Updated ionization simulation for the 4th conceptual detector

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CEPC Physics and Detector Meeting

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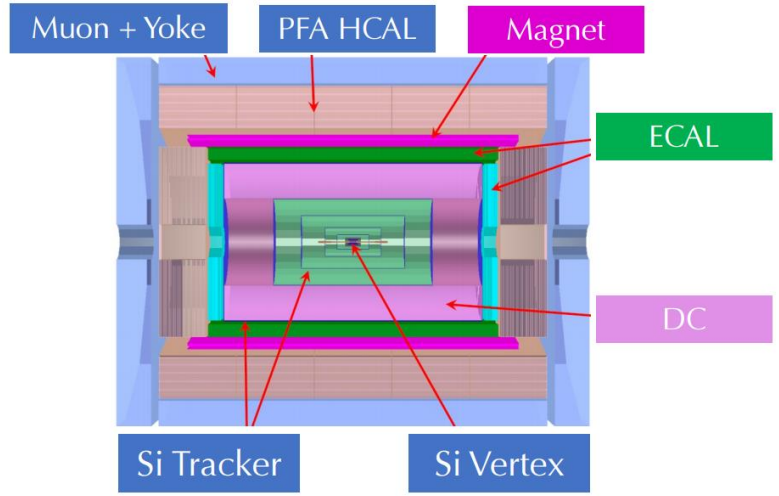
Outline

- **Introduction**
- **Progress on simulation**
  - Waveform-based simulation: principle/feasibility study
  - Fast simulation: quick application on CEPCSW
- **Summary**

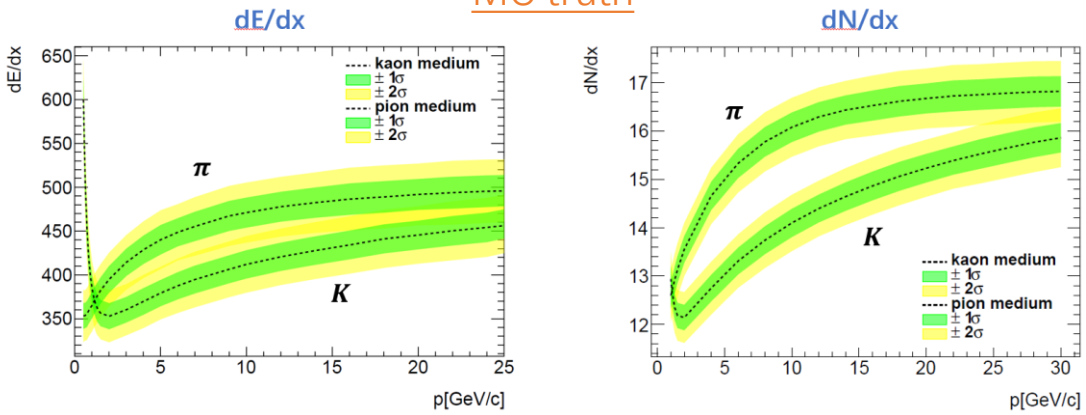
Introduction

- Particle ID with a drift chamber is a key feature for the 4th conceptual detector
- Ionization measurement using the cluster counting technique (dN/dx) can benefit from small fluctuations
- Technical issues (e.g., electronics) are the key bottleneck
- Need detailed simulation for the feasibility and performance study

4th Conceptual Detector

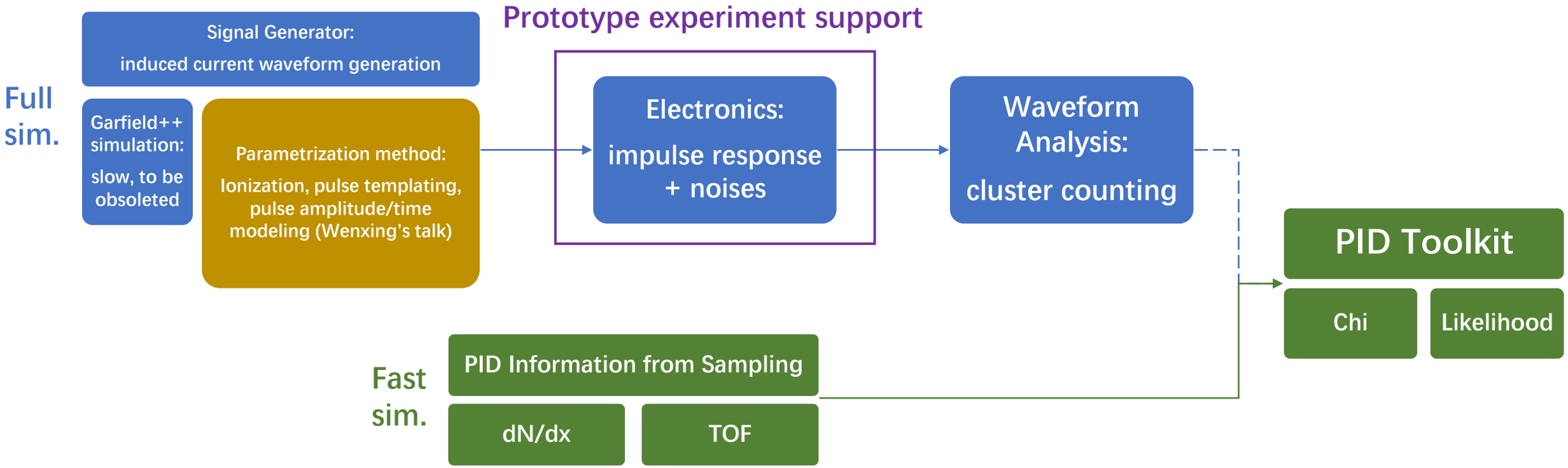


MC truth



Previous talk: @ Yangzhou workshop

The simulation workflow

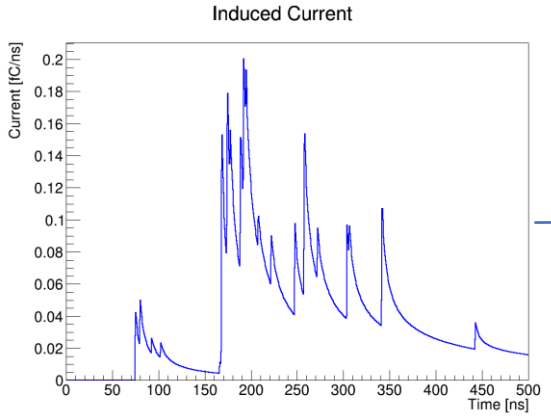


- In this talk, we are concentrating on the detector/PID performance
- See Wenxing's talk for the software development in CEPCSW

Waveform-based simulation

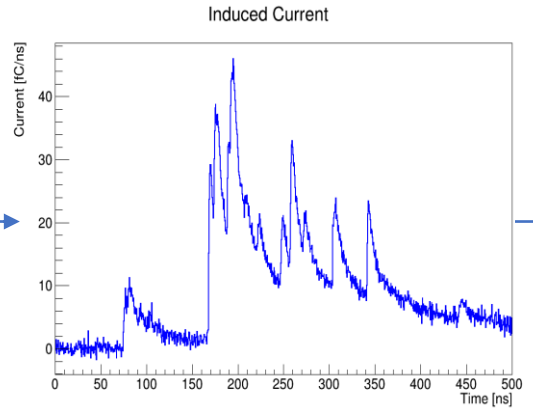
Waveform-based simulation

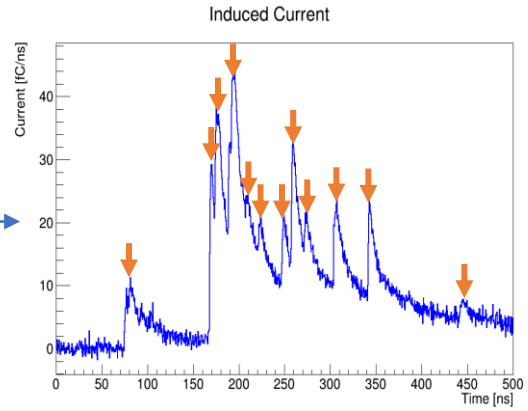
Induced current



Electronics

Realistic waveform



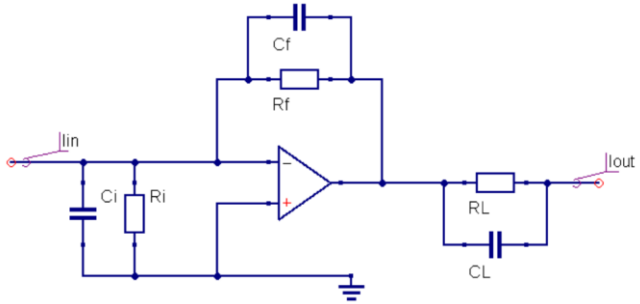


Signal generator (Garfield++):

- Heed: ionization process
- Magboltz: gas properties (drift/diffusion)

Electronics:

- Preamplifier
- Noises
- ADC



Counting method:

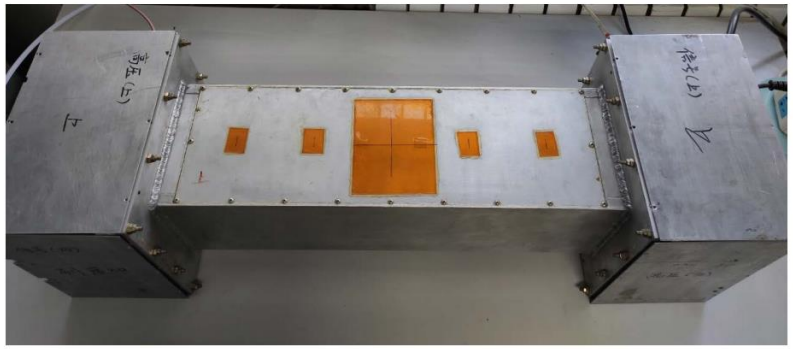
- Moving average (MA):
  - $\mathbf{MA[i]} = \frac{1}{M} \times \sum_{k=0}^{K<M} \boldsymbol{S[i-k]}$
- First difference (D1):
  - D1[i] = MA[i] – MA[i – 1]

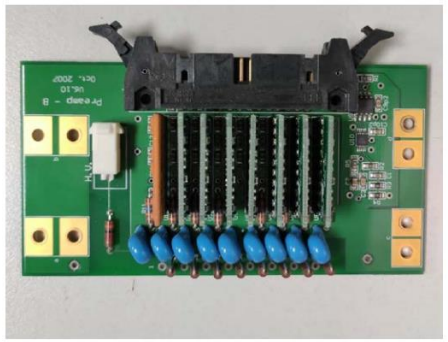
- A full simulation framework is ready
- Input from experiment is crucial for electronics simulation

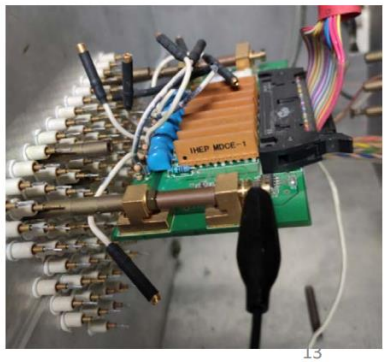
A prototype experiment

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



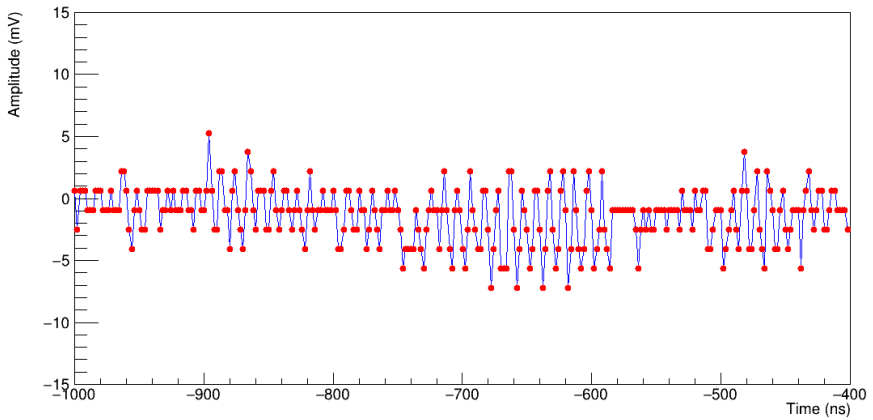




Readout by an oscilloscope that connects to the preamplifier with a 18m cable

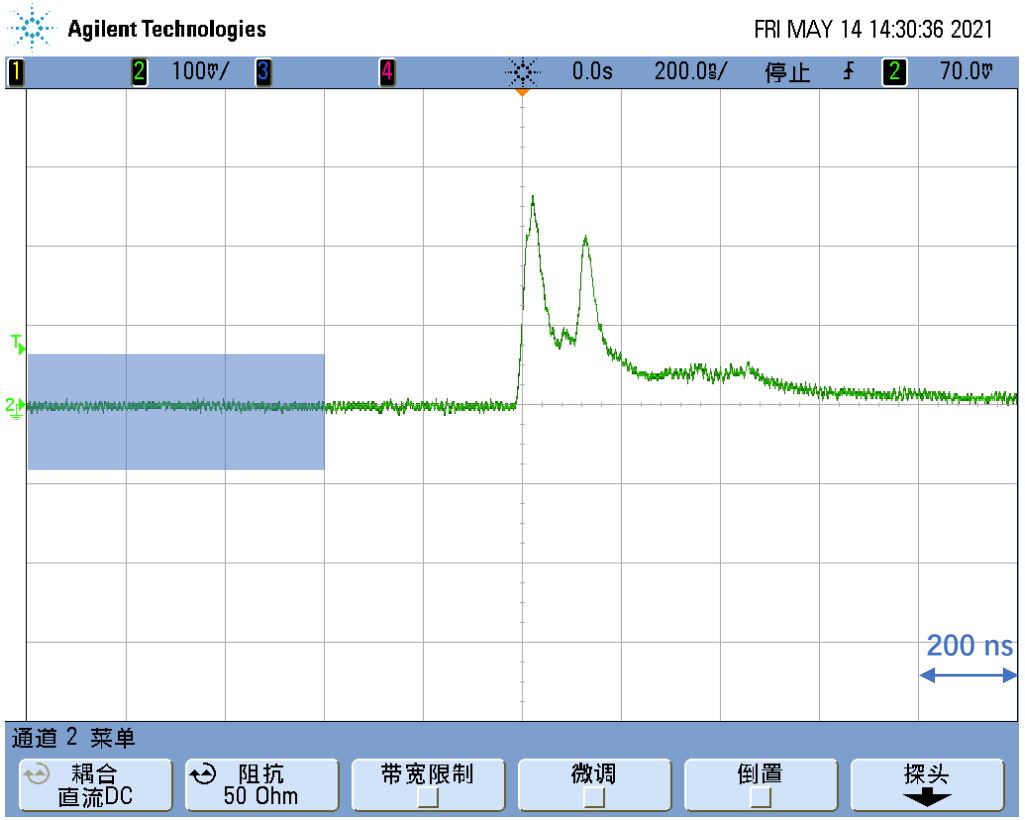
Waveform from the experiment

As a first-step study, try to extract noise information from the experimental waveform



Noises are extracted from the baseline waveform

Cosmic Ray Signal



Fourier analysis

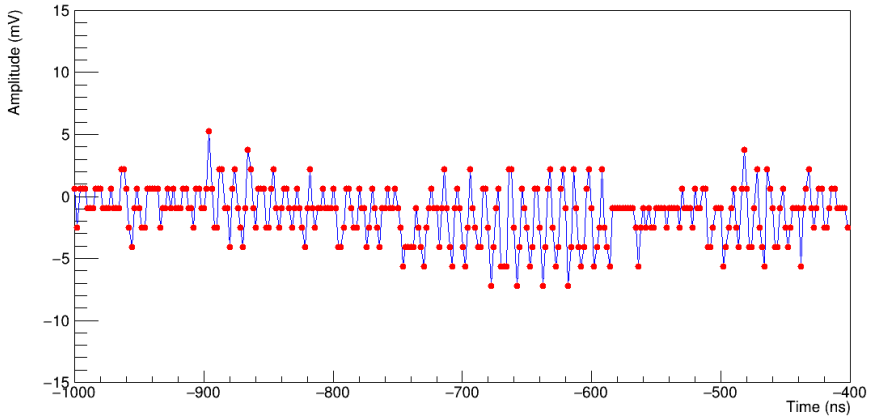
rectangular notation

$$x(t) = \sum_{k=0}^{+\infty} ReX[k]\cos(2\pi kt/T) - ImX[k]\sin(2\pi kt/T)$$

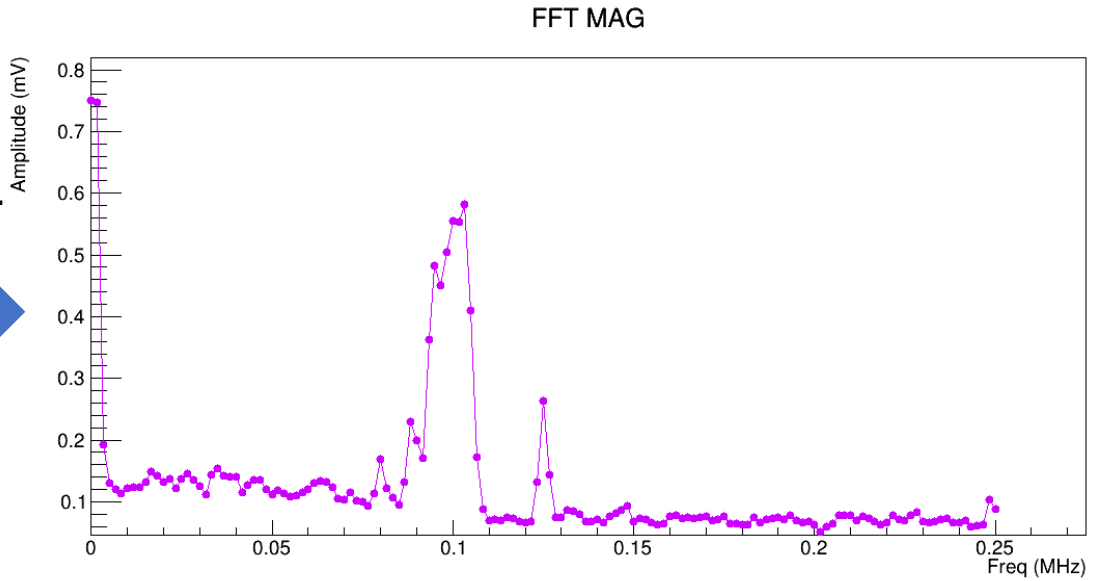
polar notation

$$MagX[k] = (ReX[k]^2 + ImX[k]^2)^{1/2}$$

$$PhaseX[k] = \arctan\left(\frac{ImX[k]}{ReX[k]}\right)$$



FFT

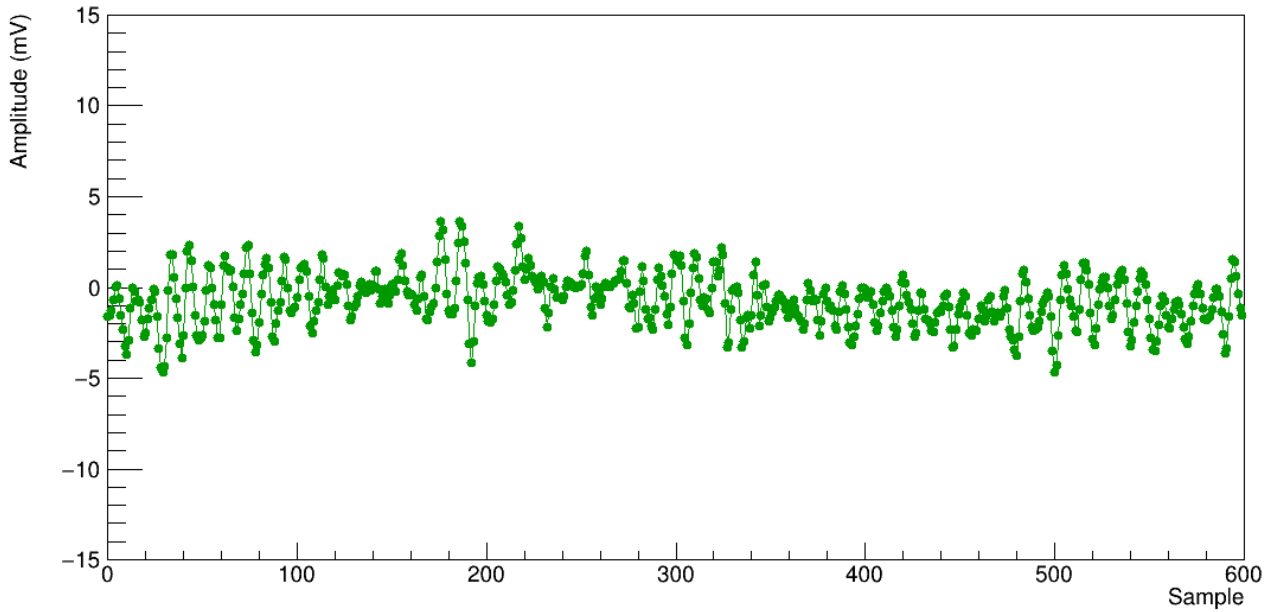


IFFT

- ✓ Average frequency spectra with 88 measurements
- ✓ Assume random phases

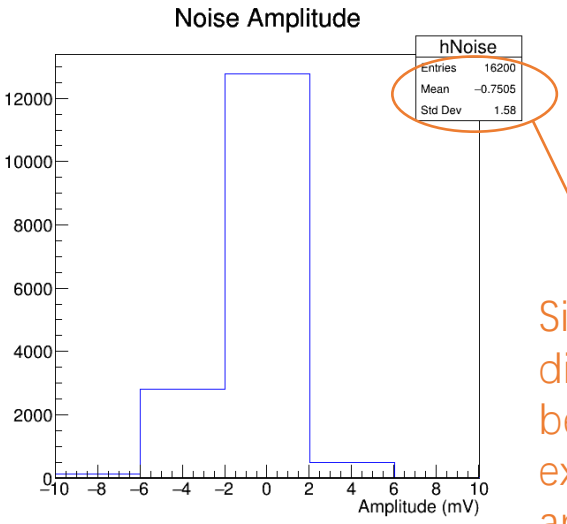
Noise generation

IFFT



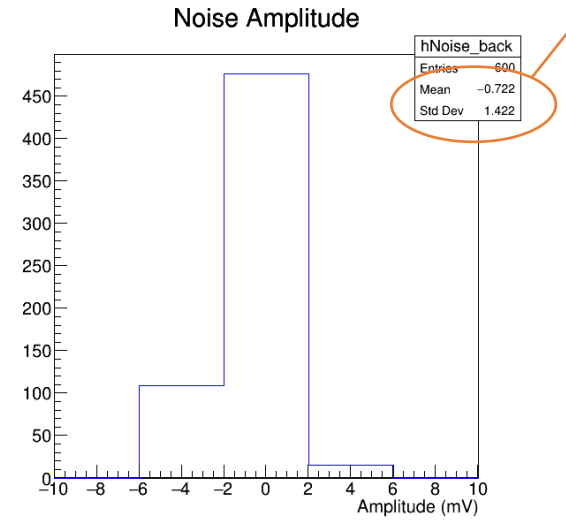
Noises are reproduced

Experiment

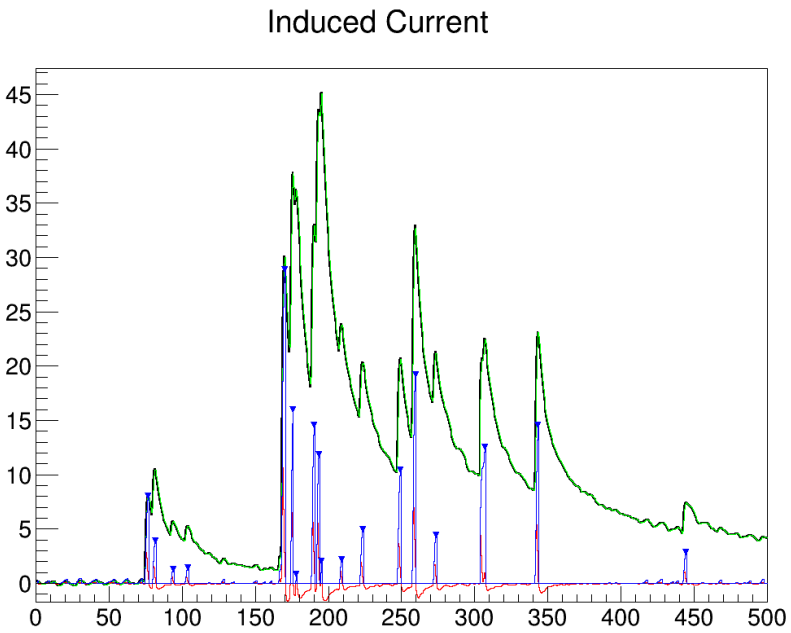


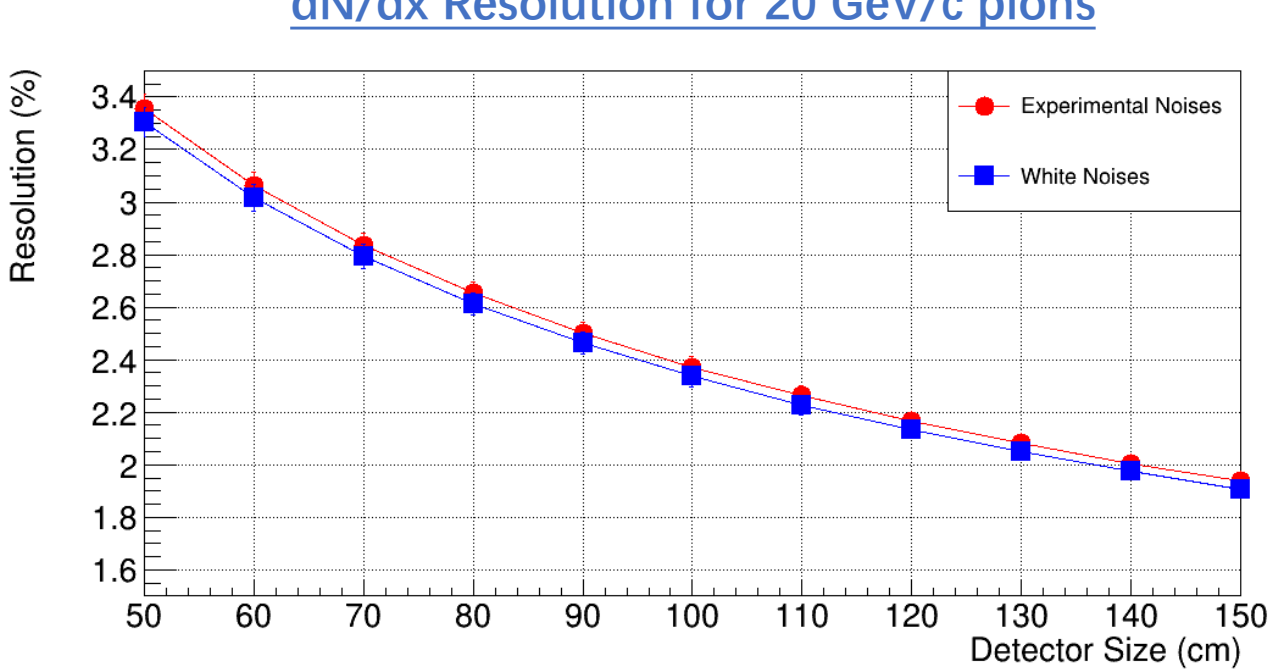
Similar distribution between experiment and simulation

Simulation



Waveform with experimental noises



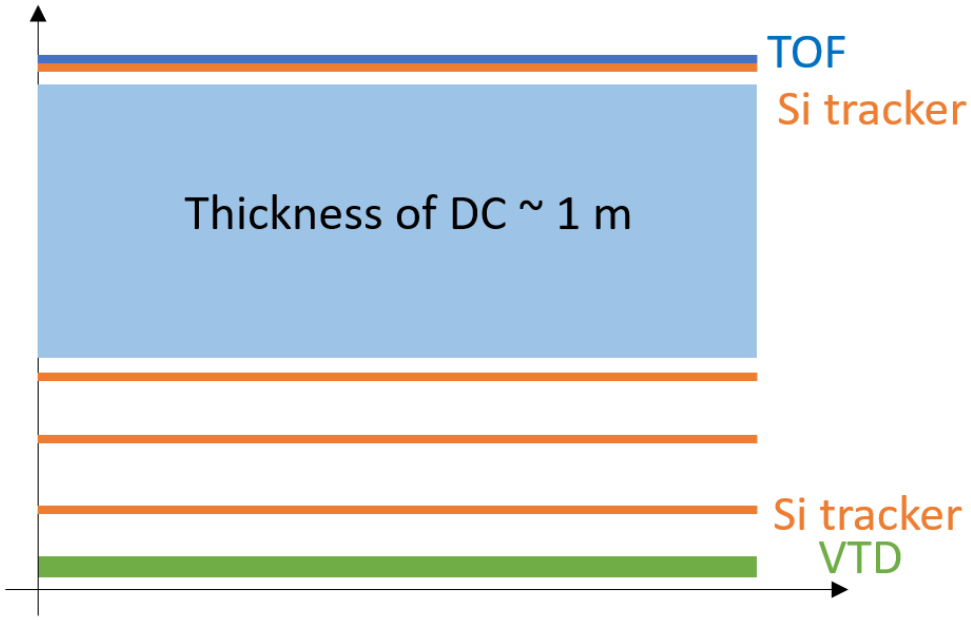


- ✓ Framework to include the experimental noises is developed
- ✓ Preliminary analysis results show similar performance compared to previous study
- ✓ There is still room to improve the experiment

Fast simulation

Fast simulation in CEPCSW

- **Main objective: Speeding up the simulation to enable the study of PID performance**
- **Method: Sampling dN/dx (truth) by a certain track length using Garfield.**
- **Geometry setup:**
  - Floating DC up to Rout =1.8m(1cm*100 layers)
  - A TOF detector surrounded at R = 1.8m
  - Can handle single particle in different angle.

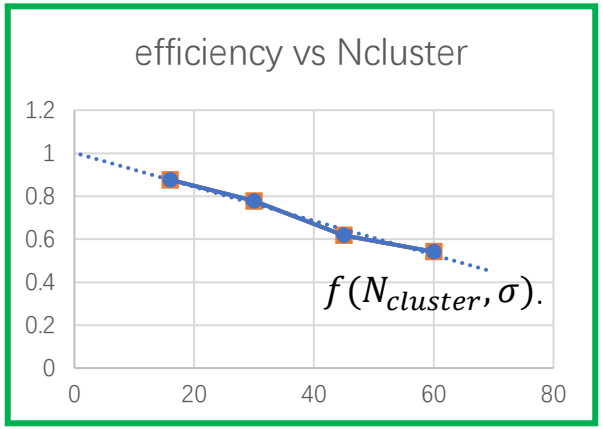


Current v1 configuration

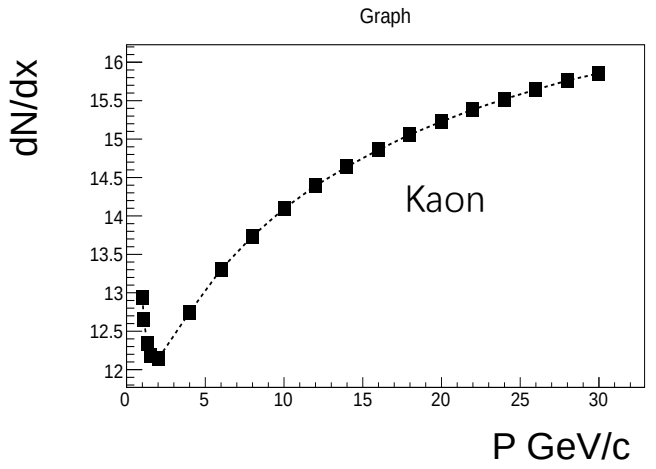
Fast simulation in CEPCSW (II)

- **dN/dx model:** $N = N_{truth} * f(N_{cluster}, \sigma)$.
  - N_{truth}: Garfield sampling
  - f: counting inefficiency, tuned based on full simulation
- **TOF model:**
  - Assuming a resolution of 50 ps

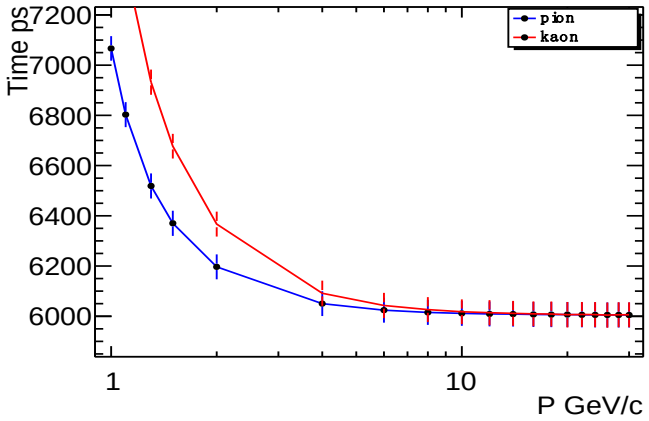
Tuned from waveform-based simulation



dN/dx model

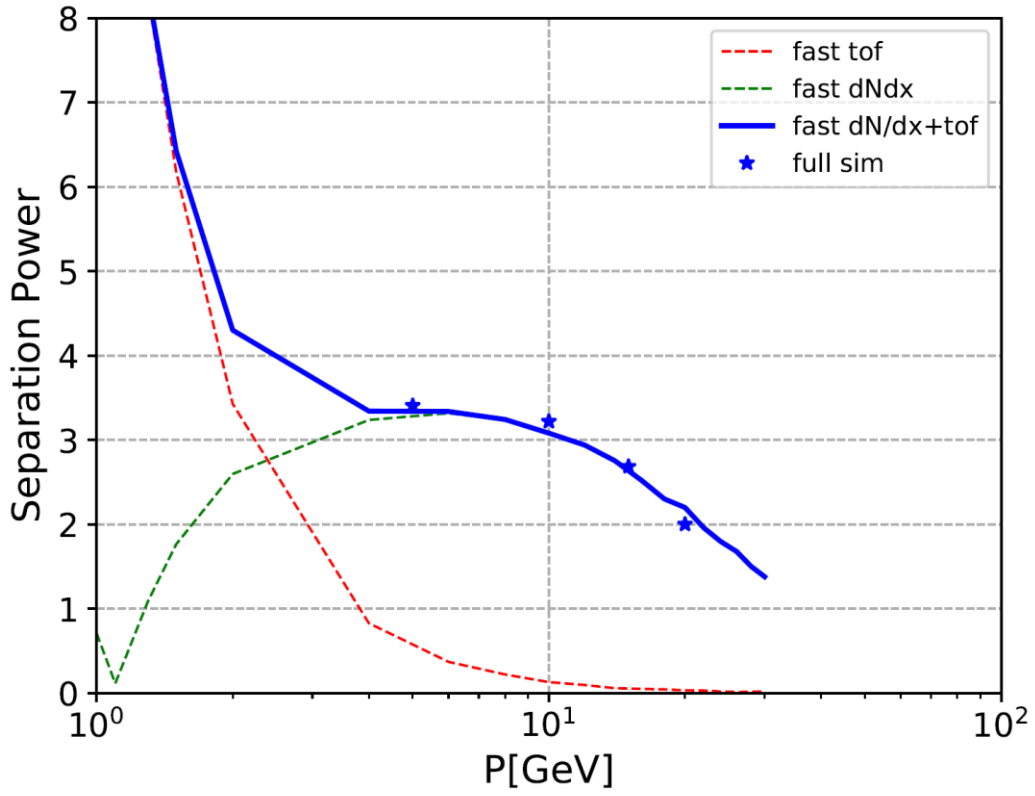


TOF model



Separation power

- ✓ A standard statistical evaluation of the PID performance
- ✓ K/pi separation can achieve 3(2) $\boldsymbol{\sigma}$ for 10(20) GeV/c
- ✓ Good agreement between fast and full simulation



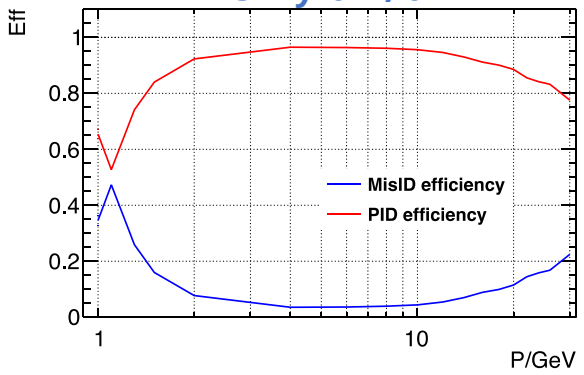
Separation power

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

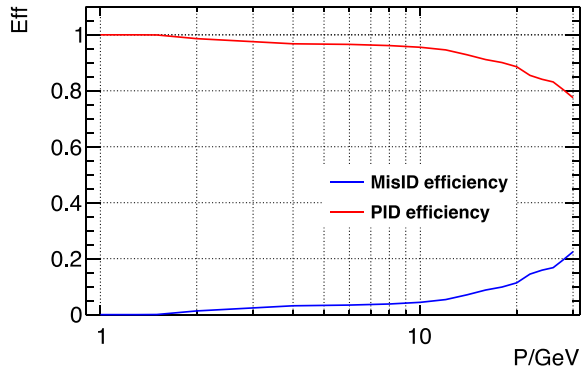
PID efficiency

- A more direct and practical way of evaluation
- $\chi_t = \frac{t-t_{exp}}{\sigma_t}$, $\chi_{\frac{\mathrm{dN}}{\mathrm{dx}}} = \frac{dN/dx-dN/dx_{exp}}{\sigma_{\frac{dN}{dx}}}$, $\chi^2 = \chi_t^2 + \chi_{\frac{dN}{dx}}^2$
- A pion (kaon) is identified if $prob_{\pi(K)} > prob_{K(\pi)}$
- ~90% efficiency, ~10% fake efficiency, for 20 GeV/c

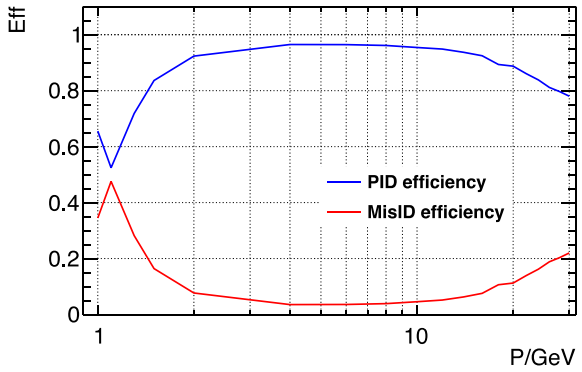
Only dN/dx

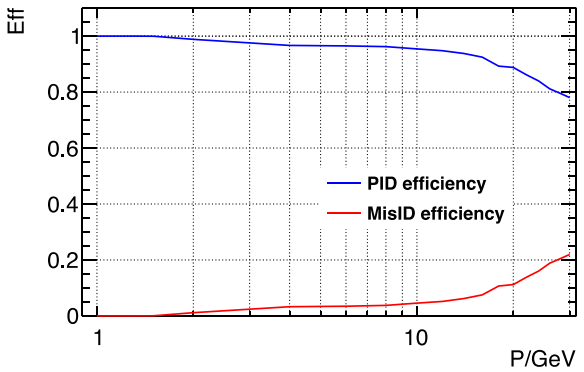


dN/dx + TOF



Kaon sample

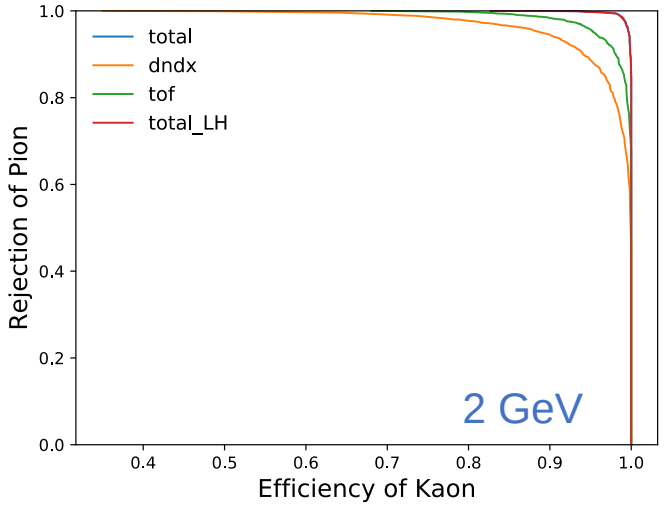


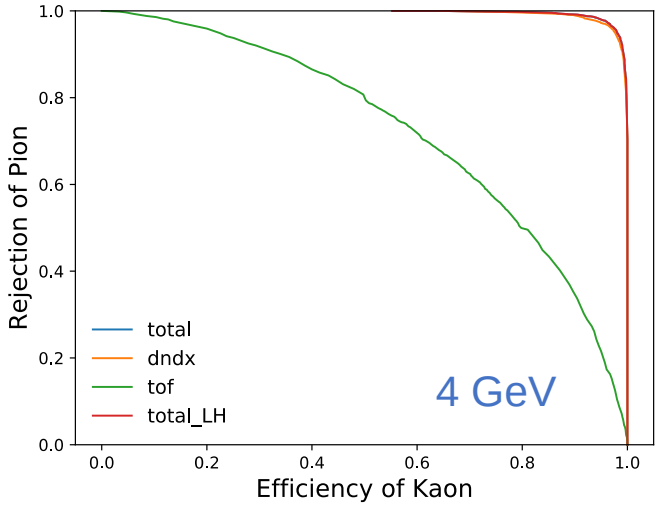


pion sample

ROC curve

- An intuitive way of comparing different classification methods
- Likelihood = $\frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi_t^2} * \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}\chi^2_{\frac{dN}{dx}}}$
- dN/dx is very effective for PID at high momentum





- 2/4 GeV/c kaon & pion performance
- Consistent value of
  - total : from chi2 probability.
  - total_LH: from Likelihood ratio.

Summary

- **Waveform-based simulation**
  - Update the framework to incorporate the experimental measurement
  - Reproduce the noises from an experiment with the BESIII preamplifier and prototype
  - We are still making our best efforts to improve the measurements
  - To investigate the counting method

- **Fast simulation**
  - A fast simulation framework is implemented in CEPCSW for end-users
  - Provide dN/dx + TOF information from sampling method
  - Preliminary PID performances are studied based on the fast simulation
    - K/pi separation can achieve 3(2) σ for 10(20) GeV/c

- **Notification: The cluster counting regular meeting will start in July, called by Linghui and Franco. Welcome to join!**

Thank you