A Study for Hit-time Reconstruction of Belle II Silicon Vertex Detector

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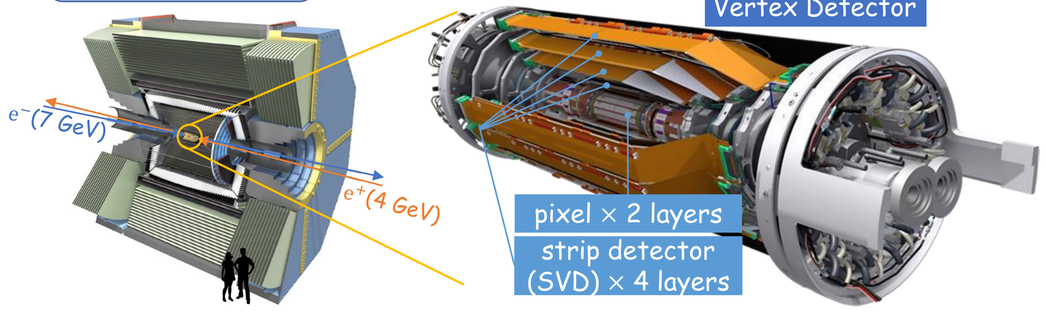
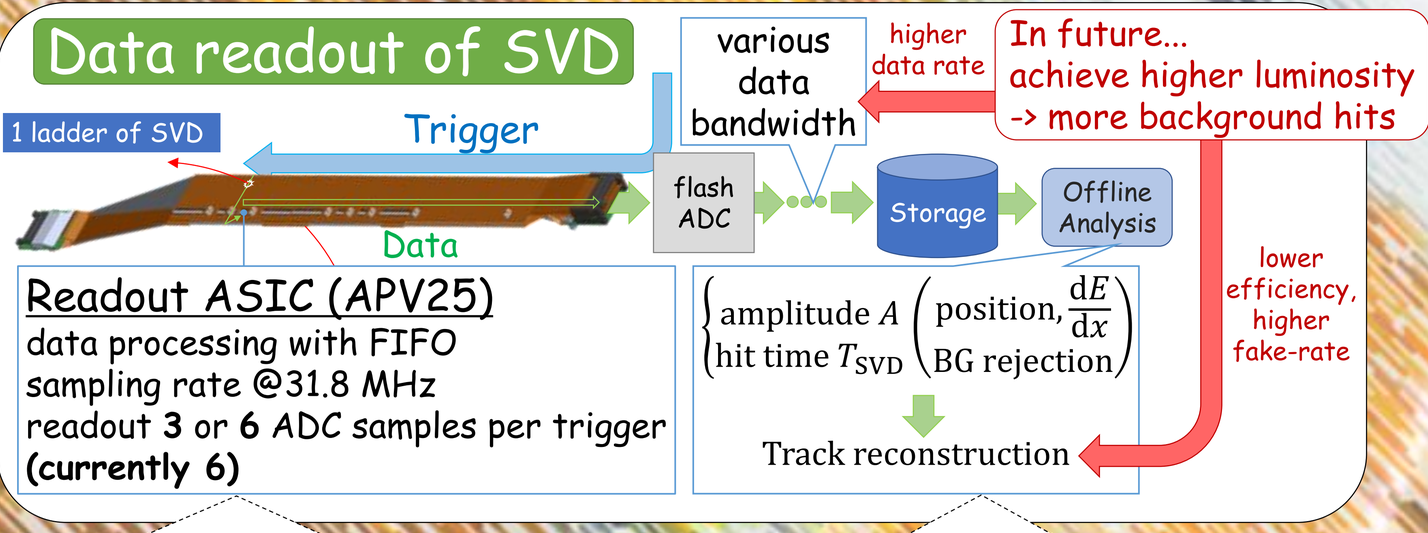
Belle II



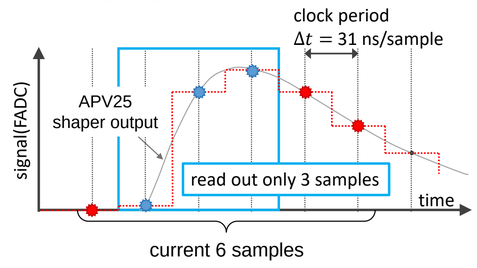
e⁻(7 GeV) e⁺(4 GeV) asymmetric collision @SuperKEKB
generate $B\bar{B}$ and measure lifetime difference by space separation
Vertex Detector just outside the beam pipe
-> measure the time-dependent CP asymmetry of $B\bar{B}$ decay, etc.
Silicon Vertex Detector (SVD):
composed of double-sided silicon strip detectors (DSSDs)
tracking with 4 layers of 2D hits

Data readout of SVD



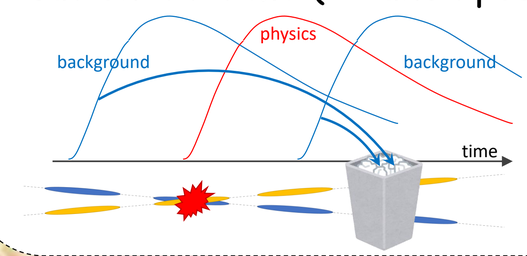
data-rate reduction

readout 3 ADC samples instead of 6
-> data-size reduced by more than a half*
* background hits also reduced



background hit rejection

physics signal hit: collision bunch
beam background hit: all bunches
-> cut on hit-time (= bunch pos.)



hit-time reconstruction study

Aim

- Construct methods/algorithms to estimate hit-time from 3 ADC samples
- Check the performance of obtained hit-time by applying them to 6-sample data

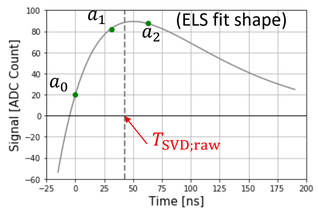
3-sample time algorithms

CoG3

Take a weighted mean of sample timing $i\Delta t$ with the ADC sample a_i:

$$T_{\mathrm{SVD;raw}} = \frac{\sum_{i=0}^{2} a_i \cdot i\Delta t}{\sum_{i=0}^{2} a_i}.$$

(We assume that peaking time is independent of amplitude.)



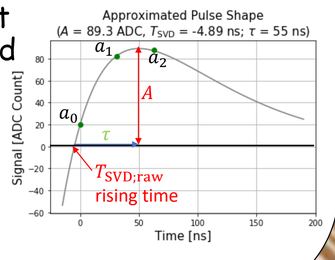
Least Squares (ELS3)

First, approximate the signal waveform with CR-RC shaper response:

$$a(t) = A\frac{t - T_{\mathrm{SVD;raw}}}{\tau}\exp\left(1 - \frac{t - T_{\mathrm{SVD;raw}}}{\tau}\right),$$

with shaping time constant $\tau = 55$ ns

Then, fit with least squares method and determine $T_{\mathrm{SVD;raw}}$ (analytically solvable)



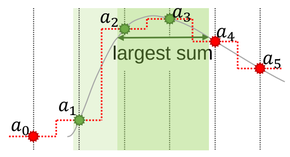
6 samples

3 samples

"raw" hit-time $T_{\mathrm{SVD;raw}}$

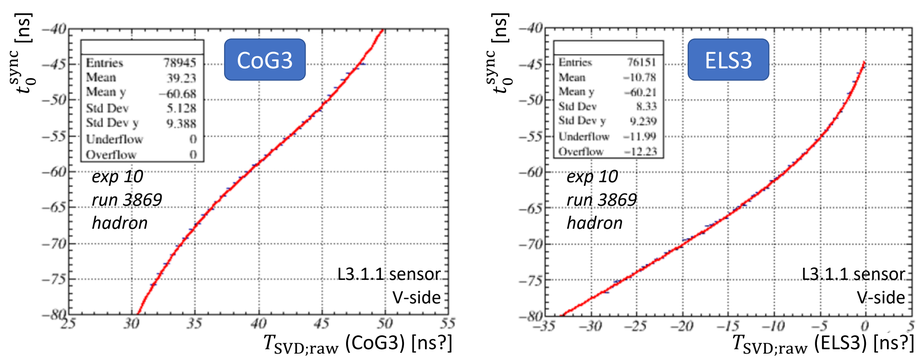
pick up 3 samples from 6

We have 6 samples.
We want 3 samples with:
a. largest ADC sample -> amplitude
b. rising edge* -> hit-time
To pick up such 3 samples offline**, we take successive 2 samples with the largest sum (a) and 1 sample before them (b) (with the best hit-time resolution among the candidates).



*edge is steeper in rising than falling
** In a real implementation, we only tune the latency (waveform unavailable)

Calibration



"raw" hit-time is calibrated for each sensor/side to the reference time t_0^{sync} — event timing estimated by outer detectors offline, called "EventT0" or "T0", synchronized to SVD reference frame.

- EventT0 resolution: 0.649 ns
- use only track-associated hits

fit functions (found empirically):

- CoG3 - pol3$(= a + bx + cx^2 + dx^3)$
- ELS3 - pol1+pol1^{-1} $\left(= a + bx + \frac{c}{x-d}\right)$

Result: SVD hit-time distribution

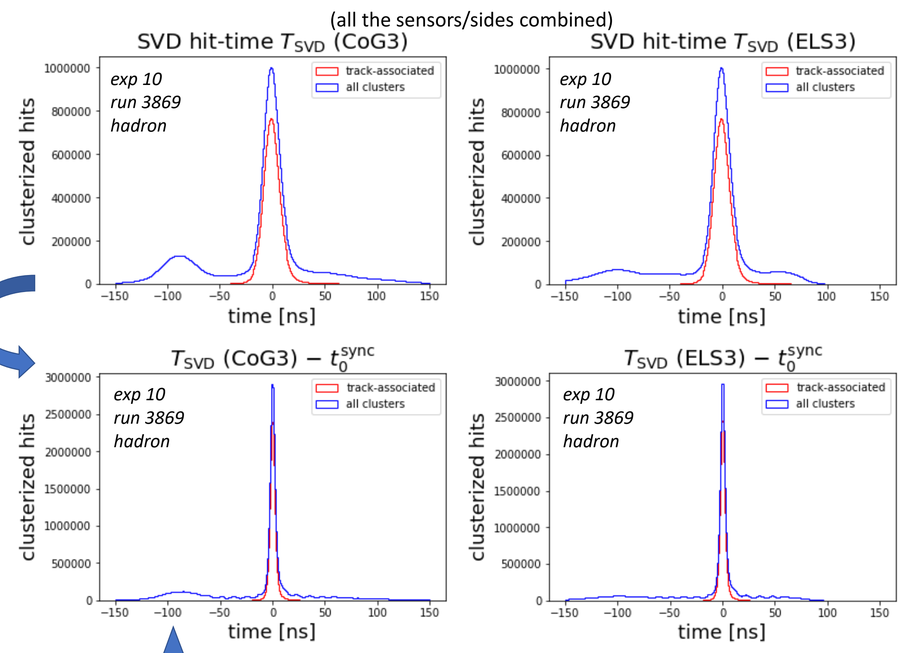
(calibrated) hit-time
Signal peak vs BG tail

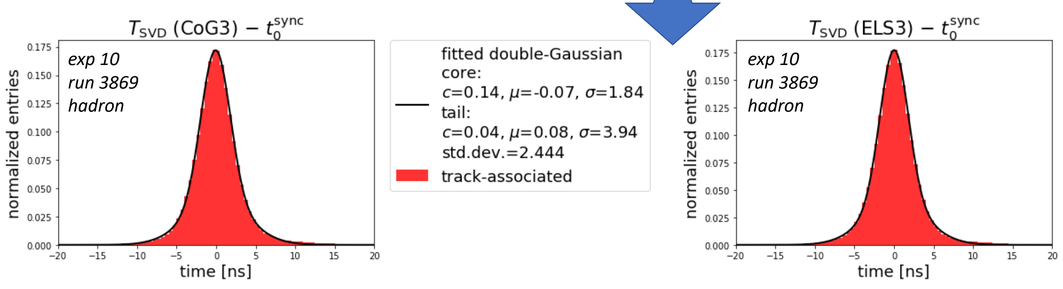
- BG separated
- different BG distribution
  <- different calibration

subtracting t_0^{sync}
= removal of trigger jitter

- sharper signal peak
  -> better separation
- intrinsic resolution*:
  2.35/2.28 ns for CoG3/ELS3
- periodical structure every 12 ns in BG distribution
  -> bunch fill pattern visible

(all the sensors/sides combined)





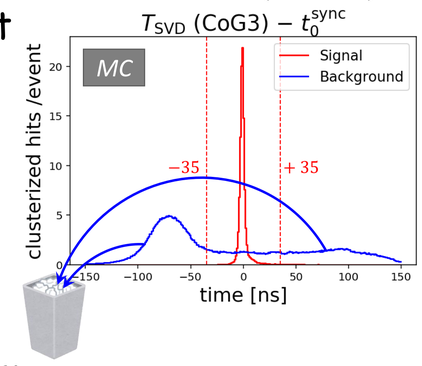
* calculated as $\sqrt{(\text{std. dev. of fitted double} - \text{Gaussian})^2 - (\text{EventT0 resolution})^2}$

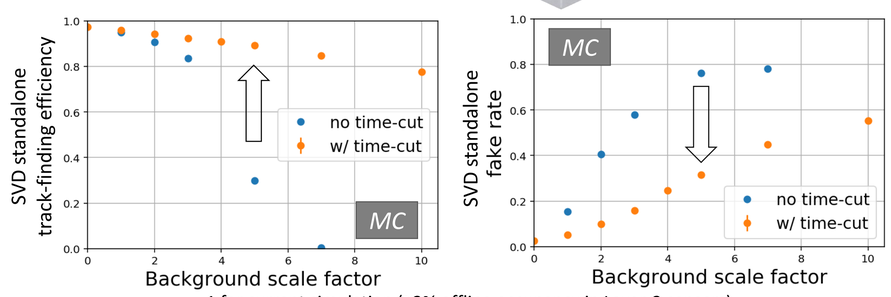
Use of hit-time (future)

Use Monte Carlo simulation with various amount of beam background and apply cut on hit-time (CoG3)

- [−35,+35] (width 70 ns) cut
- signal hit efficiency:
  99.55(2)%
- background hit rejection:
  80.89(6)%

-> higher tracking efficiency, lower tracking fake-rate





1 for current simulation (~2% offline occupancy in Layer-3 sensors)

Conclusion

- 3/6-sample mixed mode is now ready and being tested
- 3-sample time algorithms are available in analysis software
- Results are promising, further study will be done with 3-sample data acquired in the test

VERTEX2020@Virtual (5th–8th, Oct.)