Electromagnetic calorimeter of BelleII

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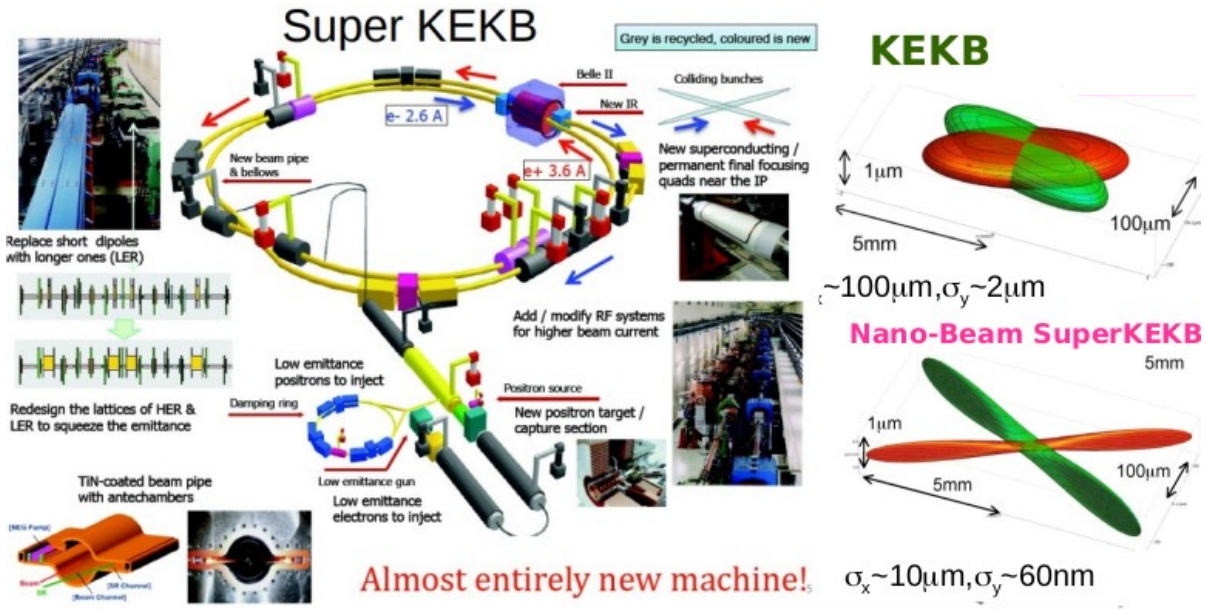
(For Belle II calorimeter team)

- SuperKEKB and Belle II
- Calorimeter upgrade
- Energy reconstruction
- Calorimeter Data acusition
- Calorimeter performance
- Photon/hadron separation
- Summary

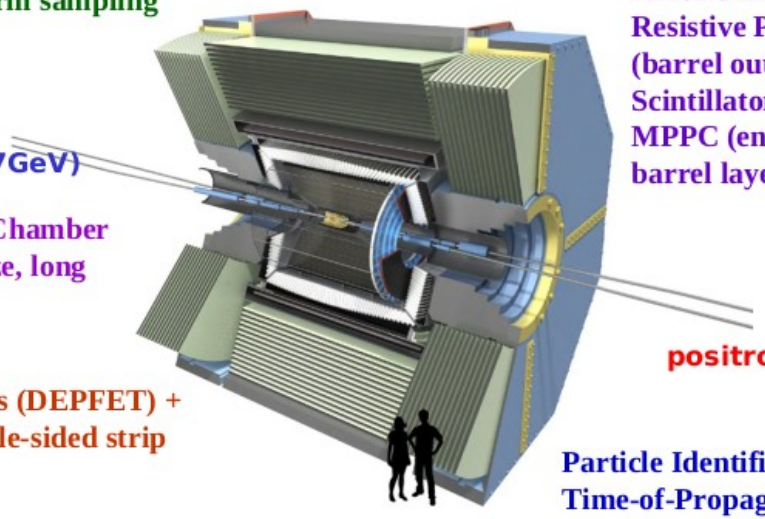
The 7th International Conference on Particle Physics and Astrophysics (ICPPA-2024)
Moscow.

Belle II



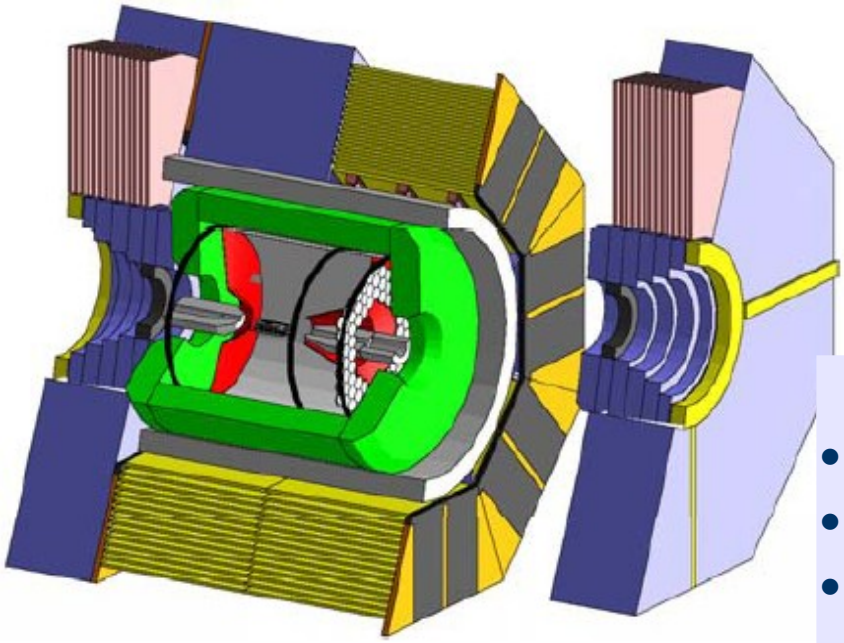
- e⁻(7GeV) -e⁺(4GeV) collider
- Target luminosity 6 10^{35} $cm^{-2}s^{-1}$
- Achived luminosity
  4.7 10^{34} $cm^{-2}s^{-1}$ (World Record)
- Accumulated luminosity
  ~500 fb^{-1}

- Study of rare decays of B-, D- mesons and τ.
- Measurement of CP violation parameters
- Search for new physics



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

Calorimeter



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

-Electron identifcation

-K_L identification

-Neutral trigger

-On-line luminosity measurement

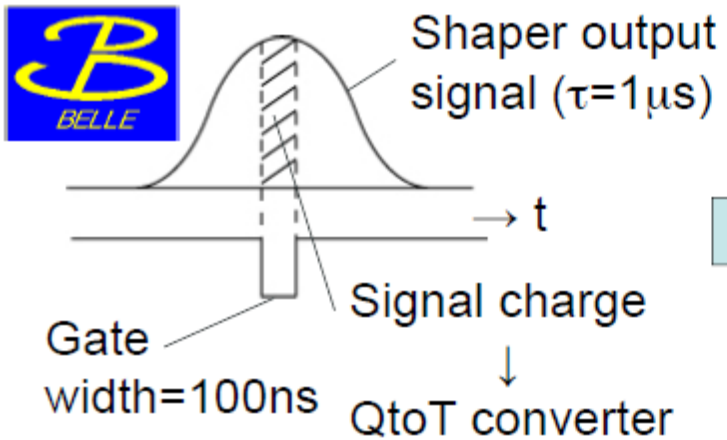
- Total 8736 counters.
- Barrel 6624
- Forward end cap 1152
- Backward end cap 960

Counter:

- 30cm long CsI(Tl) (16.1X0)
- 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 have been upgraded

Readout electronics change



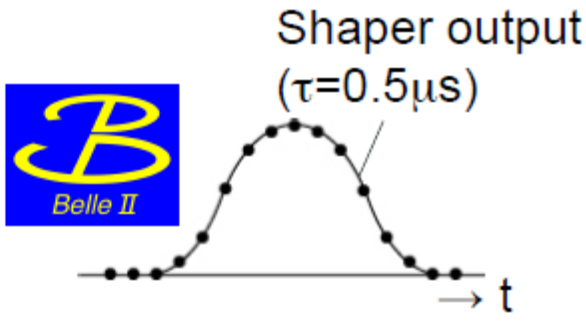
Signal charge

↓

QtoT converter
(MQT300A)

↓

Digitized by TDC

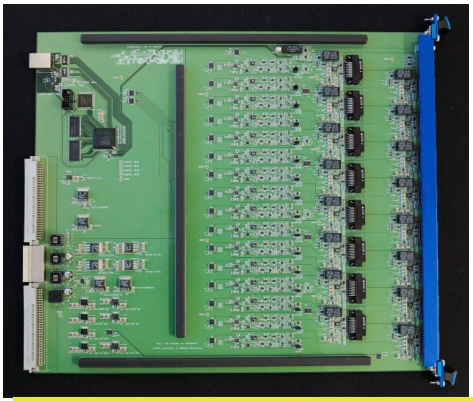


1.76MHz, 18bits digitizer

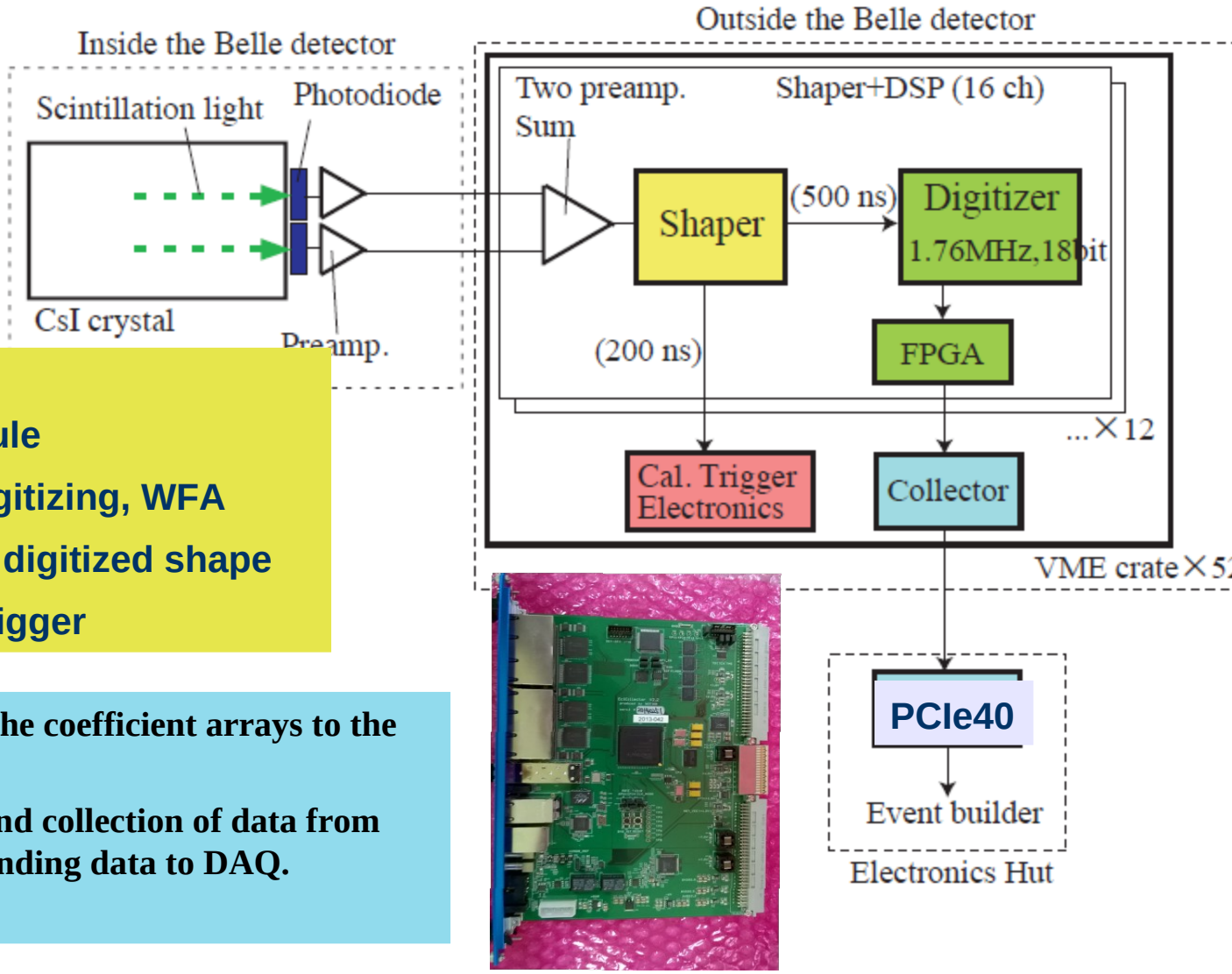
↓

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 (~500 ns), digitizing, WFA
- Output A, T, Q or\and digitized shape
- Fast sum signal for trigger

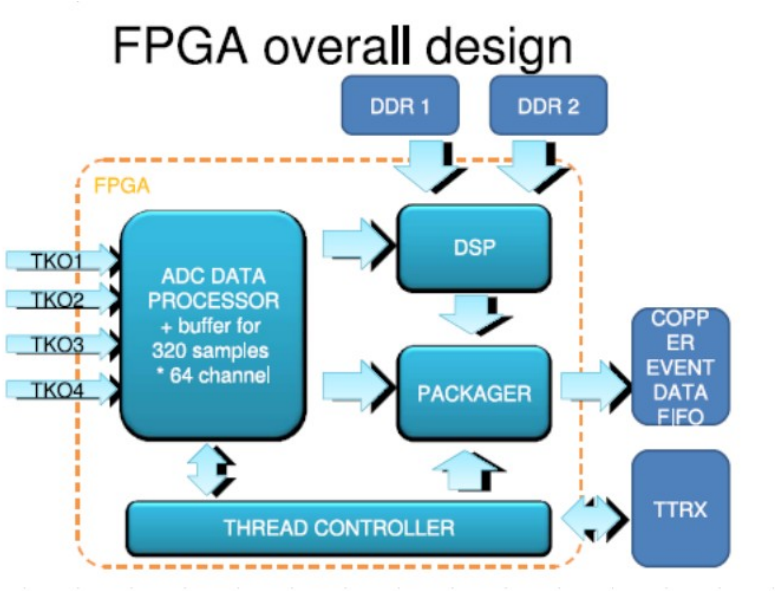


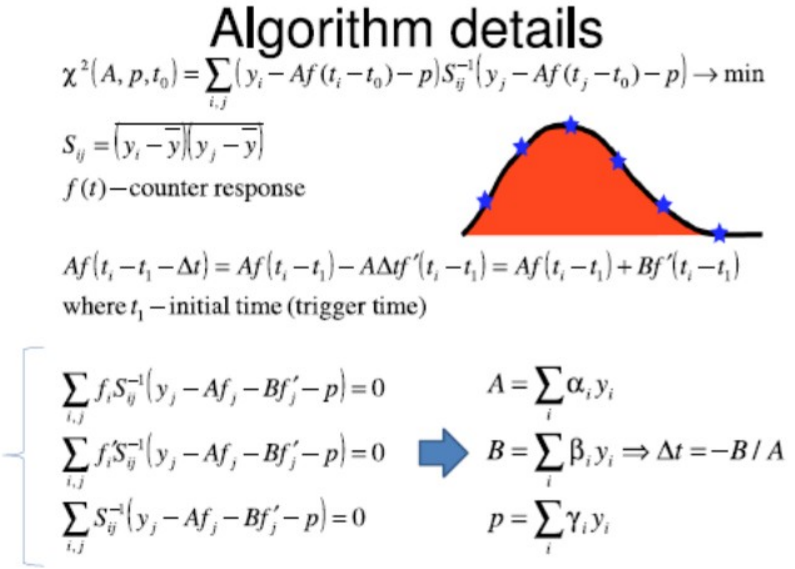
- Storage and loading of the coefficient arrays to the shaper-dsp-modules.
- Getting of the trigger and collection of data from shapers, packing and sending data to DAQ.
- Test pulses generation.

Fit algorithm in FPGA

Trigger → fit 16 points to response function taking correlations into account

- **Result Amplitude(18 bits), Time(12 bits), Quality of fit (4 bits)**
- **For some fraction of data both input and output information are sent to DAQ**





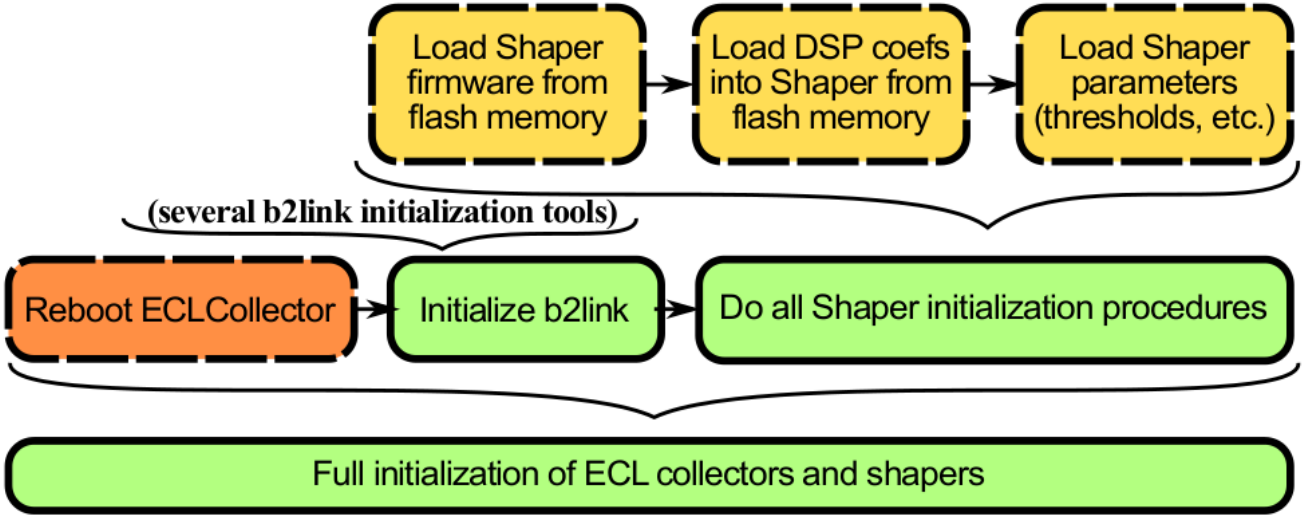
- **Algorithm can handle more than 40 kHz of the trigger rate with 100% occupancy**

(30 kHz is expected for design luminosity)

Calorimeter DAQ

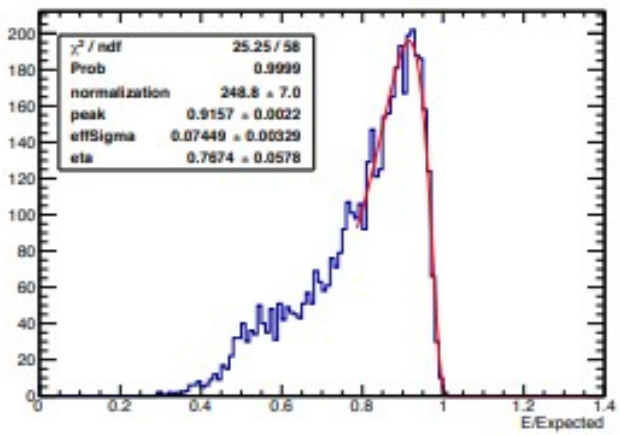
- **Calorimeter DAQ includes 576 ShaperDSP modules, 52 collectrs and 5 servers.**
- **The configuration includes ~80 000 parameters.**
- **Also we need about 1 500 000 coefficients for ShaperDSP algorithm**

- **The slow control system was developed for quick configuration and initialization of the Calorimeter DAQ**
- **The Data Quality Monitor continuesly provides histograms for shifters**



Full initialization takes ~1 minute.

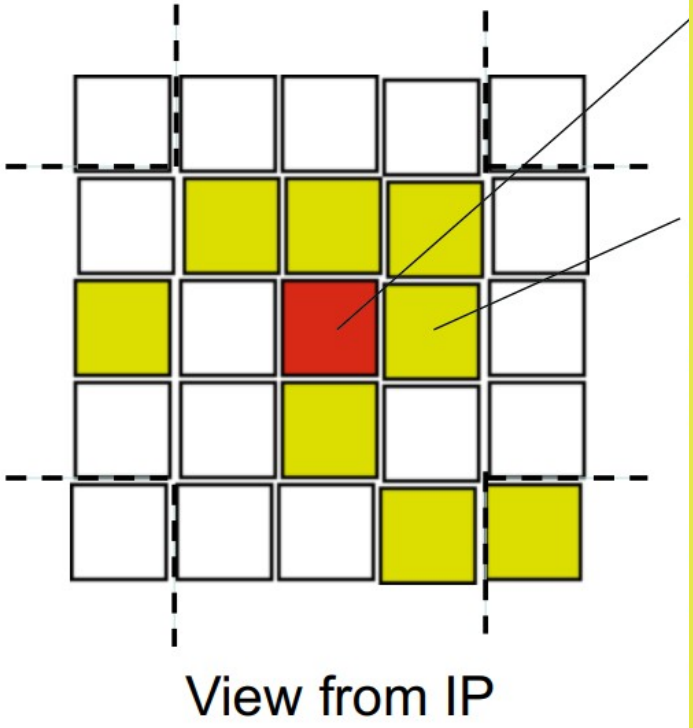
Gamma-gamma calibration



Energy response of individual crystals is calibrated using e+e- → γγ events.

- the most-energetic crystal in the shower is considered.
- right edge of the distribution doesn't depend on inactive material in front of Calorimeter.
-Accuracy is better 0.5%
-Calibration constants have changed an average of 2.0% since 2020. Decrease in light output is due to radiation damage.

Cluster reconstruction



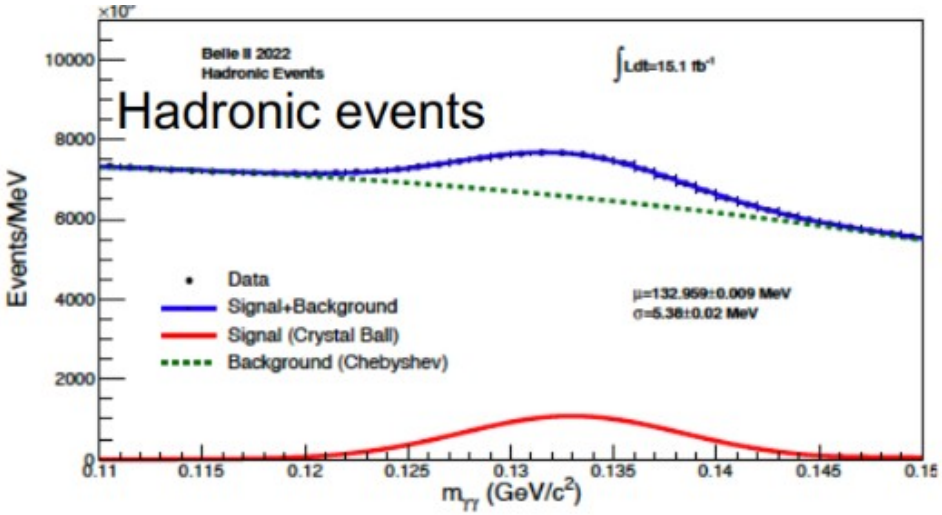
- **Seed crystal: Local maximum energy deposition exiding 10 MeV**
- **Belle: hits exeeding certain threshold inside 5x5 matrix surrounding the seed crystal are considered**
- **BelleII: highest N-hits are considered among 21 crystals (5x5 matrix without corner crystals)**

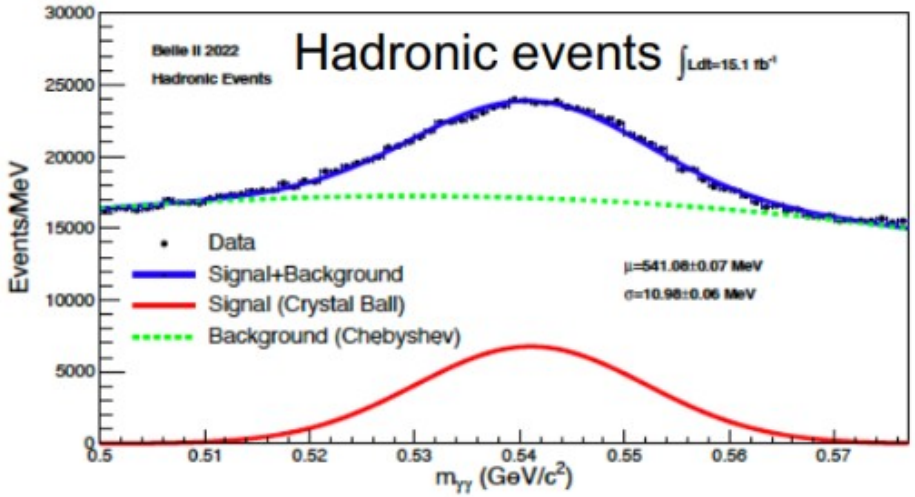
To get the photon energy: cluster energy is corrected by function depending on E, angles and the background level

Calorimeter performance

Energy resolution was studied for $e^+e^- \to \mu^+\mu^-\gamma$ events
For 1 GeV $\sigma E/E$=2.2% $\sigma\tau$ of few ns

For Hadronic events:
$\pi^0 \to \gamma\gamma$ (E_γ>25 MeV) $\sigma m_{\gamma\gamma}$=5.4 MeV/c^2 $\eta \to \gamma\gamma$ (E_γ>400 MeV) $\sigma m_{\gamma\gamma}$=11 MeV/c^2

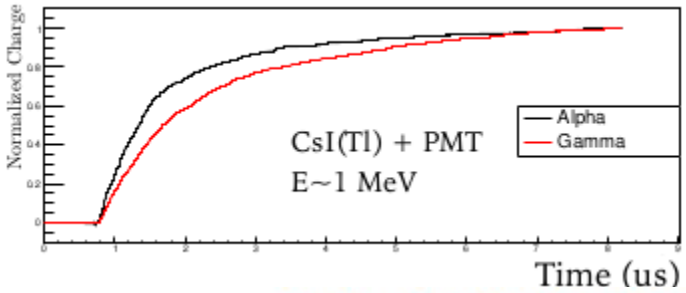


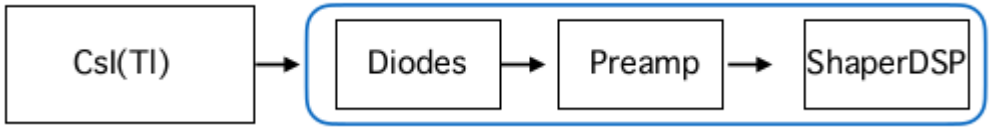


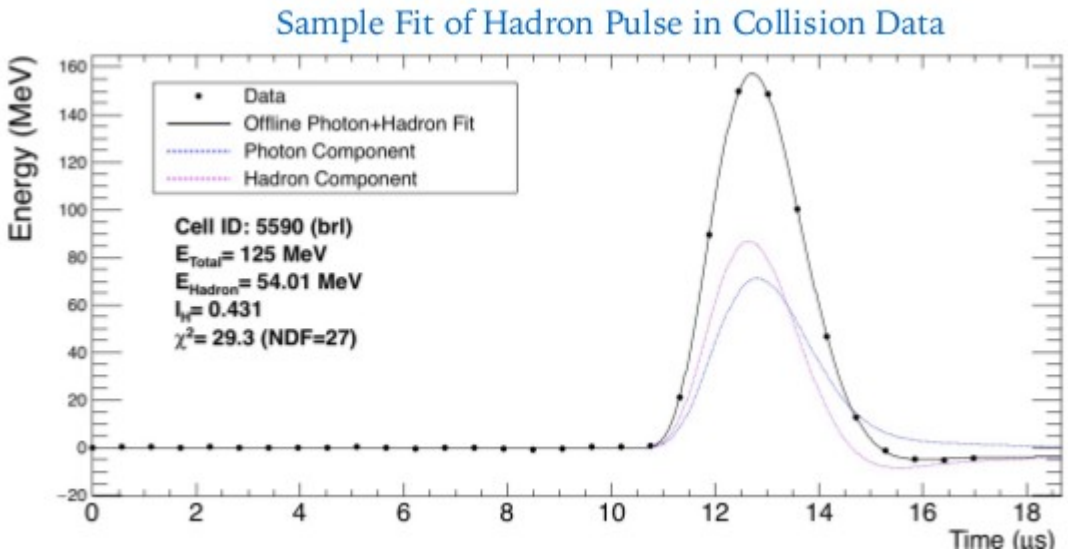
Hadron/photon separation

There is a 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.

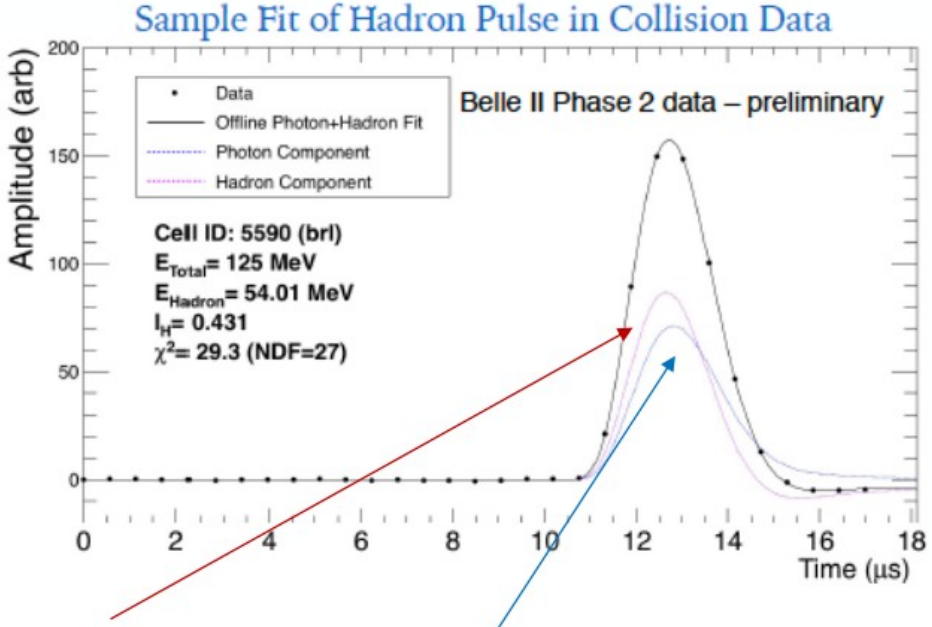
$$E_{\mathrm{Total}} = E_{\mathrm{Photon}} + E_{\mathrm{Hadron}}$$

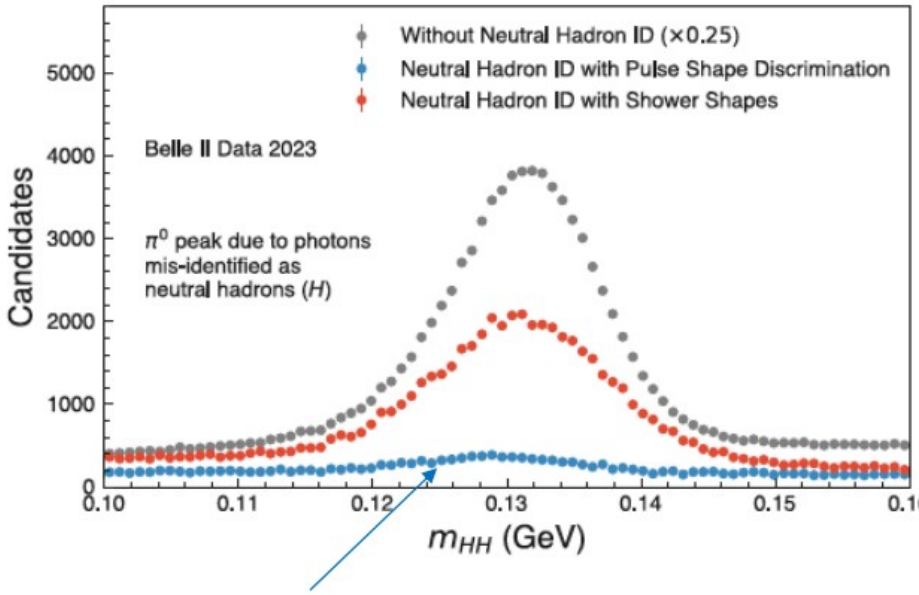
$$N_{\mathrm{H}} = \frac{E_{\mathrm{Hadron}}}{E_{\mathrm{Total}}}$$

For hits E > 50 MeV waveforms were recorded and analyzed.

Hadron/photon separation

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.

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Summary

-The electronics of Belle II calorimeter has been upgraded and works with high reliability.

-Calorimeter DAQ software provides fast initialization and configuration control.

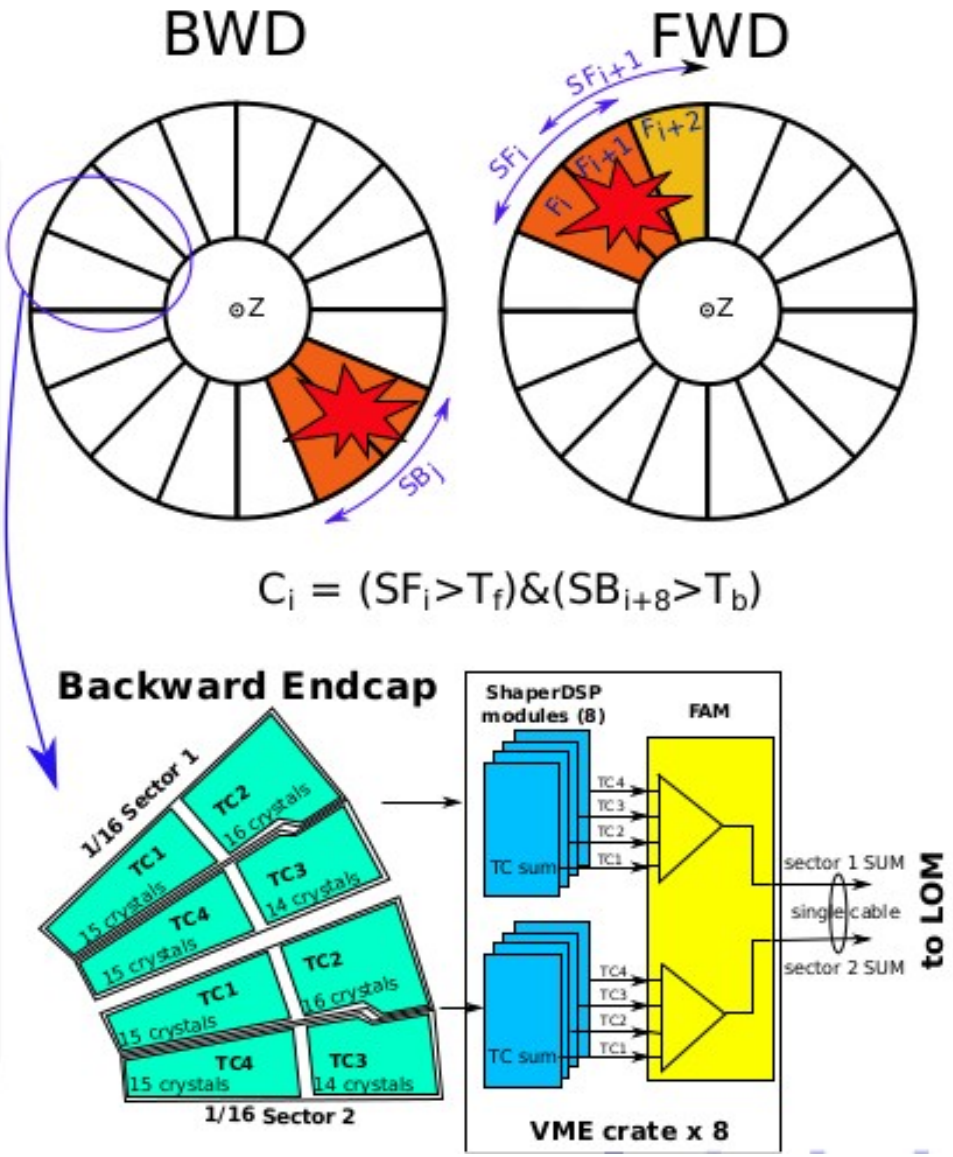
-Calorimeter shows good performance.

-Wave form information can be used for hadron identification

Backup

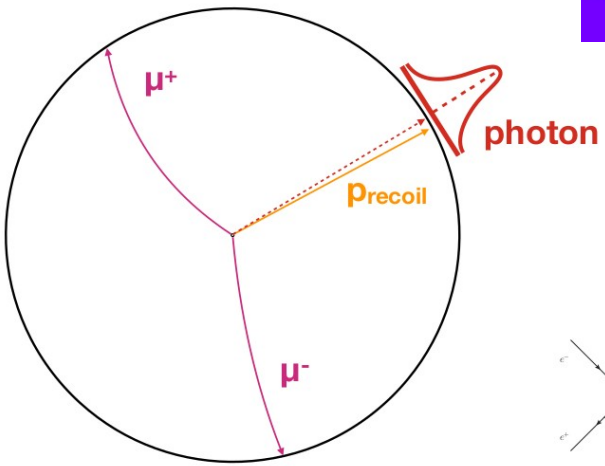
ECL luminosity monitor

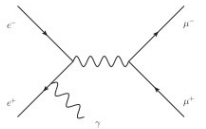
- One endcap 1/16 sector (4 Trigger Cells)
- Each FAM module processes signals from 8 ShaperDSP boards (8 TC) signals and provides analog signals from two endcap sectors to LOM module
- Inner Forward Endcap sector is excluded (may be included)
- Coincidence rate of the signals in opposite sectors is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



ECL study in ee->μμγ

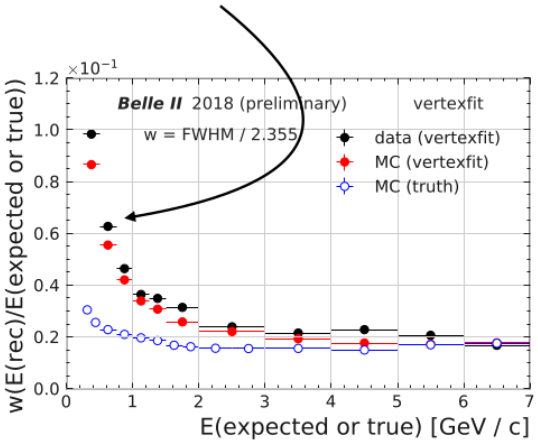
-Energy and direction of the photon can be obtained from the kinematical reconstruction and compared with the measured values





Crystal ball, iteratively

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



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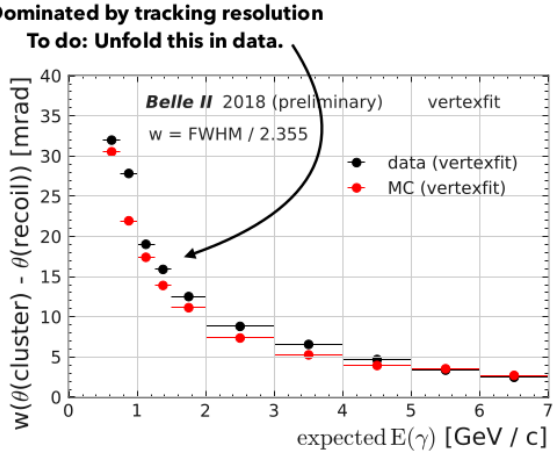
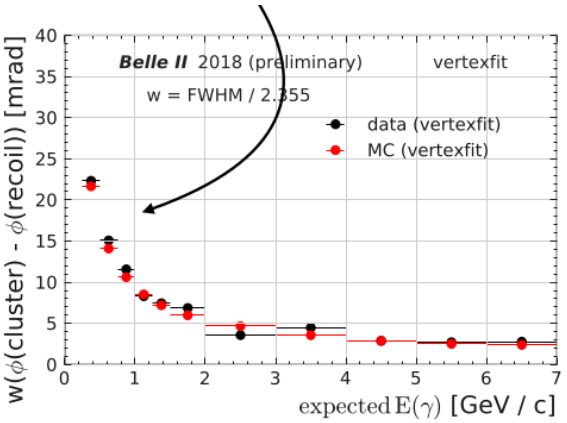




-The energy and position resolution is in agreement with MC
-At low energies the main contribution comes from the accuracy of the kinematical reconstruction

FAM (FADC Analog Module)

CsI(Tl)+PD +PreAmp

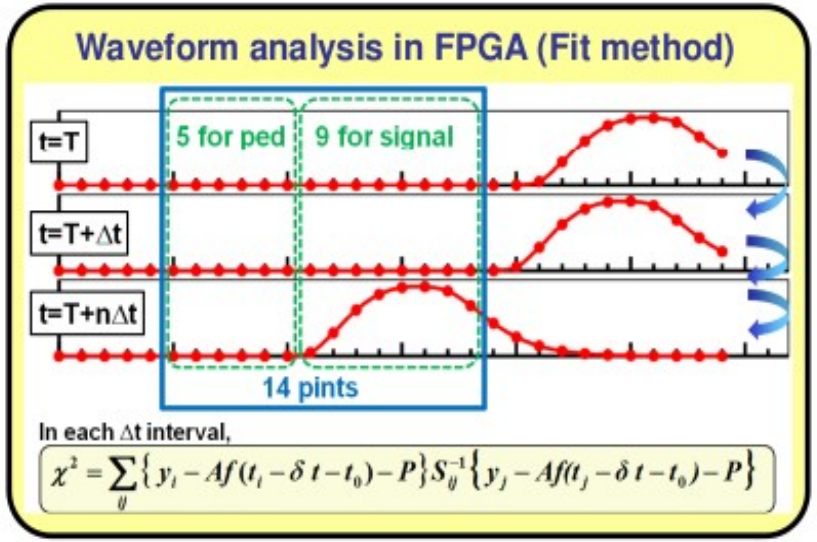
ShaperDSP (576)

FAM (52)

TMM(7)

ETM(1)

GDL/GRL/DAQ



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.