Status and Prospects of SuperKEKB

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on behalf of SuperKEKB

Accelerators and Flavor Physics

Neutrino mixing is tribimaximal.

$$U_{PMNS}=\begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

However neutrino interaction is rare.
We need strong neutrino source (and large target).
Strong proton driver is necessary.

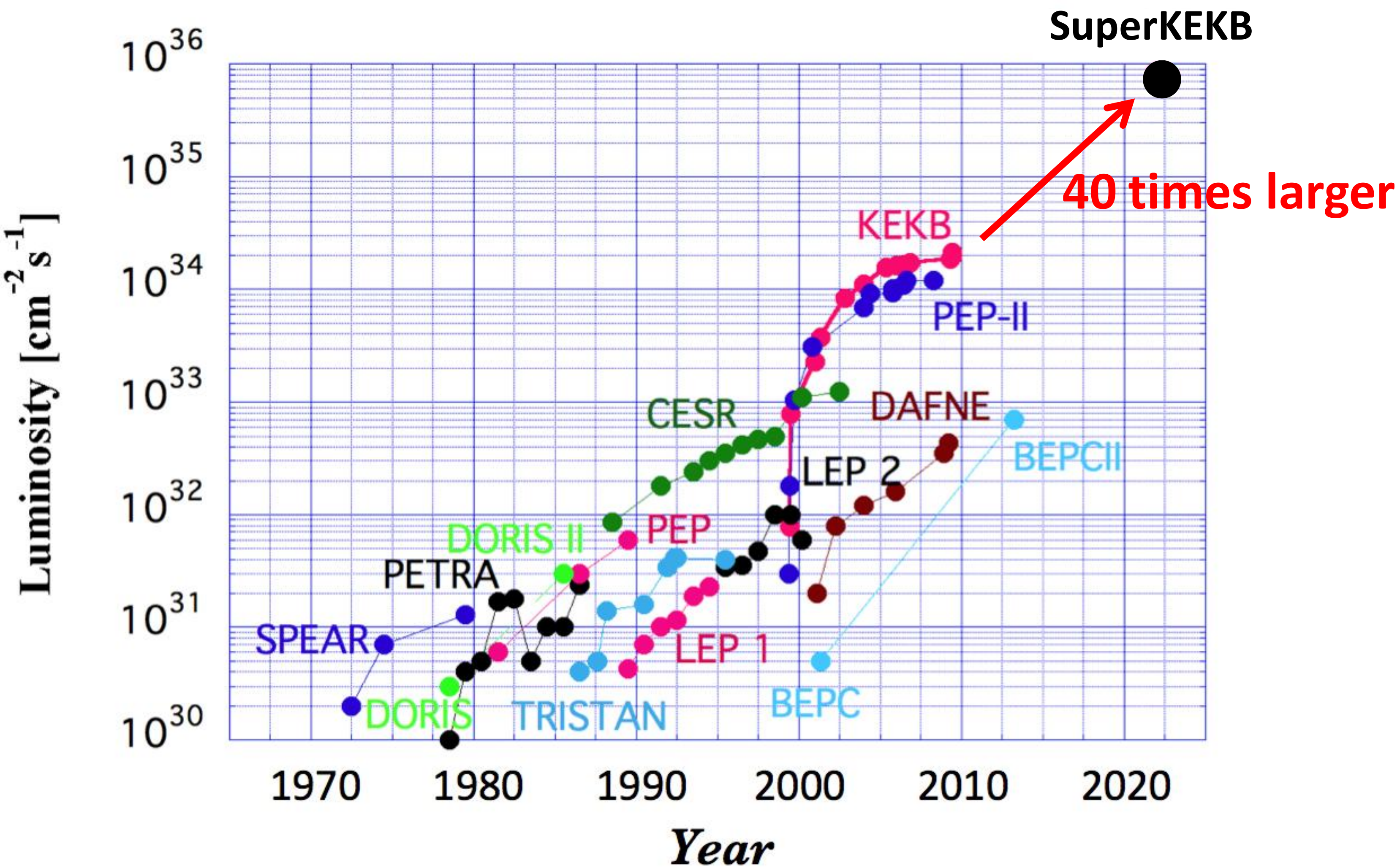
Quark mixing is diagonal.

$$U_{CKM}=\begin{pmatrix}1 & 0 & 0\\ 0 & 1-A^2\lambda^2/2 & A\lambda^2\\ 0 & -A\lambda^2 & 1-A^2\lambda^2/2\end{pmatrix}\begin{pmatrix}1 & 0 & A\lambda^3(\rho-i\eta)\\ 0 & 1 & 0\\ A\lambda^3(\rho-i\eta) & 0 & 1\end{pmatrix}\begin{pmatrix}1-\lambda^2/2 & \lambda & 0\\ -\lambda & 1-\lambda^2/2 & 0\\ 0 & 0 & 1\end{pmatrix}$$

Mixing is rare.
We need a lot of collisions.
Large luminosity collider is necessary.

Strong accelerators are necessary for future flavor physics.

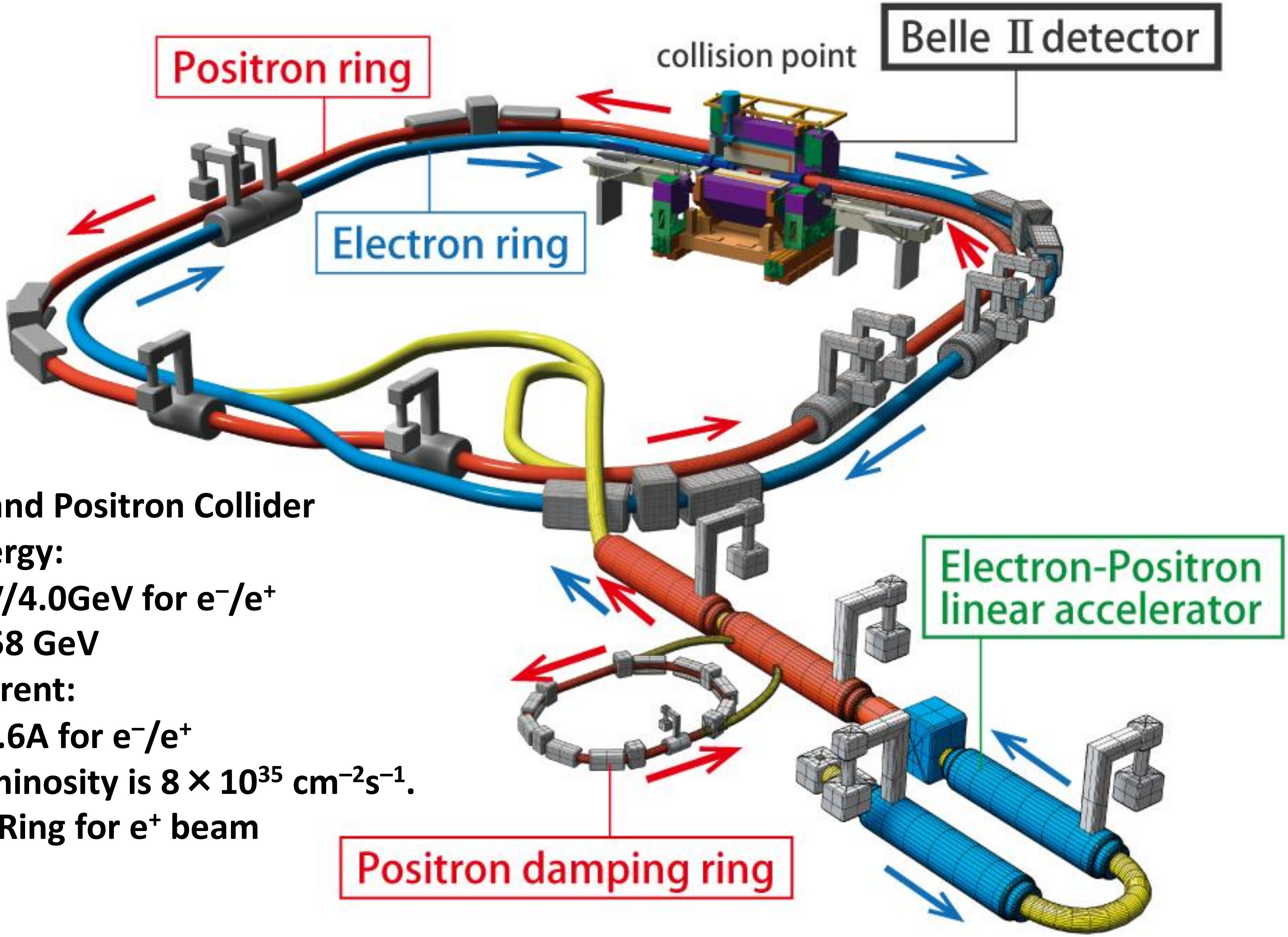
History of Luminosity Frontier



Current world's record is 2.1×10^{34} cm^{-2}s^{-1} by KEKB.

SuperKEKB aims 40 times larger luminosity.

SuperKEKB



Electron and Positron Collider
Beam Energy:
7.0GeV/4.0GeV for e^-/e^+
E_{CM} = 10.58 GeV
Beam Current:
3.6A/2.6A for e^-/e^+
Target luminosity is 8×10^{35} $cm^{-2}s^{-1}$.
Damping Ring for e^+ beam

SuperKEKB and KEK

Machine Parameters

	KEKB achieved	SuperKEKB design
Energy (electron/positron)	8.0/3.5 GeV	7.0/4.0 GeV
Current (electron/positron)	1.6/1.2 A	3.6/2.6 A
Crossing angle	22 mrad	83 mrad
Number of bunches	1584	2500
ε_x	24/18 nm	1.7/3.2 nm
β_y^*	5.9/5.9 mm	0.42/0.27 mm
ξ_y	0.09/0.13	0.09/0.09
σ_y	0.94 μm	0.059 μm
σ_z	~6 mm	5/6 mm
Luminosity	2.11×10^{34} cm^{-2}s^{-1}	8×10^{35} cm^{-2}s^{-1}

Idea of Luminosity Upgrade

2 times increase

$$L = \frac{N_{e+} N_{e-} f_c}{2\pi \sigma_x \sigma_y} \cong \frac{\gamma_{\pm}}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

20 times suppression

20 times suppression of Twiss parameter: β_y

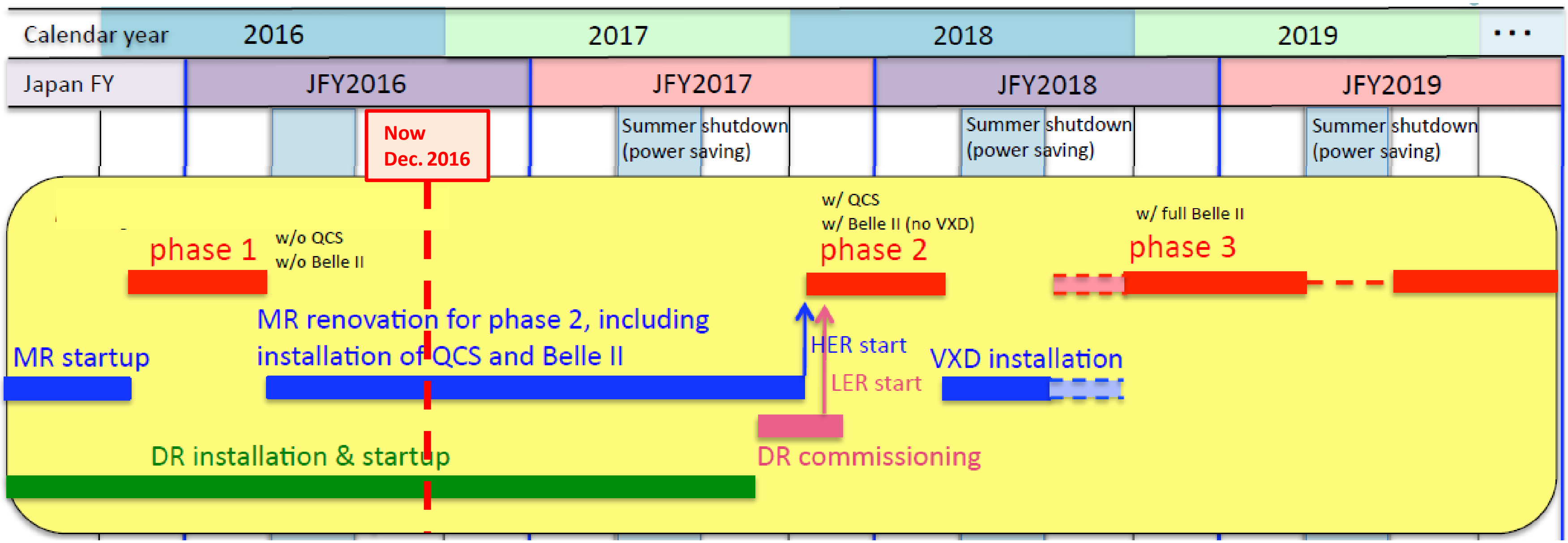
Note the condition $\sigma_y = \sqrt{\varepsilon_y \beta_y}$ is satisfied if the beam and accelerator optics are well matched.

5.9 mm (KEKB) ⇒ 0.42 mm (SuperKEKB) for electron
5.9 mm ⇒ 0.27 mm for positron

2 times larger beam current: *I*

1.64 A (KEKB) ⇒ 3.6 A (SuperKEKB) for electron
1.19 A ⇒ 2.6 A for positron

Schedule of SuperKEKB



Phase-1 operation is carried out successfully from February 2016 to June 2016.
Now we are working on the MR renovation and DR construction simultaneously.
Next target date is **November 20th, 2017** for starting DR commissioning.
Second MR operation with Belle II will be scheduled in early 2018.
Physics run will start in the end of 2018.

Achievements in Phase-1

Smooth starting up

- First beam is injected into positron ring on Feb 8th.
- Positrons are successfully stored on Feb 10th.
- First beam is injected into electron ring on Feb 22nd.
- Electrons are successfully stored on Feb 26th.

Vacuum scrubbing

- suppress radiation and raise beam current
- Temperature monitoring

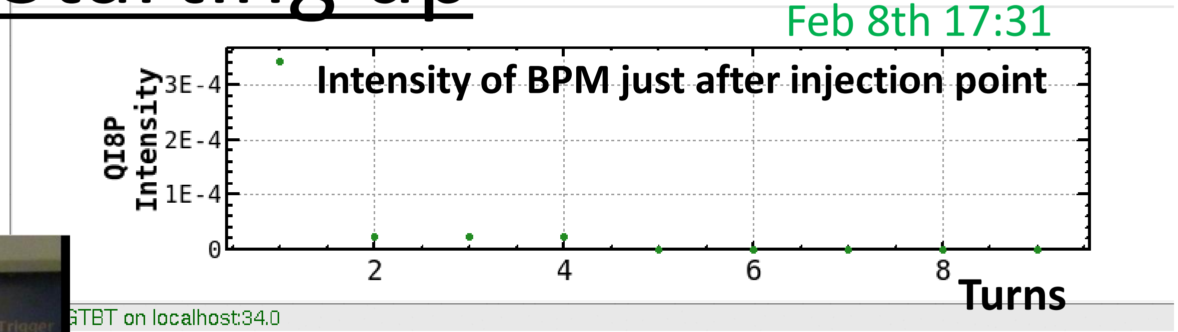
Beam Tuning

- BPM commissioning
- Optics correction

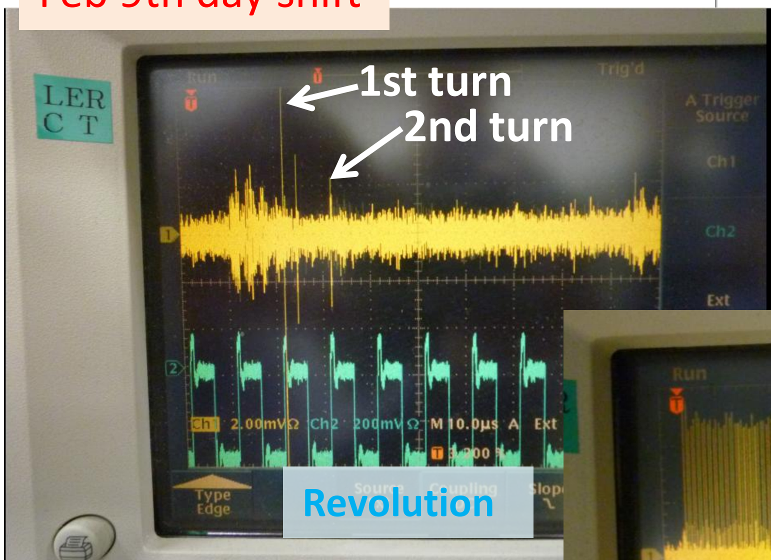
Starting up

We start operation from positron ring.

Feb 8th 17:31

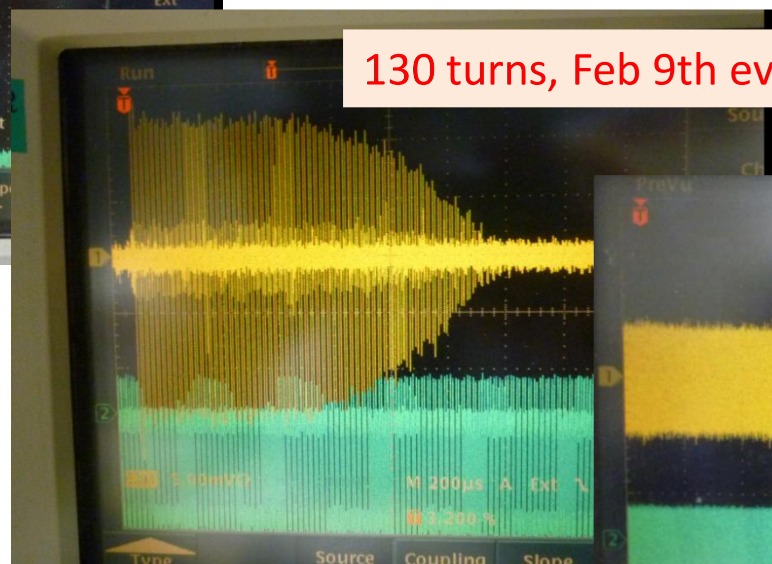


Feb 9th day shift

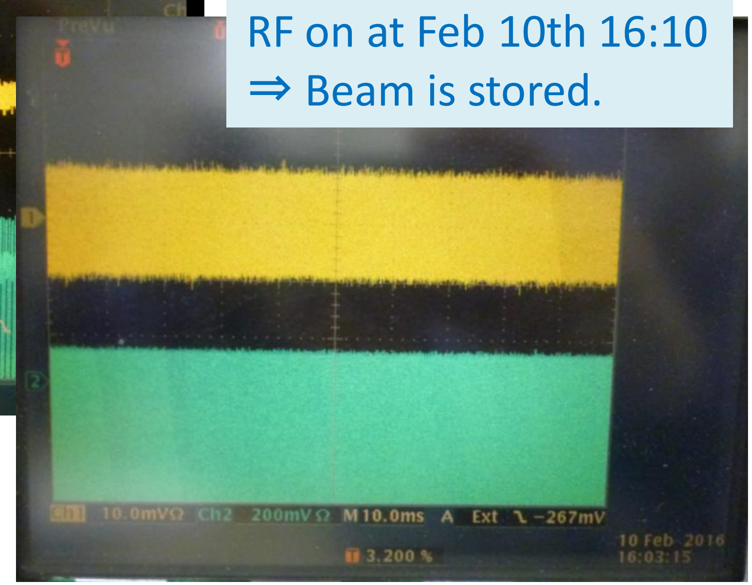


Current Transformer shows beam signal.

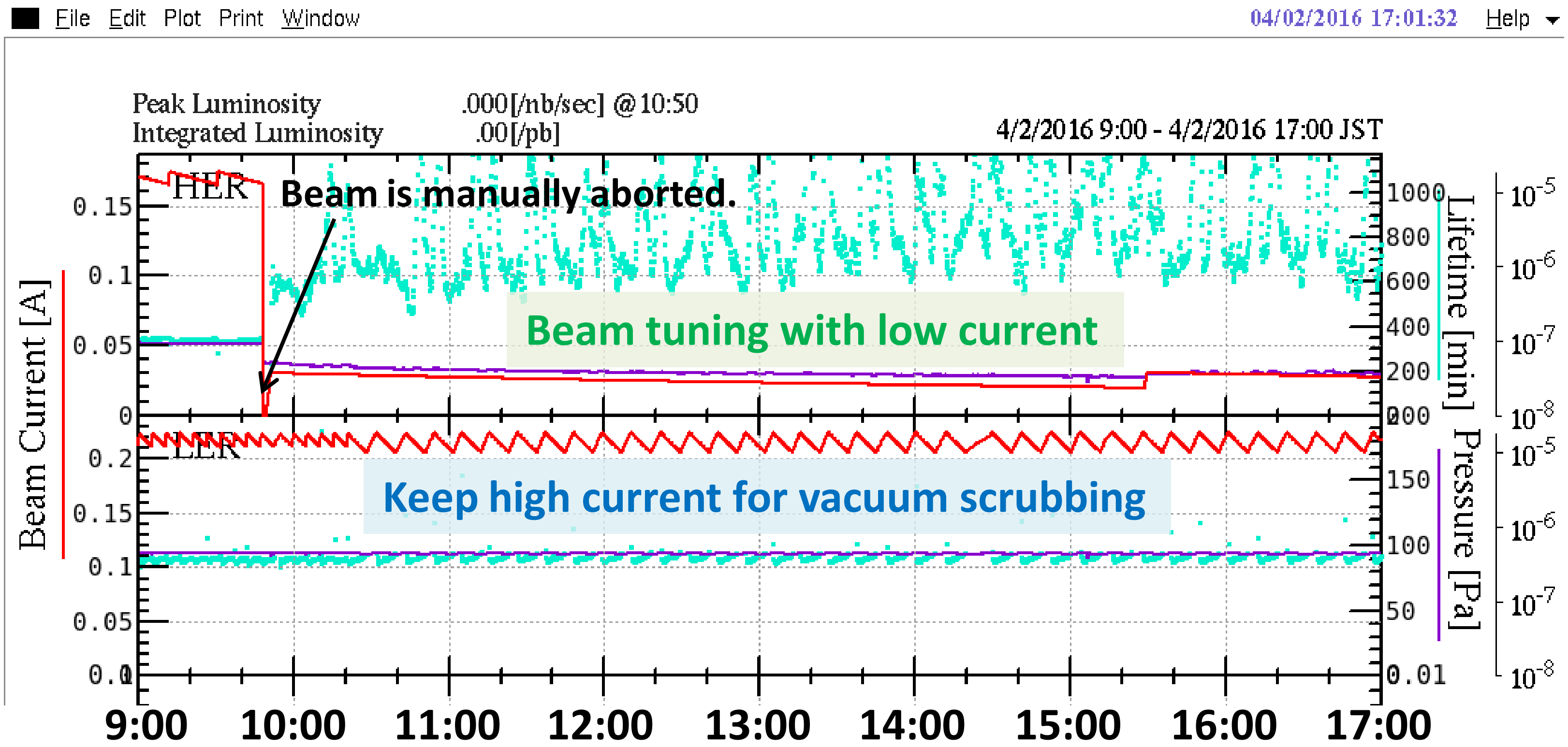
130 turns, Feb 9th evening



RF on at Feb 10th 16:10
⇒ Beam is stored.



Two Kinds of Operations



Vacuum scrubbing with high current

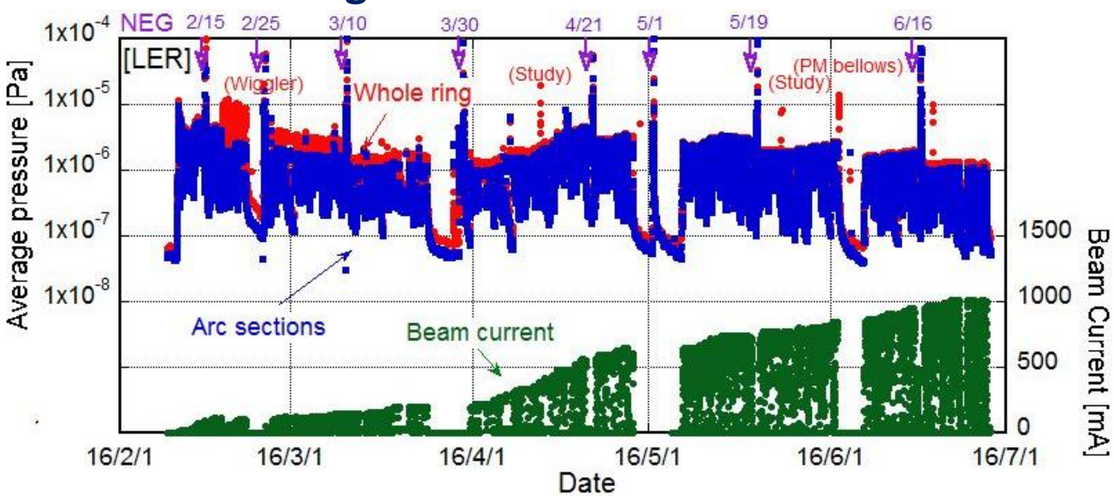
- Enlarge emittance
- Turn on feedback system

Beam tuning with low current

- without Continuous Closed Orbit Distortion Correction (CCC)

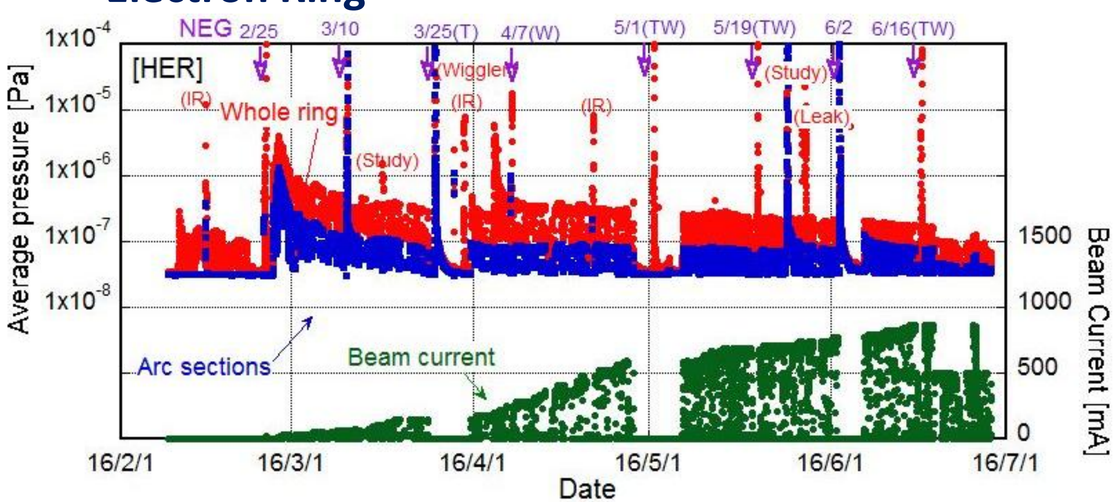
Vacuum history

Positron Ring



- Base pressure: ~5x10^{-8} Pa
- Max. beam current: 1010 mA
- Avg. Pressure: ~ 1x10^{-6} Pa
- Lifetime: ~ 60 min.

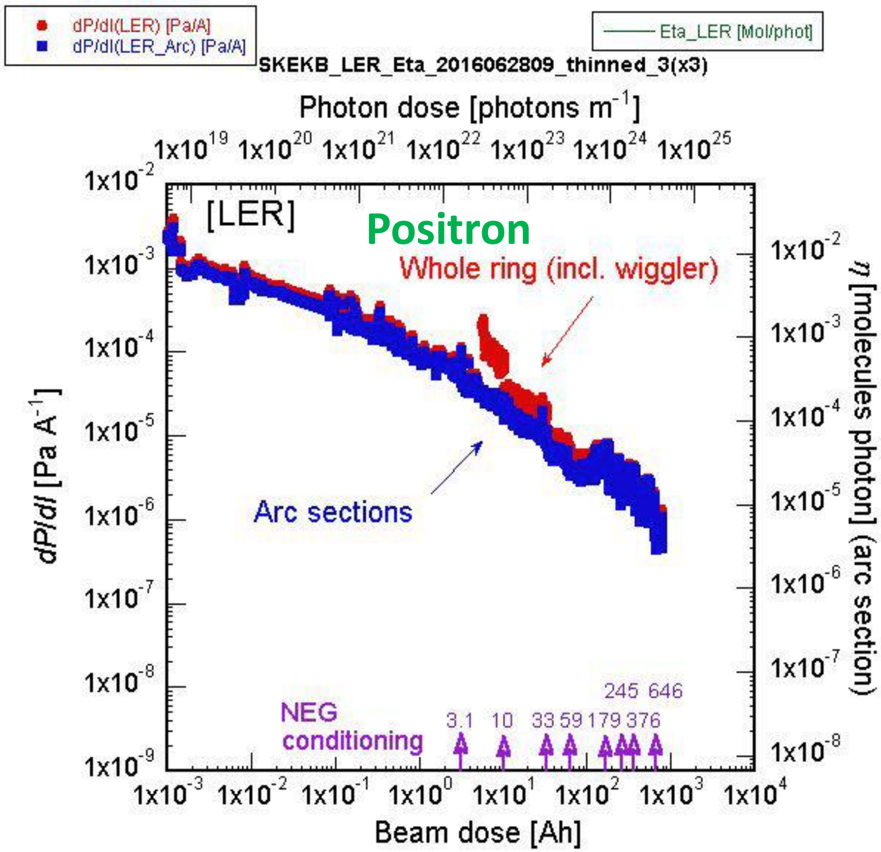
Electron Ring

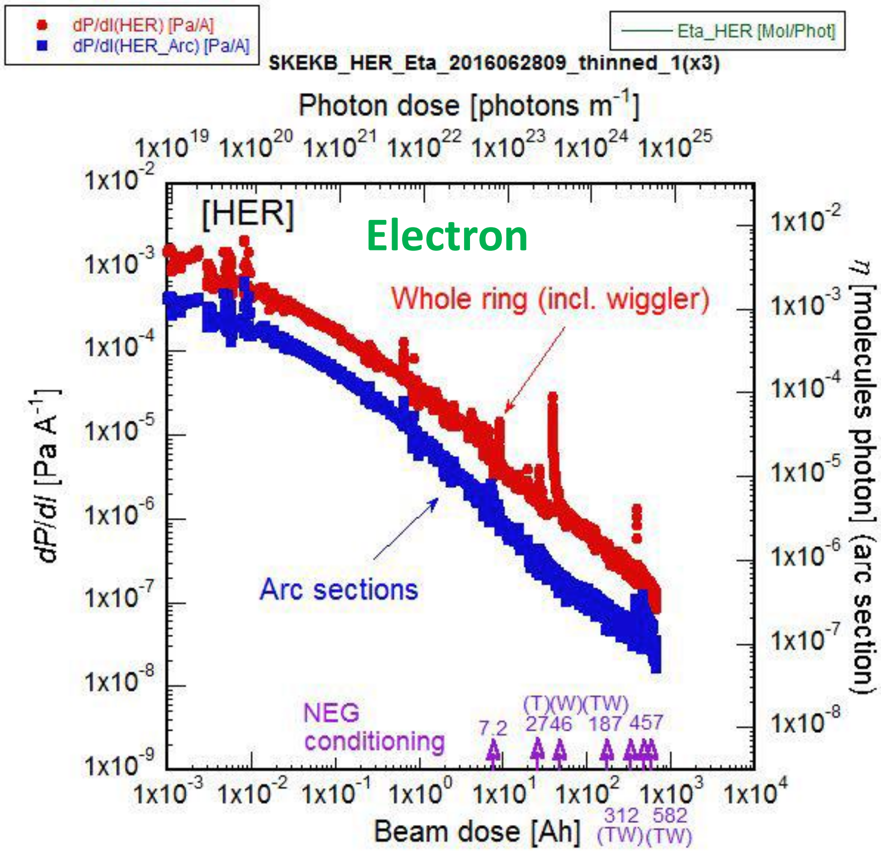


- Base pressure: ~3x10^{-8} Pa
- Max. beam current: 870 mA
- Avg. Pressure: ~ 1x10^{-7} Pa
- Lifetime ~ 200 min.

Photon Stimulated Desorption Coefficient

Target value: $\eta = 1 \times 10^{-6}$ molecules/photon for both rings





$\eta = 6 \times 10^{-6}$ molecules/photon

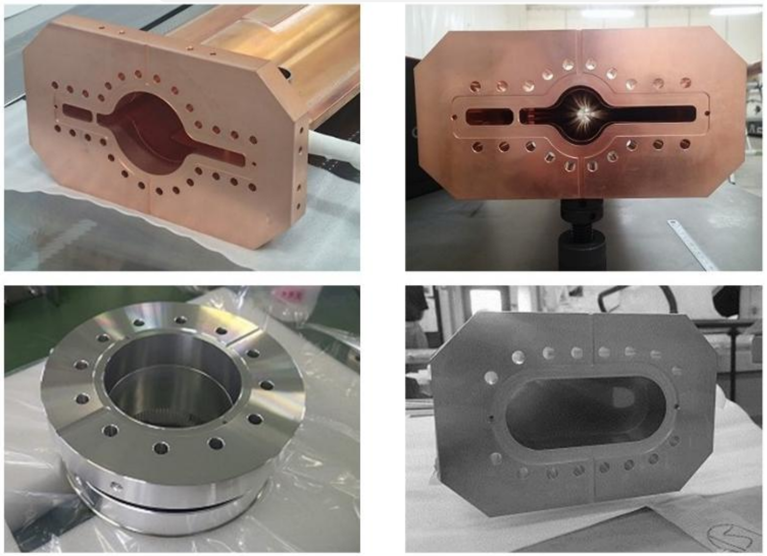
$\eta = 1 \times 10^{-7}$ molecules/photon

One order better than target value

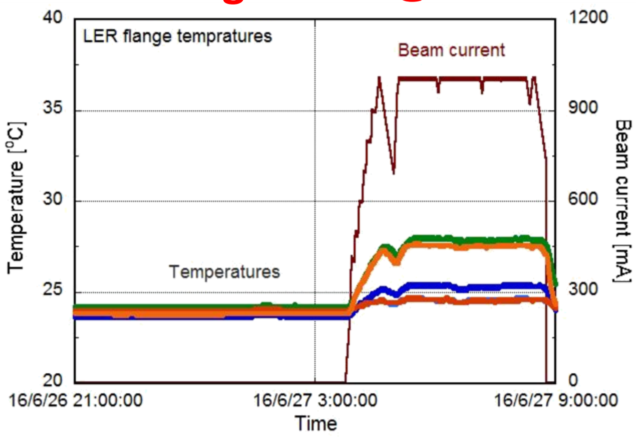
Temperature Monitoring

Temperature rise is carefully monitored for newly installed components.
They are no problem.

Various types of MO flange



2-4 degree rise@1010mA



Bellows chamber for beam pipes with antechambers

1-2 degree rise@1010mA

Gate valve for beam pipes with antechambers

2-5 degree rise@1010mA

BPM Check and Beam Based Alignment

Beam tuning is started from the check of Beam Position Monitors (BPMs).
- cable connection
- gain calibration

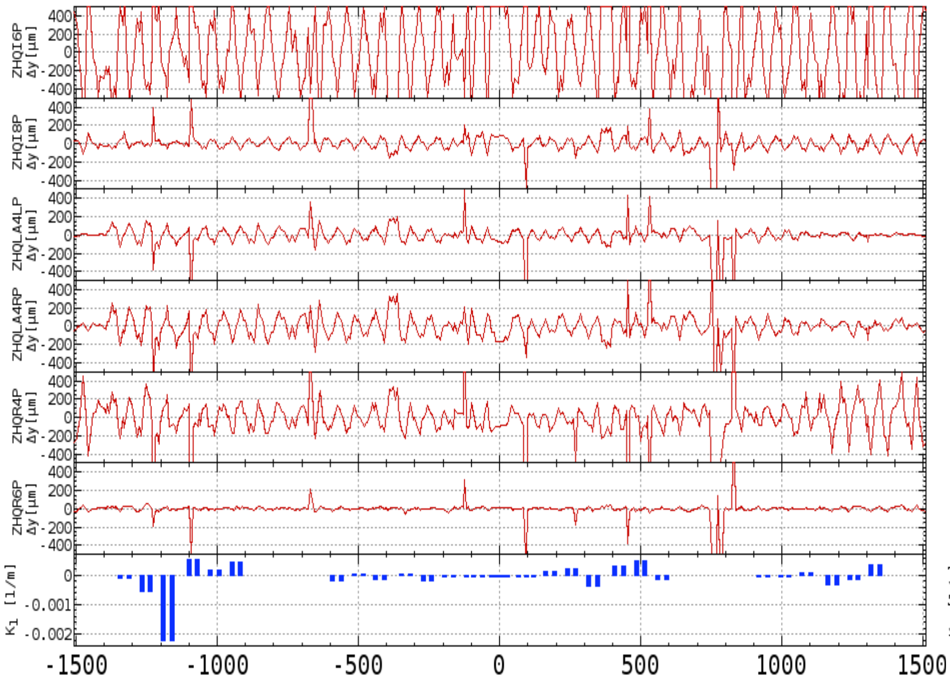
Beam Based Alignment

- steering beam to the center of quadrupole magnet
- It becomes the reference of closed orbit distortion correction.
- So called golden orbit.

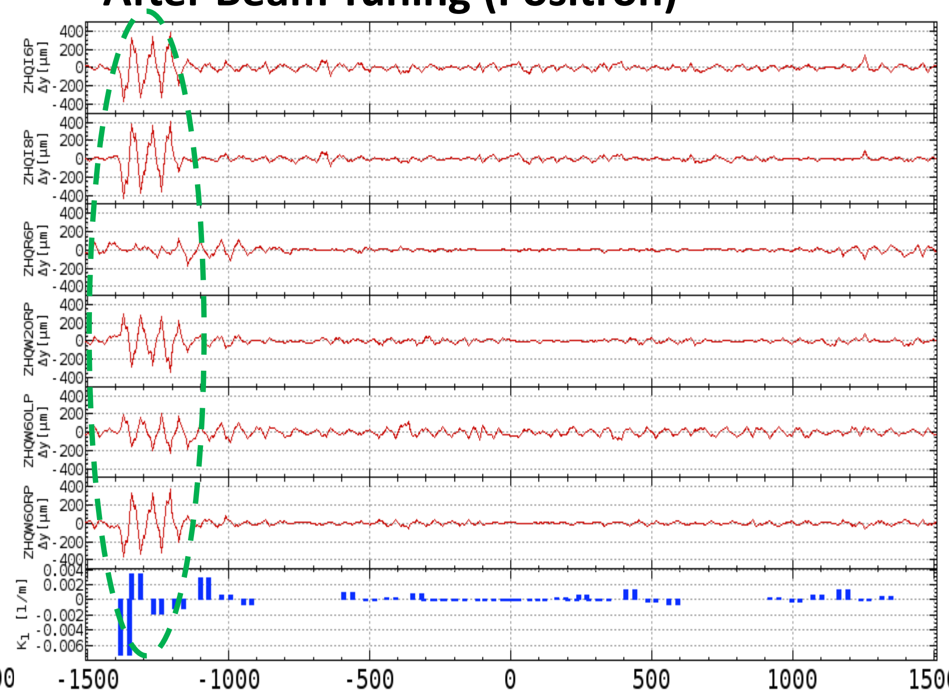
XY-coupling Correction

Beam is horizontally kicked and effects on vertical beam position are measured. Then we tune beam to suppress XY-coupling.

Before Beam Tuning (Positron)



After Beam Tuning (Positron)



XY-coupling remained near beam dump.

Suppression of XY-coupling

Lambertson-septum magnet installed on dump beam line affects storage beam line.
Its leaked magnetic field makes XY-coupling.

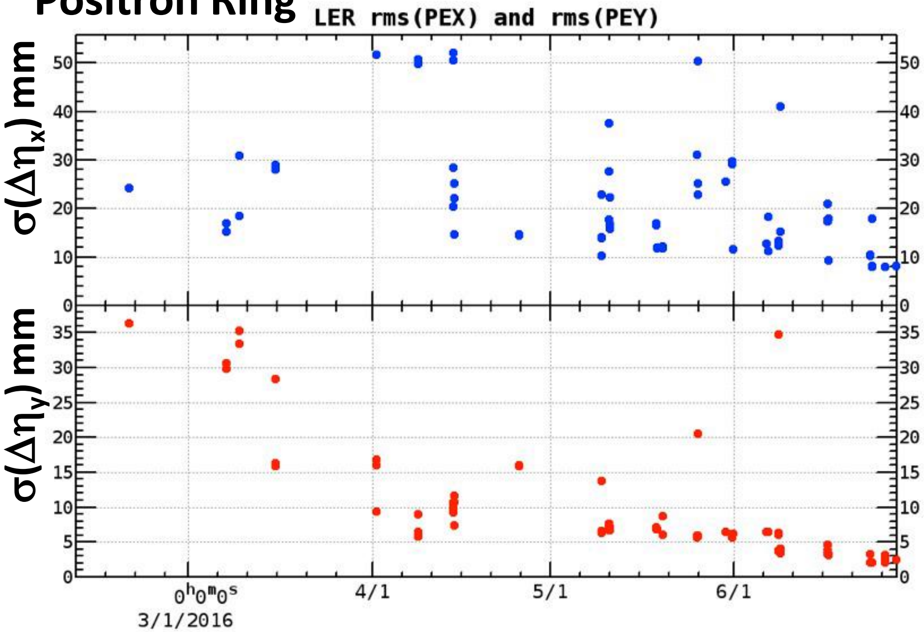
We put permanent magnet on storage beam line to cancel this leaked magnetic field.

Dispersion Correction

Dispersion: η_x, η_y
Note, $\Delta x = \eta_x \cdot (\Delta p_x/p_x)$, $\Delta y = \eta_y \cdot (\Delta p_y/p_y)$

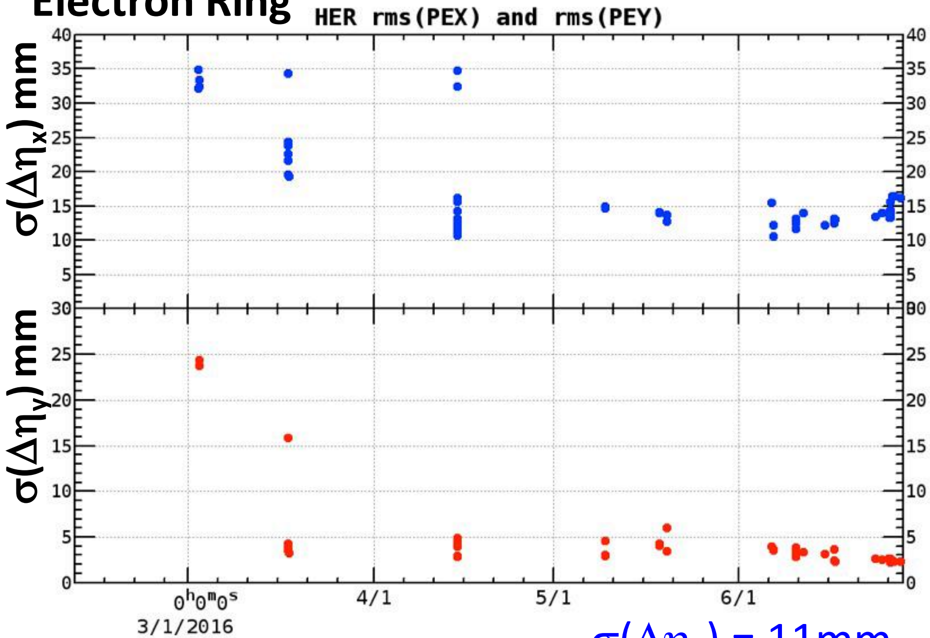
$\Delta\eta$ is size of correction by feedback system.
⇒ We can evaluate stability of beam from $\sigma(\Delta\eta)$.

Positron Ring



Finally, $\sigma(\Delta\eta_x)$ = 8mm
$\sigma(\Delta\eta_y)$ = 2.1mm

Electron Ring



$\sigma(\Delta\eta_x)$ = 11mm
$\sigma(\Delta\eta_y)$ = 2.3mm

Summary of Optics Correction

	Positron Ring	**Electron Ring**	**KEKB**
$\sigma(\Delta y)/\sigma(\Delta x)$	0.009	0.006	
$\sigma(\Delta\beta_x/\beta_x)$, $\sigma(\Delta\beta_y/\beta_y)$	0.03, 0.03	0.03, 0.03	0.03-0.06
$\sigma(\Delta\eta_x)$, $\sigma(\Delta\eta_y)$	8, 2.1 (mm)	11, 2.3 (mm)	~10 (mm)
$\Delta\xi_x$, $\Delta\xi_y$	2, −4	<1, <1	

In terms of β and η functions,
The size of correction is same level as those in the KEKB period.
We realize the stable beam orbit with phase-1 beam tuning.

Preparation for Phase-2

Renovation of Main Ring

- Installation of Final Focus Quadrupole Magnet (QCS)
- Installation of new beam collimators

Construction of Damping Ring

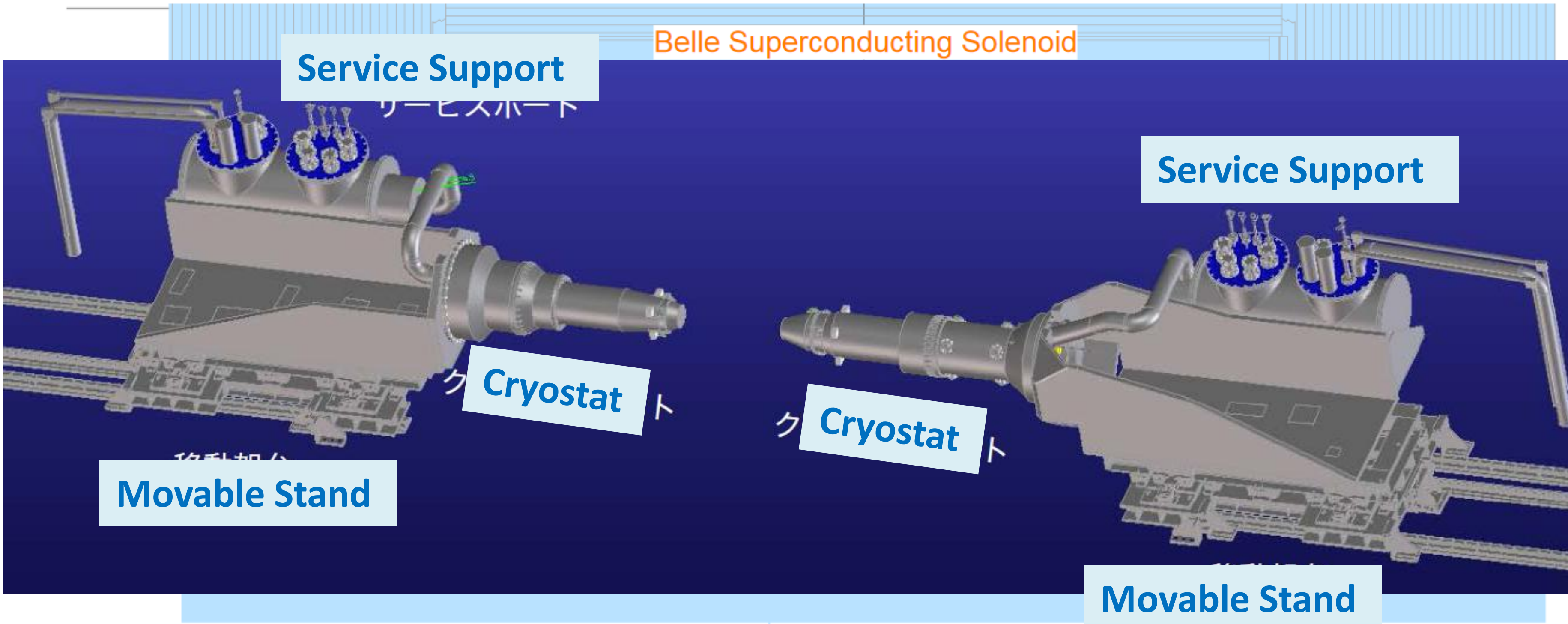
- New tunnel and accelerator
- Circumference 135.5m
- Storage energy 1.1 GeV
- For suppress beam emittance

ε_x: 1400⇒42.9 (nm), ε_y: 1400⇒3.61 (nm)

(Note, beam size: $\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$)

Final Focus Quadrupole Magnet

We will install Final Focus Quadrupole Magnet (QCS) to realize 20 times smaller vertical beam size at interaction point.



It consists of:

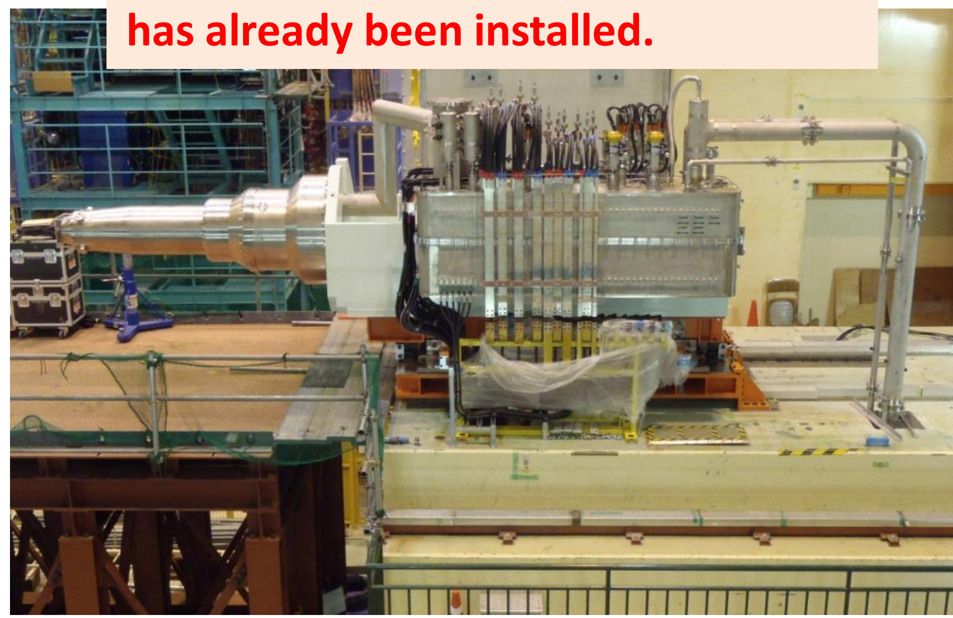
- **8 superconducting quadrupole magnets**
- **43 superconducting cancel magnet**
- **4 superconducting solenoid magnets**

QCS Installation Status

Right side of QCS (electron upstream) has been assembled.

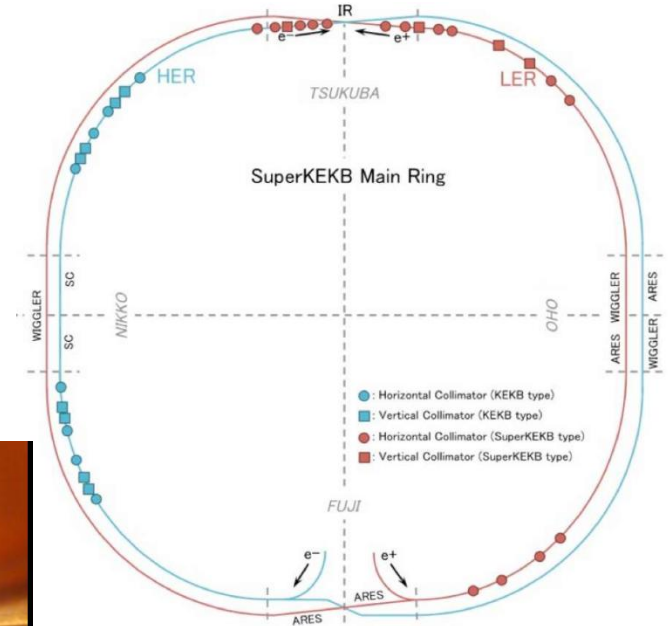
Left side of QCS (positron upstream) has already been installed.

It will be installed soon.



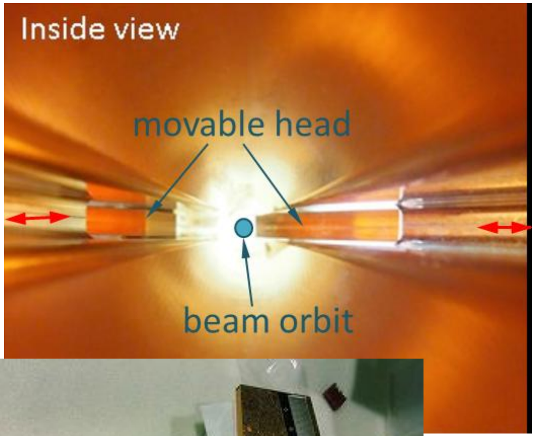
New Collimators

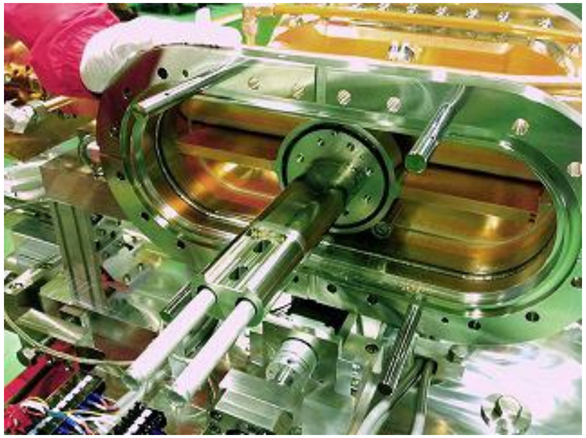
New low-impedance collimators are developed and installed.



Two horizontal collimators were installed at arc section of positron ring.
⇒ Performance with beam is checked.

We plan to install 6 more collimators for both rings.

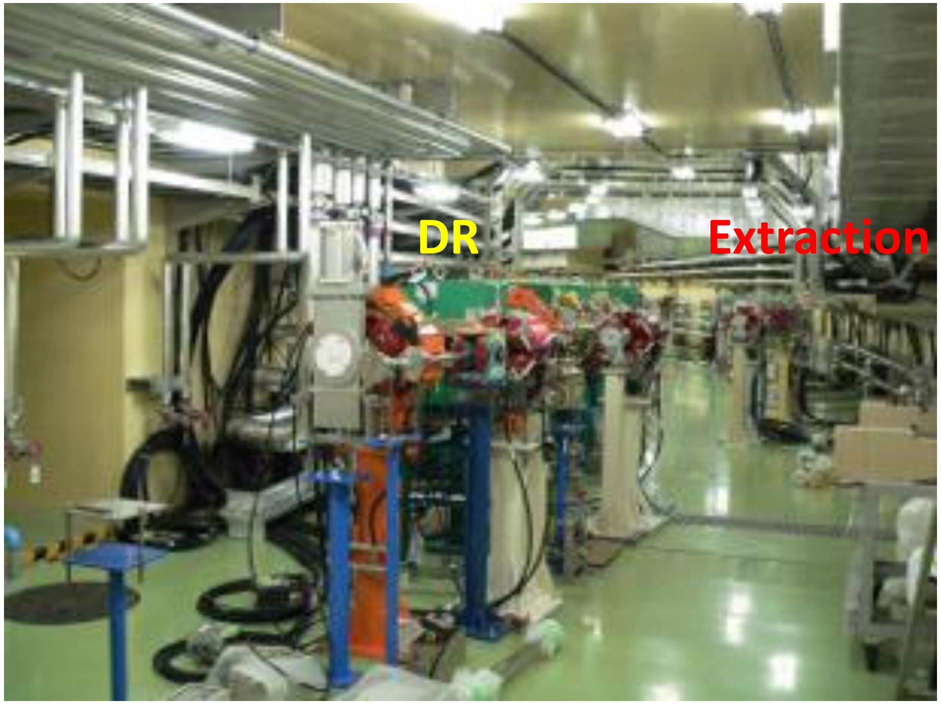




Short Summary of Damping Ring Construction

- ☑ Construction of tunnel
- ☑ Construction of power supply building
- ☑ Installation of cables for power supply and BPM
- ☑ Installation of magnets
- ☑ Installation of power supplies for magnet
- ☑ Installation of vacuum chambers for arc section
- ☑ Coarse alignment of magnets
- ☐ RF cavities and klystrons
- ☐ Septum and kicker magnets
- ☐ Beam instrumentation (BPM etc...)
- ☐ Vacuum chamber for straight section and BT
- ☐ Fine alignment of magnets

Pictures of tunnel



Magnets for injection/extraction

Septum magnets for injection/extraction:
Magnets and pulsers are assembled.
Magnetic field measurement is ongoing.

Kicker system for injection/extraction:
Magnets and power supply are delivered.

Conclusion

SuperKEKB aims 40 times larger luminosity than that of KEKB.

- **It will be the new world's luminosity record.**
- **Luminosity is enhanced from:**
  - **20 times suppression of β_y**
  - **2 time increase of beam current.**

Phase-1 operation is carried out successfully.

- **We increased beam current to be 1010 mA (e^+) and 870 mA (e^-).**
- **Beam tuning is carried out successfully.**
  - **Both beams are operated with stable orbit.**

Preparation for phase-2 is ongoing.

- **One side of final focus quadrupole magnet is installed.**
- **The other side is assembled and will be installed soon.**
- **Construction of damping ring is ongoing.**