Status and Plan of Cluster Counting Study for the Fourth Conceptual Detector

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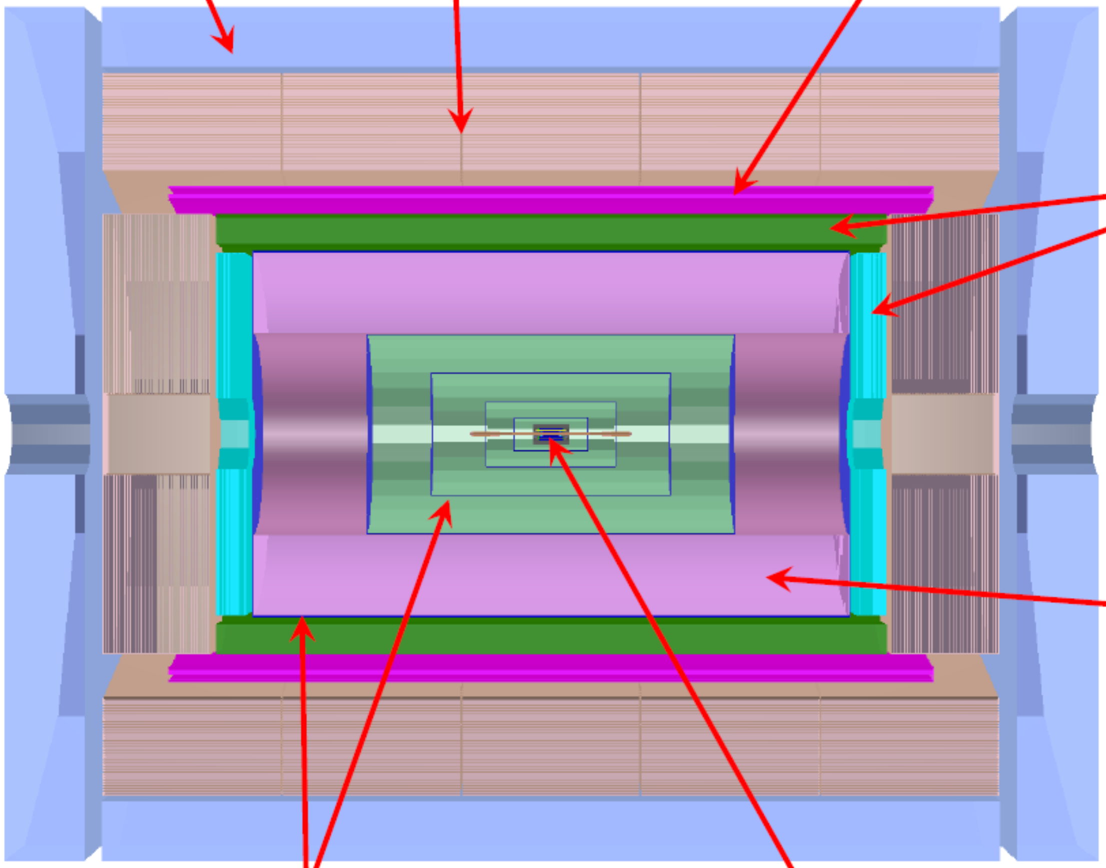
On behalf of cluster counting working group for the 4th conceptual detector

July 15, 2021

The 4th Conceptual Detector Design



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.

Advantage: better π^0/γ reconstruction.

Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

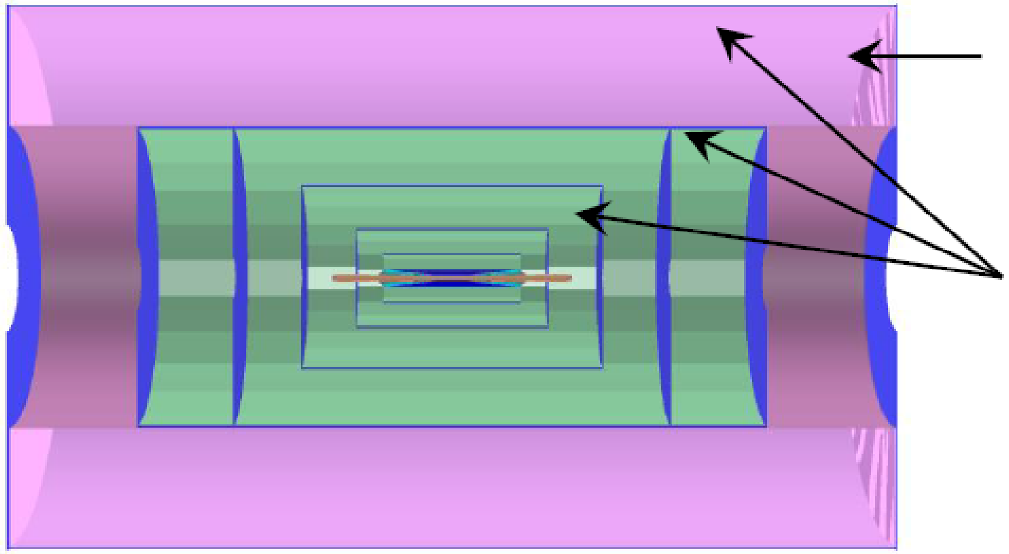
Advantage: Work at high luminosity Z runs

Challenges: sufficient PID power; thin enough not to affect the moment resolution.

From Jianchun's talk in Yangzhou workshop

A drift chamber that is optimized for PID

- Preliminary design of the tracker
  - Full silicon tracker: to provide excellent momentum resolution
  - Drift chamber: to provide PID measurement with cluster counting technique
- Requirements for DC: 2σ K/π separation up to ~20 GeV/c
- To study the PID capability of DC with cluster counting, simulation study and prototype test are performed



Key personnel

- Performance study with standalone full simulation

  Guang Zhao, Shuiting Xin, Linghui Wu, Shengsen Sun

- Fast simulation of PID in CEPCSW

  Shuiting Xin, Guang Zhao, Linghui Wu, Gang Li

- Simulation software in CEPCSW

  IHEP: Wenxing Fang, Tao Lin, Yao Zhang, Weidong Li

  SDU: Mengyao Liu, Xingtao Huang

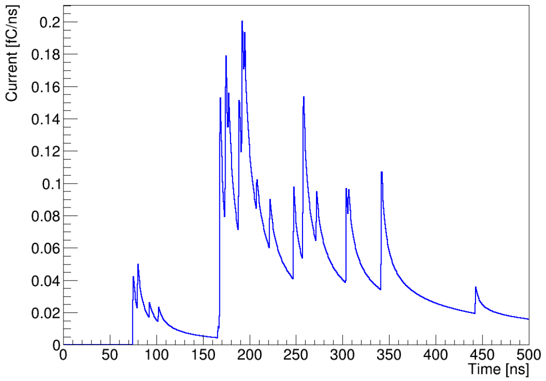
- Prototype test

  Mingyi Dong

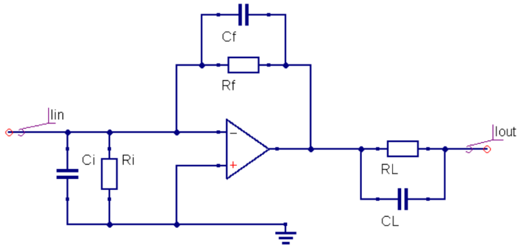
Performance study with standalone full simulation

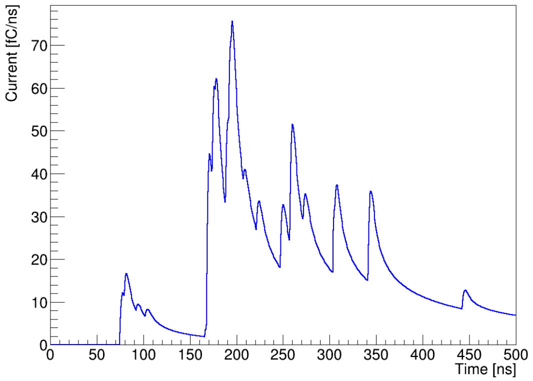
Induced current from Garfield++

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



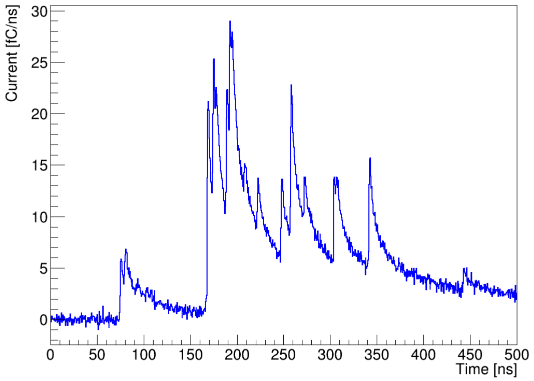
Simulation of preamplifier





Simulation of noises

- Add white noises to the raw current signal



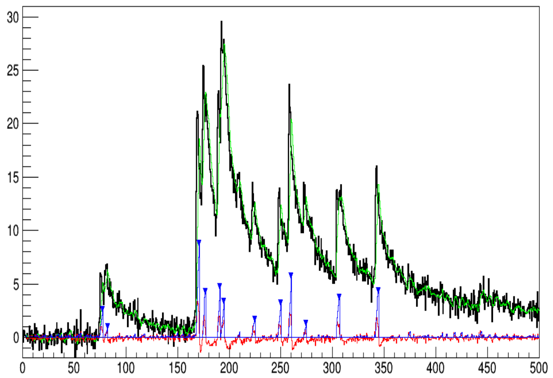
Peak finding analysis

- Moving average (MA) filter:

$\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} S[i-k]$ (smoothing)

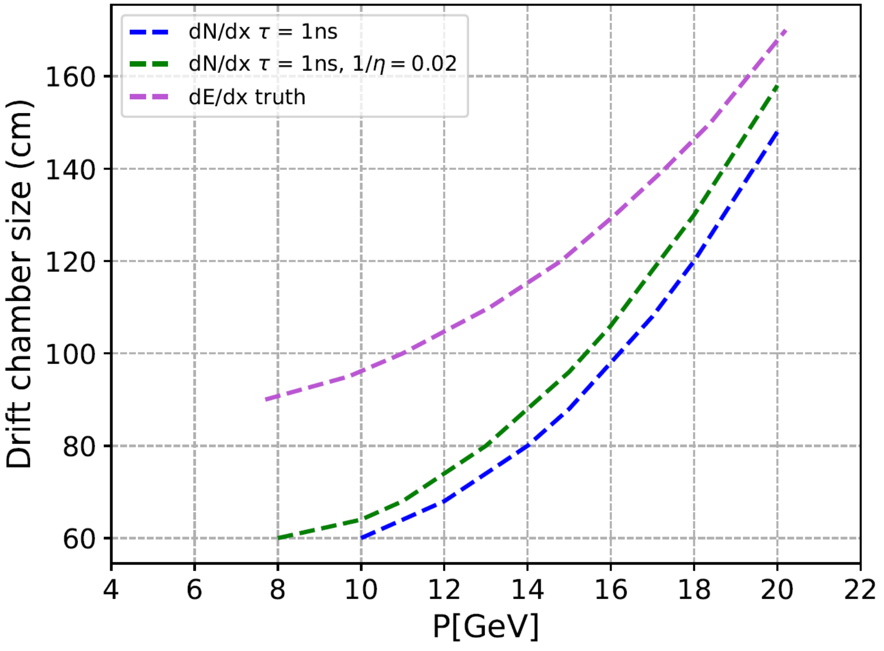
- First difference (D1) filter:

D1[i] = MA[i] – MA[i – 1]



Preliminary results

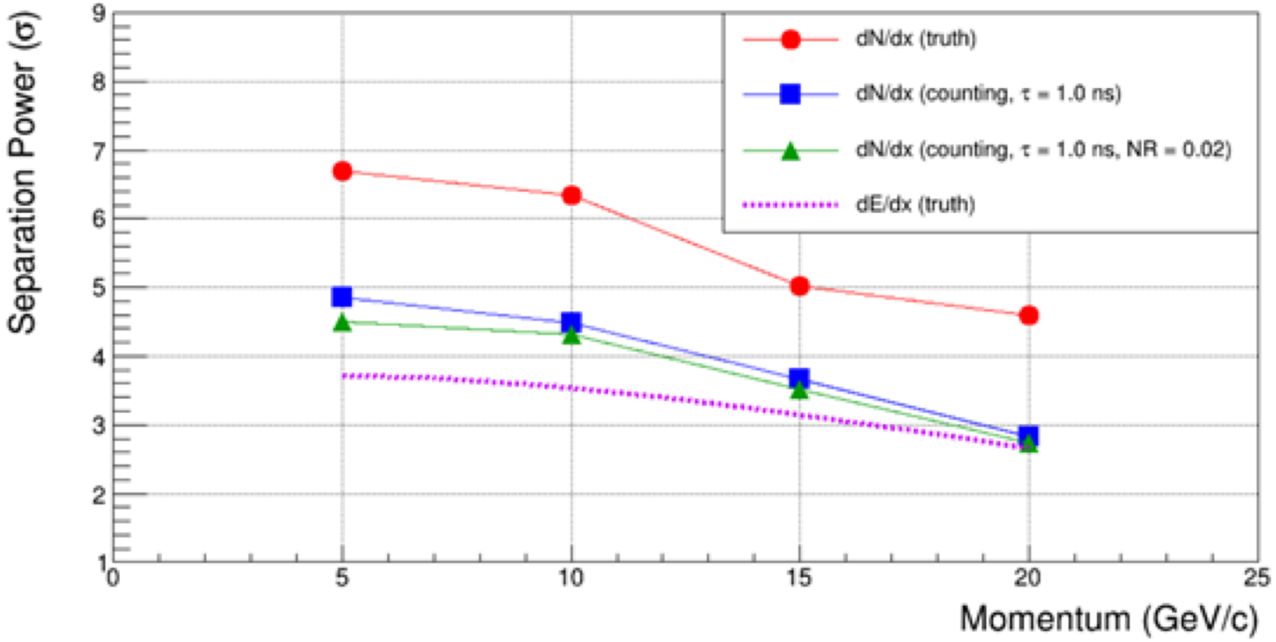
Detector size requirement for K/π separation > 2σ



K/π separation power
(thickness of DC = 100 cm)

Separation power

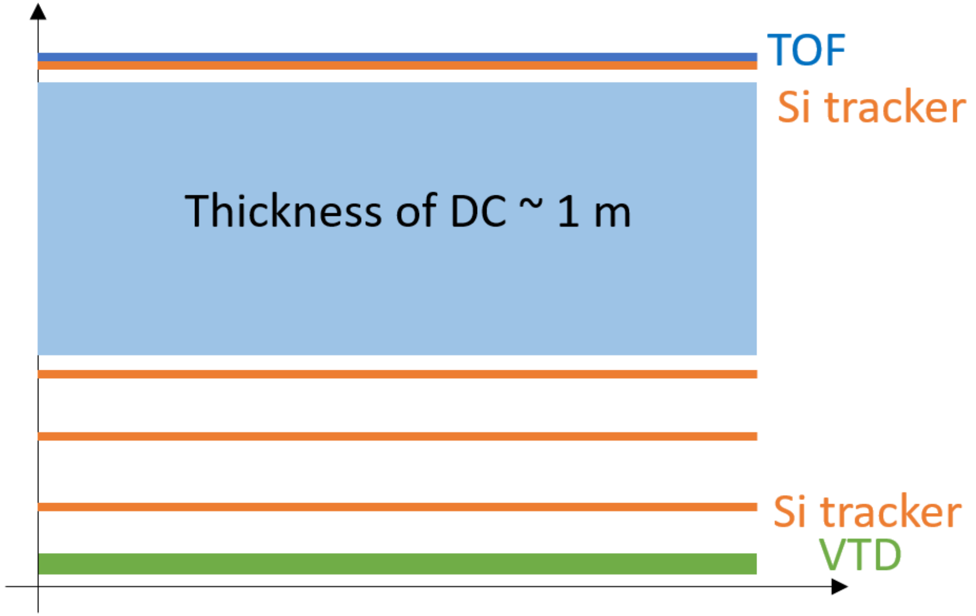
$$\frac{\left|\left(\frac{dN}{dx}\right)_{\pi}-\left(\frac{dN}{dx}\right)_{K}\right|}{(\sigma_{\pi}+\sigma_{K})/2}$$



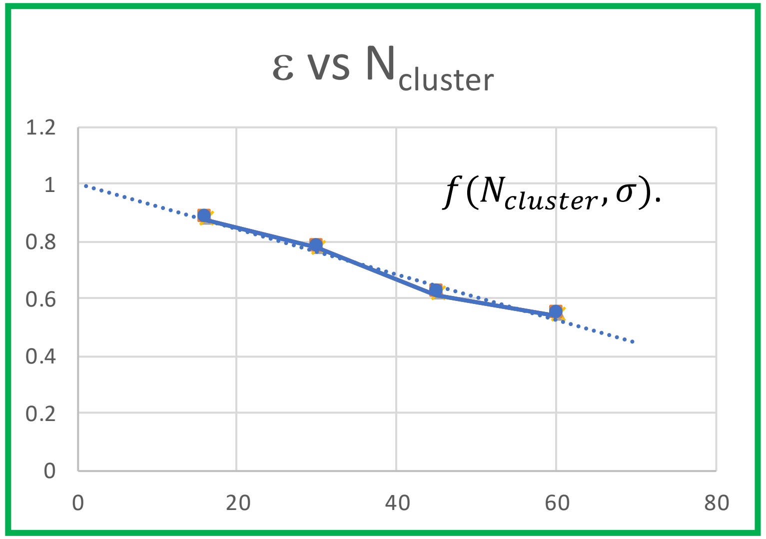
From Guang's talk in Yangzhou workshop

Fast simulation of PID in CEPCSW

- A sampling method for quick performance study
- Tracker layout:
  - Floating DC up to Rout =1.8m(1cm*100 layers)
  - A TOF detector surrounded at R = 1.8m
    (time resolution = 50 ps)

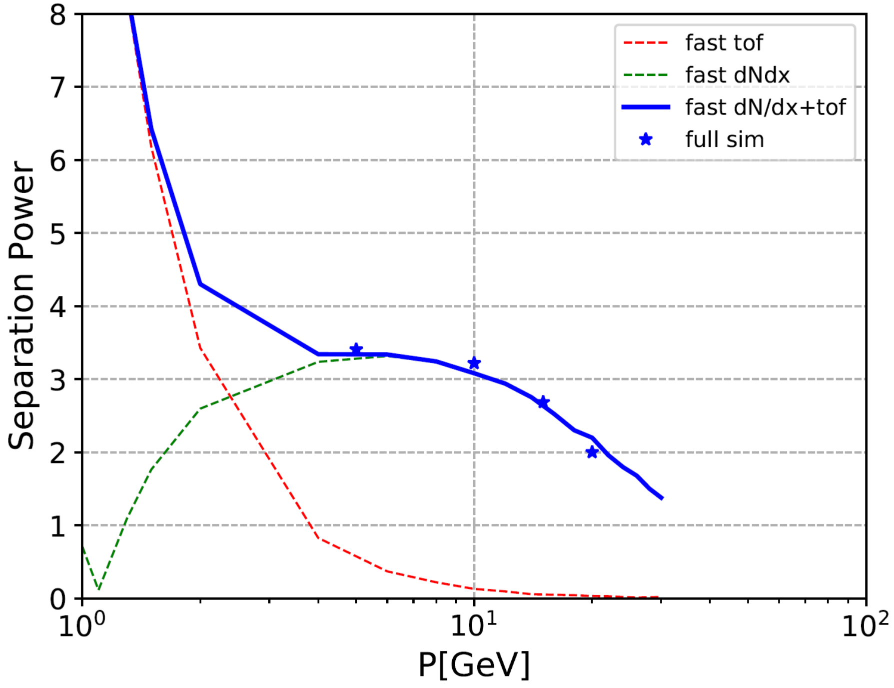


- dN/dx model: $N = N_{truth} * \varepsilon$
  - N_{truth}: Garfield sampling
  - ε: counting efficiency, is a function of the number of primary clusters and modeled with full simulation results

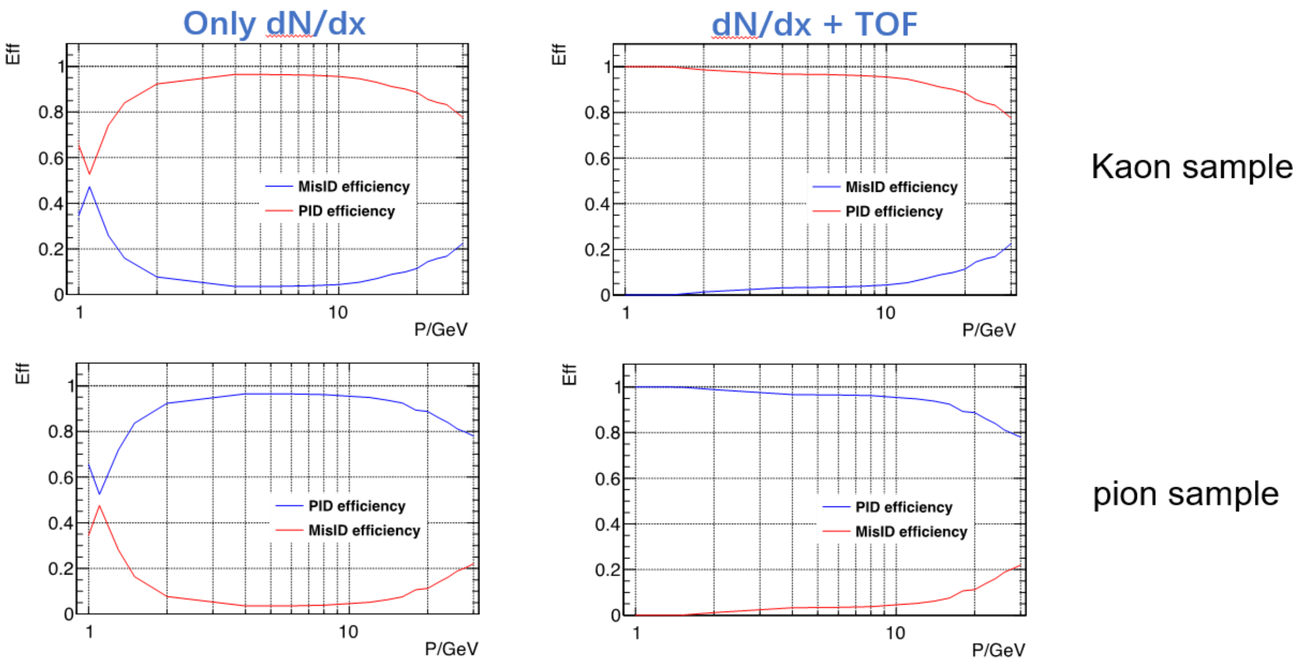


Preliminary results of PID performance

Separation power



PID efficiency

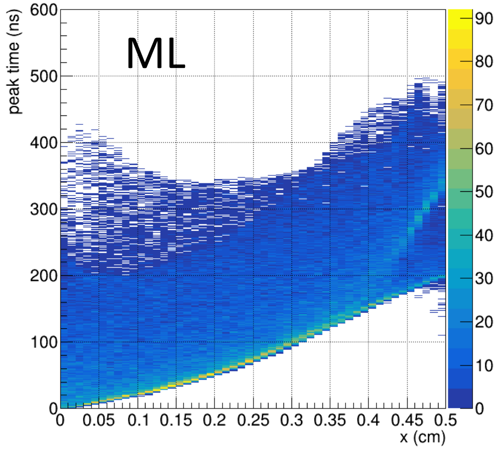


- ~90% efficiency, ~10% fake efficiency, for 20 GeV/c

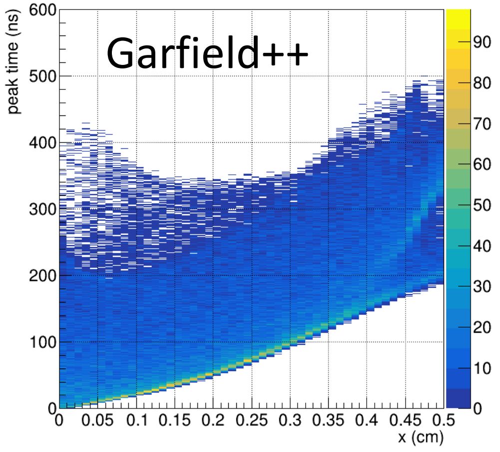
From Guang's talk in CEPC Phys/Det meeting on Jun23, 2021

Simulation software in CEPCSW

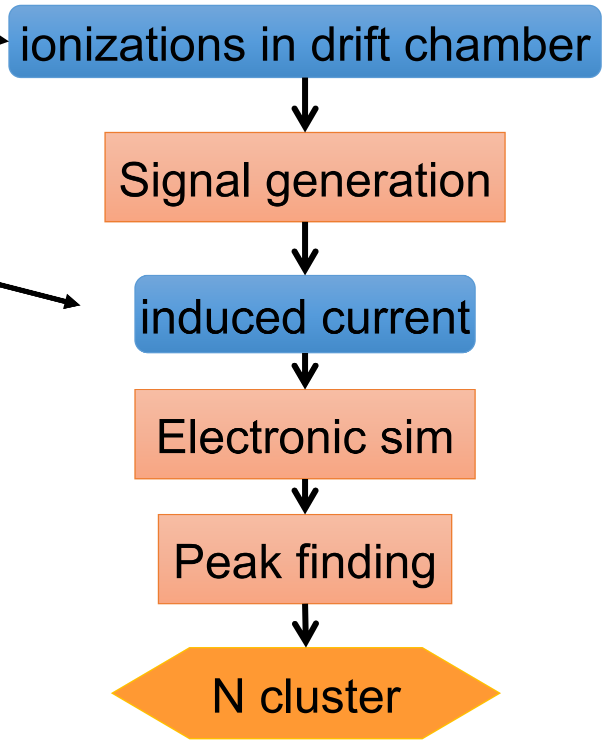
- The ionization simulation:
  - Done with Geant4 combined with TrackHeed
- Induced current simulation:
  - Using parameterized method
  - ML method is used to simulate peak time and value for each electron
  - Need to check the performance of the parameterized method with full Garfield++ simulation



Peak time vs x



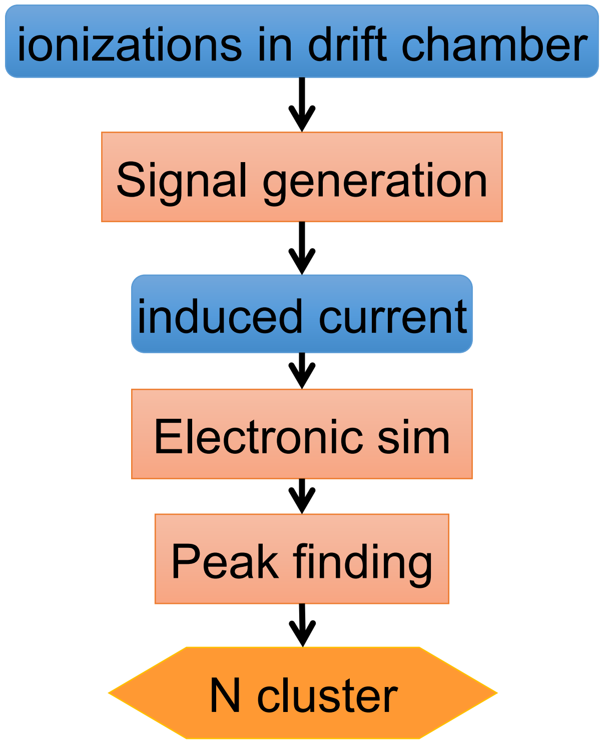
Peak time vs x



From Wenxing's talk in CEPC Phys/Det meeting on Jun23, 2021

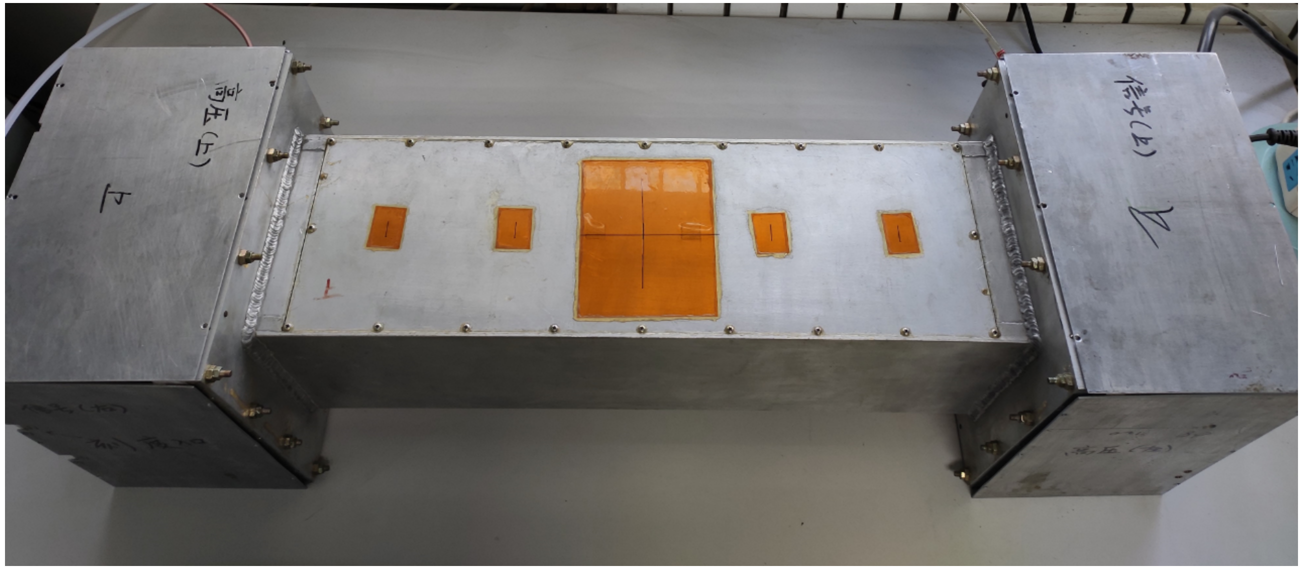
Simulation software in CEPCSW

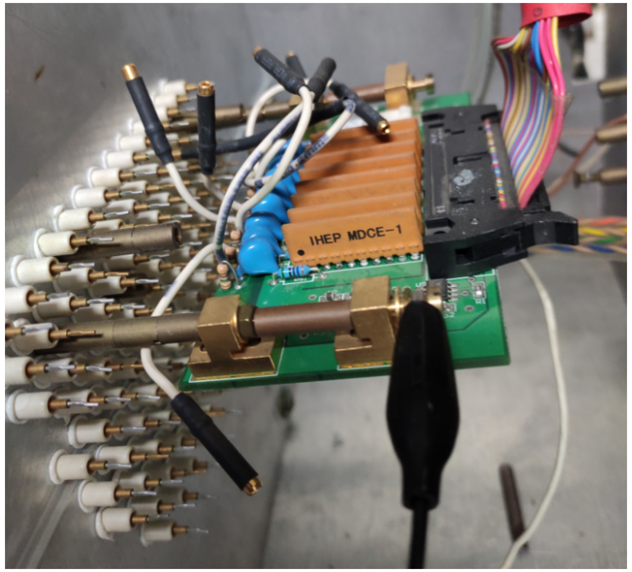
- The Electronics sim:
  - Unrealistic
- Peak finding:
  - Working on
- Working on extending EDM4hep to store waveform information (cell id, vector pairs of charge and time)



Prototype test

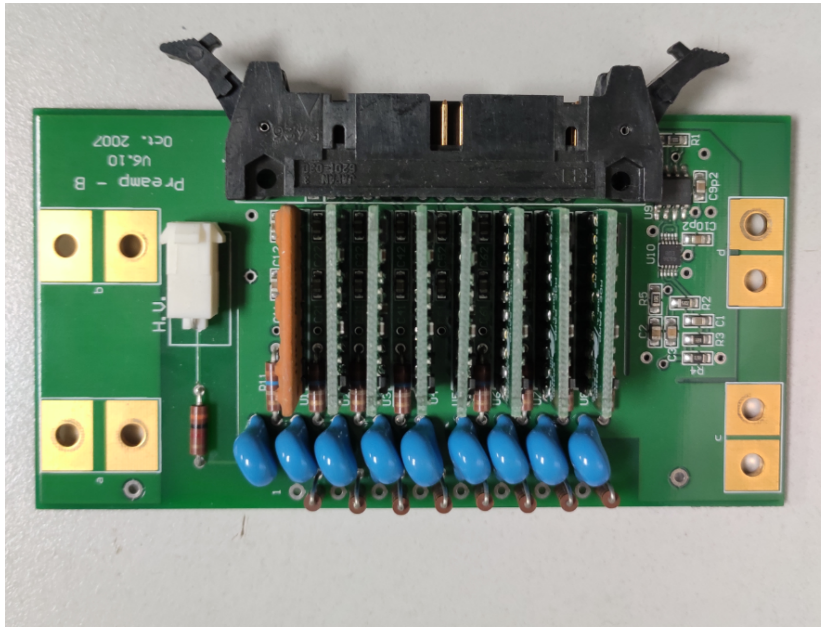
- A prototype test system was setup to provide reference for simulation and help to understand the requirements of electronics
  - 4 layers, 6 cells/layer
  - Cell size: 16×16 mm^2
  - Wire length : 600 mm
  - Read out: preamplifier + oscilloscope, Gas mixture: He/isobutene= 80:20

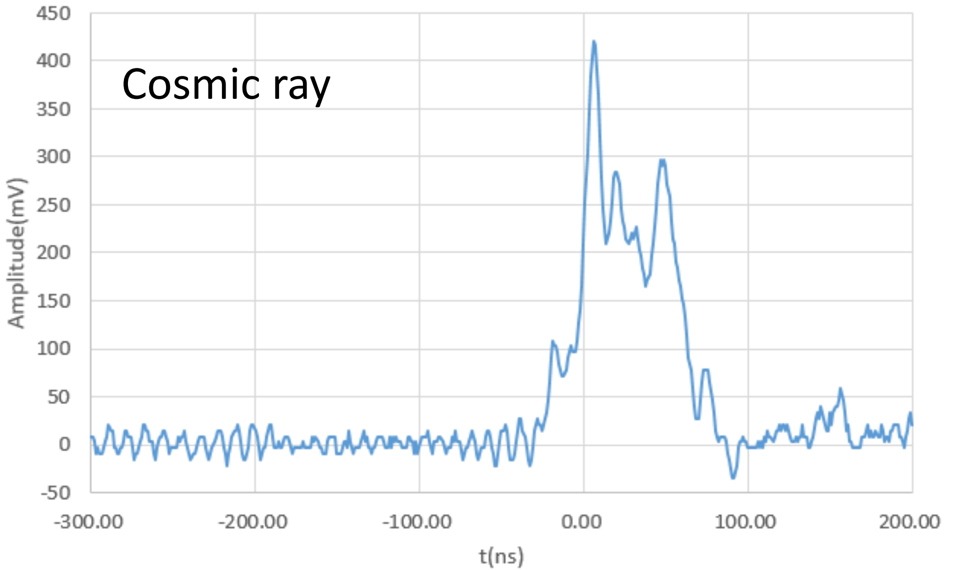




Preamplifiers used in BESIII MDC

- 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

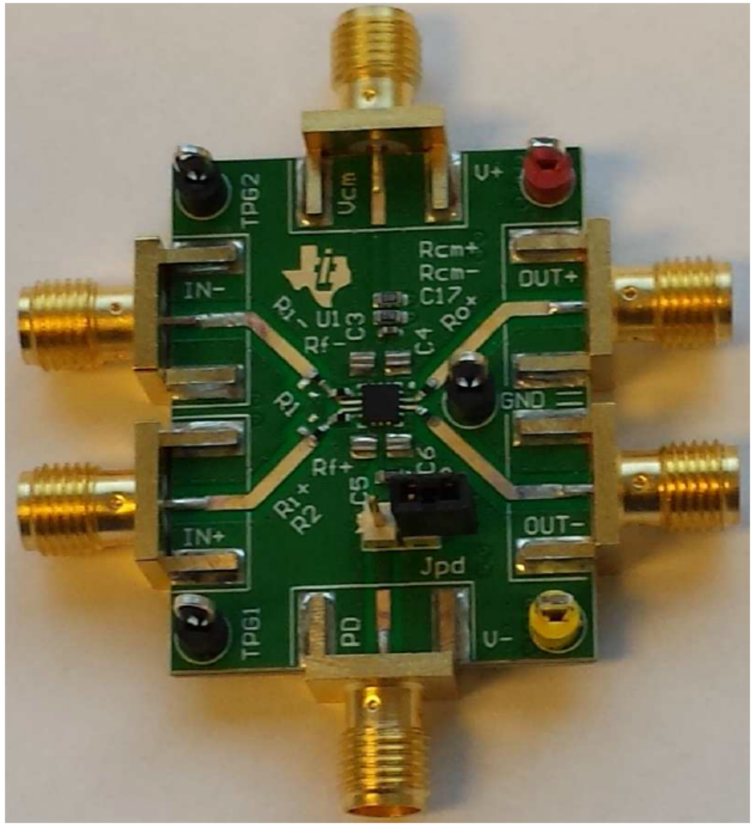




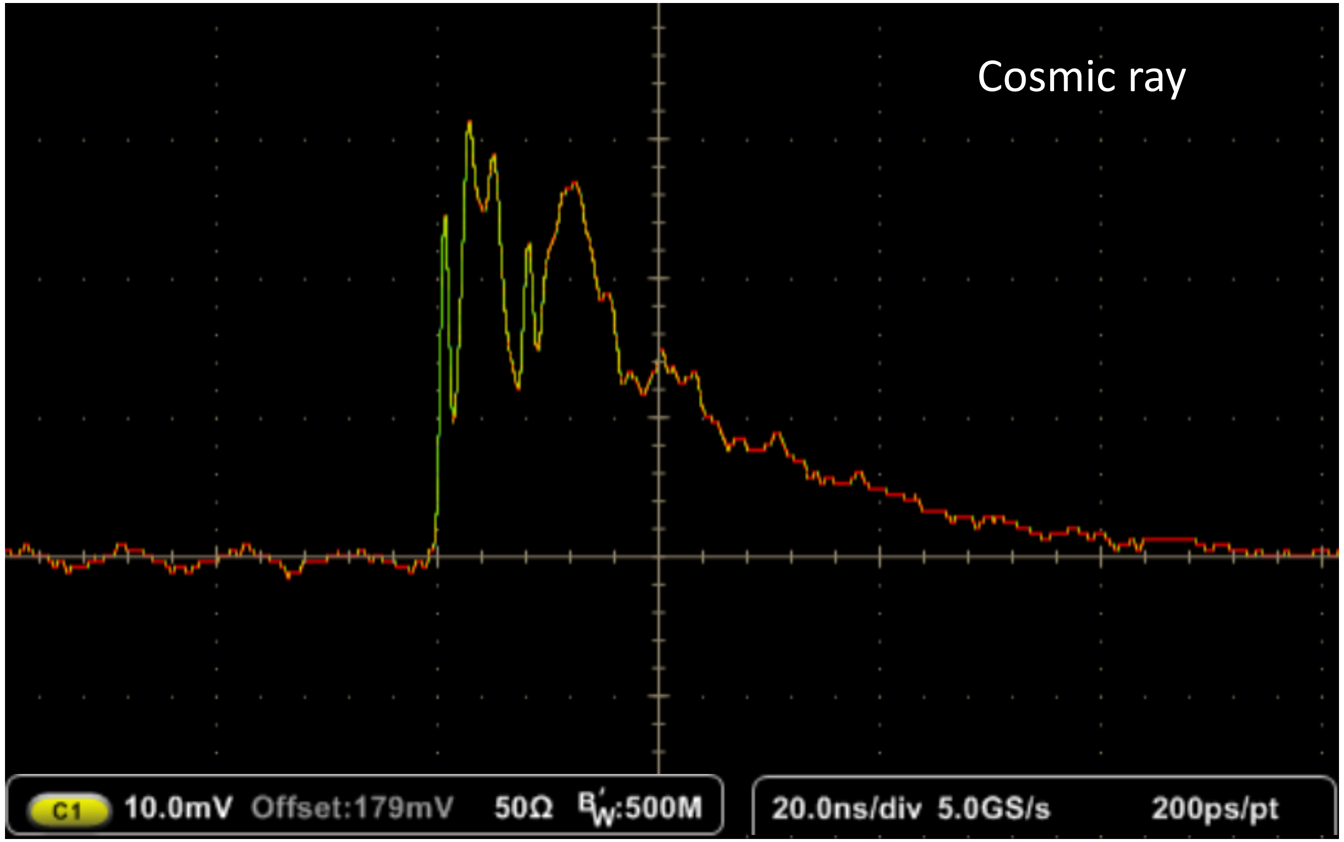
- Can separate few clusters, not very good
- Fast preamplifier (<1ns rise time) with low noise is needed

LMH5401EVM Board

- Gain bandwidth product (GBP): 8GHz
- Gain : 12 dB



- Signals with 1ns rise time can be tested
- Gain is not enough
- Next : Change the R_f to improve the gain



Summary

- A simulation workflow for the drift chamber with cluster counting method is ready. Preliminary results show that K/π separation can achieve 3(2)σ for 10(20) GeV/c with the thickness of DC about 1m
- A fast simulation parameterized from full simulation is implemented and preliminary PID performances are studied
- Simulation software for dN/dx study in CEPCSW is in development
  - Ionization simulation using Geant4 combined with TrackHeed is implemented
  - To speed up the avalanche simulation, a parameterized method has been studied and working in progress
- A prototype test system was setup to validate the simulation and help to understand the requirements of electronics

Plan

- Simulation of performance
  - Tune the simulation parameters of electronics and noises based on the experiment results
  - Optimize the detector design: layout, cell size, gas …
- Simulation software in CEPCSW
  - Extend EDM4hep to store waveform information
  - Implement electronics simulation and peak finding algorithm in CEPCSW
- Prototype test
  - Provide realistic parameters of electronics and noises for simulation
  - Design electronics test board

Thanks!