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Simulation of Particle Identification with Delphes

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CEPC Tracker Layout Working Hour

May 5th, 2022

Outline

- **Introduction**
- **The Delphes**
- **Simulation setup and algorithm**
- **Current status**
- **Summary**

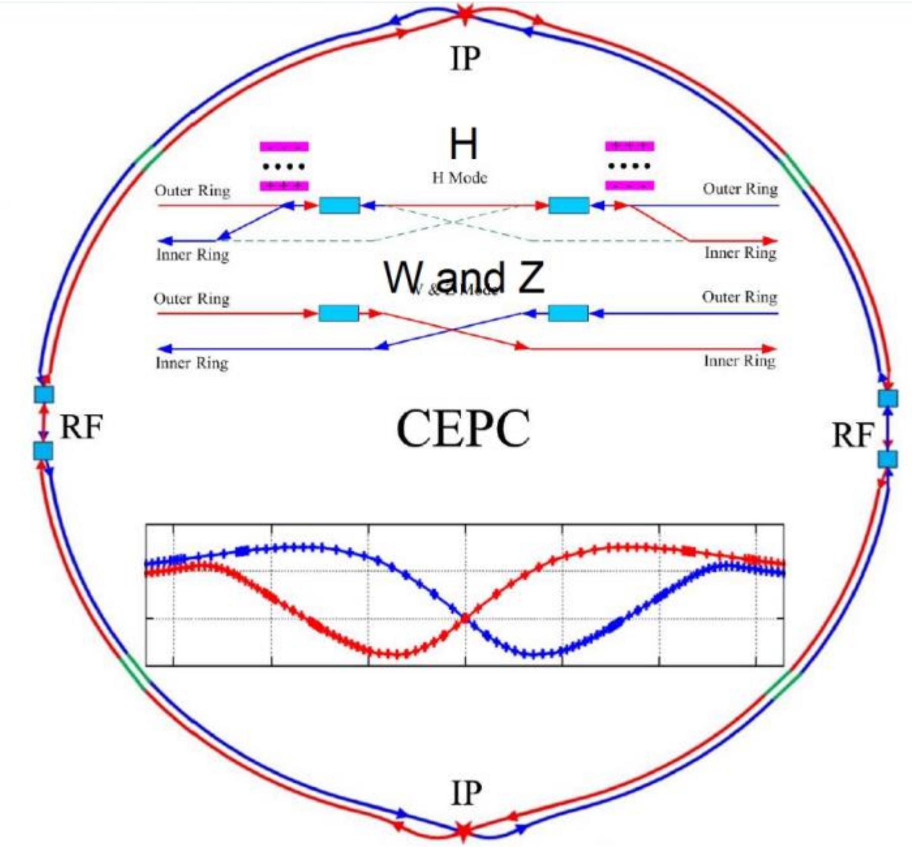
Physics background

- The Standard Model (SM)
  - It describes the **strong**, **weak** and **electromagnetic** interactions. (under the framework of quantum gauge field theory)
  - The theoretical predictions of SM are in excellent agreement with experimental measurements.
- Higgs boson
  - Helps to our understanding of the origin of mass of subatomic particles.
  - Was discovered as the predicted fundamental particle by the ATLAS and CMS experiments in 2012.
  - Its discovery confirmed the Higgs Mechanism.

Physics motivation of the CEPC

- To precisely measure Higgs boson and ElectroWeak physics as a tool to probe new physics
  - H, Z, W Factories
- QCD, favor physics, …
- Could be upgraded to a proton-proton collider
  - Reach unprecedented high energy and directly search for new physics
- Three different modes
  - H ($e^+ e^-$-->ZH) (240 GeV)
  - W ($e^+ e^-$-->$W^+ W^-$) (160 GeV)
  - Z ($e^+ e^-$-->Z) (91 GeV)

Plan of CEPC



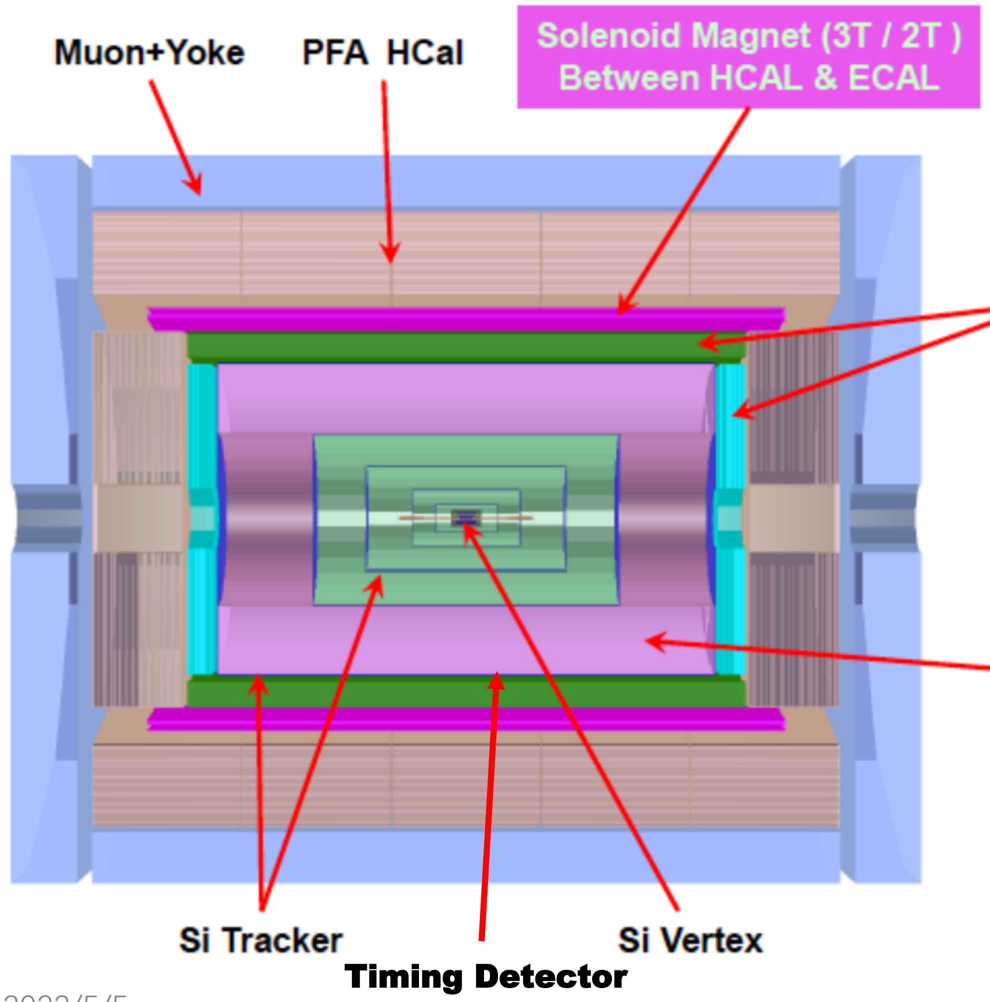
CEPC collider ring (100km)

CEPC event generate

- **H (e+ e--->ZH) (240 GeV)**
- **W (e+ e--->W+ W-) (160 GeV)**
- **Z (e+ e--->Z) (91 GeV)**

Operation mode	Z factory	W threshold scan	Higgs factory
Ecm (GeV)	~91.2	158 – 172	240
$L(10^{34}cm^{-2}s^{-1})$	17 – 32	10	3
Running time (years)	2	1	7
Integrated luminosity (ab^{-1})	8 – 16	2.6	5.6
Higgs yield	-	-	10^6
W yield	-	10^7	10^8
Z yield	10^{11-12}	10^9	10^9

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.

Transverse Crystal bar ECAL

Advantage: better π^0/γ reconstruction.

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

Drift chamber that is optimized for PID

Advantage: Work at high luminosity Z runs

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

From center away：

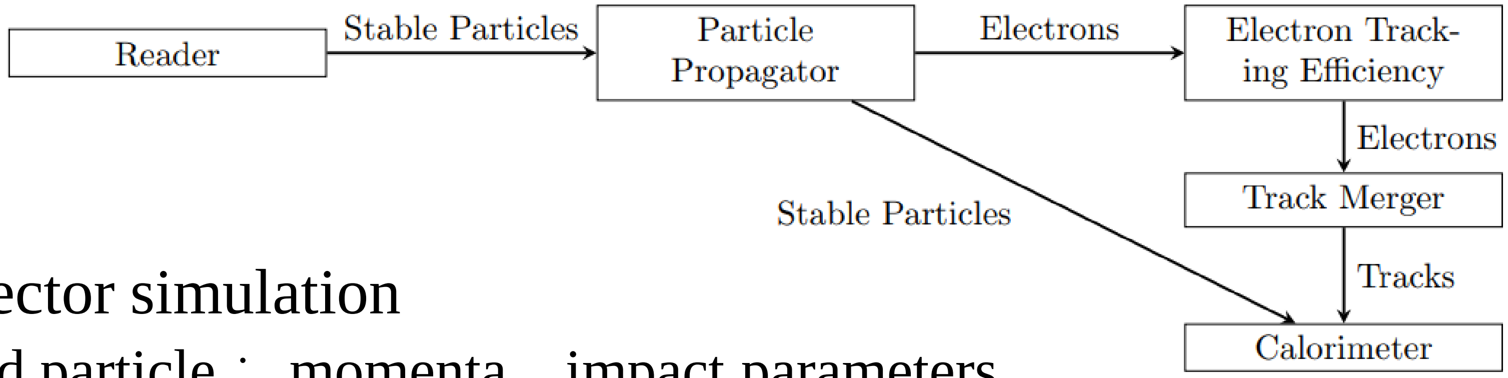
- Vertex Detector
- Silicon Tracker
- Drift Chamber
- Timing Detector
- Calorimeter
- Superconducting magnets
- Muon Detector

The Delphes

- Delphes (a detector response simulation framework)
  - Delphes is based on a modular system, whereby the input file is read and the information within is passed though a series of modules which make alterations to the passing data. The data is passed between modules in the form of an array of ‘candidates’ (a Delphes class type).
  - Input
    - A monte-carlo event file
    - A configuration card (.tcl)
  - Output
    - A root file

The Delphes

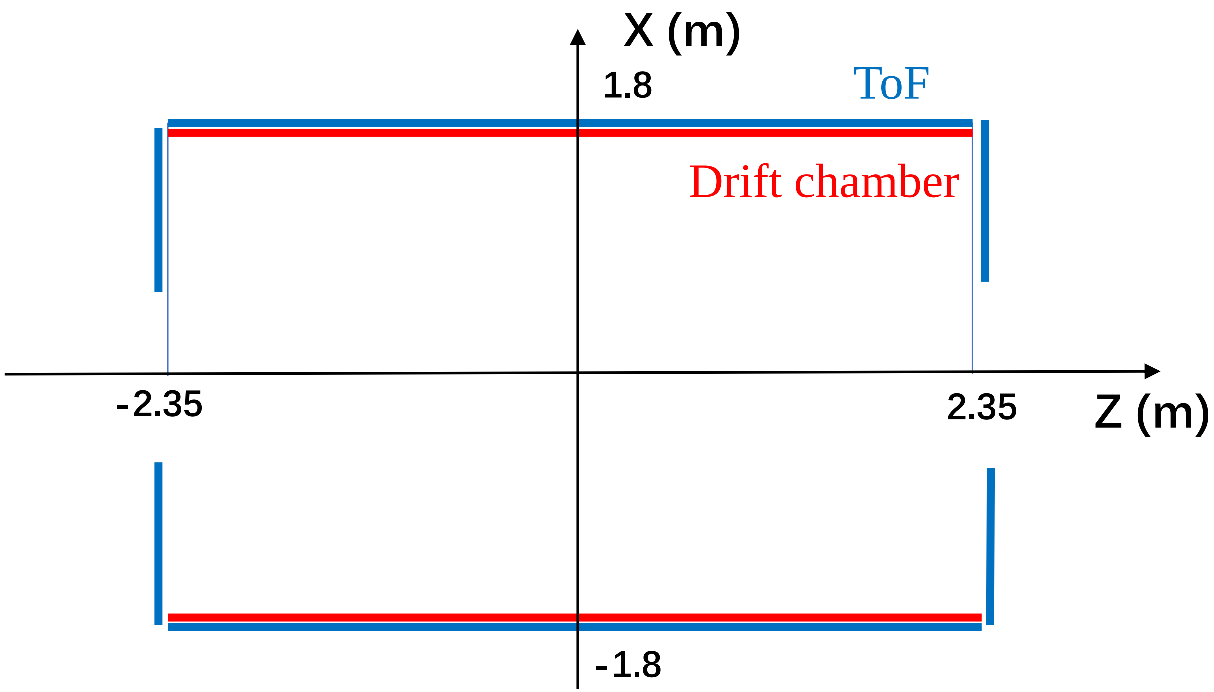
- An example of delphes:



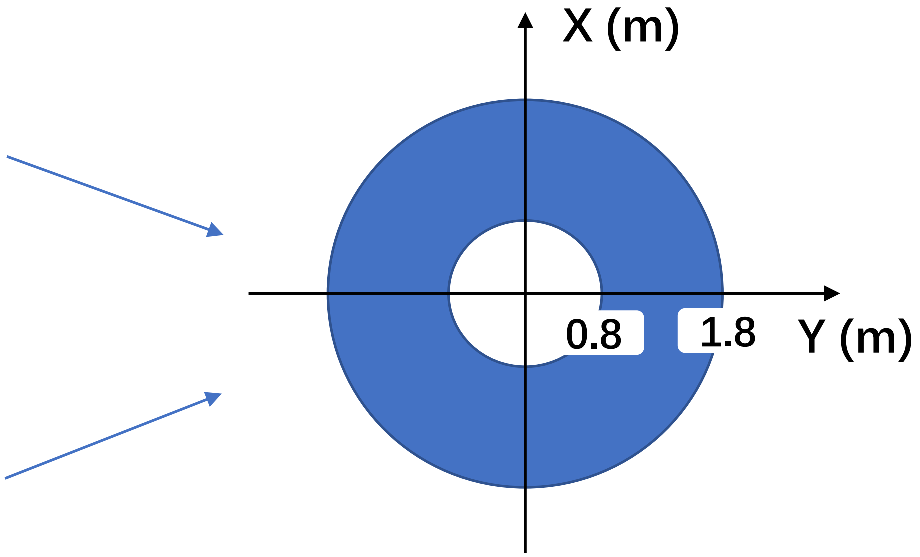
- CEPC detector simulation
  - Charged particle： momenta， impact parameters
  - Neutral particle： energy
  - Jet： perform jet-clustering with the charged and neutral particle as input
  - But PID ability needs more tuning
- This work is to realize PID in the Delphes by combining dN/dx and ToF.

Geometry of the detectors

Drift chamber : only barrel
ToF : barrel + end caps



End caps of ToF:



- The current geometry is not the final, which was put temperately to test the simulation.

Charged Particle Identification

- **In the identification of charged particles, the difference among different particles is mainly the mass.**

- **Calorimeter**
- Identification of election (0.000511GeV)

- **Muon Detector**
- Identification of muon (0.106GeV)

- **ToF + Drift chamber**
- Identification of pion (0.140GeV)
- Identification of kaon (0.494GeV)
- Identification of proton (0.938GeV)

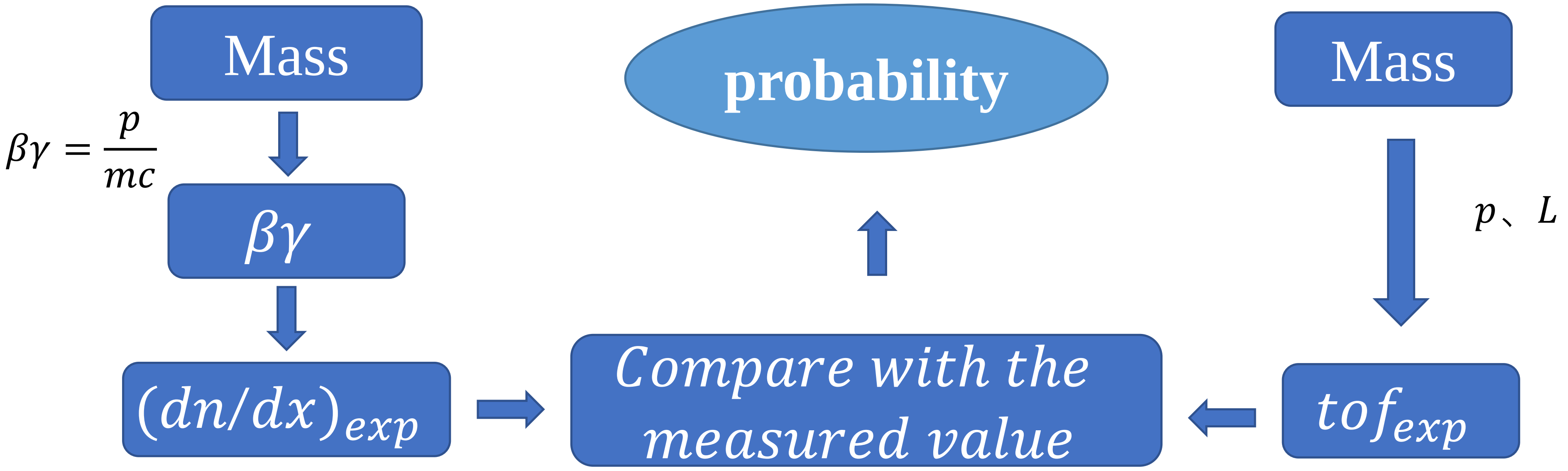
◆ The special detectors are used to identify e and μ.

◆ The mass of proton is much greater than pion's and kaon's.

◆ **Pion and kaon identification is always the hardest.**

Charged Particle Identification

- Using dN/dx and ToF
  - Calculate the probabilities of particles by assuming their masses
    - e, μ, π, K, p
- **The most likely assumption is taken**



The calculation of the probability

Define chi-square:

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

→ Calculate 5 chi-squares for different assumptions

→ Integrate for the probabilities (integral)

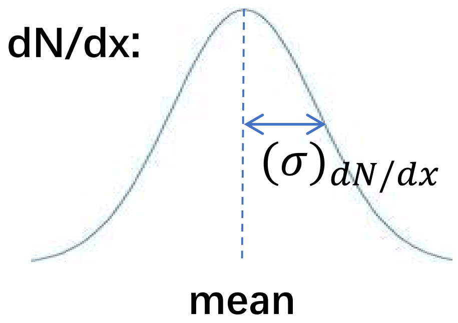
→ Compare the probabilities **The most likely assumption is taken**

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

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

The calculation of χ

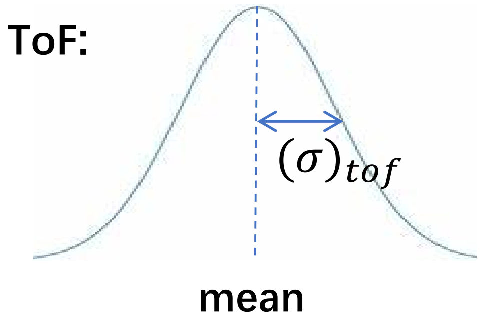
- **dN/dx** $\chi_1 = \frac{(dN/dx)_{meas} - (dN/dx)_{exp}}{(\sigma)_{dN/dx}}$



mean = $(dN/dx)_{exp}$

  - ◆ dN/dx and $(\sigma)_{dN/dx}$ are functions of $\beta\gamma$
    - ◆ dN/dx = $f(\beta\gamma)$ (f is the theoretical function that only depends on $\beta\gamma$)
    - ◆ $(\sigma)_{dN/dx} = \sqrt{f(\beta\gamma)}$
  - ◆ In the formula:
    - ◆ $(dN/dx)_{exp}$ and $(\sigma)_{dN/dx}$ are calculated with $\beta\gamma$'s for 5 particle hypotheses
    - ◆ $(dN/dx)_{meas}$ follows a Poisson distribution with mean and sigma calculated with the truth $\beta\gamma$

- **ToF** $\chi_2 = \frac{(tof)_{meas} - (tof)_{exp}}{(\sigma)_{tof}}$



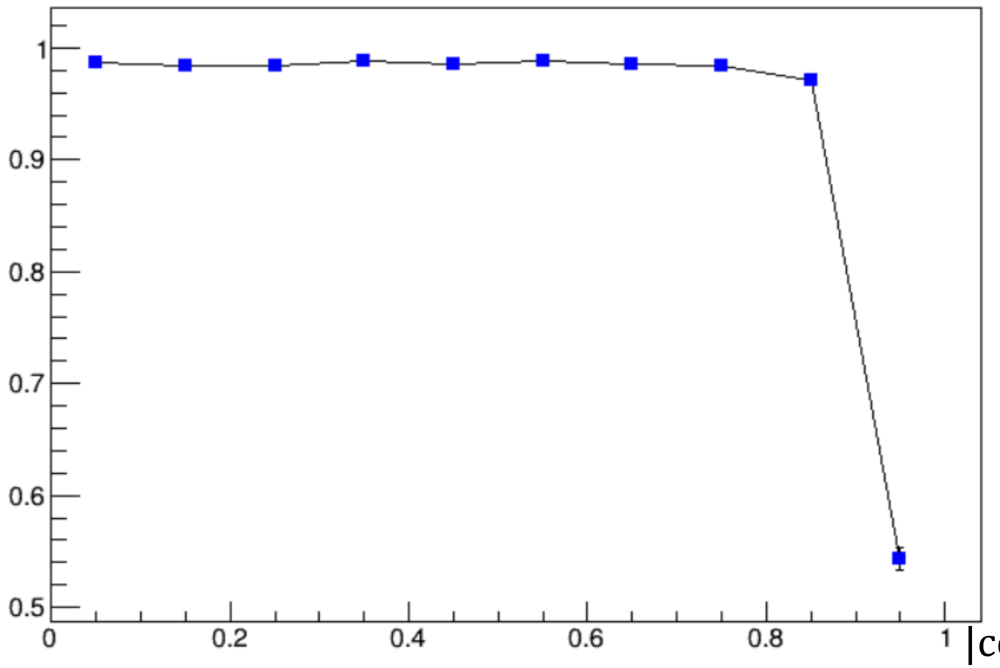
mean = $(tof)_{exp}$

  - ◆ $(tof)_{exp} = \frac{L}{v} = \frac{L}{\beta c}$ $\beta = \frac{p}{\sqrt{p^2+m^2}}$
  - ◆ $(tof)_{meas}$: follows a Gaussian distribution with mean = $(tof)_{exp}$ and $(\sigma)_{tof}$
  - ◆ $(\sigma)_{tof} = 30ps$

The $|\cos\theta|$ and momentum dependence

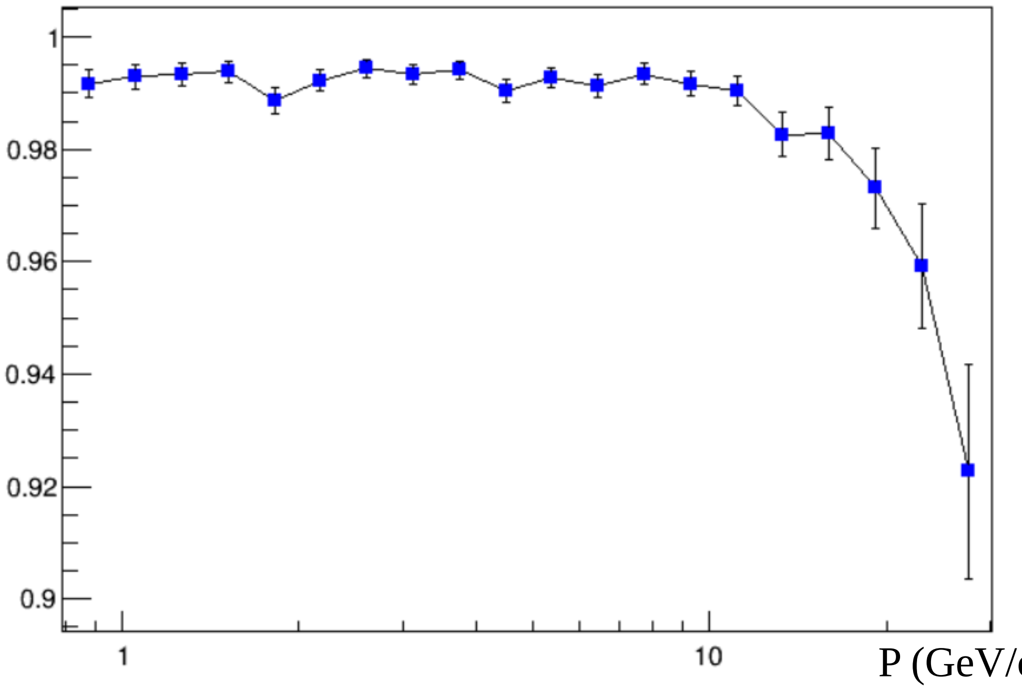
Only considering π and K:

Kaon PID efficiency



$|\cos\theta|$

Kaon PID efficiency ($|\cos\theta|$ <0.854)



P (GeV/c)

- When $|\cos\theta| < 0.85$, The PID performance is better.

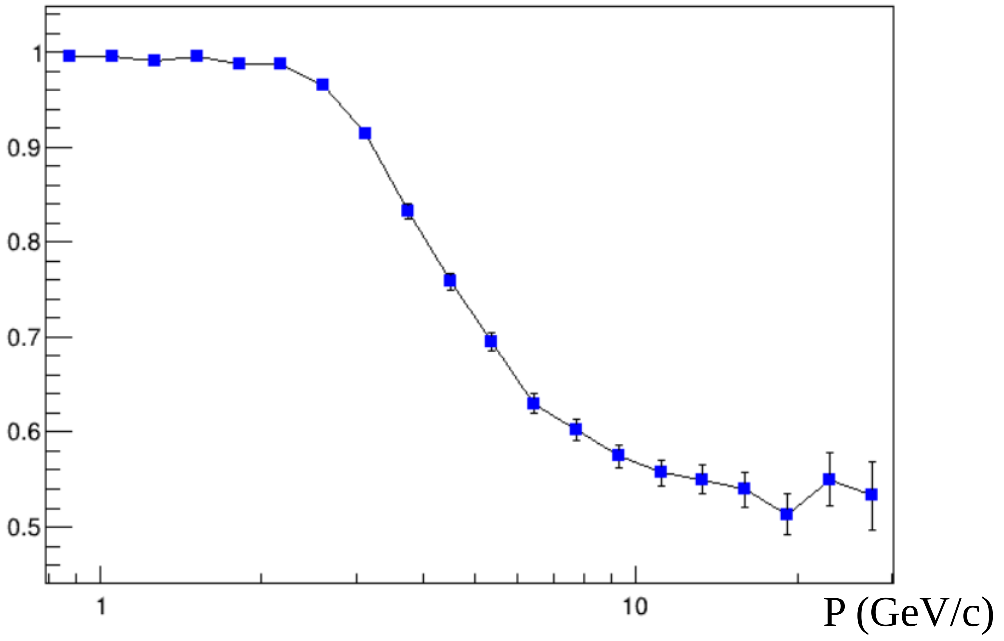
- As momentum increases, efficiency decreases.

The effects of dN/dx and tof

π / K separation only

ToF only

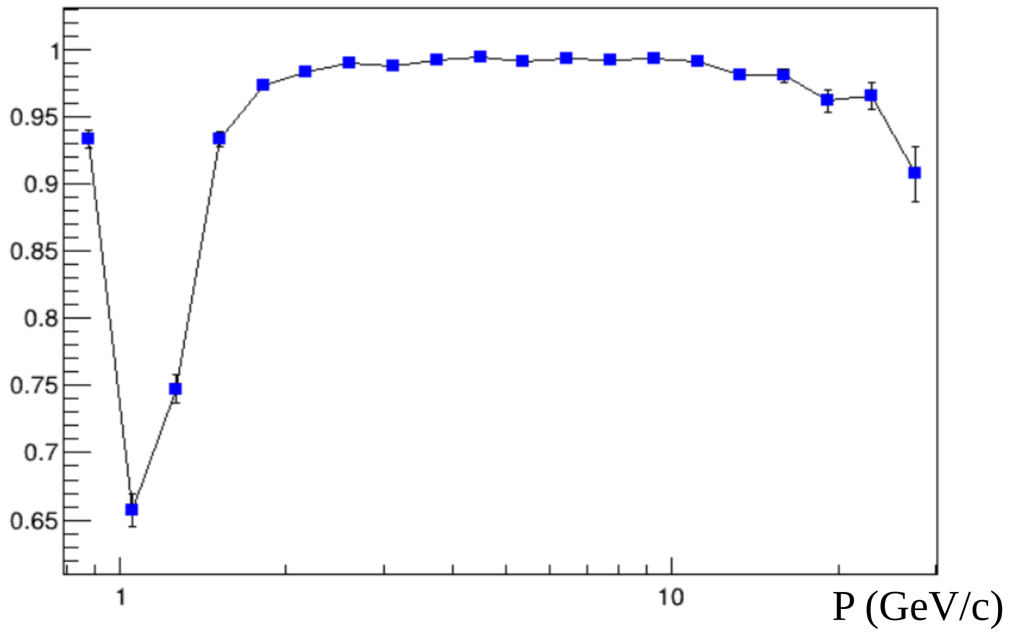
Kaon PID efficiency (|cosθ| <0.854)



dominant in the low momentum range

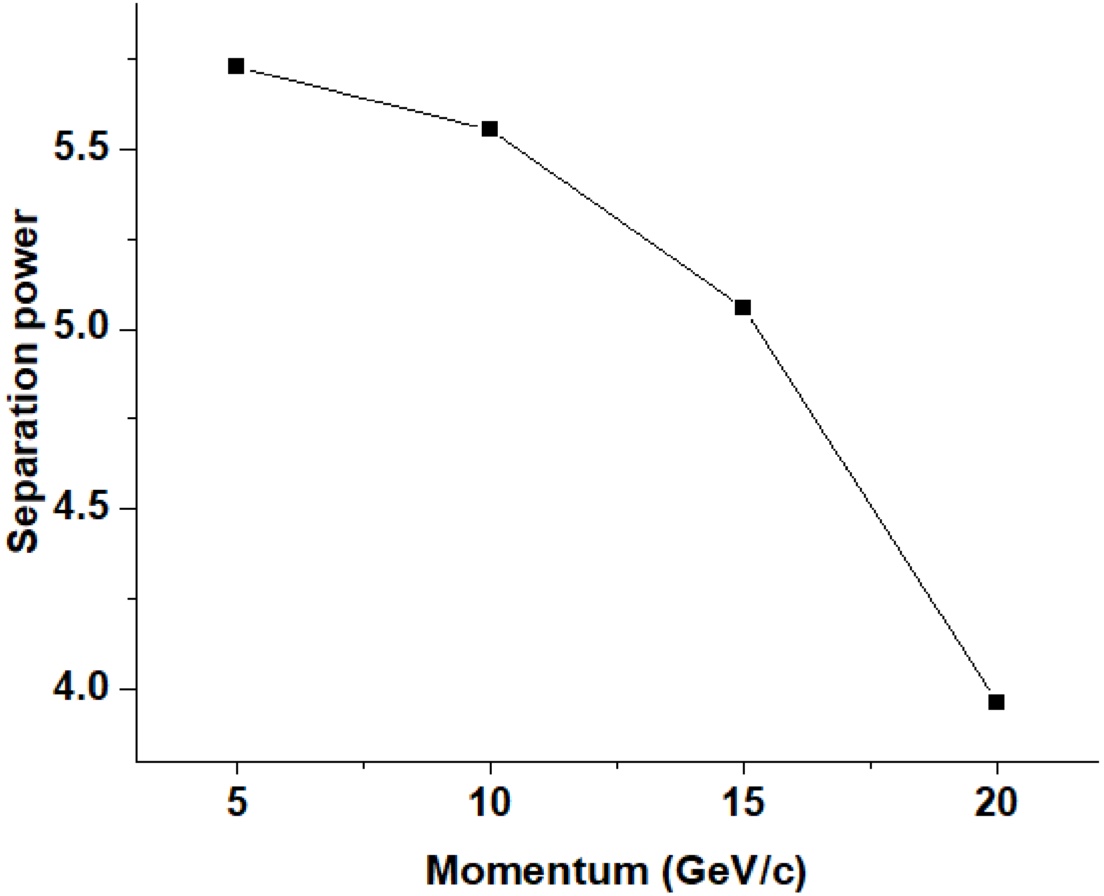
dN/dx only

Kaon PID efficiency (|cosθ| <0.854)



dominant in the high momentum range

K/pi Separation Power



Separation power

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

- **3.5 σ K/pi separation power up to 20 GeV/c**

Summary and plan

- **Summary**
  - With lots of work, the framework of PID part is in place.
  - But there are still many details that need to be revised
    - Criterion for the identification of particles.
    - More realistic simulation of dN/dx
    - Resolutions of dN/dx and ToF
    - …
- **Next to do**
  - More validations
  - Update the parameters of detectors and the resolution of dN/dx.
  - Detector optimizations
  - Demonstrate the significance of PID on physics studies.

Thanks!