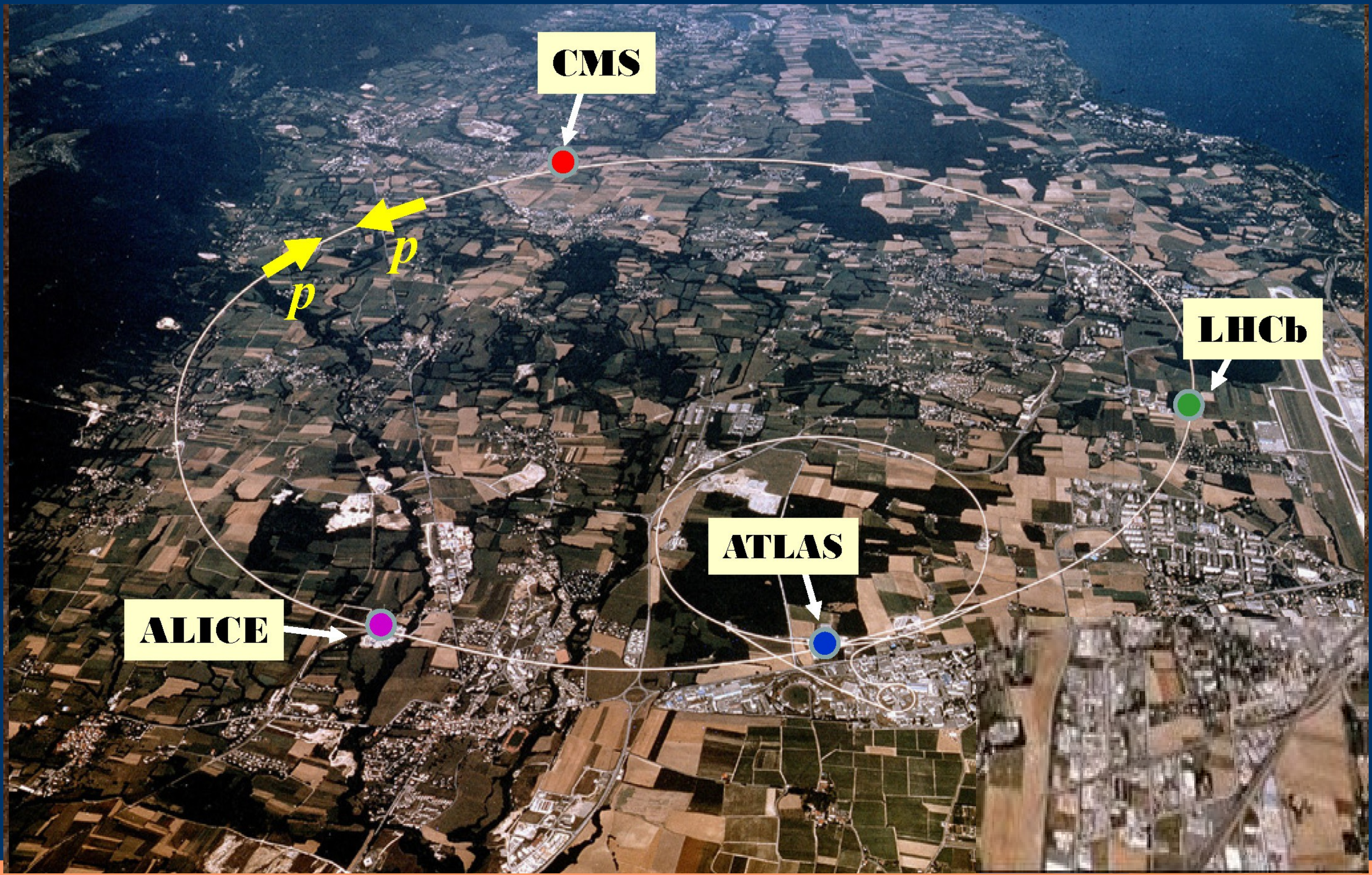
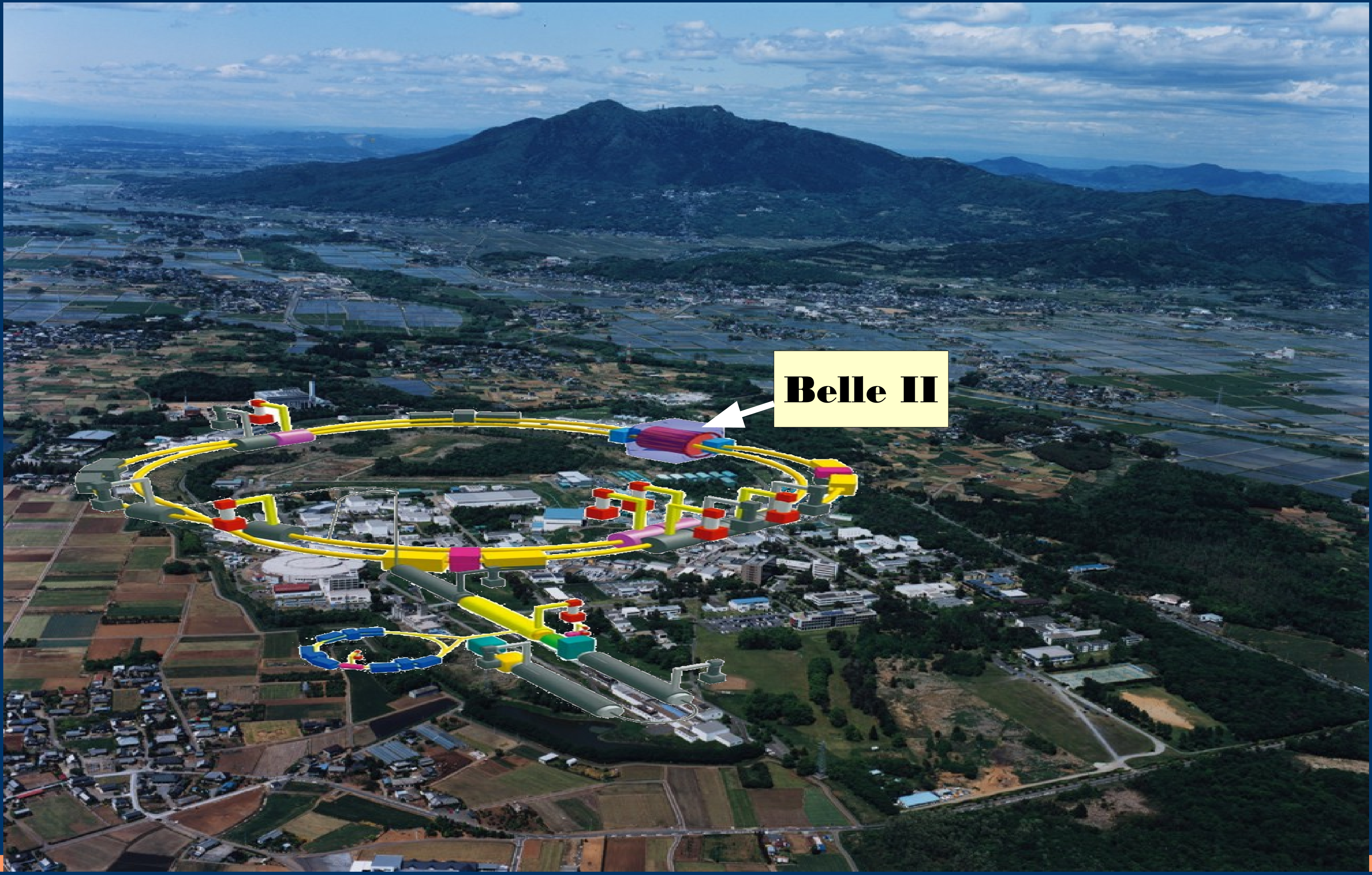
LHC, on the other side of the mountains
lake geneva
famous Mt. Jura
LINACs + small circles + a big circle



SuperKEKB, on the other side of the world
lake Kasumigaura（霞ヶ浦）
famous Mt. Tsukuba
LINACs + small circles + a big circle



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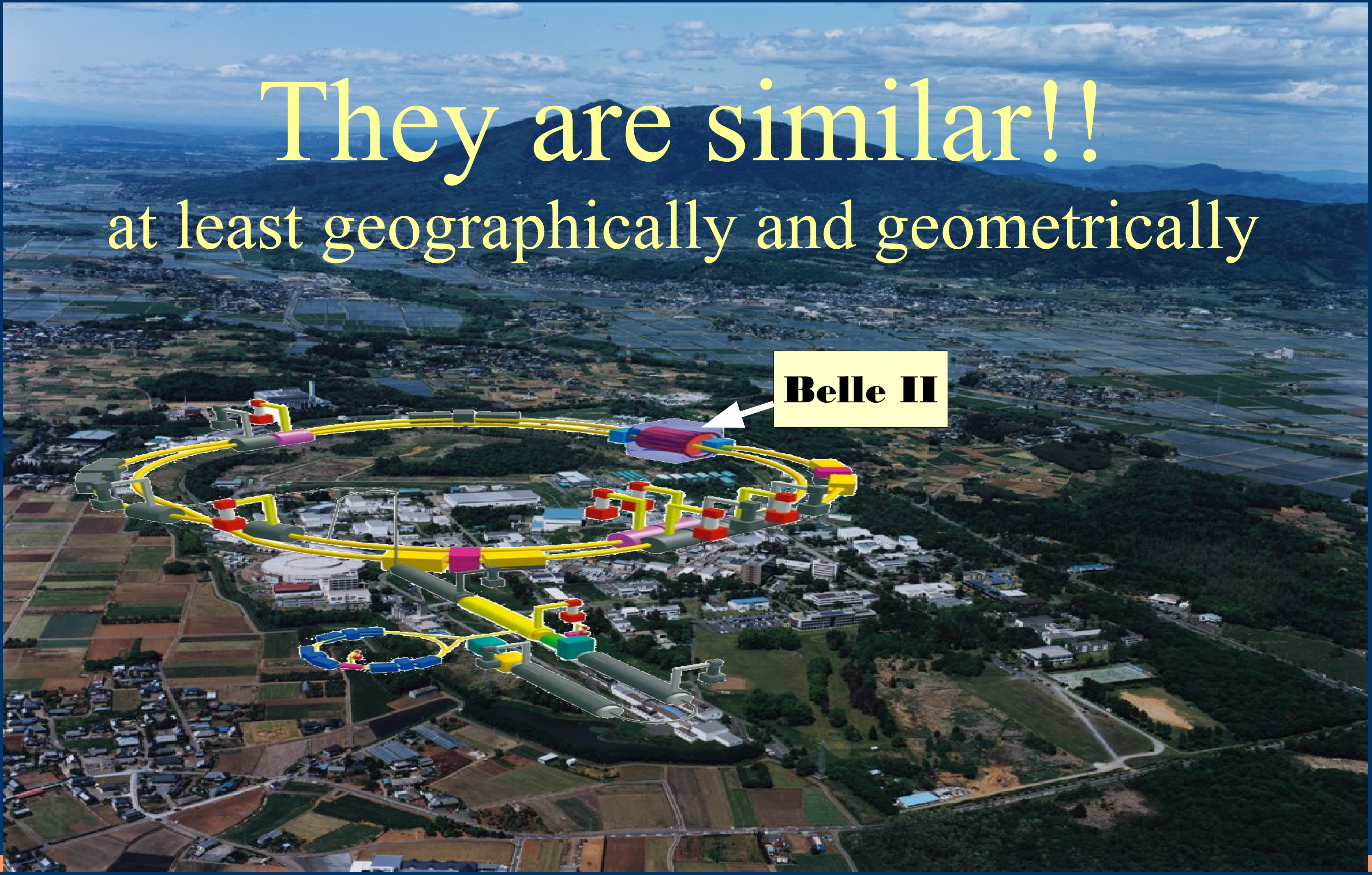


The Level 1 Trigger System for Belle II CDC

RT2016, Padova, Italy

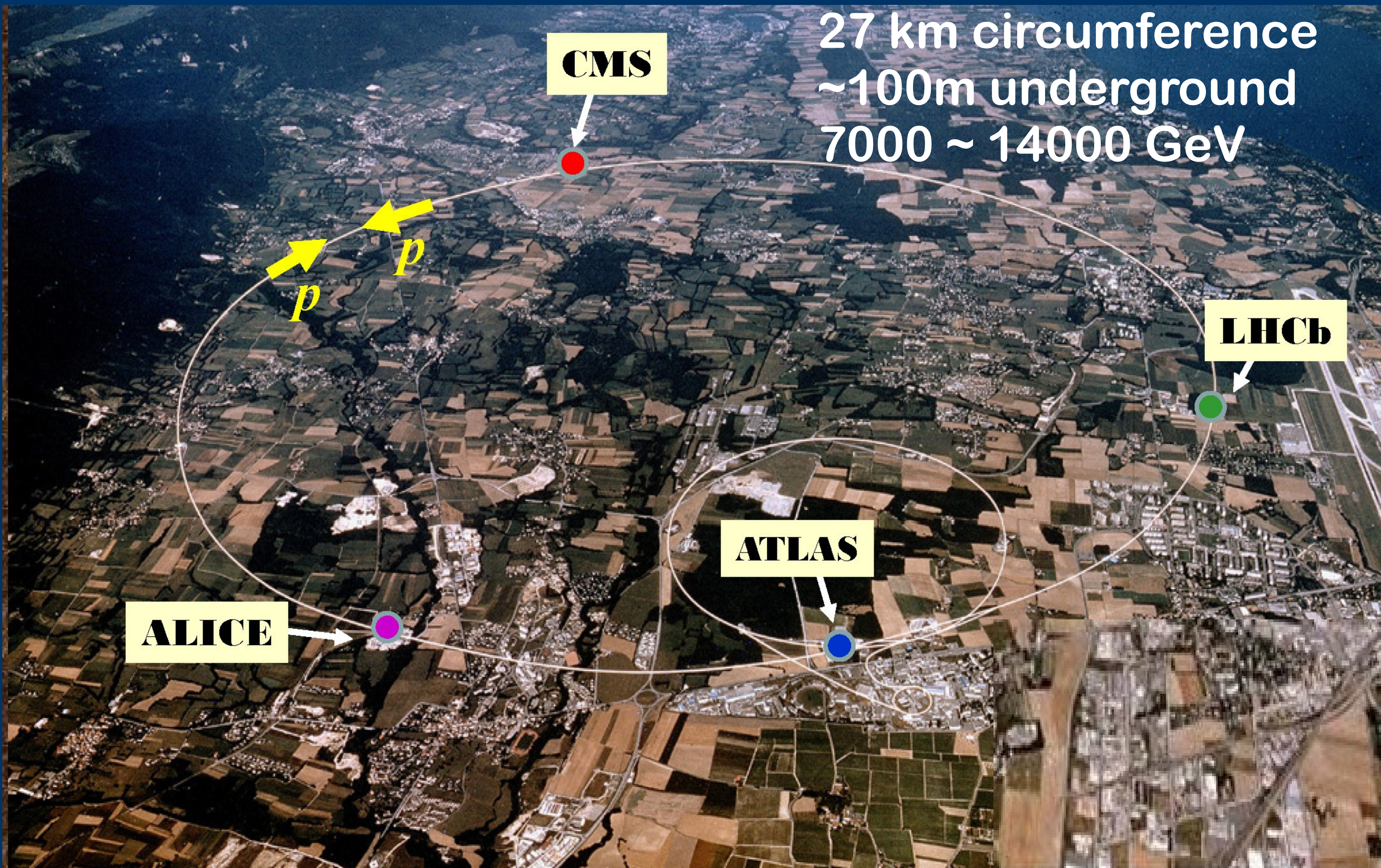
Jing-Ge Shiu (NTU) on behalf of the CDCTRG team

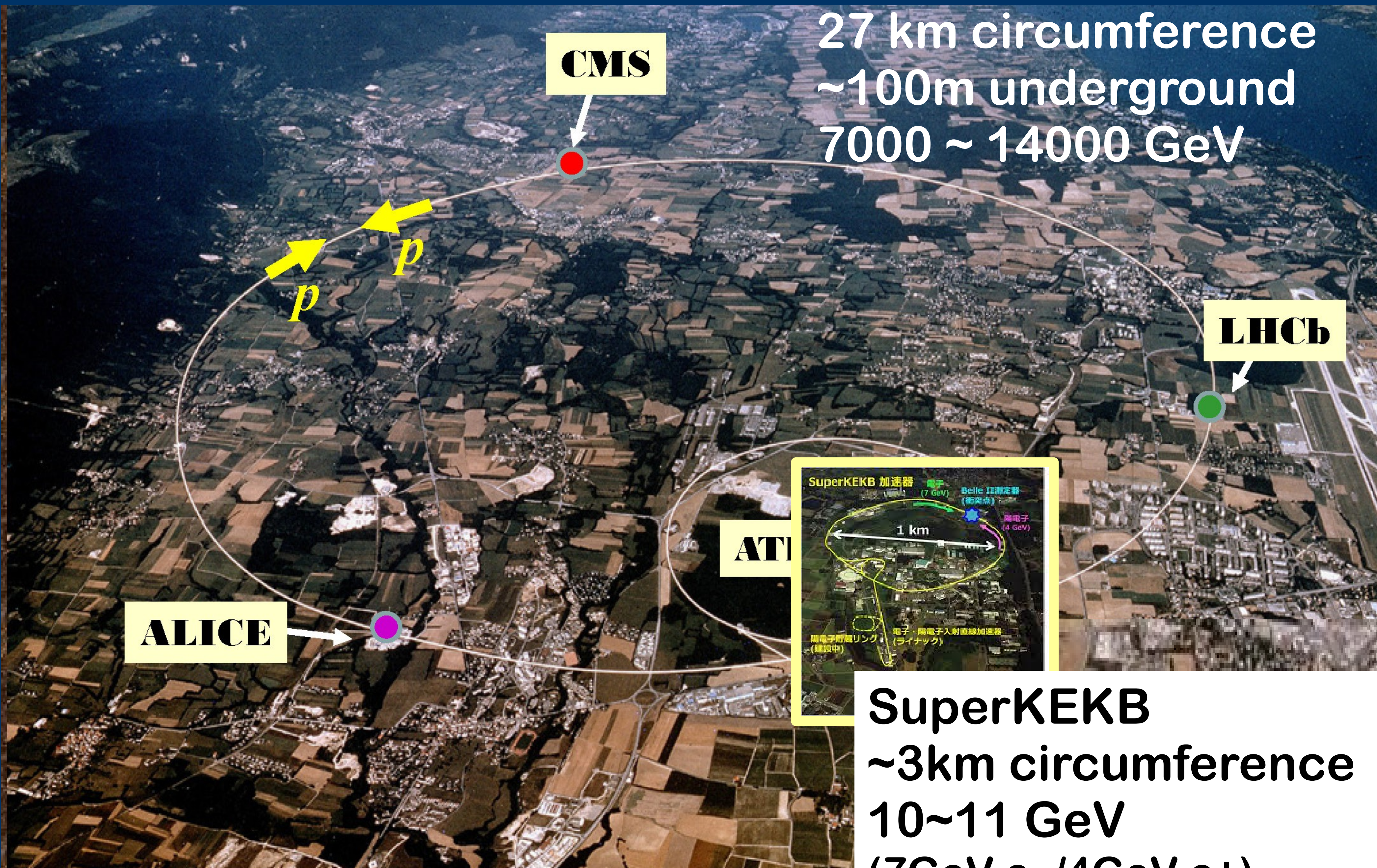
IPNS, KEK, High Energy Accelerator Research Organization, Japan
Korea University, Korea
National Taiwan University, National United University, Fu-Jen Catholic University, National Central University, Taiwan
Technical University of Munich, Ludwig-Maximilians-Universität München, Karlsruhe Institute of Technology, Germany

Outline

- Introdction
  - Belle II L1 trigger
- Belle II CDC trigger system
  - Track Segment Finder
  - 2D tracker
  - (3D) track z trigger
  - Event timing, low Pt track, GDL/GRL
  - Data transmission and flow control
- Current status and plan
- Summary

LHC
27 km circumference
~100m underground
7000 ~ 14000 GeV





LHC
27 km circumference
~100m underground
7000 ~ 14000 GeV

SuperKEKB
~3km circumference
10~11 GeV
(7GeV e- /4GeV e+)

Why do we need Super B factory?

Why do we need Super B factory?

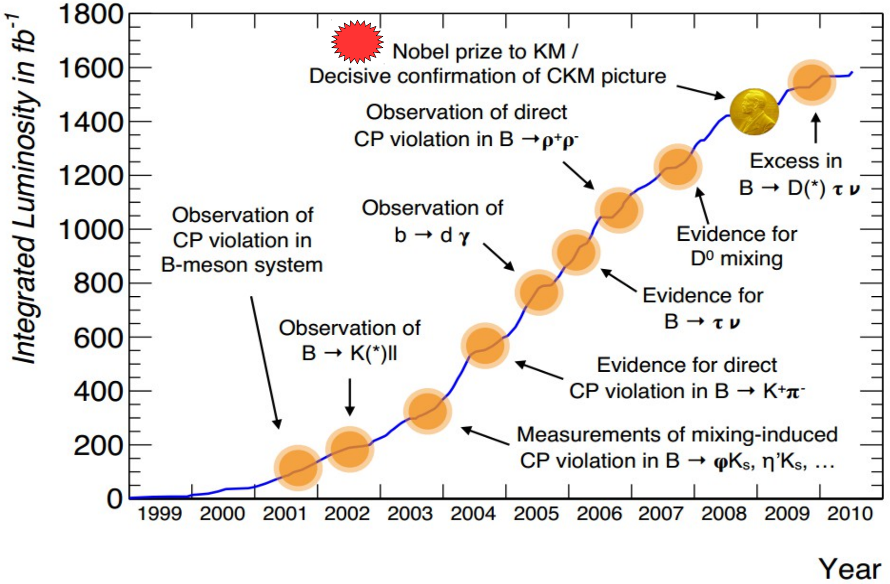
After 10 years operation, Belle and BaBar achieved a great success in B (charm, τ) physics studies and explored possible new physics

- CKM matrix elements of unitary triangle
- CP violation in B sector
- Rare decays, D mixing, exotic hadrons, …..

However, there are still remaining puzzles and open questions

- large CPV in the universe
- Higgs search, non-SM Higgs?
- how "standard" is the SM?
- …..

Which lead the HEP into two directions.



Why do we need Super B factory?

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- CP violation in B sector
- Rare decays, D mixing, exotic hadrons, …..

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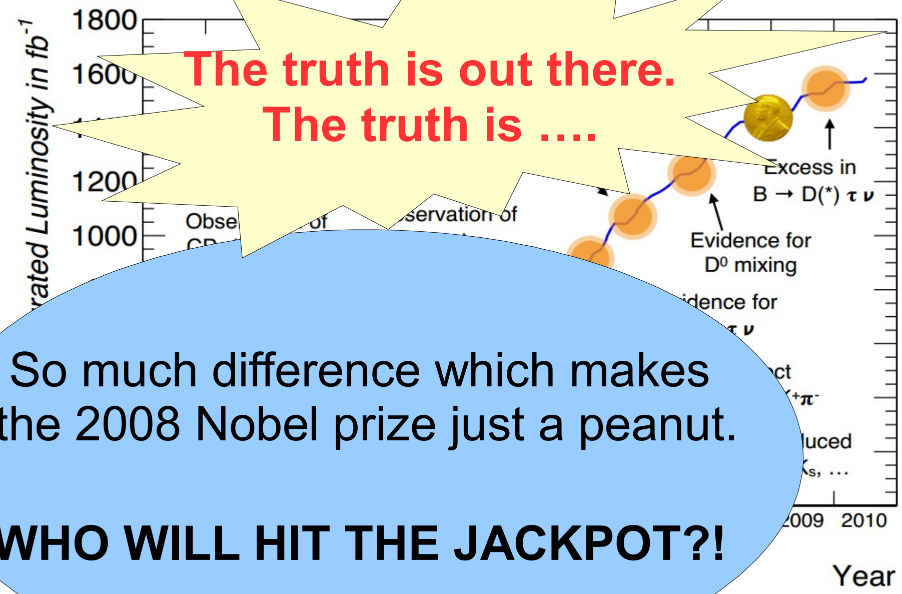


The truth is out there.
The truth is ….

So much difference which makes the 2008 Nobel prize just a peanut.

WHO WILL HIT THE JACKPOT?!

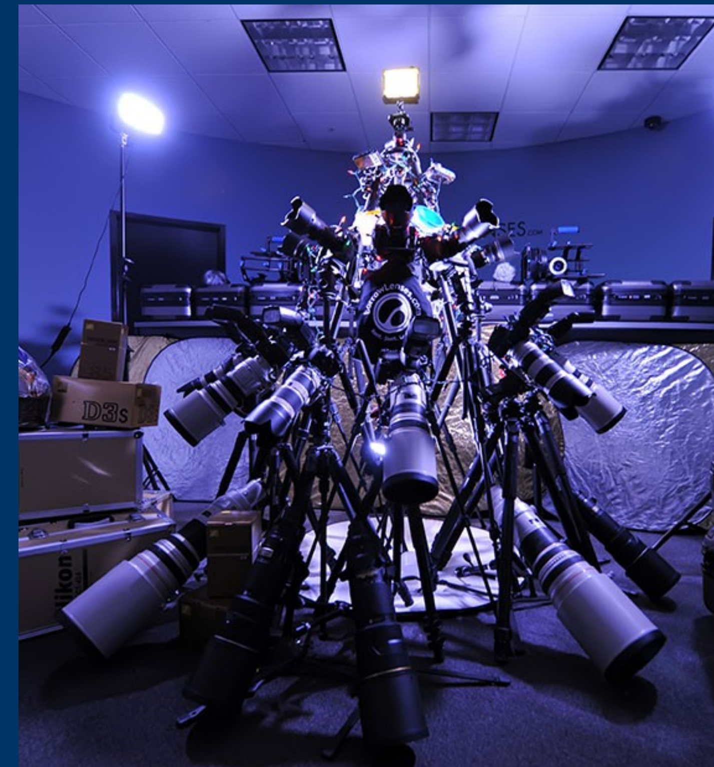
Joined collaboration of Belle II and SuperB
(work together, we can do it!)

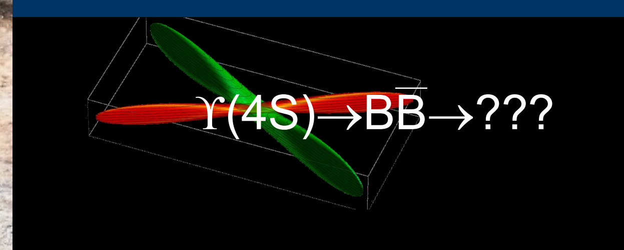
Spokesperson's wish:
to have 1st overseas collaboration meeting at INFN

Energy frontier
→ powerful in energy scale to search for new particles and physics. (LHC)

complementary with each other

Precision/intensity frontier
→ focus on a certain energy range for precision measurements to search for anomalies from the SM and new physics from rare decays (SuperKEKB + Belle II)





Belle II

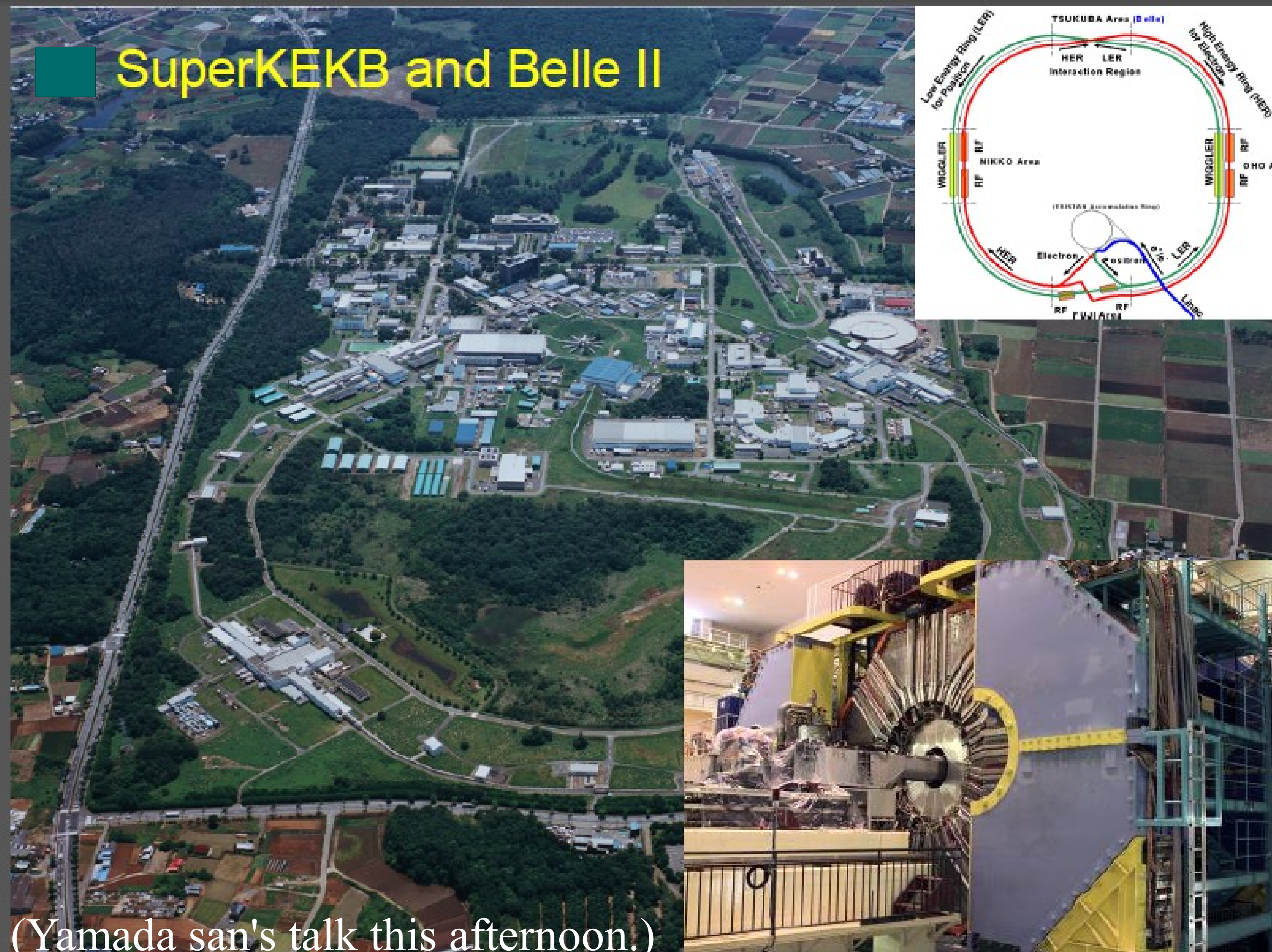
KEKB + Belle → SuperKEKB + Belle II

7 GeV e^-/ 4 GeV e^+

peak luminosity
8×10^{35} $cm^{-2}s^{-1}$
(40 x KEKB)

data collection goal
50 ab^{-1}
(50 x Belle).

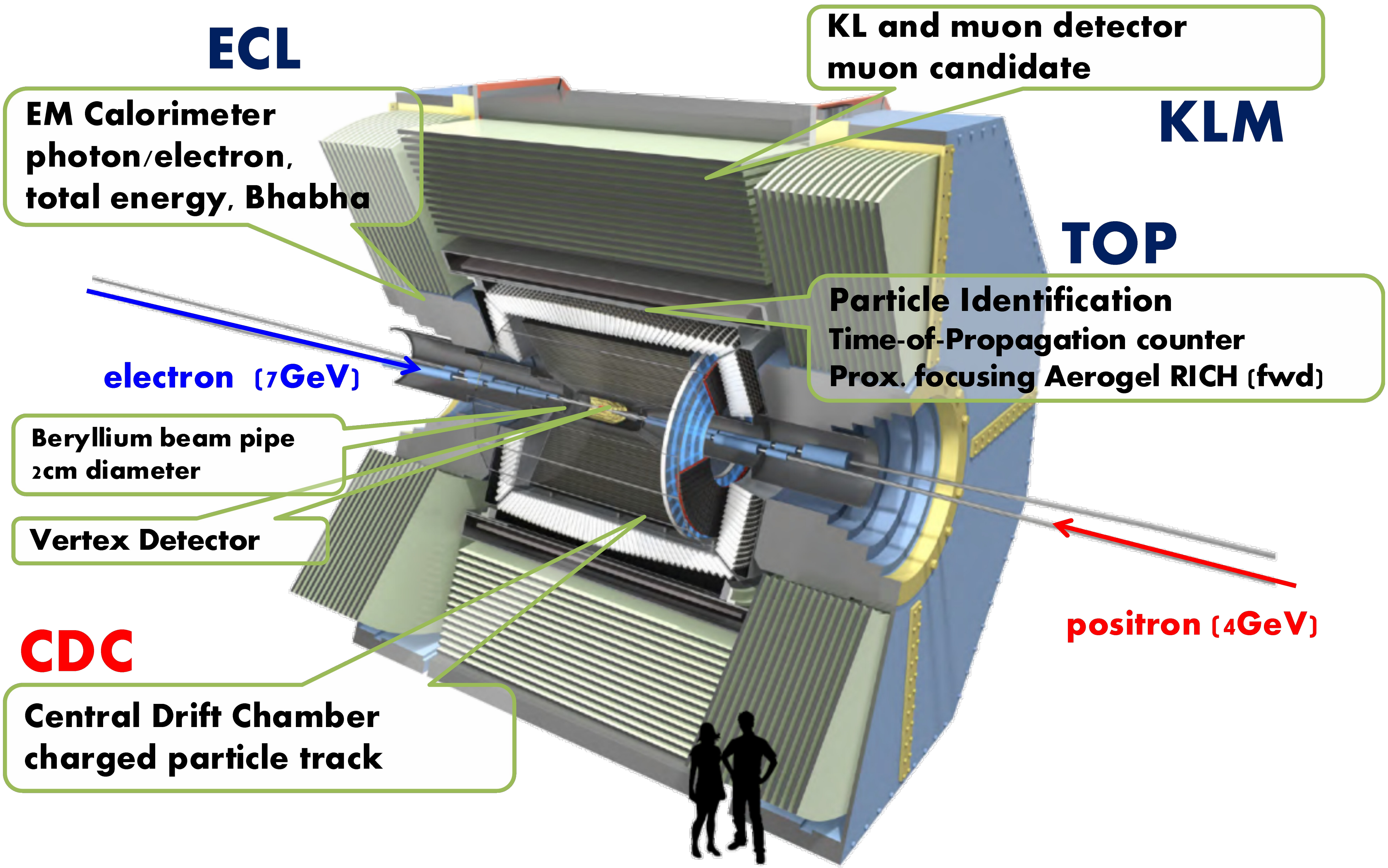
rare B decay,
high precision B
physics



(Yamada san's talk this afternoon.)

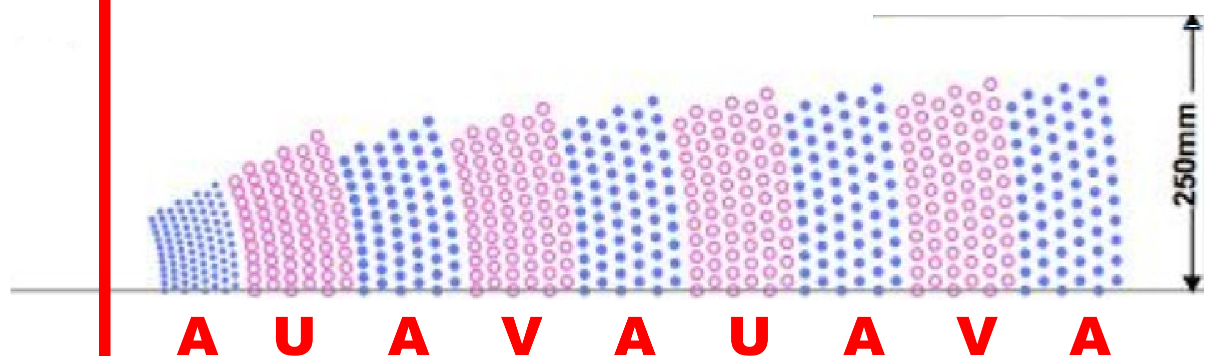
Belle II

TDR : arXiv:1011.0352v1 [physics.ins-det]



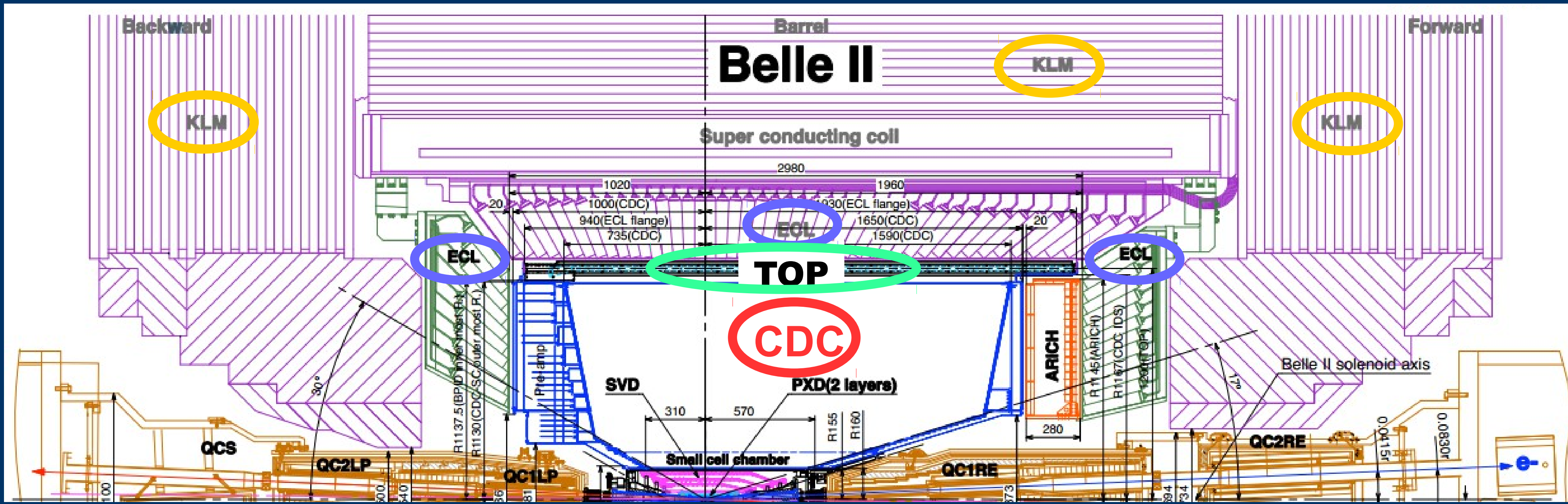
Belle II Central Drift Chamber

- ➔14336 sense wires in 56 layers/9 superlayers
  - ✔ 6-8 layers/superlayer
- ➔4 stereo superlayers sandwiched by 5 axial ones
- ➔half-cell shift from layer to layer



Status

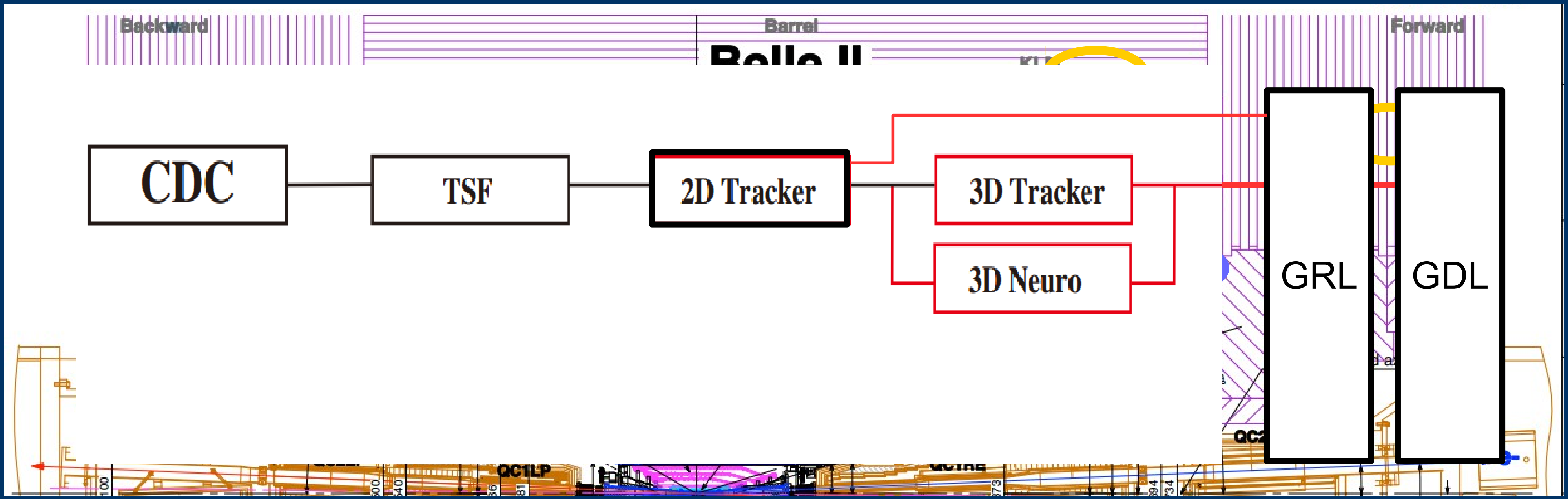
- detector built
- all front-end electronics installed
- currently doing standalone cosmic-ray test with simplified trigger function
- scheduled to move into Belle II this fall



Belle II Level 1 trigger

beam collision 254 MHz
nominal beam background rate ~10 MHz
interested physics event rate ~20 kHz

L1 max. latency 5 μs (DAQ requirement)
event time precision 10 ns (SVD requirement)
L1 max. trigger rate 30 kHz (DAQ requirement)
100% efficiency



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L1 max. latency 5 μs (DAQ requirement)
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L1 max. trigger rate 30 kHz (DAQ requirement)
100% efficiency

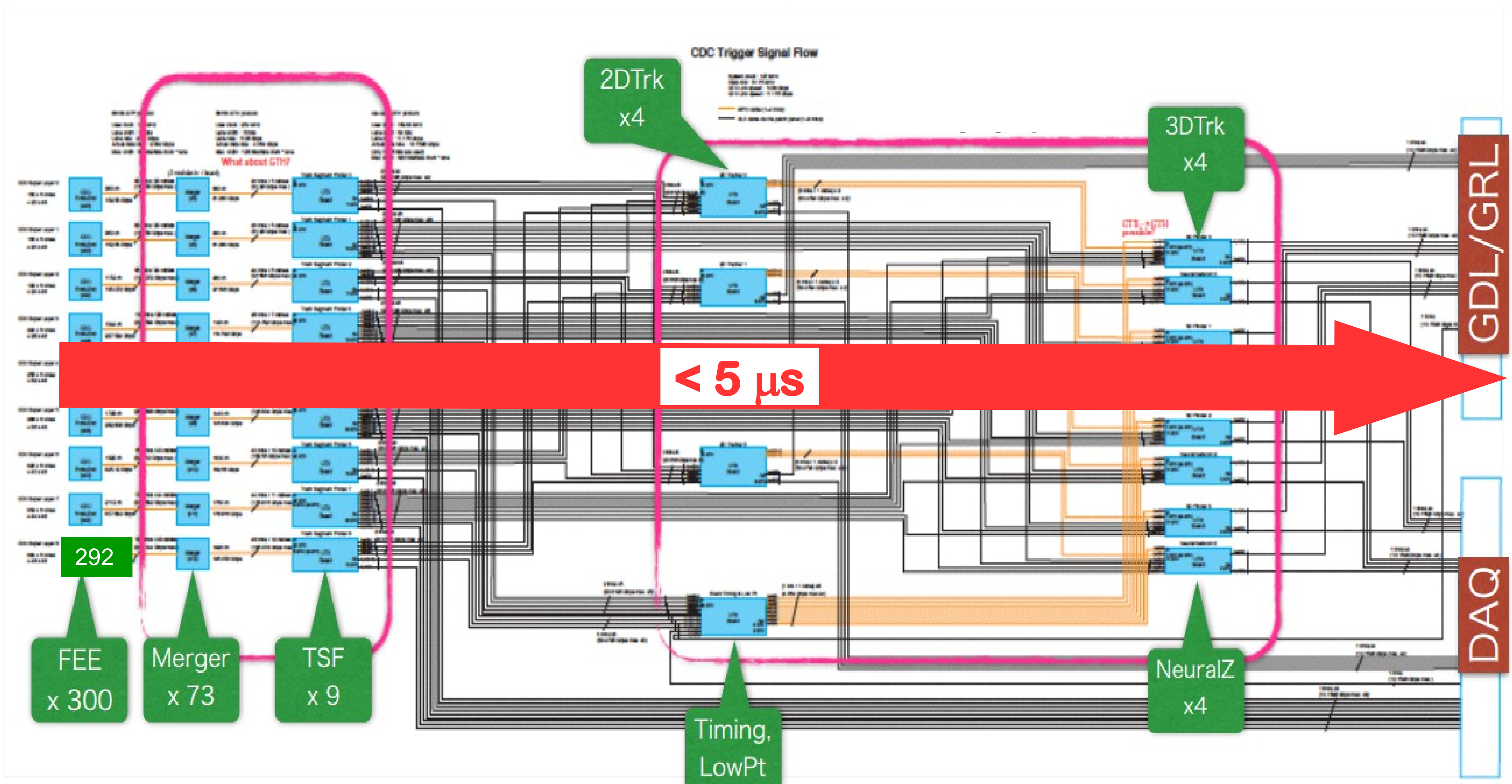
CDC L1 trigger is the most complicated one among the 4.

Belle II CDC Trigger System

and data flow structure

292 x FE → 73 x merger → 9 x TSF → 4 x 2D → 4x3D/4xNN → GRL/GDL

system clk 8ns, data clk 32ns



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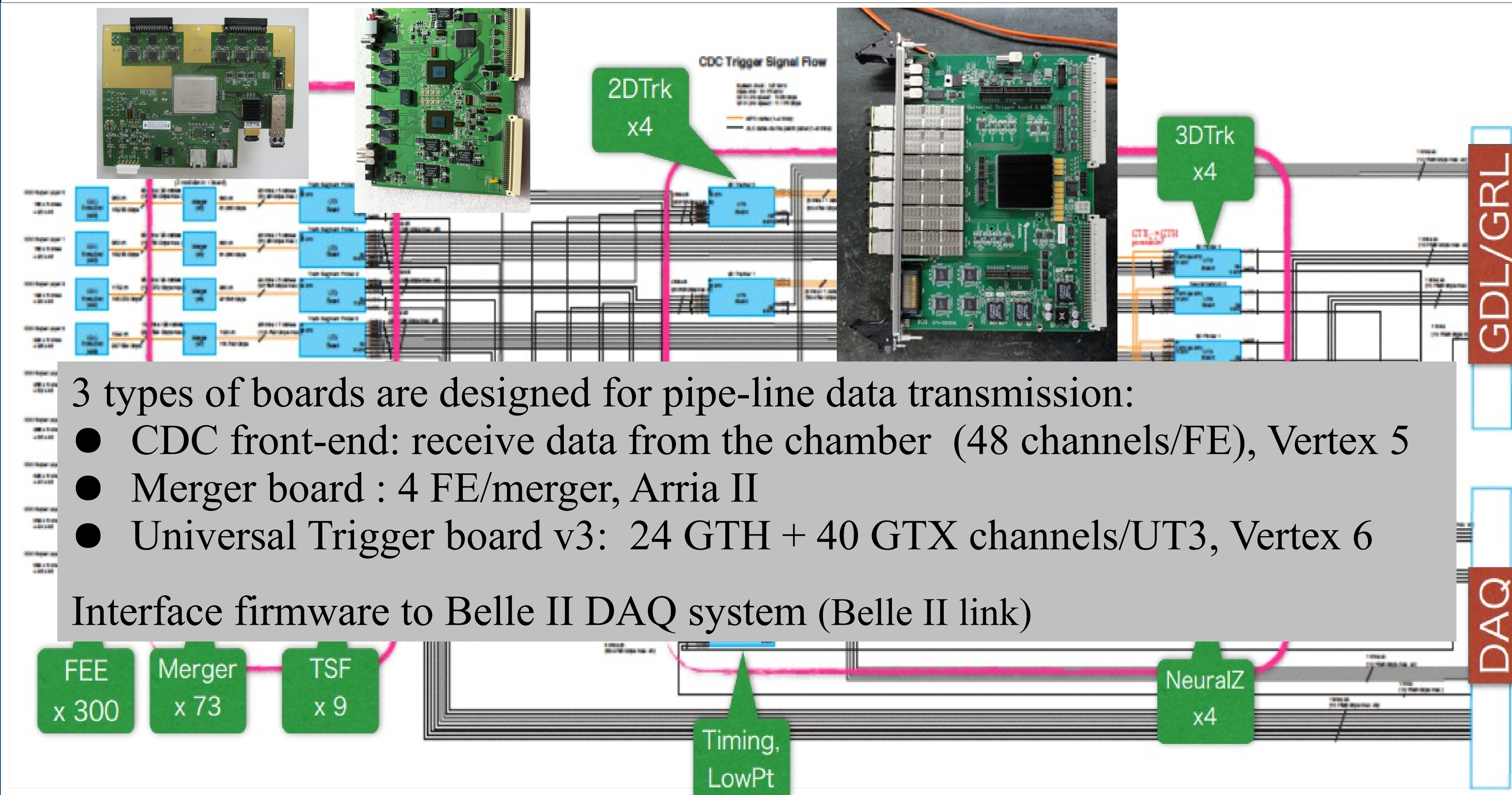


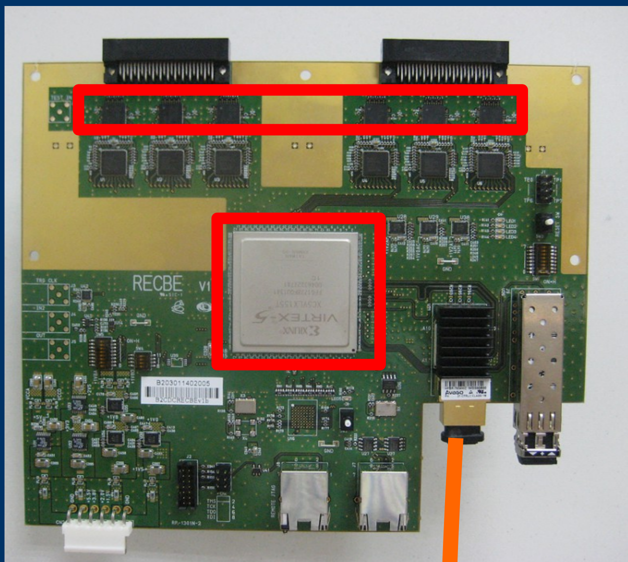
3 types of boards are designed for pipe-line data transmission:

- CDC front-end: receive data from the chamber (48 channels/FE), Vertex 5
- Merger board : 4 FE/merger, Arria II
- Universal Trigger board v3: 24 GTH + 40 GTX channels/UT3, Vertex 6

Interface firmware to Belle II DAQ system (Belle II link)

FE/merger/UT3 board

data clk 32ns

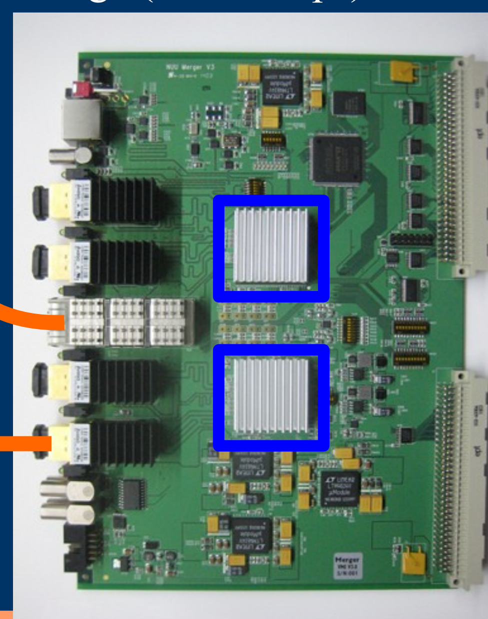


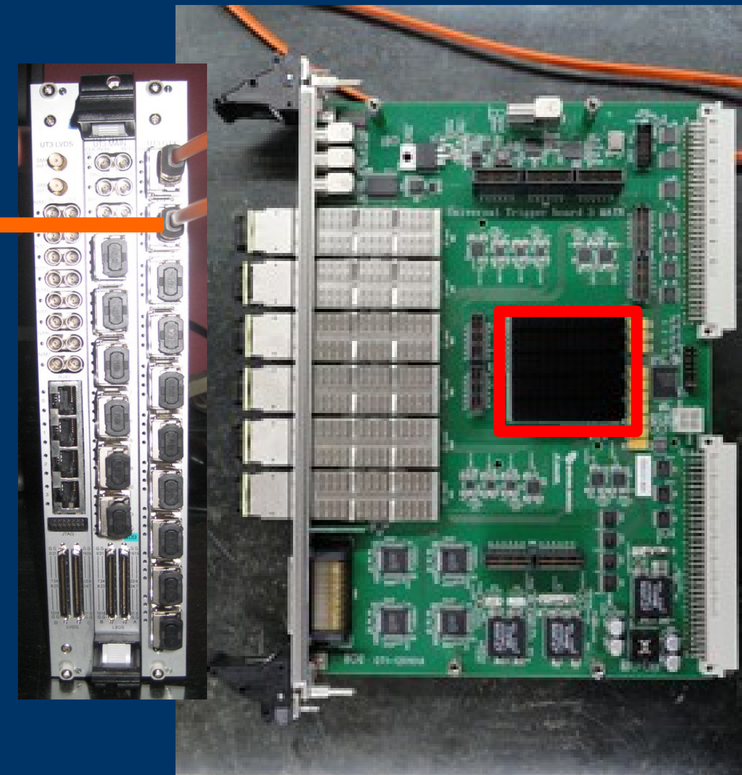
FE: on detector
8 ASIC (48 channels)
analog output
digital output (hit timing, δt 1ns)
belle2link
tigger function built-in

Vertex 5
GTP (3.750 Gbps) x 4

merger:
4 FE → 1 merger
hit information

Arria II x 2
Mega (6.375 Gbps) x 16





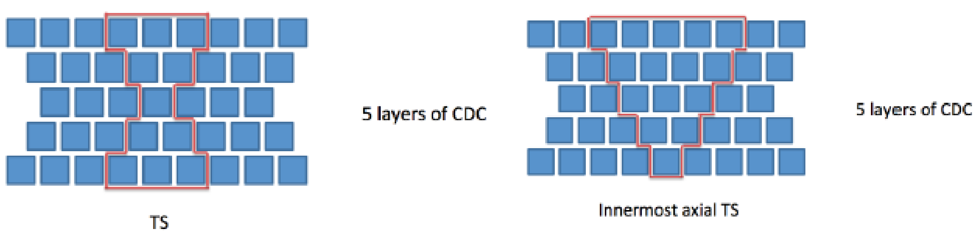
UT3: (3 units wide)
trigger data
belle2link

Vertex 6
GTH (11.18 Gbps) x 24
GTX (6.50) x 40
LVDS/NIM, RJ45/SMA

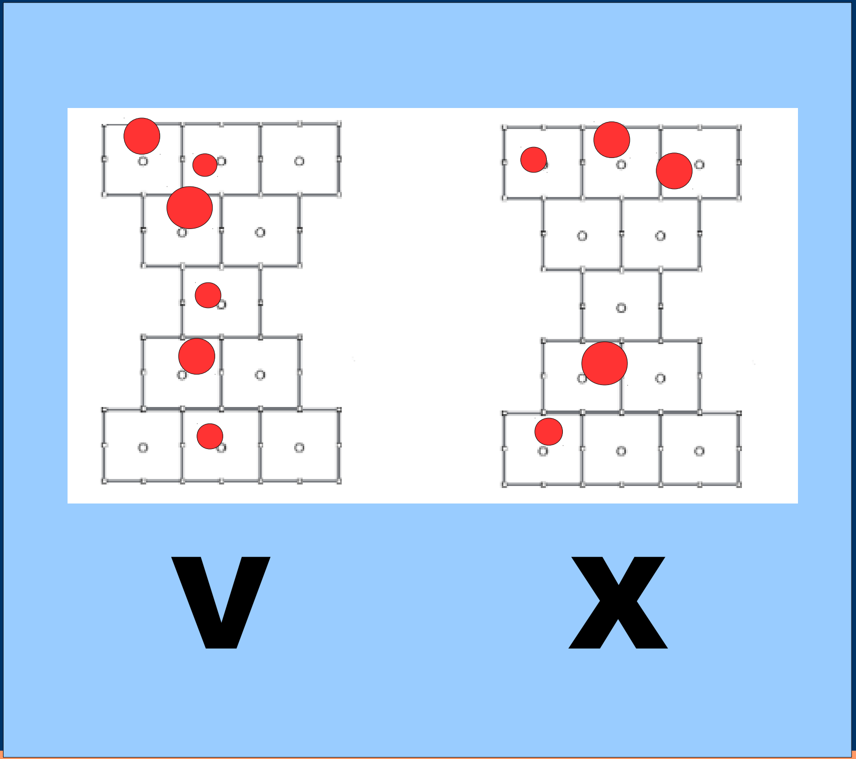
Track Segment Finder (TSF)

- Instead of using all hit directly, merger first groups the cell information (hit/time) from FE in the unit of TS geometry. (54 cell layers → 9 "TS unit" layers)
- One TSF collects all the TS inforamtion in one superlayer. (total 9 TSF)
  - find 'hit TS' by pattern recognition algorithms.
- The hit TS informations of 5 axial superlayers are sent to 2D for track reconstruction
  - axial ones directly to 3D.

About TS

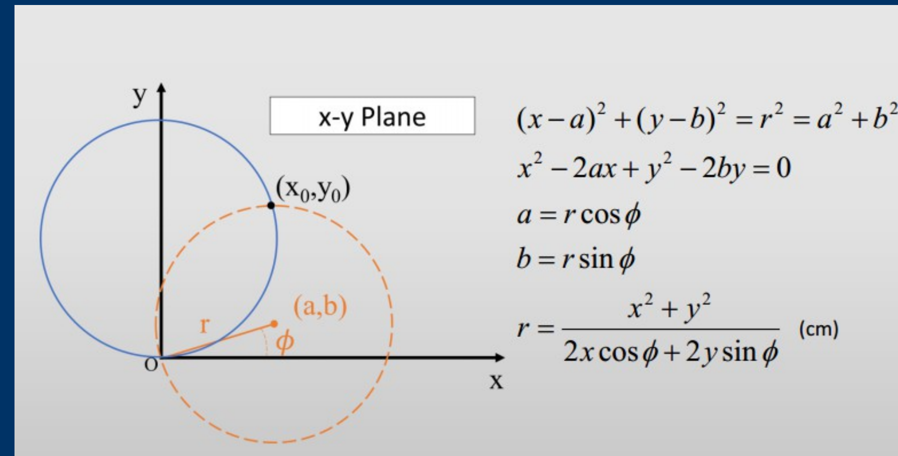


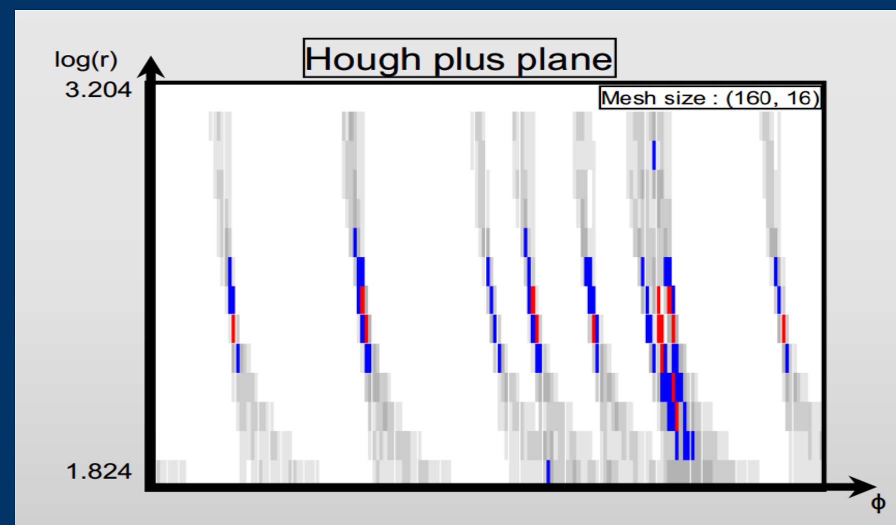
- Track segments is the basic unit in CDC Trigger.
- The center wire layer between the 5 layers is used as the position of the TS called “priority cell”.
- Drift time of priority cell is important.
- Also to determine event time, “fastest drift time” in TS is important.

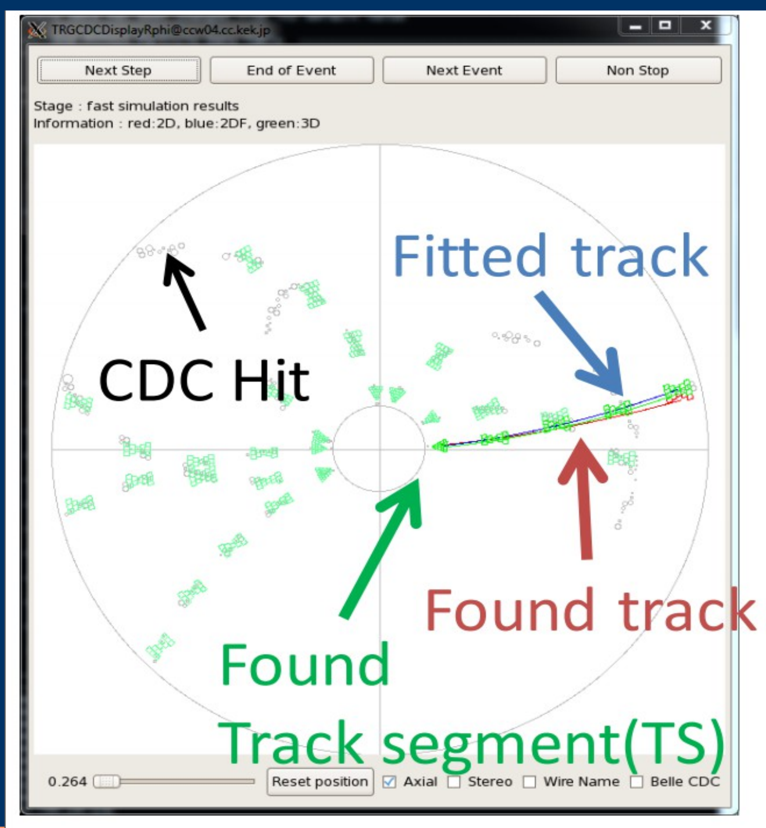


2D Tracker

- 2D finder
  - Hough transformation (to log(r)-ϕ plane)
  - voting principle for one Hough cell:
    - ✔ one superlayer one vote.
  - peak finder in a cluster (connected cells with 5 votes)
  - efficiency ~ 100% (MC)
  - for simple track counting trigger.



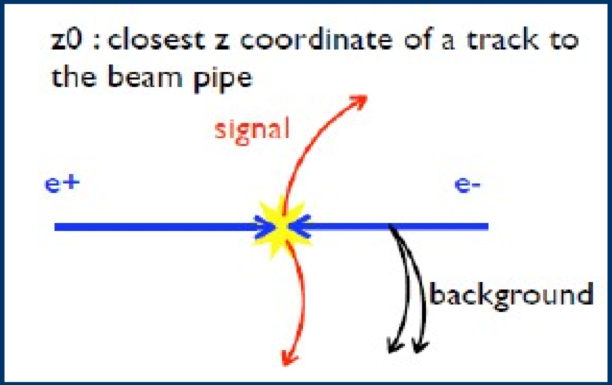




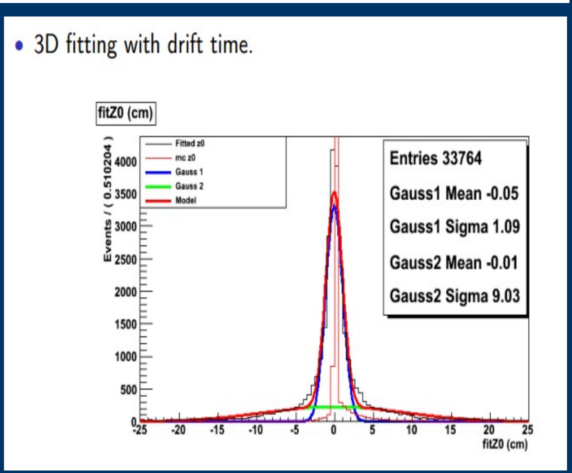
- 2D fitter
  - minimum chi-square fit
  - results sent to 3D triggers

3D Tracker/Neural-Network z trigger

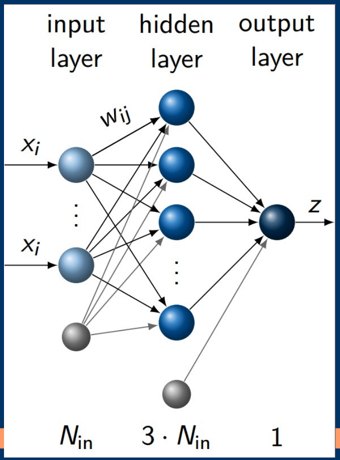
- The 3D tracker is meant to get better z ($\delta z \sim 1$cm) position of a track origin to improve background rejction.

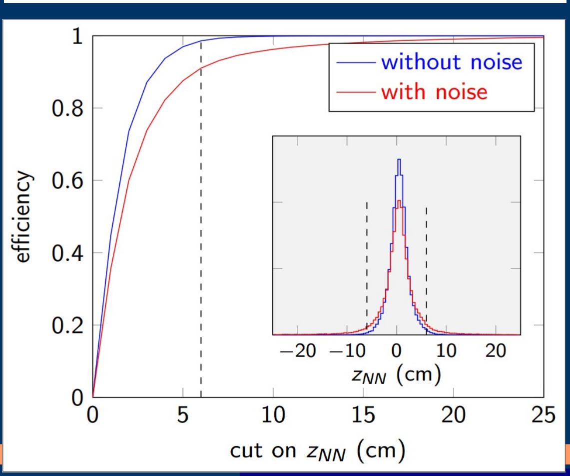


- 3D tracker
  - ➔search hit TS in 4 stereo-superlayers associated with the 2D tracks
  - ➔performs a geometric transformation and chi-square minimization to determine the track's z_0 position.
  - ➔algorithm/firmware are already developed

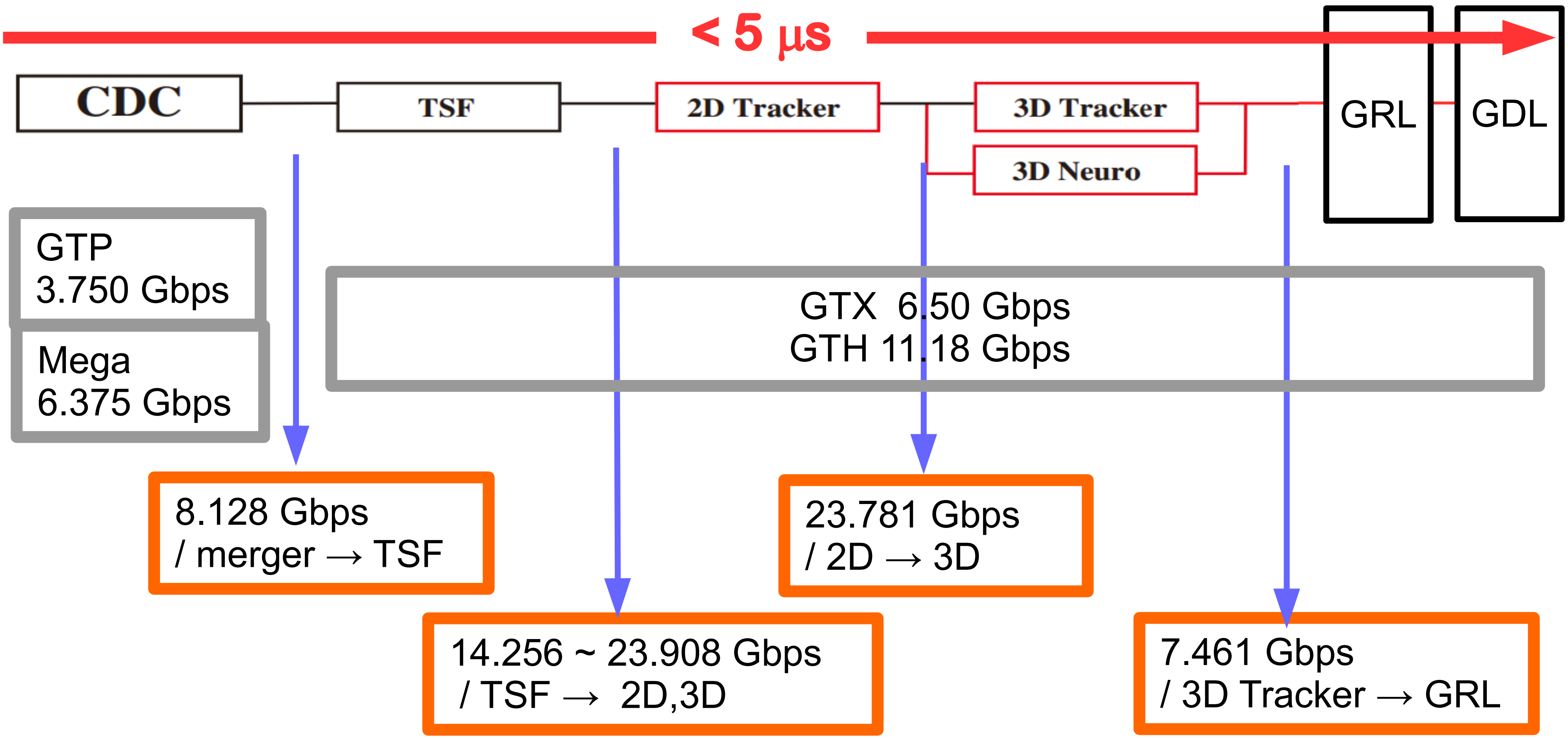


- 3D neural-network z trigger
  - ➔2D tracking output and the raw drift times from all superlayers as seeds for a feed-forward network
  - ➔trained on simulated tracks to estimate z-vertex
  - ➔simulation studies show compatible δz and close to 100% efficiency
  - ➔firmware under development





data rate (per connection)



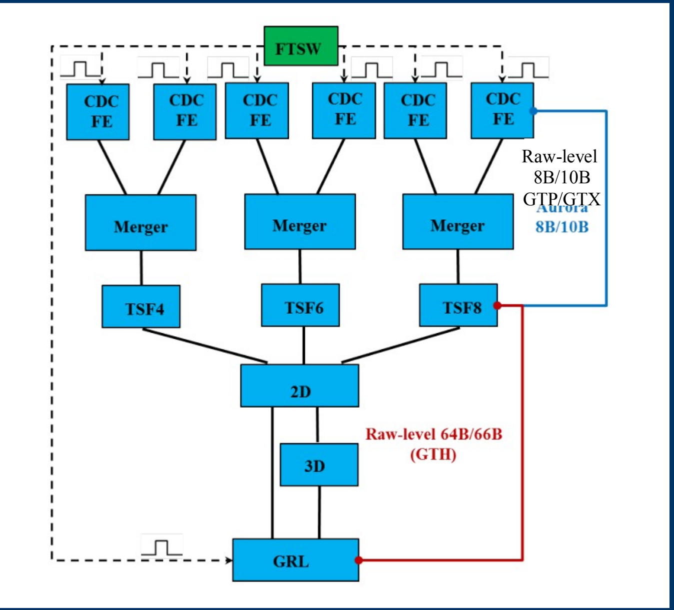
- ✔ one connection (channel) can have multiple fibers bound together.
- ✔ processing time, bandwidth are not a big problem.

Data transmission and flow control

- Aurora protocol: 70~80% latency budget is consumed for transmission.

- In order to satisfy the 5 µs latency requirement in this multi-layer pipe-line trigger system, we developed a raw-level protocol for transmission.
  - ➔template generated from Xilinx CoreGenerator and Altera MegaWizard Plug-in.
  - ➔clock-compensation disabled
  - ➔streaming transmission, no data frame
  - ➔several fibers combined as one data channel
  - ➔basic request&response handshake for transmission establishment
  - ➔stability confirmed by long-term BERT (> 6 months all merger boards)

- Protocols for transmission initilization and data synchronization are also defined
  - ➔dummy data transmission while in idle state
  - ➔GDL distributes initial command to all FE
  - ➔a time-stamp is embedded in data since FE and synchronized to the revolution clock
  - ➔synchronization checked by time-stamp at every layer
  - ➔recovery scheme when link lost



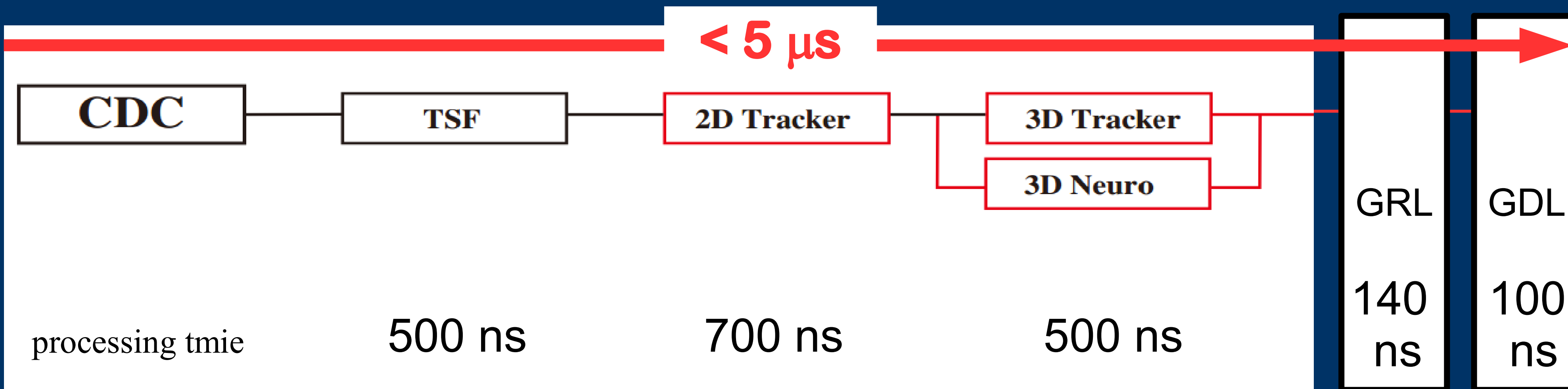
Latency comparison

Protocol	Line rate	userclk	Hardware link	Latency (# of userclk)	Latency (ns)
Aurora 8B/10B	5.08 Gbps	254 MHz	GTX – GTX	47 ~ 48	185 ~ 190
Raw-level 8B/10B	5.08 Gbps	254 MHz	GTX → GTX	33 ~ 34	133 ~ 134
	5.08 Gbps	254 MHz	GTH → GTX	33 ~ 34	133 ~ 134
	5.08 Gbps	254 MHz	GTH → GTH	23 ~ 24	91 ~ 95
	5.08 Gbps	254 MHz	GTX → GTH	23 ~ 24	91 ~ 95
Aurora 64B/66B	10.16 Gbps	158.75 MHz	GTH – GTH	47 ~ 48	296 ~ 302
Raw-level 64B/66B	11.176 Gbps	169.33 MHz	GTH – GTH	18 ~ 19	106 ~ 112

→ transmission time reduced by a factor of 3 (max.)

* FIFO latency not included

Current latency budget



transmission 2480 ns (CDC to GDL, including merger function)

total 2480 + 500 + 700 + 500 + 140 + 100 = 4420 ns

(to accommodate ~500 ns internal latency request for SVD)

Status and Plan

- Hardware production
  - all FE, merger, and UT3 boards have already been installed
  - trigger board for neural-network z trigger is not finalized yet.
- Firmware developement
  - firmware from FE to 3D tracker are basically developed, in processes of finalization and validation
    - I/O modules
    - specific function parts
    - a play&record scheme for system validation
  - neural-network z trigger part under development.
- Simulation software implemented in the Belle II software frame work
  - fast simulation for algorithm study
  - firmware simulation
- A simplified trigger stream is working with CDC for cosmic ray test now
  - counting hit TS in TSF
- A first full stream version ready before phase 2 commissioning.

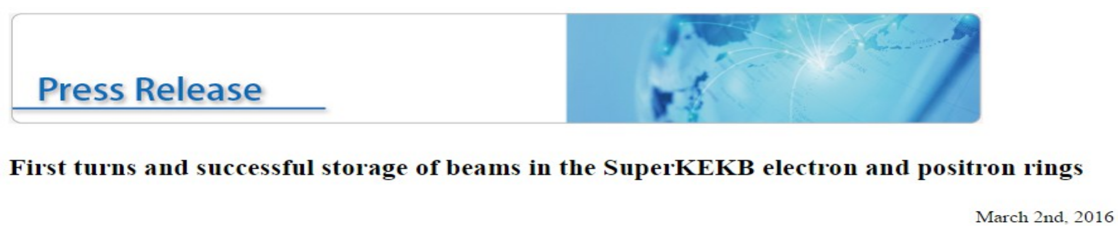
  (Yamada san's talk this afternoon.)

Phase 1,

Beast2

will pave the road for the beauty.

KEK press conference for 1st SuperKEKB LER/HER beam circulation (Mar. 02, 2016)


Press Release

First turns and successful storage of beams in the SuperKEKB electron and positron rings

March 2nd, 2016

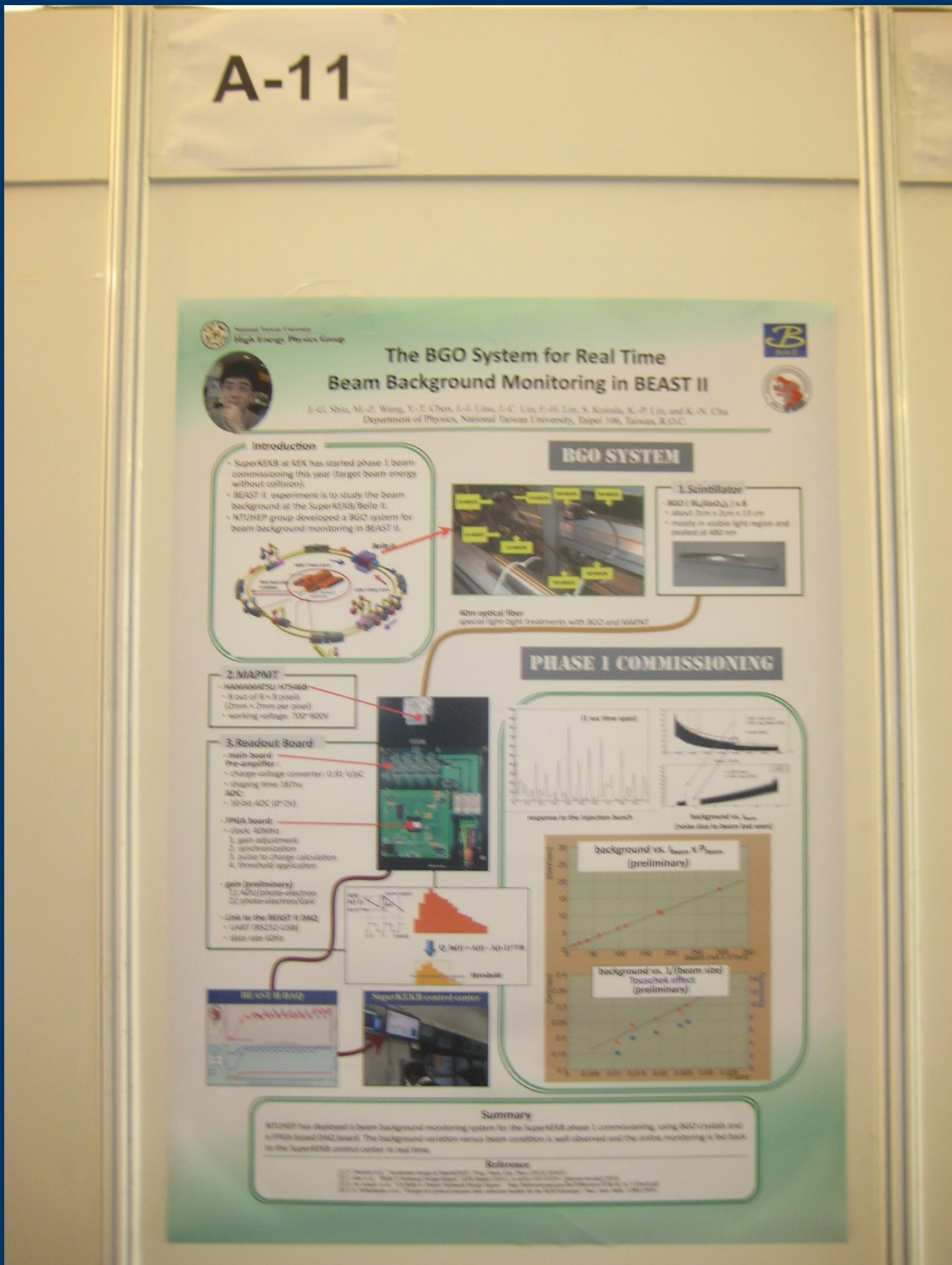
2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

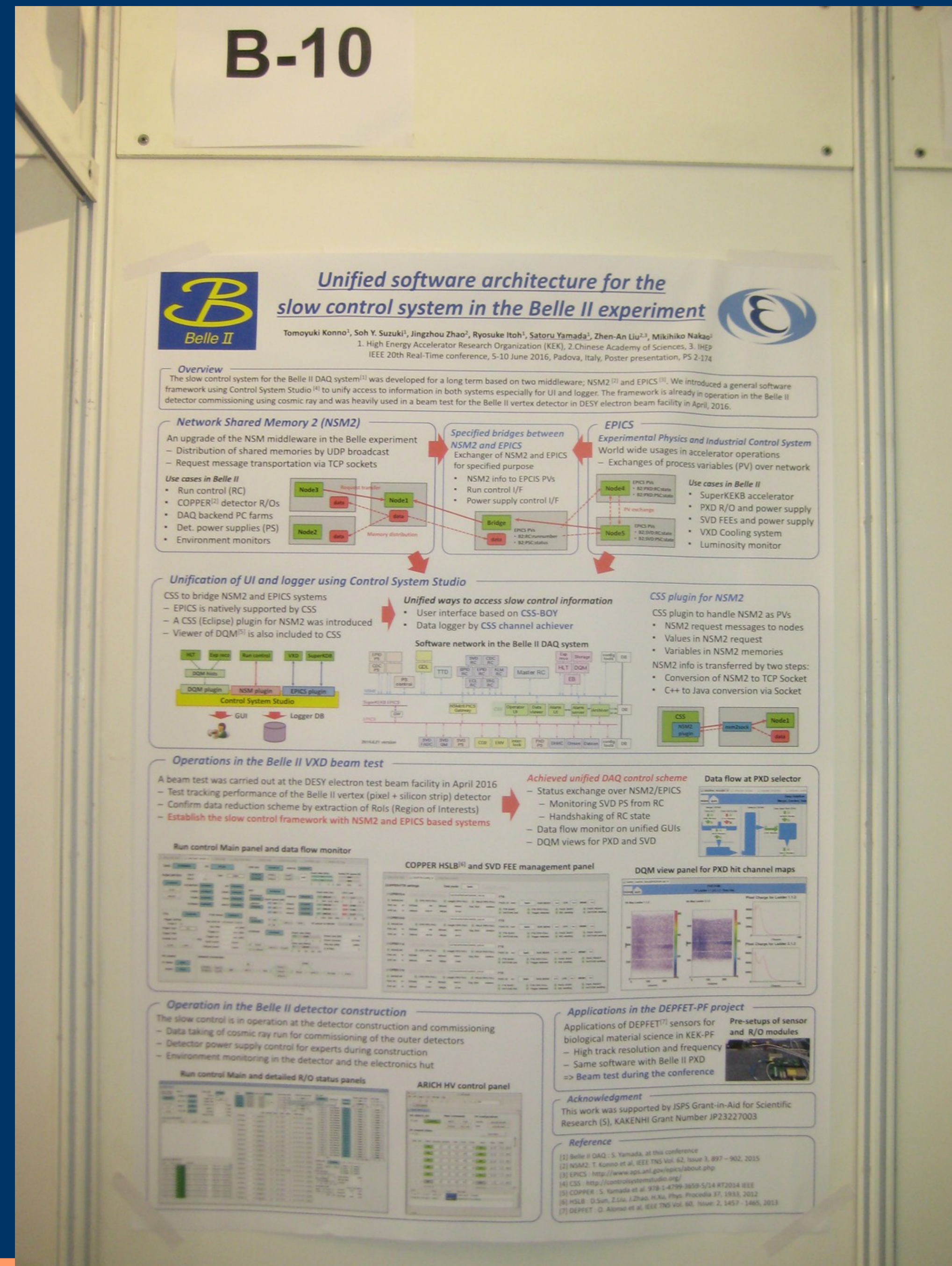
beam bg/machine study

Poster session 2, No 149

The BGO System for Real Time
Beam Background Monitoring in BEAST II

BGO + FPGA DAQ → SuperKEKB


A-11
The BGO System for Real Time
Beam Background Monitoring in BEAST II
Introduction
BGO SYSTEM
PHASE 1 COMMISSIONING
Summary


B-10
Belle II
Unified software architecture for the
slow control system in the Belle II experiment
Overview
Network Shared Memory 2 (NSM2)
EPICS
Unification of UI and logger using Control System Studio
Operations in the Belle II VXD beam test
Operation in the Belle II detector construction
Applications in the DEPFET-PF project

Phase 2, ring a *Bell* for a new era to come.

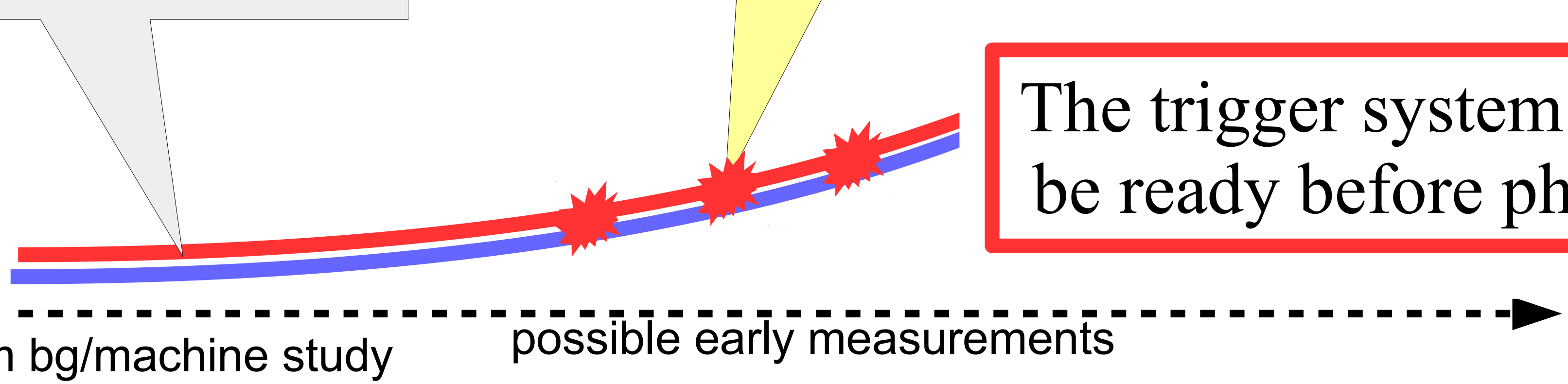
Beast 2 with partial Belle II,
some measurements possible.

2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

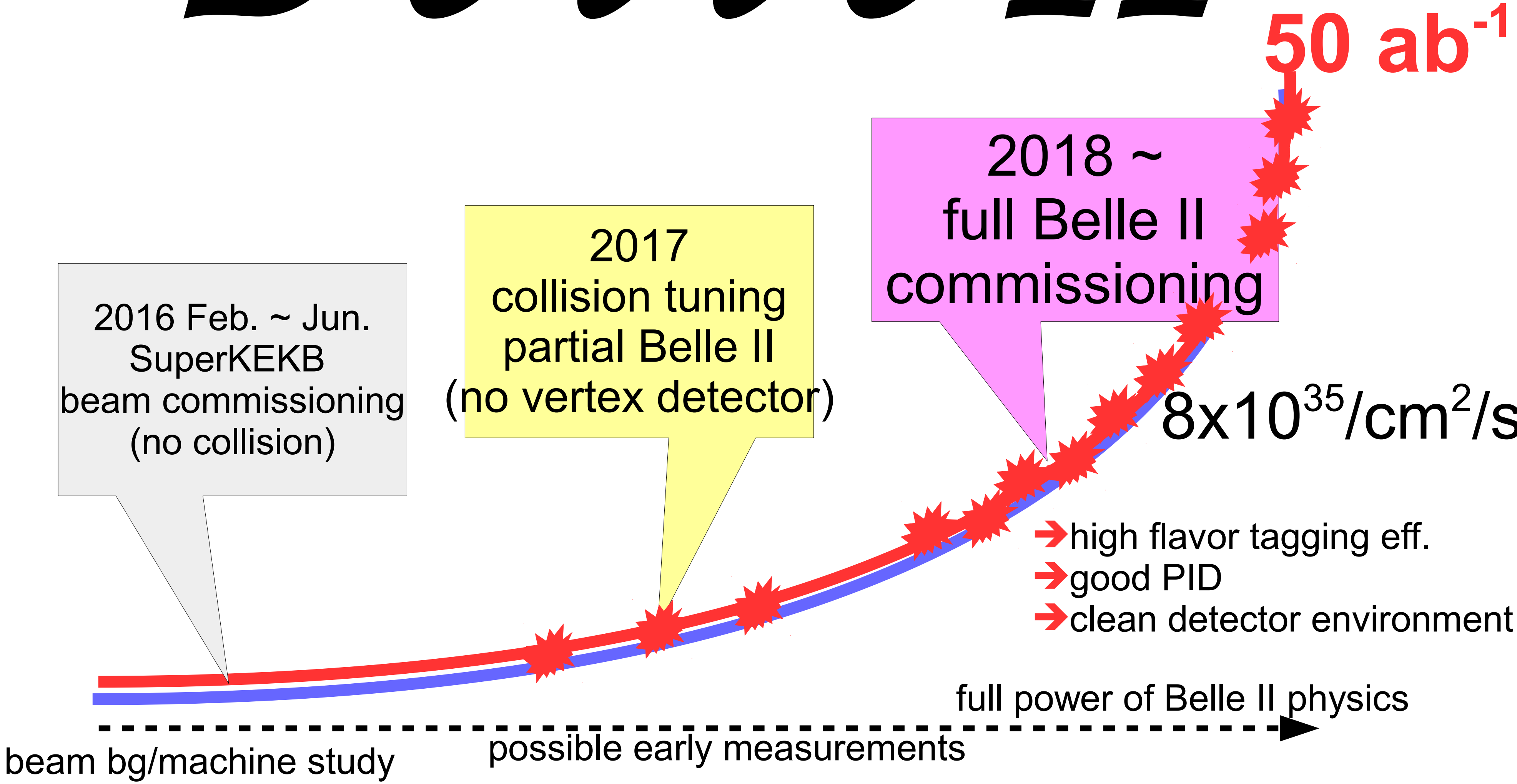
2017
collision tuning
partial Belle II
(no vertex detector)

- ➔achieve 10^{34} /cm^2/s (KEKB/Belle peak)
- ➔stable run close to $\Upsilon(4S)$ preferred
- ➔PID not fully reliable
- ➔Integrated luminosity ~(20 ± 20 fb^{-1})

The trigger system has to be ready before phase 2.



Phase 3, Belle II



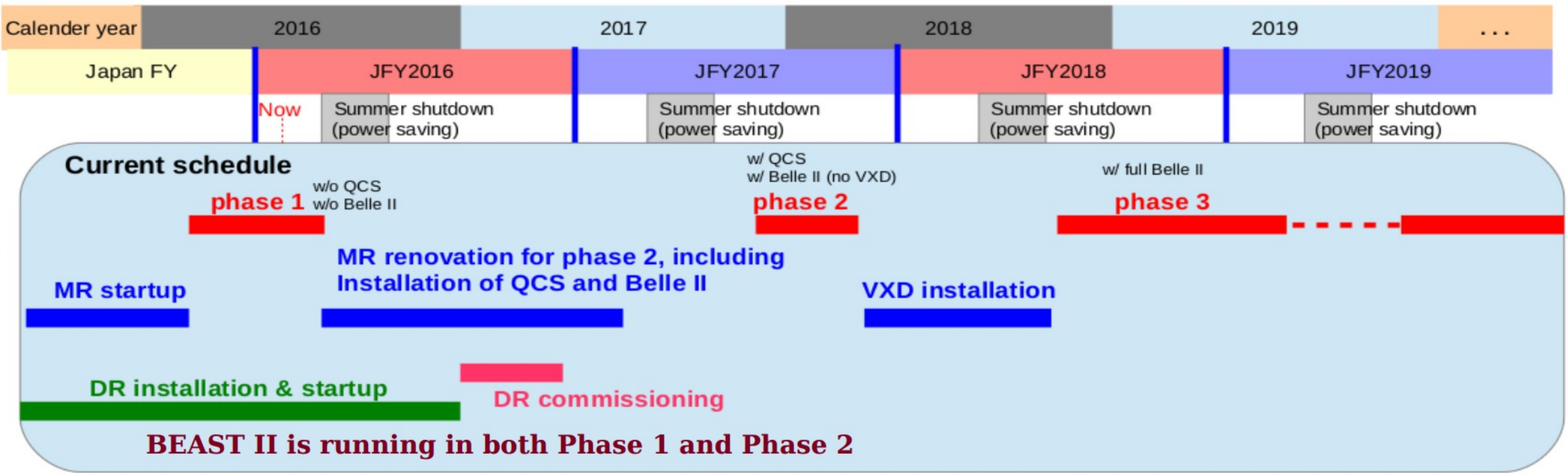
Summary

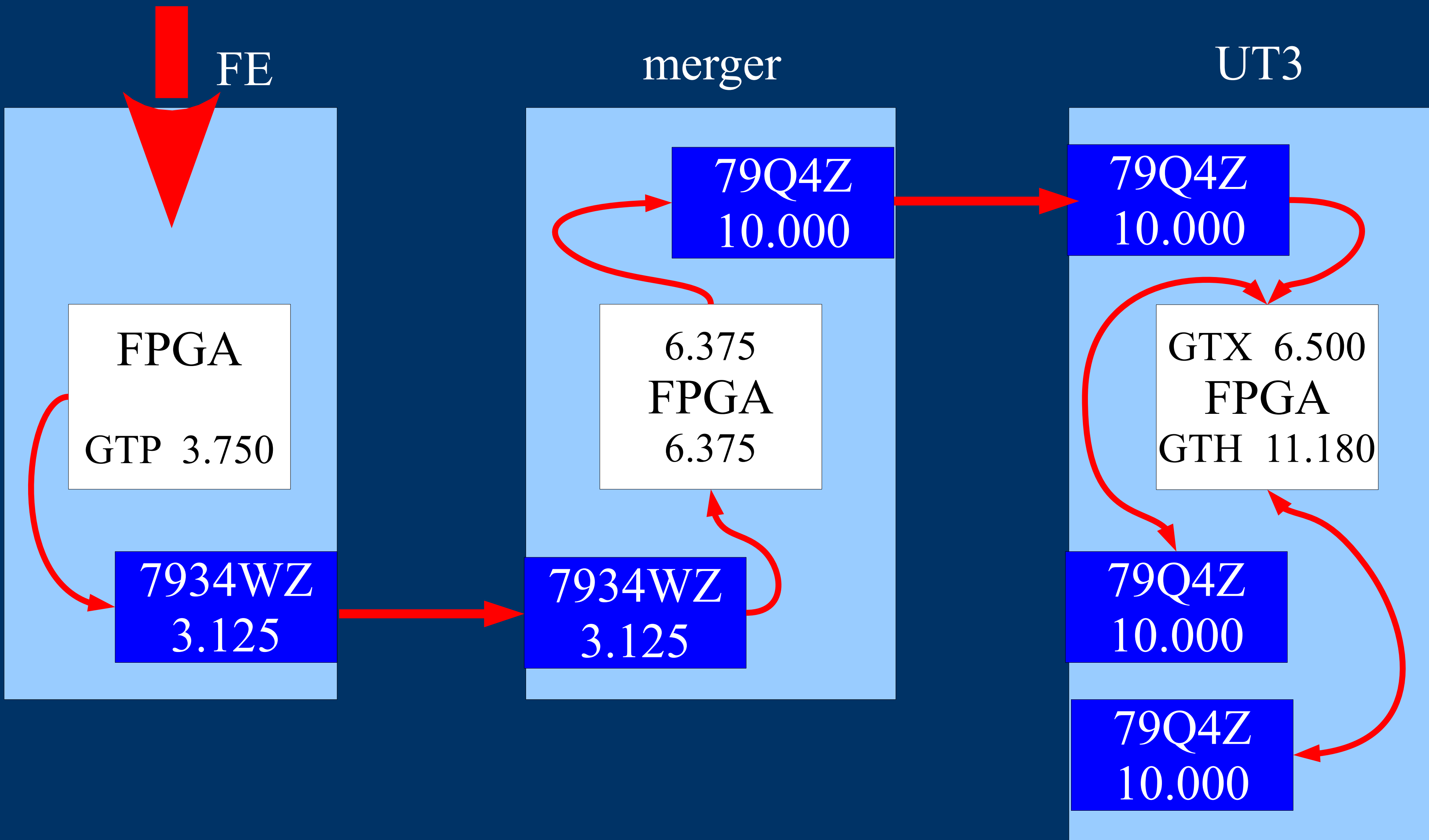
- A multi-layer real time trigger system is developed for the Belle II CDC detector.
  - ➔ simple track counting trigger (2D finder)
  - ➔ high precision track z_0 trigger (3D tracker, neural-network z trigger)
  - ➔ low Pt tracking (short track 2D finder), event timing, ...
- User-defined protocol are developed for the full chain data streaming transmission and flow control; total latency less then 5 μs is achieved.
- Algorithms and firmwares are mostly completed and now under validation and finalization.
- A full system will be ready before middle of 2017 for phase 2 run
- Belle II will be online in 2 years
  - ➔a friendly competition and complementarity with other experiments (LHCb, BESTIII), a new and exciting era to explore the physics frontier.
  - ➔expect to have 1st collision in 2017, we are looking forward to the 1st overseas collaboration meeting.

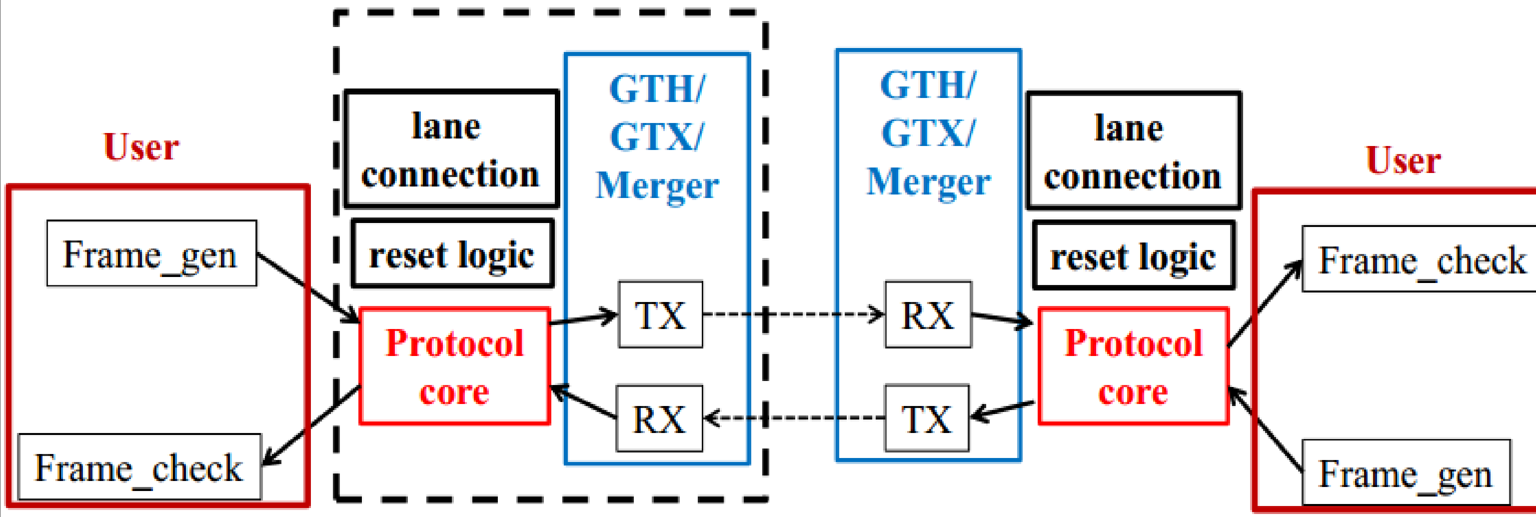
Thank you!!

BACKUP

SuperKEKB Operation Schedule




FE
merger
UT3
FPGA
GTP 3.750
7934WZ
3.125
79Q4Z
10.000
6.375
FPGA
6.375
7934WZ
3.125
79Q4Z
10.000
GTX 6.500
FPGA
GTH 11.180
79Q4Z
10.000
79Q4Z
10.000



- Designed from the Xilinx GTH/GTX and Altera Altgx wizard.

- lane connection: monitoring the health of the lane connection
- reset login: initialize lines and recover them while connection lost
- protocol core:
  - ➔ working mode
  - ➔ test mode
  - ➔ state machine with predefined data parttern

Belle II L1 Trigger

physics processes and trigger logics

Process	σ (nb)	Rate (Hz) @ L=8x10[35]
Upsilon(4S)	1.2	960.0
Continuum	2.8	2200.0
μμ	0.8	640.0
ττ	0.8	640.0
Bhabha *	44.0	350.0
γ-γ *	2.4	19.0
Two photon **	80	~15000
Total	130	~20000

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

- **Physics triggers**
  - Upsilon 4S + continuum
    - Three-track (CDC)
    - Total energy >= 1 GeV (ECL)
    - #Isolated cluster >= 4 (ECL)
  - Tau pair
    - Two-track with opening angle cut
- **Calibration triggers**
  - Bhabha
    - Pre-scaled by Bhabha trigger (ECL)
  - γ-γ
    - Pre-scaled by γ-γ trigger (ECL+CDC)
  - Mu pair
    - Two-track (CDC+KLM)
  - Random trigger
- **Veto**
  - Beam injection
  - Two photon events if necessary
    - Low level reconstruction is necessary

Trigger requirements and trigger system

Relevant times intervals and frequencies

Beam collision frequency ~508 MHz

Bunch separation: ~2ns

Good physics rate: ~20 kHz

L1 trigger max. rate: ~30 kHz

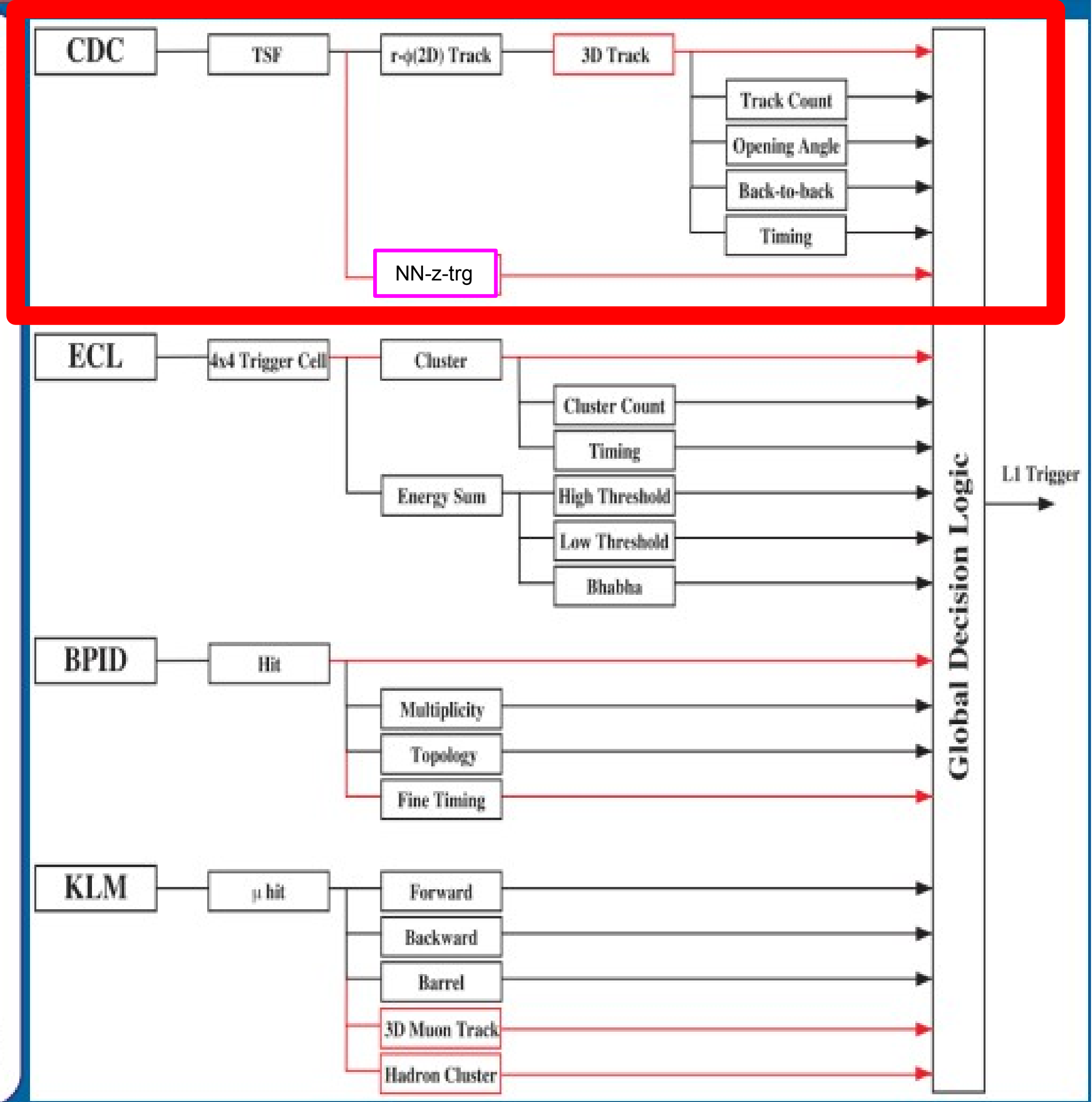
Average separation between two physics events: 25,000 bunch crossings

Nominal beam background rate 10 Mhz

Trigger time uncertainty: ~ 2ns

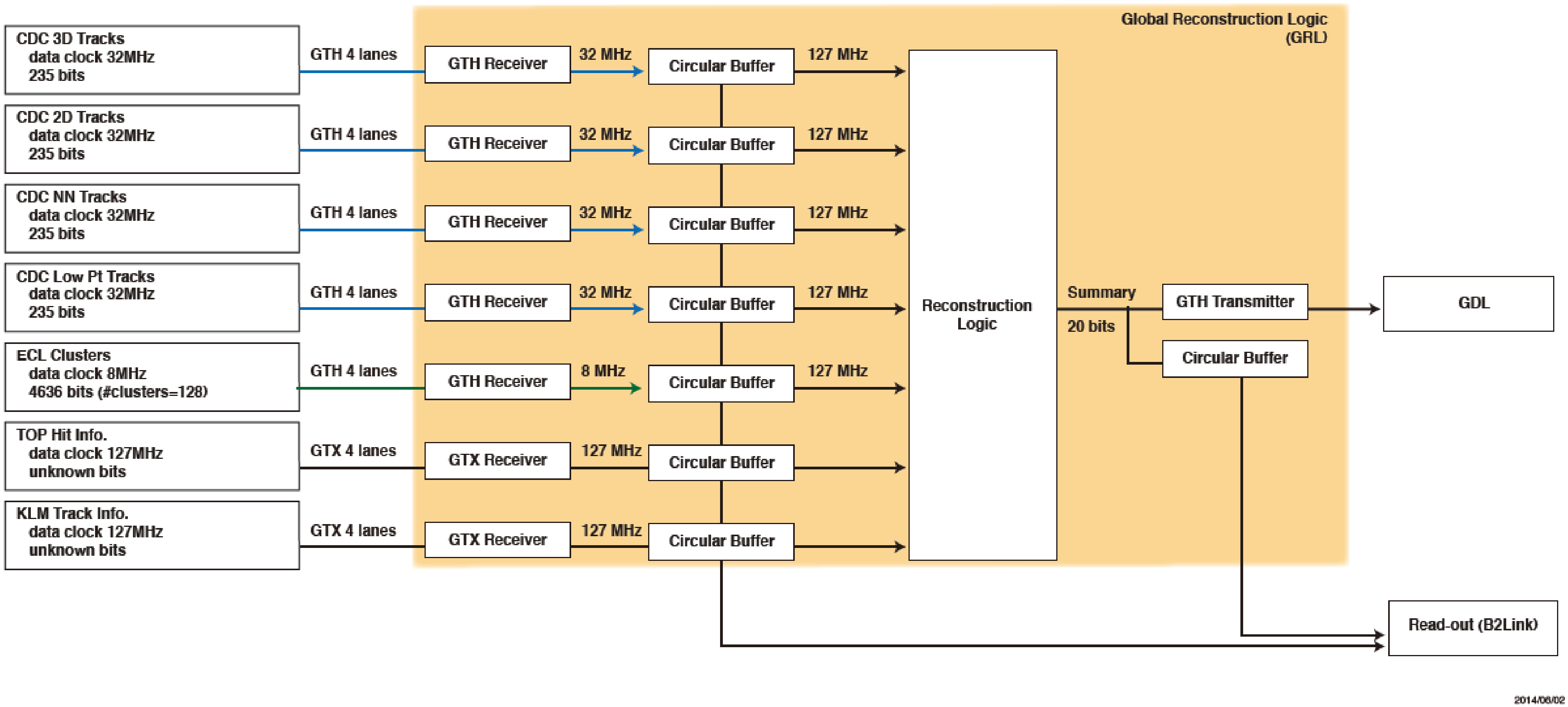
L1 trigger latency: 5µs

Min L1 time between two events: 200 ns



GDL and GRL

Global Reconstruction Logic



Full trigger information of each system is sent to GRL for a real time reconstruction (matching) trigger decision