Upgrade of the Belle II electromagnetic calorimeter

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Instr14 conf., BINP in Novosibirsk

2014 Feb. 28th

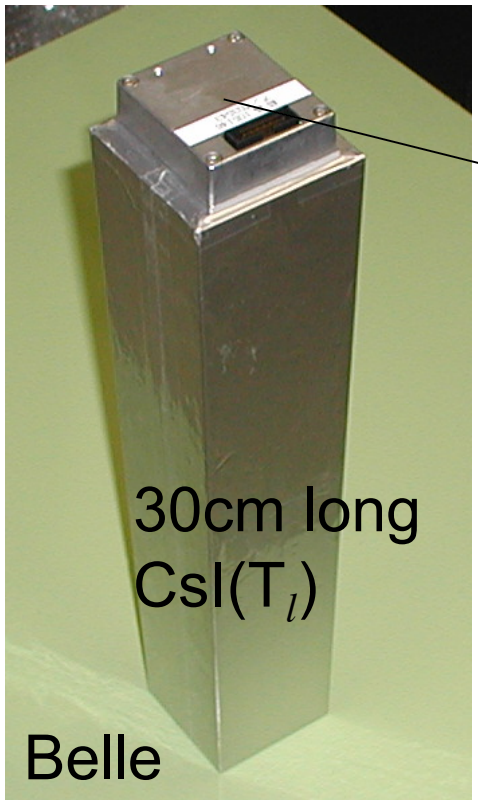
Outline

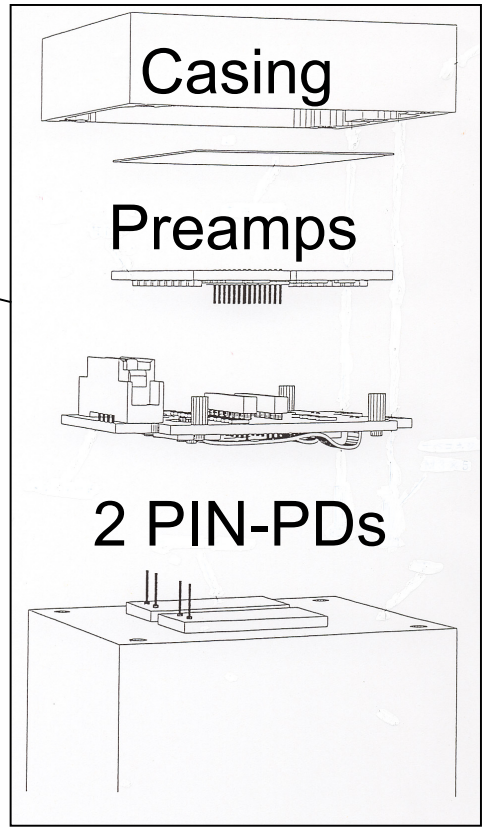
- Calorimeter for e^+e^- collider at Υ region
- SuperKEKB and Belle II
  - Challenge : beam background immunity
- Belle II electromagnetic calorimeter
  - Day-1 : CsI(Tl) with waveform sampling readout
  - Forward Endcap upgrade with Pure CsI
- Summary

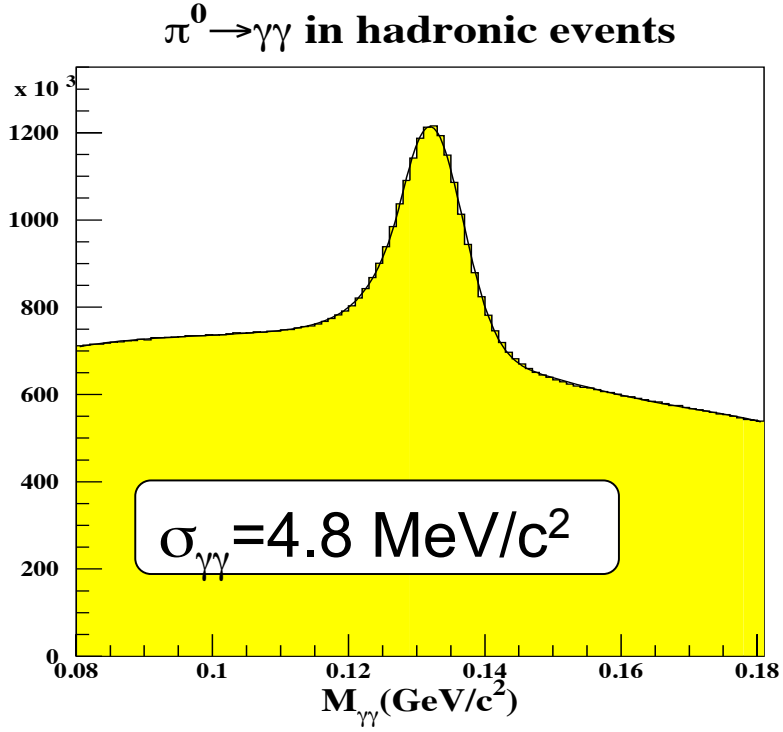
Calorimeter for e^+e^- at Υ region

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

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

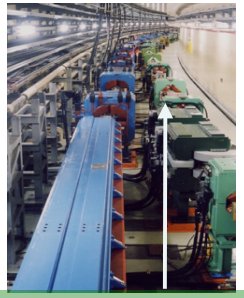




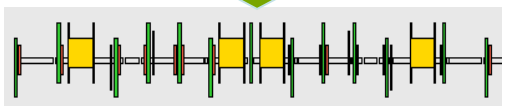


8736 CsI counters are used.

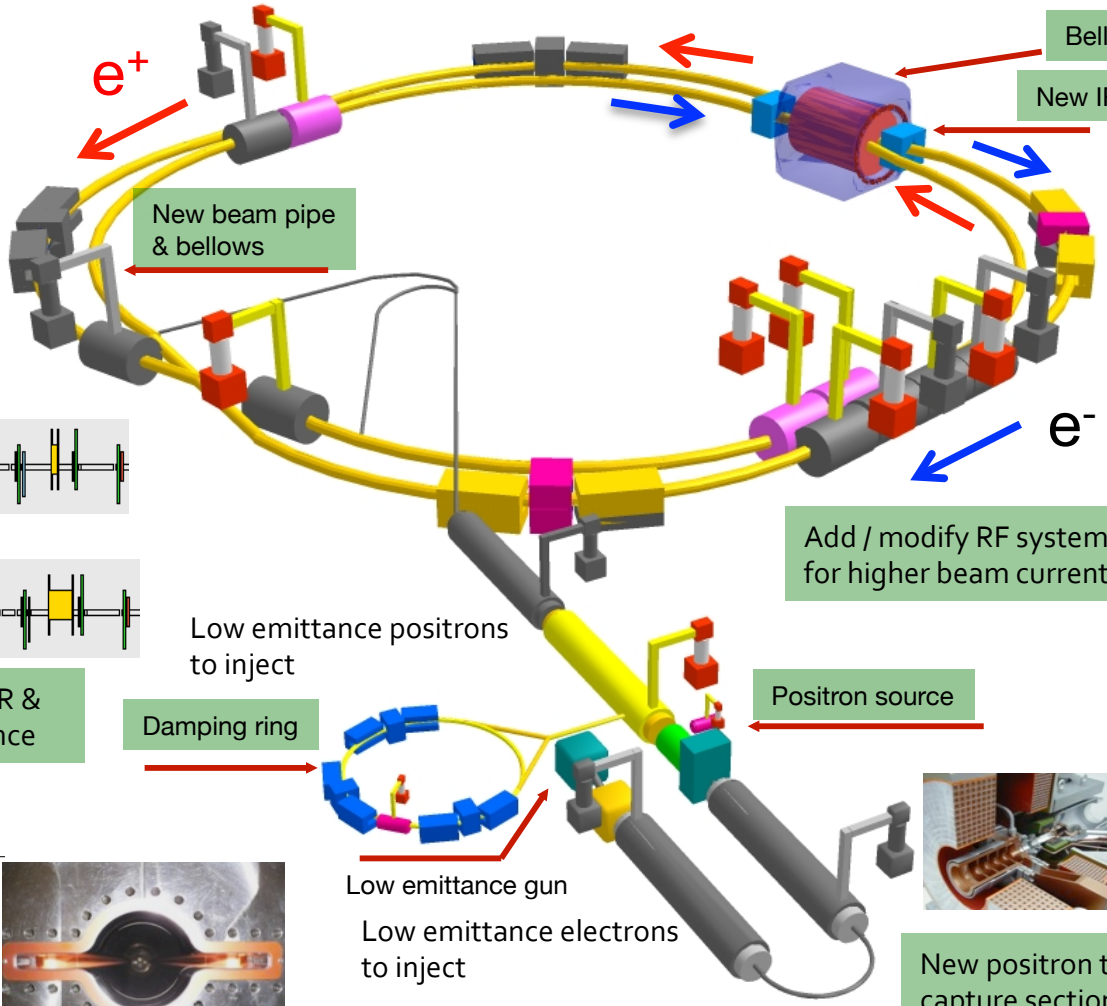
SuperKEKB



Replace short dipoles with longer ones (LER)



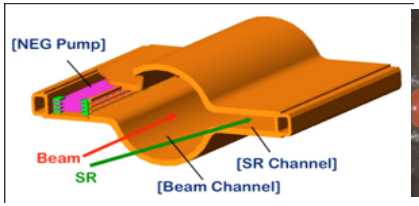
Redesign the lattices of HER & LER to squeeze the emittance



New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section



TiN-coated beam pipe with antechambers

Currents×2, β^*_y×1/20 w.r.t. KEKB
to aim ×40 luminosity

Nano-beam collision

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

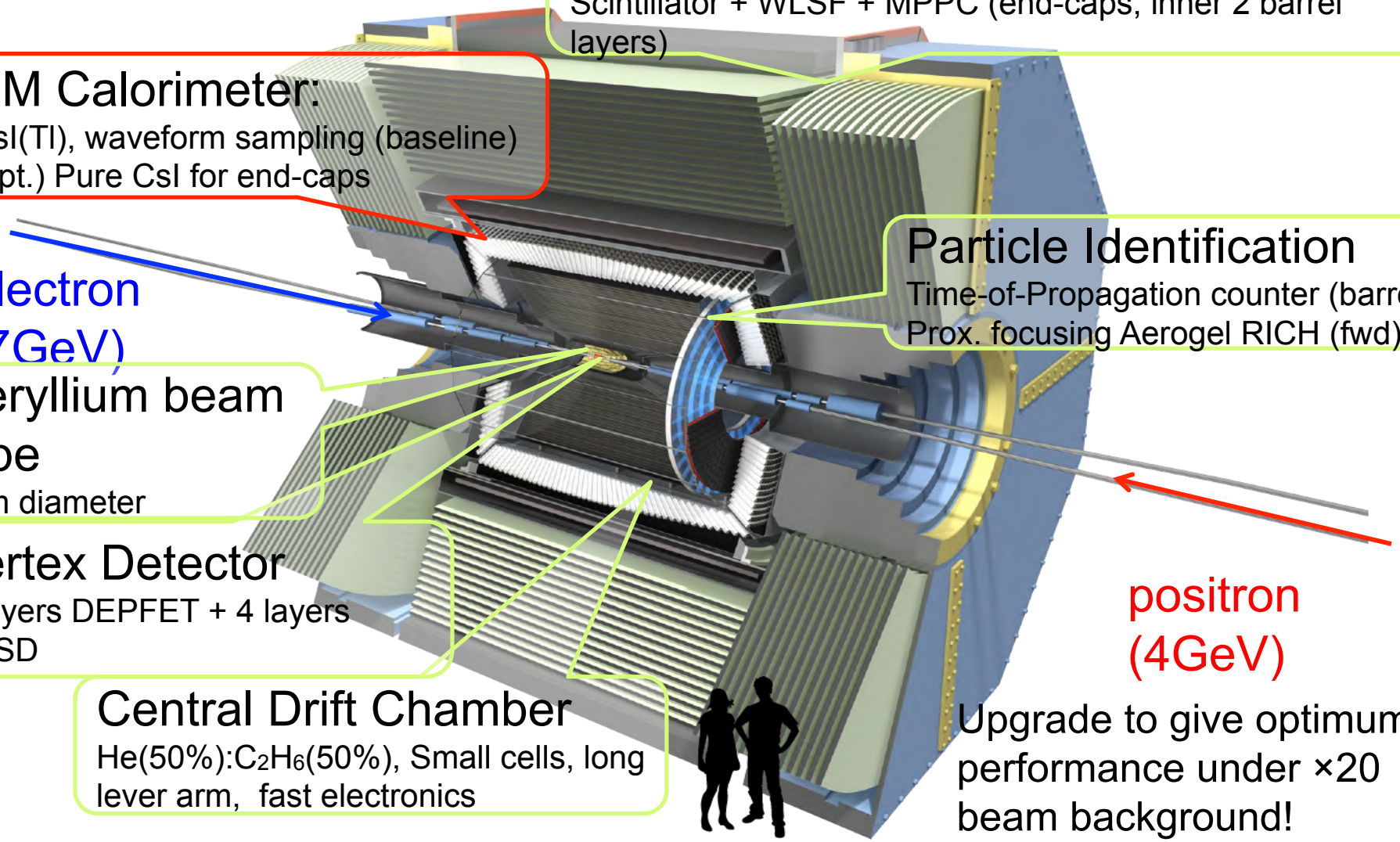
KEKB SuperKEKB

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

K_L and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps, inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling (baseline)
(opt.) Pure CsI for end-caps



Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

electron (7GeV)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layers DEPFET + 4 layers DSSD

Central Drift Chamber
He(50%):C_2H_6(50%), Small cells, long lever arm, fast electronics

positron (4GeV)

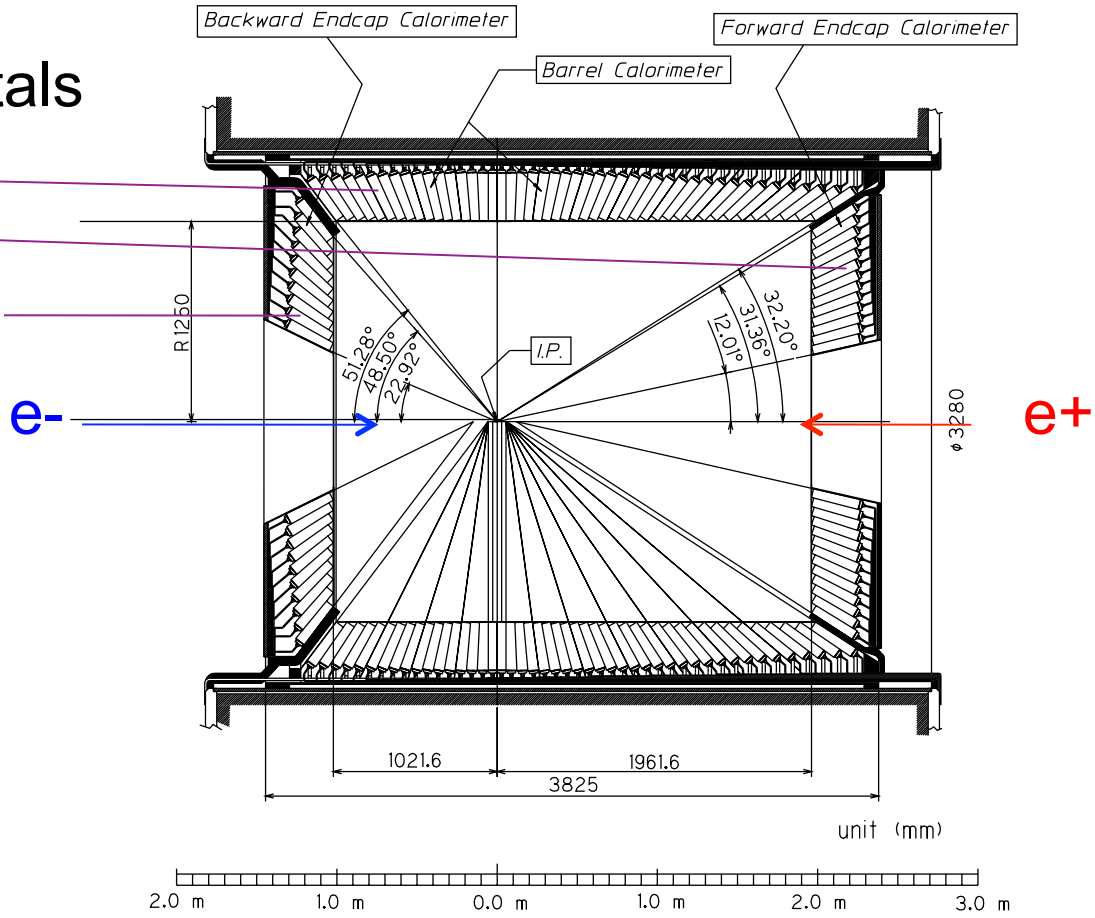
Upgrade to give optimum performance under ×20 beam background!

Day-1: existent CsI(T_l)

In total, 8736 CsI(T*l*) crystals
(6624 in Barrel,
1152 in Fwd. Endcap
and 960 in Bwd. Endcap)

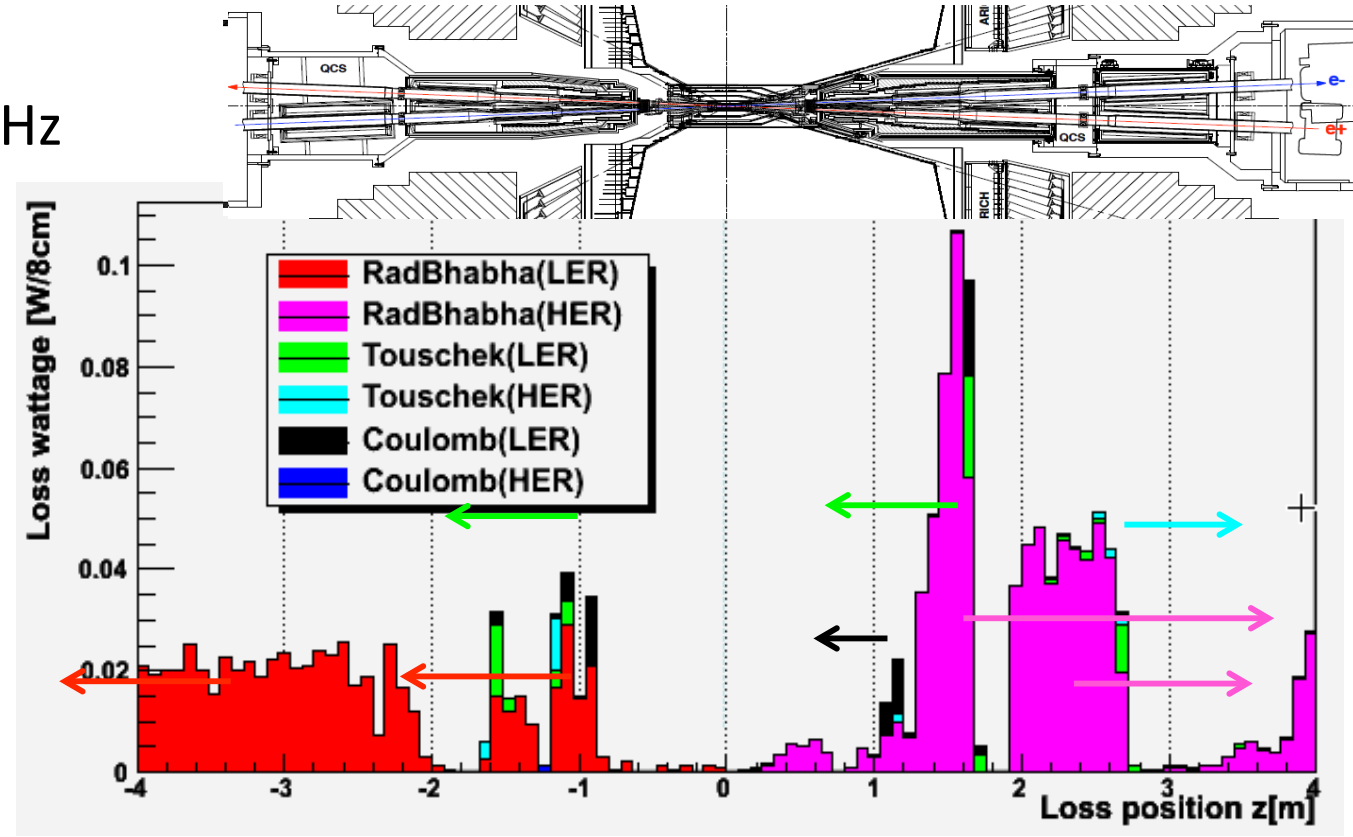
Covering 12<θ<155° in Lab. frame.

Inner radius = 1250mm.



Challenge : Beam BG immunity

1GeV ,1GHz
= 0.16W



HER
(e-)

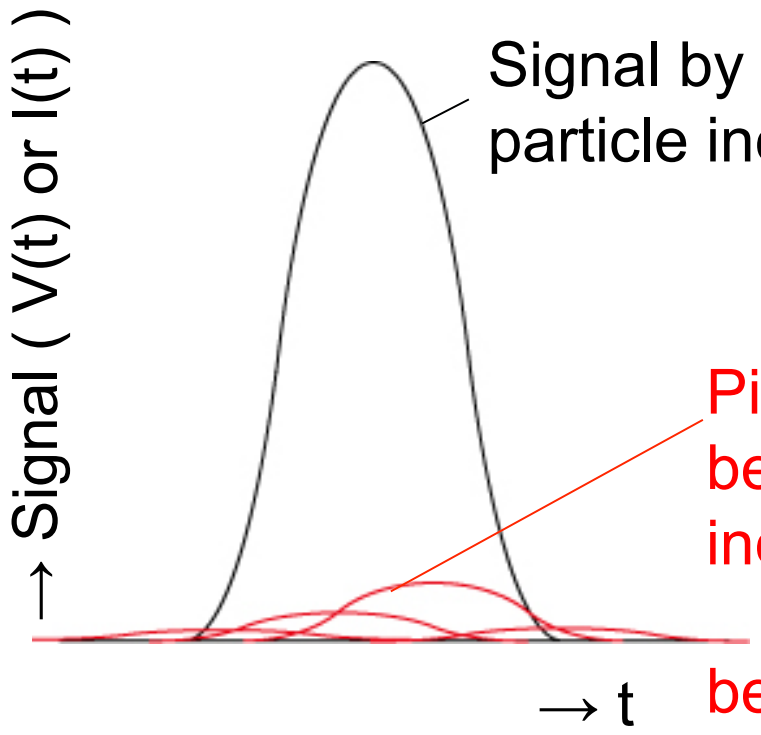
LER
(e+)

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.63 W (eff. 0.98GHz)	0.88W (eff. 0.78GHz)
Touschek	0.07 W (0.11GHz)	0.02 W (0.02 GHz)
Coulomb	0.07 W (0.10GHz)	0.001W (0.001GHz)

Mostly from Rad.Bhabha

CsI(T_l) large light output, but…

Scintillation decay time is slow, ~1μs



Signal by physics particle incident

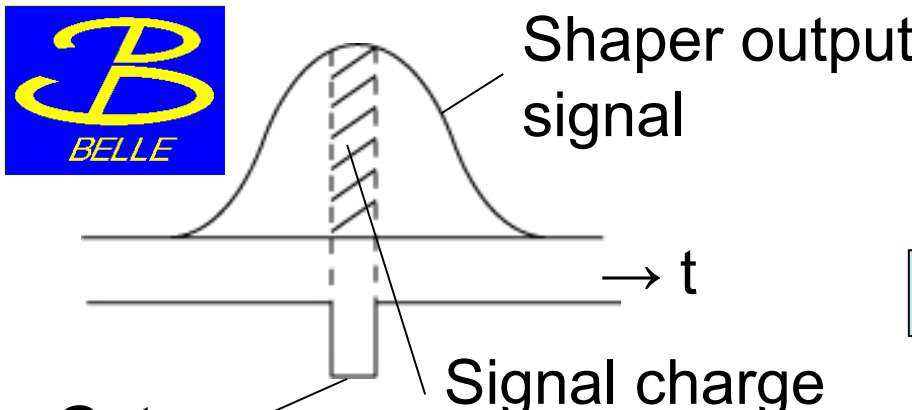
Pileup caused by beam background incident

↓

behaves as noise increase

Challenge is to realize beam background immunity

Waveform sampling readout



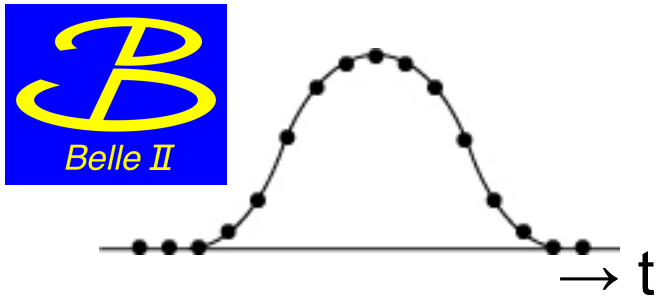
Signal charge

↓

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

↓

Digitized by TDC



2MHz, 18bits digitizer, waveform fit to get energy and timing (i.e. Digital Signal Processing)

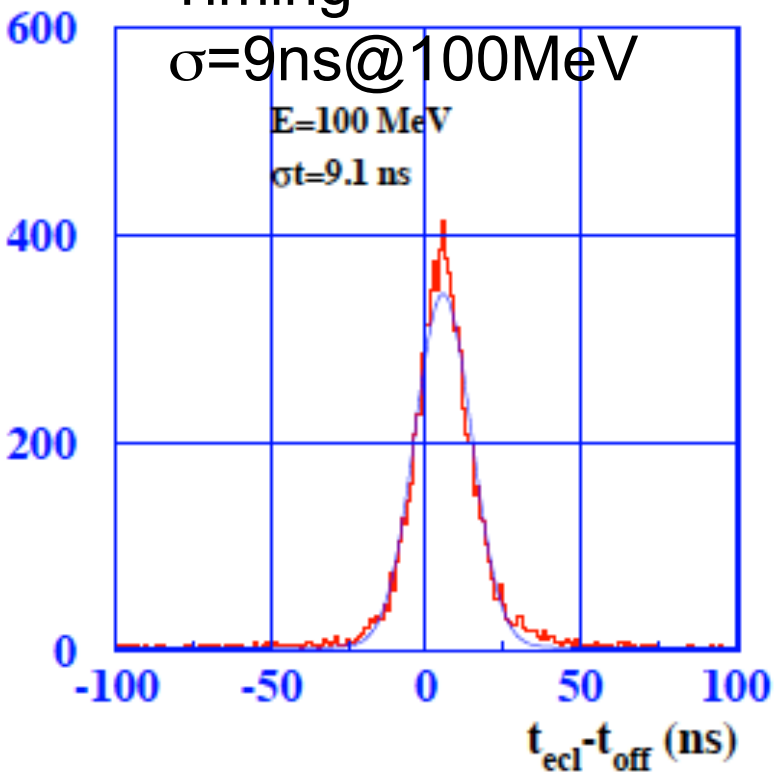
Reduction factors;
×7 BG showers
×1.5~2 pileup noise

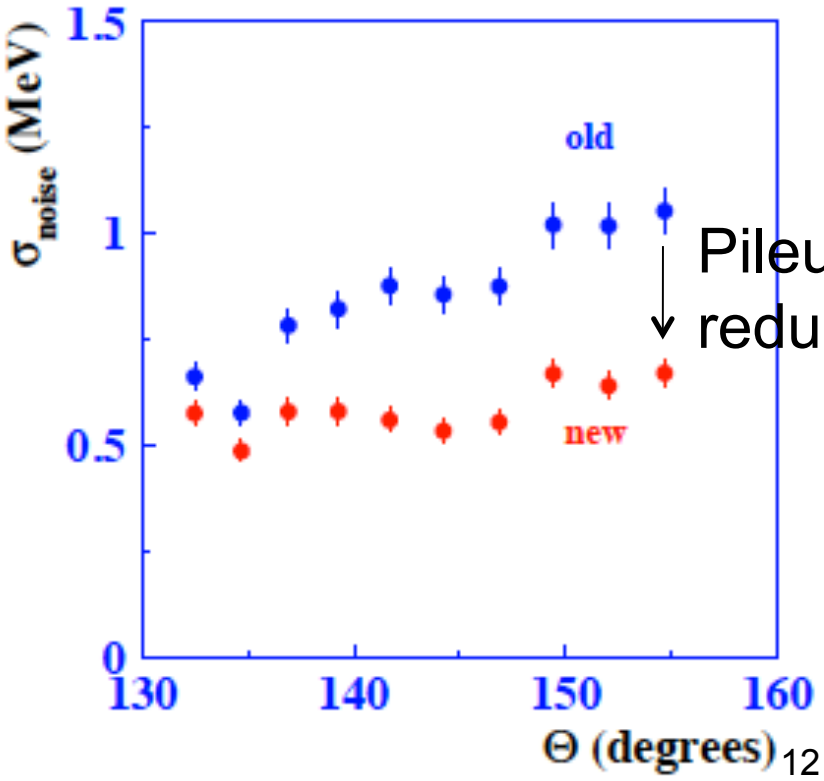
Early prototype tested at Belle

1/8 of backward endcap was connected to waveform sample readout prototype, 1fb^{-1} was taken on Υ(4S) resonance.

Timing

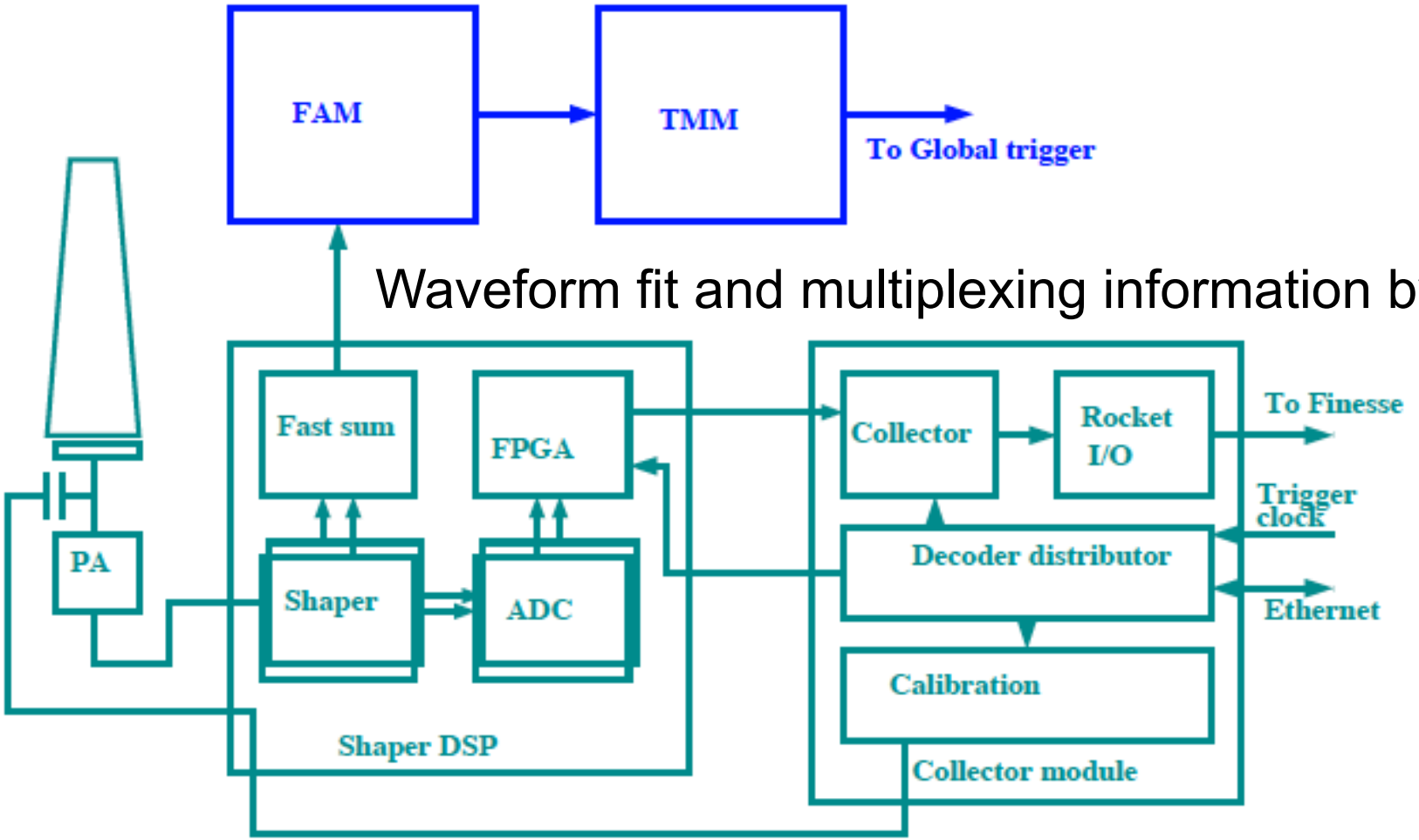
σ=9ns@100MeV





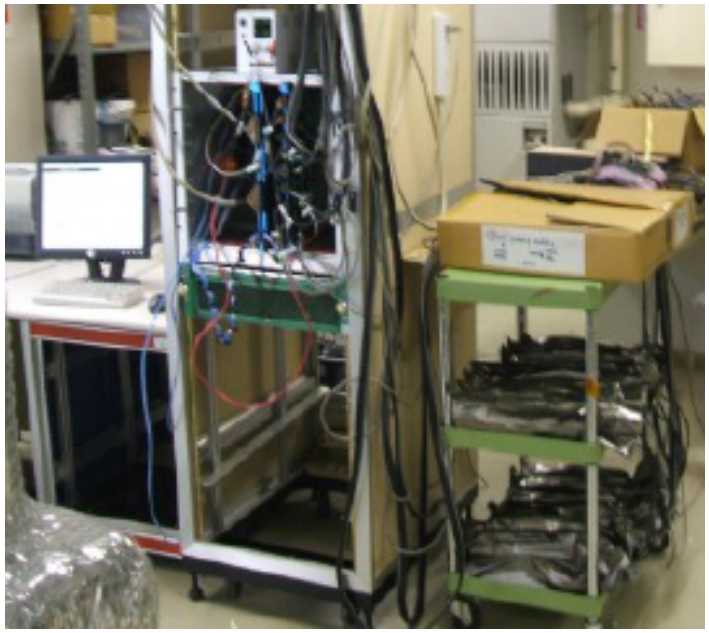
Pileup reduction

Electronics arrangement



Electronics production and test

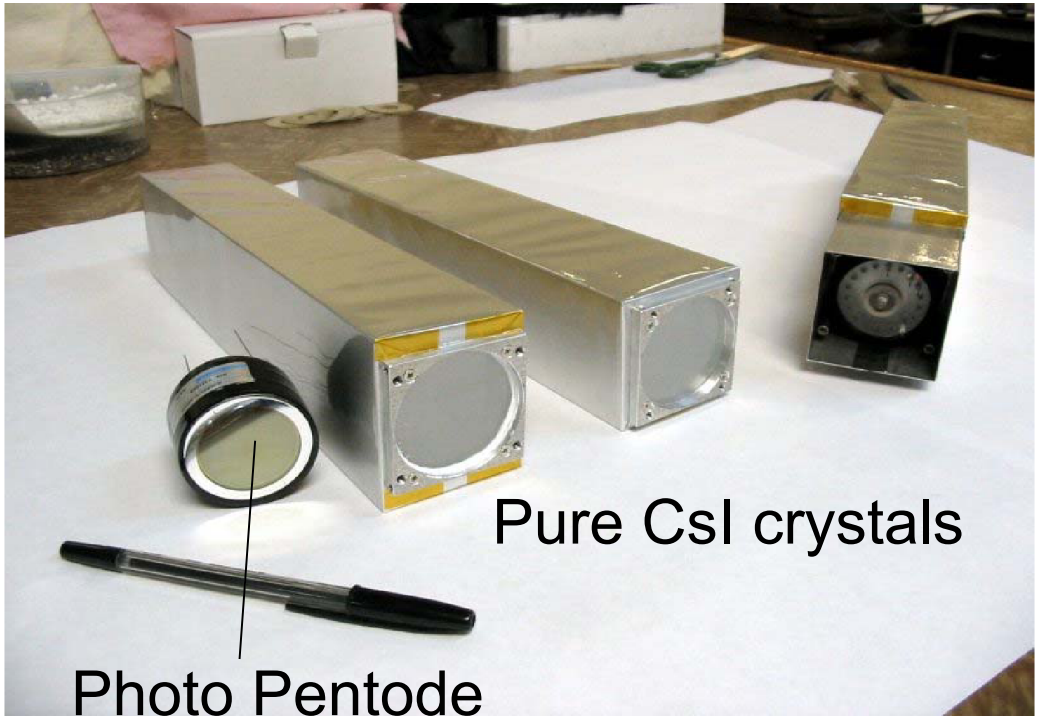
Shaper+DSP board for barrel



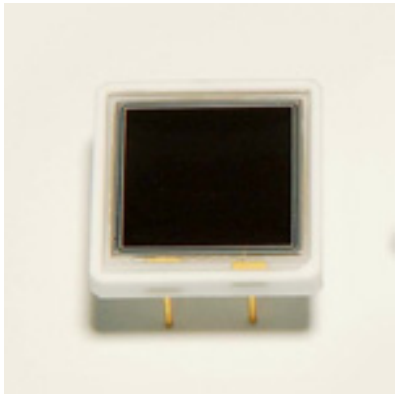
Test facility in KEK

For barrel, 112 (FY2012) + 280 (FY2013) Shaper+DSP boards have been delivered and tested. 55 in FY2014.
Most of the Shaper+DSP boards for endcaps are in FY2014.

Further pileup reduction at Endcap



Because of short scintillation decay time, ~30ns, Pure CsI crystal is almost pileup free. Photo Pentode readout is regarded as a baseline, noise~0.2MeV.



LAAPD is also being tested.

Discussing plan of replacement of inner part of forward endcap in a couple of years after first physics run.

Summary

- SuperKEKB is aiming ×40 luminosity w.r.t. KEKB.
- Mostly beam background comes from Rad. Bhabha, i.e. proportional to luminosity(!)
- Beam background immunity is a challenge for the calorimeter.
  - For day-1, use all the existent CsI(T_l) with waveform sampling readout electronics. Preparation is in good shape.
  - For further pileup suppression in forward endcap, plan to replace by Pure CsI is being figured out.