Fast Simulation of the 4th detector at CEPC and analysis with it

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Outline

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- Detector configuration
  - Track resolution
  - Particle identification
  - Calorimeter
  - Jet clustering
- Analysis : $B^0/B_s^0 \to hh'$
  - Motivation and MC samples
  - Event selection
  - Result with PID and without PID
- Summary

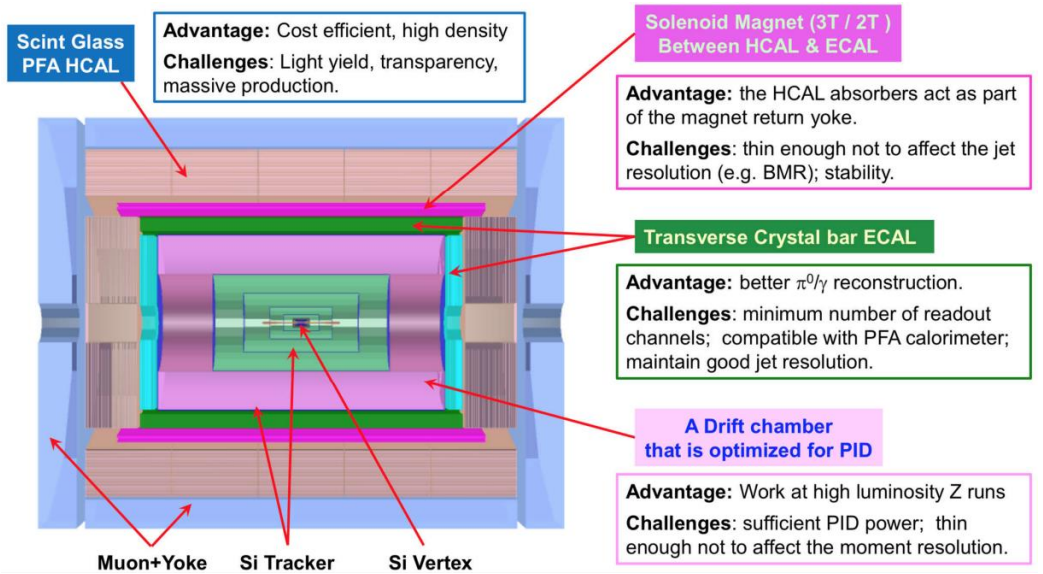
Introduction

- CEPC
  - 240 GeV Higgs factory : 4×10^5 ZH
  - 91.2 GeV Z factory : 4×10^{12} Z
  - 160 GeV WW threshold scan : 2×10^7 WW

- The 4th conceptual detector
  - Tracker with silicon trackers and a drift chamber
  - The chamber optimized for PID with dN/dx
  - PFA with scint glass HCAL and crystal ECAL

A fast simulation of the 4th conceptual detector is essential due to the large production!

Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			~240	~91.2	~160	~360
Run time [years]			7	2	1	-
CDR (30 MW)		L / IP [$\times 10^{34}$ $cm^{-2}s^{-1}$]	**3**	**32**	**10**	-
		$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	~5
Latest	30 MW	L / IP [$\times 10^{34}$ $cm^{-2}s^{-1}$]	**5.0**	**115**	**16**	**0.5**
	50 MW	L / IP [$\times 10^{34}$ $cm^{-2}s^{-1}$]	**8.3**	**191.7**	**26.6**	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	20	96	7	1
		Event yields [2 IPs]	4×10^6	4×10^{12}	2×10^7	5×10^5

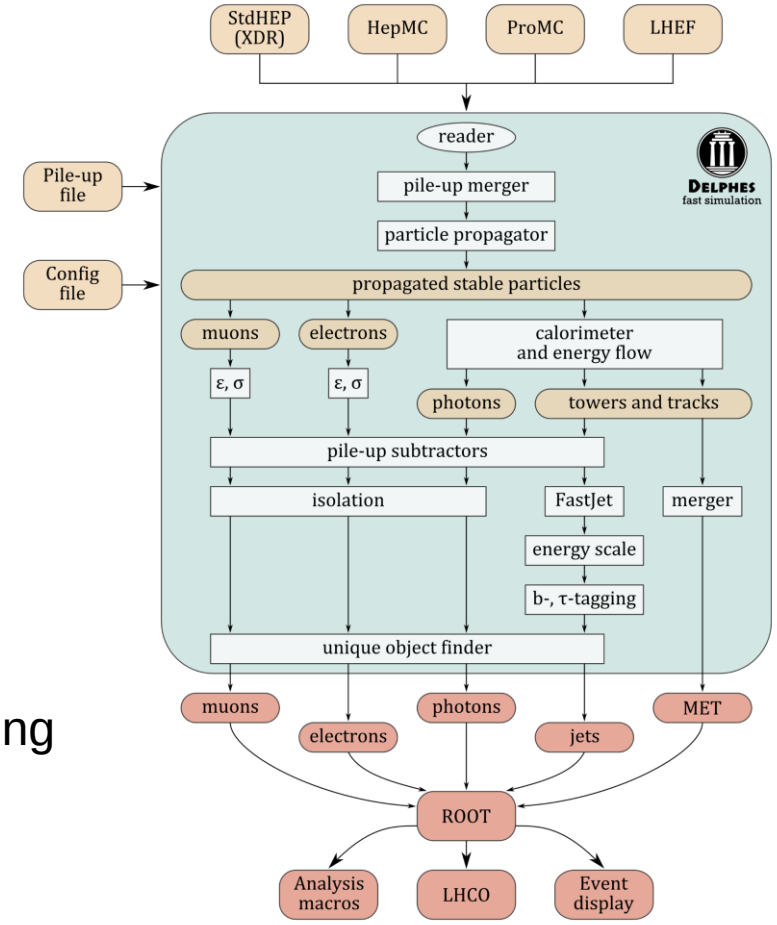


Introduction

- Delphes is a tool that simulates the response of detector
  - $10^2 \sim 10^3$ faster than the fully GEANT based simulations
  - Sufficient and widely used for phenomenological studies

- For simulations of the 4th detector at CEPC:
  - 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 https://github.com/oiunun/Delphes_CEPC.git



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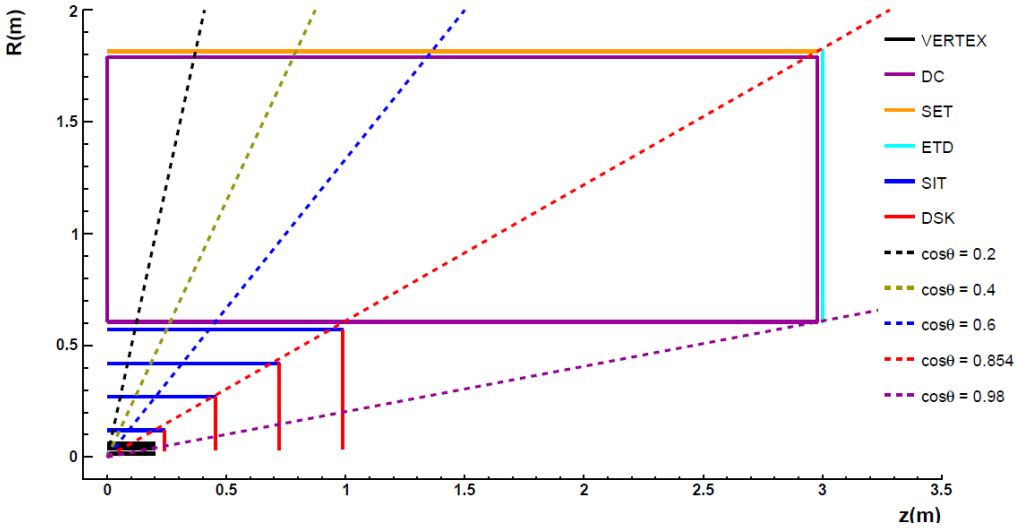
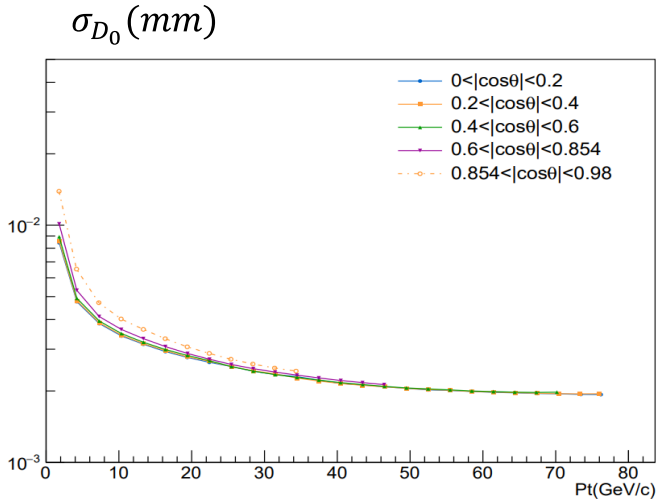
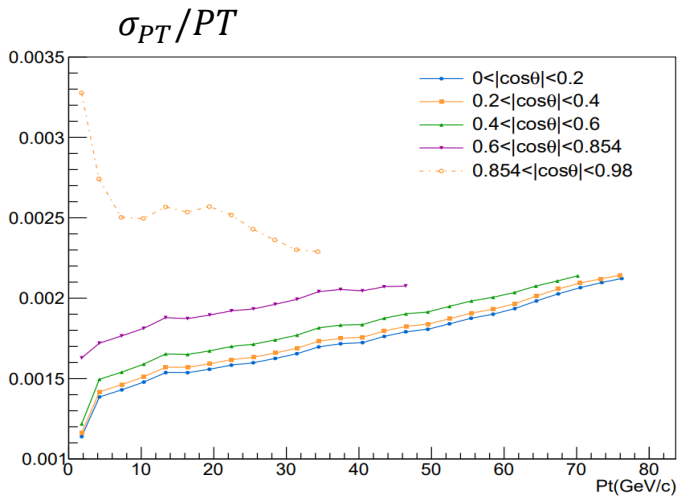
Track resolution

- Six layers of vertex detectors provide high resolution of impact parameters.
- A silicon inner tracker (SIT) cooperates with the VXD for vertex reconstruction.
- A set of forward tracking disks (FTD) increases the geometric acceptance of tracking system.
- A silicon external tracker (SET) and end-cap tracking (ETD) disks provide high precision position measurements of tracks entering the calorimetry system.
- Full covariance matrix is provided which can be used for vertex fit



- The resolution of Impact parameters and transvers momentum is shown in figures:



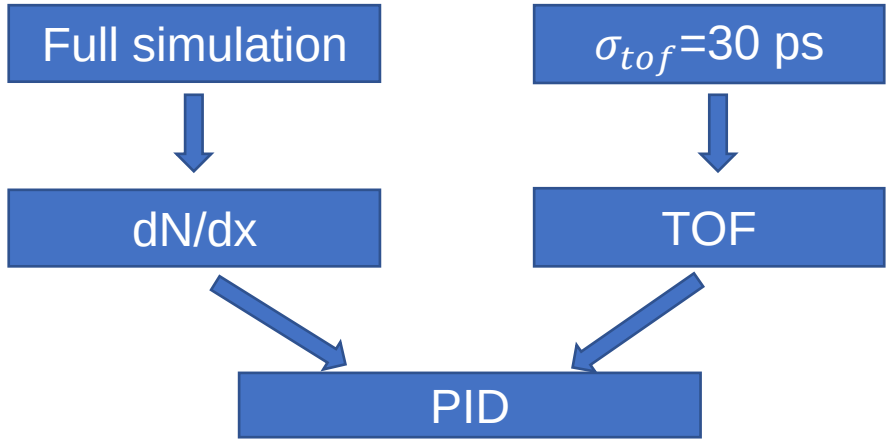


The result is consistent with full simulation!

PID with dN/dx and TOF

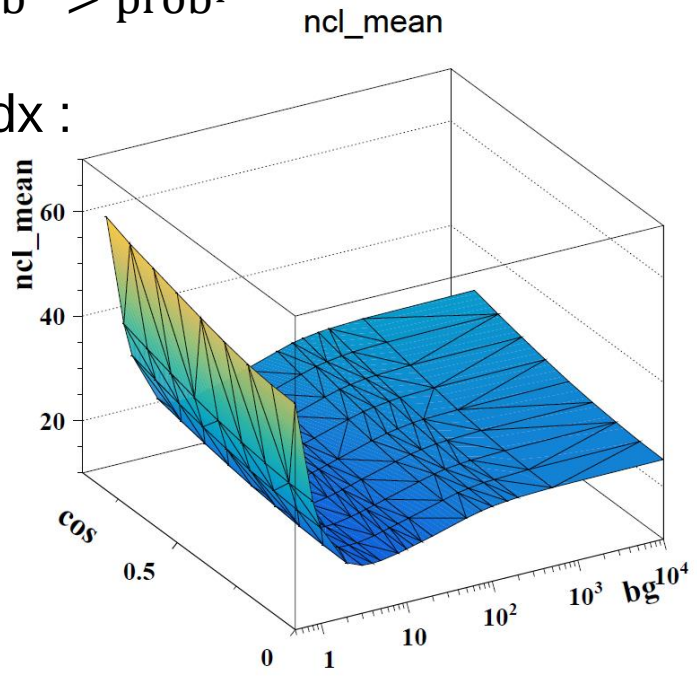
- Combine dN/dx and TOF with χ^2
  - $\chi^{2,\mathrm{i}} = \chi^{2,\mathrm{i}}_{\mathrm{dN/dx}} + \chi^{2,\mathrm{i}}_{\mathrm{tof}}$, i represent particle hypothesis
  - $\mathrm{prob}^{\mathrm{i}} = \int_{\chi^{2,\mathrm{i}}}^{\infty} \mathrm{f}(\mathrm{x},2)\,\mathrm{dx}$, $\mathrm{f}(\mathrm{x},2)$ is pdf of χ^2 that freedom is 2
  - Identify particle by $\mathrm{prob}^{\mathrm{i}}$

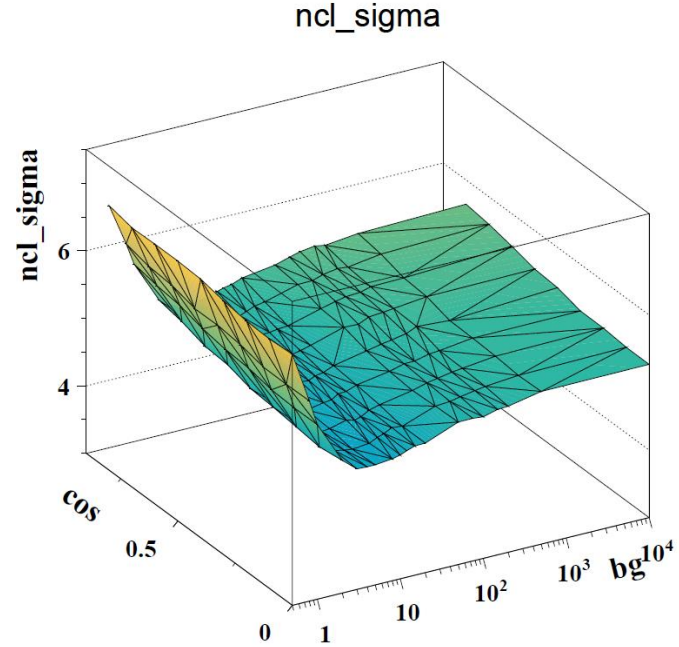
  e.g. identified as π : $\mathrm{prob}^{\pi} > \mathrm{prob}^{\mathrm{K}}$ && $\mathrm{prob}^{\pi} > \mathrm{prob}^{\mathrm{p}}$



- The latest result of full simulation of dN/dx :
  - $\mathrm{dN/dx_{mean}}$ vs. $\beta\gamma$ and $\cos\theta$
  - $\mathrm{dN/dx_{sigma}}$ vs. $\beta\gamma$ and $\cos\theta$

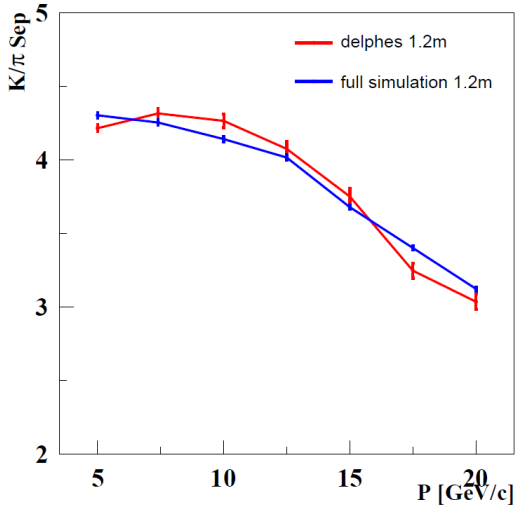
- Parameterize dN/dx in Delphes
  - Interpolate from full simulation

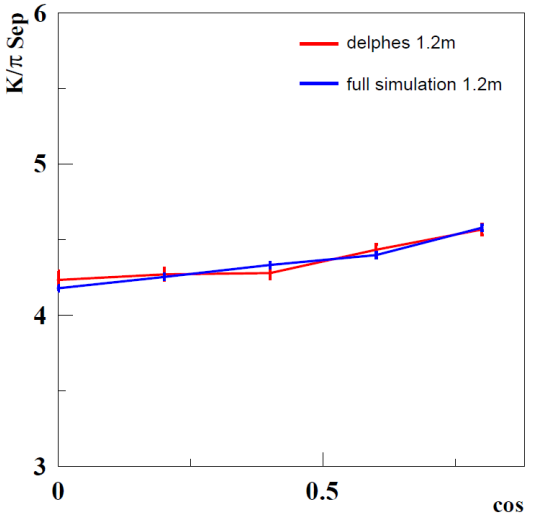




PID performance

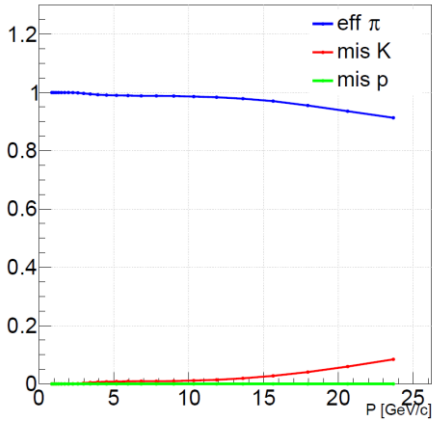
- K/π Separation power vs. full simulation
  - Sep=$\frac{|dN/dx_\pi - dN/dx_K|}{\frac{\sigma_\pi+\sigma_K}{2}}$
  - K/π Sep vs. momentum ($\cos\theta = 0$)
  - K/π Sep vs. cosθ (p=10 GeV)

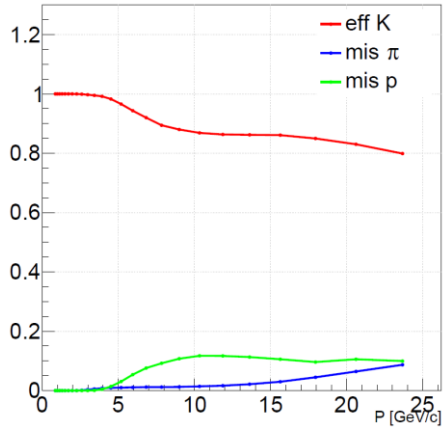


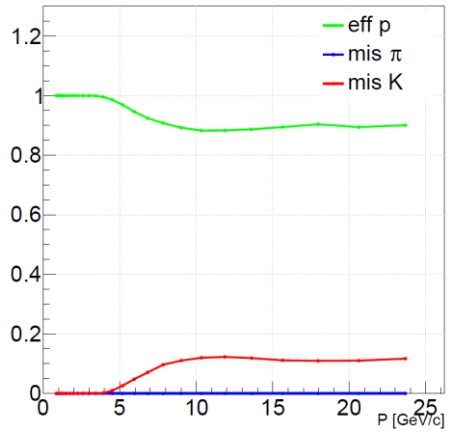


➢ Excellent agreement with full simulation

- PID efficiency and misidentification rate are shown:



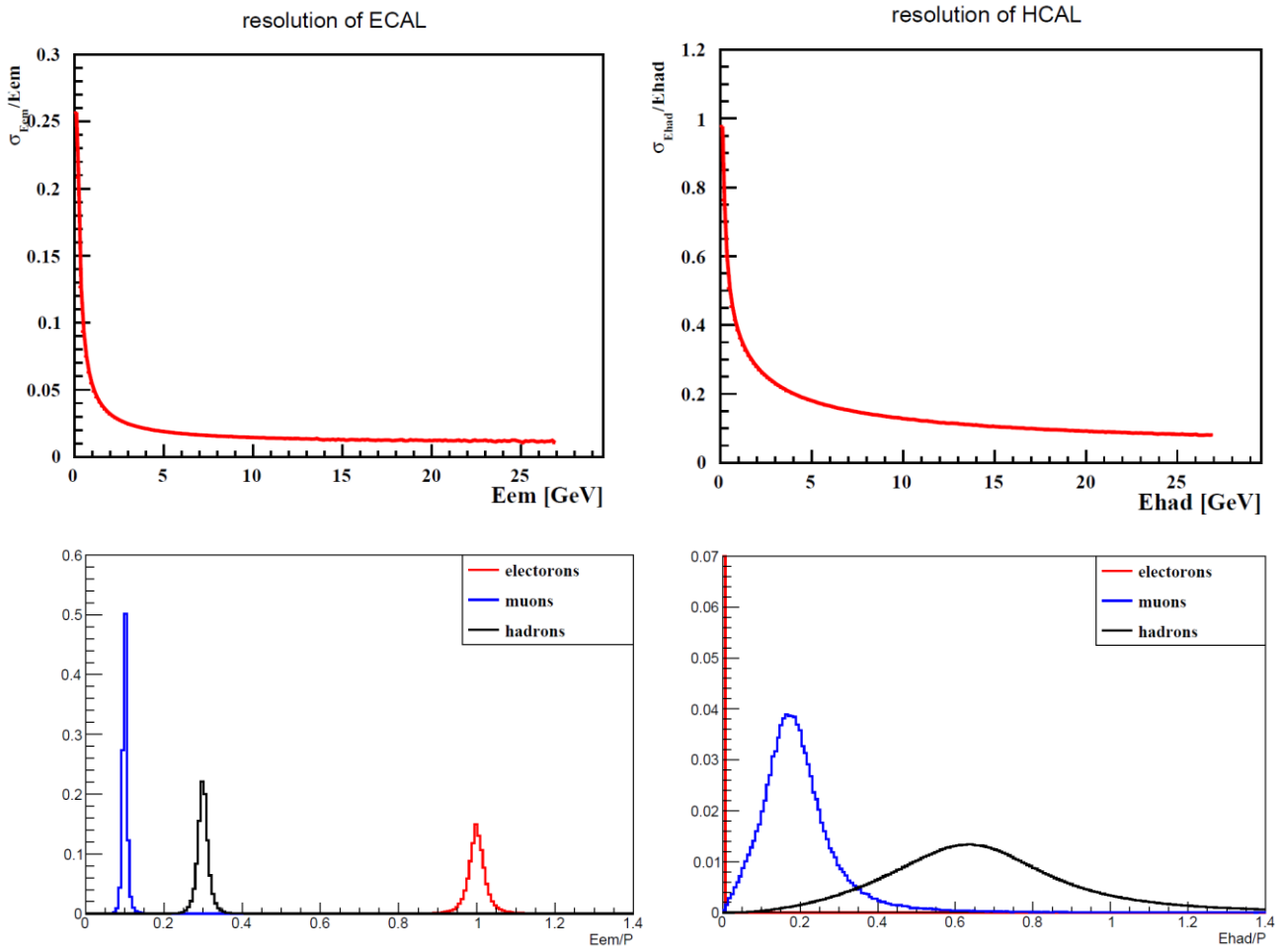




PID in Delphes achieves expected performance by interpolating the results of full simulation ! 👍

Calorimeter

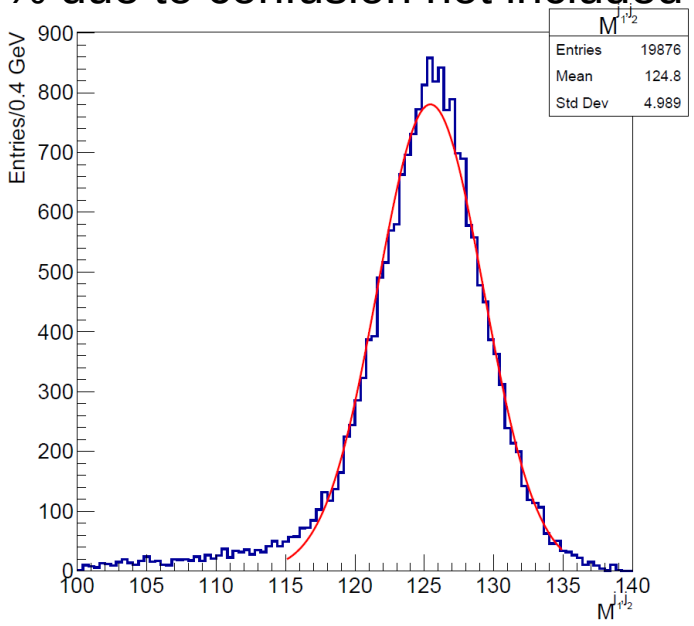
- Geometry :Preliminary geometry
- Resolution
  - $\frac{\sigma_E}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$
  - S, N, C is stochastic, noise and constant term
  - Noise term neglected temporarily
  - For ECAL, S_E=0.03, C_E=0.01
  - For HCAL, S_H=0.4,C_H=0.02
- Eem/P and Ehad/P for different particles
  - Ideal identification between e, μ and hadrons

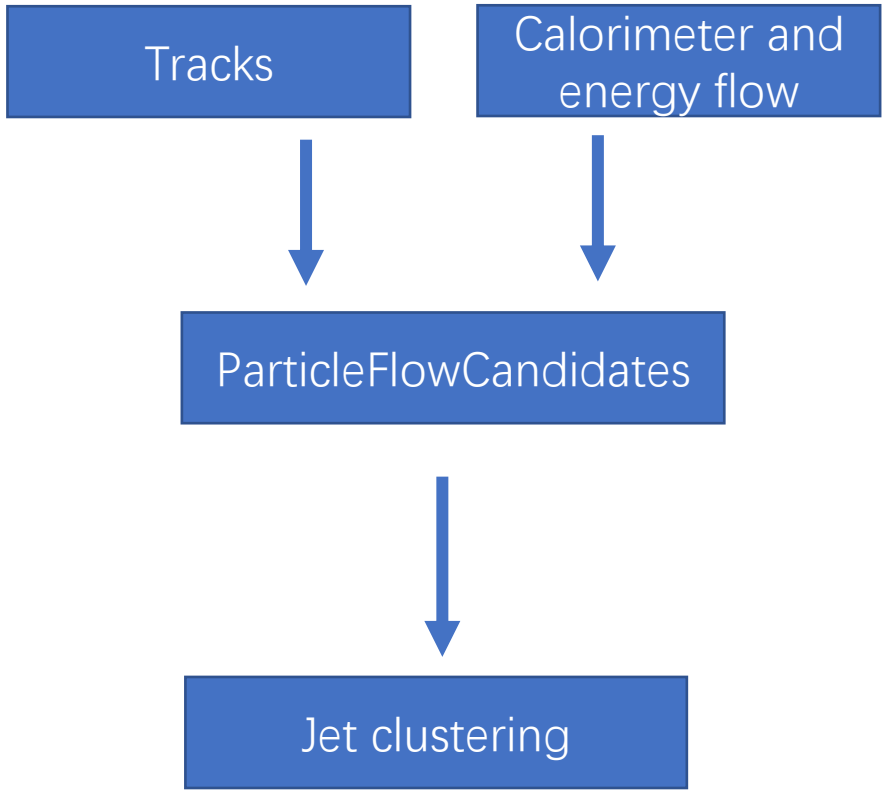


Calorimeters provide energy of photon and neutral particle for jet clustering and lepton/hadron identification

Jet clustering

- Jet clustering with the Fastjet package
  - ee-kt algorithm for ee collider
- Jet resolution for e^+e^- → Z(di-nu)H(di-jets)
  - Without ISR
  - BMR < 4% due to confusion not included





Jet energy resolution a bit ideal

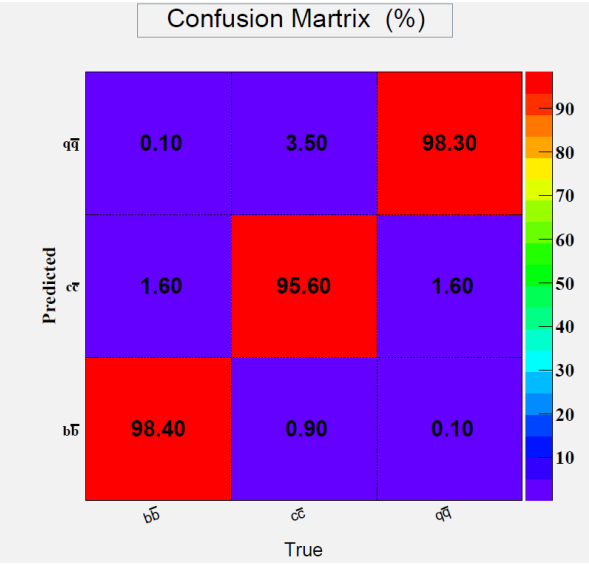
Analysis : $B^0/B_s^0 \to h^+h'^-$

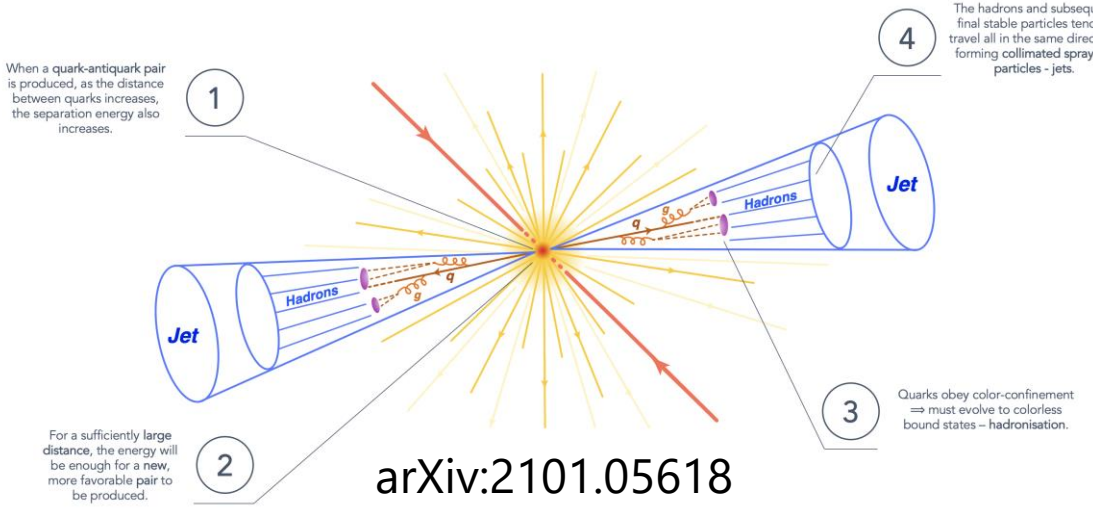
- Motivation
  - The study of charmless B meson→ $h^+h'^-$decays plays an important role in the quest for BSM in the flavor sector
  - Good test platform to study impact of PID in flavor physics
  - Explore physics potential of Tera-Z
- MC Samples
  - Only consider main background $Z \to b\bar{b}$: 2×10^9 for now
  - Signal generator: pythia8, background generator: pythia6
  - Signal branch ratios adopted by PDG

Channel	Branch ratio	Yield ($Z \to b\bar{b}$: 2×10^9)
$B0 \to \pi^+\pi^-$	5.12×10^{-6}	8335
$B0 \to K^+\pi^-$	1.96×10^{-5}	31909
$B0 \to K^+K^-$	7.8×10^{-8}	127
$Bs \to \pi^+\pi^-$	7.0×10^{-7}	283
$Bs \to K^-\pi^+$	5.8×10^{-6}	2343
$BS \to K^+K^-$	2.66×10^{-5}	10747

Event selection

- Background : $Z \to q\bar{q}$ (q is b, c, u, s, d)
- Jet flavor tagging with ParticleNet
  - Tagging two jet flavor in event level
  - High efficiency and purity
  - Remove most backgrounds from $Z \to q\bar{q}$ $(q \neq b)$
  - Only consider backgrounds of $Z \to b\bar{b}$ in the following
- Event selection → Select signal within each jet
  - $Z \to b\bar{b}$ →di-jets
  - Reduce combinatorial background between 2 jets
  - Cleaner background

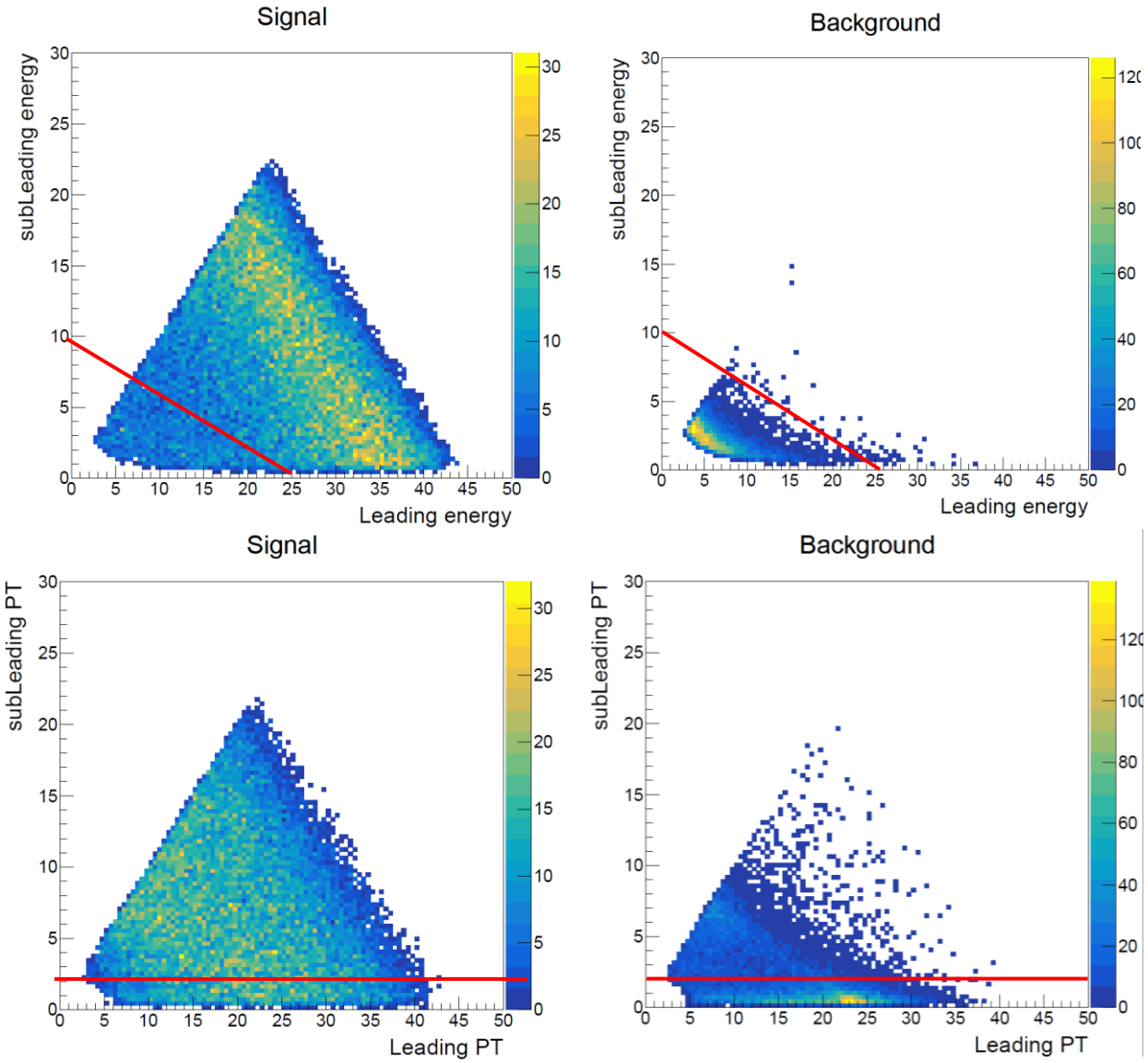




arXiv:2101.05618

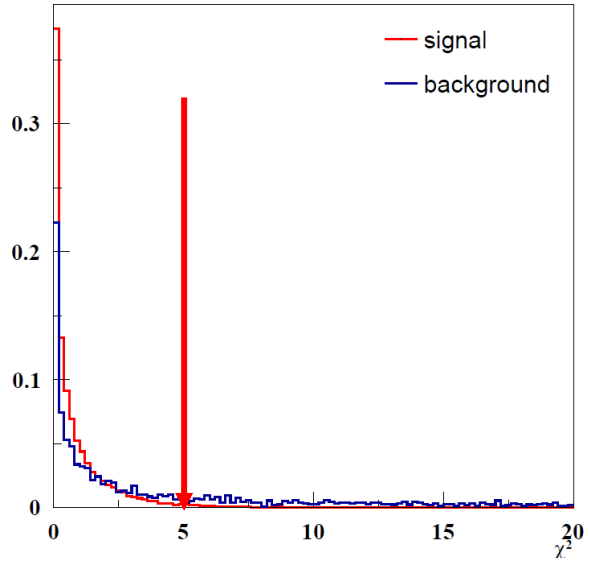
Event selection

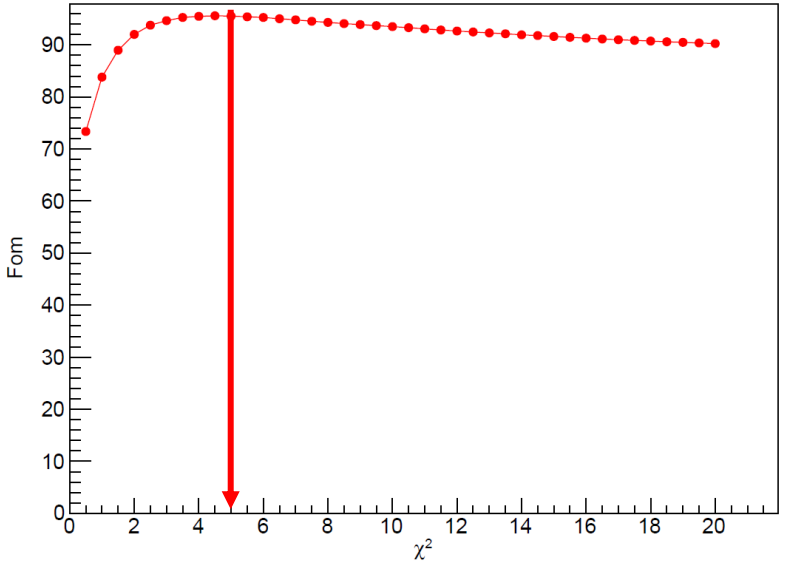
- Select B0/Bs candidates in each jet :
- PID
  - $\pi : Prob(\pi) > Prob(K)$ && $Prob(\pi) > Prob(p)$
  - $K : Prob(K) > Prob(\pi)$ && $Prob(K) > Prob(p)$
- Momentum (phase space) cut for $\mathrm{h^+h'^-}$
  - 0.4*LeadingE+subLeadingE>10 GeV
  - subLeadingPT>2 GeV
- Vertex Fit for $\mathrm{h^+h'^-}$
  - $\chi^2 < 5$
  - $\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}$>2500



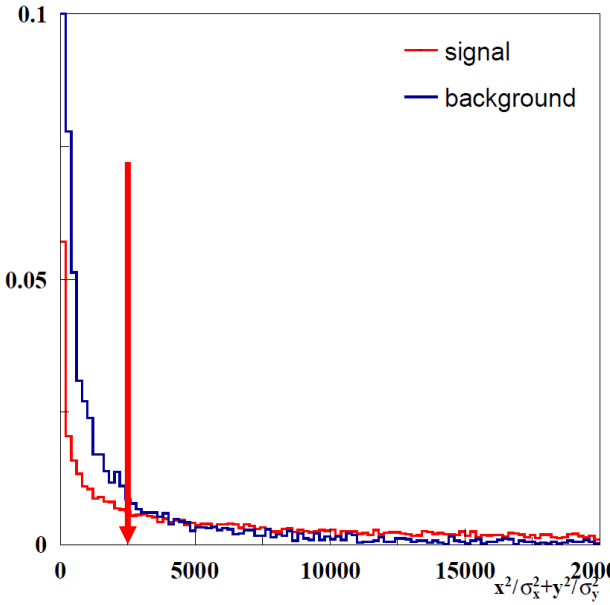
Vertex Fit

Vertex Fit for $h^+h'^-$: $\chi^2 < 5$



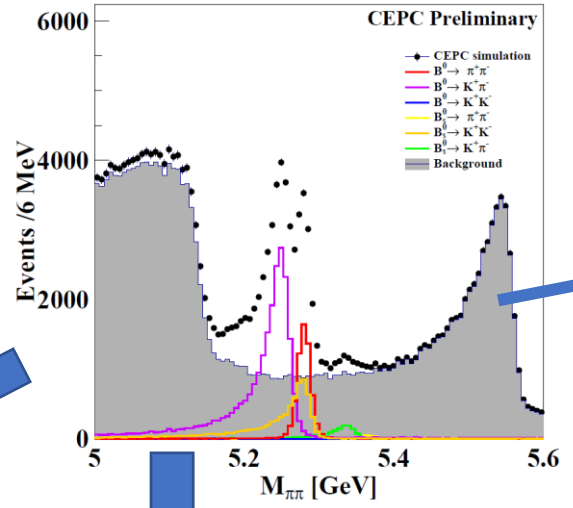


Vertex Fit for $h^+h'^-$: $\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}$ >2500



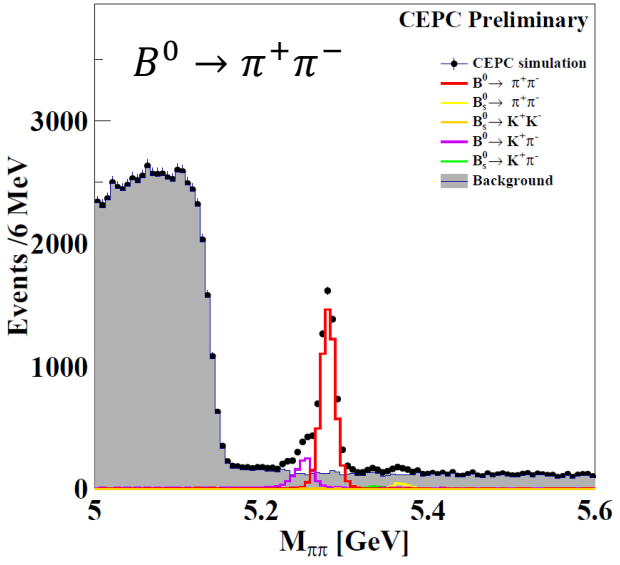
Result with PID and without PID

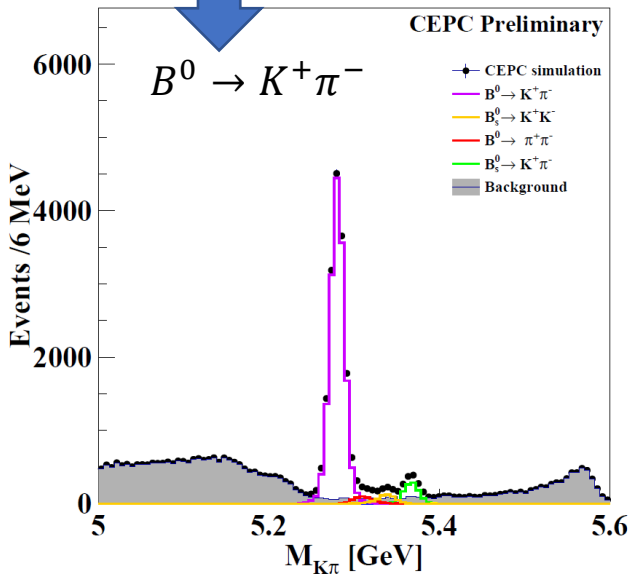
Without PID

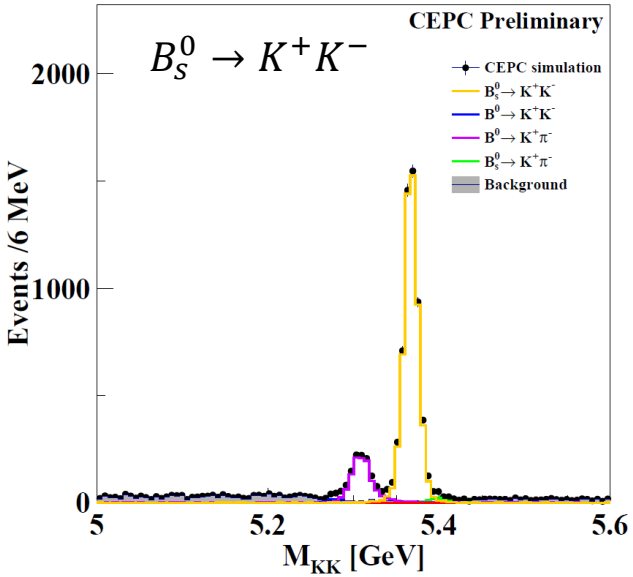


$\Lambda_b^0 \to p^+\pi^-$

With PID







Summary

- Simulation of CEPC the 4th detector ready to use
  - Tracking resolution is consistent with full simulation
  - PID with latest full simulation of clustering counting
  - Preliminary implementation of calorimeter system, reasonable resolution achieved.
- Physics sensitivity can be improved significantly with PID in flavor physics
- Future works:
  - Optimize PID by full simulation with Deep learning based algorithm
  - Optimize event selection for $\mathrm{B}^0/\mathrm{B}_\mathrm{s}^0 \to \mathrm{h}^+\mathrm{h}'^-$
  - Fit and get more information such as CP asymmetry for $B^0 \to K^+\pi^-$
  - More channels are ongoing such as $B^0 \to e^+e^-K^{*0}$

Thanks!