Belle II Status and Prospects

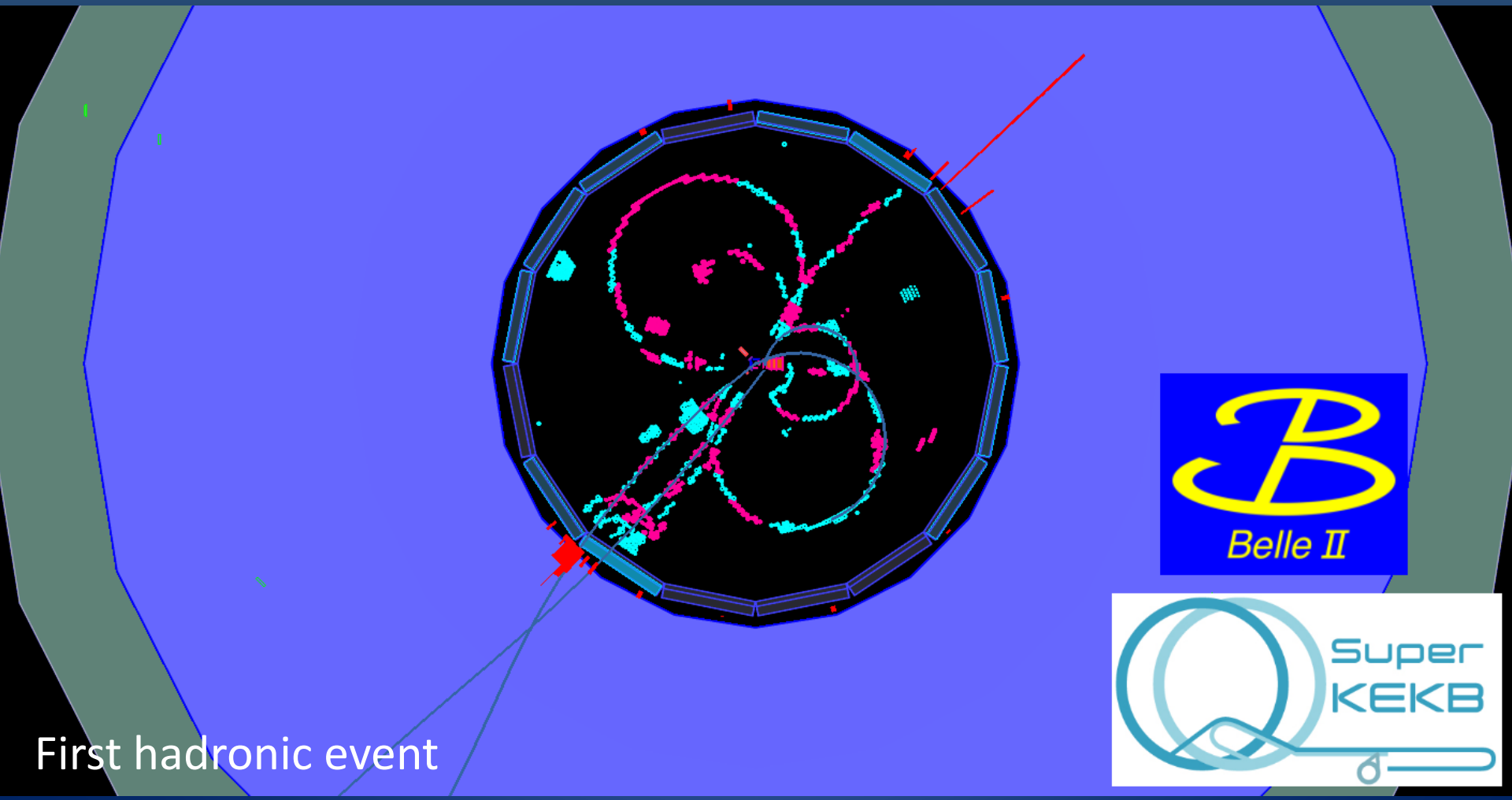
2018/5/30

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

For the Belle II Collaboration

First collisions

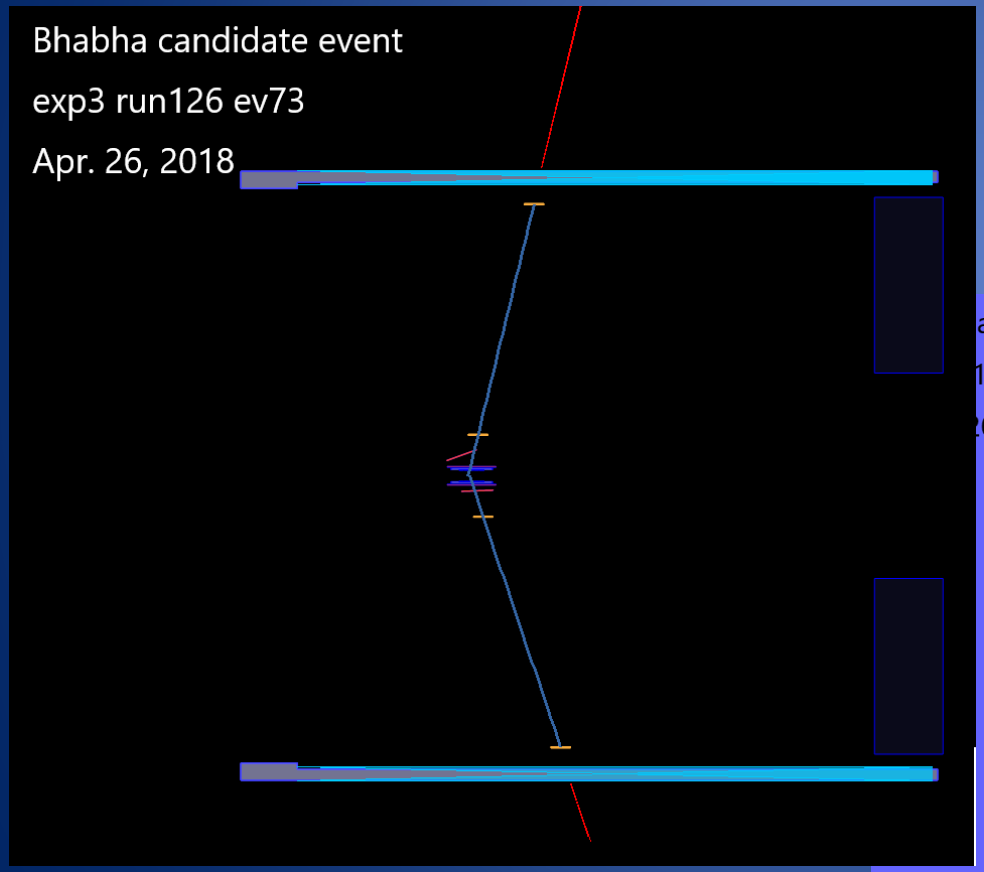
on April 26, 2018

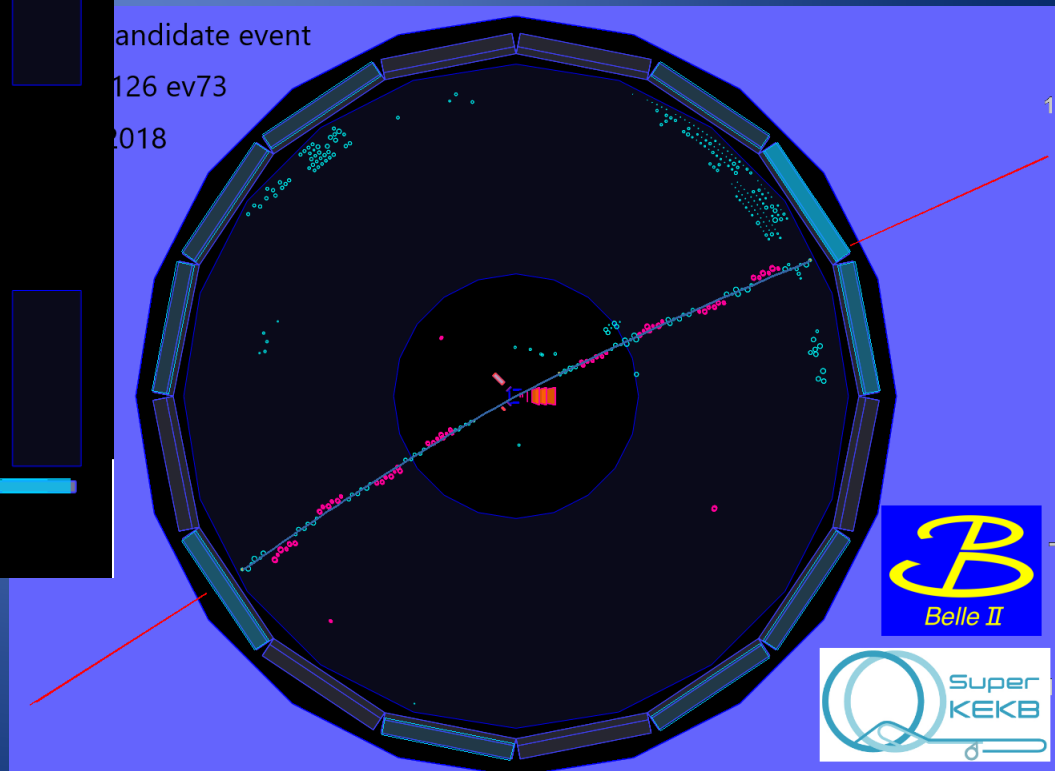


First hadronic event

First collisions

on April 26, 2018



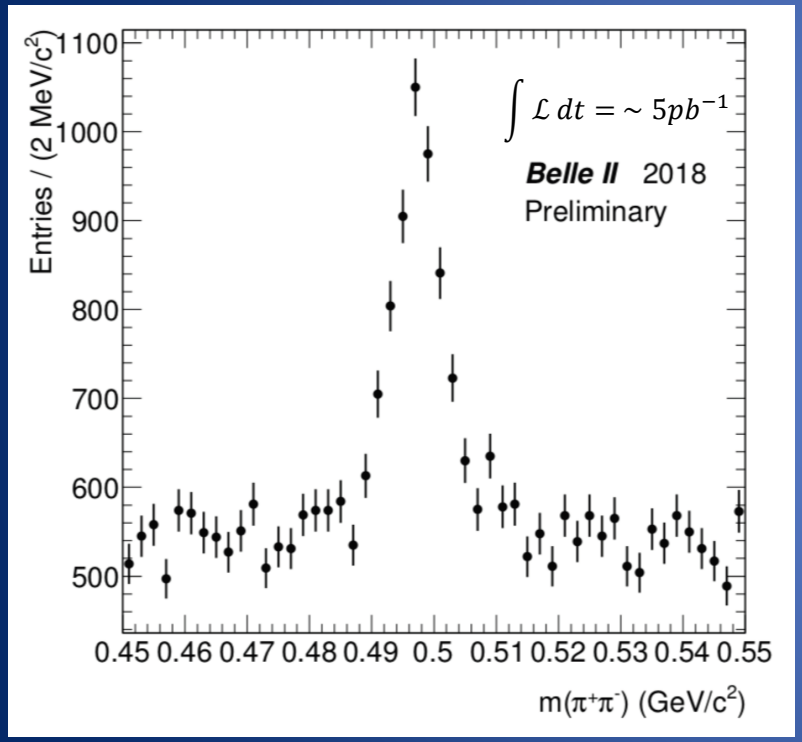


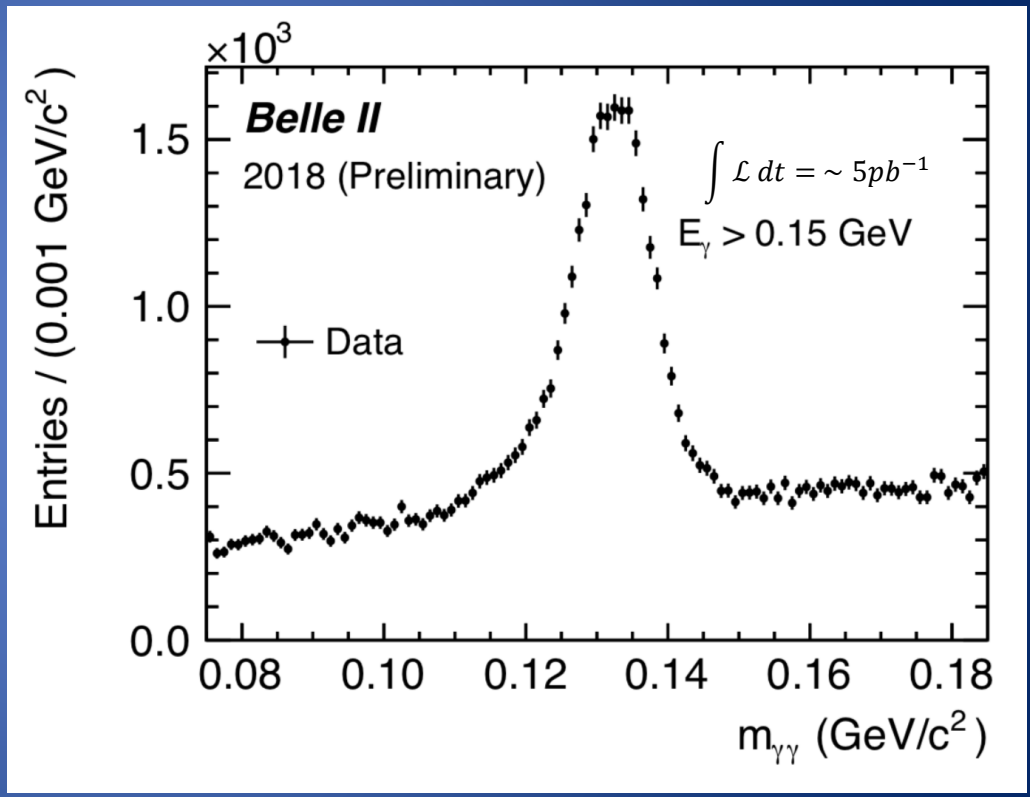
Belle II

Super KEKB

Data accumulation is on going

Mass peaks for charged tracks and gammas





Current integrated luminosity ~5pb^{-1}

Today I'll talk

1. SuperKEKB / Belle II introduction
   - Motivation of the experiment
   - SuperKEKB upgrade strategy
2. SuperKEKB construction
3. SuperKEKB operation status
4. Belle II construction
   - Upgrade strategy and construction status
5. Physics prospects
6. 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**

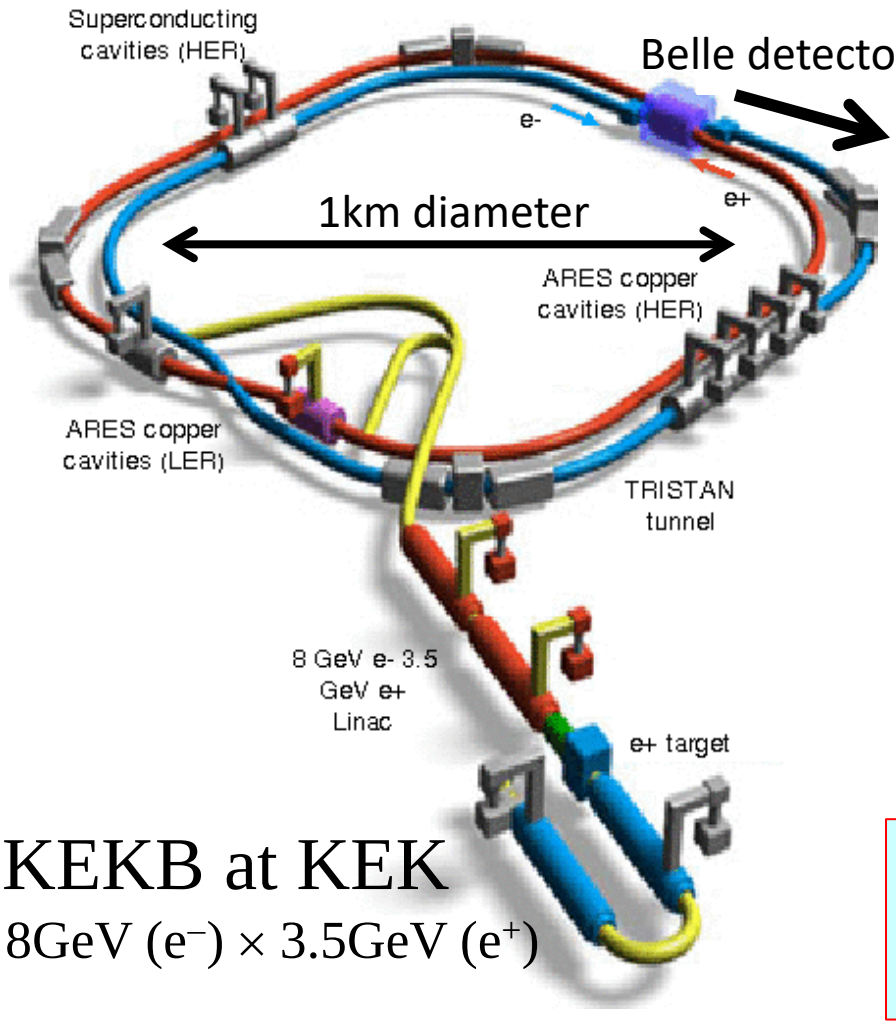
  x40 of the KEKB's world record

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

  → *Probe > O(TeV) energy scale*
- **Current on going e^+e^- collider**

  → *Important feed back to ILC*

Introduction

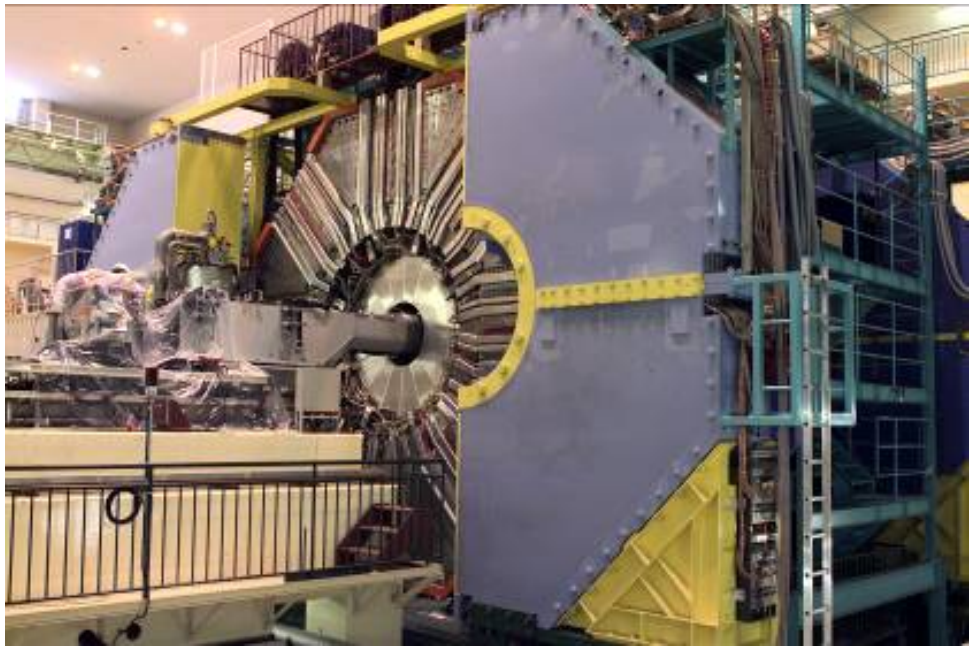


KEKB at KEK

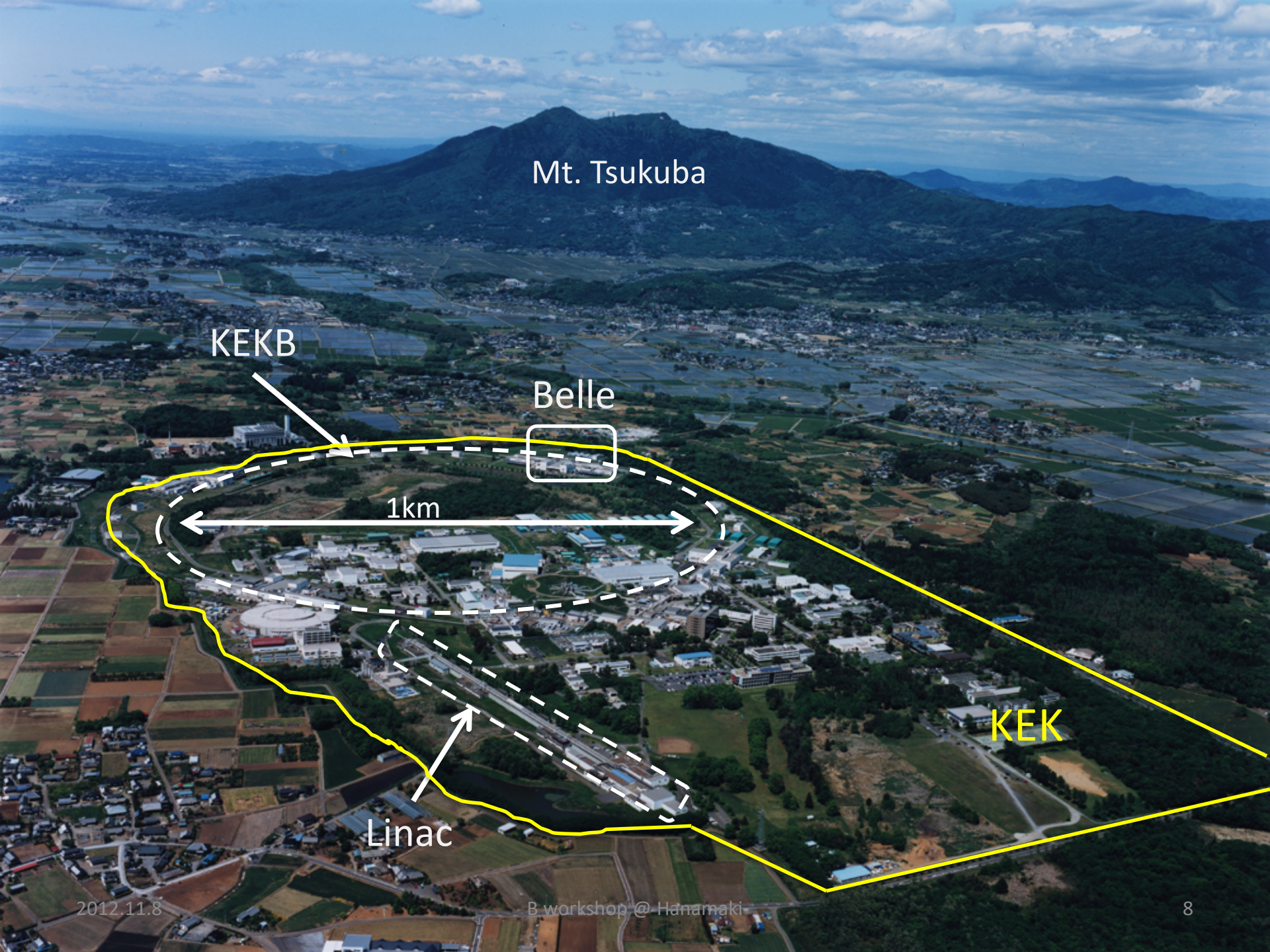
8GeV (e^-) × 3.5GeV (e^+)

Asymmetric Energy e^+ e^- collider

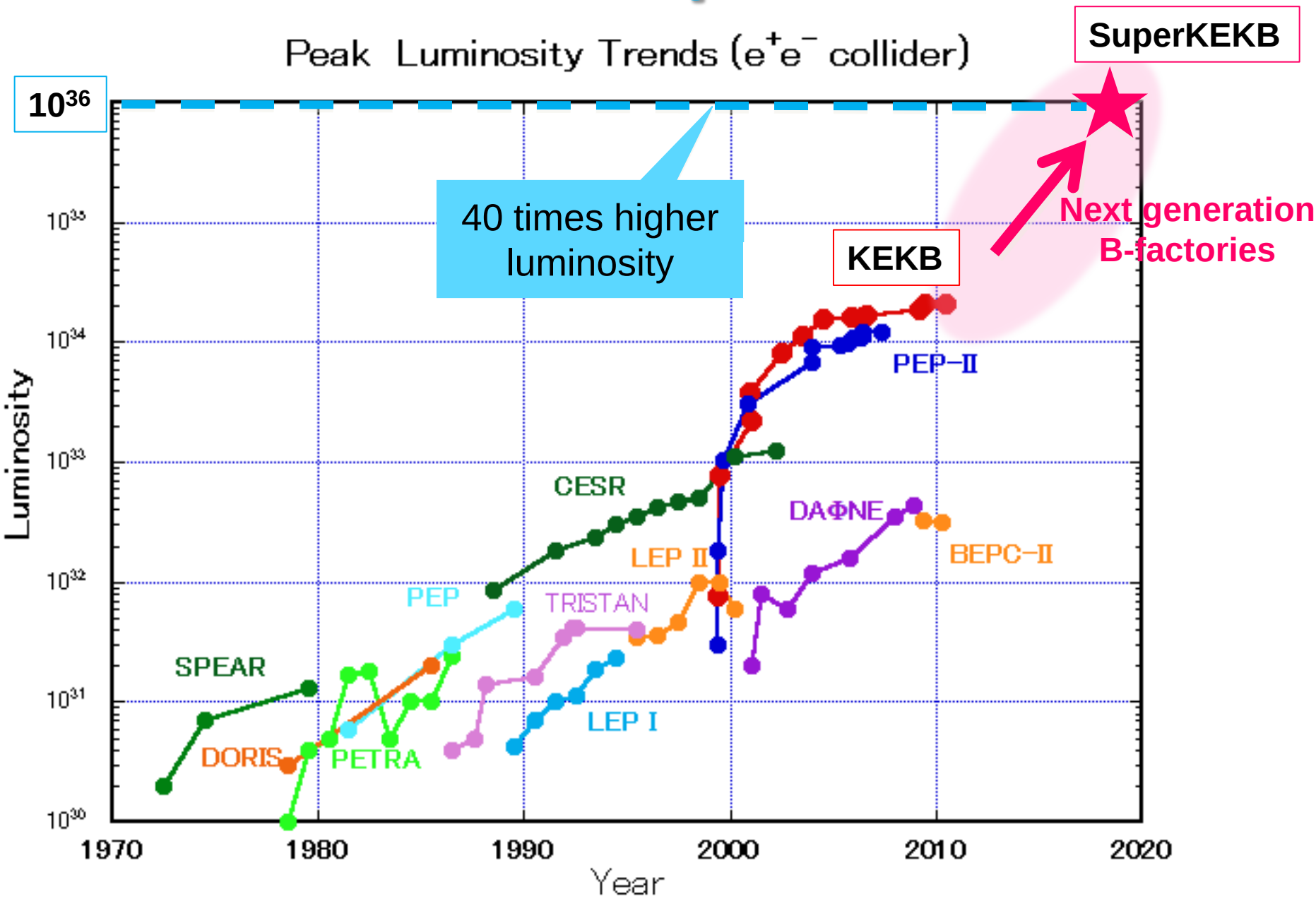
Belle



KEKB / Belle has upgraded to SuperKEKB / Belle II

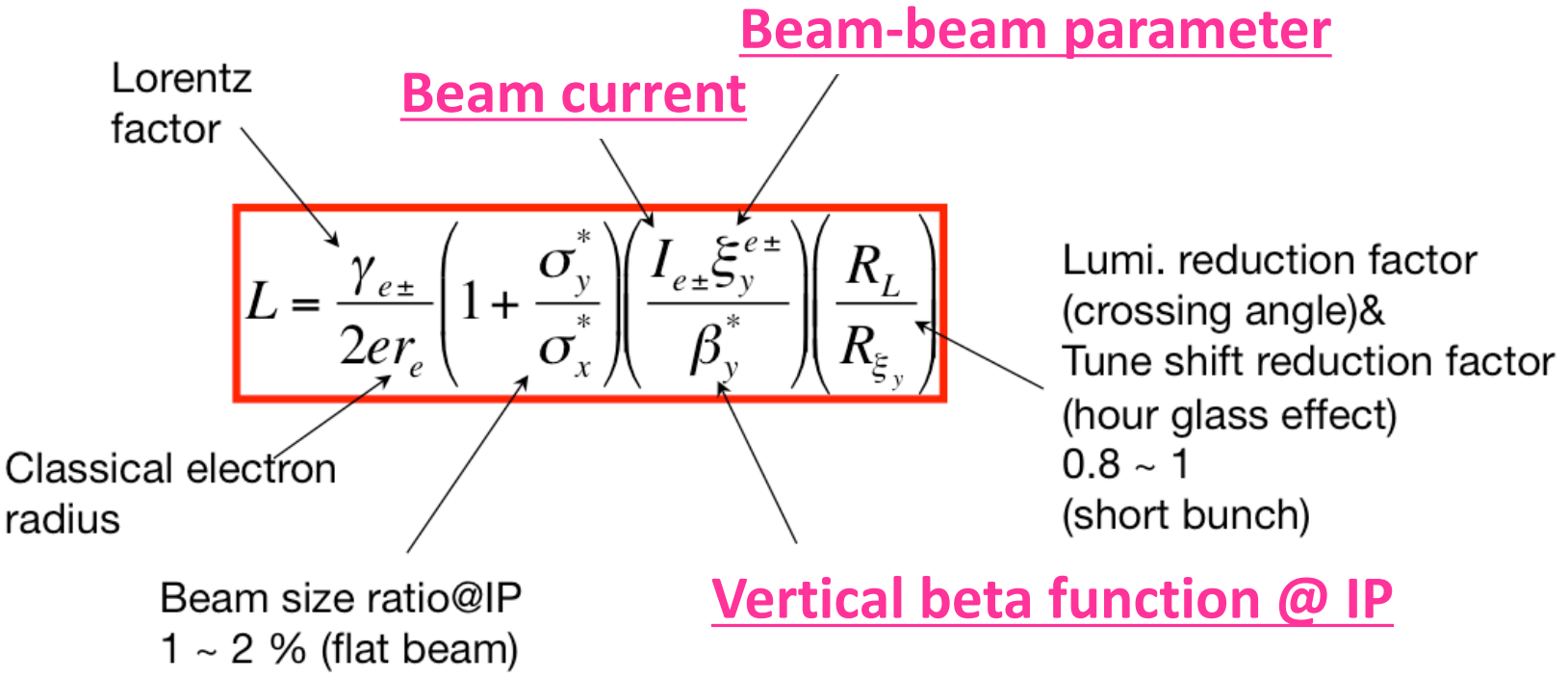

Mt. Tsukuba
KEKB
Belle
1km
KEK
Linac

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

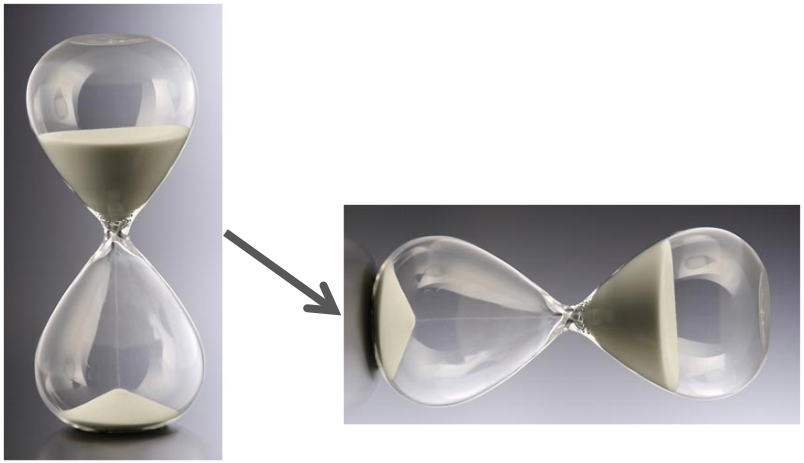
Nano-Beam scheme

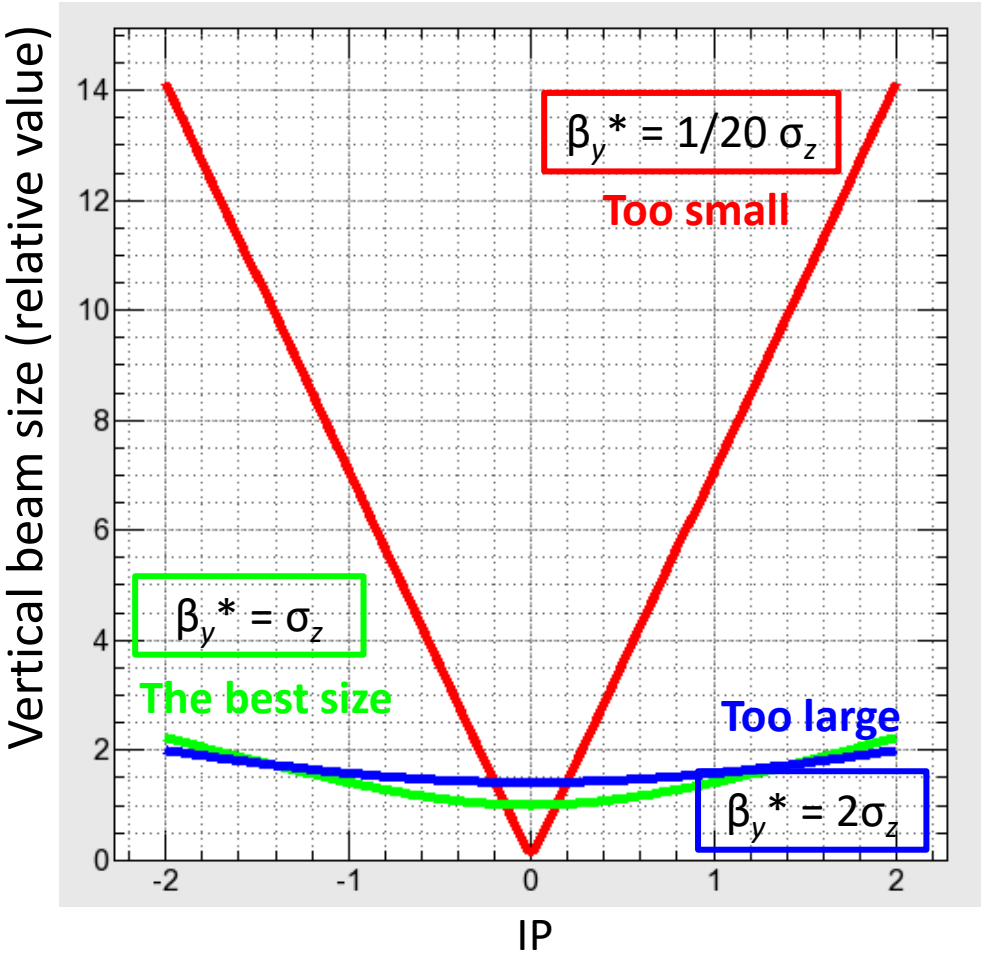
To increase L, we want to squeeze beams (=small β^*_y)
However β^*_y cannot be much smaller than the bunch length to avoid *the "hourglass" effect*

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,

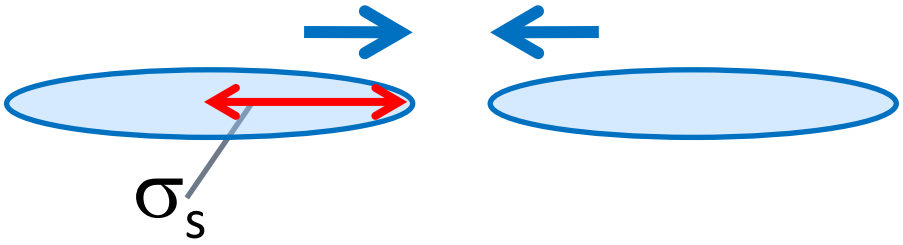
Enlarge crossing angle & Make horizontal beam size small

↓

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

Intersect bunches only at highly focused region

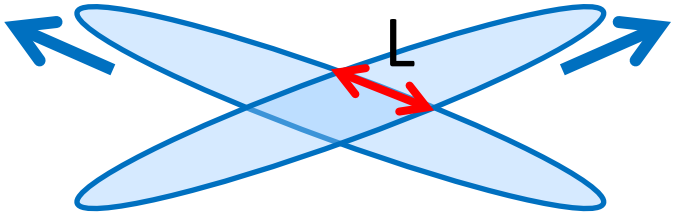
Head-on collision



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

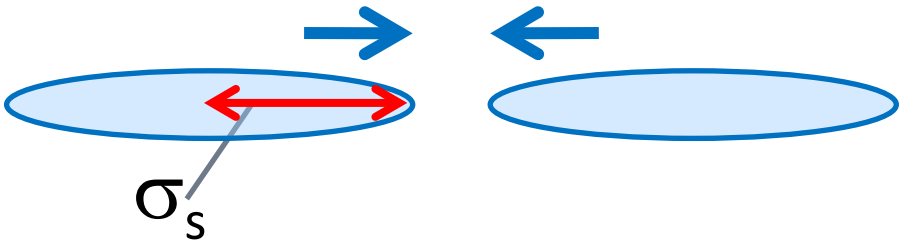
2) Make the horizontal beam size small

↓

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

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

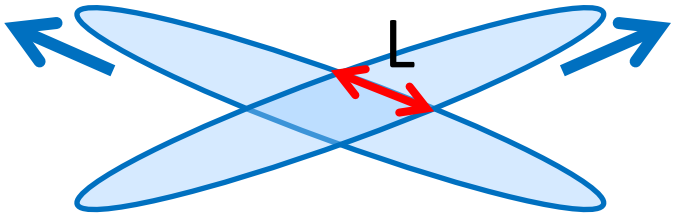
Head-on collision



overlap region = bunch length

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

Nano-beam scheme



overlap region ~L

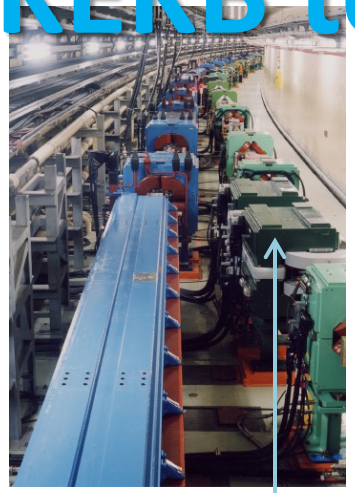
Hourglass condition: $\beta_y^* > \sim L$

Machine Design Parameters

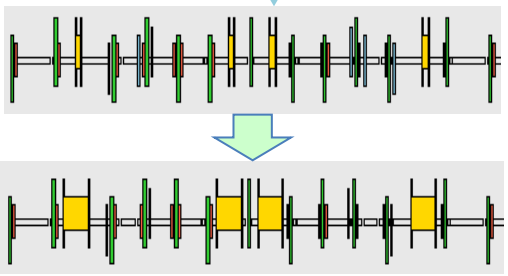
parameters		KEKB		**SuperKEKB**		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7	GeV
Half crossing angle	φ	11		41.5		mrad
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.6	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

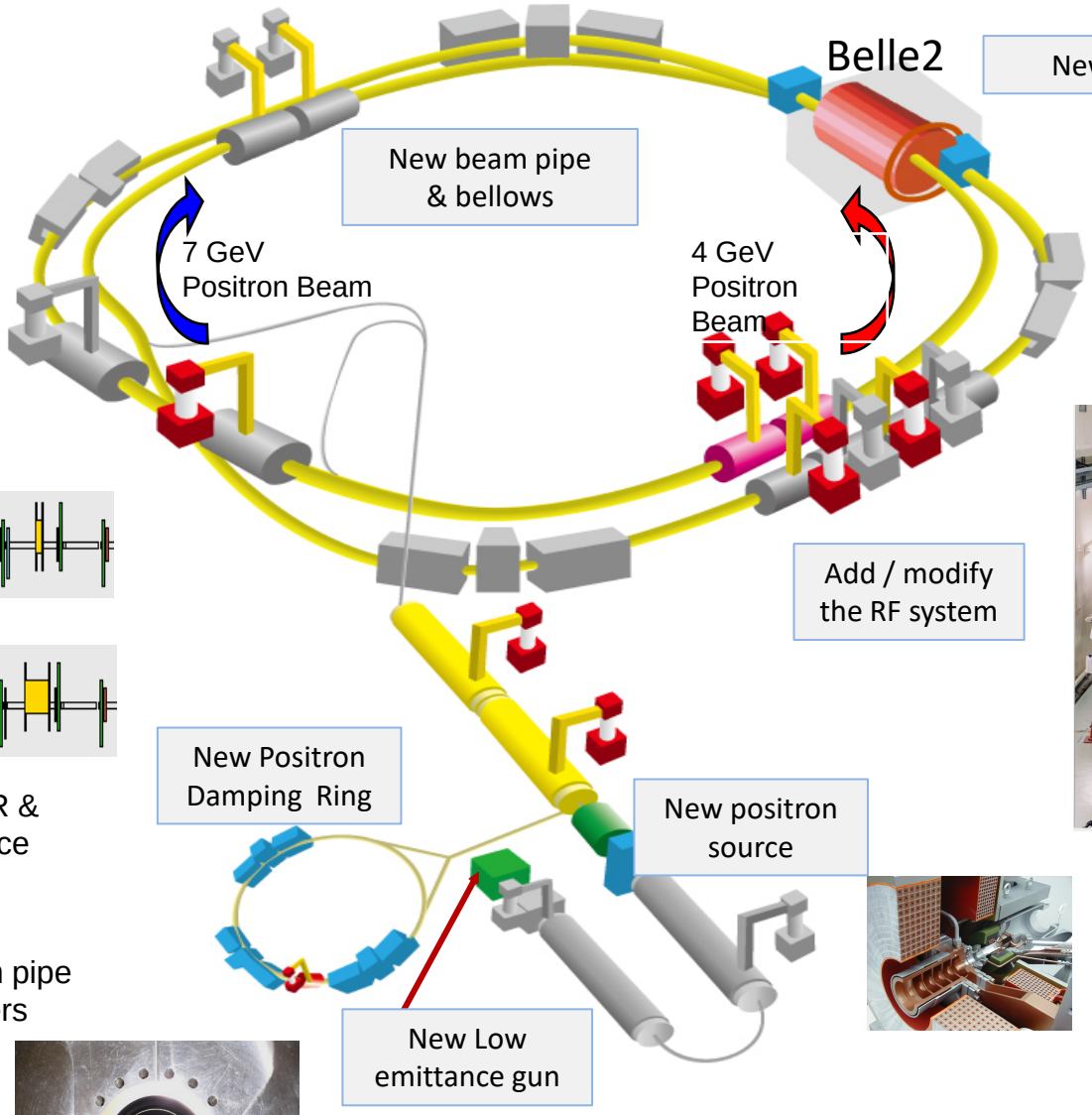
KEKB to SuperKEKB How to upgrade

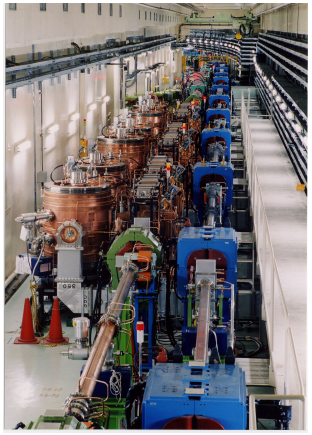


Replace short dipoles with longer ones (LER)

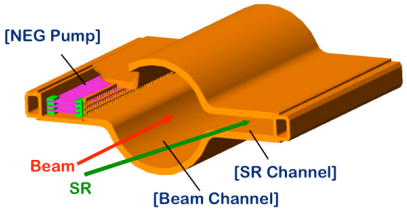


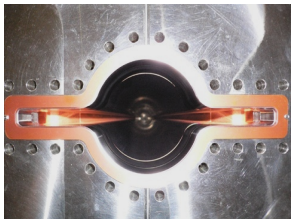
Redesign the lattices of HER & LER to squeeze the emittance





TiN-coated beam pipe with antechambers

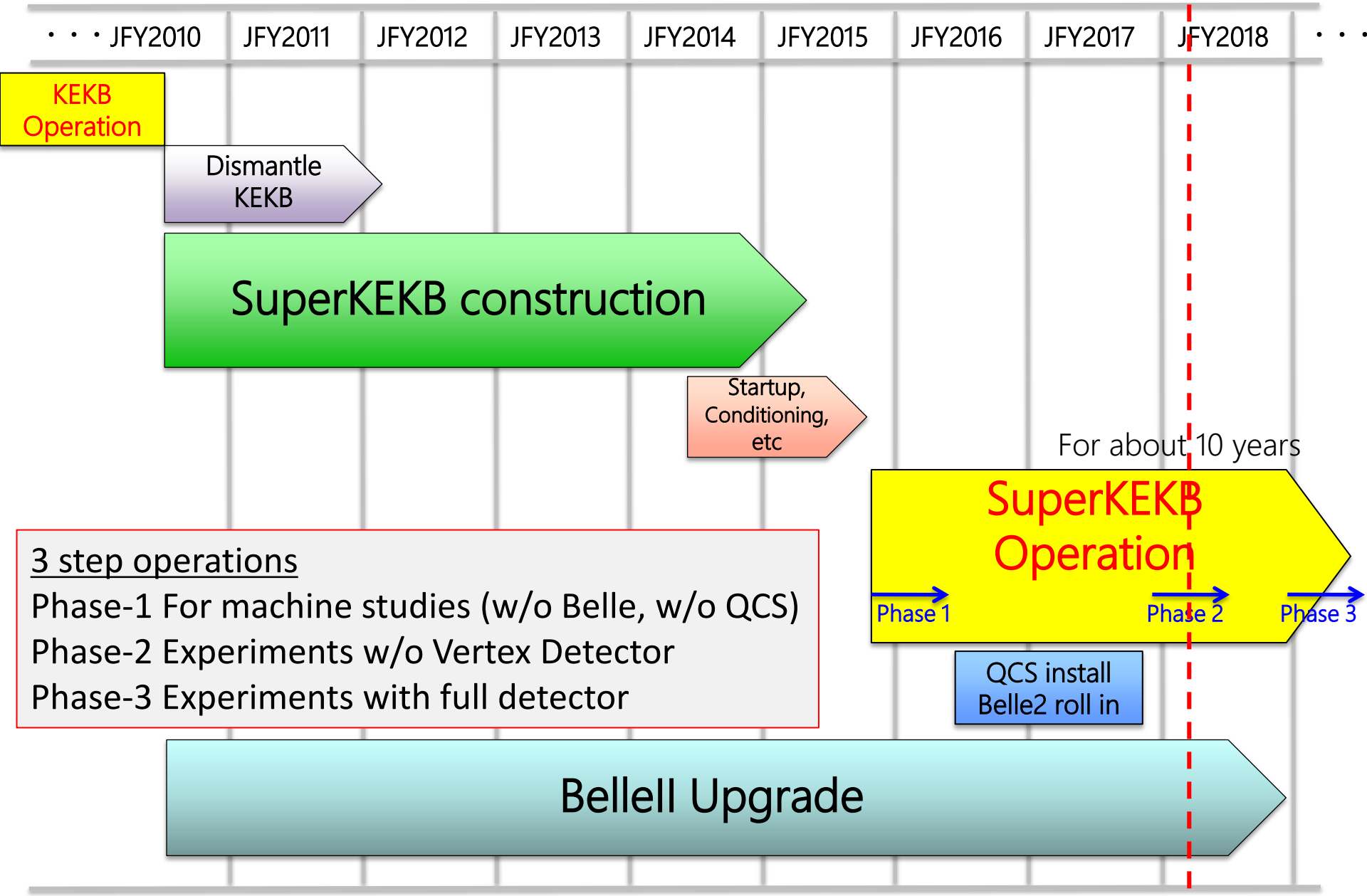




To get x40 higher luminosity

SuperKEKB Master Schedule

K. Akai



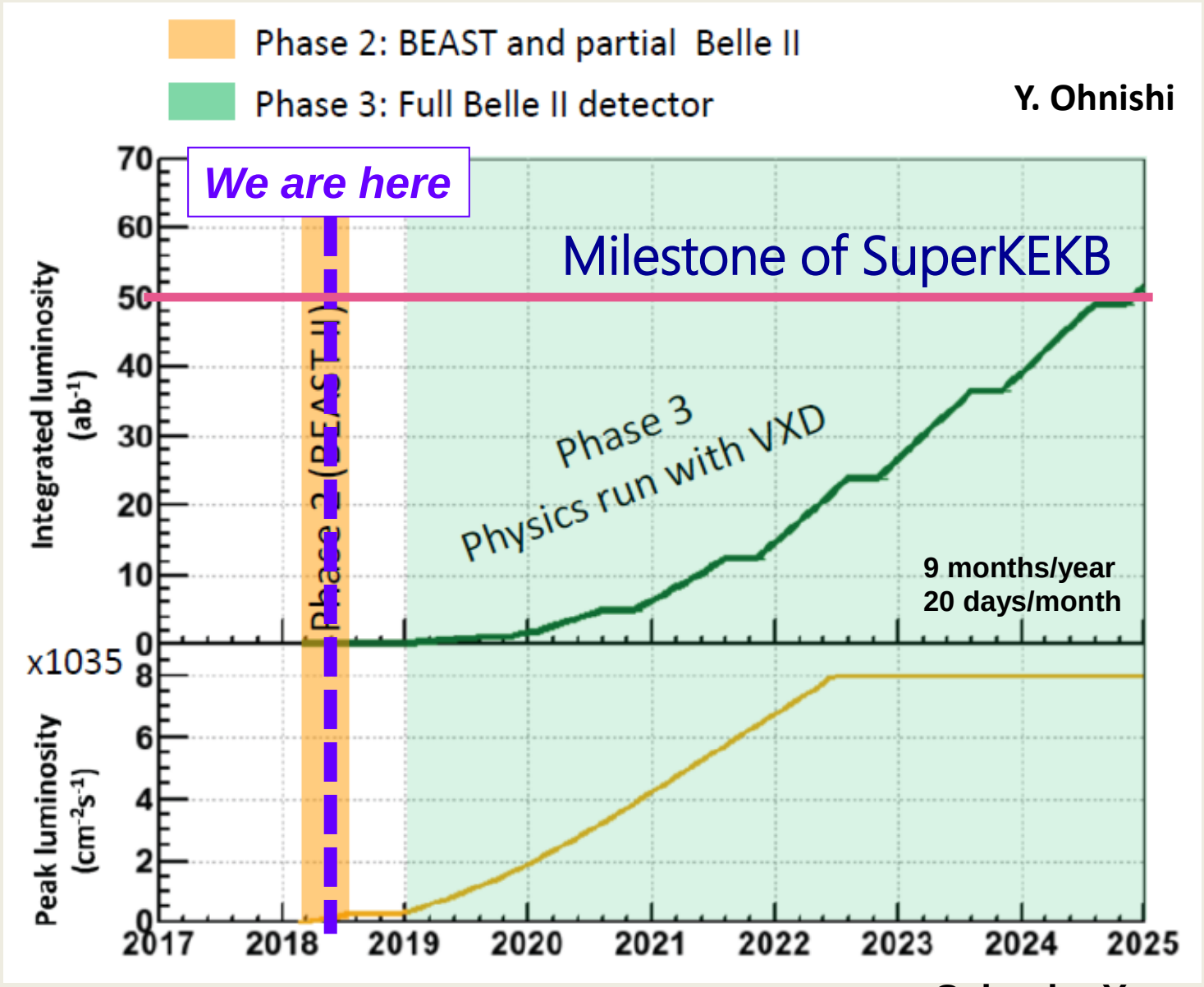
3 step operations

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

Phase-2 Experiments w/o Vertex Detector

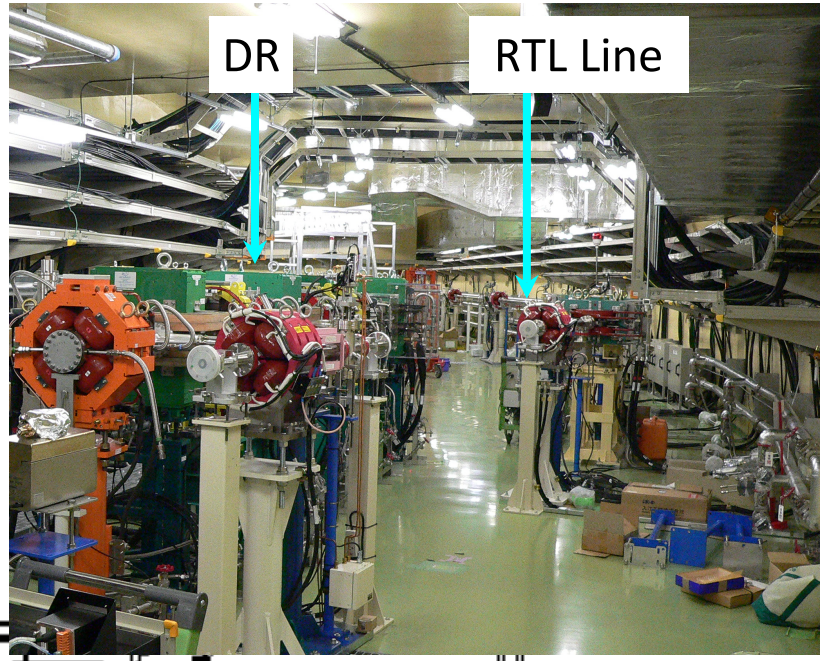
Phase-3 Experiments with full detector

SuperKEKB Luminosity Projection

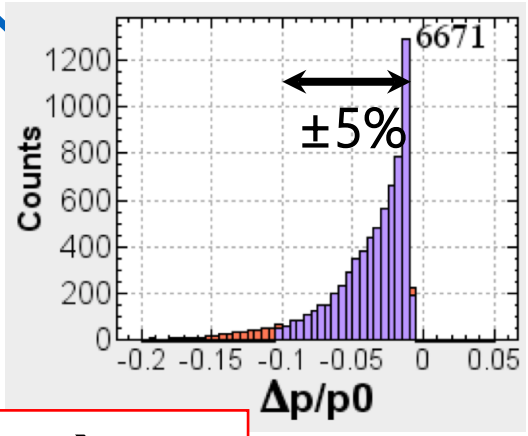


SuperKEKB Construction

New Positron Damping Ring



DR → Linac → SuperKEKB



Linac → DR

Design

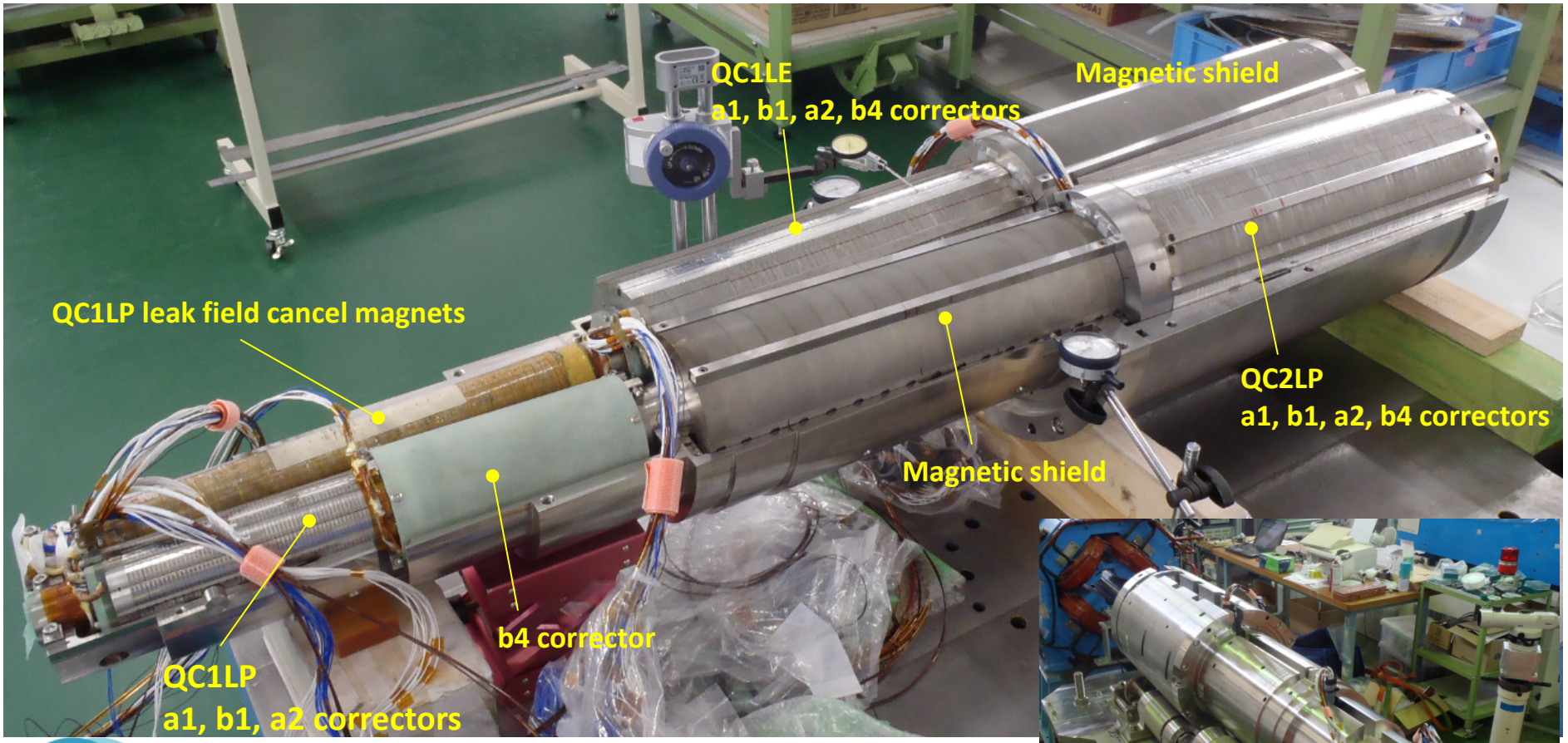
DR	Injection	Extraction	
$\gamma\varepsilon_x$(μm)	2800	89.3	64.6 (estimated)
$\gamma\varepsilon_y$(μm)	2600	4.5	< 2.0±0.36 (measured)

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)

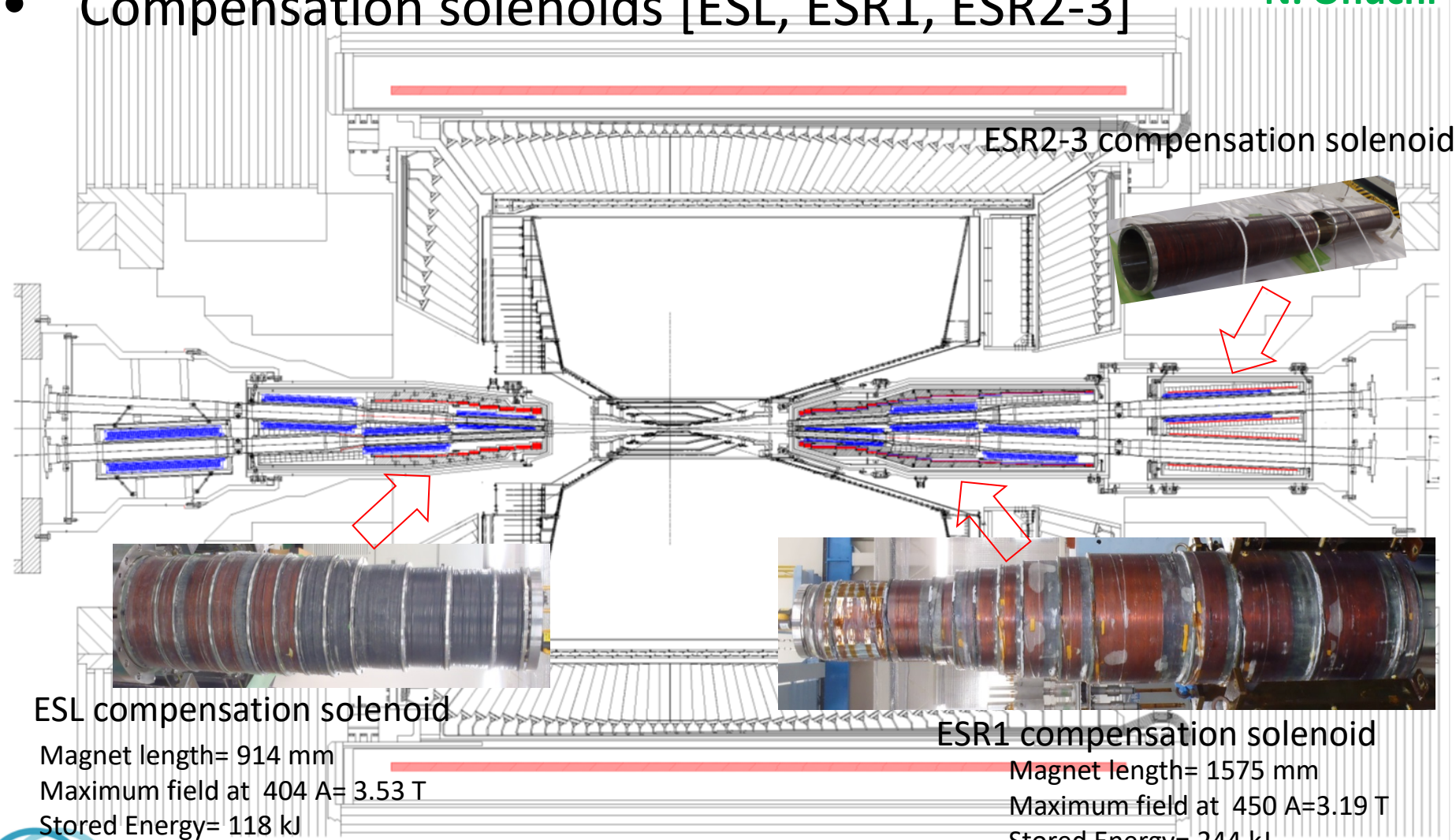
N. Ohuchi



New SC magnets around IP (QCS)

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

N. Ohuchi



ESR2-3 compensation solenoid

ESL compensation solenoid

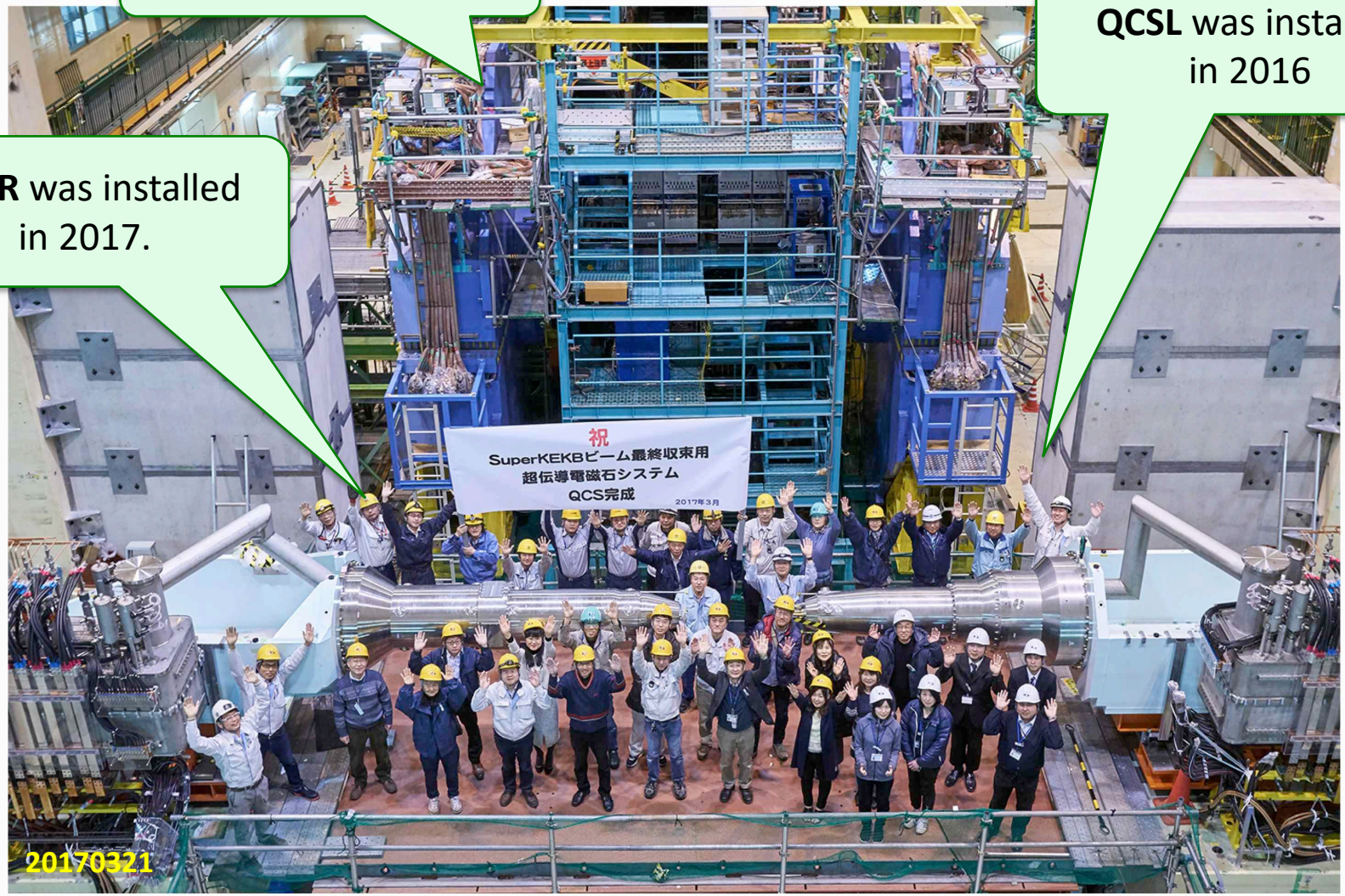
Magnet length= 914 mm
Maximum field at 404 A= 3.53 T
Stored Energy= 118 kJ

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

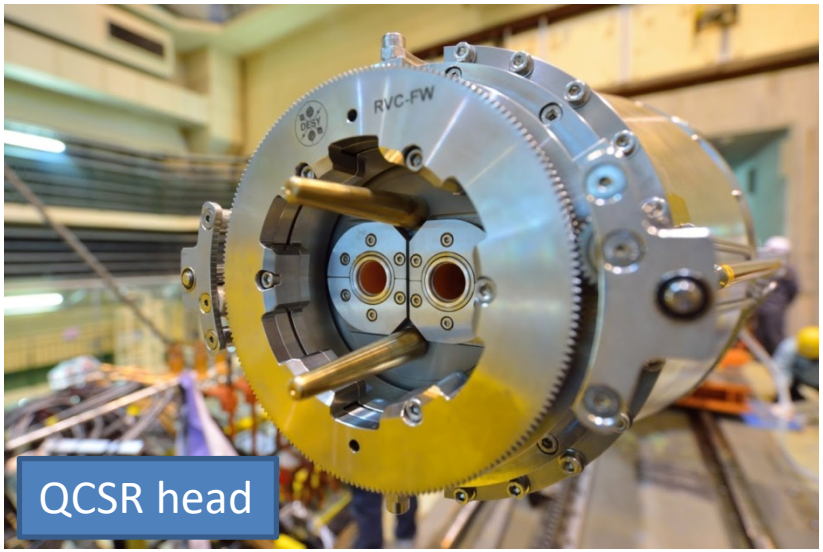
N. Ohuchi

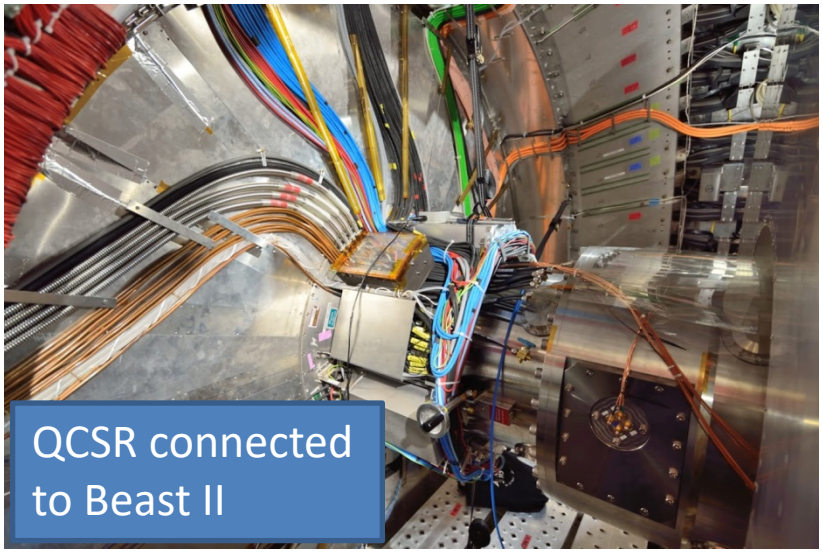


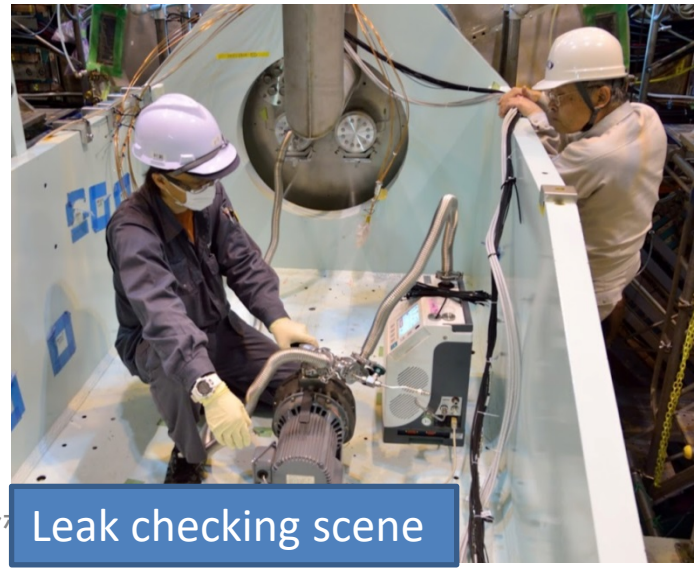
From the presentation by Prof. K. AKAI @KEKB review at Mar. 14, 2018

QCS-Belle II connection

QCS-BelleII mechanical connection is developed by DESY group.



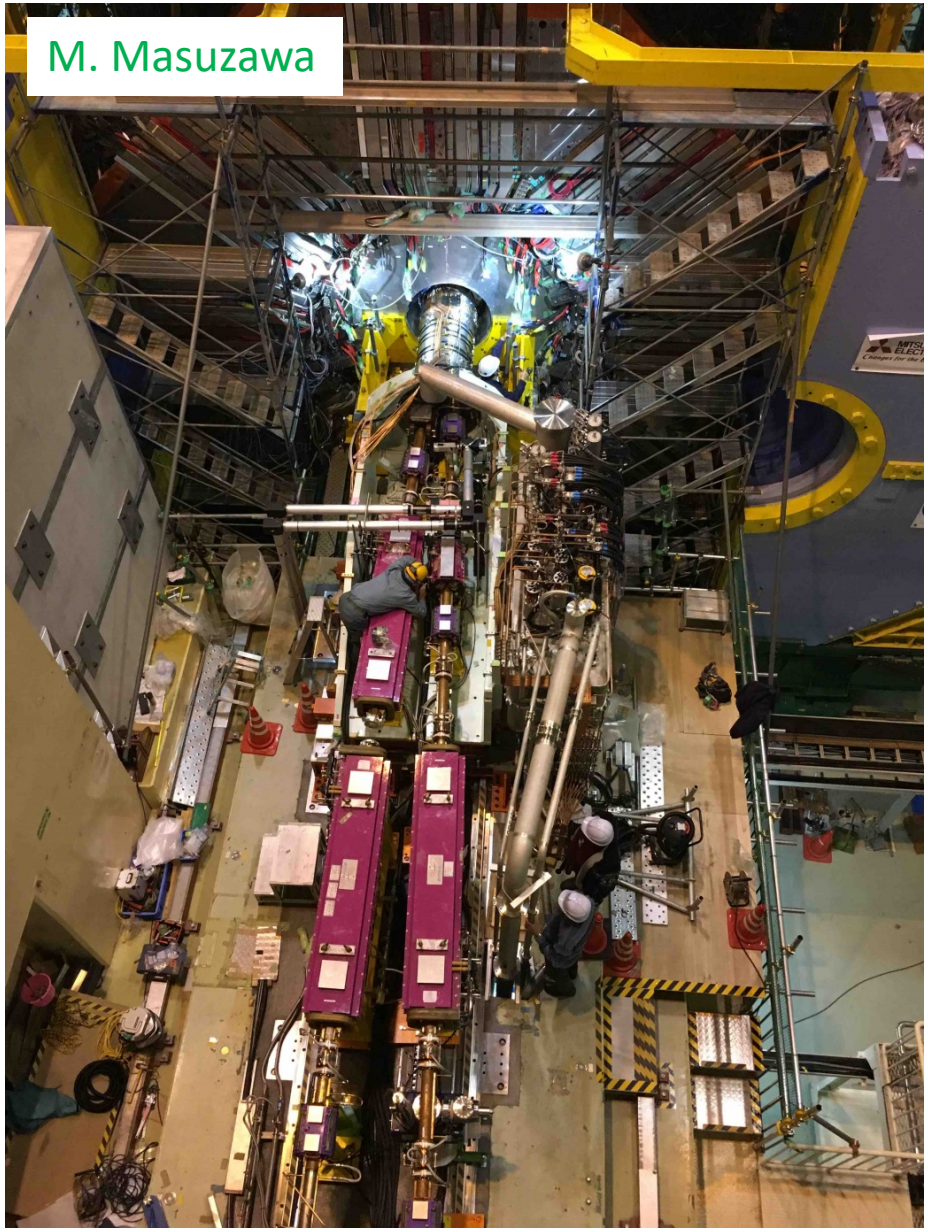


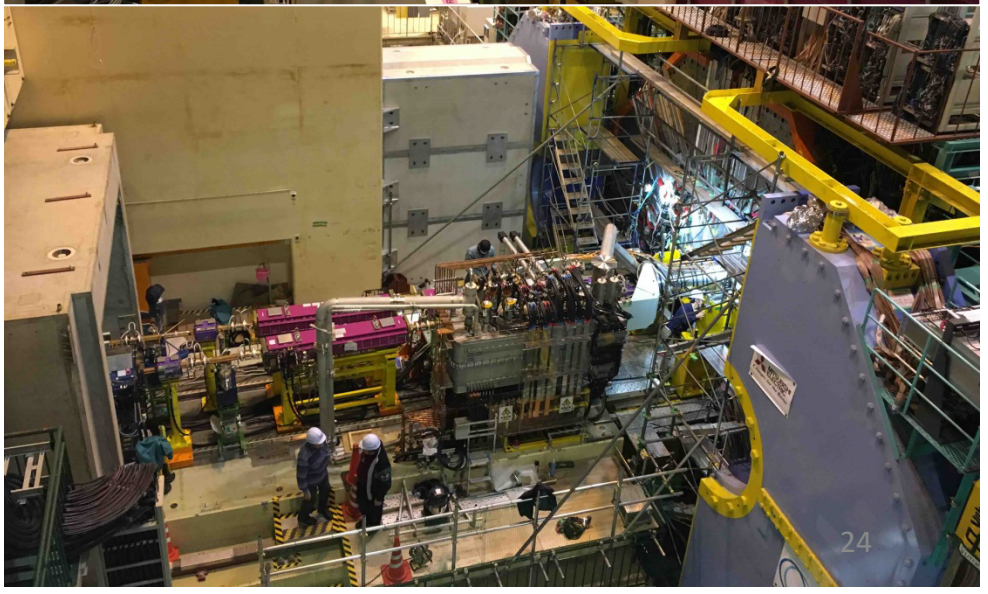


From the presentation by Prof. K. AKAI @KEKB review at Mar. 14, 2018

Final construction for beam collisions

All FF magnets are re-installed and all beam pipes are connected.





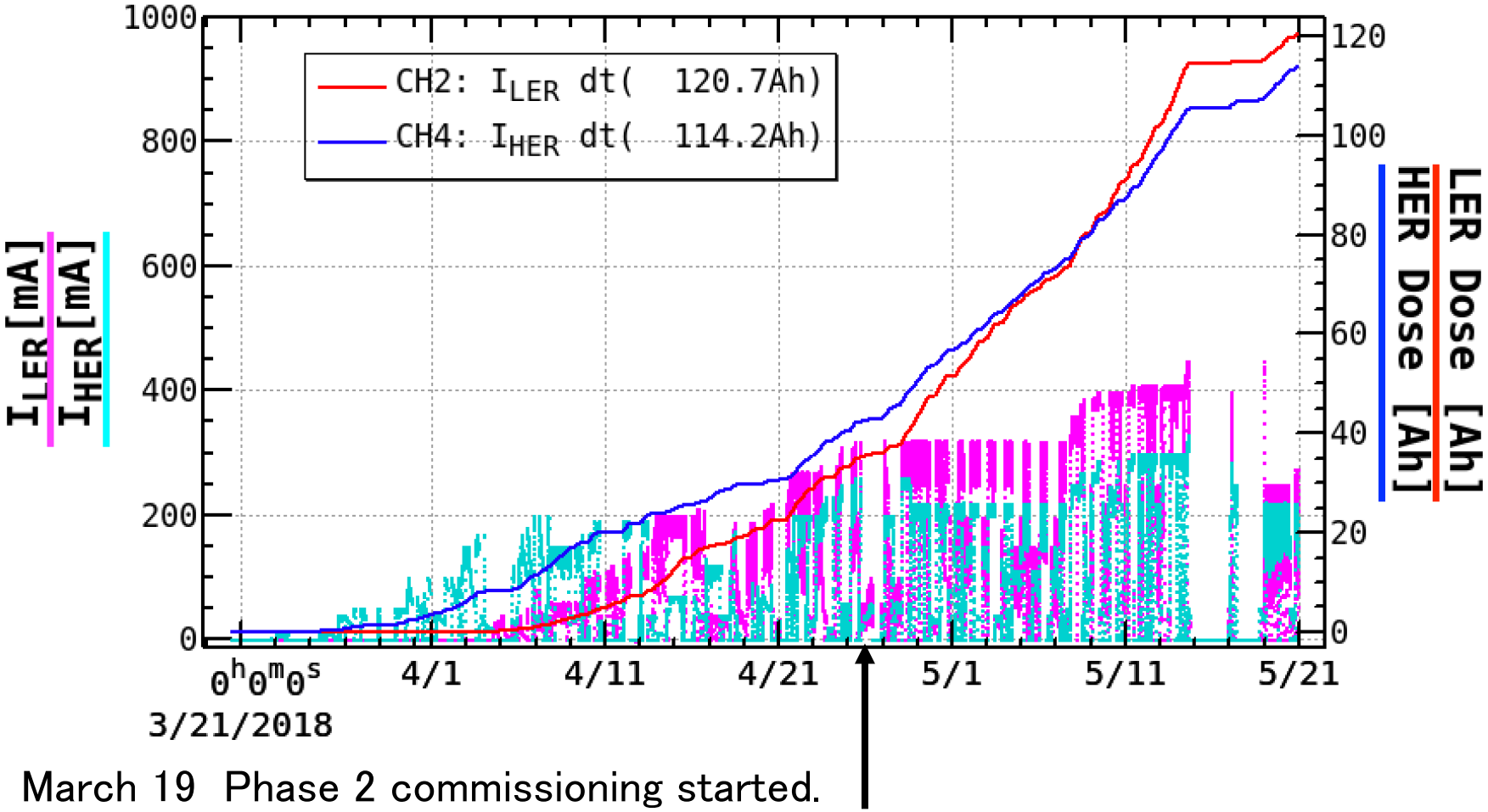
SuperKEKB Operation Status

History of Commissioning

Y. Funakoshi

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.

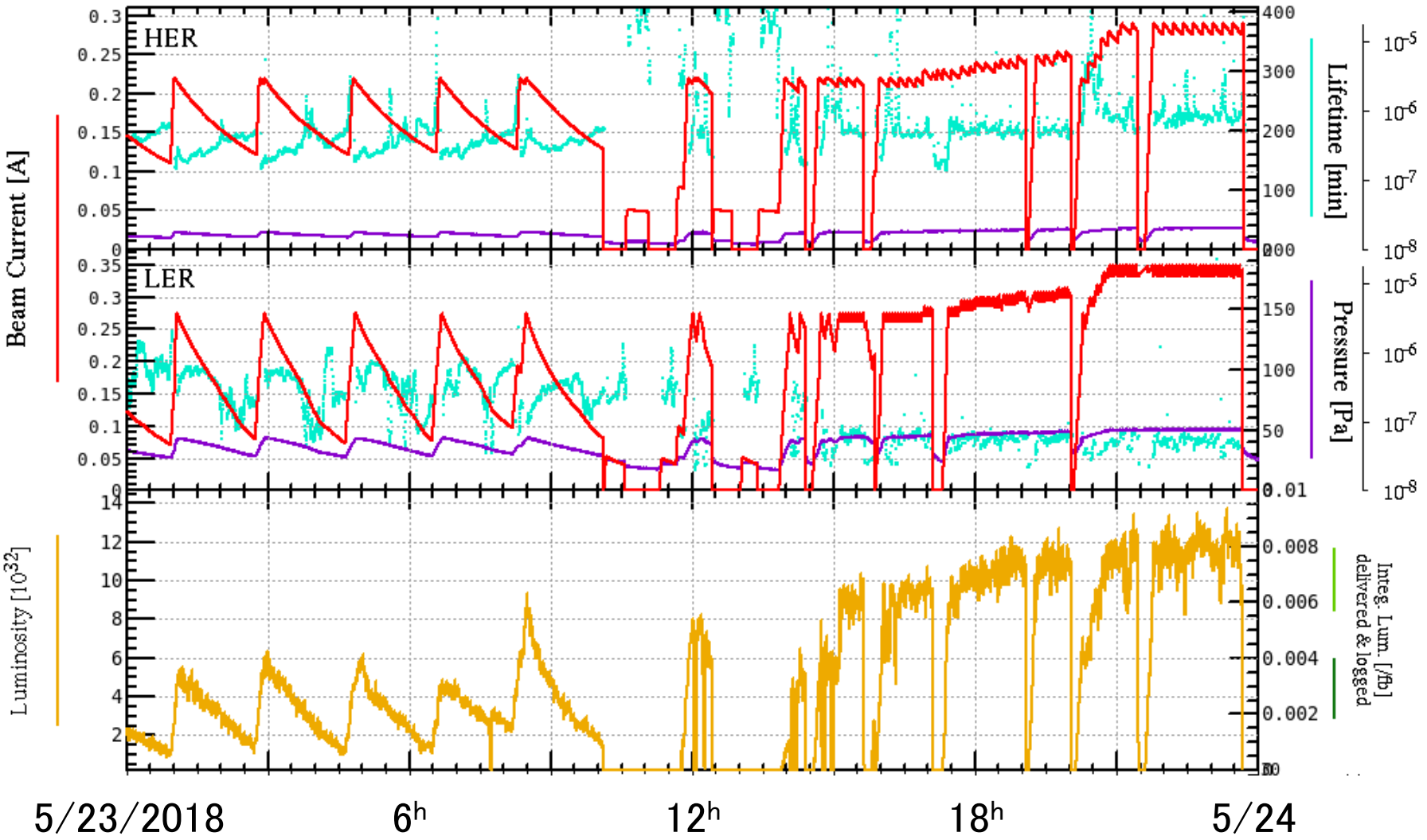
April 25 First Beam–Beam deflection was observed.

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

Luminosity

Y. Ohnishi, Y. Funakoshi

L_{peak} = 1.4 x 10^{33} /cm^2/s @ 5/23/2018



Belle II Construction

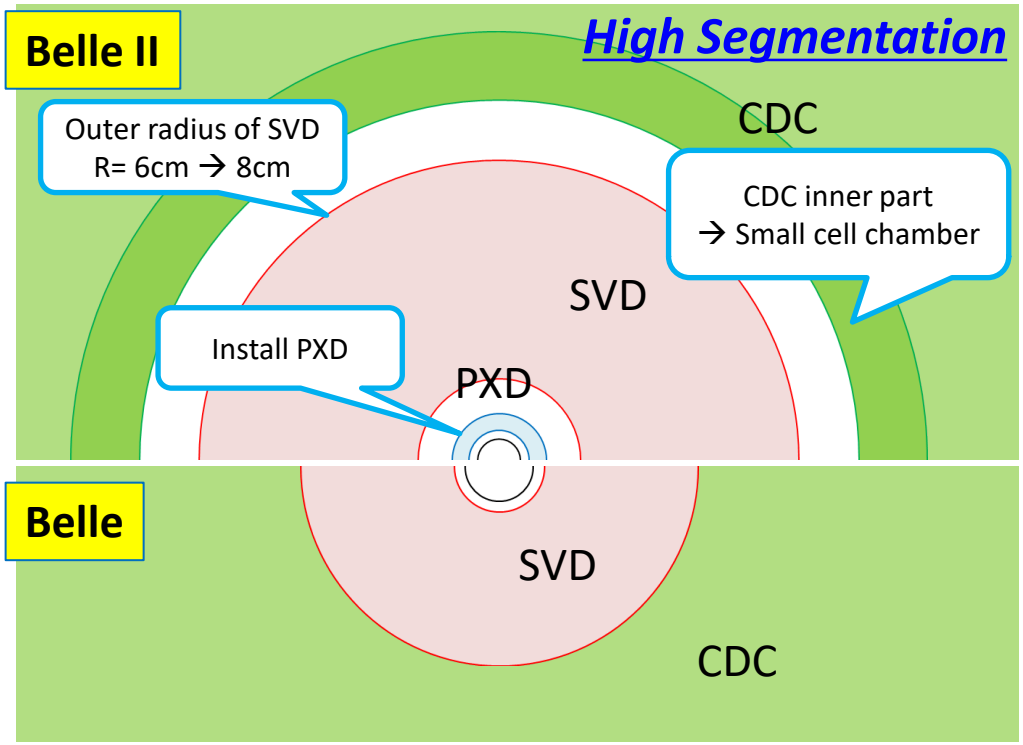
Requirements for the Belle II detector

Critical issues at L= 8 x 10^{35}/cm^2/sec

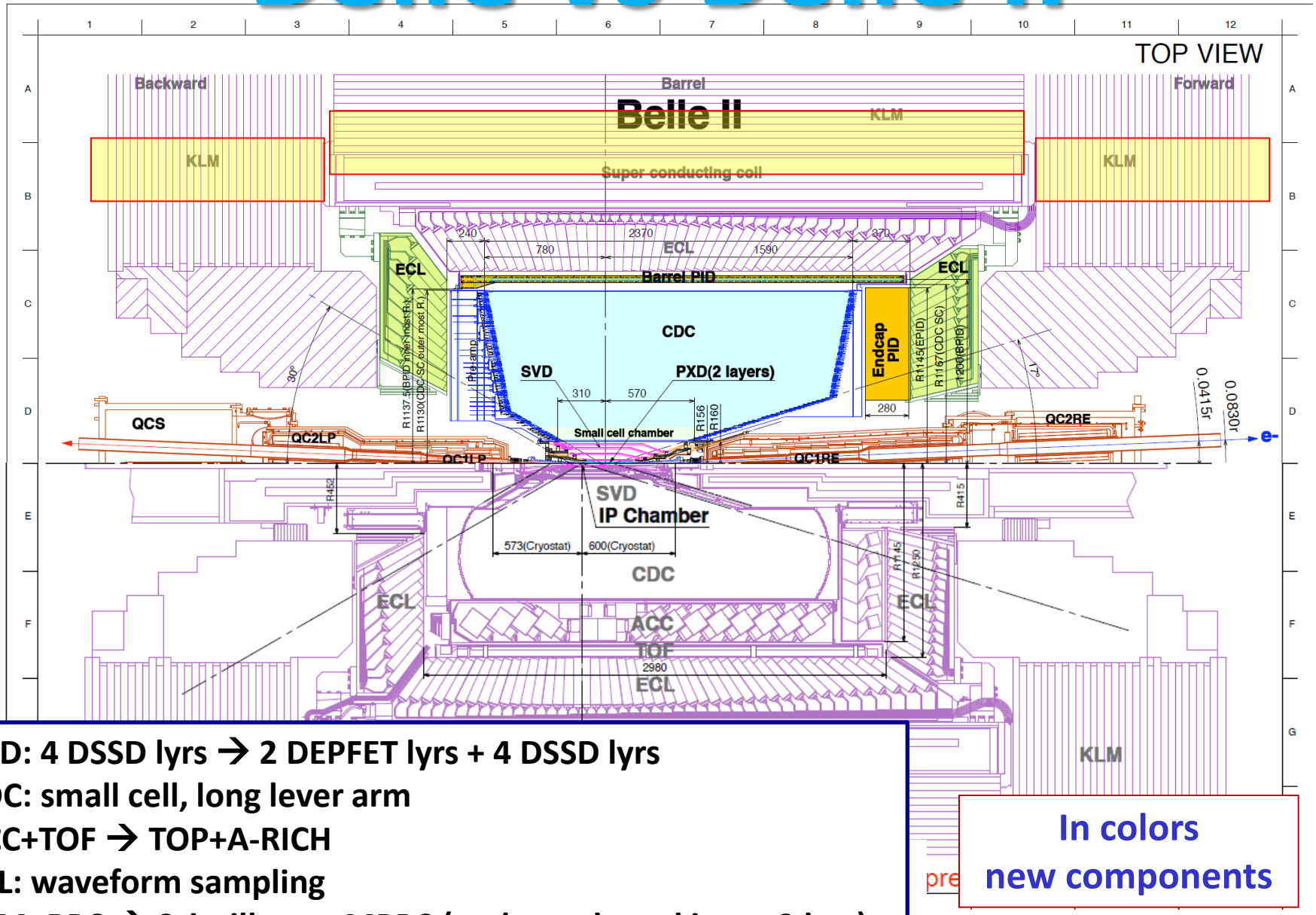
- **Higher background (x10-20)**
  Radiation damage and occupancy Fake hits and pile-up noise in the EM
- **Higher event rate (x10)**
  Higher rate trigger, DAQ and computing

Solutions

- Replace inner layers of the vertex detector with a pixel detector.
- Replace inner part of the central tracker with a silicon strip detector + small cell chamber
- Better particle identification device
- Faster readout electronics and computing system.



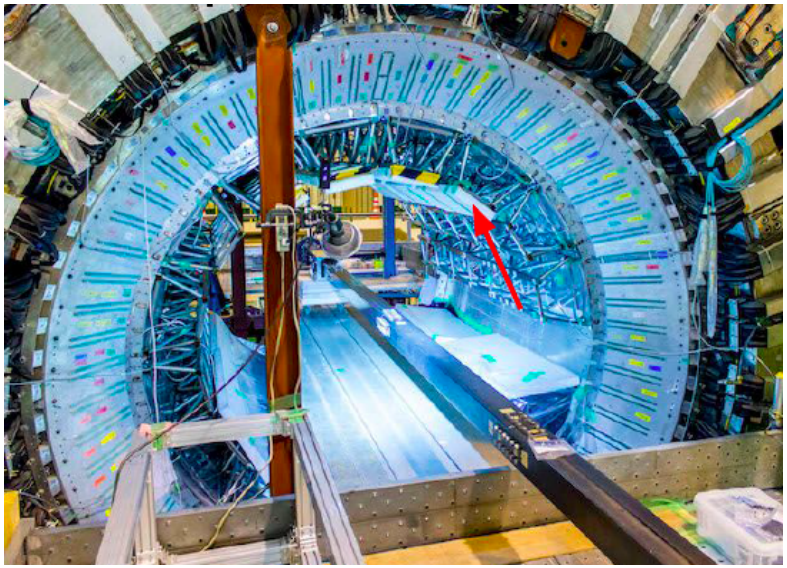
Belle vs Belle II



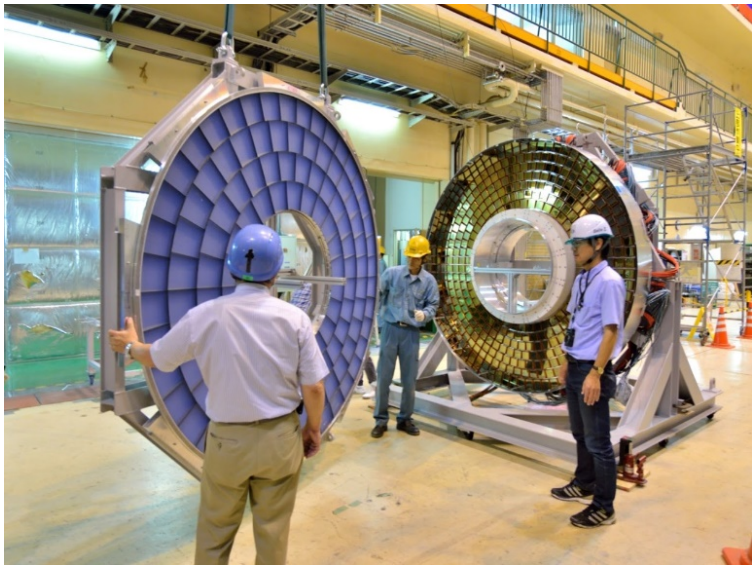
SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP+A-RICH
ECL: waveform sampling
KLM: RPC → Scintillator +MPPC (endcaps, barrel inner 2 lyrs)

In colors new components

Belle → Belle II upgrade

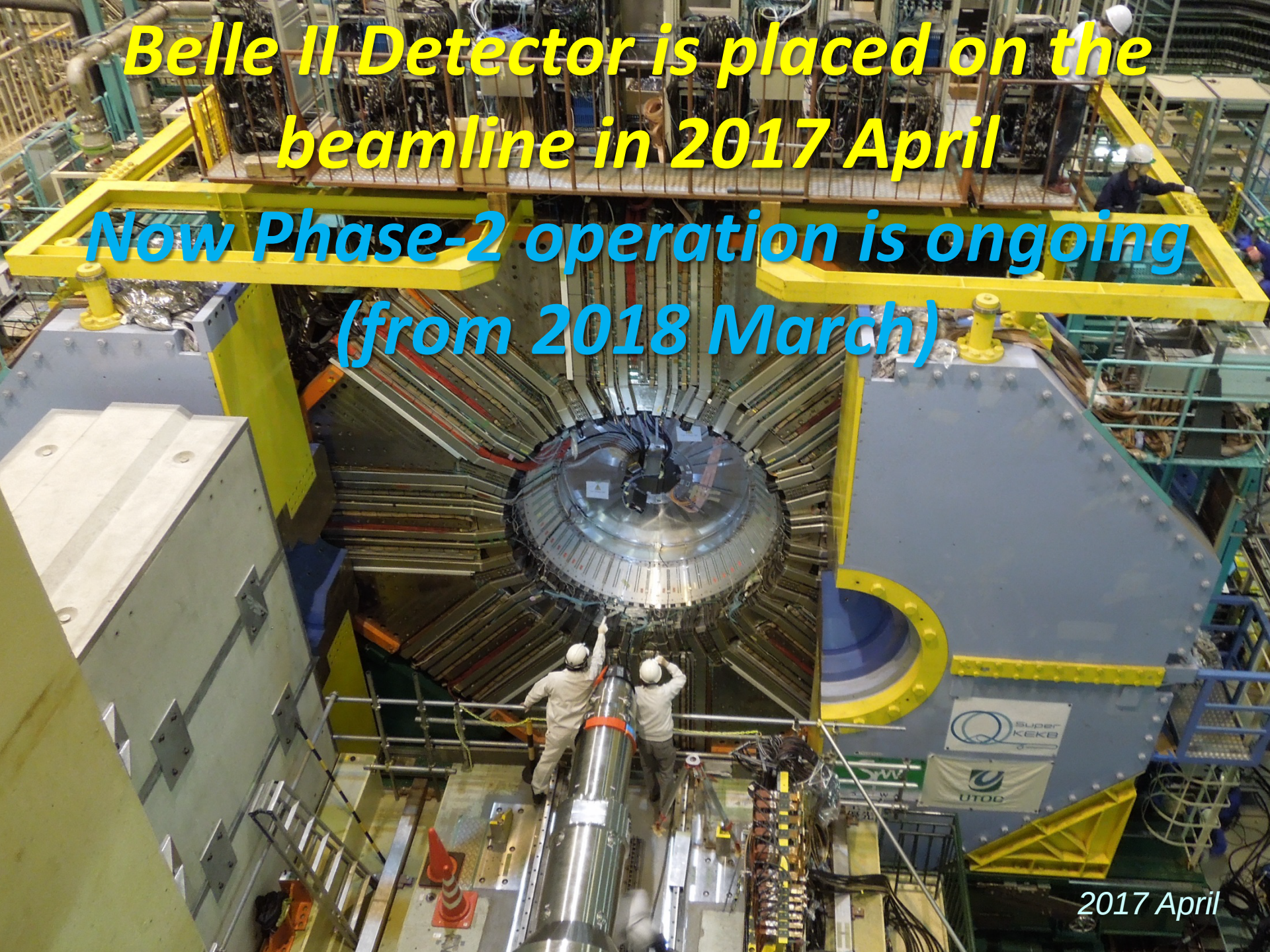


Installation of TOP to Belle II (2016/05)



Installation of ARICH to Belle II (2016/08)

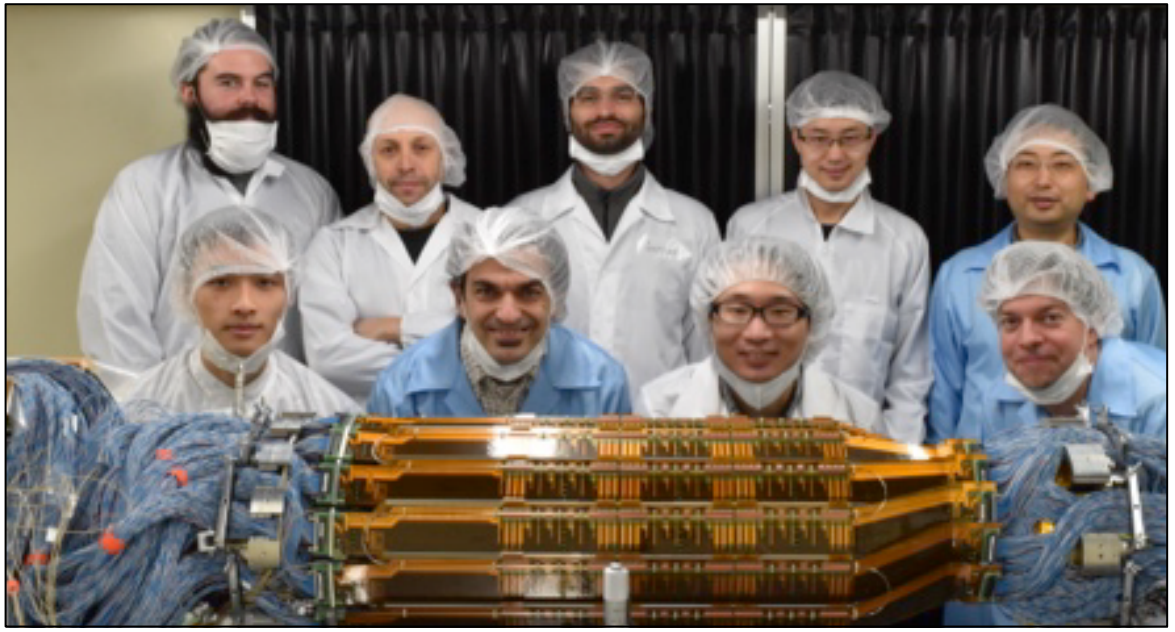
Installation of CDC to Belle II (2016/10)


Belle II Detector is placed on the beamline in 2017 April
Now Phase-2 operation is ongoing (from 2018 March)
SuperKEKB
UTOC
2017 April

Preparation for the Phase-3 operation

Inner Pixel Detector (PXD)

- Current Phase-2 operation will continue until July 17th.
- After the Phase-2, full Vertex Detector (VXD = PXD+SVD) will be installed.



Outer Silicon Vertex Detector (SVD)

Belle II Prospects

Belle II Physics

- Physics at Super B Factory, arXiv:1002.5012 (Belle II)
- SuperB Progress Reports: Physics, arXiv:1008.1541 (SuperB)
- Physics at B Factories, Eur. Phys. J. C74 (2014) 3026
- **Belle II Theory Interface Platform (B2TiP)**

Formed a new working group B2TiP in 2014 for Belle II physics with theorists and experimentalists

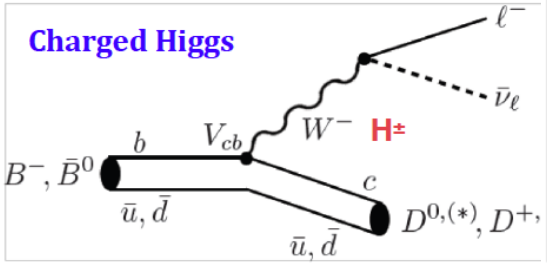
To be submitted to PTEP

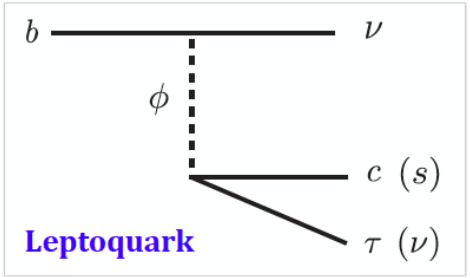
Coverage of the report

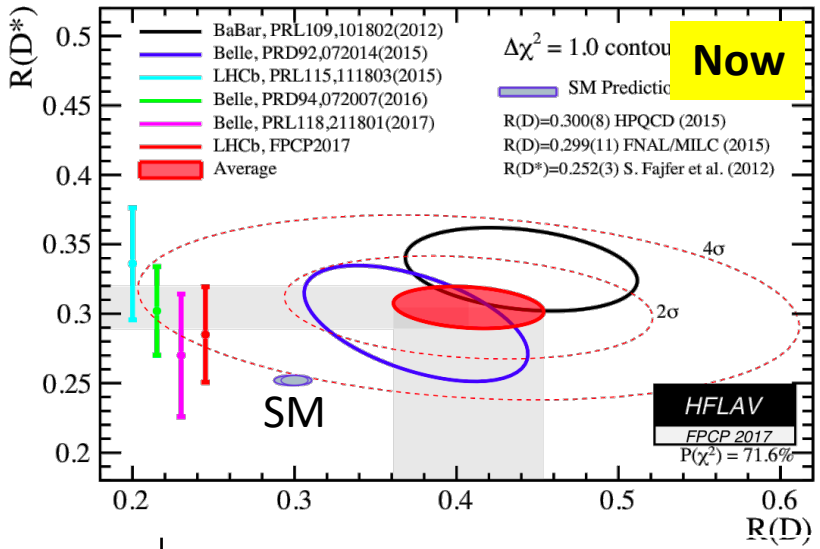
- Belle II detector
- Belle II simulation
- Reconstruction software
- Analysis software
- Theory overview
- Semi-leptonic and leptonic *B* decays
- Radiative and electroweak penguin *B* decays
- Time dependent *CP* asymmetry of *B* mesons and determination of ϕ_1 and ϕ_2
- Determination of UT angle ϕ_3
- Charm physics
- Quarkonium(like) physics
- Tau and low multiplicity physics
- Dark sector and light Higgs
- Physics beyond the SM
- Global analysis

Lepton Universality in $B \to D^{(*)}\tau\nu$

$$R(D^{(*)}) = \frac{\mathrm{Br}(B \to D^{(*)}\tau\nu)}{\mathrm{Br}(B \to D^{(*)}l\nu)}$$ (l=e or μ)







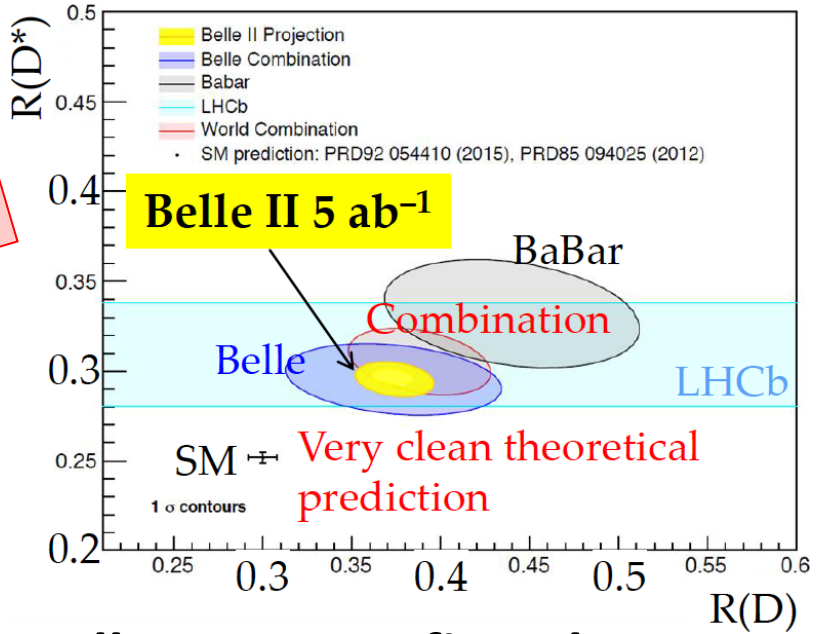
	Exp	SM
$R(D^*)$	0.304±0.013±0.007	0.252±0.003
$R(D)$	0.407±0.039±0.024	0.300±0.008

HFAG (FPCP2017)

~4σ discrepancy

$R(D^{(*)})$ is a sensitive parameter to the new physics beyond SM.

Belle II 5ab^{-1}



Belle II can confirm the excess with ~5ab^{-1} data.

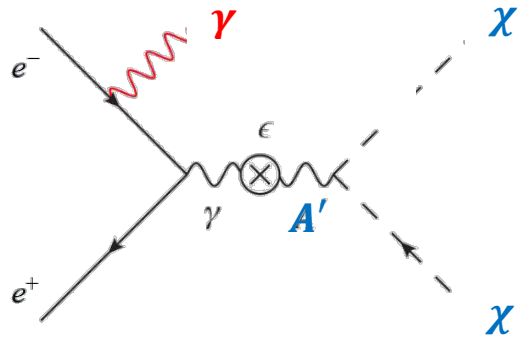
Dark Photon and Dark Matter

Possible to provide results even with very limited statistics

Single photon trigger is newly implemented in Belle II

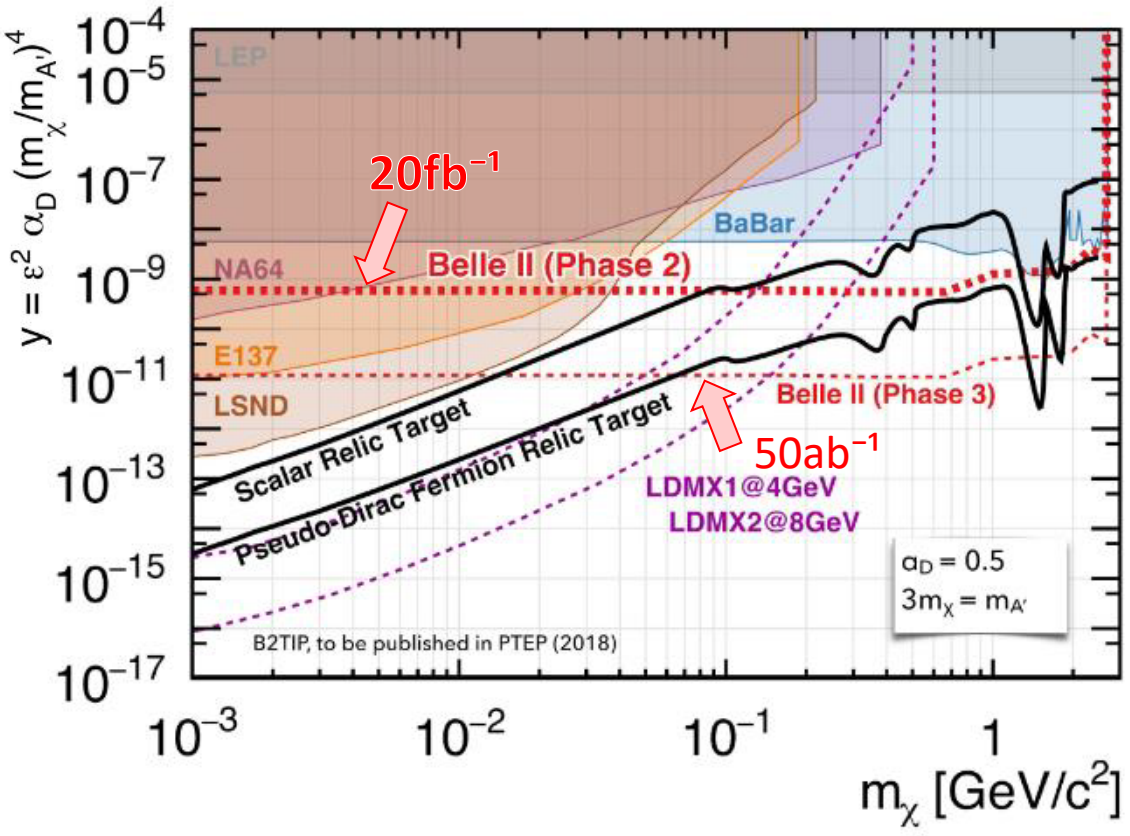
In the center of mass system Most energetic γ … $E_\gamma^{\mathrm{most}} > 1\mathrm{GeV}$

No second energetic γ or $E_\gamma^{\mathrm{second}} < 200\mathrm{MeV}$



$e^+e^- \to \gamma A', A' \to \chi\chi$

- A' … dark photon
- χ … dark matter

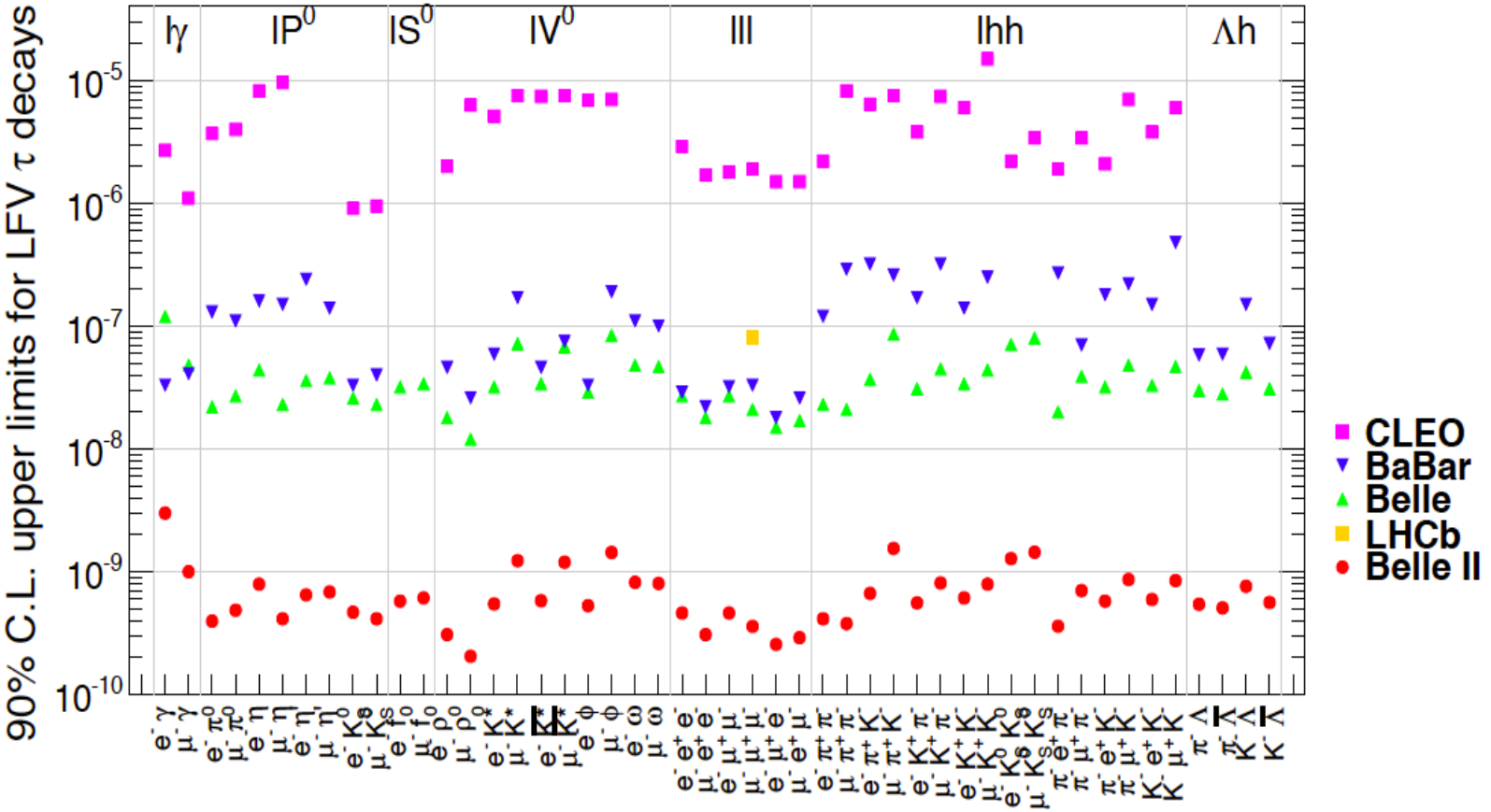


Lepton Flavor Violating τ decays

LFV is highly suppressed in the SM

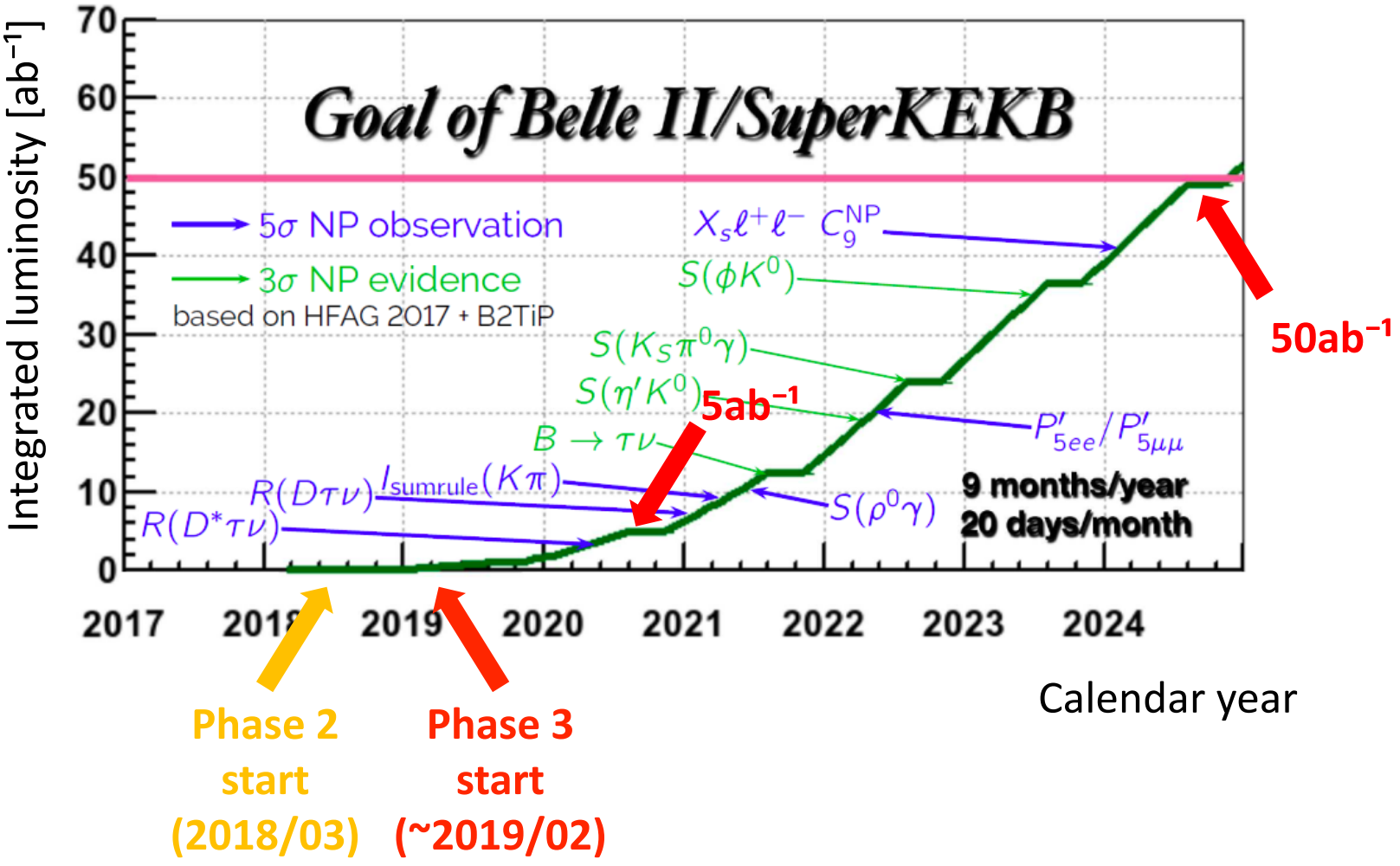
$\mathbf{Br^{SM}}(\tau \to \ell\nu) \sim \mathbf{10^{-40}}$ $\mathbf{Br^{SM}}(\tau \to 3\ell) \sim \mathbf{10^{-54}}$

→ Sensitive to the new physics effect



$\delta(\mathrm{Br}) \lesssim 10^{-9}$ with 50ab^{-1} data

Luminosity and Physics Prospect



Summary

KEKB has upgraded to SuperKEKB

First collisions in April 2018

Peak luminosity $1.4 \times 10^{33}/cm^2$ /sec

Belle has been upgrading to Belle II

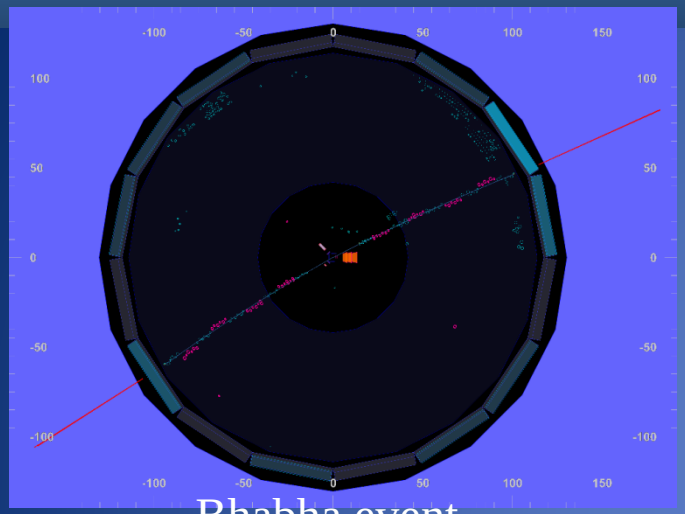
Rolled in April 2017

BG studies, detector performance checks,

1st physics studies

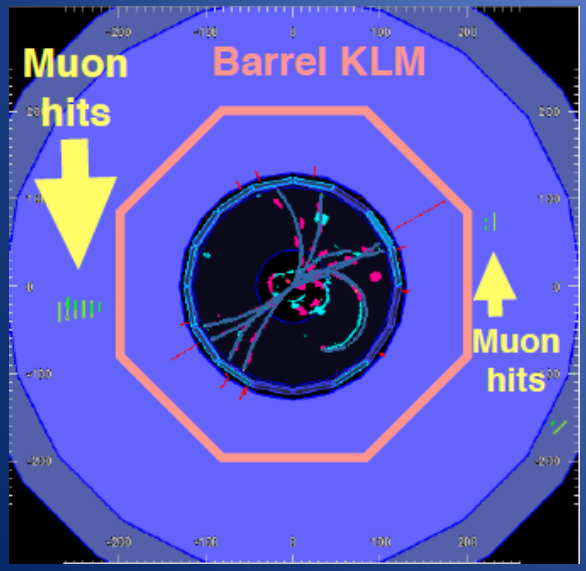
Physics commissioning with full Belle II will start from 2019 to seek New Physics!

More Events

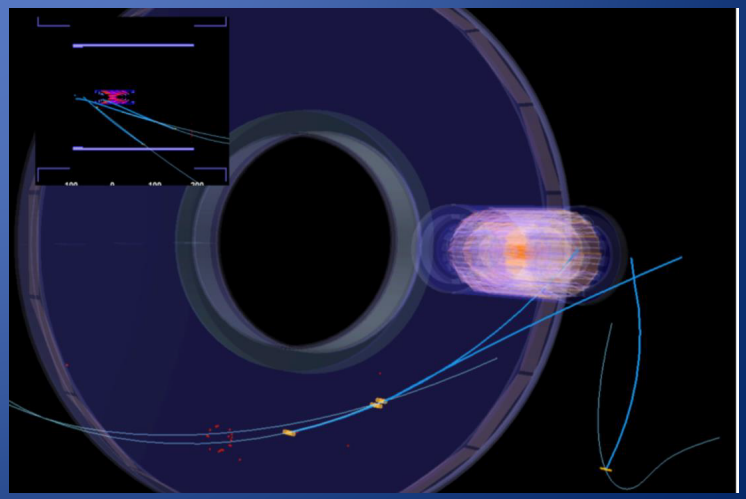


Bhabha event

$B\bar{B}$ like event



KLM is working.



ARICH is working.

Belle II Detector

8m x 8m x 8m, 1400t

K_L and muon detector
Resistive Plate Counter (barrel outer layers)
Scint. + WLSF + MPPC (end-caps , inner 2 barrel)

EM Calorimeter
CsI(Tl), waveform sampling

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

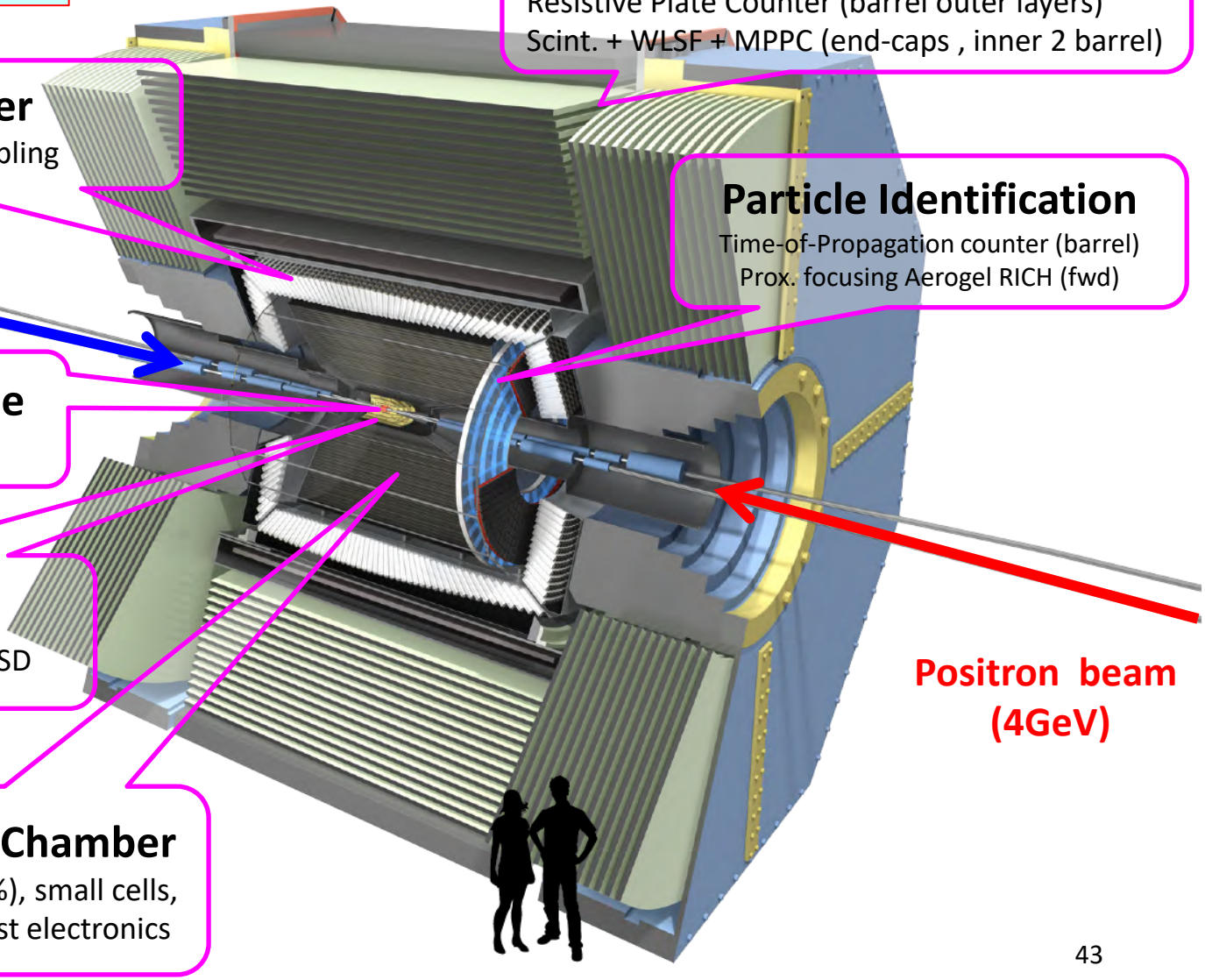
Electron beam (7GeV)

Beryllium beam pipe
2cm diameter

Vertex Detector
2 layer DEPFET + 4 layer DSSD

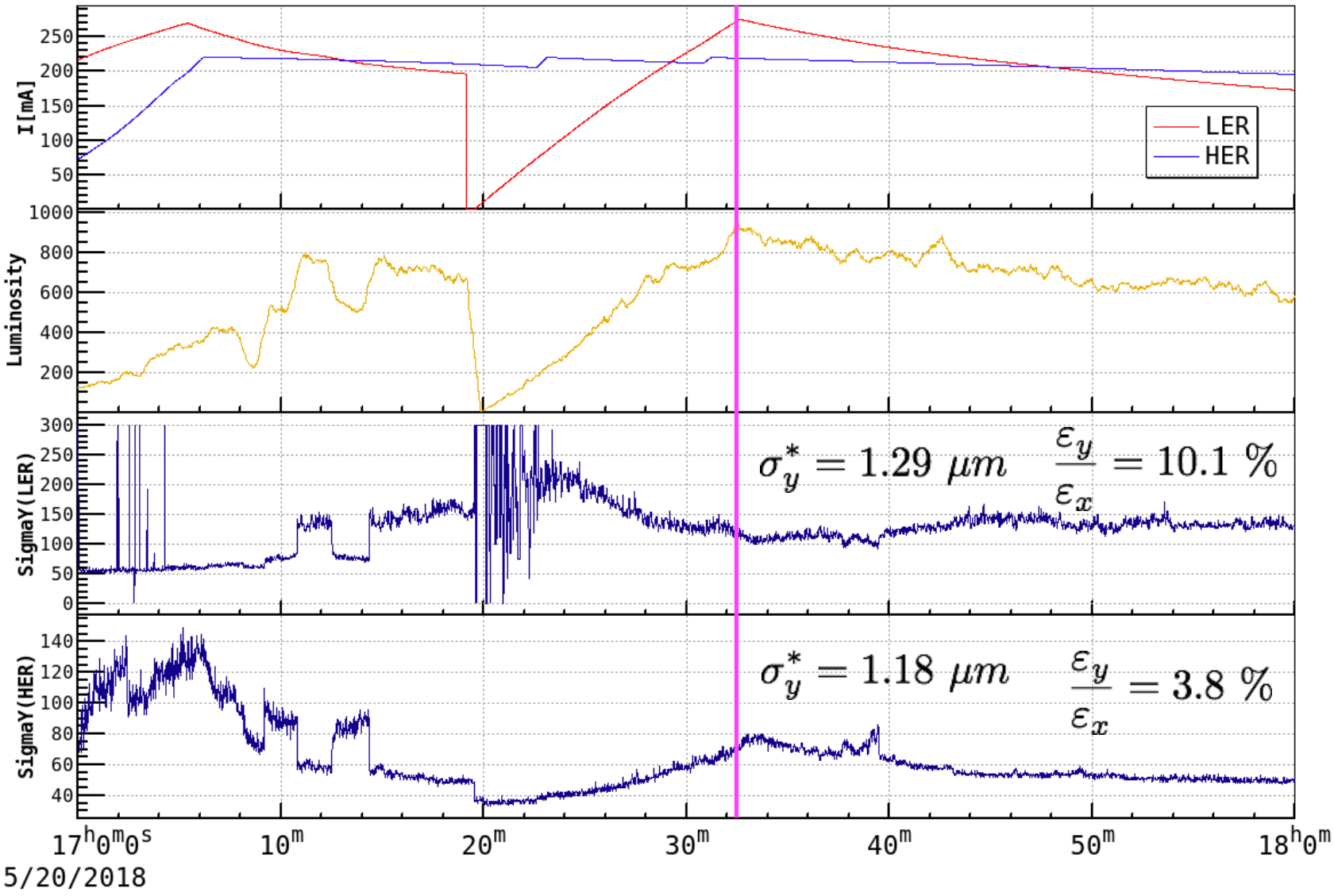
Positron beam (4GeV)

Central Drift Chamber
He(50%):C2H6(50%), small cells, long lever arm, fast electronics



Peak Luminosity

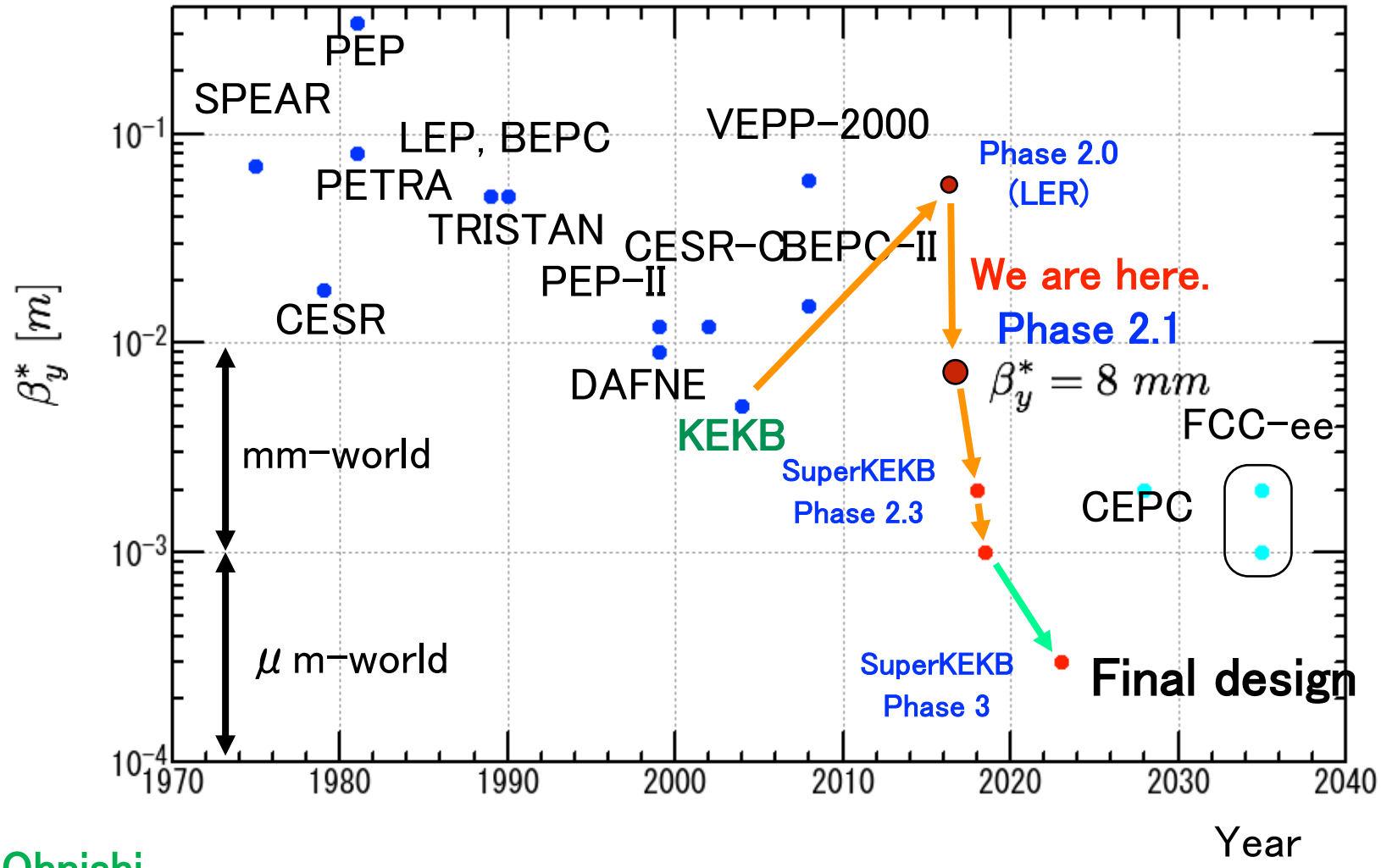
$9.3 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$



Y. Ohnishi, Y. Funakoshi

β_y^* Evolution over 50 Years

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



Y. Ohnishi