Realization of a state machine based detection for Track Segments in the Trigger System of the Belle II Experiment

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Belle II

Tsukuba

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Belle II

SuperKEKB

40 * Luminosity of predecessor KEKB

- $8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$
- Asymmetric $e^+e^-$ collider
- 32 MHz Data rate
Belle II L1 Trigger System

- Multiple Detectors and Trigger chains
- ASIC based readout
- FPGA based Trigger (Xilinx Virtex 6)
- The Trigger System works with reduced data width
- 5 µs for the L1 Trigger System
L1 Trigger System – Track Segment Finder

Focus in this Talk

- Main System for Track reconstitution
- Track Segment Finder (TSF)
- First System for data reduction
DETECTOR
CDC Central Drift Camber
Central Drift Camber

- 14336 Trigger Cells
- 56 layers
CDC Central Drift Camber

- Trigger Cell
  - Sens wires 14 336
  - Field wires 42 240
CDC Central Drift Camber

- 9 Superlayer
  - 4 Stereo Superlayer
  - 5 Axial Superlayer
2 Types of Track Segment
- Superlayer 0
- Superlayer 1-8
CONCEPT
Track Segment

- 2336 Track Segments in 9 Superlayers
  - 14336 Trigger Cells
  - Reduce the data
- Limits the tracks to tracks from the origin of the collision
  - (about 30° from the collision origin)
- Two Types of Priority
  - First Priority
  - Second Priority (need 4 additional lines hit)
- Add additional Information for following Trigger Systems
**Track Segment**

- 2336 Track Segments in 9 Superlayers
  - 14336 Trigger Cells
  - Reduce the data
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- Two Types of Priority
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- Add additional Information for following Trigger Systems
State Machine TSF

1. active 1st
2. active 2nd
3. wait
Second Priority Hit

- Second Priority Hit needs 4 additional Hits in total
- Only possible from the wait statement
- Set the counter to 64 clock cycles (127 MHz ~500ns)
- If the counter is zero the state goes back to wait
State Machine TSF

- **active 1st**
- **wait**
- **active 2nd**

Transitions:
- **Second Priority Hit** from **wait** to **active 2nd**
- **Counter = 0** from **wait** to **active 2nd**
First Priority Hit

- Needs a First Priority Hit
- Can go from wait and second priority
- Set the counter to 64 clock cycles (127 MHz ~500ns)
- If the counter is zero the state goes back to wait
State Machine TSF

- **Active 1st**
  - Transition to **Waiting**
  - Transition to **Active 2nd**

- **Wait**
  - Transition to **Active 1st**
  - Transition to **Active 2nd**
  - Second Priority Hit
  - Counter = 0

- **Active 2nd**
  - Transition to **Waiting**
  - Transition to **Active 1st**
  - First Priority Hit
State Machine TSF

First Priority Hit

Counter = 0

Second Priority Hit

Counter = 0

active 1st

active 2nd

First Priority Hit
Neighbor Hit Suppression

Sometimes Particle Tracks trigger two Track Segments
- Redundant information
- Waist of Bandwidth
Neighbor Hit Suppression

- If active a counter is set with 16 clock cycles (127 MHz ~125 ns)
- First Priority Hits are not affected

Neighbor Hit

no Neighbor Hit

Neighbor Hit

Counter = 0
IMPLEMENTATION
State Machine

- Implementation in VHDL
- 1 Process State Machine
- Mealy-Automat
## Resources use

### Superlayer 8

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<tr>
<th></th>
<th>Slice Register</th>
<th>Slice LUTs</th>
<th>LUT-FF</th>
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- State Machine Version had lower resource use
  - Simpler to implement
Dual Port Bram

- Contains precalculated values for the following trigger systems
  - Calculation in time is to complex

- Each track segment previously had its own BRAM
  - These store the same information

- Now: Neighbouring track segments share a BRAM
  - Both Ports are used now
  - A special handling for defect wire is implemented
Resources use

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- BRAM use is reduced
  - Simpler to implement
Test Date generation

- Scripts to generate the Belle II CDC Data format fast
- Good to test special cases
- Random data to test statistically
Test Flow

- Tool flow for fast testing
- Scripts to analyse data's
Random Data Analyze

- 1 million random data
- Flat Distribution
- More First Priority Hits than Second Priority Hits

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Preliminary Physics Results Phase 3

- Efficiency of Dimuon skim

- Improved by new TSF firmware and bug fix of channel mapping

- Phase 3 new TSF State Machine

2D efficiency with Dimuon skim

*Koga-sans Trigger Study (presented 33 B2GM) not official result
Preliminary Physics Results Phase 3

- Efficiency of hadronB skim

- ECL Cluster | ECL total energy > 1 GeV
  - Not from CDC!

- 2D track >= 3 | 2D track >= 2 and opening angle > 90 deg | 2D track >= 2 and track 1-5 back-to-back

- 2D track >= 3

*Koga-sans Trigger Study (presented 33 B2GM) not official result*
THANK YOU FOR YOUR ATTENTION.
BACKUP
L/R Information

First Priority Passage left
Second Priority Passage right
Second Priority Passage unknown
Complicated calculation of the passage

Precalculation already available

Saved in BROM

Hits result in address

\[ \sigma = \sqrt{(n_L + n_R) \cdot p \cdot (1 - p)} \]

LRresult = \begin{cases} 
\text{left: } n_L > p(n_L + n_R) + 3\sigma \\
\text{right: } n_R > p(n_L + n_R) + 3\sigma \\
\text{unknown} 
\end{cases} \]
## Dataframe

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- **256 bit data**
- **80 Bit Hit Information**
- **80 Bit Priority Time**
- **80 Bit Fast Time**
- **16 Bit Second Priority**
- **32 Border Information and CC**

- **31.75 MHz data rate**
- **Maximum 24 data frames in parallel**

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