Design and Operation Experience of PLS-II Vacuum System

2015.01.25

Taekyun Ha, Chongdo Park

On behalf of Vacuum Group
Pohang Accelerator Laboratory

Contents

- Brief description of PLS-II
- Design of PLS-II vacuum system
  - Tight space (20 IDs / 280 m)
  - High mechanical stability (BPM motion < 1 um)
  - TE mode suppression
  - High power (Photon absorber, RF bellows)
- Some vacuum related experiences
  - IVU problem
  - Breakdown of MCTL (Multi Chanel Transfer Line)
  - Other faults

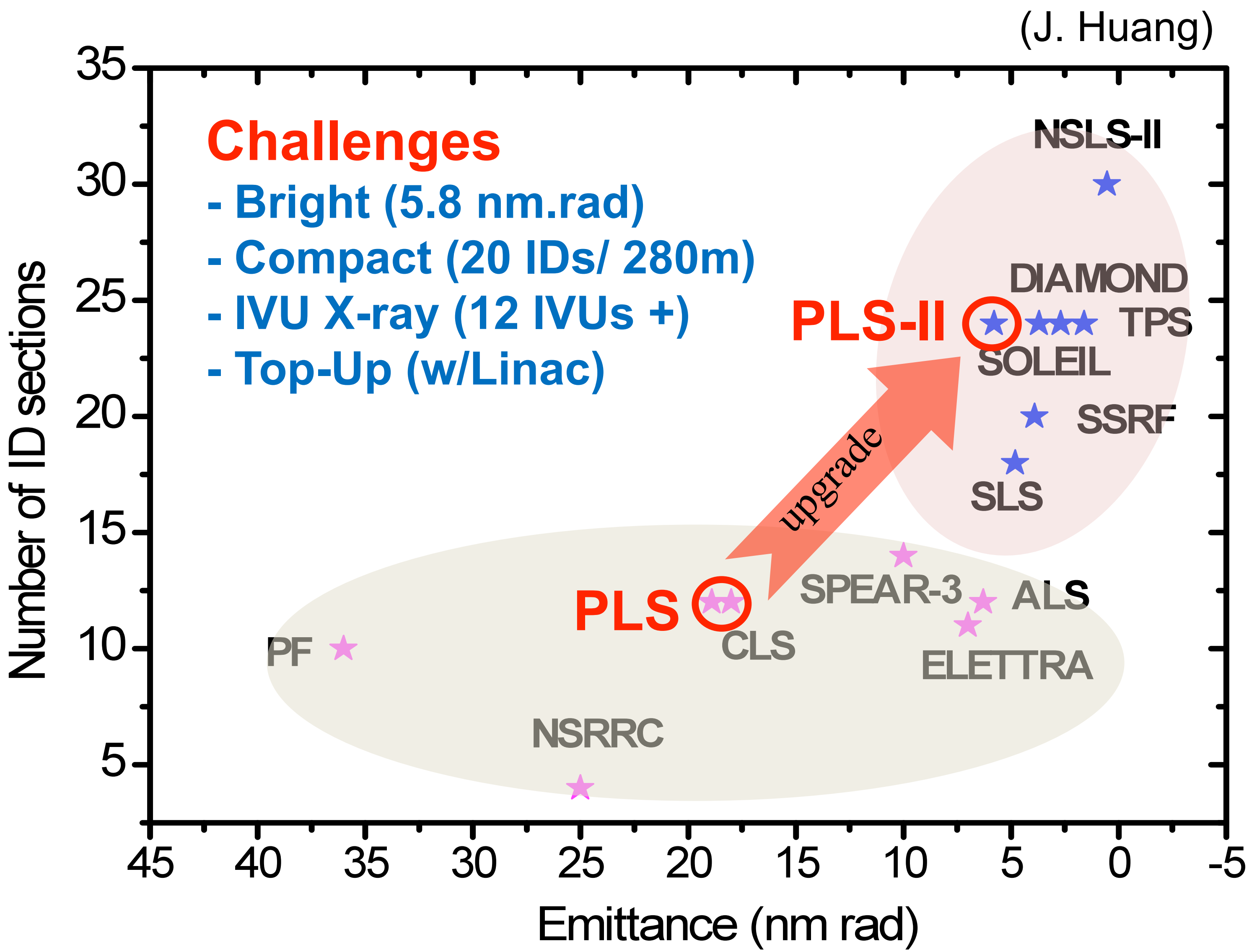
Location

Pohang Accelerator Laboratory

Main parameters of PLS-II

Parameter	PLS	PLS-II	Remark
Beam energy	2.5	**3**	GeV
Beam current	190	**400**	mA
Revolution freq.	1.06855	1.06377	MHz
No of bunches	300	400	
Bunch Charge	0.59	0.94	nC (Calculated)
Bunch length	30	20	ps (Designed)
Bunch current	8.86	18.74	A (Peak value)
Emittance	18.9	**5.8**	nm mrad
Lattice	TBA	DBA	**20 IDs** (10 IDs in PLS)
Circumference	280	280	m

Challenges of PLS-II



Challenges of PLS-II vacuum system

- **High heat load**
  - 417 kW
  - Complicated design of photon absorbers
- **Tight space (Compact ring & DBA lattice)**
  - Be built in existing building (288 m ring)
  - Limited space for vacuum components
- **High mechanical stability**
  - < 1 um (rms)
  - Ground motion
  - Thermo mechanical effect

Re-installation of PLS-II storage ring

PLS

Dismantling

DEC. '10

Re-installation

JAN. '11

PLS-II

Jun. '11

PLS-II timeline

○ **2011**

- 25 January, PLS-II installation begins
- 23 May, Linac commissioning begins
- 13 June, 3 GeV beam
- 25 June, SR installation finished
- 1 July, First turn
- 5 July, Kicker PS accident
- 5 August, First accumulation
- 7 October, 100 mA stored
- 24 October, First photons to beamline

○ **2012**

- 14 February, Commissioning with users
- 21 March, Start of operations

○ **2013**

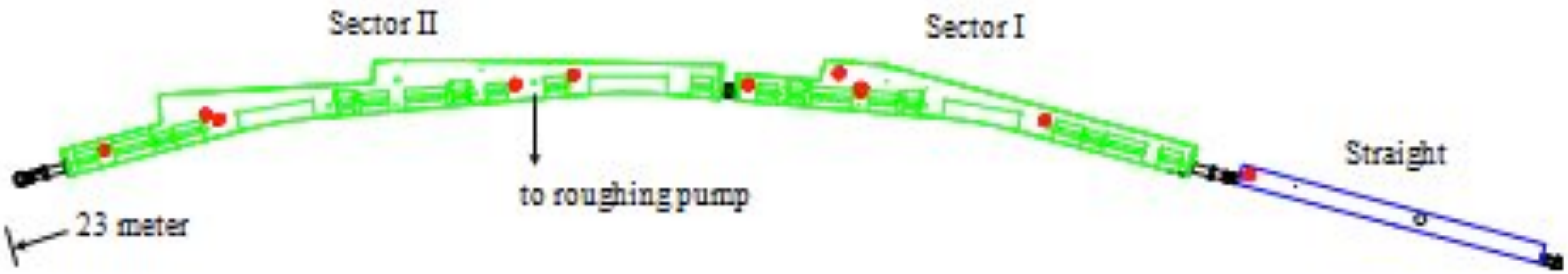
- 18, Jun, 200 mA top-up operation

○ **2014**

- January, MCTL break down (2 months for repair)
- October, IVU foil bump (3 IVUs)
- December, 400 mA top-up operation

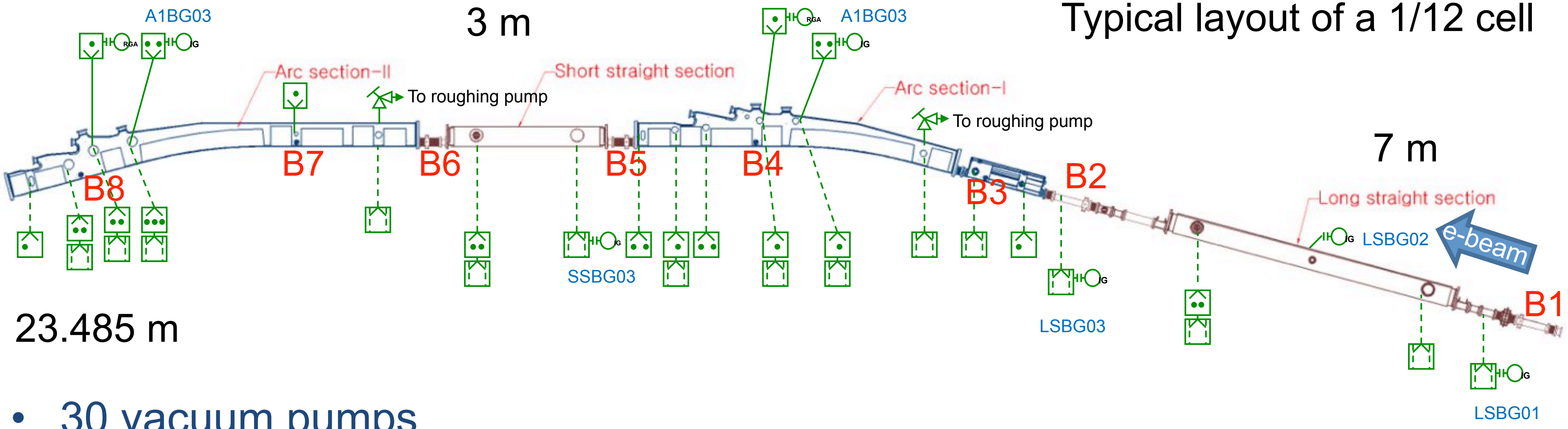
SR Vacuum

PLS Vacuum System (normal cell)

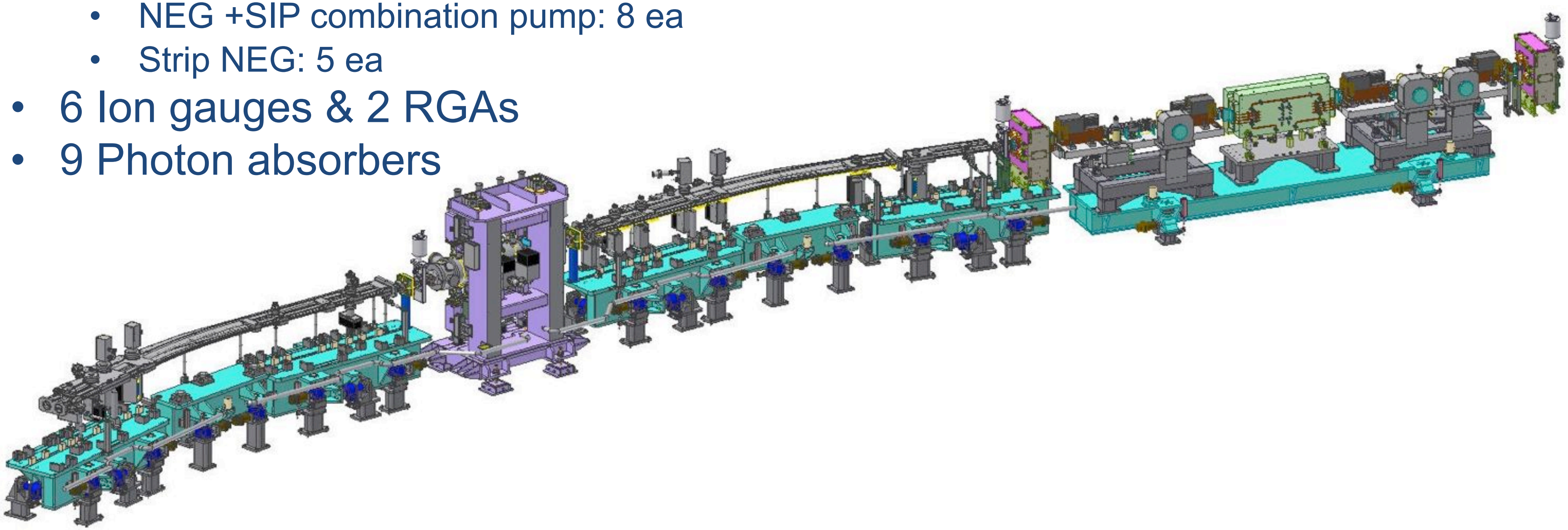


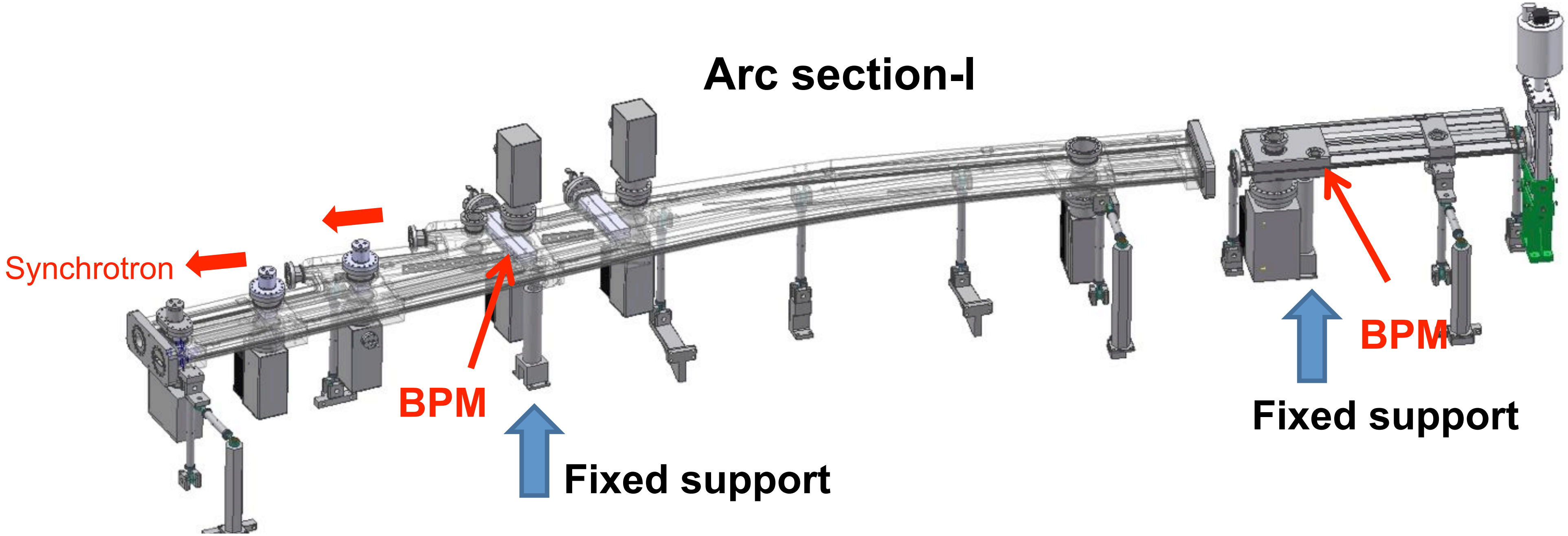
- Chamber material
  - *A5083-H321 (Machined)*
  - *A6063-T5 (Extruded)*
  - *Stainless Steel 304L/316*
- Photon absorber; *OFHC Cu*
- Roughing pump
  - *Magnetic turbo + dry pump*
- Main vacuum pump
  - *SIP; 10 * 60 l/s*
  - *NEG(ST707); 19 * WP950*

Layout of PLS-II storage ring vacuum system

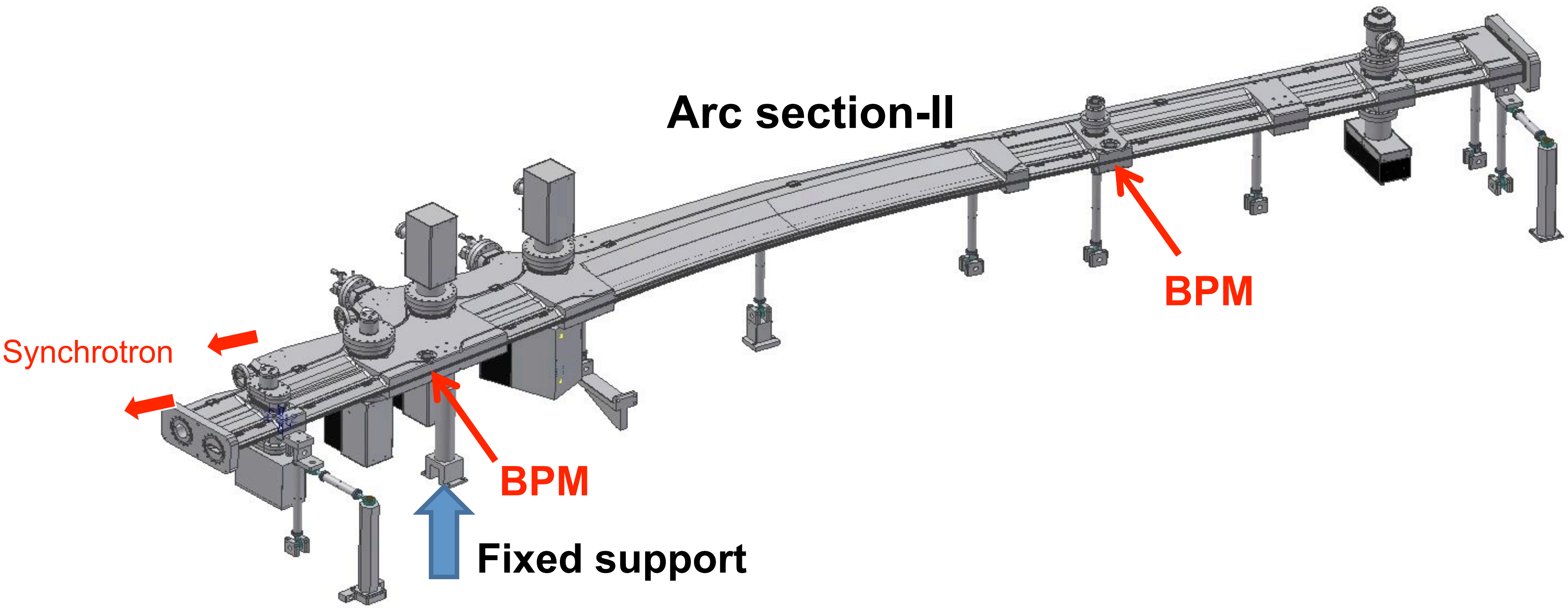


- 30 vacuum pumps
  - Sputter ion pumps (30 l/s + 60 l/s): 7 ea
  - Lumped NEG (WP950 + D-400-2): 9 ea
  - NEG +SIP combination pump: 8 ea
  - Strip NEG: 5 ea
- 6 Ion gauges & 2 RGAs
- 9 Photon absorbers



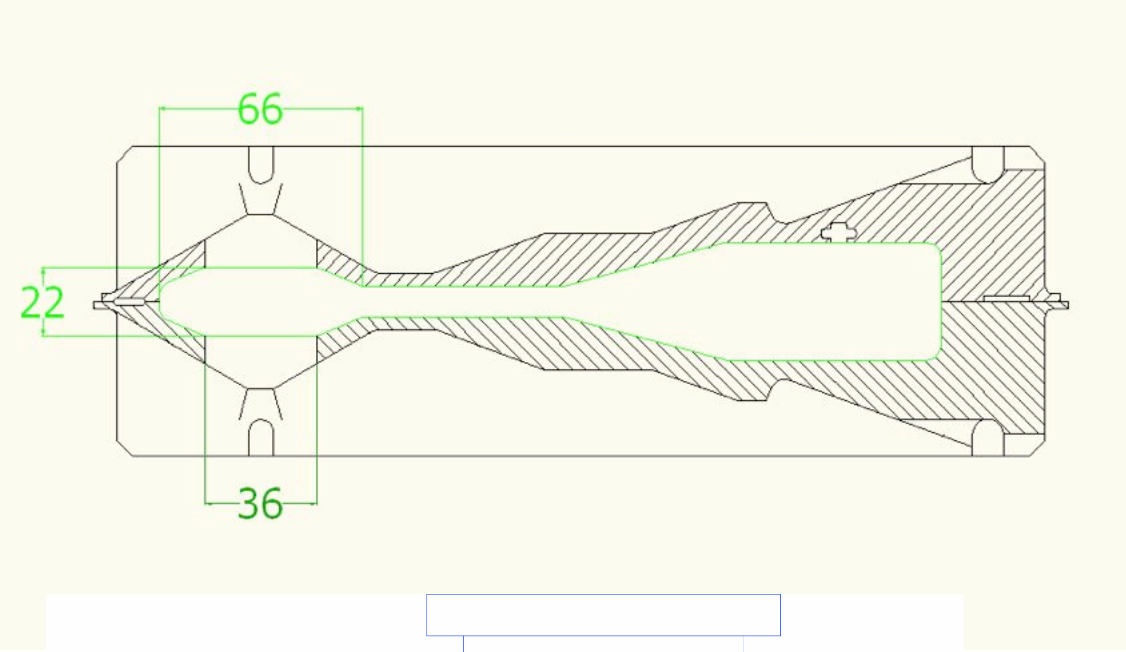


Chamber & supports (Arc section)



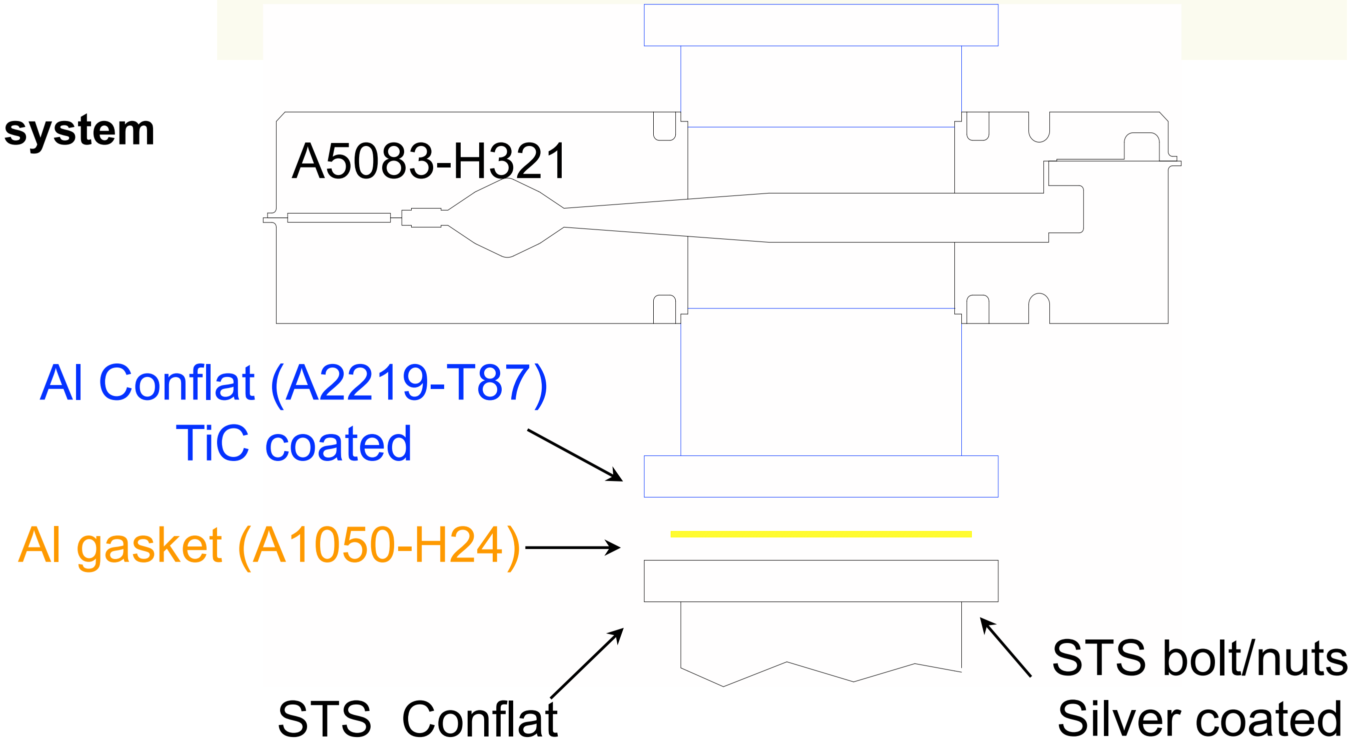
Arc-section vacuum chamber

- **Cross section**

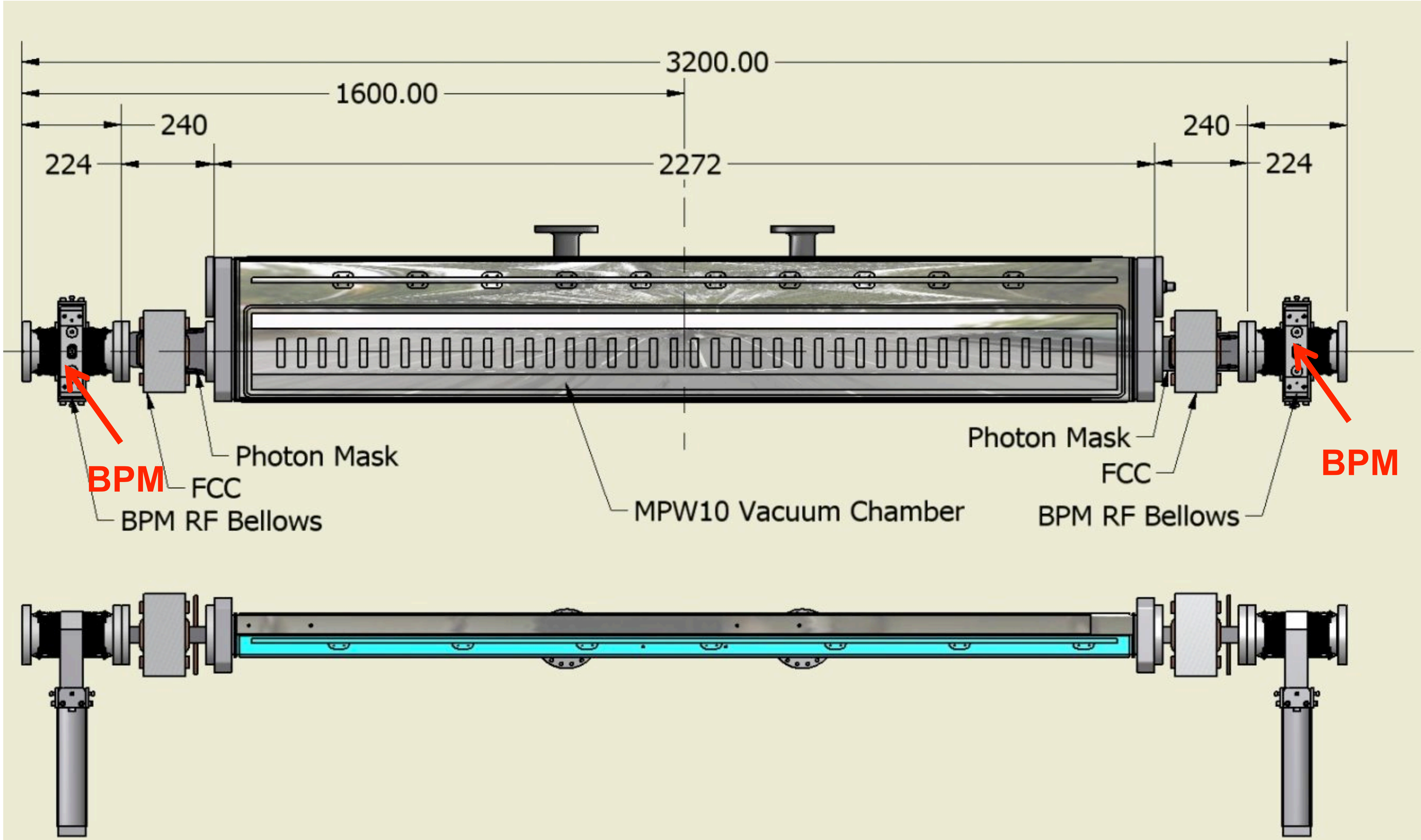


- **Vacuum seals**

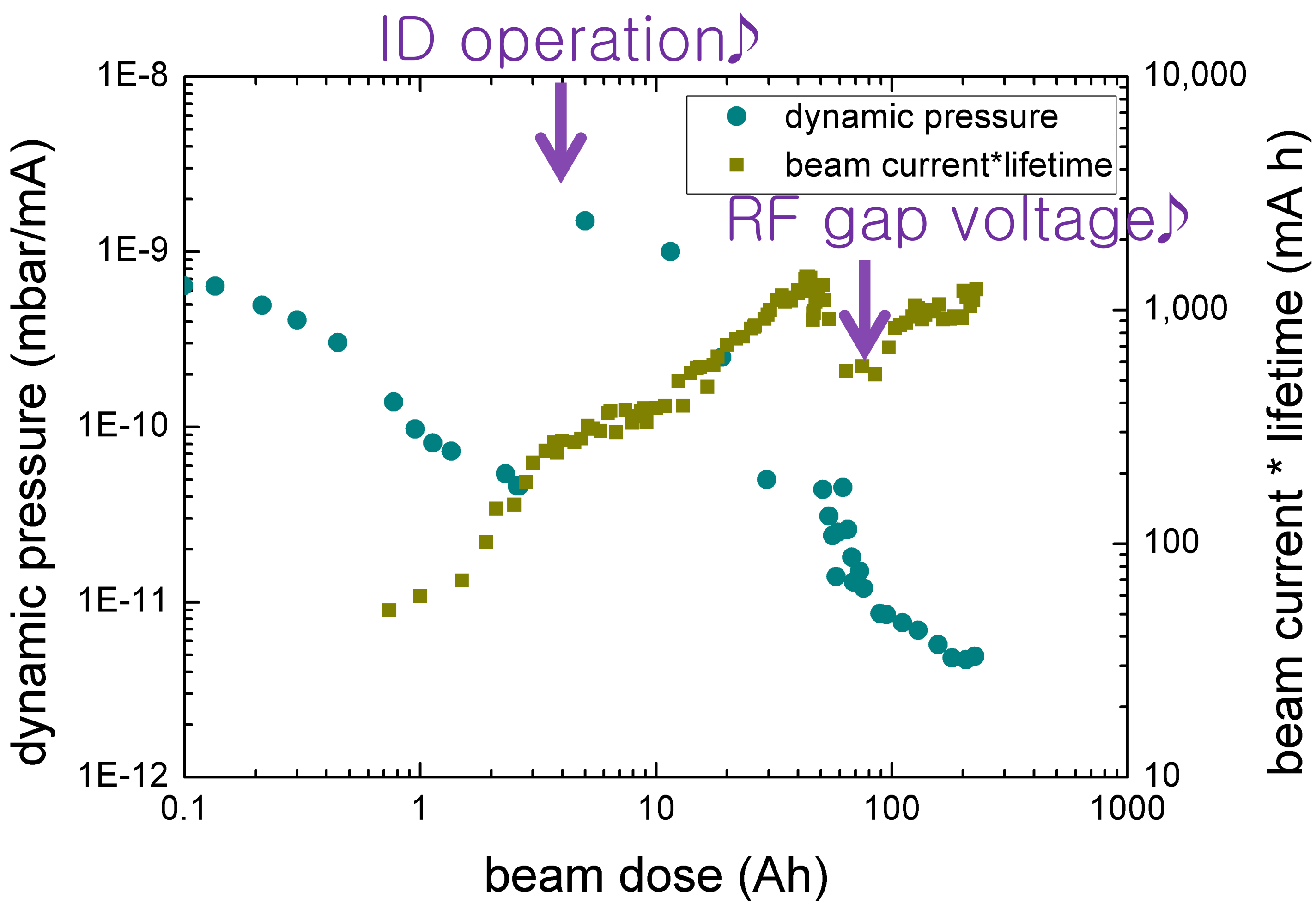
- Al/SUS hybrid Conflat system



Chamber supports (Short straight section)



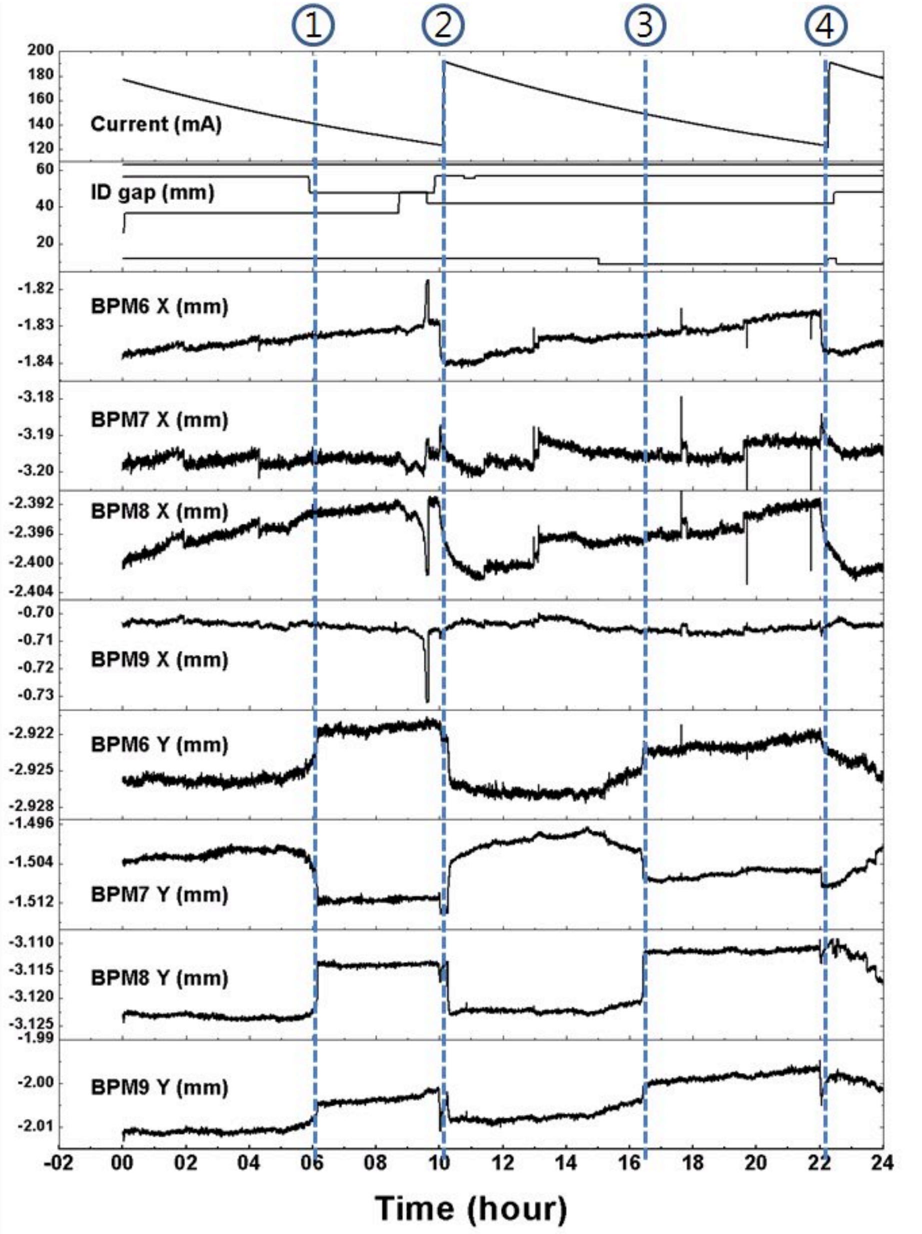
Pressure and lifetime in the early stage

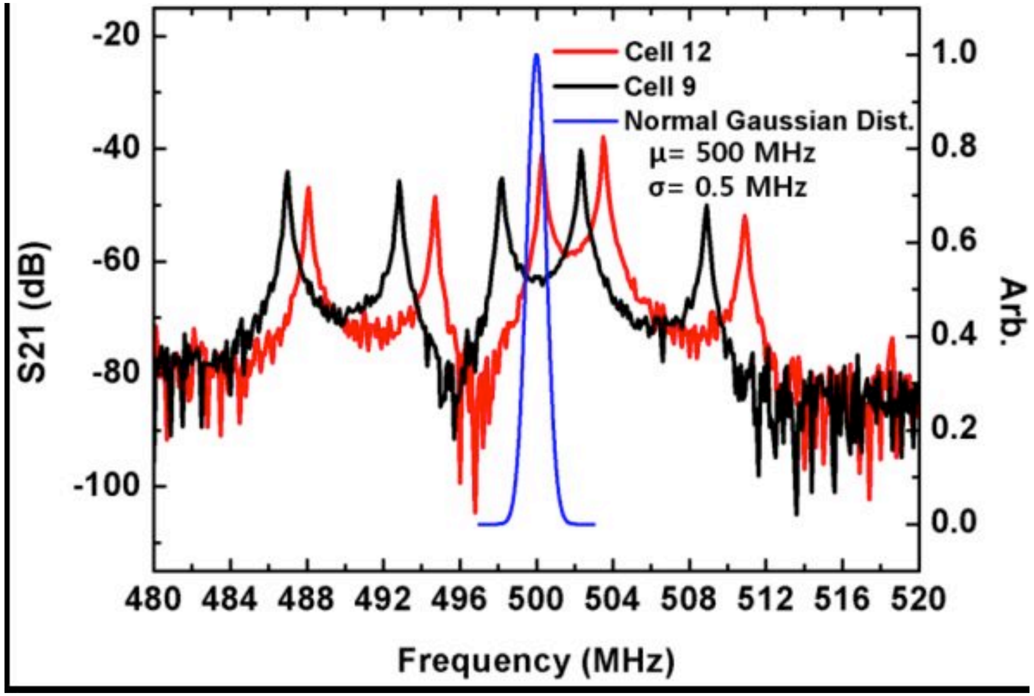


- Dynamic pressure reached to $<10^{-11}$ mbar/mA after integrated beam current of 50 Ah which is our target value.
- Beam-gas scattering lifetime dominates at the early stage of commissioning. After ~50 Ah, Tousheck effect mainly limits beam lifetime.

TE mode suppression

TE mode excited in PLS SR chamber



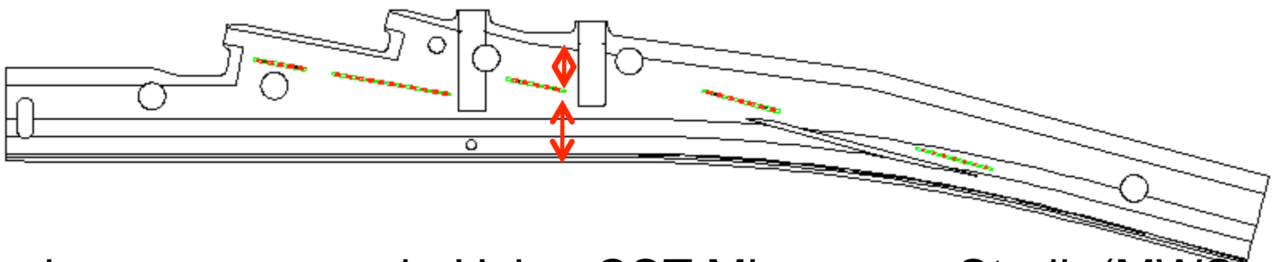


Shunt structure to avoid TE mode in PLS-II Vacuum chamber

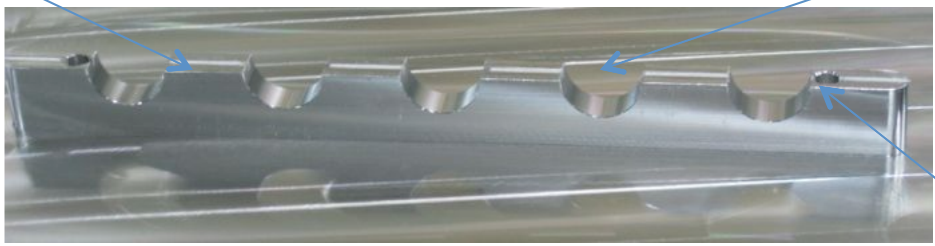
Design Goal

→ No resonance mode in the frequency band of 500 ± 5 MHz

How to ?

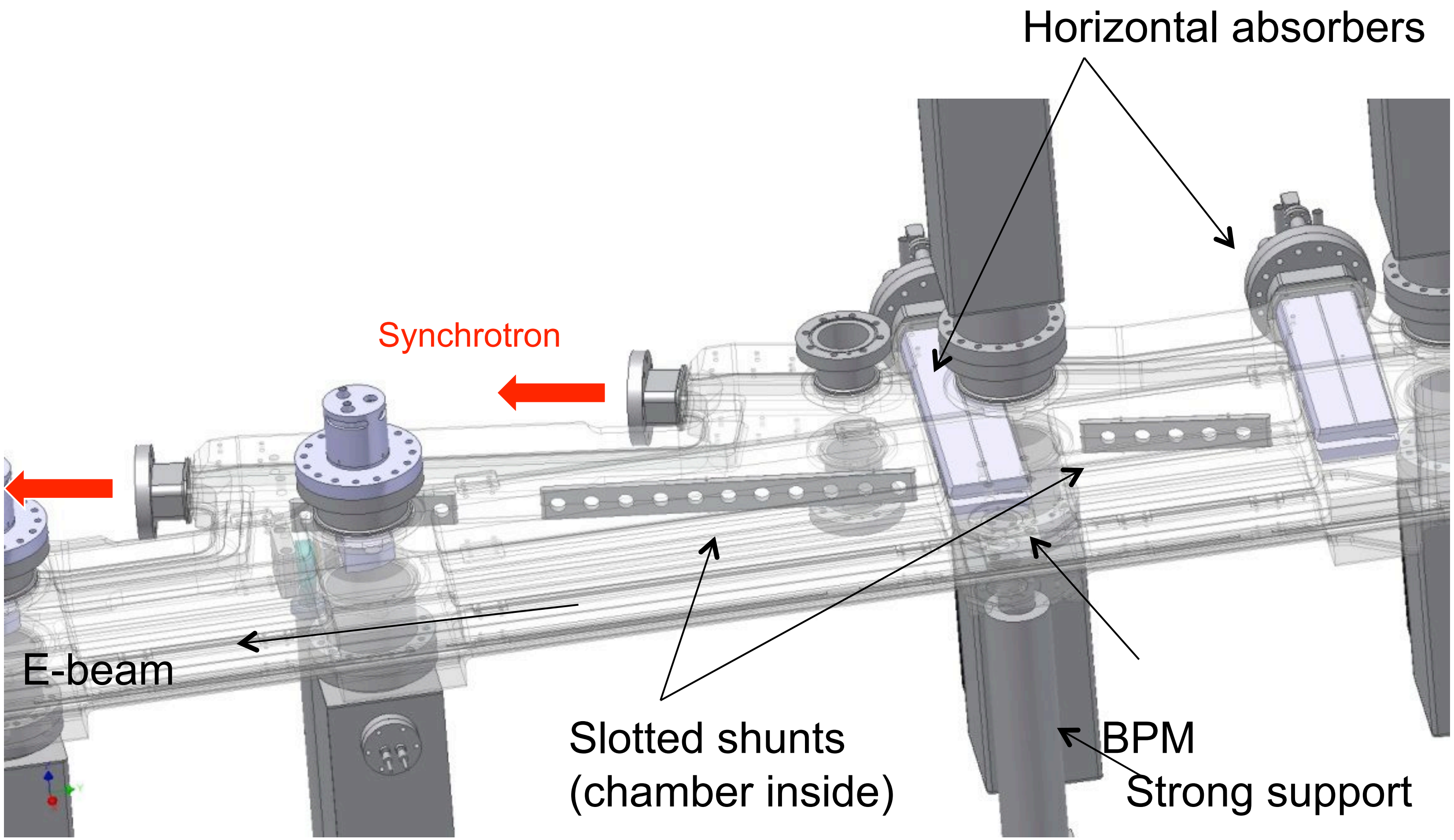


Find resonance mode Using CST Microwave Studio(MWS)
Shunt structure (stiffener)
→ Reduce effective width
→ Control of frequency of TE modes



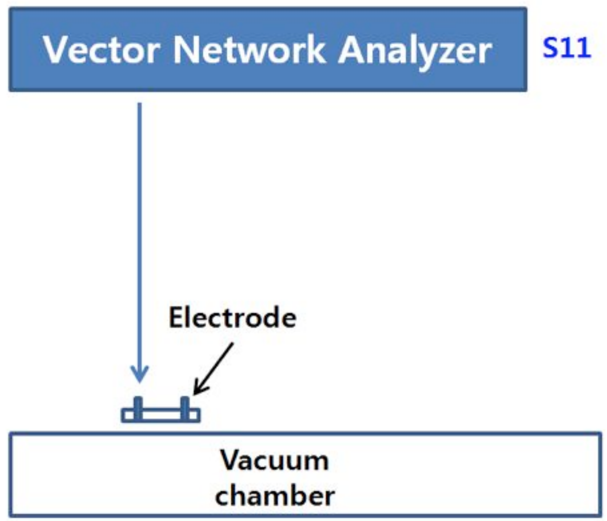
SR vacuum chamber assembled

- To control the resonance mode frequency
  - Slotted stiffeners are installed to minimize conductance reduction

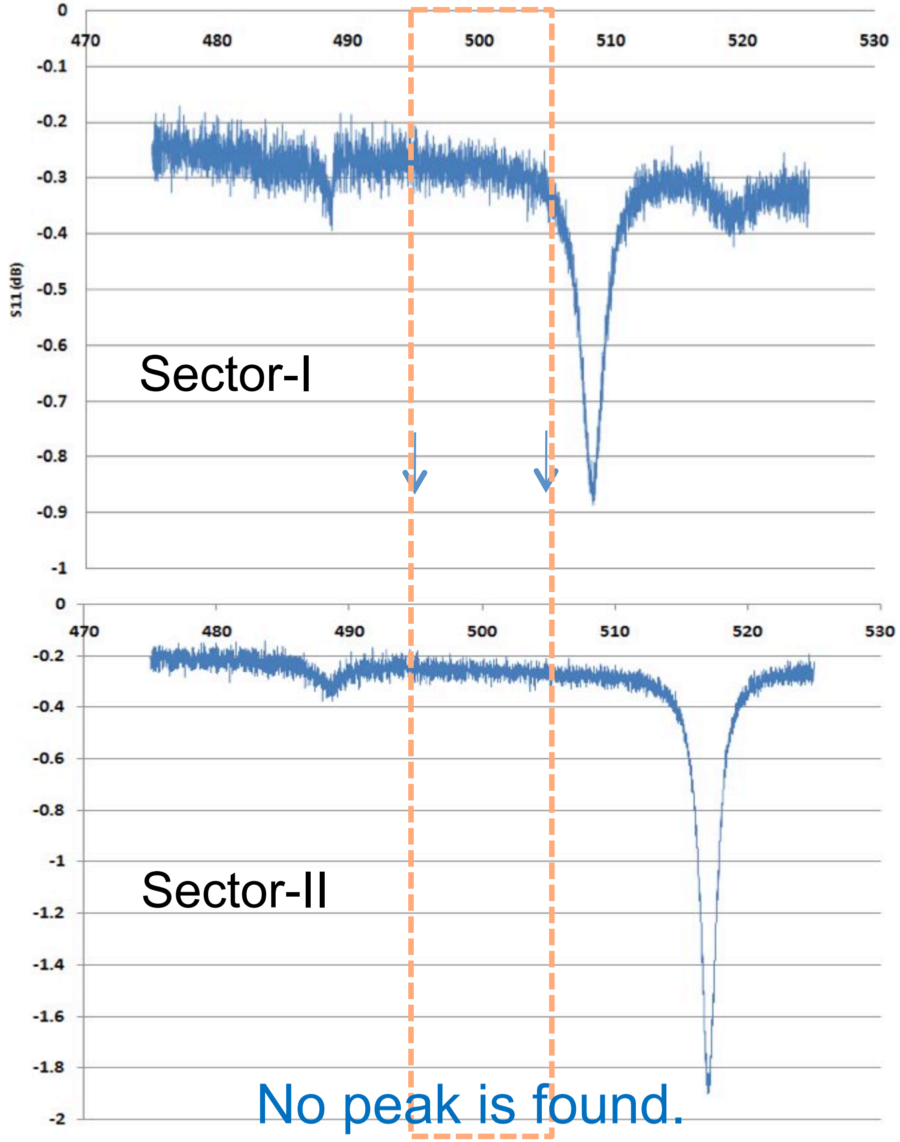


TE mode measurement results

- Setup and Results



Pickup antenna on BPM electrode



No TE mode found in PLS-II operation mode until now!

Photon absorber & RF bellows

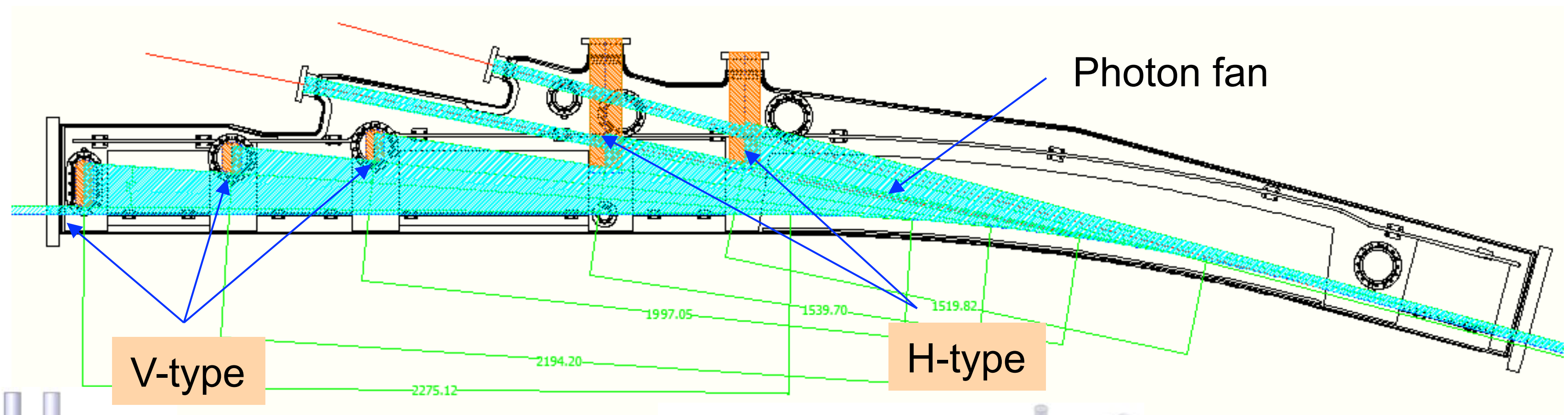
Photon absorbers in PLS-II

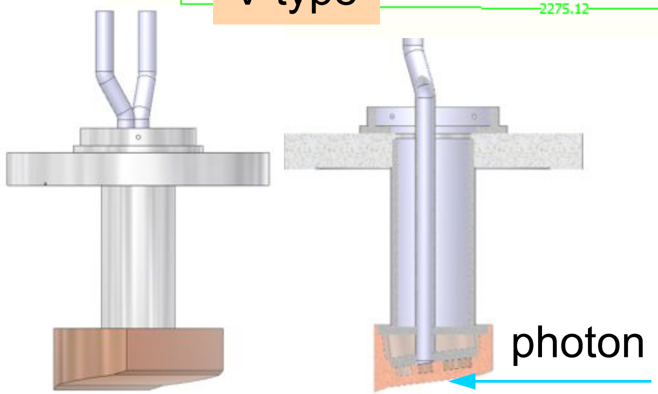
- Total synchrotron radiation power is increased from 110 kW to 417 kW.

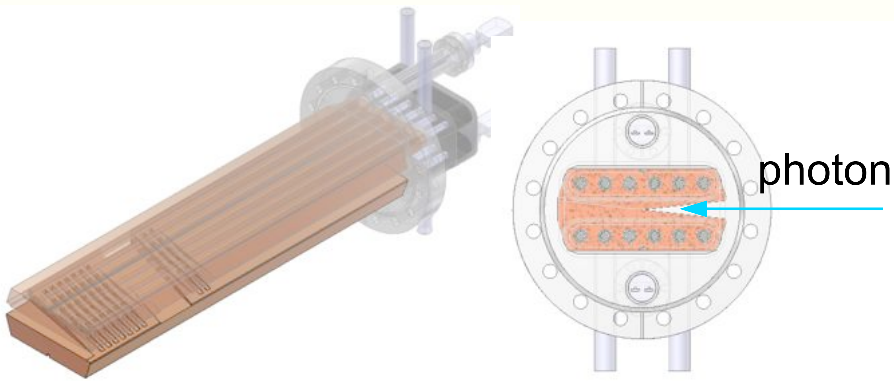
$$P[kW] = 88.463 \cdot \frac{E[GeV]^4}{\rho[m]} \cdot I[A]$$

(17 kW per bending magnet)

- ✓ E=2.5 GeV, I=200 mA, ρ=6.306 m (PLS)
- ✓ E=3.0 GeV, I=400 mA, ρ=6.875 m (PLS-II)







Parameters for PA design

Item♪	Magnitude ♪	Unit♪
Beam energy (*E*)♪	3♪	GeV♪
Beam current (*I*)♪	400♪	mA♪
Bending radius(*ρ*)	6.8775♪	m♪
Bending magnet field (*B*)♪	1.4557♪	T♪
Total power	417	kW
Beam divergence (1/gamma)	0.17	mrad

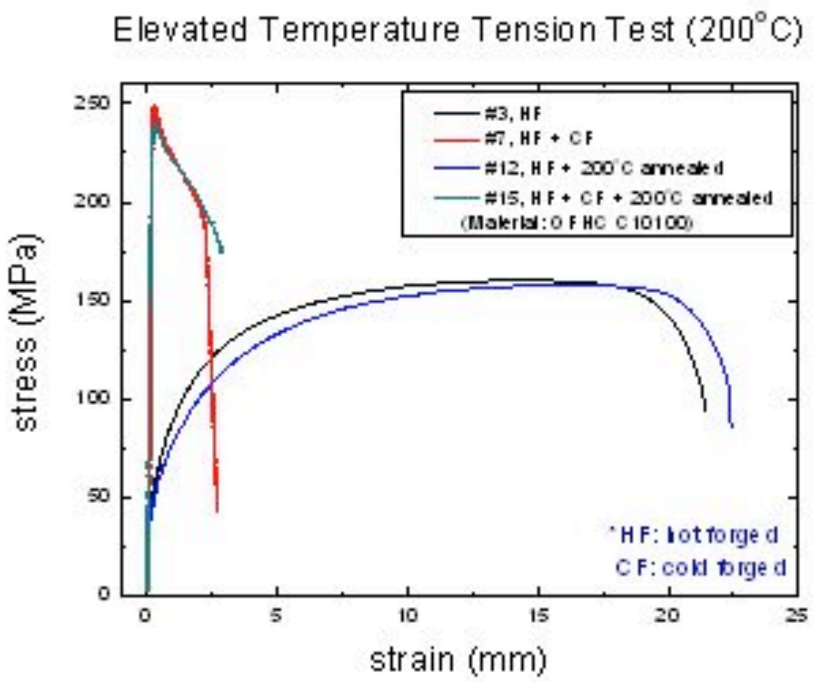
Input Parameters♪	Magnitude ♪	Unit♪
Source distance	1520	mm
Incident peak power density♪	12.23♪	W/mm^{2}♪
Rectangular approximation wid th♪	0.405	mm♪
Convection film coefficient	1♪	$W/cm^{2}K$♪
Vertical miss-steering	±1.5 mm offset	

Materials for PA (cold forged OFHC)

Material

- OFHC
  - ✓High thermal conductivity
  - ✓E-beam welding
  - ✓Easily available than Glidcop
- Elevated temperature (200℃) tension test

Material process	YS(0.2%) / MPa	TS / MPa	EL / %
Hot forged (OFHC)	48.3	160.3	42.4
Hot + Cold forged	244.4	249.1	5.2
HF + 200℃ Annealed	48.9	157.7	43.9
HF + CF + 200℃ Annealed	**240.0**	**240.3**	**5.8**

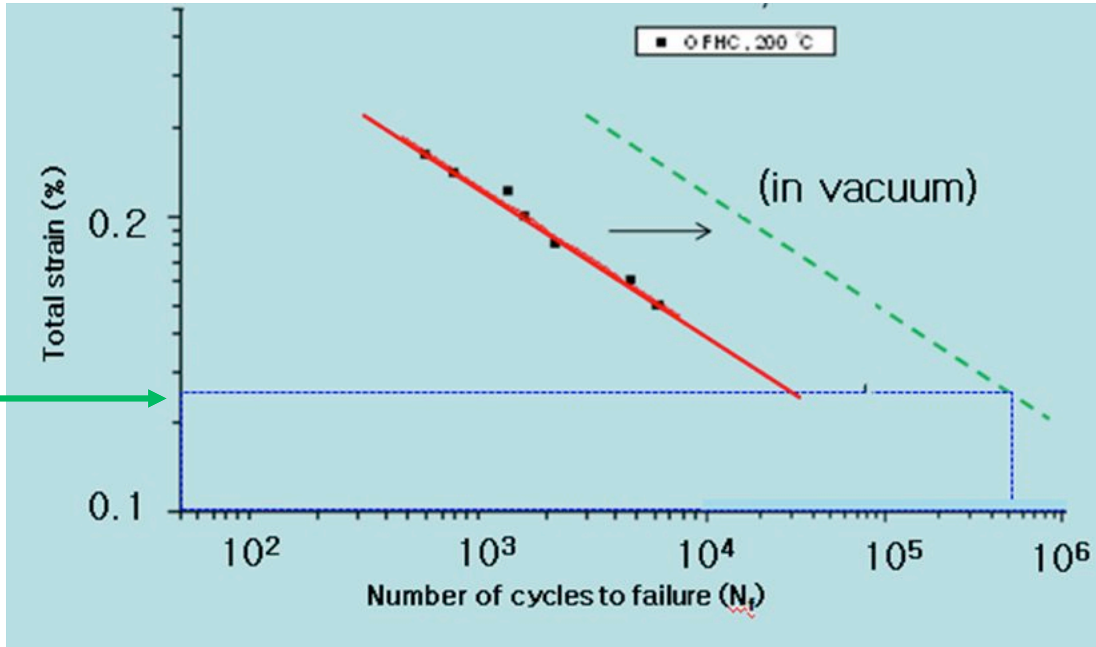


- The yield strength of the cold forged OFHC is enhanced up to 240 MPa.

Materials for PA (cold forged OFHC)

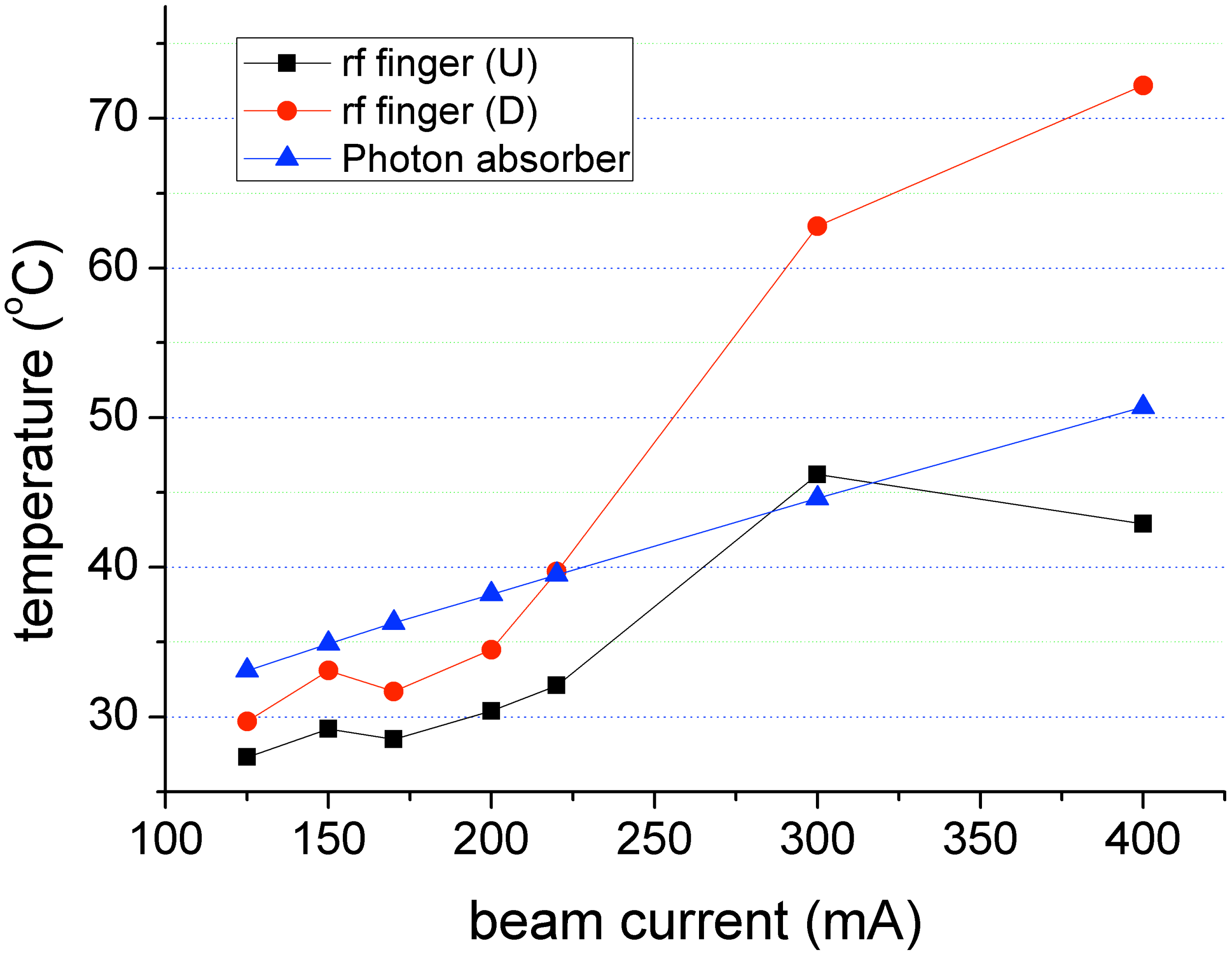
Lifetime measurement

Calculated max. strain (0.115%)



- Number of cycles to failure for total strain of 0.115 % (most severe point) in air is measured to be larger than 10,000 cycles
- Fatigue lifetime in vacuum is 10 times longer than that in air, typically.
- The lifetime of the PLS-II photon absorber is expected to be longer than 100, 000 cycles

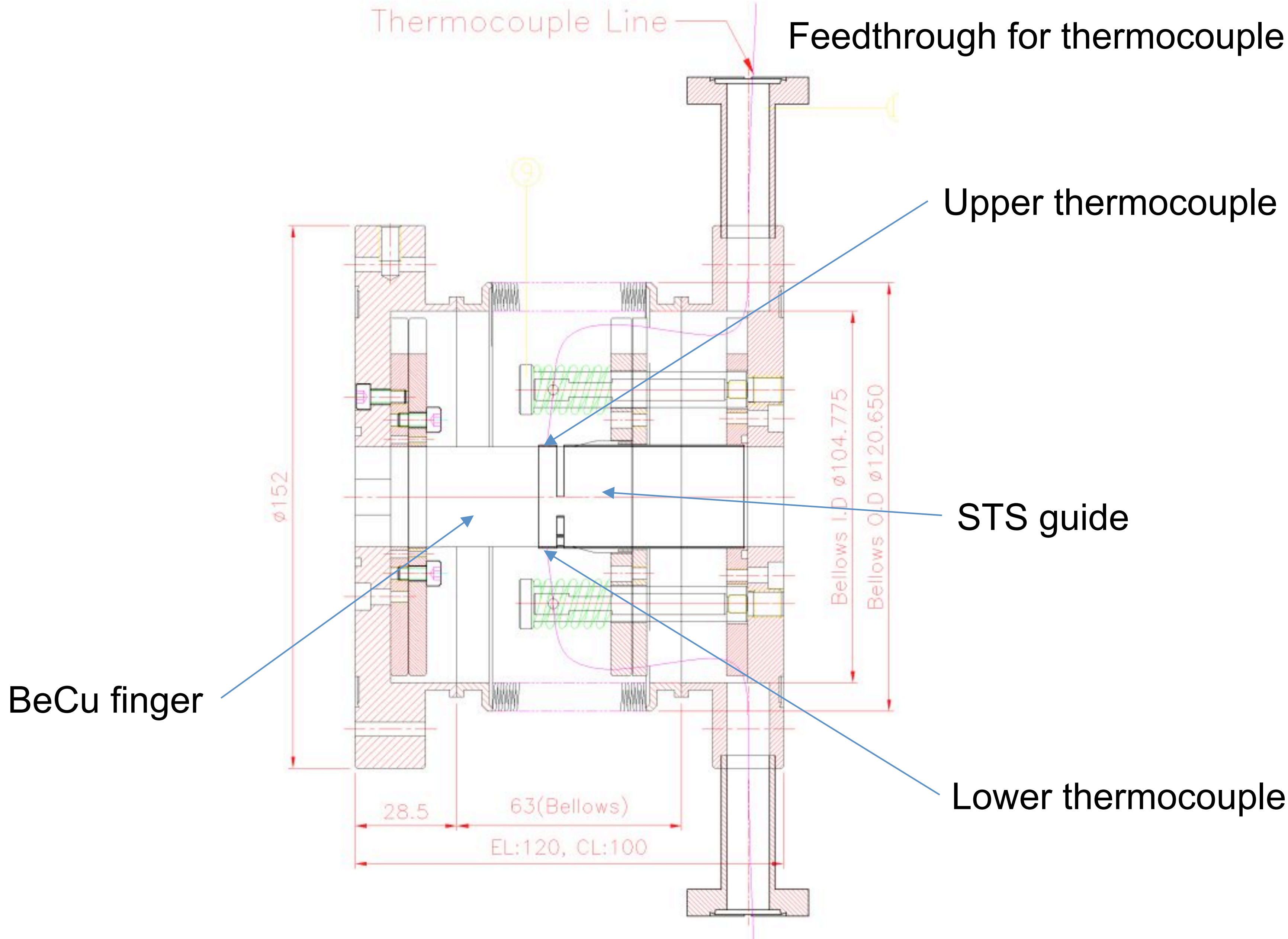
Photon absorber in operation



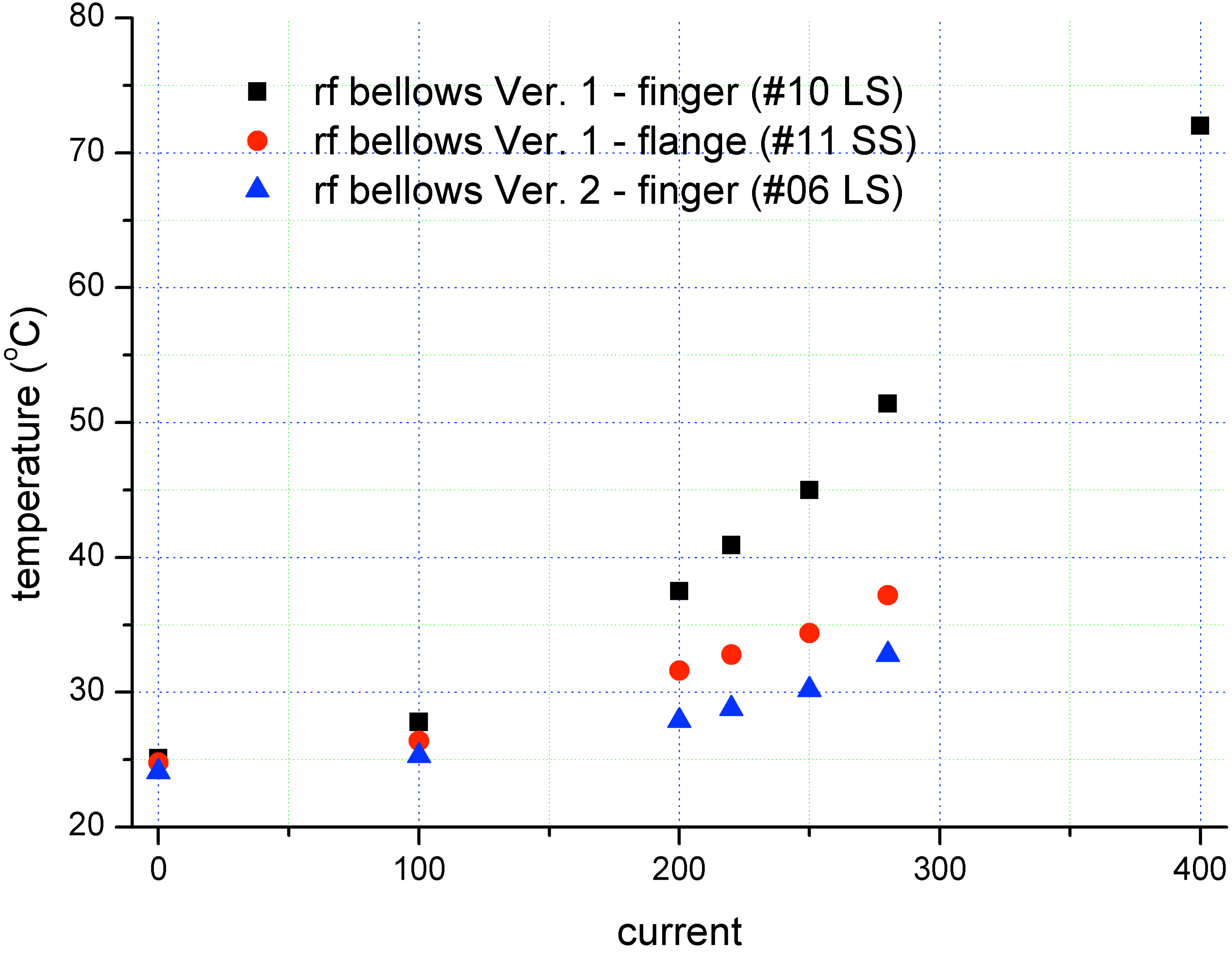
• Operating temperature of the most severe photon absorber at the sensor position is measured to be 50°C at 400 mA.

• Most severe point ~ 150°C at 400 mA (much lower than the thermal analysis result)

RF shielded bellows

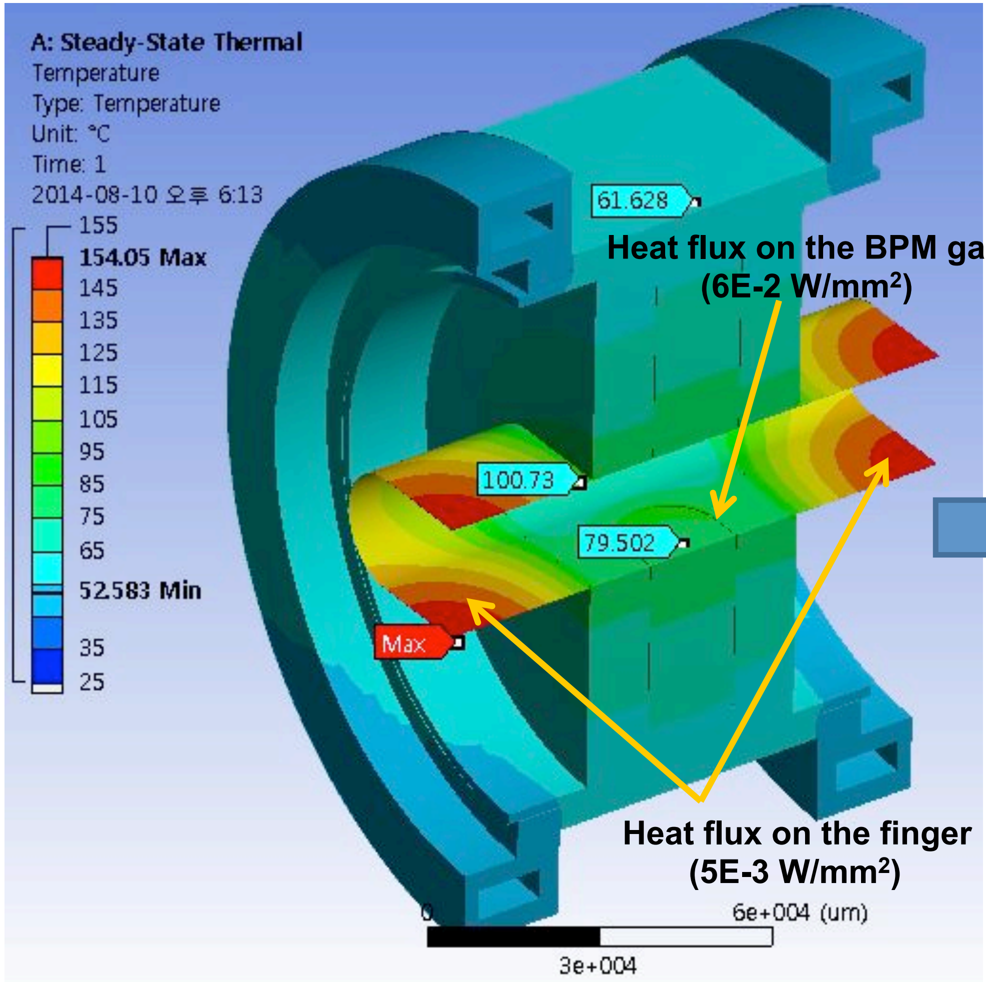


RF shielded bellows in operation

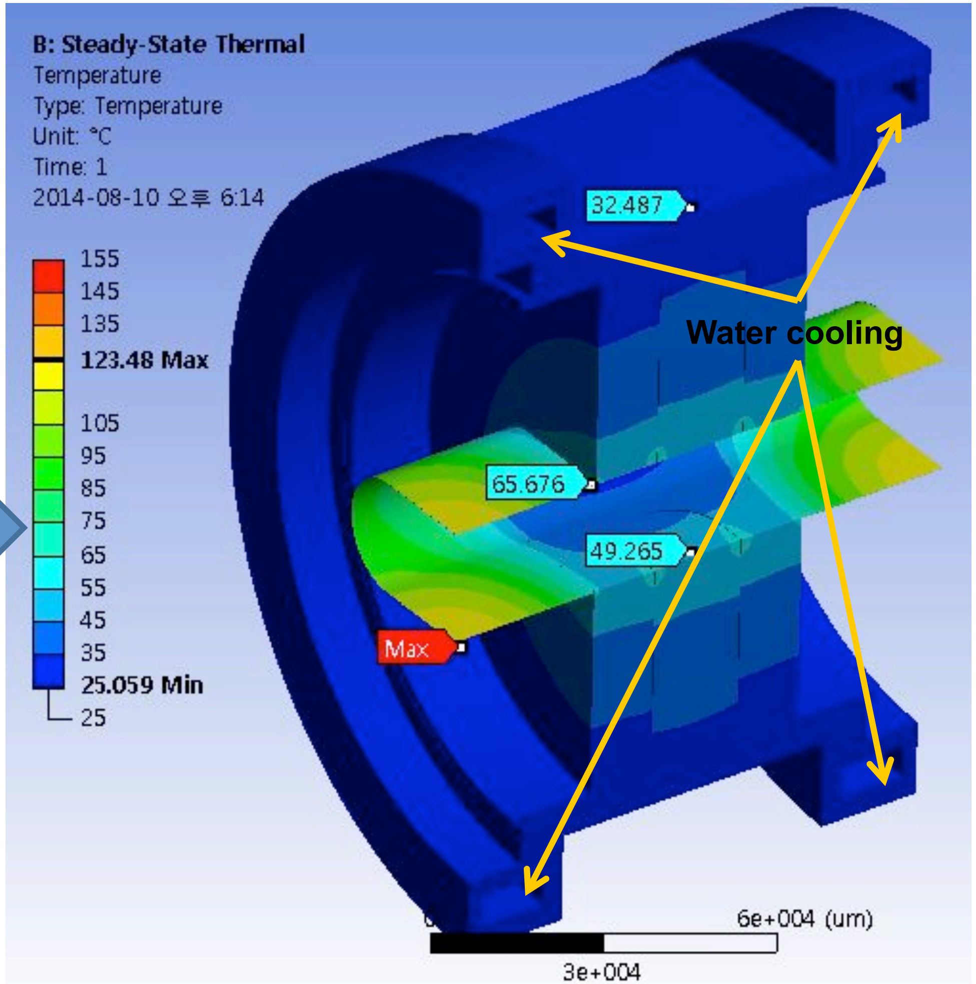


Thermal analysis of BPM-bellows module

- Temperature @ 400 mA (appropriate heat flux was assumed)
  - Water cooling reduces the temperature by ~30°C



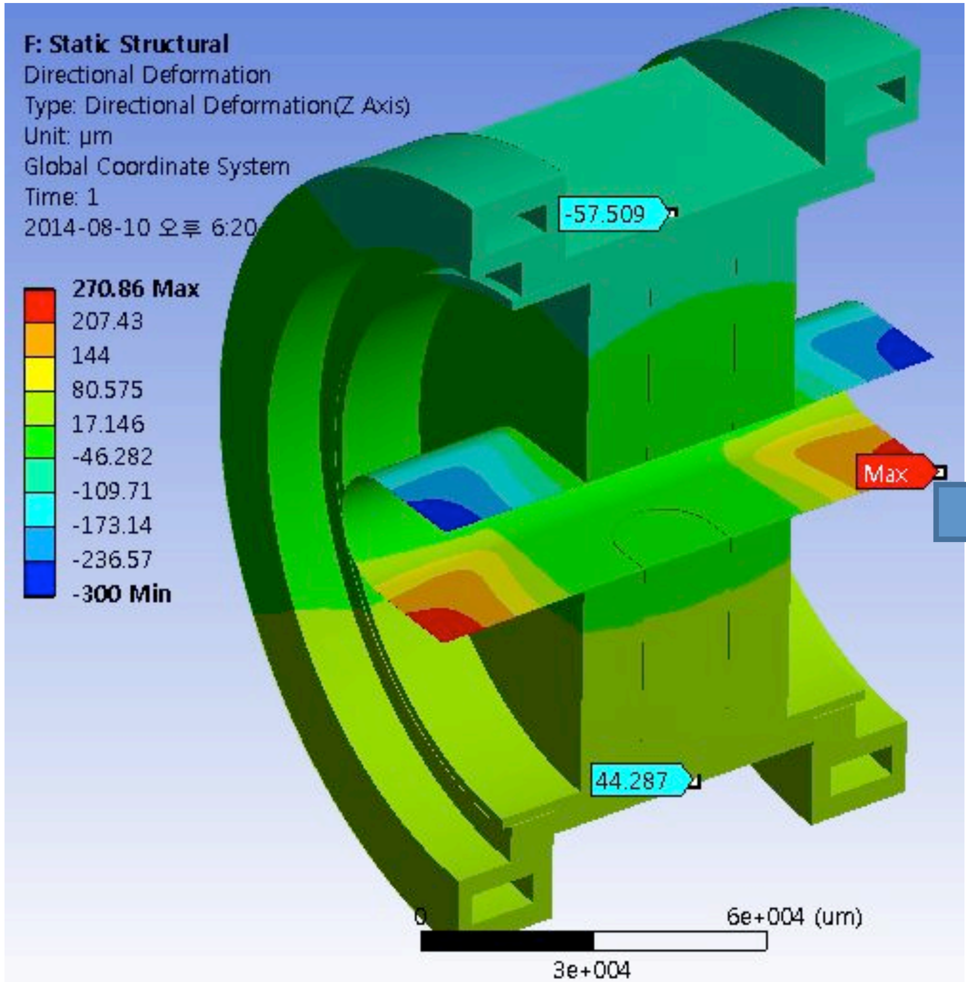
Natural air convection (2.2E-5 W/mm²K)



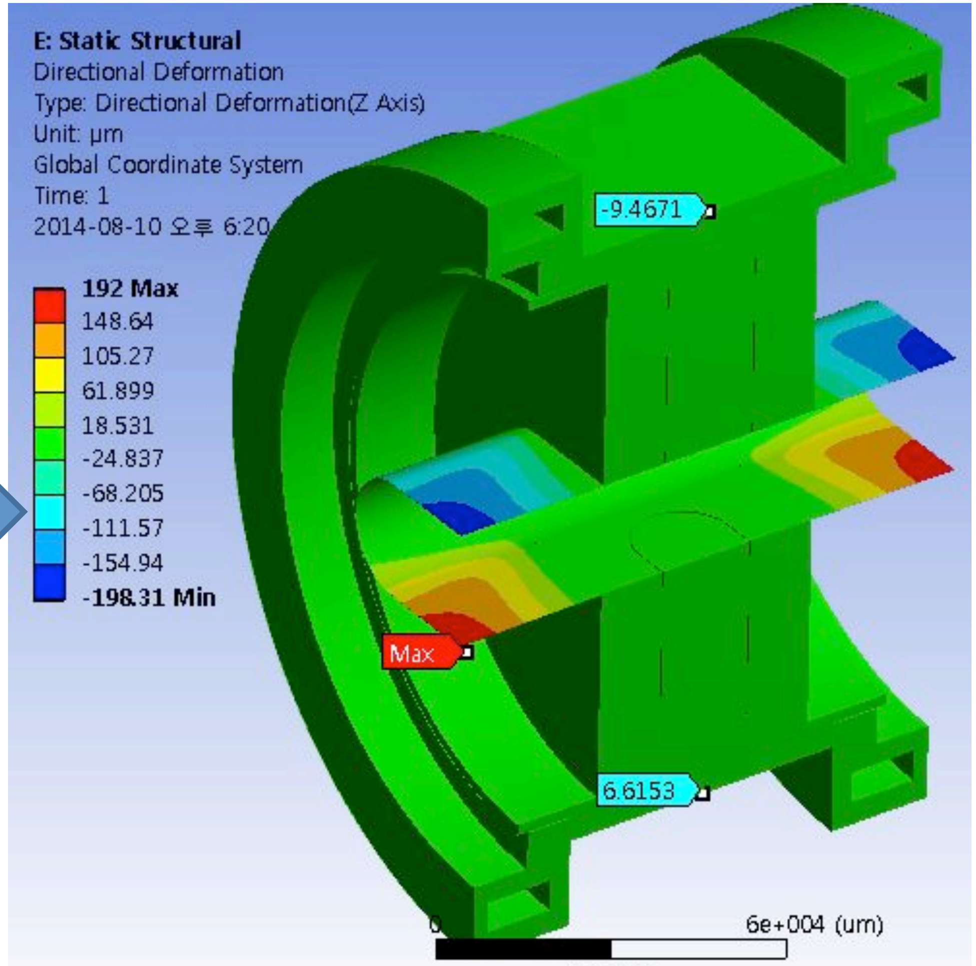
Natural air convection (2.2E-5 W/mm²K)
+ Water cooling (1E-2 W/mm²K)

Thermal analysis of BPM-bellows module

- Deformation @ 400 mA
  - Vertical displacement of the BPM center w/o water cooling is ~6.6 um
  - Vertical displacement of the BPM center with water cooling is ~**1.4 um**



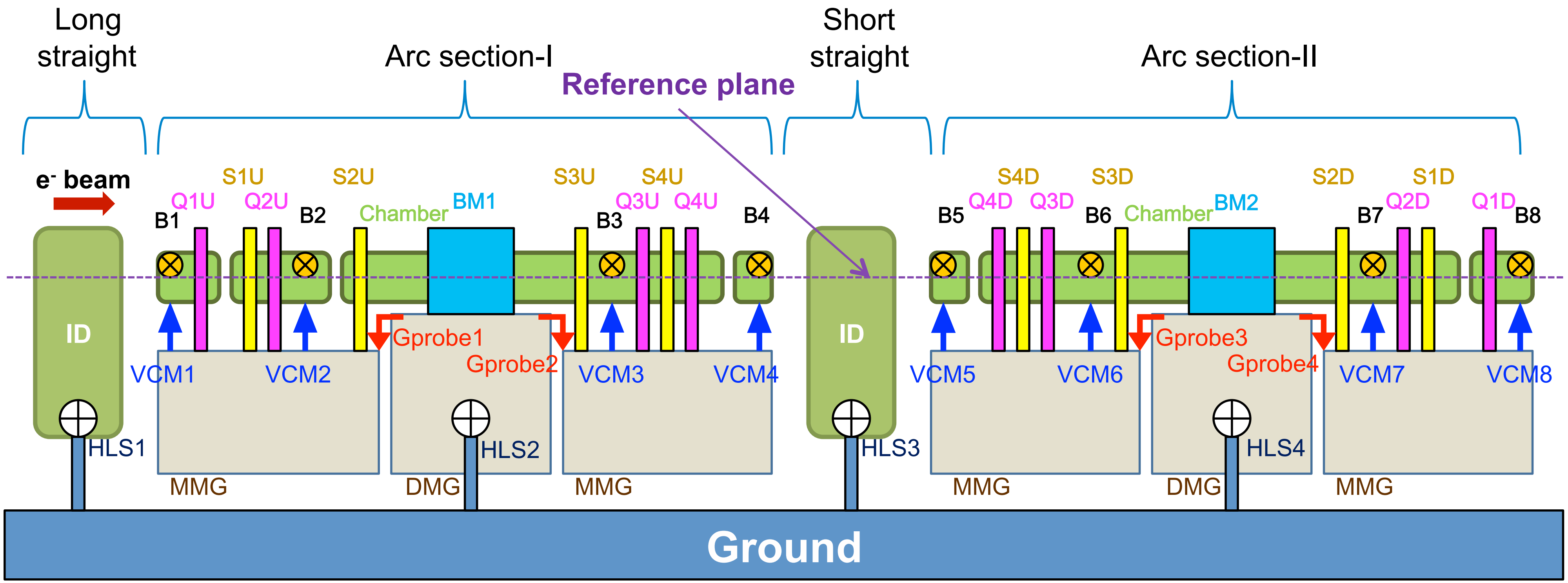
Natural air convection (2.2E-5 W/mm²K)



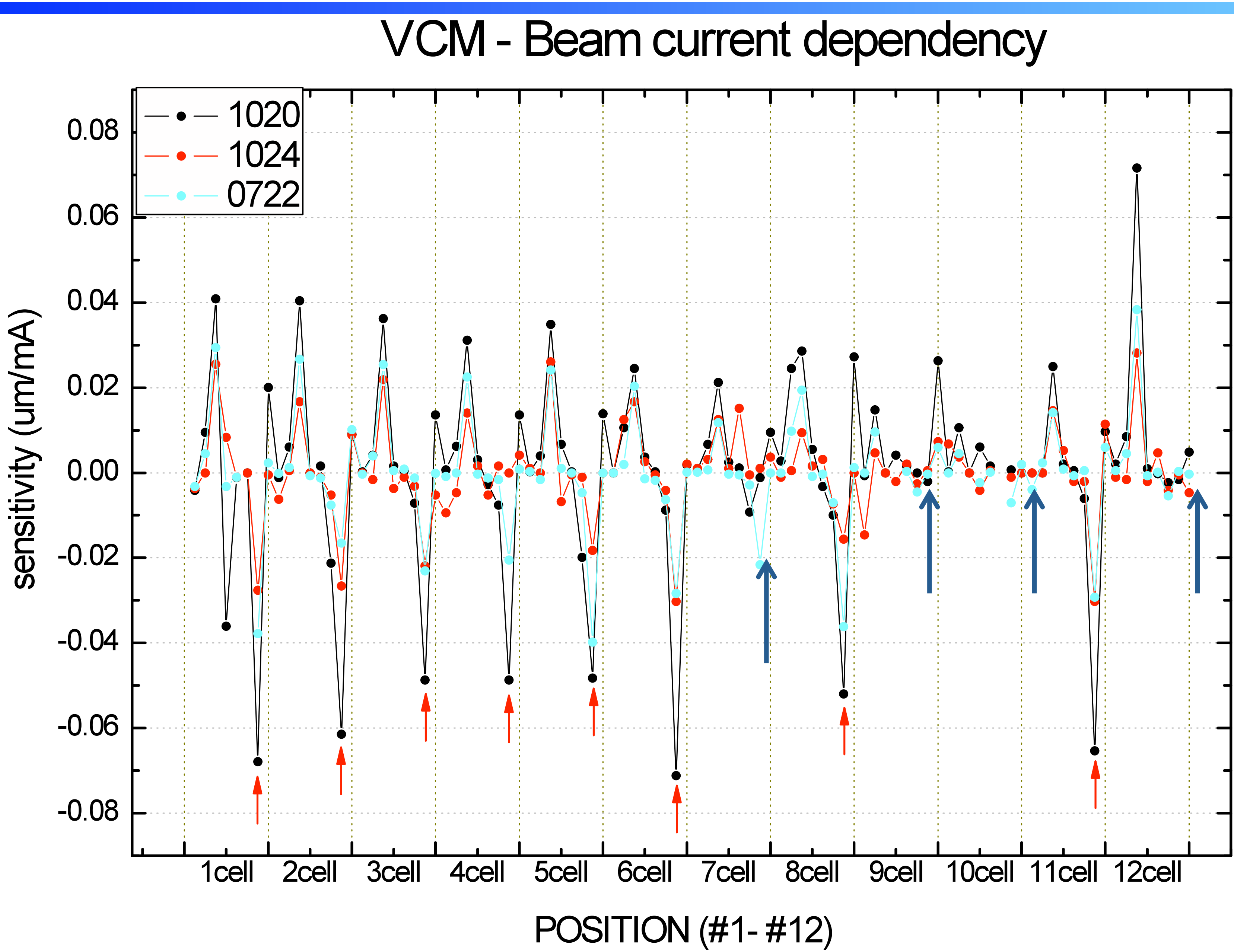
Natural air convection (2.2E-5 W/mm²K)
+ Water cooling (1E-2 W/mm²K)

BPM position monitoring

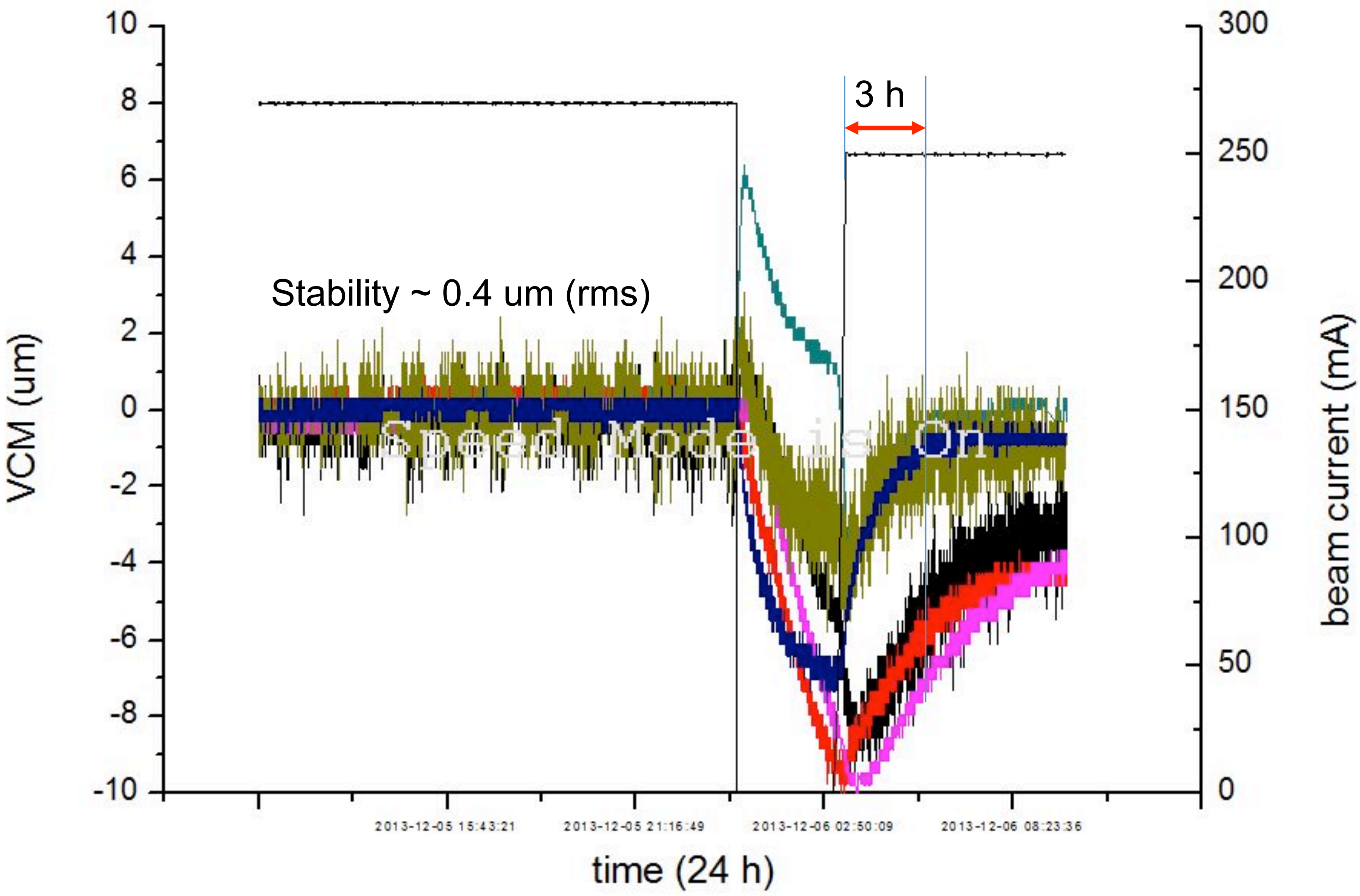
Monitoring of BPM position



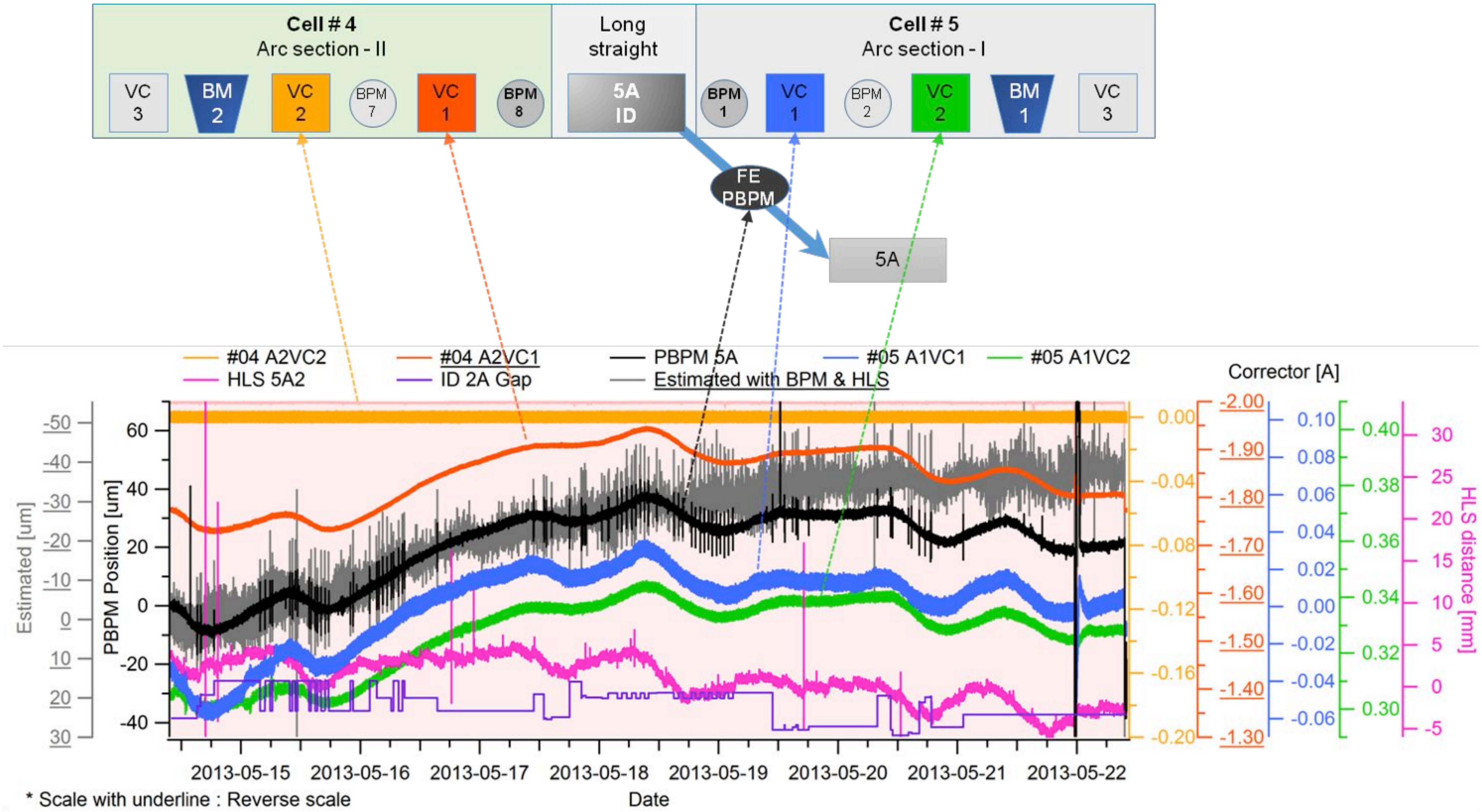
Thermo-mechanical effect



Thermo-mechanical effect

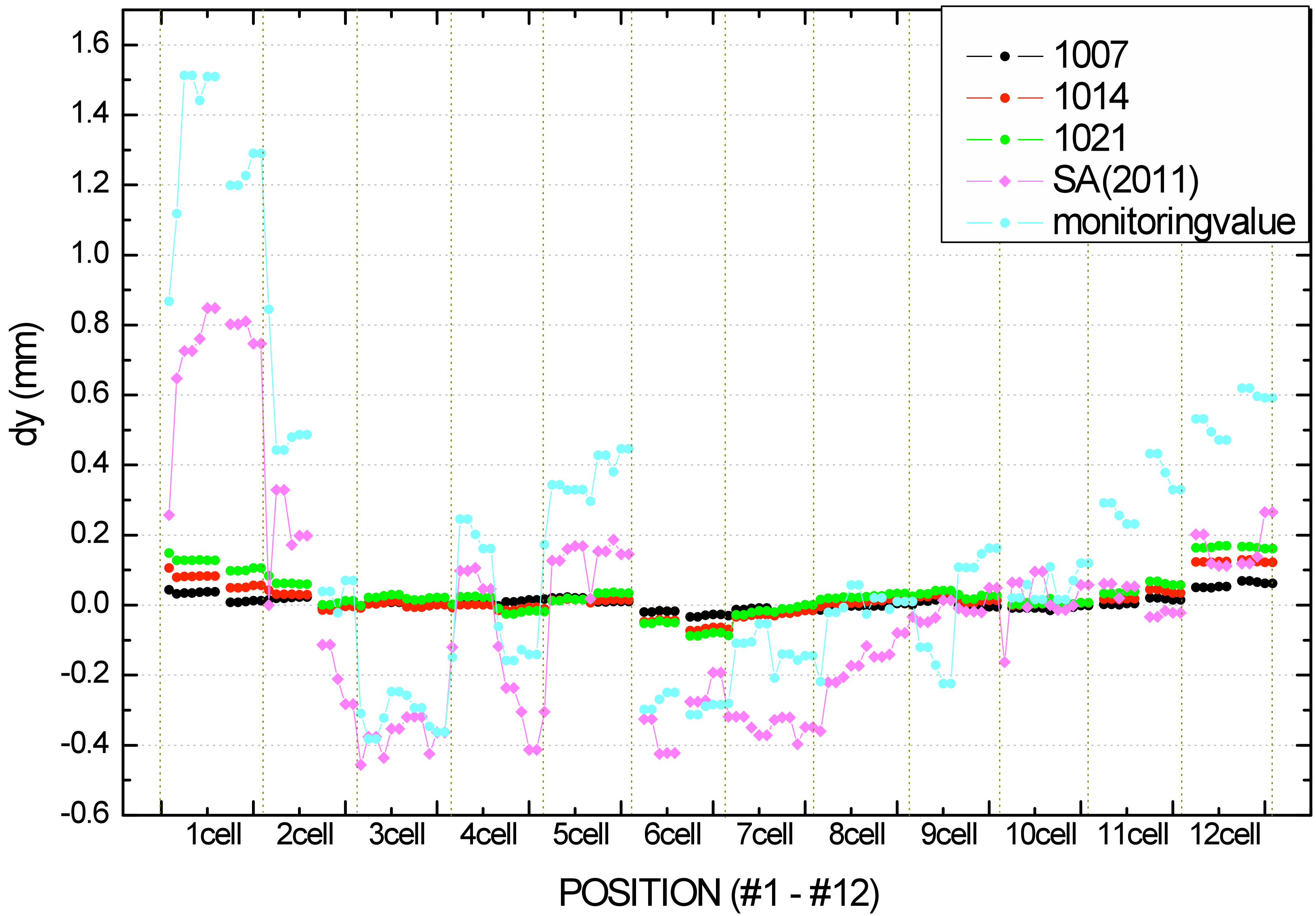


Long term variation of photon beam

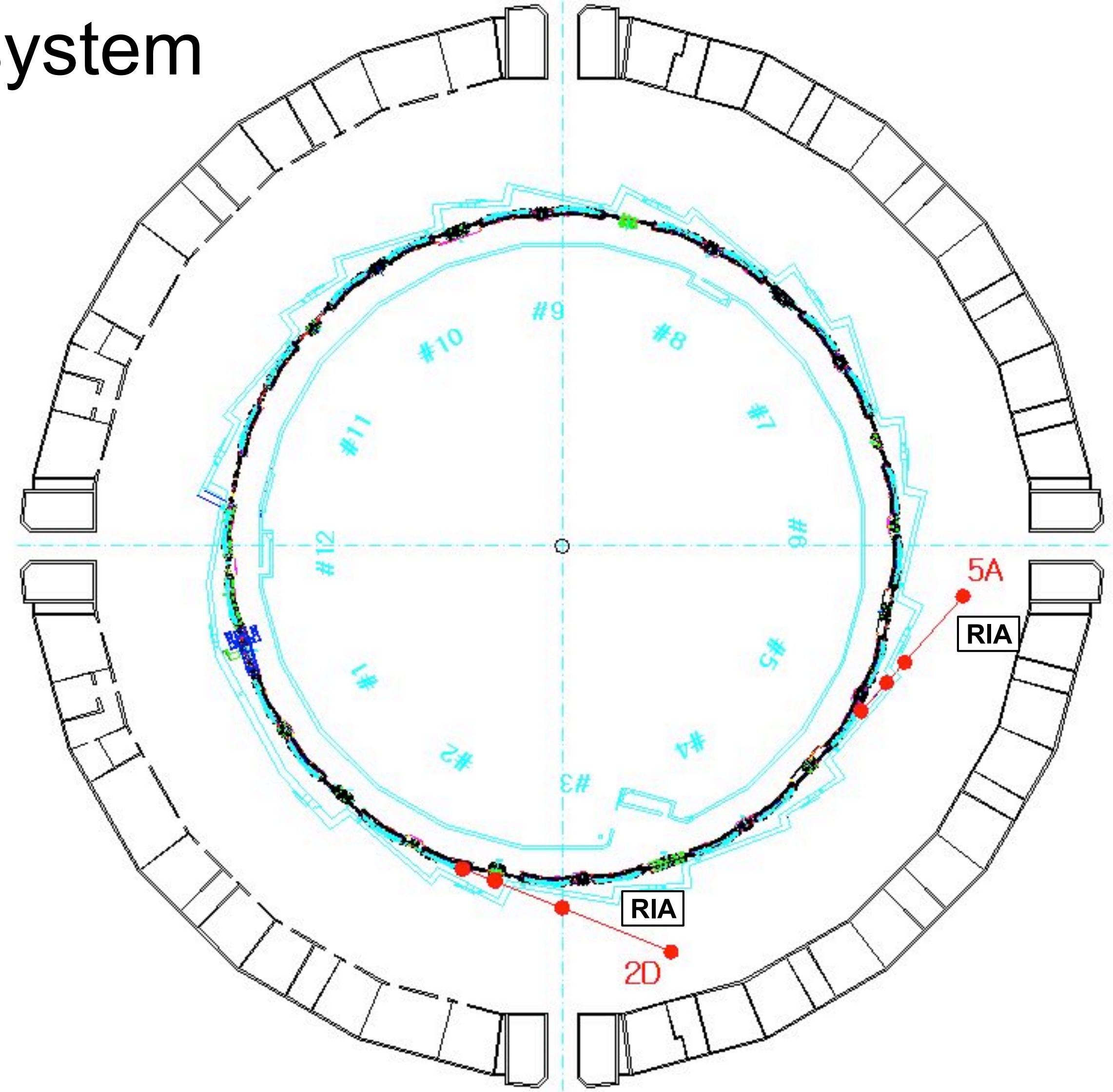


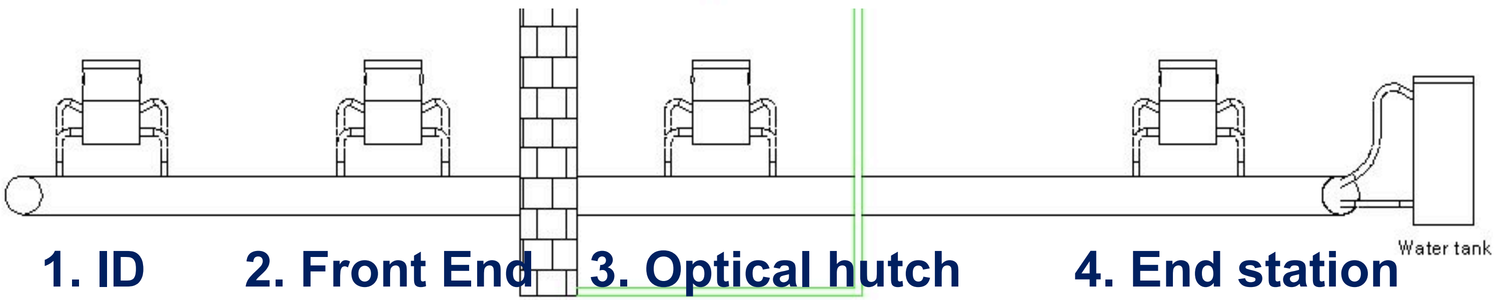
Ground motion

Measured by HLS

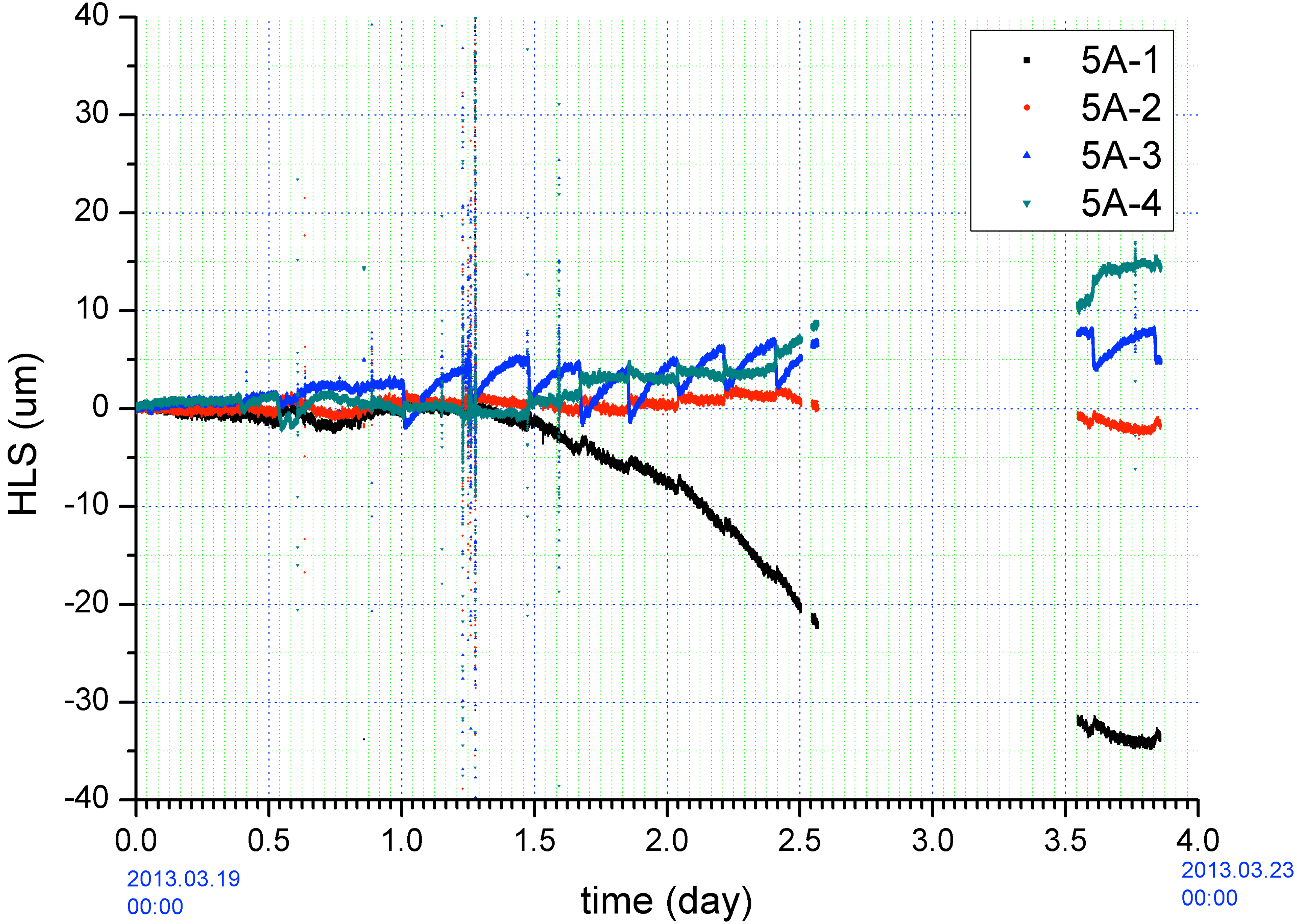


HLS system

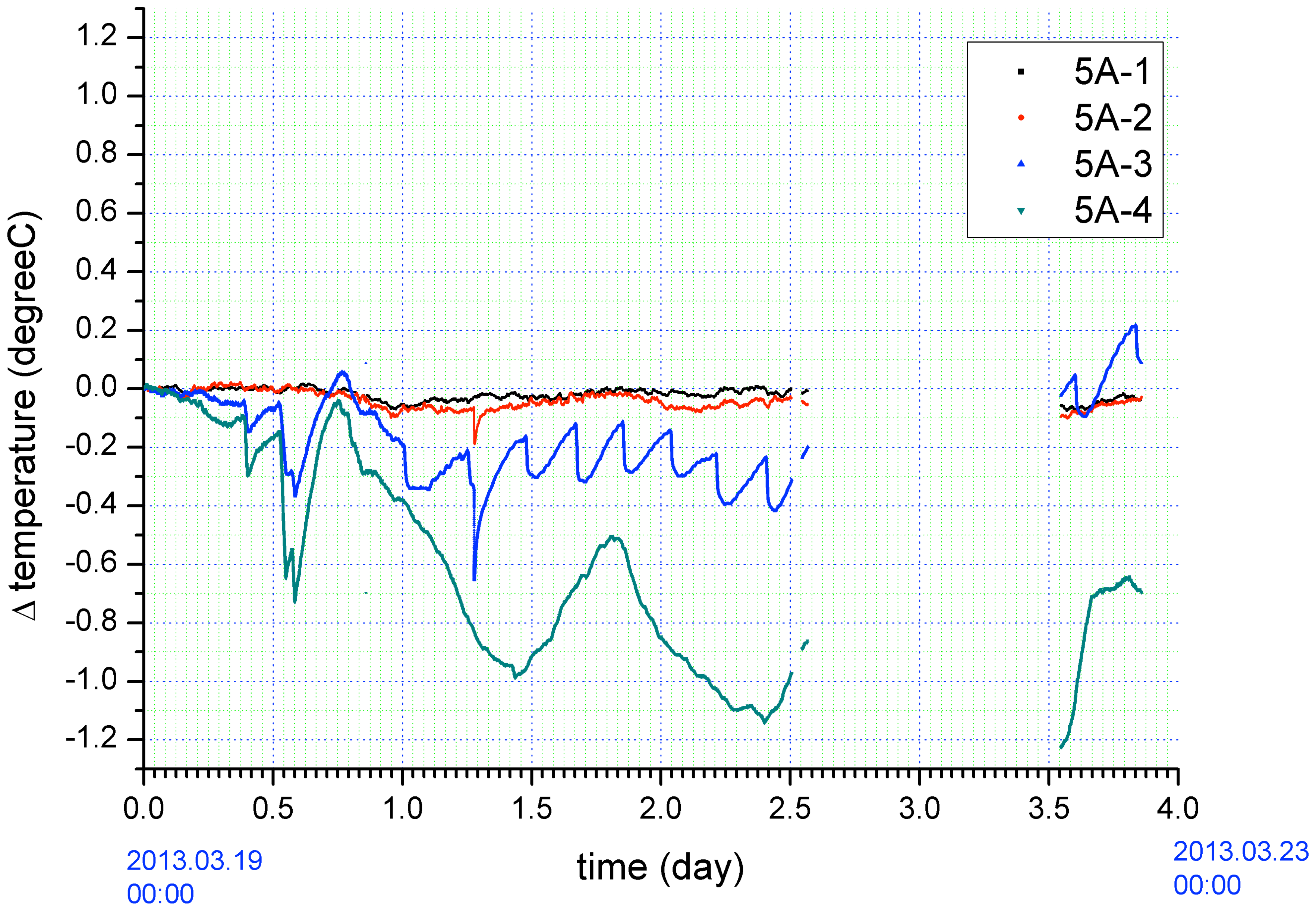

#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
#12
5A
RIA
RIA
2D


Water tank
1. ID
2. Front End
3. Optical hutch
4. End station

5A beam line HLS data



5A beam line temperature (HLS)

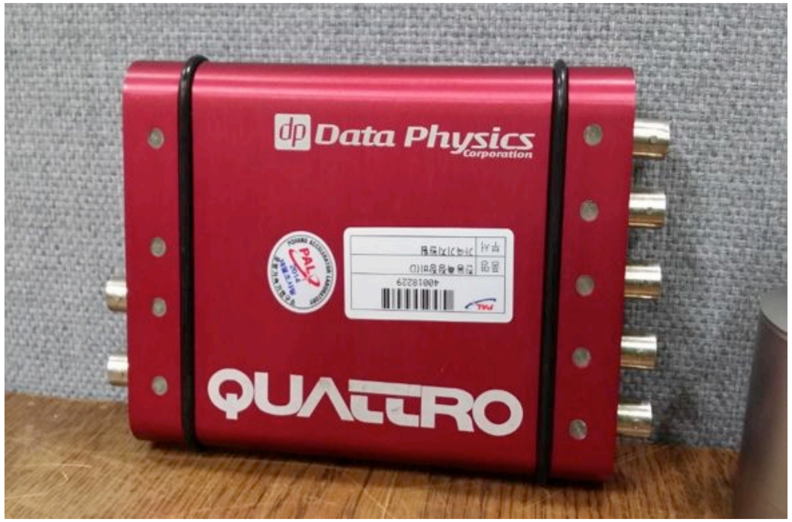


Vibration Measurement

Measurement Sensor

Electronics

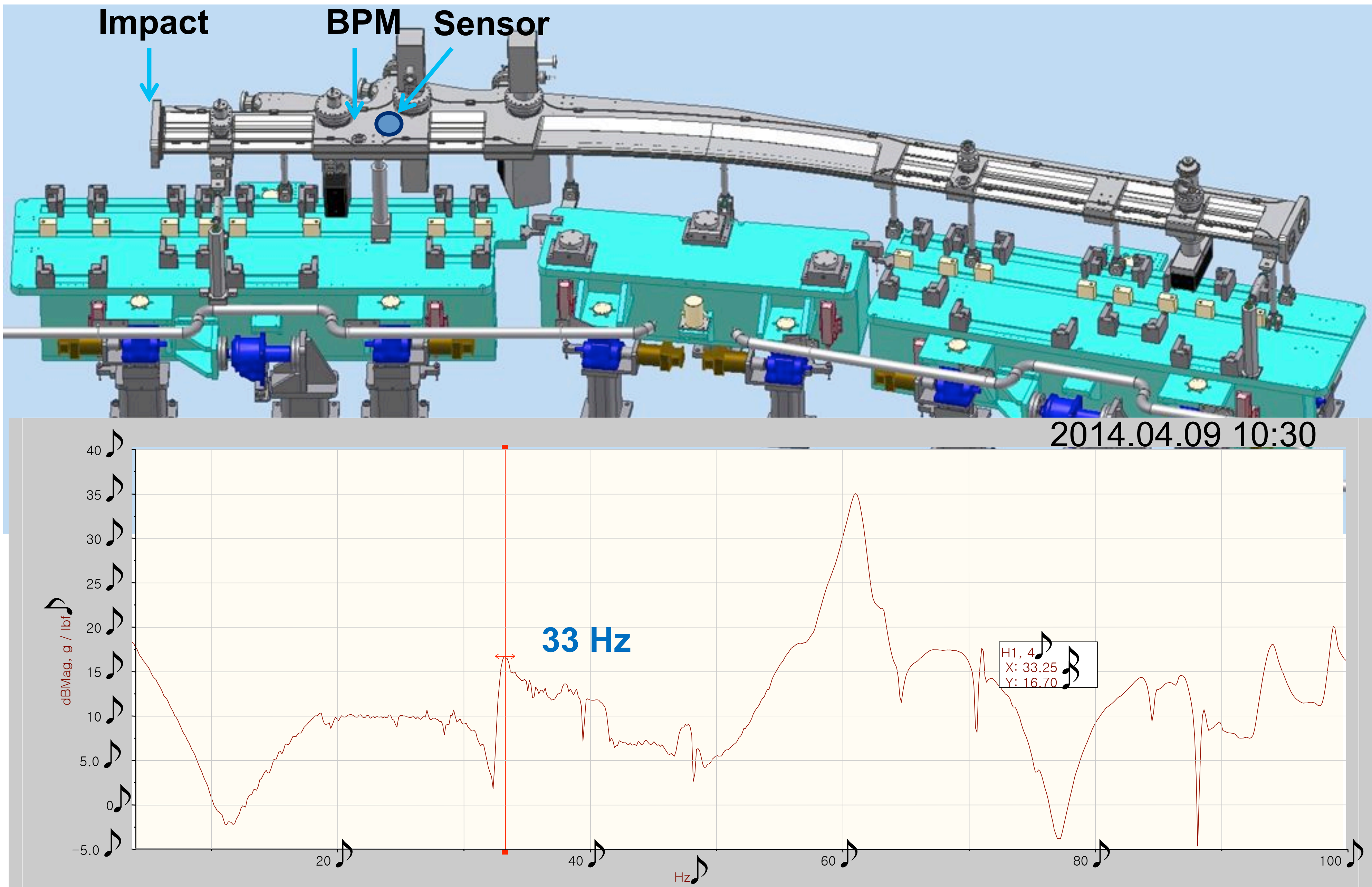
Data Physics
QUATTRO



Sensor

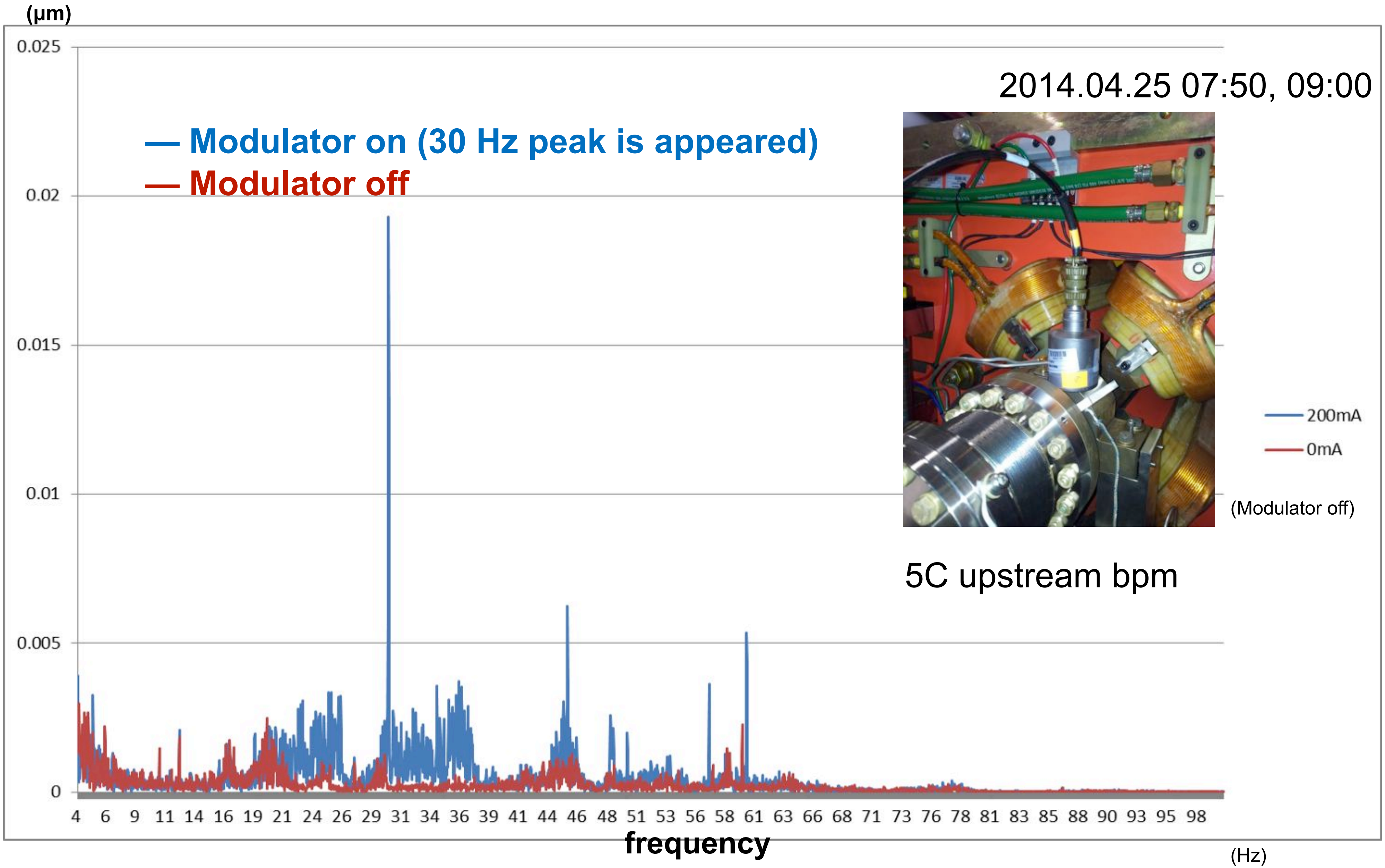
DYTRAN
3191A
SEISMIC ACCELEROMETER
SENSITIVITY 5 V/G

Natural frequency of a SR vacuum chamber



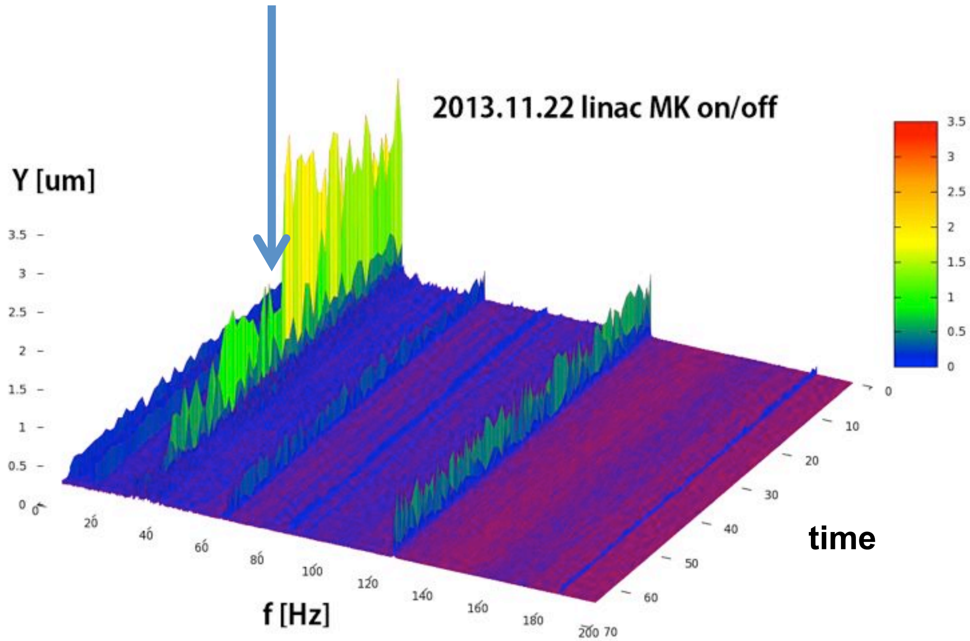
Vibration due to Linac modulator/klystron

(Operation frequency of M/K is 30 Hz)

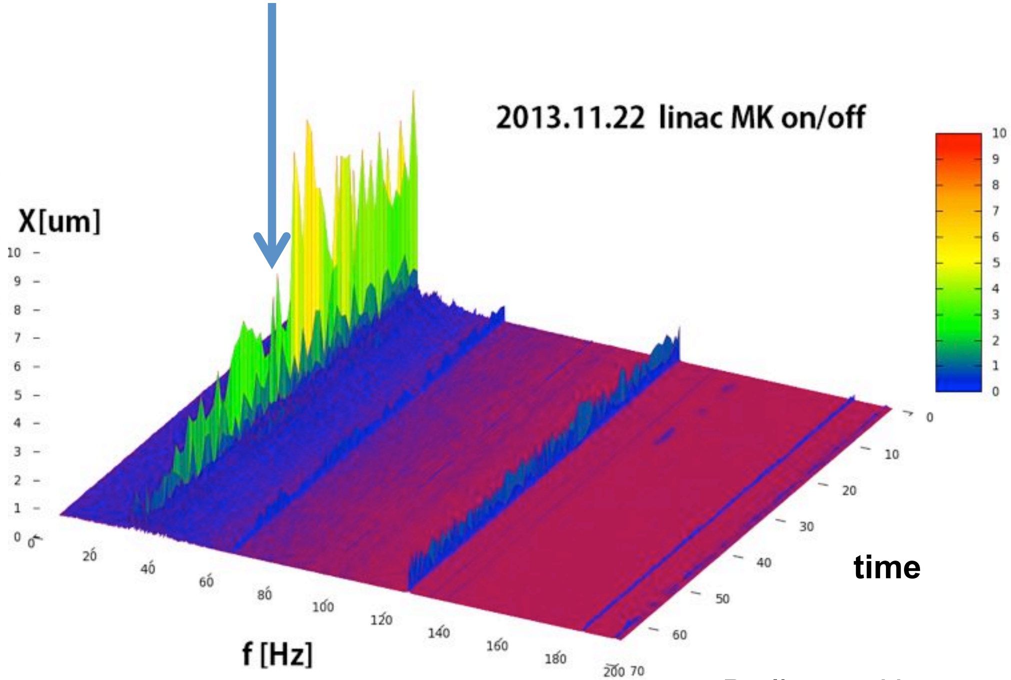


Vibration monitored by electron BPM
(Linac modulator/klystron on&off)

Modulator/klystron off



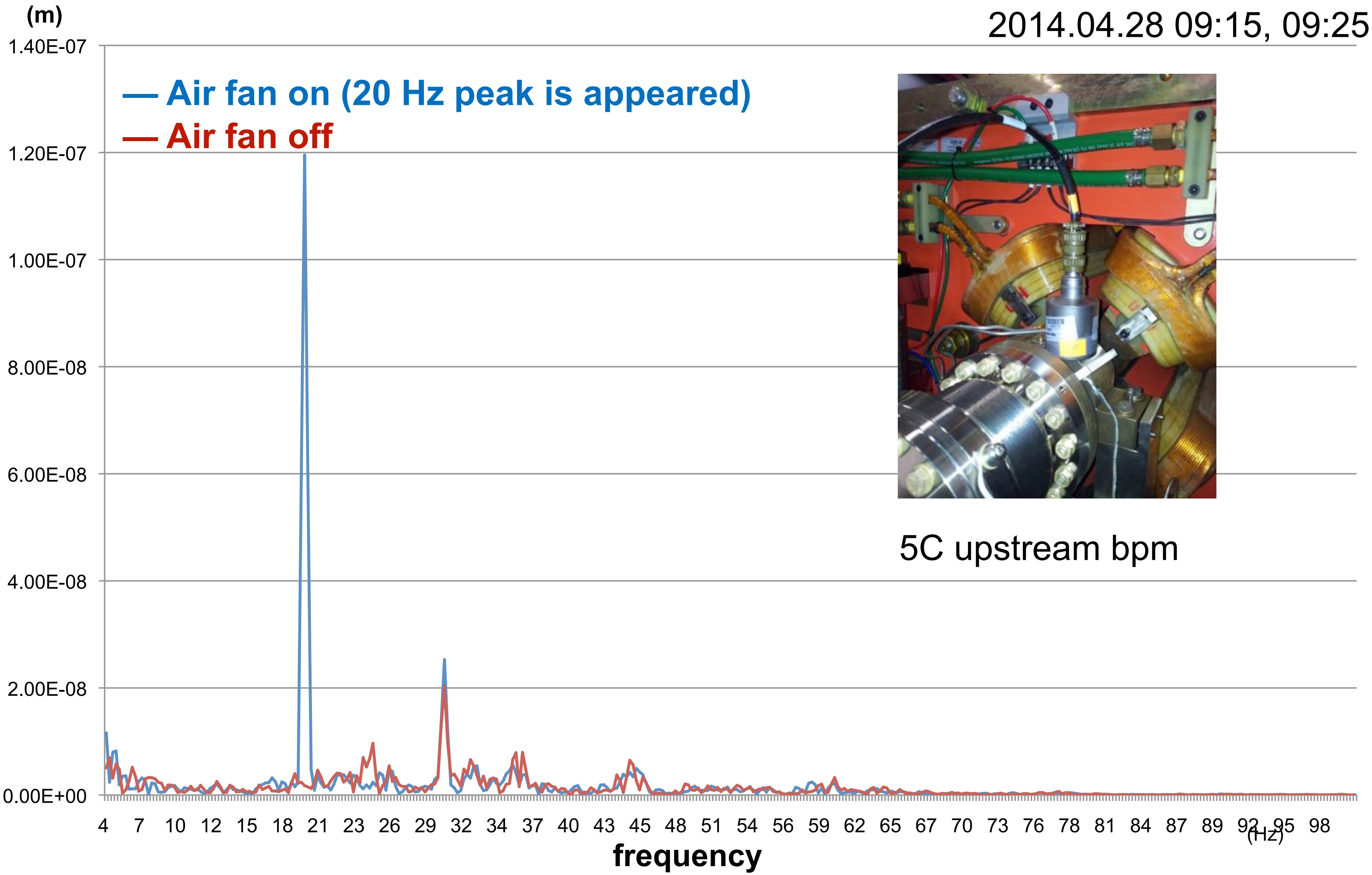
Modulator/klystron off



By Ilmoon Hwang

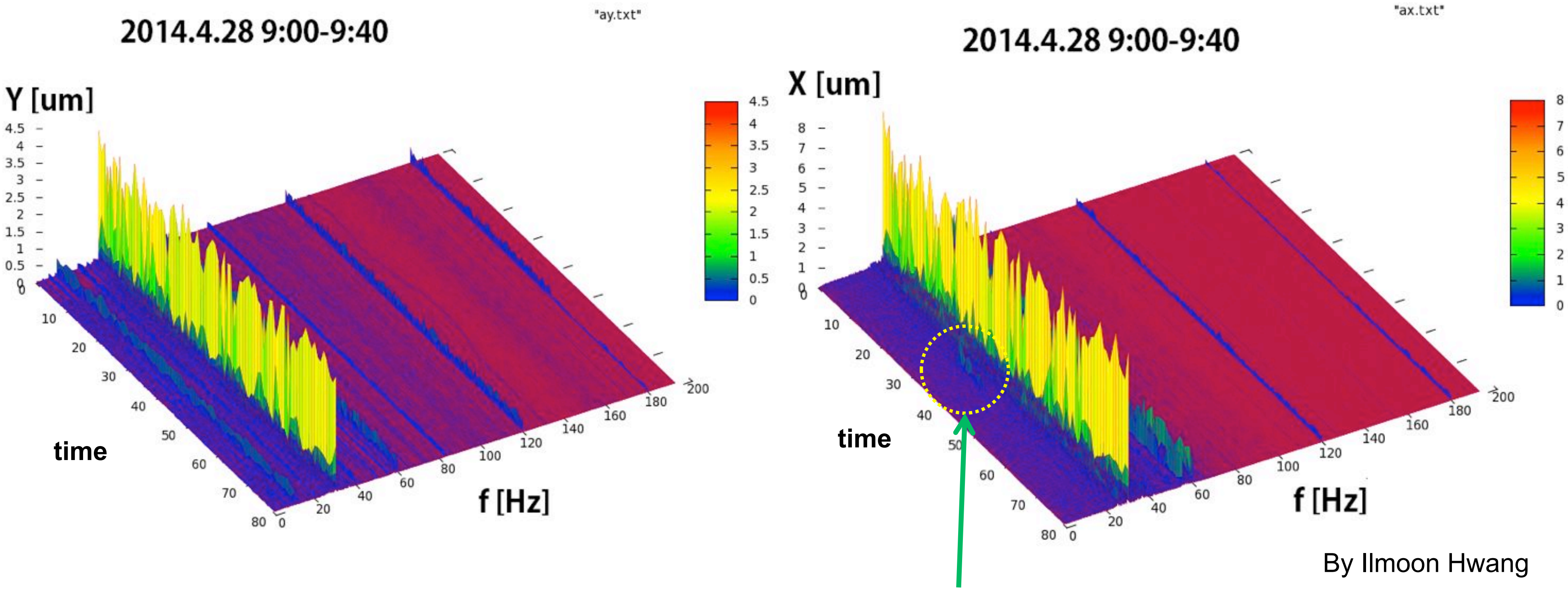
30 Hz vibration peak due to modulator/klystron is also appeared at electron BPM signal

Vibration due to air fan of experimental hall



Vibration monitored by electron BPM

(Air fan of experimental hall on&off)

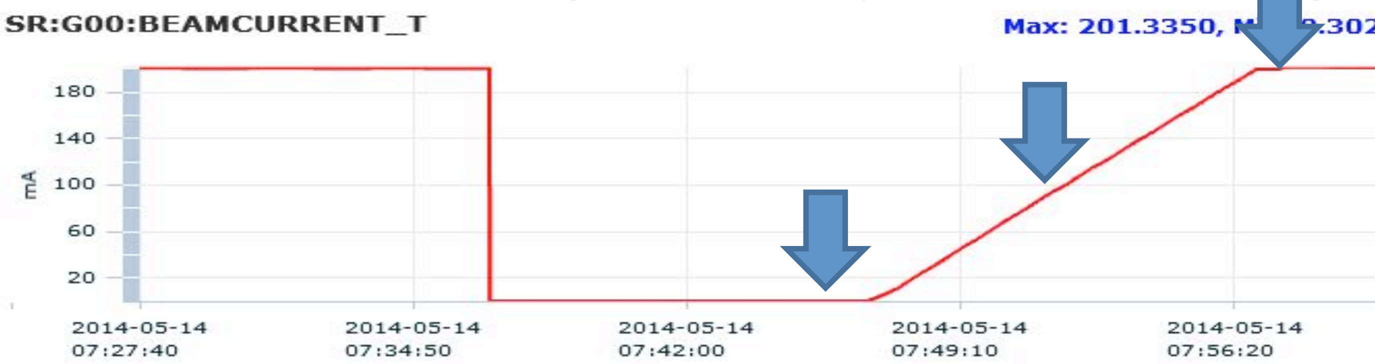


By Ilmoon Hwang

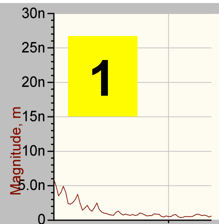
Air fan on (20 Hz peak is appeared)

Vibration during beam injection

(10 Hz injection kicker)

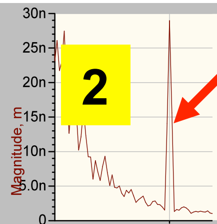


5C downstream BPM

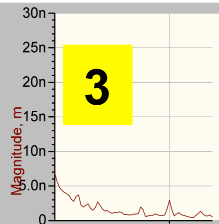


2014.05.14 07:45

10 Hz peak is appeared



2014.05.14 07:47



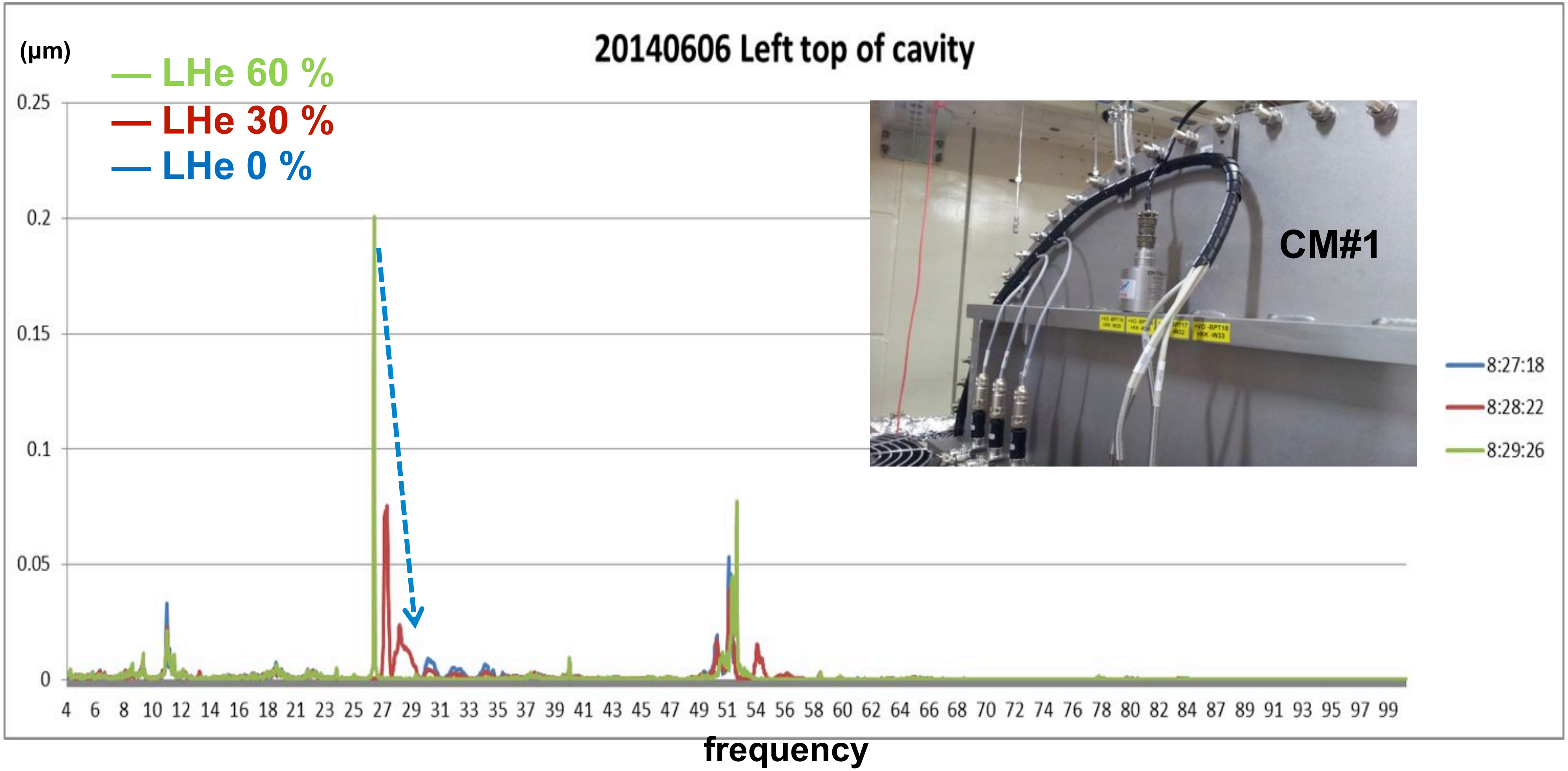
2014.05.14 07:58

frequency

Vibration of super conducting RF cryo-module

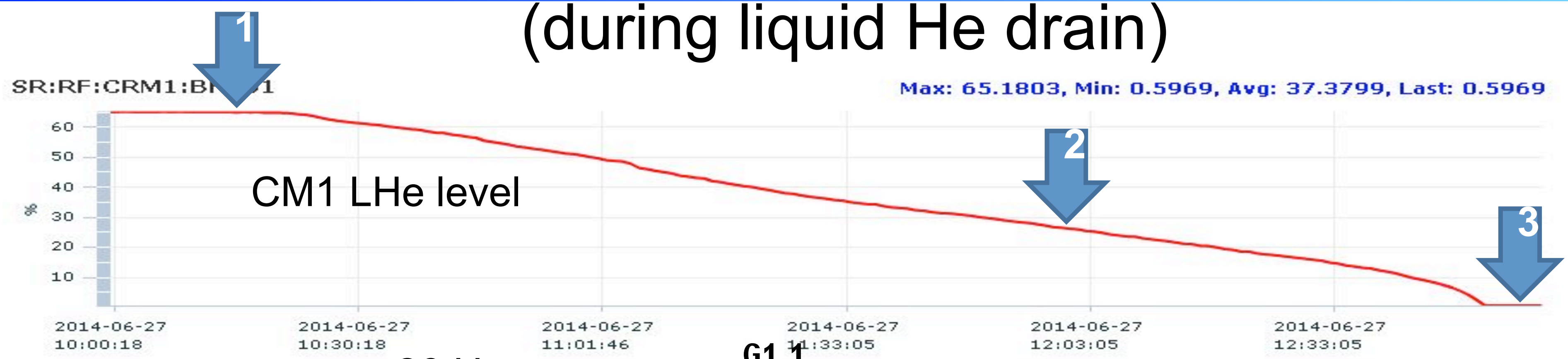
(during liquid He drain)

See next page



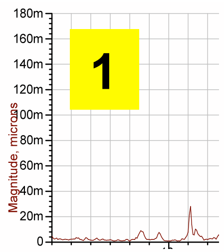
Vibration of super conducting RF cryo-module

(during liquid He drain)



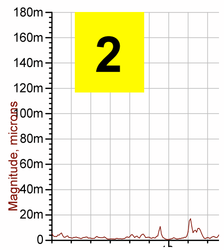
26 Hz

G1, 1



2014.06.27 10:22

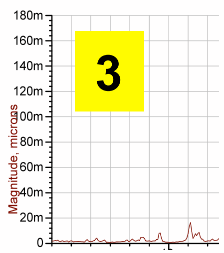
G1, 1



2014.06.27 12:00

Position and amplitude of vibration peak are changed according to LHe level

G1, 1



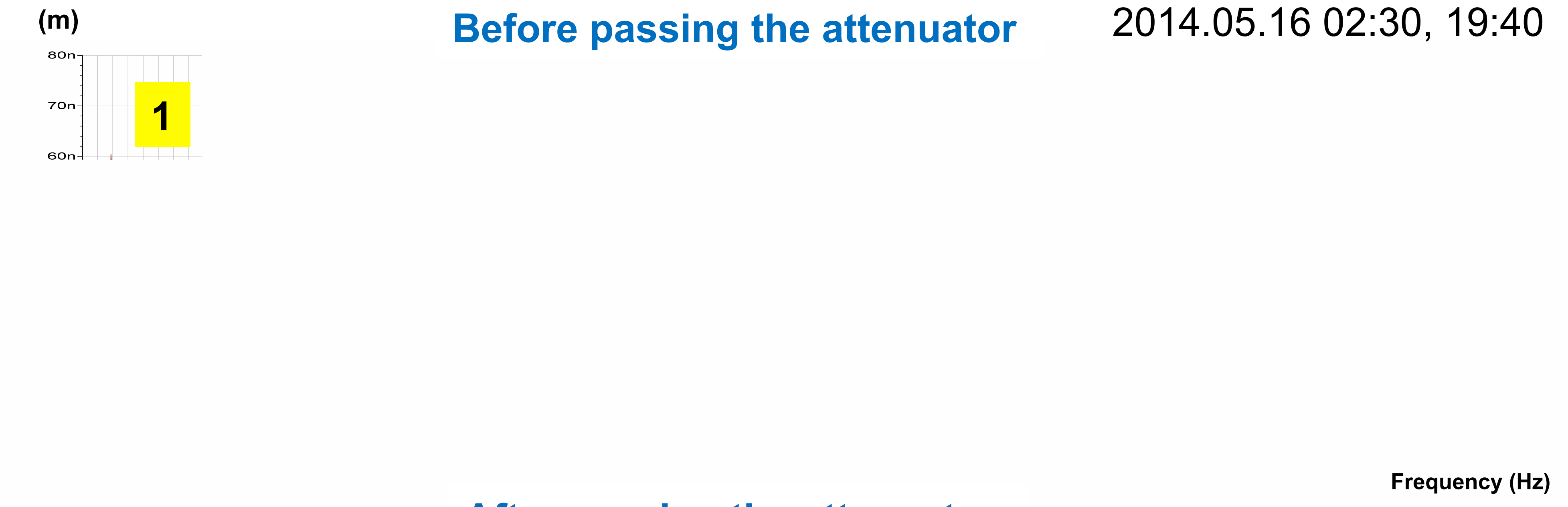
2014.06.27 13:00

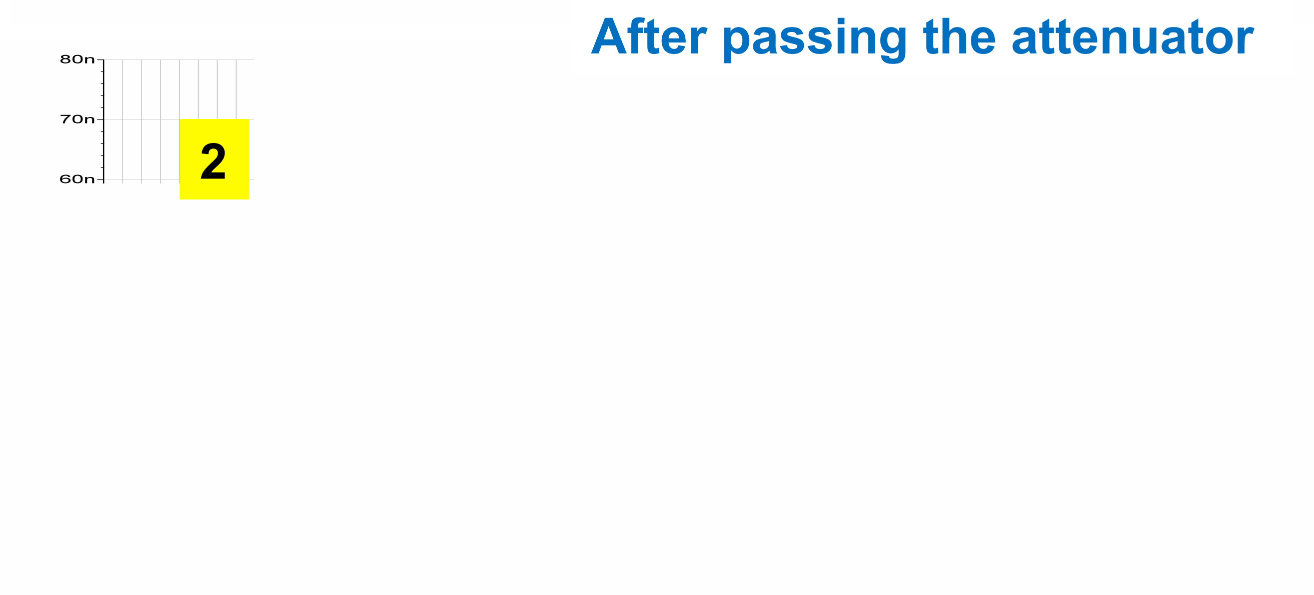
frequency

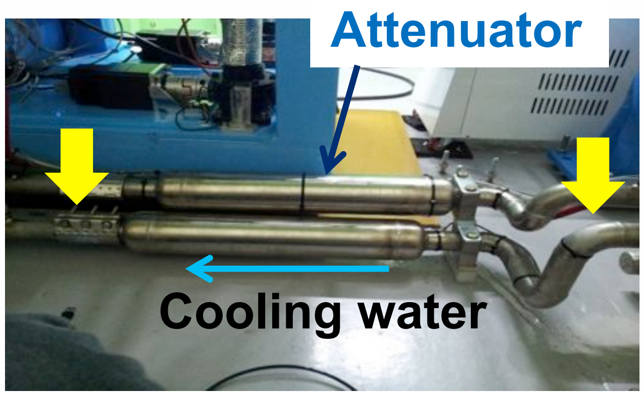
Vibration of cooling water pipe attenuator

(before and after attenuator passage)

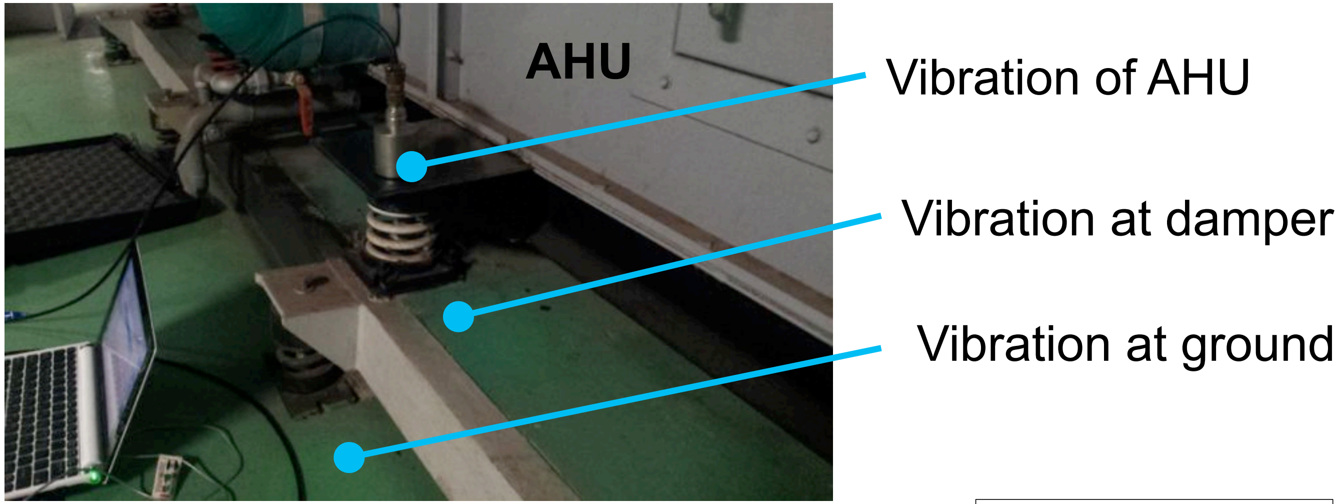
2014.05.16 02:30, 19:40

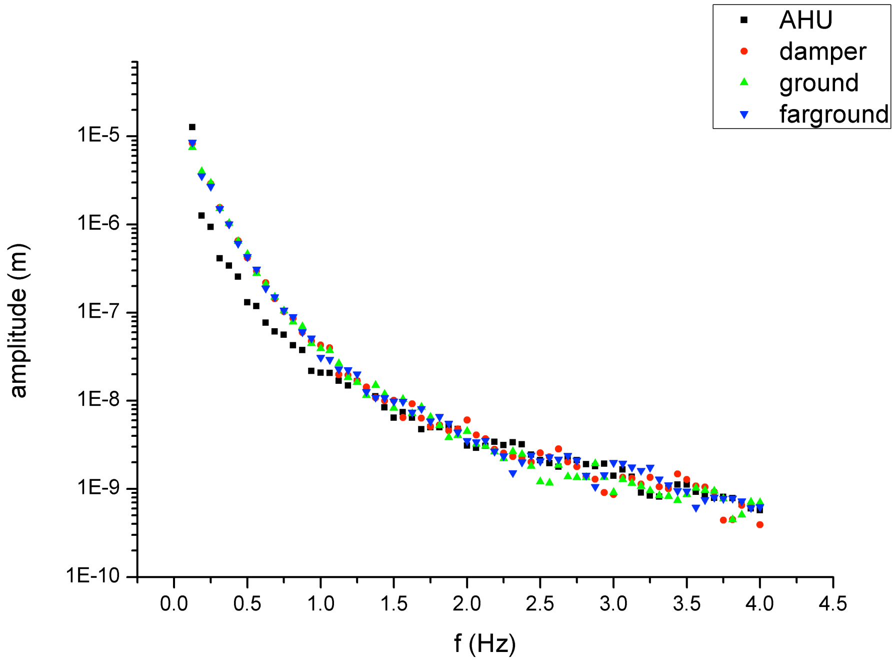




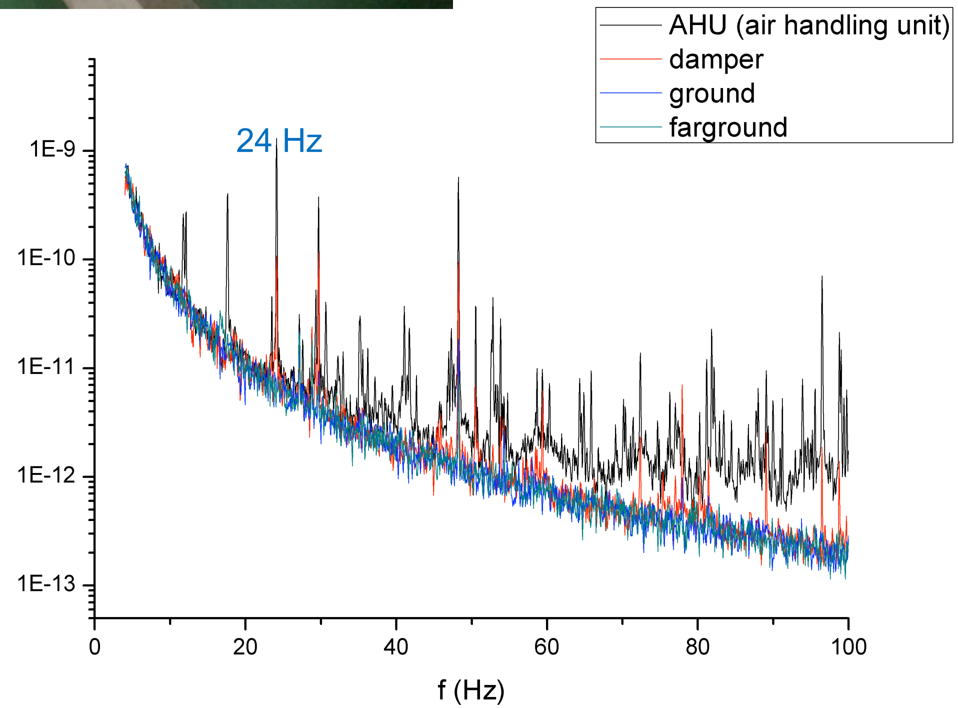


Vibration due to Air Handling Unit (AHU)



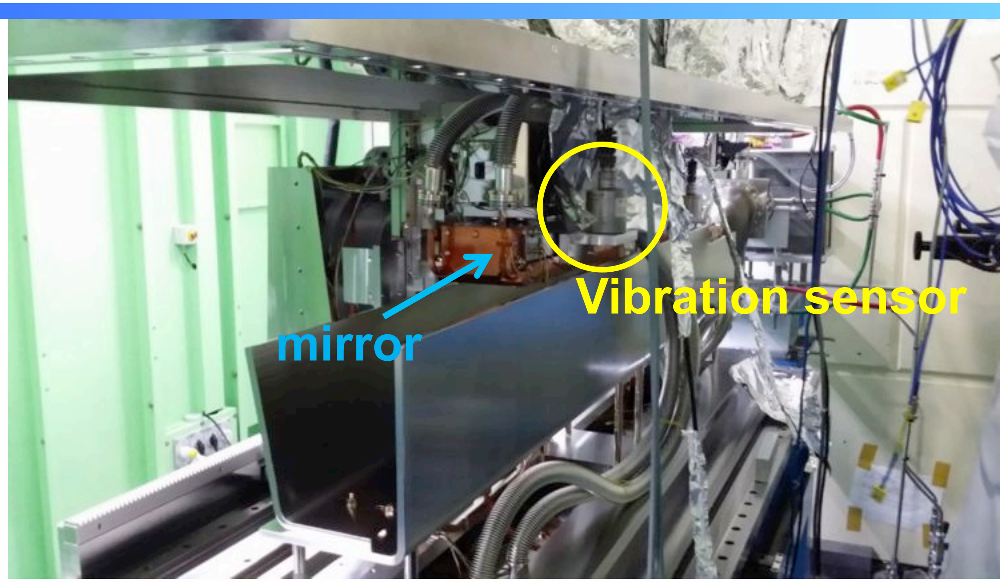


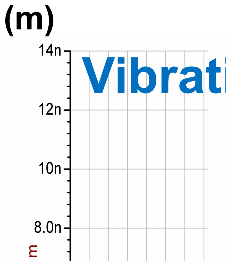
(0~4 Hz)



(4~100 Hz)

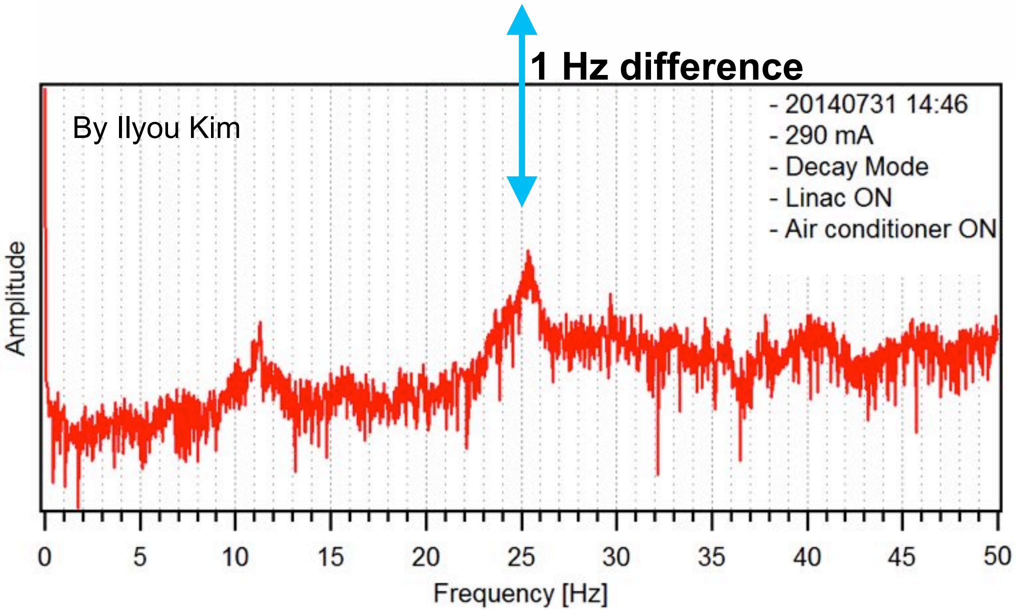
Beamline image vibration vs. mirror





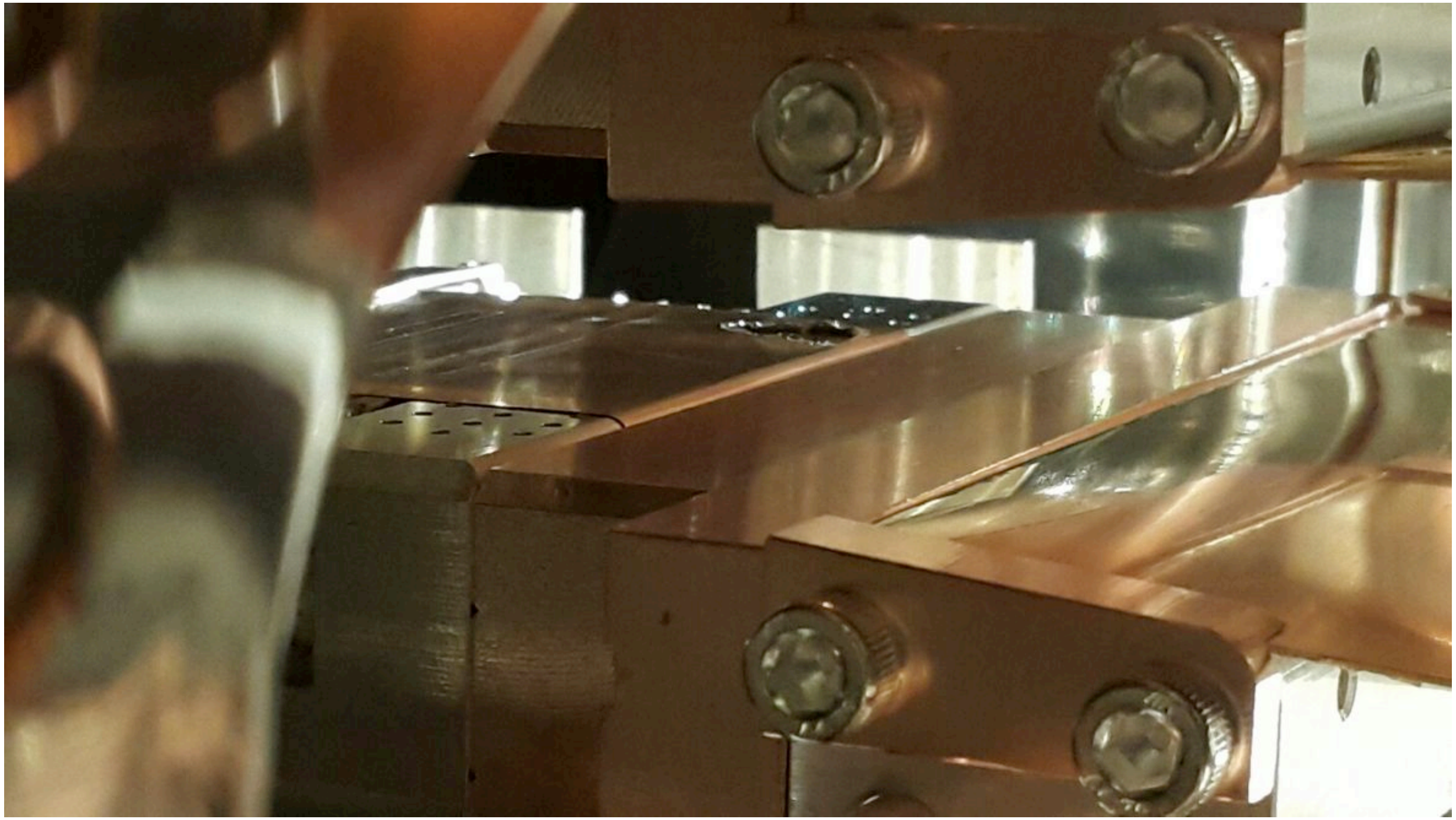
Vibration of the beamline mirror

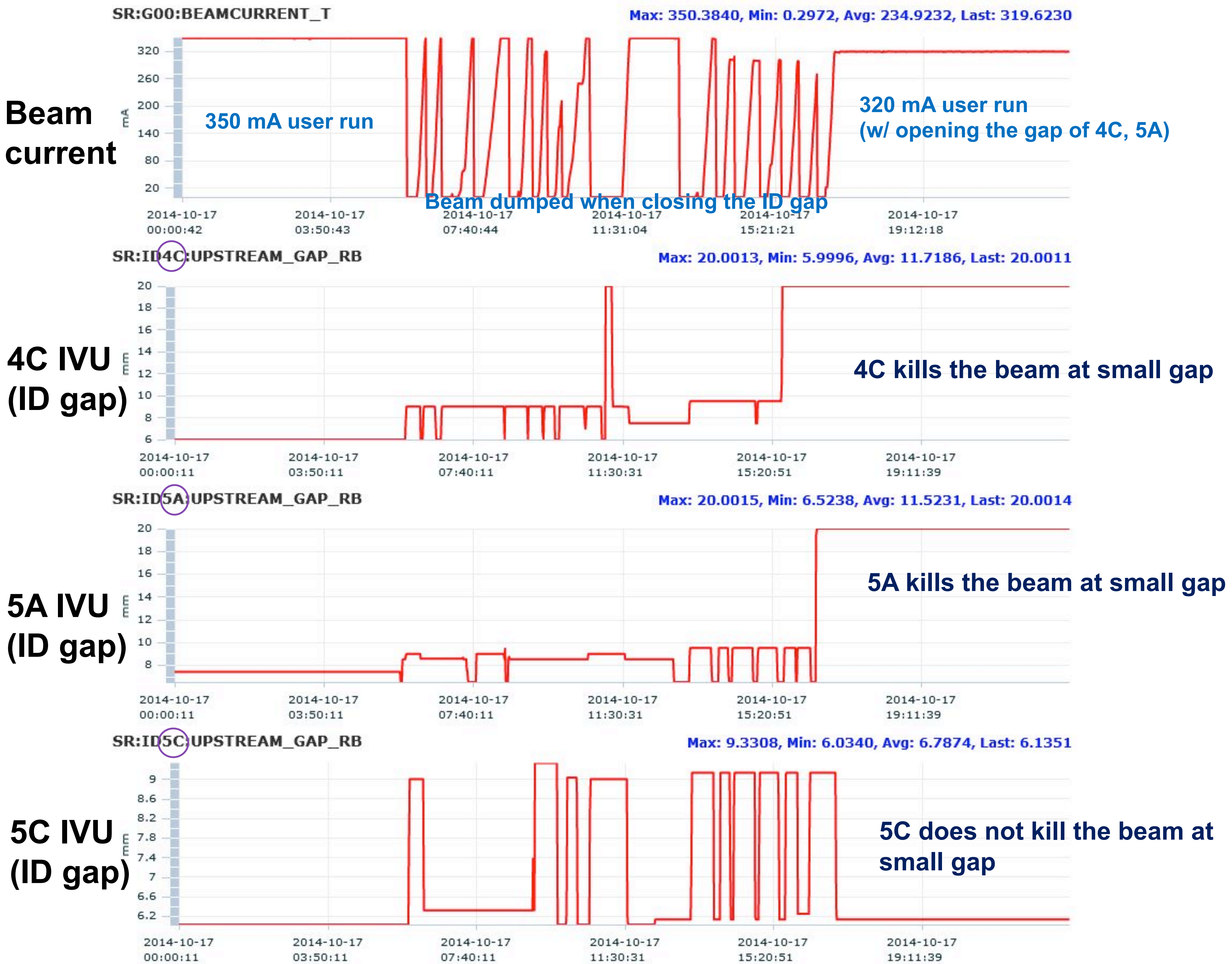
Frequency (Hz)



Frequency analysis from measured image data in 6C image beamline

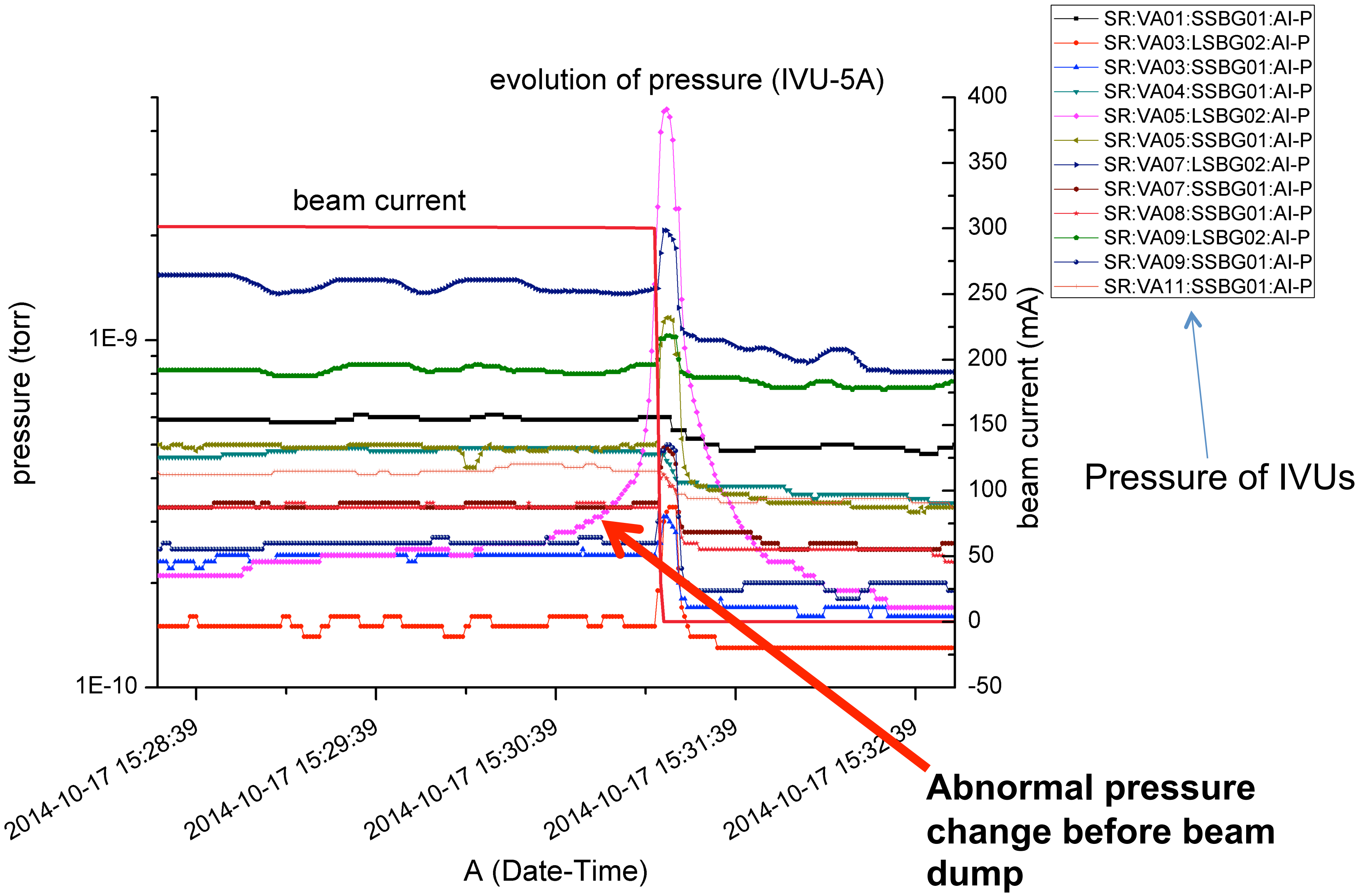
IVU foil bump



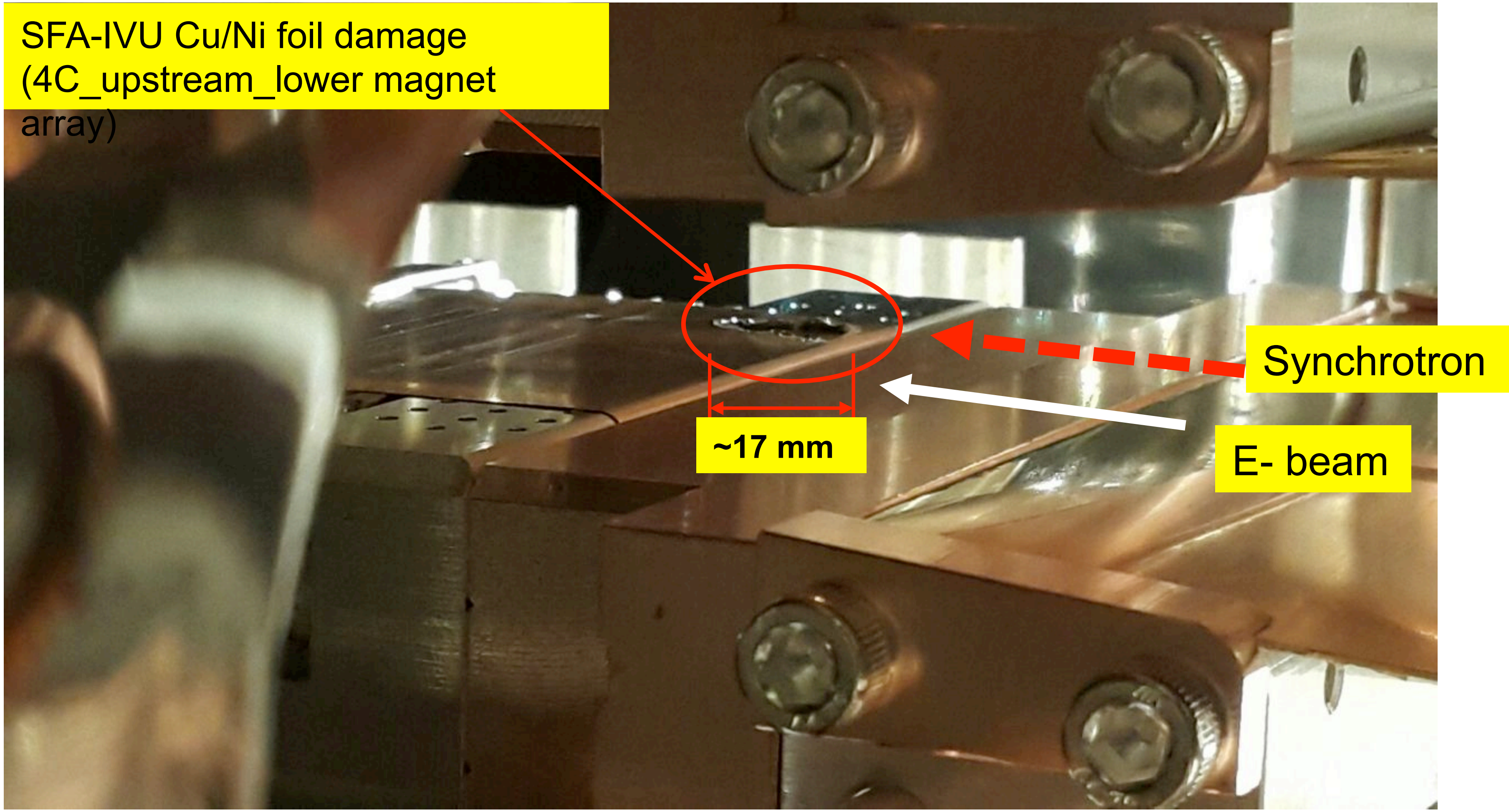


Beam current
SR:G00:BEAMCURRENT_T
Max: 350.3840, Min: 0.2972, Avg: 234.9232, Last: 319.6230
mA
350 mA user run
320 mA user run
(w/ opening the gap of 4C, 5A)
Beam dumped when closing the ID gap
4C IVU
(ID gap)
SR:ID4C:UPSTREAM_GAP_RB
Max: 20.0013, Min: 5.9996, Avg: 11.7186, Last: 20.0011
mm
4C kills the beam at small gap
5A IVU
(ID gap)
SR:ID5A:UPSTREAM_GAP_RB
Max: 20.0015, Min: 6.5238, Avg: 11.5231, Last: 20.0014
mm
5A kills the beam at small gap
5C IVU
(ID gap)
SR:ID5C:UPSTREAM_GAP_RB
Max: 9.3308, Min: 6.0340, Avg: 6.7874, Last: 6.1351
mm
5C does not kill the beam at small gap

Beam dump due to the IVU foil bump

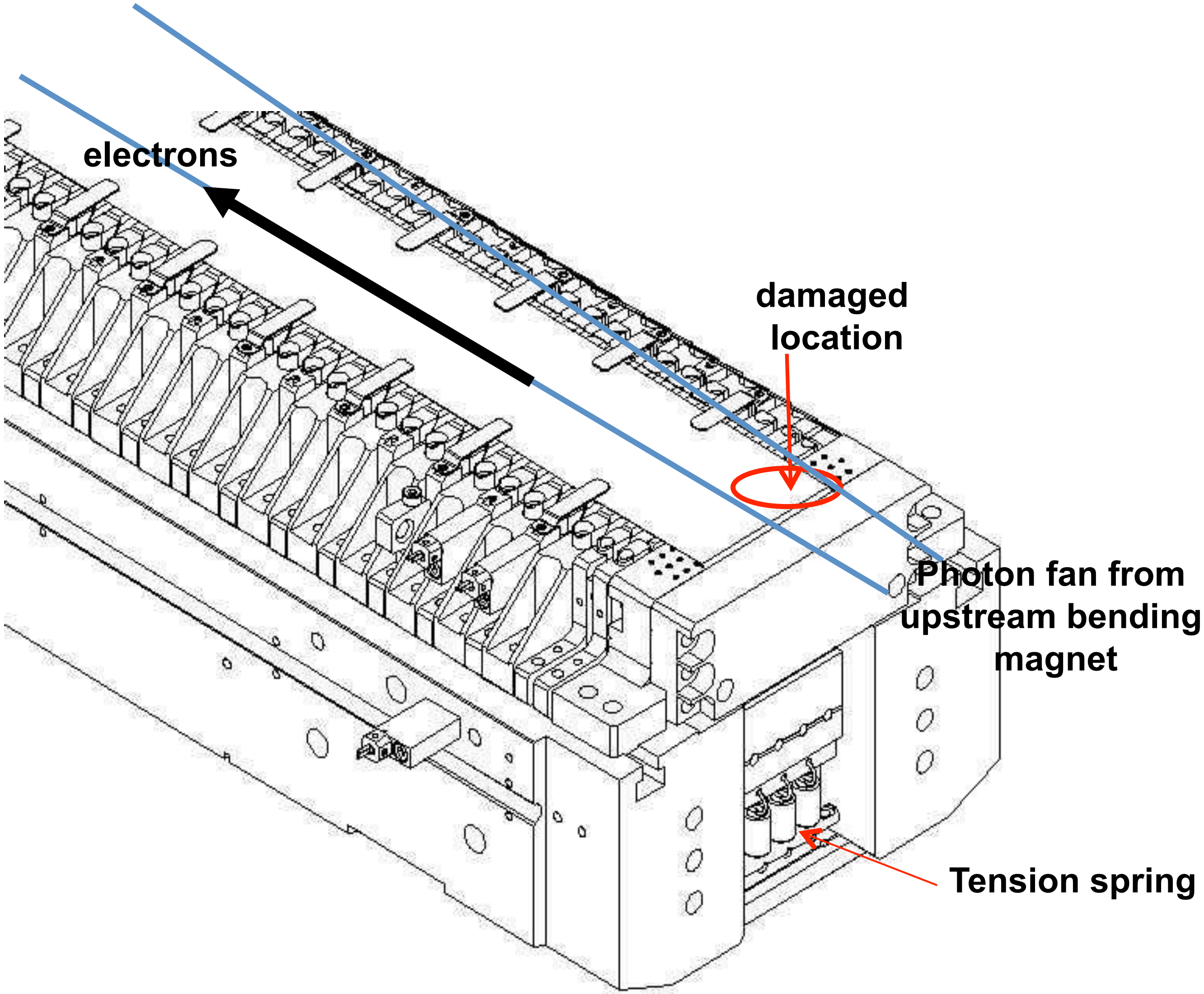


Damaged IVU (4C)

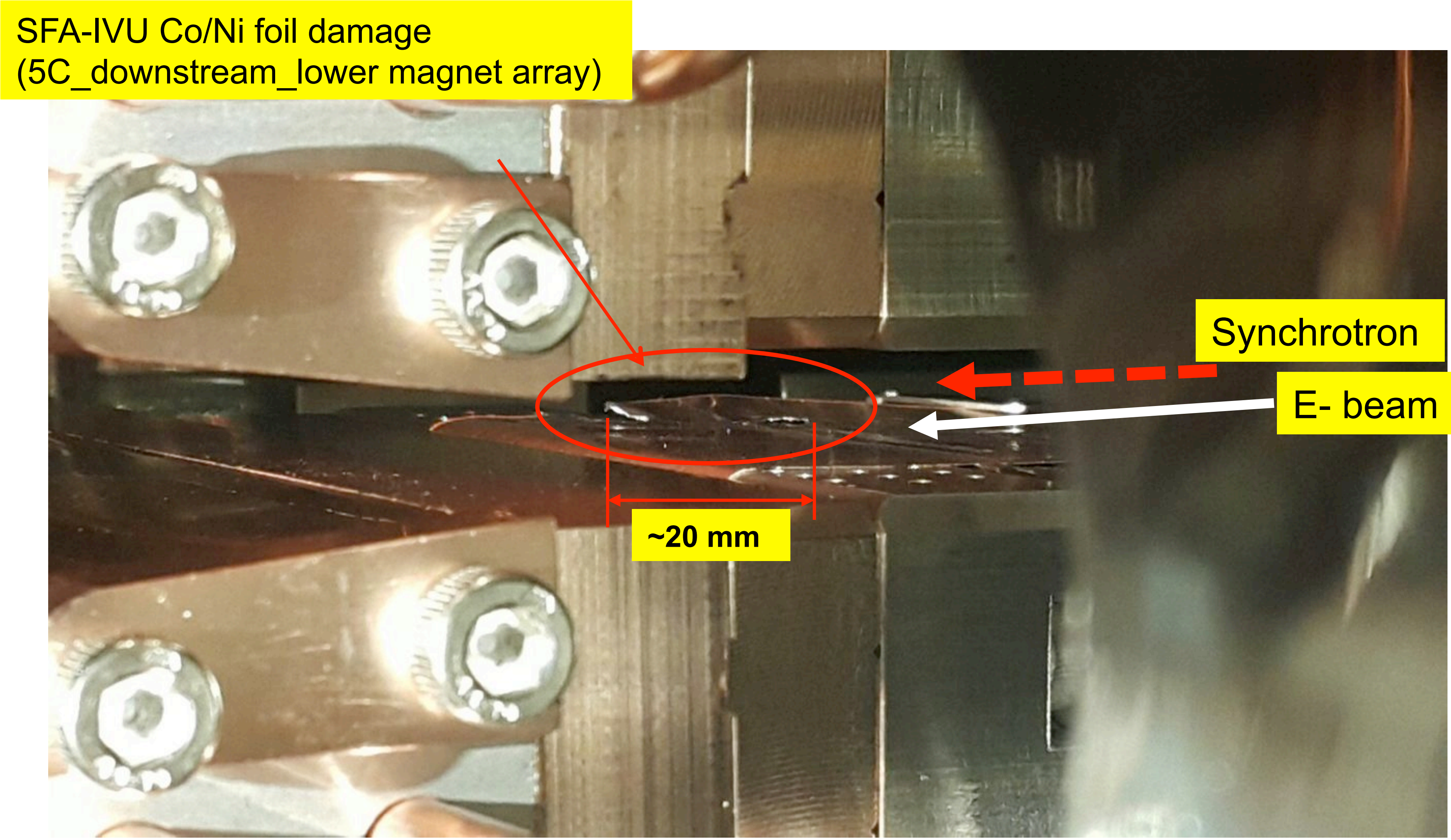


1. foil bump → image current heating → bump height ↑→ synchrotron heating → foil melting (1,2,3 호기)
2. foil bump → image current heating → bump height ↑→ Beam mis-steering (including mis-alignment) (lower foil only + cell 4,5)

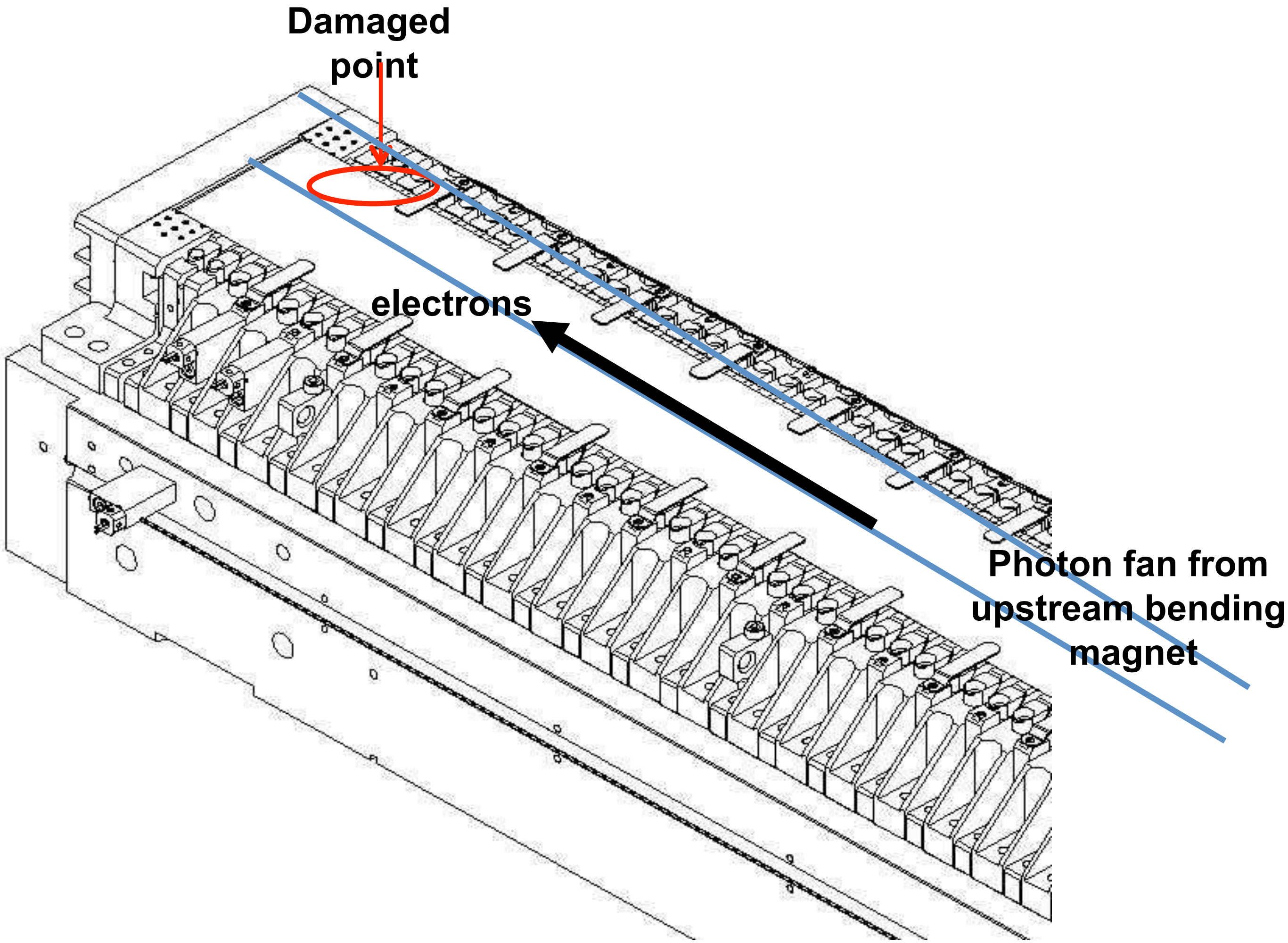
SFA-IVU Cu/Ni foil damage
(4C_upstream_lower magnet array)



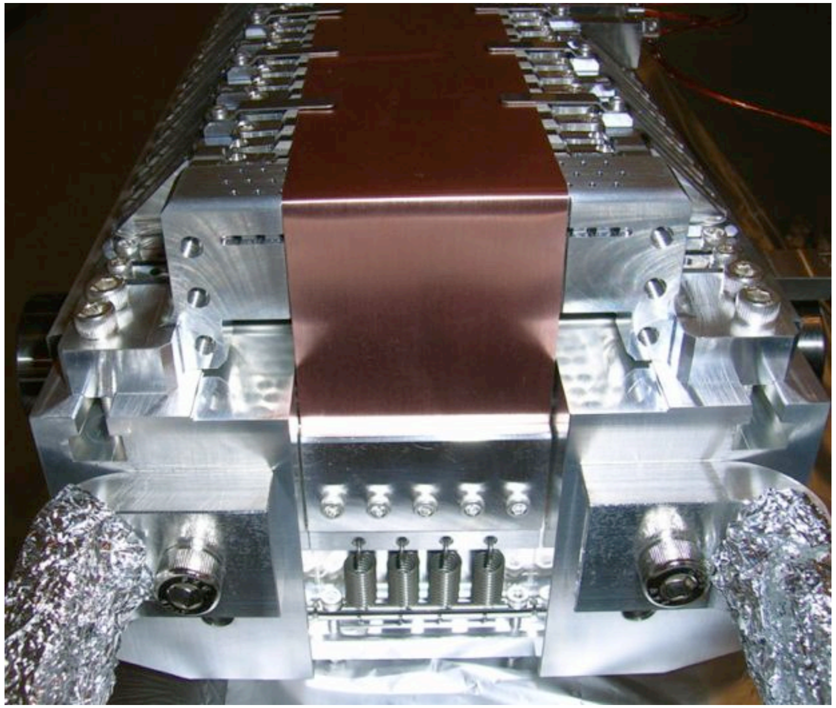
Damaged IVU (5C)



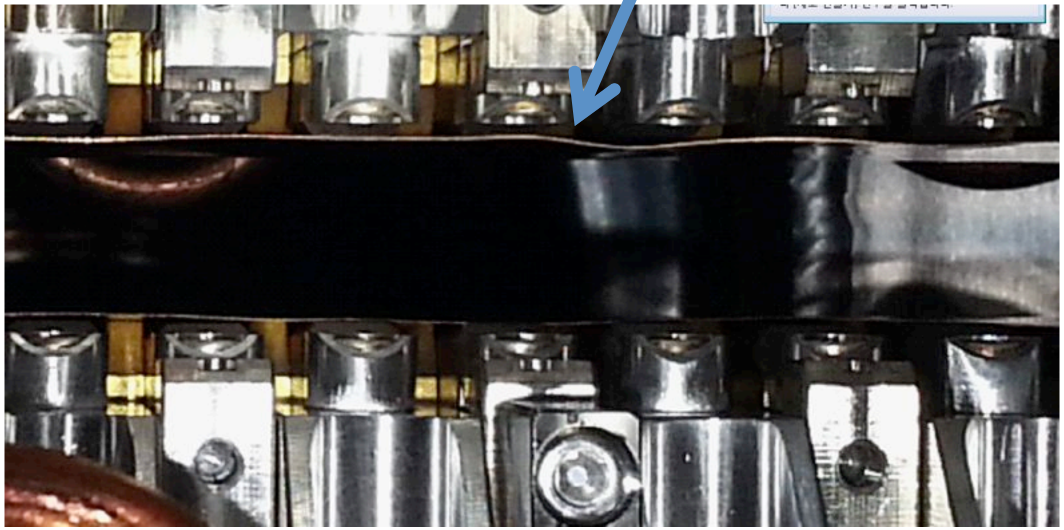
SFA-IVU Cu/Ni foil damage
(5C_downstream_lower magnet array)



Inside of the IVU20



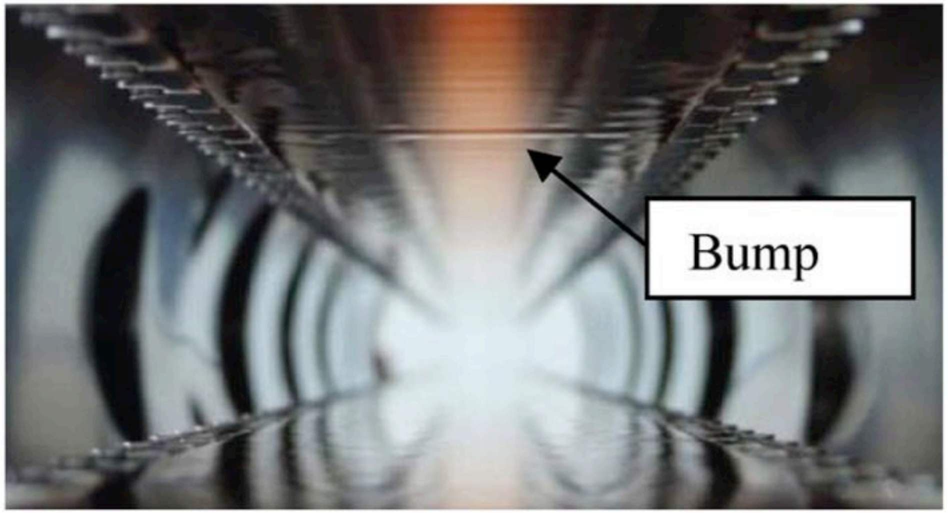
Uneven Cu/Ni foil



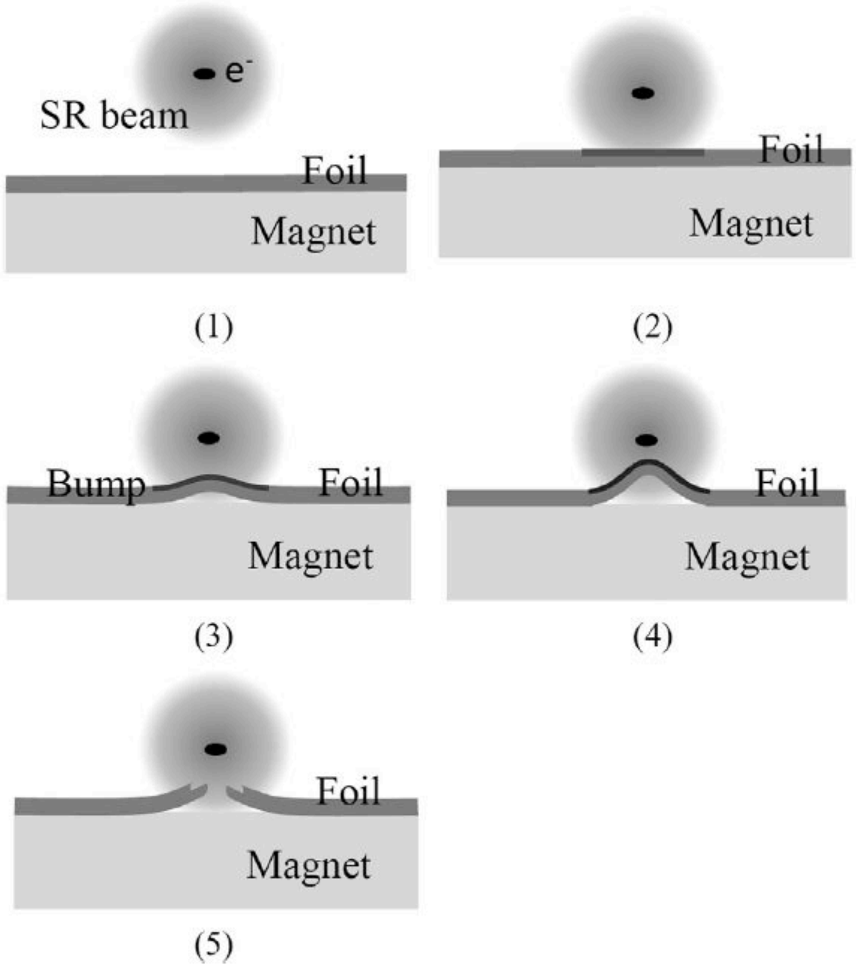
Side view

(Picture taken before assembling)

IVU trouble in NSRRC



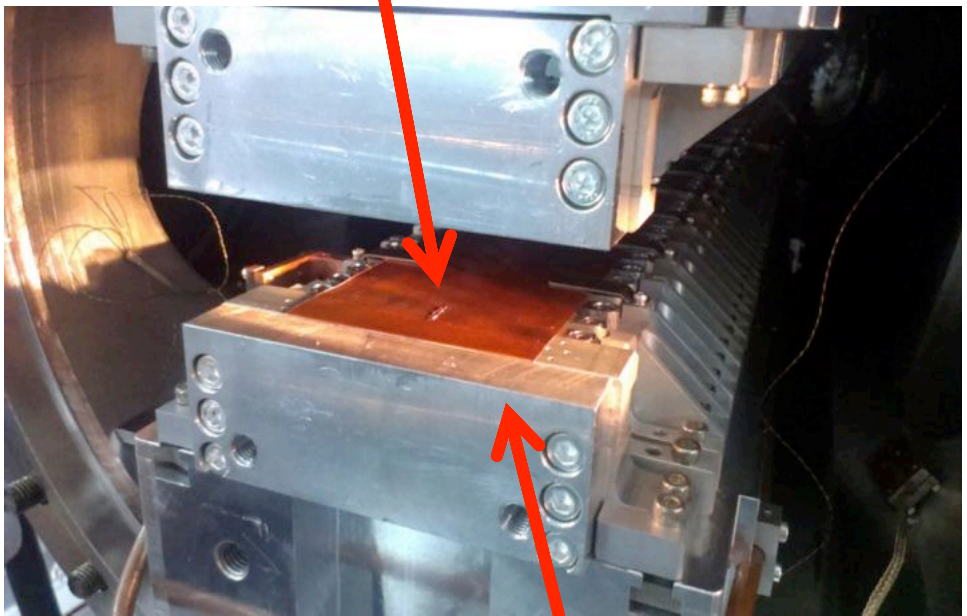
Bump on the magnet foil after baking
(Before operation)



Scenario of an avalanche meltdown
due to a beam-induced heat load

IVU trouble in SSRF

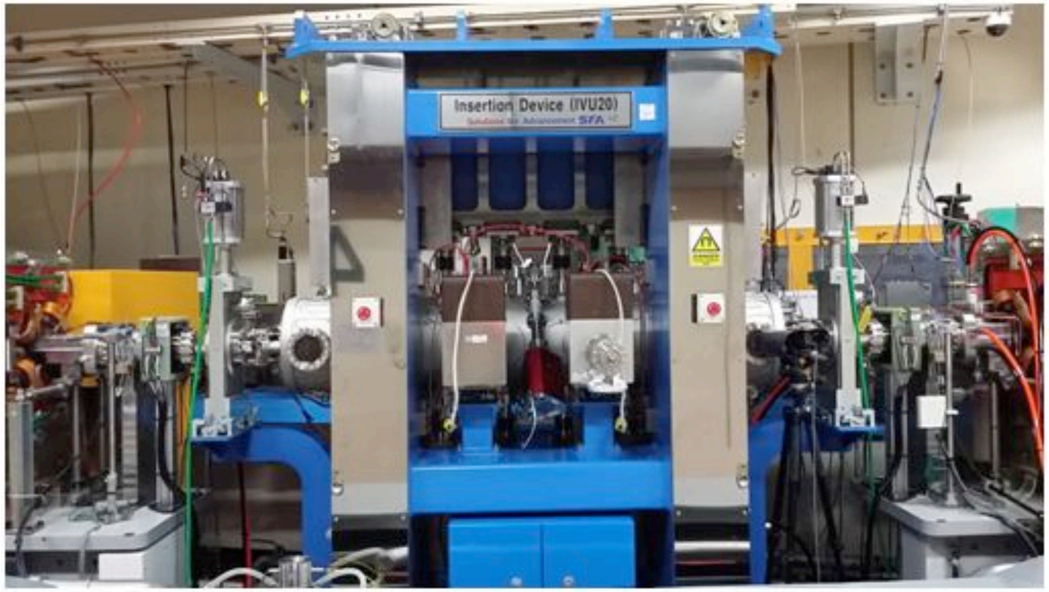
Because the copper foil drum up,
this scratch may be cut by beam



Reinstalled the block to make the copper
foil smooth

Repair status

- Cu/Ni foil (50 um/50 um thickness) has been arrived from NSRRC.
- IVU20(4C) in the SR tunnel was replaced with pre-ID chamber.
- IVU20(4C) has been moved to Support Bldg.#2 for repair. (2015.01)
- IVU20(4C) will be reinstalled in 2015.08 (summer shutdown)

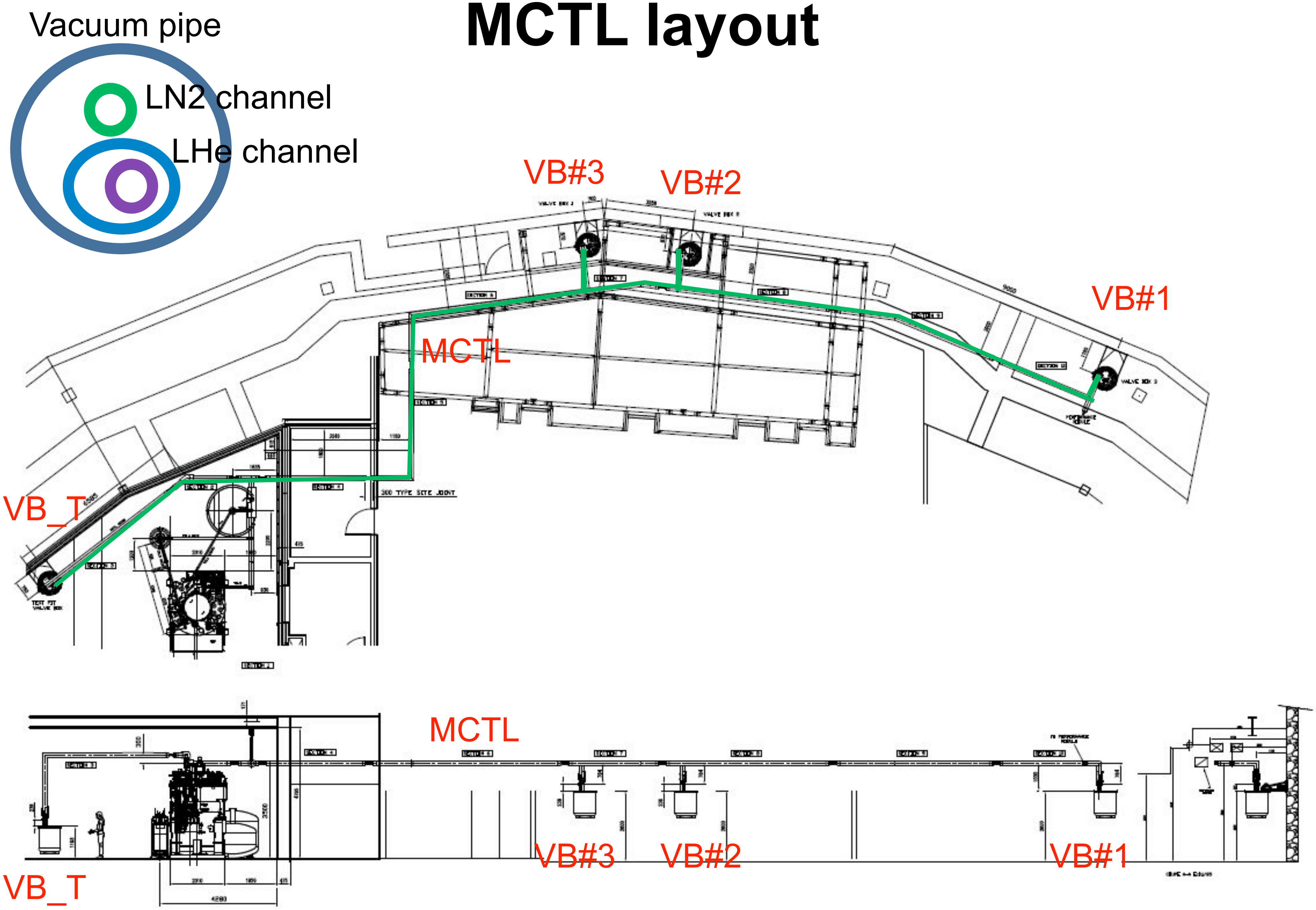


Storage Ring Tunnel

Support Bldg. #2

MCTL break down

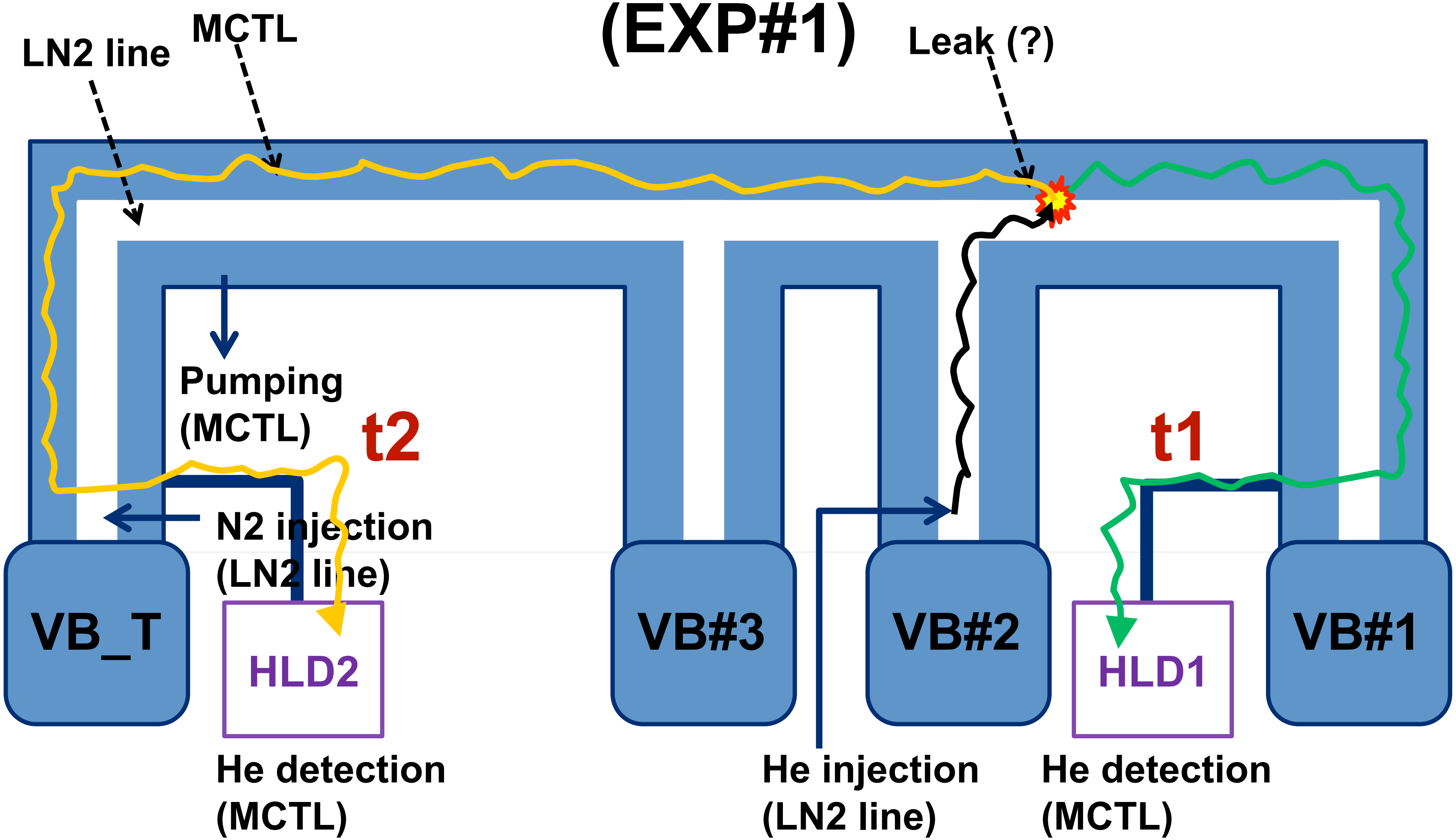
MCTL layout


Vacuum pipe
LN2 channel
LHe channel
VB#3
VB#2
VB#1
MCTL
VB_T
MCTL
VB#3
VB#2
VB#1
VB_T

Leak Detecting Procedure

1. Place two He leak detectors(HLDs) on the LN2 line and inject He gas into MCTL pipe or vice versa.
2. Check the He detecting time between two HLDs.
3. The leakage is nearer to the HLD which detects He first. (If the pressure in the LN2 pipe is uniform, then the He diffusion velocities are equivalent)
4. If the time difference is negligible, inject little amount of N2 gas into the LN2 line to increase the He diffusion time in the line. Then check the time difference again.
5. Change the N2 background pressure in the LN2 line to confirm the He arrival time delay.
6. If the pressure of LN2 line is too high then we have severe pressure gradient in the pipe (because two HLDs are pumping at different places). In this condition the He diffusion velocity is not uniform. This cause an error.

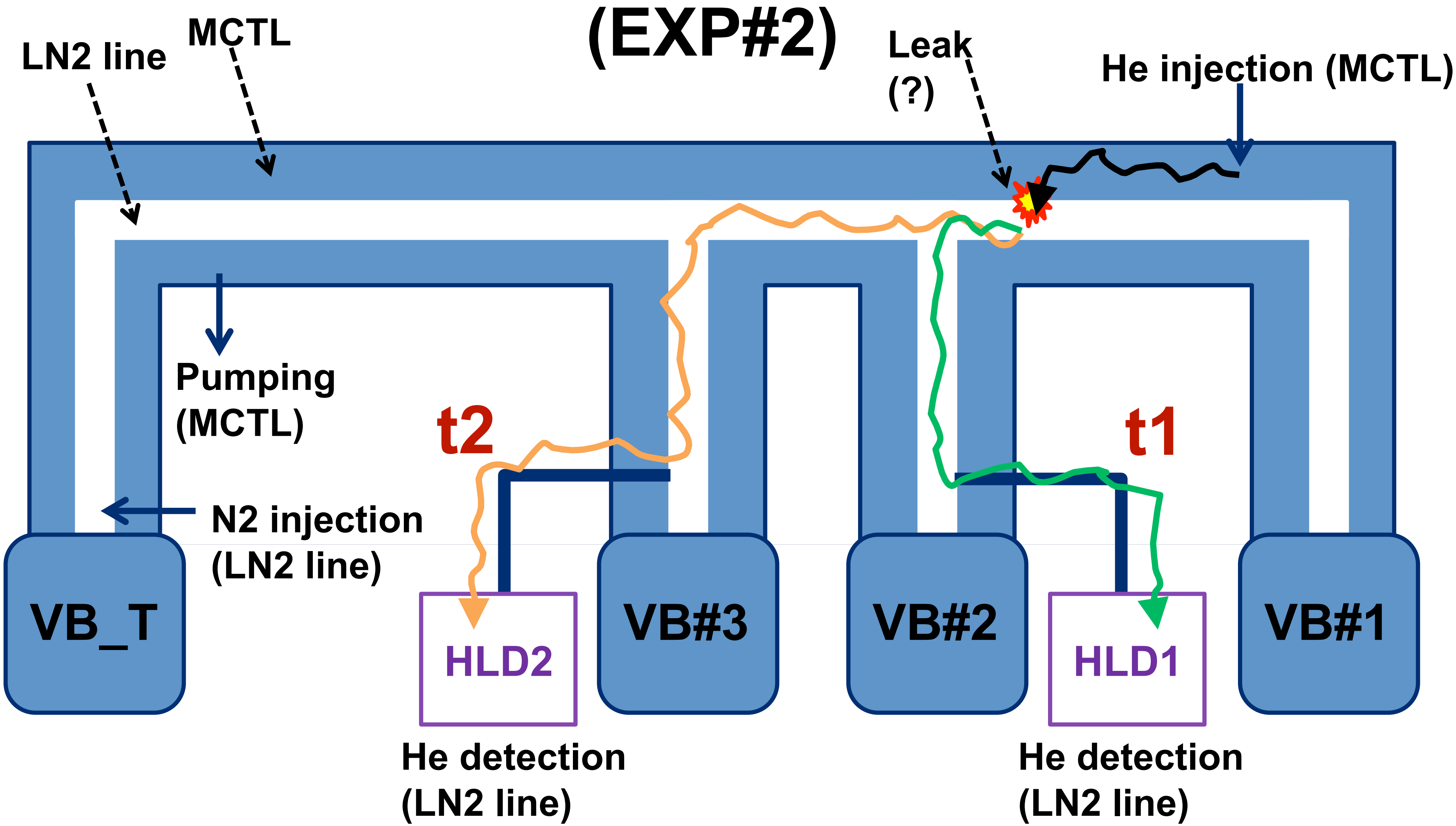
(EXP#1)



P (LN2 line)	t1	t2
< 0.01 mbar	72 sec	88 sec

➔ **Leakage is nearer to VB#1 than VB_T**

- HLD: He detector
- VB: Valve box

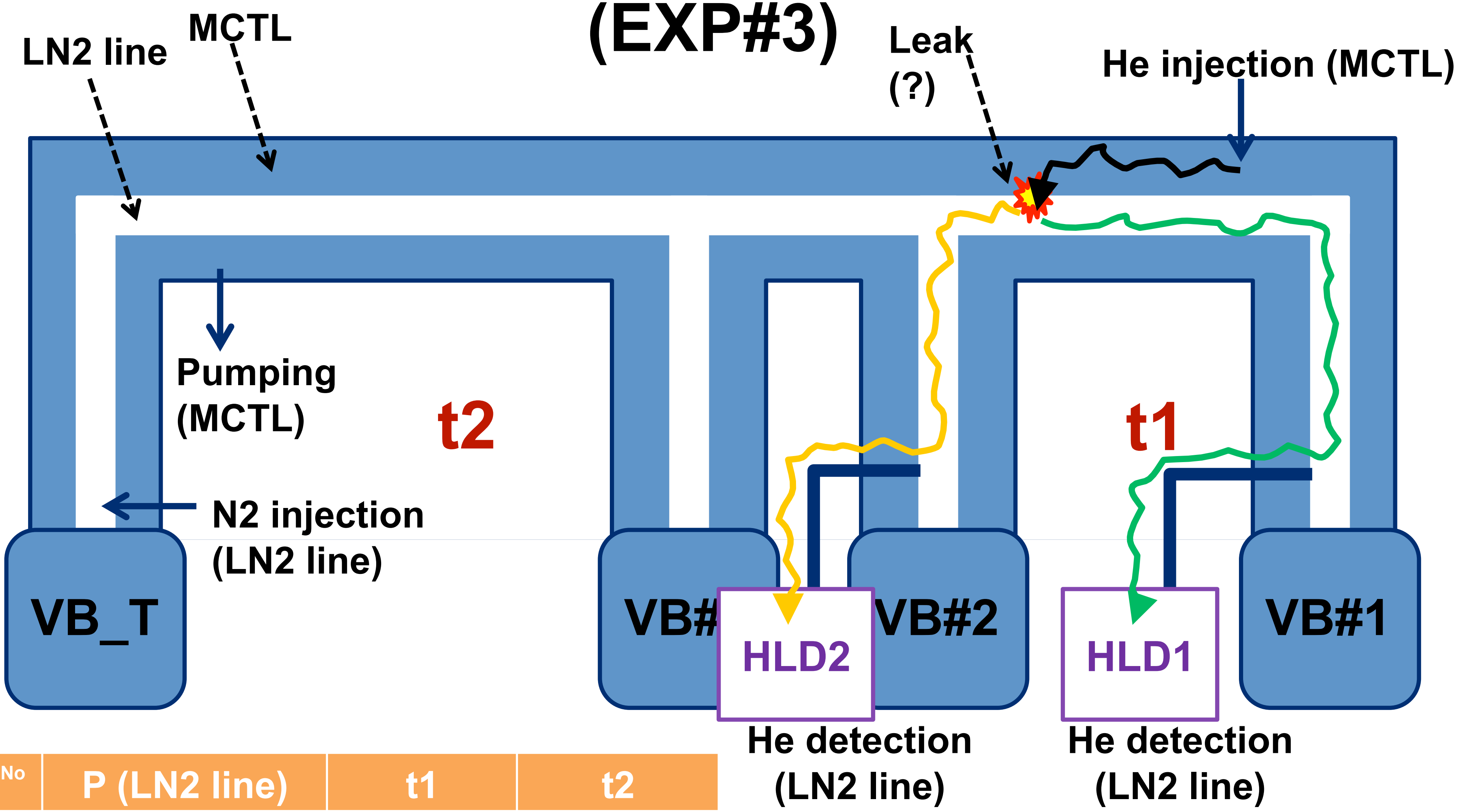


No	P (LN2 line)	t1	t2
1	< 0.01 mbar	16 sec	16 sec
2	< 0.05 mbar	12 sec	20 sec
3	< 0.1 mbar	13 sec	35 sec

➔ **Leakage is nearer to VB#2 than VB_#3**

- HLD: He detector
- VB: Valve box

(EXP#3)

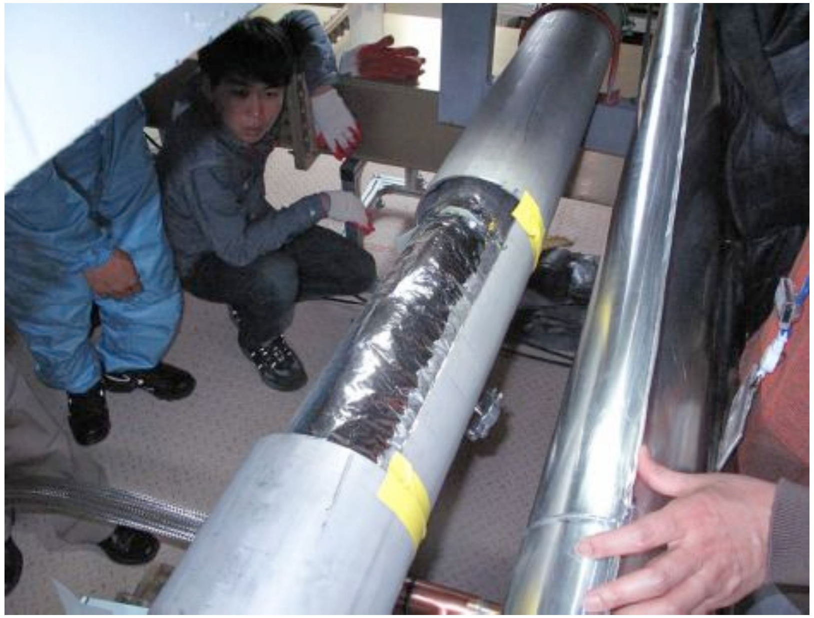


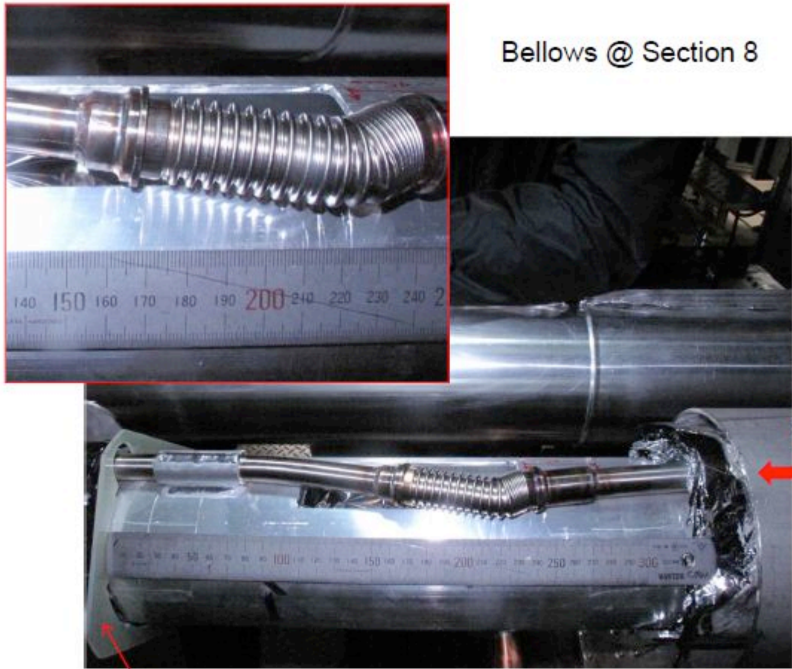
No	P (LN2 line)	t1	t2
1	< 0.01 mbar	8 sec	4 sec
2	< 0.02 mbar	18 sec	7 sec
3	< 0.05 mbar	26 sec	12 sec
4	atm (MCTL vented)	9 m 12 s	9 m 25 s

➔ Leakage is nearer to VB#2 than VB_#1

- HLD: He detector
- VB: Valve box

Damaged bellow

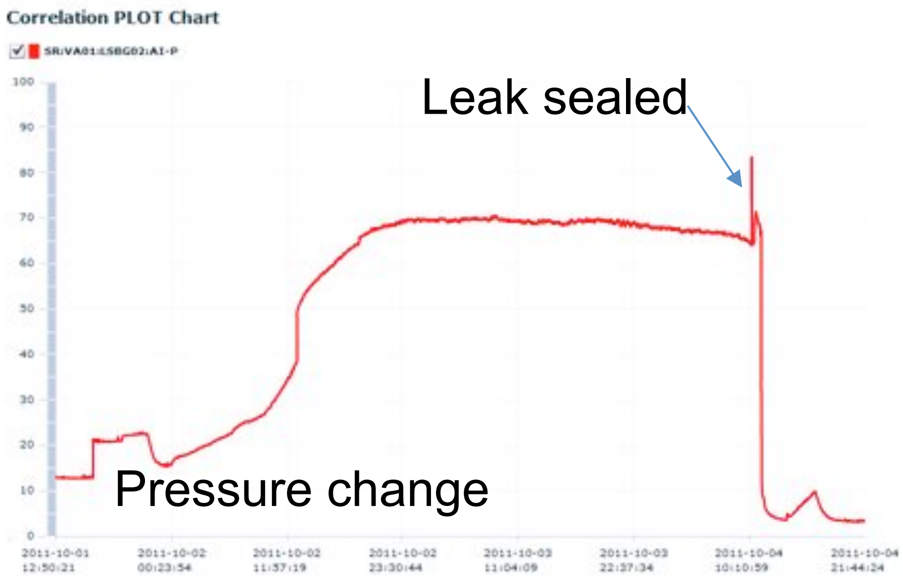


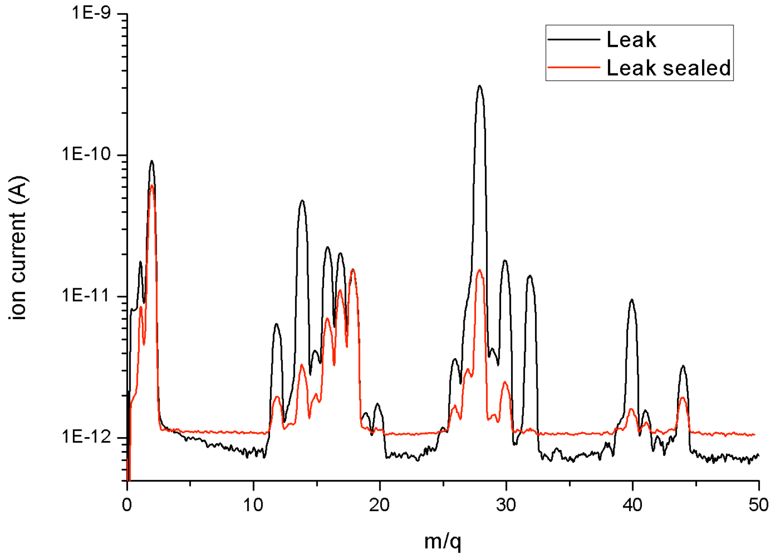


Other vacuum related events during PLS-II operation

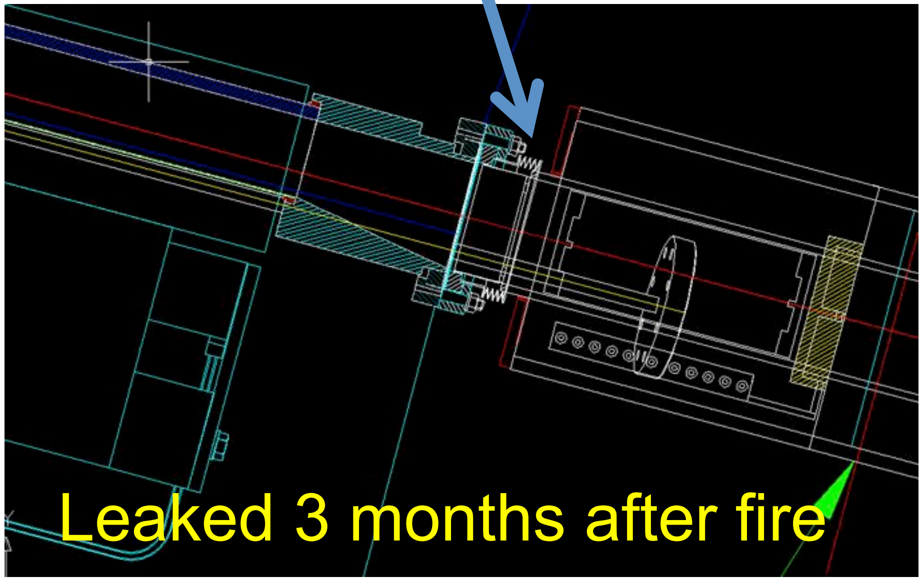
Leakage in injection section (after fire)

(2011.10)



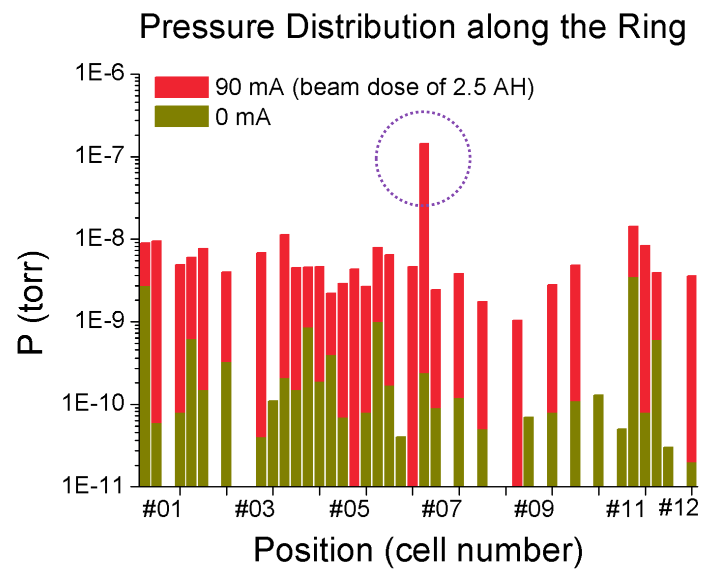


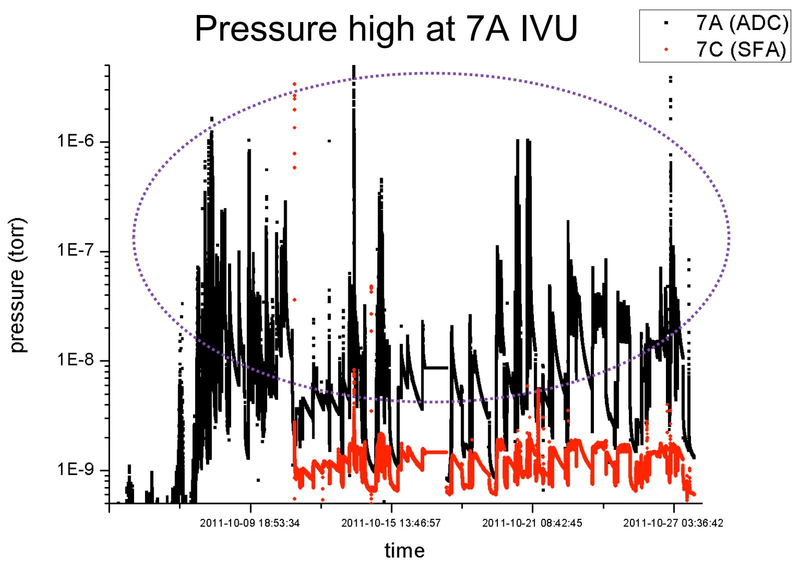
Weld join of bellows was corroded by particles produced during fire

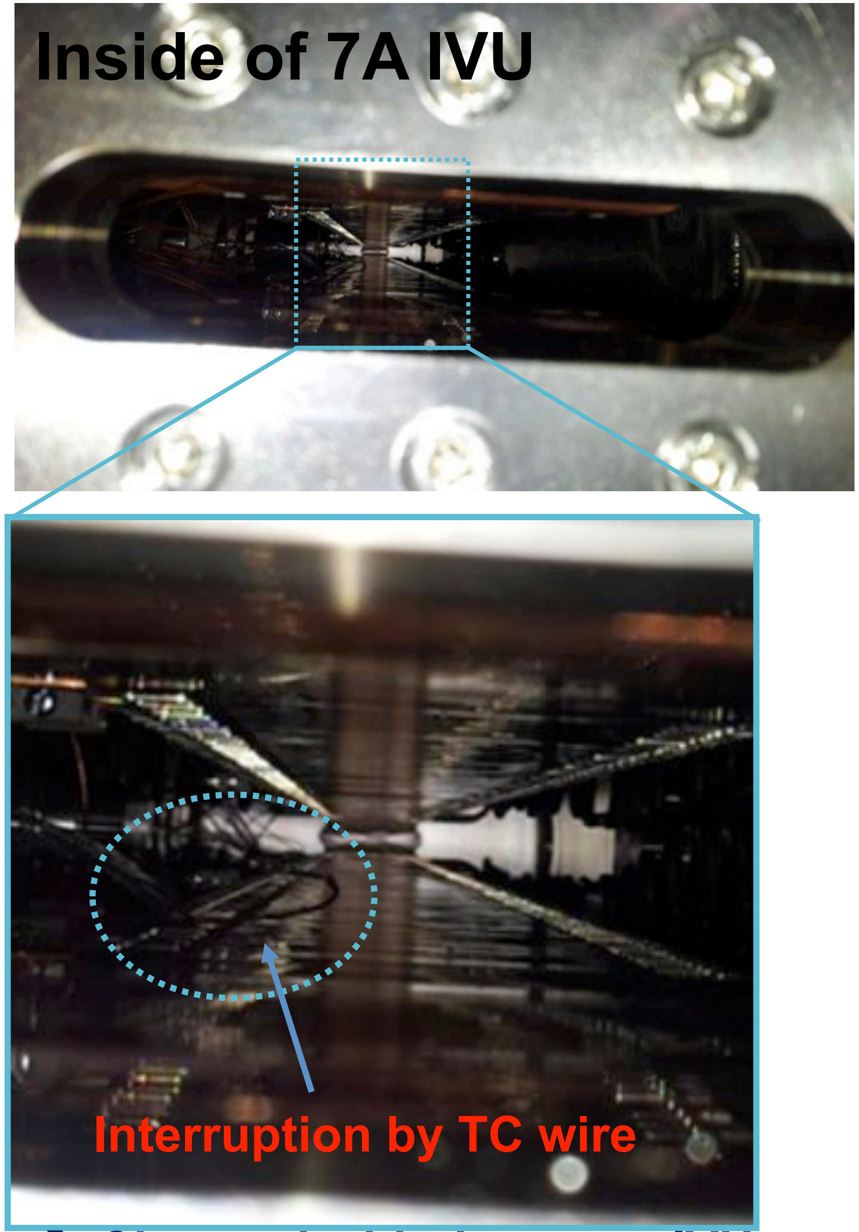


Abnormal pressure in an IVU

(2011.10)





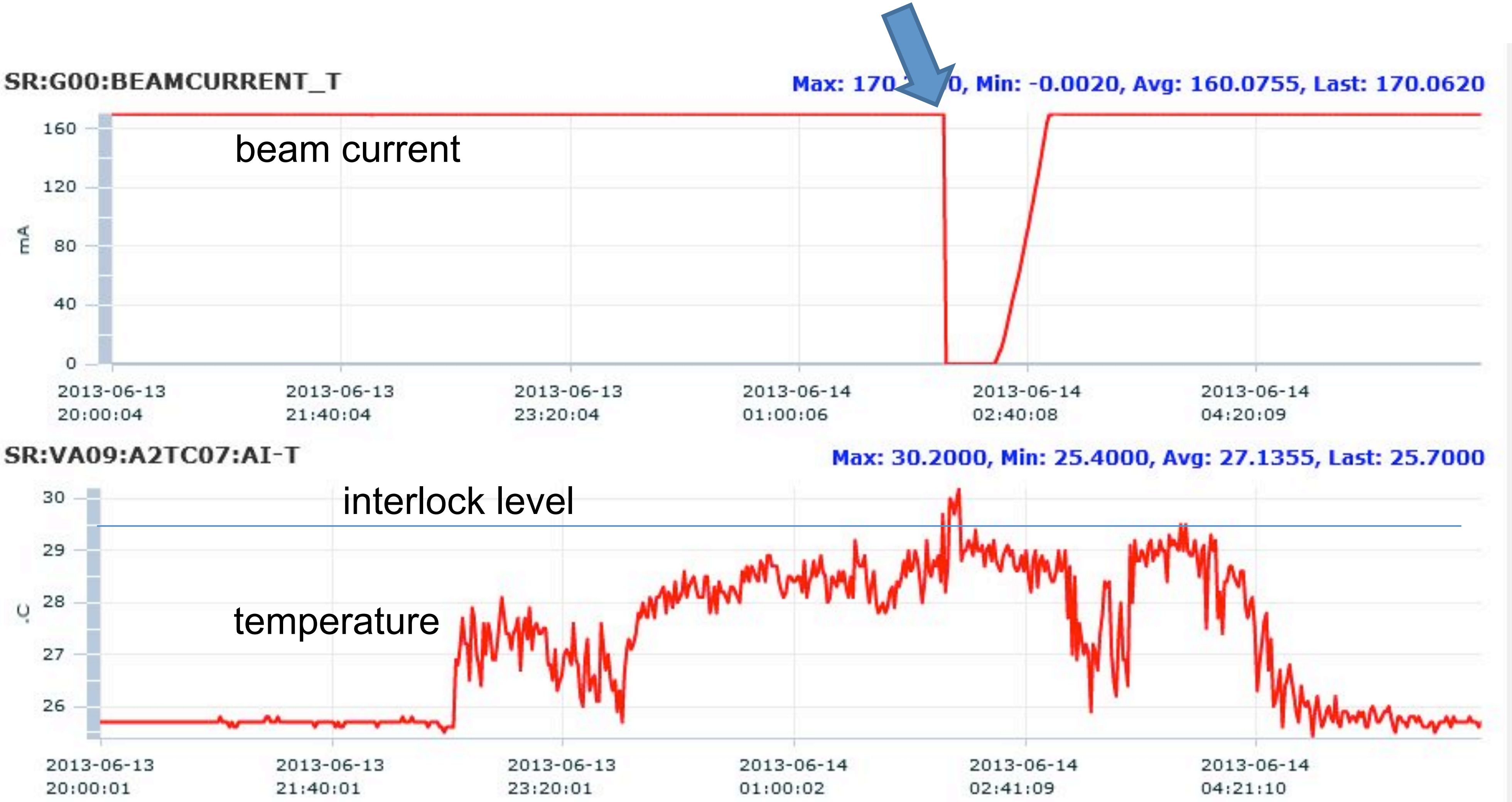


➔ **Changed with the spare IVU**

Thermocouple malfunction

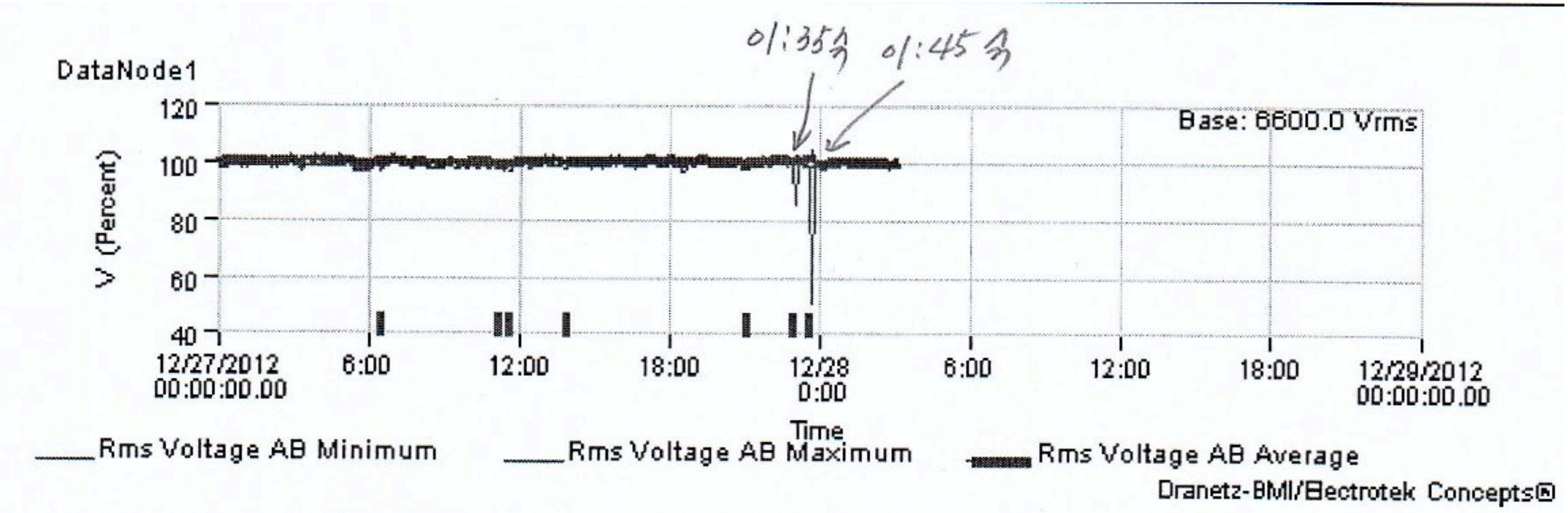
(2013.06)

Beam was dumped due to the malfunction of a thermocouple out of **720 ea**



Any recommendation to prevent this?

Gauge controller malfunction due to sag



Old Ion gauge controller (GP307)

Instantaneous voltage sag ➔ gauge controller emission off ➔

Analog output sent 10 V signal ➔ Machine Interlock System triggered

➔Gate valve closed ➔ beam dump

(The controller being in trouble was changed then it became O.K.)

Thank you for your attention!