Particle identification with a drift chamber for CEPC

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on behalf of the DC-PID working group for the CEPC 4^{th} conceptual detector

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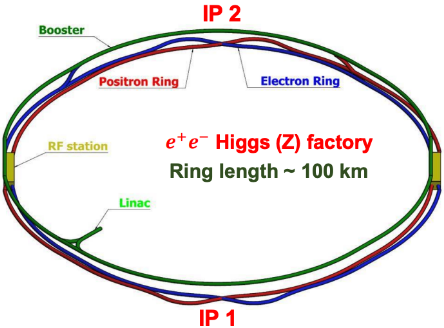
Circular Electron Positron Collider (CEPC)

The CEPC has been proposed as a Higgs (W,Z) factory, operating in several set of conditions.

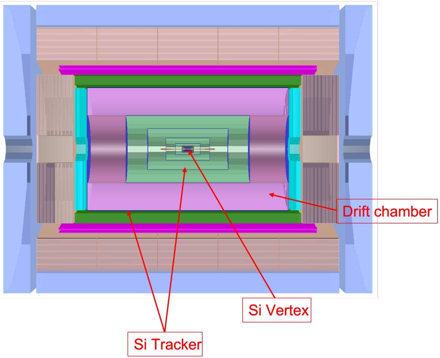
- Above ZH threshold ($\sqrt{s} = 240$ GeV) with 1M Higgs.
- Around the Z-pole for Tera Z.
- W^+W^- threshold scan.



Possible Super pp Collider (SppC) of $\sqrt{s} = 50 \sim 100$ TeV in the future.

Physics goal: Higgs, EW, flavor physics & QCD, BSM physics (eg. dark matter, EW phase transition, SUSY, LLP, ...)

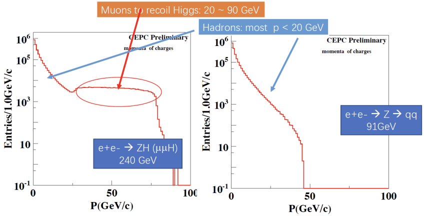
The 4^{th} conceptual detector



A drift chamber inserted into Si Tracker is optimized for PID.

Advantage Work at high luminosity Z runs.

Challenge Sufficient PID power within specific volume.

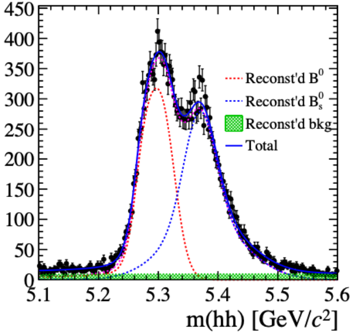


Requires a good PID for charged hadrons up to 20 GeV.

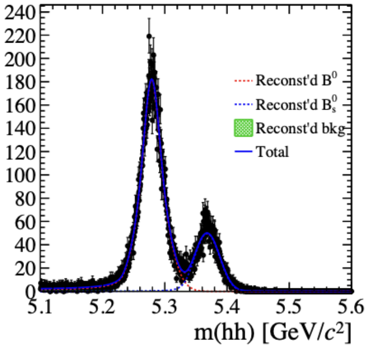
Physics impact of the PID

Hadron identification are essential for many flavour physics studies.

- Disentangle the various $B^0_S(B^0) \to h^- h^+$ in same topology final-states.

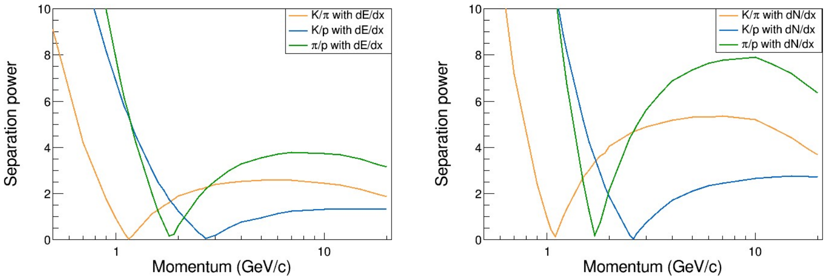


Assuming 50% PID efficiency



Assuming 100% PID efficiency

[Shanzhen Chen, Physics impact of the PID]



Energy loss (dE/dx):

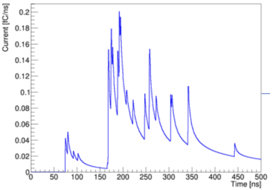
- Fluctuations of N_p and transferred energy result in Landau distribution.
- Lost information due to mean truncation.

Cluster counting (dN/dx): Measure number of clusters per length.

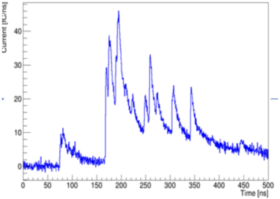
- Clean in statistics: $P(N_p, k) = \frac{N_p^k}{k!} e^{-N_p}$
- Theoretical resolution: $\frac{1}{\sqrt{N_p}} = \frac{1}{\sqrt{\rho_{cl} \times L}}$ potentially a factor of 2 better.

[Nucl.Instr. and Meth.A 386(1997)458.]

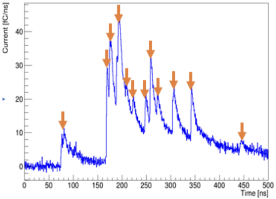
Waveform-based analysis workflow



Simulation



Digitization



Reconstruction

- Signal generation with Garfield ++
- Heed: ionization process
- Magboltz: gas properties

- Pre-amplifier
- Noises
- ADC

Essential part

- Peak finding algorithm.

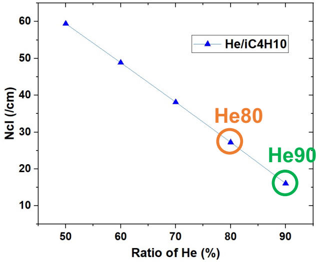
Simulation

The Monto Carlo sample of induced current takes electron transport, gas multiplication, electron avalanche etc. into account.

Simulated a single charged track going though cells.

Gas mixture decision: $He + iC_4H_{10}$ as small cluster density and large time separation.

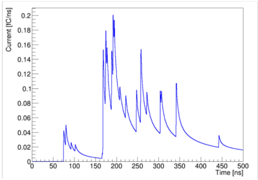
Parameters setup	
Track direction	$\cos\theta = 0$
Cell size	18 x 18 mm
Field wires / sense wires	3:1
Gas mixture	He$/iC_4H_{10} = 90/10$
Gas gain	10^5



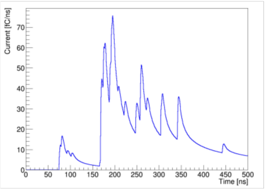
Digitization

A simple current-sensitive pre-amplifier is assumed.

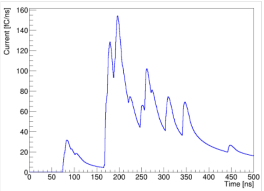
- A transform function is convoluted to signal.



$\tau = 0$ ns, rs $= 0.95$ ns



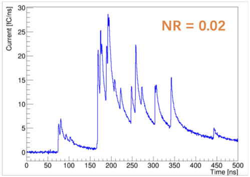
$\tau = 2$ ns, rs $= 3.70$ ns

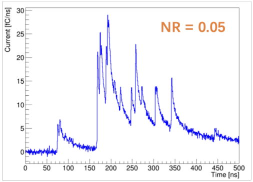


$\tau = 5$ ns, rs $= 9.20$ ns

Noise generation

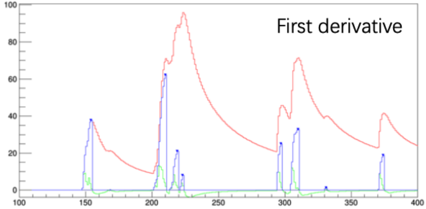
- Noise Ratio $= \frac{\sigma_{Noise}}{A_{signal}}$

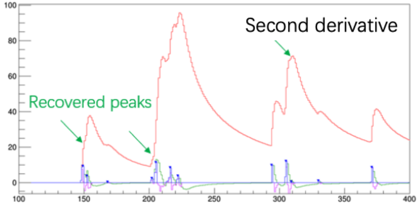




Looking for fast and efficient peak finding algorithms.

1. Smoothing: filter out frequency noises in the waveform in order to improve the S/N ratio.
2. Derivative: The start of a peak will be determined by a change in the derivative.
    - not sensitive to baseline
    - Can be easy to implement in hardware.



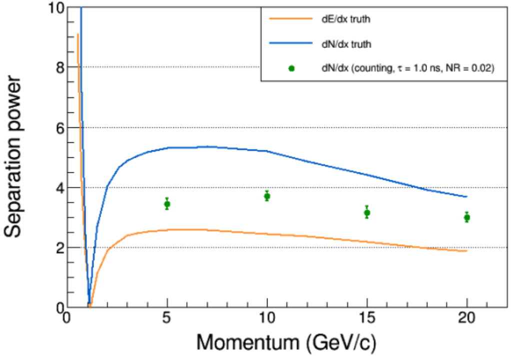


Pile-up on the failing edge is easier to recover but not for the case on the rising edge.

The figure of merit of parameters optimization is the K/π separation power

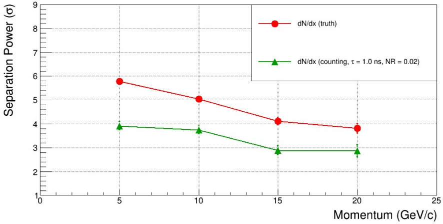
$$n = \frac{|(dN/dx)_\pi - (dN/dx)_K|}{(\sigma_\pi + \sigma_K)/2}$$

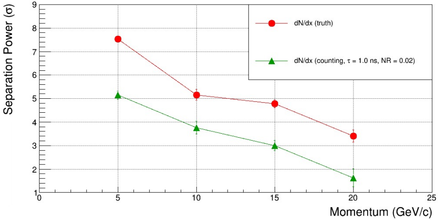
K/π (L = 1m)



PID performance

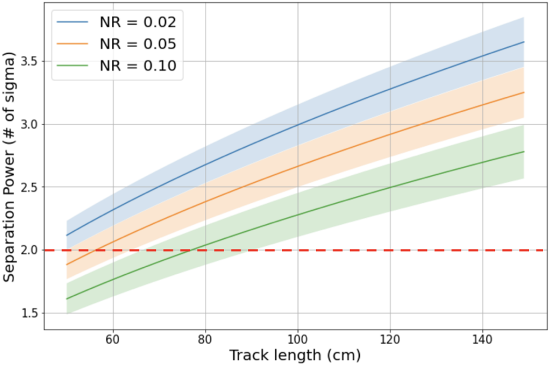
Results from different gas mixtures.





$He90\% + iC_4H_{10}$ / $He80\% + iC_4H_{20}$, L=1m, 1x1cm cell

- $He90\% + iC_4H_{10}$ has better K/π separation for high momentum.
- $He80\% + iC_4H_{10}$ has better K/π separation for low momentum.
- PID in low momentum region can be covered by timing detector $\rightarrow$ He 90% is favored.



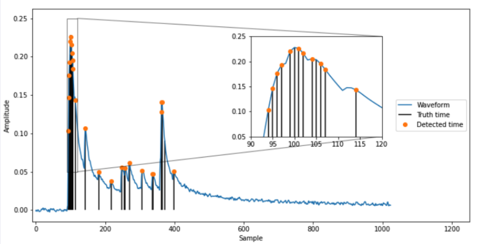
The resolution scales with $1/\sqrt{L}$

- A $2\sigma K/\pi$ separation at 20 GeV/c can be achieved with 1 m track length.
- The requirement of separation power needs further studies with physics channels.

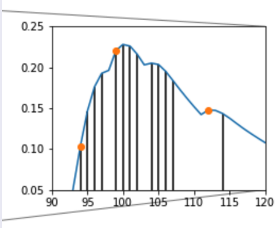
Summary and Outlook

- Studied cluster counting with CEPC drift chamber. 2 $\sigma K/\pi$ separation up to 20 GeV/c @ 1m length.

- Study the PID requirement from physics channels.
  - Physics input to constrain the detector parameters
  - Delphes fast simulation is ongoing.
- More effective peak finding algorithm.
  - An algorithm using deep learning is being developed. Preliminary study shows promising results

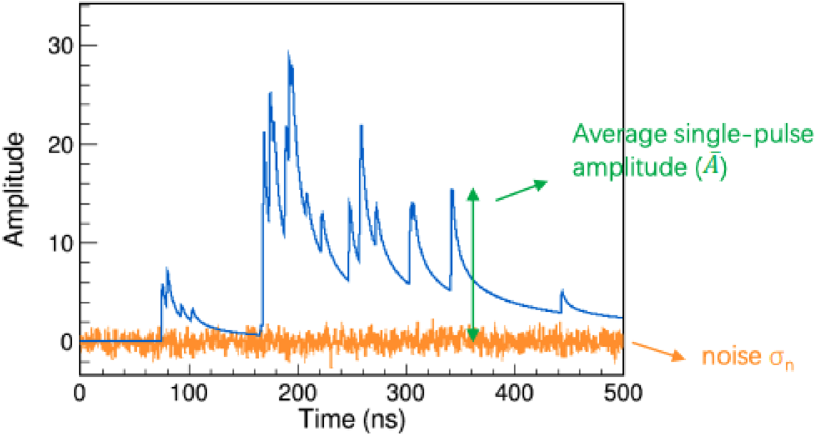


RNN



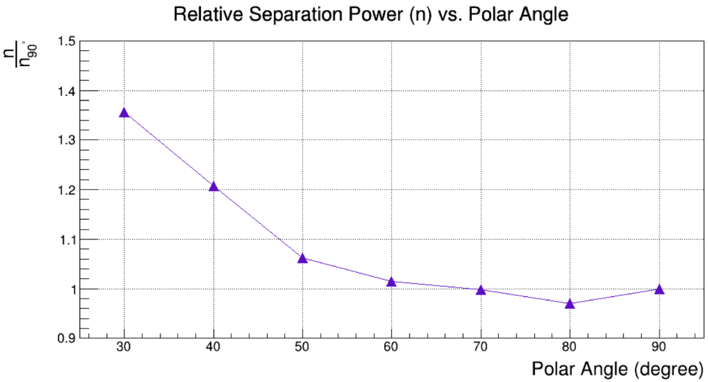
Derivative

Noise Ratio



Note: noise ratio in beam-test data is close to 10%.

K/π separation vs polar angles



No space charge in simulation