Drift chamber for CEPC 4th conceptual detector

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on behalf of DC PID Group

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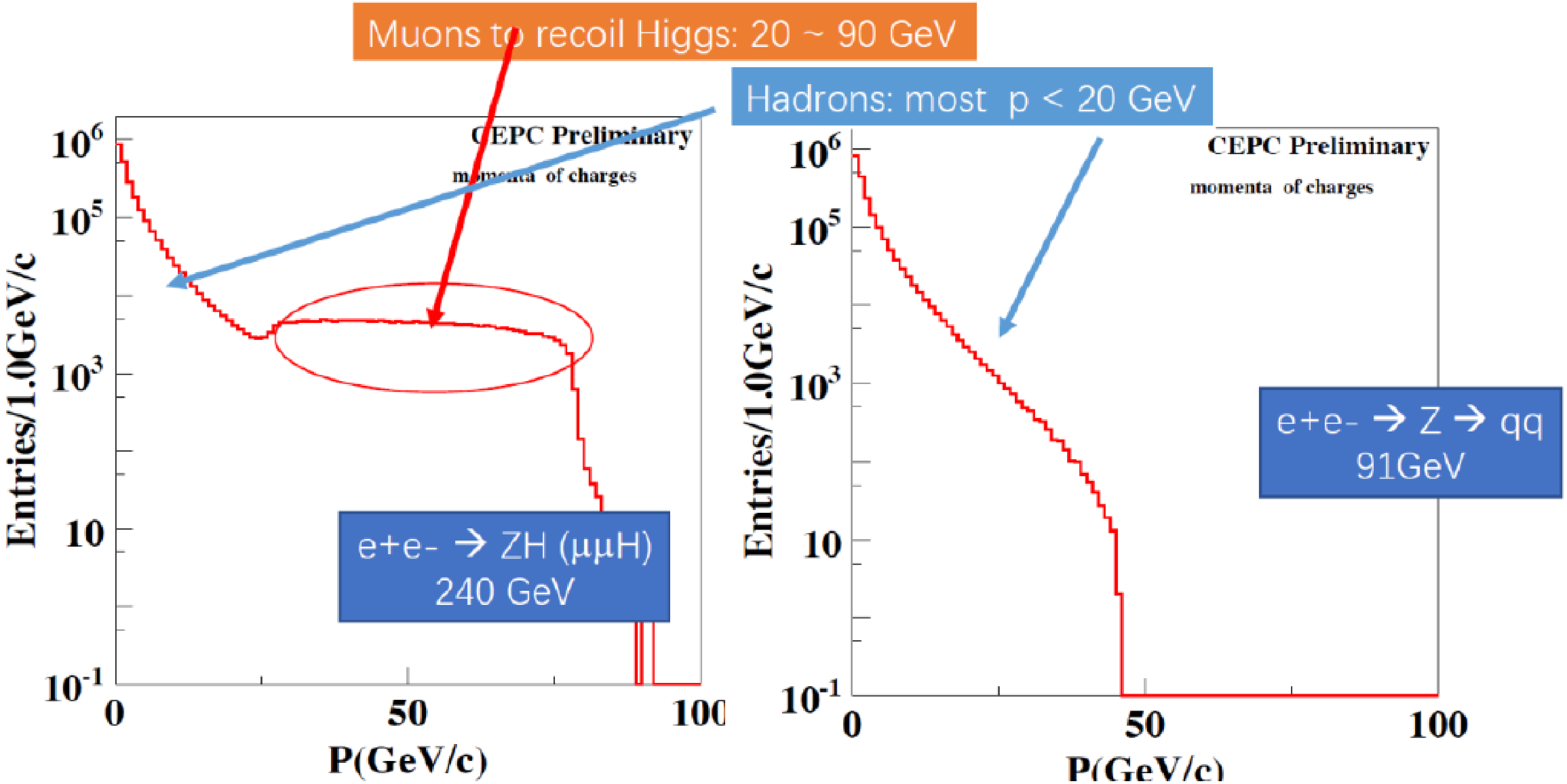
Outline

- Introduction of drift chamber for CEPC 4th conceptual detector
- Simulation study and detector preliminary parameters
- Cluster reconstruction algorithm with machine learning
- Summary and outlook

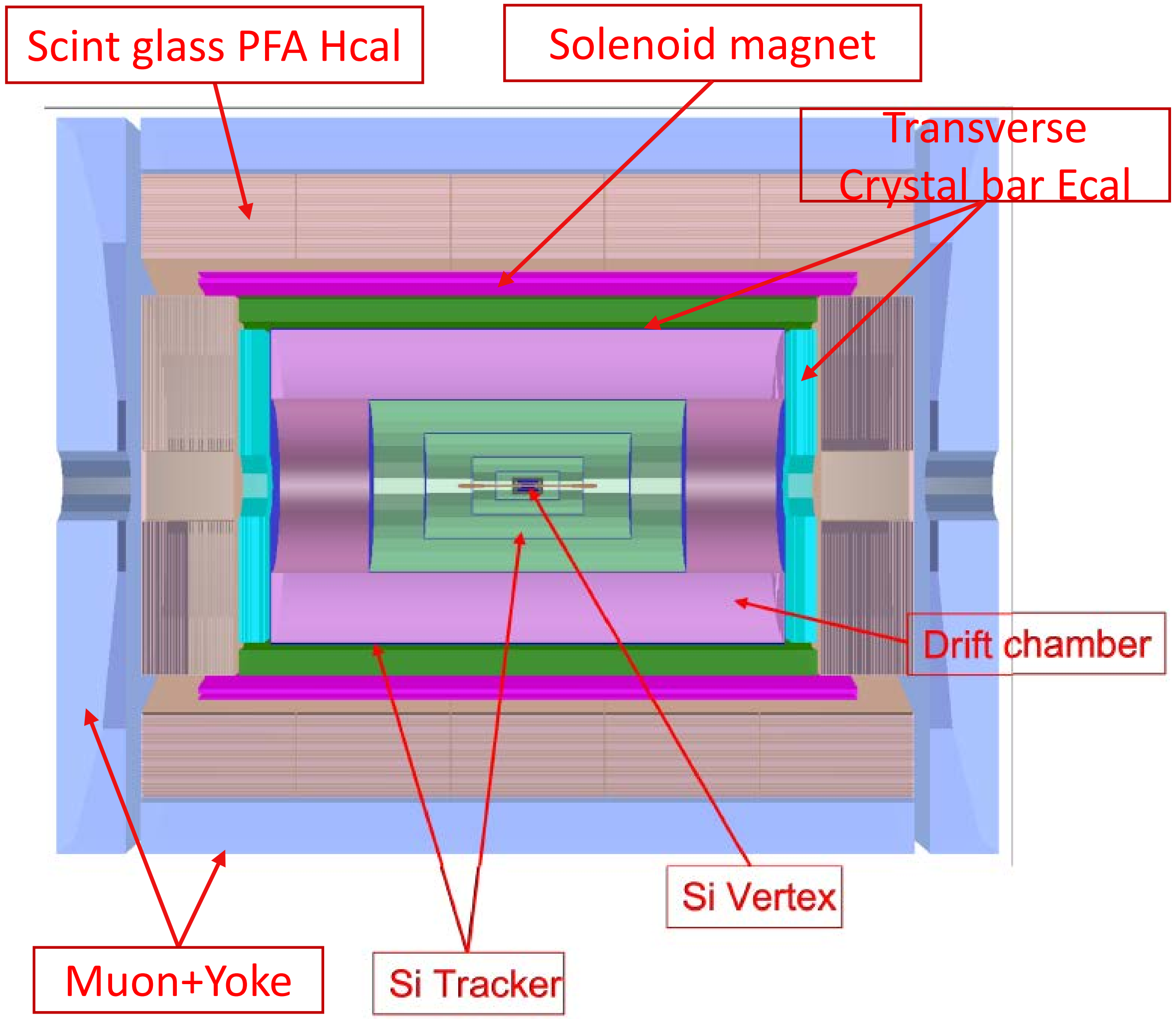
Motivation

- CEPC will produce 10^{11} -10^{12} Z bosons, offer great opportunity for flavor physics and jet study
- Most charged hadrons are concentrated on low momentum region (below 20 GeV/c)
- Particle identification (PID) would be critical

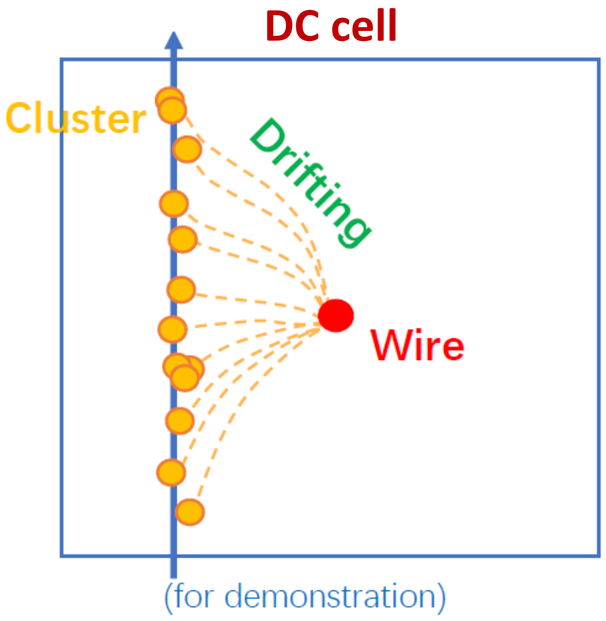


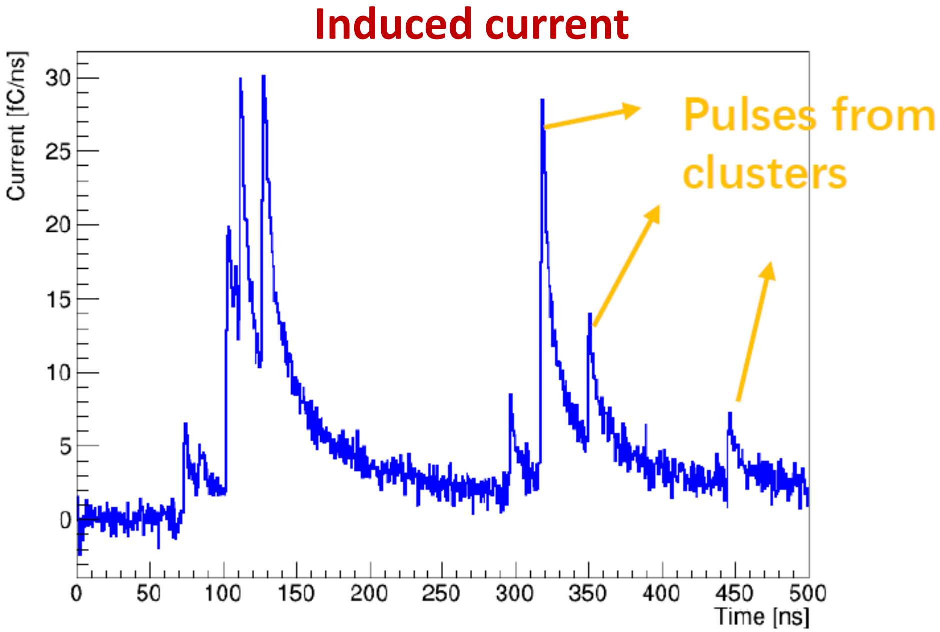
Drift Chamber for CEPC 4th detector design

- Drift Chamber is proposed in CEPC 4th conceptual detector for particle identification (PID)
  - Inserted between Si inner tracker (SIT) and Si external tracker (SET)
  - Mainly provides PID capability by using cluster counting technique while keeping a reasonable detector size
    - 3σ separation of K/π with momentum up to ~20 GeV/c
  - Could also benefit tracking and momentum measurement



Ionization measurement with dN/dX

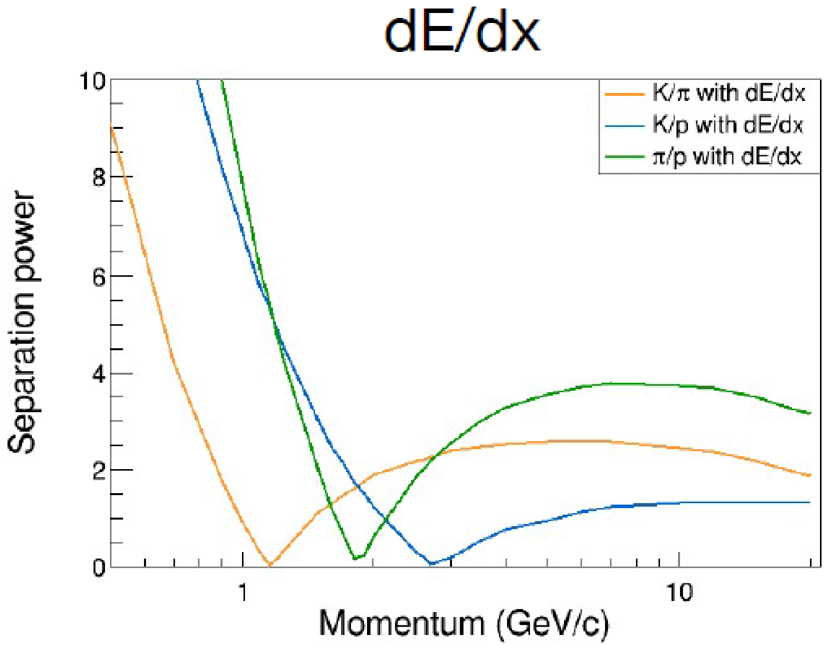


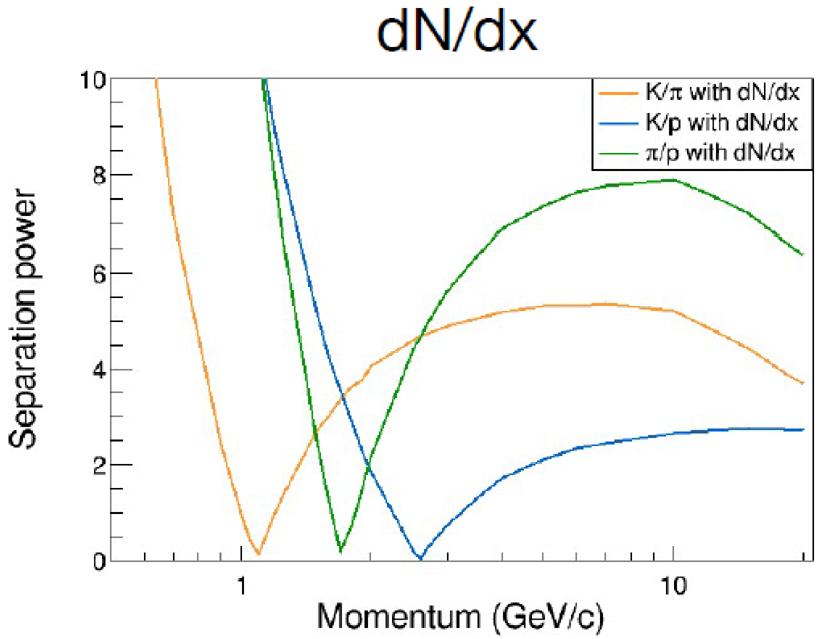


- Cluster counting (dN/dx): Measure number of clusters over the track
- Yield of primary ionization is Poisson distributed: $P(\bar{N}_p, k) = \frac{\bar{N}_p^k}{k!} e^{-\bar{N}_p}$
- Less sensitive to Landau tails than dE/dx

PID with ionization simulation

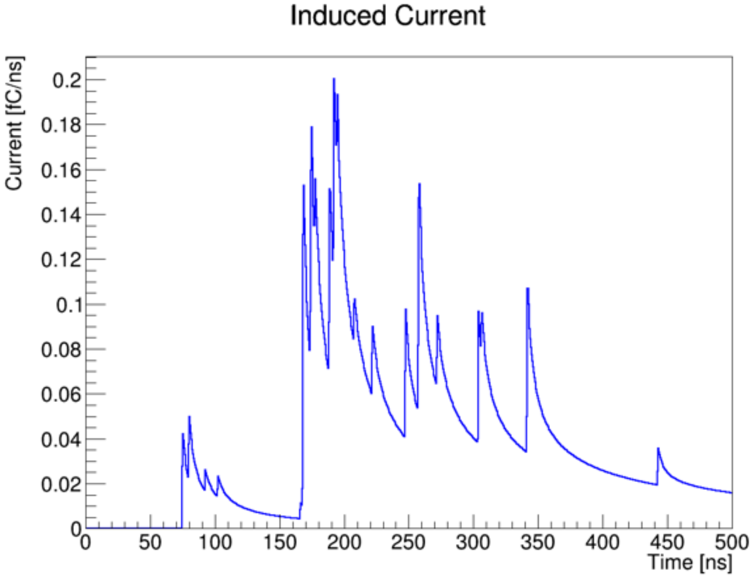
- The theoretical results are obtained from Garfield++ simulation.
- dN/dx shows better PID performance than dE/dx. (a factor of >2)



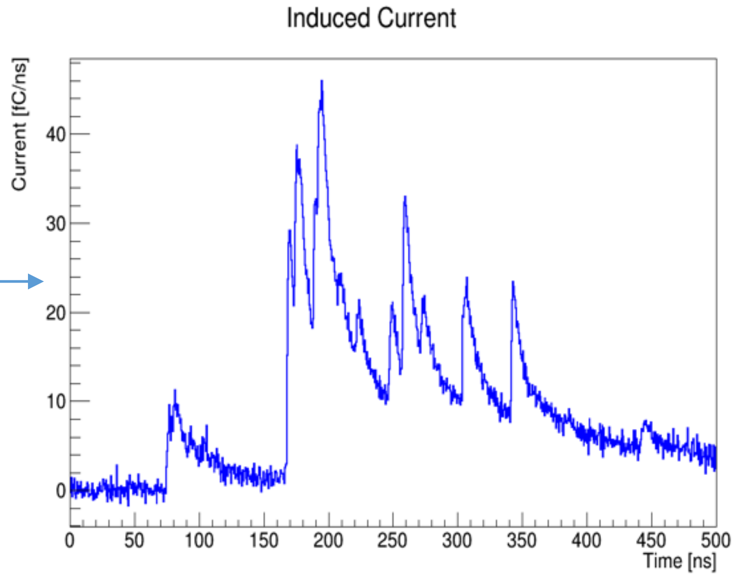


- The effect of electronics, noise should be taken into account, and efficiency of counting algorithm is important
- To study/control those factors, a waveform-based simulation is performed.

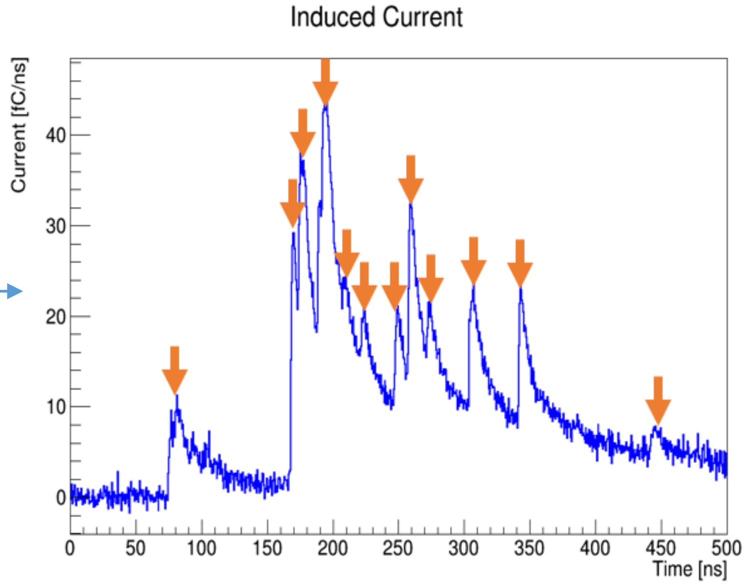
Waveform-based simulation



Simulation



Digitization



Reconstruction

Signal generator (Garfield++)

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

Electronics:

- Preamplifier
- Noise
- ADC sampling rate

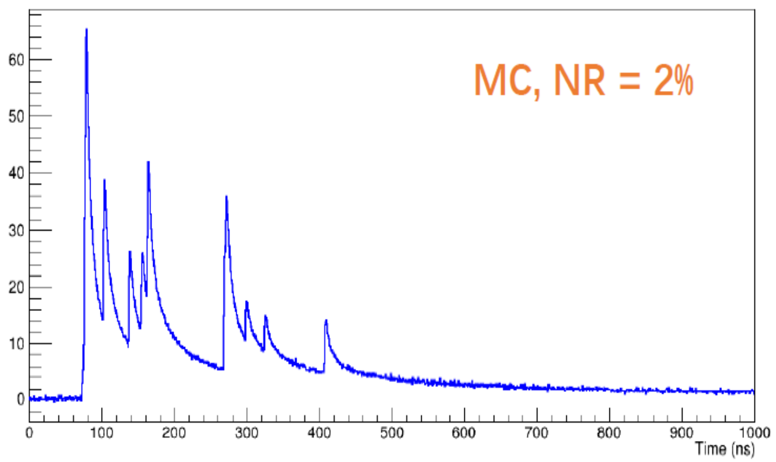
Peak finding algorithm

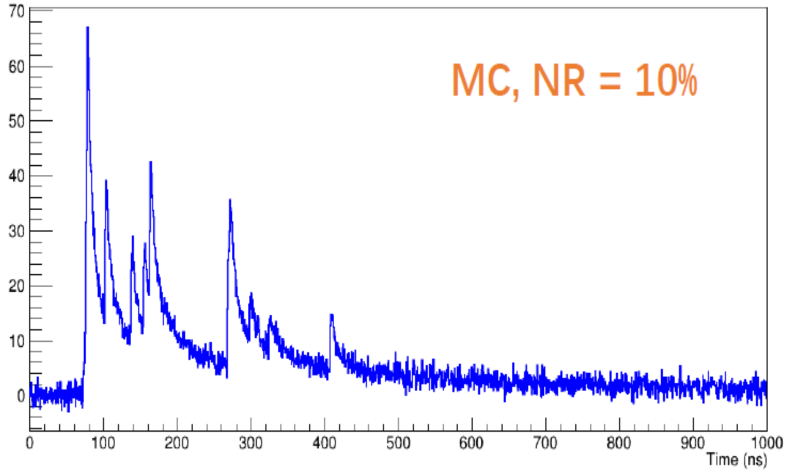
- Second derivative
- Machine Learning

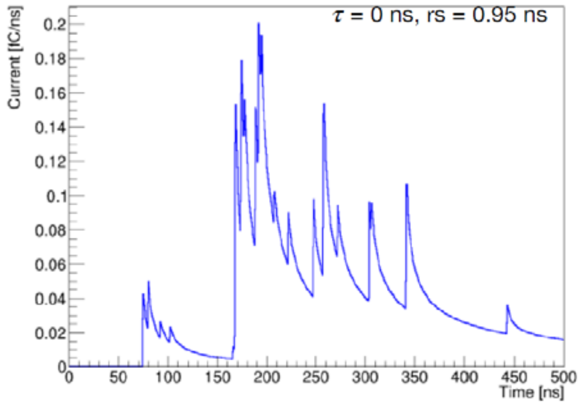
Digitization

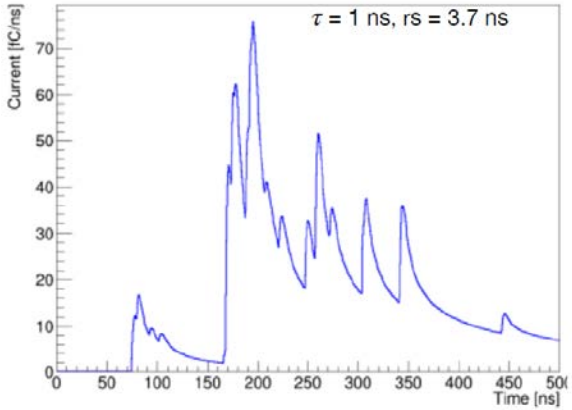
- Impulse response: parameterized by the amplification factor A and the time constant τ

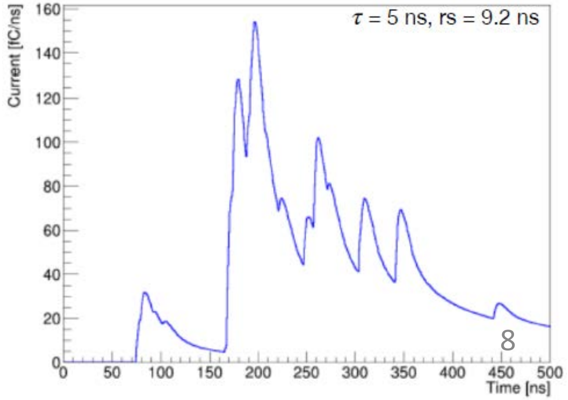
- Noise ratio definition: $\sigma_{Noise}/A_{signal}$
  - A_{signal}: Averaged single-pulse amplitude
  - σ_{Noise}: Noise RMS





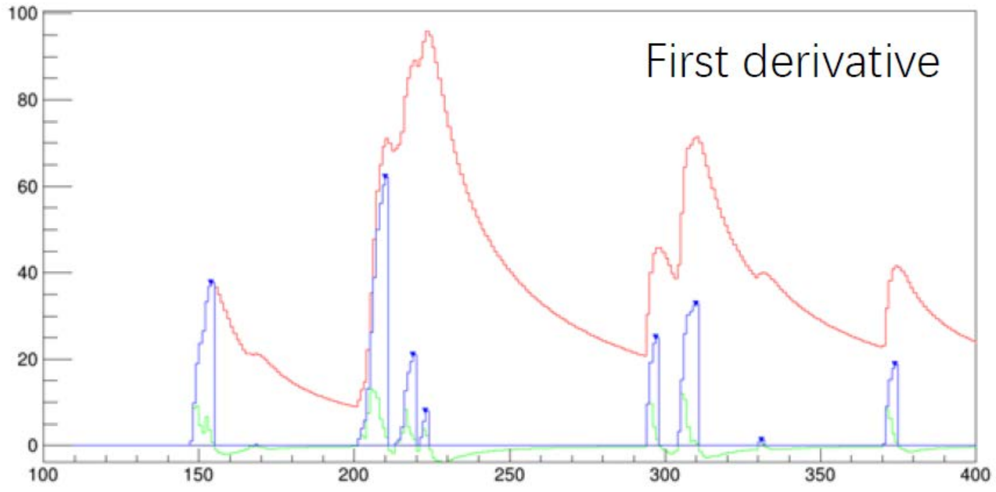


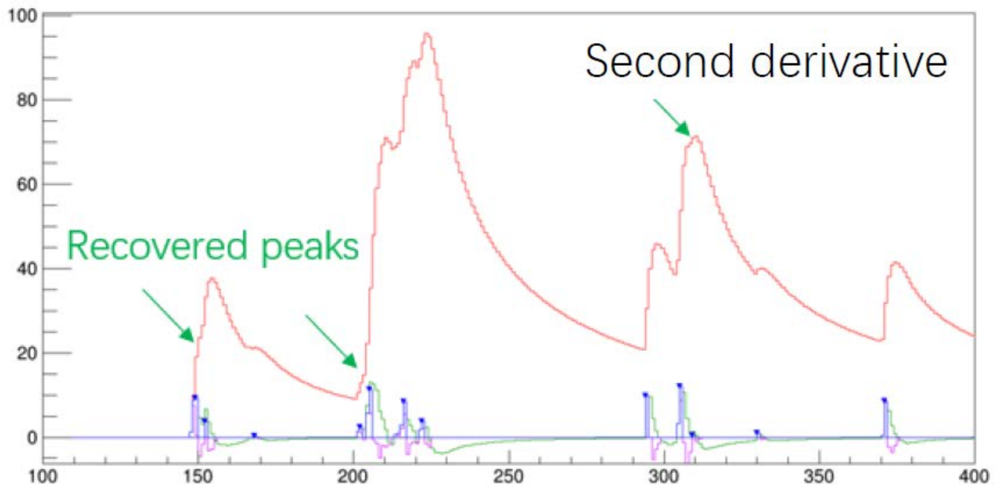




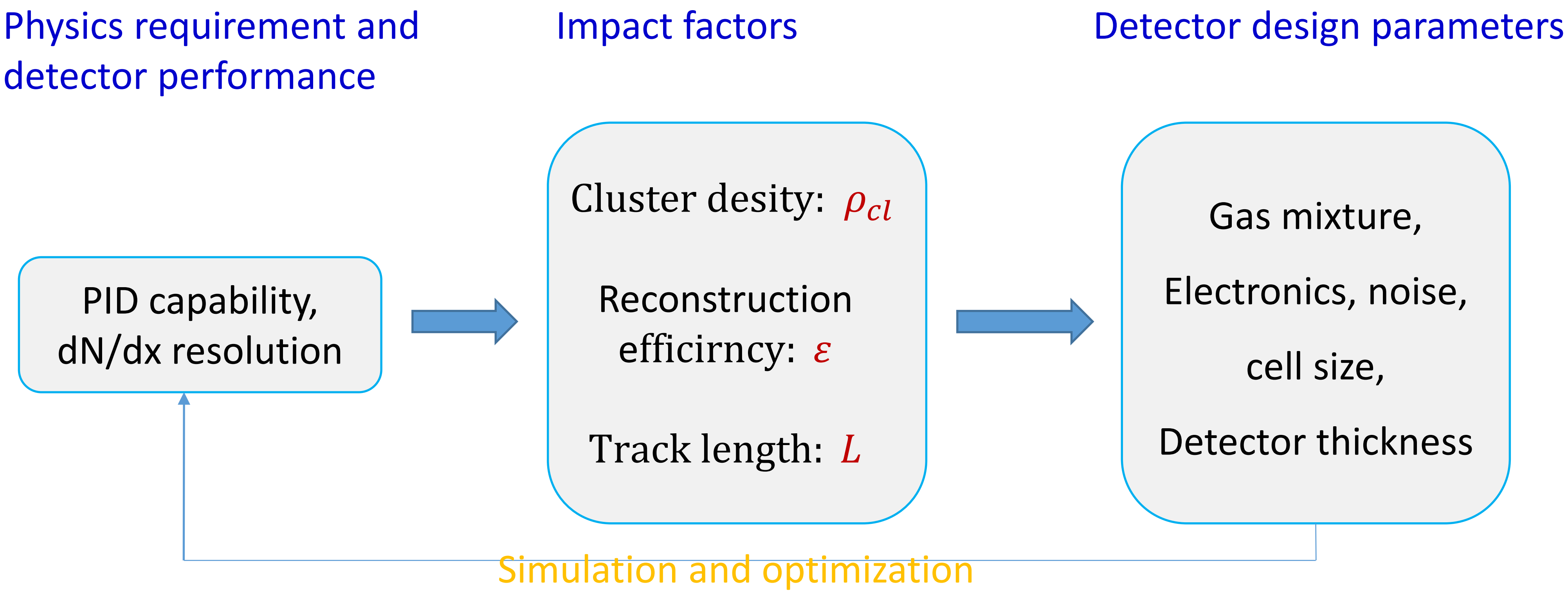
Reconstruction

- 1^{st} and 2^{nd} order derivatives
  - Fast and efficient peak finding algorithms
  - Not sensitive to baseline
  - Can be easy to implement in hardware
- More efficient reconstruction algorithm: machine learning





Detector simulation and optimization

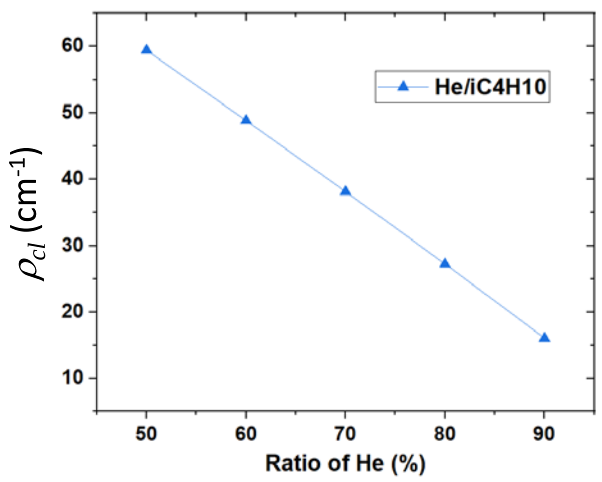


- Parameters in simulation:
  - Track direction: θ=90°
  - Impact parameter of track w.r.t. sense wire: 0.2 cm

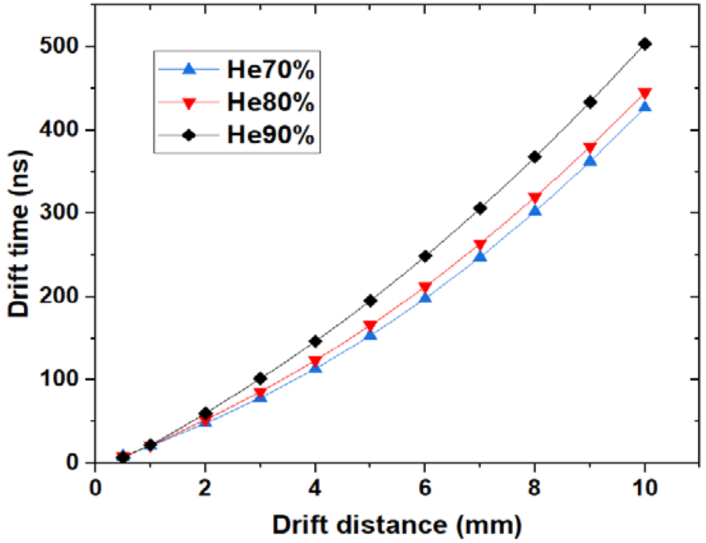
Gas mixture

- High cluster density ρ_{cl} compatibly with cluster counting efficiency ε
- Low drift velocity helps to identify clusters in time
- Small longitudinal diffusion benefits both dN/dx measurement and spatial resolution
- Prefer smaller cluster density, slower drift velocity, smaller longitudinal diffusion. He/iC_4H_{10} =90/10 is good

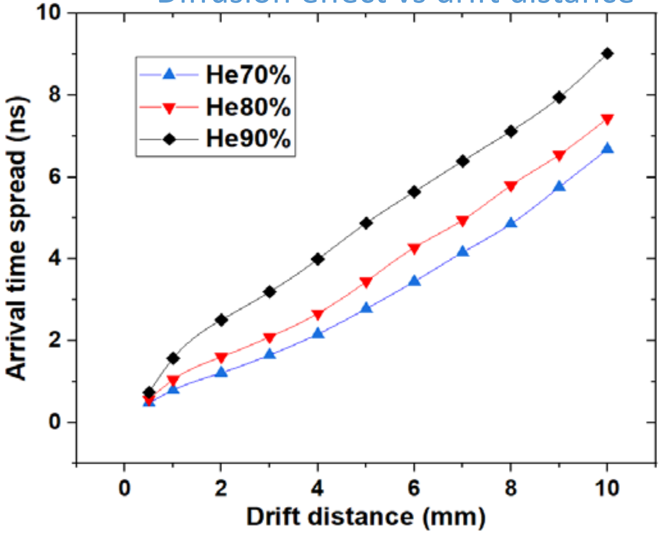
Cluster density vs ratio of He



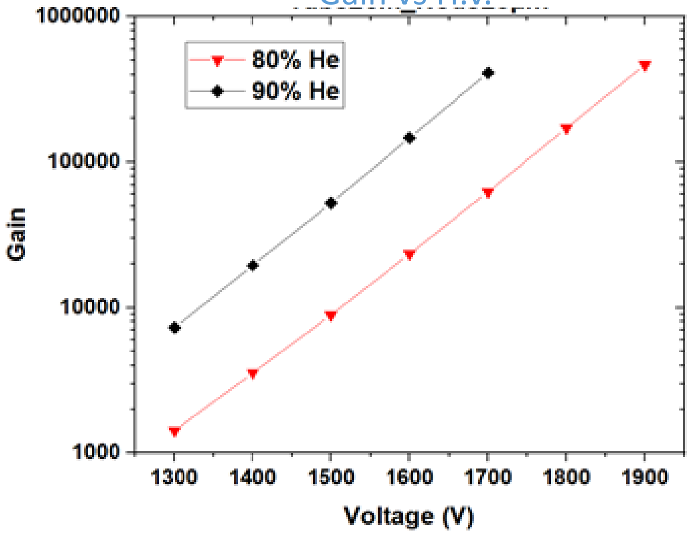
Drift time vs drift distance



Diffusion effect vs drift distance

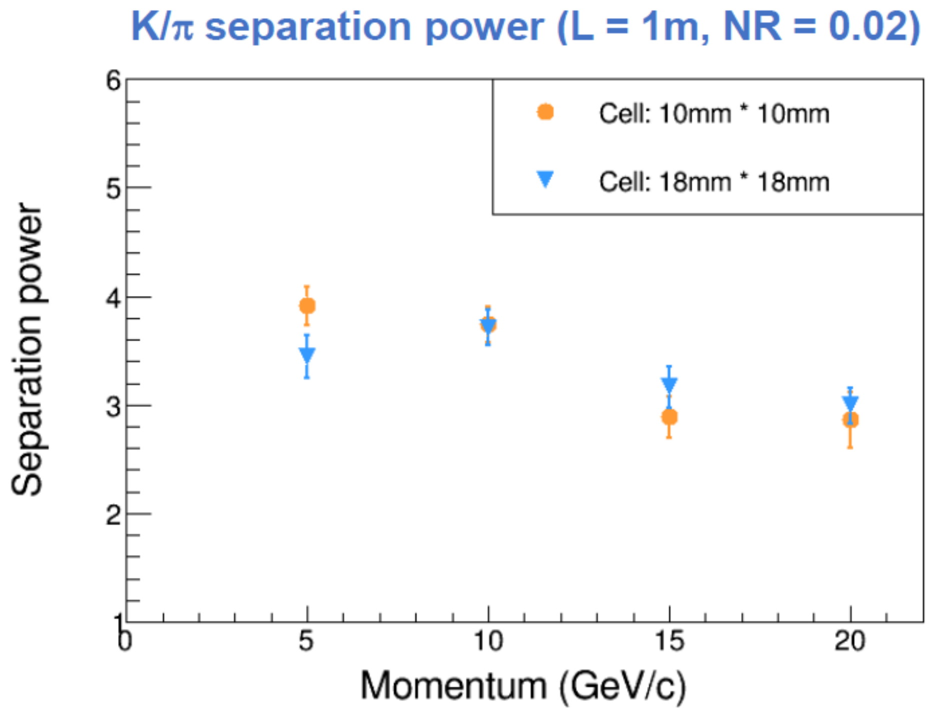


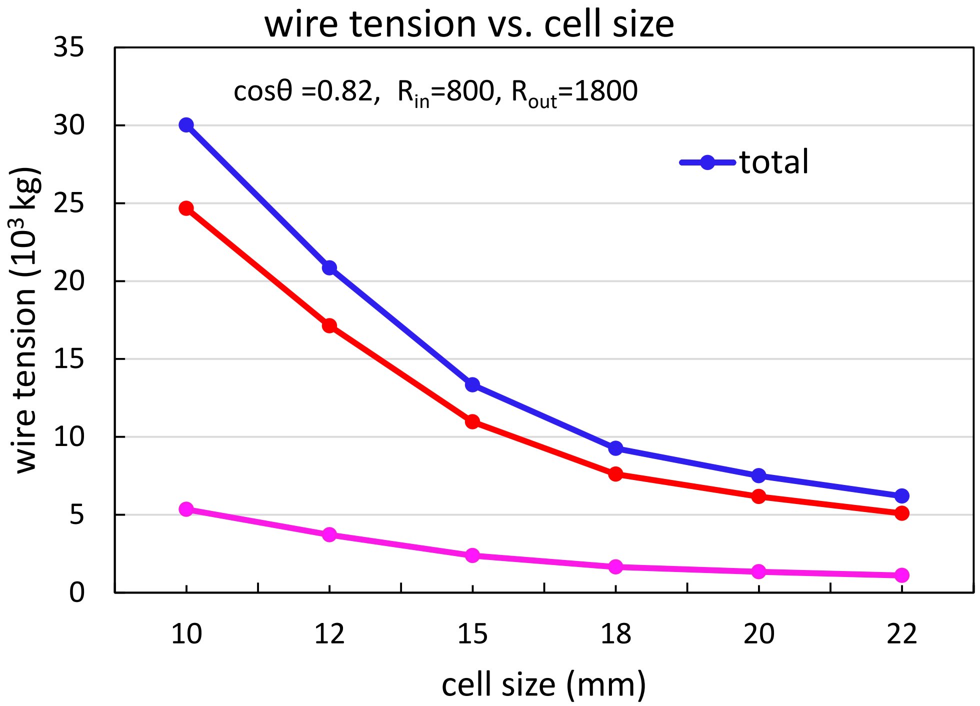
Gain vs H.V.



Cell size

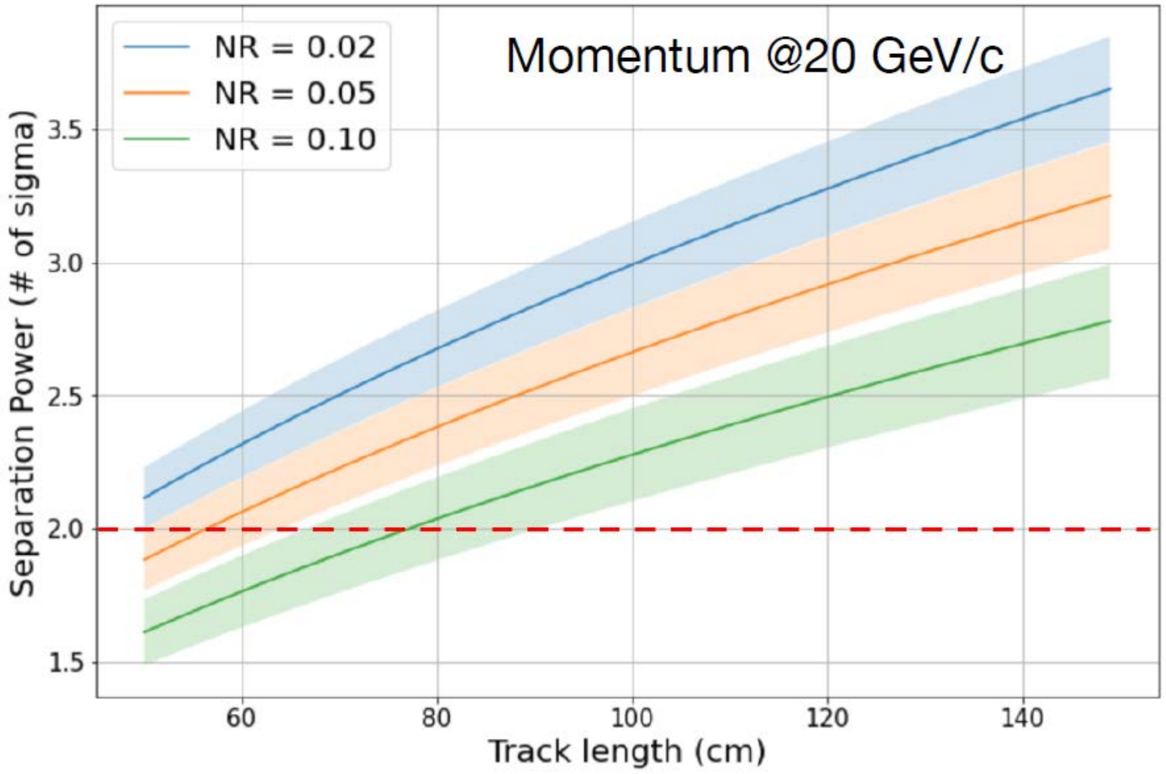
- Only total track length affects the PID with cluster counting technique, not the granularity
- The cell size impacts on engineering
- Prefer less wire tension, reduced number of wires => larger cell



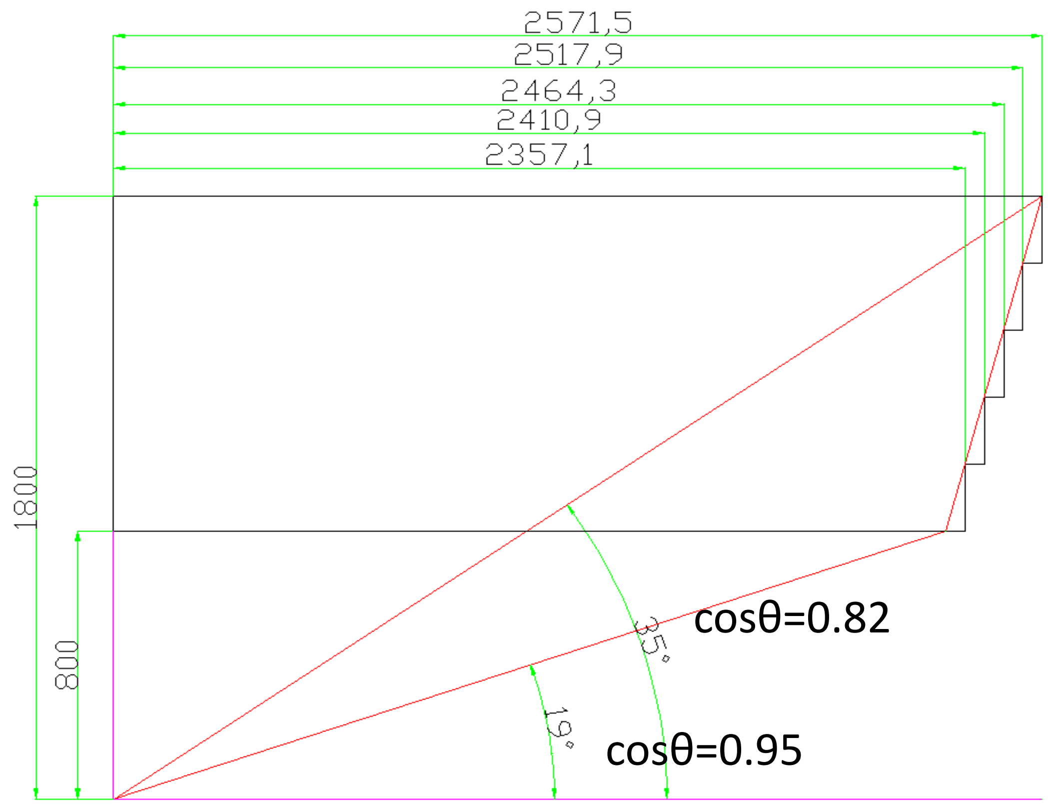


K/π separation vs. track length

- Small radial thickness (while keeping sufficient PID performance) will make the CEPC detector more compact and reduce the cost of other detectors (e.g., SiTrk, Calorimeters)
- Better than 2σ separation at 20 GeV/c is achieved within 1m track length



Preliminary parameters

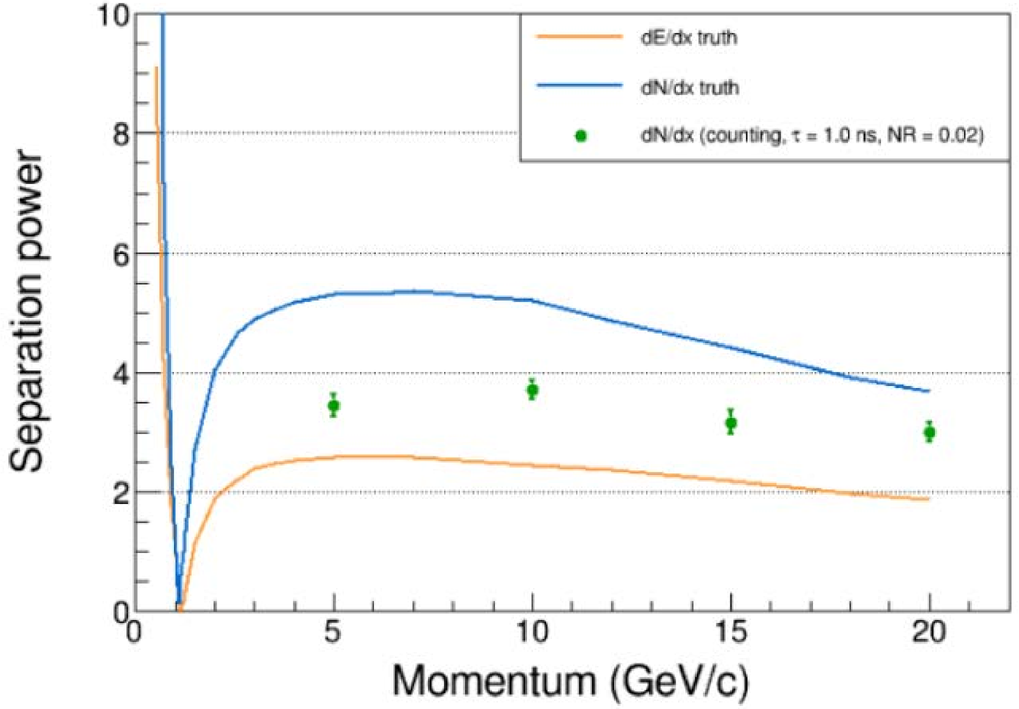


Radius extension	800-1800mm
Length of outermost wires（cosθ=0.82）	5143mm
Thickness of inner CF cylinder：	200μm
Outer CF frame structure：	Equivalent CF thickness: 1.63mm
Thickness of end Al plate	35mm
Cell size:	~ 18 mm × 18 mm
Number of cell	24766
Ratio of field wires to sense wires	3:1
Gas mixture	He/iC_4H_{10}=90:10

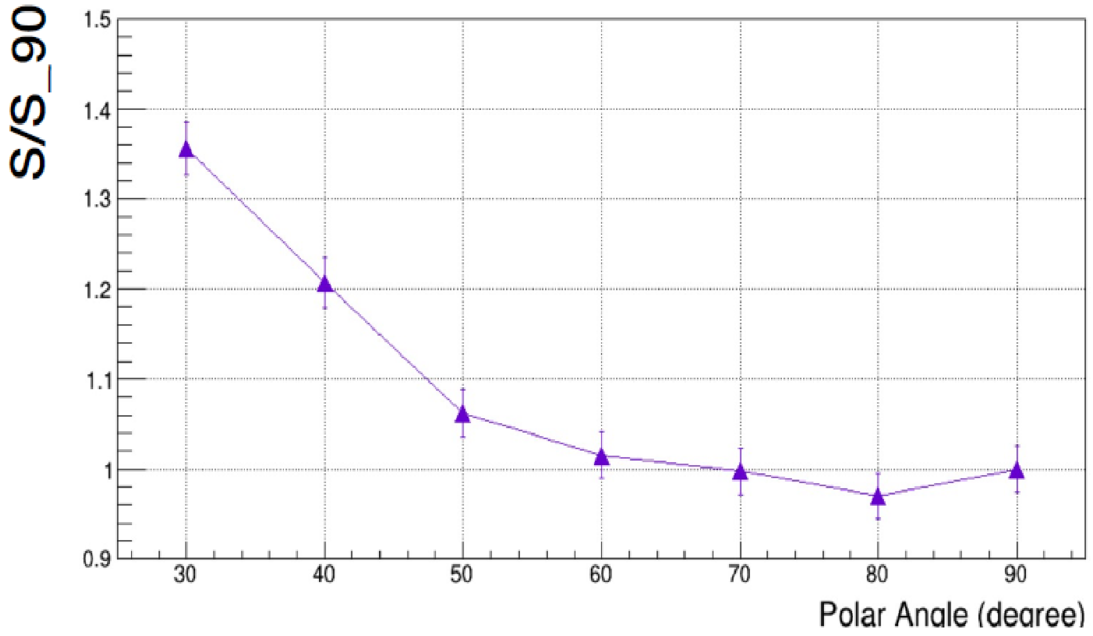
K/ π Separation power

- 3σ K/π separation at 20GeV/c, 1.5 better than dE/dx truth (θ=90˚ , NR = 0.02)
- Polar angle scan: long track length allows better separation power
- Studies with physics channels are ongoing

K/π separation vs momentum (θ=90˚)

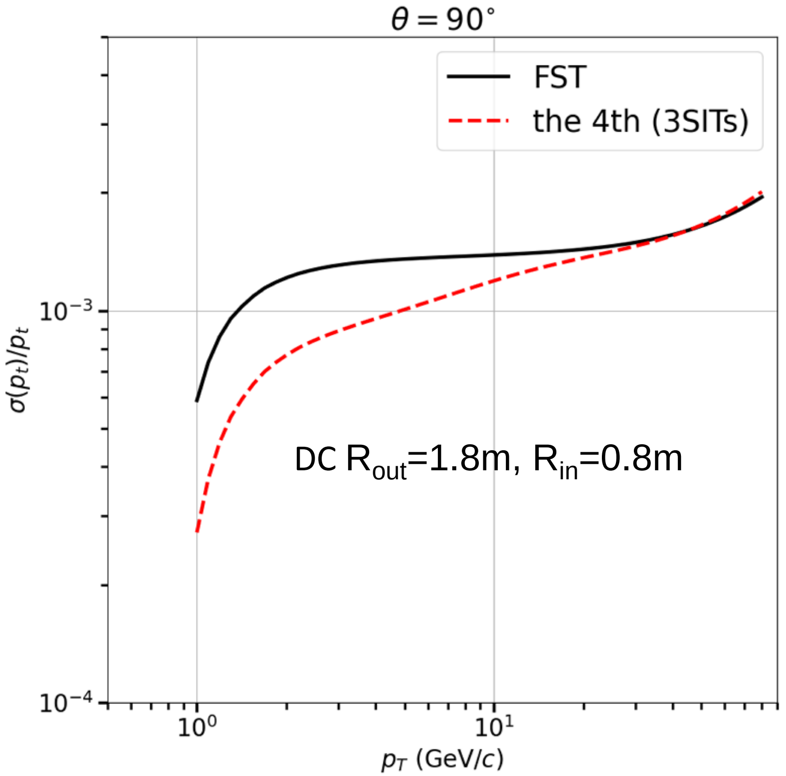


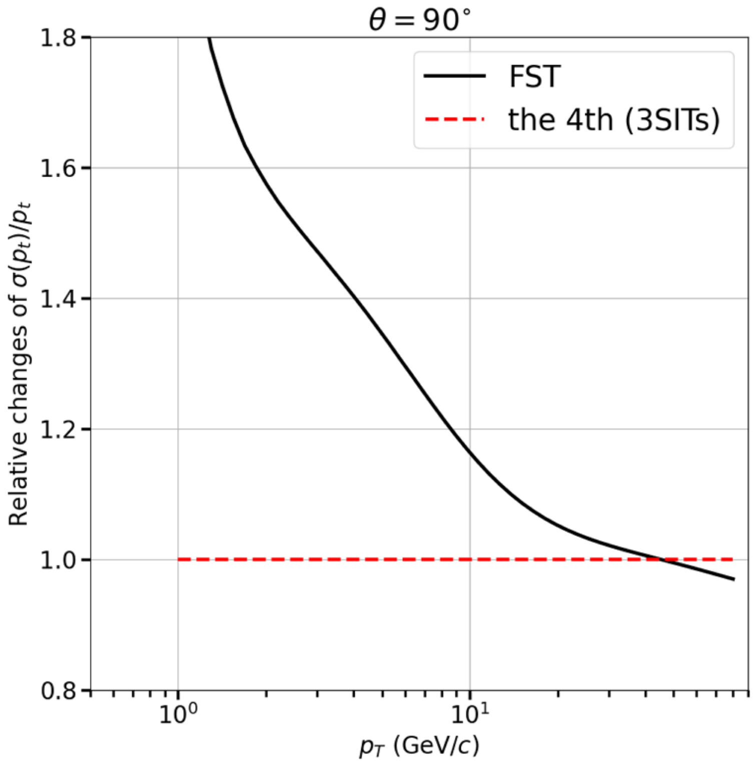
Relative Separation Power (n) vs. Polar Angle



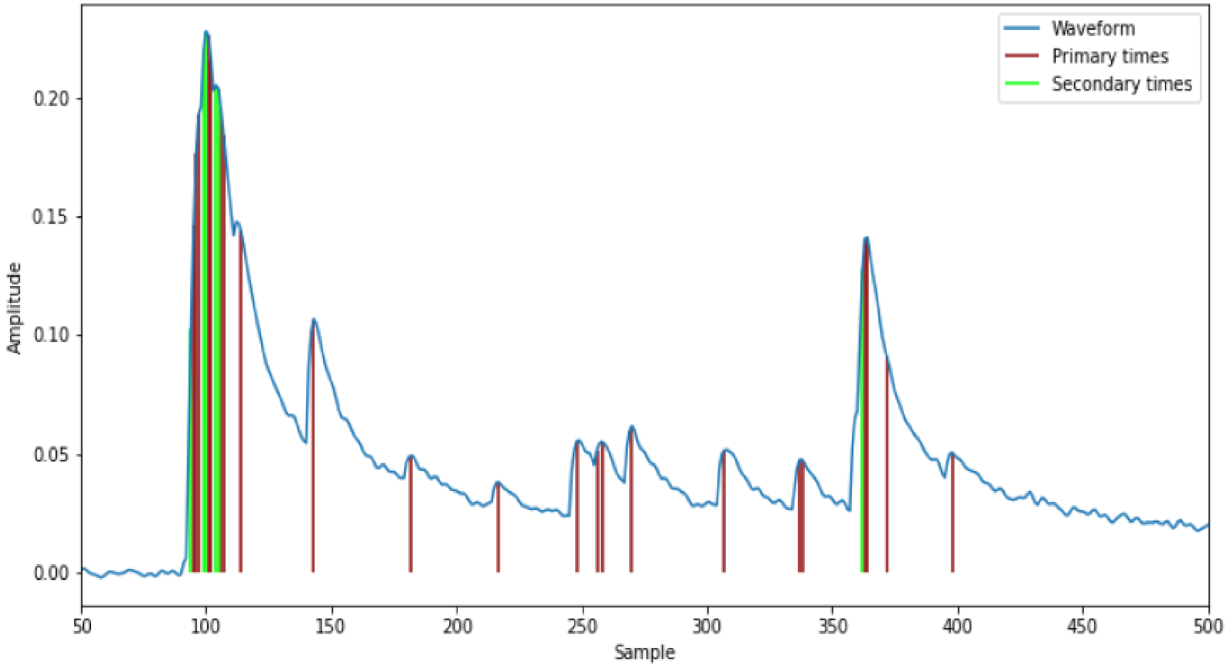
Impact on momentum measurement

- Compared with full silicon tracker (FST), P_T resolution of the hybrid tracker system with drift chamber
  - Improved significantly in momentum range of 0-20 GeV/c
  - Almost no degradation with momentum up to 80 GeV/c





Reconstruction algorithm: machine learning

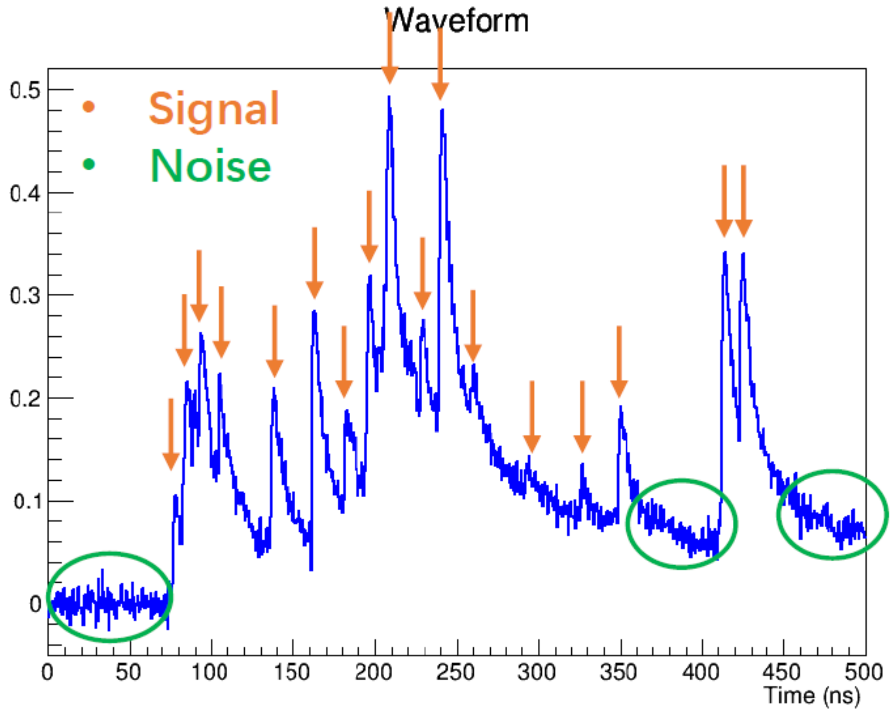


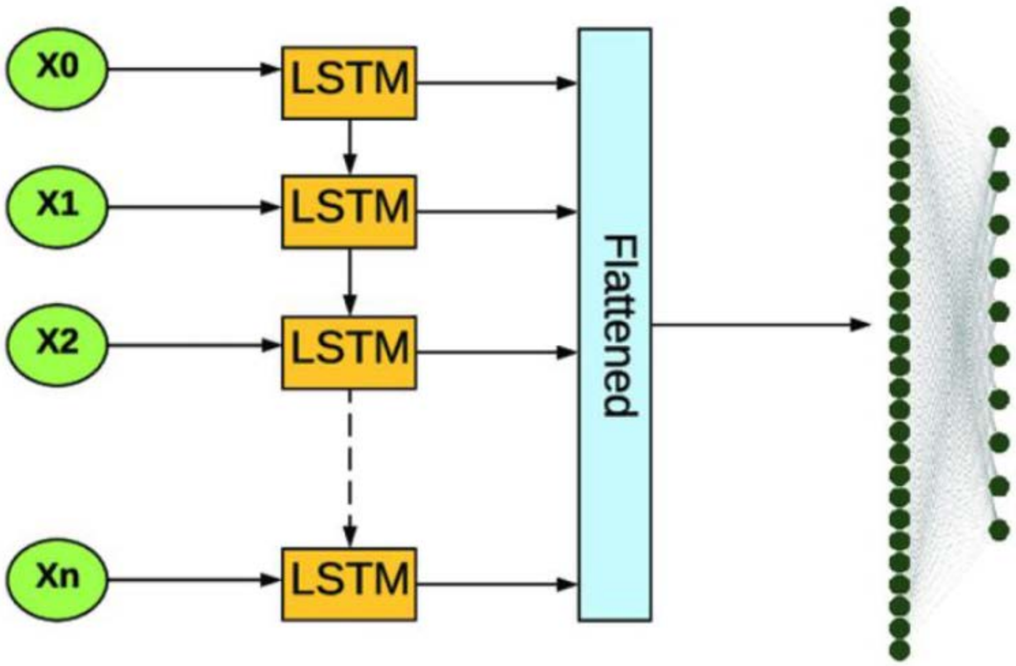
- Both primary electrons and secondary electrons contribute peaks on the waveform
- Find the number of peaks from primary electrons

- Machine learning can make full use of the waveform information,
- More effective in high pile-up region and less sensitive to noise

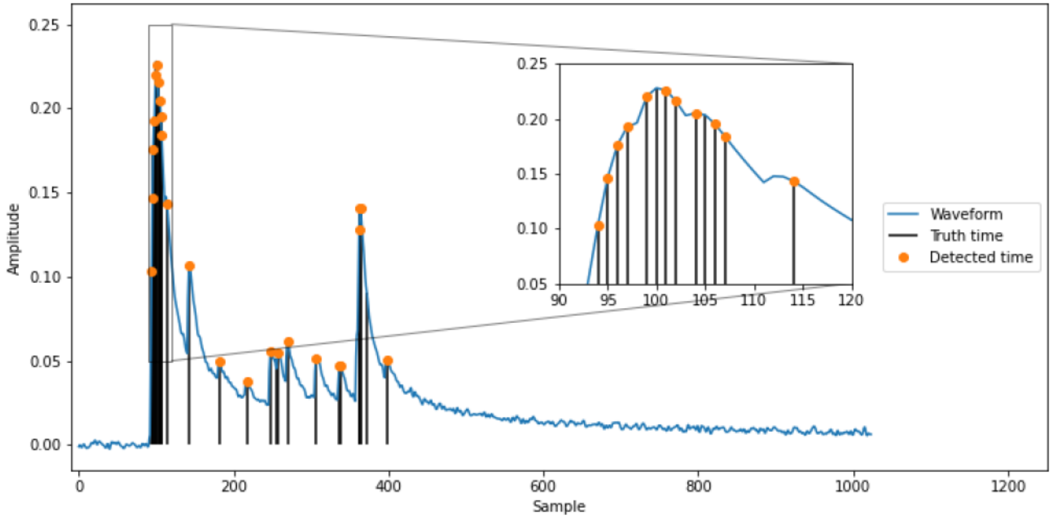
Step 1: Peak finding

- To detect all peaks from the waveform
- Classification for "signals" and "noises"
- Architecture: Recurrent Neural Network (RNN)



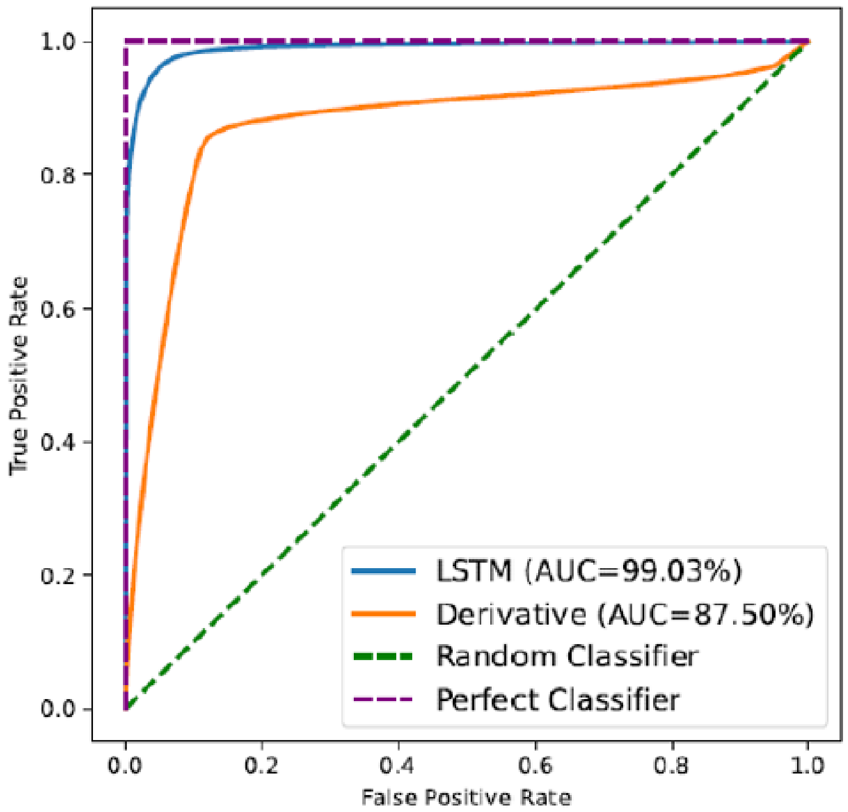


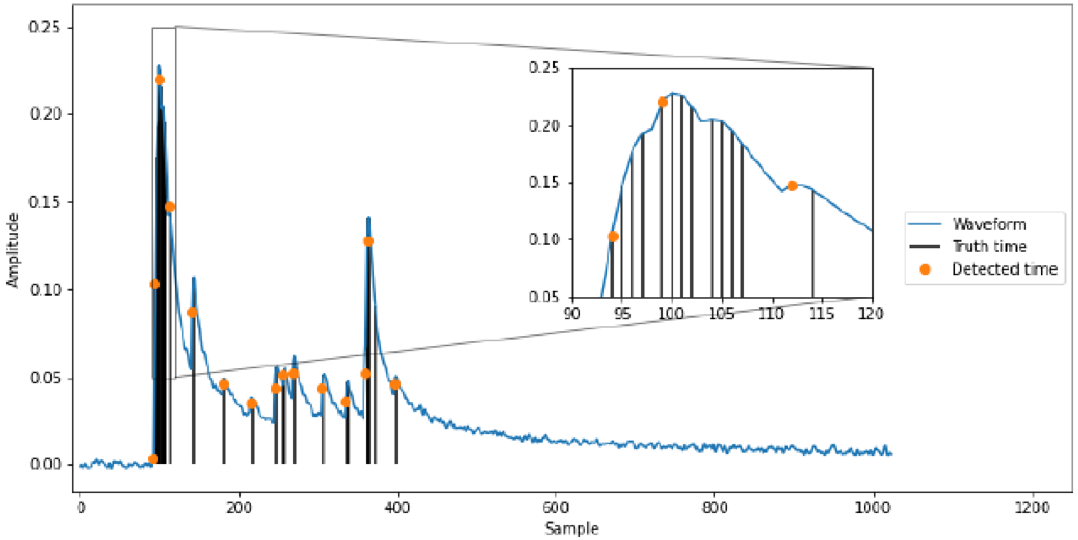
Compare to the derivative algorithm



Neural Network

ROC



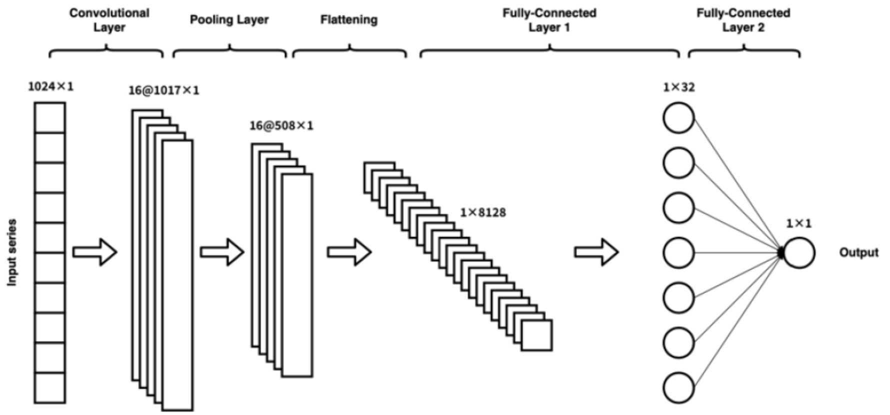


Derivative

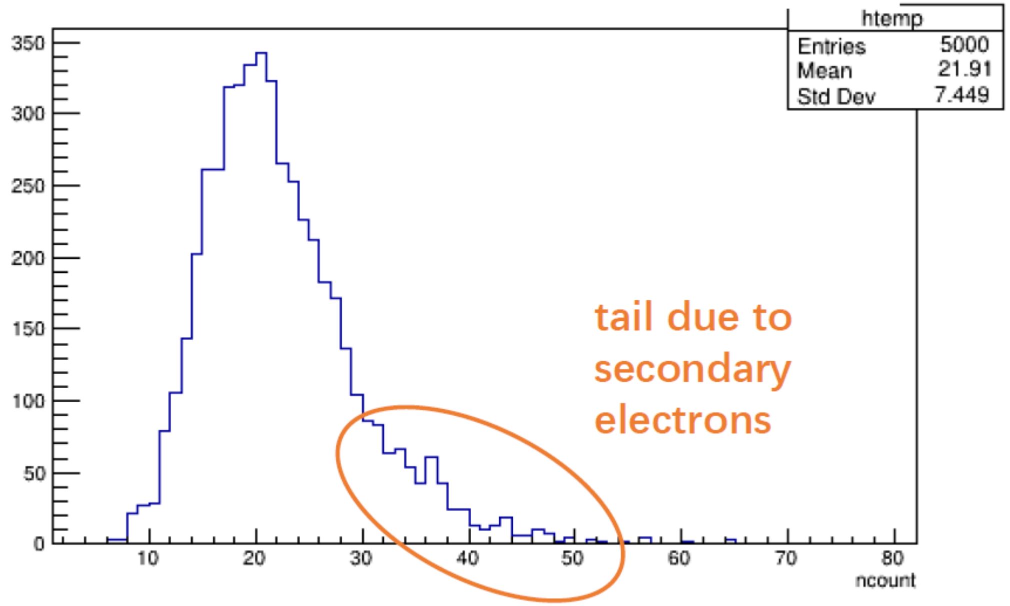
The NN can find the peaks more effective!

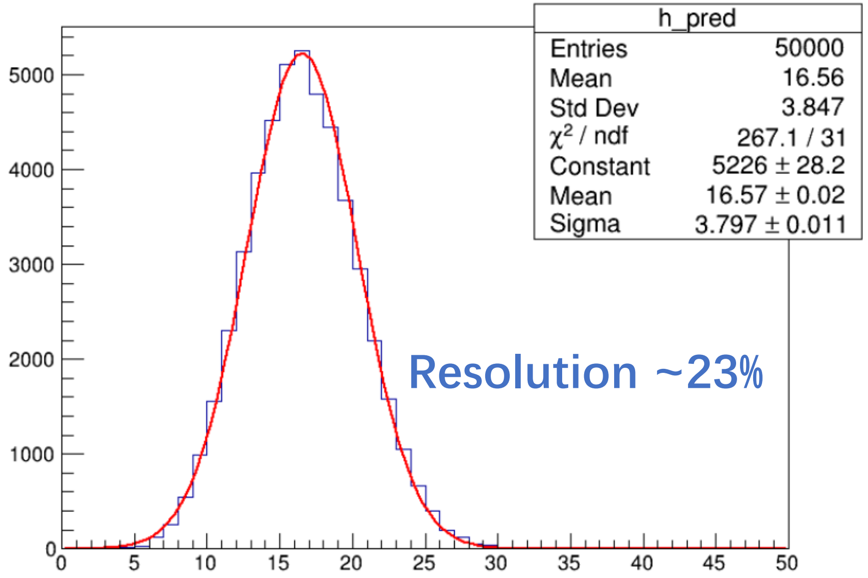
Step 2: Discrimination of the primaries

- To discriminate primary peaks from the secondary ones
- Regression problem
- Architecture: 1D Convolutional Neural Network (CNN)



Detected peaks from the peak finding



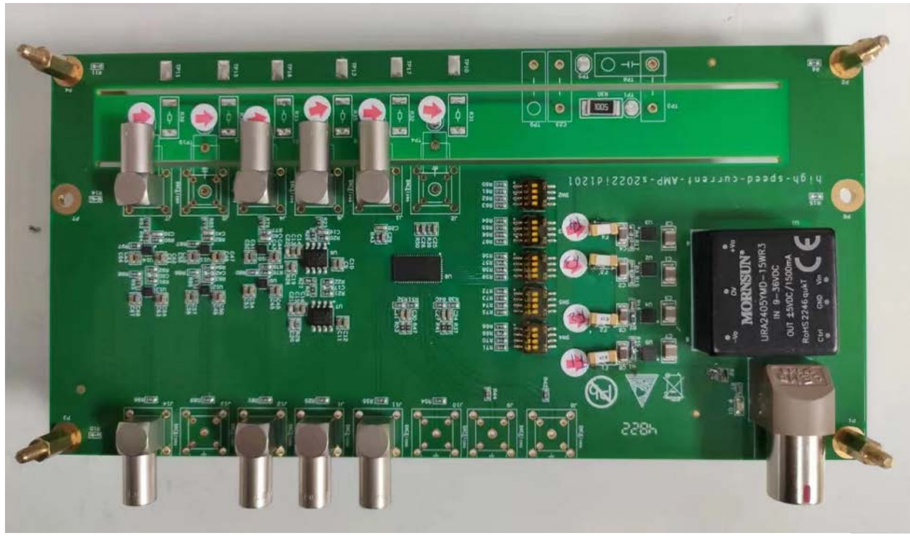


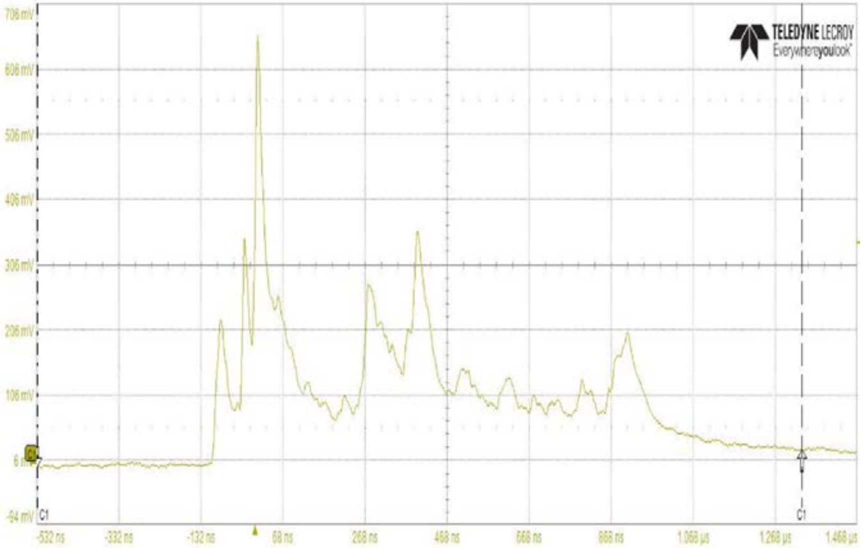
Very good Gaussian-like distribution

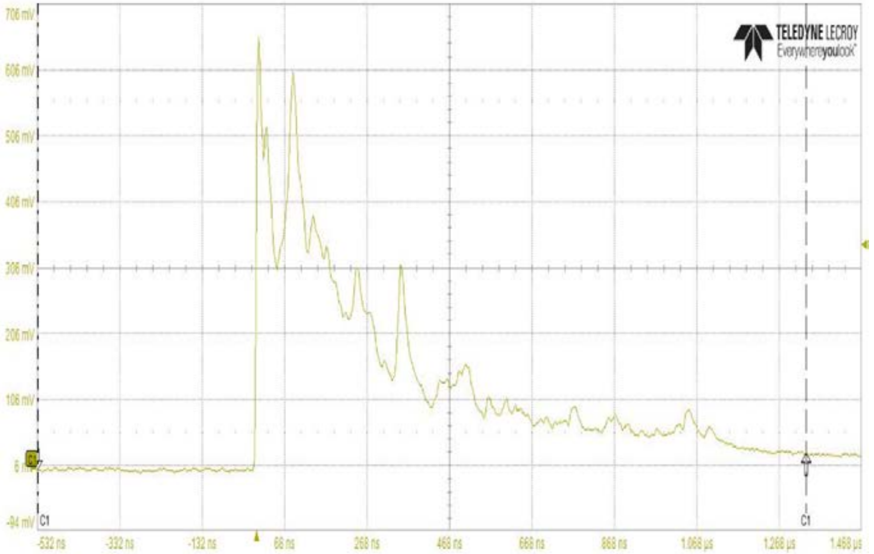
✓The resolution is very close to the truth value (~21%), which implies possible improvement on PID

Electronics development

- High bandwidth current sensitive preamplifiers based on LMH6522 and AD8099 were designed
- Test with a detector prototype







Collaboration with INFN group

- Joined prototype beam test organized by INFN group
  - First round: Nov. 2021 (Shuiting joined)
  - Second round: July 2022 (Shuaiyi joined)
  - Data analysis
- Regular meeting between INFN and IHEP
- Collaboration on MOST-MAECI project application, focusing on
  - Beam tests for the application of the cluster counting/timing techniques
  - Simulation and reconstruction
  - Design and deployment of real-time ML algorithms on FPGAs

Summary and outlook

- Drift Chamber is proposed in CEPC 4^{th} conceptual detector for particle identification
- Simulation studies show that 3σ K/π separation at 20GeV/c can be achieved with 1m track length and 2% noise level
- Cluster counting algorithm based on machine learning is developed and shows promising performance for MC samples
- Plans:
  - Optimize the reconstruction algorithm and apply to beam test data
  - Extract dN/dx parameters from full simulation and perform physics studies
  - Detector and readout electronics prototyping and test