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Detector Requirements analysis on the Pi-Kaon separation

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Outline

- Introduction
- PID(dEdx TOF) info for π, K, p
- △dEdx, △TOF, Separation Power and Average Separation Power for π, K
- Impact parameter info for π, K, p
- VTX and PID for reconstruction process
- Summary

Introduction

A event in detector: collection of final state particles

A particle: 4 + 3 + 3 variables

- $P4$: (E, p_x, p_y, p_z) or (E, m, θ, φ) … $(E^2 = p^2 + m^2)$
- Where it starts: impact parameters, not available for neutrals.
- Where it ends: K_s, Λ, B, D … , only applicable for long lived particles.

To study the fully charged decay process, we need to identify charged Kaon(hadrons) up to 20 GeV.

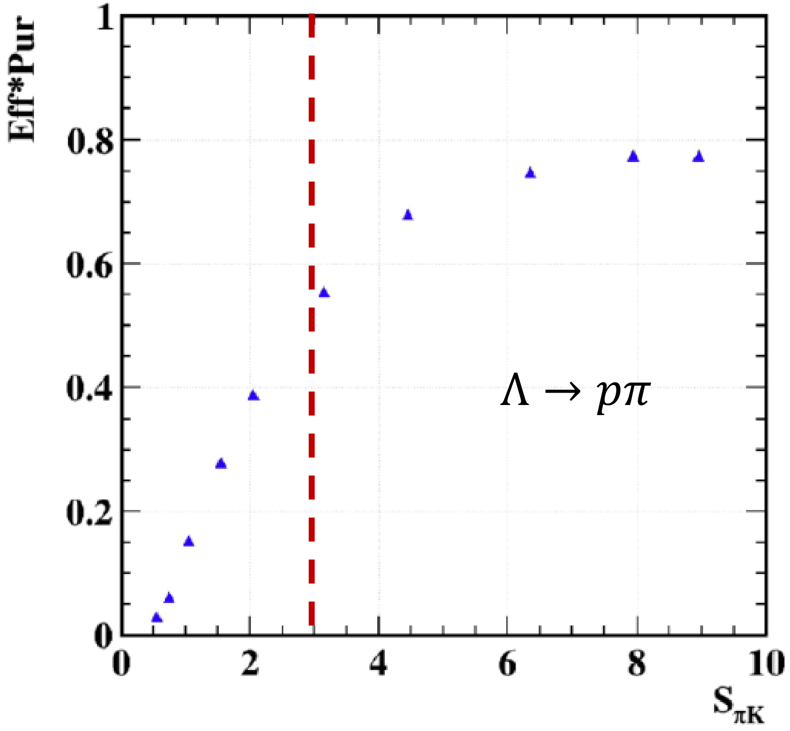
For objects with kaon and/or proton in its decay product:

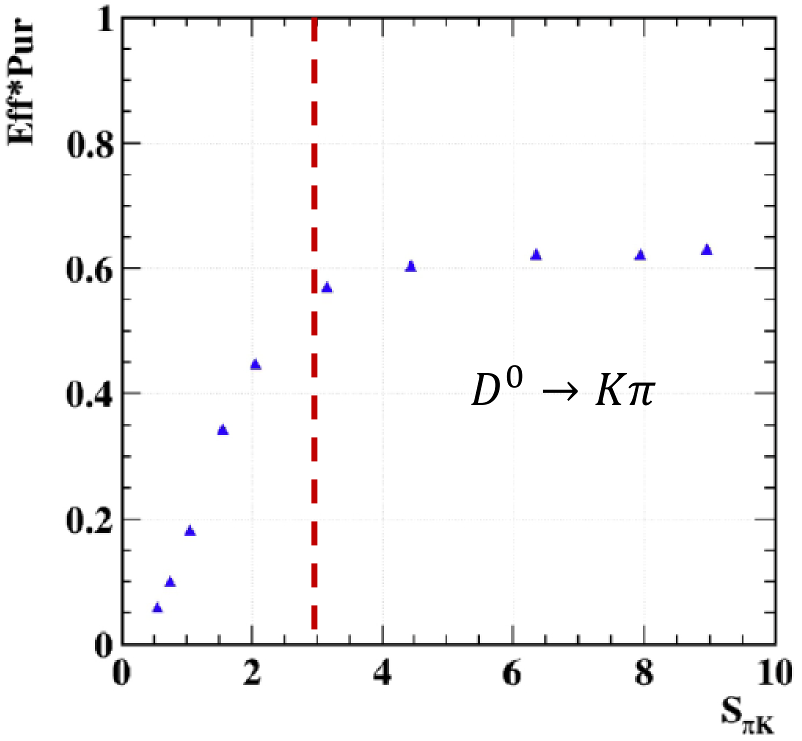
Performance depends on

- Momentum (fully charged final state)
- Hadron separation, especially π, K separation
- VTX reconstruction. (for heavy flavor hadrons)

Introduction

Preliminary





Reconstruction efficiency $*$ purity vs $\pi - K$ separation power

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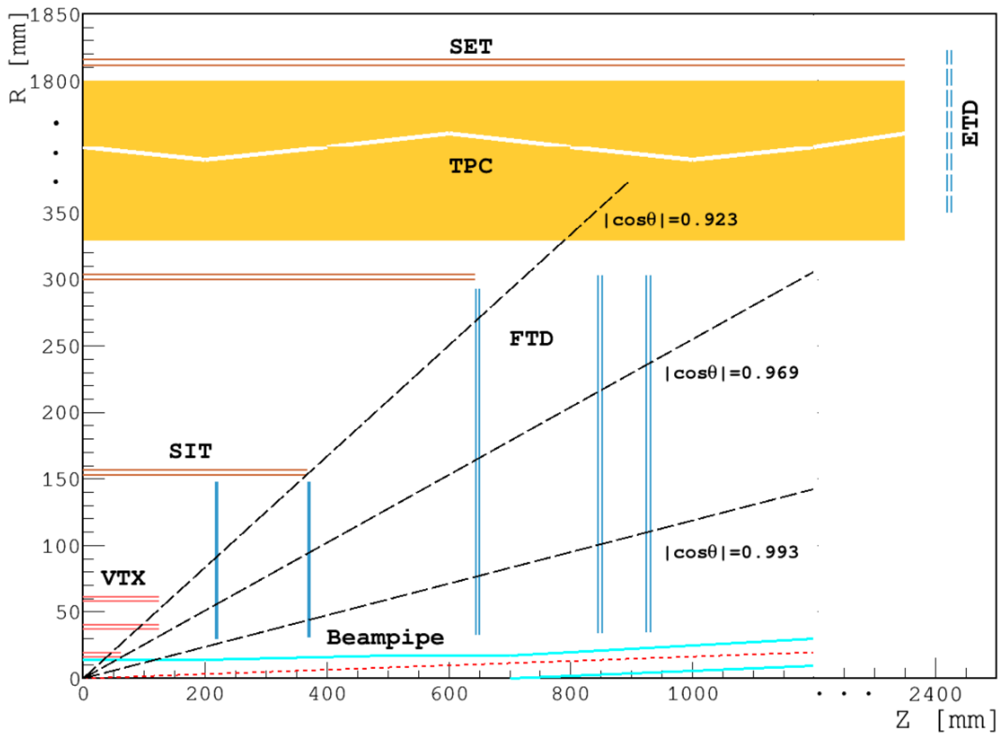
Introduction

– CEPC Baseline Detector Concept

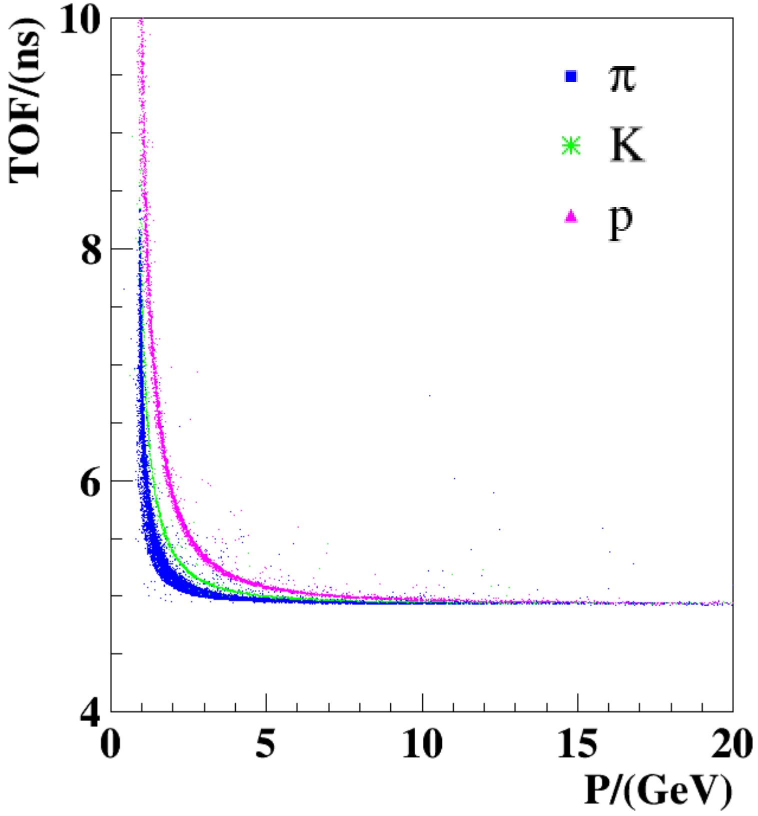


Preliminary layout of the tracking system of the CEPC baseline detector concept

The inner, outer radius and drift length of the TPC(R_{in} and R_{out}) are chosen as the boundary conditions to record the time of flight for particles π, k, p.

TOF for π, K, p

$\cos\theta = 0.5$



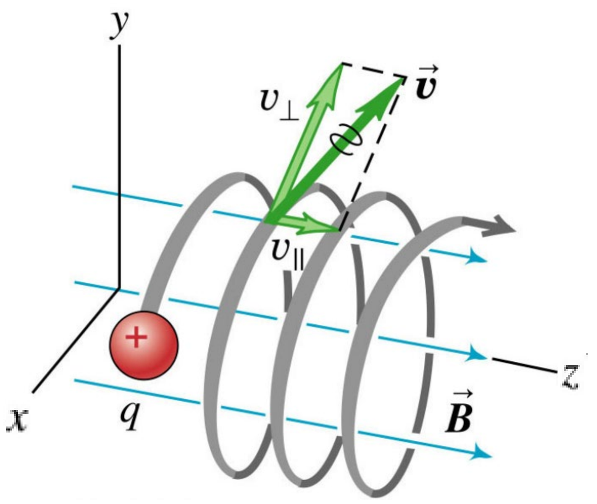
The calculation for TOF:

$$t_{total} = \frac{L_{total}}{\beta\gamma c}$$

z-direction projection is used to simplify the question.

$$t_z = t_{total} = \frac{\Delta z}{\beta_z \gamma c},$$

where Δz equals to the difference of z_{in} and z_{out}, which are depended on the inner and outer radius of the TPC(R_{in} and R_{out}).



A circular helix of radius R, slope $\frac{R}{\tan\theta}$ and central axis$\left(A_x, A_y, z_{const}\right)$ of the particle generation point is described by the following parametrization:

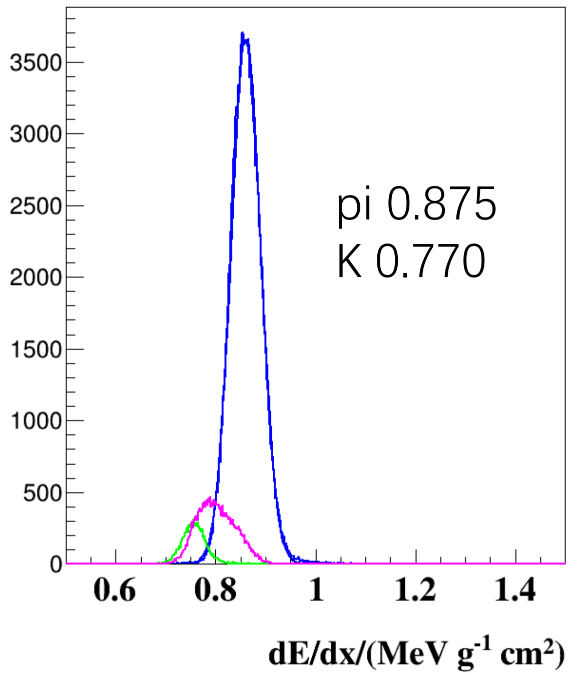
$$\begin{cases} x = R\cos\varphi + A_x, \\ y = R\sin\varphi + A_y, \\ z = \dfrac{R\varphi}{\tan\theta} + z_{const}, \end{cases}$$

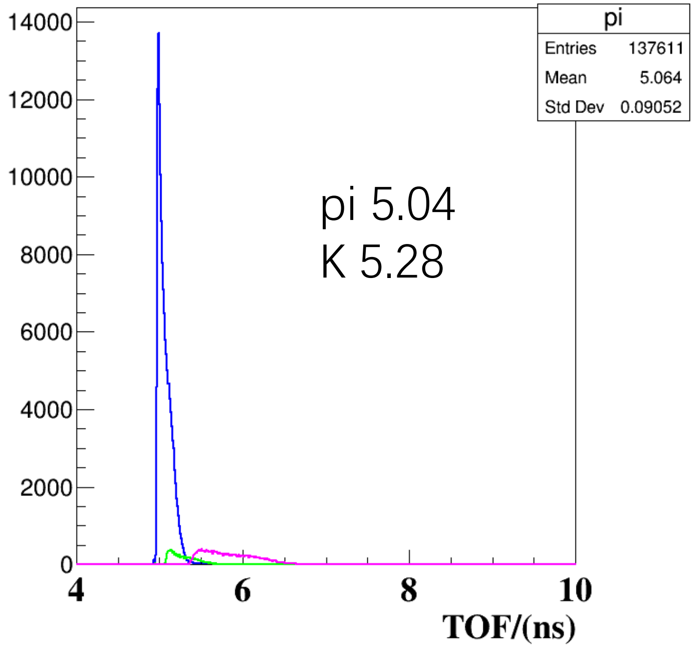
where $z_{const} = z_0 - R\frac{\varphi_{pca}}{\tan\theta}$, $\varphi_{pca} = \varphi + \frac{\pi}{2}$, $A_x = R\cos\varphi - d_0 \sin\varphi$ *and* $A_y = R\sin\varphi + d_0\cos\varphi$.

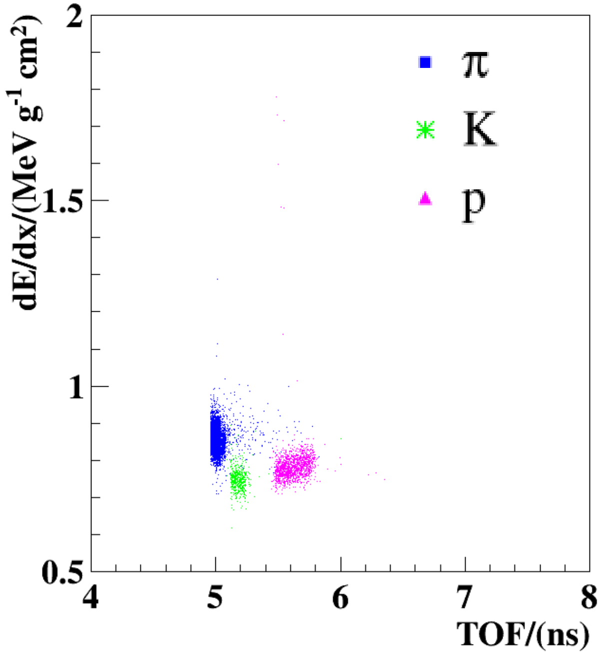
Note that if $\omega > 0$, then φ in the last equation should reverse sign and $\varphi_{pca} = \varphi - \frac{\pi}{2}$.

dEdx&TOF distribution for π, K, p

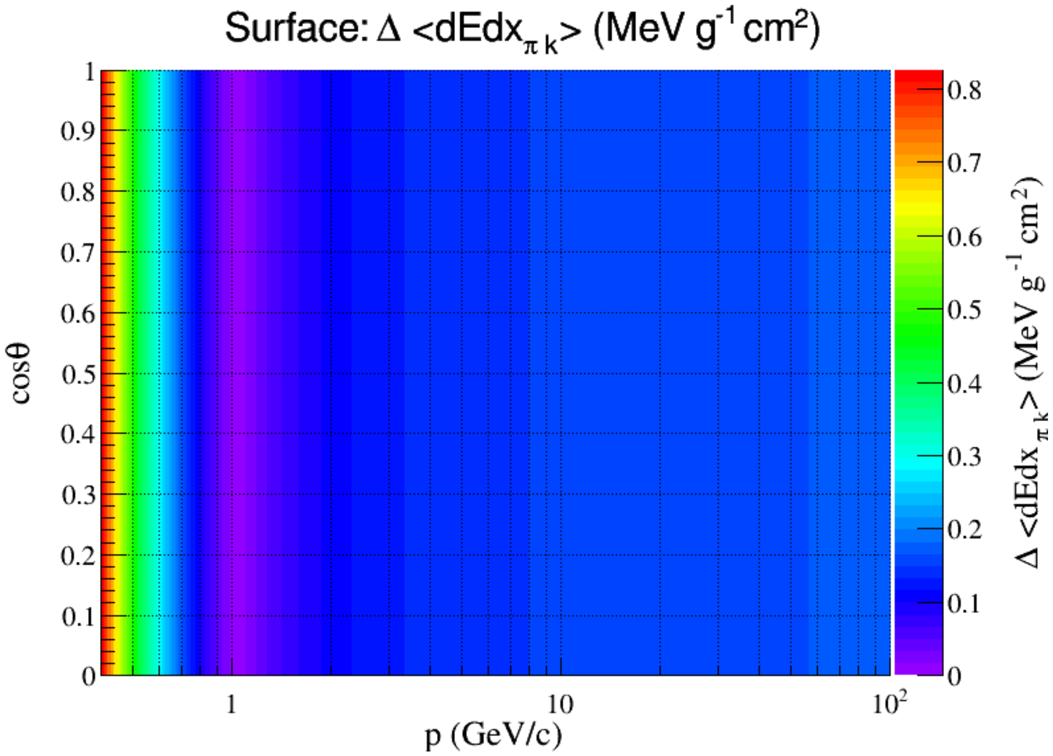
2 GeV
$\cos\theta = 0.5$

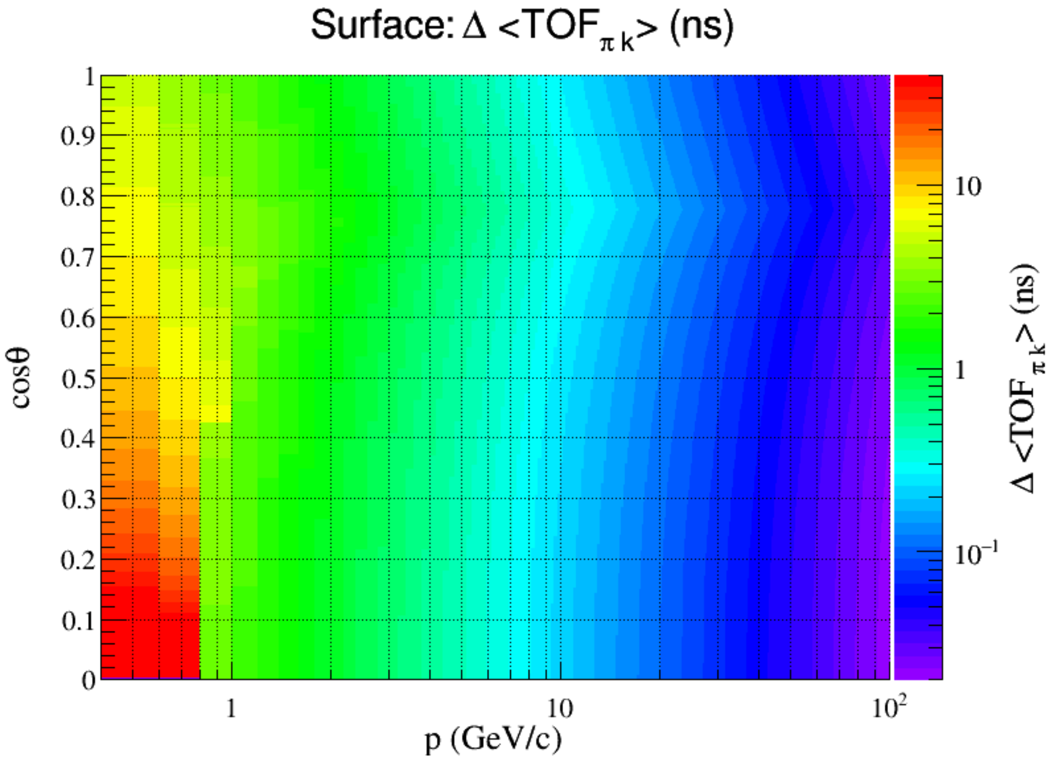






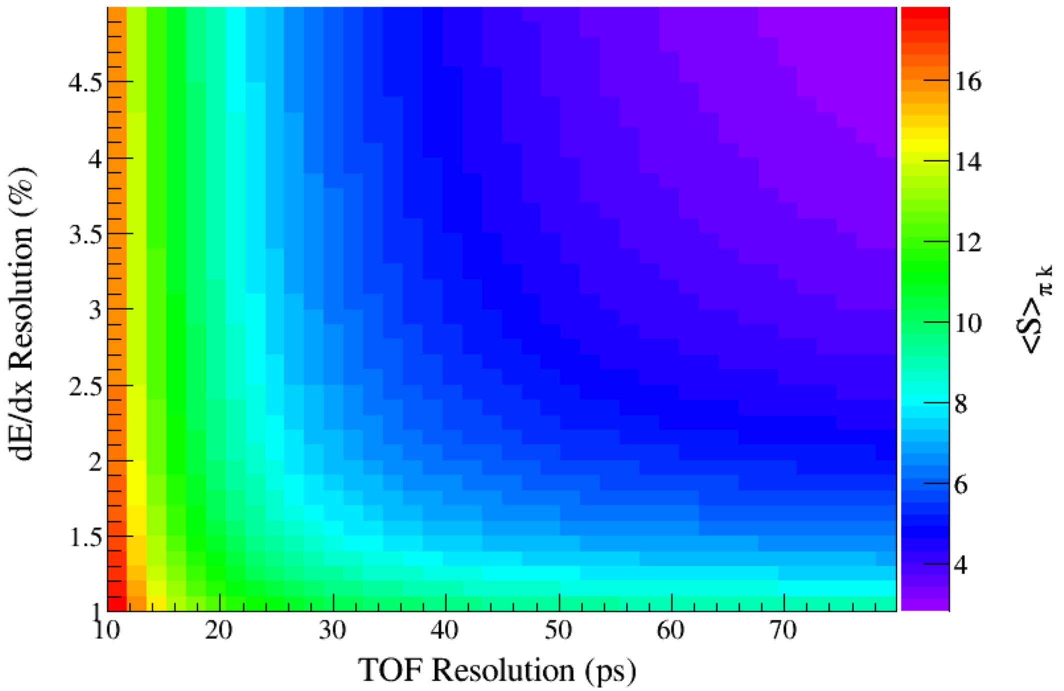
ΔdEdx & ΔTOF distribution for $\boldsymbol{\pi - K}$





Separation Power for $\pi - K$

2 GeV
$\cos\theta = 0.5$



Separation Power between particle π, K is defined as follow:

$$S_{\pi K} = \sqrt{\frac{(I_\pi - I_K)^2}{\sigma_{I_\pi}^2 + \sigma_{I_K}^2} + \frac{(T_\pi - T_K)^2}{\sigma_{T_\pi}^2 + \sigma_{T_K}^2}}$$

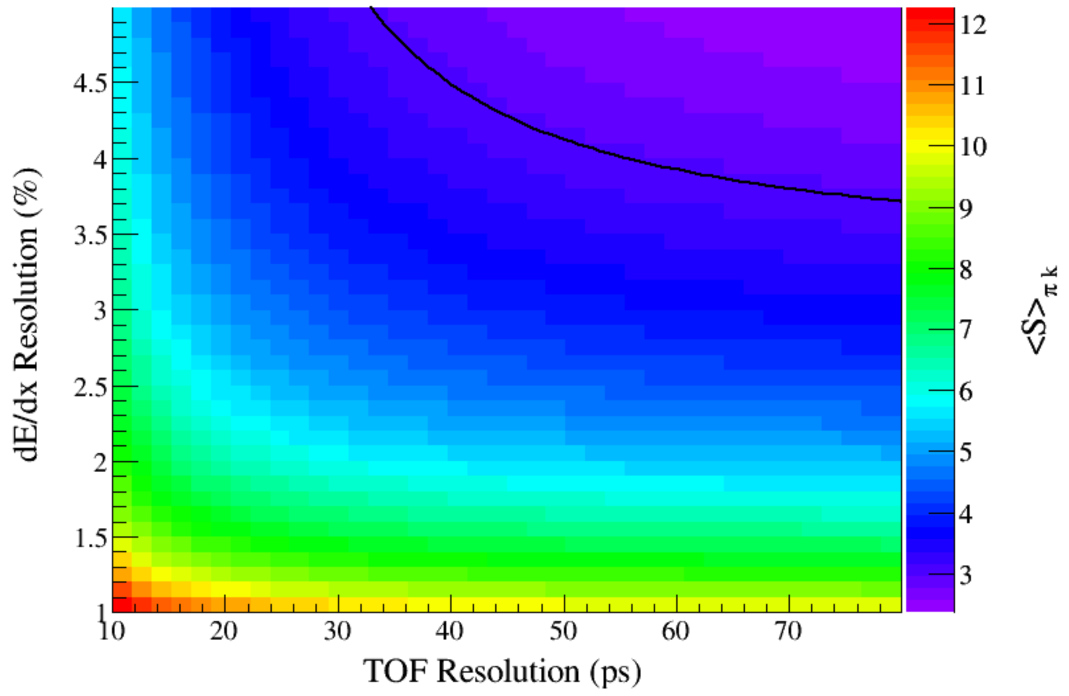
where I_π (I_K) and σ_{I_π} (σ_{I_K}) are the average dE/dx measurement of particle $\pi(K)$ and the corresponding resolution, T_π (T_K) and σ_{T_π} (σ_{T_K}) are the average TOF measurement of particle $\pi(K)$ and the corresponding resolution.

In the ideal case assuming no degradation and σ_I and σ_T are in the range of $[1-5\%]$ and $[10-80ps]$ respectively.

$S_{\pi K}$ is estimated at the CEPC as a function of σ_I, σ_T, p and $\cos\theta$.

Average Separation Power for $\pi - K$

1-20 GeV
$\cos\theta = 0 - 1$



The average separation power $\langle S \rangle$ versus σ_I and σ_T after integrating over the $\cos\theta$ and momentum dimension.

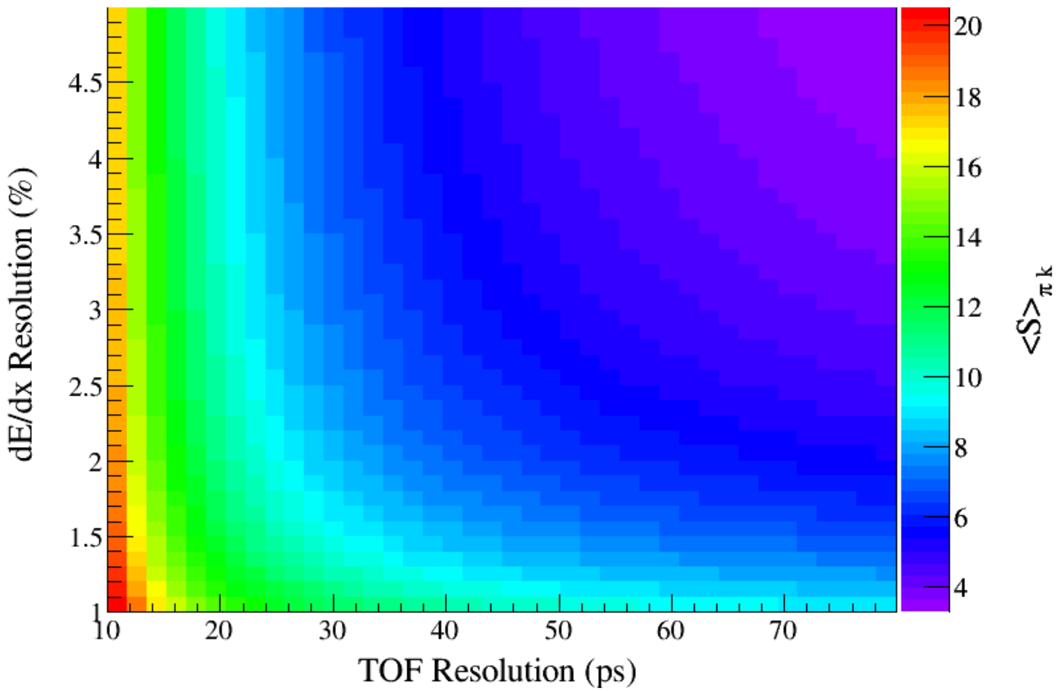
$$\langle S_{\pi K}(\sigma_I, \sigma_T) \rangle = \frac{\int_0^1 \int_1^{20} S_{\pi K}(\sigma_I, \sigma_T, p, \cos\theta) PDF(p, \cos\theta) dp\, d\cos\theta}{\int_0^1 \int_1^{20} PDF(p, \cos\theta) dp\, d\cos\theta}$$

The integral form is rewritten into a summation form：

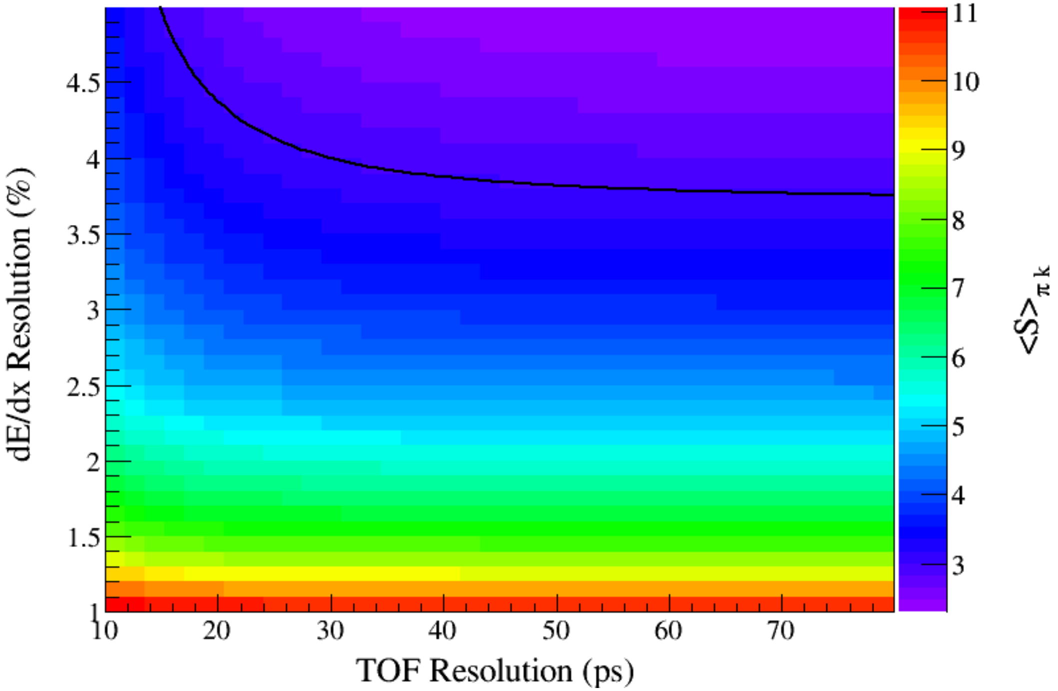
$$\langle S_{\pi K}(\sigma_I, \sigma_T) \rangle = \frac{\sum\sum S_{\pi K}\left(\sigma_I, \sigma_T, p_i, \cos\theta_j\right) PDF(p_i, \cos\theta_j) \Delta p\, \Delta\cos\theta}{\int_0^1 \int_1^{20} PDF(p, \cos\theta) dp\, d\cos\theta}$$

Average Separation Power for $\pi - K$

1-5 GeV
$\cos\theta = 0 - 1$

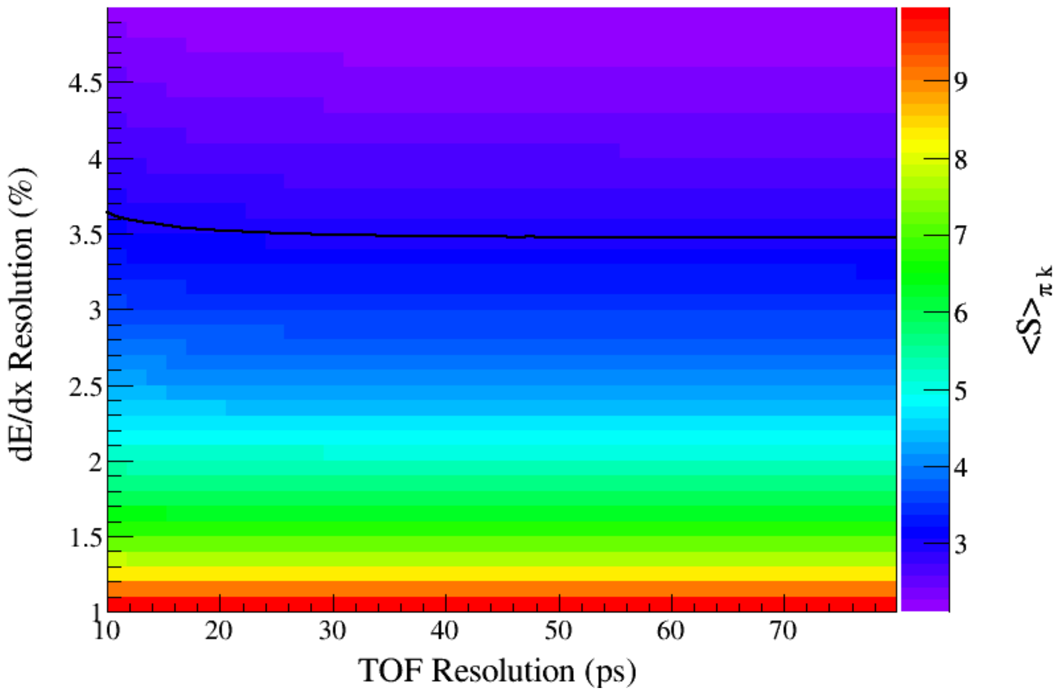


5-10 GeV
$\cos\theta = 0 - 1$

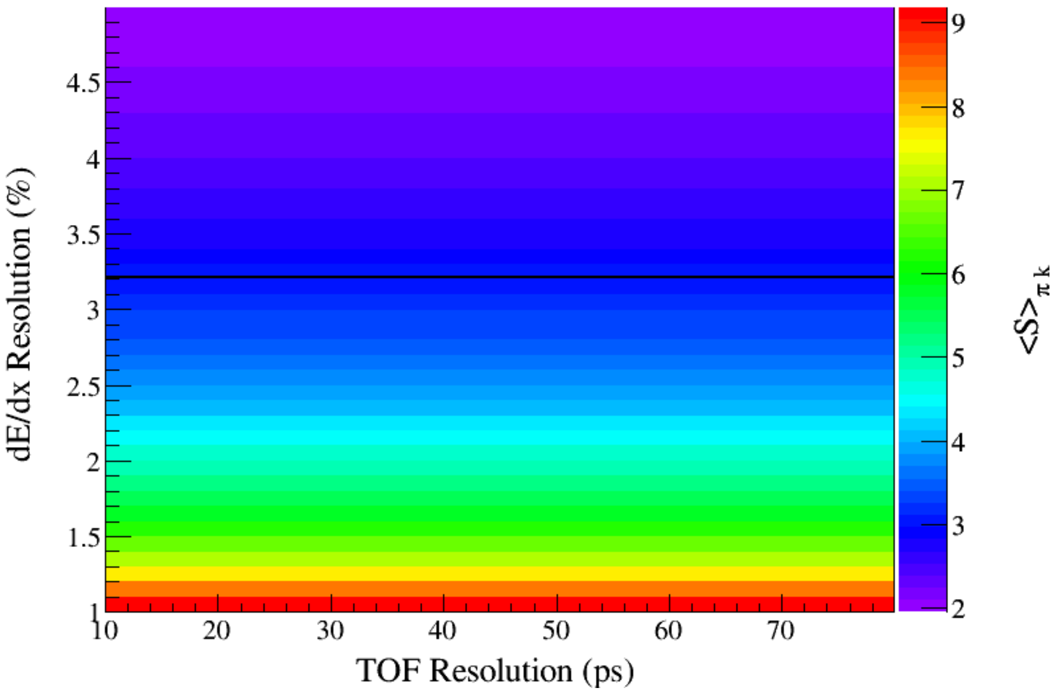


Average Separation Power for $\pi - K$

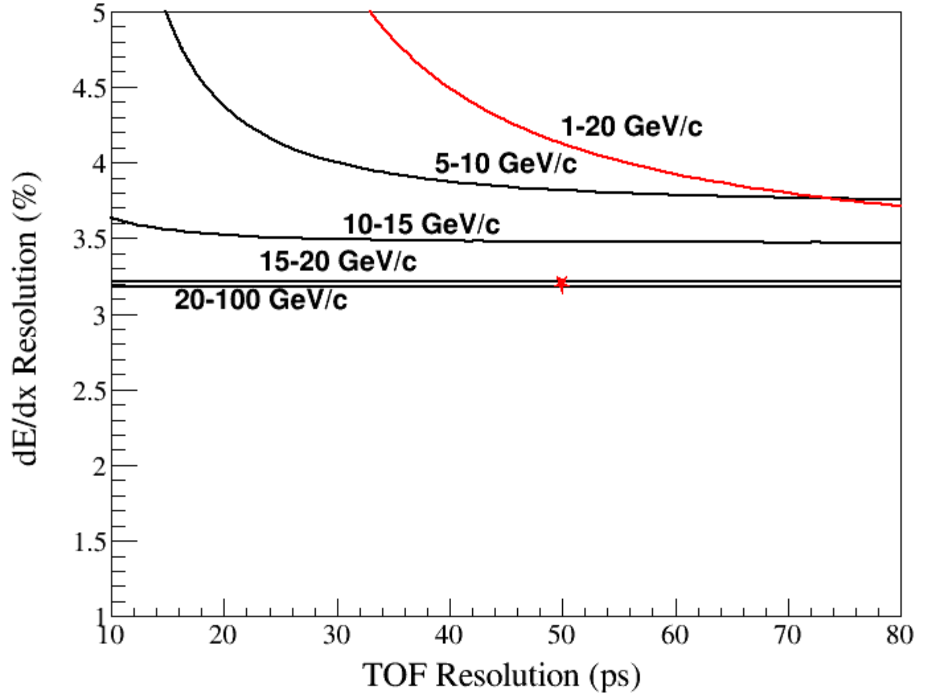
10-15 GeV
$\cos\theta = 0 - 1$

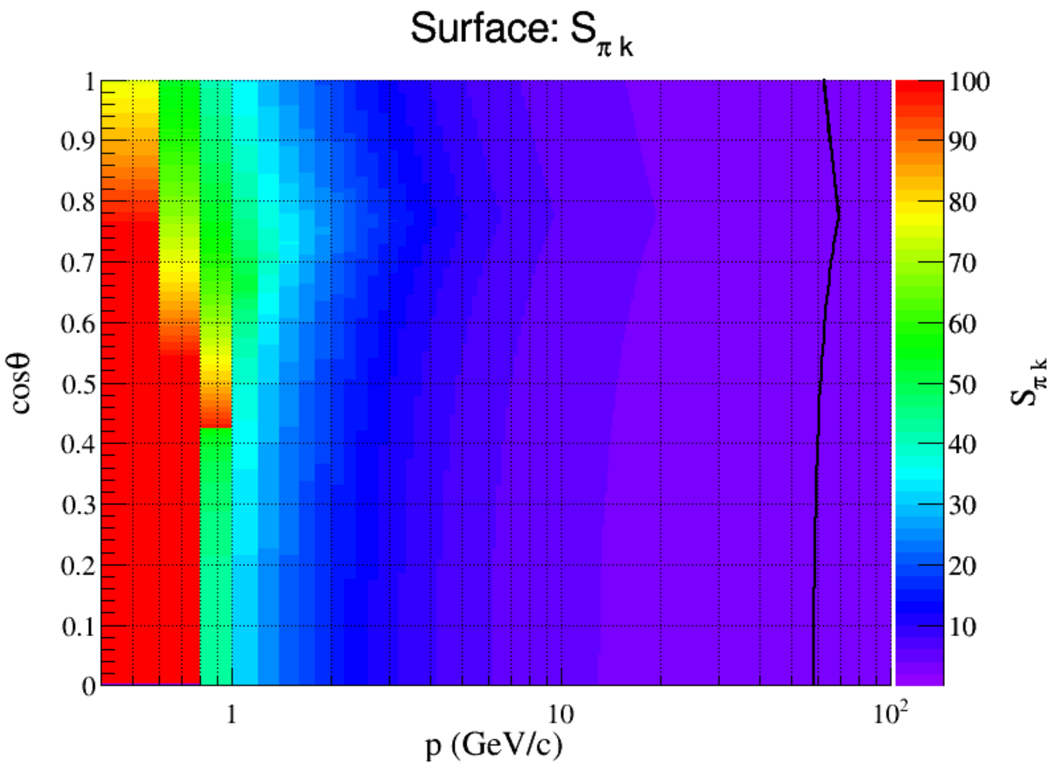


15-20 GeV
$\cos\theta = 0 - 1$

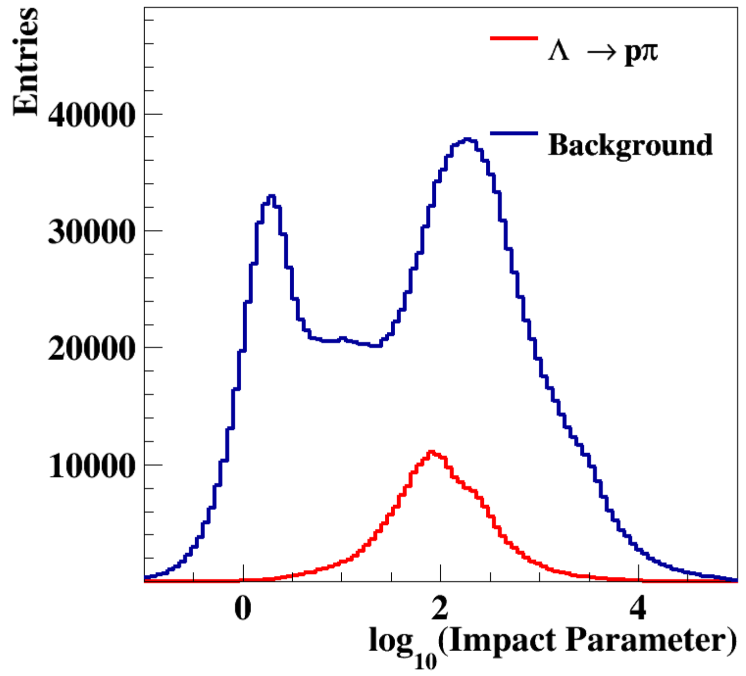


Average Separation Power for $\pi - K$

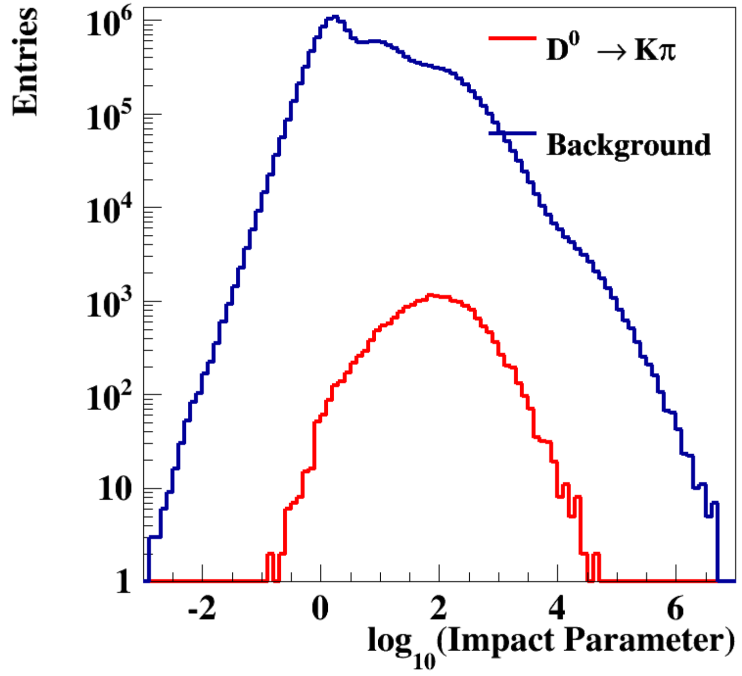




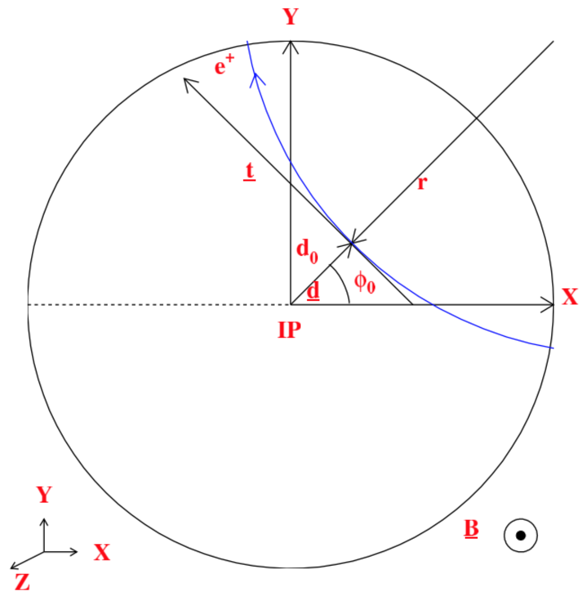
Impact parameter for π, K, p



p tracks used



π tracks used



Impact parameter is defined as

$$\sqrt{\left(\frac{d_0}{\sigma_{d_0}}\right)^2 + \left(\frac{z_0}{\sigma_{z_0}}\right)^2}$$

d_0 is the distance between the nearest point (x_0, y_0, z_0) of the track on the $r - \varphi$ plane and the reference point IP. When $\underline{d} \times \underline{t}$ and z axis are in the same direction, the sign of d_0 is positive.

VTX and PID
for reconstruction

Selection Process for $\Lambda \to p\pi$:

1. Pick two tracks with opposite charges.
2. Use truth information to get the track PID.
   - If track PID is lepton, then **end** the process.
   - If track PID is hadron, then use random number generator to mimic PID resolution.
3. If the two track PID after step 2 are p and π respectively, then fit the secondary (or tertiary vertex) with two tracks using least square method.
4. Select those which satisfy that χ^2 from the vertex fit has to be under certain threshold (<20).
5. Select those which satisfy certain constraints on mass error (<10 MeV). 4-momentum is computed using two tracks at the secondary vertex (or tertiary vertex).
6. If the gaussian distributions in this picture is too wide, then most tracks will be identified as π. Then we use the leftover tracks to perform the reconstruction again, this time without PID.

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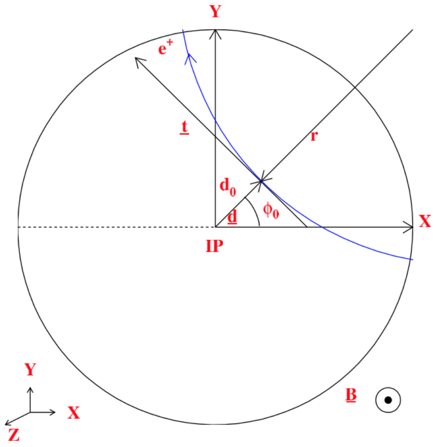

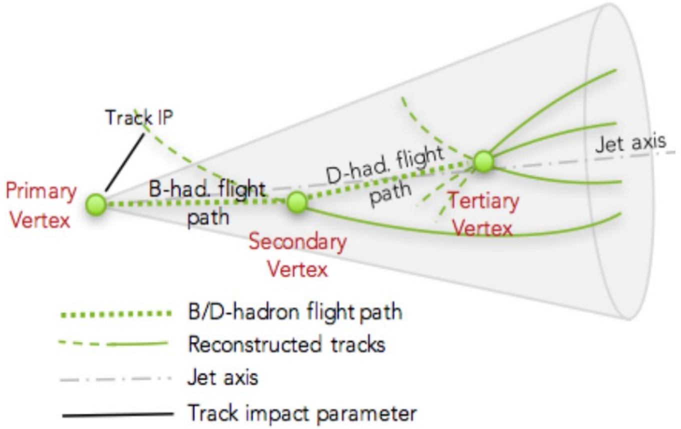

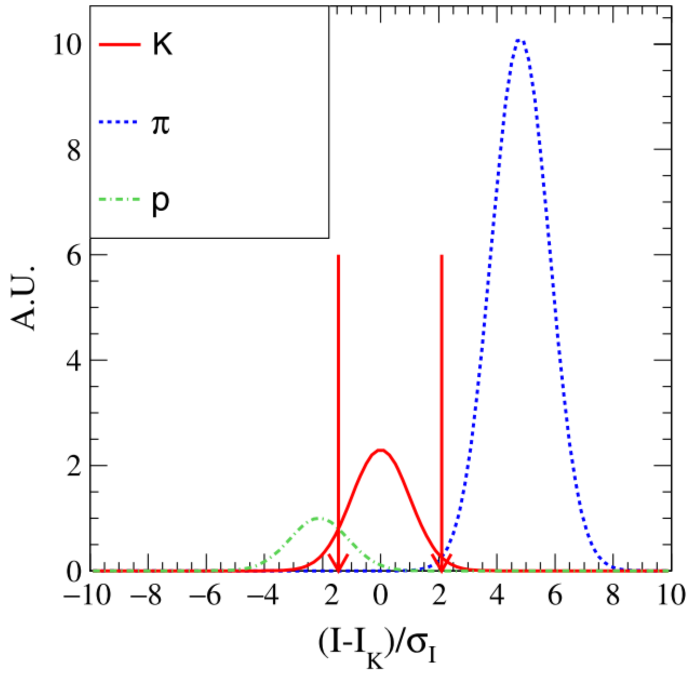

The scaled spectra of $(I - I_K)/\sigma_I$ using dE/dx measurements alone for particles with a momentum of 5 GeV/c

Summary

To identify charged Kaon(hadrons) up to 20 GeV

- VXT: χ^2, reconstructed parent mass and impact parament $\sqrt{\left(\frac{d_0}{\sigma_{d_0}}\right)^2 + \left(\frac{z_0}{\sigma_{z_0}}\right)^2}$
- PID: dE/dx and TOF

Preliminary:

- 3σ separation of $\pi - K$, corresponding to $3.2\ \%$ of dE/dx resolution and $\mathbf{50}\ ps$ TOF resolution, is appreciated.

Next:

- The impact parament will be used to optimize the reconstruction process

Check Validity