Electromagnetic calorimeter of BelleII

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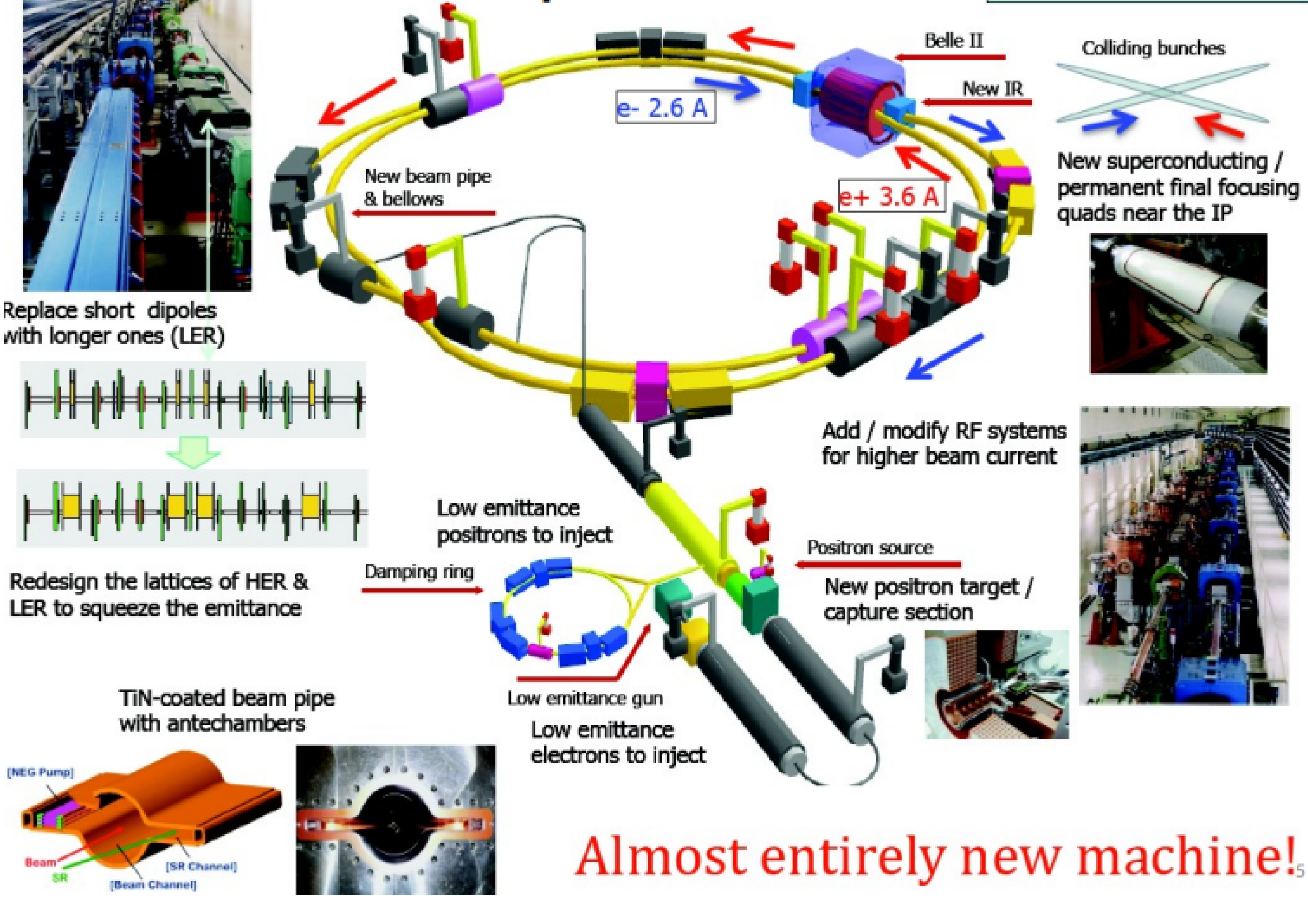
- SuperKEKB and Belle II
- Calorimeter upgrade
- Energy reconstruction
- Preliminary results from first beam data
- Summary

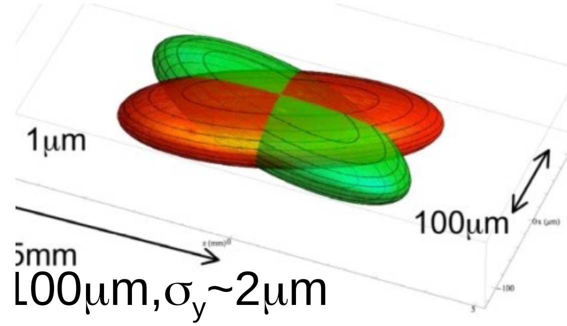
Super KEKB

Grey is recycled, coloured is new



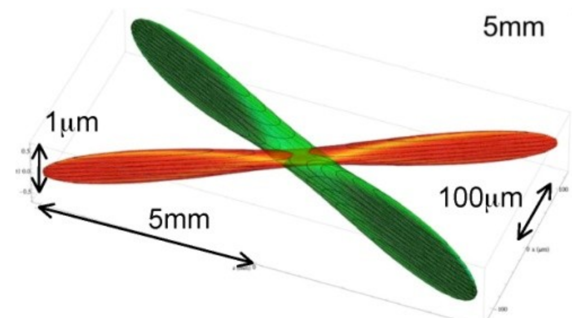
Almost entirely new machine!

KEKB



100μm, σ_y~2μm

Nano-Beam SuperKEKB



~10μm, σ_y~60nm

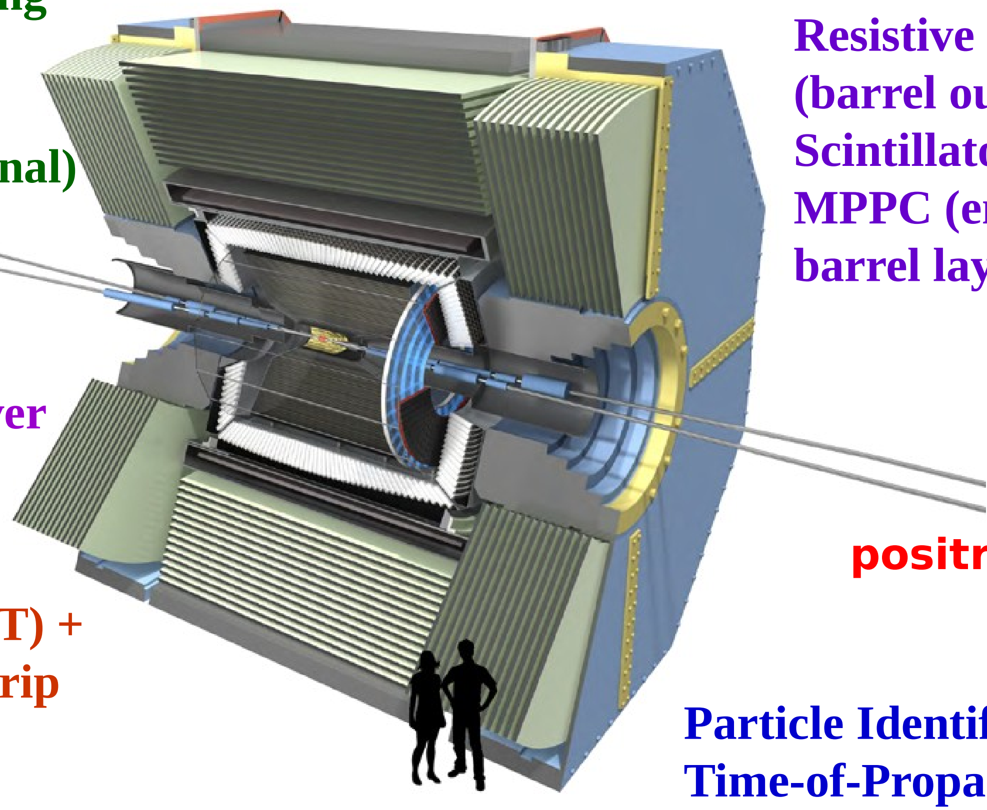
	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1 x 10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80 x 10^{34}

Belle II Detector

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

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

electrons (7GeV)



positrons (4GeV)

Central Drift Chamber
Smaller cell size, long lever arm

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

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

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

Main tasks of the calorimeter

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

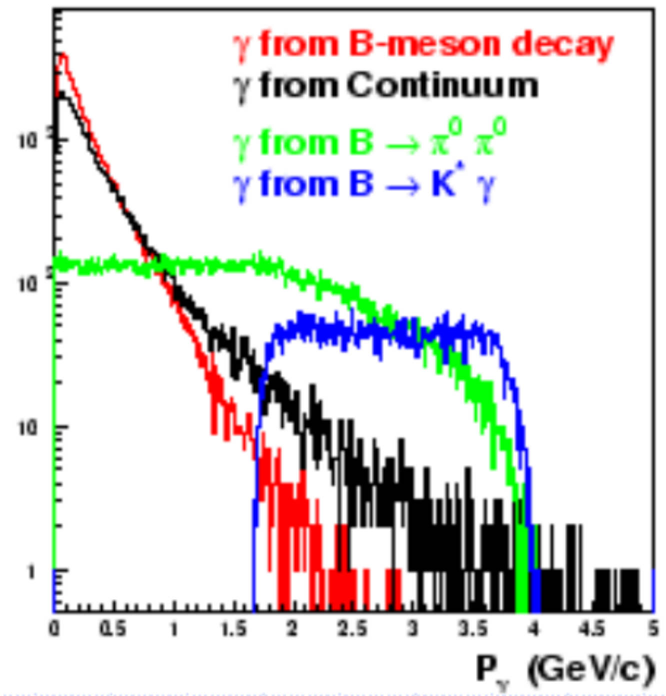
-electron identifcation

-K_L identification

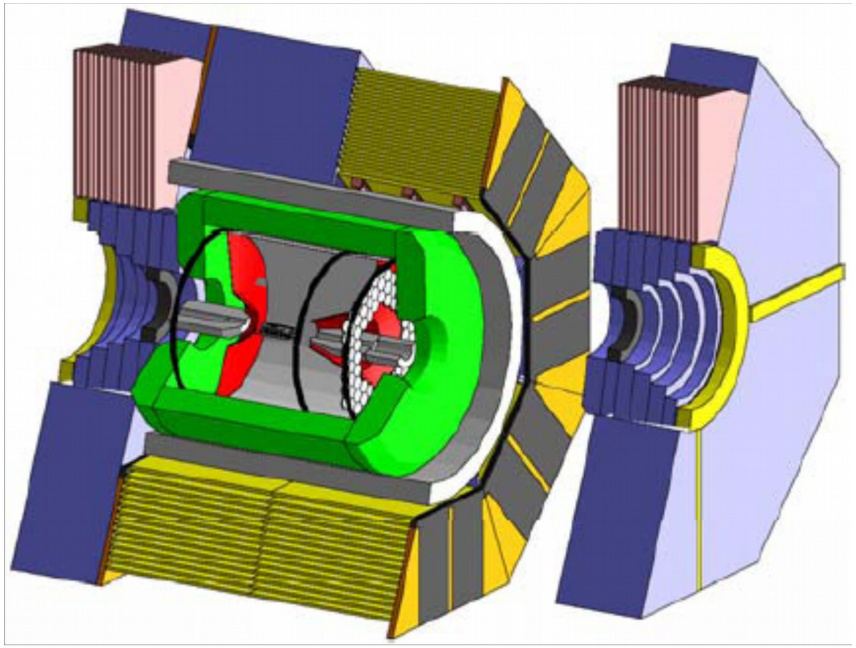
-Neutral trigger

-On-line luminosity measurement

Calorimeter should show good performance in high background environment



ECL



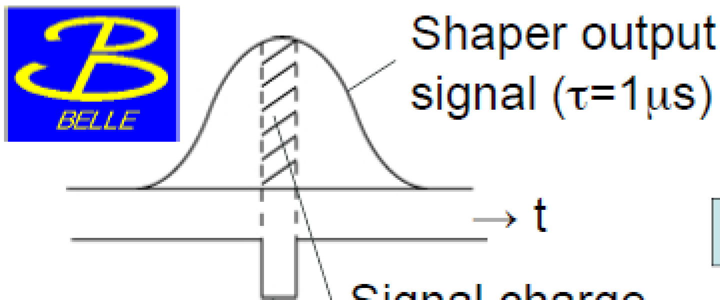
- Total 8736 counters.
- Barrel 6624
- Forward end cap 1152
- Backward end cap 960

Counter:

- 30cm long CsI(Tl) ($16.1X_0$)
- 2x $2cm^2$ PIN diodes
- 2 preamplifiers

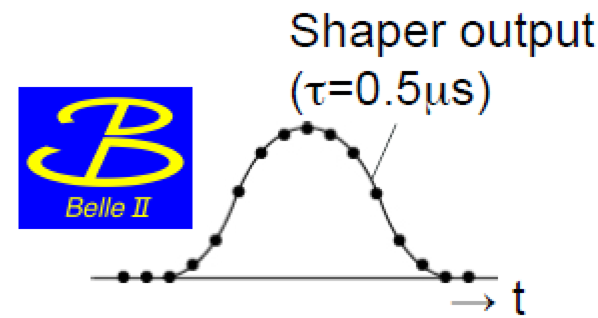
- Belle calorimeter worked for ten years – all counters are alive!
- Crystals, PINs and preamplifiers are kept from Belle
- Shaping and digitizing electronics was upgraded

Readout electronics change



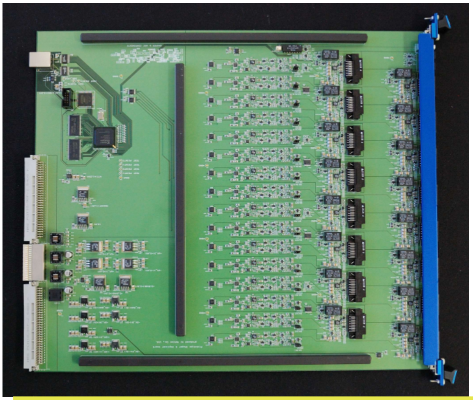
Gate width=100ns

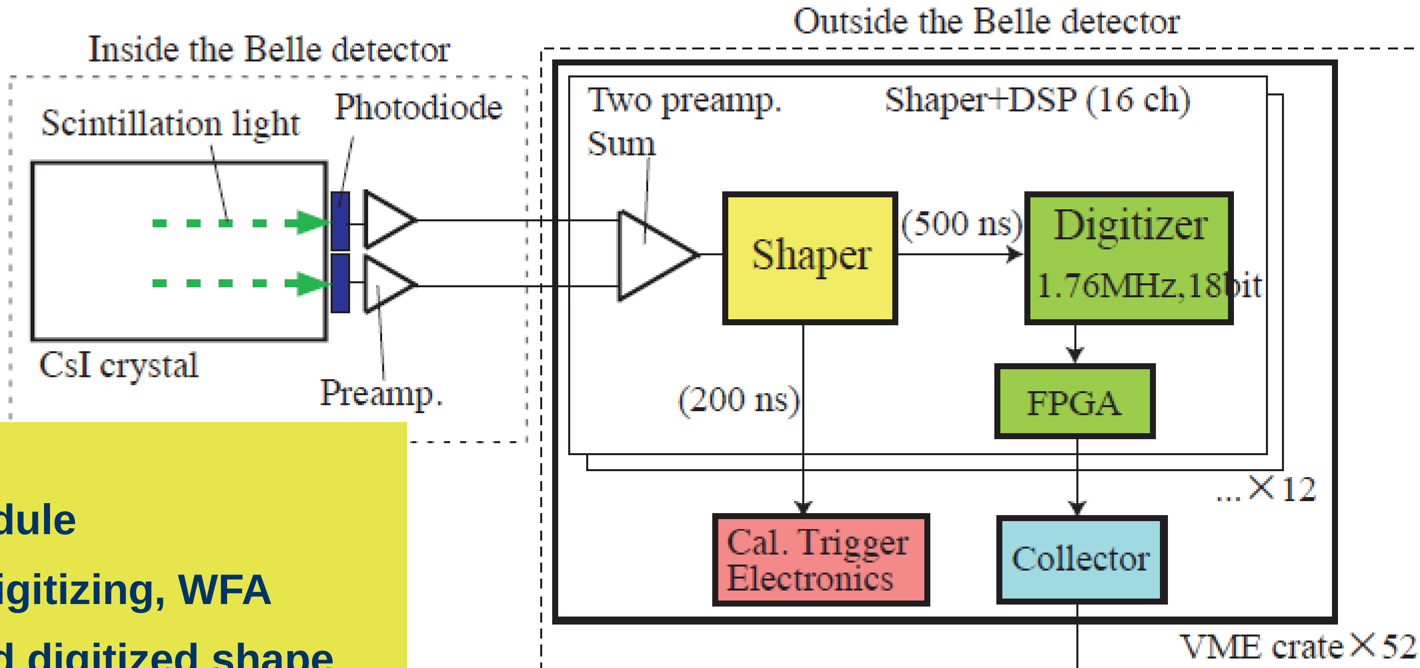
Signal charge
↓
QtoT converter (MQT300A)
↓
Digitized by TDC



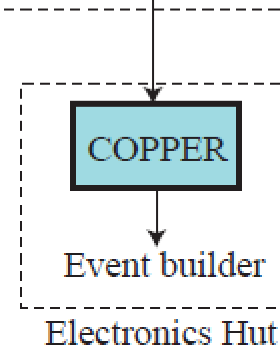
1.76MHz, 18bits digitizer
↓
waveform fit to get energy and timing (i.e. Digital Signal Processing) by FPGA

New electronics for CsI(Tl)





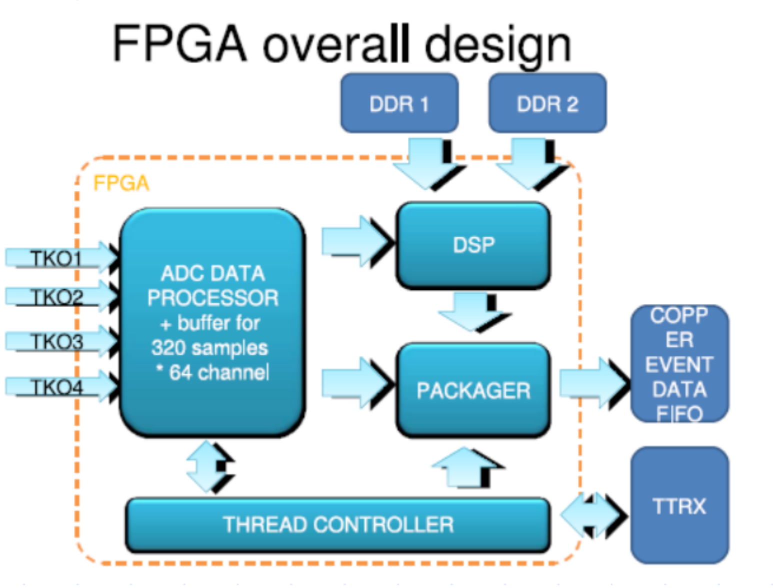
- 9U VME module
- 16 channels/per module
- Shaping (0.5mks), digitizing, WFA
- Output A, T, Q or\and digitized shape
- Fast sum signal for trigger



- 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 (4 bits)**
- **For some fraction of data both input and output information are sent to DAQ**

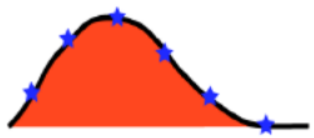


Algorithm details

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

$$S_{ij}=\overline{\left(y_i-\bar{y}\right)\left(y_j-\bar{y}\right)}$$

$f(t)$ – 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)

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

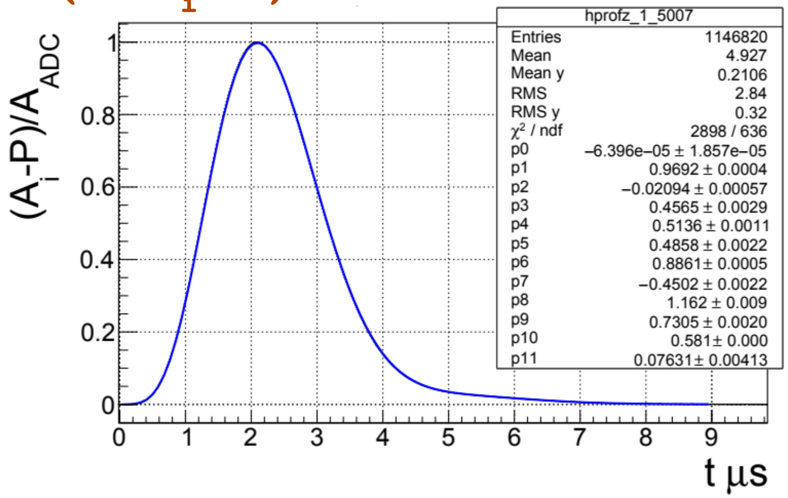
- **Algorithm works for more than 30 kHz of the trigger rate**

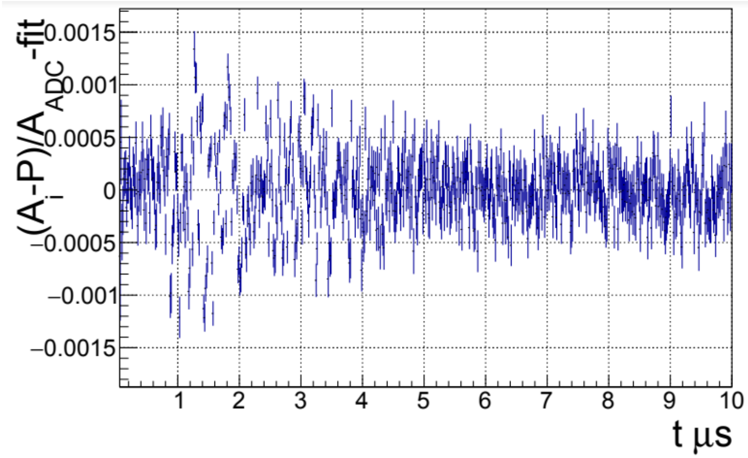
Shape calibration

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

-Estimate shape:

$(ADC_i-P)/A$ vs $i\Delta-T$





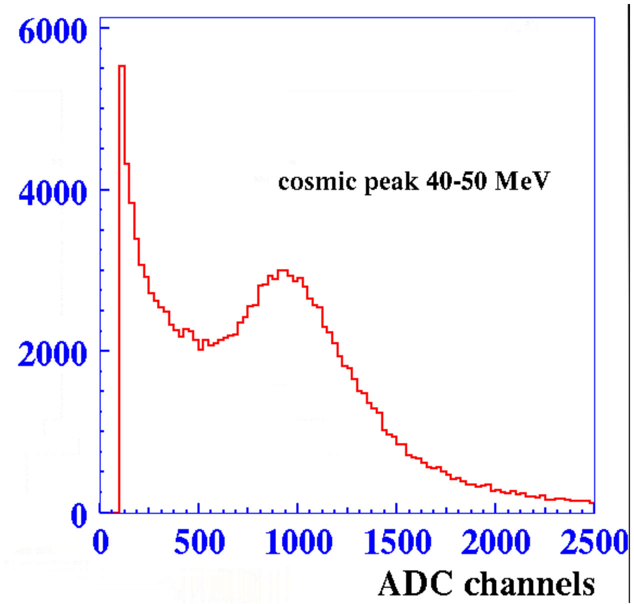
-Fit it to 12 parameter Function

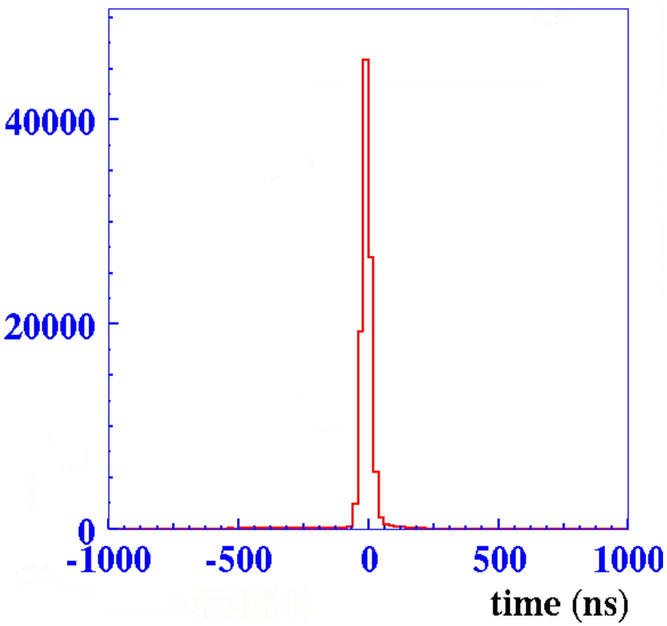
-This function is used in the calorimeter electronics to reconstruct energy, time and quality of signal

Work with cosmics

- **First calibration was performed with cosmics**

by peak position in data and MC (systematic ~2%)





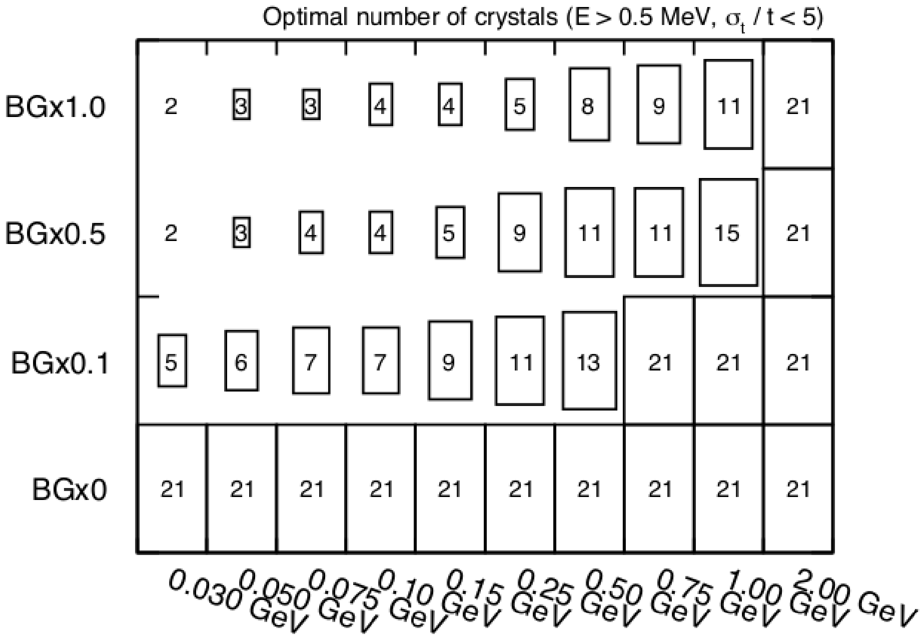
- **Time information allows to reject hits from background**

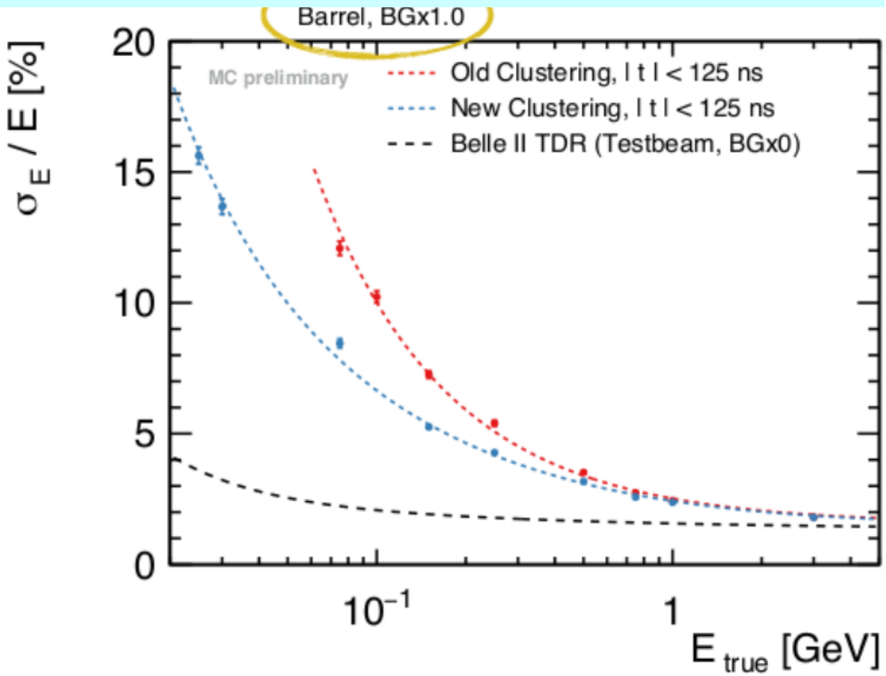
Cluster reconstruction

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





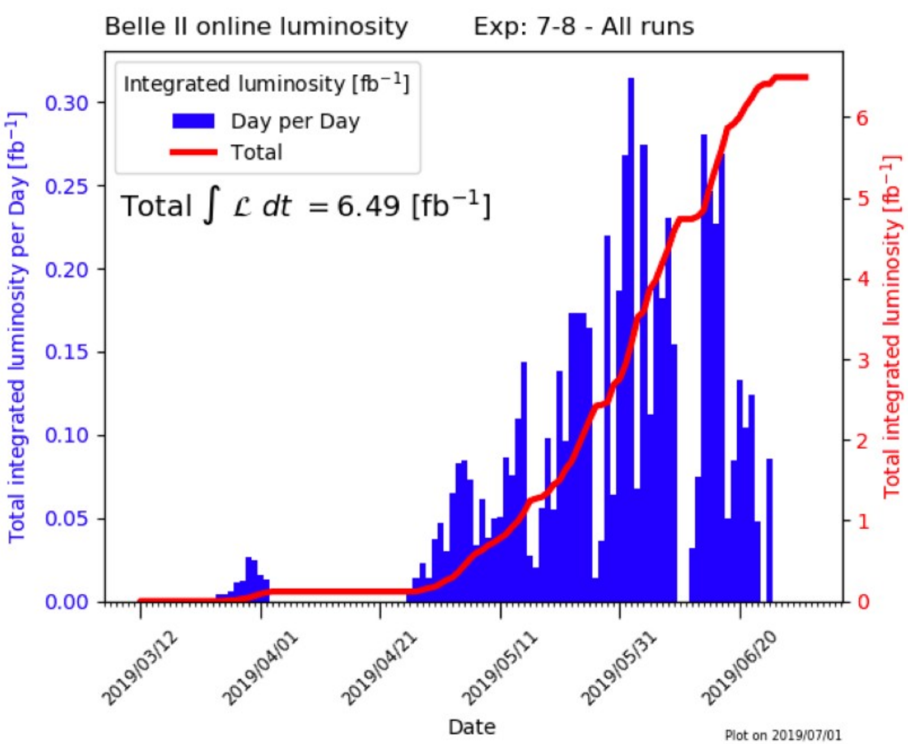
To get the photon energy: cluster energy is corrected by function depending on E, angles and the background level

Background level is estimated from multiplicity off time events

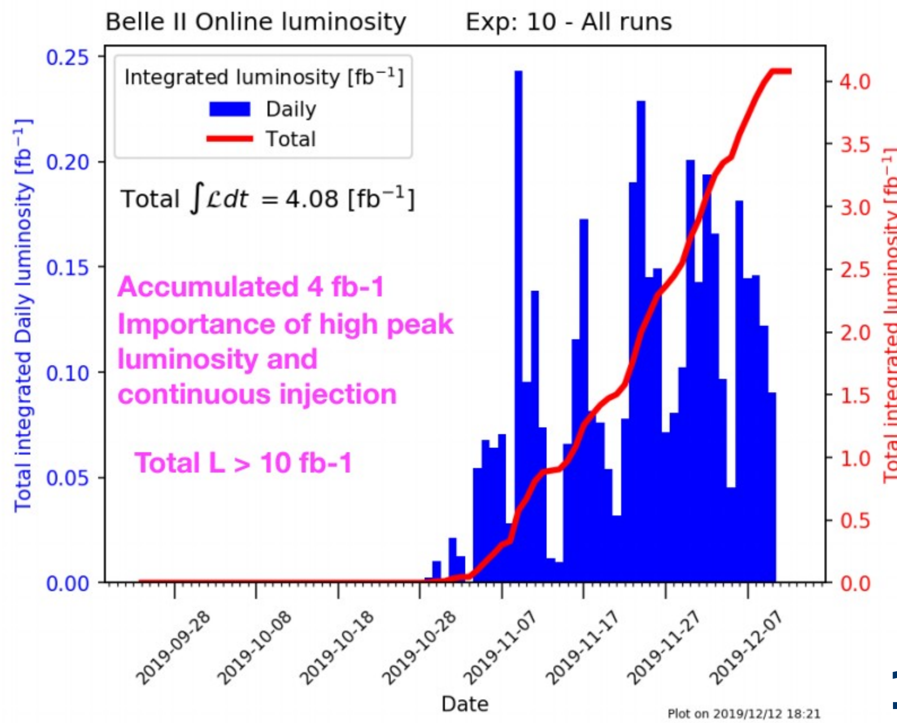
First run at SuperKEKB

- In April 2018 the first collisions were detected at SuperKEKB
- Belle II recorded the data till July 2018 without vertex detectors
- From April-June and October-December of 2019 data collection with all subsystems

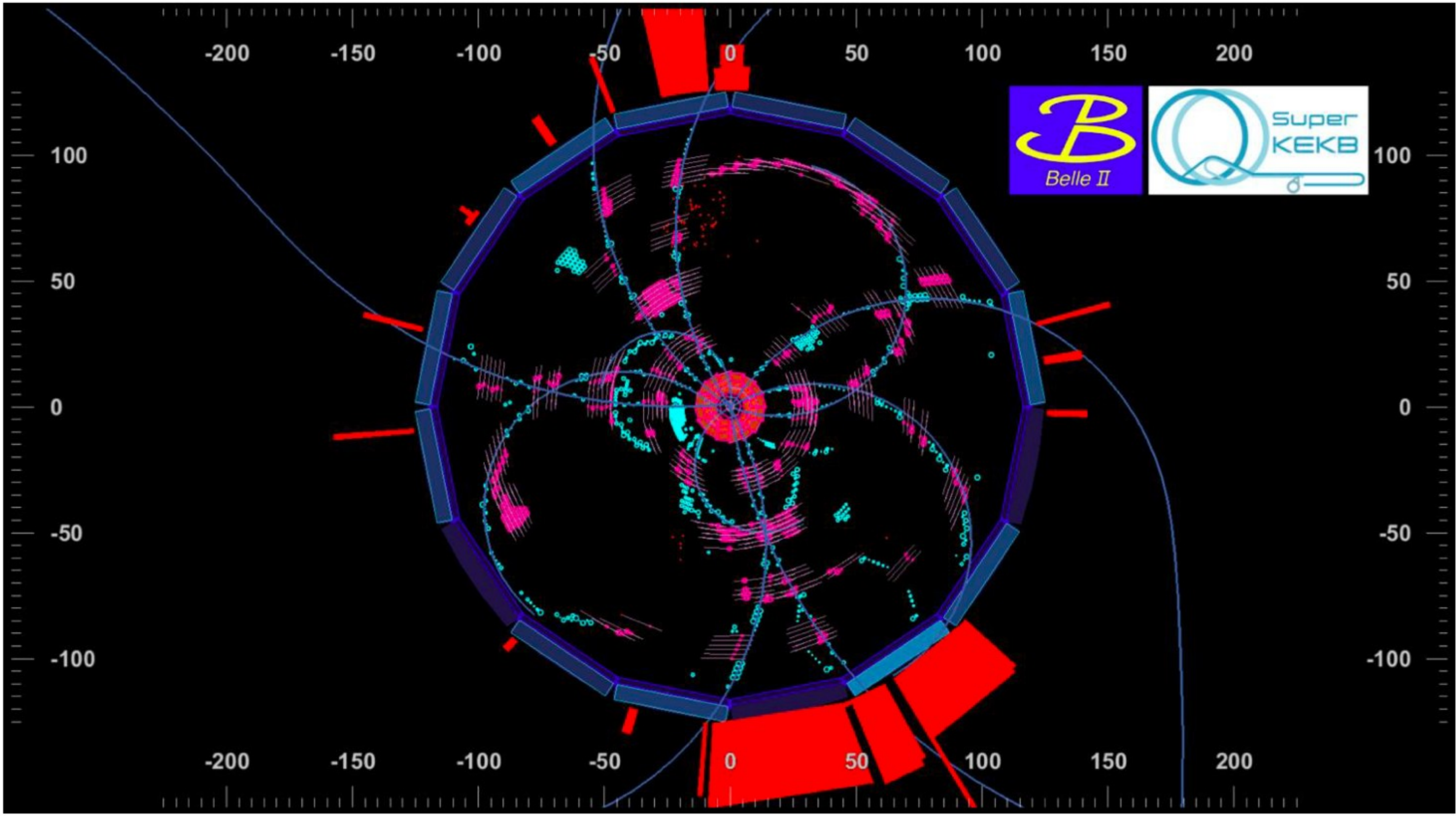
Run during 2019 spring



Run during 2019 fall

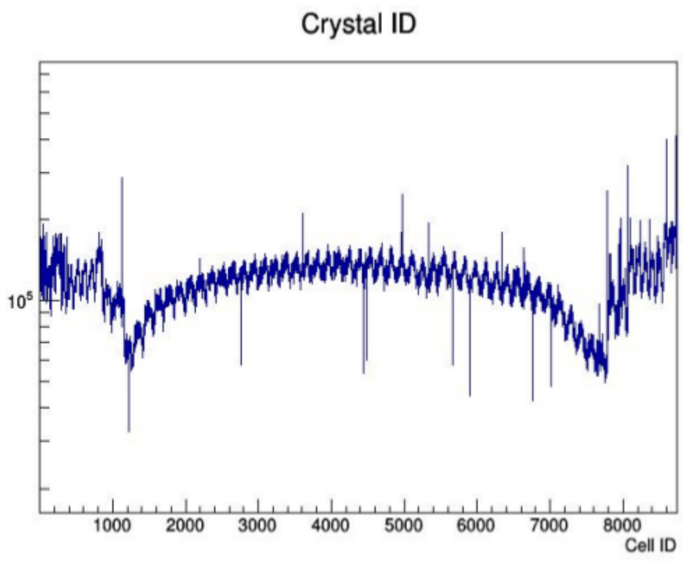


First events from BelleII

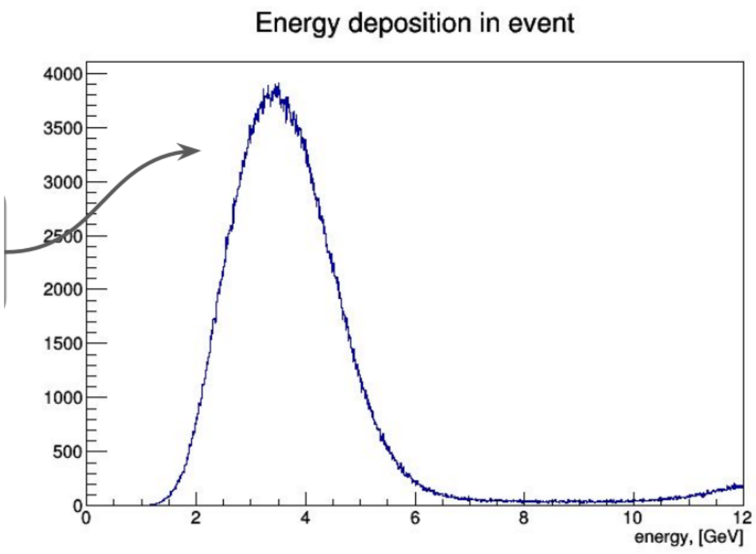


First run at SuperKEKB

- **Both barrel and endcap calorimeters were included in data taking**
- **All counters have been working**



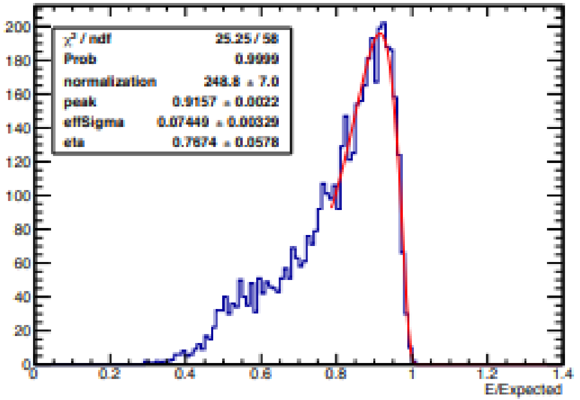
Hit occupancy map

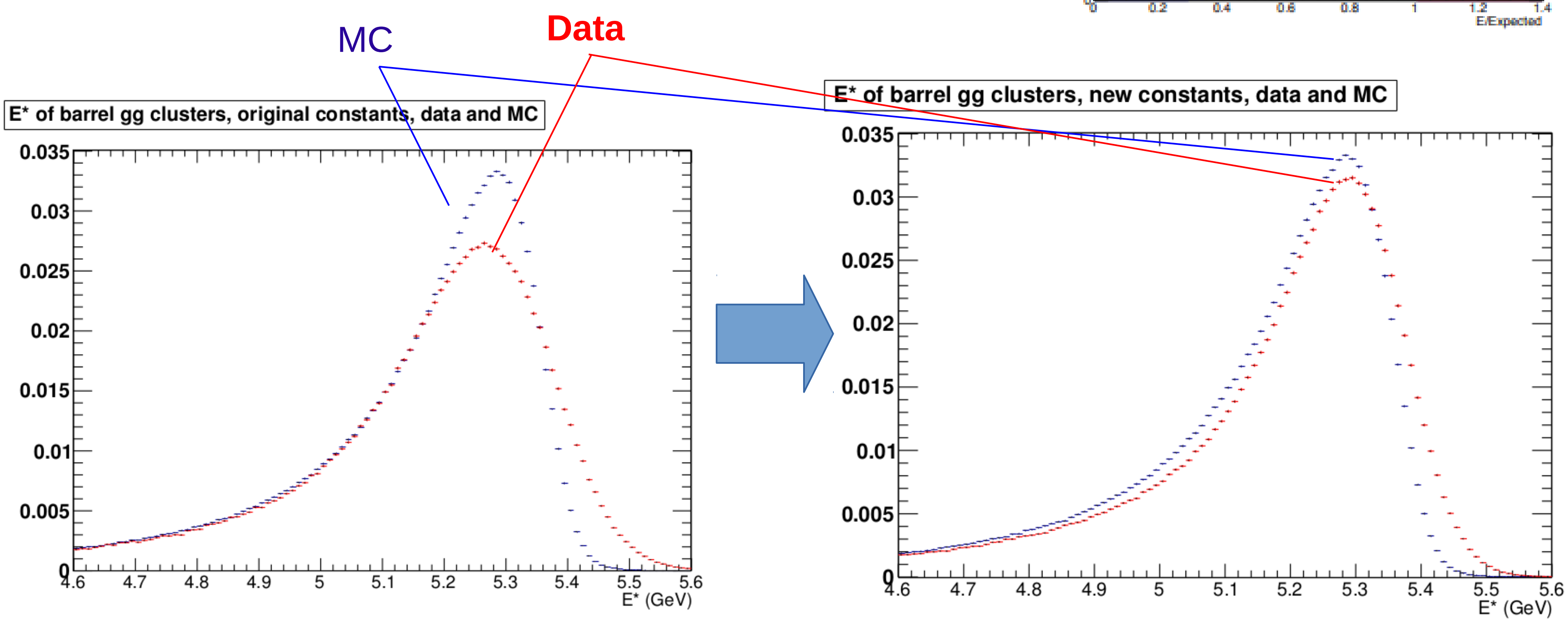


Gamma-gamma calibration

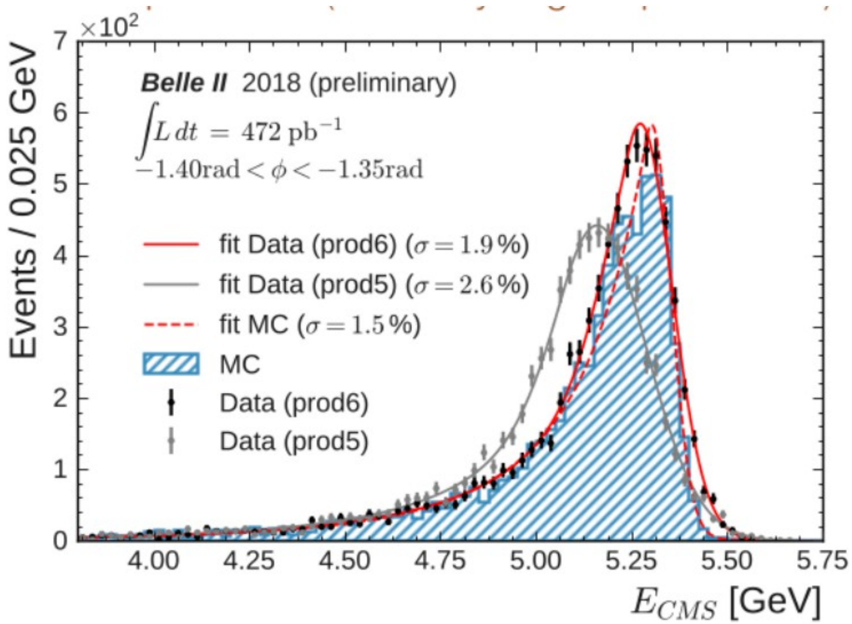
- Method compares the energy in the most energetic crystal in each photon cluster to the value predicted by MC. Energy is calculated from corresponding ECLDigit.
  - see belle2-note-te-2018-001 for details.

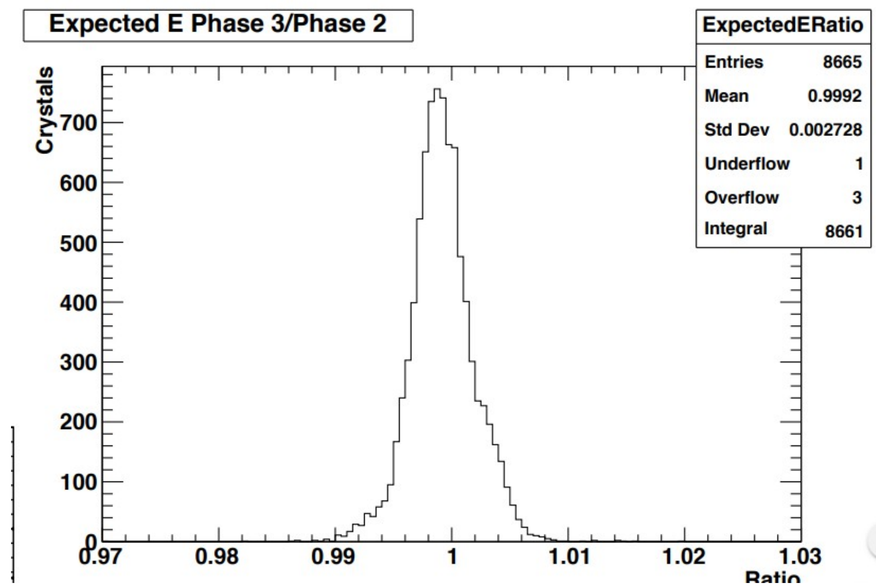
a typical uncertainty of 1.0%.



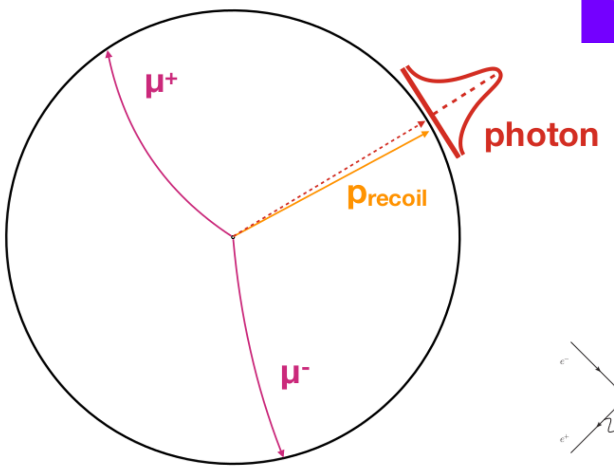


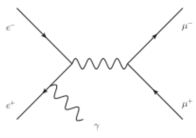
Gamma-gamma calibration





ECL study in ee->μμγ

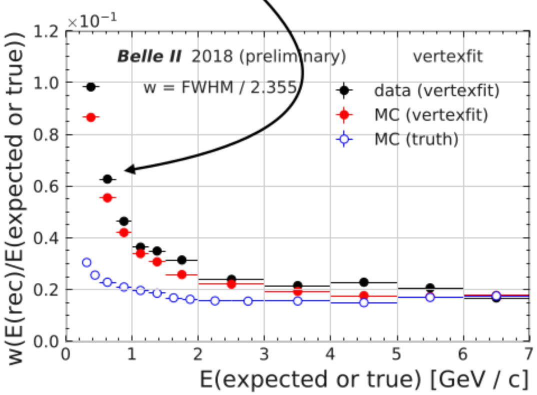




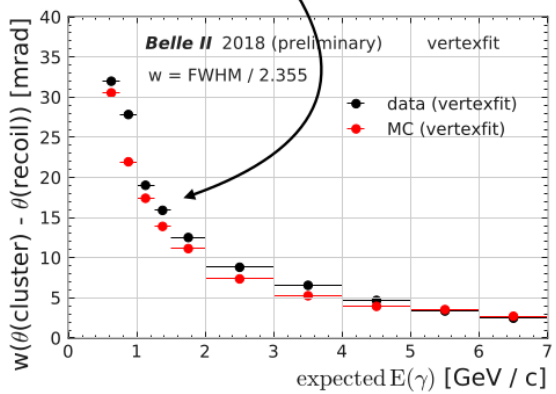
-Energy and direction of the photon can be obtained from the kinematical reconstruction and compared with the measured values

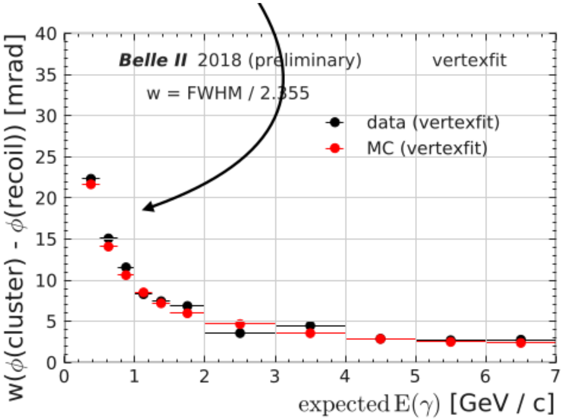
Dominated by tracking resolution
To do: Unfold this in data.

Crystal ball, iteratively



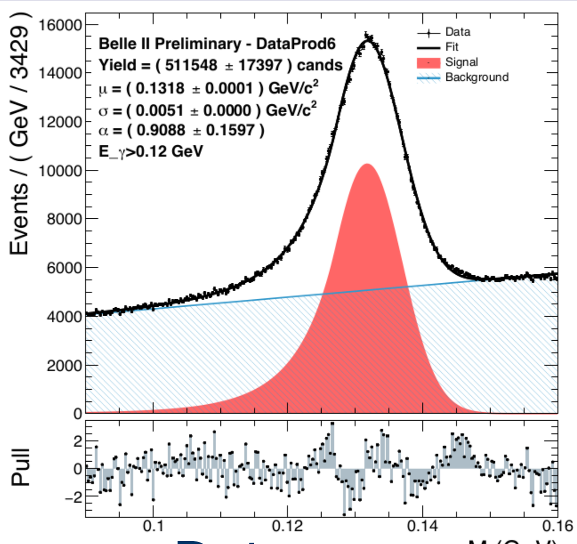
Dominated by tracking resolution
To do: Unfold this in data.



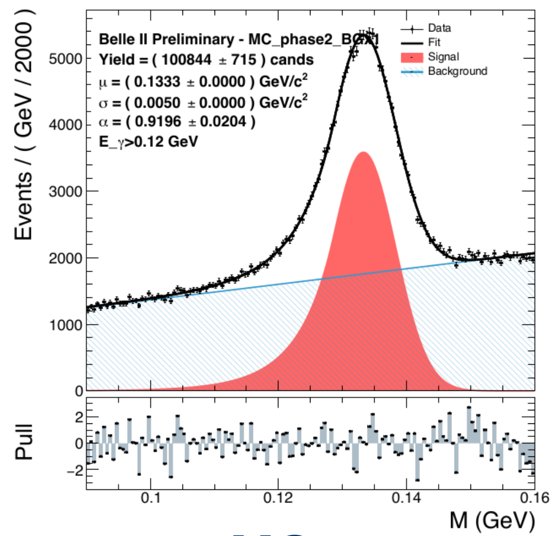


-The energy and position resolution is in agreement with MC
-At low energies the main contribution comes from the accuracy of the kinematical reconstruction

Two-photon peaks of π^0 and η



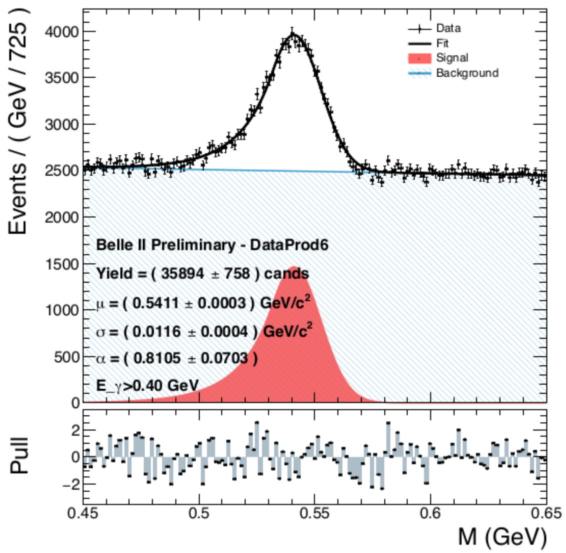
Data

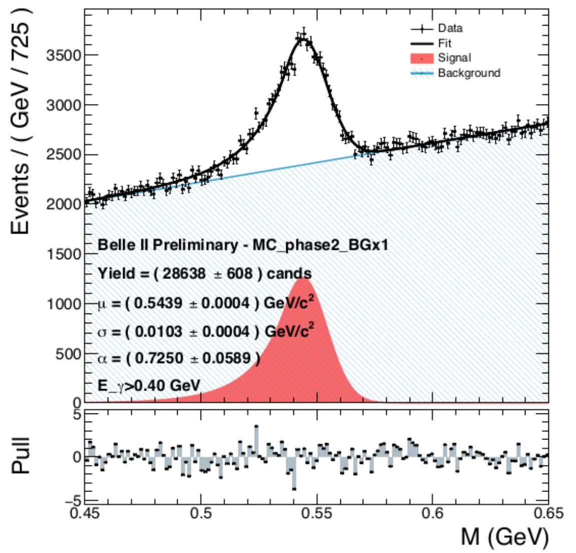


MC

σ_{data}=5.1MeV

σ_{MC}=5.0MeV





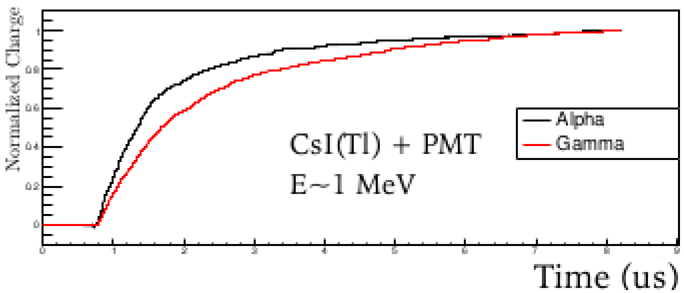
σ_{data}=11.6MeV

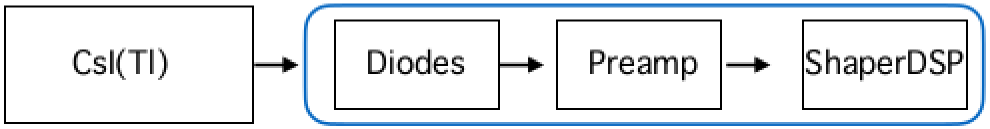
σ_{MC}=10.3 MeV

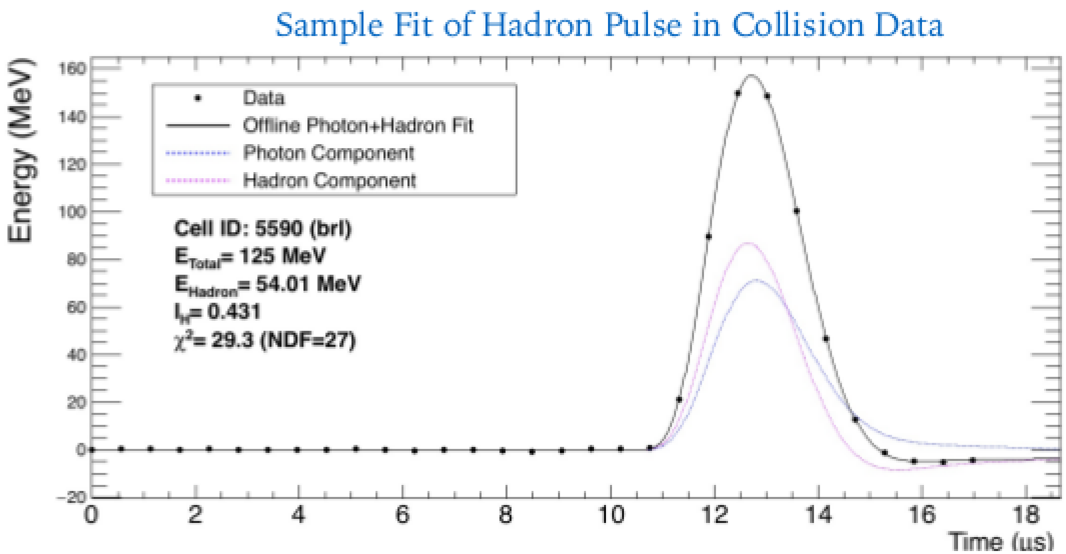
Hadron separation

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

For hadron interactins we have p, nuclear fragments etc.







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

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

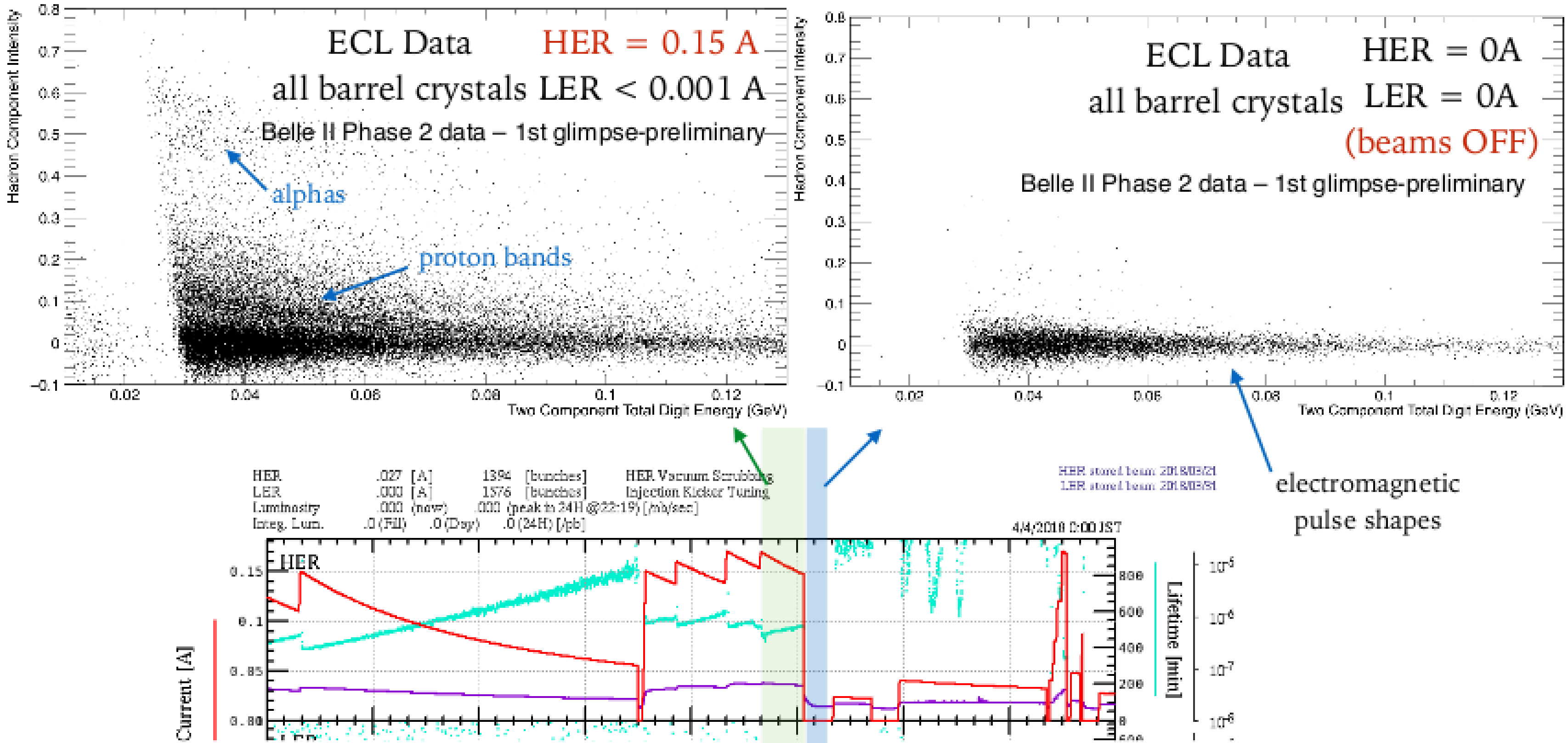
$$N_{\text{H}} = \frac{E_{\text{Hadron}}}{E_{\text{Total}}}$$

For hits E > 50 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.

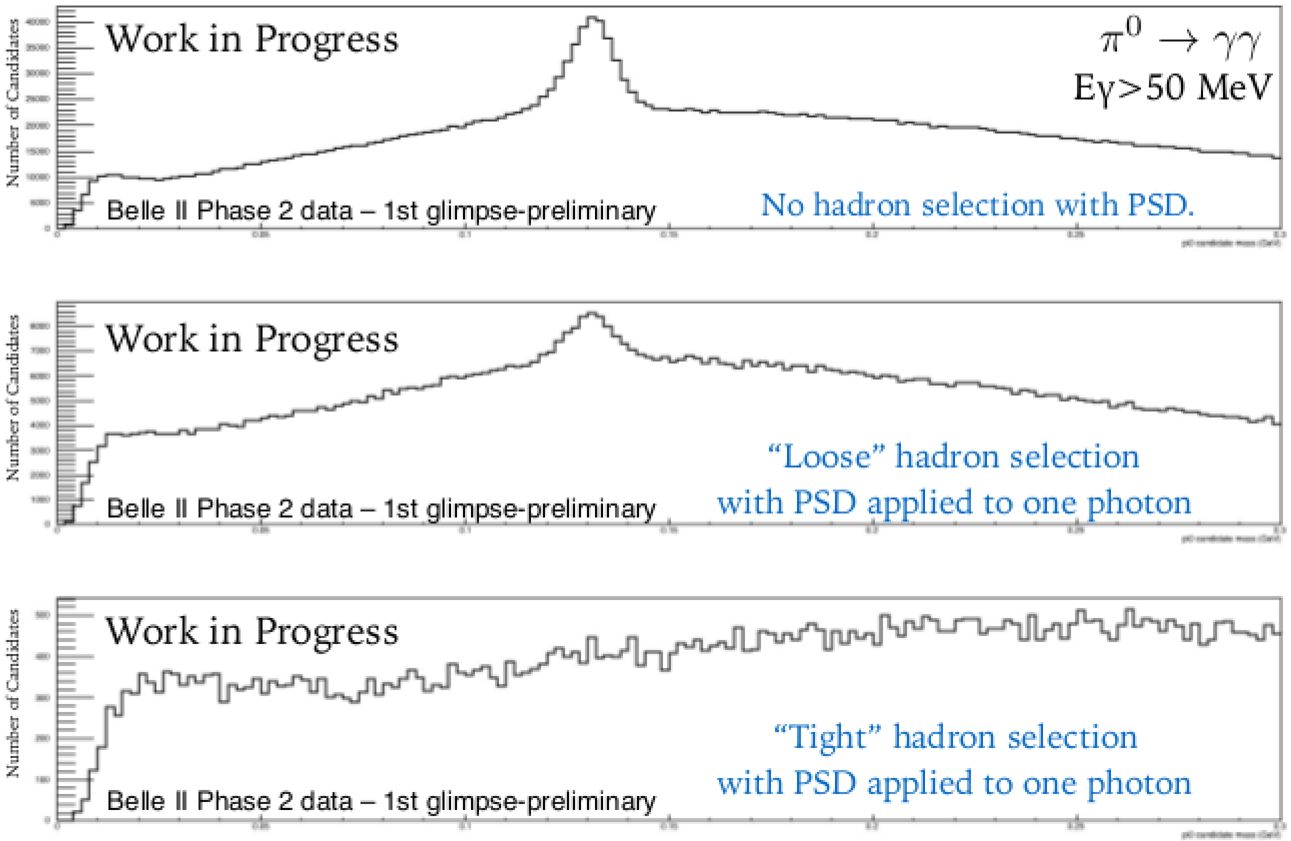
First Beam = First Hadrons Observed!



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 pi0's from hadronic neutral clusters.

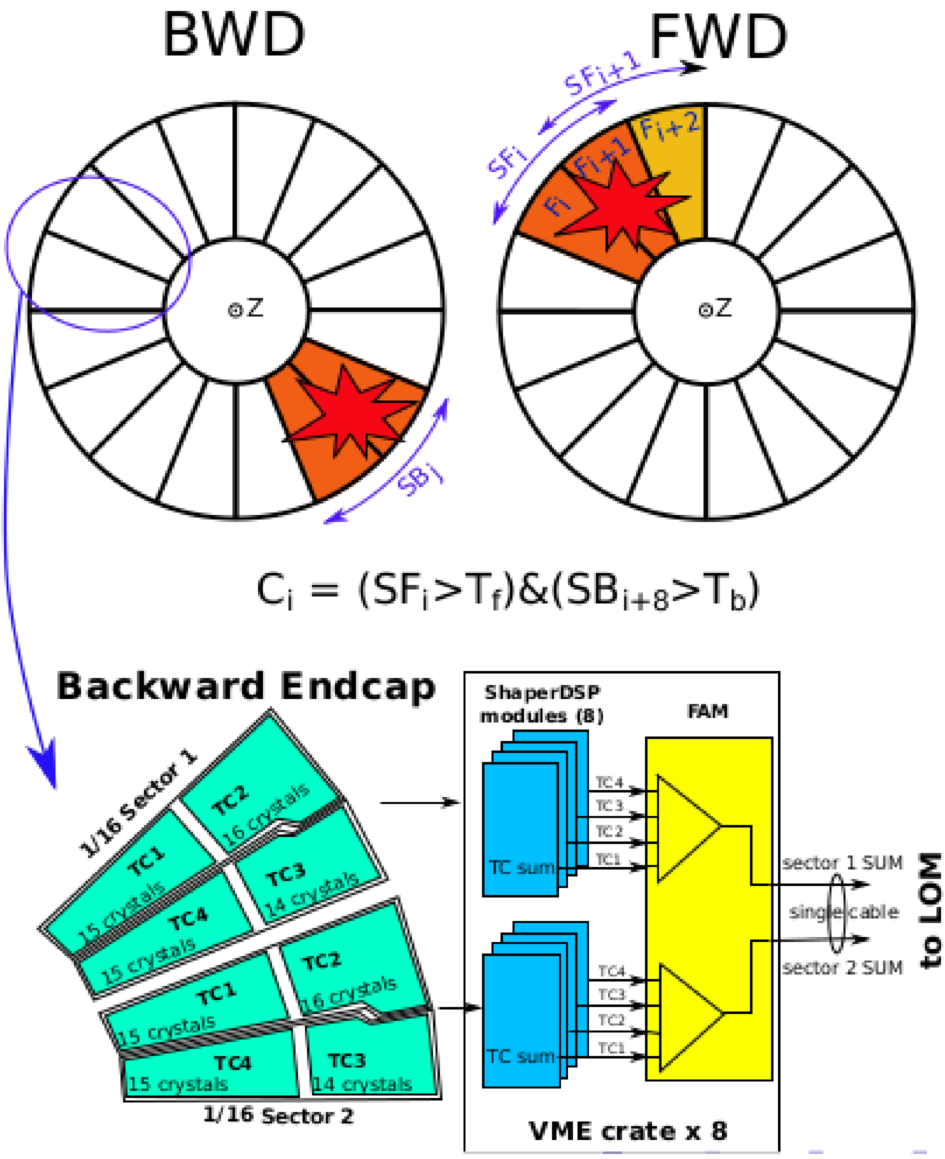
No pi0 peak when tight neutral hadron selection with PSD is applied. →



pi0 candidate mass (GeV)

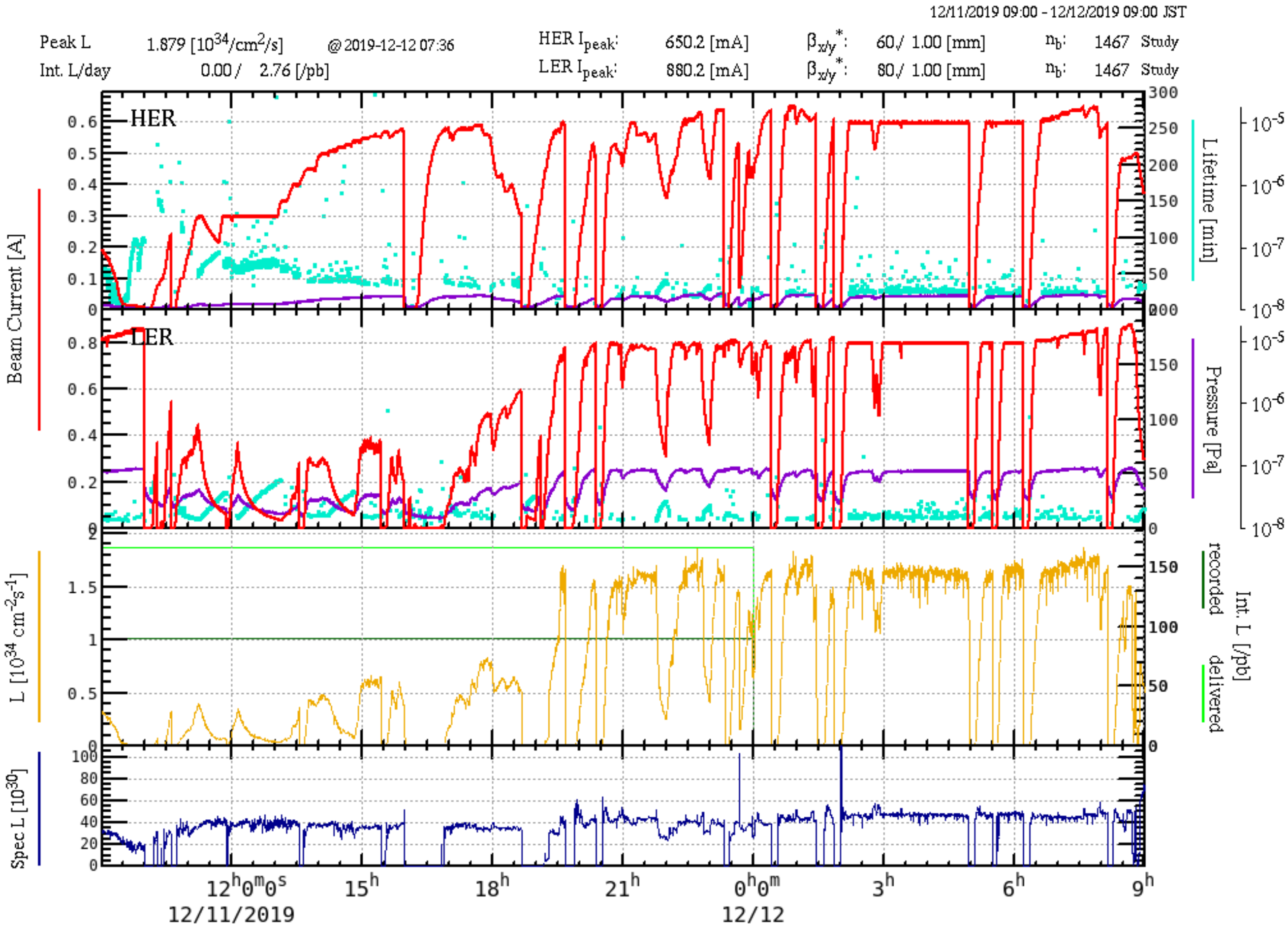
ECL luminosity monitor

- 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.

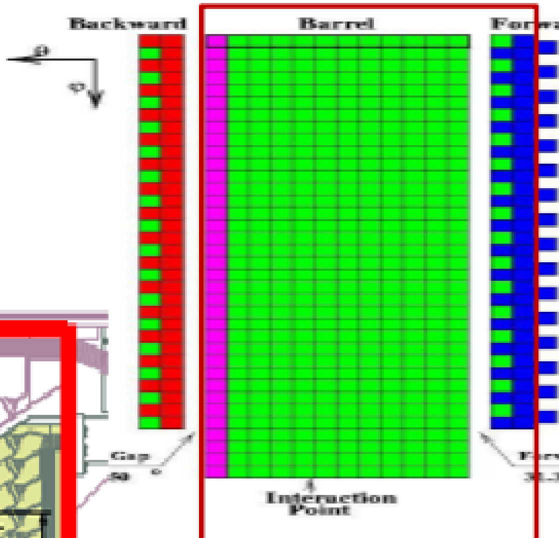
-Wafe form information can be used for hadron identification

-Calorimeter provides on-line luminosity measurement

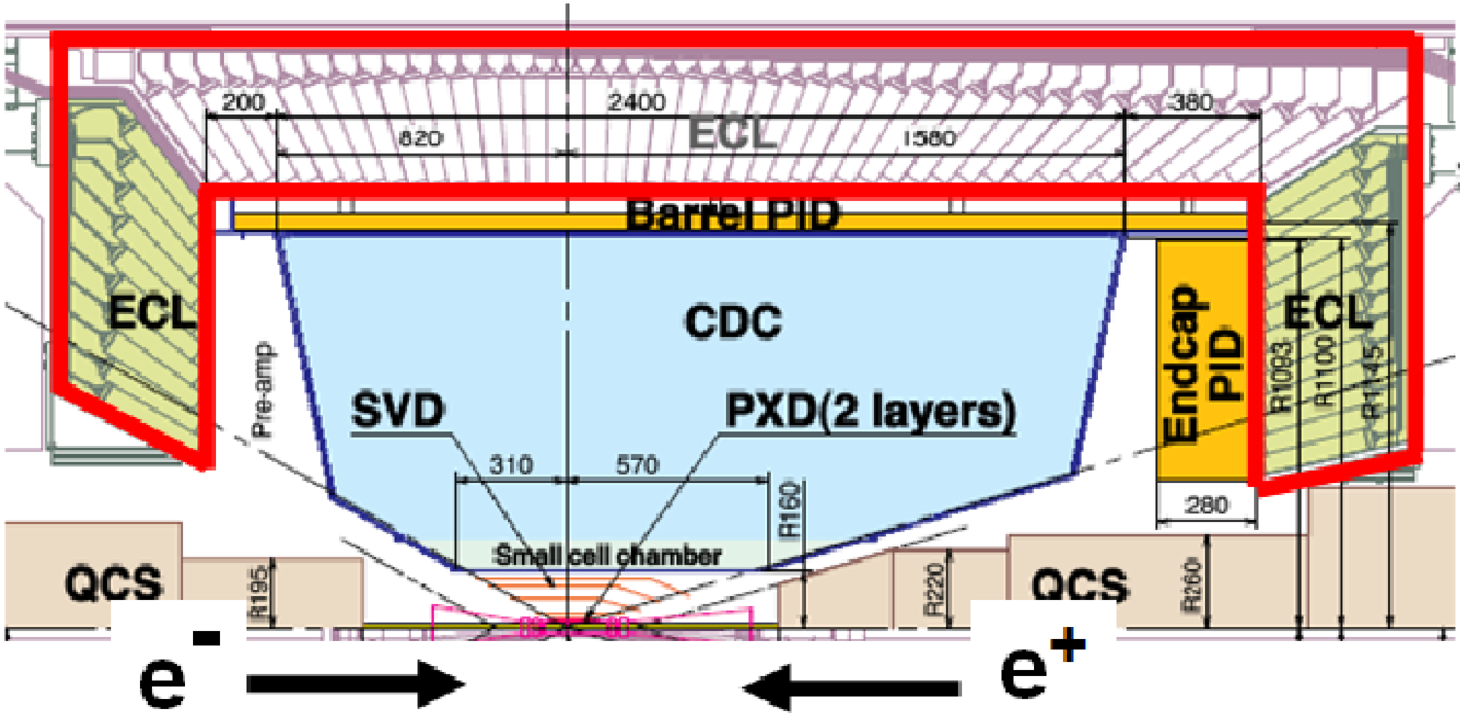
Backup

Belle II ECL trigger system

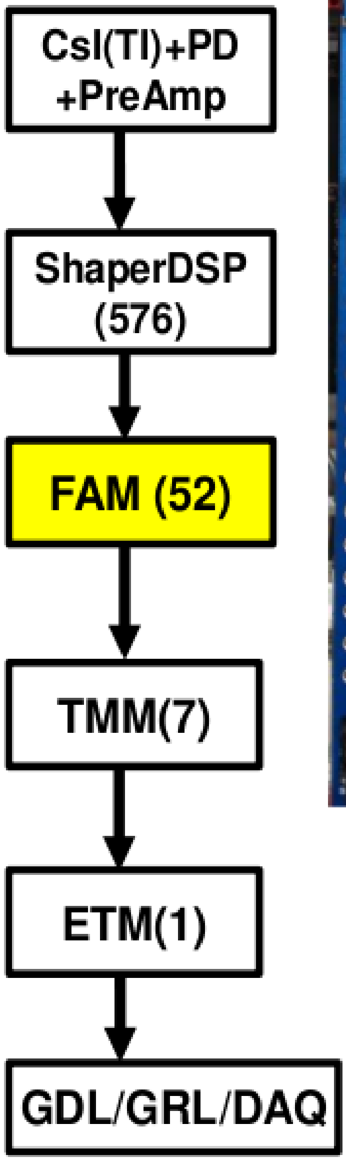
- Energy deposit and energy cluster information
  - Based on 576 Trigger Cells
  - Physics trigger : E(total) II ICN
  - Bhabha trigger : 3D back-to-back
  - BeamBG veto trigger

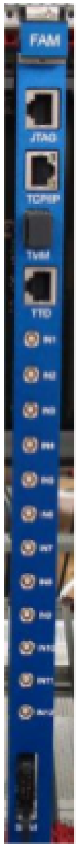


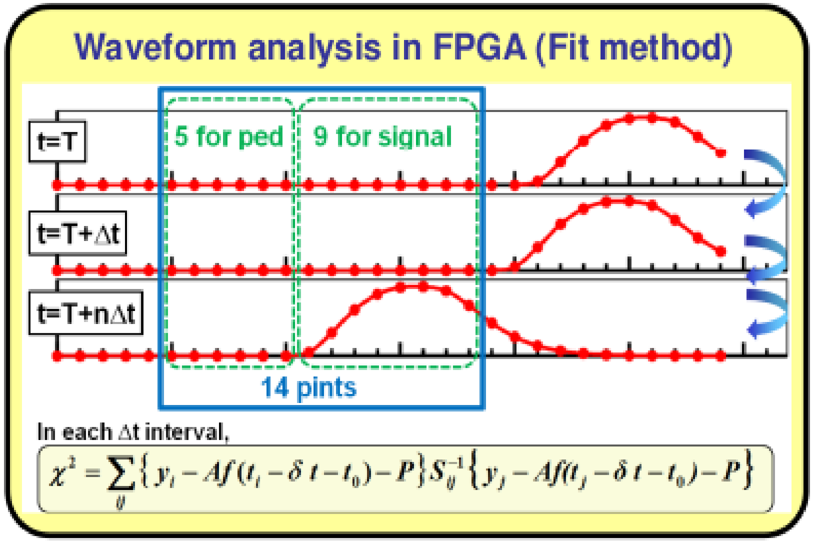
Physics trigger region



FAM (FADC Analog Module)





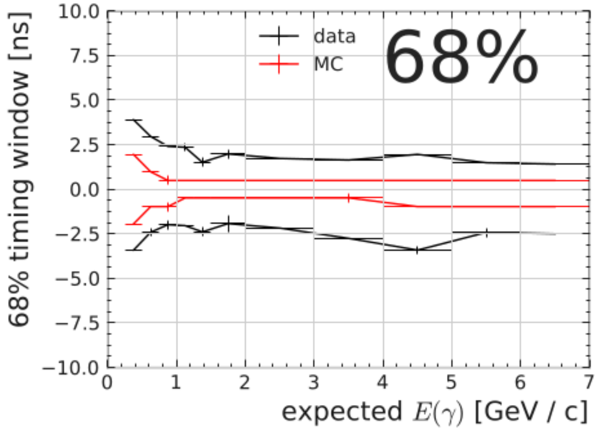


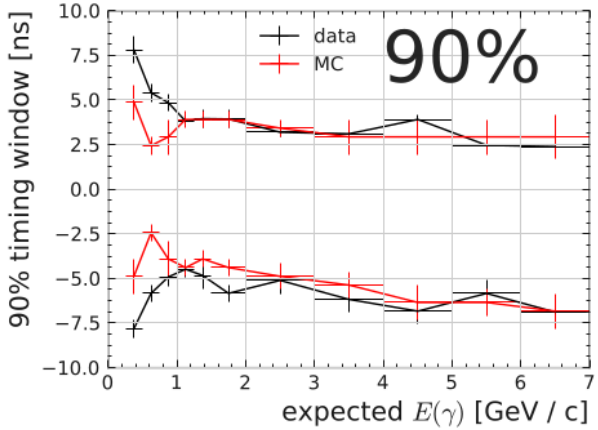
method	σ(E) MeV	σ(T) ns

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 desision is taken based on the event energy deposition, and event pattern.

Time resolution

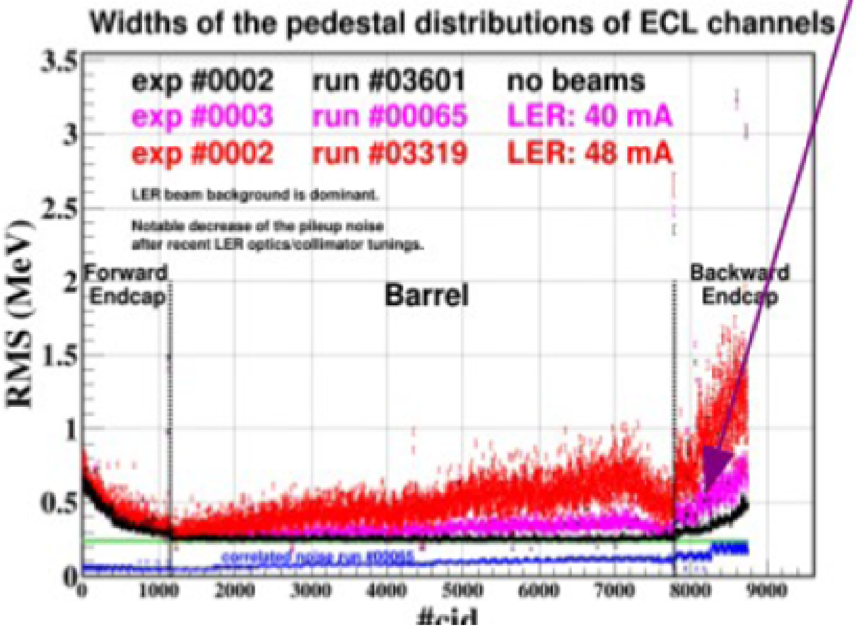




-Time resolution in data is worse than for MC
-If we take 90% fraction, the agreement is good
-more calibration and corrections should be implemented

Ecl background study

Pileup noise



Single beam HER = 285 mA

789 bunches βy = 3 mm