Construction Status of SuperKEKB

KEK

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On behalf of the SuperKEKB Accelerator Team

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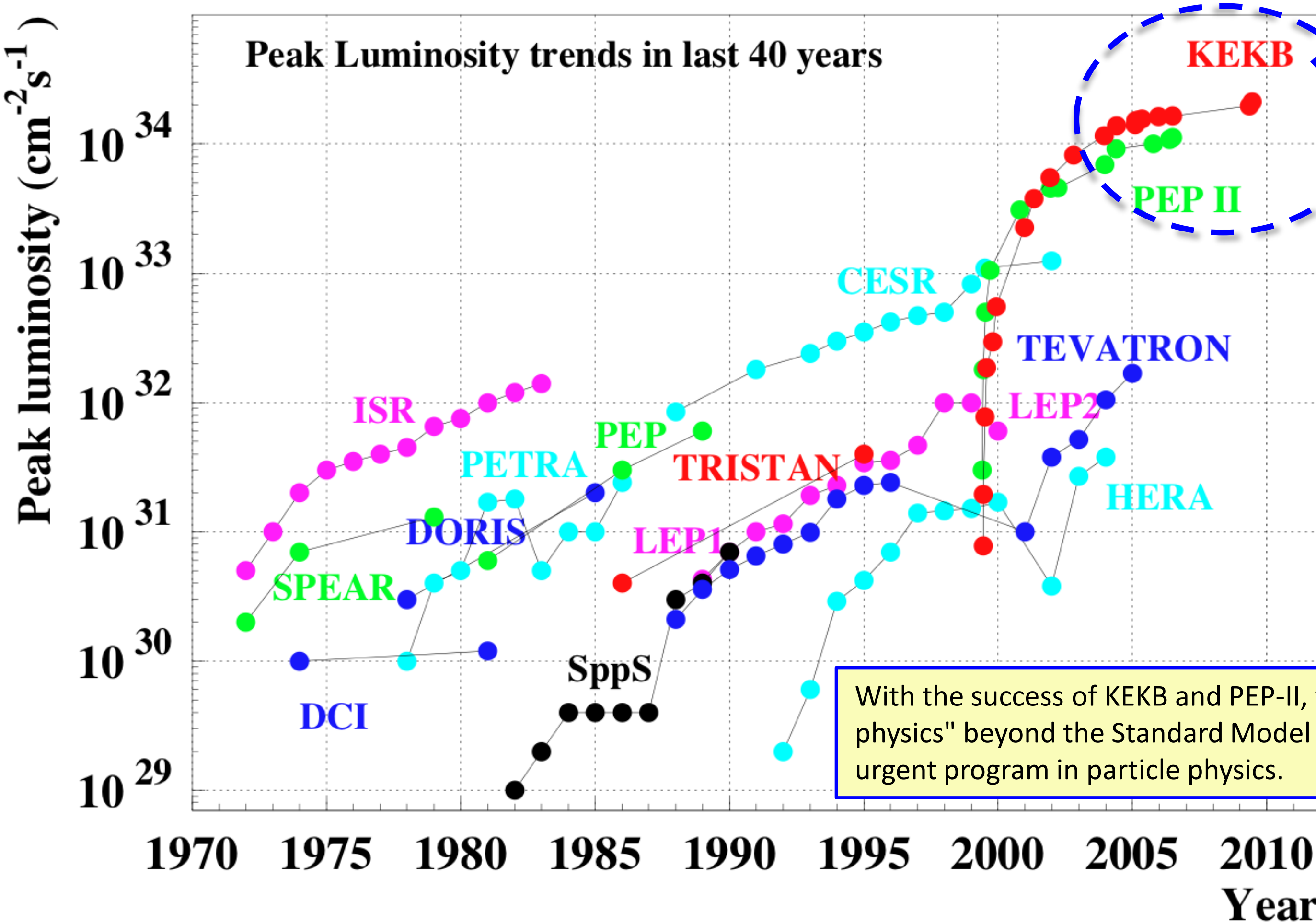
KEKB to SuperKEKB

KEKB: 1998 — 2010

Peak luminosity 2.1 × 10^{34} $cm^{-2}s^{-1}$

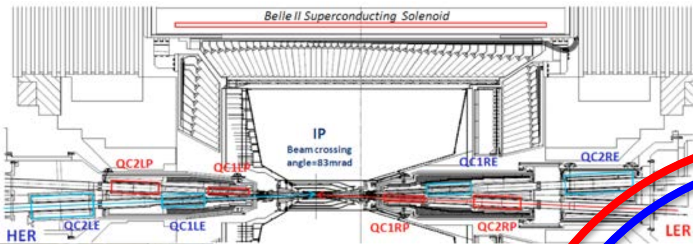
SuperKEKB

Design luminosity 8 × 10^{35} $cm^{-2}s^{-1}$



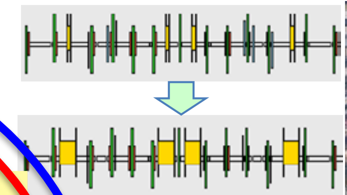
With the success of KEKB and PEP-II, the search for "new physics" beyond the Standard Model has become an urgent program in particle physics.

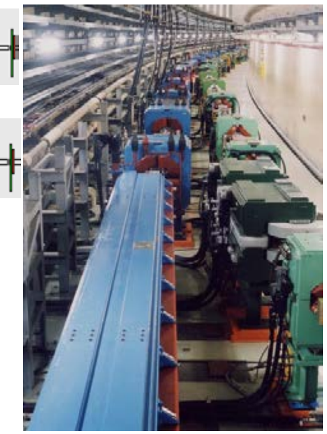
New Features of SuperKEKB

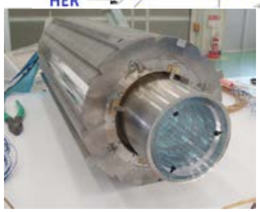


Colliding bunches

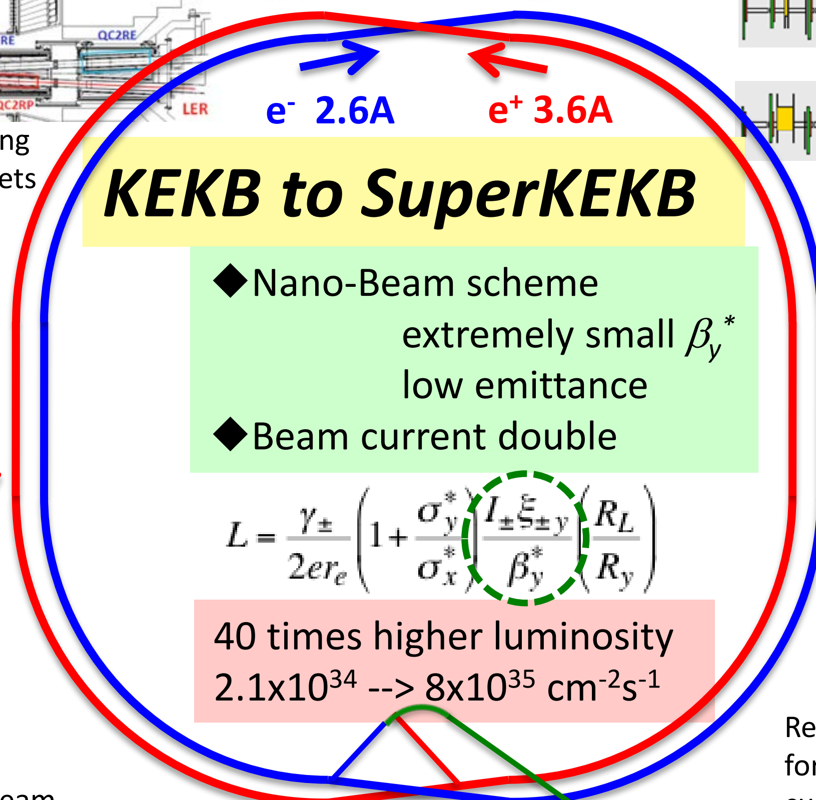
Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)







New superconducting final focusing magnets near the IP

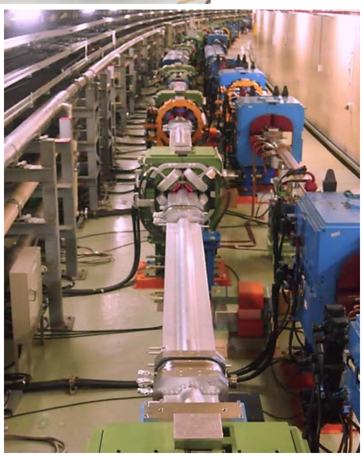


KEKB to SuperKEKB

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

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

40 times higher luminosity
2.1×10^{34} --> 8×10^{35} cm^{-2}s^{-1}



Replace beam pipes with TiN-coated beam pipes with antechambers

New HER wiggler section

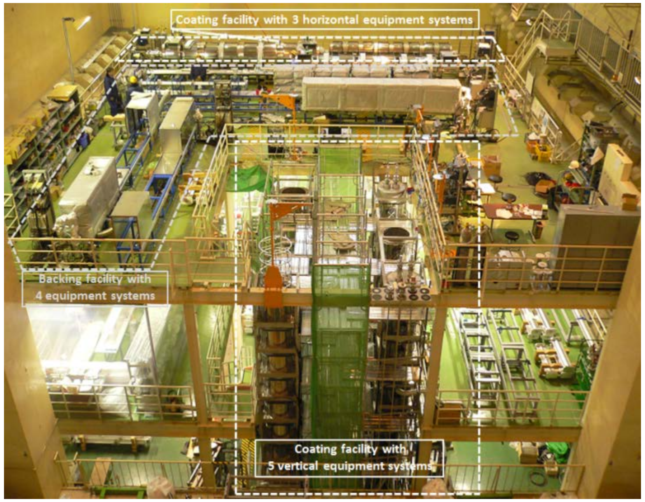
Reinforce RF systems for higher beam currents

Commissioning Scenario

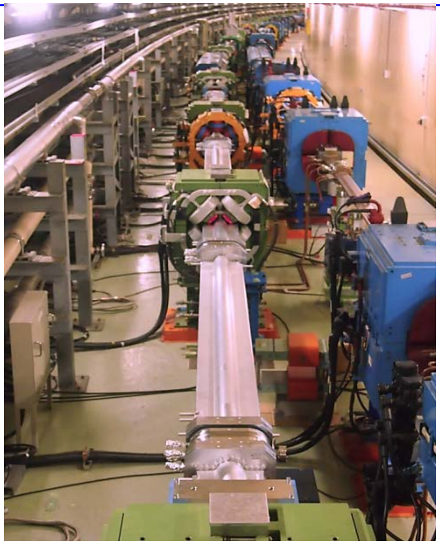
- **Phase 1**
  - **No QCS, No Belle II solenoid**
  - Basic machine tuning
  - Low emittance tuning
  - Vacuum scrubbing
    - **Belle II people request enough vacuum scrubbing in this stage (before Belle II roll in).**
    - **At least one month at beam currents of 0.5~1A /ring.**
  - DR commissioning starts before Phase 2.
- **Phase 2**
  - **With QCS and Belle II (w/o Vertex detectors)**
  - Low beta optics tuning
  - Small x-y coupling optics tuning
  - Beam collision tuning
  - Belle II background study
  - **Target luminosity at this stage is 1×10^{34} $cm^{-2}s^{-1}$**
- **Phase 3**
  - **Physics run (Vertex detectors installed)**
  - Increase beam currents
  - Beam tuning continued to increase luminosity

Vacuum System-1

- **Fabrication**
  - Most of MR vacuum components, such as beam pipes, pumps, bellows etc., required for Phase 1, were already ordered, and will be completed soon.
- **Baking and TiN coating**
  - More than 850 beam pipes have been TiN-coated with the facility in KEK site.
    - Output: 10 ~15 beam pipes per week.
    - Goal is about 1000 beam pipes.
- **Installation of beam pipes and bellows started in JFY2013.**
  - About 830 beam pipes have been installed for the arc and wiggler sections, followed by the connection of bellows.
  - Some sections were already evacuated.
- **Upgrade of monitoring and control system are in progress.**
  - Cabling and piping of cooling water are ongoing.



Preprocessing Facility at Oho Exp. Hall



Antechamber Beam Pipes Installed in LER

Vacuum System-2


North Tunnel


LER Gate Valve in West Tunnel

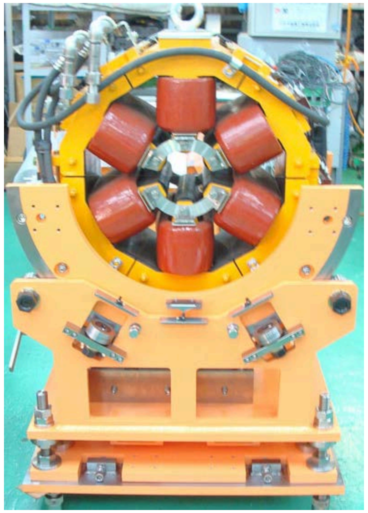

LER Wiggler Downstream in Oho Experimental Hall


LER Nikko Wiggler Downstream in Nikko Experimental Hall

Magnet System

- **Fabrication**
  - Production of more than new 500 magnets for SuperKEKB has been completed.
- **Field measurements**
  - Most of new magnets already done. IR special normal magnets fabricated in JFY2013 are ongoing.
- **Installation of magnets and alignment**
  - 100 LER bending magnets have been replaced with new 4 m long magnets.
  - Rearrangements of LER wiggler sections and new HER wiggler section are completed.
- **Power supplies**
  - Production, install, and startup of MW class, 100kW class, and small class power supplies for magnets are ongoing.
  - Cabling and piping of cooling water are ongoing.

New LER Dipole Magnet



Sextupole Magnet on Tilting Table

HER Wiggler Section and LER ARES Cavities

Tsukuba Straight Section

Before 2013

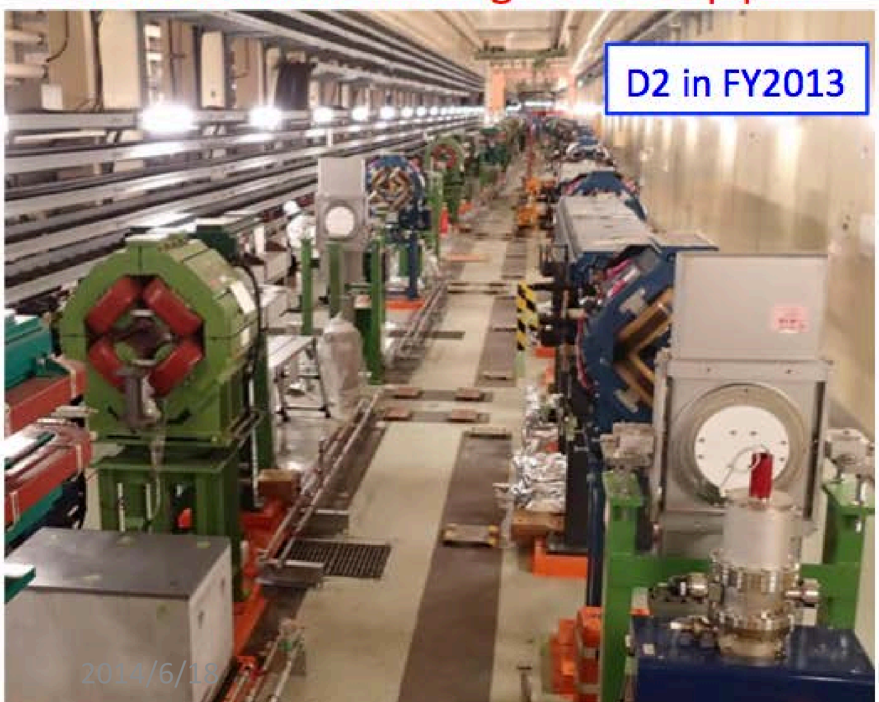
Tsukuba section waiting for beam pipes

Done

- Dismantling all magnets, beam pipes, cables, etc.
- Belle rotation, roll-out
- Installation of magnets (except close to IP)

On going 2013-14

- Beam pipes fabrication
- magnets close to the IP fabrication
- Cabling and piping
- Floor modification and Moving stage
- Radiation investigation and shielding



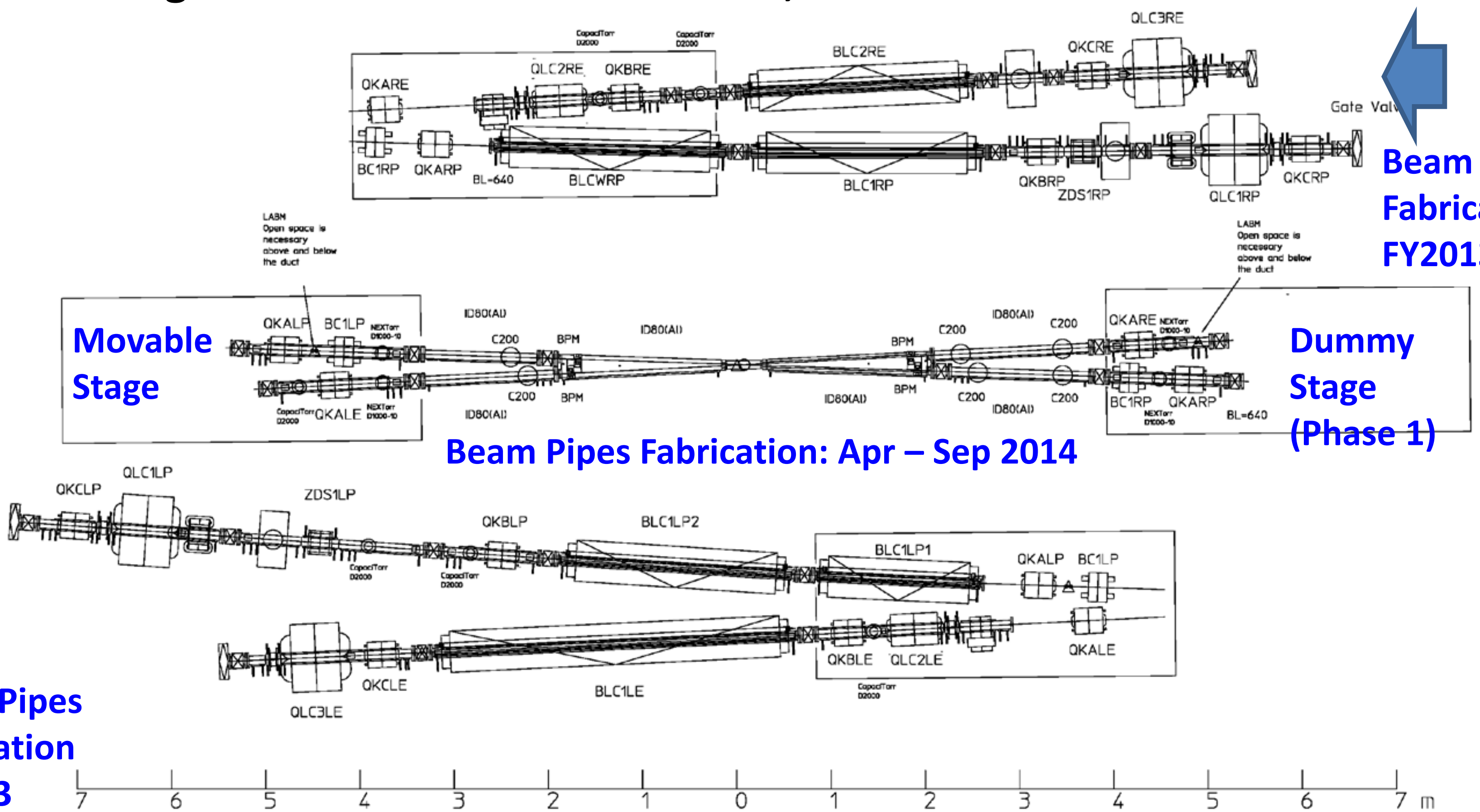
D2 in FY2013

D1 in FY2013

IR Status -Magnets and Beam Pipes

For Phase-1 Commissioning:

New IR magnets are fabricated in JFY2013, and will be installed in summer 2014.



Beam Pipes Fabrication FY2013

Movable Stage

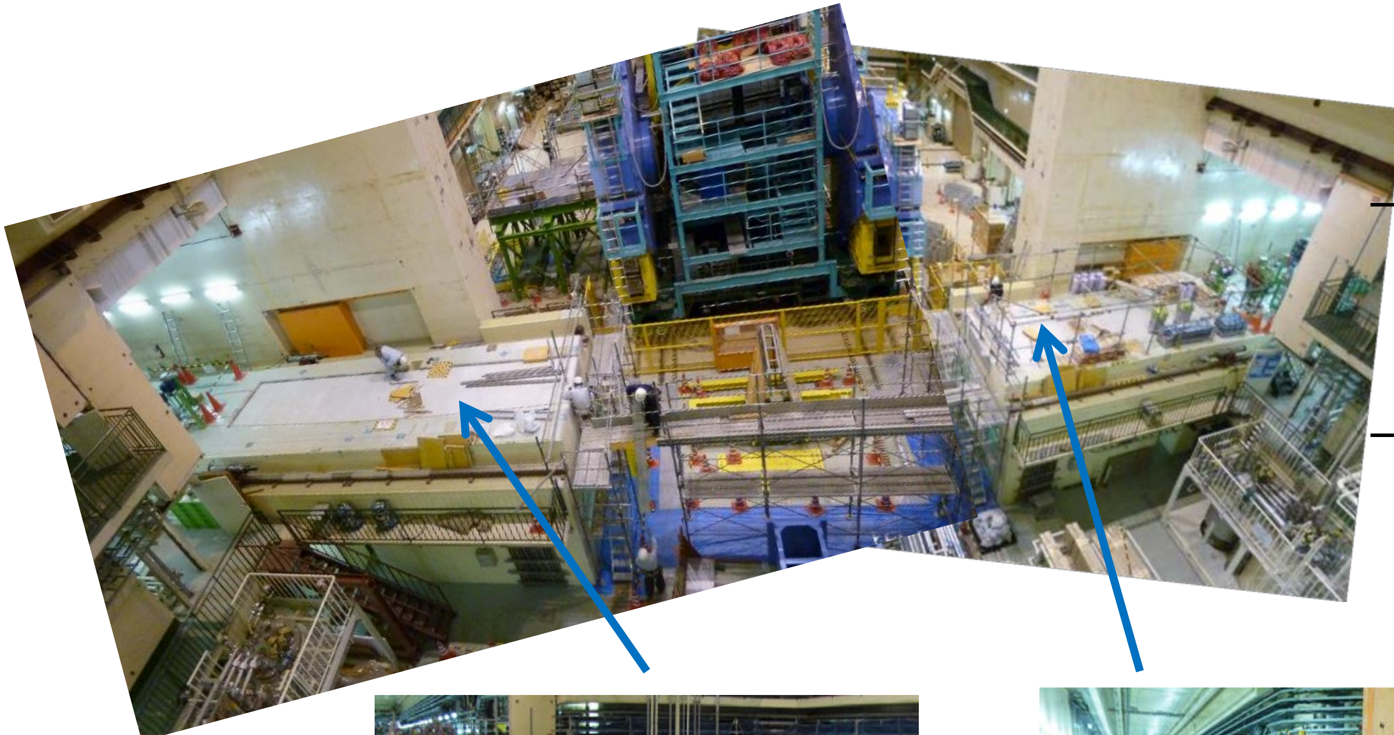
Dummy Stage (Phase 1)

Beam Pipes Fabrication: Apr – Sep 2014

Beam Pipes Fabrication FY2013

Installation of beam pipes for the IR will start around August 2014.

IR status – Accelerator floor

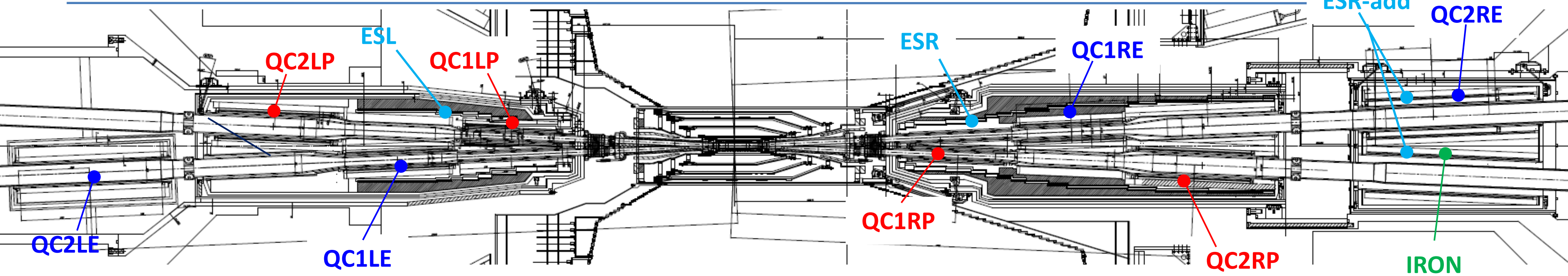


- The accelerator floor has been modified for the new QCS movable stages.
- The QCSL movable stage has been set on the floor in FY2013.

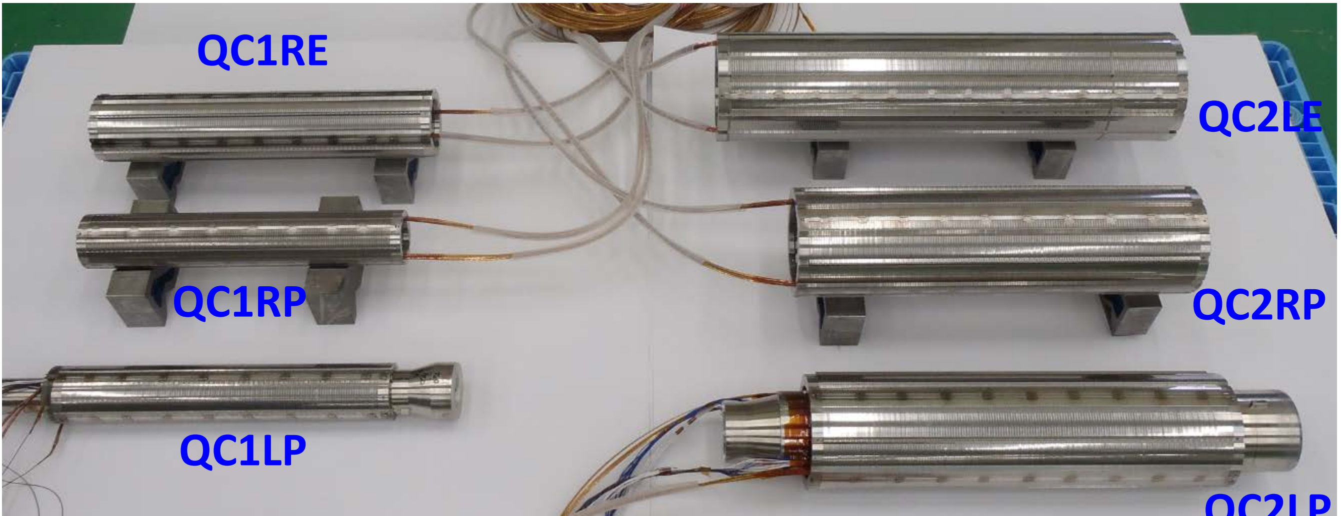
QCSR: Movable stage to be fabricated (dummy stage at Phase 1)

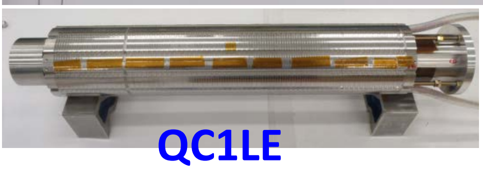
QCSL: Movable stage

Final Focus S.C. Magnets-1



- **Construction of S.C. quadrupole magnets**

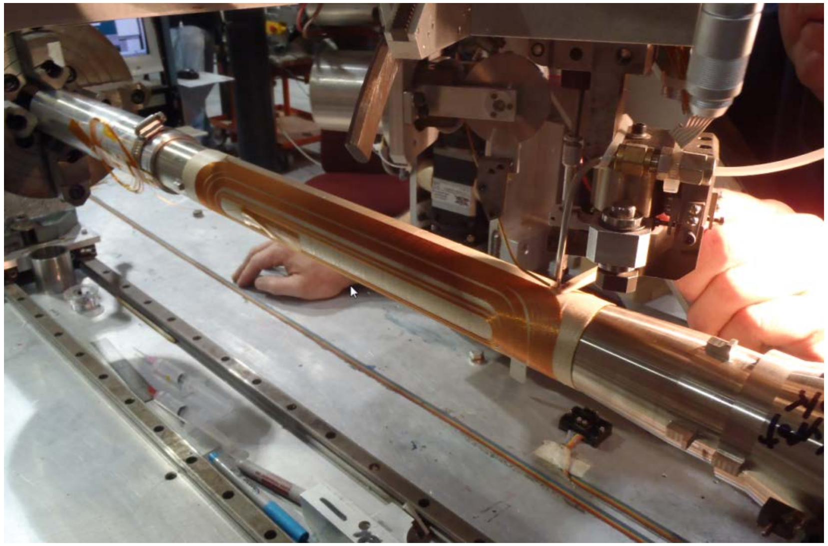




- Assemblies of eight quadrupole magnets in collaring process were completed.
- Eight quadrupole magnets showed good field performances.
- QC1LP, QC2LP and QC1LE magnets completed after assembling the S.C. correctors by BNL.

Final Focus S.C. Magnets-2

- **Construction of S.C. correctors by BNL**
  - 20 corrector coils for QCSL were completed by BNL.
    - Multi-layer correctors (maximum layer: 4)
  - The correctors are measured at room temperature in BNL, and tested at 4K in KEK.
  - 23 S.C. correctors for QCSR will be completed in JFY 2014.

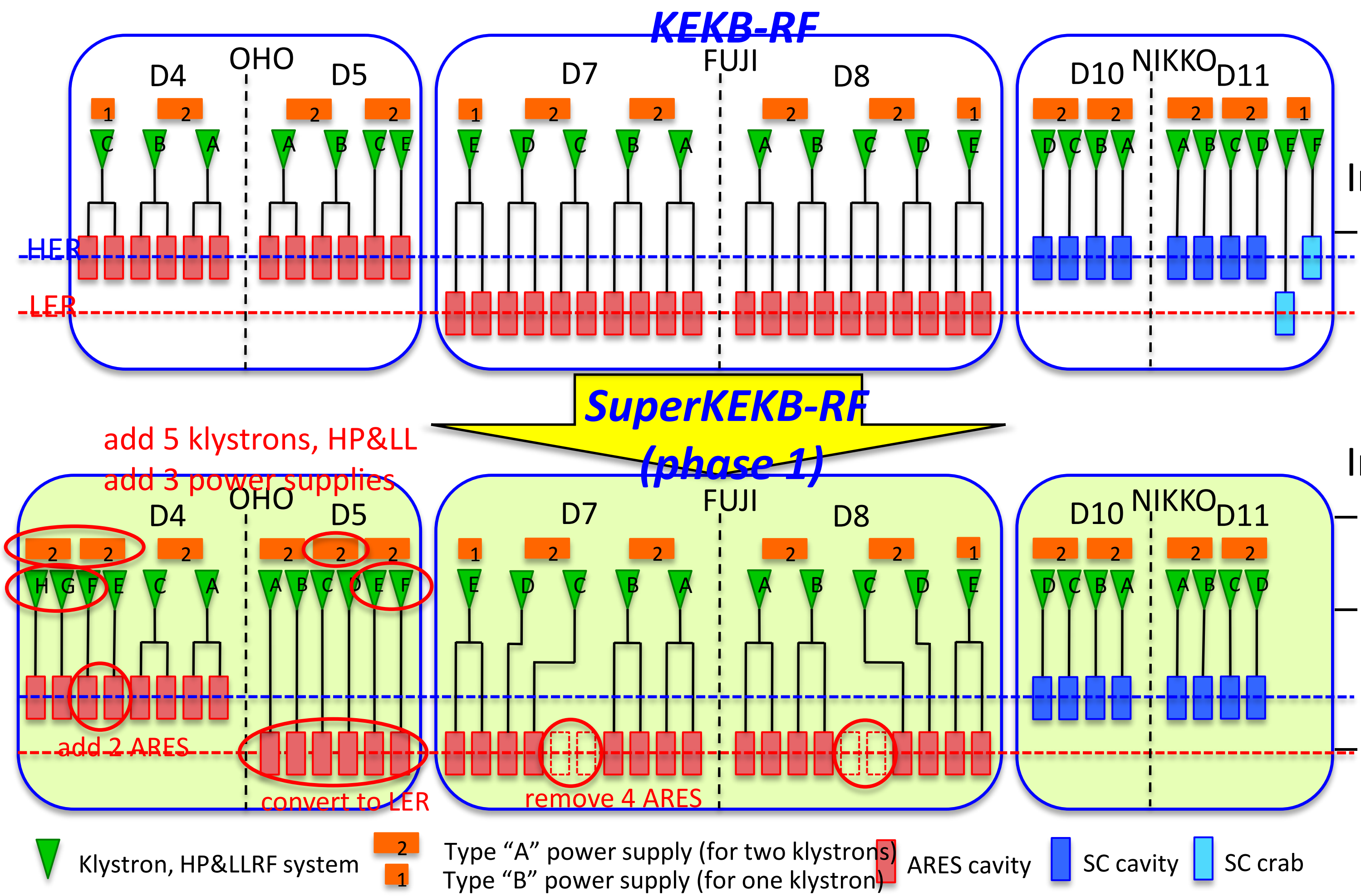


Direct Winding by BNL: Dipole corrector for QC1LP

Vertical Test Stand in KEK:
Excitation Tests and Field Measurements

RF System

• New Scheme of RF Stations



In KEKB

- One klystron powered two ARES cavities in KEKB.

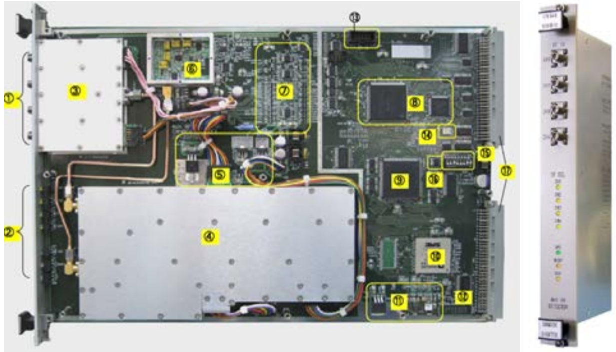
In SuperKEKB

- One klystron drives one ARES cavity.
- Rearrangement of ARES cavities has been completed.
- Construction of five new RF stations is near completion.

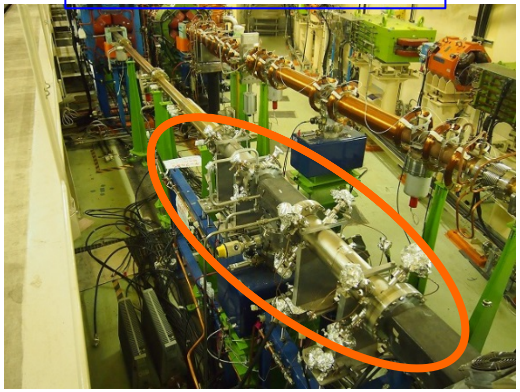
Beam Monitor System

- **Beam Position Monitors**
  - All button electrodes have been fabricated and partly installed in the tunnel.
  - One hundred and twenty 508 MHz narrowband detectors have been delivered in JFY2013.
  - Gated turn-by-turn detectors have also been fabricated.
  - R&D of IP orbit feedback system is in progress.
- **Bunch-by-bunch Feedback System**
  - Transverse kickers, button electrodes, power cables and power amplifiers have been installed.
  - LER longitudinal kickers have been ordered and will be installed in August 2014.

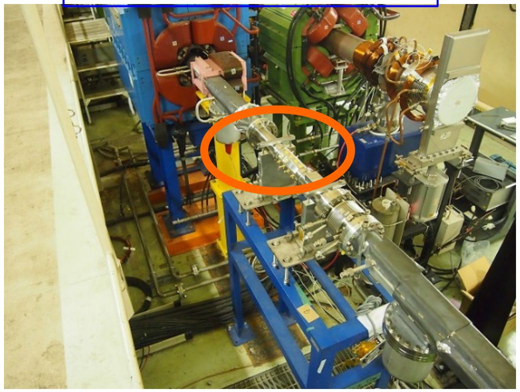
508MHz Narrowband Detector



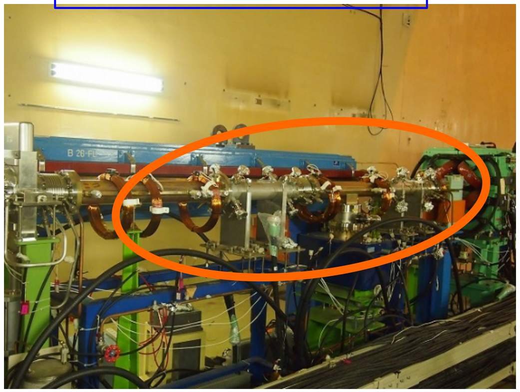
HER Transverse Kicker



HER Button Electrode

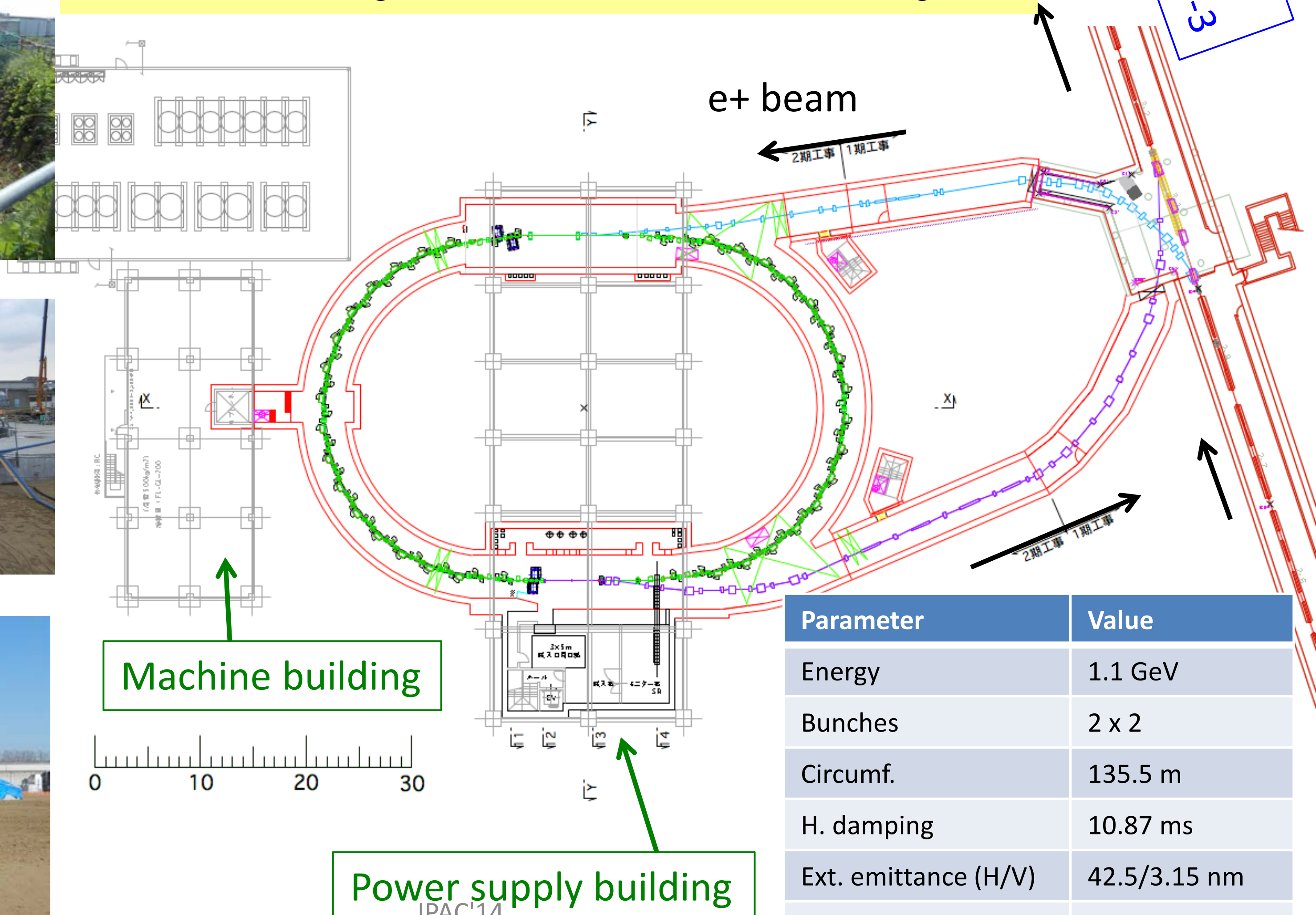


LER Transverse Kicker



New Damping Ring for Positrons

- Construction of the DR tunnel and buildings has been completed.
- Installation of accelerator components will start in JFY2014.
- DR commissioning will start before Phase 2 commissioning.



Parameter	Value
Energy	1.1 GeV
Bunches	2 x 2
Circumf.	135.5 m
H. damping	10.87 ms
Ext. emittance (H/V)	42.5/3.15 nm
Max. current	70.8 mA

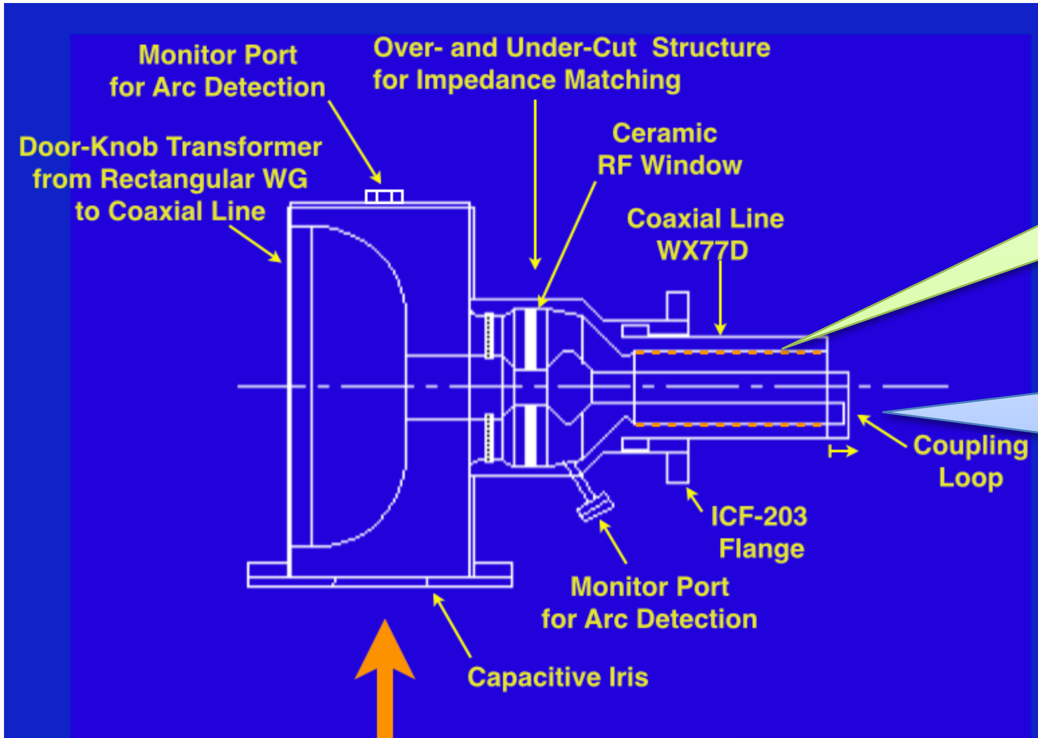
Summary

- Construction of SuperKEKB main rings (LER and HER) and the positron DR is progressing on schedule.
- The Phase 1 commissioning will start in 2015.

Thank you for your attention!

Back-up files

ARES Cavity System / Input Coupler / Performance Upgrade



Input Coupler

Fine grooving inside the outer conductor of the coaxial line to suppress multipactoring discharge.

The coupling loop is extended to increase the input coupling factor.

The optimum input coupling factor β_{opt} is given by $\beta_{opt} = 1 + P_{beam}/P_c$.

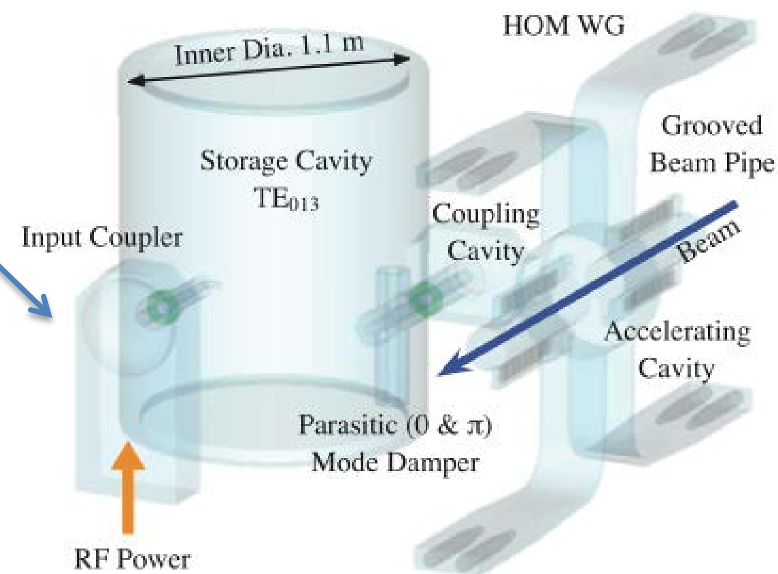
Power Handling Capability (Spec.)

P_{input} P_c P_{beam}

SuperKEKB : 750 kW = 150 kW + 600 kW

KEKB : 350 kW = 150 kW + 200 kW

P_c = 150 kW generating V_c = 0.5 MV per ARES cavity.

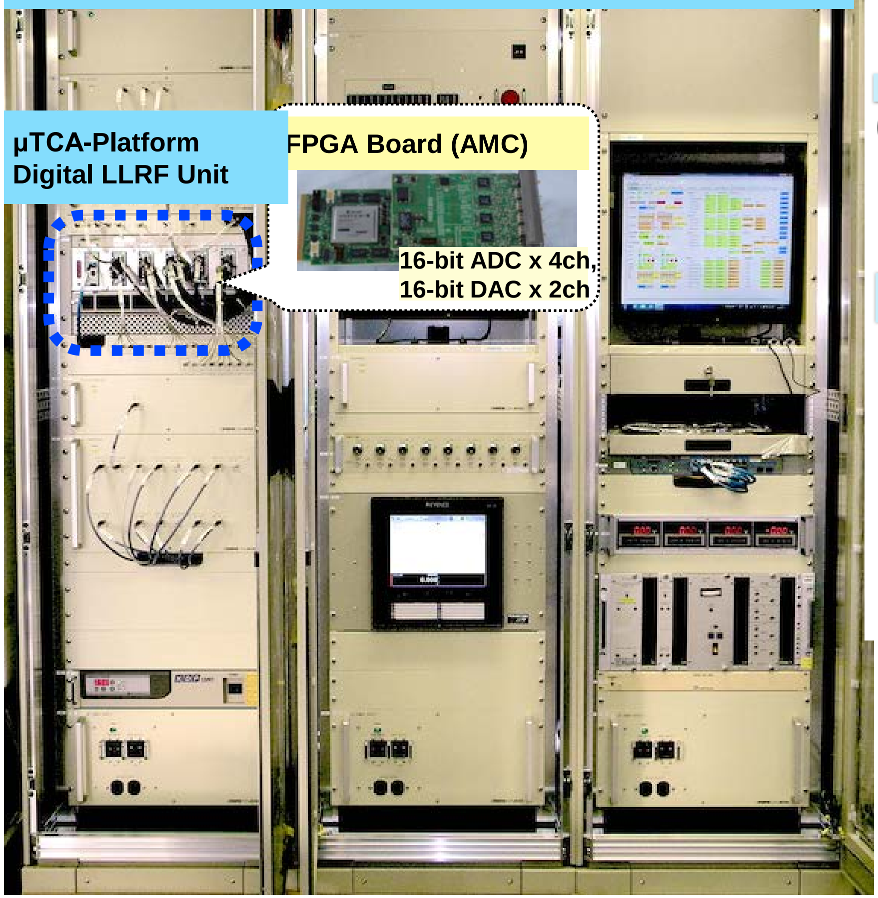


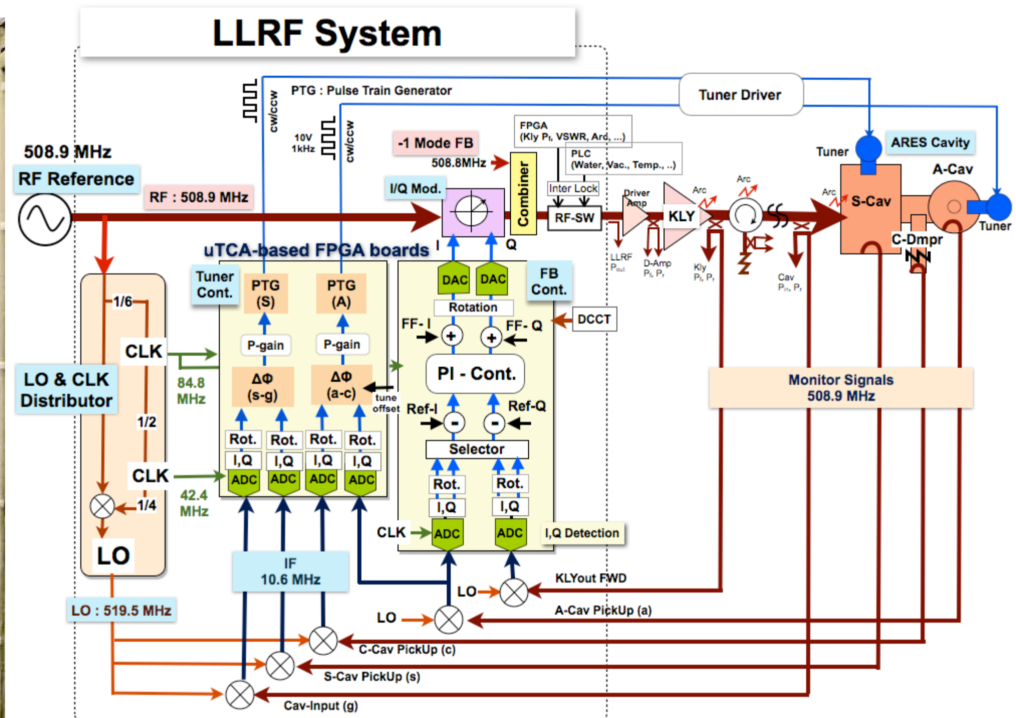
3D Transparent View of ARES Cavity System

New LLRF control system

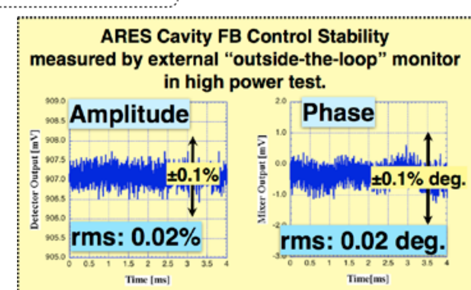
- A digital LLRF control system, which is dominated by µTCA-platformed FPGA boards, has been developed for higher accuracy and flexibility, and many improvements were applied for SuperKEKB.
- Now the quantity production of 8 systems is in progress. Six of them have been installed in D5 and two will be installed in D4 in June.

LLRF Control System for SuperKEKB



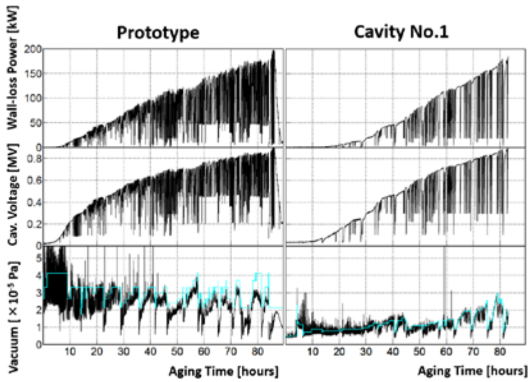


T. Kobayashi et al.



RF cavity for Damping Ring

- DR Cavity #1 (1st Production Version) has passed the High Power Test (HPT) up to Vc=0.95MV/cav over the Spec.: 0.8MV/cav.

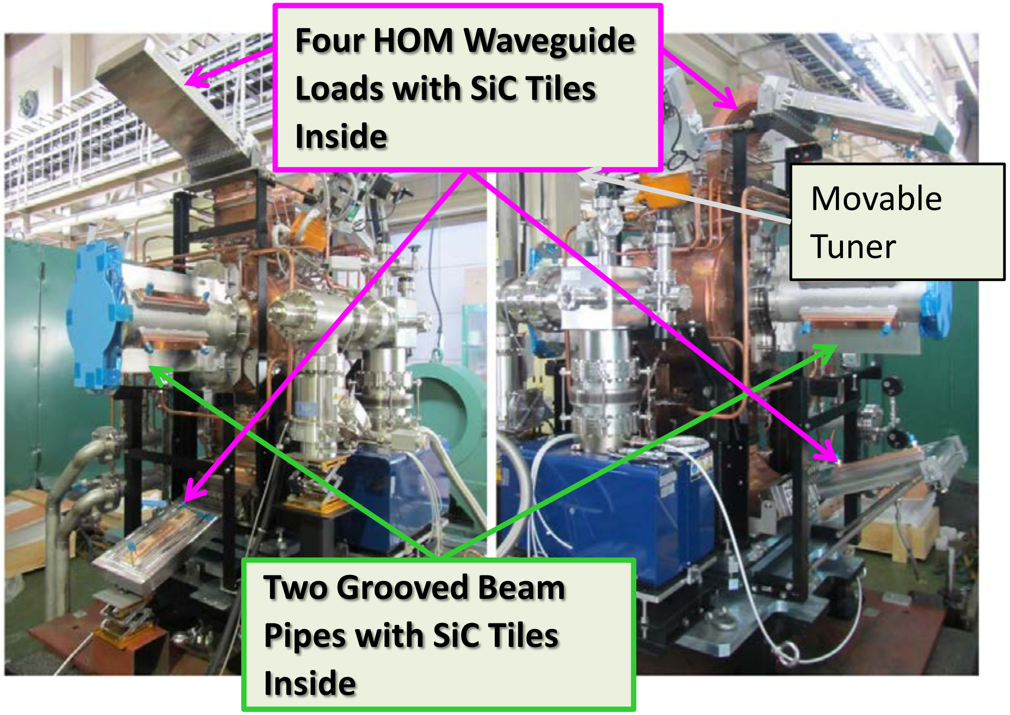


T. Abe et al.

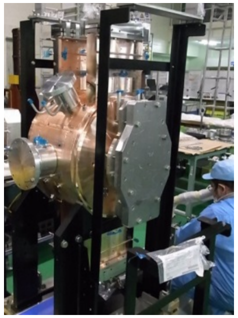
V_c-Holding Endurance Test

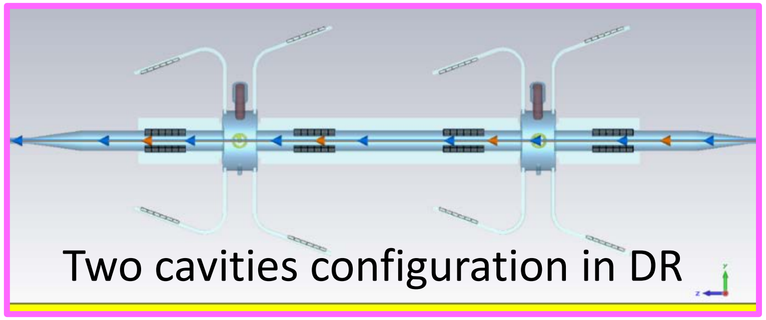
V_c [MV/cav]	Wall-loss Power [kW]	Total Holding Time [hours]	Number of Trips
0.80	144	30.5	1
0.85	164	18	0
0.90	186	14.5	3
0.95	210	8	1

- Mounting test has been performed successfully with vacuum sealing.



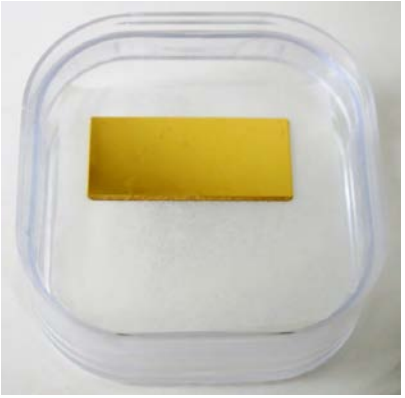
- HPT of DR #2 cavity is ongoing.





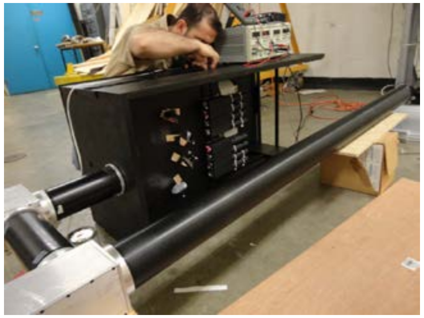
Beam Monitor (cont'd)

- Photon Monitors
  - 1) Visible light monitors (horizontal and longitudinal size measurements)
    - Design of the mirror, the holder and the chamber have been finalized.
    - Fabrication of the mirrors and the holders finished in JFY2013.
  - 2) X-ray monitors (vertical size measurements)
    - Beam line design have been finalized.
    - Under fabrication are downstream section of beam line vacuum components, high-efficiency pixel detectors and 64-channel readout system.
  - 3) Large-Angle Beamstrahlung Monitor (collision size/position offsets monitor)
    - Design of the extraction chamber has been finalized.
    - Optics boxes, optical-transfer-line components and extraction mirrors are being fabricated.



Diamond mirror for visible light monitors

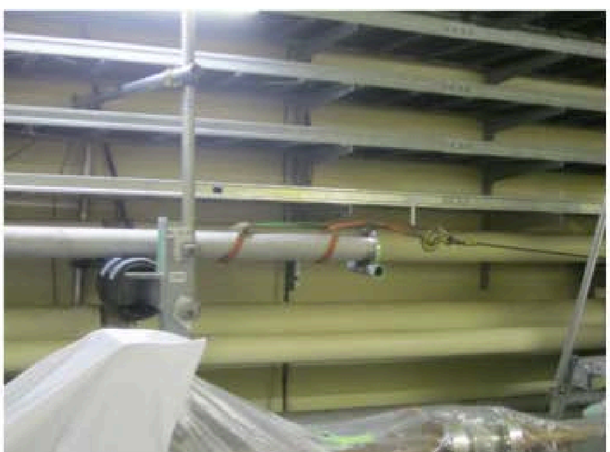
64-channel readout system for x-ray monitors

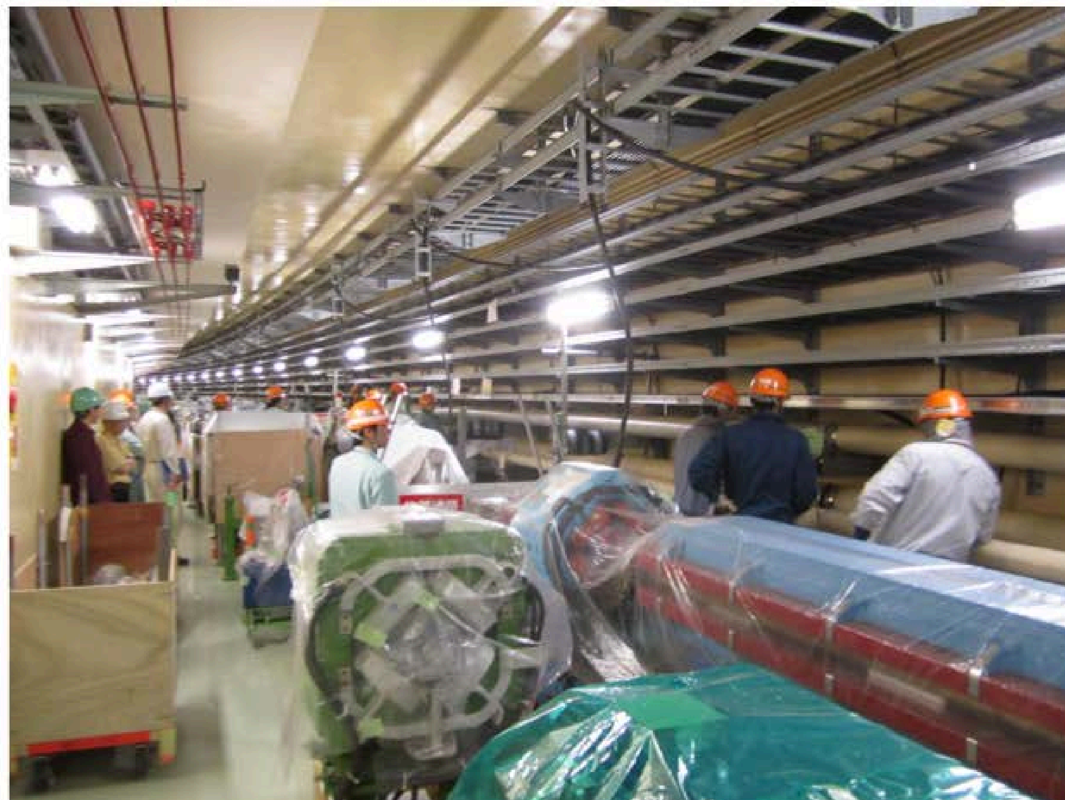


Optics box and extraction mirror for LABM

Replacing pipes around the ring for reinforcing cooling system -> completed

Adopted sliding pipes method to minimize the number of magnets to be moved.





Design Issues

Dynamic aperture reduction due to the beam-beam interaction

- The dynamic apertures of both HER and LER are mainly limited by the nonlinearities around IP.
- In recent simulation studies, it has been found that the beam-beam interaction also significantly decreases the dynamic aperture.
- HER dynamic aperture is almost recovered by re-optimizing sextupole and octupole fields.
- LER dynamic aperture has not yet been recovered well so far.

Crab waist ?

- The crab waist is being considered as one of countermeasures.
- Ideal crab waist without introducing any additional nonlinearities has considerably improved the dynamic aperture with the beam-beam interaction. However, realistic lattice design has not yet been found.
- Any substantial improvements on the crab waist lattice and other various countermeasures are being studied.

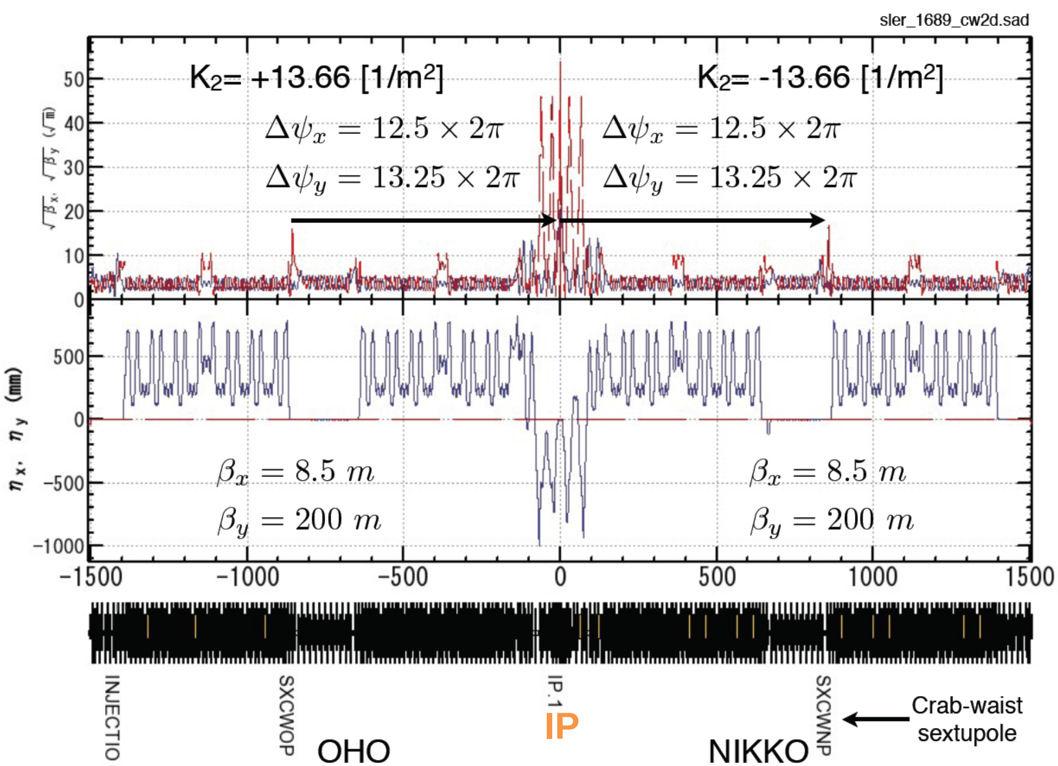
LER dynamic aperture

no beam-beam

with beam-beam

after re-optimization

A. Morita et al.



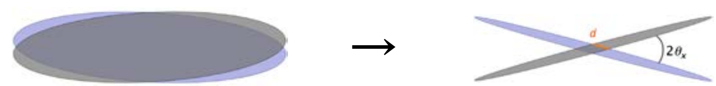
Example of the crab waist lattice

- A pair of sextupole magnets are placed in OHO and NIKKO sections for the crab waist.
- In this lattice, the dynamic aperture is drastically decreased since sextupole nonlinearities are not fully cancelled due to nonlinear fields around IP.

Y. Ohnishi et al.

SuperKEKB

- Increase the luminosity by 40 times based on "Nano-Beam" scheme



KEKB (in the case of no crab) → SuperKEKB

colliding bunches in the horizontal plane

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

- Vertical β function at IP : 5.9 → 0.27/0.30 mm (× 20)

  KEKB SuperKEKB Luminosity Gain

- Beam current : 1.7/1.4 → 3.6/2.6 A (× 2)
- Vertical beam-beam parameter : 0.09 → 0.09 (× 1)
- Beam energy: 3.5/8.0 → 4.0/7.0 GeV

LER : Longer Touschek lifetime and mitigation of emittance growth due to the intra-beam scattering

HER : Lower emittance and lower SR power

Machine Parameters

2013/July/29	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	3.18×10^{-4}	4.53×10^{-4}		
σ_δ	$8.10(7.73)\times10^{-4}$	$6.37(6.30)\times10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6.0(5.0)	5(4.9)	mm	():zero current
ν_s	-0.0244	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.86	2.43	MeV	
$\tau_{x,y}/\tau_s$	43.2/21.6	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	8×10^{35}		$cm^{-2}s^{-1}$	