Drift Chamber with Cluster Counting Techniques for CEPC

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For the DC-PID group of CEPC 4th conceptual detector

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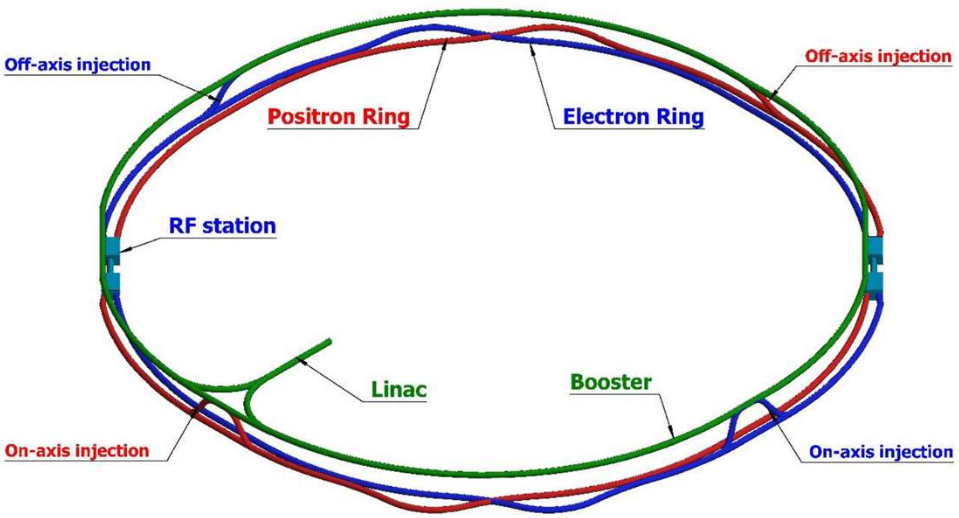
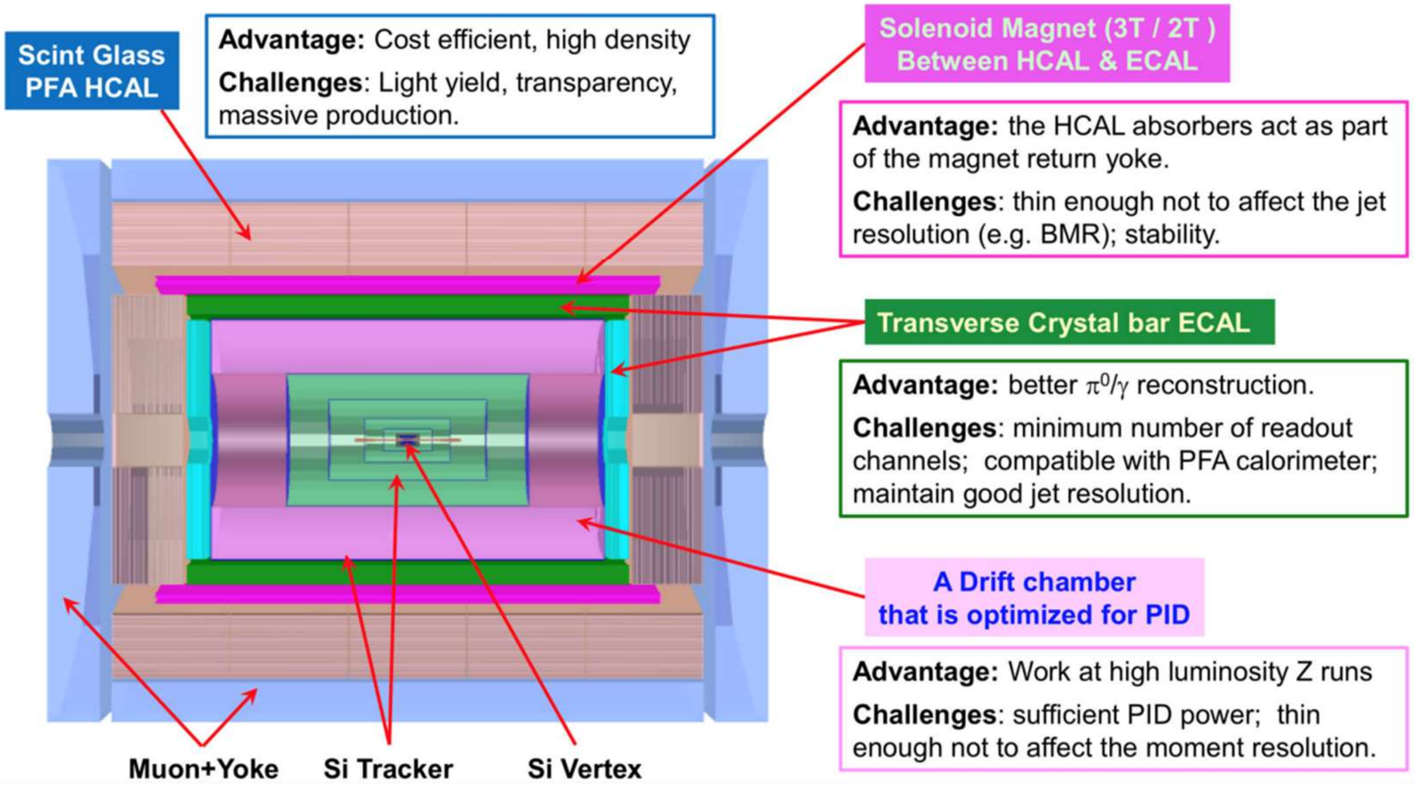
CEPC(Circular Electron Positron Collider)



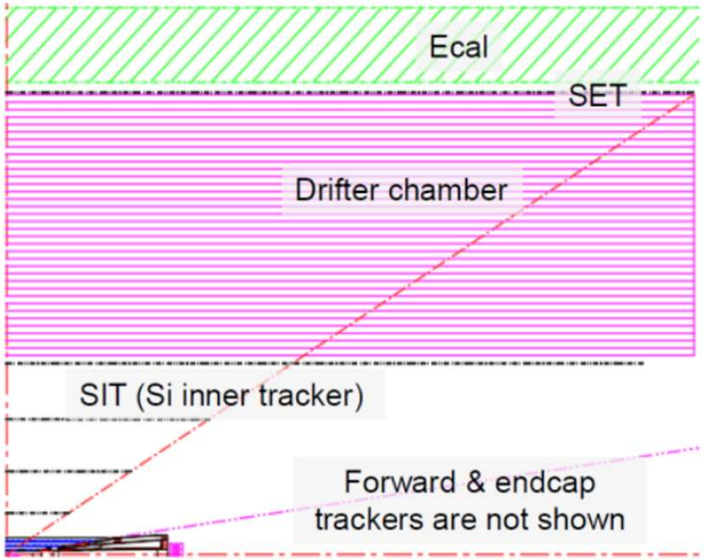
- CEPC (Circular Electron Positron Collider) is a double ring collider with two interaction points
- 100 km circumference
- 240 GeV Higgs factory
- 91.2 GeV Z factory
- 160 GeV WW threshold scan

Drift Chamber in CEPC 4th conceptual detector



- Tracker with silicon tracker and a drift chamber
- The chamber optimized for PID with cluster counting technique
- Up to 20GeV/c K/π separation power better than 2σ required
- Benefited momentum resolution at low momentum

Preliminary design



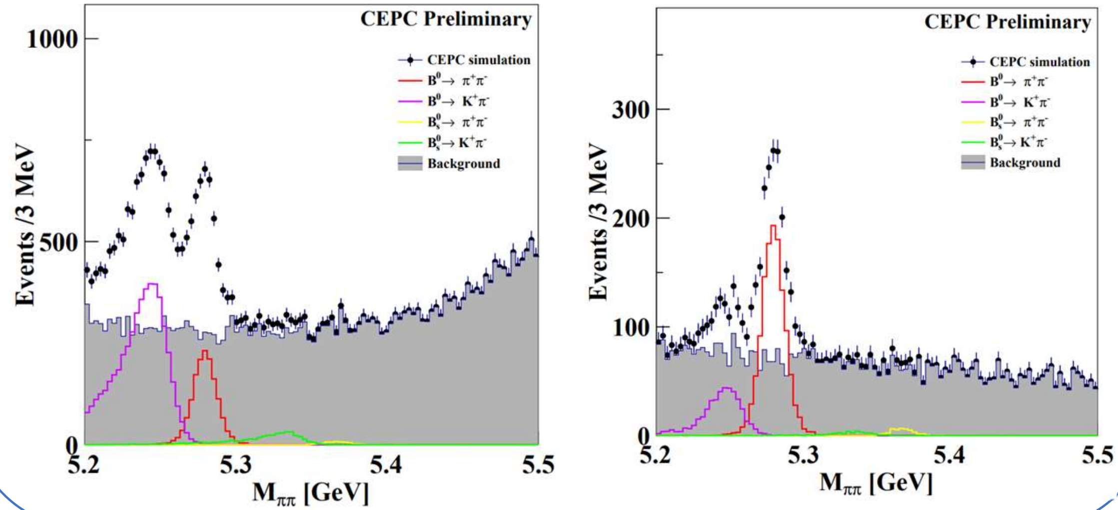
Preliminary DC parameters	
Inner radius	800mm
Outer radius	1800mm
Cell size	18 mm × 18 mm
Gas mixture	He/iC_4H_{10}=90:10
Length of outermost wires (cosθ=0.82)	5143mm

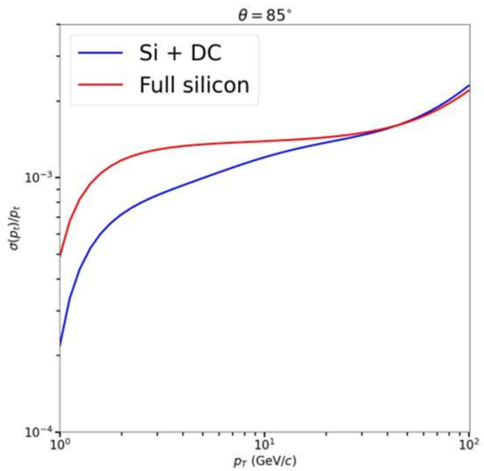
Advantages

- Particle identification
  - Reduce combination background
  - Improve mass resolution
  - Improve jet energy resolution
  - Benefit flavor tagging
- Tracking
  - Benefited momentum resolution in low momentum

Simulation of $B^0/B_s^0 \rightarrow \pi^+\pi^-$ with Delphes

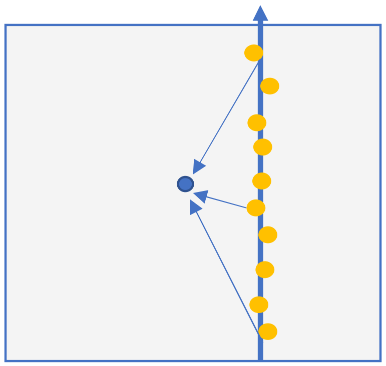
Without PID　　With PID

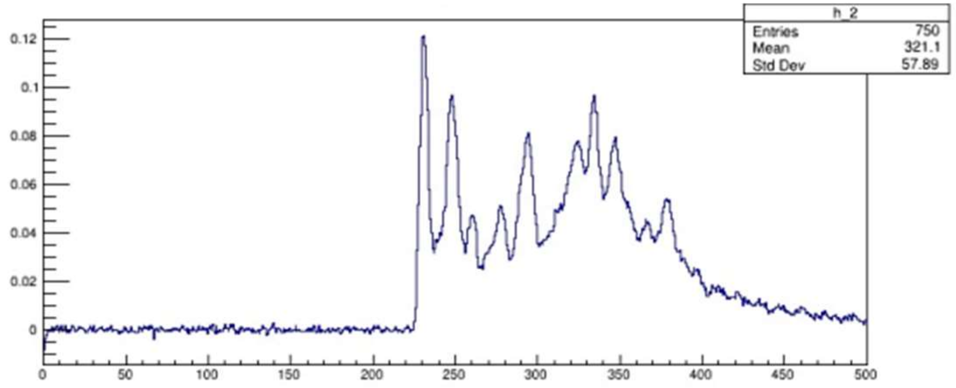




PID by ionization measurement

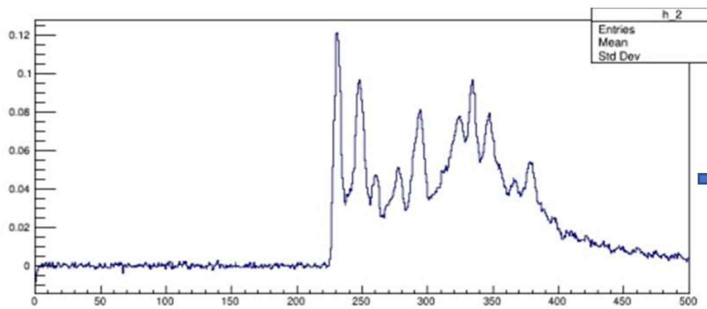
- Gas atoms interact with the particle → electron-ion pairs
- Electrons collected by anode wires
- Waveform versus time can be reconstructed from the data got from the front-end electronics.



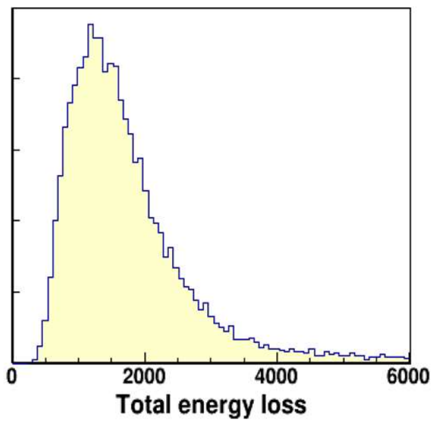


dE/dx measurement

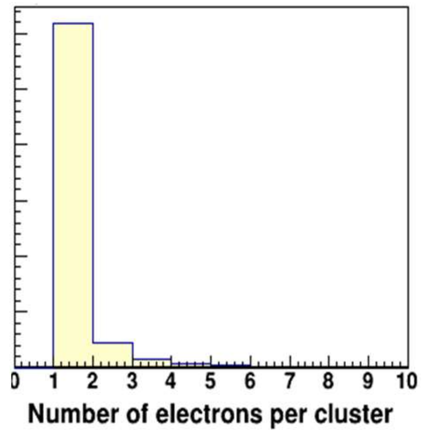
- Energy loss(dE/dx) can be calculated by applying integration to the waveform.
- Electrons with higher energy lead to secondary ionization, which makes dE/dx distribution more approximately as a Landau distribution.



integral

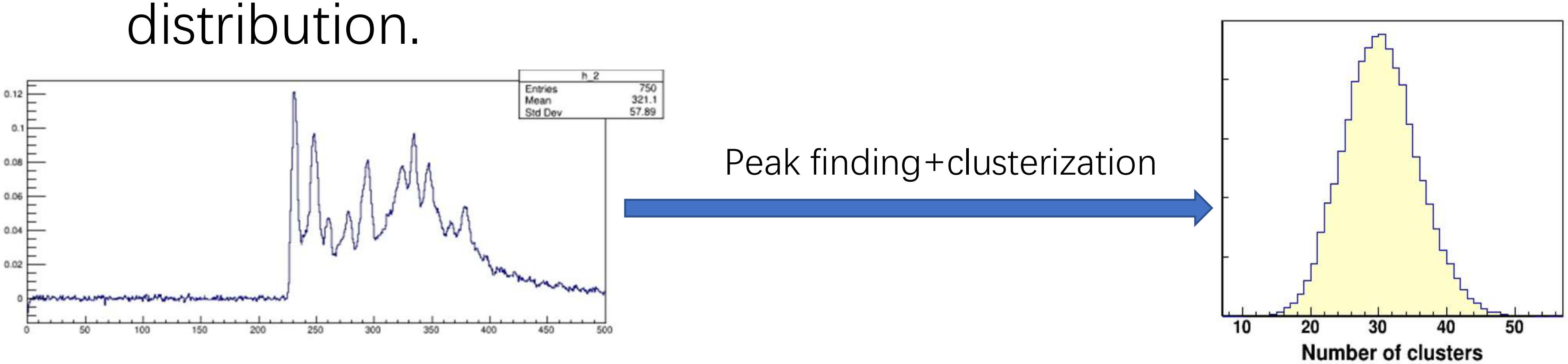


Secondary ionization



dN/dx measurement

- To eliminate the effects of secondary ionization, a new method called dN/dx based on peak finding and clusterization is proposed
- The number of clusters in dN/dx method corresponds to the number of the primary ionization
- The distribution of the dN/dx is more approximately as a Poisson distribution.



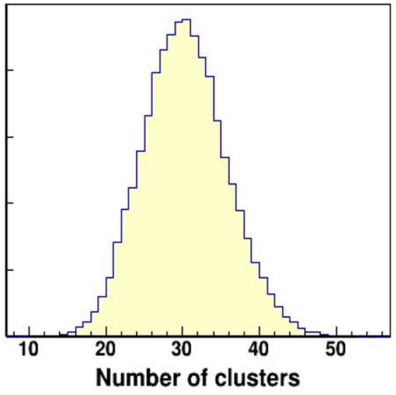
Primary ionization

dE/dx vs dN/dx

dN/dx

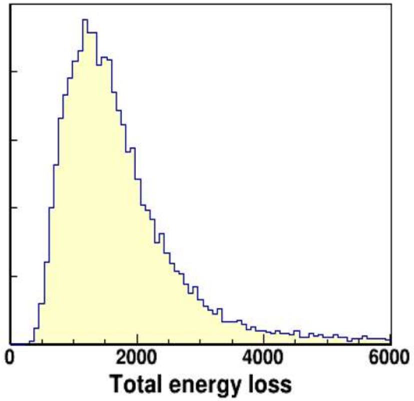
- Number of primary ionization clusters per unit length
- Poisson distribution
- Small fluctuation

Cluster counting technique

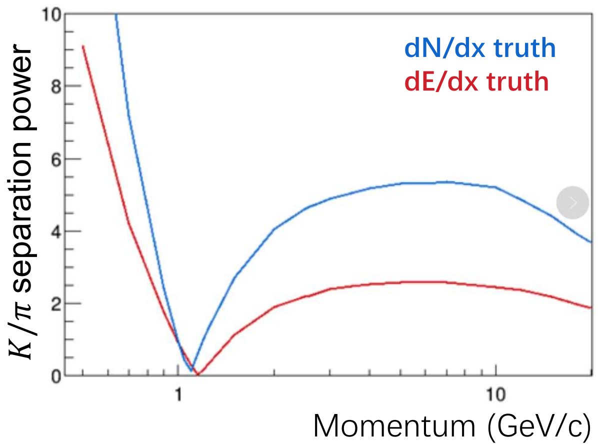


dE/dx

- Energy loss per unit length
- Landau distribution
- Large fluctuation



K/π separation power
dN/dx vs dE/dx



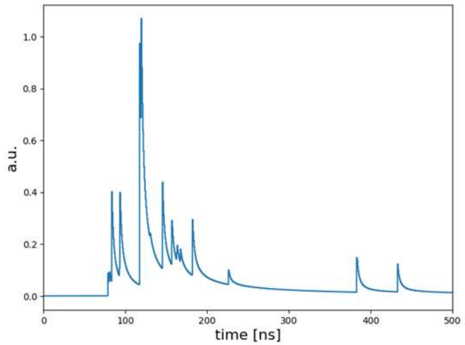
dN/dx has a much better K/π separation power up to 20 GeV/c compared to dE/dx (Simulation)

Simulation Study

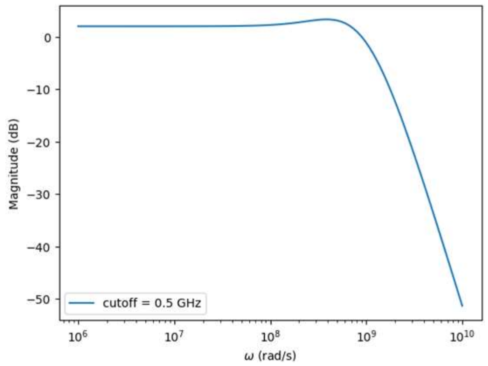
- Classical Method
- Machine Learning Method

Waveform simulation

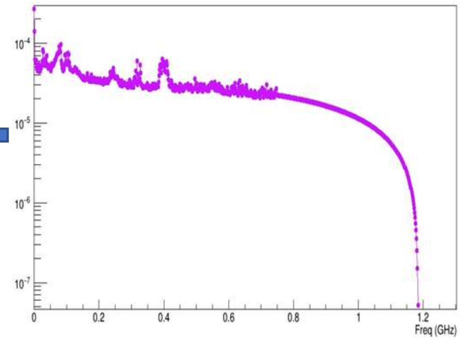
Induced signal (Simulation)



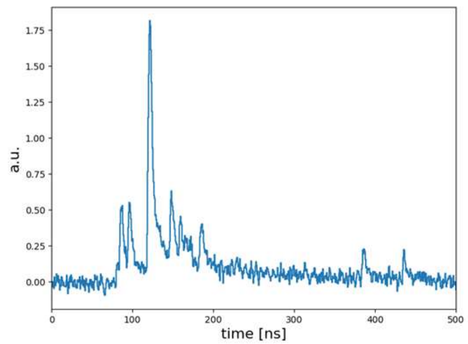
Electronics response (beam test electronics)



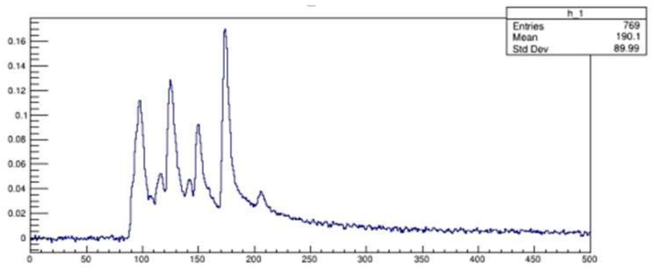
Noise (beam test)



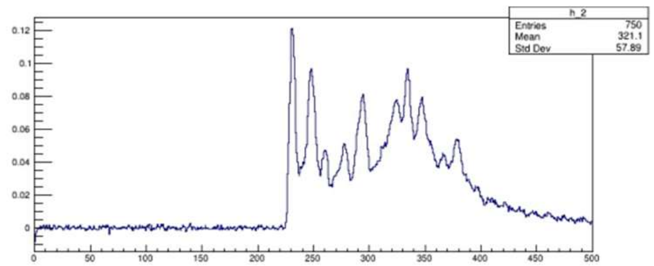
Waveform



Simulation



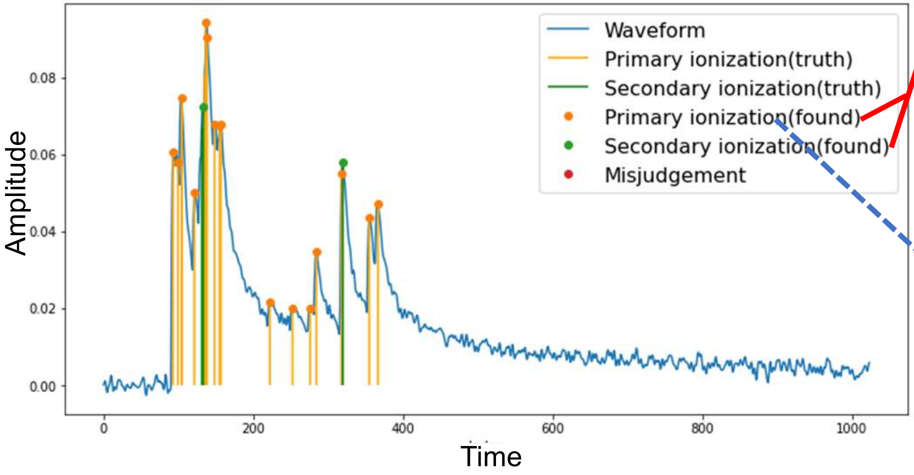
Beam test data



Reconstruction algorithms

- Two methods under study
  - Classical method (developed)
    - Derivative-based peak finding + clusterization with peak merge
  - Deep learning based algorithm (ongoing)
    - Peak finding with LSTM + clusterization with DGCNN

Two-step reconstruction algorithm



Step1. Peak Finding

Discriminate peaks (both primary and secondary) except from the noises (classification problem)

Step2. Clusterization:

Determine the number of clusters (N_{cls}) from the detected peaks (regression problem)

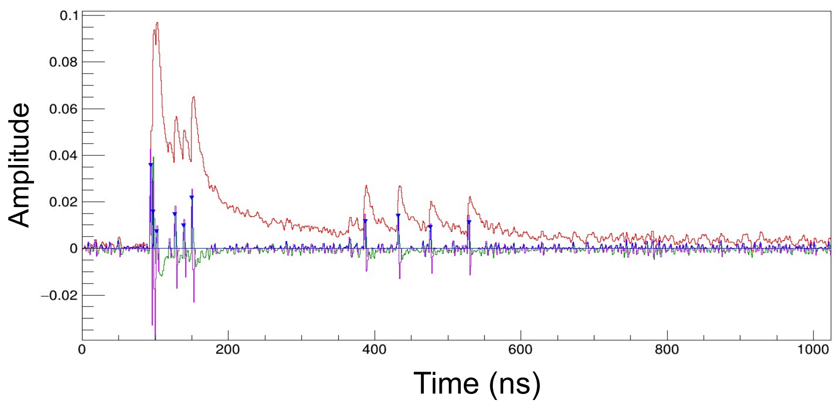
Classical method

Peak finding

- With 1st and 2nd order derivatives
- Peak detection by the slope change of the rising edge

Clusterization

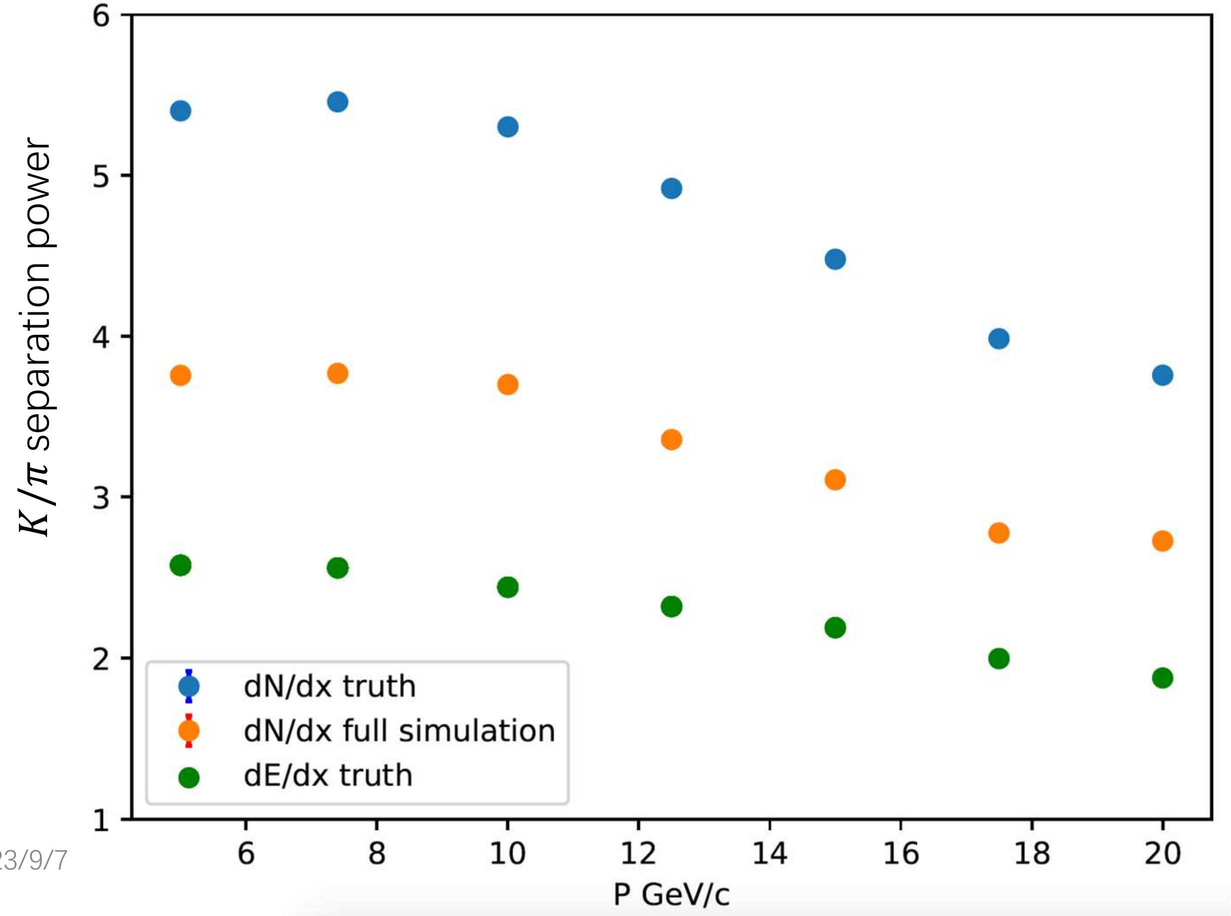
- If $\Delta t < t_{cut}$, peak merged
- The t_{cut} is related to diffusion and estimated from MC



- Advantages: Simple and fast
- Disadvantages: Lose efficiency for highly pile-up and noisy waveforms
- Developed and used in performance study

Preliminary results with classical algorithm

K/π separation power vs P (1m track length, cosθ=0)

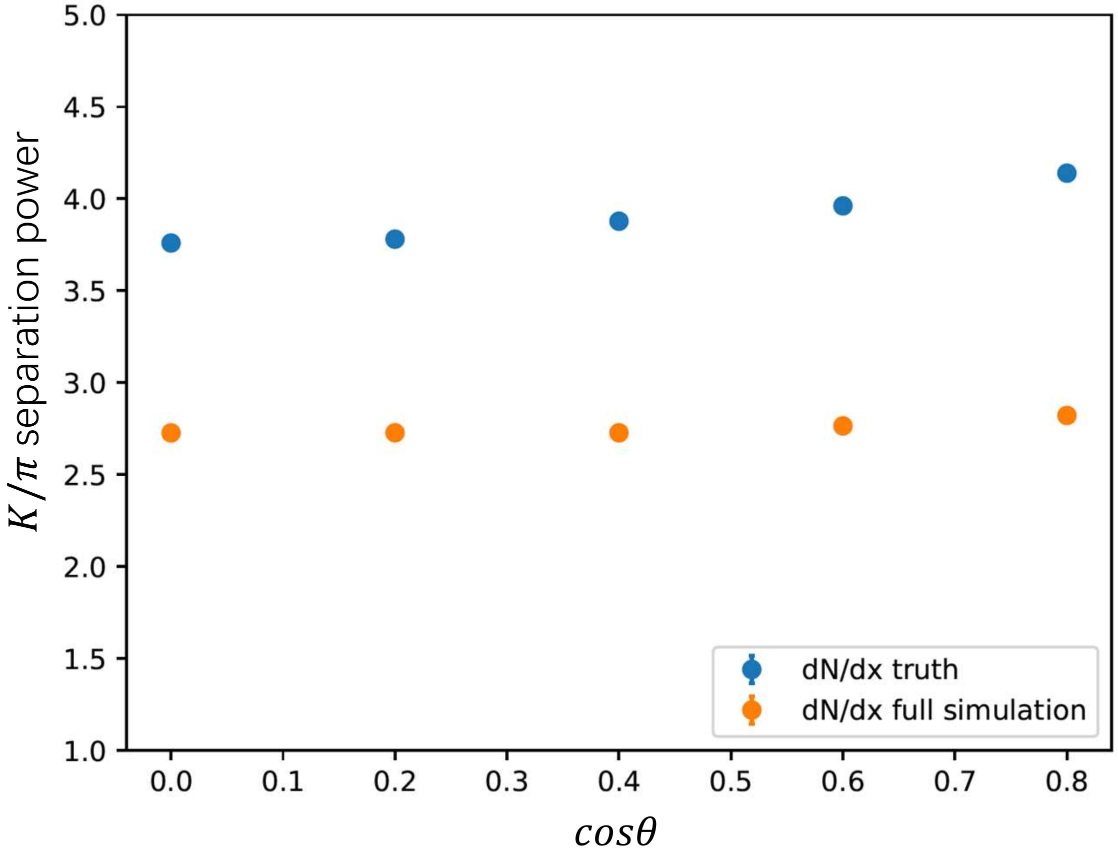


Separation power

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

Preliminary results with classical algorithm

K/π separation power vs $cos\theta$ (P=20GeV/c)

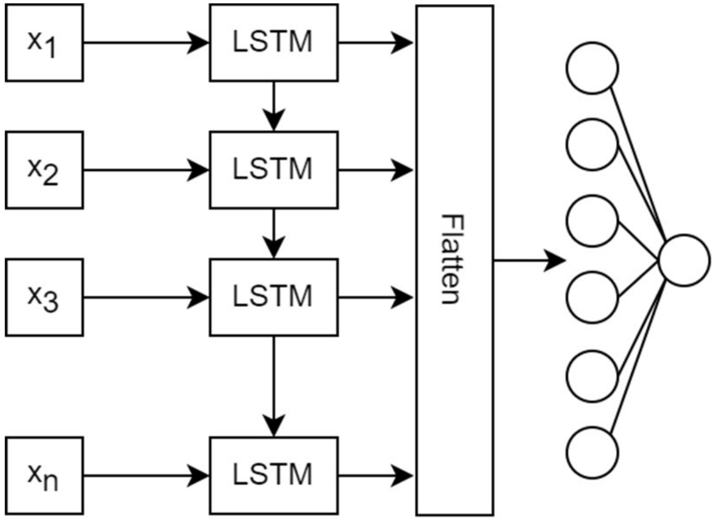


Separation power

$$S = \frac{\mid (\frac{dN}{dx})_{\pi} - (\frac{dN}{dx})_{K} \mid}{(\sigma_{\pi} + \sigma_{K})/2}$$

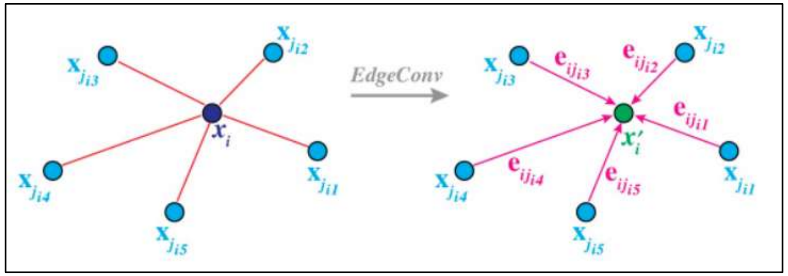
Deep learning based algorithm

Peak finding with LSTM (Long Short Term Memory)



- RNN-based architecture: LSTM
- Binary classification of signals and noises on slide windows of peak candidates

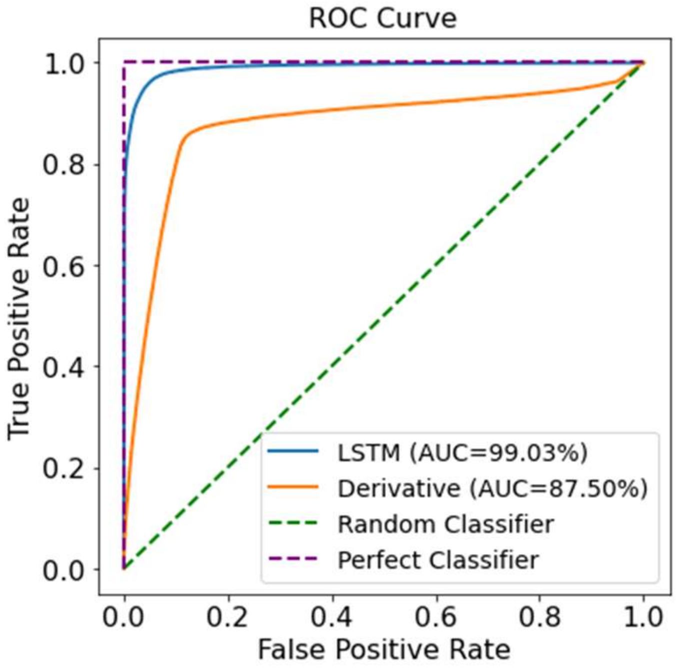
Clusterization with DGCNN (Dynamic Graphic Convolutional Neural Network)



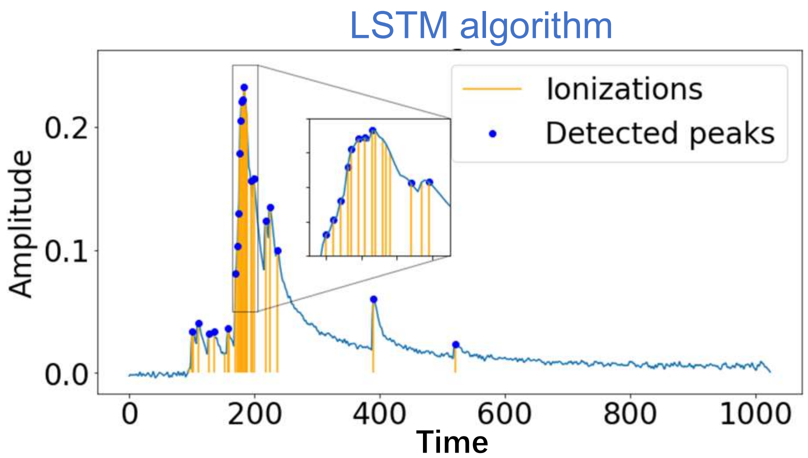
arXiv: 1801.07829

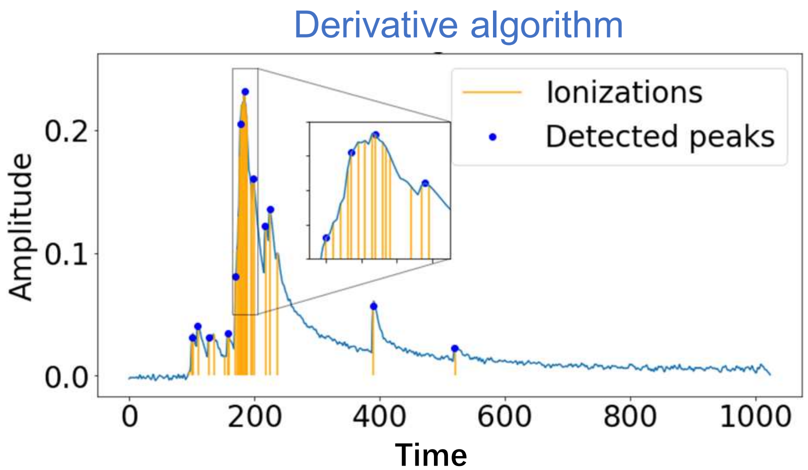
- GNN-based architecture: DGCNN
- Massage passing through neighbor nodes ⟺ Clusterization of electron timings from the same primary cluster
- Binary classification of primary and secondary electrons

Comparison between LSTM and derivative model

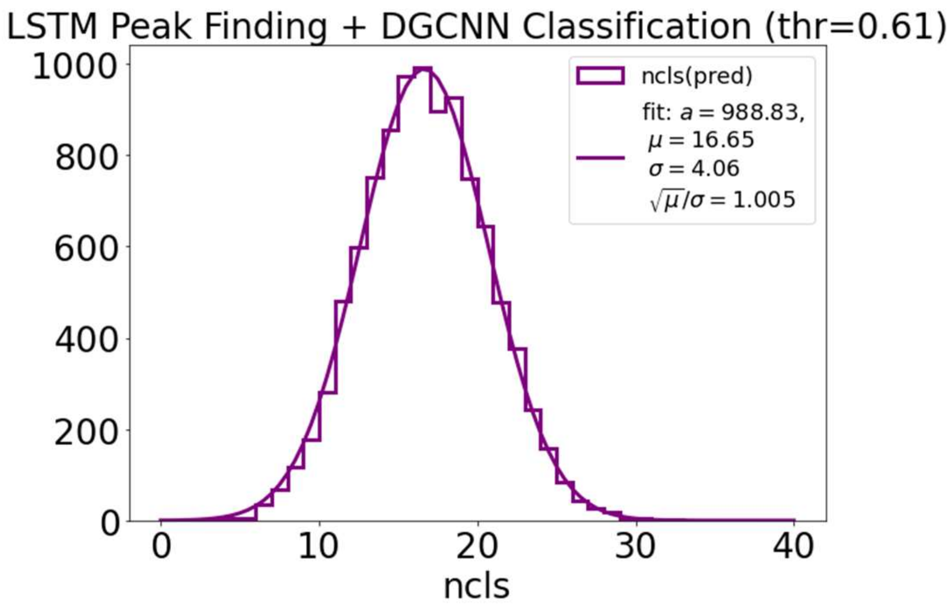


Better AUC for LSTM, due to the better pile-up recovery ability of the LSTM model





Performance with deep learning based algorithm



Clusterization Method	μ	σ	σ/μ
MC truth	**16.53**	**3.93**	**23.8%**
Classical algorithm	18.67	4.60	24.6%
Deep learning	16.65	4.06	24.4%

Closer to MC truth N_{cls} distribution

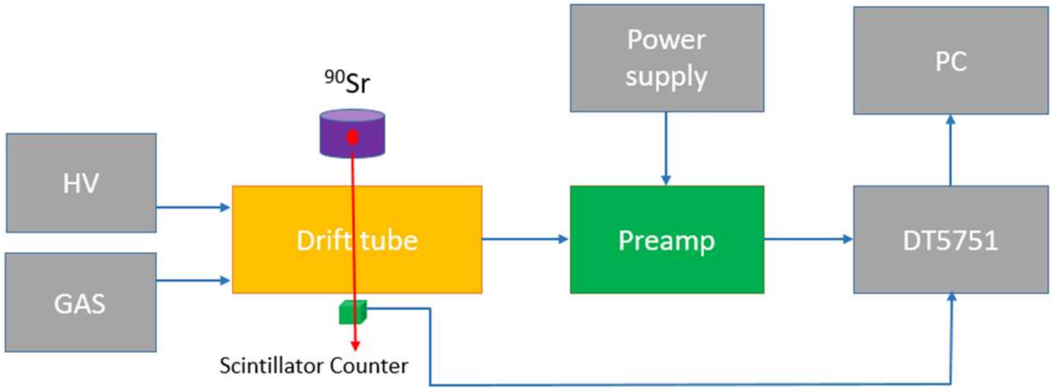
Prototype test

- Radioactive source test
- Beam test

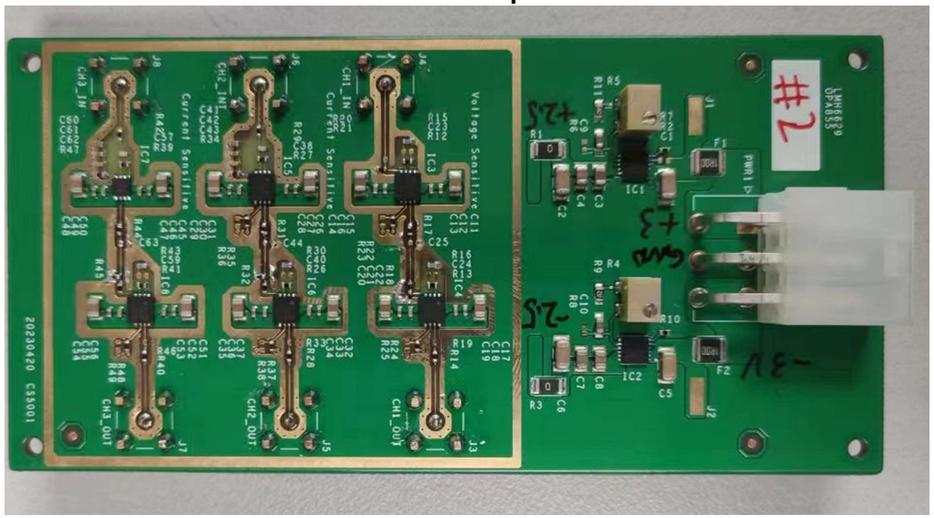
Prototype test with Sr90 source

- A prototype test with drift tube ongoing
  - diameter of the tube: 30mm
  - gas mixture: He/iC_4H_{10}=90:10
- A preamplifier has been designed and developed

Diagram of test system

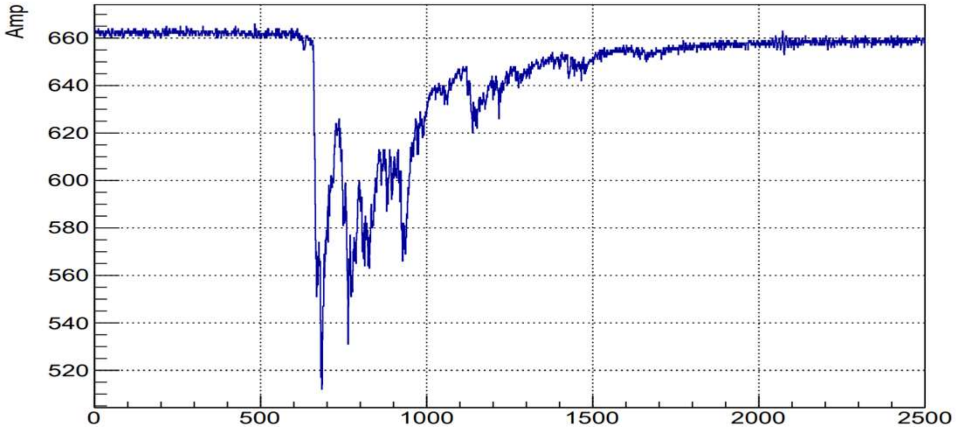


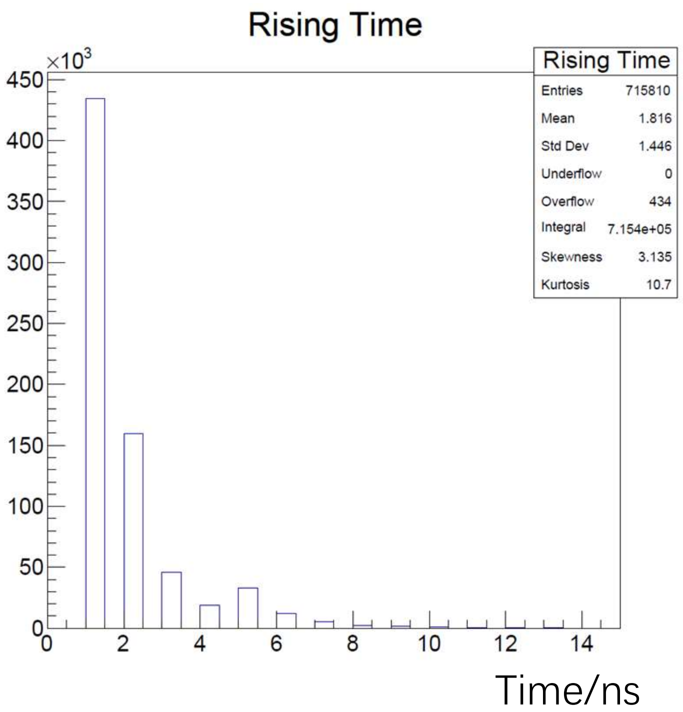
Preamplifier



Signals from preliminary test

Tested with Sr-90 source

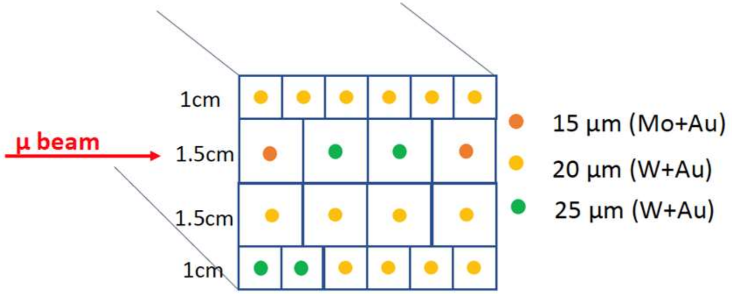


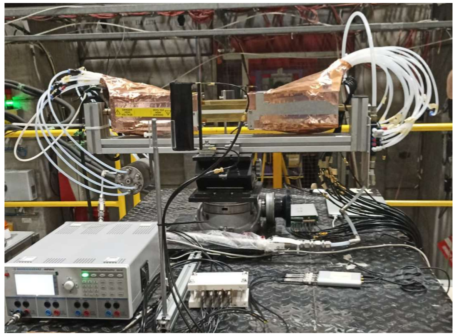


- Preliminary tests show
  - low noise
  - high bandwidth
  - Rise time of peak: a few nanoseconds

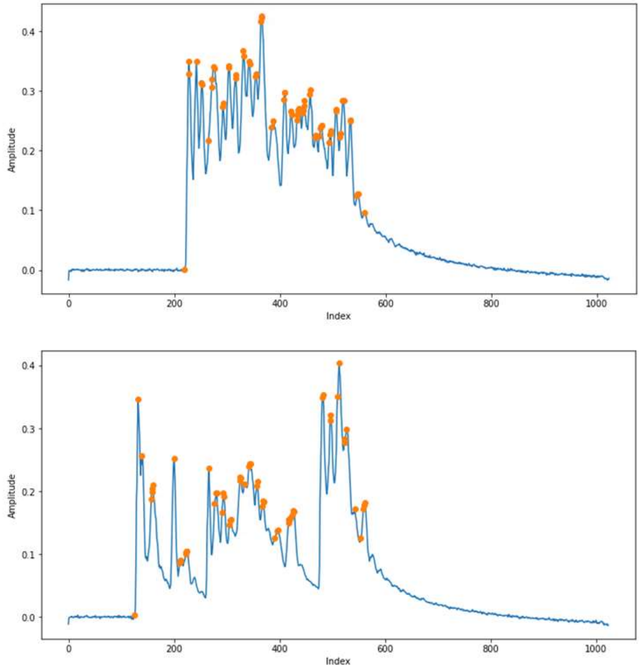
Beam test with DC prototype

- Beam tests organized by INFN group @CERN
- Joint efforts of INFN and Chinese groups
  - Data taking
  - Data analysis
  - Optimizing DC simulation
  - Plan to apply ML algorithm on online FPGA





Preliminary results of peak finding with ML algorithm



- Clusterization under optimization

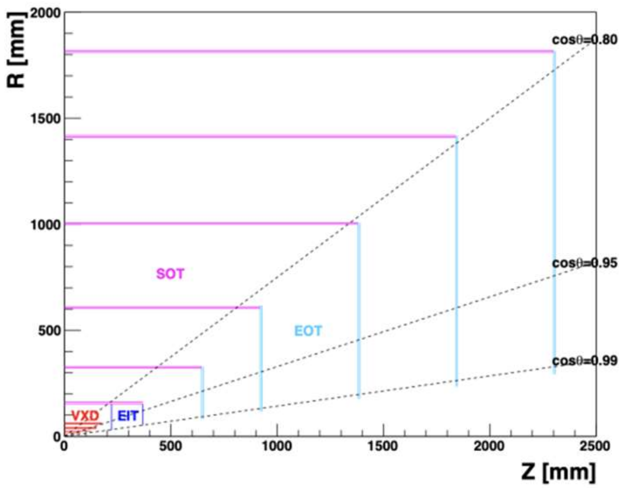
Summary

- A drift chamber with cluster counting technique for PID is proposed for CEPC the 4th conceptual detector
- Preliminary results of simulation study shows
  - dN/dx has a much better K/π separation power compared to dE/dx
- Prototype test ongoing
  - Prototype test with radioactive source
  - Beam tests
- Work to do
  - Further prototype tests
  - Optimization for detector design and reconstruction algorithm

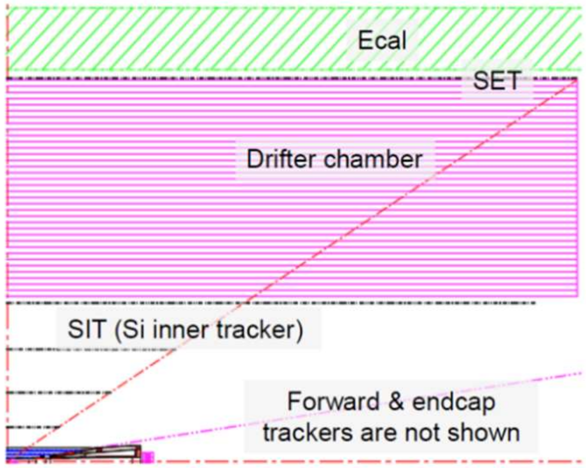
Thanks!

Backup

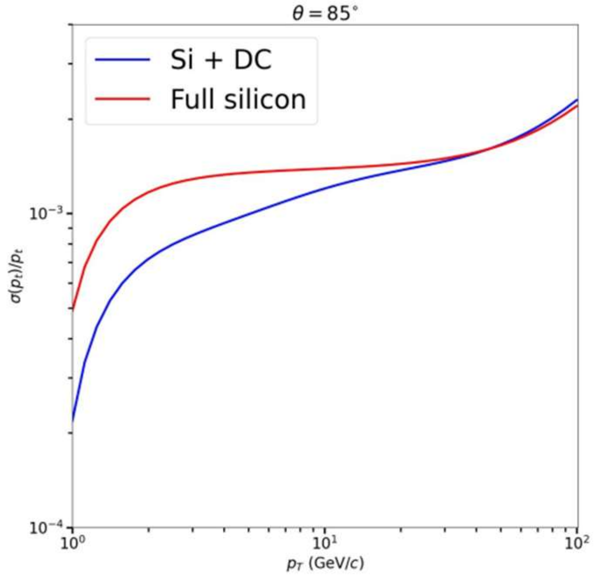
Momentum resolution with fast simulation



Full Silicon Tracker (FST) from CDR



Si + DC



- Momentum resolution in low momentum range is benefited with Si+DC

Branching ration using in Delphes

$Z \to b\bar{b}$: $695899982 \sim 7 \times 10^8$				
Branching ratio	PDG	In background	Size in background	
$f(b \to B_0)$	0.407	0.407	B_0	566462585
$\mathcal{B}(B^0 \to \pi^+\pi^-)$	5.12×10^{-6}	5.12×10^{-6}	$B^0 \to \pi^+\pi^-$	2900
$\mathcal{B}(B^0 \to K^+K^-)$	7.8×10^{-8}	7.8×10^{-8}	$B^0 \to K^+K^-$	44
$\mathcal{B}(B^0 \to K^\pm\pi^\mp)$	1.96×10^{-5}	0	$B^0 \to K^\pm\pi^\mp$	0
$f(b \to B_s^0)$	0.101	0.101	B_s^0	140571796
$\mathcal{B}(B_s^0 \to \pi^+\pi^-)$	7.0×10^{-7}	7.0×10^{-7}	$B_s^0 \to \pi^+\pi^-$	98
$\mathcal{B}(B_s^0 \to K^+K^-)$	2.66×10^{-5}	2.66×10^{-5}	$B_s^0 \to K^+K^-$	3739
$\mathcal{B}(B_s^0 \to K^\pm\pi^\mp)$	5.8×10^{-6}	1.09×10^{-4}	$B_s^0 \to K^\pm\pi^\mp$	15298

- Signal sample using Pythia8
- Background using Pythia6
- For now, only considering the background of $Z \to b\bar{b}$