Status and plan for CEPC drift chamber

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on behalf of DC PID Group

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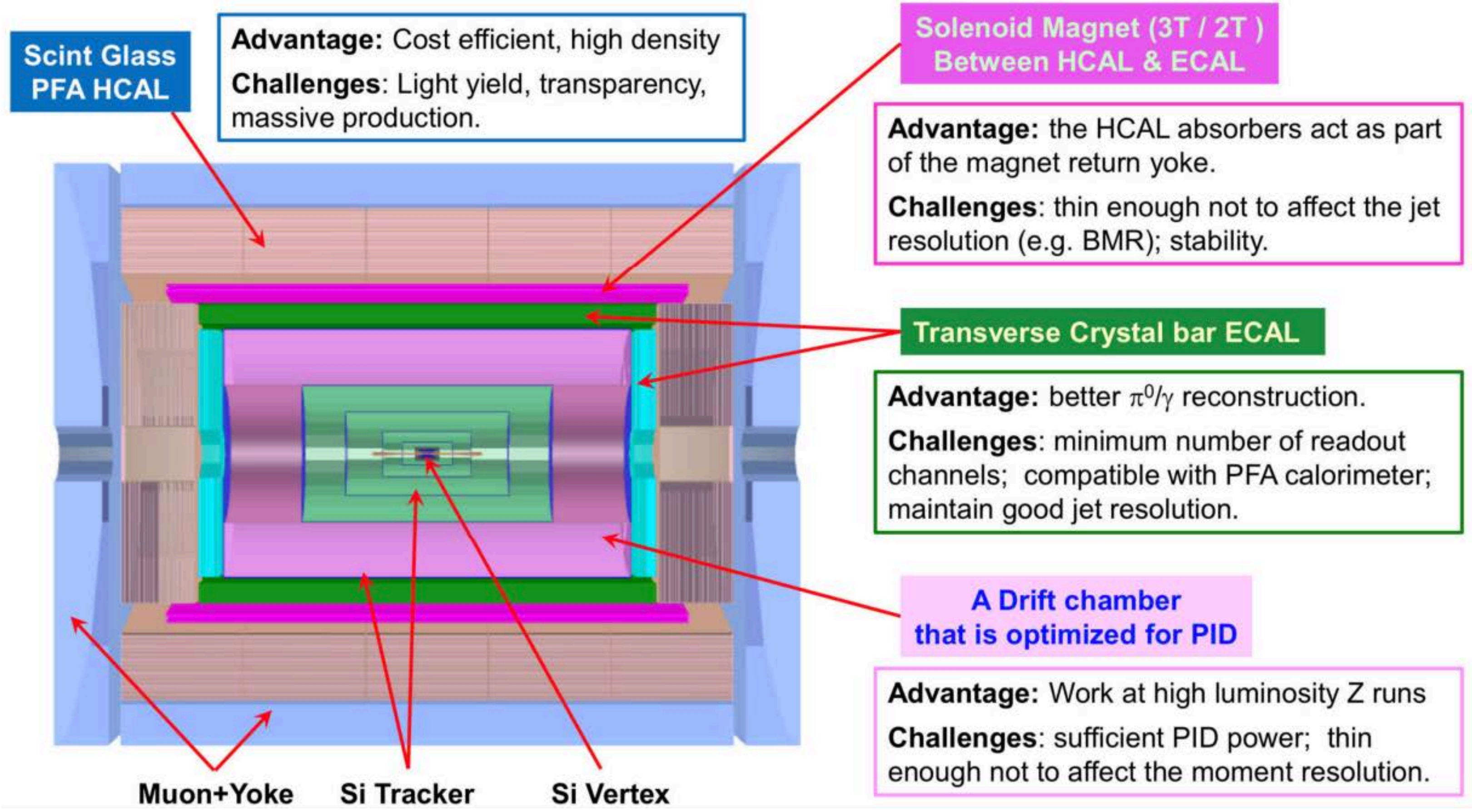
Outline

- Introduction of drift chamber based on cluster counting technique
- Key challenges and R&D status
- Plan towards TDR
- Summary

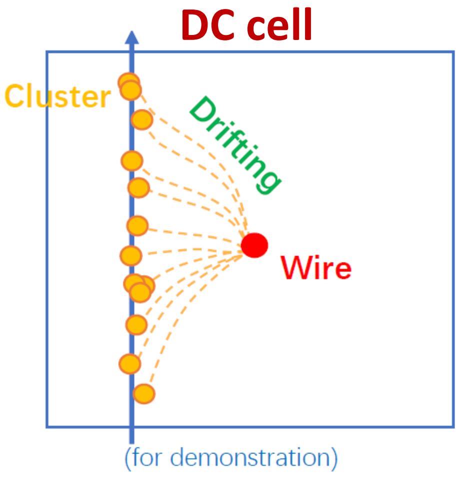
Drift Chamber in CEPC 4th conceptual detector

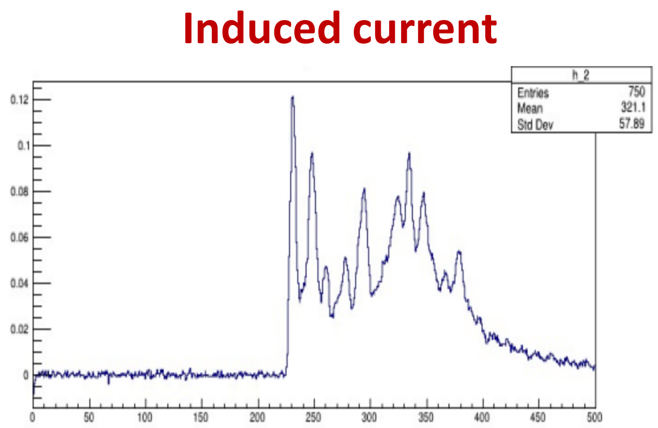


- The drift chamber optimized for PID with cluster counting technique
- Require better than 3σ separation power for K/π with momentum up to 20GeV/c
- Benefits tracking and momentum measurement

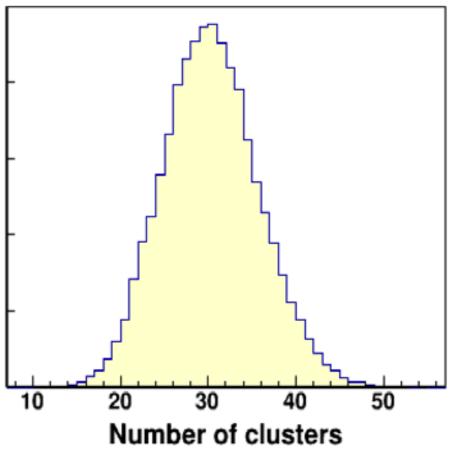
Ionization measurement with dN/dX

- Measure number of clusters over the track, the number of clusters corresponds to the number of the primary ionization
- Yield of primary ionization is Poisson distribution
- To eliminate the effects of secondary ionization, dN/dx is based on peak finding and clusterization





Peak finding +clusterization



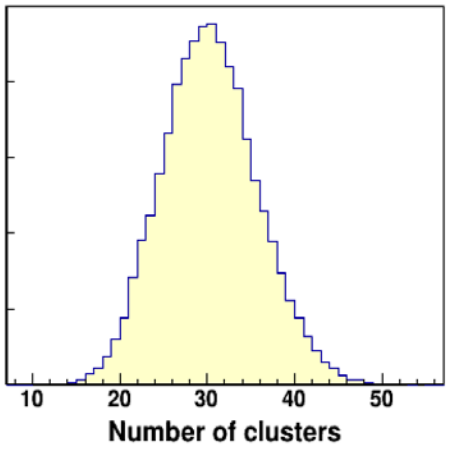
Primary ionization

dN/dx vs dE/dx

dN/dx

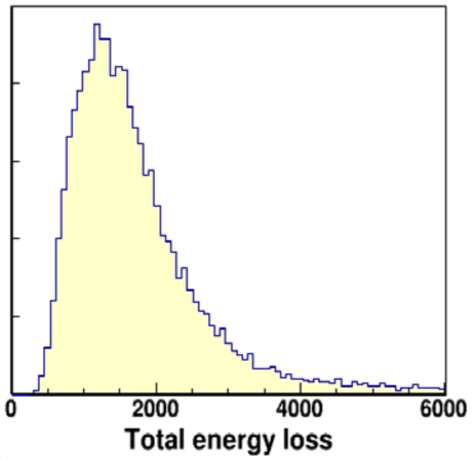
- Number of primary ionization clusters per unit length
- Poisson distribution
- Small fluctuation

Cluster counting technique

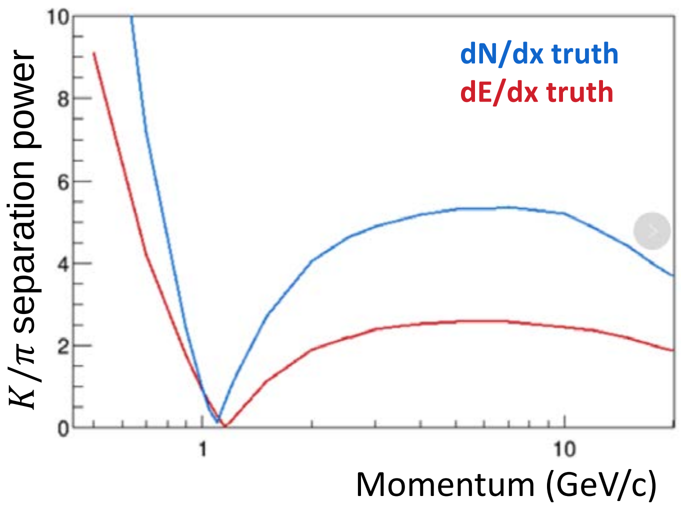


dE/dx

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



K/π separation power
dN/dx vs dE/dx

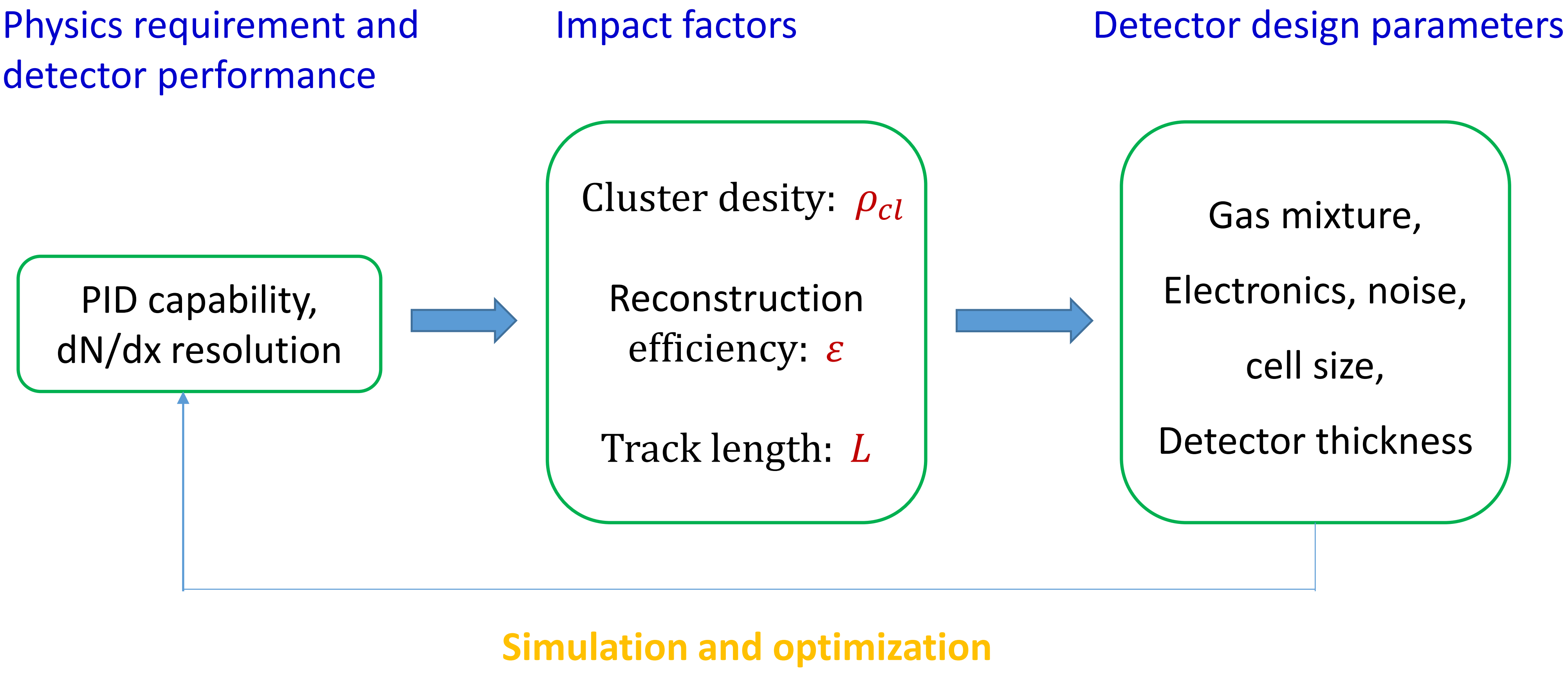


dN/dx has a much better (2 times) K/π separation power up to 20 GeV/c compared to dE/dx (Simulation)

Challenges with dN/dx measurement

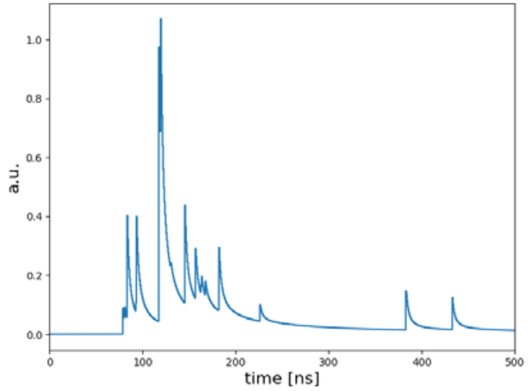
- Detector optimization and performance study
  - Thickness design of the detector (inner and outer radius)
  - low drift velocity, low ionization density gas with low diffusion and low multi electron ionization
- Waveform test
  - Fast and low noise electronics
  - Bandwidth >1GHz, preamplifier gain >10, sampling rate >1.5GS/s, bit resolution >12bit
- dN/dx reconstruction algorithm
  - Processing pile-up peaks of signal
  - Reducing noise impacts
  - Identifying primary and secondary ionization signals

Detector simulation and optimization

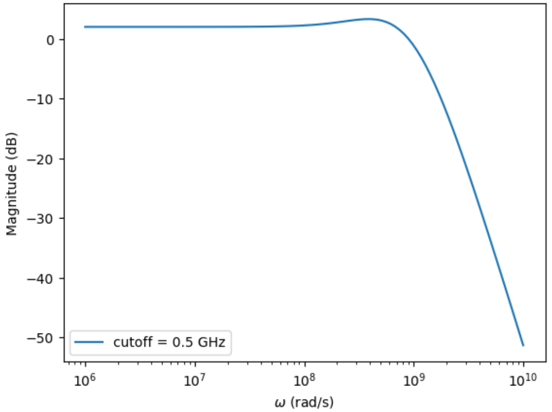


Waveform simulation

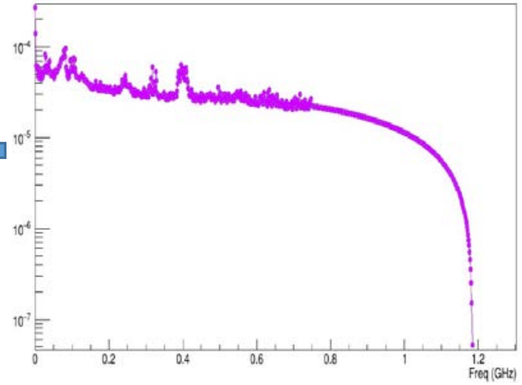
Induced signal (Simulation)



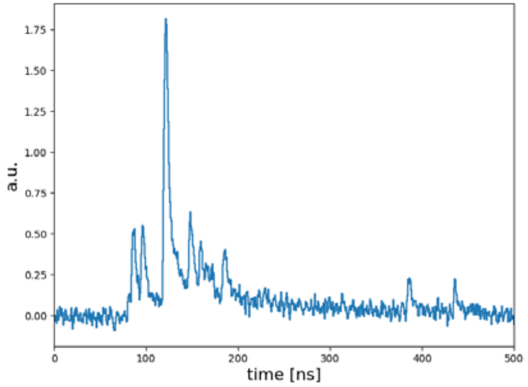
Electronics response (beam test electronics)



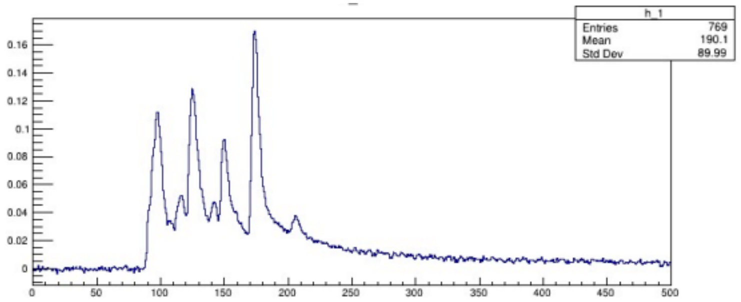
Noise (beam test)



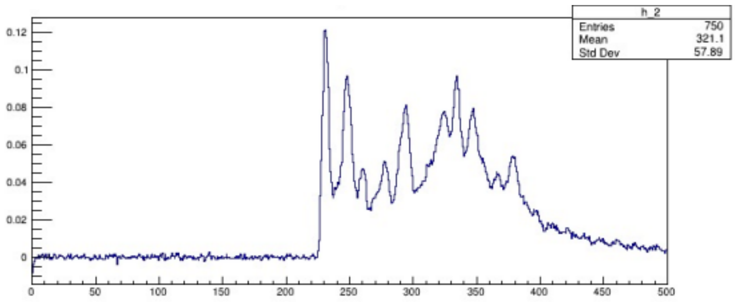
Waveform



Simulation

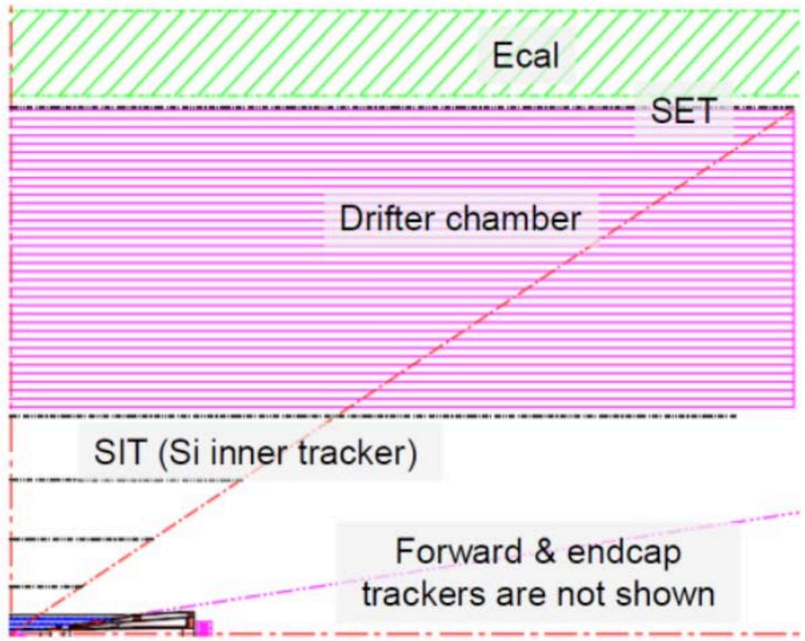


Beam test data



- A waveform based full simulation has been established for detector design and performance study

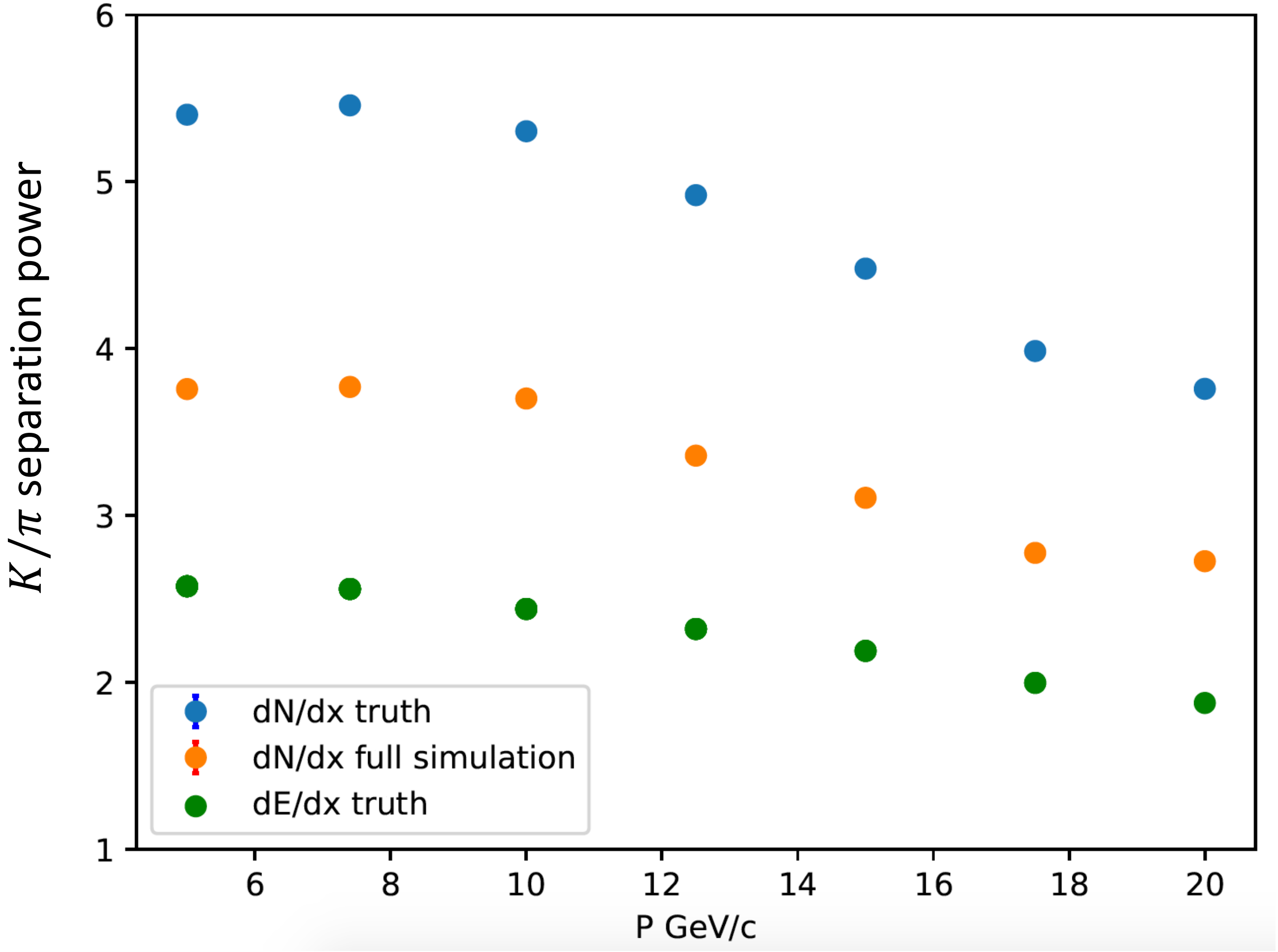
Preliminary design parameters



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

Preliminary results

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

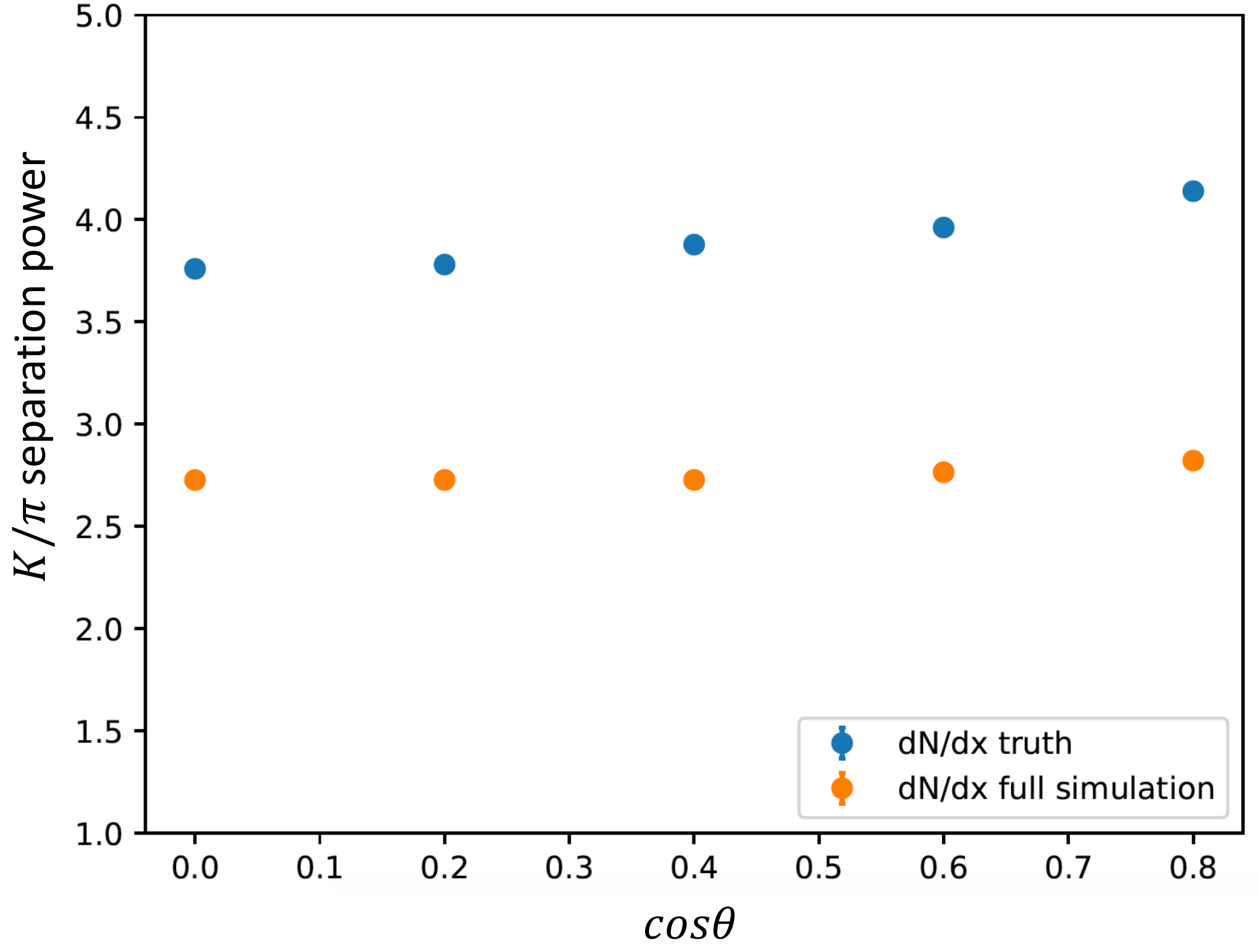


Separation power

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

Preliminary results

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

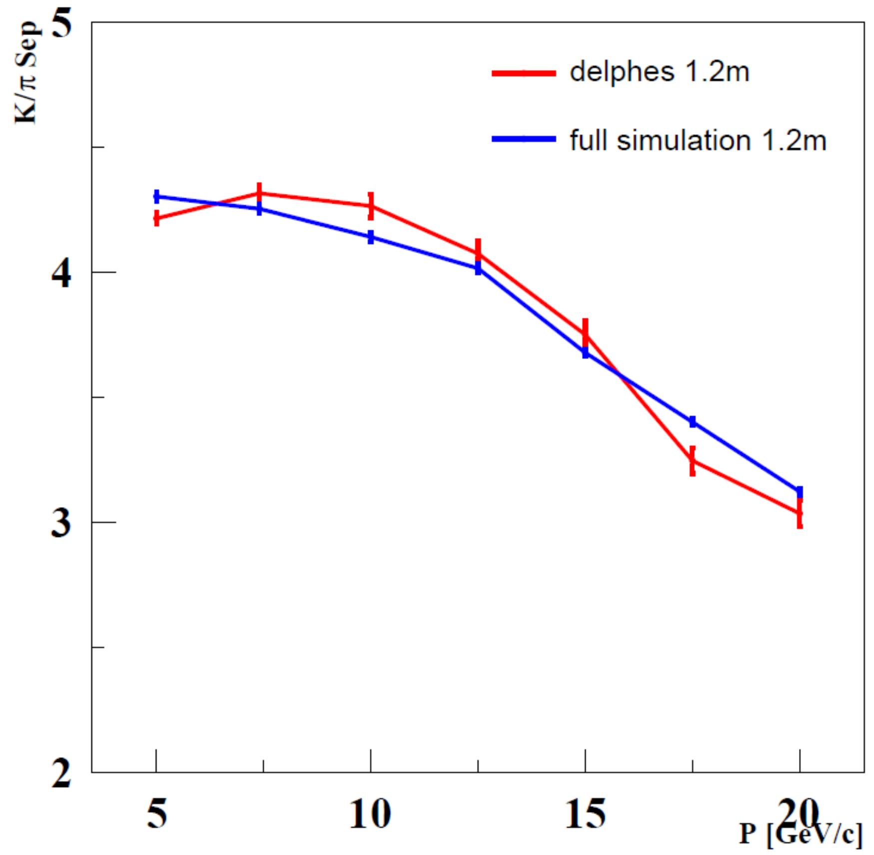


Separation power

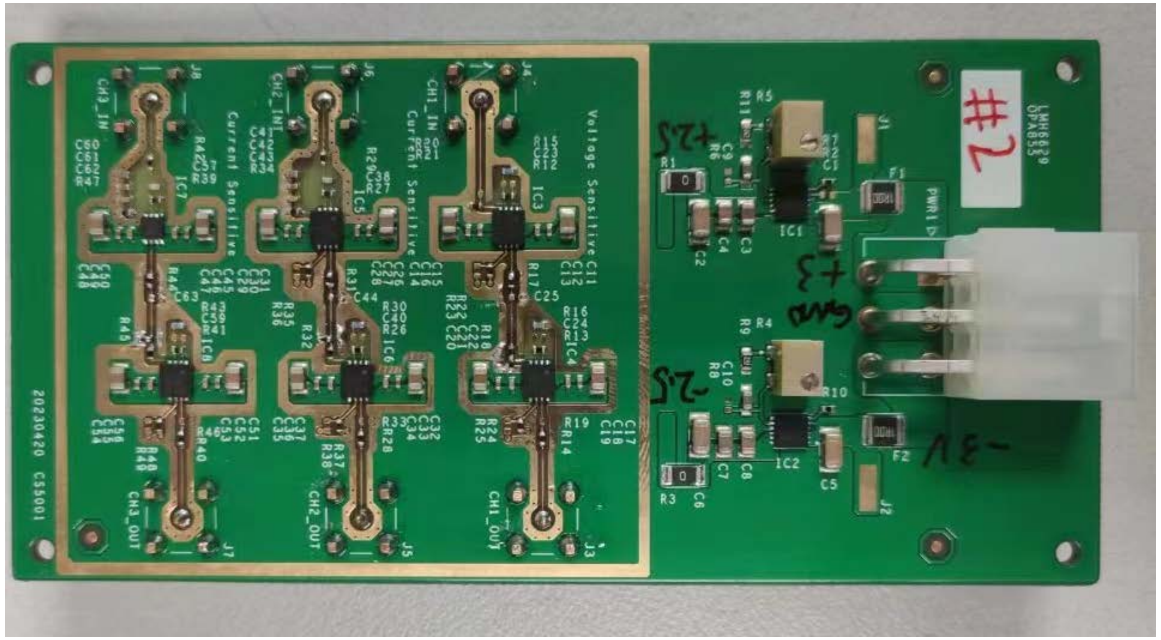
$$S = \frac{|\,(\frac{dN}{dx})_\pi - (\frac{dN}{dx})_K\,|}{(\sigma_\pi + \sigma_K)/2}$$

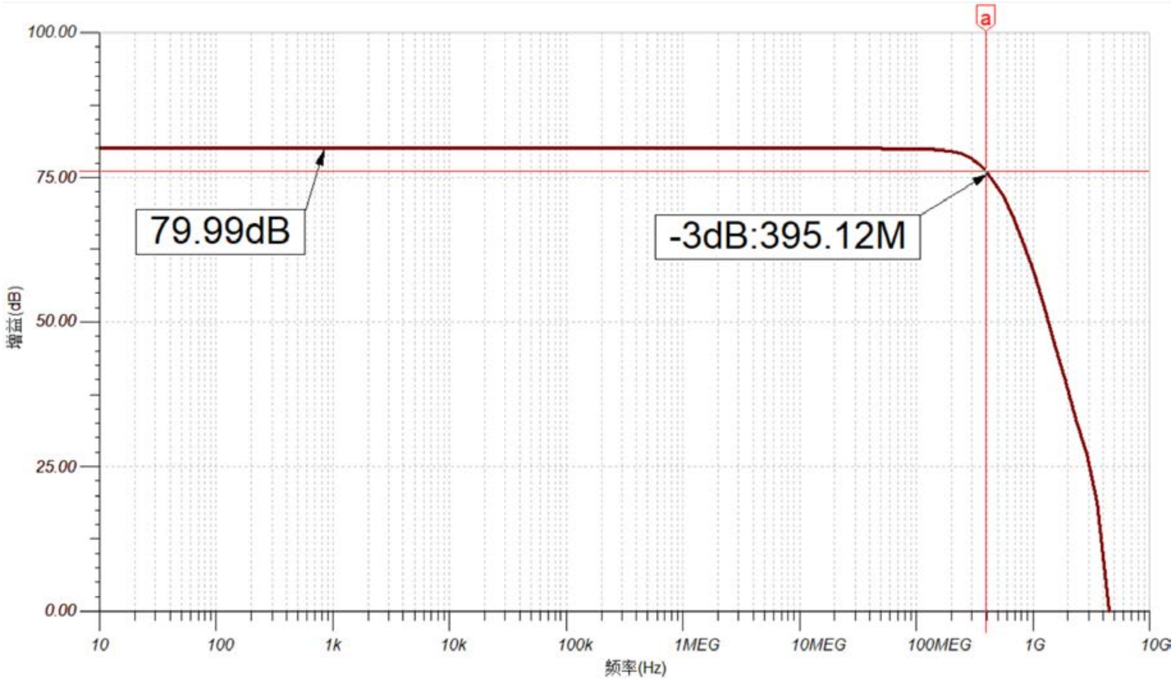
Optimization of the detector design

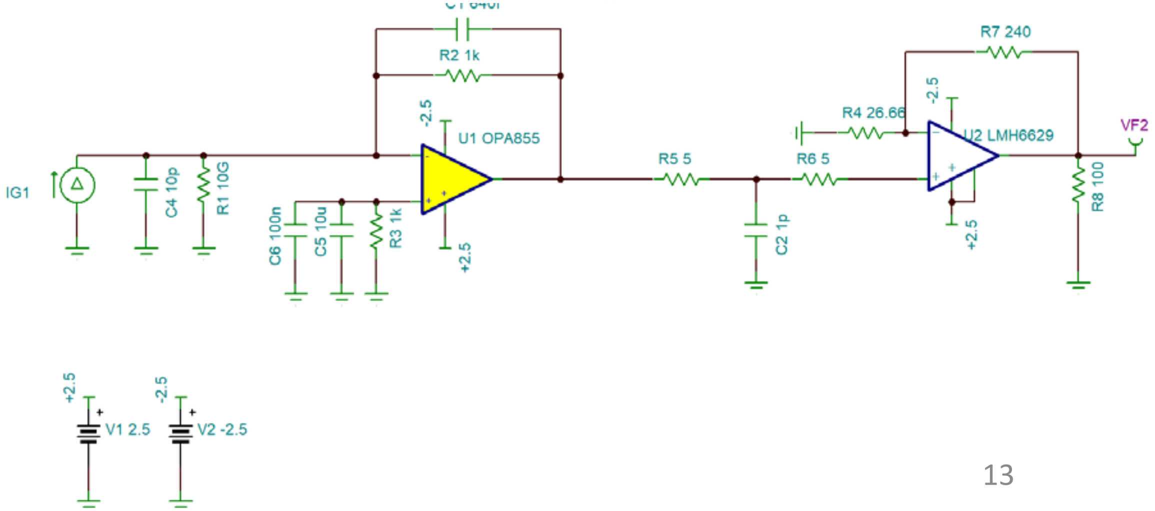
- Optimization of the inner radius
  - Inner radius: 800mm → 600mm or even smaller
  - Track length: 1m → 1.2m , increasing dN/dx resolution
  - K/pai separation power: 2.8σ →3.1σ or even better@20GeV
- Optimization of the cell size
  - Reduce the cell size of the first 10 layers to achieve stable operation at high counting rates and minimize aging effects



Fast electronics







- High bandwidth current sensitive preamplifiers based on based on LMH6629 have been designed and developed

Performance tests

- Electronics have been tested with detector Prototype
  - Diameter of the drift tube: 30mm
  - Gas mixture: He/iC_4H_{10}=90:10
  - Sr-90 source and cosmic-ray were used
  - Digitizer (DT5751) with 1GHz sampling rate

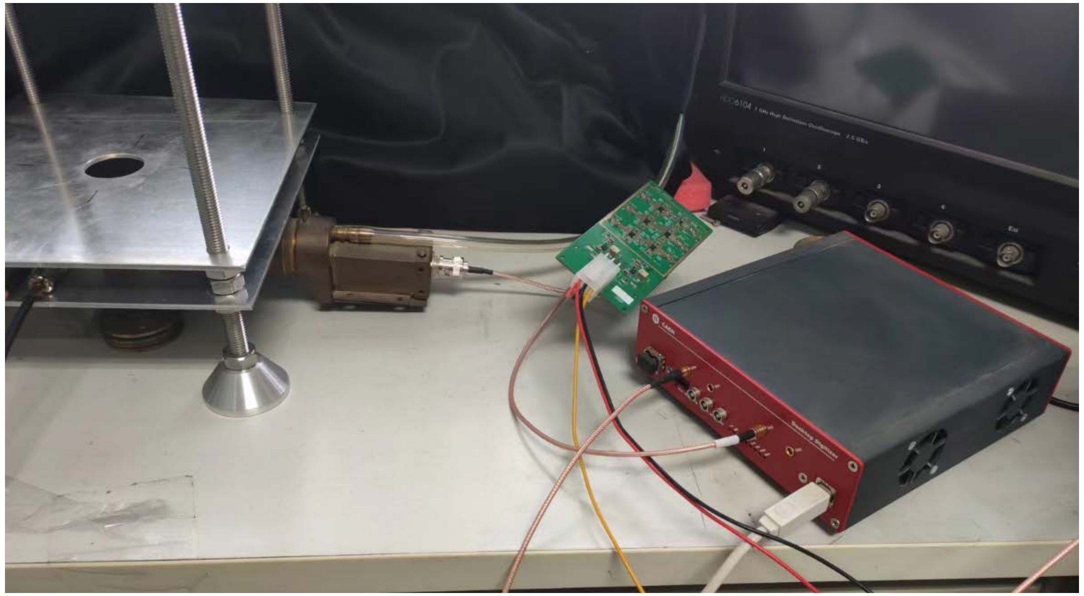
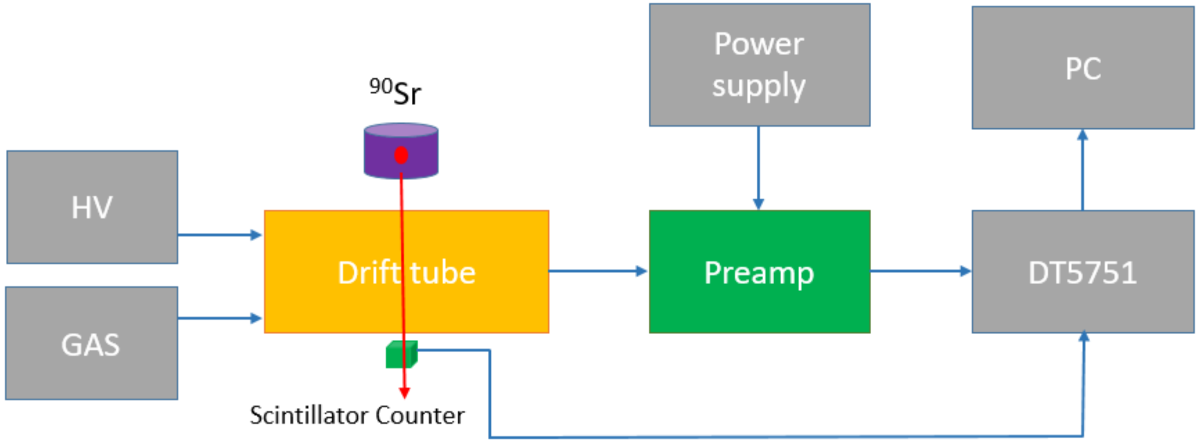
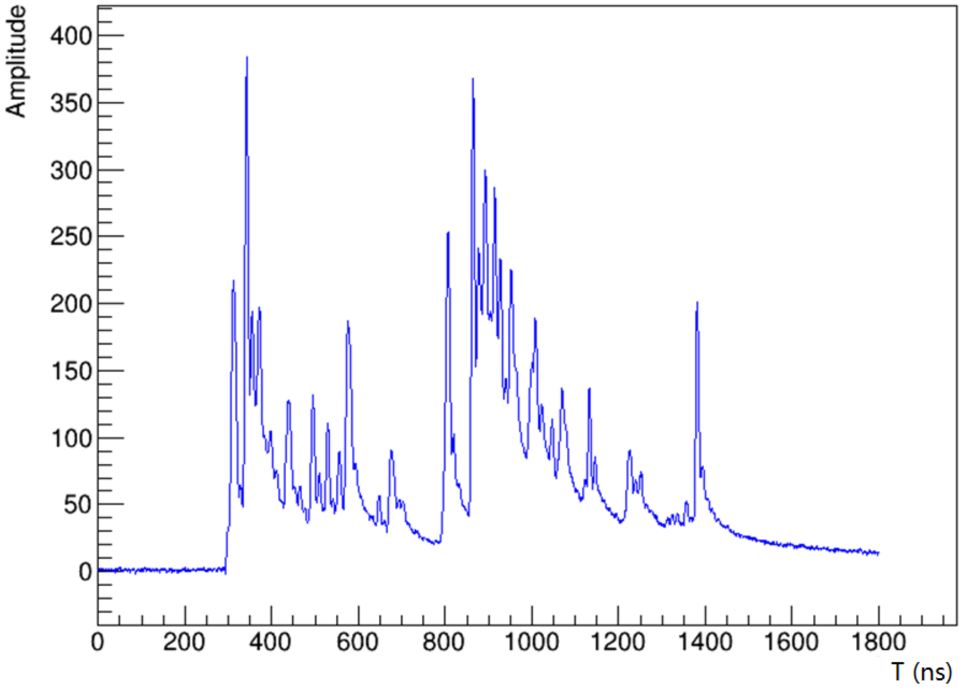


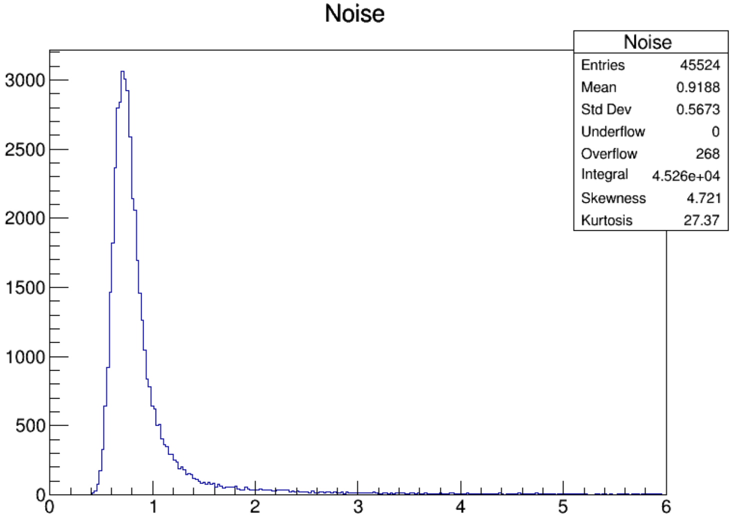
Diagram of test system



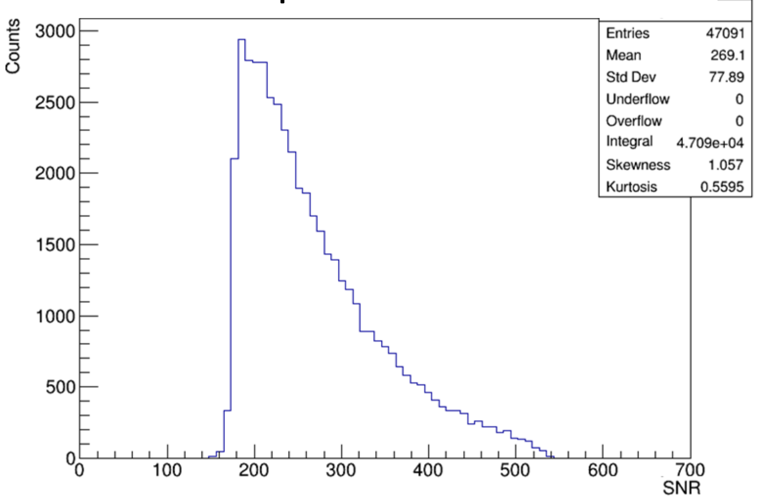
Preliminary performance

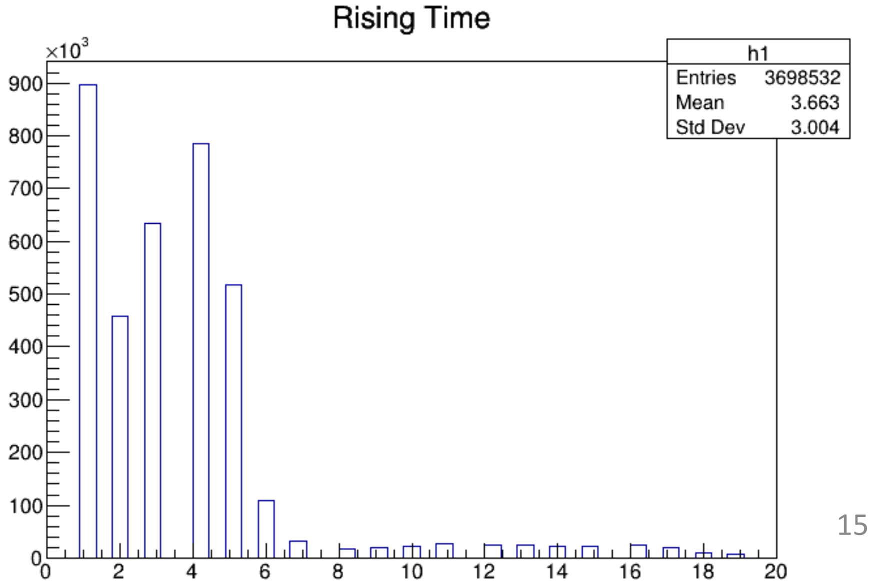
Waveform with Sr-90 β source





Maximum peak to noise Ratio





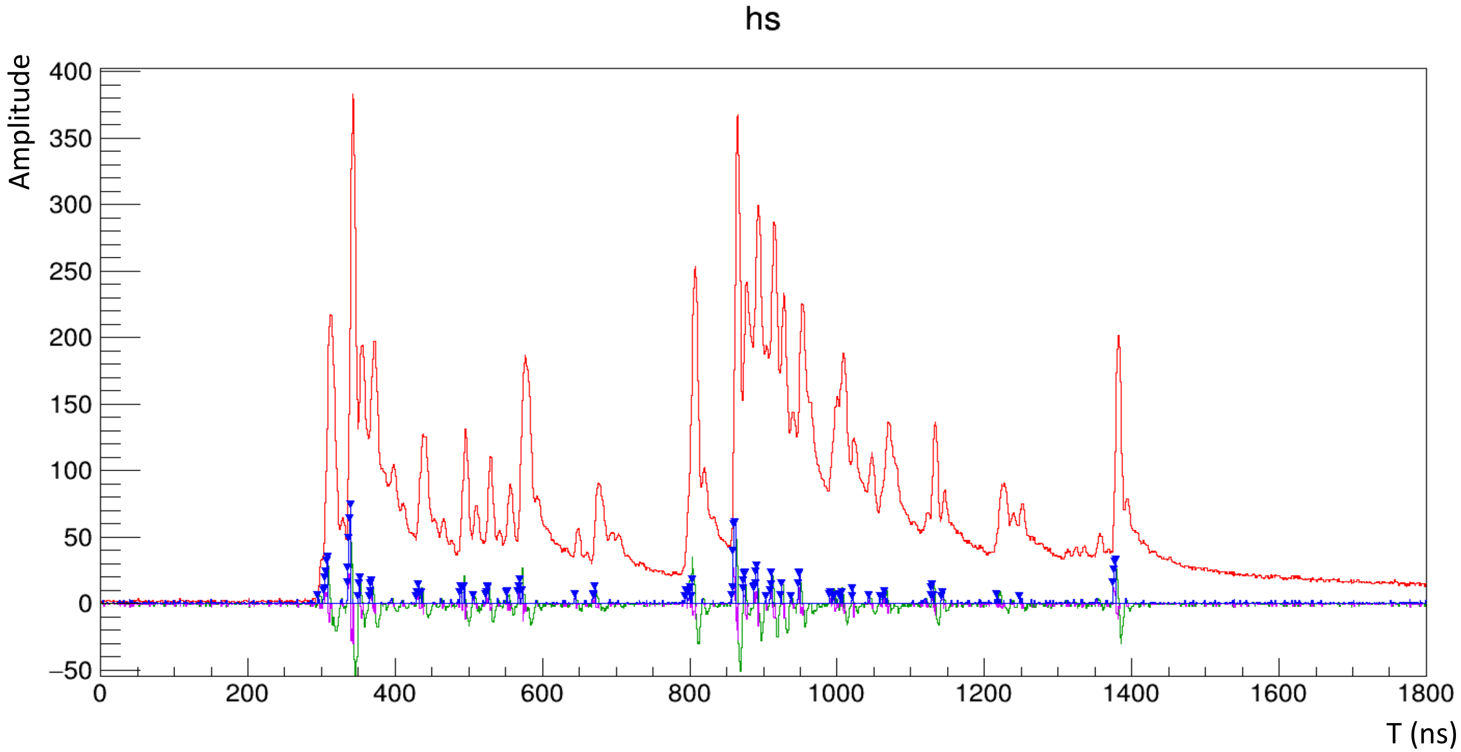
- Test results show
  - low noise
  - high bandwidth
  - Rise time of peak: a few nanoseconds

Peak finding

- 1st and 2nd order derivatives

$$D1[i] = MA[i] - MA[i-1]$$

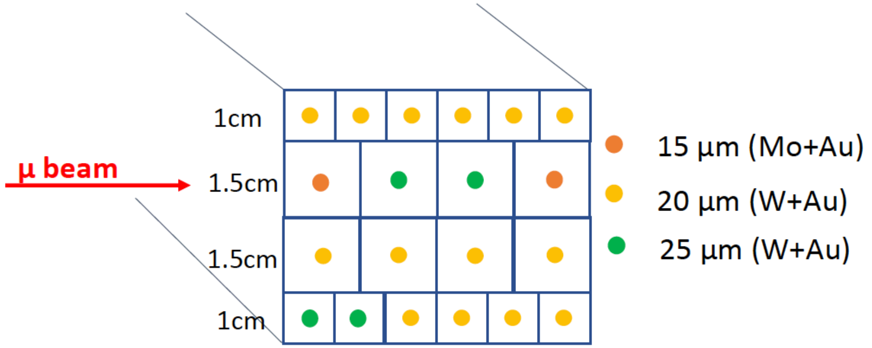
$$D2[i] = D1[i] - D1[i-1]$$

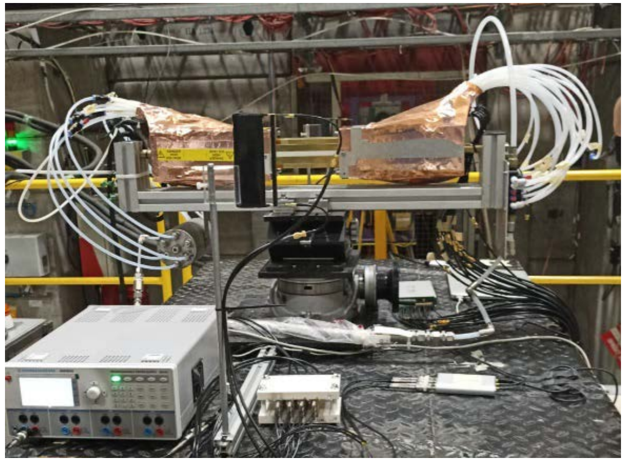


- Preliminarily validated the performance of the readout electronics and the feasibility of dN/dx method
- The design of readout electronics with a sampling rate of 1.4 GHz is on progress.
- A drift chamber test system including about 80 read out channels will be finished and tested with cosmic-rays this year

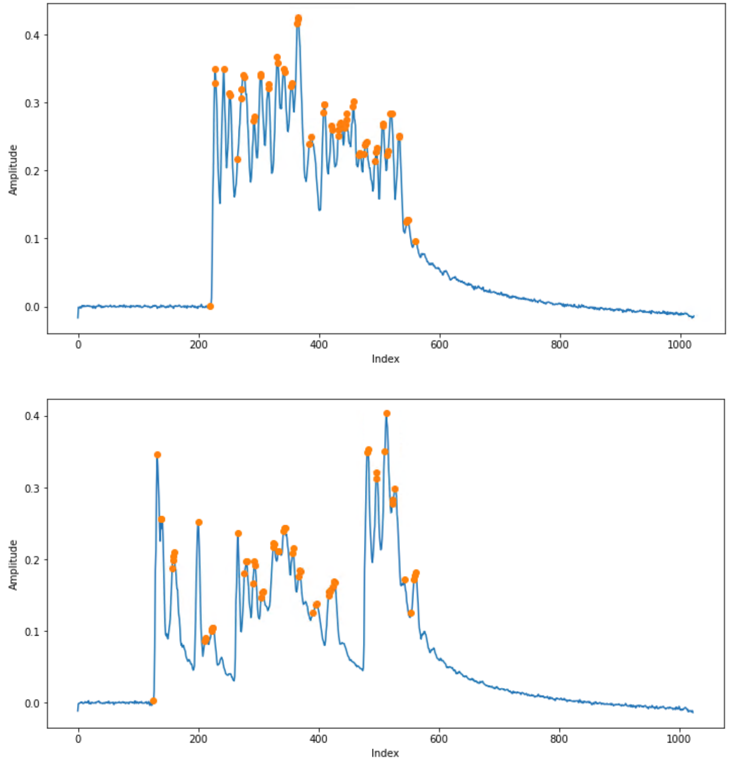
Beam test with detector prototype

- Beam tests of a detector prototype 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





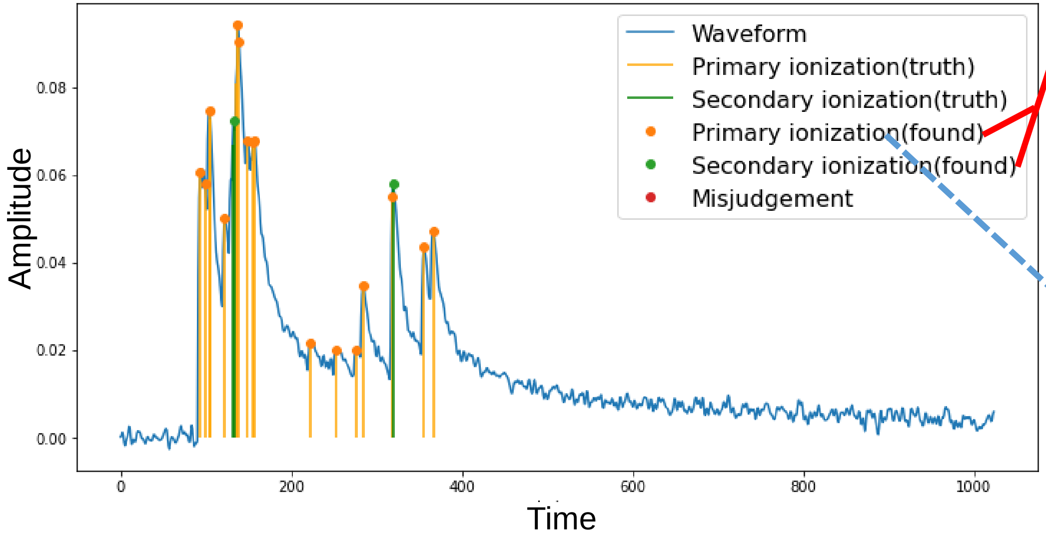
Preliminary results of peak finding with ML algorithm



- Clusterization under optimization

dN/dx reconstruction algorithm

- Reconstruction From waveform to primary ionization counting
- Includes two steps



Simulated waveform of a drift chamber cell

Step1. Peak Finding

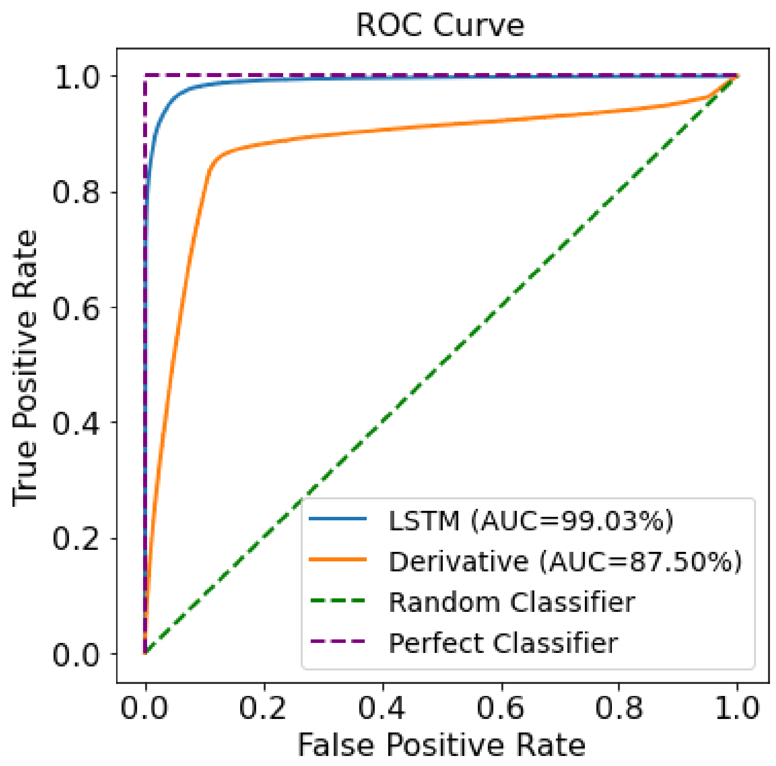
Discriminate peaks (both primary and secondary) reduce the impacts of noises

Step2. Clusterization:

Peaks merge to form clusters, and determine the number of clusters (N_{cls}) from the detected peaks

Reconstruction algorithms

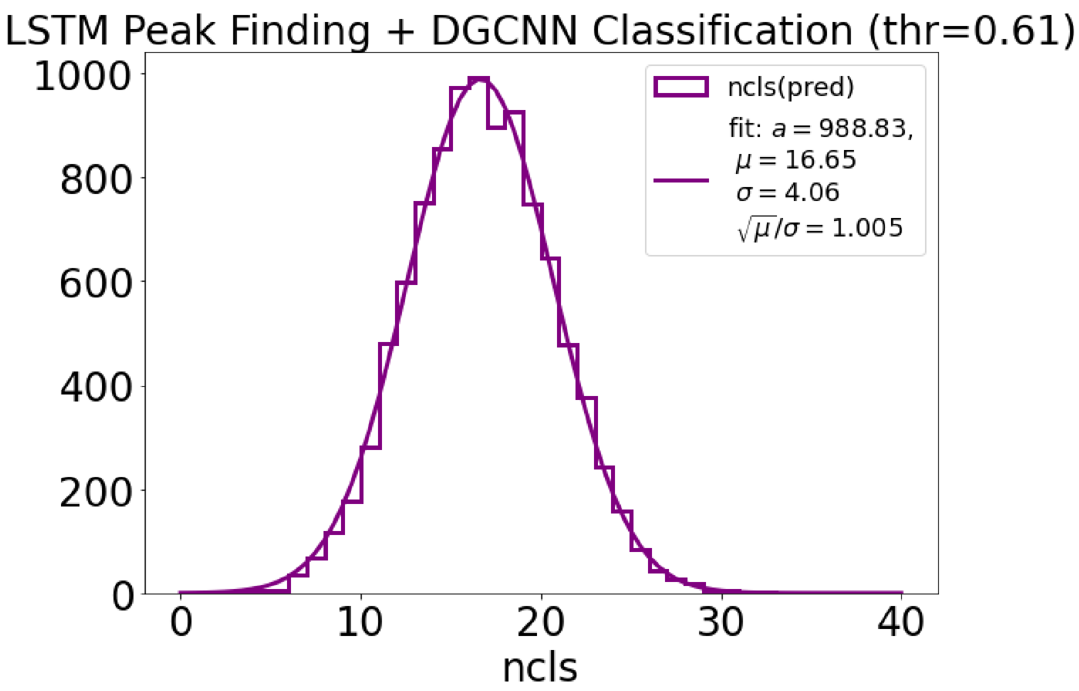
- Two methods under study
  - Classical method (developed)
    - Derivative-based peak finding + clusterization with peak merge
  - Deep learning based algorithm (ongoing)
    - Peak finding with LSTM + clusterization with DGCNN



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

See Guang Zhao's talk on Jan. 18th

Performance with deep learning based algorithm



Cluster counting reconstruction based on one cell waveform

See Guang Zhao's talk on Jan. 18th

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

Plans towards TDR

Detector optimization and performance study

- Detector parameter optimization (radius and cell size) and evaluation of cell hit density at Higgs, Z, W modes
- Mechanical design and test

Waveform test

- Design of fast readout chips and readout electronics
- Prototype performance tests with beam

dN/dx reconstruction algorithm

- Study of reconstruction algorithm (deep learning)
- Integration of the algorithm on online FPGA

Summary

- Drift Chamber is proposed in CEPC 4^{th} conceptual detector to improve particle identification
- Some progress:
  - Simulation studies show that close to 3σ K/π separation at 20GeV/c can be achieved with 1m track length
  - Development of fast electronics is under progress. Preliminary tests validated the performance of the readout electronics and the feasibility of dN/dx method
  - Cluster counting reconstruction algorithm based on deep learning is developed and shows promising performance for MC samples and test data

- Further studies for TDR: Detector optimization and performance study, fast readout electronics development, dN/dx reconstruction algorithm