Vacuum

Progress and Troubles of Upgrade Works

The 20th KEKB Accelerator Review Committee

February 23, 2015

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(on behalf of KEKB Vacuum Group)

Contents

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- Pre-installation works
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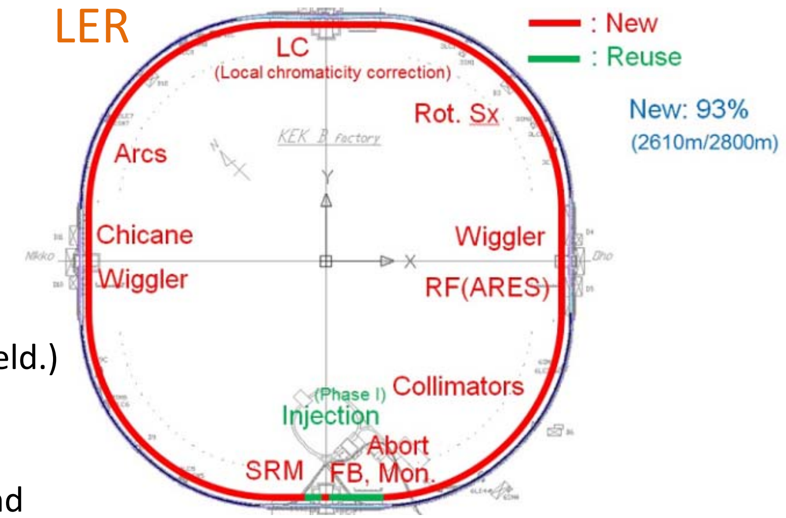
- Original slides of Installation and trouble reports in Pre-installation works were provided by Suetsugu-san.
- Original slides of Collimator and Control were provided by Ishibashi-san.
- Vacuum system around IP was presented by Kanazawa-san (IR Overview).

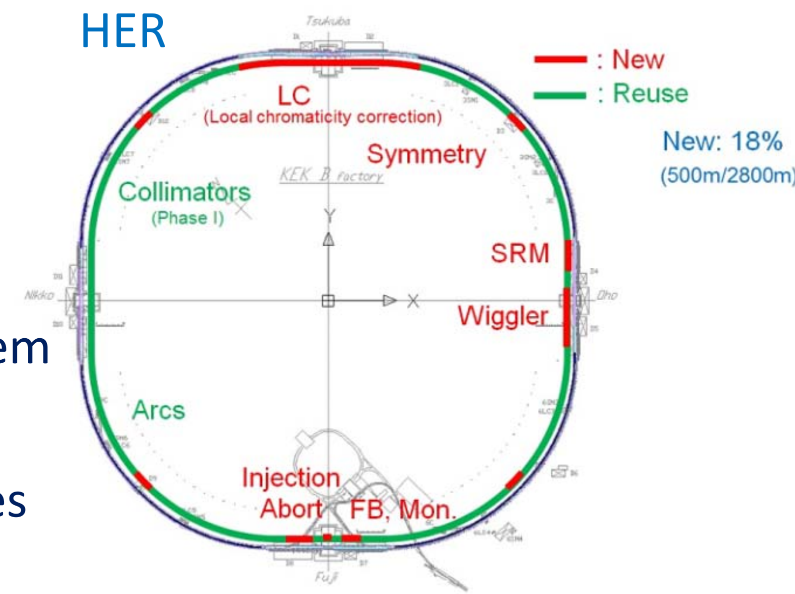
Introduction

- Outline of upgrade of MR (except IR and Damping Ring)
  - LER : Most of beam pipes and components are replaced with new ones.
    - Replacement rate : 93 % (2610 m / 2800 m)
    - New 2 horizontal collimators (for Phase-I operation)
    - Countermeasures against electron cloud (clearing electrode, groove surface, TiN coating and solenoid field.)
  - HER : Most of beam pipes and components are reused.
    - Only local chromaticity correction, wiggler sections and etc. are replaced with new ones.
    - Replacement rate : 18 % (500 m/2800 m)
  - Design of control and monitoring system follows that of the KEKB.
    - Most of control devices are reused.

- Pre-installation and installation works, fabrication of collimators, test of control system were done in this past year.

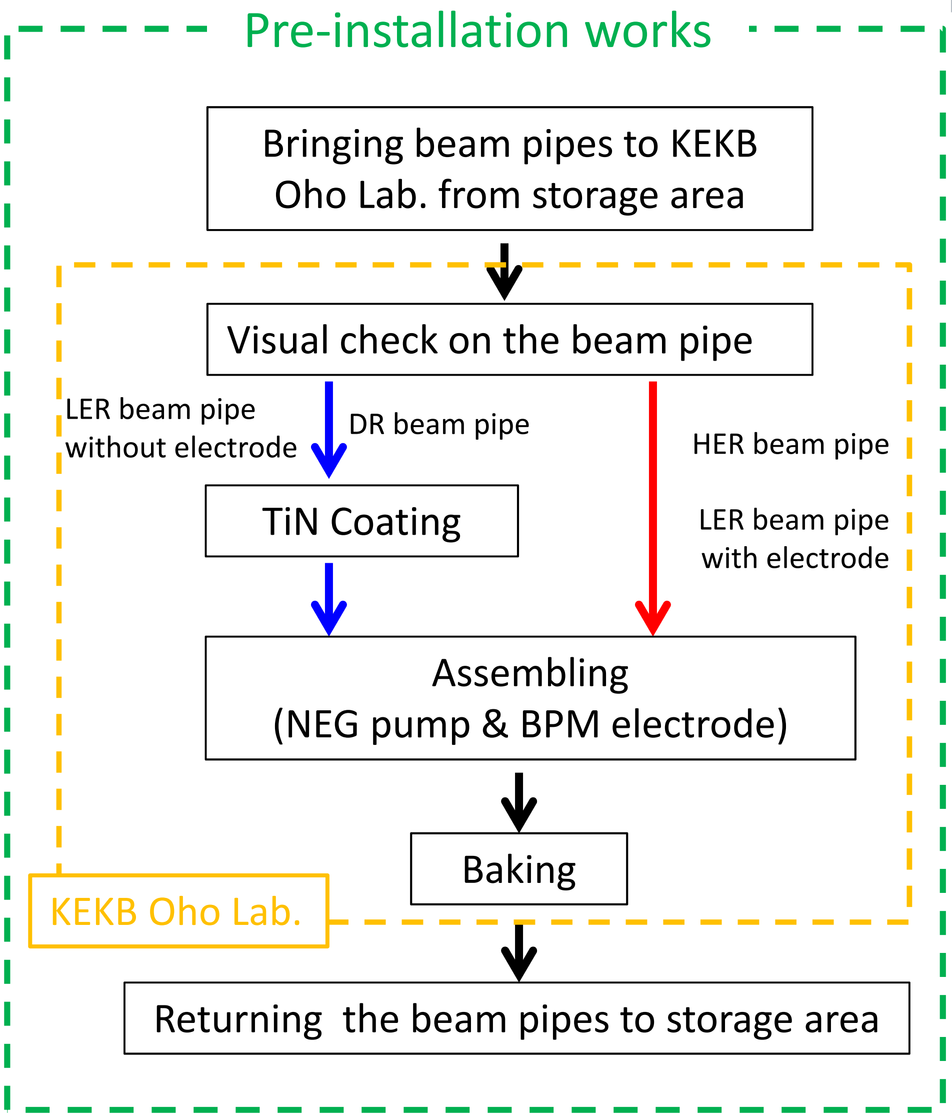
- DR : Fabrication and TiN coating of beam pipes are now in progress.





Pre-installation works 1

- Progress in this past year
  - Coating :
    - Main Ring : 179 beam pipes
    - Damping Ring : 38 beam pipes
  - Baking :
    - Main Ring : 354 beam pipes
    - Damping ring : 0 (as originally planned)
- Pre-installation works for all beam pipes required for Phase-I except IP pipe have been finished successfully.
  - IP pipe was damaged with crack on welding line in the process of installation into vertical coating equipment.
- SEY during the production and after long air venting was not measured. (pointed out in last KEKB Review)
  - Still unclear if the low SEY is conserved for a long time.
  - No air leak during the coating process.
  - Planning long-term SEY measurement .

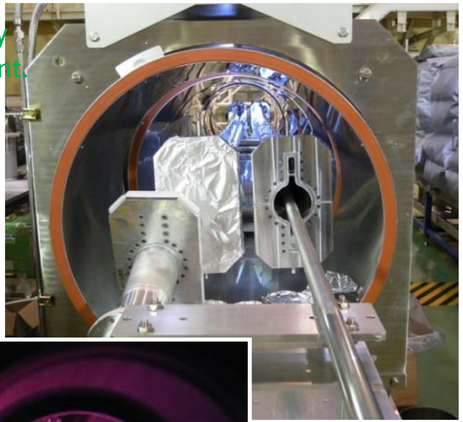


Pre-installation works 2

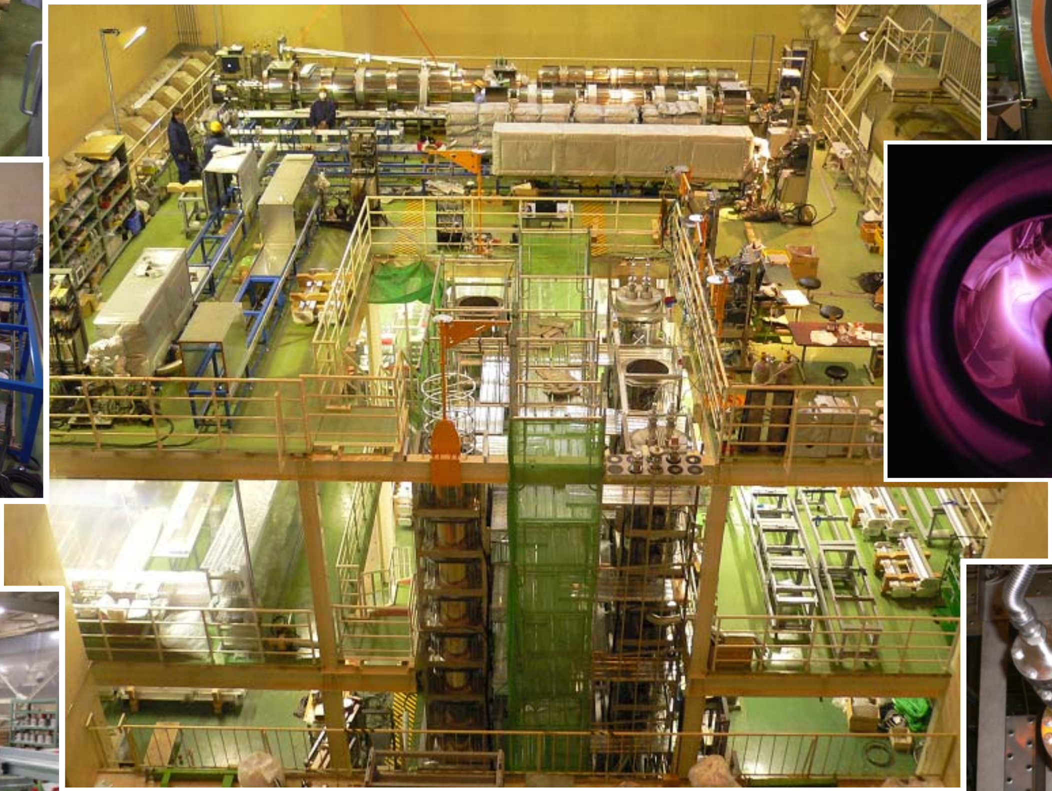
Hot-air heating method was adopted. (~150°, 26 h)

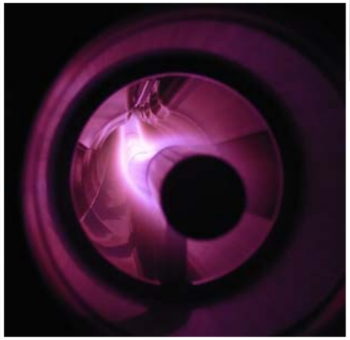
Baking equipment

Bent pipes were coated by horizontal coating equipment.



KEKB Oho Lab.

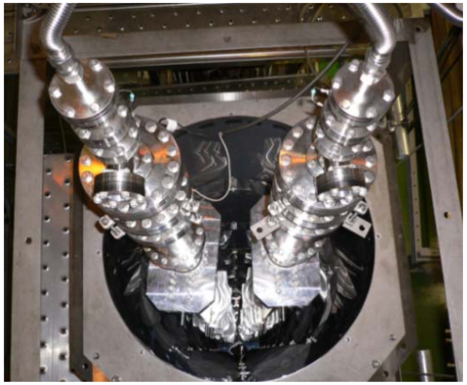




Coating was done by DC magnetron sputtering of Ti in Ar and N_2.

Visual check and assembling were done in Oho clean room.

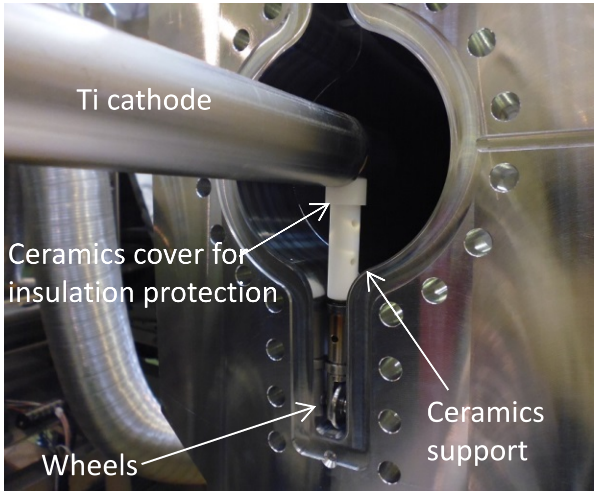
Straight pipes were coated by virtical coating equipment.



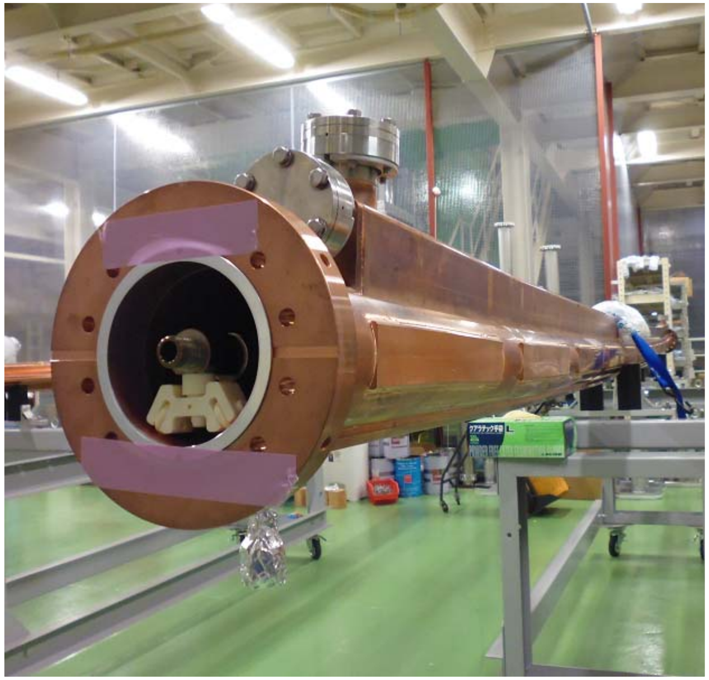
Pre-installation works 3

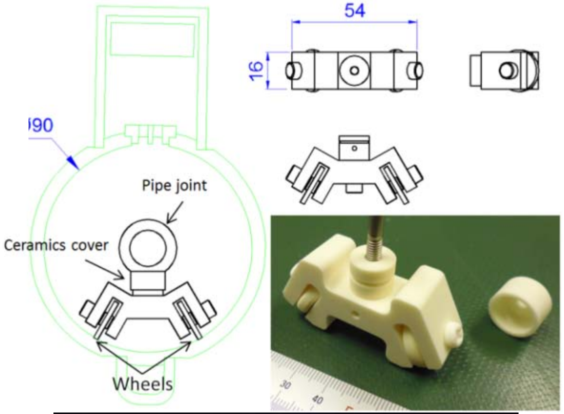
- Coating of bent pipes without antechambers by horizontal facility
  - To coat bent pipe by horizontal facility, Ti cathode position is fixed by ceramics supports.
  - Conventional ceramics support is available only for beam pipes with antechambers.
  - About 10 bent pipes without antechambers were coated with new ceramics support.

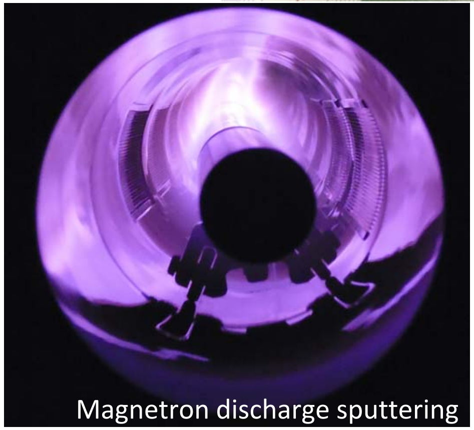
Ceramics support set in antechamber (Conventional type)



Ceramics support on sidewall of beam pipe (new type)





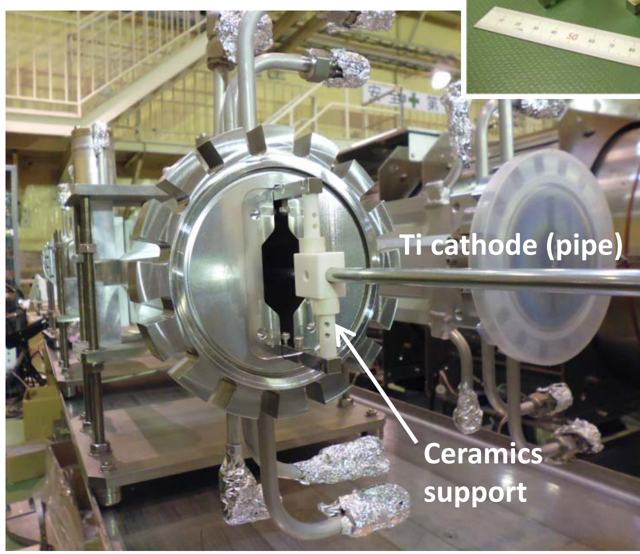

Magnetron discharge sputtering

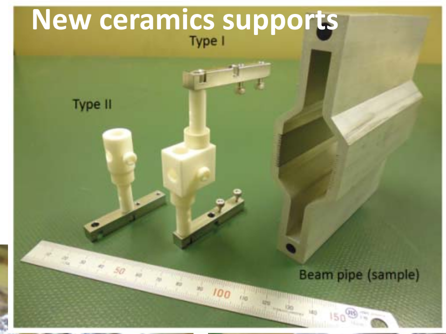
Pre-installation works 4

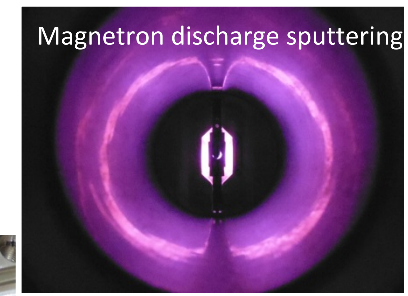
- Coating of Damping Ring beam pipes by horizontal facility
  - Flat cathode shown in last review did not work.
    - Discharge didn't occur in the center of beam pipe.
  - New cathode pipe worked well, and 38 beam pipes were coated so far.
  - More 36 beam pipes will be coated by the end of this fiscal year (3/31).

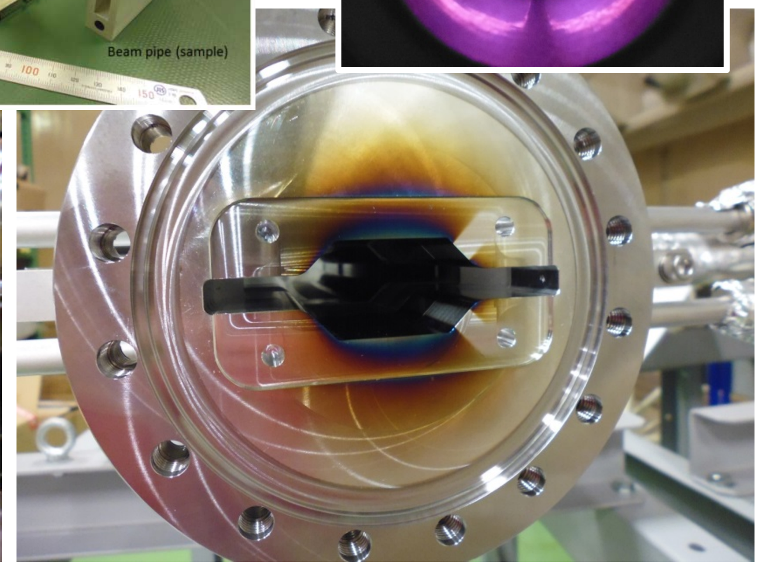
Flat cathode

New cathode pipe
and ceramics support



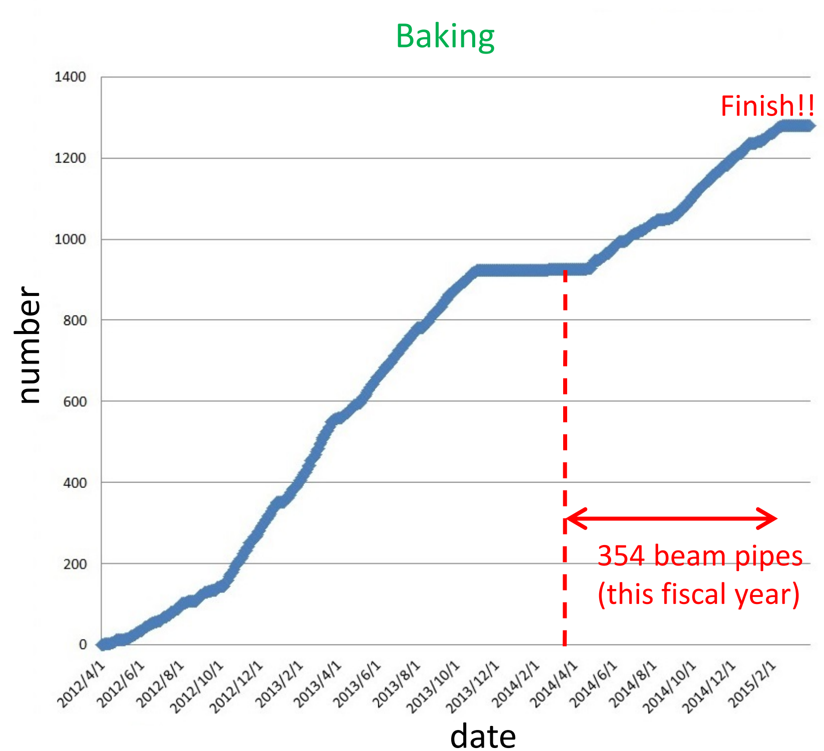


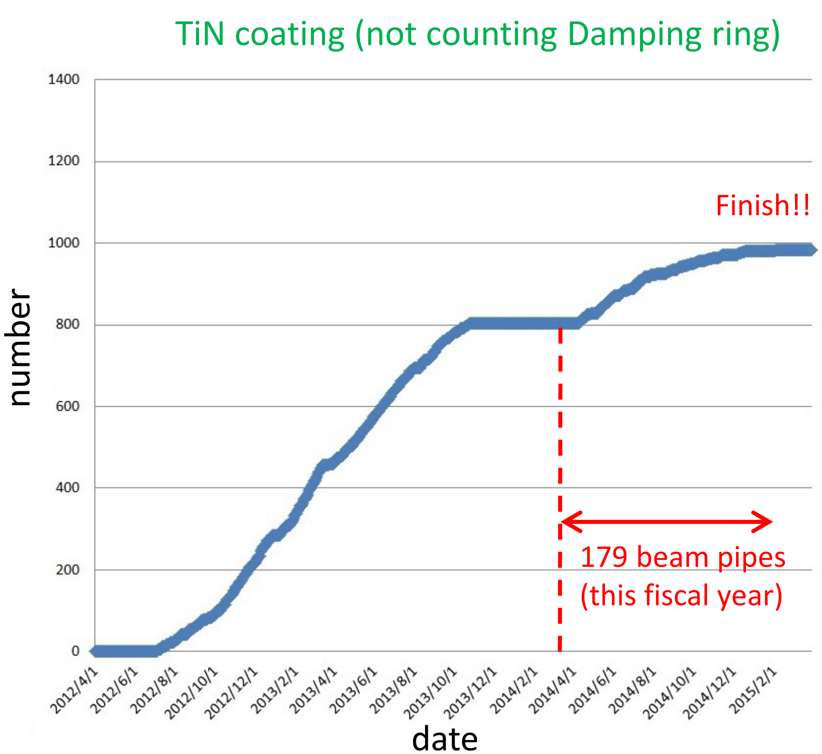




Pre-installation works 5

- Total output of pre-installation works
  - Large-scale works by 10 workers was continued until the end of 2014. (by 3-4 workers this year.)
  - All planned works for MR finished this month.
  - Work pace decreased compared to the past fiscal years because of a variety and delay in delivery of beam pipes.

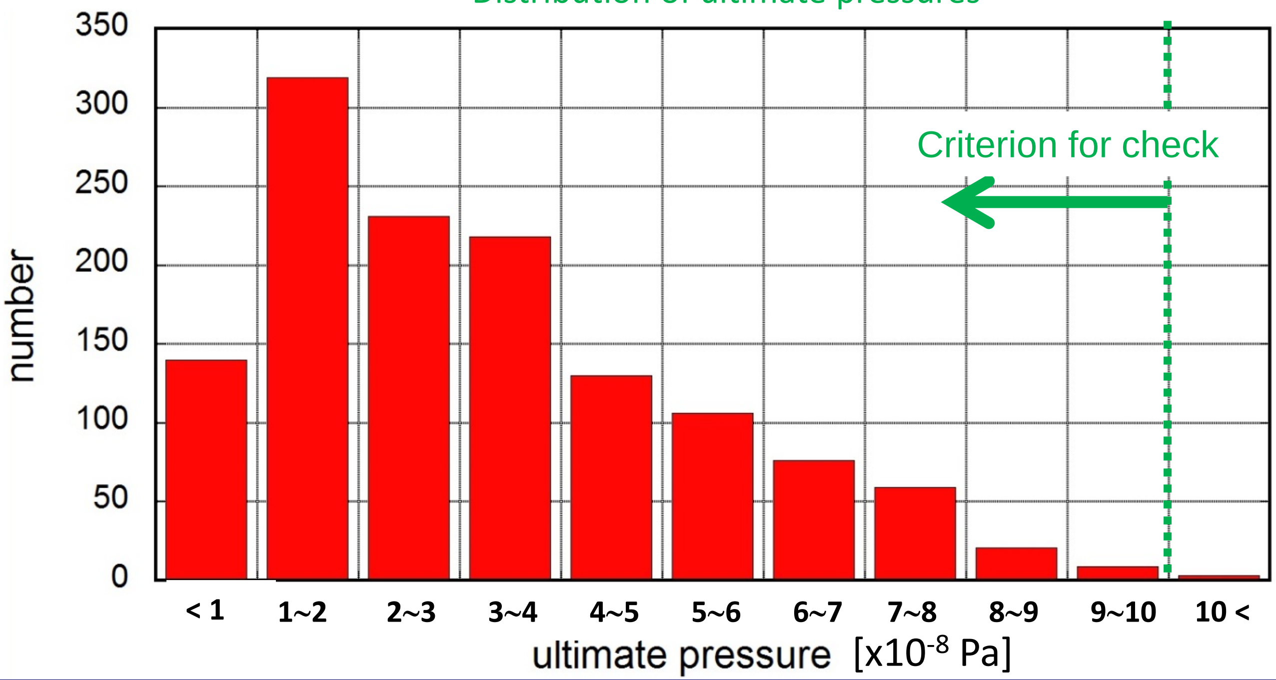




Pre-installation works 6

- Ultimate pressure after baking
  - "Less than 1×10^{-7} Pa" is set as our criterion for check. (If not, beam pipe is re-baked.)
  - Almost all beam pipes meet our criterion for check.
    - Ultimate pressures higher than 5×10^{-8} Pa have been measured for many beam pipes. (pointed out in last KEKB Review.)
    - No measurement of residual gas
    - A variety of beam pipes: long (~6 m) and short (~150 mm), w/wo NEG, Cu and Al

Distribution of ultimate pressures



Including data derived from all beam pipes.

Pre-installation works 7

- Trouble 1 : High ultimate pressure (> 1×10^{-7} Pa)

  In some beam pipes, the ultimate pressure after baking were higher than 1×10^{-7} Pa, which is our criterion of check.

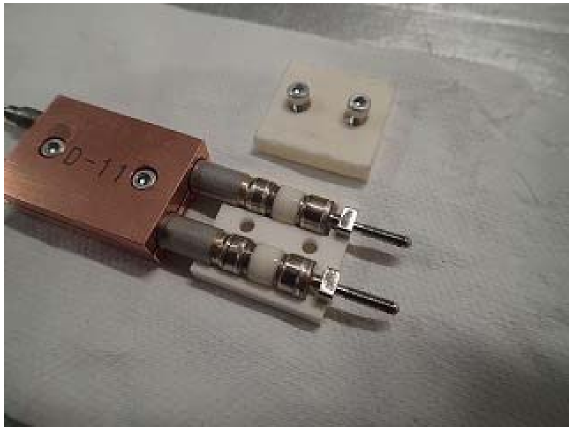
  - Case 1 : Air leak from connection flange 1 (simple case)
    - Cause : Decrease in fastening power due to baking
    - Cure : Refastening flanges. Replacement of gasket and re-baking.
  - Case 2 : Air leak from connection flange 2
    - Cause : Wrong choice of gasket (Cu gasket on Al flange(CF203))
      - A few special Al beam pipes have Al CF203 flanges, though most of them have SUS CF203 flanges.
      - At worst knife-edges were damaged, and we gave up re-baking them to avoid further damage to flanges. (two beam pipes)
  - Case 3 : Leak at ceramic brazing of sheath heaters for NEG activation.
    - Next slide
  - Case 4 : Large gas desorption from beam pipe or NEG?
    - Cure : Re-baking. (If it fails again, replacement of NEG strips and heaters.)

- In most cases the ultimate pressure reduced on the order of 10^{-8} Pa.

Pre-installation works 8

- Trouble 2 : Leak at ceramic brazing of sheath heaters for NEG activation.
  - Cracks at the brazing between ceramics and stainless steel sleeve was found.
  - Gas desorption from the cracks leaded to high ultimate pressure even after NEG activation.
  - Low insulation resistance was also observed.
- Cause :
  - Fastening of ceramic block for insulation was too strong, and the excess stress (moment) was applied to the brazing part, if the ceramic was brazed with a slight angle.
- Cures :
  - Insert a thin spacer between ceramic blocks to avoid the excess stress on the brazing part.
  - Cracked heaters were re-fabricated.

NEG with heater installed into beam pipe

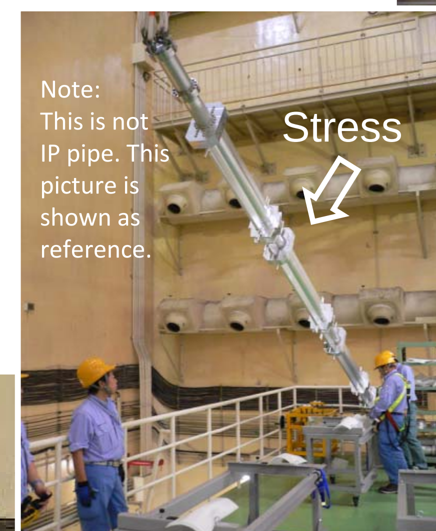


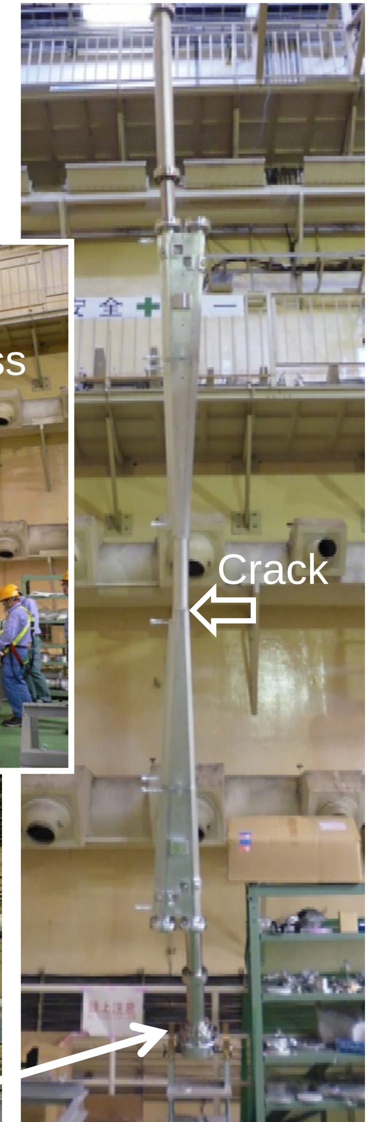
Feedthrough of heater with insulation ceramic block

Leaked feedthrough of heater

Pre-installation works 9

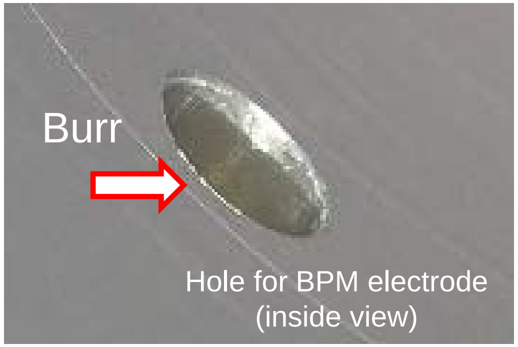
- Trouble 3 : Crack at the welding line of X-shaped IP pipe.
  - In order to install the beam pipe into the vertical coating equipment, one end of the beam pipe was lifted up by crane while other was fixed to hinge assembly.
  - Crack occurred during crane operation.
- Cause :
  - Concentration of stress (moment) at the center of beam pipe where the cross-section is smallest.
  - Cracked part has relatively weak structure.
- Cures :
  - Re-welding in the manufacturer.
  - Improvement of structural strength
  - It will be repaired next fiscal year.

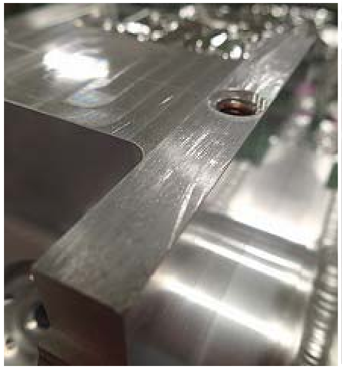




Pre-installation works 10

- Other Troubles:
  - Air leaks of welding line of beam pipe occurred during the baking and coating. (2 beam pipes)
    - Cause : Bad welding ?
    - Cure : Re-welding at the manufacturers.
  - Lots of Burrs in the holes for BPM feedthrough. (risk of discharge)
    - Cause : Insufficient quality control in the manufacturer
    - Cure : Check all holes by KEK staff of beam monitor group
      Deburring in KEK site by the manufacturer or KEK staff (in most case)
  - Bad insertion of helicoil for the tapped hole to fix the BPM electrode.
    - Cause : Bad quality control at the manufacturer
    - Cure : Re-installation of helicoil. (if failed, M4 tap was changed to M5 tap)
  - Defects or scratches on the standard surface of BPM block
    - Cause : Bad quality control at the manufacturer
    - Cure : Check all holes by KEK staff of beam monitor group
      Polishing the defects to remove “projection”
      Deburring
  - Shortage of BPM electrode and Helicoflex gasket
    - Cause : Miscalculation? Excess consuming?
    - Cure : Reorder. (Already delivered in last December and January)
      Rescheduling pre-installation works
  - And so on.

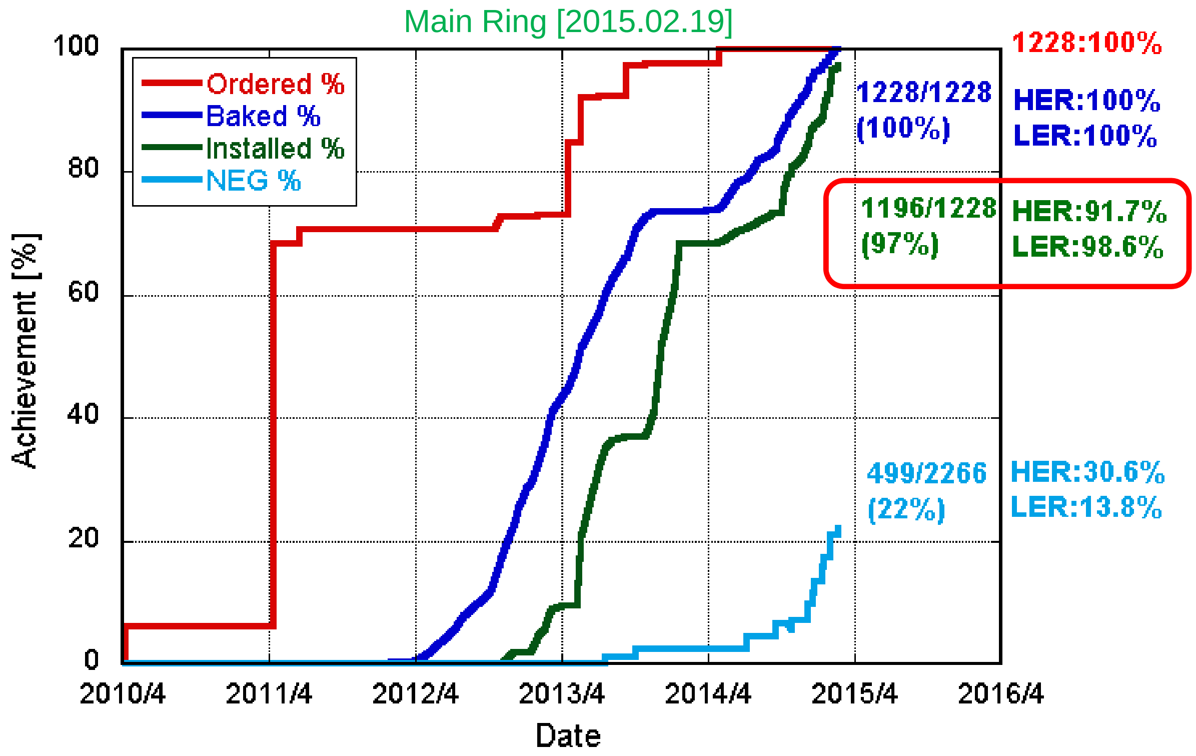




Scratches and defects

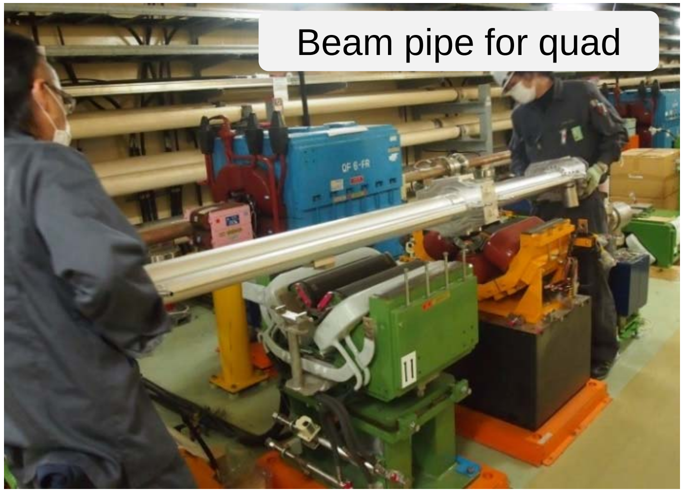
Installation 1

- Installation of components into the tunnel
  - 97% of beam pipes required for Phase-1 has been installed already.
  - Most of remained are those for HER around Tsukuba straight section and the beam injection section at Fuji straight section.



Installation 2

- Installation into arc and wiggler sections were finished.



Installation 3

- Installation of special beam pipes is almost finished.

LER beam abort section

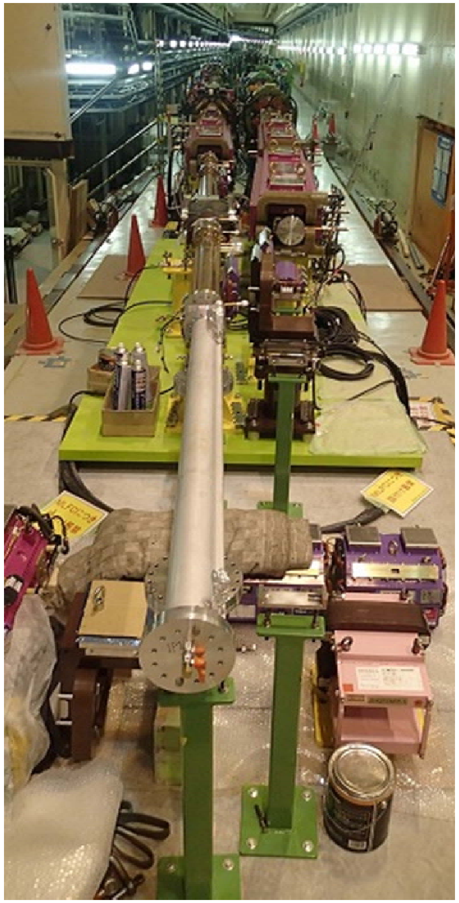
Installation 4

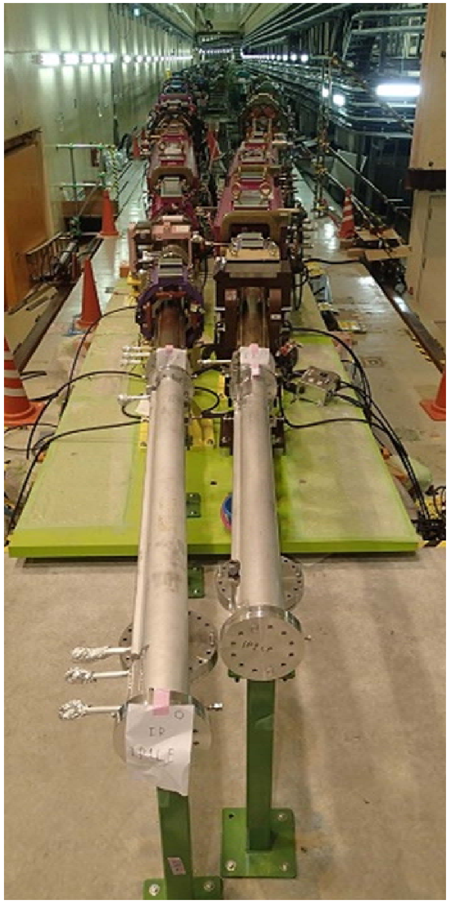
- Installation of beam pipes for Tsukuba section is on going.

Straight section

Installation 5

- Installation of beam pipes for Tsukuba section is on going.

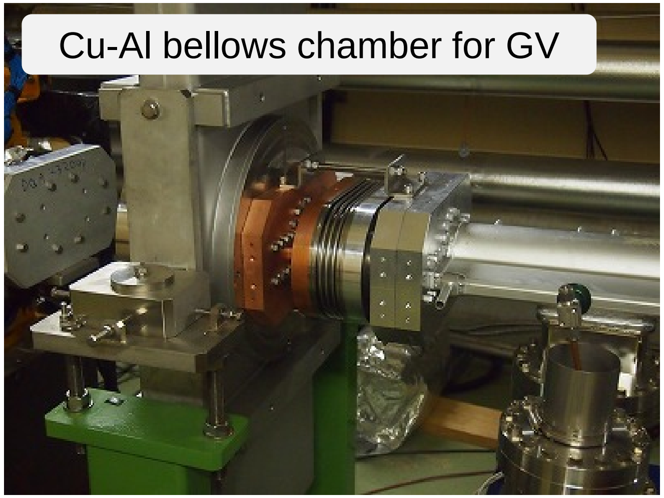




IR section

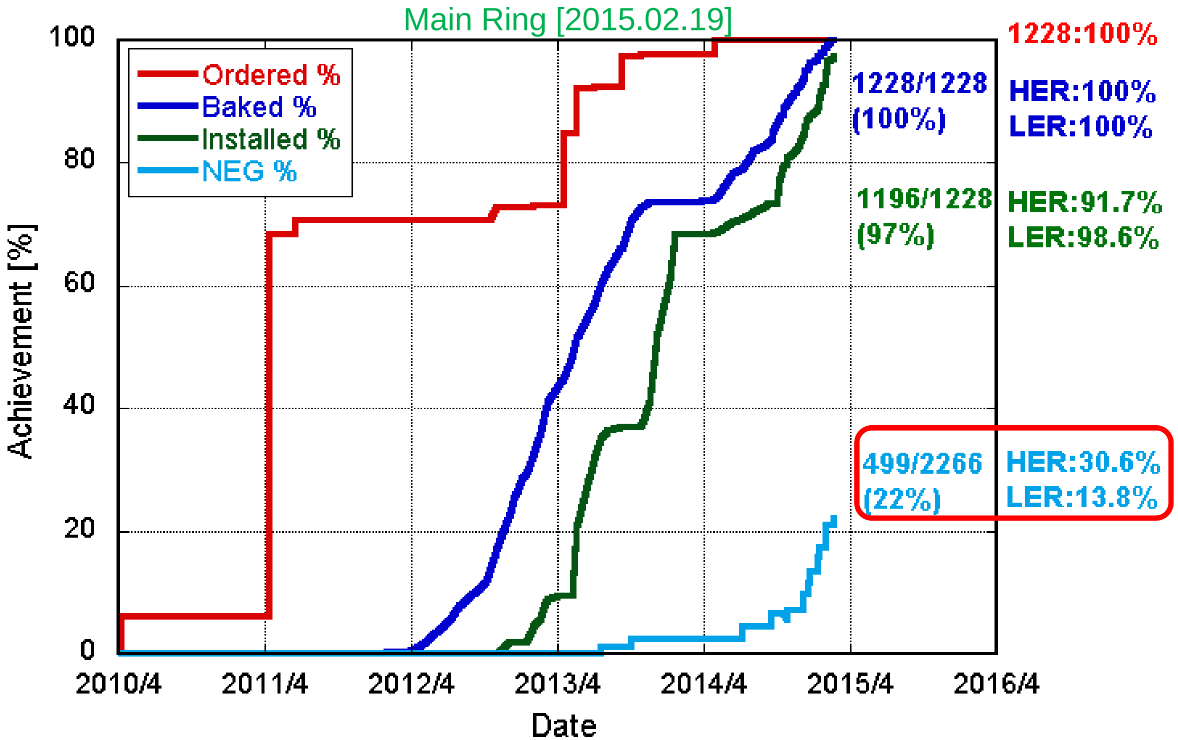
Installation 6

- Installation of bellows chambers follows that of beam pipes.



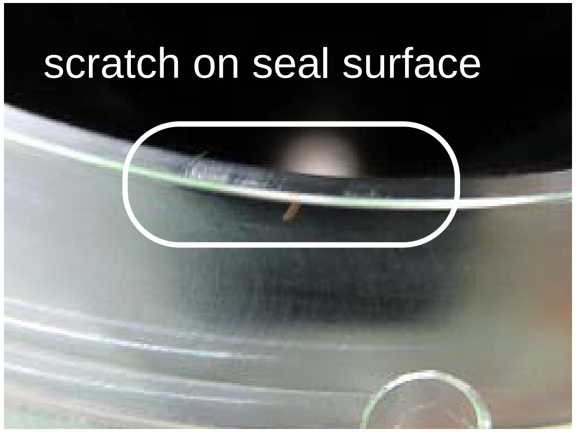
Installation 7

- Evacuation and NEG activation
  - NEG activation has started from wiggler section and arc section in each region between gate valves.
    - In approximately 21% of both of the rings, NEG activations have been finished.
    - The average pressures less than 1×10^{-7} Pa were obtained after the NEG activation without beam pipe baking *in-situ*. (Ion pumps are baked.)



Installation 8

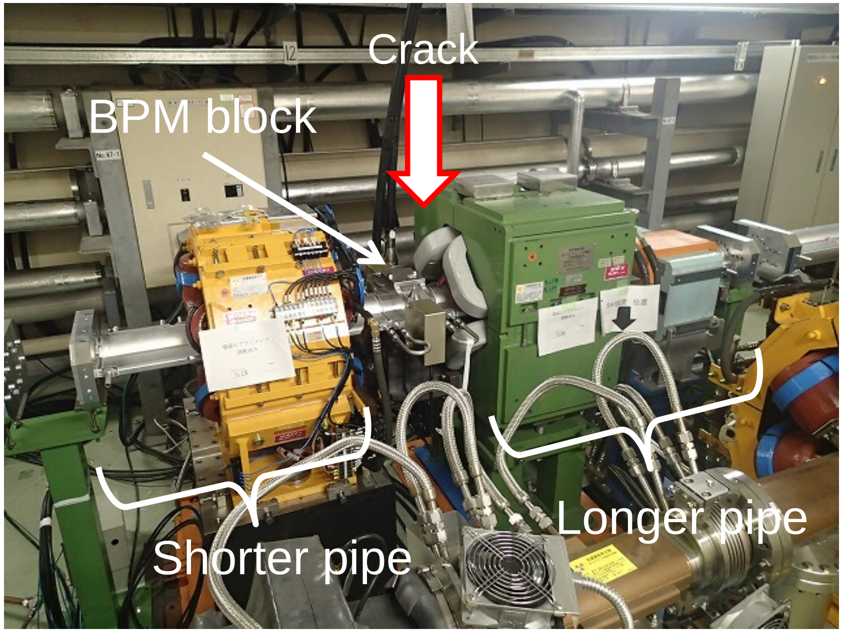
- Trouble 1 : High rate of air leak at connection flanges (reported in last KEKB Review)
  - In the initial stage of bellows connection in the tunnel, the rate of air leak at the connection was higher (~10%) than that experienced in the pre-installation work (<5%)

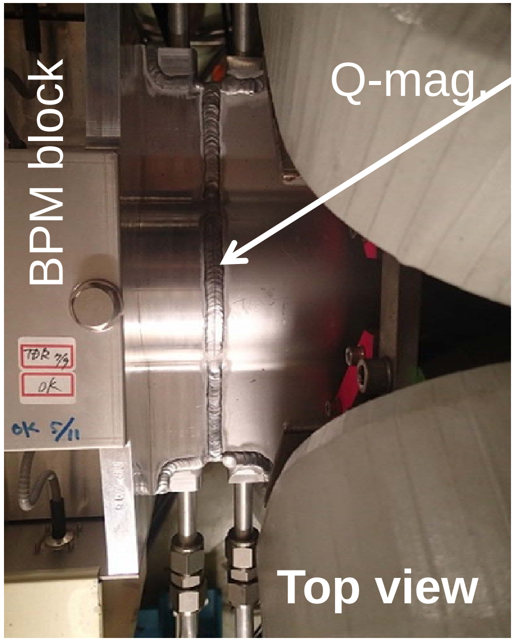


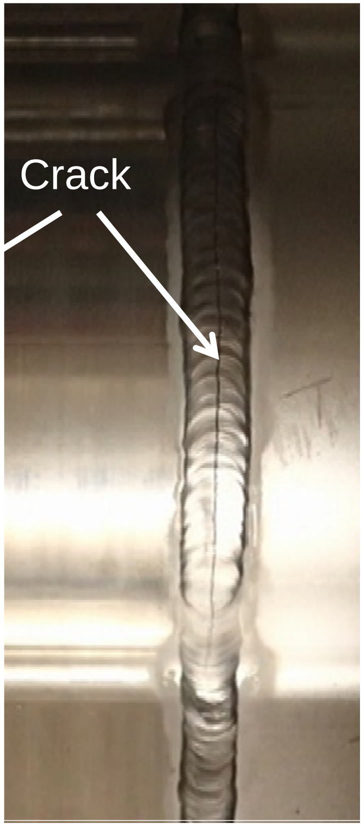
- Possible causes:
  - Scratches or traces of machining (small steps and rolling) on the seal surface of bellows chambers
  - Difficulty in alignment of flanges (bellows chamber and beam pipe)
    - Bellows chamber is heavy.
    - Some beam pipes are already fixed to magnets
  - Oxide layer of aluminum gaskets?
- Cures:
  - Polish of the sealing surfaces with abrasive cleaning pads (Scotch-Brite)
  - Polishing of gaskets (also effective sometimes)
  - The rate of leak decreased to less than 5% finally.
  - Tool to make the alignment easy (in preparation)

Installation 8

- Trouble 2 : Cracks on the welding line (Case 1)
  - Welding line of BPM block of aluminum beam pipe cracked just after starting the evacuation in the tunnel. (3 beam pipes)
  - BPM block was rigidly fixed to Q-mag. via support.
  - Crack occurred on upper welding lines at Q-mag. side, where the longer beam pipe is welded.
  - No problem was reported in the pre-installation work.

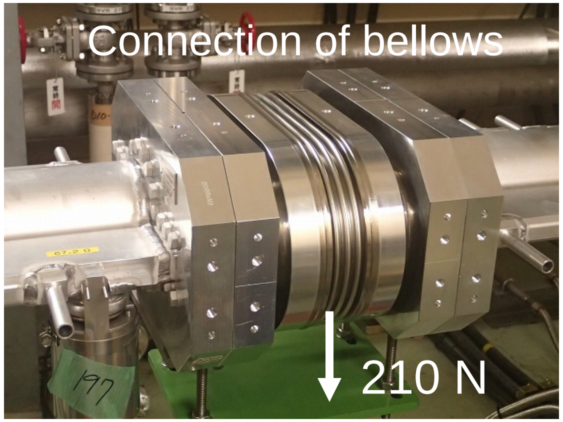




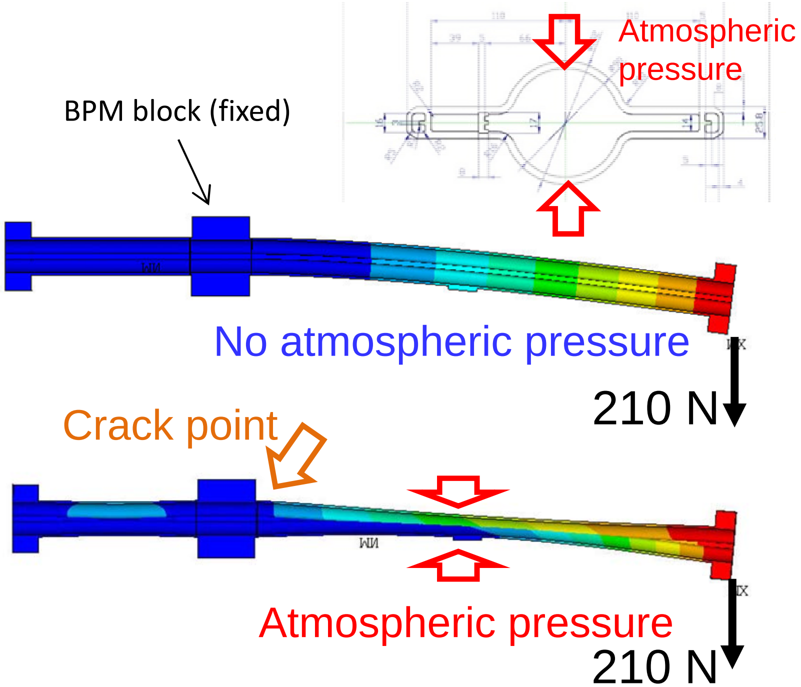


Installation 9

- Possible cause 1 : High moment due to the weight of bellows chamber at end.
  - It is suspected that the bellows chambers at ends was not rigidly fixed to the support.
  - There is also a possibility that the flange was aligned with some vertical excess-force to connect the bellows.

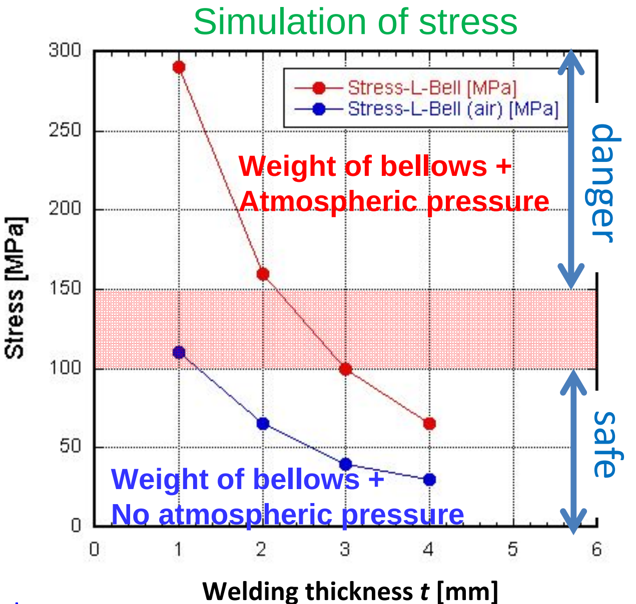


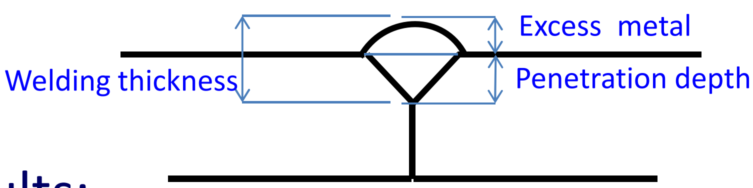
- Simulation results:
  - The stress at top and bottom side further increase by the atmospheric pressure due to the antechamber cross section.
  - The stress at upper welding line is doubled with atmospheric pressure.
  - If the welding thickness is insufficient, such as less than 2 mm, the welding is likely to be cracked.



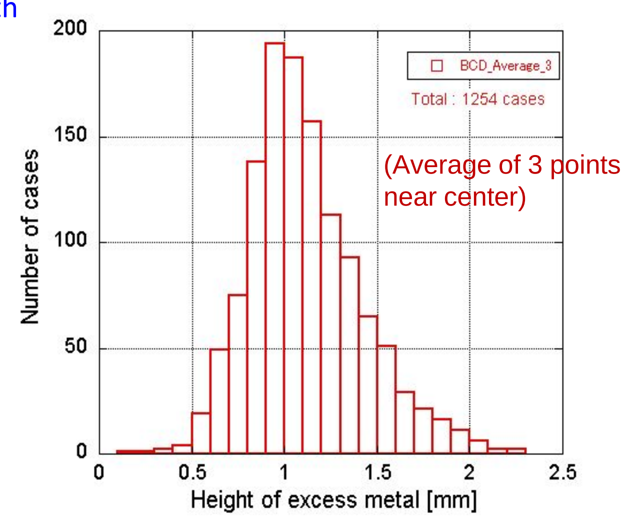
Installation 10

- Possible cause 2 : Thin welding thickness
  - With decreasing the welding thickness, the degree of cracking risk increases as shown in the simulation
  - The investigation using X-ray and cut samples revealed that the penetration depth is 1.5~2 mm, whereas the design value is 2.5~3 mm.
  - We checked the height of excess metal of most of beam pipes with BPM blocks (1254 welding lines in total).





- Measurement results:
  - The height of excess metal are mostly in the range of 0.5~2 mm.
  - If the height is less than 0.5 mm, the welding thickness can be less than 2mm.
  - It should be safe to re-weld these beam pipes.



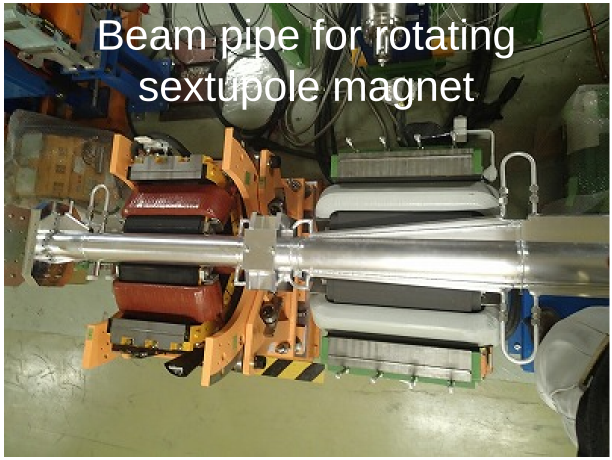
Installation 11

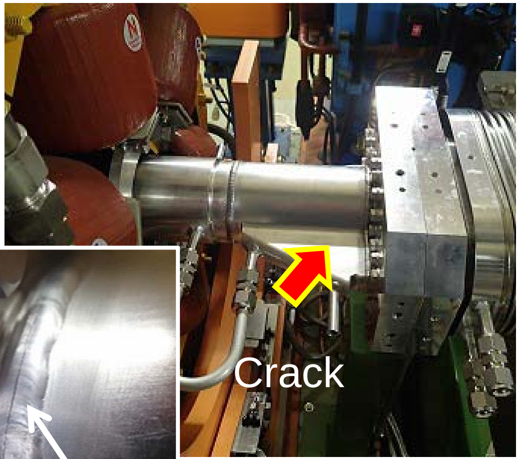
- Cures
  - Surely fix the bellows chambers to the supports before evacuation.
  - Avoid forced alignment of flanges.
  - Re-welding of the welding lines with a height of excess metal less than 0.5 mm.
  - Re-welding of the welding line with some defects, that were found in the investigation of excess metal.

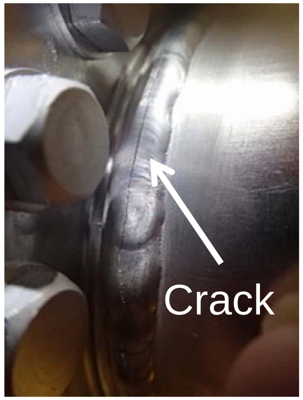
- No crack at this position has been observed since then.
  - However, great cares should be paid during the final alignment of magnets, where the beam pipes can move with magnets.

Installation 12

- Trouble 3 : Cracks on the welding line (Case 2)
  - Crack was found on the welding line of flange in the special beam pipes for the rotating sextupole magnet, with a taper section from antechamber to circular cross section. (2 beam pipes)
  - No moment by the bellows. Not top or bottom. Not in the evacuation timing. (i.e., different case from Case-1)
  - In 2013 the similar crack at the same positon (but different beam pipe) was found in Oho Lab. Some of them were re-welded. (But this trouble occurred.)
  - There are 8 beam pipes with the same structure.
- Cause:
  - Unclear (wrong welding condition? Structural stress?)
- Cure:
  - Re-welding with other new flange.
  - We have to keep watching.

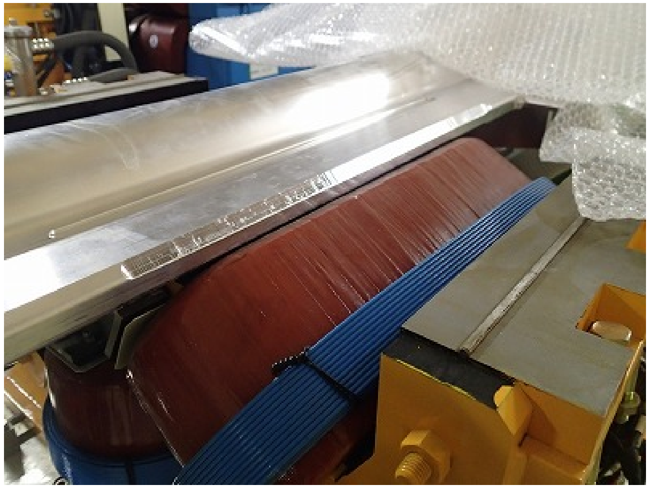




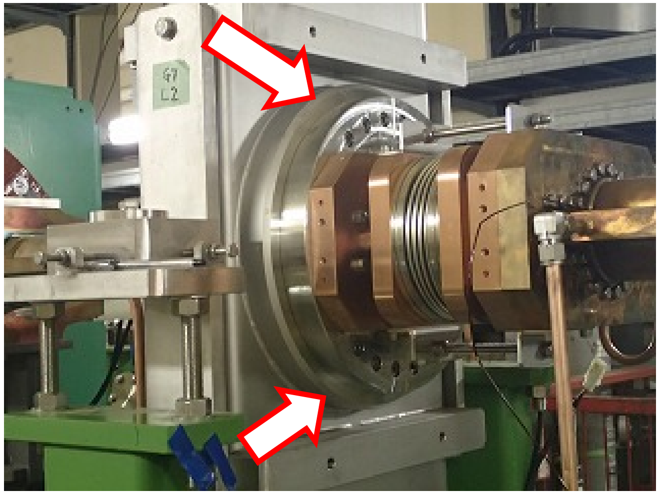


Installation 13

- Trouble 4 : Interference with other components
  - Interferences between
    - Beam pipes and magnet coil, shims and various monitor sensor
    - Cooling pipes and magnet coils
    - Beam pipe support and magnet, power cables or support
    - And so on.
- Cause :
  - Sometimes cut the beam pipe or cooling pipe
  - Sometimes move components.
  - Sometimes, re-disassembling of Q-mag. were required.
  - Thank a lot for the cooperation of other group.

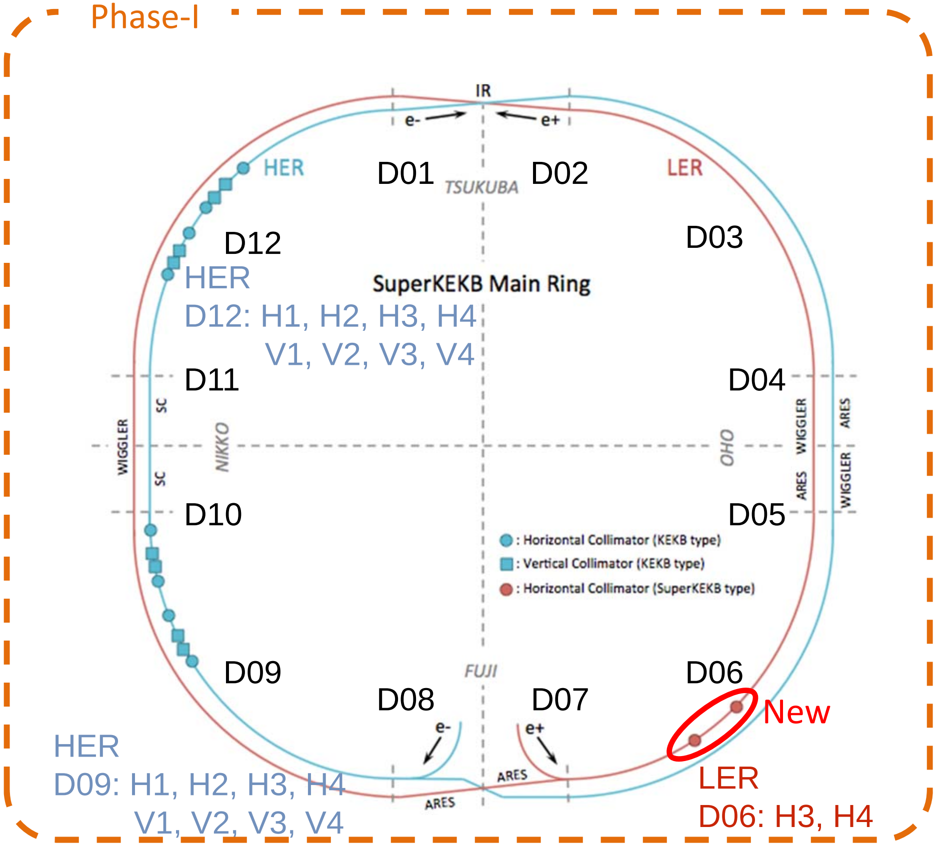


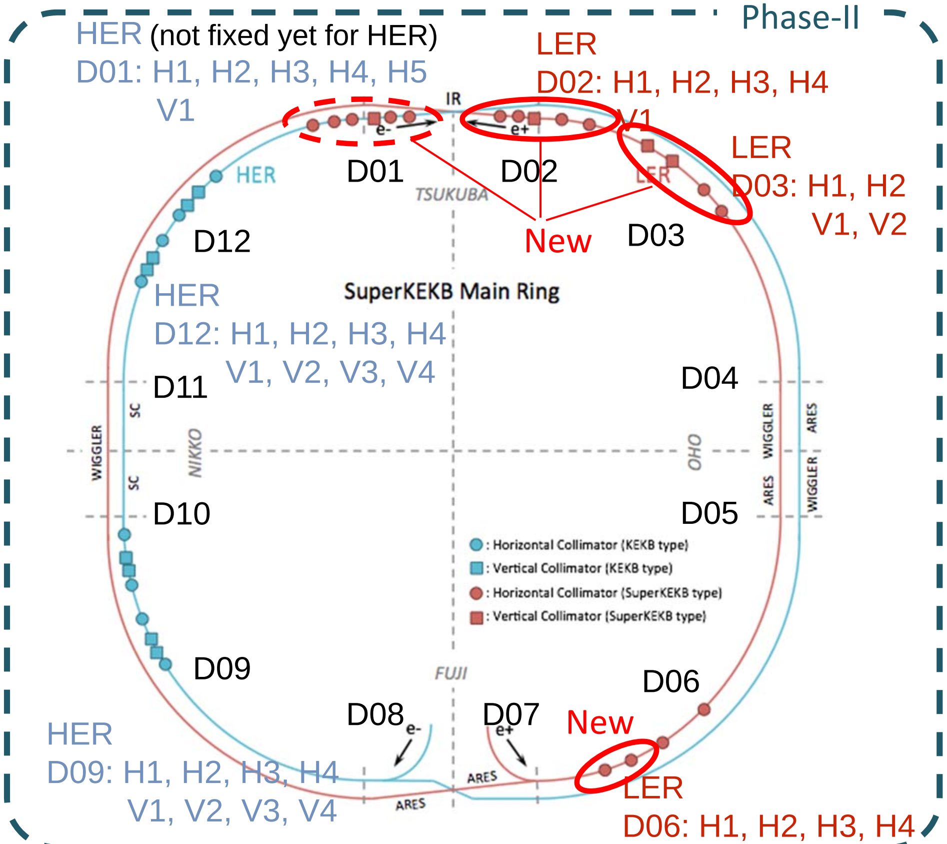
- Other troubles :
  - Air leak at welding line of gate valve (2 gate valves)
    - Cause :chemical cleaning solvent was remained at the welding line during the assembling process.
    - Cure :Re-welding at the manufacturer
      Change of structure
  - Air leak in bellows chamber (2 bellows chambers)
    - Cause : unclear. Bad HIP condition?
    - Cure : Replaced by a reserved one. Asking the investigation and re-manufacturing to the manufacture
  - And so on.



Collimator 1

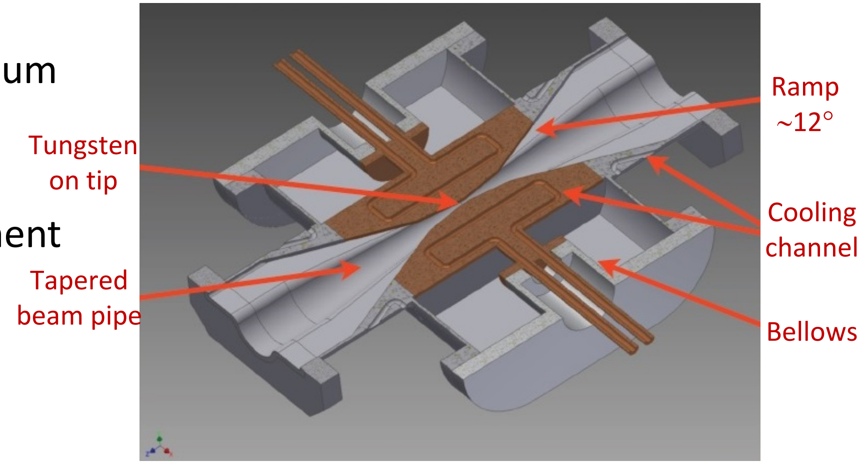
- Plan and Location
  - Phase-I : 2 new models (horizontal type) for LER. (Conventional collimators are reused in HER.)
  - Phase-II : More 11 new models for LER, and 6 for HER. (not fixed yet for HER)

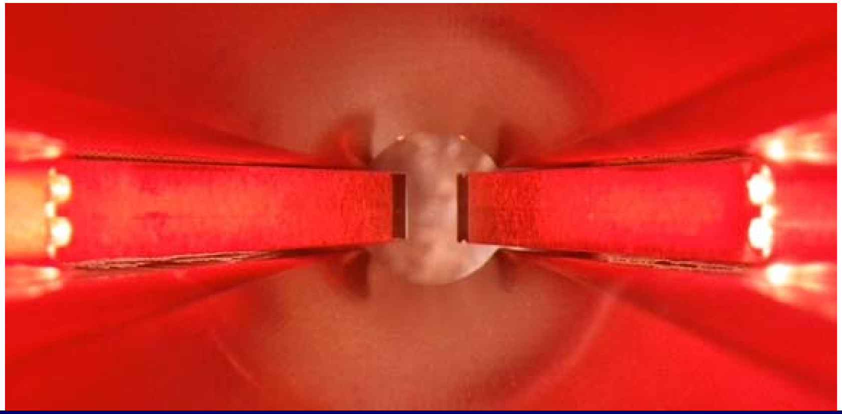


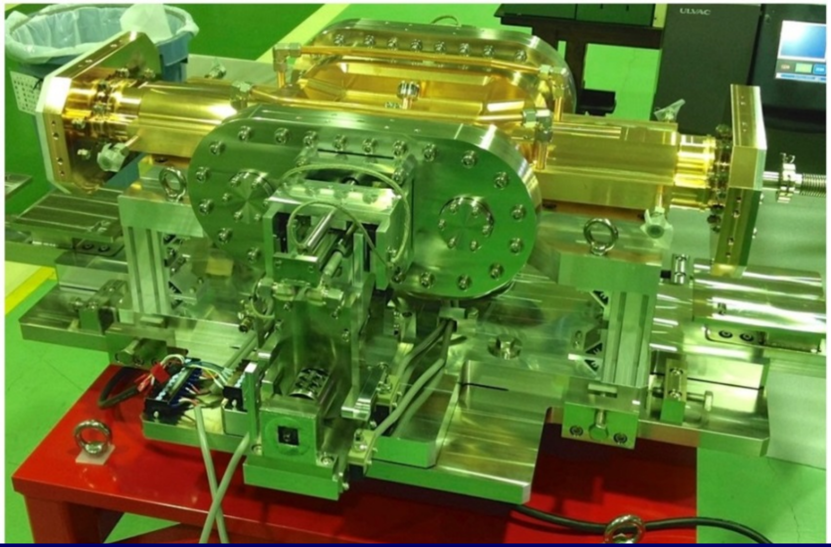


Collimator 2

- New collimators for Phase-I
  - Production of two horizontal collimators (D06H3, H4) was finished.
    - They will be installed on early next fiscal year.
  - Sliver plated INCONEL for the RF fingers and rhodium plated stainless steel for the contact surface were adopted. (pointed out in last KEKB Review)
  - Position of jaws is measured directly by displacement sensor. (pointed out in last KEKB Review)
  - Longitudinal length of the tip is 10 mm (>2 RL).
  - HOM absorber in the cavity is not considered yet. (pointed out in last KEKB Review)
    - R&D of HOM absorber chamber is now in progress.
    - Same technique may be applied to the collimator.

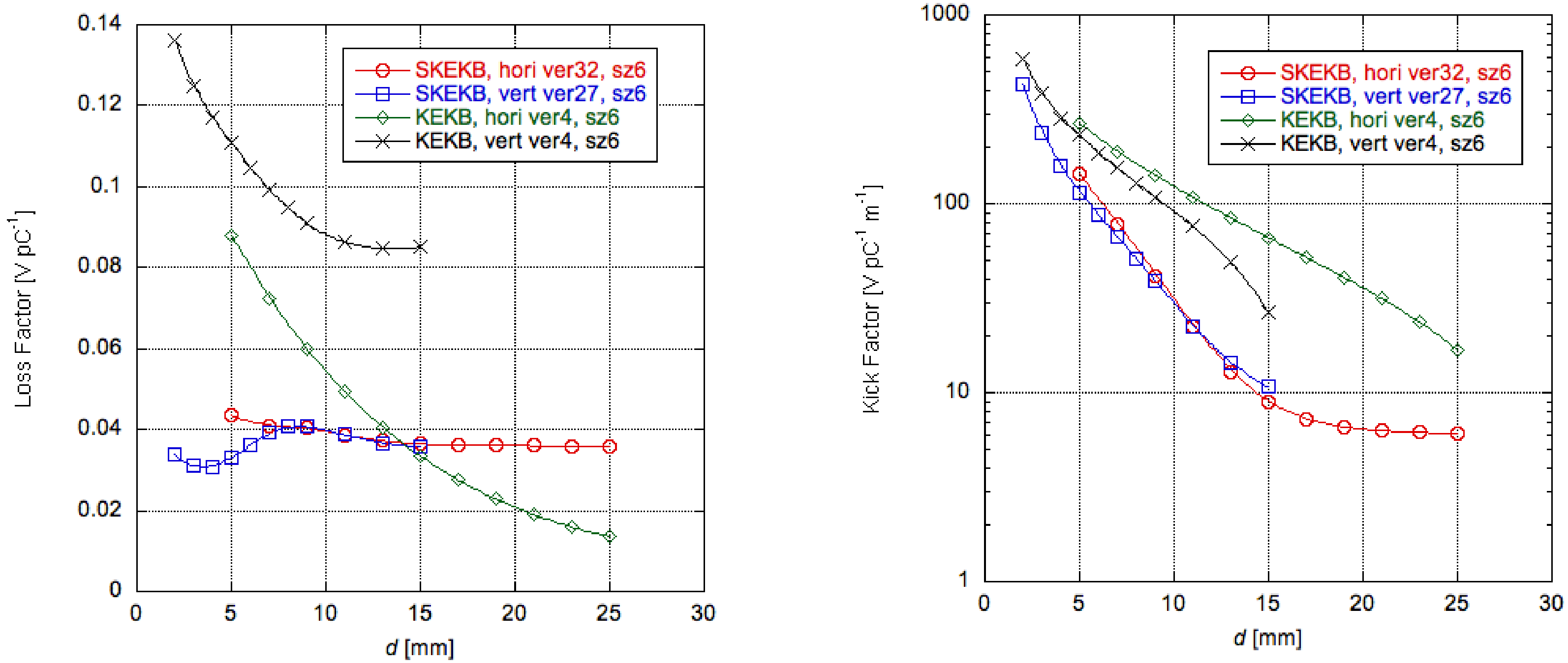






Collimator 3

- Loss and kick factor *vs d* (distance between beam axis and head)
  - Impedances were estimated with GdfidL (bunch length σ_z= 6 mm)
  - Loss and kick factors of SuperKEKB type are smaller than those of KEKB type.
  - These results were used to estimate the threshold of the Transverse Mode Coupling Instability (TMCI)



Collimator 4

- TMCI in LER (pointed out in last KEKB Review)
  - We estimated the threshold of the Transverse Mode Coupling Instability using actual β value at location of each collimator with σ_z = 6 mm.
  - D02V1 is the main impedance source because it would be used with the narrow aperture (d = ±2 mm).
  - The threshold is about 1.71 mA/bunch (Design value: 1.44 mA/bunch) in the latest collimator design.

TMC threshold (mA/bunch)

	All Closed	Actual apertures		Bunch current (design)
Horizontal	1.41	13.15	>	1.44 mA/bunch
Vertical	1.32	1.71		

$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i \kappa_{\perp i}(\sigma_z)}$$

C_1 : constant ≈8
f_s : synchrotron frequency
E : beam energy
β : beta function
$k_\perp$: kick factor

Collimator Aperture List (mm)

D06H1	-16.0/+17.0	D03H1	-21.0/+20.0	D02H1	-10.6/+12.0
D06H2	-16.0/+16.0	D03H2	-18.0/+20.0	D02H2	-16.0/+20.0
D06H3	-16.0/+15.0	D03V1	-9.0/+9.0	D02H3	-18.0/+21.0
D06H4	-13.0/+13.0	D03V2	-9.0/+9.0	D02H4	-13.0/+9.0
				D02V1	-2.0/+2.0

Control 1

- Design of control and monitoring system follows that of KEKB.
  - Most of control devices that has been used since TRISTAN or KEKB are reused.
    - Priority was given to renewal of antiquated devices. (Budgetary restrictions)
    - CMAC to cRIO, VME to F3RP61, Renewal of Ion pump controller (gradually), and so on.
  - A set of a CCG and an ion pump is installed at intervals of 10 m.
  - At least one vacuum switch is installed in a section divided by two gate valves.

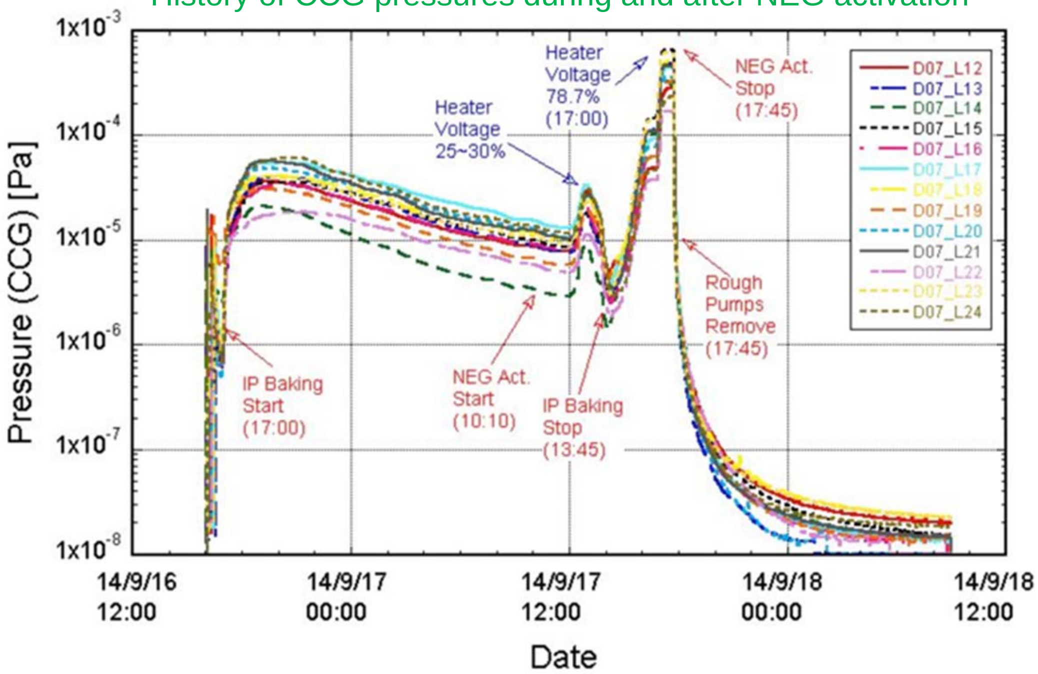
- Interlocking operations are performed by PLC (pointed out in last KEKB Review)
  - CCG, Ion pump, NEG activation
    - HV to CCGs can be applied when the vacuum switch closes in the section.
    - Each CCG within intervals of 30 m is turned on, and this refers to the steady state for the vacuum in the section.
    - Steady state allows supplying power to ion pumps and NEG activation. (Cancelable)
    - Magnet current status is also checked for NEG activation to avoid the strip type NEG in the magnet oscillating with AC for the activation.
  - Gate valve
    - The sequence CPU in PLC checks the steady statuses of two vacuum sections divided with gate valves.
    - Gate valves can be opened when the statuses are steady .
  - Beam abort
    - Temperature sensors, flow meters, gate valves and beam stoppers can activate the beam abort trigger directly.

Control 2

- Integrative tests for the control system was done successfully. (NEG activation)
  - NEG activation was performed by following procedure:

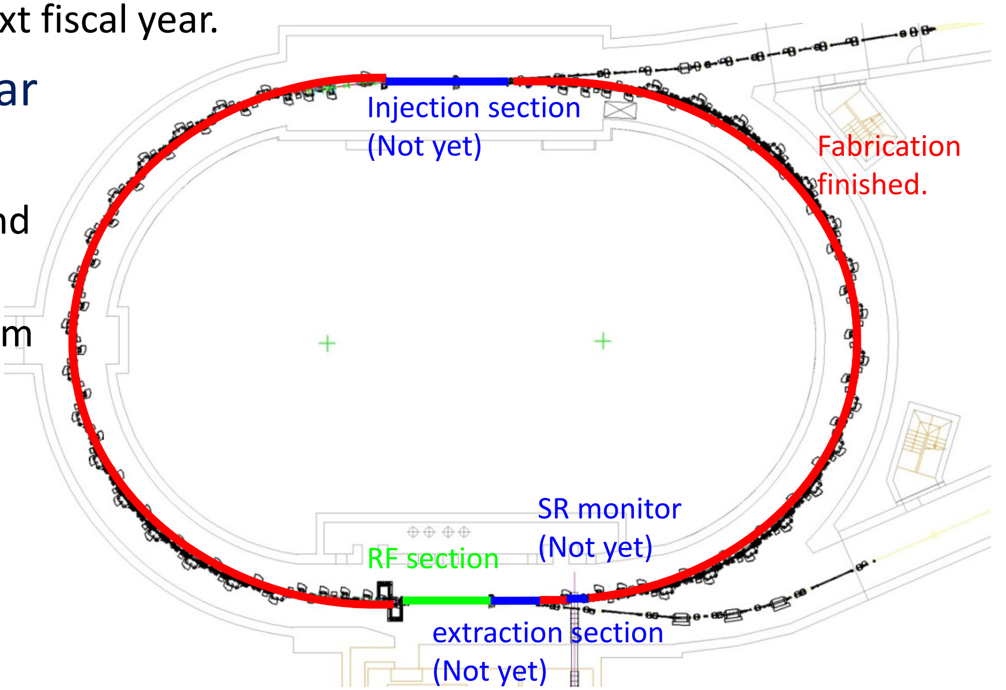
1. TMPs are started up, which are installed on angle valves.
2. High voltage is applied to CCGs and Ion pumps in the section
3. Ion pumps are baked using heaters for 1-2 days
4. NEG pumps are activated with a pattern operation for 0.5-2 days
5. Baking heaters of the ion pumps are turned off after 1-2 hours of the start of NEG activation.
6. Angle valves are closed just after the activation.

History of CCG pressures during and after NEG activation



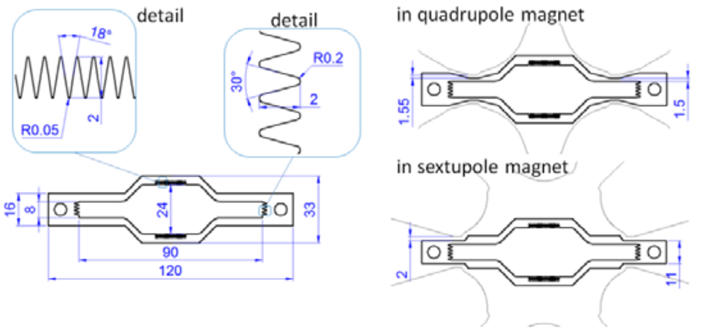
Damping Ring 1

- Fabrication of beam pipes has almost finished.
  - Remained pipes : Injection and extraction sections, beam pipe for SR monitor.
  - They will be fabricated next fiscal year.
- Pre-installation works of beam pipes for arc sections are now in progress.
  - 38 beam pipes for arc sections were coated so far.
  - More 36 beam pipes will be coated by the end of this fiscal year (3/31).
  - Baking of beam pipes will be done next fiscal year.
- Installation will start next fiscal year at the earliest.
  - Delivery of NEG pumps, gate valves and beam stopper were completed.
  - Ion pumps and power supplies to them will be purchased next fiscal year.
- Vacuum control system will be almost same as that of MR.
  - The number of control data item is much smaller than that of MR.

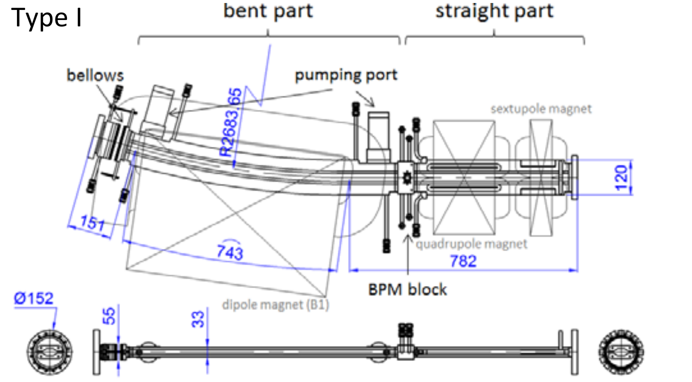


Damping Ring 2

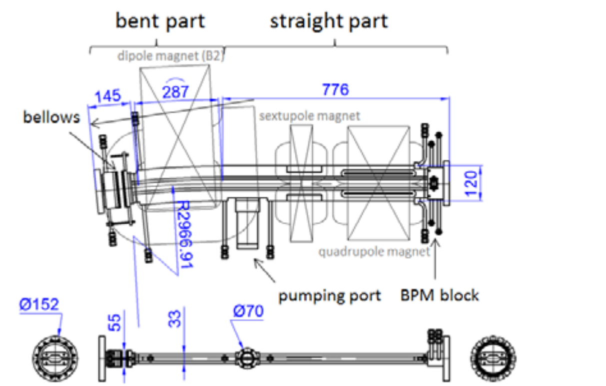
- Aluminum Beam pipes for arc sections
  - Antechambers on both sides of beam channel
  - Grooved structures at top and bottom of the beam channel (countermeasure against electron cloud)
  - Grooved structures at side walls of antechambers for antireflection of SR
  - Water cooling channel on both sides
  - Designed to fit narrow space
  - Having RF shielded bellows, BPM block and Pumping port



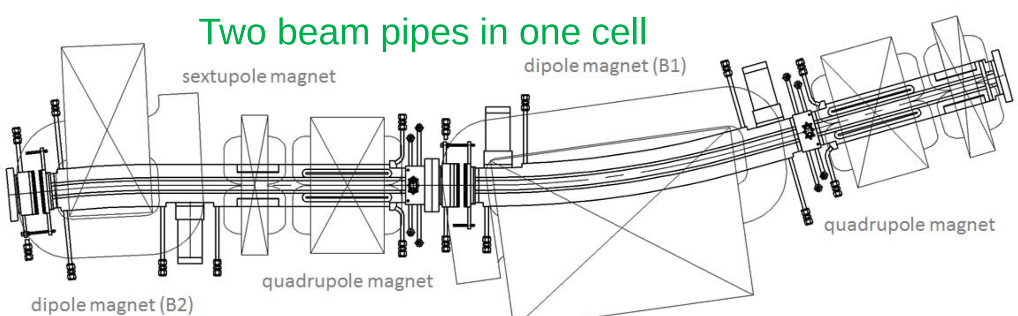
Type I

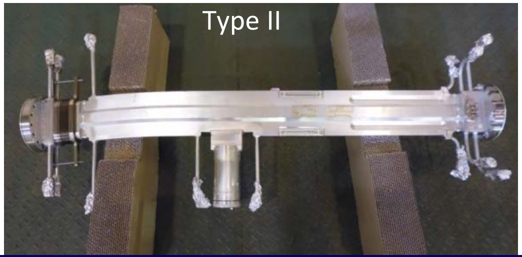


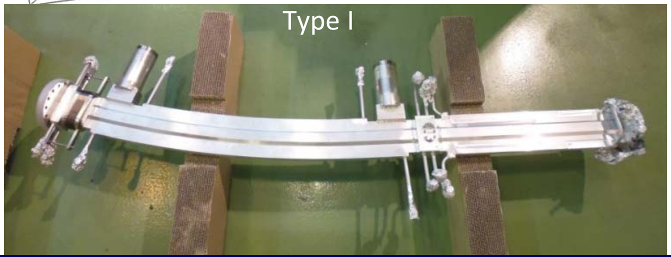
Type II



Two beam pipes in one cell

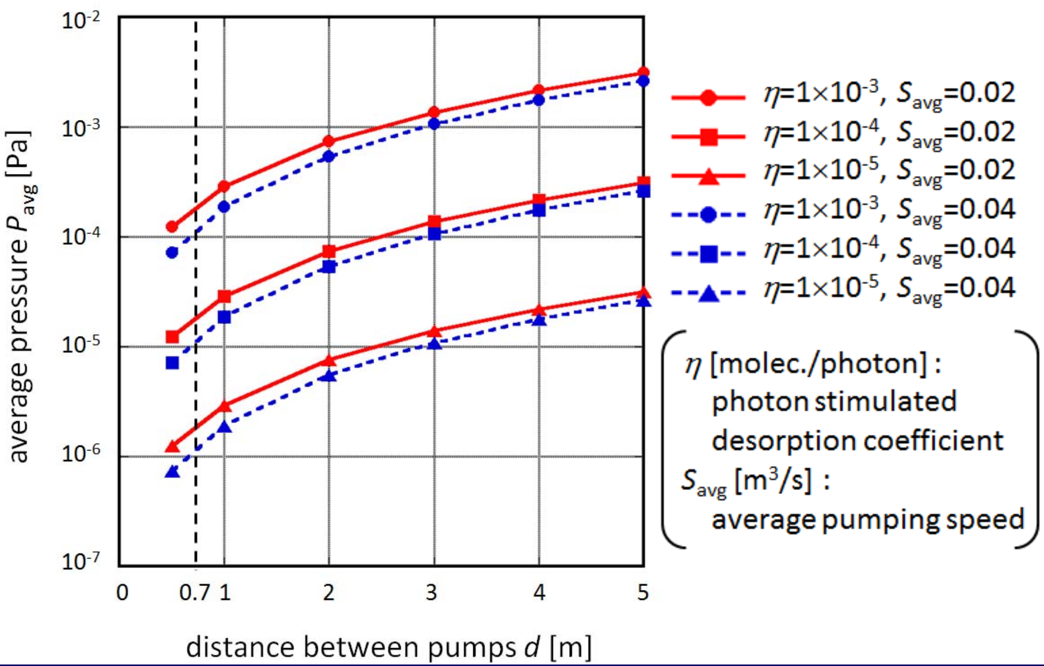






Damping Ring 3

- Rough estimation of average pressure in arc sections
  - Required averaged pressure is lower than 1×10^{-5} Pa to obtain enough beam life time.
  - Beam pipes have three pumping ports in one cell with a length of about 2 m. ($d \approx 0.7$ m)
  - Two of them are for the NEG pumps and one is for ion pump.
    - Average effective pumping speed will be 0.037 (just after activation) ~ 0.025 m^3s^{-1}
  - Photon stimulated desorption by SR is major dynamic gas load during beam operation.
    - After the sufficient scrubbing, η will drop to below less than 1×10^{-4} molec./photon.
  - 1×10^{-5} Pa is achievable goal with sufficient scrubbing.



Remained works

- Main Ring (for Phase-I operation)
  - Installation of components for Tsukuba local chromaticity region (HER) and Fuji beam injection/abort region (HER). Installation of collimators.
    - Installation will be finished by September.
  - Cabling (power supply, monitoring), piping of cooling water line at straight sections and piping of compressed air line.
  - Adjustment of flow rate of cooling water in whole ring.
  - Final alignment of beam pipes and bellows chambers.
  - NEG activation (Final check).
  - Final check of operation software.
  - All will be finished by December.
- For Phase-II operation
  - Fabrication of remained collimators.
  - Fabrication of remained beam pipes for Damping Ring.
  - Purchase order of ion pumps, power supply, etc. for Damping Ring.
  - Pre-installation and installation works of Damping Ring.
  - And so on

Summary

- Preparation for Phase-I operation is steadily in progress though some troubles occurred.
  - Pre-installation works : 100% except for IP pipe
  - Installation : ~97%
  - Evacuation and NEG activations : ~21%
  - Collimator : already completed and waiting for installation
- All remained works for Phase-I will be finished by December.
- We have begun works for Phase-II
  - Damping ring, Collimators, etc.

- We welcome any comments or suggestions especially on
  - Aluminum welding.
    - Crack trouble seems to be a frequent occurrence.
  - What we should pay attentions to.
    - At the start of evacuation.
    - During Phase-I operation (vacuum scrubbing).

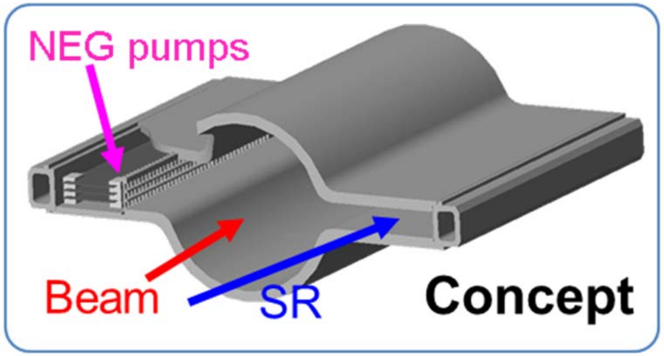
Fin.

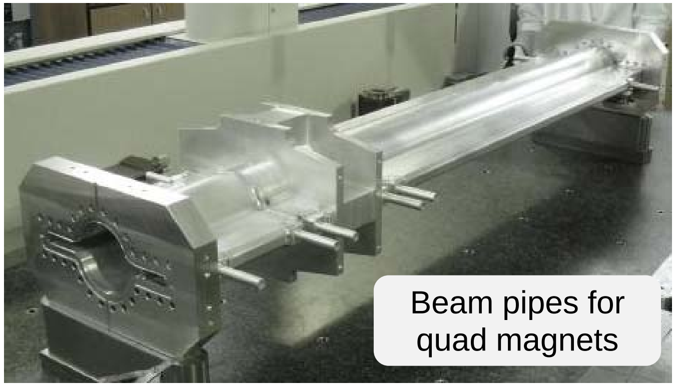
Thank you for your attentions.

Back-up

New beam pipes

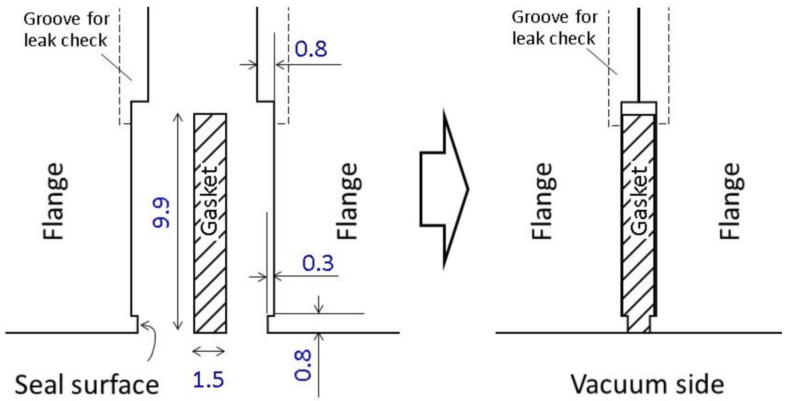
- New beam pipes have antechambers.
  - Realize low beam impedance by putting SR masks and pump ports in antechambers
  - Effective to reduce photo electron effect
  - LER arcs: Aluminum alloy (A6063)
    - Formed by extrusion method
  - HER and Wigglers: OFC (C1011)
    - Formed by cold-drawing method



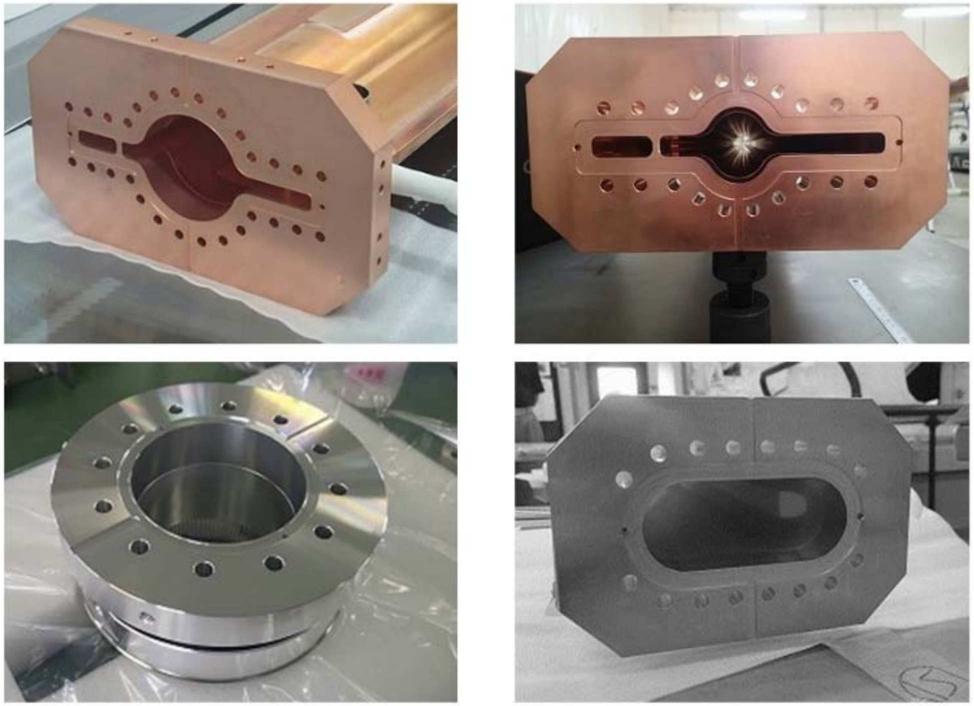


Connection flange

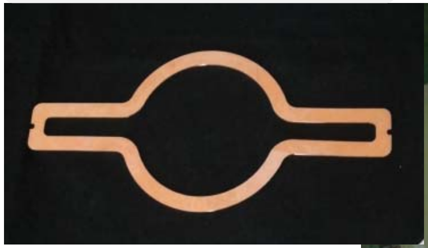
- Step-less flange: MO-type flanges
  - Little step inside and low beam impedance
  - Adaptable to various types of cross sections
  - Various types of copper (C18200) and aluminum-alloy (A2219) flanges were developed.



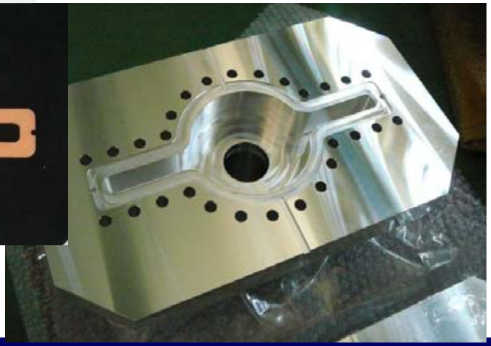
Various types of MO flange



Cu Gasket for Cu flange



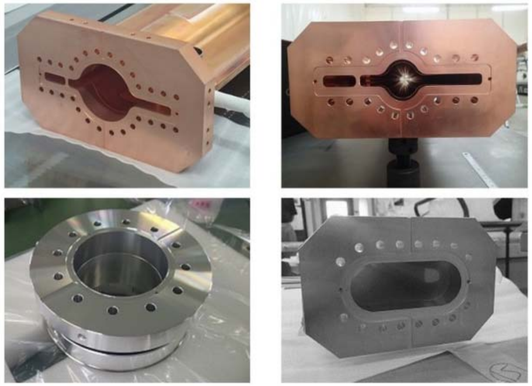
Test flange (SUS316)



Connection flange

- Result up to now.

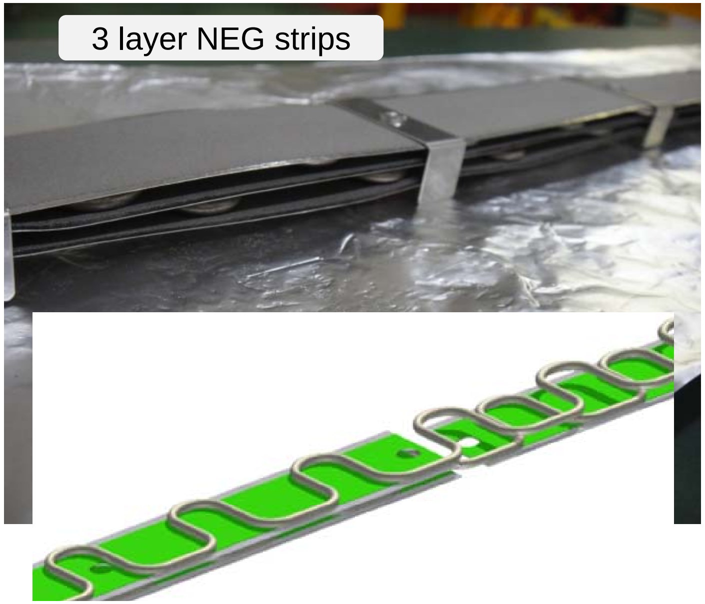
Type	Material	Cross section	Numbers
f90×220	Al	Antechamber	3288
f90×220	Cu	Antechamber	762
f90×220H24	Al	Antechamber	24
f80×220	Cu	Antechamber	20
f50×190	Cu	Antechamber	12
122×50	Al	Racetrack	8
f90	Al	Circular	24
f90	Cu, SUS	Circular	52
f80	Cu	Circular	8

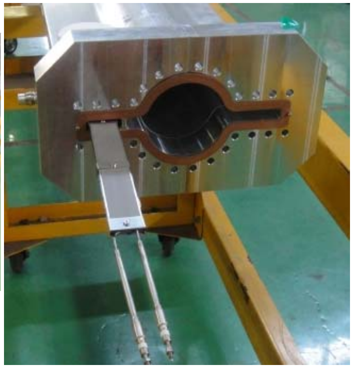


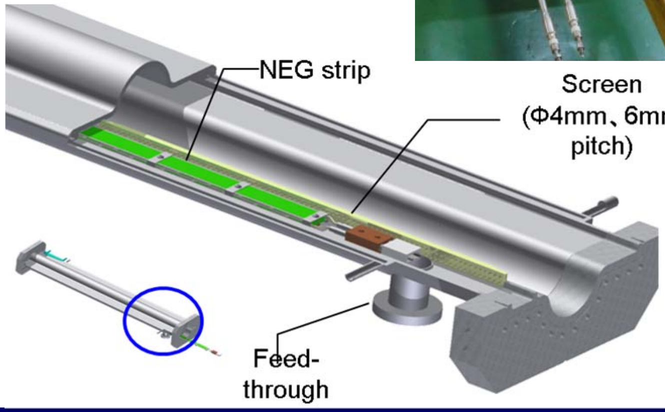
- Approximately 4140 flanges out of 4890 have been used (connections are ~2070).
- The rate of air leakage at the first fastening is less than 5 % even in the ring.

Pumps

- Main pump: Three layers of NEG strips ST707 (arc)
  - Installed into an antechamber: provide effective distributed pumping system
  - Activation by micro-heaters (sheath heaters) inserted between strips
  - Screens between pump and beam
  - Average pumping speed of 0.14 $m^3s^{-1}m^{-1}$ for CO



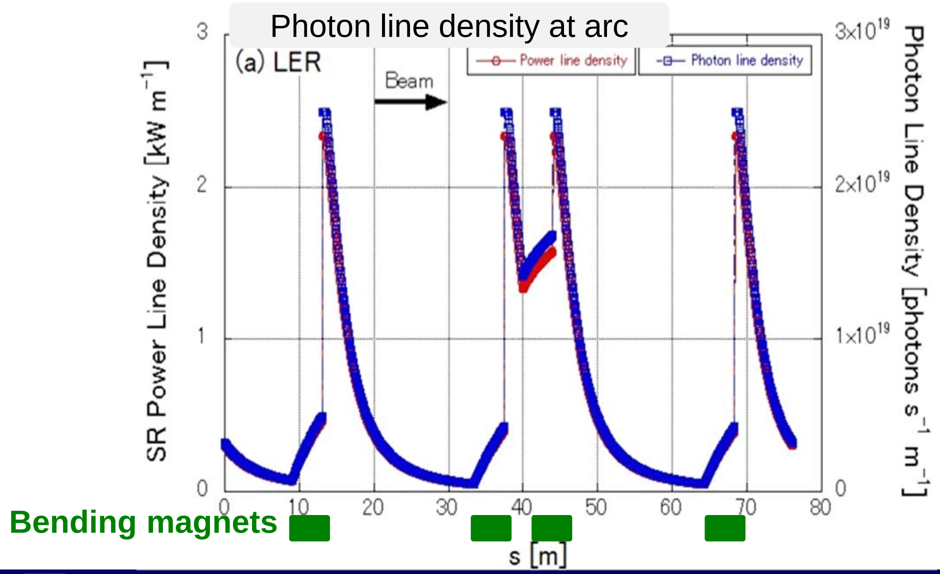


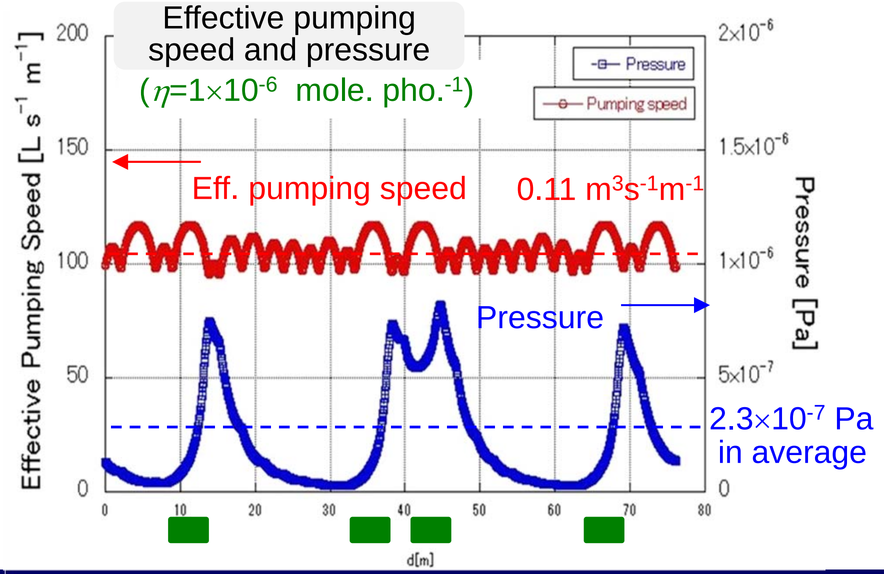


Pumps

- Auxiliary pump: Ion pumps
  - Noble pump with a pumping speed of ~ 0.4 $m^3 s^{-1}$. Every ~10 m.

- Roughing pump: Turbo-molecular pump+Scroll pump





Countermeasures against electron cloud effect

- Electron cloud instability can be a serious problem for LER (e+)
  - The threshold of electron density to excite the head-tail instability is ~1.6×10^{11} e^-/m^3.
  - By using these countermeasures, the average electron density on the order of 10^{10} e^-/m^3 will be obtained.
  - Various mitigation techniques were evaluated at KEKB LER.

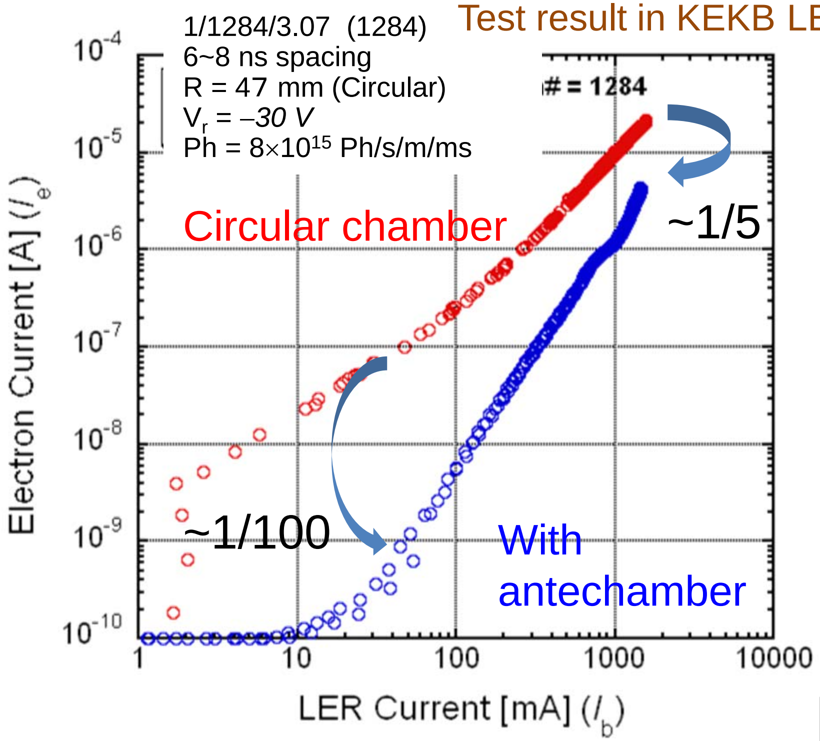
by courtesy of Y. Suetsugu

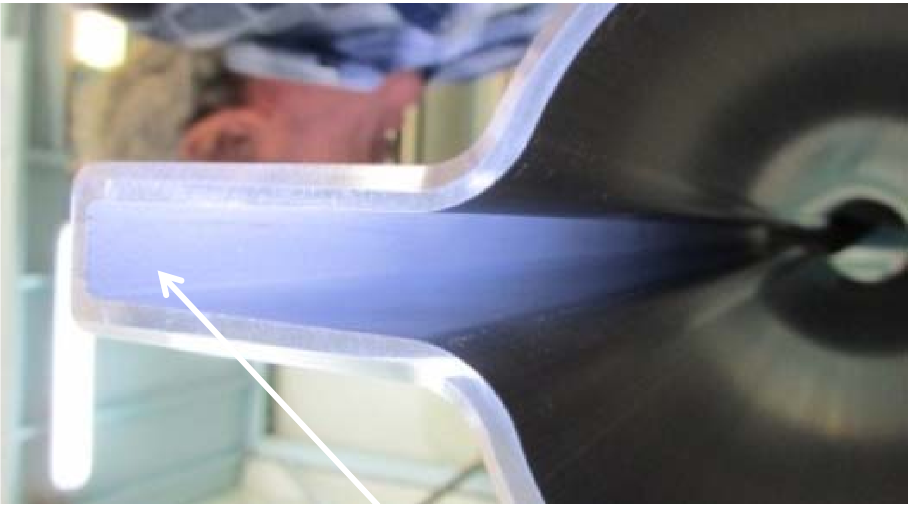
Sections	L [m]	L [%]	Countermeasure	Material
Total	3016	100		
Drift space (arc)	1629 m	54	Antechamber + TiN coating + Solenoid	Al (arc)
Steering mag.	316 m	10	Antechamber + TiN coating + Solenoid	Al
Bending mag.	519 m	17	Antechamber +TiN coating + Grooved surface	Al
Wiggler mag.	154 m	5	Antechamber + Clearing Electrode	Cu
Q & SX mag.	254 m	9	Antechamber + TiN coating	Al (arc)
RF section	124 m	4	(TiN coating +) Solenoid	Cu
IR section	20 m	0.7	(TiN coating +) Solenoid	Cu, Al

Electron cloud mitigation 1
Antechamber

- Antechamber is effective to mitigation of photoelectrons which can be source of the electron cloud.
  - Expected reduction efficiency of electron cloud in SuperKEKB LER is 1/5.
- Almost all new beam pipes of LER has antechambers.

Test result in KEKB LER



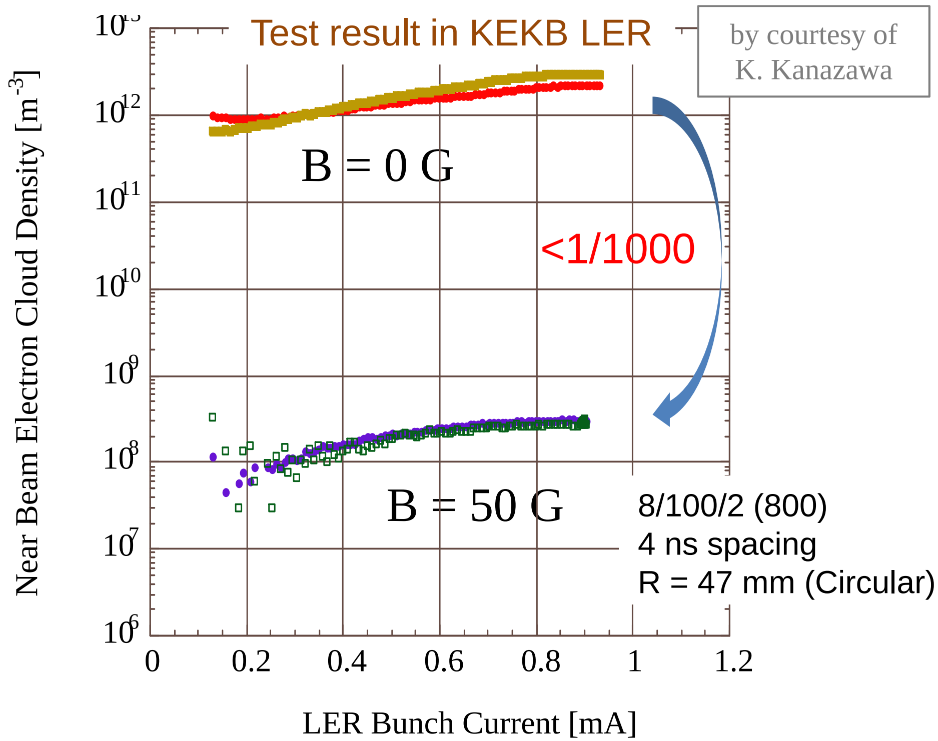


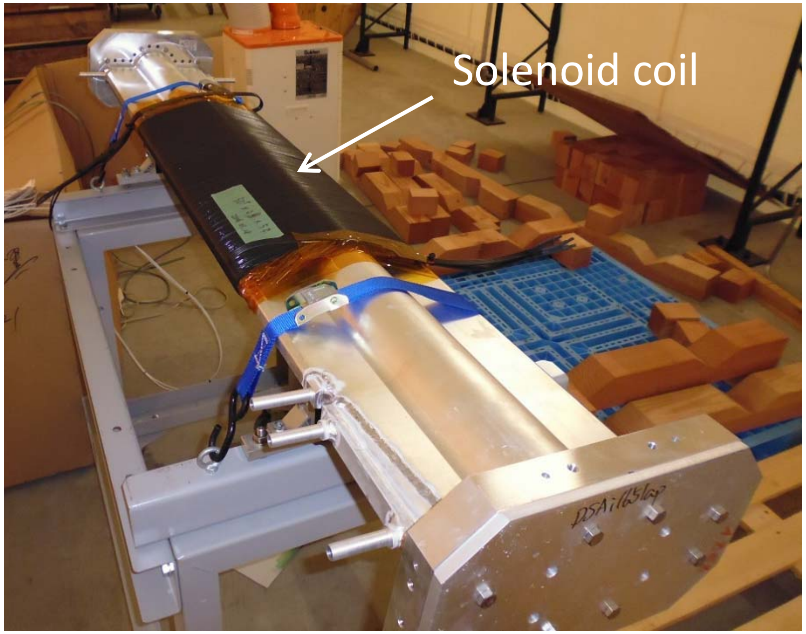
Rough surface at the side wall (Ra ~20) reduces the photon reflection.

by courtesy of Y. Suetsugu

Electron cloud mitigation 2
Solenoid field

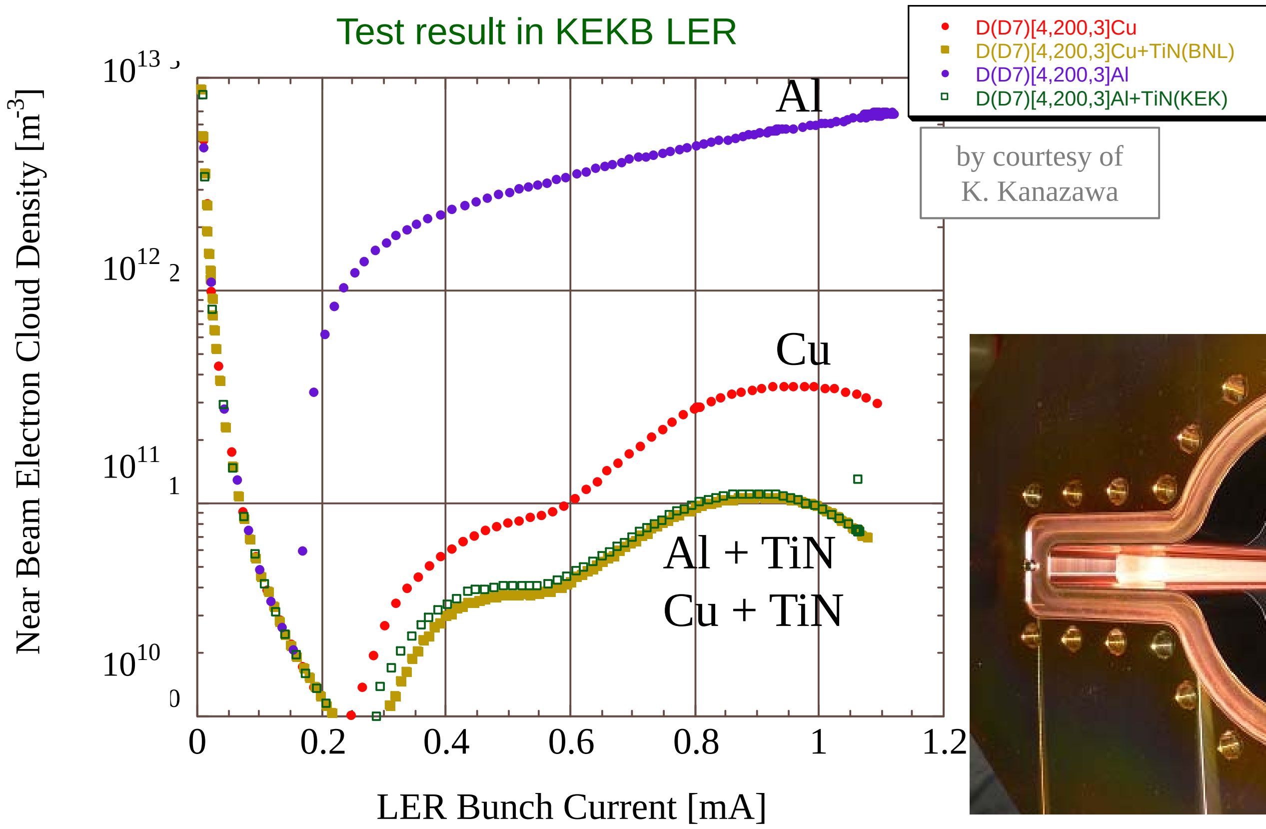
- It was confirmed that the solenoid field at drift section (50 G) is effective to both photoelectrons and secondary electrons in KEKB LER.
  - Expected reduction efficiency of electron could in SuperKEKB LER is 1/50.
- Solenoid filed will be used as widely as possible in SuperKEKB LER.
  - It can not be available in magnets other than steering magnets because of no room for coil winding.

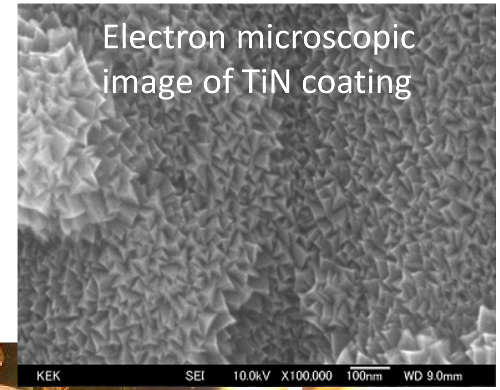


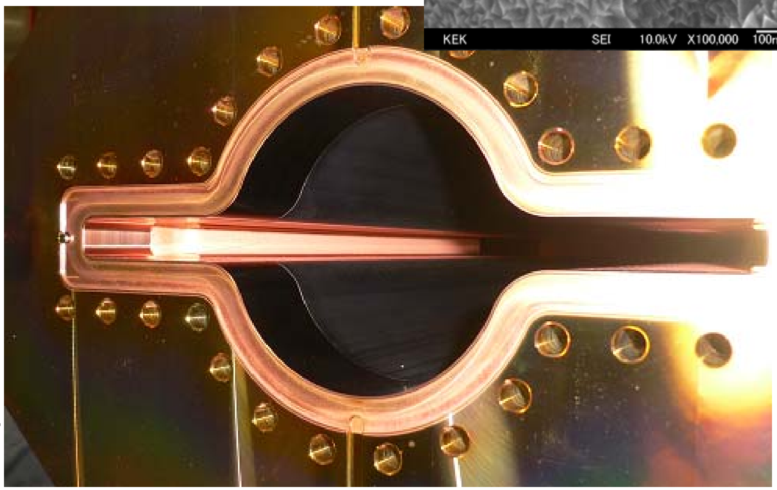


Electron cloud mitigation 3
TiN coating

- TiN coating is effective to reduction of the secondary electrons.
  - Expected reduction efficiency of electron cloud in SuperKEKB LER is 3/5.
- Almost all new beam pipes without clearing electrode are coated with TiN.

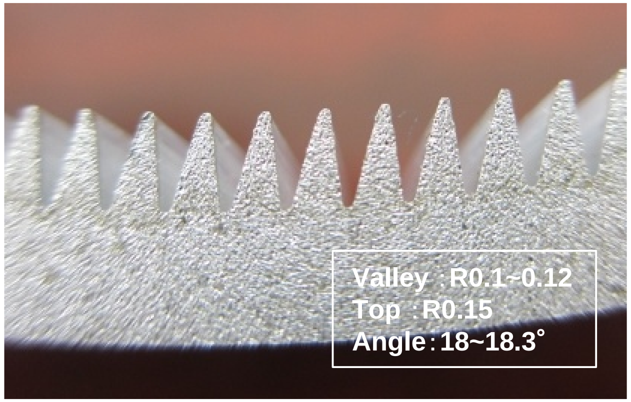


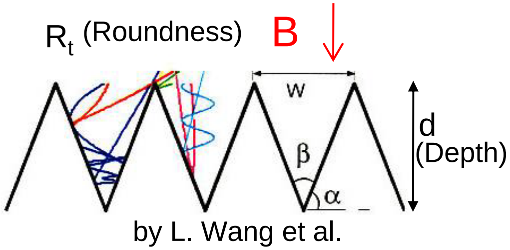




Electron cloud mitigation 4
Grooved Surface (in Bending Magnets)

- Grooved surface can reduce effective SEY of beam pipe in bending magnet.
  - Secondary electrons hardly get away from the grooved structure in the dipole field.
  - Grooved structure is formed by extrusion method.
  - Beam pipe with groove structure can be bent.
  - Expected reduction efficiency of electron cloud in SuperKEKB LER is ½.

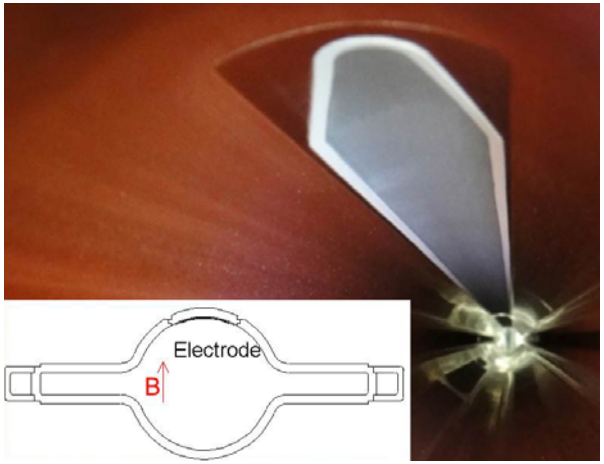


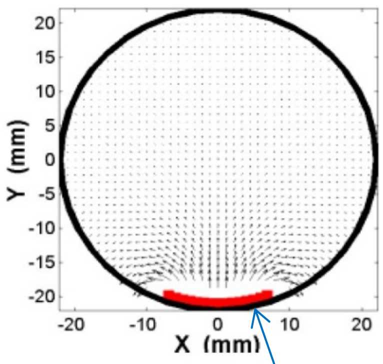


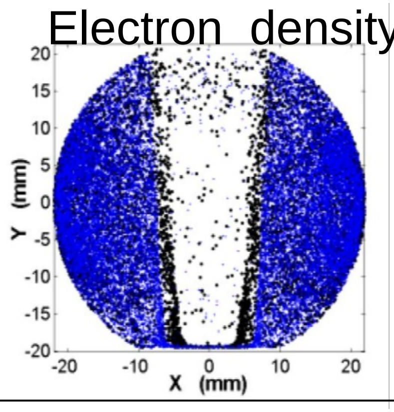
Electron cloud mitigation 5
Clearing Electrode (in Wiggler Magnets)

by courtesy of Y. Suetsugu

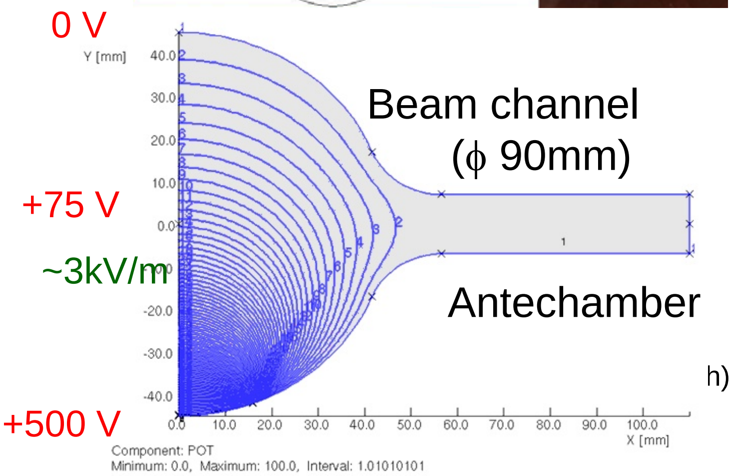
- Clearing electrode attracts the electrons by electrostatic field.
  - Very thin electrode was developed. (0.1 mm tungsten on 0.2 mm Al_2O_3)
  - It was tested in KEKB and CserTA.
  - It is expected to reduce the electron density around beam up to ~1/100.





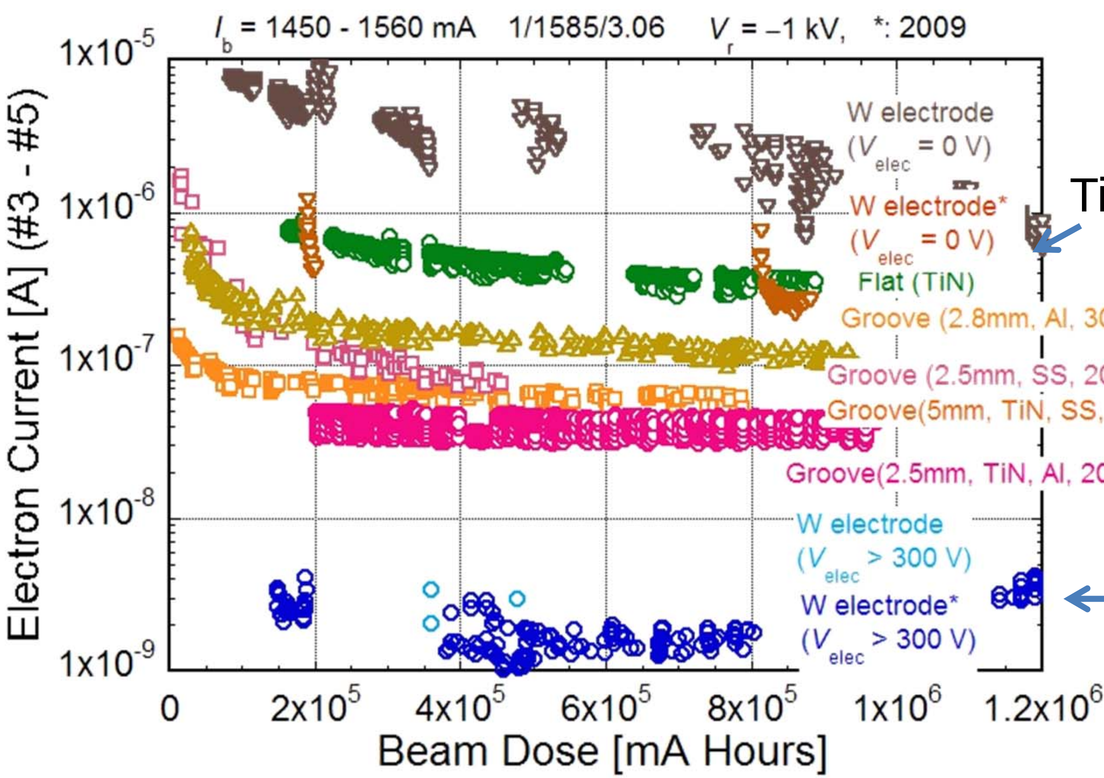


L. Wang et al, EPAC2006, p.1489



Electron Cloud Mitigation 6
Evaluation on Groove and Electrode

- Effectiveness of the grooved surface and the clearing electrode was evaluated at KEKB LER.
  - ➢ Expected reduction efficiencies of electron cloud in SuperKEKB LER are ½ (groove) and 1/100 (electrode).



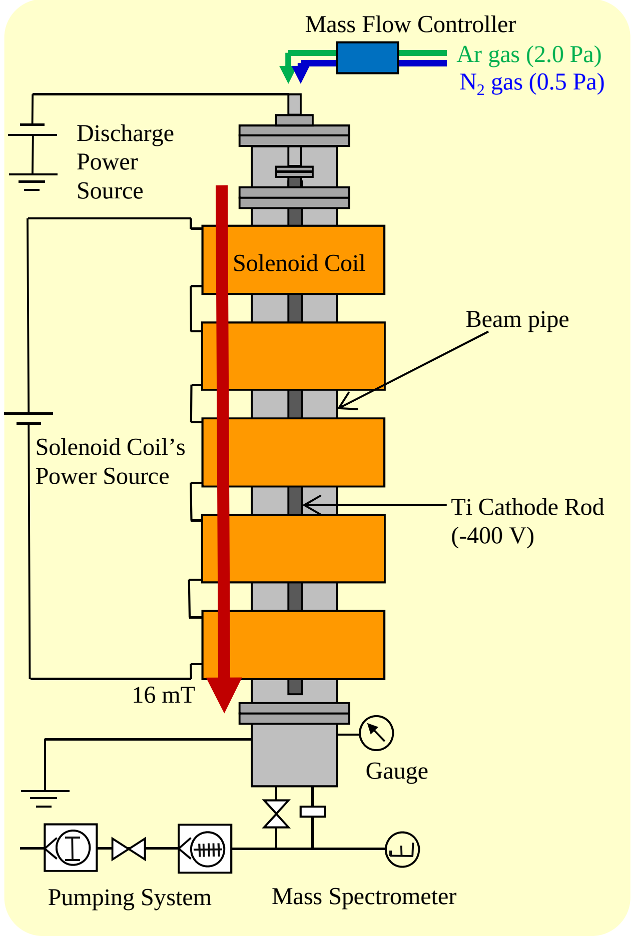
TiN-coated flat surface 》 **Grooved surface (β~20°)** 》 **Clearing electrode**

1/6~1/10 ~1/10

by courtesy of Y. Suetsugu

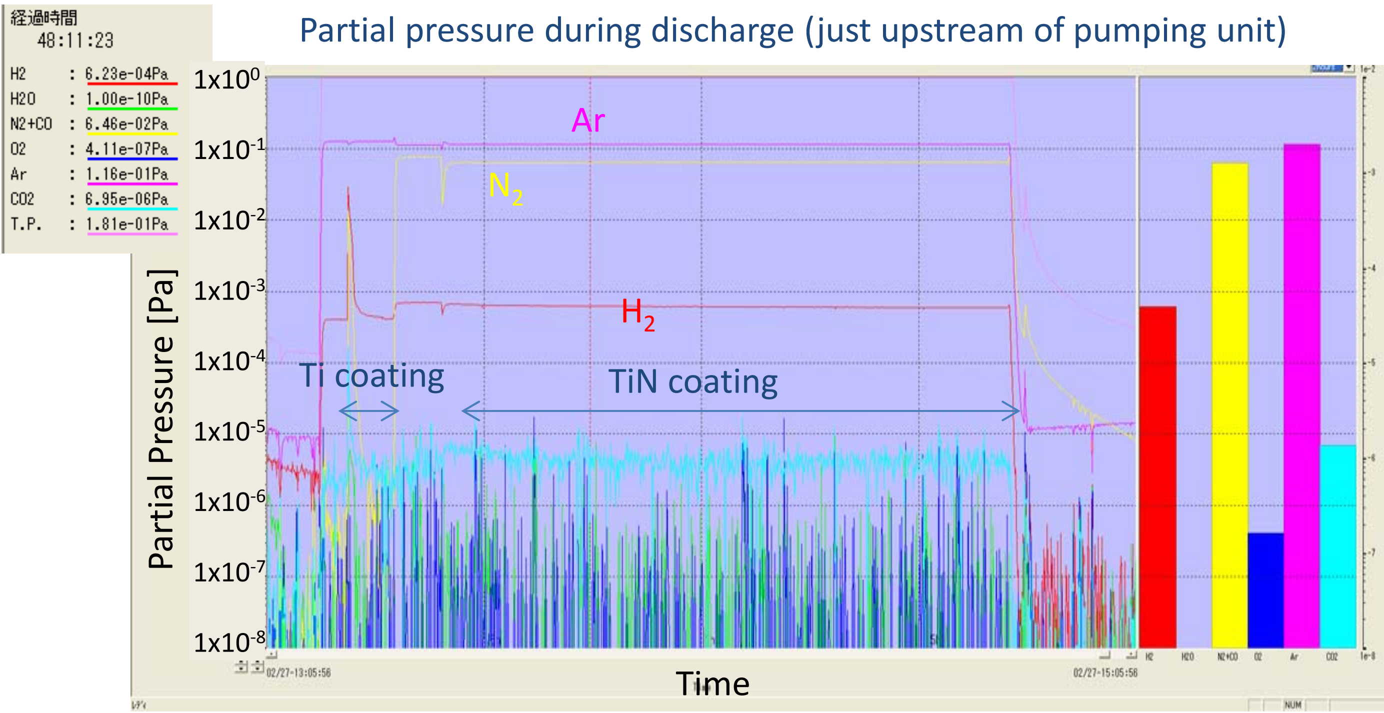
TiN coating 1 : Coating method

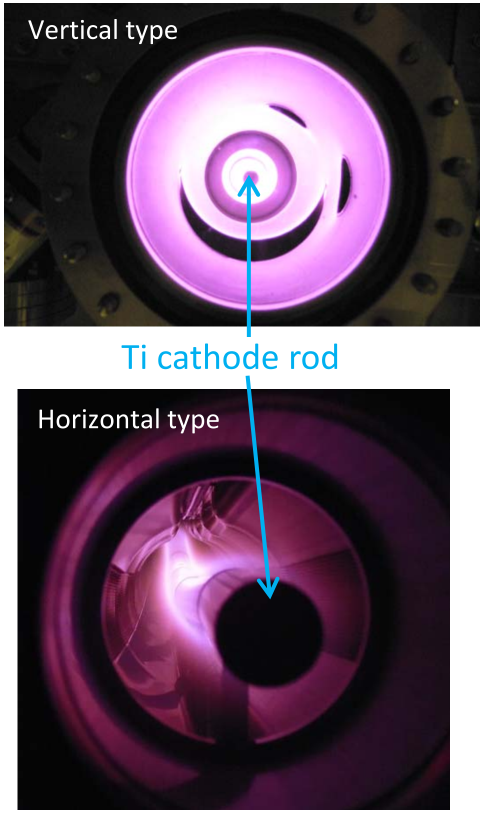
- For SuperKEKB LER, it is an important issue to mitigate the electron cloud instability.
  - In order to reduce the electron cloud, inner surfaces of almost all LER beam pipes are coated with TiN (except beam pipes with clearing electrodes).
  - TiN coating tests had been performed and the coating method was established.
- TiN coating is done by a DC magnetron sputtering of Ti in Ar and N_2 atmospheres.
  - A Ti cathode rod (-400 V) is set on the center axis of beam pipe.
  - Gases are supplied into the beam pipes uniformly though the Ti rod.
  - Magnetic field (16 mT) is supplied by solenoid coils.
  - Preliminary experiments were performed at a test stand to decide the coating parameters.
  - Thickness of TiN coating : 200 nm (at least)
  - Straight beam pipes are coated by vertical type and bent pipes are coated by horizontal type.



TiN coating 2 : Magnetron sputtering

- Introduced gases : Ar (~2.2 Pa), N2 (~1.8 Pa)
- Discharged current : 6.3 A
- Required time : 5 min (Ti coating for base of TiN) + 75 min (TiN coating)





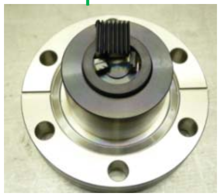
TiN coating 3 : Magnetron sputtering

- SEY of Al samples coated with TiN at this facility were measured.
  - ➢ It was confirmed that SEY of TiN coating drops to below 0.8 after sufficient electron bombardment (i.e. scrubbing). (incident electron energy : 250 eV)

Al samples before coating

TiN coated samples

Al flat



Al groove