Study of Lepton ID

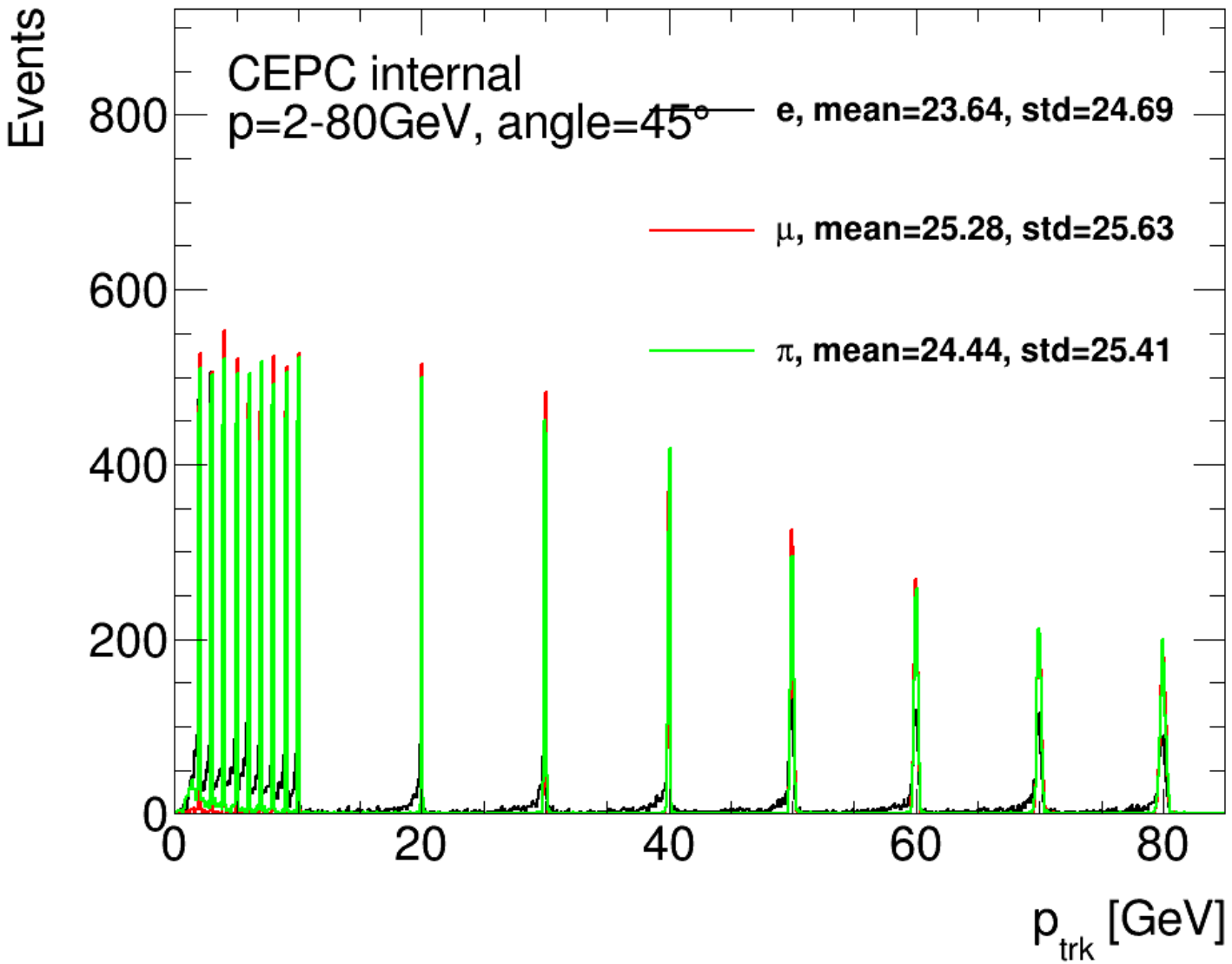
Changhua Hao, Ligang Xia

Nanjing University

MC Samples

- MC samples are produced with the CEPCSW master(2024.12.19)+ Chenguang's TofRecAlg package and the CyberPFA algorithm
- Particles in particle gun: electron, muon and pion
- Momentum:
  - 1) 2~10GeV with an interval of 1 GeV
  - 2) 20~80GeV with an interval of 10 GeV
  - 3) 1000 events for each momentum point
- Angle: 45 degrees

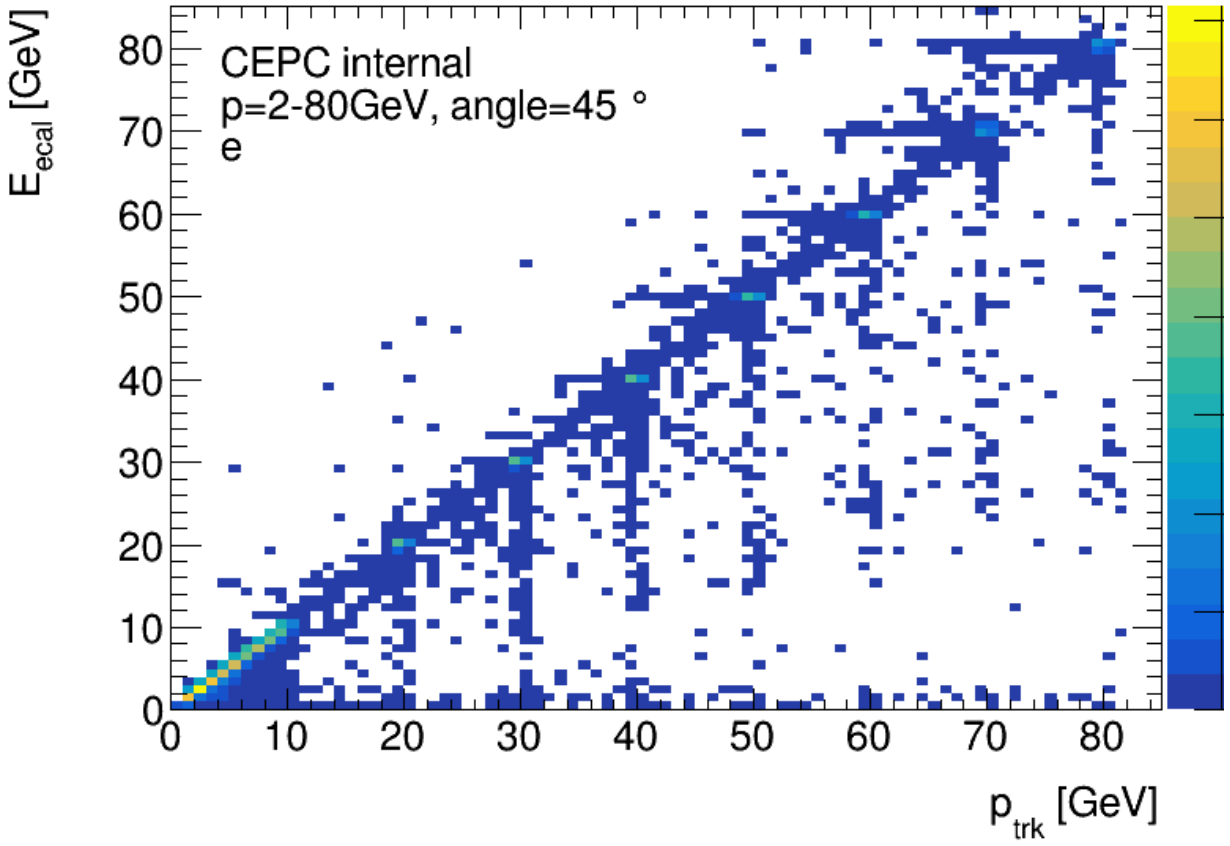
Track pT

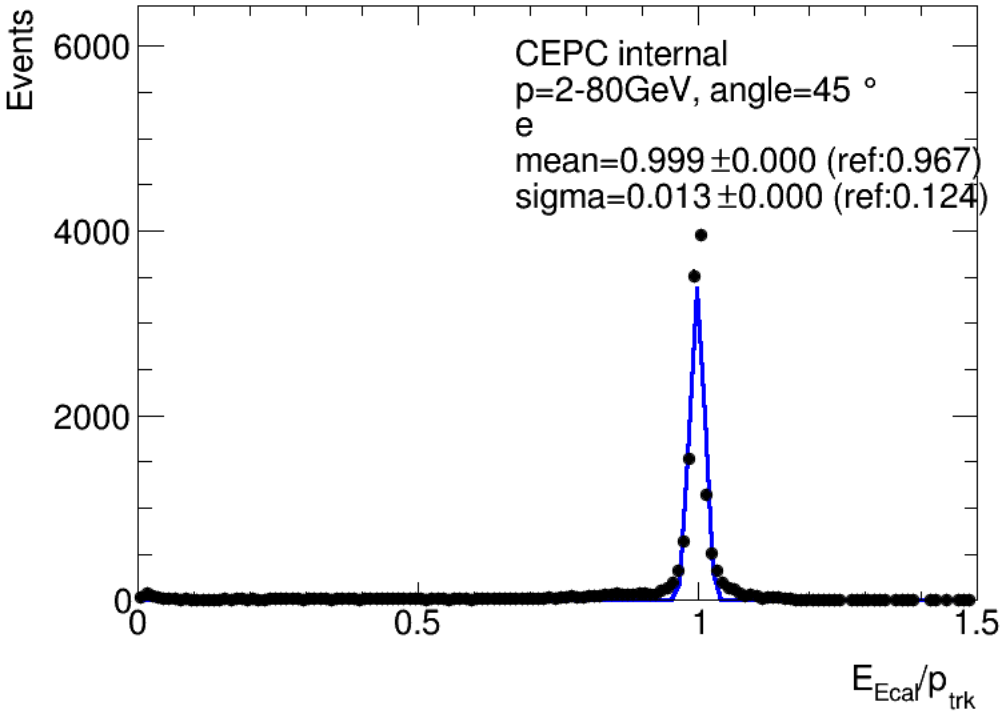


Some electron tracks have a momentum significantly smaller than that at production.

1) radiation loss
2) conversion happens and a soft secondary electron is mis-associated to a cluster

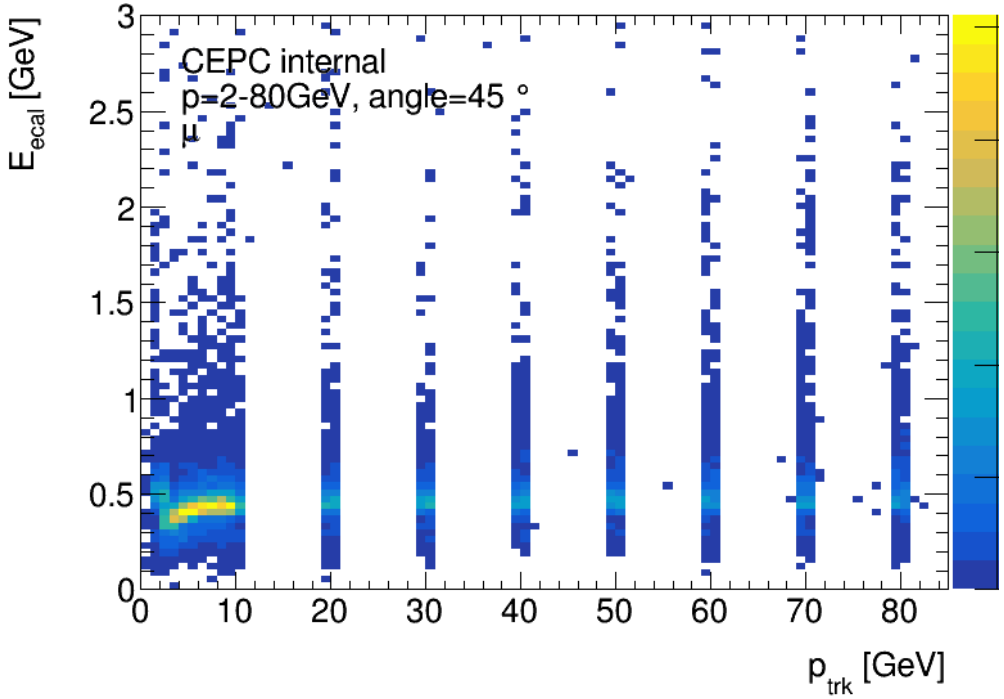
Electron ID

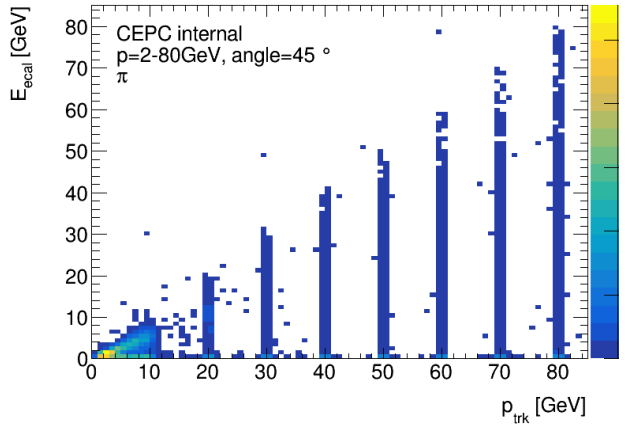


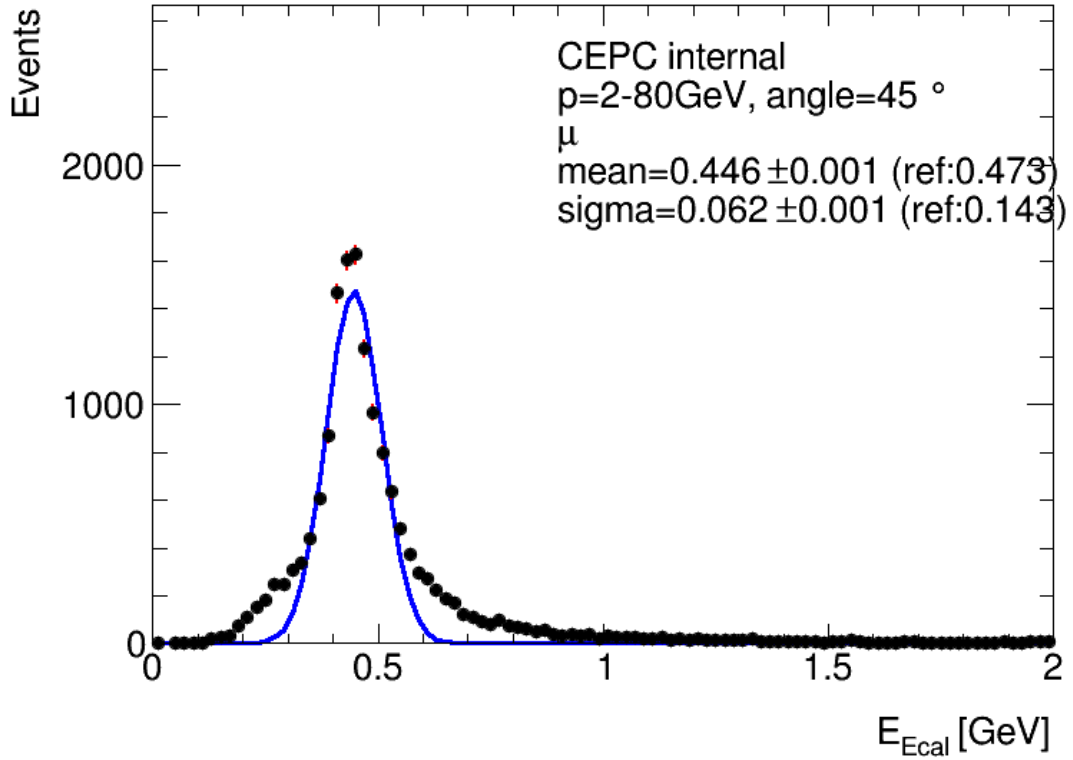


Features in PID:
- E_{Ecal}/Ptrk ~ 1 for electrons
- construct a chi2: chi2=(x-mean)^2/sigma^2
- mean, sigma: momentum/angle dependent

Muon ID (Ecal part)



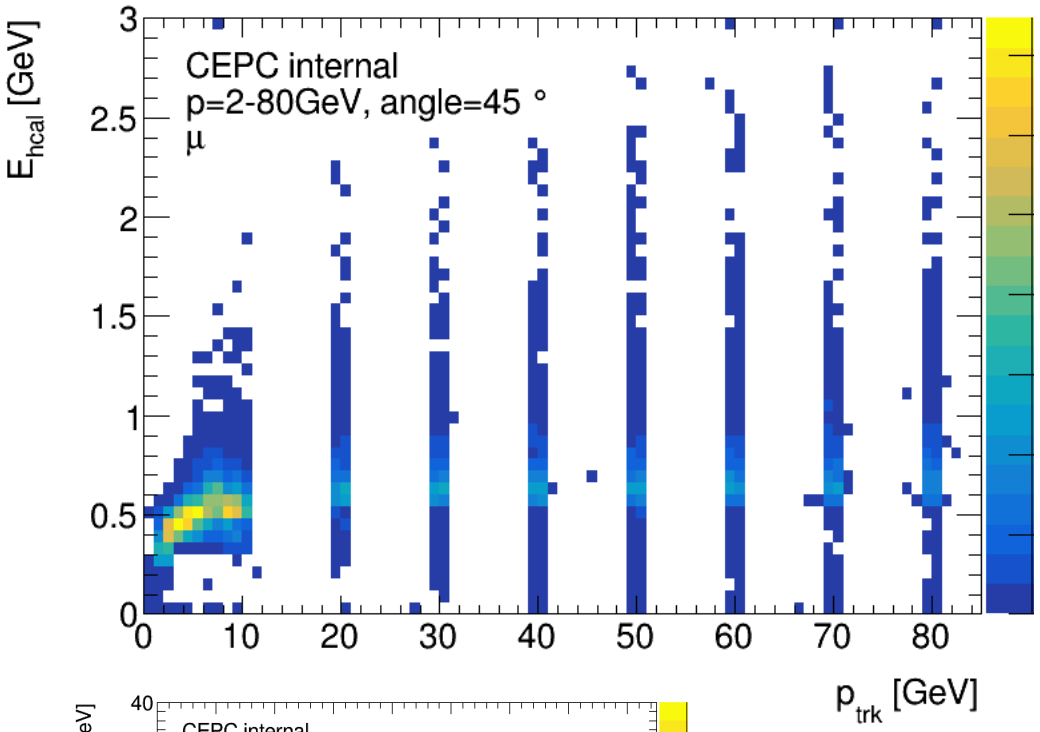


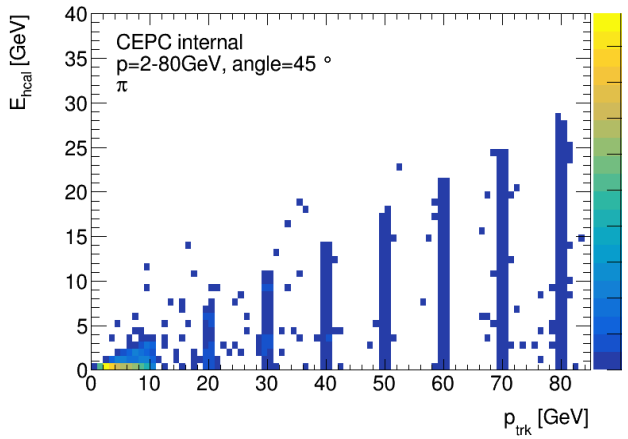


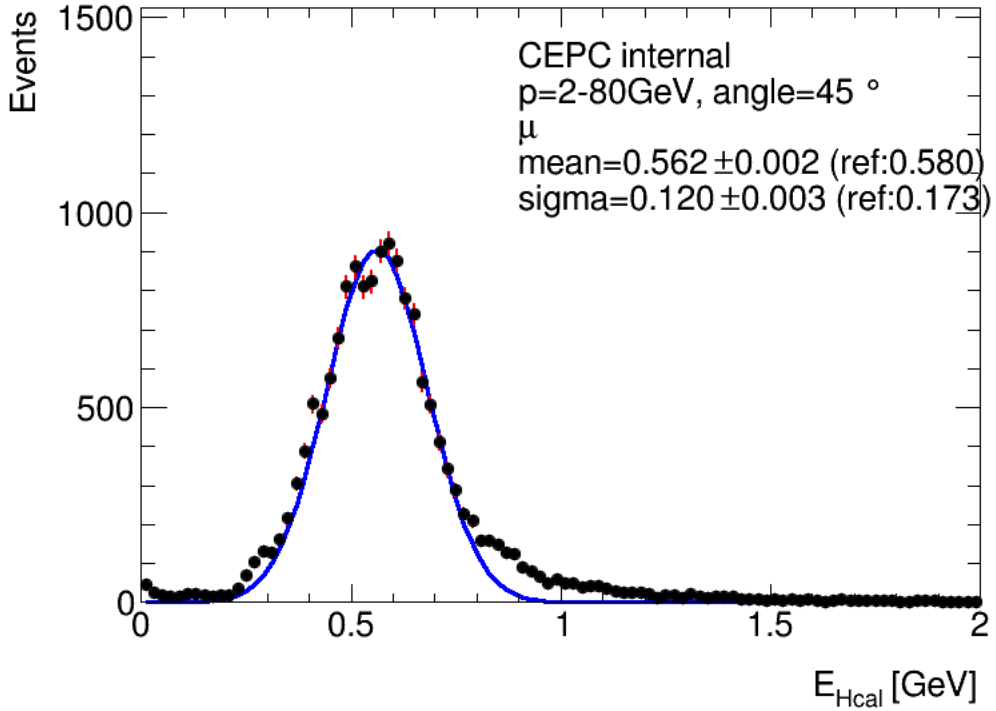
Features in PID:

- Energy deposit in Ecal: roughly single energy for muon
- Energy deposit in Hcal: roughly single energy for muon
- construct a chi2 for each energy: chi2=(x-mean)^2/sigma^2
- mean, sigma: momentum/angle dependent

Muon ID (Hcal part)







Features in PID:

- Energy deposit in Ecal: roughly single energy for muon
- Energy deposit in Hcal: roughly single energy for muon
- construct a chi2 for each energy: chi2=(x-mean)^2/sigma^2
- mean, sigma: momentum/angle dependent

Belle2 detector

- Combine all subdetectors
- For 90%WP:
  - misID(pi->e)=0.411%
  - misID(pi->mu)=7.33%
- Moriond2022: paper link

The Belle II detector is comprised of several sub-detector components arranged cylindrically around the interaction region. The vertex detector (VXD), the innermost detector element of Belle II, consists of two layers of silicon pixel detectors (PXD) and four layers of double-sided silicon strips detectors (SVD). In the data taking period discussed in this document, only the innermost layer of the PXD was fully installed while, for the second layer, only two sensors were installed. However, the PXD and the SVD were not used for particle identification for the results shown here. The central drift chamber (CDC) is filled with a helium-based gas mixture for tracking charged particles and contributes to their identification via energy loss measurements (dE/dx). The time-of-propagation Cherenkov detector (TOP), consisting of 16 bars of fused silica, and the Aerogel Ring Imaging Cherenkov detector (ARICH), are instrumental in the identification of charged hadrons. We note that the TOP detector was excluded for likelihood-based electron identification in this document due to an issue with the description of the probability density function of the electron hypothesis in the software. An electromagnetic calorimeter (ECL) consisting of 8,736 Thallium-doped CsI crystals distributed in a barrel and two endcaps (forward/backward) is used mainly for the identification of electrons/positrons and photons. Finally, the K_L^0 and muon detector (KLM) consists of a sandwich-like structure of alternating metal plates and active detector elements based on resistive plate chambers. A superconducting solenoid, situated between the ECL and the KLM, provides a 1.5 T axial magnetic field. A detailed description of the full detector is given in [1]. Information from each particle identification system $D = \{\mathrm{CDC}, \mathrm{TOP}, \mathrm{ARICH}, \mathrm{ECL}, \mathrm{KLM}\}$ is analysed independently to determine the likelihood of each charged particle hypothesis. These likelihoods may then be used to construct a combined global likelihood ratio [3]:

$$\mathrm{mis-ID}(\pi^\pm \to e^\pm) = \left(4.11^{+0.20}_{-0.20}\ (\mathrm{stat.})^{+<0.01}_{-<0.01}\ (\mathrm{syst.})\right) \times 10^{-3}$$
$$\mathrm{mis-ID}(\pi^\pm \to \mu^\pm) = \left(7.33^{+0.02}_{-0.01}\ (\mathrm{stat.})^{+0.01}_{-0.01}\ (\mathrm{syst.})\right) \times 10^{-2}.$$

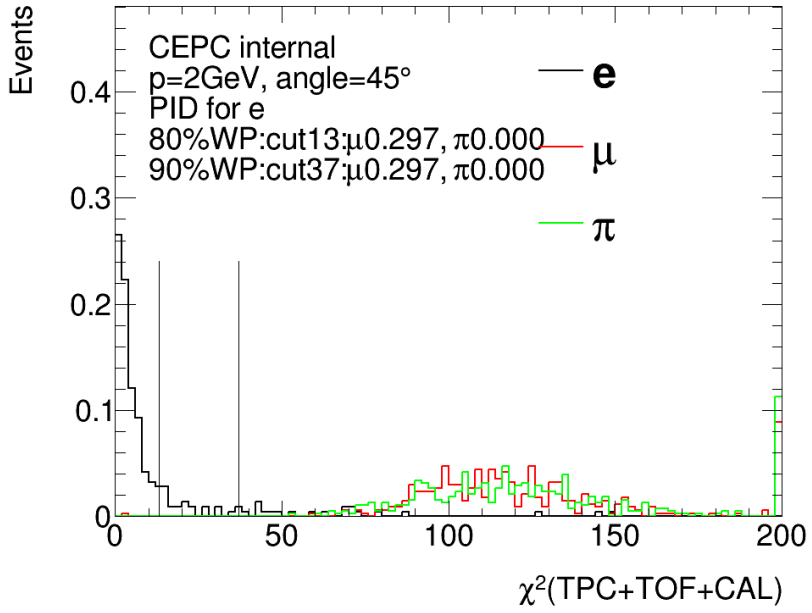
$$\ell\mathrm{ID} = \frac{\mathcal{L}_\ell}{\mathcal{L}_e + \mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K + \mathcal{L}_p + \mathcal{L}_d}, \quad (1)$$

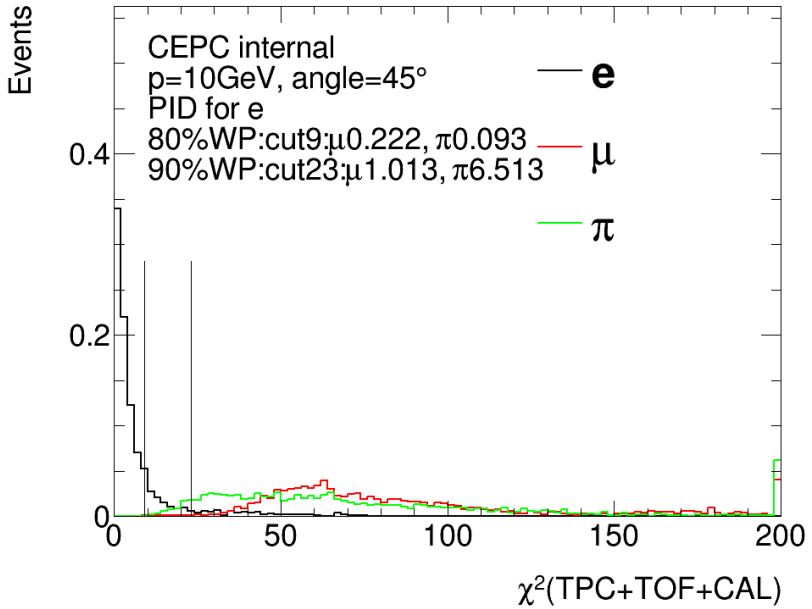
$$\mathcal{L}_i = \prod_{d}^{d \in D} \mathcal{L}_i^d, \quad i \in \{e, \mu, \pi, K, p, d\} \quad (2)$$

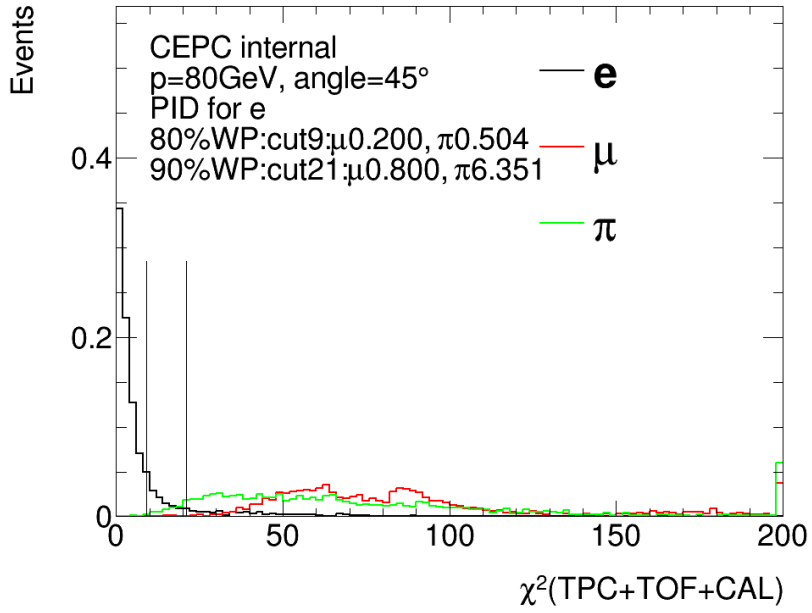
Combined leptonID

- chi2=chi2(tpc)+chi2(tof)+chi2(Eecal/p) for electrons
- chi2=chi2(tpc)+chi2(tof)+chi2(Eecal)+chi2(Ehcal) for muons
- Note: a subdetector like tof may fail to reconstruct tof and chi2(tof)=0.
- Subtlety: NDF is different. But the impact shall be minor. Will not consider it for the moment.
  - some details: chi2 abides a chi2 distribution, whose average is NDF. So the “chi2” defined above is a combined distribution of chi2 with different NDFs.

Electron ID performance







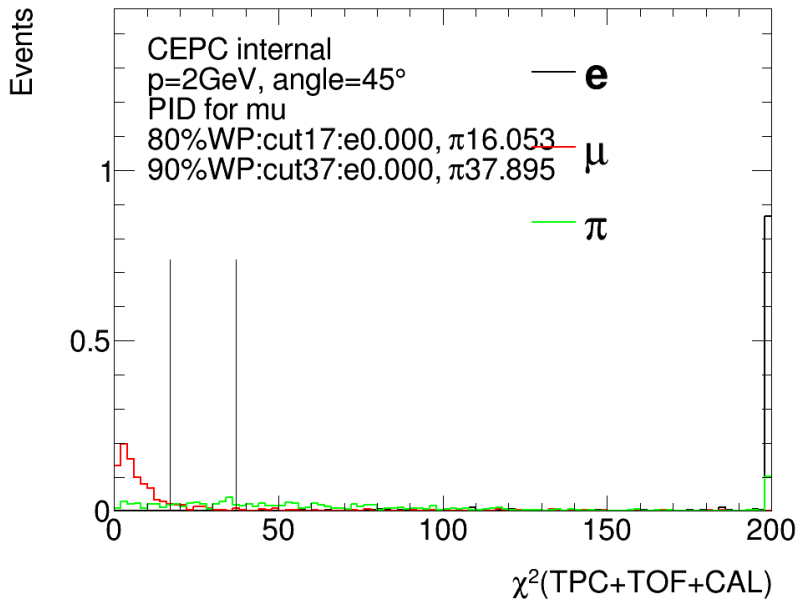
- 80% WP:
  - definition: chi2<13(2GeV), chi2<9(10GeV), chi2<9(80GeV)
  - misID(mu->e) = 0.2% - 0.3%, misID(pi->e)=0-0.5%
- 90% WP:
  - definition: chi2<37(2GeV), chi2<23(10GeV), chi2<21(80GeV)
  - misID(mu->e) = 0.2%-1.0%, misID(pi->e)=0-6.5%

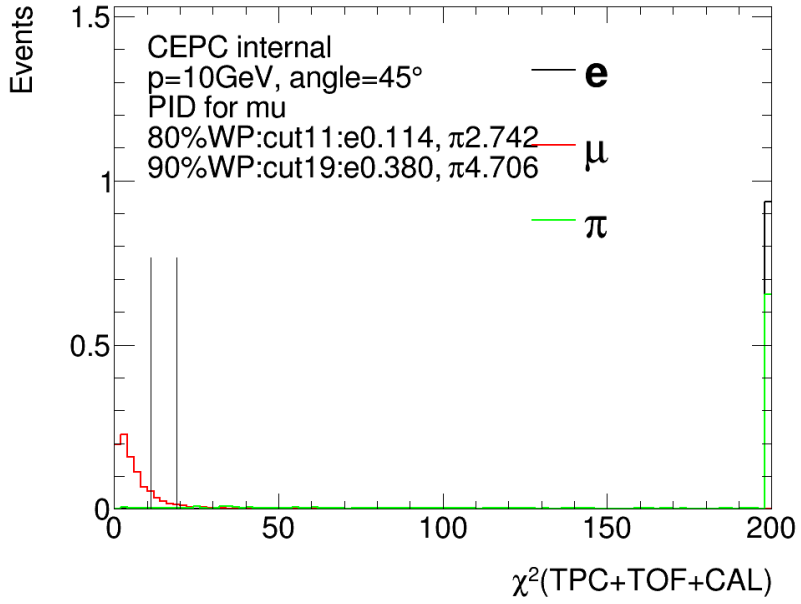
Similar performance to Belle2

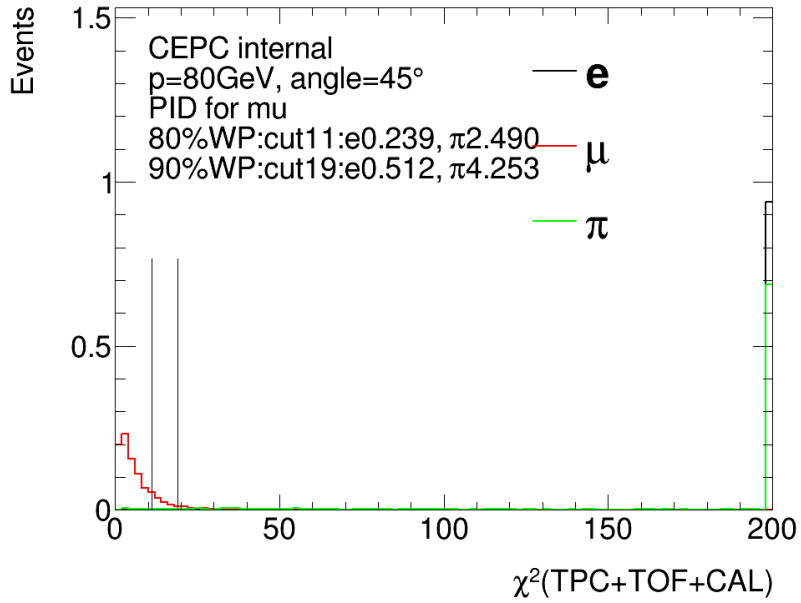
Belle2 90%WP

$$\mathrm{mis-ID}(\pi^{\pm} \to e^{\pm}) = \left(4.11^{+0.20}_{-0.20}\ (\mathrm{stat.})^{+<0.01}_{-<0.01}\ (\mathrm{syst.})\right) \times 10^{-3}$$
$$\mathrm{mis-ID}(\pi^{\pm} \to \mu^{\pm}) = \left(7.33^{+0.02}_{-0.01}\ (\mathrm{stat.})^{+0.01}_{-0.01}\ (\mathrm{syst.})\right) \times 10^{-2}.$$

Muon ID performance







- 80% WP:
  - definition: chi2<17(2GeV), chi2<11(10GeV), chi2<11(80GeV)
  - misID(e->mu) = 0.% - 0.2%, misID(pi->mu)=2-16%
- 90% WP:
  - definition: chi2<37(2GeV), chi2<19(10GeV), chi2<19(80GeV)
  - misID(e->mu) = 0.%-0.2%, misID(pi->e)=4-37%

Similar performance than Belle2

Belle2 90%WP

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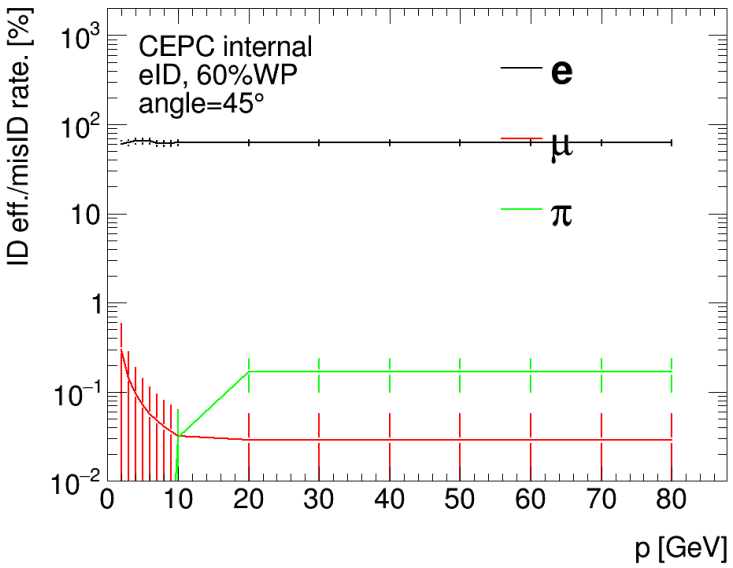
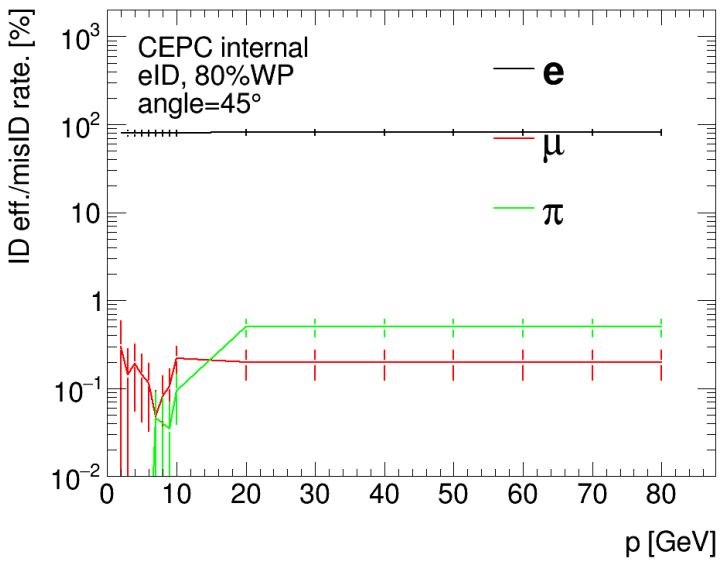
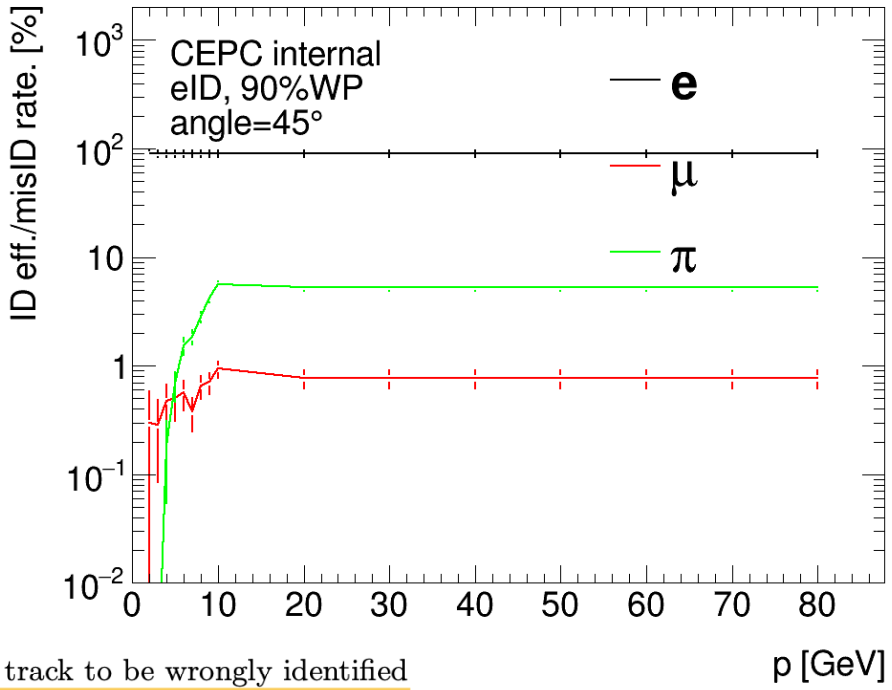
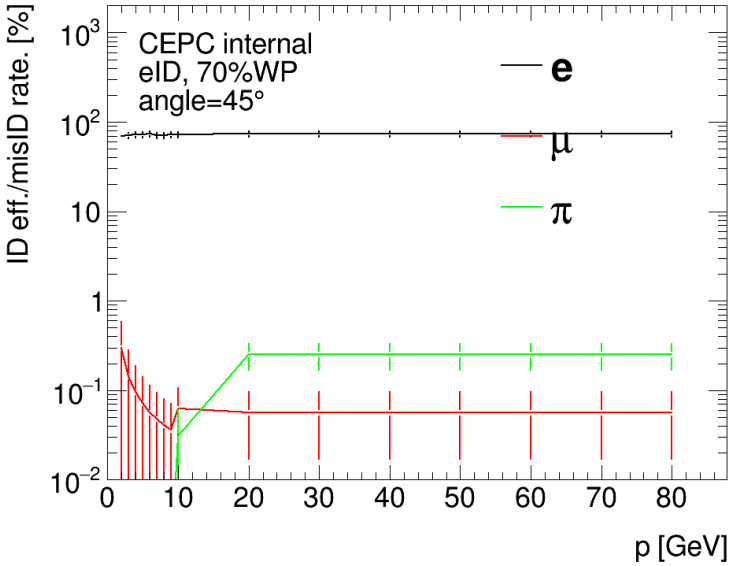
electron ID performance









correctly identified as such, and the probability for a hadron track to be wrongly identified as a lepton track. Electron and muon identification efficiencies are studied using $e^+e^- \to \ell^+\ell^-(\gamma)$, $e^+e^- \to e^+e^-\ell^+\ell^-$, and $J/\psi \to \ell^+\ell^-$, while pion mis-identification rates are studied using $K^0_S \to \pi^+\pi^-$ and $e^+e^- \to \tau^\pm(1P)\tau^\mp(3P)$. The $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ channel is used to determine kaon mis-identification rates.

Performance is evaluated in the polar angle acceptance regions corresponding to the electromagnetic calorimeter (ECL) for electrons (0.22 to 2.71 rad), and to the K^0_L-muon detector (KLM) for muons (0.40 to 2.60 rad). Combined, the set of probe channels covers a lab-frame momentum range of 0.4 GeV/c to 7.0 GeV/c for electrons and of 0.4 GeV/c to 6.5 GeV/c for muons. Results are also binned with respect to the track lab-frame polar

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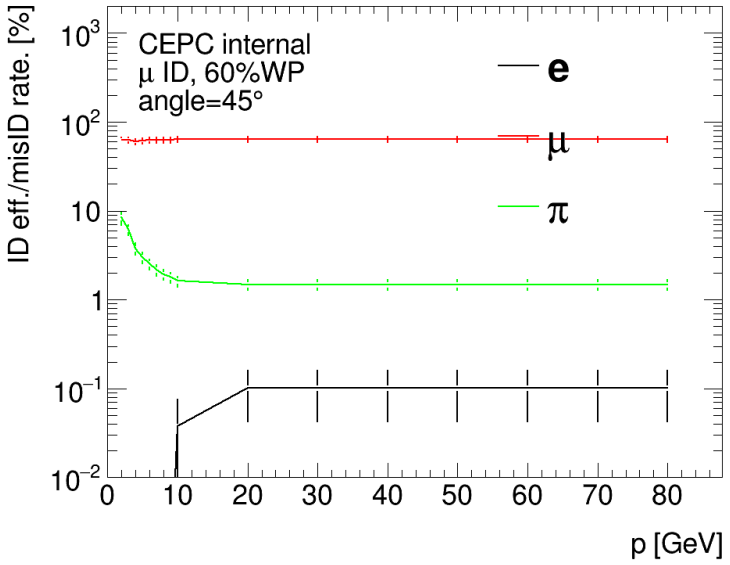

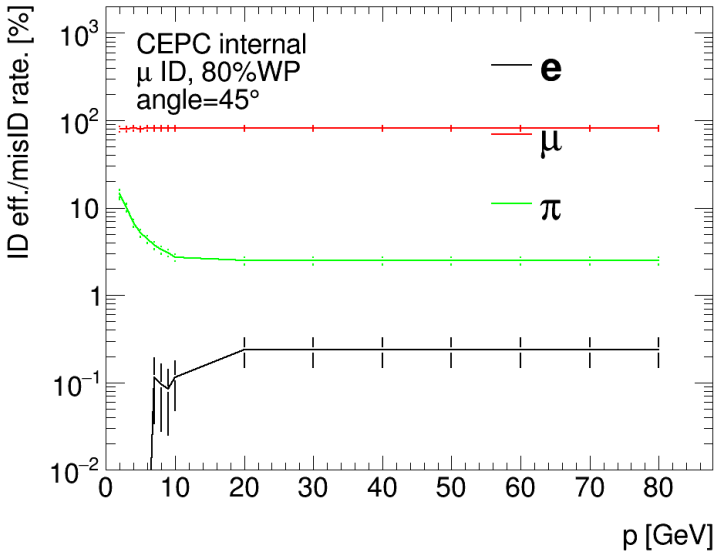

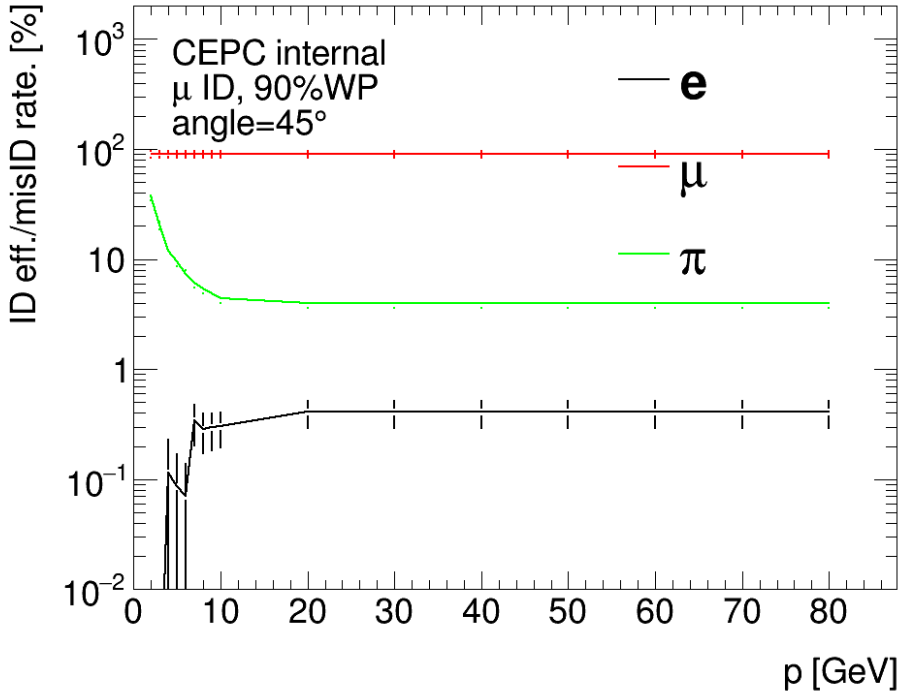

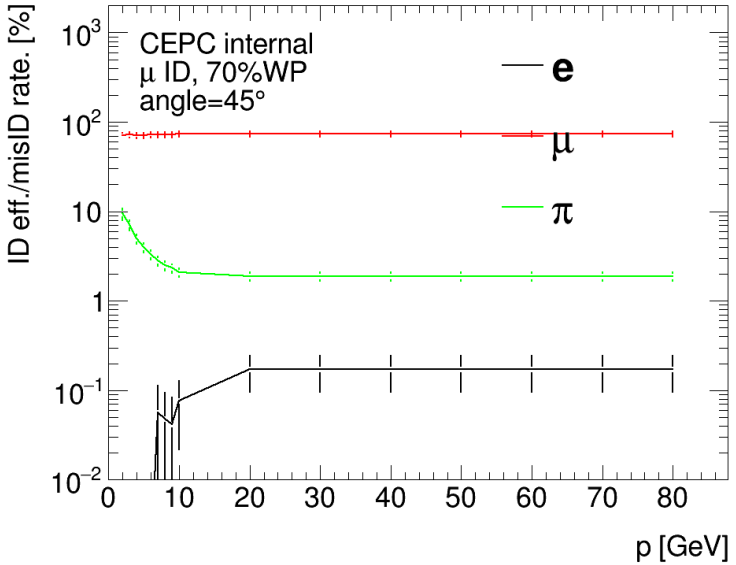

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Summary

- Lepton ID design has been finished for p=2~80GeV and angle=45degrees
- Will implement them in the CEPCSW soon.
- Meanwhile, Changhua is working on other angles.

- Some people (Shuo et al.) want to the electron ID asap. We can provide the definitions which can be used at the analysis level.

戴芳