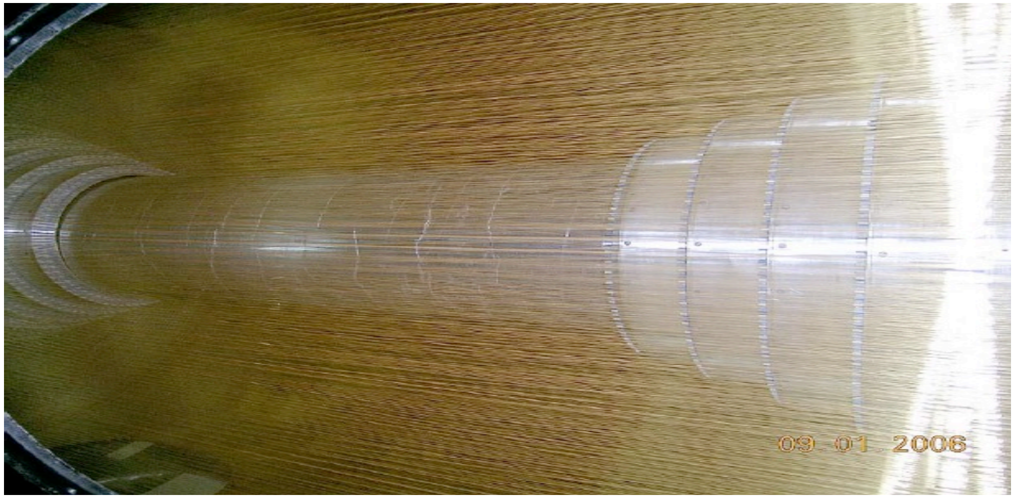
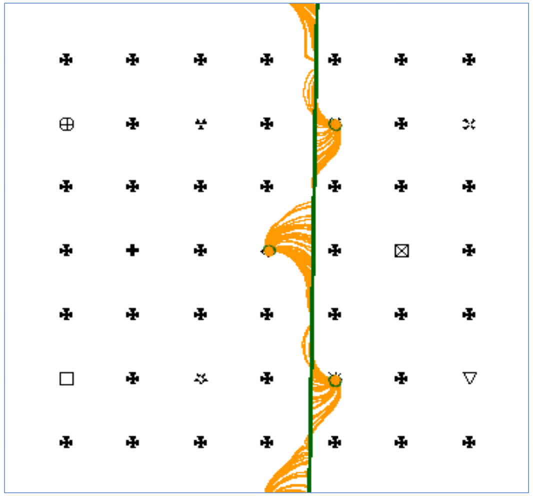
Study of cluster counting method for PID with drift chamber





Linghui Wu, Guang Zhao, Shuiting Xin, Mingyi Dong,

Gang Li, Shengsen Sun

CEPC day, Nov 25, 2020

Outline

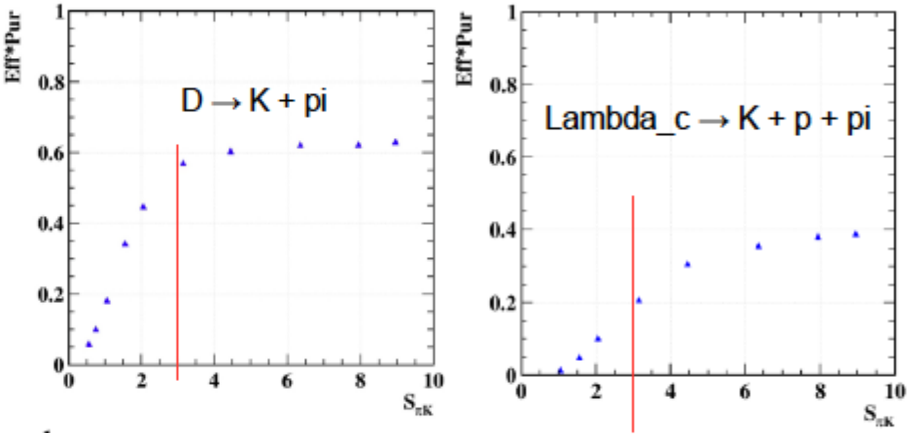
- Motivation
- Simulation on ionization with Garfield++
- Preliminary results with peak finding
- Estimation of performance for the DC in CRD
- Summary and plan

Motivation

- Particle identification is essential for flavor physics and jet study
  - Reduce combination background
  - Improve mass resolution
  - Improve jet energy resolution
  - Benefit flavor tagging
- dE/dx measurement from the drift chamber can be used for PID

  Some work has been done:

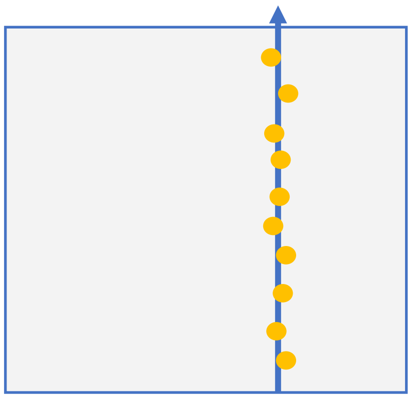
  Xin’s talk in CEPC day (Sep 23, 2020)

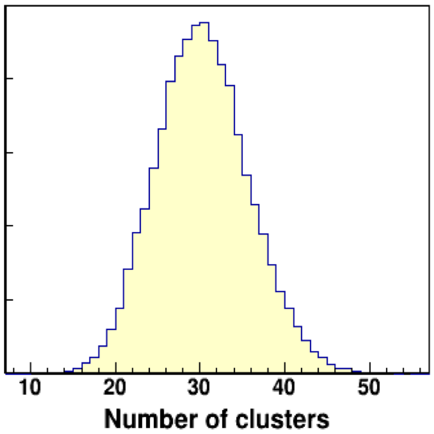


From Manqi’s talk in CEPC Day (Oct 19)

Primary ionization vs total energy loss

Primary ionization

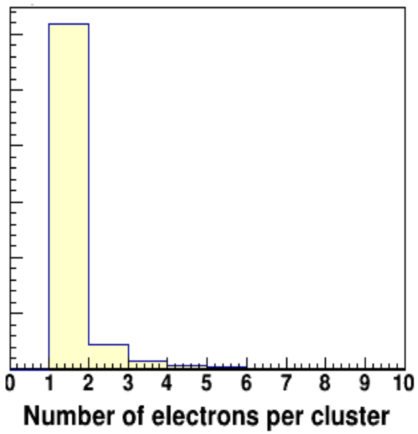


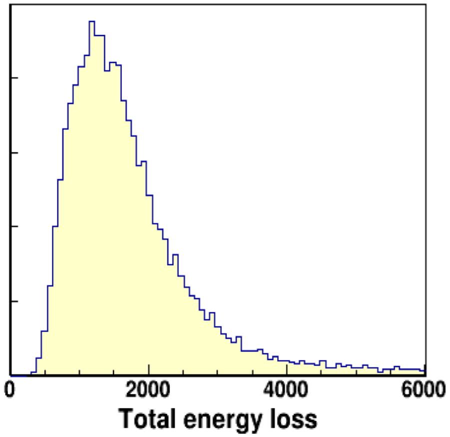


$$P(n, n_0) = \frac{e^{-n_0} n_0^n}{n!}$$

$$\sigma = \frac{1}{\sqrt{n_{Tot}}}$$

Secondary ionization





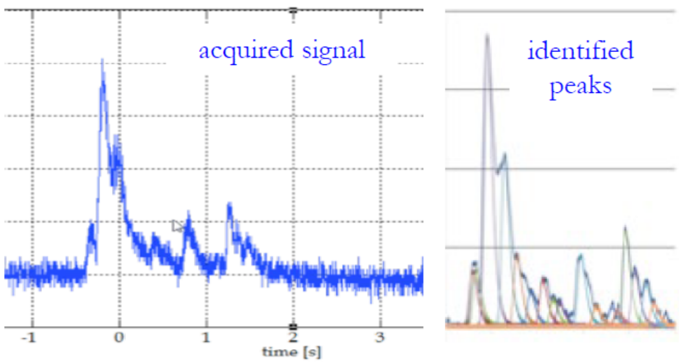
Use truncated mean for dE/dx
(track length from 0.5~5m)

σ = 3~8%

Cluster counting for IDEA

21/10/2020 CEPC Meeting
P. Azzi (INFN-PD)

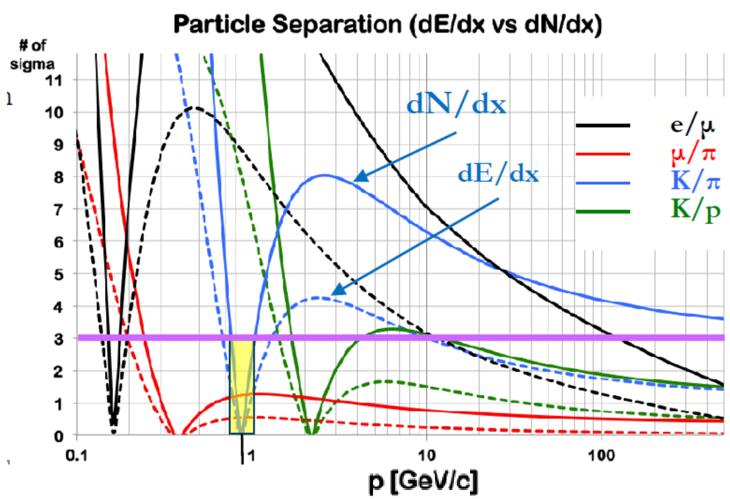
G.F. Tassielli - ICHEP2020 - Virtual (Prague)



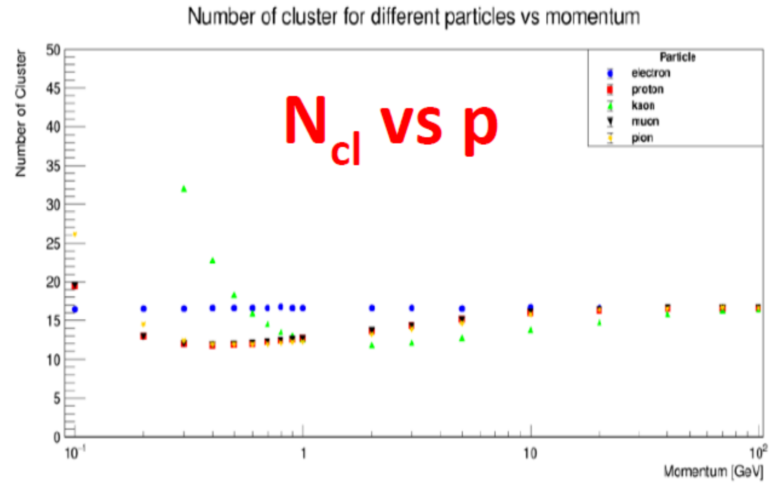
dN_{cl}/dx

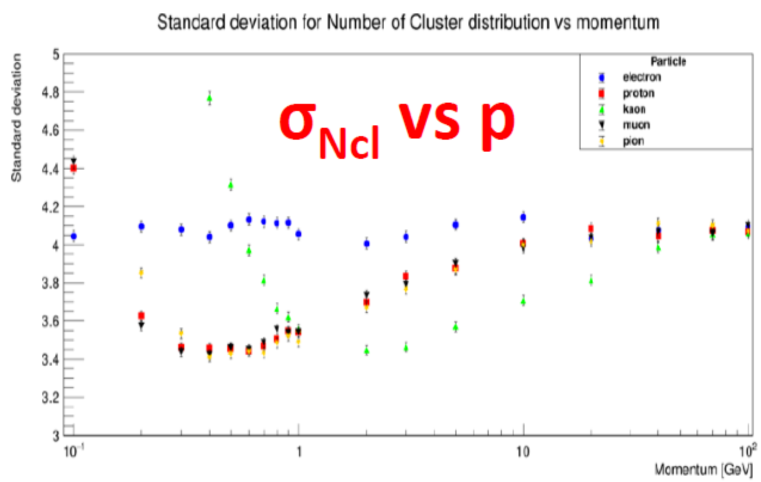
δ_{cl} = 12.5/cm for He/iC_4H_{10}=90/10 and a 2m track give

$\sigma \approx 2.0\%$



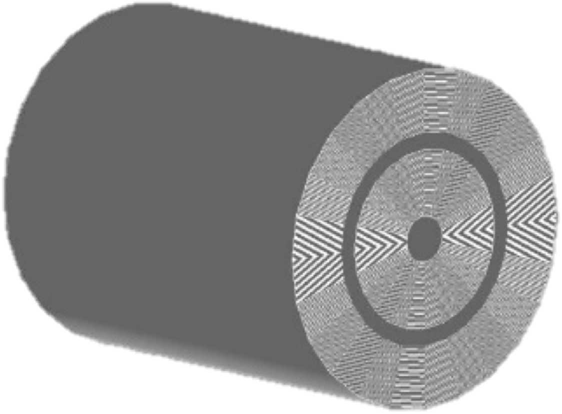
Simulation for IDEA

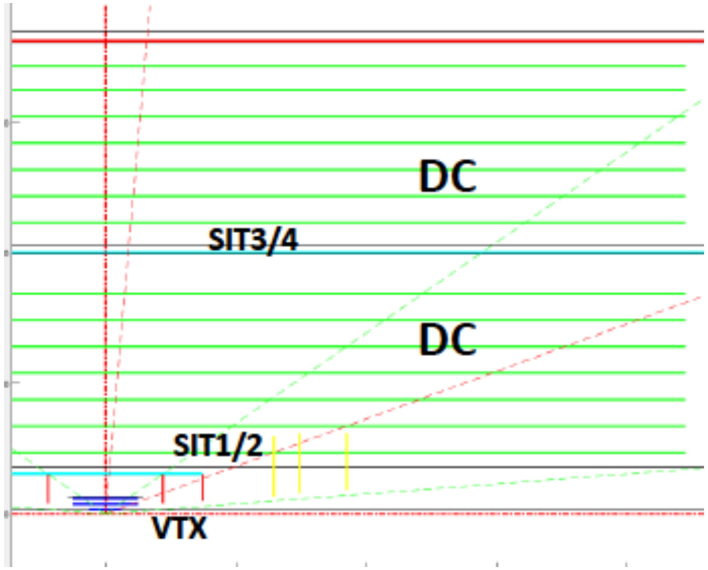




Drift chamber of CEPC reference detector

- Parameters
  - Two DC between the silicon trackers
  - Cell size: 1cm*1cm
  - 118 layers for 1.5m
  - He(50%) + iC_4H_{10}(50%)

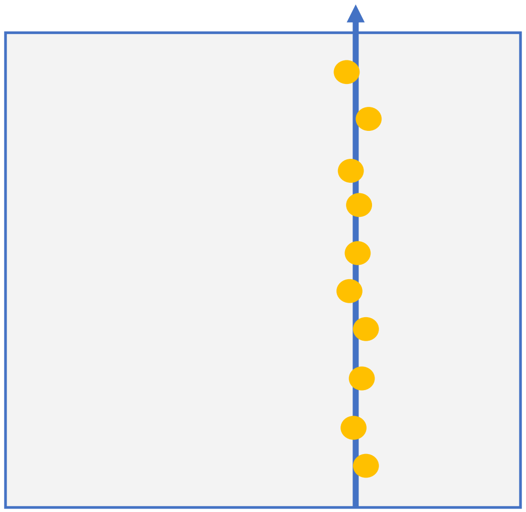




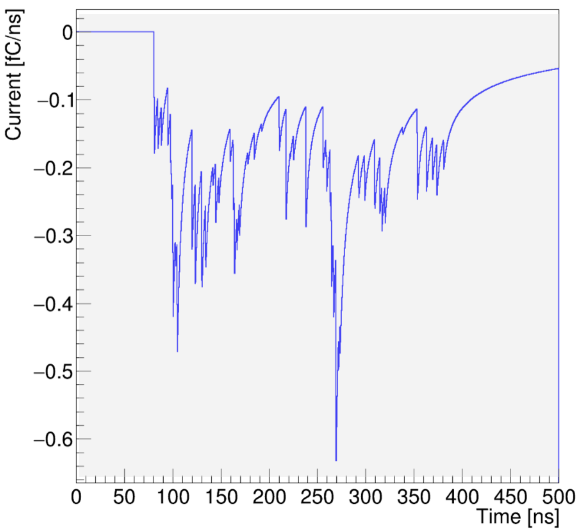
- To study the cluster counting method, a simulation with Garfield++ is performed

Simulation with Garfield++

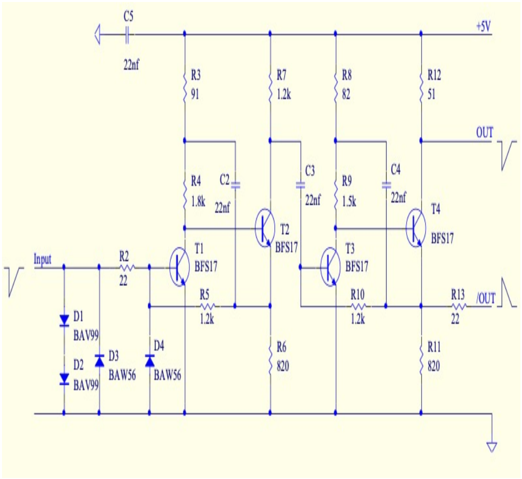
Step 1: Ionization



Step 2: peak finding in the signal



Step 3: simulation of electronics

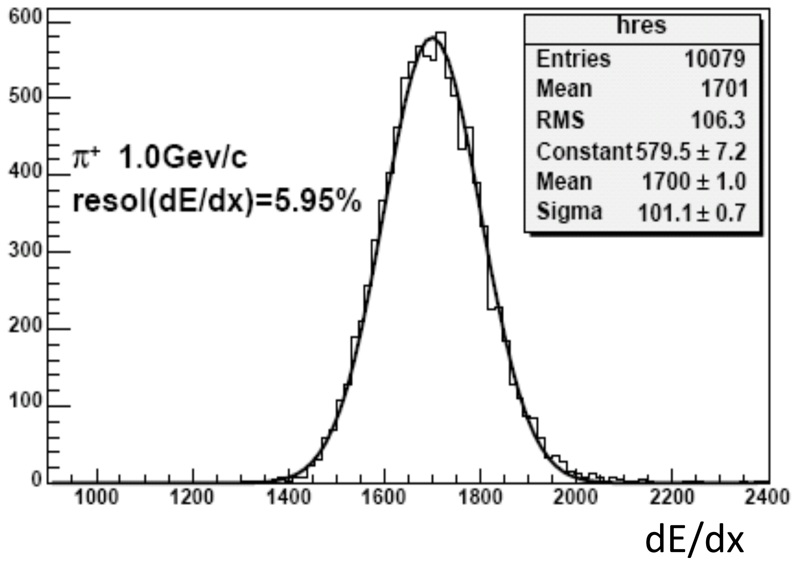


Garfield++: A widely used software for simulation of gaseous detectors

https://garfieldpp.web.cern.ch/garfieldpp

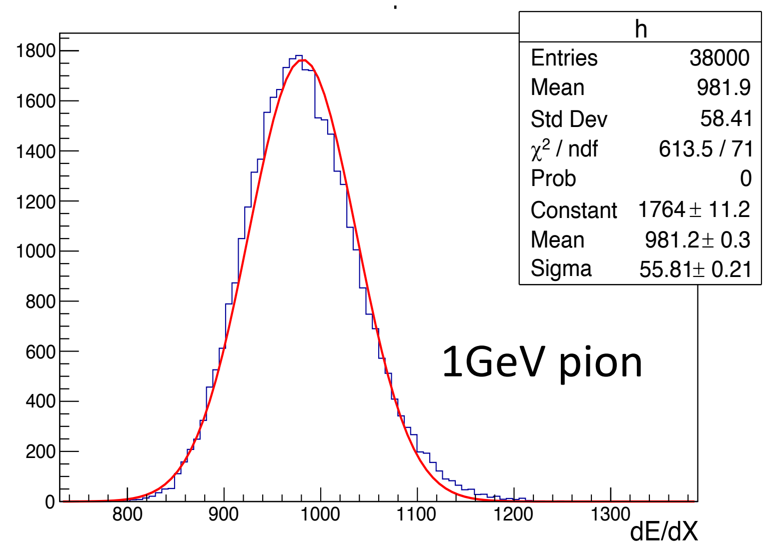
Validation of dE/dx resolution on BESIII

BESIII data



$$\frac{\sigma(dE/dx)}{dE/dx} = 5.95\%$$

Ionization simulation with Garfield

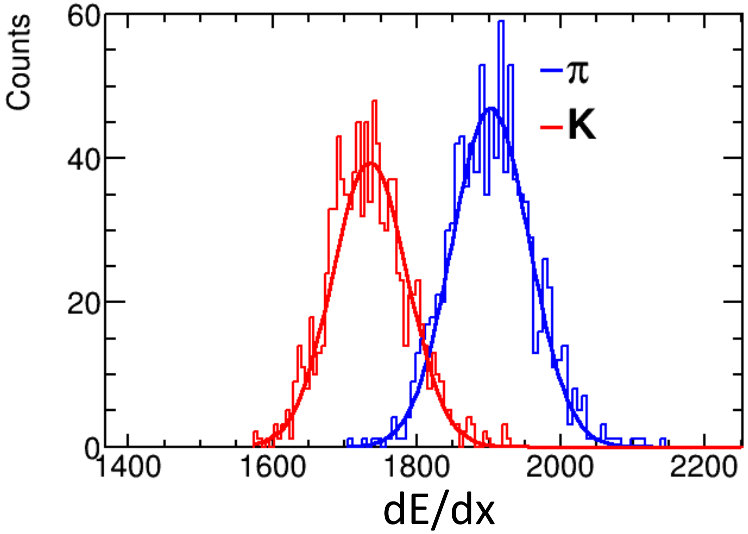


$$\frac{\sigma(dE/dx)}{dE/dx} = 5.6\%$$

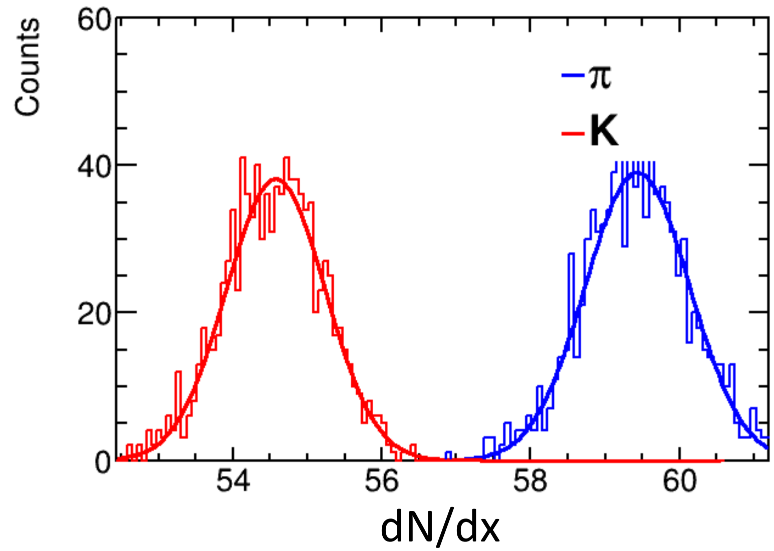
- 1 GeV/c π, cosθ=0, only simulated ionization
- Truncated mean (70%)

Comparison between dE/dx & dN/dx

dE/dx distribution



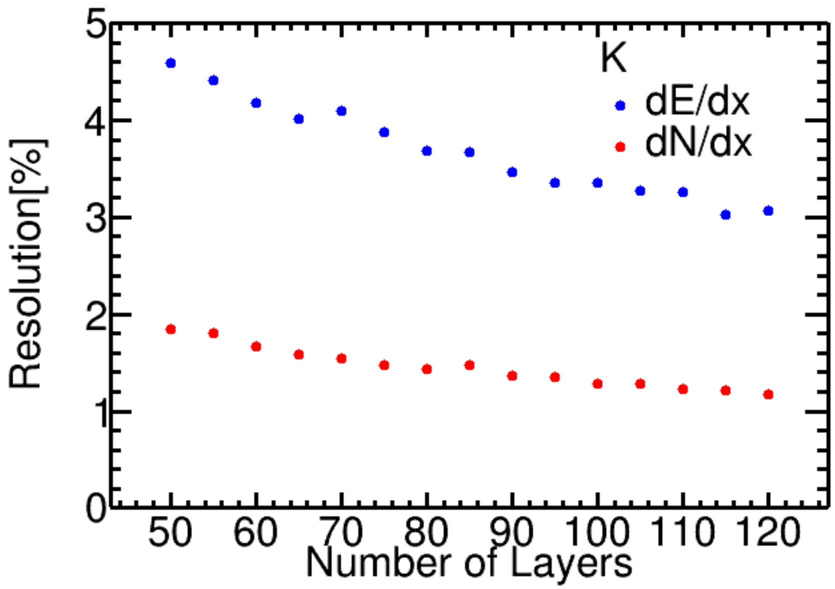
dN/dx distribution



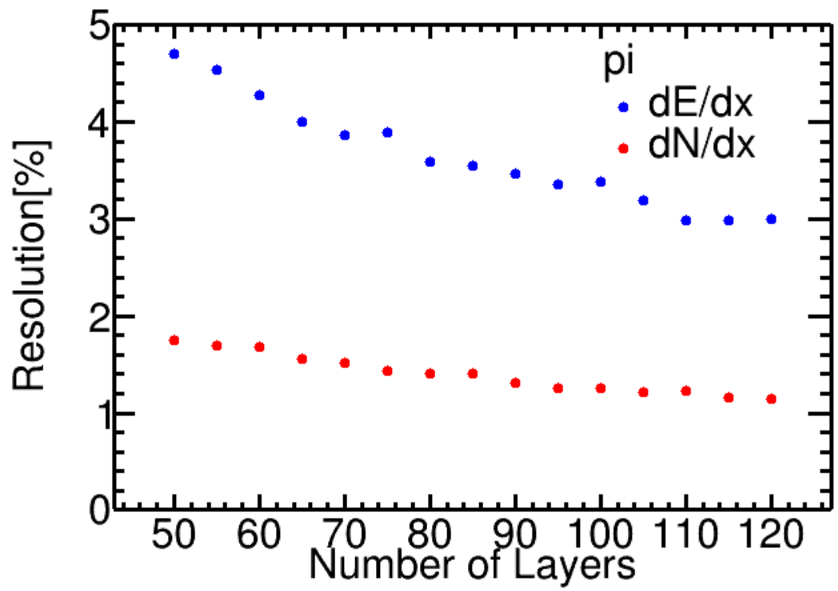
- 10 GeV/c, cosθ=0
- Cell size: 1cm*1cm, 118 layers ~ 1.5m

Resolutions vs number of layers

Resolution of kaon

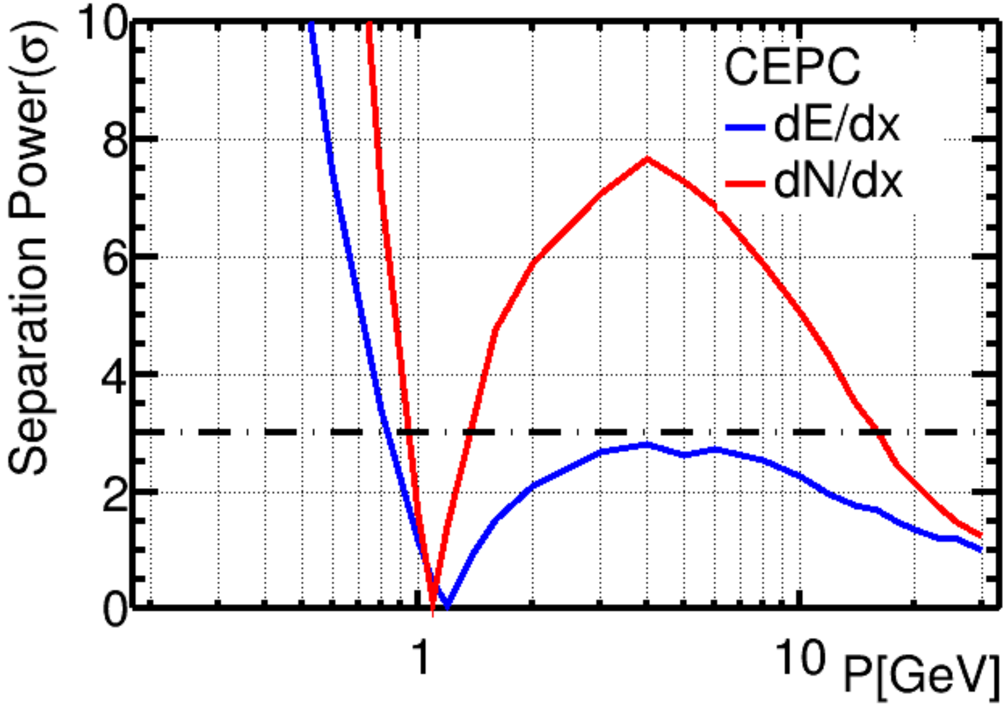


Resolution of pion



- 20 GeV/c, cosθ=0
- Cell size: 1cm*1cm, 118 layers ~ 1.5m

Separation power for K/π

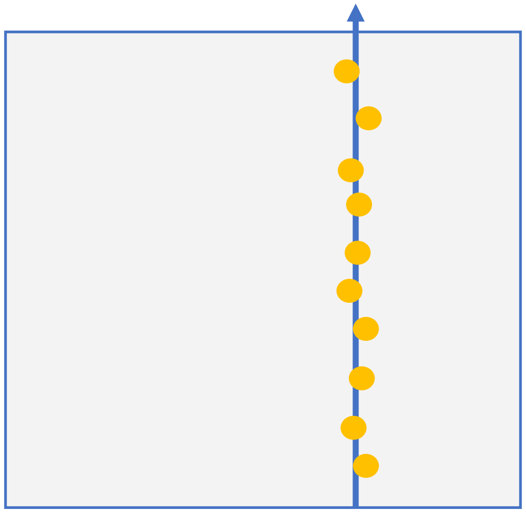


$$S = \frac{\left| < \frac{dE}{dx} >_{\pi} - < \frac{dE}{dx} >_{K} \right|}{\sqrt{\sigma\left(\frac{dE}{dx}\right)^2_{\pi} + \sigma\left(\frac{dE}{dx}\right)^2_{K}}}$$

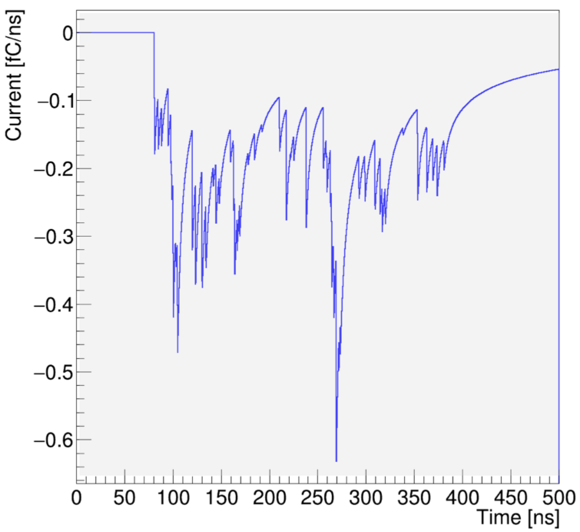
- $\cos\theta=0$, R=1.5m
- Truncated mean cut (70%) for dE/dx

Simulation with Garfield++

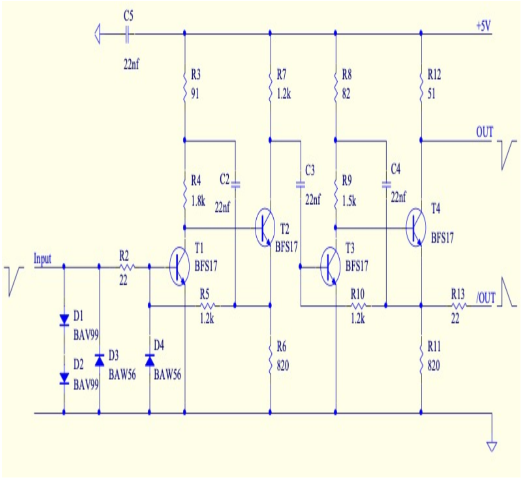
Step 1: Ionization



Step 2: peak finding in the signal



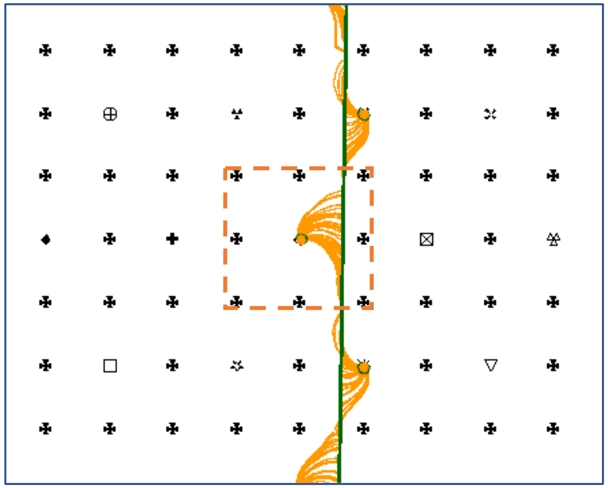
Step 3: simulation of electronics



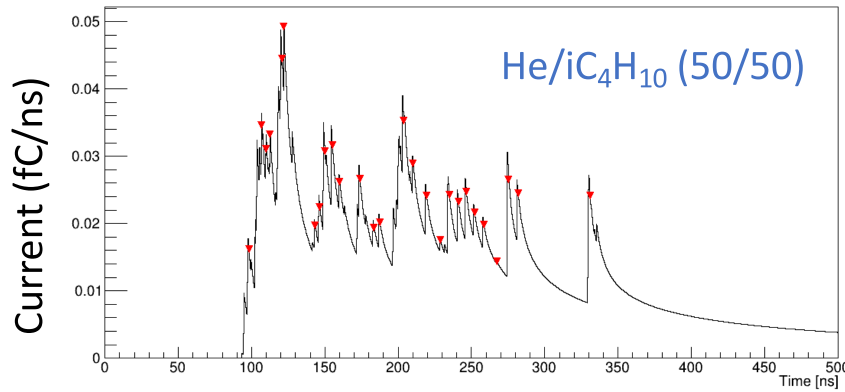
Simulation of induced signal is very time consuming (> 1 hours for each signal)

Simulation of the signal

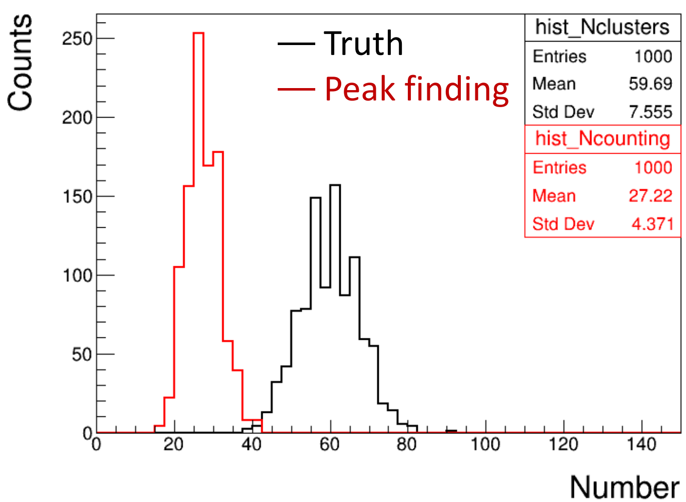
10GeV pion, cosθ=0



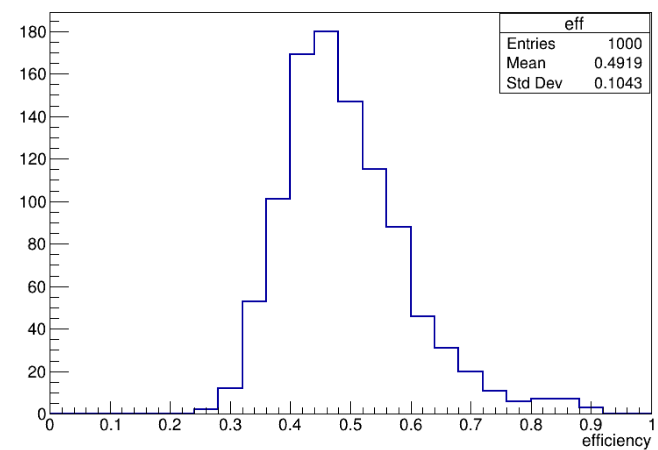
Peak finding with **TSpectrum**



Distribution of N_{cl}

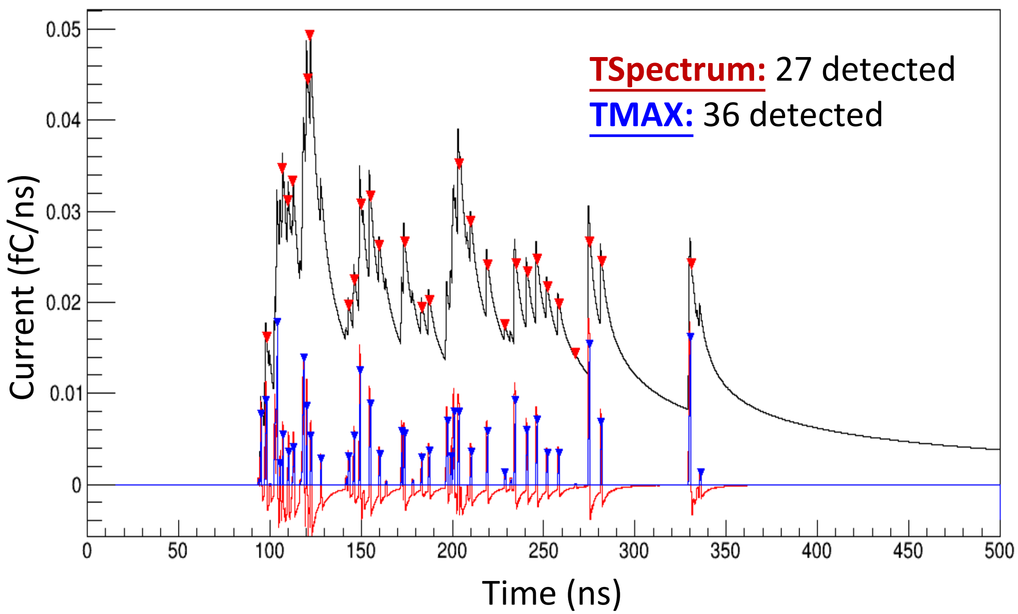


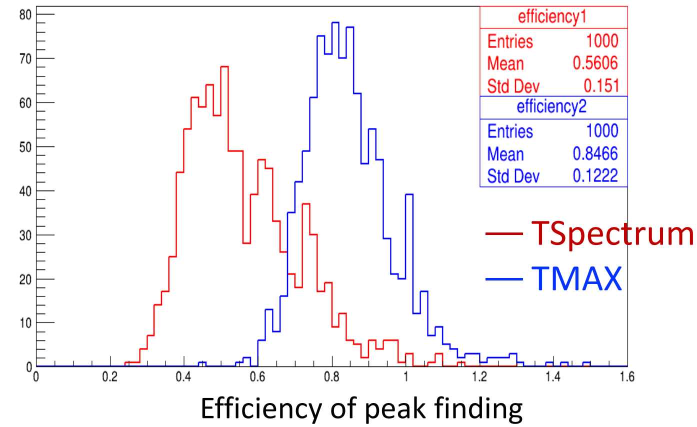
Efficiency of peak finding

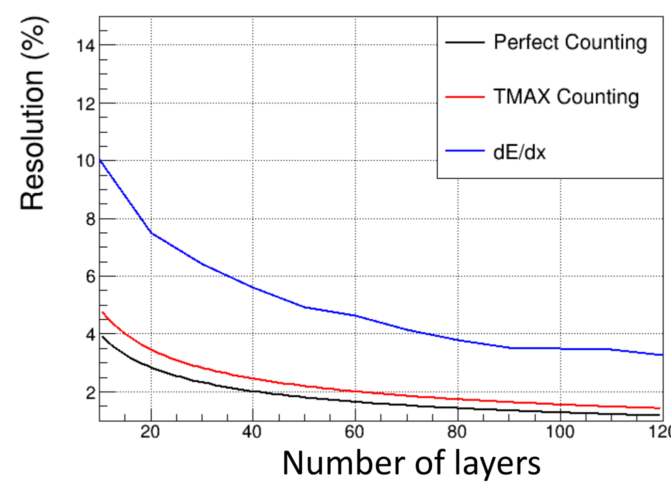


New peak finding algorithm -- TMAX

10GeV pion, cosθ=0

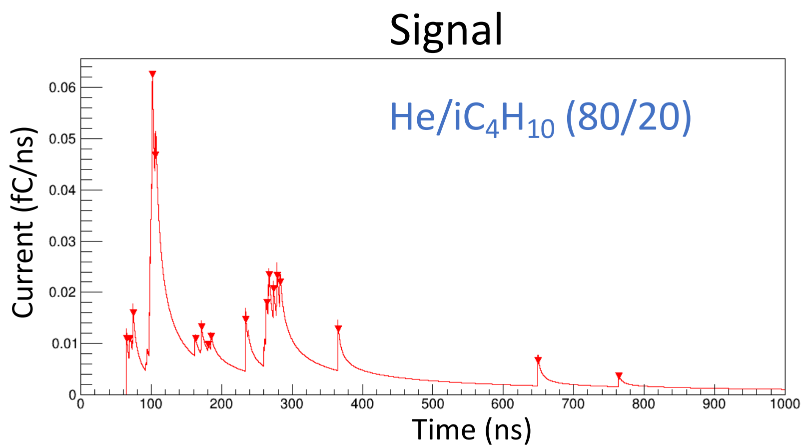




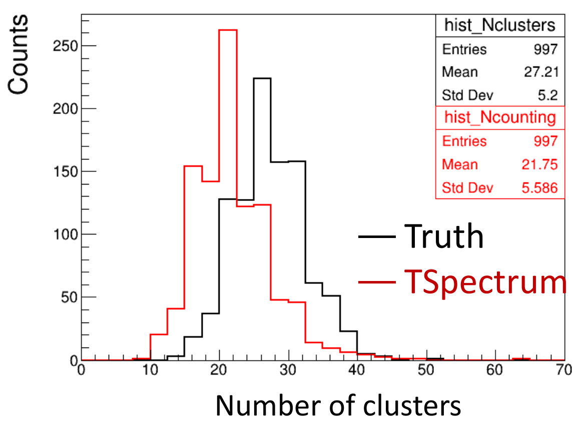


Study on different gas ratio

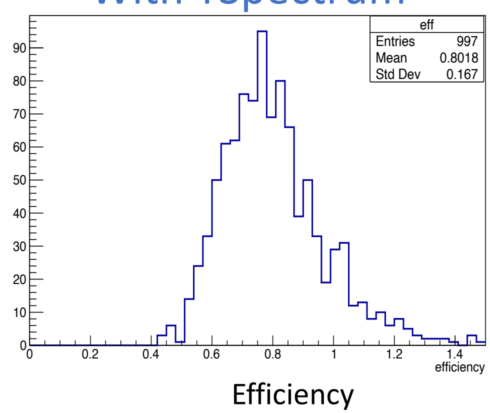
- The cluster density can be reduced by improving the ratio of He
- Lower cluster density would be better to cluster finding
- More studies ongoing
  - Impact on tracking, final dN/dx or dE/dx resolutions …



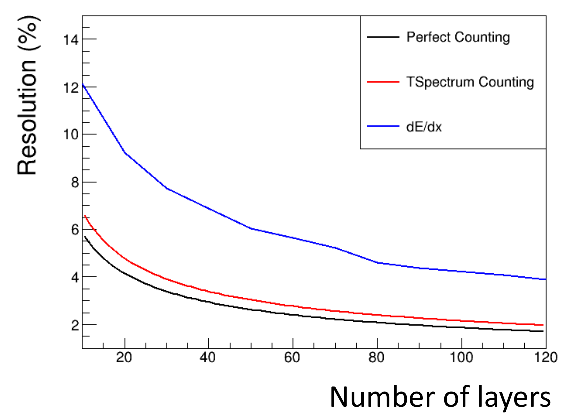
Number of clusters



Efficiency of peak finding With TSpectrum



Resolutions



Estimation of DC performances

- A fast estimation on the momentum, dE/dx and dN/dx resolutions for the Si+DC design was performed to understand the impact of different parameters on the performance
- Momentum resolution
  - Space points measurements: using toy MC
  - M.S. effect : calculation with the formula

$$\left(\frac{\sigma(P)}{P}\right)^2 = \left(\frac{\sigma(P)}{P}\right)^2_{meas} + \left(\frac{\sigma(P)}{P}\right)^2_{MS}$$

Measurements: $$\frac{\delta P_T}{P_T} = \frac{\delta y P_T}{0.3qBL^2}\sqrt{\frac{720}{N+4}}$$

MS: $$\frac{\delta p}{p} = \frac{21(\mathrm{MeV}/c)}{\beta \sin\theta}\frac{10}{3}\left(\frac{\mathrm{Tm}}{\mathrm{GeV}/c}\right)\frac{1}{B}\sqrt{\frac{C_N}{2LX_{\mathrm{rad}}}}$$

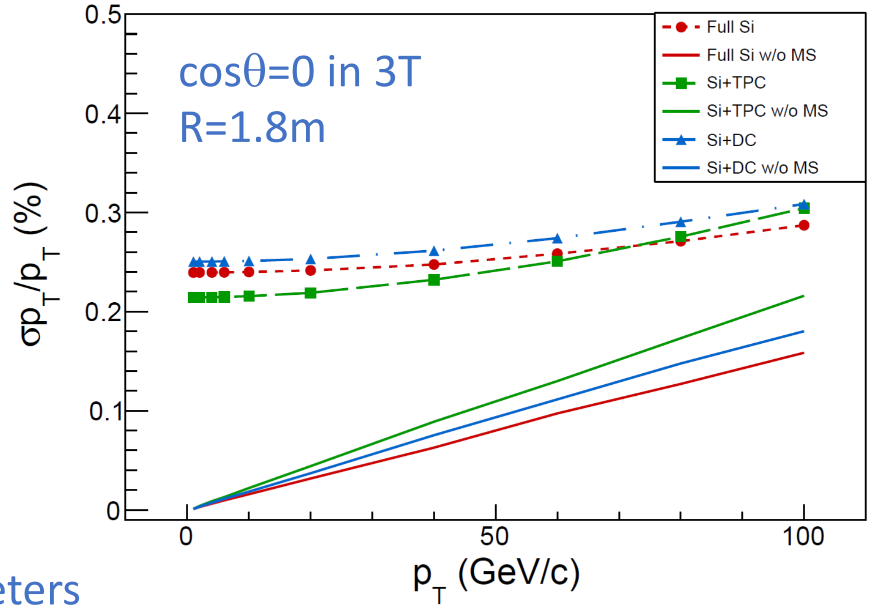
Walter Blum et al.,
Particle Detection with Drift chamber

- dE/dx & dN/dx resolution
  - Simulated with Garfield

$$\frac{\delta I}{I} = f(xp,\, n,\, \mathrm{gas}) \quad \mathrm{or} \quad g(Lp,\, n,\, \mathrm{gas})$$

Comparison of $\sigma p_T/p_T$ for three designs

- The resolution is dominated by the multiple scattering effect
- The design of Si+DC has the most material budget



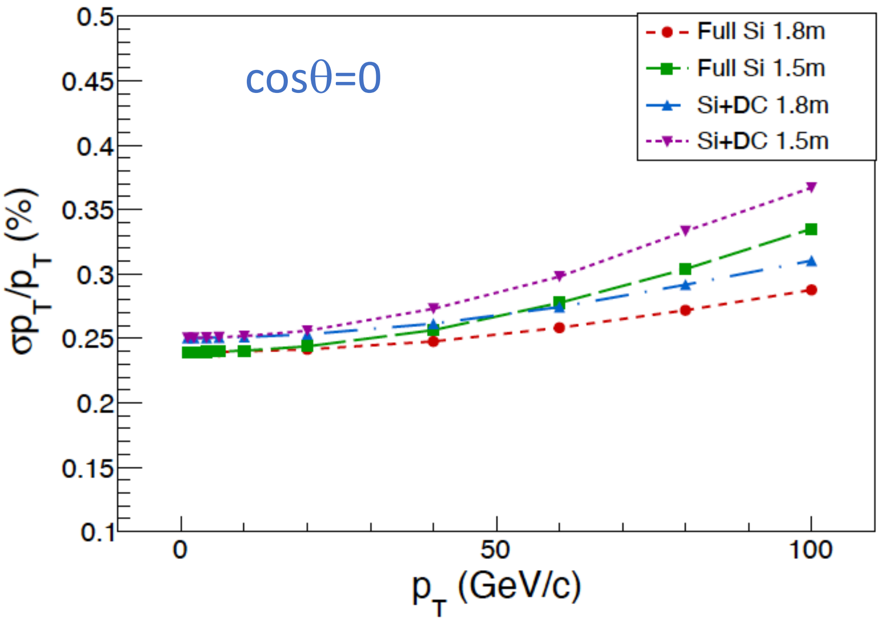
Thank Mingyi, Huirong, Hongbo and Yubo for providing material and spatial resolution parameters

Material budget in barrel region (L/X0)

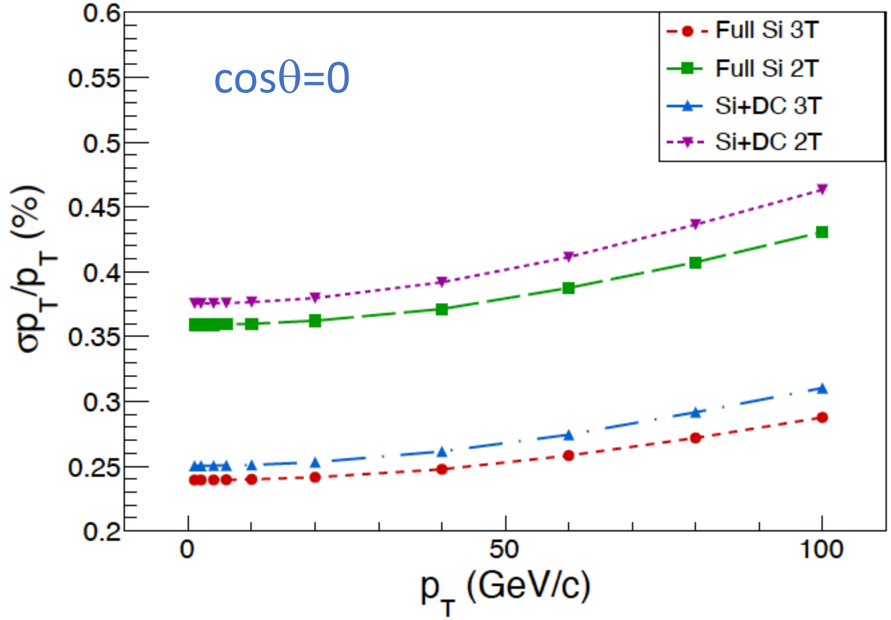
	Vertex	SIT or SET	TPC	DC	Total
Full Si	0.15% * 6	0.65% * 6	--	--	4.8%
Si+TPC	0.15% * 6	0.65% * 3	1%	--	3.85%
Si+DC	0.15% * 6	0.65% * 3	--	1.2% * 2	5.25%

Impact of detector size and magnetic field

Momentum resolution with different detector size (3T)

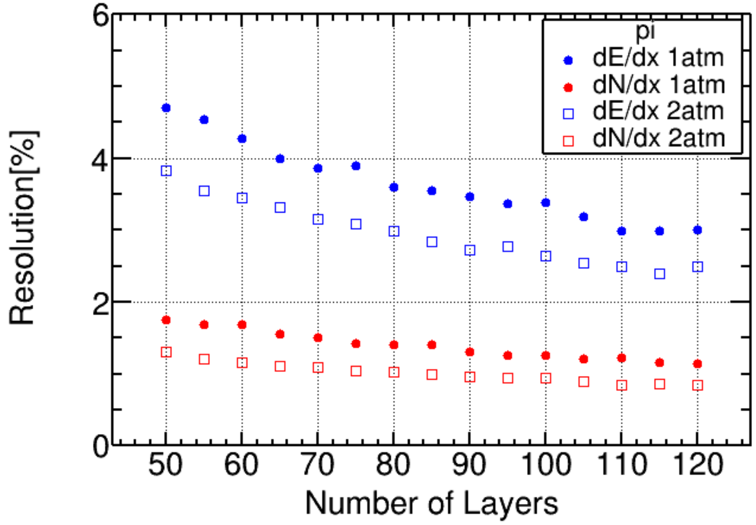


Momentum resolution with different magnetic field (1.8m)

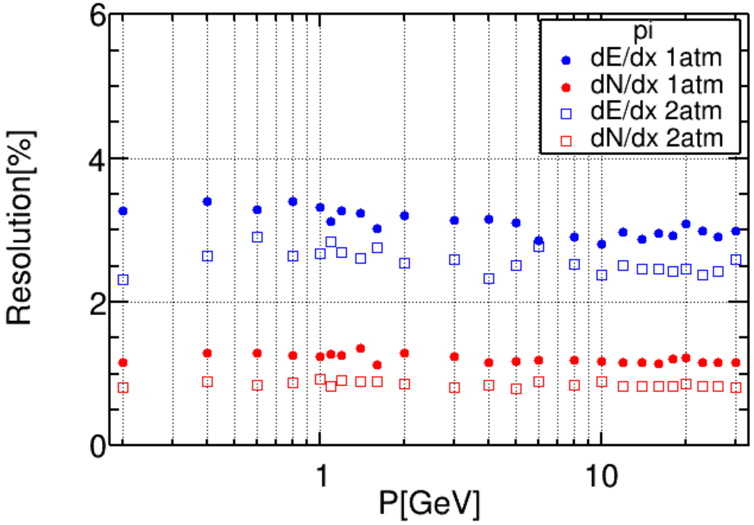


dE/dx & dN/dx resolutions

Resolution vs number of layers
20 GeV/c pion



Resolution vs momentum
R = 1.5m



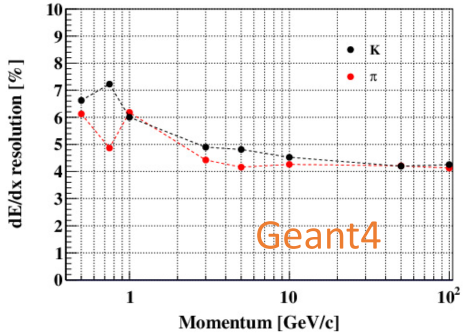
From Garfield simulation on the ionization process

Software Development for DC in CEPCSW

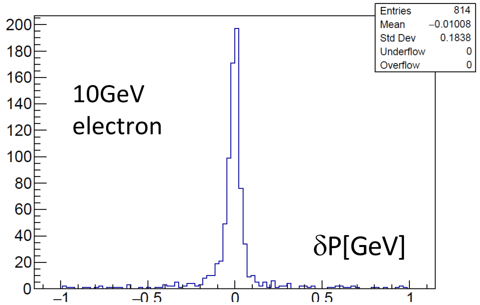
Zhang Yao

- **Geometry** (Liu Mengyao-SDU, Lin Tao, Zhang Yao, Fu Chengdong)
  - Two drift chambers + Silicon trackers
- **dE/dx simulation** (Fang Wenxing, Lin Tao, Ryuta)
  - dE/dx simulation module with sampling method
  - Configurable Gaudi tools implemented
- **Reconstruction** (Zhang Yao)
  - Track fitting with Kalman filtering
- **Plan**
  - First release of SDT in CEPCSW by the end of Nov.
  - Simulation waveform for cluster counting
  - Drift chamber performance studies
  - Development of drift chamber tracking algorithms

Resolution of dE/dx



Momentum after Kalman fitting



Summary and plan

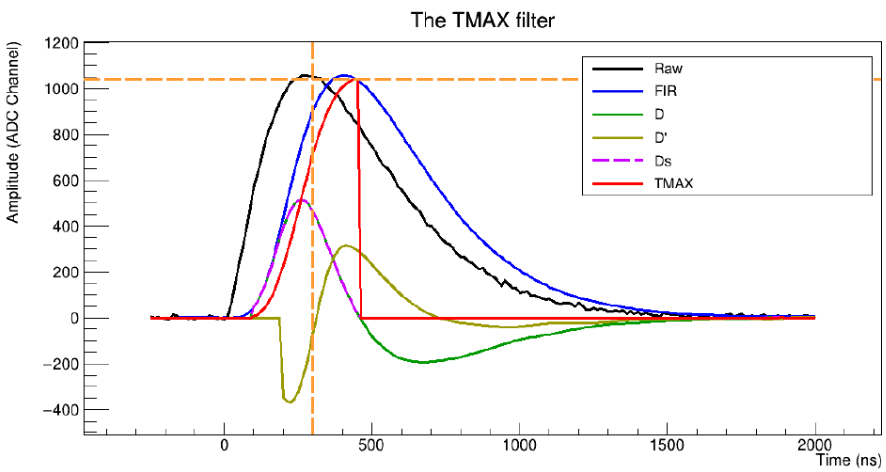
- A Garfield simulation was performed for the drift chamber of CEPC reference detector
- Preliminary results show that the resolution and separation power with cluster counting method are significantly better than traditional dE/dx method
- A fast estimation on detector performance was performed
- To do
  - Optimize the peak finding algorithm
  - Study the performance by varying detector configurations (gas, pressure …)
  - Optimize detector parameters taking into account physics requirements and hardware issues
  - A detector system is being prepared to test the signals with different gas mixture

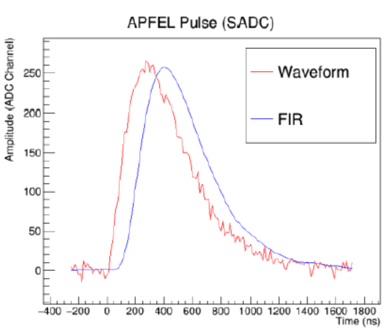
Thanks!

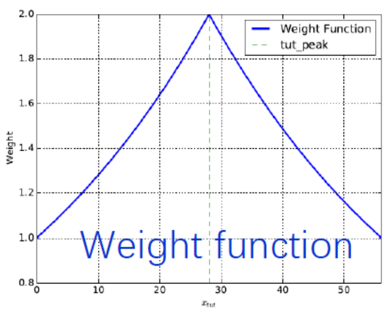
Backup

TMAX -- An updated cluster counting algorithm

Zhao Guang







FIR: 20-coefficient filtering

Derivative (D)

- D[i] = T[i + r] – T[i]

Second derivative (D')

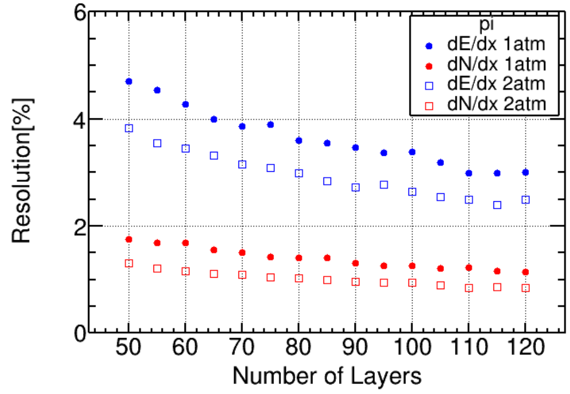
- D'[i] = D[i + r] – D[i]

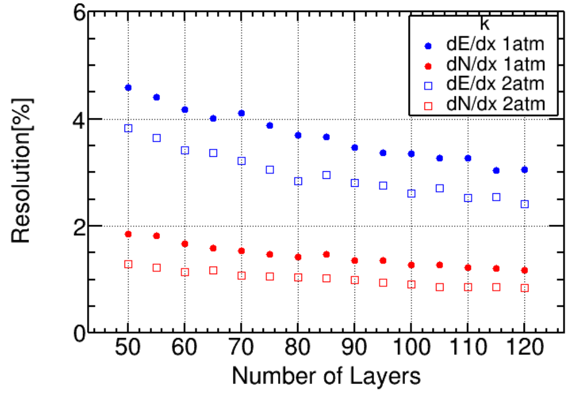
TMAX

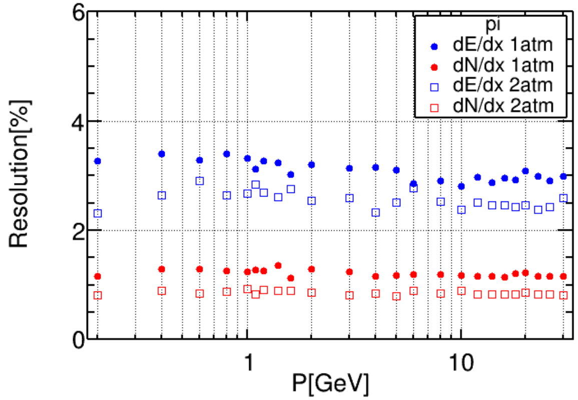
- TMAX[i] = Σ_i(D[i]) – Θ[-D[i]] * D[i]
- where Θ(x) =
  - 0 (x < 0)
  - 1 (otherwise)

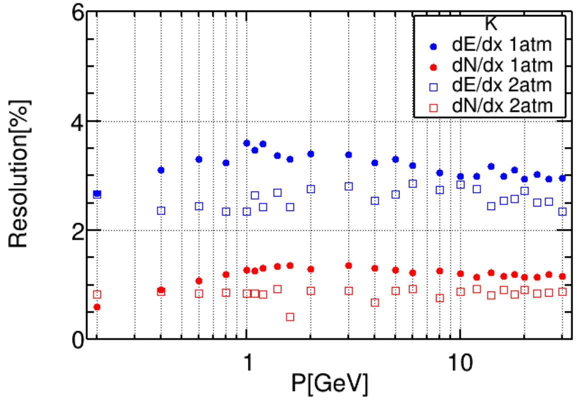
- Hit detection
  - Threshold: A weight function convoluted with the TMAX (1.35 MeV)

- Time is extracted for each peak (first derivative = 0)
- The rising edge height must pass a threshold


pi
dE/dx 1atm
dN/dx 1atm
dE/dx 2atm
dN/dx 2atm
Resolution[%]
Number of Layers


k
dE/dx 1atm
dN/dx 1atm
dE/dx 2atm
dN/dx 2atm
Resolution[%]
Number of Layers


pi
dE/dx 1atm
dN/dx 1atm
dE/dx 2atm
dN/dx 2atm
Resolution[%]
P[GeV]


K
dE/dx 1atm
dN/dx 1atm
dE/dx 2atm
dN/dx 2atm
Resolution[%]
P[GeV]