Recent operation status of Belle II electromagnetic calorimeter and relevant systems

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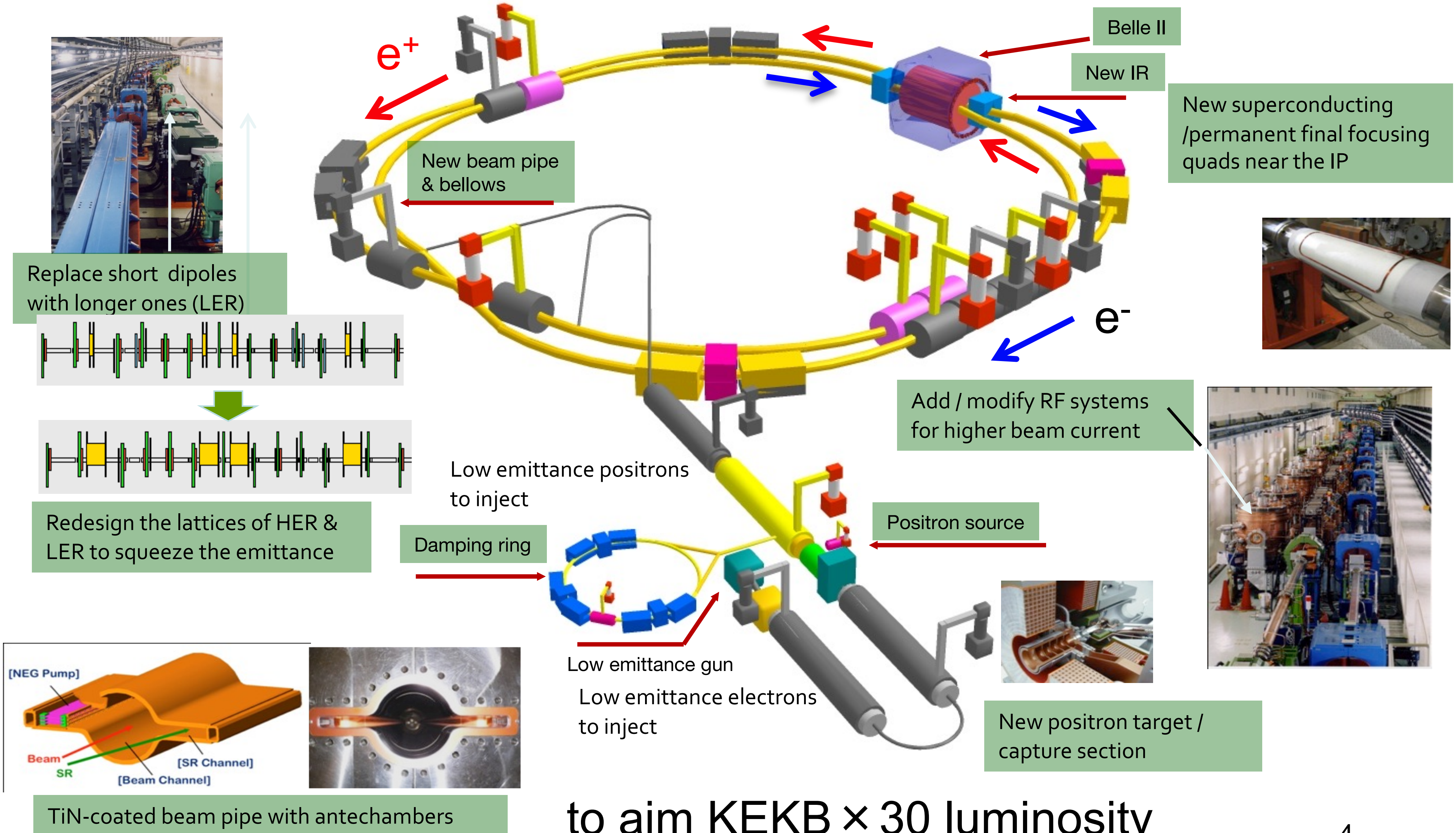
Outline

- Calorimeter for e^+e^- collider at Υ region
- SuperKEKB and Belle II
- Belle II electromagnetic calorimeter
  - CsI(Tl) with waveform sampling readout
  - Relevant systems
- Calibration and performance
- Summary

Calorimeter for e^+e^- at Υ region

- Wide dynamic range: 20MeV~7GeV
  - 1/3 of B decays have π^0, most of γ~100MeV.
  - Radiative B decays ($B \to K^*\gamma$, etc.) γ up to 4GeV
  - Bhabha, $e^+e^- \to \gamma\gamma$ calibration, up to 7GeV
- High energy resolution
  - σ_E/E ~ 2% above 1GeV
  - $\sigma_{\gamma\gamma}$ ~ 5MeV/c^2 for π^0
- High position resolution
  - σ_x : 5~10mm at the incident point

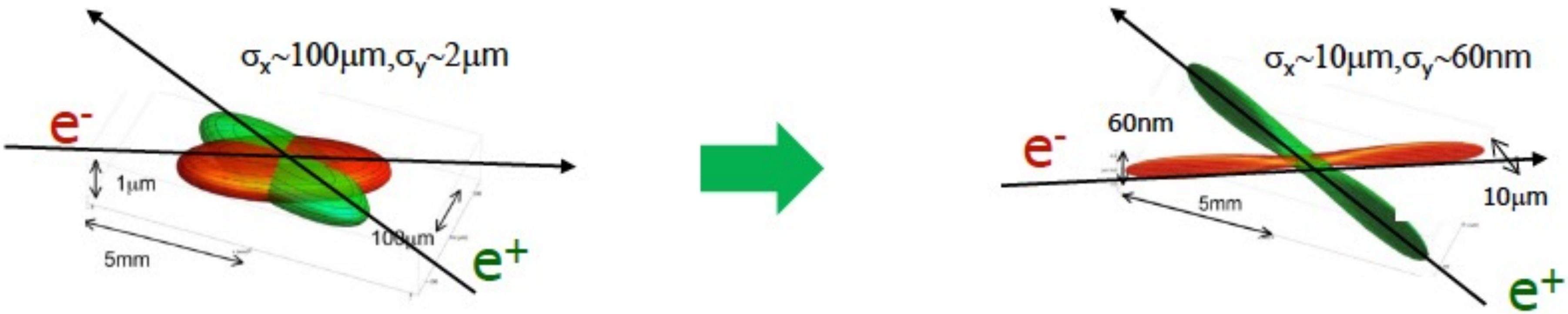
SuperKEKB



to aim KEKB × 30 luminosity

Nano-beam collision

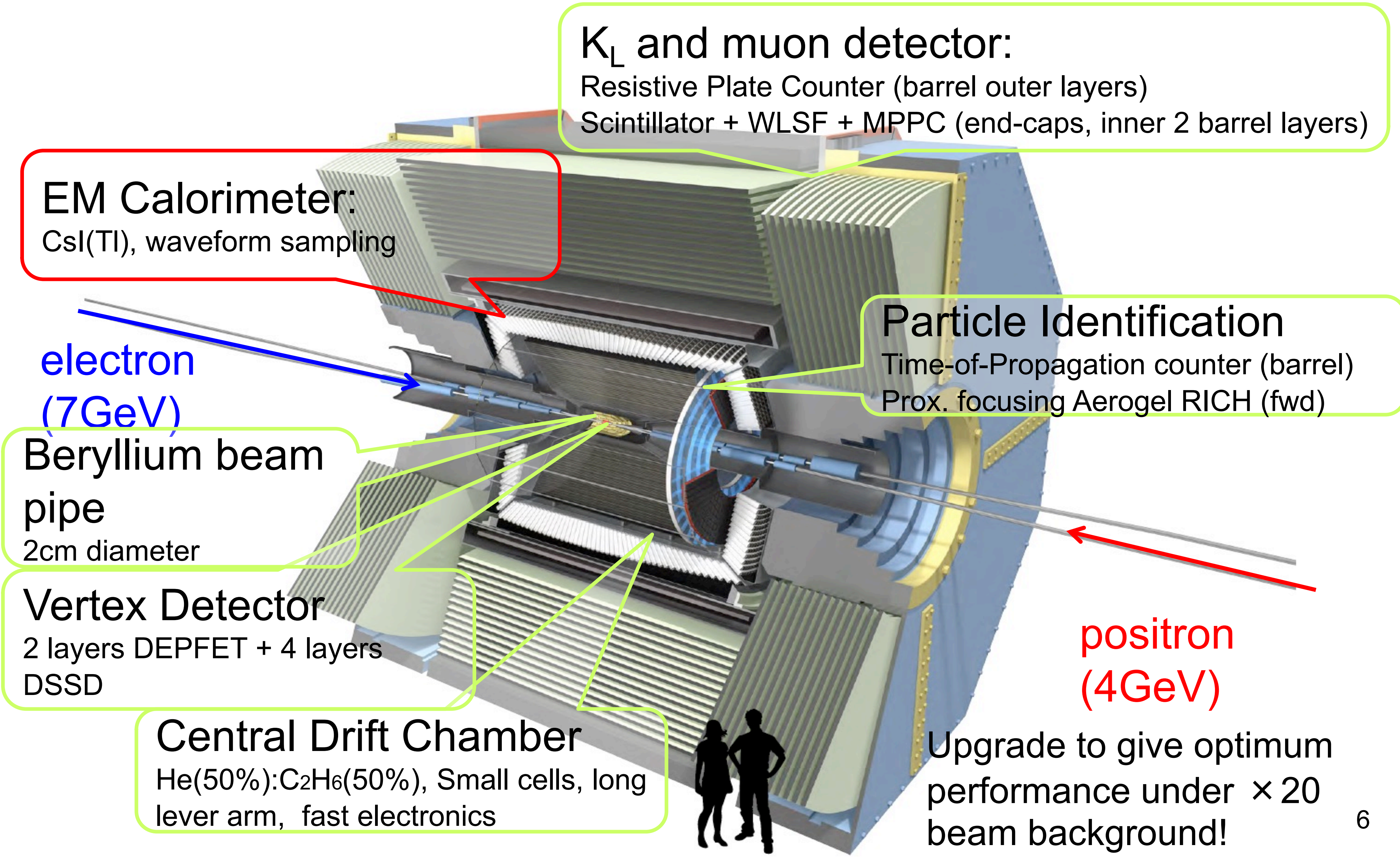
$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\cdot\xi_{y,e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$



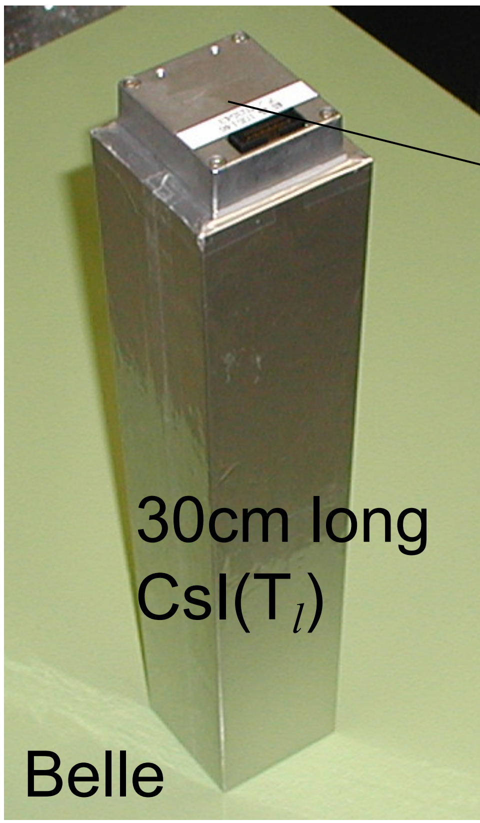
KEKB SuperKEKB

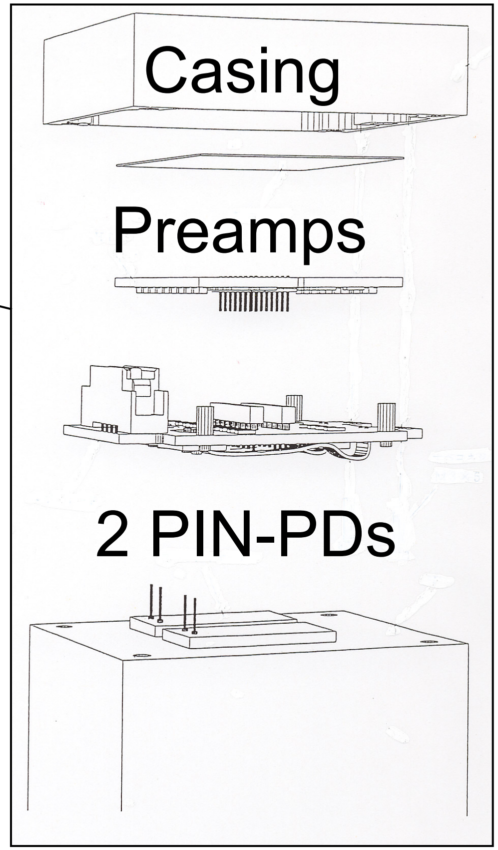
To increase luminosity, small β function is used.
To handle hourglass effect, β>size of collision spot,
large crossing angle, one bunch behaves as “super bunch”.

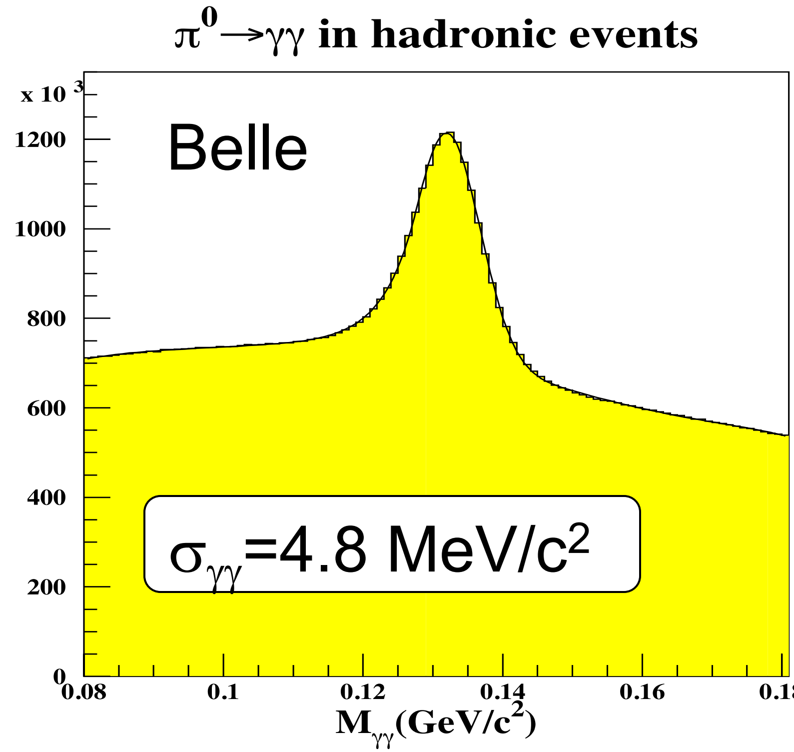
Belle II Detector



CsI(T_l) with PIN-PD readout has been used at B-factories







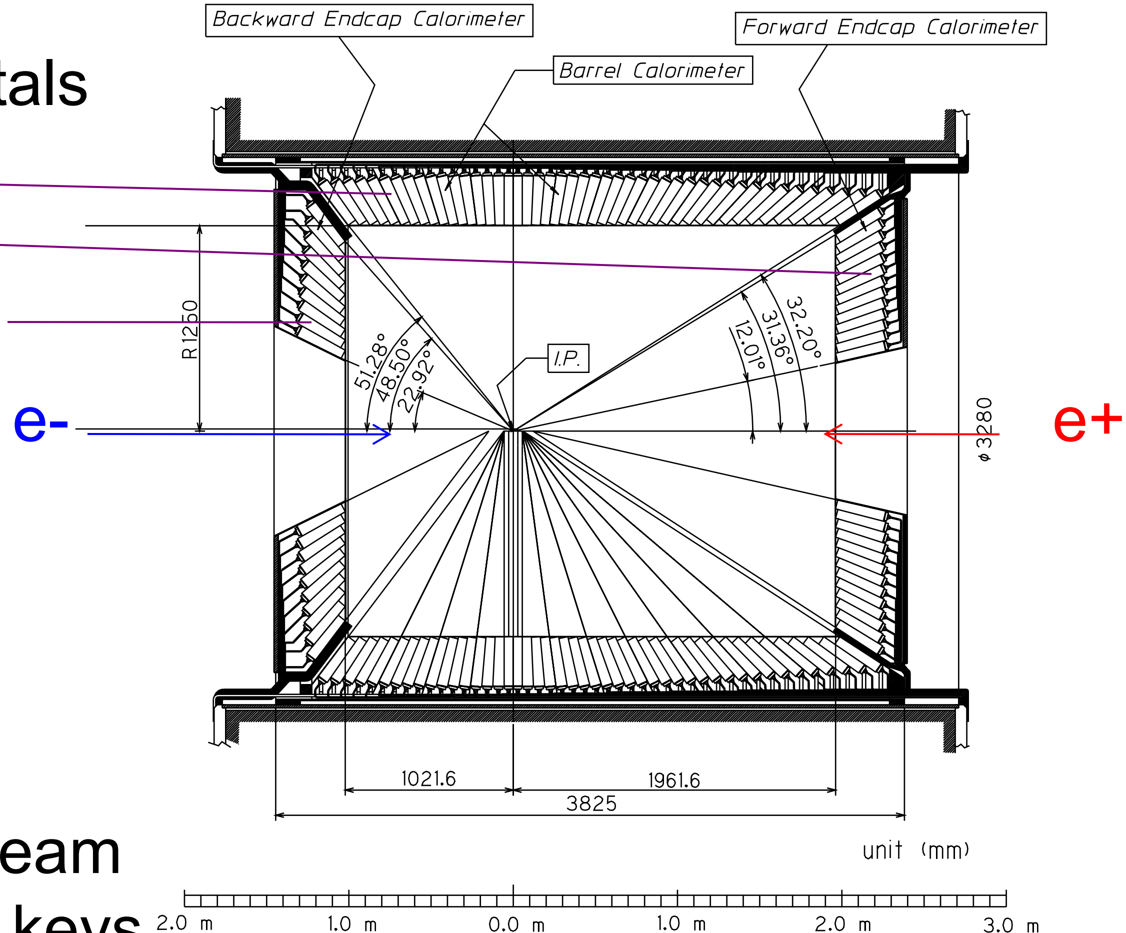
Light yield : ~5000 e-h pairs/MeV.

Belle II inherited Belle CsI(T_l) calorimeter

In total, 8736 CsI(T*l*) crystals (6624 in Barrel,
1152 in Fwd. Endcap
and 960 in Bwd. Endcap)
All are still alive, so far.

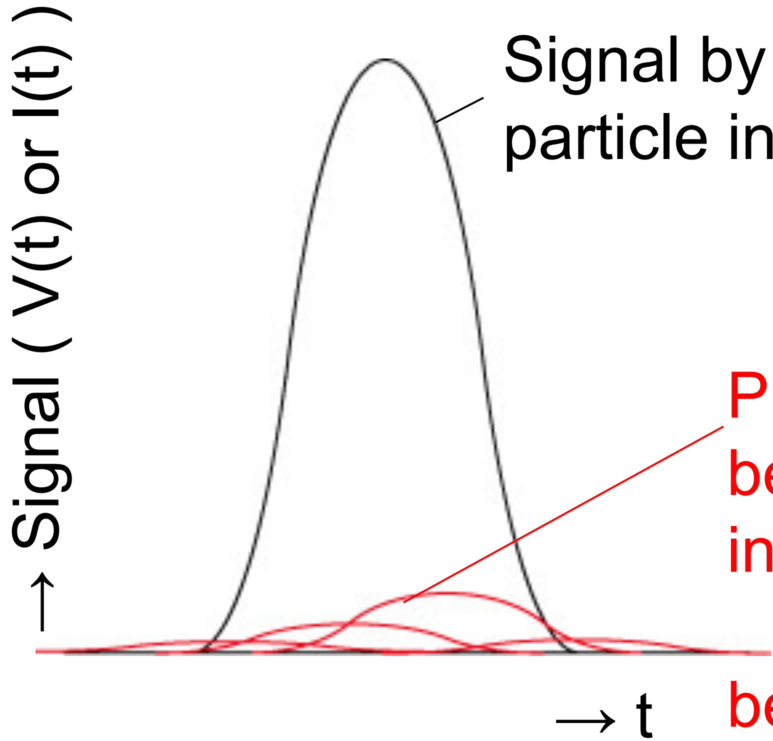
Covering 12<θ<155° in Lab. frame.
Inner radius = 1250mm.

High rate capability and beam background immunity are keys.



CsI(T_l) large light output, but…

Scintillation decay time is slow, ~1μs



Signal by physics particle incident

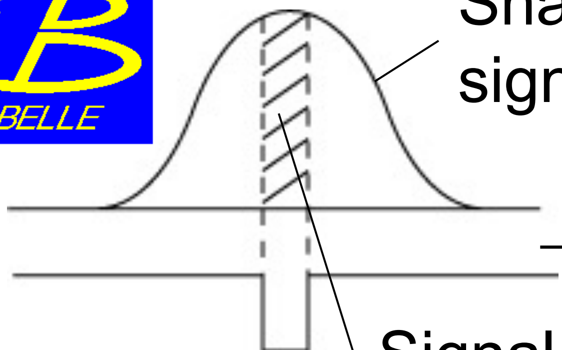
Pileup caused by beam background incident

↓

behaves as noise increase

Challenge is to realize beam background immunity

Waveform sampling readout



Shaper output signal

→ t

Gate width=100ns

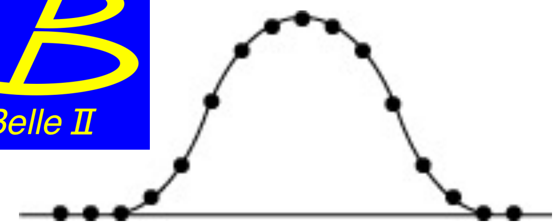
Signal charge

↓

Timing (leading/trailing edges) with range information by QtoT converter (MQT300A)

↓

Digitized by TDC



→ t

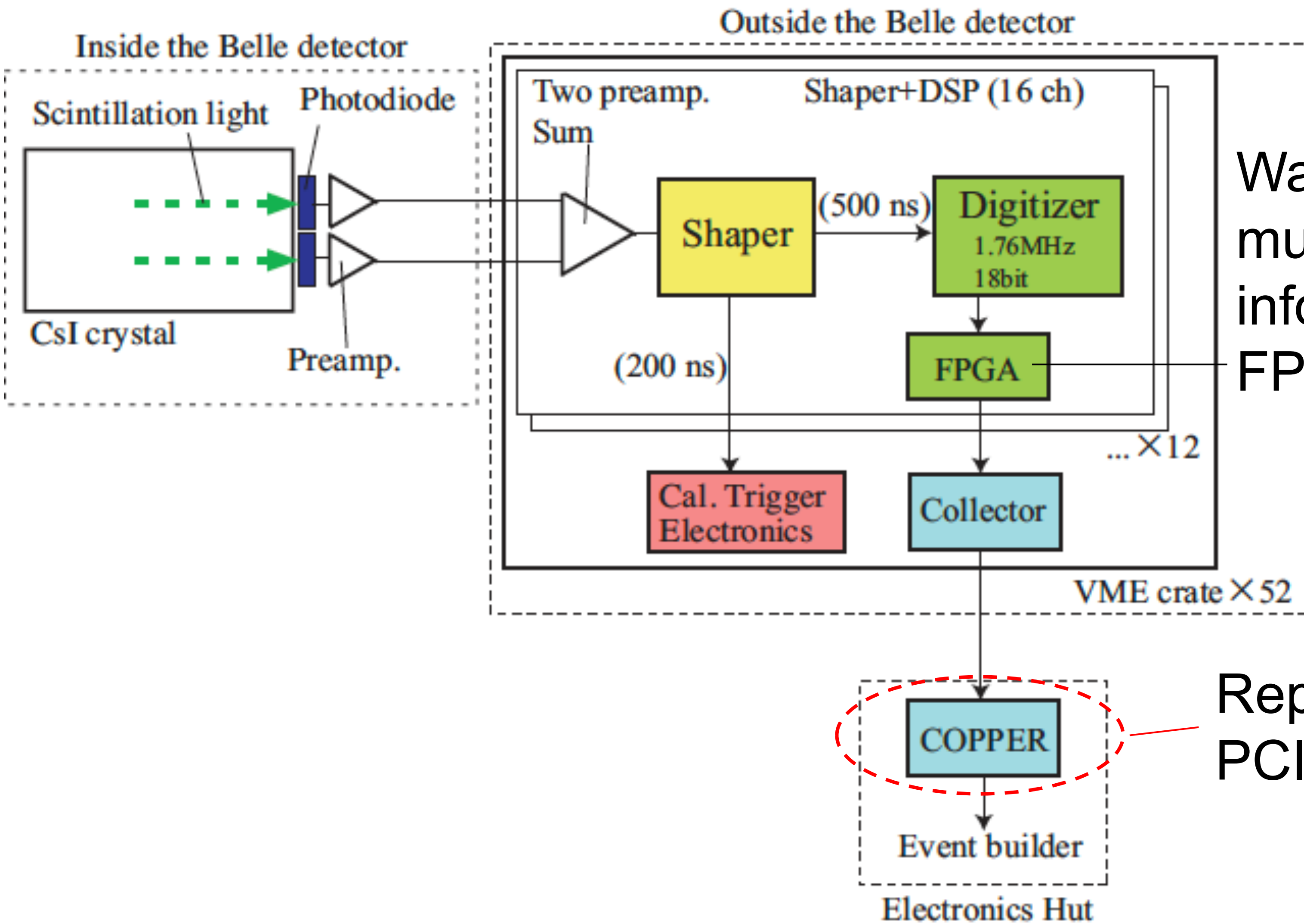
1.76MHz, 18bits digitizer, waveform fit to get energy and timing (i.e. Digital Signal Processing)

Reduction factors;

×7 BG showers

×1.5~2 pileup noise

Electronics arrangement



Waveform fit and multiplexing information by FPGA

Replaced by PCIe40 system

PCIe40 board

- PCI Express board with a large FPGA and 48 optical transceivers
- Originally developed for LHCb and ALICE
- Its functionality is also suitable for the readout hardware of the Belle II DAQ.

COPPER (VME-9U board)

PCIe40
(PCIExpress card)

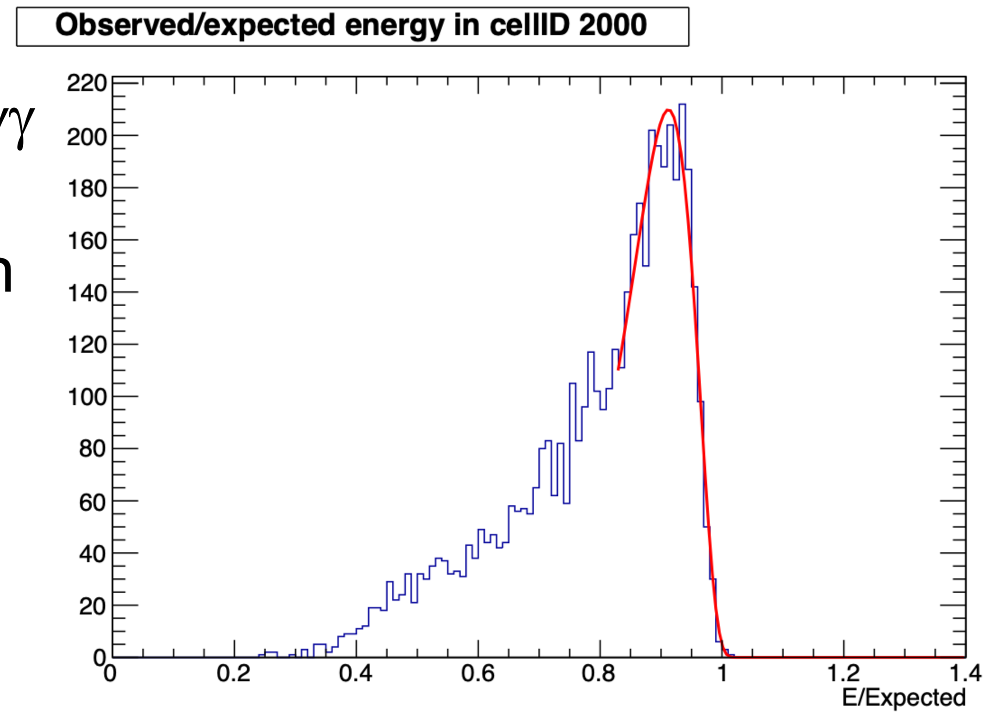
# of input channels :
COPPER : max 4
PCIE40 : max 48

# of readout boards used for Belle II :
～200 COPPER boards -> 21 PCIe40 boards

Crystal-by-crystal energy calibration

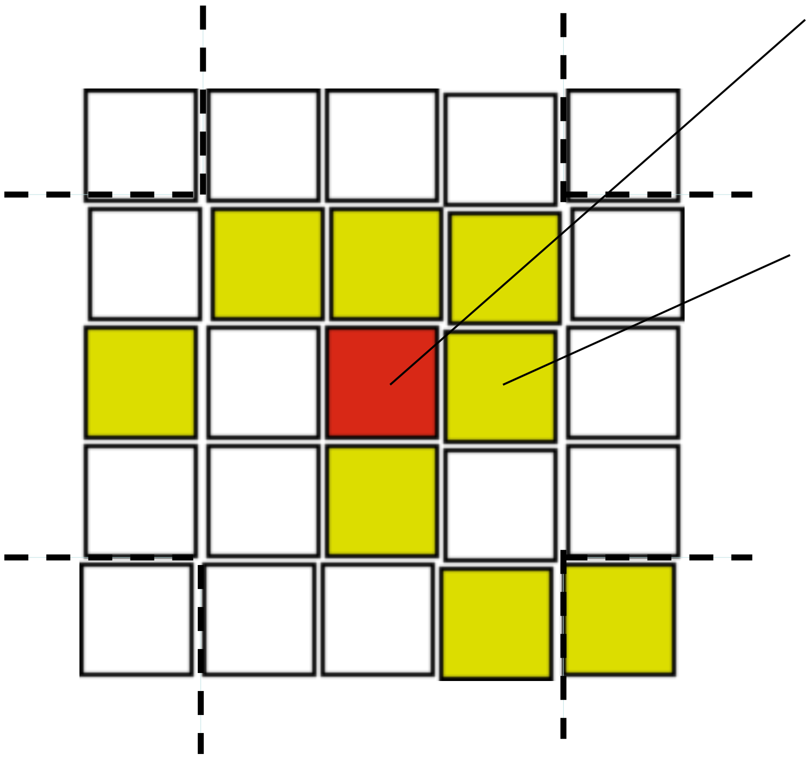
Energy response of individual crystals is calibrated using $e^+e^- \rightarrow \gamma\gamma$ events.

- only the most-energetic crystal in each shower is considered.
- upper edge (maximum energy deposit) does not depend on inactive material distribution.



11% standard deviation in calibration constants reflects the variation in light output among barrel crystals.
Calibration constants have increased an average of 2.0% since 2020: decrease in light output due to radiation damage.

Clustering algorithm



View from IP

Seed crystal : Local maximum energy, exceeding 10 MeV.

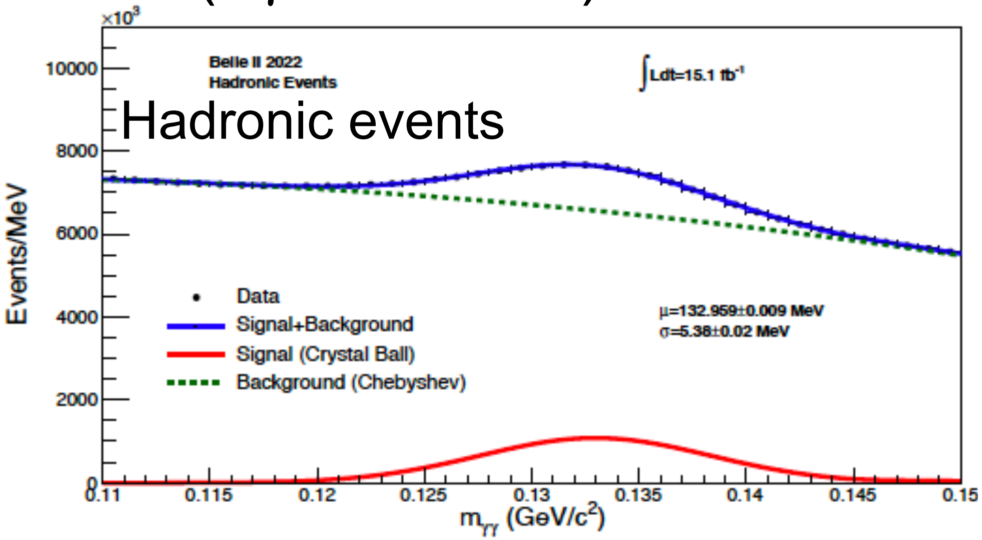
Belle : the hits exceeding proper threshold inside 5×5 crystal matrix surrounding the seed crystal are considered.

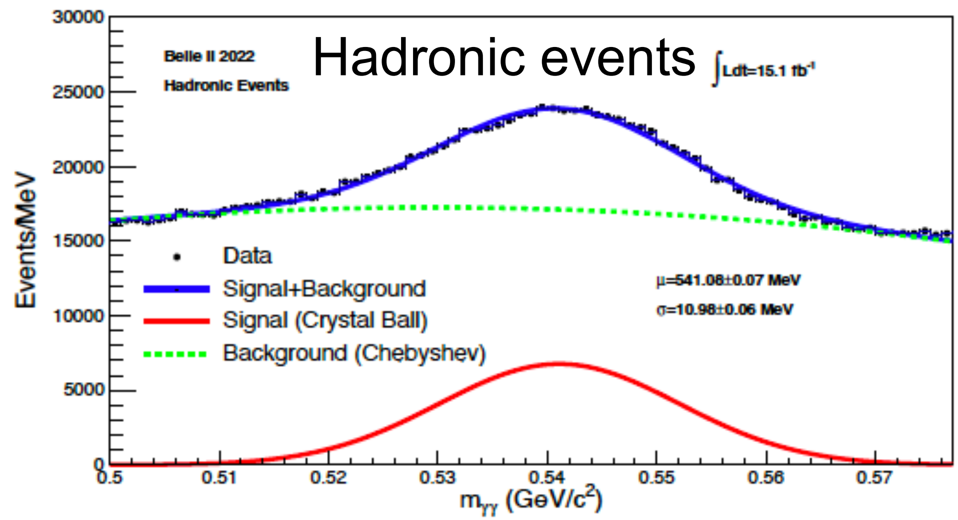
Belle II : highest-N hits are considered among 21 crystals, i.e. corner crystals of 5×5 matrix are excluded for the immunity to beam background.

Observed performance

$\pi^0 \rightarrow \gamma\gamma$, $\sigma_{\gamma\gamma}$=5.4 MeV/c^2
($E\gamma$ > 25 MeV)

$\eta \rightarrow \gamma\gamma$, $\sigma_{\gamma\gamma}$=11 MeV/c^2
($E\gamma$ > 400 MeV)

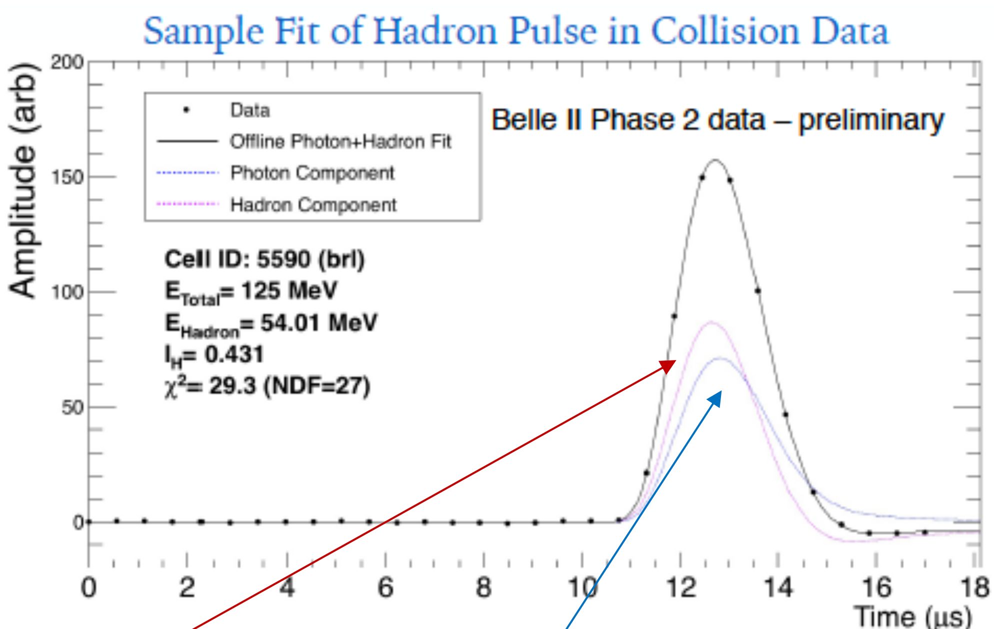


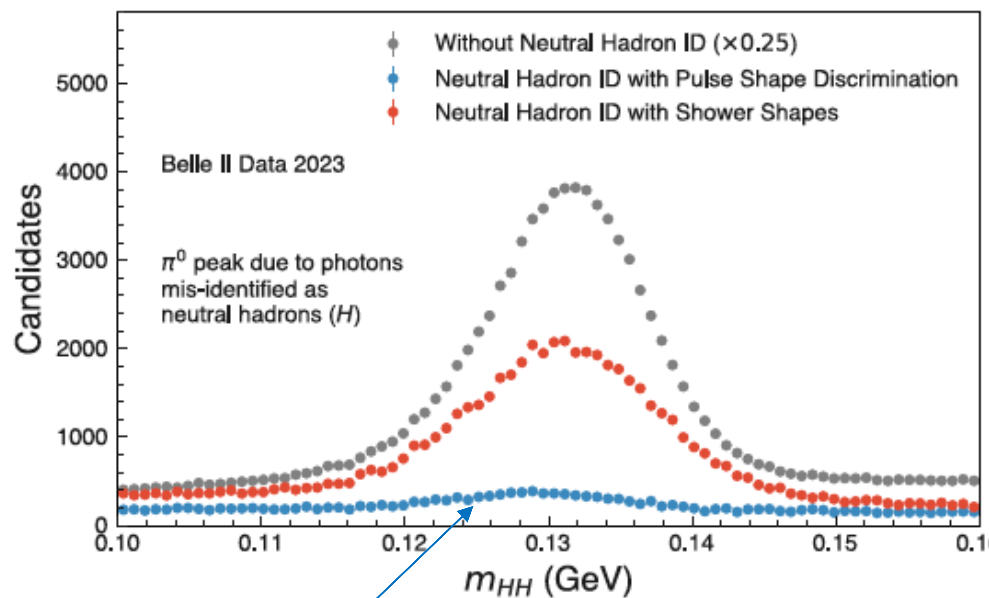


$e^+e^- \rightarrow \mu^+\mu^-\gamma$ events are also visited, for 1 GeV γ,
σ_E/E = 2.2%, timing resolution = 4 ns.

Pulse Shape Discrimination (PSD)

In CsI(T*l*), scintillation time evolution changes depending on dE/dX, i.e. difference between hadron and photon incidents.

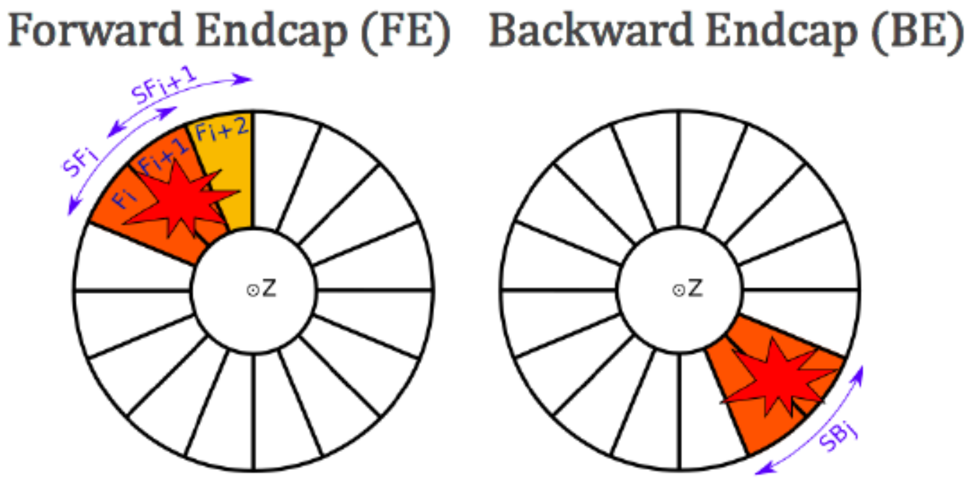




Hadron and photon components exhibit different pulse shape

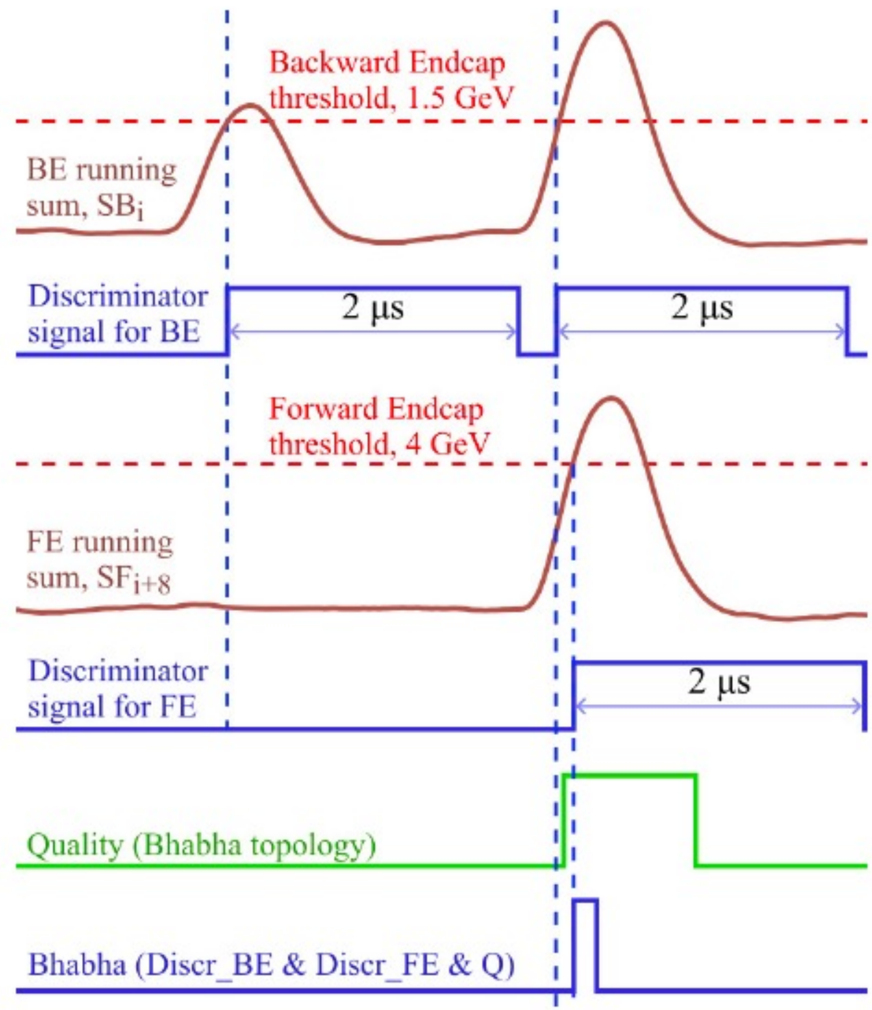
By rejecting photon-like clusters, π^0 mass peak disappears.

Luminosity monitoring



Back-to-back large energy depositions are identified by at most 2 adjacent endcap sectors.

Online measurement exhibits ~2% systematic discrepancy from offline, within possible uncertainty.



Timing diagram of the LOM logic

Summary

- SuperKEKB is aiming $\times 30$ luminosity w.r.t. KEKB.
- 8736 CsI(Tl) counters inherited from Belle, all alive.
- In order for high rate capability and beam background immunity, waveform sampling readout electronics has been introduced. COPPER $\rightarrow$ PCIe40 replacement has been done.
- Stably working, neutral particles (γ in radiative mupair, π^0 and $\eta \rightarrow \gamma\gamma$) are properly seen.
- Luminosity monitor is stably functioining.