The SuperKEKB Accelerator : Construction and Operations

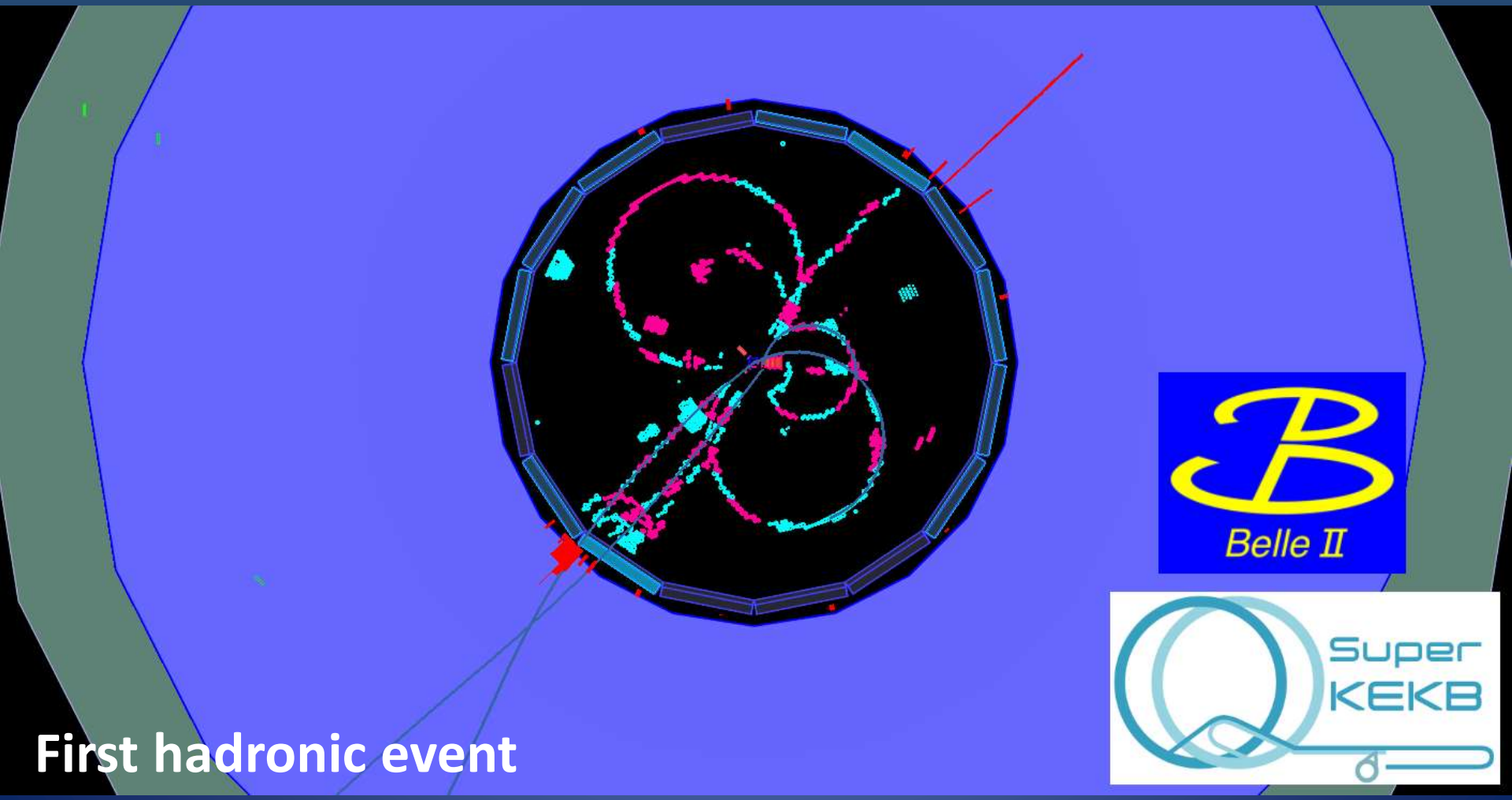
2018/12/13

M. Iwasaki (Osaka City Univ. & RCNP, Osaka Univ.)

April 26, 2018
Belle II control room

First collisions

on April 26, 2018



First hadronic event

First collisions

on April 26, 2018

SuperKEKB First Collisions Ceremony

(June 26, 2018 @ KEK)

Today I'll talk

1. SuperKEKB / Belle II introduction

- Motivation of the experiment
- SuperKEKB upgrade strategy

2. SuperKEKB construction

3. SuperKEKB operations

4. Activities at OCU for SuperKEKB

5. Summary

Introduction

SuperKEKB / Belle II experiment

"Luminosity frontier experiment"

Low energy experiment indirectly probing high energy using high statistics data

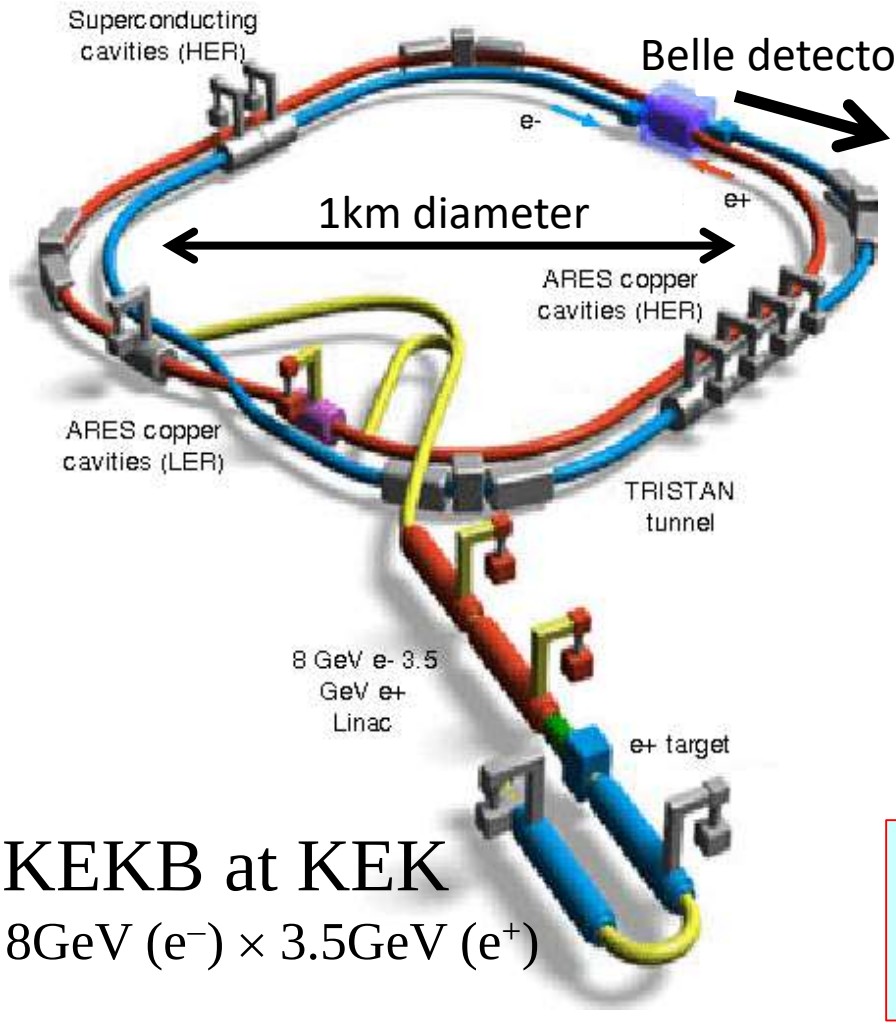
- **KEKB/Belle has upgraded to SuperKEKB/Belle II**
- **Luminosity of the SuperKEKB accelerator**

x40 of the KEKB's world record

to accumulate high statistics of $50ab^{-1}$ data

→*Probe > O(TeV) energy scale*

Introduction

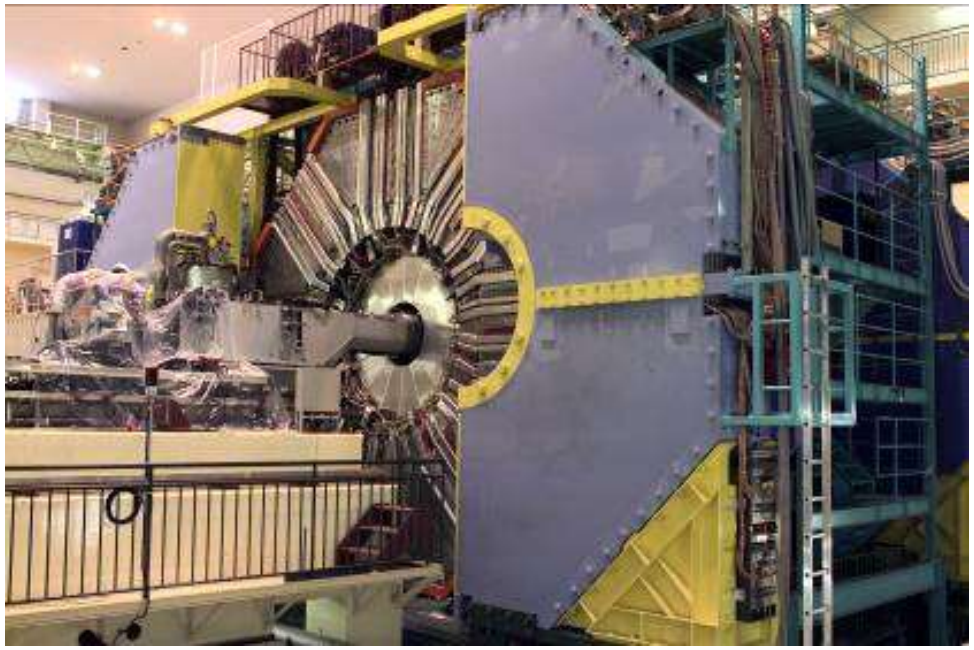


KEKB at KEK

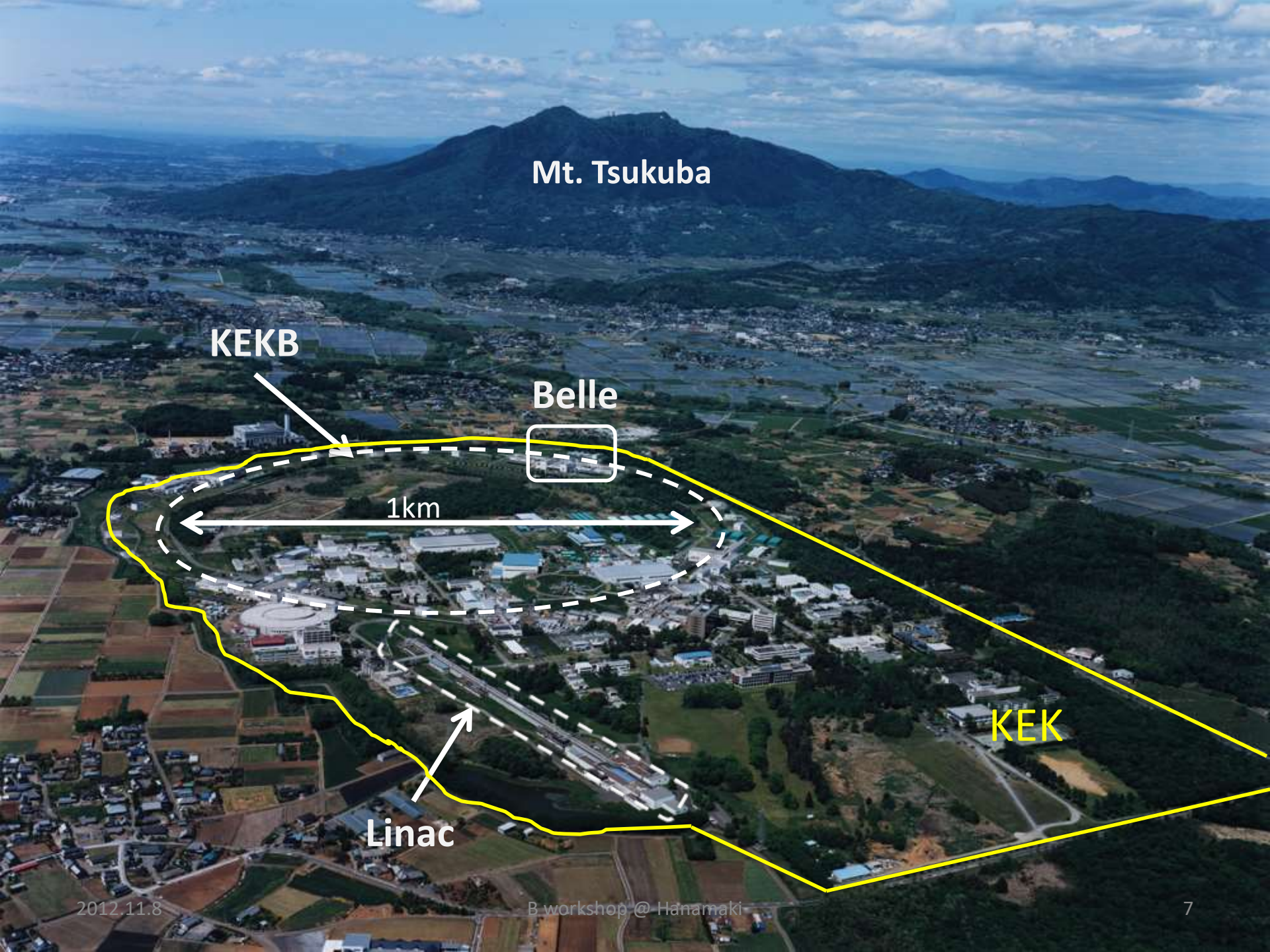
8GeV (e^-) × 3.5GeV (e^+)

Asymmetric Energy e^+ e^- collider

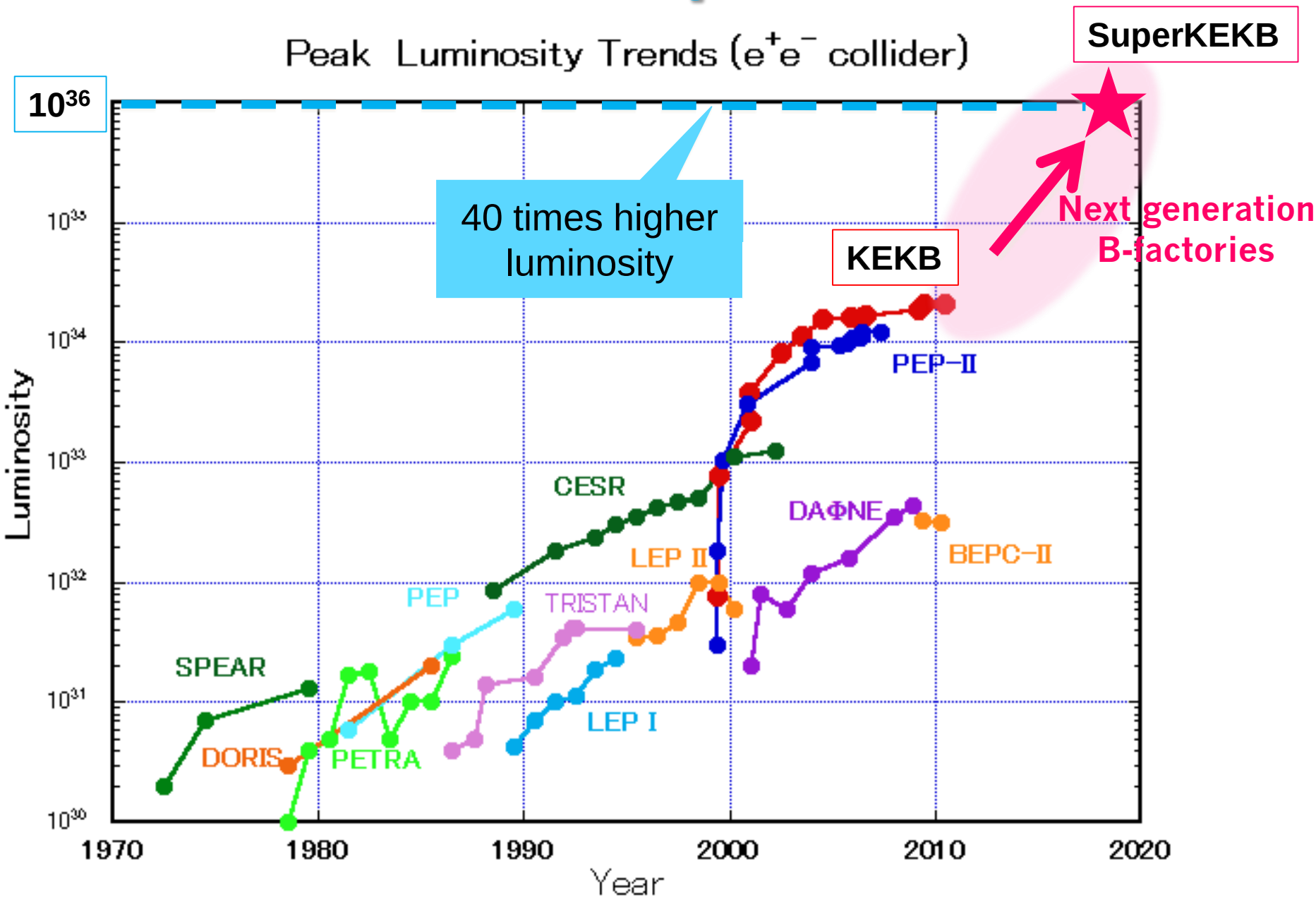
Belle



KEKB / Belle has upgraded to SuperKEKB / Belle II

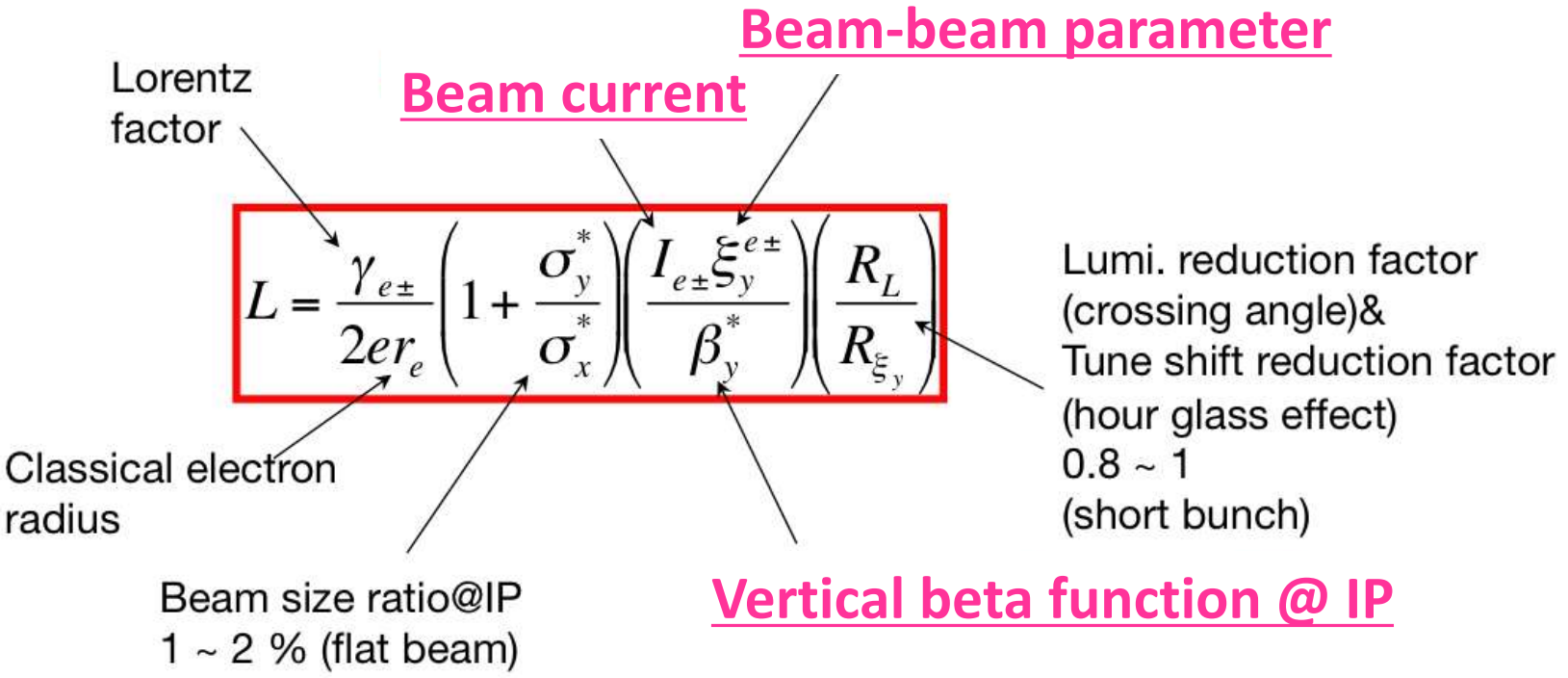

Mt. Tsukuba
KEKB
Belle
1km
KEK
Linac

KEKB to SuperKEKB



Strategies for increasing Luminosity

Three Key factors for a factor of ~40 gain



(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

"Nano-Beam" scheme

First proposed by P.Raimondi for SuperB

Collision with very small spot-size beams

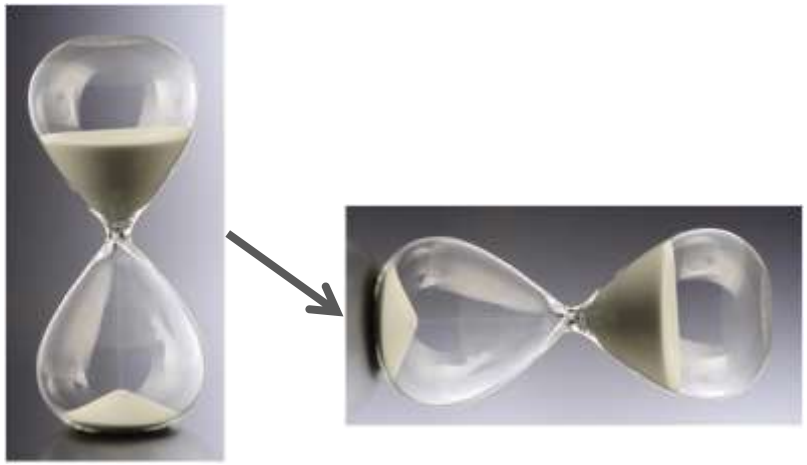
Nano-Beam scheme

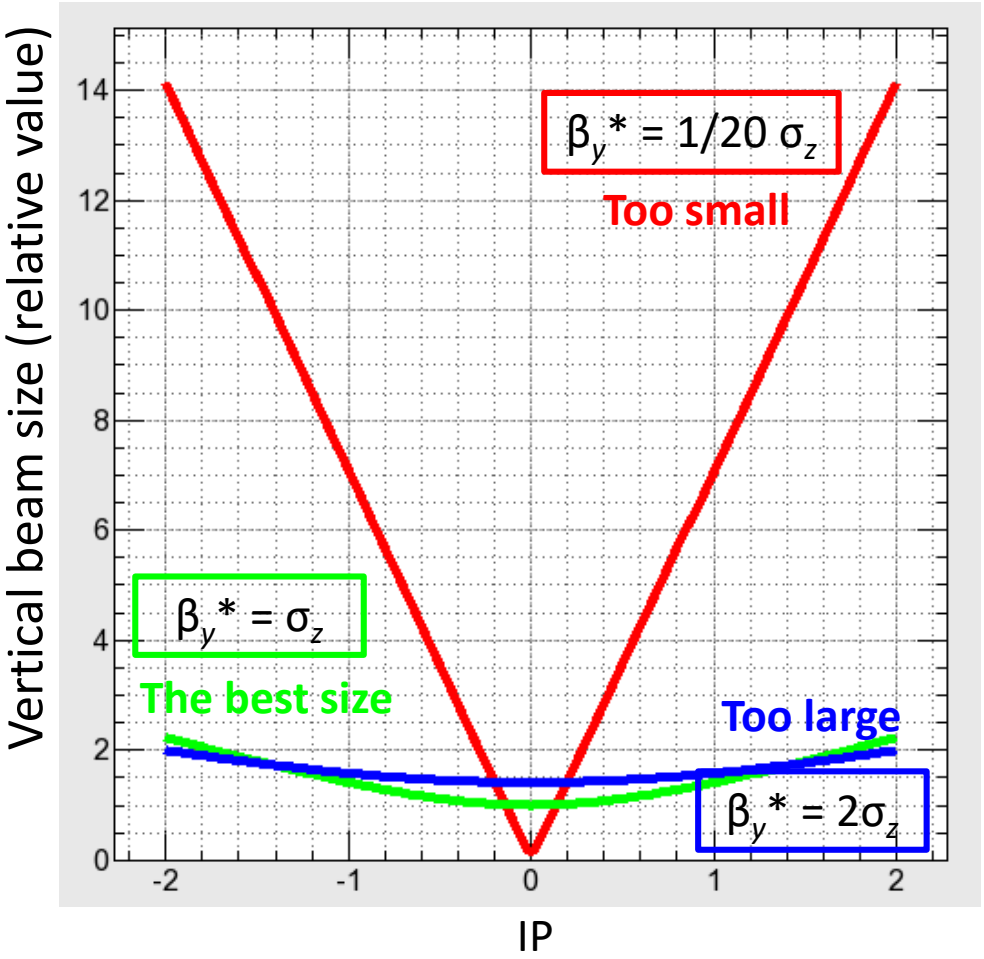
To increase L, we want to squeeze beams (=small β^*_y)
However β^*_y cannot be much smaller than the bunch length to avoid *the "hourglass" effect*

Hourglass effect

If we squeezing the beams at IP, particles in the bunch-tails experience a much higher β^*_y and loss L

→ β^*_y should be around the size of the beam overlap (~bunch length)





Nano-Beam scheme

To overcome the “hourglass” effect,

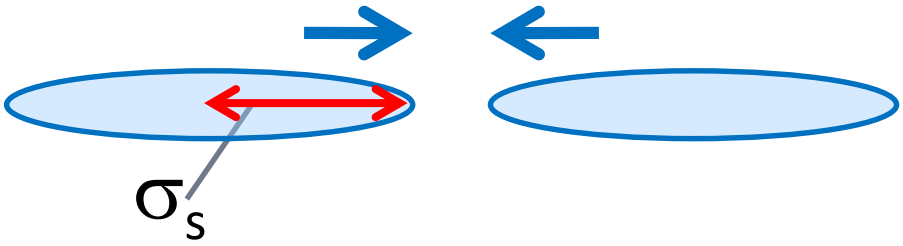
Enlarge crossing angle & Make horizontal beam size small

↓

Two colliding beams overlap region becomes much smaller than the bunch length

Intersect bunches only at highly focused region

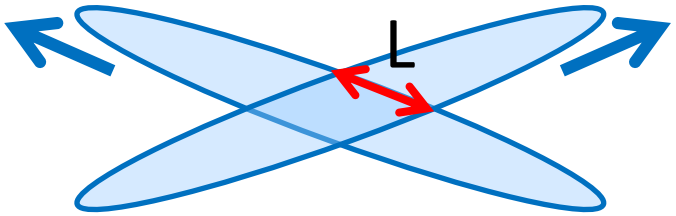
Head-on collision



overlap region = bunch length

Hourglass condition: $\beta_y^* > \sim\sigma_s$

Nano-beam scheme



overlap region ~L

Hourglass condition: $\beta_y^* > \sim L$

Nano-Beam scheme

In the nano-beam scheme, we

1) Enlarge the crossing angle, and

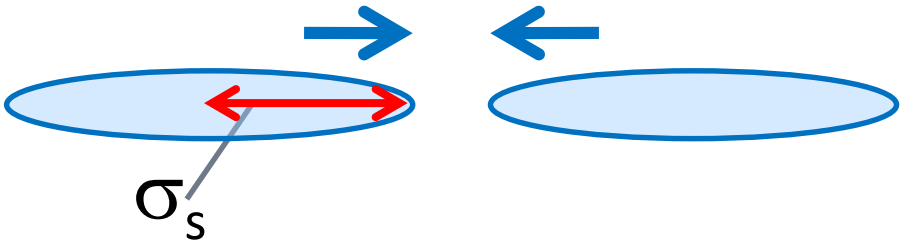
2) Make the horizontal beam size small

↓

Make β^*_y small *to increase the luminosity*

Small size horizontal beam → ***Small β^*_x and small ε_x***

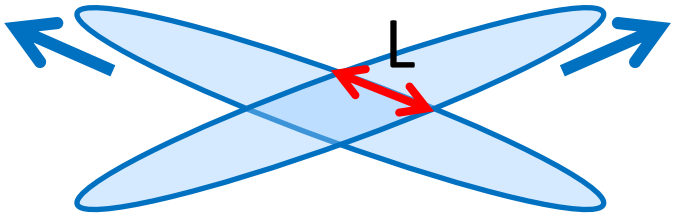
Head-on collision



overlap region = bunch length

Hourglass condition: $\beta_y^* > \sim\sigma_s$

Nano-beam scheme



overlap region ~L

Hourglass condition: $\beta_y^* > \sim L$

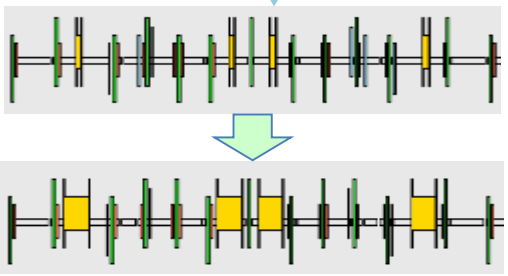
Machine Design Parameters

parameters		KEKB		**SuperKEKB**		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	ϕ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam parameter	ξ_y	0.129	0.090	0.088	0.081	
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		**$cm^{-2}s^{-1}$**

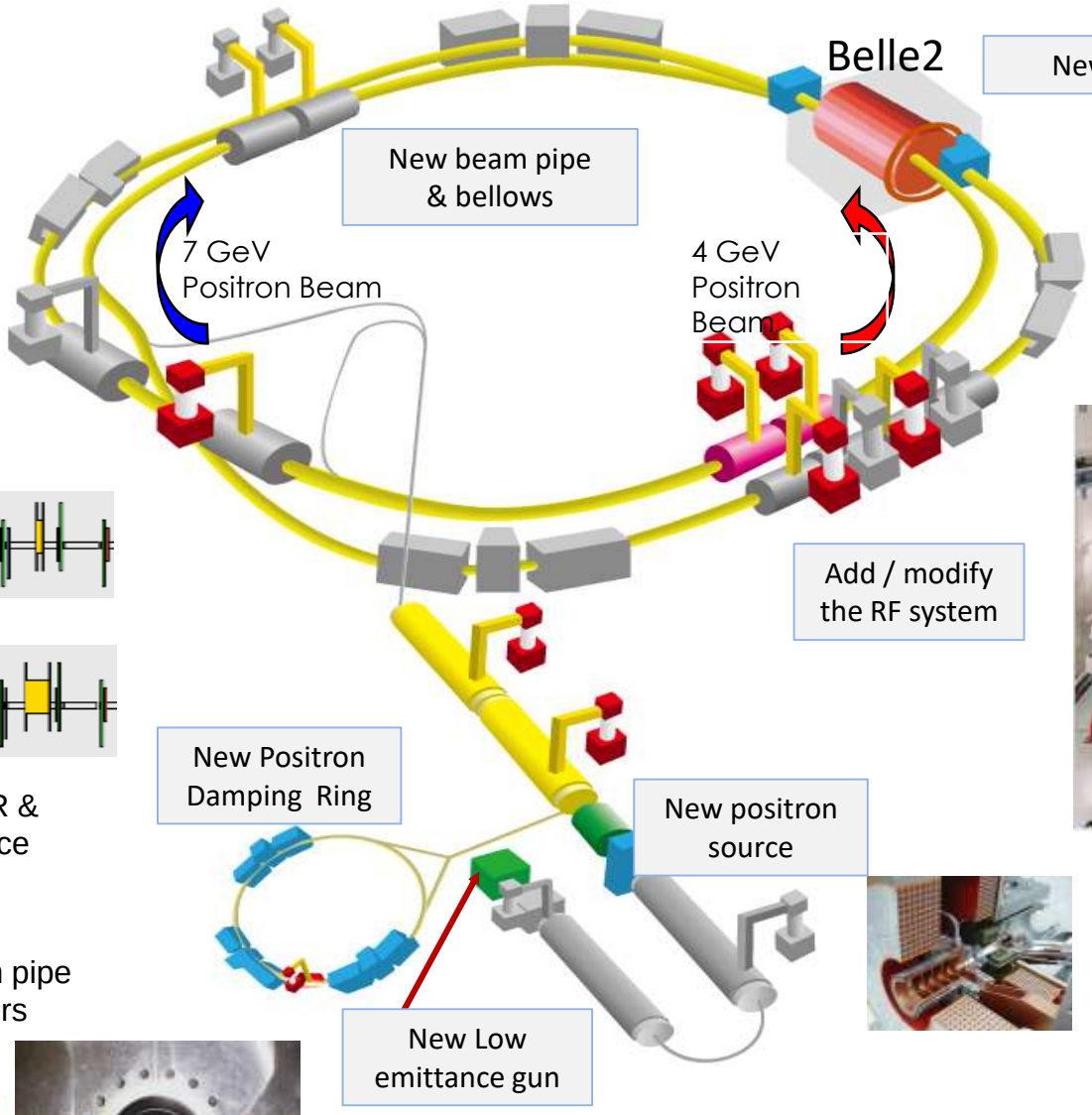
- **Small beam size & high current** to increase luminosity
- **Large crossing angle**
- **Change beam energies** to solve the problem on LER short lifetime

KEKB to SuperKEKB How to upgrade

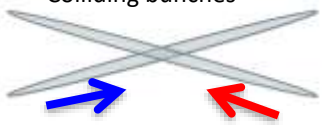
Replace short dipoles with longer ones (LER)



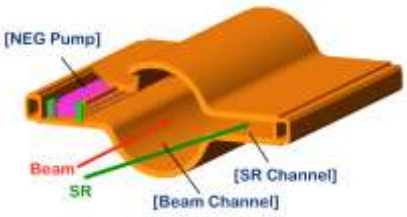
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches



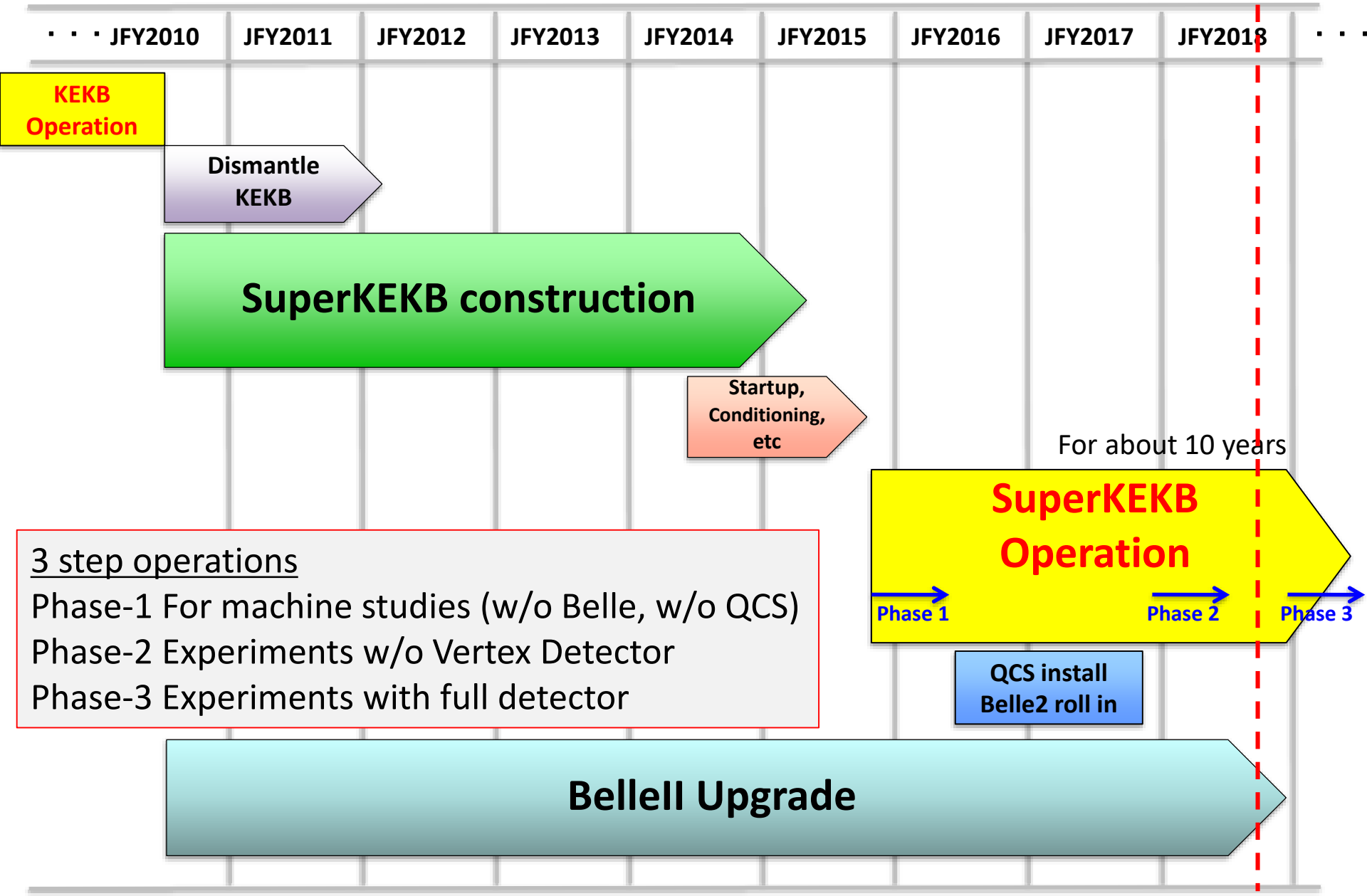
TiN-coated beam pipe with antechambers



To get x40 higher luminosity

SuperKEKB Master Schedule

K. Akai



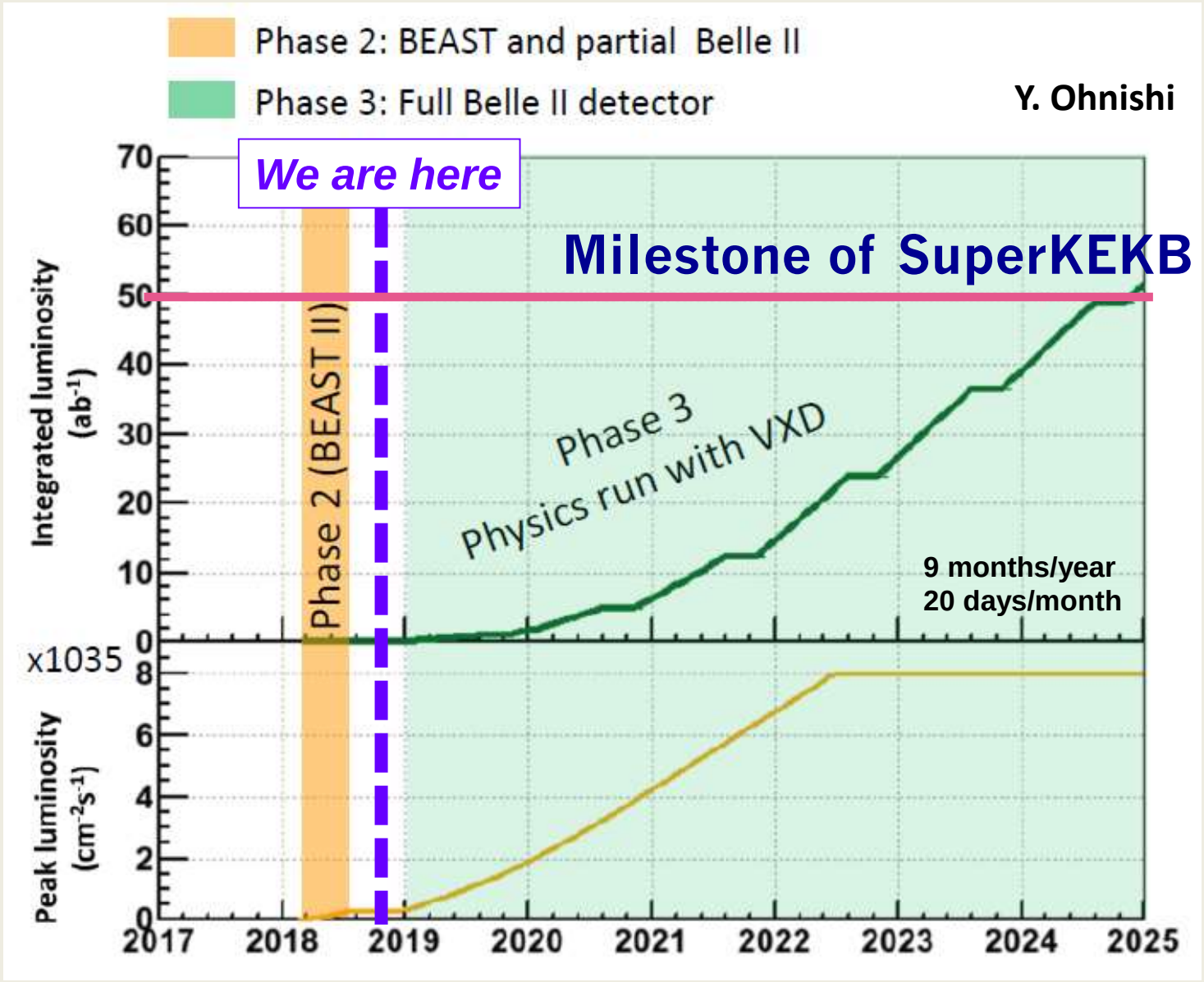
3 step operations

Phase-1 For machine studies (w/o Belle, w/o QCS)

Phase-2 Experiments w/o Vertex Detector

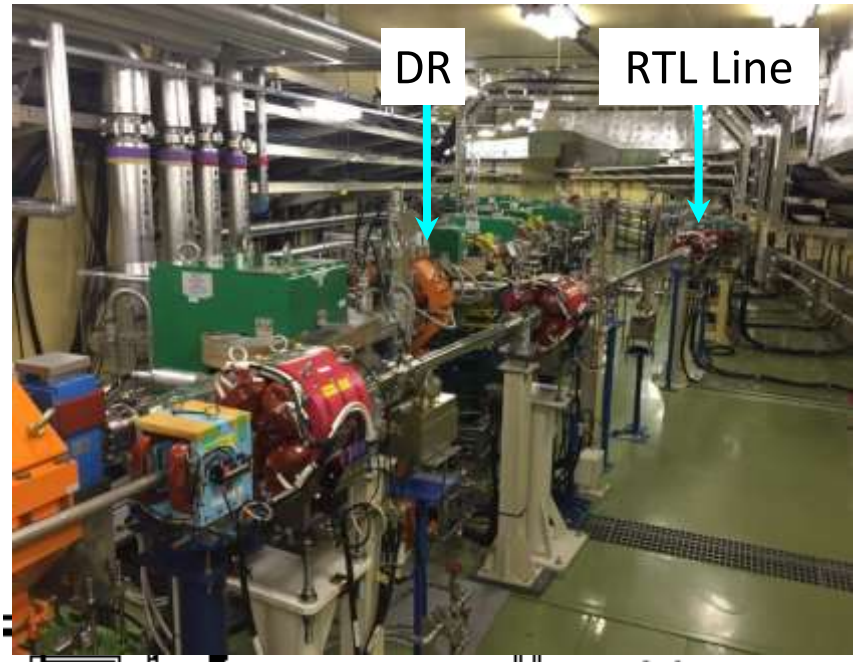
Phase-3 Experiments with full detector

SuperKEKB Luminosity Projection

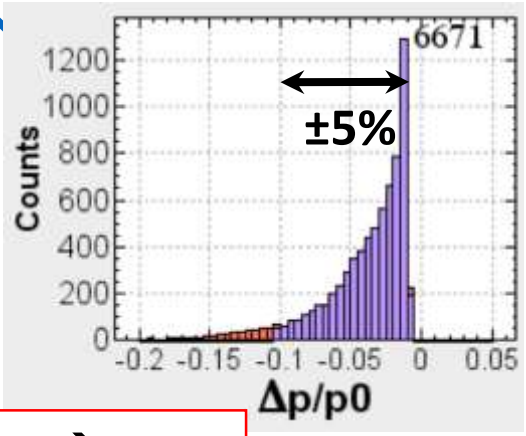


SuperKEKB Construction

New Positron Damping Ring



DR → Linac → SuperKEKB



Linac → DR

Design

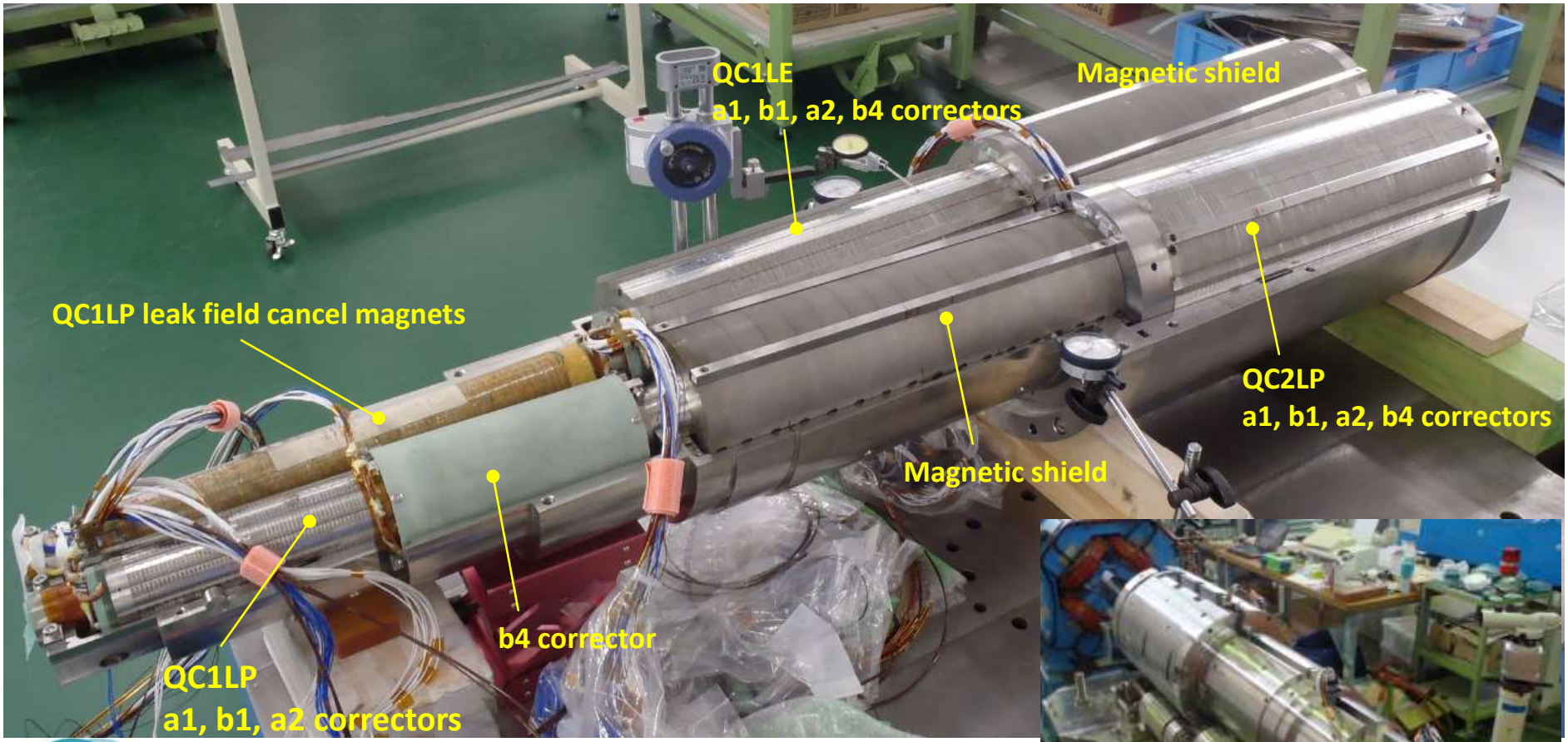
DR	Injection	Extraction	
$\gamma\varepsilon_x$(μm)	2800	89.3	64.6 (estimated)
$\gamma\varepsilon_y$(μm)	2600	4.5	< 2.0±0.36 (measured)

N. Iida, M. Kikuchi et al.

New SC magnets around IP (QCS)

Assembly of the QC1LP, QC2LP, QC1LE, correctors and QC1LP leak field cancel magnets
(Front cold mass of QCSL)

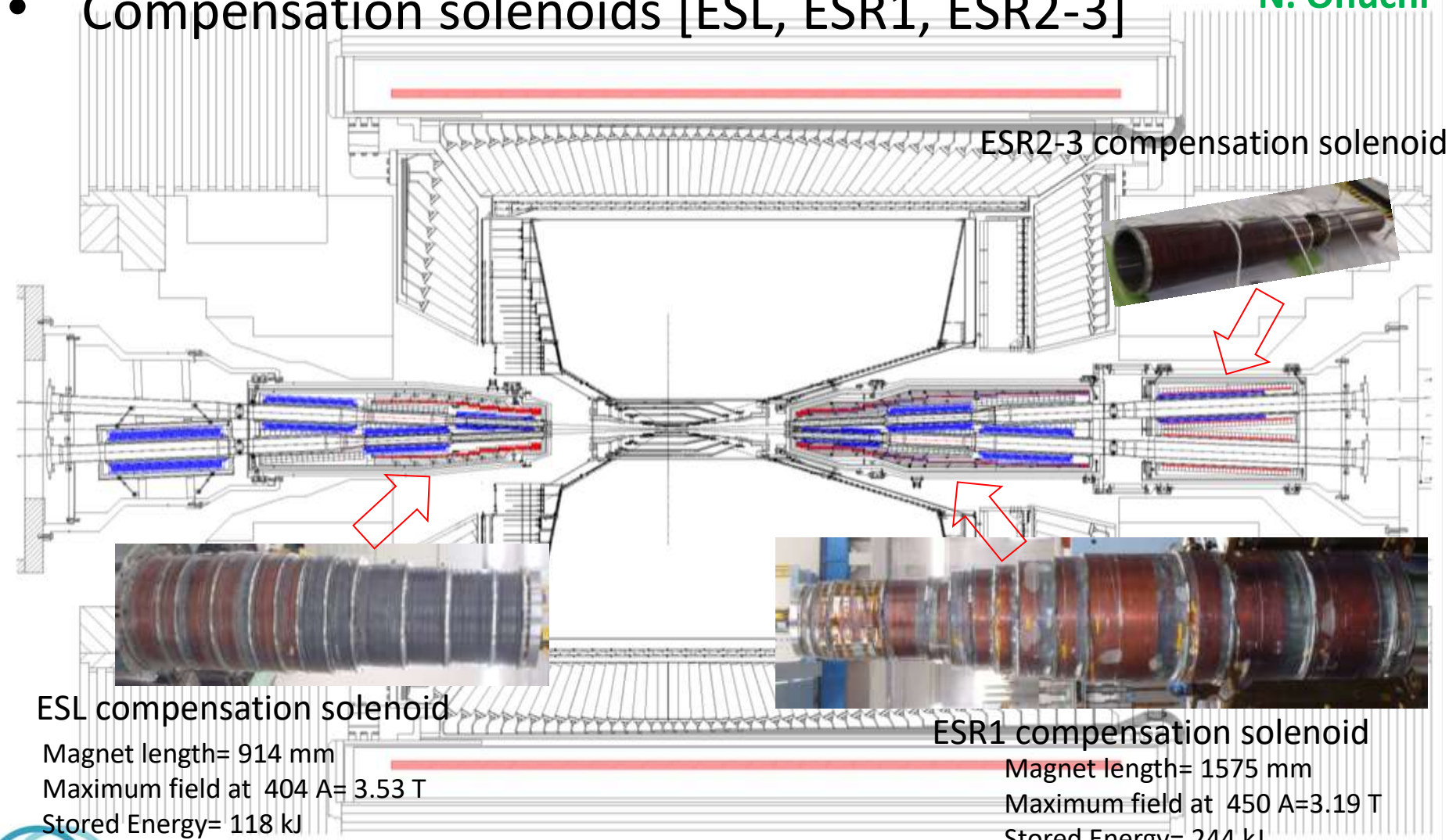
N. Ohuchi



New SC magnets around IP (QCS)

- Compensation solenoids [ESL, ESR1, ESR2-3]

N. Ohuchi



ESR2-3 compensation solenoid

ESL compensation solenoid

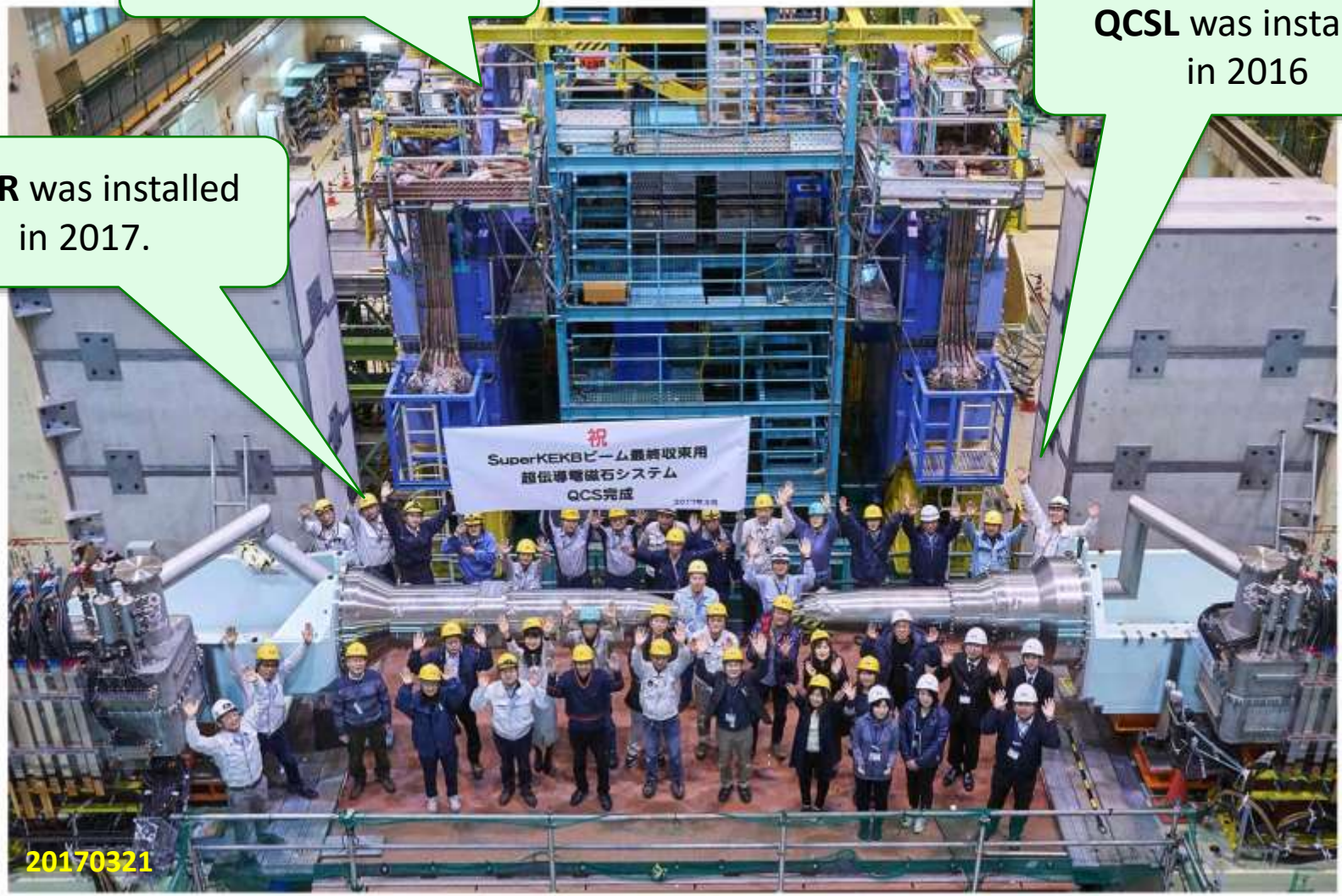
Magnet length= 914 mm
Maximum field at 404 A= 3.53 T
Stored Energy= 118 kJ

ESR1 compensation solenoid

Magnet length= 1575 mm
Maximum field at 450 A=3.19 T
Stored Energy= 244 kJ
Cold diode quench protection system

QCS cryostats in SuperKEKB IR

N. Ohuchi



From the presentation by Prof. K. AKAI @KEKB review at Mar. 14, 2018

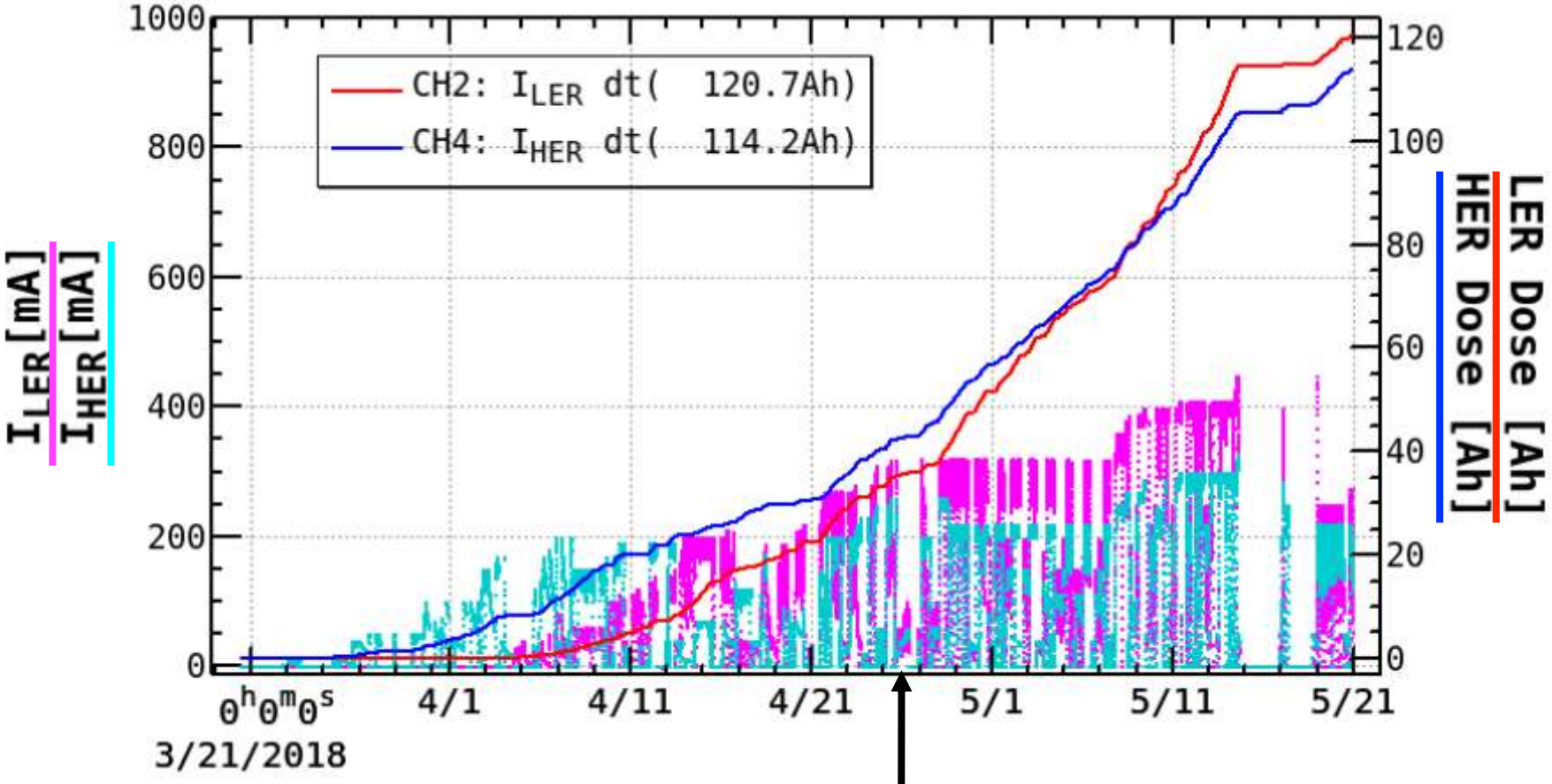
SuperKEKB Operation

History of Commissioning

Y. Funakoshi
Y. Ohnishi

Beam dose: 120 Ah in LER / 114 Ah in HER

Max. beam current: >400 mA in LER / >300 mA in HER



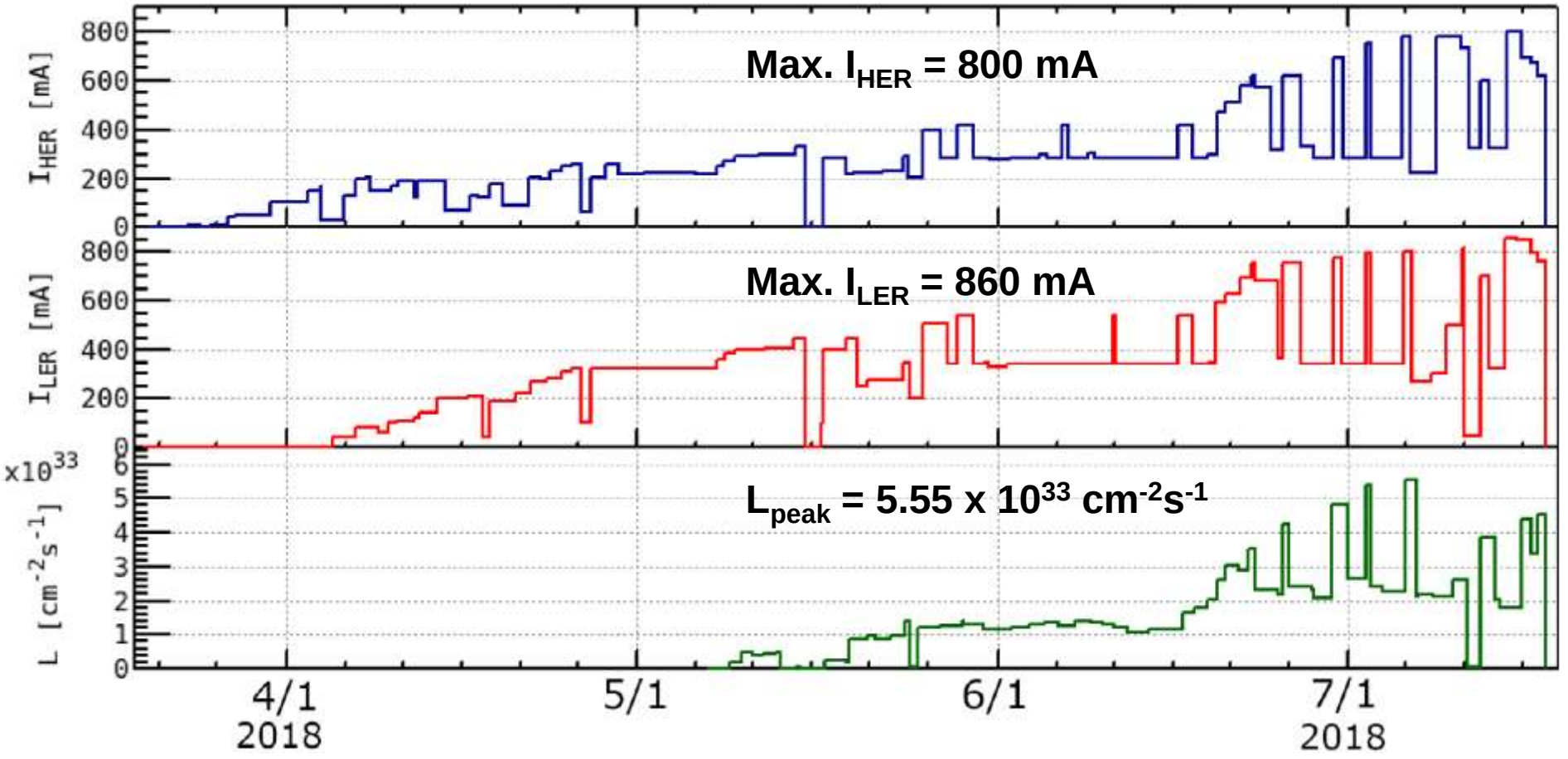
March 19 Phase 2 commissioning started.

April 25 First Beam-Beam deflection was observed.

April 26. First Collision (Physics event) was observed.

History of Commissioning

Y. Funakoshi Y. Ohnishi

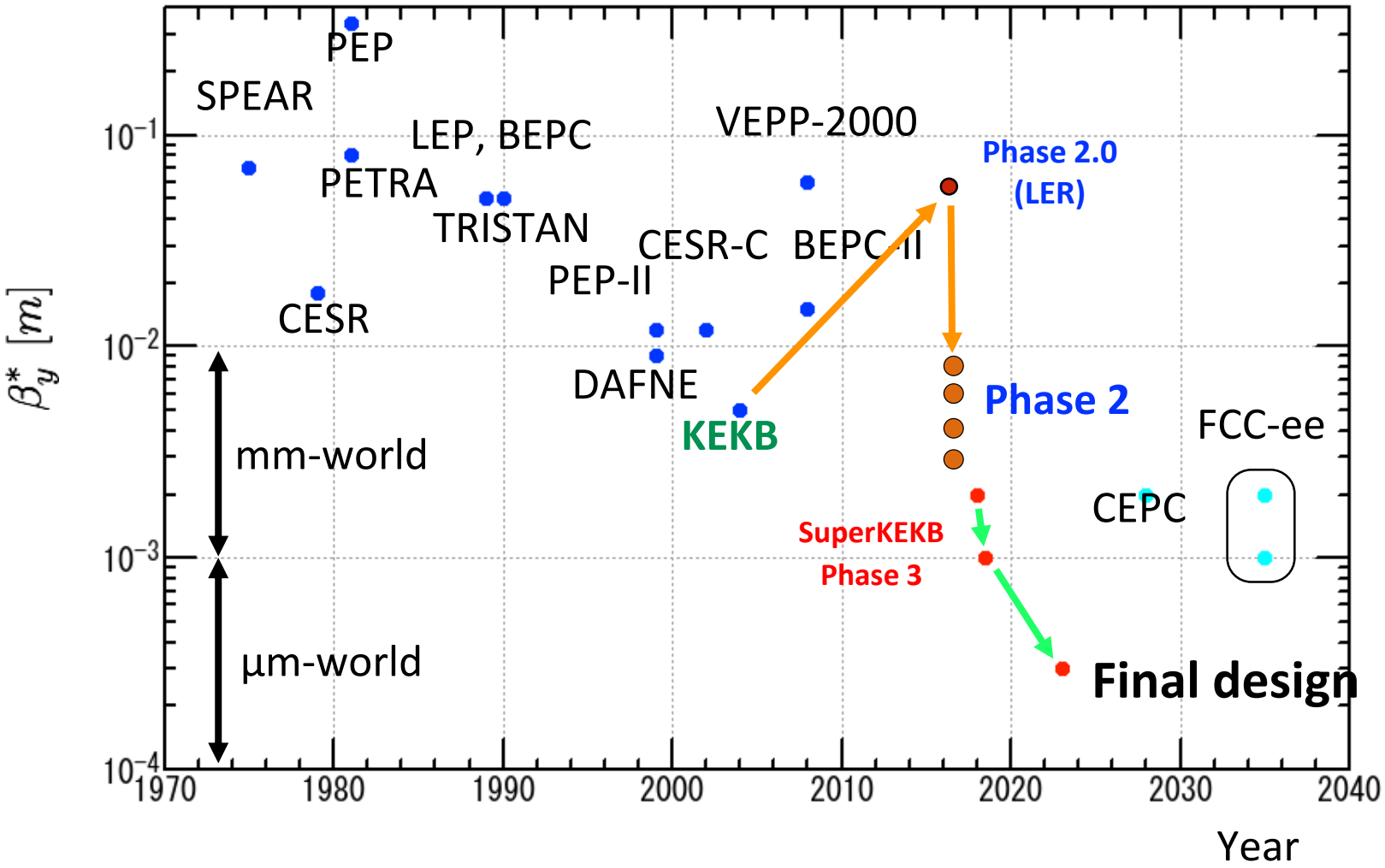


Integrated Luminosity (delivered from SuperKEKB) = 1853 pb^{-1}

β_y^* Evolution over 50 Years

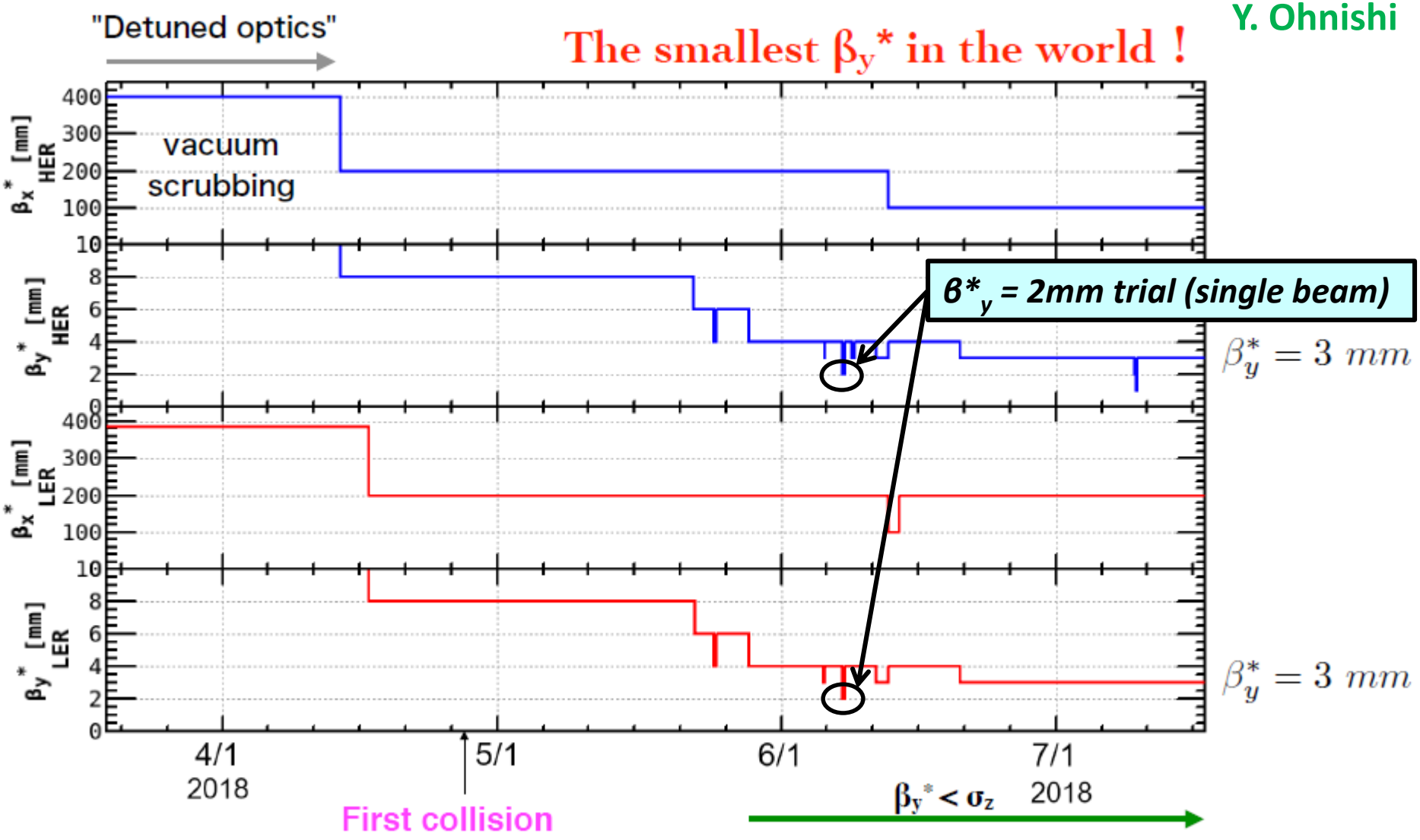
Y. Ohnishi

SuperKEKB will try to make the smallest β_y^* in the world !



Beta Squeezing at IP

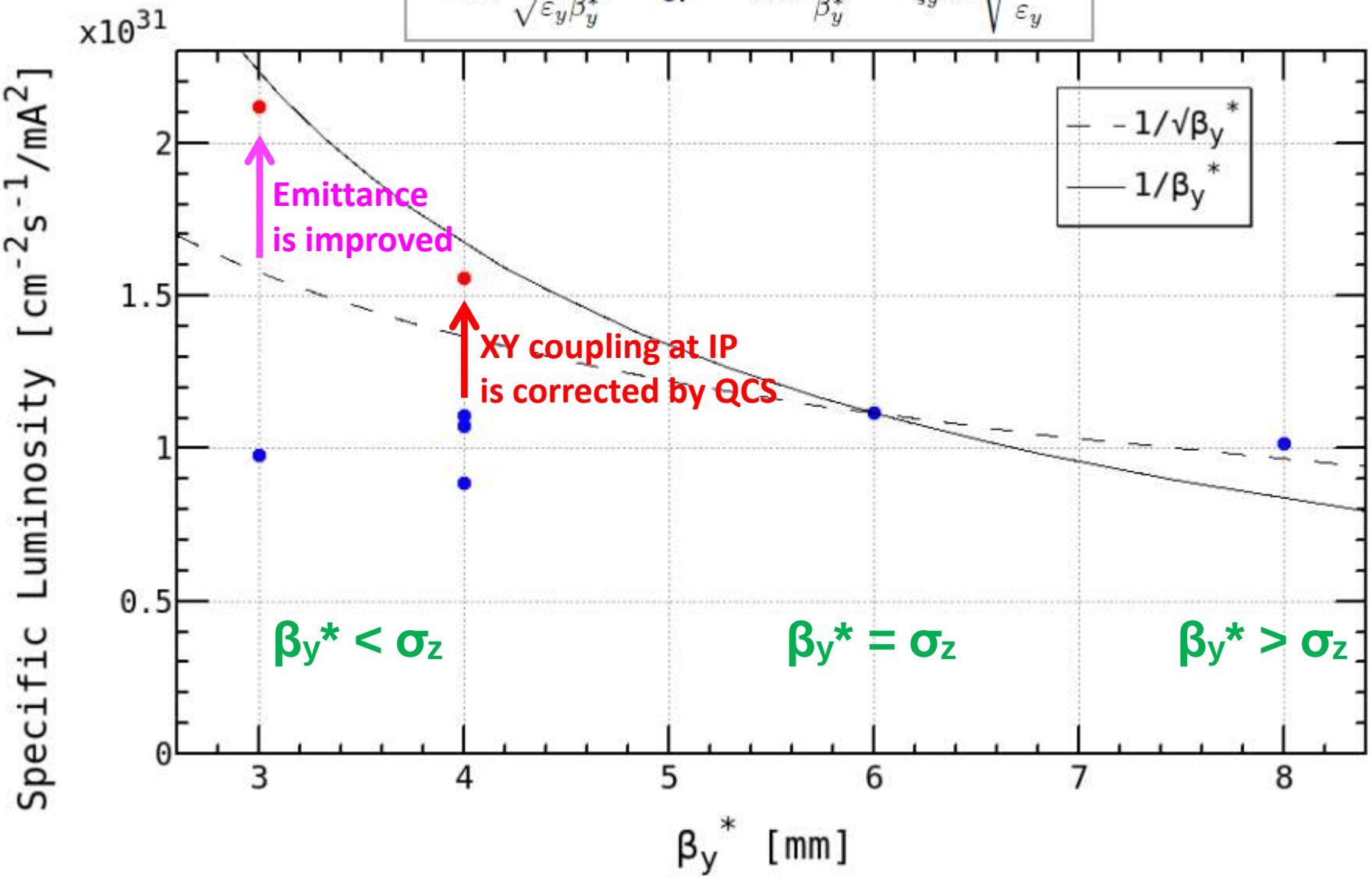
Y. Ohnishi



Verification of Nano-Beam Scheme

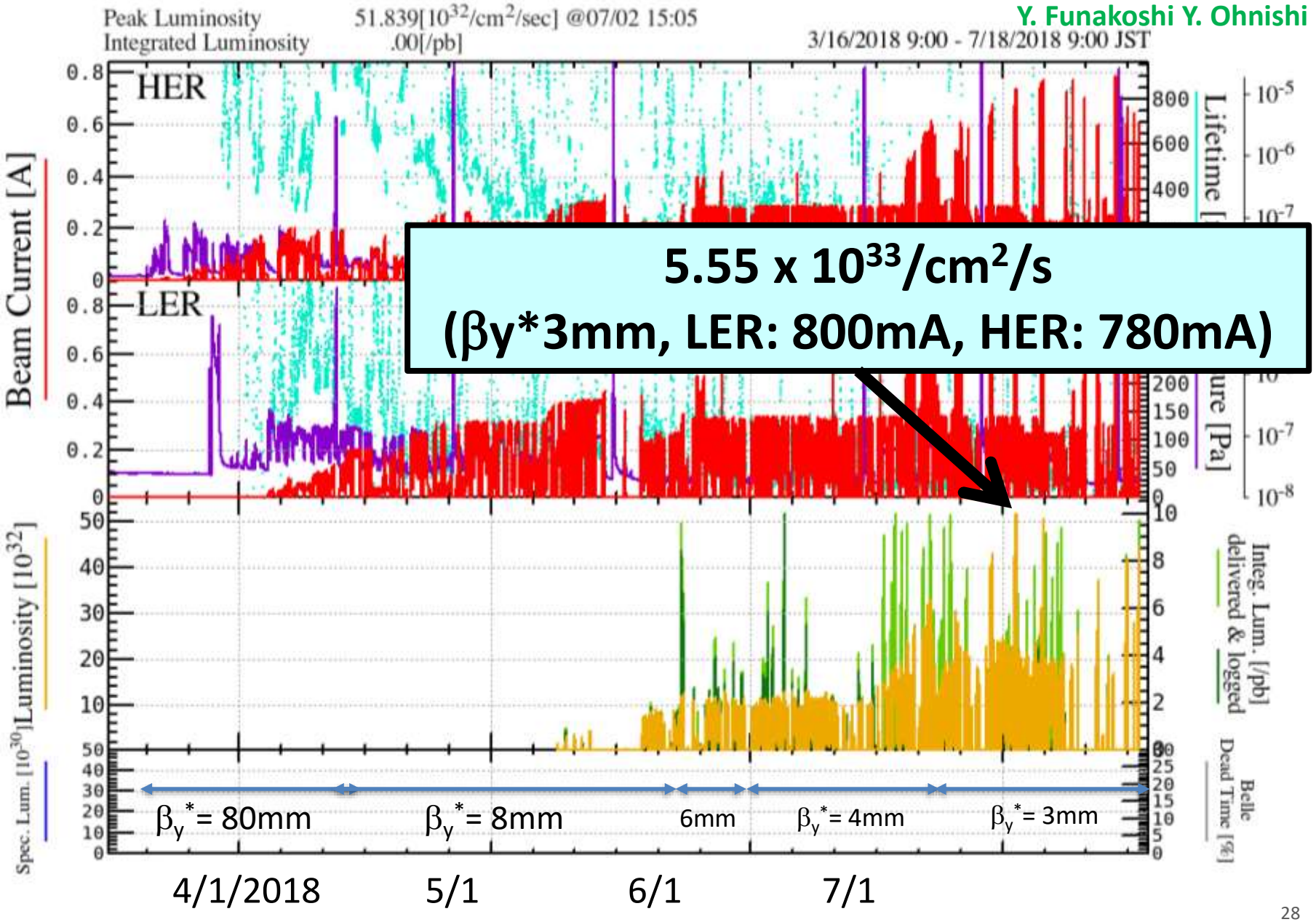
Y. Ohnishi

$$L \propto \frac{1}{\sqrt{\varepsilon_y \beta_y^*}} \quad \text{or} \quad L \propto \frac{\xi_y}{\beta_y^*} \qquad \xi_y \propto \sqrt{\frac{\beta_y^*}{\varepsilon_y}}$$



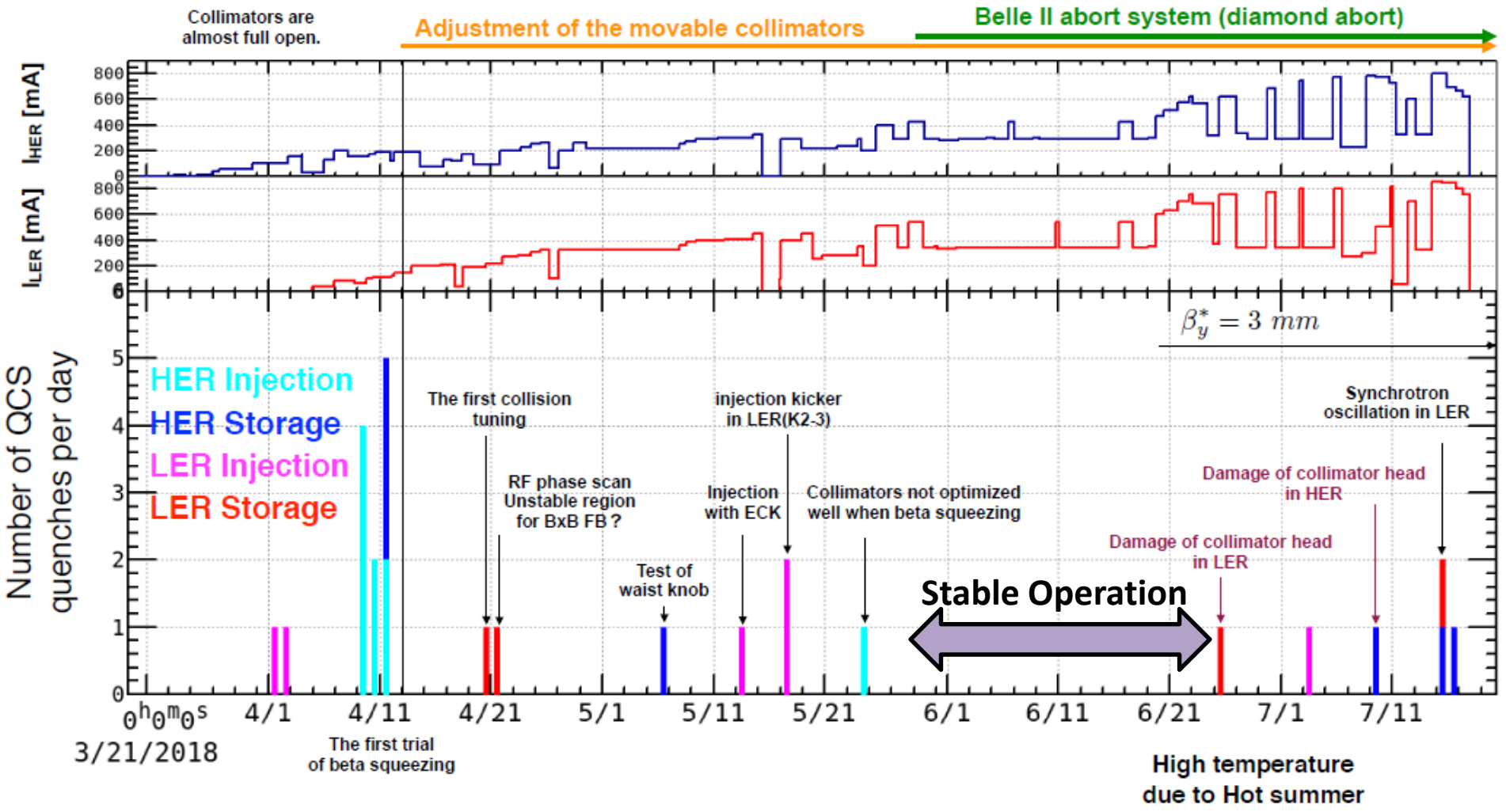
Luminosity

Y. Funakoshi Y. Ohnishi



QCS Quench

Y. Ohnishi

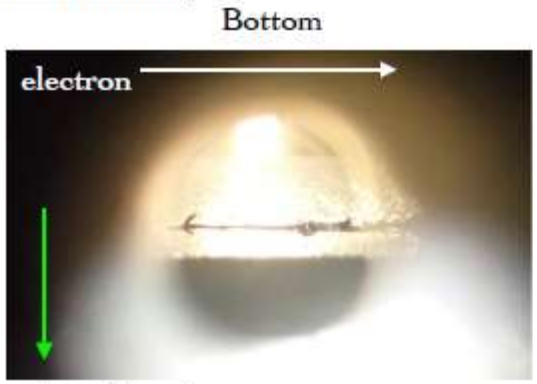


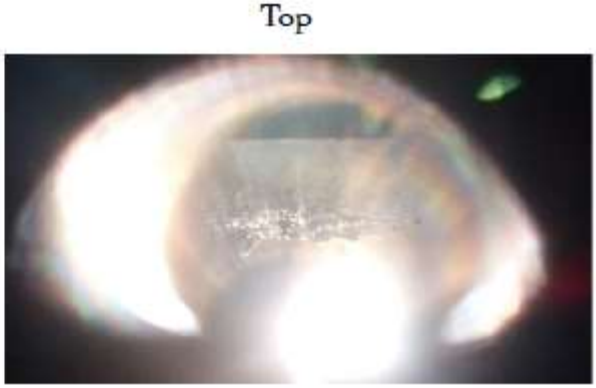
Damage of Movable Collimator Head

Vertical Collimator

LER

D02V1

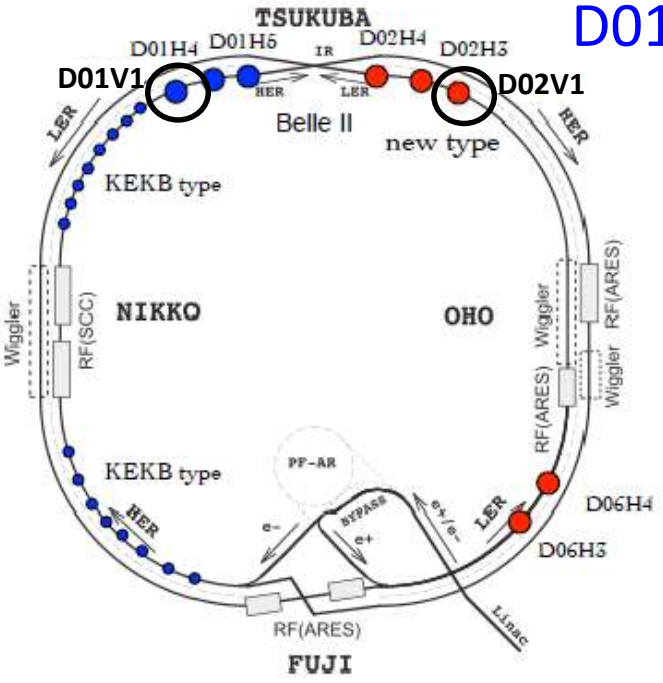


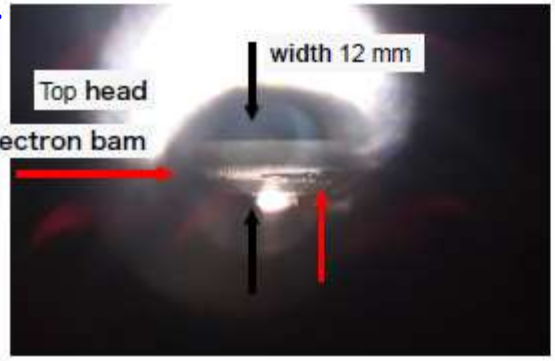


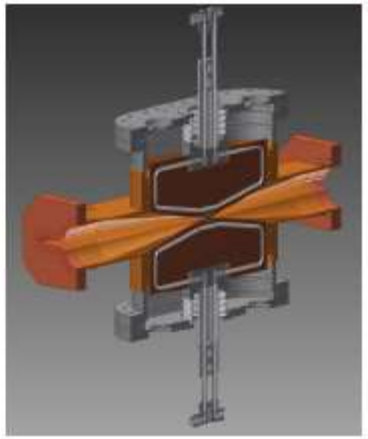
Damaged during collisions

HER

D01V1





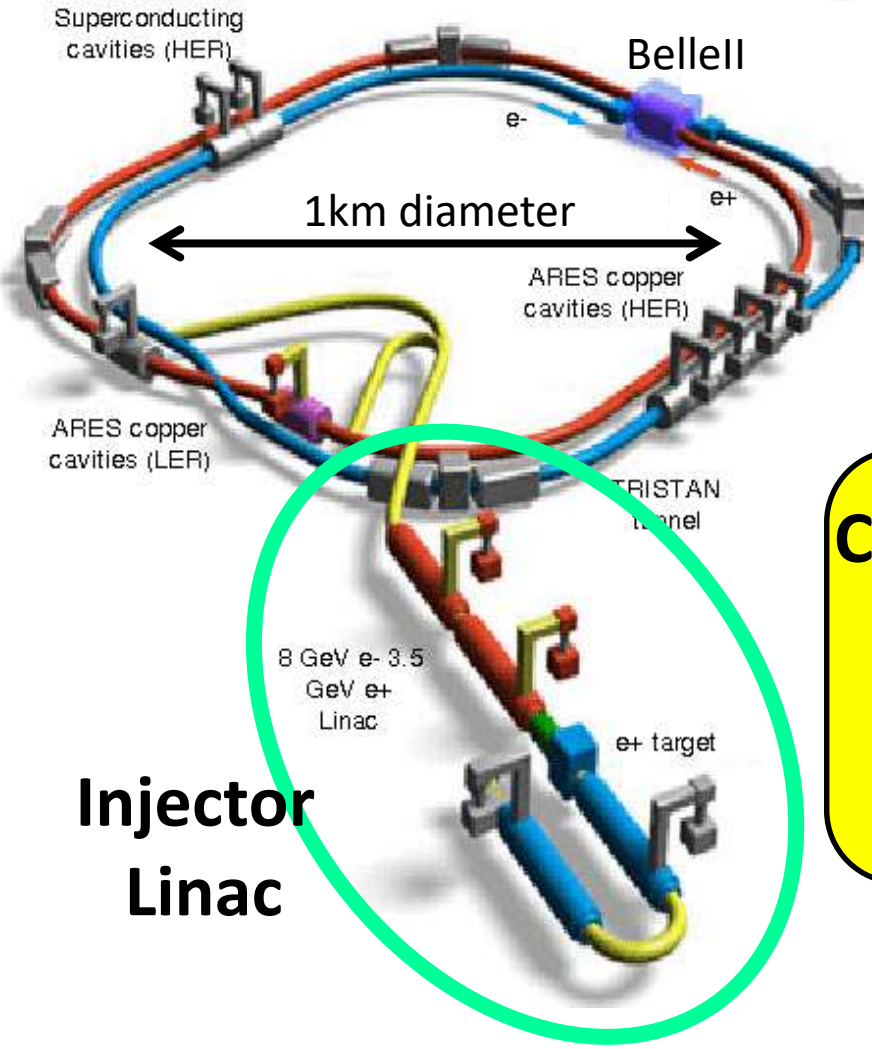


Damaged during current storage (w/o collisions)

Y. Suetsugu, T. Ishibashi, S. Terui

Activities at OCU for the SuperKEKB Accelerator

Injector Linac Operation Tuning using ML



To achieve the high luminosity, precise operation tuning to get the higher injection efficiency is very important

Currently R&D of operation tuning for the injector Linac using Machine Learning (ML) is ongoing

KEK, Osaka-City U., IDS Osaka U.

In Osaka, we form a group working on

“Application of Deep Learning for Accelerator Experiments”

→ *Approved as a RCNP project*

The group is formed with particle physicists and data scientists

Particle Physics

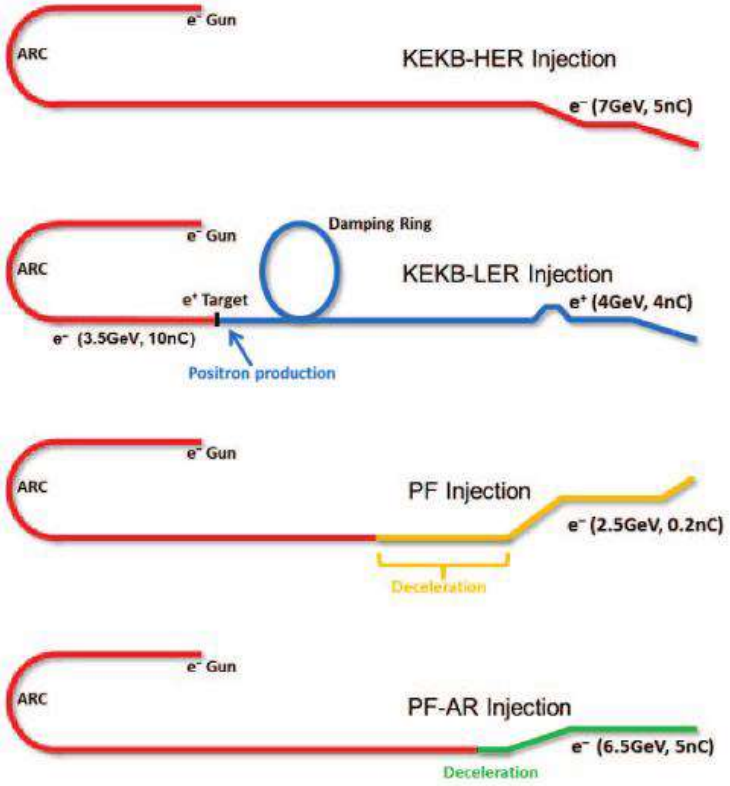
Data Science

ML applications in our project

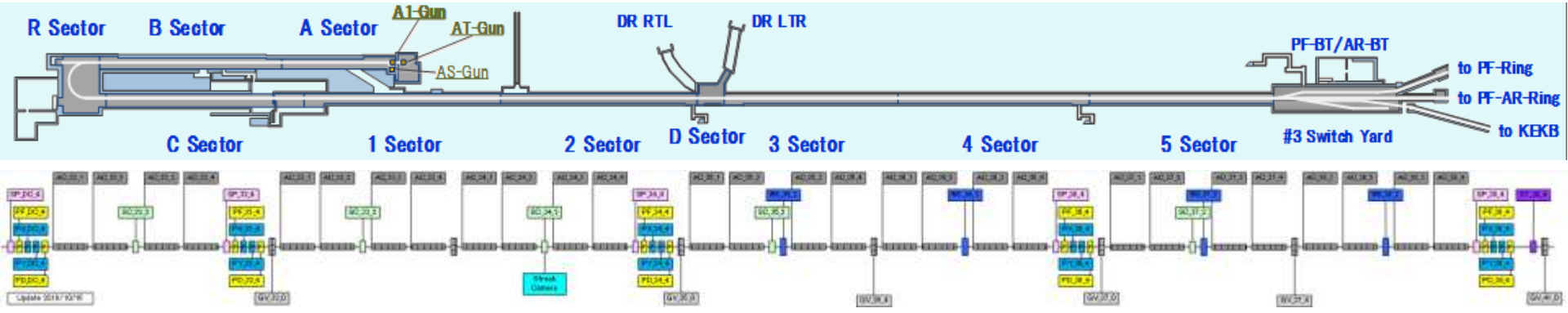
- Flavor-tag in ILC & continuum rej. in Belle (Osaka-City U., IDS, RCNP)
- Pattern recognition in medical (Showa P. U.)
- Beam size measurement in ILC (Tohoku U.)
- EM calorimeter calibration in ILC SiD (Osaka-City U., U. Oregon, PNNL, SLAC)
- Accelerator operation tuning in KEK Linac (KEK, Osaka-City U., IDS)

Online Data for the ML study

Injector Linac is for SuperKEKB, PF and PF-AR



We can accumulate online data even SuperKEKB is not running



Summary

- KEKB has upgraded to SuperKEKB

First collisions in April 2018

Peak luminosity $5.5 \times 10^{33}/cm^2$ /sec

- At OCU, R&D of the operation tuning for the injector Linac using ML is on going

Collaboration : KEK, OCU, and IDS Osaka U.

New physics commissioning (phase-3) will start from 2019!