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L1 Trigger Menu for Low Multiplicity Physics (draft version 1.0)

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Abstract

Contents

1. INTRODUCTION

We describe the proposed low multiplicity triggers for Belle II and give estimations for trigger efficiencies and trigger rates based on MC simulations and a trigger emulator based on offline reconstructed dataobjects.

2. RELEVANT SIGNAL AND BACKGROUND PROCESSES

The following physics topics were considered in developing the list. They represent the range of signatures characteristic of the low-multiplicity program.

- Bhabhas, $e^+e^- \to \gamma\gamma$, and $e^+e^- \to \mu^+\mu^-(\gamma)$, used for luminosity, calibration, and other detector studies, as well as QED physics topics. They are used in precision measurements, and require high trigger efficiency and redundant, orthogonal, triggers to achieve small systematic errors.
- Single photon: Required for dark matter searches, such as $e^+e^- \to \gamma A'$, $A' \to \chi\chi$, where A' is a dark photon and χ is a particle invisible in the detector. The maximum A' mass accessible in this analysis depends on the minimum energy threshold on the single photon.
- Initial state radiation (ISR) production of $\pi^+\pi^-$ and similar final states, $e^+e^- \to \gamma\pi^+\pi^-$, where all three particles are in the detector. This is a precision measurement, important in understanding the muon $g-2$ measurements. It is not uncommon for the two tracks to overlap and be detected as one by the trigger.
- Tau 1 vs 1 final states: Tau events in which both taus decay to a single charged track. This includes high-profile analyses such as $\tau \to \mu\gamma$ and studies involving tau polarization.
- π^0 transition form factor: This is a specific analysis studying the production of π^0 in two photon fusion, in which one of the two outgoing electrons is at a sufficiently wide angle to be measured in the detector ("single tag"). The electron in the beam pipe carries longitudinal momentum, but essentially no transverse momentum, so the tag electron and the π^0 are back-to-back azimuthally, but not in three dimensions. The

π^0 is sufficiently boosted that it will generally be detected as a single cluster by the ECL trigger. This analysis suffered low efficiency and distorted kinematics due to the level 1 trigger of Belle.

- Υ di-pion transition: Invisible decays of the $\Upsilon(1S)$ can be identified using the decay $\Upsilon(2,3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$, if it is possible to trigger the event on the two charged tracks. This is particularly challenging for the $\Upsilon(2S)$, where the tracks have quite low transverse momentum.

- $\gamma\gamma \rightarrow \pi^0\pi^0$: two photon fusion production of π^0 π^0 and similar all-neutral final states.

The goal of the proposed triggers is to have good efficiency for these physics processes and orthogonal triggers, while keeping background rates below the maximum L1 throughput, 30 kHz. There are three high-rate backgrounds: Bhabhas, $e^+e^- \rightarrow \gamma\gamma$, and two-photon fusion production of two-track final states, such as $e^+e^- \rightarrow e^+e^-e^+e^-$, where both high-momentum outgoing electrons are within the beampipe.

3. LIST OF PROPOSED L1 TRIGGERS

The list of proposed low multiplicity triggers is shown in Table I. Each trigger is described below in qualitative terms.

3.1. Bhabha triggers (IDs: 1, 2, 3)

Bhabha veto (ID: 1)

The Bhabha veto must select Bhabha events with very high purity: any physics events selected by this line will be lost. Veto requires two high-energy ECL clusters that are collinear in three dimensions (3D) in the center of mass (COM) frame, with both tracks matched to CDC tracks. This veto will not identify Bhabhas in which one leg is in the gaps between the ECL barrel and endcaps. These events will need to be rejected in the high-level trigger.

Note that a veto that requires the two legs to be back-to-back in azimuth only (2D veto) will reject the events used for the π^0 transition form factor analysis.

TABLE I: List of L1 trigger lines proposed by the low multiplicity physics group. Trigger lines marked with a filled circle (•) are physics trigger whereas trigger lines marked with an empty circle (◦) are used for efficiency determination or monitoring. The columns correspond to a selection of physics channels sensitive to a variety of different triggers

ID	Name	Logic	Prescale	Bhabha	$\gamma\gamma$	γ	$\mu^+\mu^-(\gamma)$	$h^+h^-(\gamma)$	τ 1 vs. 1	$\gamma\gamma* \to \pi^0/\eta^{(\prime)}$	$\Upsilon\pi\pi$	$\gamma\gamma \to \pi^0\pi^0$	Comment
1	Bhabha veto	ECL bhabha veto && exactly 2 CDC tracks && both ECL clusters matched to CDC tracks	-										pure
2	Bhabha accept 1	ECL bhabha accept && $\geq$ 1 CDC track && at least 1 ECL cluster matched to CDC track	$f(\theta)$	•									efficient (missing 1 track)
3	Bhabha accept 2	$\geq$ 2 CDC tracks && a pair of CDC tracks in Bhabha configuration && at least 1 matched to a high energy ECL cluster	$f(\theta)$	•									efficient (missing 1 cluster)
4	gg veto	ECL bhabha veto && 0 CDC tracks	-										pure
5	gg accept	ECL bhabha accept && !Bhabha veto	10		•								efficient
6	single leg g trigger	at least one high energy ECL cluster not matched to CDC track	20		◦	◦							
7	1g barrel 2 GeV	2 GeV ECL barrel cluster && !gg veto && !Bhabha veto	1			•		•		•			ECL/CDC match in HLT
8	1g barrel 2 GeV no gg veto	2 GeV ECL barrel cluster && !Bhabha veto	400		◦	◦				◦			
9	1g endcap 2 GeV	2 GeV ECL endcap cluster && !gg veto && !Bhabha veto	1			•		•		•			ECL/CDC match in HLT
10	1g endcap 2 GeV no gg veto	2 GeV ECL endcap cluster && !Bhabha veto	400		◦	◦				◦			
11	1g barrel 1 GeV	1 GeV ECL barrel cluster && $\leq$ 1 CDC track && !gg veto	1			•				•		•	
12	1g endcap 1 GeV	1 GeV ECL barrel endcap && $\leq$ 1 CDC track && !gg veto	1			•				•		•	
13	two tracks	two CDC tracks && !Bhabha veto	1				•	•	•		•		standard two track trigger
14	two tracks no veto	two CDC tracks	2000				◦	◦	◦		◦		
15	one tracks one muon	$\geq$1 CDC track && $\geq$1 KLM muon separated by $\Delta\phi$ >45deg	1				•		•				
16	two KLM muons	$\geq$2 KLM tracks $\Delta\phi$ >45deg	10				◦						no CDC, no ECL
17	single KLM muon	high momentum CDC track matched to KLM cluster	1				•		•				single track, no ECL
18	single ECL muon	CDC track matched to ECL cluster < 0.5 GeV && !Bhabha veto	10				◦		◦				
21	two back to back tracks	2 CDC tracks separated by >45 deg && !Bhabha veto	1				◦		•		•		looser track selection
22	two back to back tracks no veto	2 CDC tracks separated by >45 deg	2000						◦				looser track selection
19	one track one cluster	$\geq$1 ECL cluster >500 MeV && $\geq$1 CDC track separated by >45 deg && !Bhabha veto	1				◦	•	•	•			
20	one track one cluster no veto	$\geq$1 ECL cluster >500 MeV && $\geq$1 CDC track separated by >45 deg	2000				◦	◦	◦	◦			
23	back to back clusters	ECL clusters >500 MeV separated by >45 deg && !Bhabha veto && !gg veto	1						•	•		•	
24	back to back clusters no veto	2 ECL clusters >500 MeV separated by >45 deg	200	•	◦					◦			
25	total energy	Sum of ECL clusters >3 GeV	200	•	◦					◦			
26	two ECL muons	2 ECL clusters >100 MeV and <500 separated by >45 deg	100				◦						
27	two ECL muons with KLM	2 ECL clusters >100 MeV and <500 separated by >45 deg, at least one matched to KLM cluster	10				◦						with KLM
28	three clusters	3 ECL clusters > 100 MeV separated by η < 170 deg	1				◦	◦				•	

Bhabha accept 1 (ID: 2)

Events selected by the two Bhabha accept triggers are used for the luminosity measurement. These triggers are designed to be very efficient, so as to minimize systematic errors. Bhabha accept 1 requires two relatively high energy ECL clusters, approximately back-to-back (3D) in the COM frame, at least one of which is matched to a CDC track.

The trigger will be highly prescaled, using a prescale factor that depends on the polar angle of the ECL cluster associated with the negatively-charged track. An example of a prescale algorithm that produces an overall reduction by a factor of 100 is:

$$\text{double prescale}[17] = 600, 400, 144, 72, 36, 36, 30, 15, 15, 15, 15, 15, 15, 15, 15, 15, 15;$$

where the index is the thetaID of the corresponding ECL trigger tower.

Bhabha accept 2 (ID: 3)

This second Bhabha accept trigger complements the first. It requires two high momentum tracks, roughly back-to-back, one of which is matched to a relatively high-energy ECL cluster. Prescaling is done as for Bhabha accept 1. If the negatively-charged track is not associated with an ECL cluster, the prescale will be based on the ECL trigger thetaID of the cluster associated with the positively-charged track.

3.2. $\gamma\gamma$ triggers (IDs: 4, 5, 6)

$\gamma\gamma$ veto (ID: 4)

A veto for $e^+e^- \to \gamma\gamma$ events is needed for single photon and other ECL-only triggers. This is a very high purity selection. It requires two high-energy ECL clusters back-to-back (3D) in the COM frame, with no CDC tracks.

$\gamma\gamma$ accept (ID: 5)

This is the standard trigger for $e^+e^- \to \gamma\gamma$ events used for ECL calibration and the luminosity measurement. It should be highly efficient, and the efficiency should not be sensitive to variations in beam backgrounds. It requires a pair of relatively high energy ECL clusters, approximately back-to-back in the COM frame. The Bhabha veto is applied. It has a prescale, nominally a factor of 10, but adjustable to match luminosity levels.

Single leg γ (ID: 6)

This trigger selects a sample of $e^+e^- \to \gamma\gamma$ events based on a single photon, regardless of whether or not the other photon is detected, converts, or is lost. This sample is needed to study the distribution of material in the detector and the efficiency of the $\gamma\gamma$ accept trigger. It is not a trigger for physics, because it is prescaled. It requires at least one high-energy ECL cluster that is not associated with a CDC track. The Bhabha veto is not applied.

3.3. Single photon triggers (IDs: 7, 8, 9, 10, 11, 12)

There are separate triggers for barrel and endcap, and for two different energy thresholds, to allow greater flexibility in prescaling in the presence of backgrounds that may be difficult to predict and which will vary with luminosity. There are also highly prescaled triggers used to study the impact of the $\gamma\gamma$ veto.

Single photon, barrel 2 GeV (IDs 7 and 8)

This trigger requires at least one ECL cluster in the barrel ($32^\circ < \theta_{lab} < 50^\circ$) with COM energy $E^* > 2\,\mathrm{GeV}$, not associated with a CDC track. Bhabha and $\gamma\gamma$ vetos are applied. Note that there are no requirements (other than the vetos) on CDC tracks or other ECL clusters, so it will accept a variety of physics events, including those that contain only a single photon in the final state, ISR production of $\pi^+\pi^-$ and other low multiplicity final states, and the π^0 transition form factor analysis.

ID 8 is the same trigger without the $\gamma\gamma$ veto, and with a large prescale.

Single photon, endcaps 2 GeV (IDs 9 and 10)

These are the same triggers as IDs 7 and 8, but with the ECL cluster in an endcap. The irreducible single-photon background is peaked at low angles, so the endcap region may require a separate threshold or prescale level.

Single photon, barrel 1 GeV (ID 11)

Lower threshold than ID 7. The background rates are likely to be much higher, so this trigger also includes a requirement that there be at most one CDC track. The trigger is suitable for single photon final states, and for the π^0 transition form factor analysis, but not ISR production of $\pi^+\pi^-$.

Single photon, endcap 1 GeV (ID 12)

Endcap version of ID 11.

3.4. Track triggers (IDs: 13, 14, 15, 16, 17, 18, 21, 22)

A wide range of physics final states include two charged tracks in the final state, as do the two highest-rate background processes. We define a variety of two-track triggers to have the flexibility to obtain good efficiency for signal while permitting an acceptable amount of background. Some of the physics topics are precision measurements, and require redundant triggers to improve and quantify trigger efficiency.

Two tracks (IDs 13 and 14)

This is the basic two-track trigger. (Other triggers exist for larger number of tracks). Kinematic requirements may need to be applied to reduce two-photon backgrounds, such as requiring one track to have moderately high transverse momentum. Bhabha veto is applied. ID 21 is a similar trigger with different kinematic requirements.

ID 14 is the same trigger without the Bhabha veto and with a large prescale factor.

One track one muon (ID 15)

A second trigger for muon pairs or tau 1 muon versus 1 track events. It will reduce the sensitivity to the single track trigger efficiency, and will enable a measurement of this efficiency.

Two KLM muons (ID 16)

This is a prescaled trigger that does not use the CDC. It is useful for systematic studies of the muon pair luminosity measurement, and to collect cosmic rays useful for ECL and other calibrations.

Single KLM muon (ID 17)

A relatively high momentum CDC track associated with a KLM cluster, with no requirement placed on the ECL. No restriction is placed on the number of CDC tracks, so this trigger will be useful for any process with an energetic muon in the final state.

Single ECL muon (ID 18)

Prescaled trigger for trigger studies. Requires at least one relatively-high momentum CDC track associated with an ECL cluster that is consistent with a minimum ionizing particle. Bhabha veto is applied. May be sensitive to two-photon production of $\mu^+\mu^-$ and similar backgrounds; requires study.

Back-to-back tracks (IDs 21 and 22)

Two CDC tracks approximately back-to-back. Aimed at the tau 1-vs-1 topology, it may allow lower transverse momentum requirements than the standard two-track trigger, ID 13. May need additional constraints to reject two track events from two photon production. Ideally, these could be delayed until the high-level trigger.

ID 22 is a highly-prescaled version without the Bhabha veto.

3.5. Track/Cluster triggers (IDs: 19, 20)

One ECL cluster above threshold (to be studied), roughly back-to-back with a full-length CDC track. This is aimed specifically at the π^0 transition form factor and $\gamma\pi^+\pi^-$ analyses, but will also provide additional efficiency for the tau 1-vs-1 topology.

ID 20 is a prescaled version without Bhabha veto.

3.6. Neutral triggers (IDs: 23, 24, 25, 26, 27)

These triggers are aimed at two photon physics, or as non-CDC triggers for trigger studies.

Back-to-back clusters (IDs 23 and 24)

A pair of ECL clusters above threshold (to be studied), roughly back-to-back, Bhabha veto and $\gamma\gamma$ veto. Note that there are no requirements on CDC tracks, other than the vetoes. Aimed at π^0 transition form factor and tau 1-vs-1 topologies.

ID 24 is a prescaled version without vetos.

Total energy (ID 25)

Unbiased Bhabha and $\gamma\gamma$ sample with large prescale.

Two ECL muons (ID 26)

Requires a pair of ECL clusters consistent with minimum ionizing particles, roughly back-to-back. Prescaled; for trigger studies, not physics.

Two ECL clusters with KLM (ID 27)

Requires a pair of ECL clusters consistent with minimum ionizing particles, roughly back-to-back, with at least one associated KLM cluster. May be usable with a lower prescale rate than ID 26.

Three ECL clusters (ID 28)

Trigger for two photon production of π^0 π^0 or similar all-neutral final states, or un-tagged ISR production of such states. Three ECL clusters that are not collinear (maximum angle between any two $< 170°$ in 3D), each above a 100 MeV threshold. No requirement is placed on the number of CDC tracks. The acollinearity requirement should make the Bhabha and $\gamma\gamma$ vetoes unnecessary, but the background rates (and possible prescale rate) require study.

Note there is a four-cluster trigger that has no acollinearity requirements.

3.7. Cosmic veto

The un-prescaled two-track triggers will accept cosmic rays. This requires study, but the rate is likely to be acceptable at level 1. These can then be rejected by the high level trigger. Non-CDC cosmics will also be triggered by ID 16, two KLM muons.

4. EVENT SAMPLES AND SELECTION

All generators are described in [1].

4.1. $e^+e^-(\gamma)$

Radiative Bhabha events are generated using `BABAYAGA.NLO`.

4.2. $\gamma\gamma(\gamma)$

Radiative photon pair events are generated using `BABAYAGA.NLO`.

4.3. $\mu^+\mu^-(\gamma)$

Radiative muon pairs events are generated using `KKMC`.

4.4. $\pi^+\pi^-\gamma_{ISR}$

Radiative pion pairs events with a tagged ISR photon are generated using `PHOKHARA9.1b`.

4.5. $\tau \to \mu\gamma$ and $\tau \to e\gamma$

Radiative tau pairs events with one τ decaying into the lepton flavour violating (LFV) mode $\tau \to \mu\gamma$ or $\tau \to e\gamma$ are generated using `KKMC`.

4.6. $A(\to \chi\bar{\chi})\gamma_{ISR}$

Invisible dark photon decays with a tagged ISR photon are generated `MadGraph` with the dark photon model from R. Essig.

4.7. Single Photon Background

Weighted single photon background events are generated with `TEEGG` in the GAMMAE and GAMMA configuration with and `BABAYAGA.NLO` running at fixed $\mathcal{O}(\alpha^3)$.

5. TRIGGER EMULATOR

The usage of L1 Emulator is descriped in BELLE2-NOTE-PH-2015-010 [2].

6. TRIGGER EFFIENCIES AND TRIGGER RATES

6.1. MC samples

The MC samples used in the analysis are produced on build-2016-03-02. The MC events without background mixing are reconstructed with offline recontruction algorithm with all of detectors except PXD. Table II lists the MC samples with the correspongding generators and configurations.

For the QED processes including $ee(\gamma)$, $\mu\mu(\gamma)$, and $\gamma\gamma(\gamma)$, two samples are generated, respectively, one with small scattering angle ([25°, 140°]) is used to study the trigger efficiency, and another with large scattering angle ([15°, 165°]) is to study the event rate level after L1 trigger menu.

TABLE II: MC samples

Process	σ(nb)	Generator	Cut in generator
BB	1.1	KKMC	-
continuum (udsc)	2.9		-
$B \to \pi^0\pi^0$, $B \to$generic	-		-
$\tau \to$generic	0.9		-
$\tau \to$1-prong, $\tau \to$1-prong	-		two tracks are in CDC acceptance $[17°,\ 150°]$
$\tau \to e/\mu\gamma$, $\tau \to$1-prong	-		two tracks are in CDC acceptance $[17°,\ 150°]$, one photon in ECL acceptance $[15°,\ 165°]$
$\pi\pi(\gamma)$	-	Phokhara	$\pi\pi$ invariant mass is less than 4 GeV, two tracks are in CDC acceptance $[17°,\ 150°]$
$\pi\pi(\gamma)[0,1]$	-		$\pi\pi$ invariant mass is less than 1 GeV, two tracks are in CDC acceptance $[17°,\ 150°]$
$ee(\gamma)$	125	Babayaga.NLO	ScatteringAngleRangle:$[15°, 165°]$, MinEnergy: 0.1 GeV, MaxAcollinearity: 180°
$\gamma\gamma(\gamma)$	3.9		
$\mu\mu(\gamma)$	0.9		
$ee(\gamma)'$	-		ScatteringAngleRangle:$[25°, 140°]$, MinEnergy: 0.1 GeV, MaxAcollinearity: 180°
$\gamma\gamma(\gamma)'$	-		
$\mu\mu(\gamma)'$	-		
$eeee$	38.8	AAFH	invariant mass of the secondary pair larger than 0.5 GeV
$ee\mu\mu$	22.1		

6.2. Trigger Efficiencies and Rates

1. Trigger variables at L1 trigger

The informations used in trigger are listed in Table III

TABLE III: Trigger variables at L1 trigger.

Name	Description
	CDC
N_{st}	Number of short tracks with $p_T > 0.2$ GeV in CDC
N_{lt}	Number of long tracks with $p_T > 0.3$ GeV in CDC
P_1	Largest momentum of tracks (trk1) in CMS
P_2	Largest momentum of tracks (trk2) in CMS
θ_{tt}	Angle between trk1 and trk2
	ECL
N_c	Number of clusters with $E > 0.1$ GeV in ECL
E_1	The largest energy clusters in CMS
E_2	The secondary largest energy of the cluster in CMS
$\theta_{\gamma\gamma}$	Angle between clusters
	KLM
N_μ	Number of tracks passing larger than 1 layers in KLM
θ_{tm}	Angle between CDC tracks and KLM tracks
	CDC-ECL
N_{tc}	Number of CDC tracks with associated ECL clusters
E_{t1}	ECL Cluster energy with associated track with the largest momentum
$\theta_{t\gamma}$	Angle betwenn CDC track and ECL clusters

The vetos listed in Table IV are developed for the background suppression. These are priliminary logics based on the information from offline reconstruction, the further study on these vetos are needed with the L1 trigger simulation.

TABLE IV: Veto logics.

Item	Logic
eclBhabhaVeto	$E_1 + E_2 > 7.0\ GeV,\ \theta_{\gamma_1\gamma_2} > 100^\circ$
BhabhaVeto	$N_{st} = 2,\ N_{tc} = 2$, eclBhabha
SBhabhaVeto	$N_c \geq 2,\ E_1 + E_2 > 5.0\ GeV,\ \theta_{\gamma\gamma} > 100^\circ,\ N_{tc} = 1,\ E_\gamma > 0.5,\ P_1 > 2.5\ GeV,\ E_{t1} > 2.0\ GeV$
$\gamma\gamma$Veto	$N_{st} = 0$, eclBhabha

2. Bhabha Accept

The "Bhabha Accept" aims to select Bhabha sample for the detector calibration and monitoring. The efficiency should be high (100%). Due to the large cross section of Bhabha, the samples is proposed to be prescaled as a function of polar angle of electron.

Figure 1 shows the number of tracks versus the number of ECL clusters from the MC sample. Most of events have two tracks and clusters, but still some events miss one track or one cluster. So two Bhabha Accept triggers are deveoped to select these events. The trigger logics and efficiencies are listed in Table V. The combined efficiency of these two triggers are about 98%.

TABLE V: Efficiency of Bhabha.

	Logic	ϵ (%)
Bhabha Accept1	$N_{st} \geq 1$, eclBhabhaVeto	88.6
Bhabha Accept2	$N_{st} \geq 2,\ N_{tc} \geq 1,\ \theta_{tt} > 150^\circ,\ E_1 > 1.0$ GeV	95.2
Combined		98.0

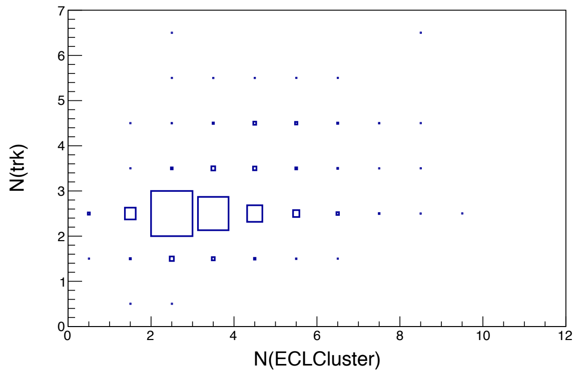

FIG. 1: The number of tracks vs. the number of ECL clusters.

3. *Two Track Triggers*

This trigger items mainly aim to trigger the processes with two charged tracks and with or without photons in the final states. Four lines are developed to keep high efficiency of physics as listed in Table VI.

TABLE VI: Trigger Logics.

Item	Logic
T1:2trk	$N_{st} = 2$, $N_{sl} \geq 1$, !BhabhaVeto
T2:1trk1mu	$N_{st} \geq 1$, $N_{\mu} \geq 1$, $\phi_{tm} > 45$
T3:1mu	$N_{st} \geq 1$, at lease one track with momentum (CMS) larger than 0.5 GeV and associated KLM track.
T4:1trk1c	$N_{st} \geq 1$, $N_c \geq 1, \theta_{t\gamma} > 45$, $E_1 > 0.5\ GeV$, !BhabhaVeto,!SBhabhaVeto

1. T1:2trk

This is the standard two tracks trigger. The dominant physics backgrounds are from the two lepton processes *eeee* or $ee\mu\mu$. Figure 2 shows the transverse momentum (pT) of tracks for the events of *eeee* and $ee\mu\mu$ passing T1:2trk. To supress the background from this processes, at least one long track with pT>0.3 GeV are required.

TABLE VII: Efficiencies (%)

	Processes	T1:2trk	T2:1trk1mu	T3:1mu	T4:1trk1c	Combine
	$\tau\tau$(1v1)	81.0	58.1	61.8	61.3	96.0
	$\tau \to e\gamma$	80.0	55.1	56.0	91.7	96.7
	$\tau \to \mu\gamma$	76.1	48.1	46.2	87.7	94.6
ϵ(%)	$\pi\pi(\gamma)$	67.9	51.9	67.4	80.0	96.3
	$\pi\pi(\gamma)$[0,1]	66.7	49.4	66.3	79.1	96.0
	$B \to \pi^0\pi^0$	11.1	83.4	35.4	96.3	99.0
	$\mu\mu$	98.9	94.5	99.7	-	> 99.9
	eeee	2.2	0.1	0.1	1.1	3.0
σ(nb)	$ee\mu\mu$	2.6	0.8	0.7	0.1	3.1
	$ee(\gamma)$	7.2	7.3	10.5	11.1	21.9

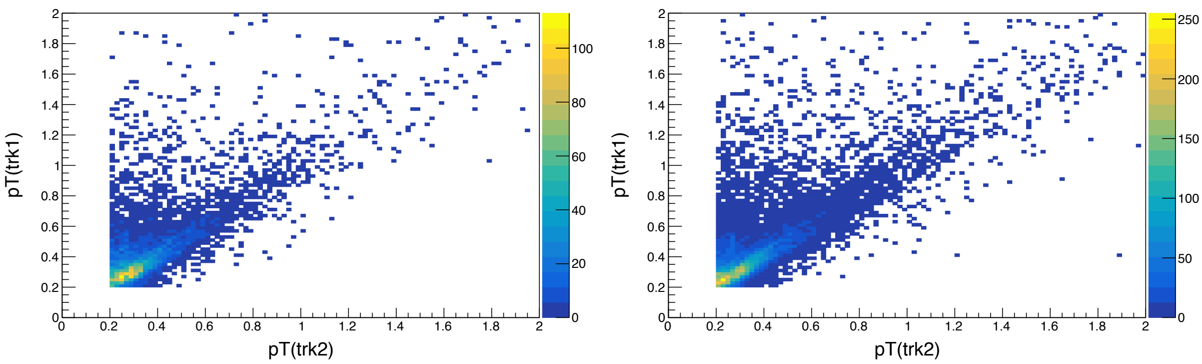

FIG. 2: The transverse momentum of trk1 vs. that of trk2 for the events of $eeee$ (left) and $ee\mu\mu$ (right) passing T1:2trk.

2. T4:1trk1c

The line is to trigger the processes with two tracks and one photon at least in the final state, but one track is failed to be found during the reconstrucion. This is a quite efficient trigger, especially for the τ decay as shown in Table VII, while the side effect is that many Bhabha are triggered (11 nb) due to the similar topology.

The logic listed in Table VI shows that the veto SBhabhaVeto is used to suppress the background.

If SBhabhaVeto is not applied in the line, the triggered cross section of Bhabha is about 29 nb which is too high for DAQ system.

Left plot in Figure 3 shows the track multiplicity of Bhahba events passing this line without SBhabhaVeto. The events with one track are dominant. Middle plot shows the distribution of the polar angle of tracks for the events with only one track in the left plot. These tracks are electrons. The tracking of positron is failed due to the limited material at the border of CDC's backward endcap. In order to suppress this kind of events, the "SBhabhaVeto" is developed. The cross section of Bhabha is suppressed to 11 nb from 29 nb with SBhabhaVeto while the reduction for the efficiencies of signal is less than 1%.

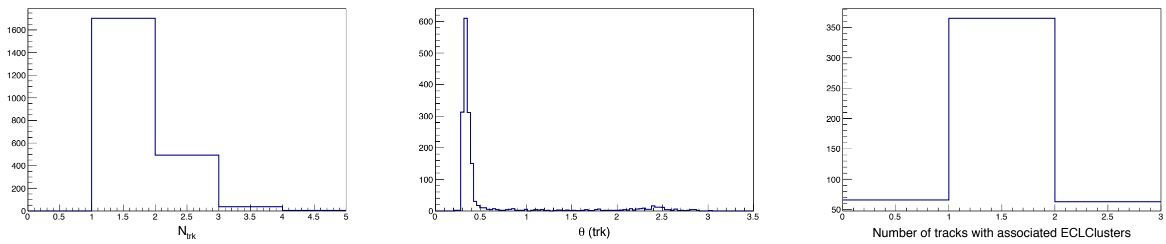

FIG. 3: Left: the track multiplicity of Bhabha events passing T4:1trk1c; Middle: the θ distribution of tracks of events corresponding to the second bin (one track) in the left plot. Right: the number of tracked matched to ECL clusters of the events corresponding to the third bin (two tracks) in the left plot.

Right plot in Figure 3 shows the number of tracks with associated ECL clusters per event in the third bin (two tracks) of the left plot. Most events have only one track with associated ECL cluster. These tracks are electron. One possible reason on the failure of the matching between the positron and ECL cluster is that the tracking quality of positron is bad due to the limited material at the border of backward endcap of CDC, which lead to extrapolation from CDC to ECL has large uncertainty and finally failed to find the associated cluster in ECL.

The tracking in the border of CDC and matching of track and cluster may have large uncertainty compared to the L1 simulation, which causes large uncertainty of the event rate. So a more stable estimation for the level of physics background will be studied with L1 simulation.

4. Single Photon

Two dedicated lines for single photon physics are developed. One requires that at least one ECL cluster with energy larger than 2 GeV, another requires a loose threshold of 1 GeV and the number of tracks is no more than one. Both of them should be rejected by BhabhavVeto and ggVeto.

1. T1:SinglePhoton, $E_1 > 2.0\ GeV$, !BhabhaVeto, !ggVeto

   The dominant physics background for this trigger is Bhabha. The cross section of Bhabha passing this line is about 59 nb.

   Figure 4 shows the track multiplicity of the Bhabha events passing this trigger. We can see that the events without CDC track are dominant. Left plot in Figure 5 shows the polar angle in lab frame of the cluster with the largest energy in CMS. Most clusters accumulate in the ECL endcaps. If we zoom in the regions of forward and backward endcaps, we can see the clear structure of the crystal in ECL as shown in the middle and right plots. The geometry of ECL is three and two crystals larger than that of CDC for the forward and backward coverage , repectivley, The Bahbah events which enter these regions are quite easy to be triggered by this line due to the above reasons.

2. T2:SinglePhoton $E_1 > 1.0\ GeV$,$N_{st} \geq 1$, !ggVeto

   The cross section of Bhabha passing this line is about 61 nb. The dominant physics background for this trigger is also Bhabha process. The plots with the same definition as T1 are shown in Figures 6 and 7.

5. Other Triggers

Some other trigger lines listed below are also developed for the dedicated physics processes.

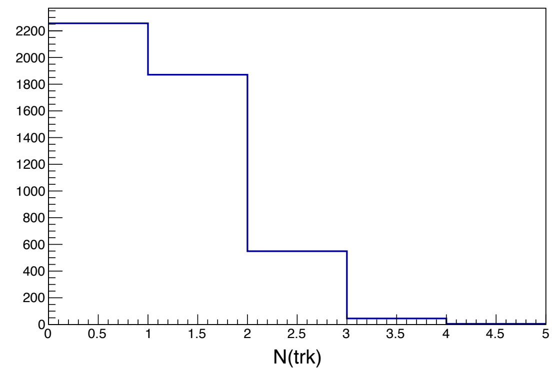

FIG. 4: Track multiplicity of the Bhabha events passing this trigger.

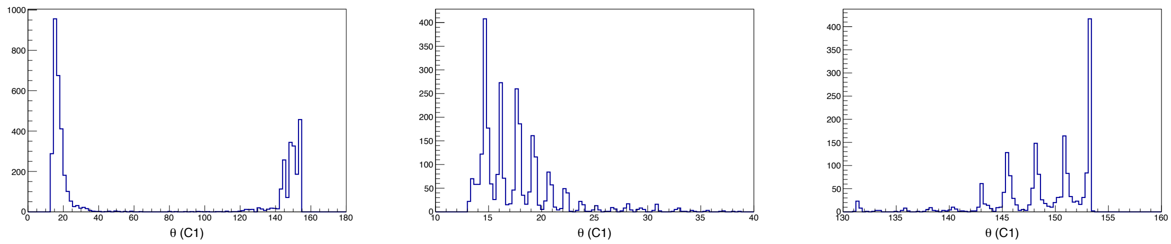

FIG. 5: The polar angle in lab frame of the cluster with the largest energy in CMS. Left is for the whole region [0°,180°], middle and right are for the forward and background endcap of ECL, respectively.

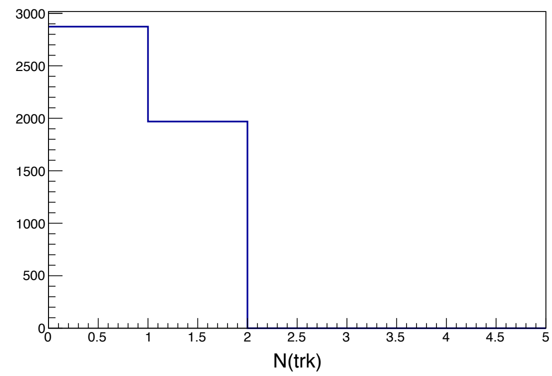

FIG. 6: The number of tracks of the Bhabha events passing this trigger.

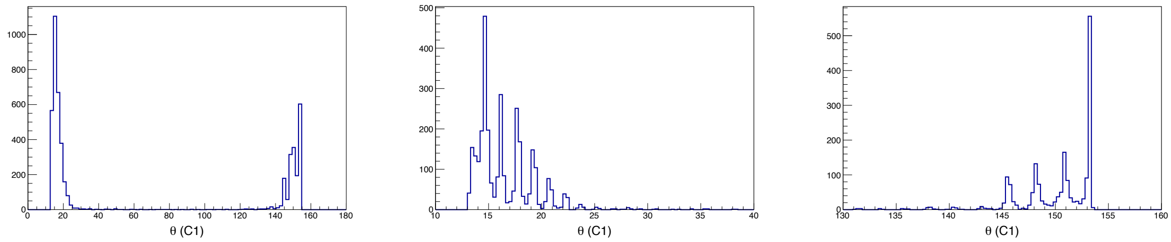

FIG. 7: The polar angle in lab frame of the cluster with the largest energy in CMS. Left is for the whole region [0°,180°], middle and right are for the forward and background endcap of ECL, respectively.

1. T1:ccb $N_c \geq 2$, $E_1 > 0.5$ GeV $E_2 > 0.5$ GeV, $\theta_{\gamma\gamma} > 45°$!BhabhaVeto, !ggVeto
2. T2:3g $N_c \geq 3$, $\theta_{\gamma\gamma} \subset [20°, 170°]$, !BhabhaVeto, !ggVeto
3. T3:3t $N_{st} \geq 3$, $N_{lt} \geq 2$

6.3. Efficiencies

The efficiencies of signal processes and cross sections of physical backgrounds after triggers are listed in Table VIII (The triggers of SinglePhoton are not included in the trable).

The efficiencies of hadronic processes are almost 100%, the efficiencies of low multiplicity are larger than 97%, and is about 94% for the generic τ decay

The cross sections of two photon processes $eeee$ and $ee\mu\mu$ after triggers are about 3 nb. while for Bhabha, 32 nb events are triggered. The event rate based on the designed luminosity 8^{35} cm^{-1} s^{-1} is 25.6 kHz which is quite close to the maximum readout rate of DAQ (30 kHz), so the Bhabha need to be further suppressed.

All of the efficiencies and cross sections in the analysis are estimated by using the information from the offline reconstruction. The reconstruction at border of detectors may cause large uncertainty compared to the L1 hardware simulation as we pointed already, so these results are taken as a reference for the background level and performance of triggers. The precious study on the performance of L1 trigger will be done with L1 Simulation.

TABLE VIII: Efficiencies and Cross section after triggers

	Processes	T1:2trk	T2:1trk1mu	T3:1mu	T4:1trk1c	T1:bbc	T2:3g	T3:3t	Combine
$\epsilon(\%)$	$B^0\bar{B}^0$	-	96.5	50.0	82.9	44.8	93.4	99.4	> 99.9
	B^+B^-	-	96.5	51.7	84.1	46.2	92.6	99.5	> 99.9
	ccbar	-	96.8	65.9	89.4	52.1	84.8	98.0	> 99.9
	uds	-	96.5	68.0	89.1	50.0	81.1	97.2	> 99.9
	$\tau \to$generic	51.0	60.0	57.2	62.6	28.1	55.6	29.1	94.3
	$\tau\tau$(1v1)	81.0	58.1	61.8	61.3	27.9	47.4	-	97.3
	$\tau \to e\gamma$	80.0	55.1	56.0	91.7	52.3	85.7	-	99.0
	$\tau \to \mu\gamma$	76.1	48.1	46.2	87.7	57.9	82.2	-	97.1
	$\pi\pi(\gamma)$	67.9	51.9	67.4	80.0	43.4	42.5	-	97.4
	$\pi\pi(\gamma)$[0,1]	66.7	49.4	66.3	79.1	43.0	38.6	-	97.2
	$B \to \pi^0\pi^0$	11.1	83.4	35.4	96.3	92.4	17.0	81.7	> 99.9
	$\mu\mu$	98.9	94.5	99.7	-	-	-	-	> 99.9
σ(nb)	eeee	2.2	0.1	0.1	1.1	0.8	0.9	0.1	3.4
	$ee\mu\mu$	2.6	0.8	0.7	0.1	0.1	0.5	0.1	3.3
	$ee(\gamma)$	7.2	7.3	10.5	11.1	13.1	2.9	0.6	32.2

[1] P. Urquijo and T. Ferber, ‘Overview of the Belle II Physics Generators’, Belle II Internal Note BELLE2-NOTE-PH-2015-006 (2015).

[2] C. H. Li, ‘Guide to the L1 Emulator’, Belle II Internal Note BELLE2-NOTE-PH-2015-010 (2015).