Studies of L1 trigger performance for low-multiplicity final states using Fast TSIM

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Purpose of the studies

- Goal is to develop a proposal for a set of level 1 triggers, with particular emphasis on final states that contain a small number of particles, in cooperation with physics and trigger groups.

Considerations

- Algorithms should be reasonable to implement in FPGA
- Acceptable L1 rate at target luminosity
- High efficiency for wide range of signals
- Independent (orthogonal) triggers for precision measurements
- Delay decisions the HLT where possible (e.g. $\gamma\gamma$ veto; flattening Bhabha angular spectrum).
- Flexible response (e.g. vetoing or prescaling) in response to observed backgrounds.

Technical details

- Release = head (newer than release-00-09-00).

- Two stages:
  - event generation, plus add_subdetector_tsim(main)
  - add_grl_gdl_tsim, plus my additional analysis module
  - See Chunhua's instructions on confluence:

    https://confluence.desy.de/pages/viewpage.action?spaceKey=BI&title=Trigger+TSIM

- Unless otherwise noted, Phase 2 geometry and Phase 2 background mixing (recent ones for MC9).

- Focus is on luminosity = 2 × 10^{35} cm^{-2}/s = 200 nb^{-1}/s
  - 25% of full luminosity; 5× Phase 2 target.
  - nominally 2020

- CDC and ECL only.
- Tracks require 4 SL. Currently only 2D tracking.
- Clusters have a ±100 ns timing cut; 100 MeV minimum per trigger cell (TC).
- Center-of-mass thresholds on ECL energies are implemented as a look up table of laboratory energies keyed by the TC cellID (576 elements)
- Angular regions are keyed using the TC Theta ID of the ECL cluster (ranges from 1 to17)
- One trigger uses the difference in ϕ between ECL clusters. This is not implemented in a useful fashion (atan2).

MC samples

- Generated by Torben Ferber
- Wide range of signals with a variety of different signatures, plus high-rate QED samples.
- For longer discussion of the physics, see my talk at the last B2GM: https://kds.kek.jp/indico/event/24563/session/44/contribution/31

MC samples

Signal Mode	Signature
2 photon production of ALP, 0.2, 0.5, 2, 10 GeV/c2	Two photons back to back in phi
2 photon production of pi0, zero tag	Two photons back to back in phi
2 photon production of pi0, single tag	e- back to back in phi with merged pi0
ALP --> invisible, 9.3 GeV/c2	single photon, E* = 1.2 GeV
ALP --> two merged photons, 0.2 GeV/c2	two merged photons back-to-back with photon
a' --> e+e-, 0.5 GeV/c2	ISR photon plus e+ e- pair
a' --> invisible, 0.5 and 9.3 GeV/c2	single photon, 1.2 or 5.2 GeV
gamma pi+ pi-	ISR photon plus pi+ pi- pair
tau to e gamma	generic tau plus e gamma
tau to mu gamma	generic tau plus mu gamma
Y3S --> pi+ pi- Y1S, Y1S --> invisible	low pt pi+ pi- pair

- ALP = axion-like particle
- a' = dark photon

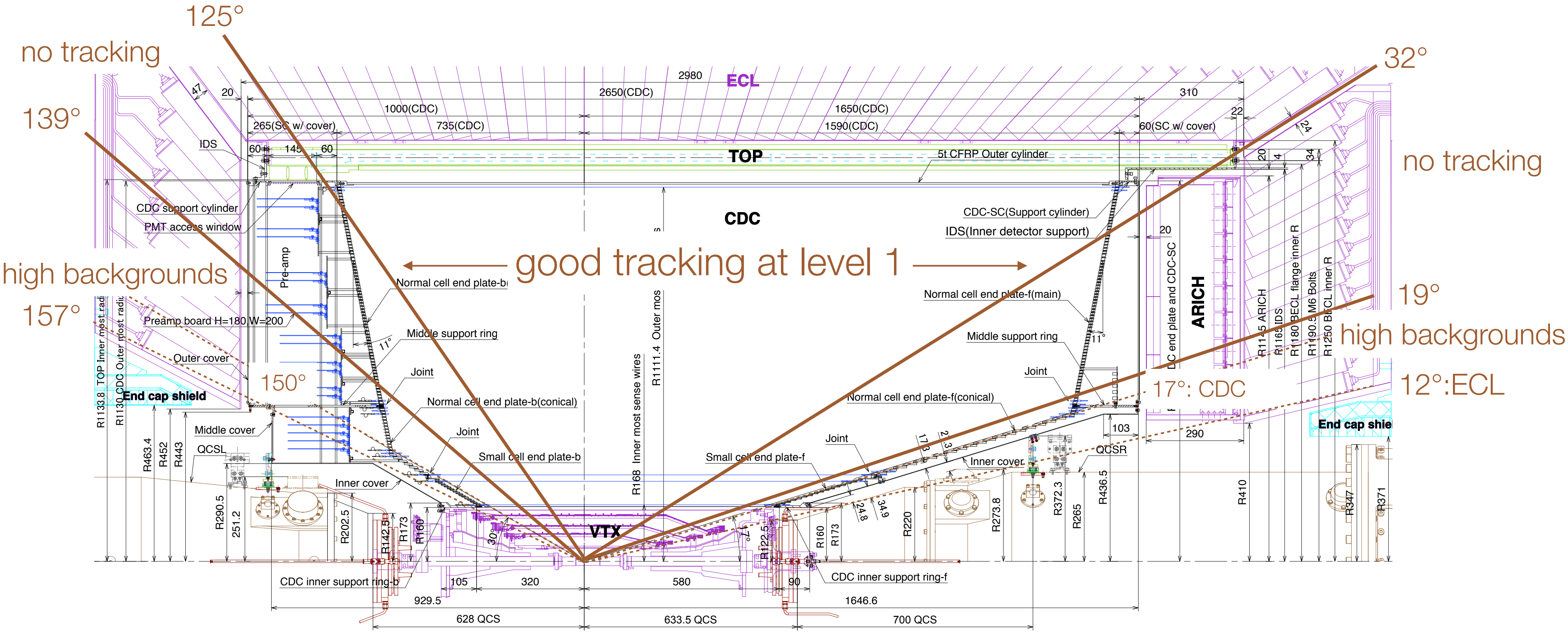
New ECL trigger objects

- Number of clusters with center of mass energy above 1 or 2 GeV

- Angular region of each
  - ThetaID [4,14]: region covered by L1 CDC tracking
  - ThetaID [4,15]: region covered by ECL barrel
  - ThetaID 1 or 17: innermost ring of each endcap; high backgrounds
  - ThetaID 2, 3, 4, or 16: region with no tracking

- Pairs of clusters back to back in ϕ (150°)

ECL angular regions with significantly different responses at Level 1



125°

no tracking

139°

high backgrounds

157°

150°

good tracking at level 1

32°

no tracking

19°

high backgrounds

17°: CDC

12°:ECL

Trigger bits (lines)

- I have changed some definitions to make bits mutually exclusive, to make it easier to understand the individual contributions to the overall rate.
- Technical descriptions will be in the forthcoming trigger note.
- Table excludes triggers with prescales ≥100
- Two versions of a Bhabha veto: “Bhabha” uses CDC and ECL information; “eclBhabha” uses only ECL information.

Fourteen trigger bits used in this study

	Bit #	Description	Prescale	
mutually exclusive	0	≥3 tracks	1	CDC
	1	2 tracks, not a Bhabha	1	
	21	2 track, Bhabha	1	
	23	1 track, ≥1 neutral clusters, no 2 GeV cluster exactly 1 track	1	Both
	3	≥3 clusters, ≥1 300 MeV, not an eclBhabha	1	ECL
	22	clusters back-to-back in phi, no 2 GeV cluster	1	
mutually exclusive	12	2 GeV E* in [4,14], not a Bhabha	1	
	13	2 GeV E* in [4,14], Bhabha	1	
mutually exclusive	14	2 GeV E* in 2,3,15,16, not a Bhabha or eclBhabha	1	
	15	2 GeV E* in 2,3,15,16, Bhabha or eclBhabha	1	
mutually exclusive	16	2 GeV E* in 1,17, not a Bhabha or eclBhabha	10	
	17	2 GeV E* in 1,17, Bhabha or eclBhabha	10	
mutually exclusive	18	exactly 1 E*>1 GeV and 1 E>300 MeV, in [4,15]	1	
	19	exactly 1 E*>1 GeV and 1 E>300 MeV, in 2,3,16	1	

Trigger summary table

- Three “efficiency” type numbers:
  - Percentage Selected: percentage of generated events that satisfy at least one trigger
  - Fiducial Efficiency: percentage of events that satisfy at least one trigger when all relevant final state particles are in the region 17° < θ_{lab} < 150°
  - Barrel Efficiency: percentage of events that satisfy at least one trigger when all relevant final state particles are in the region that has L1 tracking 36° < θ_{lab} < 120°

Trigger summary table

Sample	Note	Generated sigma nb	Percentage selected	Accepted sigma nb	Rate Hz 200 nb-1/sec	Fiducial efficiency %	Barrel efficiency %
Bhabha	0.5 deg	122760	0.30	370.6	74129	92.1	
gamma gamma		25.2	12.71	3.2	641	97.1	100
e e e e		39.8	6.78	2.7	540		
e e mu mu		18.9	13.28	2.5	502		
tau tau		0.919	93.14	0.9	171		
mu mu		1.115	72.5	0.8	162	92.9	99.9
2gamma production of ALP	0.2 GeV					13.2	
	0.5 GeV					88.7	
	2 GeV					98.1	
	10 GeV					99.1	100
2gamma production of pi0	no tag					2.4	0.4
	1 tag					N/A	
ALP--> invisible	9.3 GeV					83.1	93.5
ALP to merged photons	0.2 GeV					99.1	100
a' --> e e	0.5 GeV					98.1	100
a' --> invisible	0.5 GeV					83.9	100.0
	9.3 GeV					74.9	94.2
gamma pi+pi-	0.5 GeV					97.1	100.0
tau --> e gamma						99.5	100
tau --> mu gamma						99.1	100
Y3S --> pi pi Y1S						55.5	60.4
TOTAL					76144		

- Final states that include only 2 low-energy particles are challenging.

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- Single photon efficiencies are very good in the barrel region.
  - lower in Fiducial due to ThetaIDs 1 & 17 and endcap/ barrel gaps

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- Overall rate is too high for this luminosity.
  - recall this is for 5× phase 2 target luminosity

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Bhabha sample

- This sample was generated with the requirement that both outgoing electrons be scattered more than 0.5° (COM).
- In the vast majority of cases, the electrons are showering in the magnets and other inactive material. ~12% of the trigger rate is from events in which both electrons have $17° < \theta_{lab} < 150°$.
- This sample is a subset of the RBB/BHWIDE background samples; a more complete study will give higher values.

Contributions of each trigger to Bhabha trigger rate

Percentage of events selected by each trigger bit			e+e-	0.5 deg		
			122760	nb		
Bit #	Description	Prescale	% Selected	exclus.	Rate	excl. rate
0	≥3 tracks	1	0.006	0.003	1473	737
1	2 tracks, not a Bhabha	1	0.036	0.026	8839	6384
21	2 track, Bhabha	1	0.008	0	1964	0
23	1 track, ≥1 neutral clusters, no 2 GeV cluster	1	0.153	0.135	37565	33145
3	≥3 clusters, ≥1 300 MeV, not an eclBhabha	1	0.029	0.007	7120	1719
22	clusters back-to-back in phi, no 2 GeV cluster	1	0.076	0.038	18660	9330
12	2 GeV E* in [4,14], not a Bhabha	1	0.005	0	1228	0
13	2 GeV E* in [4,14], Bhabha	1	0.008	0	1964	0
14	2 GeV E* in 2,3,15,16, not a Bhabha or eclBhabha	1	0.008	0.002	1964	491
15	2 GeV E* in 2,3,15,16, Bhabha or eclBhabha	1	0.025	0.021	6138	5156
16	2 GeV E* in 1,17, not a Bhabha or eclBhabha	10	0.004	0.003	982	737
17	2 GeV E* in 1,17, Bhabha or eclBhabha	10	0.002	0.001	491	246
18	exactly 1 E*>1 GeV and 1 E>300 MeV, in [4,15]	1	0.002	0.001	491	246
19	exactly 1 E*>1 GeV and 1 E>300 MeV, in 2,3,16	1	0.005	0.003	1228	737
	Percentage selected by at least 1 trigger		0.302	0.242	74147	58925
	Cross section (nb)		371			
	Rate, phase2 backgrounds, luminosity (nb-1/s) =	200	74147			

events selected by only 1 trigger

- 2 tracks, not a Bhabha (8.8 kHz):
  - essential for physics.
  - I believe that the rate is dominated by tracks that don’t come from the IP.
  - 3D tracking at L1 is needed to get this under control.

- 1 track, ≥1 cluster, no 2 GeV cluster (37.6 kHz):
  - useful for Υ(3S) → $\pi^+\pi^-$Υ(1S); ~half of efficiency
  - secondary importance for other modes
  - probably non-IP tracks as well.

- 2 GeV E* in 2, 3, 15, or 16, Bhabha or eclBhabha (6.1 kHz):
  - important for ALP → $\gamma\gamma$, a′ → e^+e^-, and $\gamma\gamma$ events.
  - only one of the high-rate triggers identified as a Bhabha
  - we could support this rate if we can get the others under control.
  - in the HLT, we could distinguish Bhabhas from the desired physics.

- Clusters back-to-back in ϕ, no 2 GeV cluster (18.7 kHz):
  - trigger for 2-photon fusion production of ALP/π^0.
  - only trigger for muon pairs in the endcap
  - orthogonal trigger for muon pairs in barrel
  - needs study. Maybe split into a 3D trigger for muon pairs, and prescale 2D.
  - physics needs low thresholds (even below 100 MeV); raising threshold would not be the way to go.
  - could look at requiring exactly 2 clusters, but maybe too sensitive to backgrounds.

Summary

- Good progress on developing a set of triggers.
- Efficiency for most modes is very good, with the exception of final states that are two low-energy particles.
- Need 3D tracking in fast TSIM to understand how to deal with high trigger rate from background events.
- Probably the rate is acceptable for at least the start of Phase 2, but needs work for even the next experiment.
- Back-to-back cluster trigger needs thought and work.