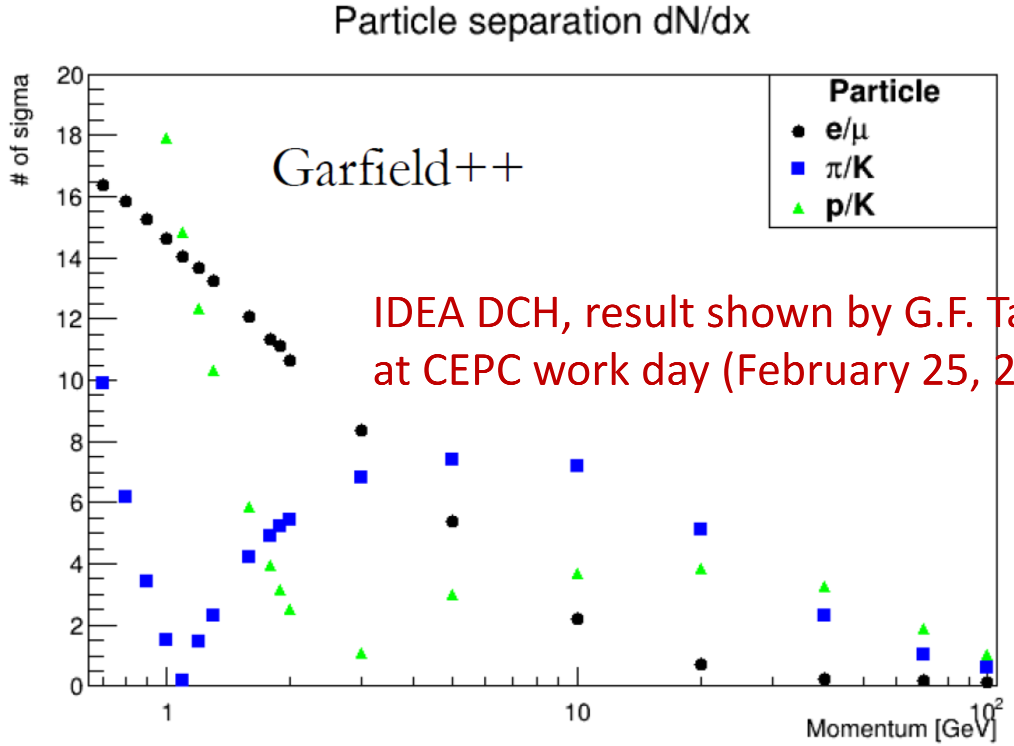


Cell size: 1cm × 1cm, Gas mixture: 90% He / 10% iC4H10, Sampling frequency : 2GHz

Comparison with IDEA DCH simulation result

150 layer (R_O=1.8m, R_i=0.3m)





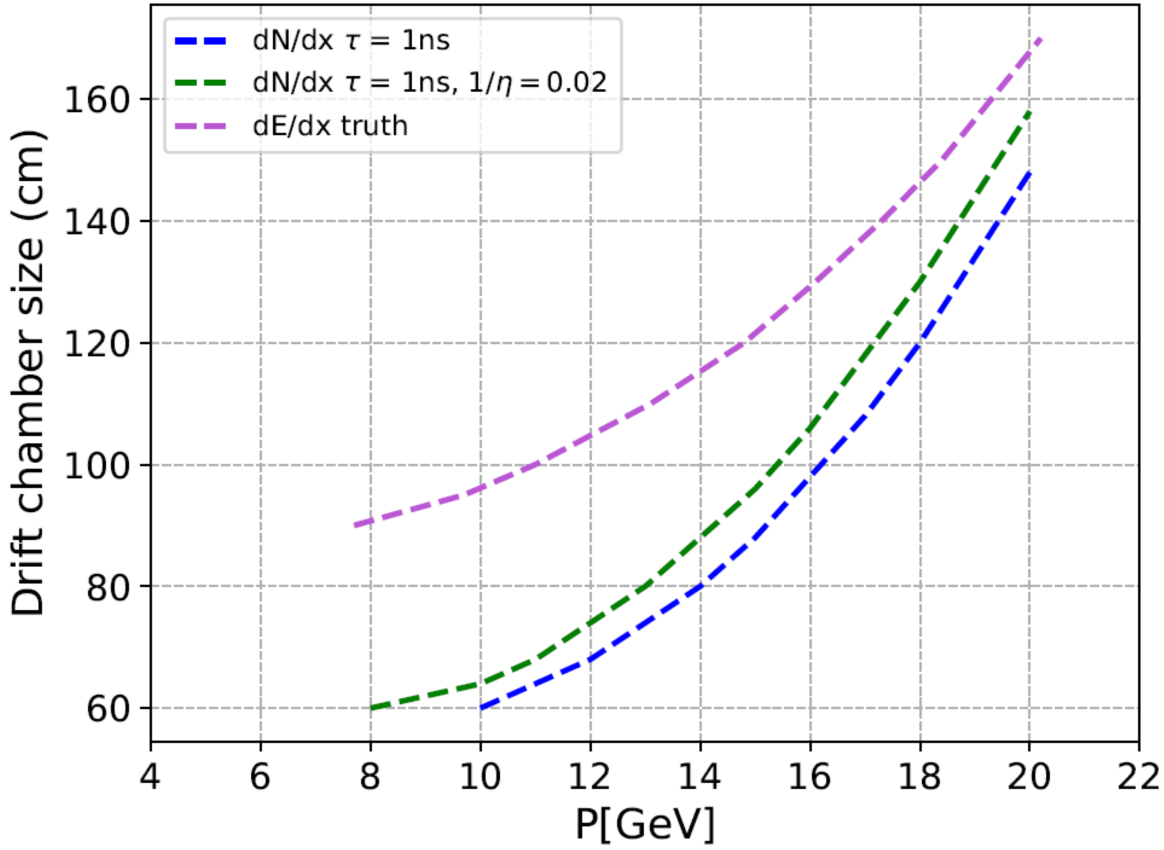
IDEA DCH, result shown by G.F. Tassielli, at CEPC work day (February 25, 2021)

- Same gas mixture
- Different track length, 4th conceptual detector DC: 1.5m, IDEA DCH: 2m
- Different definition : 4th conceptual detector DC: $S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma_{I_A}^2 + \sigma_{I_B}^2}}$, IDEA DCH: $S_{AB} = \frac{|I_A - I_B|}{\langle \sigma_{I_A,I_B} \rangle}$

- The results is roughly consistent taking into account the different factors

Thickness of DC for K/π separation > 2σ

K/π separation > 2σ

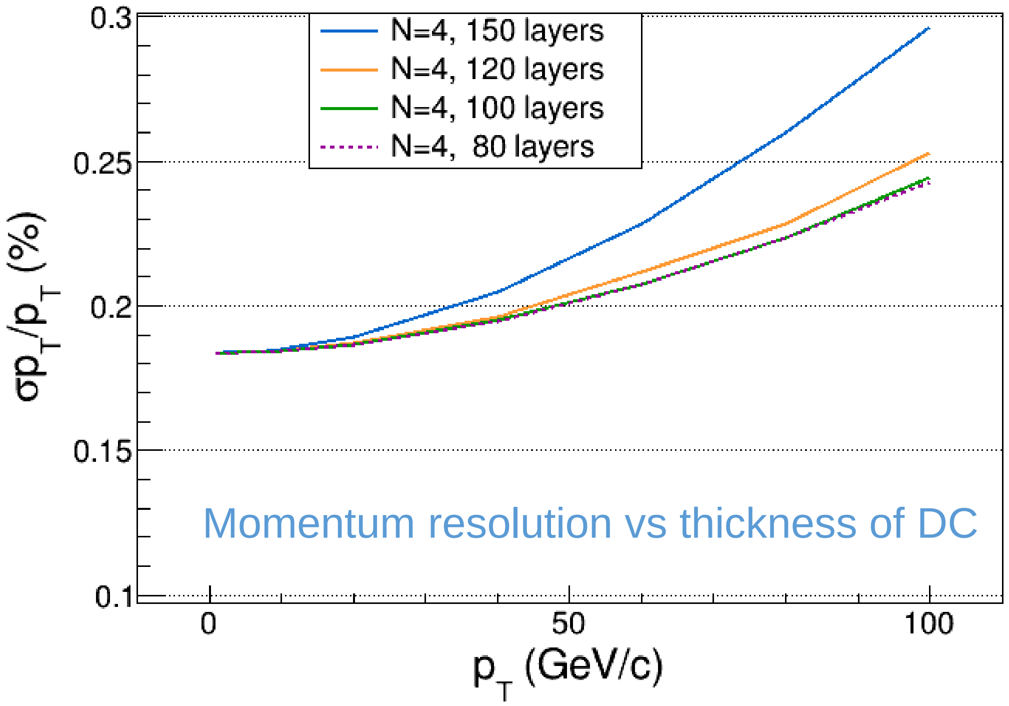


- A thickness of ~1m can provide 2σ separation of K/π up to 15 GeV/c
- A thickness of ~1.5m is needed for 2σ separation up to 20 GeV/c
- Gas ratio, electronics parameters and noise level should be optimized. See details in Guang Zhao's talk

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

Layout of drift chamber

- Increasing thickness of DC could benefit PID
- Reducing thickness of DC could provide more space for Si tracker, which can improve momentum resolution significantly (See details in Xin Shi's talk)
- 100 layers (1m thick, i.e. from 0.8 to 1.8m) might be reasonable taking into account both tracking and PID



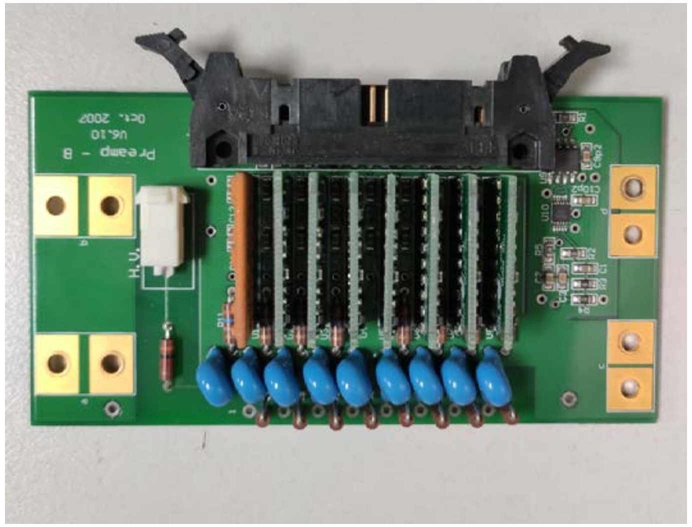
Cell size: 1cm × 1cm,
Gas mixture: 90% He / 10% iC4H10

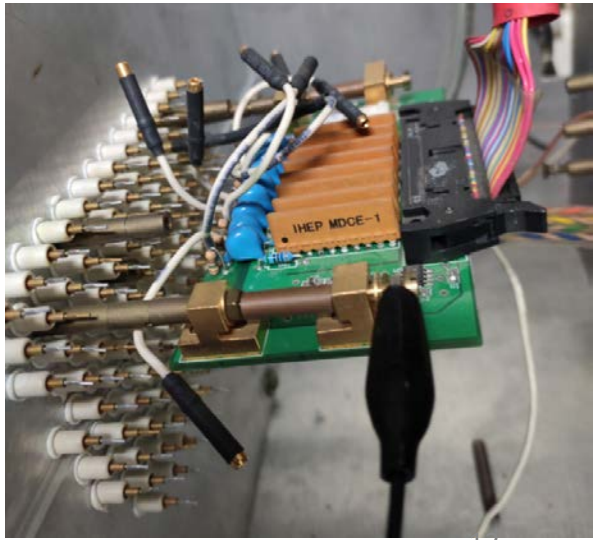
N is the layers of Si tracker,
Different layers of DC mean different space and layout for Si tracker

R & D of drift chamber

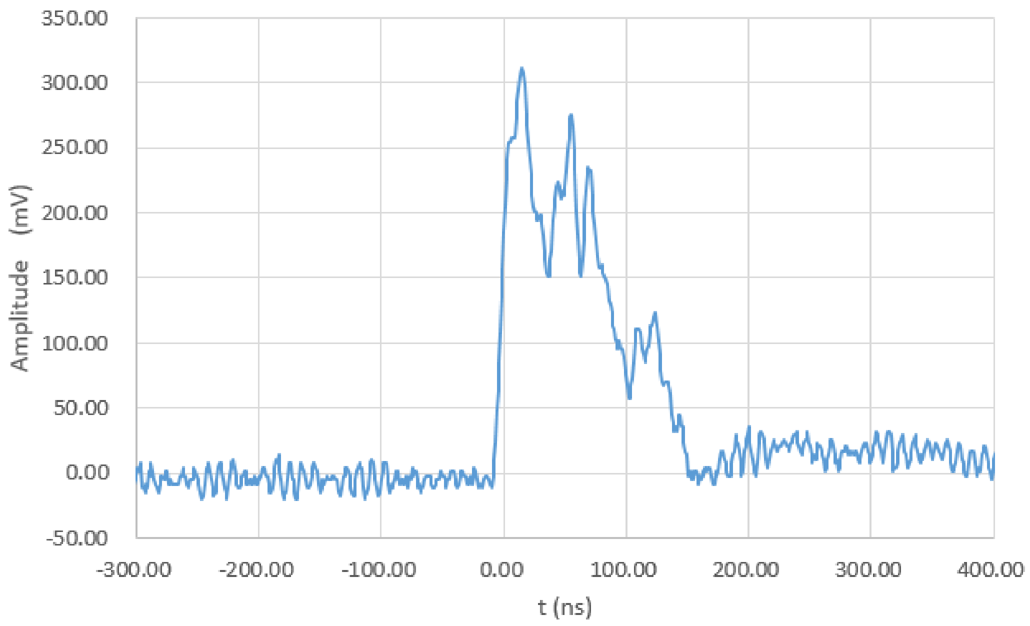
- A prototype test system was setup to provide reference for simulation
  - 4 layers, 6 cells/layer
  - Cell size: 16×16 mm^2
  - Wire length : 600 mm
  - Read out: preamplifier + oscilloscope

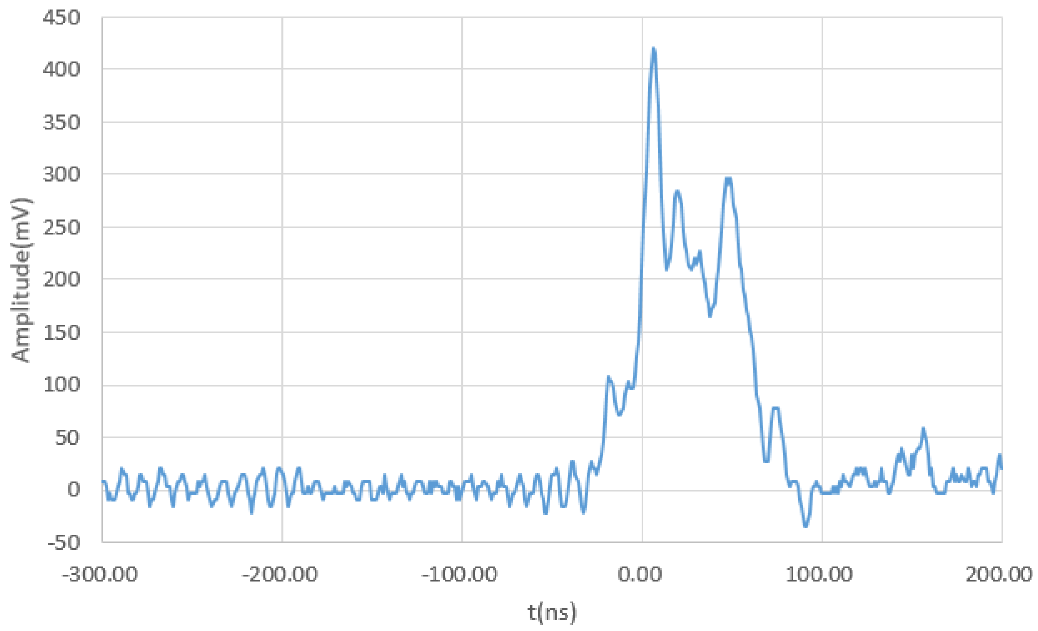
- Temporarily tested with the transimpedance preamplifiers used in BESIII MDC
  - Gain: 12 kΩ (12 mV/μA)
  - Rise time: 5 ns
  - Band width: 70 MHz
  - Output impedance 2×50 Ω
  - Power dissipation 30 mW @ 6 V





Preliminary test

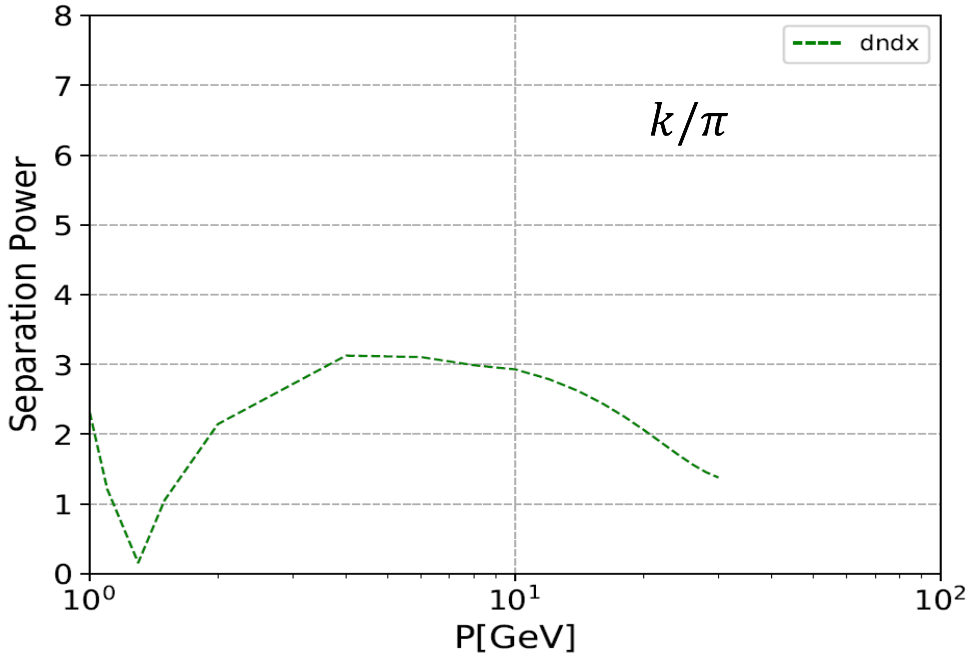


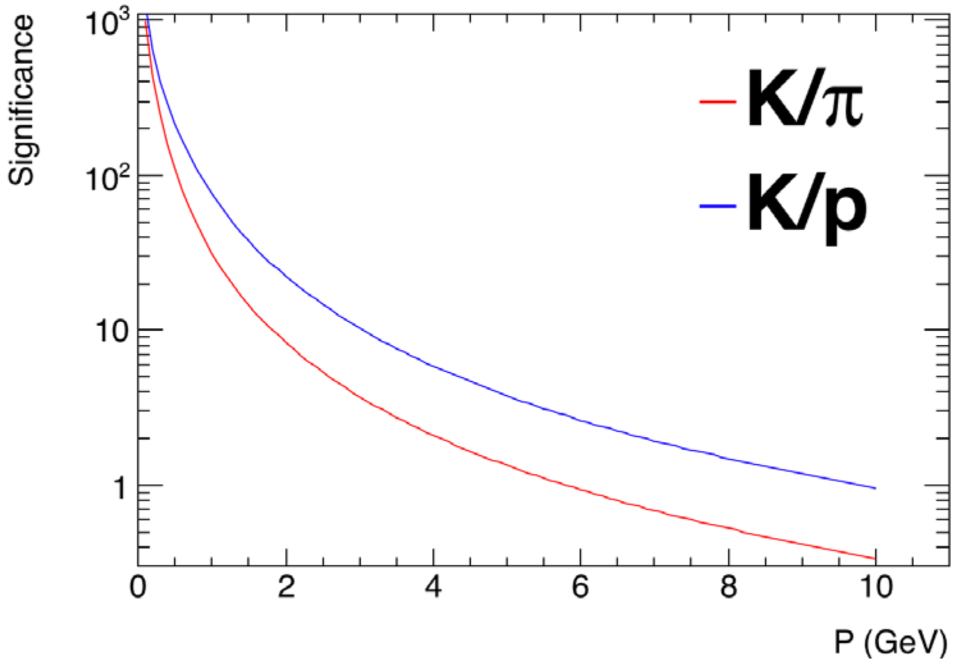


- Tested by cosmic rays
- Gas mixture: He/isobutene= 80:20
- Can separate few clusters, not very good. Cables, connection should be further optimized
- Fast preamplifier (<1ns rise time) with low noise is needed. Electronics group start R&D

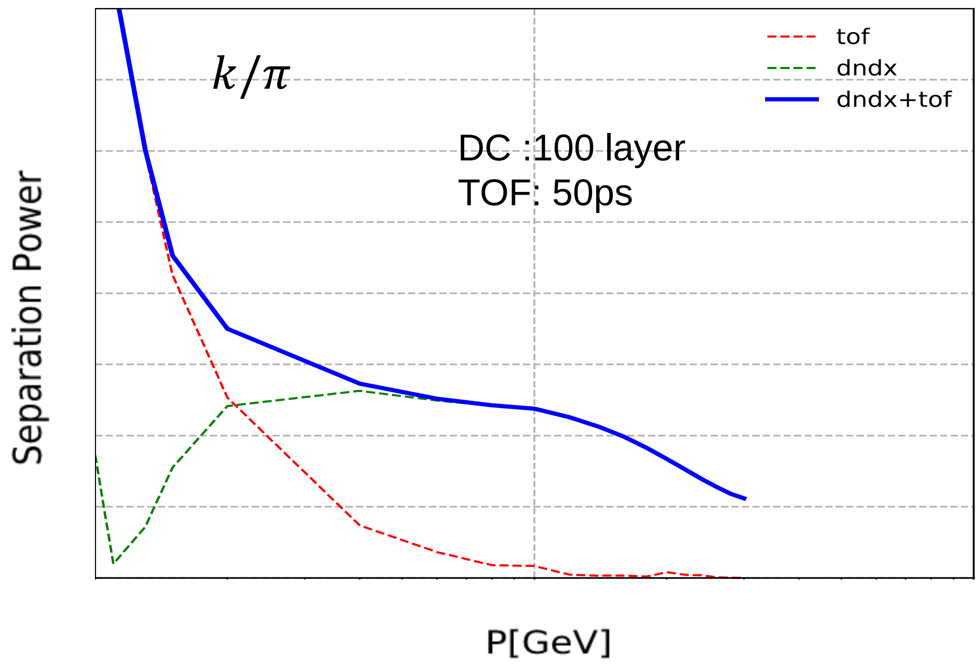
Timing detector

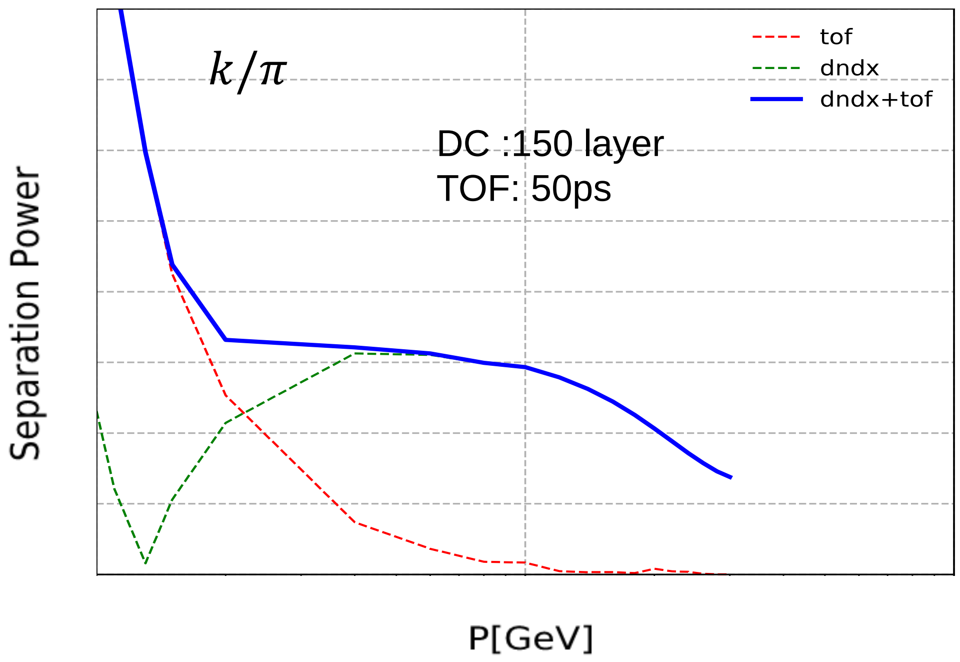
- Gas detector is responsible for particle identification in flavor (dN/dx)
  → Challenge: 0.5-2GeV for K/π separation
- Timing detector is complementary to drift chamber→ 0-3GeV for K/π separation, 0-5 GeV for K/p separation
- Time detector could be set close to Silicon External Tracker (SET), Radius ~1.8m





Combined TOF and dN/dx of DC





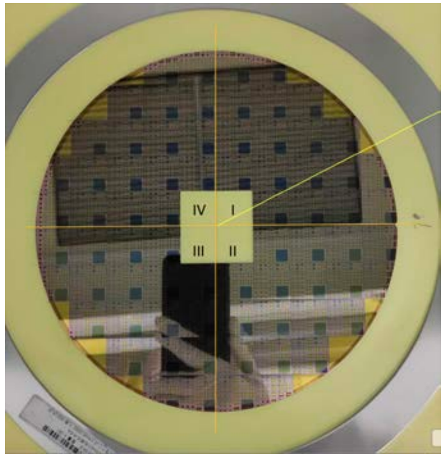
- Use truth track algorithm in CEPCSW to get the track information, and calculate the time of flight with a 50ps smearing. Combined two discriminating information
- TOF: To compensate the gap of dN/dx measurement, it has 2σ k/π separation power up to 2.5GeV @50ps time resolution
- 100 layer of drift chamber : 2σ k/π separation up to 15GeV. 150 layer : 2σ k/π separation up to 20GeV

Technology of timing detector

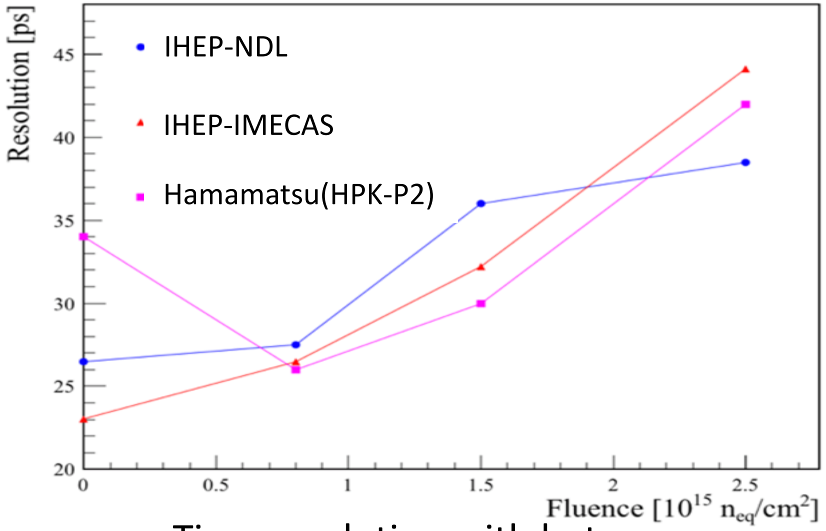
- Silicon timing detector based on LGAD sensor
  - ATLAS HGTD ,CMS MIP timing detector(https://cds.cern.ch/record/2719855/, https://cds.cern.ch/record/2667167)
- Time of Propagation detector
  - Bell II TOP (Belle II Technical Design Report , arXiv:1011.0352)
- TORCH (Time Of internally Reflected Cherenkov light)
  - LHCb TORCH detector (reported by Michal Kreps in IAS HEP 2021)

R&D of LGAD sensor at IHEP (arXiv:2006.11691, arXiv:2005.07323)

IHEP-NDL sensor



IHEP-IME sensors 8 inch wafer



Time resolution with beta source

Summary

- Drift chamber and timing detector are considered for PID for the 4^{th} conceptual detector
- Simulation study and preliminary technology R&D are in progress
- Preliminary results of dN/dx simulation show that :
  - DC with150 layers: 2 sigma K/pi separation could up to 20 GeV
  - DC with 100 layers: 2 sigma K/pi separation could up to 15 GeV
- Need further validation and optimization with full simulation and experiment
- Possible optimization to improve PID capability : counting algorithm, gas mixture, cell, drift velocity, …

Thanks for your attention