Overview of Trigger/DAQ design for Super-KEKB

based on discussions at Belle Trigger/DAQ workshop in Nara (Nov.03)

Ryōsuke Itoh, KEK

1. Introduction
2. Design of Trigger
3. Design of DAQ
4. Data Reduction
5. Summary

Super B Factory Workshop in Hawaii, 1/20/04
1. Introduction

- Expected trigger rate @ Super-KEKB is more than 10KHz with an event size of a few hundred kilobytes.

- Belle DAQ: running at ~400Hz with the size of ~40KB/event.
  - currently using Q-to-T conversion + multihit TDC

=> no pipeline is used.
=> has readout dead time.

~2% @ 400Hz

becomes >50% @ 10KHz
(linear extrapolation)

Belle's DAQ is not usable for SuperKEKB

-> need to develop pipelined DAQ
* Data flow rate

- Assume 10KHz trigger with 200KB/event size
  - results in 2GB/sec data flow at Level 1

- Online data reduction @ Belle
  So-called L2.5 trigger
  - ultra-fast tracking to discard off-IP events
  - take "physics-trig'd events" (like Etot > 3GeV)
  - Reduction factor : ~50%
  - flow rate -> reduced to 1GB/sec
  - still too much

  c.f. Expected data flow at storage in LHC experiments
  ~ 200-300MB/sec

We need a factor 5 more reduction!

- Trigger tightening?  <- already tight enough
- Sophisticated event selection
- A large scale Level 3 farm is required.
Design strategy

- Make use of know-hows in current Belle’s Trigger/DAQ systems as much as possible
- Pipeline based readout is essential
- Use of common electronics as possible
  → CoPPER (Common readout platform)
    * unified handling of pipeline readout using on-board PC module
    * detail will be covered in Higuchi’s talk
- Scalability
  → to keep up with gradual increase in luminosity
2. Design of Trigger

- Belle's trigger scheme is working fine and scalable to SuperKEKB environment.
  * Belle's design was made in order to minimize the trigger rate to reduce the DAQ deadtime. -> suitable for SuperKEKB

- Main Triggers
  - CDC : charged track trigger
  - ECL : Total energy and cluster counting

**Things not yet fixed**

- Event Timing (required for CDC tracking/SVD L0 trigger)
  * Belle's timing : TOF/TSC -> jitter < 10ns
  * SuperKEKB : CsI ~ 20ns

- Z-trigger
  * No fast Trigger output from SVD readout chip
  * Need to think about intelligent z-trigger using CDC stereo.
### Available Sub-Triggers

<table>
<thead>
<tr>
<th>Trigger Type</th>
<th>Belle</th>
<th>Super-Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Charged Track</td>
<td>r/phi</td>
<td>CDC</td>
</tr>
<tr>
<td></td>
<td>z</td>
<td>CDC or SVD</td>
</tr>
<tr>
<td>Energy</td>
<td>ECL</td>
<td>ECL</td>
</tr>
<tr>
<td>Cluster</td>
<td>ECL</td>
<td>ECL</td>
</tr>
<tr>
<td>Timing</td>
<td>TOF</td>
<td>ECL</td>
</tr>
<tr>
<td></td>
<td>ECL</td>
<td></td>
</tr>
<tr>
<td>Muon</td>
<td>KLM</td>
<td>KLM</td>
</tr>
<tr>
<td>Bhabha</td>
<td>ECL</td>
<td>ECL</td>
</tr>
<tr>
<td></td>
<td>EFC</td>
<td></td>
</tr>
<tr>
<td>Cosmic</td>
<td>ECL</td>
<td>ECL</td>
</tr>
</tbody>
</table>

- **Charged Track Z-Trigger**
  - It is very powerful to reduce BG
  - We should think about it: special device or use CDC stereo hits

- **Timing source**
  - Redundant timing sources are preferable
L1 Rate @ SKEKB : Rough Estimation

<table>
<thead>
<tr>
<th>Exp</th>
<th>Rate</th>
<th>Luminosity</th>
<th>Current</th>
<th>Magic Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Rate / Lum</td>
<td>Rate @ 10^35</td>
<td>Rate / Current</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>13</td>
<td>13 k</td>
<td>210</td>
</tr>
<tr>
<td>17</td>
<td>250</td>
<td>4.5</td>
<td>4.5 k</td>
<td>130</td>
</tr>
<tr>
<td>27</td>
<td>350</td>
<td>4.4</td>
<td>4.4 k</td>
<td>150</td>
</tr>
</tbody>
</table>

- Vacuum is the biggest factor to estimate the rate
- CDC Z-trigger is included in above numbers
  - We have to live @ SKEKB without Z triggers
    - ~30% increase without Z trigger (Exp.31)
      - 4.4 kHz x 1.3 = 5.7 kHz
    - On the other hand, if we have SVD Z-trigger, we can reduce L1 rate by factor 2~5.
- Very important
  - We can not know real BG situation in SKEKB
# 3. Design of DAQ

## Requirements to DAQ

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>SuperKEKB($&gt;10^{35}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics trigger rate</td>
<td>100Hz</td>
<td>&gt;1KHz</td>
</tr>
<tr>
<td>Maximum trigger rate</td>
<td>500Hz</td>
<td>10-30 KHz</td>
</tr>
<tr>
<td>Event size at L1</td>
<td>40KB/ev</td>
<td>200-300KB/ev</td>
</tr>
<tr>
<td>Data flow rate at L1</td>
<td>20MB/s</td>
<td>&gt; 2 GB/sec</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&gt;5 GB/sec w/o z trigger)</td>
</tr>
<tr>
<td>Data flow at storage</td>
<td>10MB/s</td>
<td>250MB/sec</td>
</tr>
<tr>
<td>Reduction factor in DAQ</td>
<td>2</td>
<td>5~10</td>
</tr>
</tbody>
</table>

How to achieve higher event reduction factor

→ Key of DAQ design
Reference Design

Input: ~ 50-100K channels

~1000 CoPPERs

~50 Readout PCs

Transfer Network

~10 Event Building Farms

~10 L3 Farms

mass storage

Current Belle's Event Builder

all components are Linux-based PC's
Schematic of the DAQ Platform (CoPPER)

- Detector signals
- mezzanine (add-on) module
  - ADC/TDC Module
  - ADC/TDC Module
  - ADC/TDC Module
  - ADC/TDC Module

- FIFO
- local bus
- PCI bus
- PMC
  - PMC CPU
  - Network IF
  - Trigger Module

VME 9U sized board

Higuchi@Nara WS
Pipeline and CoPPER

This part is expected to be supplied by each subdetector group.
Detector Electronics Quick Summary

- SVD : CMS APV25 chip -> promising!
- Pixel : candidate = CAP(continuous acq.)  "striplet" option
  large data size : 620-1280KB/evt (4bytes/pixel,1% occ.) too much!
- CDC : 3 approaches
  1) ADC with waveform sampling (10bit@200MHz)
  2) pipelined TDC with current Q-to-T conversion
  3) TDC + FADC (TMC+12bitFADC@20MHz)
- ECL : waveform sampling needed to avoid pileup effect
  (12bit FADC@2MHz for barrel, 20MHz(?) for pure CsI)
- TOP/RICH : need to manage pixel photo-detector
  * Time stretcher(Varner)/AMT(Arai), analog pipeline(Ikeda)
- KLM : readout scheme is not so much different from Belle's
  regardless of choice of detection device (RPC/Sci. Tile)
  * "hit" info multiplexing + on-board data compression

all electronics will be equipped as "FINESSE"
implemented as daughter board on CoPPER.
Expected event size at L1

<table>
<thead>
<tr>
<th></th>
<th>Belle</th>
<th>SuperKEKB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel(Striplet)</td>
<td>-</td>
<td>~1000KB(!?) (30KB)</td>
</tr>
<tr>
<td>SVD</td>
<td>15KB</td>
<td>~30KB</td>
</tr>
<tr>
<td>CDC</td>
<td>6KB</td>
<td>~10KB</td>
</tr>
<tr>
<td>PID</td>
<td>3KB (TOF/ACC)</td>
<td>~20KB</td>
</tr>
<tr>
<td>ECL</td>
<td>8KB</td>
<td>~100KB</td>
</tr>
<tr>
<td>KLM</td>
<td>3KB</td>
<td>~3KB</td>
</tr>
<tr>
<td>TRG/others</td>
<td>3KB</td>
<td>~3KB</td>
</tr>
<tr>
<td></td>
<td>~40KB</td>
<td>~200KB</td>
</tr>
</tbody>
</table>

* Pixel: event size compression is absolutely necessary
* ECL: wave form sampling to obtain required resolution (~10 buckets/hit*12bit)
  -> can be reduced to 1/5 by feature extraction
* Other: event size compression using word-packing/"zip"

Event Processing on CoPPER ➔ ~100KB/ev
Timing Distribution

2-step cascade

High-speed serial bus on LVDS

- Master TT-IO module
- 1-8 TT-Switch (TT-SW) switches
- 64 distribution by 2-step cascade (4096 by 4-step)
- TT-Receiver (TT-RX) on each COPER
**Multi-stage event building**

* Event Building is done in 3 steps.
  Stage 1: Gather event fragments from CoPPERs in a crate
  Stage 2: Gather event fragments from one subdetector
  Stage 3: Build complete one event

* Event reduction at each stage
  Stage 1: Feature extraction, further sparcification -> size reduction
  Stage 2: Level 2.5 trigger using partial subdetector info.
    ex. Trigger Info + fast CDC tracking -> z trigger
    fast SVD-only tracking -> vertex trigger
  Stage 3: -> L3 Farm

Common event building software framework at all stages
("switchless event builder" + BASF)
Stage 1 Event Building

* "switchless event builder" software on Readout PC
* Network switch is used to share (a) 1000base-T port(s) on readout PC. Connection between each CoPPER to Readout PC is fixed port-to-port basis and the switch is "transparent".
* Further event size reduction on Readout PC
Stage 2 event building

* Readout from 1 subdetector can be from multiple CoPPER crates
* Gather them to form an event from the subdetector using network switch complex.
* The same "switcholess event building software" on E1 node
* Transparent port-to-port connection from ReadoutPC to E1
Stage 3 event building

Current system at Belle: **switchless event building farm**

- BASF framework running on all nodes
- Level 2.5 trigger software on E1 node
- Event rejection at E2 node
Level 3 Trigger Farm

* Full event reconstruction capability is necessary to achieve ultimate data reduction.
* A PC cluster is connected to event builder output.

1 Unit → processing power for $L=10^{34}/cm^2/sec$
Storage

Belle: Currently using high speed tape device w/ robot (DTF/PetaSite)
  * SONY gave up to release faster DTF drives
  * market is small → expensive

- Recent disks are much faster than tape drive
  * ex. Dell/EMC CX600 / Fujitsu ETERNUS
    - 200MB/sec (2Gbps FiberChannel I/F)
      * preliminary test (Dell CX600) shows
        >100MB/sec read/write speed
        cf. DTF : 24MB/sec

Record data on disk directly. Multiple data streams.
→ R&D has been started with Computing people.
4. Data reduction

- Data Reduction is very important in high-intensity experiments to keep mass-storage manageable.
- We need a versatile and powerful software trigger/event size reduction scheme to obtain reduction factor of <1/10 after L1 trigger.

1) Level 2 trigger (on CoPPER modules)
   - event trigger after pipeline readout
   - trigger signal is generated by dedicated hardware (ex. Z-trigger by SVD fast readout)
     - latency < ~50µsec (cf. L1 latency : ~10µsec)
   - trigger signal is distributed to CoPPER via timing logic with event tag
   - software running on CoPPER CPU rejects the event by looking at the trigger event tag

Trigger rate reduction : ~1/3-1/5 (30~50KHz -> 10KHz)
Event size reduction : 1 (~200-300 KB)
2) Event processing on CoPPER/Readout PC

CoPPER : linux-operated PC on board
→ possibility of versatile event data processing

- Software data sparcification
  * Feature extraction for wave-form sampling
  * Event size compression by various method
    (bit-squeezing, zip, etc.)

- Raw Data Formatting (to Panther / ROOT I/O (?)

Trigger rate reduction : 1 (10KHz)
Event size reduction : 1/3 (~200 KB->100KB)
3) Level 2.5 trigger
- Software trigger using partially-built event data
  (data from one subdetector/several related subdetectors)
- Current Belle's "L3" scheme can be used

* Fast Tracking + Hardware trigger information (Belle)

Trigger rate reduction : 1/2 (10KHz->5KHz)
Event size reduction : 1
4) Level 3 trigger
- Software trigger using fully-built and fully-reconstructed data
- Trigger at a level of "Physics Skim"
  * hadronic event selection
  * selection of specially-interested events

Power of event reduction by "physics skim" at Belle

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Fraction in events after L2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic</td>
<td>14.2%</td>
</tr>
<tr>
<td>$\tau^+\tau^-/2\text{photon}$</td>
<td>9.6%</td>
</tr>
<tr>
<td>Monitor($=e^+e^-,\mu^+\mu^-,\text{etc}$)</td>
<td>$\sim$1% (can be scaled)</td>
</tr>
</tbody>
</table>

Trigger rate reduction : 1/4 ($\sim$2KHz)
Event size reduction : 1 (+ reconstruction info($\sim$100KB/ev))

* Data flow rate will increase by a factor of 2 if we leave reconst. info together on storage → requires more multiplicity in storage
5. Summary

Trigger/DAQ for SuperKEKB are being designed based on

* "Tight" L1 trigger strategy based on Belle's

* Timing Distribution based on multi-level tree structure utilizing a high-speed serial bus on LVDS

* Pipeline Readout implemented on a Common Readout Platform FINESSE + CoPPER

* Multi-step event building based on the "switchless event building"

Data Reduction is performed by multi-step software trigger

- Level 2 on CoPPER ~30KHz->10KHz
- Event processing on CoPPER/PC 300KB/ev -> 100KB/ev
- Level 2.5 on event building farm 10KHz -> 5KHz
- Level 3 on Reconstruction (L3) farm 5KHz -> ~2KHz

R.Itoh, Hawaii WS
Backup Slides
Physics Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>C.S. (nb)</th>
<th>R @ $10^{34}$ (Hz)</th>
<th>R @ $10^{35}$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upsilon(4S)</td>
<td>1.2</td>
<td>12</td>
<td>120</td>
</tr>
<tr>
<td>Continuum</td>
<td>2.8</td>
<td>28</td>
<td>280</td>
</tr>
<tr>
<td>$\mu\mu$</td>
<td>0.8</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>$\tau\tau$</td>
<td>0.8</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>Bhabha</td>
<td>44</td>
<td>4.4</td>
<td>44</td>
</tr>
<tr>
<td>$\gamma-\gamma$</td>
<td>2.4</td>
<td>0.24</td>
<td>2.4</td>
</tr>
<tr>
<td>Two photon</td>
<td>15</td>
<td>35</td>
<td>350</td>
</tr>
<tr>
<td>Total</td>
<td>67</td>
<td>96</td>
<td>960</td>
</tr>
</tbody>
</table>

- Cross-sections are calculated in acceptance
- Bhabha and $\gamma-\gamma$ are pre-scaled by factor 100
- Two photon is with $p_T > 0.3$ GeV cut
## ECL Trigger (B.G. Cheon)

<table>
<thead>
<tr>
<th>Trigger bit</th>
<th>Rate @ $10^{35}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{TOT}&gt;0.5\text{GeV}$</td>
<td>6.5K</td>
</tr>
<tr>
<td>$E_{TOT}&gt;1.0\text{GeV}$</td>
<td>3.4K</td>
</tr>
<tr>
<td>$E_{TOT}&gt;3.0\text{GeV}$</td>
<td>2.5K</td>
</tr>
<tr>
<td>ICN bit-0</td>
<td>18.0K</td>
</tr>
<tr>
<td>ICN bit-1</td>
<td>5.0K</td>
</tr>
<tr>
<td>ICN bit-2</td>
<td>0.5K</td>
</tr>
<tr>
<td>ICN bit-3</td>
<td>0.2K</td>
</tr>
<tr>
<td>Bhabha</td>
<td>5.0K</td>
</tr>
<tr>
<td>Pre-Bhabha</td>
<td>1.5K</td>
</tr>
<tr>
<td>Cosmic</td>
<td>38.0K</td>
</tr>
<tr>
<td>CsI timing</td>
<td>110.0K</td>
</tr>
</tbody>
</table>

- Extrapolated by Lum.
- TC pulse width : 1us
  - TC occupancy $<10\text{KHz @ 1035}$
- Current L1 trigger system may be kept.
  - Too optimistic ???
  - Beam BG level ???
- More simple/fast/flexible system against $>10^{35}$
Design Concept of Backend DAQ

- Multi-stage event building and selection
  "Build and select" scheme at each level of event building

- Versatile and powerful level 3 trigger farm
  -> "Full event reconstruction" is performed to obtain ultimate data reduction factor

- Maximum use of existing technology
  * Switchless event building technology
  * NSM based control

- Common software framework at all levels
  * BASF + Panther is used from CoPPER to L3 farm
  * Full use of Belle Software Library
  <- the same software environment as that in offline
  => easy development of data reduction software