SuperKEKB Interaction Region

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Outline

SuperKEKB accelerator / Belle II detector, from the KEKB / Belle

- KEKB accelerator, the target luminosity of the SuperKEKB, machine parameters of the Nano-beam scheme, main upgrades, and commissioning status.

Overview of the SuperKEKB interaction region (±8 m)

SC magnet system for final focusing (QCS)

- Superconducting magnets, cryostats, cryogenic systems, and performance tests, magnetic field measurements.

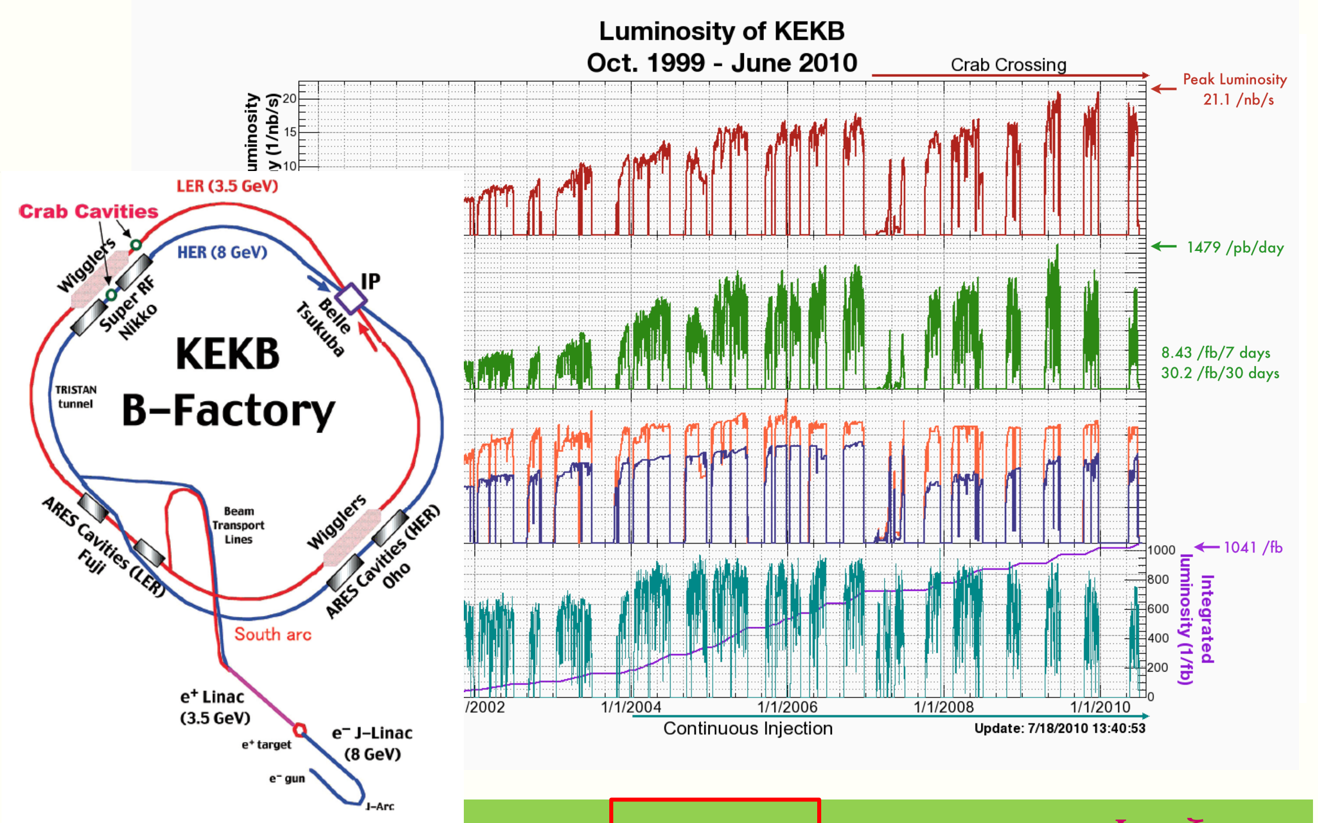
Beam pipes in the crysotats, BPM-bellow tubes, IP chambers (K. Kanazawa, KEK)

- Their design considerations, connections with the cryostats, operations with the Phase II commissioning

SuperKEKB project: the upgraded KEKB

KEKB accelerator / Belle detector (1999 ~ 2010)

- The detection of CP violation in B mesons predicted on the basis of the Kobayashi–Maskawa theory
- The total integrated luminosity collected of 1041 fb^{-1}
- Leader in the race to provide the highest luminosity



The SuperKEKB accelerator/the Belle II detector

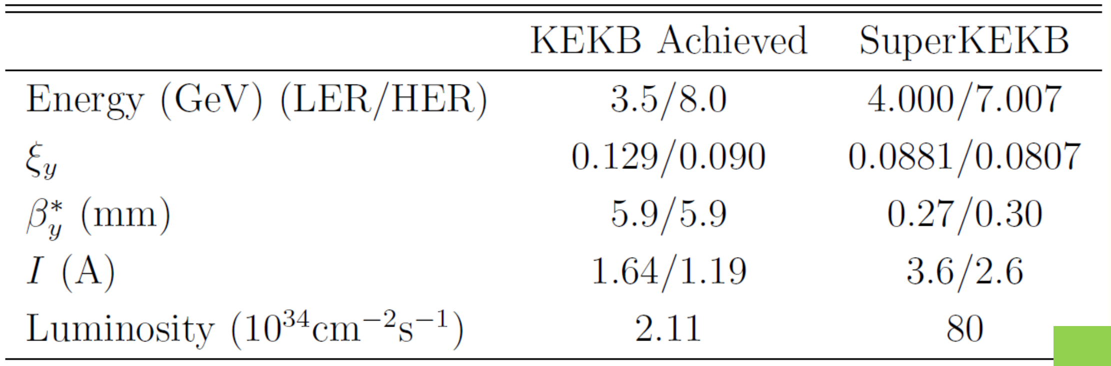
- To discover new physics beyond the Standard Model on the luminosity frontier.
  - Upgrading the KEKB and the BELLE detector
  - The target luminosity: 8×10^{35} cm^{-2}s^{-1}, 40 times than the world highest record at its predecessor, KEKB, by collecting 50 times more data.
  - Based on the Nano-beam scheme, in which the Luminosity is mainly determined by the total beam current, the vertical beam-beam parameter, and the vertical beta function at IP.

$$L = 40\times\boxed{2\times10^{34}}\,[cm^{-2}s^{-1}] \propto \frac{I_{e\pm}\xi_{\pm y}}{\beta_y^*}$$

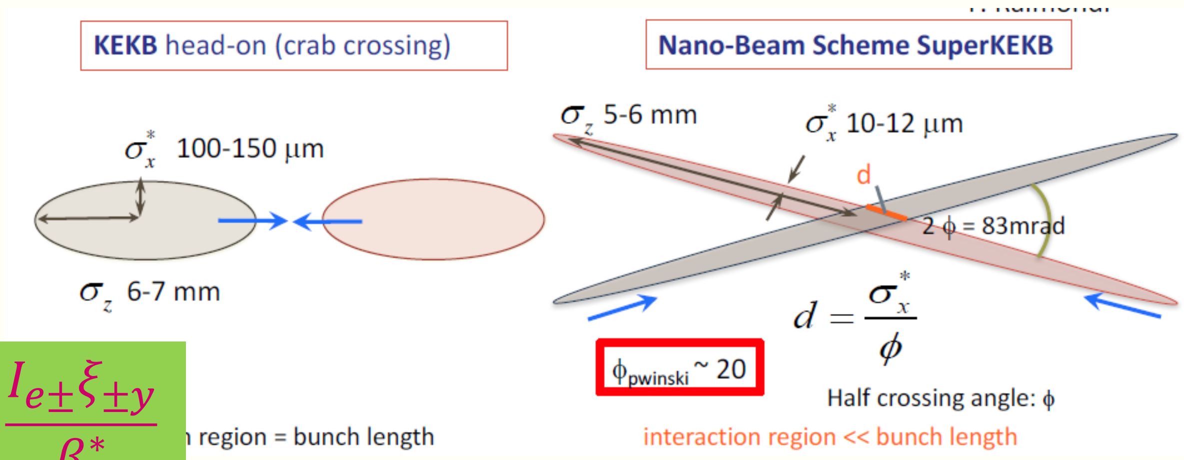
$$\Downarrow$$

$$\boxed{L_{\text{KEKB maximum Peak}}}$$

Machine parameters of the the SuperKEKB project



	KEKB Achieved	SuperKEKB
Energy (GeV) (LER/HER)	3.5/8.0	4.000/7.007
ξ_y	0.129/0.090	0.0881/0.0807
β_y^* (mm)	5.9/5.9	0.27/0.30
I (A)	1.64/1.19	3.6/2.6
Luminosity ($10^{34}\text{cm}^{-2}\text{s}^{-1}$)	2.11	80



$$L \propto \frac{I_{e\pm}\xi_{\pm y}}{\beta_y^*}$$

Beam collision in “nano-beam” scheme

- To squeeze the vertical beta function at IP to extremes by minimizing the size of an overlap region of the two beams at IP. The overlap region: bunch length for head-on collision, the length *d* for nano-beam scheme
- The design value of cross angle has been determined mainly considering the IR optics, magnet design and the detector background. SuperKEKB: the crossing angle of 83 mrad, about 4 times of KEKB (~20mrad).
  - The final focus quadrupole magnets can be independent for the two beams which brings a great merit of much lower detector background due to the synchrotron radiation.
  - The final focus quadrupole magnets can be placed closer to the IP, which contributes to widening dynamic aperture.

The luminosity is further increased by a factor of two, higher currents than KEKB.

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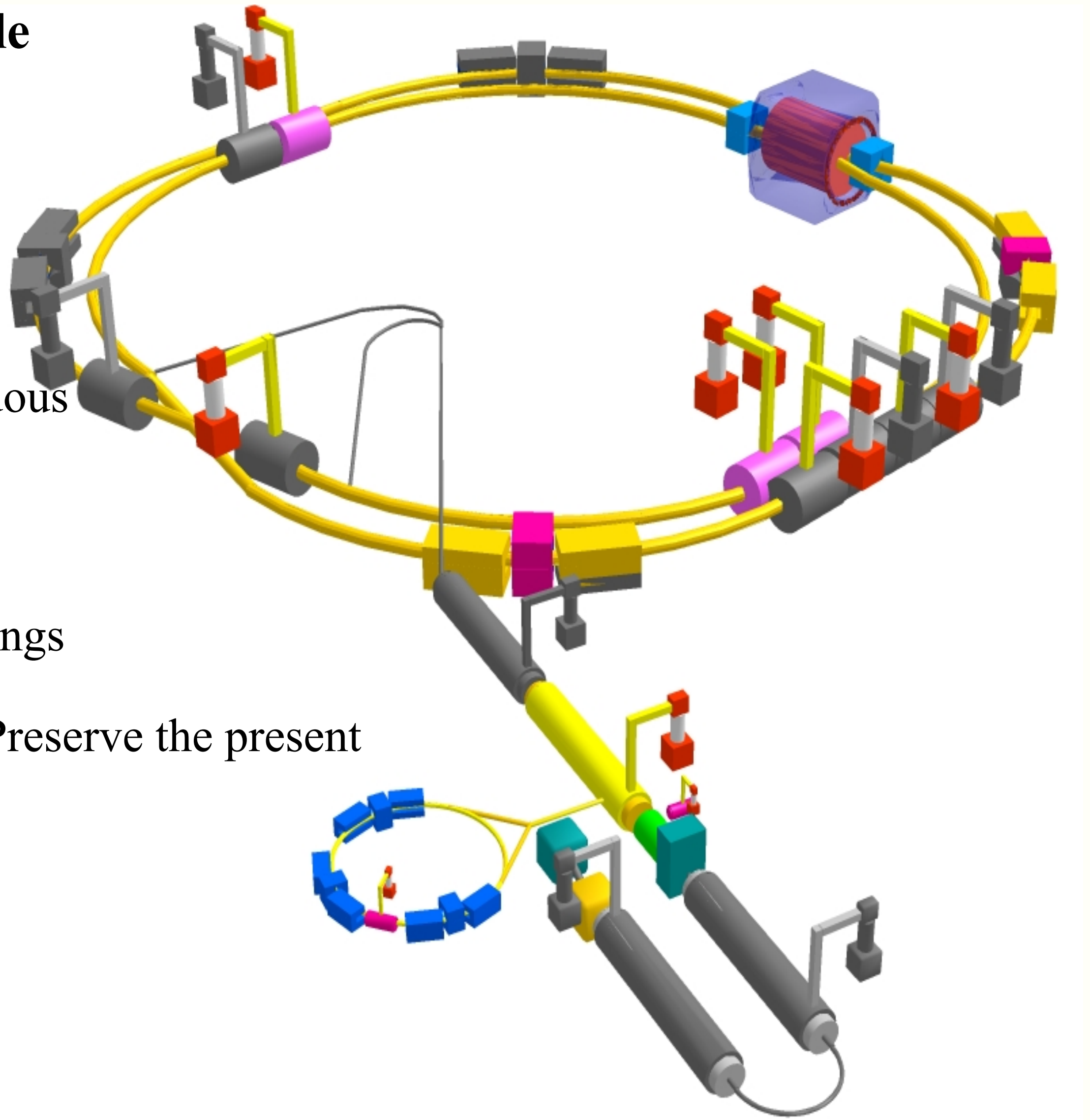
The SuperKEKB: towards KEKB ×40



Using the KEKB tunnel, and components as much as possible

- The infrastructures, such as the water cooling system, and the compressed air system for magnets and vacuum pipes

Main upgrades towards 40 times luminosity

- New low-emittance electron gun, and positron source, for continuous injection to maintain constant luminosity against a short lifetime
- Newly constructed damping ring for positron beams
- Main ring arc and straight section: Redesign the lattices of both rings
    - Main ring arc section:LER: Replace all main dipoles HER: Preserve the present cells, to reduce the emittance
- New beam pipes & bellows (TiN-coated with antechambers)
- Add/modify RF system for high beam currents
- New sc quadrupole magnets for final focusing (QCS)

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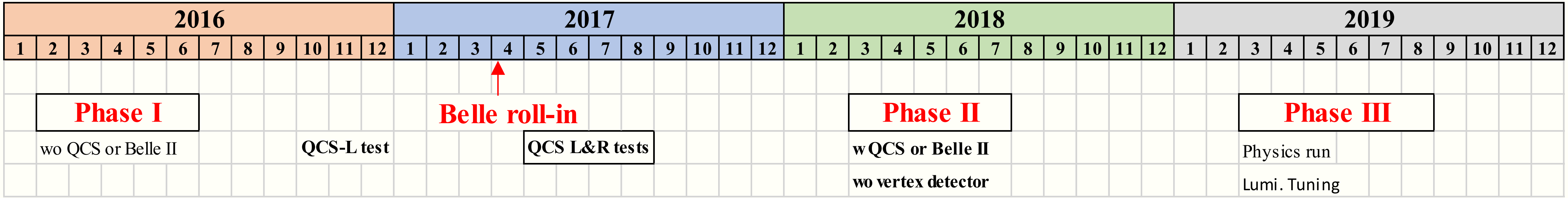
Accelerator commissionings with three phases

- Phase I: Feb.~Jun. 2016, machine tuning and vacuum scrubbing, without QCS or Belle II detector
- Works at the interaction region, after the Phase I and Belle Roll-in
  - Install the QCS-L&QCS-R cryostat, cooling tests with cryogenic systems, magnetic field measurement, and replacing beam pipes
  - Installation of the Belle detectors, assembly with the IP chamber by RVC, and installation of the normal magnets in the IR
- Phase II: Mar. 16~ July 17, 2018, Background study, Luminosity and collision tuning, vacuum scrubbing
- Phase III: Mar. 11~, Luminosity and collision tuning, Physics run



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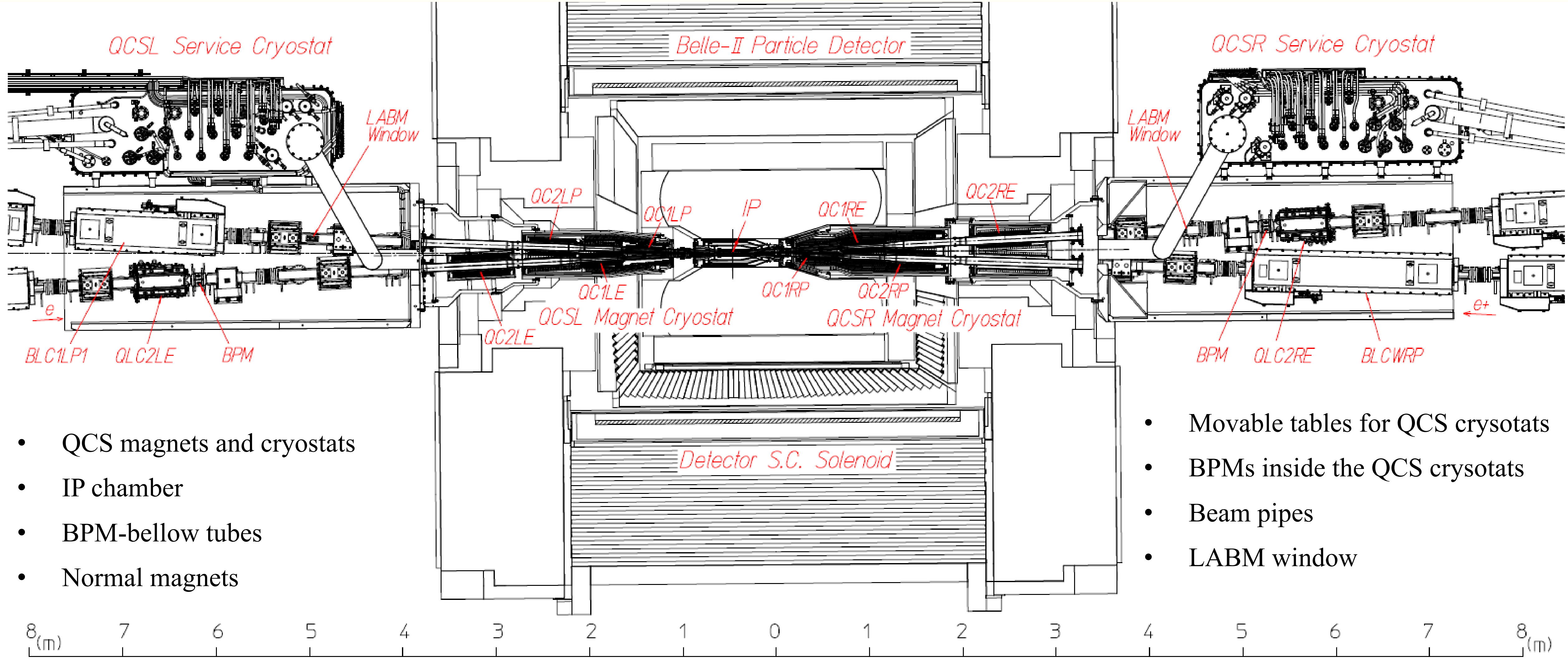
Interaction region of the SuperKEKB (±8 m)



- QCS magnets and cryostats
- IP chamber
- BPM-bellow tubes
- Normal magnets

- Movable tables for QCS crysotats
- BPMs inside the QCS crysotats
- Beam pipes
- LABM window

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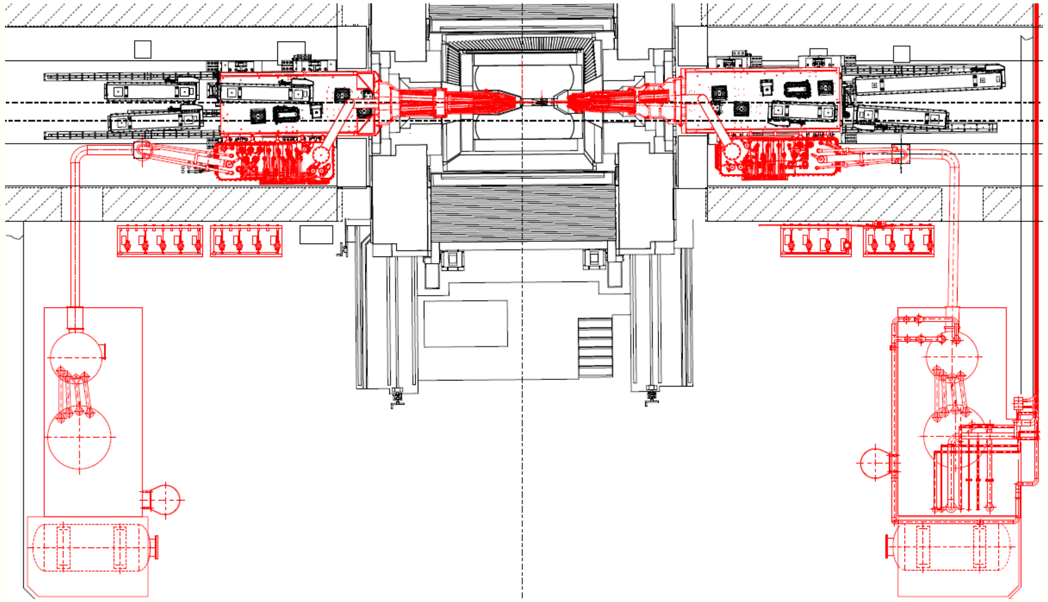
Overall views of the QCS cryostats in IR

Movable tables for QCS

- QCSs are inside the detector
- Move in and out for works
- Reproduce the QCS aligned position very precisely
- Stand for a very strong force

Coldboxes and sub-coolers



2018/11/14

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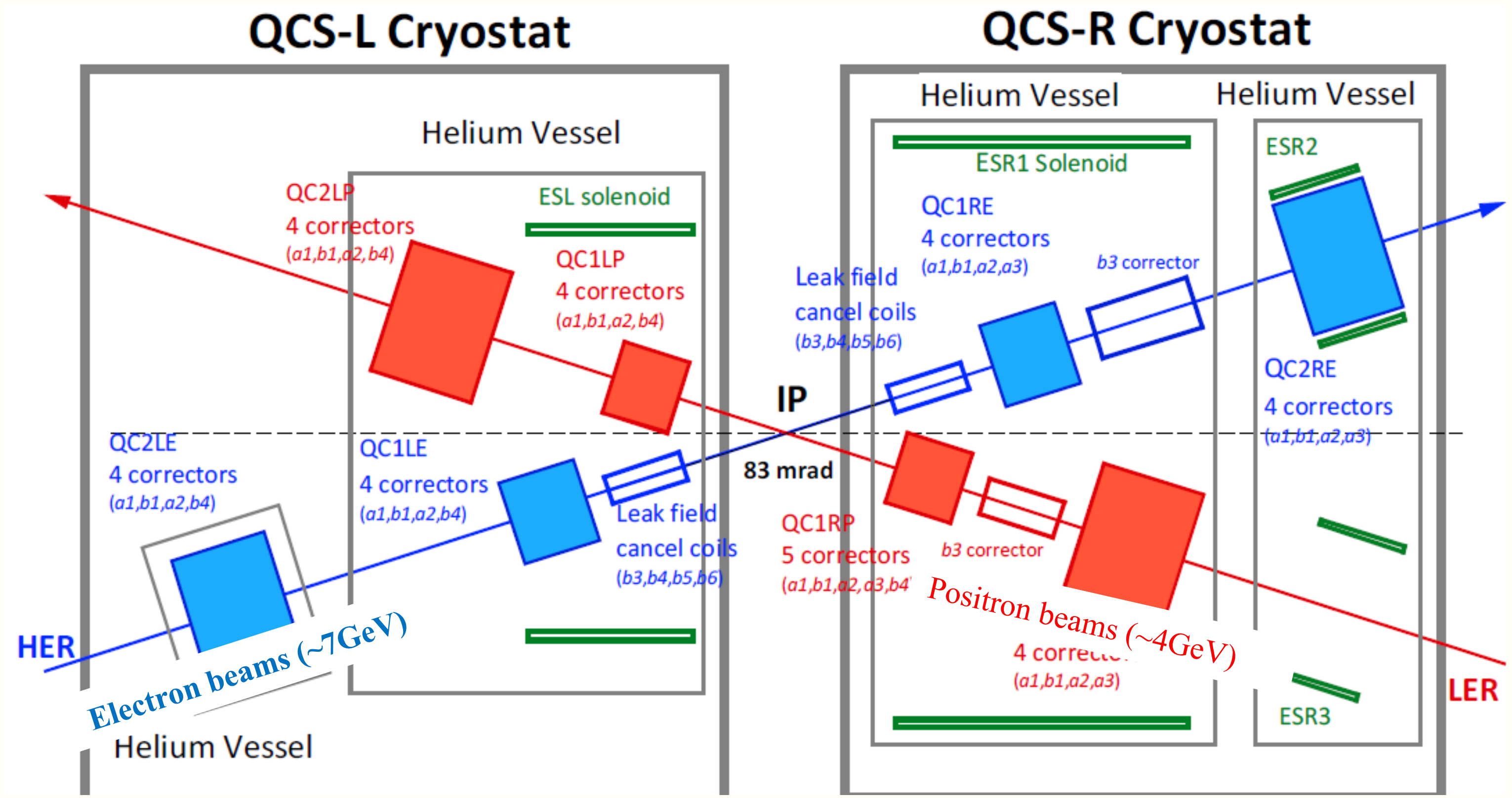
SC magnet system for final focusing



Items	Unit	QC1P	QC1E	QC2P	QC2LE	QC2RE
Coil inner radius	mm	25	33	53.8	59.3	
Coil outer radius	mm	30.49	38.49	59.29	64.79	
Field gradient at I_d	T/m	76.4	91.6	32	36.4	39.3
Magnetic length	mm	333.6	373.1	409.9	537	419
Design current	A	1800	2000	1000	1250	1350
I_d/I_c	%	72	73	47	50	49
Turns in a pole	-	25	34	54	58	
Magnetic yoke	-	No	Perm.	Perm.	Iron	
Collar/Yoke R_{outer}	mm	35.5	70	93	115	

Main Q	Correctors
QC1LP	a1, b1, a2, b4
QC2LP	a1, b1, a2, b4
QC1LE	a1, b1, a2, b4
QC2LE	a1, b1, a2, b4
QC1LP-Cancel leak fields	b3, b4, b5, b6
QCS-L – 20 coils	

Main Q	Correctors
QC1RP	a1, b1, a2, a3, b4
QC2RP	a1, b1, a2, a3
QC1RE	a1, b1, a2, a3
QC2RE	a1, b1, a2, a3
QC1RP-Cancel leak fields	b3, b4, b5, b6
Between QC1RP and QC2RP	b3
Between QC1RE and QC2RE	b3
QCS-R – 23 coils	

- 8 main quadrupoles (QC1s-vertical focusing and QC2s-horizontal) to form the beam doublets
- 43 Correction coils (To calibrate misalignments, to cancel leakage field, 20 coils for the left)
- 4 anti-solenoids (ESL, ESR1 ESR2, and ESR3) to fully compensate the detector solenoid field.

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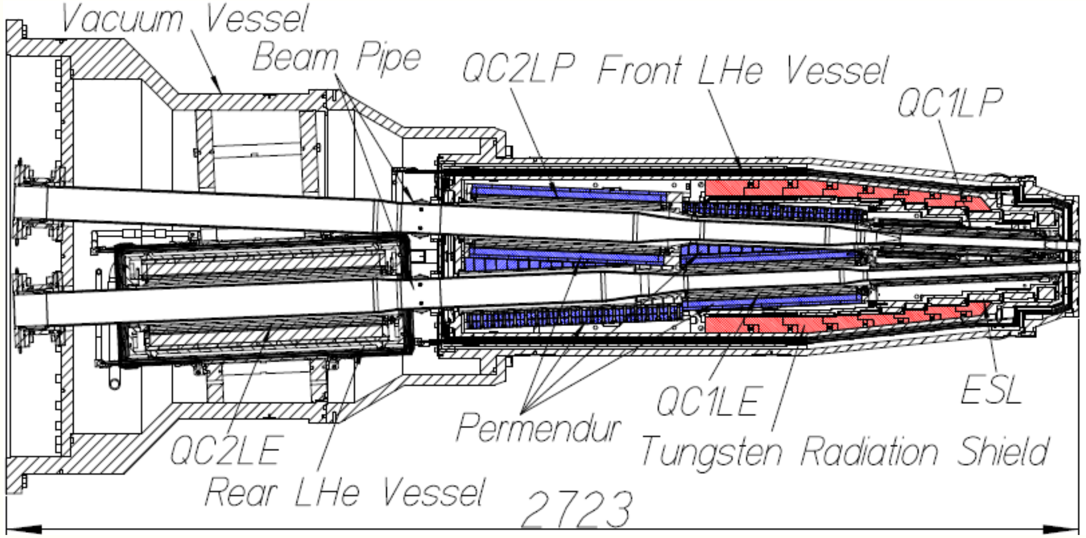
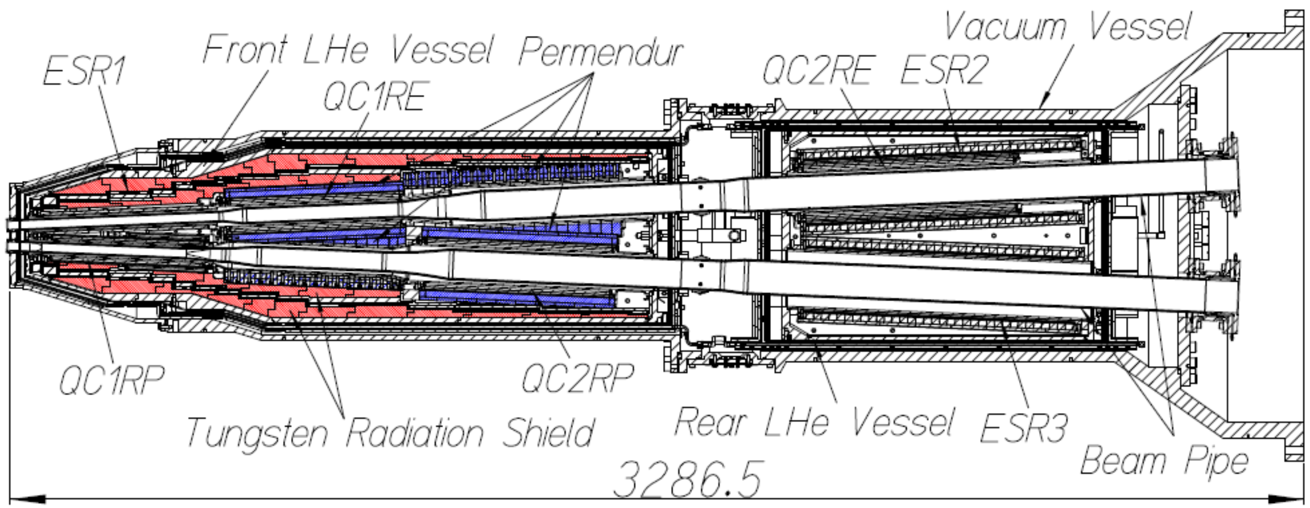
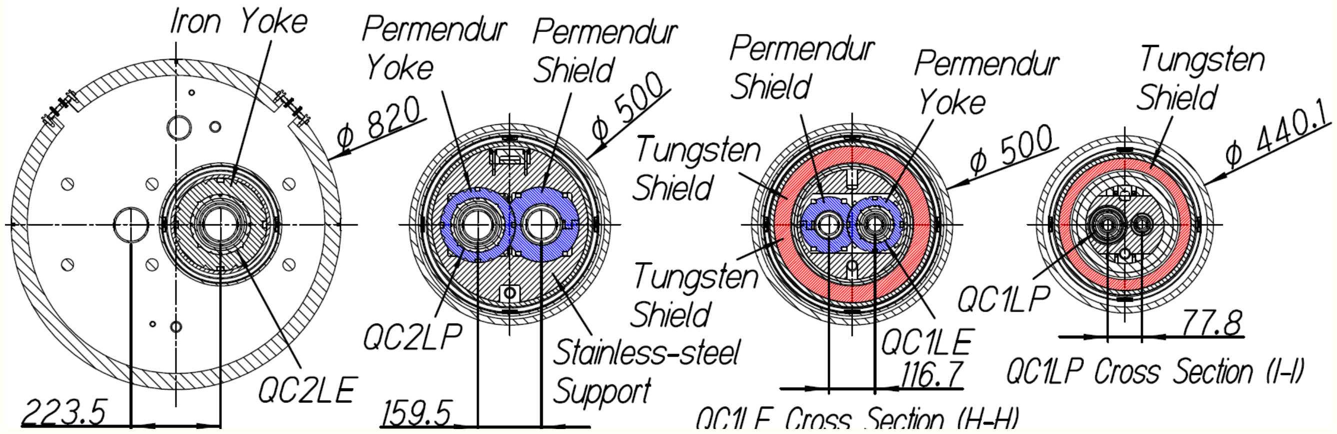
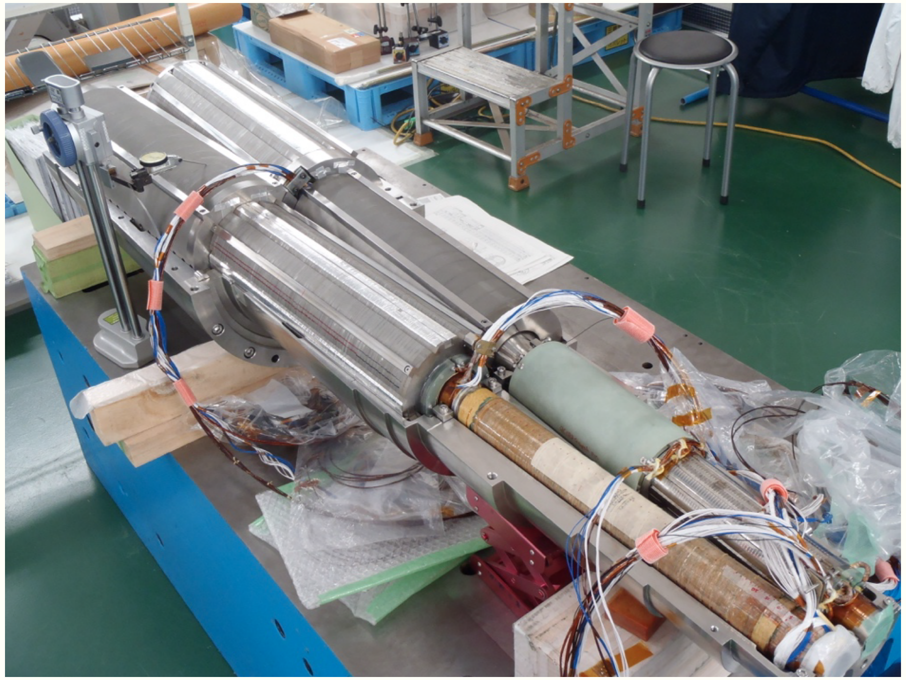
The SC magnet cryostats



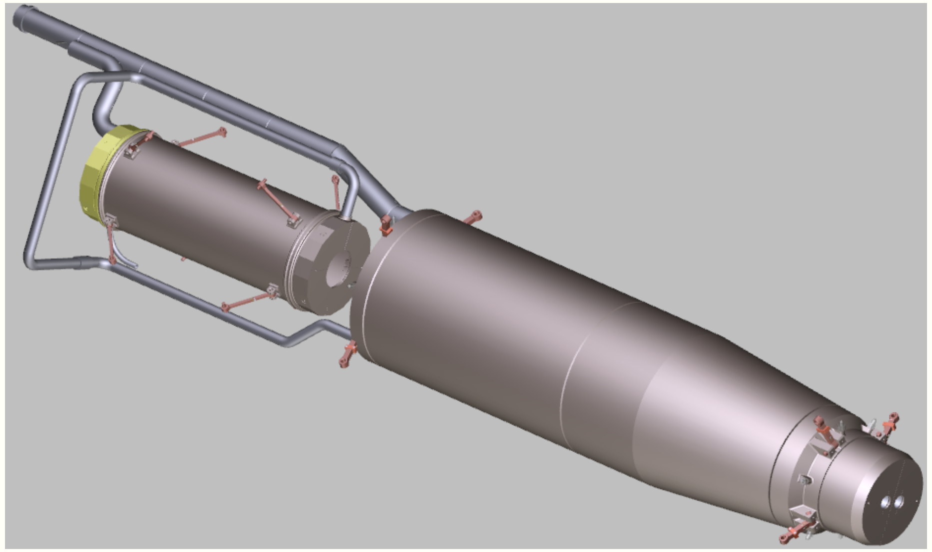


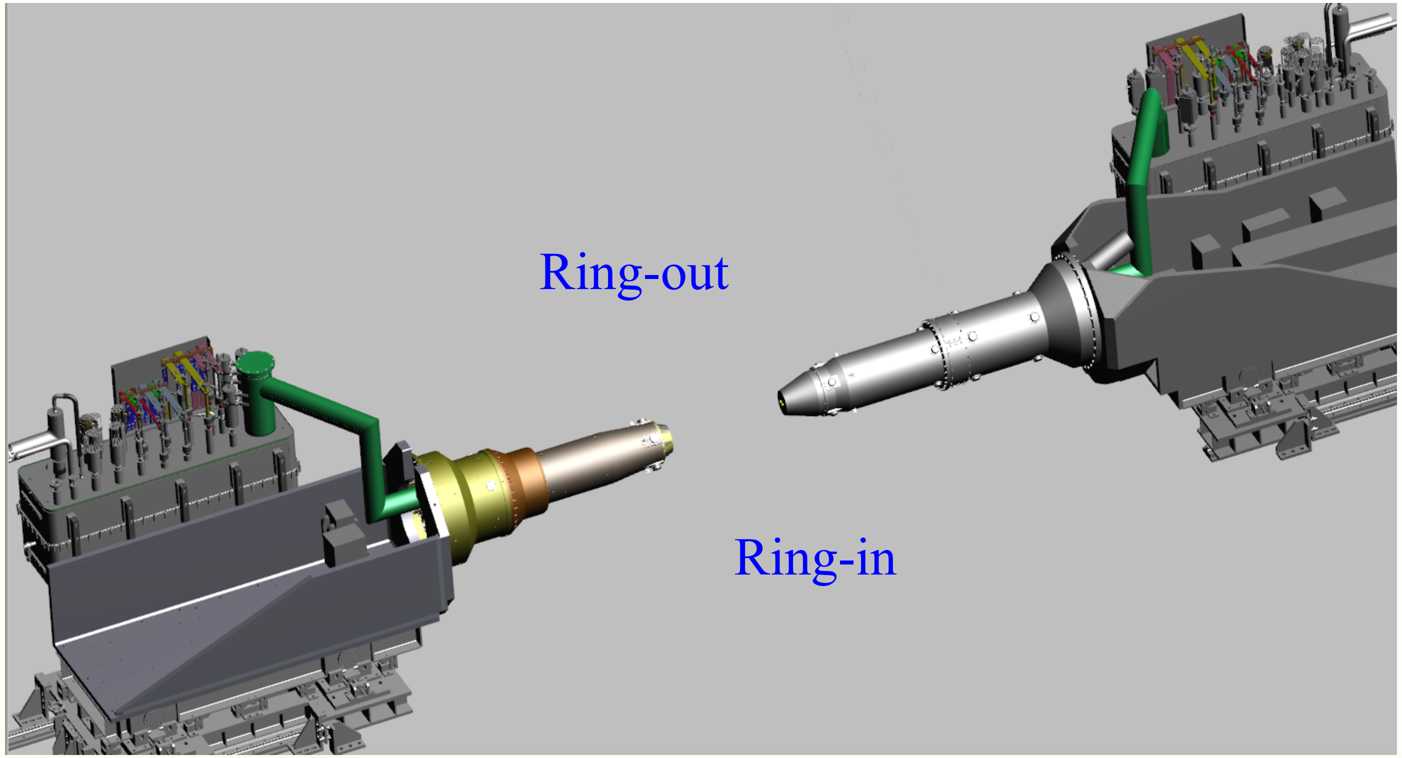


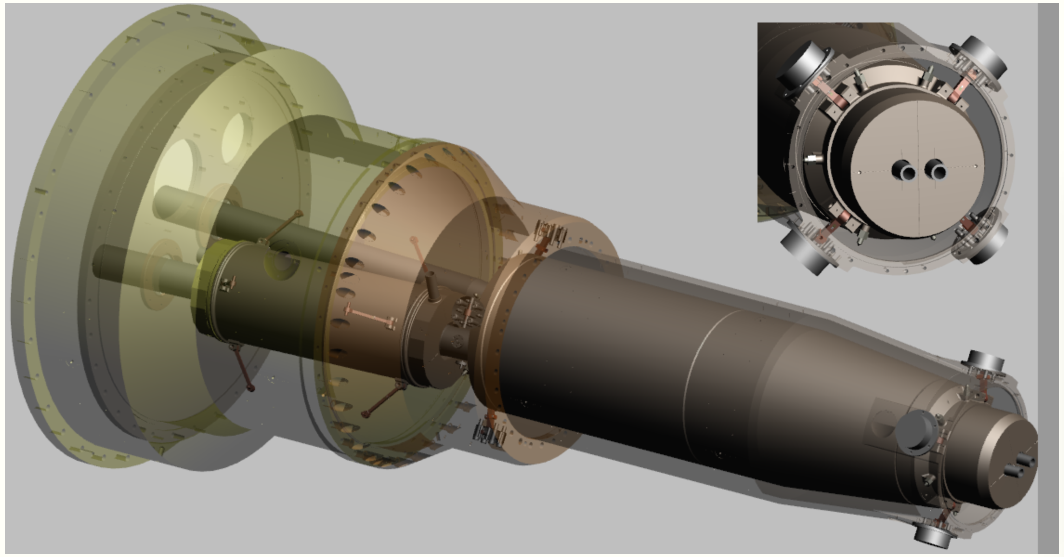


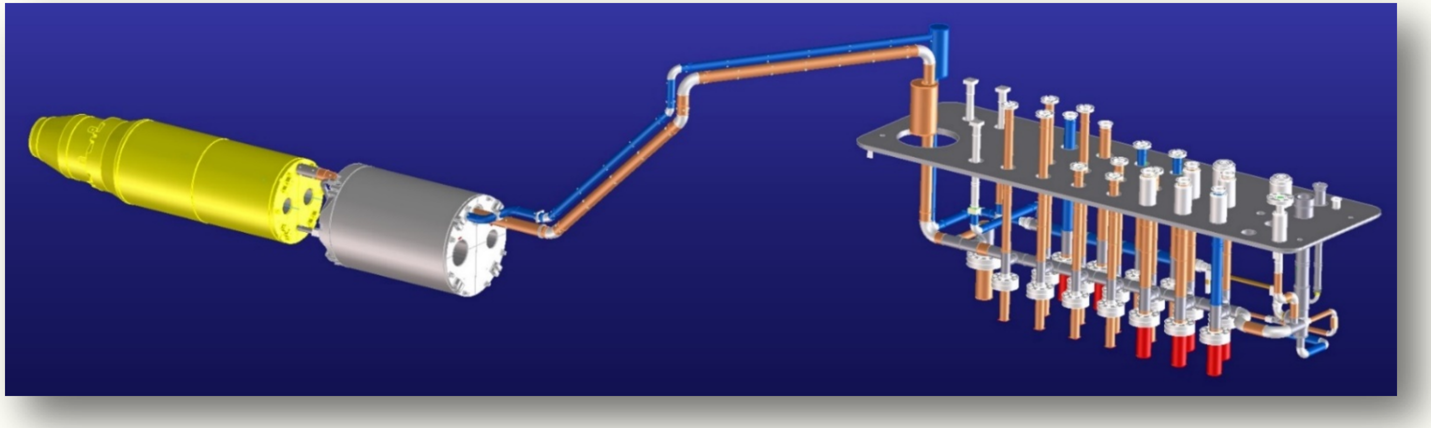
- Components: beam pipes with room temperatures, Permendur yoke, tungsten shields, and SUS supports
- long and slim cooling channels or pipes (more than 6 m for a round-trip)

The service crysotats

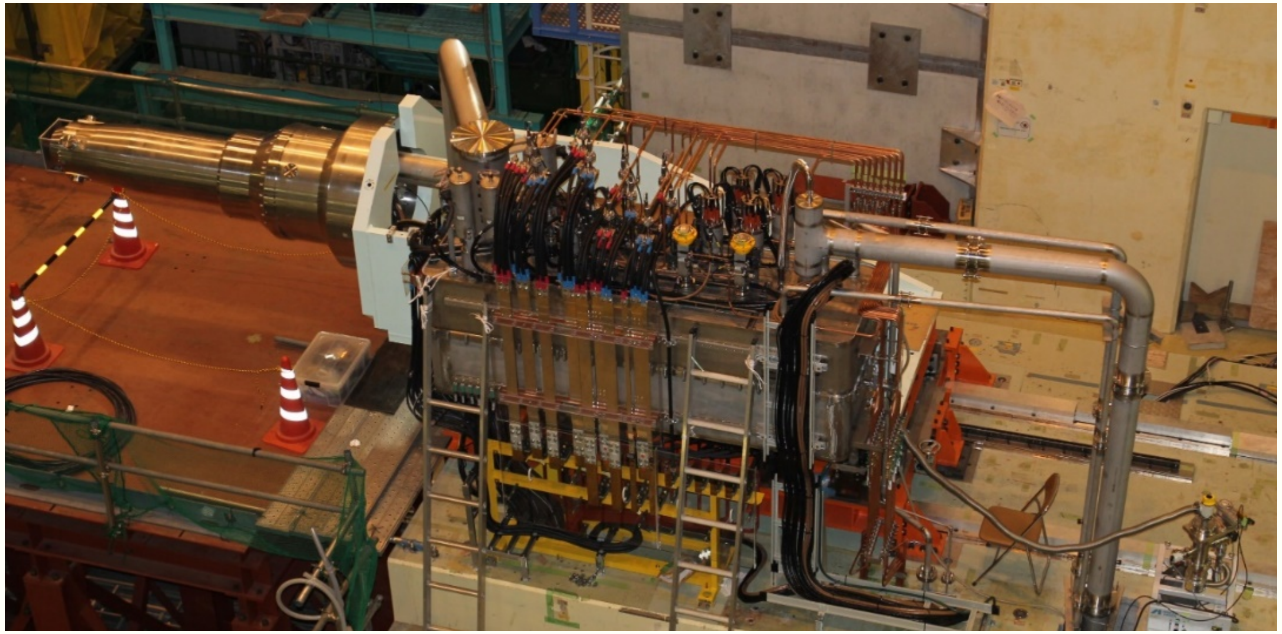


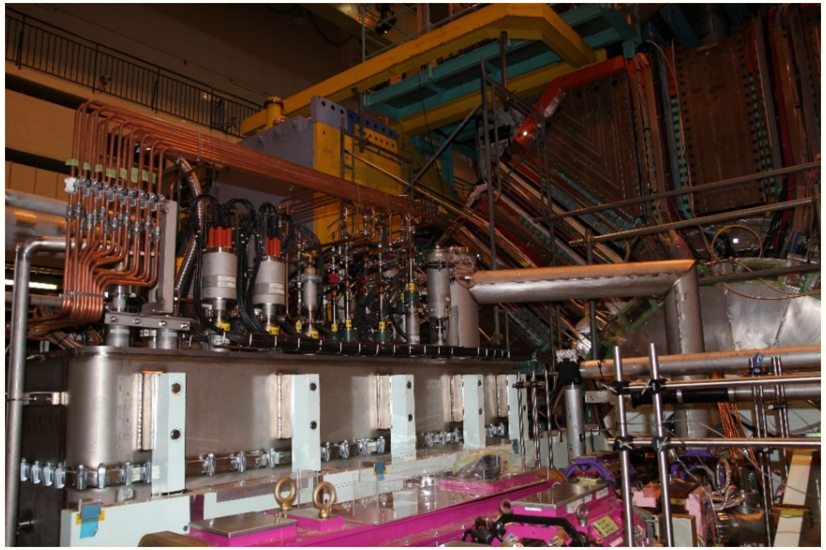


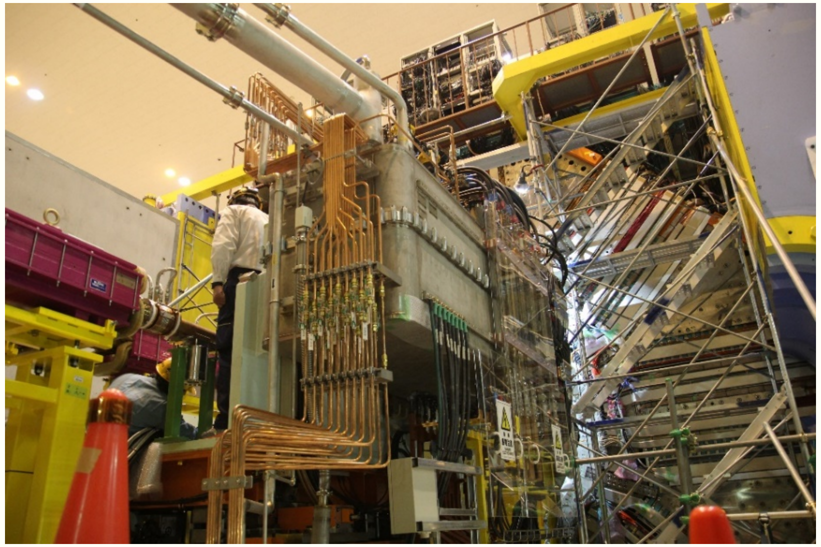




The cryostats in cryogenic systems







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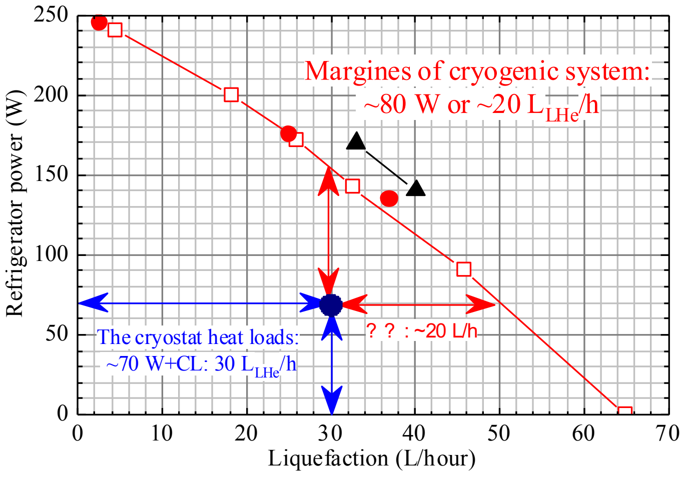
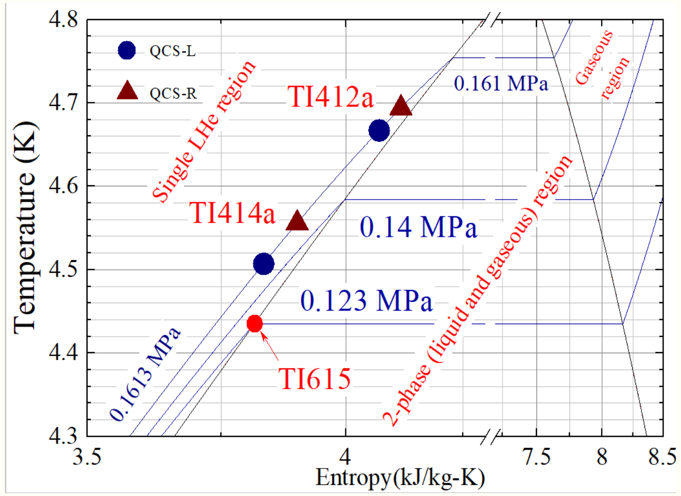
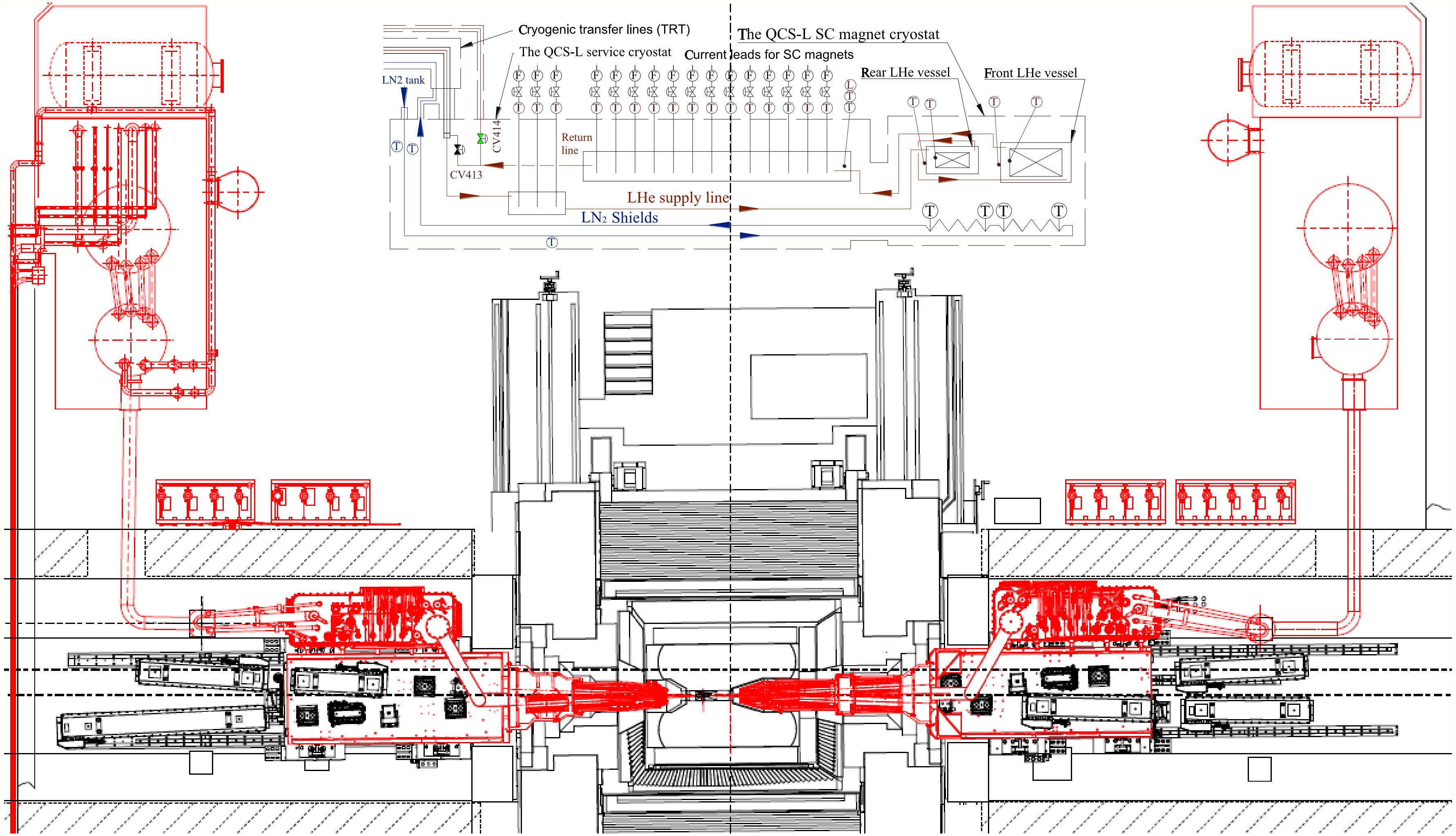
The cryostats in cryogenic systems







- Each cryostat has an individual coldbox, with the cooling powers of 250 W.
  - The cold boxes has served for the Tristan and KEKB project for about 30 years.

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Performance tests of the SC magnets and cryogenic system

On April 11, 2017, Belle-II rolled in to the SuperKEKB beam lines

Performance and Interlock tests of cryogenic systems with the crysotats

- Operation sequence programs are designed to realize the system automatic processes, such as cool down, warm up, recovery from some troubles with compressors, turbines, and quenches of sc magnets
- Tuning parameters of the current supplies for sc magnets

Magnetic field measurements with the Belle solenoid magnetic fields (1.5 T)

- Single Stretched Wire measurements (SSW) to measure the magnetic field centers, and angles of the quadrupole field of QC1. and QC2s
- Harmonic coil measurement for integral magnetic field quality measurements of superconducting magnets, and higher order multipole field profile measurements along the beam lines
- 3 axis-hall probe measurement to measure solenoid field profiles along the beam lines

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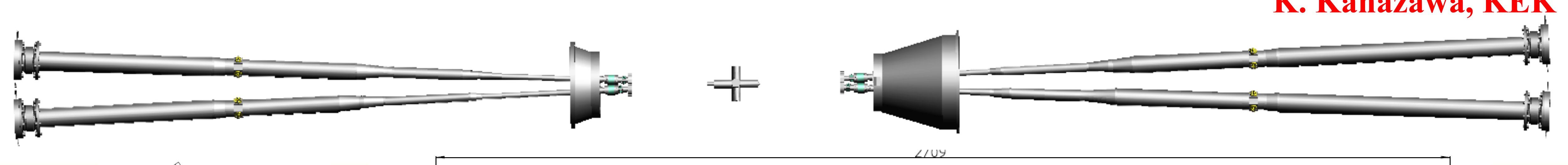
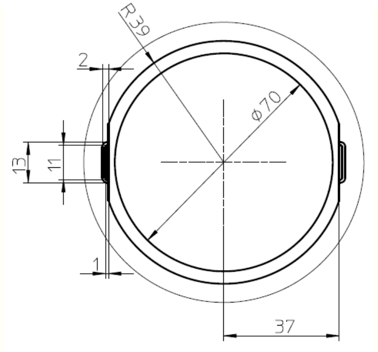
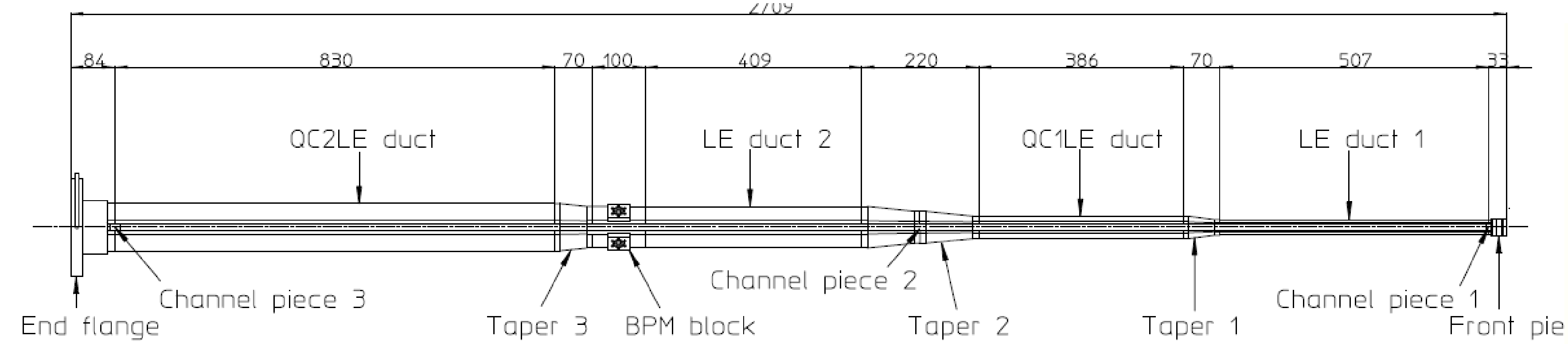
Beam pipes inside the cryostats

K. Kanazawa, KEK





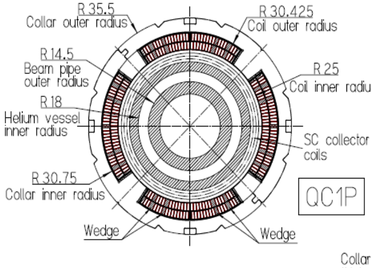


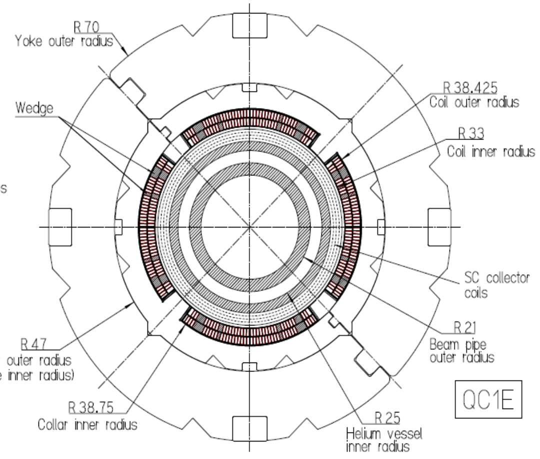
Pipes with a 4 mm thick wall, and with water cooling channel

- Cu coated inside (10 um)
- O-ring sealing with the cryostats, and is independent.

Heat through the gap between the warm beam pipes and LHe vessels

- LN_2 shield are not applied
- To elevate the operation temperature
- To increase heat loads of the cryostats.
- Special care is needed to avoid freezing the water inside beam pipes





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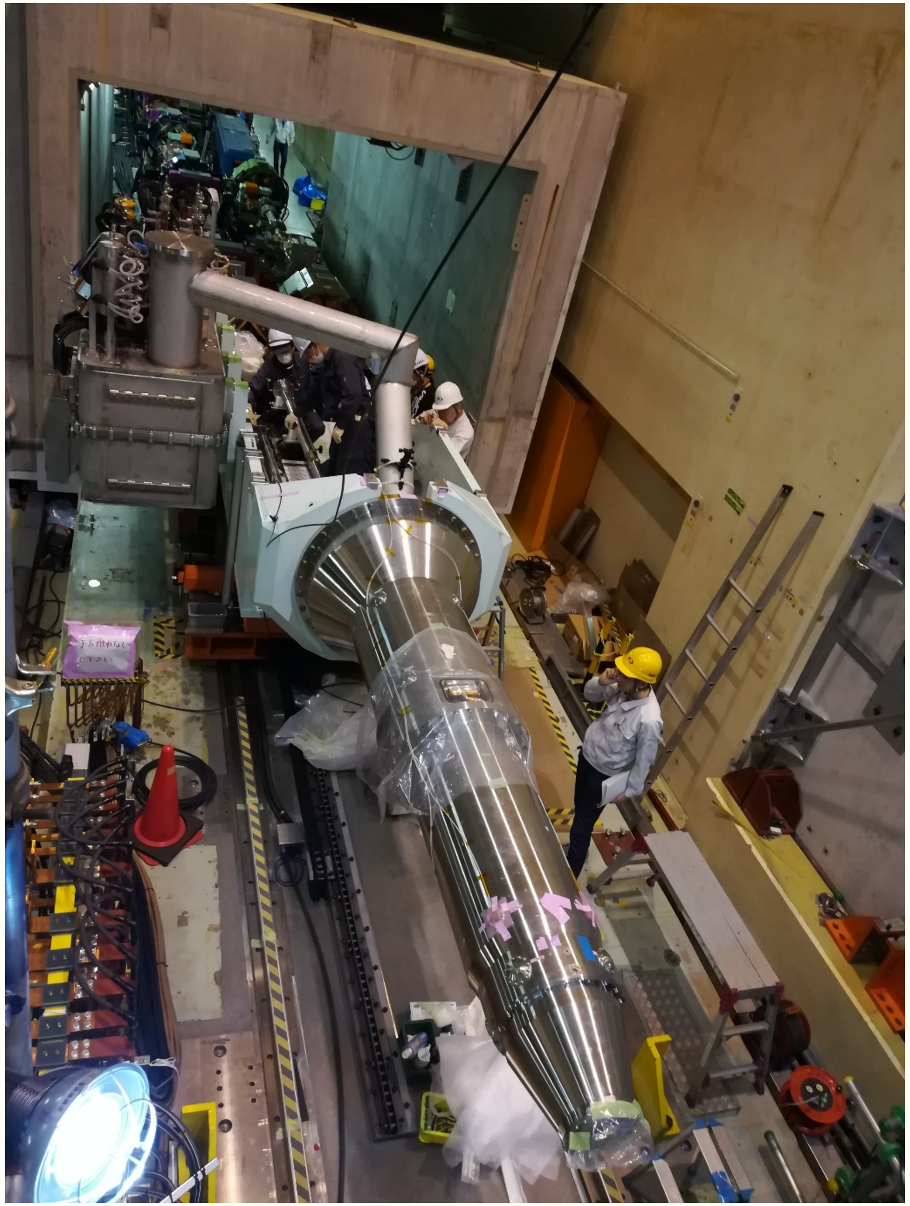
Beam pipe installation

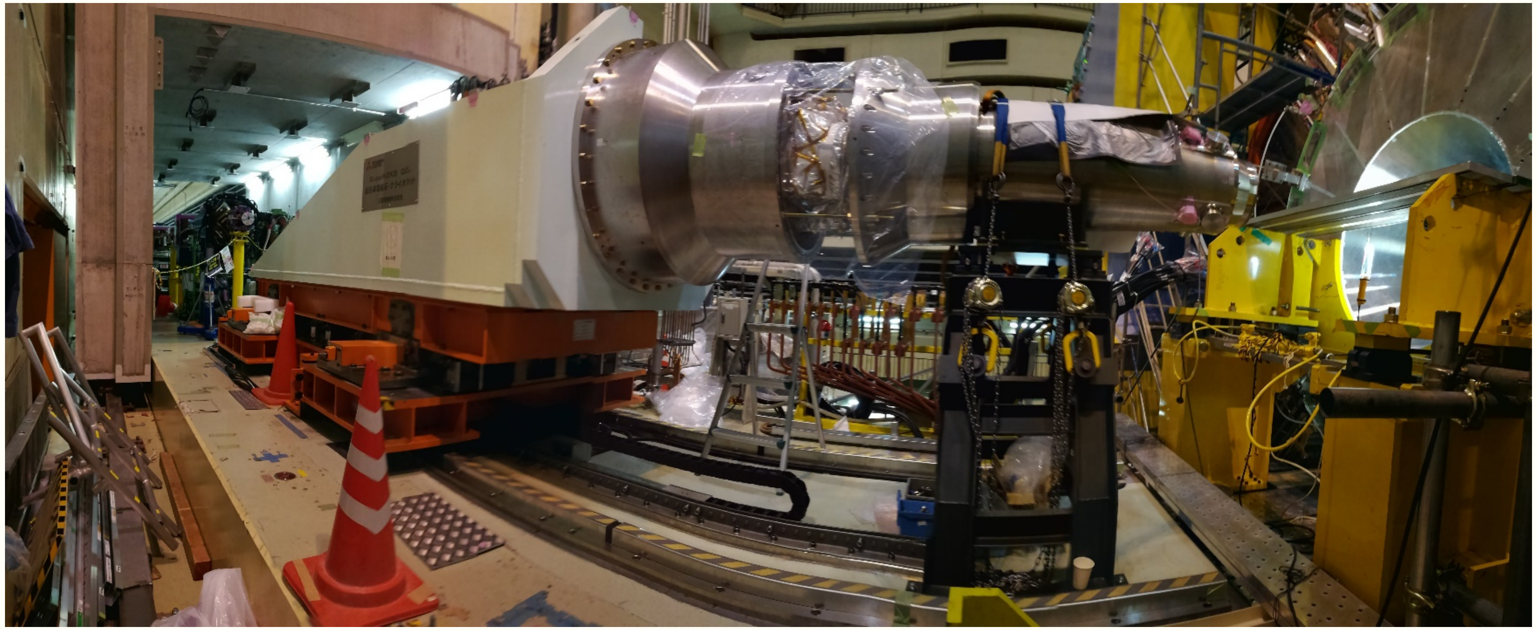
K. Kanazawa, KEK

Using a special tool forward

- QCS-R with service window
- QCS-L: disassembled

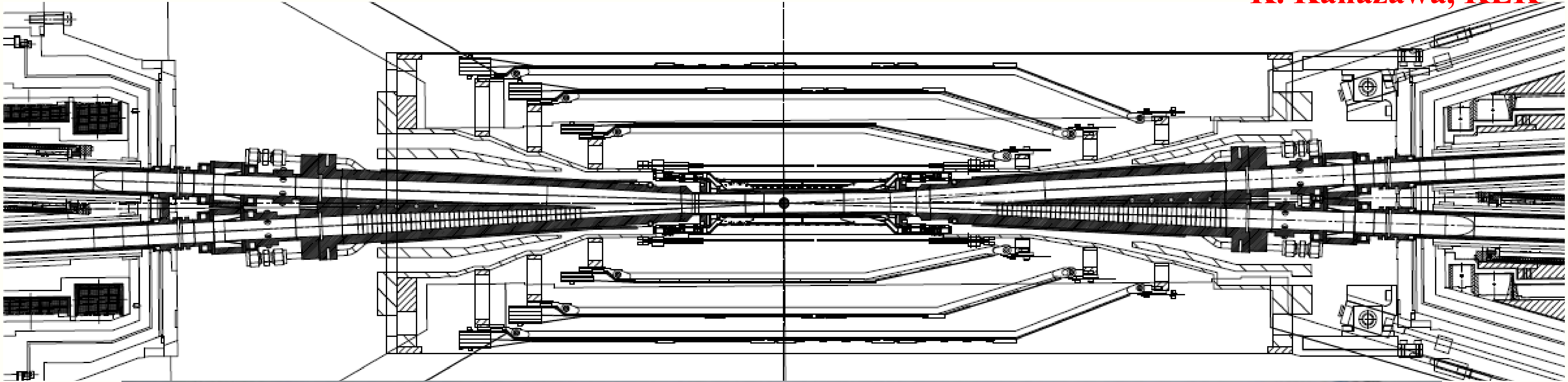
Connect BPM cables and leak check of the cryostats.





IP chamber

K. Kanazawa, KEK

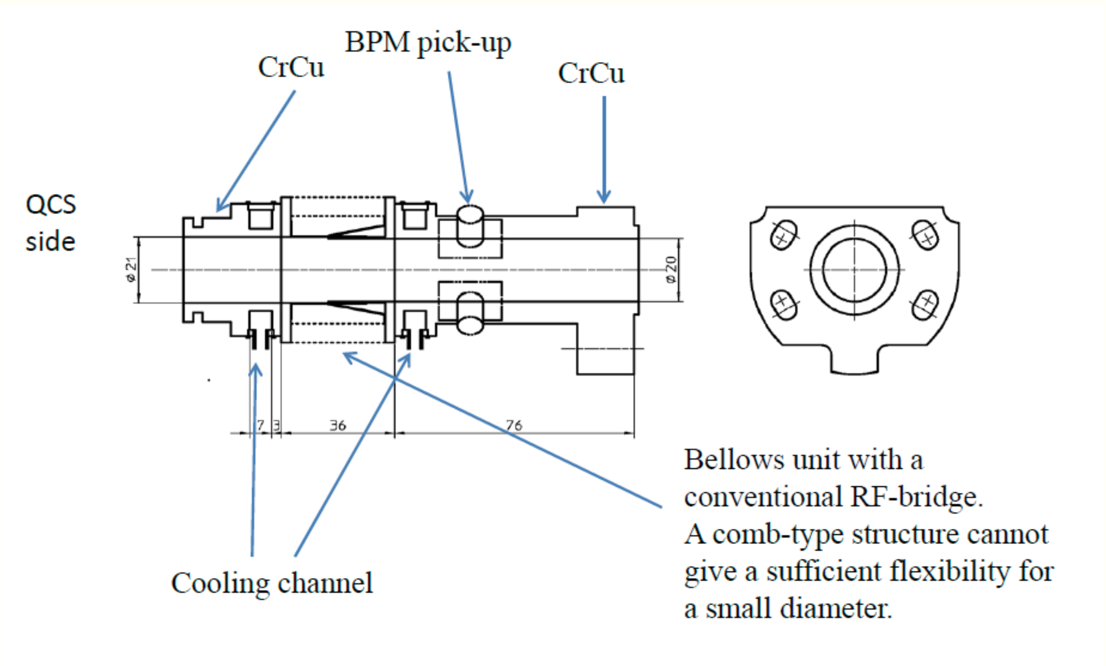


Related works performed for the design and production

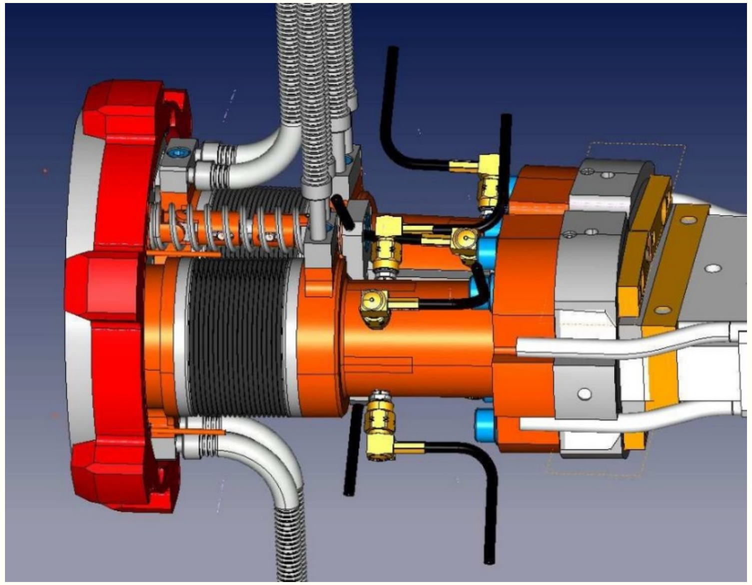
- Cooling test of the central part using a dummy model, mechanical analysis, impedance estimation
- Measurement of tip-scattering of photon, Photon-induced desorption measurement of Au coat, Cu, and Ta
- Estimation of SR background inside chamber, DC sputter coating test, HIP and welding test under various conditions

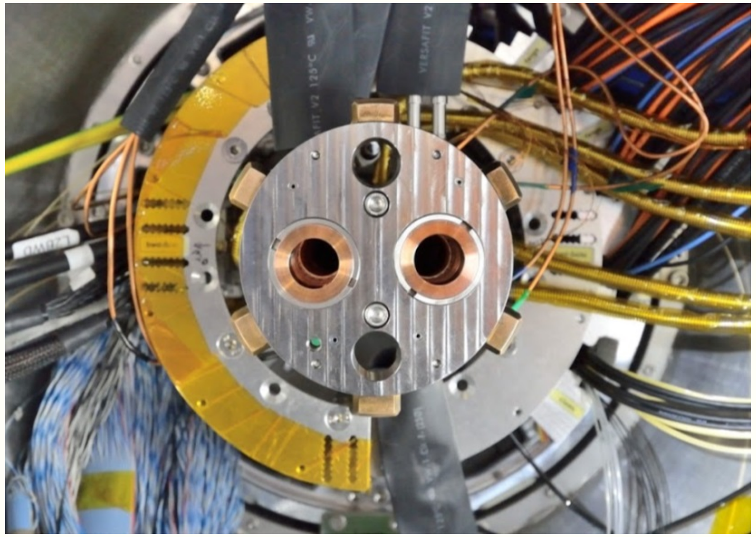
BPM-bellow tubes between the IP chamber and the QCS cryostats

K. Kanazawa, KEK



Bellows unit with a conventional RF-bridge.
A comb-type structure cannot give a sufficient flexibility for a small diameter.





The BPM-bellow tubes were connected to the IP chamber before Beast II installation

- It is practically impossible to connect BPM-bellow tubes to the IP chamber after the Beast II is installed into the Belle detector.
- The bellow tubes (14 cm long), set on a flange for Remote Vacuum Connection (RVC from DESY)

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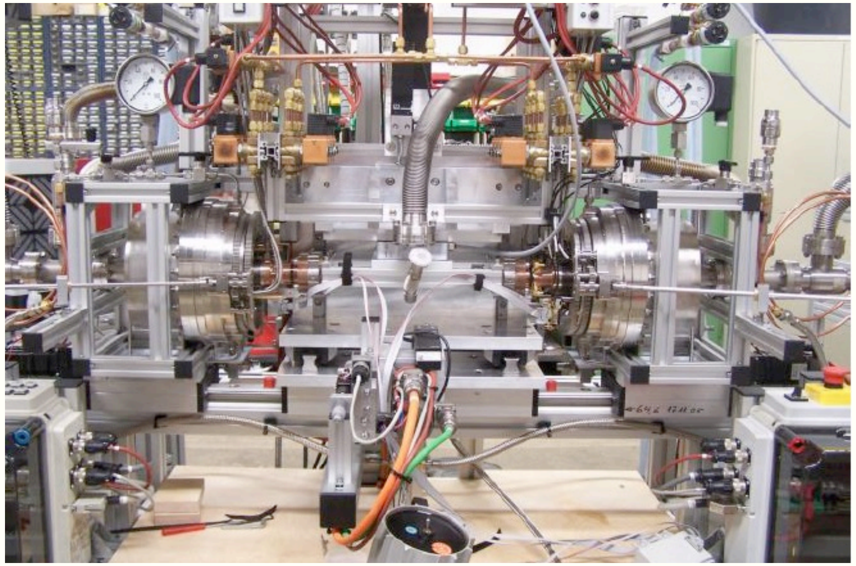
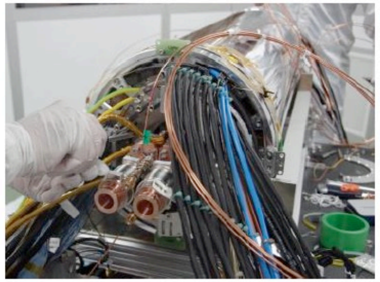
RVC

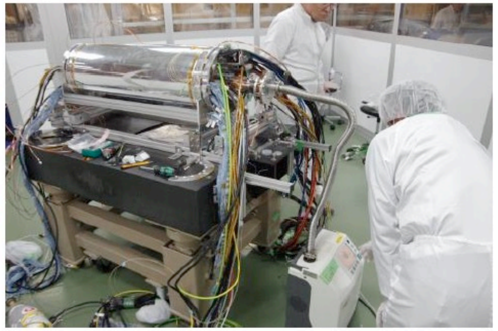
K. Kanazawa, KEK



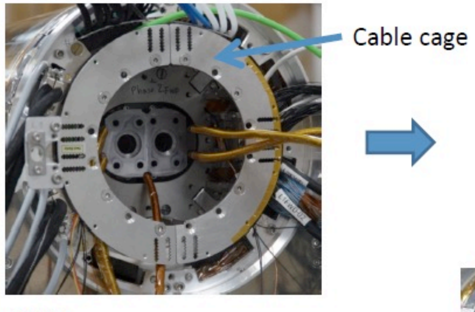
RVC test mock-up at DESY



BWD
The vacuum flanges of IP chamber is in front of the cable cage.

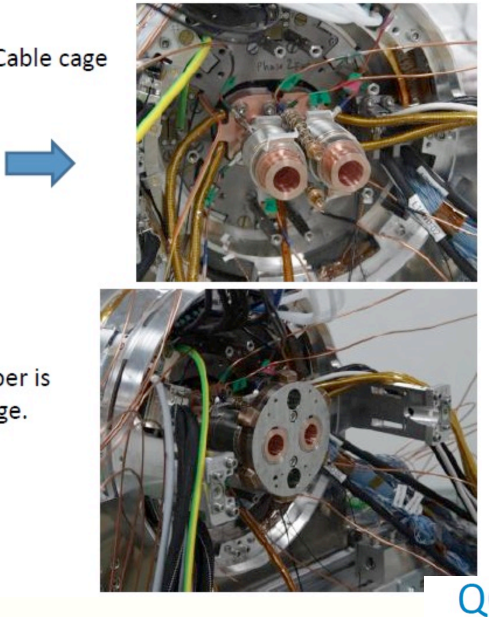


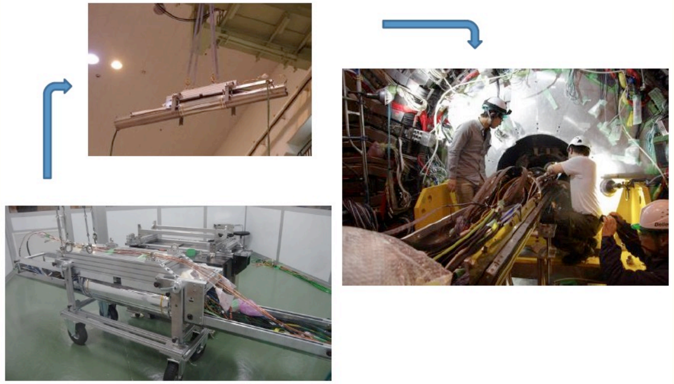
Vacuum leak check



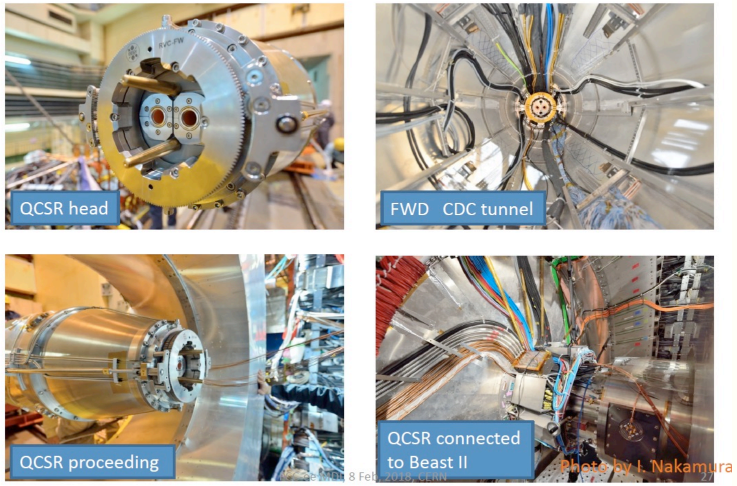
FWD
The vacuum flanges of IP chamber is about 8 cm behind the cable cage.

The cable cage interfered with connecting work. It is temporally removed.

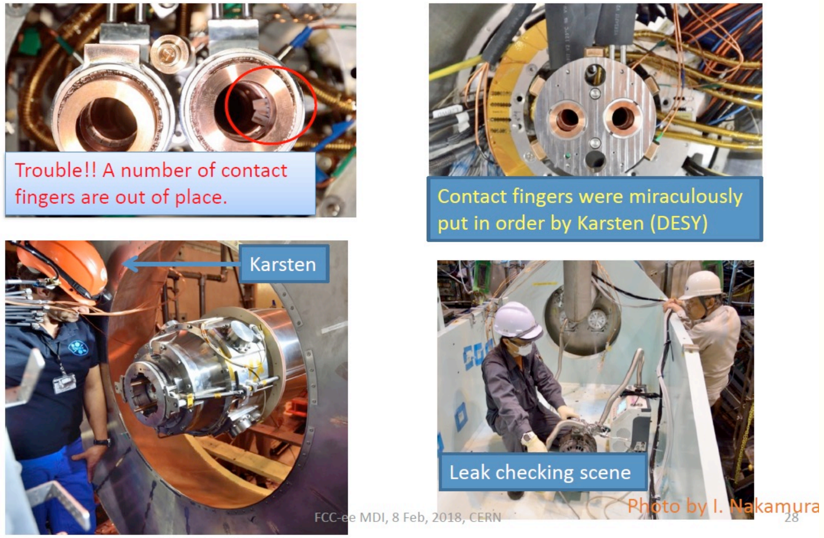




QCSR-Beast II connection (Jan. 9, 2018)



QCSL-Beast II connection (Jan. 15, 2018)



Trouble!! A number of contact fingers are out of place.

Contact fingers were miraculously put in order by Karsten (DESY)

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Operation in the Phase II commissioning

Peak luminosity: 5.55 ×10^{33} $cm^{-2}S^{-1}$ with beam currents LER=800 mA and HER=780 mA

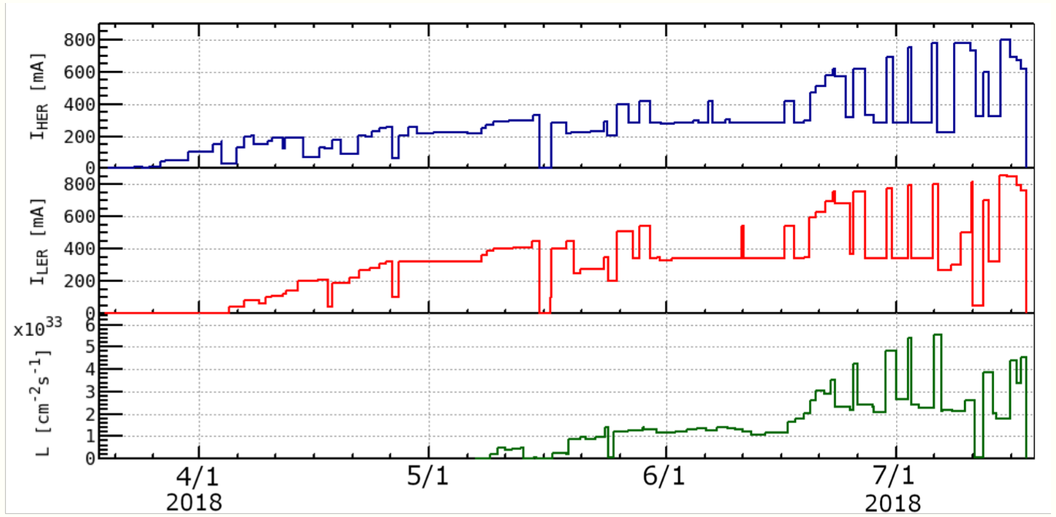
Max. currents: LER=860 mA, HER=800 mA

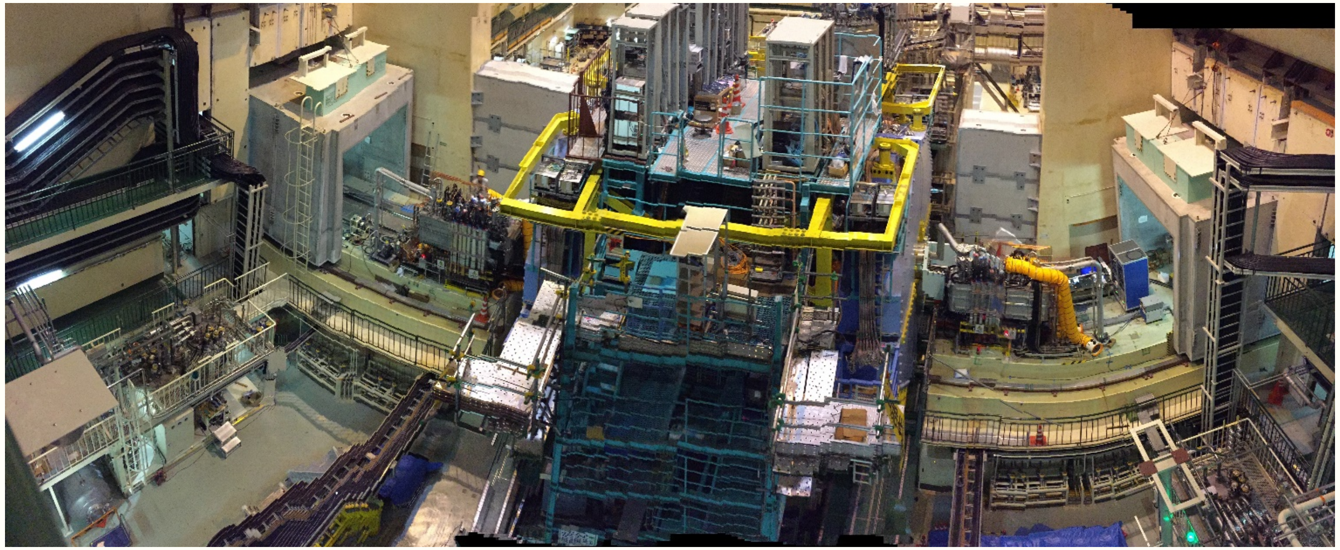
SC magnet system for final focusing

- Worked and was operated for commissioning
- QCS quenches induced by beams (unexpected)

– For Phase III, more movable collimators to control beam loss and background

– Improvements of magnet quench detection system





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