SuperKEKB and possible enhanced collaboration with FCCee

CERN-KEK Committee, 19th Meeting

26th November 2024

Kyo Shibata (KEK Accel. Lab.)

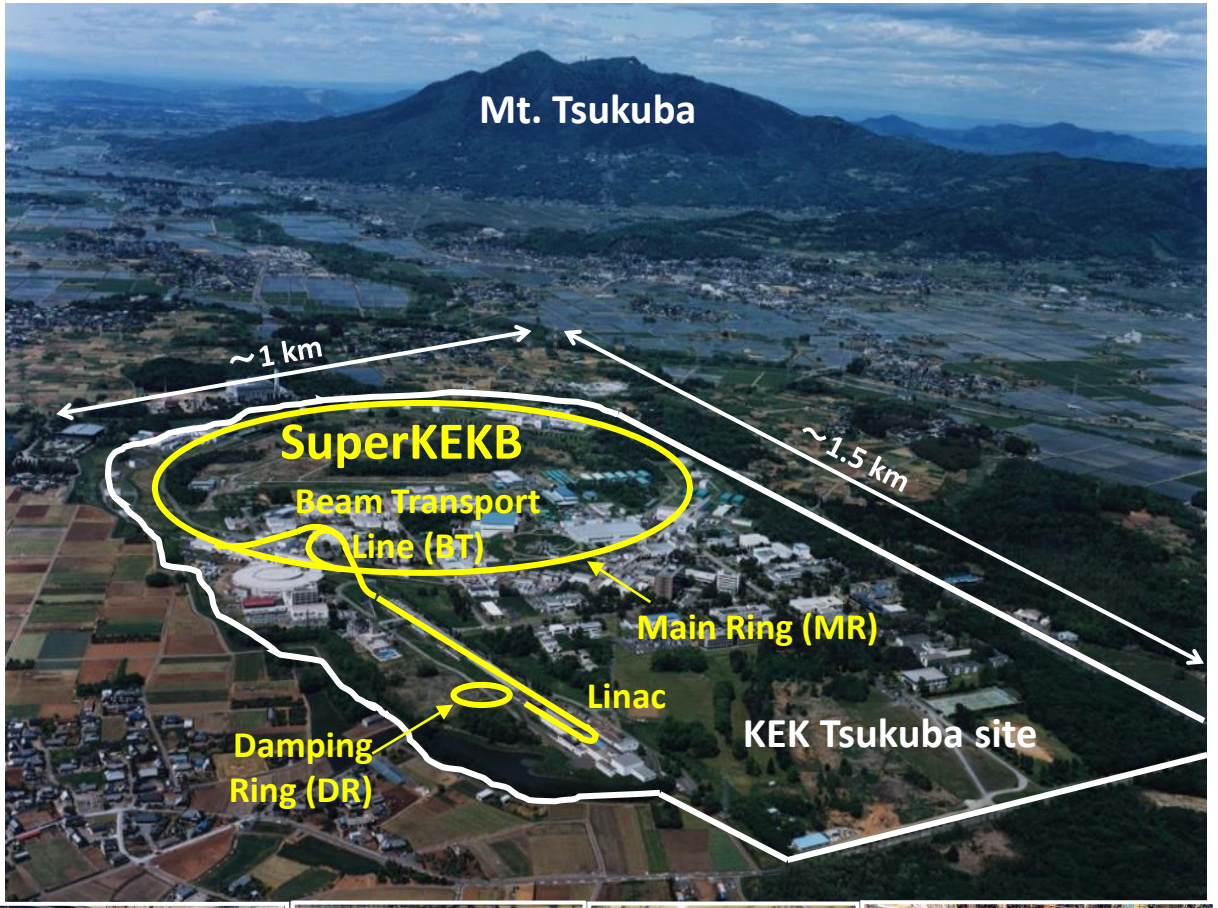
On behalf of the SuperKEKB

Contents

- SuperKEKB
  - Nano-beam collision scheme
- Project history & Recent status
- Luminosity projection
- Strategy toward 2.4×10^{35} $cm^{-2}s^{-1}$
- Collaboration proposal
  - Beam-Beam simulations

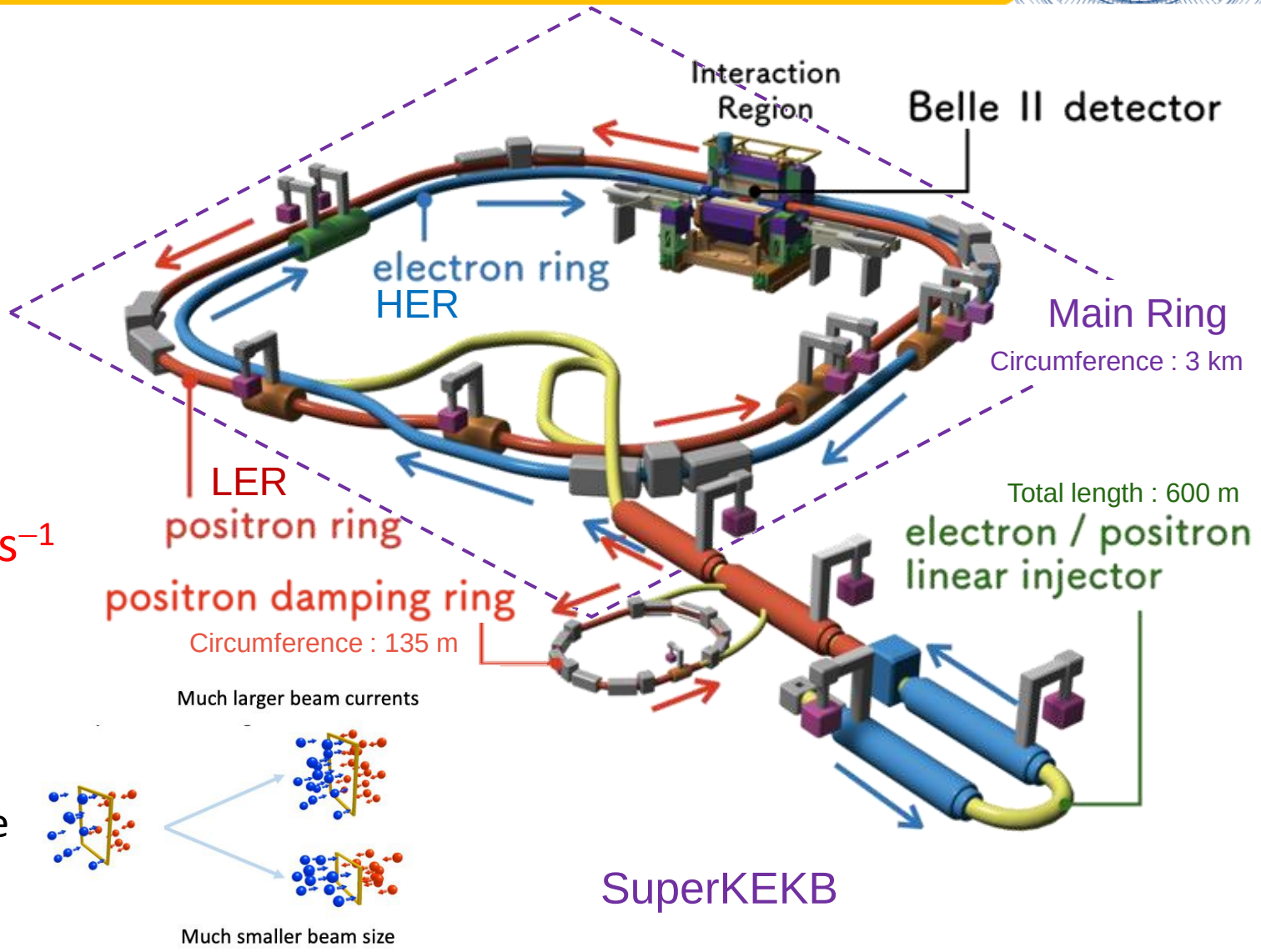
SuperKEKB

- SuperKEKB;
  - Asymmetric-energy electron-positron collider operating at KEK Tsukuba site
    - An upgrade of KEKB B-factory (KEKB)
    - High-luminosity machine in search of new physics in the B-meson regime.
  - Accelerator complex consisting of;
    - Injector (Linac)
    - Positron Damping Ring (DR)
    - Beam Transport Lines (BT)
    - Main Ring (MR) with Belle II Detector
  - The world's first practical application of the "nano-beam scheme"



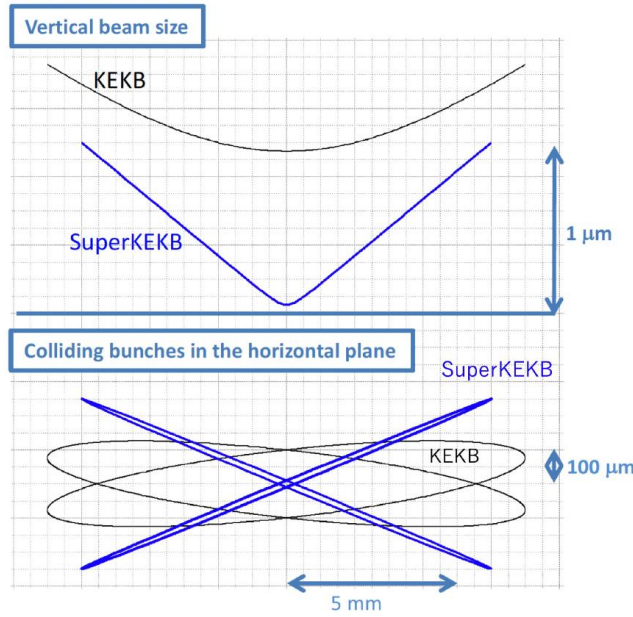
SuperKEKB

- Main ring (MR) is composed of
  - High Energy Ring (HER)
    - 7.0 GeV electron
    - Design beam current : 2.6 A
  - Low Energy Ring (LER)
    - 4.0 GeV Positron
    - Design beam current : 3.6 A
  - Target Luminosity : $\sim 6\times10^{35}$ cm^{-2}·s^{-1}
    - ~30 times maximum luminosity of KEKB
    - Higher beam current than those of KEKB (×2)
    - β_y^* squeezing and smaller emittance for nano-beam collision scheme

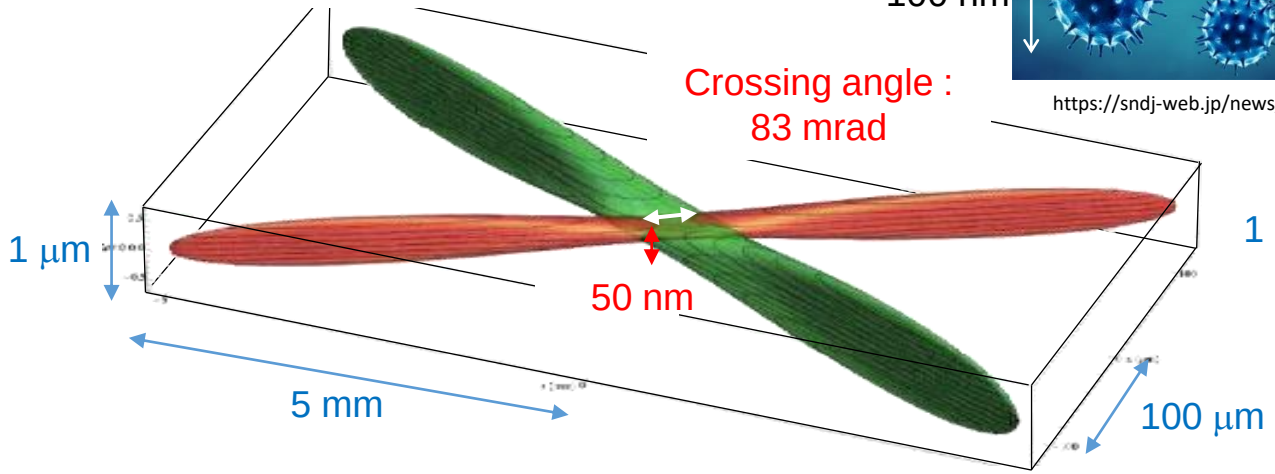


Nano-beam collision scheme

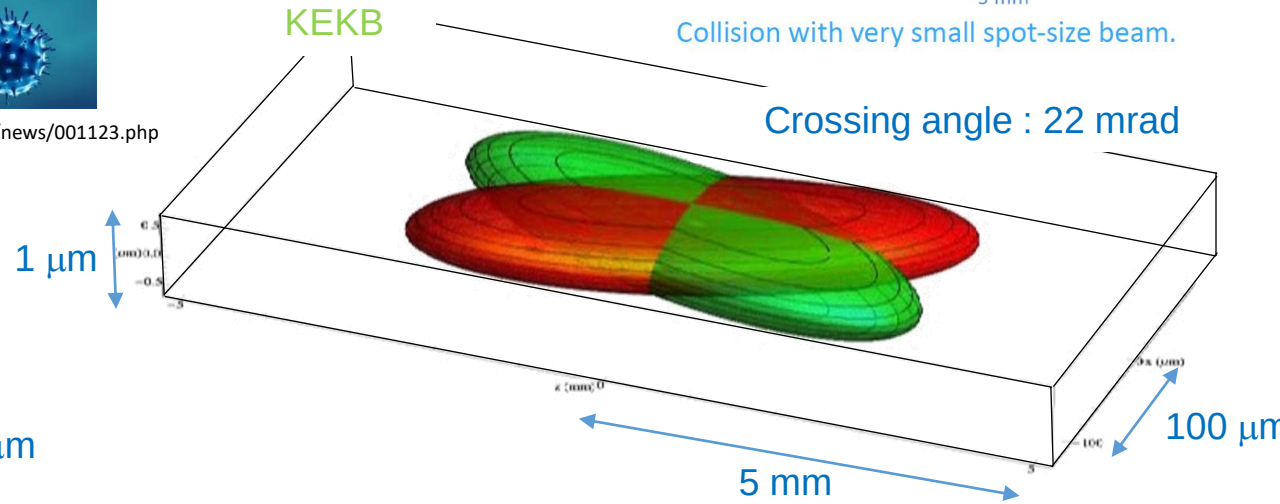
- Proposed by P. Raimondi at INFN-LNF for the Italian SuperB project around 2006 and tested successfully at DAΦNE.
- Extremely vertically squeezed bunches collide with sufficiently small σ_x^* at a large horizontal crossing angle to avoid the Hourglass effect.
  - Luminosity increases in proportion to $1/\beta_y^*$.
- Implemented at SuperKEKB, for the first time, with low-emittance beams on a high-energy collider.
  - SuperKEKB is the only operating machine with the nano-beam collision scheme.
  - Future Higgs factory colliders will follow a lattice design with nano-beam collision scheme.



Collision with very small spot-size beam.

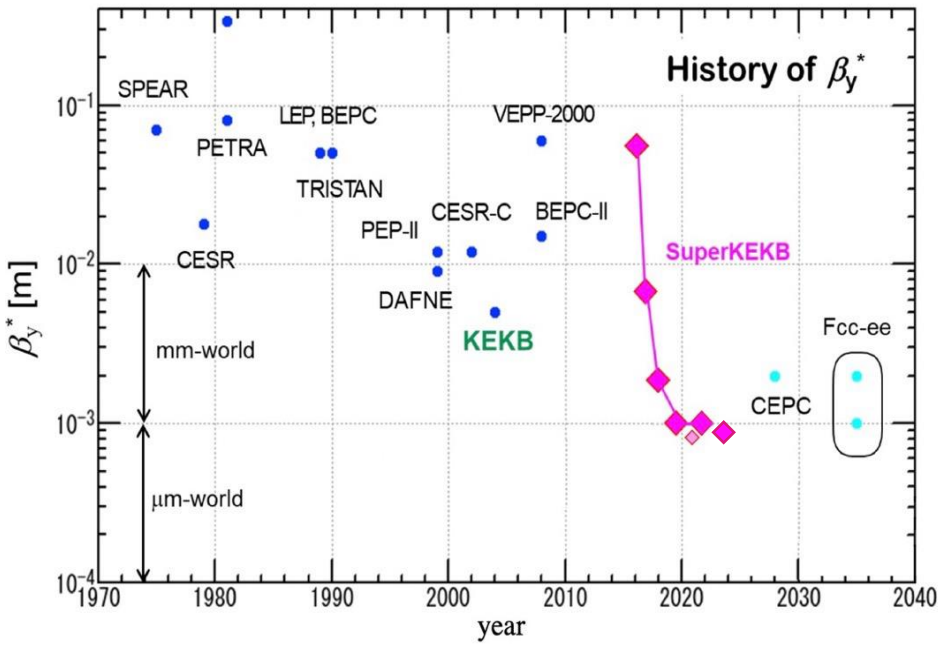


https://sndj-web.jp/news/001123.php



Machine parameters

	KEKB (LER/HER)		SuperKEKB (LER/HER) 2022/6/8		SuperKEKB (LER/HER) Design	
Beam Energy [GeV]	3.5/8.0		4.0/7.0		4.0/7.0	
Beam current [A]	1.64/1.19		1.3/1.1		3.6/2.6	
# of bunches	1584		2249		2500	
β_x^*/β_y^* [mm]	1200/5.9	1200/5.9	80/1.0	60/1.0	32/0.27	25/0.3
σ_x^*/σ_y^* [μm]	147/0.94	170/0.94	17.9/0.22	16.6/0.22	10.1/0.048	10.7/0.062
Half crossing angle θ [mrad]	11		41.5		41.5	
Piwinski angle [rad]	0 with crab crossing		~10		~20	
Luminosity [$\times 10^{34}$ cm^{-2}s^{-1}]	2.1		4.65		60	

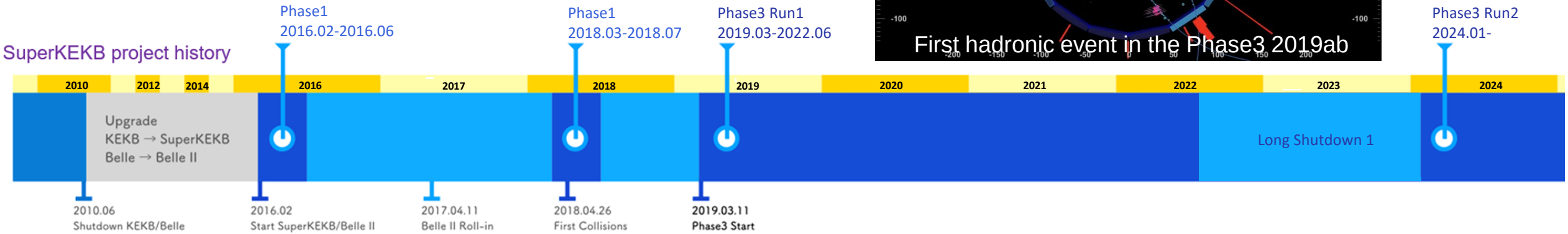


SuperKEKB project history

- Phase1 operation (2016.Feb. ~ June);
  - Vacuum scrubbing, low emittance beam tuning, and background study for Belle II detector installation
  - w/o final focusing system (QCS) and Belle II detector
- Phase2 operation (2018.Mar. ~ July);
  - Pilot run of SuperKEKB and Belle II w/o pixel vertex detector (PXD)
  - Demonstration of nano-beam collision scheme
  - Study on background larger than at KEKB due to much lower beta functions at IP.

- Phase3 operation (2019.March~);
  - Physics run with fully instrumented detector.
  - Phase3 Run1 : 2019.10~2022.7
  - Long shutdown 1 : 2022.7~2024.01
  - Phase3 Run2 : 2024.01~

First hadronic event in the Phase3 2019ab



Phase3 commissioning history

- Phase3 operation (2019.March~);
  - Physics run with fully instrumented detector
  - Naming rule of Phase3 operation

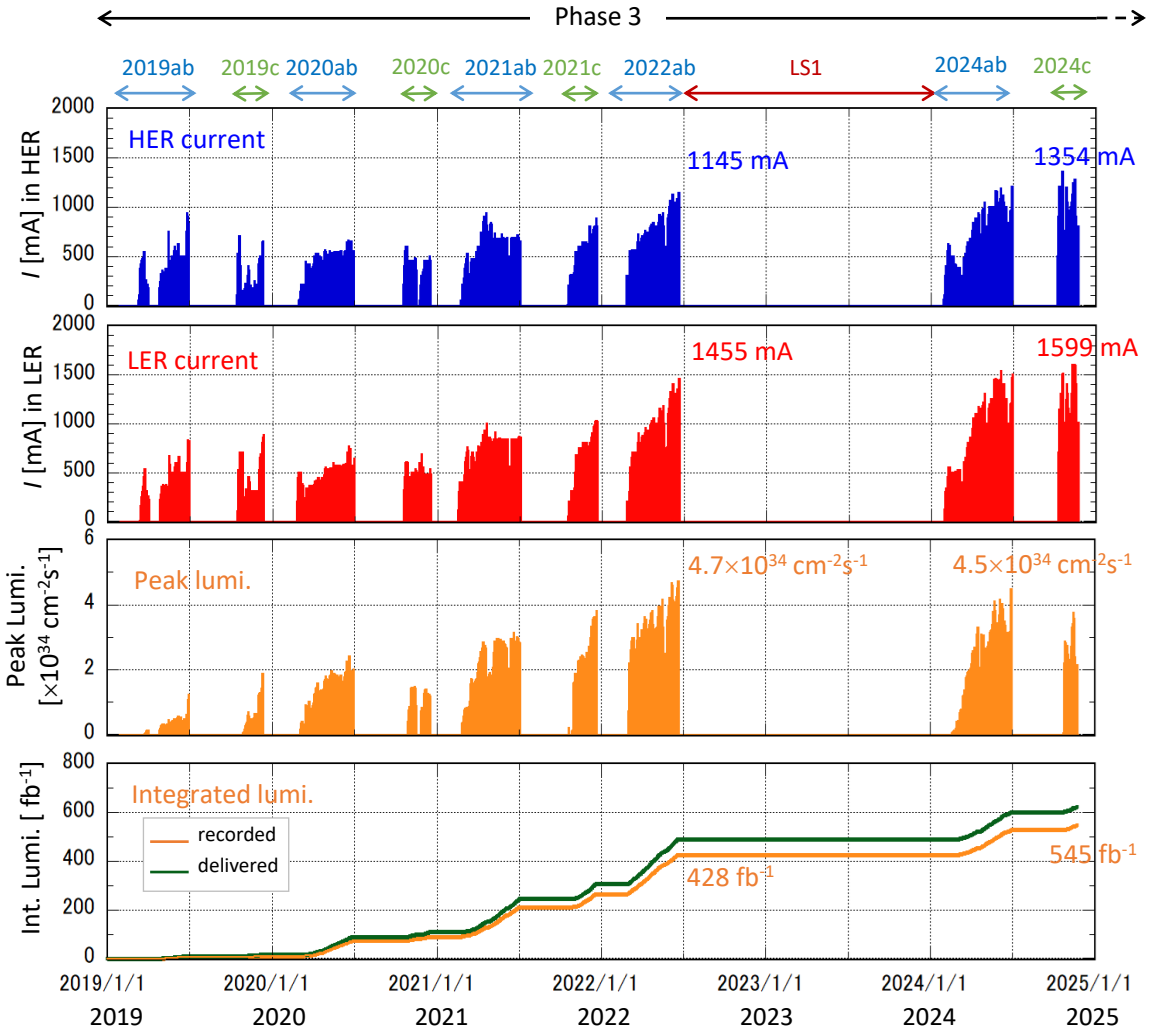
March is end of Japanese fiscal year.

"YYYYxx run"

Calendar year

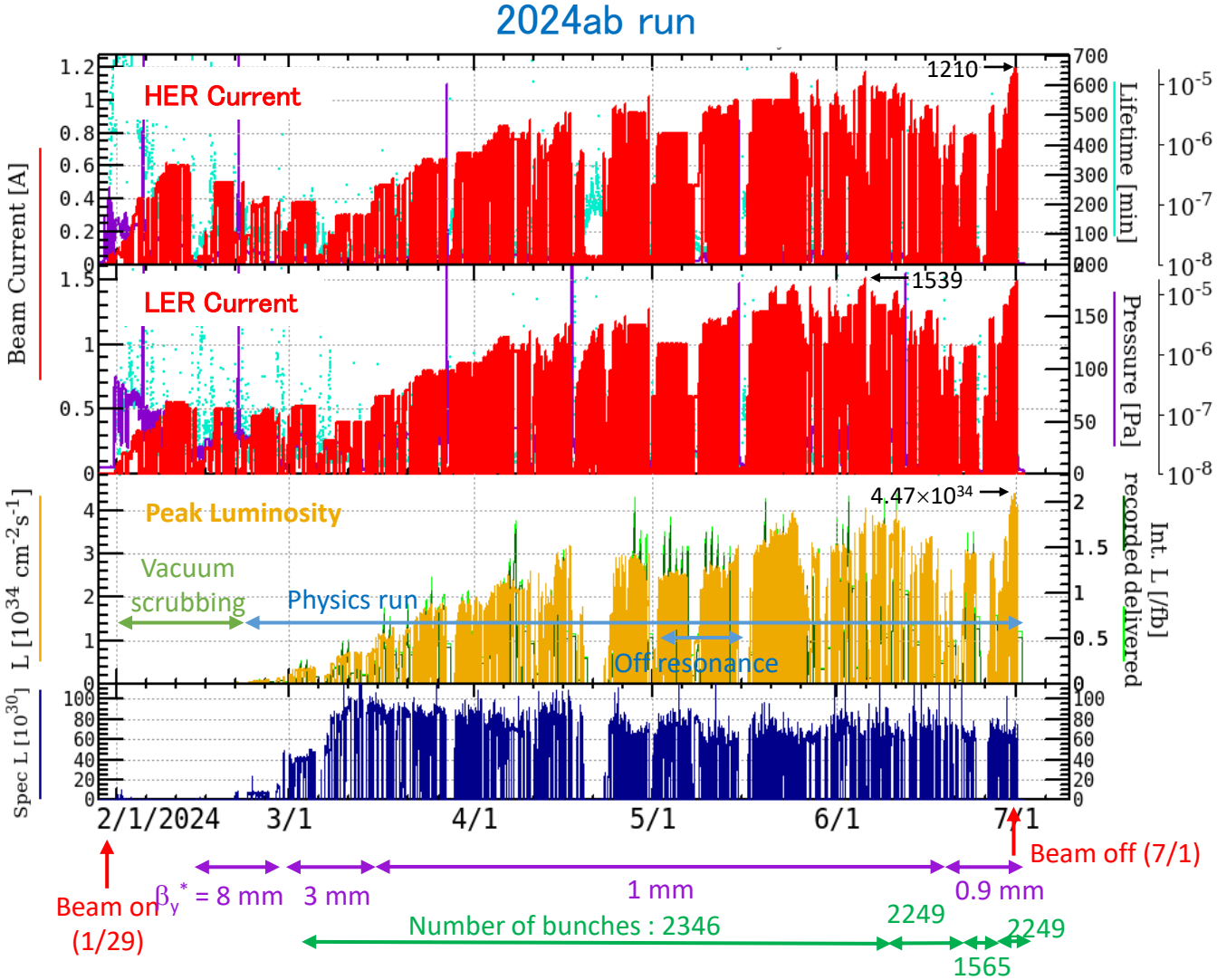
a : End of winter shutdown - March
b : April – Start of summer shutdown
ab : End of winter shutdown – Start of summer shutdown
c : End of Summer shutdown – Start of winter shutdown

  - 2019/March-2022/Jun : Run1
    - 2019c, 2020ab, 2020c, 2021ab, 2021c, 2022ab
    - Luminosity (peak/integrated) : 4.7×10^{34} $cm^{-2}s^{-1}$/428 fb^{-1}
    - β_y^* squeezing : ~0.8 mm (1 mm for most of the time)
    - Maximum beam current : HER/LER = 1145/1455
    - Facing various challenges for luminosity improvement
      - Severe beam-beam effect, Shorter beam lifetime, Lower bunch current limit, Low machine stability, Low injection efficiency, Sudden beam loss, Aging of hardware and facilities.
  - 2022-2024 : Long shutdown 1 (LS1)
    - Accelerator upgrades
    - Belle II reinforcement and maintenance
  - 2024/Jan.- : Run2
    - 2024ab (2024/Jan.-July)
      - Start-up after a long shutdown
    - 2024c (2024/Oct. – Dec.)
      - Currently In progress
      - Aiming to make new word luminosity record



Recent operation - 2024ab run overview

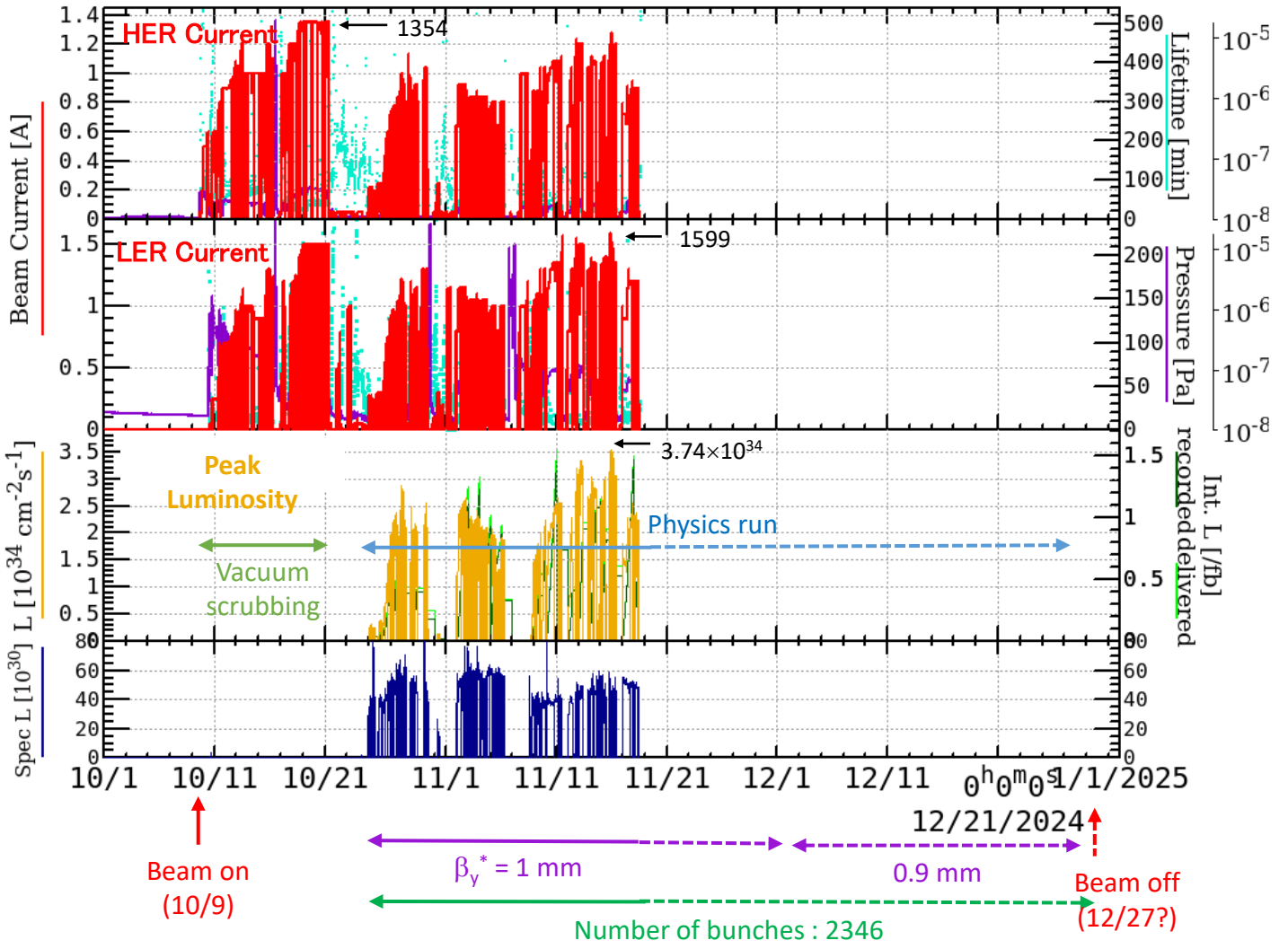
- Jan./29 – Feb./20
  - Vacuum scrubbing, Machine tuning, Machine study
- Feb./20 – July/1
  - Physics run, Machine tuning, Machine study
    - Struggling with Sudden Beam Loss, poor injection efficiency, low machine stability.
    - Many beam abort caused by SBL and injection beam
    - May/1-12 : Off resonance operation
  - Peak luminosity : 4.47×10^{34} $cm^{-2}s^{-1}$
  - Integrated luminosity (2024ab) : 103 fb^{-1}
    - Max. Int. lumi. per day : 2.0 fb^{-1}/day
    - Total integrated luminosity : 527 fb^{-1}
  - Maximum beam current : HER/LER = 1210/1539 mA
  - β_y^*-squeezing (Vertical β-function at IP) : ~0.9 mm
    - Mostly operated with β_y^* = 1.0 mm
  - Others :
    - Fixed number of bunches mostly at 2346, finally at 2249
    - Crab waist ratio : HER/LER = 40/80 -> 60/80 %
    - Chromatic X-Y coupling correction by rotatable sextupole magnets.



Recent operation - 2024c run overview

- 2024c run plan
  - Target luminosity : 1×10^{35} $cm^{-2}s^{-1}$
    - β_y^*-squeezing : Kept at 0.9 mm
    - Target beam current :
      LER/HER =2.58 A/1.83 A with 2346 bunches
  - Verification of SBL measures during summer shutdown
    - Upside-down rotation of beam pipes and beam pipe knocking
  - Machine studies to increase beam current
- Vacuum scrubbing (10/9-10/21)
  - Increasing beam current at an unprecedented pace.
- Physics run (10/24-12/27?)
  - Peak luminosity : 3.74×10^{34} $cm^{-2}s^{-1}$
    - β_y^* = 1.0 mm due to HER beam blow-up
  - Struggling to increase beam current and suppress emittance growth
    - Many SBLs with vacuum spike at one bellows chamber
      - Black deposits fund in the bellows chamber were removed
      - New candidate of the cause of SBL
    - High radiation dose, large pressure increase, etc.
  - Operation will be continued by the end of December.

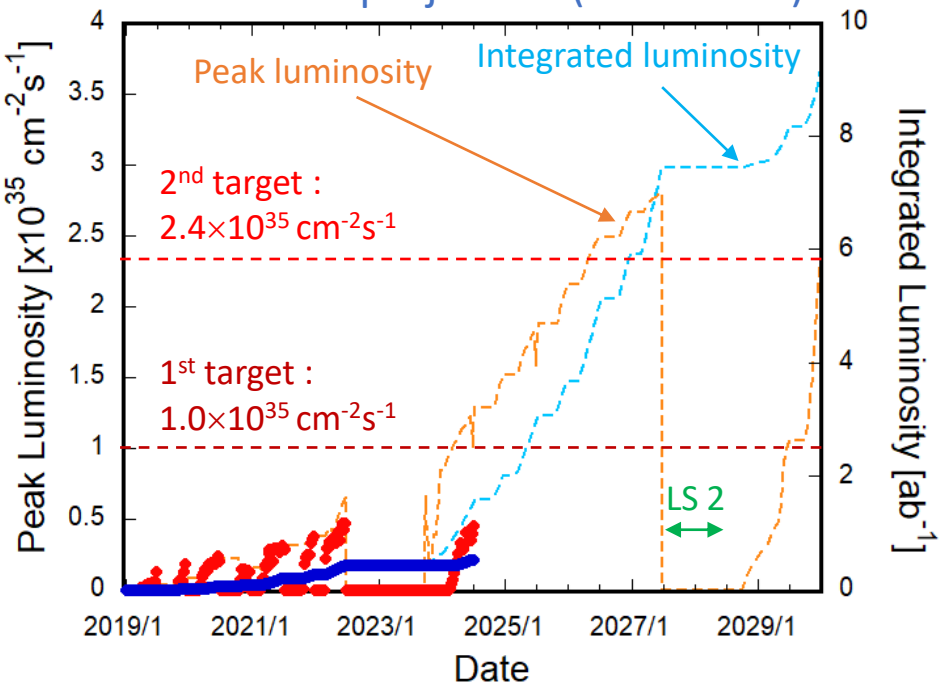
2024c run (in progress)



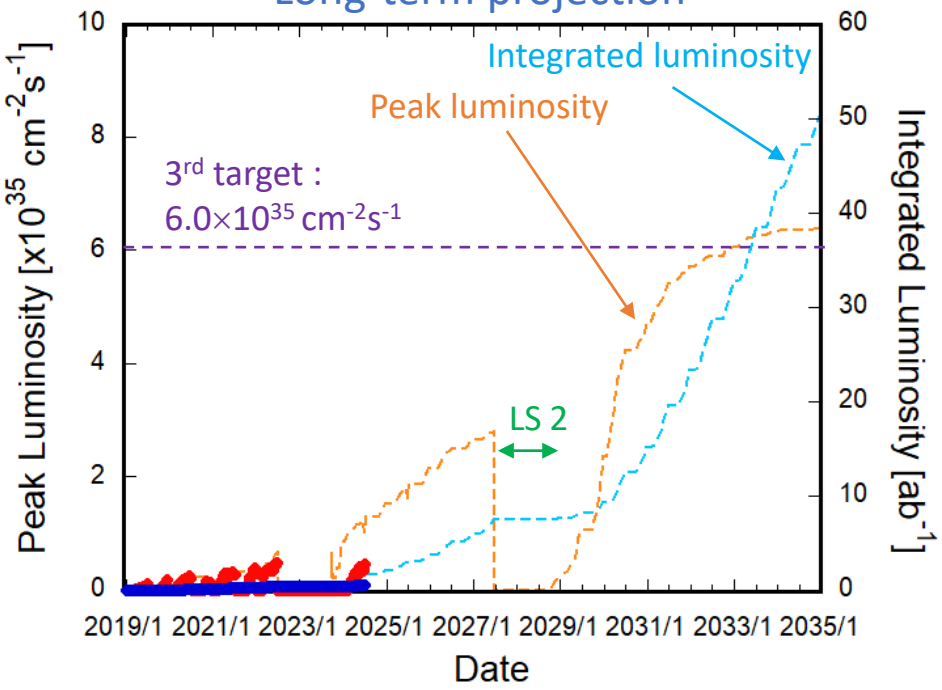
Luminosity projection#

Consideration of modification of long-term operation plan has begun.

Short-term projection (before LS2)



Long-term projection



- Increase the luminosity in 3 steps
  - 1st step : 1.0×10^{35} $cm^{-2}s^{-1}$
    - By the end of JFY2024
    - Increasing beam current
  - 2nd step : 2.4×10^{35} $cm^{-2}s^{-1}$
    - Further simulation study is required to understand the machine

Without accelerator upgrade

- Long shutdown 2
  - IR upgrade ?
  - RF system reinforcement
  - Etc.
- 3rd step : 6.0×10^{35} $cm^{-2}s^{-1}$ ⇐ Accelerator upgrade is required.

Strategy before LS2 (toward 1.0×10^{35})

- Strategy toward 1.0×10^{35} $cm^{-1}s^{-1}$: Route (B)
  - Increase beam current with β_y^* = 0.9 mm
  - Target current : 2.58 A/ 1.83 A
    - Improve injection under influence of Beam-Beam interactions
    - Reduce injection errors with modified injection scheme
  - Required specific luminosity : $L_{sp} = 5\times10^{31}$ $cm^{-1}s^{-1}$ mA^{-2}

- 2024ab results and outlook
  - With 393 bunches (Result of High bunch current study)
    - L(393 bunches) = 1.38×10^{34} $cm^{-2}s^{-1}$
    - L_{sp}(393 bunches) = ~4×10^{31} $cm^{-1}s^{-1}$ mA^{-2}
      - Degradation due to beam blowup at high bunch current
  - With 2346 bunches (outlook)
    - L(393 bunches) = 1.38×10^{34} $cm^{-2}s^{-1}$

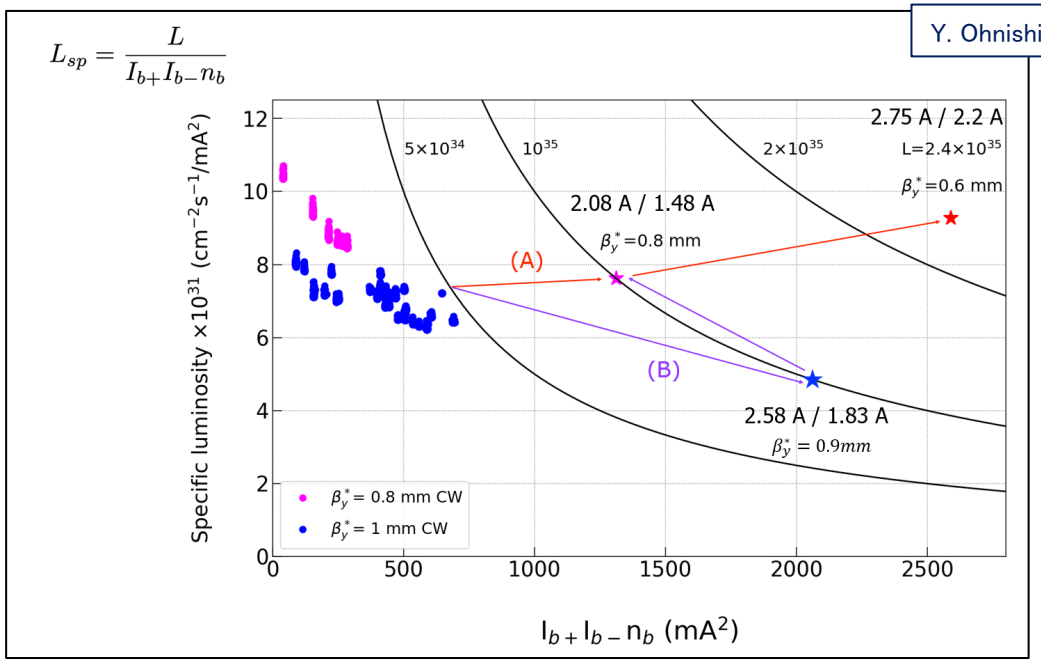
      ⇩ × 2346/393 (increase bunches)

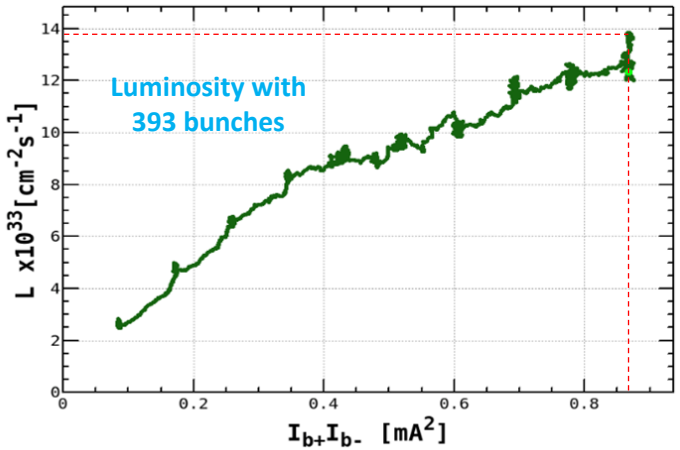
      8.27×10^{34} $cm^{-2}s^{-1}$

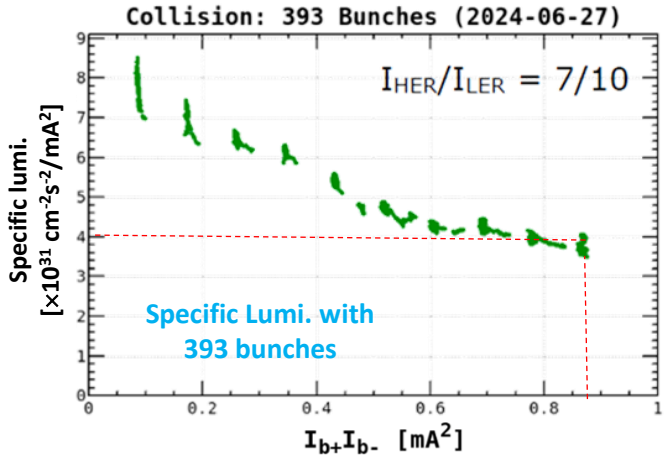
      ⇩ × 5/4 (L_{sp} improvement)

      1.0×10^{35} $cm^{-2}s^{-1}$

Y. Ohnishi



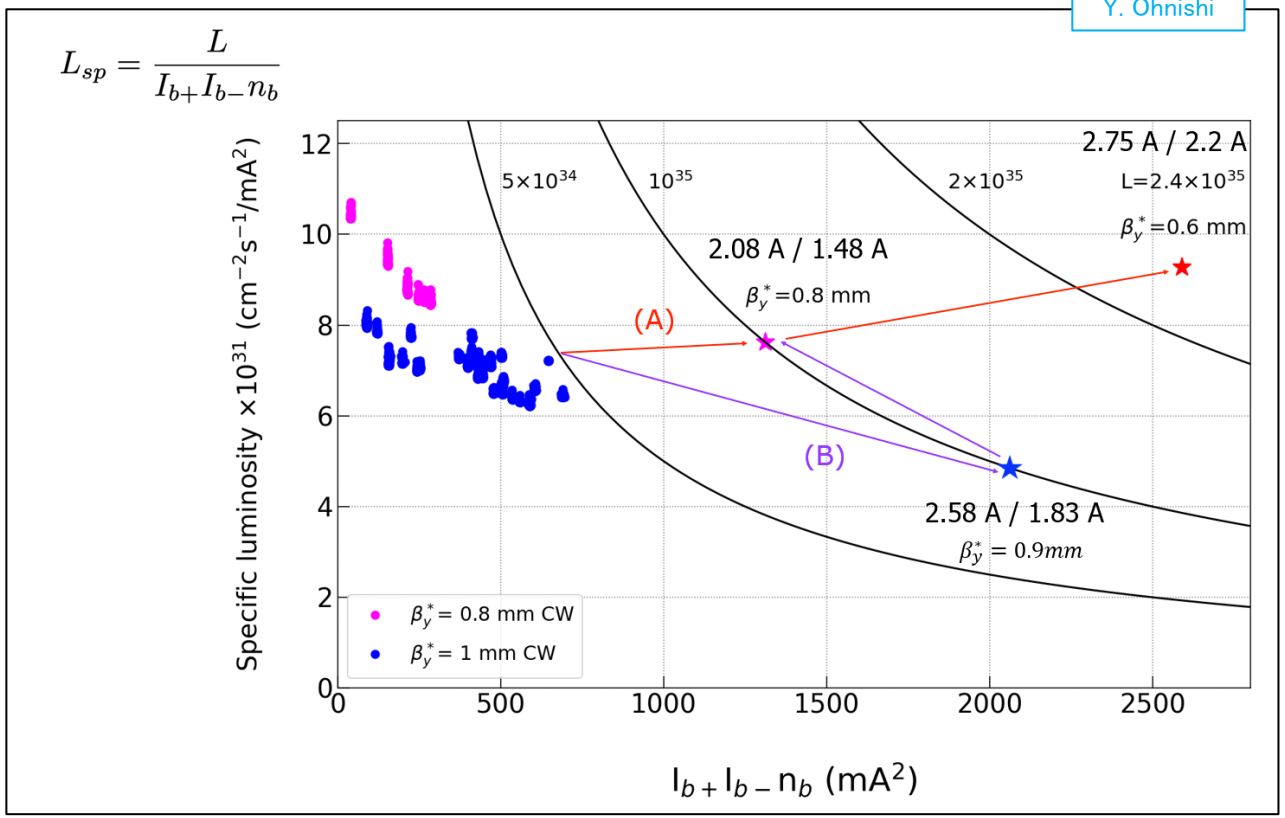




Strategy before LS2 (toward 2.4×10^{35})

- Strategy toward 2.4×10^{35} $cm^{-1}s^{-1}$: Route (A)
  - β_y^* squeezing down to 0.6 mm :
    - Down to 0.6 mm from 0.9 mm (3 steps)
    - Dynamic aperture improvement :
      - Sextupole optimization
      - Off-momentum optics tuning
      - Comparison between simulations and measurement Increase beam current with β_y^* = 0.6 mm
  - Increase beam current : 2.75 A/ 2.2 A
  - Increase specific luminosity (Beam-beam parameter)
    - Up to $L_{sp} \sim 9\times10^{31}$ $cm^{-1}s^{-1}$ mA^{-2}
    - Improve prediction accuracy of Beam-Beam simulation

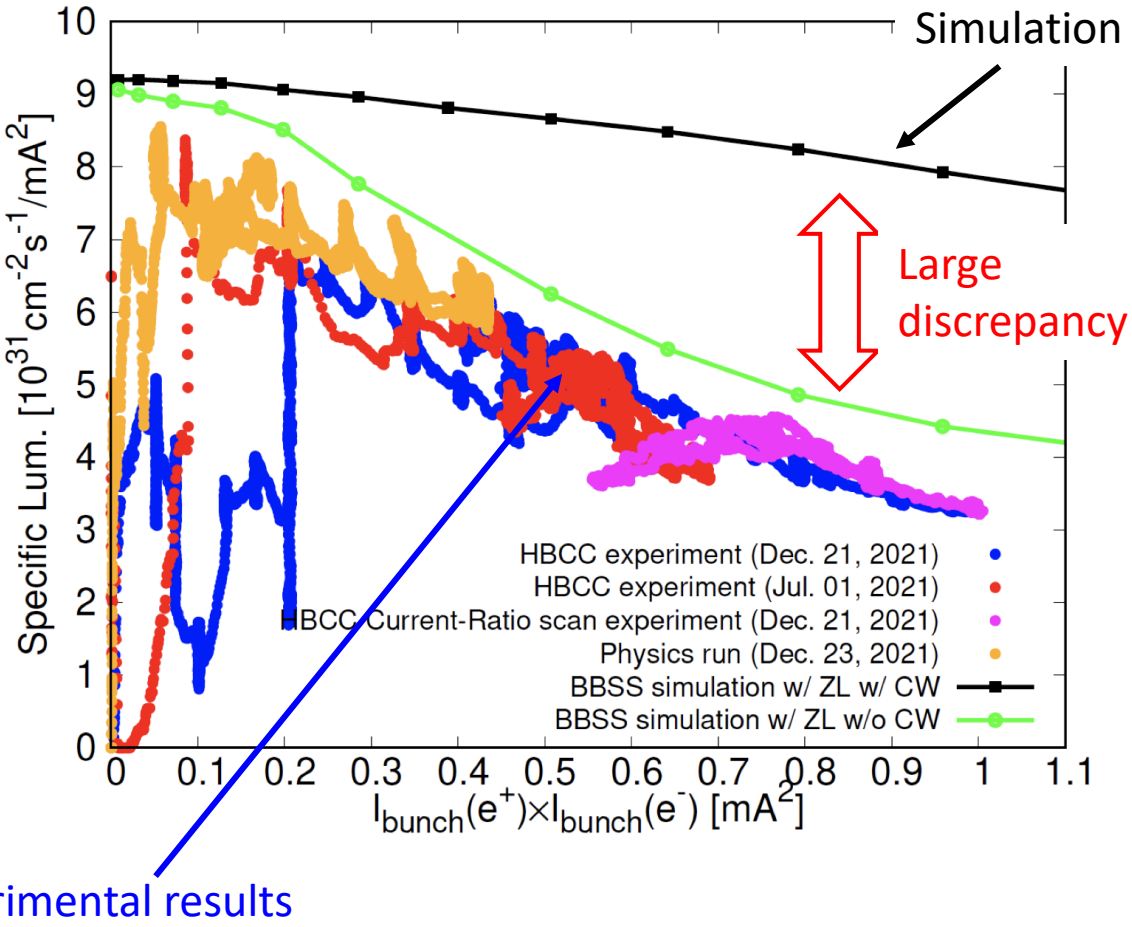
Y. Ohnishi



Collaboration proposal

- Beam-Beam simulation shows much higher specific luminosity
  - It is still unclear why experimental results are much smaller than the simulation.
    - Can simulation miss some important factors?
  - There should be hints to increase luminosity of SuperKEKB.
    - If we identify the cause of the reduction in the luminosity, measures can be taken to improve luminosity.
- Important issue not just for SuperKEKB, but for future colliders with nano-beam collision scheme.
- SuperKEKB would like to collaboration with FCCee on Beam-Beam simulations.
  - Beam-Beam with impedance
  - Beam-Beam with machine errors
  - Beam-Beam with lattice

Strong-Strong Beam-Beam simulation (D. Zhou)



Summary

- SuperKEKB;
  - Asymmetric-energy electro-positron collider operating at KEK Tsukuba site.
  - The world's fist practical application of the "Nano-beam collision scheme".
- Project History and Recent Status;
  - Operation started from 2016.
    - Demonstration of "Nano-beam collision scheme", vacuum scrubbing, Belle II background study, etc.
  - Physics run started from 2019.
    - Luminosity record : 4.7×10^{34} $cm^{-2}s^{-1}$
    - 2024c run is currently underway.
- Luminosity projection;
  - Luminosity will be increased in 3 steps
    - 1^{st} step (1.0×10^{35} $cm^{-2}s^{-1}$) : Increasing beam current
    - 2^{nd} step (2.4×10^{35} $cm^{-2}s^{-1}$) : Further simulation study is required to understand the machine
    - 3^{rd} step (6×10^{35} $cm^{-2}s^{-1}$) : Accelerator upgrade is required, such as IR upgrade, RF system reinforcement, etc.
- Collaboration proposal;
  - SuperKEKB would like to collaboration with FCCee on Beam-Beam simulations.
  - Let's find out what is causing the big discrepancy between simulations and experimental results for future colliders.

Fin.

Thank you for your attention.

Back up