PID Study for CEPC Drift Chamber

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For the DC-PID group of the CEPC 4th conceptual detector

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The CEPC Workshop on Flavor Physics, New Physics and Detector Technologies

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Outline

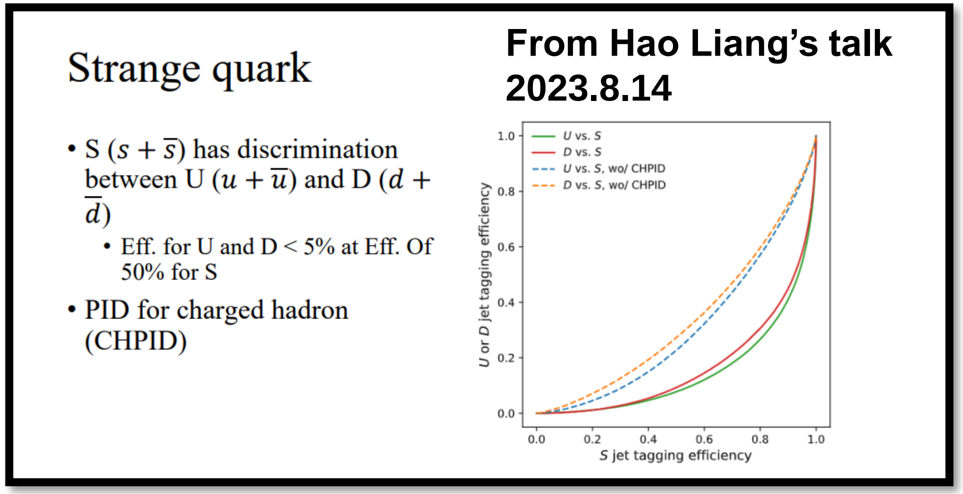
- Introduction
- Waveform-based full simulation
- Fast simulation with Delphes
- Activities on prototype test
- Summary

CEPC

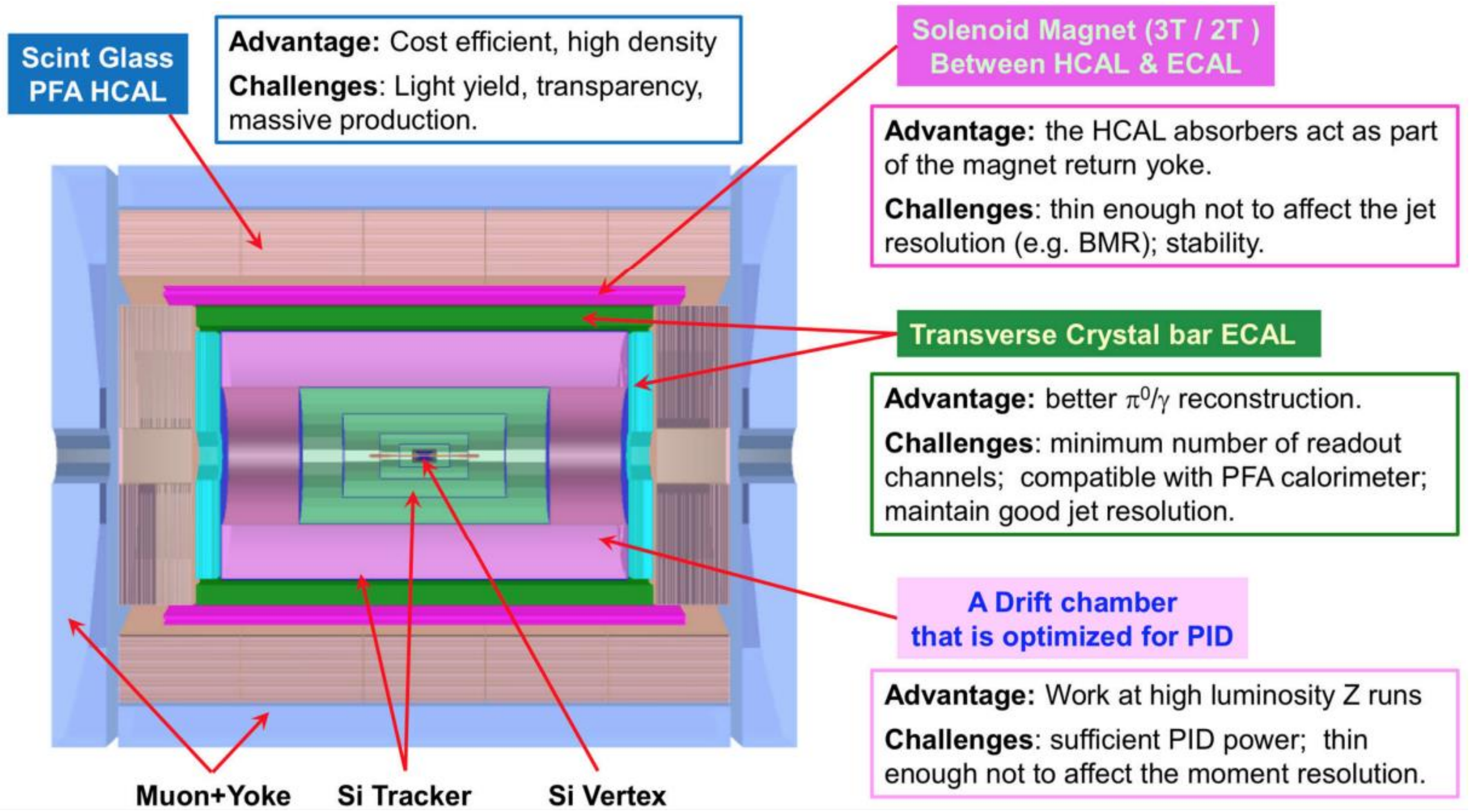
- CEPC
  - 240 GeV (Higgs factory),
  - 91.2 GeV (Z factory or Z pole)
  - 160 GeV (WW threshold scan)

4×10^{12} Z:
provide diverse flavor measurements

- Particle identification (PID) is essential for flavor physics and jet study
  - Reduce combination background
  - Improve mass resolution
  - Benefit flavor tagging



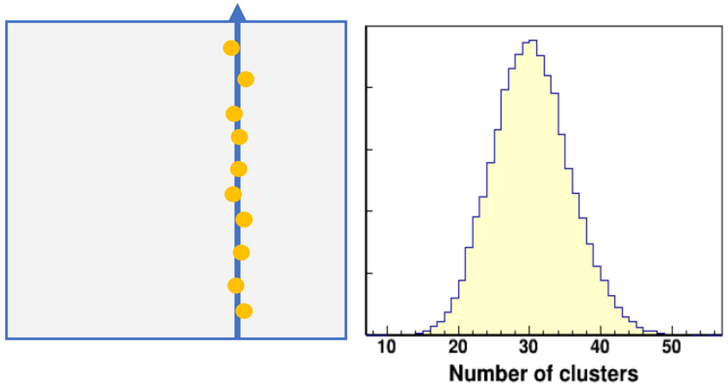
CEPC the 4th conceptual detector



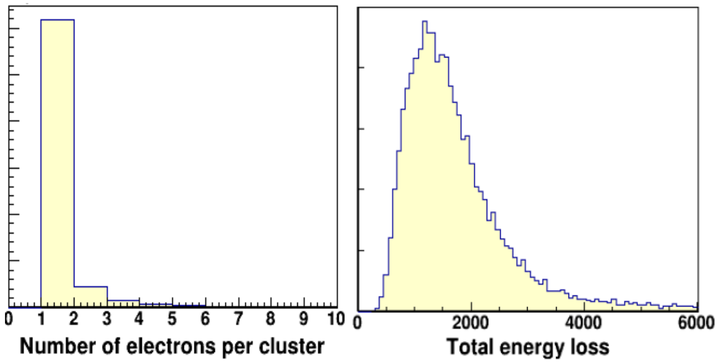
- Tracker with silicon tracker and a drift chamber
- The chamber optimized for PID with cluster counting technique
- Up to 20 GeV/c K/π separation power required

dE/dx vs dN/dx

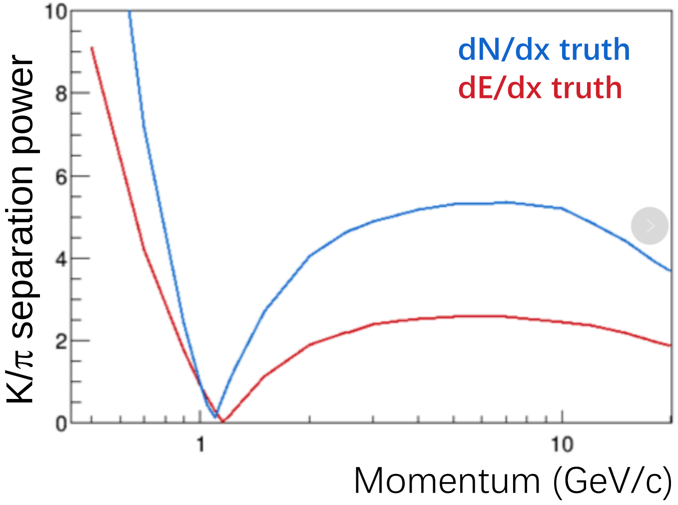
Primary ionization



Secondary ionization



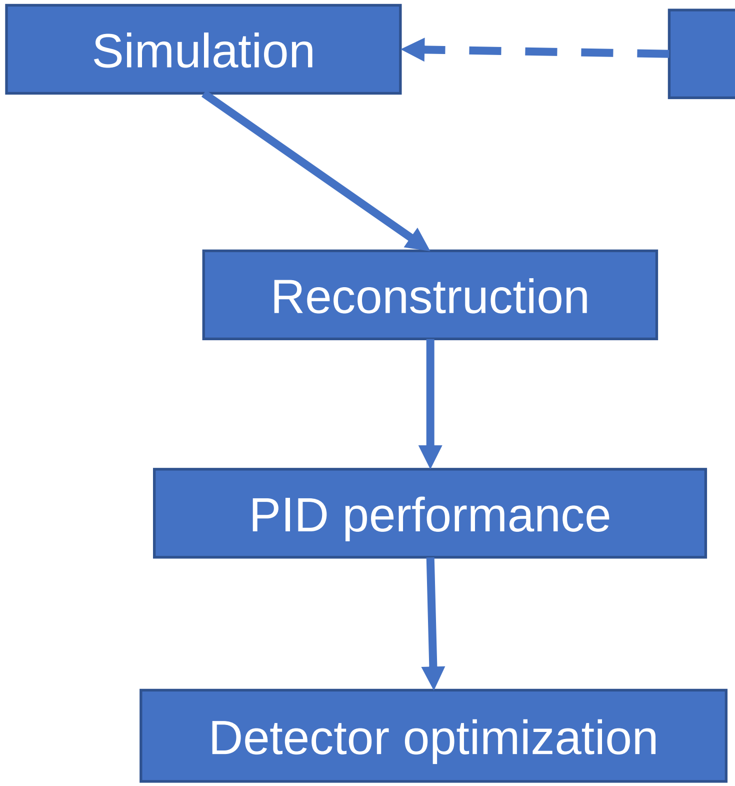
K/π separation power
dN/dx vs dE/dx

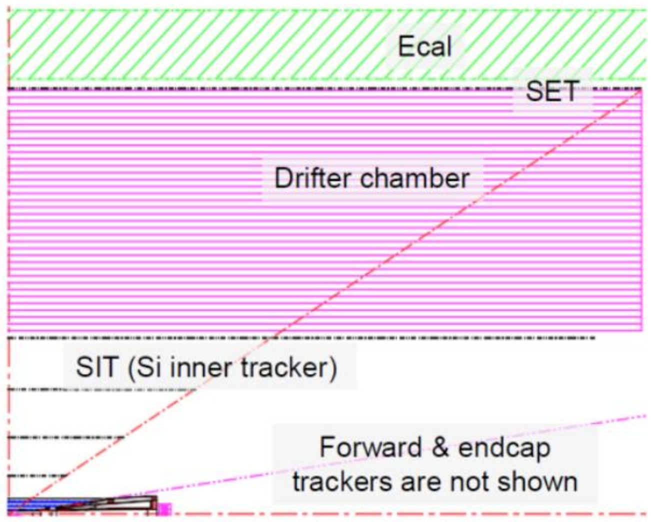


- dE/dx: Energy loss per unit length, Landau distribution, large fluctuation
- dN/dx: Number of primary ionization clusters per unit length, Poisson distribution, small fluctuation → cluster counting technique

In theory, dN/dx has a significant advantage over dE/dx.

workflow and DC preliminary design



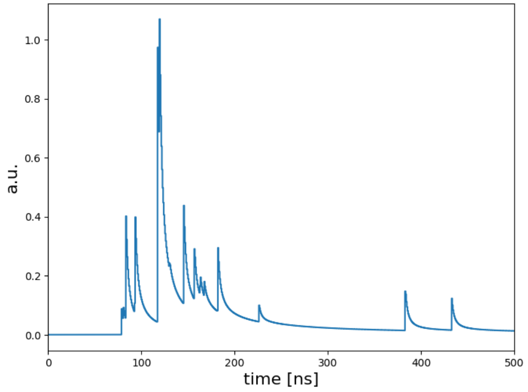


Preliminary DC parameters	
Inner radius	800 mm
Outer radius	1800 mm
Cell size	18 mm × 18 mm
Gas mixture	He/iC4H10=90:10

Waveform-based full simulation

Simulation process

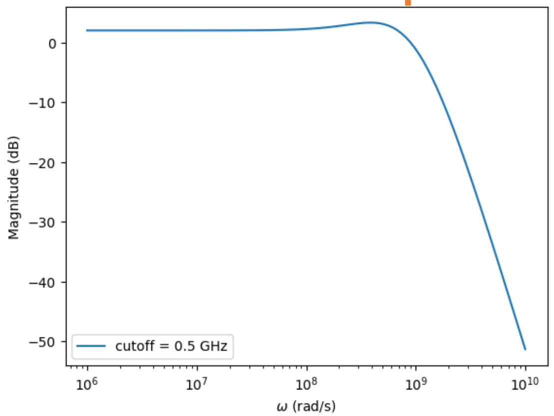
Induced signal



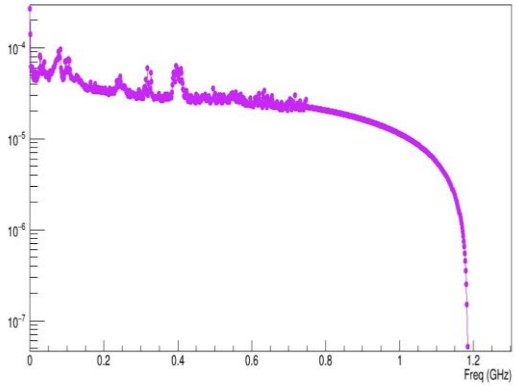
Based on Garfield++ simulation

a toolkit for simulation of detectors based on ionization measurement in gases and semiconductors.

Electronics response

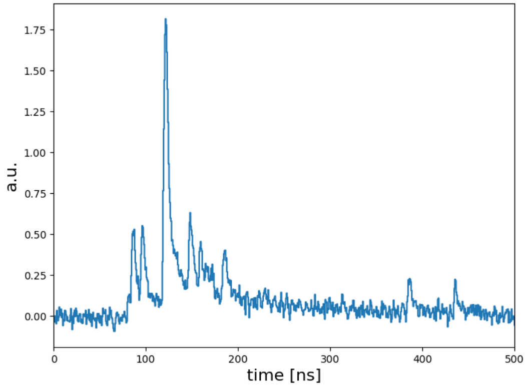


Noise

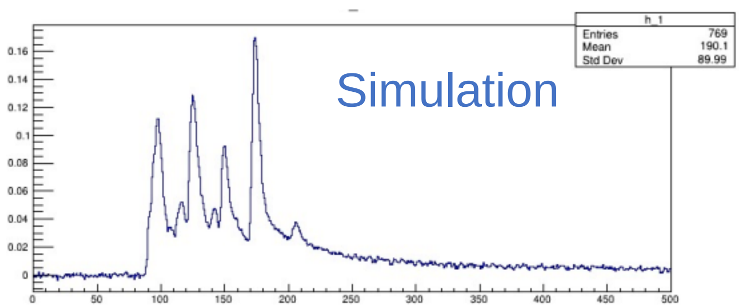


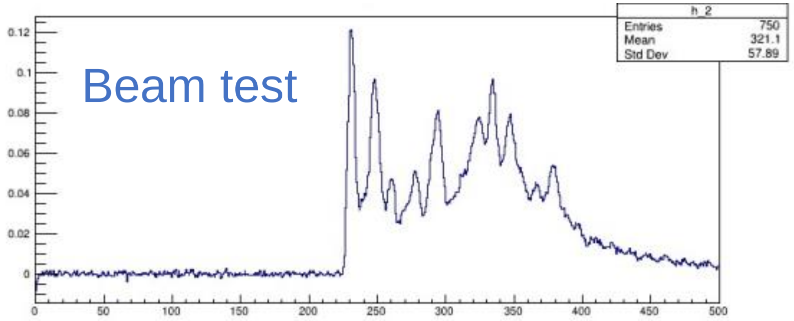
From the beam test

Waveform



Good consistency between simulation and data

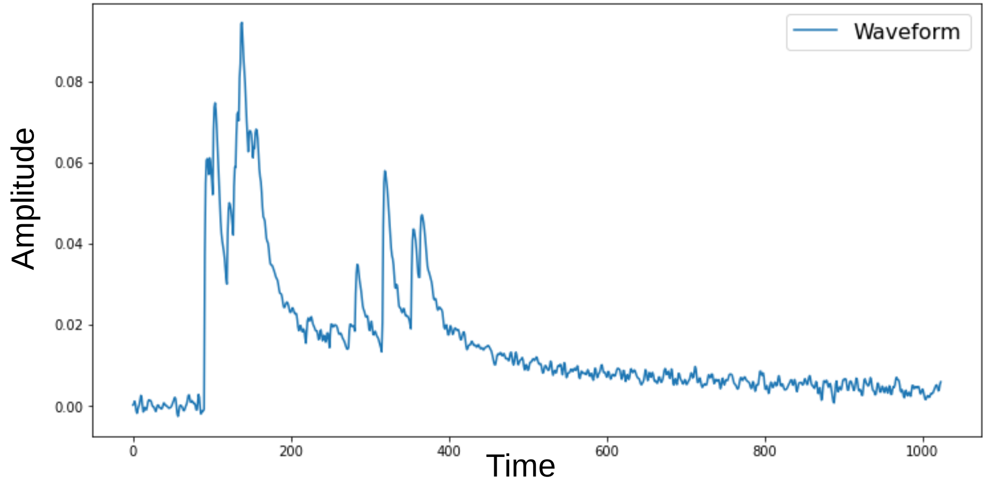




Reconstruction algorithm

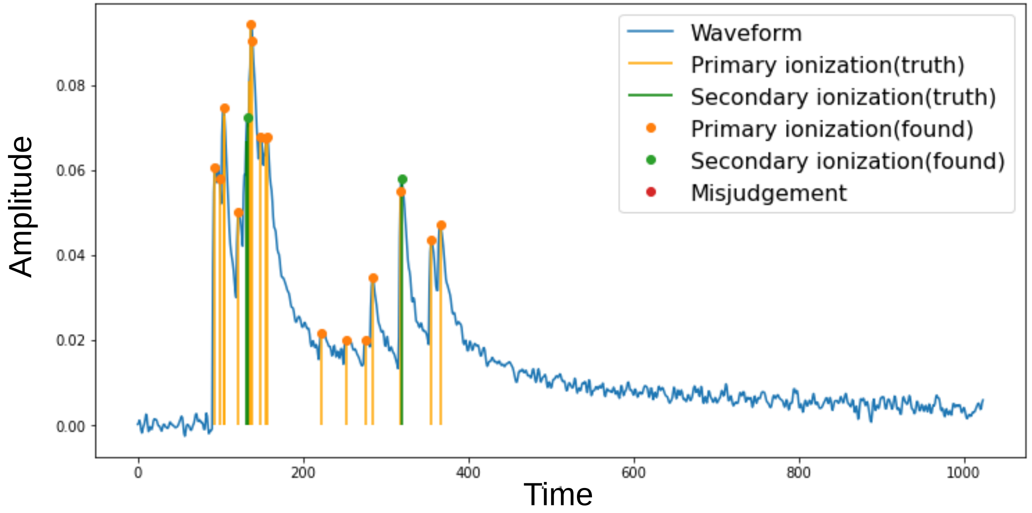
Step1. Peak Finding

Discriminate peaks (both primary and secondary) from the noises



Step2. Clusterization:

Determine the number of clusters (N_{cls}) from the detected peaks



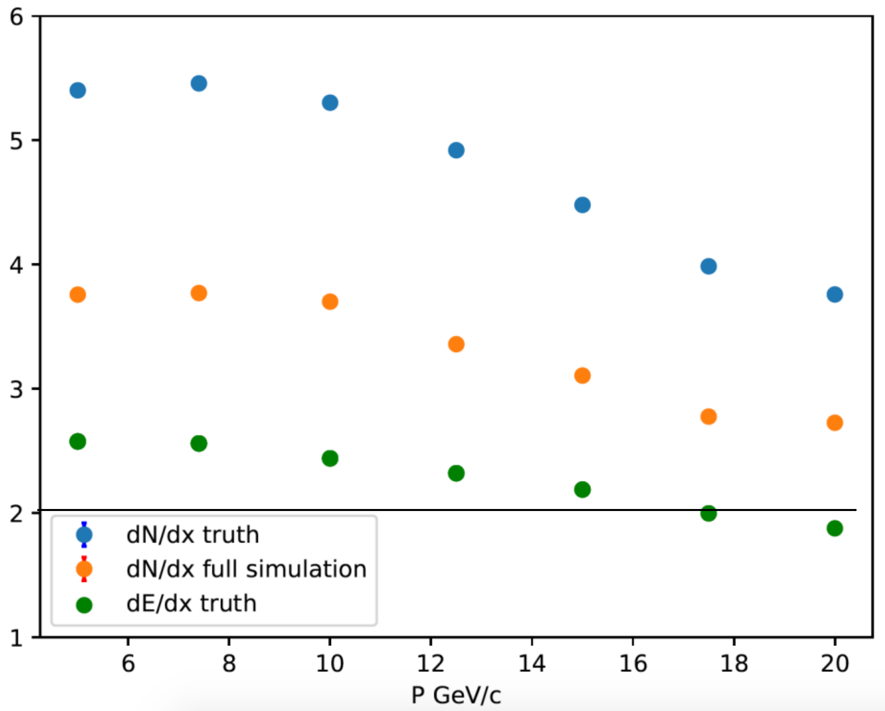
- Two methods under study

  Classical method (developed): Derivative-based peak finding + clusterization with peak merge

  Deep learning based algorithm (ongoing): Peak finding with LSTM + clusterization with DGCNN

K/π separation power with Classical method

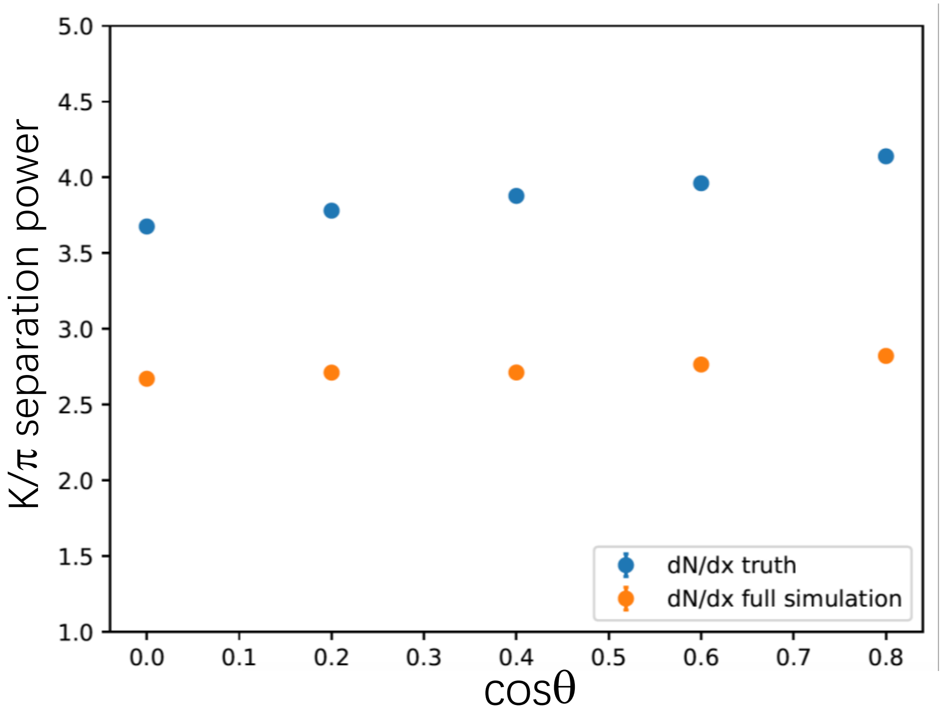
K/π separation power vs P (1m track length, cosθ=0)



Separation power

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

K/π separation power vs cos(θ)

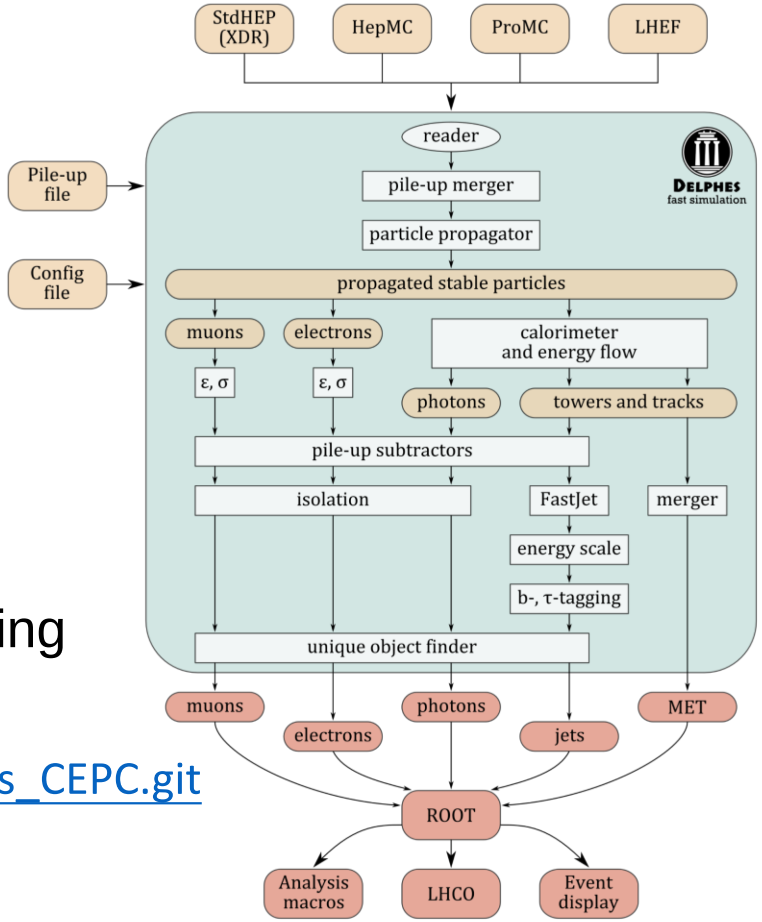


2σ K/π separation power is reached up to 20 GeV/c

Deep learning based algorithm （under development）is expected to provide better performance

Fast simulation with Delphes

- Delphes is a modular framework that simulates the response of a multipurpose detector
  - $10^2 \sim 10^3$ faster than the fully GEANT based simulations
  - Sufficient and widely used for phenomenological studies
- For simulations of the CEPC 4th concept detector :
  - Detector layout based on preliminary optimization
  - A dedicated PID module(dN/dx and TOF) developed
  - Consistent workflow for lepton/photon isolation and jet-clustering
  - …
- More details in github repository: https://github.com/oiunun/Delphes_CEPC.git



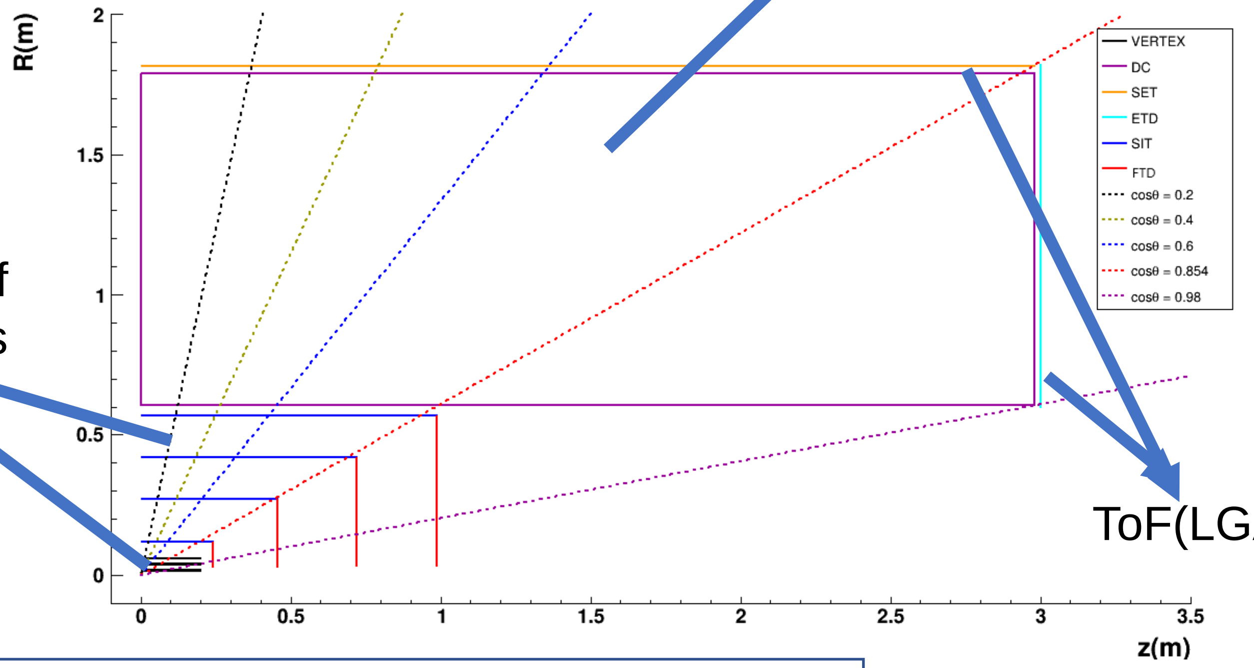
J. High Energ. Phys. **2014**, 57 (2014)

Detector configuration

Tracker system:

- DC:0.6 m-1.8 m, larger DC, better PID

- Silicon vertex and silicon tracker: provide accurate measurement of charged particle track parameters



ToF(LGAD) $(\sigma)_{tof}$ = $30\ ps$

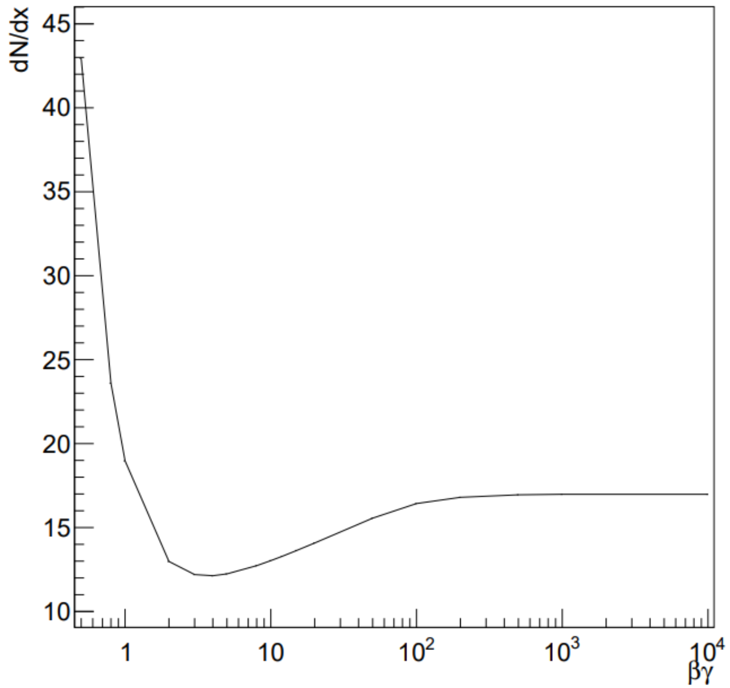
Pt resolution is consistent with full simulation

Calorimeter system:

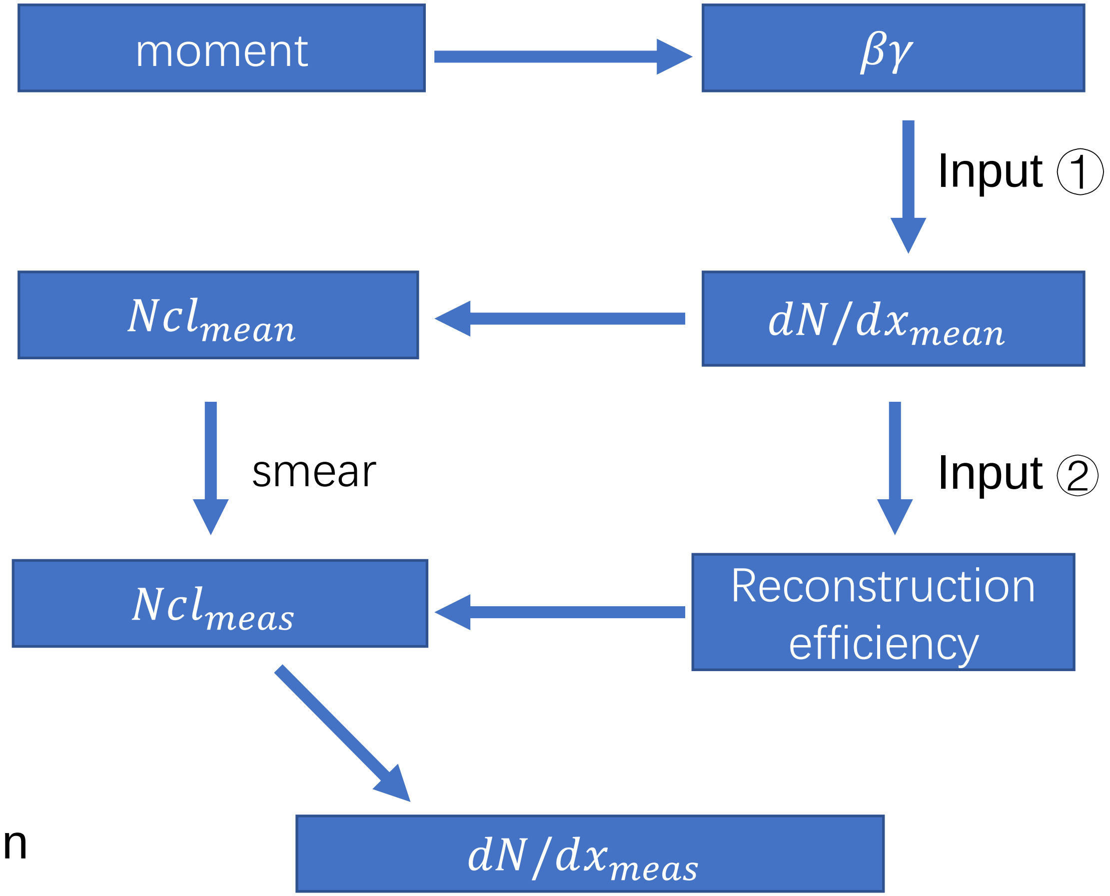
- Preliminary implementation, reasonable resolution achieved. Needs more tuning

dN/dx model in Delphes

Input ①: mean of dN/dx with $\beta\gamma$



Input ②: reconstruction efficiency from full simulation



Parameterized simulation of dN/dx_{meas}

The calculation of the probability

dN/dx + TOF combined chi-square:

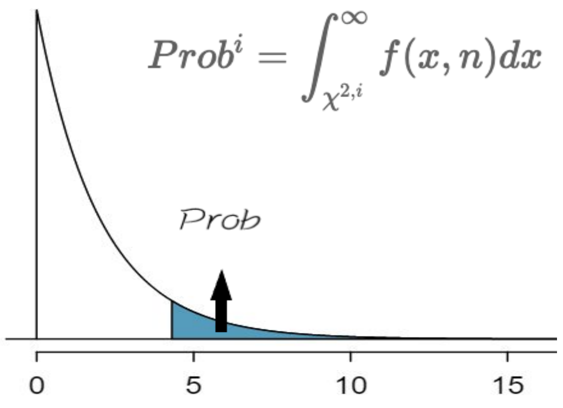
$(\chi^i)^2 = (\chi_1^i)^2 + (\chi_2^i)^2$ (It follows a Chi-square distribution of 2 degrees of freedom)

$$\chi_1^i = \frac{(dN/dx)_{meas} - (dN/dx)_{exp}^i}{(\sigma)_{dN/dx}^i}$$

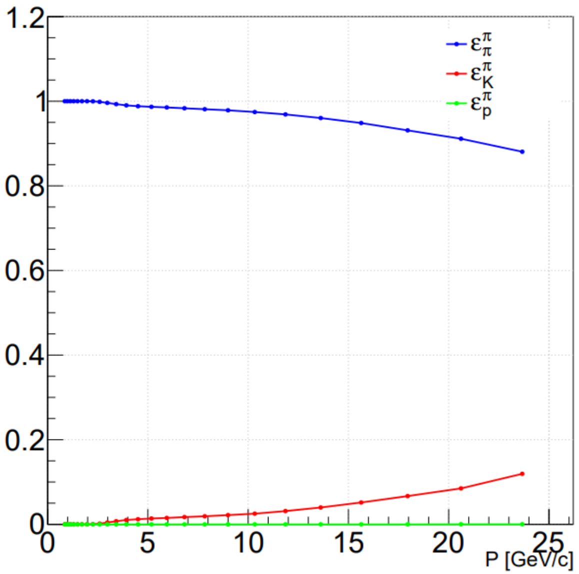
$$\chi_2^i = \frac{(tof)_{meas} - (tof)_{exp}^i}{(\sigma)_{tof}^i}$$

PID selection with probability calculated by chi-square:

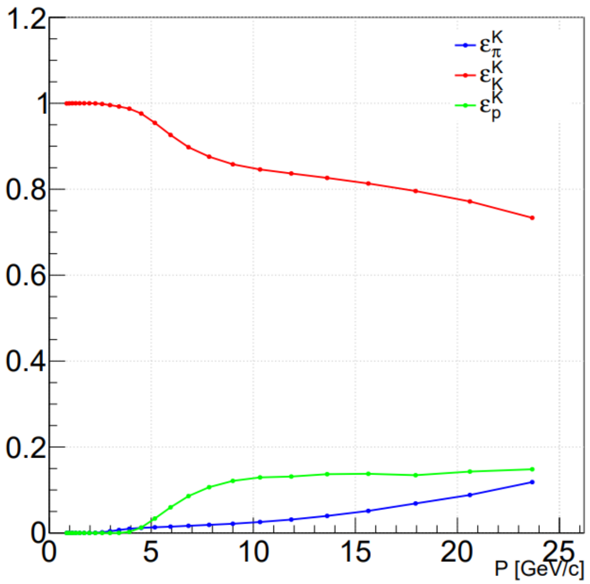
- e.g. identified as π: Prob(π)>Prob(K) & Prob(π)>Prob(p)



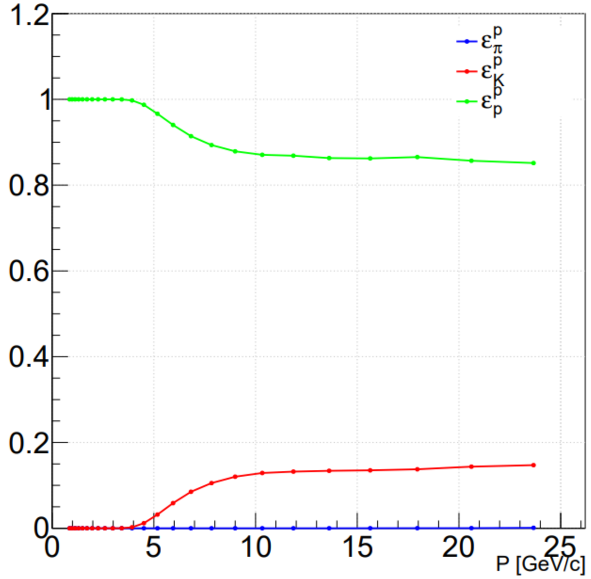
PID efficiency



π



K



p

efficiency : $\varepsilon^{i}_{j} = \frac{n^{i}_{j}}{n^{j}_{tot}}$

- n^{i}_{j}:number of j being identified as i.
- n^{j}_{tot}:number of j

Good PID performance up to 20 GeV/c

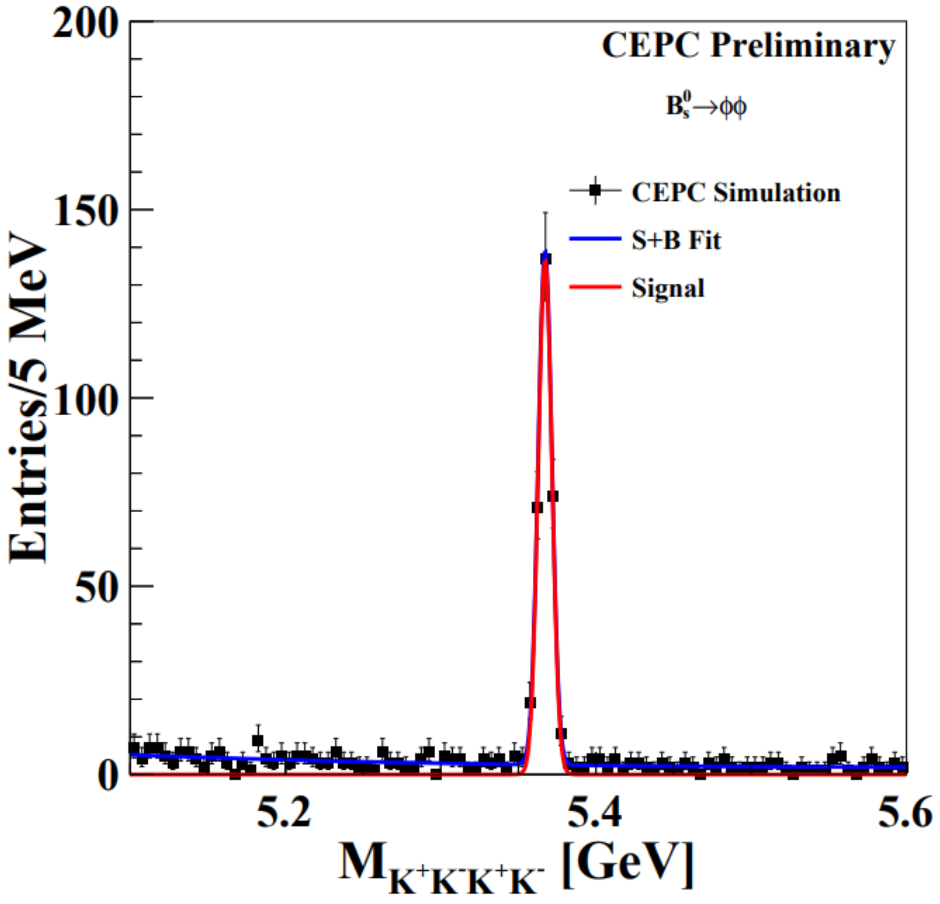
PID performance with B_s^0/B^0 decays

- $B_s^0 \to \phi\phi, \phi \to K^+K^-$
- $B^0/B_s^0 \to hh, h = \pi, K$
- Background: $Z \to b\bar{b}$ (7×10^8)

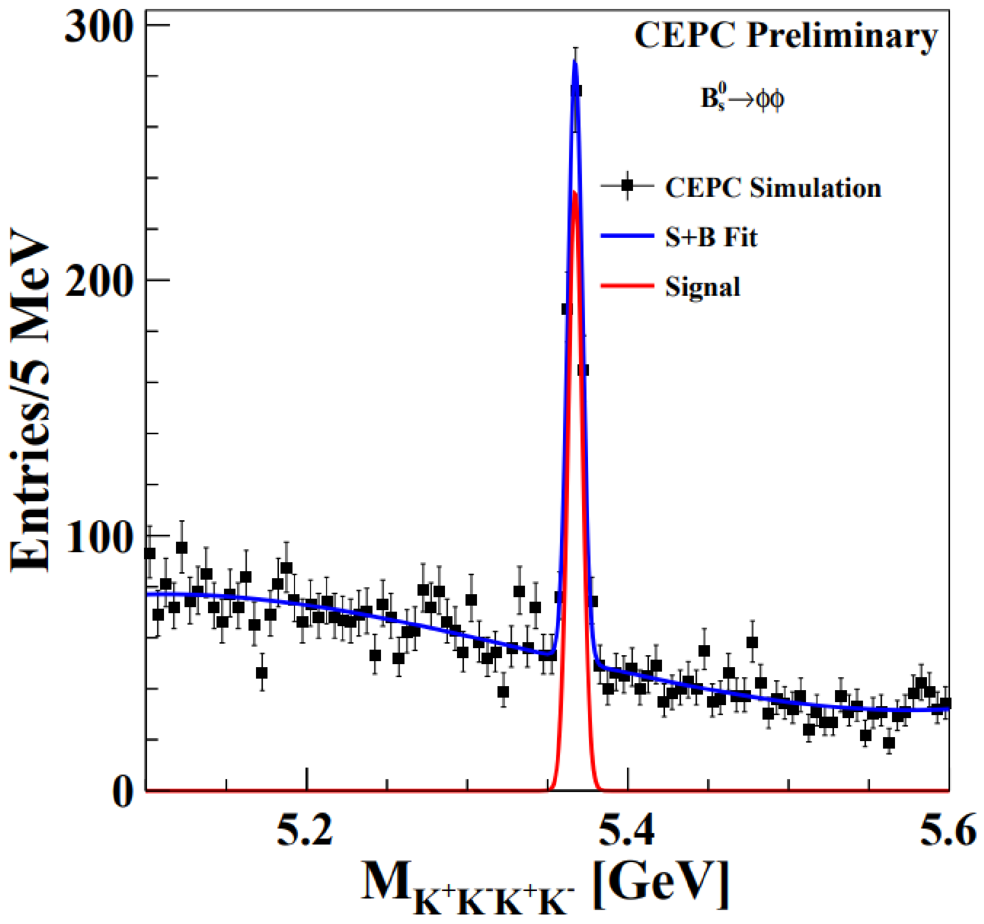
channel	Sample size	Tera-Z yield
$B_s^0 \to \phi\phi, \phi \to K^+K^-$	630	561,600
$B^0 \to \pi^+\pi^-$	2,900	2,585,142
$B^0 \to K^+K^-$	44	39,222
$B_s^0 \to \pi^+\pi^-$	98	87,360
$B_s^0 \to K^+K^-$	3,739	3,333,051

Demonstration of the significance of PID: $B_s^0 \to \phi\phi$

With PID



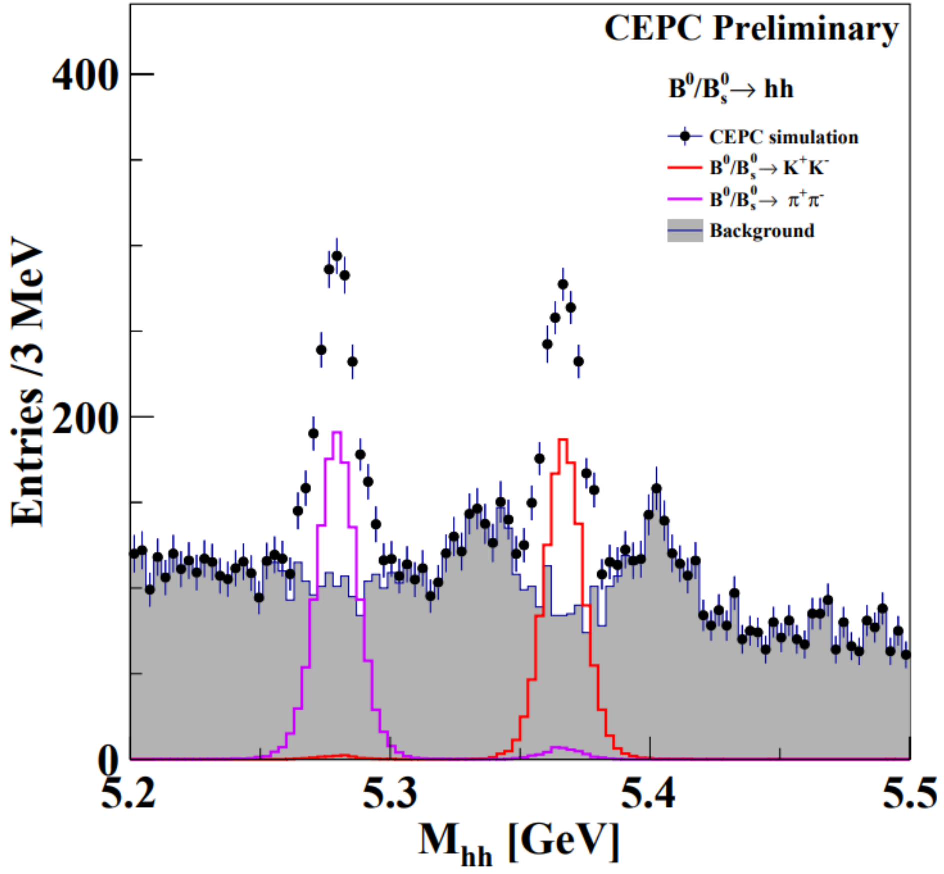
Without PID



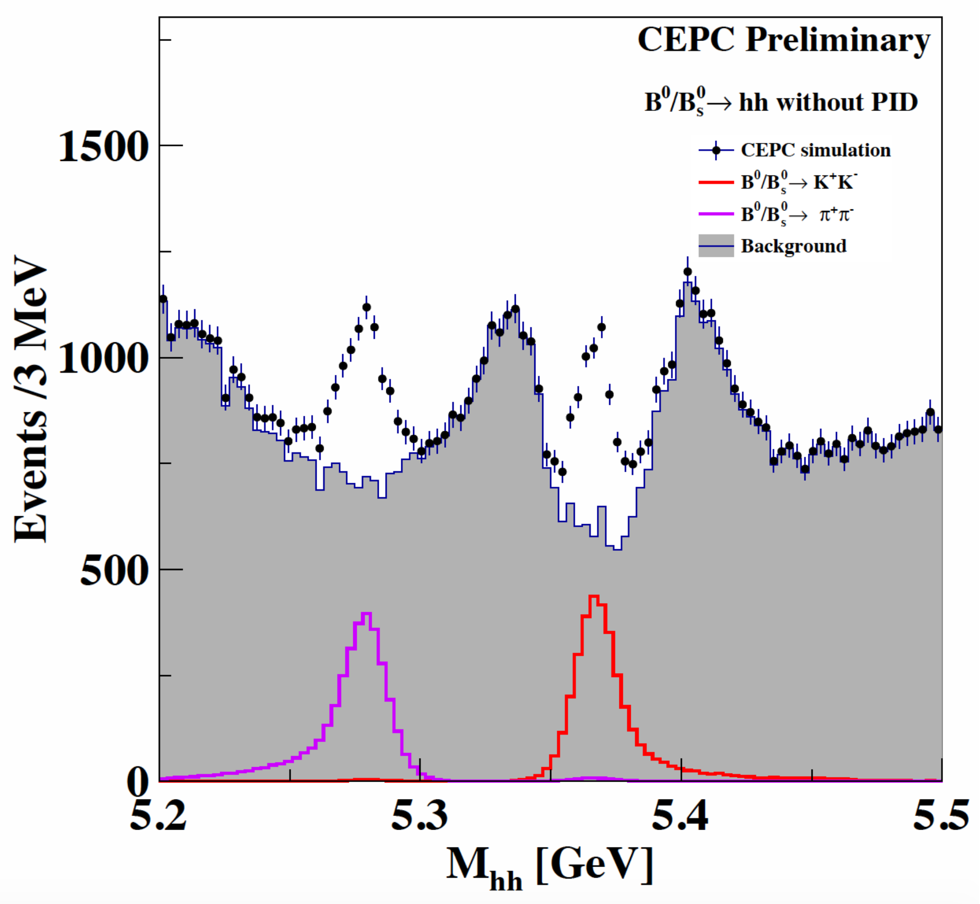
Improved signal sensitivity with PID

Demonstration of the significance of PID: $B^0/B_s^0 \to hh$

With PID



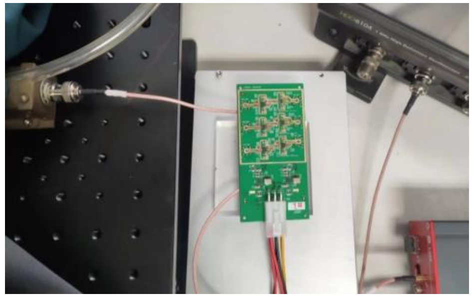
Without PID

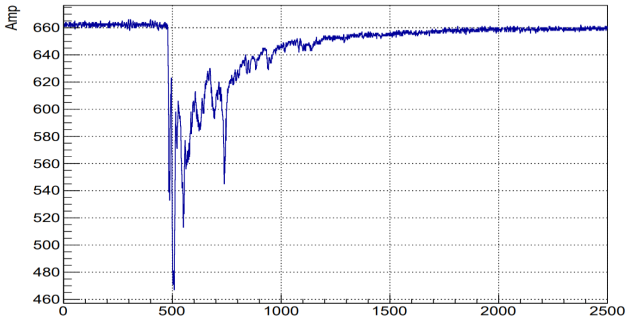


Improved signal sensitivity with PID

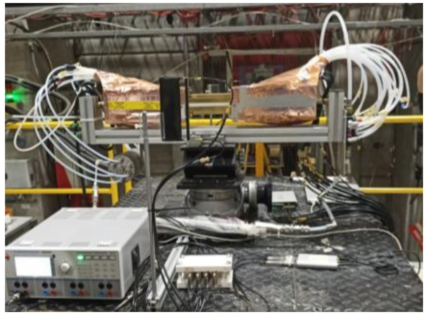
Activities on prototype test

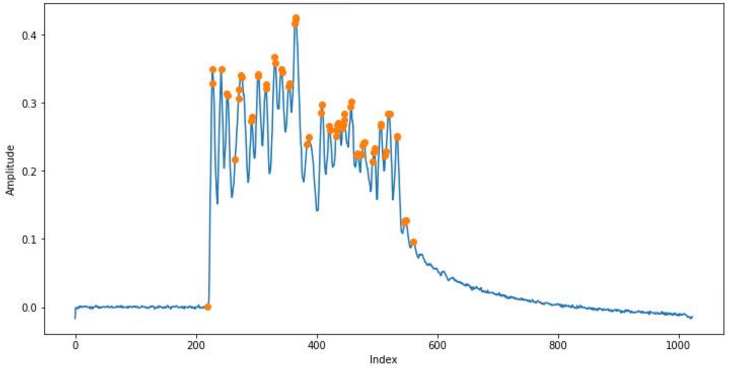
- Prototype test at IHEP
  - A preamplifier is designed and tested with a drift tube using Sr-90 source
  - Preliminary tests show a promising future
- Further tests and optimization are on going





- Beam test organized by INFN group
- Cooperation between IHEP and INFN
  - Data taking
  - Data analysis
  - Optimizing DC simulation
  - Plan to apply ML algorithm on online FPGA





Summary

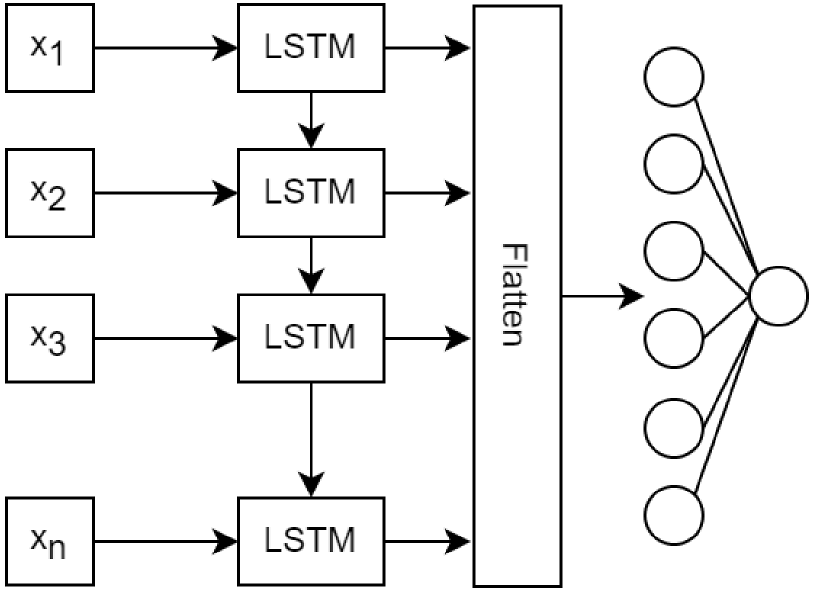
- A drift chamber with cluster counting technique for PID is proposed for CEPC the 4th conceptual detector
- $2\sigma\ K/\pi$ separation power is reached up to 20 GeV/c with waveform-based full simulation
- Physics sensitivity is improved significantly with PID in flavor physics with Delphes fast simulation
- Prototype test is ongoing

Thanks!

Backup

Deep learning based algorithm

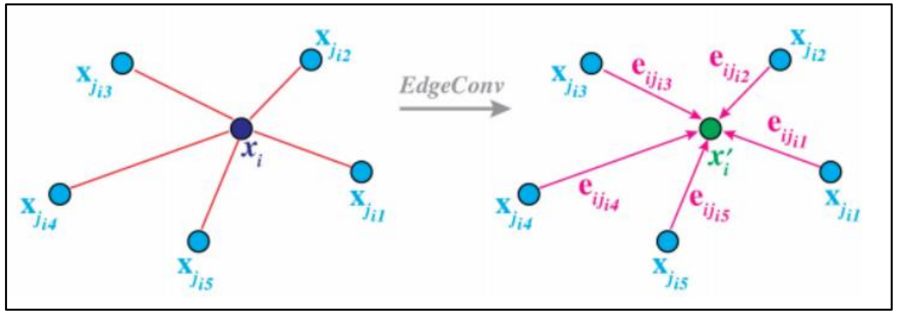
Peak finding with LSTM



- With Long short-term memory (LSTM) model
- Labels: Signal or Noise.
- Features: Slide windows of peak candidates, with a shape of (15, 1)

⇒ A binary classification problem

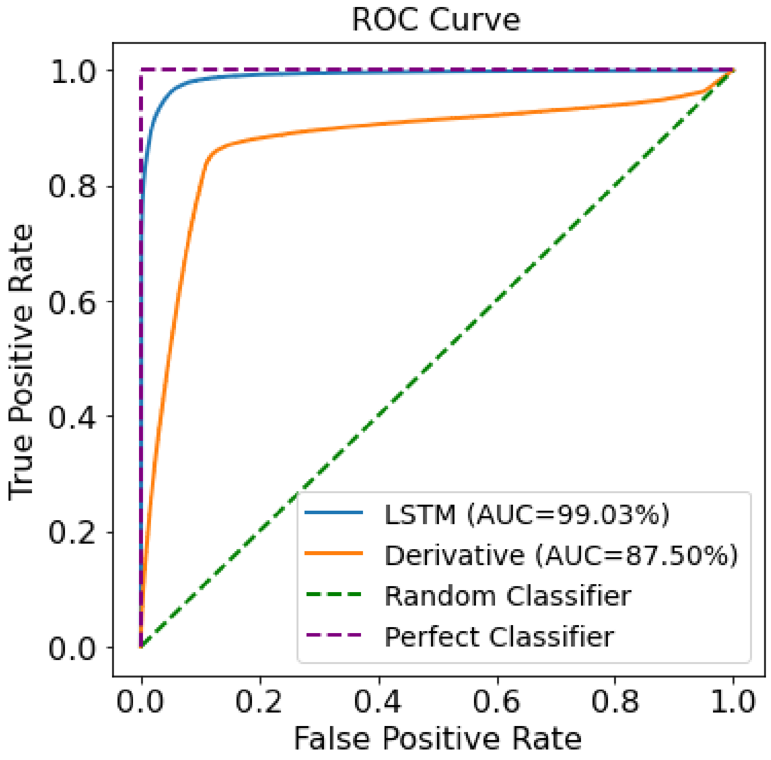
Clusterization with DGCNN



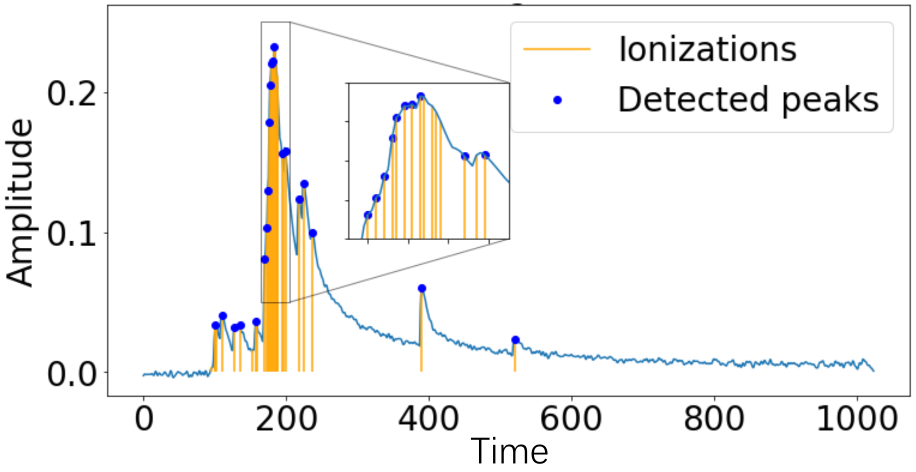
arXiv: 1801.07829

- GNN-based architecture: DGCNN
- Massage passing through neighbor nodes ⟺ Clusterization of electron timings from the same primary cluster

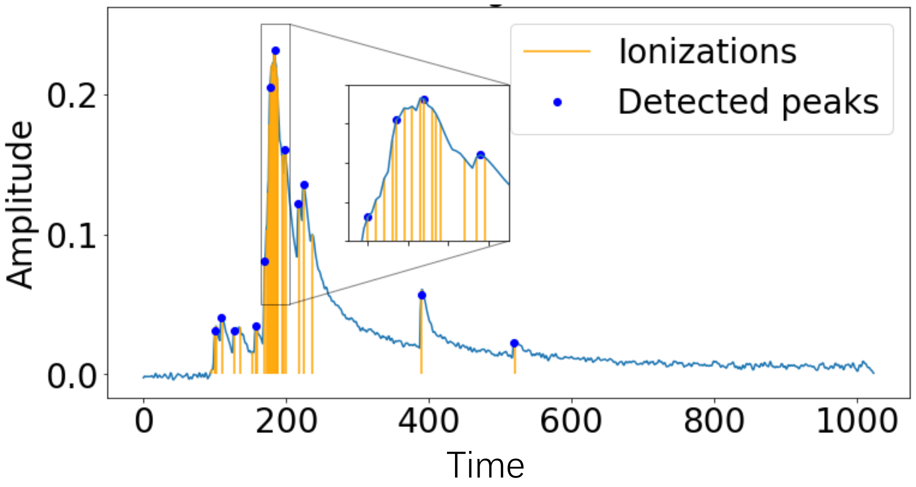
Comparison between LSTM and derivative model



LSTM algorithm

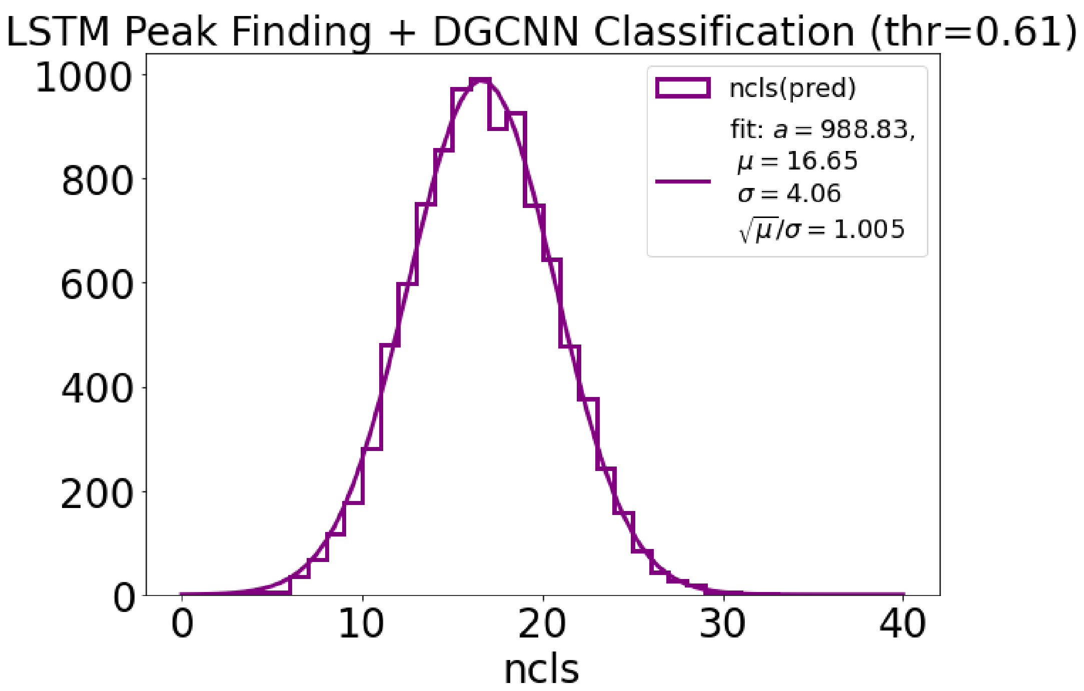


Derivative algorithm



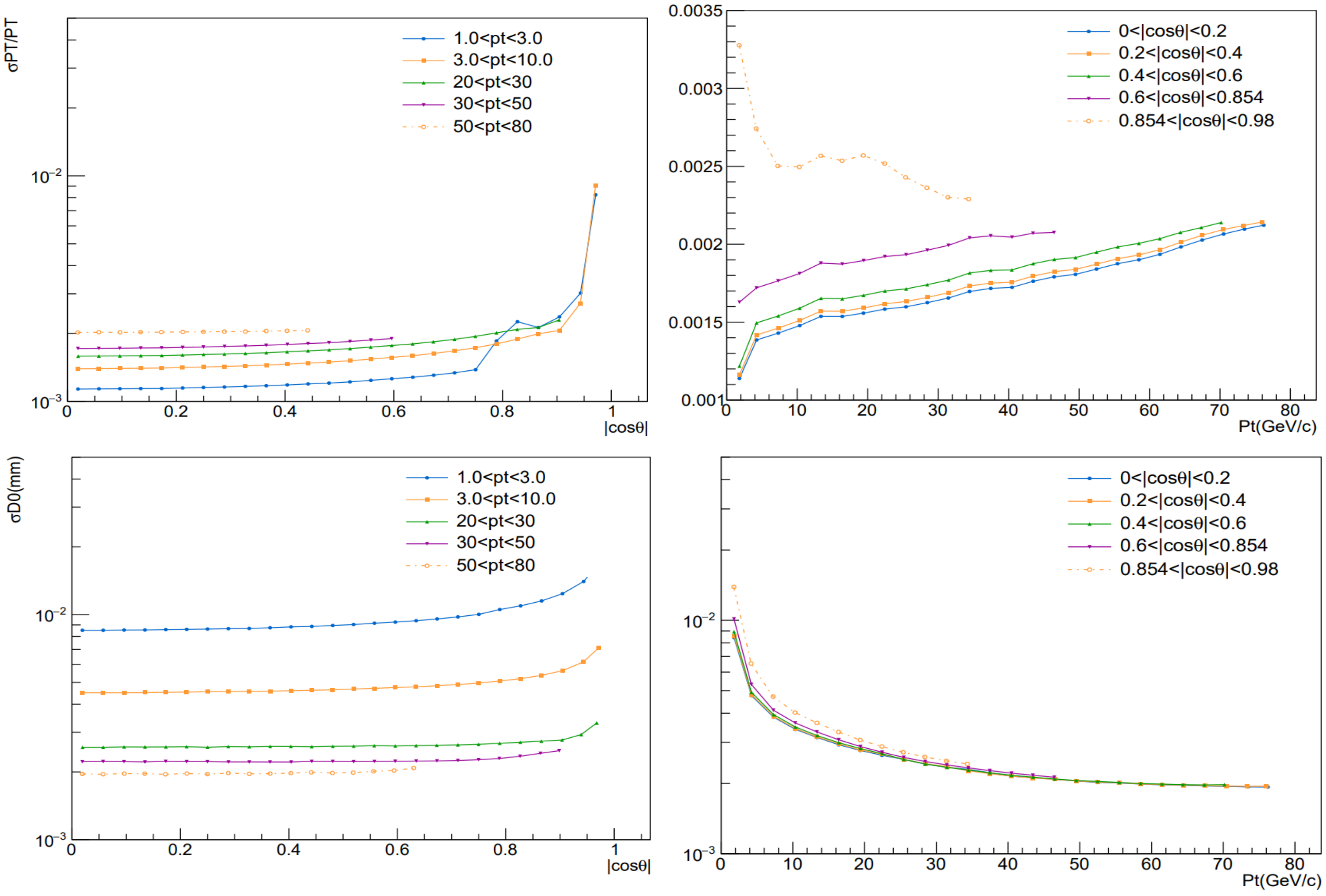
Better AUC for LSTM, due to the better pile-up recovery ability of the LSTM model

Performance with deep learning based algorithm

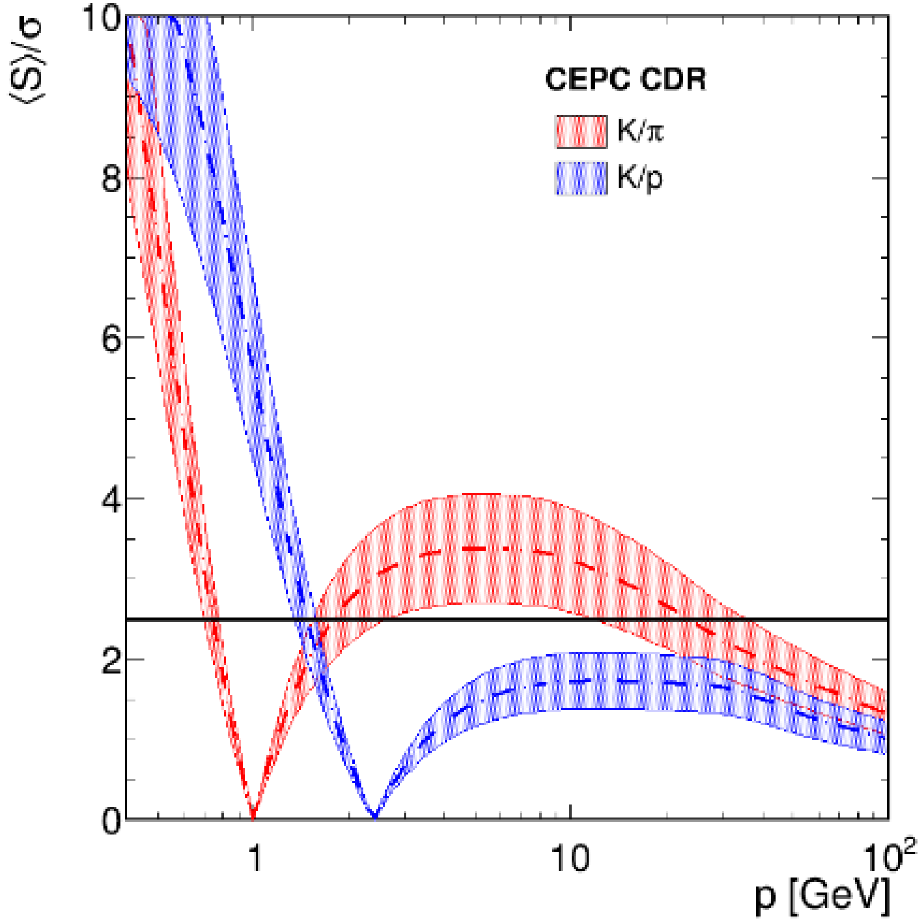


Method		μ	σ	σ/μ
Input		**16.53**	**3.93**	**23.8%**
Output	Classical algorithm	18.67	4.60	24.6%
	ML	16.65	4.06	24.4%

Tracking resolution

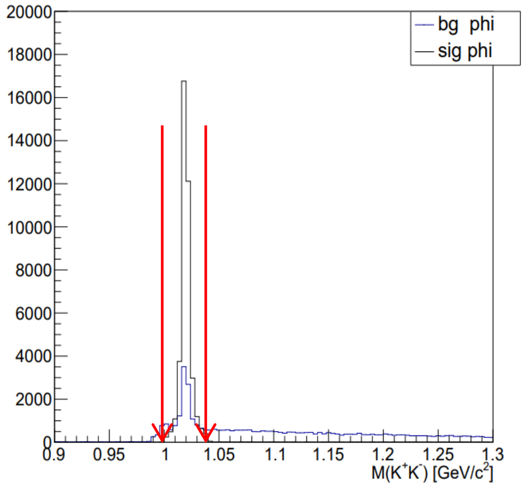


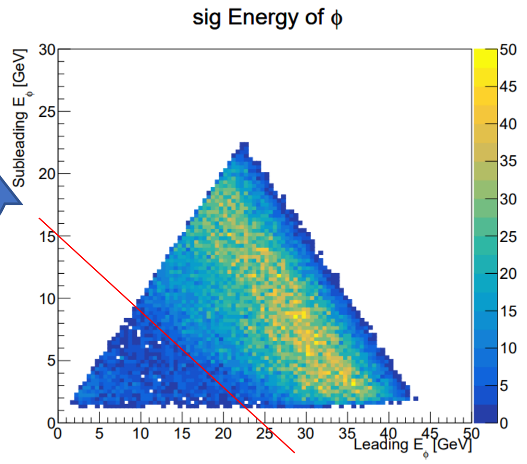
CDR K/π K/p S

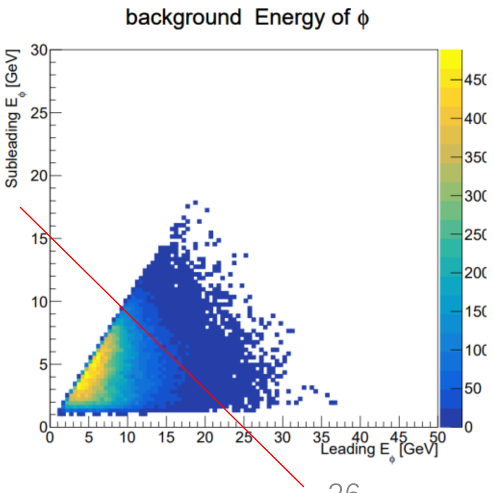


Event selection for $B_s^0 \rightarrow \phi\phi$

- $Z \rightarrow b\bar{b} \rightarrow di - jet$, so the following selections is done in each jet
- And the $M_{\phi\phi}$ in [5.1,5.6] is retained.
- Final state:$K^+K^-K^+K^-$
- Kaon PID(dN/dx +TOF)
  - $Prob_K > Prob_\pi \;\; \&\& \;\; Prob_K > Prob_p$
- ϕ reconstruction
  - $|M_{K^+K^-} - m_\phi| < 0.02\ GeV/c^2$
  - $0.6 \times leading\ E_\phi + subleading\ E_\phi > 15\ GeV$

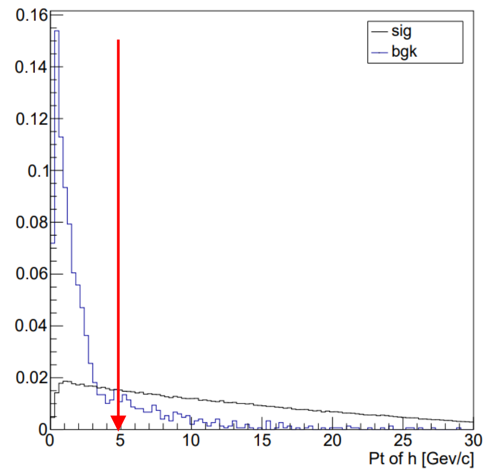


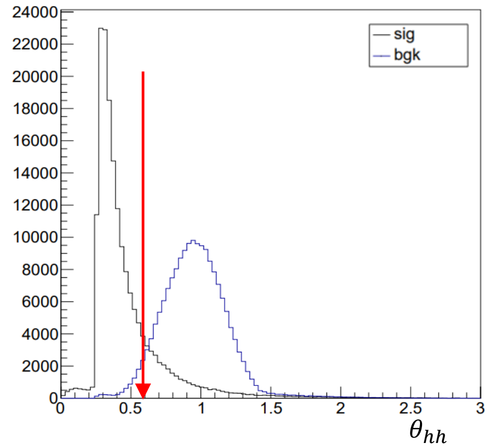




Event selection for $B_s^0/B^0 \rightarrow hh$

- $Z \rightarrow b\bar{b} \rightarrow di-jet$, so the following selections is done in each jet
- And the M_{hh} in [5.2,5.5] is retained.
- Final state:$K^+K^-/\pi^+\pi^-$
- PID(dN/dx +TOF)
  - K: $Prob_K > Prob_\pi$ && $Prob_K > Prob_p$
  - π: $Prob_\pi > Prob_K$ && $Prob_\pi > Prob_p$
- K/π criteria
  - $Pt > 5\ GeV$
- Reconstruct B^0 & B_s^0 in $M_{hh} \in [5.2,5.5]\ GeV$
  - $\theta_{hh} < 0.6$





Signal samples

Tested with Sr-90 source