Institute of High Energy Physics Chinese Academy of Sciences

Fast simulation of the 4th detector at CEPC with Delphes

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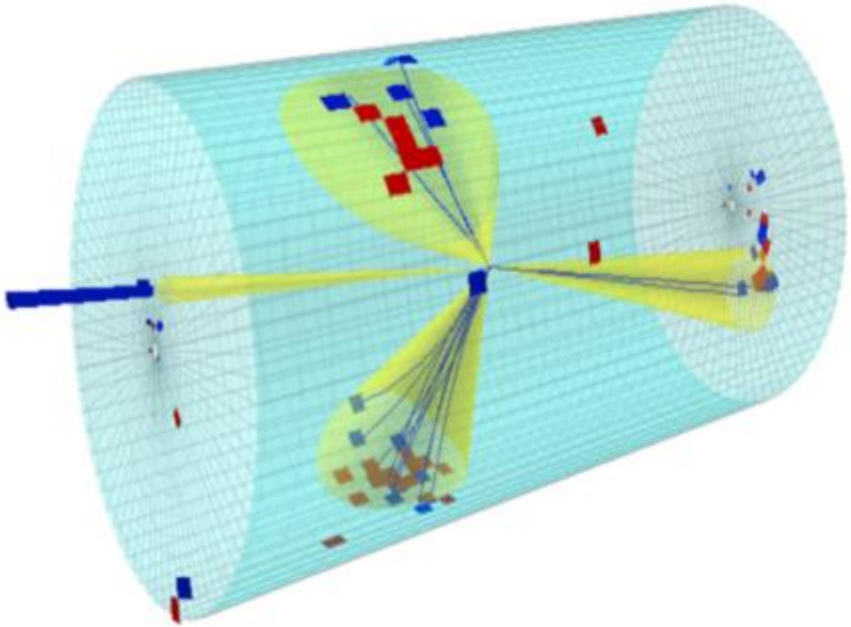
Outline

- Introduction
- Implementation and validations of CEPC new detector
  - Tracker
  - Particle identification(PID)
  - Calorimeter
- Summary

The Delphes

- Delphes is a modular framework that simulates the response of a multipurpose detector
- Includes:
  - charged particle propagation in B field
    - Full Covariance
  - EM/Had calorimeters
  - particle-flow
  - ……
- Provides:
  - tracks, photons, neutral hadrons
  - Lepton/photon isolation
  - Jets(eekt), missing energy

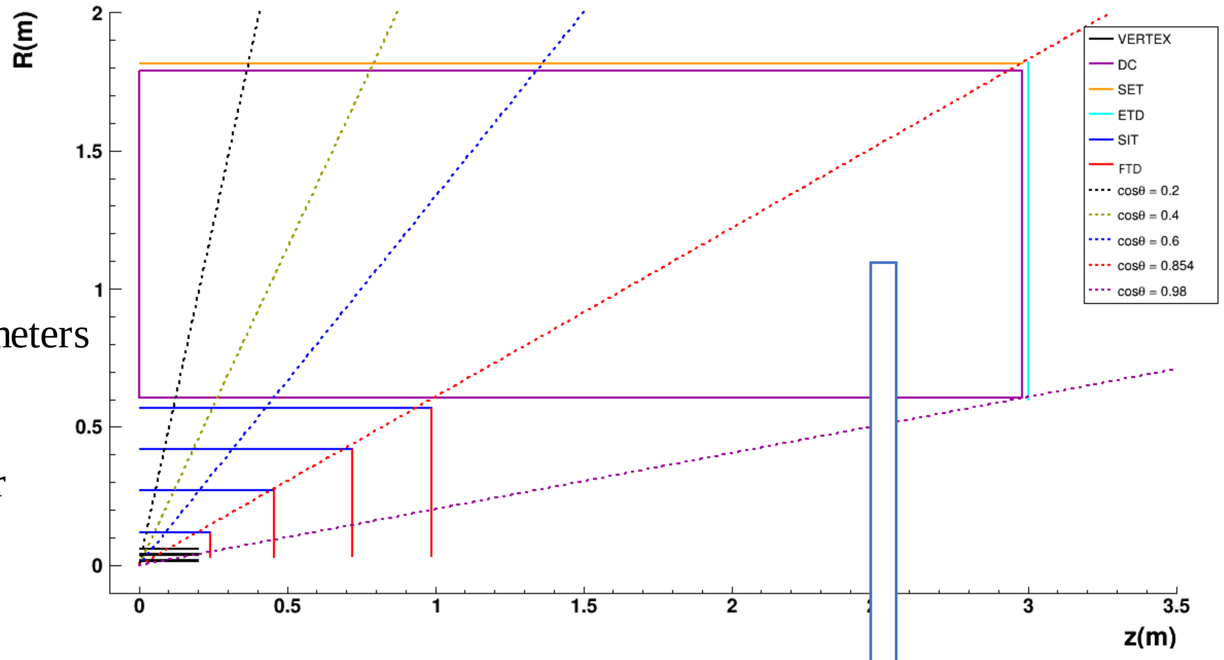


Fast simulation of the 4th detector at CEPC

- Delphes can provide a way for physics studies at a fast speed but it is unsatisfactory in simulation of CEPC detector

- In order to physics with new CEPC detector more work
  - Implement the detector with a tcl card
  - Provide a dedicated PID module
  - Provide more flexibility between lepton/photon isolation and jet cluster

The detector layout



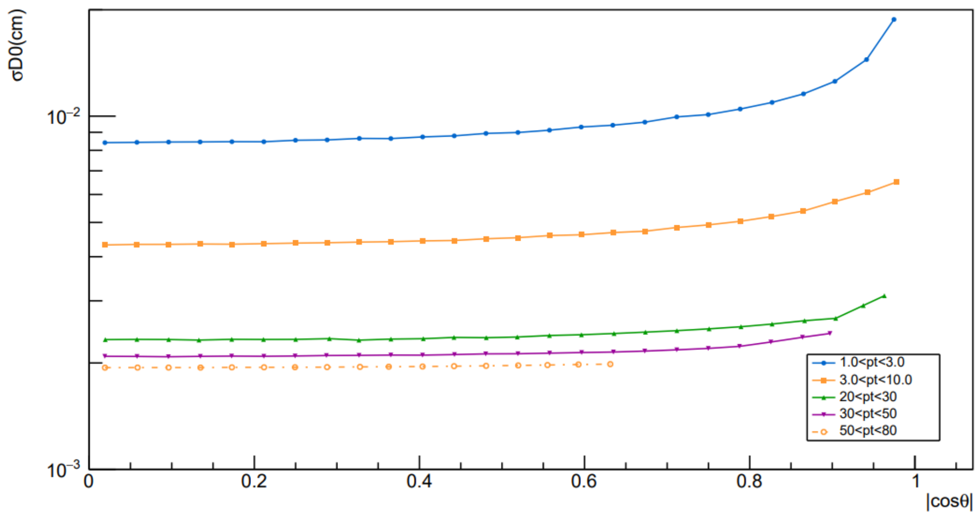
- **VTX(Vertex Detector):**
  - Six high spatial resolution pixel detector.
  - Accurate measurement of charged particle track parameters
- **Drift Chamber:**
  - A cylinder with an inner diameter of 0.6 m and an outer diameter of 1.8 m.
  - Determine the momentum of charged particle
- **Silicon Tracker:**
  - Consist of SIT(Silicon Inner Tracker), FTD(Forward Tracking Detector), SET(Silicon External Tracker), ETD(Endcap Tracking Detector).

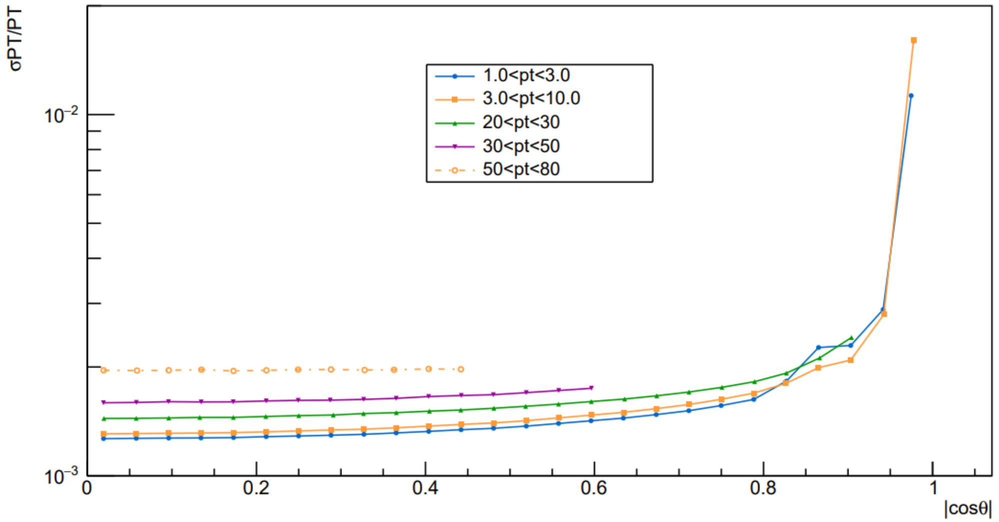
  Provide high precision information of collision points on the trajectory.
- **Calorimeter**
- **Superconducting magnets**
- **Muon Detector**

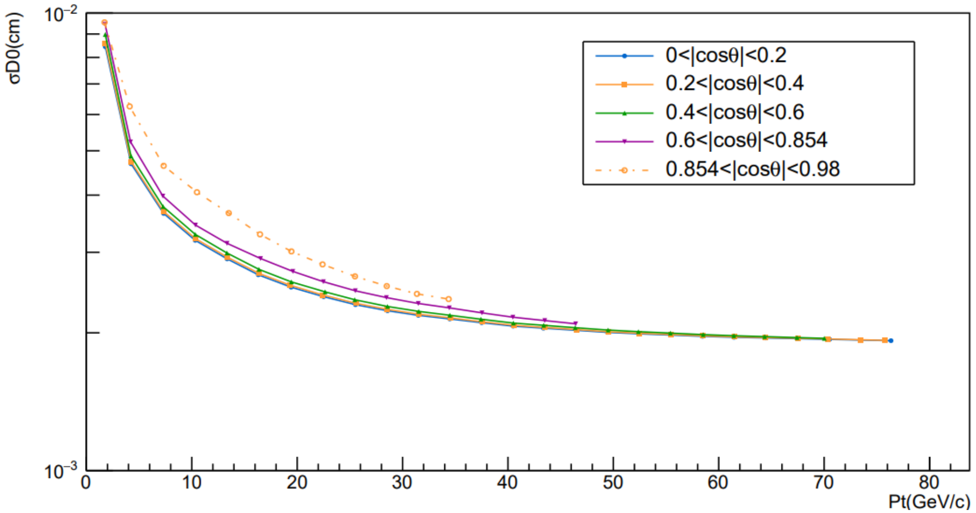
Inner diameter from 0.8m to 0.6m

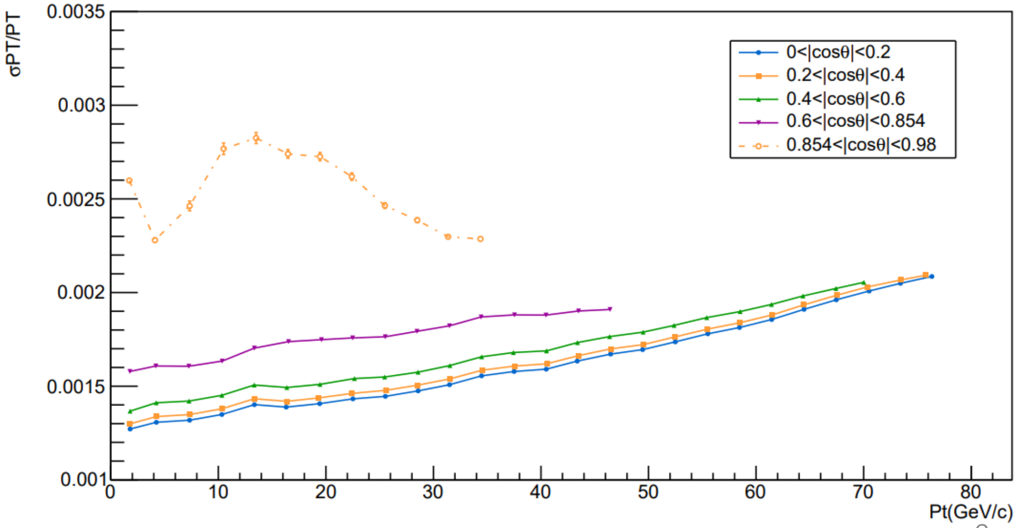
Tracker performance

σD0 with the above detector geometry and σPT/PT

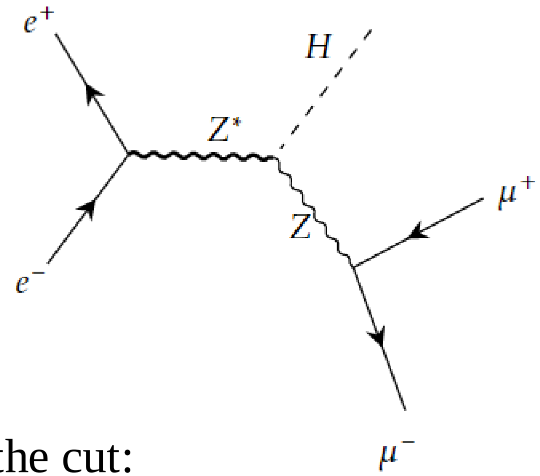








Tracker performance

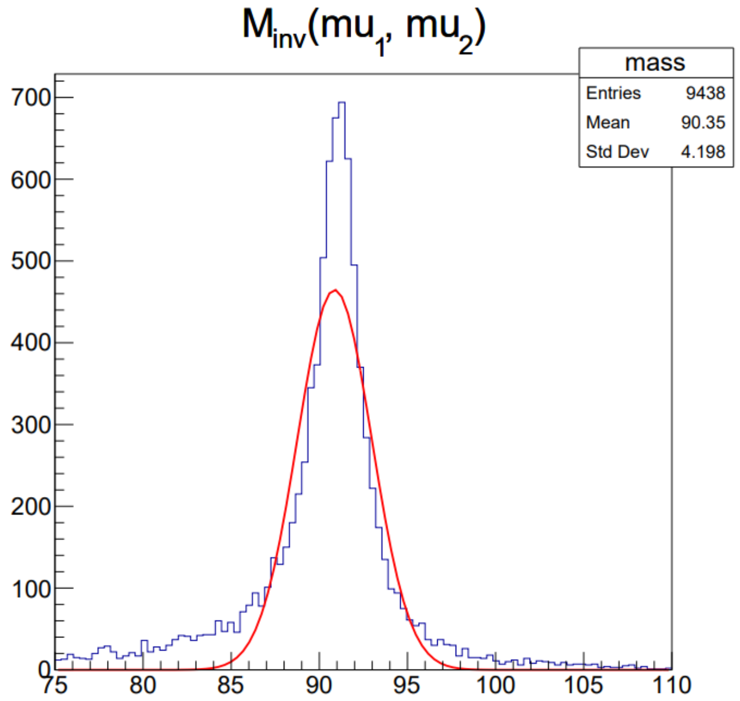
Test for  at 240GeV

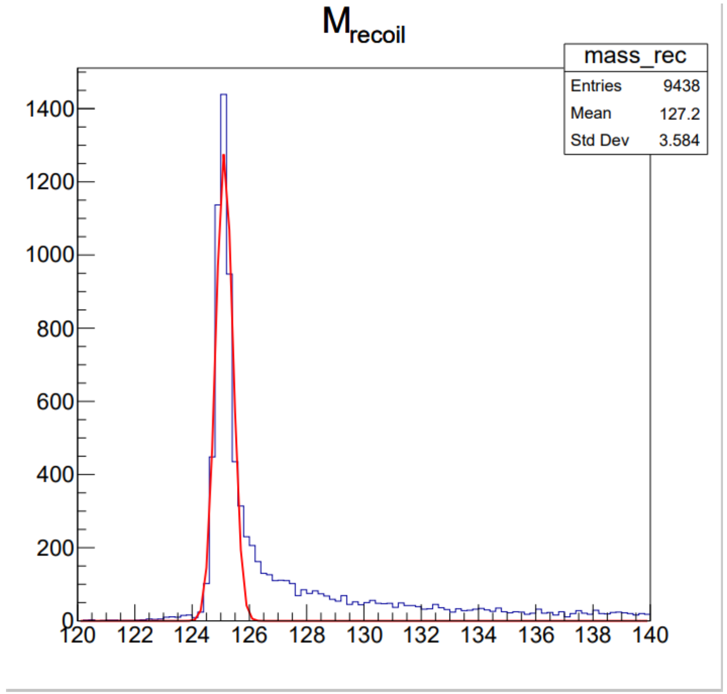
we can choose the cut:

- a $\mu+$ and a $\mu-$
- Both momentum greater than 18.GeV
- Invariant mass around 91 GeV

to find the two muons ,the recoil mass is related to Higgs.

Total entries =10000， efficiency ≈95 %
Muons invariant mass peak:90.9GeV
Recoil invariant mass peak:125.1GeV， resolution： 0.3GeV
Basically as expected.

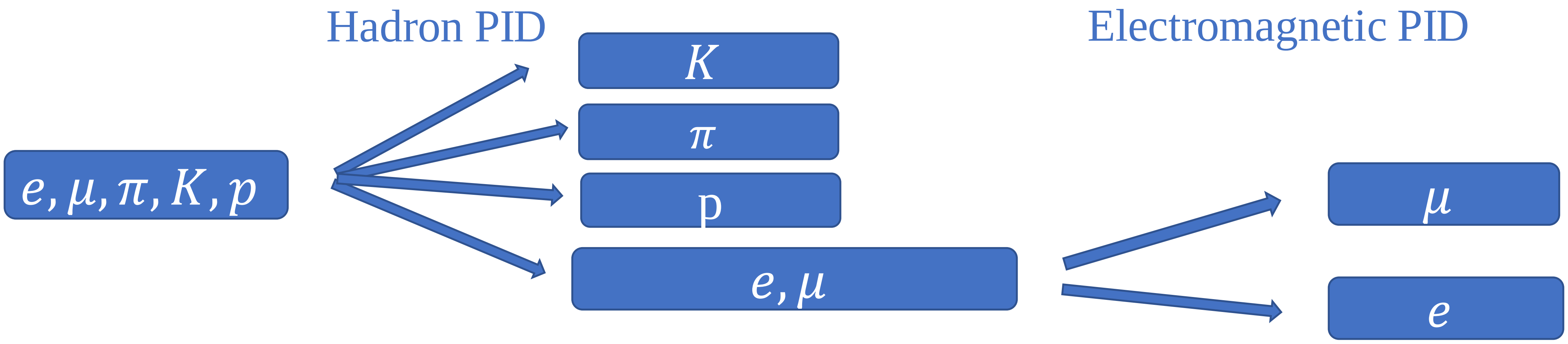




PID

- **PID to identify e, μ, π, K, p , according to the different mass among different particles**

- Hadron PID : identify π, K, p in Drift Chamber
- Electromagnetic PID : identify e, μ using Energy Calorimeter and Muon Detector

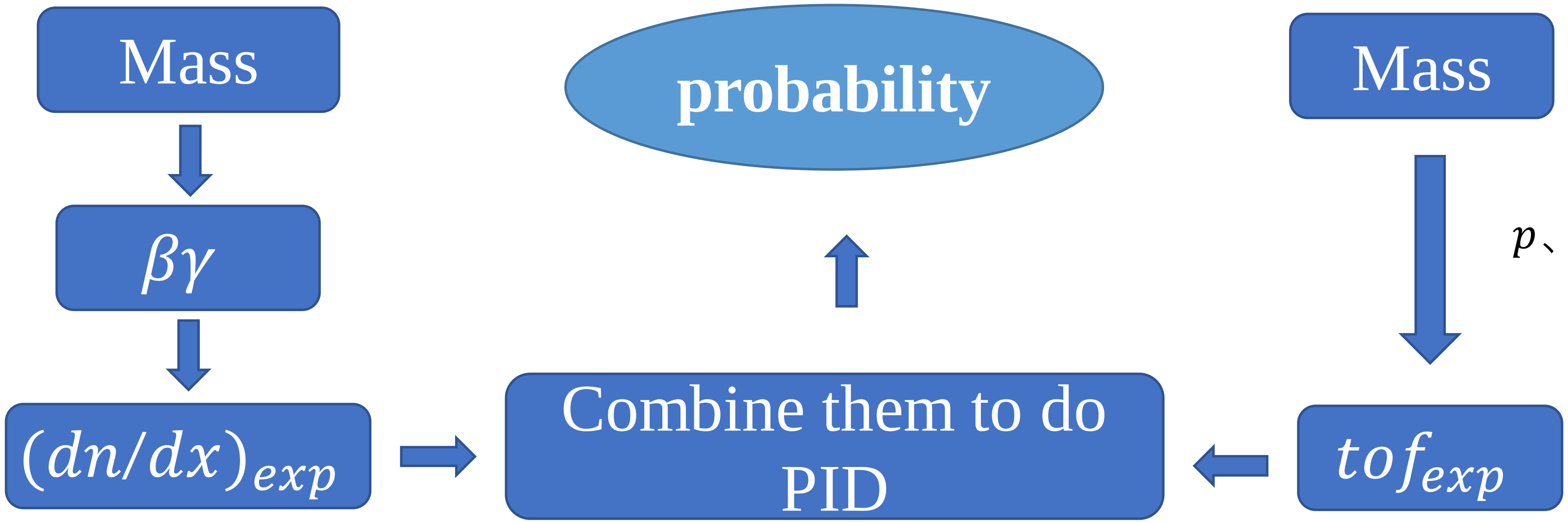


◆ **Pion and kaon identification is always the hardest, because the mass of proton is much greater than pion's and kaon's.**

Hadron PID

- Calculate the probabilities of particles by assuming their masses
  - $\pi, K, p \cdots$

- **The most likely assumption is taken**



The calculation of the probability

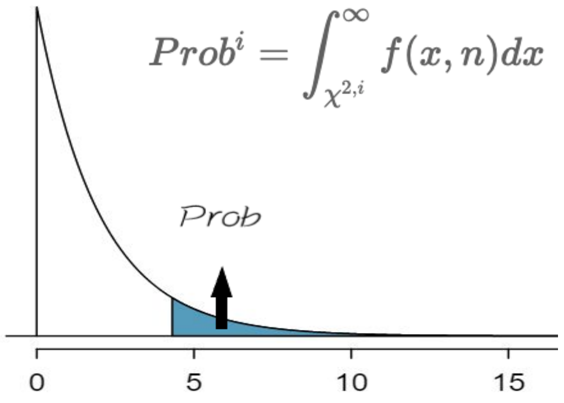
Define chi-square:

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

$$\chi_1^i = \frac{(dN/dx)_{meas} - (dN/dx)_{exp}^i}{(\sigma)_{dN/dx}^i} \qquad \chi_2^i = \frac{(tof)_{meas} - (tof)_{exp}^i}{(\sigma)_{tof}^i}$$

Calculate 3 chi-squares for different assumptions

Integrate for the probabilities (integral)



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

K/pi Separation Power(dN/dx)

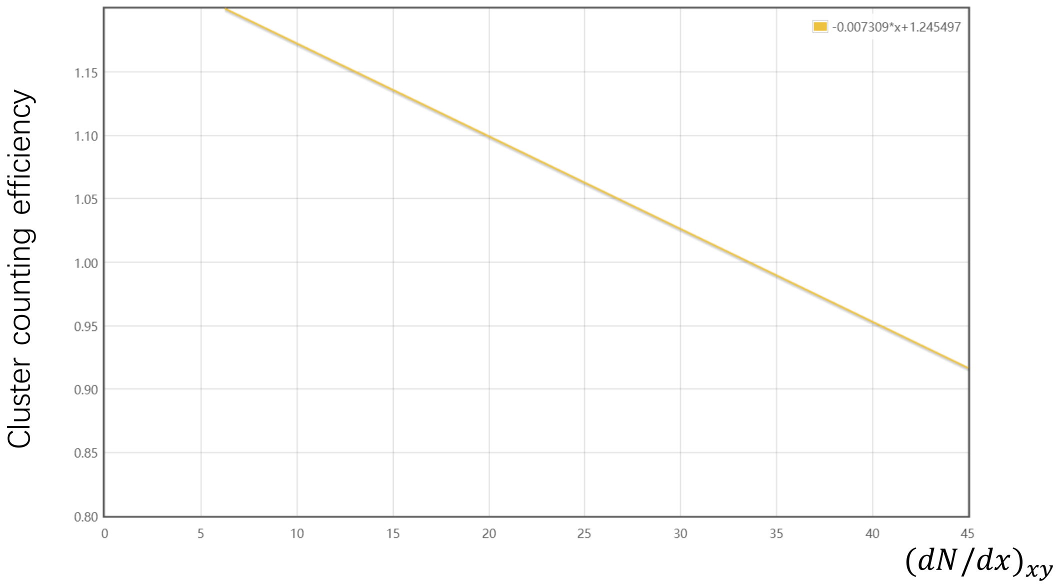
Separation power

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

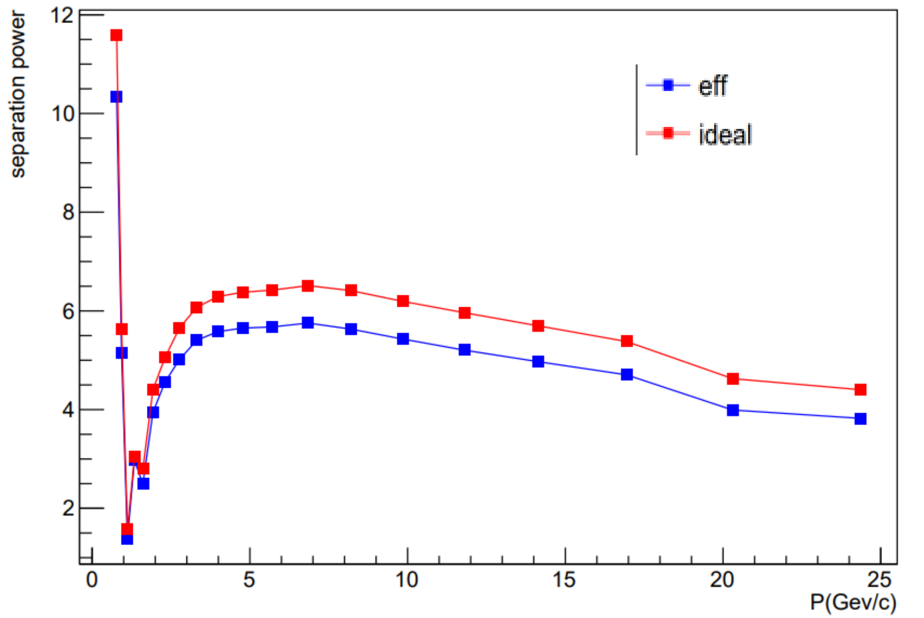
Consider effect of cluster counting efficiency as a function of dN/dx in xy plane

$$\varepsilon_{counting} = \frac{dN/dx_{meas}}{dN/dx_{real}}$$

Cluster counting efficiency curve is tested with 2% noise



Ideal vs consider cluster counting efficiency



Only considering π and K later

PID efficiency only using dN/dx and tof respectively

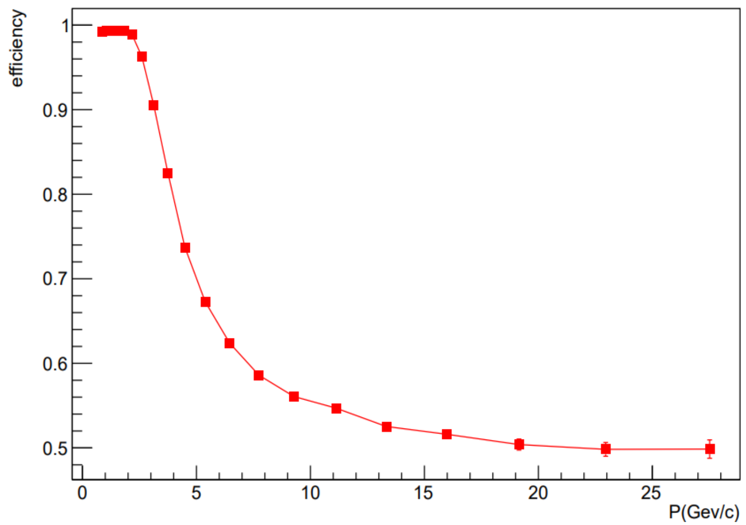
$$\epsilon^K = \frac{n_{sel}^K}{n_{tot}^K}$$

- ϵ^K is Kaon PID efficiency
- n_{sel}^K is number that K is identified as K ($Prob^k > Prob^{\pi}$)
- n_{tot}^K is number of K

dominant in the low momentum range

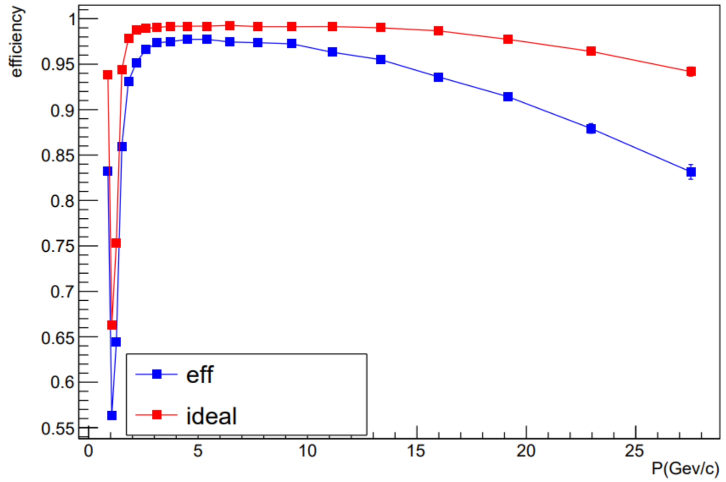
kaon PID efficiency $(|\cos\theta| < 0.854)$

ToF only



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

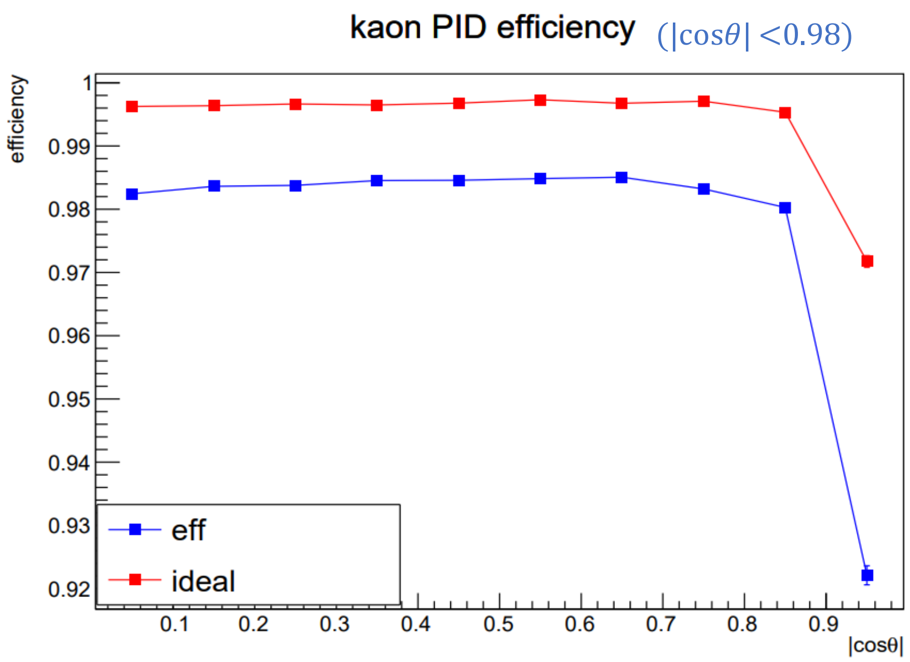
dN/dx only

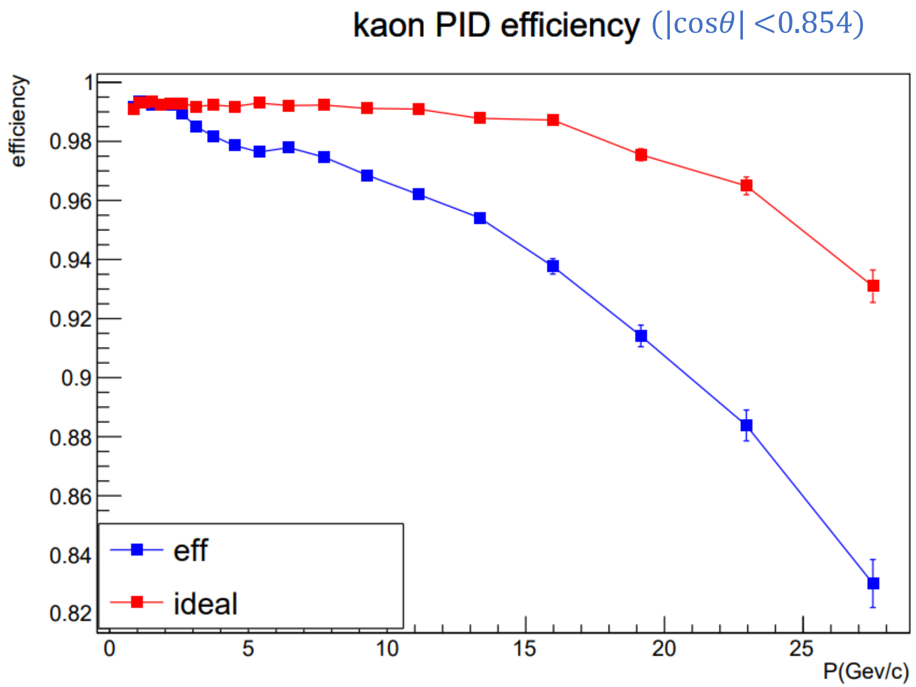


dominant in the high momentum range

PID efficiency

Combine dN/dx and tof





When $|\cos\theta|$ < 0.90, The PID performance is better

As momentum increases, efficiency decreases quickly

Calorimeter Resolution

Set the resolution formula as a function of energy:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{c}{E} \oplus \text{b}$$

- a , stochastic term:Fluctuations in the number of signal generating processes
- c , noise term:Noise in readout electronics, ‘pile-up’ due to other particles from other collision events
- b , constant term:Imperfections in calorimeter construction,Non-uniform detector response,etc.

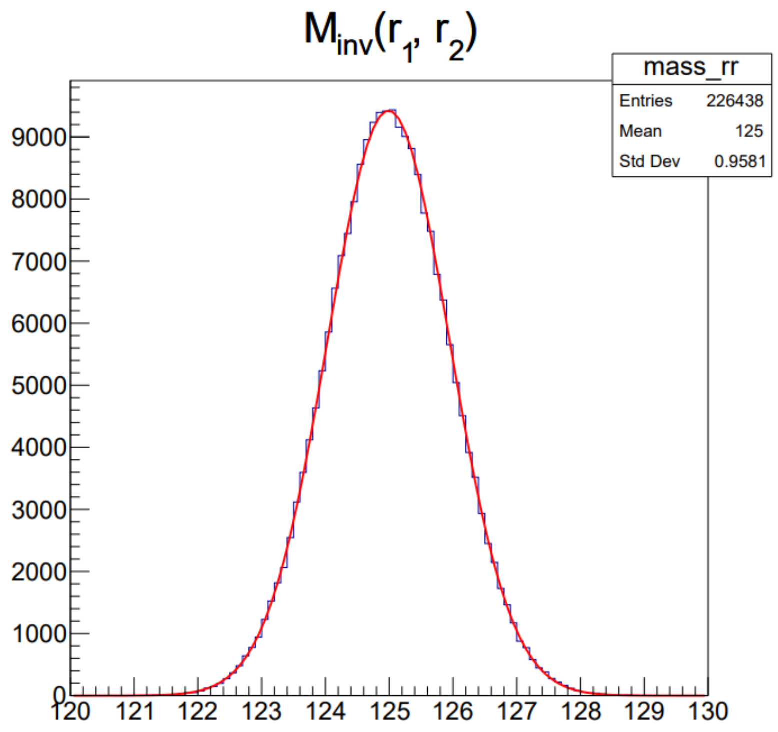
Ignoring the noise term,

- for ECAL, set a_E=0.03, b_E=0.01
- for HCAL:set a_H=0.4,b_H=0.02

consider H→γγ ,H→gg→2 jets,draw the invariant mass spectrum

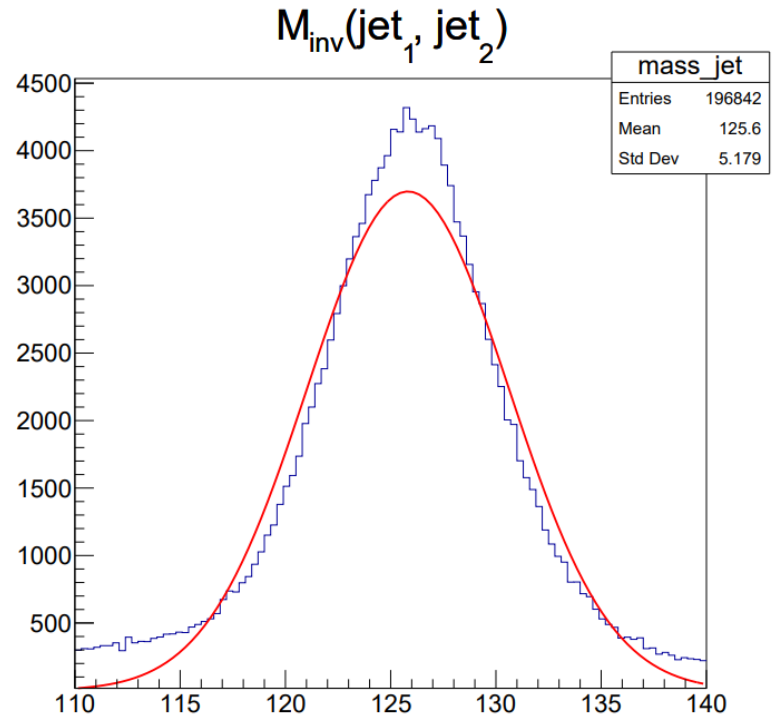
Gamma and jet

$H \to \gamma\gamma$



Mean = 124.99±0.002 GeV ,
Resolution = 0.96 ±0.01 GeV

$H \to gg \to 2jet$



Mean = 125.82±0.013 GeV ,
Resolution = 4.78 ±0.013 GeV

Summary

- Simulation of CEPC the 4th detector with Delphes is ready to use
    - The detector layout is implemented and validated
    - PID : probabilities of different hypotheses of tracks provided for analyzers
    - Guarantee there is no overlap between lepton/photon isolation and jet clustering with eekt
- Still many works need to do
    - More validation
    - updates according to detector optimization.
    - More realistic simulation of dN/dx and cluster counting efficiency curve will be improved
    - …
- Welcome to use and feedback!

Thanks!

Backup

Tracker layout

Detector	Layer	Radius(mm)	Halfz(m)	Material budget[x/X0]
VXD(	1	16	0.2	0.0015
	2	18	0.2	0.0015
	3	38	0.2	0.0015
	4	40	0.2	0.0015
	5	58	0.2	0.0015
	6	60	0.2	0.0015
Shell	1	65	0.2	0.0015
SIT	1	120	0.241	0.0065
	2	270	0.455	0.0065
	3	420	0.721	0.0065
	4	570	0.988	0.0065
Inner wall	1	600	2.98	0.00104
DC	80	600-1800	2.98	0.002
Outer wall	1	1800	2.98	0.01346
SET	1	1815	2.98	0.0065

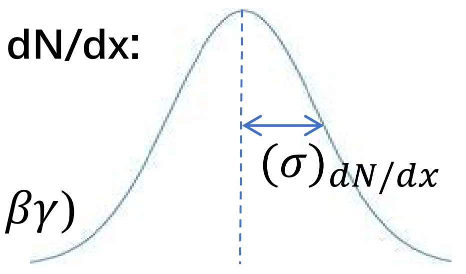
Tracker layout

Detector	Rin(mm)	Rout(mm)	Z(m)	Material budget[x/X0]
DSK1A	29.5	120	0.241	0.0065
DSK1B	29.5	120	-0.241	0.0065
DSK2A	30.5	270	0.455	0.0065
DSK2B	30.5	270	-0.455	0.0065
DSK3A	32.5	420	0.721	0.0065
DSK3B	32.5	420	-0.721	0.0065
DSK4A	34	570	0.988	0.0065
DSK4B	34	570	-0.988	0.0065
ETD1	600	1822	3.0	0.0065
ETD2	600	1822	-3.0	0.0065

The calculation of χ

- **dN/dx** $\chi_1^i = \frac{(dN/dx)_{meas} - (dN/dx)^i_{exp}}{(\sigma)^i_{dN/dx}}$
  - ◆ dN/dx and $(\sigma)_{dN/dx}$ are functions of $\beta\gamma$
    - ◆ $dN/dx_{exp} = f(\beta\gamma) * \varepsilon_{counting}$ (f is the theoretical function that only depends on $\beta\gamma$)
    - ◆ $(\sigma)_{dN/dx} = \varepsilon_{counting} * \sqrt{f(\beta\gamma)}$
  - ◆ 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 $\beta\gamma$

dN/dx:

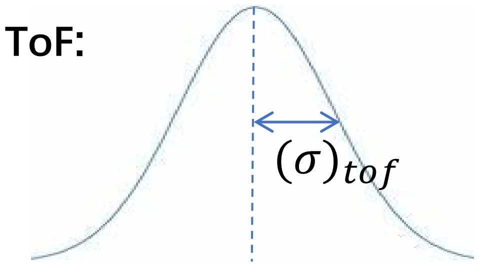


mean

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

- **ToF** $\chi_2^i = \frac{(tof)_{meas} - (tof)^i_{exp}}{(\sigma)^i_{tof}}$
  - ◆ $(tof)_{exp} = \frac{L}{v} = \frac{L}{\beta c}$ $\beta = \frac{p}{\sqrt{p^2 + (m^i)^2}}$
  - ◆ $(tof)_{meas}$: follows a Gaussian distribution with mean = $(tof)_{exp}$ and $(\sigma)_{tof}$
  - ◆ $(\sigma)_{tof} = 30ps$

ToF:



mean

mean = $(tof)_{exp}$