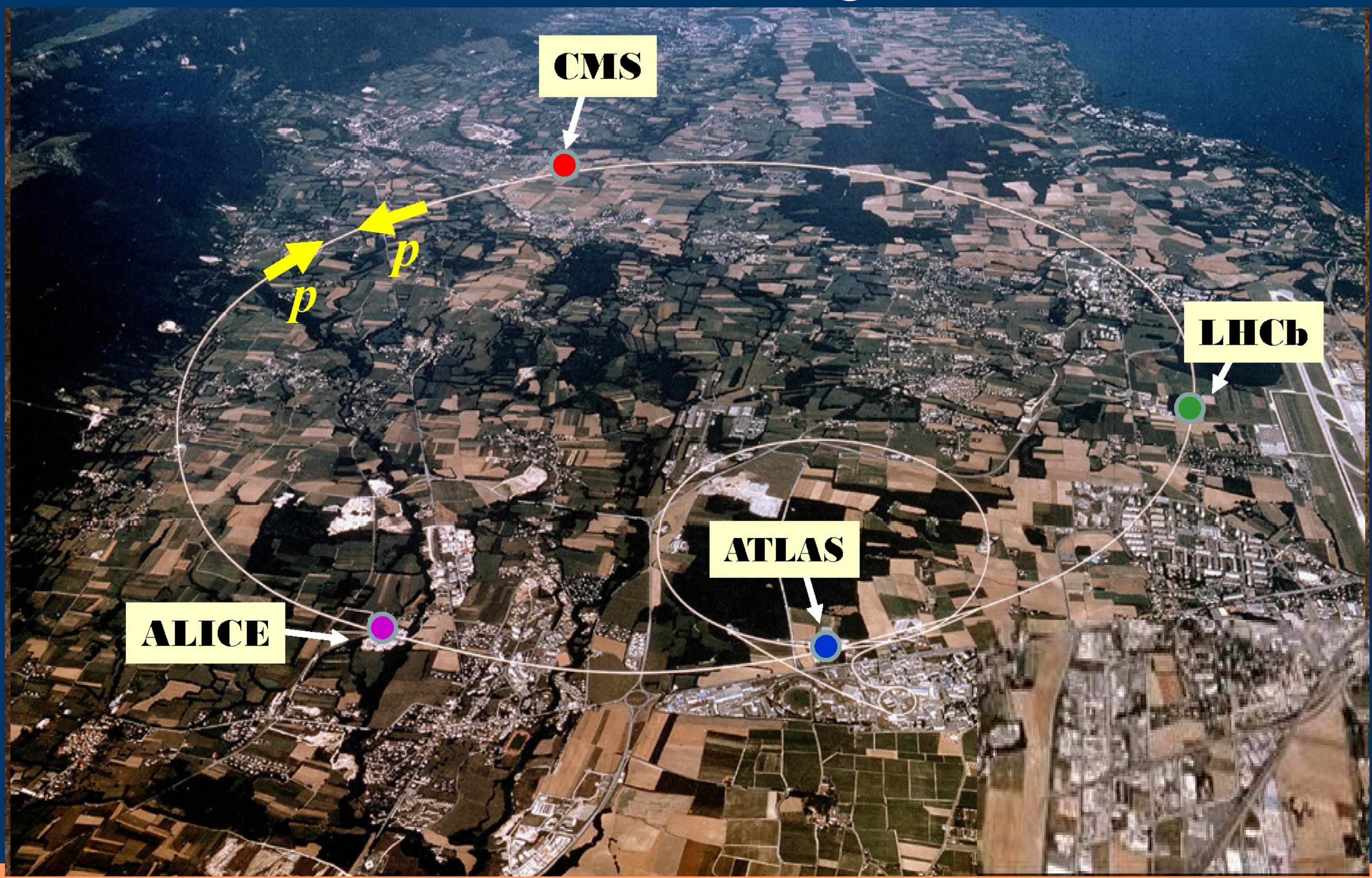
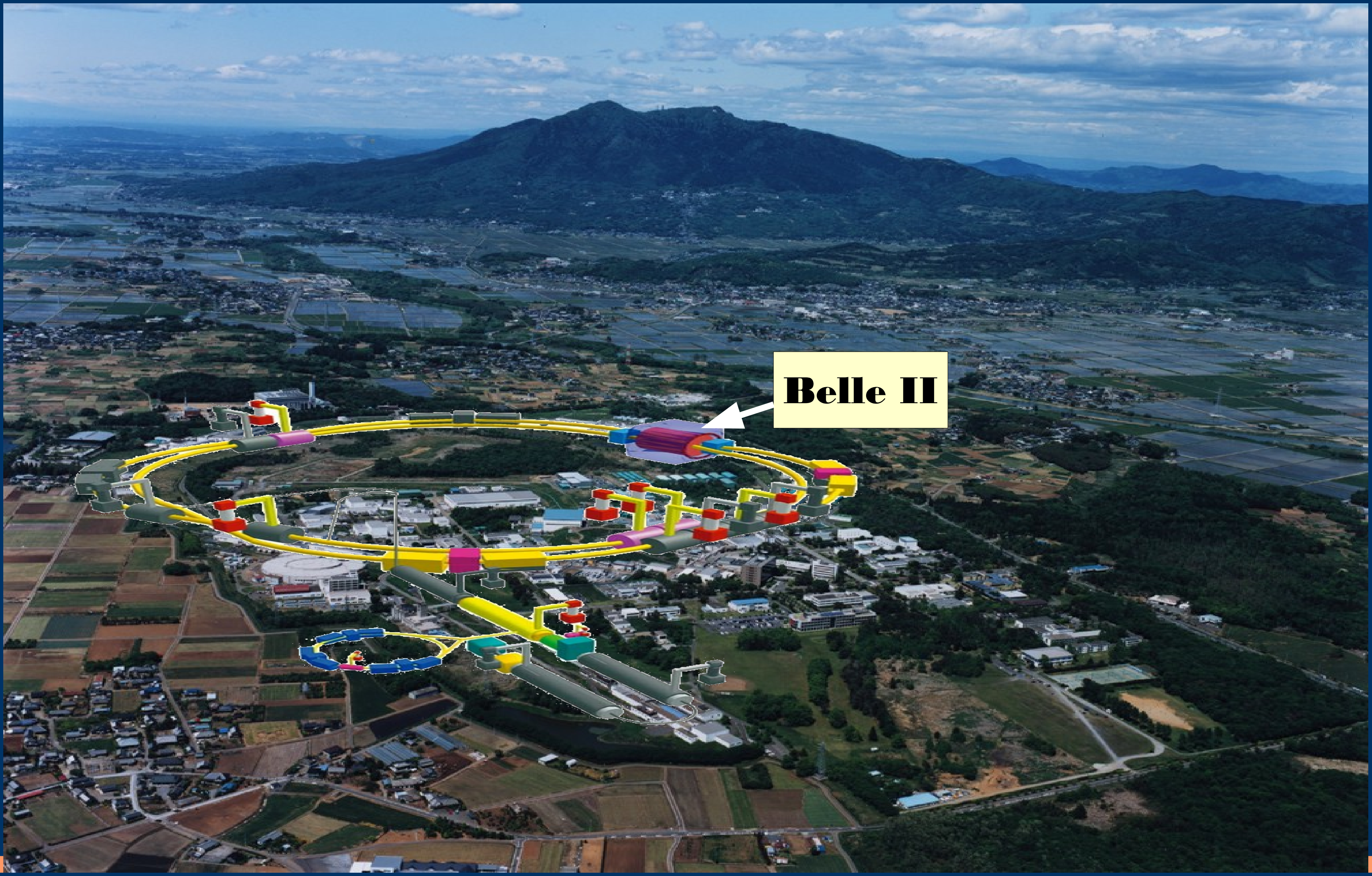
LHC, on the other side of the mountains
lake geneva
famous Mt. Jura
LINACs + small circles + a big circle



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



SuperKEKB, on the other side of the world
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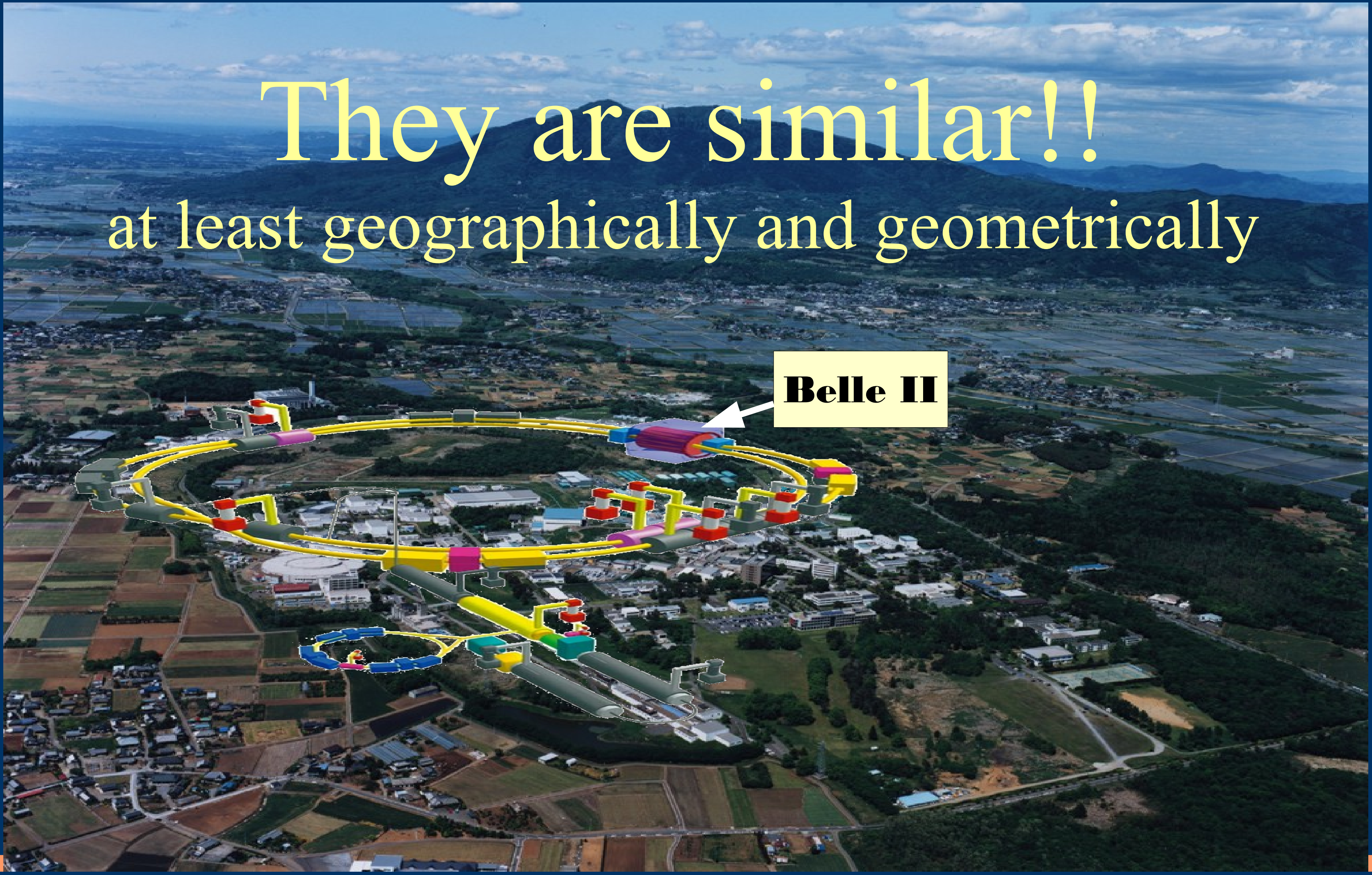


The Level 1 Trigger System for Belle II CDC

RT2016, Padova, Italy

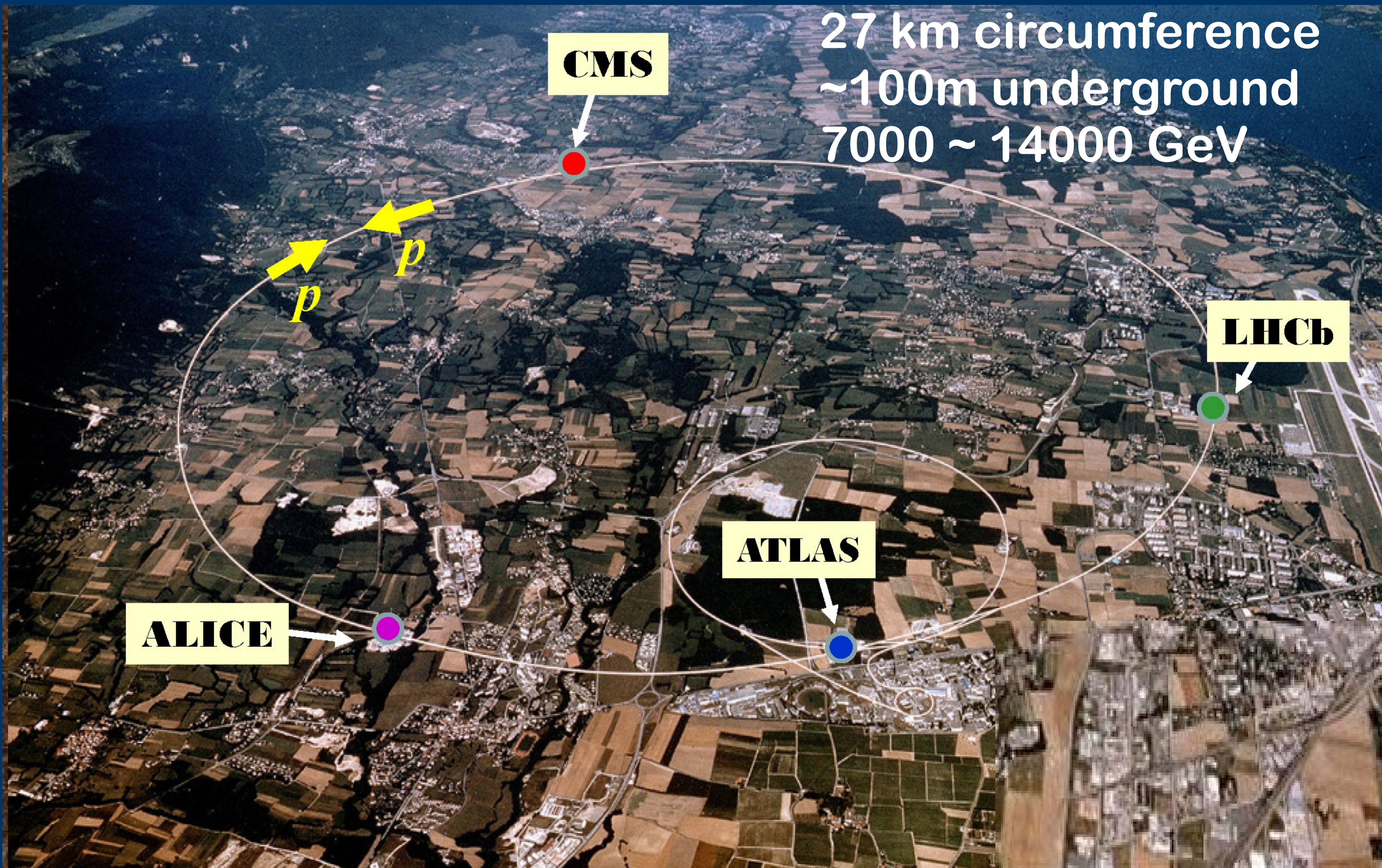
Jing-Ge Shiu (NTU) on behalf of the CDCTRG team

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



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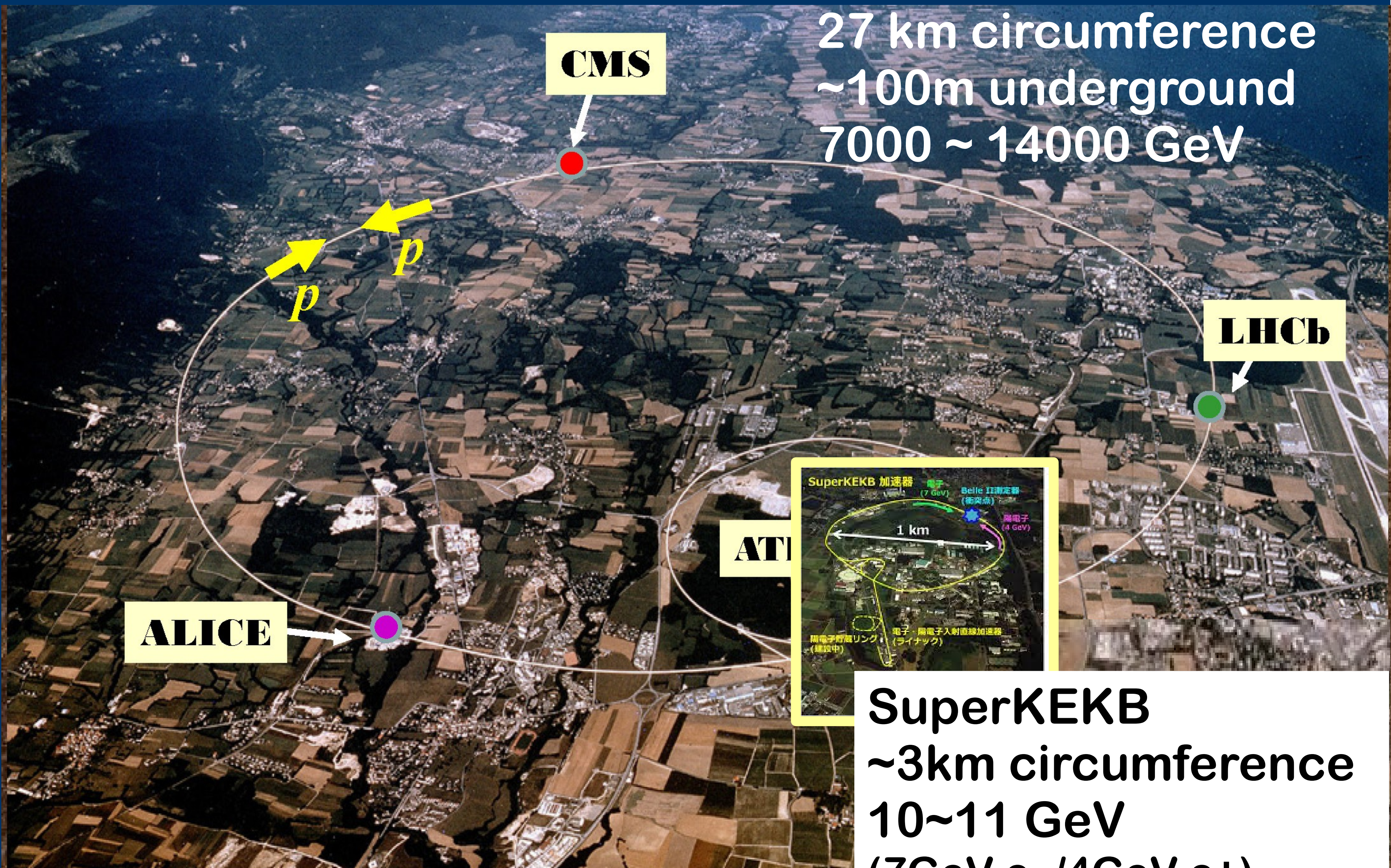


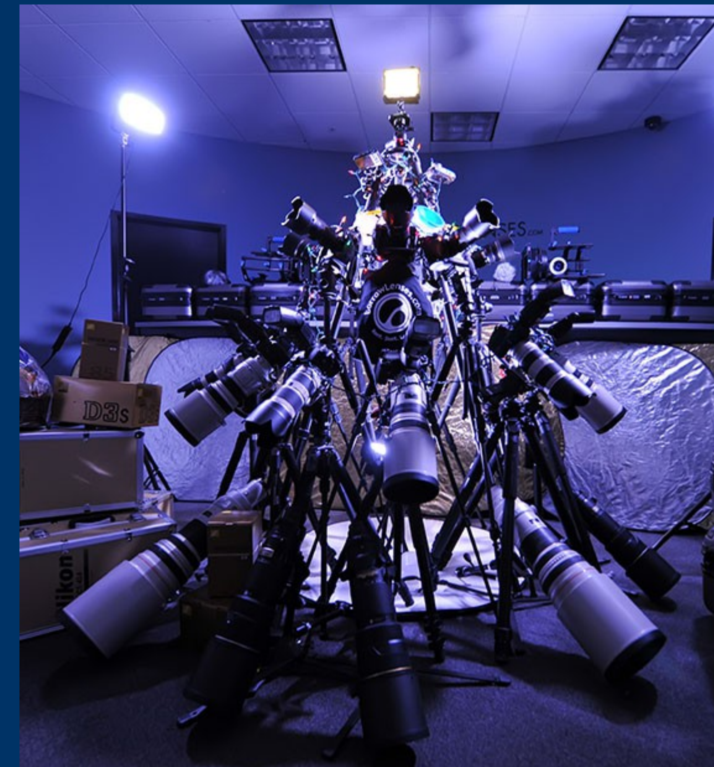
SuperKEKB
~3km circumference
10~11 GeV
(7GeV e- /4GeV e+)

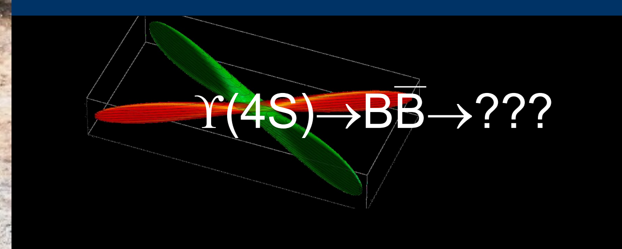
Why do we need Super B factory?

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

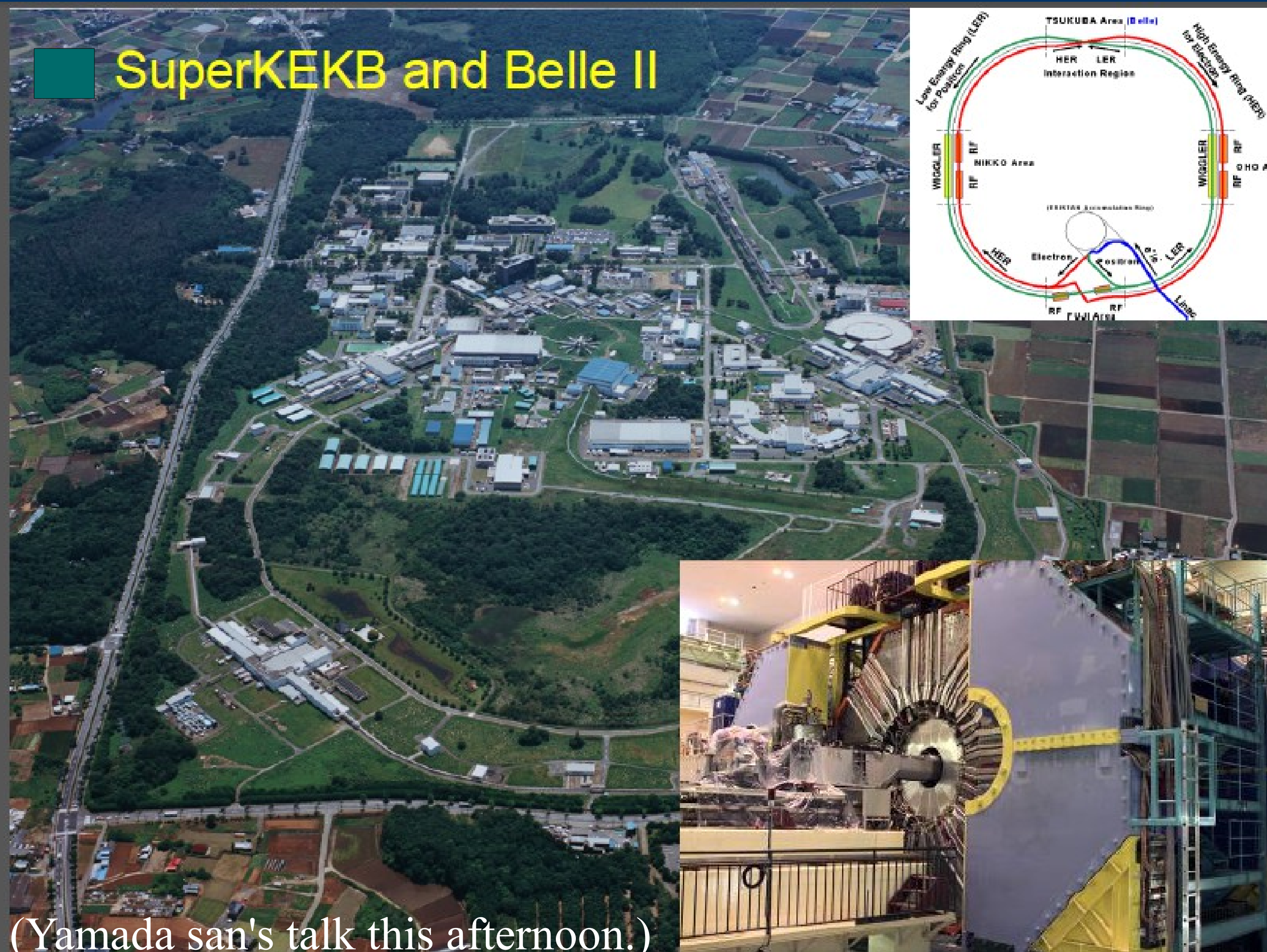
KEKB + Belle → SuperKEKB + Belle II

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).

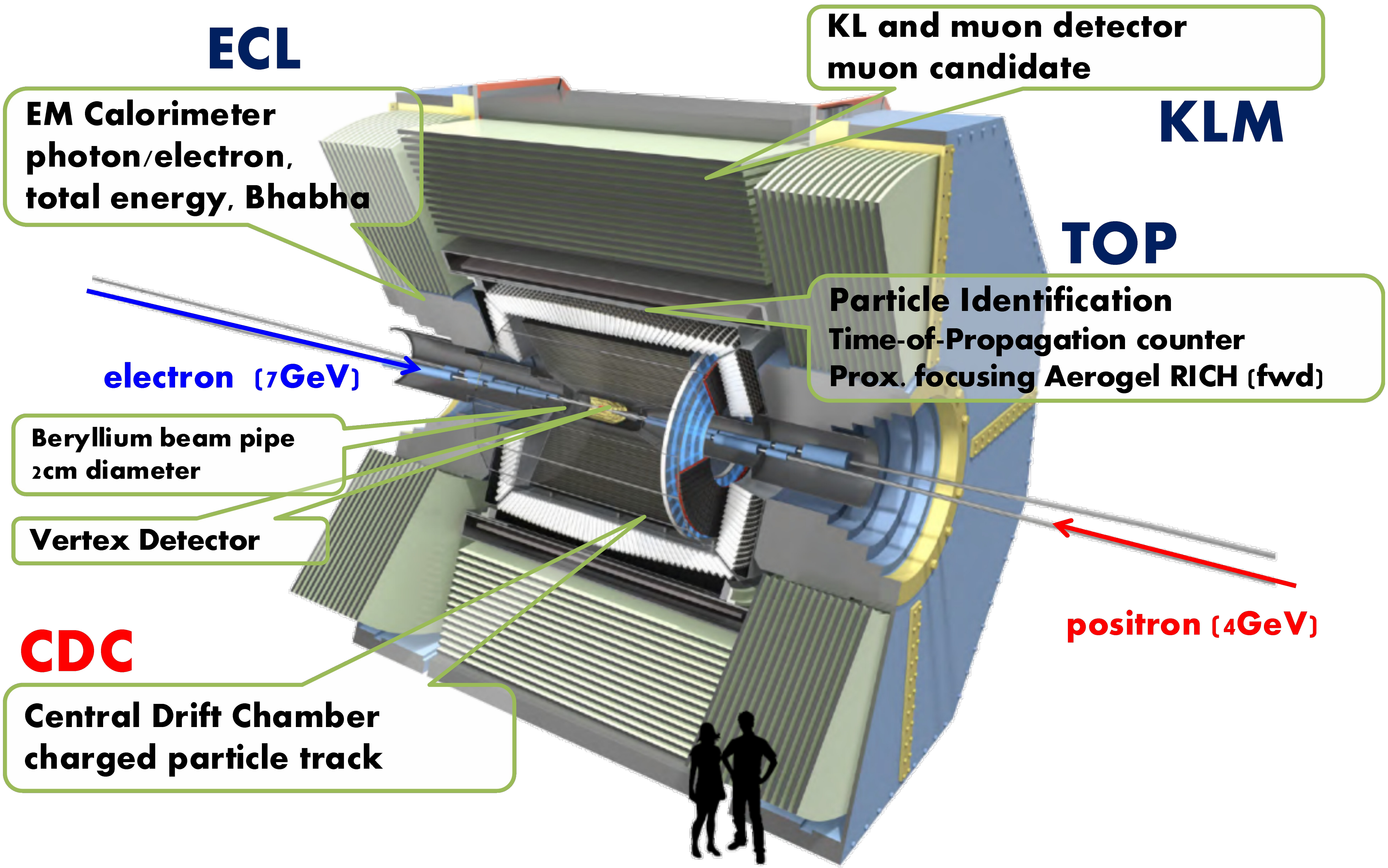
rare B decay,
high precision B
physics



(Yamada san's talk this afternoon.)

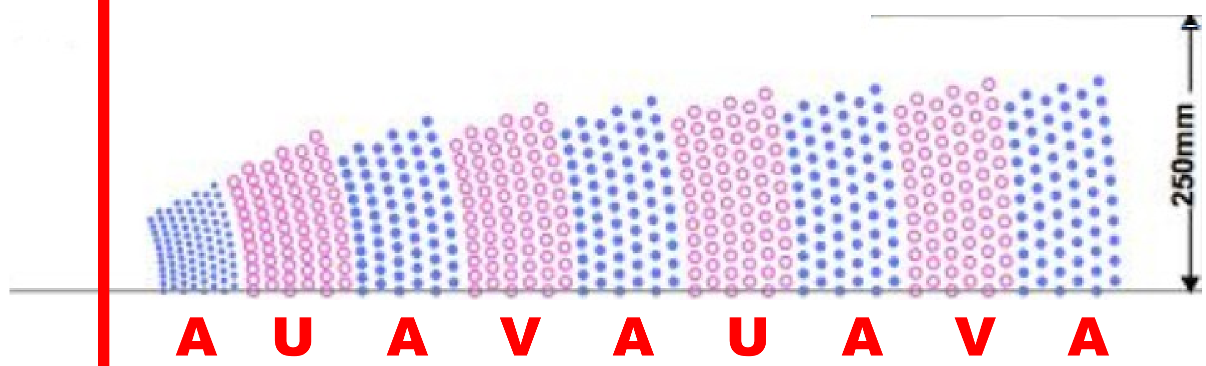
Belle II

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



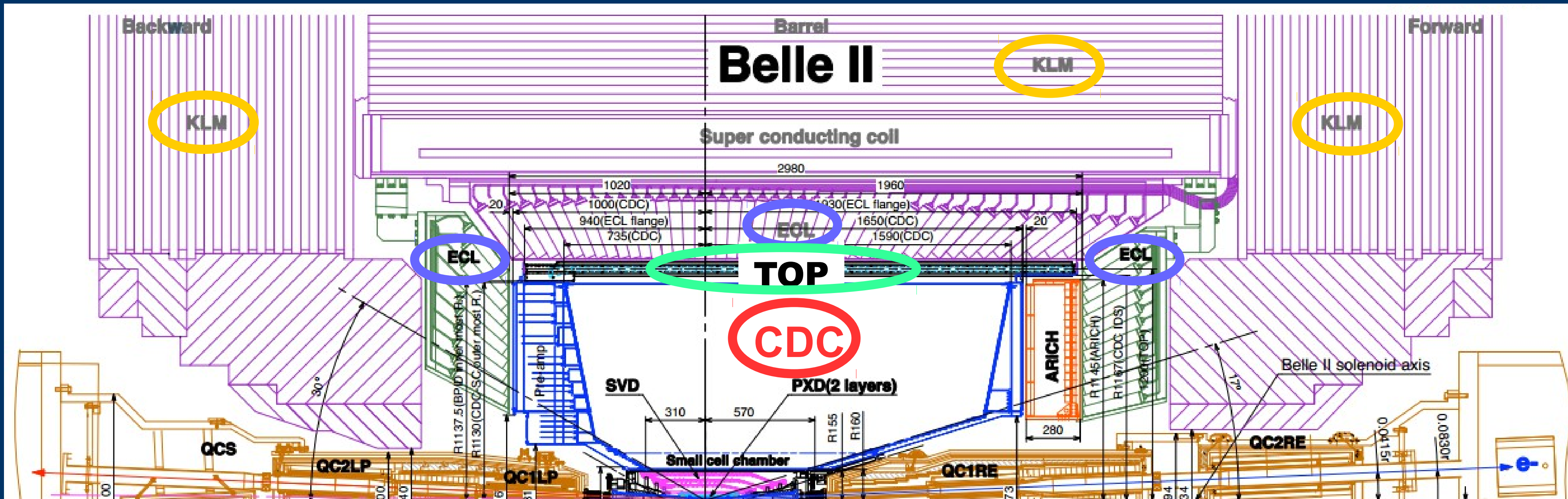
Belle II Central Drift Chamber

- ➔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

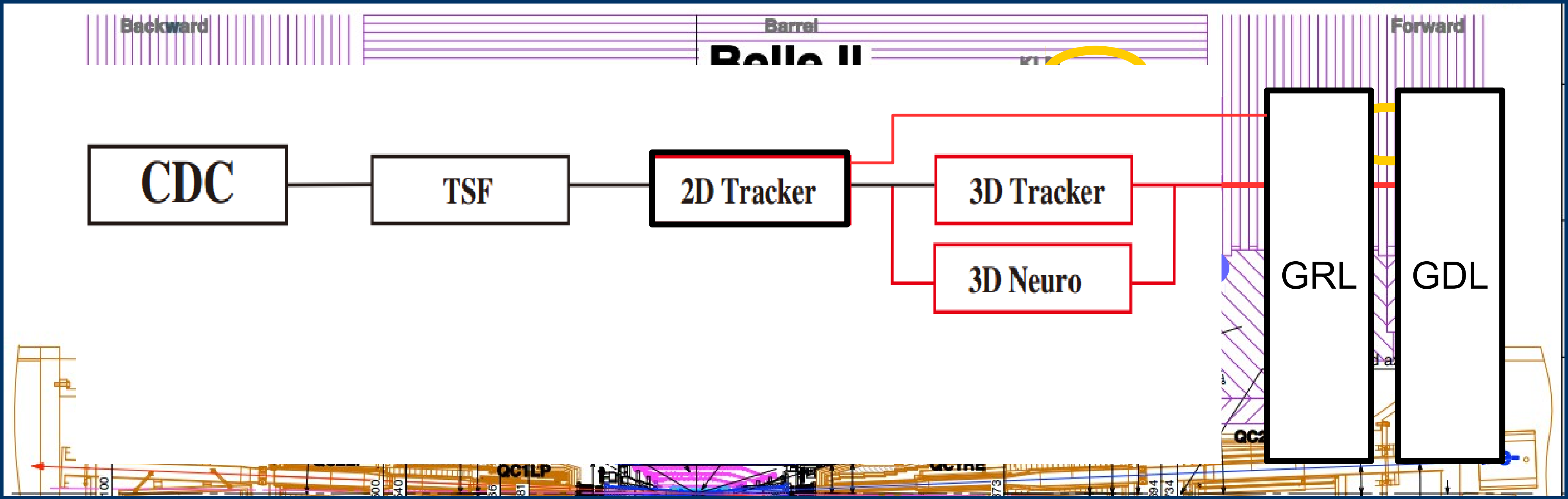
- detector built
- all front-end electronics installed
- currently doing standalone cosmic-ray test with simplified trigger function
- scheduled to move into Belle II this fall



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. trigger rate 30 kHz (DAQ requirement)
100% efficiency

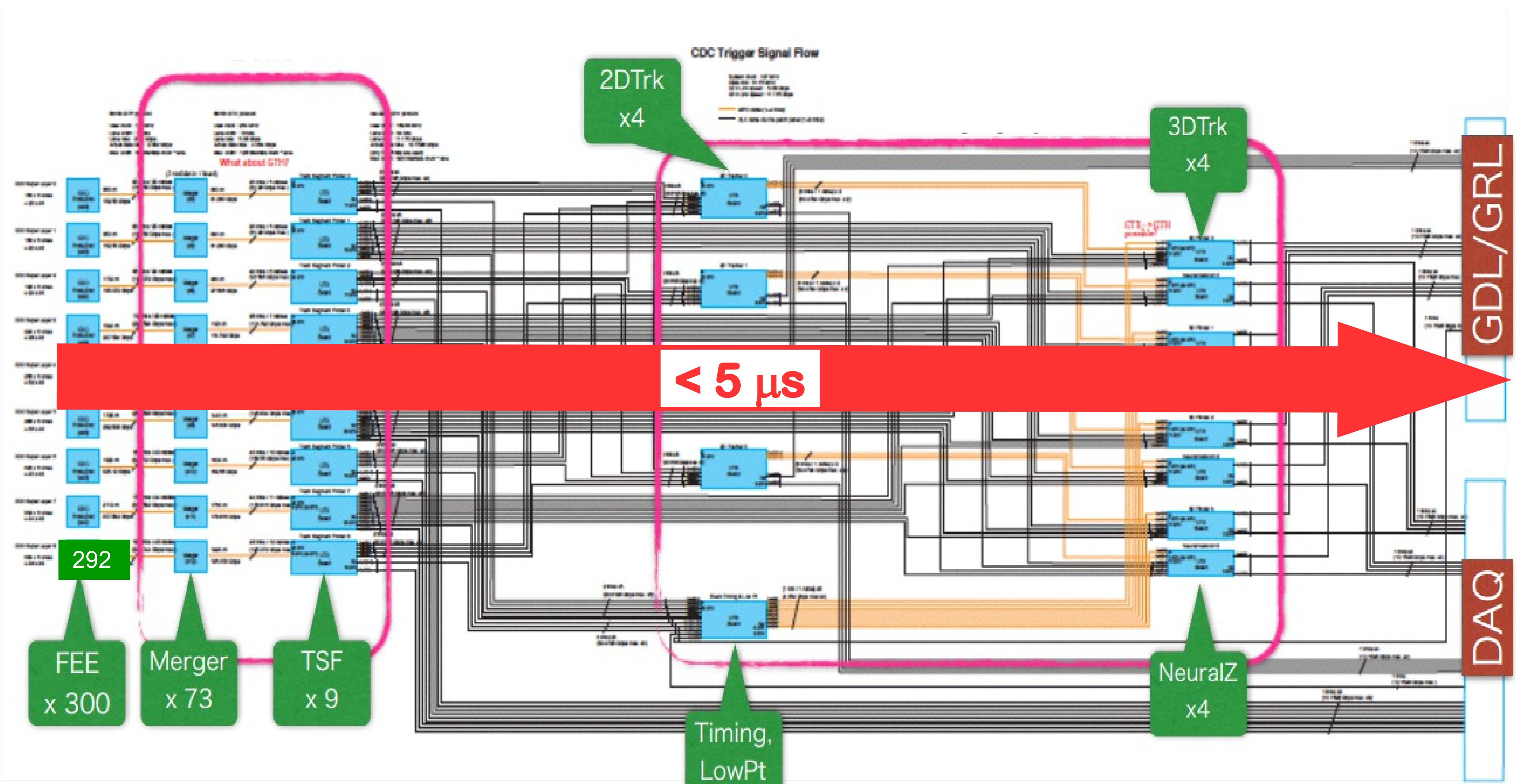
CDC L1 trigger is the most complicated one among the 4.

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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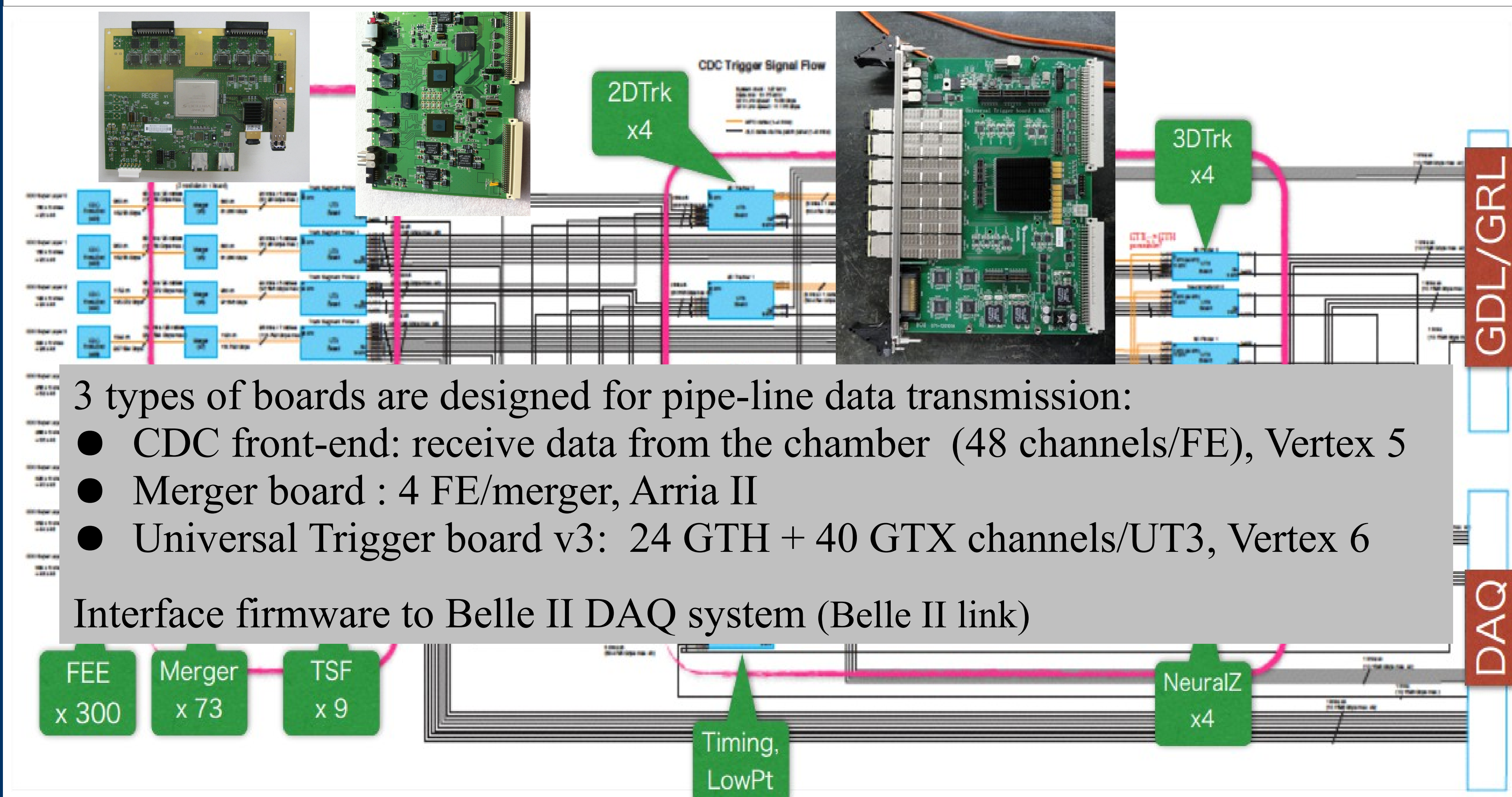


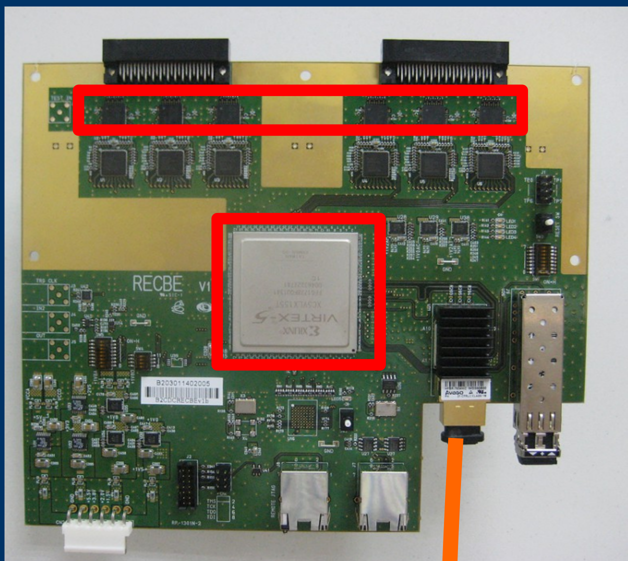
3 types of boards are designed for pipe-line data transmission:

- 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

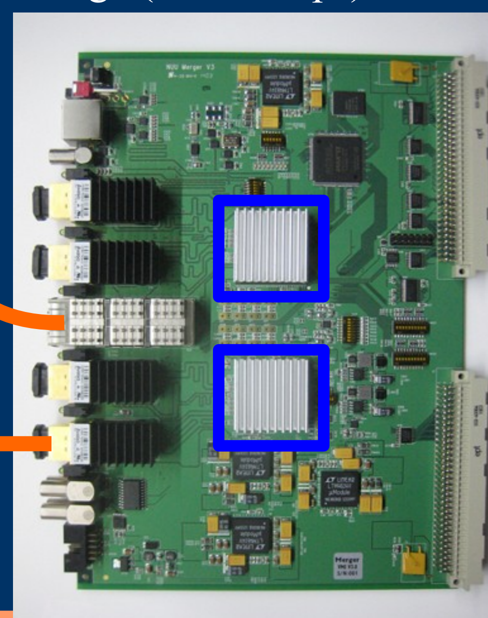


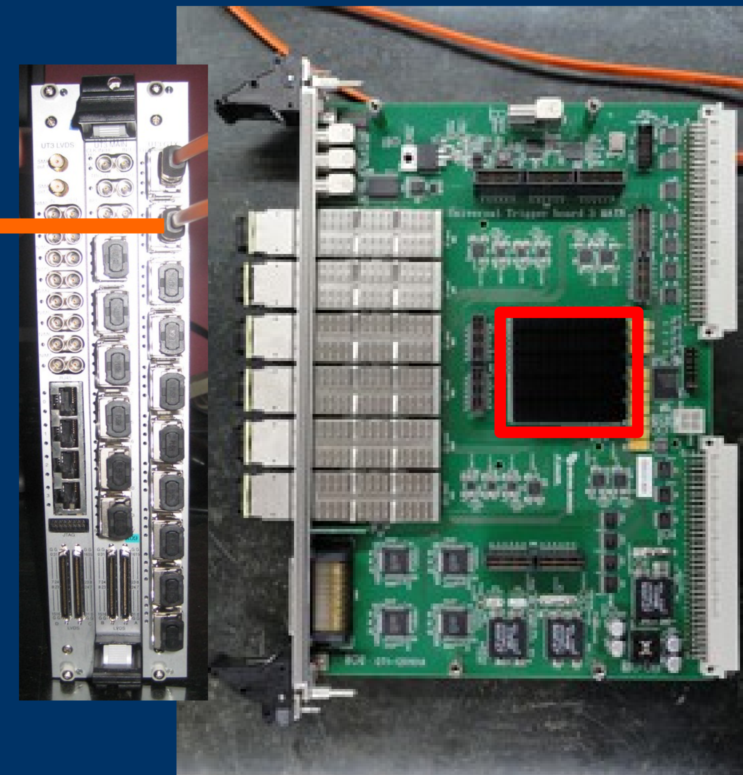
FE: on detector
8 ASIC (48 channels)
analog output
digital output (hit timing, δt 1ns)
belle2link
tigger function built-in

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





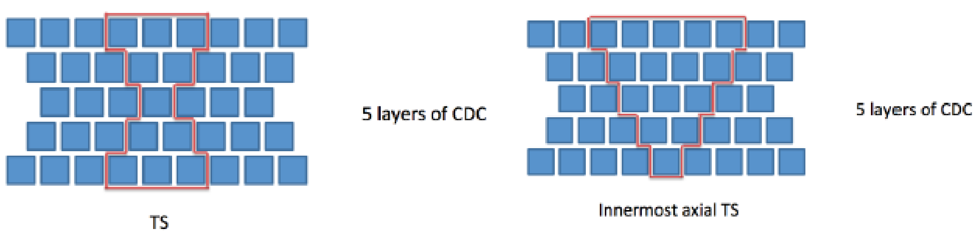
UT3: (3 units wide)
trigger data
belle2link

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

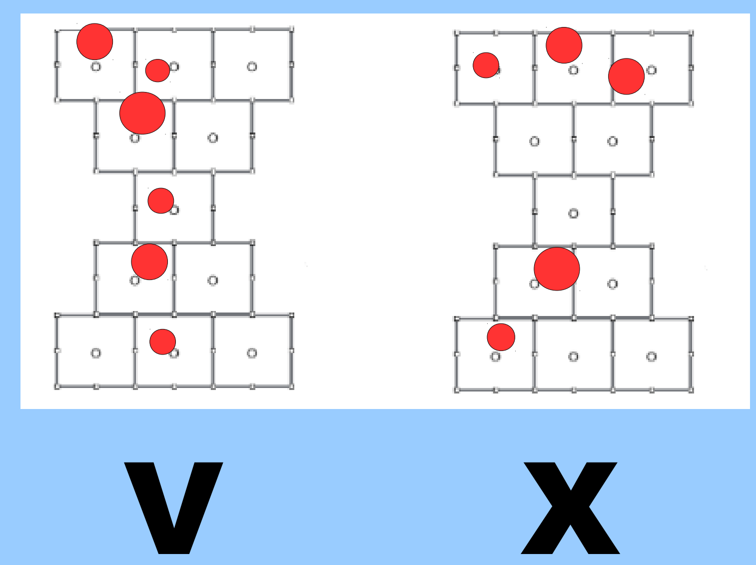
Track Segment Finder (TSF)

- 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

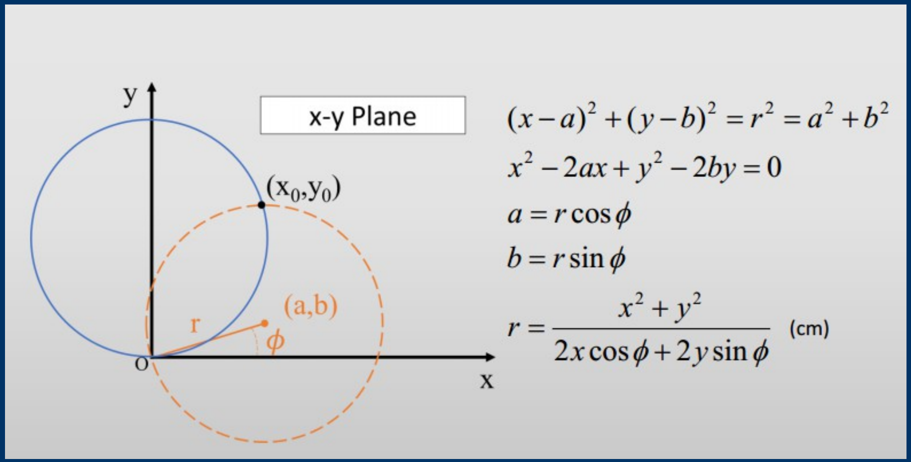


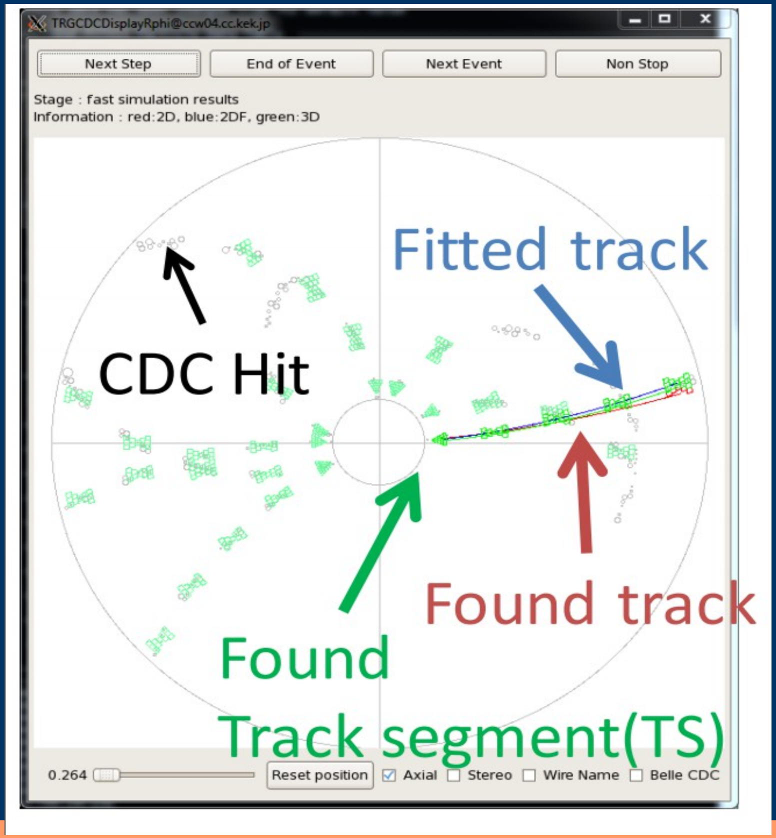
- Track segments is the basic unit in CDC Trigger.
- The center wire layer between the 5 layers is used as the position of the TS called “priority cell”.
- Drift time of priority cell is important.
- Also to determine event time, “fastest drift time” in TS is important.

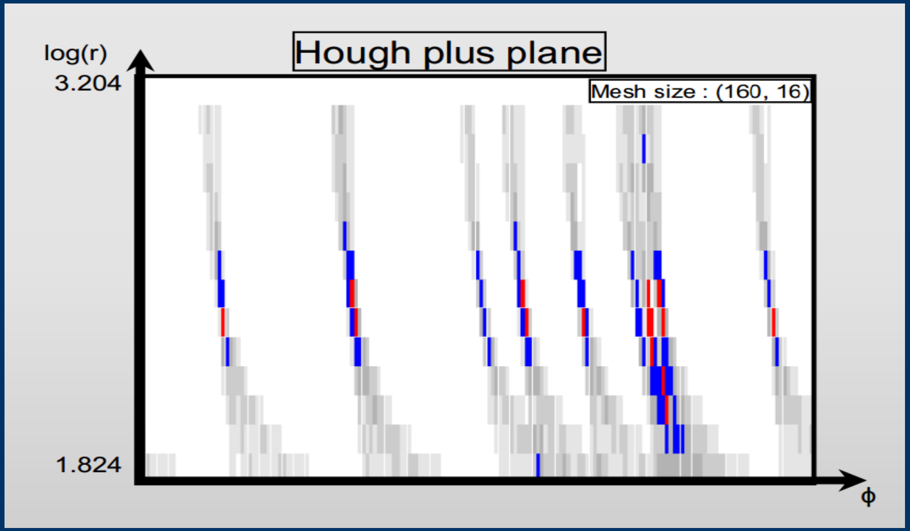


2D Tracker

- 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.



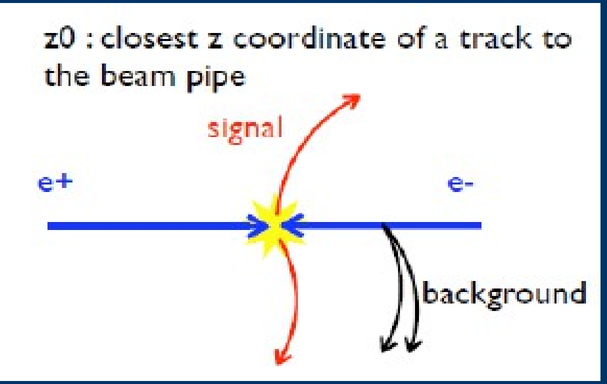




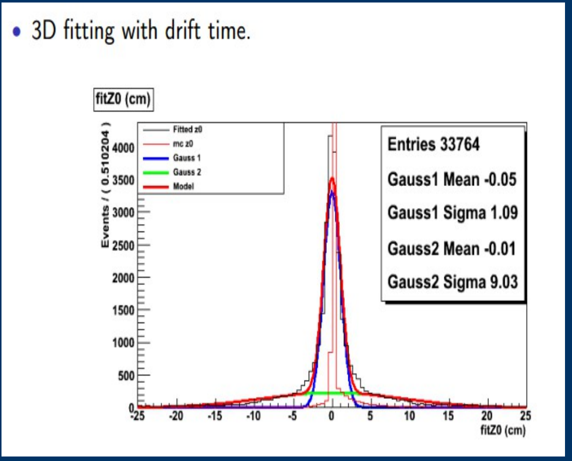
- 2D fitter
  - minimum chi-square fit
  - results sent to 3D triggers

3D Tracker/Neural-Network z trigger

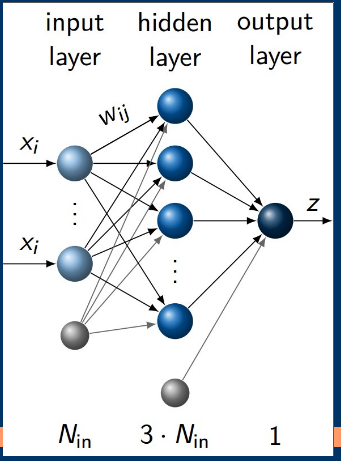
- The 3D tracker is meant to get better z ($\delta z \sim 1$cm) position of a track origin to improve background rejction.

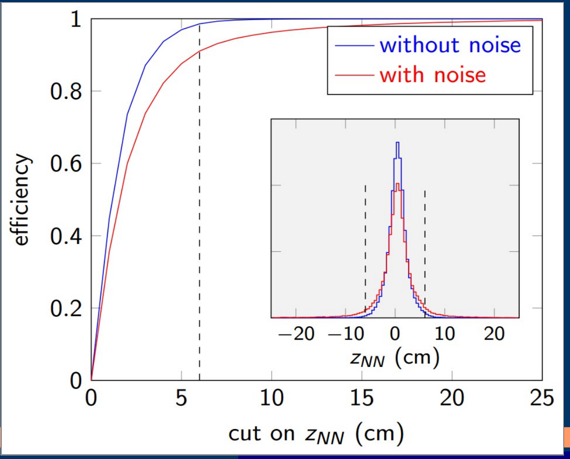


- 3D tracker
  - ➔ search hit TS in 4 stereo-superlayers associated with the 2D tracks
  - ➔ performs a geometric transformation and chi-square minimization to determine the track's z_0 position.
  - ➔ algorithm/firmware are already developed

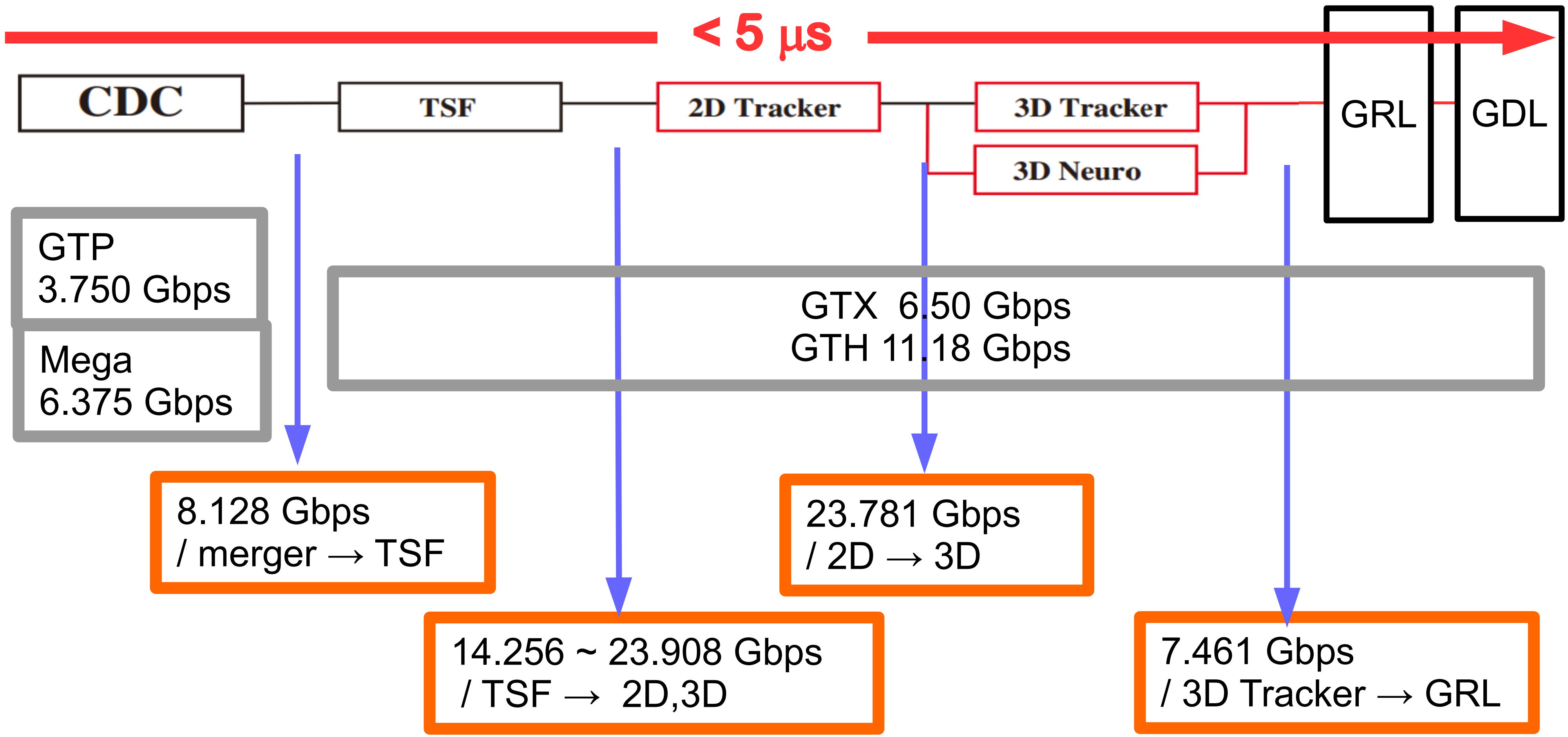


- 3D neural-network z trigger
  - ➔ 2D tracking output and the raw drift times from all superlayers as seeds for a feed-forward network
  - ➔ trained on simulated tracks to estimate z-vertex
  - ➔ simulation studies show compatible δz and close to 100% efficiency
  - ➔ firmware under development





data rate (per connection)



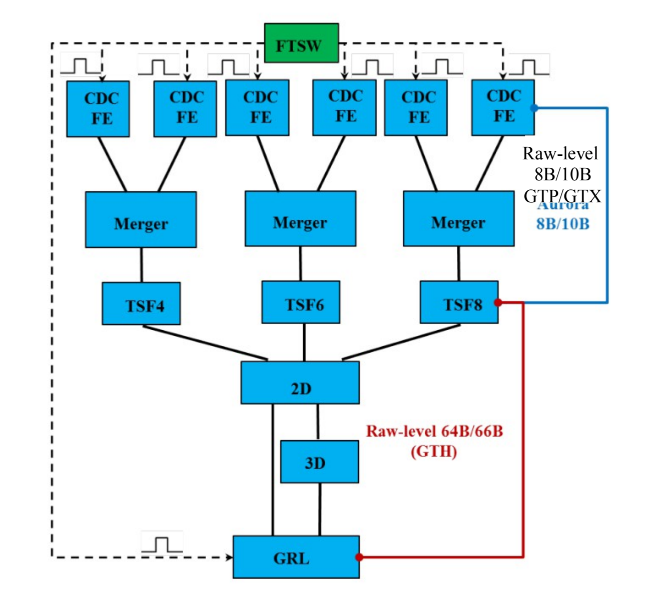
- ✔ one connection (channel) can have multiple fibers bound together.
- ✔ processing time, bandwidth are not a big problem.

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



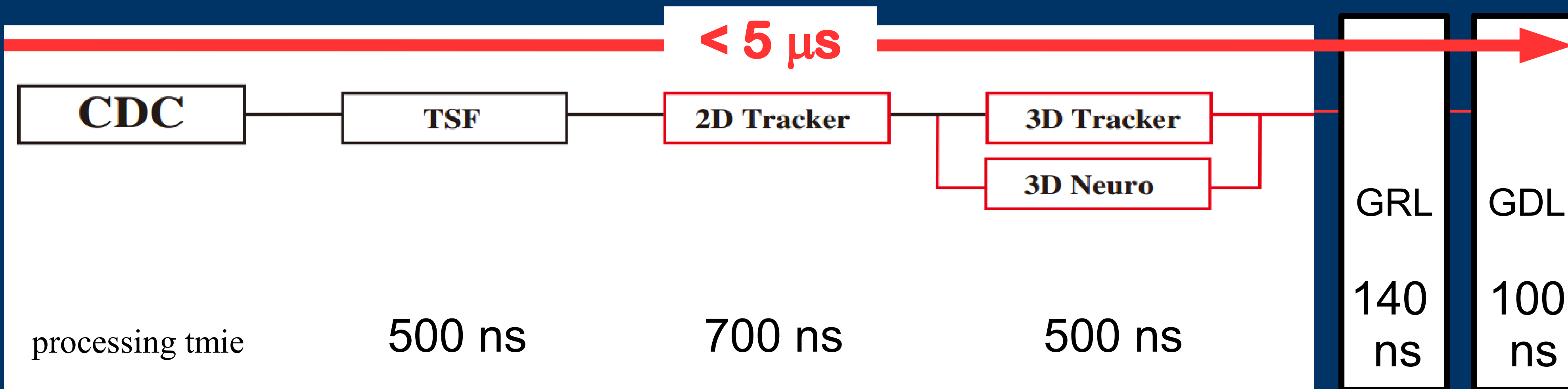
Latency comparison

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)

Poster session 2, No 149

The BGO System for Real Time
Beam Background Monitoring in BEAST II
BGO + FPGA DAQ → SuperKEKB

beam bg/machine study

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

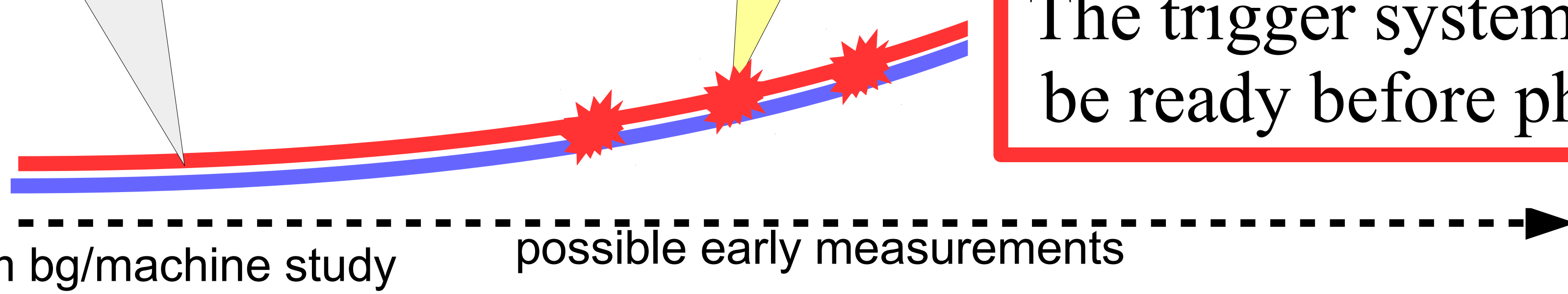
Beast 2 with partial Belle II,
some measurements possible.

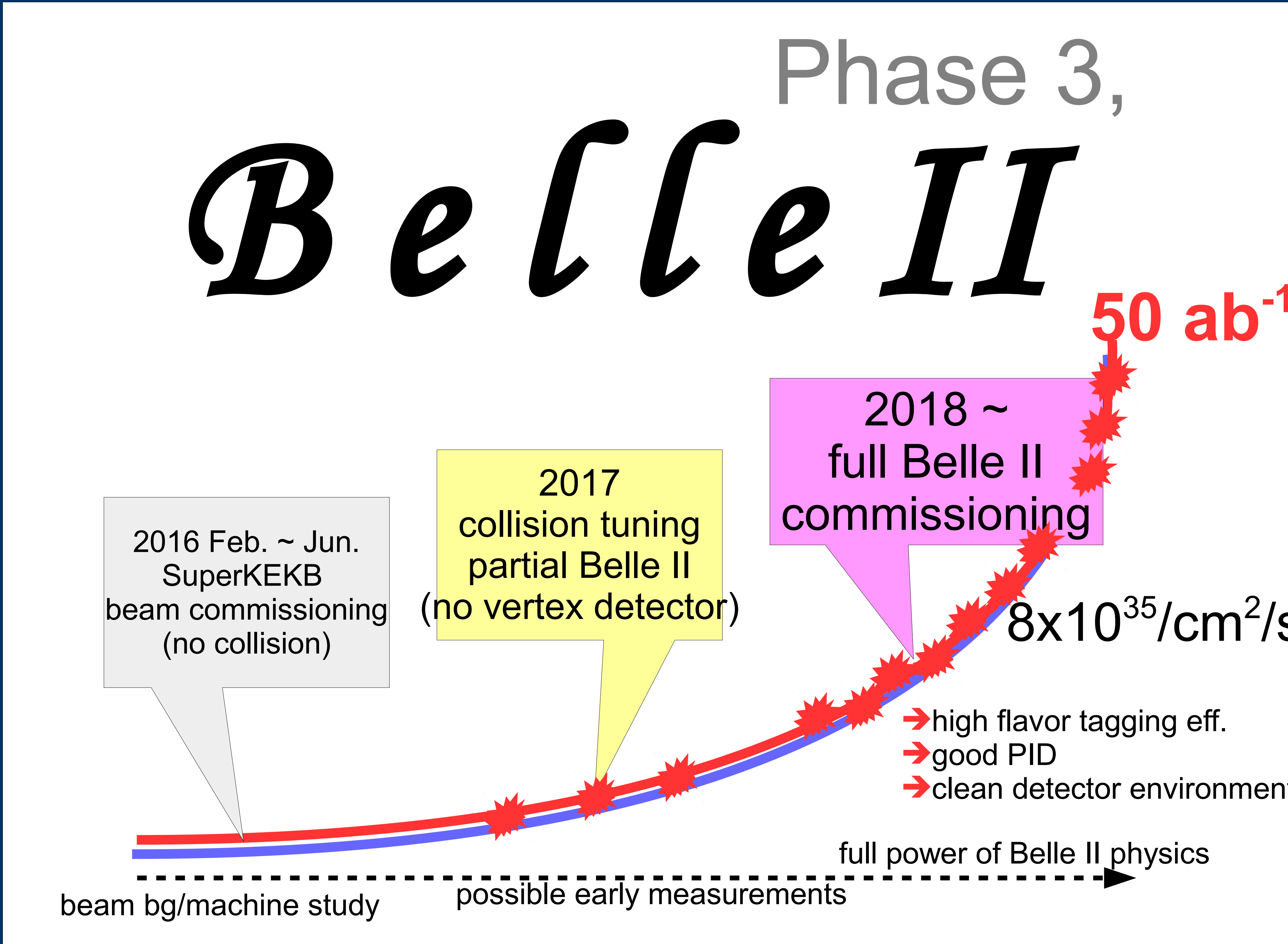
2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)

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
50 ab^{-1}
2016 Feb. ~ Jun.
SuperKEKB
beam commissioning
(no collision)
2017
collision tuning
partial Belle II
(no vertex detector)
2018 ~
full Belle II
commissioning
8x10^{35}/cm^2/s
→high flavor tagging eff.
→good PID
→clean detector environment
full power of Belle II physics
beam bg/machine study
possible early measurements

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!!