SuperKEKB

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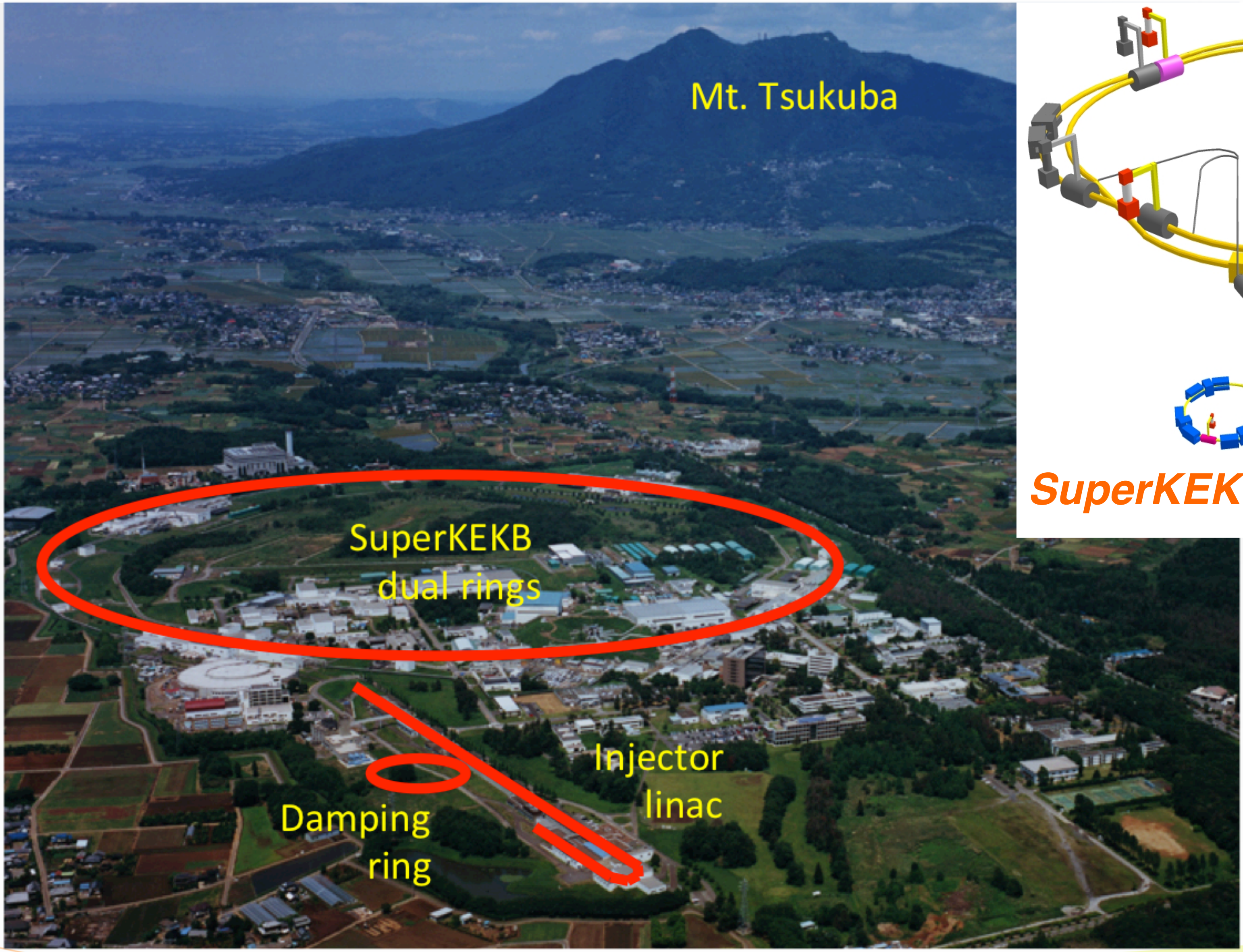
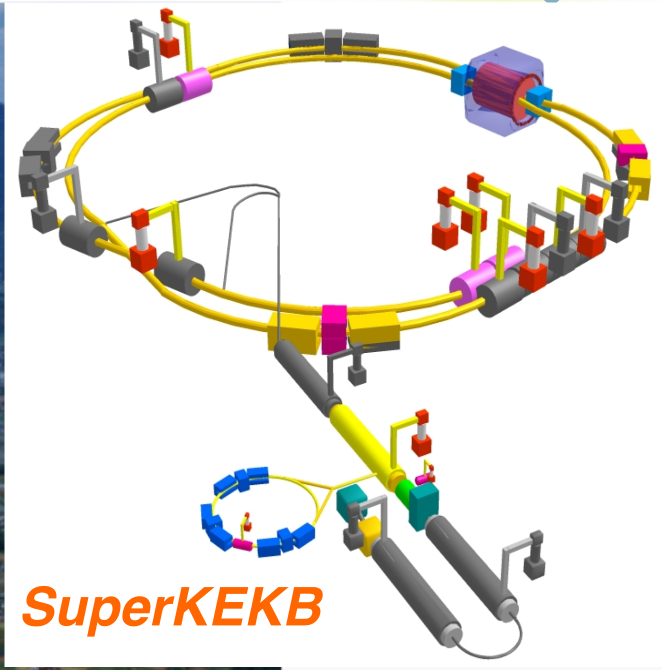
SuperKEKB Optics&Commissioning Group
KEK

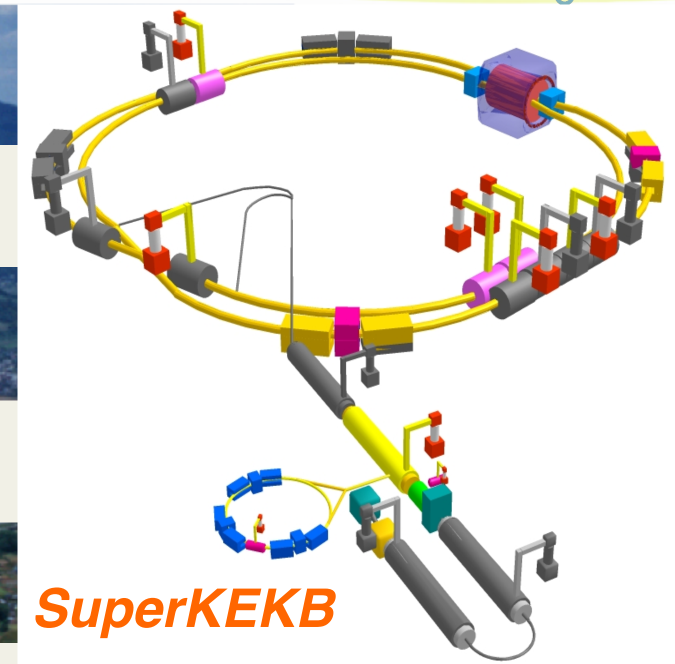
This Talk


Mt. Tsukuba
SuperKEKB
dual rings
Injector
linac
Damping
ring


SuperKEKB

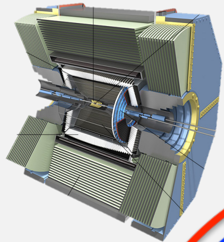
This Talk

- SuperKEKB project
- Main ring status
- Linac status
- Commissioning plan
  and issues on optic control

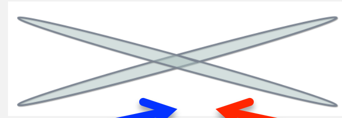


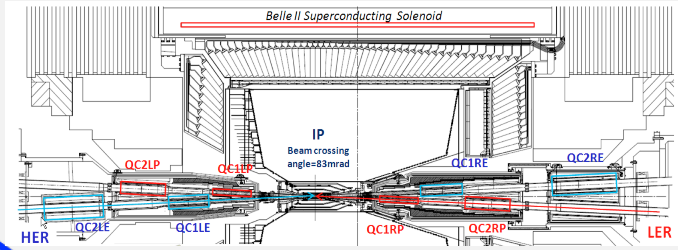
SuperKEKB

Upgrade to Belle II detector



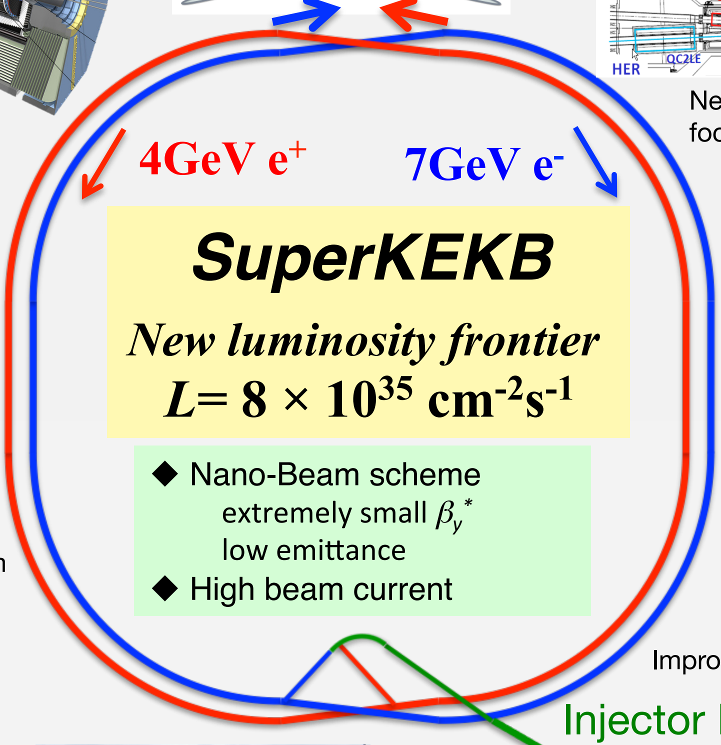
Nano-beam scheme





New superconducting final focusing magnets near the IP

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)

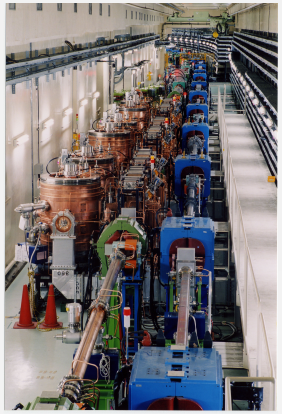


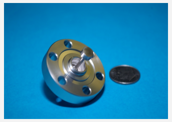
SuperKEKB

New luminosity frontier

$L = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$

- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- High beam current

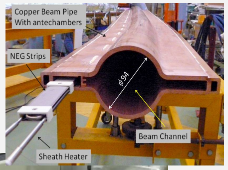




Reinforce RF systems for higher beam currents

Improve monitors and control system

Replace beam pipes with TiN-coated beam pipes with antechambers

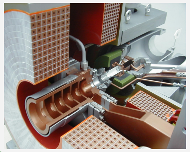



DR tunnel

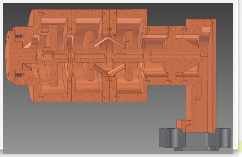
New e+ Damping Ring

Injector Linac upgrade

New capture section



RF electron gun



KEKB to SuperKEKB

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right) = 8 \times 10^{35}\ \mathrm{cm^{-2}s^{-1}}$$

e^+ e^-

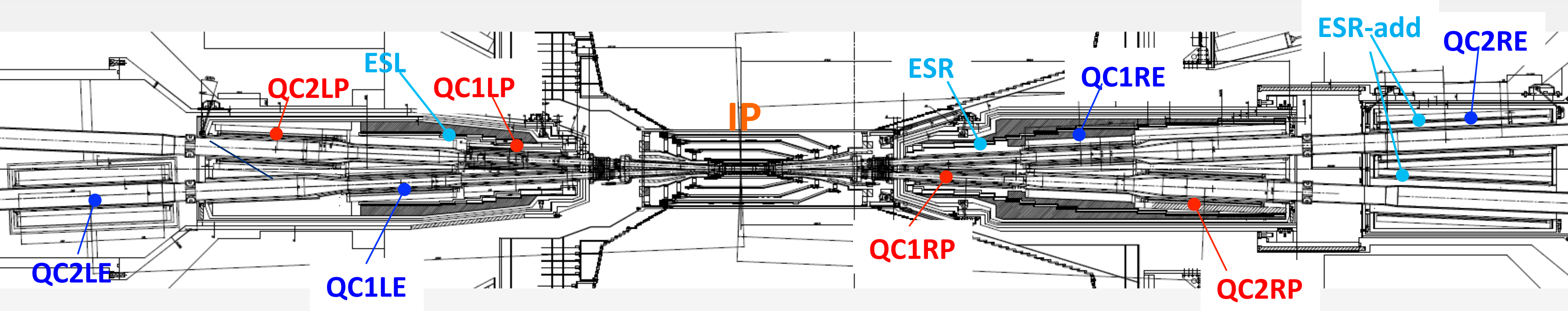
- Vertical β function at IP: 5.9 → 0.27/0.30 mm **(× 20)**
- Beam current: 1.7/1.4 → 3.6/2.6 A **(× 2)**
- Beam energy: 3.5/8.0 → 4.0/7.0 GeV
- Beam-beam parameter: .09 → .09 **(× 1)**

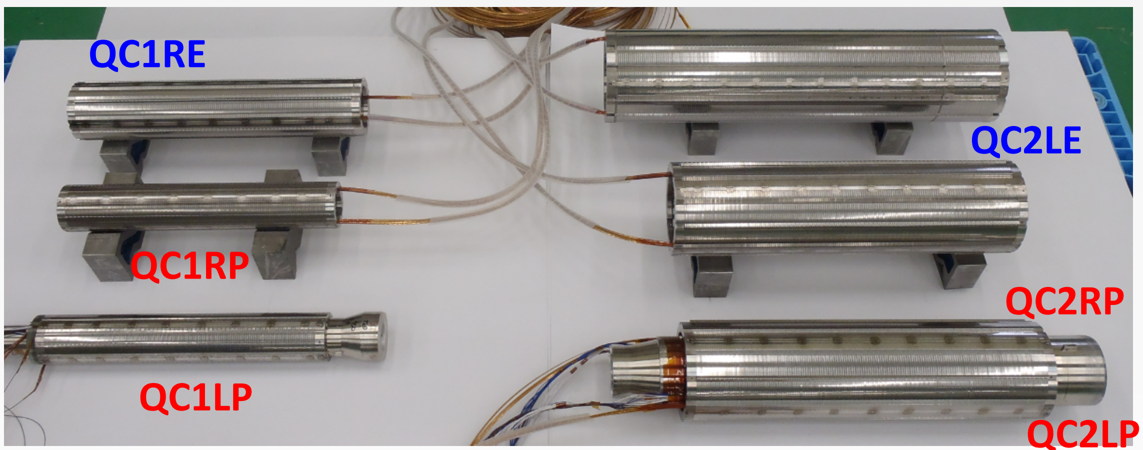
High current, Small IP beta, Low emittance

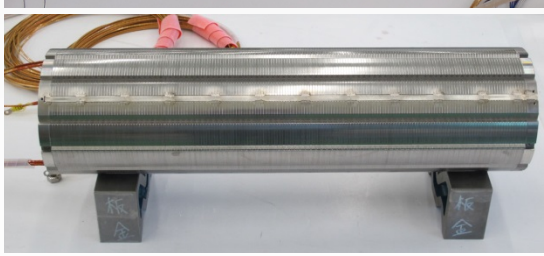
Main Ring Status

Focus on Magnets in Interaction Region

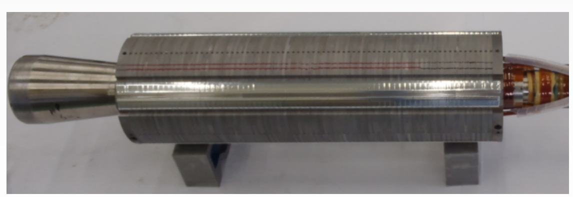
Final Focus Magnets System (QCS)







QC2RE

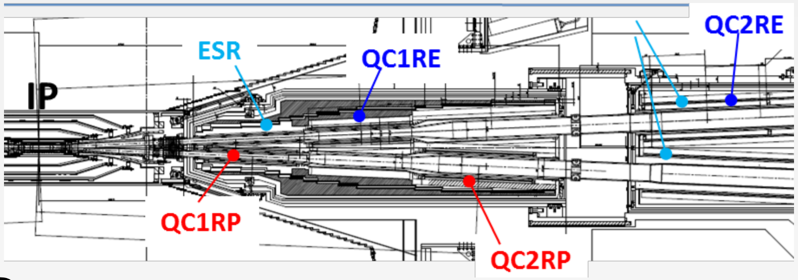


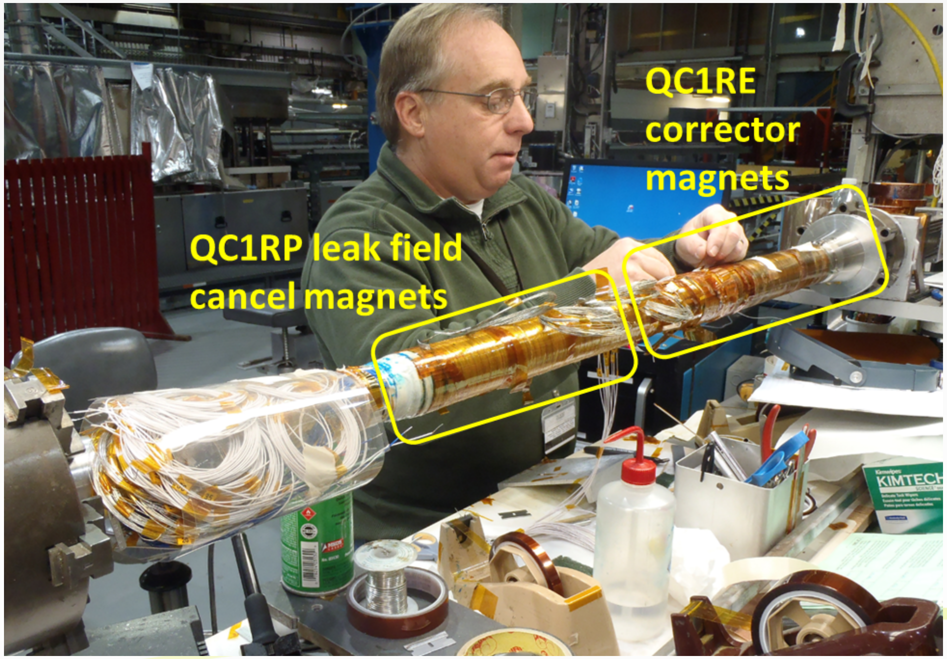
QC1LE

- Assemblies of eight quadrupole magnets in collaring process were completed in March 2014.
- 4 quadrupole magnets for the left side were assembled with the S.C. corrector magnets sent from BNL, and they were cold tested at 4K.
  - **The quadrupole magnets and the correctors were excited to the nominal current without quench.**
  - **The magnetic field qualities were acceptable for the beam operation.**

Corrector Magnets

- S.C. corrector magnets are fabricated by BNL.
- All coil windings of 43 corrector magnets have been completed.
- The final assembly is the QC1RE corrector magnets and the QC1RP leak field cancel magnets on the same support bobbin.
- The assembled magnets will be delivered to KEK in February.

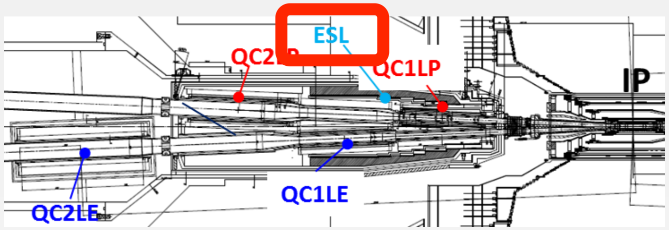




Final assembly of the corrector magnet in BNL.
BNL technician is handling the cables from 8 magnets on the support bobbin.

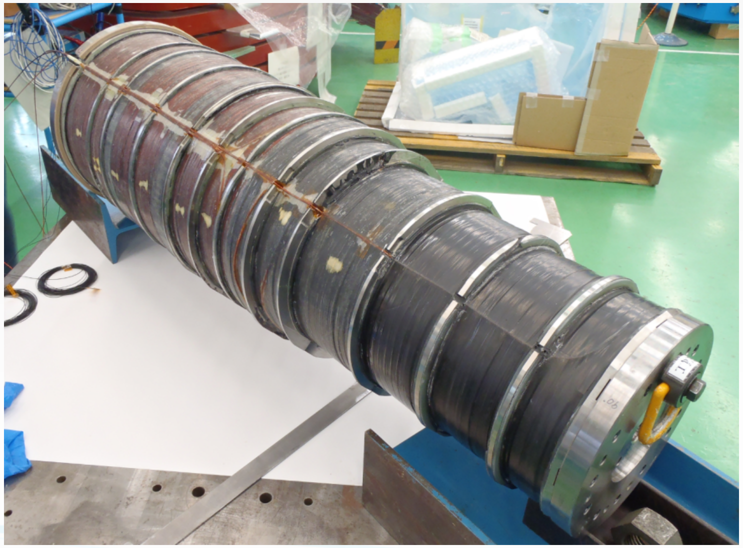
Anti-solenoid (ESL, ESR)

- Construction of S.C. compensation solenoid (ESL) is on going.
- Although the solenoid had a damage of the electrical insulation between the superconducting cable and the support bobbin, Mitsubishi well recovered the damage, and the solenoid was delivered to KEK in Dec.

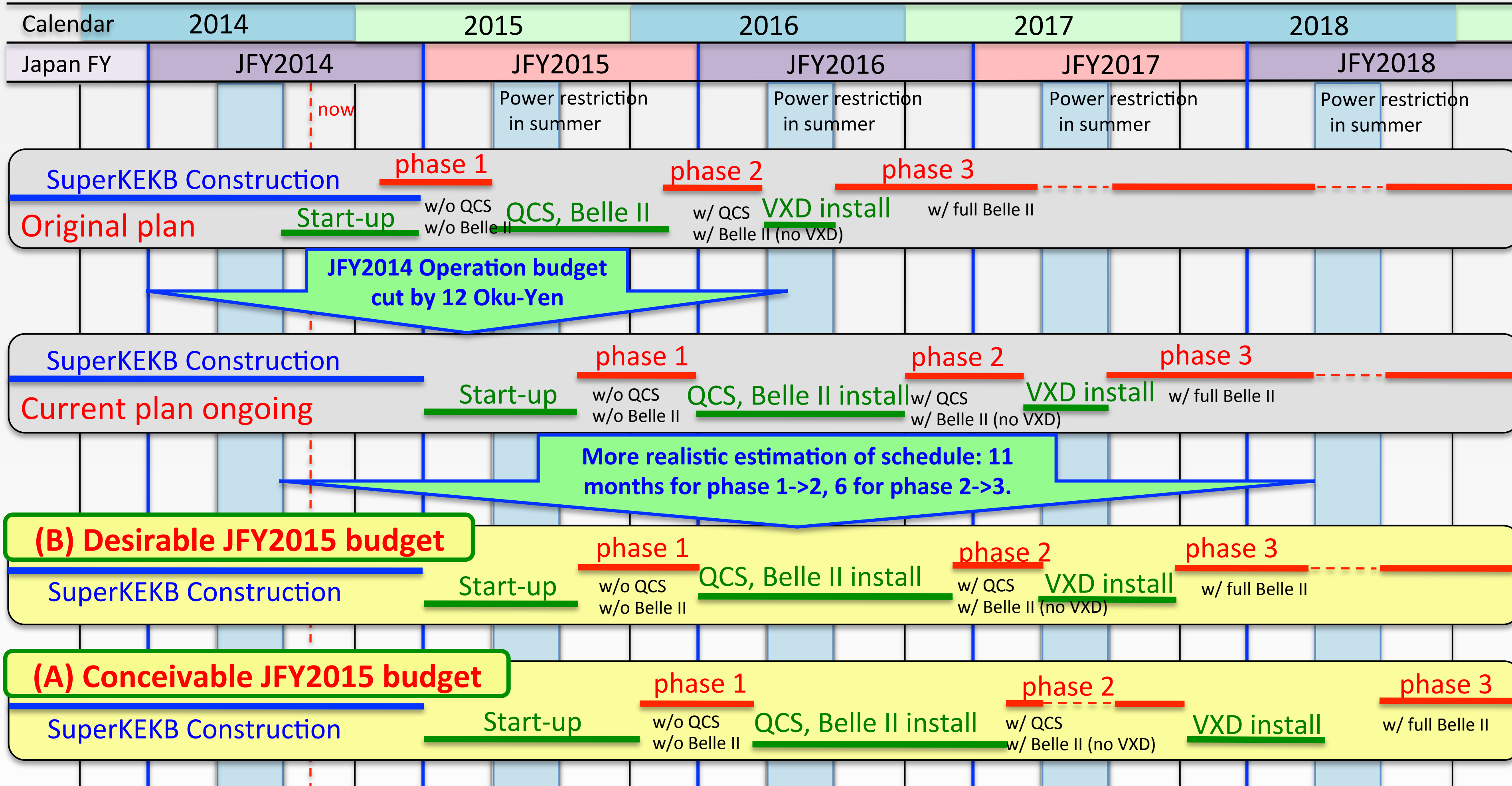


The cold test of ESL was performed in KEK from Jan. 5th 2015 . ESL was successfully excited to the design current without any quench.

Completed ESL compensation solenoid.
The solenoid was divided into the 12 small solenoids.



Schedule

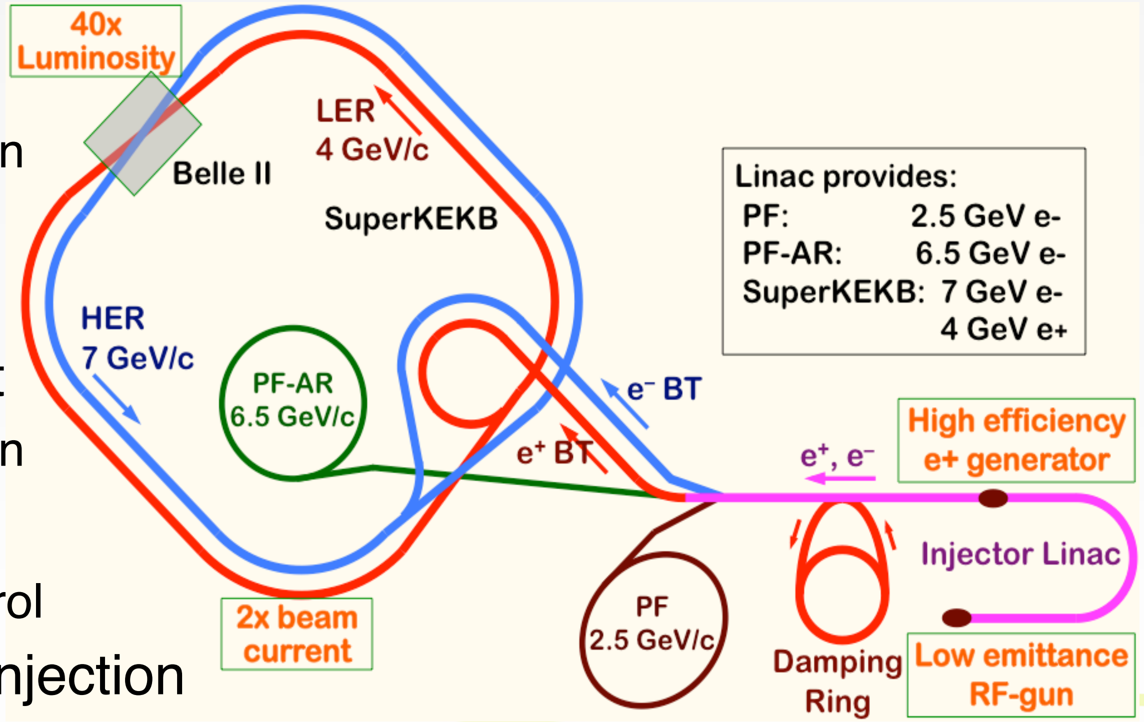


Commissioning will start in JFY 2015.

Linac Status

Mission of Injector Linac

- 40-times higher Luminosity
  - Twice larger storage beam → Higher beam current at Linac
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime → Higher Linac beam current
- Linac challenges
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section
  - Emittance preservation
    - with precise beam control
  - 4+1 ring simultaneous injection



Upgrade Items

- Low emittance photo-cathode rf gun
- New positron source
- Damping ring
- Timing system
- LLRF development

Linac commissioning is on-going in parallel with its upgrade.

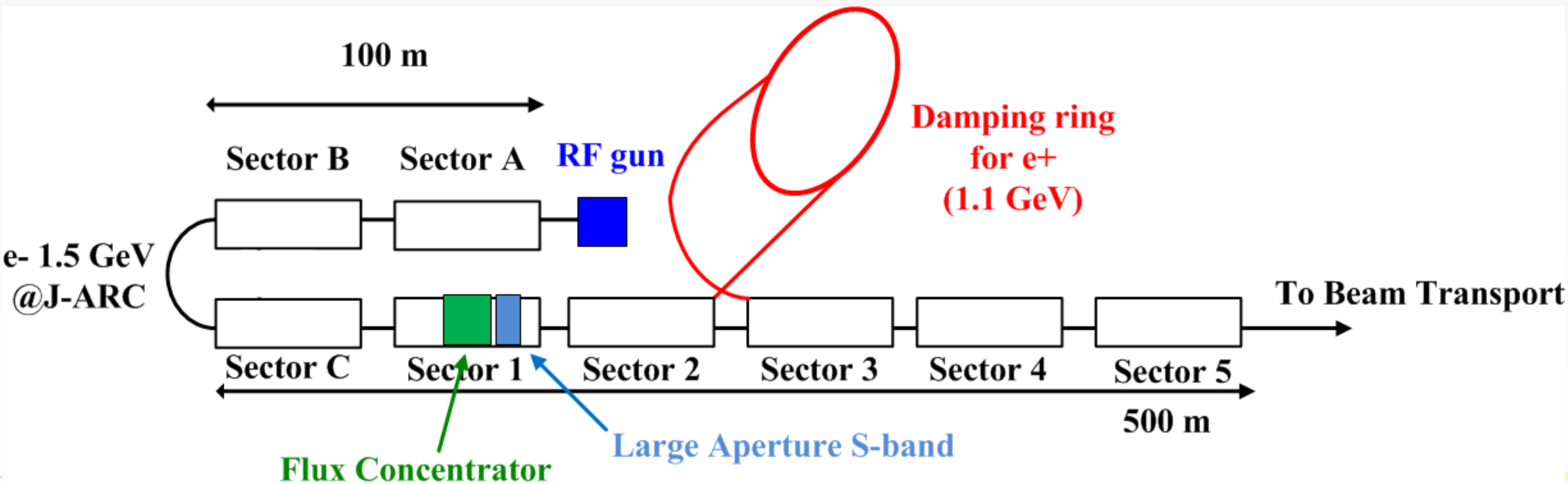
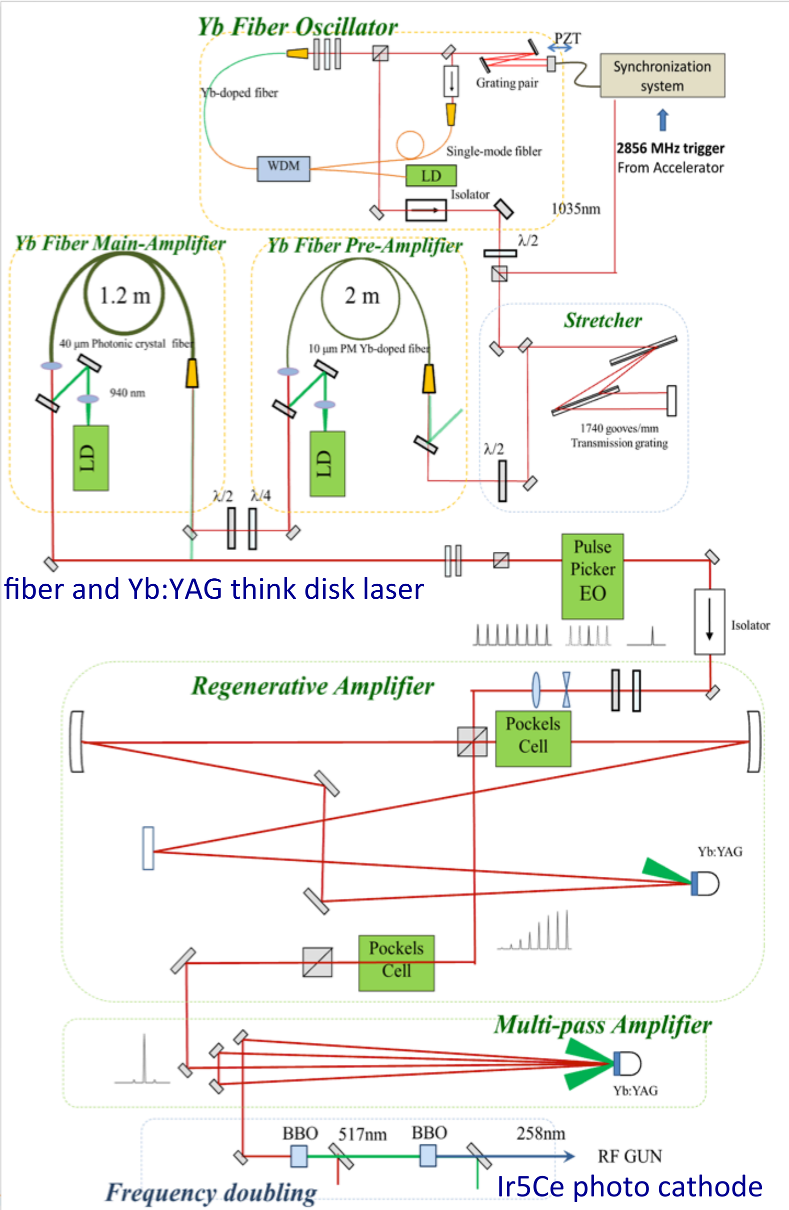
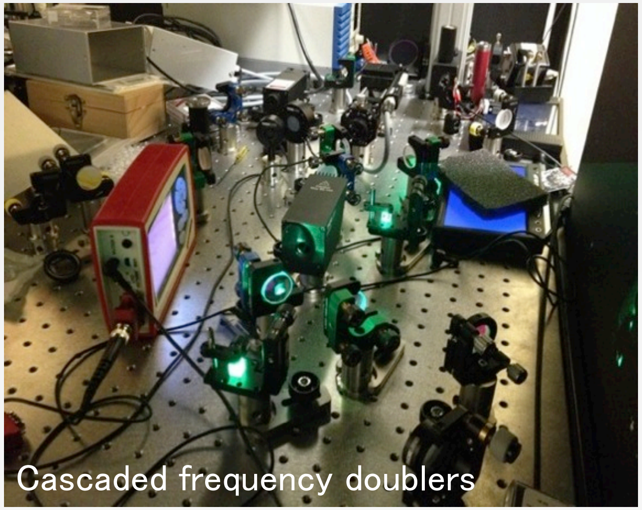
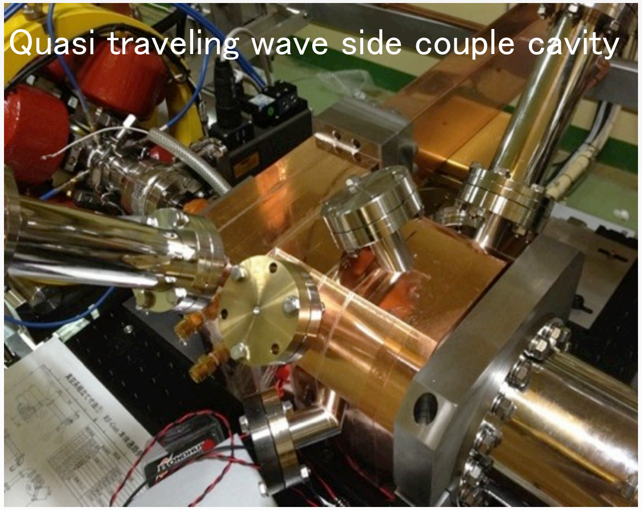
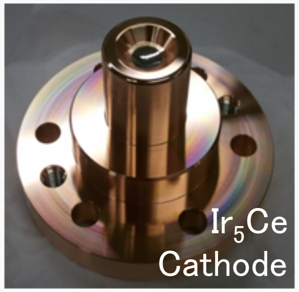


Photo Cathode RF Gun Development



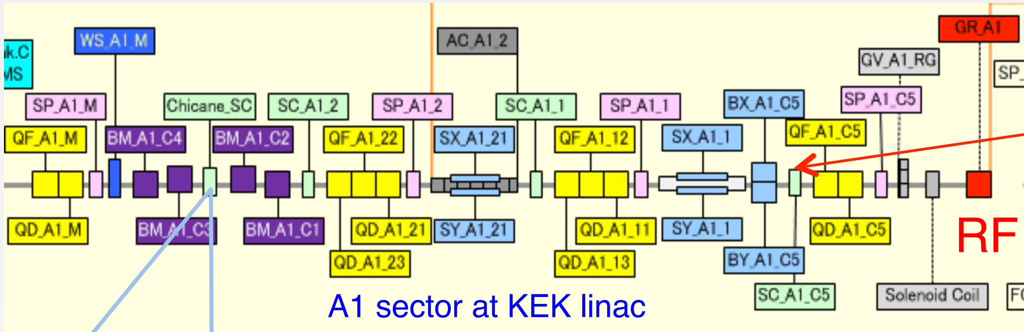




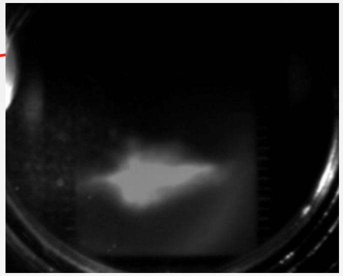


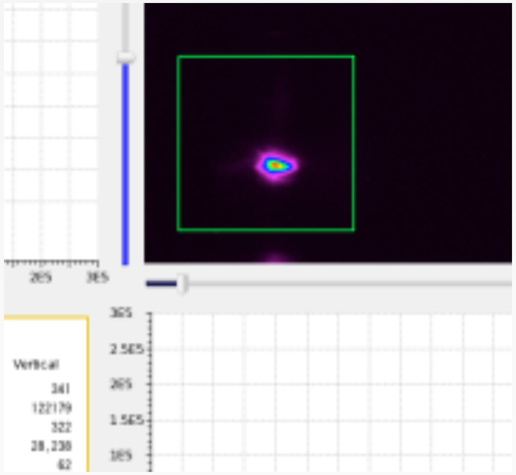
- 5.6 nC / bunch was confirmed
- Next step: 50-Hz beam generation & Radiation control

A-1 RF Gun Results

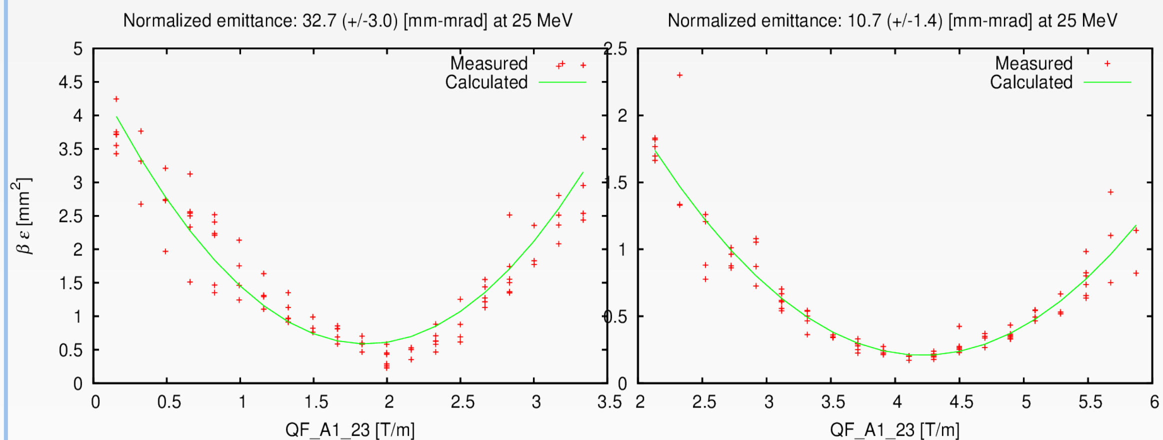


5.6 nC bunch charge was observed.





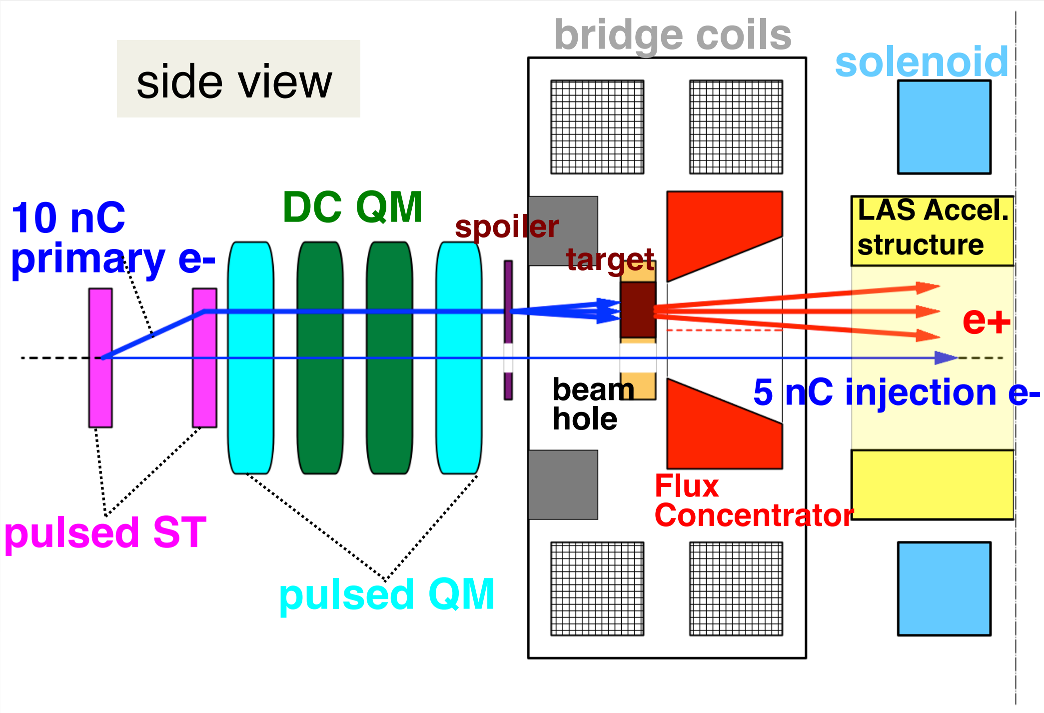
beam size measurement for Q-scan

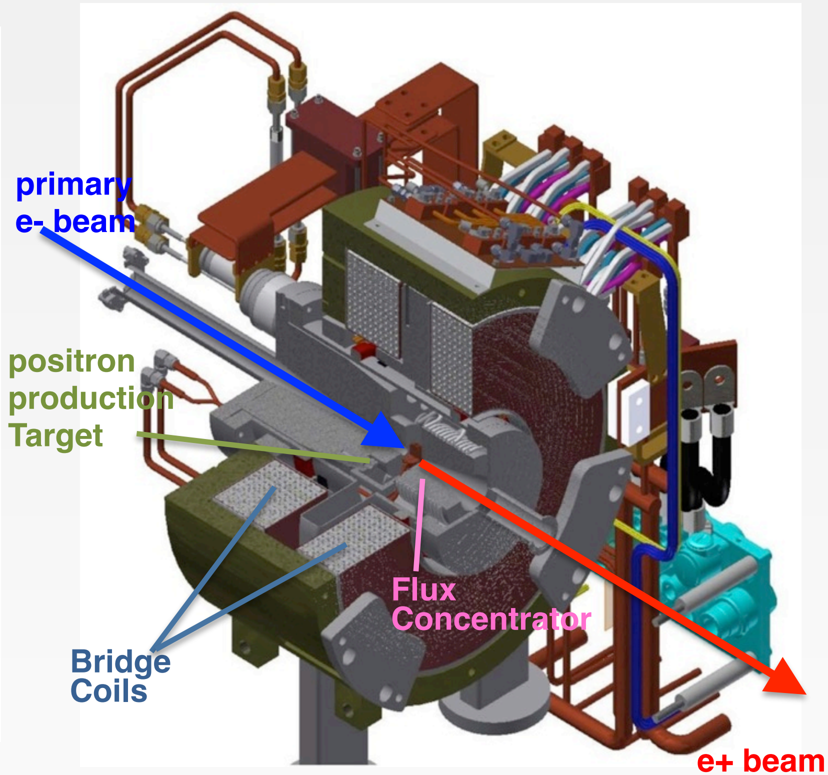


Q-scan emittance measurement

Horizontal	Vertical
32.7 ±3.1 mm-mrad	10.7 ±1.4 mm-mrad

Positron Source for SuperKEKB

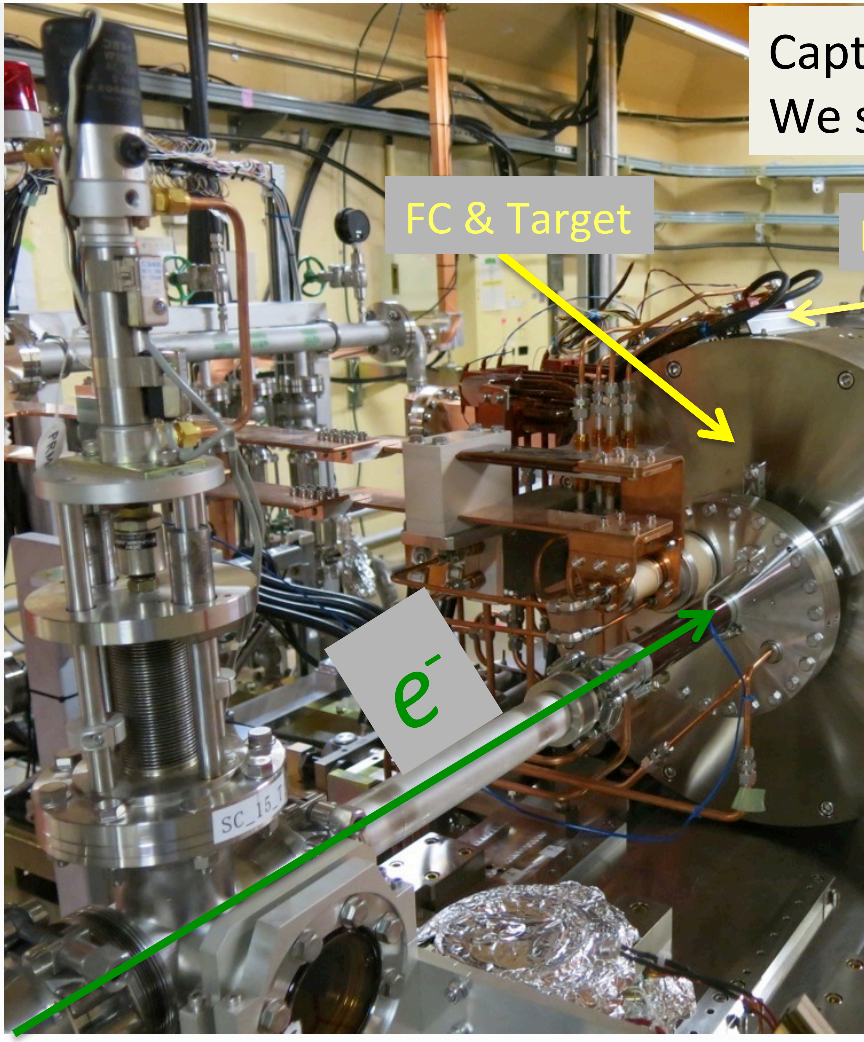


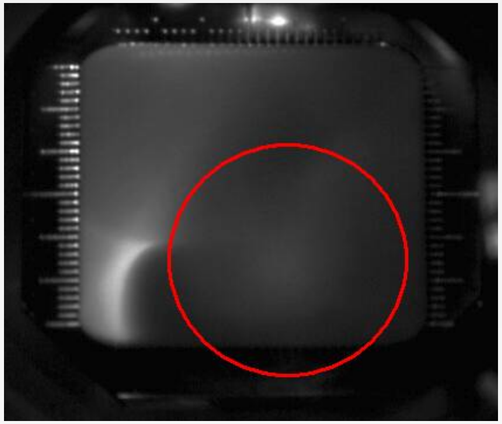


- New positron capture section after target with Flux concentrator (FC) and large-aperture S-band structure (LAS)
- Satellite bunch (beam loss) elimination with velocity bunching
- Pinhole (2mm) for electrons beside target (3.5mm)
- Beam spoiler for target protection

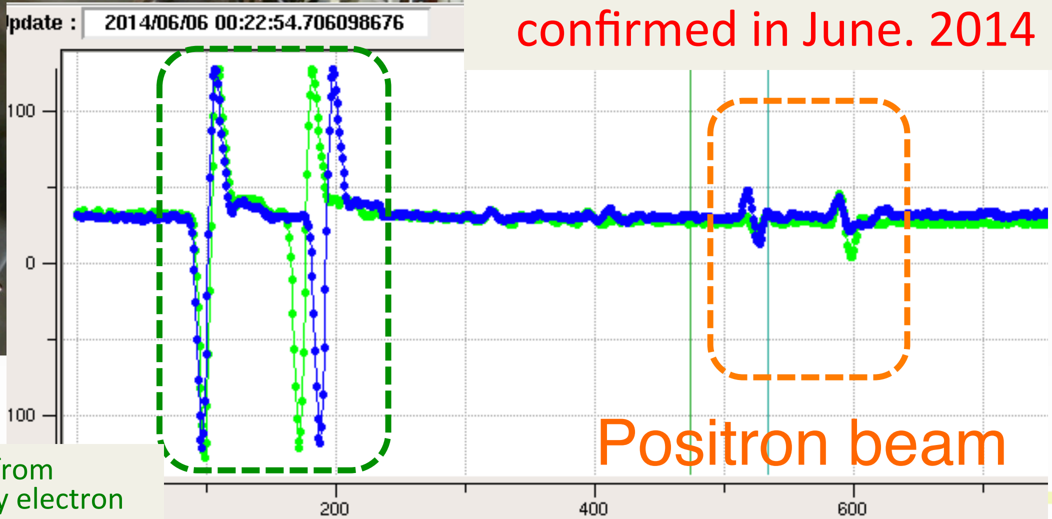
Positron Capture Section

Capture section has been constructed in April 2014.
We started positron commissioning in May 2014.





Positron generation was confirmed in June. 2014



Commissioning Plan and Issues on Optics Control

Commissioning Phase

- Phase 0:
  - Main ring construction
  - Linac commissioning and construction
  - Development of the commissioning software

We are here.

- Phase 1: ~6 months
  - No QCS, No physics detector
  - Basic commissioning, hardware check, low emittance tuning, etc.
- Phase 2: ~6 months
  - W/ QCS and physics detector
  - Optics, collision, and luminosity tuning
- Phase 3: 6 months ~ several years?
  - W/ QCS, W/ physic detector (Physics run)
  - Toward to the target luminosity.
  - Study on many difficult problems inherent in the nano-beam scheme.

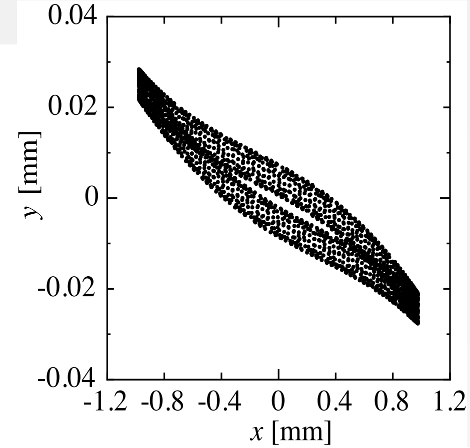
Optics Measurement

- All quadrupole magnets have BPM.
  (~ 450 BPMs per ring)

- Optics measurement with orbit response analysis
  - Horizontal & vertical coupling:
    Vertical leakage orbits associated with horizontal kicks.
  - Dispersion:
    Response with RF frequency change.
  - Beta function:
    Orbit response analysis with steering kicks.

- 135 BPMs (per ring) can be used with turn by turn mode.

X-Y Coupling Measurement



Physical coordinate = Coupling parameters × Betatron coordinate

$$\begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} = \begin{pmatrix} \mu & 0 & r_4 & -r_2 \\ 0 & \mu & -r_3 & r_1 \\ -r_1 & -r_2 & \mu & 0 \\ -r_3 & -r_4 & 0 & \mu \end{pmatrix} \begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix}$$

We can solve the equations

$$\begin{pmatrix} < xy > \\ < xp_x > \\ < xp_y > \\ < p_x p_y > \end{pmatrix} = -\frac{1}{\mu}\Sigma \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix}$$

Need to estimate p_x and p_y using two BPMs

where

$$\Sigma = \begin{pmatrix} < x^2 > & < xp_x > + < yp_y > & 0 & - < y^2 > \\ < xp_x > - < yp_y > & < p_x^2 > & < y^2 > & 0 \\ 0 & < p_y^2 > & < x^2 > & < xp_x > - < yp_y > \\ < p_y^2 > & 0 & < xp_x > + < yp_y > & < p_x^2 > \end{pmatrix}$$

- A similar method is applicable to measurement of betatron phase advance.

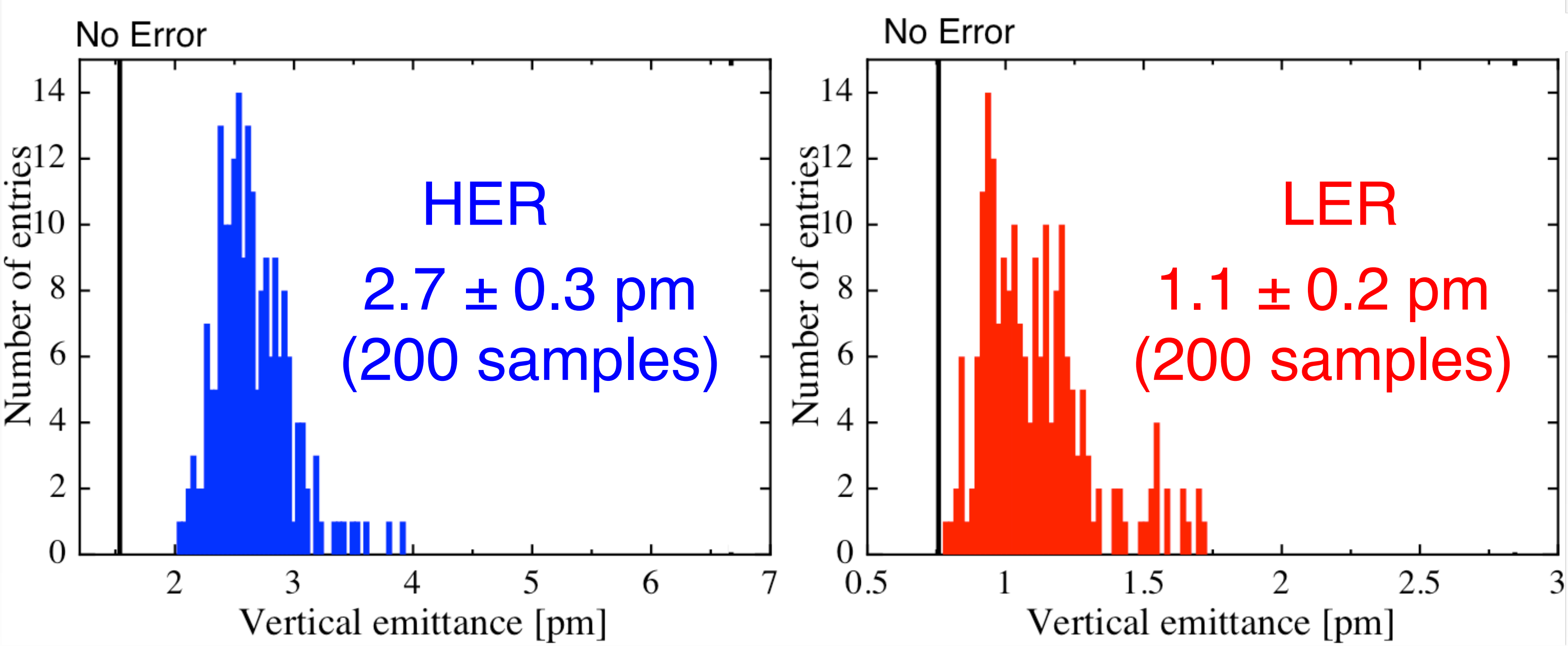
Y. Ohnishi, 19th KEKB Review

Low Emittance Tuning(LET) - Simulation -

Assumed errors

	$\sigma_x = \sigma_y$ [μm]	σ_θ [μrad]	$\Delta K/K$
Normal Quad	100	100	2.5×10^{-4}
Sext	100	100	2.5×10^{-4}
Bend	0	100	0
QCS	100	0	0

BPM jitter : 2 μm
BPM tilt : 10 mrad

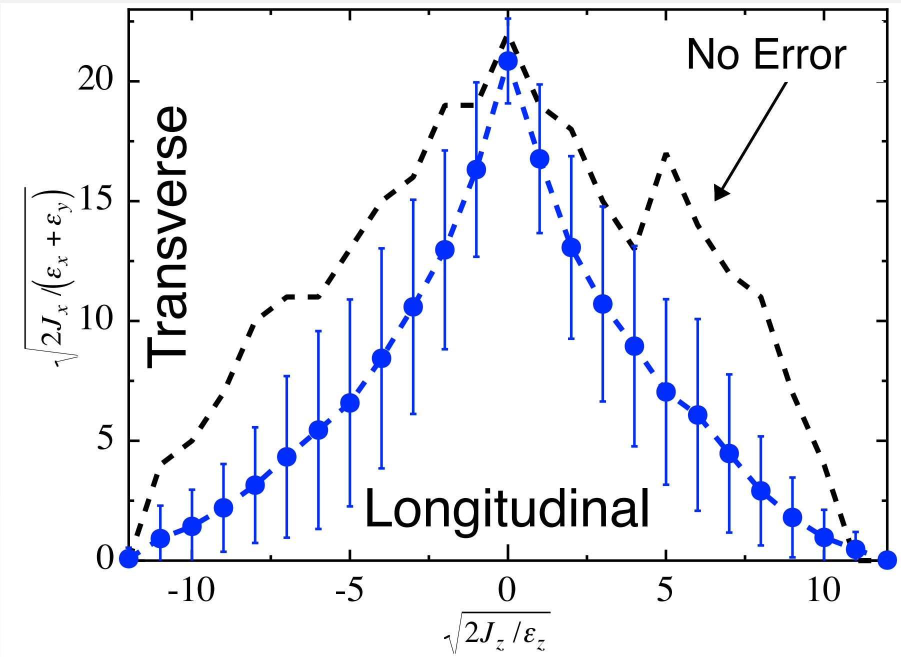


- Vertical emittance after LET is a few pm, which satisfy the required value for the target luminosity.

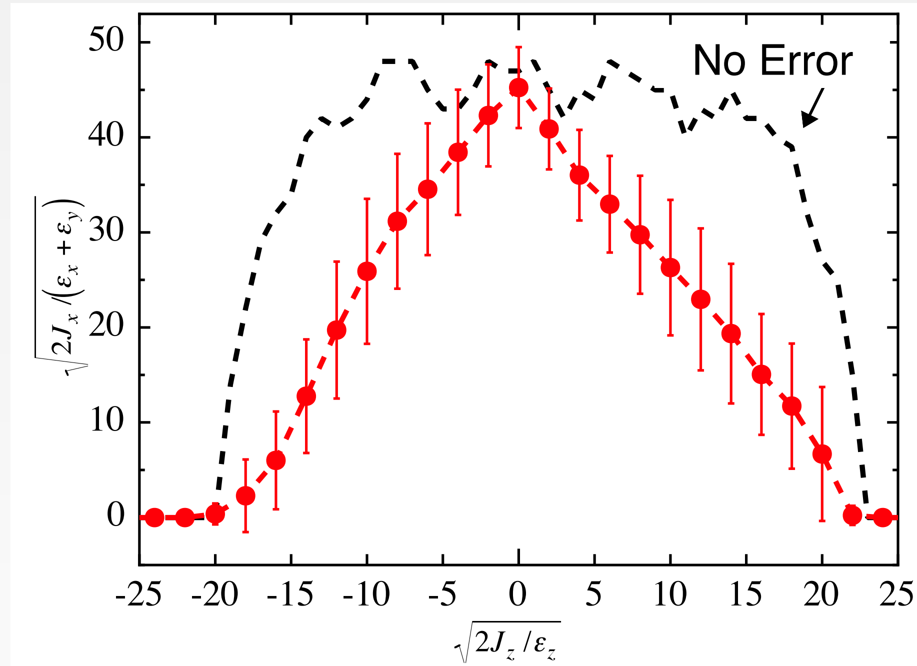
Dynamic Aperture after LET

200 samples

HER



LER

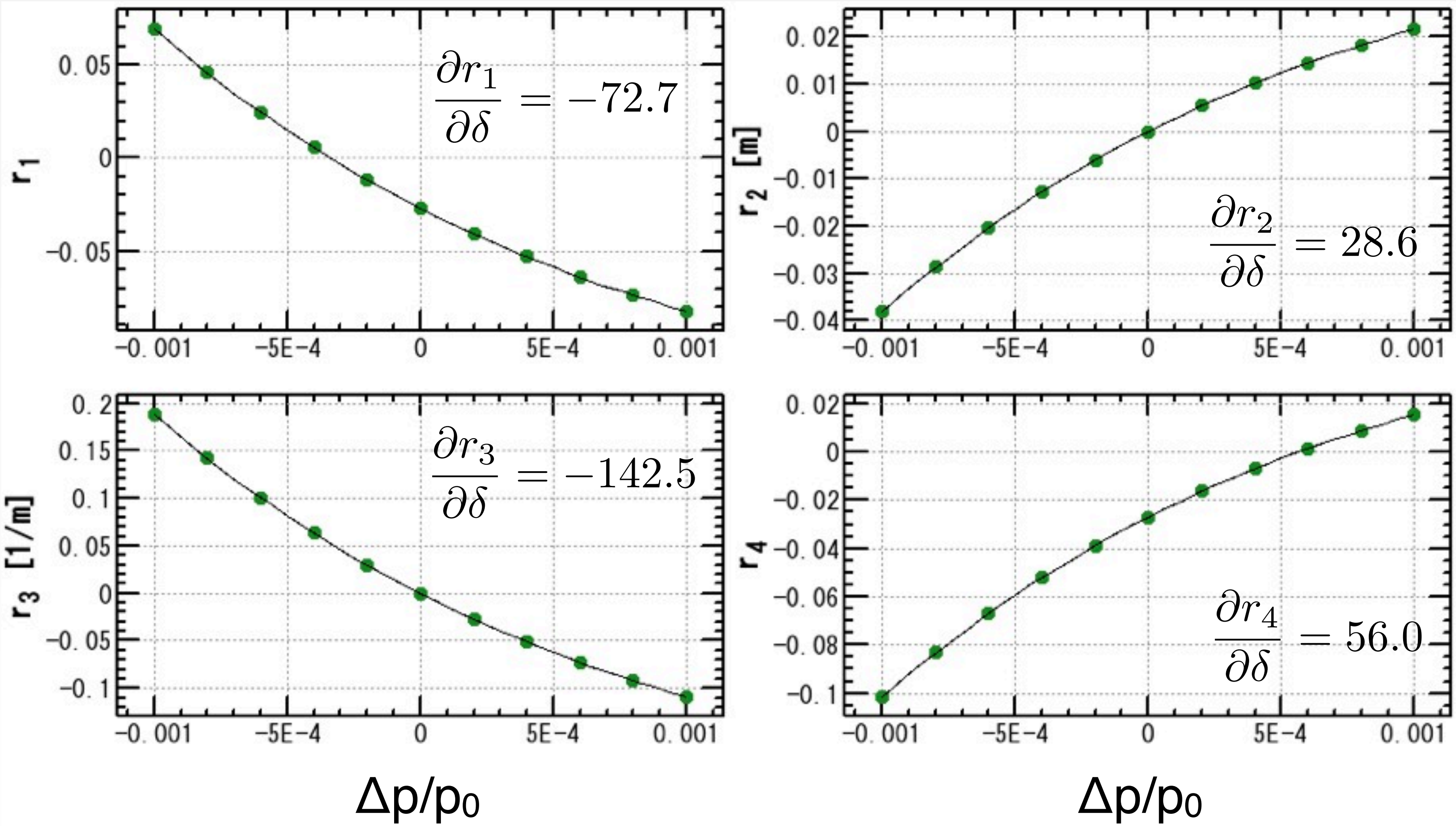


- On-momentum DA is recovered.
- Off-momentum DA is not resumed.
- Need off-momentum optics correction.

Chromatic X-Y coupling Measurement

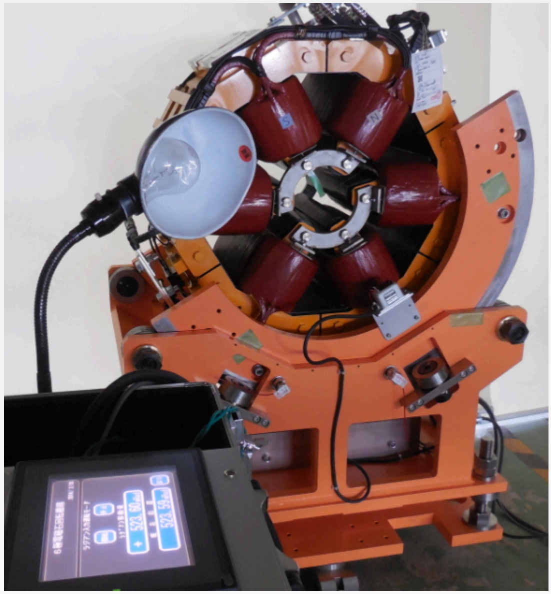
Y. Ohnishi, 19th KEKB Review

- Example: one-pass BPM at QC1LP
- Measurement of X-Y coupling with rf-frequency shift (-0.1<δ<+0.1 %)



Correction of Chromaticity

Rotatable sextupole magnet



- Available tuning knobs
  - A normal sextupole coil installed in QCS
  - Normal sxtupoles (54 families per ring)
  - Skew sextupoles installed in QCS (2 per ring)
  - Rotatable sextuplole (12 families in LER)
  - Skew sextupole (12 families in HER)

- Unsolved Issues
  - Beam dose not pass through the center of sextupole magnets in general.
    Change of those magnets also affects the on-momentum optics, thus, emittance.
  - Unfortunately, realistic procedure for tuning of dynamic aperture with LET is still an open question.

Summary

- Construction of the main rings for Phase 1 commissioning is in the final stage.
  Commissioning of the main ring will start in JFY2015.

- In parallel to the main ring construction,
  the linac construction and its commissioning are ongoing.

- Phase 1 commissioning
  - Basic commissioning and low emittance tuning.
  - Optics control based on KEKB is expected to work well.

- Unresolved Issues for optics control after Phase 2.
  - Realistic procedure for tuning nonlinear magnets.

Thank you for your attention!

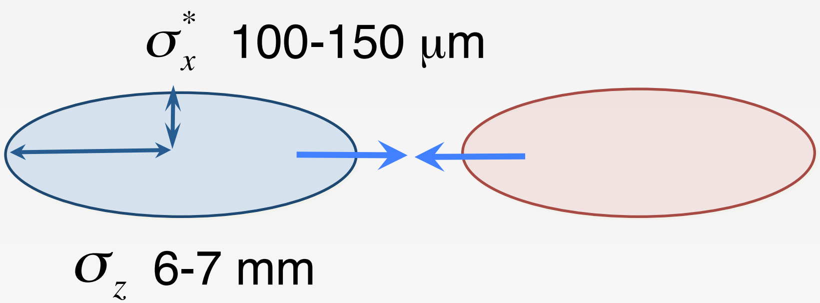
Backup

Machine Parameters

	LER	HER
Energy (GeV)	4.0	7.00729
Current (A)	3.6	2.6
#of bunches	2500	2500
β_x^* (mm)	32	25
β_y^* (mm)	0.27	0.30
ε_x^* (nm)	3.2	4.6
ε_y^* (pm)	8.64	11.5
σ_z^* (mm)	6	5
ν_x, ν_y	44.53 , 46.57	45.53 , 43.57
ν_s	-0.0247	-0.0280
ξ_y	0.0881	0.0807
Luminosity (10^{35} cm^{-2} s^{-1})	8	

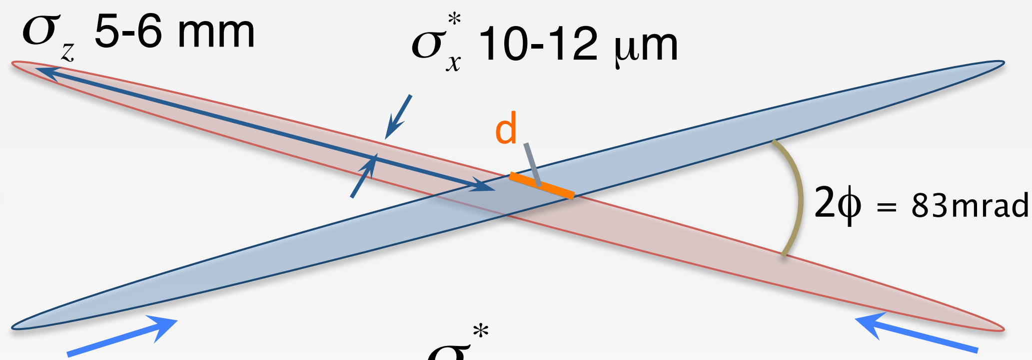
Collision Scheme

KEKB head-on (crab crossing)



overlap region = bunch length

Nano-Beam SuperKEKB



$$d = \frac{\sigma_x^*}{\phi}$$

Half crossing angle: ϕ

overlap region << bunch length

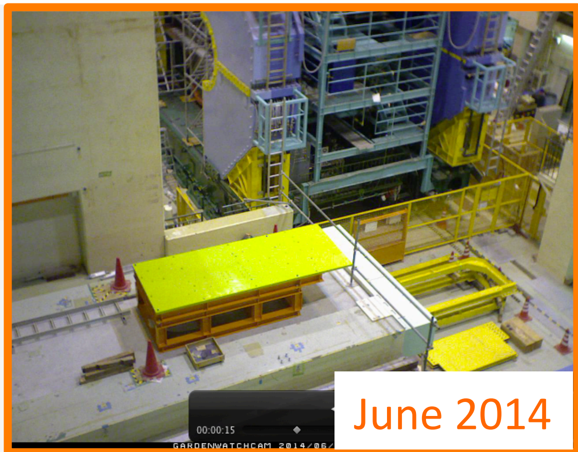
Hourglass requirement

$$\beta_y^* \geq \sigma_z \quad \sim 6\ \text{mm}$$

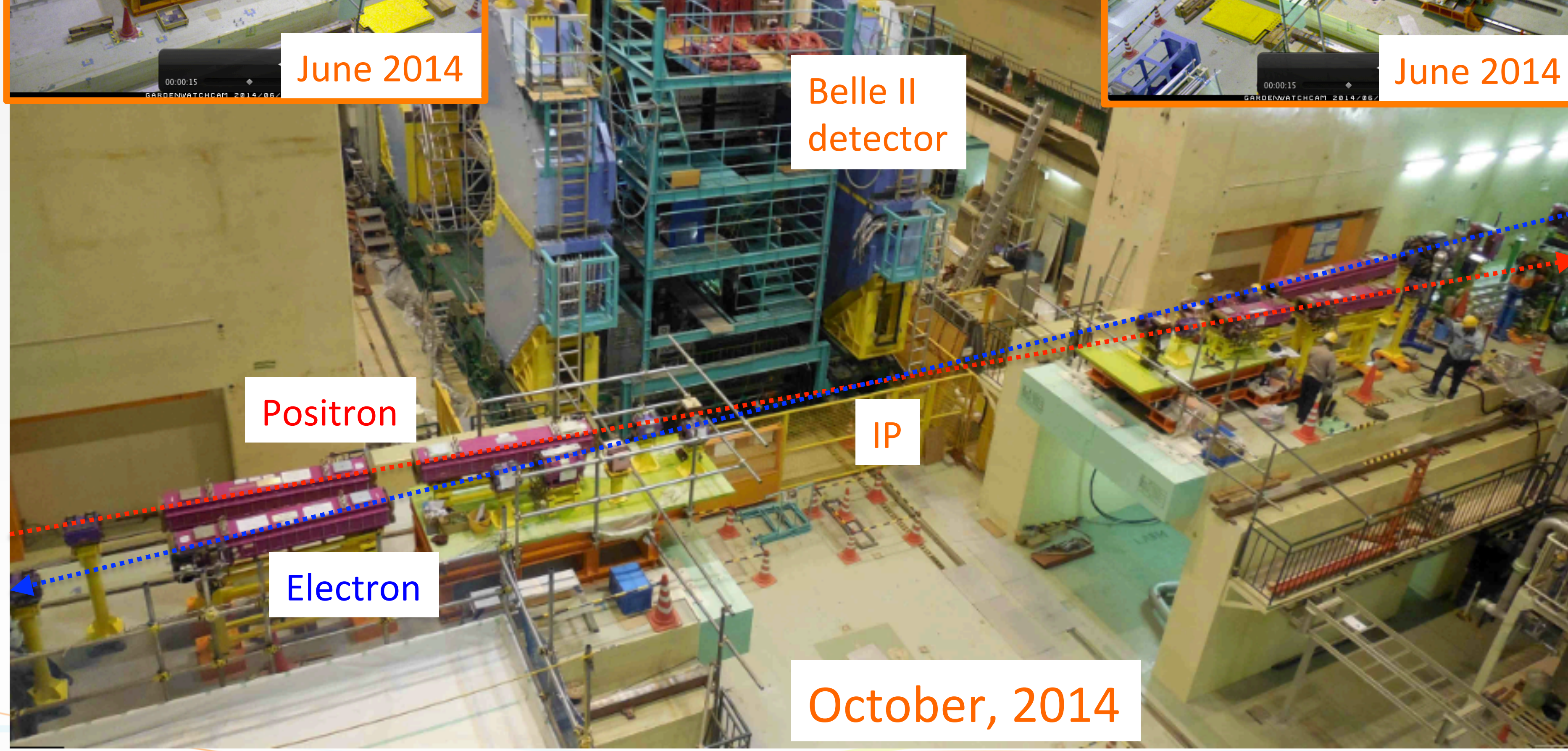
$$\beta_y^* \geq \frac{\sigma_x^*}{\phi} \quad \sim 300\ \mu\text{m}$$

Vertical beta function at IP can be squeezed to ~300μm.
Need small horizontal beam size at IP.
→ low emittance, small horizontal beta function at IP.

Magnet Installation around IP

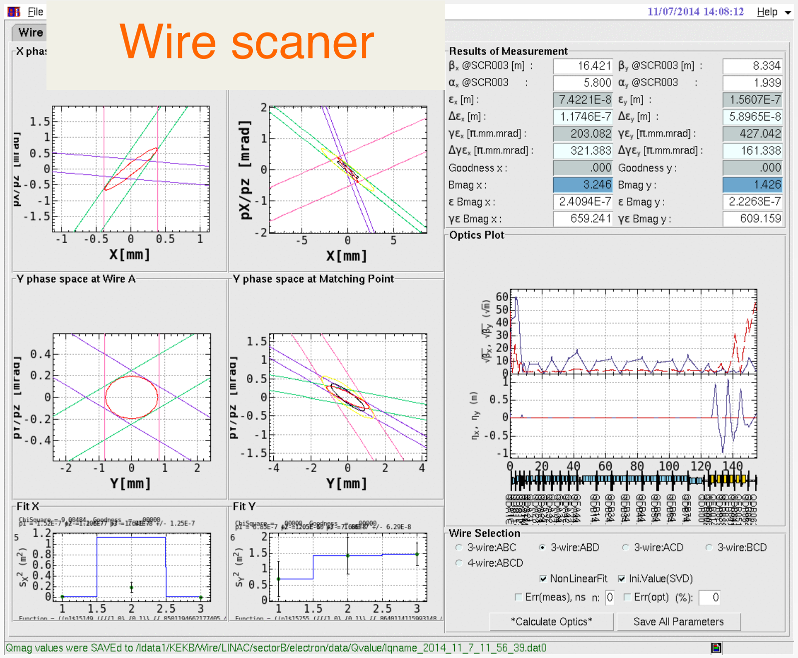


Normal conducting magnets in the IR have been installed & the 1st round of alignment has been carried out.

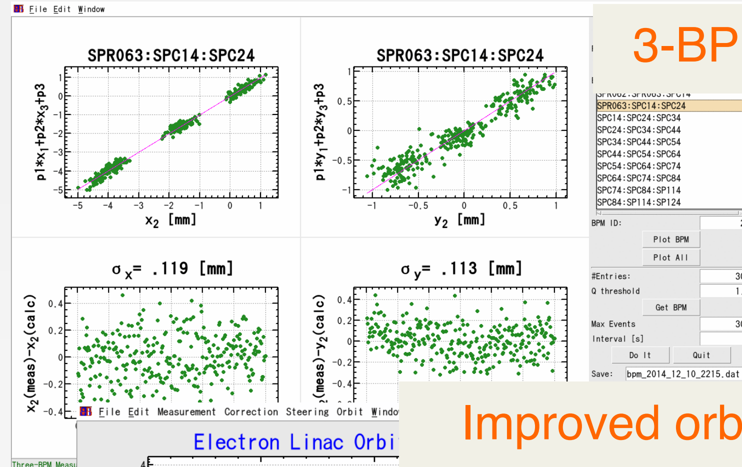


Commissioning Tool and Diagnostics System

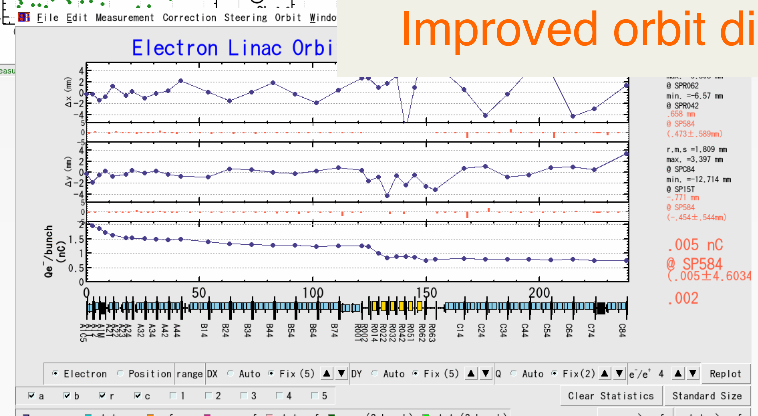
Wire scaner



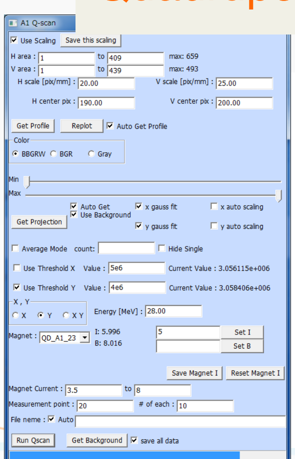
3-BPM method

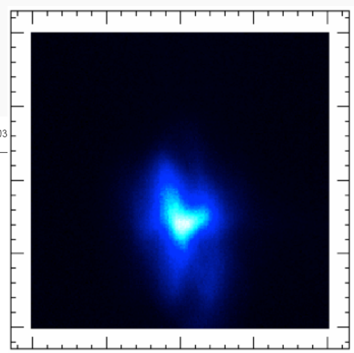


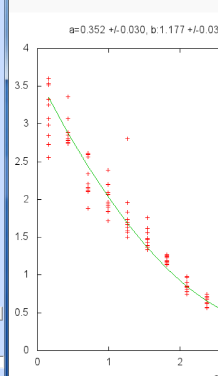
Improved orbit display



Quadrupole -scan







Bunch length measurement with streak camera