Belle-II Level-1 Trigger

(2019/10,11,and12 so called "2019c")

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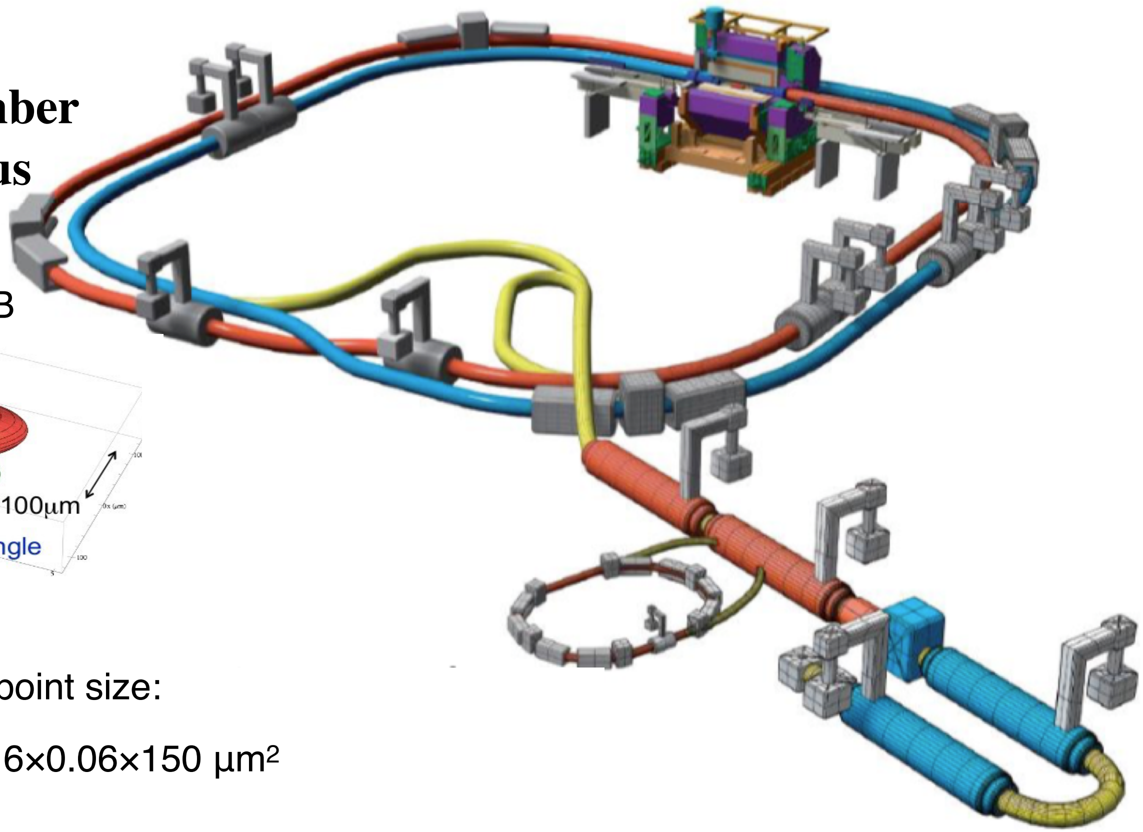
2020/02/25

@

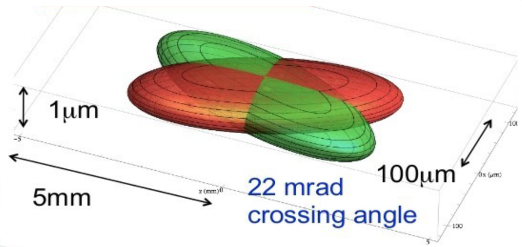
INSTR'20

SuperKEKB

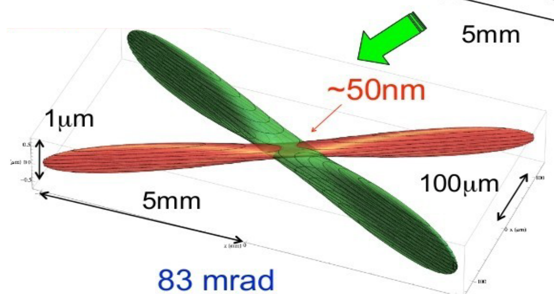
- **Asymmetric energy e+ e– collider to produce Upsilon(4s)**
  - **Beam energies : e+ : 4 GeV, e– : 7 GeV**
- **Target luminosity : 8×10^{35} $cm^{-2}s^{-1}$**
  - **40 times higher than the KEKB luminosity record**
    Beam currents x2, nano beam scheme x20
- **New**
  - **e+ damping ring**
  - **3km e+ ring vacuum chamber**
  - **Superconducting final focus**



Beams at IP in KEKB



Beams at IP in SuperKEKB



Interaction-point size:

$\sigma_x\times\sigma_y\times\sigma_z = 6\times0.06\times150\ \mu m^2$

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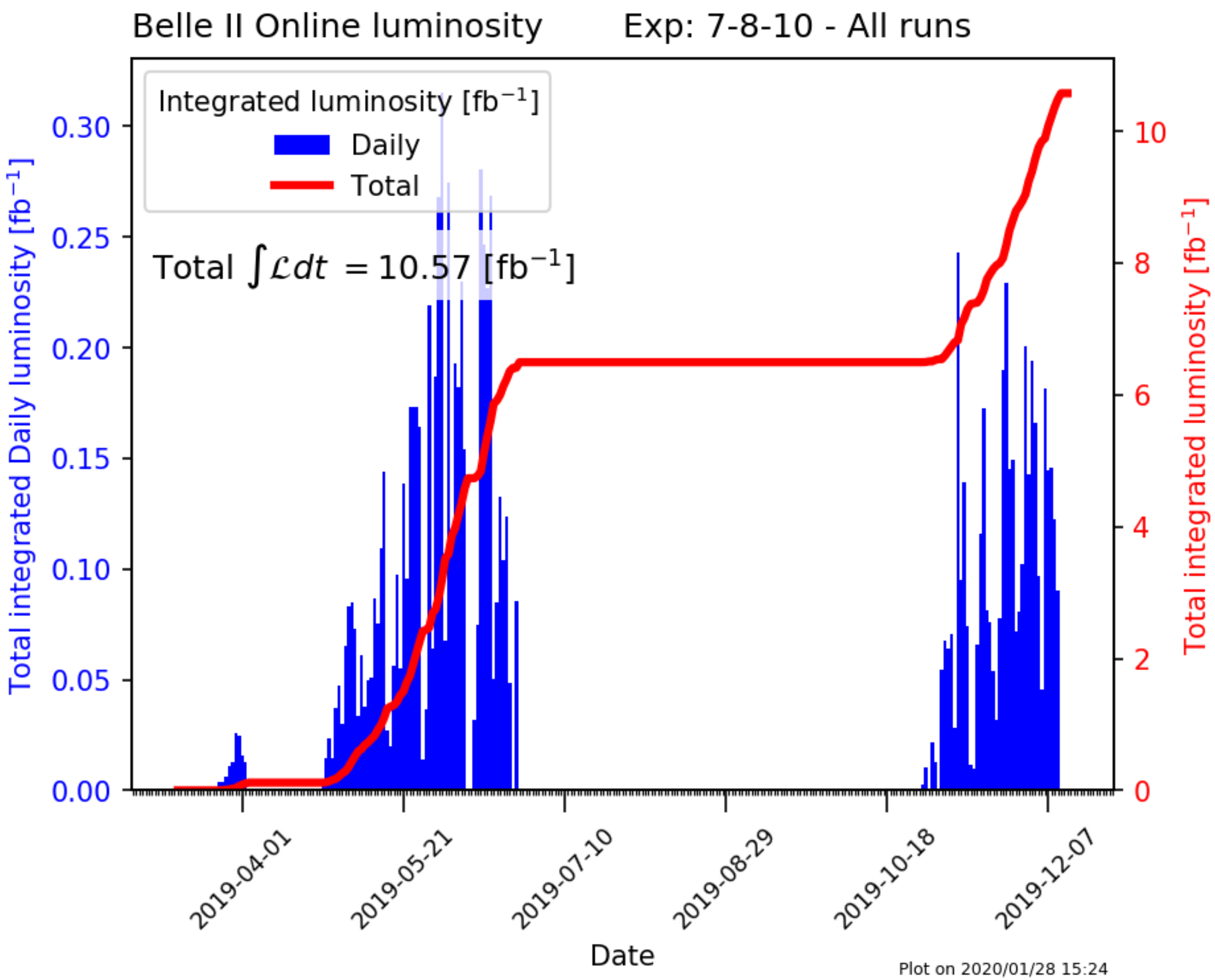
SuperKEKB : Luminosity in 2019c

- **Peak luminosity record : 1.138x10^{34} cm^{-2}s^{-1}**
  - **With detector HV on**
  - **1/80 of the target luminosity**



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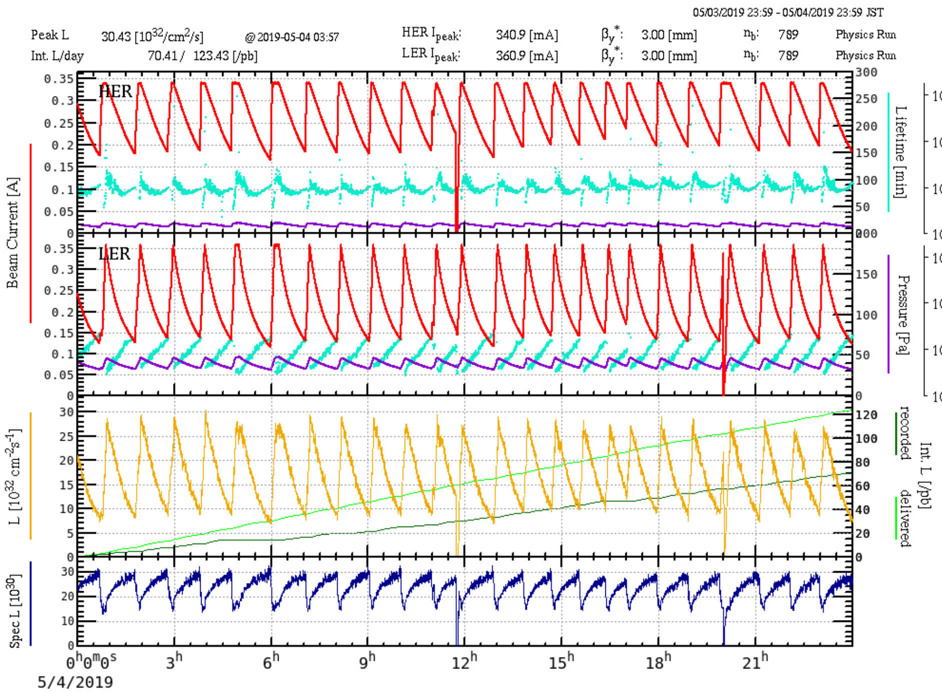
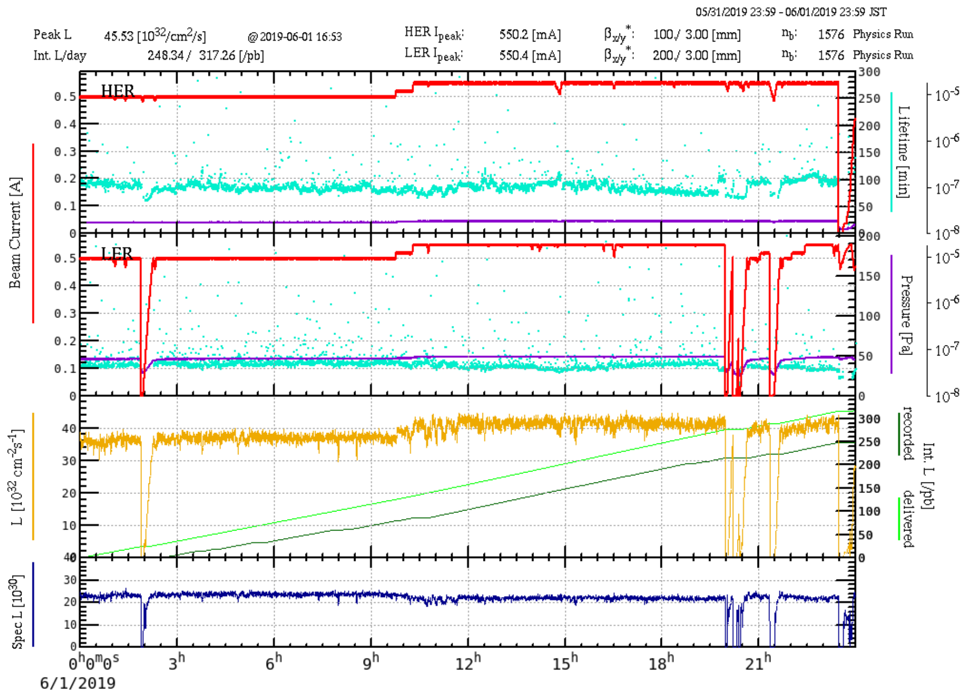
SuperKEKB Continuous Injection

- KEKB employed continuous injection to maintain high instantaneous luminosity
- SKEKB needs it because of short lifetime of beams
- Injection occurs during detector HV on
  - L1 trigger should be vetoed to avoid contamination of injection noise

Normal Injection Mode



Continuous Injection Mode



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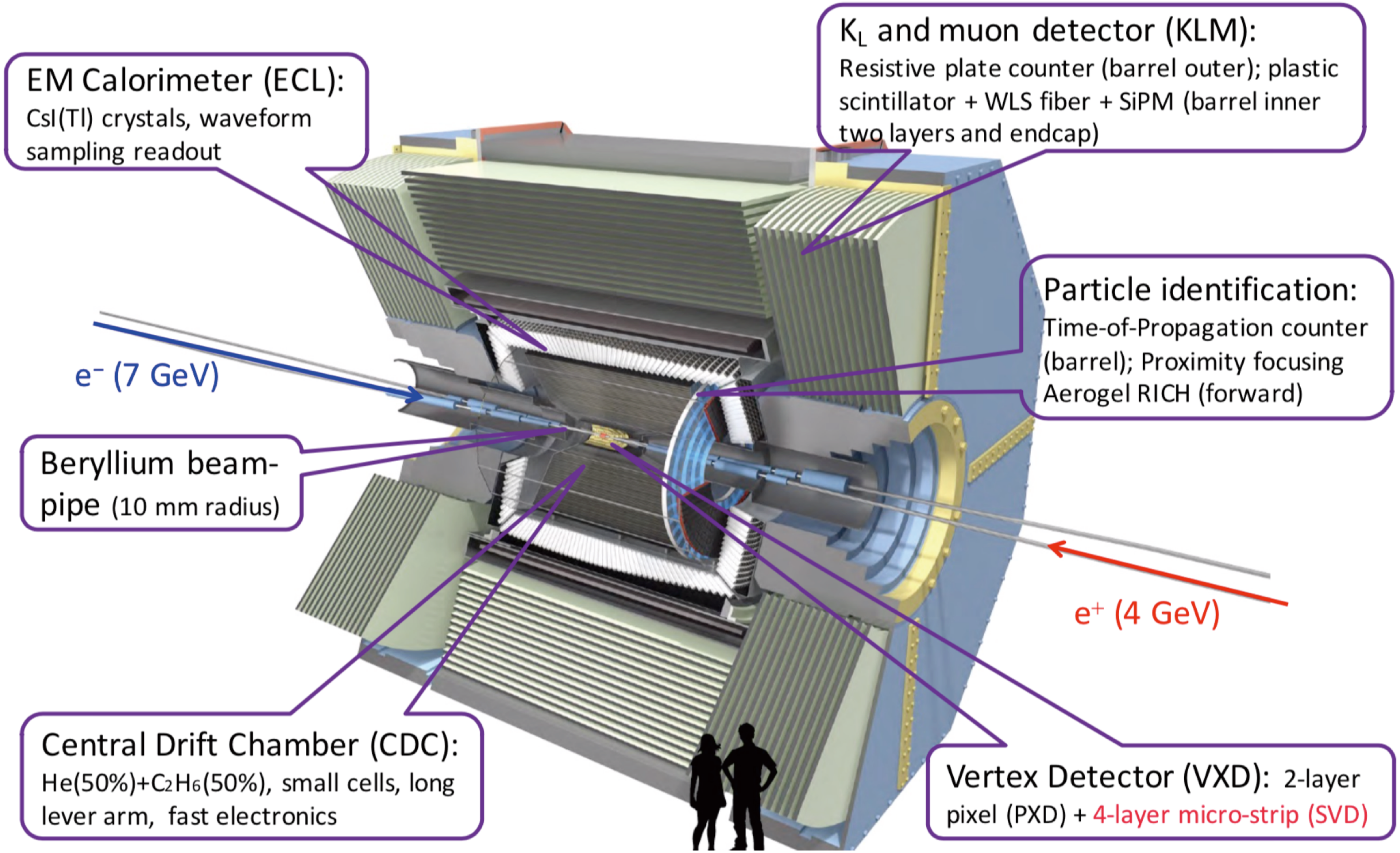
Belle-II Detector

- **General purpose detector**
  - **Aiming for CPV in B and D mesons, SM tests, precise flavor physics, new particles, and search for dark sectors**



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Physics Targets

Physics Process	Cross-Section (nb)	Rate @ $L=8x10^{35}$ (Hz)
Upsilon(4S)	1.2	960
Continuum	2.8	2200
μμ	0.8	640
ττ	0.8	640
Bhabha *	44	350
γ-γ *	2.4	19
Two photon **	13	10000
Total	67	~15000

"Hadronic Events"

~1/2 of the max. L1 TRG rate (30kHz)

* Rate of Bhabha and γ-γ are pre-scaled by factor 100

** Rates are estimated by the luminosity component in Belle L1 trigger rate

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Requirements for L1 TRG

- High efficiency almost 100% for hadronic events
  - No dead-time -> pipeline logic
  - Redundant and independent TRG logics -> CDC and ECL triggers
- Max. average L1 rate 30 kHz @ $8x10^{35}$ $cm^{-2}s^{-1}$
  - Limited by DAQ capability
  - Good background reduction necessary : S/N should be better than 1
  - Flexible TRG logics to manage BG rates : FPGA
- L1 latency 4.400 usec
  - Limit from SVD front-end
- Event timing precision less than 10 nsec
  - Request from SVD front-end
- Two-event separation 500 nsec
  - CDC max. drift time

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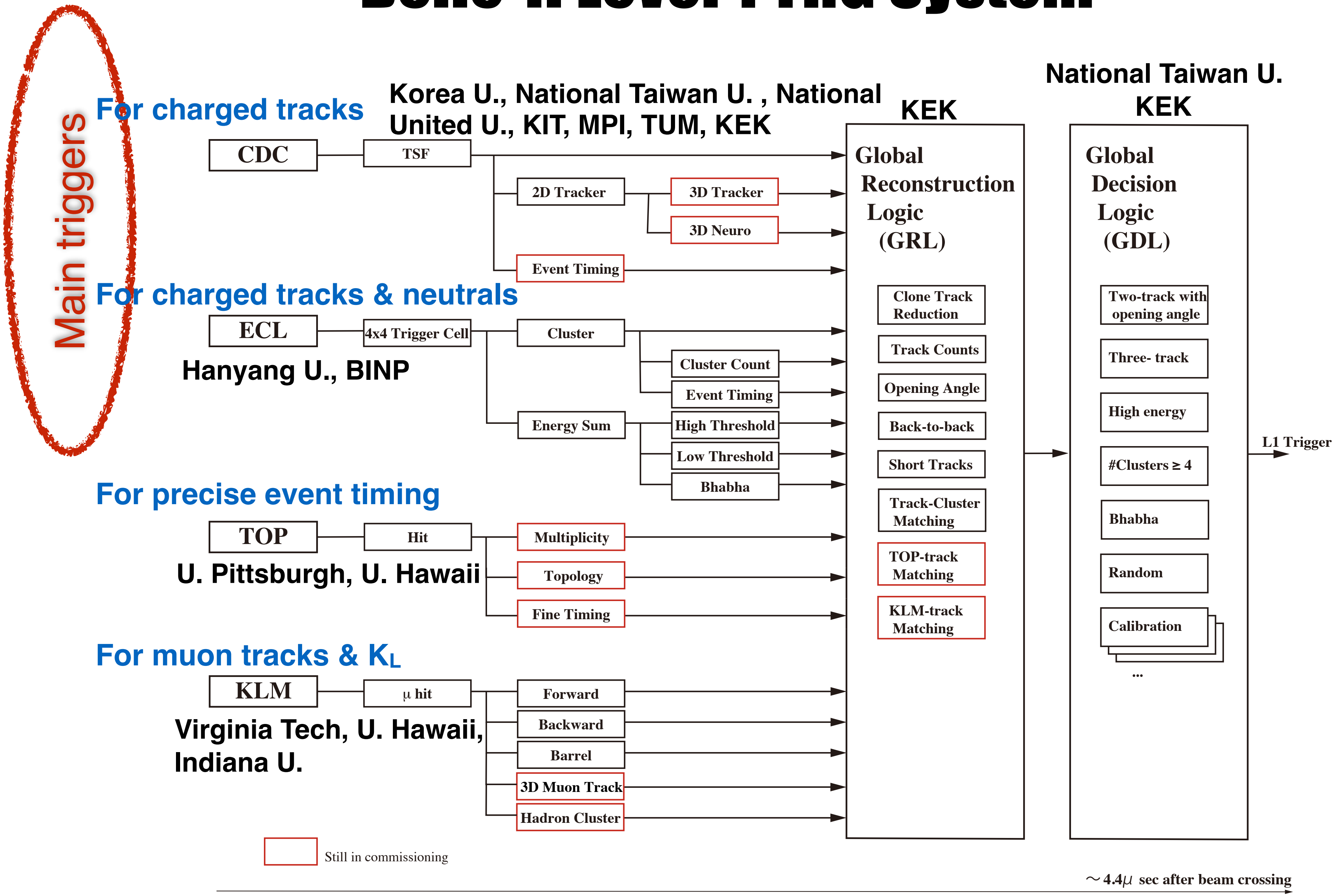
Belle-II Level 1 TRG System



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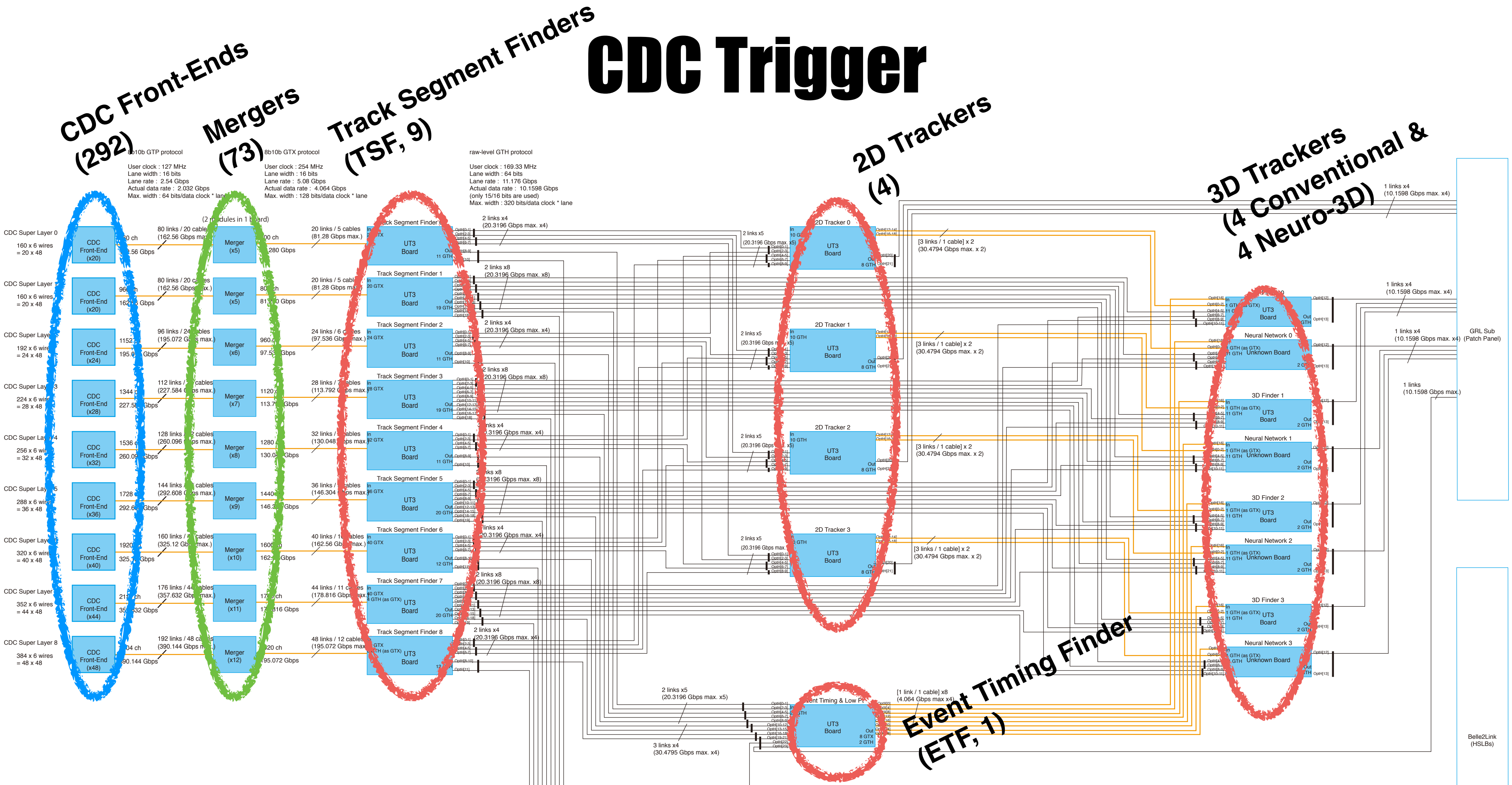
CDC Trigger



- All logics are pipelined := no dead time
- No data truncation up to TSF
  - 370Gbps in Merger-TSF links
  - All connections are optical links (2.54 - 6.27 Gbps)
- Each tracker can handle up to 4 tracks (total 16 tracks in each data clock)
- TSF, 2D, 3D, and ETF use Universal Trigger board (UT3, modules in ◯)

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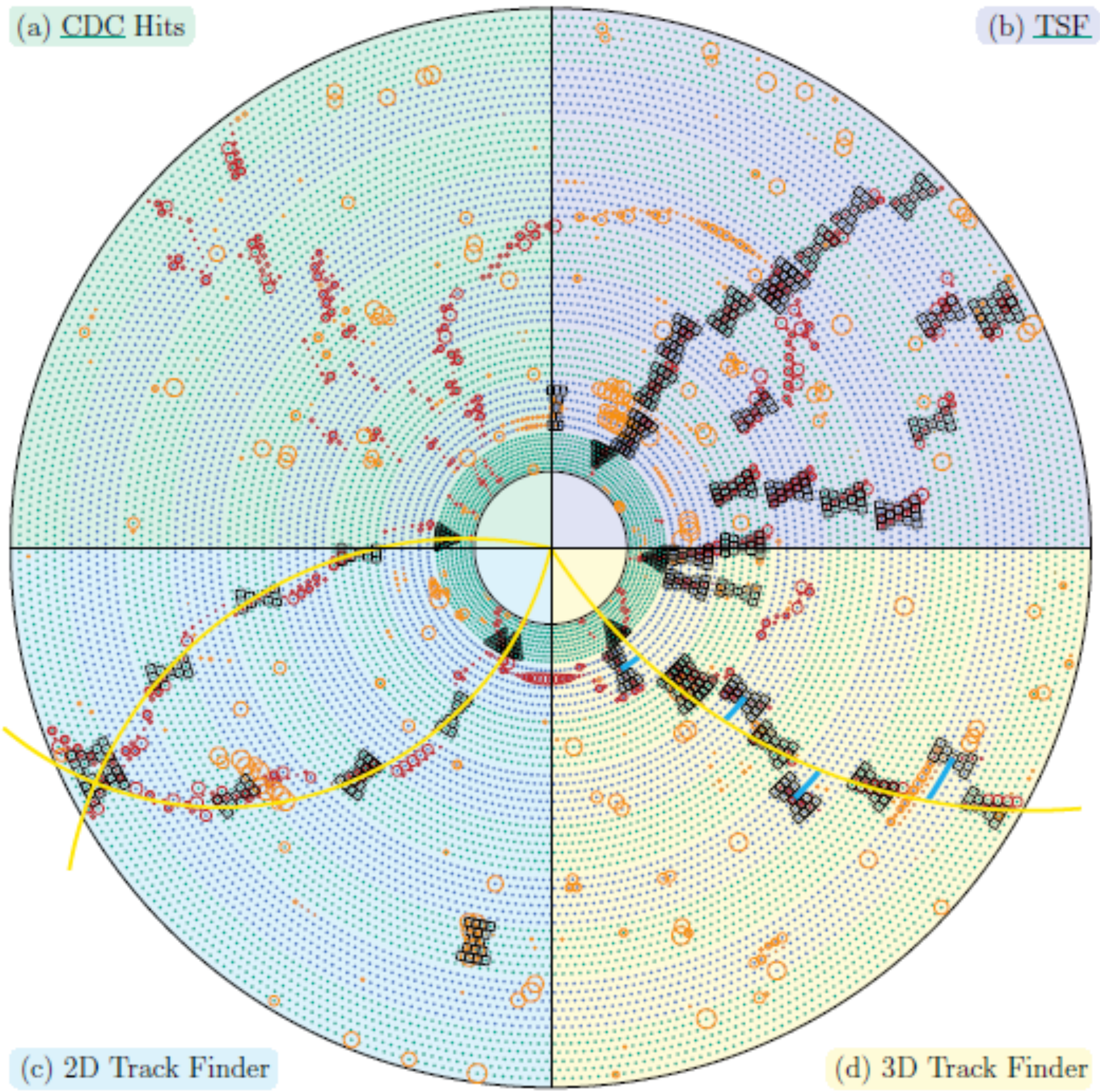
CDC Trigger (2)



(a) CDC Hits on Front-ends

(b) Track Segment Finding

(c) 2D Track Finding

(d) 3D/Neuro Track Finding

Please check :
Development of the Level-1 track trigger with Central Drift Chamber detector in BelleII experiment and its performance in SuperKEKB 2019 Phase 3 operation,
By YunTsung Lai (Poster session)

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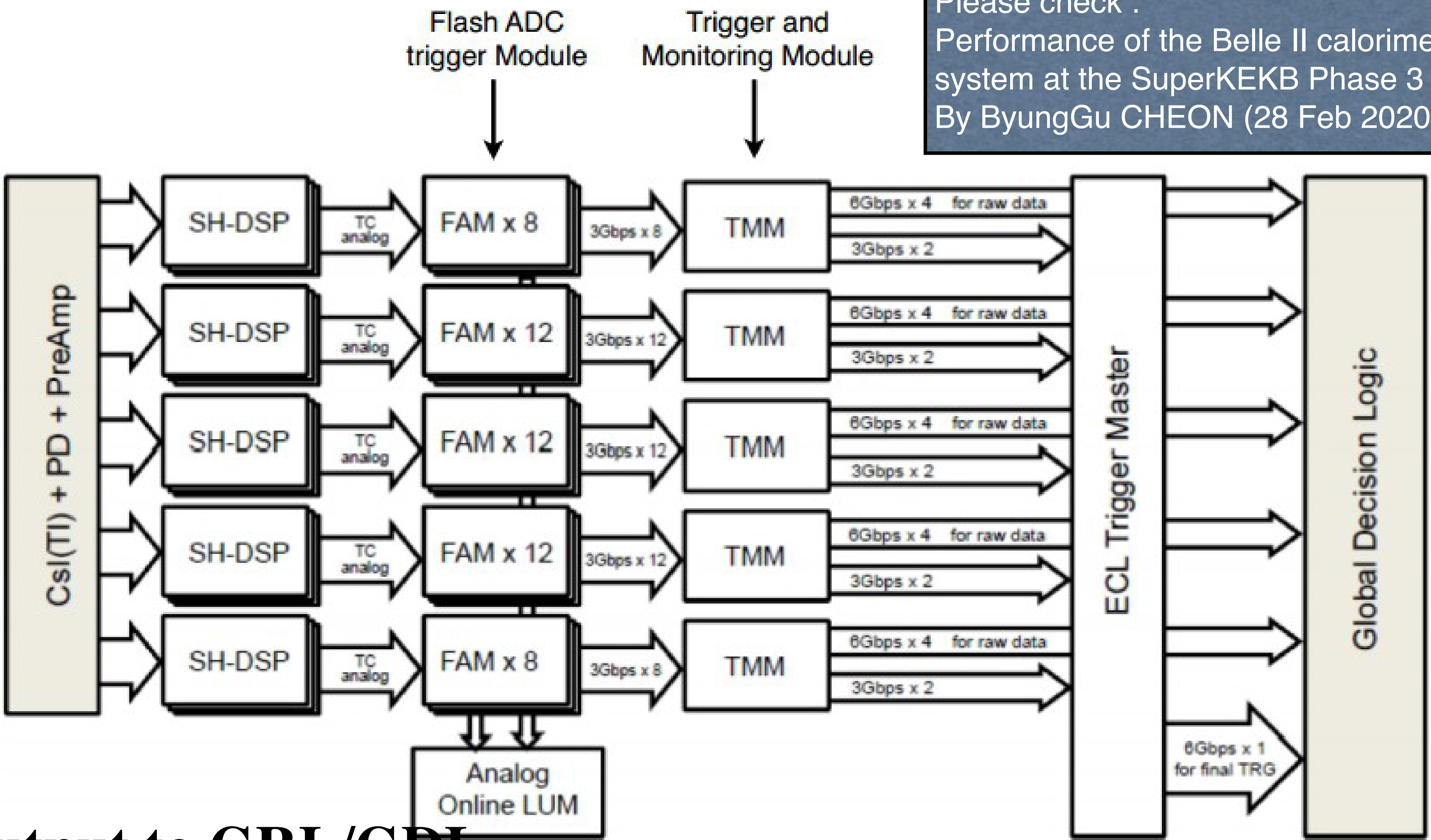
ECL Trigger

Please check :
Performance of the Belle II calorimeter trigger system at the SuperKEKB Phase 3 run
By ByungGu CHEON (28 Feb 2020 at 15:50)



- **Output to GRL/GDL**
  - **Energy sum**
  - **Cluster info. with energy and position (6 clusters of most energetic)**
  - **Identification of Bhabha**
  - **Event timing**

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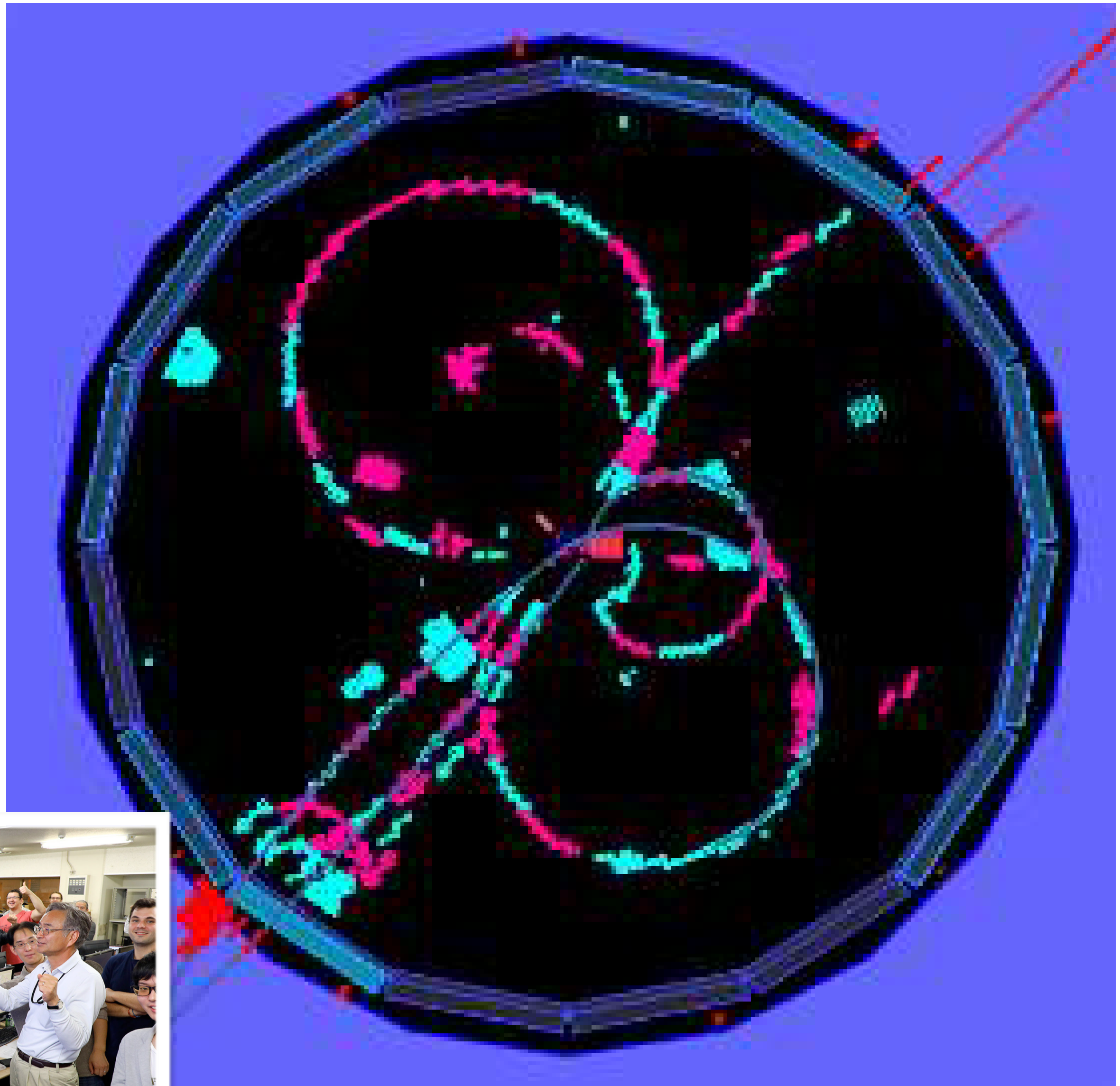
The First “hadronic”-like event triggered by L1 TRG

26 April, 2018



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L1 TRG Condition in 2019c

- **Hadronic events (e+e– → $q\bar{q}$)**
  - **Three-track, high energy(>1GeV), and #clusters≧4**
- **Low multi. events (τ pairs, mu pairs, two photons)**
  - **Two-track with opening angle(>90°), cluster combinations, etc**
- **Dark sector**
  - **Single cluster(>1GeV) w/o charged track, etc**
- **Bhabha and γ-γ**
  - **No pre-scale, all taken**
- **Calibration and test triggers**
  - **Many triggers were on for calibration and test purpose**
- **Random**
  - **Background data to overlay in MC data**
  - **Delayed Bhabha**
    - **Generate a trigger 7 revolutions after Bhabha : proportional to luminosity**
- **Event timing**
  - **ECL timing : 92%**
    - **Resolution was ~5ns for Bhabha, ~8ns for hadronic events**
  - **CDC timing (if no ECL timing) : 8%**
    - **Resolution was ~20ns**

Because L1 TRG rate was quite lower than the DAQ limit, we could take these triggers w/o pre-scaling

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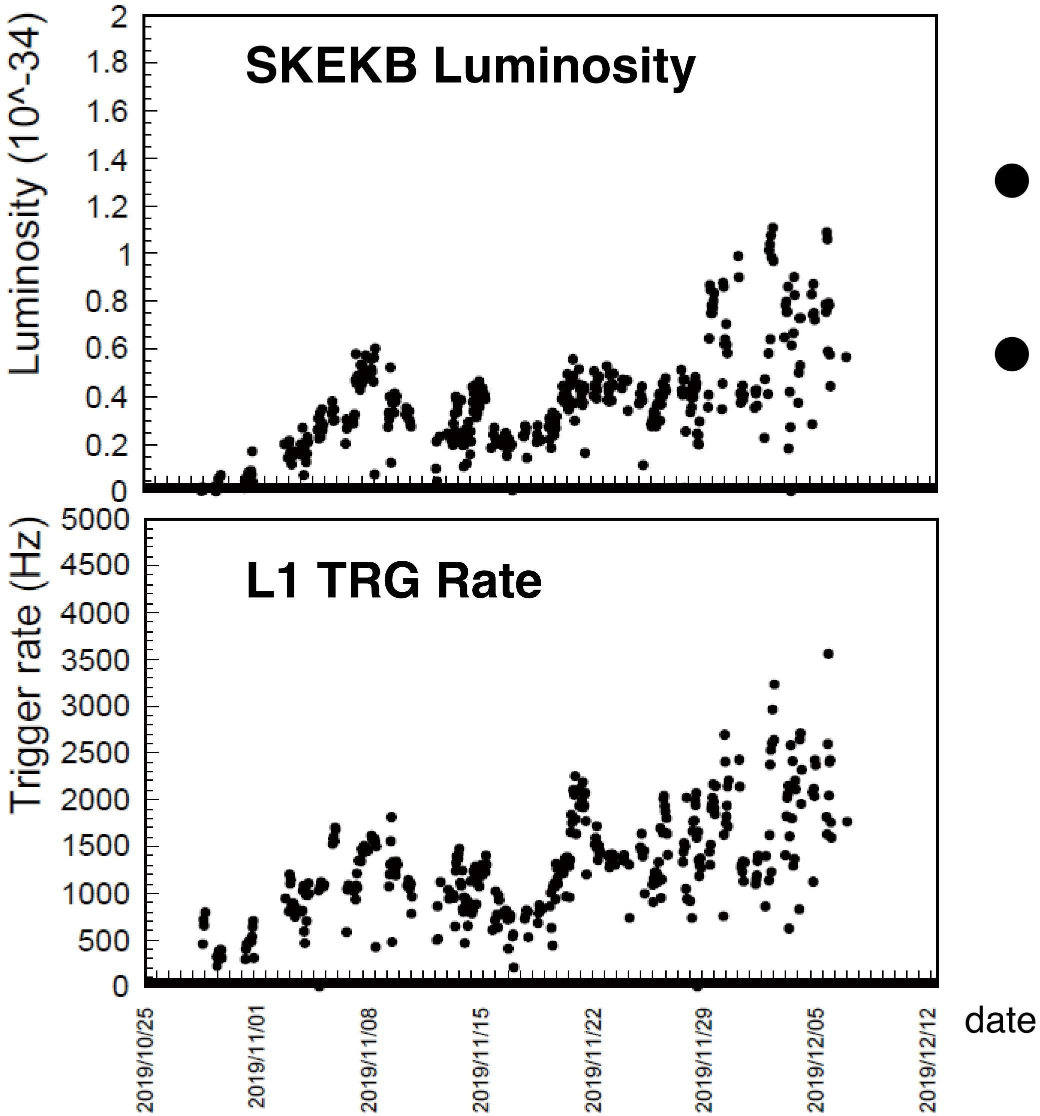
L1 TRG Rate in 2019c



- **Luminosity record 1.14x10[34] cm[−2]s[−1] with detector HV on**
- **Total L1 TRG rate was 1 to 3 kHz**
  - **DAQ limit was ~15 kHz**
  - **TRG condition was quite loose**
  - **Expected physics rate was 0.7 kHz at luminosity record**
  - **Others are beam backgrounds and calibration/test triggers**
  - **Low purity : S/N = 0.7/2.3 ~ 0.3**

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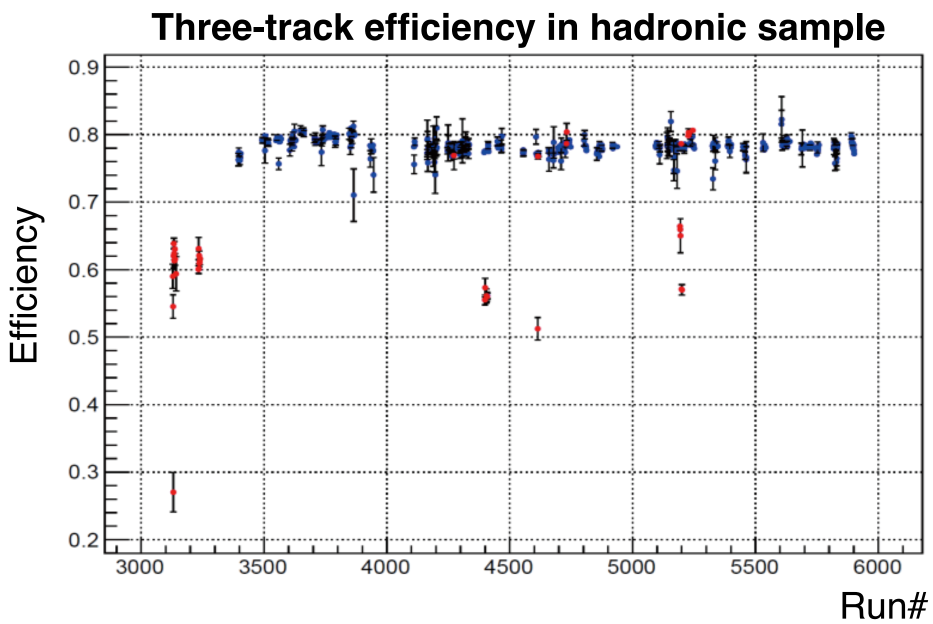
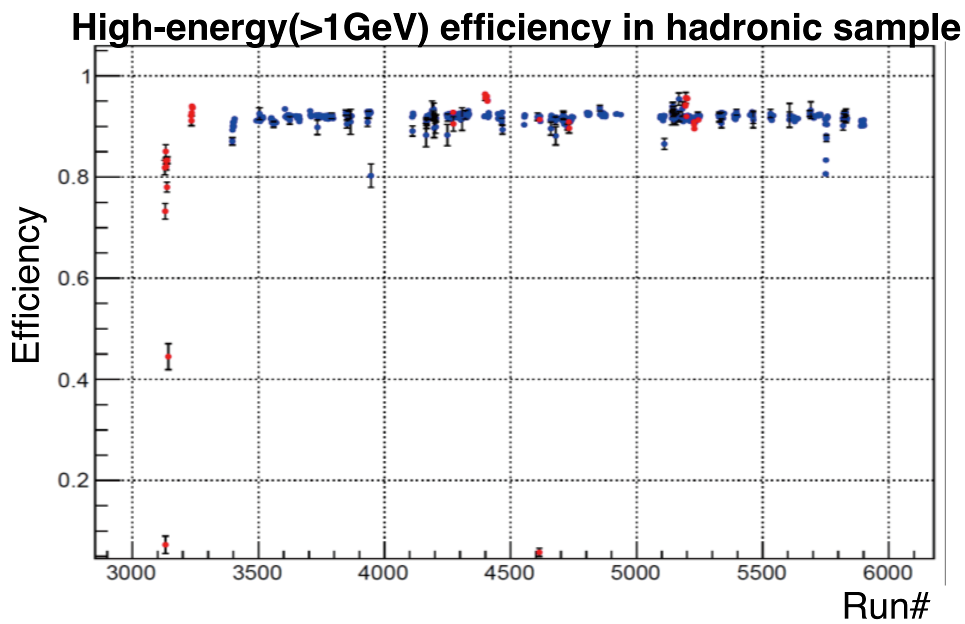
TRG Efficiency in 2019c

- TRG performance in the online reconstructed data
  - Sample purity is not high enough to know real efficiencies
  - Efficiencies are underestimated
    - Three-track in hadronic events : ~ 80%
    - High-energy in hadronic events : ~ 90%
- In the offline reconstructed data, we confirm
  - Three-track in hadronic events = 98.3%
  - High energy in hadronic events = 93.0% (at least)
  - Inefficiency for hadronic events = (1–0.98)*(1-0.93) < 0.01





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L1 TRG Operation in 2019c

- **TRG control online software had some troubles**
  - **Cause downtime of data taking**
  - **It was improved drastically during 2019 but still we have**
- **TRG performance online monitors were improved**
  - **We could know TRG malfunction as quick as possible**
- **CDC neuro 3D tracker**
  - **We confirmed neuro 3D tracker could reduce track trigger rate by 30% at least with lose of 1% hadronic event at most**
  - **Position resolution of z (along beam direction) was ~4cm**
- **TOP timing trigger operation**
  - **TOP timing logic worked well in cosmic test runs, but not usable in collision data taking**
- **KLM muon trigger operation**
  - **KLM trigger logic worked but suffered by large timing jitter so that we couldn't coincide with other triggers**

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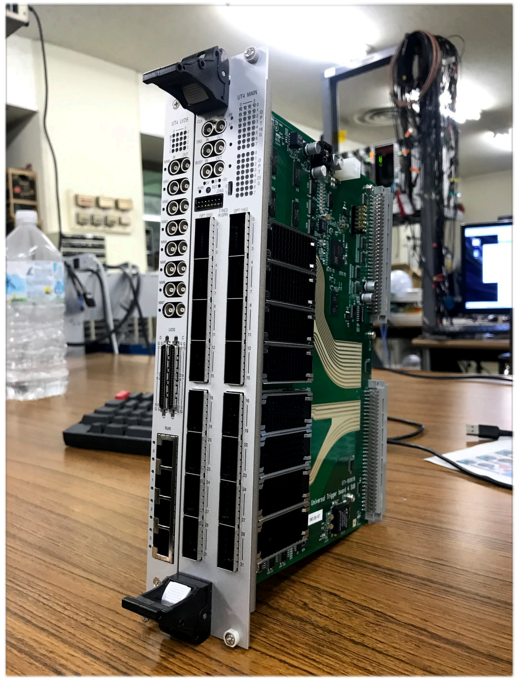
UT3 and UT4

- **Universal Trigger board (UT) has been developed since Belle experiment**
  - **General IO capability (optical transceiver was used since UT2)**
  - **All IO are connected to single large FPGA**
- **Belle-II L1 TRG heavily utilizes UT3 in all sub-triggers**
  - **Sharing common functions : clocking, IO I/F, VME I/F, data readout**
- **UT3 will be replaced with UT4**
  - **More complex trigger logics can be used with larger size of data**

UT4



	FPGA	#cells	Max. Transfer speed / ch	Total Transfer speed
UT3	Virtex6 XCVHX565	566,784	11 Gbps	550 Gbps
UT4	UltraScale XCVU160	2,026,500	25 Gbps	1280 Gbps

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Summary

- **TRG condition was quite loose**
  - **Because L1 TRG rate was far below the DAQ limit**
  - **TRG studies, developments, and debugging were easier**
  - **We may keep this condition in early 2020 runs**
    - **Until L1 TRG rate approach the DAQ limit**
- **L1 TRG performance was good**
  - **Main triggers (CDC and ECL) worked as expected**
  - **Inefficiency for hadronic events are less than 1%**
  - **Event timing jitter was OK (SVD data was fine)**
  - **Still we are trying to improve performance**
- **L1 TRG operation was stable**
  - **TRG control online softwares needs some improvements**
  - **Performance monitors worked well, still improving them**
- **Some L1 TRG components are still in commissioning**
  - **CDC 3D trackers will come soon**
    - **Neuro 3D tracker showed promising performance**
    - **Background induced track trigger rate will be decreased**
  - **TOP timing trigger and KLM muon trigger will come soon**

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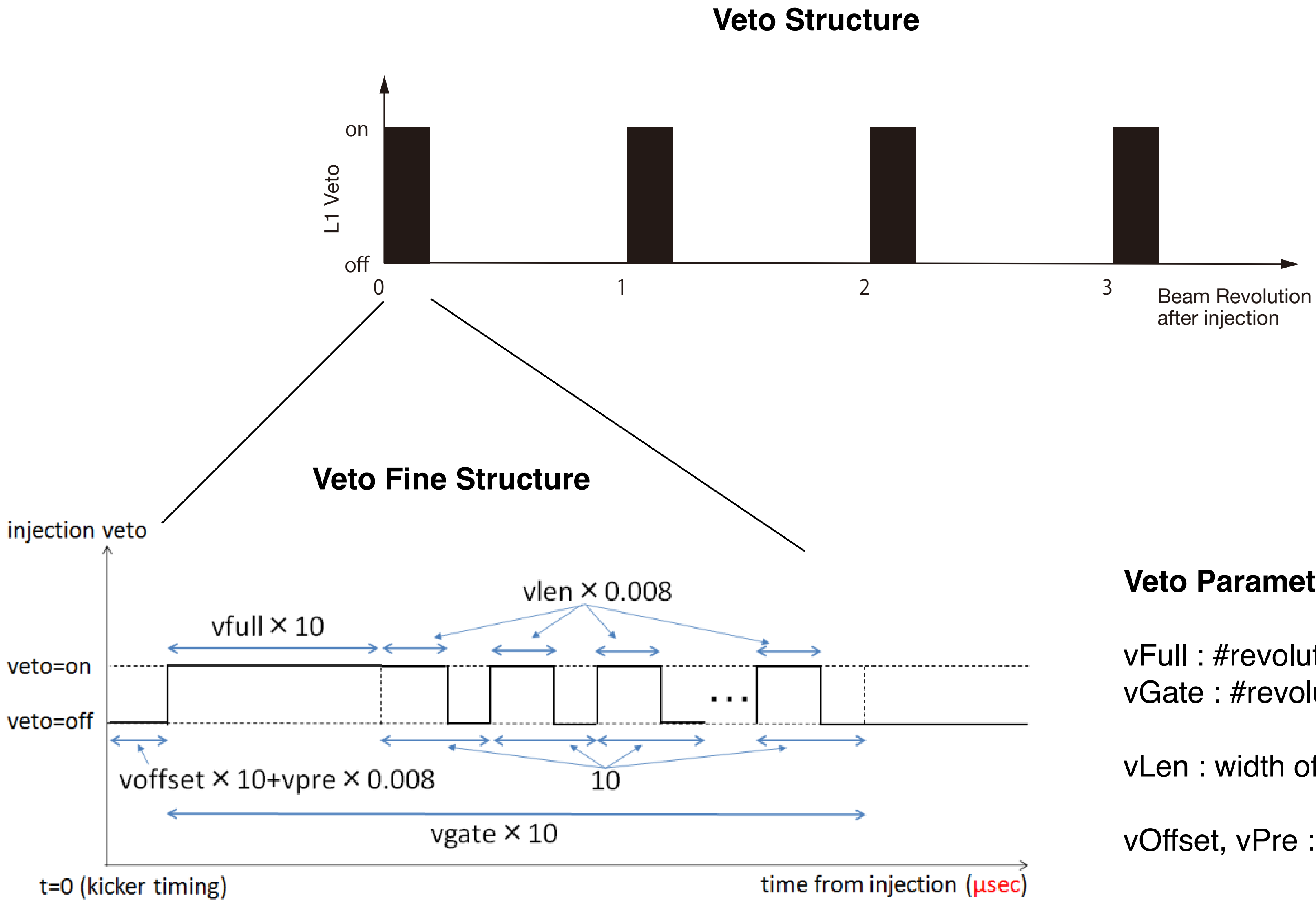
Back-up

L1 TRG Veto for Cont. Injection



Veto Parameters

vFull : #revolution to veto completely
vGate : #revolution to partial veto

vLen : width of partial veto

vOffset, vPre : timing adjustment

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Expected TRG Rates

2019c Lum. Record

Process	C.S. (nb)	R@L=11x10^33 (Hz)	R@L=8x10^35 (Hz)	TRG logic
Upsilon(4S)	1.2	13.2	960	CDC 3trk(fff) ECL high energy(hie) ECL 4 clusters(c4)
Continuum	2.8	30.8	2200	
μμ	0.8	8.8	640	CDC 2trk(ffo) etc
ττ	0.8	8.8	640	
Bhabha	44	484	350 *	ECL Bhabha(bhabha, 3D bhabha)
γ-γ	2.4	26.4	19 *	
Two photon	13	143	10000	CDC 2trk(ffo) etc
Total	67	715	~15000	

- **PS=1 for Bhabha in 2019c**

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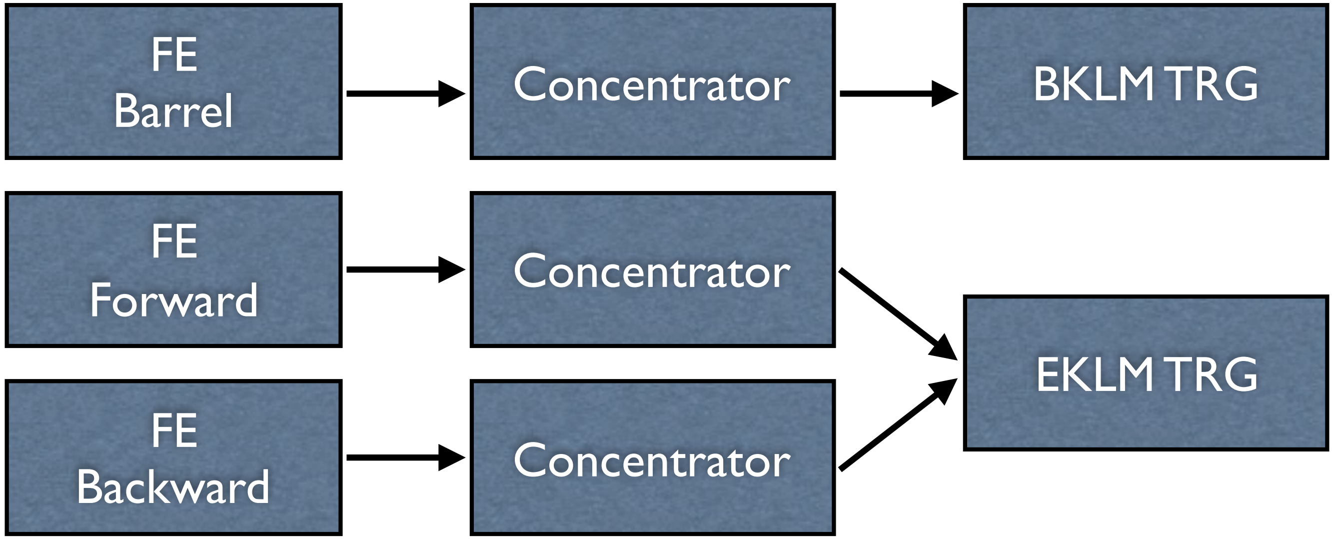
KLM Trigger



- **To provide muon hit information in L1 TRG**
- **Stably operated in 2019c**
- **Timing jitter was quite large**
- **Efficiency analysis is on going**

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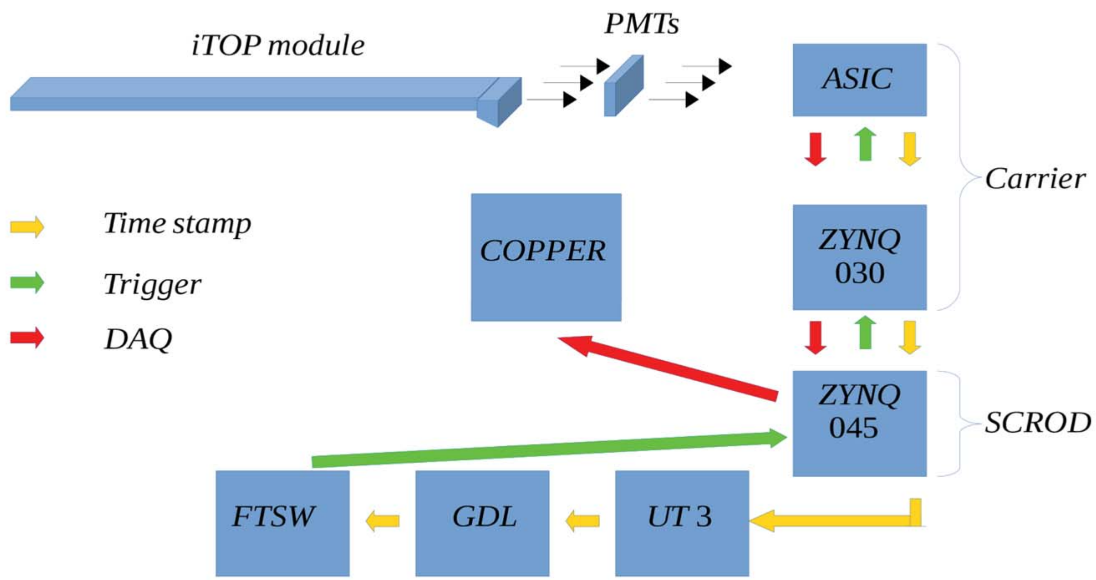
TOP TRG



- To provide a good event timing information in L1TRG
- Hit timing information of 16 TOP bars are sent to two UT3s
- Stably operated in 2019c
- Timing performance was good in cosmic runs
- Efficiency was very low in collision data taking

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