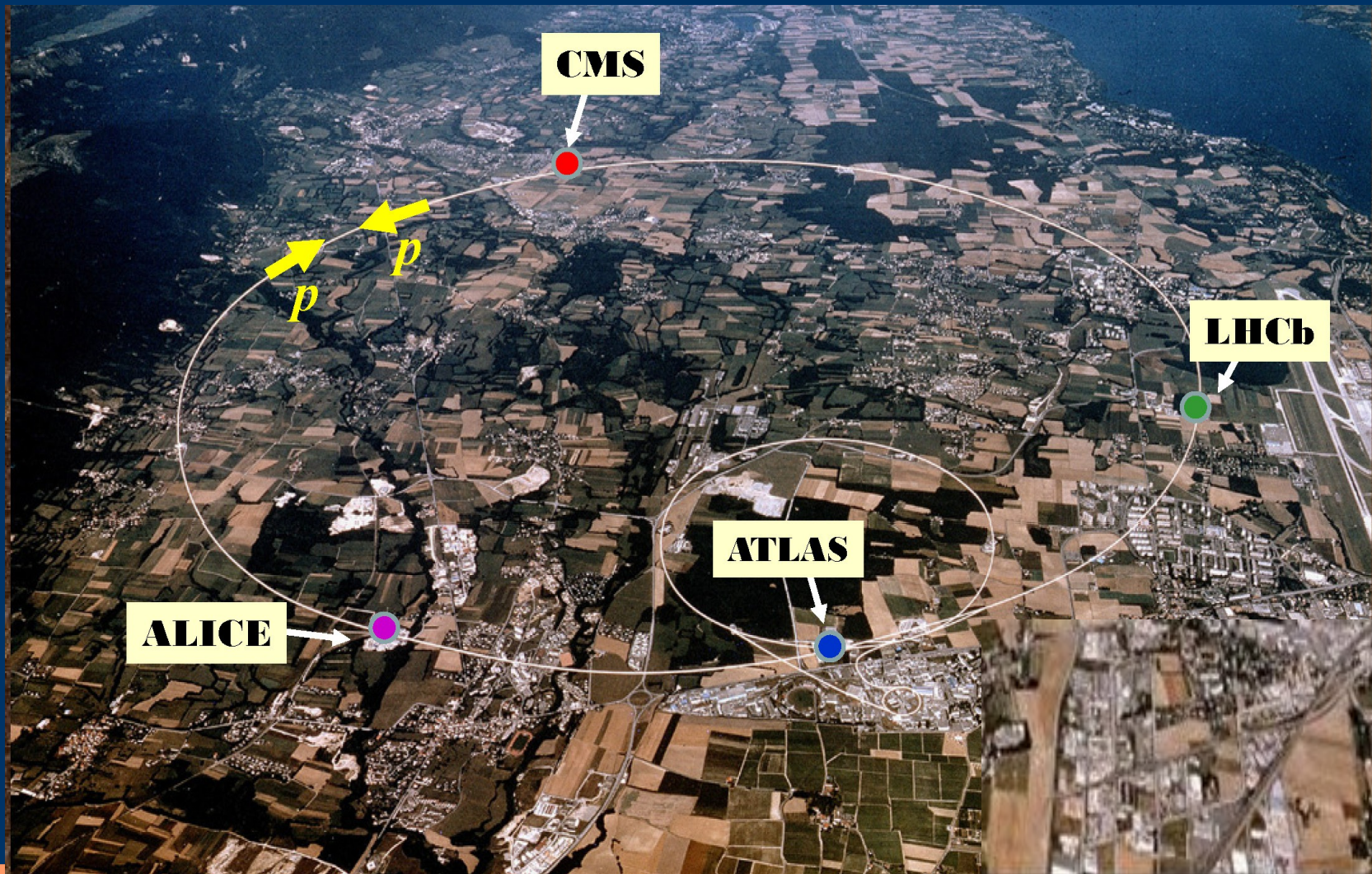
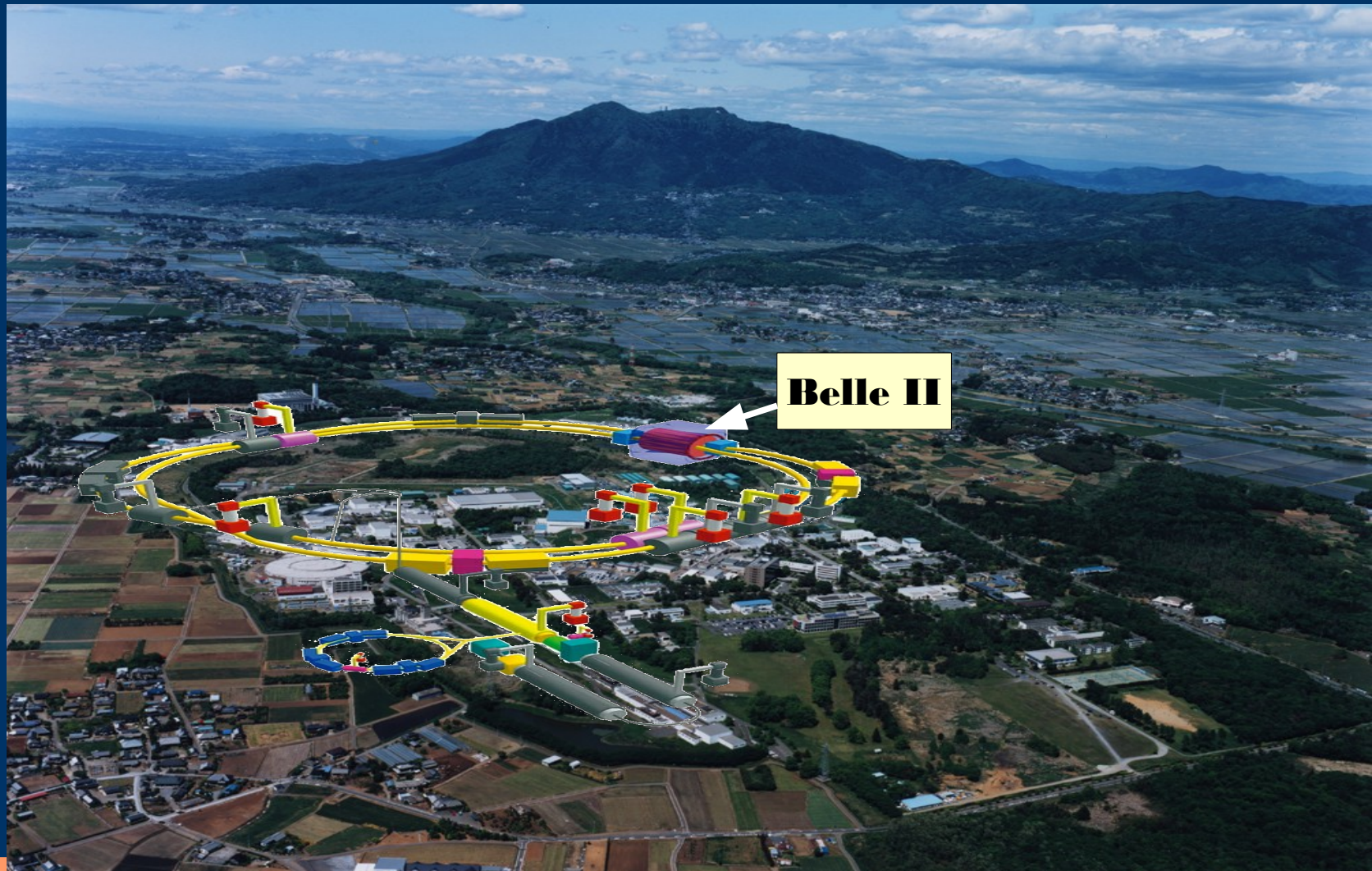


LHC, on the other side of the mountains  
lake geneva  
famous Mt. Jura  
LINACs + small circles + a big circle





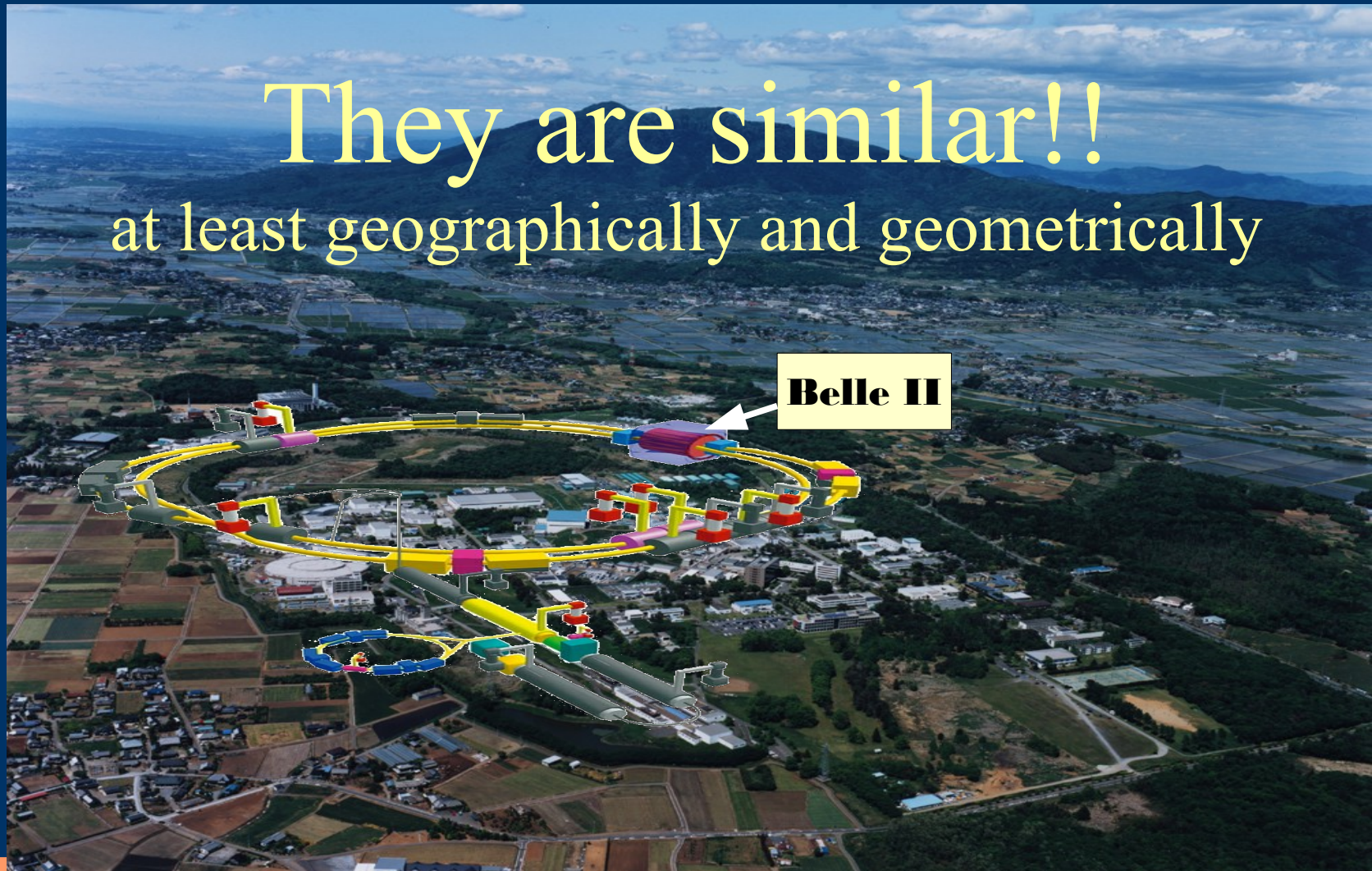
SuperKEKB, on the other side of the world  
lake Kasumigaura (霞ヶ浦)  
famous Mt. Tsukuba  
LINACs + small circles + a big circle





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

They are similar!!  
at least geographically and geometrically



# 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



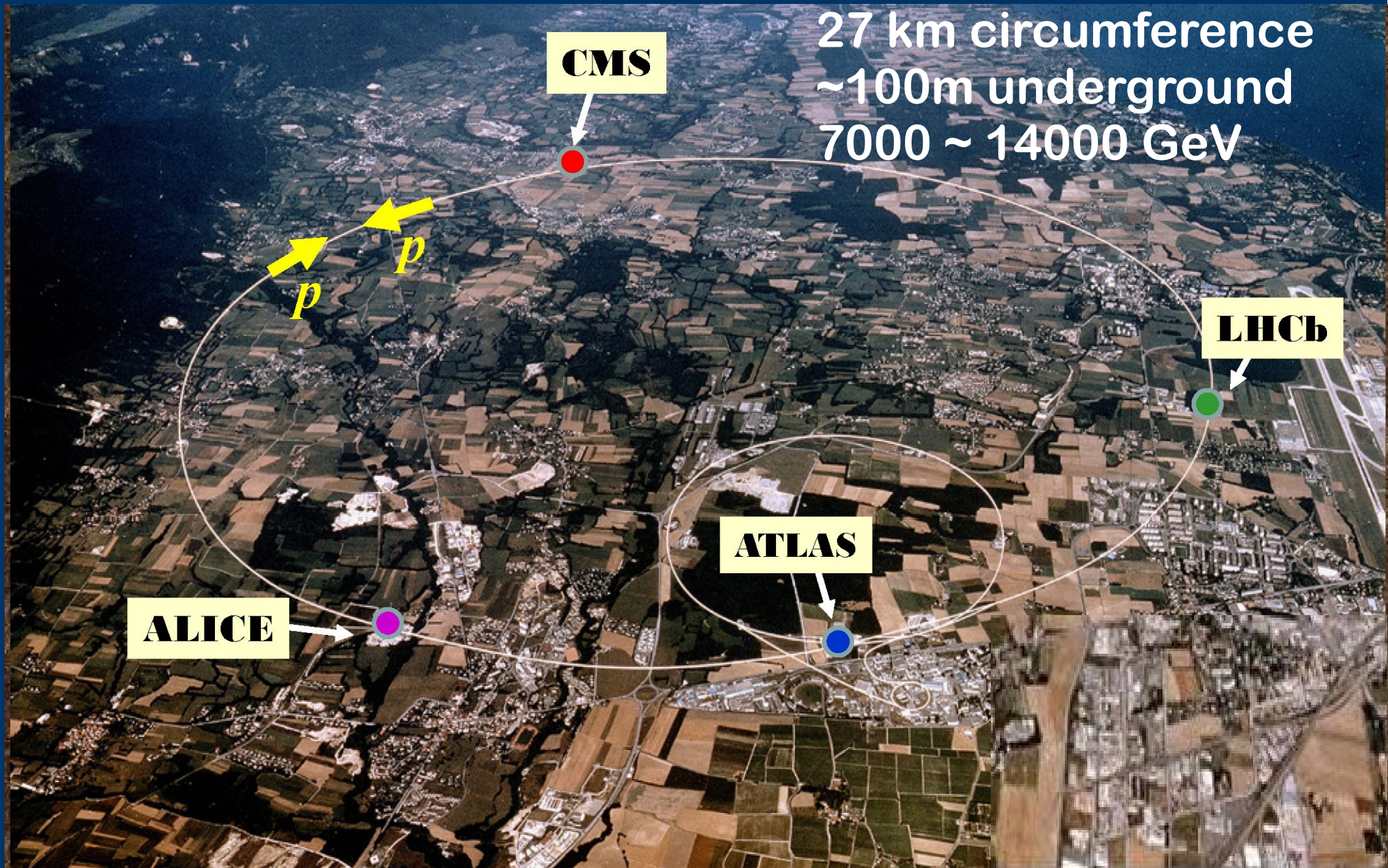
# Outline

- Introduction
  - 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

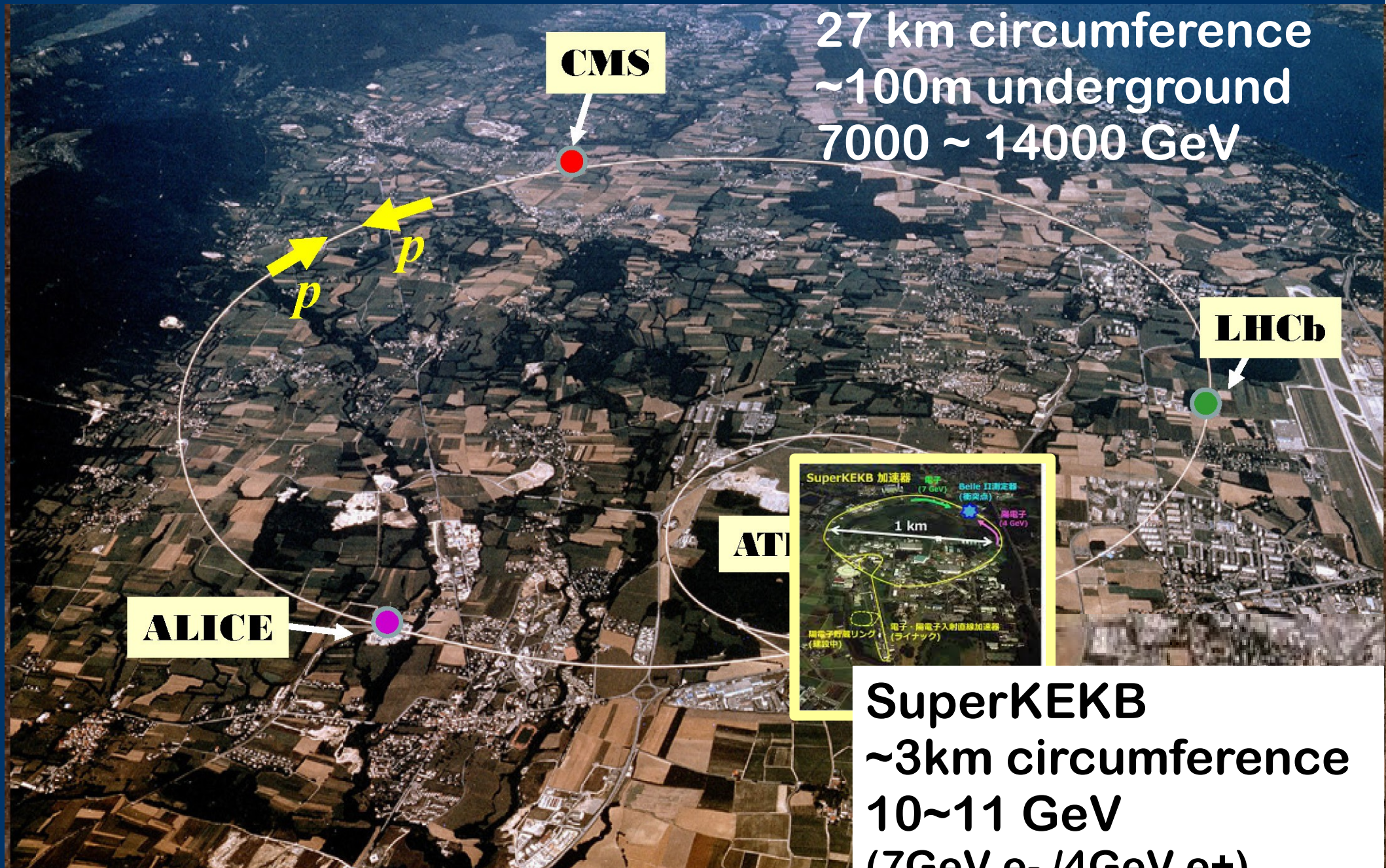
27 km circumference  
~100m underground  
7000 ~ 14000 GeV





# 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?

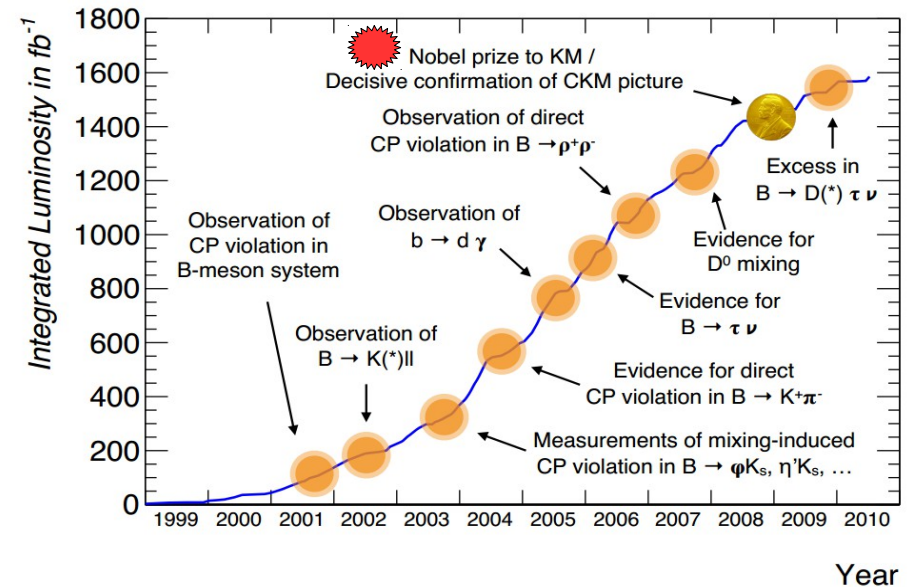
After 10 years operation, Belle and BaBar achieved a great success in B (charm,  $\tau$ ) physics studies and explored possible new physics

- 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?

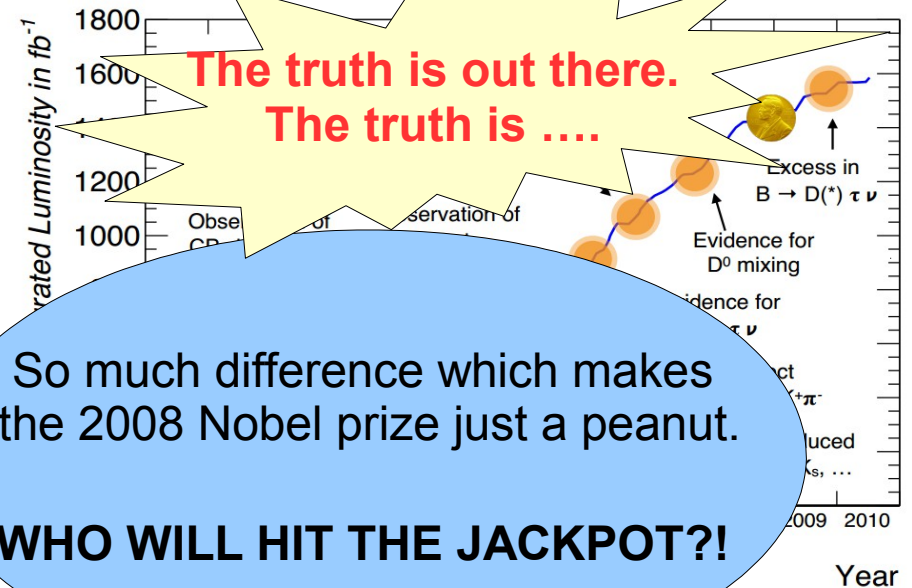
After 10 years operation, Belle and BaBar achieved a great success in B (charm,  $\tau$ ) physics studies and explored possible new physics

- 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.



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

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



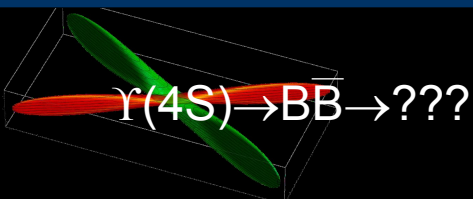
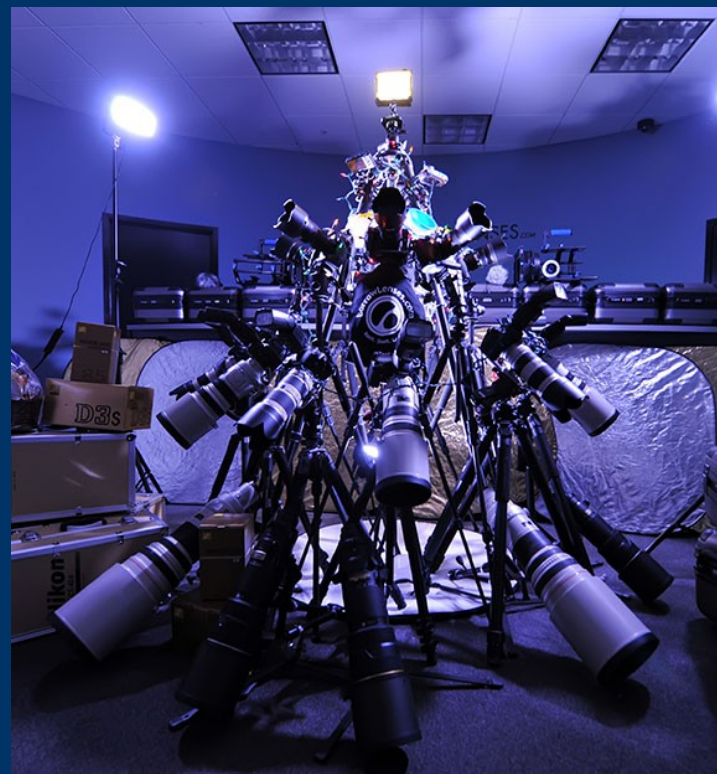
## Energy frontier

→ 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)





# KEKB + Belle → SuperKEKB + Belle II

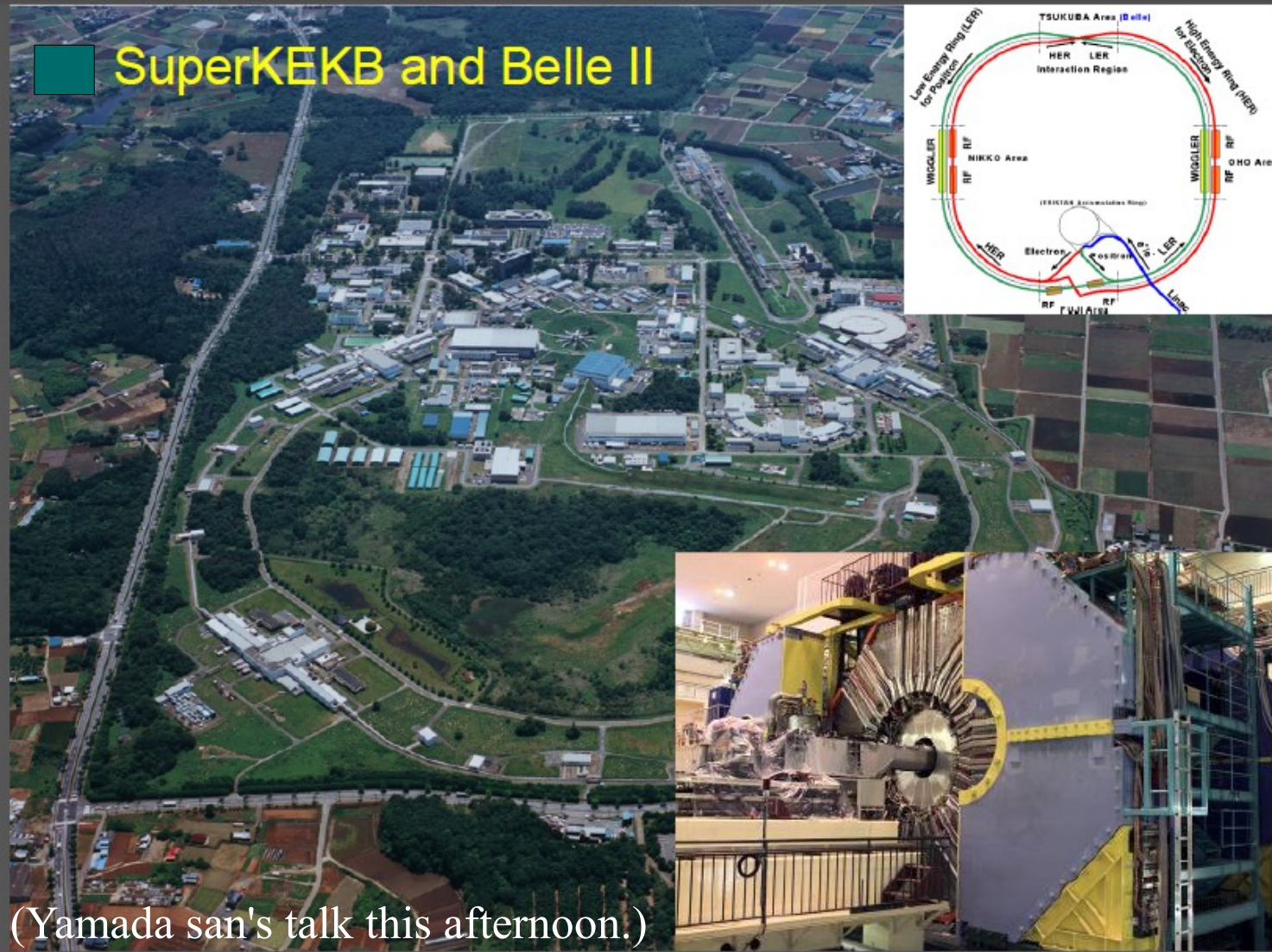
7 GeV  $e^-$  / 4 GeV  $e^+$

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

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

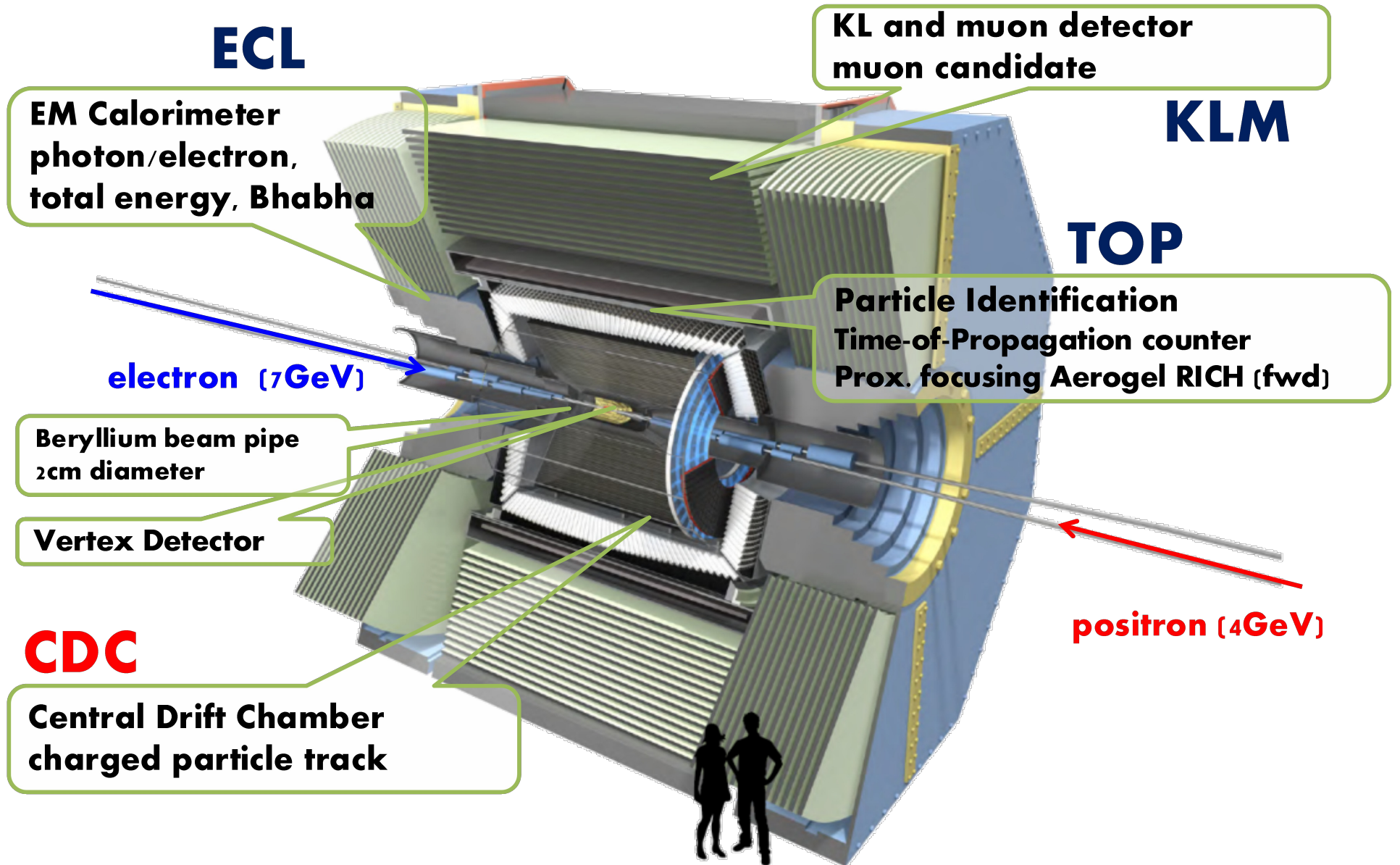
rare B decay,  
high precision B  
physics

## SuperKEKB and Belle II



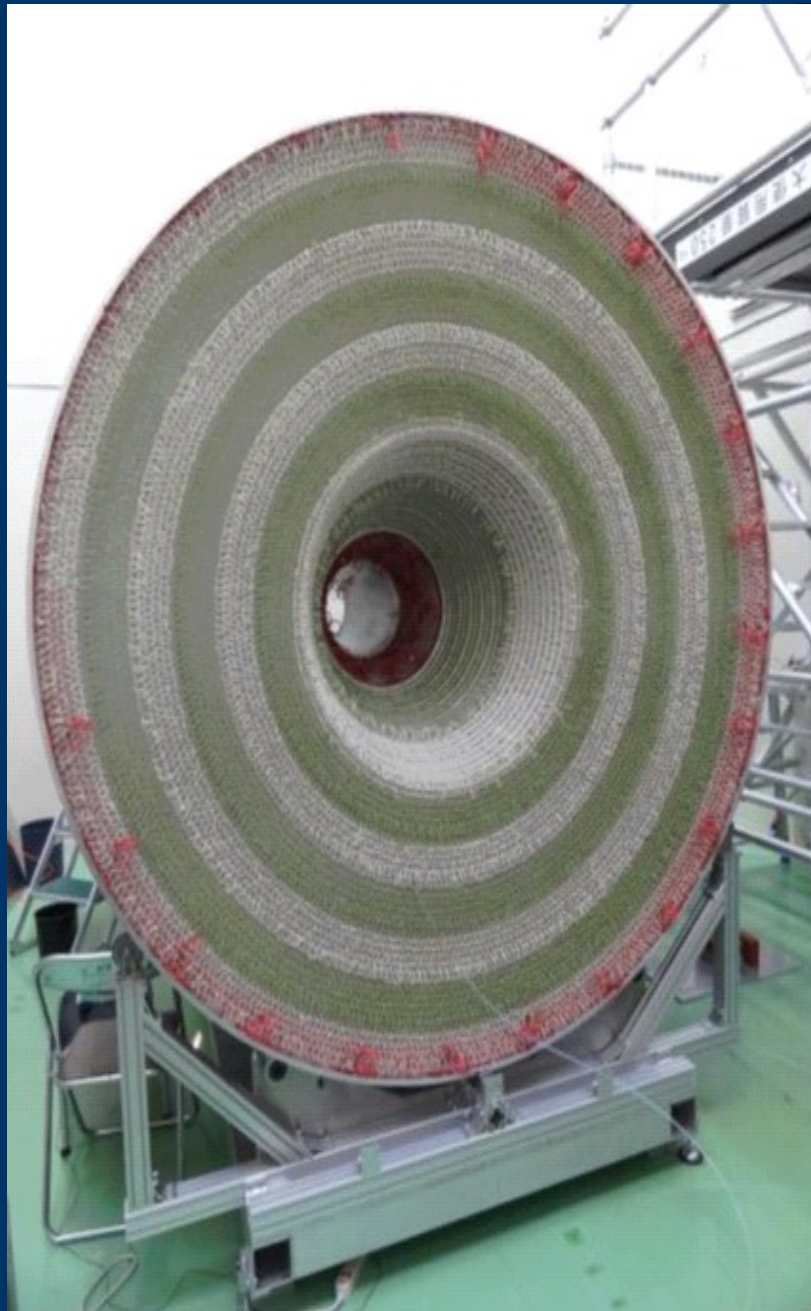
(Yamada san's talk this afternoon.)



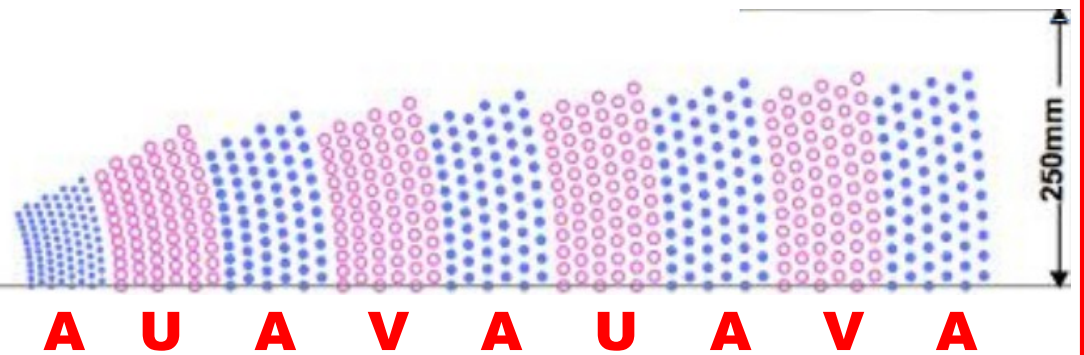




# Belle II Central Drift Chamber



- 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



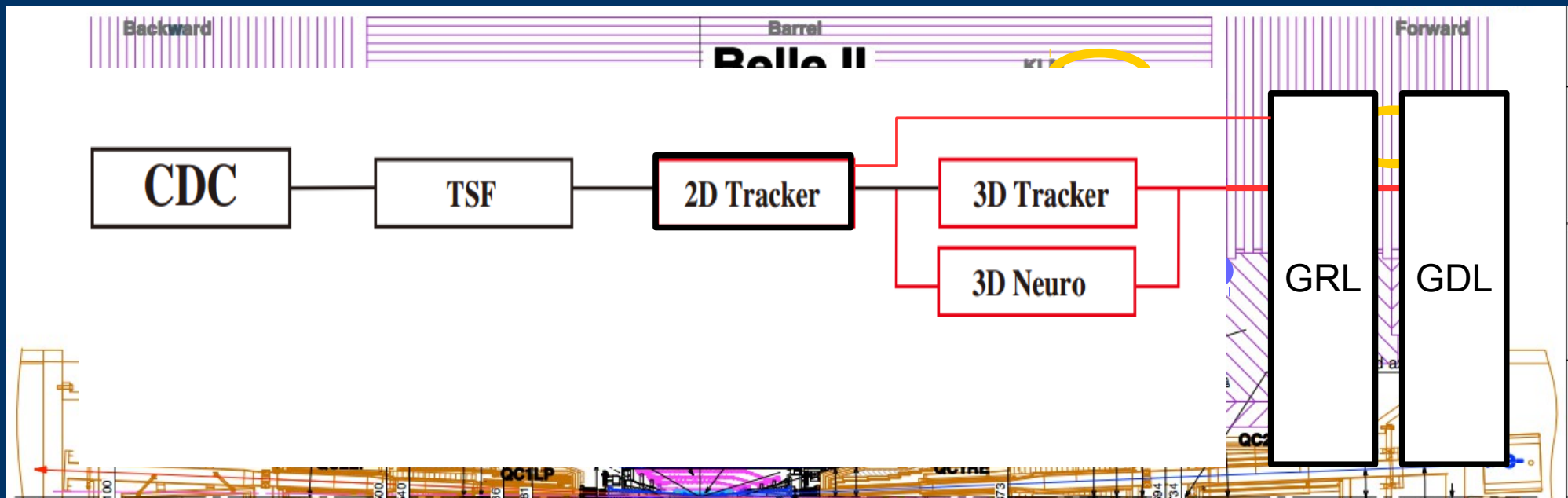
## Status

- 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  $\sim 10$  MHz

interested physics event rate  $\sim 20$  kHz

L1 max. latency  $5 \mu\text{s}$  (DAQ requirement)

event time precision 10 ns (SVD requirement)

L1 max. trigger rate 30 kHz (DAQ requirement)

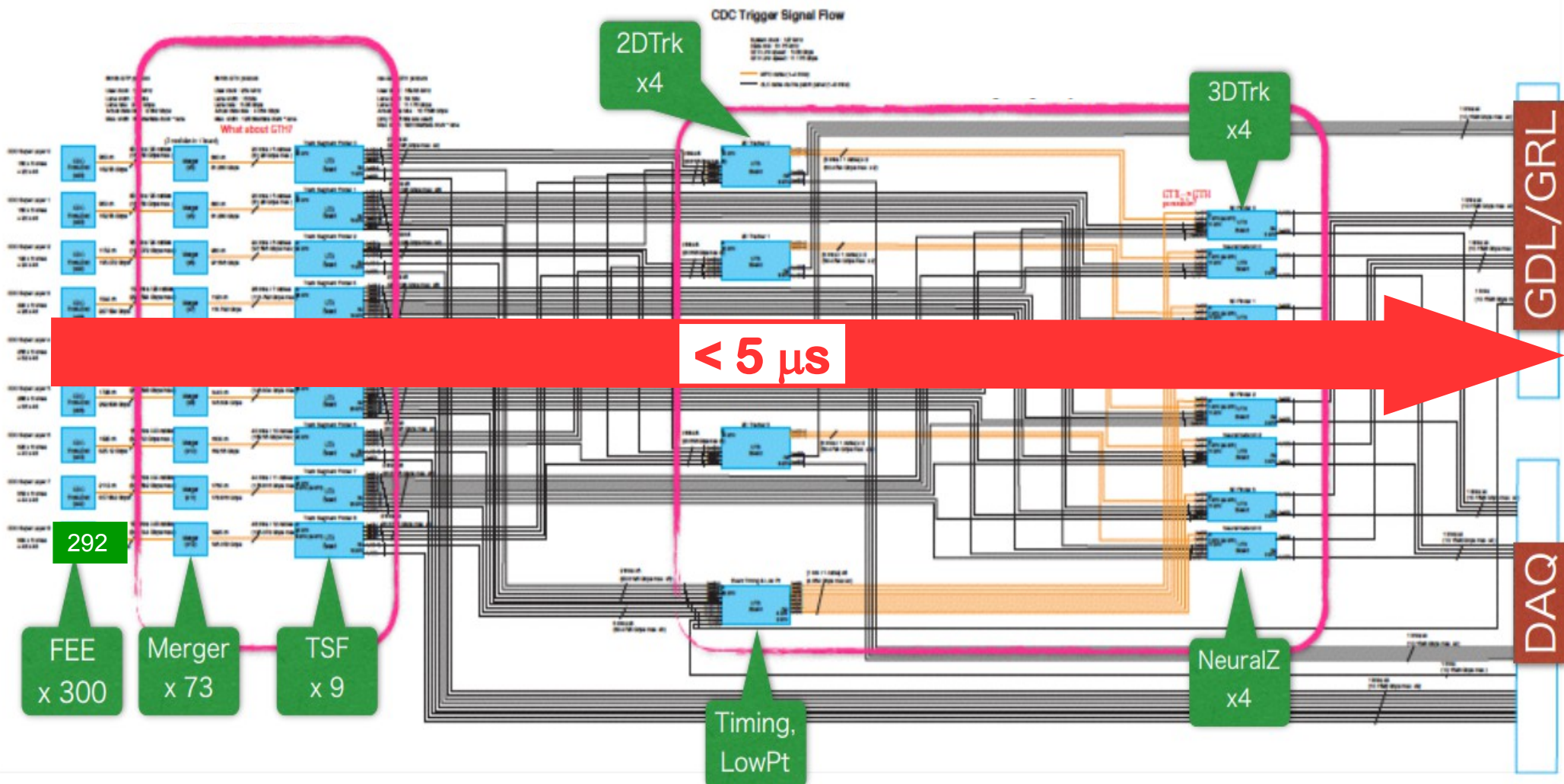
100% efficiency

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



# Belle II CDC Trigger System and data flow structure

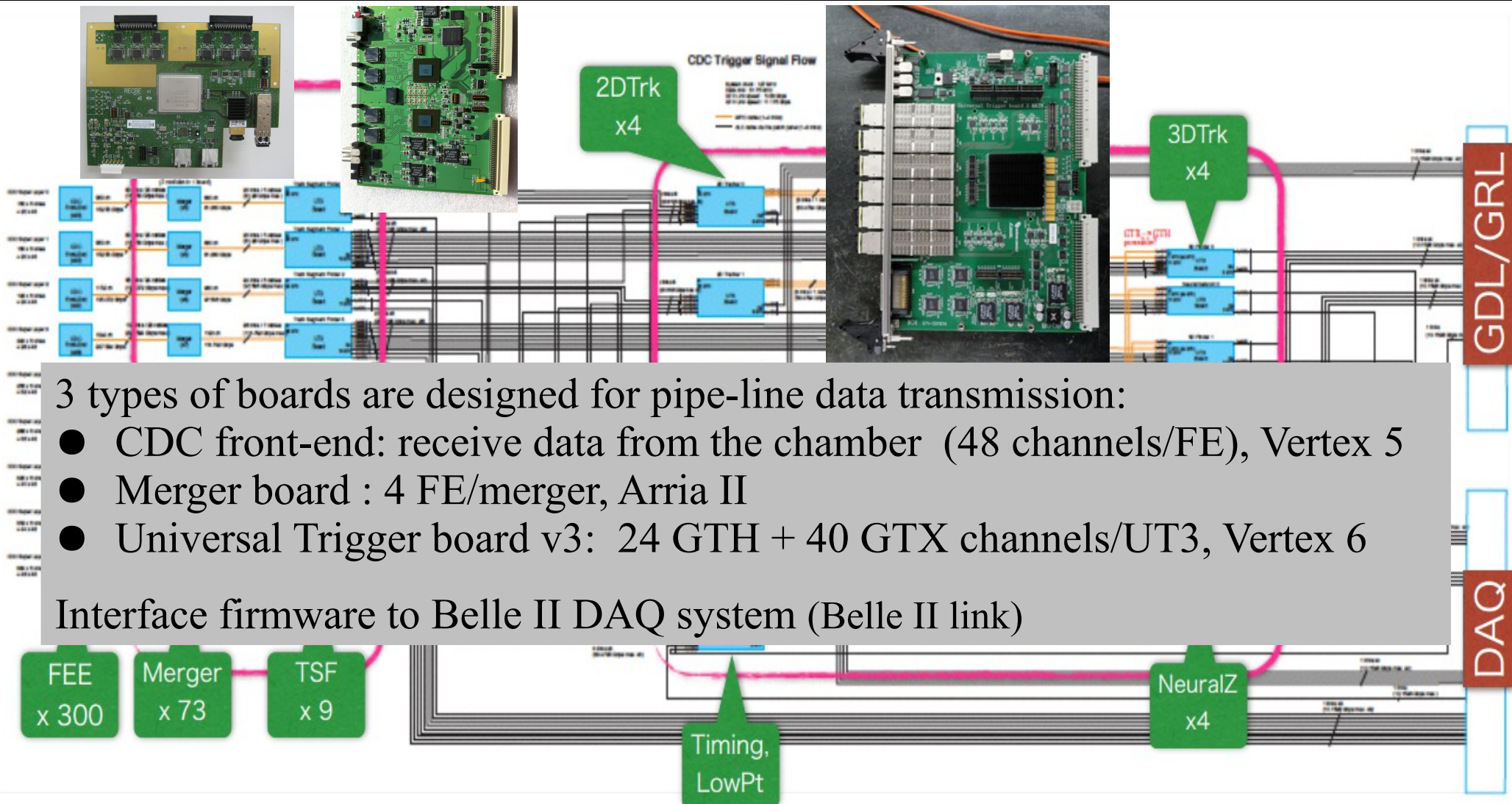
292 x FE → 73 x merger → 9 x TSF → 4 x 2D → 4x3D/4xNN → GRL/GDL  
system clk 8ns, data clk 32ns





# Belle II CDC Trigger System and data flow structure

292 x FE  $\rightarrow$  73 x merger  $\rightarrow$  9 x TSF  $\rightarrow$  4 x 2D  $\rightarrow$  4x3D/4xNN  $\rightarrow$  GRL/GDL  
**system clk 8ns, data clk 32ns**



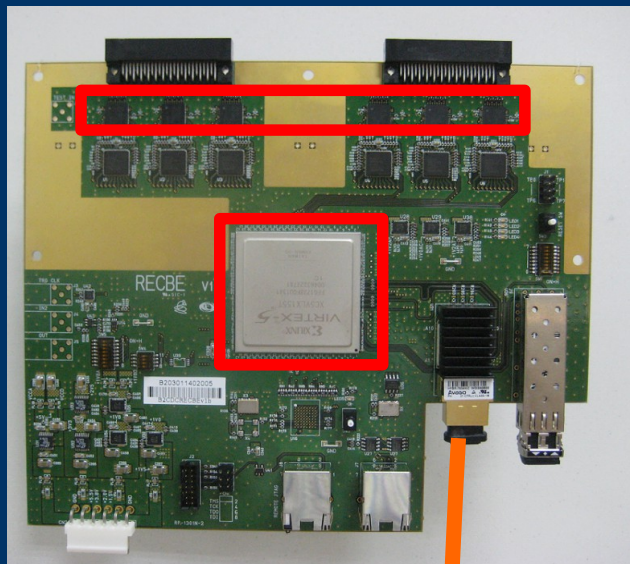
3 types of boards are designed for pipe-line data transmission:

- 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)

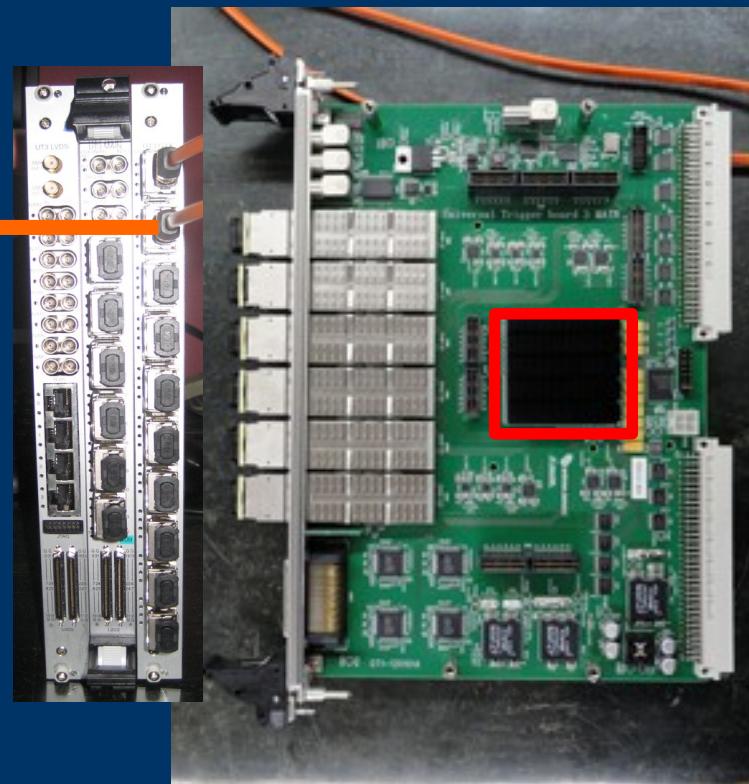
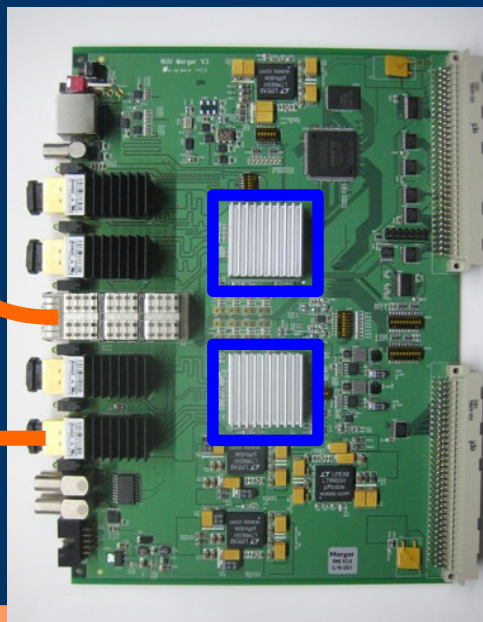
# FE/merger/UT3 board

data clk 32ns



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

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

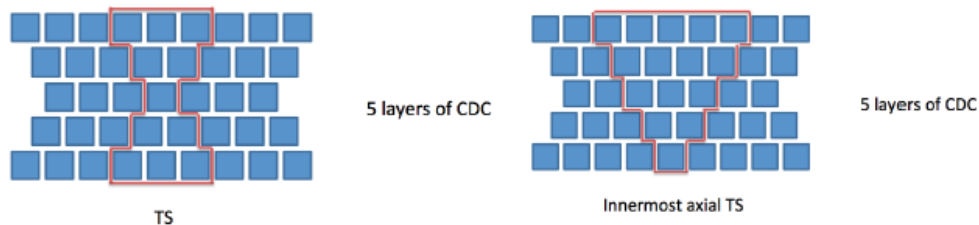
Vertex 5  
GTP (3.750 Gbps) x 4



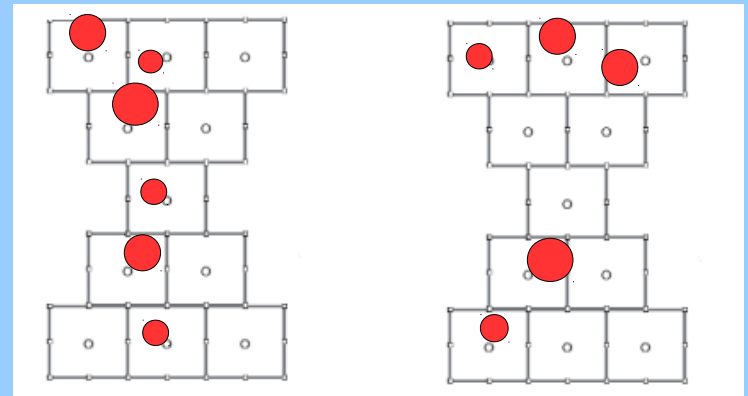
# Track Segment Finder (TSF)

- 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 information 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



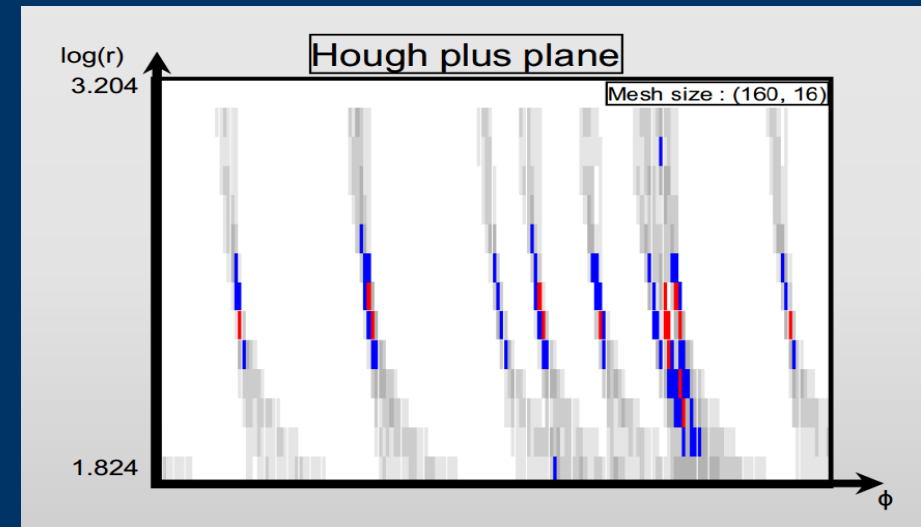
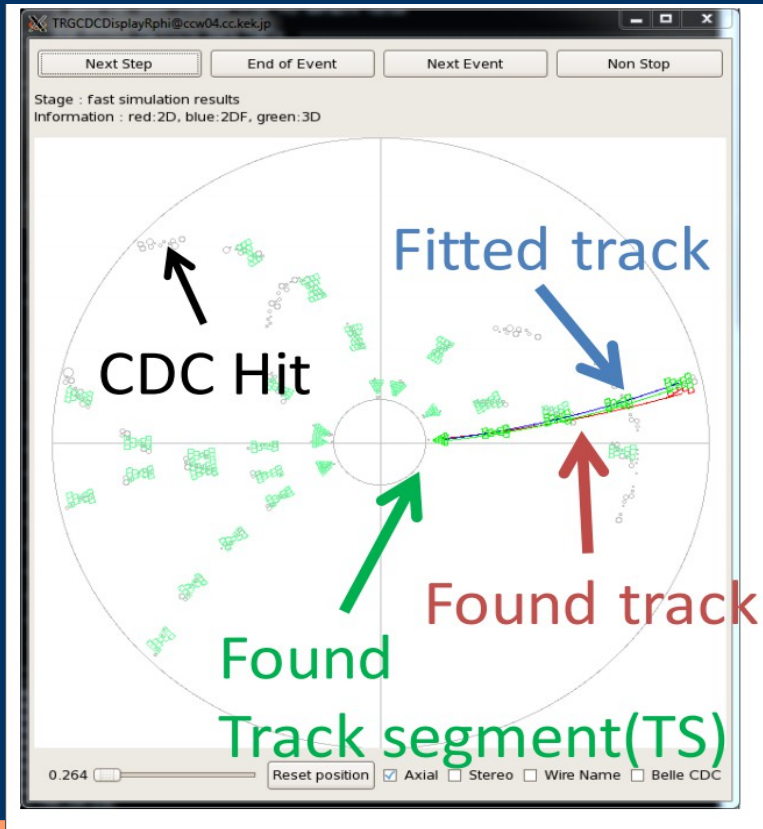
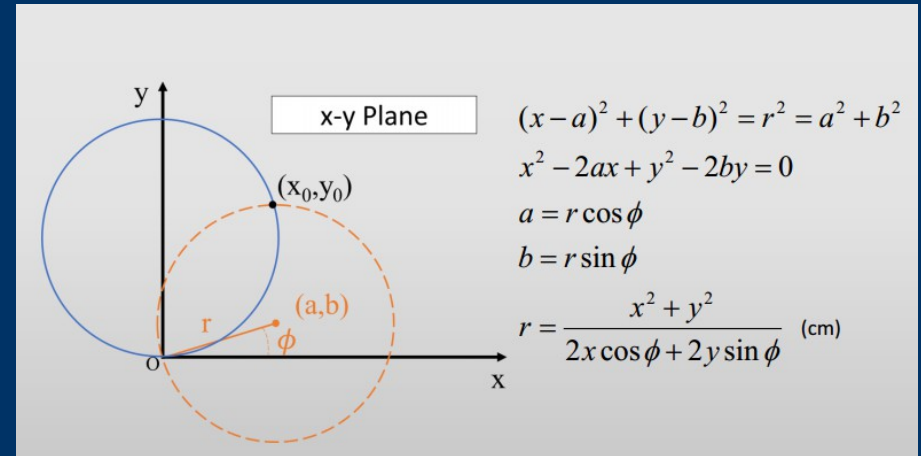
- Track segments is the basic unit in CDC Trigger.
- The center wire layer between the 5 layers is used as the position of the TS called "priority cell".
- Drift time of priority cell is important.
- Also to determine event time, "fastest drift time" in TS is important.



# 2D Tracker

- 2D finder

- ➔ Hough transformation (to  $\log(r)$ - $\phi$  plane)
- ➔ voting principle for one Hough cell:
  - ✓ one superlayer one vote.
- ➔ peak finder in a cluster (connected cells with 5 votes)
- ➔ efficiency  $\sim 100\%$  (MC)
- ➔ for simple track counting trigger.



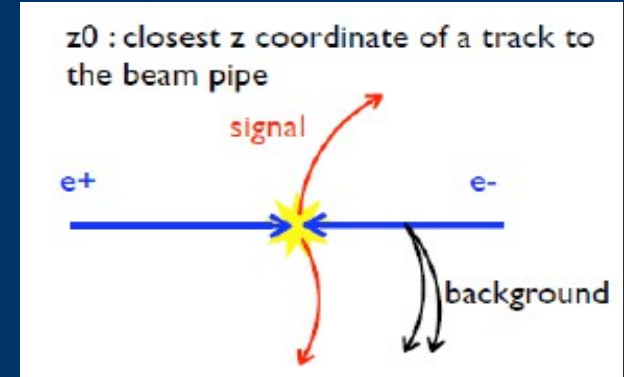
- 2D fitter

- ➔ minimum chi-square fit
- ➔ results sent to 3D triggers

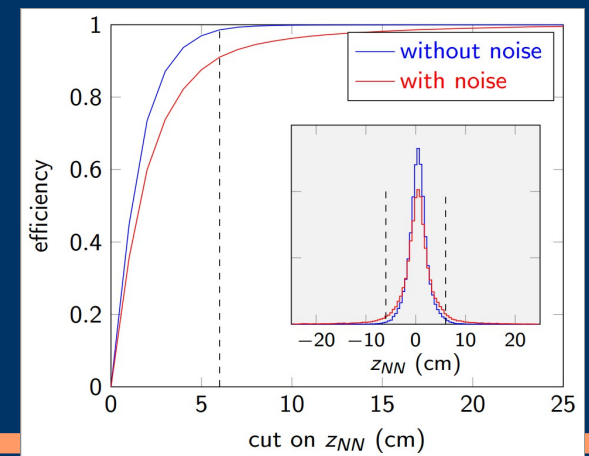
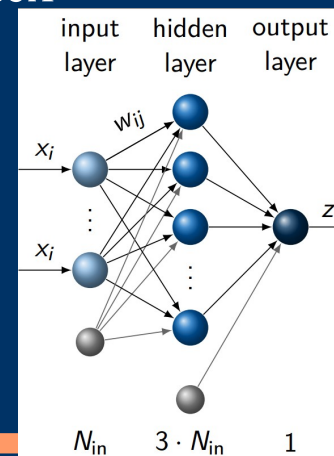
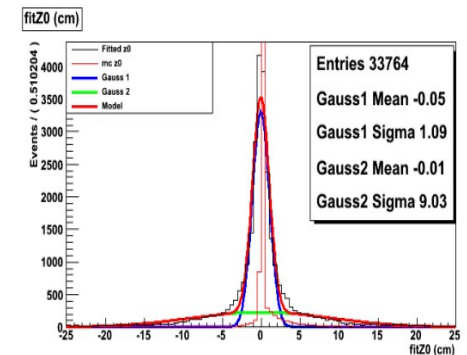


# 3D Tracker/Neural-Network z trigger

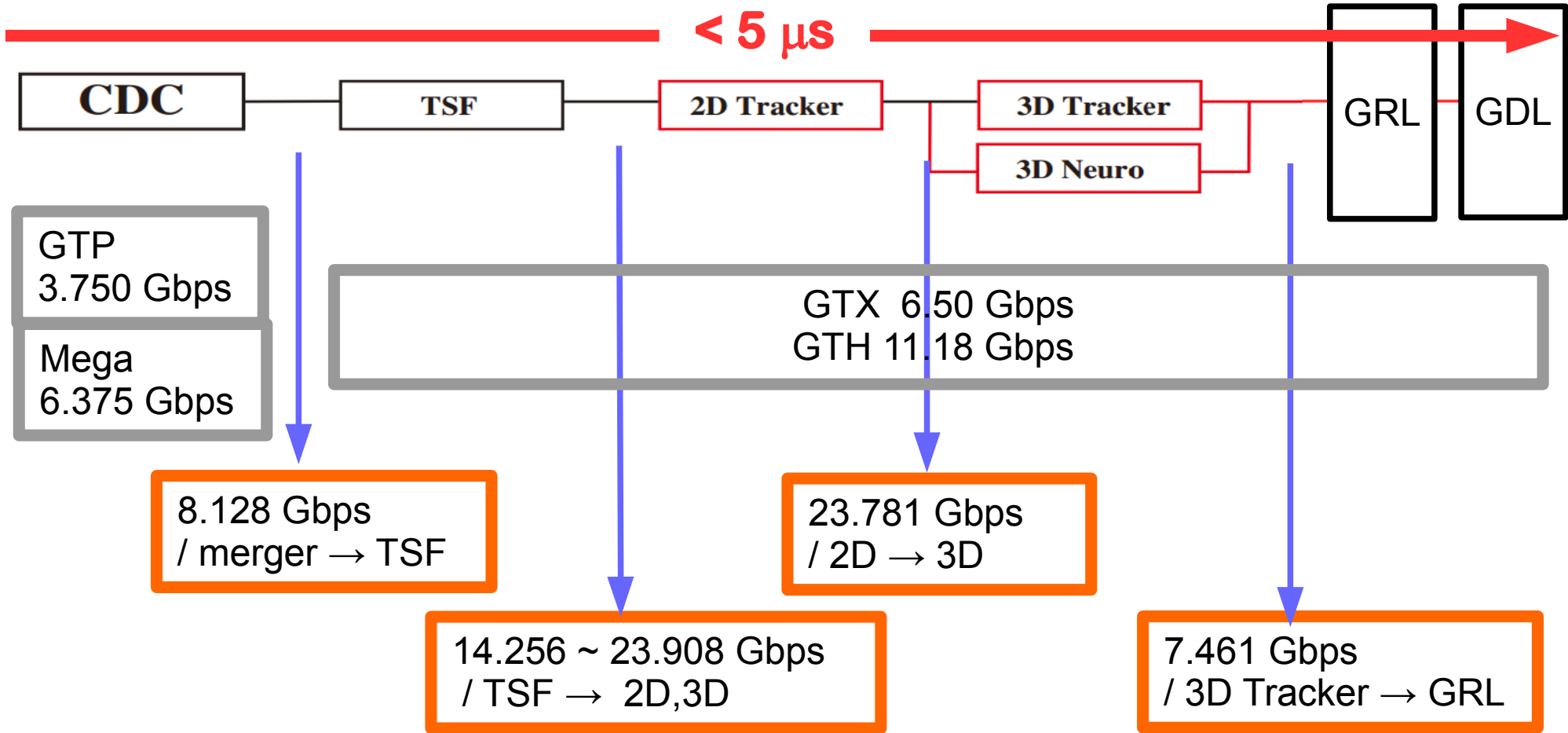
- The 3D tracker is meant to get better  $z$  ( $\delta z \sim 1\text{ cm}$ ) position of a track origin to improve background rejection.
- 3D tracker
  - ➔ search hit TS in 4 stereo-superlayers associated with the 2D tracks
  - ➔ performs a geometric transformation and chi-square minimization to determine 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  $\delta z$  and close to 100% efficiency
  - ➔ firmware under development



- 3D fitting with drift time.



# data rate (per connection)



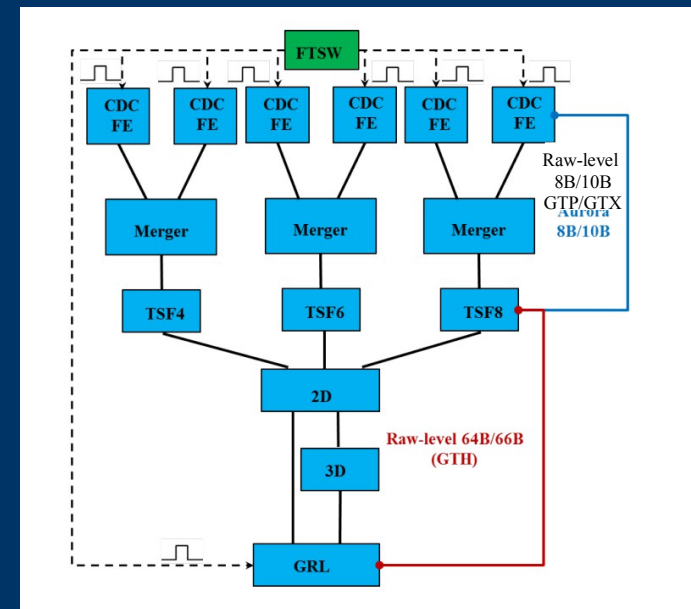
- ✓ one connection (channel) can have multiple fibers bound together.
- ✓ processing time, bandwidth are not a big problem.



# Data transmission and flow control

- Aurora protocol: 70~80% latency budget is consumed for transmission.
- In order to satisfy the 5  $\mu$ s 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 initialization 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

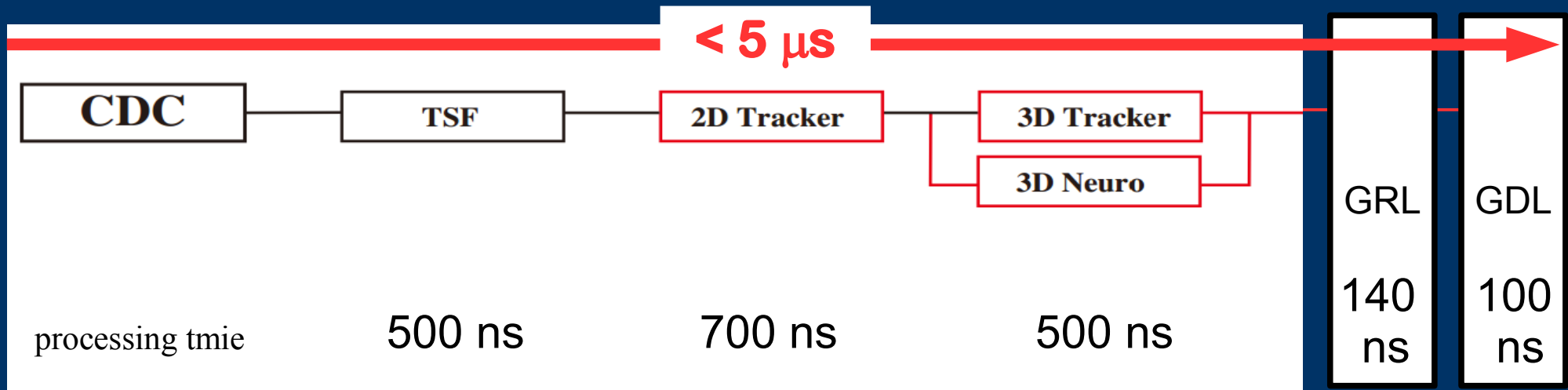
Protocol	Line rate	userclk	Hardware link	Latency (# of userclk)	Latency (ns)
Aurora 8B/10B	5.08 Gbps	254 MHz	GTX – GTX	47 ~ 48	185 ~ 190
Raw-level 8B/10B	5.08 Gbps	254 MHz	GTX → GTX	33 ~ 34	133 ~ 134
	5.08 Gbps	254 MHz	GTH → GTX	33 ~ 34	133 ~ 134
	5.08 Gbps	254 MHz	GTH → GTH	23 ~ 24	91 ~ 95
	5.08 Gbps	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  $\sim 500$  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 development
  - 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.)



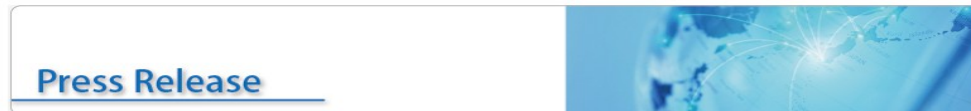
Phase 1,

# *B*e*a*s*t* 2

will pave the road for the beauty.

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

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



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

March 2nd, 2016

**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

# A-11

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

J.-G. Shiu, M.-Z. Wang, Y.-T. Chen, J.-J. Liou, J.-C. Liu, F.-H. Liu, S. Kusada, K.-P. Lin, and K.-N. Chiu  
Department of Physics, National Taiwan University, Taipei 106, Taiwan, R.O.C.

### Introduction

- SuperKEKB at KEK has started phase 1 beam commissioning this year (target beam energy without collision).
- BEAST II experiment is to study the beam background at the SuperKEKB/Belle II.
- NTUPEP group developed a BGO system for beam background monitoring in BEAST II.

### BGO SYSTEM

40m optical fiber special light-tight treatments with BGO and MAPMT

### PHASE I COMMISSIONING

#### 1. Scintillator

BGO ( $\text{Bi}_4\text{Ge}_2\text{O}_{12}$ )  $1 \times 8$   
 - about 2cm x 2cm x 13 cm  
 - mostly in visible light region and peaked at 480 nm

#### 2. MAPMT

HAMAMATSU R7548S  
 - 8 out of 8 x 8 pixels  
 (2mm x 2mm per pixel)  
 - working voltage: 700-800V

#### 3. Readout Board

- main board  
 - pre-amplifier  
 - charge-voltage converter: 0.5V/VyC  
 - shaping time: 187ns ADC  
 - 10-bit ADC (7-20)  
 - FPGA board  
 1. clock: 40MHz  
 2. gain adjustment  
 3. synchronization  
 4. pulse-to-charge calculation  
 5. threshold application  
 - gain [preliminary]  
 11 ADU/photo-electron  
 22 photo-electrons/GaE  
 - Link to the BEAST II DAQ  
 - UART (RS232-USB)  
 - data rate: 50Hz

background vs. beam size  $\times P_{beam}$  (preliminary)  
 background vs.  $1/2$  (beam size) Touchback offset (preliminary)

### Summary

NTUPEP has deployed a beam background monitoring system for the SuperKEKB phase 1 commissioning, using BGO crystals and a FPGA based DAQ board. The background variation versus beam condition is well-observed and the online monitoring is fed back to the SuperKEKB control center in real time.

### Reference

[1] Belle II DAQ, S. Yamada, at this conference  
 [2] NSM2, T. Amano et al., IEEE TNS Nucl. Sci., 62, Issue 1, 887-892, 2015  
 [3] EPICS, <http://www.epics.gov/public/about.php>  
 [4] CSS, <http://controlsystemstudio.org/>  
 [5] COPPER, S. Yamada et al., IEEE 47TH ASPE 2014 RT2014 IEEE  
 [6] HSLB, G. Sun, Z. Liu, J. Zhou, N. Xu, Phys. Procedia 87, 1983, 2012  
 [7] DEPFET, G. Aloisi et al., IEEE TNS Nucl. Sci., 58, Issue 2, 1407-1408, 2012

# B-10

## Unified software architecture for the slow control system in the Belle II experiment

Tomoyuki Konno<sup>1</sup>, Soh Y. Suzuki<sup>1</sup>, Jingzhou Zhao<sup>2</sup>, Ryoosuke Itoh<sup>1</sup>, Satoru Yamada<sup>1</sup>, Zhen-An Liu<sup>2,3</sup>, Mikihiko Nakao<sup>1</sup>  
 1. High Energy Accelerator Research Organization (KEK), 2. Chinese Academy of Sciences, 3. IHEP  
 IEEE 20th Real-Time conference, 5-10 June 2016, Padova, Italy, Poster presentation, PS 2.114

### Overview

The slow control system for the Belle II DAQ system<sup>[1]</sup> was developed for a long term based on two middleware; NSM2<sup>[2]</sup> and EPICS<sup>[3]</sup>. We introduced a general software framework using Control System Studio<sup>[4]</sup> to unify access to information in both systems especially for UI and logger. The framework is already in operation in the Belle II detector commissioning using cosmic ray and was heavily used in a beam test for the Belle II vertex detector in DESY electron beam facility in April, 2016.

### Network Shared Memory 2 (NSM2)

An upgrade of the NSM middleware in the Belle experiment  
 - Distribution of shared memories by UDP broadcast  
 - Request message transportation via TCP sockets

### EPICS

Experimental Physics and Industrial Control System  
 World wide usages in accelerator operations  
 Exchanges of process variables (PV) over network

### Use cases in Belle II

- Run control (RC)
- COPPER<sup>[5]</sup> detector R/Os
- DAQ backend PC farms
- Det. power supplies (PS)
- Environment monitors

### Unified ways to access slow control information

- User interface based on CSS-BODY
- Data logger by CSS channel achiever

### Software network in the Belle II DAQ system

### Operations in the Belle II VXD beam test

A beam test was carried out at the DESY electron test beam facility in April 2016  
 - Test tracking performance of the Belle II vertex (pixel + silicon strip) detector  
 - Confirm data reduction scheme by extraction of RoIs (Region of Interest)  
 - Establish the slow control framework with NSM2 and EPICS based systems

### Achieved unified DAQ control scheme

- Status exchange over NSM2/EPICS
- Monitoring SVD PS from RC
- Handshaking of RC state
- Data flow monitor on unified GUIs
- DQM views for PXD and SVD

### Data flow at PXD selector

### Run control Main panel and data flow monitor

### COPPER HSLB<sup>[6]</sup> and SVD FEE management panel

### DQM view panel for PXD hit channel maps

### Operation in the Belle II detector construction

The slow control is in operation at the detector construction and commissioning  
 - Data taking of cosmic ray run for commissioning of the outer detectors  
 - Detector power supply control for experts during construction  
 - Environment monitoring in the detector and the electronics hut

### Applications in the DEPFET-PF project

Applications of DEPFET<sup>[7]</sup> sensors for biological material science in KEK-PF  
 - High track resolution and frequency  
 - Same software with Belle II PXD  
 => Beam test during the conference

### Pre-setups of sensor and R/O modules

### Acknowledgment

This work was supported by JSPS Grant-in-Aid for Scientific Research (S), KAKENHI Grant Number JP23227003

### Reference

[1] Belle II DAQ, S. Yamada, at this conference  
 [2] NSM2, T. Amano et al., IEEE TNS Nucl. Sci., 62, Issue 1, 887-892, 2015  
 [3] EPICS, <http://www.epics.gov/public/about.php>  
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 [6] HSLB, G. Sun, Z. Liu, J. Zhou, N. Xu, Phys. Procedia 87, 1983, 2012  
 [7] DEPFET, G. Aloisi et al., IEEE TNS Nucl. Sci., 58, Issue 2, 1407-1408, 2012



# Phase 2, ring a *Belle II* for a new era to come.

Beast 2 with partial Belle II,  
some measurements possible.

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

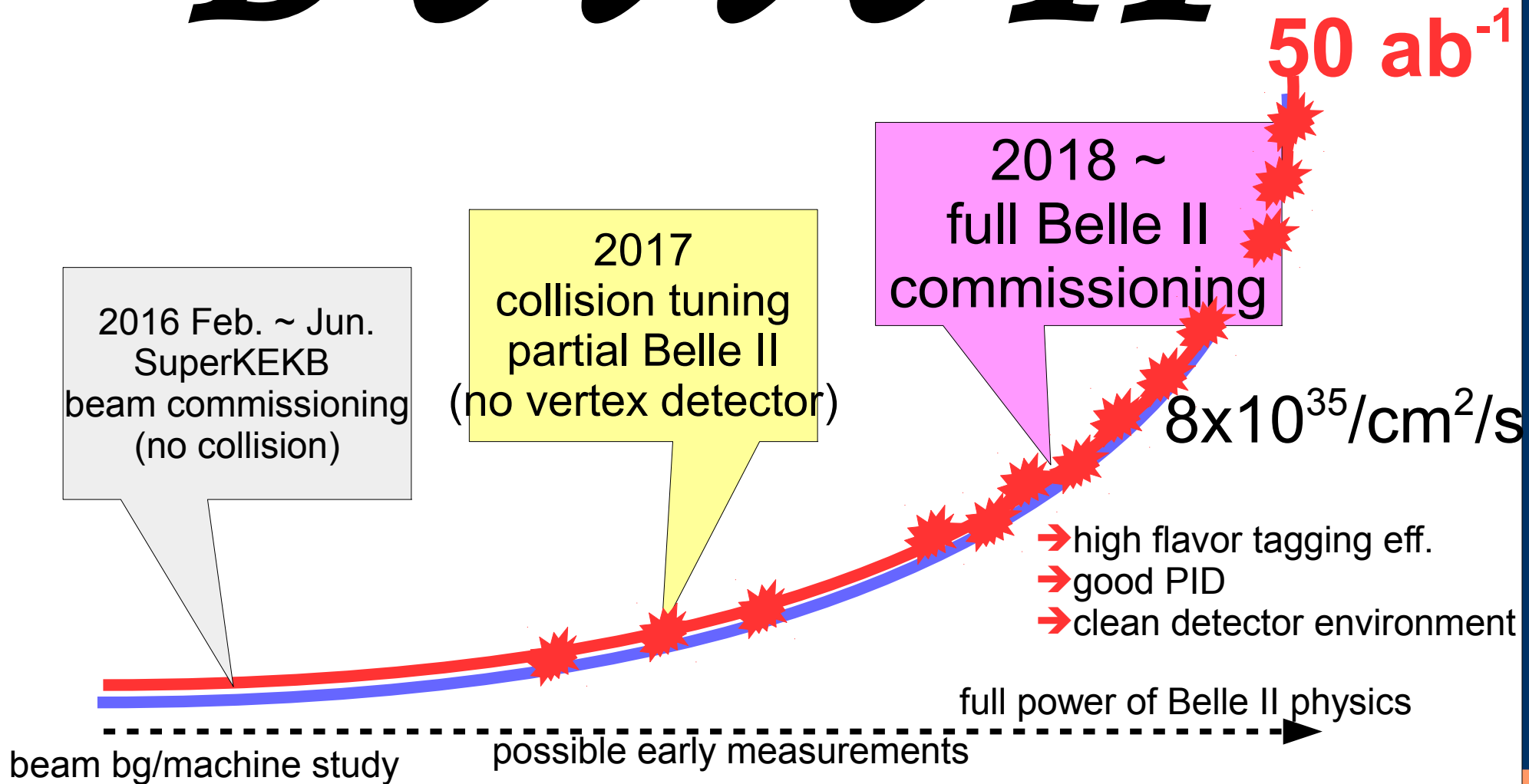
2017  
collision tuning  
partial Belle II  
(no vertex detector)

- achieve  $10^{34}$  /cm<sup>2</sup>/s (KEKB/Belle peak)
- stable run close to  $\Upsilon(4S)$  preferred
- PID not fully reliable
- Integrated luminosity  $\sim(20\pm 20 \text{ fb}^{-1})$

The trigger system has to be ready before phase 2.

beam bg/machine study      possible early measurements

# Phase 3, *Belle II*





# Summary

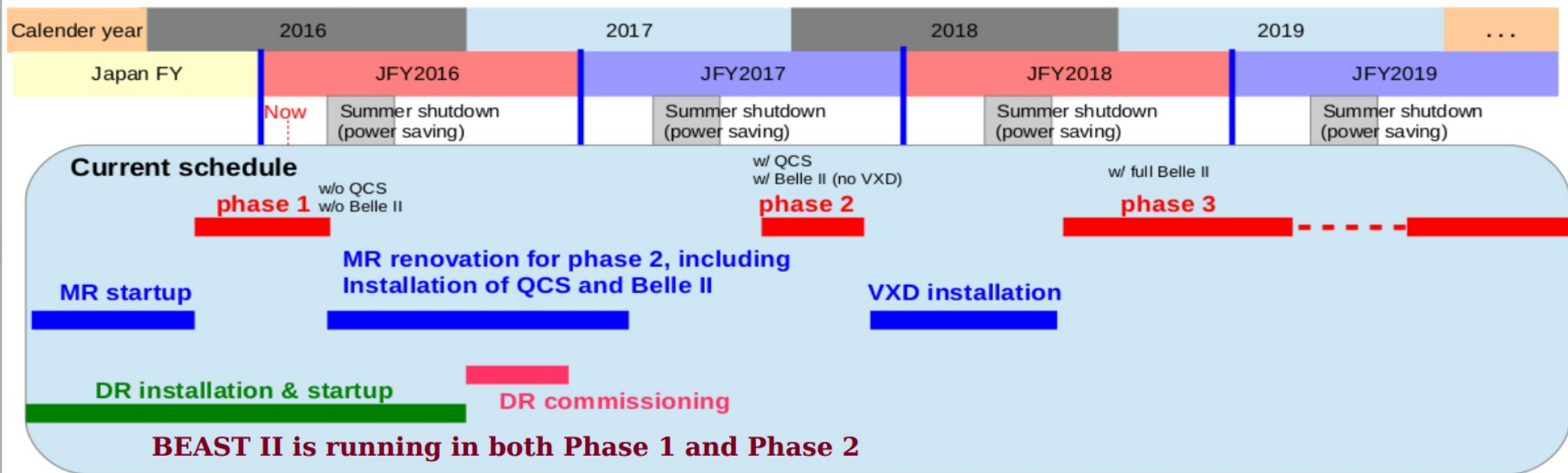
- A multi-layer real time trigger system is developed for the Belle II CDC detector.
  - simple track counting trigger (2D finder)
  - high precision track  $z_0$  trigger (3D tracker, neural-network  $z$  trigger)
  - low Pt tracking (short track 2D finder), event timing, ...
- User-defined protocols are developed for the full chain data streaming transmission and flow control; total latency less than  $5 \mu\text{s}$  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.

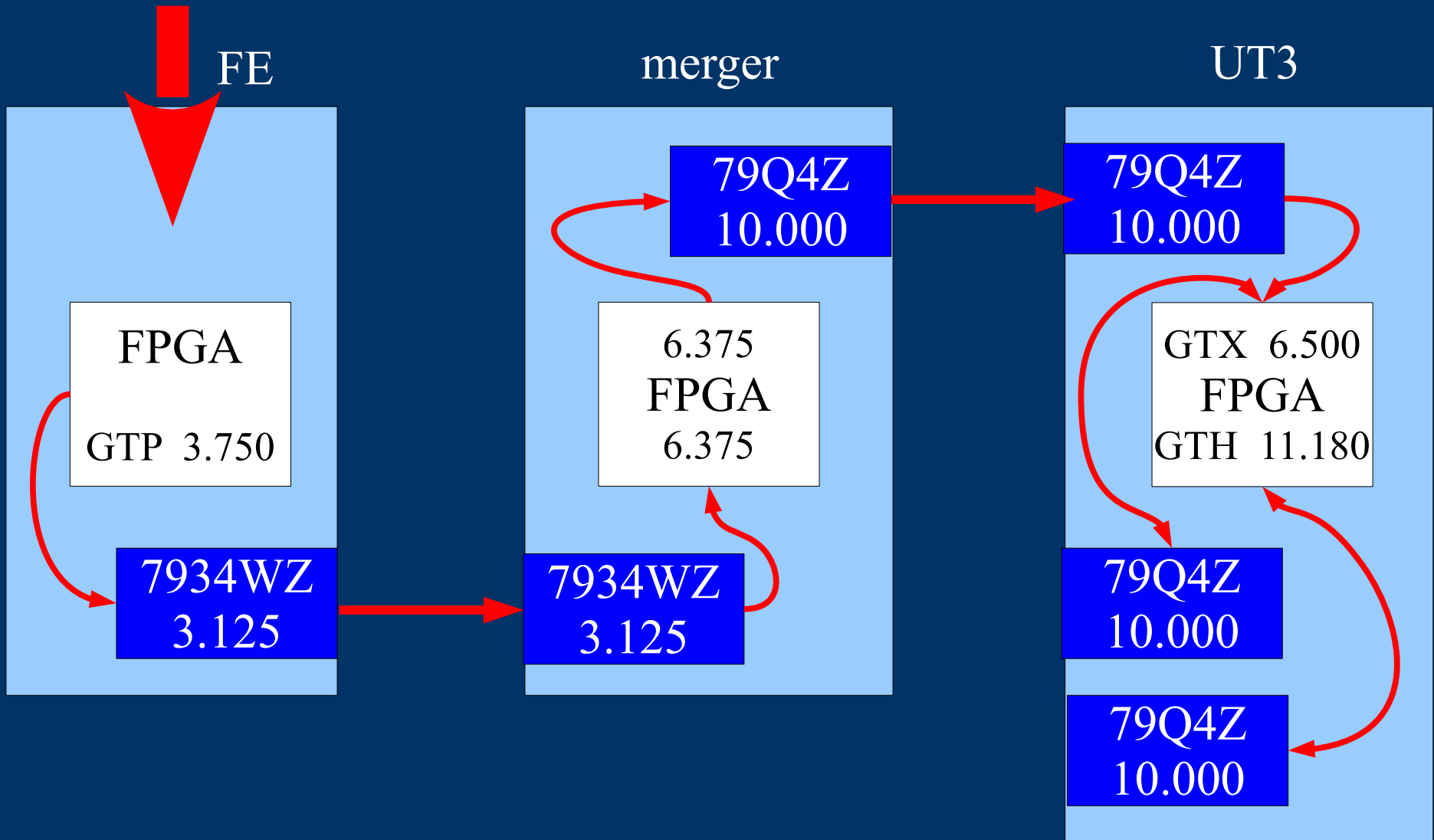
*Thank you!!*

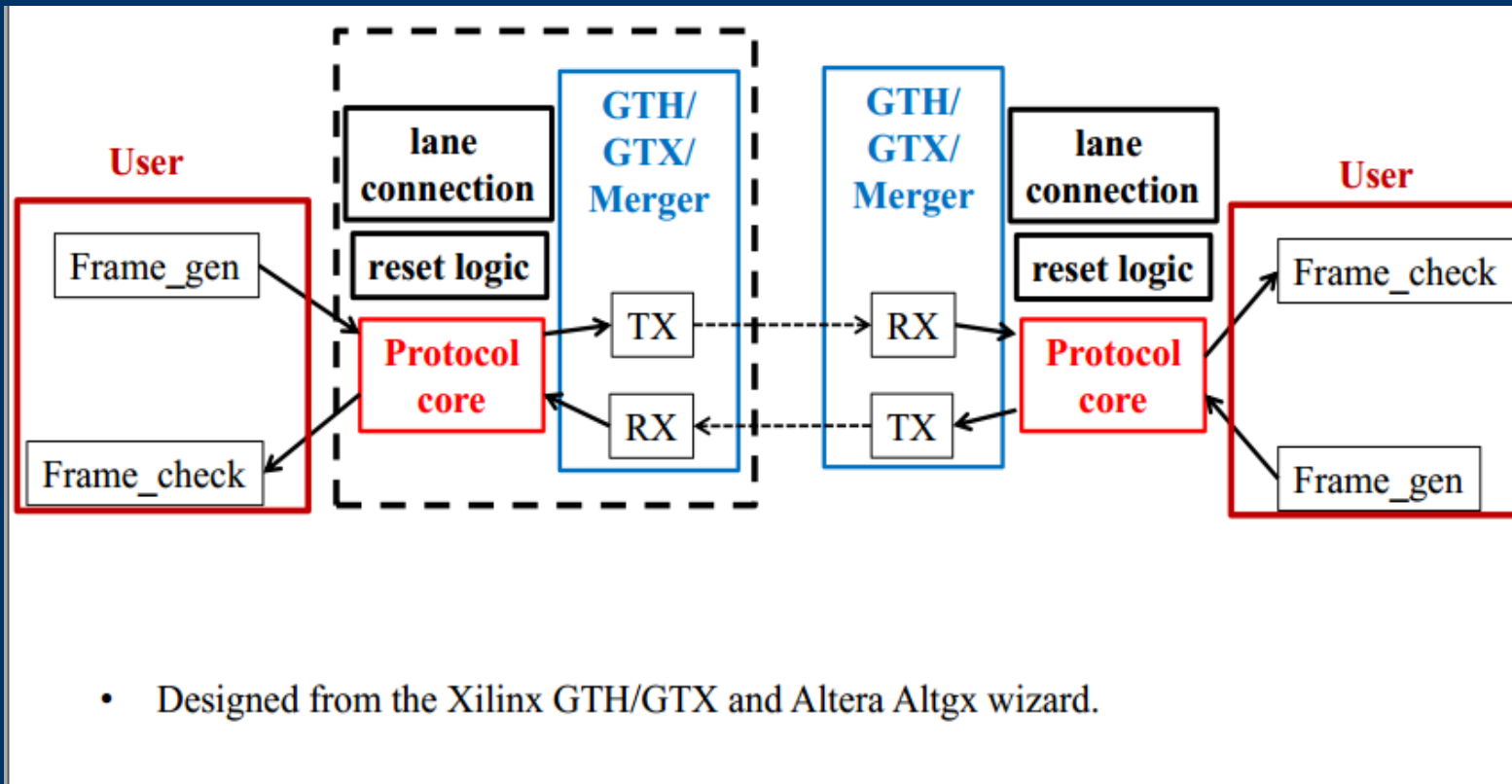
# BACKUP



# SuperKEKB Operation Schedule







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



# Belle II L1 Trigger

physics processes and trigger logics

Process	$\sigma$ (nb)	Rate (Hz) @ $L=8 \times 10^{35}$
Upsilon(4S)	1.2	960.0
Continuum	2.8	2200.0
$\mu\mu$	0.8	640.0
$\tau\tau$	0.8	640.0
Bhabha *	44.0	350.0
$\gamma\text{-}\gamma$ *	2.4	19.0
Two photon **	80	~15000
<b>Total</b>	<b>130</b>	<b>~20000</b>

\* Rate of Bhabha and  $\gamma\text{-}\gamma$  are pre-scaled by factor 100

## ● Physics triggers

### ● Upsilon 4S + continuum

- Three-track (CDC)
- Total energy  $\geq 1$  GeV (ECL)
- #Isolated cluster  $\geq 4$  (ECL)

### ● Tau pair

- Two-track with opening angle cut

## ● Calibration triggers

### ● Bhabha

- Pre-scaled by Bhabha trigger (ECL)

### ● $\gamma\text{-}\gamma$

- Pre-scaled by  $\gamma\text{-}\gamma$  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  $\sim 508$  MHz

Bunch separation:  $\sim 2$  ns

Good physics rate:  $\sim 20$  kHz

L1 trigger max. rate:  $\sim 30$  kHz

Average separation between two

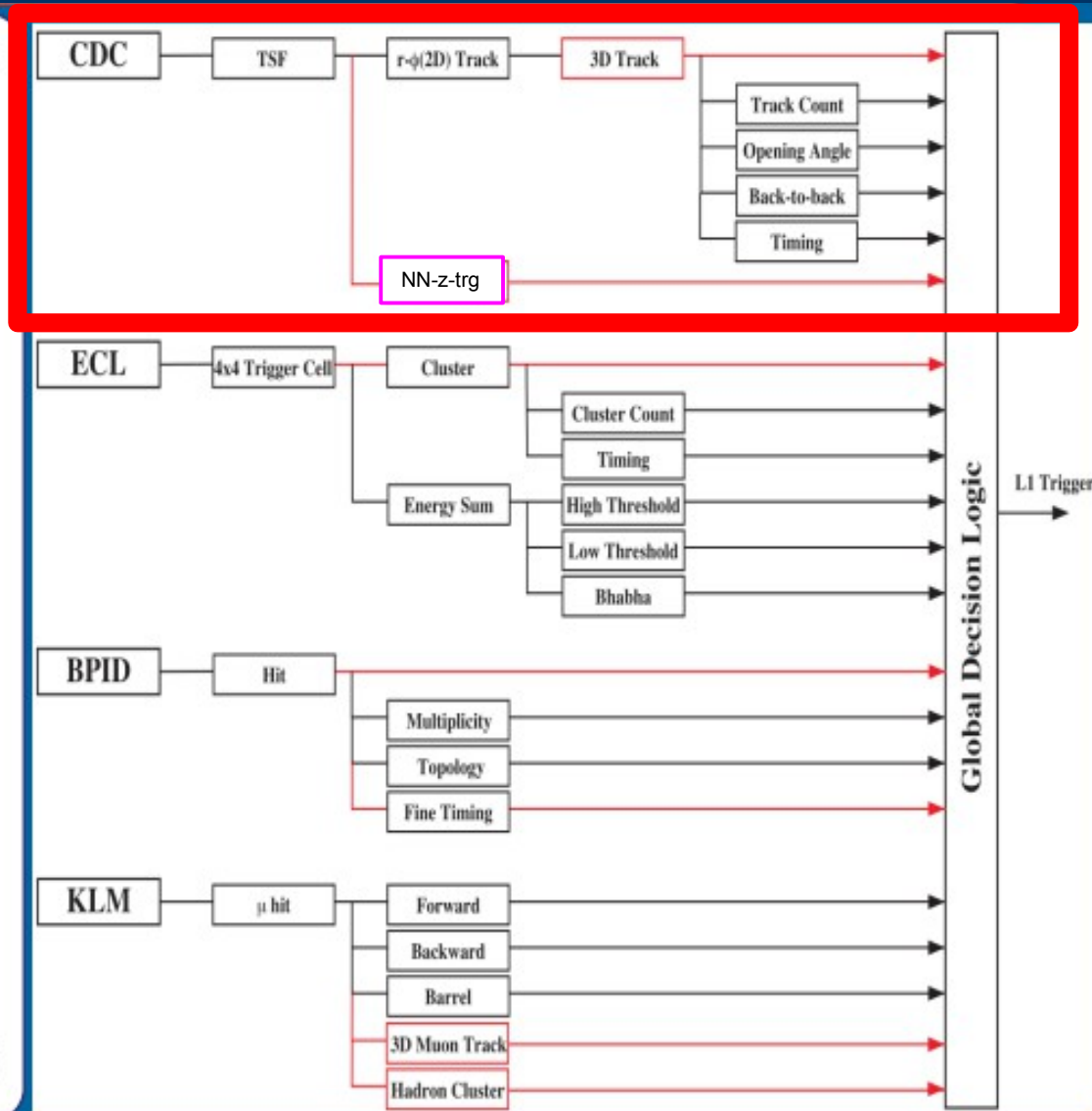
physics events: 25,000 bunch crossings

Nominal beam background rate 10 MHz

Trigger time uncertainty:  $\sim 2$  ns

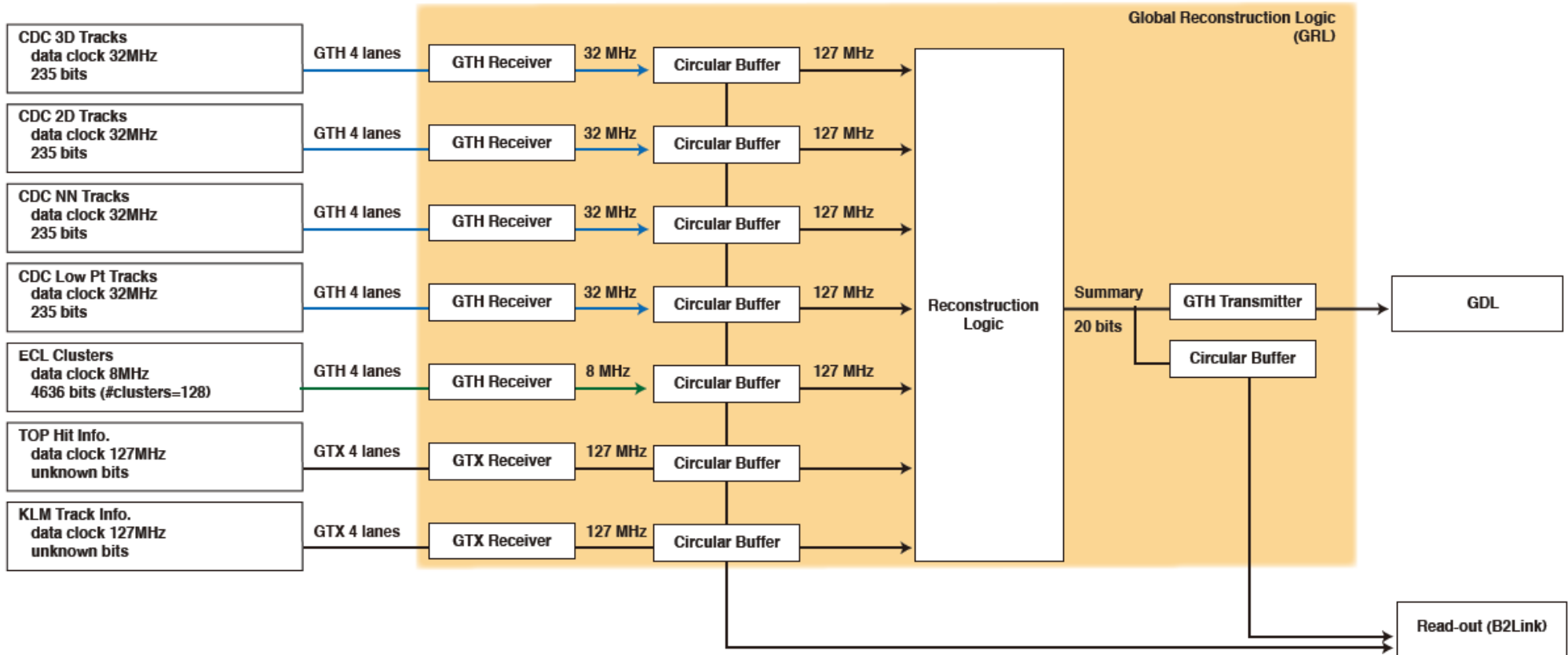
L1 trigger latency:  $5 \mu$ s

Min L1 time between two events: 200 ns



# GDL and GRL

## Global Reconstruction Logic



2014/06/02

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