Physics Requirement for the particle identification in terms of dE/dx for gaseous detector

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Motivation :

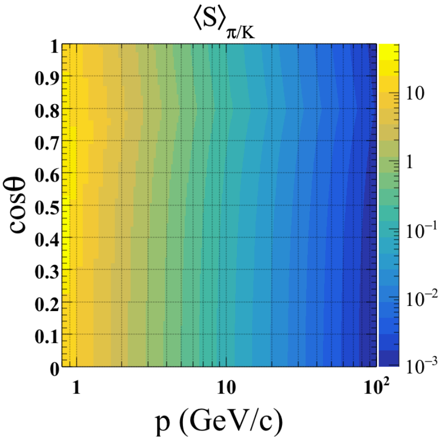
- The charged pions, kaons, protons and their antiparticles have identical interactions in sub-detectors. We use TOF and dE/dx information to separate these kinds of particles.
- The PID performance is essential for flavor physics.
- Tagging s quark ($K^{\pm}$, K_L, and K_S) is essential for CKM elements measurement.

Contents:

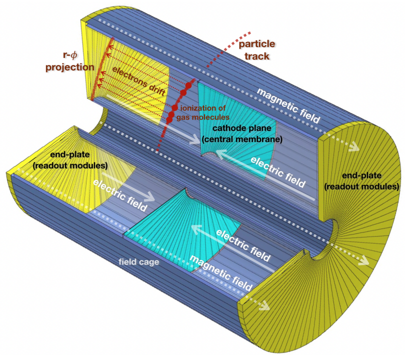
- charged $\pi/K/P$ separation with:
  1. TOF
  2. dE/dx
  3. dE/dx and TOF
- PID evaluation with inclusive hadronic Z-pole samples
  1. $K^{\pm}$ identification
  2. $D^0 \rightarrow \pi^+K^-$ identification
  3. $\phi \rightarrow K^+K^-$ identification

TOF

- The particle flight time t over a given distance along the track trajectory.
- particles A/B separation power with TOF: $(S_{A/B} = \frac{|t_A - t_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}})$
- suppose σ_{TOF} = 50 ps that can be achieved by modern sensor technology



TPC

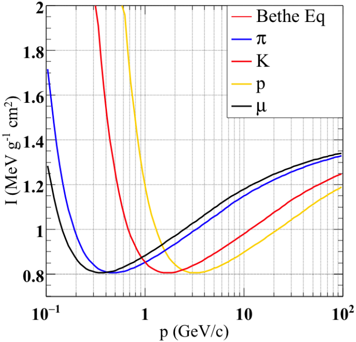


TPC parameters

- 4.7 m long with an inner and outer radii of 0.325 and 1.8 m
- 93%Ar + 5% CH_4 + 2% CO_2
- atmospheric pressure
- room temperature
- 3 Tesla along the beam direction
- In the endcaps, Micromegas detector modules with pad size of 6 mm along the radial direction and 1 mm along the azimuthal direction are arranged in 222 concentrical rings.

dE/dx

- The dE/dx measurement by each pad is defined as the energy deposit divided by the track length.
- The dE/dx measurements of a track follow a Landau distribution.
- We estimate average dE/dx for a track by using the truncated mean method.
- The distribution of average dE/dx for a track, denoted as I, as a function of particle's momentum is shown in the following figure.

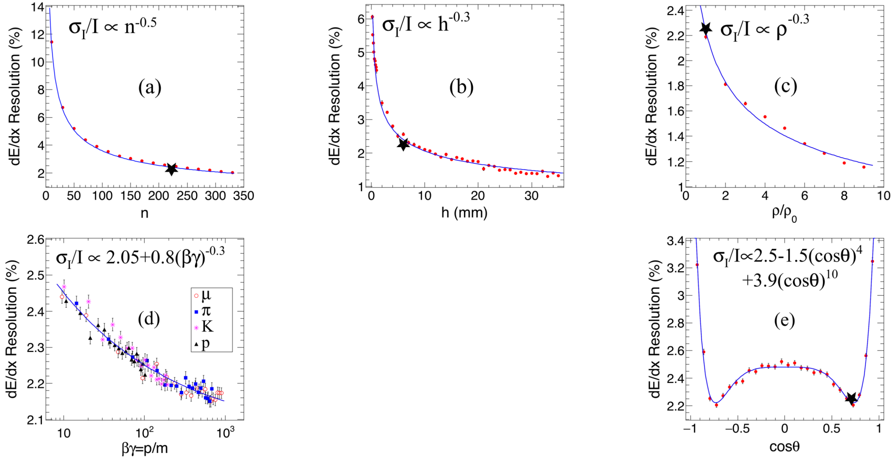


arXiv:1803.05134

dE/dx resolution

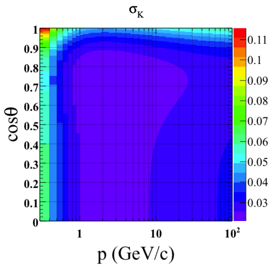
- intrinsic dE/dx resolution depends on the number of the pad rings n, the pad height along the radial direction h, the density of the working gas ρ, the relativistic velocity $\beta\gamma$ and the polar angle θ of the particle trajectory.
- actual dE/dx resolution will be deteriorated by the detector effects arising in the processes of electron drift, signal amplification and readout in TPC.

We only consider intrinsic resolution and study them with single-particle MC events:

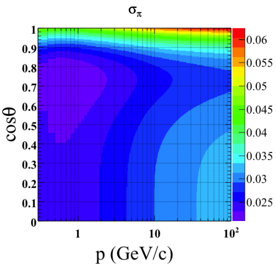


$$\sigma_I/I = \frac{13.5}{n^{0.5}\cdot(h\rho)^{0.3}}\left[2.05+0.8(\beta\gamma)^{-0.3}\right]\times\left[2.5-1.5(cos\Theta)^4+3.9(cos\Theta)^{10}\right]$$

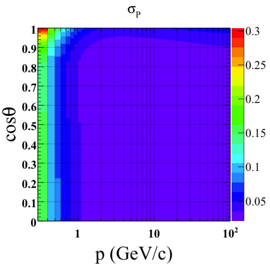
The following plots show the distribution of dE/dx resolution, which is a function of momentum and polar angle of incident particle.



$K^{\pm}$

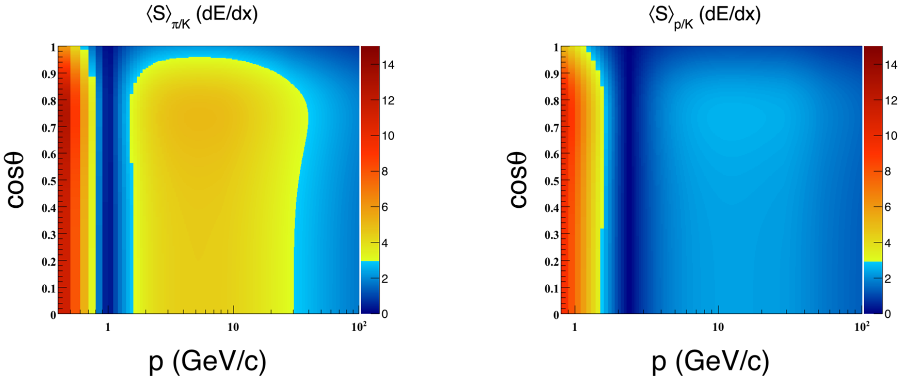


$\pi^{\pm}$

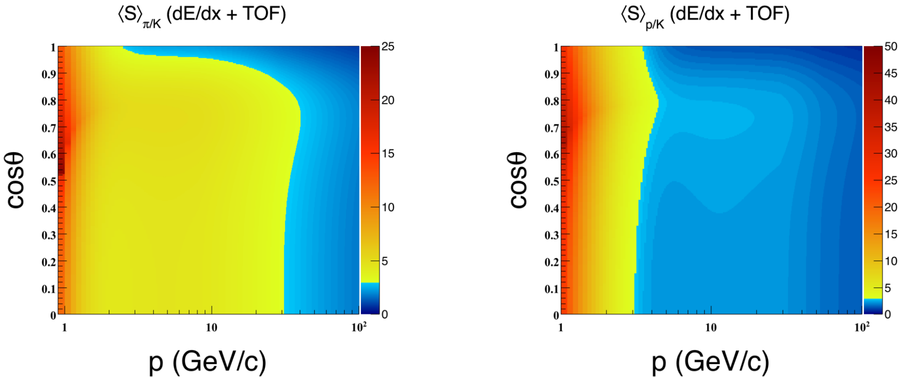


proton

separation power $S_{AB} = \frac{|dE/dx_A - dE/dx_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$



combine TOF and dE/dx



separation power at different conditions

$$S_{AB} = \frac{|t_A - t_B|}{\sqrt{2} \cdot \sigma_{TOF}}$$

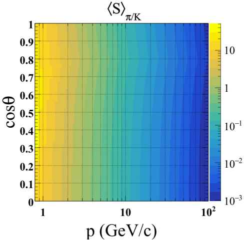
$$S_{AB} = \frac{|dE/dx_A - dE/dx_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}$$

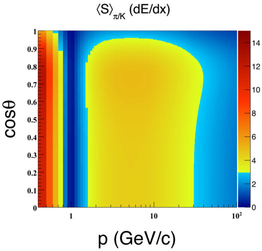
TOF

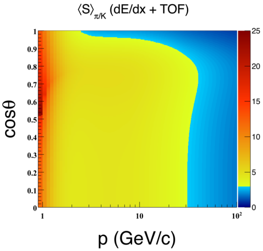
dE/dx

combine

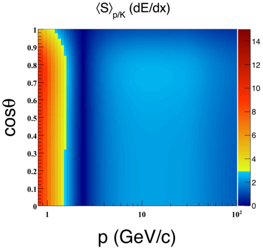
π/K

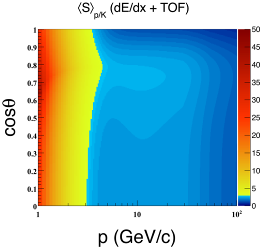






proton/K

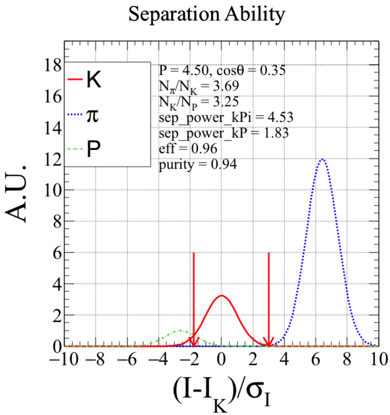


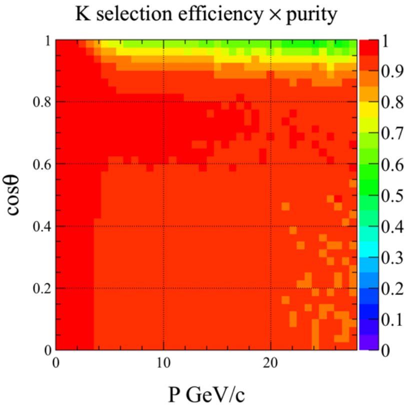


PID evaluation with $K^{\pm}$ identification, $D^0 \to \pi^+ K^-$ and $\phi \to K^+ K^-$ reconstruction based on the full simulation of $Z \to q\bar{q}$ samples.

Process	$\mathcal{B}$	Tera-Z yield	Sample used
$Z \to u\bar{u}$	11.17%	1.117×10^{11}	
$Z \to d\bar{d}$	15.84%	1.584×10^{11}	
$Z \to s\bar{s}$	15.84%	1.584×10^{11}	2.525×10^{-6} *of Tera − Z*
$Z \to c\bar{c}$	12.03%	1.203×10^{11}	
$Z \to b\bar{b}$	15.12%	1.512×10^{11}	

$K^{\pm}$ identification only with dE/dx





- $\epsilon_K = \frac{N_{K\to K}}{N_K}$
- $p_K = \frac{N_{K\to K}}{N_{K\to K}+N_{\pi\to K}+N_{P\to K}}$
- overall efficiency $= \frac{\sum_{bins}\epsilon_K\cdot N_k}{\sum_{bins} N_k}$ 95.97%
- overall purity $= \frac{\sum_{bins} p_K\cdot N_k}{\sum_{bins} N_k}$ 81.56%

the dependence of $K^{\pm}$ identification performance on dE/dx resolution

$\sigma_{actual} = factor \cdot \sigma_{intrinsic}$

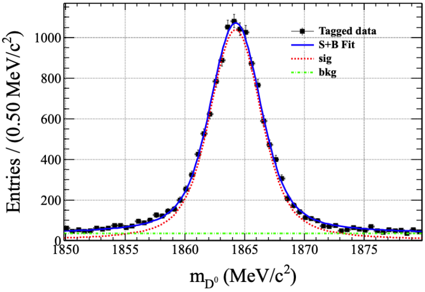
σ : dE/dx resolution

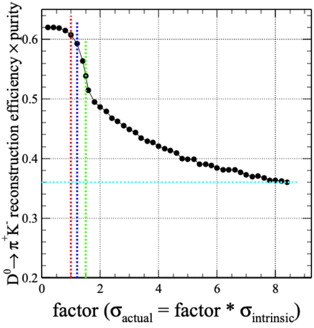
The factors are selected according to other detectors, such as PEP-4, TOPAZ, DELPHI, ALEPH, ALICE.

	factor	1.	1.2	1.5	2.
dE/dx	ε_K (%)	95.97	94.09	91.19	87.09
	$purity_K$ (%)	81.56	78.17	71.85	61.28
dE/dx & TOF	ε_K (%)	98.43	97.41	95.52	92.3
	$purity_K$ (%)	97.89	96.31	93.25	87.33

$D^0 \to \pi^+ K^-$ reconstruction

	ϵ (%)	p (%)
$\lvert mass - mass_{D0} \rvert < 0.01\, GeV/c^2$	90.39	2.16
IMP $> 0.02\, mm^2$	79.12	5.04
vertex fitted $\chi^2 < 5.15$	72.62	15.36
dis of vertex to IP $> 0.305\, mm$	69.24	28.41
PID	68.19	89.05

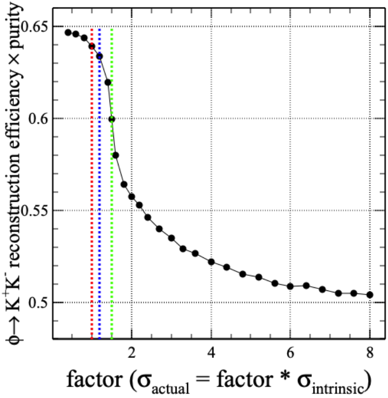




fitted mass : $1864.259 \pm 0.025\, \mathrm{MeV/c^2}$

$\phi \rightarrow K^+K^-$ reconstruction

	ϵ(%)	p (%)
$\lvert mass - mass_{D0} \rvert < 8\, MeV/c^2$	89.42	6.43
vertex fitted $\chi^2 < 9.95$	83.15	9.14
PID	82.26	77.70



Summary

- Once uncertainties in the processes of electron drift, signal amplification and readout in TPC are under control, the dE/dx resolution could reaches 2.5% in the barrel region for GeV level hadron.
- The performance of $K^{\pm}$ identification, $D^0 \rightarrow \pi^+ K^-$ reconstruction and $\phi \rightarrow K^+ K^-$ reconstruction all suggest that the dE/dx resolution need to be better than 3% in the barrel region for GeV level hadron, which corresponds to a degradation of the dE/dx resolution of less than 20%, with which the $K^{\pm}$ identification efficiency/purity can be better than 97%/96%.
- It would be appreciated if an alternative technology, e.g., dN/dx, could achieve significantly better resolution.

Many thanks !