THE UNIVERSITY OF BRITISH COLUMBIA

INSTITUTE OF PARTICLE PHYSICS

Trigger menu

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Big picture

- The goal of the trigger menu is to keep the events of interest while satisfying the constraints on the total rate/ number of events that can be accepted.

- For the level 1 trigger, the constraint is from data acquisition. Specifically, the rate at which events can be processed by the high-level trigger.

- For the high-level trigger, the constraint is the availability of offline computing and storage.

The events of interest

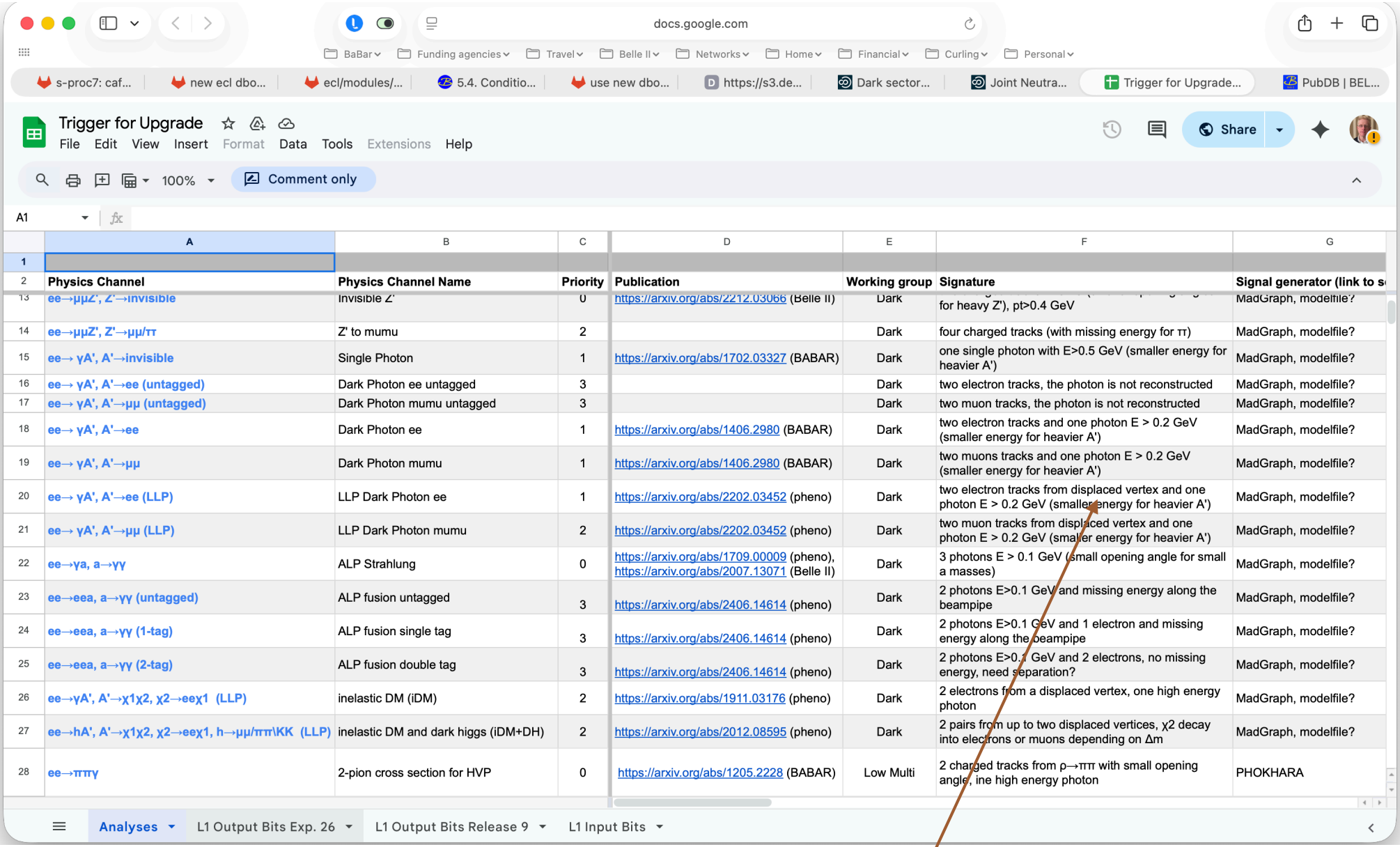
- In BaBar (and I suppose Belle), the focus was almost entirely on CP violation in B mesons. Corresponding trigger menu was relatively simple.

- B and charm physics (“hadronic events”) are still at the core of the Belle II physics program, but it also includes an extensive program of low-multiplicity analyses
  - dark sector
  - precision standard model
  - tau (especially 1 vs 1)

- Torben Ferber (trigger upgrade convener) is collecting physics processes and signatures (and corresponding generators).
  - an update of what we did in 2016
  https://docs.belle2.org/pub_data/documents/439/

- Can trigger upgrades (e.g. finer segmentation for ECL level 1) help retain sensitivity to the full physics program in the face of luminosity and background increases?

- Focused on level 1.



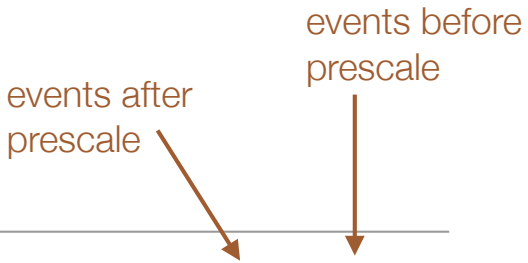
Trigger for Upgrade

	Physics Channel	Physics Channel Name	Priority	Publication	Working group	Signature	Signal generator (link to s
13	ee→μμZ', Z'→invisible	Invisible Z'	0	https://arxiv.org/abs/2212.03066 (Belle II)	Dark	for heavy Z'), pt>0.4 GeV	MadGraph, modelfile?
14	ee→μμZ', Z'→μμ/ττ	Z' to mumu	2		Dark	four charged tracks (with missing energy for ττ)	MadGraph, modelfile?
15	ee→ γA', A'→invisible	Single Photon	1	https://arxiv.org/abs/1702.03327 (BABAR)	Dark	one single photon with E>0.5 GeV (smaller energy for heavier A')	MadGraph, modelfile?
16	ee→ γA', A'→ee (untagged)	Dark Photon ee untagged	3		Dark	two electron tracks, the photon is not reconstructed	MadGraph, modelfile?
17	ee→ γA', A'→μμ (untagged)	Dark Photon mumu untagged	3		Dark	two muon tracks, the photon is not reconstructed	MadGraph, modelfile?
18	ee→ γA', A'→ee	Dark Photon ee	1	https://arxiv.org/abs/1406.2980 (BABAR)	Dark	two electron tracks and one photon E > 0.2 GeV (smaller energy for heavier A')	MadGraph, modelfile?
19	ee→ γA', A'→μμ	Dark Photon mumu	1	https://arxiv.org/abs/1406.2980 (BABAR)	Dark	two muons tracks and one photon E > 0.2 GeV (smaller energy for heavier A')	MadGraph, modelfile?
20	ee→ γA', A'→ee (LLP)	LLP Dark Photon ee	1	https://arxiv.org/abs/2202.03452 (pheno)	Dark	two electron tracks from displaced vertex and one photon E > 0.2 GeV (smaller energy for heavier A')	MadGraph, modelfile?
21	ee→ γA', A'→μμ (LLP)	LLP Dark Photon mumu	2	https://arxiv.org/abs/2202.03452 (pheno)	Dark	two muon tracks from displaced vertex and one photon E > 0.2 GeV (smaller energy for heavier A')	MadGraph, modelfile?
22	ee→γa, a→γγ	ALP Strahlung	0	https://arxiv.org/abs/1709.00009 (pheno), https://arxiv.org/abs/2007.13071 (Belle II)	Dark	3 photons E > 0.1 GeV (small opening angle for small a masses)	MadGraph, modelfile?
23	ee→eea, a→γγ (untagged)	ALP fusion untagged	3	https://arxiv.org/abs/2406.14614 (pheno)	Dark	2 photons E>0.1 GeV and missing energy along the beampipe	MadGraph, modelfile?
24	ee→eea, a→γγ (1-tag)	ALP fusion single tag	3	https://arxiv.org/abs/2406.14614 (pheno)	Dark	2 photons E>0.1 GeV and 1 electron and missing energy along the beampipe	MadGraph, modelfile?
25	ee→eea, a→γγ (2-tag)	ALP fusion double tag	3	https://arxiv.org/abs/2406.14614 (pheno)	Dark	2 photons E>0.1 GeV and 2 electrons, no missing energy, need separation?	MadGraph, modelfile?
26	ee→γA', A'→χ1χ2, χ2→eeχ1 (LLP)	inelastic DM (iDM)	2	https://arxiv.org/abs/1911.03176 (pheno)	Dark	2 electrons from a displaced vertex, one high energy photon	MadGraph, modelfile?
27	ee→hA', A'→χ1χ2, χ2→eeχ1, h→μμ/ππ\KK (LLP)	inelastic DM and dark higgs (iDM+DH)	2	https://arxiv.org/abs/2012.08595 (pheno)	Dark	2 pairs from up to two displaced vertices, χ2 decay into electrons or muons depending on Δm	MadGraph, modelfile?
28	ee→πππγ	2-pion cross section for HVP	0	https://arxiv.org/abs/1205.2228 (BABAR)	Low Multi	2 charged tracks from ρ→ππ with small opening angle, ine high energy photon	PHOKHARA

displaced vertex is new since 2016

High level trigger menu (2024c)

- 68 lines
- 23 of which have prescale = 1
  - mostly physics
- Four categories
  - physics
  - control samples
  - trigger studies
  - data production



	events after prescale	events before prescale	
ECL - Physics			
filter Elab gt 0.3 plus 3 others with Elab gt 0.18 plus no clust with Ecms gt 2.0	149 (32.96%)	149 (32.96%)	1.0
filter Elab gt 0.5 plus 2 others with Elab gt 0.18 plus no clust with Ecms gt 2.0	50 (11.06%)	50 (11.06%)	1.0
filter ge1 Estargt2 GeV neutral clst 2232 or 130145 not gg2clst ee2clst eelleg eeBremB	11 (2.43%)	11 (2.43%)	1.0
filter ge1 Estargt2 GeV neutral clst 32130 not gg2clst eelleg1clst eelleg1trk eeBremB	40 (8.85%)	40 (8.85%)	1.0
ECL - Potentially Prescaled			
filter 0.3ltEstar max clustlt2 GeV plus 2 others gt 0.2 GeV	1 (0.22%)	199 (44.03%)	100.0
filter 1 electron Estargt1 GeV clust in 45115 and no other clust Estargt0.3 GeV	3 (0.66%)	21 (4.65%)	10.0
filter 1 electron Estargt1 GeV clust in 32130 and no other clust Estargt0.3 GeV	1 (0.22%)	31 (6.86%)	100.0
filter 1 Estargt1 GeV cluster no other cluster Estargt0.3 GeV	0 (0.00%)	66 (14.60%)	200.0
filter 1 photon Estargt1 GeV clust not low not 45115 no other clust Estargt0.3 GeV	1 (0.22%)	5 (1.11%)	50.0
filter gg2clst	0 (0.00%)	0 (0.00%)	100.0
filter ge1 Estargt2 GeV chrg clst 22145 not gg2clst ee2clst eelleg	2 (0.44%)	65 (14.38%)	50.0
filter ggEndcapLoose	0 (0.00%)	0 (0.00%)	1.0
filter n2GeVPhotonBarrelge1	1 (0.22%)	28 (6.19%)	100.0
filter n2GeVPhotonEndcapge1	0 (0.00%)	10 (2.21%)	50.0
filter Estargt2 GeV cluster	2 (0.44%)	122 (26.99%)	100.0
filter ECLMuonPair	0 (0.00%)	12 (2.65%)	10.0
CDC - Physics			
filter ge3 looseB tracks inc 1 tightB not ee2leg	38 (8.41%)	38 (8.41%)	1.0
filter 2 looseB tracks inc 1 tightB q==0 pstarmaxlt0.8 GeVc not eexx	11 (2.43%)	11 (2.43%)	1.0
filter 2 looseB tracks 0.8ltpstarmaxlt4.5 GeVc not ee2leg eelleg1trk eexx	356 (78.76%)	356 (78.76%)	1.0
filter 2 looseB tracks pstarmaxgt4.5 GeVc not ee2leg eelleg1trk eellegle eeBremB muonPairVB	18 (3.98%)	18 (3.98%)	1.0
CDC - Potentially Prescaled			
filter 2 loose tracks pstarmaxlt0.8 GeVc	0 (0.00%)	11 (2.43%)	100.0
filter 2 loose tracks 0.8ltpstarmaxlt4.5 GeVc	3 (0.66%)	357 (78.98%)	100.0
filter 2 loose tracks pstarmaxgt4.5 GeVc	0 (0.00%)	18 (3.98%)	500.0
filter ge1 tight track	0 (0.00%)	451 (99.78%)	1000.0
Targeted Physics Lines			
filter 1 photon Estargt1 GeV clust in 45115 and no other clust Estargt0.3 GeV	5 (1.11%)	5 (1.11%)	1.0
filter 1 photon Estargt1 GeV clust in 32130 and no other clust Estargt0.3 GeV	8 (1.77%)	8 (1.77%)	1.0
filter 1 photon Estargt0.5 GeV clust in 4498 and no other clust Estargt0.3 GeV	6 (1.33%)	6 (1.33%)	1.0
filter ggBarrelLoose	0 (0.00%)	0 (0.00%)	1.0
filter singleTagLowMassB	0 (0.00%)	0 (0.00%)	1.0
filter singleTagHighMassB	0 (0.00%)	0 (0.00%)	10.0
filter b2b phi photons	0 (0.00%)	0 (0.00%)	1.0
filter displaced vertex	0 (0.00%)	0 (0.00%)	1.0
QED / Control Samples			
filter ee flat 0 19	0 (0.00%)	0 (0.00%)	62.0
filter ee flat 19 22	0 (0.00%)	0 (0.00%)	36.0
filter ee flat 22 25	0 (0.00%)	0 (0.00%)	30.0
filter ee flat 25 30	0 (0.00%)	0 (0.00%)	10.0
filter ee flat 30 35	0 (0.00%)	0 (0.00%)	36.0
filter ee flat 35 45	0 (0.00%)	0 (0.00%)	30.0
filter ee flat 45 60	0 (0.00%)	0 (0.00%)	10.0
filter ee flat 60 90	0 (0.00%)	0 (0.00%)	4.0
filter ee flat 90 180	0 (0.00%)	0 (0.00%)	2.0
filter selectee	0 (0.00%)	0 (0.00%)	20.0
filter seleelleg1clst	0 (0.00%)	6 (1.33%)	1000.0
filter seleelleg1trk	0 (0.00%)	21 (4.65%)	1000.0
filter eexxSelectB	2 (0.44%)	13 (2.88%)	4.0
filter eexxHighP	2 (0.44%)	2 (0.44%)	1.0
filter radiative BhabhaB	9 (1.99%)	39 (8.63%)	4.0
filter selectmumu	21 (4.65%)	21 (4.65%)	1.0
filter single muon	6 (1.33%)	79 (17.48%)	10.0
filter cosmic	0 (0.00%)	0 (0.00%)	1.0
filter rad Bhabha 1trkB	0 (0.00%)	1 (0.22%)	4.0
filter Bhabha one cluster	0 (0.00%)	0 (0.00%)	10.0
Level 1 Passthrough			
filter L1 trigger	0 (0.00%)	452 (100.00%)	1000.0
filter passthrough l1 trigger delayed bhabha	0 (0.00%)	0 (0.00%)	1.0
filter passthrough l1 trigger random	0 (0.00%)	0 (0.00%)	1.0
filter passthrough l1 trigger poisson	0 (0.00%)	0 (0.00%)	1.0
filter L1 Bhabha veto	0 (0.00%)	0 (0.00%)	10.0
filter L1 Bhabha select	0 (0.00%)	0 (0.00%)	100.0
filter L1 trigger nn info	0 (0.00%)	0 (0.00%)	8.0
filter passthrough l1 trigger f	0 (0.00%)	0 (0.00%)	1.0
filter dummy	0 (0.00%)	0 (0.00%)	1000.0
Prescaled Vetoes			
filter eelleg	0 (0.00%)	0 (0.00%)	1000.0
filter eelleg1clst	0 (0.00%)	0 (0.00%)	1000.0
filter eellegle	0 (0.00%)	0 (0.00%)	1000.0
filter eelleg1trk	0 (0.00%)	0 (0.00%)	1000.0
filter ee2clst	0 (0.00%)	0 (0.00%)	1000.0
filter ee2leg	0 (0.00%)	0 (0.00%)	1000.0
filter eeBremB	0 (0.00%)	0 (0.00%)	1000.0
filter eexx	0 (0.00%)	7 (1.55%)	1000.0
filter muonPairVB	0 (0.00%)	0 (0.00%)	1000.0

Physics lines

- Goal is to keep every e^+e^- annihilation except
  - Bhabhas (radiative Bhabhas);
  - two-photon fusion production of fermion pairs.

- Two categories of physics line:

  - Generic signatures
    - lots of energy or tracks
    - explicit vetoes on Bhabhas and eeXX

  - Specific final states

Generic physics lines

- Track based (tracks from the IP):
  - ≥3 tracks
  - exactly 2 tracks (three different momentum ranges)

- ECL based:
  - ≥3 clusters (charged or neutral)
  - photon with Ecms > 2 GeV

- We try to keep the track and ECL lines orthogonal.
  - measure efficiencies; redundancy

- However, vetoes use both tracks and clusters.

- Covers most of our physics, including
  - hadronic (B, charm)
  - tau pairs
  - Initial state radiation events (e.g. $e^+e^- \to \gamma\pi^+\pi^-$)
  - two (prompt) track dark sector (dark photon, Z′)
  - single photon (high energy)

Bhabha and other vetoes

- Seven Bhabha vetoes, constructed from combinations of high-momentum tracks with or without associated clusters, or high-energy clusters with no track.
  - depending on the line.

- Two-photon fusion production of lepton pairs.

Targeted physics lines

- All are low multiplicity:
  - single photon (0.5 GeV, 1.0 GeV thresholds)
  - single-tag π^0 form factor
  - Axion-like particle, two processes
  - single displaced vertex
  - di-photon event (e.g. single π^0) new for 2025c

- I add these as they come up.

Control samples

- Used for luminosity measurements, and physics performance control samples.
- Bhabhas, eeee, eeμμ, muon pairs. All of these are explicitly vetoed from the generic physics lines.
- Bhabhas and eeXX are prescaled; we try to keep all muon pairs.
  - prescale is a function of θ for Bhabhas.
- Cosmics (for alignment)

Trigger studies

- Keep samples to enable analysts to understand loss of efficiency.
  - event may not satisfying the criteria of a physics line
  - or it may be rejected by a veto

- Loose lines, e.g.
  - single muon
  - two track, no vetoes

- Vetoed events
  - including L1 Bhabha veto

Data production / other

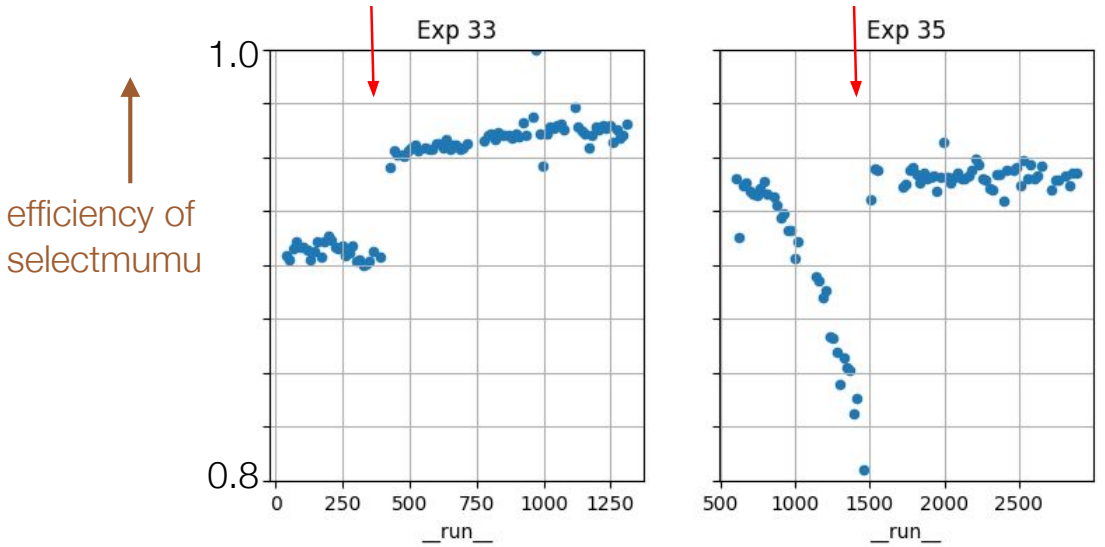
- Delayed Bhabhas, randoms
  - background overlays

- Events for CDC neural net L1 trigger training

New track list for 2025c

- Noticeable drop in HLT tracking efficiency in 2024 running (release-08-02). More details at
  - https://gitlab.desy.de/belle2/performance/trigger-event-properties/issues/-/issues/6

- No impact on hadronic efficiency due to high number of tracks and redundant ECL lines.



Marcello Campajola

- This was due to a configuration error in the reconstruction code.

- But it reminded us that we were sensitive to CDC performance, since (at that time) the HLT only used tracks that have CDC information.

- Starting with 2025c running, we have added five lines that do not require CDC hits.
  - ≥3 track hadronic line (prescale = 1)
  - selectmumu variant (prescale = 1)
  - three 2-track lines (prescaled; noticeable eeXX background).

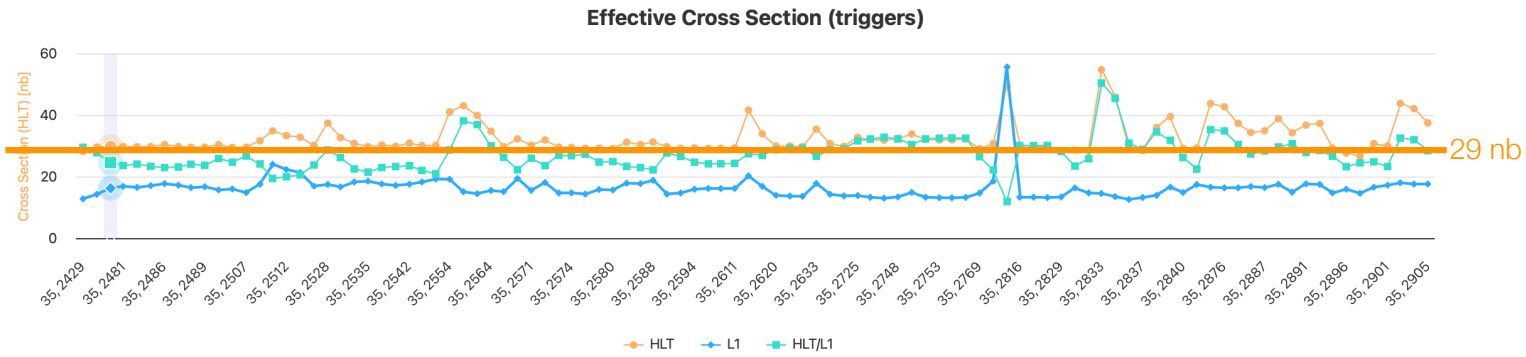
Effective cross section

- Defined as (events kept by HLT)/(integrated luminosity). Current estimate (for the computing steering group)

Simulated sample	Selected cross section (nb)
Y(4S)	1.05
c c-bar	1.30
uds	2.12
tau+ tau-	0.80
mu+ mu-	0.83
gamma gamma	1.96
Bhabha	7.31
eeee	0.18
eemumu	0.32
eeX, hhISR	0.34
Prediction from simulation	16.2
L1 pass through	1.1
unsimulated low multiplicity	11.7
TOTAL	29.0
Observed in exp 35	29.0

← prediction

← observed



Effective cross section — looking forward

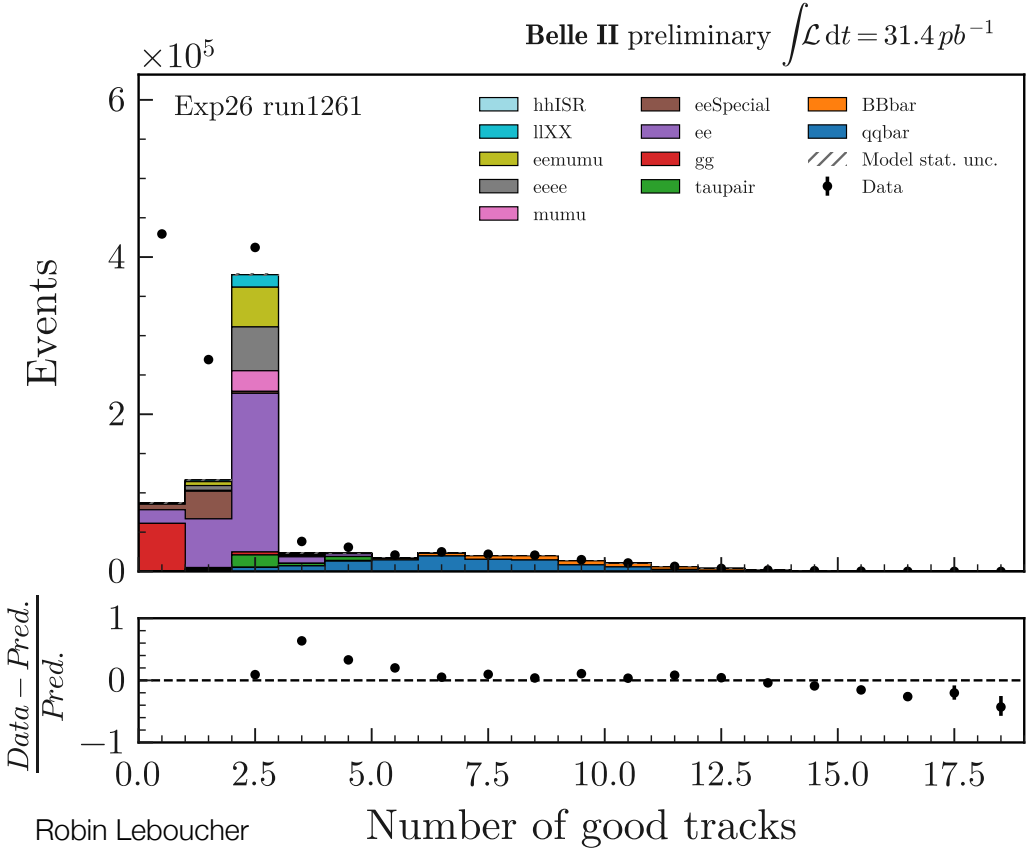
- With our current luminosity, we have been able to keep the HLT quite loose.
  - $B\bar{B}$ events are ~3% of the total.

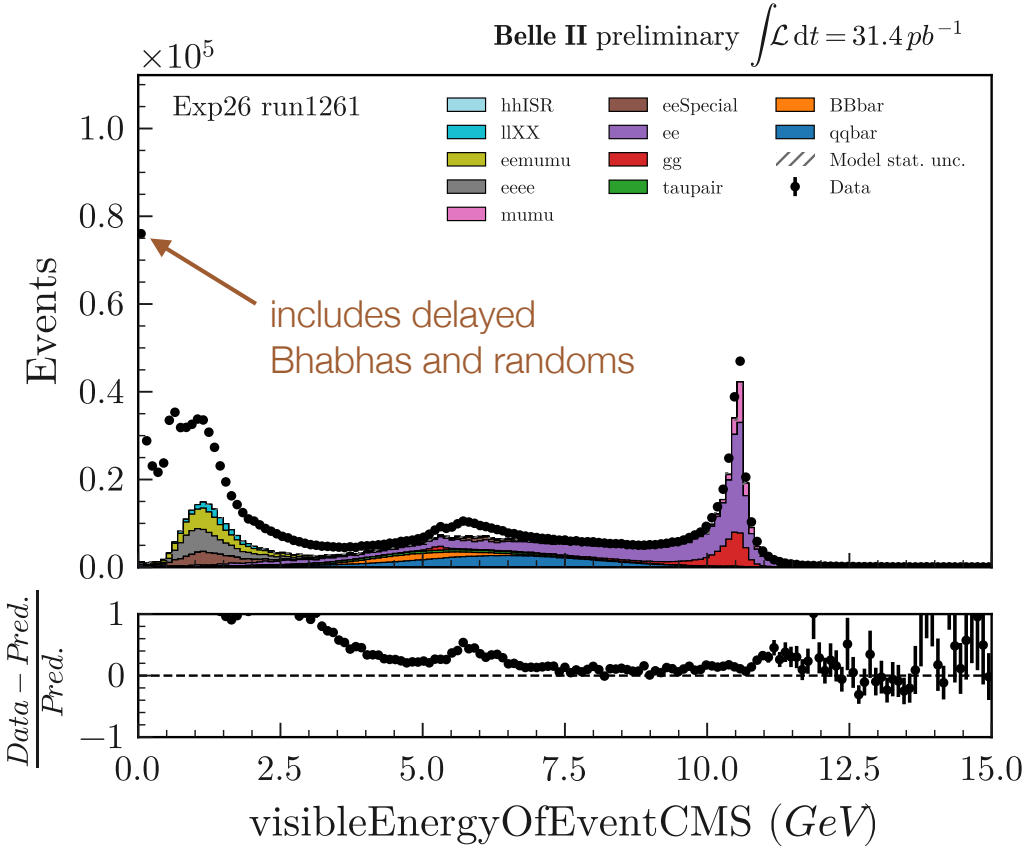
- Goal over the next year or so would be to reduce this to maybe 20 nb.

- Robin Leboucher (UBC postdoc) has been working on a fastBDT to improve Bhabha rejection. But main focus will be on understanding and suppressing the unsimulated high-cross section background.
  - two photon production of $q\bar{q}$ is my guess.

Comparison between data (points) and MC, exp 26 run 1261

- Unsimulated events mostly have 0 or 1 tracks & low energy





Robin Leboucher

Summary

- Torben has started revisiting the L1 trigger menu in view of possible trigger upgrades. Challenge will be keeping the physics in light of much higher luminosity, without an equally large increase in headroom.

- HLT trigger menu currently has >70 lines, with generic lines that cover most of our physics, and targeted lines for specific final states.

- Many additional lines for control samples, trigger studies, and technical samples.

- Have recently tried to reduce sensitivity of HLT efficiency to CDC performance.

- Next step is to reduce contribution from unsimulated low-multiplicity physics.

- Note that if we add a level 3 trigger, we will need to replicate this trigger menu.