Pattern recognition for TOP counter

Marko Starič

Jožef Stefan Institute
Ljubljana

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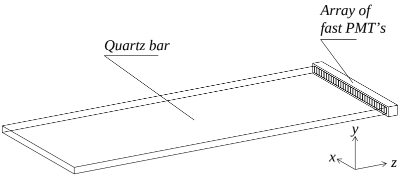
Outline

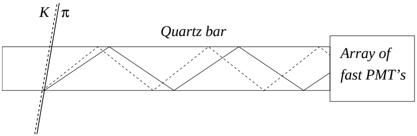
- Introduction
- Extended likelihood method for PID with TOP
- TOP counter for Belle II: performance studies
- Conclusions

Time-of-propagation (TOP) counter

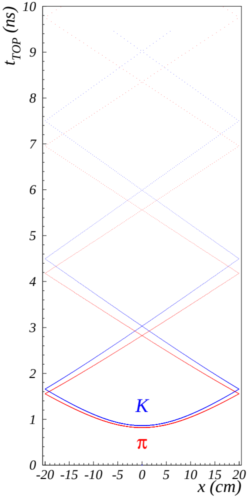
- schematic view of a module



- principle of operation

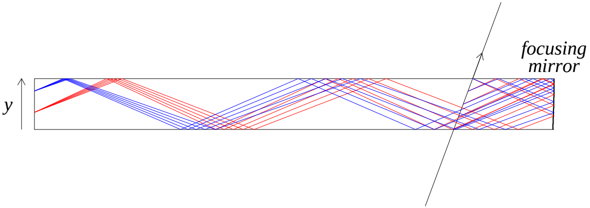


- example of ring images

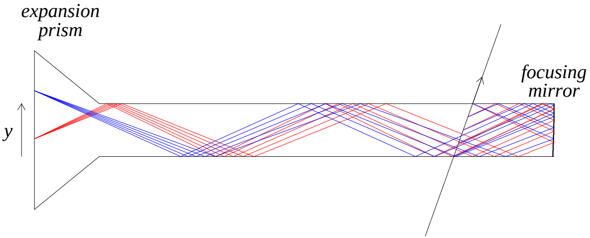


f-TOP and i-TOP

- focusing TOP $\longrightarrow$ chromatic error correction



- focusing TOP with expansion prism = imaging TOP



Extended Likelihood probability

For a given mass hypothesis $h = e, \mu, \pi, K, p$:

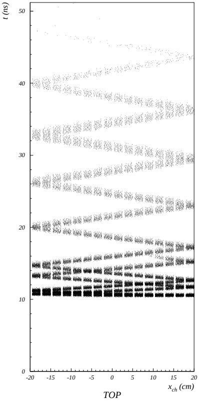
$$\log \mathcal{L}_h = \sum_{i=1}^{N} \log\left(\frac{S_h(x_i, t_i) + B(x_i, t_i)}{N_e}\right) + \log P_N(N_e)$$

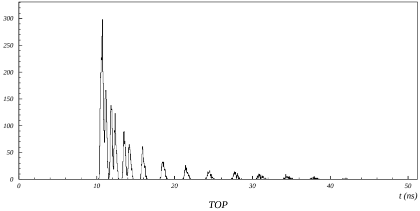
- N ... number of detected photons
- $N_e = N_h + N_B$ ... expected number of photons
- $S_h(x, t)$ ... signal distribution for mass hypothesis h
- $B(x, t)$ ... distribution of background photons
- $P_N(N_e)$ ... Poisson probability of mean N_e to obtain N photons

Distributions normalized as:

$$\sum_{j=1}^{n_{ch}} \int_0^{t_m} S(x_j, t)dt = N_h, \qquad \sum_{j=1}^{n_{ch}} \int_0^{t_m} B(x_j, t)dt = N_B$$

Parametrization of signal distribution





$$S_h(x_j, t) = \sum_{k=1}^{m_j} n_{kj} g(t - t_{kj}; \sigma_{kj})$$

- n_{kj} ... number of photons in the k-th peak
- t_{kj} ... position of the k-th peak
- σ_{kj} ... width of the k-th peak
- $g(t - t_{kj}; \sigma_{kj})$ ... normalized Gaussian

Signal distribution: analytical construction

Poster at RICH 2007
NIM A 595 (2008) 252-255

- Problem: find analytical expressions for n_{kj}, t_{kj} and σ_{kj}
- Functions of:
  - track impact position (x_0, z_0) and impact angles (θ, ϕ)
  - Cerenkov angle θ_c for given mass hypothesis
  - photon detection coordinate x_j
- Geometric view: intersection of Cerenkov cone with a plane
  - well known, quadratic equations
- Total reflections:
  - Imagine the detector plane divided into cells of a size of Q-bar transverse dimensions $(a \times b)$
  - total reflections - the same as folding the detector plane at cell boundaries
  - unfolded coordinate for k-th reflection: $x_D^{kj} = ka \pm x_j$

Solutions for n_{kj}, t_{kj} and σ_{kj}

- Input:
  - track impact position (x_0, z_0) and impact angles (θ, ϕ)
  - Cerenkov angle θ_c for given mass hypothesis
  - photon detection coordinate $x_j \to x_D^{kj}, \quad k = 0, \pm 1, \pm 2, ...$
- Solve for unknown Cerenkov azimuthal angle ϕ_c^{kj}
- Knowing ϕ_c^{kj} the photon direction vector is fully determined
- The k-th peak position in channel j is:

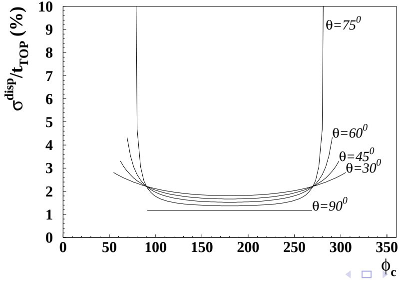
$$t_{kj} = \frac{z_D - z_0}{(\cos\theta\cos\theta_c - \sin\theta\sin\theta_c\cos\phi_c^{kj})}\frac{n_g}{c_0} + t_{TOF}$$

- Number of photons in the peak:

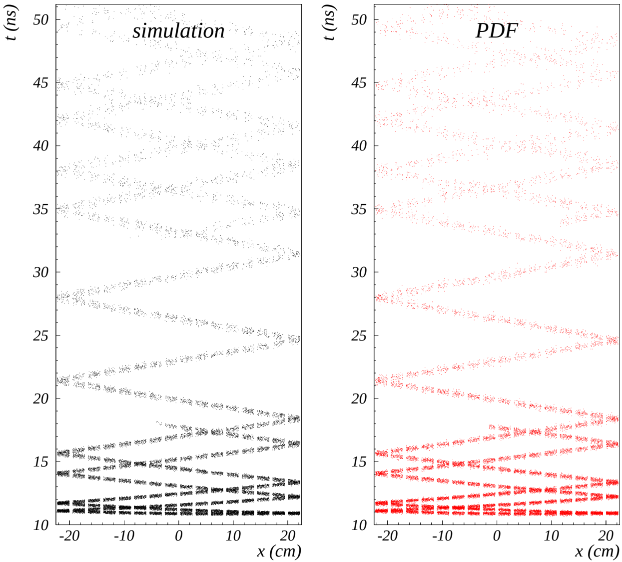
$$n_{kj} = N_0 \ell \sin^2\theta_c \frac{\Delta\phi_c^{kj}}{2\pi}$$

Peak width σ_{kj}

- Contributions (summed in quadrature):
  - photon emission point spread (parallax) $\rightarrow \ \sigma_\ell = \frac{dt_{kj}}{d\ell}\frac{\ell}{\sqrt{12}}$
  - multiple scattering of particle in quartz $\rightarrow \ \sigma_{\mathrm{scat}} = \frac{dt_{kj}}{d\theta_c}\theta_0(\ell/2)$
  - dispersion (chromatic) $\rightarrow \ \sigma_{\mathrm{disp}} = \frac{dt_{kj}}{de}\sigma_e$
  - detection channel size $\rightarrow \ \sigma_{\mathrm{ch}} = \frac{dt_{kj}}{dx_j}\frac{\Delta x_j}{\sqrt{12}}$
  - transit time spread of PMT (TTS) $\rightarrow \ \sigma_{\mathrm{TTS}}$
- Derivatives $\frac{dt_{kj}}{d\ell}$, $\frac{dt_{kj}}{d\theta_c}$, $\frac{dt_{kj}}{de}$ and $\frac{dt_{kj}}{dx_j}$ calculated numerically



Comparison: simulated vs. analytic $S_h(x, t)$



Focusing TOP

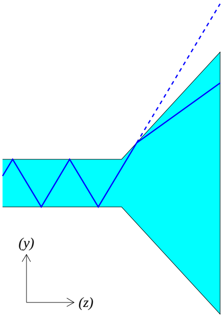
- Focusing mirror: cylindrical or spherical
- Photon detector must be segmented also in y

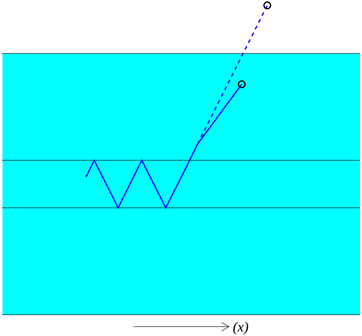
- Cylindrical mirror with focusing in y easier to implement:
  - $x - z$ projection (almost) not affected $\longrightarrow \phi_c^{kj}$ solved in the same way
  - t_{kj} and y_{kj} obtained by ray-tracing
  - both are functions of ℓ, x and e $\rightarrow$ linearize them:
    $y = y_0 + \frac{dy}{d\ell}(\ell - \ell_0) + \frac{dy}{dx}(x - x_0) + \frac{dy}{de}(e - e_0)$
  - loop over channels in y direction in unfolded detector plane and calculate mean photon energy (e) and r.m.s. (σ_e) for each channel
  - use e to calculate t from linearized function

- Spherical mirror: "kink" also in $x - z$ projection
  - ϕ_c^{kj} solved iteratively, starting with linear optics approximation
  - the rest then the same as for cylindrical mirror

Expansion prism

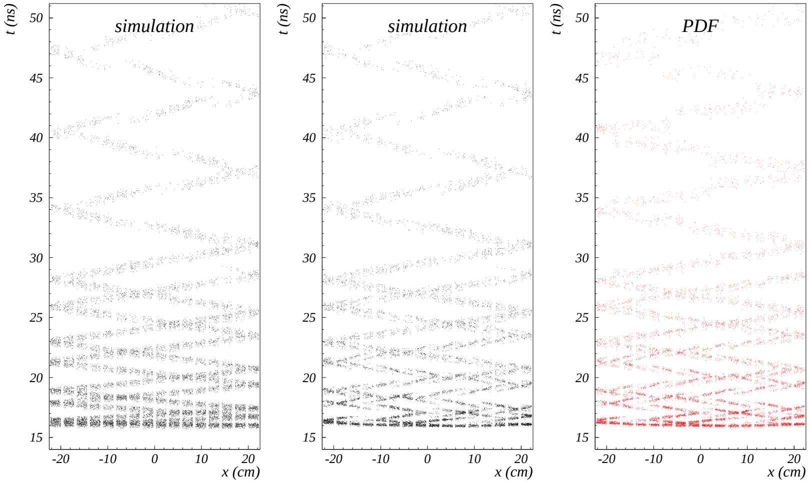
- Some photons reflected at upper/lower surface
- obtain "kink" in $x - z$ projection
  - ϕ_c^{kj} solved iteratively
  - the rest then the same as for f-TOP





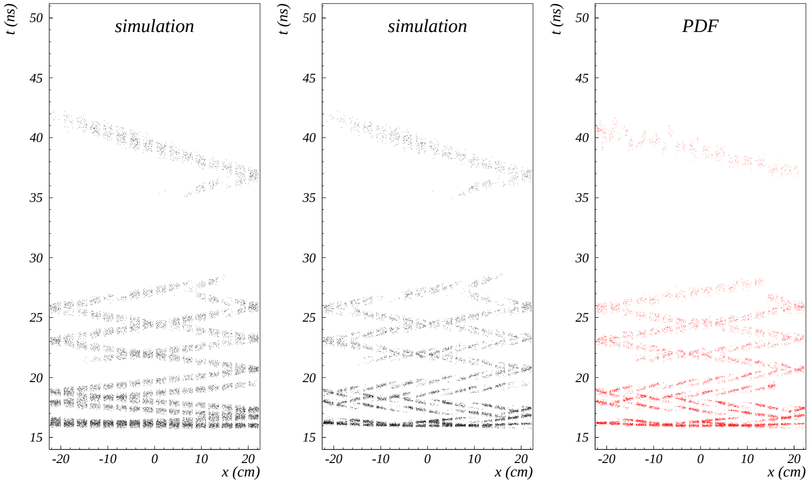
f-TOP with cylindrical mirror

all channels | one row of channels (out of 4)



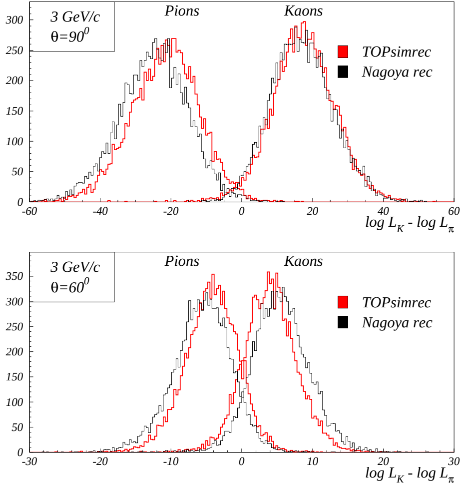
f-TOP with spherical mirror

all channels — one row of channels (out of 4)



Reconstruction of Geant3 simulation

- analytical PDF
- PDF constructed with MC simulation (5000000 photons)



Kaon selection:

$$\log \mathcal{L}_K > \log \mathcal{L}_\pi$$

efficiency

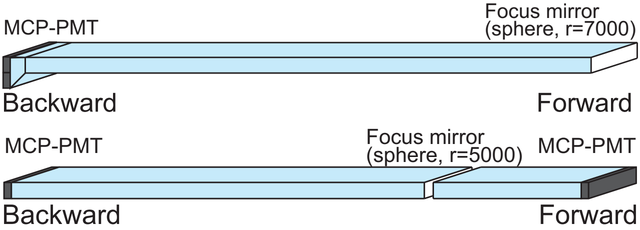
θ	MC PDF	anal.PDF
90^0	97.9%	97.2%
60^0	92.8%	86.6%

fake

θ	MC PDF	anal.PDF
90^0	0.5%	0.9%
60^0	7.5%	11.9%

TOP counter for Belle II

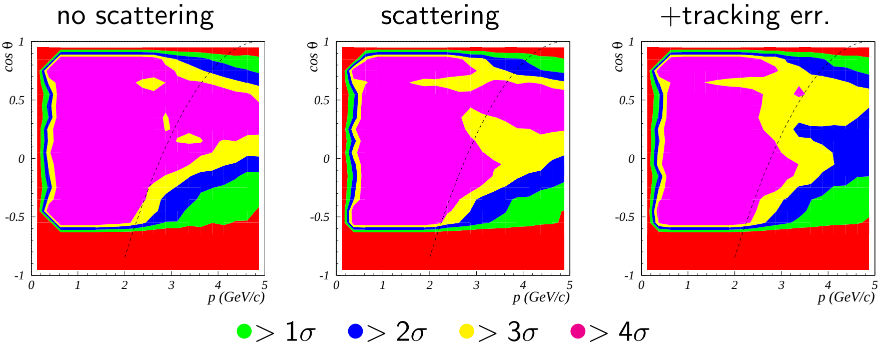
- Two baseline designs:
  - 1-bar option (focusing i-TOP)
  - 2-bar option (f-TOP + TOP)
- bar dimensions: 44 cm $\times$ 2 cm $\times$ 270 cm (not fixed jet)
- 16 modules in ϕ at $R = 1.2$ m
- each module: 2$\times$16 MCP-PMT (SL-10, 4$\times$4 ch.)
- multi-alkali (super bi-alkali) PC



Some performance studies

Impact of multiple scattering and tracking errors

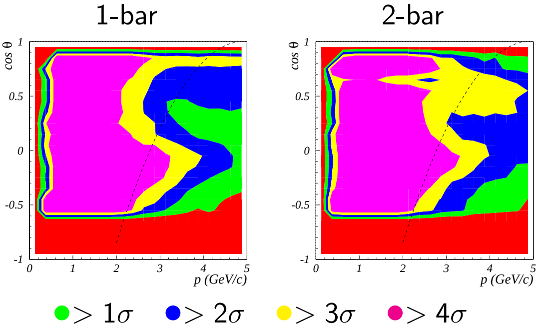
- 2-bar option, super bi-alkali PC, 25 ps T_0 jitter
- Plots show K/π separation powers



Some performance studies

1-bar vs. 2-bar option

- super bi-alkali PC, 25 ps T_0 jitter
- Plots show K/π separation powers



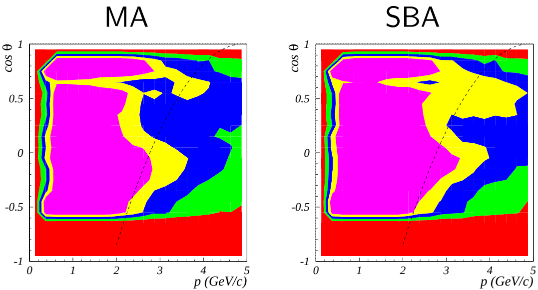
$B^0 \to \pi^+\pi^-$

	π effi	K fake
1-bar	94%	3%
2-bar	97%	3%

Some performance studies

Multi-alkali vs. super bi-alkali

- 2-bar option, 25 ps T_0 jitter
- Plots show K/π separation powers



● $> 1\sigma$ ● $> 2\sigma$ ● $> 3\sigma$ ● $> 4\sigma$

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

	π effi	K fake
MA	95%	4%
SBA	97%	3%

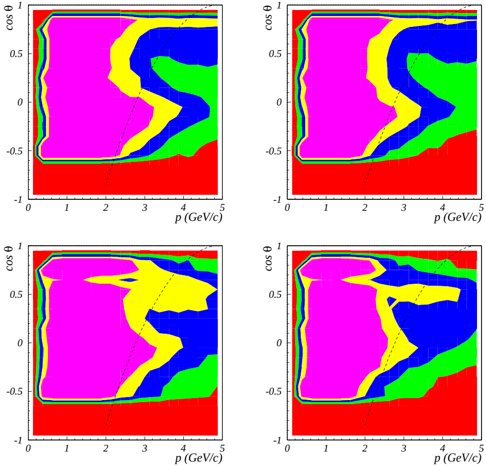
Some performance studies

Impact of T_0 jitter

(super bi-alkali PC)

25 ps

50 ps



● $> 1\sigma$ ● $> 2\sigma$ ● $> 3\sigma$ ● $> 4\sigma$

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

1-bar	π effi	K fake
25 ps	94%	3%
50 ps	92%	5%

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

2-bar	π effi	K fake
25 ps	97%	3%
50 ps	92%	8%

Conclusions

- Extended likelihood method for particle identification with the TOP counter has been presented.
- The method is based on an analytical construction of likelihood function.
- The method is adopted to various types of TOP counter, including those with a focusing mirror and an expansion volume at the quartz bar exit window.
- Using this method and a Monte Carlo simulation the performance of the two baseline configurations designed for the Belle II detector has been discussed.