Progress on the Electromagnetic Calorimeter Trigger Simulation at the Belle II Experiment

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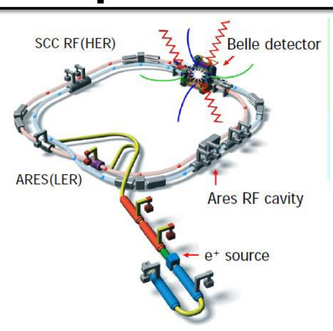
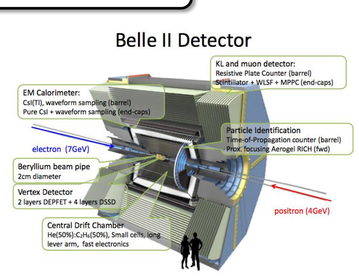
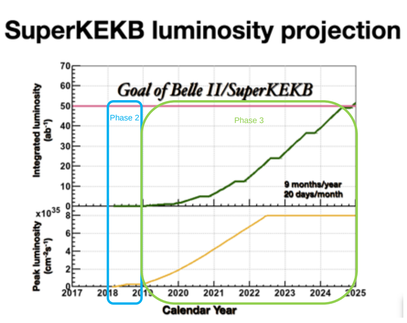
Abstract

The Belle II experiment at KEK in Japan start beam collision from early of 2018 to probe a New Physics beyond the Standard Model by measuring CP violation precisely and rare weak decays of beauty, charm quark and tau lepton. The experiment is performed at the SuperKEKB e^+e^- collider with $80 \times 10^{34}\mathrm{cm}^{-2}s^{-1}$ as an ultimate instantaneous luminosity. In order to develop and test an appropriate trigger algorithm under much higher luminosity and severe beam background environment than previous KEKB collider, a detail simulation study of the Belle II calorimeter trigger system is very crucial to operate Belle II trigger/DAQ system in stable. We report preliminary results on various trigger logic and efficiencies using physics and beam background events upon the Belle II Geant4-based analysis framework called Basf2.

SuperKEKB/Belle II





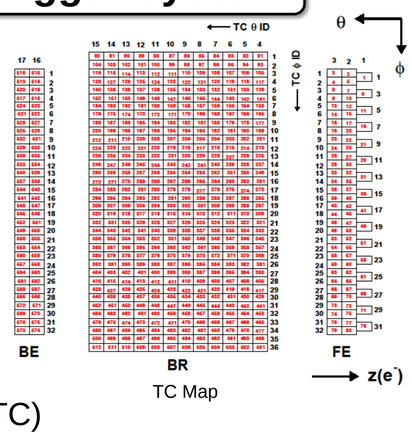


- New intensity frontier facility at KEK
  - Target Luminosity : $\mathcal{L}_{\mathrm{peak}} = 80 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
    $\mathcal{L}_{\mathrm{Int}} > 50\ \mathrm{ab}^{-1}$ ➡ $10^{10} B\bar{B}, \tau^+\tau^-, \mathrm{charms}$ per year!
- Goal of Belle II
  - CP violation studies by precise determination of decay vertices of B mesons and tagging of D mesons
  - New Physics in decays of heavy flavor particles
  - New exotic states (X, Y, Z, …)
- Operation Schedule
  - Phase 2 : First beam collision has been started with $4.0 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ from 2018.
  - Phase 3 : Beam collision with the target luminosity $80 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ planned from 2019.

Electromagnetic Calorimeter(ECL) Trigger System

CsI(Tl)+PD +PreAmp (8736)
↓
ShaperDSP (576)
↓
FAM(52)
↓
TMM(7)
↓
ETM(1)
↓
GRL(1)
↓
GDL(1)

- **ECL Trigger System**
  - Physics Trigger
  - Bhabha Trigger
  - Event timing
  - Luminosity monitor
  - Cluster counting (ICN)
- **Hardware System**
  - **ShaperDSP**
    - ✓ 4x4 Crystal → 1 Trigger Cell (TC)
    - ✓ Fast shaper for Trigger
    - ✓ Slow shaper for precise energy measurement
  - **FADC Analysis Module (FAM)**
    - ✓ Digitize analog TC signals
    - ✓ Energy & Timing measurement using minimum χ^2fitting.
  - **Trigger Merger Module (TMM)**
    - ✓ Merge FAM signals and send it to ETM
  - **ECL Trigger Master (ETM)**
    - ✓ Make ECL trigger decision and event timing based on trigger logic.
    - ✓ Send the trigger signal to Global reconstruction logic(GRL) and Global decision logic(GDL)
- **Trigger Logic** for **Phase 2** operation.
  - **Physics Trigger logic**
    - ✓ (Total Energy > 1GeV or ICN > 3) and ! Bhabha
  - **Event Timing logic**
    - ✓ The most energetic TC Timing
    - ✓ ~4 ns resolution (1 sigma)
  - **Bhabha Trigger logic**
    - ✓ Use back-to-back topology
    - ✓ Set 15 θ-id combinations
    - ✓ Apply ICN < 4 .
  - **Luminosity monitor**
    - ✓ Measure luminosity using cross section estimated by Bhabha logic
    - ✓ $\mathcal{L} = \frac{\text{Bhabha Trigger rate}}{\text{Cross section}}$
  - **ICN Logic**
    - ✓ Cluster counting logic

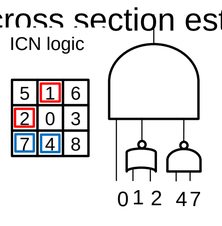


TC Map

Bhabha combination

Combination (θ id)		Energy Threshold (GeV)	
1 + 2 + 3	16 + 17	4.0	2.5
3	15	4.0	2.5
4	14 + 15	4.0	2.5
5	14 + 15	4.0	2.5
4+5	14	4.0	2.5
5	13 +14	4.0	2.5
5	12 +13	4.0	2.5
5 + 6	13	4.0	2.5
5 + 6	12	4.0	2.5
6 + 7	12	4.0	2.5
6 + 7	11	4.0	2.5
7 + 8	11	4.0	2.5
8	10 + 11	3.0	3.0
8 + 9	9 + 10	3.5	3.0

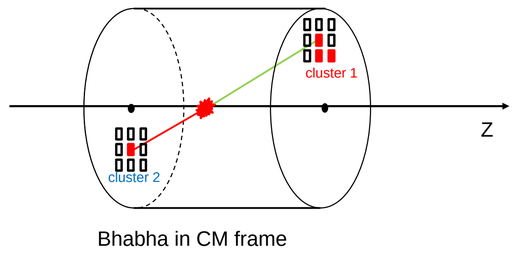
ICN logic



ECL Trigger Simulation Study

- ECL Trigger simulation package is implemented in Belle II analysis framework having a same structure with Belle II ECL Trigger system to develop appropriate trigger algorithms.

3-D Bhabha Trigger Logic



Bhabha in CM frame

Sample	Bhbaha tagging efficiency(%)	
	3-D	2-D
Bhabha	91.8	91.8
Radiation Bhabha	78.9	78.2
$ee \to \gamma\gamma$	75.8	78.2
$ee \to \mu\mu$	0	0.1
ISR($ee \to (\gamma)\mu\mu$)	0	0.2
ISR($ee \to (\gamma)\pi\pi$)	0.1	0.4
$\tau \to$generic	0	0.5
$\tau \to \mu\gamma$	0.1	2.0
$\tau \to e\gamma$	0.4	3.7
Single photon	0	1.4
Υ(4s)	0	0

error < 0.03

- **3D Bhabha logic**
  - In order to avoid tagging a similar topology of physics events as Bhabha trigger, we introduce cluster base 3-D Bhabha logic.
  - **Cluster** : Groups of connected TC hits base on the ICN logic.
  - **Bhabha condition**
    - ✓ $160° < \Delta\phi_{\mathrm{cm}}, \Delta\theta_{\mathrm{cm}} < 200°$
    - ✓ Both clusters $E_{cm} > 3$ GeV and One of clusters $\mathrm{E_{cm}} > 4.5$ GeV
  - 3-D Bhabha logic provide better selection for low multiplicity events than 2-D logic.

Offline Data Analysis (Logic confirmation)

- Reproduce trigger output from beam data using Trigger Simulation package to check the trigger system work properly.
- By comparing the Bhabha combination bit in MC and Data, we confirm the ECL Trigger logic works properly.

Bhabha combination bit	MC	Data (run #120)
0	0.67 ± 0.00	0.62 ± 0.02
1	0.02 ± 0.00	0.03 ± 0.01
2	0.05 ± 0.00	0.08 ± 0.01
3	0.01 ± 0.00	0.02 ± 0.01
4	0.05 ± 0.00	0.08 ± 0.01
5	0.04 ± 0.00	0.07 ± 0.01
6	0.03 ± 0.00	0.05 ± 0.01
7	0.03 ± 0.00	0.06 ± 0.01
8	0.02 ± 0.00	0.03 ± 0.01
9	0.02 ± 0.00	0.04 ± 0.01
10	0.01 ± 0.00	0.02 ± 0.01
11	0.02 ± 0.00	0.02 ± 0.01
12	0.02 ± 0.00	0.03 ± 0.01
13	0.02 ± 0.00	0.01 ± 0.01

Conclusion

- The Belle II aim to find the new physics phenomena.
- SuperKEKB/Belle II operation started from March in 2018.
- The Belle II ECL trigger system is optimized for high efficient physics event selection as well as beam background suppression.
- In order to develop appropriate trigger algorithms in Belle II environment, ECL trigger simulation has been prepared.
- Newly introduced 3-D bhabha trigger logic provide better selection for low multiplicity events than 2-D logic.
- Using Trigger simulation package, we confirm the ECL Trigger logic.