Performance studies of the Belle II TOP counter

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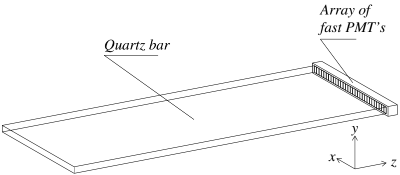
Outline

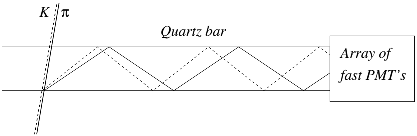
- Introduction
- Belle II TOP counter
- Performance studies
- Physics cases
- Conclusions

Time-of-propagation (TOP) counter

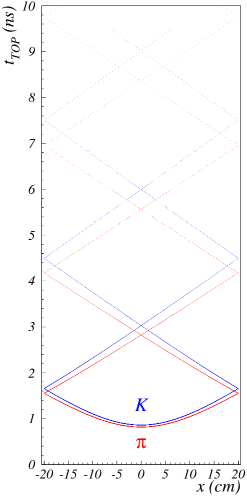
- schematic view of a module



- principle of operation

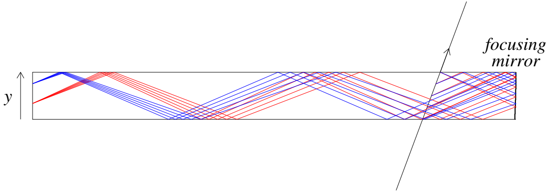


- example of ring images



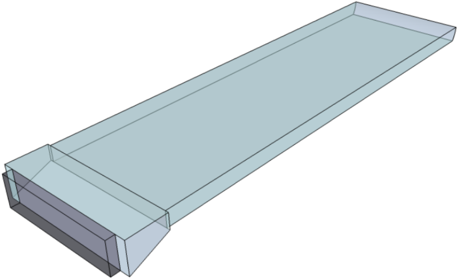
f-TOP and i-TOP

- focusing TOP $\longrightarrow$ chromatic error correction



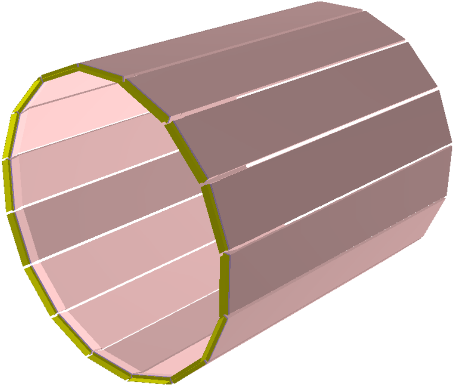
- focusing TOP with expansion prism = imaging TOP

  $\rightarrow$ choice for Belle II

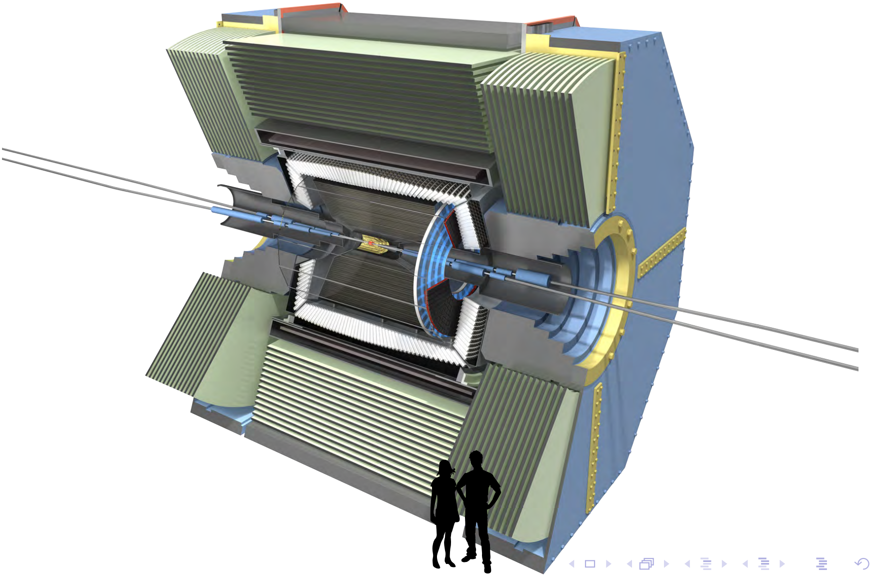


Belle II TOP detector

- 16 modules at $R = 119\ \mathrm{cm}$
- Quartz bars:
  - $2 \times 45\ \mathrm{cm}^2$ in cross section
    2.6 m long
- Spherical mirrors:
  - radius of curvature: 6.5 m
- Expansion prisms:
  - 100 mm long, 51 mm high
- MCP-PMT:
  - Hamamatsu SL-10 with quartz window and NaKSbCs photo cathode
  - 2 rows of 16 per module

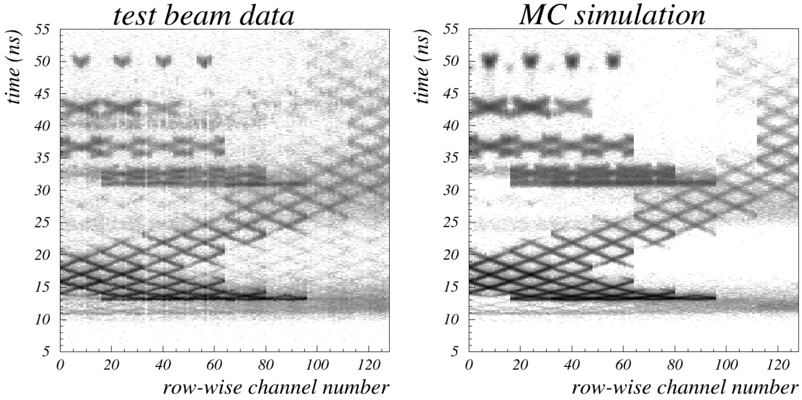


Belle II detector



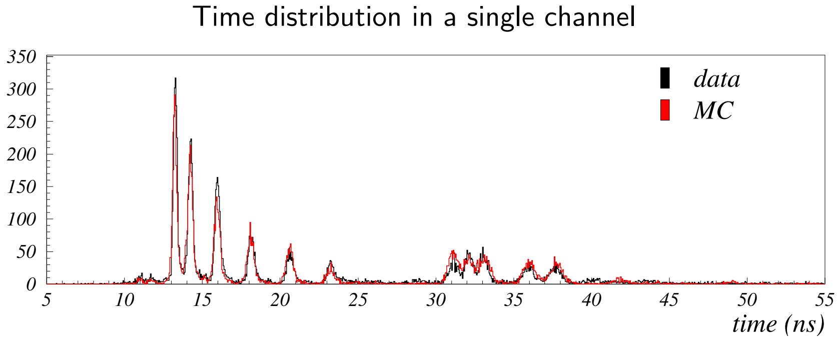
TOP counter response

- Ring image consists of complicated patterns



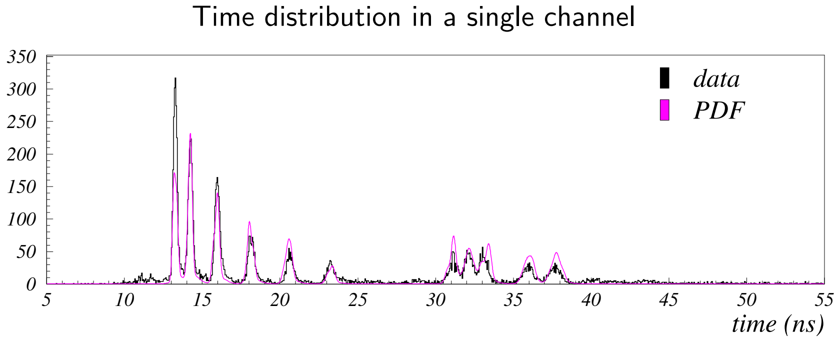
Perpendicular impact of a narrow 2.1 GeV/c positron beam
(data obtained at Spring-8 facility in Japan)

Particle identification: using extended likelihood method



- PDF in a single channel described with a series of Gaussian distributions
  - positions, widths and normalizations determined analytically
  - method presented at RICH2010 (NIM A 639 (2011) 252-255)

Particle identification: using extended likelihood method



- PDF in a single channel described with a series of Gaussian distributions
  - positions, widths and normalizations determined analytically
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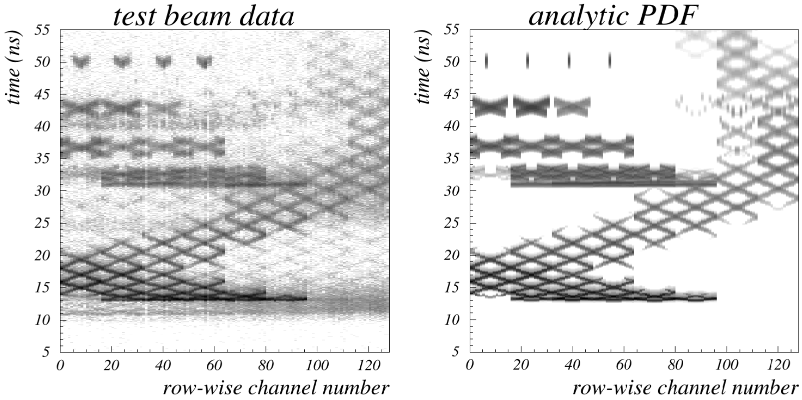
TOP counter response: analytic PDF

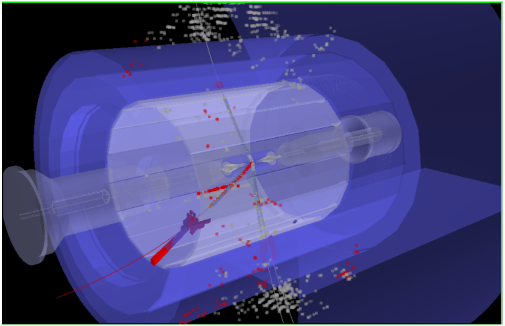
- Ring image consists of complicated patterns



Perpendicular impact of a narrow 2.1 GeV/c positron beam (data obtained at Spring-8 facility in Japan)

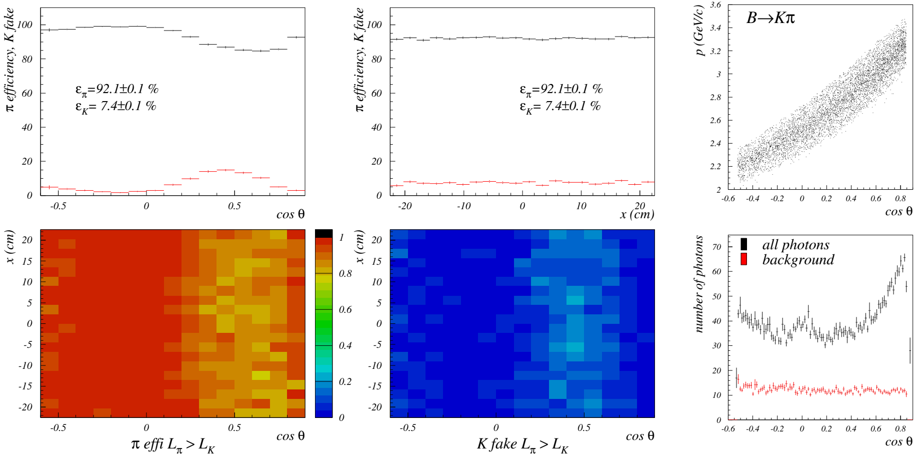
Performance studies

- With realistic simulated events, using $B^0 \to K^+\pi^-$ signal MC
  - EvtGen to generate $B^0\overline{B^0}$ events (with generic decay of other B)
  - add beam background
  - Full simulation of detector response (all components included)
  - Event reconstruction including tracking and TOP



Efficiency and fake rate

$B \to K\pi$ signal MC



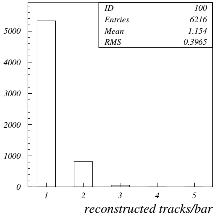
- Overall: 92% pion efficiency, 7.4% kaon fake rate
- No significant azimuthal dependence

Impact of multiple tracks

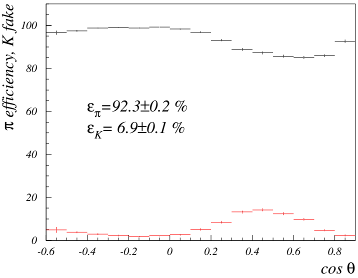
$B \to K\pi$ signal MC

- About 15% chance for two or more reconstructed tracks to hit the same bar

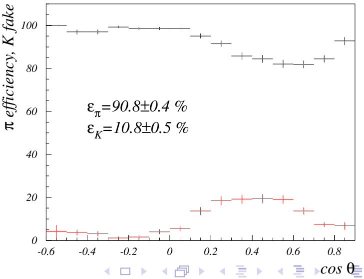
	single/bar	two or more/bar
$\epsilon_\pi(\%)$	92.3 ± 0.2	90.8 ± 0.4
$\epsilon_K(\%)$	6.9 ± 0.1	10.8 ± 0.5



single track/bar

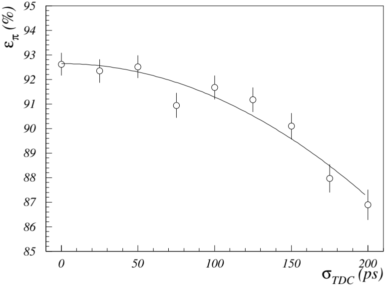


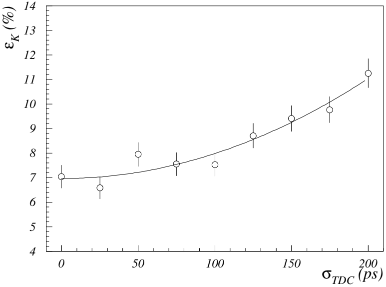
two or more tracks/bar



- Additional Gaussian smearing of photon arrival times (up to 200 ps)

for each data point different MC sample used





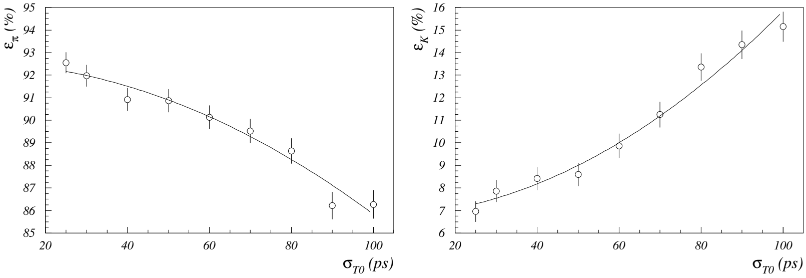
- Quadratic dependence
- Negligible up to 50 ps
- Small performance degradation observed for 100 ps ($\sim$1%)

Impact of T0 jitter

$B \to K\pi$ signal MC

- Varied from 25 ps to 100 ps

for each data point different MC sample used

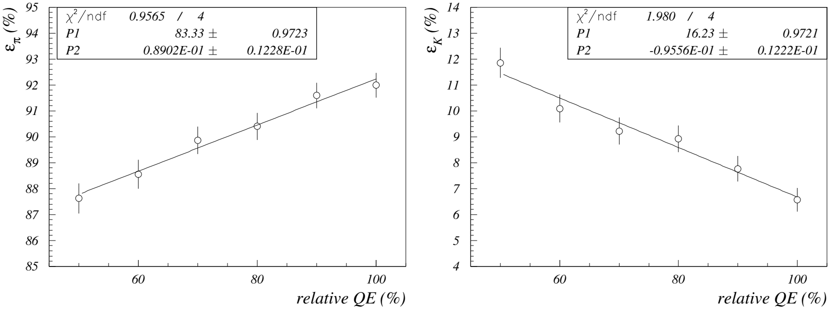


- Quadratic dependence
- Small performance degradation observed for 50 ps (∼1.5%)
- N.B.: at Belle T0 jitter was ∼40 ps

Impact of smaller QE $B \to K\pi$ signal MC

- Checked from 100% to 50% of nominal value

  for each data point different MC sample used

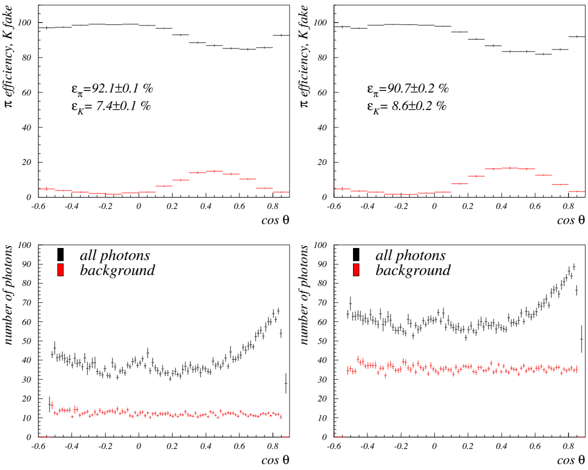


- Linear dependence
- Relative decrease of QE by 10%:
  - ~1% smaller pion efficiency
  - ~1% larger kaon fake rate

Impact of beam background

$B \to K\pi$ signal MC

no beam background   8× beam background



- With 8× nominal background (1 MHz/channel)
  - efficiency: 1.4% decrease
  - fake rate: 1.2% increase
- With nominal background:
  - negligible impact to performance

Physics case: $B^0 \to \pi^+\pi^-$

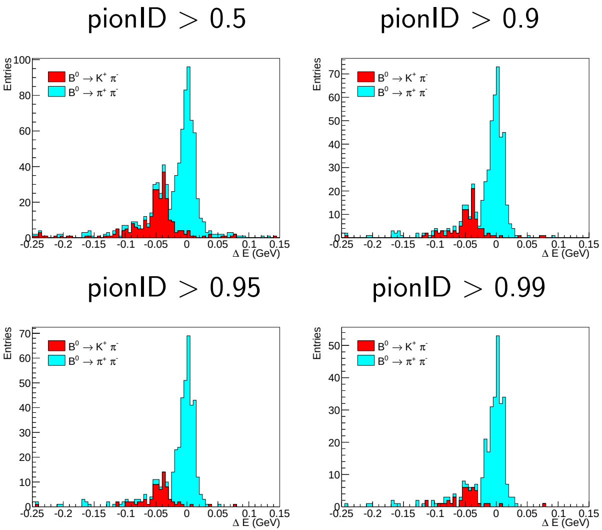
Challenge:

- to discriminate against $B^0 \to K^+\pi^-$ (4-times larger Br)
- Due to large B-meson mass kinematic discrimination barely possible
  - peaks not resolvable in beam constrained mass
  - only small separation possible in ΔE

  $\to$ good pion/kaon separation helps a lot
- K/π momentum range 2-3.5 GeV/c challenging for PID

Continuum and other backgrounds not included in this study

Results: $B^0 \to \pi^+\pi^-$



Generated in ratio:

$\pi\pi : K\pi = 1 : 4$

overall efficiency:

pionID	$\epsilon_{B\to\pi\pi}$
0.50	57%
0.90	40%
0.95	35%
0.99	27%

Physics case: $B^0 \to \rho^0\gamma$

Challenge:

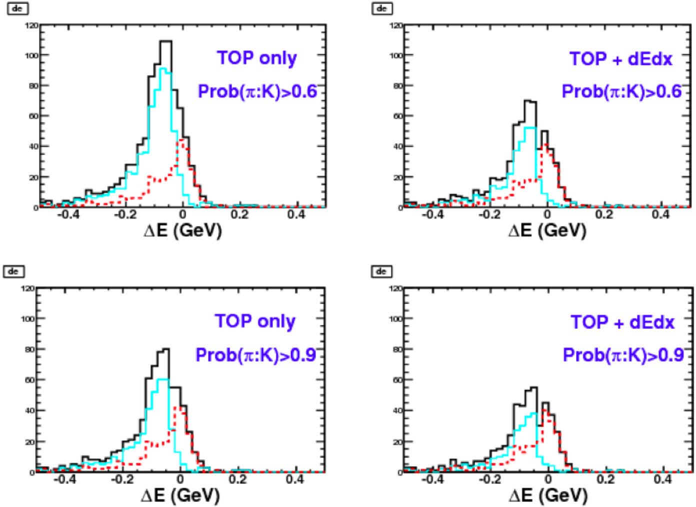
- to discriminate against $B^0 \to K^{*0}\gamma$ (40-times larger Br)
- Due to large B-meson mass, kinematic discrimination not possible
  - almost no separation in ΔE
  - ρ^0, K^{*0} resonances too wide for efficient separation

  $\to$ good pion/kaon separation mandatory
- K/π momenta up to 2 GeV/c
  - TOP combined with dE/dx measurement

Continuum and other backgrounds not included in this study

Results: $B^0 \to \rho^0\gamma$

- $B^0 \to \rho^0\gamma$ (red), $B^0 \to K^{*0}\gamma$ (cyan), 3.0 fb^{-1}



Conclusions

- Performance of the future Belle II barrel PID has been discussed
- PID is based on an extended likelihood method that uses analytically constructed PDF's
- With $B \to K\pi$ signal MC we studied the impact of the most critical parameters to the performance of the TOP counter:
  - time resolution: acceptable up to 100 ps (rms)
  - T0 jitter: acceptable up to 50 ps (rms)
  - photon yield: $\Delta\epsilon_{\pi/K} = \mp 1\%$ for 10% smaller yield
  - beam background: negligible up to 2 MHz/PMT
- We also demonstrated the capabilities of Belle II PID in reconstruction of two challenging decay modes: $B^0 \to \pi^+\pi^-$, $B^0 \to \rho^0\gamma$