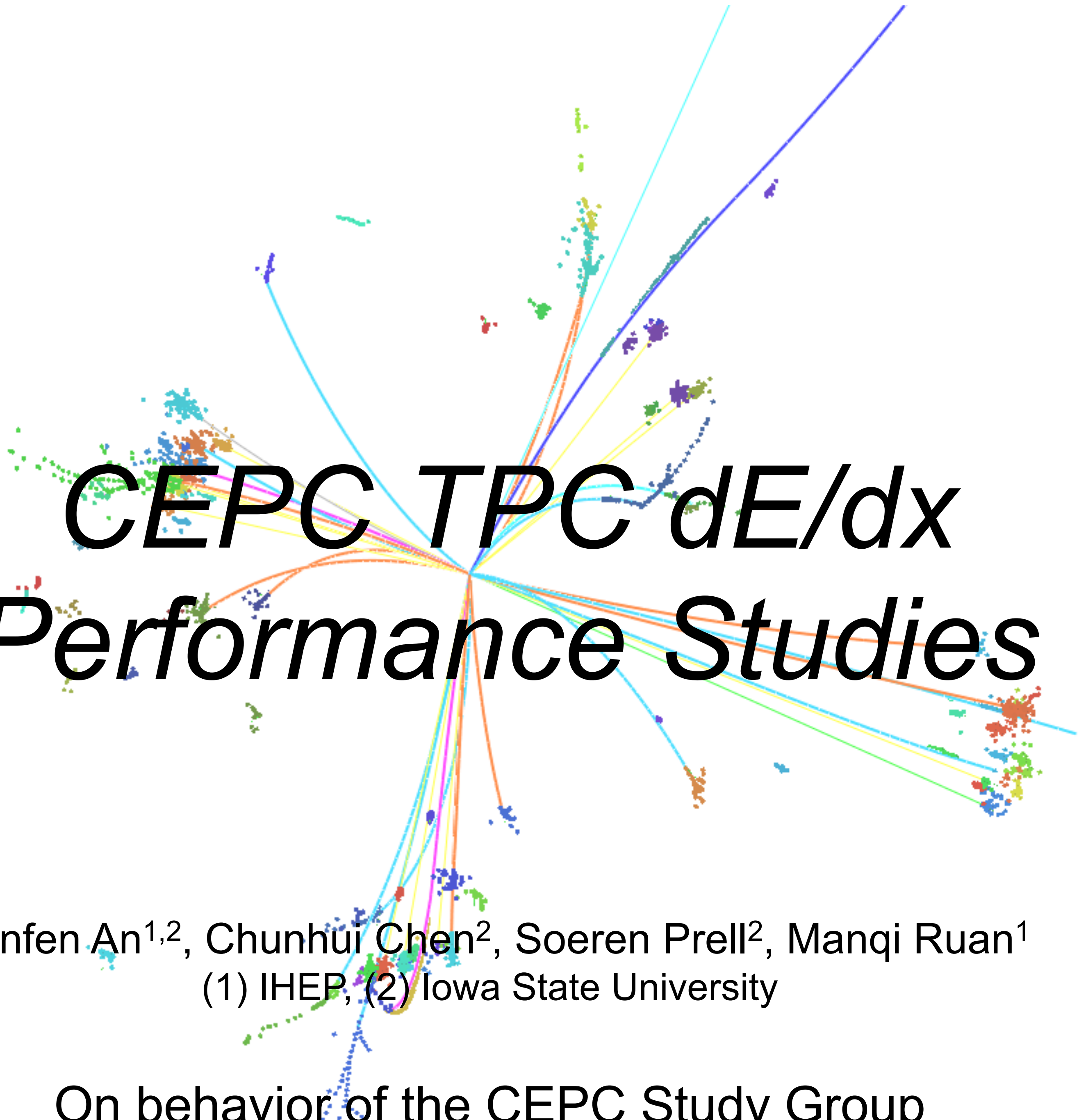

# *CEPC TPC dE/dx Performance Studies*

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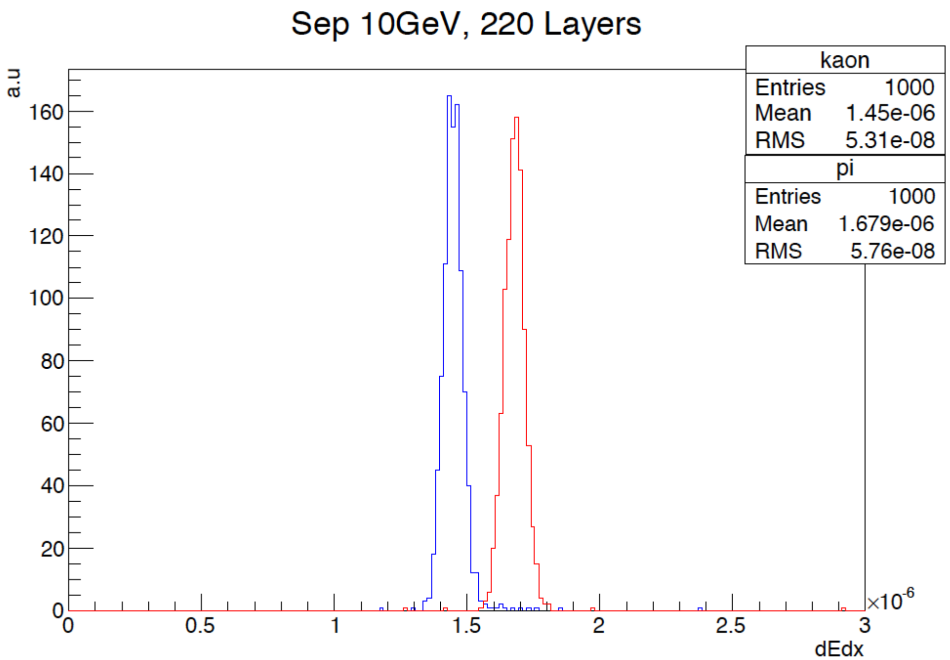
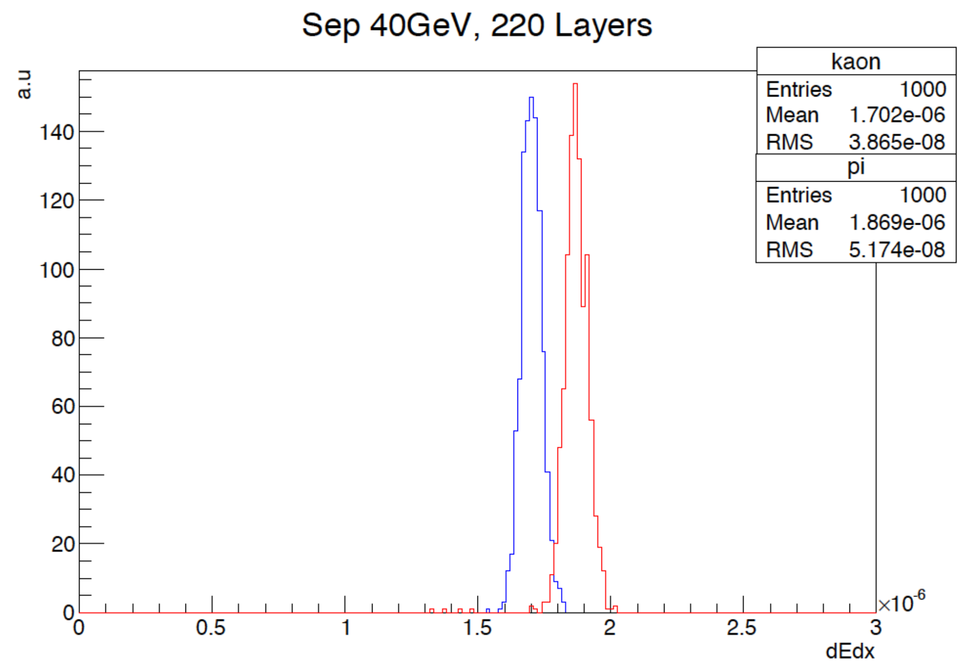
On behavior of the CEPC Study Group

# π-K separation with dE/dx at TPC




*Efficient π - K separation is highly appreciated for CEPC Z pole program*

*dE/dx is a natural tool for π - K separation, even at E > 10 GeV*

*Study done at CEPC-v1 (ILD TPC Geometry):*

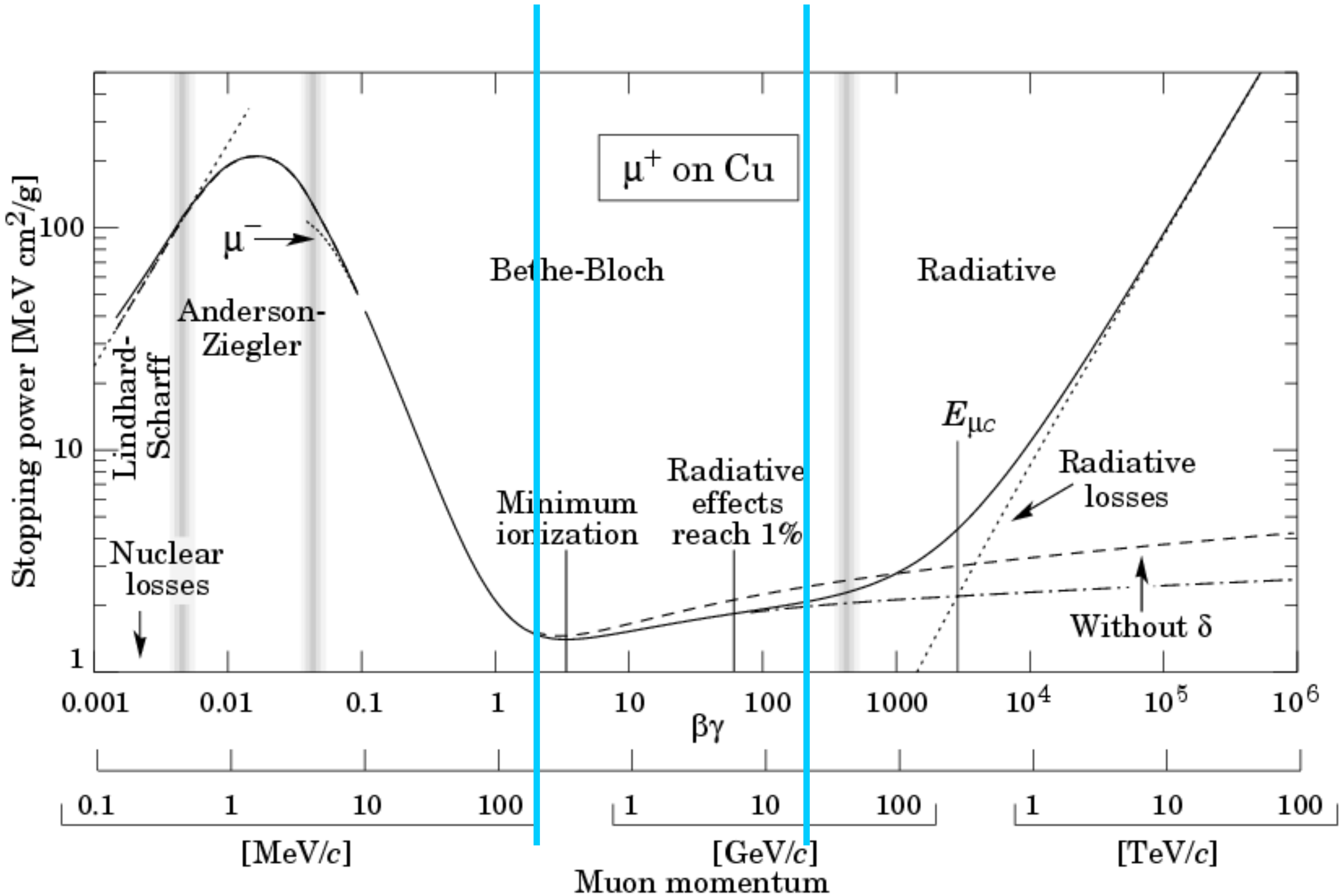
*220 radial layers (with 6*1 mm$^2$ cells) between R = 390 – 1710 mm*

*Key questions:*

*How good is the performance?*

*How well is the dE/dx resolution preserved after readout?*

# Prediction of Bethe-Bloch...



# Validation of Geant 4 Simulation...

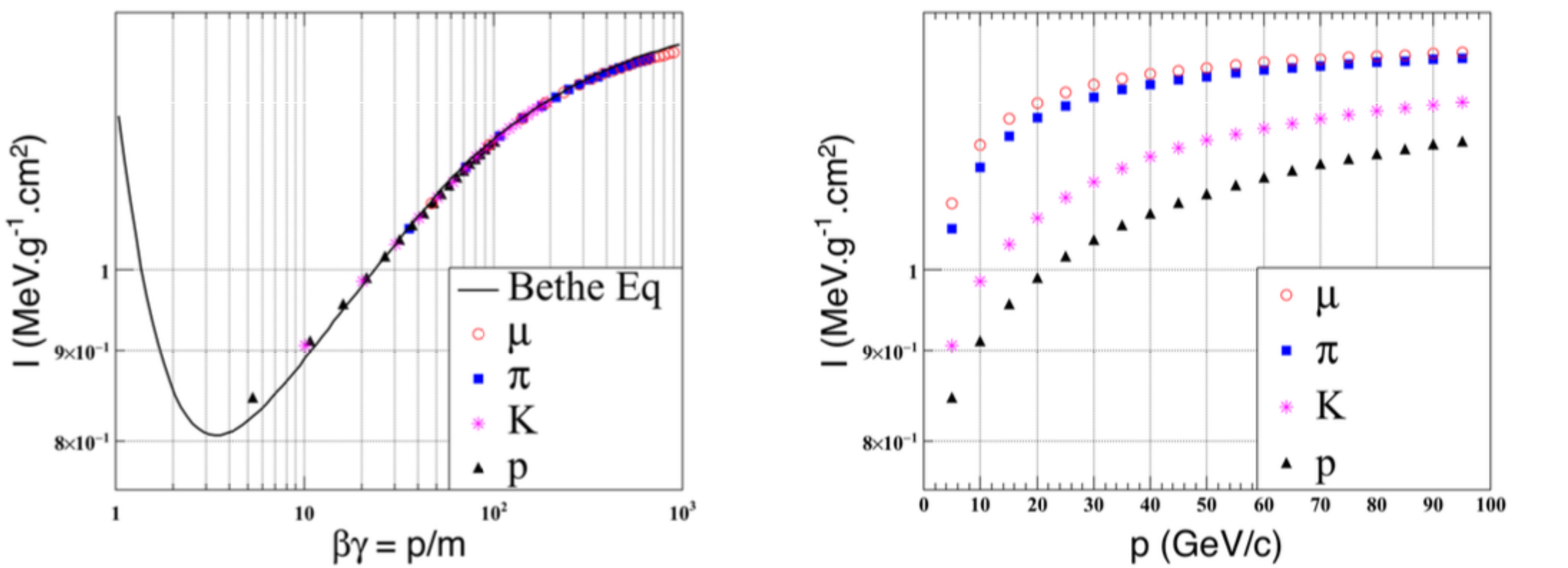
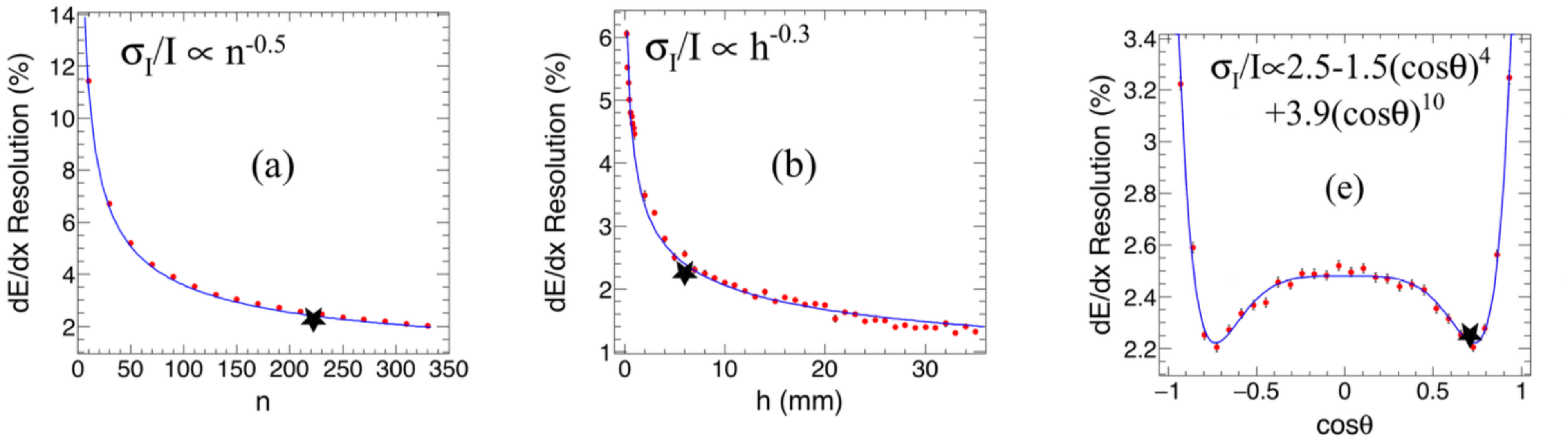
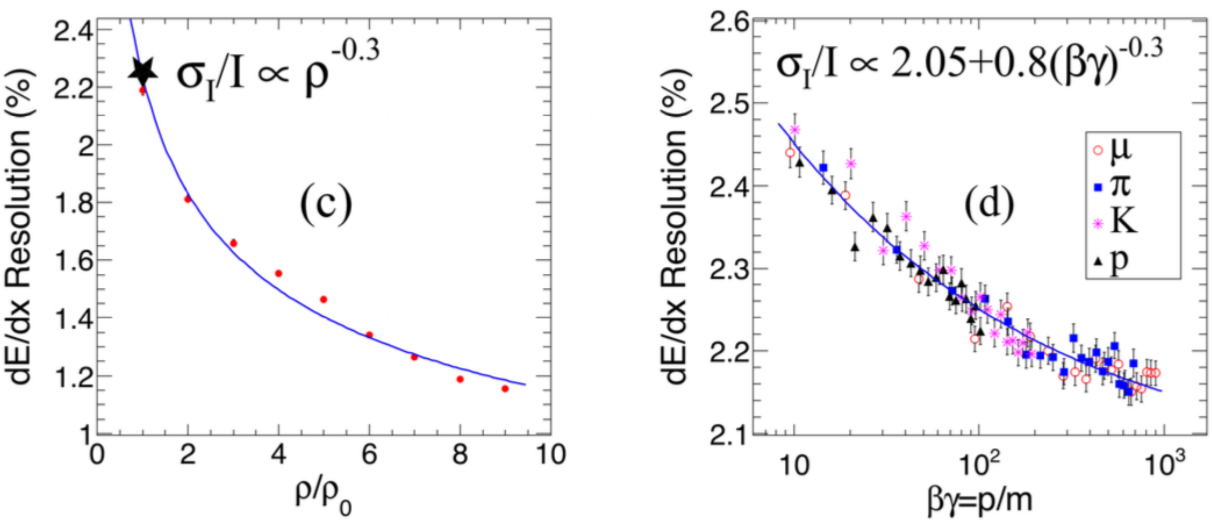



**Fig. 1** Variation of the ionizing energy $I$ versus (left) $\beta\gamma$ and (right) $p$ of particles in argon-based gas (93% Ar+5% $CH_4$+2% $CO_2$) in simulation.

*Good agreement between Geant4 simulation and Bethe-Bloch prediction*

# Parameterized dE/dx Truth Resolution




$$\frac{\sigma_I}{I} = \frac{13.5}{n^{0.5}\cdot(h\rho)^{0.3}}\left[2.05+0.8(\beta\gamma)^{-0.3}\right] \times \left[2.5-1.5(\cos\theta)^4+3.9(\cos\theta)^{10}\right].$$

*Including ionization, drift, diffusion to read-out pads, but not including readout (amplification, cross-talk, etc.), backgrounds, etc.*

# Reference to existing experiments

**Table 1** Properties of TPCs in previous experiments. Comparison of the relative dE/dx resolution between MC and experimental measurements.

| Experiment | PEP-4 [21–23] | TOPAZ [24] | DELPHI [25, 26] | ALEPH [27, 28] | STAR [29, 30] | ALICE [4, 31] | CEPC |
|---|---|---|---|---|---|---|---|
| Year | 1982 | 1987 | 1989 | 1989 | 2000 | 2009 | - |
| Particle Collide | $e^-/e^+$ | $e^-/e^+$ | $e^-/e^+$ | $e^-/e^+$ | Au/Au | p/p | $e^-/e^+$ |
| $E_{beam}$ (GeV) | 14 | 26 | 45.6 | 45.6 | 100 | 1380 | 125 |
| Gas | Ar: 0.8<br>CH4: 0.2 | Ar: 0.9<br>CH4: 0.1 | Ar: 0.8<br>CH4: 0.2 | Ar: 0.91<br>CH4: 0.09 | Ar: 0.9<br>CH4: 0.1 | Ne: 0.857<br>CO2: 0.095<br>N2: 0.048 | Ar: 0.93<br>CH4: 0.05<br>CO2: 0.02 |
| Pressure (atm) | 8.5 | 3.5 | 1 | 1 | 1 | 1 | 1 |
| $\rho$ (mg/ml) | 12.43 | 5.47 | 1.46 | 1.57 | 1.56 | 0.95 | 1.73 |
| n | 183 | 175 | 192 | 344 | 13, 32[2] | 63,64,32 | 222 |
| h (mm) | 4 | 4 | 4 | 4 | 12, 20 | 7.5,10,15 | 6 |
| L (mm) | 2000 | 3000 | 2680 | 4400 | 4200 | 4994 | 4700 |
| Control Sample | e | $\pi$ | $\pi$ | e | $\pi$ | $\pi$ | $\pi$ |
| (GeV/c) | 14 | 0.4-0.6 | 0.4-0.6 | 45.6 | 0.4-0.6 | 6.0 | 5.0 |
| Truncation | 0-65% | 0-65% | 8-80% | 8-60% | 0-70% | 0-60% | 0-90% |
| $N_{eff}$ | n | 0.7n[3] | 0.6n[4] | 338 | 44 | 149 | 0.9n |
| $(\sigma_I/I)_{MC}$ | 2.6% | 3.8% | 5.4% | 3.0% | 5.3% | 3.3% | 3.1% |
| $(\sigma_I/I)_{exp}$ | 3.5% | 4.6% | 6.2% | 4.4% | 6.8%[5] | 5.0% | 4.6% |
| $\lvert\frac{(\sigma_I/I)_{exp}}{(\sigma_I/I)_{MC}}-1\rvert$ | 0.35 | 0.21 | 0.15 | 0.47 | 0.28 | 0.52 | 0.50 |

*Worst case: total dE/dx resolution is 50% worse than MC Truth*

$$S = \frac{\langle dE/dx \rangle_A - \langle dE/dx \rangle_B}{\sqrt{(\sigma_{dE/dx})_A^2 + (\sigma_{dE/dx})_B^2}}$$

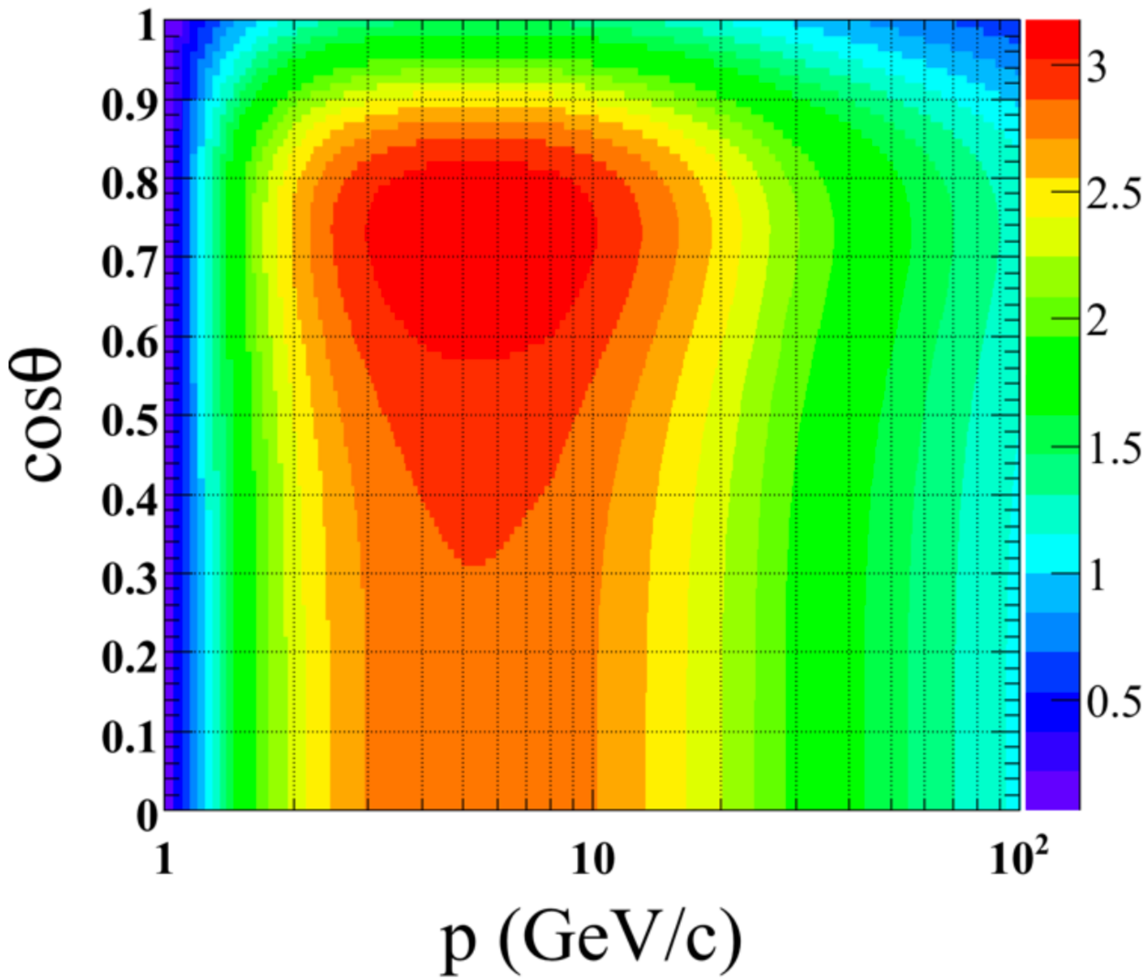
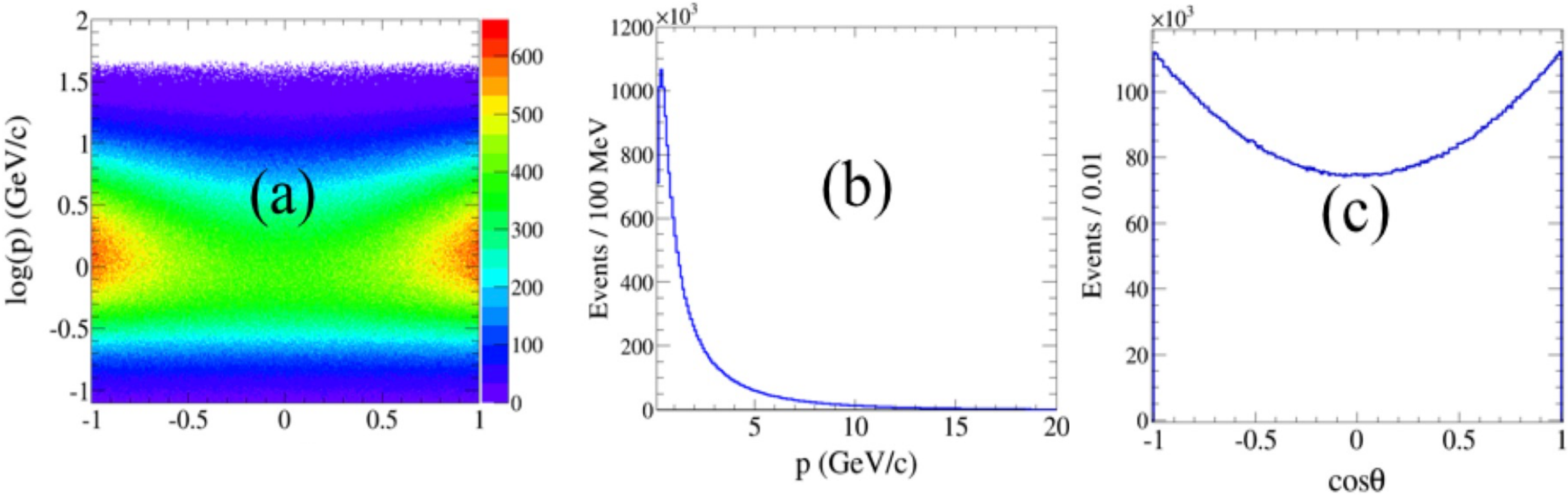



**Fig. 4** Separation power between kaon and pion in 2-D ($p$, $\cos\theta$) space assuming 90% effective hits and deterioration of 0.5 arising in experimental measurements.

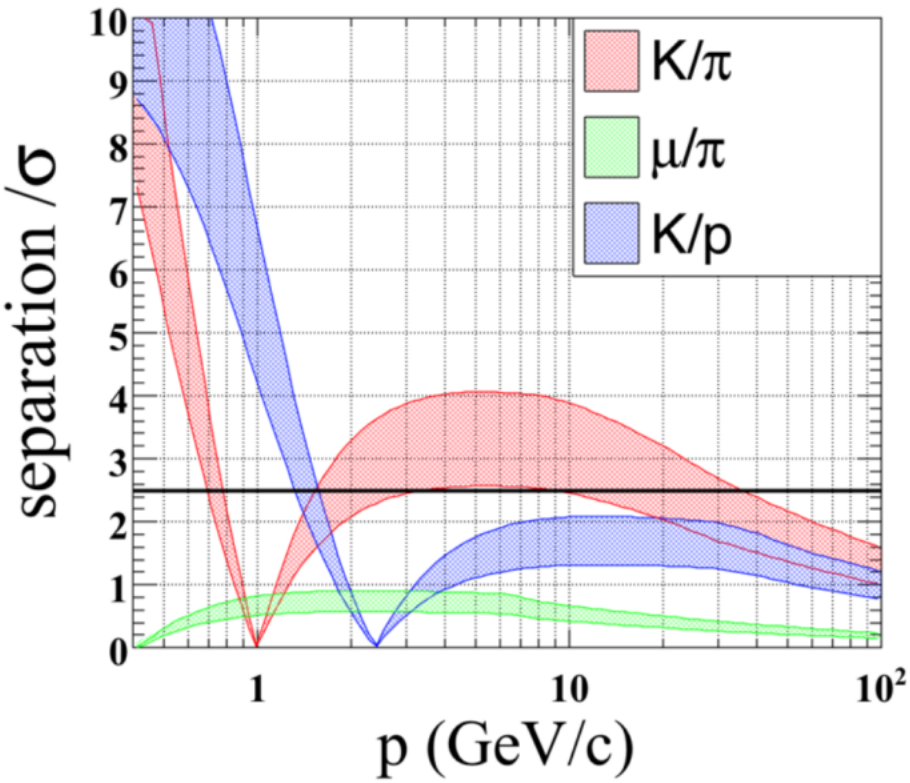
# Z→qq Differential Distributions of Track Momenta



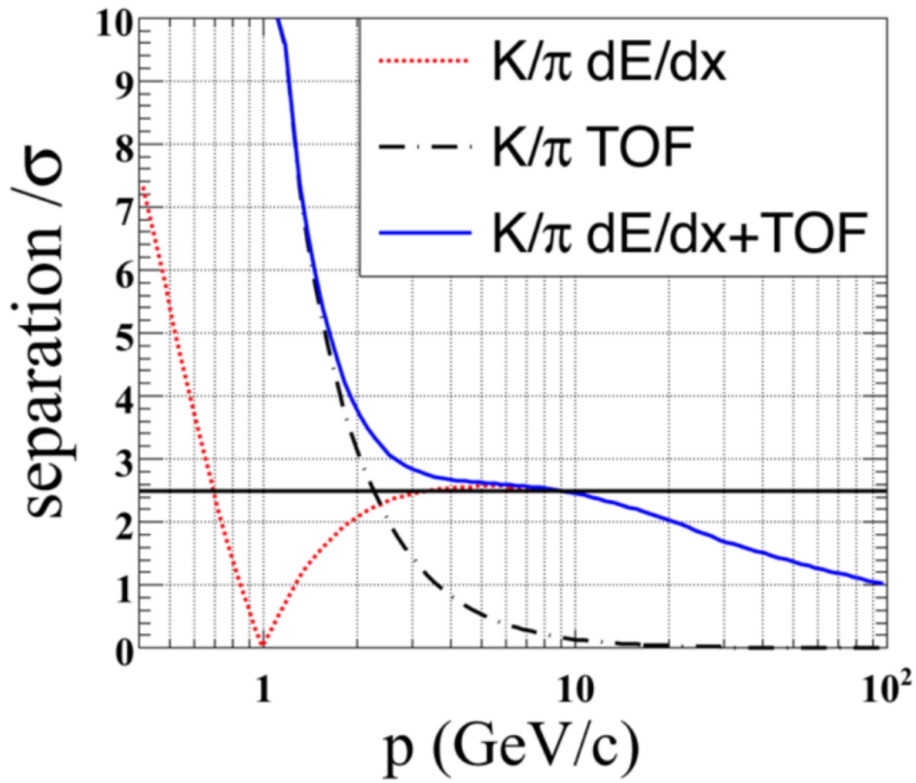

*Overall performance:*

*integrate separation over polar angle and/or momentum*

# Particle Identification (PID) Performance




*Separation range:*
*MC truth w/o degradation (top of band)*
*to 50% degradation (bottom of band)*




*50% degraded performance*
*+ 50 ps σ ToF information*
*(measured from the ECAL)*

# Overall PID Performance

*K efficiency & purity at Z pole*

*π yield is roughly 8x kaon yield, which is 1.4x proton yield*

*Integrated over 2 – 20 GeV momentum range and the fiducial polar angle range*

| Condition | | #σ(π-K / K-p) | K Efficiency | K Purity |
|---|---|---|---|---|
| MC Truth | dE/dx only | 3.9 / 1.5 | 88% | 86% |
| | + TOF | 4.0 / 3.2 | 98% | 98% |
| 20% degraded | dE/dx only | 3.1 / 1.2 | 81% | 79% |
| | + TOF | 3.3 / 3.0 | 96% | 96% |
| 50% degraded | dE/dx only | 2.4 / 0.9 | 68% | 68% |
| | + TOF | 2.8 / 2.9 | 91% | 94% |

*Hand waving objective:*

*To understand the source of degrading, and control it to be less than 20%.*

# dE/dx and PID Summary

*dE/dx (LCTPC setup) + ToF (50 ps resolution) has reasonable π - K separation for CEPC at Z pole – good for flavor physics*

*Effect of Gain / DAQ / Readout:*

*Experimental data exhibits degrading of 15 - 50% w.r.t. MC Truth*

*Induced by hit energy resolution, gain homogeneity, stability, etc.*

*ToF information:*

*Closes the K - π gap at 1 GeV*

*Makes a significant impact for the conservative case of (degrading ~ 50%)*

*Would be great if the degradation can be controlled to 20% or less*

***Is it feasible? & HOW? & Tests & Roadmap?***

*Remark:*

*Depends on the Bethe-Bloch prediction – How is it validated on experimental data at hadrons with E ~ 10 GeV?*

*Geometry optimizations may lead to improvements on dE / dx measurements*