



Electromagnetic calorimeter of BelleII

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BINP/NSU

- SuperKEKB and Belle II
- Calorimeter upgrade
- Energy reconstruction
- Preliminary results from first beam data
- Summary

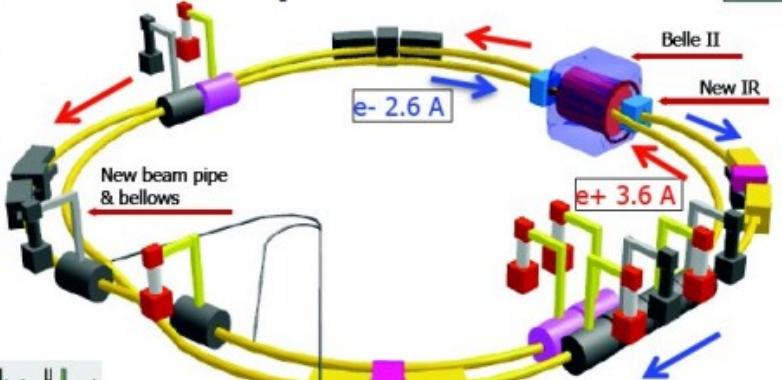
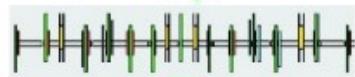
Super KEKB

KEKB

Grey is recycled, coloured is new



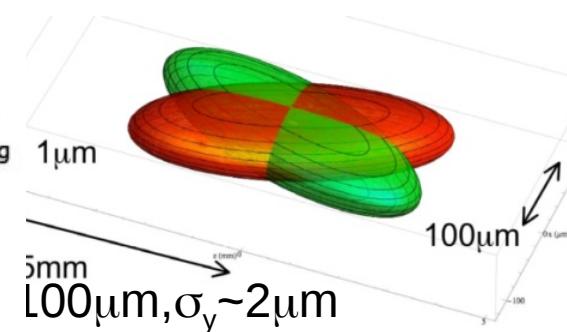
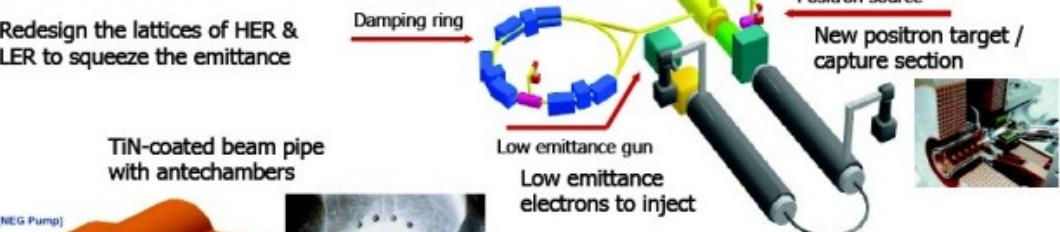
Replace short dipoles
with longer ones (LER)



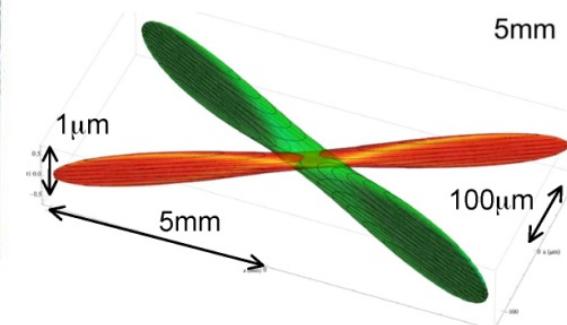
Redesign the lattices of HER &
LER to squeeze the emittance



Low emittance positrons to inject



Nano-Beam SuperKEKB



Almost entirely new machine! $\sim 10 \mu\text{m}, \sigma_y \sim 60 \text{ nm}$

	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	ϕ (mrad)	I (A) LER/HER	L ($\text{cm}^{-2}\text{s}^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

Belle II Detector

EM Calorimeter:

CsI(Tl), waveform sampling
electronics (barrel)
(Pure CsI + waveform
sampling (end-caps) optional)

electrons (7GeV)

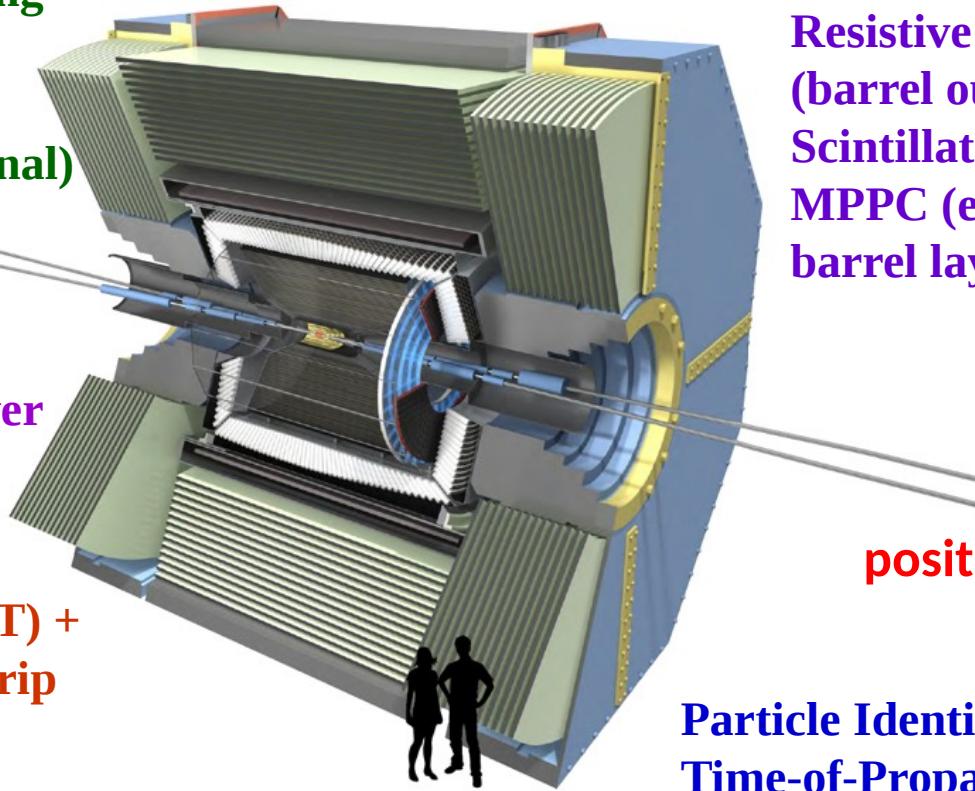
Central Drift Chamber

Smaller cell size, long lever
arm

Vertex Detector

2 layers Si Pixels (DEPFET) +
4 layers Si double-sided strip
DSSD

- + New software, improved tracking, ...
- + Optimization for low multiplicity trigger
- + Improved simulation, generators and GRID



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

positrons (4GeV)

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

Main tasks of the calorimeter

-Measurement energy, time and angles of the photons (30 MeV -7 GeV)

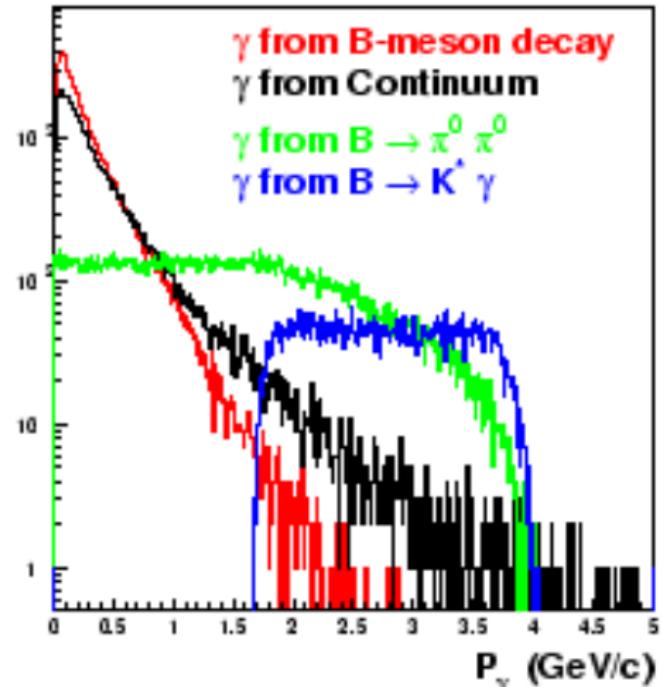
-electron identifcation

- K_L identification

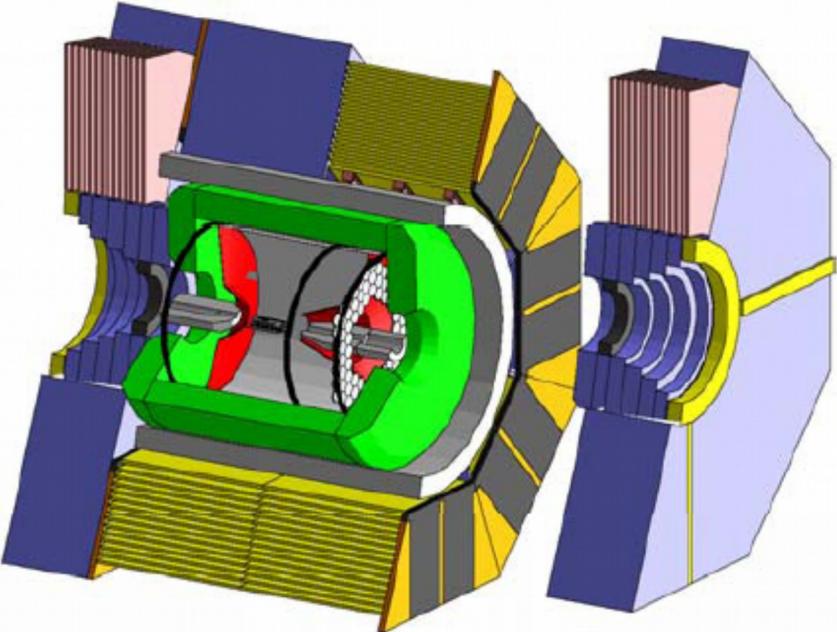
-Neutral trigger

-On-line luminosity measurement

Calorimeter should show good performance in high background environment



ECL



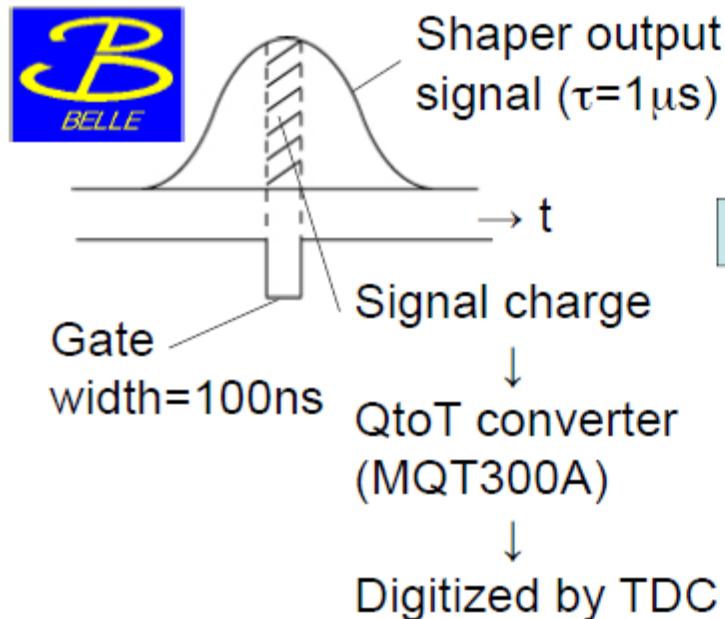
- Total 8736 counters.
- Barrel 6624
- Forward end cap 1152
- Backward end cap 960

Counter:

- 30cm long CsI(Tl) (16.1X0)
- 2x 2cm² PIN diodes
- 2 preamplifiers

- 
- Belle calorimeter worked for ten years – all counters are alive!
 - Crystals, PINs and preamplifiers are kept from Belle
 - Shaping and digitizing electronics was upgraded

Readout electronics change



Shaper output ($\tau=0.5\mu s$)

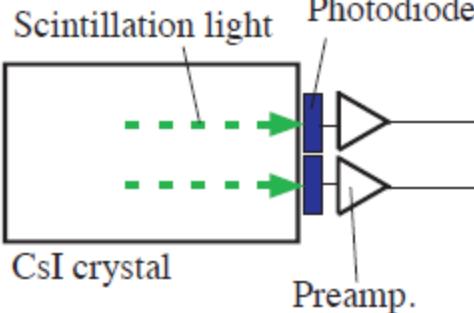
1.76MHz, 18bits digitizer

waveform fit to get energy and timing (i.e. Digital Signal Processing) by FPGA

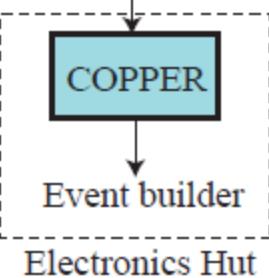
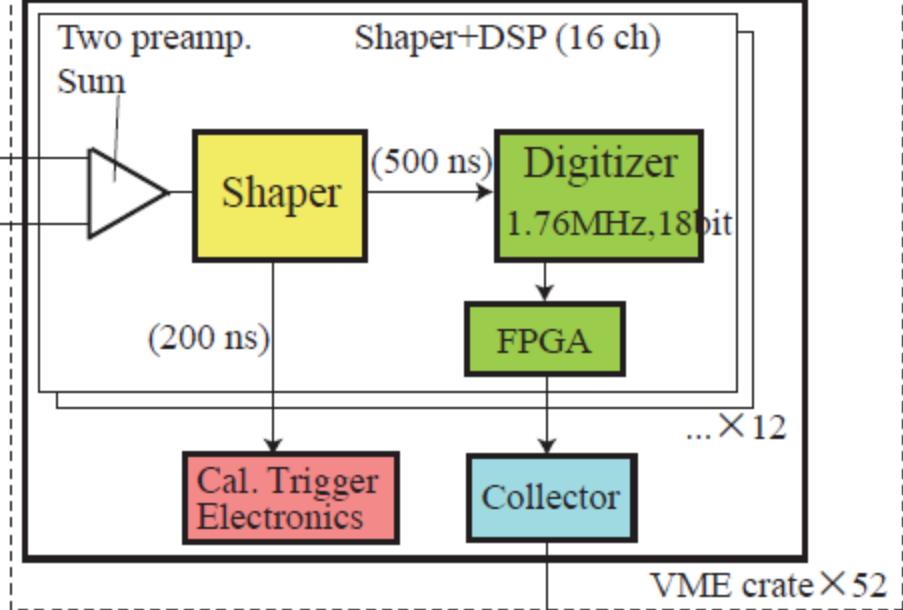
New electronics for CsI(Tl)



Inside the Belle detector



Outside the Belle detector



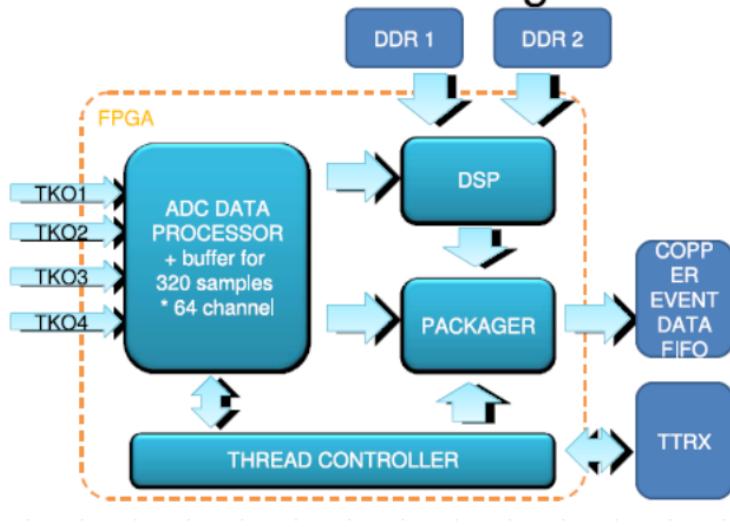
- 9U VME module
- 16 channels/per module
- Shaping (0.5mks), digitizing, WFA
- Output A, T, Q orland digitized shape
- Fast sum signal for trigger

- Storage and loading of the coefficient arrays to the shaper-dsp-modules.
- Getting of the trigger and collection of data from shapers, packing and sending data to DAQ.
- Test pulses generation.

Fit algorithm in FPGA

- Trigger → fit 16 points to response function taking into account correlations
- Result A(18 bits), T(12 bits), Q – quality of fit (2 bits)
- For some fraction of data both input and output information are sent to DAQ

FPGA overall design

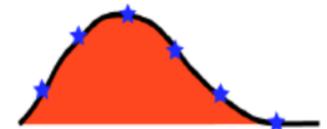


Algorithm details

$$\chi^2(A, p, t_0) = \sum_{i,j} (y_i - Af(t_i - t_0) - p) S_{ij}^{-1} (y_j - Af(t_j - t_0) - p) \rightarrow \min$$

$$S_{ij} = \sqrt{y_i - \bar{y}} \sqrt{y_j - \bar{y}}$$

$f(t)$ – counter response



$$Af(t_i - t_1 - \Delta t) = Af(t_i - t_1) - A\Delta t f'(t_i - t_1) = Af(t_i - t_1) + Bf'(t_i - t_1)$$

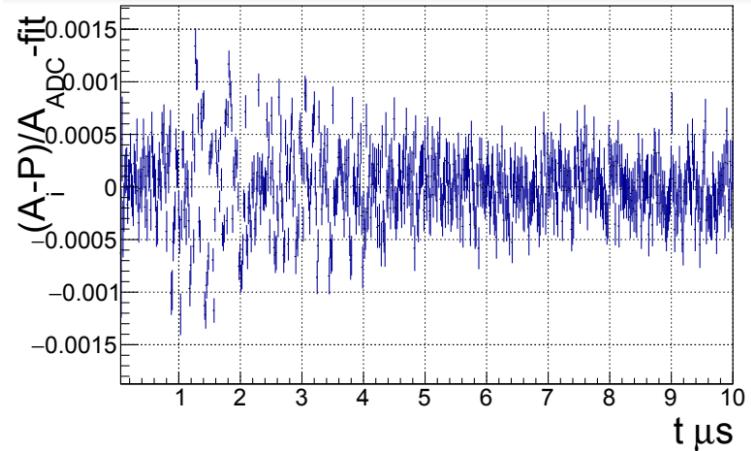
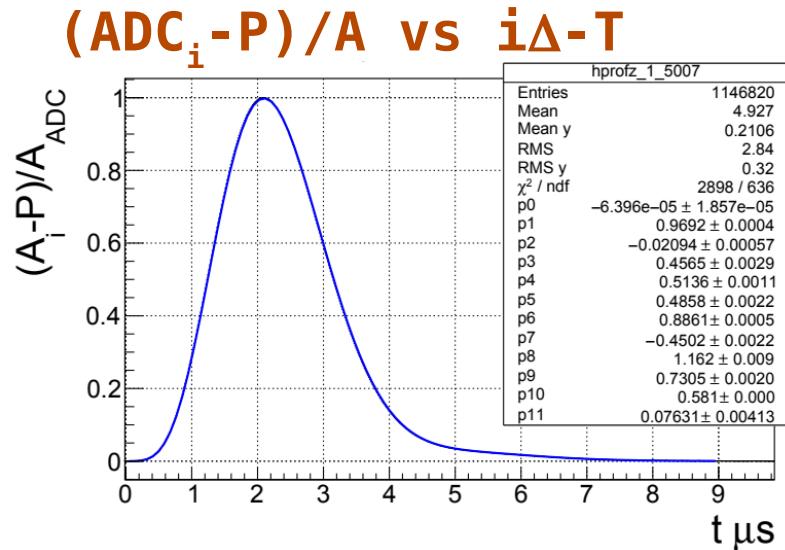
where t_1 – initial time (trigger time)

$$\left. \begin{aligned} \sum_{i,j} f_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) &= 0 \\ \sum_{i,j} f'_i S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) &= 0 \\ \sum_{i,j} S_{ij}^{-1} (y_j - Af_j - Bf'_j - p) &= 0 \end{aligned} \right\} \quad \begin{aligned} A &= \sum_i \alpha_i y_i \\ B &= \sum_i \beta_i y_i \Rightarrow \Delta t = -B/A \\ p &= \sum_i \gamma_i y_i \end{aligned}$$

- Algorithm works for more than 30 kHz of the trigger rate

Shape calibration

- Using preliminary function parameters -time(T) and amplitude(A) are reconstructed
- Estimate shape:

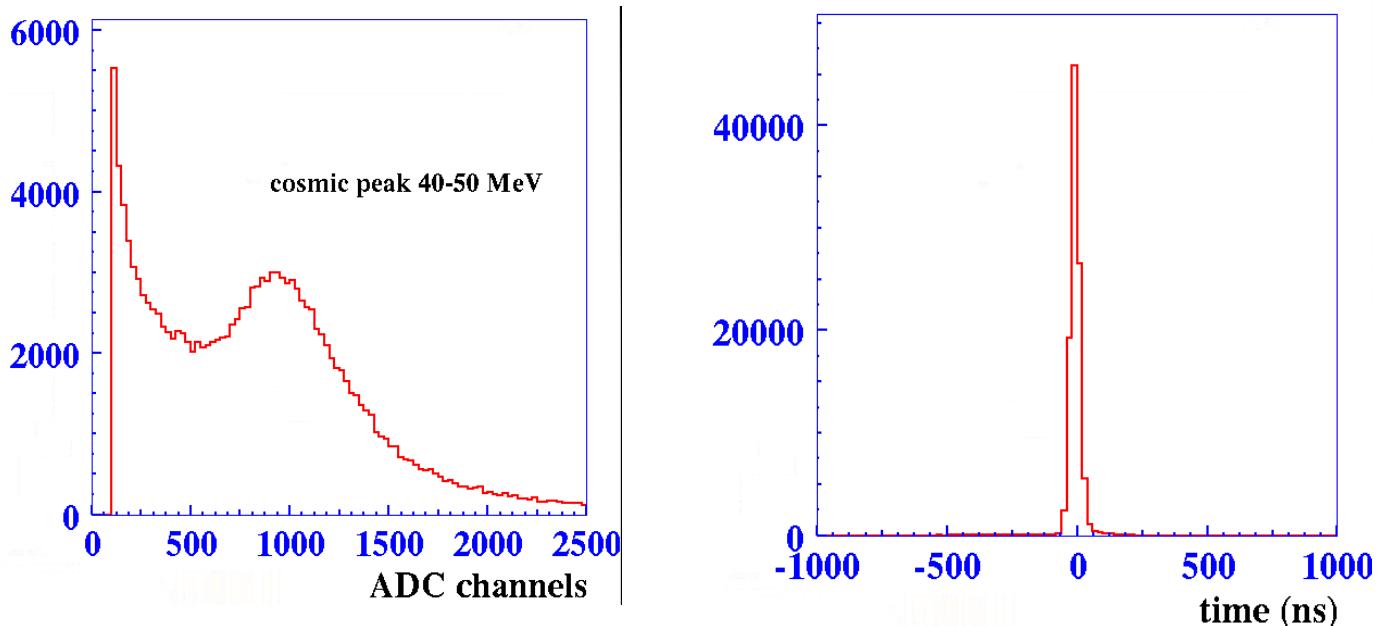


- Fit it to 12 parameter Function

- This function is used in the calorimeter electronics to reconstruct energy, time and quality of signal

Work with cosmics

- First calibration was performed with cosmics
by peak position in data and MC (systematic ~2%)



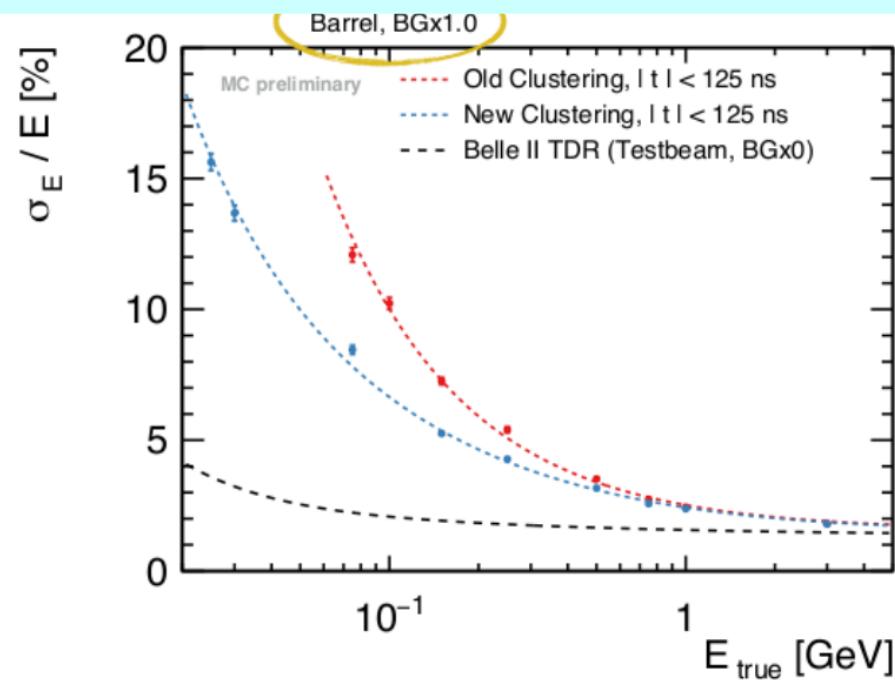
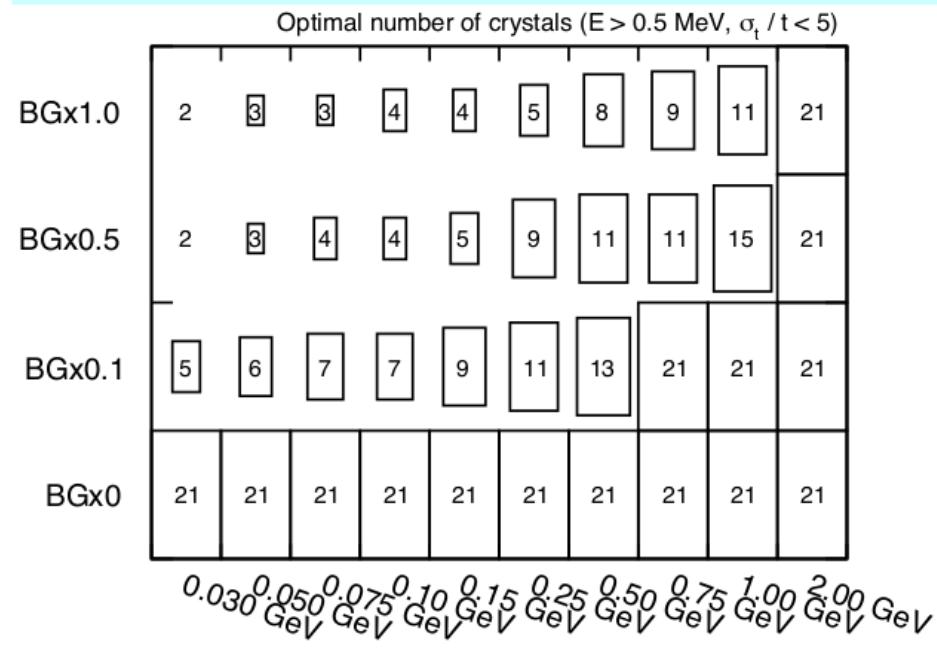
- Time information allows to reject hits from background

Cluster reconstruction

Belle 1: sum of the E_i in 5x5 matrix $E_i > 0.5$ MeV

- For the case of the large pile-up noise the Belle algorithm for cluster reconstruction is not optimal

Other approach: Sum of N most energetic hits, N depends on energy and background

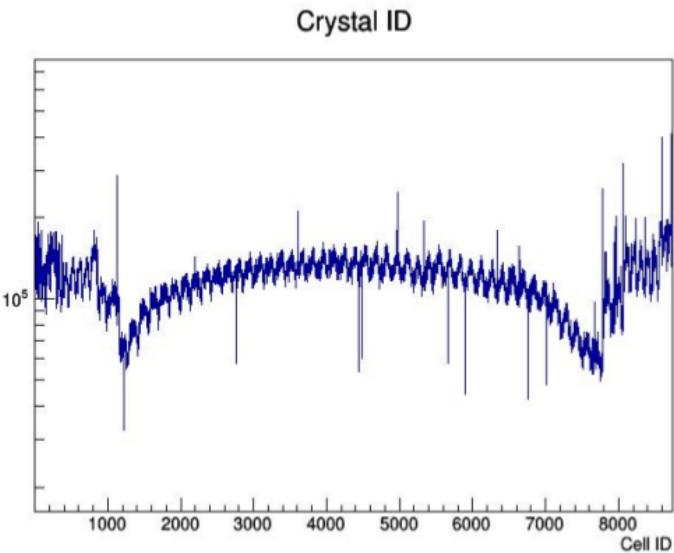


To get the photon energy: cluster energy is corrected by function depending on E, angles and the background level

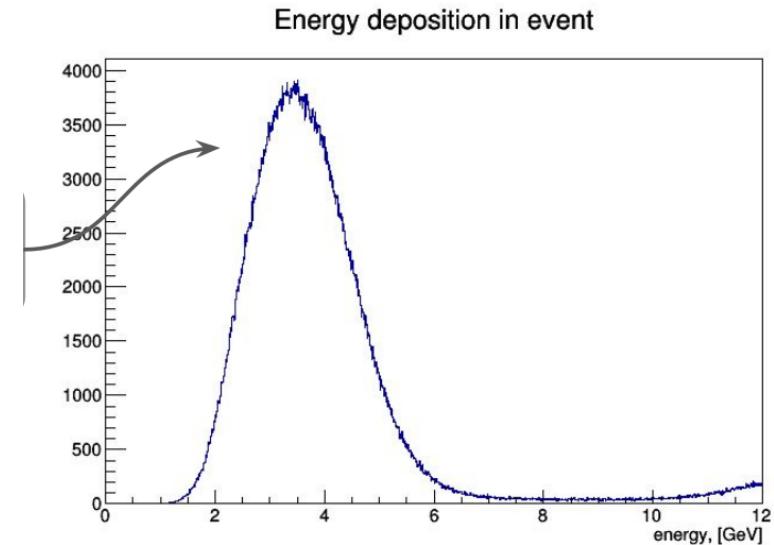
Background level is estimated from multiplicity off time events

First run at SuperKEKB

- In April 2018 the first collisions were detected at SuperKEKB
- Belle II recorded the data till July 2018 without vertex detectors
- Both barrel and endcap calorimeters were included in data taking.

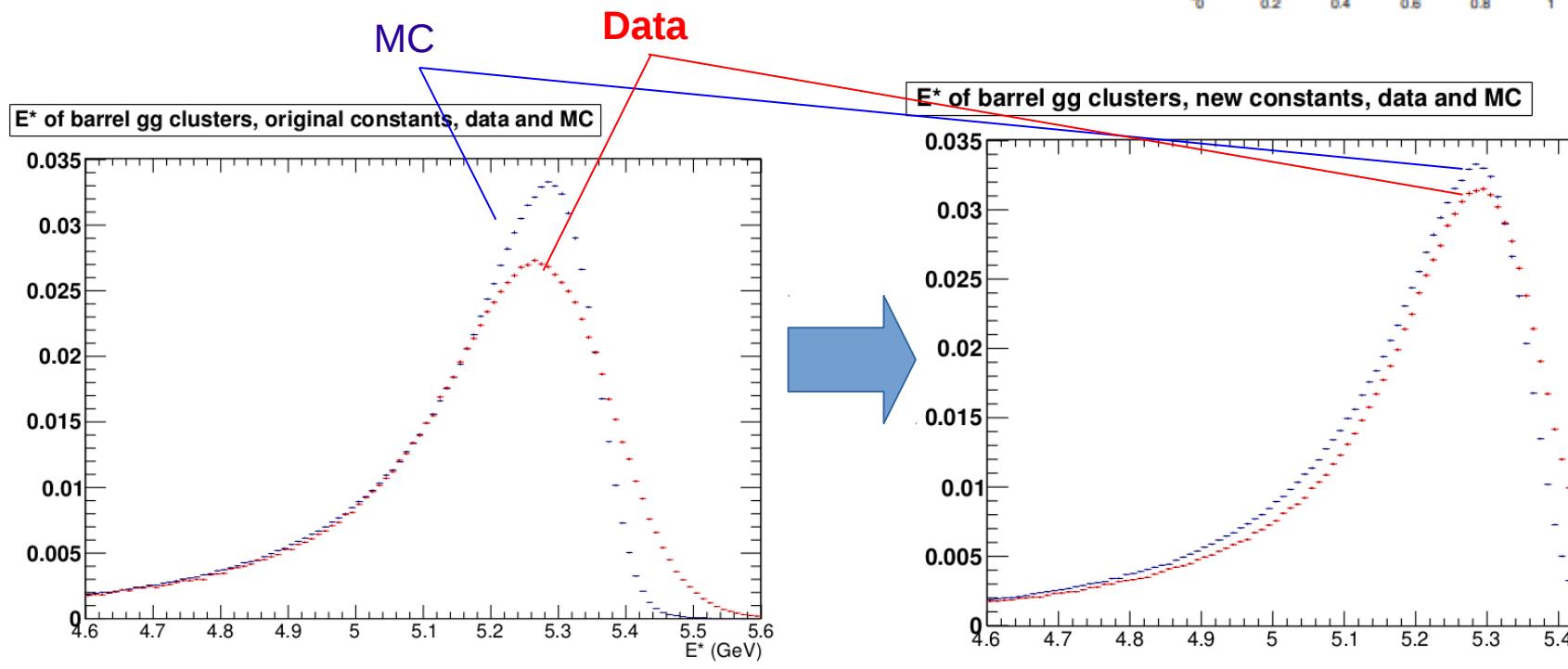
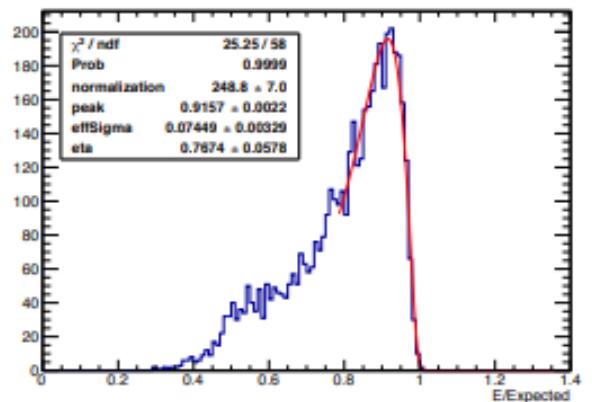


Hit occupancy map

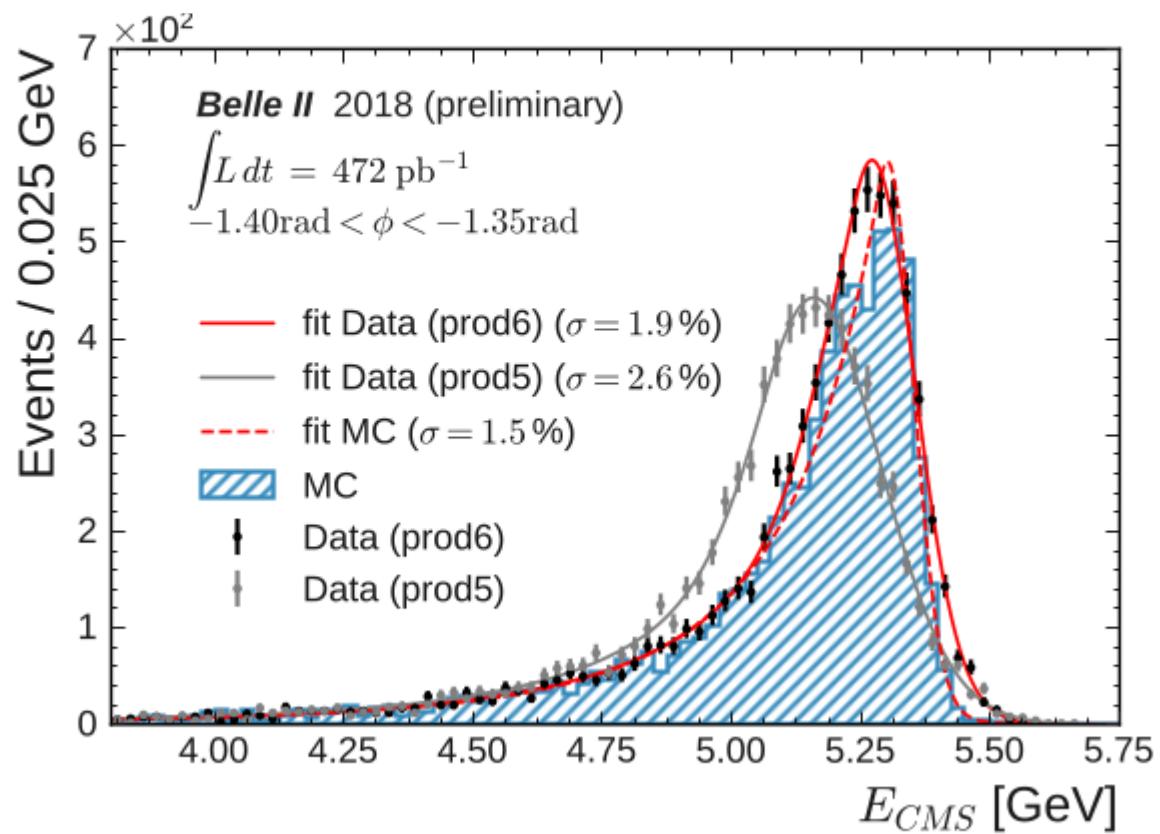


Gamma-gamma calibration

- Method compares the energy in the most energetic crystal in each photon cluster to the value predicted by MC. Energy is calculated from corresponding ECLDigit.
 - see belle2-note-te-2018-001 for details.
 - a typical uncertainty of 1.0%.

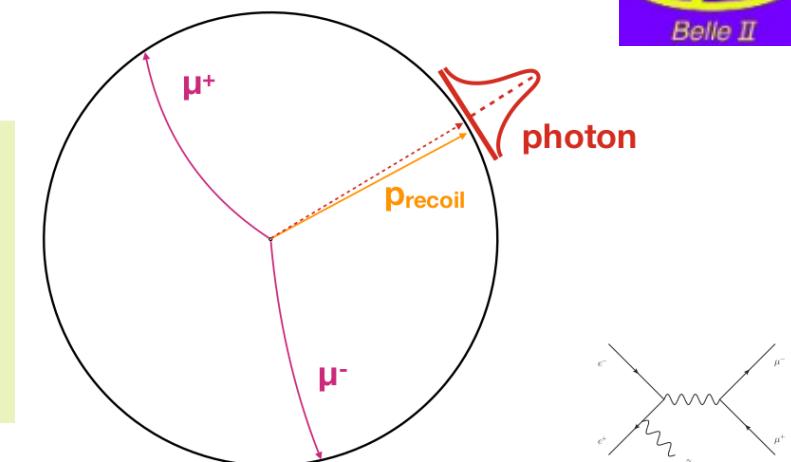


Novosibirsk fit, sum over theta.

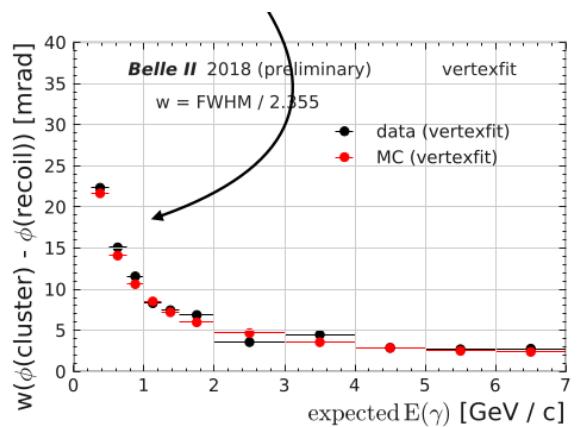
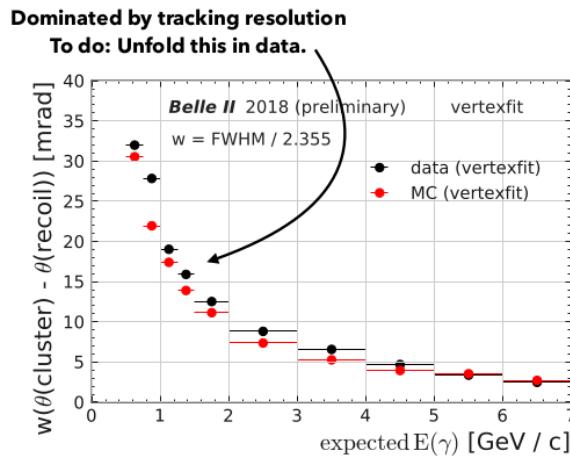
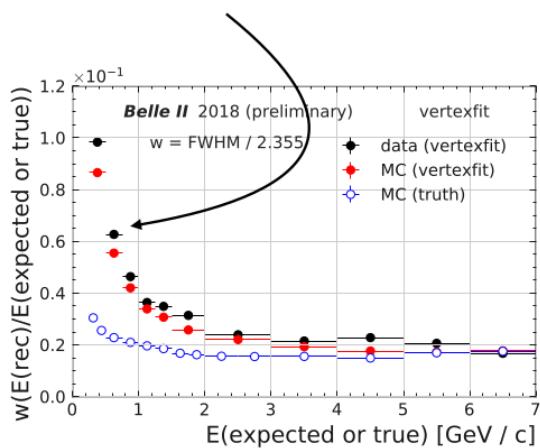


ECL study in ee->μμγ

-Energy and direction of the photon can be obtained from the kinematical reconstruction and compared with the measured values

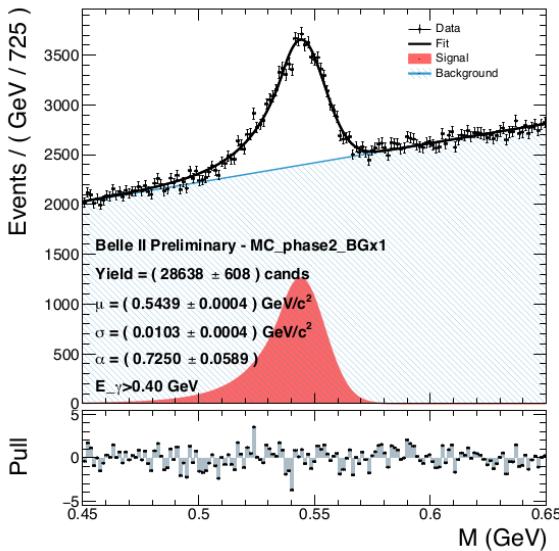
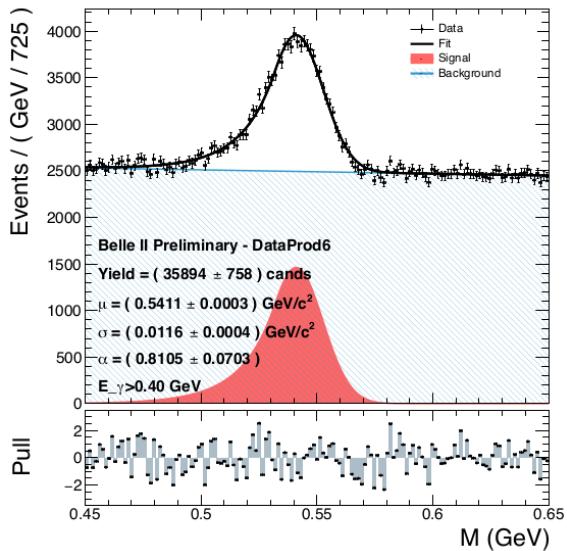
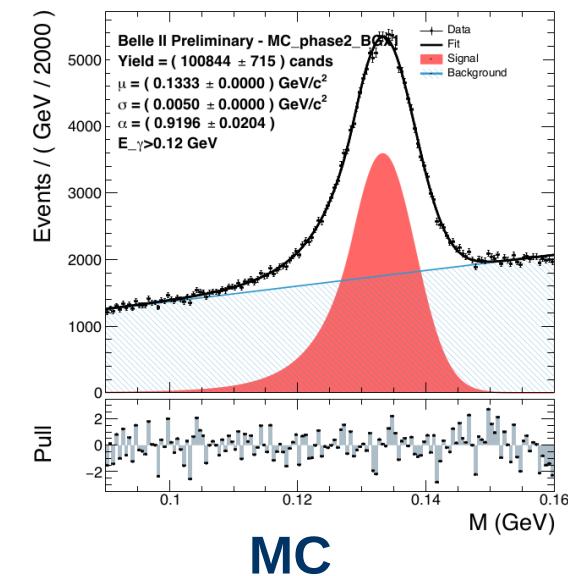
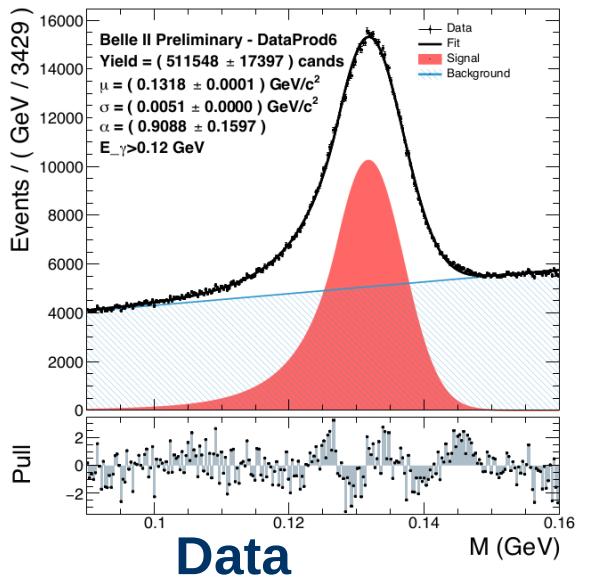


Dominated by tracking resolution
To do: Unfold this in data.



-The energy and position resolution is in agreement with MC
-At low energies the main contribution comes from the accuracy of the kinematical reconstruction

Two-photon peaks of π^0 and η



$$\sigma_{\text{data}} = 5.1 \text{ MeV}$$

$$\sigma_{\text{MC}} = 5.0 \text{ MeV}$$

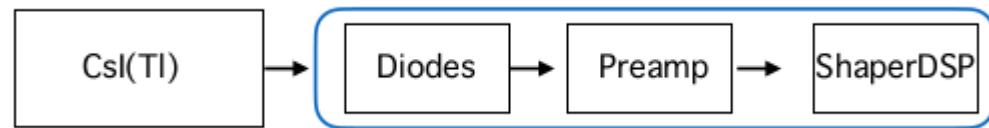
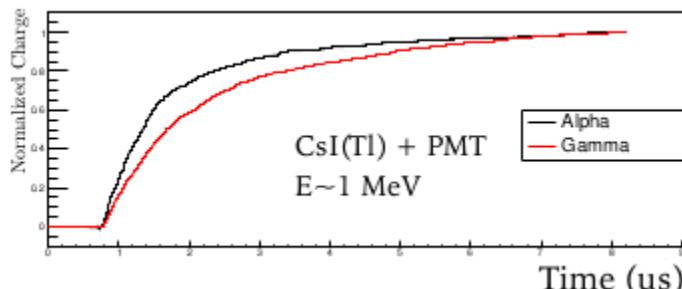
$$\sigma_{\text{data}} = 11.6 \text{ MeV}$$

$$\sigma_{\text{MC}} = 10.3 \text{ MeV}$$

Hadron separation

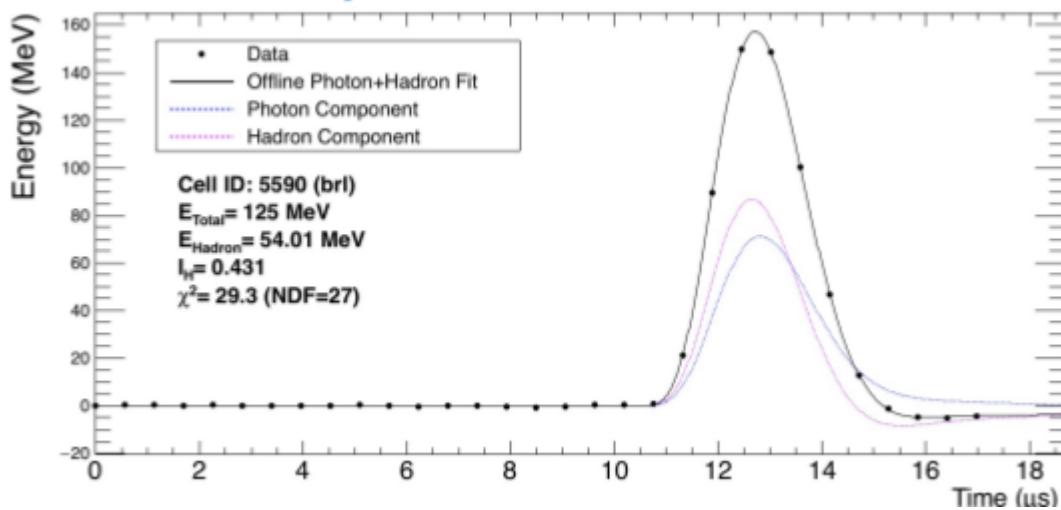
There is difference in pulse shape for MIP and High density ionization

For hadron interactins we have p, nuclear fragments etc.



S.~Longo, J.~M.~Roney, JINST {\bf 13}, no. 03, P03018 (2018)

Sample Fit of Hadron Pulse in Collision Data



We can evolve function for shaper output and analyzing data separate MIP and hadron component.

$$E_{\text{Total}} = E_{\text{Photon}} + E_{\text{Hadron}}$$

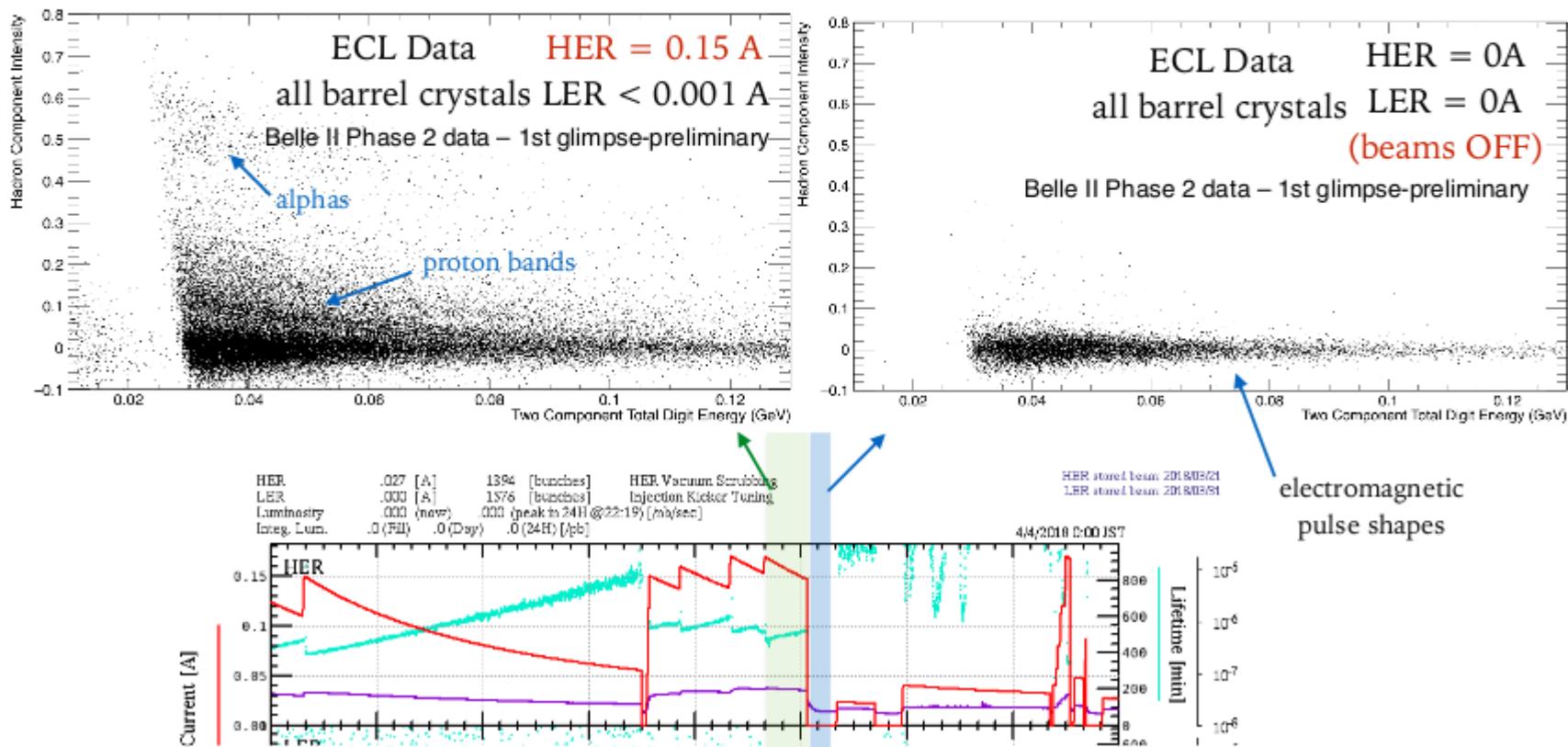
$$N_H = \frac{E_{\text{Hadron}}}{E_{\text{Total}}}$$

For hits $E > 30 \text{ MeV}$ waveforms were recorded and analyzed.

Observing Hadronic Pulse Shapes with Belle II Calorimeter

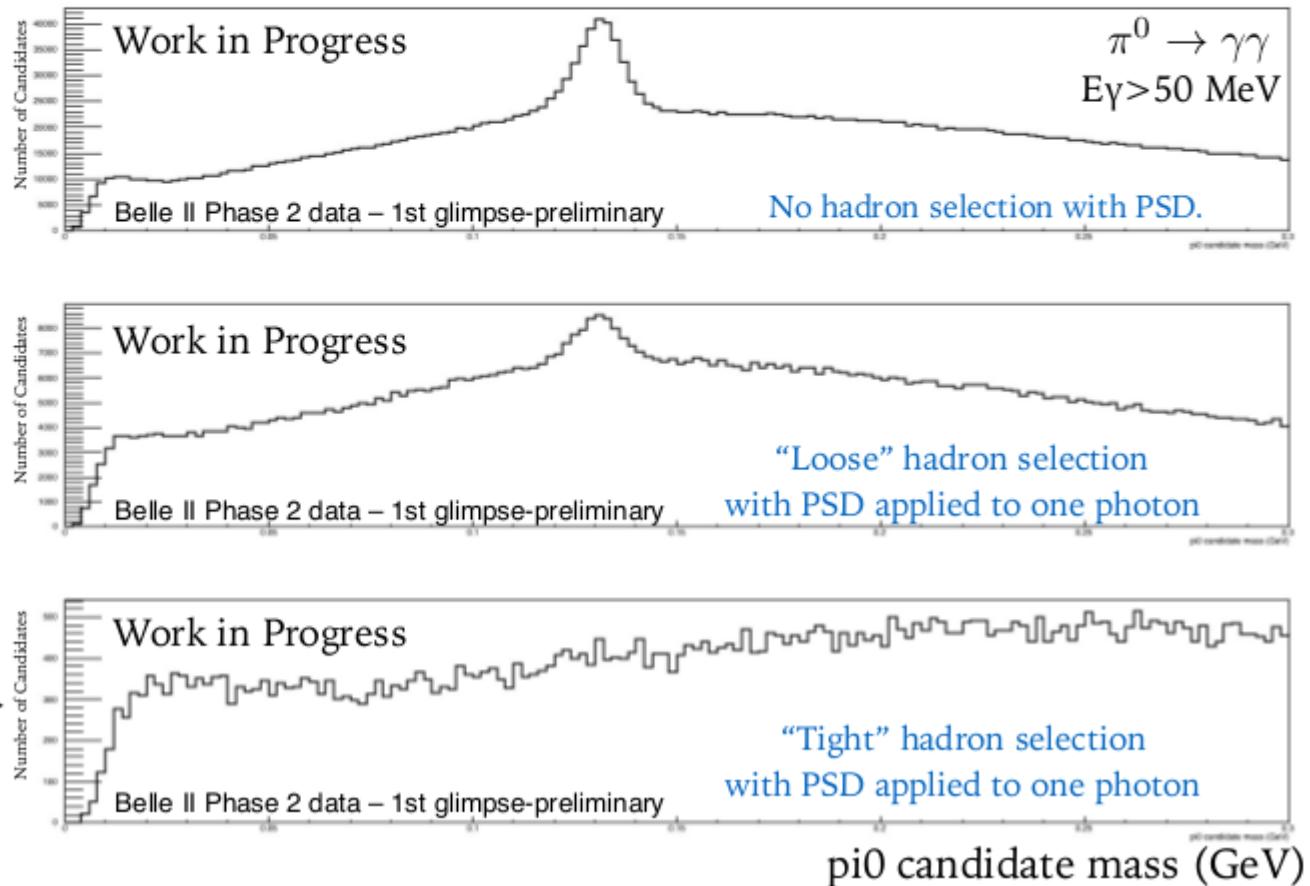
- When SuperKEKB beams started circulating (April 2018) hadronic backgrounds in ECL allowed for hadronic pulse shapes to be observed at Belle II.

First Beam = First Hadrons Observed!



Identifying Hadronic Showers with Pulse Shape Discrimination

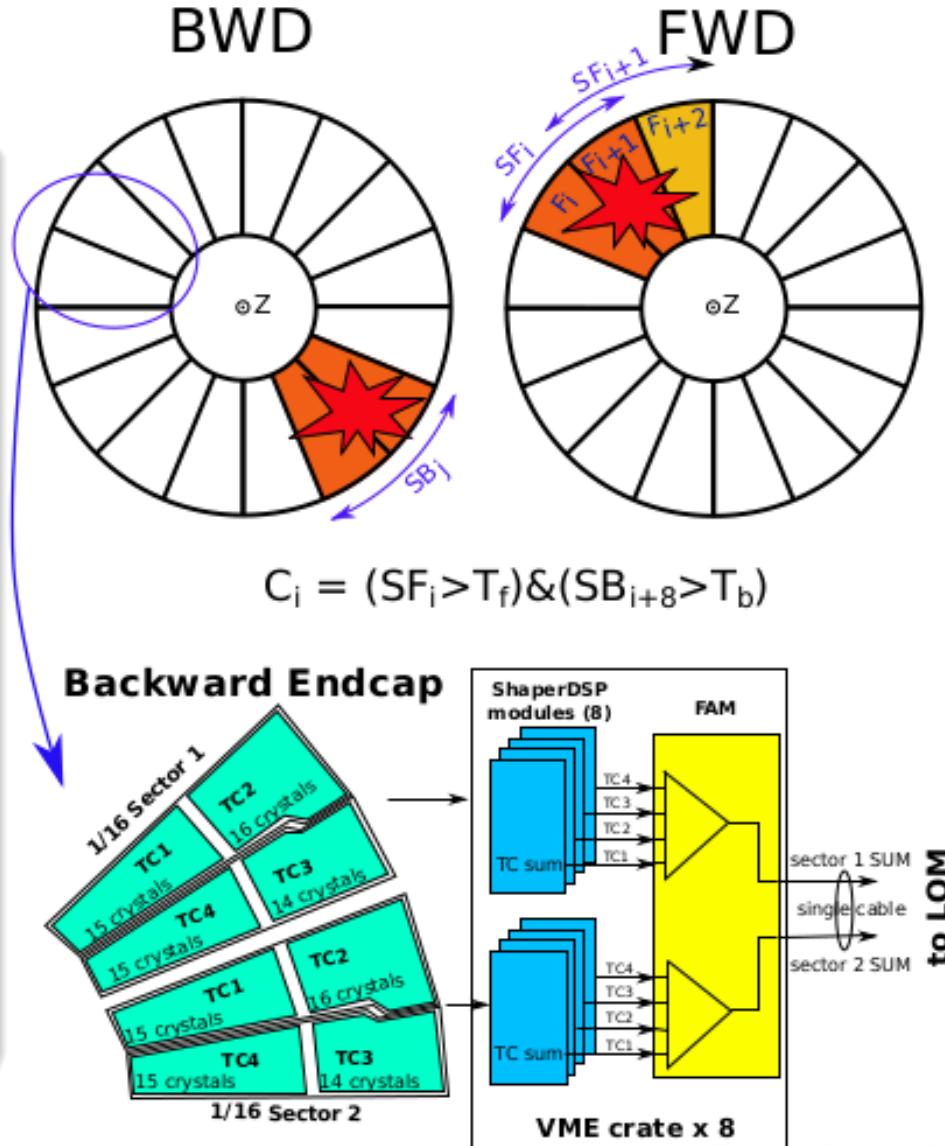
- Work is now ongoing to incorporate PSD into neutral and charged particle ID at Belle II.
- The preliminary result below illustrates hadronic cluster selection at Belle II with PSD.
- Expect no π^0 's from hadronic neutral clusters.



No π^0 peak
when tight
neutral hadron
selection with
PSD is applied. →

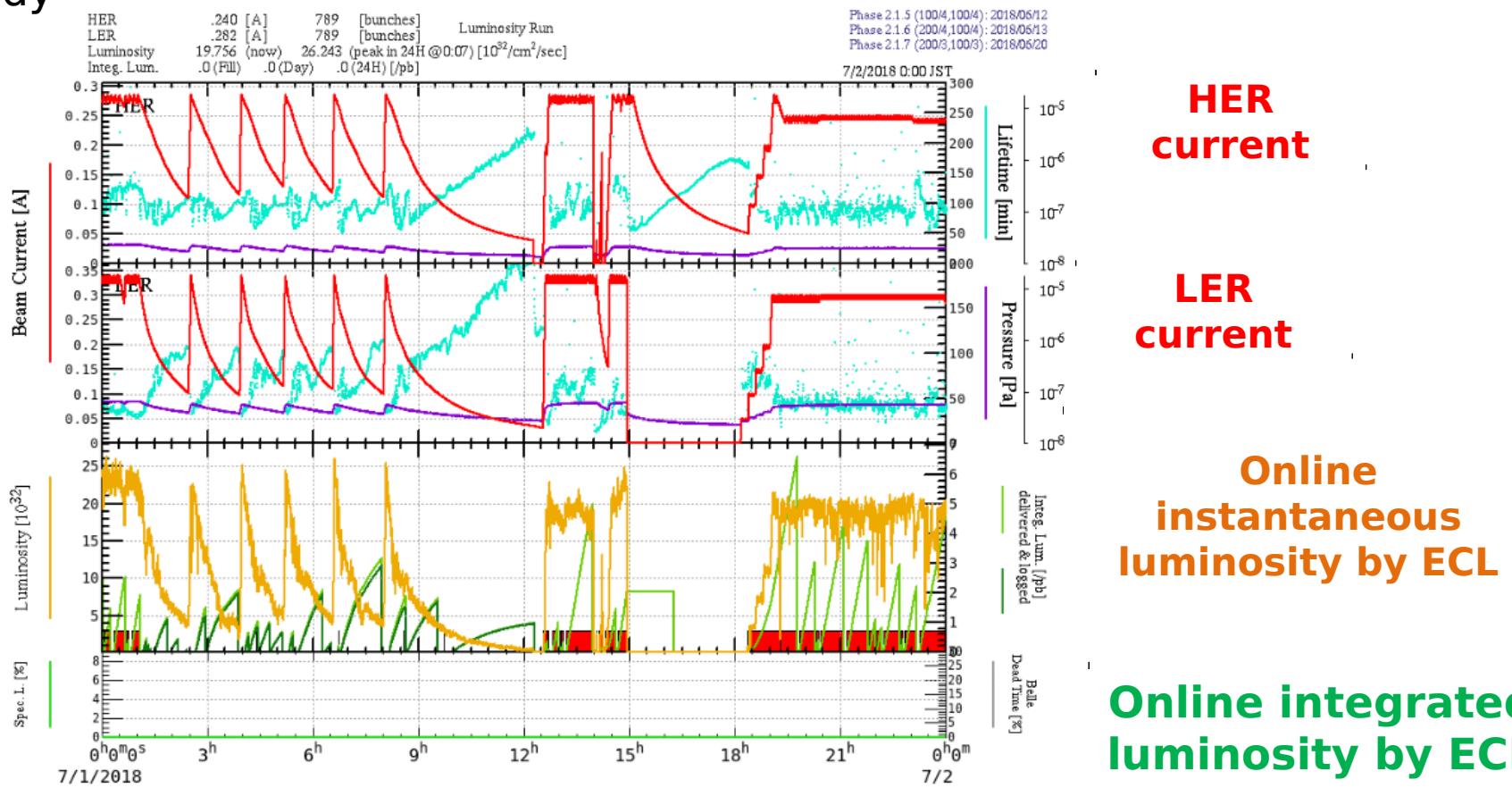
ECL luminosity monitor

- One endcap 1/16 sector (4 Trigger Cells)
- Each FAM module processes signals from 8 ShaperDSP boards (8 TC) signals and provides analog signals from two endcap sectors to LOM module
- Inner Forward Endcap sector is excluded (may be included)
- Coincidence rate of the signals in opposite sectors is counted and luminosity is calculated



Calorimeter luminosity monitor

- ECL online luminosity monitor was working very well during Phase2
- Used not only for luminosity measurement but also for SuperKEKB machine study



Summary

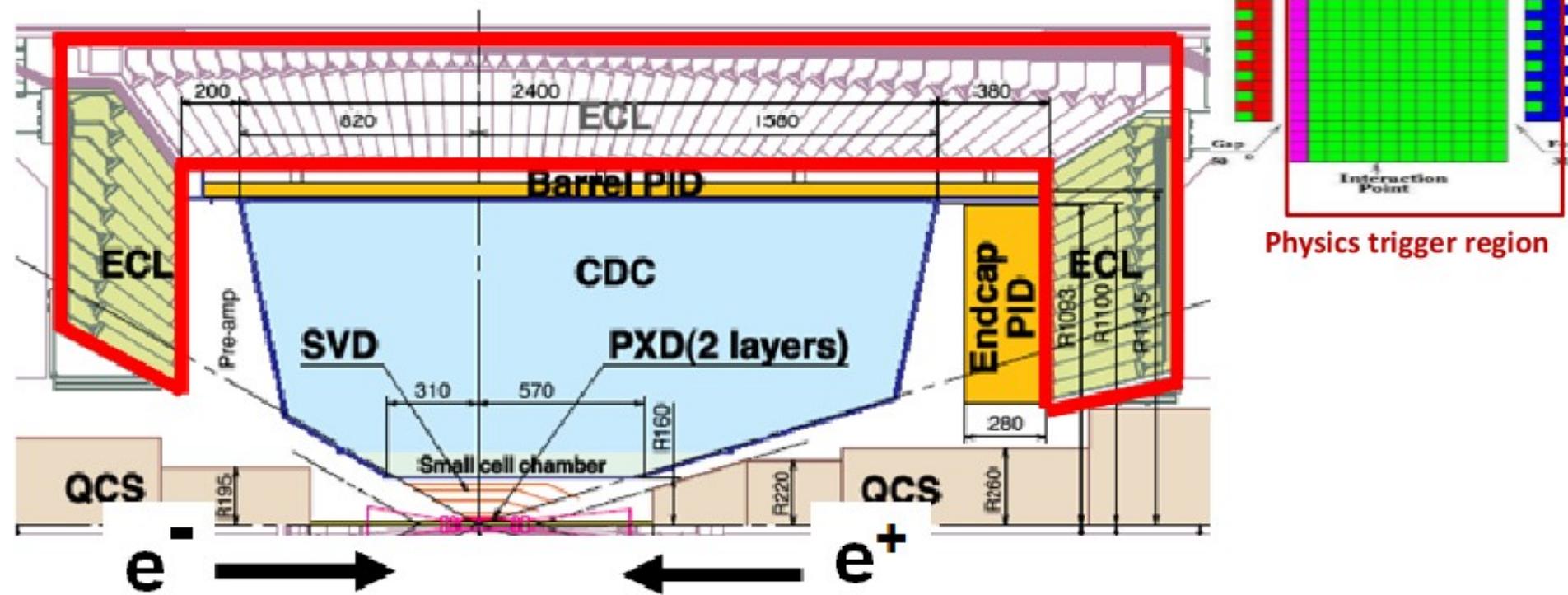


- The electronics of Belle calorimeter was upgraded and works.
- Cosmic and gamma-gamma energy calibrations were performed.
- First beam run shows that the energy and position resolution of the calorimeter is consistent with MC predictions.
- Wave form information can be used for hadron identification
- Calorimeter provides on-line luminosity measurement

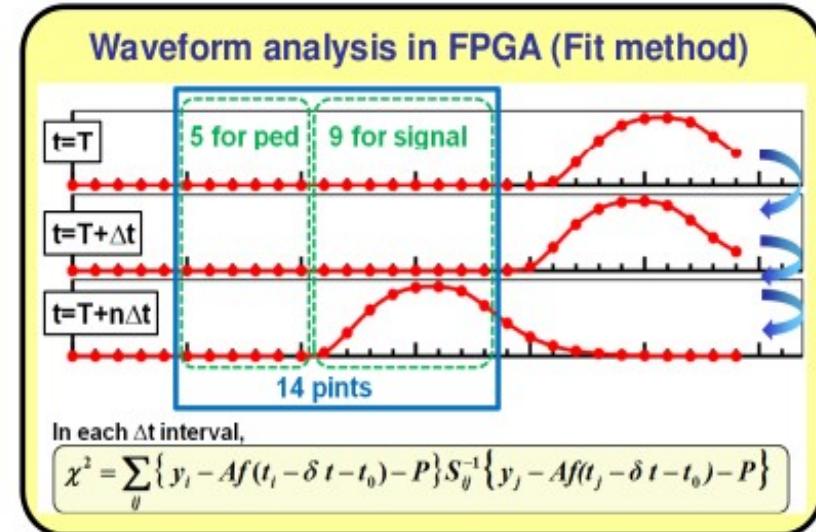
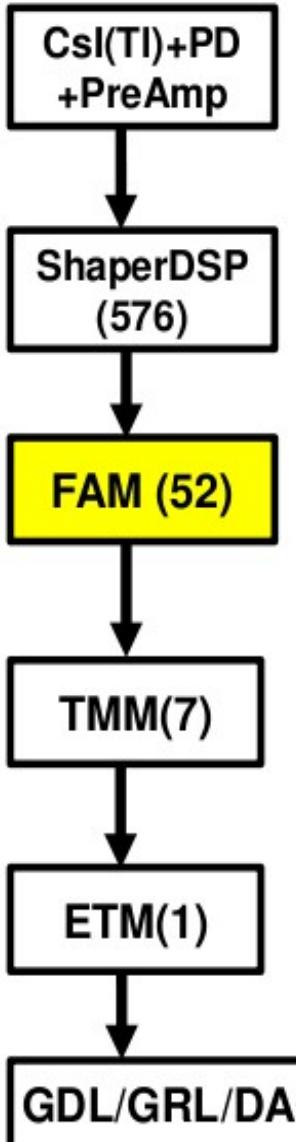
Backup

Belle II ECL trigger system

- Energy deposit and energy cluster information
 - Based on 576 Trigger Cells
 - Physics trigger : $E(\text{total}) \geq 10\text{ GeV}$
 - Bhabha trigger : 3D back-to-back
 - BeamBG veto trigger



FAM (FADC Analog Module)

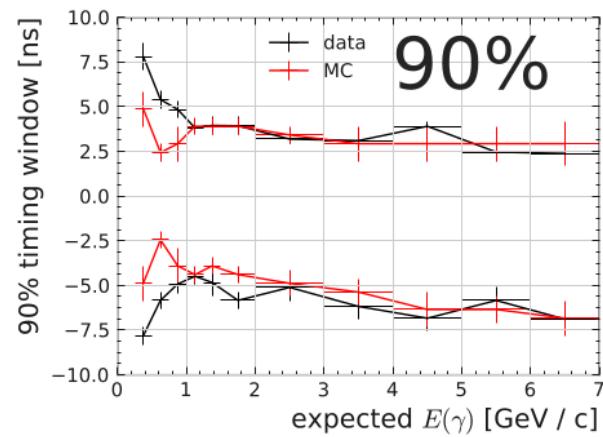
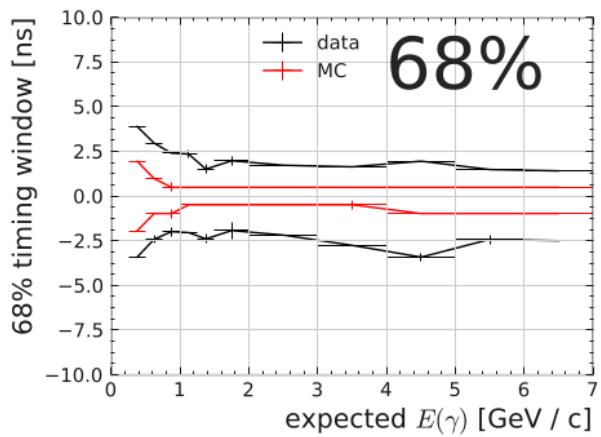


method	$\sigma(E)$ MeV	$\sigma(T)$ ns
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Trigger signals in FAM are digitized and A and T are calculated each time clock.

The digitized data are sent to TMM and ETM, where the decision is taken based on the event energy deposition, and event pattern.

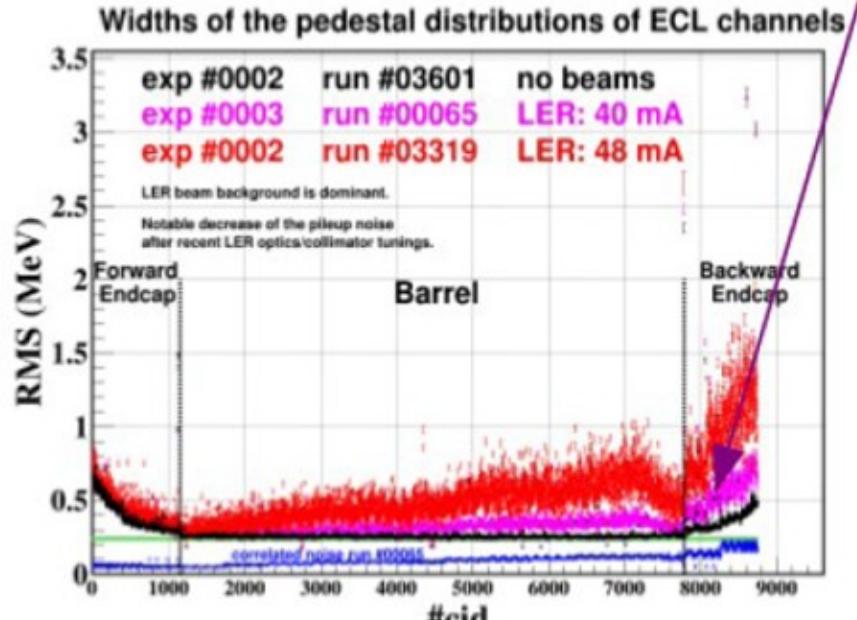
Time resolution



- Time resolution in data is worse than for MC
- If we take 90% fraction, the agreement is good
- more calibration and corrections should be implemented

Pileup noise

ECL background study



Single beam HER = 285 mA

789 bunches $\beta_y = 3$ mm

