$K^{\pm}$ identification at the CEPC

朱永峰

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Motivation :

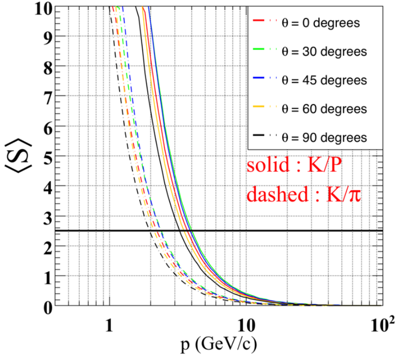
- Tagging s quark ($K^{\pm}$, K_L, and K_S) is essential for CKM elements measurement. This report focus on the identification of $K^{\pm}$, which is effectively stable.
- The charged pions, kaons, protons and their antiparticles have identical interactions in sub-detectors. We use the following information to separate these kinds of particles.
  1. TOF measurement
  2. measurement of the energy deposit by ionization (dE/dx)

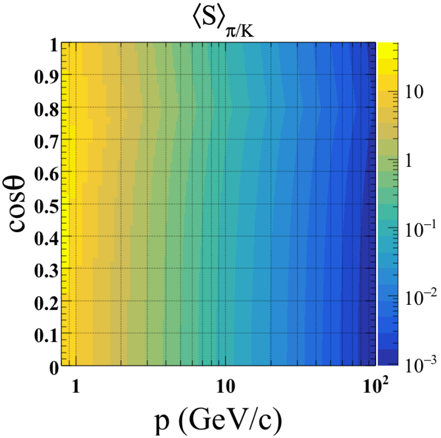
Contents:

- charged $\pi/K/P$ separation with:
  1. TOF
  2. dE/dx
  3. dE/dx and TOF
- $K^{\pm}$ identification in Z-pole mode
- $D^0 \to \pi^+ K^-$ identification in Z-pole mode

TOF

- The particle flight time t over a given distance along the track trajectory L.
- particles A/B separation power with TOF: $\left(\frac{|t_A - t_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}}\right)$
- σ_{TOF} = 50 ps (CEPC white paper)

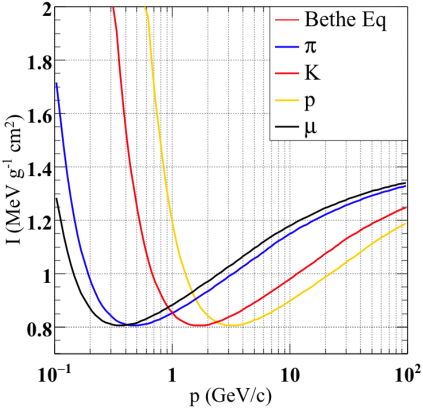




dE/dx

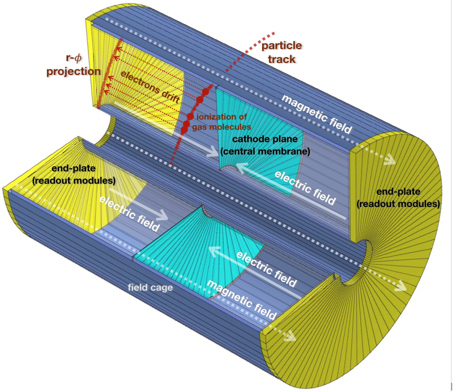
- Moderately relativistic charged particles other than electrons lose energy in matter primarily by ionization and atomic excitation. The mean rate of energy loss is given by the Bethe-Bloch equation.
- $-\frac{dE}{dx}(MeV \cdot cm^2 \cdot g^{-1}) = Kq^2 \frac{Z}{A\beta^2}[0.5ln\frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}]$

In the following, we denote dE/dx as *I*.

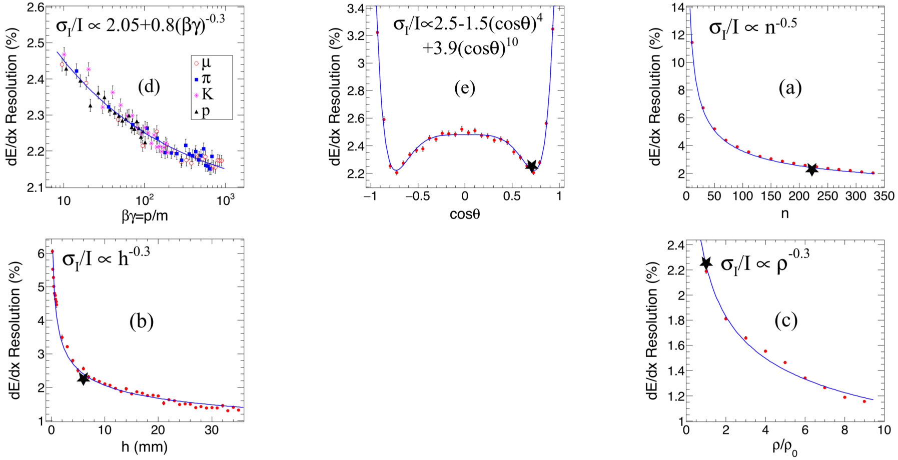


dE/dx resolution

- dE/dx resolution : σ_I/I
- 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.

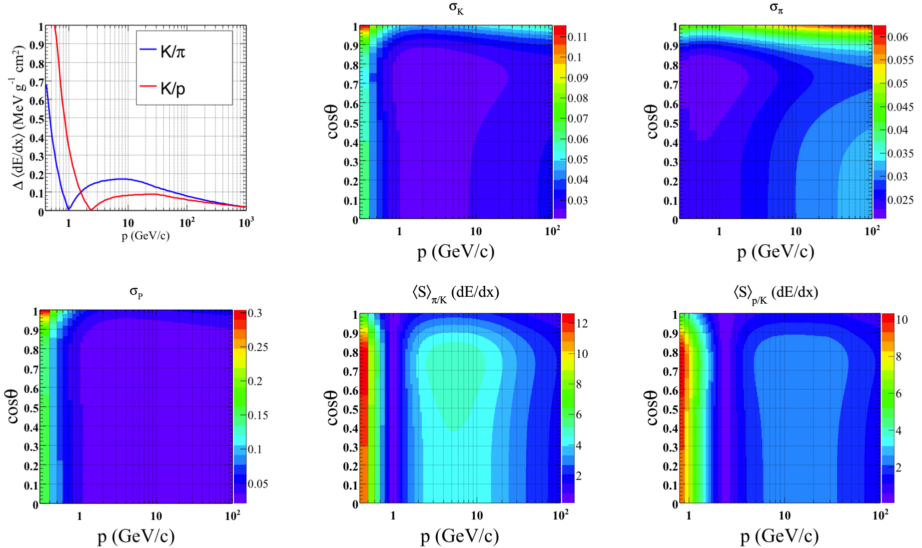


We only consider intrinsic resolution and study them with single-particle MC events:

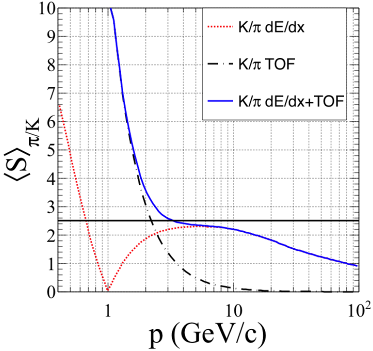


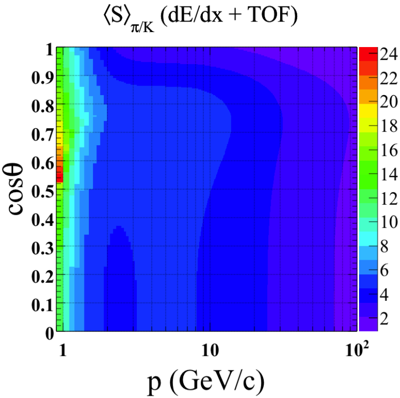
$$\sigma_I/I = \frac{13.5}{n^{0.5}\cdot(h\rho)^{0.3}}\left[2.05+0.8(\beta\gamma)^{-0.3}\right]\times\left[2.5-1.5(cos\Theta)^4+3.9(cos\Theta)^{10}\right]$$

separation power with dE/dx ($S_{AB} = \frac{|I_A - I_B|}{\sqrt{\sigma_{I_A}^2 + \sigma_{I_B}^2}}$)

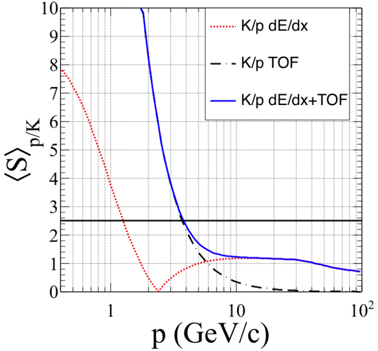


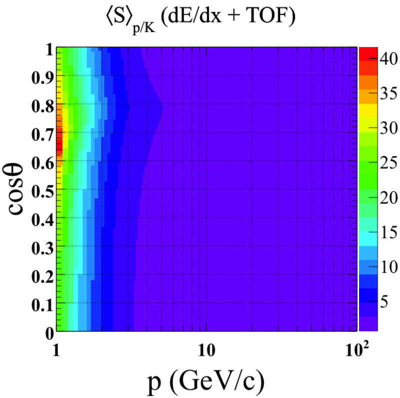
combine dE/dx and TOF for K/π separation





combine dE/dx and TOF for K/P separation





The above slides verify the result in the paper Monte Carlo study of particle identification at the CEPC using TPC dE/dx infromation (link)

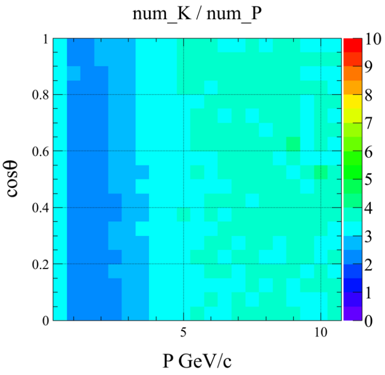
$K^{\pm}$ identification from $\pi^{\pm}$ and $P^{\pm}$ backgrounds

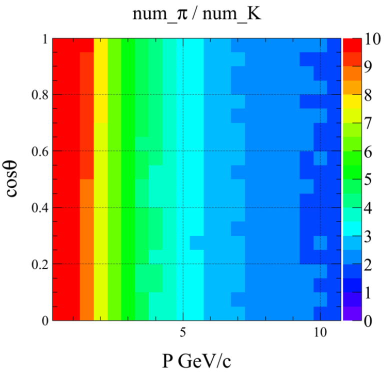
Samples:

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}	

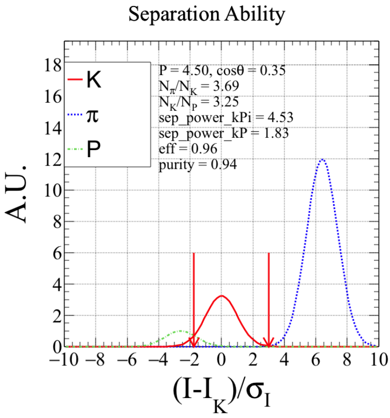
- $\epsilon_K = \frac{N_{K\to K}}{N_K}$
- $p_K = \frac{N_{K\to K}}{N_{K\to K}+N_{\pi\to K}+N_{P\to K}}$

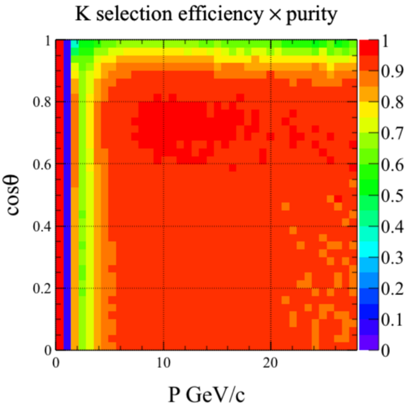
the relative populations of charged K/P/π versus momentum and polar angle



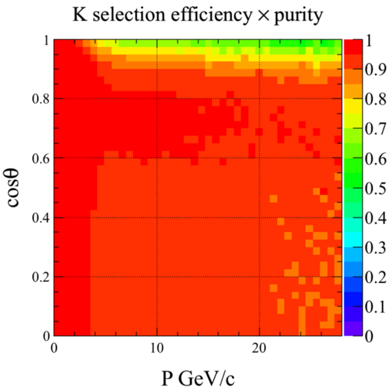


$K^{\pm}$ selection only with dE/dx

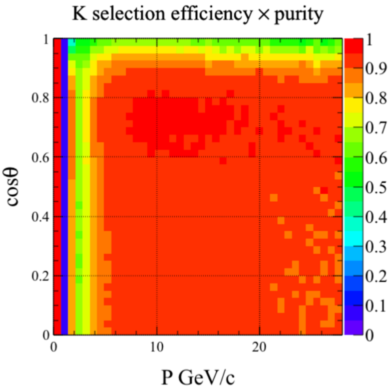




$K^{\pm}$ selection with dE/dx and TOF

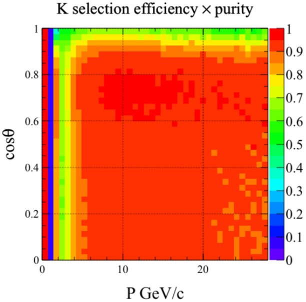


$K^{\pm}$ selection only with dE/dx

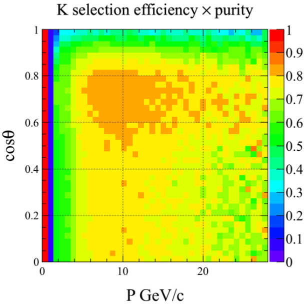


the dependence of K identification performance on dE/dx resolution

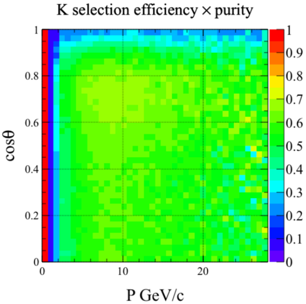
dE/dx



$\sigma_{actual} = 1.0 \cdot \sigma_{intrinsic}$



$\sigma_{actual} = 1.5 \cdot \sigma_{intrinsic}$



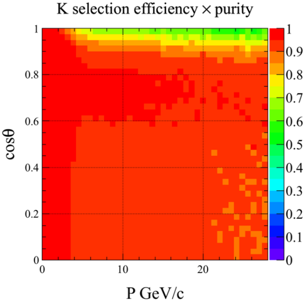
$\sigma_{actual} = 2.0 \cdot \sigma_{intrinsic}$

dE/dx

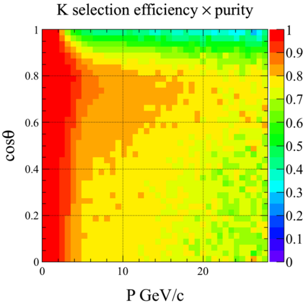
+

TOF

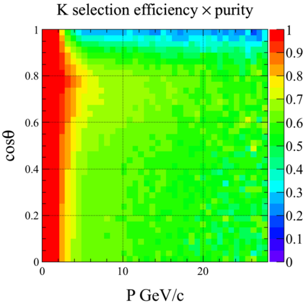
$(\sigma_{TOF} = 50ps)$



$\sigma_{actual} = 1.0 \cdot \sigma_{intrinsic}$



$\sigma_{actual} = 1.5 \cdot \sigma_{intrinsic}$



$\sigma_{actual} = 2.0 \cdot \sigma_{intrinsic}$

$K^{\pm}$ identification performance in various conditions

the sample used : 2.525×10^{-6} *of Tera* $-Z$

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

$$\varepsilon_K = \frac{N_{K\to K}}{N_K}$$

$$purity_K = \frac{N_{K\to K}}{N_{K\to K}+N_{\pi\to K}+N_{P\to K}}$$

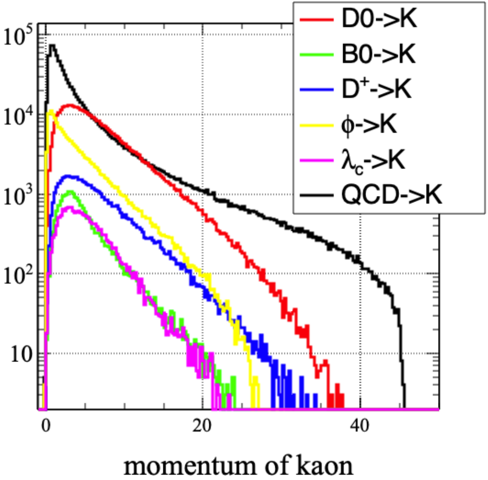
$$prob_{\pi\to K} = \frac{N_{\pi\to K}}{N_\pi}$$

$$prob_{P\to K} = \frac{N_{P\to K}}{N_P}$$

	factor	1.	1.5	2.
dE/dx	ε_K (%)	91.58	87.15	79.37
	$purity_K$ (%)	84.71	73.2	64.23
	$prob_{\pi\to K}$ (%)	5.71	13.16	17.48
	$prob_{p\to k}$ (%)	21.15	31.56	40.61
dE/dx & TOF	ε_K (%)	98.21	94.38	89.08
	$purity_K$ (%)	98.05	94.19	89.62
	$prob_{\pi\to K}$ (%)	0.05	0.32	0.8
	$prob_{p\to k}$ (%)	3.67	8.29	11.92

The other paper has done the same analysis, but our result is better, this is because we has consider the relative populations in different bin. The PID performance is mainly limited by the proton contamination.

the sample used : 2.525×10^{-6} *of Tera* $-$ *Z*



$K^{\pm}$ identification performance in various processes

	factor	1.		1.5		2.	
		eff	pur	eff	pur	eff	pur
dE/dx	$D0 \rightarrow K + X$	93.55	88.75	85.96	78.35	76.01	68.06
	$B0 \rightarrow K + X$	92.72	86.18	85.54	75.9	75.92	65.94
	$\lambda_c \rightarrow K + X$	93.1	87.66	85.85	77.28	76.02	67.26
	$D^+ \rightarrow K + X$	93.5	88.66	86.03	78.24	76.14	67.98
	$\phi \rightarrow K + X$	91.77	85.05	87.43	73.86	79.72	65.04
	K from QCD	90.97	83.58	84.21	69.1	77.1	60.6
dE/dx & TOF	$D0 \rightarrow K + X$	97.25	96.87	91.3	90.75	83.11	83.54
	$B0 \rightarrow K + X$	97.79	97.56	92.95	92.81	85.85	86.95
	$\lambda_c \rightarrow K + X$	97.45	97.13	91.99	91.68	84.25	85.11
	$D^+ \rightarrow K + X$	97.27	96.9	91.38	90.83	83.25	83.67
	$\phi \rightarrow K + X$	98.26	98.1	94.55	94.37	89.27	89.87
	K from QCD	94.98	94.87	91.6	91.47	87.07	87.52

$D^0 \to \pi^+ K^-$ identification performance with TOF and dE/dx in various dE/dx resolution

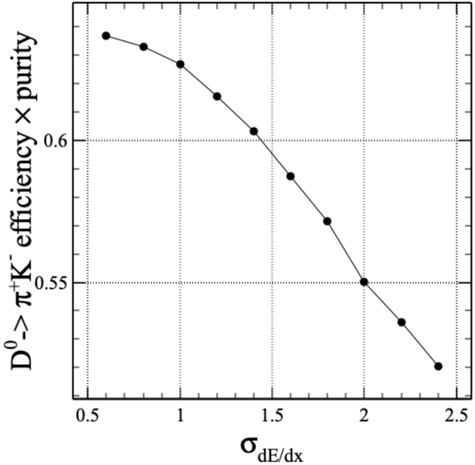
the sample used : 2.525×10^{-6} $of\ Tera-Z$

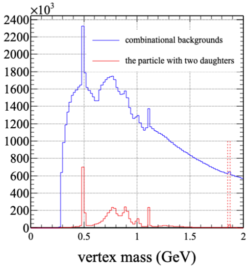
$$efficiency = \frac{number\ of\ correctly\ selected\ track\ pair\ candidates}{number\ of\ D^0\ daughters\ (\pi^+ K^-)\ track\ pairs}$$

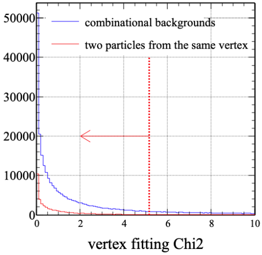
$$purity = \frac{number\ of\ correctly\ selected\ track\ pair\ candidates}{number\ of\ selected\ track\ pair\ candidates}$$

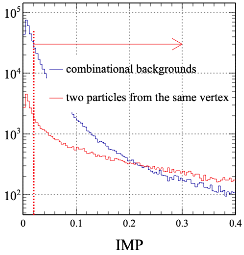
$D^0 \to \pi^+ K^-$

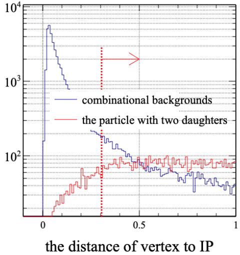
	signal	bkg	$\frac{\sqrt{S+B}}{S}$	efficiency	purity
total	15415	160005687	0.82		
$\|mass - mass_{D0}\| < 0.01 GeV$	13935	631787	0.06		
vertex fitted $\chi^2 < 5.15$	13319	265745	0.04		
IMP > 0.02	11657	68538	0.024		
dis of vertex to IP > 0.305	11176	30161	0.018		
PID ($1. \cdot \sigma_{dE/dx}$)	10996	1530	0.01	71.33%	87.78%
PID ($1.5 \cdot \sigma_{dE/dx}$)	10527	1557	0.01	68.29%	87.11%
PID ($2.0 \cdot \sigma_{dE/dx}$)	9938	1600	0.01	64.47%	86.13%

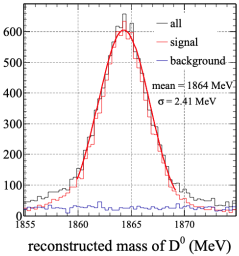

D0-> π+K- efficiency × purity
0.6
0.55
0.5
1
1.5
2
2.5
σdE/dx


×10^3
combinational backgrounds
the particle with two daughters
vertex mass (GeV)


combinational backgrounds
two particles from the same vertex
vertex fitting Chi2


combinational backgrounds
two particles from the same vertex
IMP


combinational backgrounds
the particle with two daughters
the distance of vertex to IP


all
signal
background
mean = 1864 MeV
σ = 2.41 MeV
reconstructed mass of D^0 (MeV)

Summary

- We start from the previous analysis of TOF and dE/dx at the CEPC (link) and give the differential identification performance of charged kaon in various processes.
- With the sample 2.525×10^{-6} *of Tera* $-$ *Z*, the charged kaon can been identified with efficiency times purity more than 96% combing dE/dx and TOF in the MC truth level. Assume the dE/dx resolution degrades 50%, the charged kaon identification efficiency times purity can reach more than 88%.
- With the sample 2.525×10^{-6} *of Tera* $-$ *Z*, we also study the $D^0 \to \pi^+ K^-$ identification performance and find its efficiency times purity can reach 60%.

Backup

Table 2 Expected PID performance parameters at the CEPC in different scenarios. Shown are the average value of particles with momenta from 2–20 GeV/c in the $e^+e^- \rightarrow Z \rightarrow q\bar{q}$ decays

	Deterioration	0	0.5	0.2
	$\langle S_{K\pi} \rangle$	3.9	2.6	3.2
	$\langle S_{Kp} \rangle$	1.5	1.0	1.2
dE/dx	ε_K (%)	93.2	84.5	90.9
	p_K (%)	86.5	76.1	82.4
	$p_{\pi \rightarrow K}$ (%)	0.1	1.3	0.5
	$p_{p \rightarrow K}$ (%)	33.0	47.2	40.1
	$\langle S_{K\pi} \rangle$	4.0	2.8	3.4
dE/dx	$\langle S_{Kp} \rangle$	3.2	2.8	3.0
&	ε_K (%)	96.8	90.4	95.0
TOF	p_K (%)	97.0	90.1	94.5
	$p_{\pi \rightarrow K}$ (%)	0.1	1.1	0.4
	$p_{p \rightarrow K}$ (%)	6.4	13.8.	9.6