The BELLE Electromagnetic Calorimeter and its upgrade to BelleII

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Outline:

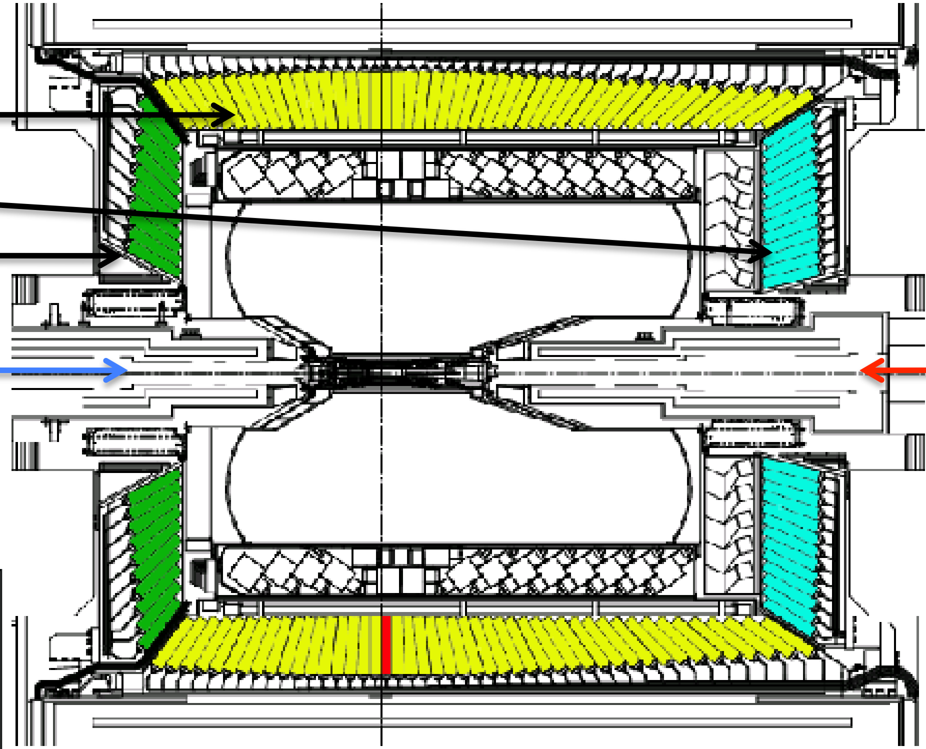
- BELLE CsI(Tl) calorimeter
- SUPERKEKB and BelleII
- Front End electronics upgrade for BelleII
- Commissioning of ECL for phase 2 and 3
- Upgrade of the CsI(Tl) to pure CsI
- Summary and Conclusions

Electromagnetic calorimeter @B-factories

- Large dynamic range: 20MeV~8GeV
  - 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 8GeV
- High energy resolution
  - σ_E/E ~ 4% at 100MeV
  - π^0 Mass resolution ~5MeV
- High position resolution
  - σ_x : 5~10mm at the incident point

BELLE CsI(Tl) Calorimeter

8736 CsI(Tl) crystals
- 6624 Barrel
- 1152 Fwd. Endcap
- 960 Bwd. Endcap



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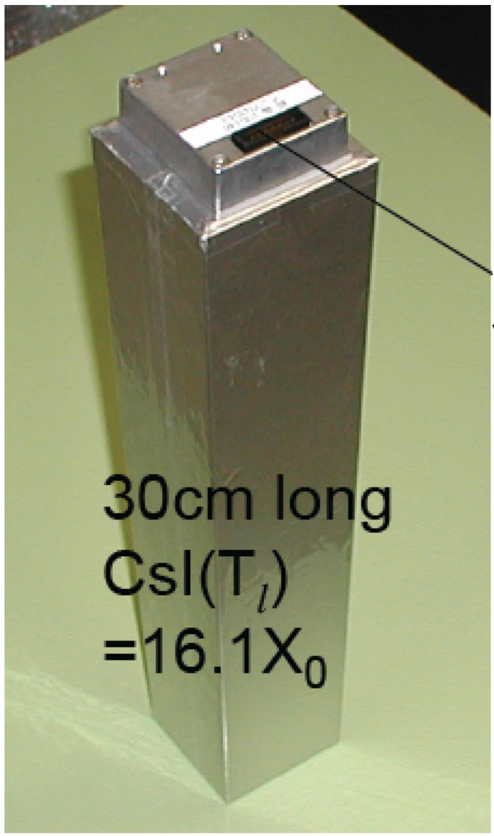

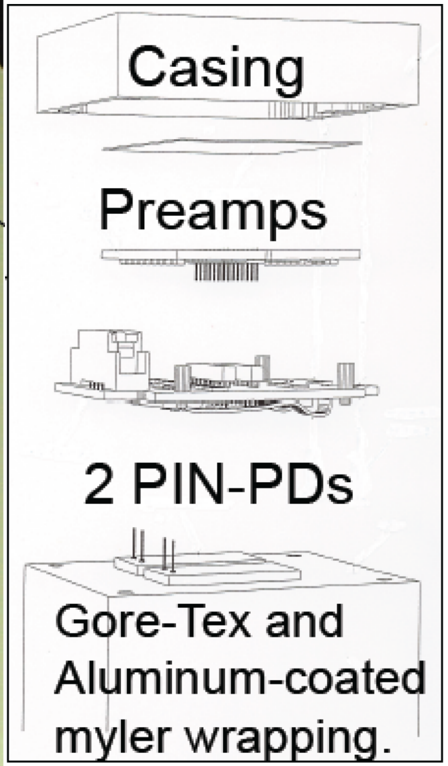

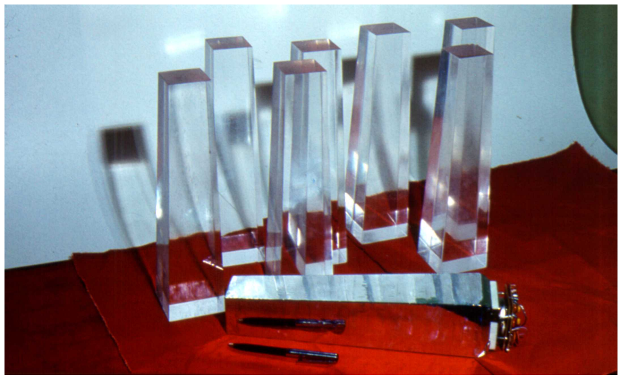

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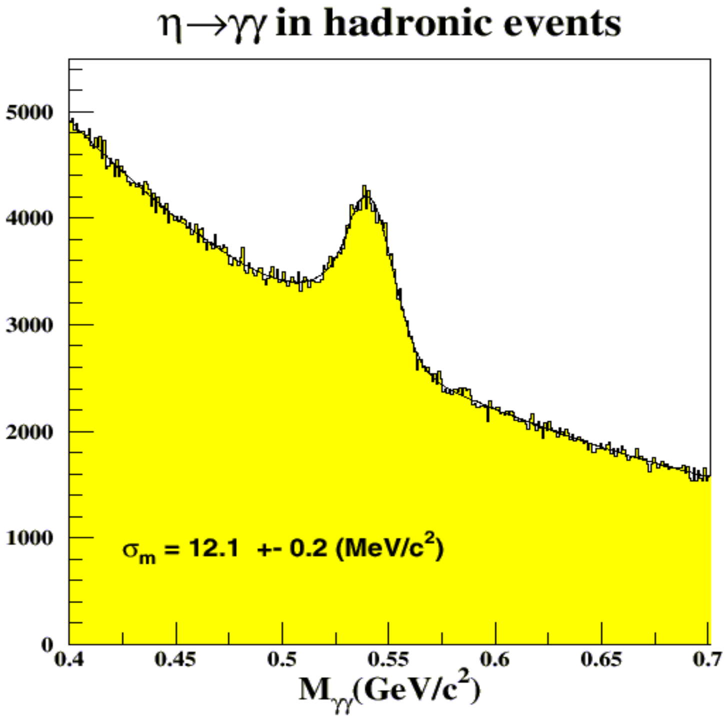
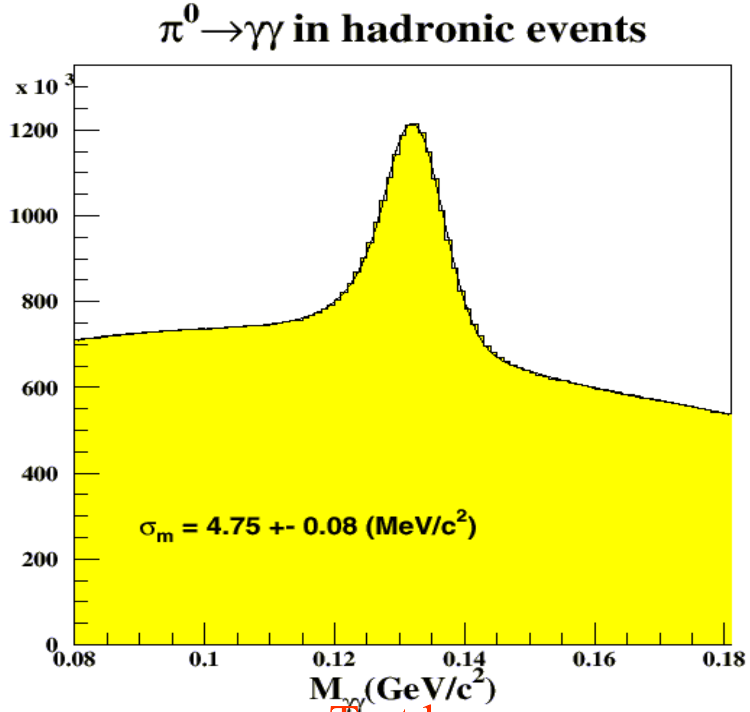
$L_{cr} = 30\ \text{cm} = 16.2X_0$

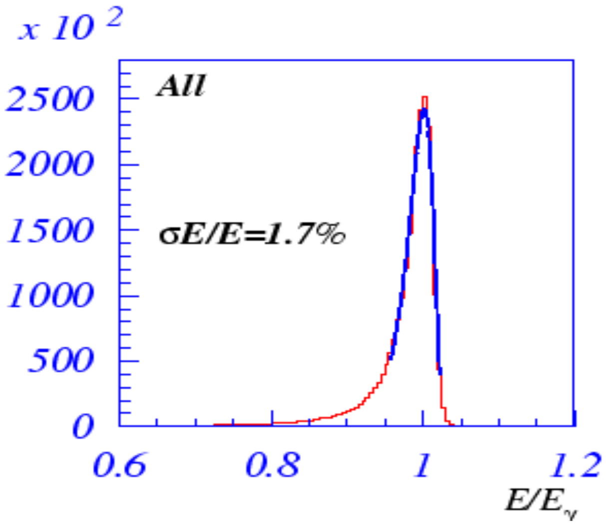
Light output – 5000 ph.el./MeV

electronics noise $\sigma \sim 200$ keV

Performances







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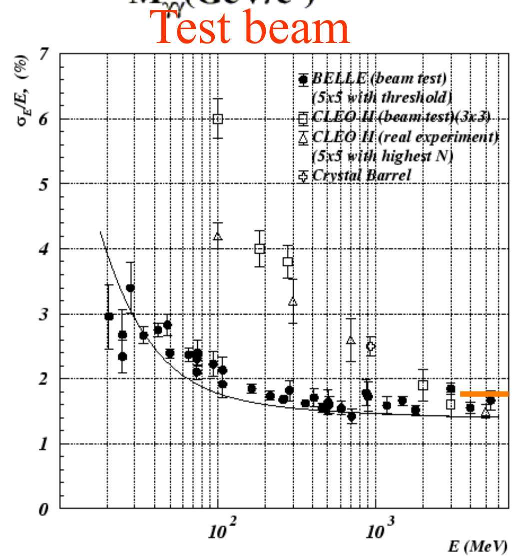
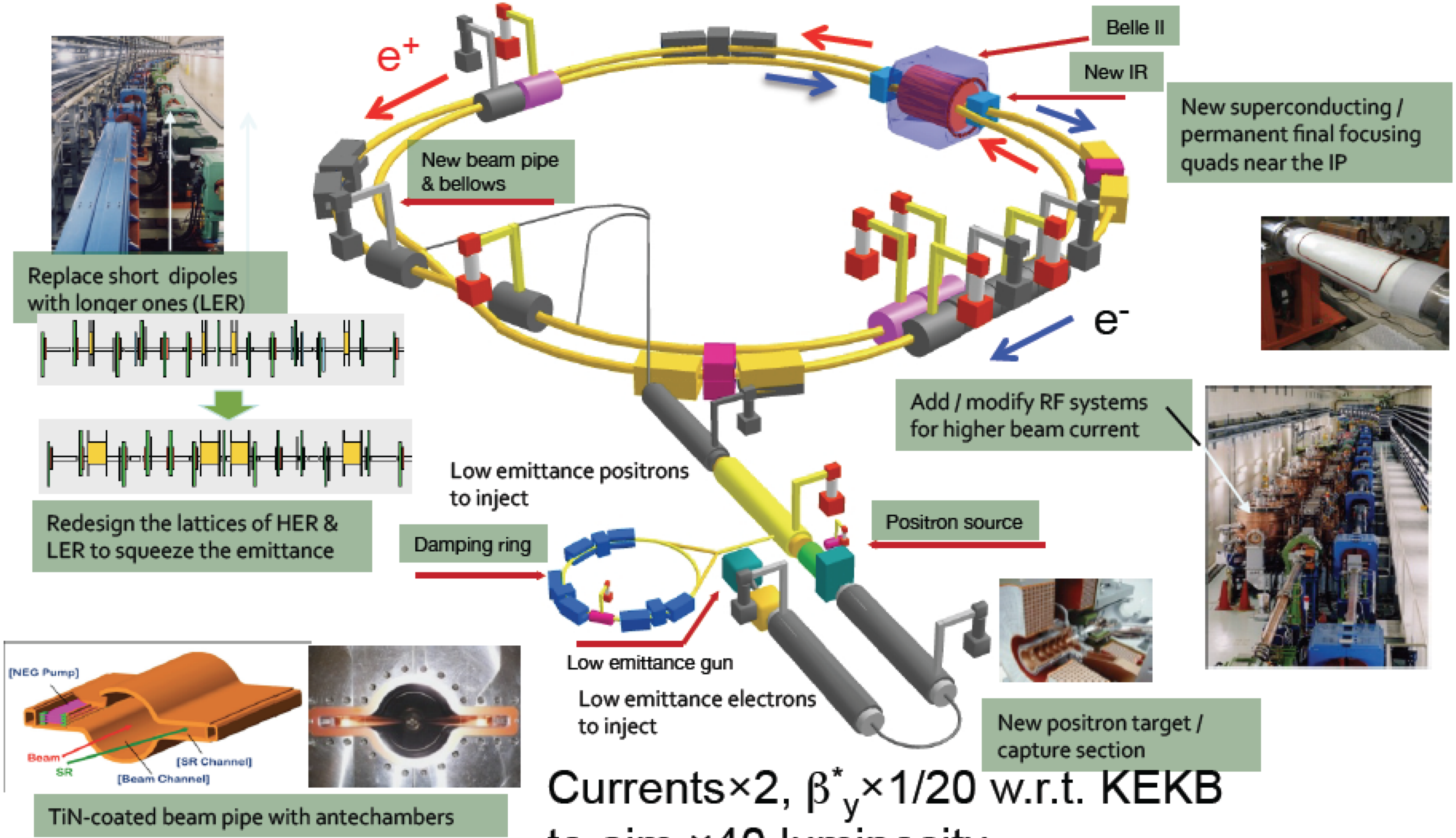


SuperKEKB

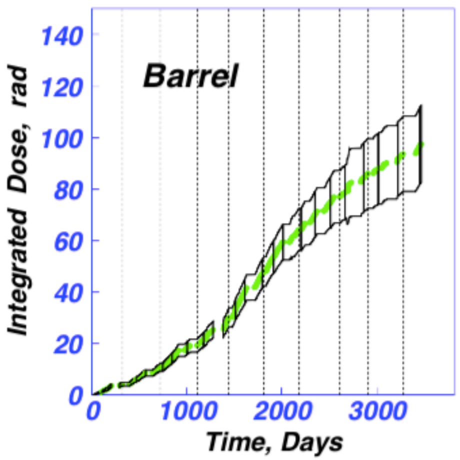


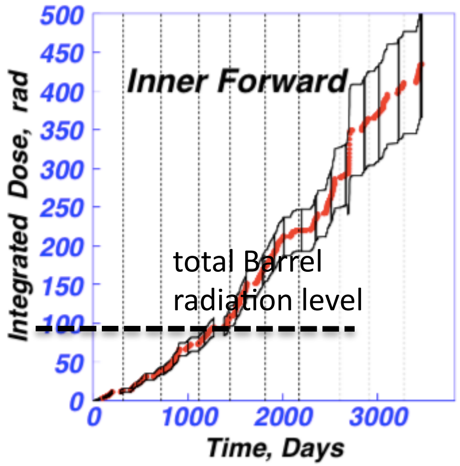
Currents×2, β^*_y×1/20 w.r.t. KEKB
to aim ×40 luminosity

See P. Krizan's talk

ECL in view of luminosity increase

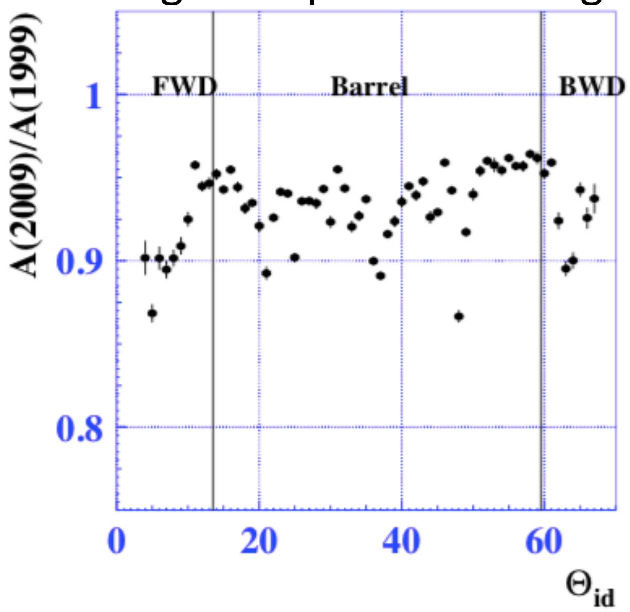
Radiation damage of crystals after BELLE (1 ab^{-1})





Expected dose in crystal @ Belle-II FWD ECL: 5-6 Gy/yr x 10 yr of data taking → a factor of 13 higher than in BELLE

Light output decreasing

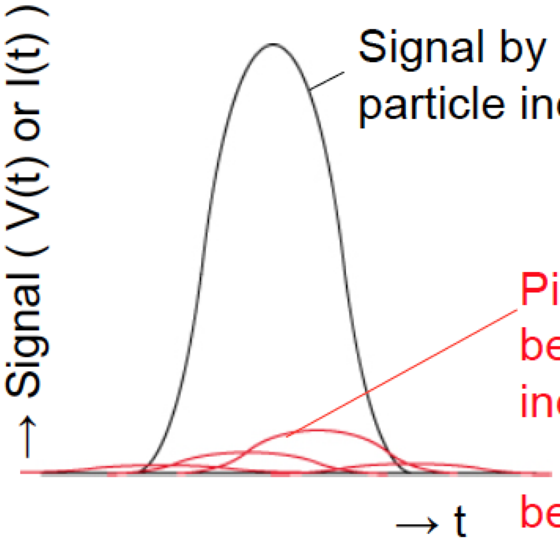


In the most loaded part the light output degradation is about 10%

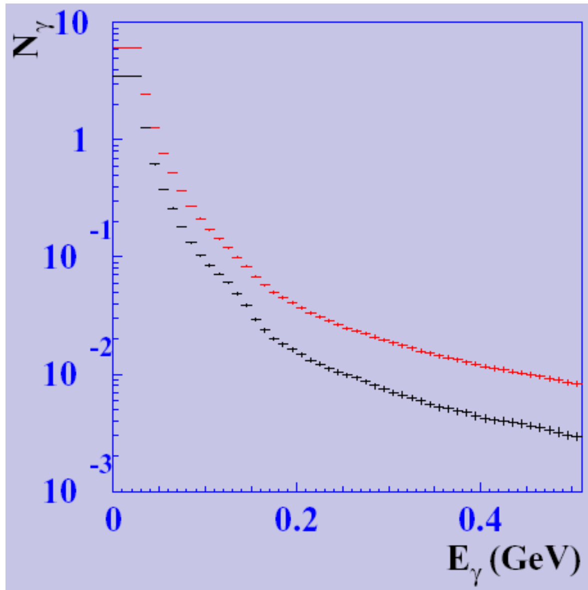
See D.Matvienko's poster

Background increase: pile-up effect

Scintillation decay time is ~1μs



Fake clusters



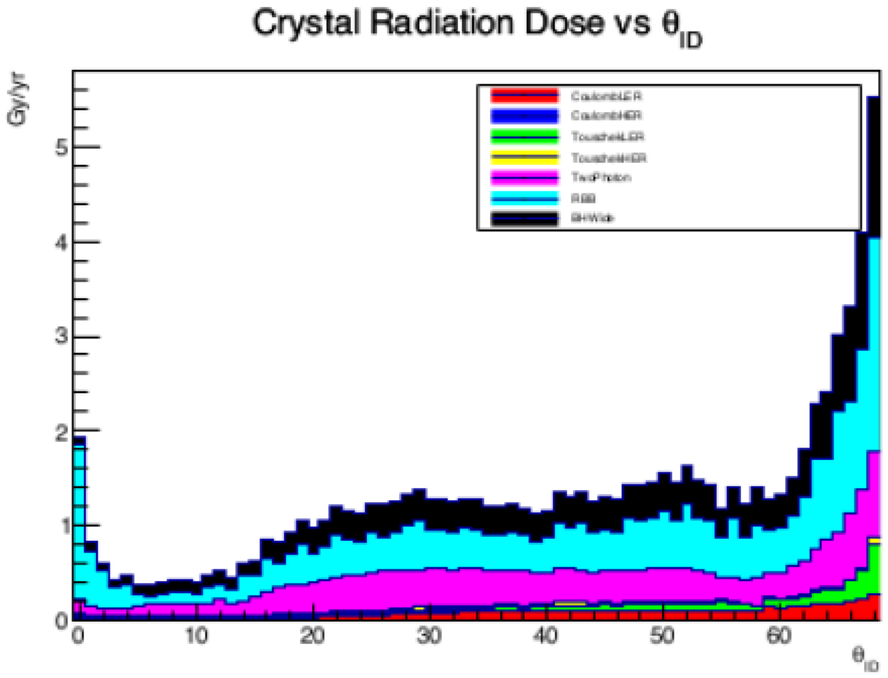
(E>20 MeV) 6 fake clusters, 3 in barrel 3 in endcaps background

CsI(Tl):

- very high light output 😃
- very slow device 😔

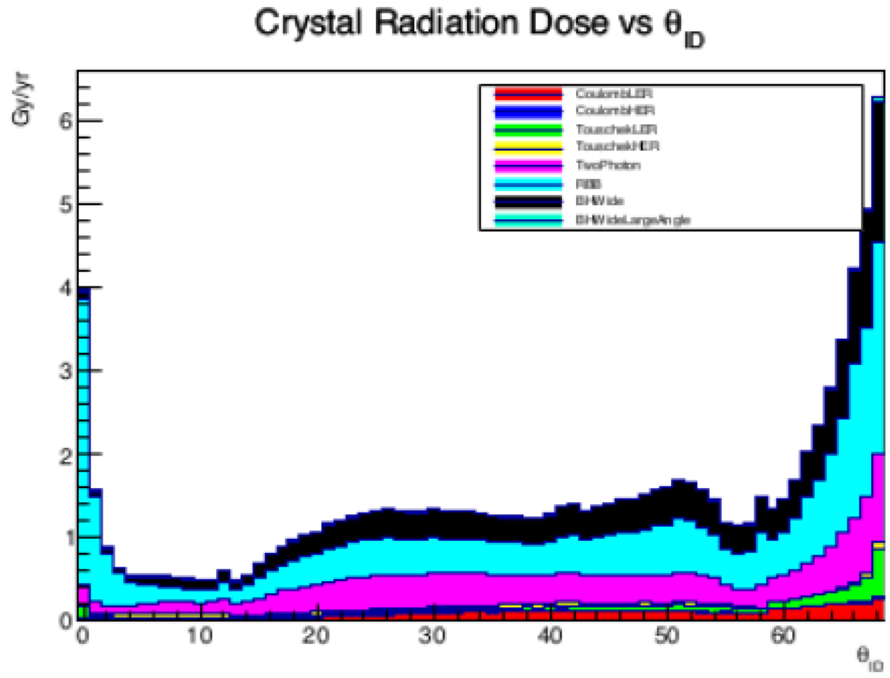
Need a fast and rad-hard detector

Background MC campaign



14.5th campaign

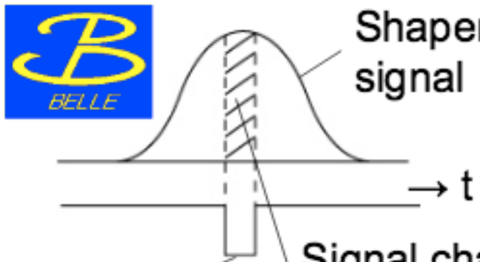
maximum dose: 5.52 Gy/yr



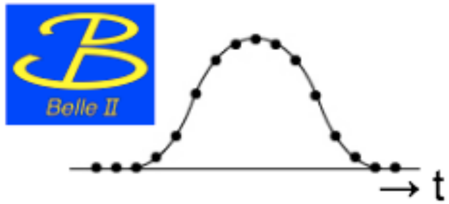
15th campaign

maximum dose: 6.27 Gy/yr

Read-out electronic upgrade

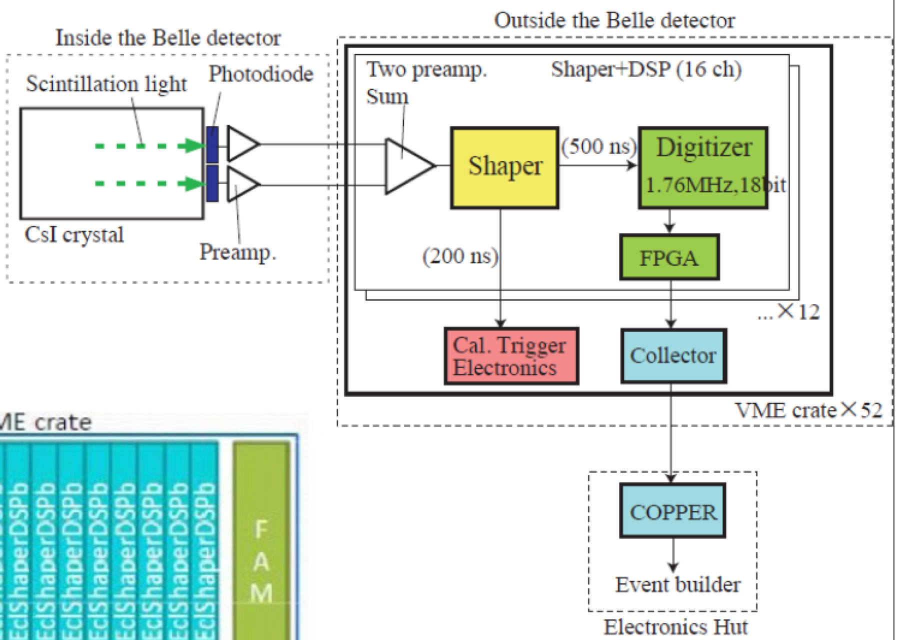


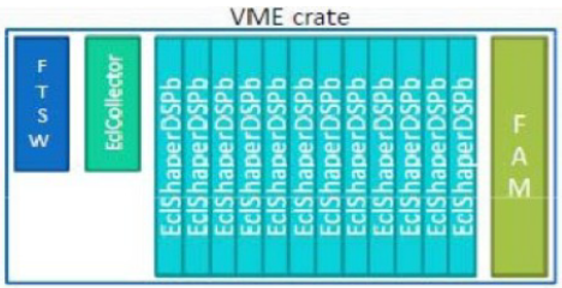
Signal charge
↓
Timing (leading/trailing edges) with range information by QtoT converter (MQT300A)
↓
Digitized by TDC



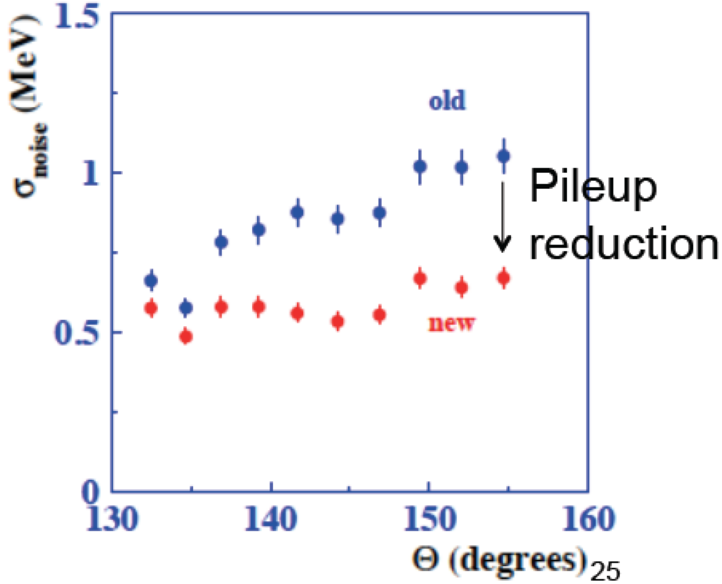
1.76MHz, 18bits digitizer, waveform fit to get energy and timing (i.e. Digital Signal Processing)

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

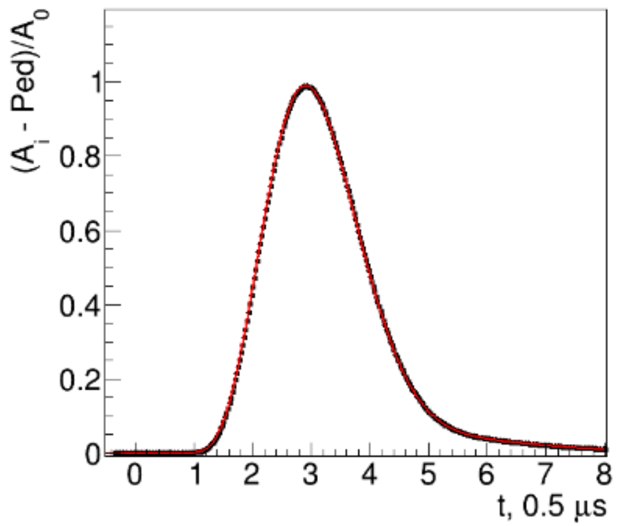


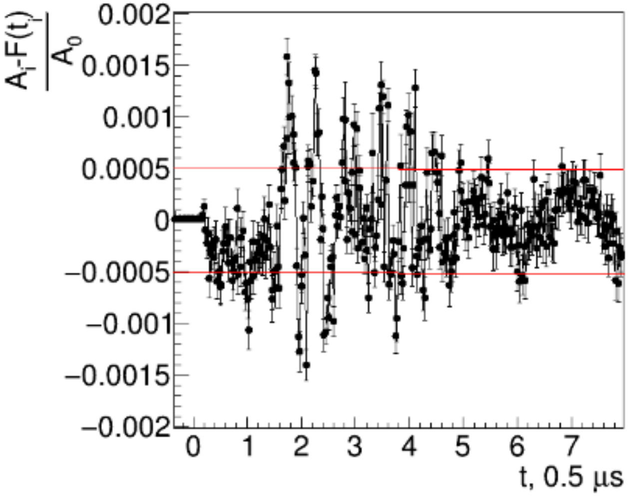


EARLY PROTOTYPE TESTED AT BELLE

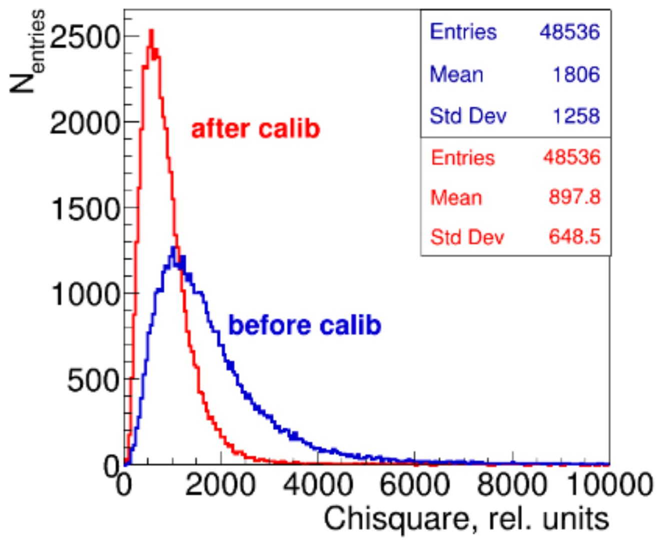


ECL pulse-shape calibration





- First calibration with very preliminary start coefficients is done by about 130 iterations and takes about 30 min. The next calibrations take about 10 min.
- Whole calibration time (including data taking and copying raw files to KEKCC) takes about 1.5 days.



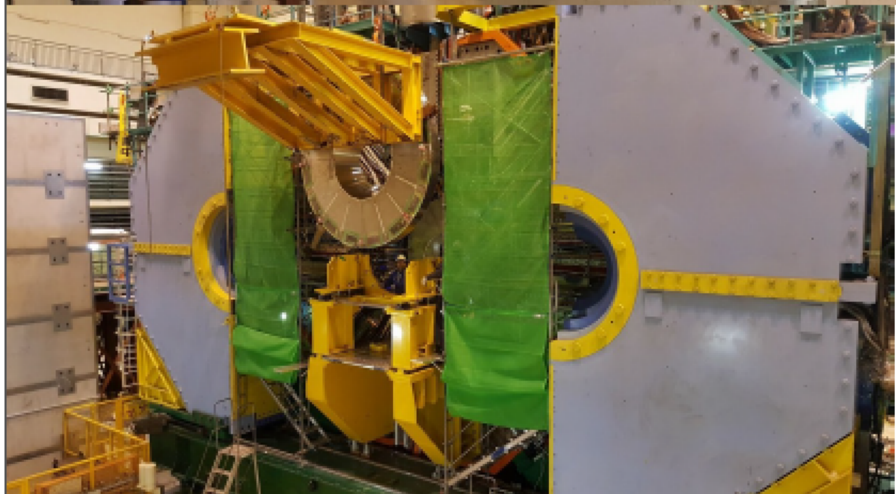
See A.Bobrov's poster

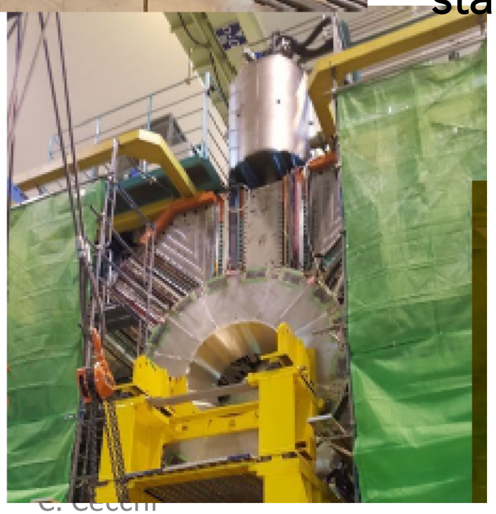
Endcap Installation

Endcap tested before and after installation → all channels working and all DSP shapers

FWD Endcap installation September 2017

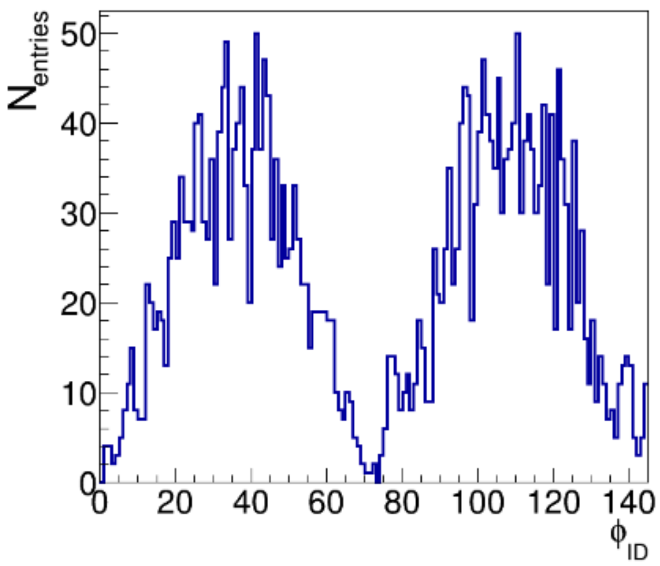
Barrel and Backward are being monitored and calibrated (barrel) → stability 10^{-3}

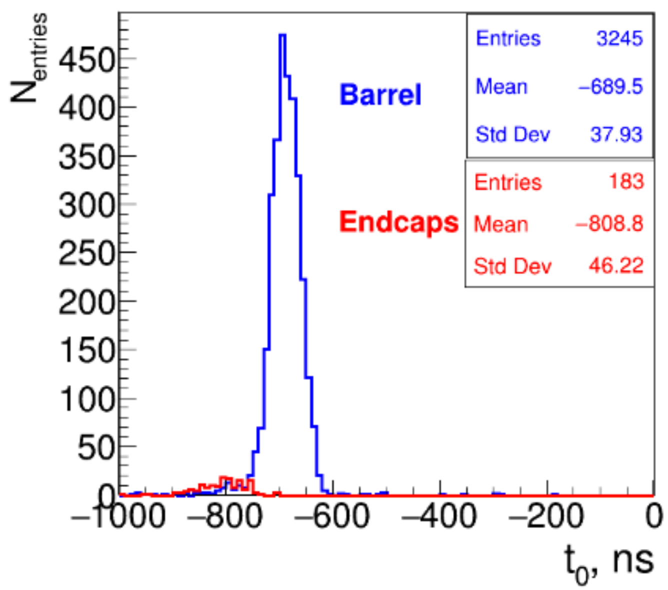


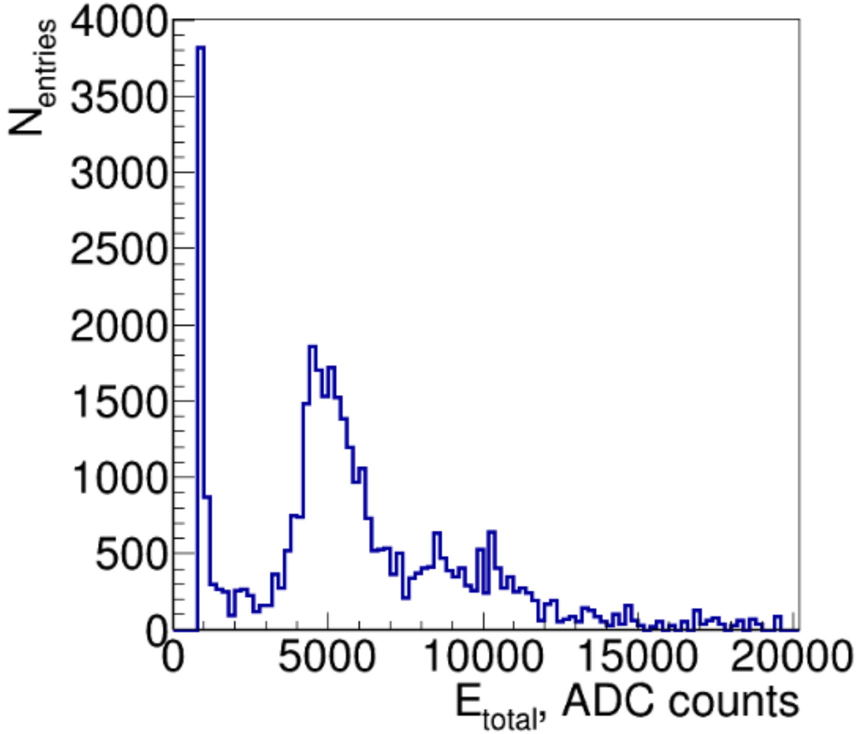


ECL cosmic test

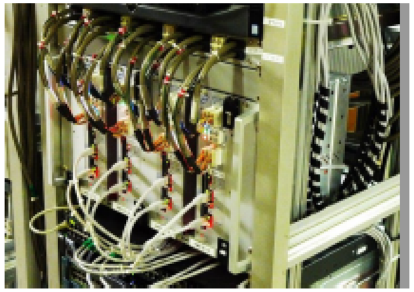
- CDC-ECL cosmic run was performed Feb. 2 2017
- Short runs with total statistic of about 4000 events
- ECL distributions seems to be reasonable

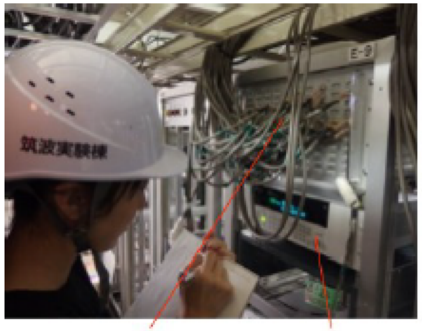


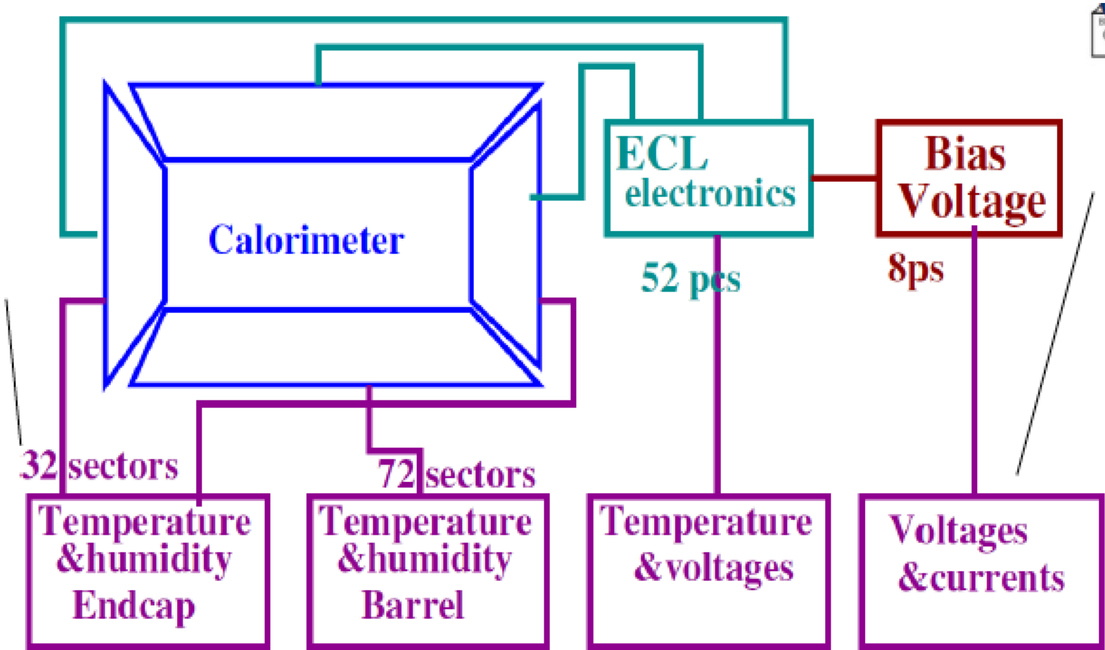


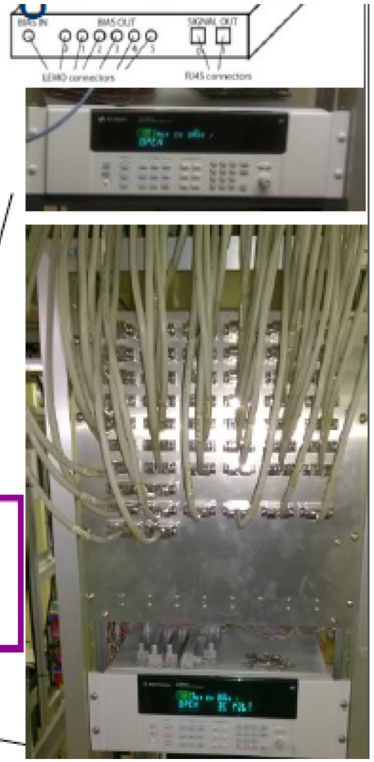


Environment monitoring

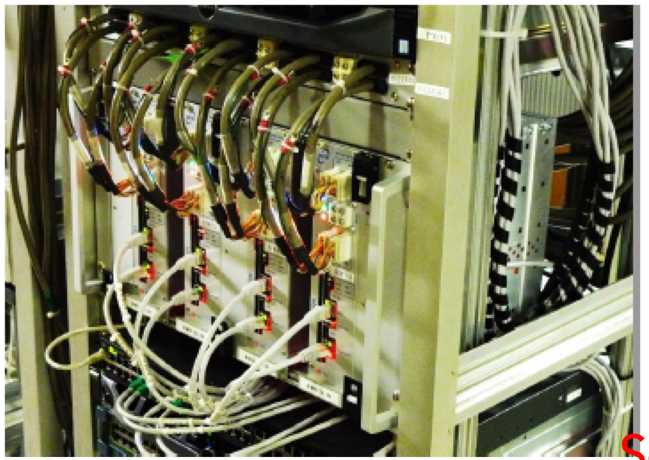






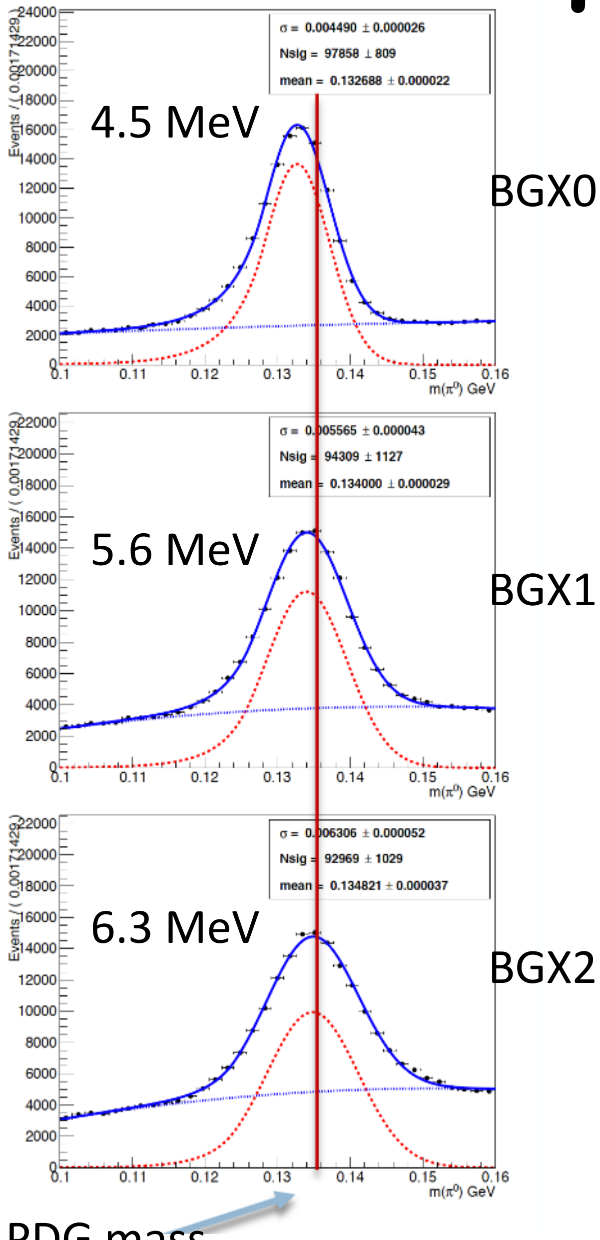


Connector box Data Logger

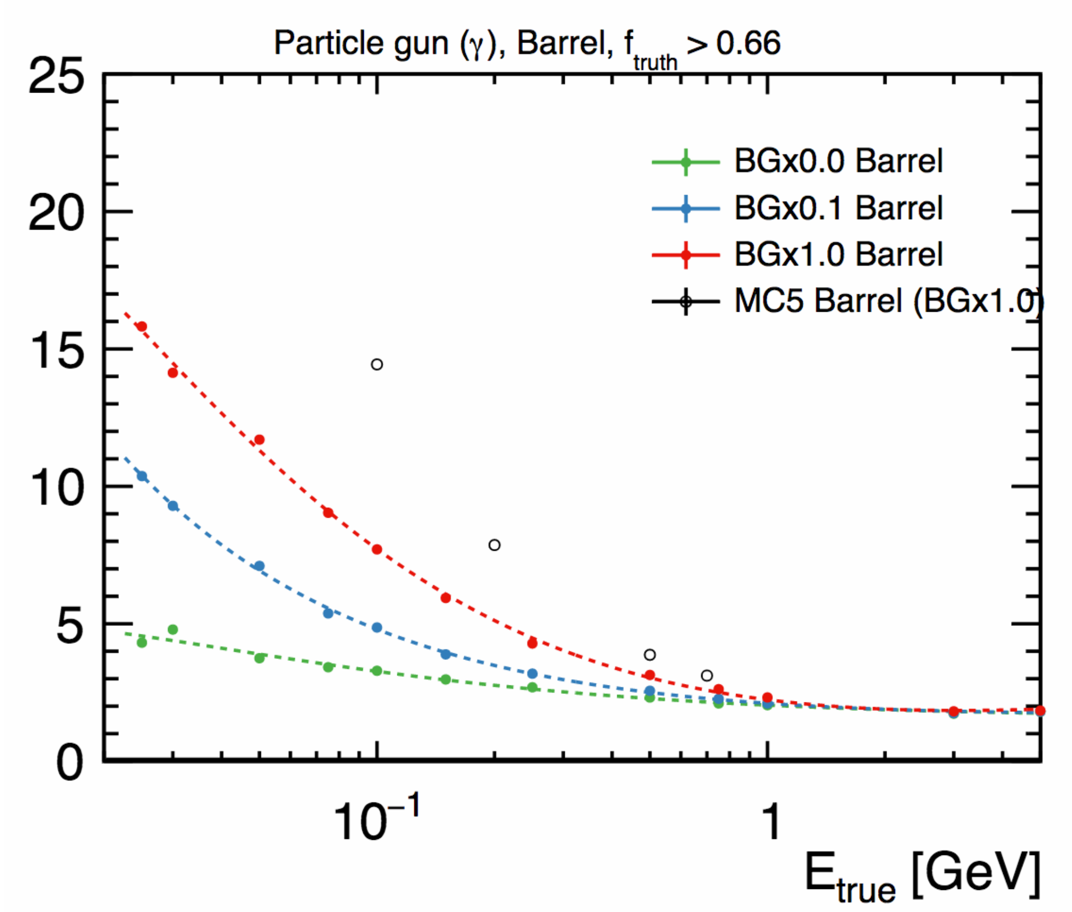


See F. Di Capua's talk

New ECL reconstruction



Written from scratch and optimized for different backgrounds



FWD Endcap Upgrade pure CsI

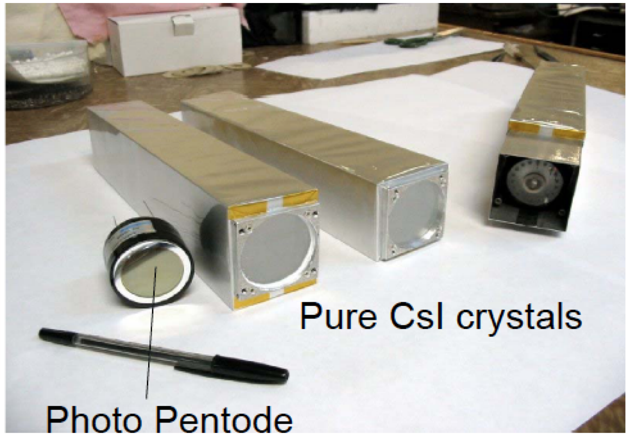
Electronics upgrade may not be sufficient for the forward endcap

Crystal	CsI(Tl)	CsI
Density (g/cm^3)	4.51	4.51
Melting Point (°CC)	621	621
Radiation Length (cm)	1.86	1.86
Molière Radius (cm)	3.57	3.57
Interaction Length (cm)	39.3	39.3
Refractive Index[a]	1.79	1.95
Hygroscopicity	Slight	Slight
Luminescence[b] (nm)	560	420
(at Peak)		310
Decay Time[b] (ns)	1220	30
		6
Light Yield[b,c]	165	3.6
		1.1
d(LY)/dT[b,d] (%/°CC)	0.4	−1.4

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.

- same density and radiation length allow to reuse Belle mechanical structure

- much lower light yield
  - fast component of emitted light in the near-UV region
- much faster light decay time
  - but slow component is an issue for pile-up

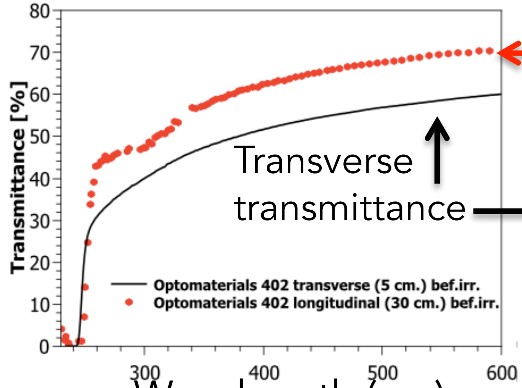


- Use of Pure CsI requires R&D studies on:
  - photodetectors in the near-UV and wavelength shifters
  - radiation hardness of crystals, photodetectors, and wavelength shifters
  - electronics

Pure CsI optical properties: transmittance

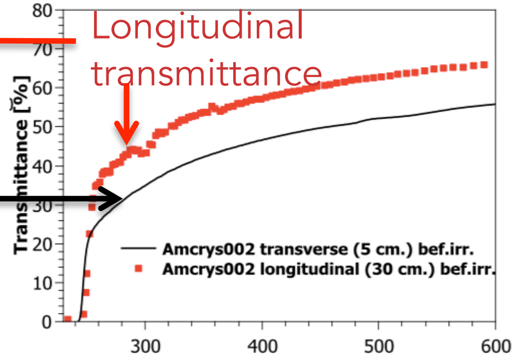
- No irradiation
- @ 310 nm: L.T. ~ 50%, T.T. ~ 40% for Optomaterials, lower for Amcrys

Optomaterials (Italy), 5x5x30 cm^3



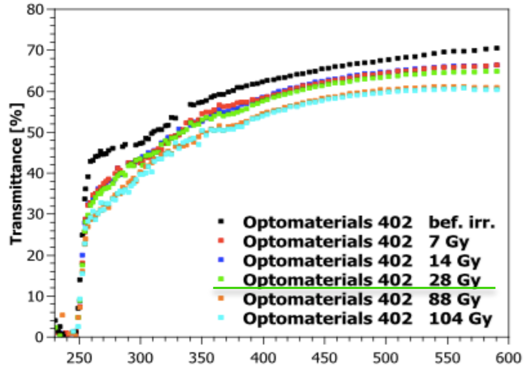
Wavelength (nm)

Amcrys (Karchov, Ukraine), trapezoidal shape, ~7.5x7.5x30 cm^3

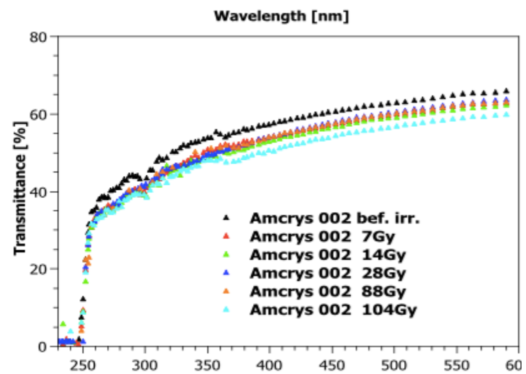


Wavelength (nm)

- Transverse transmittance at different irradiated doses (7 to 104 Gy)
- Maximum variation @ 310 nm ~ -7%
- Saturation effects
- Completed and fast recovery for doses < 7 Gy (not shown here)



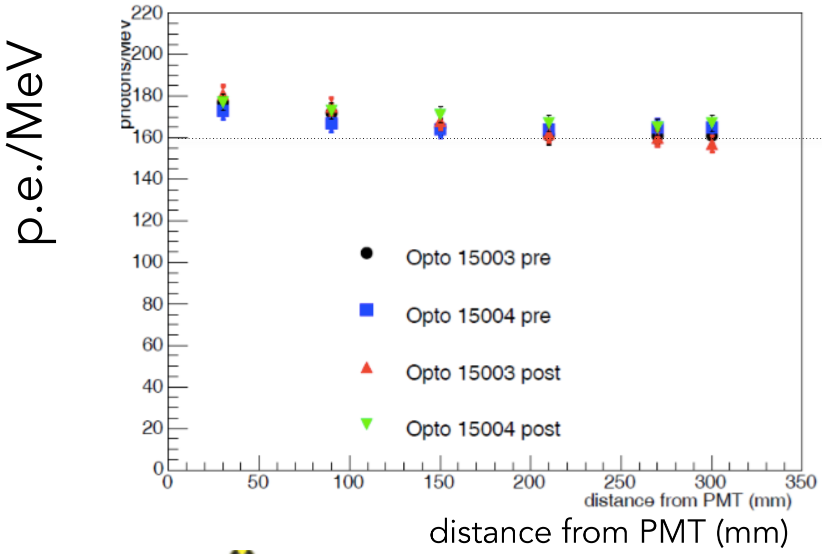
Wavelength (nm)



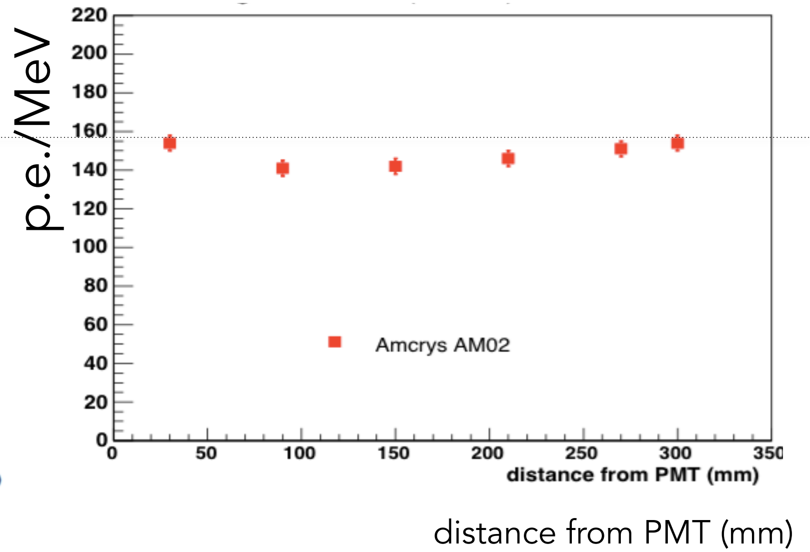
Wavelength (nm)

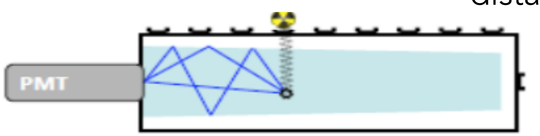
Pure CsI Optical properties: Light Yield

Optomaterials (Italy), 5x5x30 cm^3



Amcrys (Karchov, Ukraine), trapezoidal shape, ~7.5x7.5x30 cm^3





Measured without wrapping and without optical grease

- Longitudinal LY variation (Irradiated)
- before irr. : ~ 6-10%
- after irr: ~ 7-15%
- LY variation before and after irr.: ~1-5%

- No irradiation
- Longitudinal LY variation < 10%

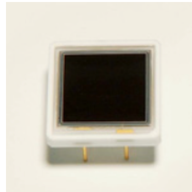
Photodetector options

Requirement: photodetector ENE < pile-up noise (O(1MeV))

Photodetector options:

Hamamatsu photonics
R11283 photopentode
Belle-II baseline

Hamamatsu
photonics
Large Area
APD
R8664-1010



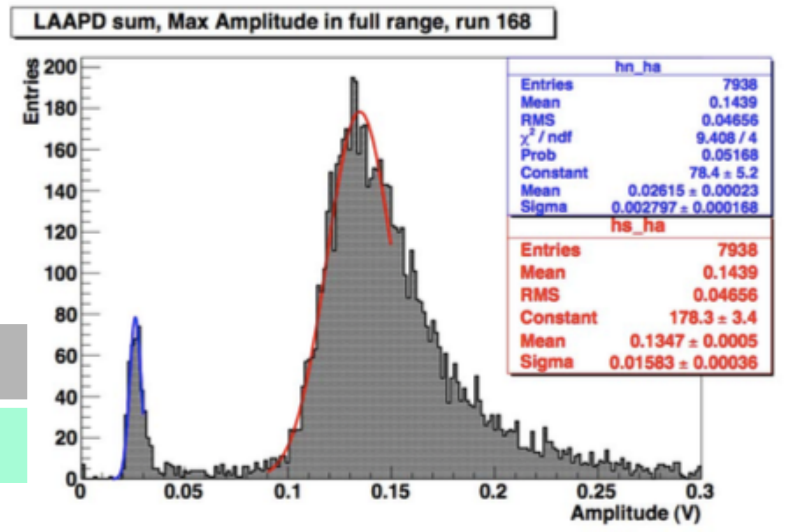
	PhotoPentodes	Large Area APD (LAAPD)
C (pF)	10	270
Gain@V_{op}	150-250 [*]	50 [**]
Q.E.@310 nm (%)	25	50
Area (cm^2)	20	10x10
Comments	• [*] gain reduced by 75% in 1.5T magnetic field • 1 PP per crystal, no redundancy • back plane of the mechanical structure need to be replaced	• [**] special production with G=200 • 2 LAAPD per crystal

R&D on LAAPD

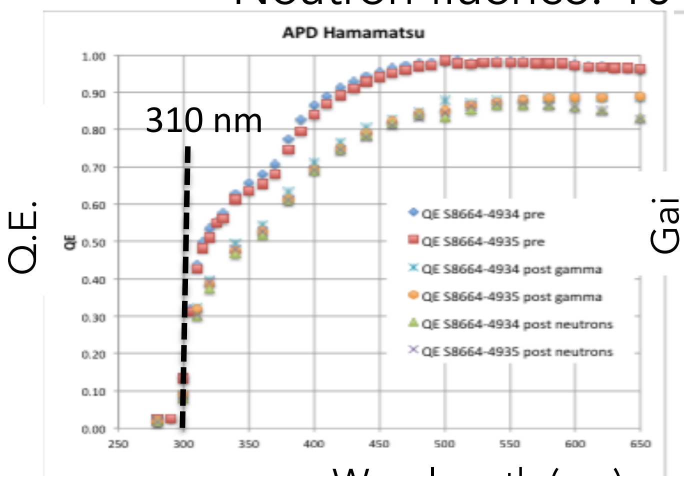
Extensive R&D has been done on Pure CsI + LAAPD

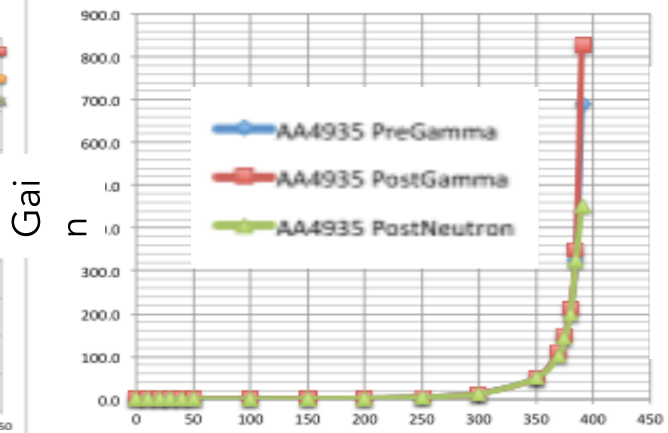
They meet the experiment requirement (ENE O(1MeV))

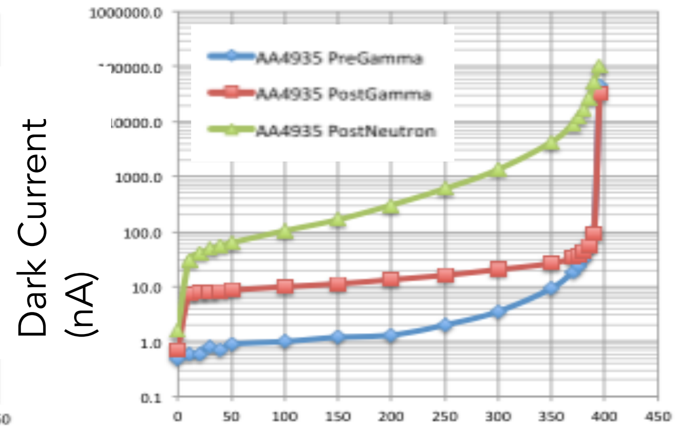
σ[mV]	Signal [mV]	S/N	ENE[MeV]
2.80±0.17	108.6±0.6	38.8±2.4	0.77±0.05



- Study effect of ionizing and non-ionizing radiation:
  - gamma: 250 Gy = 10 y data taking x ~10 safety factor
  - Neutron fluence: 10^{12} n/cm^2 = 10 y data taking x 5 safety factor







Quantum efficiency:

- Decrease after irradiation with γ at 250 Gy

Gain:

- almost stable

C. Cecchi

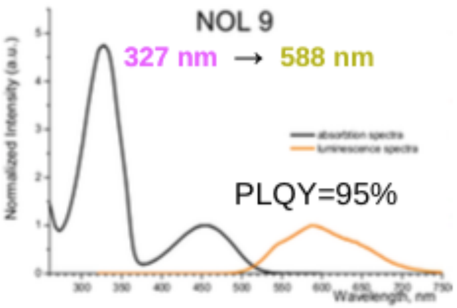
Dark current

- 2 orders of magnitude increase after neutrons + gamma

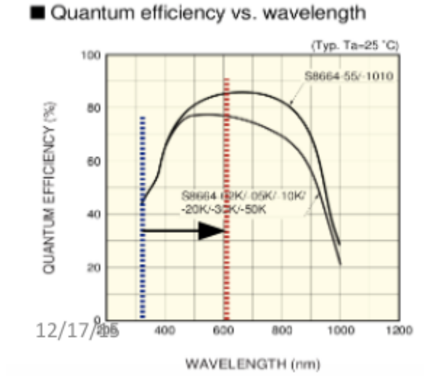
R&D on Wavelength Shifters

- Novel wavelength (WLS) plates containing nanostructured organosilicon luminophores provides essential increase in light output

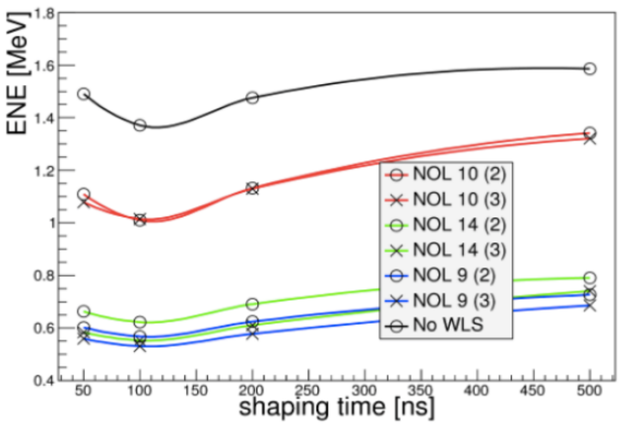
LuminoTech Co, (60x60x2 mm^3) WLS plates



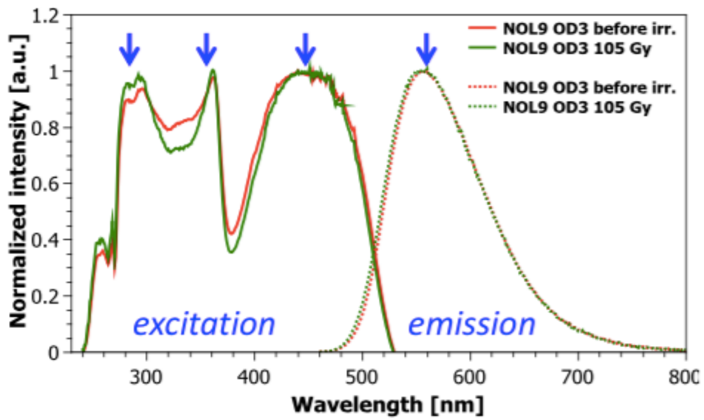
Increase in LAAPD Q.E. of a factor of 2-3



- Results:



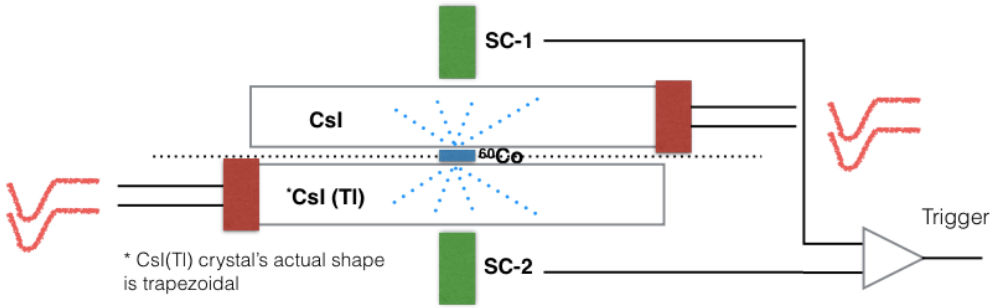
Enhancement on signal of a factor of about 3 (n.b. test performed with G=50 LAAPD)



Radiation hardness tests on NOL9 WLS: no irradiation effects on excitation/emission peaks up to 105 Gy

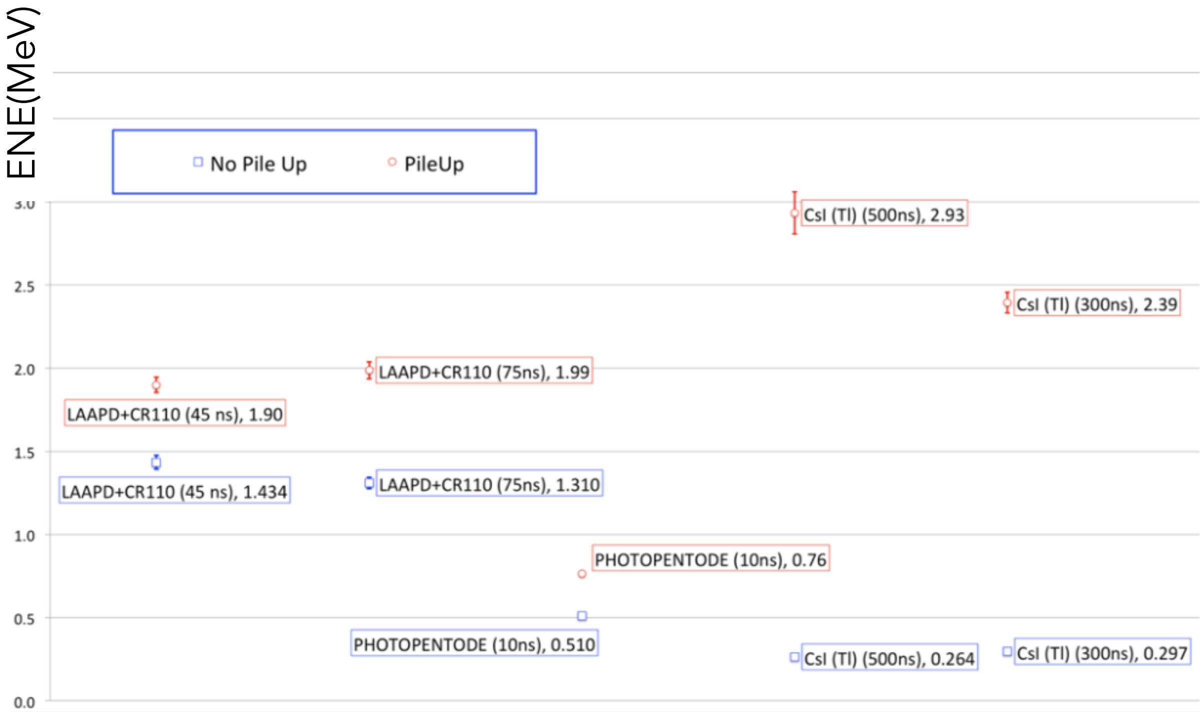
Pile-up study: cosmic+source

- Signal from cosmic rays superimposed to 1.33 and 1.17 MeV g produced by ^{60}Co
  - 1.77±0.04 hits/μsec from source



- From the difference in quadrature of the meas. with and without source, pile-up effect can be estimated: CsI(Tl) shows twice the ENE of pure CsI

- [nb: wrt to pag 12 (ENE=0.77MeV), different shaping times and signal window used, optimization of such parameters underway]



The ENE with pile-up is ~**2 MeV** for pure CsI and ~**3 MeV** for CsI(Tl)

Conclusions

- Belle CsI(Tl) calorimeter successfully operated for 10 years to bring various physics output

- SuperKEKB is aiming x40 luminosity w.r.t. KEKB.
  - Beam background control is a challenge for the detector and its performances

    Use all the existent CsI(Tl) with waveform sampling readout electronics.

    Full simulation studies for CsI(Tl) deterioration → new reconstruction algorithm

- PureCsI upgrade
  - Extensive R&D on crystals and photodetectors shows that the upgrade represents an improvement in dealing with beam background and pile-up
  - a real estimation of the background is necessary before the decision is taken → after the first run of BelleII for the background measurement