The Belle Calorimeter
— Operation and Upgrade —

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The Belle Calorimeter (1)

- **Requirement to the Calorimeter**
  
  - Detection of $\gamma$ and $\pi^0$
  - Good Energy Resolution from Low $E$  
    - 10 MeV to 10 GeV  
    - $\sigma$ has linear effect for some physics
  - Hermeticity for final state with $\nu$
  - Rate resistance

- **8736 CsI(Tl) Crystals**
  
  - $5.5 \times 5.5 \times 30$ cm$^3$
  - $6624(B) + 1152(FWD) + 900(BWD)$
  - $\lambda = 560$ nm/$\tau = 1.3$ $\mu$s (Slow)
  - $12^\circ \leftrightarrow 155^\circ$
  - 50000 p.e./MeV (No stochastic term)
  - 64 Different Shapes
  - Read out by two PIN photodiode

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The Belle Calorimeter
The Belle Calorimeter (2)

- **Readout Electronics**
  - Hamamatsu 10×20 mm² PIN photodiod (S2744-08)
  - Preamplifier (Charge Integration)
  - Two Shapers
    - 1 µsec ⇒ for $E$ measurement
    - 0.2 µsec ⇒ for Trigger
  - Q → 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 ($\sim 30$ µsec)
  - Energy information Only, no timing
Calibration

- **Energy Reconstruction**

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

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

- Pedestals and Gains Monitored 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

\[
\chi^2 = \sum \frac{(E_{exp} - \sum_{i \in \text{cls}} C_i \cdot E_i)^2}{\sigma^2}
\]

- Sparse Matrix Inversion
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
Problems – Radiation Damage –

- **Unexpected increase of Dark Current**
  - $\gamma$-ray resistance tested
    - CsI(Tl) crystals up to 1 krad
    - PD up to 70 krad
  - $\gamma$-ray dose can be measured by
    \[
    \int (I_{on} - I_{off}) dt \sim \int E_\gamma dt
    \]
    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 $\Leftrightarrow 7 \times 10^8$ n/cm$^2$
    - $10^{11}$ n/cm$^2$ for Forward
  - PD and crystals can survive up to $10^{13}$
Problems – Accelerator Background –

- A lot of accelerator Background ($\gamma$)
  - $\sum E_{cel} = 3$–$4$ GeV/event with $E_{th} = 0.5$ MeV
  - $E_{cel}^{bkg}(\theta) = 0.3$–$1$ MeV
  - $\sum E_{cls} = 500$ MeV after clustering
  - Several Fake clusters / Event
  - Proportional to $I_{beam} \times P_V \sim I_{beam}^2$
    $\Rightarrow$ expect $\times20$ 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
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
Upgrade Plan

- **Expected Situation @ \(10^{35}\)**
  - Trigger Rate as high as 10 kHz
  - \(\times 20\) 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 Crystals

- **Frontend @ Detector**
  - Faster shaper ($1 \mu \text{sec} \rightarrow 0.5 \mu \text{sec}$)
  - 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 (60$\mu \text{sec}$)
  - Hardware waveform fitting (FPGA)
    - 16 sampling points
    - $F(t) = A \cdot S(t - t_0) + B \cdot B(t)$
  - Data Suppression
    - 128 ch/board, ~70 boards, 4 crates

- **Background Reduction Factor ~7**

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**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](image1)

![Stability Test](image2)
Step 2 – Crystal Replacement

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

- **CsI(Pure) Crystal**
  - Bought from different producers
  - Measured basic properties
    - # p.e./MeV, uniformity...
  - Radiation Hardness
    - 100 krad for $\gamma$
    - $10^{13}$ neutron/cm$^2$

- **Phototube**
  - Gain
  - Effect of Magnetic Field

- **Test beam**
  - @ BINP (70–160 MeV $\gamma$ beam)
  - 4×5 crystals with phototubes
Belle Calorimeter

- CsI(Tl) + PIN PD
- Traditional(Conservative) Trigger/ADC readout

Problems

- Radiation Damage of PD
- Increase of Accelerator Background (0.5 MeV/ceil)
- 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
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