Commissioning status of SuperKEKB vacuum system

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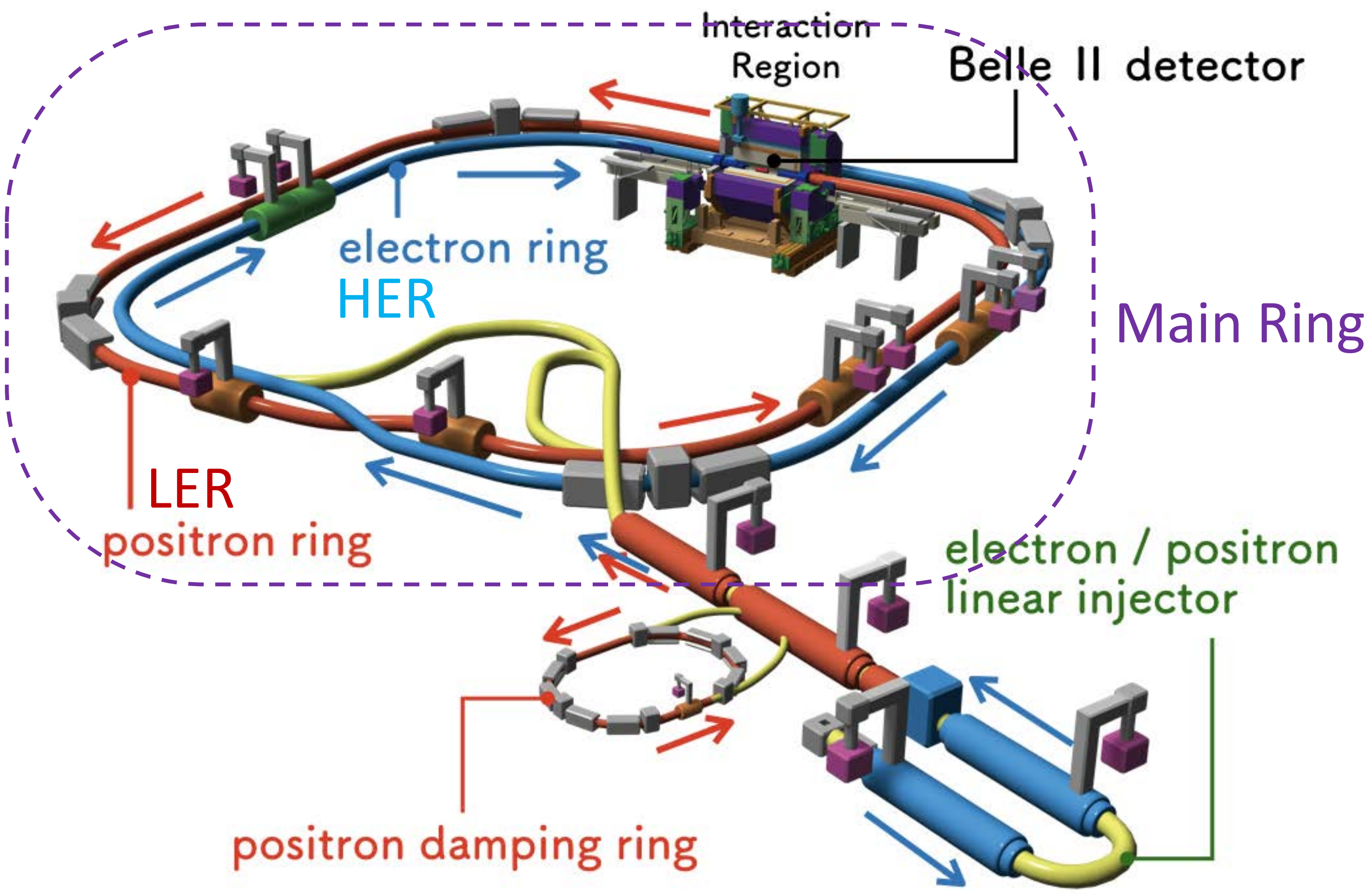
HIGH LUMINOSITY CIRCULAR e^+e^- COLLIDERS (eeFACT2018)

Introduction

- SuperKEKB;
  - An upgrade of the KEKB
  - High-luminosity electron-positron collider
  - Main ring (MR) is composed of
    Low Energy Ring (LER) :
    4.0 GeV positron, 3.6 A
    High Energy Ring (HER) :
    7.0 GeV electron, 2.6 A
  - Luminosity : 8.0×10^{35} $cm^{-2} \cdot s^{-1}$
    - Twice the beam current of KEKB
    - Smaller emittance for “nano-beam collision scheme”
- Many upgrades are required.
  - Upgrade of the vacuum system is a significant requirement.

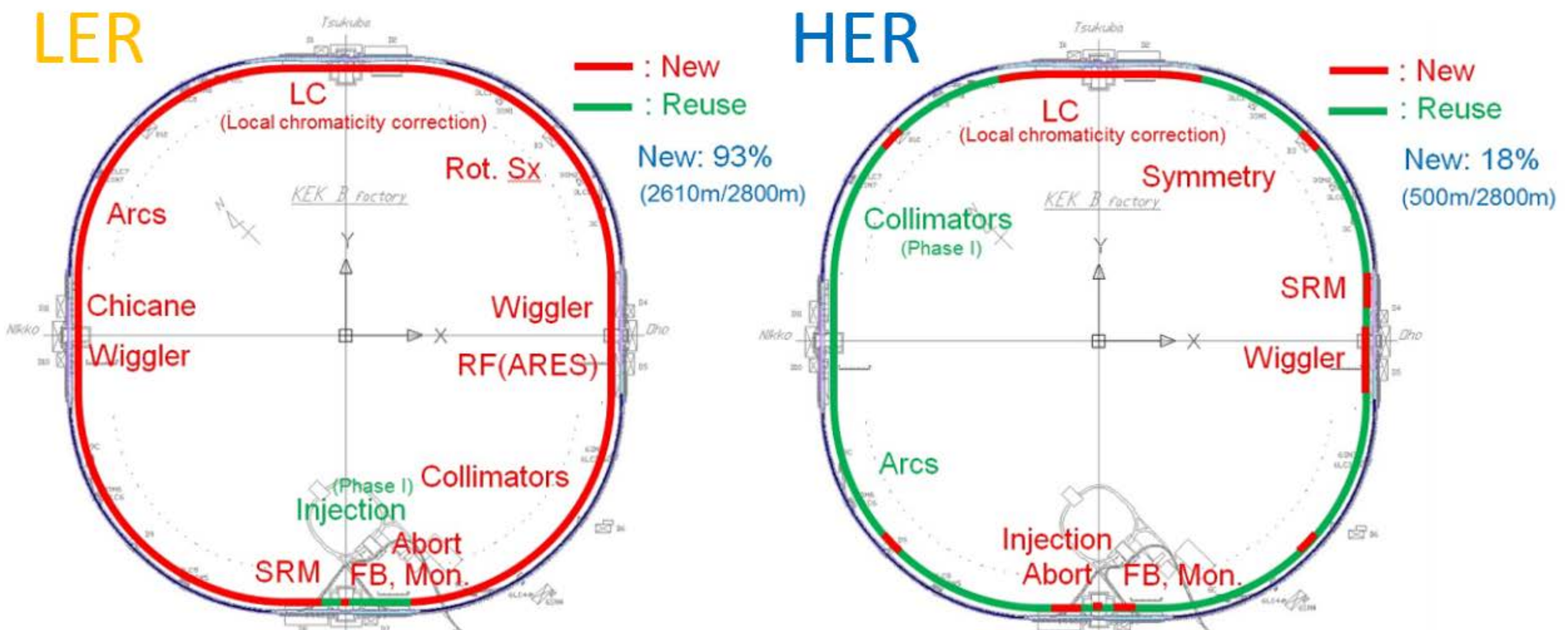


SuperKEKB

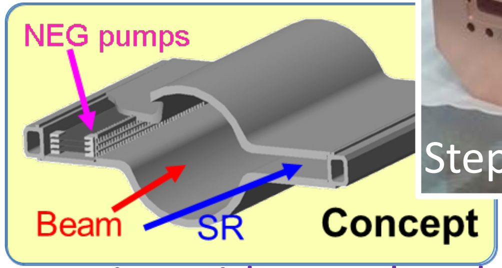
New vacuum system for SuperKEKB

- Upgradation of the vacuum components.
  - LER : ~93% of the vacuum components was replaced with new ones.
  - HER : ~80% of the vacuum components was reused from the KEKB.

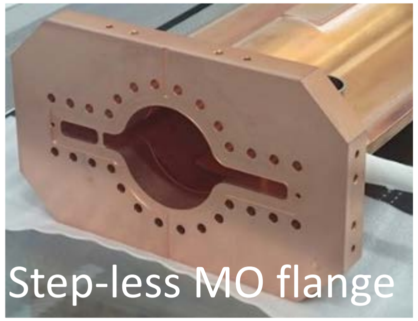
- New vacuum components for high beam current and low emittance beam
  - Beam pipe with antechambers
  - Step-less MO-type flange
  - Comb-type rf-shield (Bellows chamber & Gate Valve)
  - Low-impedance collimator



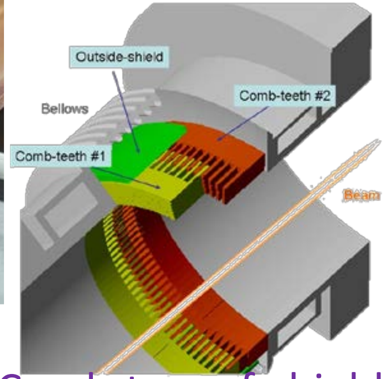
Locations where the vacuum components were replaced.



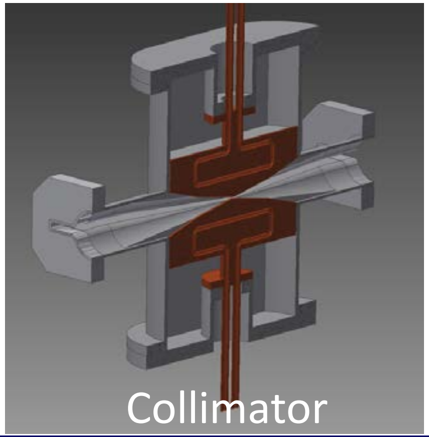
Beam pipe with antechambers



Step-less MO flange



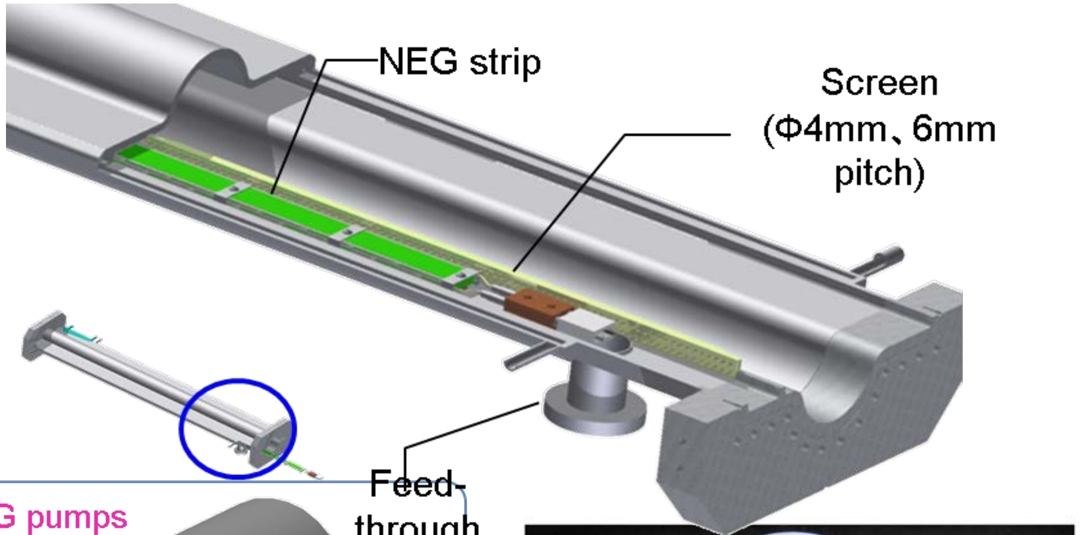
Comb-type rf-shield

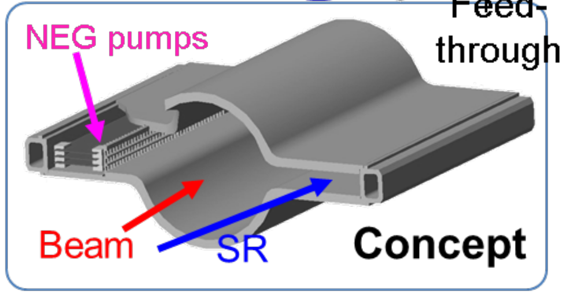


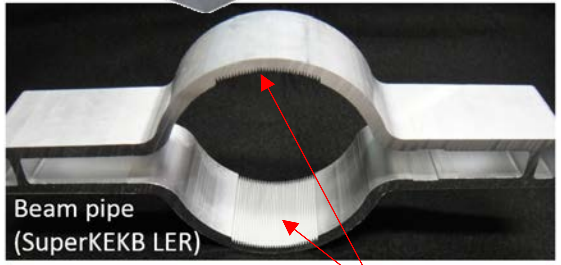
Collimator

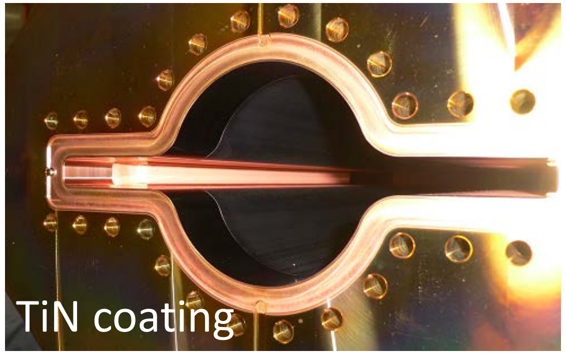
Beam pipe with antechambers

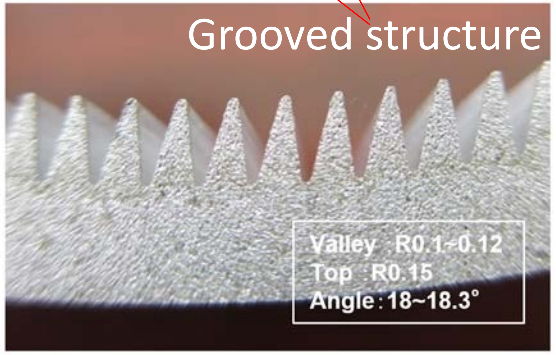
- New beam pipes with antechamber
  - ➢Intense SR passes through antechambers, and irradiates the side wall.
  - ➢NEG strips are installed in one of antechambers (in arc sections)
    - Effective distributed pumping scheme
    - 0.14 $m^3 \cdot s^{-1} \cdot m^{-1}$ for CO just after NEG activation
    - Target pressure : ~10^{-7} Pa at the design currents
  - ➢Effective for reducing impedance and suppressing photoelectron
  - ➢TiN coating & Grooved structure (only in dipole magnets) for LER
    - Countermeasures against electron cloud effect
  - ➢Material : Al-alloy or Copper (wiggler sections)





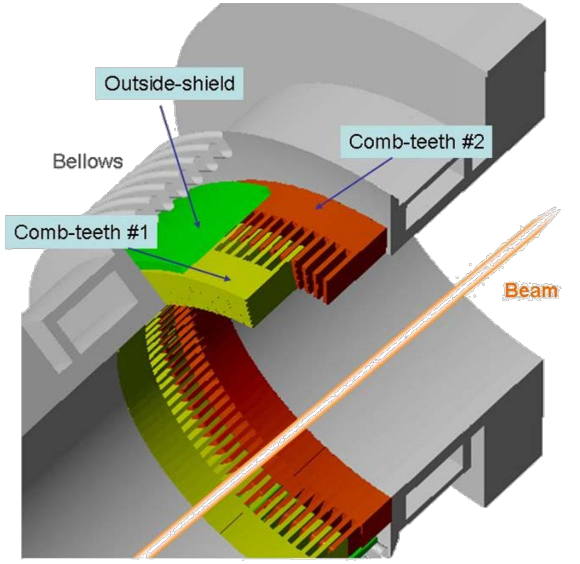




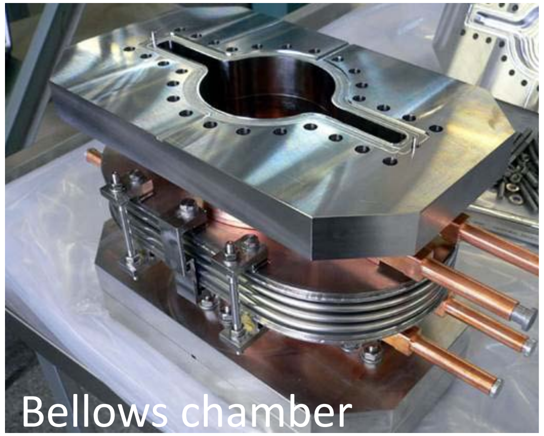


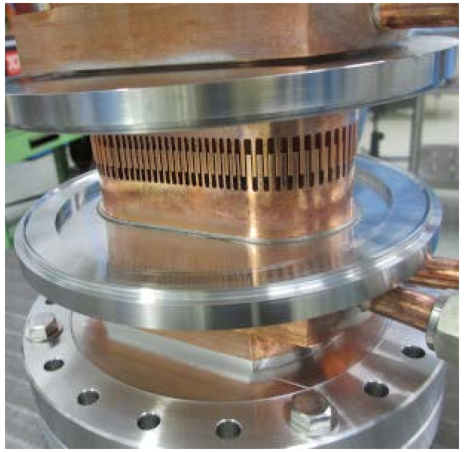
Comb-type rf-shield

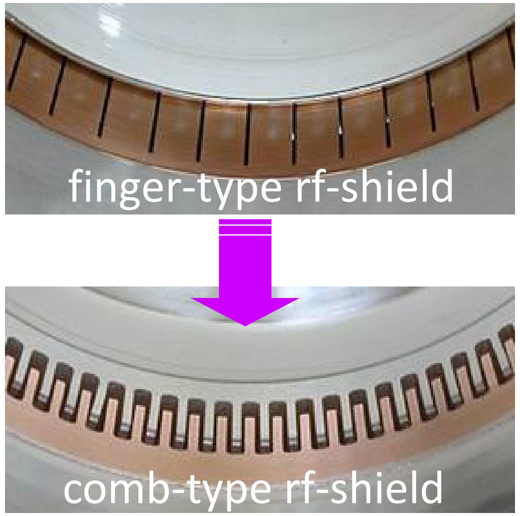
- 1200 bellows chambers & 40 gate valves are used in one ring.
- Comb-type rf-shield for new bellows chamber and gate valves
  - Higher thermal strength than conventional finger-type shield.



Comb-type rf-shield

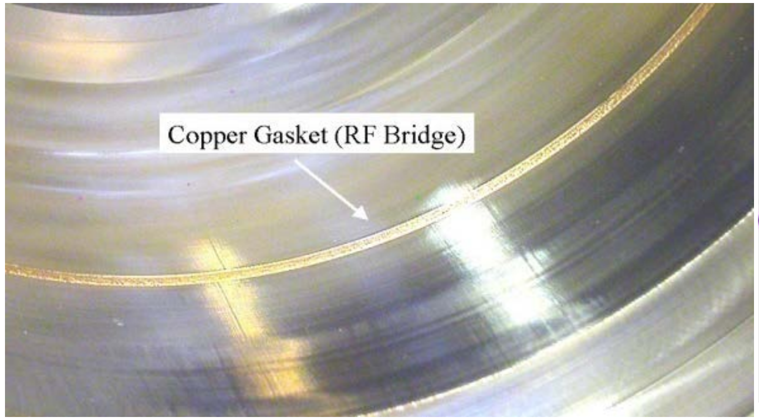


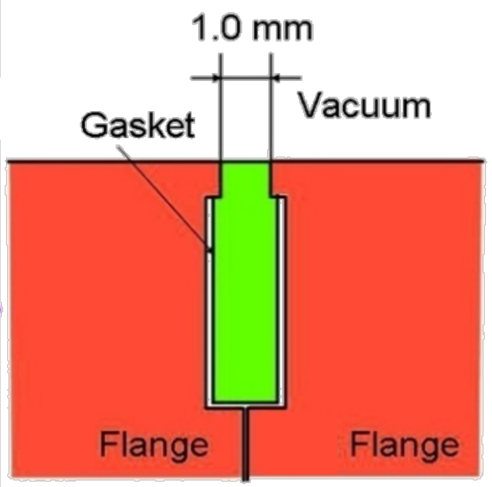


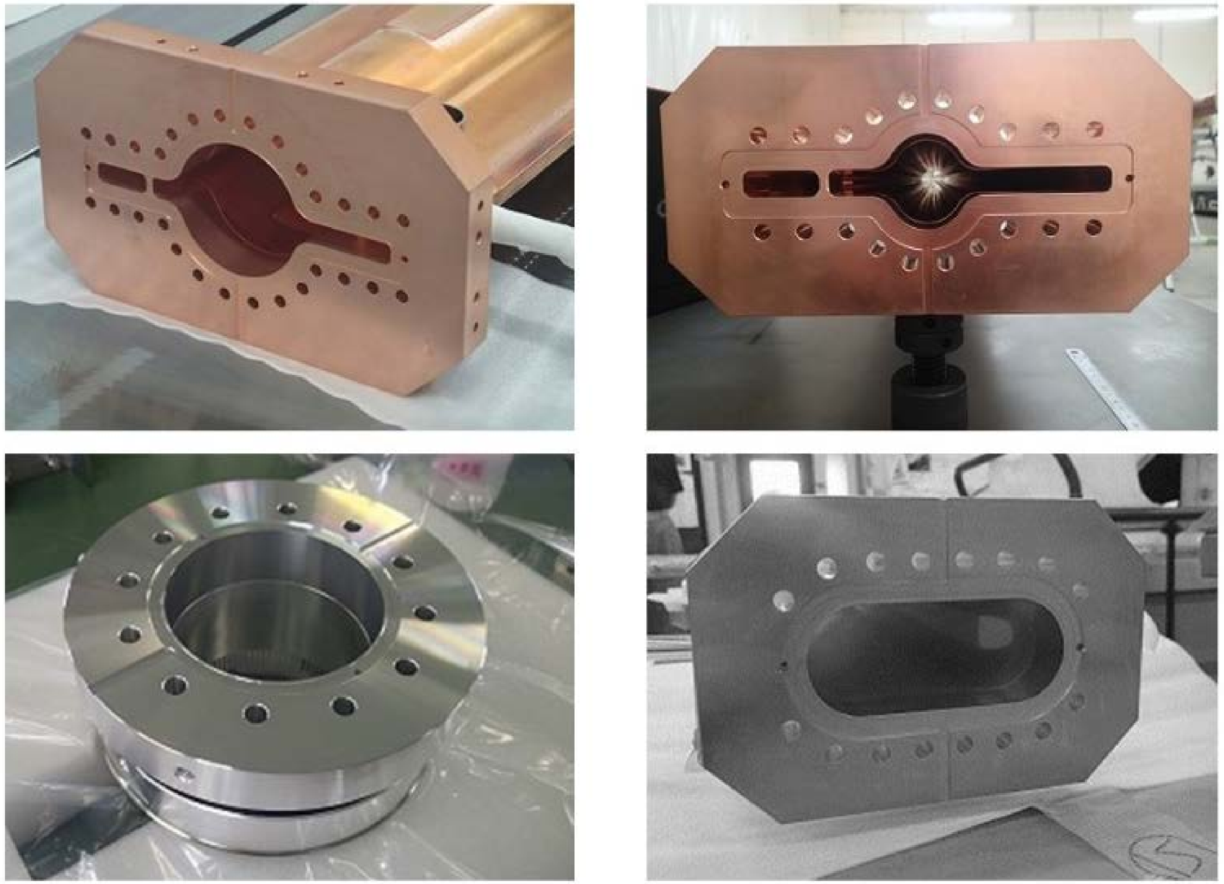


Step-less MO-type flange

- High bunch currents (1.4 mA/bunch) and short bunch length (~6 mm) of SuperKEKB is likely to excite HOM.
- Step-less MO-type flange is adopted.
  - ➢Vacuum-tight seal at the inner surface
  - ➢Maintaining smooth flow of the wall current across a gasket.





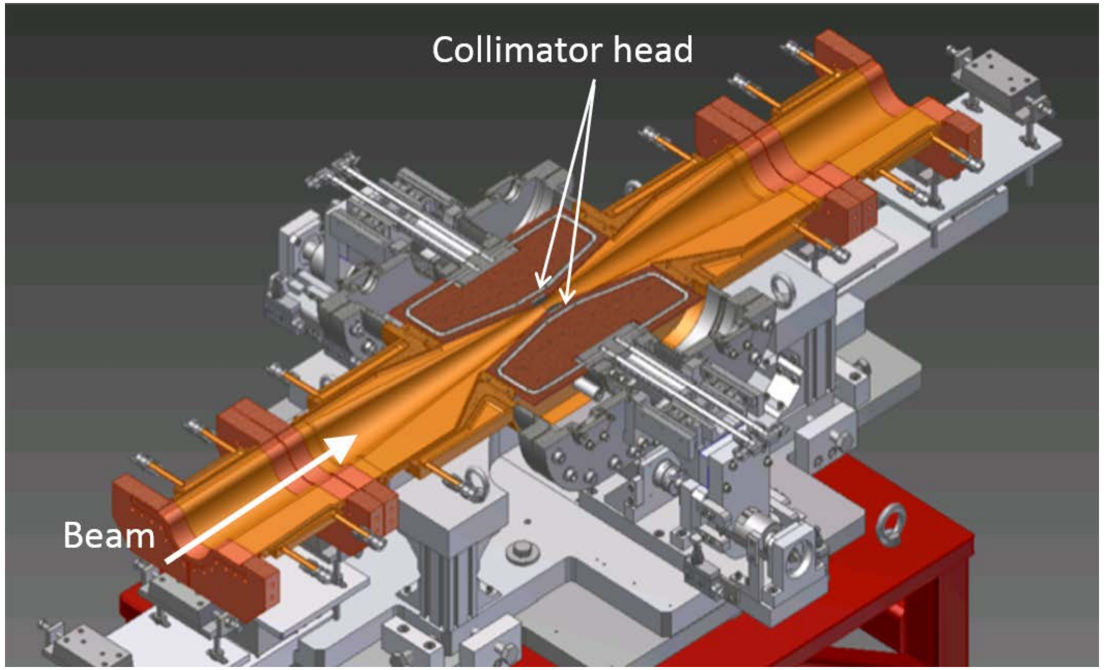


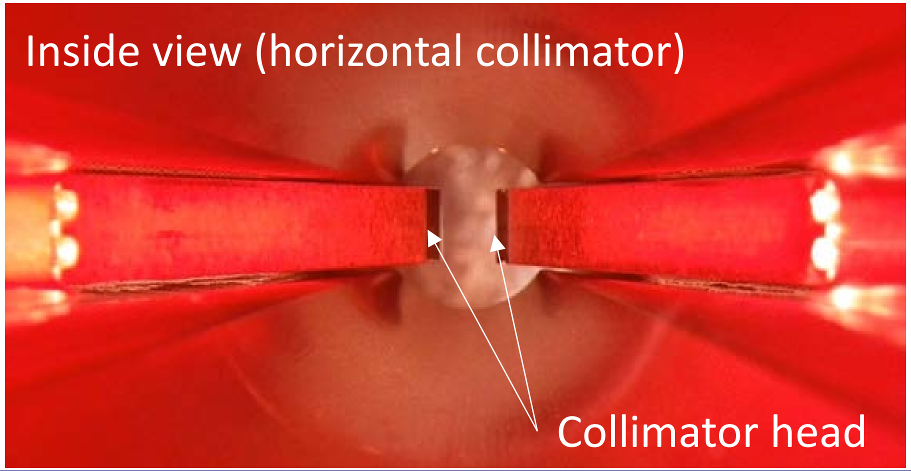
Various types of the step-less MO-type flanges for SuperKEKB

- SuperKEKB is the first machine to adopt the step-less MO-type flanges and comb-type rf-shield on the large scale.

Low-impedance collimator

- New collimator was designed based on that used in the PEP-II at SLAC with the objective of minimizing the impedance.
- Two horizontal collimators were installed into the LER before starting commissioning (Phase-1).
    - ➢In the HER, 16 KEKB-type beam collimator were reused.

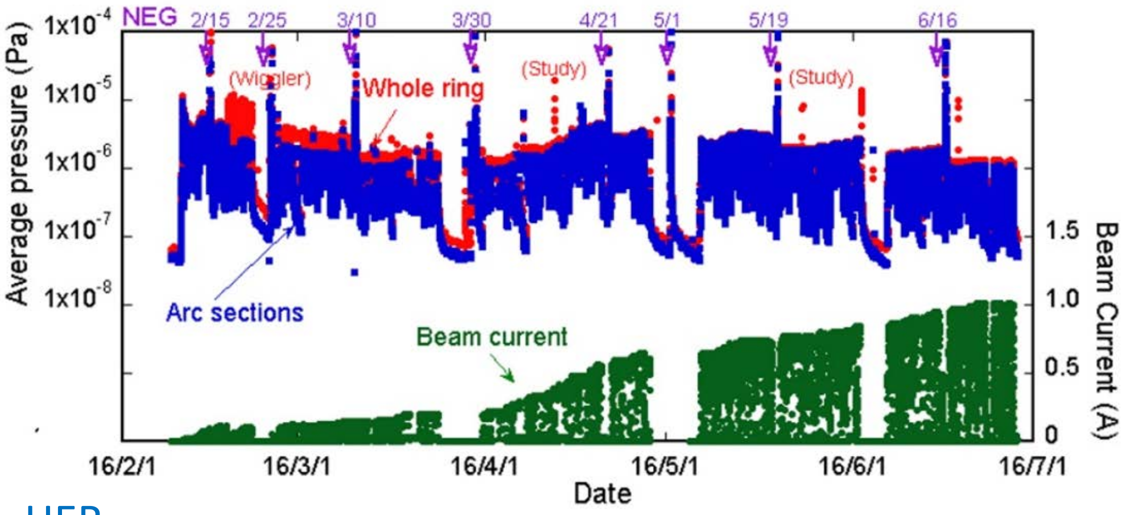




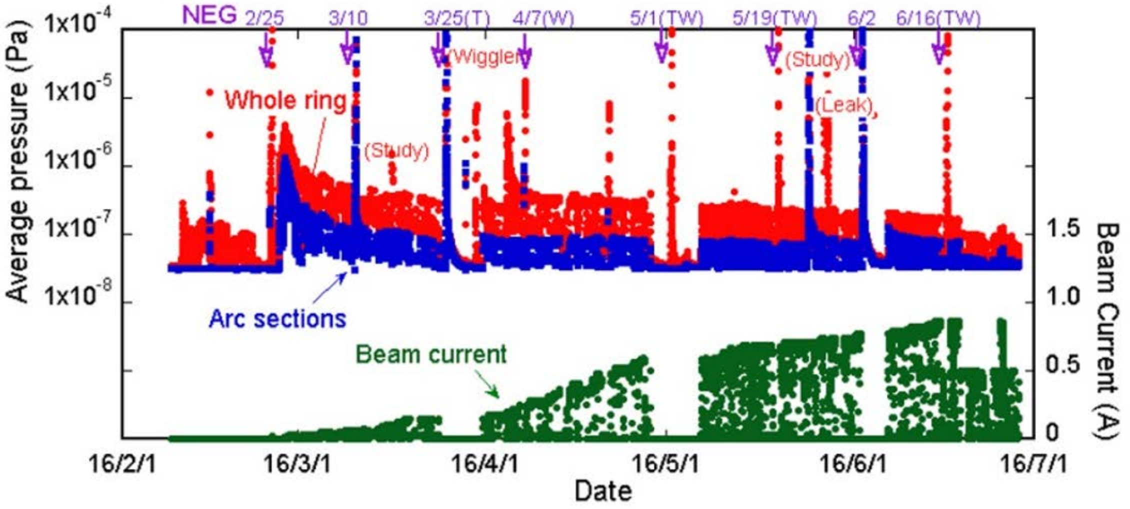
Phase-1 commissioning 1

- Phase-1 commissioning (Feb.- June 2016)
  - ➢ Dedicated to accelerator tuning without Belle-II detector.
  - ➢ Vacuum scrubbing & confirmation of the stabilities of new vacuum component at ~ 1 A
  - ➢ Maximum stored current (I_{max}) & beam dose
    - LER : I_{max} = 1.01 A, 780 A·h
    - HER : I_{max} = 0.87 A, 660 A·h
  - ➢ Base pressure (p_{base}) & average pressure at I_{max} (p_{max})
    - LER : p_{base} = ~5 × 10^{-8} Pa, p_{max} = ~1 × 10^{-6} Pa
    - HER : p_{base} = ~3 × 10^{-8} Pa, p_{max} = ~2 × 10^{-7} Pa (whole), ~6 × 10^{-8} Pa (Arc)
  - ➢ Vacuum system experienced no serious problem.
    - Newly installed vacuum components worked well.

LER



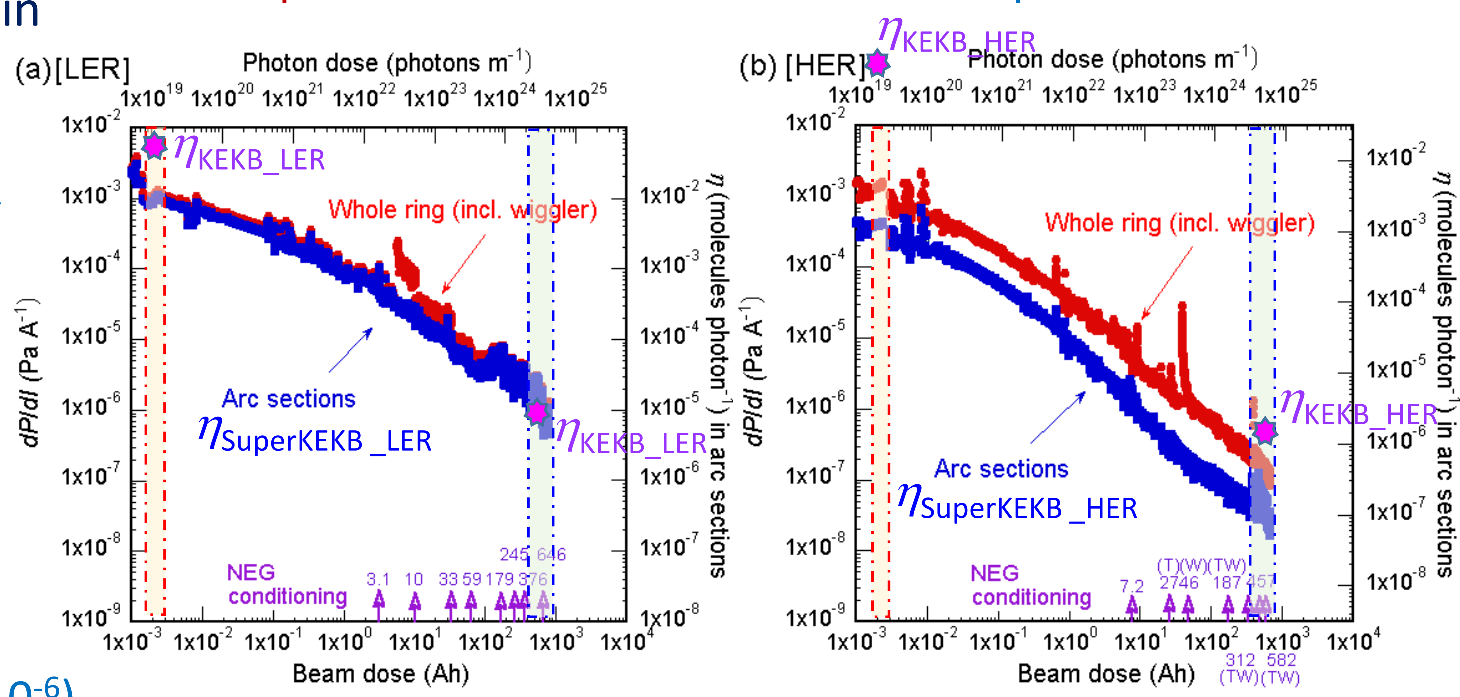
HER



Phase-1 commissioning 2

- Vacuum scrubbing in arc sections
  - ➢ Vacuum scrubbing progressed smoothly in both rings.
  - ➢ Photo stimulated desorption (PSD) rate (η) in the arc sections
    - LER : 1×10^{-3} -> 7×10^{-6} molec.·photon^{-1}
    - HER : 3×10^{-4} -> 1×10^{-7} molec.·photon^{-1}
  - ➢ In the early stage
    - LER : $\eta_{\mathrm{SuperKEKB}} < \eta_{\mathrm{KEKB}}$ (4×10^{-3})
    - HER : $\eta_{\mathrm{SuperKEKB}} \ll \eta_{\mathrm{KEKB}}$ ($> 2 \times 10^{-2}$)
    - $\eta_{\mathrm{HER}} < \eta_{\mathrm{LER}}$
  - ➢ In the final stage
    - LER : $\eta_{\mathrm{SuperKEKB}} = \eta_{\mathrm{KEKB\ at\ same\ beam\ dose}}$
    - HER : $\eta_{\mathrm{SuperKEKB}} < \eta_{\mathrm{KEKB\ at\ same\ beam\ dose}}$ (1×10^{-6})
  - ➢ Reused beam pipes of HER "remembers" the conditions in the KEKB.
    - HER : $\eta_{\mathrm{SuperKEKB}}$ in the final stage ≈ final value of η_{KEKB}

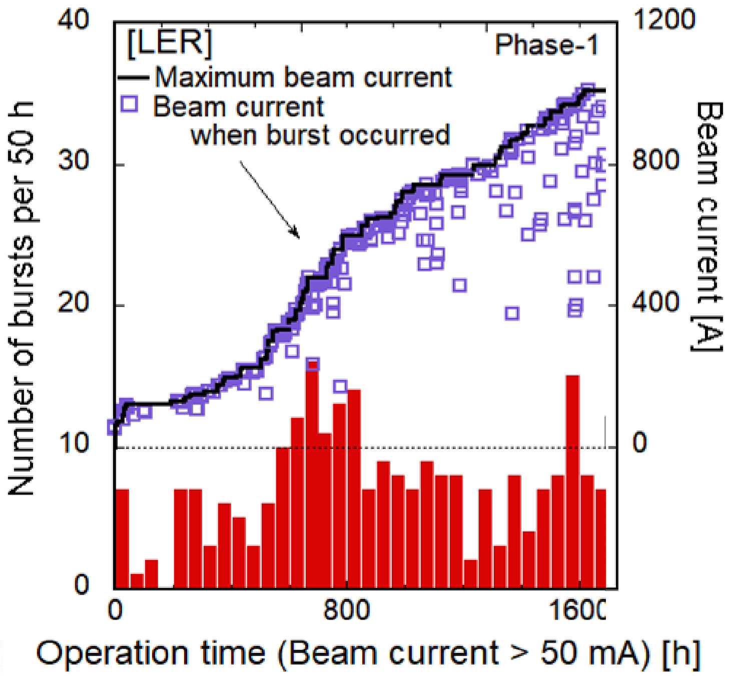
Vacuum scrubbing status

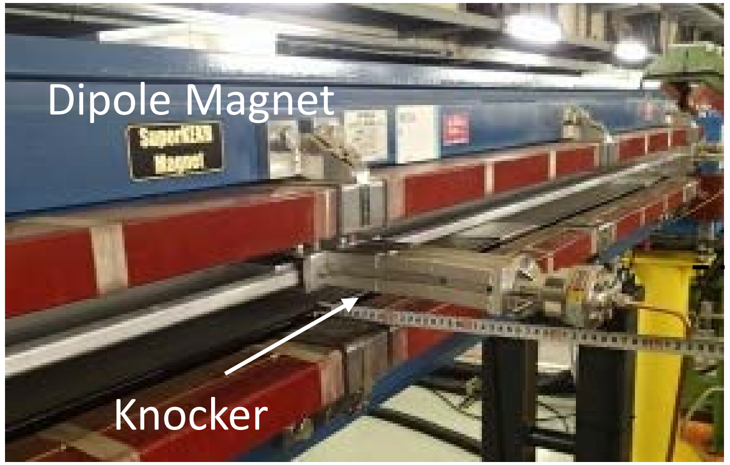


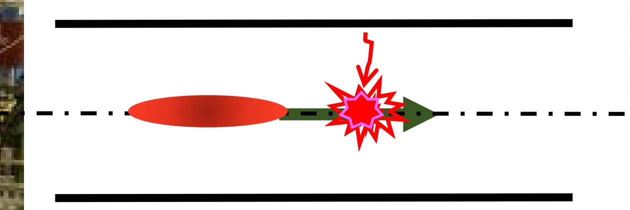
Phase-1 commissioning 3

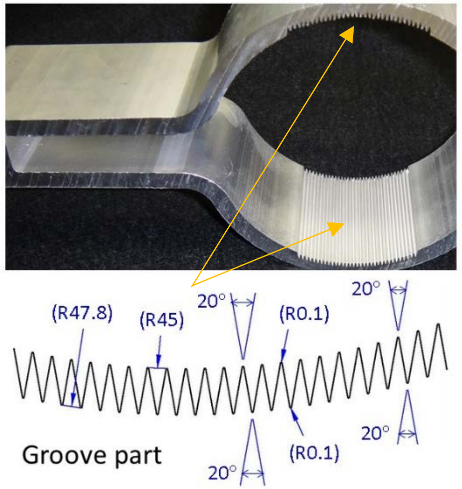
- Major problem 1 : Localized pressure burst accompanied with beam loss in the LER
  - Became obstacle to beam commissioning.
  - More frequent near or inside Al-alloy beam pipes with grooved surfaces in dipole mag. in the Tsukuba straight section.
  - Seems likely to occur when the maximum beam current is increased.
  - Was reproduced by a knocker which impacts the beam pipe to drop dust particles from their ceilings.

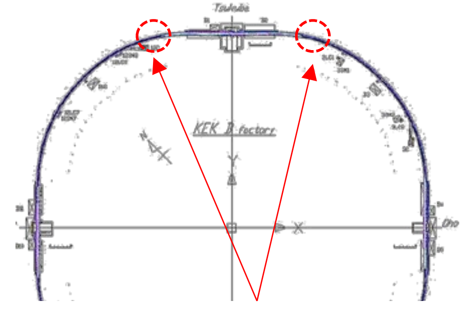
➡ Most probable cause is collisions between the circulating beams and dust particles falling from grooved structure on top surface.







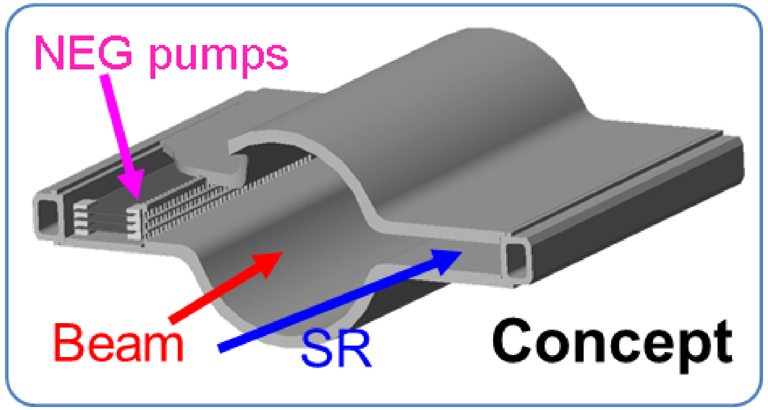




Locations where the pressure bursts occurred most frequently

Phase-1 commissioning 4

- Major problem 2 : Overheat of beam pipes and connection flanges in the wiggler sections in LER.
  - ➢ Temperature was sensitive to the vertical beam orbit upstream of the heated beam pipes, and the vertical position of the beam pipes.
  - ➢ SR emitted in the wiggler magnets upstream irradiated the beam pipes in the question.
    - Vertically steered SR or SR spreading in the vertical direction emitted from a distance can irradiate the upper and lower surfaces of the antechambers.
    - SR masks are located only at the side of the antechamber.
  - ➡ The connection flanges was overheated and air leak due to excess heating was observed in the worst case.



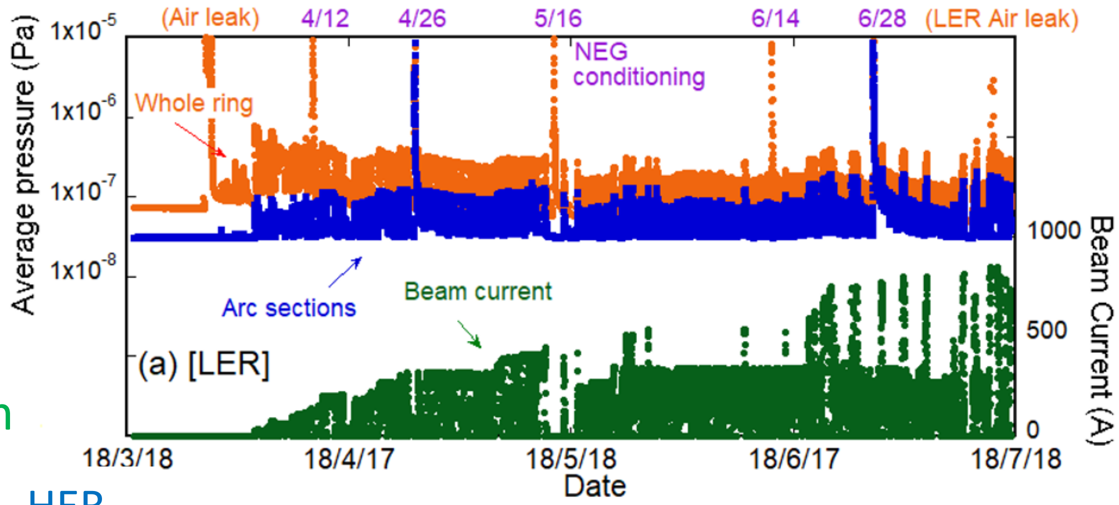
- Countermeasures:
  - Flat beam orbit, Re-alignment of the beam pipes,
    SR mask to protect the connection flange,
    Enhancement of cooling.

Phase-2 commissioning 1

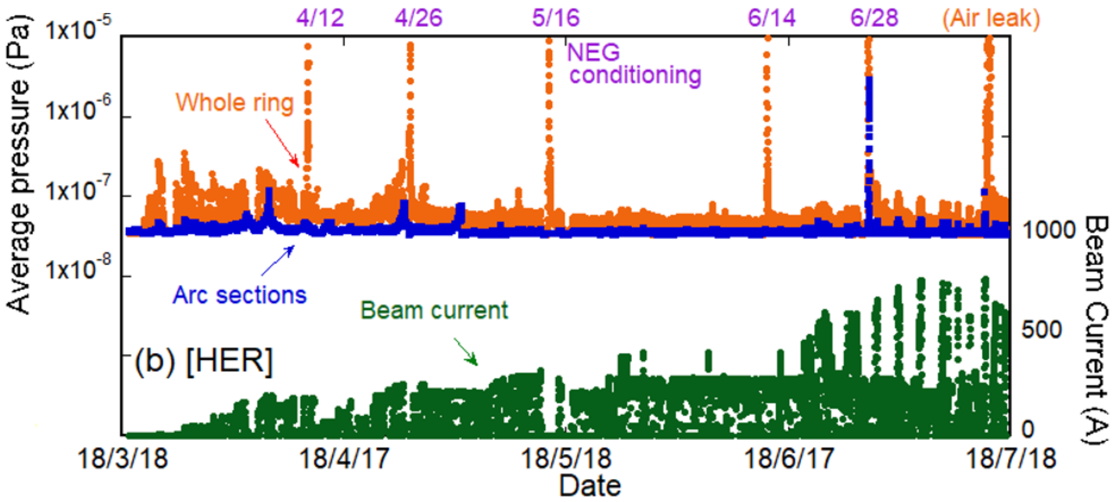
- Major works for Phase-2
  - Installation of new beam pipes and components for the Belle-II detector and the QCS magnets at IR
  - Installation of six additional beam collimators
  - Replacement of the beam pipes at the LER injection region for low-emittance beam injection
  - Countermeasures against the problems in the Phase-1
- Phase-2 commissioning (March- July 2018)
  - Dedicated to collision tuning for verification of "nano-beam scheme"
  - Maximum stored current (I_{max}) & beam dose
    - LER : I_{max} = 0.86 A, 340 A·h
    - HER : I_{max} = 0.80 A, 340 A·h

    (lower currents than Phase-1)
  - Base pressure (p_{base}) & average pressure at I_{max} (p_{max})
    - LER : p_{base} = ~5×10^{-8} Pa, p_{max} = ~3×10^{-7} Pa (whole), ~1×10^{-7} Pa (arc)
    - HER : p_{base} = ~3×10^{-8} Pa, p_{max} = ~7×10^{-8} Pa (whole), ~4×10^{-8} Pa (arc)
  - Lifetime was determined mainly by the Touschek effect.
  - Vacuum system experienced no serious problem.

LER



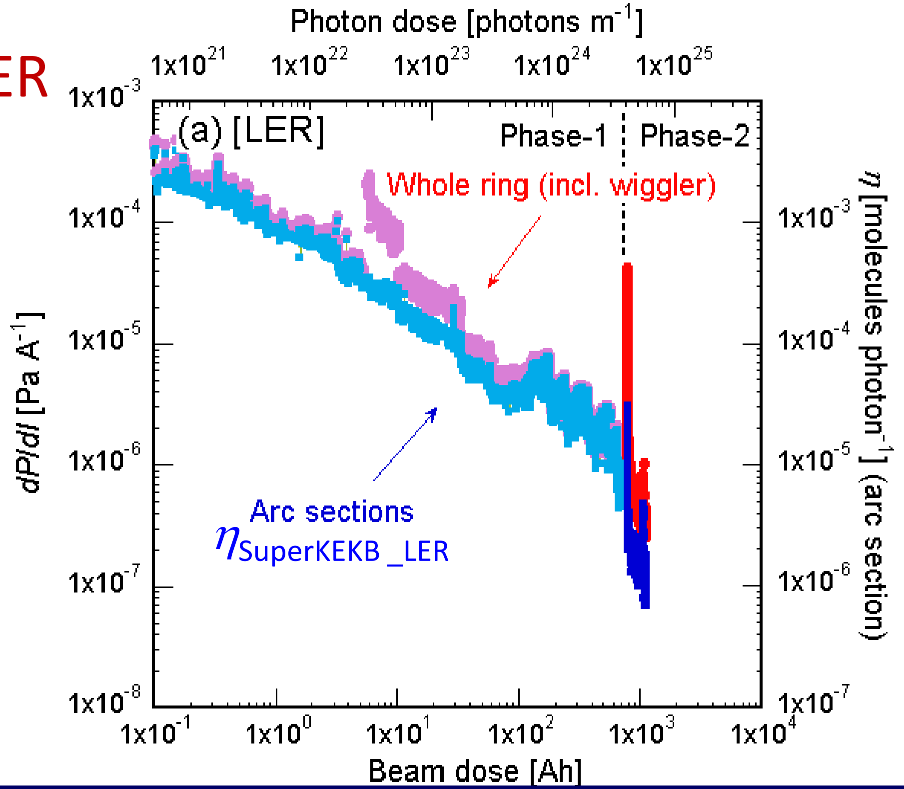
HER



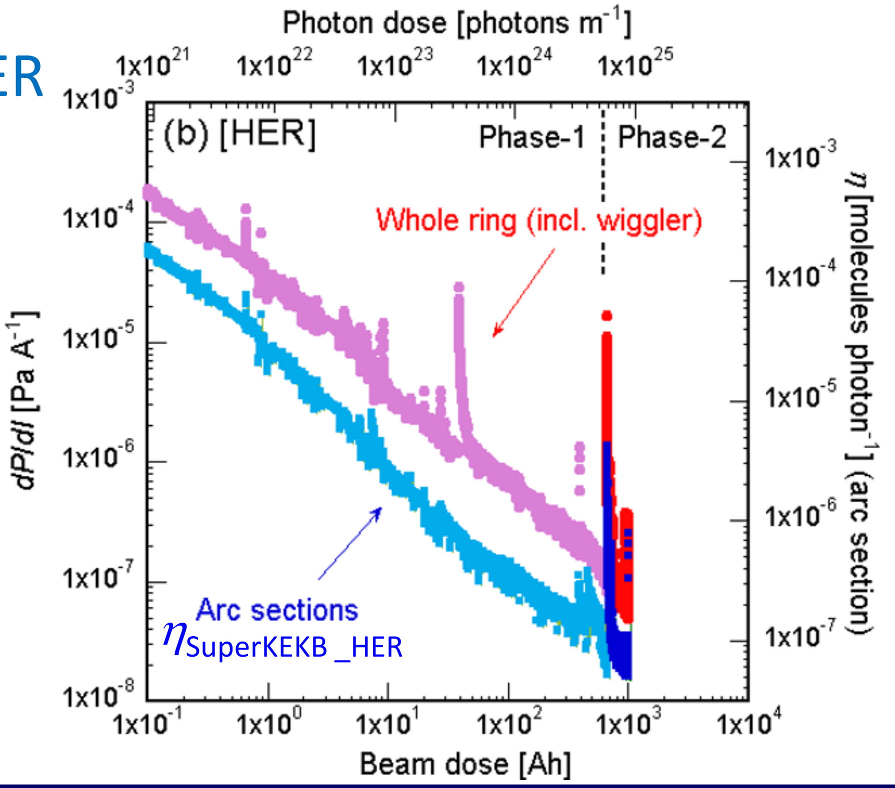
Phase-2 commissioning 2

- Vacuum scrubbing in arc sections during Phase-1 and Phase-2
  - ➢ Vacuum scrubbing progressed smoothly in both rings.
  - ➢ At the final stage of Phase-2
    - LER : ~1×10^{-6} molec.·photon^{-1} (Total photon dose = 5.9×10^{24} photons·m^{-1})
    - HER : ~7×10^{-8} molec.·photon^{-1} (Total photon dose = 9.3×10^{24} photons·m^{-1})

LER

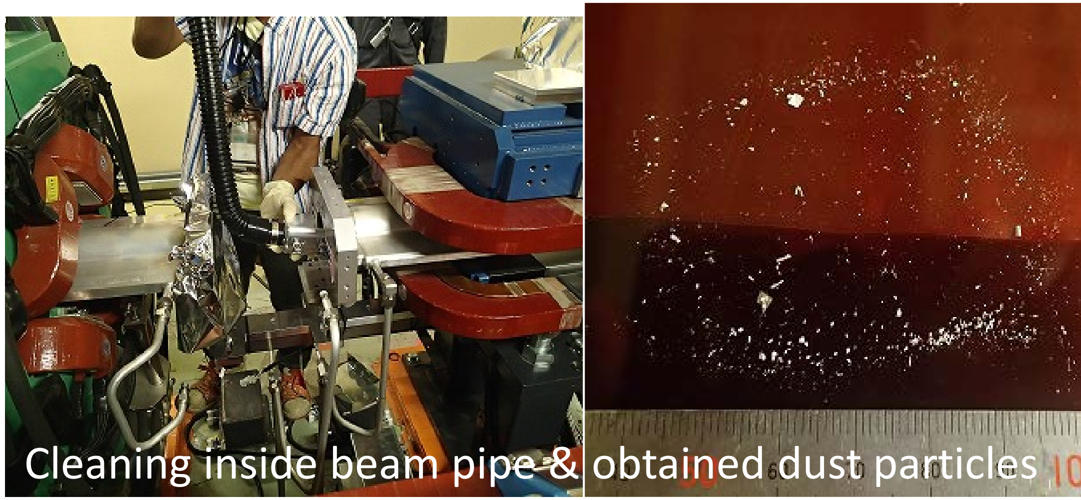


HER

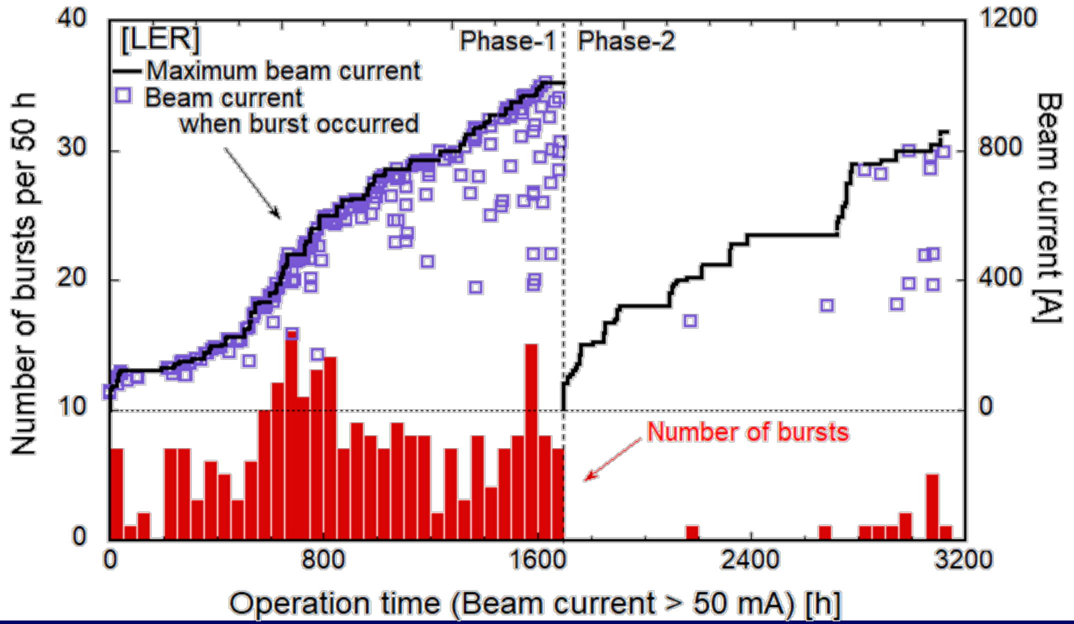


Phase-2 commissioning 3

- Effect of countermeasures against problems 1 : Localized pressure burst accompanied with beam loss in LER
  - ➢Countermeasures during the shutdown before Phase-2
    - Gathering of dust particles from the beam pipes where the bursts were frequently observed by special tool & vacuum cleaner (2 beam pipes.)
    - ➡ Many dust particles were obtained!!
    - Knocking the beam pipes by the knocker to drop dust particle in advance. (24 beam pipes)
    - ➡ Frequency of pressure burst was greatly reduced in Phase-2.
      - But, not only at the location where the beam pipes were knocked but also at other locations.
      - Operation time with high beam currents was much shorter than that during the Phase-1.
      - Knocking is effective? The study will be continued.

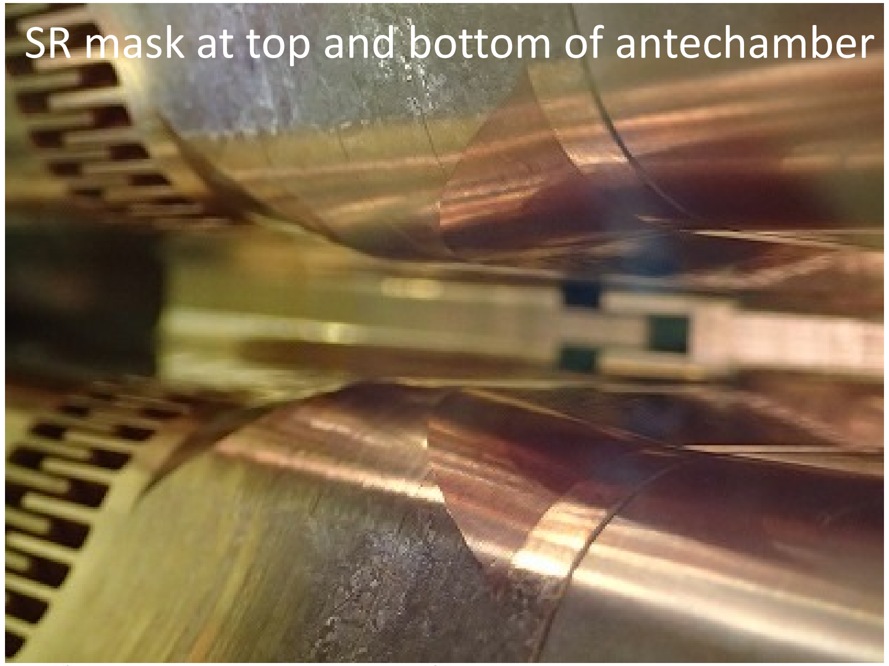


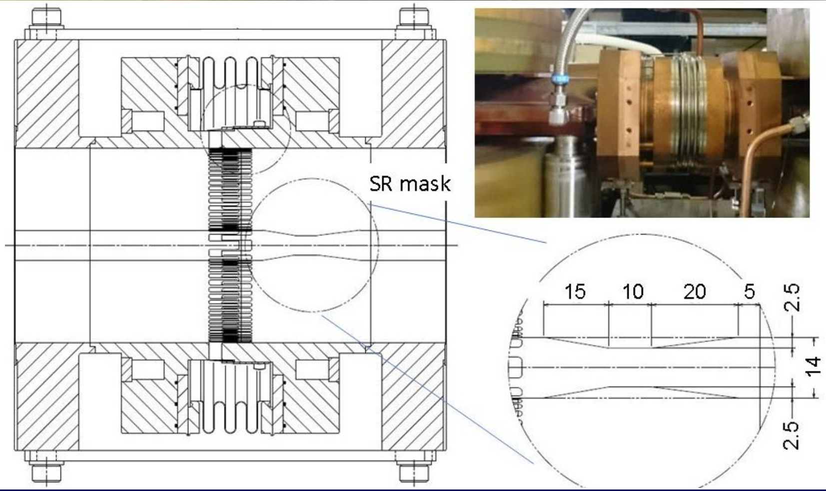
Cleaning inside beam pipe & obtained dust particles



Phase-2 commissioning 4

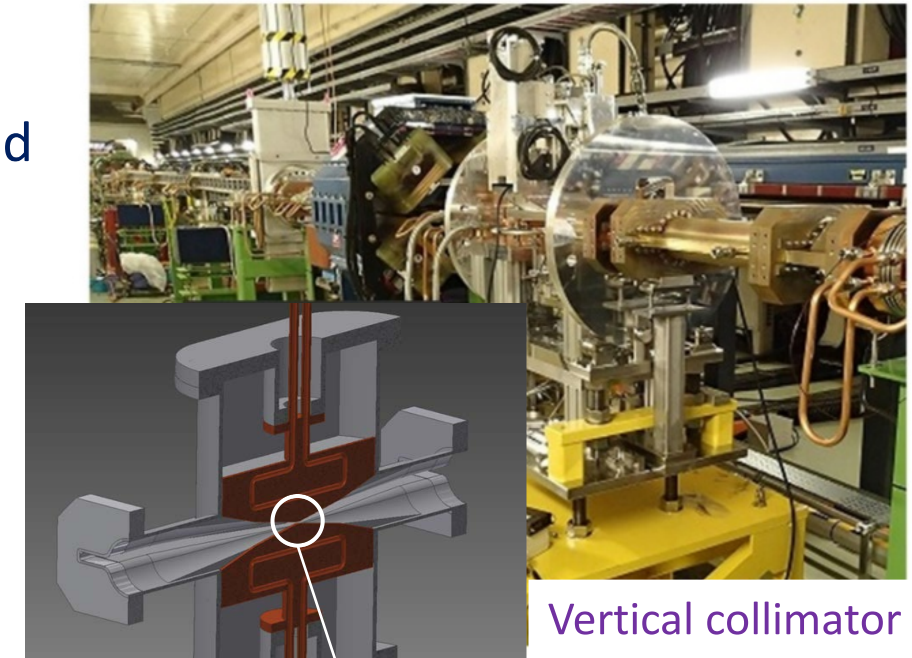
- Effect of countermeasures against problems 2 : overheating of the beam pipes in the wiggler section
  - ➢Countermeasures during the shutdown and Phase-2
    - Installation new bellows chamber having SR masks at the top and bottom of the antechamber.
    - Re-alignment of the beam pipes in vertical direction.
    - Increase of the flow rate of the cooling water
    - Flat beam orbit in wiggler section in Phase-2
    - Overheating of the beam pipes and connection flanges were still observed.
      - Temperature rise became smaller.
      - No air leak at the connection flange.
      - New bellows functioned well.
    - Overheating was not a serious problem in Phase-2, but it will be necessary to enhance the cooling of the beam pipes in Phase-3.



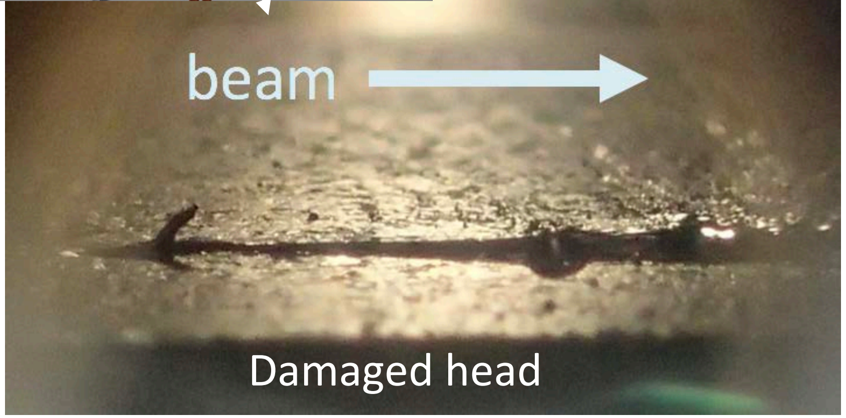


Phase-2 commissioning 5

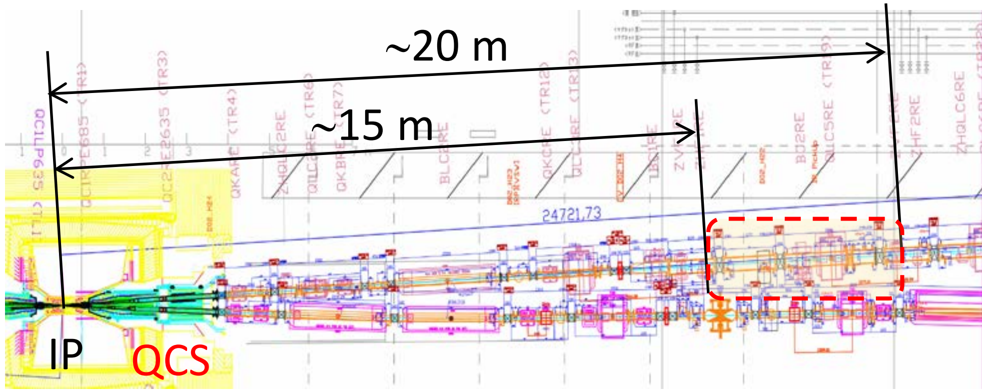
- New collimator
  - ➢Tuning of beam collimators watching the detector background and the beam injection rate was carried out.
  - ➢New collimators worked very well.
    - To suppress the background noise of the Belle-II detector
    - To prevent the QCS magnets from quenching cased by the penetration of the particles which deviated from their ideal trajectory.
  - ➢Problems in Phase-2
    - The beam of the LER suddenly became unstable, and intense beam hit and damaged the collimator head (vertical type).
    - When the damaged head was brought close to the beam, the background noise did not decrease but increased.
      - As a first aid, the collimator chamber was slightly moved to make undamaged surface available.
      - Damaged heads will be replaced with new ones before Phase-3.

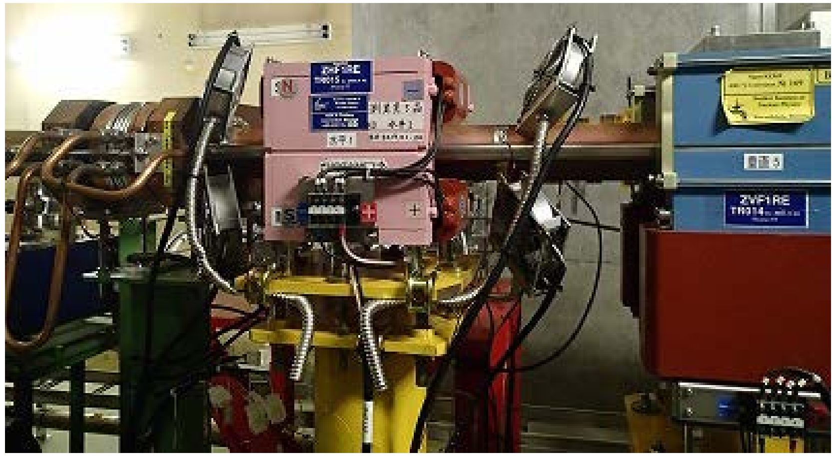


Vertical collimator



- Others problem
  - ➢ Two stainless steel beam pipes in the HER exhibited overheating and air leaks.
    - At 15-20 m downstream of the collision point.
    - They were installed before the Phase-1 commissioning.
  - ➢ Cause of the overheating was the irradiation of the SR emitted from the QCS magnet.
    - The SR emitted from the QCS was not considered when designing the beam pipes.
    - Air leaks were occurred between the SUS MO-type flange and Cu MO-type flange.
    - The cause of the air leak is considered to be the heat cycle.
  - ➢ Countermeasures
    - The beam pipes and bellows chamber with SR masks will be installed at the upstream
    - SUS beam pipes with Cu MO-flanges will also be adopted.





Summary

- Through the Phase-1 and Phase-2 commissioning,
  - Vacuum system bas been working generally well.
  - Pressures of the both rings decreased according to our expectation.
  - New components, such as the beam pipes with antechamber, the step-less MO flange, and the comb-type rf-shield functioned very well.
  - New low-impedance collimators worked very well not only to suppress the background noise of the Belle-II detector, but also prevent the QCS magnets from quenching.
- For Phase-3 commissioning
  - Beam pipes for the interaction point is once removed for the upgradation work of the Belle-II detector, and reinstalled again with completed Belle-II detector.
  - Five more new collimators are installed mainly in the LER.
- During the Phase-3 commissioning
  - It is necessary to continue to monitor carefully whether there will occur new problem associated with an increase in the beam current in the vacuum system.

Fin.

Thank you for your attention.

Back-up