Overview of SuperKEKB, Status and Plans

Contents

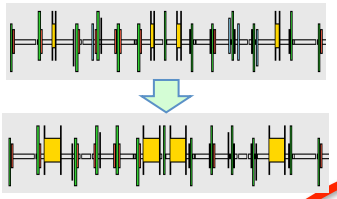
- Overview of upgrading KEKB to SuperKEKB
- Completion of construction for Phase 1
- (Phase 1 commissioning) ---> Funakoshi-san's talk
- Status and plans for Phase 2

K. AKAI

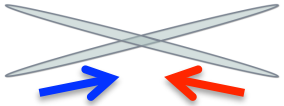
Accelerator Laboratory, KEK

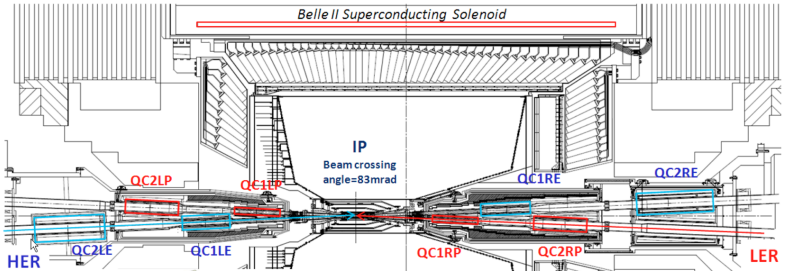
Jun. 13, 2016 @21th KEKB Accelerator Review Committee

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

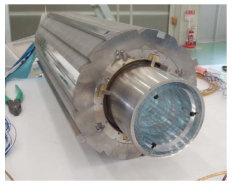


Colliding bunches





New superconducting final focusing magnets near the IP



e^+ 3.6A

e^- 2.6A

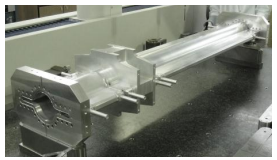
SuperKEKB

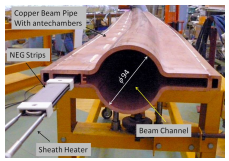
- Nano-Beam scheme
  extremely small β_y^*
  low emittance
- Beam current double

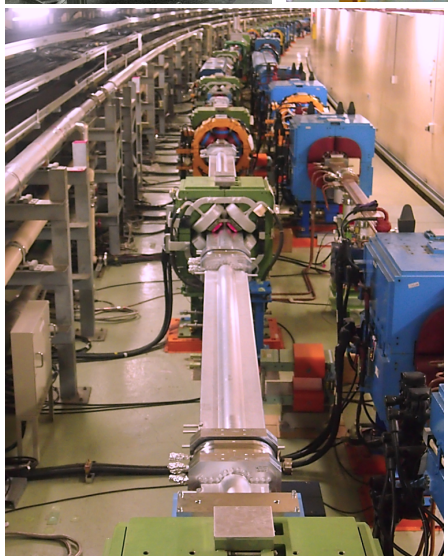
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

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

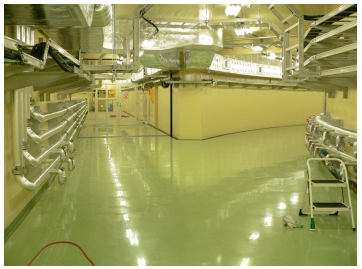
Wiggler sections upgrade







Replace beam pipes with TiN-coated antechamber-type ones



Improve monitors and control system

Injector Linac upgrade
- RF electron gun
- improve e+ source

Injector Linac upgrade

New e+ Damping Ring

Reinforce RF systems for higher beam currents

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}		$cm^{-2}s^{-1}$	

Major points of construction

- Main Rings (LER and HER)
  - A large number of magnets and power supplies need to be rearranged, replaced, and added to reduce the horizontal and vertical emittance of both beams.
  - To cope with the electron cloud issues, ante-chamber type beam pipes are adopted with a combination of TiN coatings, grooved shape surfaces, and clearing electrodes. The ante-chamber is also used for mitigating heating problems in a part of HER.
  - A new final focus magnet system will be installed to squeeze βy^* to 0.3 mm.
  - The RF system needs to be strengthened with the accelerating cavities modified and rearranged to cope with the increased beam currents and power.
  - The beam monitor and control system also are improved.
- Damping Ring (DR)
  - A new 1.1 GeV positron DR is built to reduce emittance of positron beam before injection into the LER.
- Injector
  - The injector Linac needs to be upgraded including a new, low-emittance RF electron gun and improvements to the positron source.
- Infrastructure
  - Cooling system is reinforced for the increased heat load for magnets and vacuum system.
  - Buildings for increased number of power supplies for magnets, additional transformers for RF reinforcement are newly built.
- At the same time, the existing resources of KEKB are used as much as possible.

Commissioning phases

- Commissioning will be performed in three phases. The three-phases scenario was agreed between KEKB accelerator and Belle II groups.
- Phase 1: No QCS, No Belle II solenoid:
  - Low emittance beam 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.
  - Beast II study for beam background
  - DR is not needed in this phase.
- Phase 2: with QCS and Belle II (w/o VXD)
  - Low beta and small x-y coupling optics tuning
  - Beam collision tuning
  - Belle II background study
  - DR commissioning
  - Target luminosity at this stage is 1 x 10^{34} $cm^{-2}s^{-1}$
- Phase 3: Full Belle II detector with VXD installed
  - Physics run
  - Improve luminosity

Since construction budget supply is until JFY2014, the cost needed for transition from Phase 1 to 2 and 3 must be supplied within annual operation budget and/or supplementary budget.

SuperKEKB master schedule

···	JFY2010	JFY2011	JFY2012	JFY2013	JFY2014	JFY2015	JFY2016	JFY2017	···

Now (Jun. 2016)

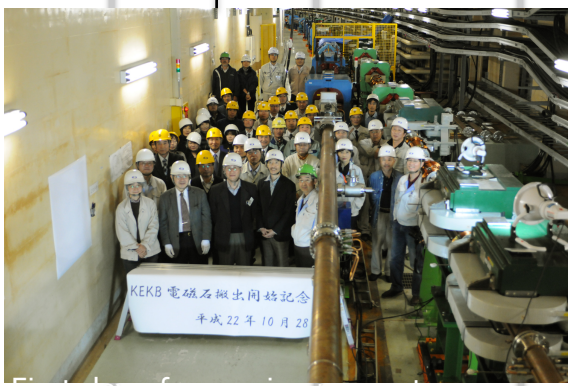
KEKB operation

SuperKEKB construction

Phase 2 commissioning:
- Low beta* tuning
- Collision tuning
- Start physics data taking

Phase 3:
- Install VXD to complete Belle II
- Continue physics data taking

Dismantle KEKB



Startup and conditioning

Phase 1 commissioning:
- Low emittance beam tuning
- Vacuum scrubbing

Phase 1 beam commissioning ongoing

Phase 1 — Phase 2、3

SuperKEKB operation

DR

Install QCS and Belle II

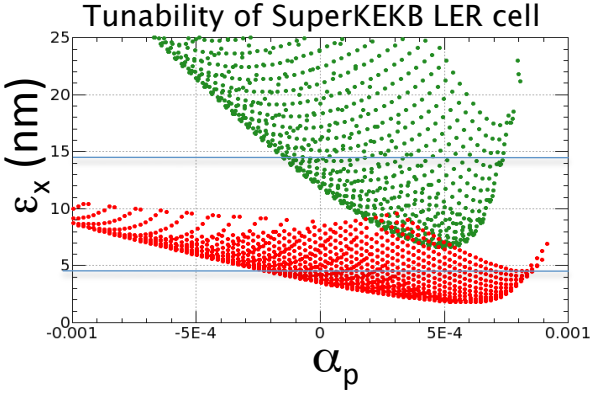
For about 10 years

Completion of construction for phase 1

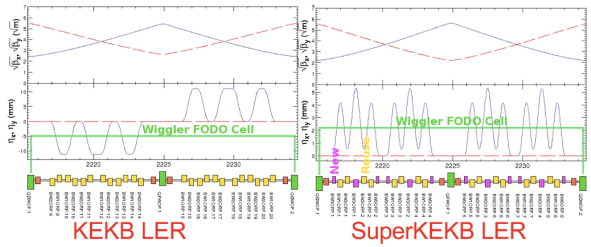
Magnet system upgrade

- Replacement of bending magnets in LER (~100) with new longer ones to reduce horizontal emittance.

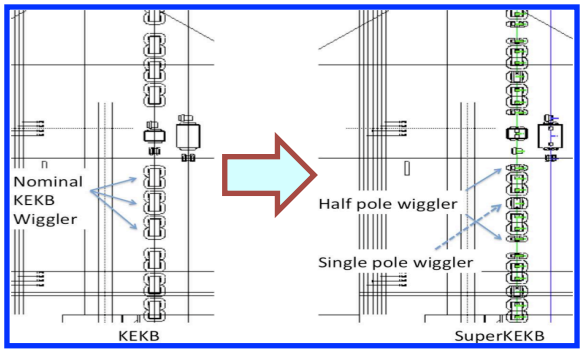
L= 0.89 m → 4 m

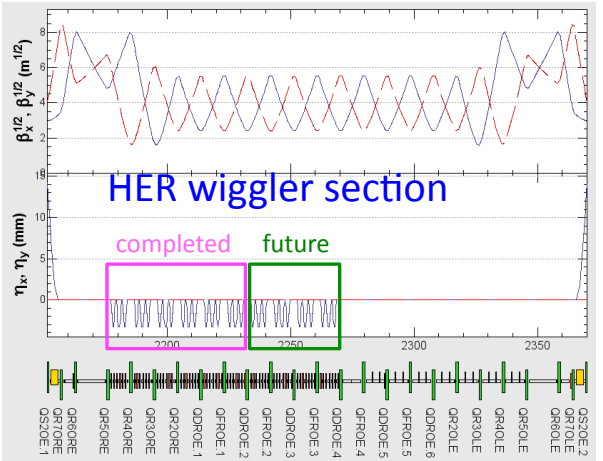


- Wiggler sections:
  - In LER, new 56 single pole wigglers and 112 half pole wigglers has been added to the normal ones used in KEKB to double the wiggler cycles.
  - In HER, a new wiggler section has been constructed with reused wiggler magnets from LER to reduce the HER horizontal emittance.



LER wiggler section

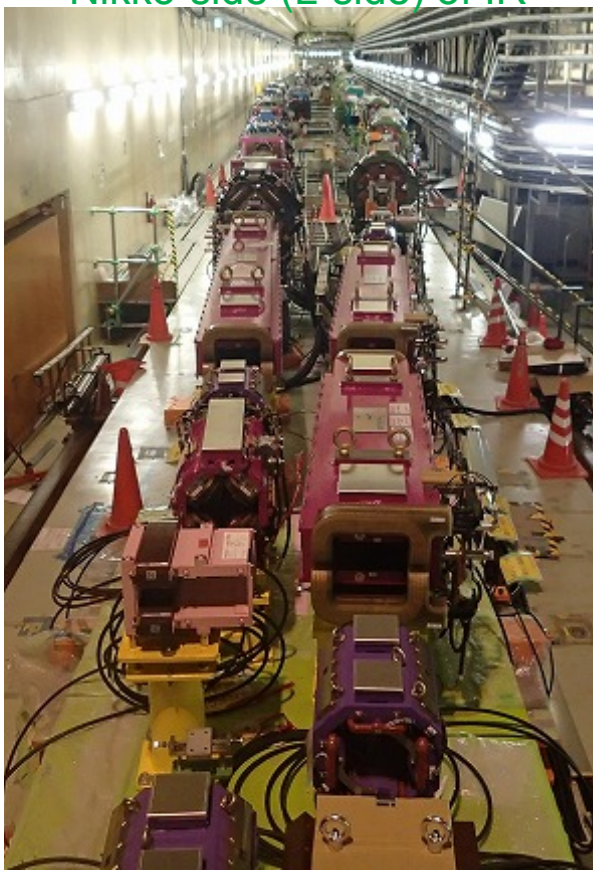




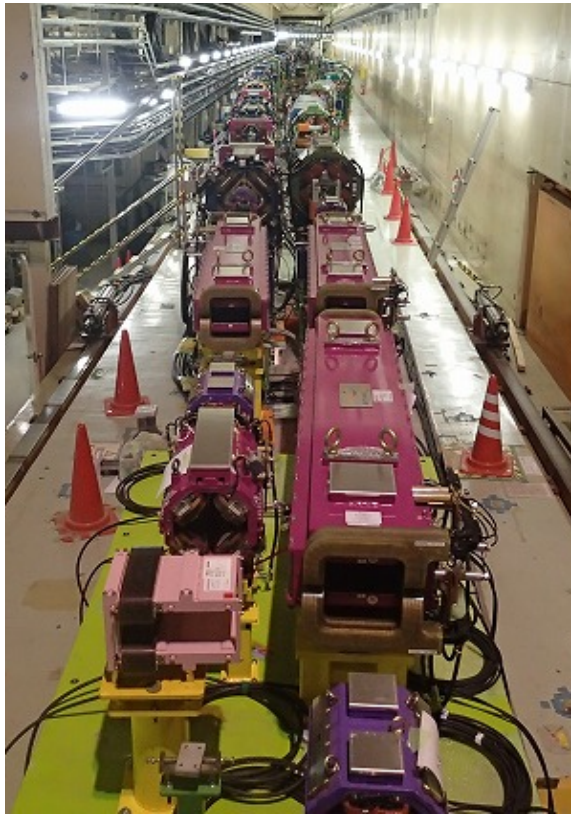
Tsukuba straight section

- Completely new beam line
  - All magnets, beam pipes, power cables in both sides of IP for about 300 m length used in KEKB were dismantled.
  - Construction of new beam line is completed in early 2015.

Nikko-side (L-side) of IR



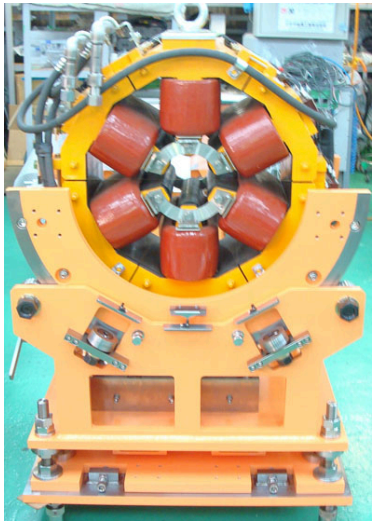
Oho-side (R-side) of IR



Magnet system upgrade (cont'd)

- 24 rotating sextupole magnets have been fabricated and installed.
- Precise measurement and alignment of magnets in whole rings performed in Jun-Sep 2015.
- Production of power supplies needed for phase 1 has been completed.
- Full-scale start-up tasks such as polarity check, cable connection check, network test, magnet standardization test, interlock system test and so on have been completed in time for phase 1 commissioning.

Rotating sextupole magnet



Wiggler magnets

Power supply check

MR magnet system for QCS (for phase 2)

QCS power supply cable laying work to B4 area

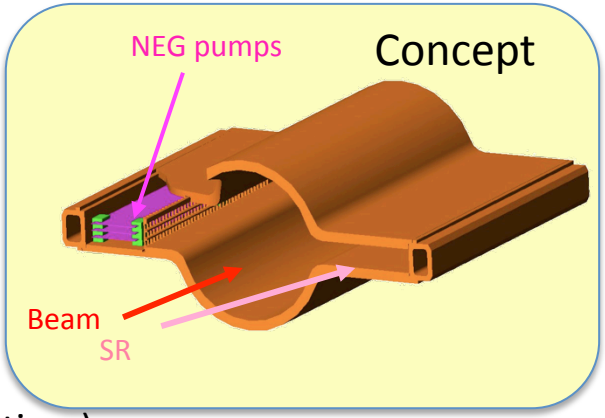
New survey monuments added and surveyed for phase2 QCS installation

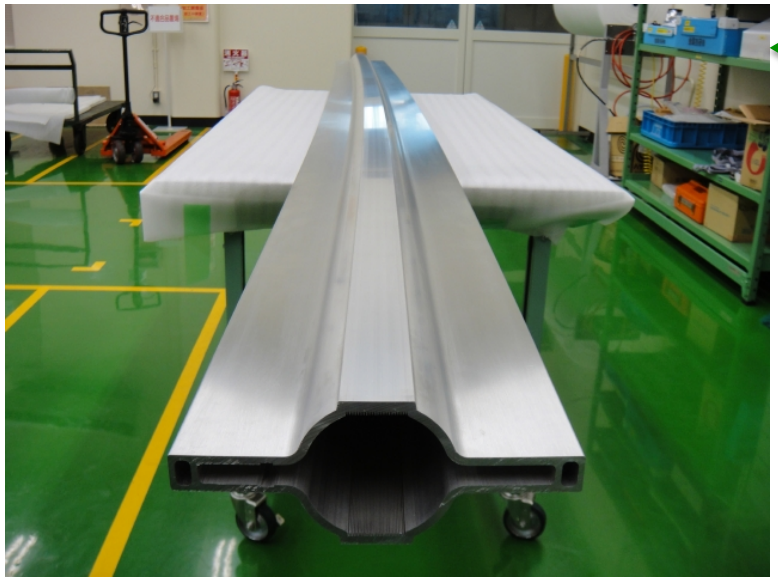
Vacuum system upgrade

- To cope with the electron cloud issues in LER, ante-chamber type beam pipes are adopted with a combination of TiN coatings, grooved shape surfaces, and clearing electrodes. The ante-chamber is also used for mitigating heating problems in a part of HER.
  - Beam pipes at LER arc section are replaced with new aluminum-alloy ante-chamber pipes (~2000m).
  - Copper ante-chambers are installed at wiggler sections in LER and HER. With clearing electrodes for LER.
  - Tsukuba straight section for both rings are made new.
    - Optics changes. Ante-chambers are used, copper for most part.
- Present copper beam pipes at HER arc section are reused.
  - Since the HER energy is reduced from 8.0 to 7.0 GeV, SR power at normal arc section for the design beam current will be about the same as KEKB.
  - This reduces construction cost and work largely.
- New collimators are developed under collaboration with SLAC.
  - Two new horizontal collimators are installed in LER arc section.
  - More new collimators will be installed in LER and HER for phase 2.

Ante-chamber type beam pipe

- **Structure**
  - SR from beam is guided to the ante-chamber.
  - NEG pumps in the ante-chamber.
  - TiN coating inside.
- **Merits**
  - **Suppress electron clouds.**
  - Reduce beam impedance.
  - Reduce SR power density at the wall.
- **Material**
  - Copper at wiggler magnet section.
  - Aluminum alloy at arc section (reduce cost and manufacture time).

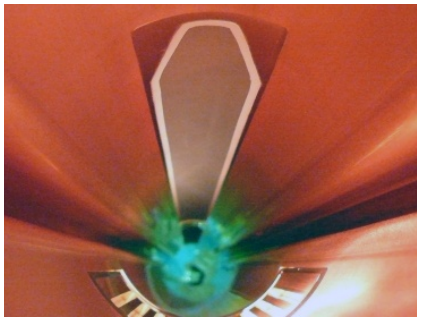




Arc section (aluminum)

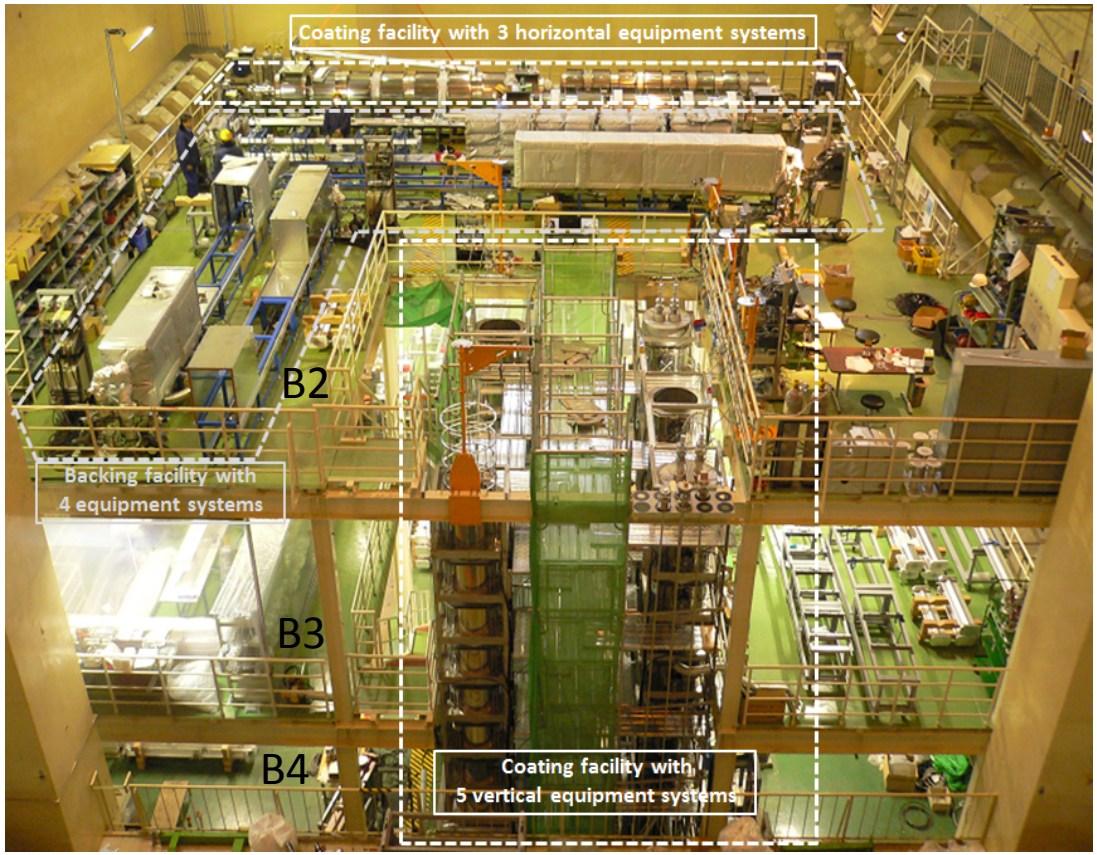
Wiggler section (copper)

Inside view
(clearing electrode for wiggler section)



Beam pipes treatments

- Baking and TiN coating system have been constructed at Oho experimental hall in KEK for treatment of beam pipes.
  - More than 1000 beam pipes have been baked and TiN-coated. They were installed in the rings.



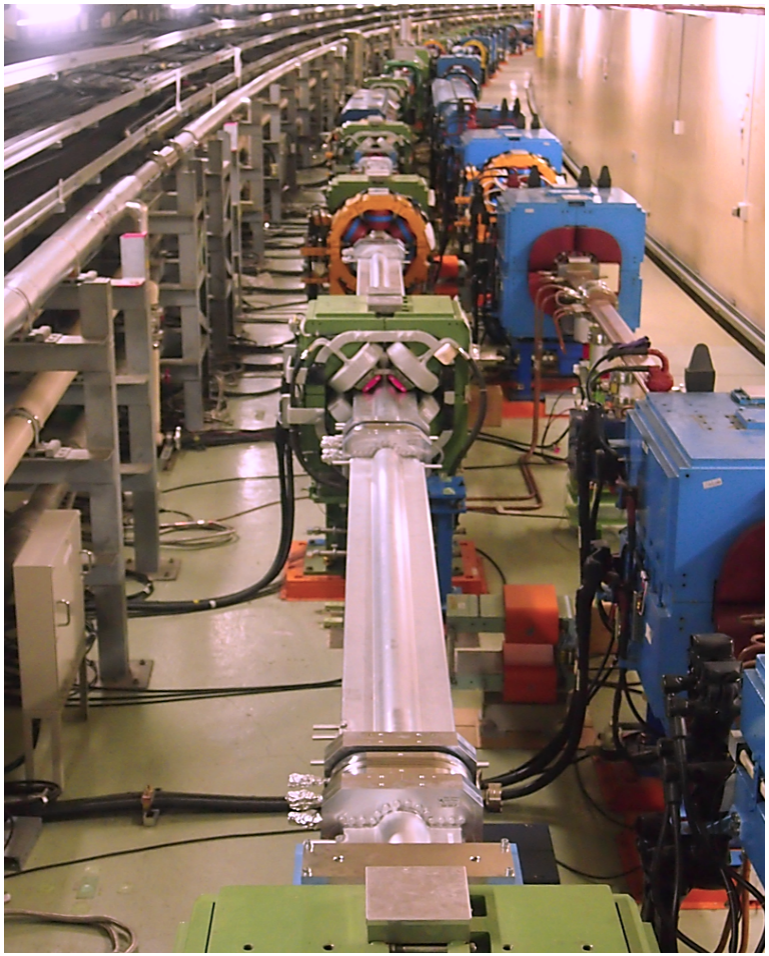
Vacuum group working deck in Oho exp. building
- Four baking systems operating on the upper floor (B2).
- Checking and preparation work on the middle floor (B3).
- Five vertical TiN coating systems from B4 to B2 through.

Copper and Aluminum beam pipes after baking and TiN coating. They are temporary stocked in Oho B4 until moved to tunnel or other stock houses.

North tunnel

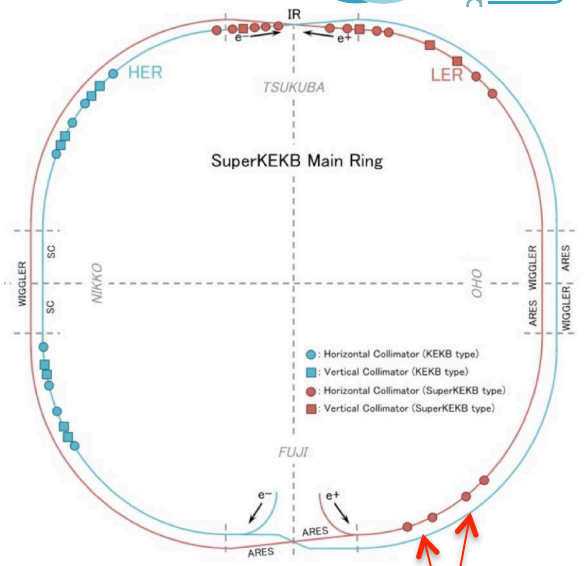
LER Gate valve in West tunnel

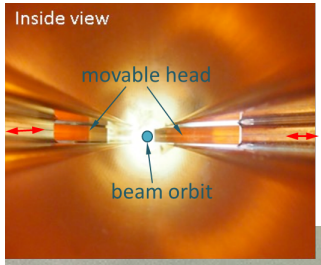
Beam pipes installed into arc section



New collimators

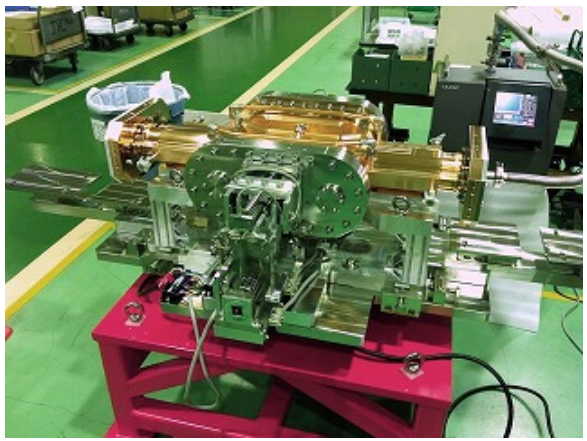
- New low-impedance collimators
  - Beam collimators are devices to cut off halos around the beam orbit and reduce backgrounds in Belle-II detector.
  - The new low-impedance collimators, which fit antechamber scheme, are being developed in collaboration with SLAC. It has a pair of horizontally or vertically opposed movable heads, which approach the beam orbit.
  - Two horizontal collimators were manufactured and installed at an arc section for test with beams in phase 1.
  - Mass production is scheduled from JFY2016 to JFY2016 to 2017 summer, in time for phase 2.



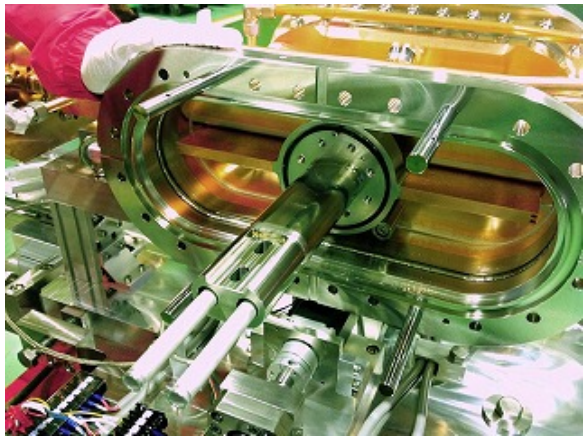


New collimators in LER for Phase 1

Horizontal type collimator



Collimator head



RF-related parameters

	unit	KEKB (operation)		SuperKEKB (design)			
Ring		LER	HER	LER	HER	HER (base line)	HER
Wiggler		Full	None	Full	None	6/10	Full
Beam Energy	GeV	3.5	8.0	4.000	7.007	7.007	7.007
Beam Current	A	1.8	1.4	3.6	2.6	2.6	2.6
Number of Bunches		1585	1585	2500	2500	2500	2500
Bunch Length	mm	6 ~ 7	6 ~ 7	6	5	5	5
Energy loss/turn	MV	1.5	3.5	1.87	2.07	2.43	2.67
Momentum compaction				3.49E-4	4.55E-4	4.55E-4	4.54E-4
Radiation Loss	MW	2.7	4.9	6.73	5.38	6.32	6.94
Loss factor, assumed	V/pC			30	40	40	40
Parasitic Loss	MW			1.56	1.09	1.09	1.09
Total Beam Power	MW	~ 3.5	~ 5.0	8.30	6.47	7.41	8.03
RF Voltage	MV	8.0	15.0	9.4	12.4	14.7	15.8

twice

twice

three times

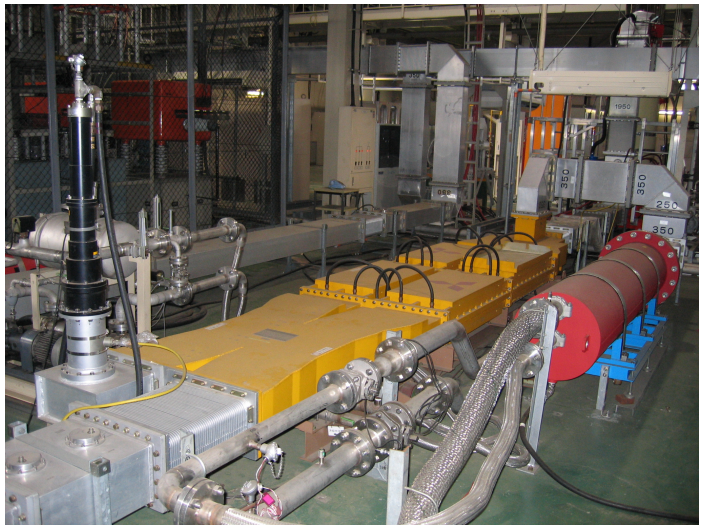
- Add HP&LL RF system and rearrange ARES cavities.
- Change ARES input couplers to larger coupling ones.
- Improve HOM dampers (ARES, SCC).

} Change to 1 Kly: 1ARES system (currently 1 Kly: 2 ARES)

RF system upgrade

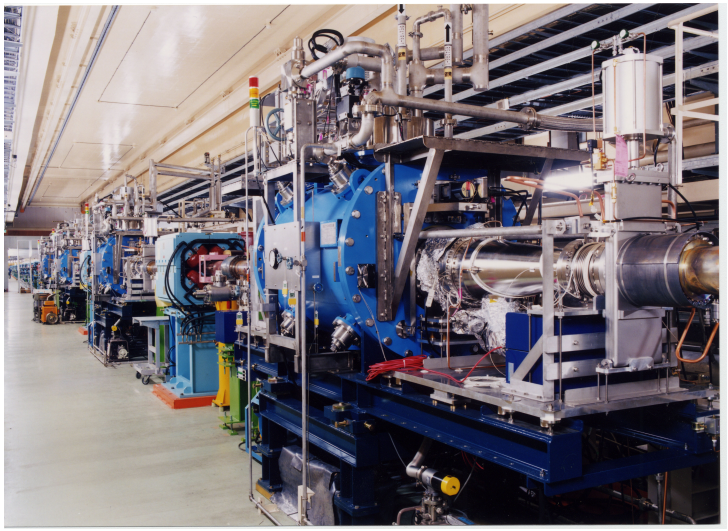
- The RF system is reinforced to handle twice beam currents and much higher beam power, with existing RF system reused as much as possible.
- The ARES and SC cavities, which have proven excellent performance during KEKB operation, are reused with the improvements required for the input couplers and HOM dampers. Configuration of the ARES changed: six cavities were converted from HER to LER.
- The RF power source systems, including klystrons, waveguides and cooling systems, are reinforced to provide larger beam power.
- A new LLRF system, which is based on a recent digital control technique using FPGA's, has been developed. For nine RF stations, among a total of thirty, the LLRF used in KEKB has been replaced with new ones.

RF high power system

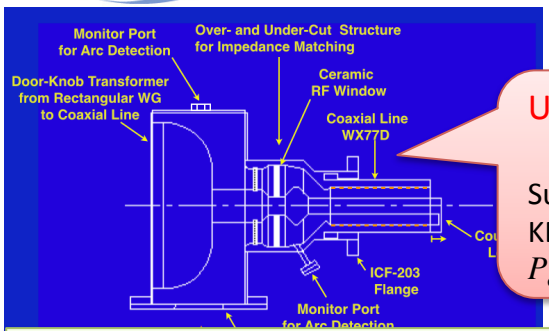


1.2MW CW kystron

Superconducting cavities



RF System (cont'd)



Upgrade of Input couplers for ARES cavities

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 cavity.

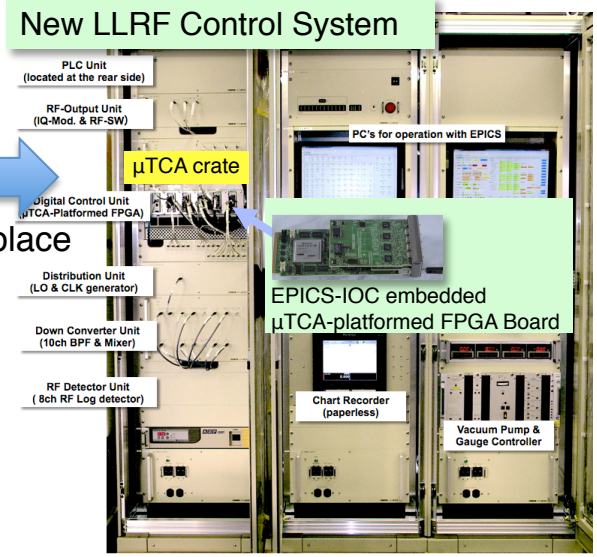
Status & Plans

- So far, 13 input couplers have been processed up to 750-800 kW.
- Every ARES cavity in Oho D5 has been equipped with an upgraded coupler.
- Additionally in Oho D4 before T=0, upgraded couplers will be installed in the RF stations each configured as one klystron driving one ARES cavity.

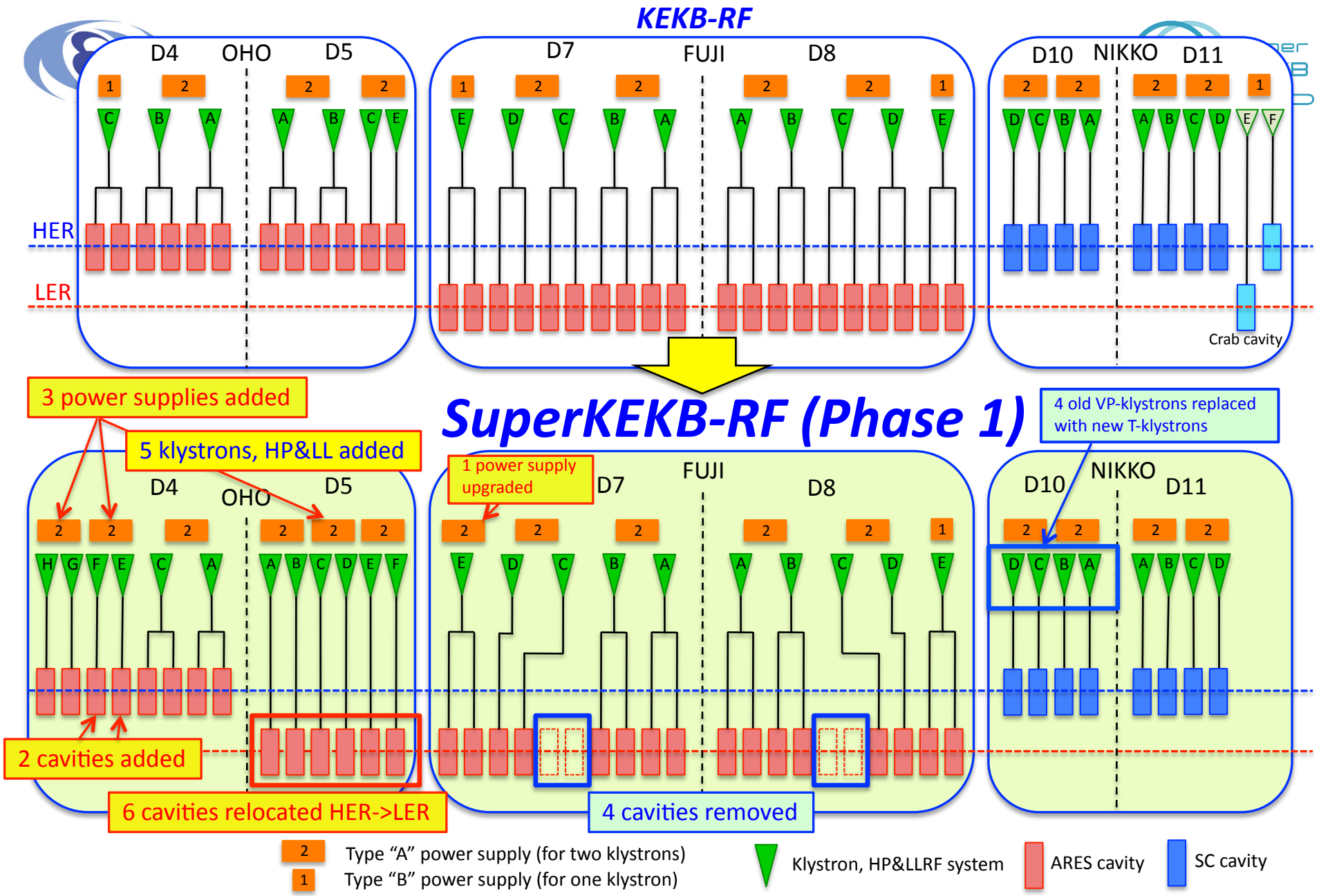
Existing KEKB Analog LLRF System

Replace

New LLRF Control System



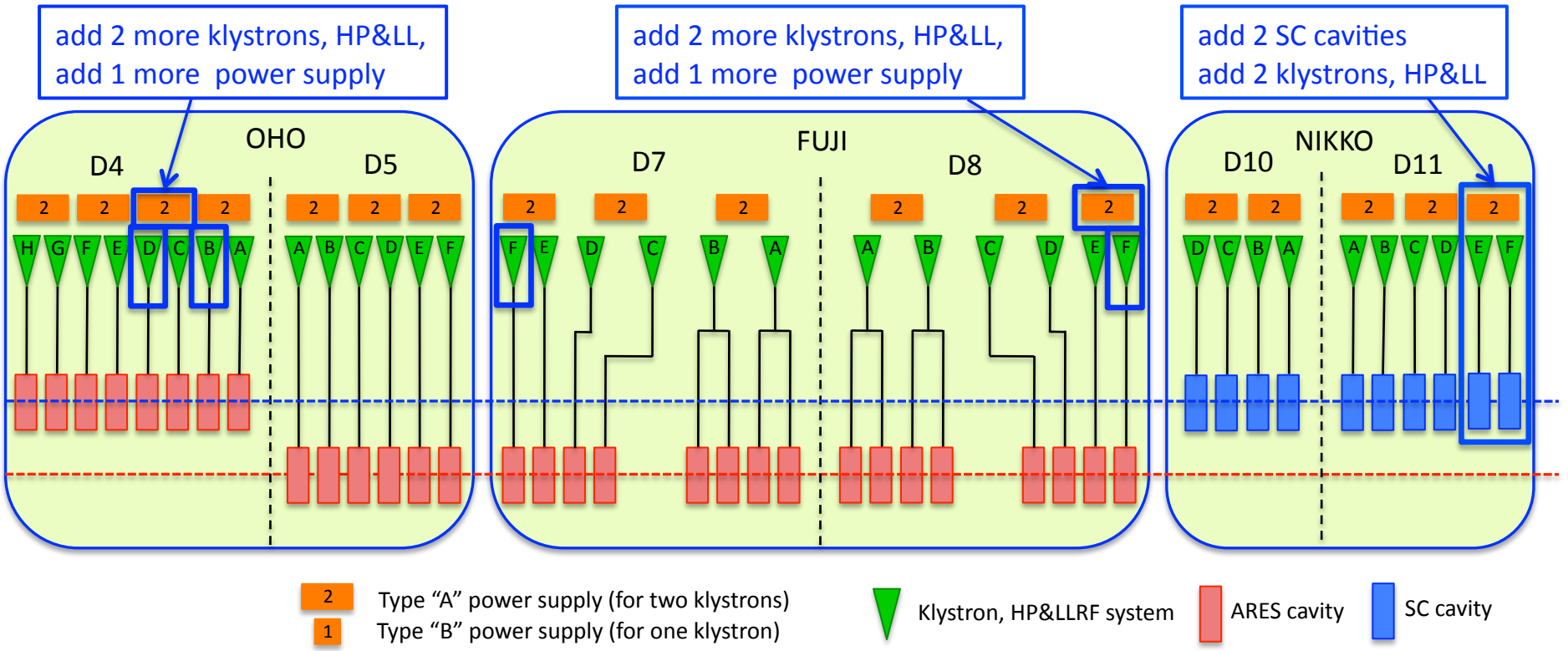
New LLRF Control Systems @OHO D5 Control Room



The RF system with reinforcement done for Phase 1 can support 70% design beam current.

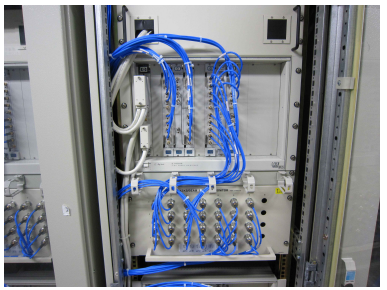
More RF reinforcement plan to further increase beam current after Phase 2,

depending on budget, demand and machine performance.

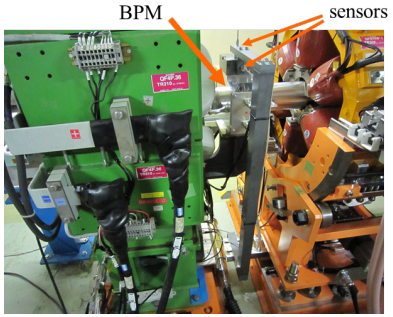


Beam instrumentation

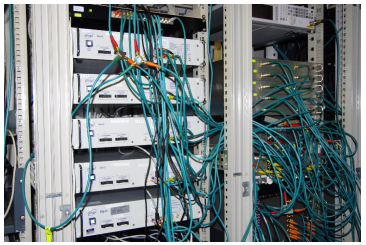
- BPM
  - A hundred twenty 508 MHz narrowband detectors have been installed at the site buildings.
  - 117 units of gated turn-by-turn detectors are completed for phase 1 commissioning.
  - Several displacement sensors for BPM near rotatable sextupoles have been installed.
  - New electronics for IP orbit feedback system has been fabricated. The system will be ready for phase 2.
- Feedback System
  - Bunch-by-bunch feedback system has been renewed by making use of new bunch detection electronics, 12bit digital filters and longitudinal kickers.
  - Two longitudinal kickers have been installed in LER.



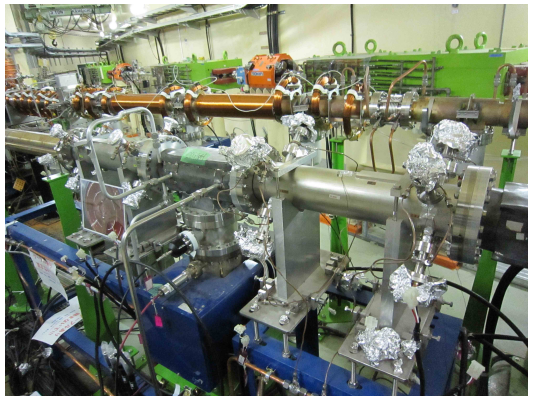
New narrowband detectors for the BPM system.



Displacement sensor near a rotatable sextupole magnets.



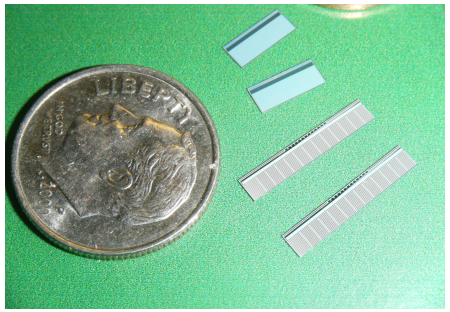
iG12 digital filters



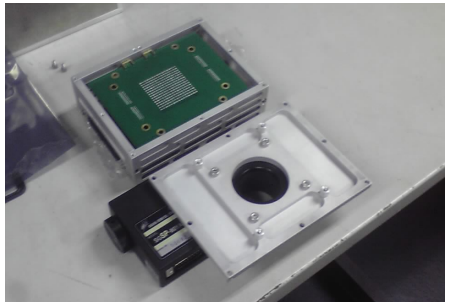
Transverse kickers of the bunch feedback system in HER.

Beam Instrumentation (cont'd)

- X-ray and visible light beam size monitors
  - X-ray and visible beam size monitors were completed in 2015. They are in use for beam size measurement in phase 1 operation.
- Large-Angle Beamstrahlung Monitor (LABM)
  - Components of the LABM were prepared at Wayne State University. The system was installed at the IP in summer 2015.

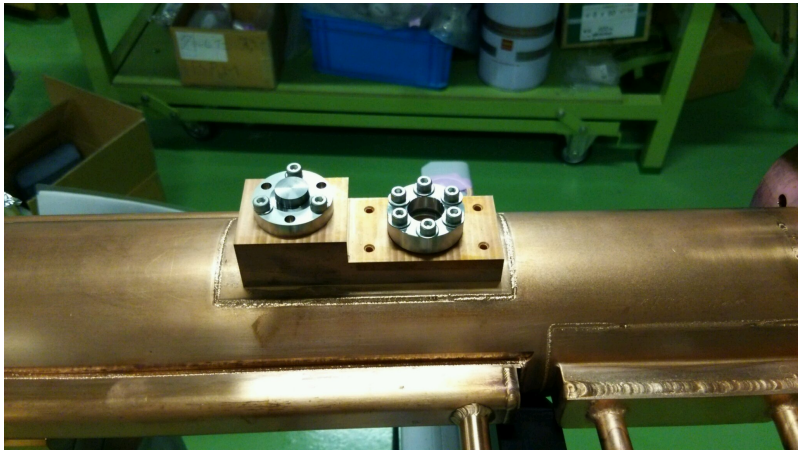


Detector mount for the X-ray monitor. (U of Hawaii)



Si deep-pixel detectors and spectrometers for the X-ray monitor. (SLAC)

Extraction mirror

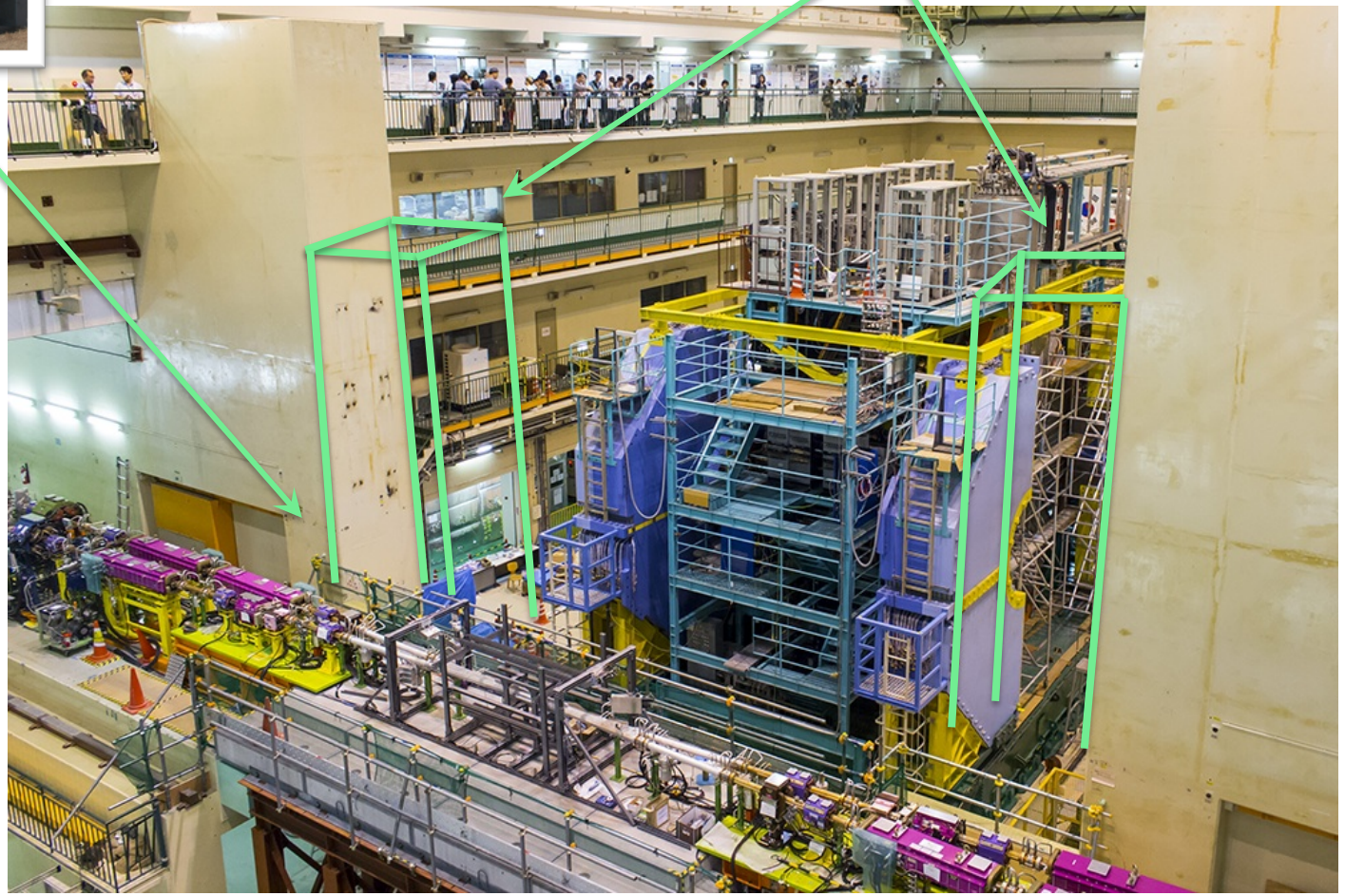


Test fit of LABM extraction mirror (left) and extraction window (right) on IR beam pipe.

IR for phase 1

Gate shape concrete shields for the IR

Additional shielding walls were constructed in autumn 2015.



Beam pipe installation

Picture of IR taken in Sep. 2015 before the IR is covered by large concrete shields.

Final works for phase 1 in JFY2015

- Installation of remaining components and startup works for phase 1 have been completed, and phase 1 beam operation started in Feb. 2016.
  - Installation of magnets completed in early 2015.
  - The last component of beam pipes installed in Dec. 2015.
  - Startup and electric current tests of magnets and power supplies.
  - Final precise survey and alignment of magnets all around the ring.
  - Complete lines of light monitors.
  - Complete improvements of safety and control system.
  - Reinstall concrete radiation shield blocks at four experimental halls.
  - Operate refrigerators and cool down superconducting cavities.
  - Startup klystrons and condition the ARES and SC cavities with high RF power.
  - Startup vacuum, monitor, control and other systems.

Phase 1 commissioning

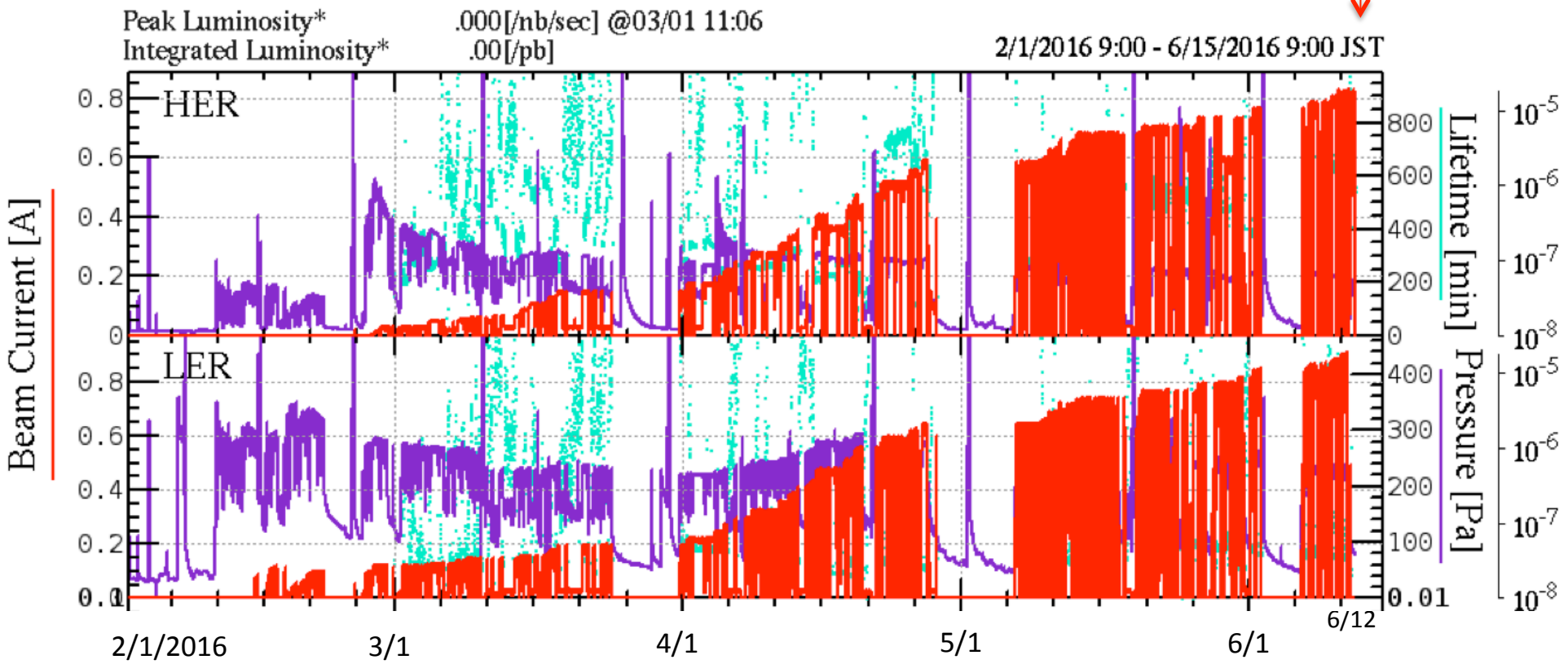
Details will be presented by Funakoshi-san.

Phase 1 commissioning status

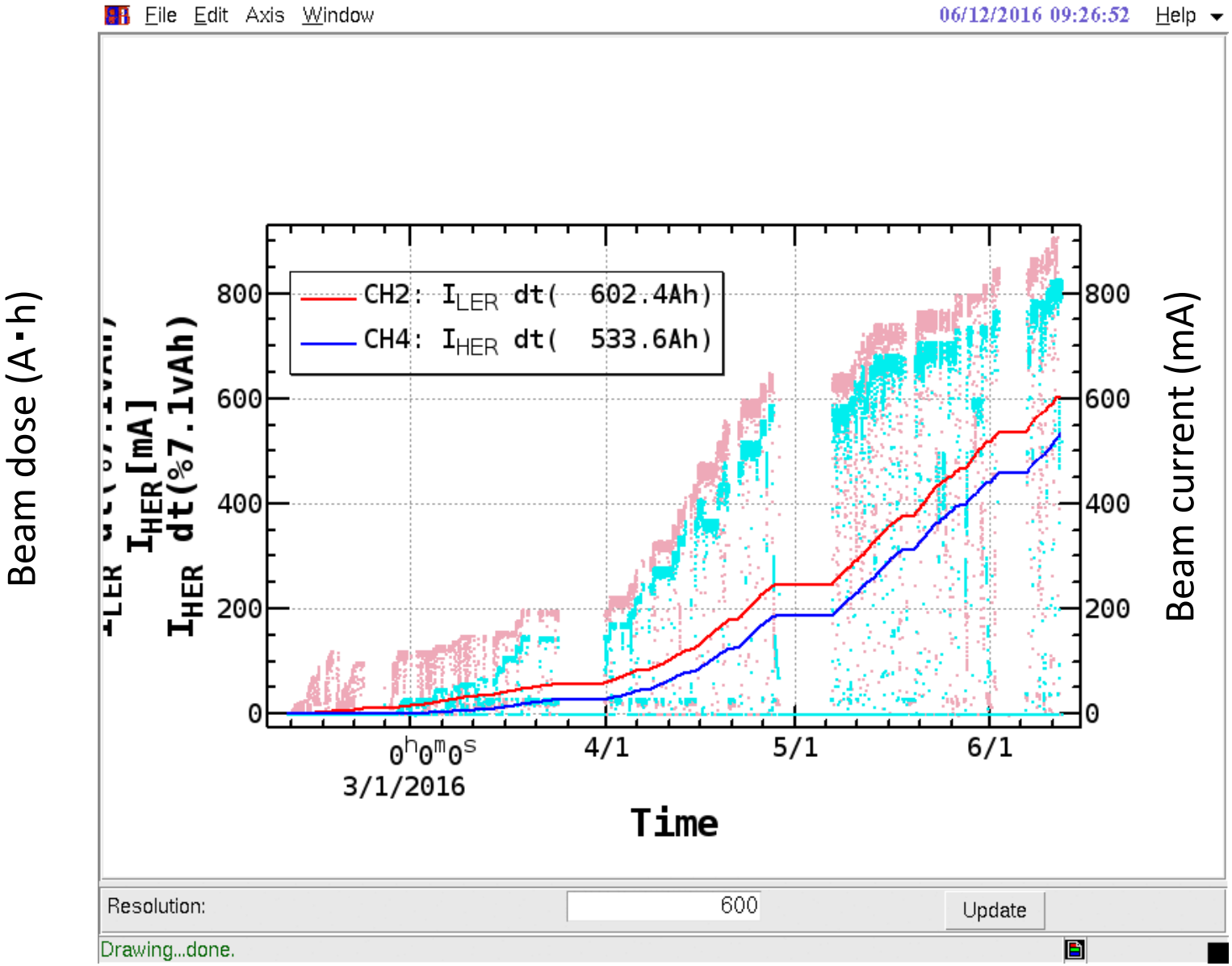
Phase 1 milestones
- Feb. 1: BT tuning started
- Feb. 8: LER injection tuning started
- Feb. 10: beam storage in LER
- Feb. 22: HER injection tuning started
- Feb. 26: beam storage in HER

Tasks during phase 1 operation
- Vacuum scrubbing
- Low emittance beam tuning
- Machine studies including Beast studies

Beam current
830 mA (HER)
910 mA (LER)

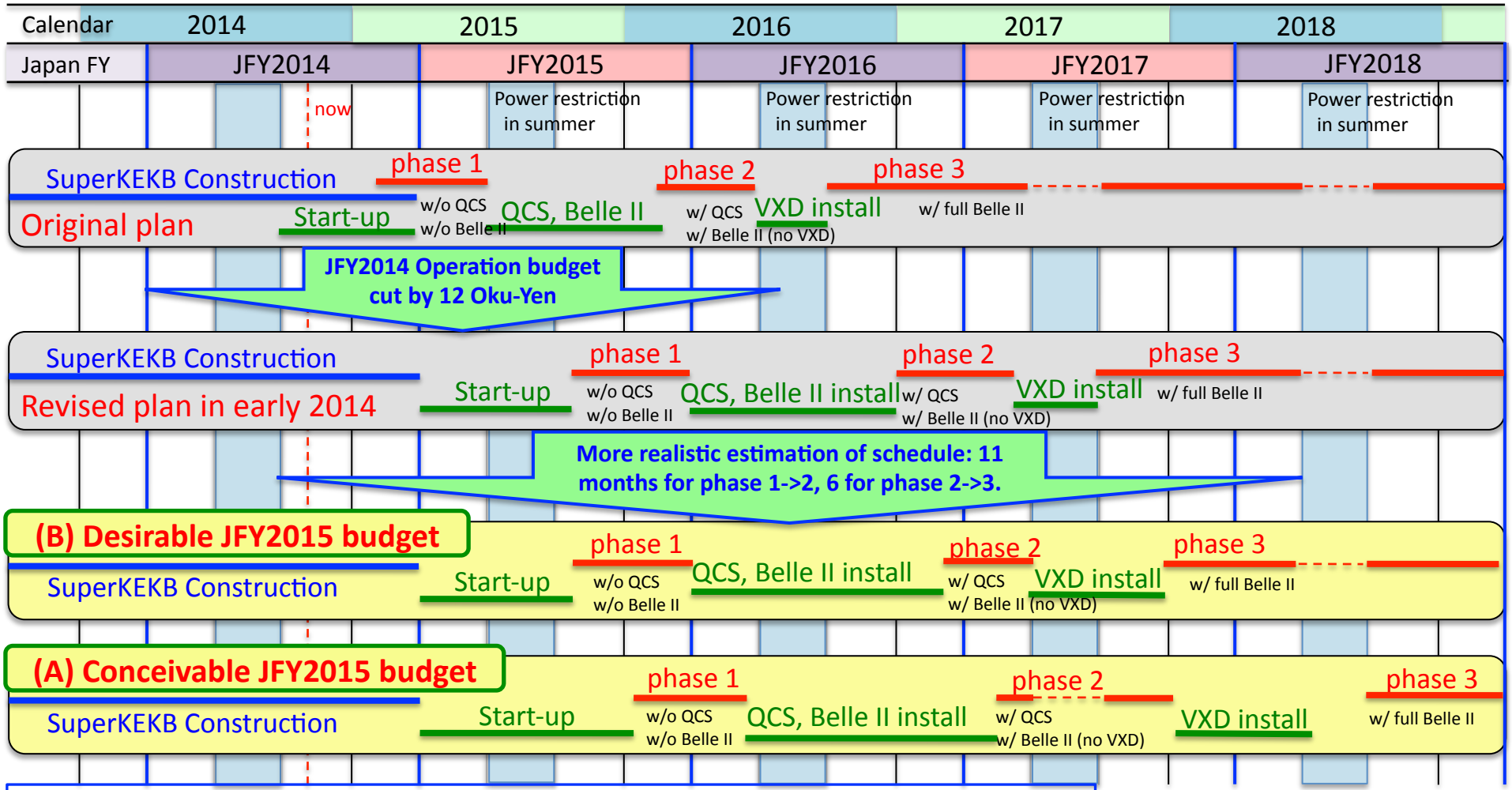


Beam current and beam dose



Schedule plan and status for phase 2

SuperKEKB/Belle II Schedule



Possible scenarios discussed in B2EB, B2GM and BPAC on Nov. 2014.
JFY2015 budget situation turned out to be close to scenario (A).

presented at last ARC (Feb. 2015)

Current situation (as of Feb. 2015)

- In early 2014, the master plan was changed due to the significant cut of JFY2014 operation budget for KEKB.
  - Most of startup work needed before beam operation were postponed to JFY2015.

- JFY2015 budget
  - Budget request was sent from KEK to MEXT with the amount that is needed to perform all preparation works after construction to startup the accelerator components and to start Phase 1 beam operation in autumn 2015 ("desirable" scenario; (B)).
  - JFY2015 budget including strong support from KEK turned out to be close to the "conceivable" scenario; (A), which allows us to start Phase 1 commissioning in early 2016 within the period of JFY2015.

- Construction and startup work has been rearranged and optimized to meet the situation as much as possible.

presented at last ARC (Feb. 2015)

Result of JFY2015 budget

- In early 2014, the master plan was changed due to the significant cut of JFY2014 operation budget for KEKB.
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- Construction and startup work has been rearranged and optimized to meet the situation as much as possible.

● SuperKEKB has been proceeding with scenario (A) with "conceivable" JFY2015 budget. Phase 1 commissioning started in Feb. 2016.

Budget situation in JFY2016

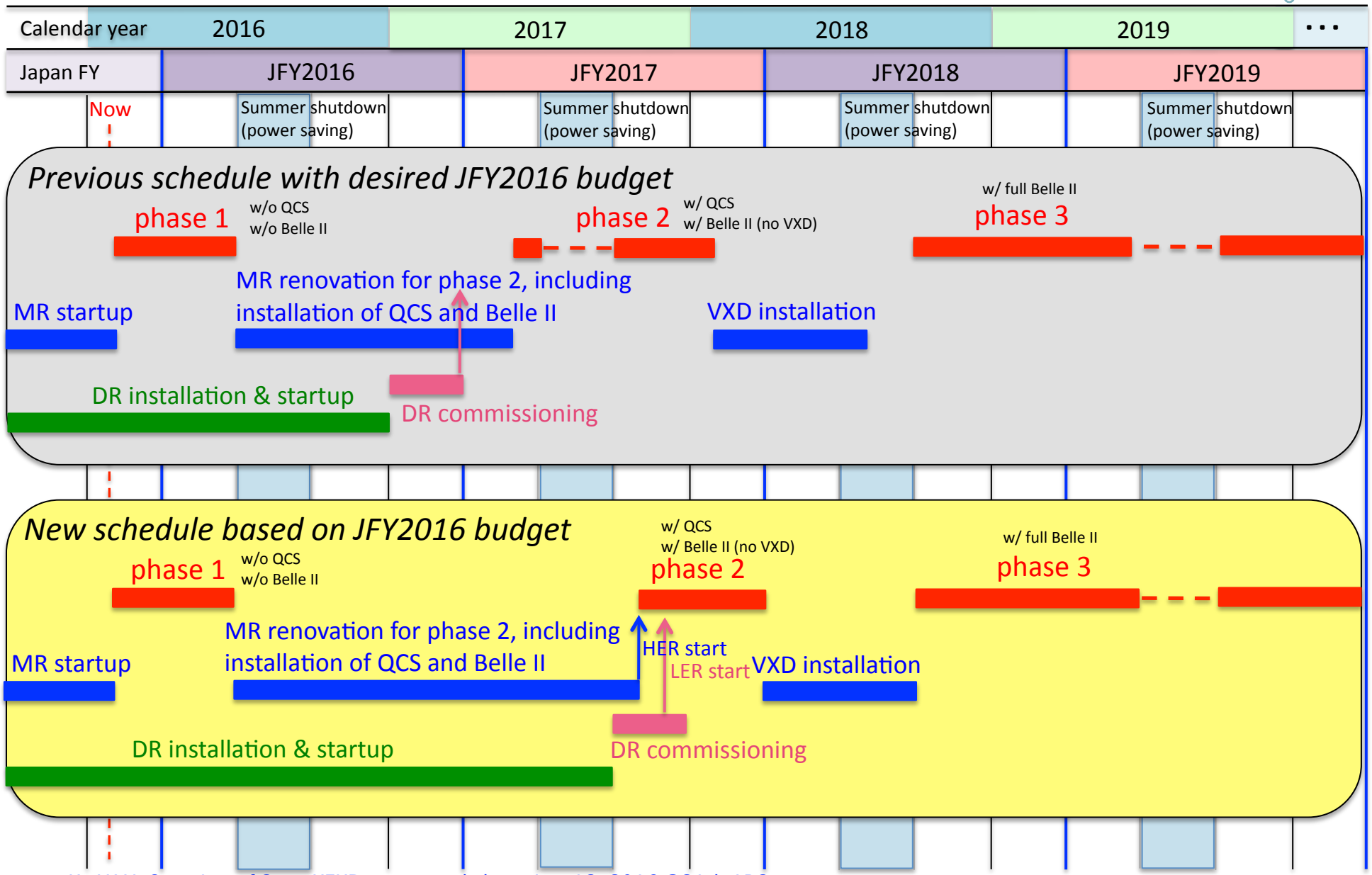
- JFY2016 budget request was sent, which covers:
  - Electricity charges and other cost needed to perform phase 1 operation for three months (April – June), and
  - Cost for transition works from phase 1 to phase 2, which includes renovation of the interaction region, Belle II roll in, startup of QCS, fabricating more collimators, completion and startup of DR, Linac upgrade, etc.
- New schedule based on JFY2016 budget
  - The FY2016 budget was announced last December, which turned out to be much less than that needed to pursue these works on the earliest possible schedule.
  - So, in the last January, we reexamined SuperKEKB/Belle II schedule plans for phase 2 and 3. The phase 2 start is shifted from before summer to after summer 2017, with an expectation for possible supplementary budget which comes early enough.
  - The new plan was agreed between the accelerator and Belle II groups.

Renovation for Phase 2

- After phase 1 operation ends, renovation of MR from phase 1 to phase 2 will be conducted, which starts in July 2016.
  - QCS and Belle II installation and related works
    - Installation of QCS, cabling, piping, cool down, refrigerator test, and field measurements
    - Belle II roll-in
  - Related work to change IR configuration
    - Floor leveling, change concrete shields, remove/set normal-conducting magnets, etc.
  - More collimators
    - Two collimators are used in LER for phase 1. Six collimators will be added for phase 2.
    - Furthermore, after phase 2, more collimators are planned to be added.
  - Change injection part of LER
    - Septums and some vacuum components need to be changed to adopt low-emittance beam from DR and to match to smaller aperture at the IR.
  - Other improvements in LER and HER.
    - More turn-by-turn BPM detectors
    - Solenoid windings for electron-cloud, etc.
- Installation and startup of accelerator components for DR continues to start DR commissioning prior to (or during) phase 2.

SuperKEKB operation schedule

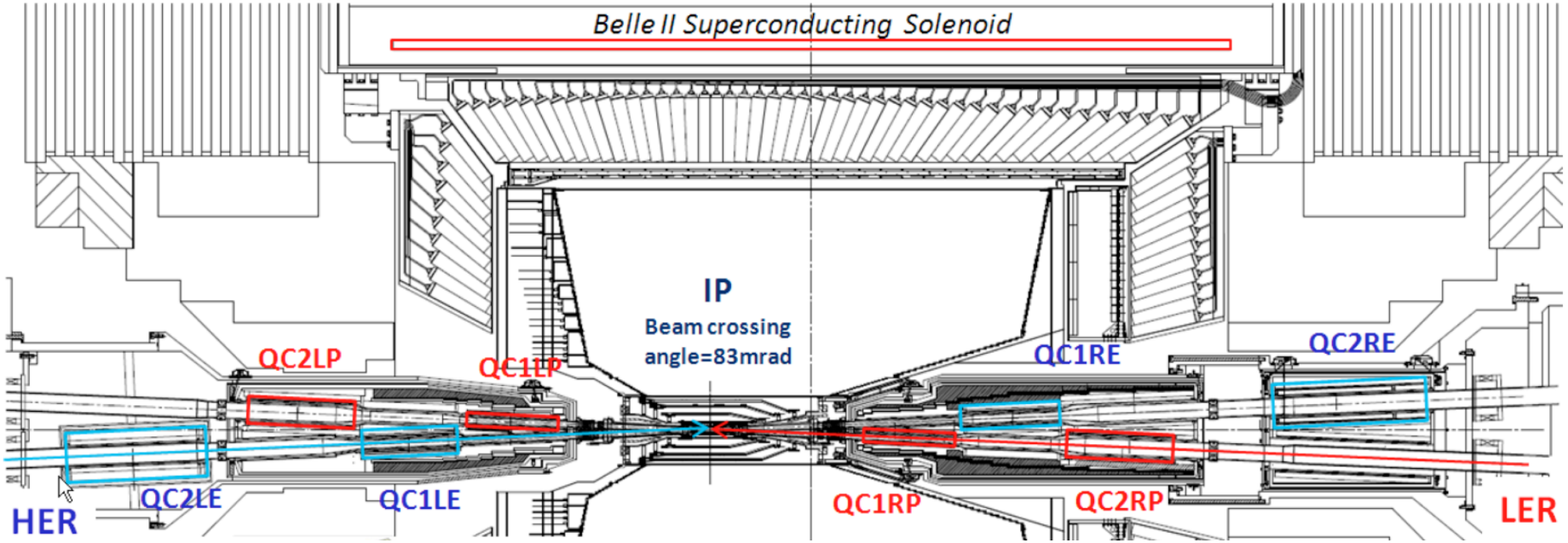
28 Jan. 2016
@B2EB



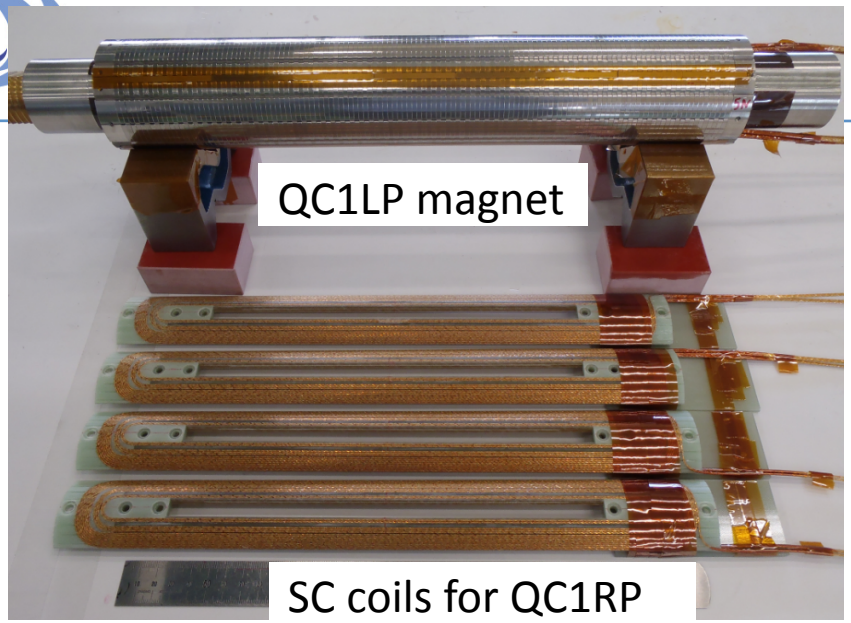
Current status as of June 2016

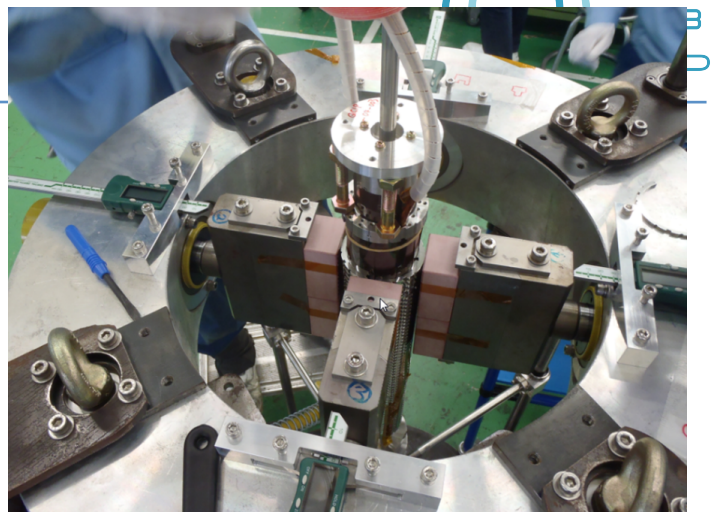
- Phase 1 oeration
  - Phase 1 operation has been progressing as planned with scenario (A).
  - Continuous efforts have been made to reduce operation cost.
- Preparation for phase 2
  - So far no supplementary budget has come yet.
  - Contract procedure is being made within available budget which is already allocated.
  - Best efforts are being made to fit to the new schedule.

Final focus SC magnet (QCS)

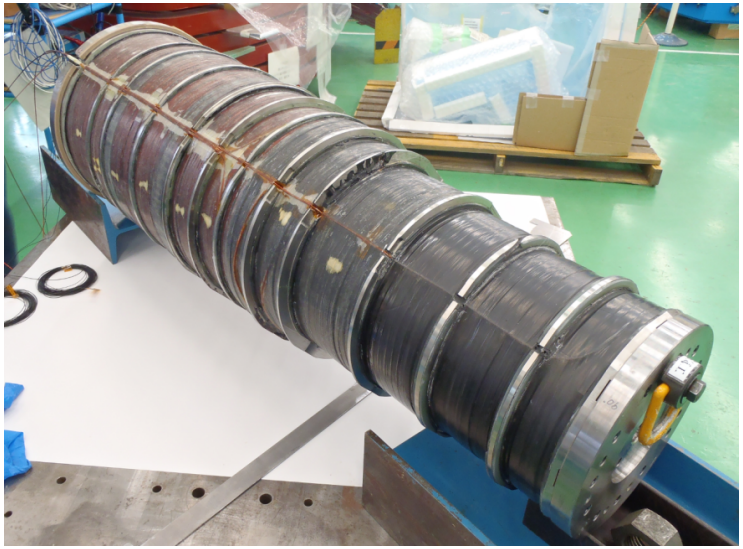


- Eight final focus QCS with 40 corrector coils are to be used.
- Corrector coils were wound at BNL under BNL/KEK collaboration.
- Fabrication of QCS-L magnet/crostat started in July 2012 and completed in Dec. 2015. Test of QCS-L is being conducted at an exp. laboratory from Feb. through Jun. this year.
- Fabrication of QCS-R magnet/crostat will be completed in autumn 2016.
- After phase 1 operation ends in June 2016, QCS-L will be installed on beam line, followed by QCS-R installation and Belle II roll-in.

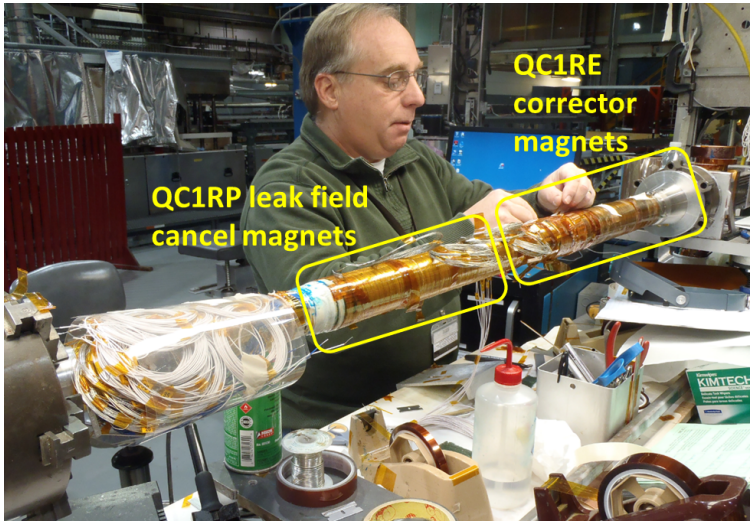




QC1LP collaring work at Mitsubishi Company



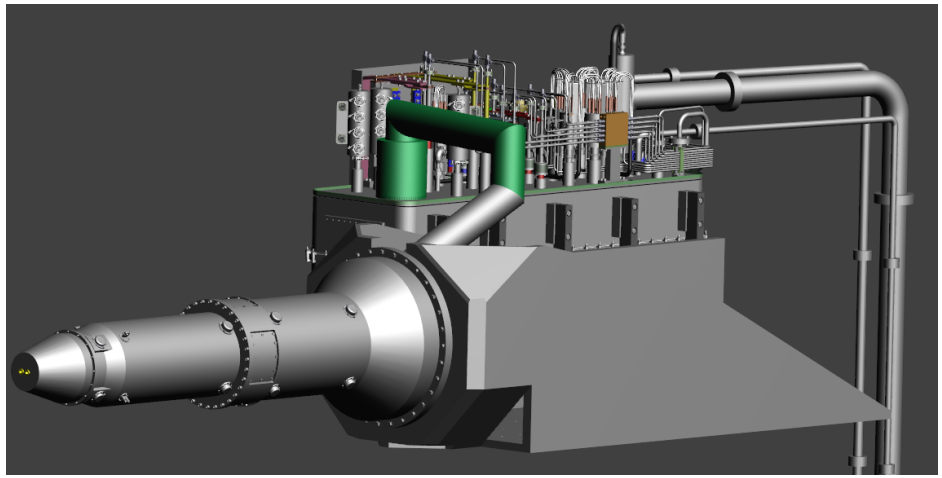
Completed ESL compensation solenoid.
The solenoid was divided into 12 small solenoids.



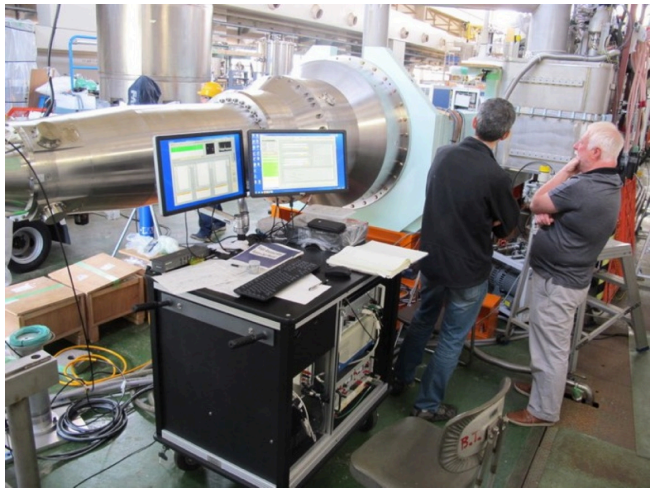
Final assembly of the corrector magnet in BNL. A technician is handling the cables from 8 magnets on the support bobbin.

QCSL magnet cryostat was delivered to KEK from Mitsubishi on Dec. 25, 2015.

QCSL magnet cryostat was set in the Super. Cryo. Vac. Experimental Laboratory at Dec. 25 and 26, 2015.

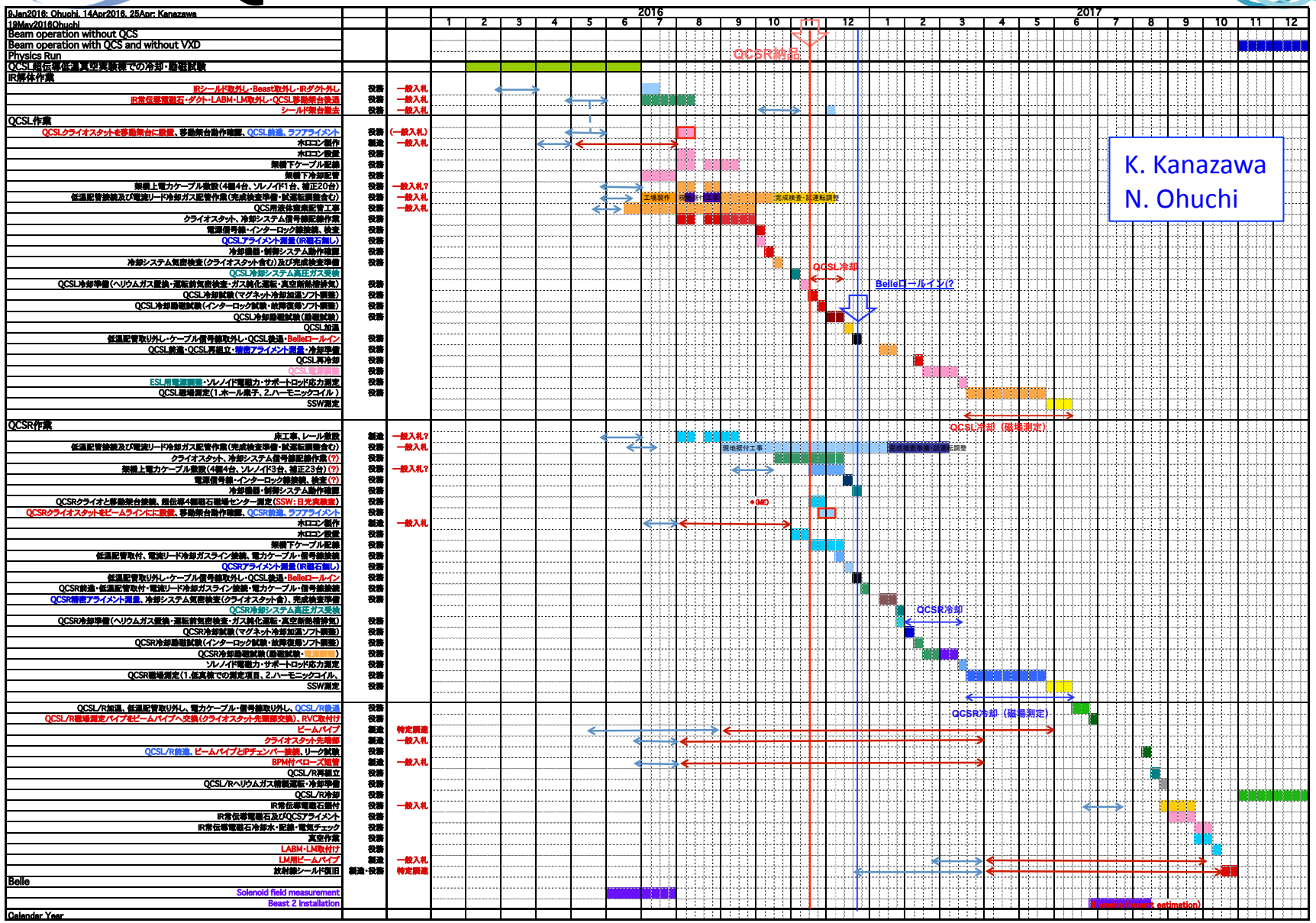


Drawing of QCSR cryostat. QCSR is now under fabrication at Mitsubishi, and will be completed this autumn.



Single stretched wire measurement was done in May 2016, under collaboration with FNAL.

QCS/IR schedule for Phase 2

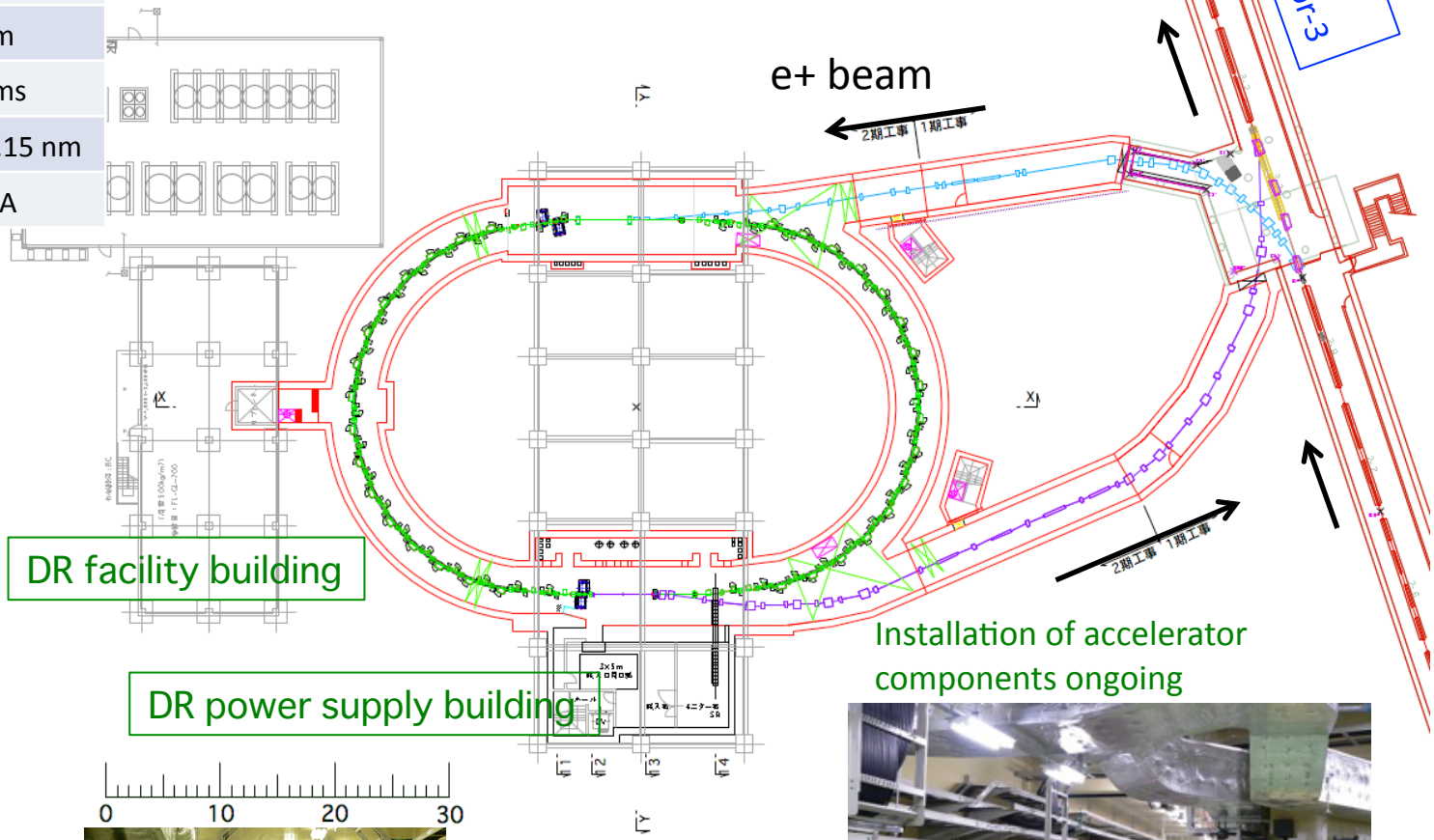


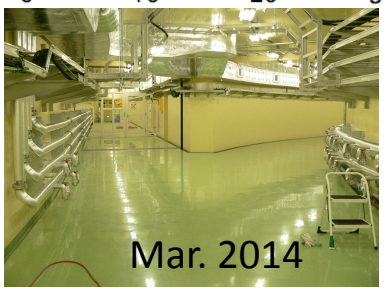
Damping Ring

Design parameters

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

DR tunnerl construction





Tunnel and buildings completed (by Mar. 2014)

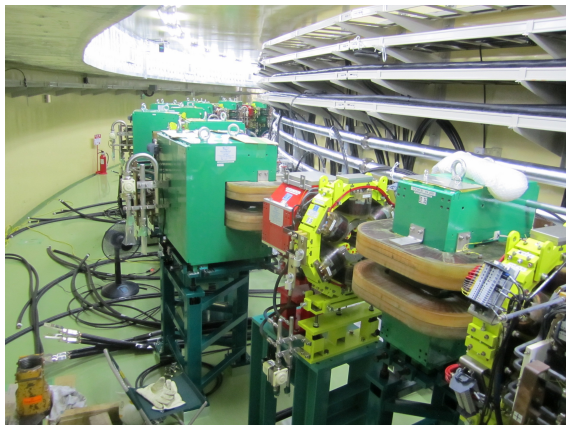
Installation of accelerator components ongoing

Damping Ring (cont'd)

- Installation and startup status
  - Installation of all magnets has been completed. Alignment of magnets on going.
  - All power supplies for the magnets (except ones for steerings) have been delivered.
  - Installation of beam pipes started.
  - After successful HP test, two RF cavities have been installed into tunnel.
  - Klystrons, power supplies, and other RF high power system on going. Startup of RF system is planned in winter 2016.
  - The DR will be commissioned for phase 2 in JFY2017.

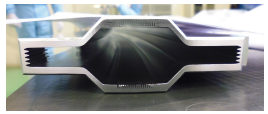
power supplies for magnets

power supply for klystron



arc section

RF cavity for DR



cross-section of ante-chamber beam pipe

arc section

Summary

- Construction and startup works for phase 1 has been completed on schedule with the plan based on JFY2016 budget.
- In parallel with the phase 1 operation, preparation works for phase 2 including renovation of MR, startup of DR and improvements of Linac continues.
- After phase 1 operation ends, transition works from phase 1 to 2 will start in July 2016.
- Commencing time of phase 2 (and 3) depends on future budget situation.
  - Schedule plans for the DR commissioning and Phase 2 and 3 start were reexamined after the announcement of JFY2016 budget, which turned out to be much less than that required to pursue with the earliest schedule.
  - A new plan is set with an expectation for additional budget which comes early enough. In this plan, phase 2 start is delayed after summer 2017, but phase 3 start is not delayed. This plan was agreed btw. accelerator and Belle II.