DR Vacuum

The 22nd KEKB Accelerator Review Committee

March 14, 2018

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(on behalf of KEKB Vacuum Group)

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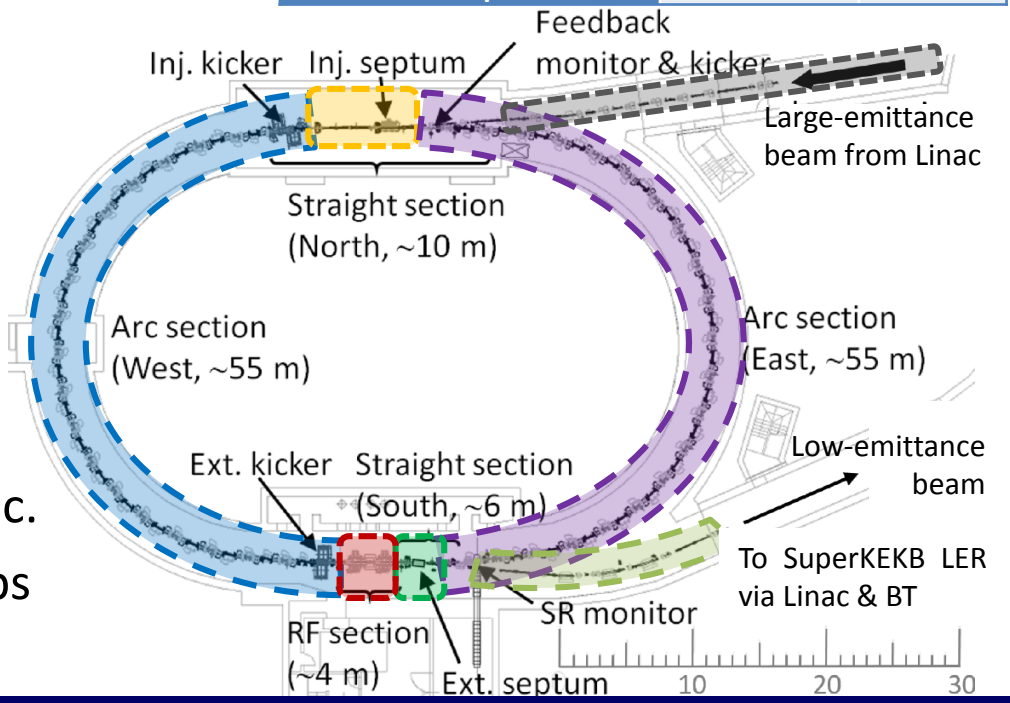
– “Updates of MR Vacuum system” will be presented by Suetsugu-san (3/14)
– “IR assembly” will be presented by Kanazawa-san (3/15)

Overview

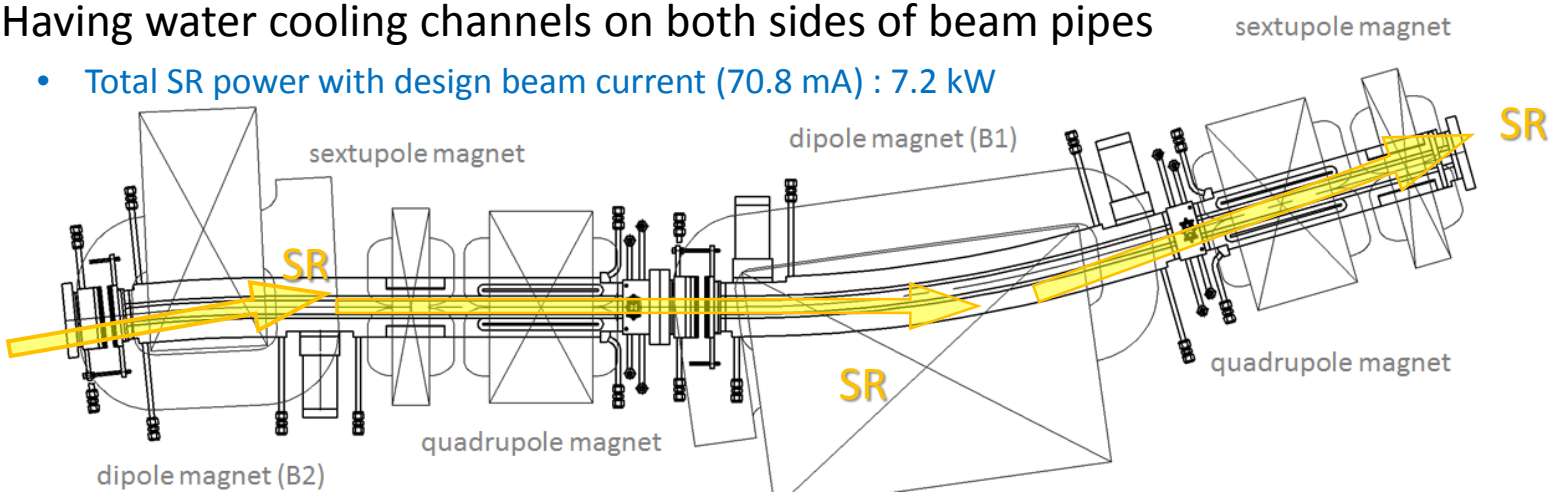
- Vacuum system is divided into 7 sections by GVs.
  - East arc sect. : SR monitor, FB monitor & kicker, DCCT, RGA
  - West arc sect. : Inj. kicker, Ext. kicker
  - South straight sect. : Ext. septum, Beam stopper for safety system
  - North straight sect. : Inj. septum
  - RF sect. : RF cavities
  - LTR
  - RTL
- Target pressure : < 1×10^{-5} Pa
  - Required beam lifetime due to residual gas scattering : > 1000 sec.
  - Vacuum pumps : NEG & ion pumps

Beam energy	1.1	GeV
Bunch number	4	
Circumference	135.5	m
Maximum stored beam current	70.8	mA
Maximum bunch charge	8	nC
Bunch length	6.53	mm
Bending radius	2632/2967	mm
Critical energy	0.93/0.82	keV
Total SR power	7.2	kW



Overview (Arc sect.)

- Beam pipes for arc sections (Al alloy)
  - Two types of beam pipes corresponding to B1&B2 magnets
    - Each beam pipe covers one dipole, one quadrupole and one sextupole magnet.
  - Designed to fit narrow spaces between the closely-located magnets
  - Having BPM blocks, pumping ports, RF-shielded bellows, CF flange with RF contact
  - Having antechambers on both sides of a beam channel to deal with SR which irradiates both side of the beam pipes and reduce beam impedance.
  - TiN coating & grooved surfacing are adopted as countermeasures against ECE.
  - Having water cooling channels on both sides of beam pipes
    - Total SR power with design beam current (70.8 mA) : 7.2 kW

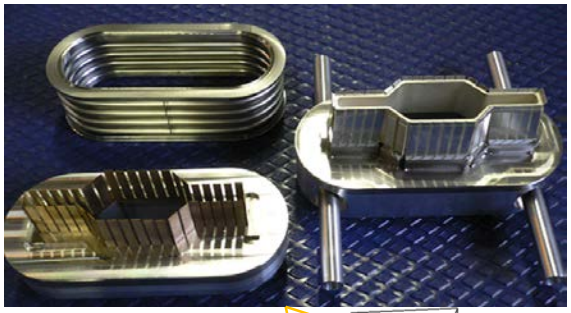


Layout of the beam ducts in one cell of the reverse-bend FODO lattice.

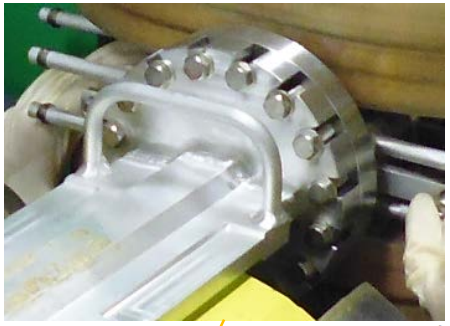
Overview (Arc sect.)

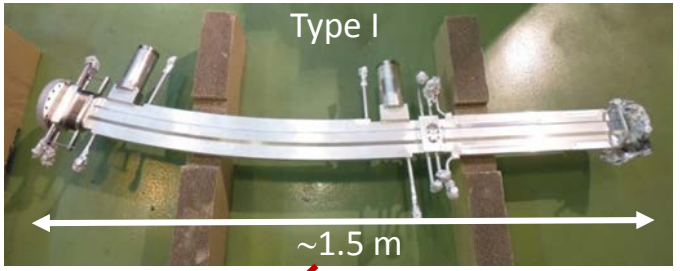
Aluminum beam pipes for arc sections :

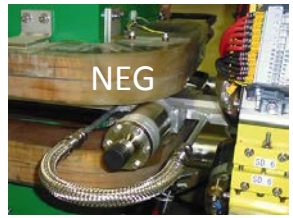
RF shielded bellows



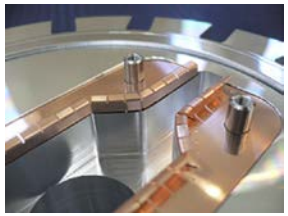
Space-saving connection flange



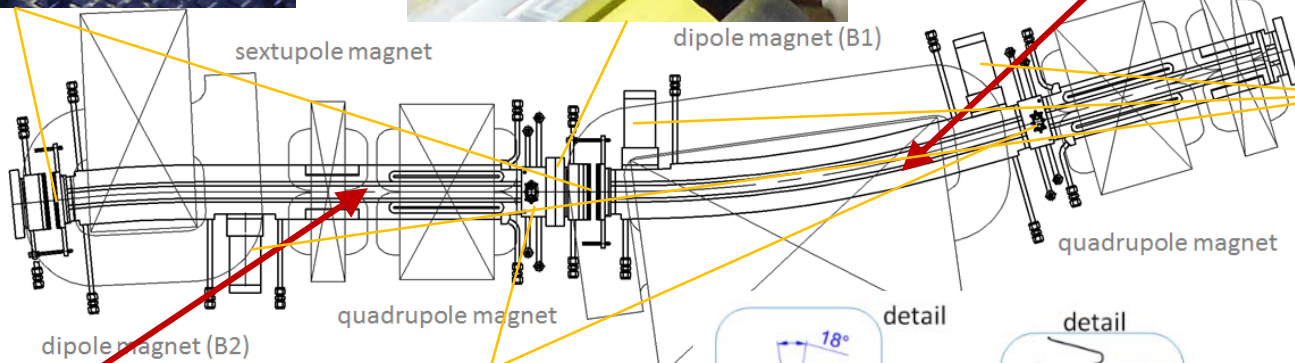


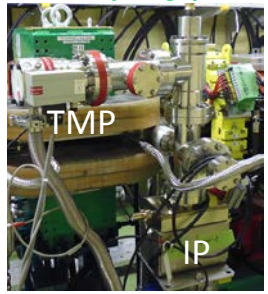


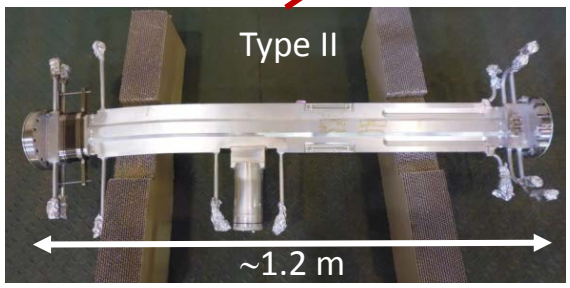
Pumping port

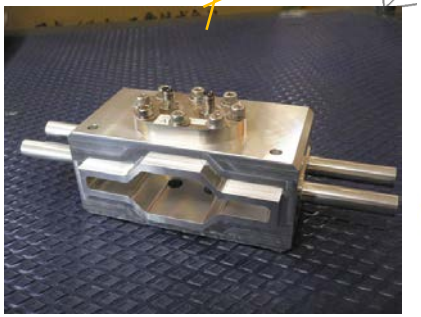


RF contact on Conflat flange

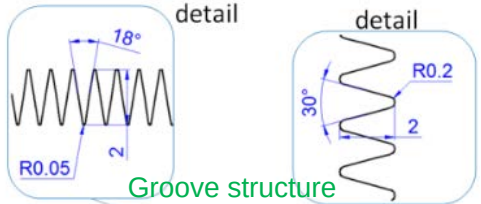


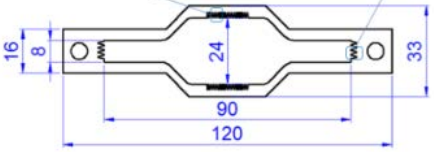




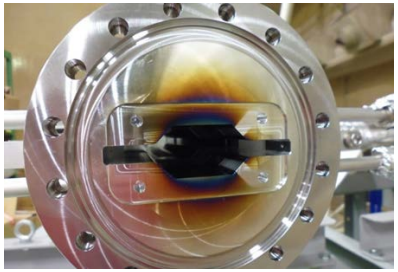


BPM block





Cross-section

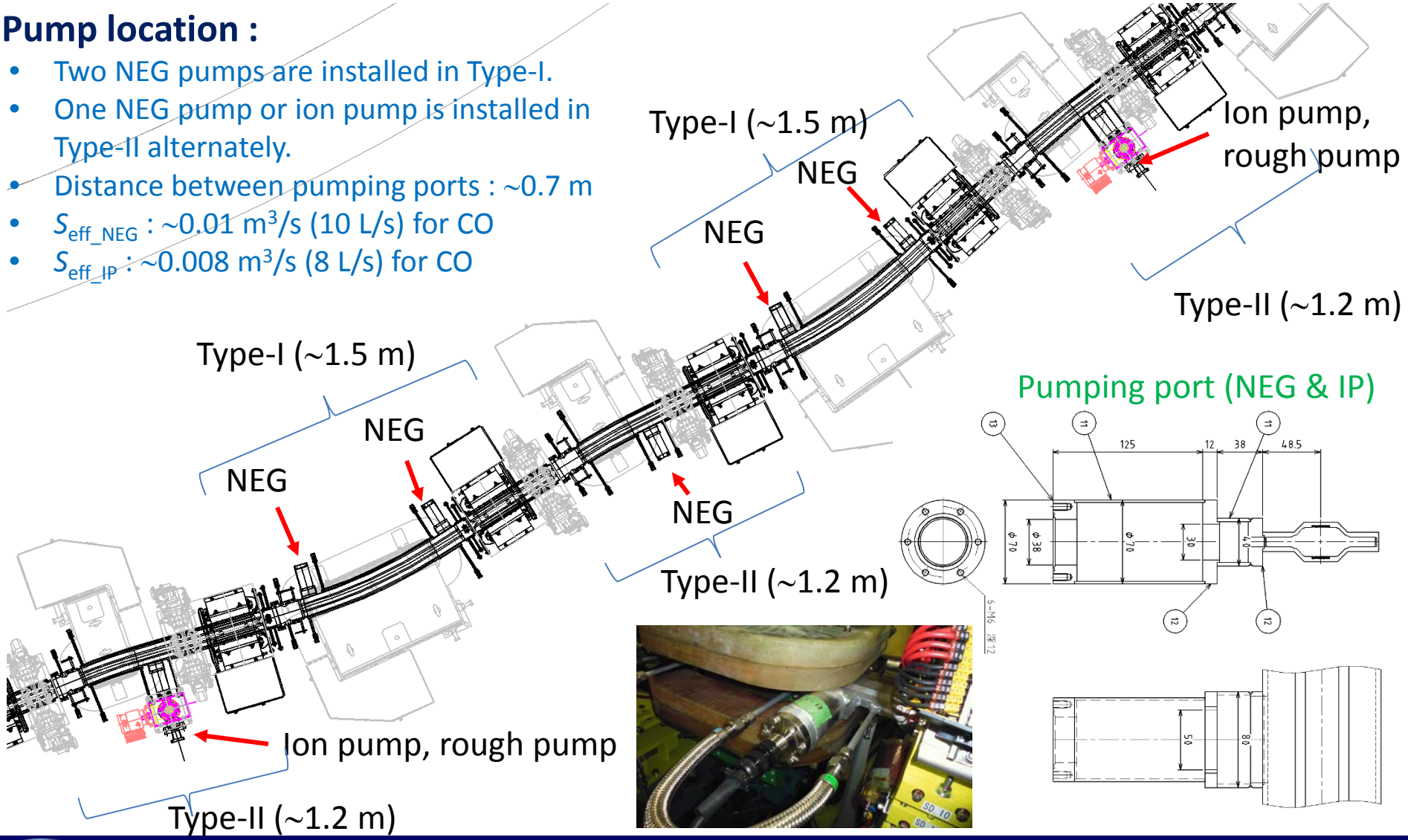


TiN coating

Overview (Arc sect.)

Pump location :

- Two NEG pumps are installed in Type-I.
- One NEG pump or ion pump is installed in Type-II alternately.
- Distance between pumping ports : ~0.7 m
- S_{eff_NEG} : ~0.01 m^3/s (10 L/s) for CO
- S_{eff_IP} : ~0.008 m^3/s (8 L/s) for CO

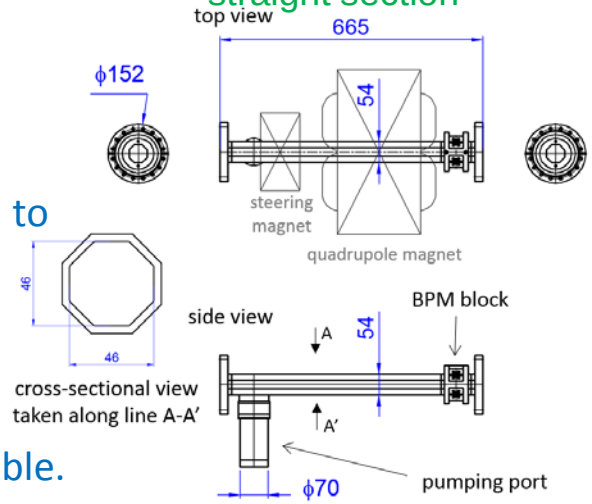


Pumping port (NEG & IP)

Overview (straight sect.)

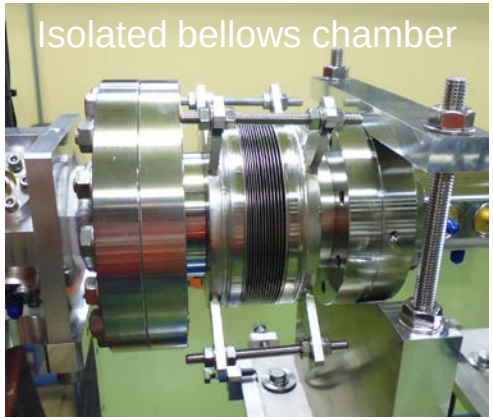
- Beam pipes for straight section. (Al alloy)
  - Much simpler than beam pipes in the arc sections.
    - No antechamber
    - No groove surfacing
    - No water cooling channel
    - Isolated bellows chambers instead of bellows part welded to the beam pipe
  - Having different cross-sections to fit special components installed in the straight sections.
    - Cross-sections of beam pipes change as smoothly as possible.

Example of beam pipe for the straight section



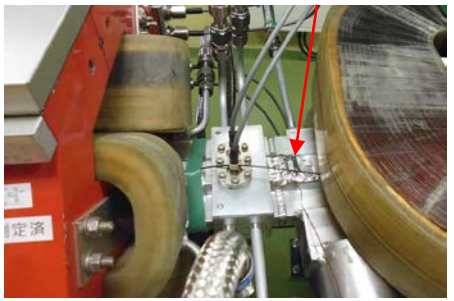
Cross-sections of vacuum components in the straight sections.

RF section	Circular	ϕ150 mm
Feedback kicker	Octagonal	62.8 mm (face-to-face)
Feedback monitor	Octagonal	46 mm (face-to-face)
Inj. and Ext. kicker	Rectangular	42 mm × 37 mm
Inj. and Ext. septum	Circular	ϕ41.2 mm
Adjacent area of the east arc section, etc.	Octagonal	46 mm (face-to-face)



Overview (Control system)

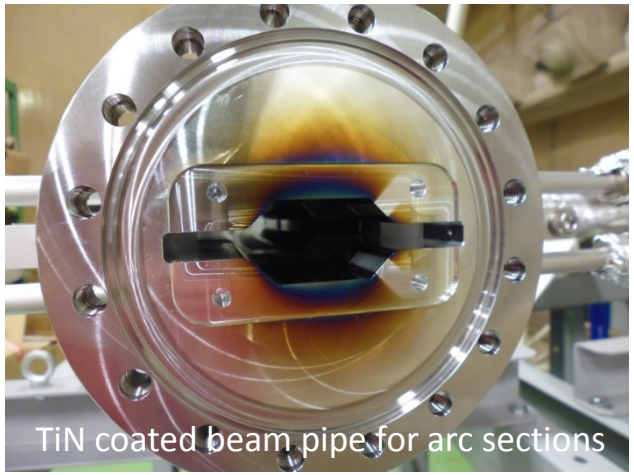
- Pressures are monitored by ion pumps.
  - Number of IPs :
    - East sect.; 11, West sect.; 11, North sect.; 4 + 4(septum), South sect.; 3
    - Installation interval of IP : ~ 6 m
  - When the pressures exceed 1×10^{-4} Pa at several points at the same time in one section, the section is isolated by gate valves and beam injection is inhibited.
  - One CCG is also installed in each section. (4 CCGs in DR, 1 CCG in LTR, 1 CCG in RTL)
  - One RGA is installed in East arc section.
- Temperatures of beam pipes are monitored.
  - Number of monitoring points :
    - East sect.; 13, West sect.; 12, North sect.; 4, South sect.; 1
  - When the temperature exceeds 80°C, an alarm is raised.
    - Temperature rise due to beam operation has not been observed so far.
- Flow rates of cooling water are continuously monitored.
  - Water flows rate of every blanch is monitored by water flow switch. (10 blanches)
  - When the flow rate falls below the threshold value, an alarm is raised.
    - Since two flow switches occasionally malfunctioned due to the magnetic field from the magnet, they were wrapped in high permeability magnetic shield (Permalloy).

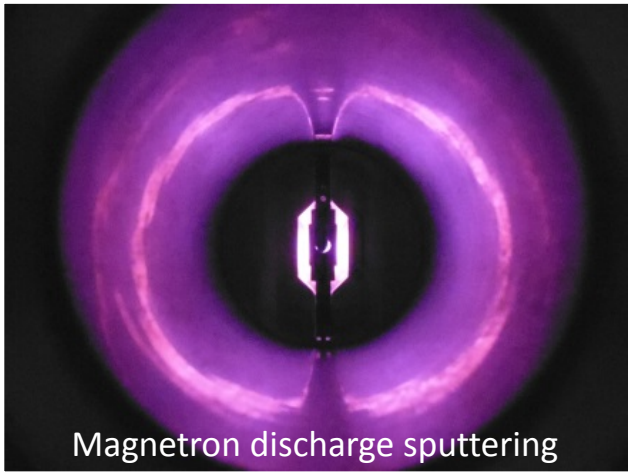


Construction 1

- Pre-installation works :
  - Almost all beam pipes (105) were coated with TiN film (^{t}200 nm) and baked (150°C, 24 h) at the coating & baking facility in KEK.
    - Not including ceramics pipes for Inj. & Ext. kickers, Ext. septum, special beam pipes for RF sections, FB monitor & kicker, DCCT, Inj. & Ext. septums.
    - NEG pumps were activated during the baking.
    - Not baked in-situ after installation.

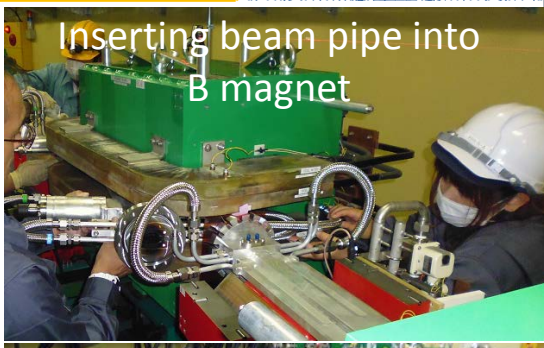

Coating & baking facility in KEK

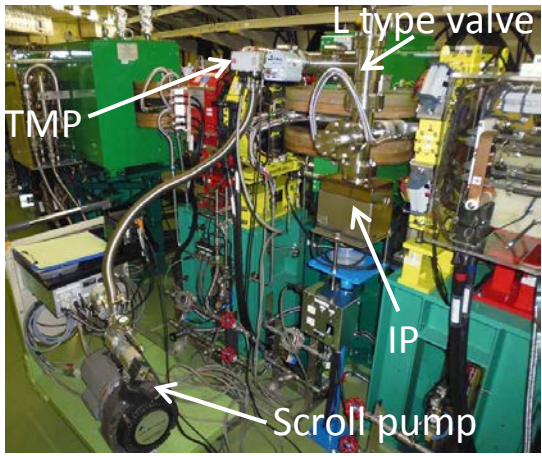

TiN coated beam pipe for arc sections


Magnetron discharge sputtering

Construction 2

- Installation works :
  - The installation of the beam pipes commenced in May 2016 and finished in January 2018.
- Evacuation from atmospheric pressure :
  - Each section was evacuated by rough pumps (TMP + scroll pump) & ion pumps before and during NEG activation.
    - When the pressure decreased to ~10^{-4} Pa, ion pumps were operated.
    - When the pressure decreased to ~10^{-5} Pa, NEG activation was started.
    - It takes about several days before NEG activation.
  - After NEG activation, rough pumps were isolated by angle valves and removed.

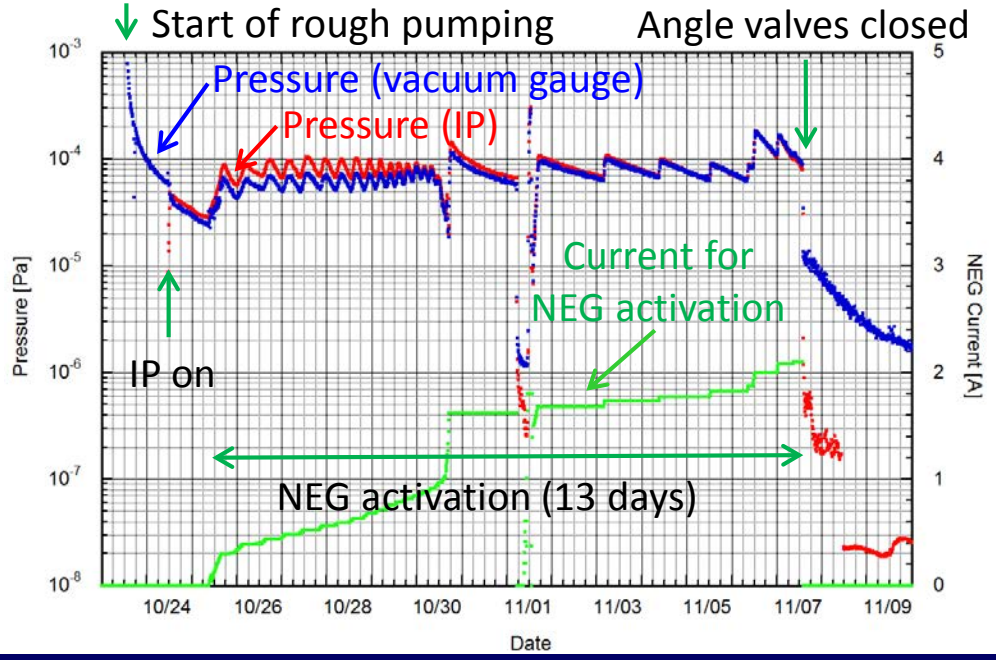


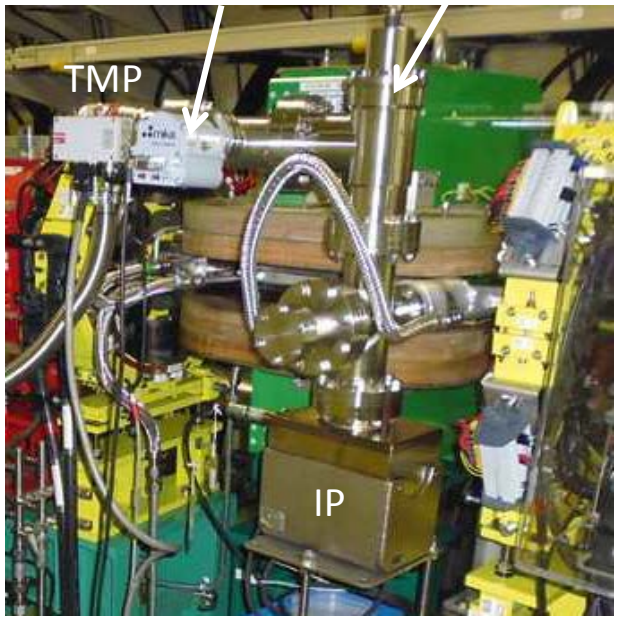


NEG activation

- Heating power for NEG activation was controlled so that the pressure did not exceed 1×10^{-4} Pa.
  - The pressure was monitored by ion pumps and vacuum gauges at manifold between TMP and IP port.
  - Since the conductance of beam pipe and the conductance between pumping port and beam duct are small, the pressure in NEG port during activation is higher than measured value.
  - It takes about 3 weeks from the start of evacuation to the end of NEG activation.

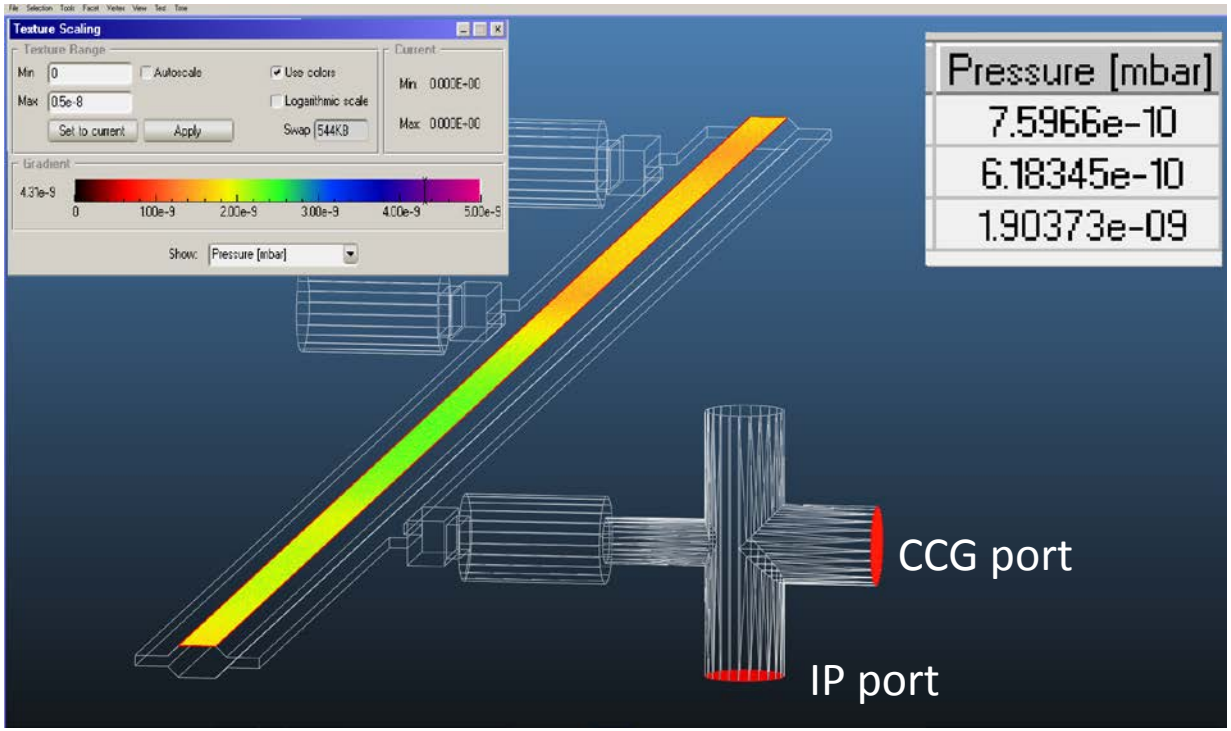
Pressure during NEG activation (East arc section)





Pressure estimation

- Pressure in the beam pipes was estimated by Molflow+ (Monte-Carlo Simulator developed at CERN)
  - Model : 1 Type-I beam pipe + 1 Type-II beam pipe
  - Pumps : 2 NEG pumps (0.05 m^3/s) in Type-I, 1 ion pump (0.04 m^3/s) in Type-II.
  - Mass : 28, Temp. : 20 °C, Thermal gas desorption rate : 1×10^{-9} $Pam^3/s/m^2$ = 1×10^{-11} $mbarL/s/cm^2$
  - PSD rate : η=0 molec./photon (No stored beam)

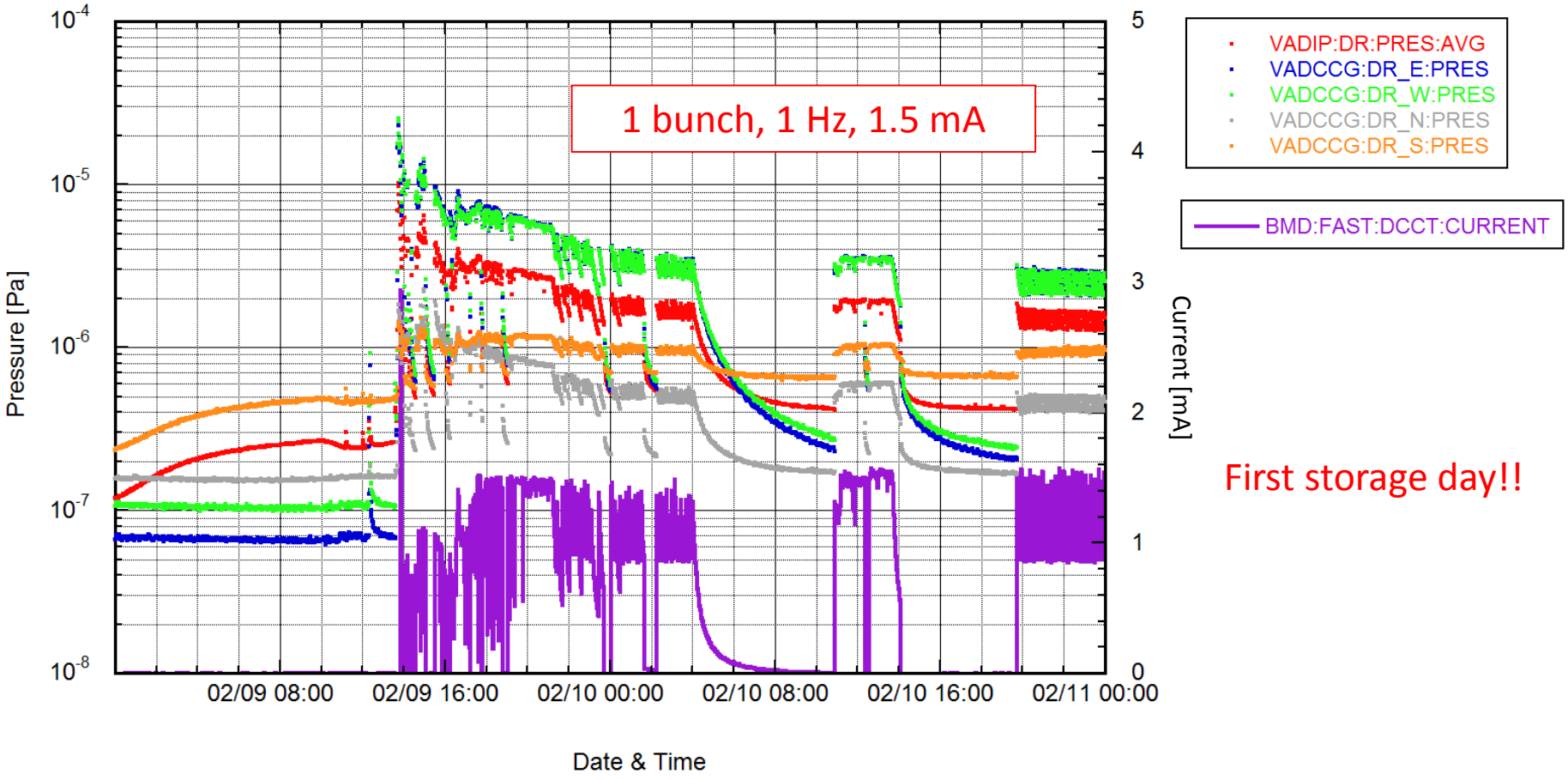


CCG port
IP port
Average in beam channel

Result is similar to the measured pressure before beam operation.

Dynamic pressure 1

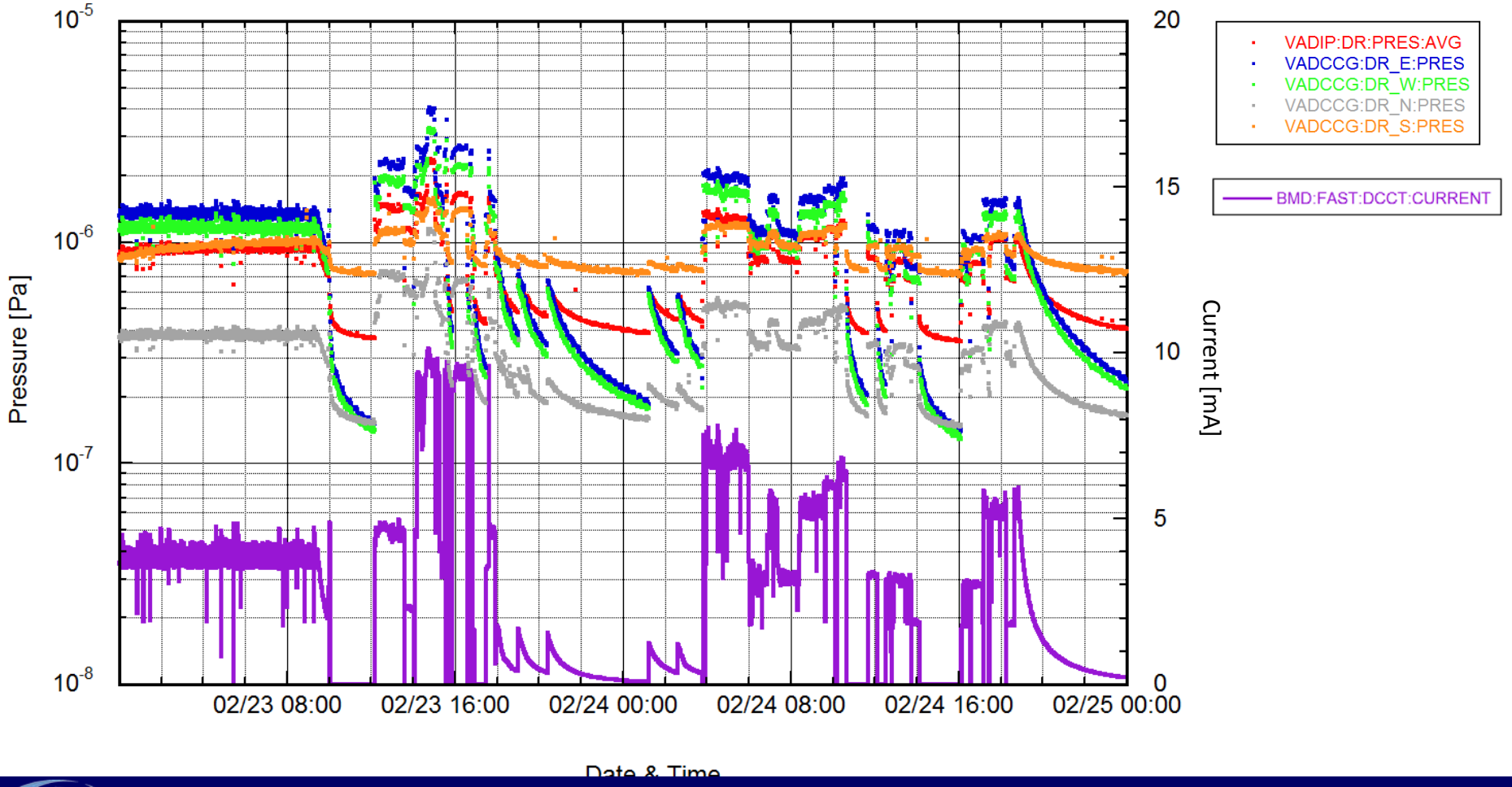
- Beam operation started on Feb. 8th.
  - Storage of beam started on Feb. 9th.
  - The pressure exceeded 1×10^{-5} Pa, when the beam was accumulated for the first time.



First storage day!!

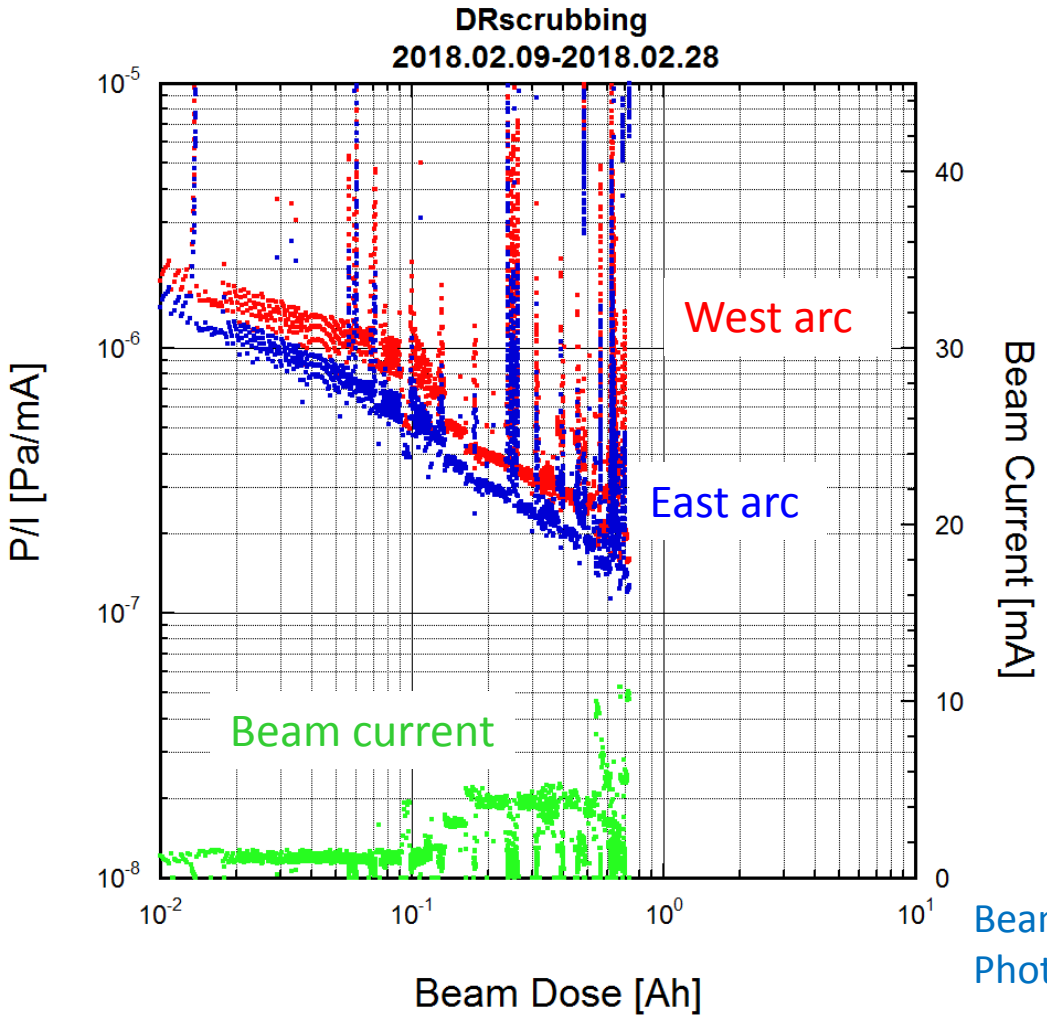
Dynamic pressure 2

- Beam current gradually increased and pressure gradually decreased.
  - Maximum storage current reached 10 mA (4 bunch, 25 Hz) on Feb. 23rd.



Vacuum scrubbing

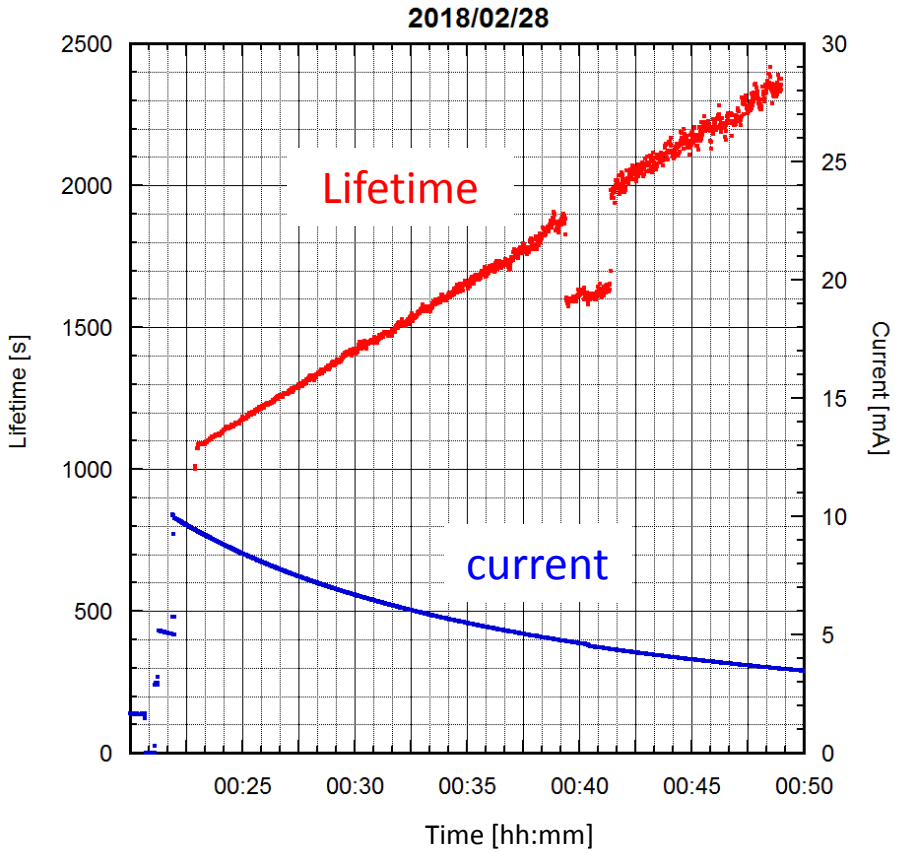
- Vacuum scrubbing has been progressing smoothly so far.

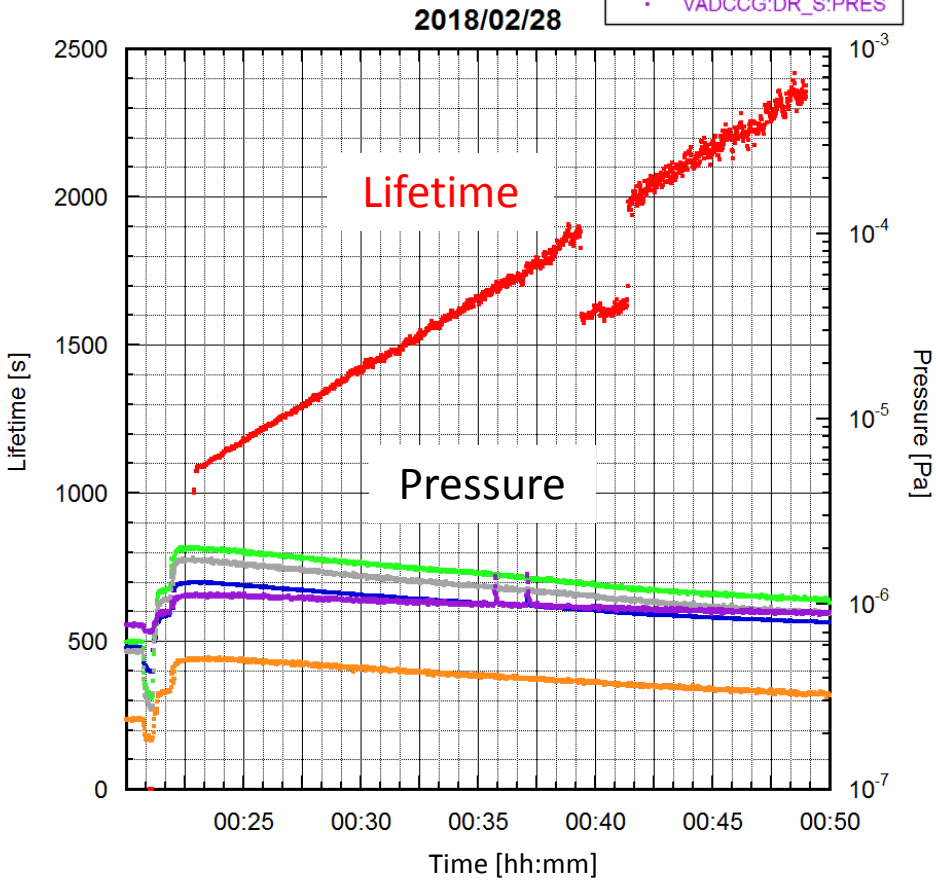


Beam dose : 1 Ah =
Photon dose 5.2×10^{22} photon/m

Beam lifetime

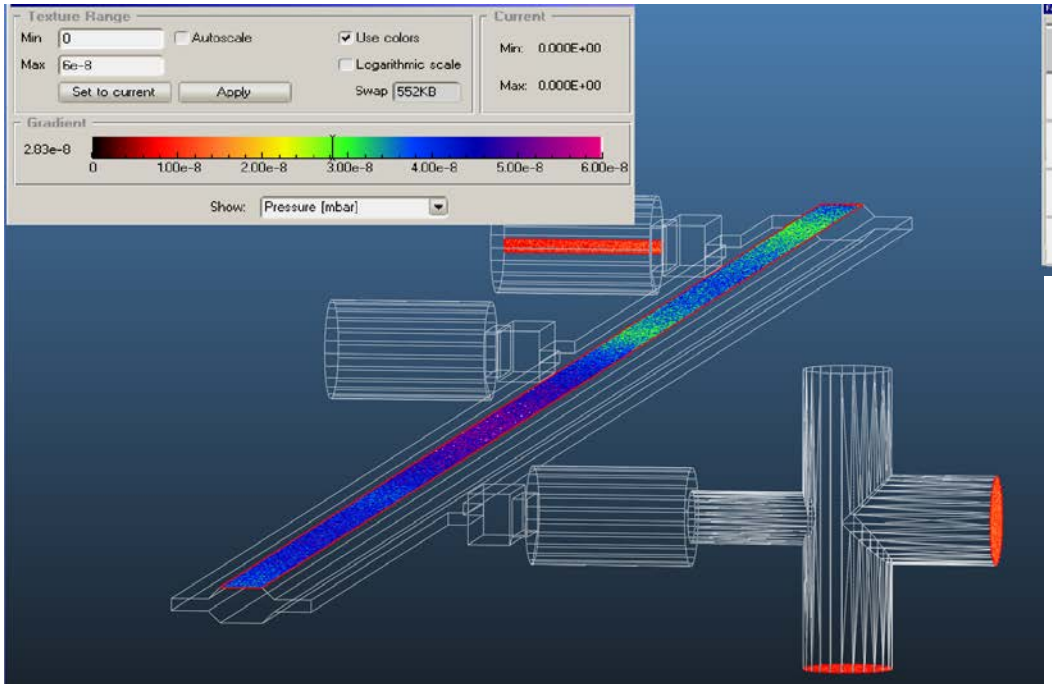
- Beam lifetime was larger than 1000 s when beam current was 10 mA.
  - Operation mode : 4 bunch, storage mode
  - Beam dose : 0.7 Ah (Photon dose : 3.6×10^{22} photon/m)





PSD rate estimation

- Pressure in the beam pipes was estimated by Molflow+ (Monte-Carlo Simulator developed at CERN) to estimate PSD rate.
  - Pumps : 2 NEG pumps (0.05 m^3/s) in Type-I, 1 ion pump (0.04 m^3/s) in Type-II.
  - Mass : 28, Temp. : 20 °C, Thermal gas desorption rate : 1×10^{-9} $Pam^3/s/m^2$ = 1×10^{-11} mbarL/s/cm^2
  - PSD : η=1×10^{-4} molec./photon, stored beam current = 8.85 mA
    - SR irradiates both sides of antechambers evenly.



#	Pressure [mbar]
41	1.04401e-08
250	1.24291e-08
251	1.01434e-08
360	4.08547e-08

NEG port
CCG port
IP port
Average in beam channel

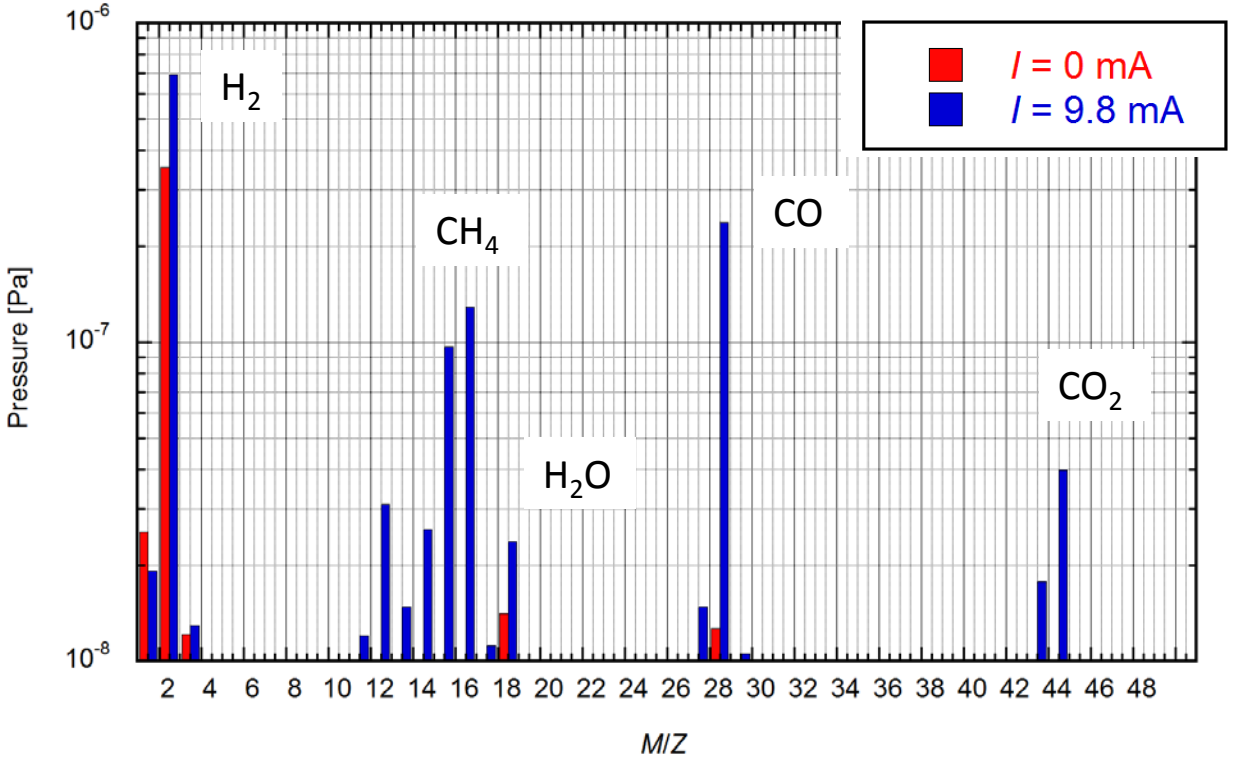
The calculated pressure is close to the measured pressure.
($P_{measured\_CCG}$: $1\sim2\times10^{-8}$ mbar)

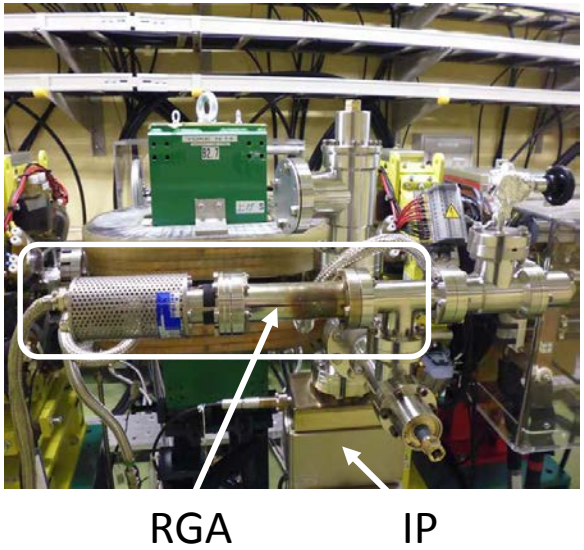
$\eta \approx 1\times10^{-4}$ molec./photon (beam dose : 0.7 Ah, photon dose : 3.6×10^{22} photon/m)
Almost as expected!!

$\eta \approx 1\times10^{-5}$ molec./photon is required to obtain enough lifetime (1000 s) with design beam current (70.8 mA).

Residual gas components

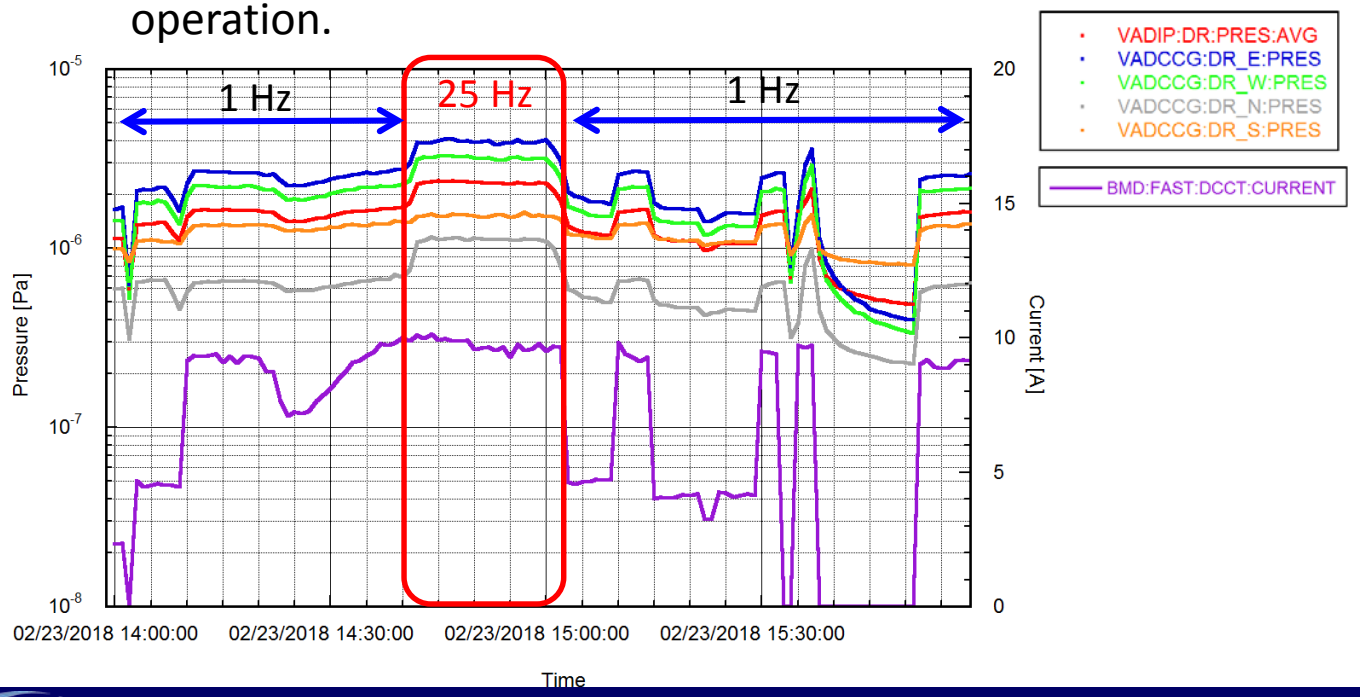
- RGA data of the dynamic pressure was taken at the east arc section.
- Main gas components at beam dose = 0.7 Ah
  - H_2 (beam current = 0 mA, $P_{IP} = 4.3\times10^{-7}$)
  - H_2, CO, CH_4, CO_2 (beam current = 9.8 mA , $P_{IP} = 1.4\times10^{-6}$)
    - They are typical residual gas components in beam pipes irradiated by SR and evacuated by NEG.

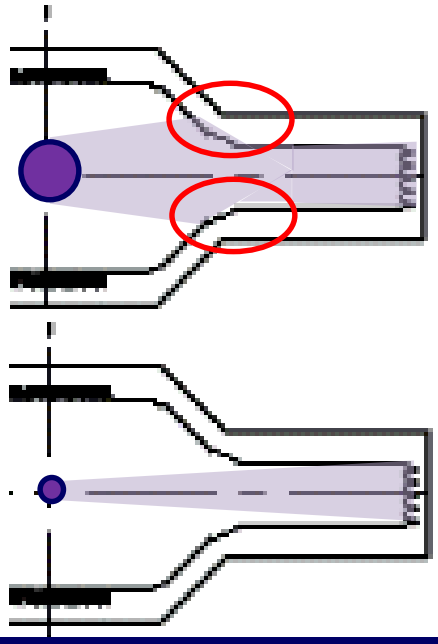




Concerns 1

- Pressure rise during beam operation at a repetition rate of 25 Hz.
  - Pressure at a repetition rate of 25 Hz is larger than that of 1 Hz.
    - Vacuum scrubbing was performed by storage mode or at a repetition rate of 1 Hz, and time of beam operation at a repetition rate of 25 Hz is very short.
    - It may be caused by the increase in the time stored with large-size beam.
    - It seems there are places where only large-size beam can scrub.
  - It is expected that the vacuum scrubbing of such places will progress during Phase-II operation.



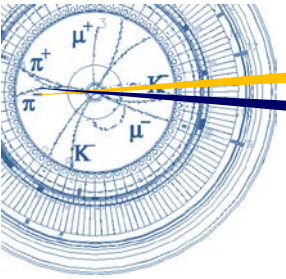


Concerns 2

- Saturation of NEG pump
  - Re-activation (conditioning) of NEG pumps is required when pumping speed of NEG pump becomes small.
  - It takes several days to re-activate NEG pumps.
    - DR can not be operated during re-activation of NEG pumps.
  - There is no indication that the pumping speed of NEG decreases up to now.
  - Re-activation will be performed during long shutdown. (this summer?)
- Electron cloud issue
  - Antechamber, TiN coating and Grooved surfacing are adopted as countermeasures against ECE.
  - It is expected that electron cloud density integrated over the ring is 0.13×10^{14} m^{-2} by using TiN coating and antechamber (not including grooved surface) when stored beam current is 70.8 mA.
    - Assumption : δ_{max} of TiN coating = 1, photons irradiating beam channel/whole photon = 0.1
    - Threshold of electron cloud instability : 1.4×10^{14} m^{-2}
  - Electron cloud instability will not occur in DR.
    - It is necessary to continuously observe whether the ECE occurs or not as the stored beam current increases.

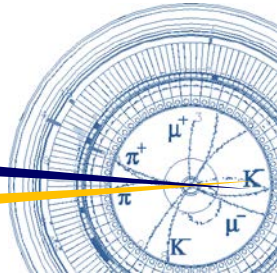
Summary

- Beam operation of DR started on Feb. 8th, and DR vacuum system have no problems so far.
- Vacuum scrubbing has been progressing smoothly so far.
  - The pressure in the beam channel is estimated to be less than 1×10^{-5} Pa with a stored beam current of 10 mA at present. (beam dose = 0.7 Ah)
  - Currently, beam lifetime is larger than 1000 s when the stored beam current is 10 mA.
  - It seems that vacuum scrubbing by beam operation at a repetition rate of 25 Hz is insufficient.
  - ~10 times the beam dose is required to achieve enough lifetime (>1000 s) with design beam current (70.8 mA).
- There is no indication of decrease in the NEG pumping speed.
  - Re-activation will not be required until this summer shutdown.
- As countermeasures against ECE, antechamber, TiN coating and Grooved surface are adopted.
  - It is necessary to continuously observe whether the ECE occurs or not as the stored beam current increases.

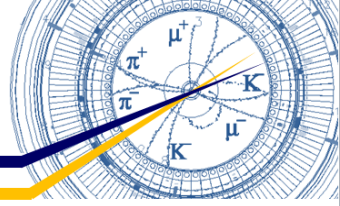


Fin.

Thank you for your attention.

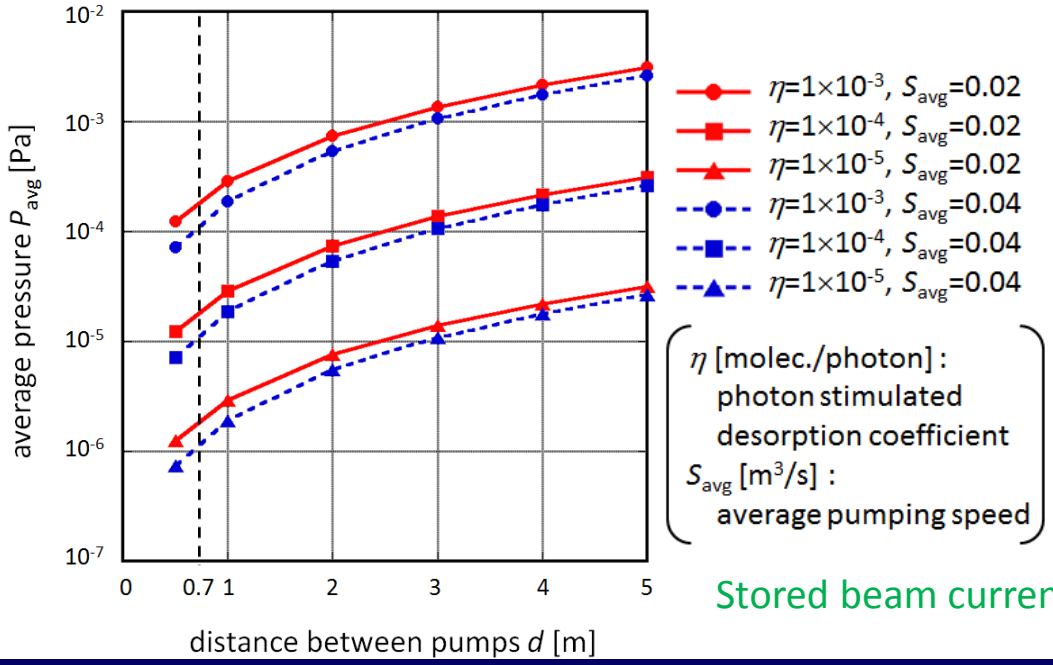


Back-up



Average pressure estimation

- Rough estimation of average pressure in arc sections
  - Required averaged pressure is lower than 1×10^{-5} Pa to obtain enough beam lifetime.
  - 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 0.01 m^3s^{-1} (just after activation) .
  - 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^{-5} molec./photon.
  - 1×10^{-5} Pa with a stored beam current of 70 mA is achievable goal with sufficient scrubbing.



Stored beam current : 70 mA

Average pressure estimation

- Rough estimation of average pressure in arc sections
  - Required averaged pressure is lower than 1×10^{-5} Pa to obtain enough beam lifetime.
  - 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 0.01 m^3s^{-1} (just after activation) .
  - 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^{-5} molec./photon.
  - 1×10^{-5} Pa with a stored beam current of 70 mA is achievable goal with sufficient scrubbing.