
Kaon Identification in BELLE

w/ Aerogel Cherenkov Counter

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Particle ID for B-factory

CP violation in B decays -- Our Major Physics Goal !

- Time-dependent CP asymmetry through $B^0 - \bar{B}^0$ mixing (indirect CPV):

$$A_f(t) = \frac{\Gamma_f(t) - \bar{\Gamma}_f(t)}{\Gamma_f(t) + \bar{\Gamma}_f(t)} = \sin(2\phi_f) \cdot \sin(\Delta m t)$$

ex. $B \rightarrow J/\psi K_s \Rightarrow \phi_1$

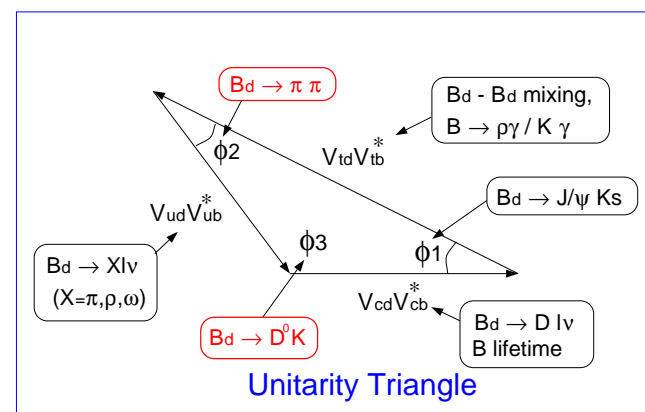
$B \rightarrow \pi\pi \Rightarrow \phi_2$

- Decay rate asymmetry (direct CPV):

$$\Gamma(B \rightarrow f) \neq \Gamma(\bar{B} \rightarrow \bar{f})$$

ex. $B \rightarrow DK \Rightarrow \phi_3$

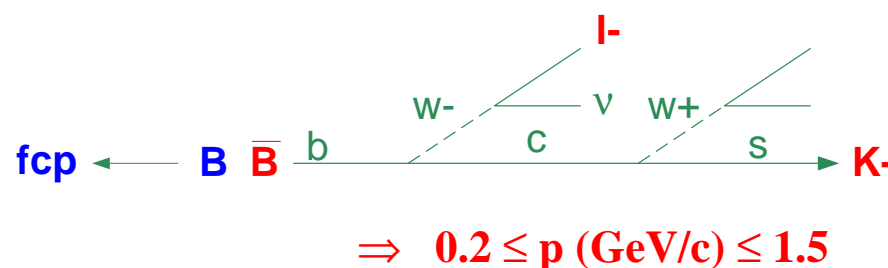
$B \rightarrow K\pi$



Two important aspects of kaon ID.

- Flavor tagging**

Charge of high momentum lepton
kaon from cascade decays



- Reconstruction of exclusive decay modes**

Two-body B decays \rightarrow high momentum kaon/pion

$$\Rightarrow 1.5 \leq p \text{ (GeV/c)} \leq 3.8$$

Particle ID for B-factory (cont'd)

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Requirements

- **Flavor Tagging**
 $0.2 \leq p(\text{GeV}/c) \leq 1.5$
Rejection factor $O(10^{-2})$
- **Two-body Decays**
 $1.5 \leq p(\text{GeV}/c) \leq 3.8$
Rejection factor $O(10^{-1})$

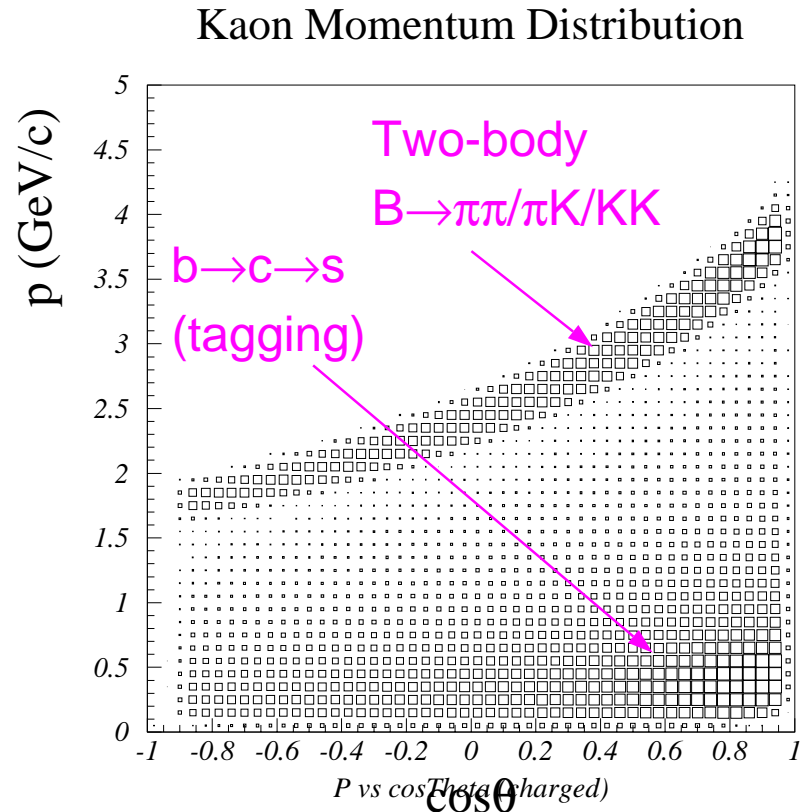
Technology choices

- $dE/dx \propto 1/\beta^2 \left[1/2 \cdot \ln \frac{2m_e \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \delta/2 \right]$
- $\text{TOF} \propto L/\beta$
... effective for low momentum region
- **Cherenkov** If $\beta > 1/n \Rightarrow \cos\theta_c = 1/(\beta n)$
[θ_c :Cerenkov angle]

Threshold device

Ring imaging device

Need(ed) technology development!



BELLE : Aerogel (threshold)

BaBar : DIRC

CLEO-III: RICH with LiF+TEA

Silica Aerogel

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● Silica aerogels ...

- Collidal form of SiO₂
- $\rho \approx 0.1 \text{ g/cm}^3$, porosity $\approx 95\%$ ($n=1.03$)
- $n=1.006 \sim 1.06$

\Rightarrow useful for π/K separation in GeV region.

If threshold counter,

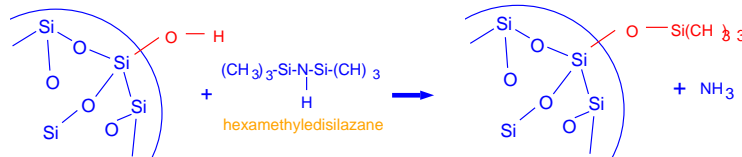
required n can be obtained only with aerogels

● New development for BELLE-ACC

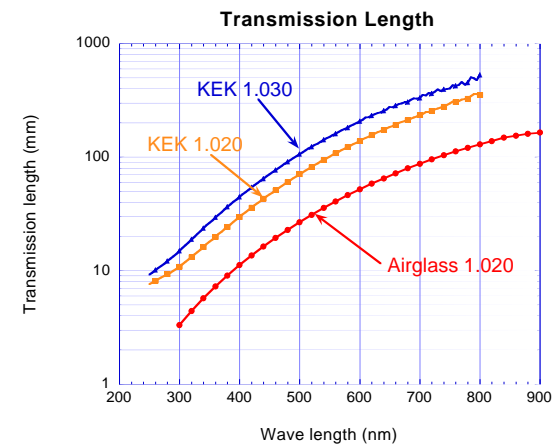
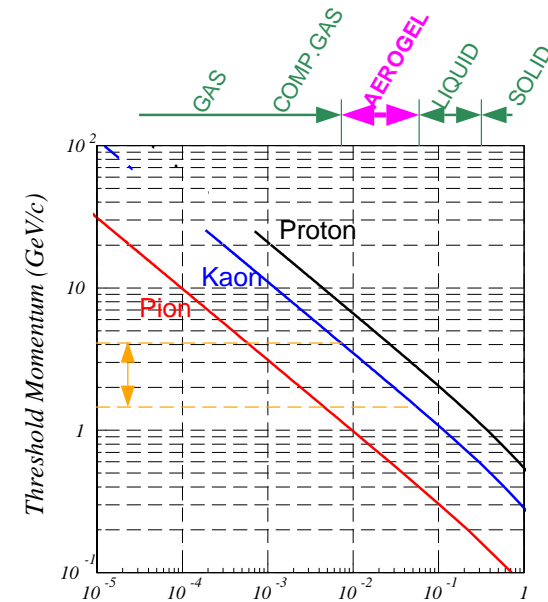
- New single-step method developed in collaboration with Matsuhita E.W.Co.
- High optical quality

Δt (@400nm) = $\sim 46\text{mm}$ ($n=1.028\sim 1.030$),
 $\sim 26\text{mm}$ ($n=1.010\sim 1.020$)

- Surface Treatment \Rightarrow Hydrophobic



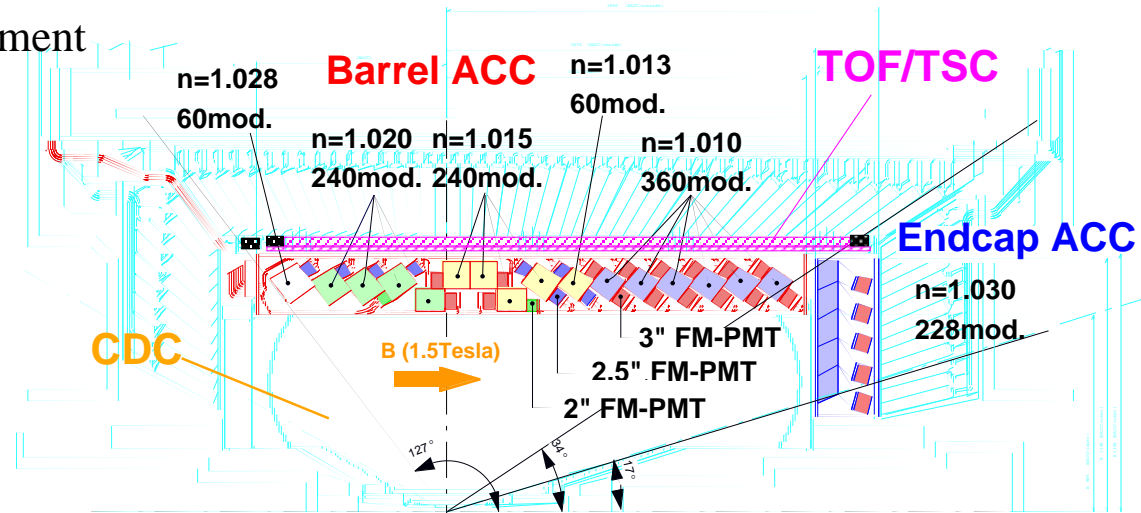
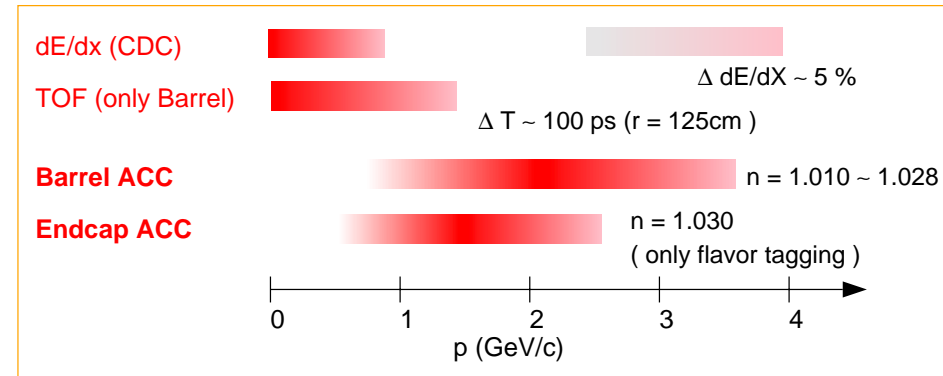
- Radiation hardness;
tested up to 10Mrad @ Nat'l Tsing Hua Univ.



BELLE KID System

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- **dE/dx** 50%He / 50% C₂H₆ , 50 layers
 $\Delta dE/dx \sim 5\%$ (design)
- **TOF** BC408(4cmT \times 6cmW \times 255cmL),
256 ϕ -segment
Read-out by 2" FM-PMT at both ends
TSC(0.5cmT) for γ background rejection
 $\Delta T \sim 100\text{ps}$ (design)
- **ACC** Barrel 960 modules in 60 ϕ -segment
 $n = 1.010 \sim 1.028$
Endcap 228 modules in 5 layers
 $n = 1.030$
(only for flavor tagging)
Read-out by 2", 2.5" and 3"
FM-PMTs



Expected Performance

● Flavor tagging

- 1) Tag the b flavor with high p^* lepton (≥ 1.1 GeV/c)
- 2) Tag the b flavor with the sum of kaon charges

⇒ Generic B-Bbar decays

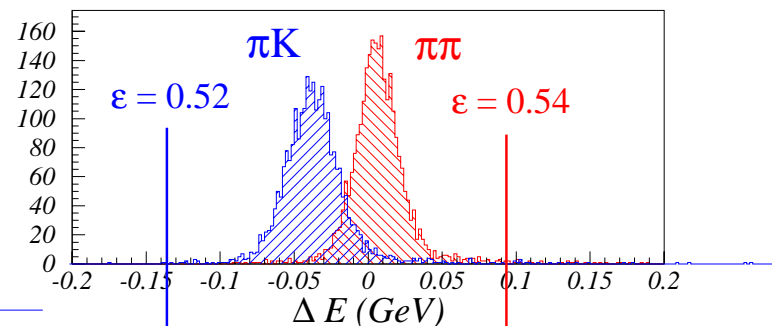
(mixing = 0.66) 2M events

	$\epsilon(\%)$	$w(\%)$	$\epsilon_{\text{eff}}(\%)$
lepton	12.18 ± 0.02	8.17 ± 0.04	8.53 ± 0.02
kaon	29.03 ± 0.02	16.58 ± 0.04	12.97 ± 0.03
sum			21.50 ± 0.03

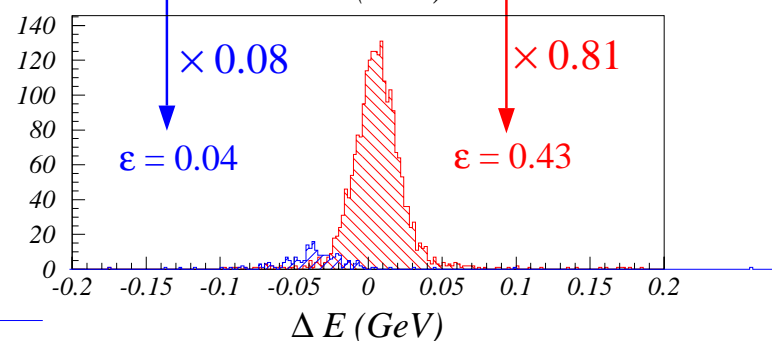
● $B \rightarrow \pi\pi/K\pi$

Energy imbalance, $\Delta E = E_1 + E_2 - E_{\text{beam}}$
based on $\pi\pi$ hypothesis

w/o Kaon ID



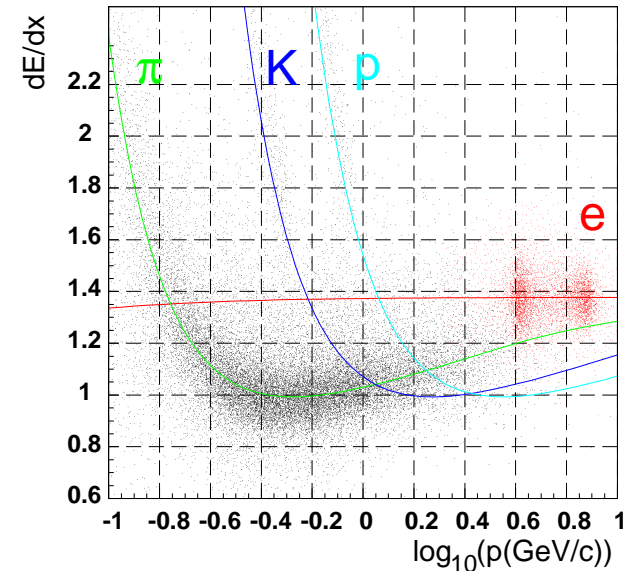
w/ Kaon ID
two track consistent
with $\pi\pi$



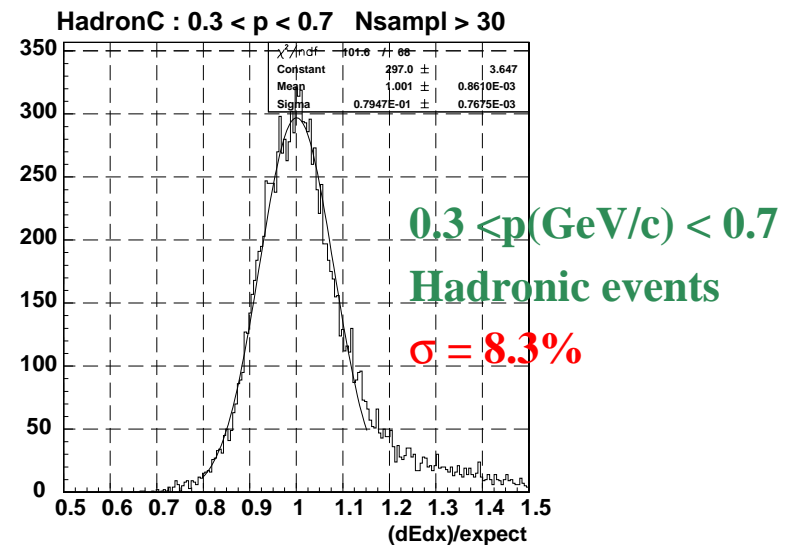
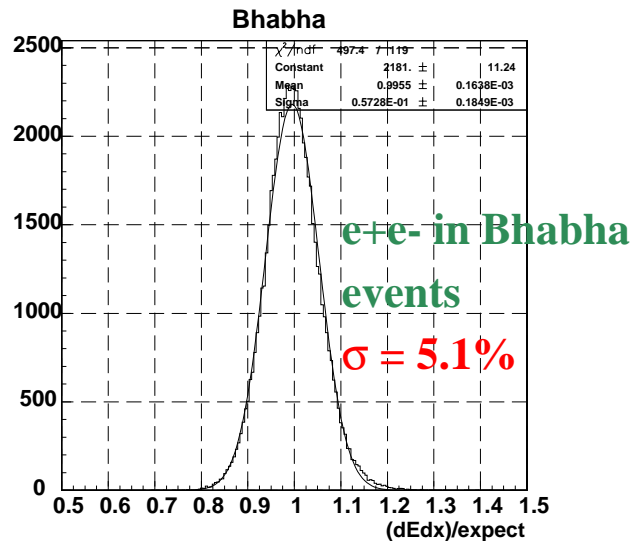
dE/dx Performance

dE/dx performance from collision data

- 8.3% for MIPS \Leftrightarrow 7.4% in MC
- 5.7% for Bhabha $e+e^-$ \Leftrightarrow 5.1% in MC
- Fluctuation due to gas pressure change
 \Rightarrow run-by-run correction



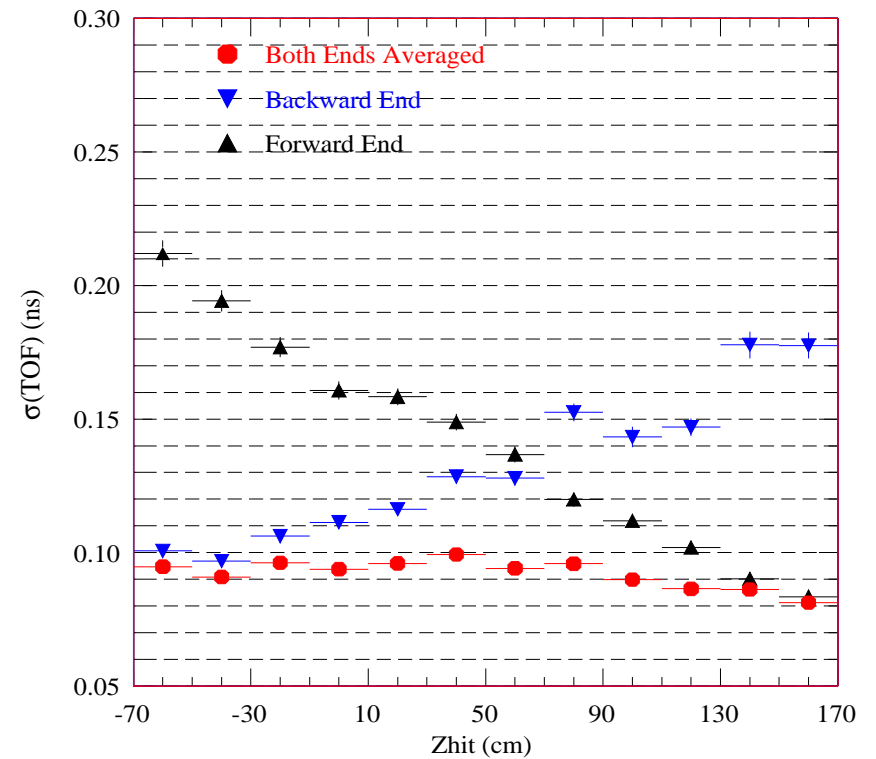
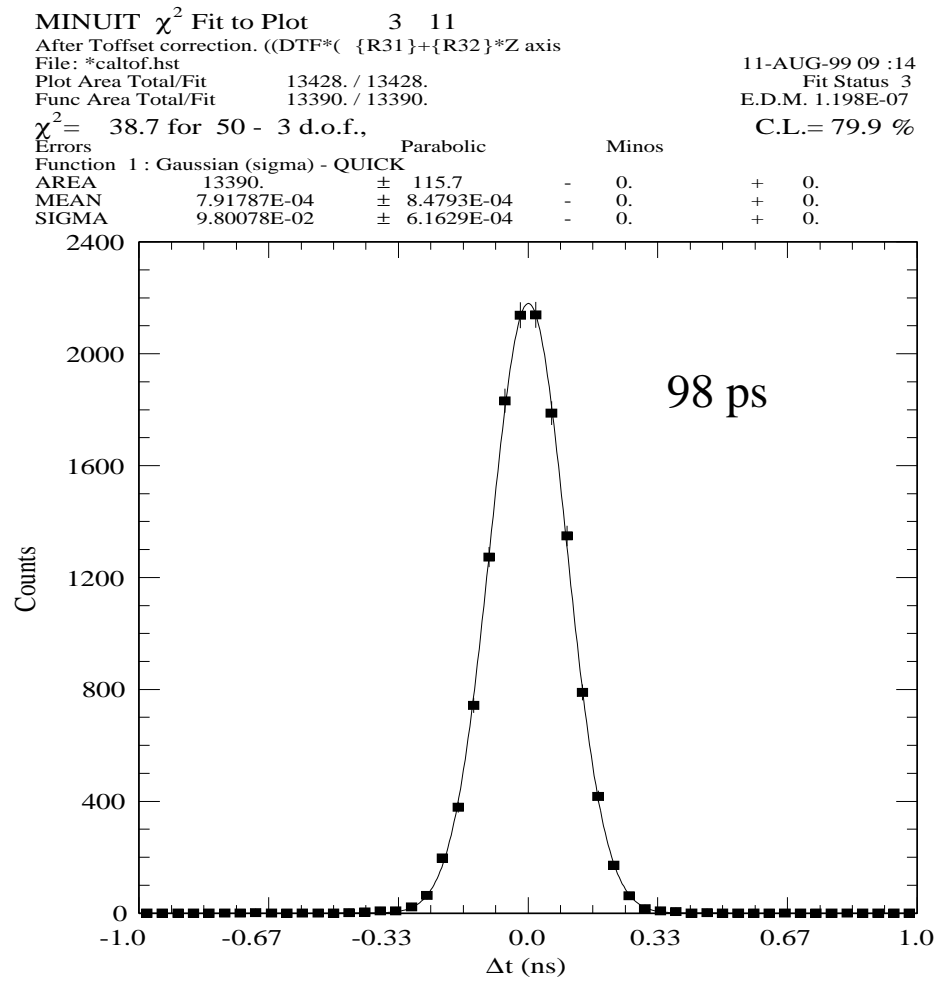
dE/dx measured/expected



TOF Performance

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TOF time resolution for mu-mu+ events in run 142 to 469

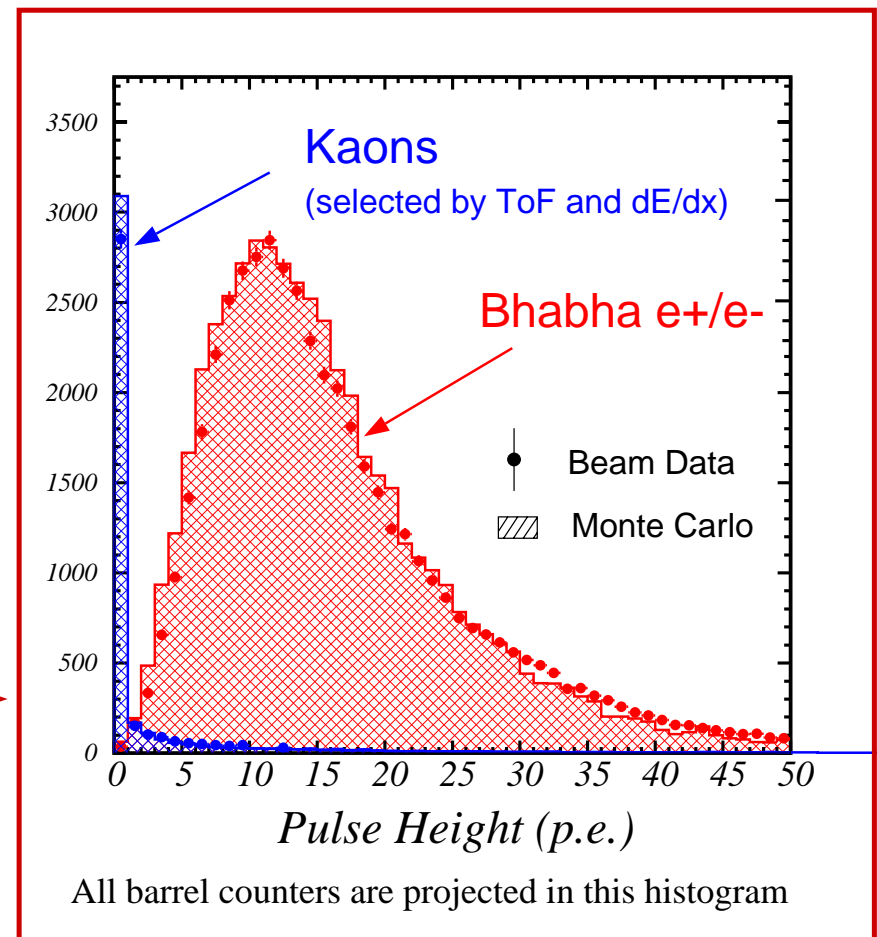


ACC Performance

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ACC performance from collision data

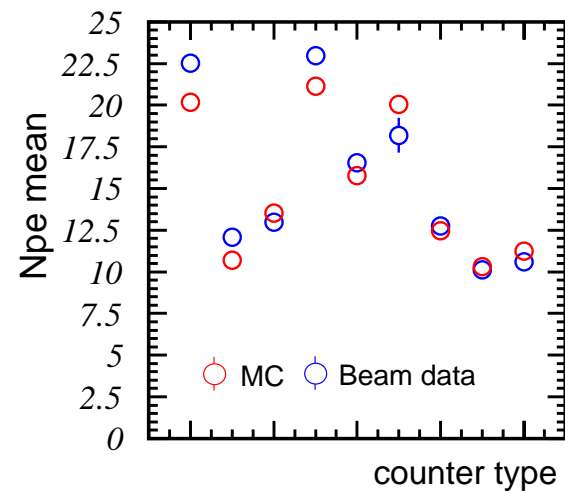
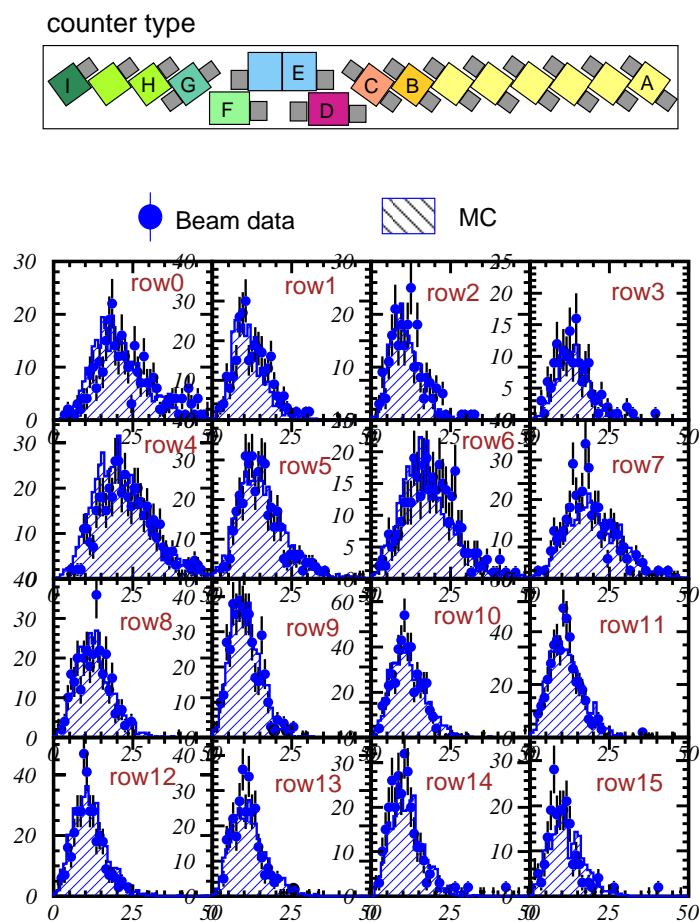
- Initial calibration constants \Leftarrow cosmic muons
- PMT gain monitored by LED light source and corrected.
- Npe distribution has been tested with
 - Bhabha e^+e^-
 - μ pair
 - Kaons in hadronic events
 - selected by TOF and dE/dx
- Npe mean @ $\beta=1$
 - BACC: 10~20**
 - EACC: ~ 30**
- Effective #pe $\cong 0.5 \times \langle N_{pe} \rangle$
- **Data are in good agreement with MC!**



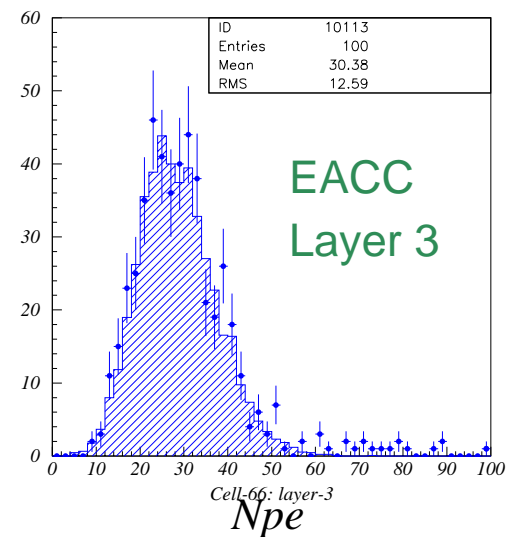
ACC Performance (cont'd)

Npe distribution for μ -pair events

● Barrel ACC



● Endcap ACC (Layer3)



KID Performance

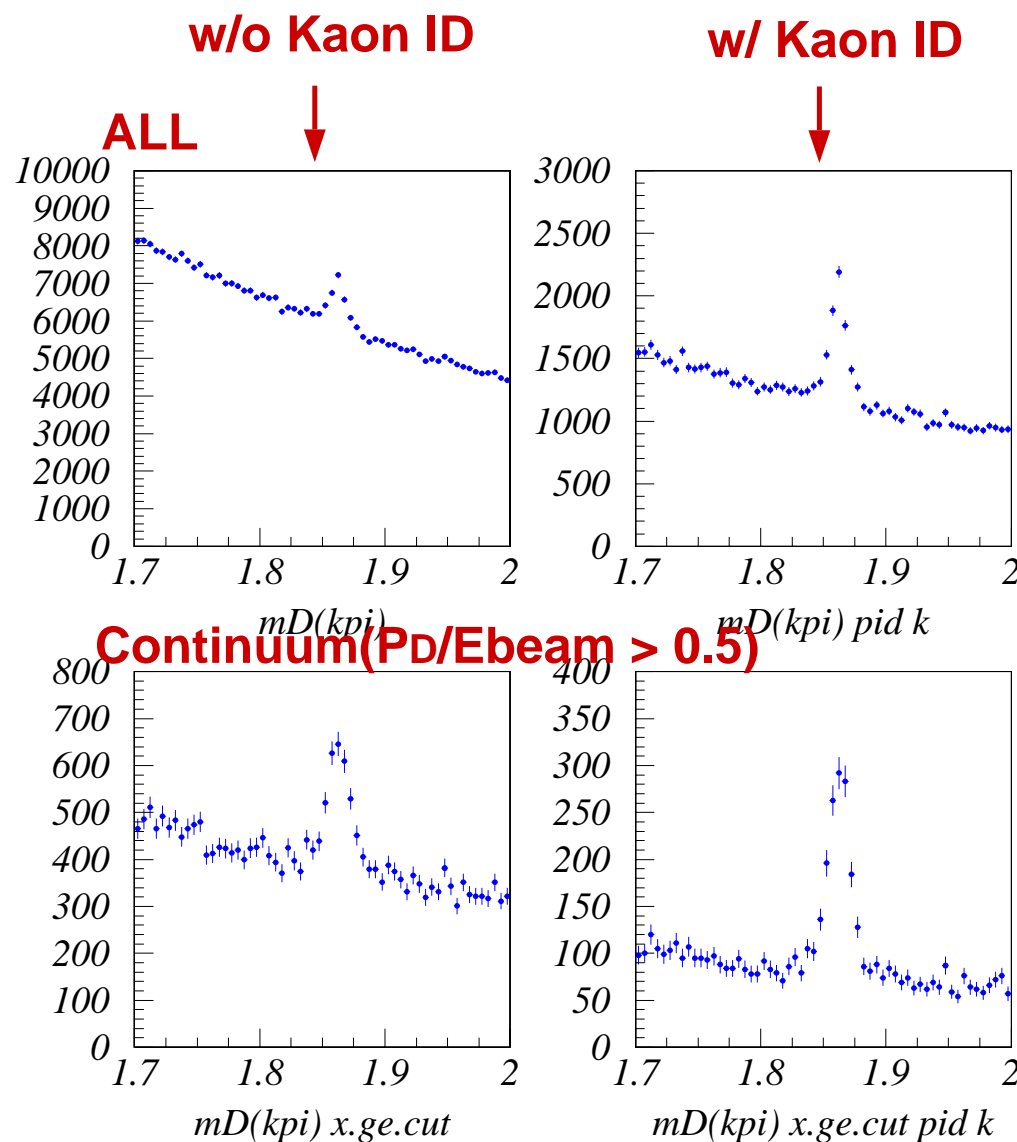
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Kaon ID in data analysis

- Each device provides probability
for e, μ , π , K, p
- Calculate combined probability
 $P_i = P_i(\text{ACC}) \times P_i(\text{TOF}) \times P_i(dE/dx)$
- Use relative ratio; $P_k / (P_k + P_\pi)$

example; **D0** \rightarrow **K⁻** π^+ \longrightarrow

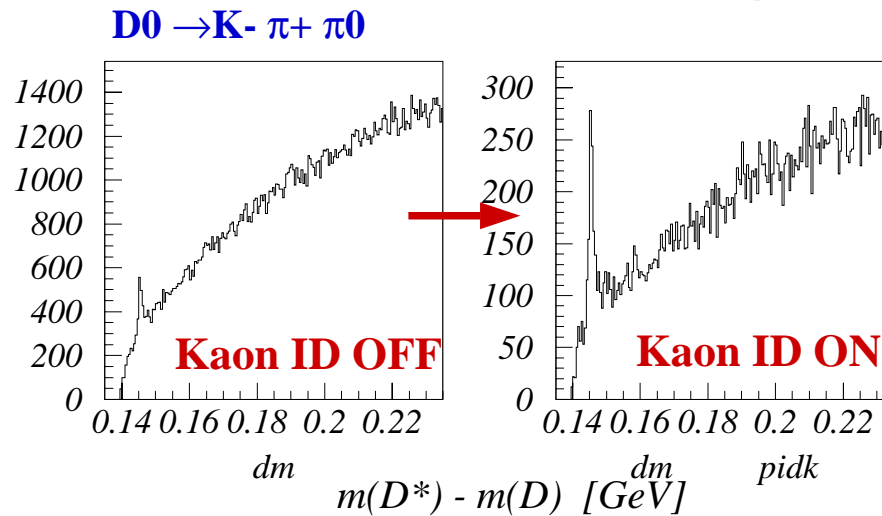
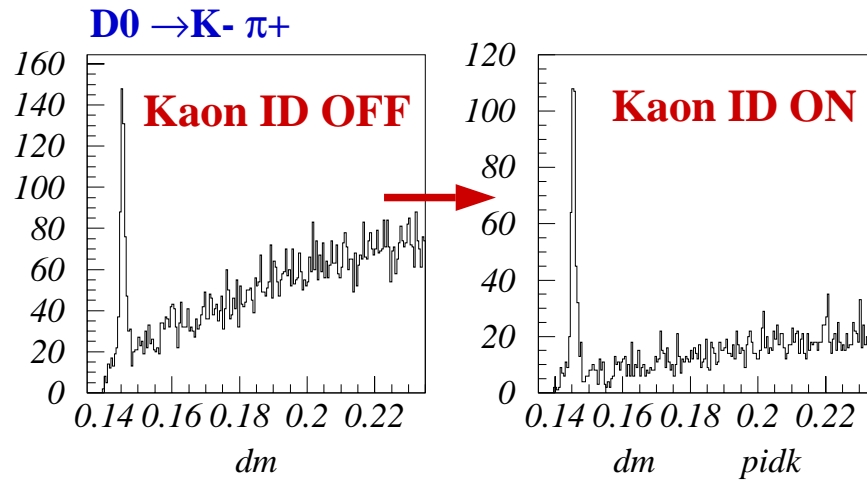
$P_k / (P_k + P_\pi) > 0.6$ for "kaon track"



KID Performance (cont'd)

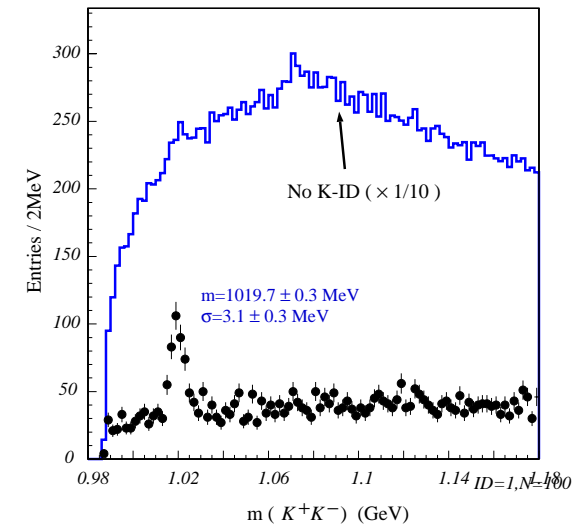
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● $D^{*+} \rightarrow D^0 \pi^+$

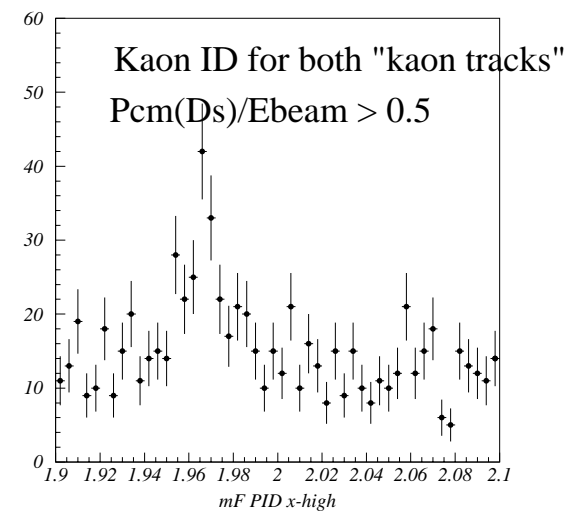


● $\phi \rightarrow K^+ K^-$

Kaon ID for both tracks



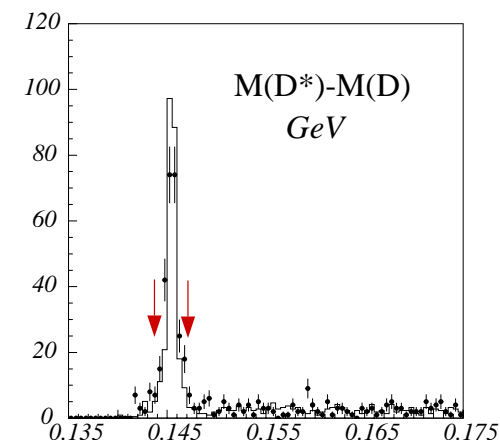
● $D_s \rightarrow K^+ K^- \pi^+$



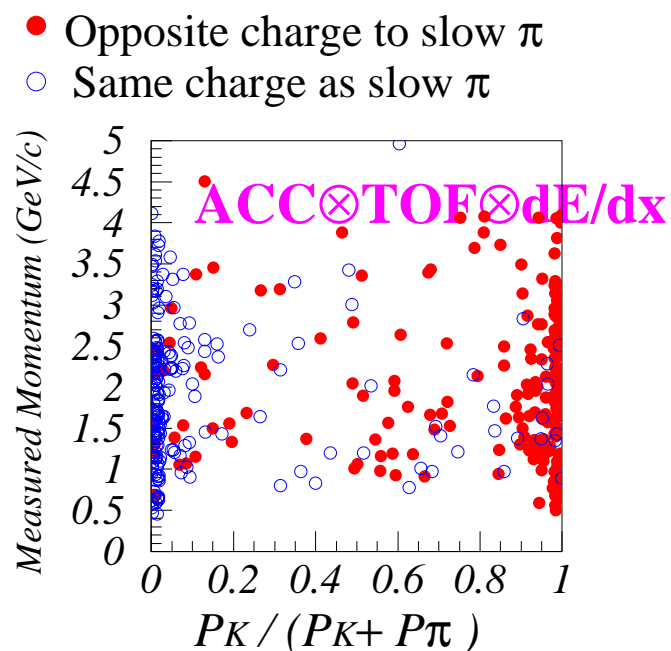
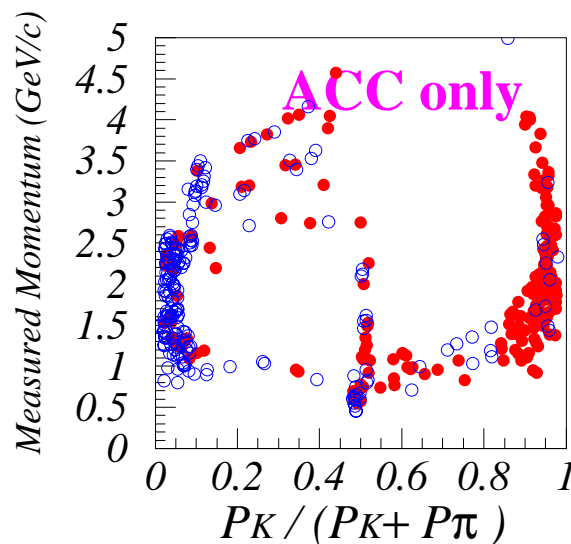
KID Test w/ $D^* \rightarrow D\pi$

Test of KID w/ $D^{*+} \rightarrow D^0 \pi^+$

- $|M(D) - 1.865| \leq 0.030$ $\rightarrow K^- \pi^+$
 - $P(D^*)/E_b(\text{CM}) > 0.5$
 - $|\cos \theta_k| \leq 0.8$
- \Rightarrow Estimated purity $\sim 95\%$



π/K Separation Plot



Summary

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- Kaon ID in BELLE, based on dE/dx , TOF and ACC, provide excellent K/π separation up to ~ 3.5 GeV/c
Aerogel Cherenkov counter system has been successfully developed and constructed.
- The three detectors are working fine in the BELLE physics run (no major problem).
- Basic performance of the total Kaon ID system has been proven and demonstrated in data.
ACC has already shown performance, almost identical to expectations.
- Calibration efforts are still in progress, and we hope to obtain better results in near future.
- We hope to provide good physics results with excellent kaon ID in the coming years !