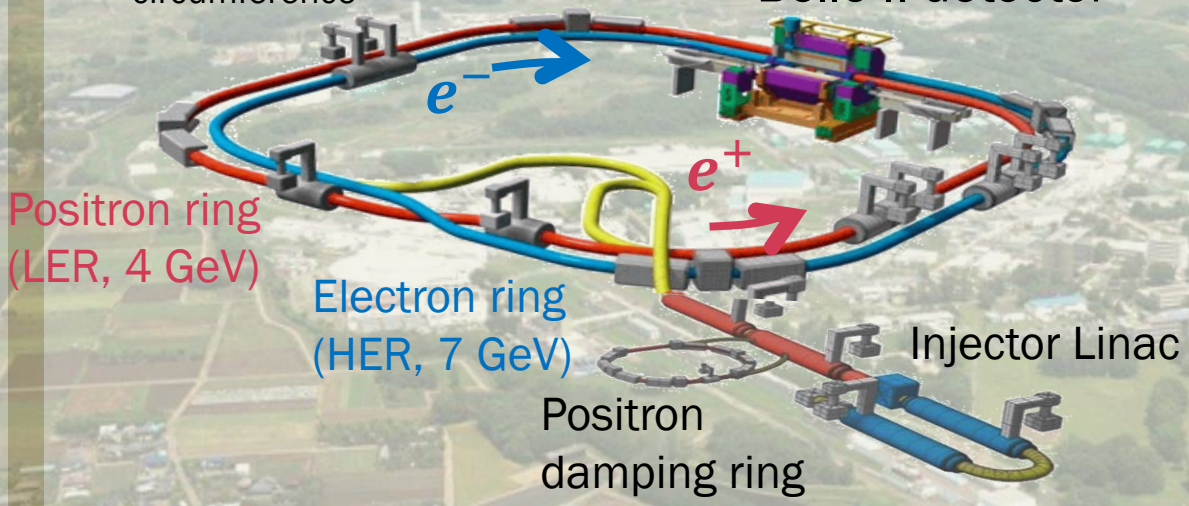
Status of SuperKEKB

Kodai Matsuoka (KEK, Nagoya Univ.)
for the KEK Super-B Factory Project

November 5, 2026

The SuperKEKB accelerator

- Main goal: Test the energy limits of the CKM framework and search for physics beyond the Standard Model via the decays of B, D, and τ.
- Asymmetric e^+e^- collider operating mainly at $\Upsilon(4S)$ resonance (10.58 GeV)
- World's highest peak luminosity of 5.3×10^{34} $cm^{-2}s^{-1}$ (KEKB x 2.5)



Nano-beam collision scheme

- World's smallest vertical beam size at IP ($\sigma_y^* \approx 200$ nm)

Powerful injector Linac

- Compensate the short beam lifetime due to the narrow dynamic aperture of the main rings caused by the nano-beam collisions

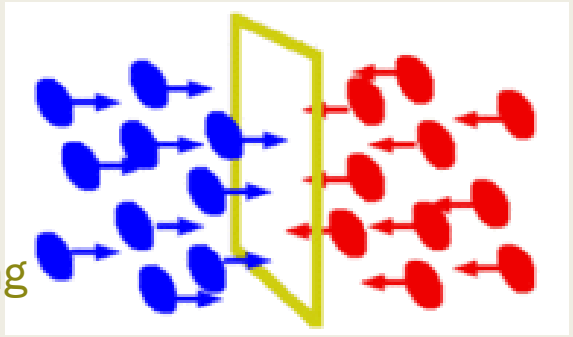
SuperKEKB is a pioneer of e^+e^- colliders.

The technologies developed here will be the basis of the future Higgs factories. Collaborations with FCC-ee is ongoing.

Nano-beam collision

$$\mathcal{L} = \frac{N_{e^+} \cdot N_{e^-}}{S} \cdot f$$

N_{e^+}: number of e^+
N_{e^-}: number of e^-
S: Area of the beam crossing
f: beam crossing rate

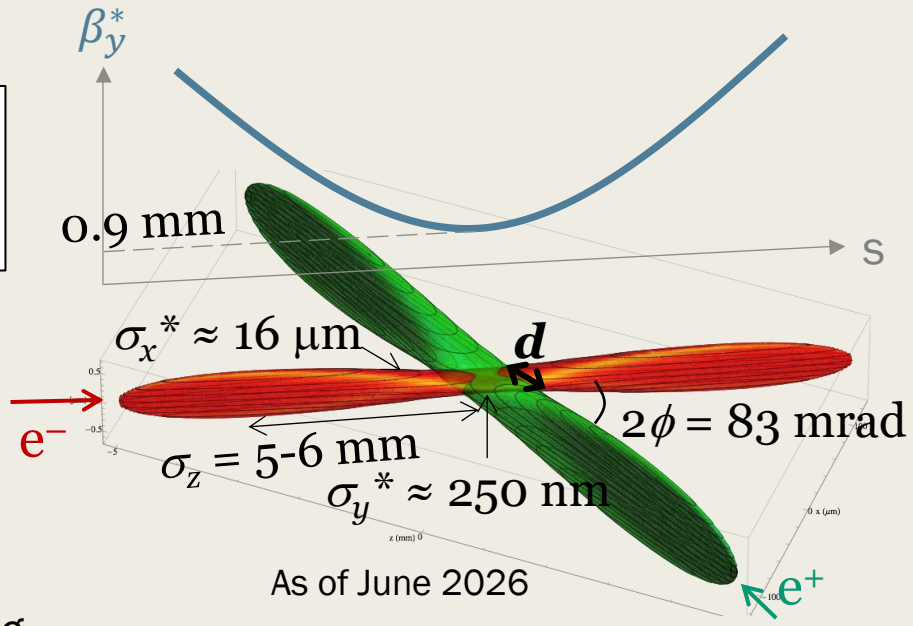


In conventional head-on collisions, the luminosity is limited by the hourglass effect. A large crossing angle relaxes this constraint, enabling a much smaller β_y^* and thus a higher luminosity.

$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{y\pm}}{\beta_y^*}\frac{R_L}{R_{\xi_{y\pm}}}$$

$$\sigma_i^* = \sqrt{\beta_i^* \varepsilon_i}$$

$$\xi_{y\pm} = \frac{r_e N_\mp}{2\pi\gamma_\pm(\sigma_x^* + \sigma_y^*)}\sqrt{\frac{\beta_y^*}{\varepsilon_y}}R_{\xi_{\pm y}} \lesssim 0.1 \text{ (empirical limit)}$$

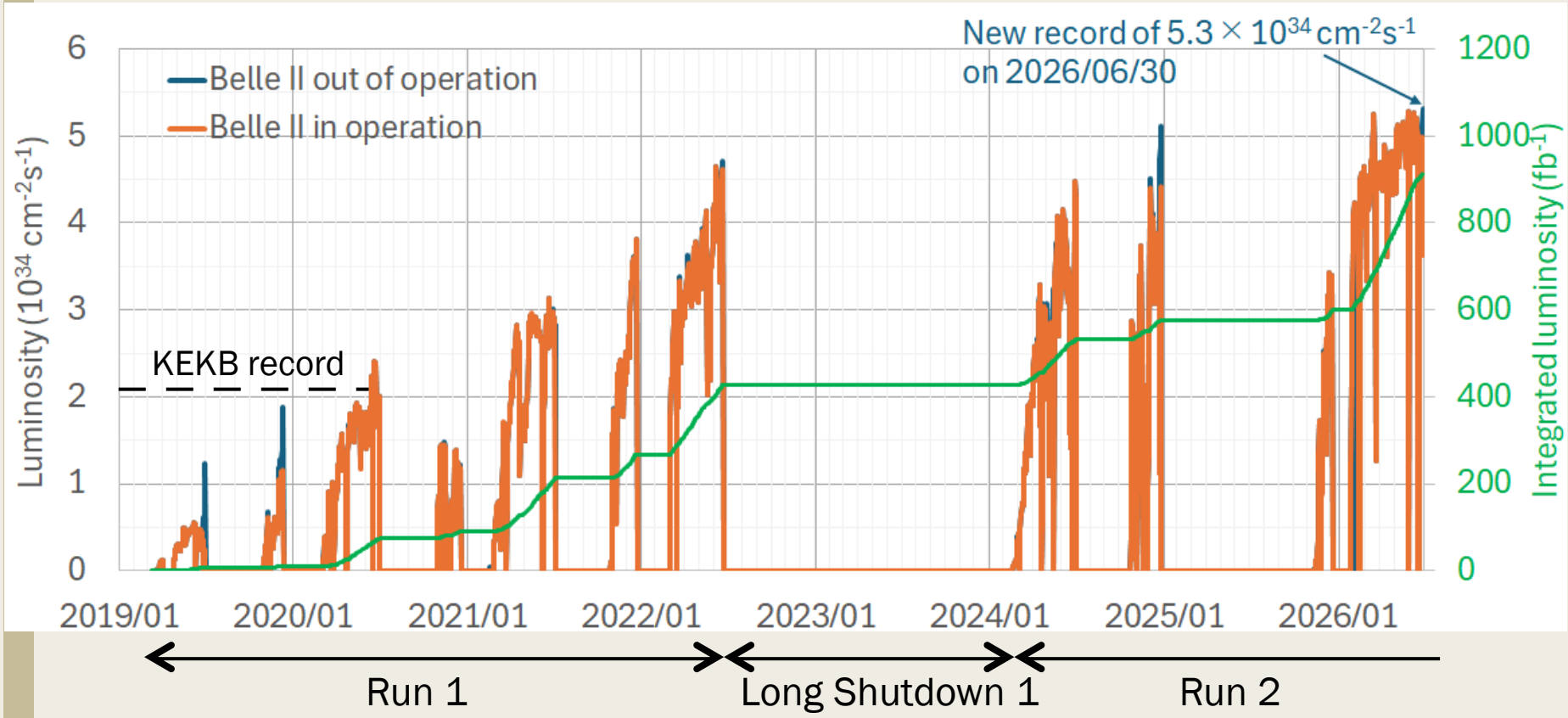


As of June 2026

A small ε_y is also essential for maintaining a high $\xi_{y\pm}$ while squeezing β_y^*.

Interaction length: $d = \frac{\sigma_x^*}{\sin\phi} = 0.24 \text{ mm} \lesssim \beta_y^*$

Luminosity



Established stable operation at 5 x 10^{34} $cm^{-2}s^{-1}$
(with β_y^* = 0.9 mm, LER 1.6 A, HER 1.2 A).

→ 0.5 ab^{-1}/year (7 months/year x 60% $\varepsilon_{\text{physics run}}$ x 90% ε_{DAQ})

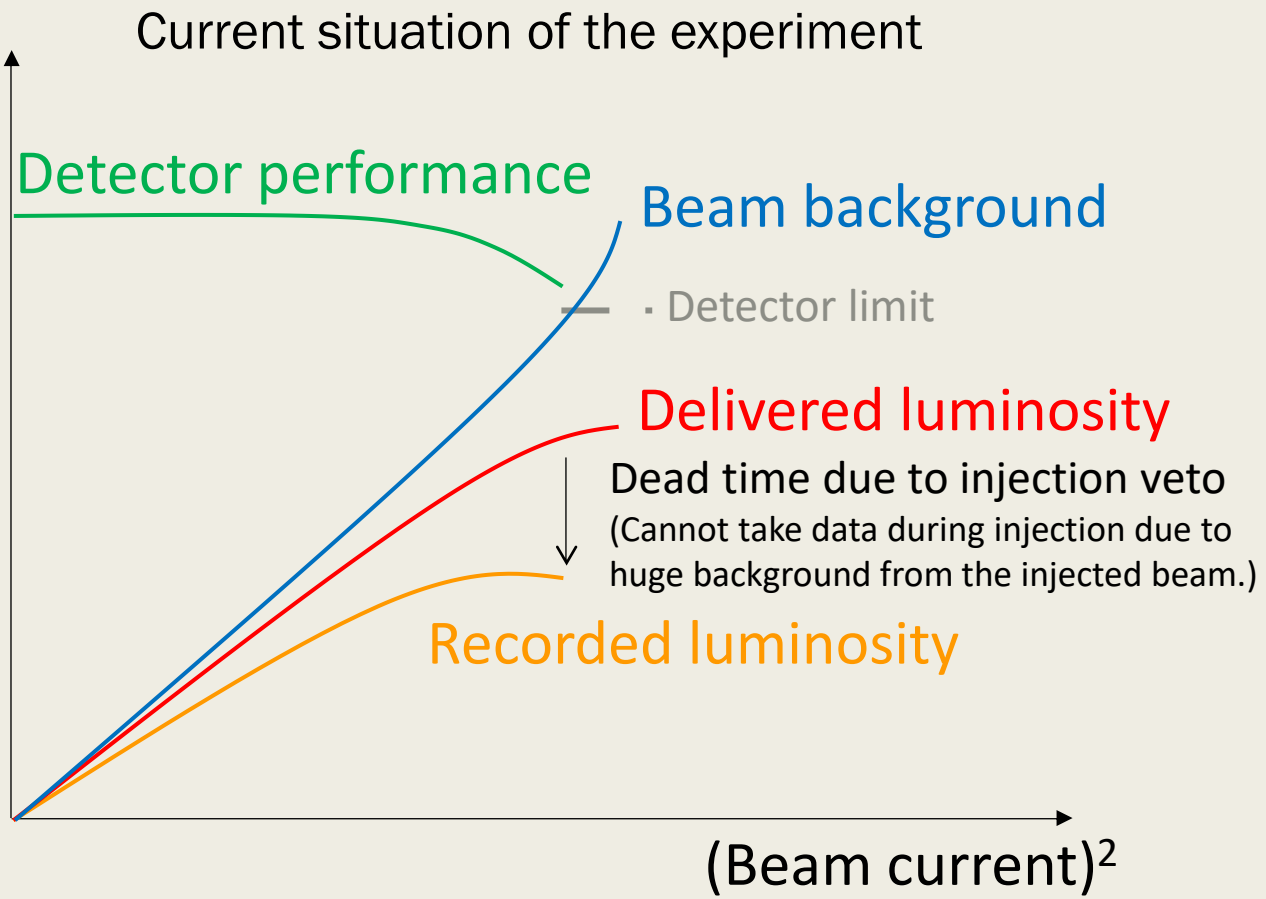
Luminosity



Recorded 808 fb^{-1} at $\Upsilon(4S)$ (> Belle), and 914 fb^{-1} in total.

Physics output =

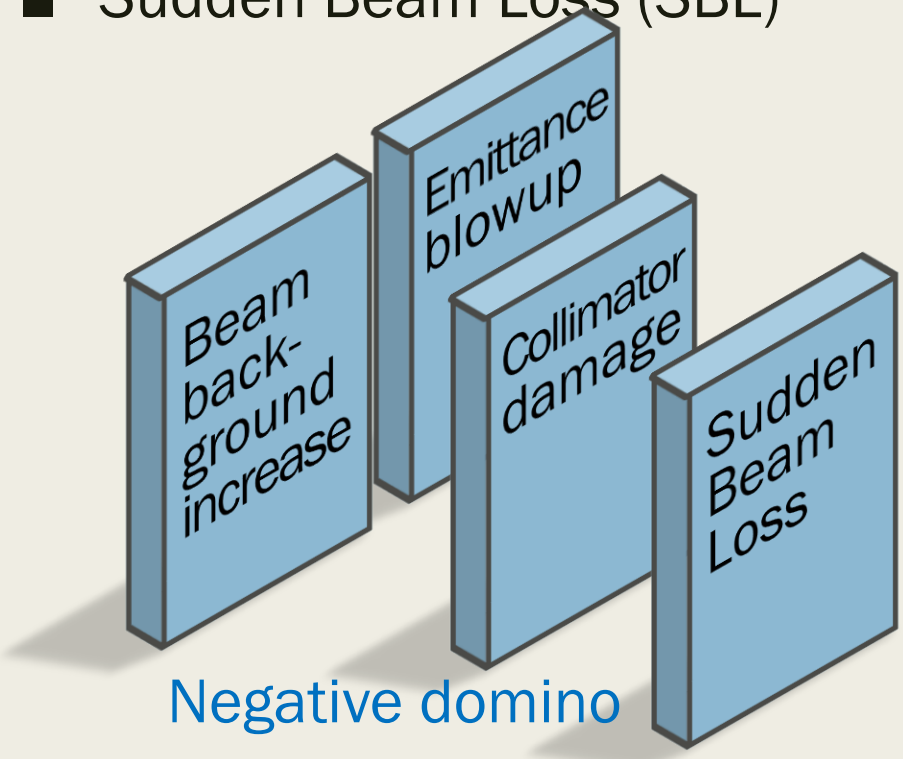
SuperKEKB accelerator (high luminosity)	×	Belle II detector (high performance)	×	Analysis technique (high efficiency)



To maximize the physics output, a common strategy for the accelerator and detector as a whole and joint efforts are essential.

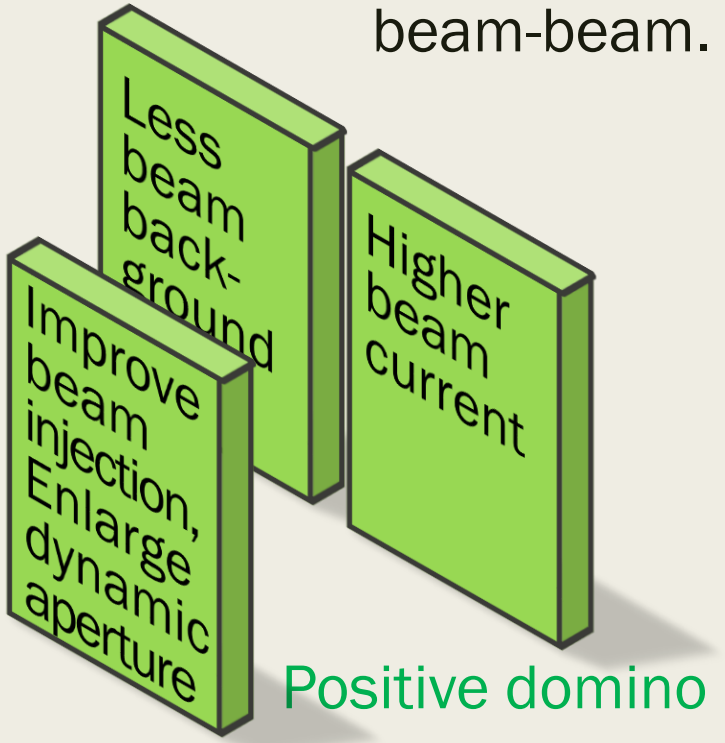
Major challenges of SuperKEKB

- Emittance blowup
  - Need to isolate the causes.
- Small dynamic aperture
  - Sextupole optimization
- Beam background
- Sudden Beam Loss (SBL)



Negative domino

- Beam injection
  - Reduce the injection beam emittance.
  - Increase the charge while keeping the emittance.
  - Understand the effect of beam-beam.



Positive domino

Sudden Beam Loss (SBL)

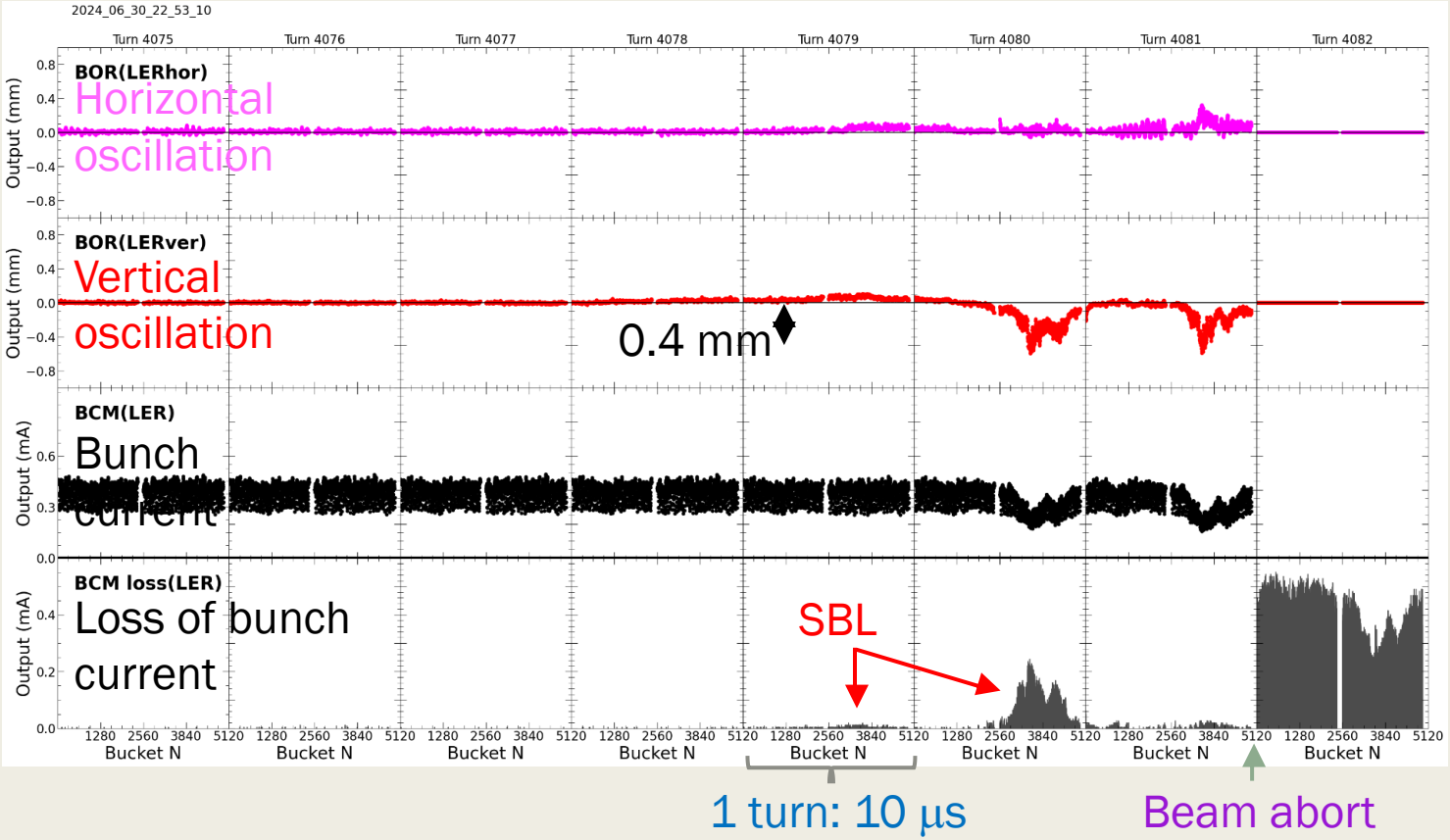


The beam is suddenly lost without clear precursors.

→ Damaged PXD and collimators.

→ PXD off since May 7, 2024 (until the risk of damage is reduced.)

… Fast shutdown of PXD will soon be implemented.

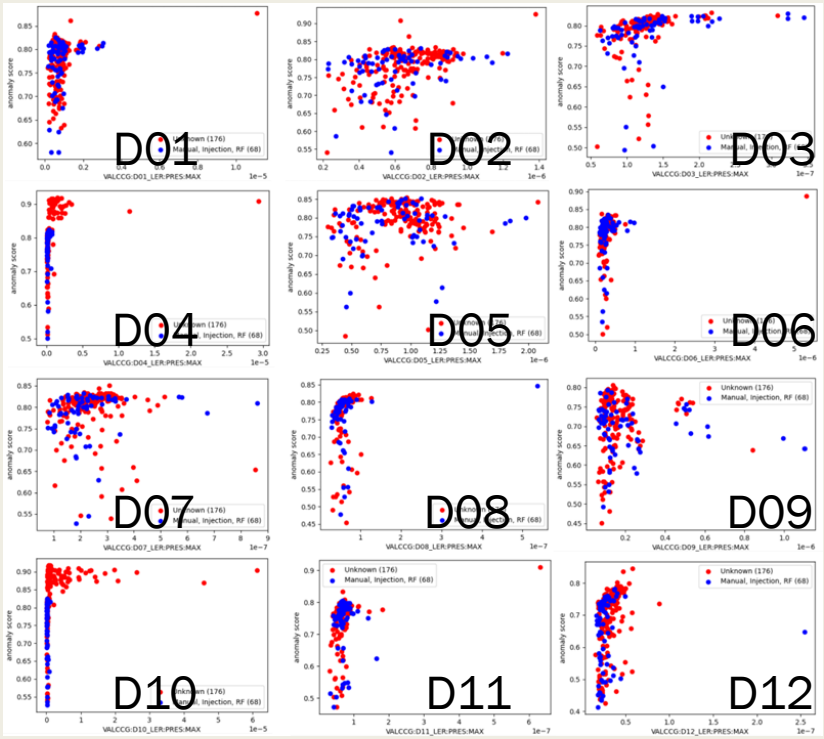


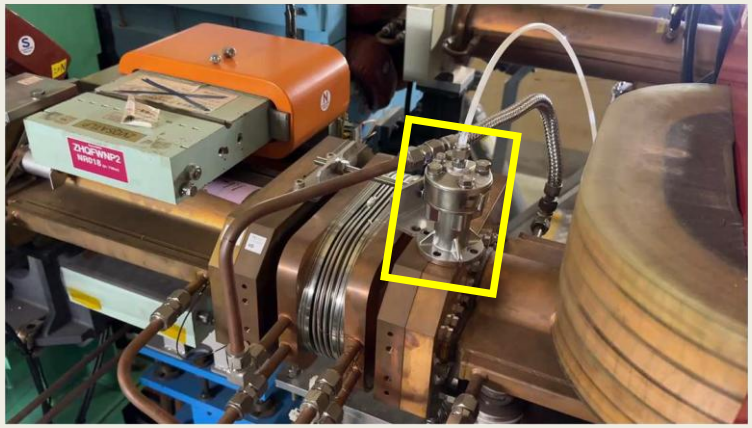
The cause of SBL remained completely unknown for many years.

Hunting the sources of the SBLs

Using an anomaly detection algorithm, anomalous PVs (Process Variables) correlated with SBL were identified from among more than 100,000 PVs stored in the EPICS archiver.

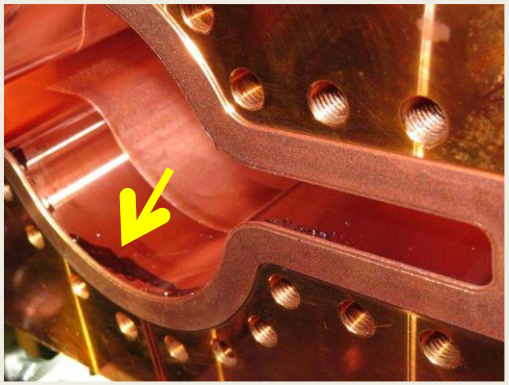
D01...D12: location of MR





SBLs were artificially induced by knocking the beam pipes during the beam operation.

Vacuum sealant was identified as a cause in 2024 and was cleaned.

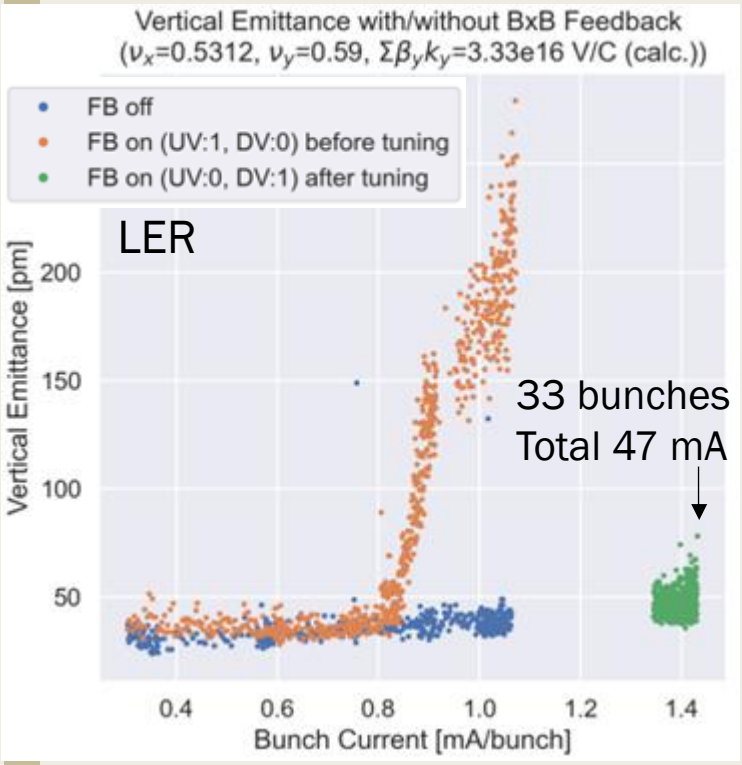


The frequency of the SBLs was drastically reduced, but still 0.1-0.2 SBLs/hour remain.

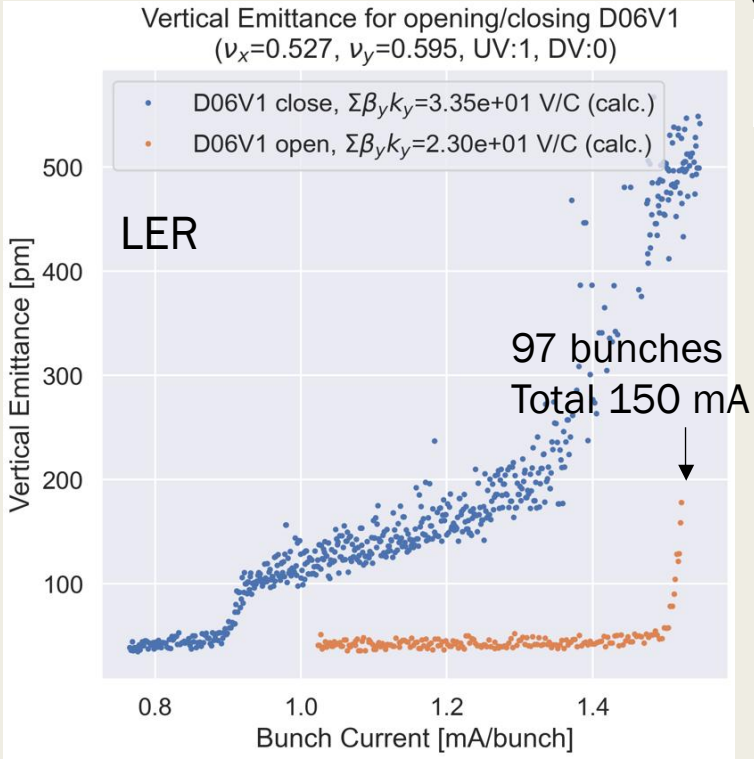
Emittance blowup (single beam)

Phys. Rev. Accel. Beams 27, 081001, 2024

Effect of the bunch-by-bunch vertical feedback (Mar 1, 2022)



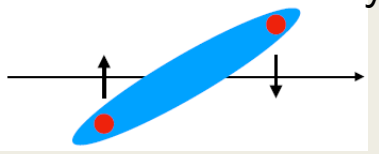
Effect of D06V1 collimator (Feb 28, 2022)



0 mode instability



−1 mode instability



Same eigen frequency at a high bunch current

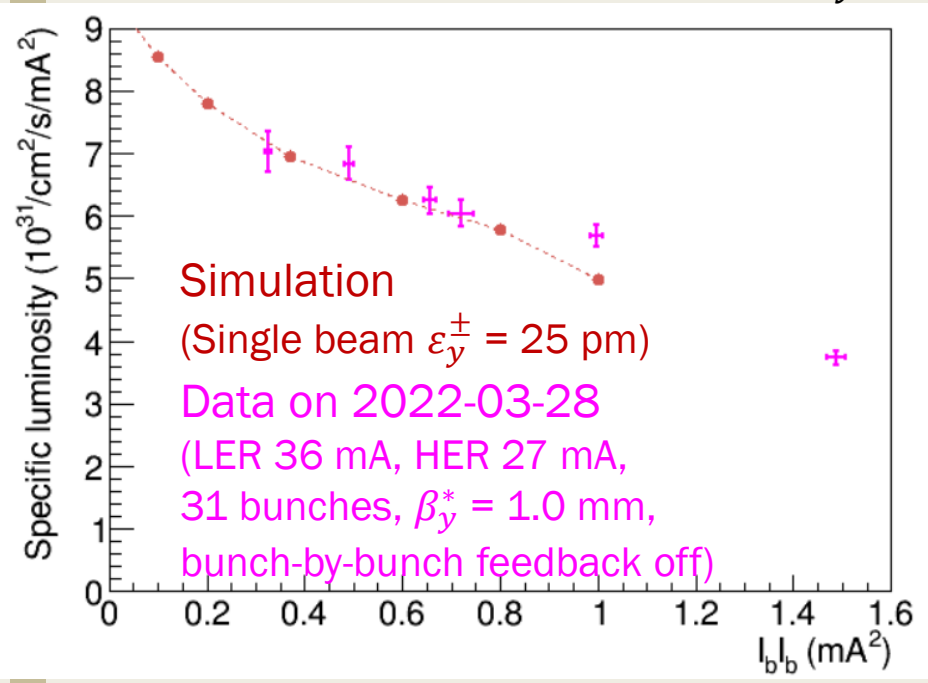
⇩

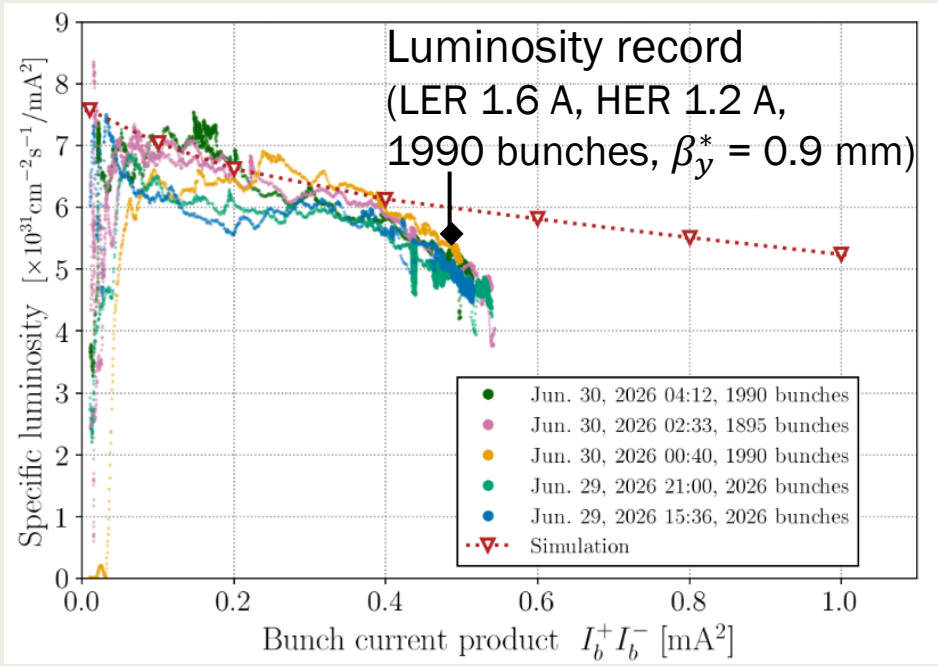
Transverse mode coupling instability (TMCI)

- ✓ The TMCI threshold is higher than the design bunch current (1.44 mA/bunch).
- ✓ The emittance blowup due to the −1 mode instability can be mitigated by tuning the feedback for this mode or opening the collimator.
  - ➢ The threshold is lowered by increased impedance (damaged collimators).
- At a higher total beam current, RF phase shift due to beam loading and optics distortion due to thermal deformation caused by synchrotron radiation also need to be examined.

Emittance blowup (in collisions)

Specific luminosity $= \dfrac{L}{N_b I_{b+} I_{b-}} \propto \dfrac{1}{\sigma_y^*}$





[Advances in the beam-beam simulation]

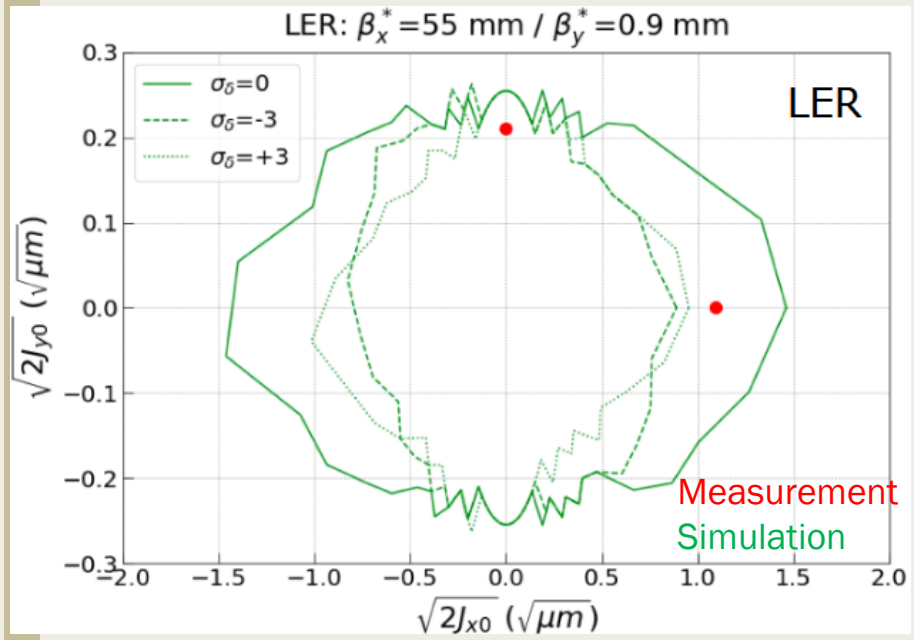
The simulation can reproduce the observed emittance blowup for a small number of bunches by introducing Particle-In-Cell, the full lattice, and transverse impedance.

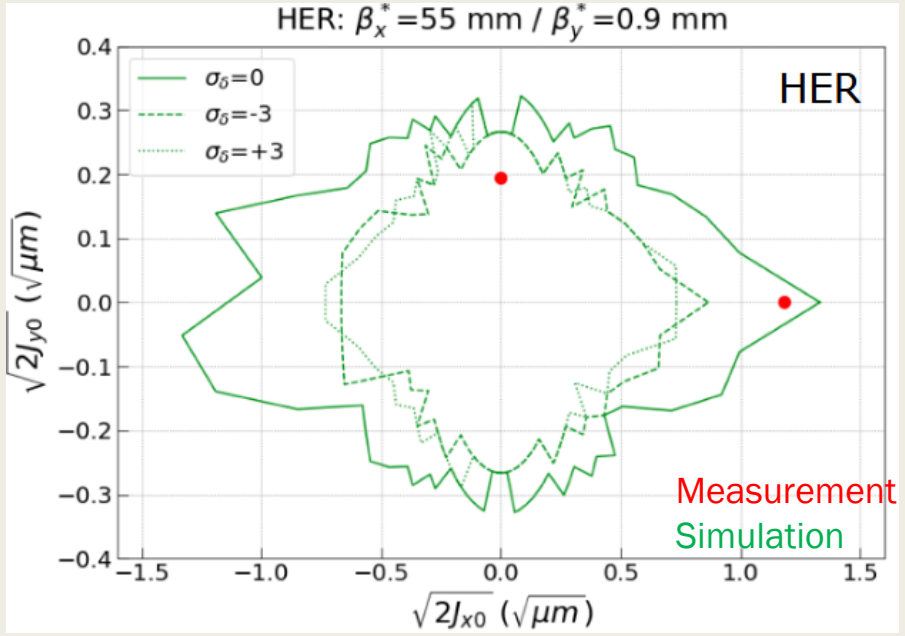
The emittance blowup above 0.4 mA^2 could be caused by the single-beam effects.
(The collimators were damaged.)

Possible two-beam effects:

- Incoherent emittance growth due to beam-beam coupled with nonlinear lattice resonance structure etc.

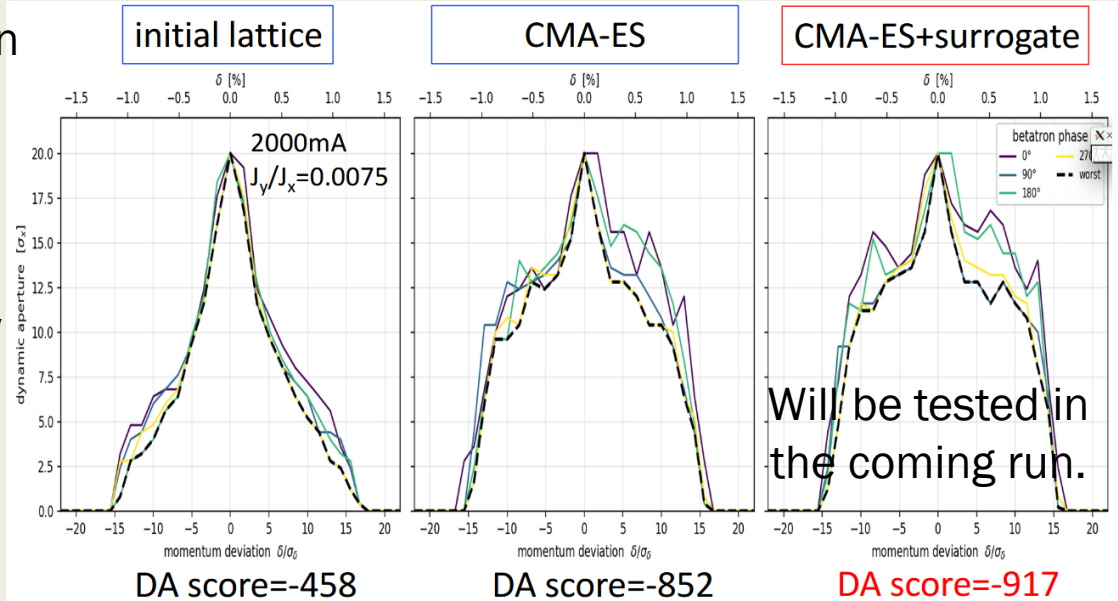
Dynamic aperture



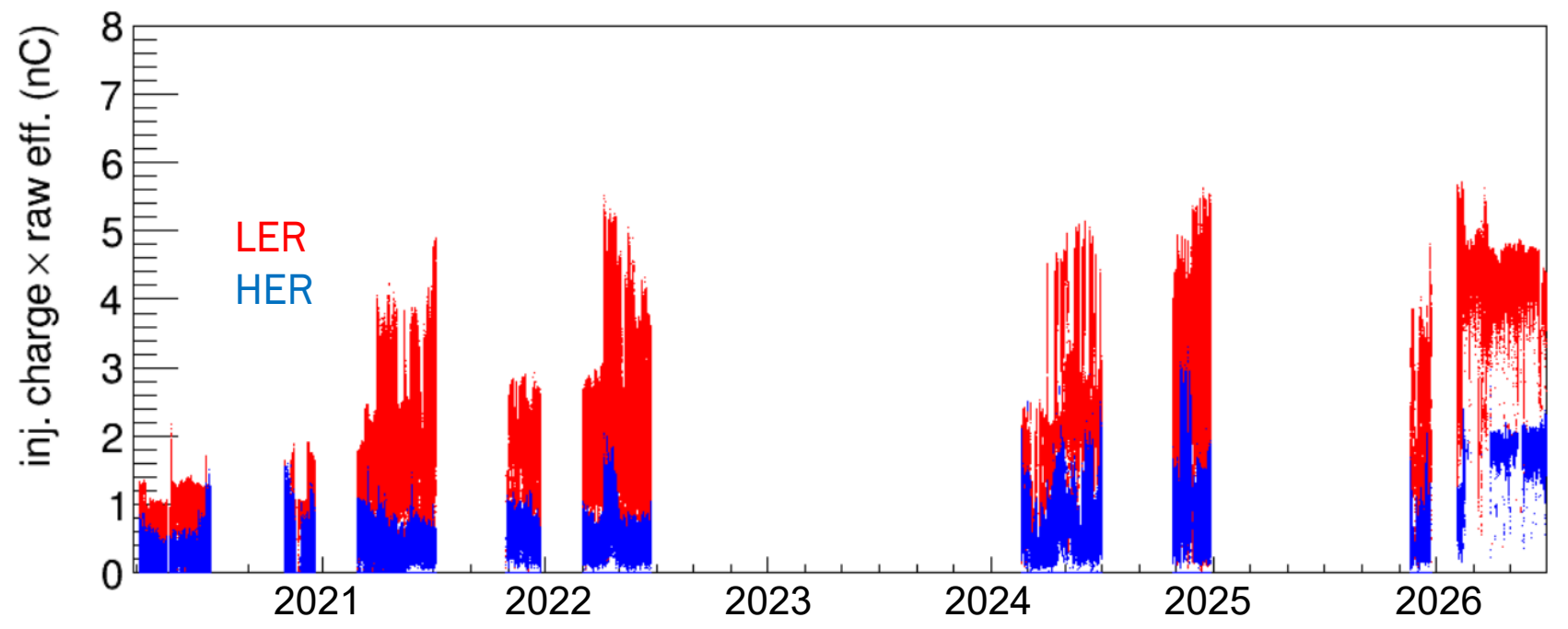


- There are 50 pairs of sextupoles in the arc sections of each ring for chromaticity correction. These are optimized to maximize the dynamic aperture in a simulation.
- A CMA-ES and surrogate model by AI was newly adopted and was found to outperform the previous downhill simplex method.

For more details



Beam injection



- The injection charge and efficiency have been improved.
  - LER: (~2.5 + ~3) nC x ~60%, HER: (~2 + ~2) nC x ~50% (at high currents)
- Stable two-bunch injection has been established.
  - cf. Target: 4 nC/bunch x 2 bunch
- Energy spread for the electron/positron beam has been suppressed to/below the required level
  - thanks to the energy compression system introduced in the e^- transport line.
- Automatic emittance tuning and orbit feedback have improved the stability.
- The emittance increase in the beam transport lines is under study.

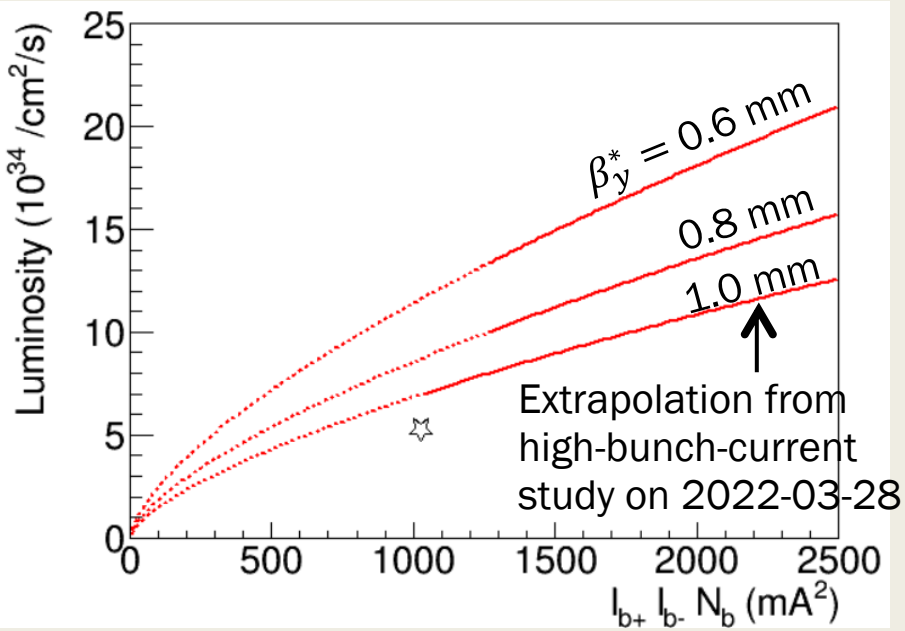
Path toward 1 x 10^{35} /cm^2/s and beyond

[Observation]

0.17 x 10^{34} /cm^2/s

LER 36 mA, HER 27 mA, 31 bunches

(LER inj. 2.9 nC x 5 Hz x 8% (net) = 0.12 mA/s,
loss 0.06 mA/s;
HER inj. 1.2 nC x 5 Hz x 12% (net) = 0.07 mA/s,
loss 0.02 mA/s)



↓ Scale (x75) with the number of bunches

[Expectation]

12 x 10^{34} /cm^2/s

LER 2.6 A, HER 2.0 A, 2346 bunches

(LER injection 4 nC x 2 bunch x 25 Hz x 16% (net) = 3.1 mA/s, loss 4.3 mA/s x 90% (Coulomb) x 80% (Touschek);
HER injection 3 nC x 2 bunch x 23 Hz x 12% (net) = 1.6 mA/s, loss 1.5 mA/s)

- Improve the injection charge and efficiency.
- Improve the beam lifetime for LER (vacuum scrubbing and sextupole optimization).

The luminosity can be further increased by squeezing β_y^* down to 0.6 mm.

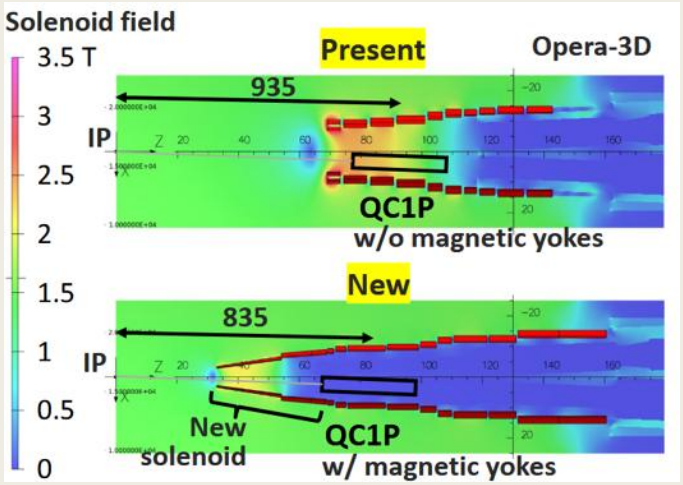
Objectives of the LS2 upgrade

Major upgrades during Long Shutdown 2 (LS2) starting in 2032

- To enhance Belle II's physics reach for physics beyond the Standard Model with 30–50 ab^{-1}.
  - 3–6 x 10^{35} /cm^2/s will be necessary to achieve it.
  - Need to break through performance limitations of both the accelerator and detector.
- Open new unique windows of discovery
  - Chiral Belle (polarized e^- beam for precision neutral-current physics and τ g – 2 through left-right asymmetries)
  - Higher collision energy up to 11.6 GeV ($\Lambda_b\overline{\Lambda}_b$ production)
  - Forward tagger (tag two-photon events by detecting the scattered $e^{\pm}$ for potential improvement in ALP search)

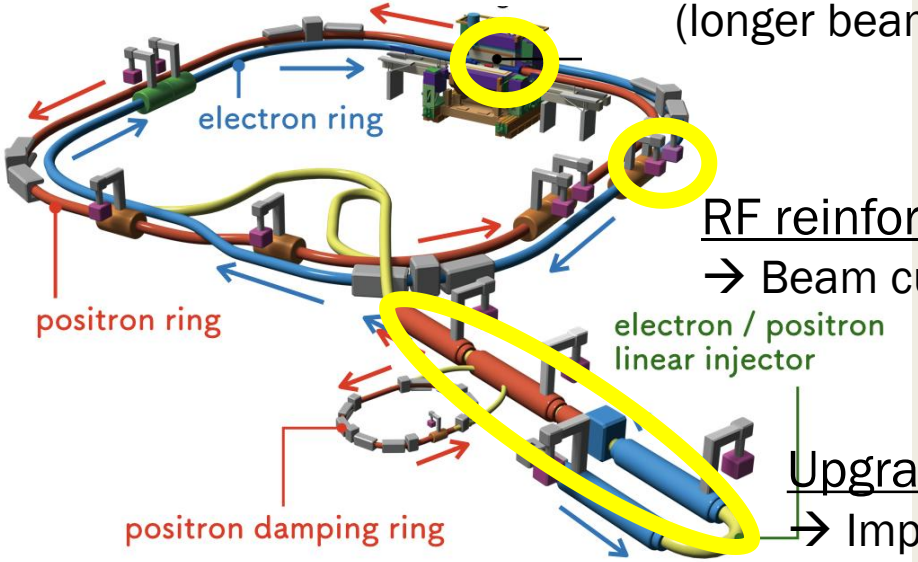
Technologies and experience developed for this upgrade will lead to next-generation collider experiments.

Accelerator upgrade



Upgrade of the final focusing system

→ Smaller emittance, lower beam background,
(longer beam lifetime)

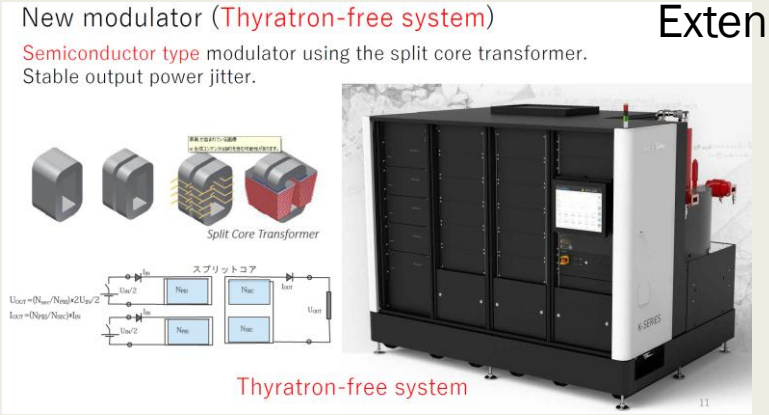


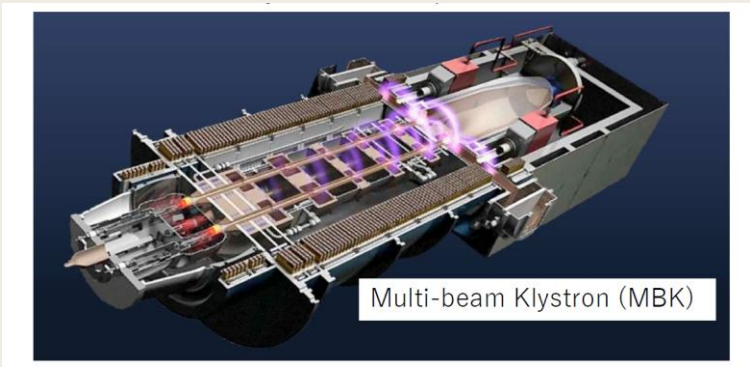
RF reinforcement for the electron ring

→ Beam current: 2.0 → 2.6 A

Upgrade of injector accelerator unit

→ Improved stability and reproducibility
Enhanced injection beam power
(How to reflect it in DR and MR is under discussion.)
Extended collision energy: 11.24 → up to 11.6 GeV





Summary

- SuperKEKB is a luminosity-frontier collider that employs the nano-beam collision scheme and is the most important factor for the Belle II physics.
- We achieved the world's highest peak luminosity of 5.3×10^{34} cm^{-2}s^{-1} and stable operation at 5×10^{34} cm^{-2}s^{-1} with β_y^* = 0.9 mm, LER 1.6 A, HER 1.2 A.
- The next milestones are 1×10^{35} cm^{-2}s^{-1} and the major upgrades during LS2 starting in 2032.
- There are many challenges (= cutting-edge research topics).
  - Opportunities for real-world testing and practical experience with the operational accelerator and the LS2 upgrade

  → An ideal platform for collaboration, paving the way for future e^+e^- colliders. We would highly welcome collaborative research opportunities.