Triggering at BelleII

2022/11/29

KEK Taichiro Koga

Self introduction

-Taichiro Koga

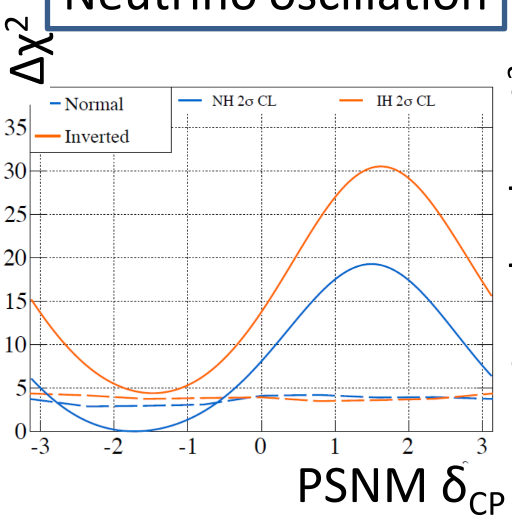
-2013-2018: T2K experiment
- -neutrino oscillation analysis
- -neutrino detector development

no trigger !

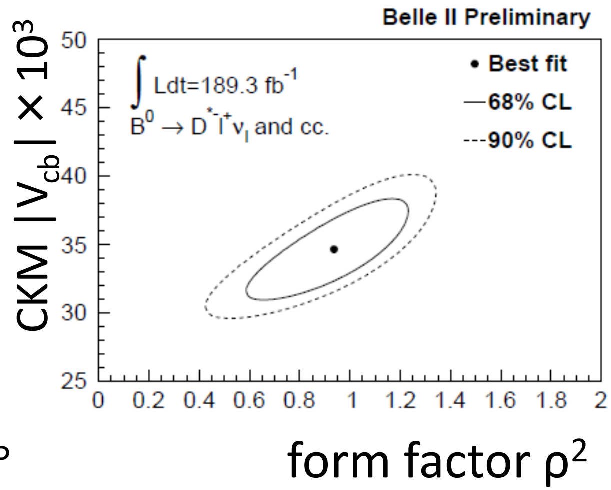
-2018-2022: BelleII
- -B semileptonic decay analysis
- -trigger system development

learned trigger after join BelleII !

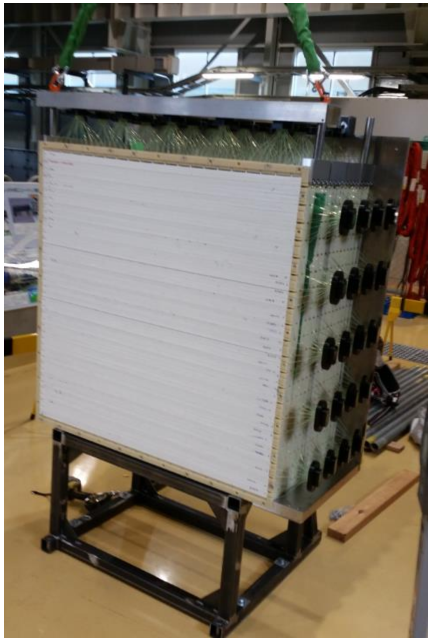
Neutrino oscillation



B semi-leptonic decay



neutrino detector



trigger system

Trigger?

-"Trigger" in dictionary

trig·ger[1] /ˈtrɪɡə $ -ər/ ●●○ AWL (also **trigger off**) verb [transitive]

1 to make something happen very quickly, especially a series of events

- The assassination triggered off a wave of rioting.
- Certain forms of mental illness can be triggered by food allergies.

trigger a memory (=make you suddenly remember something)

- His action **triggered** a massive **response** from the government.

▶ 詳細は シソーラスの 参照 **cause**

2 to make something such as a bomb or electrical system start to operate 類義語 **set off**

- The burglars fled after **triggering** the **alarm**.

-"Trigger" in particle physics (wikipedia)

-a **trigger** is a system that uses criteria to rapidly decide which events in a particle detector to keep when only a small fraction of the total can be recorded.

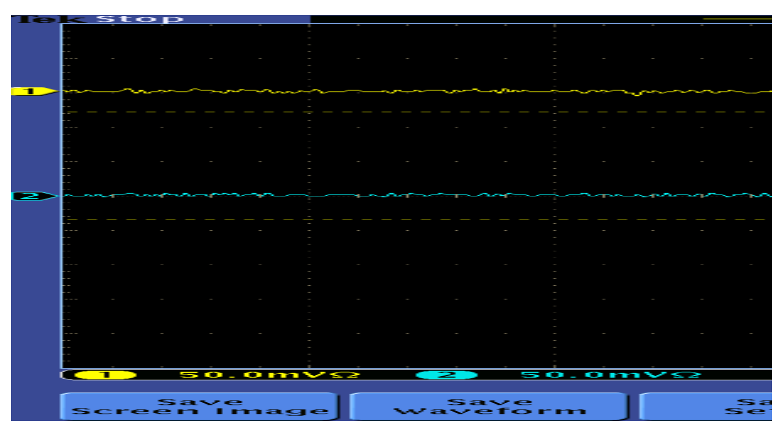
Example of cosmic trigger with scintillator

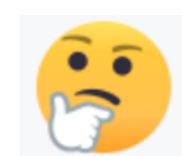
-Take cosmic muon with two scintilaltors and an oscilloscope

- -oscilloscope can record data with 1ms timing window
- -cosmic rate = 1Hz

-If we record waveform randomly by hand, we can not see cosmic signal

- -Expected cosmic signal per a record = 1ms × 1Hz= 10^{-3}
- -Most of data is garbage





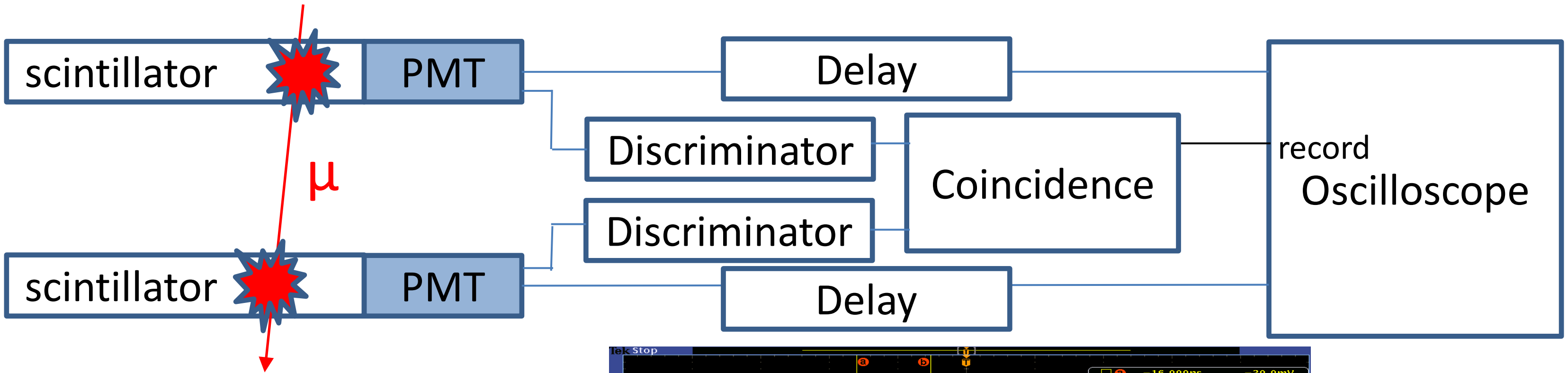
Example of cosmic trigger with scintillator

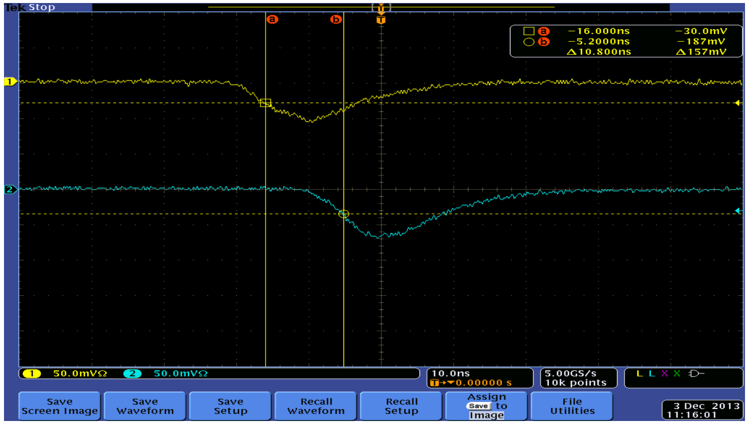
-Add cosmic trigger circuit to take coincidence of two scintillator signals

- -Discriminator: detect rising of analog signal.
- -Coincidence: take AND of digital signal.
- -Delay: delay analog signal.

-Now we can record the cosmic signal !

- -Most of data is interested signal





Example of cosmic trigger with scintillator

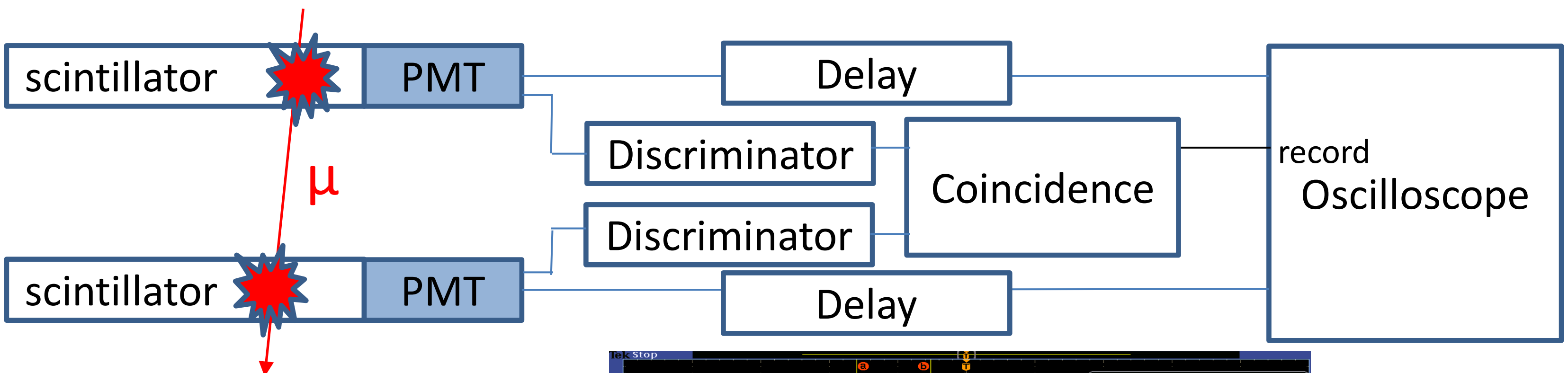
-Add cosmic trigger circuit to take coincidence of two scintillator signals

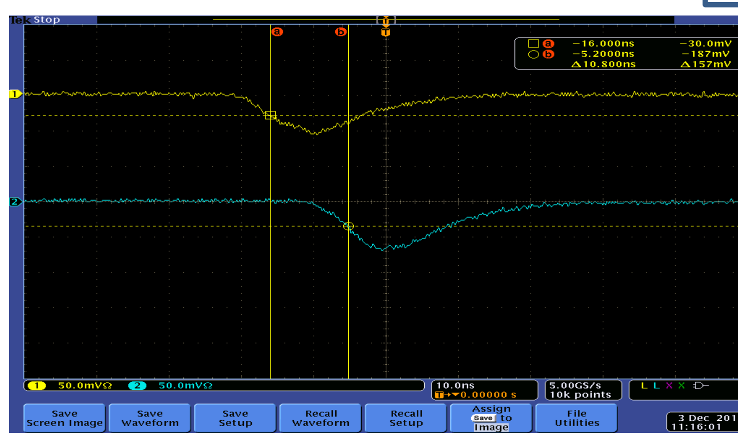
- -Discriminator: detect rising of analog signal. ← no deadtime digital conversion
- -Coincidence: take AND of digital signal. ← no deadtime digital calculation
- -Delay: delay analog signal. ← Signal buffer with fixed latency

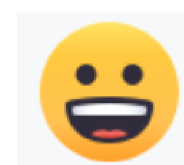
general trigger elements

-Now we can record the cosmic signal !

- -Most of data is interested signal ← Data size reduction







Necessity of trigger in real experiments

-If your experiment can record all of data, trigger not needed. It depends

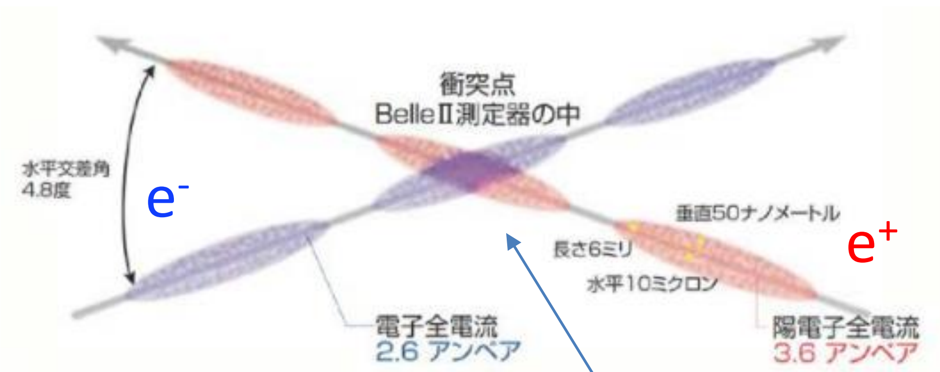
- -signal and background event rate
- -recorded data size per an event
- -budget

-Otherwise, trigger is needed. Example of BelleII:

- -beam crossing rate: ~250MHz, minimum 2ns interval
- -BelleII data size per an event: ~1MB
- -Trigger less data size per second: ~250MHz × ~1MB = ~250TB/s

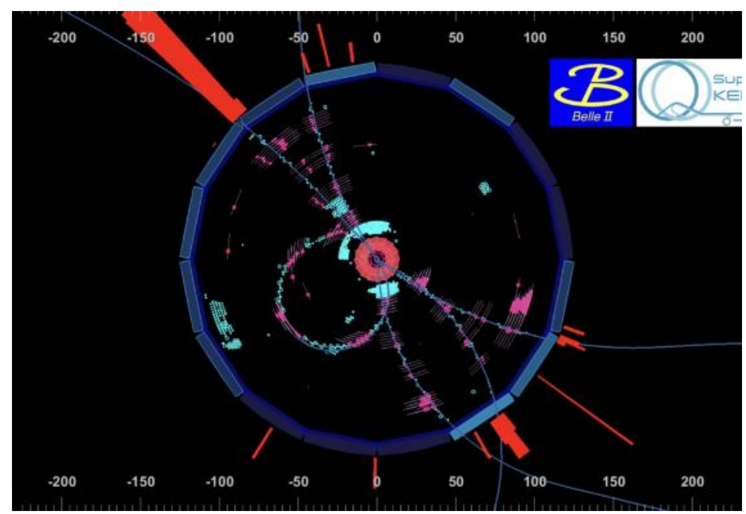
too large!→select events

e^+e^- beam



~250MHz collision

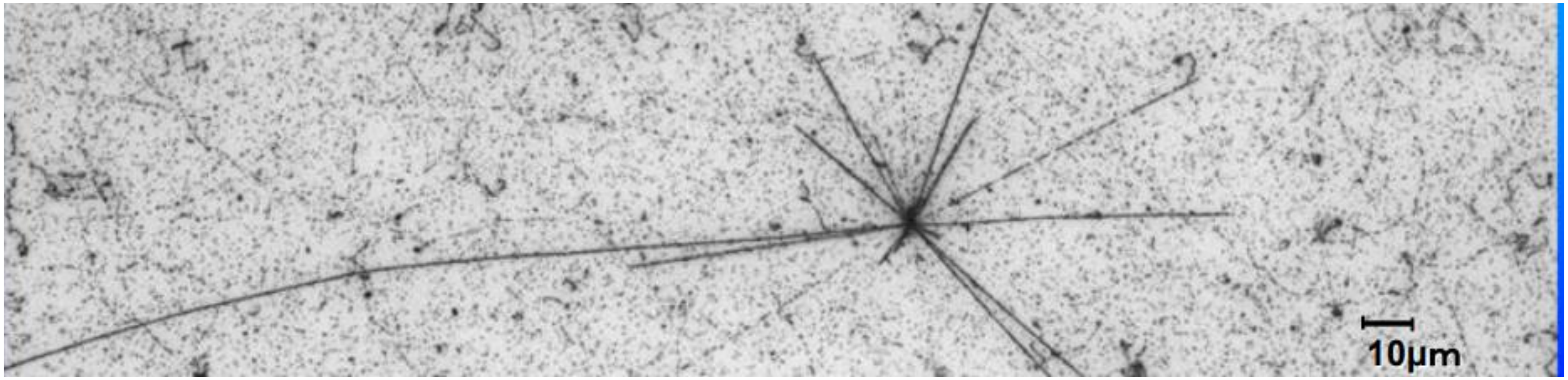
~1MB data size per an event

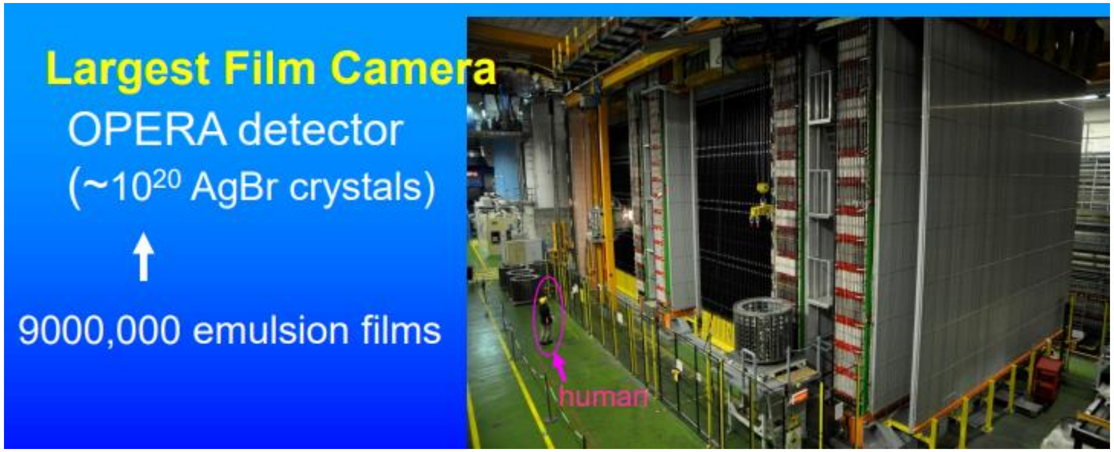


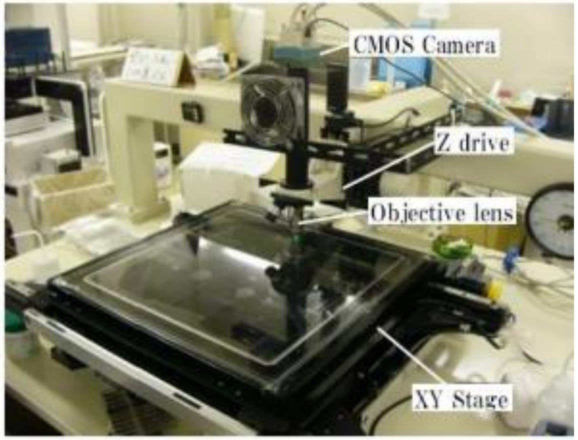
Trigger in various experiments: emulsion

-Emulsion: special photographic film with ultimate position resolution

- -Record trajectories of all charged particles passing through the film
- -Develop a photo and analysis with microscope
- -OPERA, NINJA, GRAINE experiments etc. recently.







NINJA

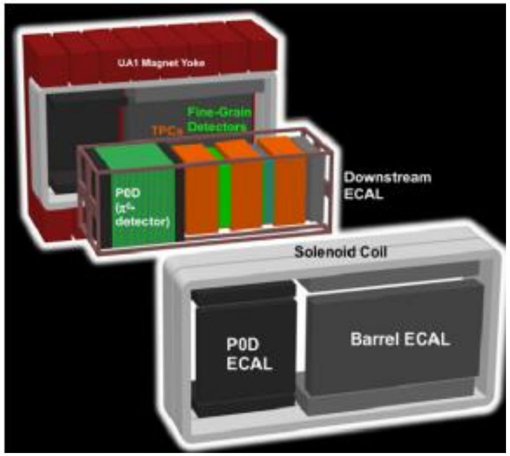
-Trigger is not needed at all for the emulsion

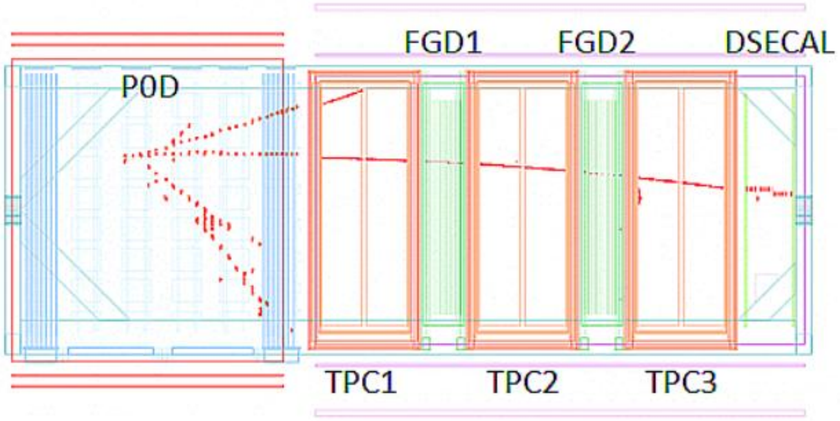
Trigger in various experiments: accelerator neutrino (T2K)

-T2K: long-base line accelerator neutrino experiment

- -beam rate: 8bunch/2.48s
- -data size at near detector: a few~10MB/s
- -near detector can record all data in each bunch

Low!→record all events





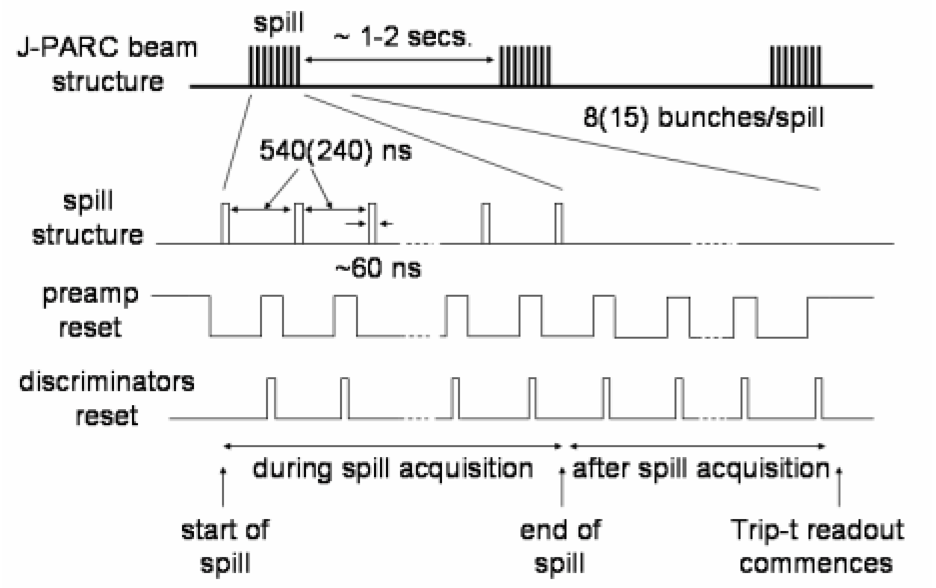


Fig. 7. T2K beam structure and corresponding Trip-t sequencing.

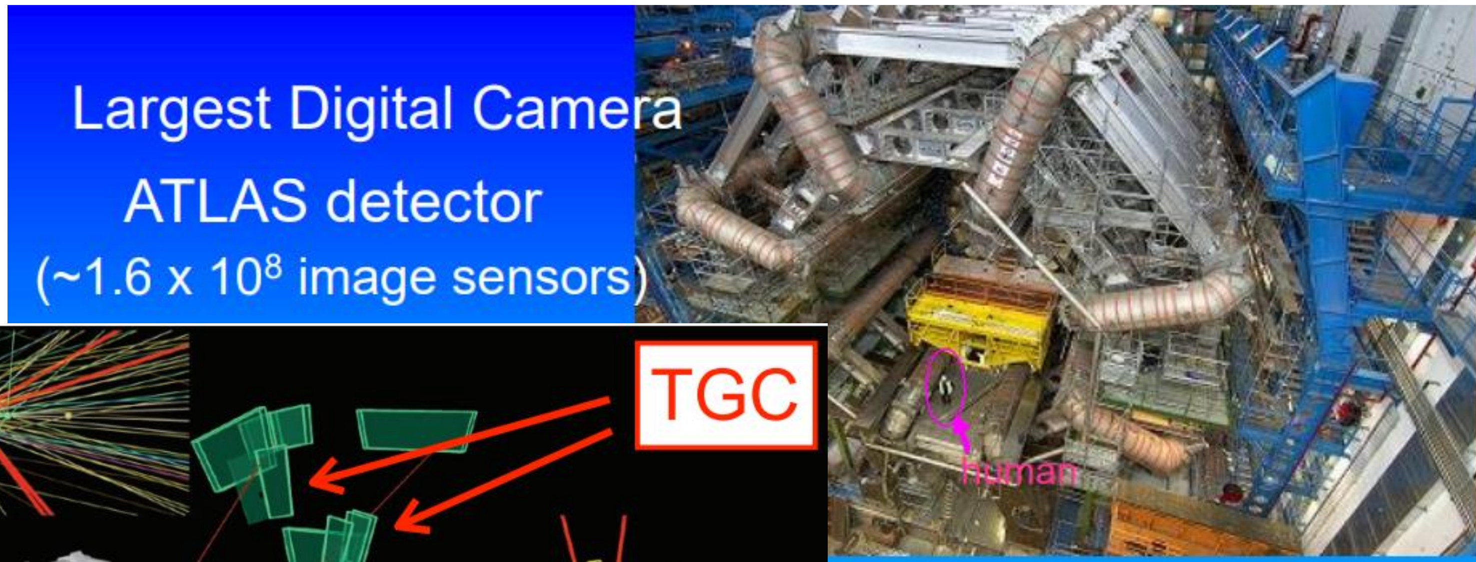
ND280 DAQ

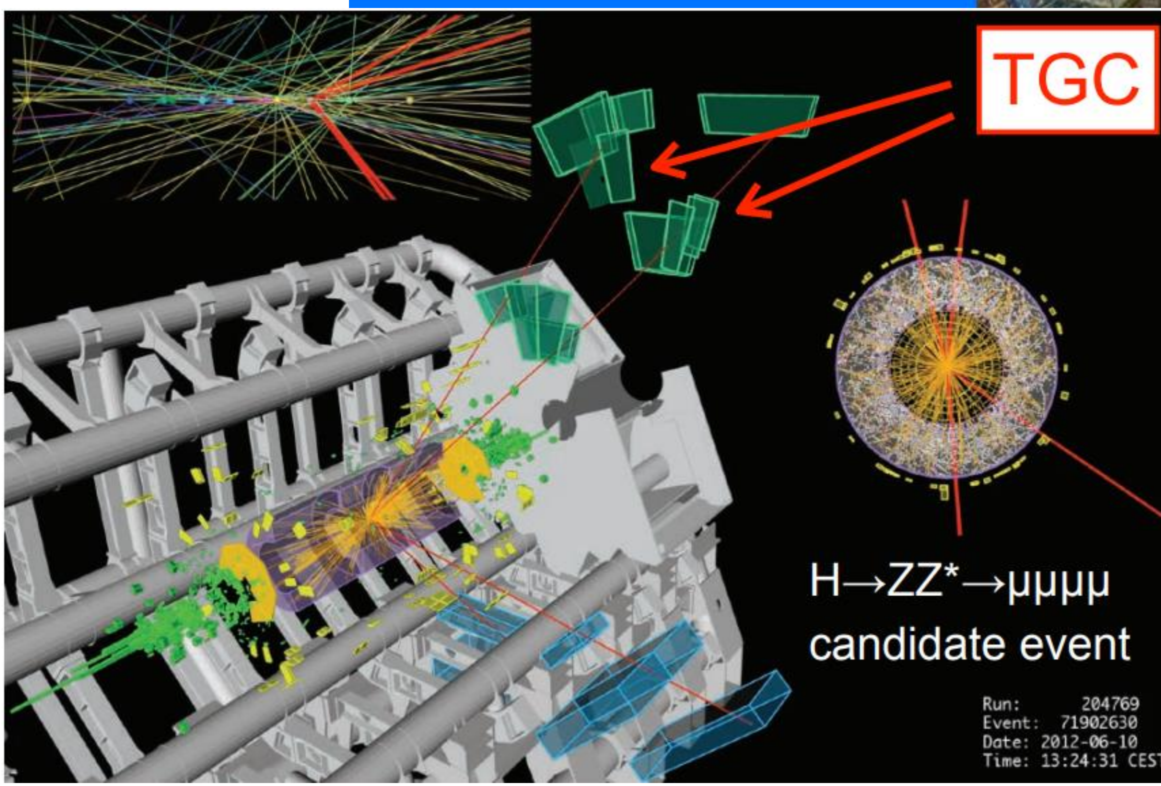
-Beam induced trigger is sufficient

Trigger in various experiments: collider

-Collider experiments

-More than MHz beam crossing rate with huge pileup and data size: need trigger



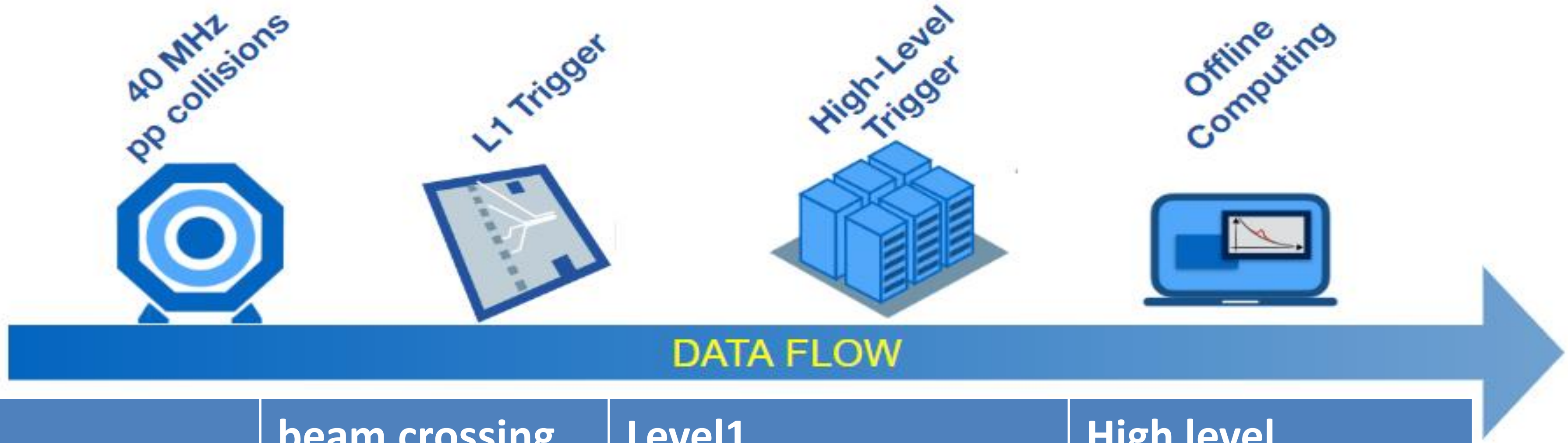


[kek electronics forum]

Trigger in various experiments: collider

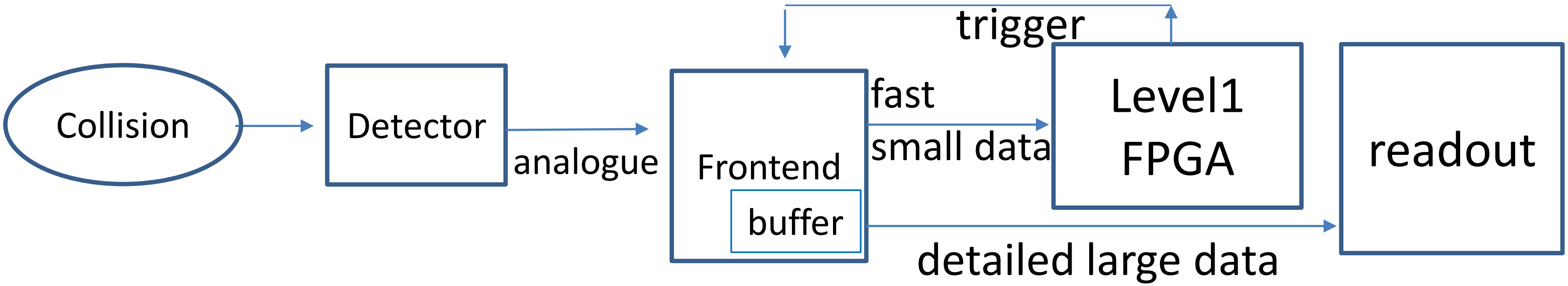
-Collider experiments
- -Level1(0) Trigger: Hardware (electric circuit)
- -High-level Trigger: Software (computer)

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

Recent level1 trigger system

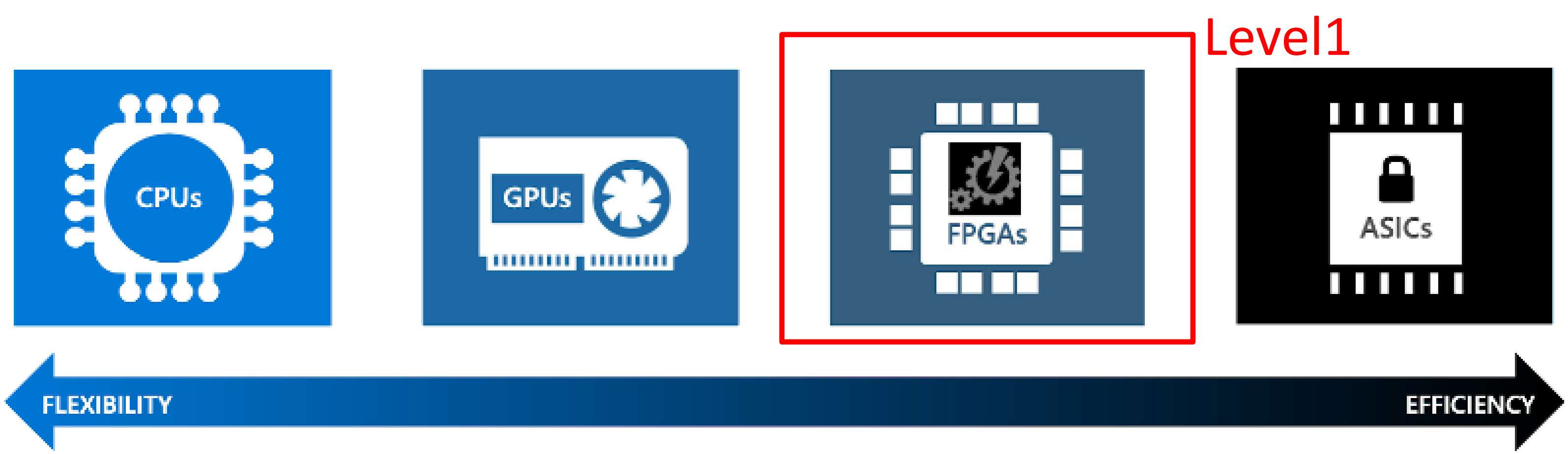


-Digitize detector signal on front end board. Multiple detectors provide trigger.

-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

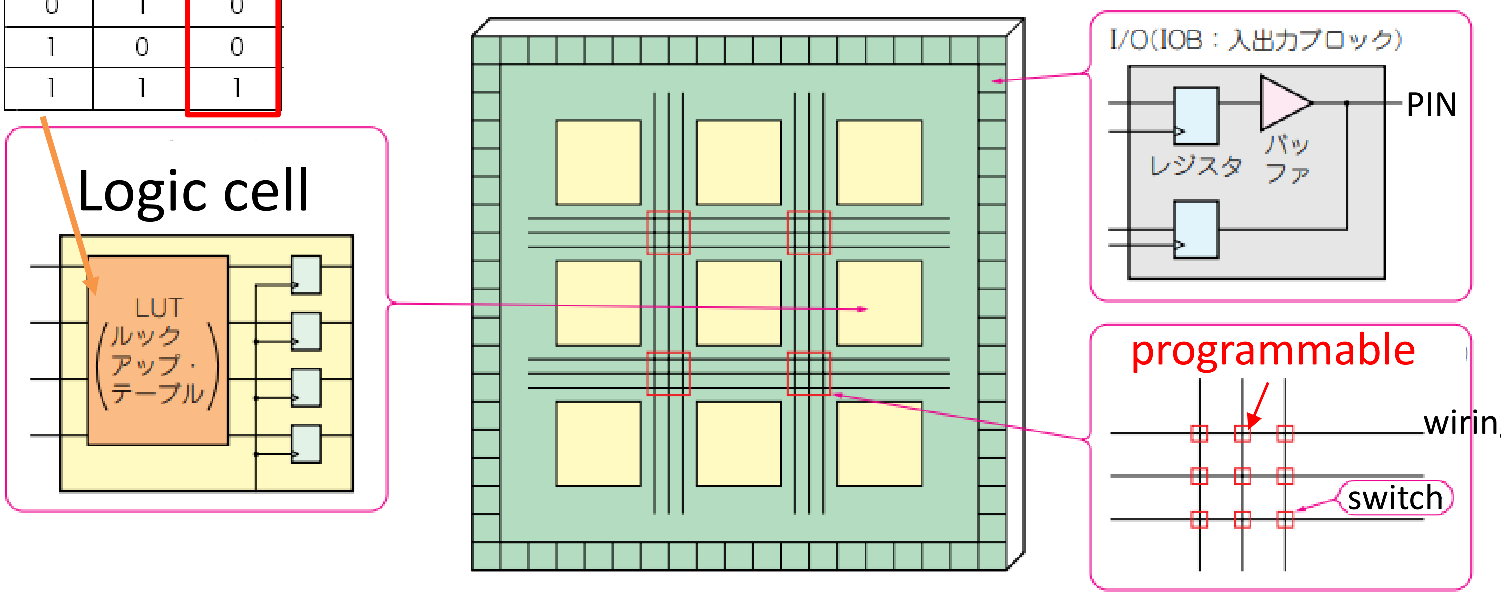
-"Field Programmable Gate Arrays" are programmable integrated circuits
  -flexible modification of trigger logic, depends on operation condition or any issue

-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

programmable



トラ技

BelleII trigger

e^+e^- collision

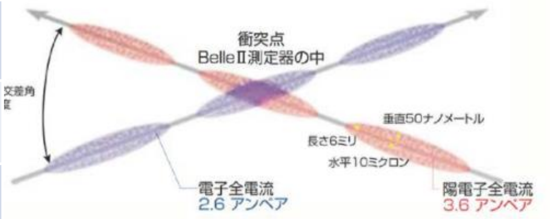
-What kind of phenomena happen at BelleII, how often ?

Process	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 ?	???

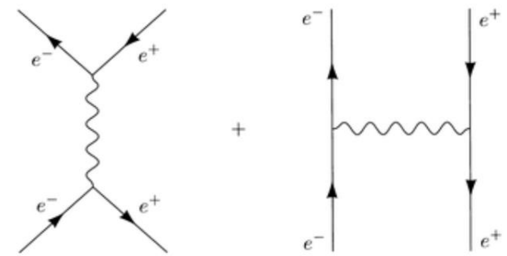
background >~300kHz

Physics target ~15kHz

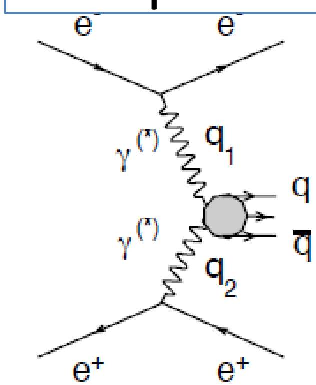
e^+e^- beam



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 luminosity than Belle

- -maximum trigger rate is increased accordingly
- -latency is increased 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

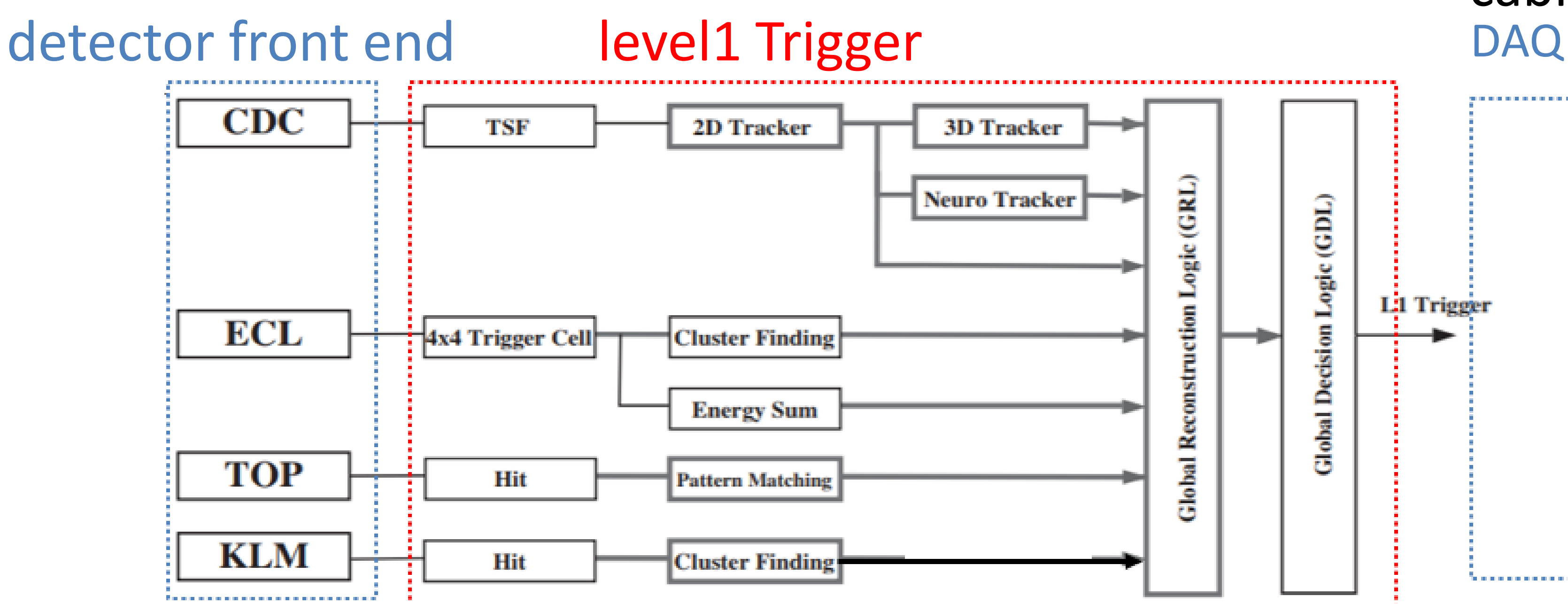
-CDC, ECL: main triggers for charged particles and gamma

-KLM: trigger muon

-TOP: measure event T0 timing

□: board

—: cable



-Basic of BelleII trigger system is the same as Belle. Major changes:

- -FPGA for all logic: flexible changes
- -Large resource of FPGA(10~100times): compact system and high level logic
- -Optical transceiver with high bandwidth(10~100times): rich information

Universal Trigger board

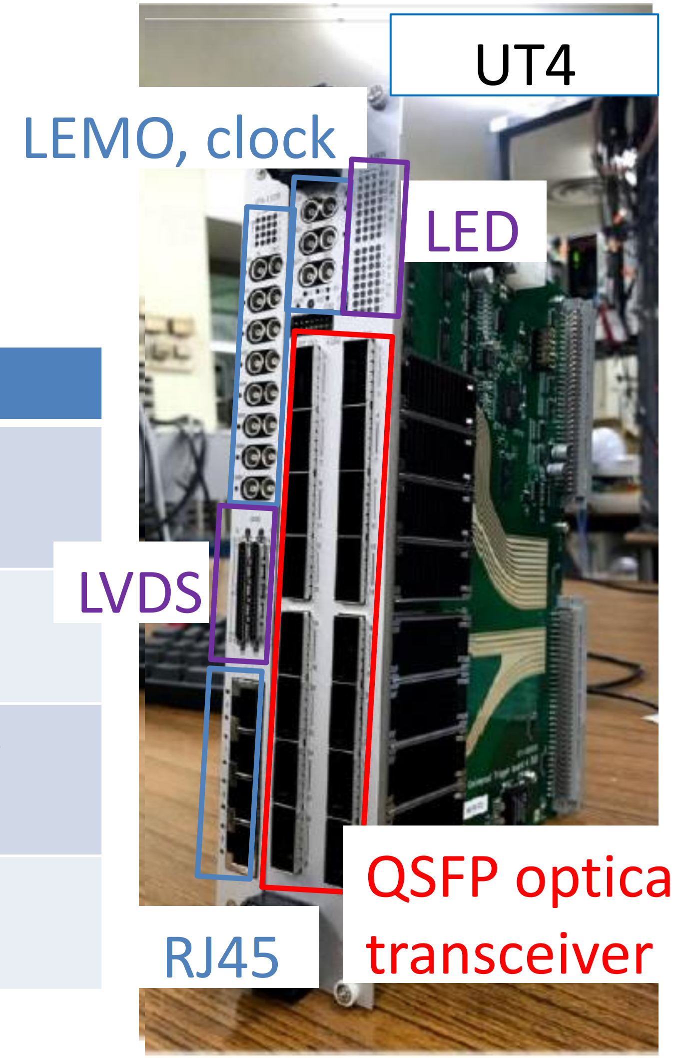
-Main board used by different subtriggers commonly

-Large IO with optical transceiver

-Large FPGA resource

-IO: RJ45, LVDS, LEMO, LED, Jtag, VME 6U

-127MHz system clock



History of UT development

Name	Year	Main FPGA	Main IO
UT (test)	2006	Spartan3	LVDS 448ch
UT2 (test)	2008	Virtex5 LX220T	GTP 3.1Gbps × 16lane
UT3	2011	Virtex6 HX380T,565T	GTX 6.2Gbps × 40lane GTH 11Gbps × 24lane
UT4	2018	Virtex Ultrascale XCVU080/160	GTH 16Gbps × 32lane GTY 25Gbps × 32lane

-~3000000 JPY/board, ~30 boards are used

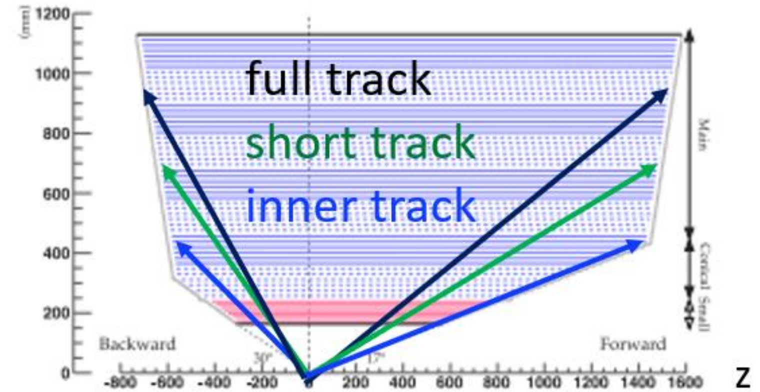
-In addition, sub trigger dependent merger board are used

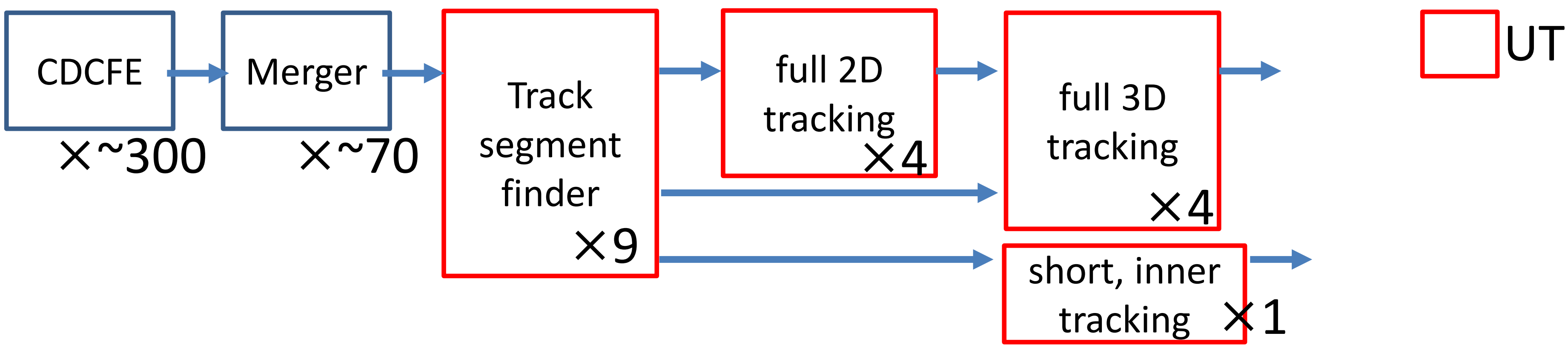
CDC Trigger

-Trigger charged particles

-Three kind of tracking with θ:

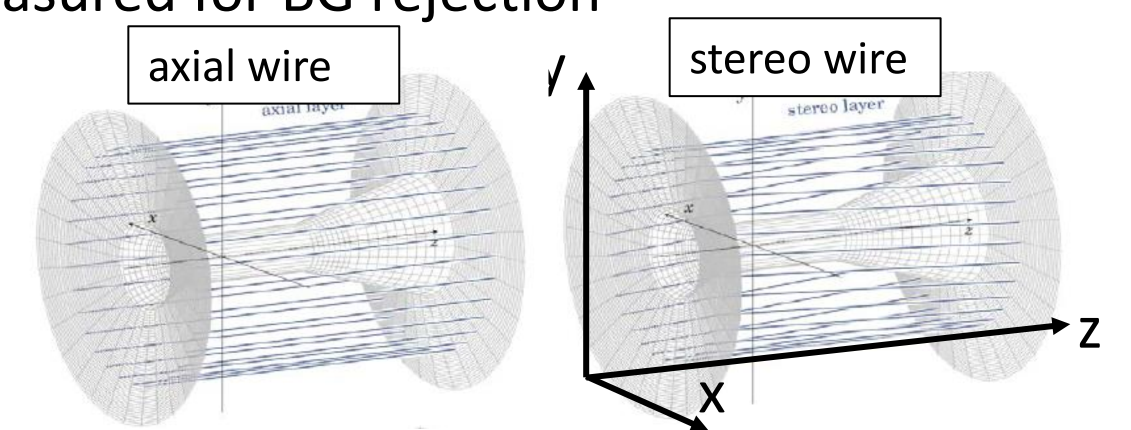
-full track (f,y)
-short track (s)
-inner track (i)





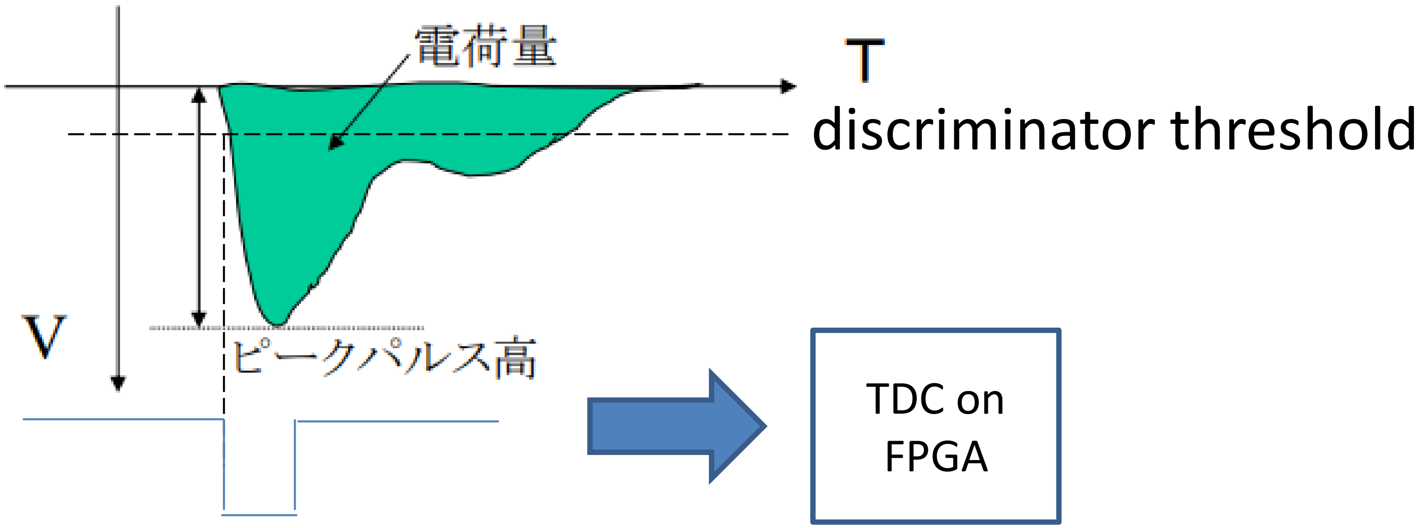
-For full track, z position is measured for BG rejection

-3D tracking is needed with axial and stereo wire



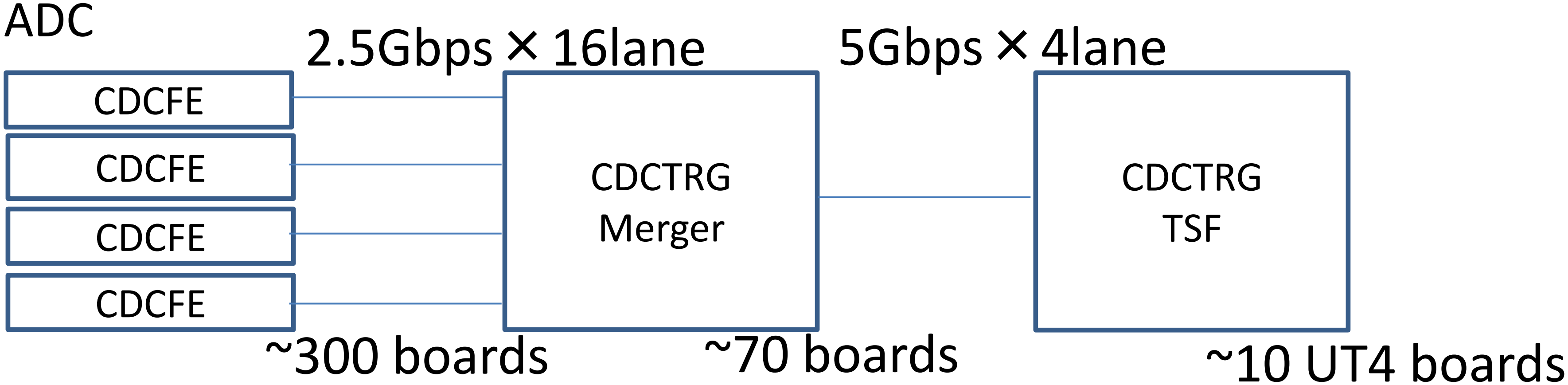
CDC trigger: CDCFE->CDCTRG

-digitize analogue signal on CDCFE



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

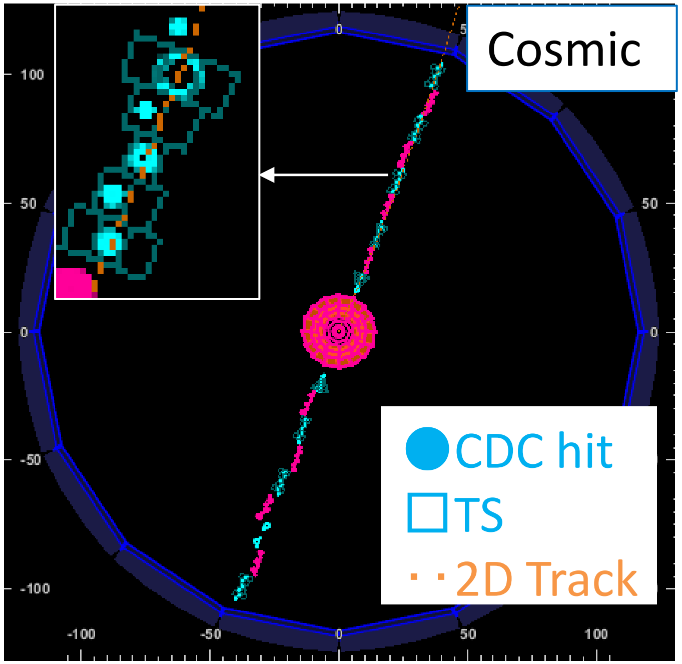
- -wire hit information (0 or 1): 80% of all wires
- -TDC (2ns precision): 15% of all wires
- -no ADC

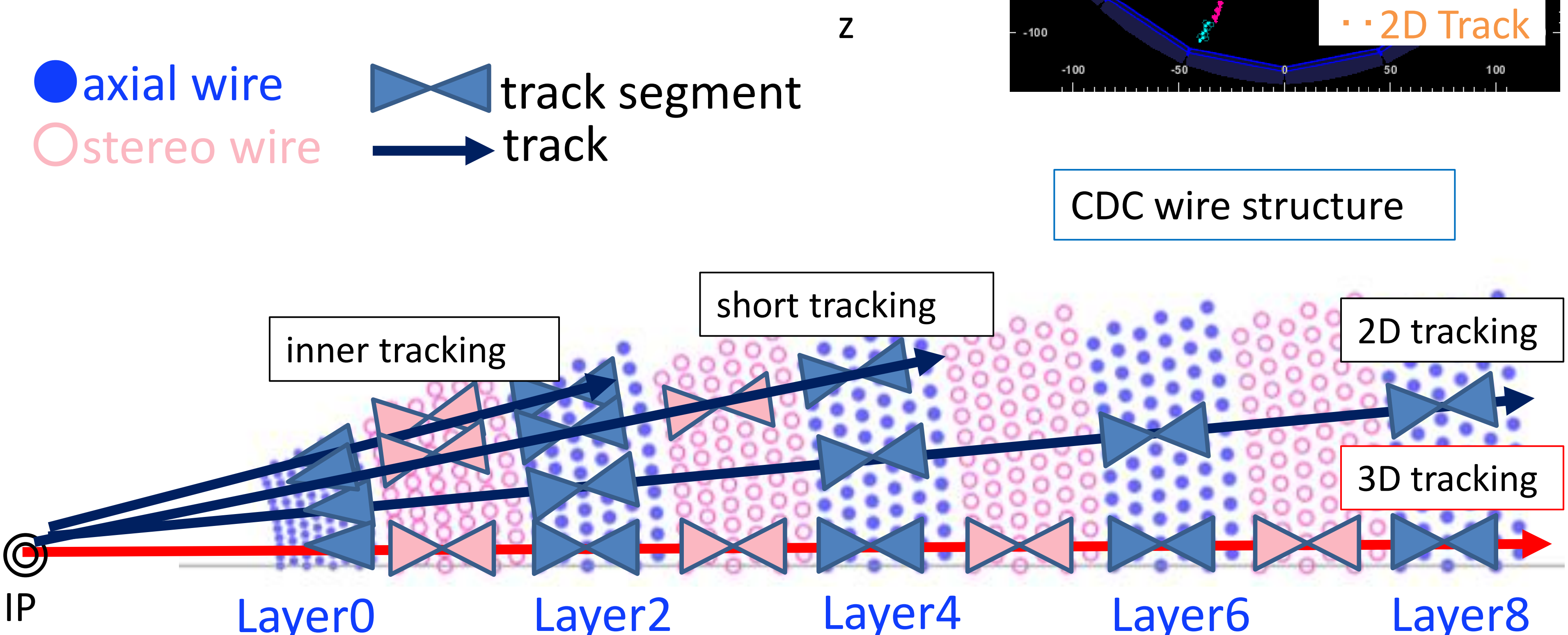


CDC trigger

-Measure ϕ, p, vertex of charged particles

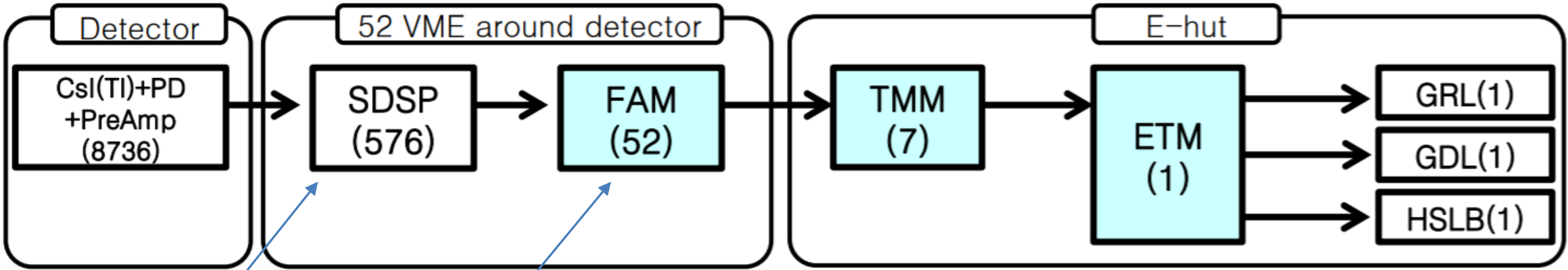
- -track segment finder ← minimum unit
- -2D Hough transfer (2D full tracking)
- -Machine learning (3D full track with z)
- -Pattern matching (short, inner track without z)





ECL trigger

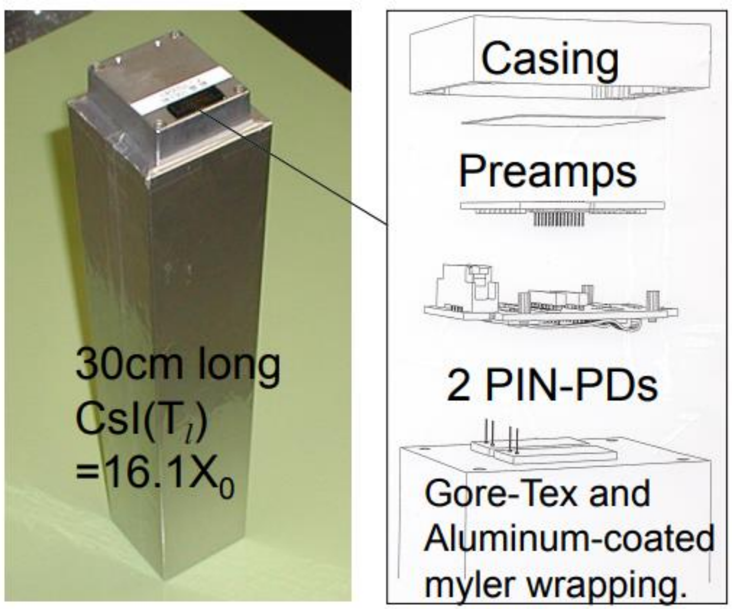
ECLTRG logic



Degitization, waveform fit

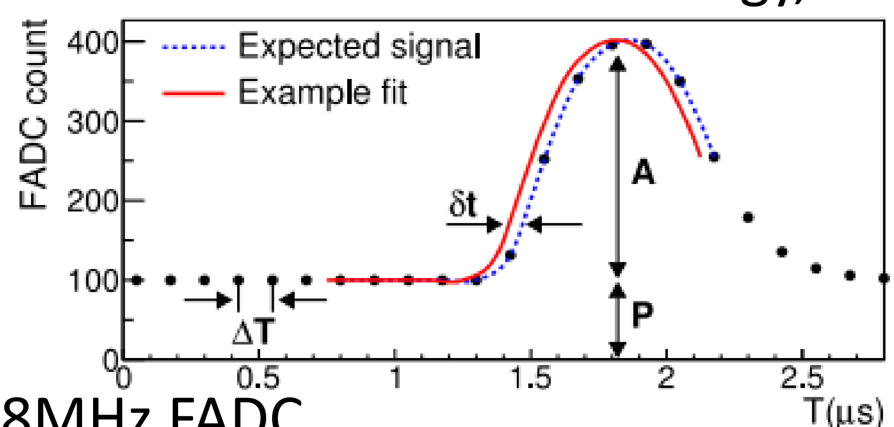
Analogue sum of 16(4x4) crystals

8736 CsI -> 546TC



-Take analog sum of 16 crystals
(Trigger cell, TC. 22cm × 22cm × 30cm.
cluster shape information is lost.)

-Waveform fit to estimate energy, timing

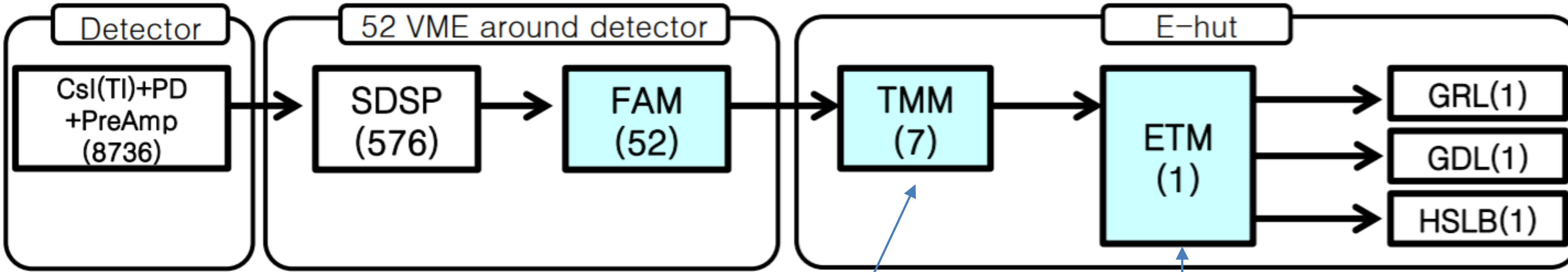


8MHz FADC

200ns shaper

ECL trigger

ECLTRG logic



merger

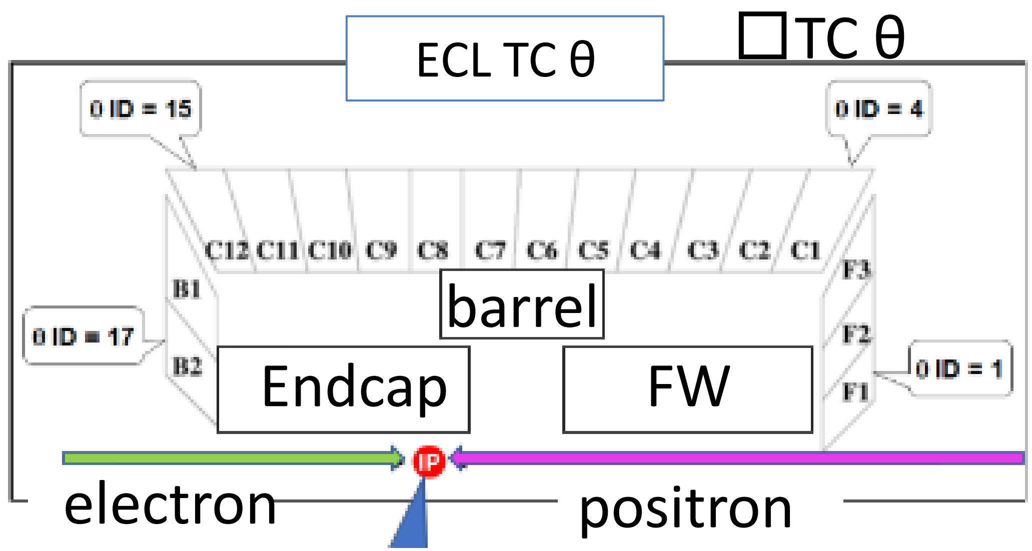
Clustering and
ECL trigger decision

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

-Combine next TCs as a cluster

-if two TCs are combined, 22cm × 44cm × 30cm size. Big.

-Finally measure cluster energy, timing and position.
>100MeV required to clusters.

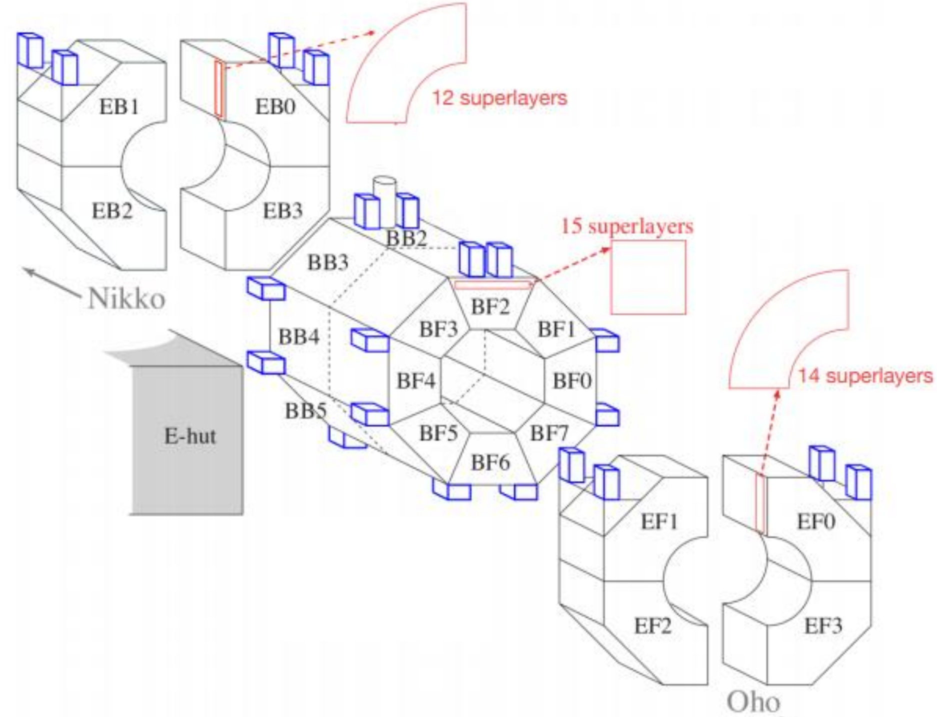


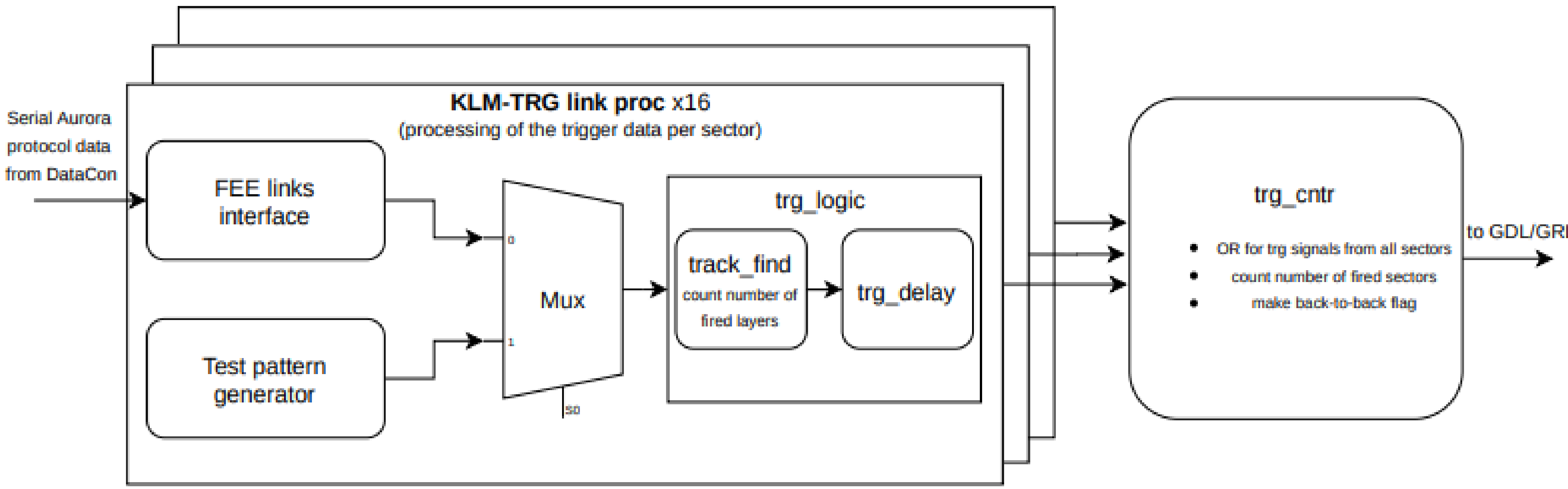
KLM Trigger

-Search muon in each sector

-Simply count number of hits:
 if #hit>7, it is judged as muon

-Tracking development is on-going





Output from subtriggers

-Following information is sent from subtriggers to GRL/GDL

-CDCTRG:
 -kind of track, ϕ, pt (z and θ for 3D track in addition) of all tracks
 -event timing
 ※number of full track is 12 at maximum

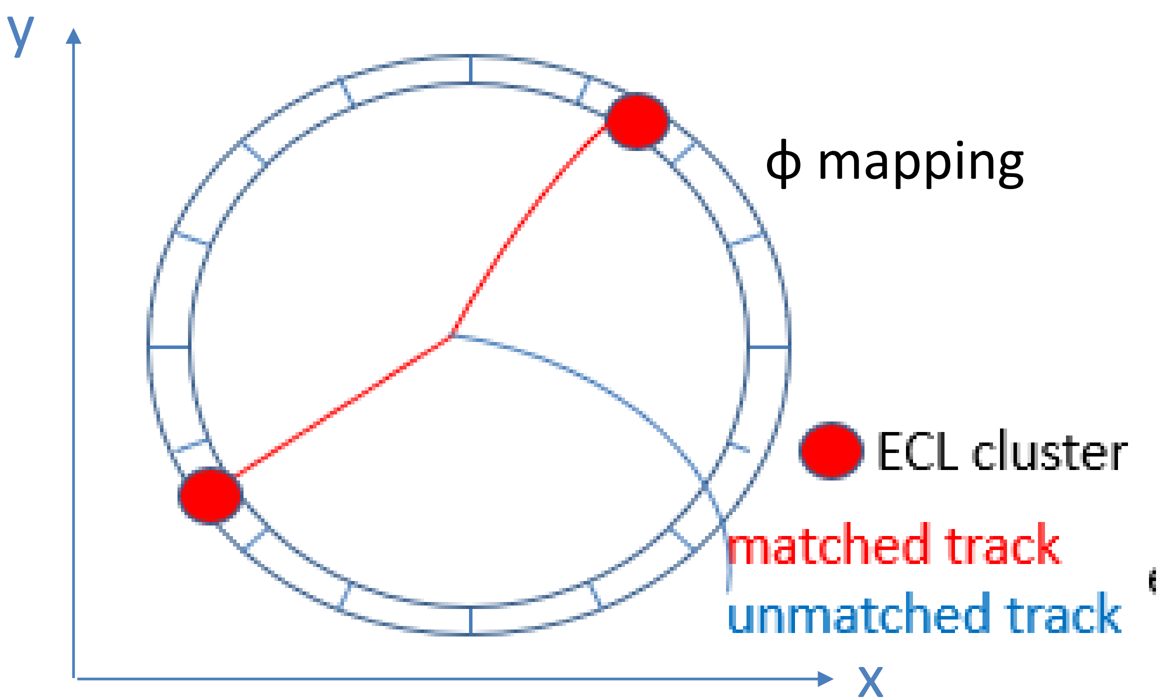
-ECLTRG:
 -energy, position of all clusters
 -event timing
 ※number of clusters is 6 at maximum

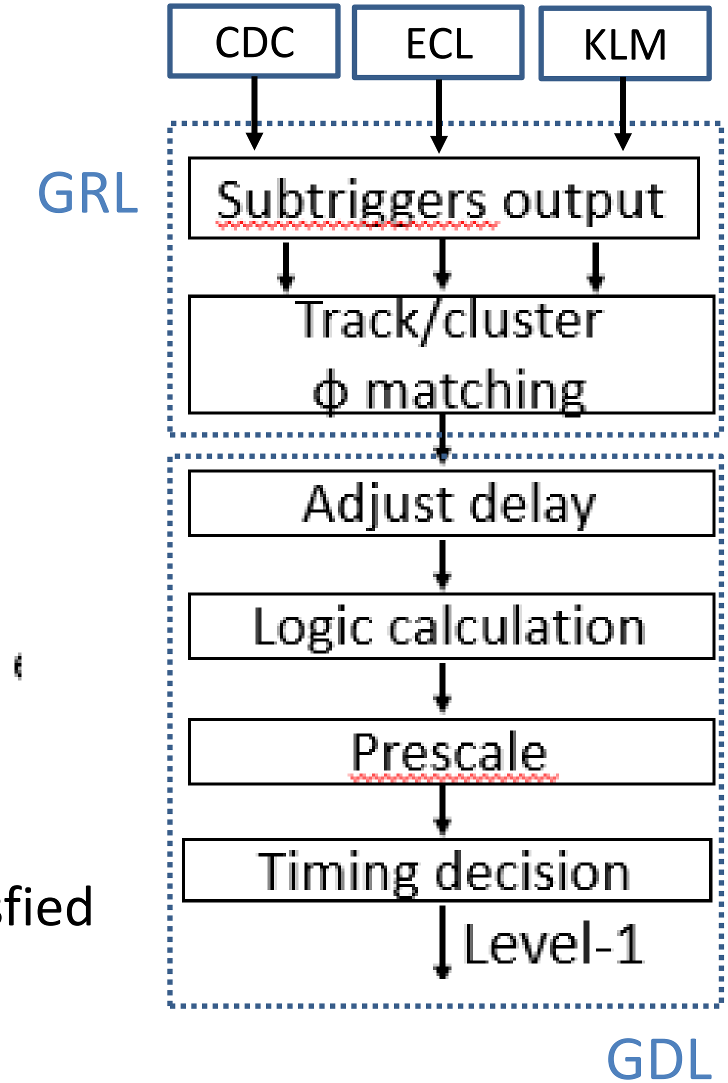
-KLMTRG:
 -sector position of all muon candidates

GRL/GDL

-GRL: Global reconstruction logic

-take ϕ matching of CDC/ECL/KLM/TOP





-GDL: Global decision logic

-calculate if trigger condition (output bit) is satisfied or not with subtrigger input

-apply prescale

-If one of trigger bit satisfied, provide Level1 signal to take data

List of output bit and rate 2022b

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

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

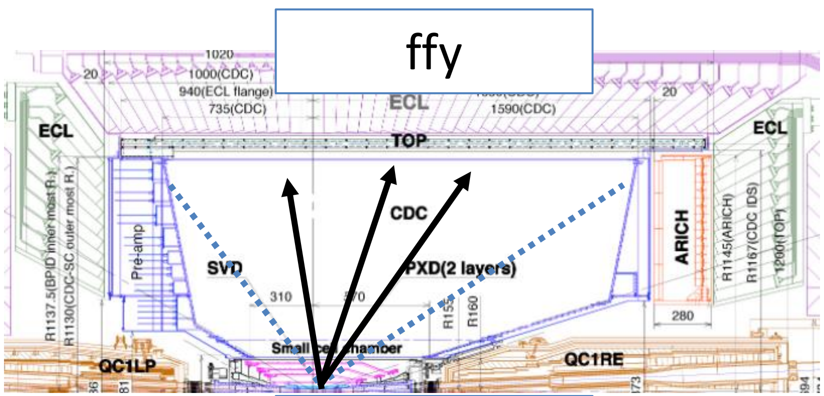
Category	Bit name and condition	Raw rate (kHz)	Exclusive rate (kHz)
CDC ~~B physics~~ standard bits	**ffy**: #full track>=3, |z|<20cm **fyo**: #full track>=2, Δϕ>90deg, |z|<20cm	2.18 1.77	2.18 0.73
ECL ~~B physics~~ standard bits	**c4**: #cluster>=4 **hie**: Energy sum>1GeV	0.47 2.02	0.26 1.54
Subtotal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

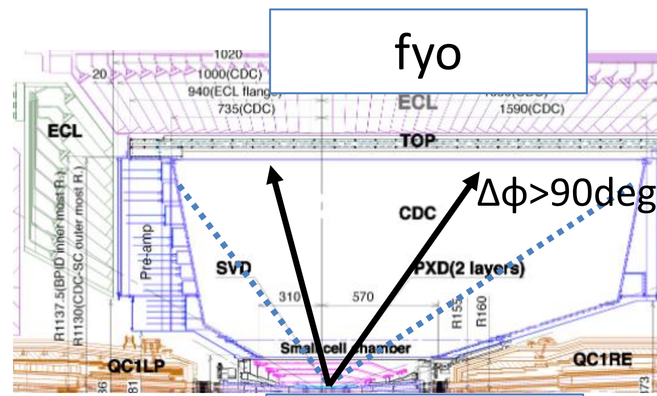
List of output bits: B physics

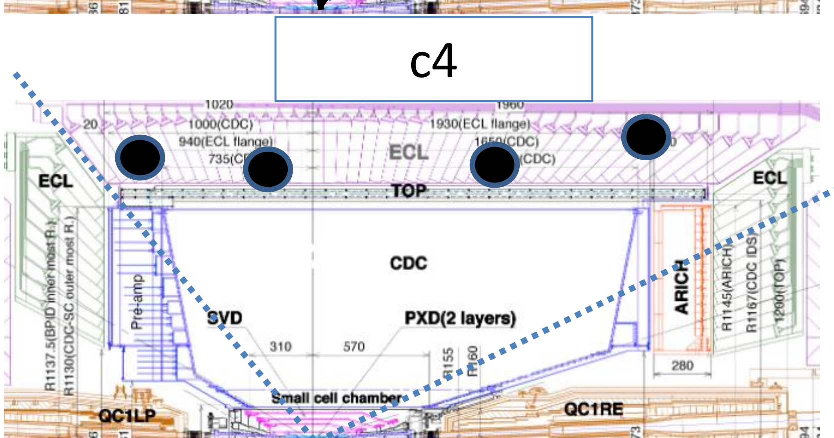
-Traditional condition same as Belle

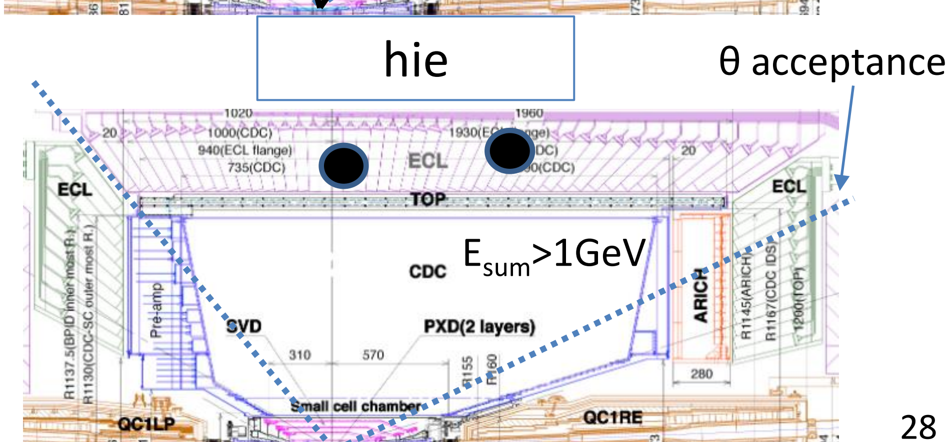
2021c

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, 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		



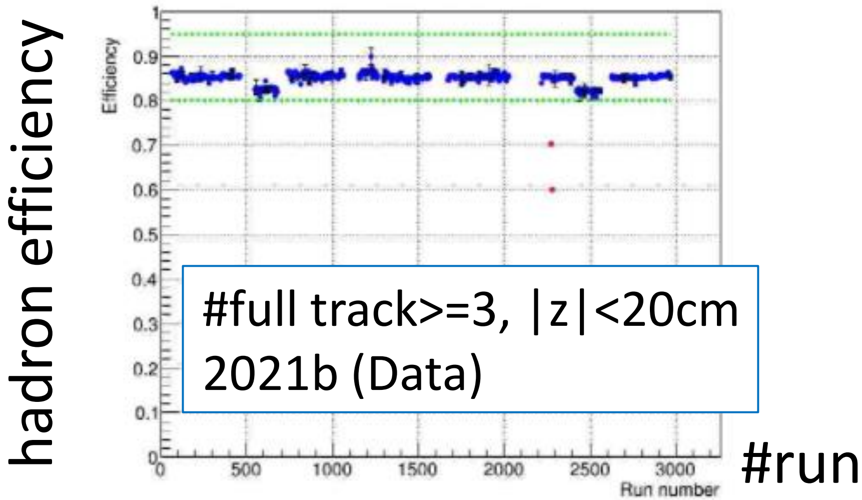


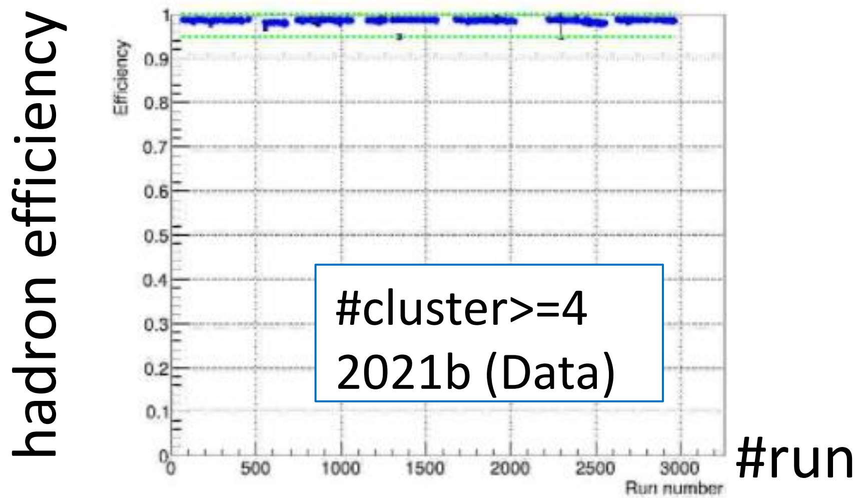




BB efficiency performance

->99% efficiency for BB pair





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

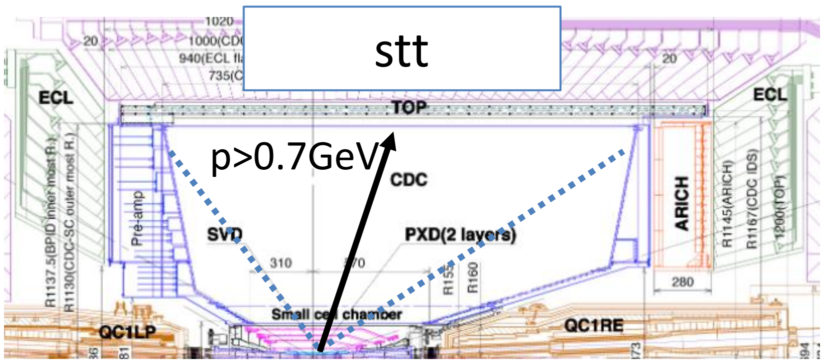
BitName	eff(%)
lml0	81.02
lml1	0.94
lml2	0.03
lml3	0
lml4	0.01
lml5	0
lml6	1.82
lml7	0.02
lml8	12.12
lml9	27.82
lml10	30.16
lml12	0
lml13	0

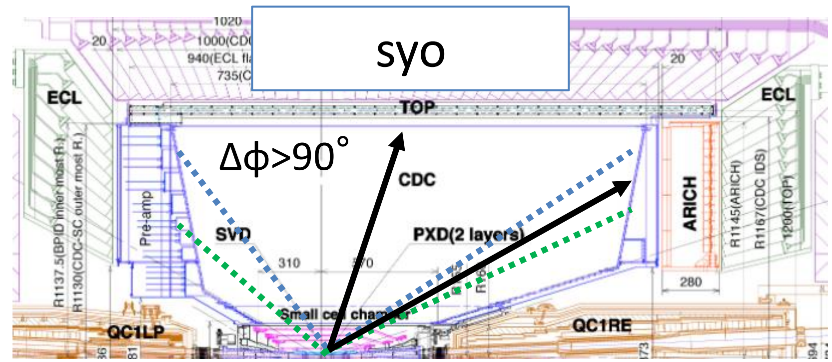
List of output bits: τ

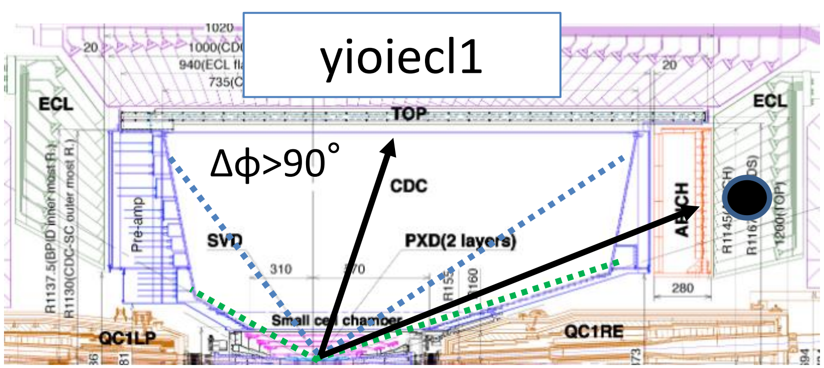
-CDC-KLM, ECL-KLM matching trigger

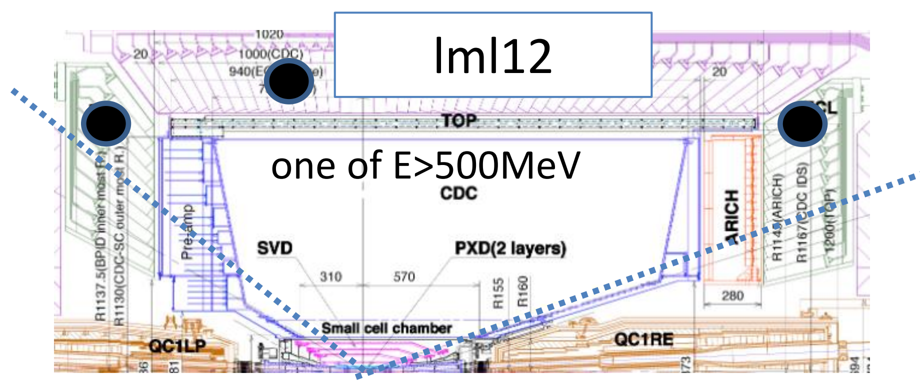
2021c

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	-	-





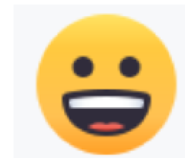




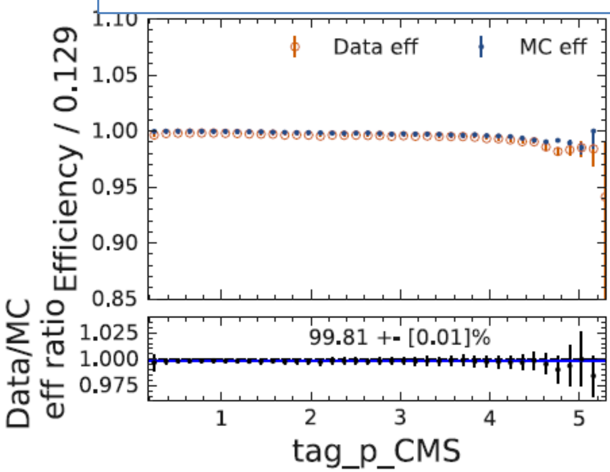
τ efficiency performance

- >~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%

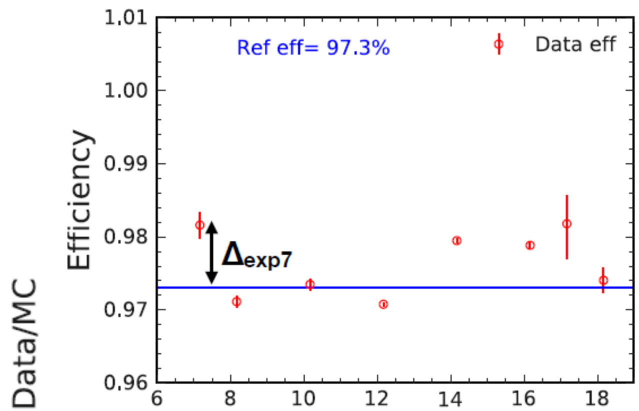


ECLTRG efficiency with e



nu

ECLTRG efficiency with μ



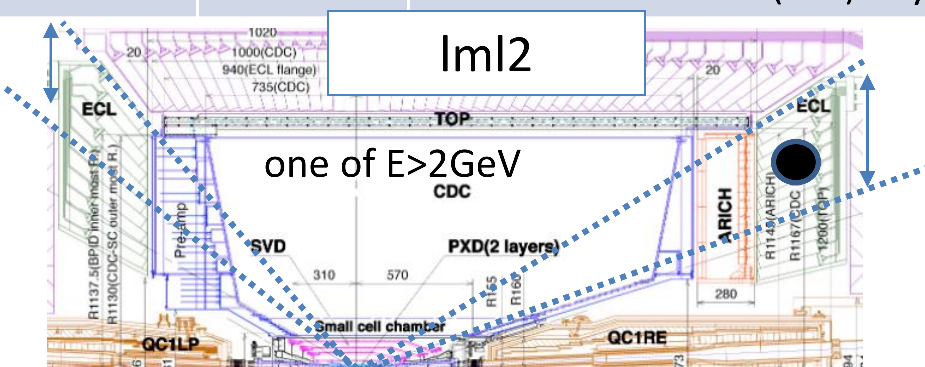
Sys	e	μ
Data-MC	0.05	0.05
Ref trig	0.11	0.34
Exp dep	0.13	0.26
Total (%)	**0.124**	**0.437**

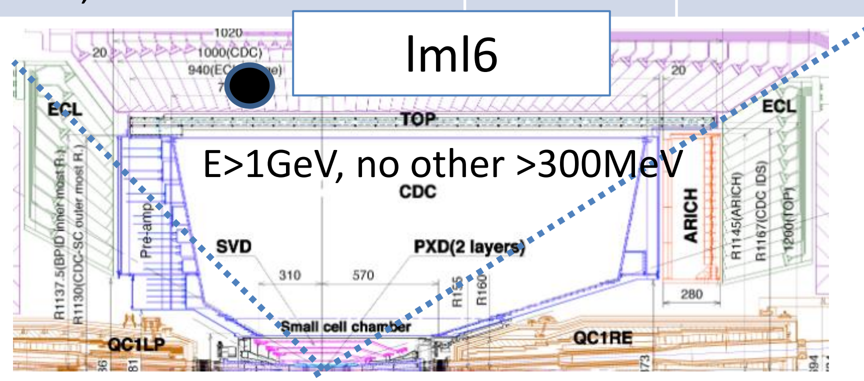
List of output bits: lowmulti/dark

-Mainly ECL based photon trigger

2021c

Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
Z’	fy30	CDC #full track>=2, $\Delta\phi$>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 $170^{\circ} < \Delta\varphi CM < 190^{\circ}$, both CL > 250 MeV(Lab), no 2GeV(CM) CL in an event	0.08	0.05
ALP	lml9	ECL $170^{\circ} < \Delta\varphi CM < 190^{\circ}$, 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



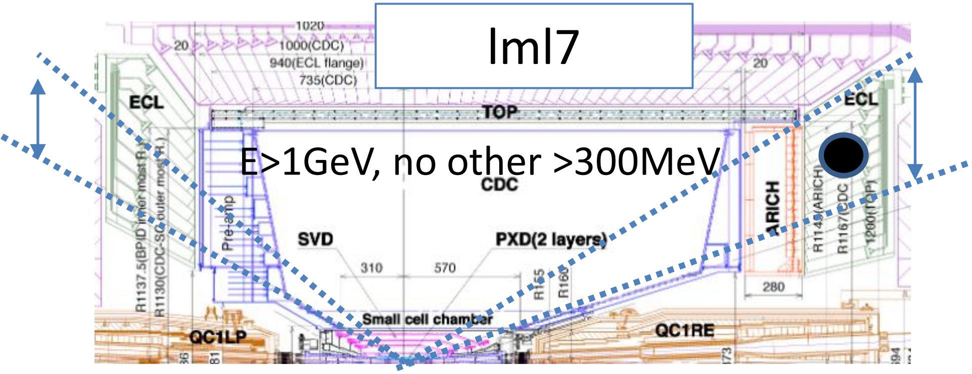


List of output bits: lowmulti/dark

-Mainly ECL based photon trigger

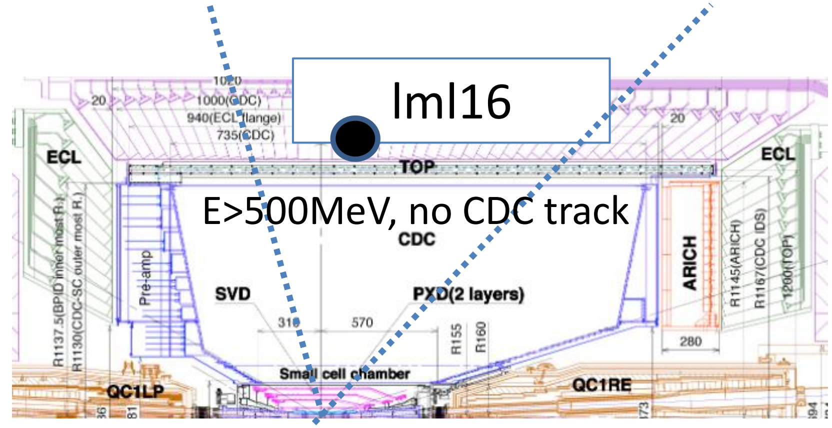
lml7

E>1GeV, no other >300MeV

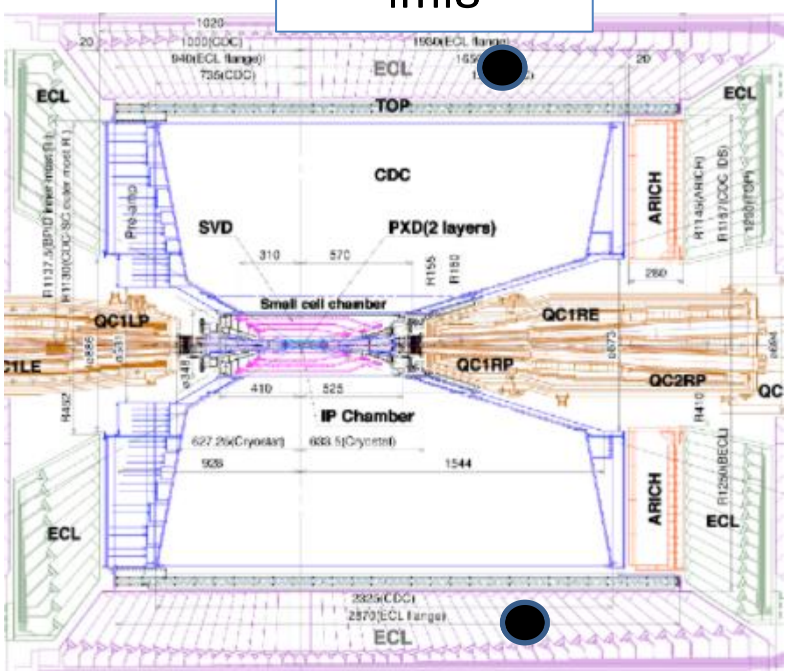


lml16

E>500MeV, no CDC track

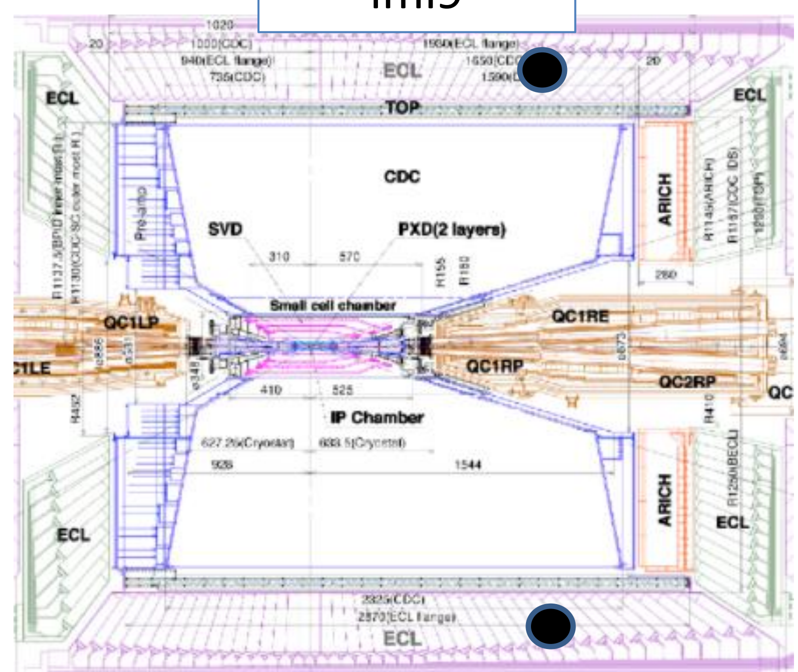


lml8



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

lml9

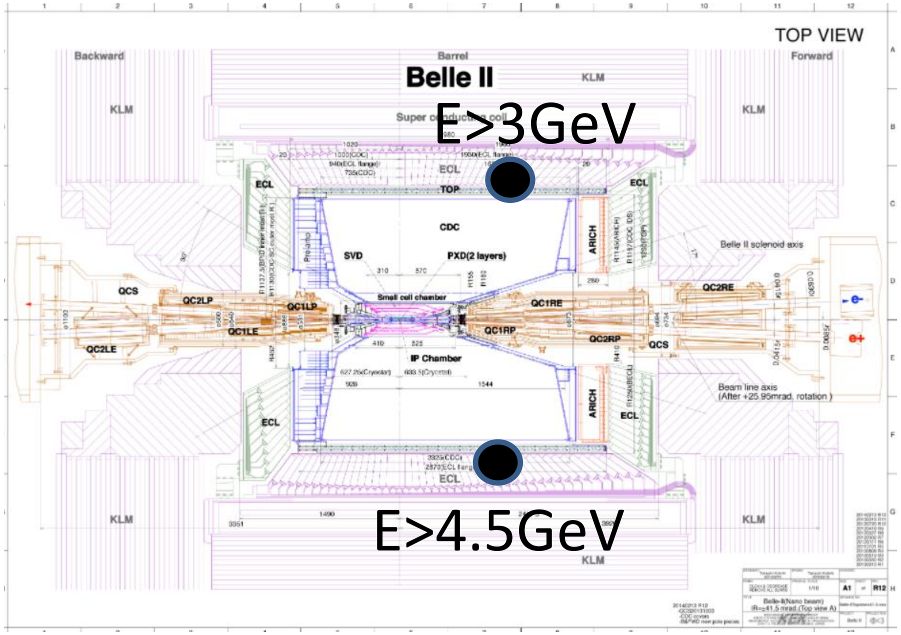


back to back, one E>250MeV, one E<250MeV, no other >2GeV, all θ region

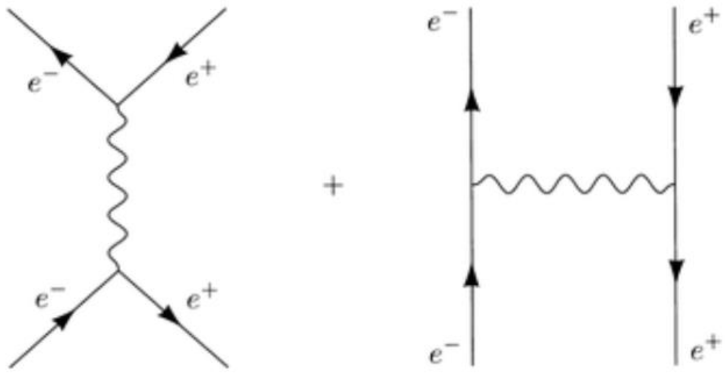
Bhabha veto with ECL trigger

-Two back-to-back high energy electron is produced by Bhabha.
-If following condition satisfied at ECLTRG, it is judged as bhabha
[E1>4.5GeV, E2>3.0GeV, $160<\Delta\phi_{CM}<200$deg, $165<\Sigma\theta_{CM}<190$deg]
->~80% Bhabha rejection

-Modification of veto logic is on-going for small scattering angle (radiative) Bhabha



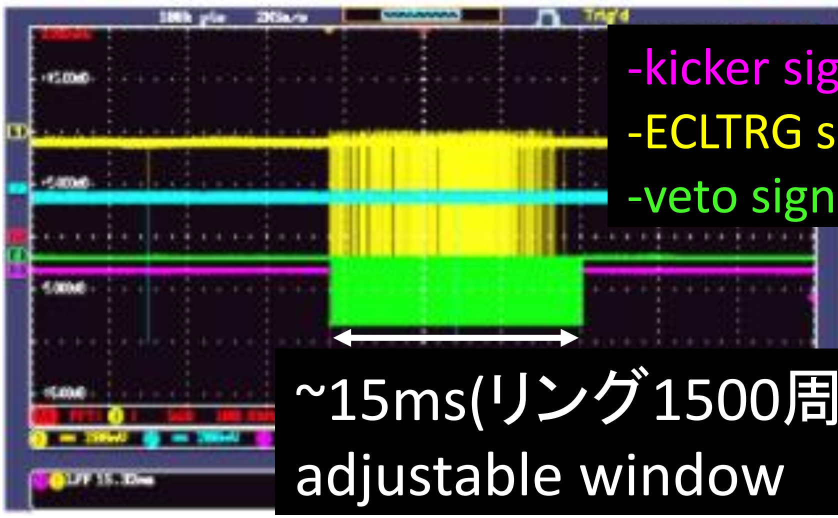
Bhabha



Injection BG rejection with kicker signal

-Huge background appear just after beam injection

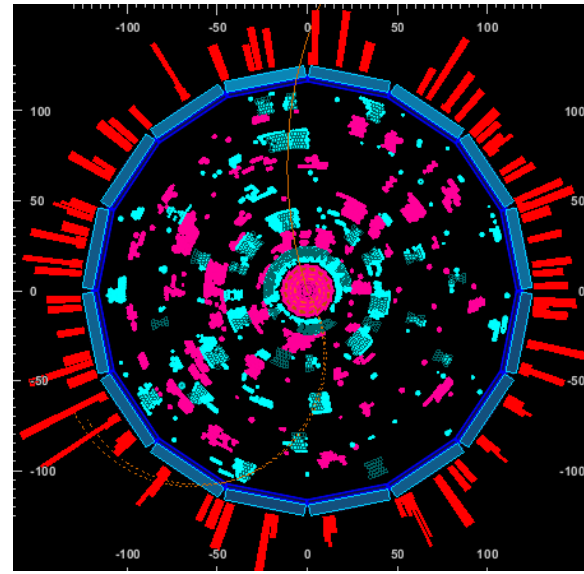
-L1 is vetoed when pre-kicker signal sent
 from machine ->~99% BG rejected

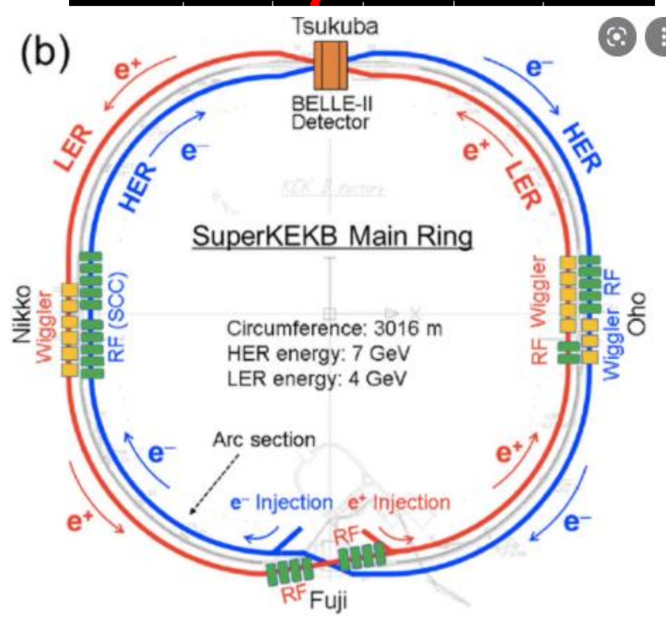


-kicker signal
-ECLTRG signal
-veto signal

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

Injection BG





-It causes the largest DAQ deadtime of ~5%..

- -continuous monitoring to minimize the BG duration corporate with SKEKB people
- -improving veto logic to minimize deadtime

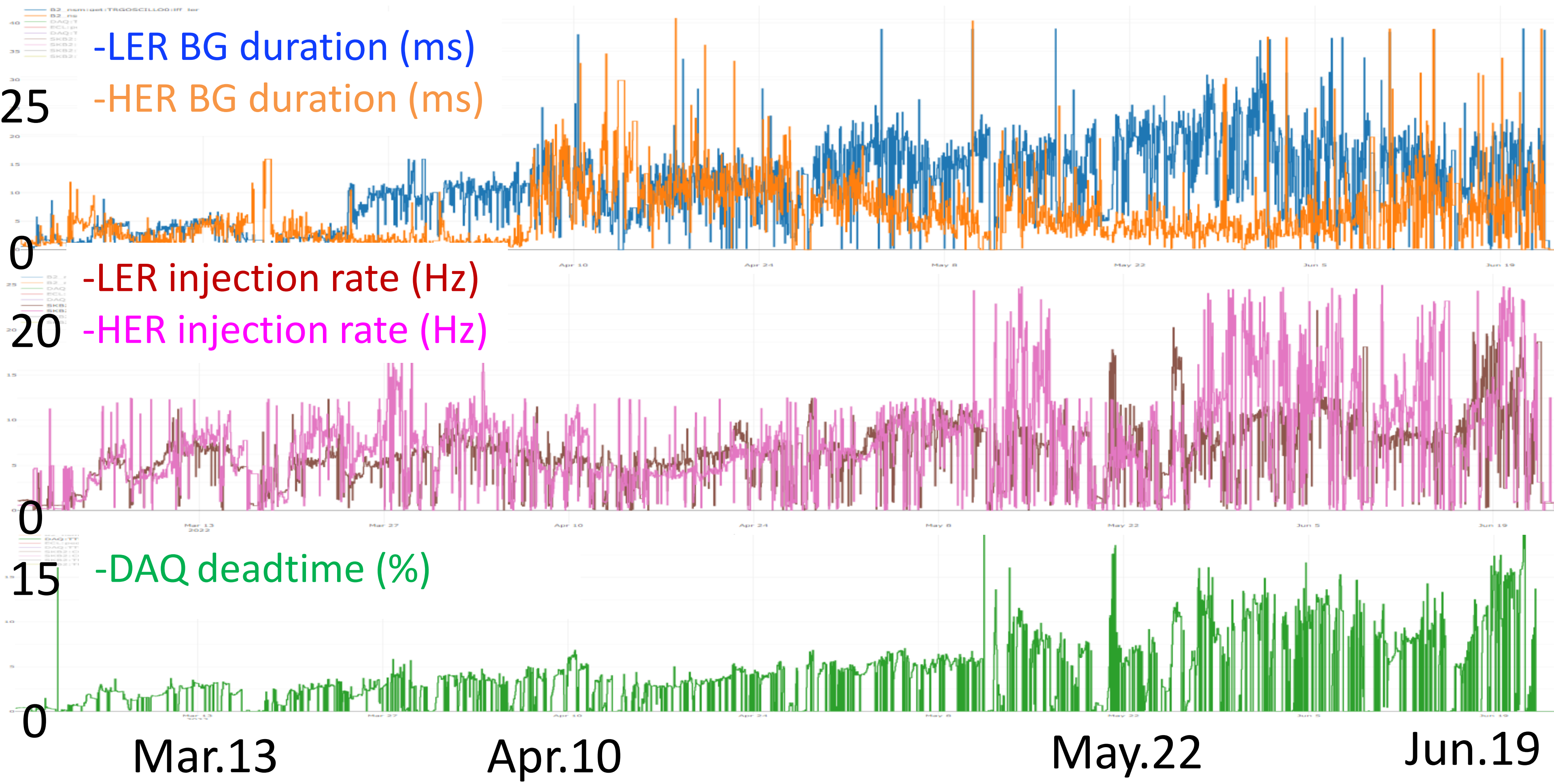
Dead time issue

-Injection veto causes the DAQ dead time:

∝length of injection veto

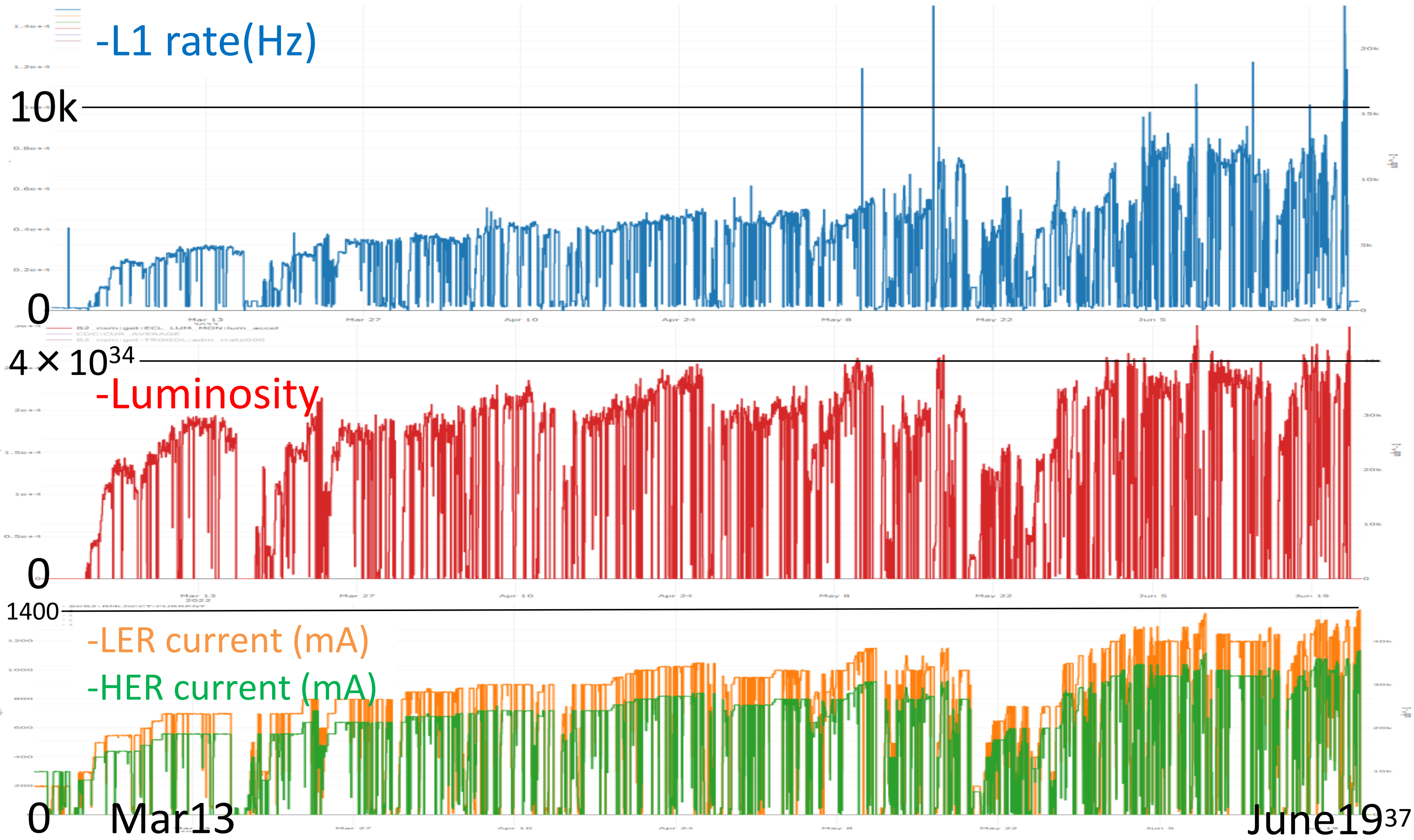
Dead time = (dead time per injection) × (averaged injection rate)

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



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.

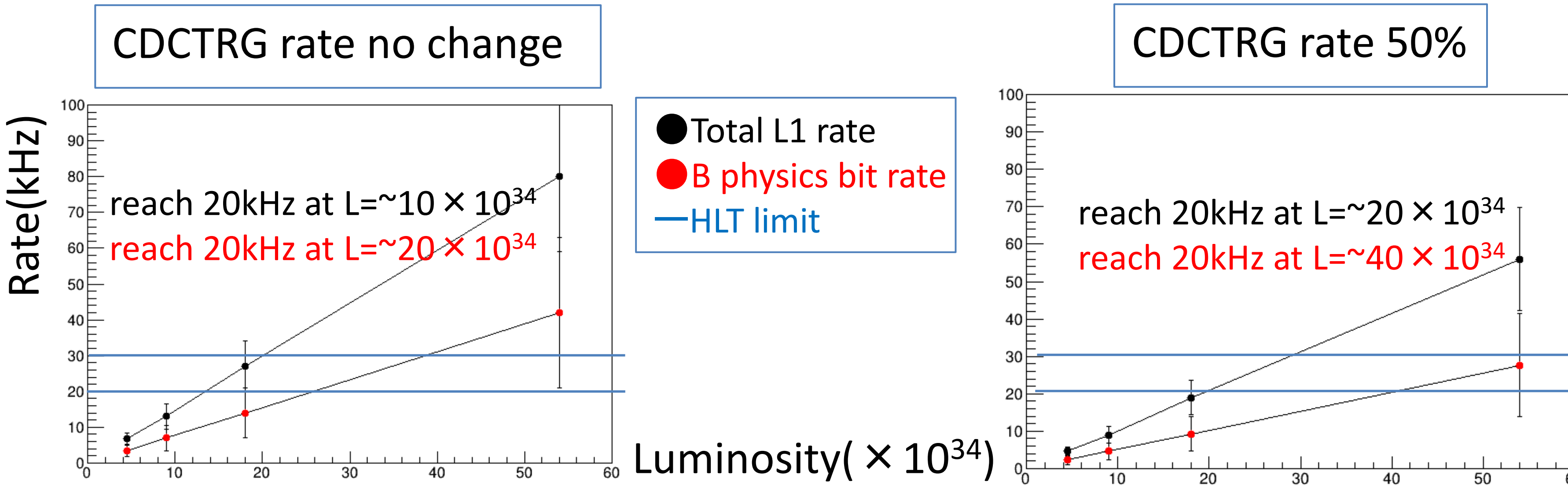


High trigger rate issue

-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

	Session	Speaker / Time
	Trigger bit for lowmulti physics *Nara Women's University*	*Enrico Graziani* 15:30 - 15:50
16:00	**Trigger bit for tau physics** *Nara Women's University*	*Alberto Martini* 15:50 - 16:10
	Trigger bit for PID (two photon) *Nara Women's University*	*Kenta Uno* 16:10 - 16:30
	Bhabha veto *Nara Women's University*	*Junhao Yin* 16:30 - 16:50
17:00	**Physics performance vs time since injection** *Nara Women's University*	*Petar Kevin Rados* 16:50 - 17:10
	Trigger menu discussion after LS1 and beyond *Nara Women's University*	*Taichiro Koga* 17:10 - 17:30

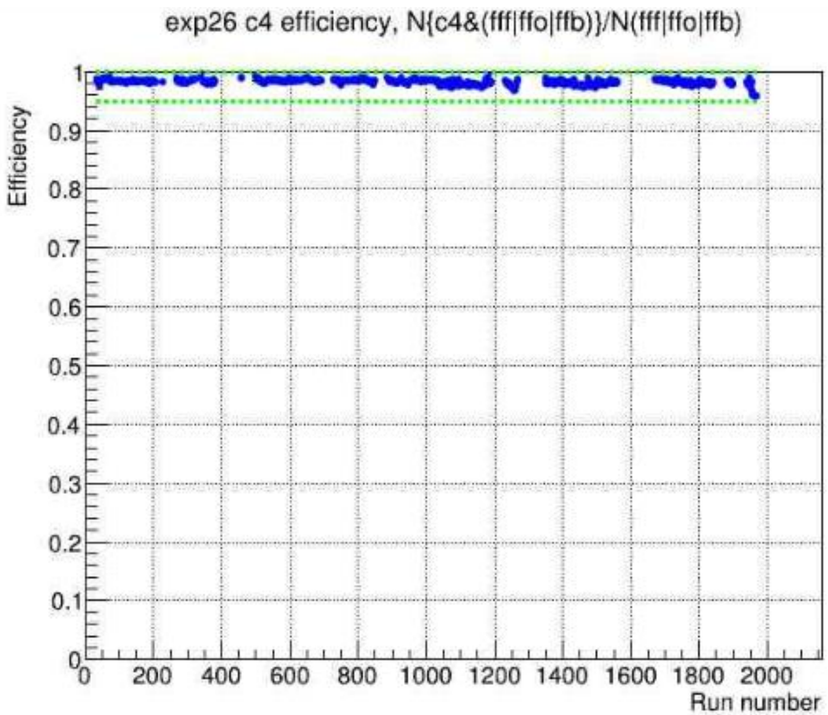
When you start physics analysis

-If your physics mode has high multiplicity, high efficiency is expected

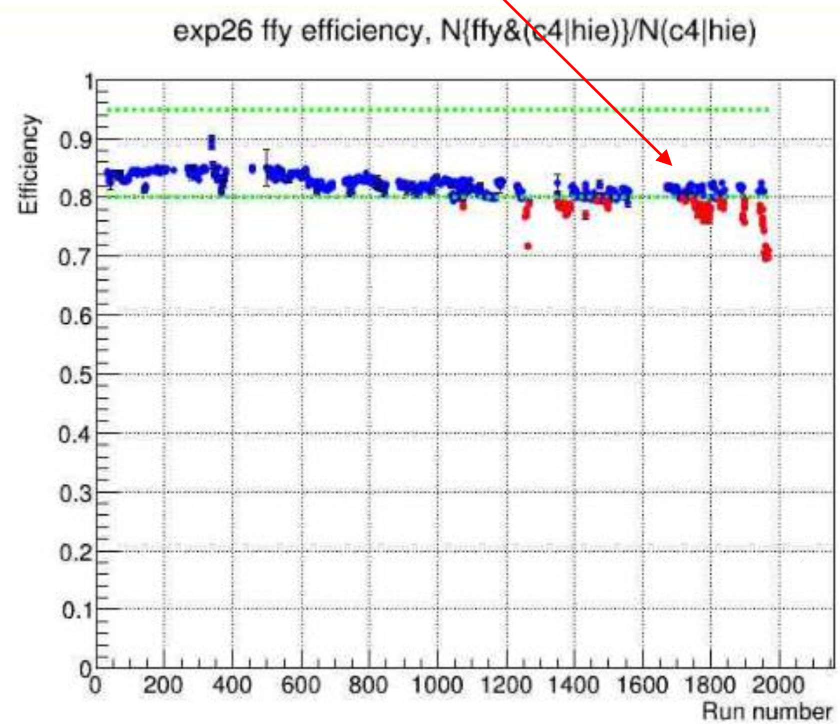
-we expect no need to take care trigger so much for your analysis

-※recently, degradation of CDCTRG has seen with gain drop.
signal yield check in each bucket etc. is needed and very welcome
to ensure the expectation and stability

#cluster>=4 efficiency
with hadronb2



#fulltrack>=3 efficiency
with hadronb2



When you start physics analysis

-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:

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

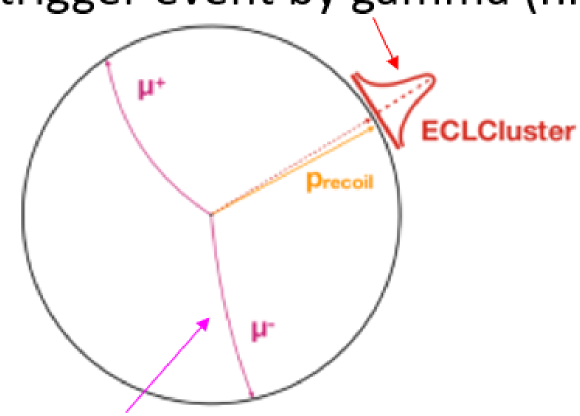
signal bit

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 trigger

- -various importance with various experiments
- -hardware(FPGA) and/only software(computer) trigger for collider

-BelleII trigger

- -CDC, ECL, KLM, TOP with ϕ matching
- -Unique logics on FPGA
- -Many trigger conditions with B, τ and low multi physics

-TRG-DAQ workshop is on-going

- -https://indico.belle2.org/event/7727/timetable/#20221129
- -useful for more detailed discussion and information
- -welcome physics-TRG session on 1st December

backup

List of output bit and rate 2021c

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

-Total rate of physics trigger bits is ~6kHz @ L=~1.5 × 10^34 with bad BG

Physics target	bit	PS	Raw rate (kHz)	HLT pass rate (kHz)	Exclusive rate (kHz)
BB	ffy	1	1.40	0.10	1.40
	fyo	1	1.03	0.13	0.47
	c4	1	0.13	0.07	0.08
	hie	1	0.69	0.24	0.56
	subtotal				**2.52**
muon	mu_b2b	1	0.35	0.017	0.32
	eklm2	1	0.04	0.004	0.04
	beklm	1	0.20	0.004	0.18
	lml10	1	0.49	0.06	0.36
	eclmumu	1	0.30	0.034	-
	cdcklm12	1	0.27	0.034	0.15
	eclklm1	1	0.42	0.023	0.30
	subtotal				**1.35**
τ	stt	1	1.74	0.18	0.96
	syo	1	0.74	0.09	0.38
	yioiecl1	1	0.37	0.06	0.08
	lml12	1	0.17	0.10	0.03
	ecltaub2b	1	-	-	-
	subtotal				**1.45**

Physics target	bit	PS	Raw rate (kHz)	HLT pass rate (kHz)	Exclusive rate (kHz)
ISR,π0 FF	lml2	1	0.18	0.076	0.01
single γ	lml6	1	0.18	0.020	0.03
single γ	lml7	1	0.15	0.016	0.04
ALP	lml8	1	0.08	0.020	0.05
ALP	lml9	1	0.34	0.051	0.28
dark γ	lml16	1	0.32	0.035	0.23
	subtotal				**0.64**

-Raw rate = rate of each bit

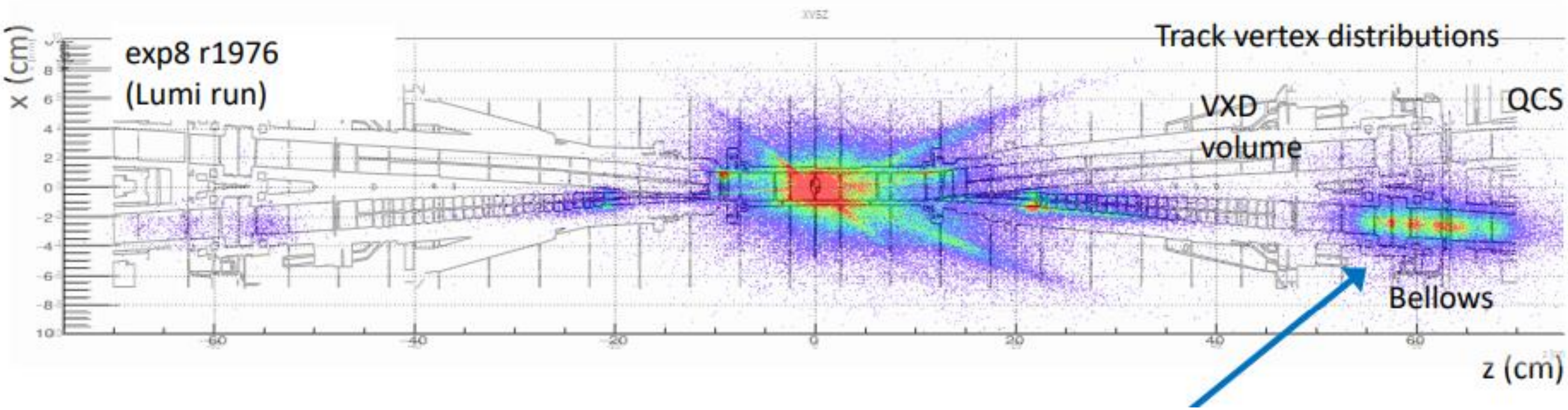
-HLT pass rate = rate of each bit after HLT filtering

-Exclusive rate = rate after excluding event overlap between different bits. upper bits are prioritized.

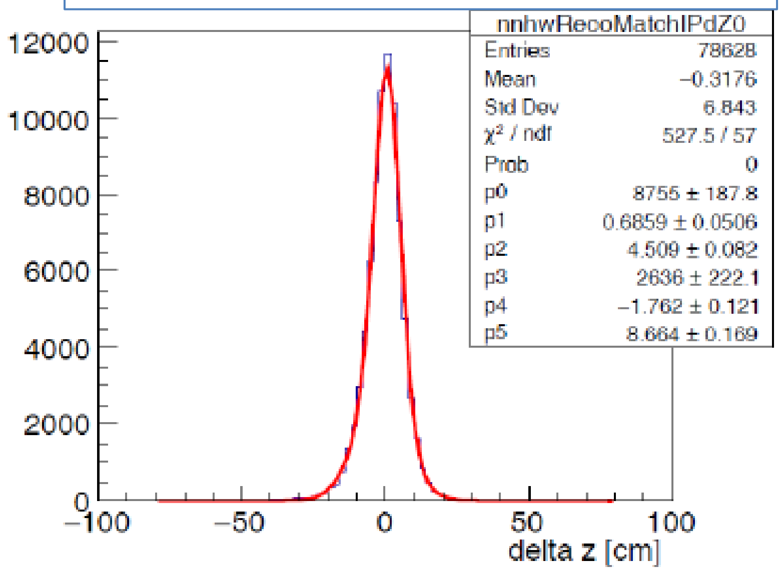
storage beam BG rejection with CDC trigger

-beamBG is coming from large Z vertex with low momentum

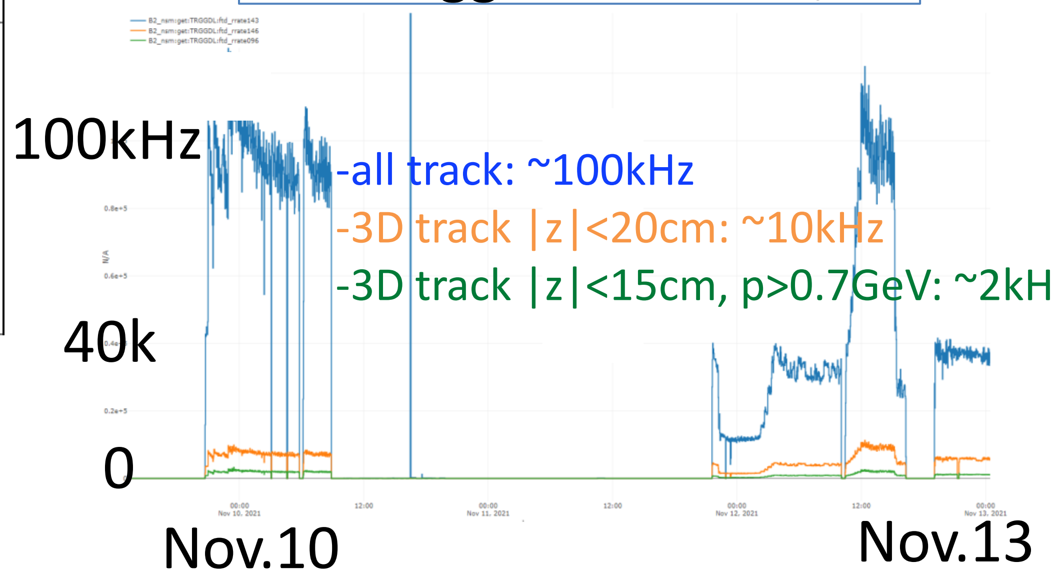
→ ~50times BG rejection by vertex and momentum cut



CDCTRG Z resolution at IP



CDC trigger rate 2021/11



CDC trigger: Track segment finder (TSF)

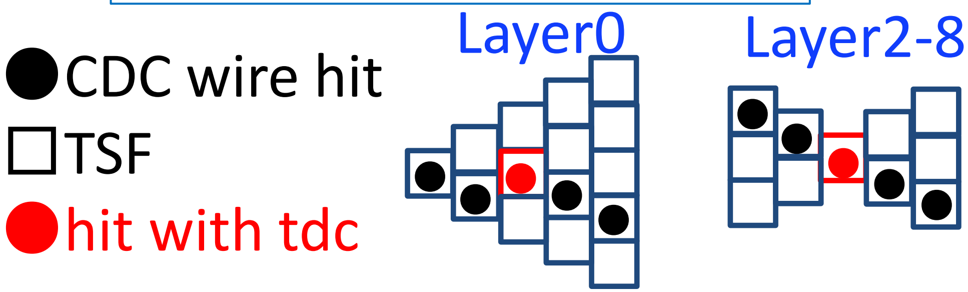
-Find bunch of wire hits (Track segment, TS) in each super layer

-TS is a minimum unit of CDC Trigger

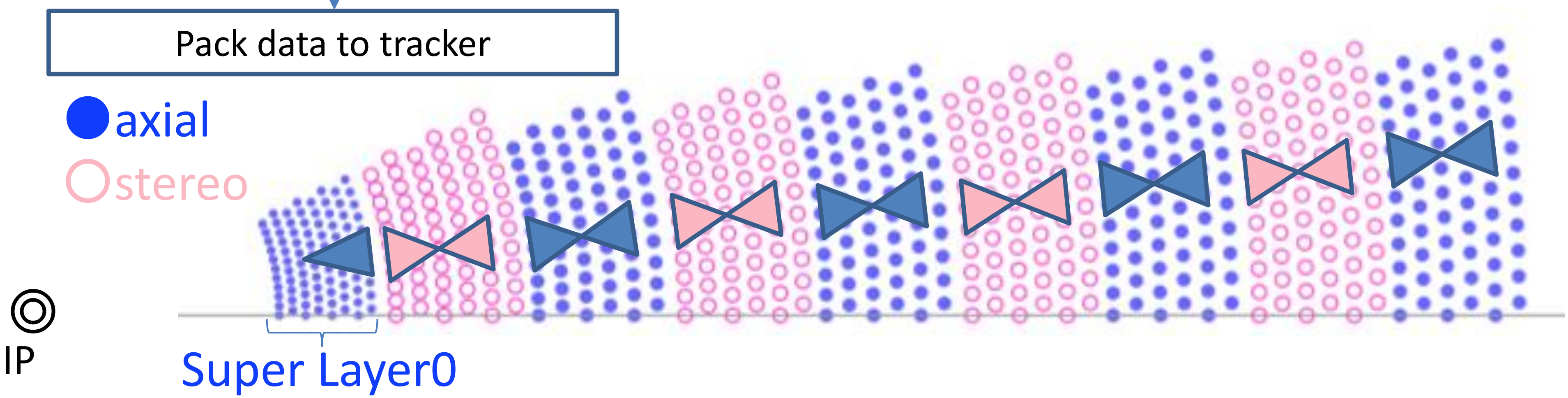
-pt>~0.35 is required (low pt with large curvature does not form TS)

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

TSF clustering pattern



CDC wire structure

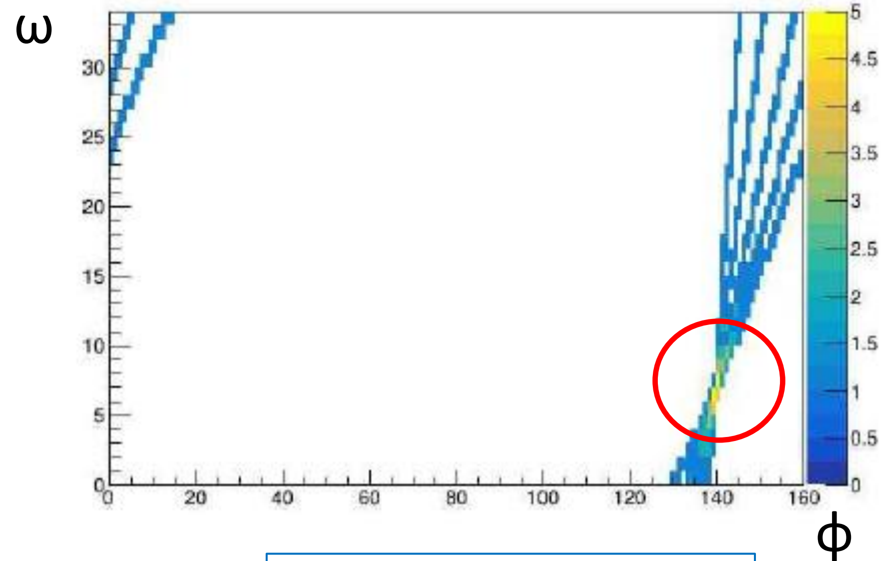


CDC trigger: 2D tracking

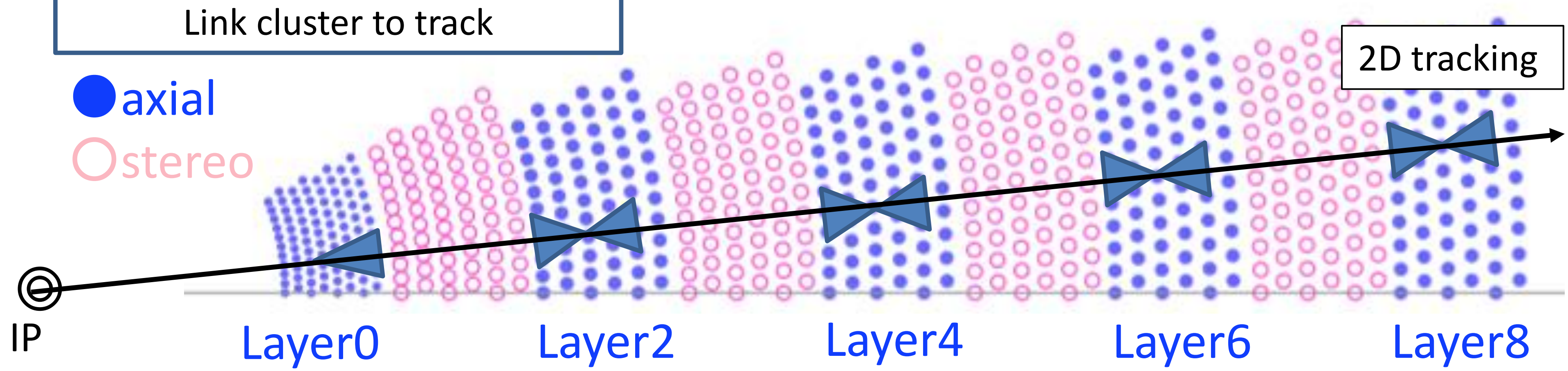
-Transform TS in axial layer to Hough plane (pt, ϕ) with curcle

-Find a peak to reconstruct 2D track

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



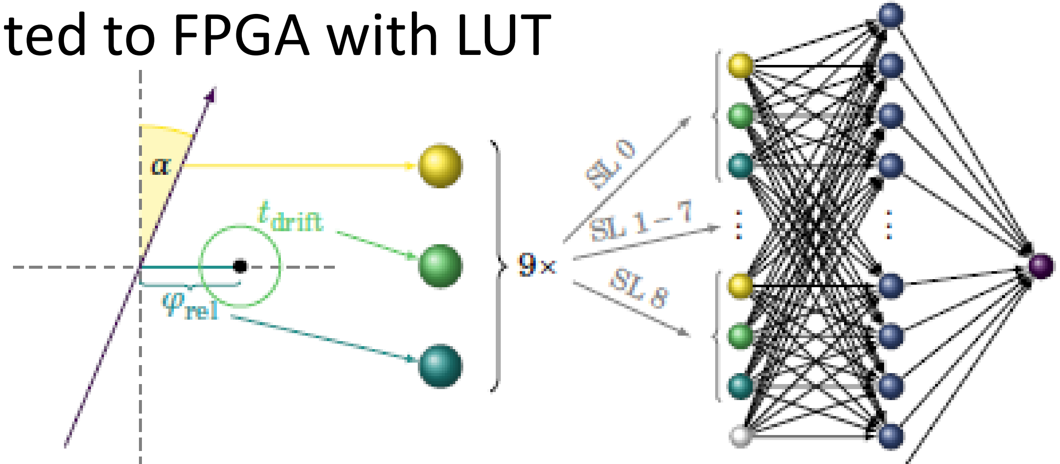
CDC wire structure



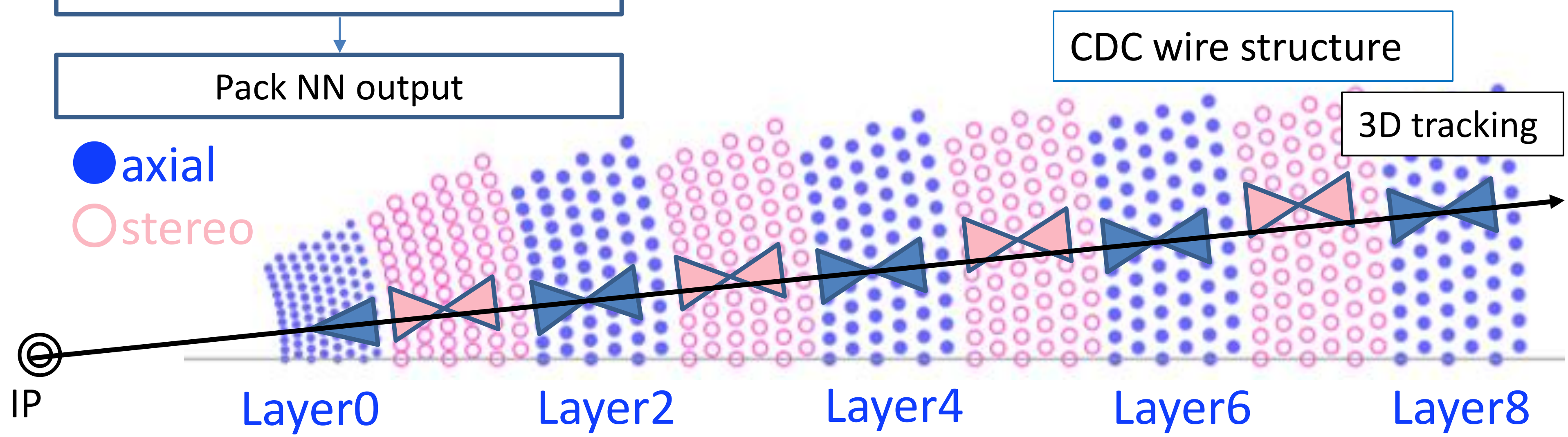
CDC trigger: 3D tracking

-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



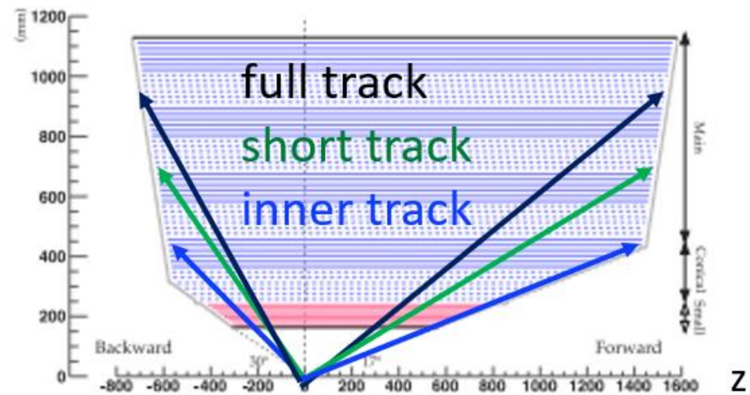
CDC trigger: inner track, short track

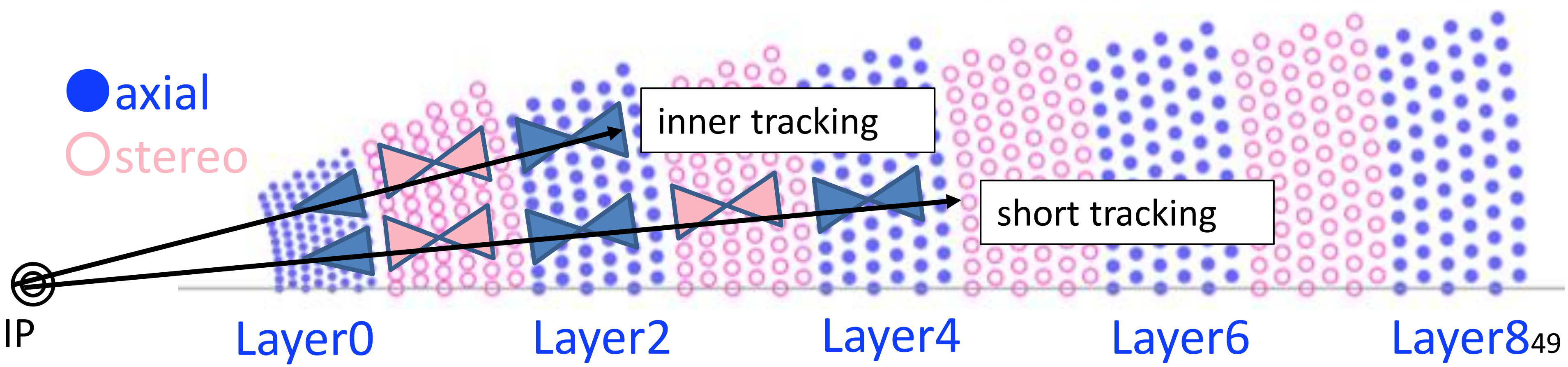
-Short/inner track is reconstructed with coincidence of 5/3 TSFs

- -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**





Trigger menu and rate @ 2022/6/9, exp26r1261

-Total L1 rate=~11.5kHz, Luminosity=~4.5 × 10^34

-Rate of standard bits (ffy+fyo+c4+hie) = 4.7kHz: need to keep until end of BelleII

-Others = 6.8kHz

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

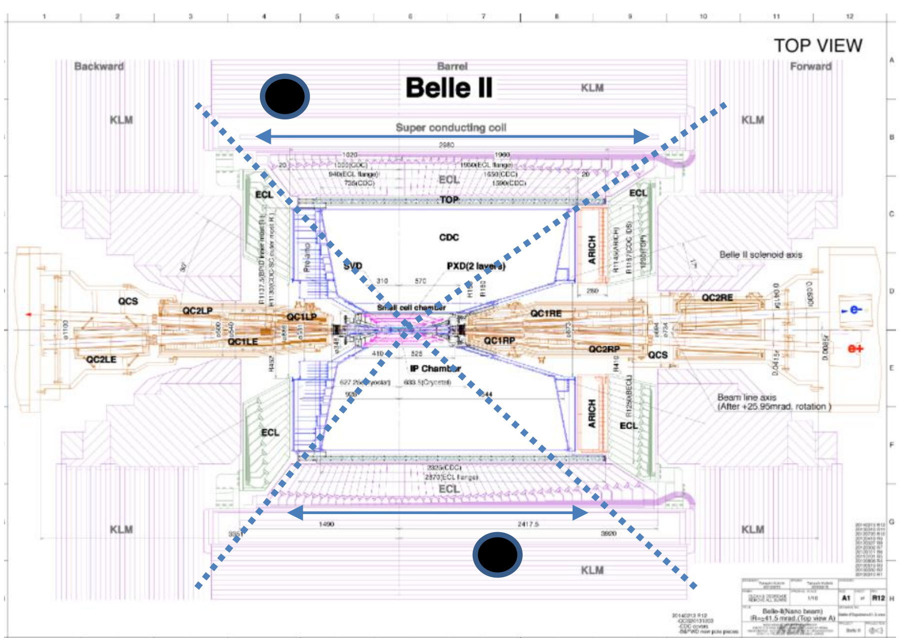
Category	Bit name and condition	Raw rate (kHz)	Exclusive rate (kHz)
CDC ~~B physics~~ standard bits	**ffy**: #full track>=3, |z|<20cm **fyo**: #full track>=2, $\Delta\phi$>90deg, |z|<20cm	2.18 1.77	2.18 0.73
ECL ~~B physics~~ standard bits	**c4**: #cluster>=4 **hie**: Energy sum>1GeV	0.47 2.02	0.26 1.54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

List of output bits: muon pair

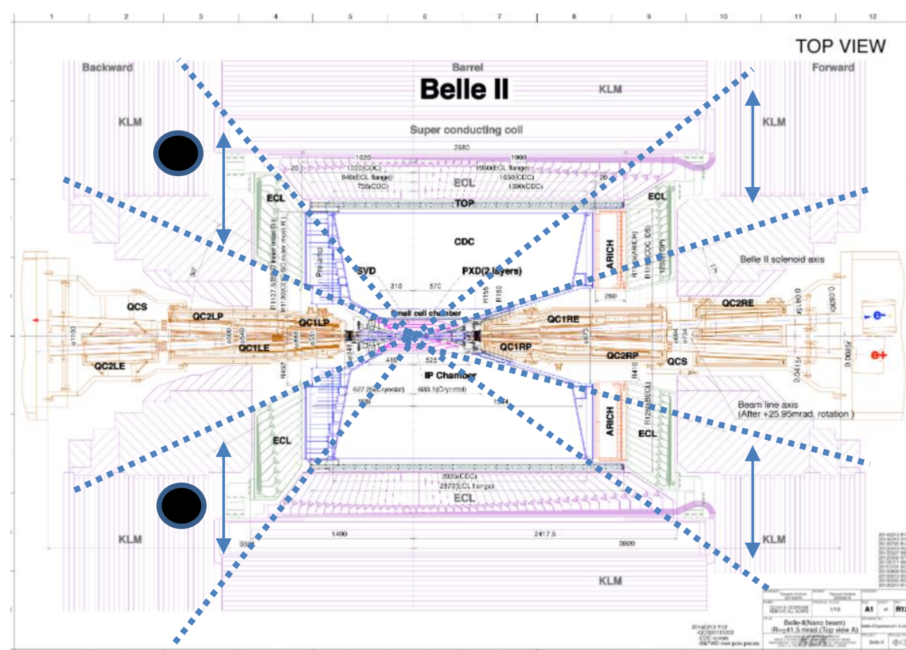
-KLM and ECL stand alone trigger

Physics target	bit name	condition	Raw rate (kHz)	Exclusive rate (kHz)
Muon pair	mu_b2b	#BKLM cluster>=2, $\Delta\phi$>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

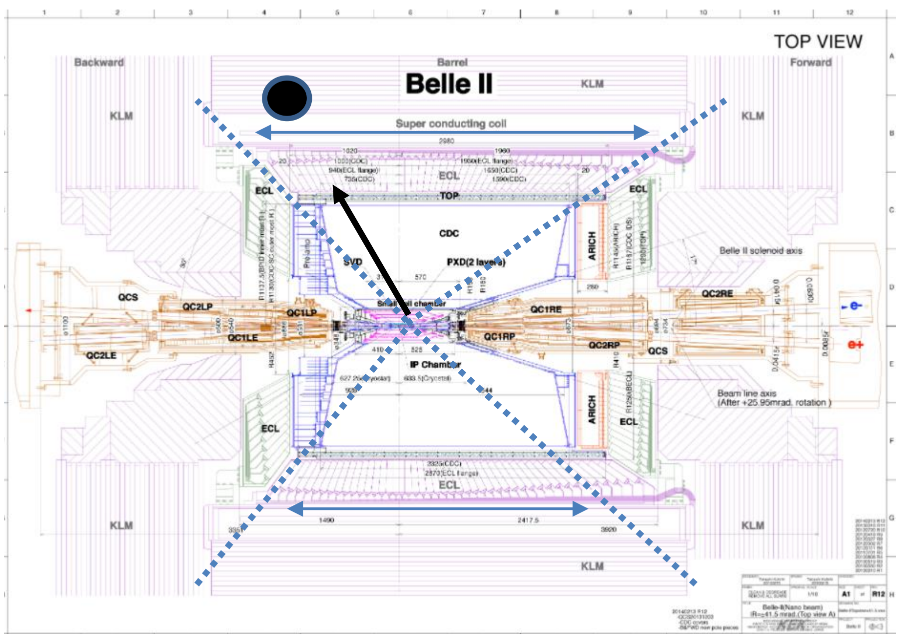


List of output bits: single muon

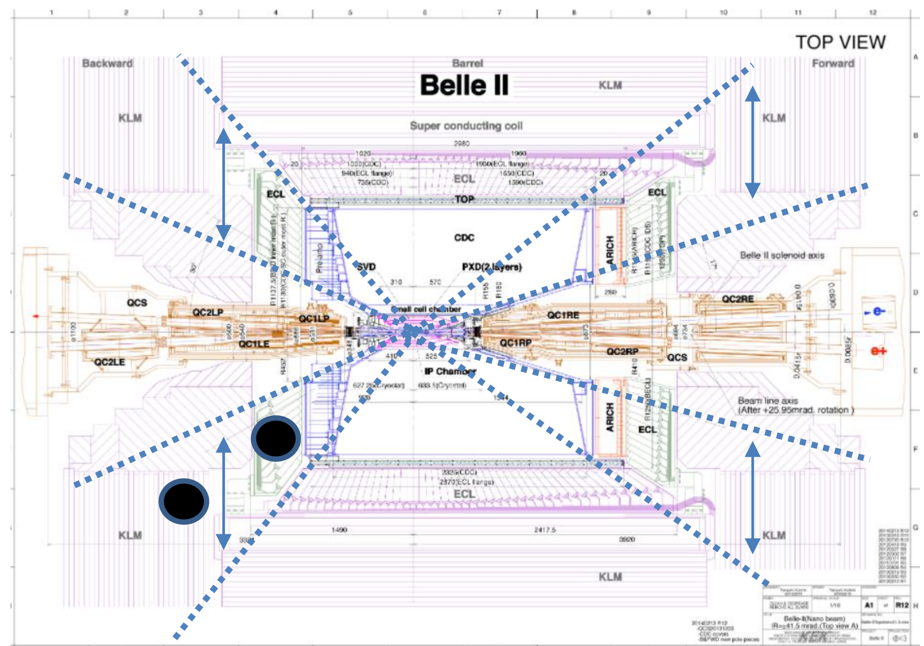
-CDC-KLM, ECL-KLM matching trigger

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

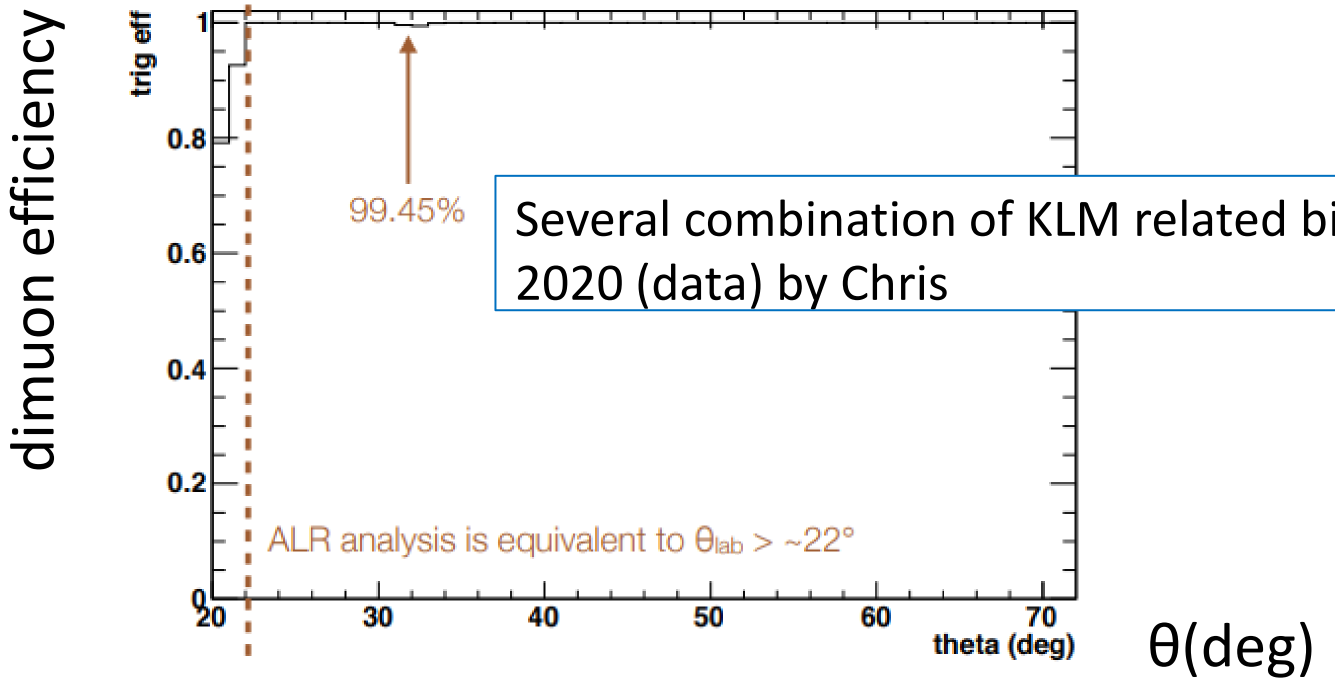


ecleklm1



Dimuon efficiency performance

-High efficiency for Dimuon with wide angle coverage

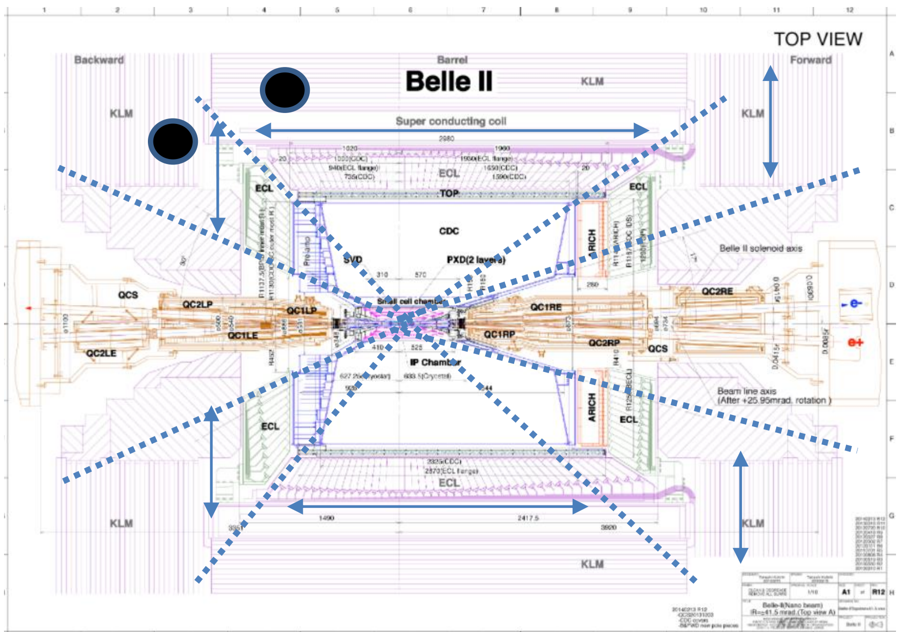


Several combination of KLM related bits
2020 (data) by Chris

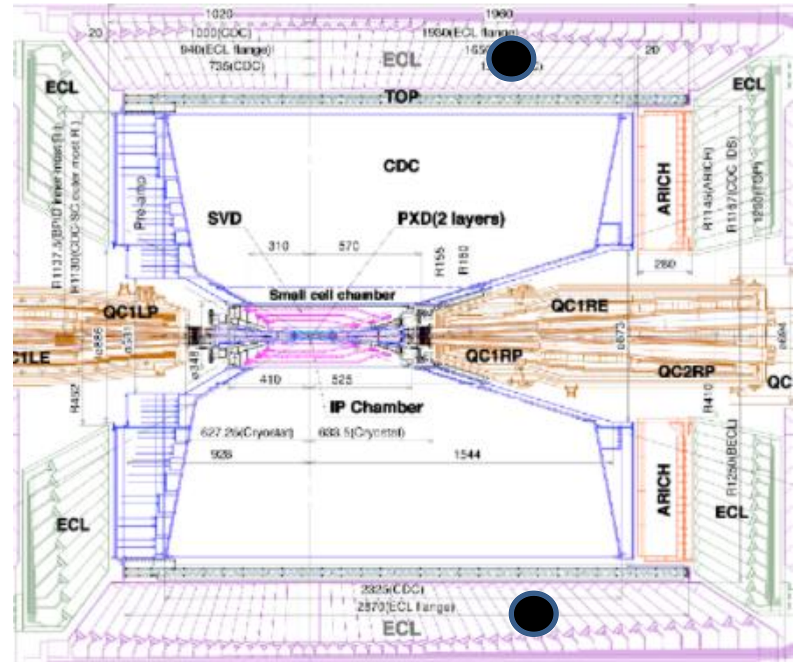
List of output bits: muon pair

-KLM and ECL stand alone trigger

beklm



eclmumu



back to back, E<2GeV
all θ region

TSIM

- TSIM has been developed and can be used for physics analysis
  - KLMTRG core logic modified with release06 to be consistent with firmware
  - most of trigger bits are implemented with release06
  - ~5% data/MC agreement for signal efficiency estimation (tau)

- Useful links
  - Available and missing trigger bits in TSIM release05
  - How to generate signal MC with release06
    - example code
    - release-06-00-05 or later with global tag of "L1_config_exp_22_run_290"

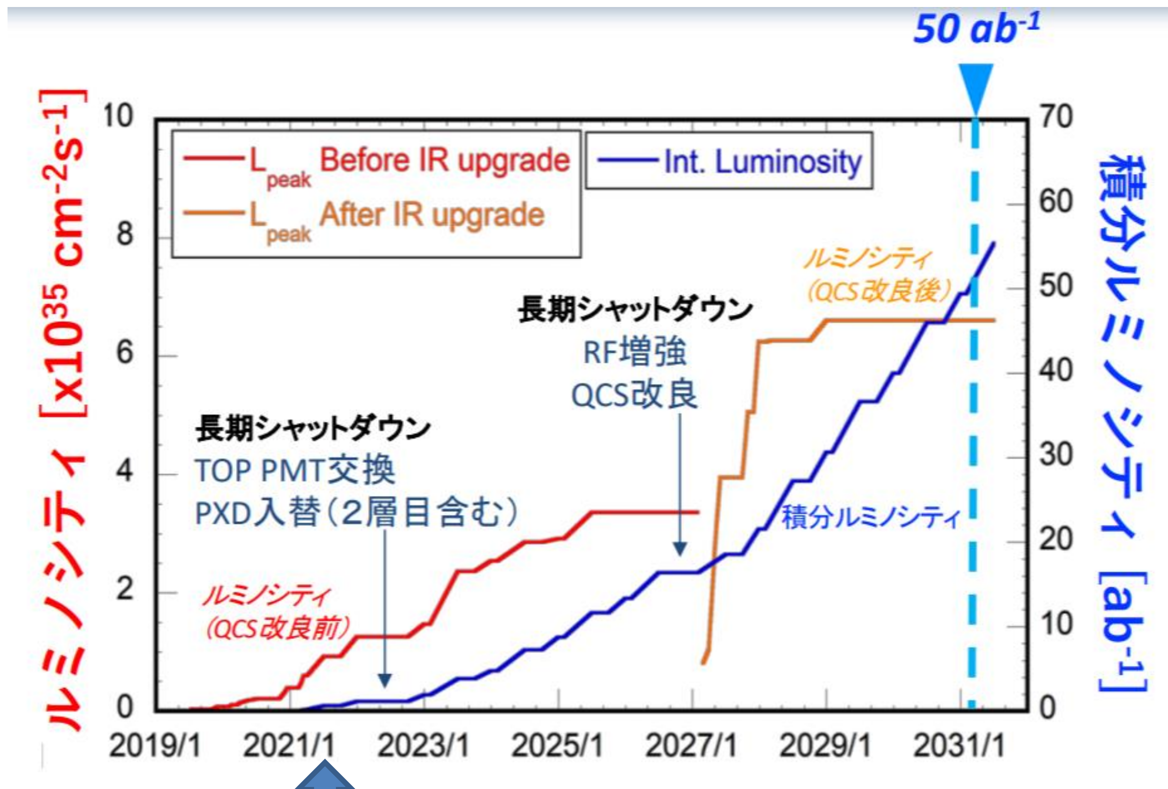
- Available event variables
  - L1FTDL(name),L1FTDLBit(bitnumber) returns if the output bit satisfied w/o prescale.
  - L1PSNM(name),L1PSNMBit(bitnumber) returns if the output bit satisfied w/ prescale.
  - L1Input(name),L1InputBit(bitnumber) returns if the input bit satisfied
  - source code: analysis/variables/src/TriggerVariables.cc

- Make Jira ticket and notify us if you have any TRG software request ☺

Data taking with trigger

-Bファクトリー
- -電子(7GeV)・陽電子(4GeV)衝突型加速器(SuperKEKB)
- -衝突点の周りに粒子検出のための装置(BelleII検出器)
- -KEKBの数十倍のルミノシティ(~6×$10^{35}cm^{-2}s^{-1}$). 積分$50ab^{-1}$.

-測定する物理
- -B,D,τの精密測定
- -ダークマター探索
- -ハドロン物理　など



いまここ　ルミノシティ ~0.3×$10^{35}cm^{-2}s^{-1}$

積分~$0.2ab^{-1}$

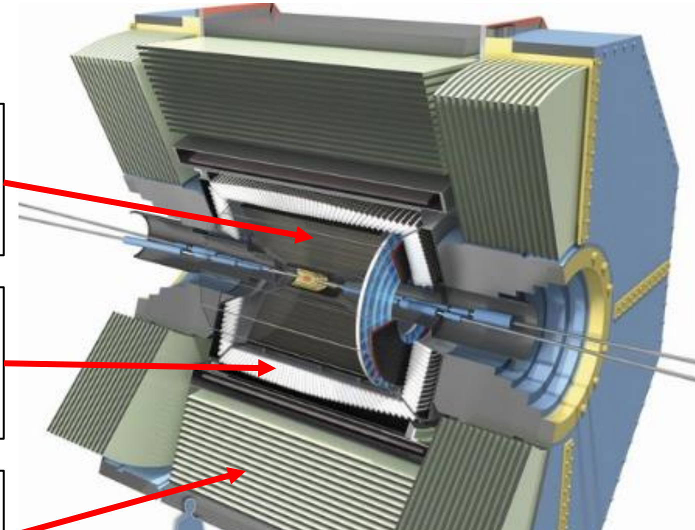
Level 1 trigger system

-複数のデジタル回路(FPGA)の組み合わせ

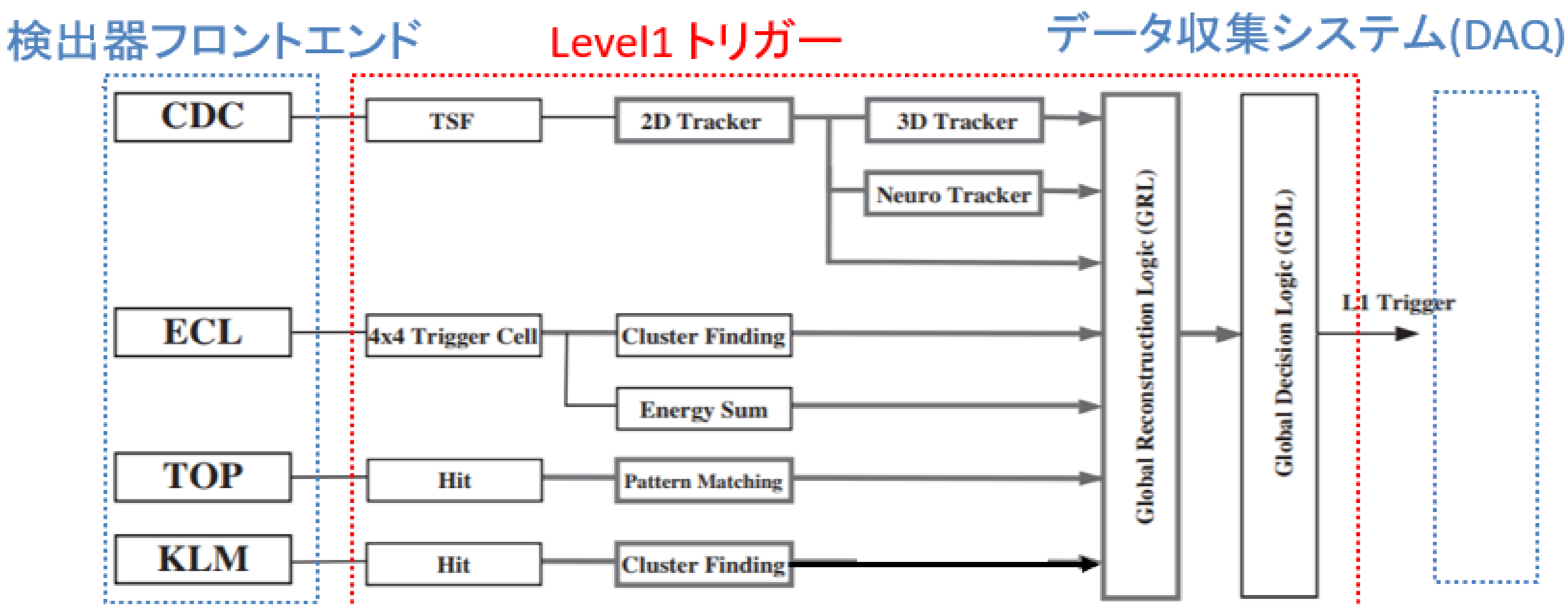
中央飛跡検出器(CDC)トリガー
荷電粒子の本数、飛跡、生成点

電磁カロリメータ(ECL)トリガー
荷電粒子・光子のエネルギー、クラスター数、位置

ミューオン(KLM)トリガー
ミューオンの本数、位置



□:ボード
ー:光通信



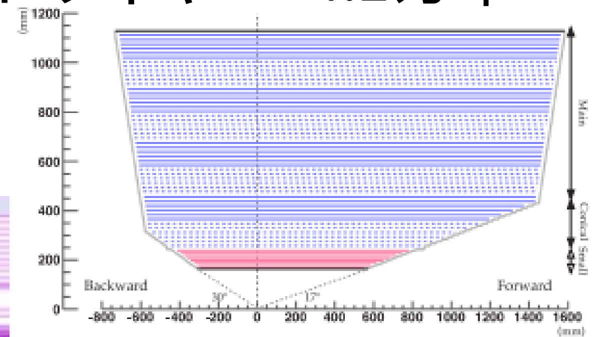
CDC

-CDC:セントラルドリフトチェンバー

-荷電粒子の飛跡を再構成. 本数、電荷、運動量、生成点

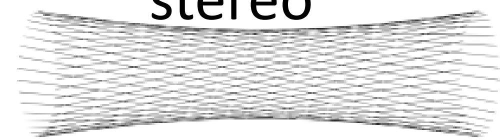
-He:C_2H_6 ガス増幅　-センスワイヤー~1.4万本
フィールドワイヤー~4.2万本

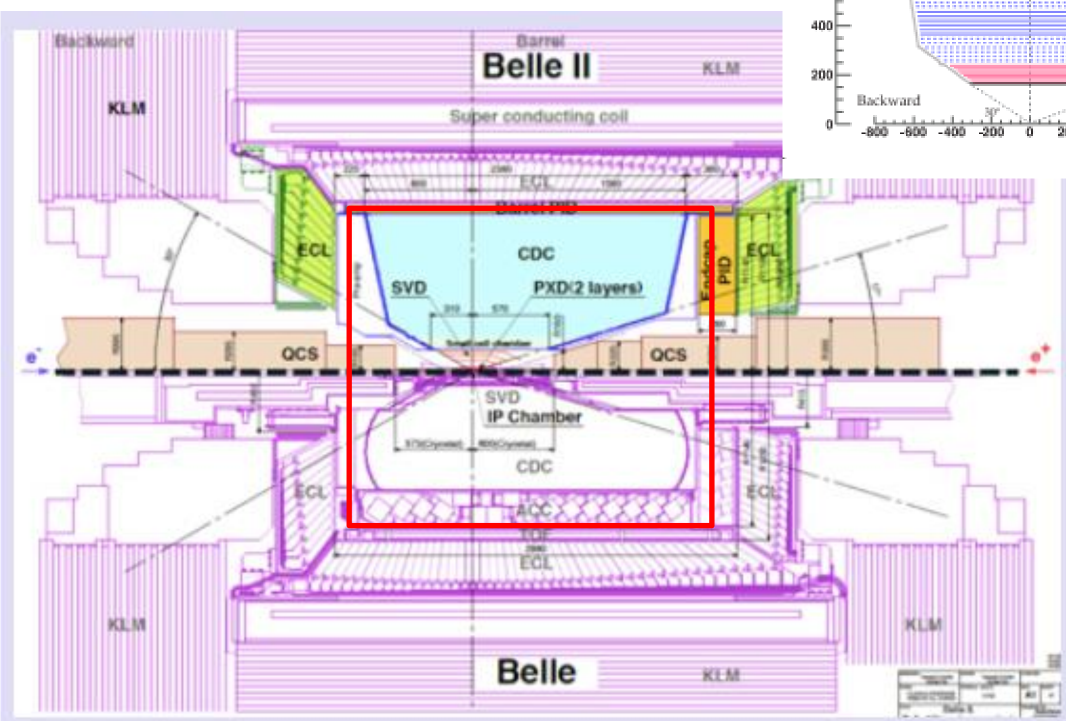
-ドリフトタイム~500ns



axial

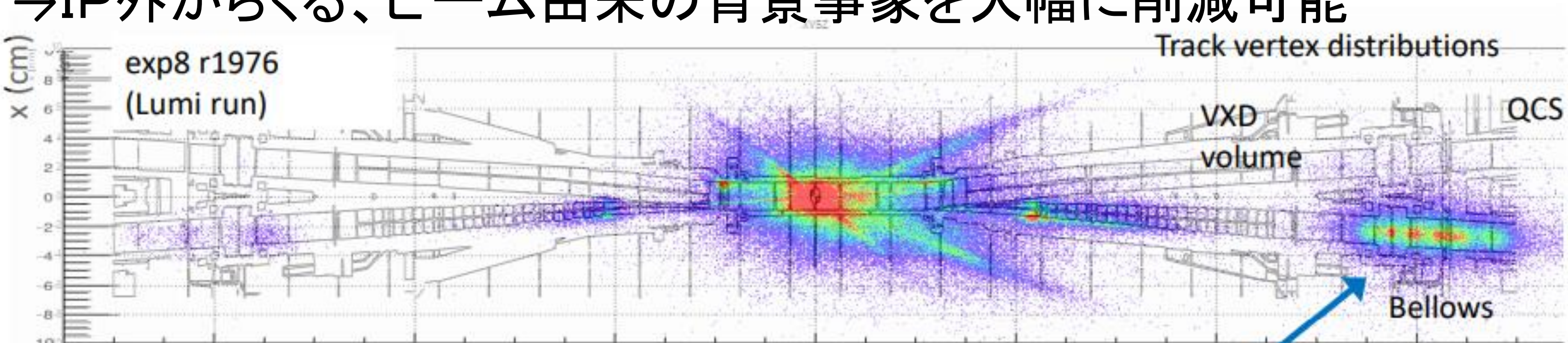
stereo



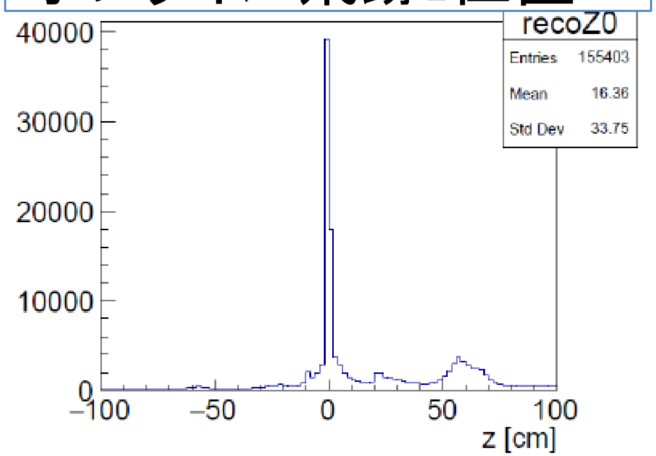


CDC trigger: BG rejection

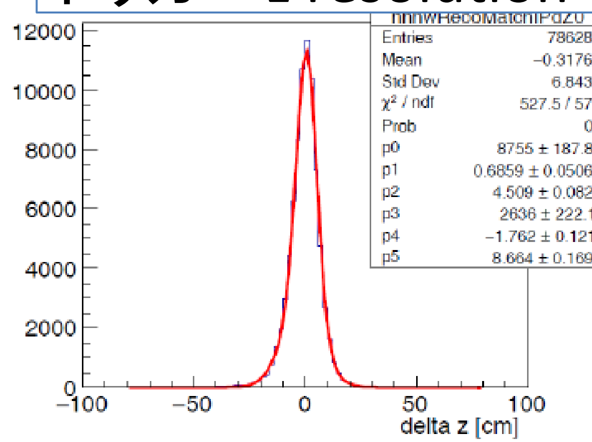
-飛跡の生成点(z位置)が 3次元飛跡再構成でわかる
→IP外からくる、ビーム由来の背景事象を大幅に削減可能



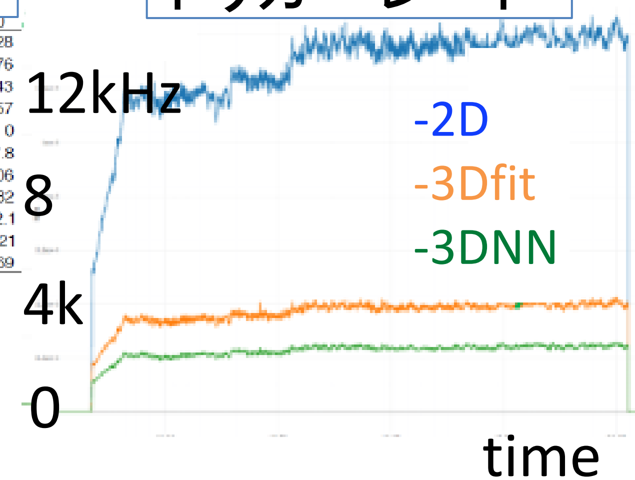
オフライン飛跡z位置



トリガーz resolution



トリガーレート



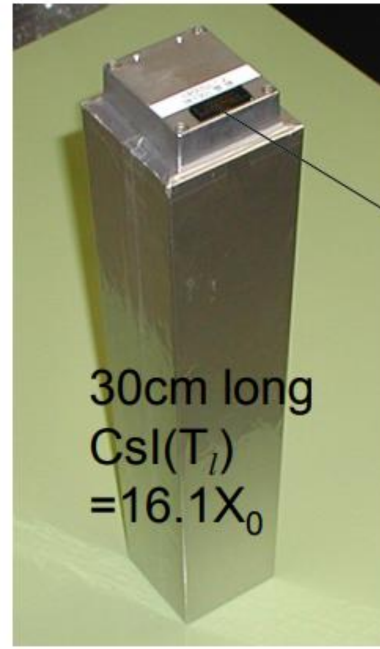
-2021年春から3Dtrackを運転に使用 |z|<20cmを要求
- -トリガーレートを半分以下に削減、efficiencyの変化1%未満
- -"1荷電粒子イベント"がトリガー可能に →τのefficiency 1.5倍

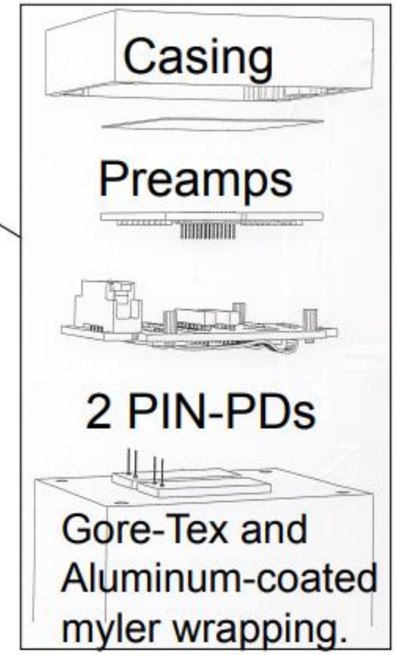
ECL

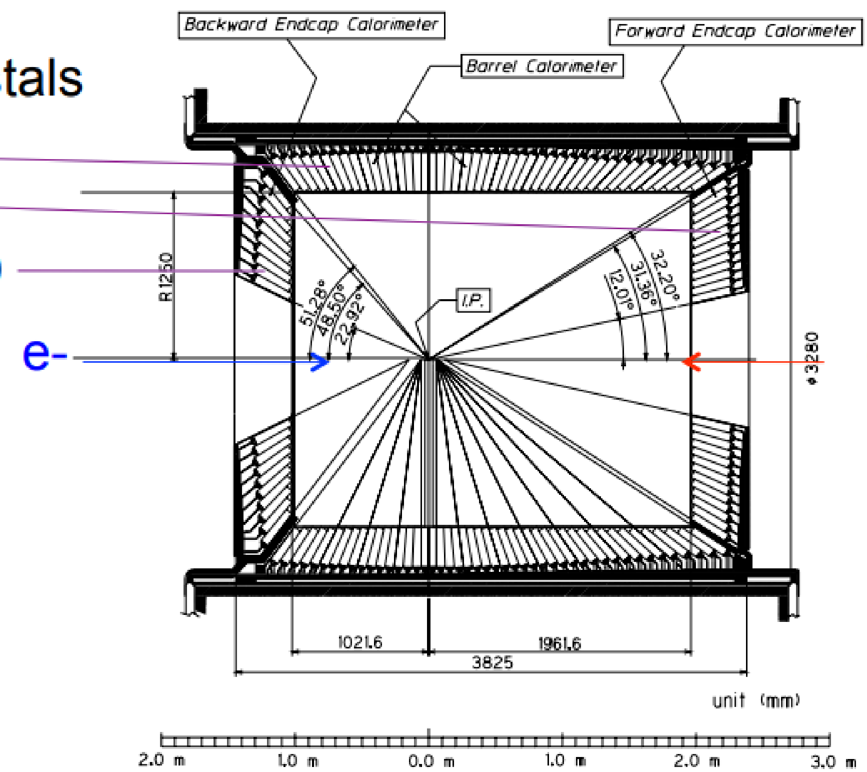
合計8736本

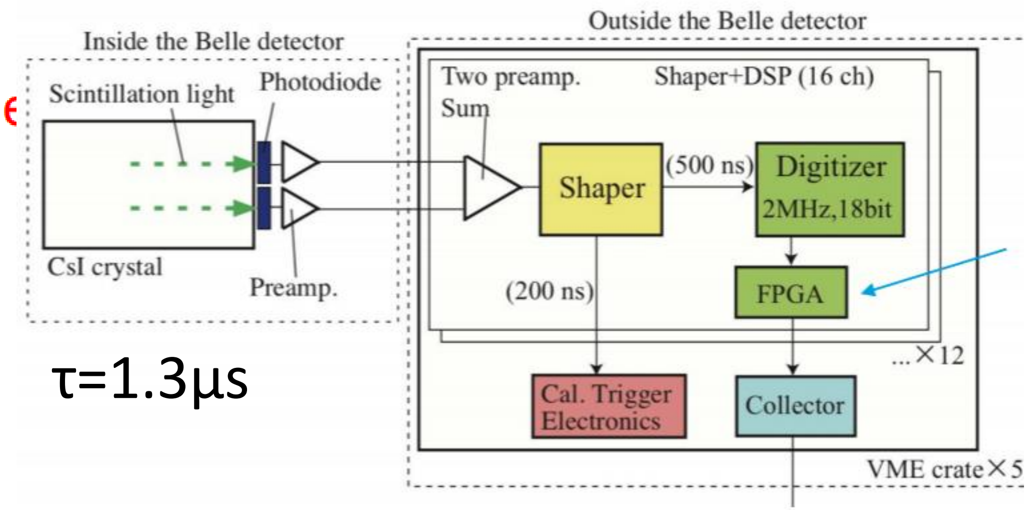
-ECL:電磁カロリメータ

-光子・荷電粒子のエネルギー
クラスター数





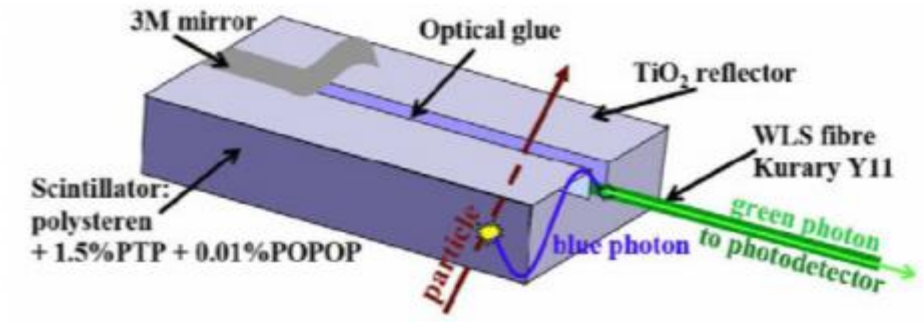




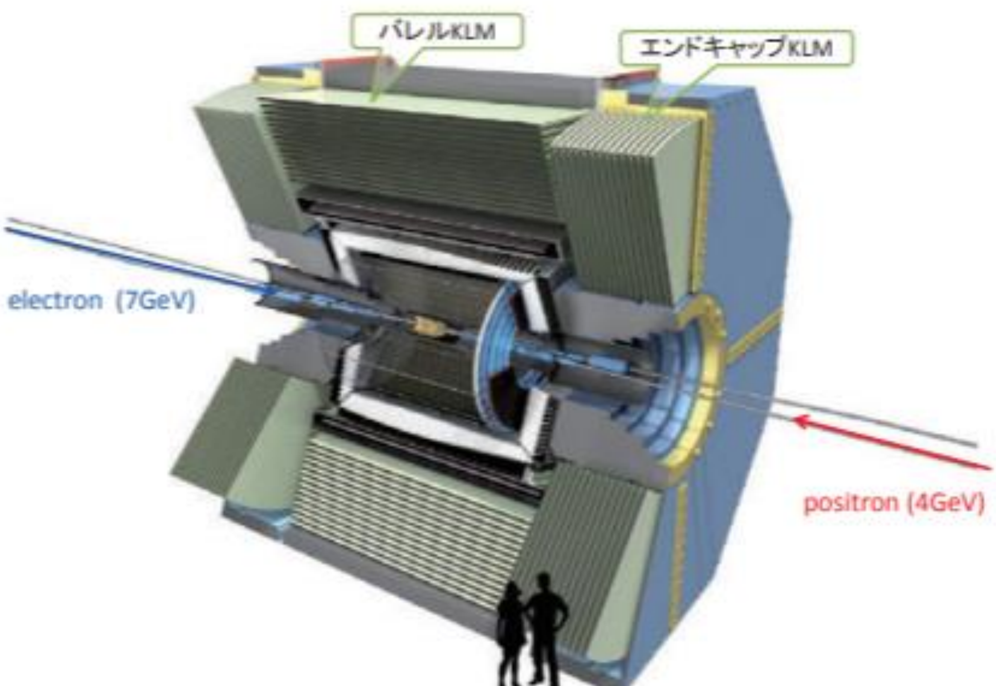
τ=1.3μs

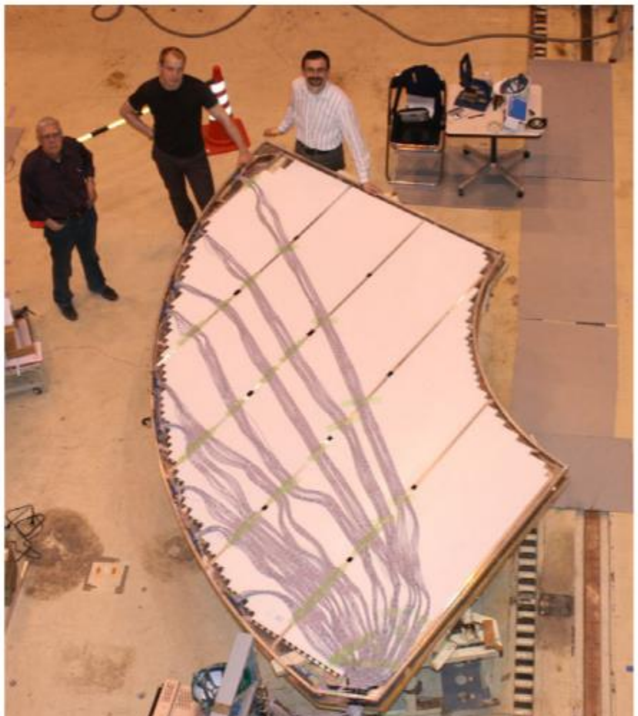
KLM

-KLM:KL/μ検出器
- -μの同定
- -K_L^0の検出



-鉄+プラスチックシンチレータ or RPCのサンドイッチ構造×15
  -BelleII でendcapとbarrelの一部をプラシンへ交換
  (放射線による不感への耐性)





トリガー条件 veto

-Bhabha散乱 (e+e-→e+e-) veto
- -断面積が大きい ECL triggerでveto
- -条件: E1>4.5GeV, E2>3.0GeV, $160<\Delta\phi_{CM}<200$deg, $165<\Sigma\theta_{CM}<190$deg
- -現在はvetoなし 今後×10,100にプレスケール

表 1: 物理事象の反応断面積

Process	σ (nb)	Rate (Hz)
Υ (4S)	1.2	960
Continuum	2.8	2200
$\mu^+\mu^-$	0.8	640
$\tau^+\tau^-$	0.8	640
Bhabha	44	350 [3]
γγ	2.4	19 [3]
Two photon	12	10000 [4]
Total	67	~15000

1/100

-入射ビームバックグラウンド veto
- -ビーム入射後 数~十数ms 入射バンチ前後をveto
- -DAQ dead time ~数% 今後の改善が必要

deadtime（%） 2020秋