

Injection Beam Measurement Using Synchrotron Radiation Monitor at the SuperKEKB Electron Ring

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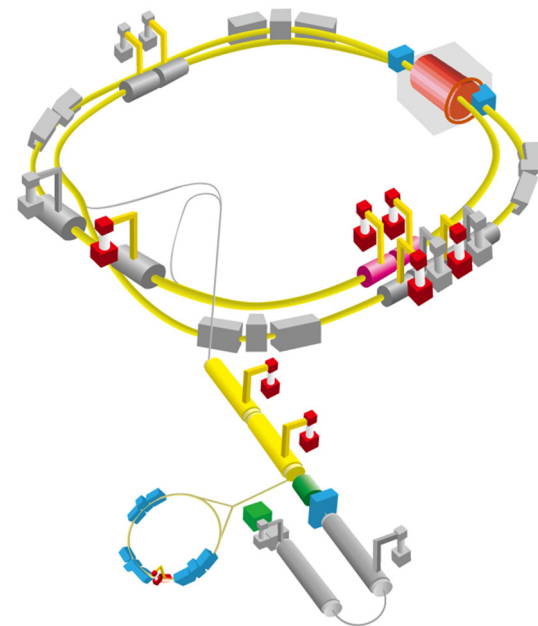
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SuperKEKB

- ▶ SuperKEKB
 - ▶ collider with 7 GeV electron and 4 GeV positron.
 - ▶ Circumference 3km
- ▶ Aiming for the highest luminosity in world, we have adopted a nanobeam scheme
 - ▶ Squeezing By^* with nano-beam collision scheme (x20)
 - ▶ Twice beam current of KEKB (x2)
- ▶ Recorded a peak luminosity twice that of KEKB.

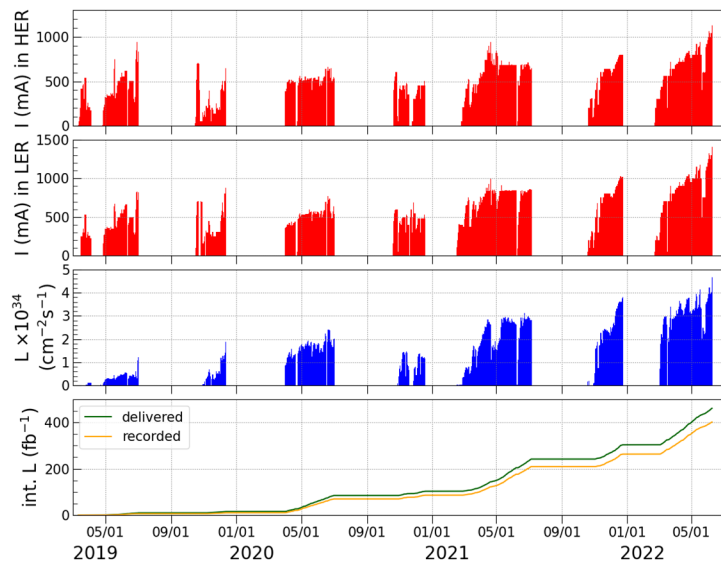
Y. Funakoshi, MOPLXGD1



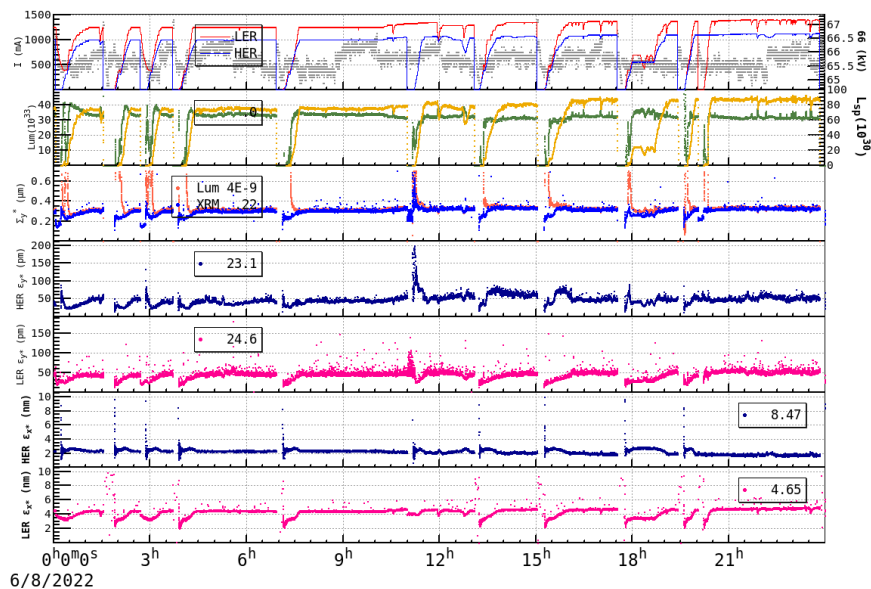
	KEKB achieved		SuperKEKB 2022/6/8	
	LER	HER	LER	HER
Ibeam [A]	1.673	1.188	1.321	1.099
# of bunch	1585		2249	
Ibunch [mA]	1.033	0.7495	0.5873	0.4887
By^*	5.9	5.9	1.0	1.0
Luminosity[$10^{34}\text{cm}^{-2}\text{s}^{-1}$]	2.11		4.65	

SuperKEKB

- ▶ Beam size measurement is very important for collision tuning to improve luminosity.
- ▶ The beam size is constantly measured and used for luminosity tuning.
- ▶ Use synchrotron radiation X-rays for beam size measurement and visible light for beam size measurement and other behaviour measurements.

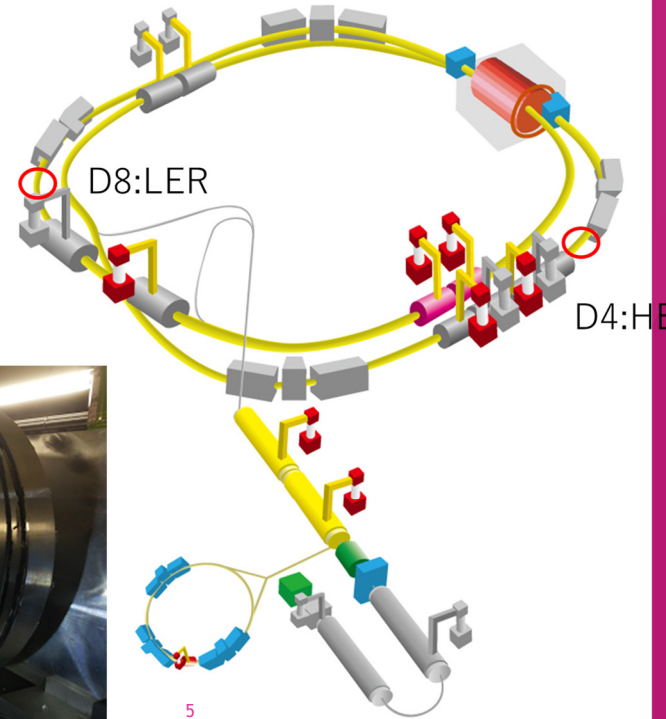
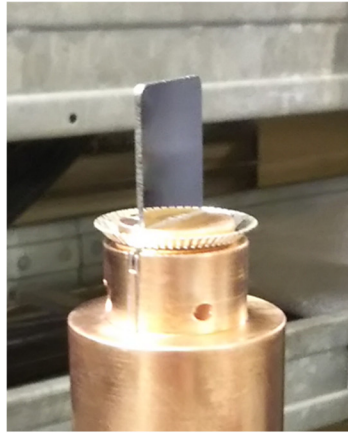
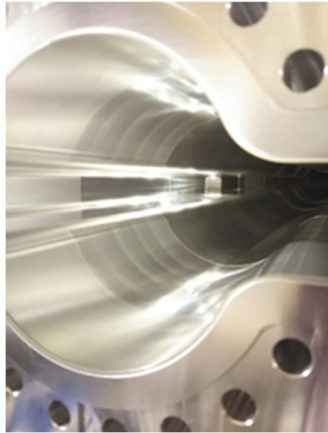


Record of increased luminosity

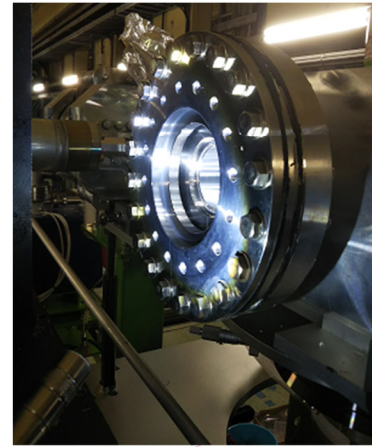


Parameters of the day when the highest luminosity was recorded

SuperKEKB Synchrotron Radiation Monitor(SRM)

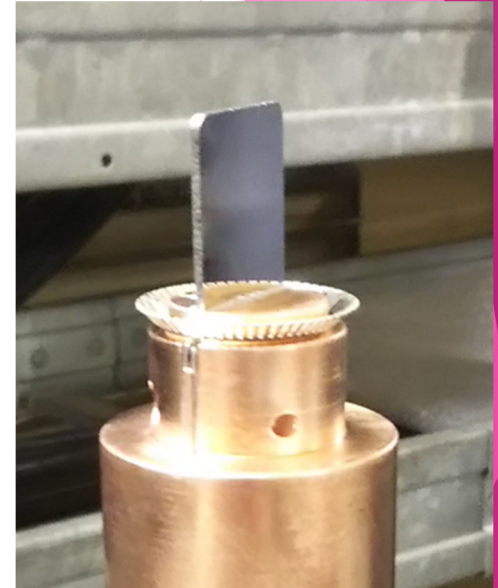


- ▶ We take emission light out of the bending magnet that set in last part of the arc section.
- ▶ Extraction chamber
 - ▶ Set up to downstream 23 m of source bend magnet.
 - ▶ Diamond mirror is inserted
 - ▶ Optical window



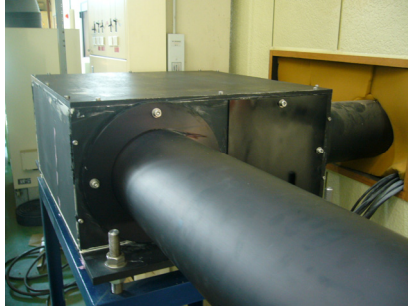
SuperKEKB Synchrotron Radiation Monitor(SRM) :SRM mirror

- ▶ An extraction mirror of visible light is made of diamond to suppress the thermal deformation.
 - ▶ Developed a single crystal diamond mirror and made efforts to suppress the current dependence of thermal deformation, but the mirror had not only the current dependence of the deformation at high currents, but also some deformations made during manufacturing at beginning of SuperKEKB.
 - ▶ Made a new thick polycrystalline diamond mirror that is not easily deformed by heat and installed it in 2020.
 - ▶ Resistance to thermal deformation is similar to single crystal.
 - ▶ Reflectance is high because the coating is changed from gold to platinum.
- ⇒ obtain a sufficient amount of light for beam profile measurement for each bunch, and it became possible to measure the injection beam for each turn.

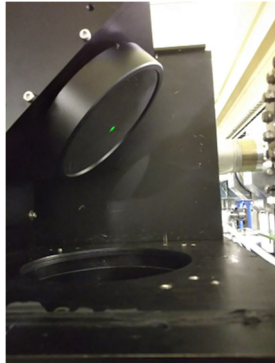


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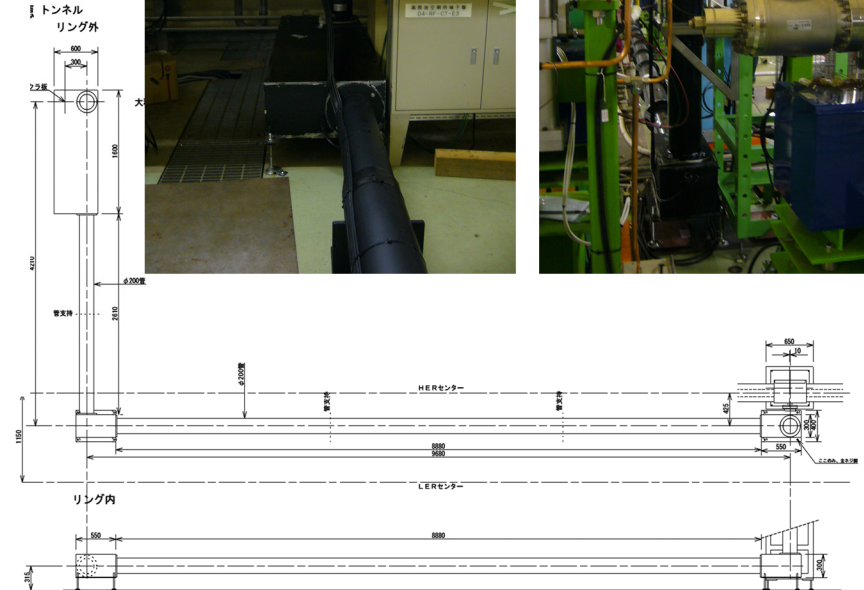
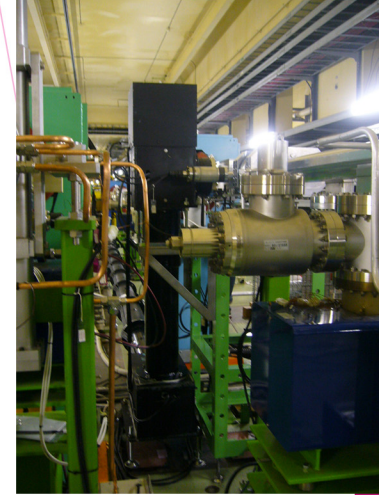
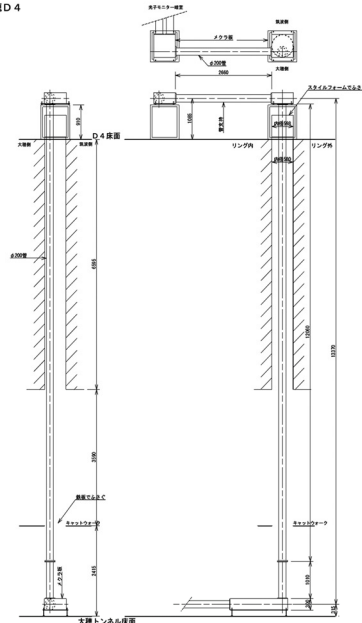
SuperKEKB Synchrotron Radiation Monitor(SRM)



- ▶ transfer mirrors
 - ▶ 6 mirrors are used to relay light to the above-ground SRM hat about 30 m downstream of chamber.

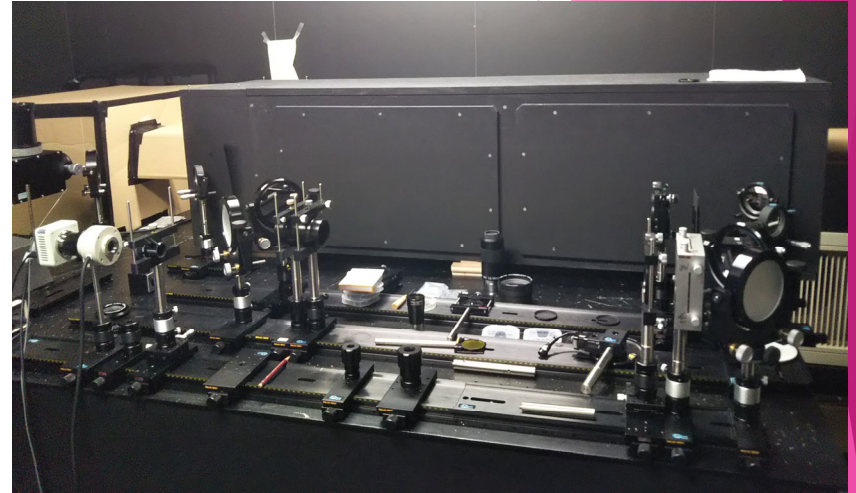
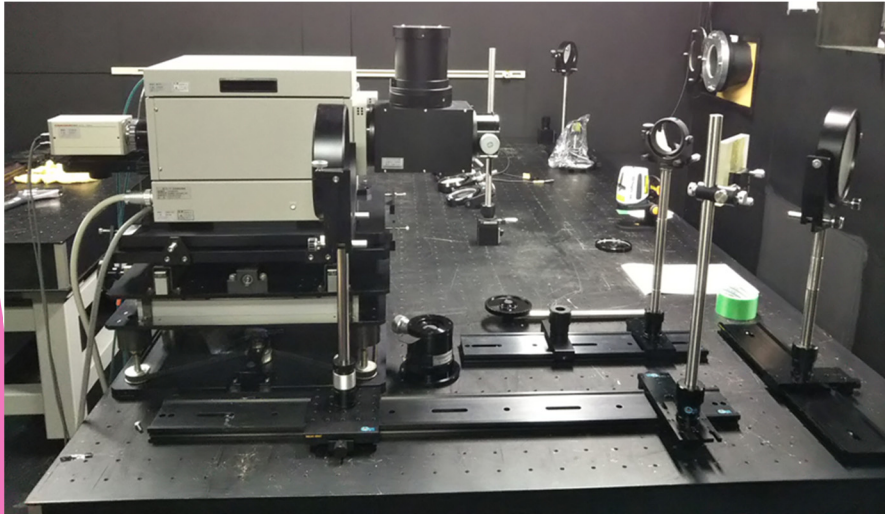


φ150mm



SuperKEKB Synchrotron Radiation Monitor(SRM)

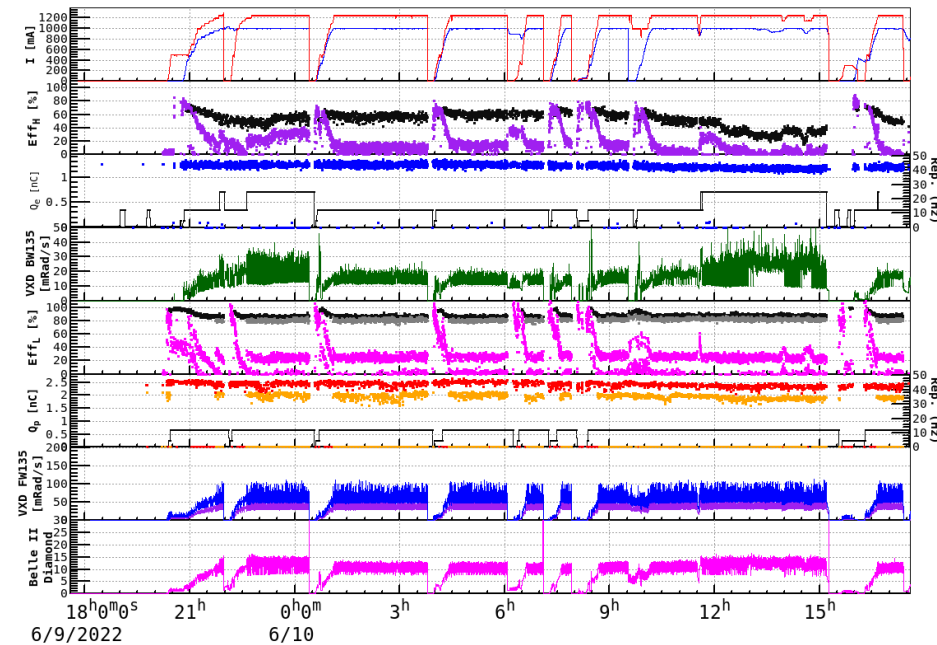
- ▶ SRM hut
 - ▶ optical system
 - ▶ Streak camera (bunch length)
 - ▶ Gated camera (corona graph, injection beam etc.)
 - ▶ Interferometer (beam size)



Injection beam measurement

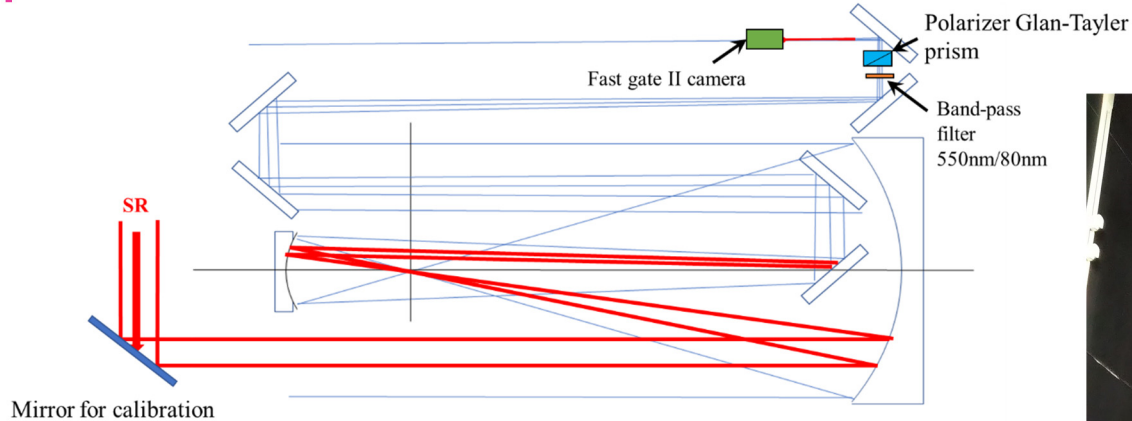
:Motivation

- ▶ In order to improve the luminosity, it is necessary to increase the current value, and a stable beam supply from the injector linac.
- ▶ When the injection efficiency becomes unstable, it becomes difficult to accumulate the beam and the background to the detector increases, which interferes with physics experiments.
- ▶ It is important to observe how the injection beam turn in the ring usually and prepare for the measurement of difference with worth efficiency injection beam.
- ▶ Since it became possible to measure the beam for bunch by bunch, we tried to see the state of the injection beam.



Relationship between injection efficiency and background

Injection Beam Measurement :Setup



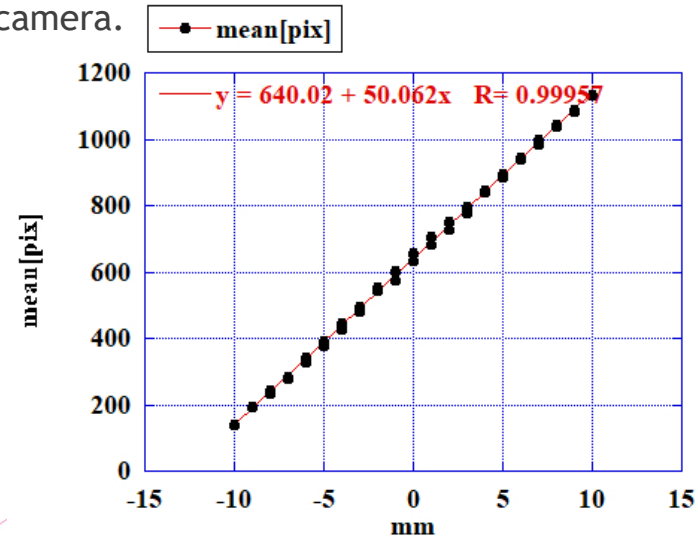
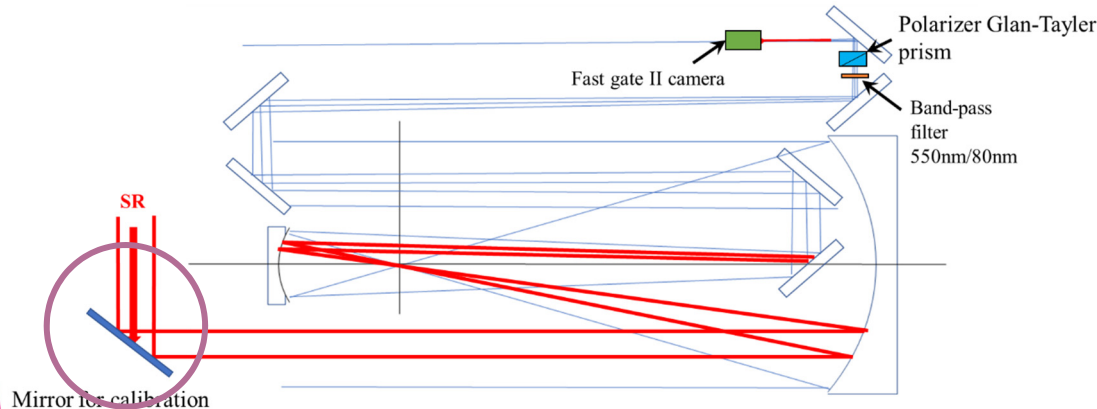
- ▶ Object system which designed for corona graph is used to measure the injection beam.
- ▶ Single-turn injection was applied on the HER beam. (Each injection bunch kicks out the previous injected bunch. Then the ring always has only one bunch).
- ▶ Measure the beam shape for each turn after injection by using gated camera.



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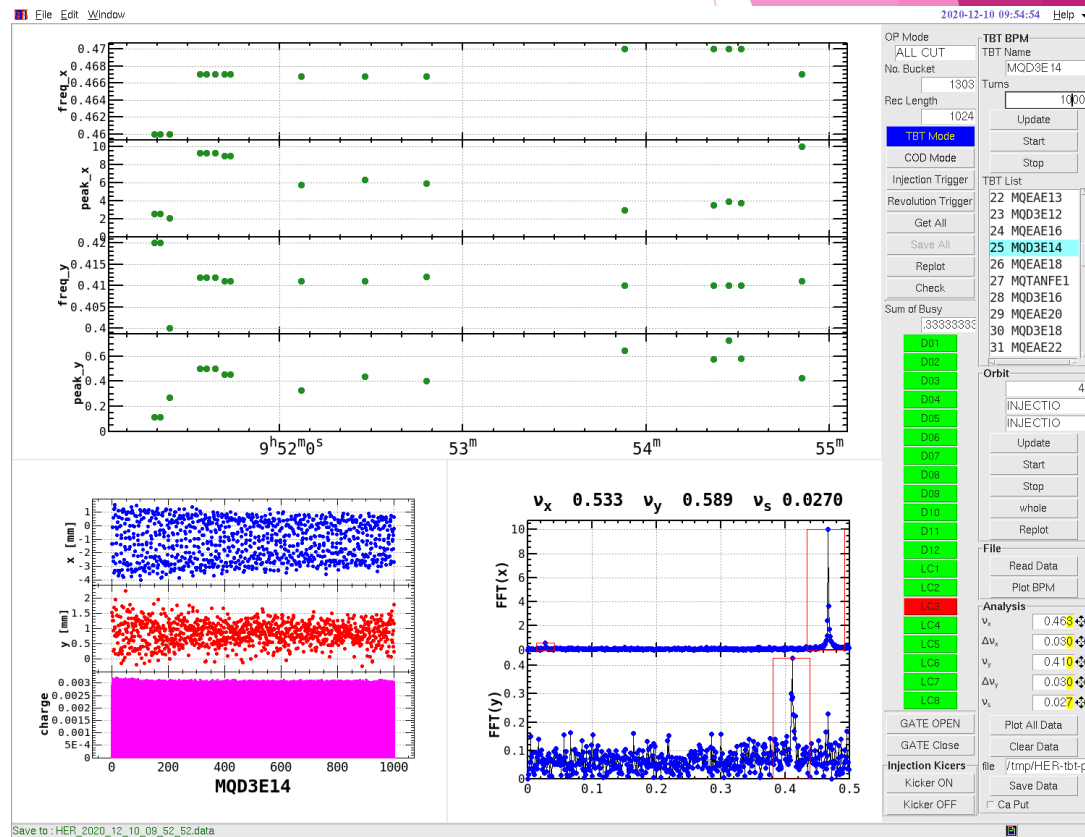
Injection Beam Measurement :Calibration

- ▶ The mirror was placed on a cross roller stage equipped with a micro-meter and moved horizontally by ± 15 mm to measure the position on the screen. This corresponds to moving the beam virtually.
- ▶ Calibration was performed using a stored beam with the gate width of the gated camera reduced when the beam was stable.
- ▶ The error bars due to measurement variability are smaller than the plot, and the variability of circles at the same position comes from the displacement of the beam due to the difference in measurement time. No large distortion is seen on the photoelectric surface of the CCD camera.



Injection Beam Measurement

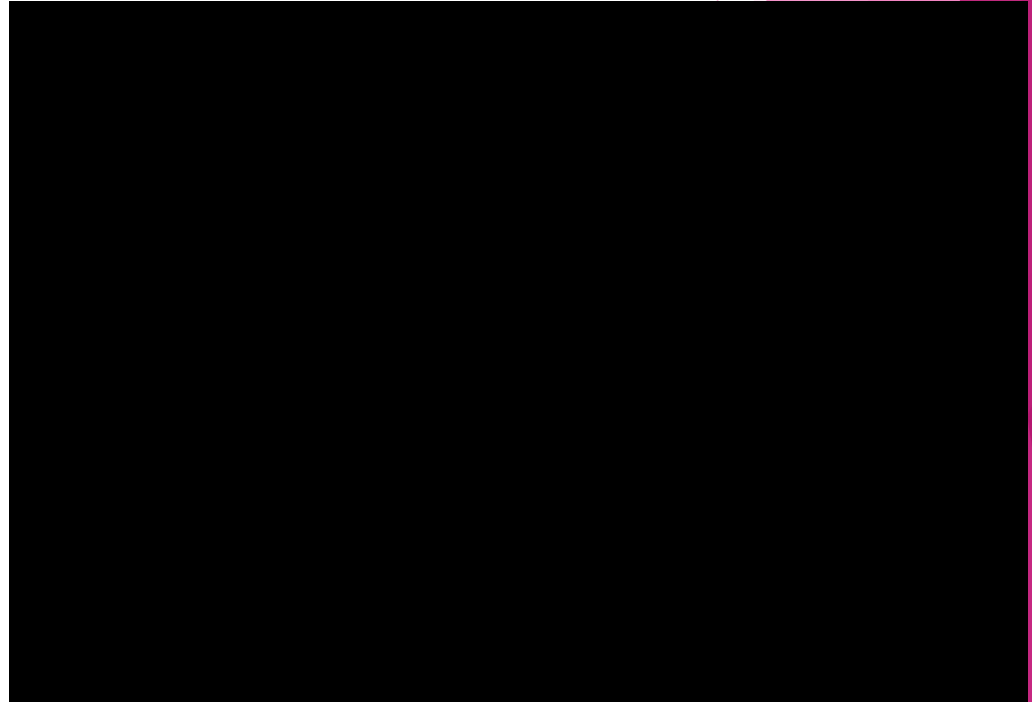
- Check the beam charge and orbit by turn-by-turn monitor before the SRM measurement.



Injection Beam Measurement

Result : HER injection beam

- Gate width : one turn ($10\mu\text{s}$).
- Trigger was applied at the injection timing
- After finding the first turn, the beam behaviour was observed turn by turn.
- The beam just after the injection repeatedly oscillation.
- Since SuperKEKB operating tune is close to a half-integer, it can be seen that the bunch moves left and right at every turn.
- The beam size does not shrink monotonically, but shrinks while repeating oscillation.



Injection Beam Measurement

Result : HER injection beam

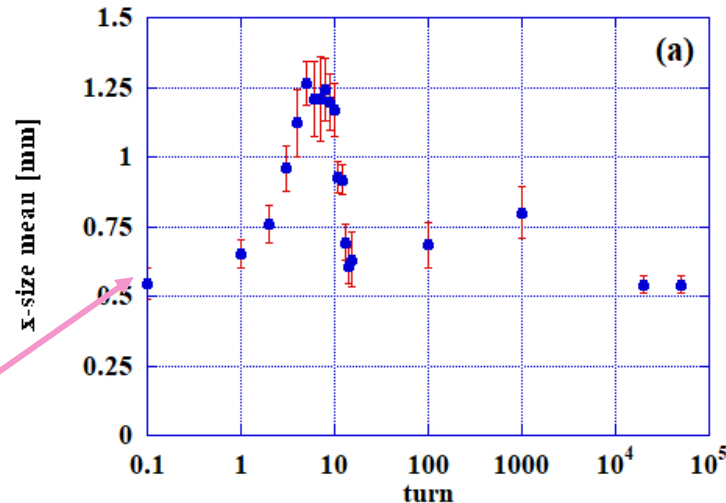
Diffraction analysis of optical system

- ▶ Transverse magnification of the focus system = 0.0204.
- ▶ Image size at imaging point of the beam $s_x=300\text{mm}$ = 6.13mm.
- ▶ Image size with diffraction is roughly given by
 - ▶ $\text{Sqrt}(6.13^2 + 6.24^2)=8.75\text{mm}$
- ▶ Then using transverse magnification, expected beam size with diffraction will be $8.75/0.0204=429\text{mm}$

Injection Beam Measurement

Result : HER injection beam

- ▶ Horizontal beam size for each turn of the injection beam after calibration.
 - ▶ The injection beam repeatedly expands and contracts and damped after 10,000 turns (10 ms).
 - ▶ The beam size is including the diffraction effect.



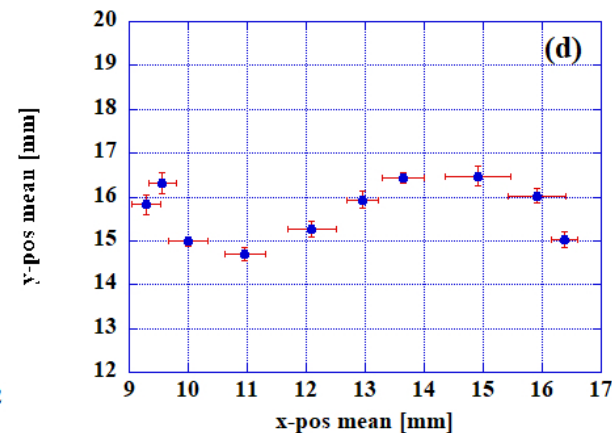
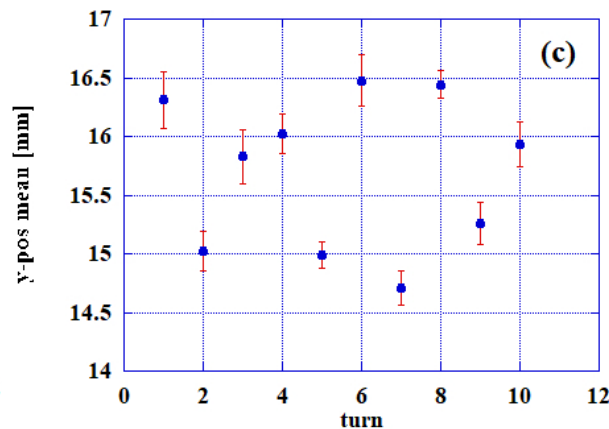
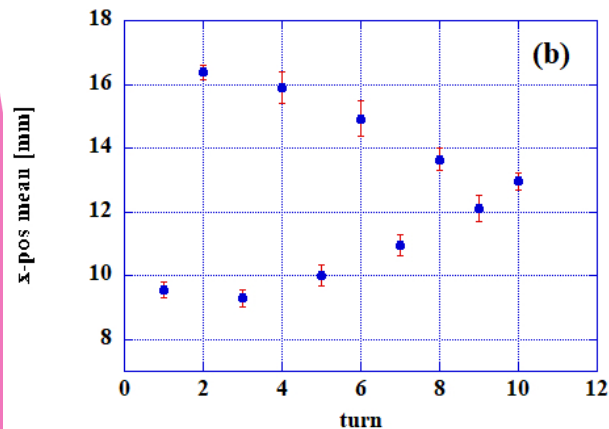
previously injection beam
and corresponds after a
complete dump for
comparison

Injection Beam Measurement

Result : HER injection beam

- The injection beam oscillation

- it can be seen that the amplitude becomes stable while oscillate with a width of about ± 4.5 mm at the maximum.

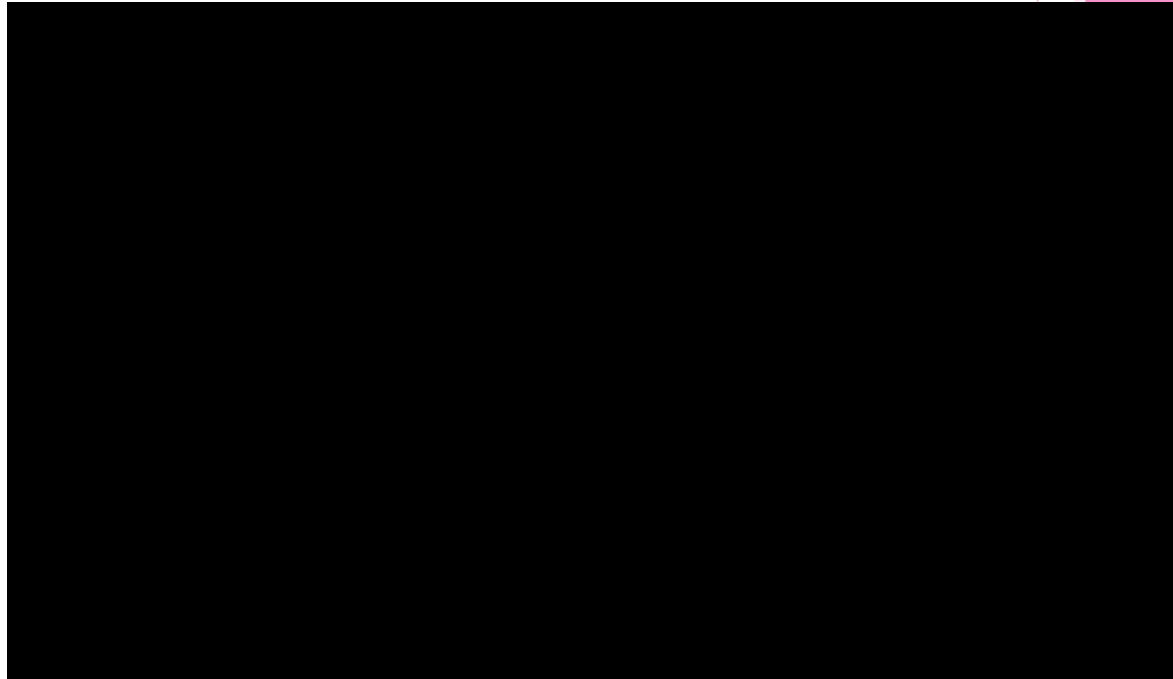


The correlation between the vertical and the horizontal oscillation width

Injection Beam Measurement

Result : LER injection beam

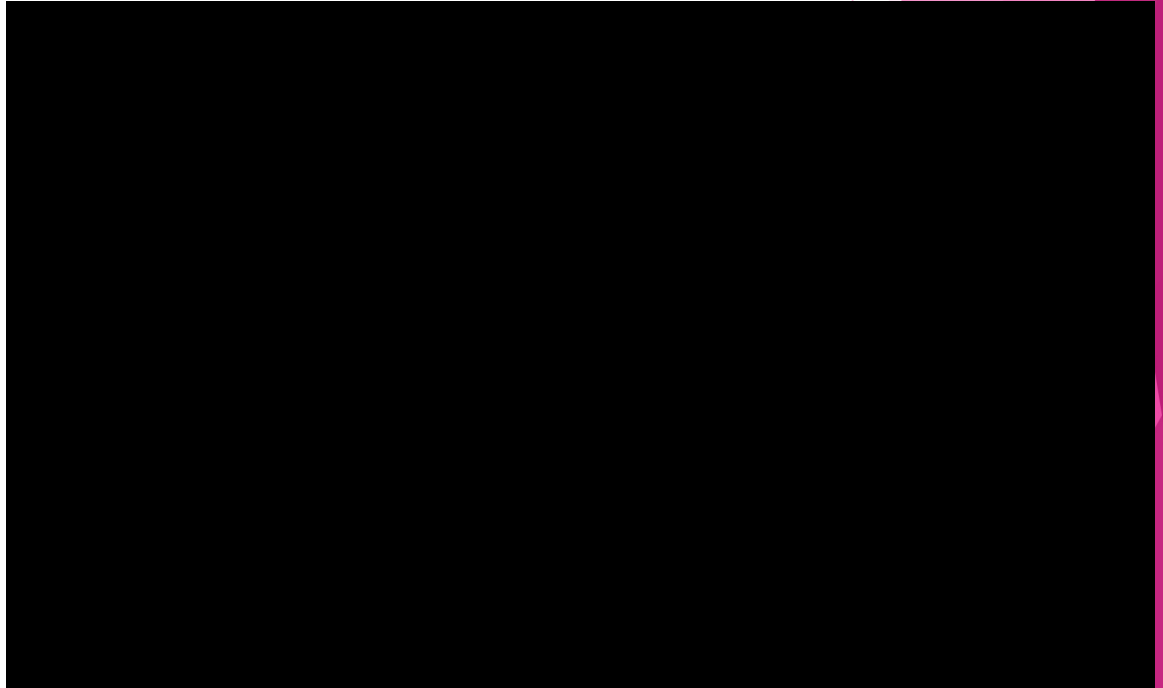
The LER Injection beam also expands and shrinks once while oscillation like the HER.



Injection Beam Measurement

Result: with stored beam

We also observed the injection beam when stacking normal collision beams.

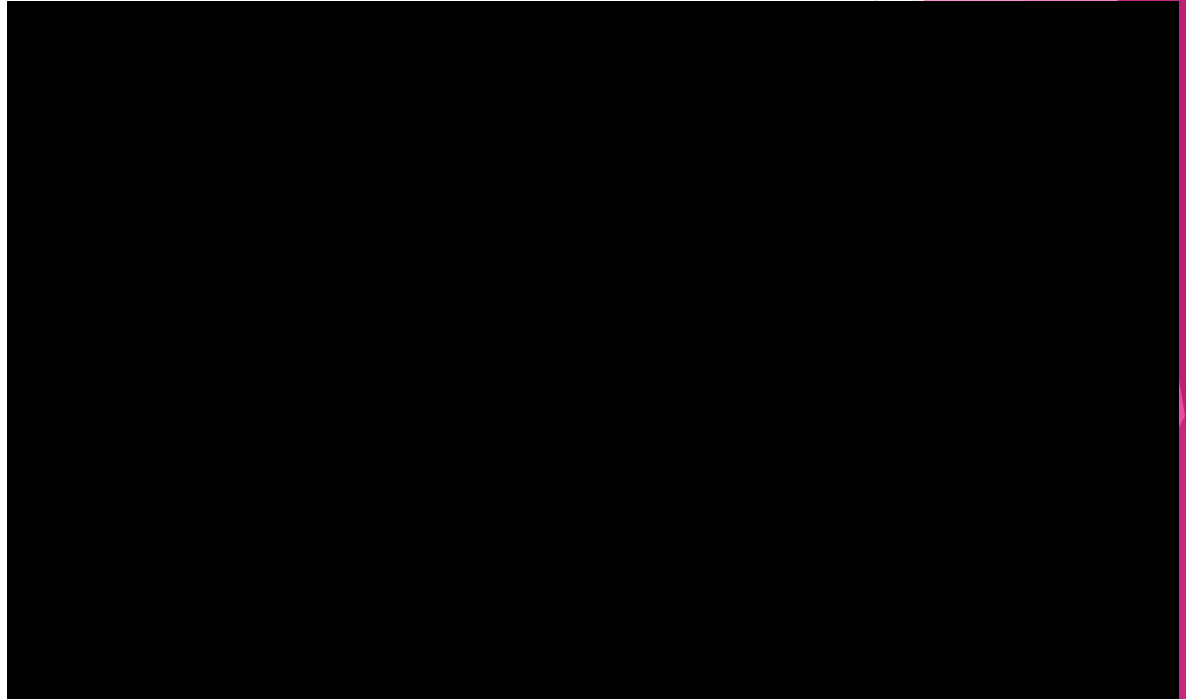


Injection Beam Measurement

Result : masked stored beam

In order to see the injection beam during the collision, we put a mask in front of the camera to hide the stored beam.

Some measurement is possible.



Summary

- ▶ SuperKEKB has prepared a system for observing the behaviour of the injection beam in the ring when the injection efficiency becomes unstable.
- ▶ By exchanging the light extraction mirrors for both the electron ring and the positron ring, the image of the beam can be clearly focused, and the injection beam, which has a smaller charge than the storage beam, can be measured turn by turn.
- ▶ It was observed that the injection beam size was dumped while oscillating even when the beam condition was stable.
- ▶ The reference data was measured in the study mode, which can measure only the injection beam in a single turn injection and by masking the stored beam, it is possible to measure some injection condition even during collision operation.