The Belle Calorimeter

— Operation and Upgrade —

XIII International Conference on Calorimetry in High Energy Physics

Pavia, Italy, 26–30.May.2008

中村 勇 / 高エネルギー研

The Belle Calorimeter (1)

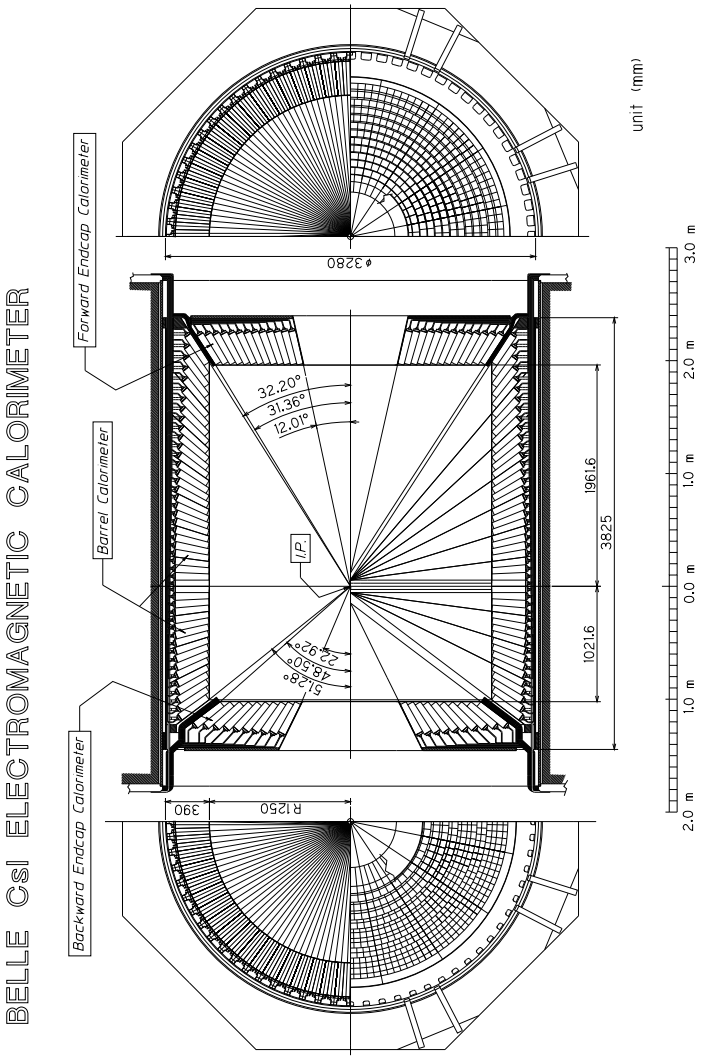
❑ Requirement to the Calorimeter

- Detection of γ and π^0
- Good Energy Resolution from Low E
  - ◇ 10 MeV to 10 GeV
  - ◇ σ has linear effect for some physics
- Hermeticity for final state with ν
- Rate resistance

❑ 8736 CsI(Tl) Crystals

- 5.5×5.5×30 cm^3
- 6624(B)+1152(FWD)+900(BWD)
- λ =560 nm/τ =1.3 μsec (Slow)
- 12° ↔ 155°
- 50000 p.e./MeV (No stochastic term)
- 64 Different Shapes
- Read out by two PIN photodiode

The Belle Calorimeter



The Belle Calorimeter (2)

❑ Readout Electronics

- Hamamatsu 10×20 mm^2 PIN photodiod (S2744-08)
- Preamplifier (Charge Integration)
- Two Shapers
  - ◇ 1μsec ⇒ for E measurement
  - ◇ 0.2μsec ⇒ for Trigger
- $Q \rightarrow T$ Translation
  - ◇ LeCroy MQT300A (12 bit×3 ranges)
  - ◇ 16ch/Board (TKO)
- Recorded by FastBus TDC
  - ◇ LeCroy 1877S (16 bit, C.Start)
  - ◇ 96ch/Board (5 Crates)
  - ◇ 3 VME Systems
  - ◇ Sparsification at E_{th} = 0.5 MeV
  - ◇ Readout Deadtime (~ 30 μsec)
- Energy information Only, no timing

Counter

Calibration

❑ Energy Reconstruction

$$E = \mathcal{G} \cdot C(T - T_0)$$

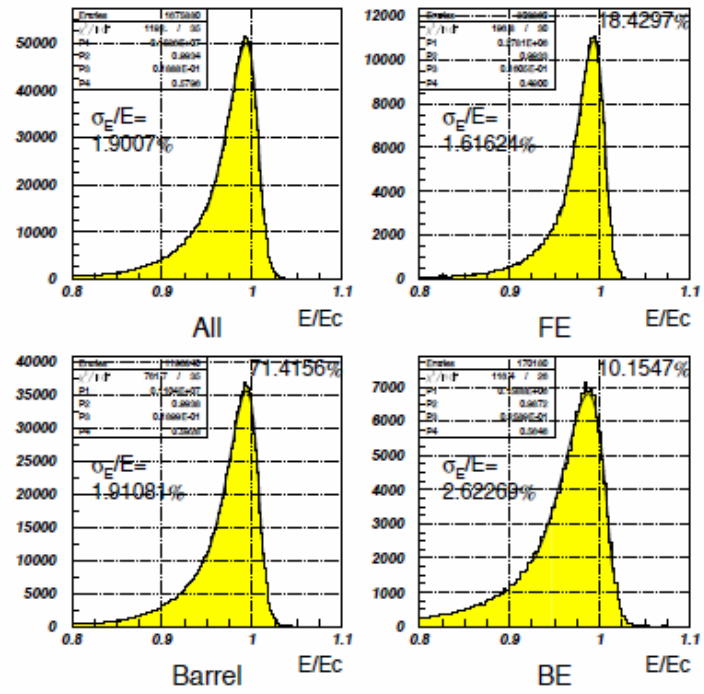
- T_0 : Pedestal
- $\mathcal{G}$: Electronics Gain
- C : Conversion Factor

- Pedestals and Gains Monitord every day
  - Calibration circuit in the Frontend
- Conversion factor determined by
  - $e^-e^+ \rightarrow e^-e^+$ Events (Main Mode)
  - $e^-e^+ \rightarrow \gamma\gamma$ Events
  - Cosmic Ray Events near beampipe
- Bhabha Calibration
  - minimize

$$\chi^2 = \sum^{N_{bb}} \frac{\left(E_{exp} - \sum_{i \in cls} C_i \cdot E_i\right)^2}{\sigma^2}$$

  - Sparse Matrix Inversion

Energy Distribution



Environment and Monitoring

To keep constant environment

- Water Cooling (for Temperature)
- Dry Air circulation (for Humidity)

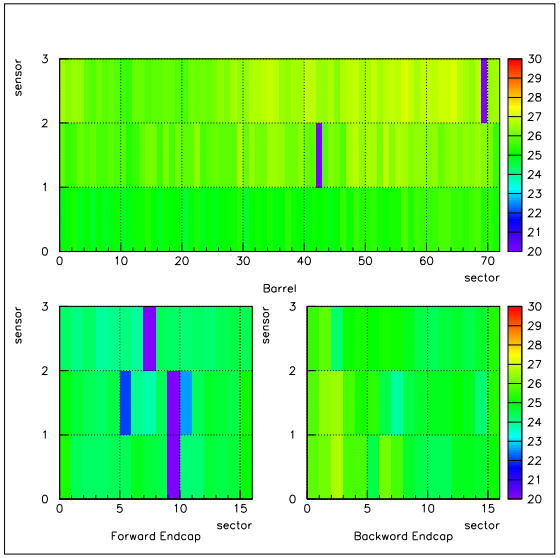
Environment Monitor

- Monitors
  - 312 Temperature Probes
  - 104 Humidity Probes
  - Bias Current Monitors
  - Power Supply Monitors
- All logged,
- connected to interlock/alarm system
- watched by safety shift

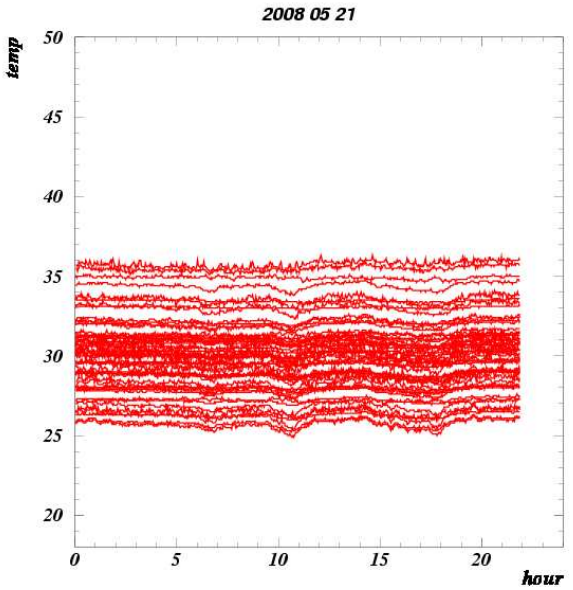
Data Quality Monitor

- Monitored by DAQ shift

Temperature of Calorimeter

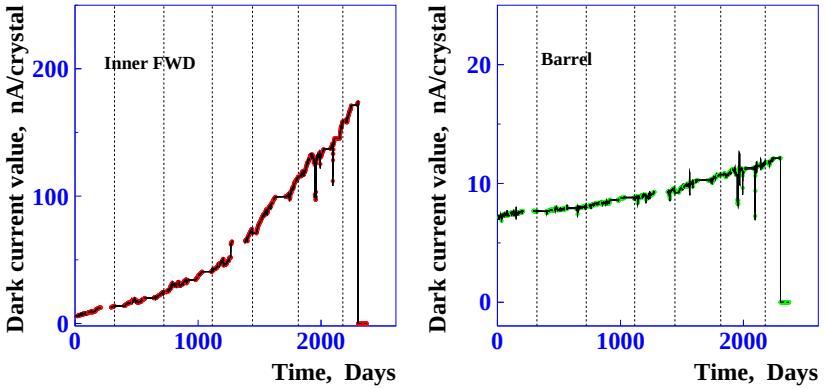


Temperature of Power Supply

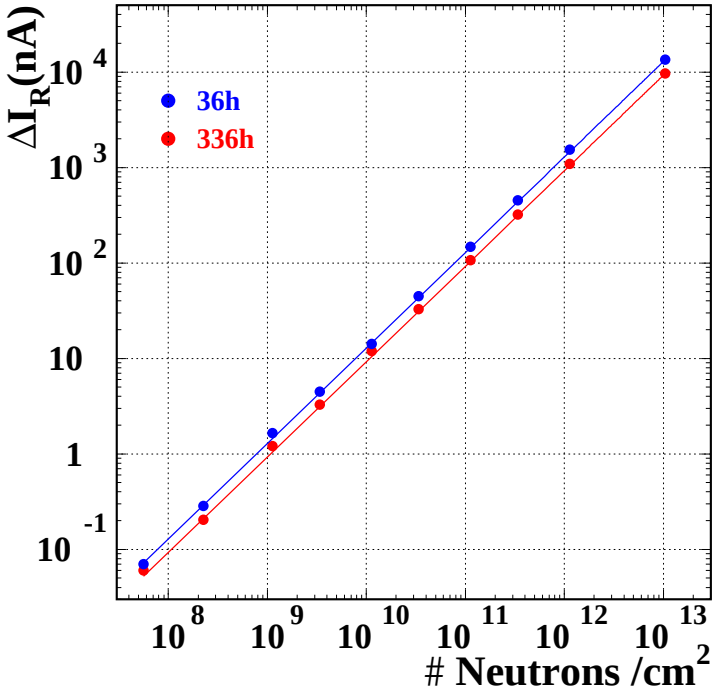


Problems – Radiation Damage –

Increase of Dark Current



ΔI vs Neutron Fluence



- **Unexpected increase of Dark Current**
  - γ-ray resistance tested
    - CsI(Tl) crystals up to 1 krad
    - PD up to 70 krad
  - γ-ray dose can be measured by
    $$\int (I_{\rm on} - I_{\rm off})dt \sim \int E_\gamma dt$$
    estimated to be $O(100)$ rad
  - From ^{60}Co test $\Rightarrow$ $O(100)$ krad
- **Turned out to be Neutron**
  - Crystals and PD tested @ Reactor "弥生"
    - 1 nA $\Leftrightarrow$ 7×10^8 n/cm^2
    - 10^{11} n/cm^2 for Foward
  - PD and crystals can survive up to 10^{13}

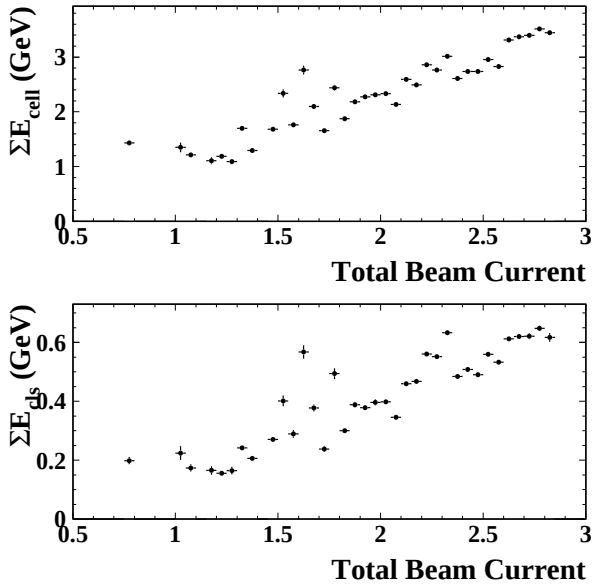
Problems – Accelerator Background –

- **A lot of accelerator Background (γ)**
  - $\sum E_{\mathrm{cel}} = 3$–$4$ GeV/event with $E_{\mathrm{th}} = 0.5$ MeV
  - $E_{\mathrm{cel}}^{\mathrm{bkg}}(\theta) = 0.3$–$1$ MeV
  - $\sum E_{\mathrm{cls}} = 500$ MeV after clustering
  - Several Fake clusters / Event
  - Proportional to $I_{\mathrm{beam}} \times P_{\mathrm{V}} \sim I_{\mathrm{beam}}^2$
    $\Rightarrow$ expect $\times 20$ at 10^{35}

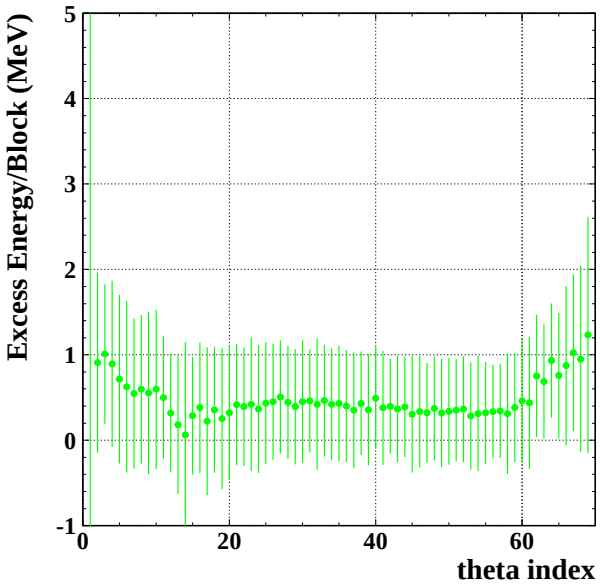
- **Effect to Physics**
  - Fake photons
  - Photon finding Efficiency
    - Cluster Shape changes
  - Energy Scale/ Resolution
  - Random-Triggered events overlaid to Monte Carlo

- **Need to introduce Timing information**

Background Energy vs Current



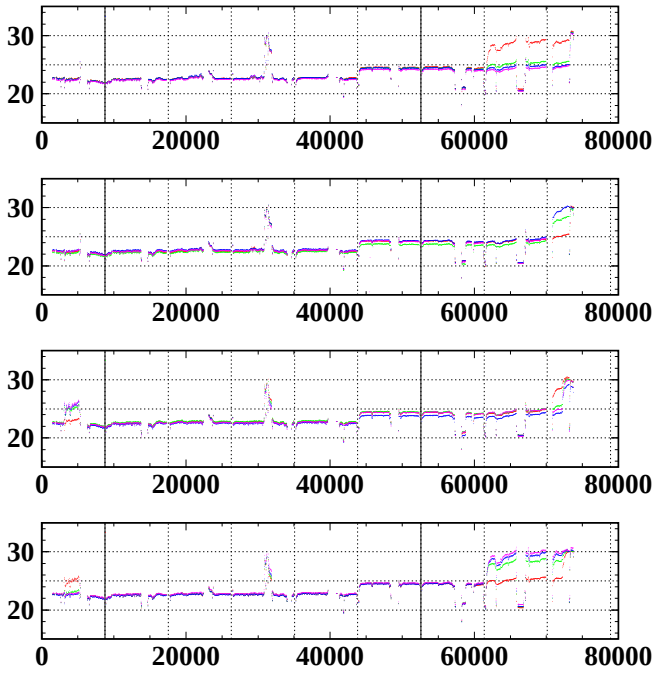
Energy shift vs θ



Problems – Accident –

- **Broken connection circuit**
  - Bias disconnected (one dead counter)
- **Water Circulation Stopped**
  - Rusted Water Tube Joint
- **Fastbus**
  - Bad contacts (~20 year old crates)
- **Power Supply**
  - Many broken cooling FANS
- **Human Resources**
  - No original member/expert on site
  - only a few amateur to maintain
  - No New student anymore
- **In short, Everything gets OLD**

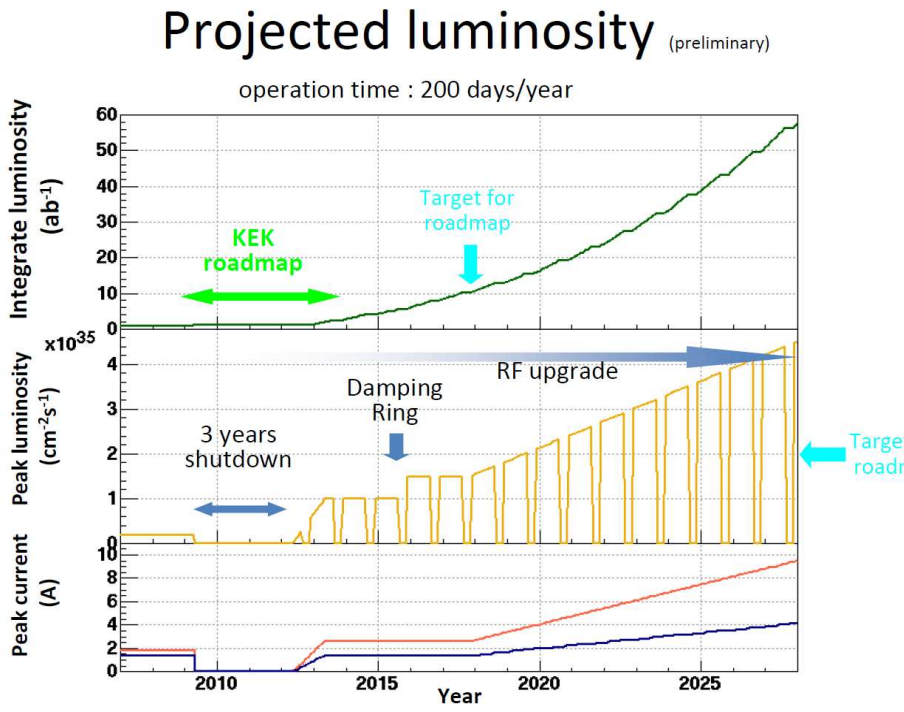
History of ECL Temperature

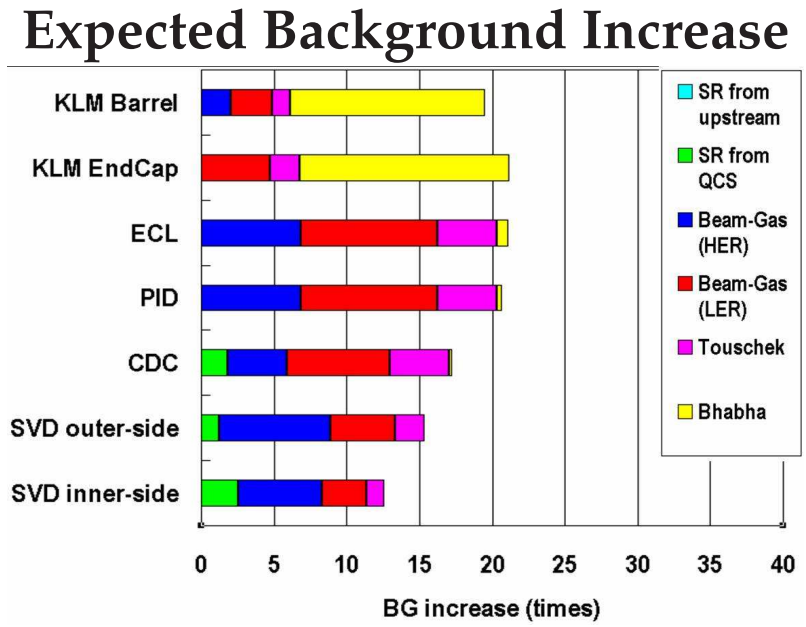


Damaged Joint

Upgrade Plan

- **Expected Situation @ 10^{35}**
  - Trigger Rate as high as 10 kHz
  - ×20 Background ($\propto I^2$)
- **Solutions**
  - Pipelined read out
  - Waveform sampling
  - Replacement to Faster Crystal
- **Restrictions**
  - Budget
  - Barrel Replacement Unrealistic
  - Human Resources
  - Reuse Endcap Container

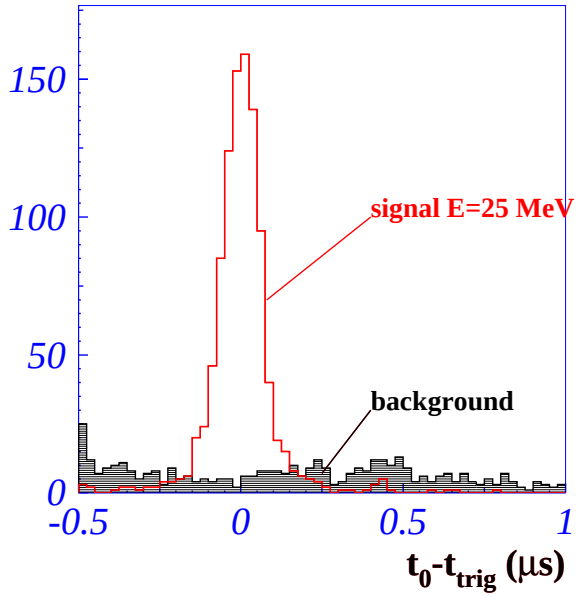




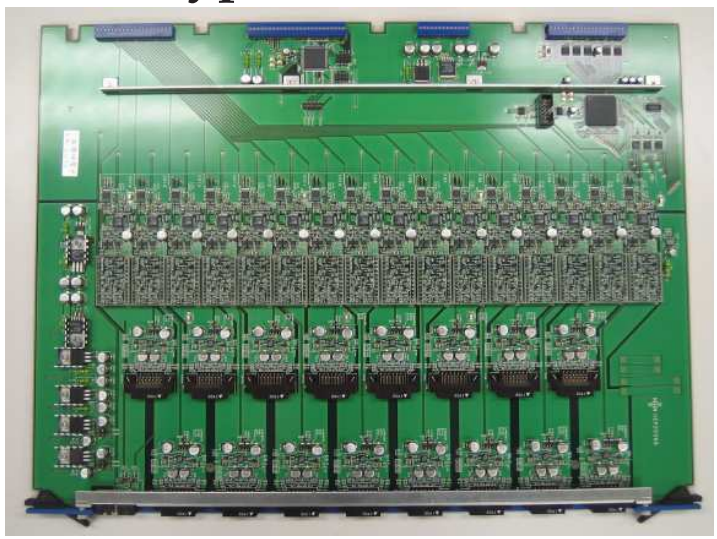
Step 1 – Electronics Upgrade

- **Reuse Crystal/PD/PreAmp**
  - Unrealistic to Dismount Cryatals
- **Frontend @ Detector**
  - Faster shaper (1μsec $\rightarrow$ 0.5 μsec)
  - Waveform sampling (18 bit/2 MHz)
  - keep same trigger signal
  - 16ch/board, ~550 boards, 50 crates
- **Backend @ E-hut**
  - Pipelined DAQ (COPPER/VME by KEK)
    - 128 deep (60μsec)
  - Hardware waveform fitting (FPGA)
    - 16 sampling points
    - $F(t) = A \cdot \mathcal{S}(t - t_0) + B \cdot \mathcal{B}(t)$
  - Data Suppression
  - 128 ch/board, ~70 boards, 4 crates
- **Background Reduction Factor ~7**

Expected Timing Distribution



Prototype Frontend Board



Electronics Upgrade – Preparation Status

❑ Cosmic Ray Testbench

- 4×4 matrix
- TKO version of digitizer board
- 64 ch FINESSE for Fitting

❑ Digitizer Board

- Basic Function working
- Form Factor in discussion (avoid TKO)
- Link to E-Hut in discussion (TRG/DAQ)

❑ Readout Board (FINESSE)

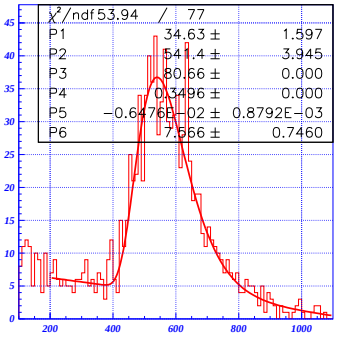
- Working w/o Problem
- Hardware waveform fitting Working

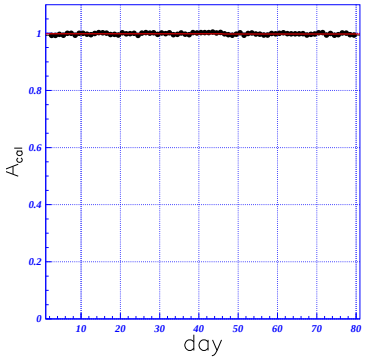
❑ Test in Belle

- will be installed to Belle in this summer
- take cosmic

Cosmic Ray Testbench

Stability Test

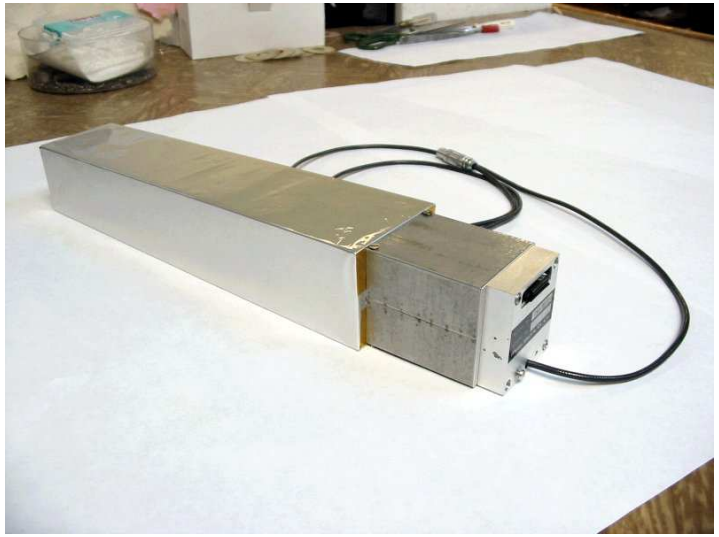




Step 2 – Crystal Replacement

- **Reuse containers**
- **Undoped CsI crystal**
  - Only Resonable Solution
    - LSO/LYSO is nice but too expensive
  - 50 万円/crystal
  - 0.1× p.e. compared with CsI(Tl)
  - $\tau_{\mathrm{fast}} = 10 - -30$ ns, $\lambda_{\mathrm{fast}} = 310$ nm
- **Photo Detector candidates**
  - Short Finemesh Phototube ($\mathcal{G}$ ~200)
  - Flat MCP/PMT with 10 μmϕ pore
  - Avalanche Photo Diode (CMS type)
- **Frontend**
  - Fast Shaping
  - 3×12 bit FADC/42 MHz sampling
  - Hardware fitting in frontend

Prototype Counter



Short Phototube

Crystal Replacement – Preparation Status

❑ CsI(Pure) Crystal

- Bought from different producers
- Measured basic properties
  - ◇ # p.e./MeV, uniformity ..
- Radiation Hardness
  - ◇ 100 krad for γ
  - ◇ 10^{13} neutron/cm^2

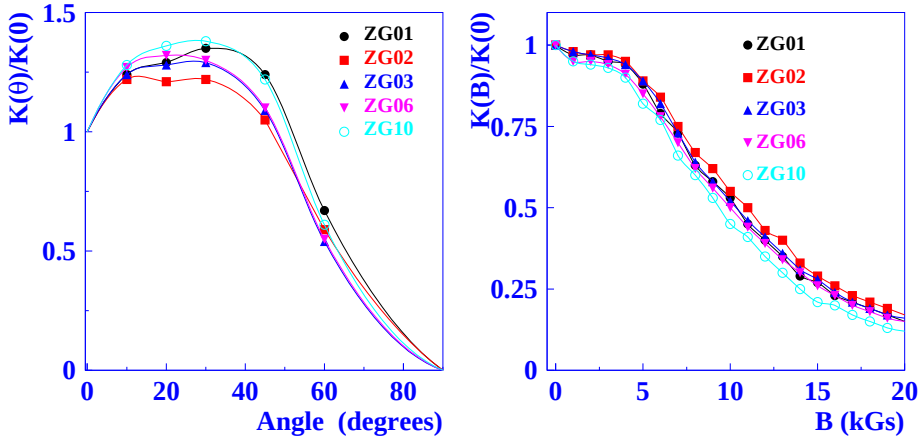
❑ Phototube

- Gain
- Effect of Magnetic Field

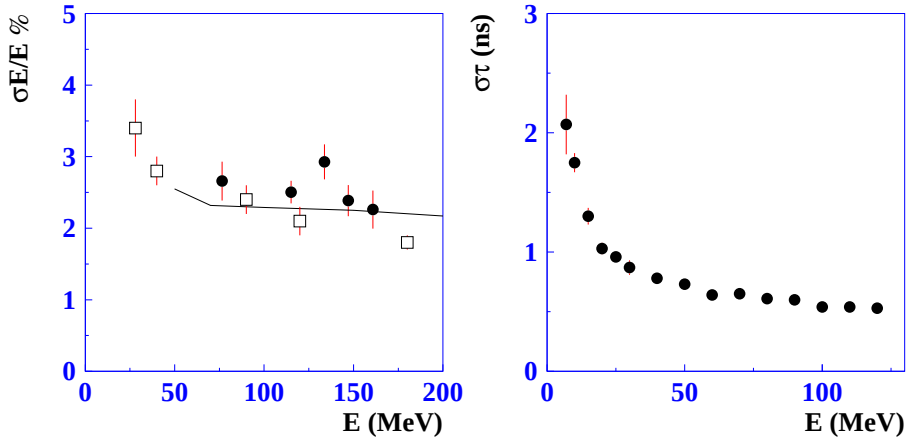
❑ Test beam

- @ BINP (70–160 MeV γ beam)
- 4×5 crystals with phototubes

Magnatic Field Test



Test Beam Results



纏め

- **Belle Calorimeter**
  - CsI(Tl) + PIN PD
  - Traditional(Conservative) Trigger/ADC readout
- **Problems**
  - Radiation Damage of PD
  - Increase of Accelerator Background (0.5 MeV/cel)
  - Many Troubles as the Detector gets Old
- **Upgrade Step.1**
  - Waveform Readout (1 μs)
  - Pipelined Readout
  - Factor 7 Improvement
- **Upgrade Step.2**
  - CsI(Pure) + Phototube (10 ns) for Endcaps
  - Factor 20 Improvement