Trigger at BelleII

2023/7/25

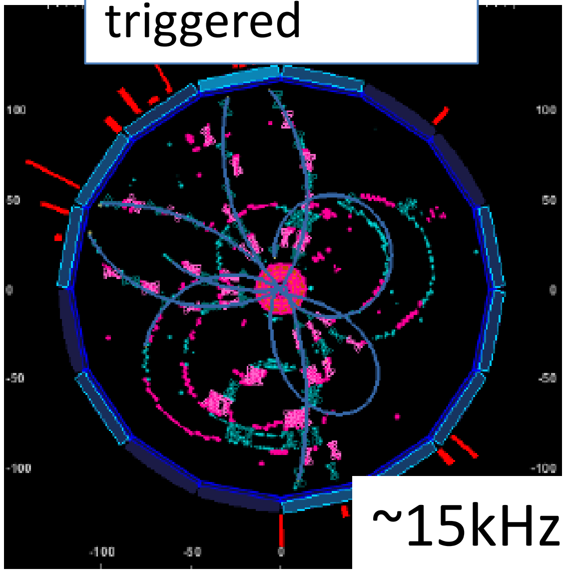
KEK Taichiro Koga

Trigger ?

- -BelleII can not record all collision events
  - -e$^+$e$^-$ bunch crossing rate: ~200MHz
  - -maximum event rate at DAQ: ~30kHz

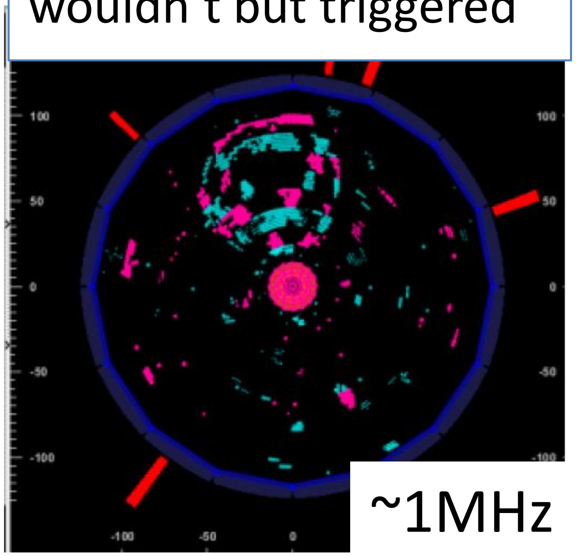
- -Trigger is needed to reduce recorded event rate and data size
  - -electronic circuit to react interested physics events
  - -judge if the event is recorded or not

physics signal triggered



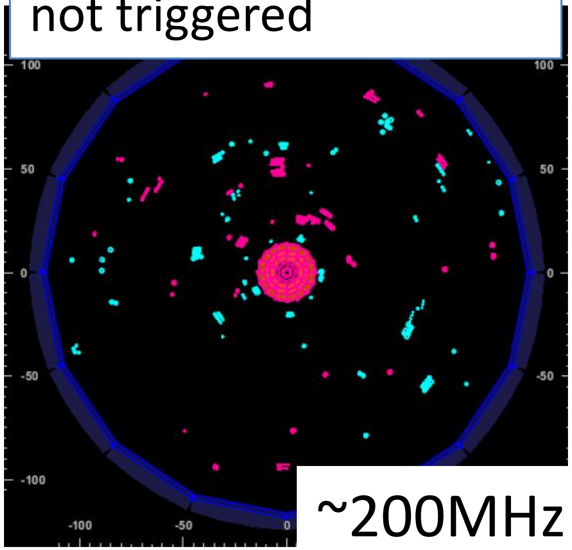
~15kHz

beam background wouldn't but triggered



~1MHz

collision w/o interaction not triggered



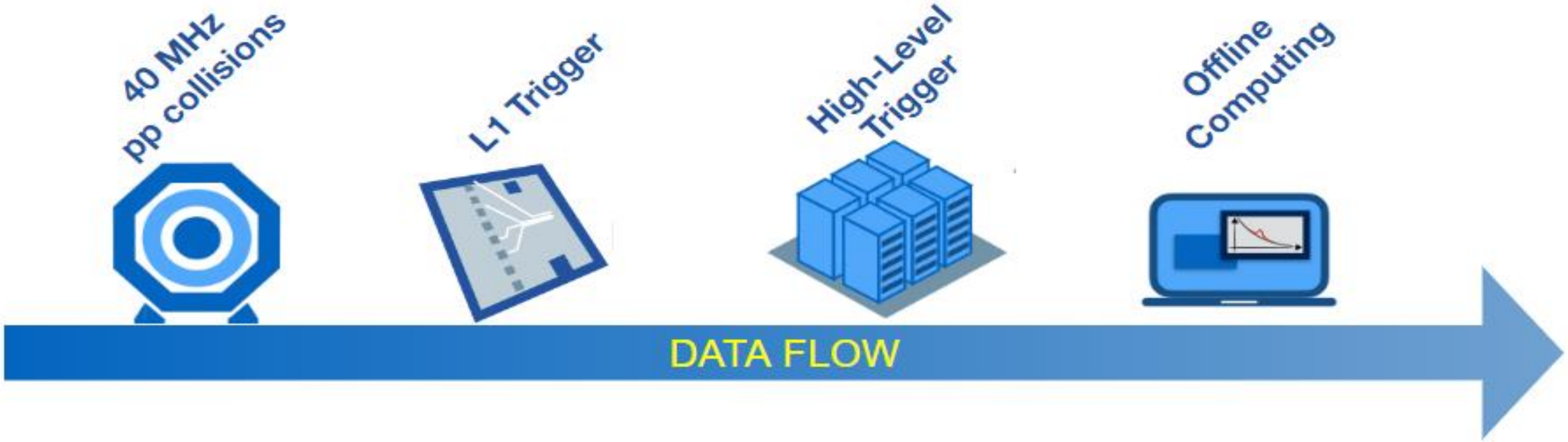
~200MHz

Trigger in collider experiments

-Recent collider experiments have several level of triggers

- -Level1(0) Trigger: Hardware (electric circuit) with small latency
- -High-level Trigger: Software (computer) with high accuracy

ATLAS workshop



	beam crossing	Level1	High level
ATLAS	40MHz	100kHz, 2.5μs latency	1kHz
LHCb	40MHz	1MHz, 4μs latency	12.5kHz, 0.6GB/s
LHCb upgrade	30MHz	no Level1!	2-5 GB/s
BelleII	250MHz	30kHz, 5.0μs latency	5~10kHz, 1.8GB/s

-Today, I will focus on BelleII Level1 trigger only

e^+e^- collision

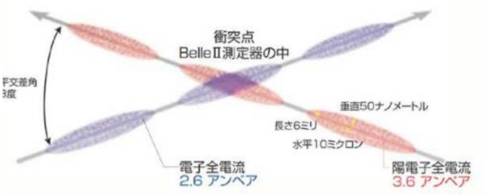
-What kind of phenomena happen at BelleII, how often ?

Process	Event rate @designed Lumi.
e^+e^- bunch collision	~200MHz
Bhabha scattering ($e^+e^- \rightarrow e^+e^-$)	>~50kHz
Storage beam BG	>~150kHz(ECL 2022) >~100kHz(CDC 2022)
Injection beam BG	~1MHz instantly
Two photon ($e^+e^- \rightarrow e^+e^-e^+e^-$ etc.)	~10kHz
$e^+e^- \rightarrow \gamma\gamma$	~2kHz
Continuum ($e^+e^- \rightarrow$ uubar,...)	~2kHz
$e^+e^- \rightarrow \Upsilon(4S)$	~1kHz
$e^+e^- \rightarrow \mu^+\mu^-$	~0.6kHz
$e^+e^- \rightarrow \tau^+\tau^-$	~0.6kHz
dark matter/new particle ?	???

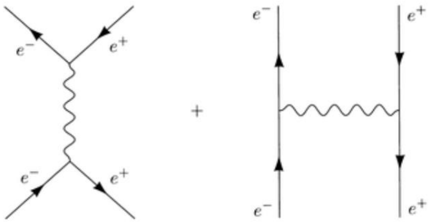
background
>~300kHz

Physics target
~15kHz

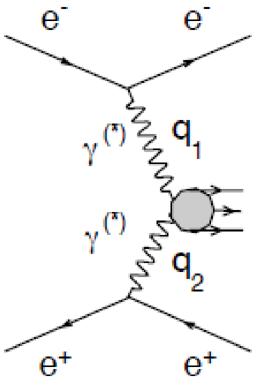
e^+e^- bunch collision



Bhabha



Two photon



-Treasure hunting with large amount of garbage

Requirement for BelleII level1 trigger

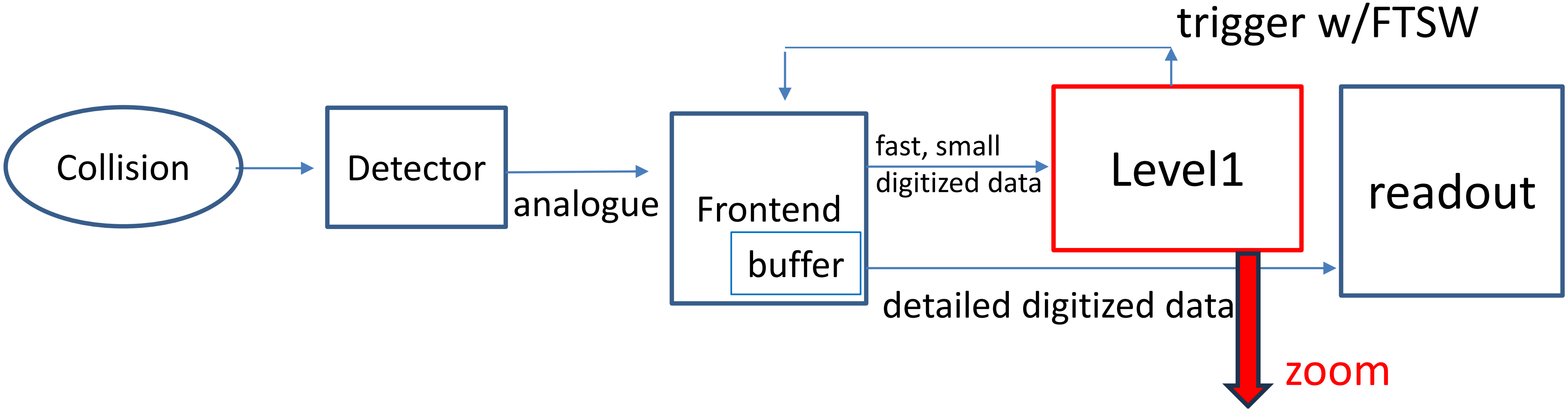
-BelleII TDR in 2010: https://arxiv.org/abs/1011.0352

-BelleII: ~40times higher luminosity than Belle

-maximum trigger rate increase accordingly. required Signal/BG=~1.
-latency limit increase by upgrade of detector FE with large buffer

	requirement for BelleII	**requirement for Belle**
Efficiency	~100% for BB pair	~100% for BB pair
Maximum trigger rate	30kHz	~0.5kHz
Latency	5.0μs	2.2μs
Deadtime	no deadtime	no deadtime
Event timing resolution	10ns	~16ns

BelleII level1 trigger system



trigger w/FTSW

Collision

Detector

analogue

Frontend

buffer

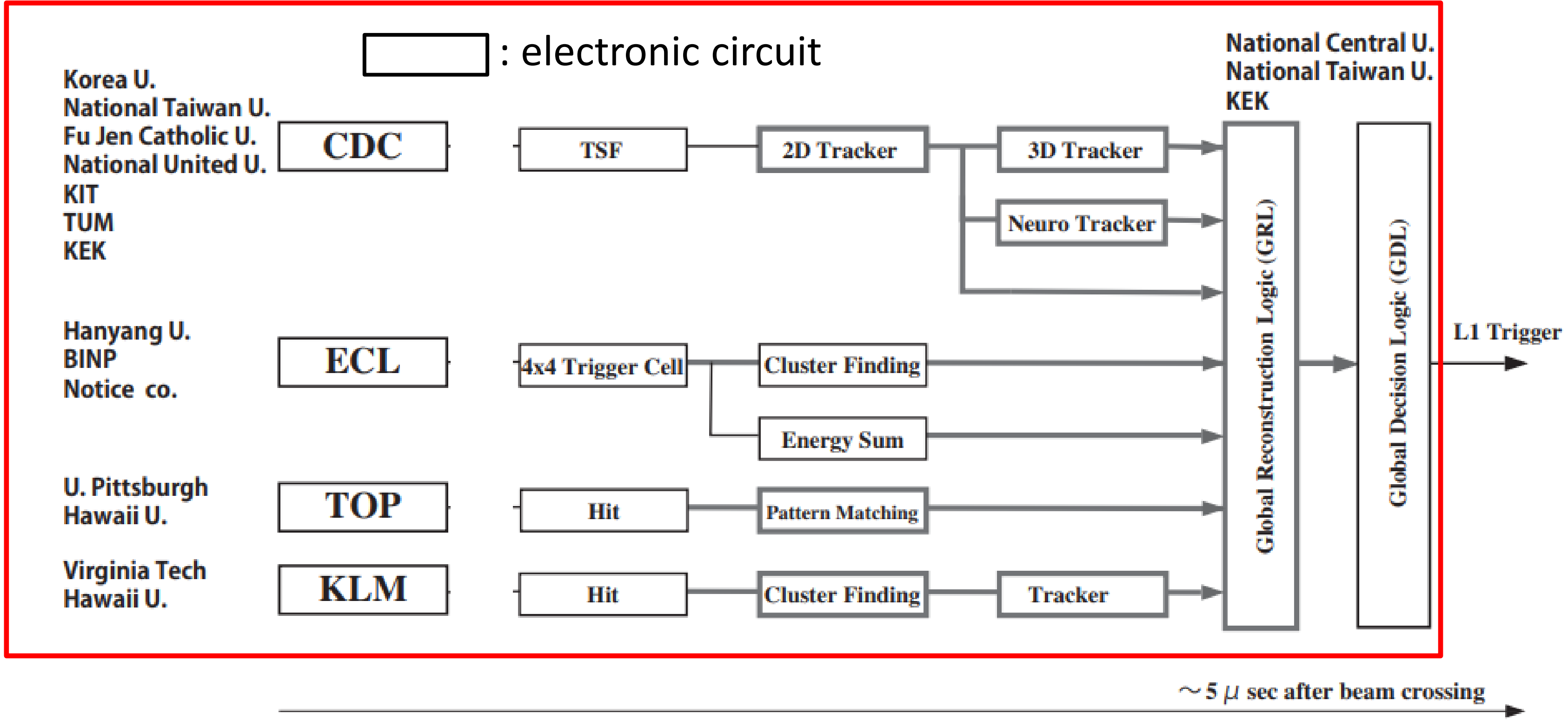
fast, small
digitized data

Level1

readout

detailed digitized data

zoom



: electronic circuit

Korea U.
National Taiwan U.
Fu Jen Catholic U.
National United U.
KIT
TUM
KEK

Hanyang U.
BINP
Notice co.

U. Pittsburgh
Hawaii U.

Virginia Tech
Hawaii U.

National Central U.
National Taiwan U.
KEK

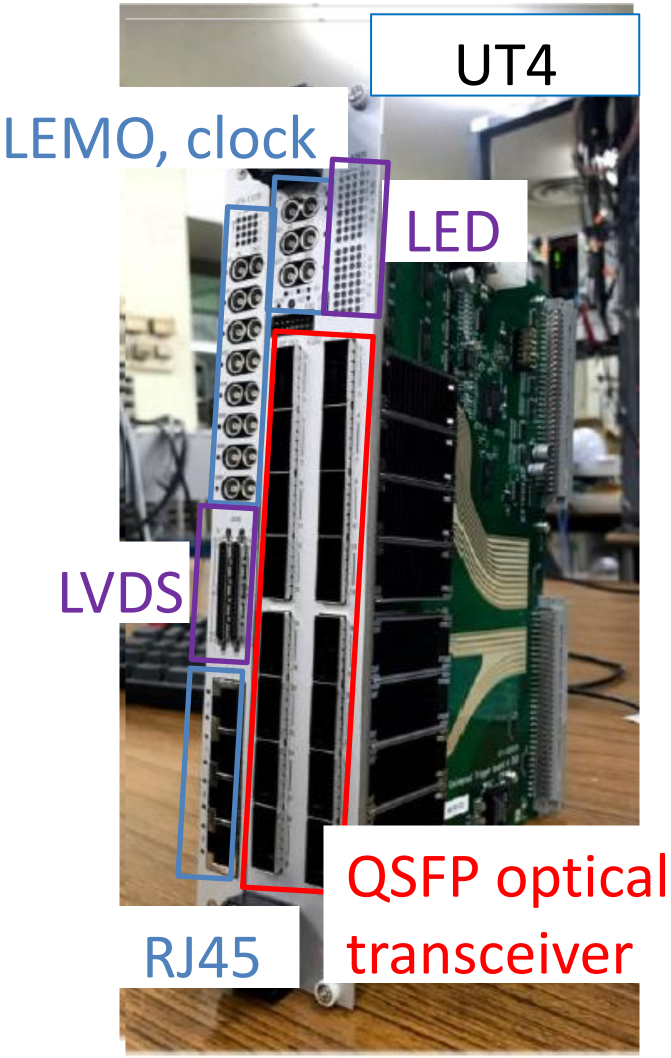
Universal Trigger board (UT)

-Main board of trigger system

- -Large bandwidth with optical transceiver: send large data to TRG system from detector
- -Large FPGA (Field programmable gate array): implement complex logic on electronics circuit

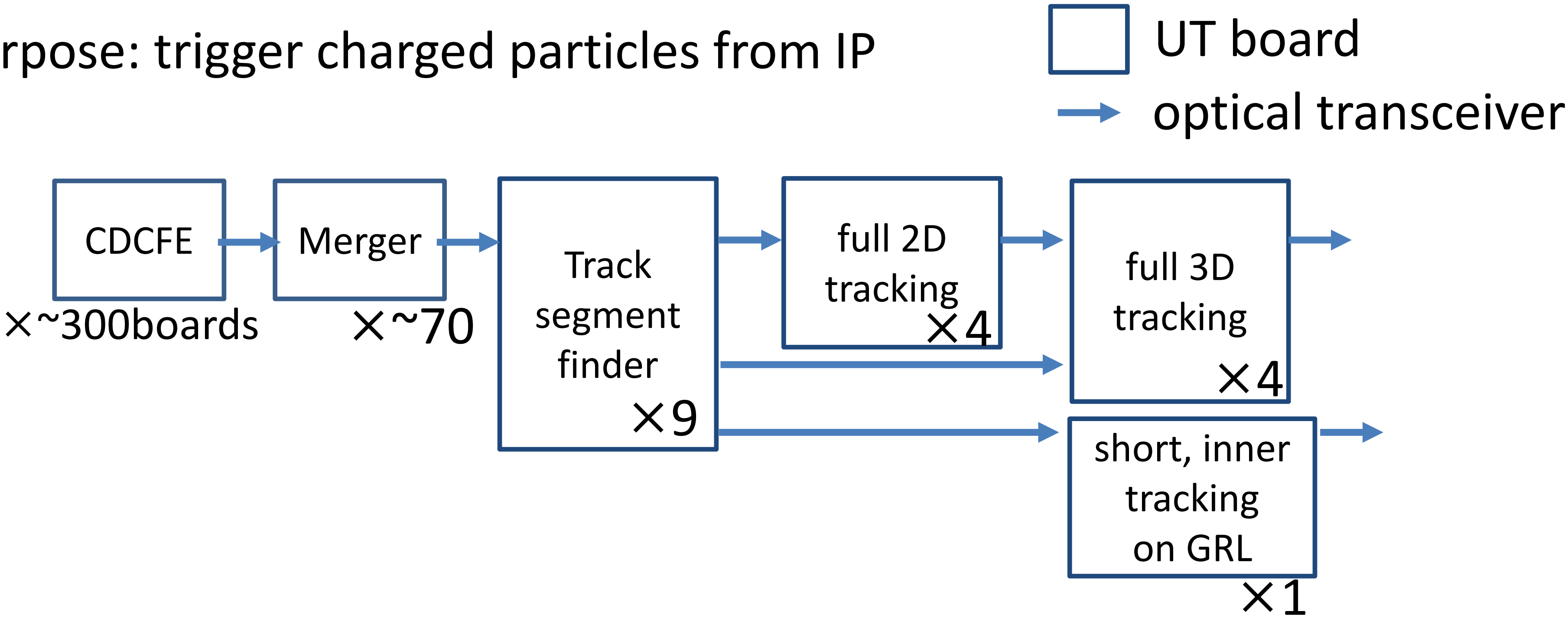
History of UT development

Name	Year	Main FPGA
UT(test)	2006	Spartan3
UT2(test)	2008	Virtex5 LX220T
UT3	2011	Virtex6 HX380T,565T
UT4	2018	Virtex Ultrascale XCVU080/160



CDC Trigger

-Purpose: trigger charged particles from IP



UT board

optical transceiver

CDCFE ×~300boards

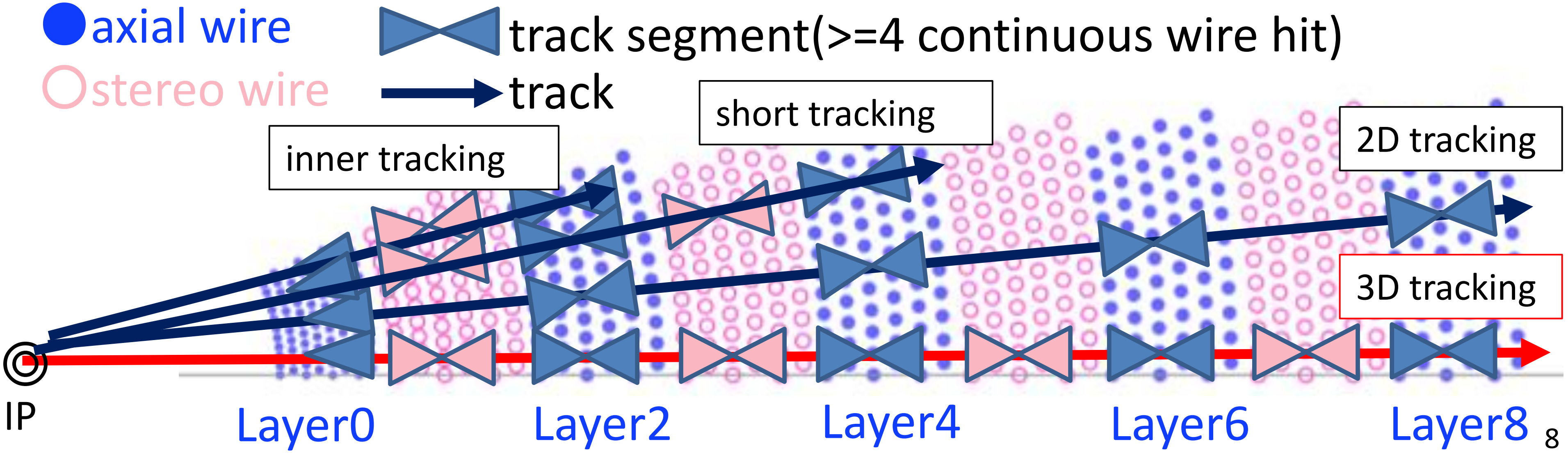
Merger ×~70

Track segment finder ×9

full 2D tracking ×4

full 3D tracking ×4

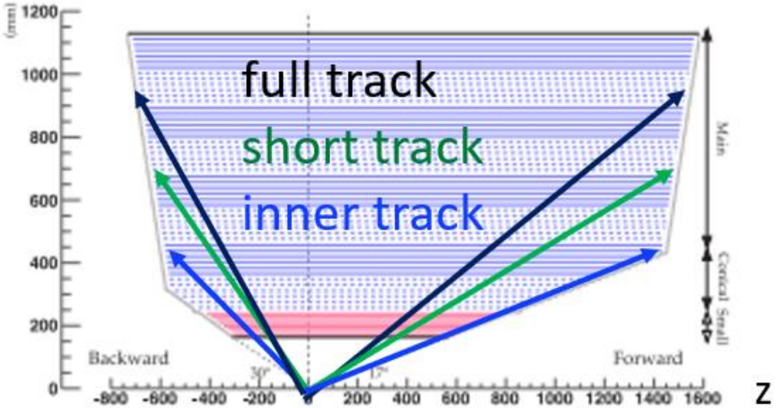
short, inner tracking on GRL ×1



CDC Trigger

-Covered phase space:

	P_t	θ	raw rate 2022b
full track	>~0.4GeV	~30-125deg	~10kHz
short track	>~0.4GeV	~25-130deg	~50kHz
inner track	>~0.4GeV	~20-140deg	>100kHz



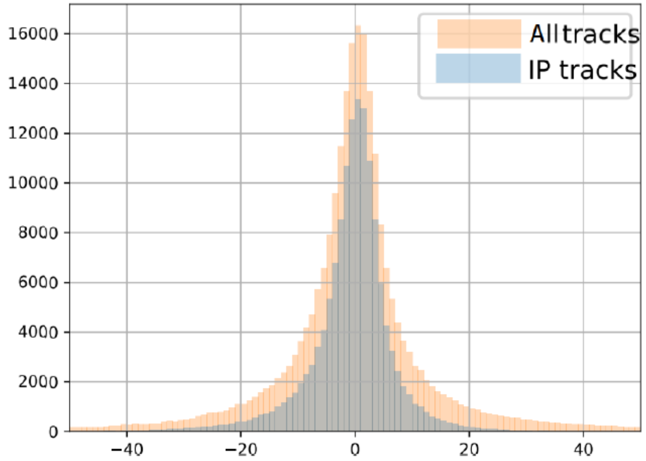
-Performance

-93~98% tracking efficiency per a track

-σ=5~10cm z resolution (full track only)

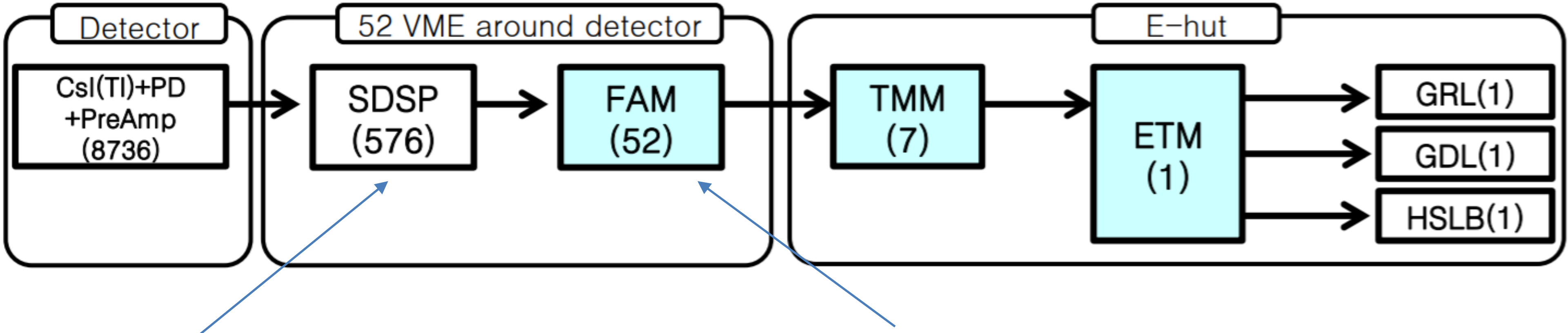
-σ=~0.1 GeV p resolution (full track only)

-run-dependent due to CDC gain decrease issue, induced by beamBG



$\Delta z = z_{trigger} - z_{offline}$(cm)

ECL trigger



Detector

CsI(Tl)+PD +PreAmp (8736)

52 VME around detector

SDSP (576)

FAM (52)

E−hut

TMM (7)

ETM (1)

GRL(1)

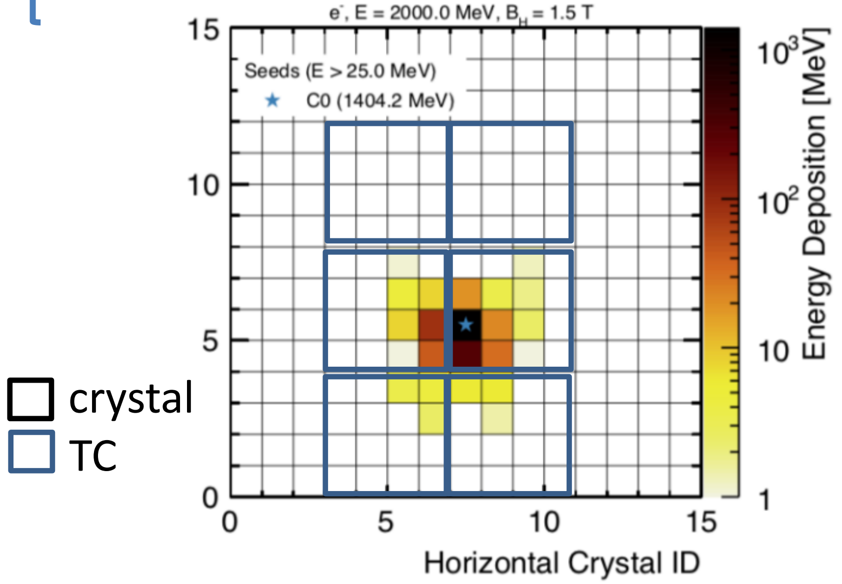
GDL(1)

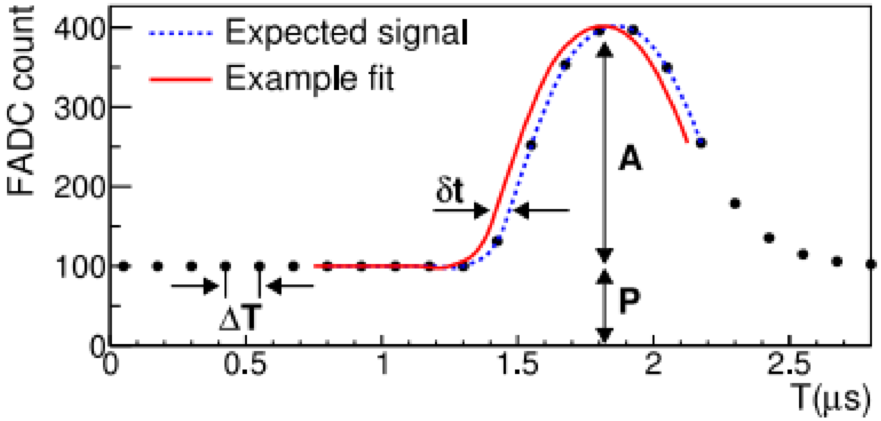
HSLB(1)

Analogue sum of 16(4x4) crystals

- -Trigger Cell(TC) is minimum unit
- -8736 CsI -> 546TC
- -shower shape information is lost

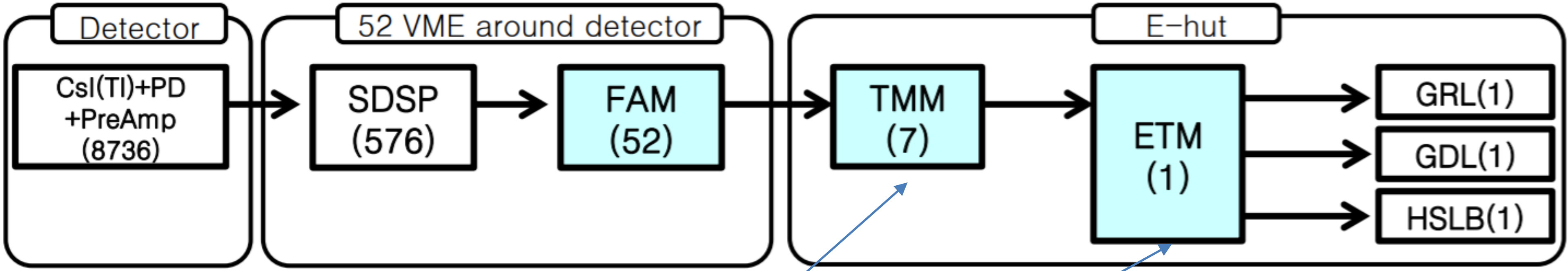
-Waveform fit to estimate energy, timing for all TC. Digitization.





8MHz FADC, 200ns fast shaper

ECL trigger



Detector

CsI(Tl)+PD
+PreAmp
(8736)

52 VME around detector

SDSP
(576)

FAM
(52)

E-hut

TMM
(7)

ETM
(1)

GRL(1)

GDL(1)

HSLB(1)

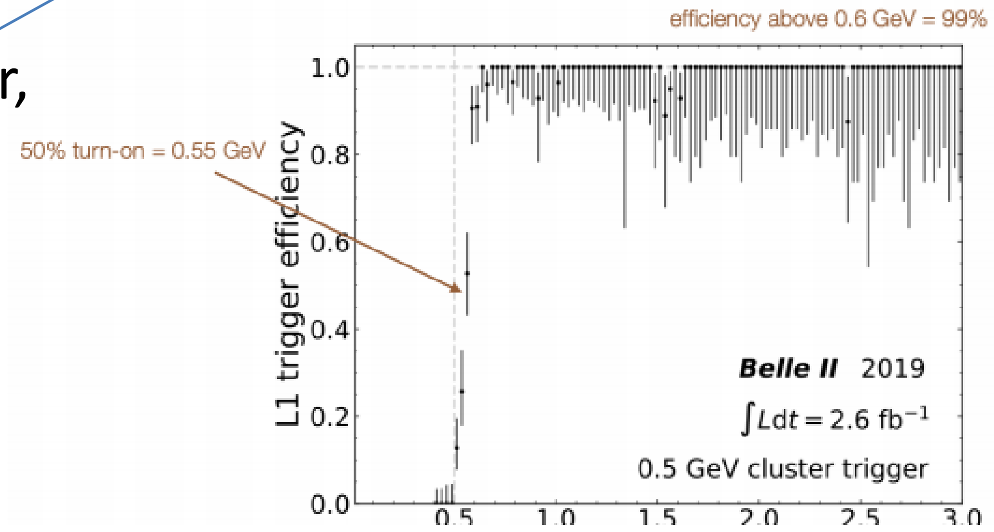
-Send all TC energy and timing to a UT4 (ETM)

-Combine neighbor TCs as a cluster,
 with energy, position, timing

-Acceptance
- >100MeV required to all TC
- full θ region covered

-Performance
- near ~100% efficiency, if energy >> 100MeV
- ~a few % energy difference from offline, depending on energy and angle

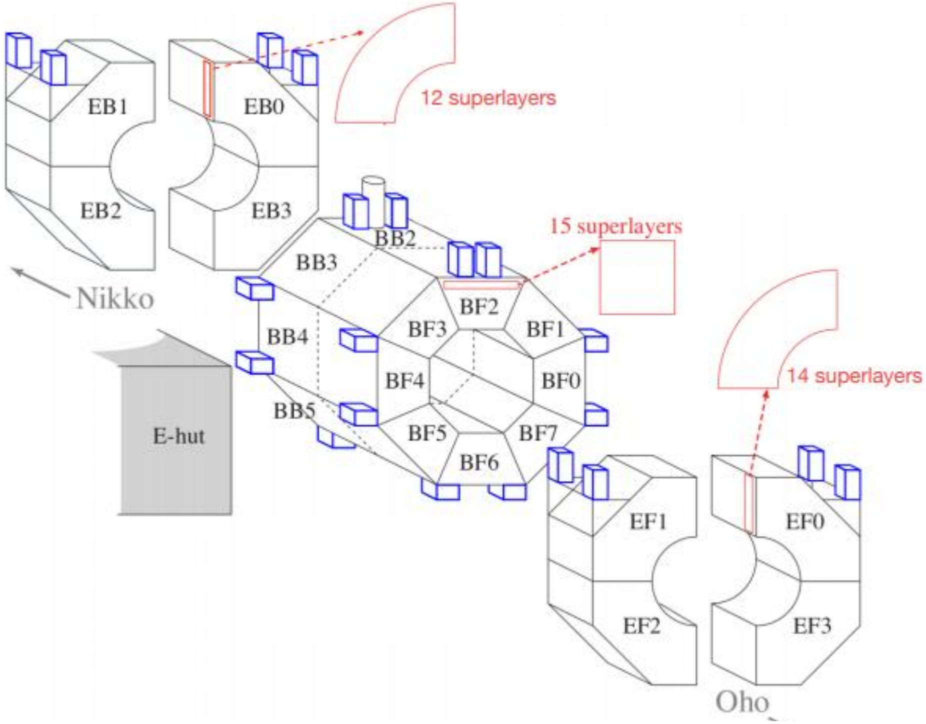
ECLTRG energy >0.5GeV

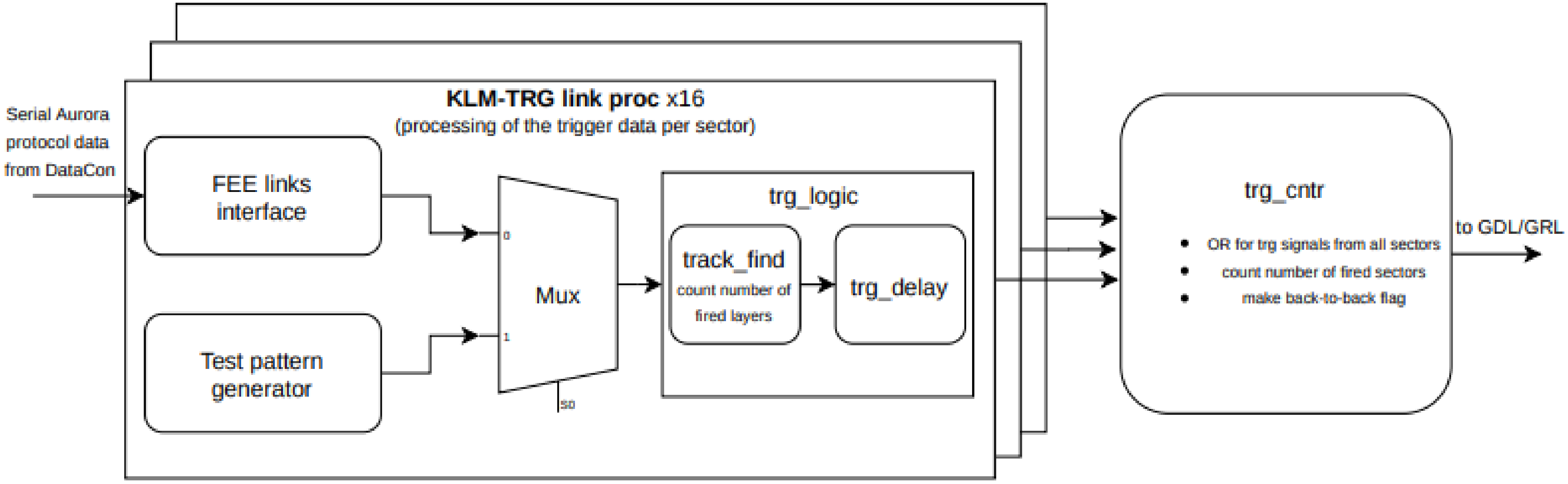


KLM Trigger

-Purpose: Trigger muon

- -Simply count number of hits: if #hit>7 in each sector, it is judged as muon candidate
- -Development of tracking algorithm is on-going

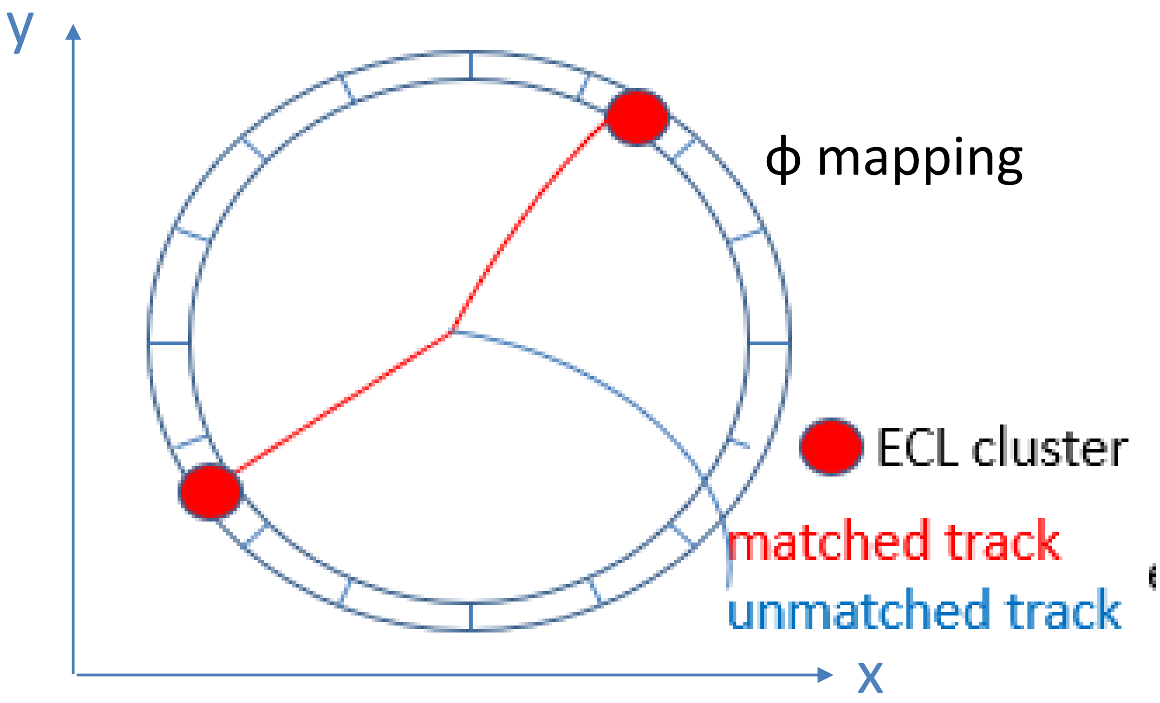




GRL/GDL

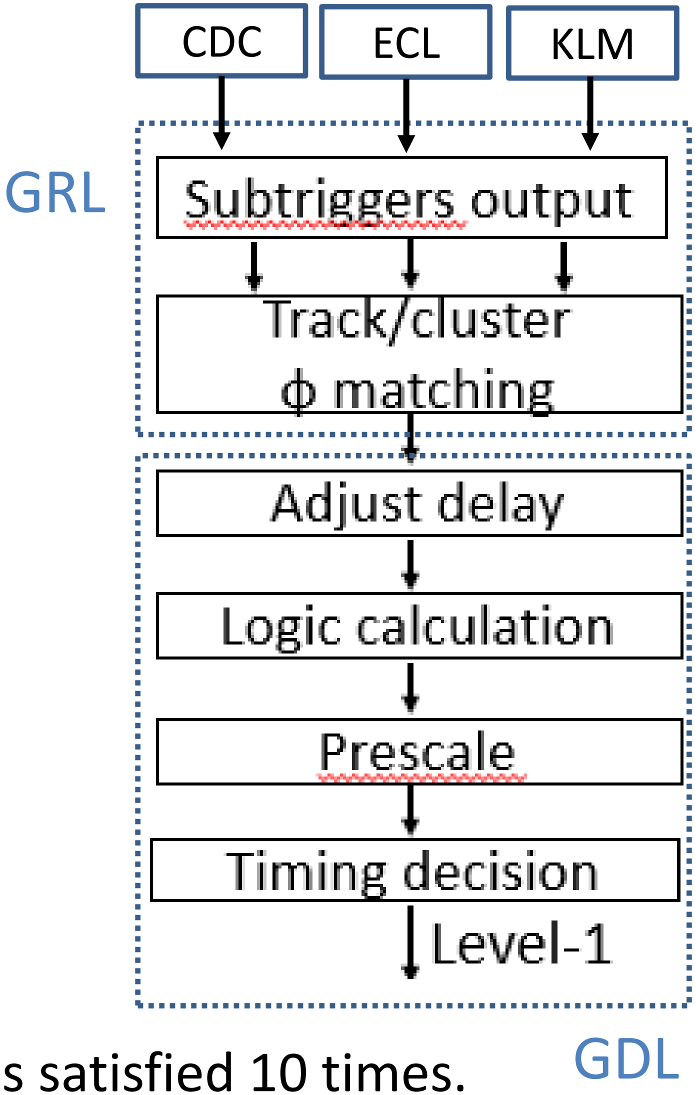
-GRL: Global reconstruction logic

- -take ϕ matching of CDC/ECL/KLM/TOP



-GDL: Global decision logic

- -calculate if trigger condition is satisfied
- -apply “prescale”
  - -if prescale=10, 1 event is triggered if condition is satisfied 10 times.
- -If one of trigger condition is satisfied, provide Level1 signal



List of trigger condition and rate in 2022b

-List of output bit and prescales are listed in confluence, B2N, basf2, GT (difficult for beginner due to many many jargons..)

event triggered by upper bits are excluded in lower bits in table

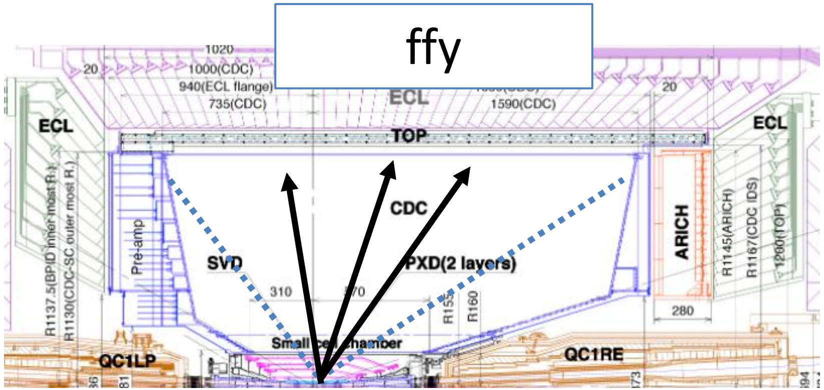
Category	Bit name and condition	Raw rate (kHz)	Exclusive rate (kHz)
CDC ~~B physics~~ standard bits	**ffy**: #full track>=3, |z|<20cm	2.18	2.18
	fyo: #full track>=2, Δϕ>90deg, |z|<20cm	1.77	0.73
ECL ~~B physics~~ standard bits	**c4**: #cluster>=4	0.47	0.26
	hie: Energy sum>1GeV	2.02	1.54
Subtotal		**4.7**	**4.7**
KLM τ/dark	**klmb2b, eklmb2b, beklm**: Back to back sector hits	0.51	0.46
	cdcklm, seklm, ecleklm: #CDC-KLM, ECL-KLM matching>=1	1.11	0.83
CDC τ/dark	**stt**: #full track>=1, |z|<15cm, p>0.7GeV	2.93	1.37
	syo: #full track>=1, #short track>=1, Δϕ>90deg, |z|<20cm	1.93	0.63
	fy30: #full track>=2, Δϕ>30deg, |z|<20cm	2.59	0.22
ECL τ/dark	**lml**: several combination of #cluster and energy	3.92	2.18
	eclmumu: back to back low energy hit	0.63	0.01
Calibration with prescale>1	PID (two photon)	0.35	0.16
	Other (Bhabha, γγ, random, trg)	1.00	0.60
Total L1	**OR of all bits**	**11.5**	**11.5**

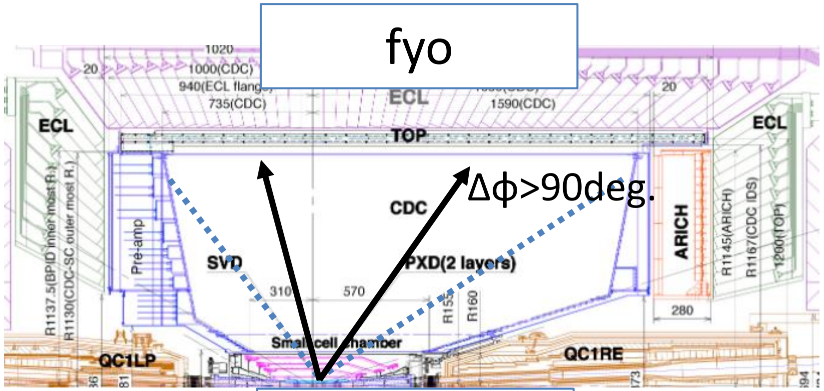
List of output bits: B physics

-Traditional condition same as Belle

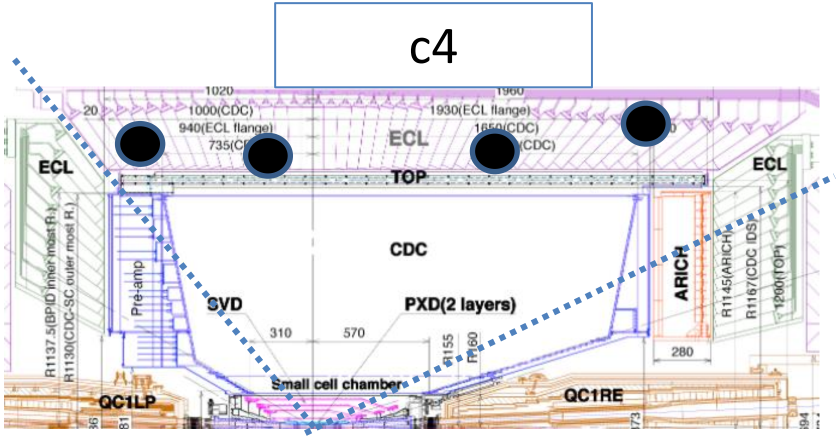
2021c

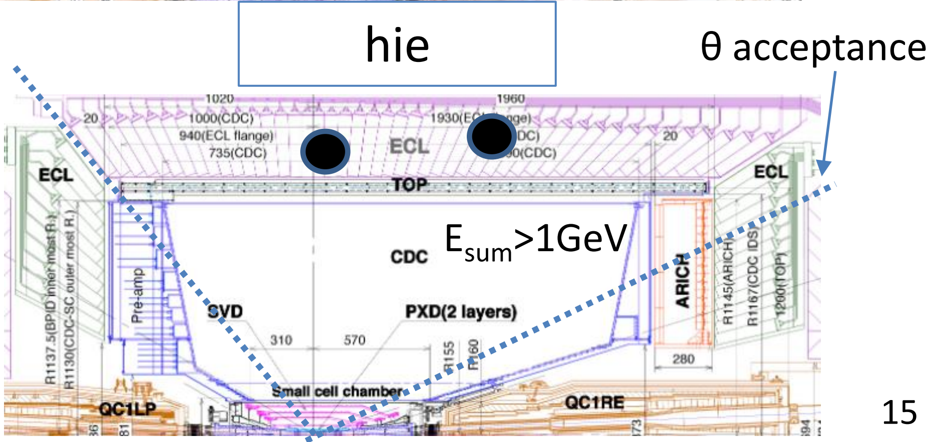
Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
BB pair	ffy	CDC #2track>=3, NNtrack>=1 with |z|<20cm >=1	1.40	1.40
	fyo	CDC #2track>=2, NNtrack>=1 with |z|<20cm >=1,	1.03	0.47
		Δϕ>90deg	0.13	0.08
	c4	ECL #cluster>=4, 2<θid<15	0.69	0.56
	hie	ECL Energy sum>1GeV, 2<θid<15		


ffy


fyo

Δϕ>90deg.


c4


hie

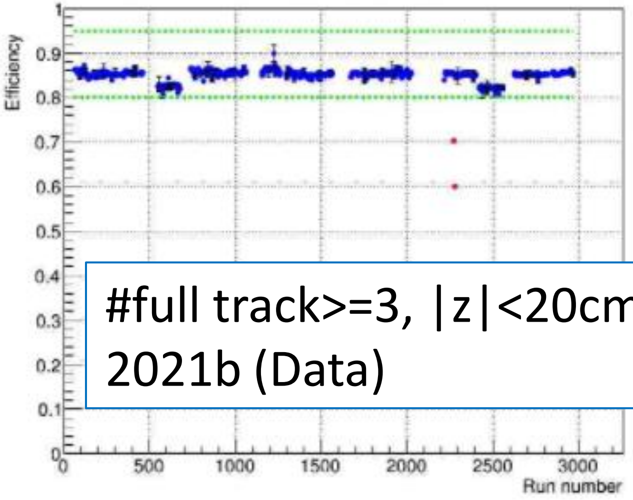
θ acceptance

E_{sum}>1GeV

BB efficiency performance

->99% efficiency for BB pair

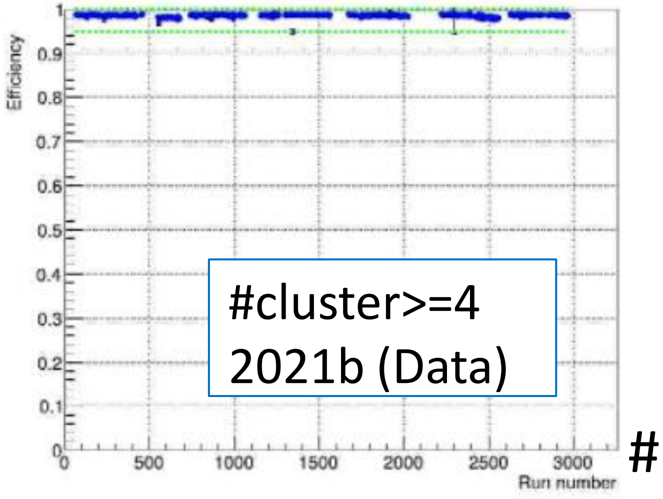
hadron efficiency



#full track>=3, |z|<20cm
2021b (Data)

#run

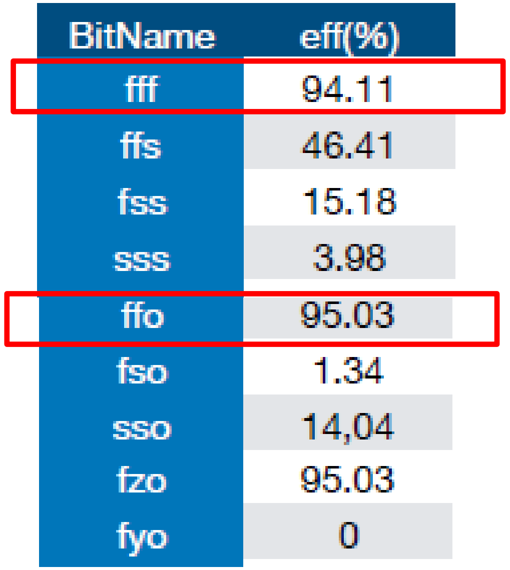
hadron efficiency



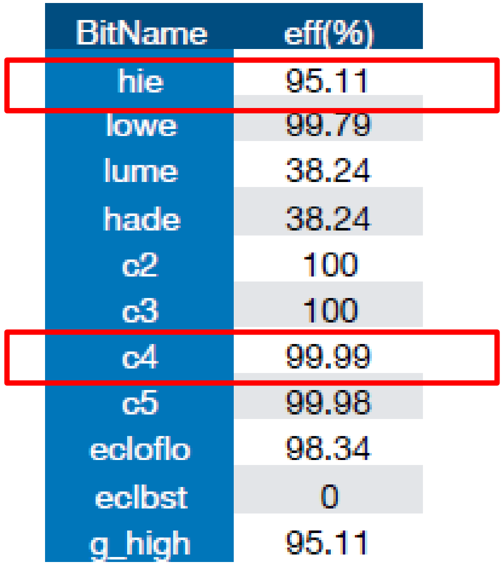
#cluster>=4
2021b (Data)

#run

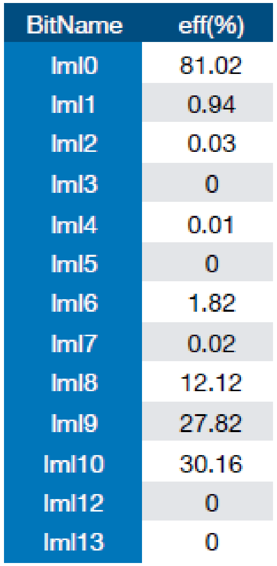
Expected efficiency to generic BB (MC)



BitName	eff(%)
fff	94.11
ffs	46.41
fss	15.18
sss	3.98
ffo	95.03
fso	1.34
sso	14,04
fzo	95.03
fyo	0



BitName	eff(%)
hie	95.11
lowe	99.79
lume	38.24
hade	38.24
c2	100
c3	100
c4	99.99
c5	99.98
ecloflo	98.34
eclbst	0
g_high	95.11



BitName	eff(%)
lml0	81.02
lml1	0.94
lml2	0.03
lml3	0
lml4	0.01
lml5	0
lml6	1.82
lml7	0.02
lml8	12.12
lml9	27.82
lml10	30.16
lml12	0
lml13	0

Bhabha veto with ECL trigger

-Two back-to-back high energy electron is produced by Bhabha.

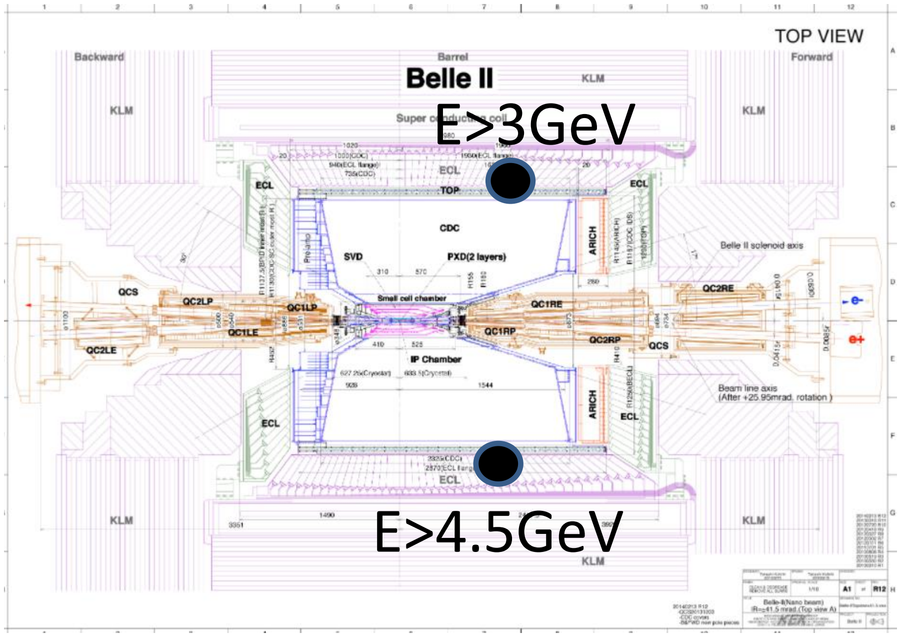
-If following condition satisfied at ECLTRG, it is judged as Bhabha

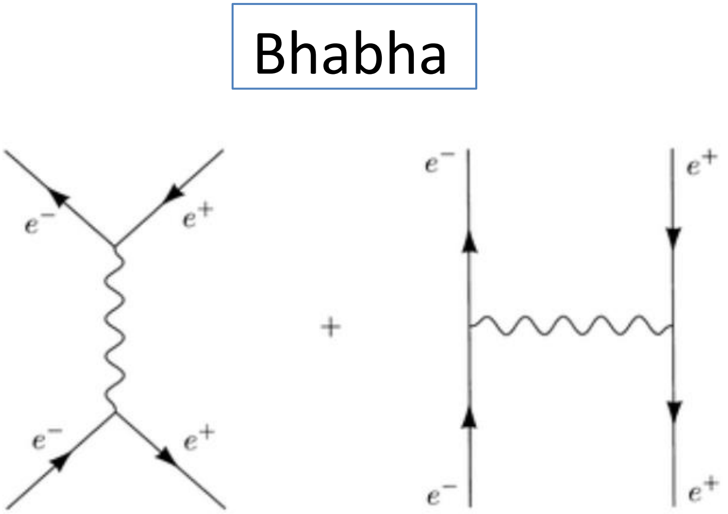
[$E1>4.5$GeV, $E2>3.0$GeV, $160<\Delta\phi_{CM}<200$deg, $165<\Sigma\theta_{CM}<190$deg]

-~80% trigger rate reduction from Bhabha

-Most of trigger conditions has Bhabha veto

-for example, fyo, hie, c4

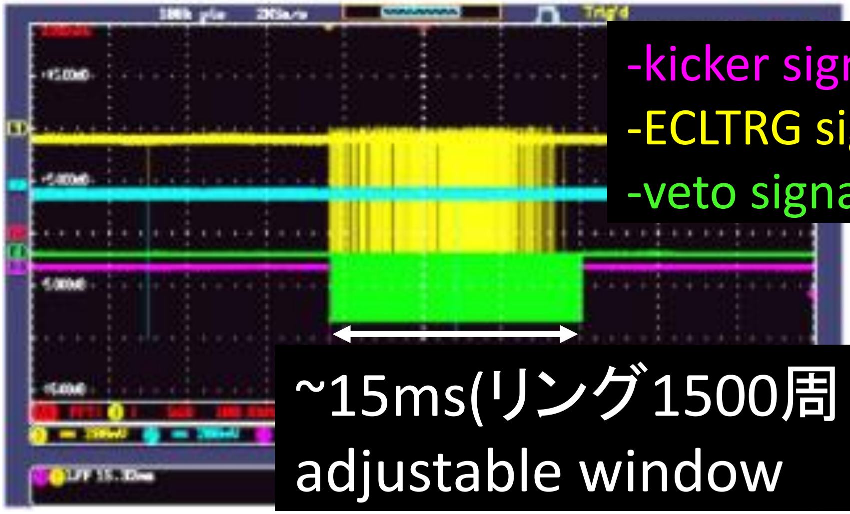




Injection BG rejection with kicker signal

-Huge background appear just after beam injection

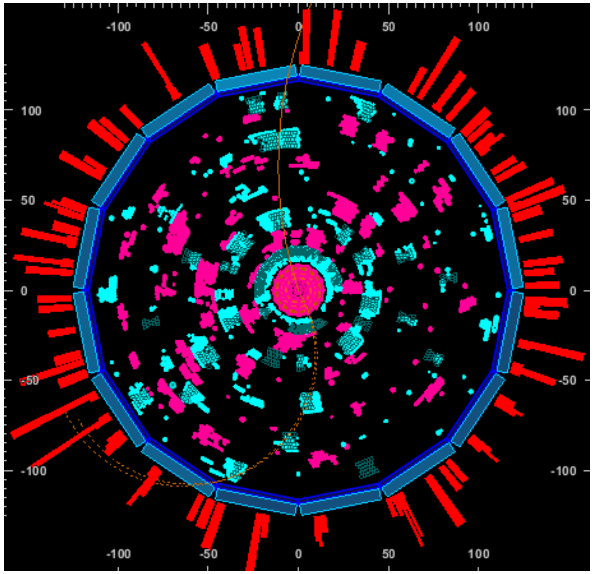
-Almost all trigger condition is vetoed
when pre-kicker signal sent from machine

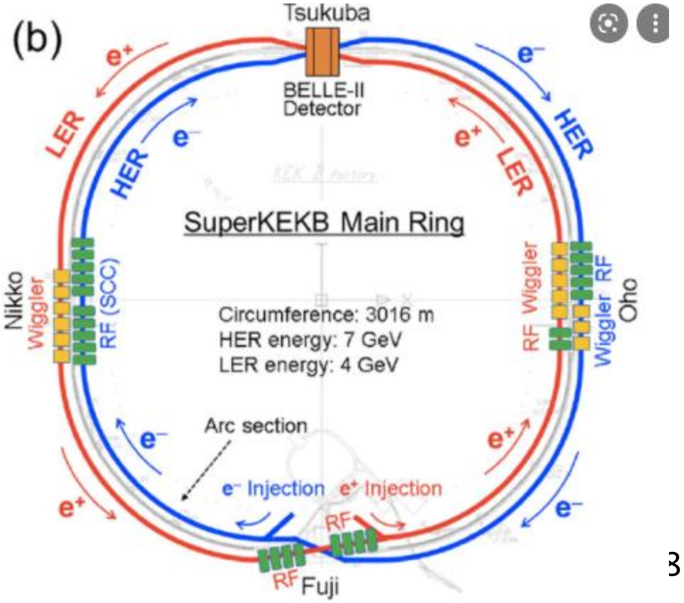


-kicker signal
-ECLTRG signal
-veto signal

~15ms(リング1500周!)×~2μs
adjustable window

Injection BG





Trigger menu for dark/low-multi

-TRG-DAQ workshop 2022, physics-TRG session

-In backup, definition of conditions are shown..

Triggers

Analyses	triggers
Z’ invisibile, dark Higgs	fy30, cdcklm, stt
Z’→ττ, μμ	fff/ffy, cdcklm,stt (fy30, fyo)
A’ invisible (single γ)	hie, lml6, lml16 (lml1, prescaled)
A’ visible without γ	stt, fyo, hie
X17/ A’ visible + γ	dpee (lml,,hie, c2hie)
ALP→ γ γ (3γ final state)	hie (high mass) , ggsel (low mass)
ALP→ γ γ fusion (ee → γ γ e)	lml2, hie (stt, lml1 barrel)
Single $\pi^0/\eta/\eta'$ (ee → γ γ e)	hie (stt)
μμ(γ) control sample (for invisible A’ + …)	stt, beklm, cdcklm (fyo, syo)
IDM + Dark Higgs	hie (lml12, stt [stt4/5])
ππγ for HVP	hie, (ff, stt)
$\pi\pi\pi^0\gamma$ for HVP	hie, bha3d (lml1)
Dark showers	stt, stt-ecl, hie for electrons (displaced VTX)

—— CDC
—— ECL
—— KLM

Triggers used now or in already planned extensions of analyses to the full dataset (and beyond)

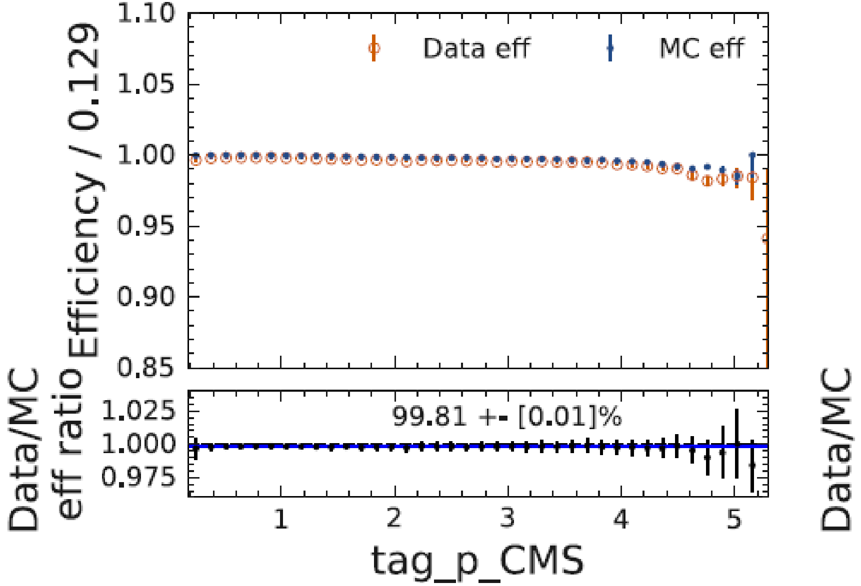
TSIM

-Trigger logic is simulated on basf2 software, in order to estimate trigger efficiency of signal and background. (Trigger simulation, TSIM.)

-Since MC14, most of trigger logic has been implemented with good data/MC agreement, level of less than 1%.

-Example of tau 1x1 study

ECLTRG efficiency with tau 1x1, electron mode



Systematics of TRG for tau 1x1 analysis

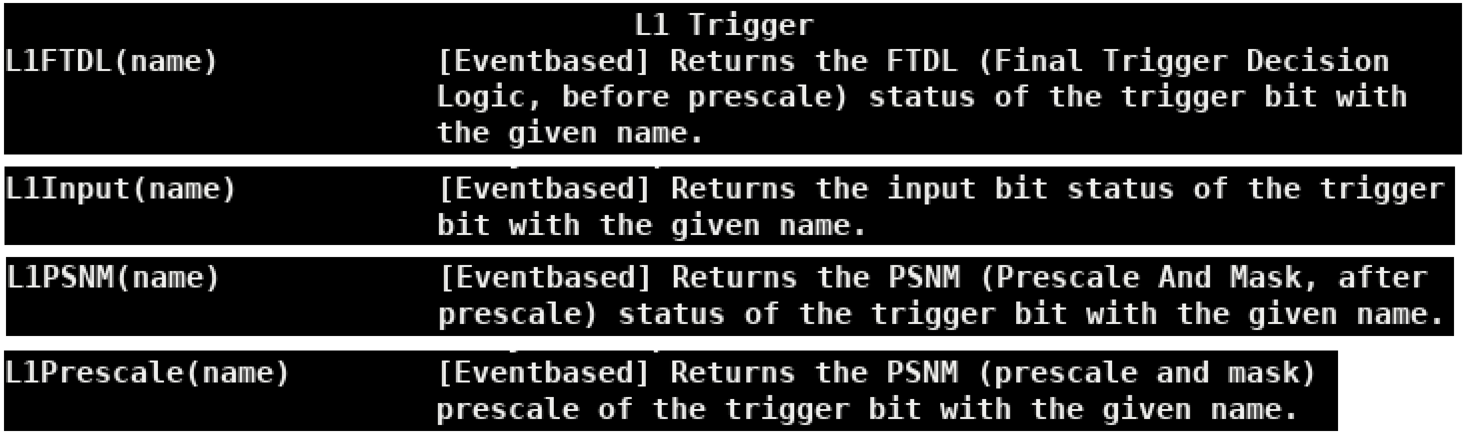
Sys	e	μ
Data-MC	0.05	0.05
Ref trig	0.11	0.34
Exp dep	0.13	0.26
Total (%)	**0.124**	**0.437**

TSIM for physics analysis

-On mdst, trigger information is stored on TRGSummary class.
Event variables are available for user. (Sphinx)

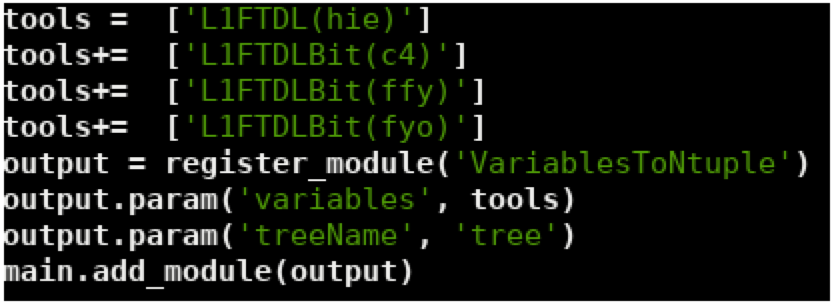
-$basf2 variables.py will show list of the available variables

-ex. if L1PSNM(hie)==1, event is triggered by hie. if ==0, not triggered.



```
                              L1 Trigger
L1FTDL(name)            [Eventbased] Returns the FTDL (Final Trigger Decision
                        Logic, before prescale) status of the trigger bit with
                        the given name.
L1Input(name)           [Eventbased] Returns the input bit status of the trigger
                        bit with the given name.
L1PSNM(name)            [Eventbased] Returns the PSNM (Prescale And Mask, after
                        prescale) status of the trigger bit with the given name.
L1Prescale(name)        [Eventbased] Returns the PSNM (prescale and mask)
                        prescale of the trigger bit with the given name.
```

-Example of implementation on your steering file



```
tools =  ['L1FTDL(hie)']
tools+=  ['L1FTDLBit(c4)']
tools+=  ['L1FTDLBit(ffy)']
tools+=  ['L1FTDLBit(fyo)']
output = register_module('VariablesToNtuple')
output.param('variables', tools)
output.param('treeName', 'tree')
main.add_module(output)
```

-※With run-independent MC, prescale configuration and trigger menu can be different from data. Please be careful.

When you start physics analysis: high multiplicity

-If your physics mode has high multiplicity, like hadronic B decay, high efficiency is expected. Effect from trigger expected to be small.

-Example of simple test to check the trigger efficiency:

-1. check ECLTRG energy 1GeV(hie) and ECLTRG #cluster>=4 (c4) efficiency by MC, after all event selection

efficiency(hie) = (#events with FTDL(hie)==1)/(#events)
efficiency(c4) = (#events with FTDL(c4)==1)/(#events)

-2. If efficiency is almost 100%, effect from trigger is small.

-3. If efficiency is not 100%, effect from trigger may not be negligible. Please consult with trg-performance group (Chris).

- -If you measure absolute signal yield (like Branching ratio), higher effect.
- -If you measure ratio of signal yield (like A_{CP}), smaller effect.

When you start physics analysis: low multiplicity

-If your physics mode has low multiplicity, you should care trigger

-0. contact trg-performance group (Chris) to consult with it. Read Sphinx.

-1. choose high efficient trigger bit for your physics mode

-2. estimate trigger efficiency of your signal with MC:

$$\epsilon = \frac{N_{\mathrm{ffy}}}{N_{\mathrm{all}}}$$

where N_{all} is the number of all generated events, and N_{ffy} is the number of `ffy` satisfied events

-3. check data/MC agreement with reference bit, independent from signal bit:

$$\epsilon_{\mathrm{exp}} = \frac{\boxed{N_{\mathrm{fff}}}\ \mathrm{and}\ \boxed{(N_{\mathrm{hie}}\ \mathrm{or}\ N_{\mathrm{c4}})}}{\boxed{N_{\mathrm{hie}}\ \mathrm{or}\ N_{\mathrm{c4}}}}$$

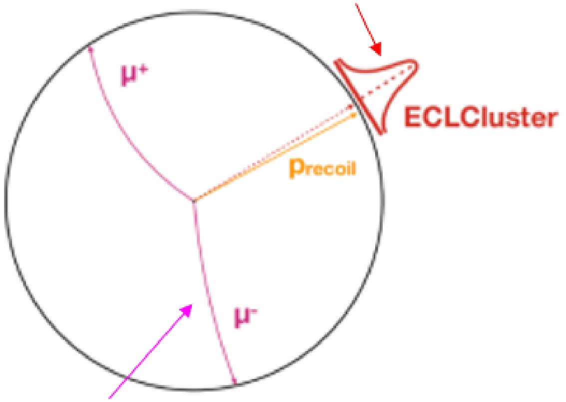
signal bit

reference bit

-4. if you are using CDC-ECL matching etc.,
control sample (like μμγ) is needed to ensure independence of reference bit and signal bit.

Estimation of matching efficiency

trigger event by gamma (hie)



estimate matching eff. with μ

Summary

-Try to introduce BelleII trigger

- -Hardware trigger is used to reduce event rate and file size
- -CDC, ECL, KLM, TOP are used for TRG with ϕ matching on GRL
- -Many trigger conditions with B, τ and low multi physics
- -Simulation with good data/MC agreement in general

-When you start physics analysis, you should consider effect from trigger.

- -Higher effect for low-multiplicity physics channel
- -consult with trg-performance group

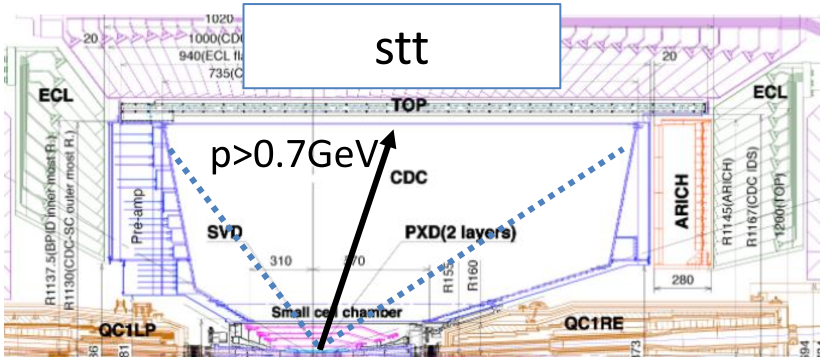
backup

List of output bits: τ

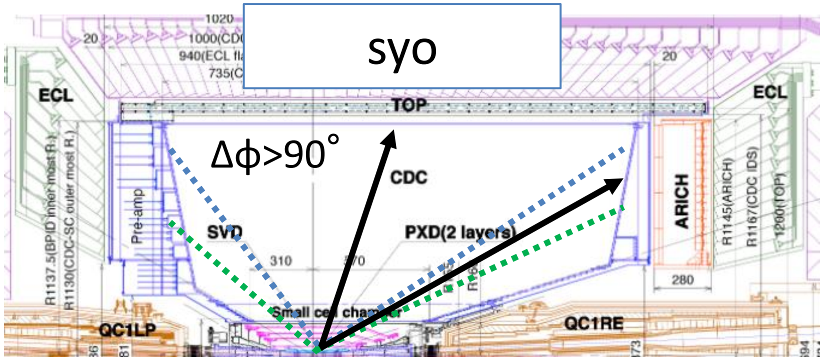
-CDC-KLM, ECL-KLM matching trigger

2021c

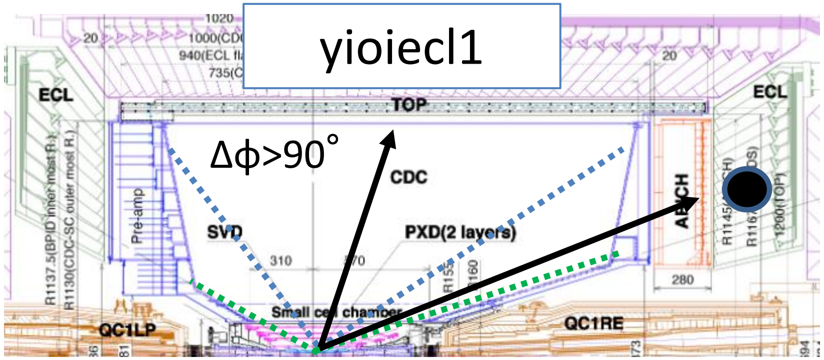
Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
τ	stt	CDC #full track>=1, |z|<15cm, p>0.7GeV	1.74	0.96
	syo	CDC #full track>=1, |z|<15cm, #short track>=1, Δϕ>90deg.	0.74	0.38
	yioiecl1	CDC #full track>=1, |z|<15cm, #inner track>=1, Δϕ>90deg.	0.37	0.08
	lml12	NCL ≥ 3, at least 1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



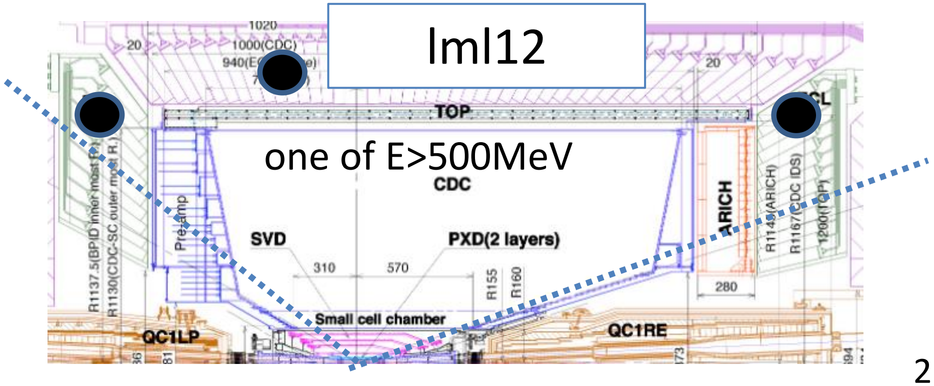
stt



syo



yioiecl1



lml12

τ efficiency performance

- >~90% efficiency for tau 1x1 with good data/MC agreement
  - -CDC:~90% eff. with stt
  - -ECL: ~90% eff. with hie, lmlx

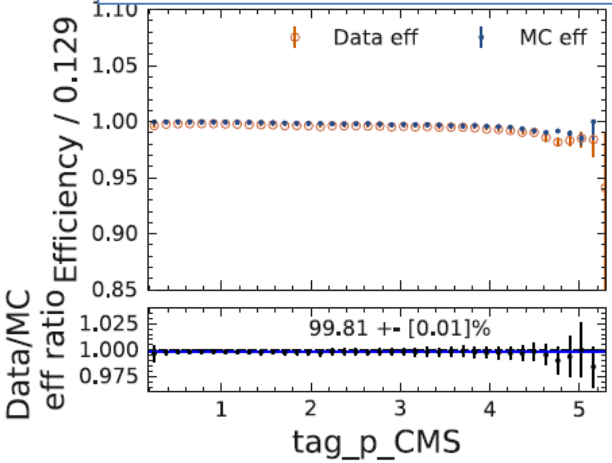
-Data/MC check is on-going with tau experts

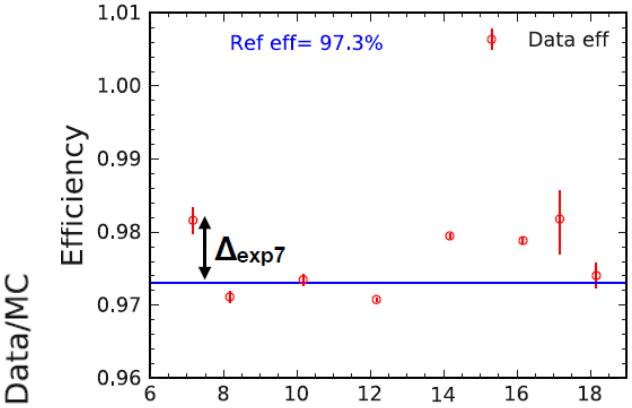
- -ECLTRG Data/MC agreement is ~1% level with MC14
- -Trigger systematic is ~0.5%

ECLTRG efficiency with e

nu

ECLTRG efficiency with μ





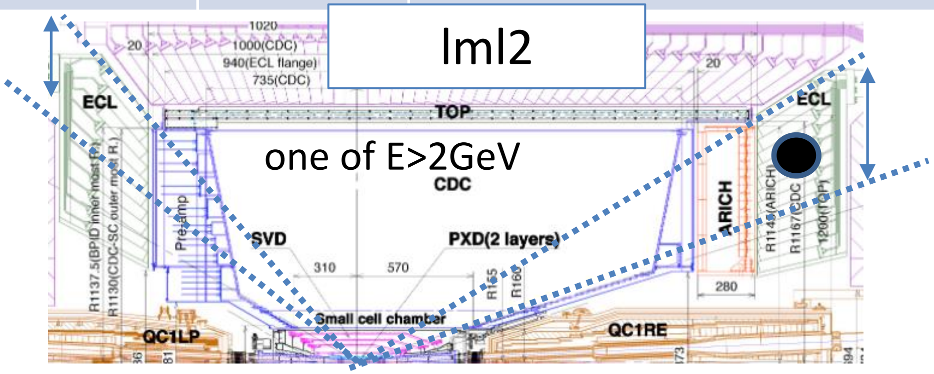
Sys	e	μ
Data-MC	0.05	0.05
Ref trig	0.11	0.34
Exp dep	0.13	0.26
Total (%)	**0.124**	**0.437**

List of output bits: lowmulti/dark

-Mainly ECL based photon trigger

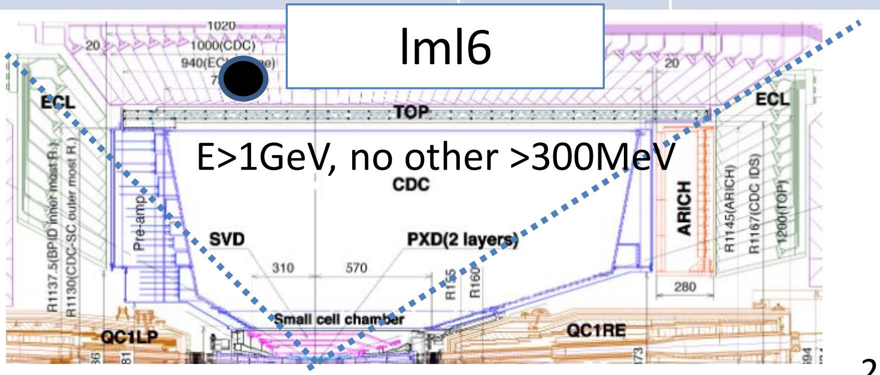
2021c

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



lml2

one of E>2GeV

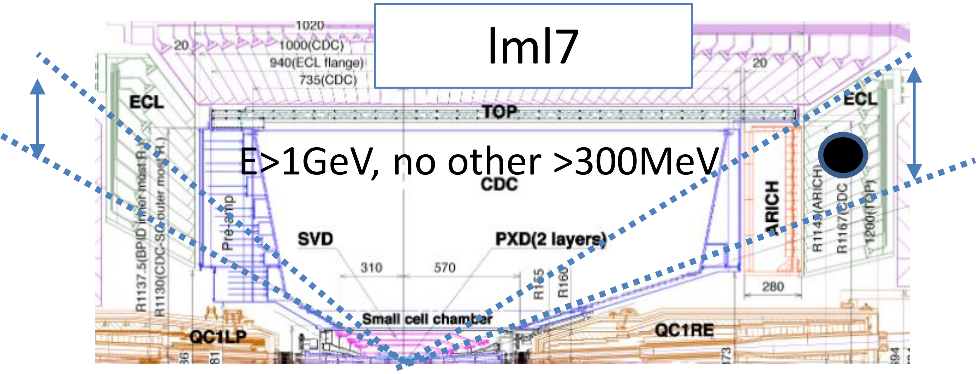


lml6

E>1GeV, no other >300MeV

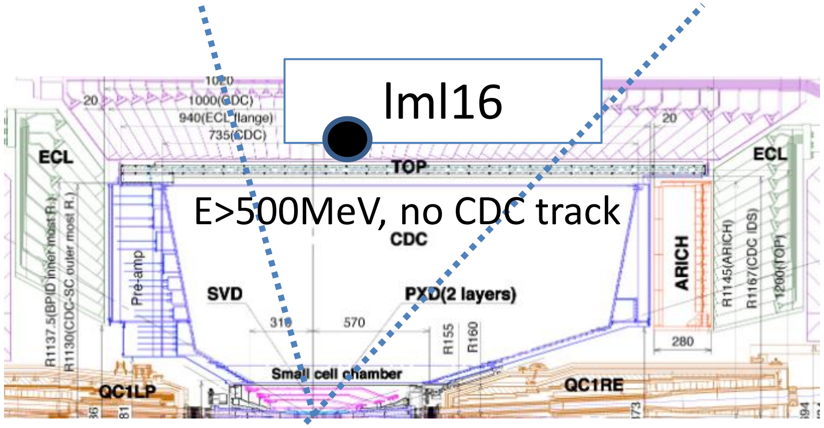
List of output bits: lowmulti/dark

-Mainly ECL based photon trigger



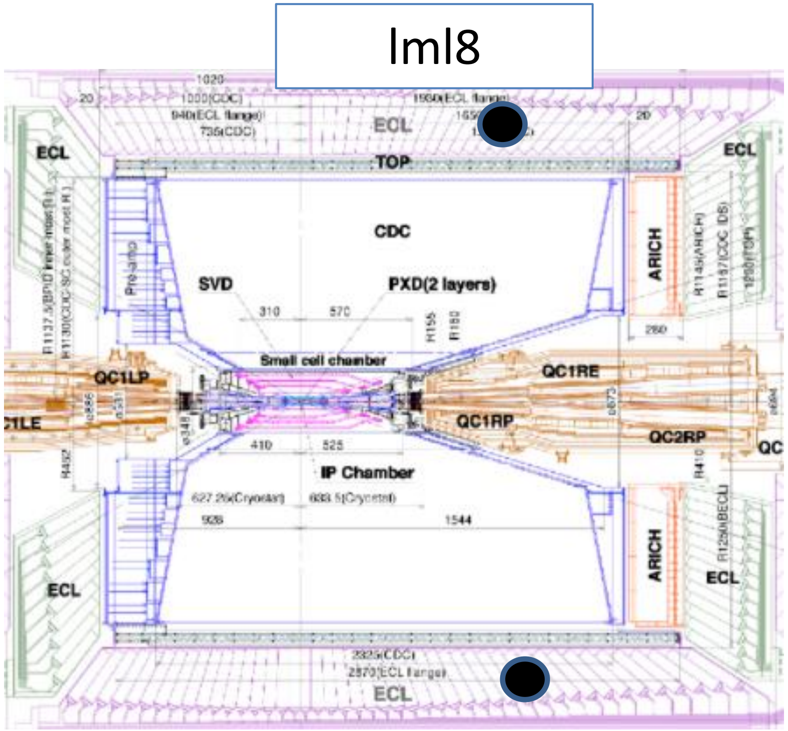
lml7

E>1GeV, no other >300MeV



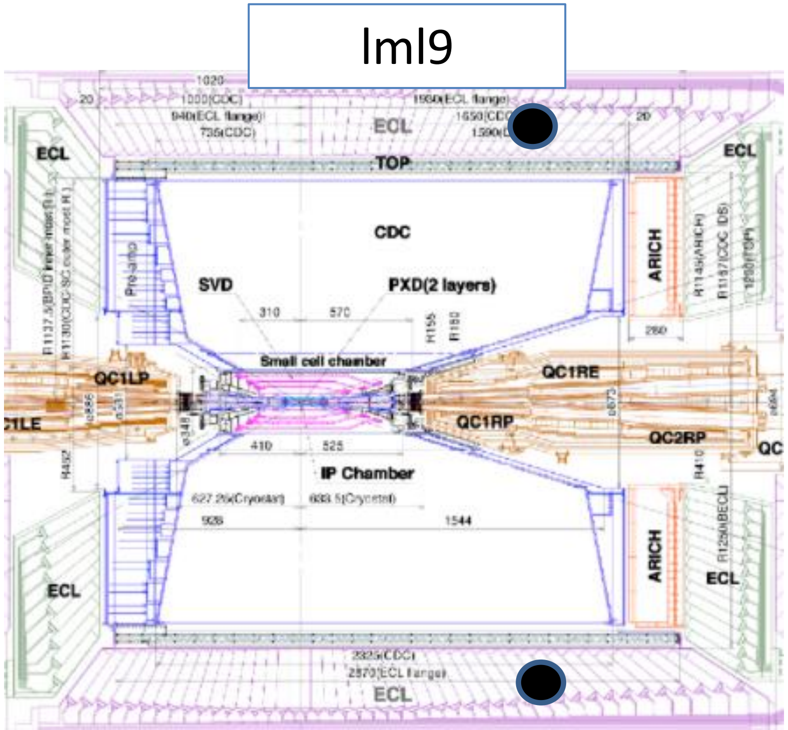
lml16

E>500MeV, no CDC track



lml8

back to back, both E>250MeV, no other >2GeV, all θ region



lml9

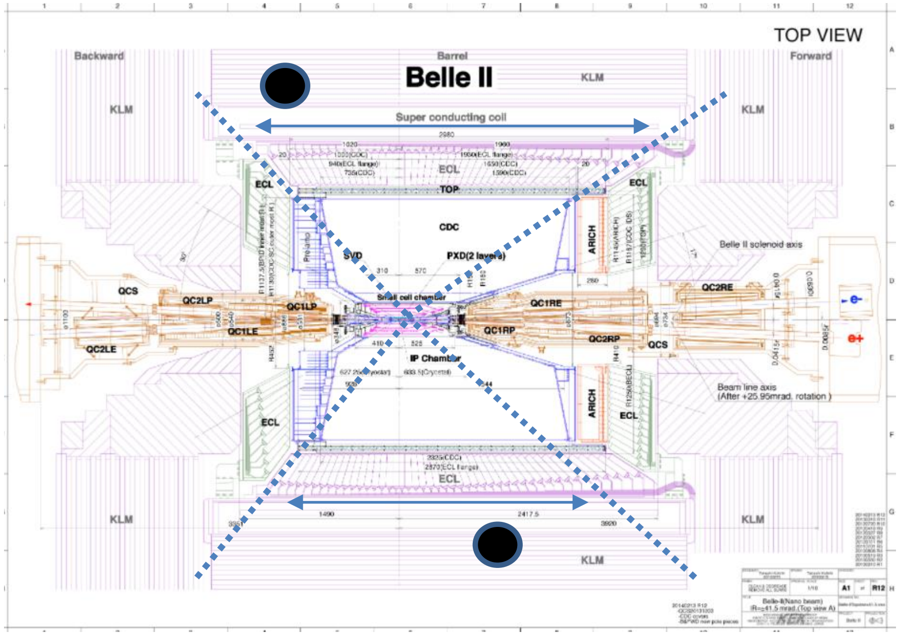
back to back, one E>250MeV, one E<250MeV, no other >2GeV, all θ region

List of output bits: muon pair

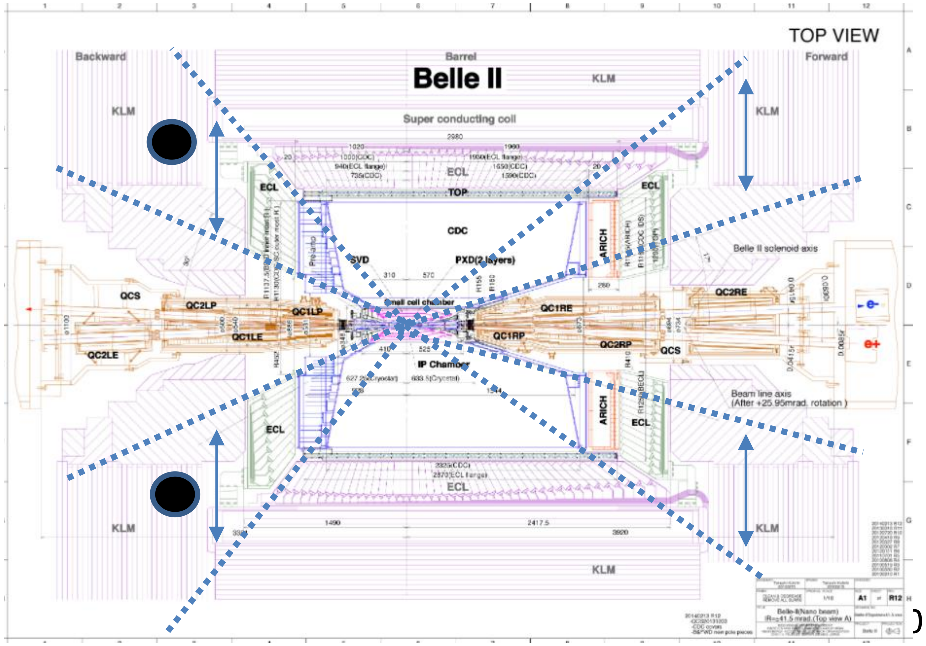
-KLM and ECL stand alone trigger

Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
Muon pair	mu_b2b	#BKLM cluster>=2, Δϕ>90 deg.	0.35	0.32
	eklm2	#EKLM cluster>=2	0.04	0.04
	beklm	#EKLM cluster=1, #BKLM cluster=1	0.20	0.18
	lml10	ECL 160 $<\Delta\varphi_{CM}<$ 200 deg, 160 $< \Sigma\theta_{CM} <$ 200deg, no 2GeV(CM) CL in an event	0.49	0.36
	eclmumu	ECL 160 $<\Delta\varphi_{CM}<$ 200 deg, 165 $< \Sigma\theta_{CM} <$ 190deg, E<2GeV	0.30	-

mu_b2b



eklm2

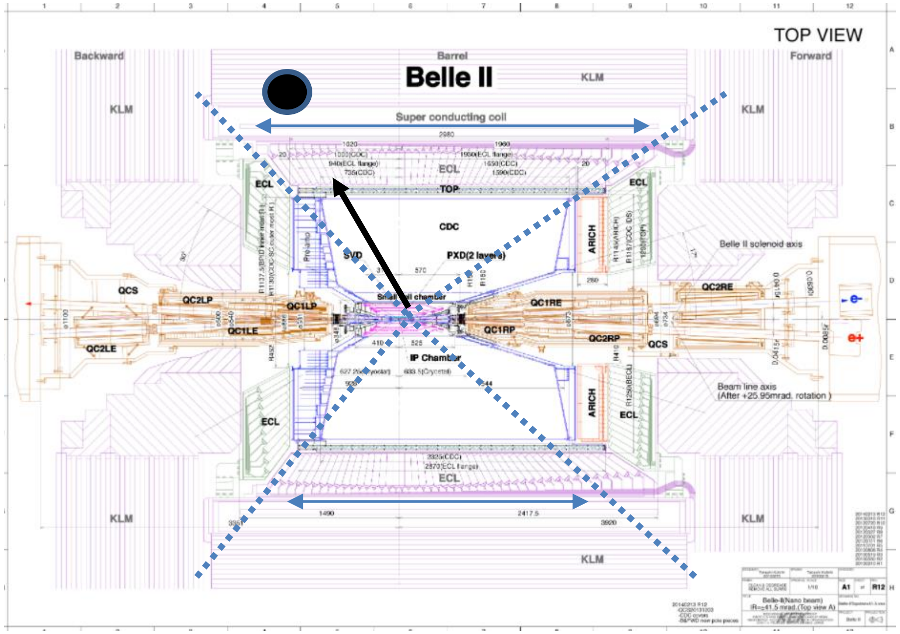


List of output bits: single muon

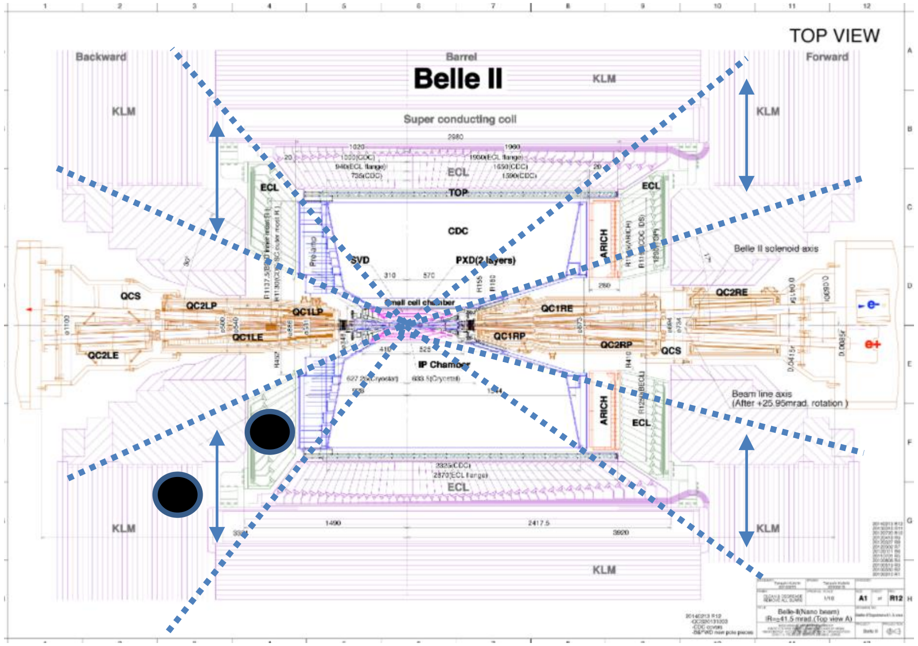
-CDC-KLM, ECL-KLM matching trigger

Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
Single muon	cdcklm1-2 ecleklm1	#CDC-BKLM matching>=1 #CDC-EKLM matching>=1	0.27 0.42	0.15 0.30

cdcklm1

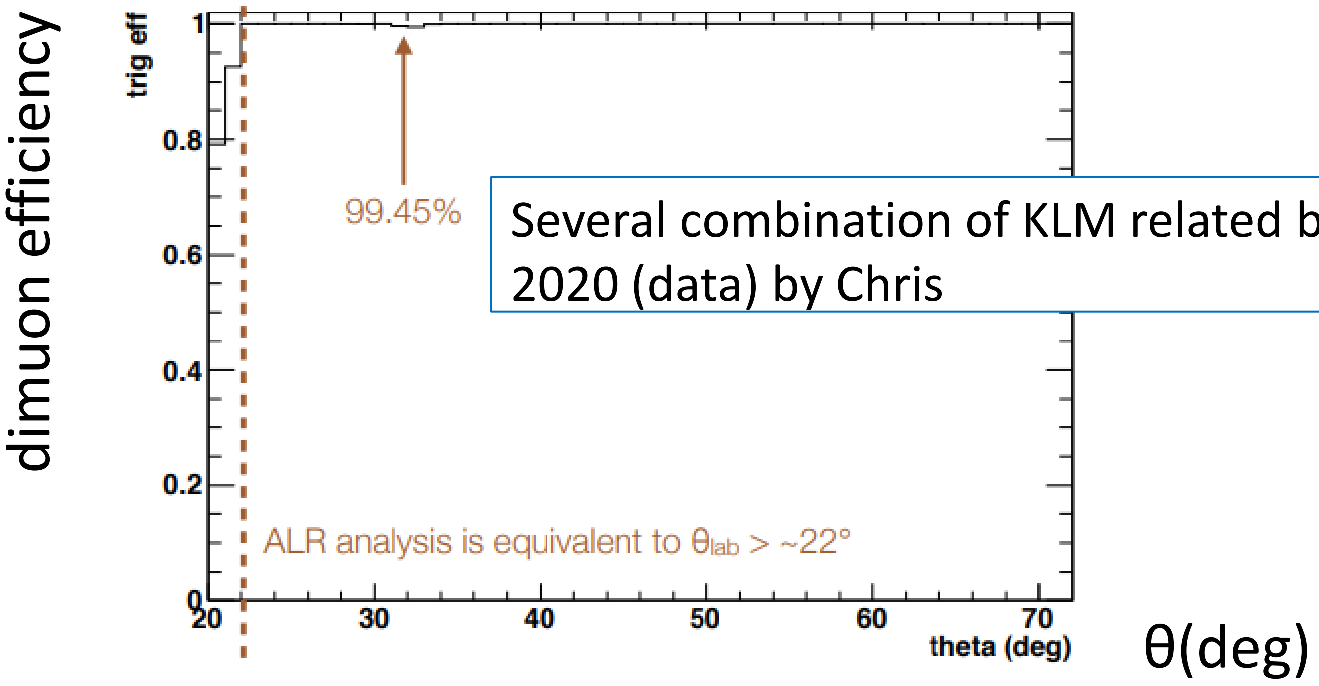


ecleklm1



Dimuon efficiency performance

-High efficiency for Dimuon with wide angle coverage

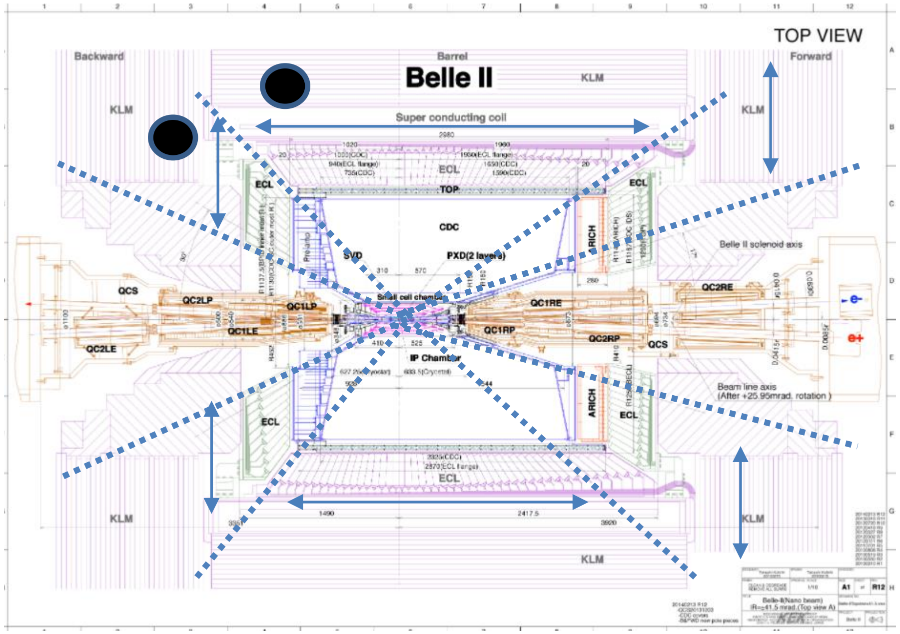


Several combination of KLM related bits
2020 (data) by Chris

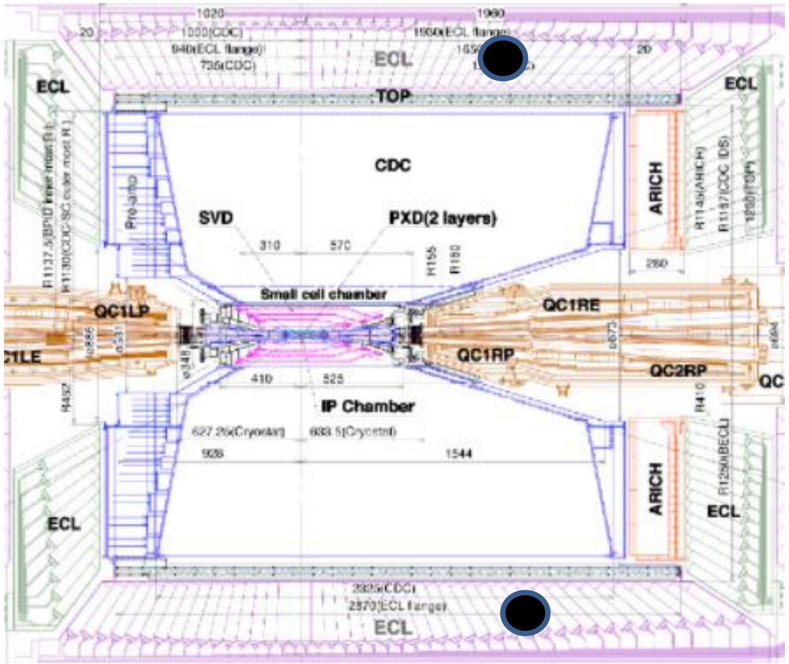
List of output bits: muon pair

-KLM and ECL stand alone trigger

beklm



eclmumu

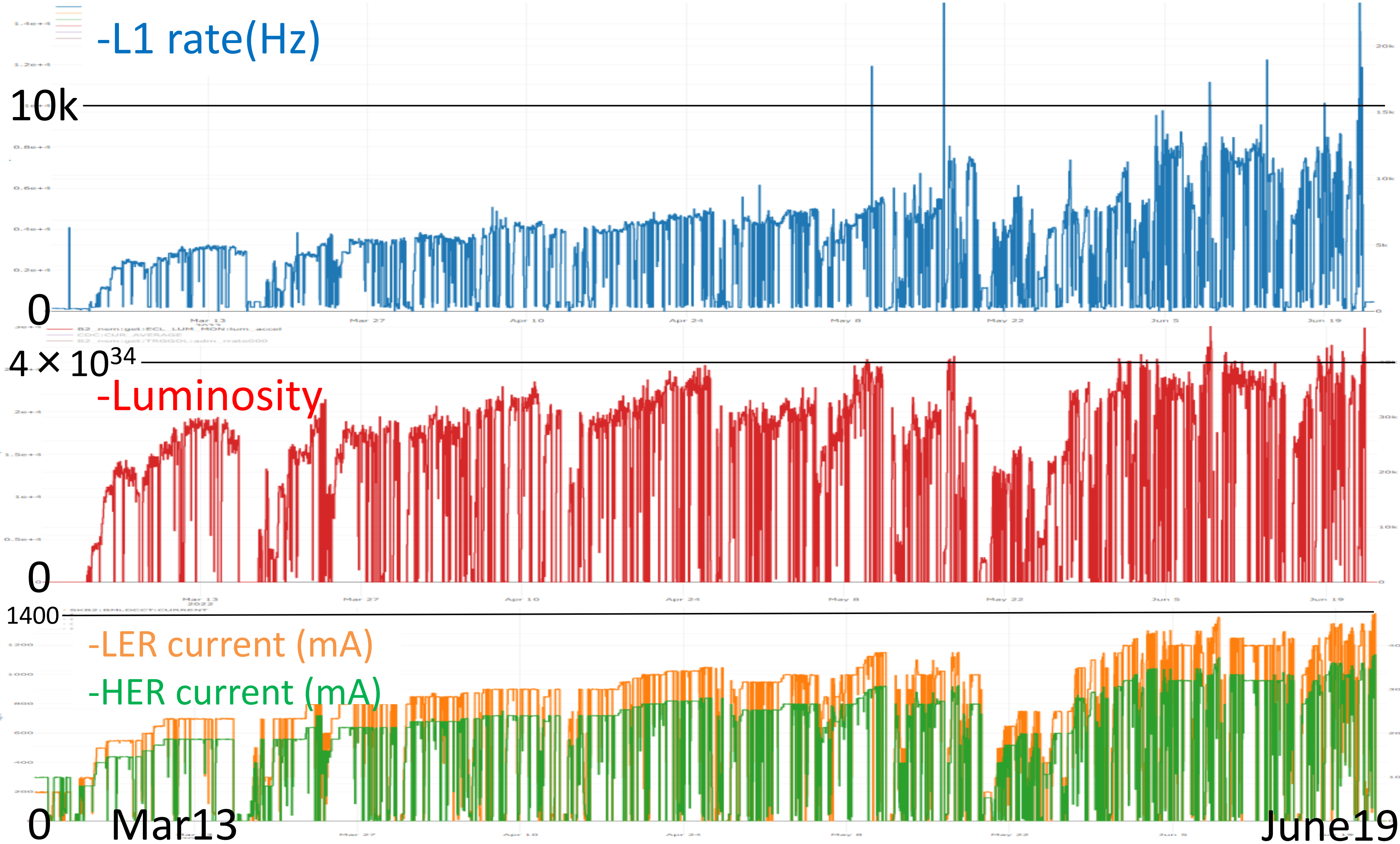


back to back, E<2GeV
all θ region

High trigger rate issue

-L1 rate reached ~11kHz at maximum. It is almost DAQ limit before LS1.

-Reduction of L1 rate and reinforcement of HLT are needed during LS1.

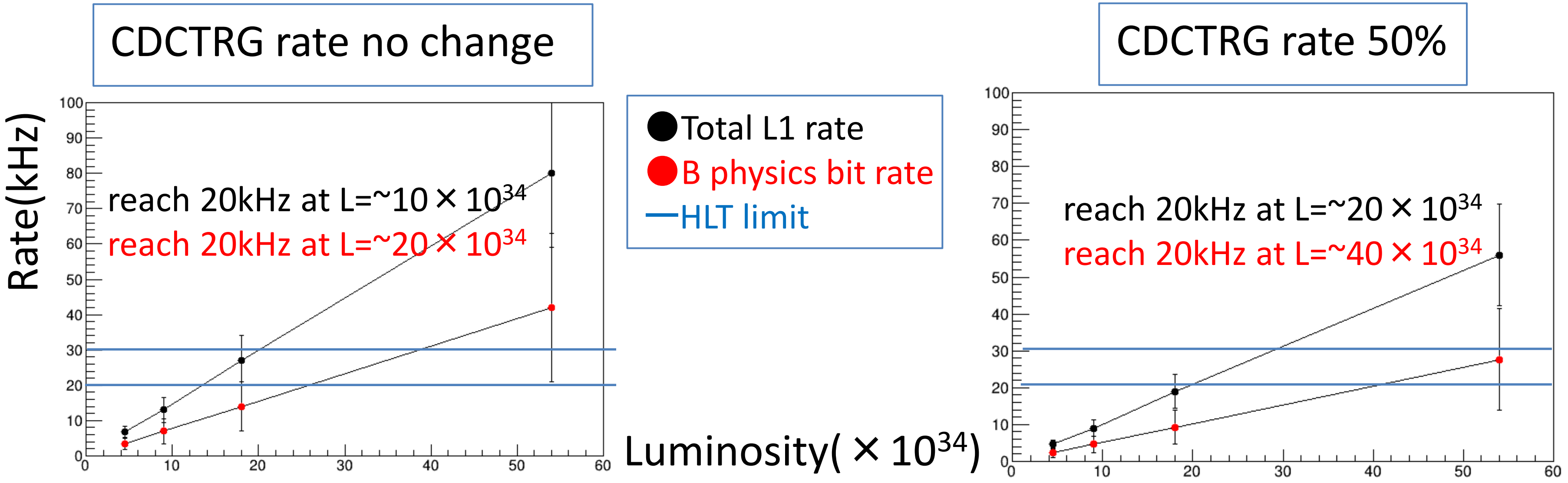


High trigger rate issue

-Trigger rate in 2022b was very high

- -Total L1 rate=~11.5kHz, Luminosity=~4.5 × 10^34
- -Trigger rate will exceed DAQ limit of 30kHz in future

-We can not keep high B physics efficiency with present system.



-Major Upgrade is on-going during LS1:

- -aim to reduce ~50% CDCTRG rate (challenge!)
- -optimization and priority of trigger bits for low muliti phycis

Prescale discussion

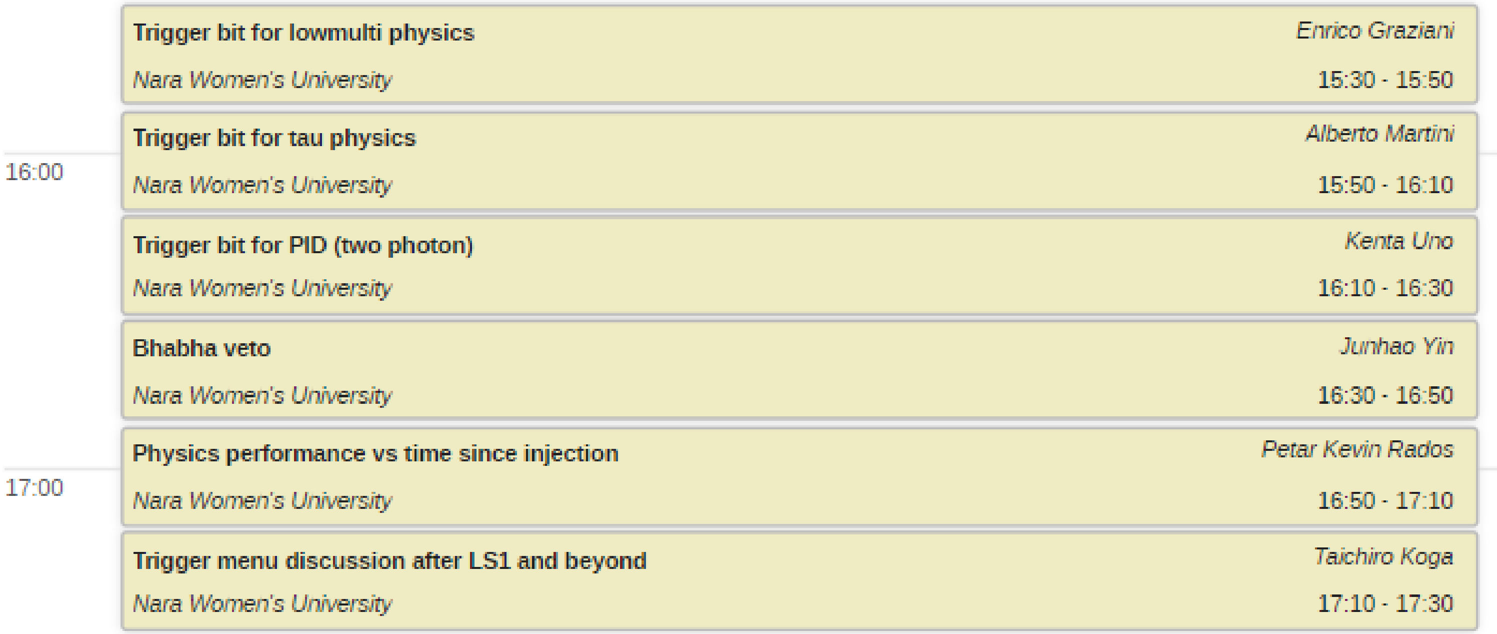
-We are now discussing trigger menu and prescale after LS1

-If you are using specified trigger bits for your analysis, please let us know

-Otherwise the trigger bits can be discarded or CDC-ECL matching applied

-Jira

-physics-TRG session at Dec.1st on TRG-DAQ workshop



16:00

17:00

Trigger bit for lowmulti physics *Enrico Graziani*
Nara Women's University 15:30 - 15:50

Trigger bit for tau physics *Alberto Martini*
Nara Women's University 15:50 - 16:10

Trigger bit for PID (two photon) *Kenta Uno*
Nara Women's University 16:10 - 16:30

Bhabha veto *Junhao Yin*
Nara Women's University 16:30 - 16:50

Physics performance vs time since injection *Petar Kevin Rados*
Nara Women's University 16:50 - 17:10

Trigger menu discussion after LS1 and beyond *Taichiro Koga*
Nara Women's University 17:10 - 17:30

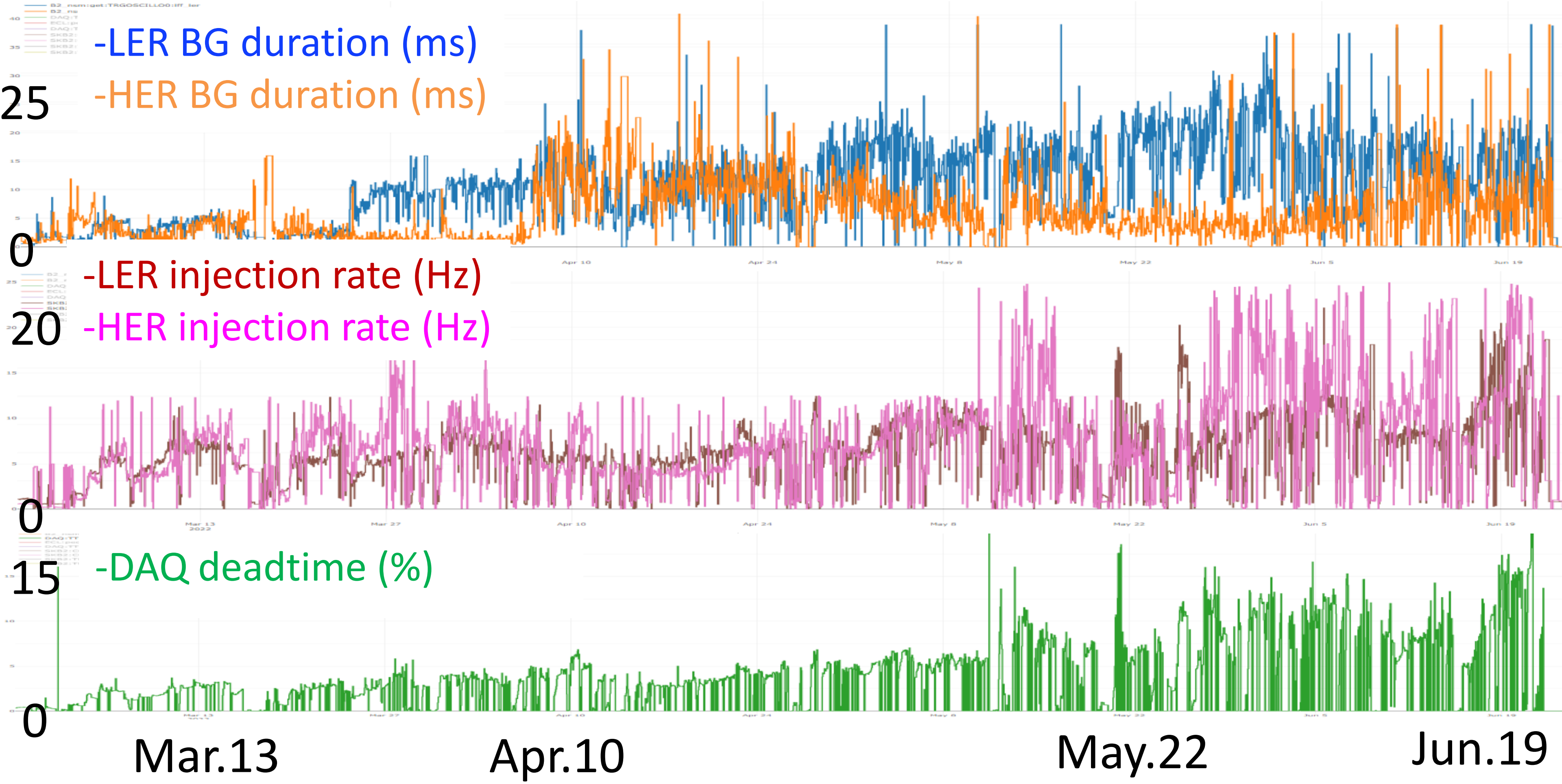
Dead time issue

-Injection veto causes the DAQ dead time:

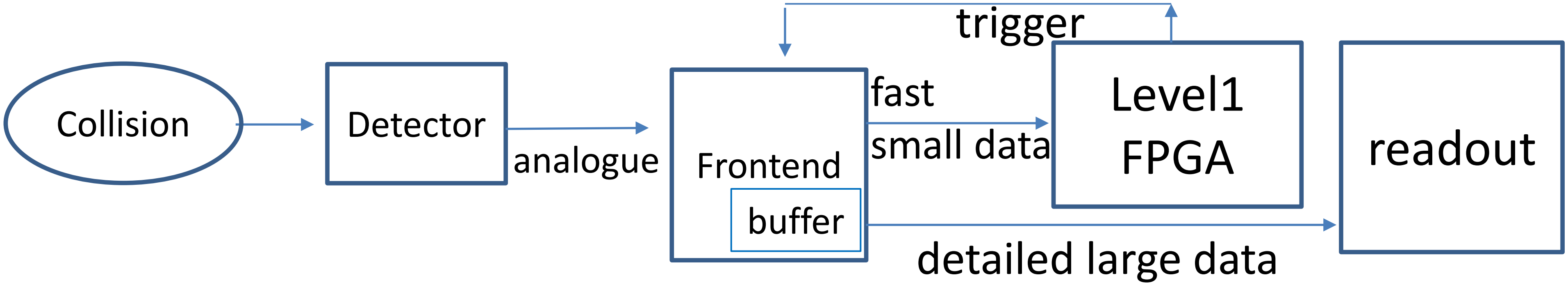
∝length of injection veto

Dead time = (dead time per injection) × (averaged injection rate)

-Injection veto causes the largest DAQ deadtime (2022ab: 5~15%)



Recent level1 trigger system

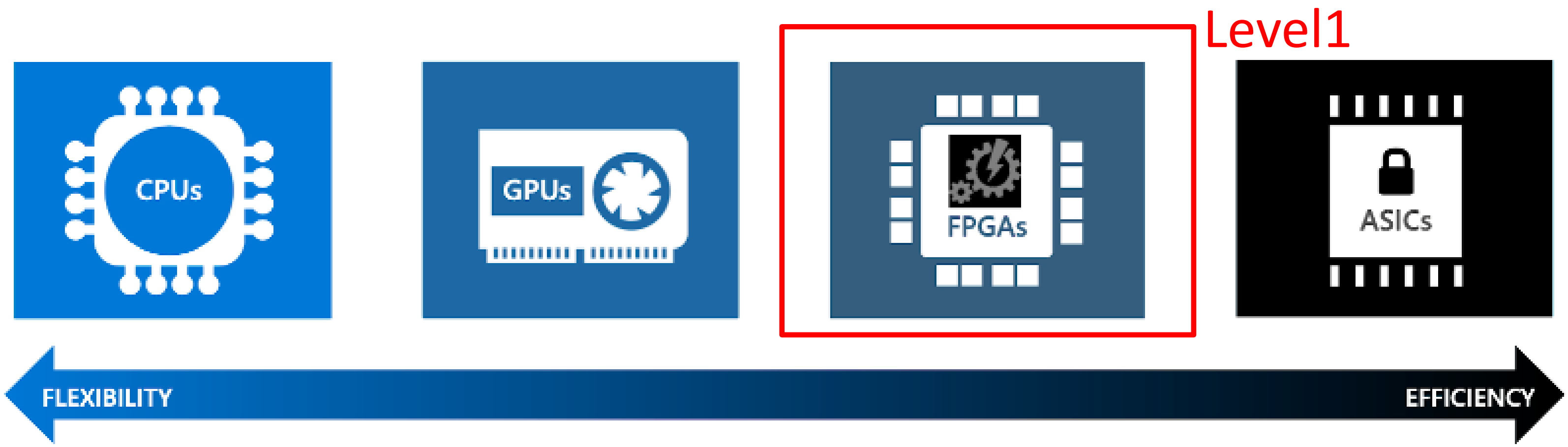


-Digitize detector signal on front end board. Multiple detectors provide trigger.

-Send the signal to the trigger system with pipeline(no dead time, every clock)

  -due to limited bandwidth of optical transceiver, detailed data not sent

-Decide to record the event with fixed latency of a few µs with FPGA.

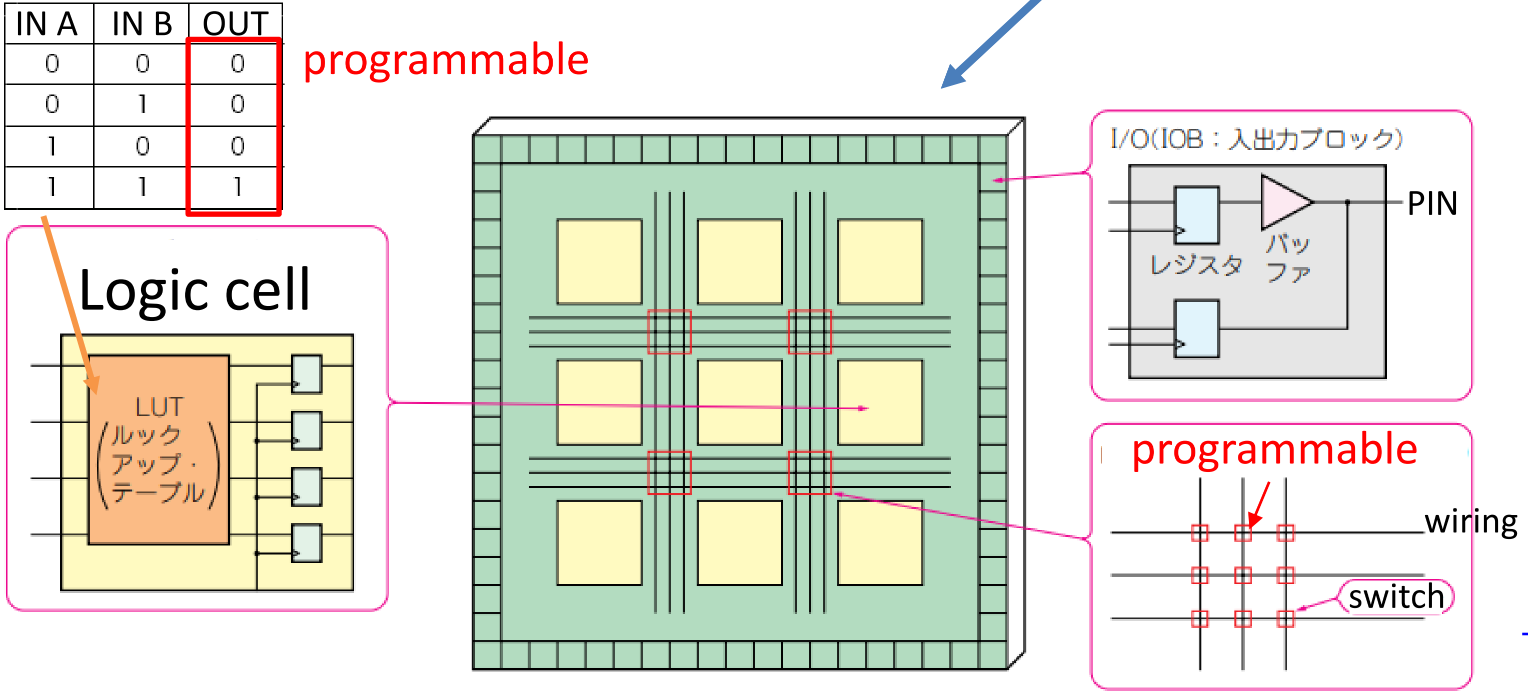


FPGA

-”Field Programmable Gate Arrays” are programmable integrated circuits
  -flexible modification of trigger logic, depends on operation condition or any issue

-Satisfy latency requirement for Level1 trigger
  -one digital calculation takes a few ~ a few tens ns
  -optical transmission takes ~a few hundread ns

-Programmed by hardware description language
  -VHDL, Verilog etc.



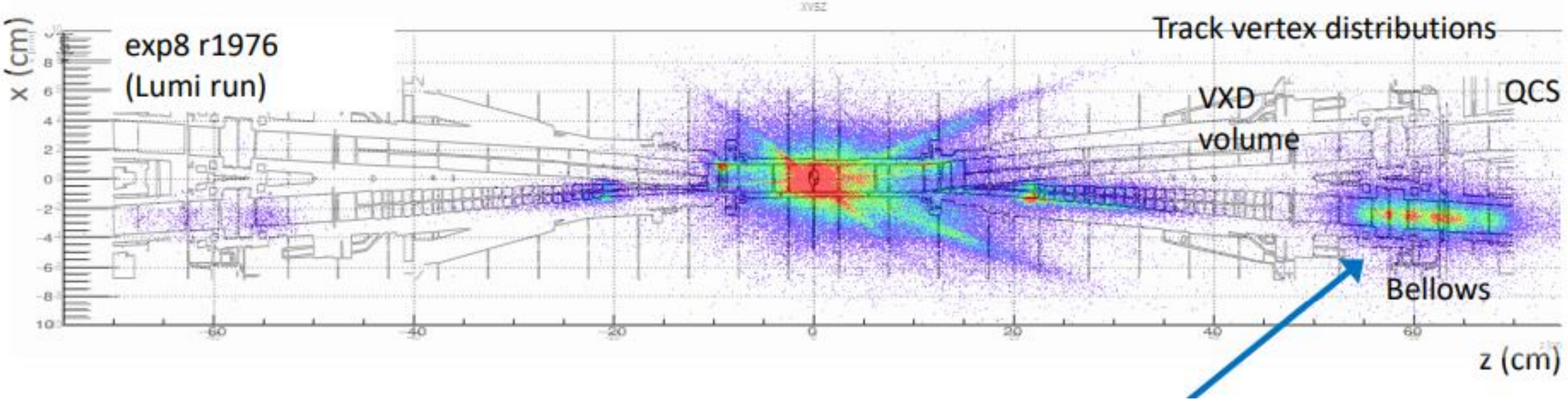
IN A	IN B	OUT
0	0	0
0	1	0
1	0	0
1	1	1

トラ技

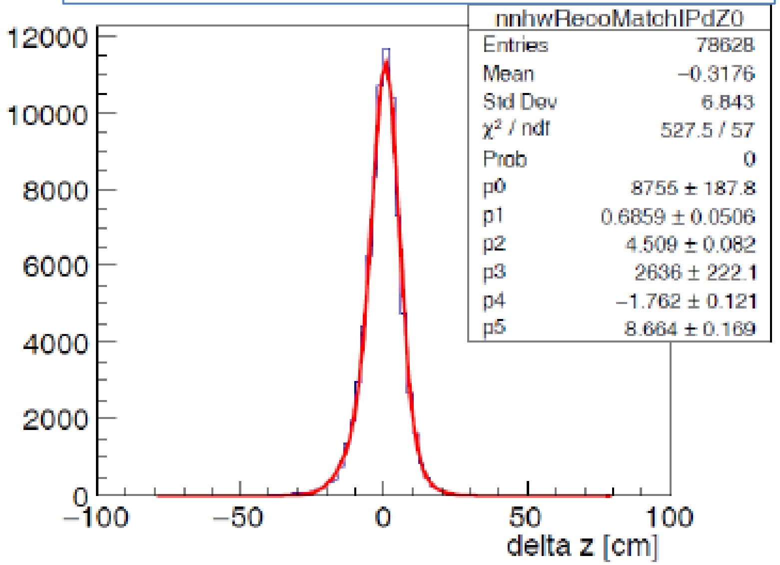
storage beam BG rejection with CDC trigger

-beamBG is coming from large Z vertex with low momentum

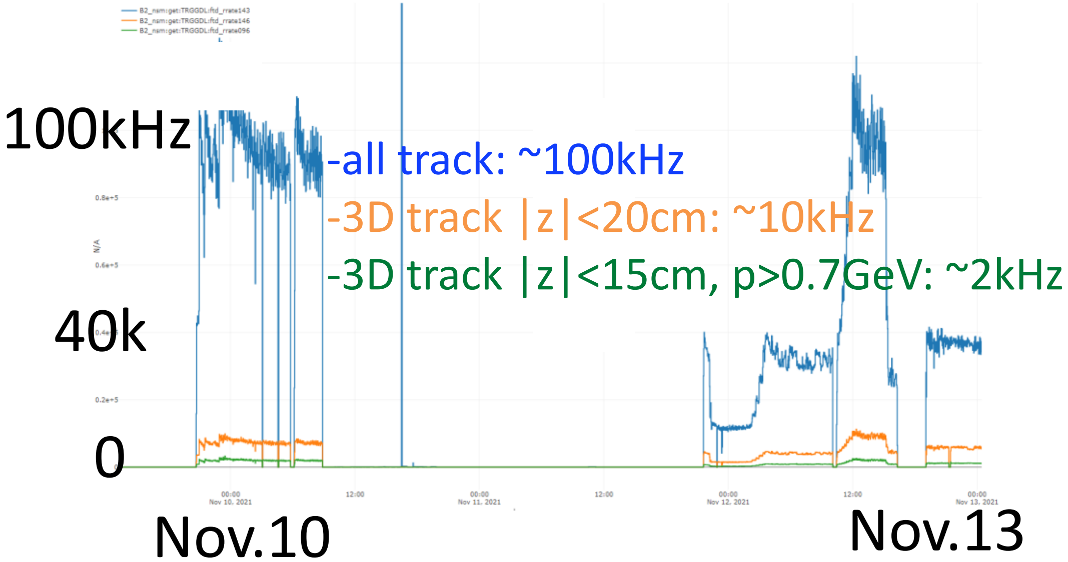
→ ~50times BG rejection by vertex and momentum cut



CDCTRG Z resolution at IP



CDC trigger rate 2021/11



CDC trigger: Track segment finder (TSF)

-Find bunch of wire hits (Track segment, TS) in each super layer

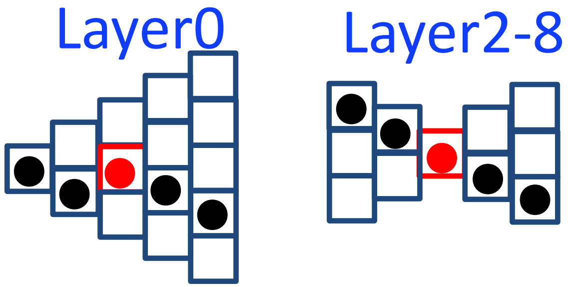
-TS is a minimum unit of CDC Trigger

-pt>~0.35 is required (low pt with large curvature does not form TS)

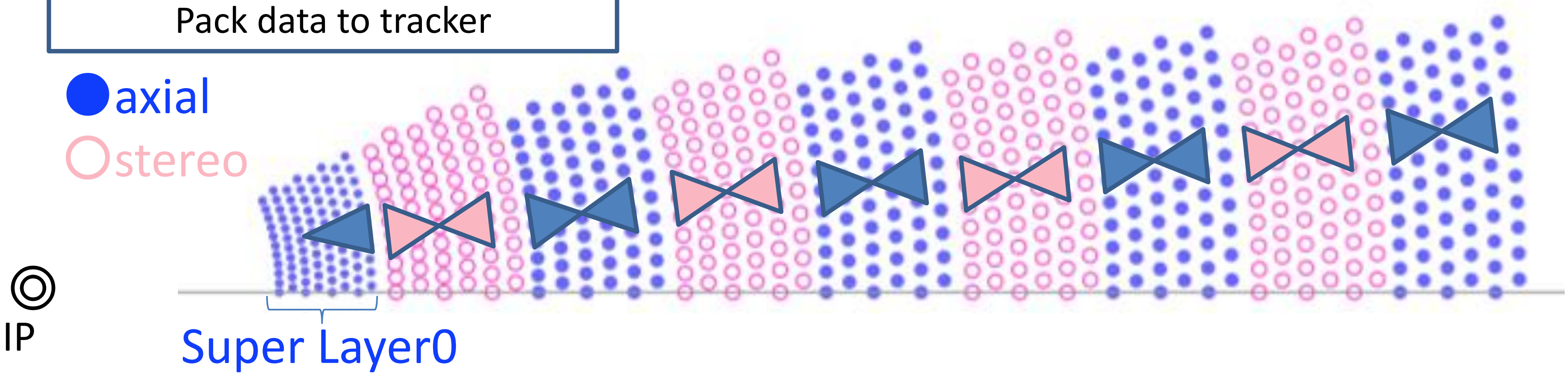
Unpack data from Merger
↓
Combine edge between mergers
↓
Persist signals
↓
Clustering
↓
Arrange cluster order
↓
Pack data to tracker

TSF clustering pattern

● CDC wire hit
☐ TSF
● hit with tdc

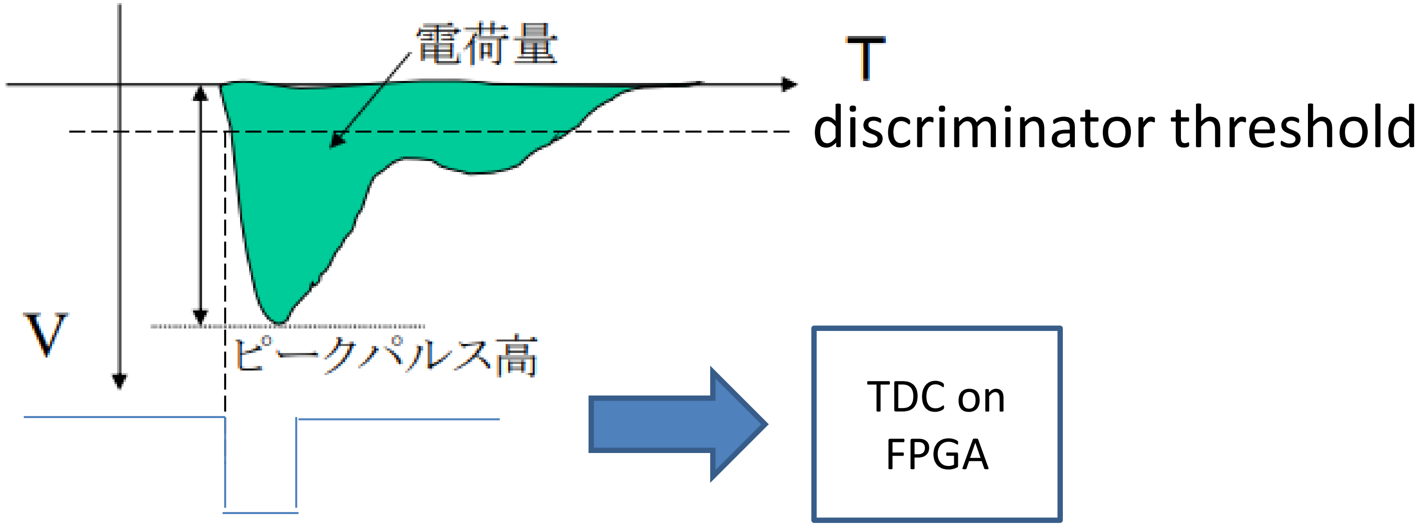


CDC wire structure



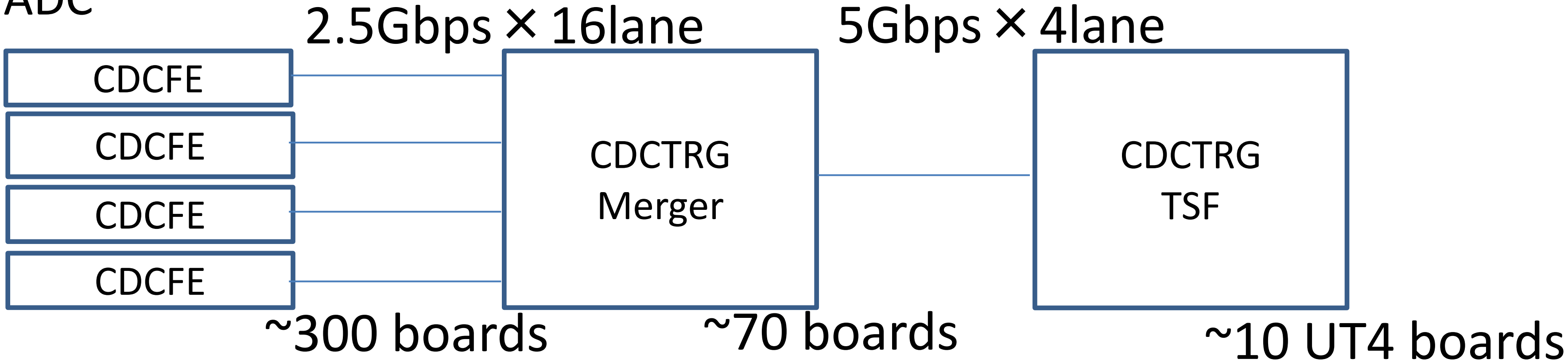
CDC trigger: CDCFE->CDCTRG

-digitize analogue signal on CDCFE



-Only part of information is sent to CDCTRG with every 32MHz

- -wire hit information (0 or 1): 80% of all wires
- -TDC (2ns precision): 15% of all wires
- -no ADC

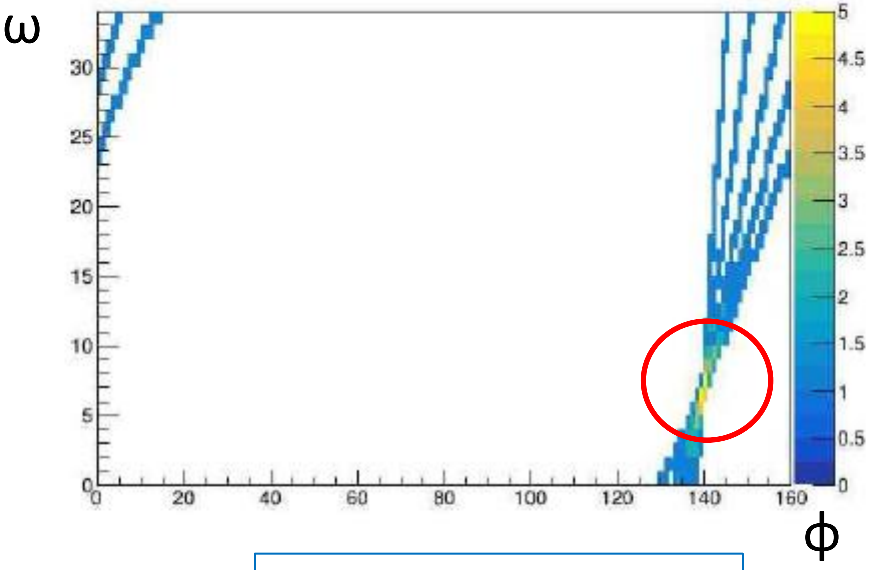


CDC trigger: 2D tracking

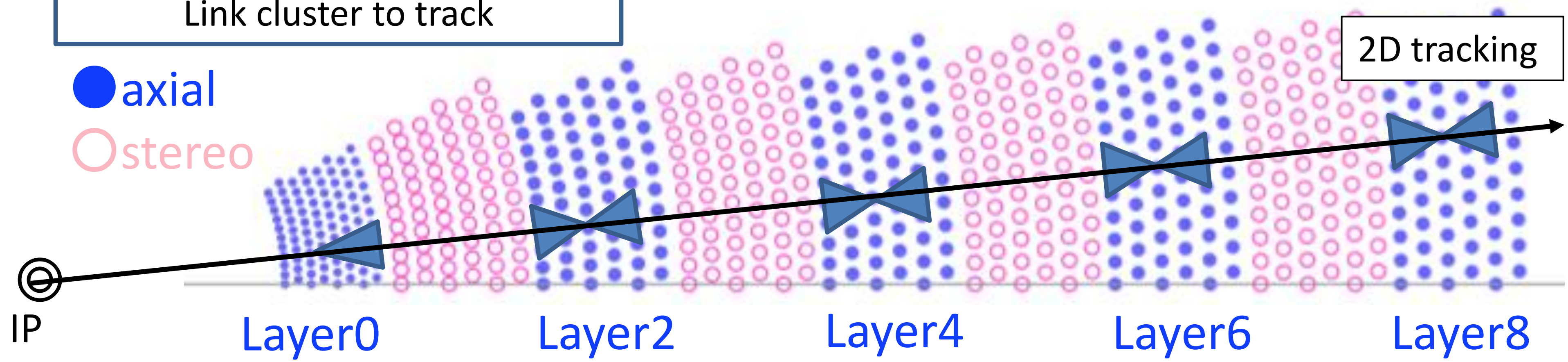
-Transform TS in axial layer to Hough plane (pt, ϕ) with curcle

-Find a peak to reconstruct 2D track

- Persist cluster input
- Hough voting
- Coincidence
- Hough clustering
- Track finding
- Link cluster to track



CDC wire structure



CDC trigger: 3D tracking

- -Neural net with 2D track and TS in stereo layers to measure z position
- -Training is done at offline with offline reconstructed track as teacher
- -Result of training is implemented to FPGA with LUT
- -|z|<15cm track selected

Persist cluster and track input

↓

Search stereo cluster

↓

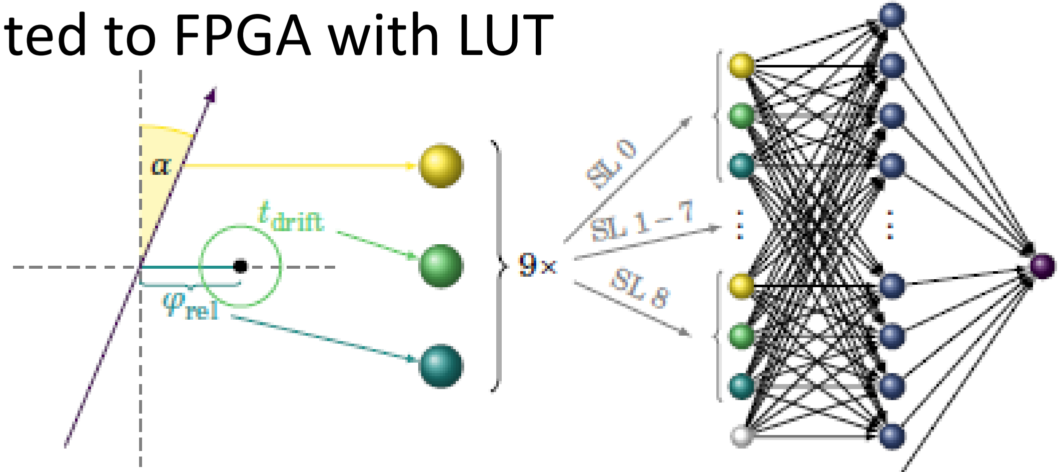
Prepare Neural net input

↓

Calculate NN nodes with LUT

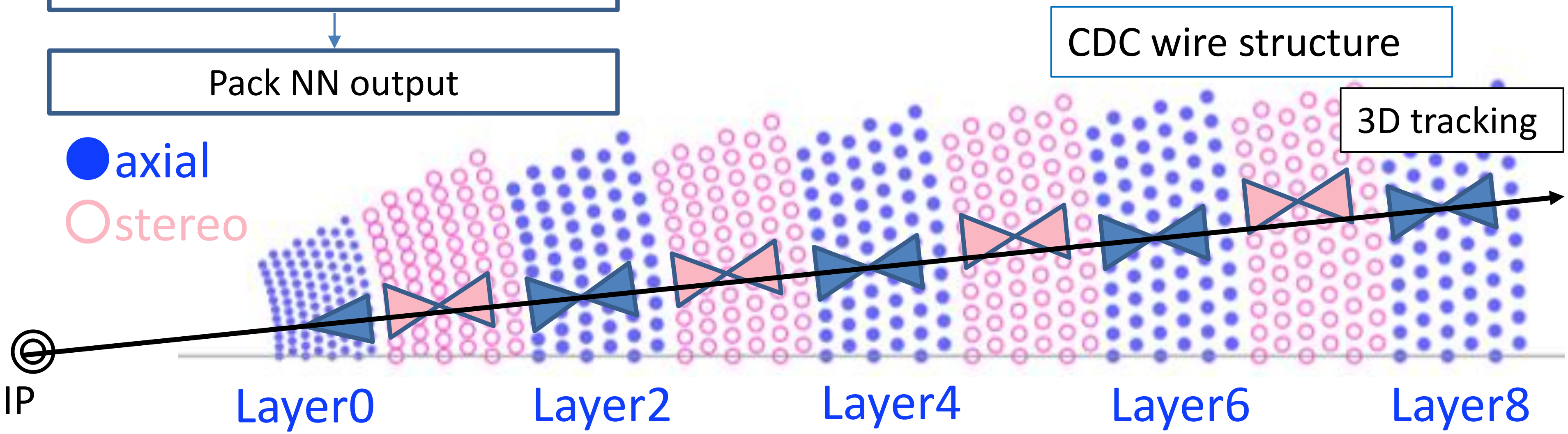
↓

Pack NN output



-input: event timing, wire TDC, α, ϕrel

-output: track z, θ



CDC trigger: inner track, short track

-Short/inner track is reconstructed with coincidence of 5/3 TSFs

  - -short: Look up table is made to search required ϕ pattern
  - -inner: just require three TSFs in ±4 wire in ϕ

-Not planned at BelleII but added since 2020

  - -**large θ acceptance** for low multi physics and two photon
  - **-no z measurement: high trigger rate**