US-Japan

HAWAII

SYMPOSIUM

Symposium of the US-Japan
Science and Technology Cooperation Program

R&D for SuperKEKB and the next generation high luminosity colliders

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US-Japan Hawaii Symposium

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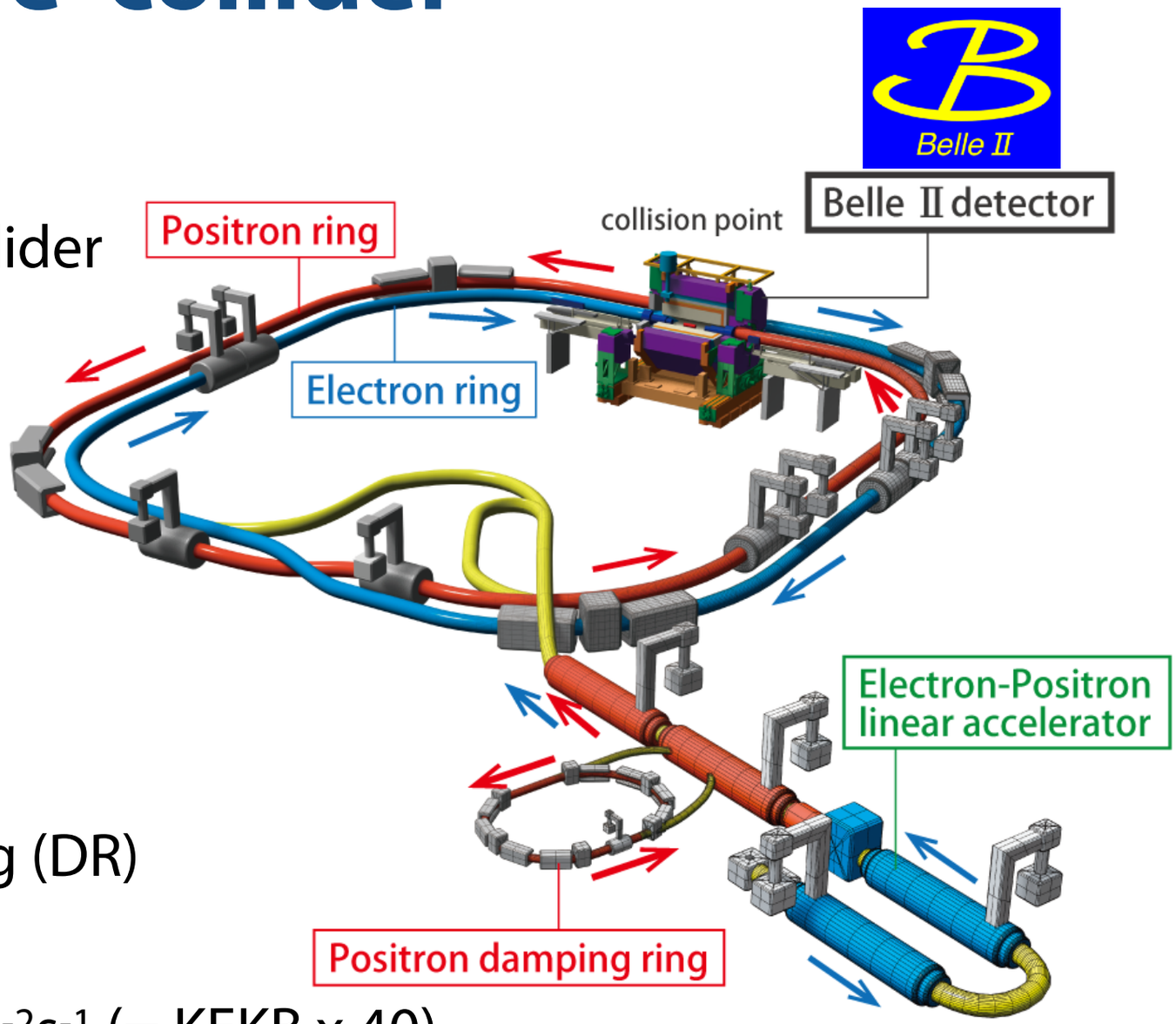
The SuperKEKB e^+e^- collider

- Major upgrade to the KEKB e^+e^- collider providing tons of B, τ, etc. to Belle II
- Main rings
  - 7 GeV e^- storage ring (HER)
  - 4 GeV e^+ storage ring (LER)
- Injector complex
  - Electron/positron linac
  - 1.1 GeV positron damping ring (DR)
- Design parameters
  - Target Luminosity: 8×10^{35} $cm^{-2}s^{-1}$ (= KEKB x 40)
  - Maximum beam currents: 3.6 A (LER) and 2.6 A (HER)
  - $\beta_y^* \sim 0.3$ mm
  - $\sigma_x^* \sim 10$ μm, $\sigma_y^* \sim 50$ nm, $\sigma_z \sim 6$ mm



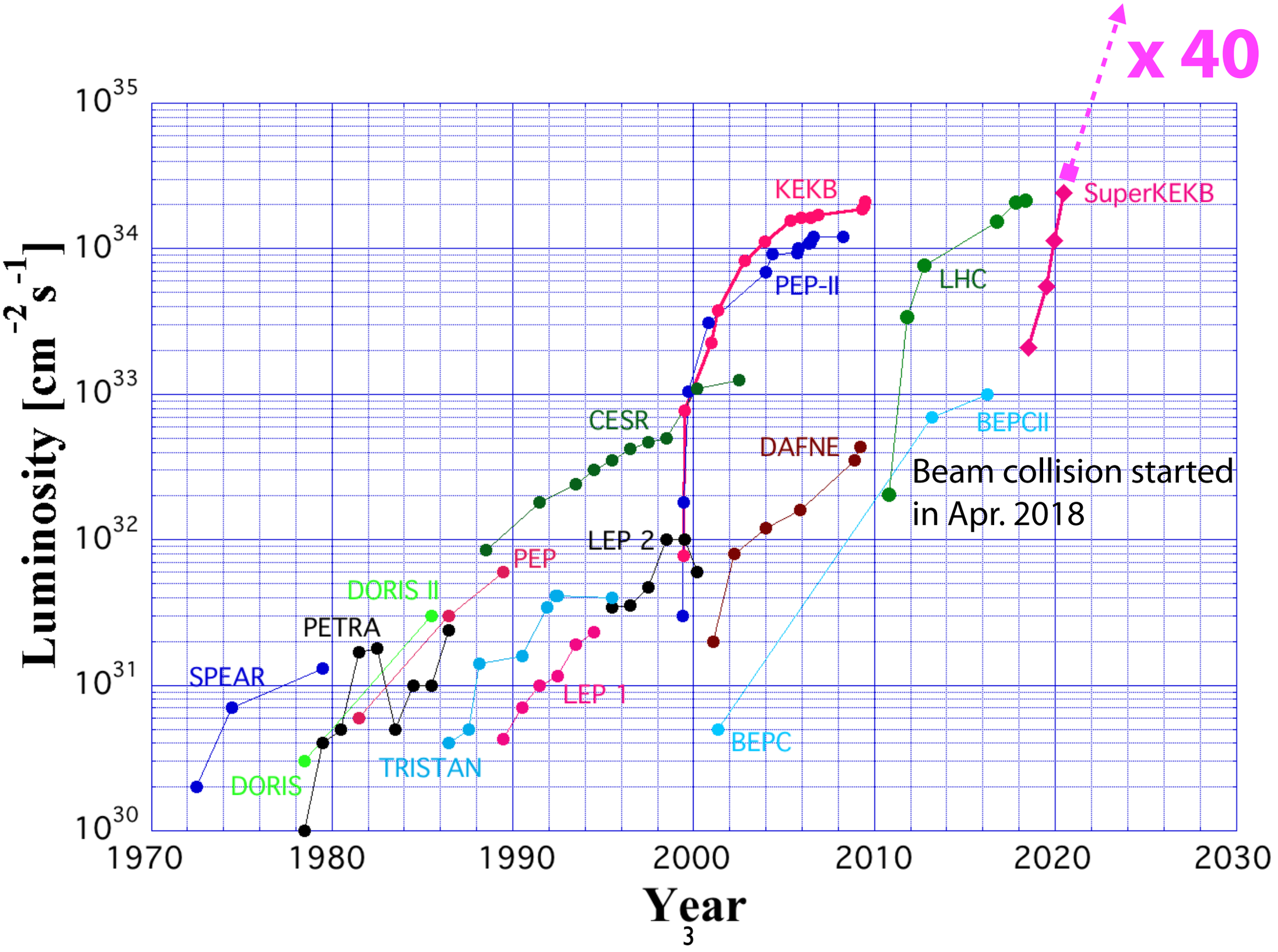
Experiments need

$$\mathcal{L} = \frac{1}{\sigma}\frac{dN}{dt}$$

Accelerator delivers

New physics predicts

History of peak luminosity (e^+e^- collider)

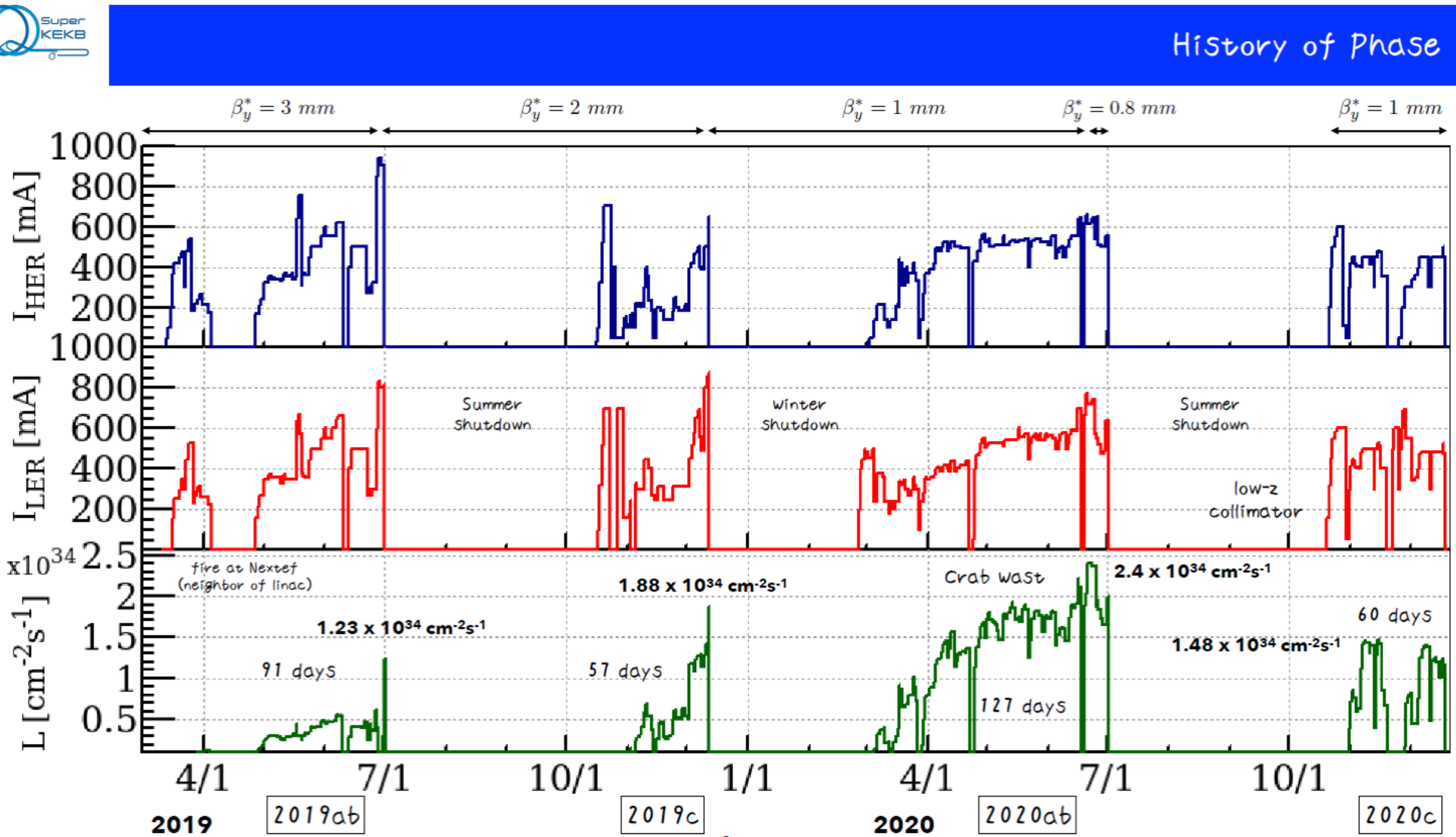


Overview of the project

- US-Japan collaborative R&D for SuperKEKB and next generation high-luminosity colliders
    - *Orbit feedback system at the interaction point*
    - *X-ray beam size monitor*
    - *Beam collimators*
    - *Higher-order mode absorber*
    - *Very-high bandwidths and sampling rates digital circuits*
    - Electlon-cloud effects, secondary electron yield
    - Large angle beamstrahlung monitor
    - Beam dynamics
    - Next-generation beam-injectors
- Realization of the target luminosity at SuperKEKB
    - Training of young scientists and engineers for future accelerators
- The project has been continued for ~20 years since FY2003.

SuperKEKB operation in 2019 and 2020

History of Phase 3



The SuperKEKB operation in 2020

- Crab waist and $\beta_y^* = 1$ mm enabled the instantaneous luminosity 2.4e+34 $cm^{-2}s^{-1}$ with half beam currents with respect to the KEKB beam currents for 2.1e+34 $cm^{-2}s^{-1}$.
- β_y^* could be down to 0.8 mm in physics operation condition.
- Fast beam-orbit feedback system at the IP worked successfully.
- In the operation 2020c (Oct-Dec 2020), encountering many troubles slowed down beam studies and an increase in luminosity.
  - Unexpectedly large impedance of newly introduced low-Z collimators and replacements of damaged collimators
  - Poor injection efficiency to the main rings
  - Trouble in the cooling water system
- **Social**  **Distancing**
  - affects R&D and operation efficiencies at some level…

Accelerator schedules after FY2021

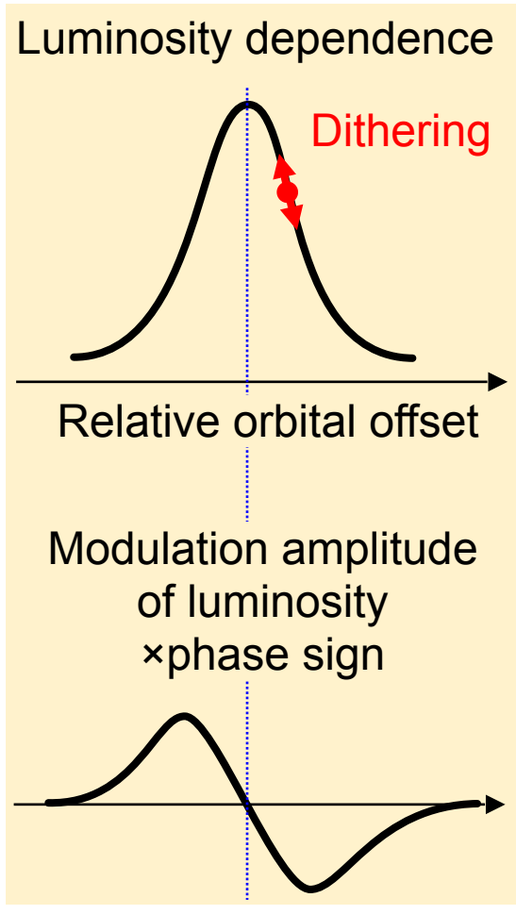
- FY2021
  - 7 months operation (Apr-Jul, Oct-Dec, Feb-Mar)
  - Primary task is to integrate luminosity as much as possible.
- FY2022
  - Operation will end on middle July followed by long shutdown for the Belle II pixel detector replacement.
  - Improvements of the SuperKEKB components
- FY2023
  - Expect resume the operation around May

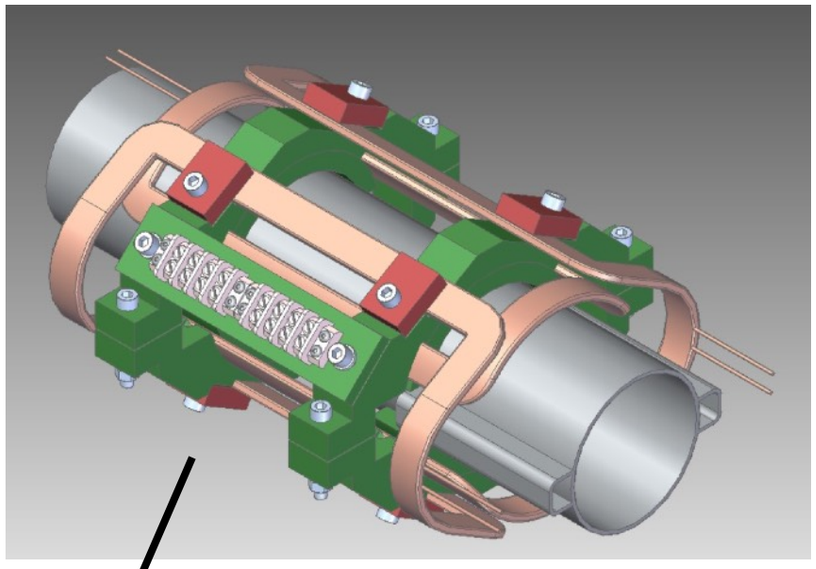
Project status

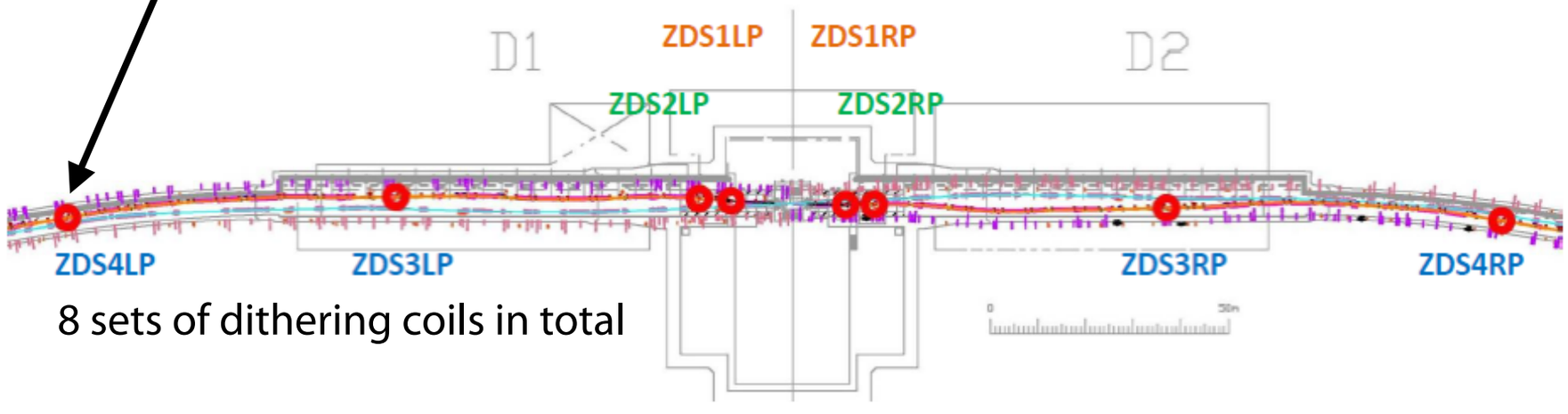
- Orbit feedback system at the interaction point
- X-ray beam size monitor
- Beam collimators
- Higher order mode absorber
- Very-high bandwidths and sampling rates digital circuits

Orbit feedback system at the IP

- Modulate orbit positions and angles at the IP using a sinusoidal signal (~70 Hz), and detect the frequency and phase response using the luminosity monitors via lock-in amplifiers
- Constructing dithering feedback systems as collaborating with SLAC



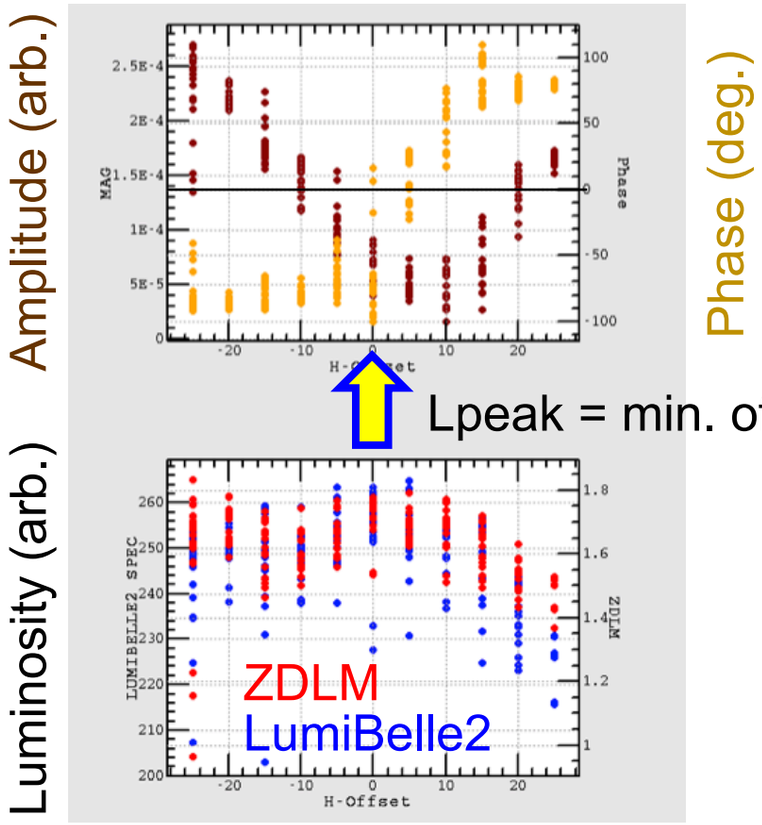


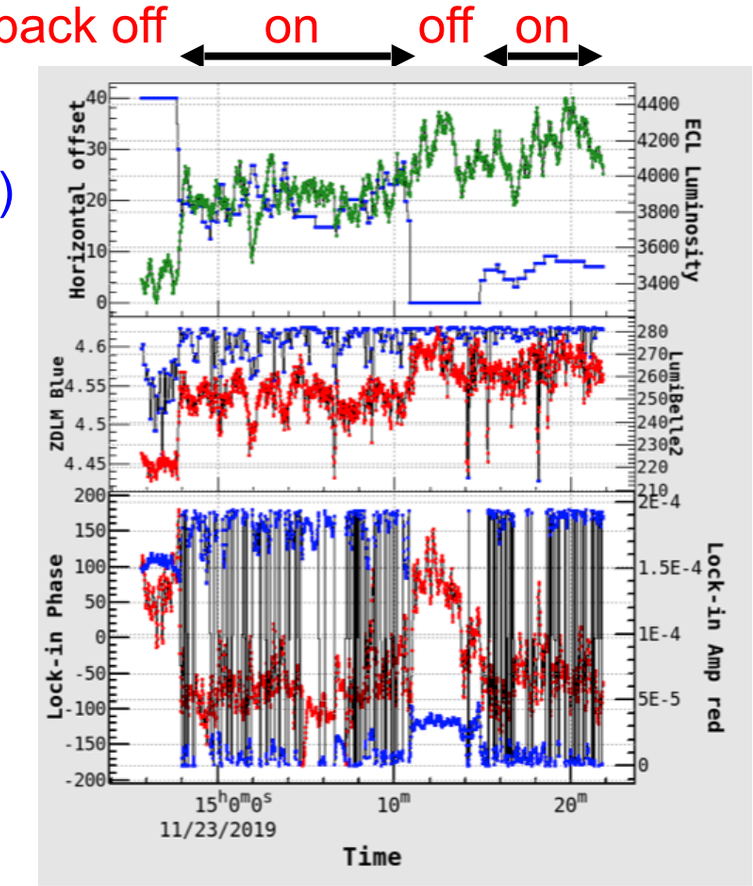


8 sets of dithering coils in total

Orbit feedback system at the IP

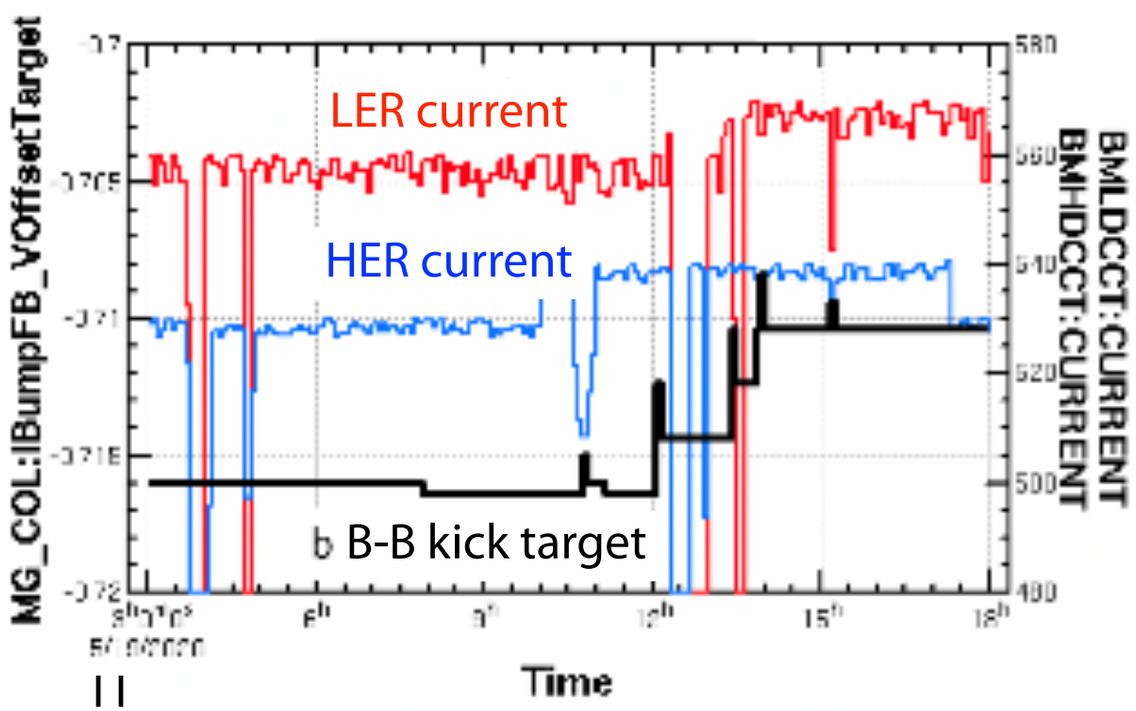
- FY2019
  - The dithering system worked as horizontal IP-orbit feedback.
  - Basic functionalities were confirmed in the horizontal axis.
  - A. Fisher (SLAC) and U. Wienands (ANL) visited KEK and joined beam tests.
- Started R&D for the existing dithering system to be inclusive of hor. and ver. axes.



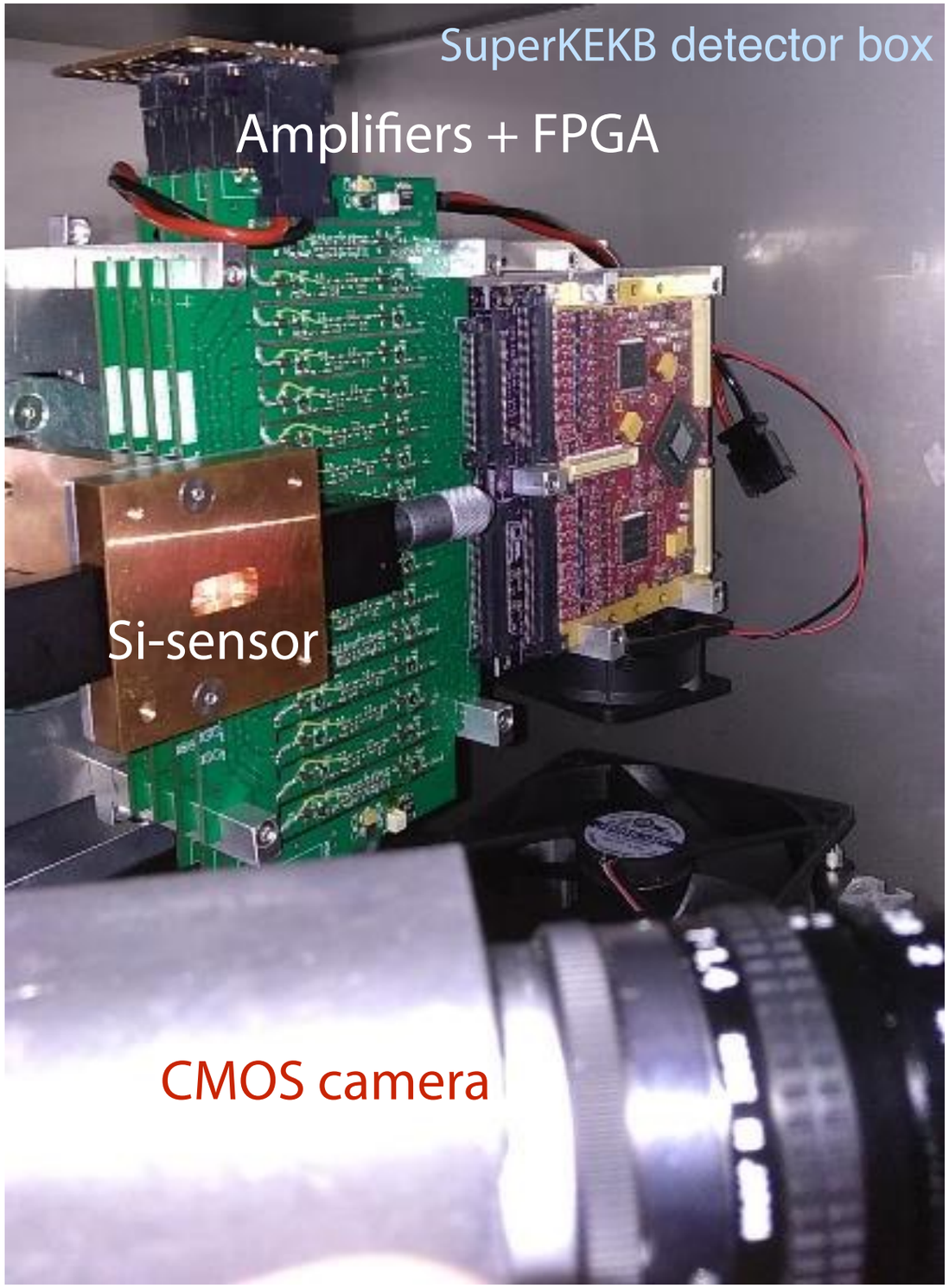


Orbit feedback system at the IP

- The dithering system is planned to extend to vertical position and possibly vertical angle to work with horizontal position simultaneously.
    - Existing mainly-used vertical orbit feedback system measures a canonical “beam-beam" kick and changes the electron orbit to keep a beam-beam kick constant so as to get the instantaneous luminosity maximum.
- Due to a dependence of the beam-beam kick’s target value on beam currents, at each the beam current we have to explore the target value by manually setting a knob parameter.
    - Can we use the dithering system to automatically search the best beam-beam kick target value?
- Vertical dithering feedback system can keep higher luminosity even during “decay mode” operation.



SiXRM : Silicon-strip X-ray beam size monitor

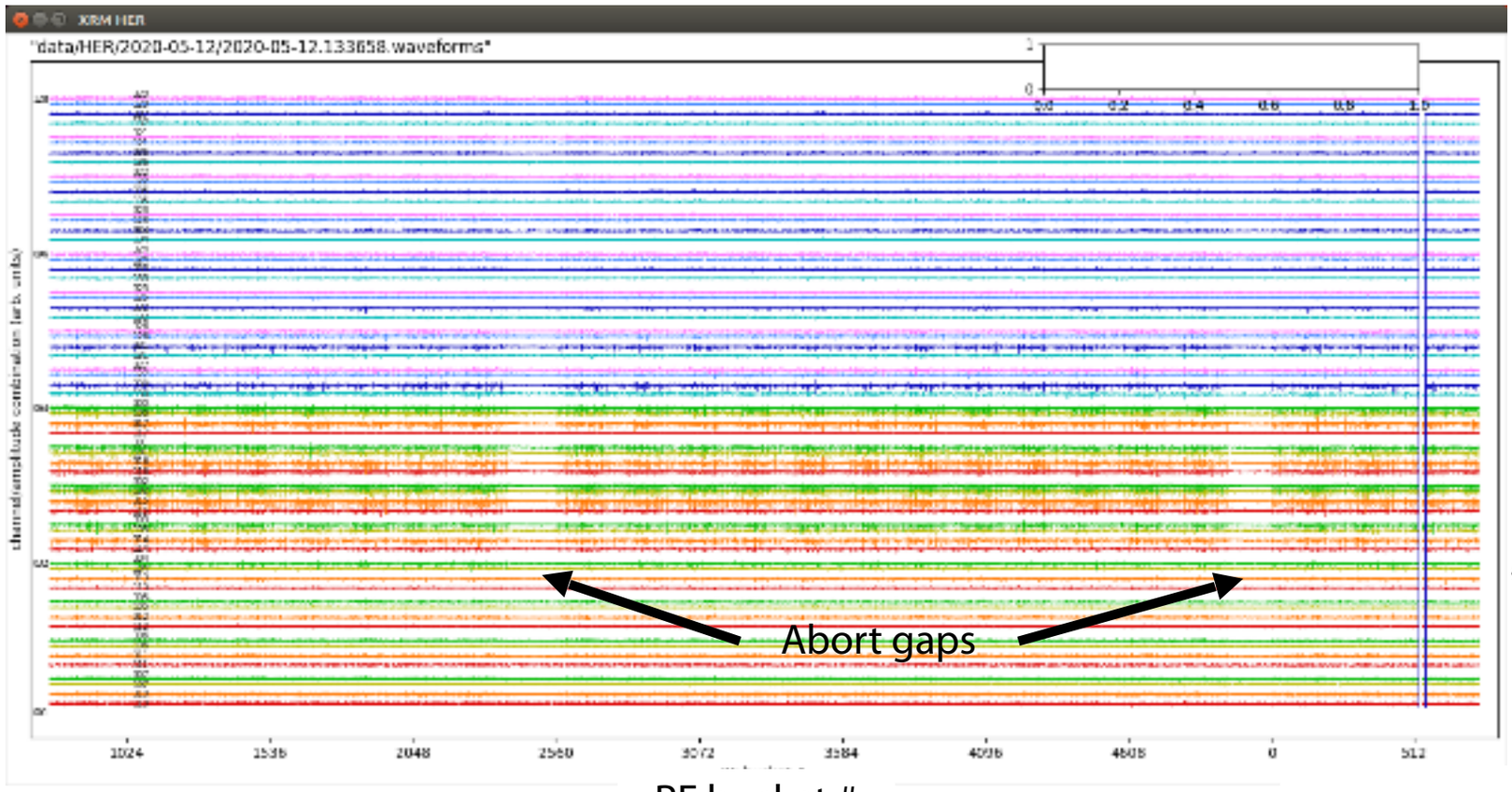


(See also Poster session #4 by Matt Andrew)

- **X-ray beam size monitors at SuperKEKB**
  1) CMOS area cameras
  → Cheep and robust, but generally slow. Suitable for streaming beam size measurements
  2) Silicon strip sensors
  → 2.7 Gsps enables bunch-by-bunch measurements. Good for beam study

CMOS cameras and Si-strip sensors are complementary monitors.

SiXRM data at HER (2020/5)



- Achievements in FY2020

  1) The HER detector measures beam-induce signals showing clear signature of two abort gaps and X-ray coded aperture mask.

  2) Stable operation for two months.

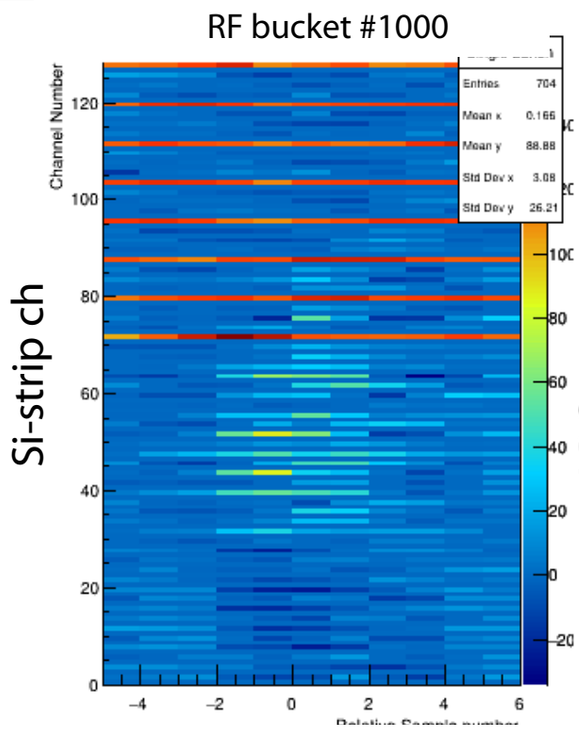
- Tasks and future plans

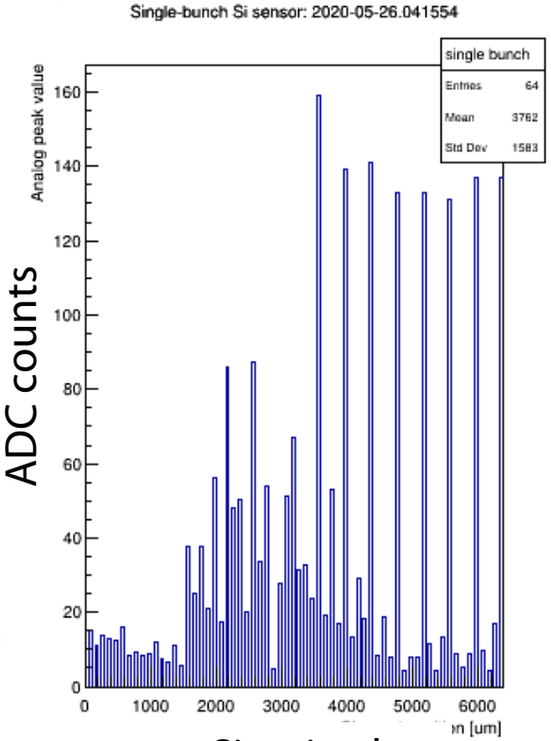
  1) Dead-channels and oscillation on the full complement

  → Hawaii University and SLAC developed new pre-amplifier being tested at Hawaii. New amplifier will be installed in 2021.

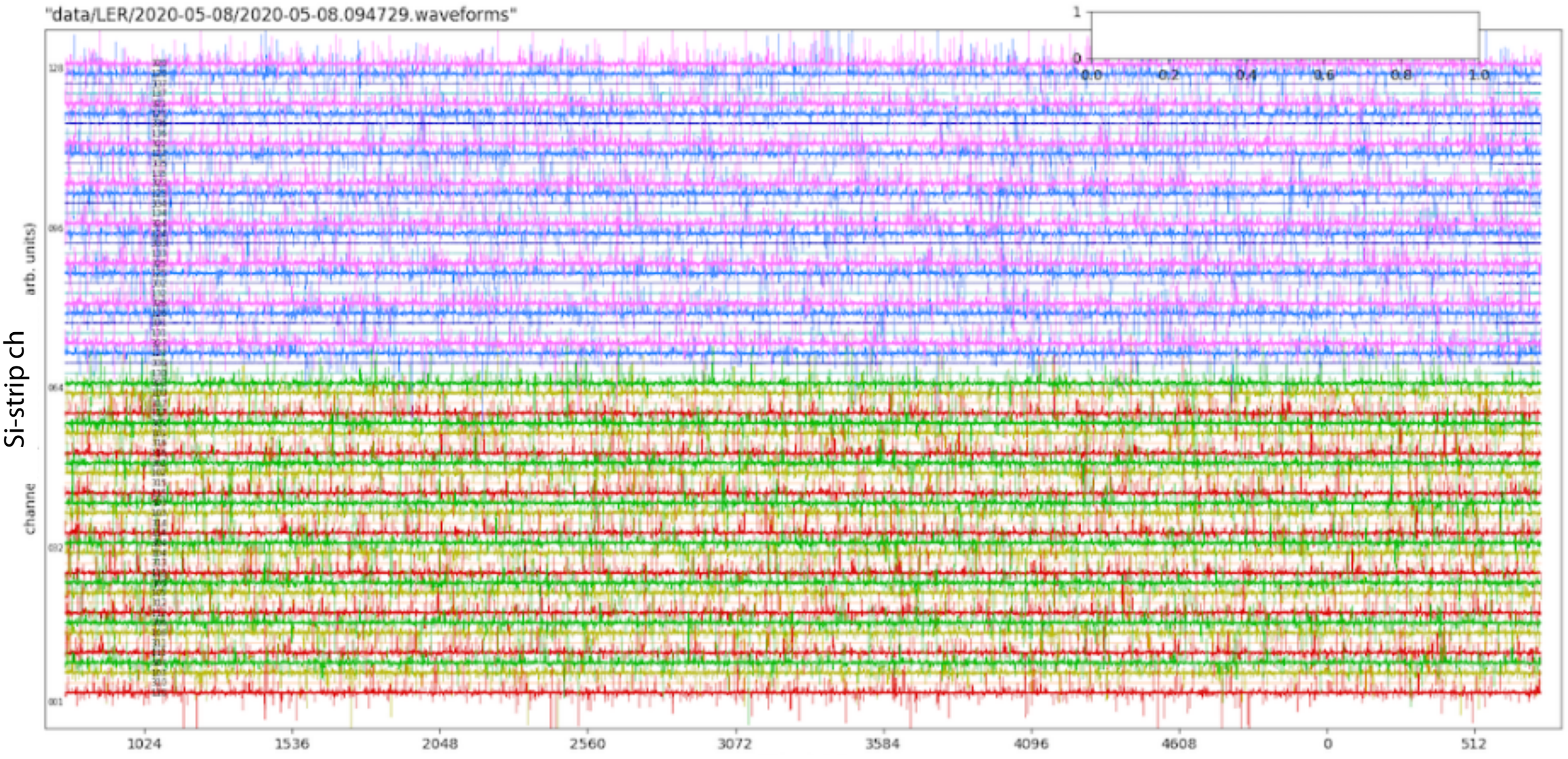
  2) Channel-by-channel gain calibration

  → The calibration bench using an infra-red laser was made at KEK. X-ray tube bench will be constructed in 2021-2022.





SiXRM data at LER (2020/5)



- **Achievement in FY2020**

  We could not take good data at LER due to large oscillation, though the LER detector was healthy before installation.

- **Tasks and future plans**

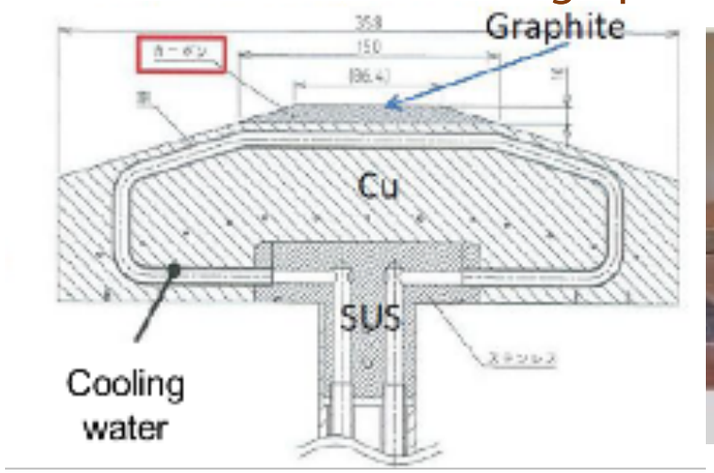
  1) New sensor and pre-amplifier will be installed in LER as well as HER.

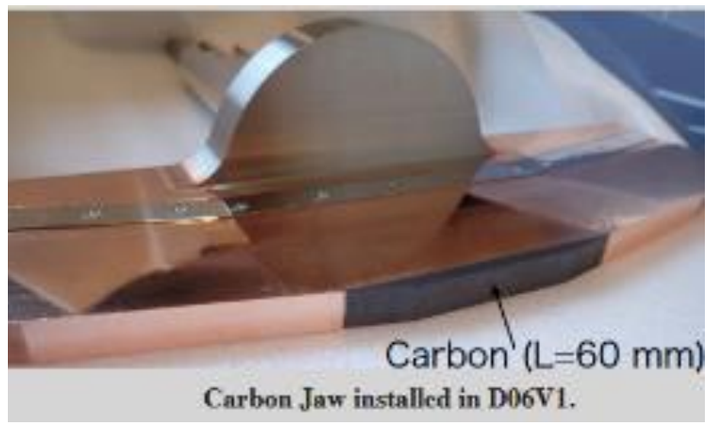
  2) Need spare amplifier and sensor at least one for each?

Low-Z beam collimators

- A new collimator with low-Z-material-made (graphite) jaws was installed in the arc section of LER in 2020.
    - A 60 mm long jaw corresponds to 1/3 of the graphite's radiation length.
    - Expected to protect "key collimators" near IP from strayed beams.
- The low-Z collimator actually well suppressed the Belle II background.
- As a side effect the high impedance induced a strong beam instability (TMCI).
- The low-Z collimator was tentatively replaced with the tantalum one.
- R&D on a new collimator jaw with a short (3 mm) tantalum head is undergoing on behalf of carbon head.

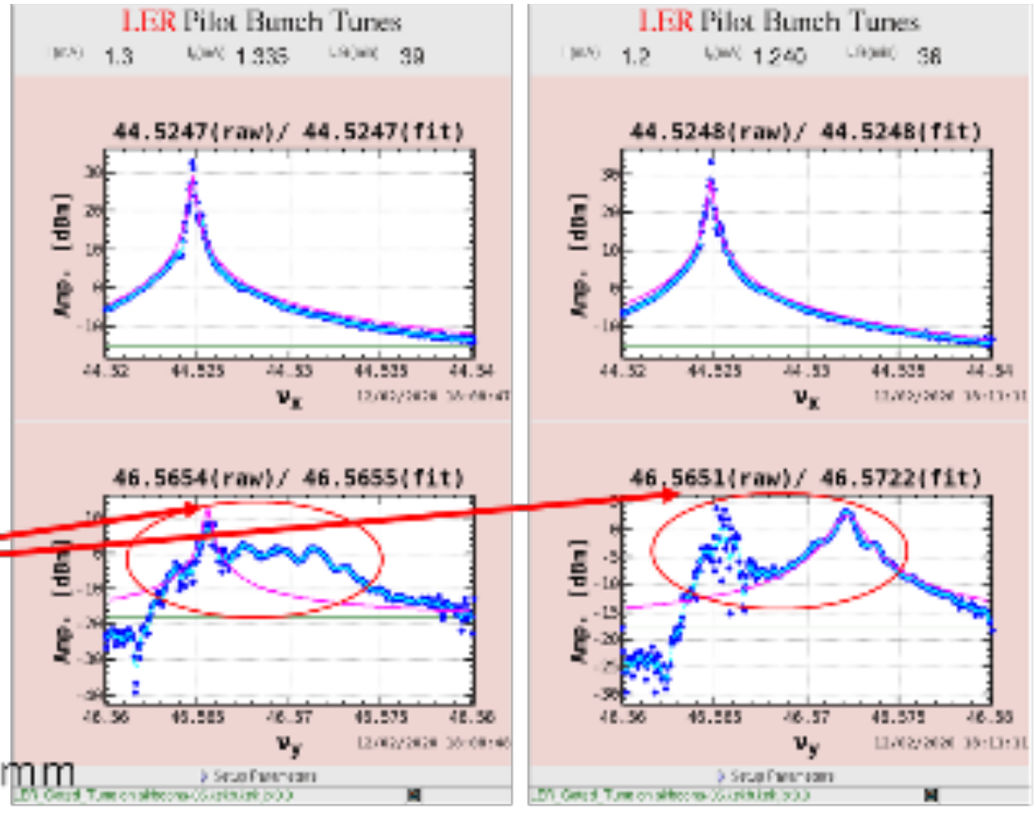
Jaw with graphite at the tip part





Carbon Jaw installed in D06V1.

LER tune spectrum (left:1.3 mA, right:1.25 mA)



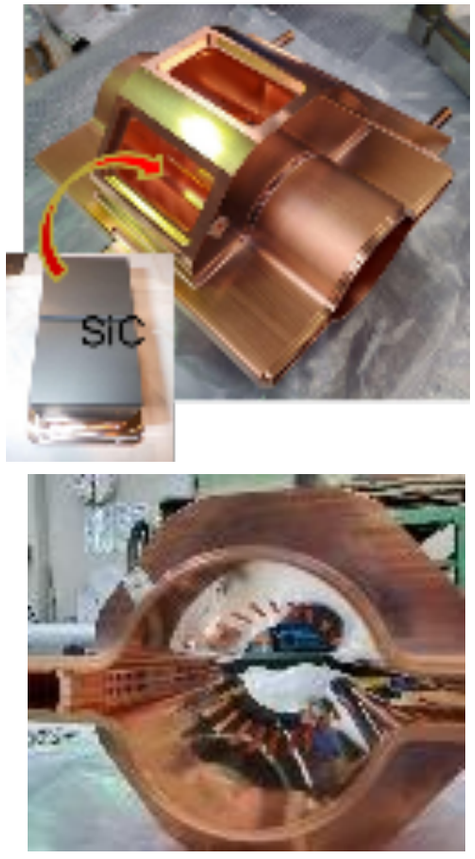
Sideband appeared and bunch current could not be accumulated

Half gap 2.5mm

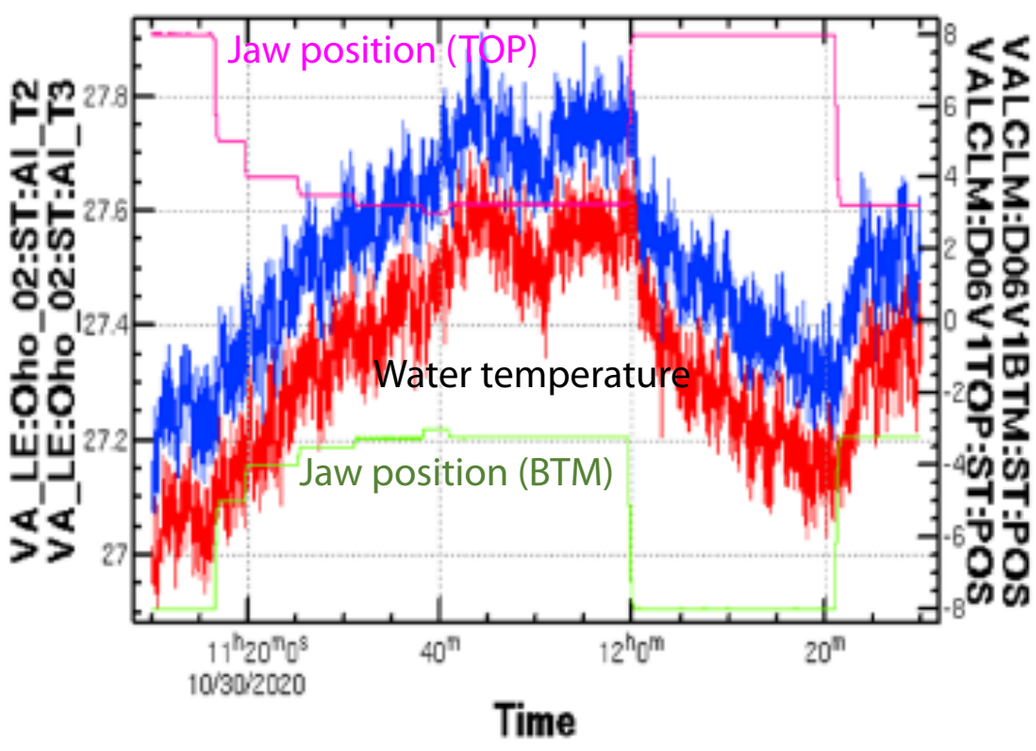
HOM (higher-order mode) absorber

- Vacuum pressure bursts near the IP might be owing to HOM heating.
- A prototype HOM absorber chamber using SiC blocks was installed in LER near a beam collimator in 2020.
- Performed beam tests with the test chamber in Oct 2020
    - Cooling water temperature changes as synchronized with the collimator jaws' position. Further detailed study is ongoing.

HOM absorber chamber installed in the ring



Temperature of cooling water and jaw positions



Beam diagnostics and control electronics

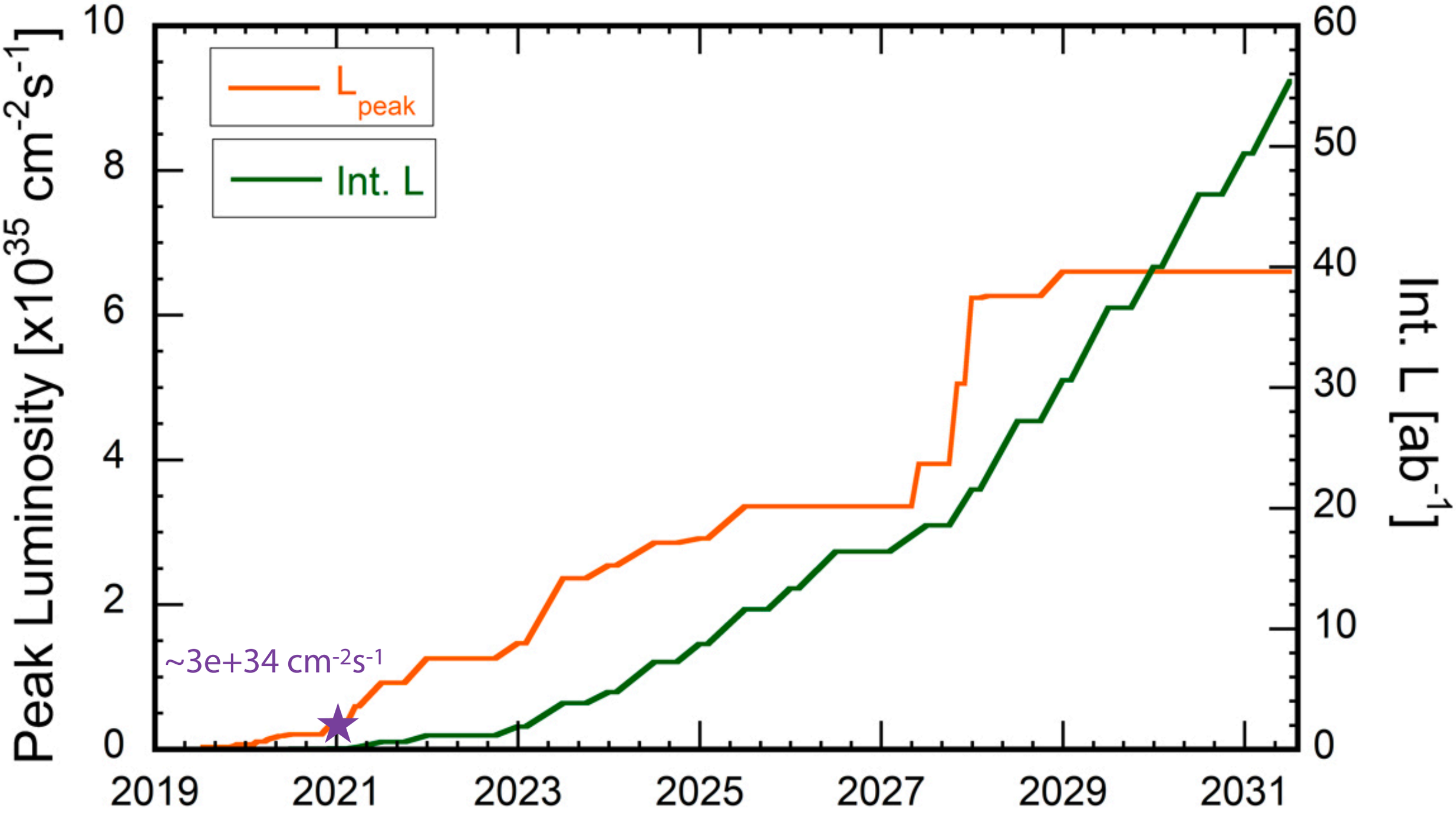
- For accelerator applications such as beam instability feedback and low-level RF control, a multi-GHz sampling RFSoc device will be a powerful tool to enable required very-high bandwidths and sampling rates.
- Evaluation test and R&D for accelerator (and detector) application are ongoing at SLAC.
    - Initial test at KEK started using the same RFSoC evaluation board as SLAC (Xilinx ZCU111).
    - Towards new bunch feedback system FPGA code developments started with a fixed frequency and then for a variable frequency.

Overall plans in FY2021-2023

- Commissioning of SuperKEKB
  - There would be no major issue due to COVID-19 for now.
  - Hope US researchers and engineers visit KEK to accelerate further!!
  - Theoretical study on impedance and beam dynamics are of importance.
- IP-orbit feedback system
  - Extension to horizontal and vertical simultaneous operation
- X-ray beam size monitor
  - Aim to complete the present detector systems and perform stable operation
  - Next challenge is to measure head-tail separate beam sizes
- Beam collimators and HOM absorber
  - Low impedance and “hard-to-break” collimators are urgent issue
- Bunch-by-bunch feedback and high-speed digital circuits
  - Develop the RFSoC-based feedback system synchronized with the RF freq.
  - Investigate possible luminosity degradation owing to noise in the feedback loop

Stay tuned!!

Luminosity projection

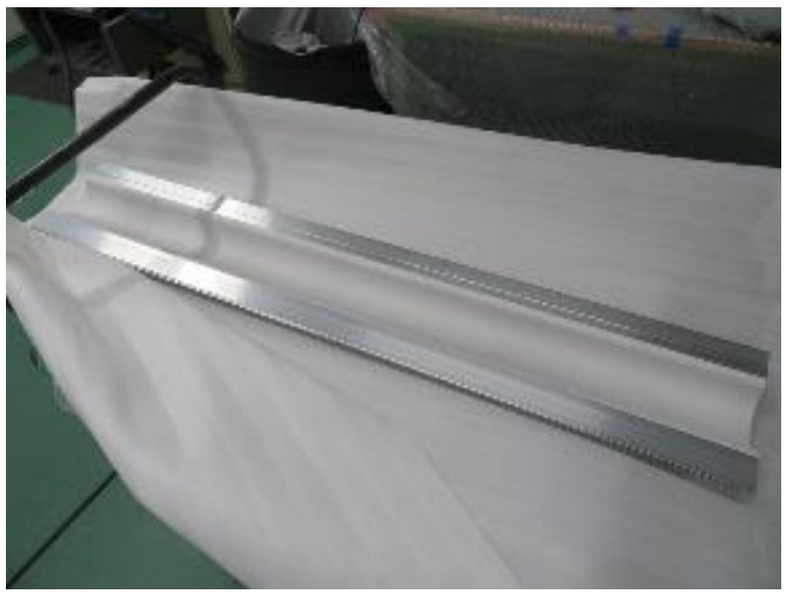


Electron cloud effects

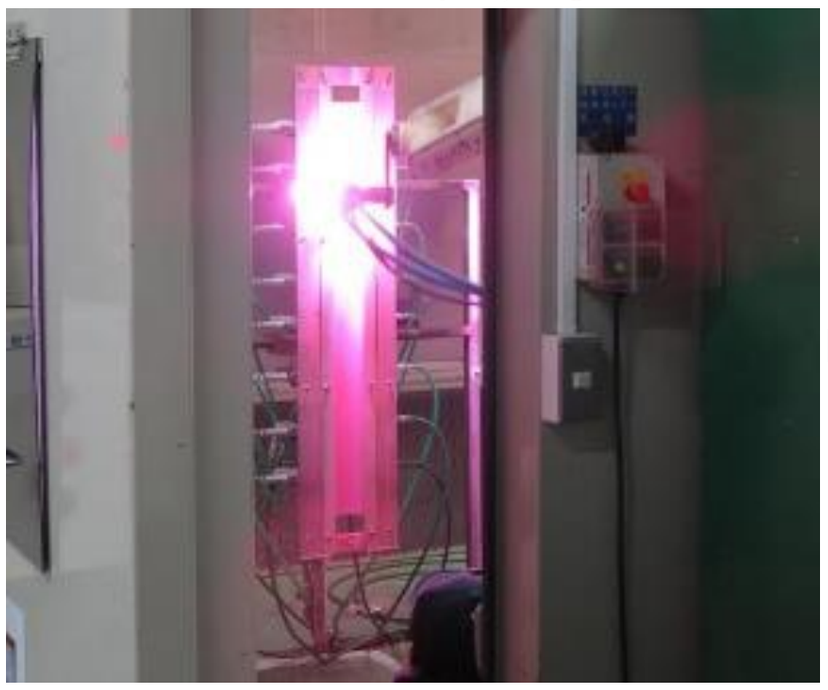
[M. L. Yao, PASJ2020, FRPP41]

- Investigating effects of rough surfaces on reducing the secondary electron yield (SEY)
  - Aluminum subtract coated with copper powder by thermal spraying showed low SEY. It is of importance to establish thermal spray conditions and beam-pipe production method.
  - Aluminum alloy beam pipe is under production now, where the inner surface was copper thermal spray coated.
- Beam pipe will be delivered soon and installed in LER in 2021 summer shutdown.
  - Electron cloud mitigation will be tested in the autumn run (a.k.a. 2021c).

Al beam pipe cut in half
(pre thermal-spraying)



Thermal splaying



After coating with rough Cu film