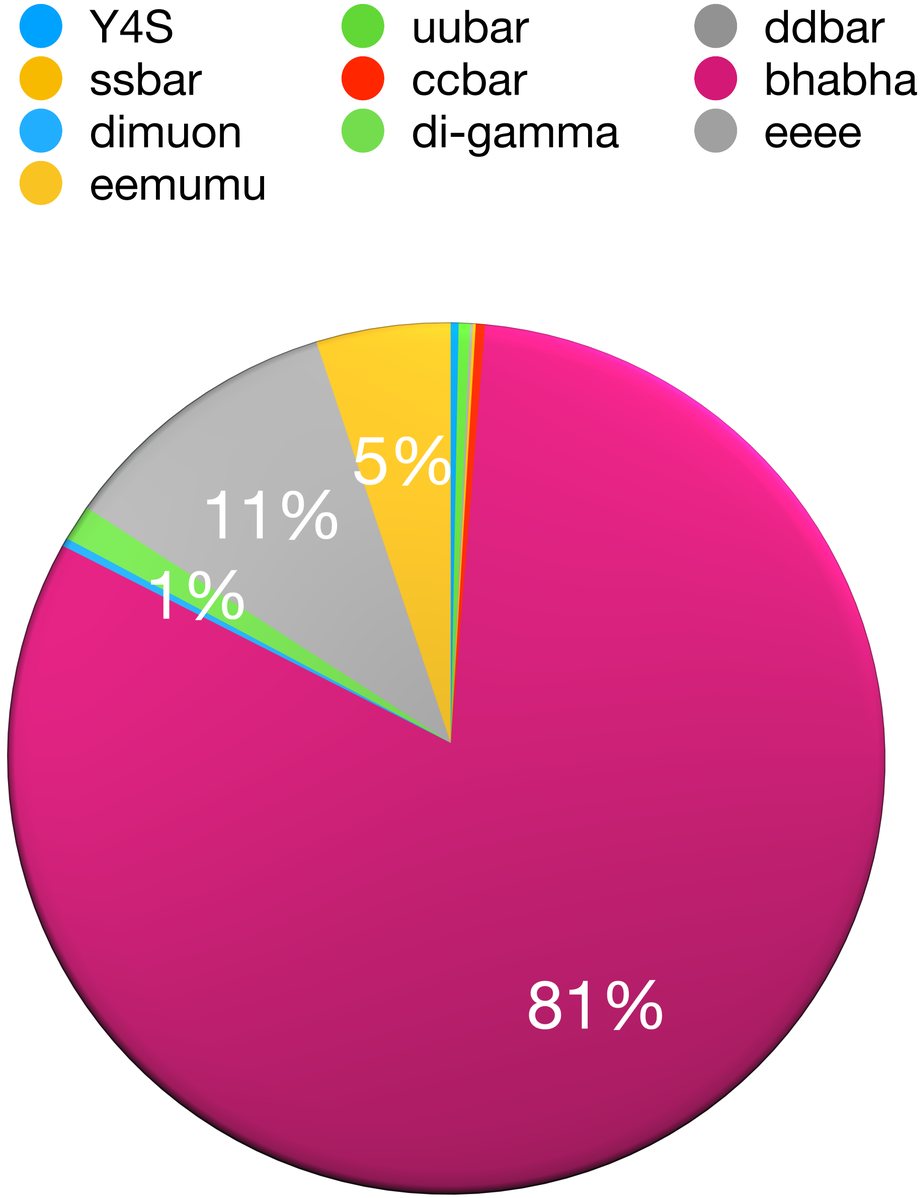
background suppression in Belle II TRG

Junhao Yin

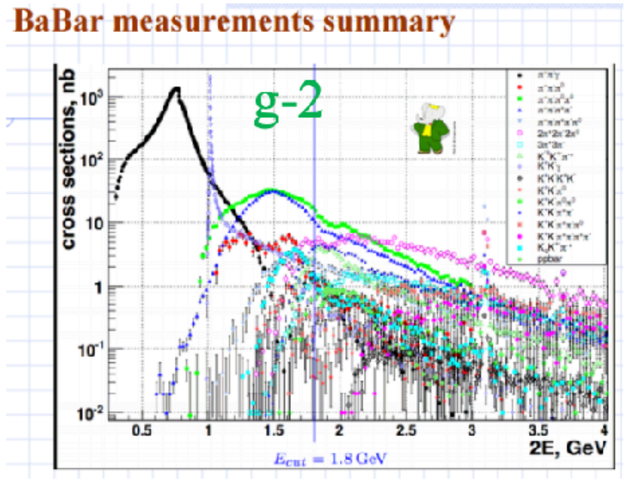
Physics process	Cross section [nb]	Selection Criteria	Reference
$\Upsilon(4S)$	1.110 ± 0.008	-	[2]
$u\bar{u}(\gamma)$	1.61	-	KKMC
$d\bar{d}(\gamma)$	0.40	-	KKMC
$s\bar{s}(\gamma)$	0.38	-	KKMC
$c\bar{c}(\gamma)$	1.30	-	KKMC
$e^+e^-(\gamma)$	300 ± 3 (MC stat.)	$10^\circ < \theta_e^* < 170^\circ$, $E_e^* > 0.15\,\text{GeV}$	BABAYAGA.NLO
$e^+e^-(\gamma)$	74.4	$p_e > 0.5\,\text{GeV}/c$ and e in ECL	-
$\gamma\gamma(\gamma)$	4.99 ± 0.05 (MC stat.)	$10^\circ < \theta_\gamma^* < 170^\circ$, $E_\gamma^* > 0.15\,\text{GeV}$	BABAYAGA.NLO
$\gamma\gamma(\gamma)$	3.30	$E_\gamma > 0.5\,\text{GeV}$ in ECL	-
$\mu^+\mu^-(\gamma)$	1.148	-	KKMC
$\mu^+\mu^-(\gamma)$	0.831	$p_\mu > 0.5\,\text{GeV}/c$ in CDC	-
$\mu^+\mu^-\gamma(\gamma)$	0.242	$p_\mu > 0.5\,\text{GeV}$ in CDC, $\geq 1\ \gamma\ (E_\gamma > 0.5\,\text{GeV})$ in ECL	-
$\tau^+\tau^-(\gamma)$	0.919	-	KKMC
$\nu\bar{\nu}(\gamma)$	0.25×10^{-3}	-	KKMC
$e^+e^-e^+e^-$	39.7 ± 0.1 (MC stat.)	$W_{\ell\ell} > 0.5\,\text{GeV}/c^2$	AAFH
$e^+e^-\mu^+\mu^-$	18.9 ± 0.1 (MC stat.)	$W_{\ell\ell} > 0.5\,\text{GeV}/c^2$	AAFH



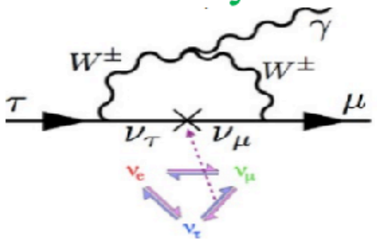
Cross section of bhabha will increase to 1.23×10^5 nb if $0.5^\circ < \theta_e^* < 179.5^\circ$

Trigger Challenges

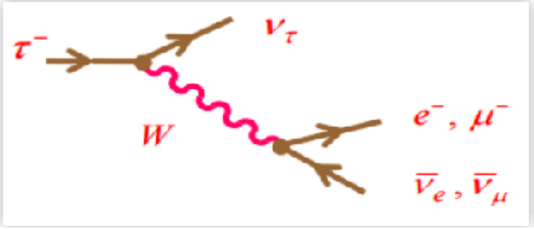
- High luminosity, high background
  - Total physics trigger rate: 15 kHz @ $8.0 \times 10^{35}/cm^2/s$ (designed)
  - Large beam-related, QED background
- Physics process trigger
  - $\Upsilon(4S)$ + continuum, ~100% efficiency
  - Low multiplicity process, challenge trigger



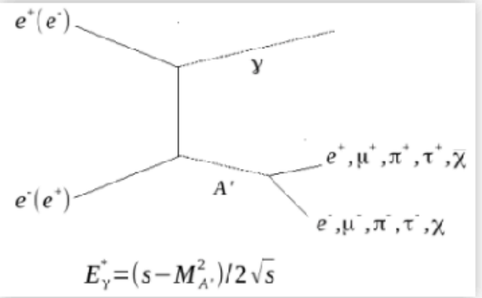
LFV tau decay



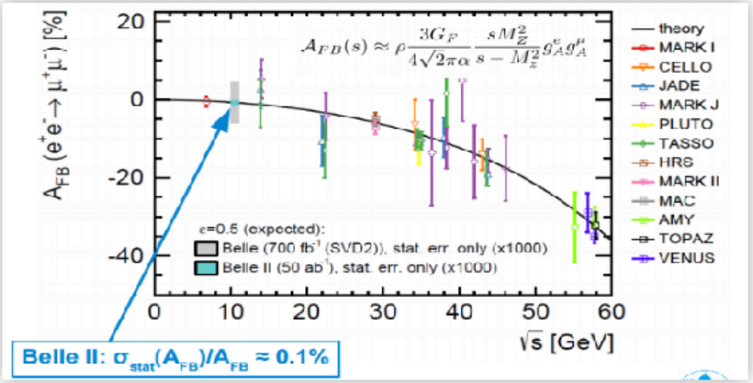
Leptonic tau decay



Dark photon

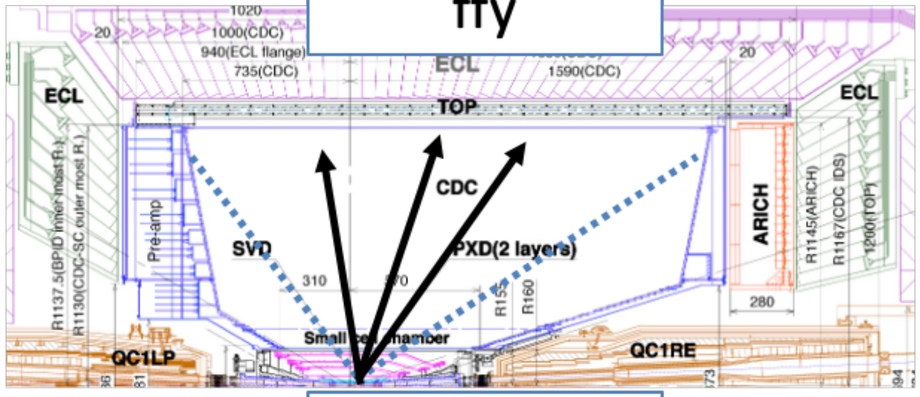


Precision electroweak tests

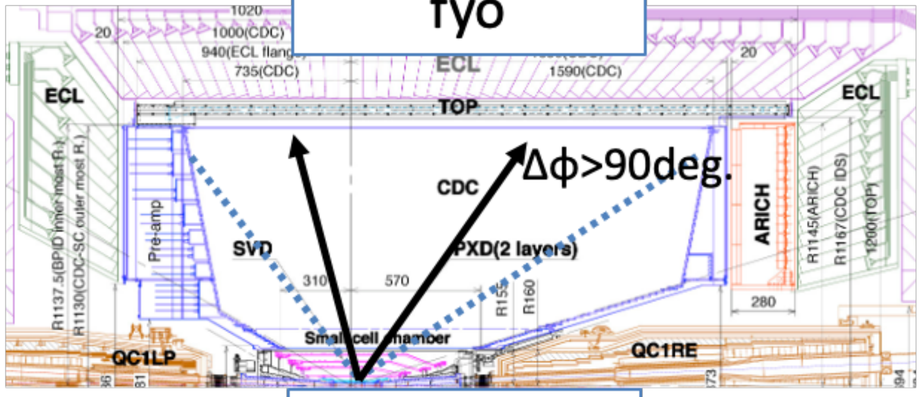


Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
BB pair	ffy	CDC #2track>=3, NNtrack>=1 with |z|<20cm >=1	1.40	1.40
	fyo	CDC #2track>=2, NNtrack>=1 with |z|<20cm >=1, Δϕ>90deg	1.03	0.47
			0.13	0.08
	c4	ECL #cluster>=4, 2<θid<15	0.69	0.56
	hie	ECL Energy sum>1GeV, 2<θid<15		

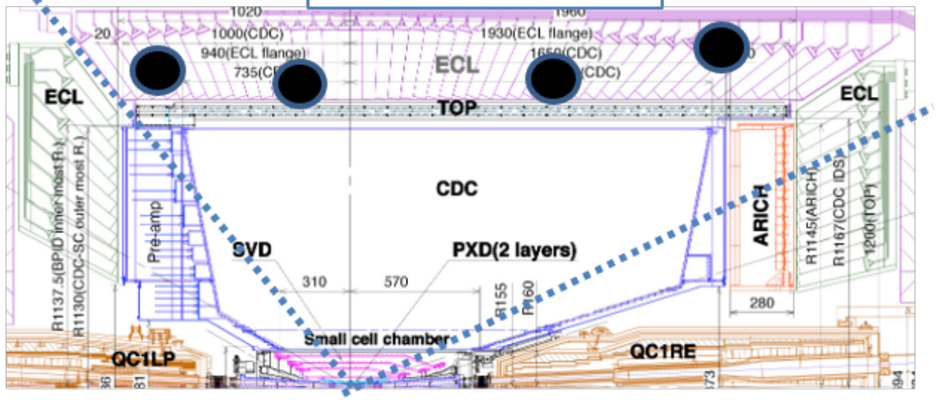
ffy



fyo

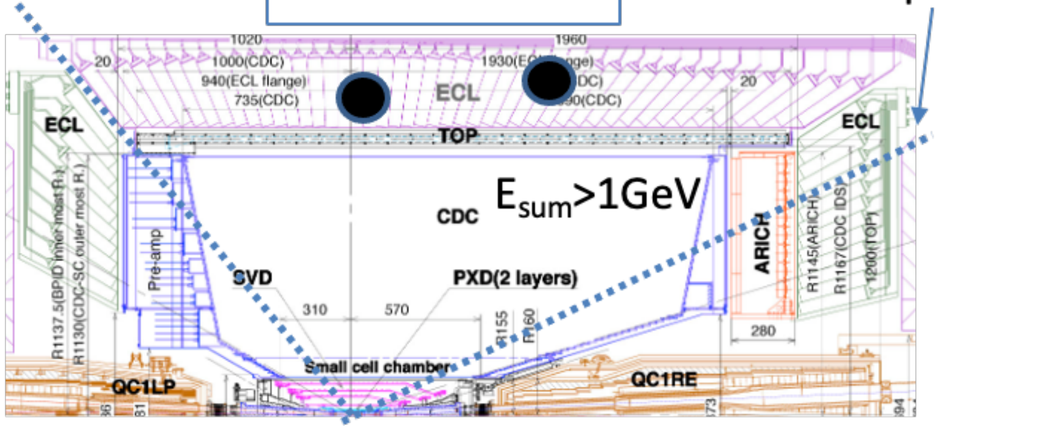


c4

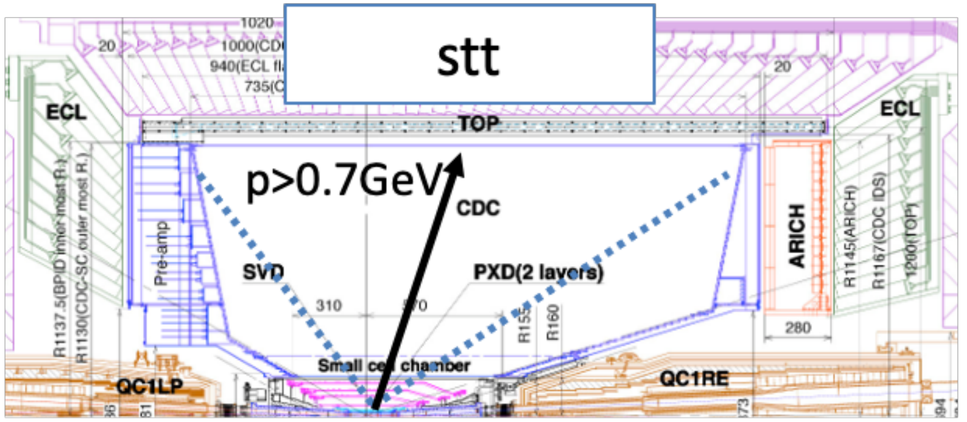


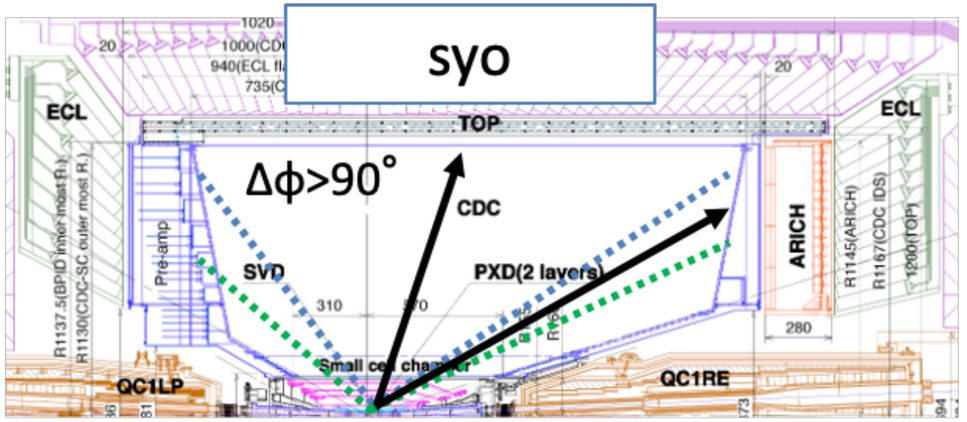
hie

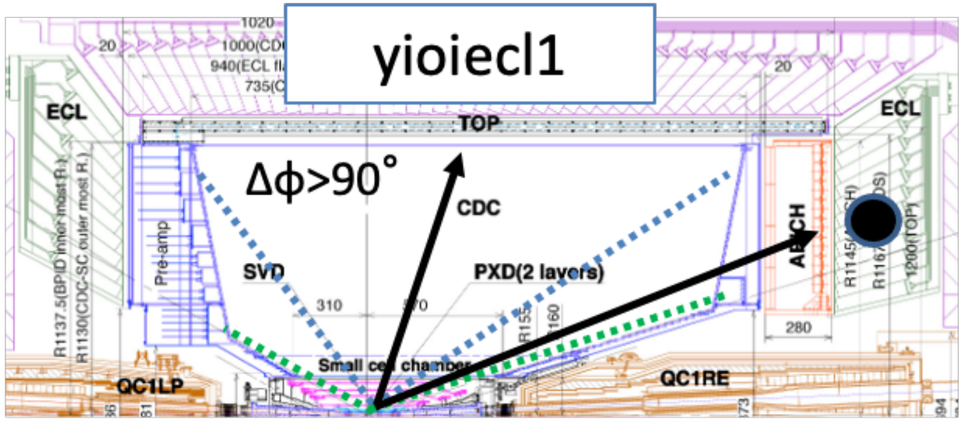
θ acceptance

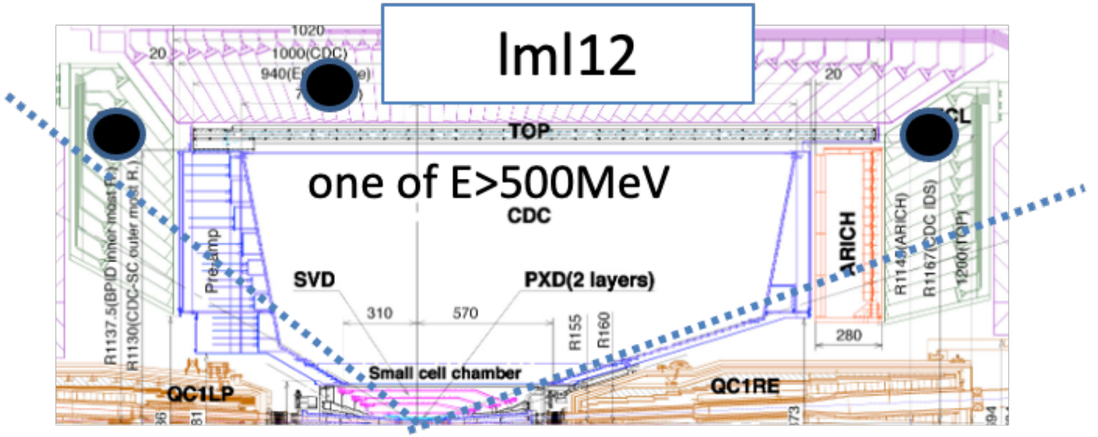


Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
τ	stt	CDC #full track>=1, |z|<15cm, p>0.7GeV	1.74	0.96
	syo	CDC #full track>=1, |z|<15cm, #short track>=1, Δϕ>90deg.	0.74	0.38
	yioiecl1	CDC #full track>=1, |z|<15cm, #inner track>=1, Δϕ>90deg.	0.37	0.08
	lml12	NCL ≥ 3, at least 1 CL ≥ 500 MeV(Lab)) (with θID = 2 - 16)	0.17	0.03
	ecltaub2b	under optimization	-	-

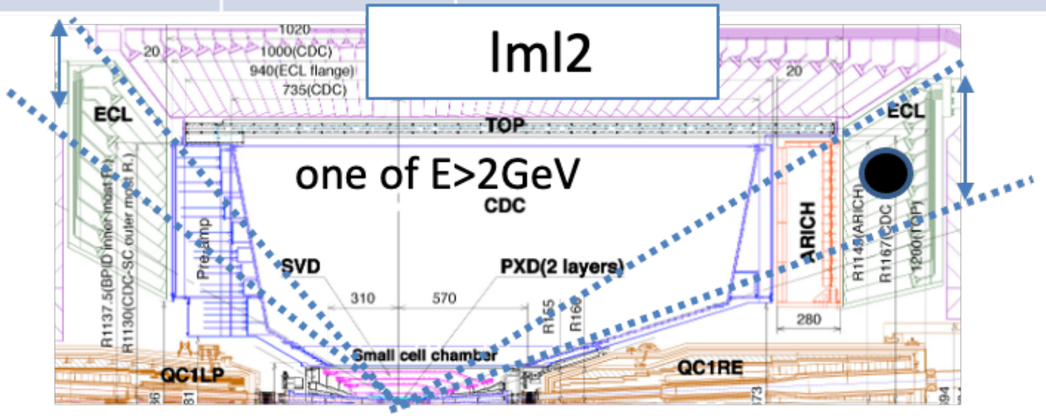


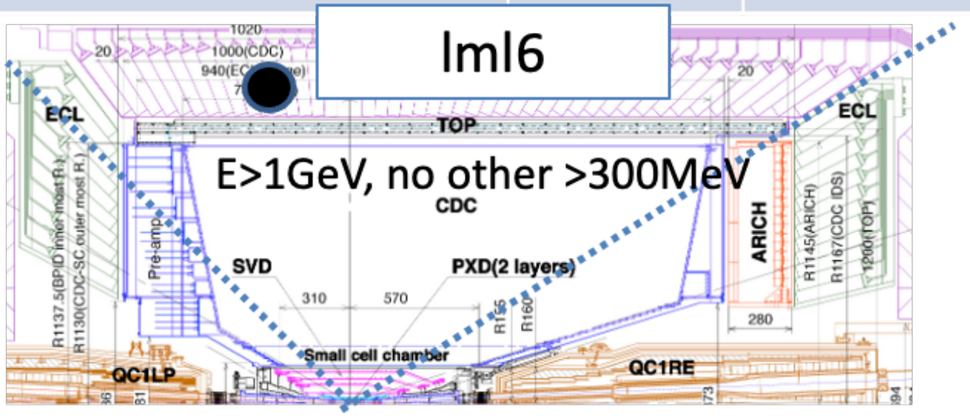






Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
Z’	fy30	CDC #full track>=2, Δϕ>30deg, #|z|<20cm >=1	1.59	0.14
ISR,π0 FF	lml2	ECL one CL ≥ 2 GeV(CM) with θID = 2, 3, 15 or 16	0.18	0.01
single γ	lml6	ECL only one CL ≥ 1 GeV(CM) with θID = 4 - 15 and no other CL ≥ 300 MeV(Lab) anywhere	0.18	0.03
single γ	lml7	ECL only one CL ≥ 1 GeV(CM) with θID = 2, 3, or 16 and no other CL ≥ 300 MeV(Lab) anywhere	0.15	0.04
ALP	lml8	ECL 170° < ΔφCM< 190° , both CL > 250 MeV(Lab), no 2GeV(CM) CL in an event	0.08	0.05
ALP	lml9	ECL 170° < ΔφCM< 190° , one CL < 250 MeV(Lab), one CL > 250 MeV(Lab), no 2GeV(CM) CL in an event	0.34	0.28
dark photon	lml16	ECL only one CL ≥ 0.5 GeV(CM) with θID = 6-11 and no other CL ≥ 300 MeV(Lab) anywhere, #CDC full track==0	0.32	0.23





From Koga-san

Trigger menu and rate in 2020c

Category	Trigger logic	rate (KHz)
CDC B physics	CDC three 2Dtrack, two 2Dtrack Δϕ>90deg	0.57
ECL B physics	ECL #cluster>3,	0.11,
	ECL Energy>1GeV	0.51
KLM τ/dark	KLM back to back, #CDC-KLM matching >0	0.45
CDC τ/dark	2D-short track ϕ>90deg two 2Dtrack Δϕ>30deg	0.34, 0.52
ECL τ/dark, bhabha	Several combinations of cluster and energy	2.03
Bhabha veto	ECL 3D Bhabha veto	0.50 (no prescale)
Others	Calibration etc.	0.41
Total L1		**3.5**

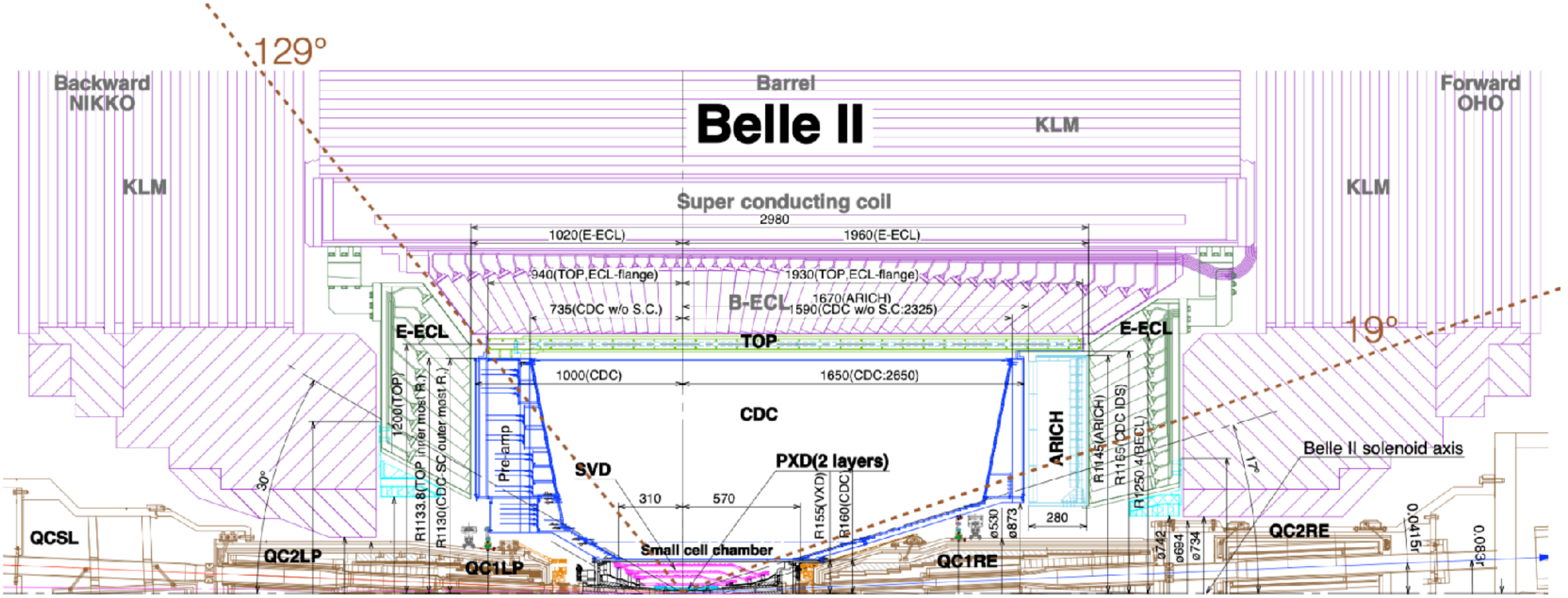
From Koga-san

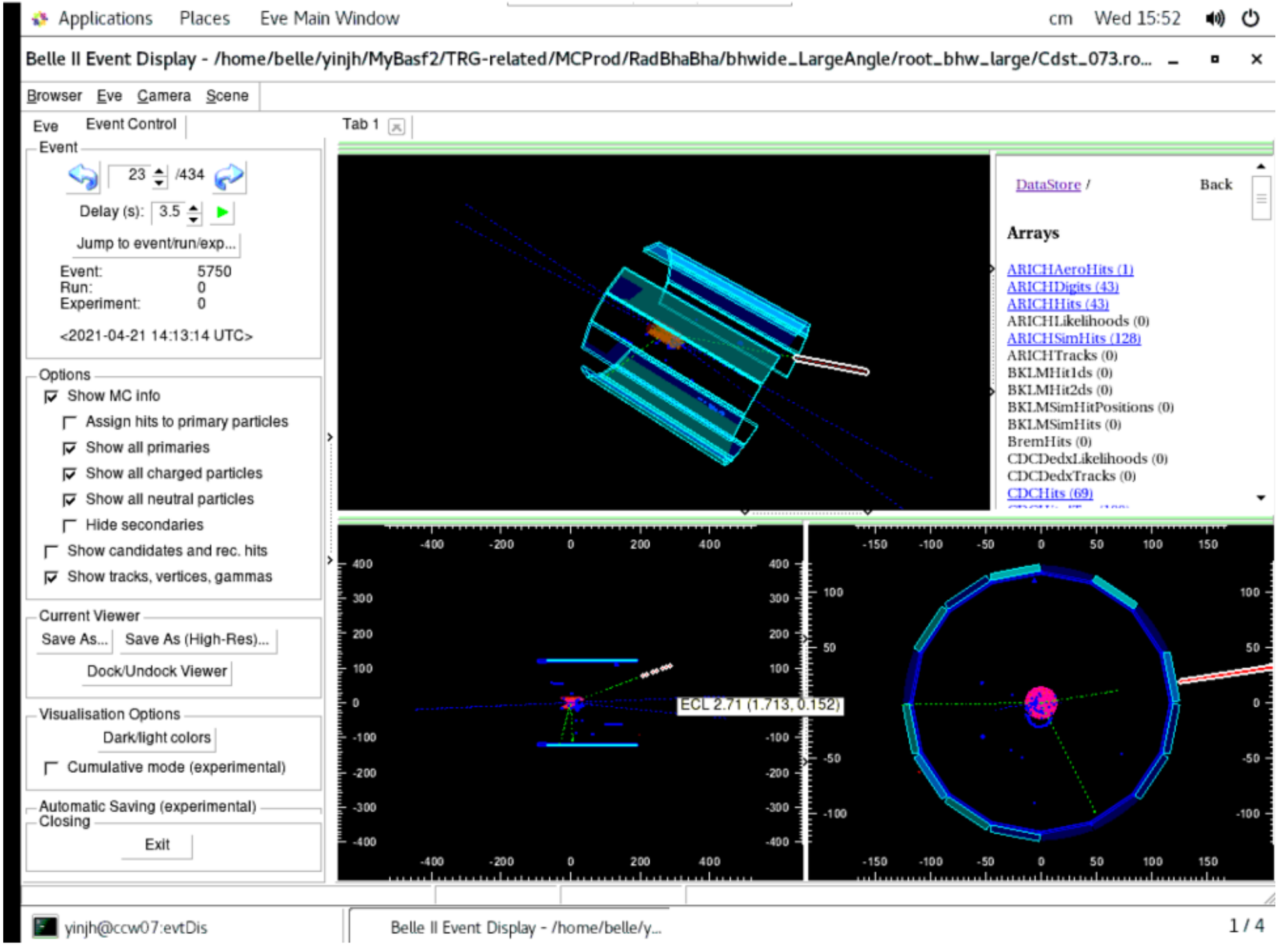
L1 rate after Bhabha prescale in 2021 (e18r67)

-L1 rate is ~2.5kHz @ L=1.5 × 10^34. Roughly consistent with expectation

		raw rate(KHz)	effect to L1(kHz)
CDC B physics	CDC three full track (ffy) two full track Δϕ>90deg (fyo)	0.13 0.19	**0.13** **0.11**
ECL B physics	ECL #cluster>3 (c4)	0.11	**0.05**
	ECL Energy>1GeV (hie)	0.56	**0.44 <- dominant**
KLM τ/dark	KLM back to back (mu_b2b, mu_eb2b, ,beklm,eklm2) #CDC/ECL-KLM matching (cdcklm1,seklm1,ieklm1,ecleklm1)	0.44 0.13	**0.40** **0.07**
CDC τ/dark	NN single track (stt) 2D-short track ϕ>90deg (yso,fioiecl1) two 2Dtrack Δϕ>30deg (fy30) Two inner tracks (ioiecl2)	0.44 0.19 0.22 0.17	**0.18 <- 2nd dominant** **0.06** **0.01** **0.08**
ECL τ/dark, Bhabha	Several combinations of cluster and energy (lmlxx)	1.28	**0.67 <- dominant**
gamma gamma	ECL3Dbhabha without track (ggsel)	0.04	**0.03**
Bhabha	ECL loose Bhabha (bhapur)	0.07	**0.05**
Other		-	**0.22**
Total L1		2.5	**2.5**

- **hie**: Basic ECL trigger. Requires sum of trigger towers >1GeV, with 100 MeV threshold per tower.
  - tower ≈ 4×4 crystals.
  - sum is over θ_{ID}^{L1} range [2,15]
  - Bhabha veto




Applications
Places
Eve Main Window
cm
Wed 15:52
Belle II Event Display - /home/belle/yinjh/MyBasf2/TRG-related/MCProd/RadBhaBha/bhwide_LargeAngle/root_bhw_large/Cdst_073.ro...
Browser
Eve
Camera
Scene
Eve
Event Control
Tab 1
Event
23
/434
Delay (s):
3.5
Jump to event/run/exp...
Event:
5750
Run:
0
Experiment:
0
<2021-04-21 14:13:14 UTC>
Options
Show MC info
Assign hits to primary particles
Show all primaries
Show all charged particles
Show all neutral particles
Hide secondaries
Show candidates and rec. hits
Show tracks, vertices, gammas
Current Viewer
Save As...
Save As (High-Res)...
Dock/Undock Viewer
Visualisation Options
Dark/light colors
Cumulative mode (experimental)
Automatic Saving (experimental)
Closing
Exit
DataStore /
Back
Arrays
ARICHAeroHits (1)
ARICHDigits (43)
ARICHHits (43)
ARICHLikelihoods (0)
ARICHSimHits (128)
ARICHTracks (0)
BKLMHit1ds (0)
BKLMHit2ds (0)
BKLMSimHitPositions (0)
BKLMSimHits (0)
BremHits (0)
CDCDedxLikelihoods (0)
CDCDedxTracks (0)
CDCHits (69)
ECL 2.71 (1.713, 0.152)
yinjh@ccw07:evtDis
Belle II Event Display - /home/belle/y...
1 / 4

newhie = hie && 1-cluster-veto && 2-clusters-veto

FW endcap

1-cluster-veto: !(ncluster = 1 && tcid <= 80)

but we have several different proposals for 2-cluster veto…

case I

2-cluster-veto: !(ncluster = 2 && $\Delta\theta_{\rm cms} > 120$ && $\Delta\phi_{\rm cms} > 150$)

bit logics	bhabha	taupair	eeee	data
hie	1531	735879	2628	2950
fff|ffo|c4|hie	1601	856847	3506	4476
newhie	937	730233	2331	2100
fff|ffo|c4|newhie	1007	851252	3210	3630

case II

2-cluster-veto: !(ncluster = 2 && $\Delta\theta_{\rm cms} > 120$ || $\Delta\phi_{\rm cms} > 150$)

newhie	354	474811	1297	1051
fff|ffo|c4|newhie	562	802404	2507	2857

case III

BW endcap FW endcap

2-cluster-veto: !(ncluster = 2 && ($\text{tcid}_{\rm 2nd} \geq 500$ || $\text{tcid}_{\rm 2nd} \leq 80$))

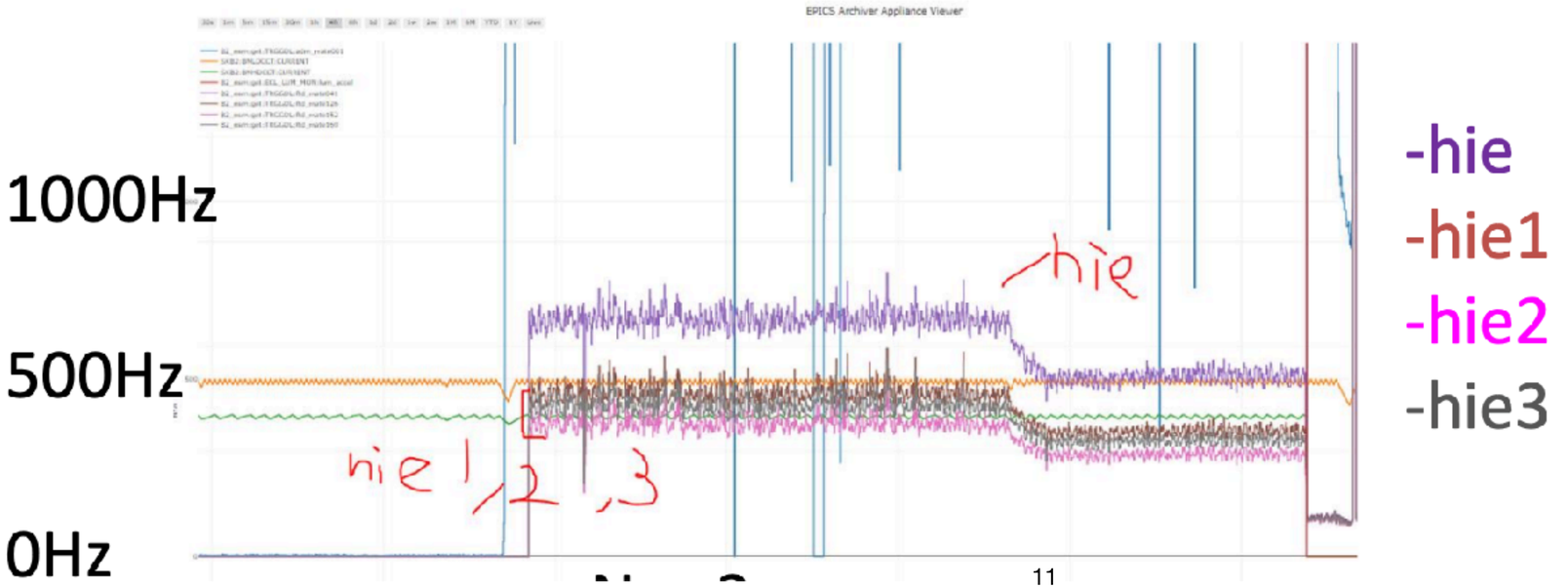
newhie	510	695997	1173	1640
fff|ffo|c4|newhie	558	823458	2165	3185

For a bhabha scattering event, the second energetic cluster is very likely to be the radiative photon

90	hie w/ additional Bhabha veto 1	**hie1**	• New hie to reduce Bhabha contribution(condition-1)
			• hie && 1CL veto && 2CL veto
			  • 1CL veto = not (N(CL)=1 && θ_{CM} in FW)
			  • 2CL veto = not (N(CL)=2 && 160°< $\Sigma\theta_{CM}$ < 200° && 150°< $\Delta\phi_{CM}$ < 250°)
			• See (link) for details
			• BIITRG-30 - Performance evaluation and optimization of new bhabha veto TO DO

91	hie w/ additional Bhabha veto 2	**hie2**	• New hie to reduce Bhabha contribution(condition-2)
			• hie && 1CL veto && 2CL veto
			  • 1CL veto = not (N(CL)=1 && θ_{CM} in FW)
			  • 2CL veto = not (N(CL)=2 && 160°< $\Sigma\theta_{CM}$ < 200° || 150°< $\Delta\phi_{CM}$ < 250°)
			• See (link) for details
			• BIITRG-30 - Performance evaluation and optimization of new bhabha veto TO DO

92	hie w/ additional Bhabha veto 3	**hie3**	• New hie to reduce Bhabha contribution(condition-3)
			• hie && 1CL veto && 2CL veto
			  • 1CL veto = not (N(CL)=1 && θ_{CM} in FW)
			  • 2CL veto = not (N(CL)=2 && CL_{LowerE} in FW or BW)
			• See (link) for details
			• BIITRG-30 - Performance evaluation and optimization of new bhabha veto TO DO



stt: CDC triggers

Number of neuro 3D track with p>0.7 GeV/c > 0

!bhabha_3D

!veto

$L_{ins} \sim 2.1 \times 10^{34}$ $L_{ins} \sim 3.5 \times 10^{34}$

		MC	Run with beam filter	Run without beam filter	add beam filter manually
Nevts	total	358421	881163	19939728	2800098
	stt	10365	323314	4698662	945197
	stt&&nclus==1	4399	25116	2134753	103477
	stt&&nclus==2	4033	143461	1694201	406439
TRG rate	stt	214.69Hz	193.25Hz	1706.74Hz	343.33Hz
	stt&&nclus==1	83.53Hz	15.01Hz	775.43Hz	37.59Hz
	stt&&nclus==2	83.45Hz	85.75Hz	615.4Hz	147.63Hz

From bhabha MC: ~40% of stt events have only 1 cluster, and ~40% have 2 clusters

TRG rate of MC is estimated with the luminosity from run1780.

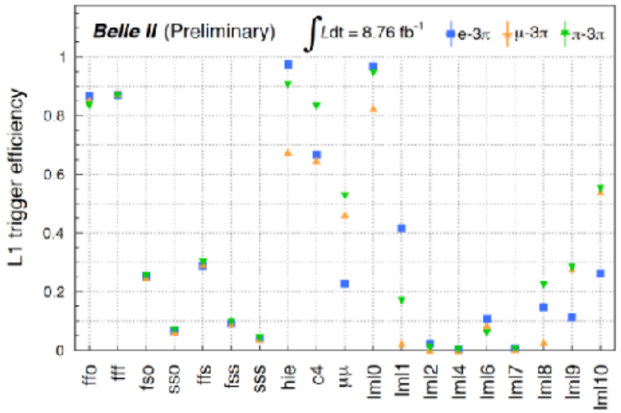
We tried same veto as we did in hie study

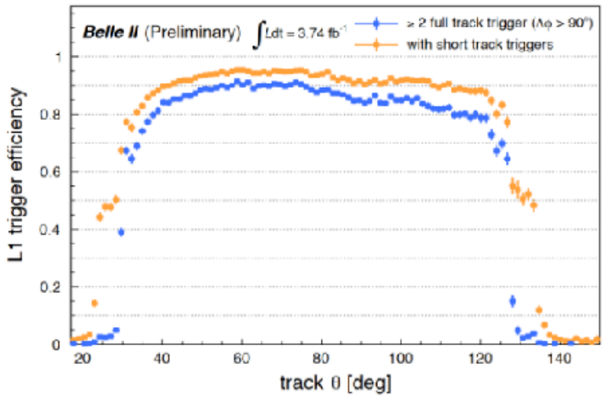
Name of cut	Definition	Index
stt	outBits[96]==1	a
1 cluster cut	!(ncluster = 1 && tcid <= 80°)	b
2 cluster cut (1)	!(ncluster = 2 && ($\Delta\theta$cms > 120° && $\Delta\phi$cms > 150°))	c
2 cluster cut (2)	!(ncluster = 2 && ($\Delta\theta$cms > 120° ‖ $\Delta\phi$cms > 150°))	d
2 cluster cut (3)	!(ncluster = 2 && (tcid2nd ≥ 500°‖tcid2nd ≤ 80°))	e
2 cluster cut (4)	!(ncluster = 2 && ($\Delta\theta$cms > 120°))	f
2 cluster cut (5)	!(ncluster = 2 && ($\Delta\phi$cms > 150°))	g
2 cluster cut (6)	!(ncluster = 2 &&((160°<Σ"θcms"<200°) && (150<$\Delta\phi$cms < 250)))	h
2 cluster cut (7)	!(ncluster = 2 &&((160°<Σ"θcms"<200°) ‖ (150°<$\Delta\phi$cms <250°))	i
2 cluster cut (8)	!(ncluster = 2 && (160°<Σ"θcms"<200°))	j
2 cluster cut (9)	!(ncluster = 2 && (150°<$\Delta\phi$cms < 250°))	k

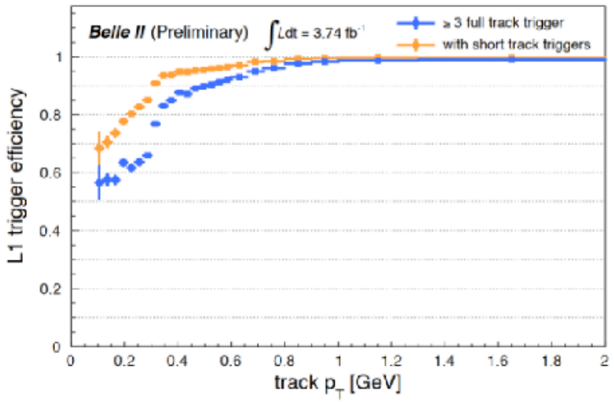
GetEntries	TRG rate	GetEntries	TRG rate
a	386.43Hz	a+k	268.14Hz
a+b	364.1Hz	a+b+c	363.95Hz
a+c	386.28Hz	a+b+d	188.02Hz
a+d	207.85Hz	a+b+e	256.17Hz
a+e	278.5Hz	a+b+f	363.88Hz
a+f	386.21Hz	a+b+g	244.95Hz
a+g	267.28Hz	a+b+h	302.03Hz
a+h	324.36Hz	a+b+i	183.69Hz
a+i	203.53Hz	a+b+j	294.49Hz
a+j	316.83Hz	a+b+k	246.8Hz
total		358421	

Requirement on $\Delta\phi$ is far more powerful than others.
Tracker-calorimeter matching is also powerful to suppress the beam background, but need dedicated validation.

Bhabha veto in tau selection

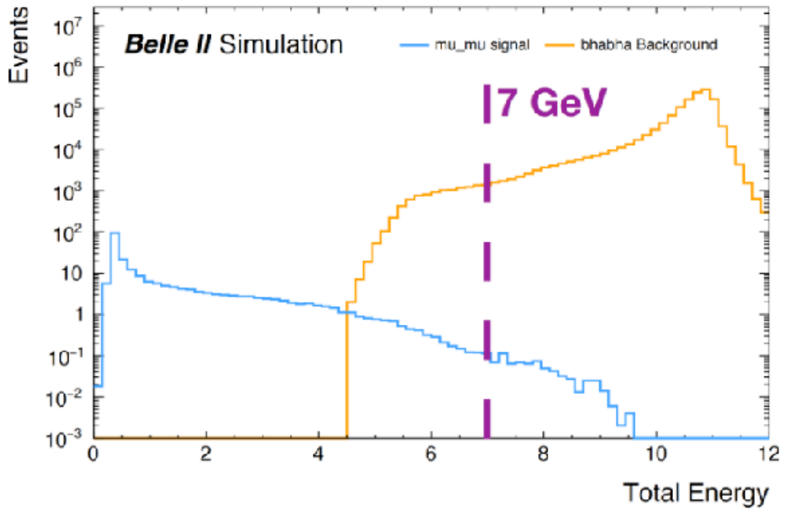


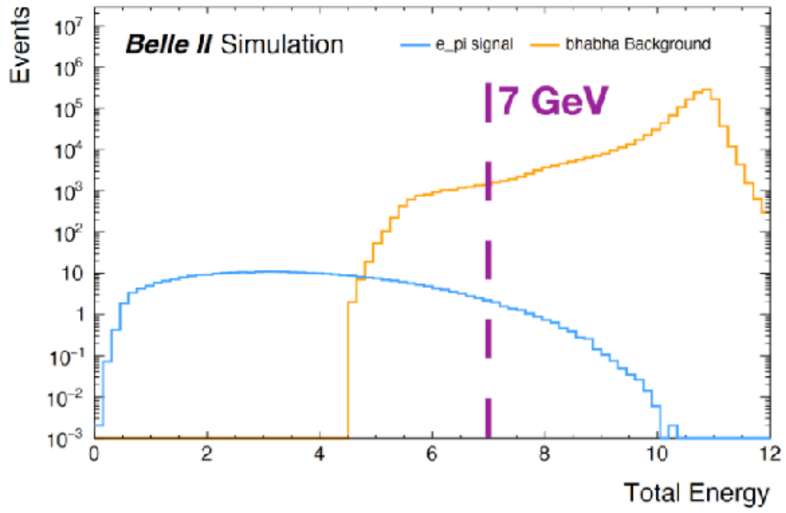




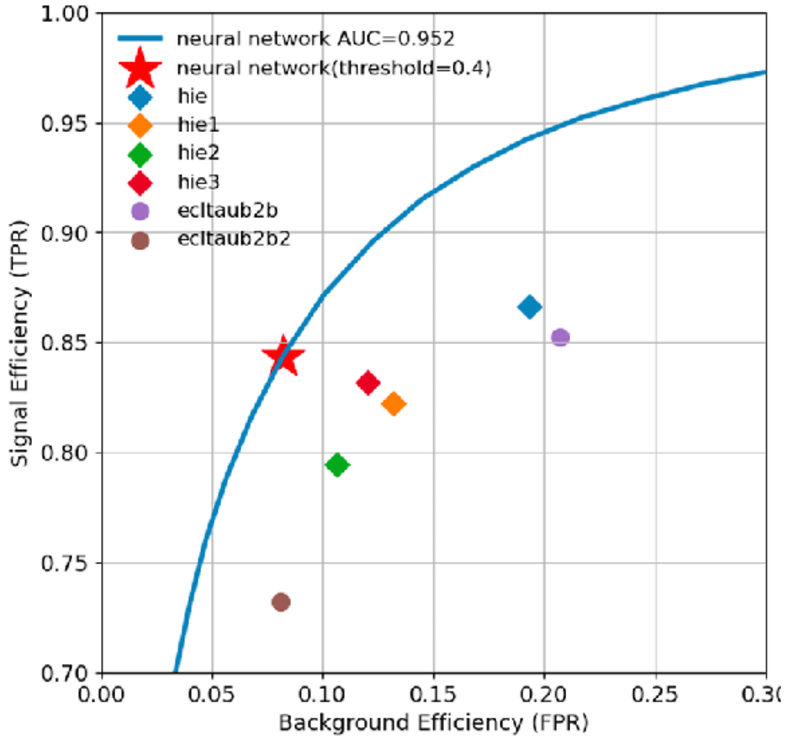
Overall trigger efficiency is acceptable

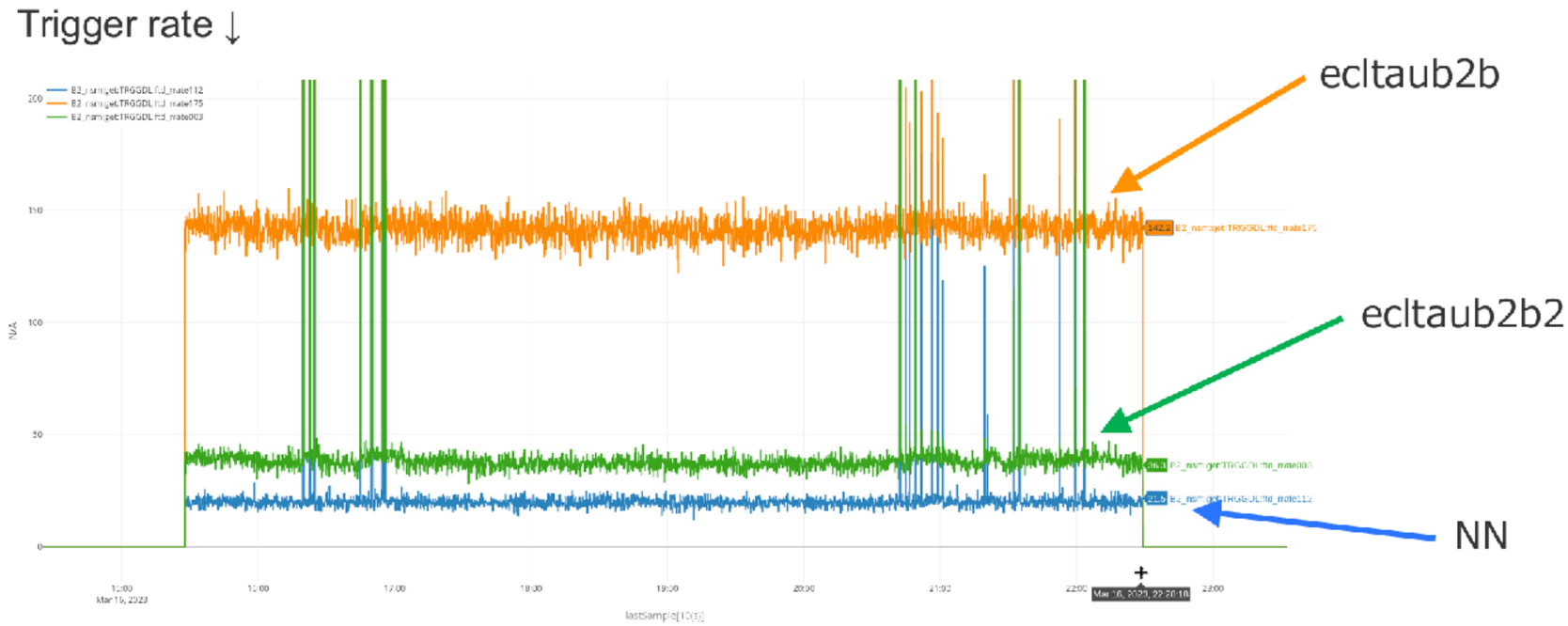
BUT: too many contamination from Bhabha





Performance of NN trigger





Better selection efficiency and lower background rate

Summary

- Experience in Belle II TRG background study and suppression.
  - Even a small fraction, could be innegligible due to the huge cross section
- Other works
  - Software maintenance and validation
  - TRG DQM