Vacuum Performance of the Prototype Chamber for the Korea-4GSR

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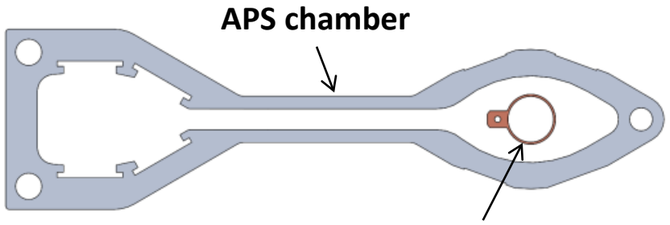
POSTECH, Korea

Contents

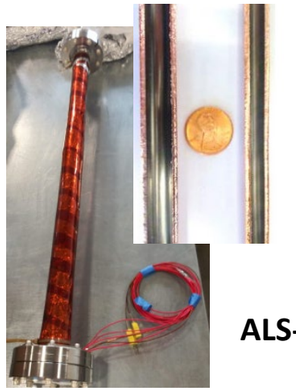
- Introduction
- Proto-type chamber
- Outgassing rate : Aluminum extrusion chambers
- Pumping speed : Pill type getter
- Ultimate pressure
- Summary

Distributed pumping using NEG coating

Cross section comparison



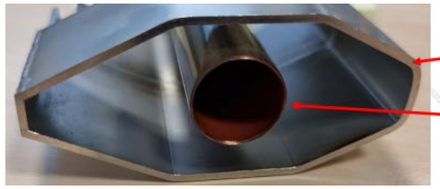
J.A. Carter et al., (2019)



ALS-U

Insertion device chamber (d=6mm)

Erik Wallén., (2019)

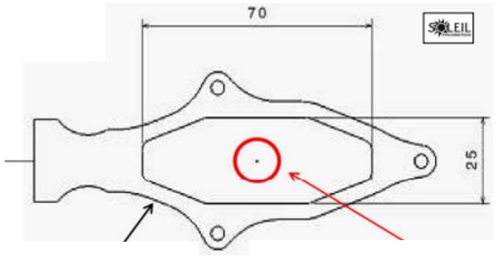


Diamond vessel cross section (typically 80mm H x 40mm V)

Diamond-II vessel cross section (typically 20 mm inside diameter)

Strongly conductance limited

Matthew Cox., (2024)



SOLEIL

Standard vac. Chamber
Qpole, Spole

SOLEIL upgrade project

center achromat
ø 10 mm internal diameter

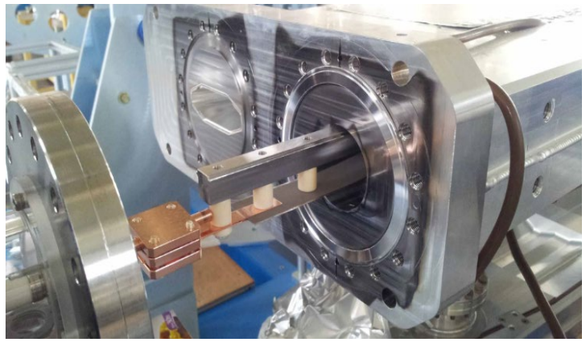
Vincent Le Roux., (2020)

Accelerator	Main Pump
MAX-Ⅳ (Sweden)	NEG coating : d= 20 mm (OFS-C10700, Silver-bearing 0.085%)
SIRIUS (Brazil)	NEG coating : d= 20 mm (OFS-C10700, Silver-bearing 0.085%)
SOLEIL-U (FRANCE)	NEG coating: d= 10 mm OFS (Silver-bearing 0.12 %) for chambers/absorbers
ALS-U (USA)	NEG coating: d= 6 mm, Insertion device chamber
SLS-II (Switzerland)	NEG coating (columnar structure)
ELETTRA 2 (Italy)	NEG coating
Diamond II (UK)	NEG coating
APS-U (USA)	NEG coating: d= 22 mm, Insertion device chamber
HEPS (China)	NEG coating : d= 22 mm
PETRA Ⅳ (German)	NEG coating
ESRF-EBS (Italy)	Aluminum chamber + lumped pump NEG coating chamber (2 chambers)
Korea-4GSR (Korea)	**Aluminum extruded chamber + Pill NEG**

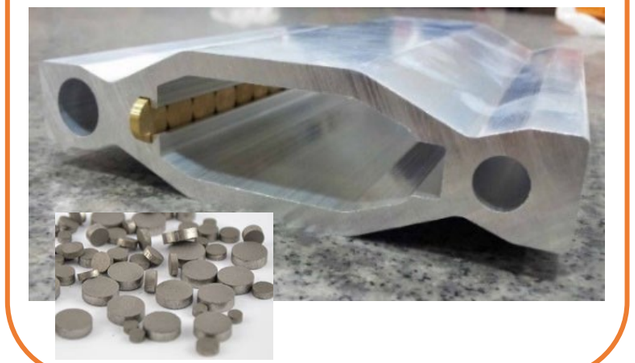
* OFS (Ag 0.085~0.12%): substantial strength and high resistance to softening due to elevated temperature

Distributed pumping [PLS-II Storage ring]

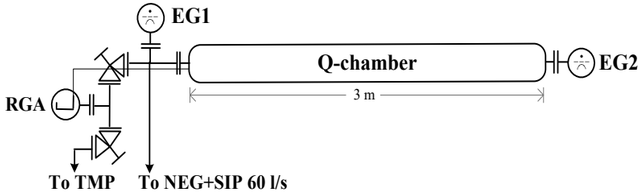
Traditional

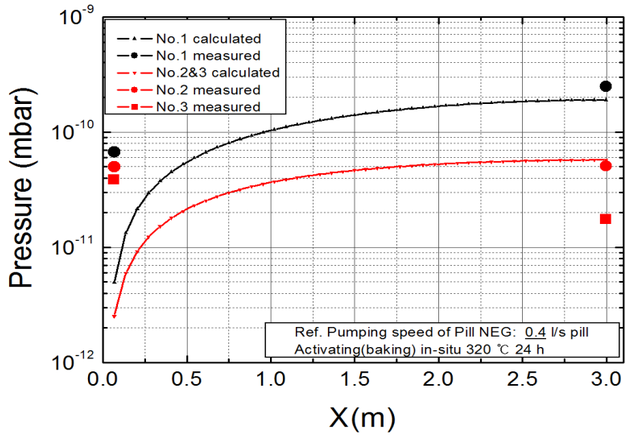


With Pill NEG



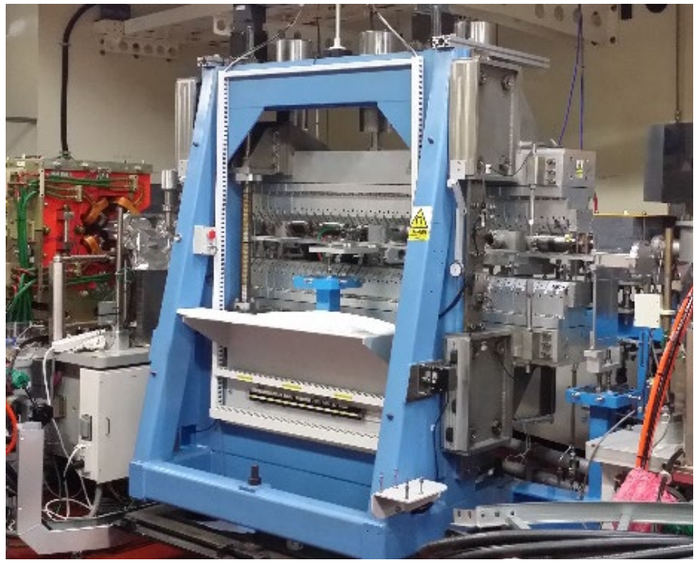
Ultimate Pressure





TEST No.	Pill getter	NEG Activating (CP) (roughing port)		NEG Activating (Pill) (inside of Q Ch)		Ultimate pressure (mbar)	
		Temp. (℃)	Time (h)	Temp. (℃)	Time(h)	EG1	EG2
No.1	X	400	1.5	150	48	6.7E-11	2.5E-10
No.2	O	350	16	**180**	**48**	**5.0E-11**	**5.1E-11**
No.3	O	350	24	300	48	3.9E-11	1.8E-11

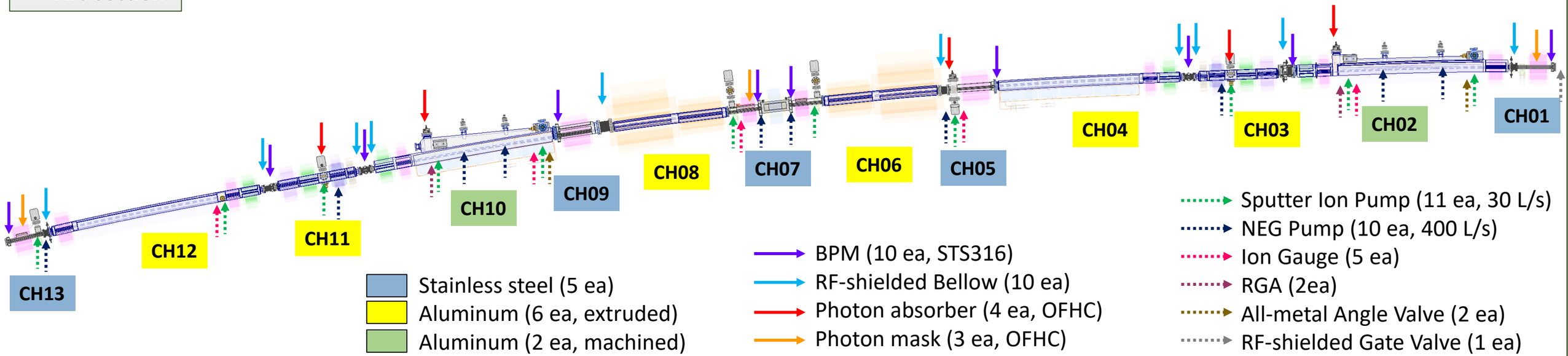
Cell No. 10 SS MPW10



Long Straight section

Korea-4GSR: 1 cell layout of Storage Ring

▪ Arc-section



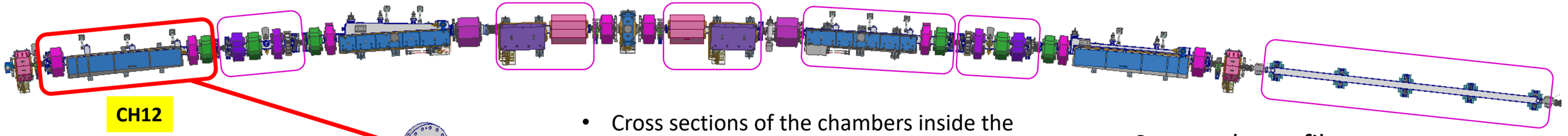
▪ Straight section

Proto-type chamber

Very limited space available between magnets for flanges, valves, bellows, BPMs …

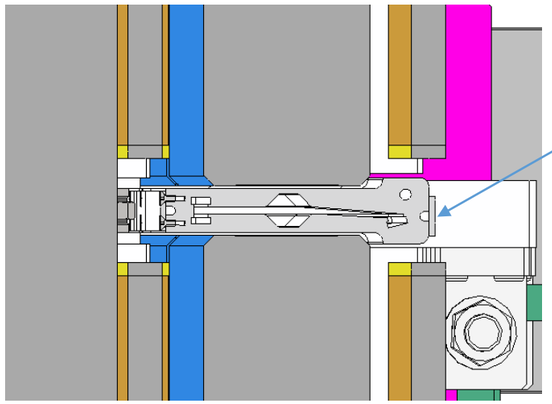
- Distributed pumping chamber :
  - ✓ Arc-section - 6 ea
  - ✓ Straight section – 1 ea (Pre-ID chamber)

Aluminum extrusion vacuum chamber (Pill type NEGs inserted)

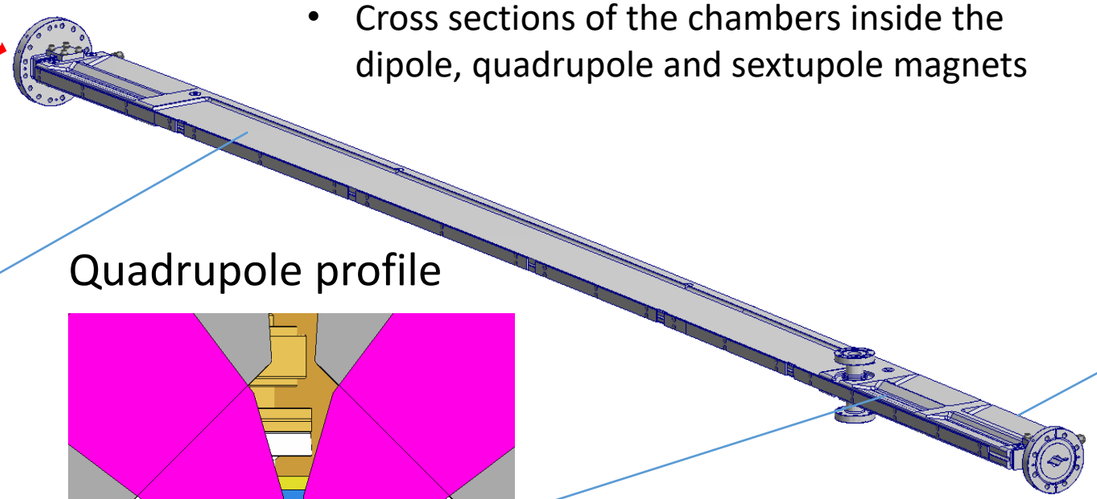


- Cross sections of the chambers inside the dipole, quadrupole and sextupole magnets

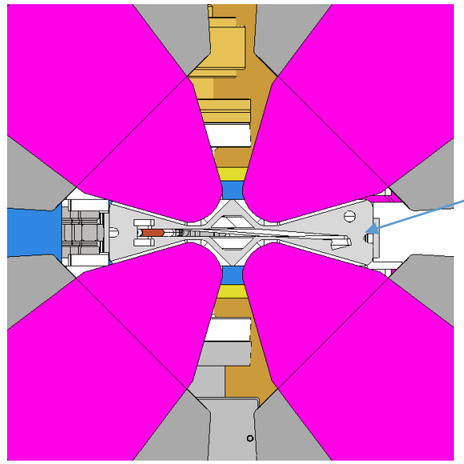
Dipole profile



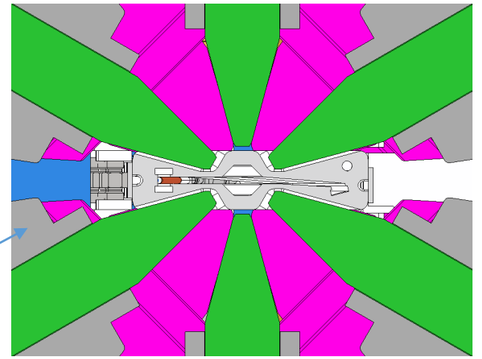
LGBM: Longitudinal Gradient Bending Magnet (5 ea)



Quadrupole profile



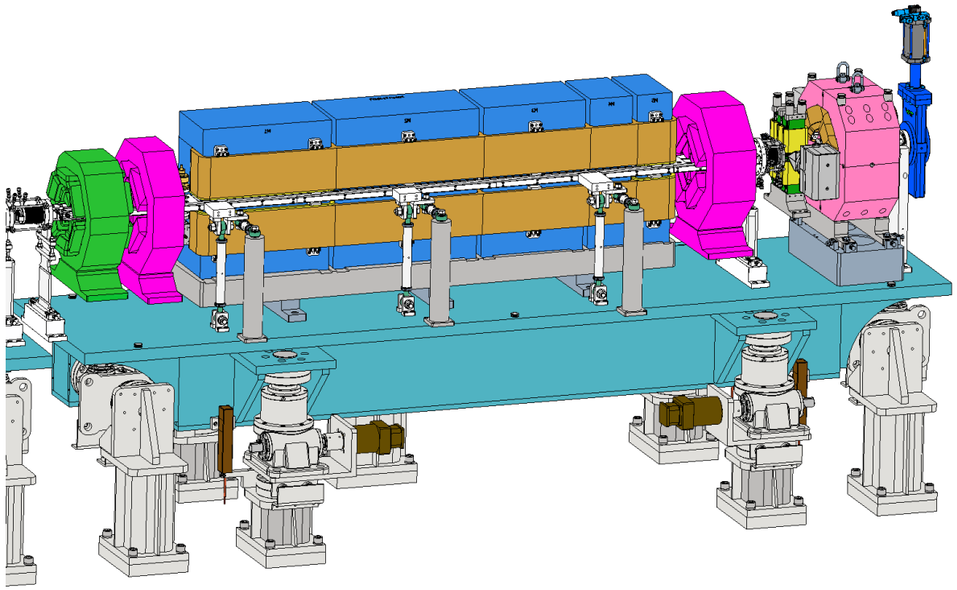
Sextupole profile



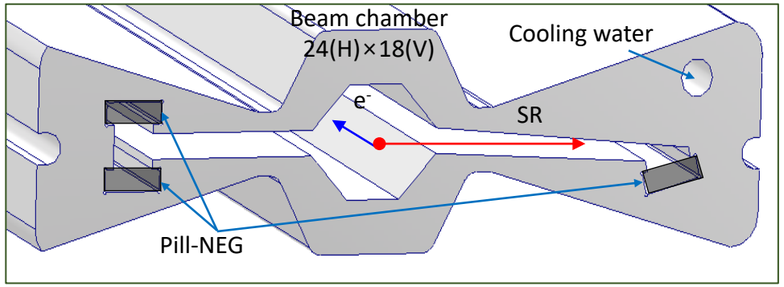
- Clearance between vacuum chamber and magnet < 1.5 mm
- The magnets quantities, spacing, and narrow pole gaps drive partially thin walled vacuum chamber designs

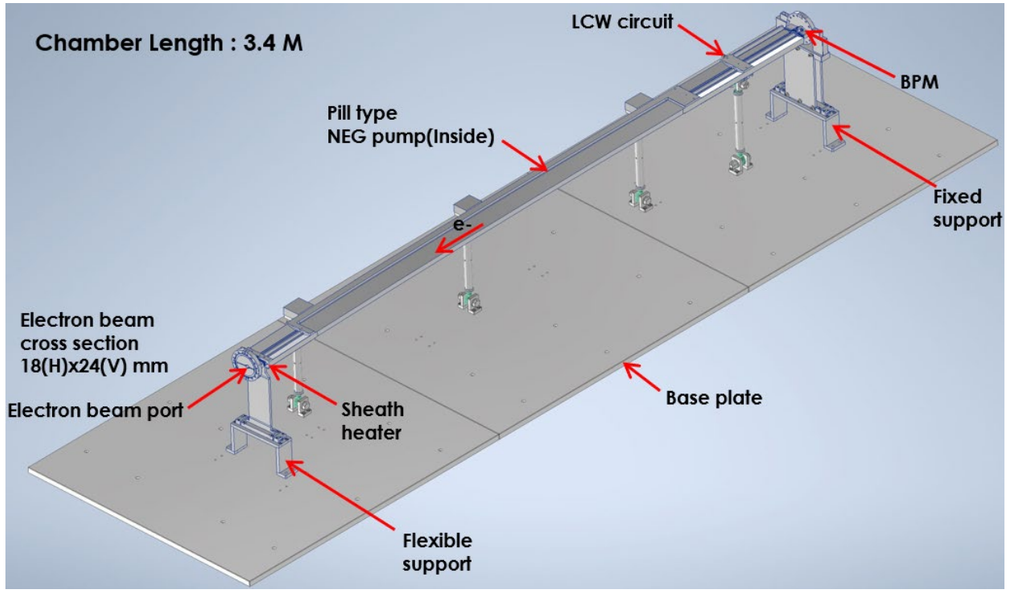
Vacuum system requirements (Ch 12)

- Ultimate pressure : < 5×10^{-10} mbar (After Bake-out and NEG activation)
- Aluminum extruded material: A6063
- Heat treatment condition of extruded material: T5
- Internal surface roughness : < Ra 0.5 μm (After chemical polishing)
- Chamber dimension: 24(H) x 18(V) x 3425(L) mm, octagonal cross-section
- Flatness of extruded material: < 0.5 mm/total length (After Stretching)
- Curvature tolerance of vacuum chamber: ± 0.5 mm
- Material of aluminum flange: A2219-T87/T851 or A6061-T651
- Coating of aluminum flange: TiC (2~3 μm)
- Vacuum pumps: Distributed Pill-type NEG pump + Sputter ion pump

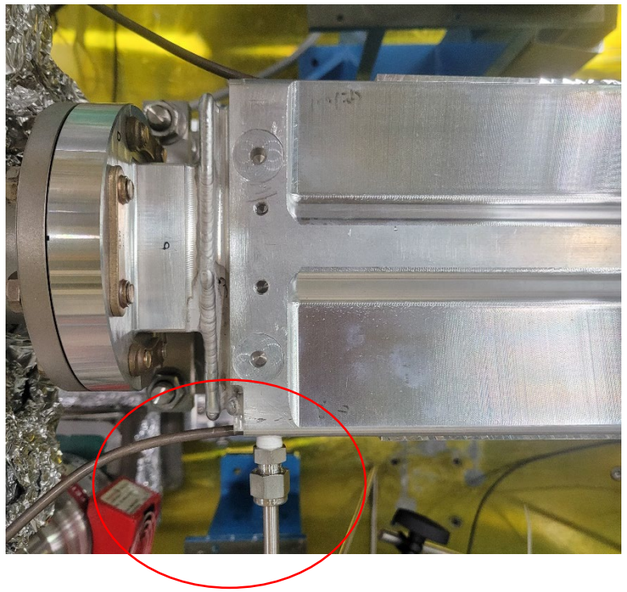


Vacuum chamber cross-section



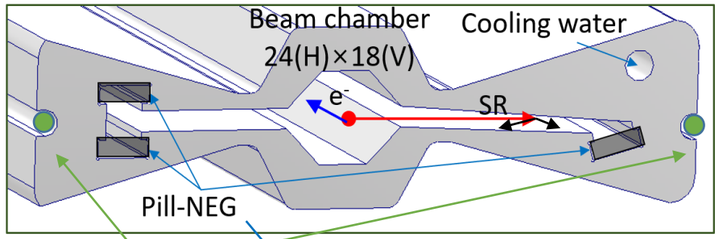


Vacuum system requirements (Ch 12)



- Heating method : **In-situ bake-out using a sheath heater**
  d= 4.5 mm (2 core), 1140W
  Bakeout & NEG activation Temperature : 180 ℃
- Cooing method: **Manufactured through aluminum extrusion**
  (without installing a outboard water cooling channel)

Cross-section of the SR vacuum chamber



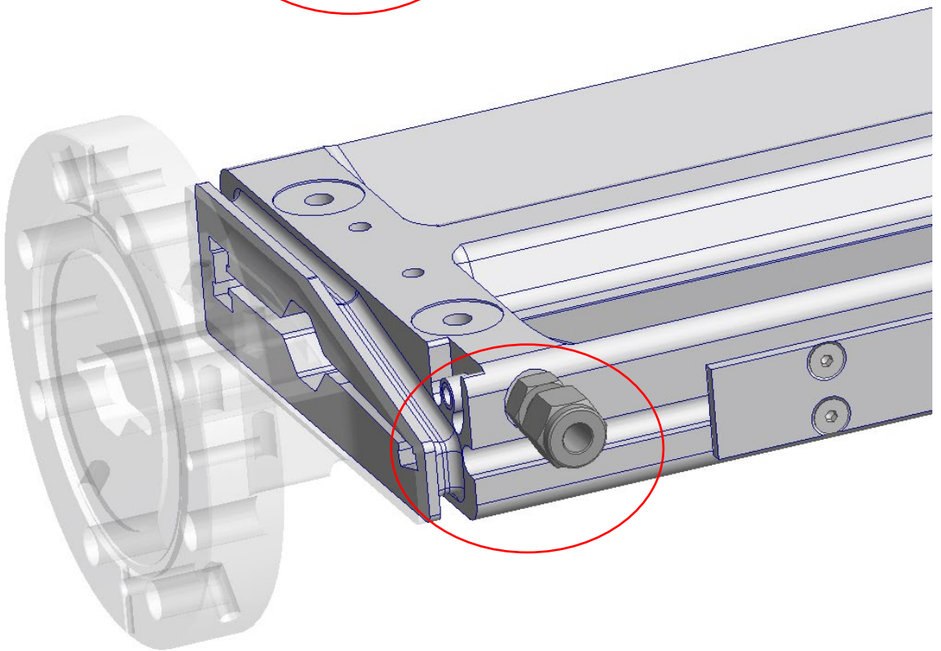
Sheath heater

Diameter: 10 mm

Height: 3 mm

Geometric surface: 250 mm^2

Nominal weight: 1200 mg



Aluminum chamber extrusion process

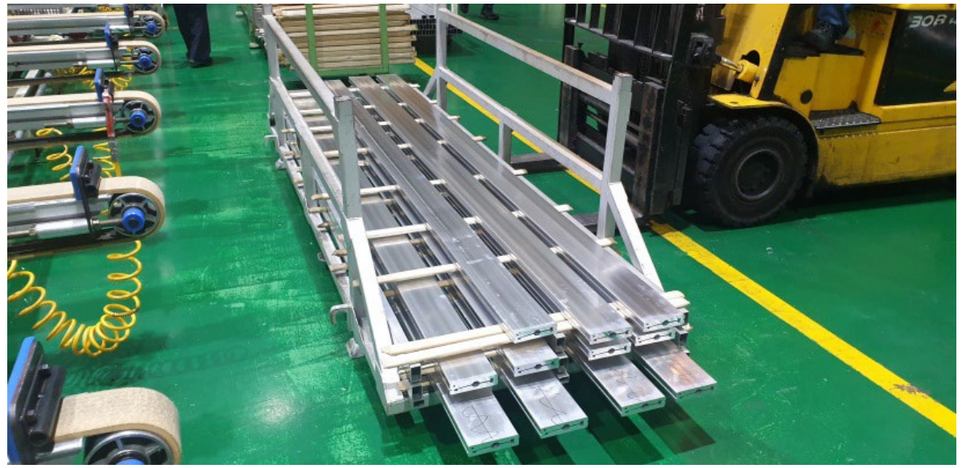
- **Dipole agnet chamber (Extruded Type, CH12)**

Al6063 T5 (185℃, 5h)

Extrusion

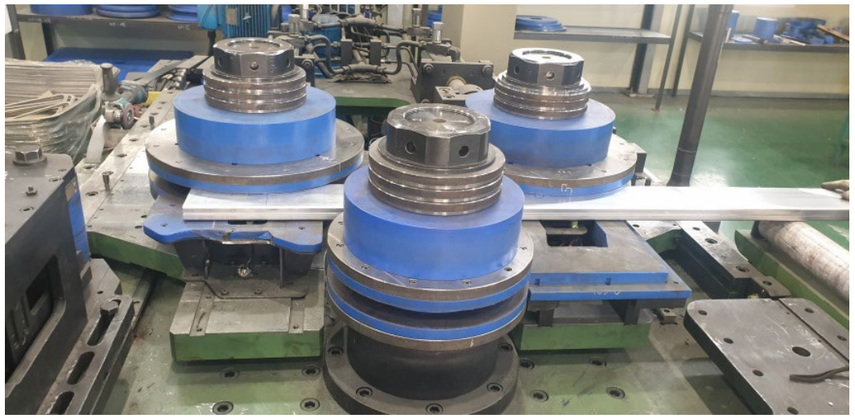
Stretching

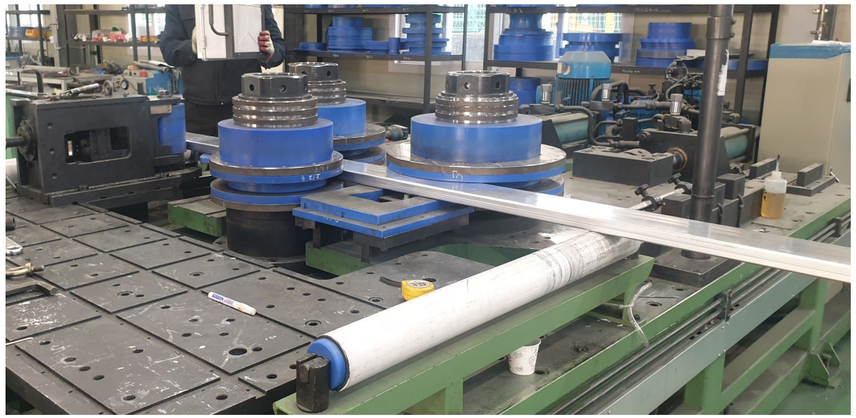
Chamber cutting

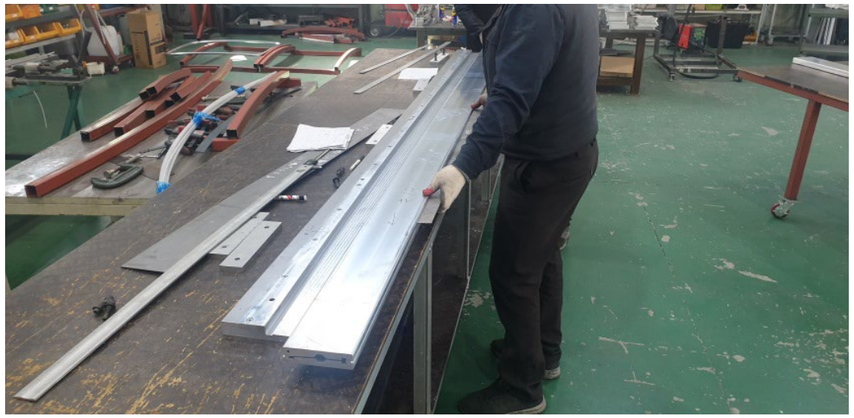


Transfer - Bending - T5 heat treatment

Extruded chamber bending



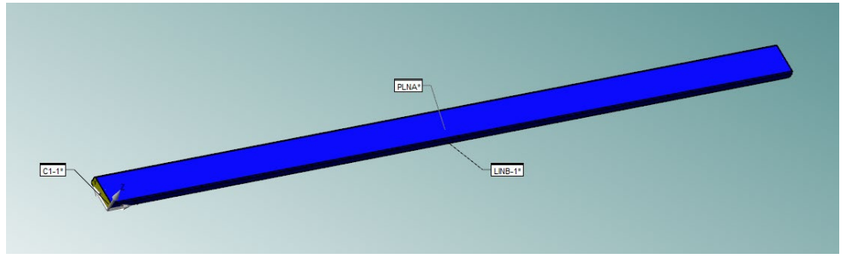


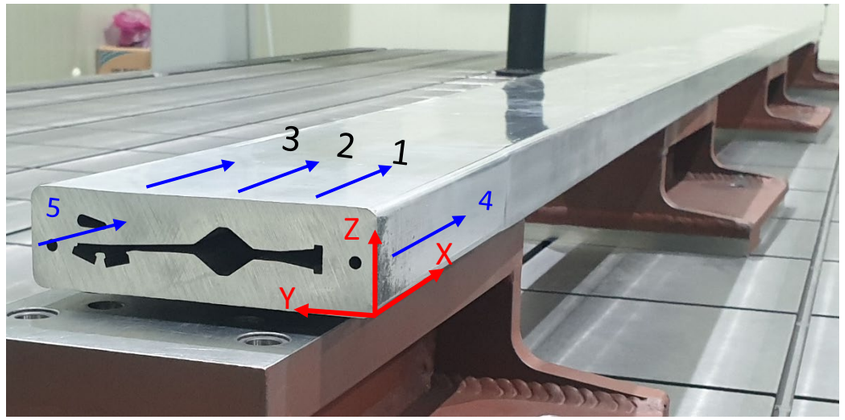


- Curvature Test: Primary Banding Inspection in the Field Using Templates

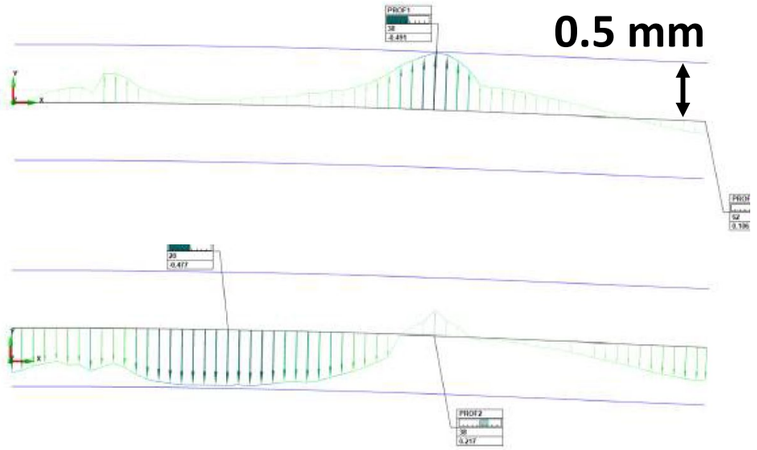
Extruded chamber bending

- Curvature Test : CMM [Coordinate Measuring Machine] - 3D contour measurement

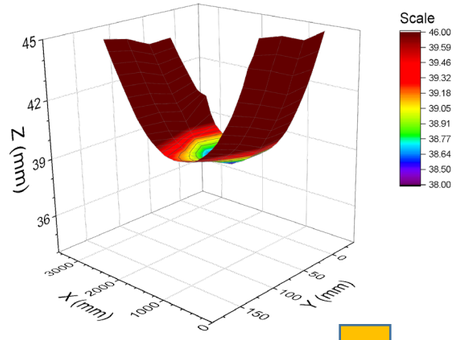




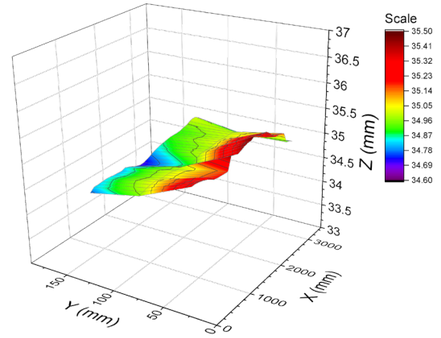
Y-direction



Z-direction

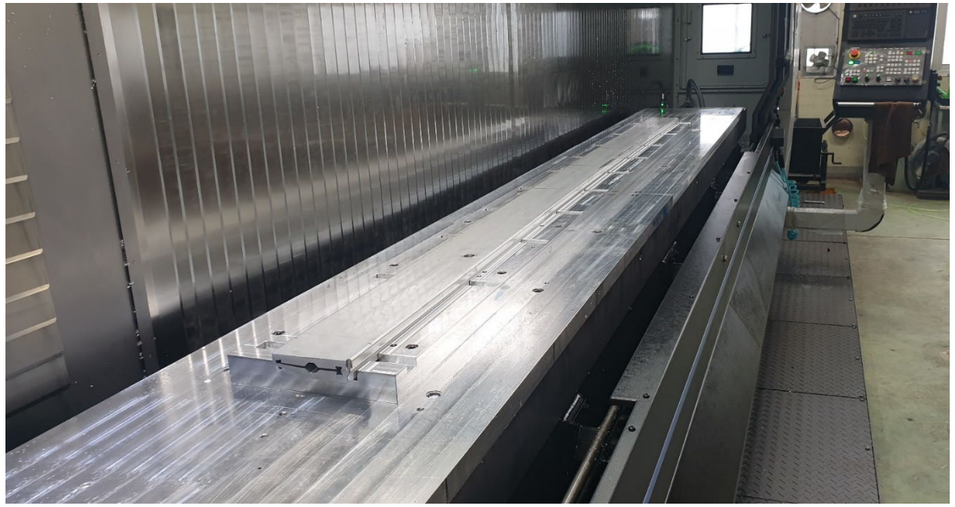


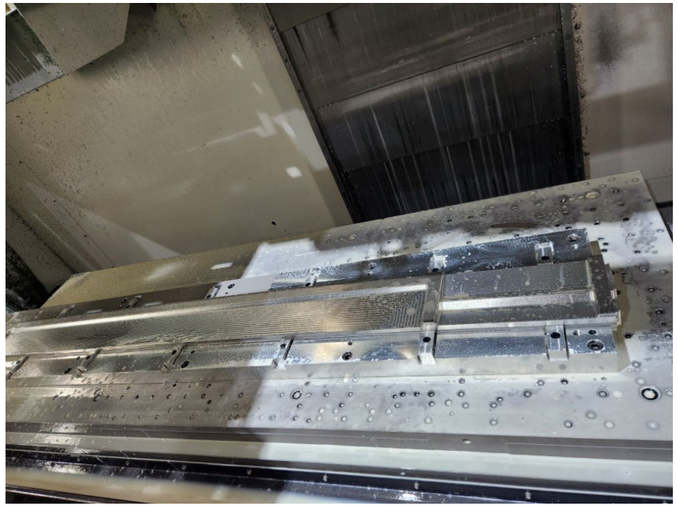
7.1 mm
Min. 38.4
Max. 45.5



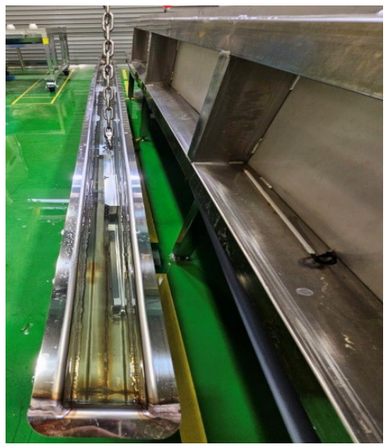
0.8 mm
Min. 34.7
Max. 35.5

Proto-type Chamber Machining

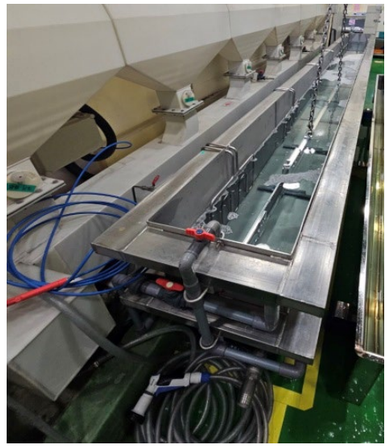




Aluminum vacuum chamber cleaning



(a) Degreasing



(b) Oxide removal

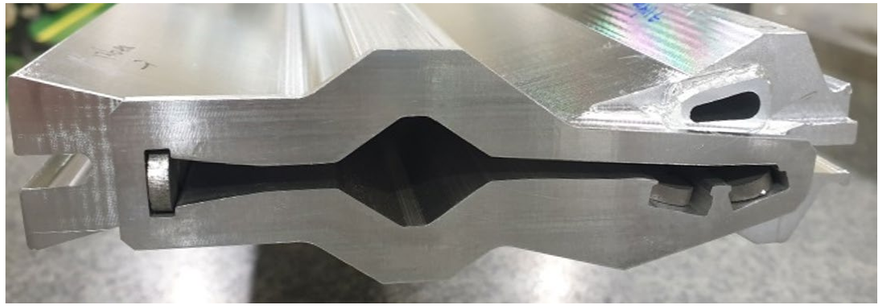
(c)Nitrogen bubble treatment

(d) pH check

Degreasing Weak base (Almeco, 45°C)	Deionized water cleaning	Oxide removal weak acid (Citranox, 60°C)	Deionized water cleaning	IPA treatment and high purity nitrogen treatment	Bake out 130 °C

※ In the case of extrusion type, two additional processes are required in the oxide removal process to clean the inside of the chamber.
- Tilt the chamber to prevent the formation of an internal air layer due to cavitation phenomenon.
- Create a flow with an acid-resistant pump to allow all reagents to flow inside.

Pill NEG insertion & Welding

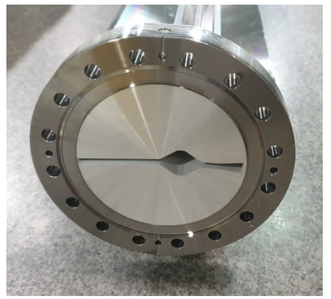


Ver. 1

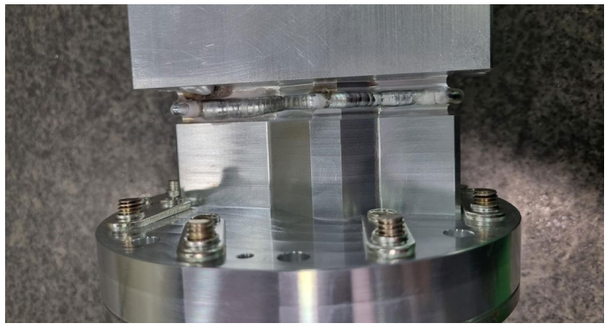
Ver. 2

Ver. 3..

900 Pill-type getters were inserted into the interior wall slits
of a 3m long aluminum extrusion chamber

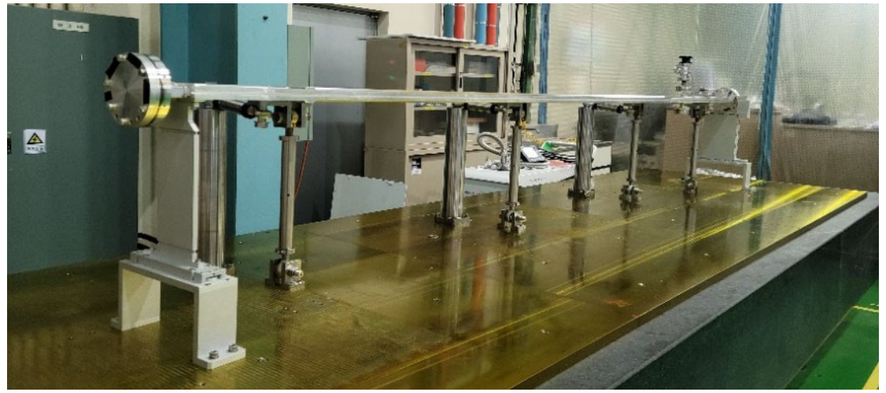


TiC coated flange



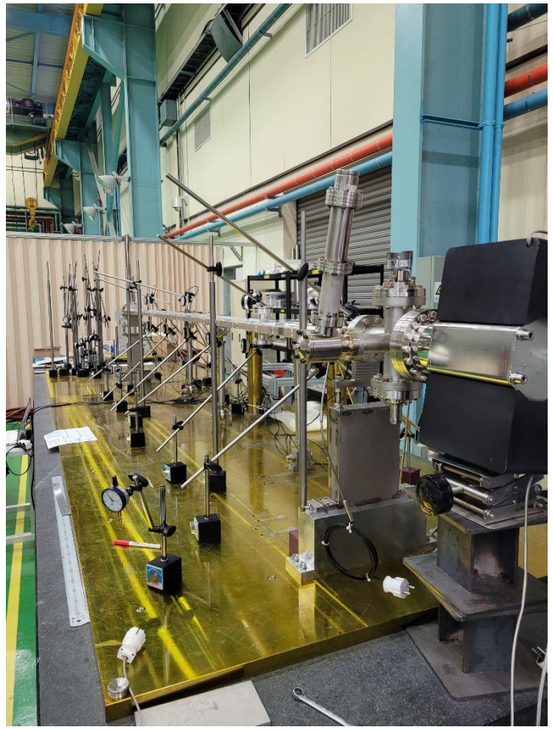
Welding

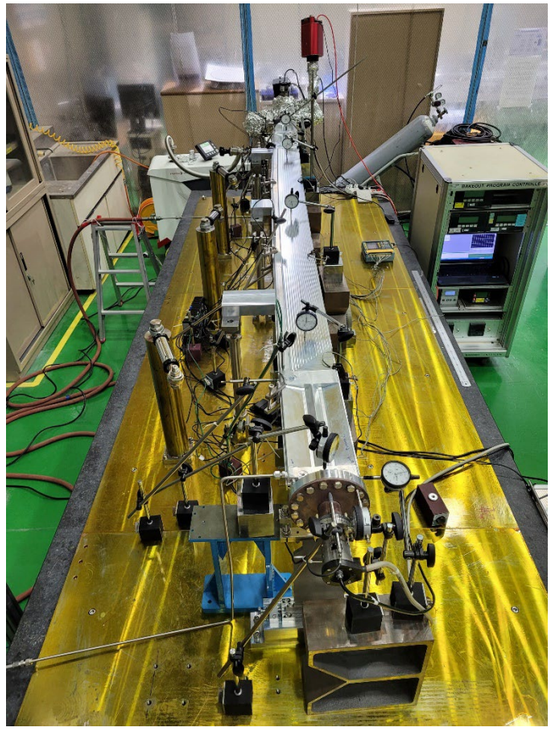
※ He leak rate < 10^{-10} mbar l/s

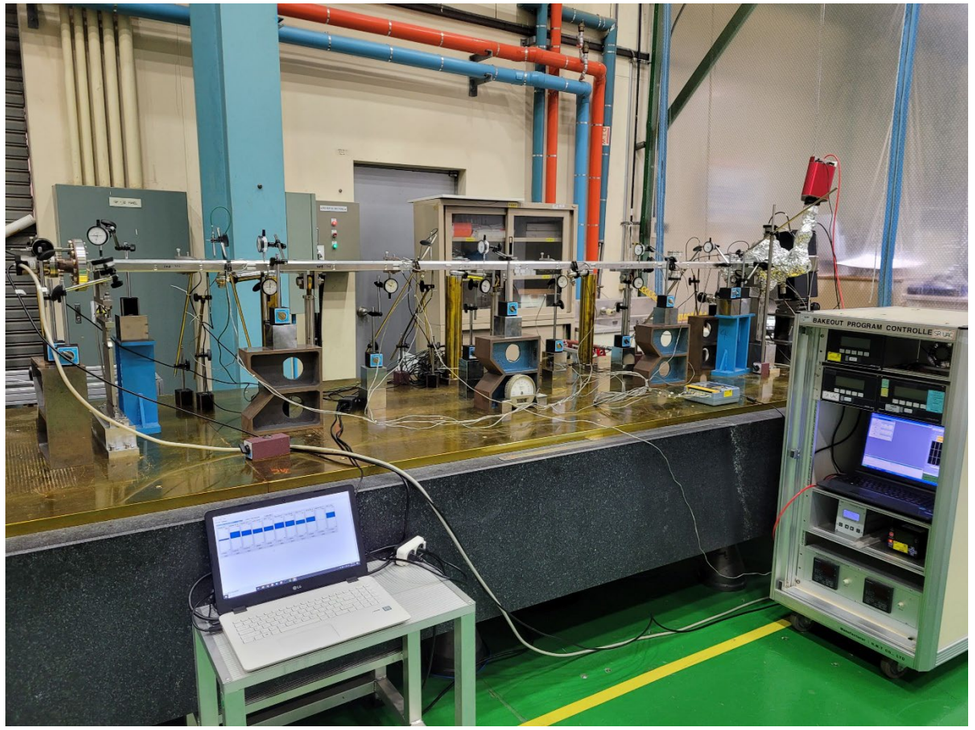


Assemble & alignment

Proto-type chamber & Supporter assemble



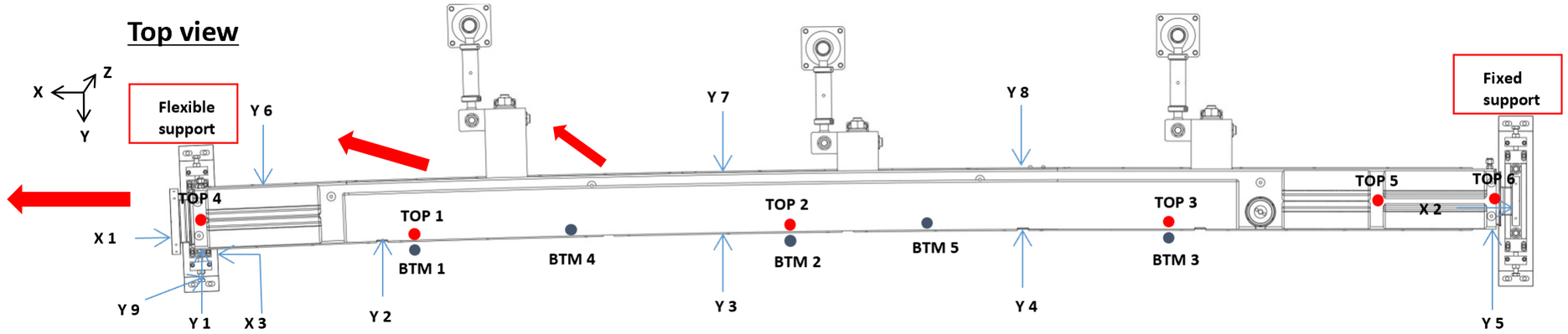




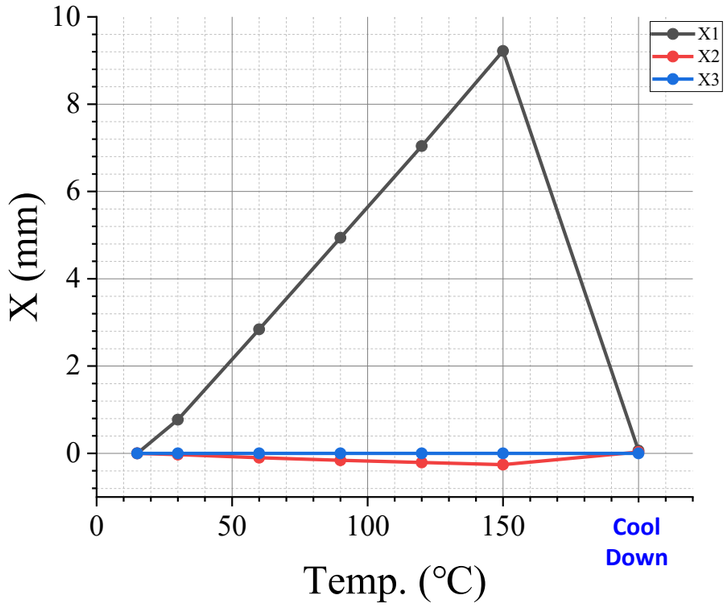
Chamber Displacement

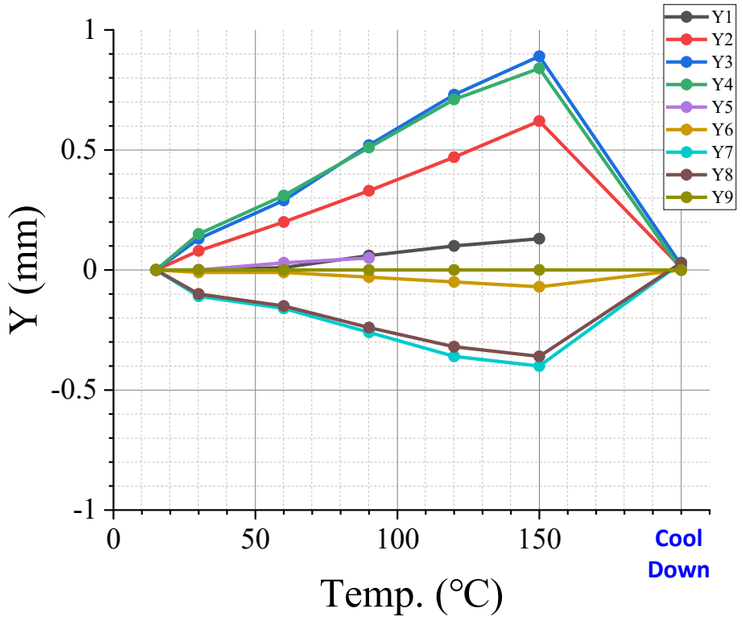
Displacement of Prototype chamber Before and After Bake-out

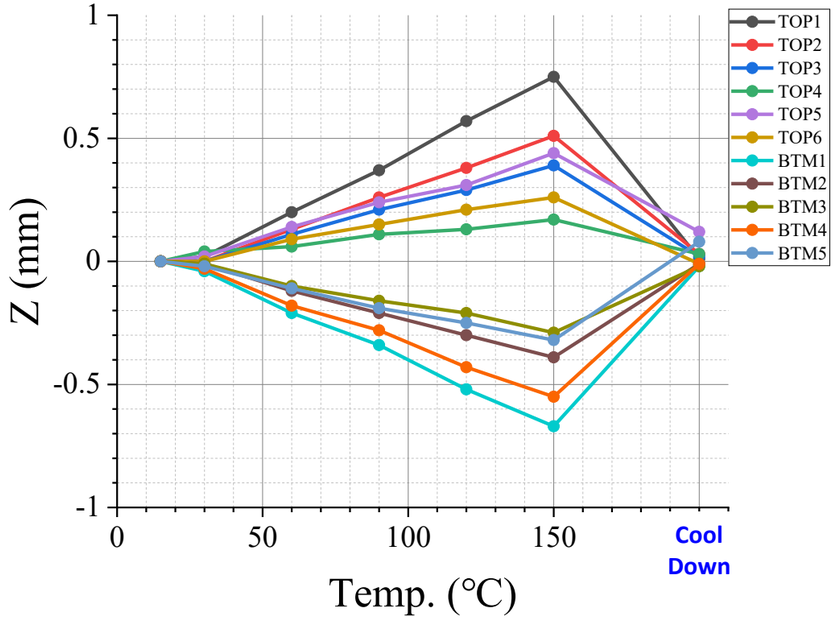
- Bake-out @ 150 ℃
- Measurement instrument: Dial gauge (Resolution: 0.01 mm)



- X1 : Outer side of the flange
- X2 : Inner side of the flange
- X3 & Y1 : Displacement of the base support

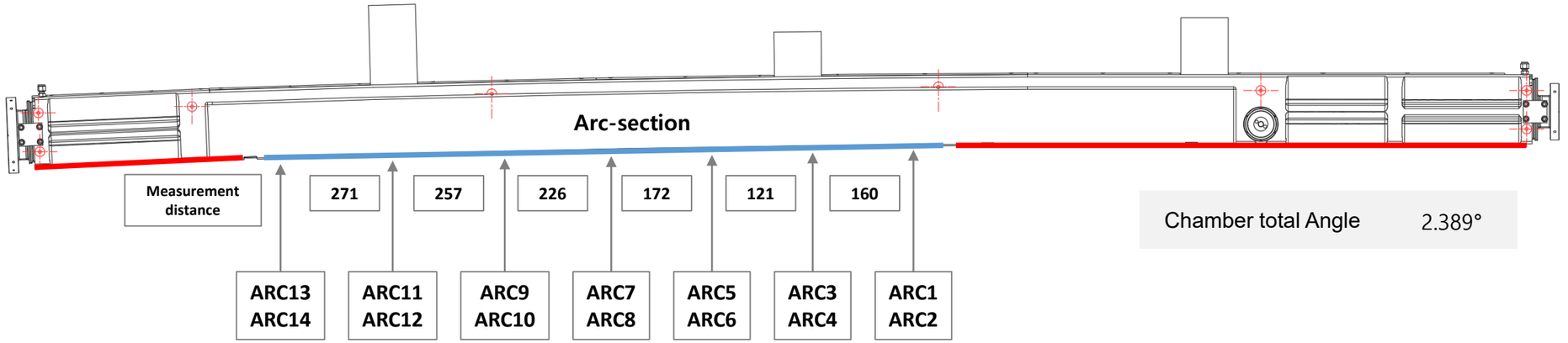






Chamber Displacement

Displacement of the Arc-section Before and After Bake-out
- Bake-out @ 150 ℃
- Measurement instrument: Dial gauge (Resolution: 0.01 mm)

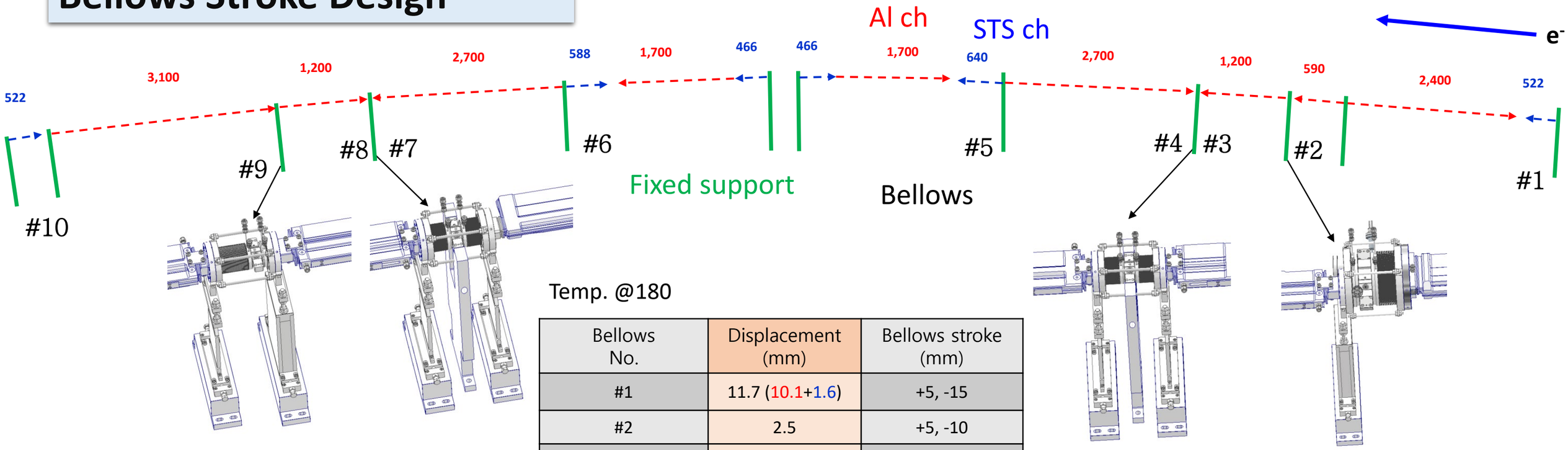


Chamber total Angle 2.389°

Unit : mm

Point		ARC14	ARC13	ARC12	ARC11	ARC10	ARC9	ARC8	ARC7	ARC6	ARC5	ARC4	ARC3	ARC2	ARC1
Before	dR	-0.16	-0.13	-0.27	-0.27	-0.25	-0.27	-0.18	-0.19	-0.09	-0.10	0.03	0.05	0.27	0.27
	Average	-0.14		-0.27		-0.26		-0.18		-0.09		0.04		0.27	
After	dR	-0.12	-0.16	-0.30	-0.32	-0.30	-0.32	-0.22	-0.25	-0.13	-0.14	0.01	0.00	0.21	0.19
	Average	-0.14		-0.31		-0.31		-0.23		-0.13		0.00		0.20	
Dev.	dR	0.03	-0.03	-0.03	-0.05	-0.05	-0.06	-0.04	-0.06	-0.05	-0.04	-0.02	-0.05	-0.07	-0.08
	Average	0.00		-0.04		-0.05		-0.05		-0.04		-0.04		-0.07	

Bellows Stroke Design

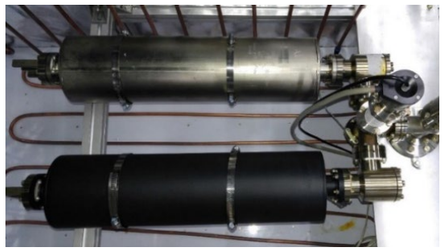


Material	Thermal expansion coefficient (μm/℃)
Al	23.5
STS316L	17

Temp. @180

Bellows No.	Displacement (mm)	Bellows stroke (mm)
#1	11.7 (10.1+1.6)	+5, -15
#2	2.5	+5, -10
#3	5.1	+5, -8
#4	11.5	+5, -15
#5	10.5 (7.2+1.9+1.4)	+5, -14
#6	10.4 (7.2+1.4+1.8)	+5, -15
#7	11.5	+5, -15
#8	5.1	+5, -8
#9	13.2	+5, -16
#10	1.6	+5, -15

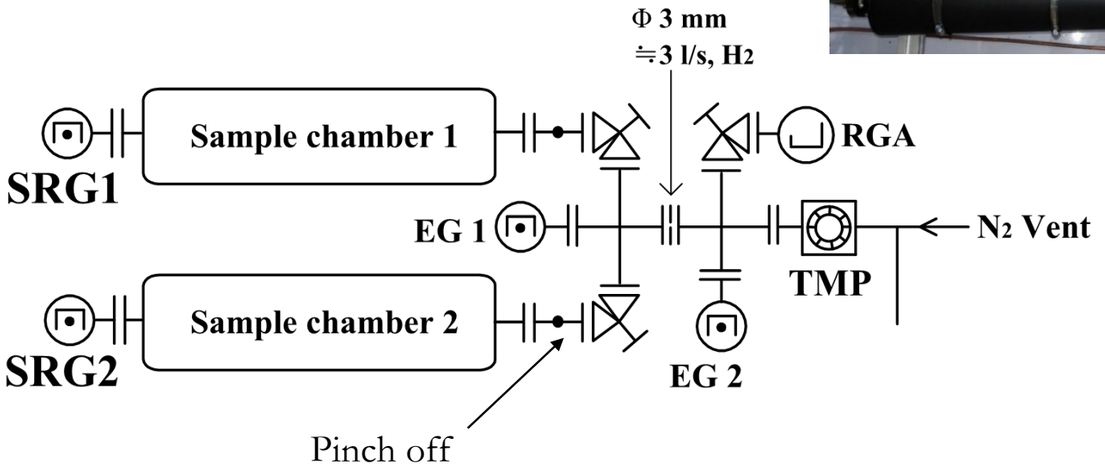
Thermal Outgassing rate of the aluminum extruded chamber

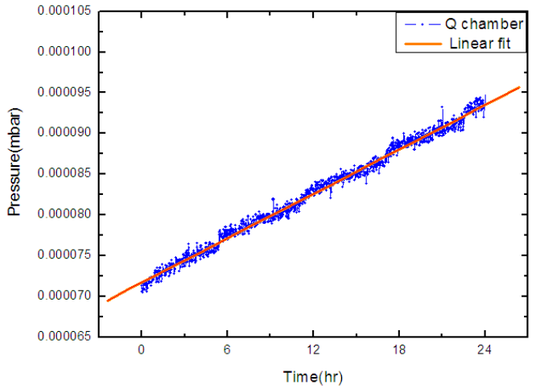


➢ Aluminum Extrusion Chamber Vacuum Characteristics

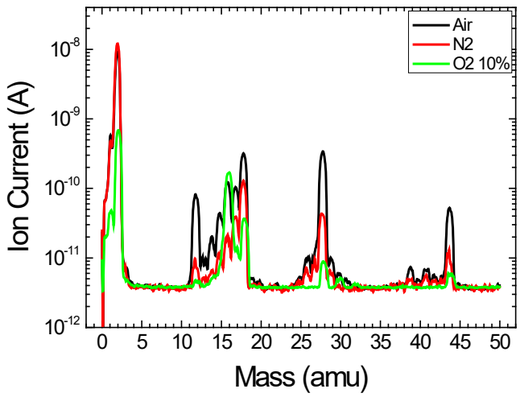
- Outgassing rate & partial pressure to extrusion condition

Extrusion Condition	q (mbar l/s·㎠)
Air	1.9e-13
N_2	1.6e-13
O_2 10 % + Ar	8.0e-14

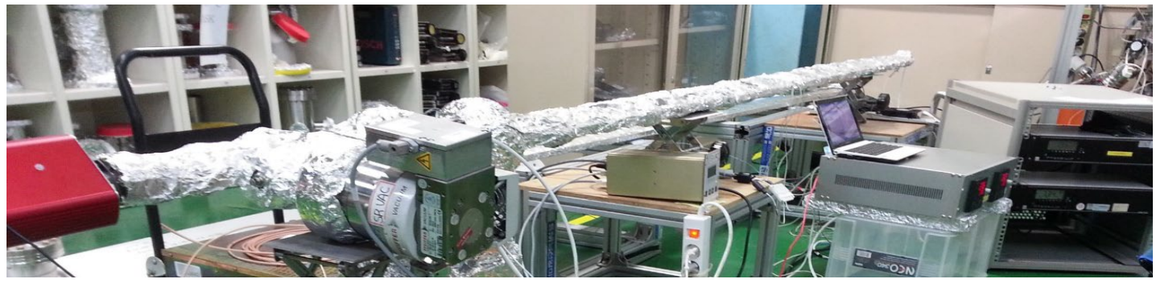




Pressure rise method using SRG



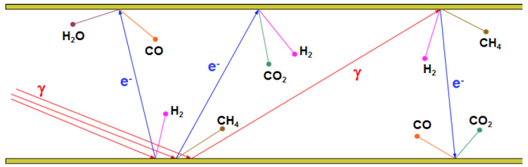
RGA (After Bake-out)



Pumping speed of the pill-type getters

Photon stimulated gas desorption (PSD)

✓ Residual gases in beam pipes during beam operation mainly come from the PSD.



Oleg B. Malyshev, Vacuum in Particle Accelerators (2020)

Total photon numbers

$$\dot{N}_{ph,I_e} = \frac{15\sqrt{3\pi}}{4} C_\psi I_e E_e$$
$$= 8.08\times10^{20}\, I[\mathrm{A}] E_e[\mathrm{GeV}]\ [\mathrm{photons/s}]$$
$I = 400$ mA, $E_e = 4$ GeV
$$= 1.29\times10^{21}\ [\mathrm{photons/s}]$$
$$\dot{N}_{ph,I_e,line} = \dot{N}_{ph,I_e}/C$$
C=798.84 m
$$= 1.65\times10^{18}\ [\mathrm{photons/s/m}]$$

Estimation of gas load

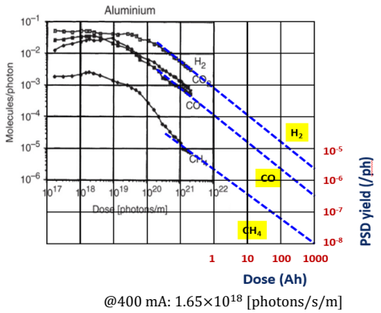
$\dot{N}_{ph,I_e,line} = 1.65\times10^{18}$ [photons/s/m]
if h=1×10^{-6}[molecules/photon]
$\dot{N}_{mol,I_e,line} = 1.65\times10^{12}$ [molecules/s/m]

$$\dot{Q}_{av,line} = \dot{N}_{ph,I_e,line} \times k_B T$$
$$= 1.65\times10^{12} \times 1.38\times10^{-23} \times 298$$
$$= 6.79\times10^{-9}\ \mathrm{Pa\ m^3\ s^{-1} m^{-1}}$$
$$= 6.79\times10^{-8}\ \mathrm{mbar\ l\ s^{-1} m^{-1}}$$
$\dot{Q}_{av,line} = P_{av} S_{av,line}$, if $P_{av} = 1\times10^{-9}$ mbar

Pumping speed

$$S_{av,line} = \frac{\dot{Q}_{av,line}}{P_{av}} = \frac{6.79\times10^{-8}\ \mathrm{mbar\ l\ s^{-1} m^{-1}}}{1\times10^{-9}\ \mathrm{mbar}}$$
$$\fallingdotseq 68\ \mathrm{l\ s^{-1} m^{-1}}$$

Photon stimulated gas desorption yield

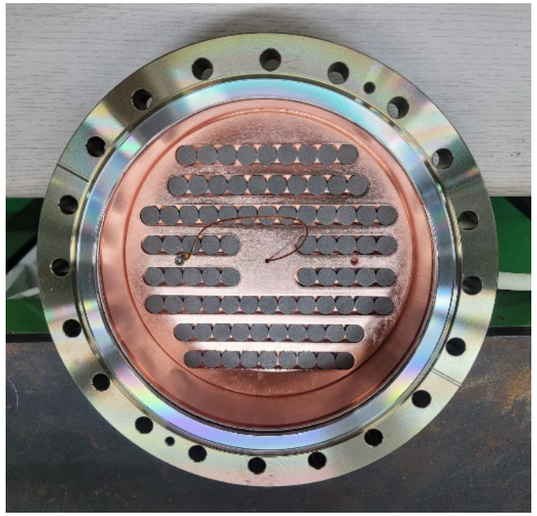


@400 mA: 1.65×10^{18} [photons/s/m]

A.G. Mathewson et al. AIP 236, 313 (1991)

	Dose	PSD yield (molecules/photon)		
	(photons/m)	H_2	CO	CH_4
1000 Ah	1.50E+25	1e-6	1E-07	1E-8

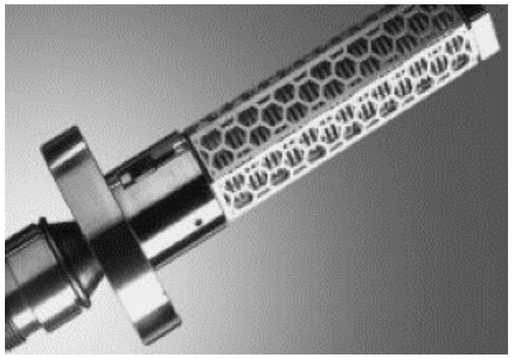
St2002 Pill (Saes getters)



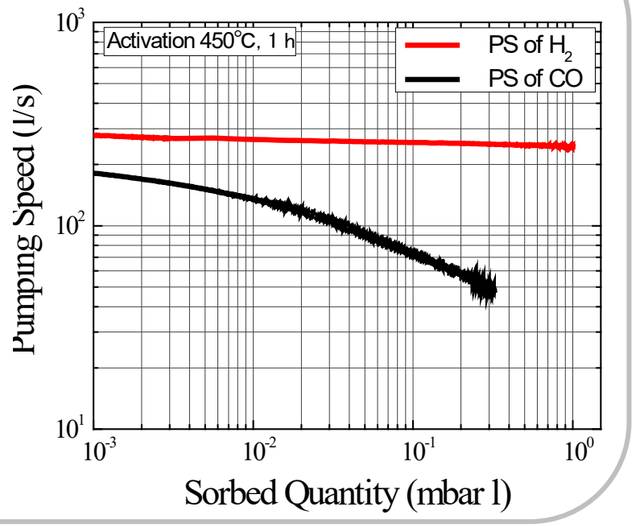
ZAO (Saes getters)

\+ Noble Diode SIP

St172-D400 (Saes getters)



With body



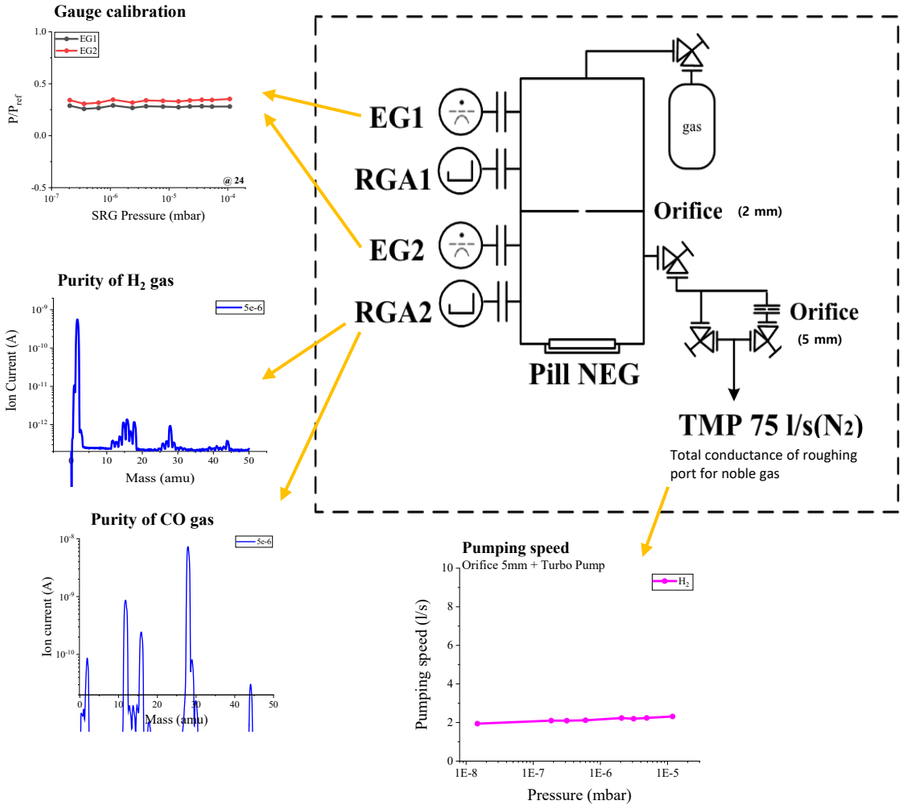
Pumping speed of the pill-type getters

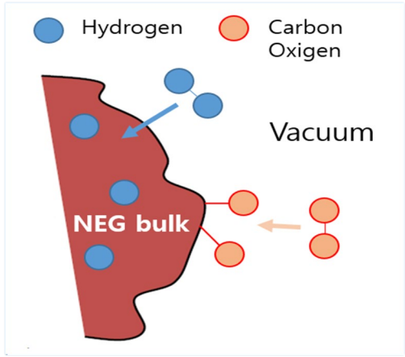
✓ Throughput method

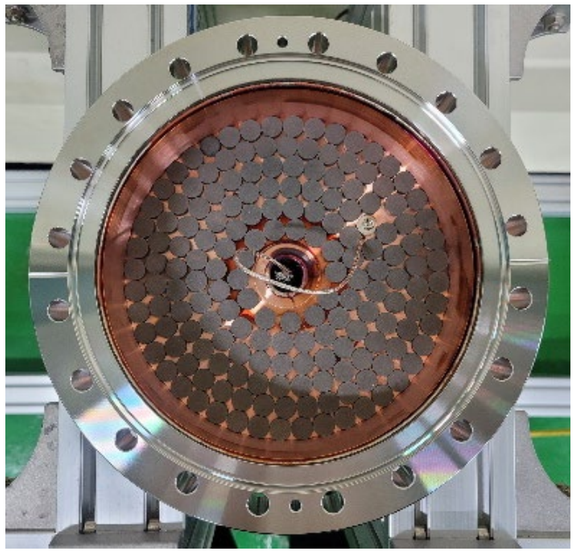
$Q = C\,(P_1 - P_2) = P_2\,S$

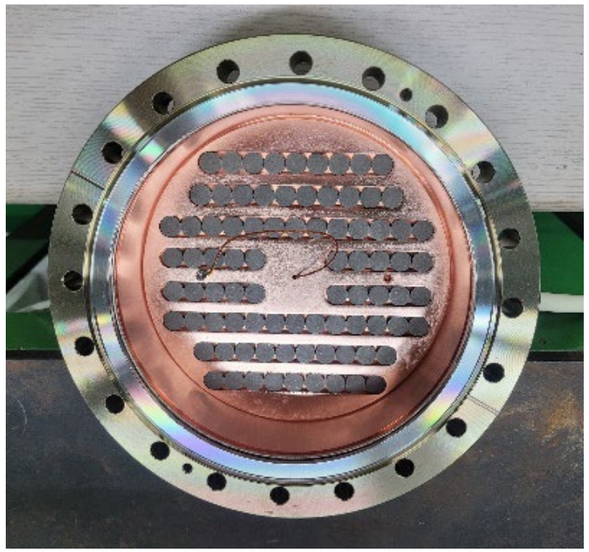
$S = C\,(\frac{P_1}{P_2} - 1)$

ASTM F798-97

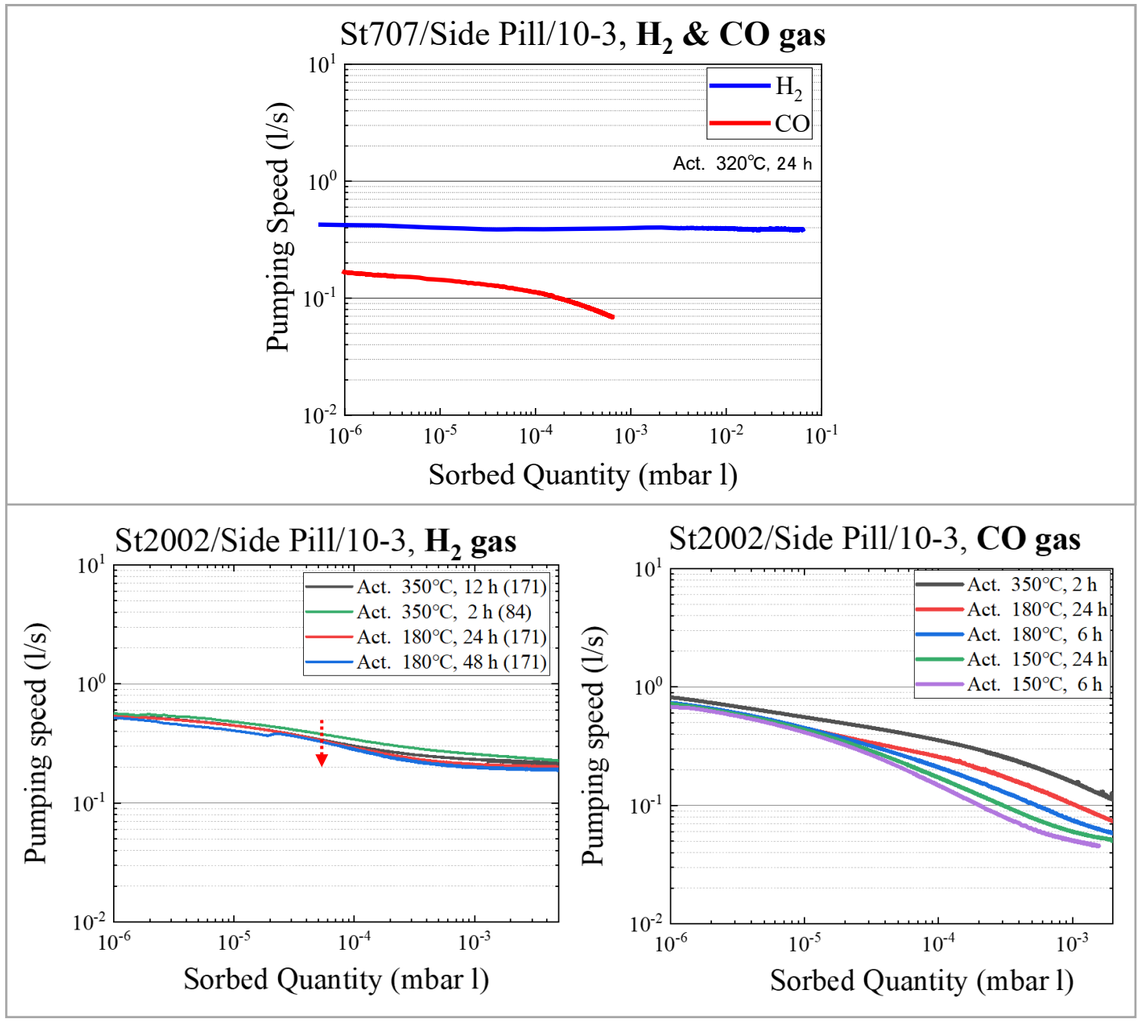








Pumping speed of NEG pills



✓ Composition of Non-evaporable getter pill

* ST707 : Zr (70%) - V (24.6%) - Fe (5.4%)
* ST2002: Zr (70%) - V (15%) - Fe (3%) – Mn (9%) – Rare earth (3%)

✓ H_2 Initial Pumping Speed (S_0)

* ST707 : ~ **0.4** l/s/side pill (Act 320℃, 24 h)
* ST2002: ~ **0.5** l/s/side pill (Act 180℃, 24 h, Venting X)

s=0.0035

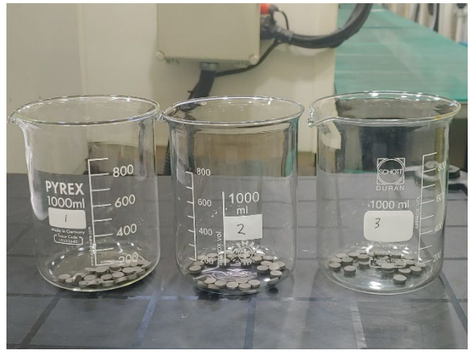
Ref. ※ 1 side pill ≒ 1㎠

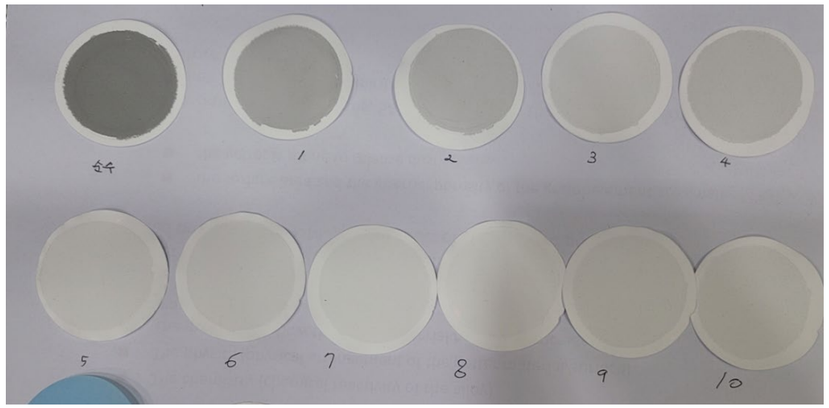
Comparison of initial pumping speed S_0 per A_N and initial apparent sticking probability α_0 obtained in this study with those obtained in previous studies [14,19,25–27].

Material	Reference	NEG type	Activation conditions	S_0 per A_N [(m³/s)/m²]		α_0		Test method
				H_2	CO	H_2	CO	
St707	This study	Pill	450 °C for 10 min	5.3	21	0.011	0.18	ASTM method
	Ref. [19]	Pill	450 °C for 10 min	4.0	–	0.009	–	ASTM method
	Ref. [25]	Strip	390 °C for 25 min	5.0	3.1	0.011	0.026	Throughput method with test dome
	Ref. [14]	Strip	350 °C for 24 h	10	–	0.029	–	ASTM method
	Ref. [26]	Strip	300 °C for 45 min	3.8	–	0.017	–	Throughput method with test dome (Fischer-Morrumsen dome)
			400 °C for 45 min	8.3	17	0.038	0.28	
			500 °C for 45 min	5.0	17	0.023	0.28	
			600 °C for 45 min	7.5	17	0.034	0.28	
			740 °C for 45 min	10	23	0.045	0.38	
	Ref. [27]	Strip	450 °C for 10 min	4.0	–	0.009	–	Throughput method with test dome
ZAO	This study	Pill	450 °C for 10 min	13	25	0.030	0.21	ASTM method

Hajime Yoshida et al. Vacuum 197 (2022) 110797

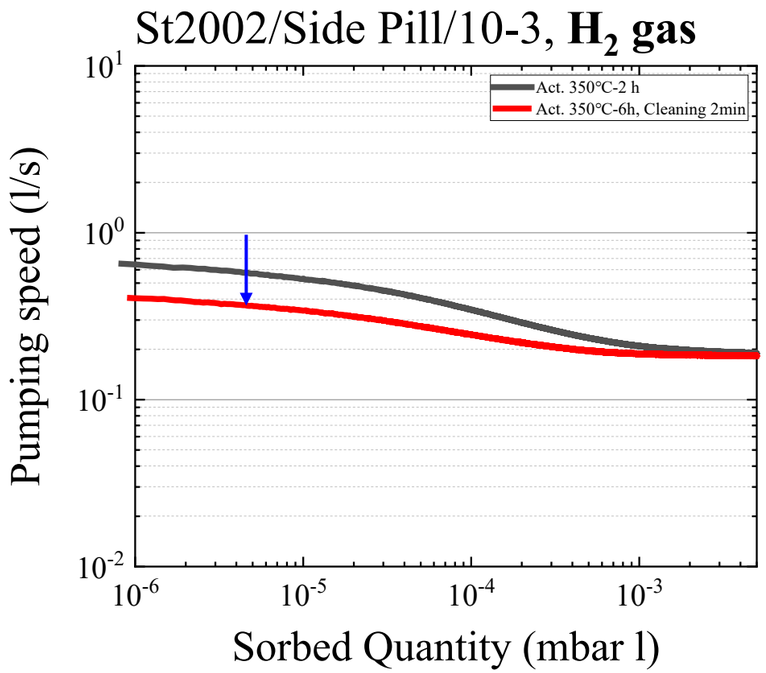
Pumping speed of Pill-type getters after ultrasonic cleaning (IPA)

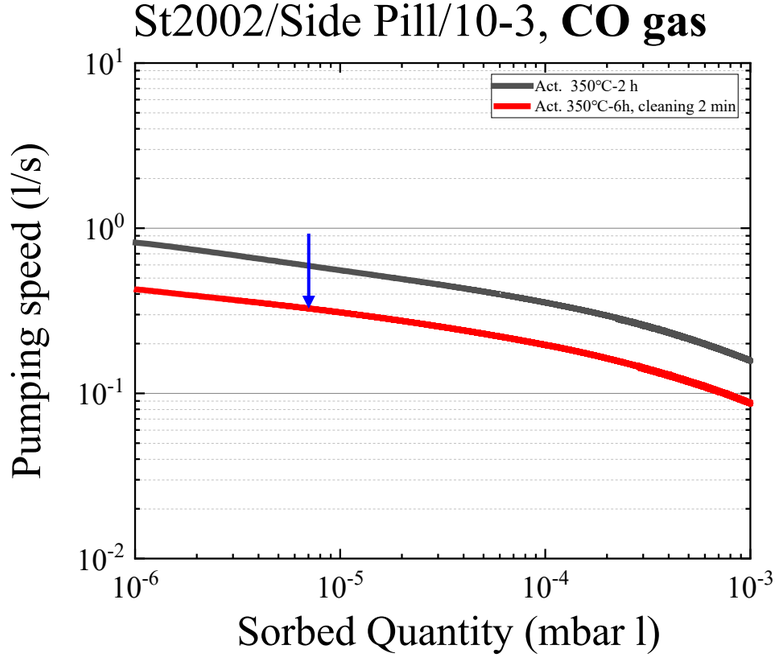




초음파시간	초기게터	후기게터	결손값		초기필터	후기필터	추출값
1	1.191				0.0717	0.0752	0.0035
2					0.071	0.0729	0.0019
3					0.071	0.0715	0.0005
4					0.0715	0.0716	0.0001
5		1.1822	0.0088		0.0713	0.0714	0.0001
							0.0061

Ultrasonic with IPA 2 min

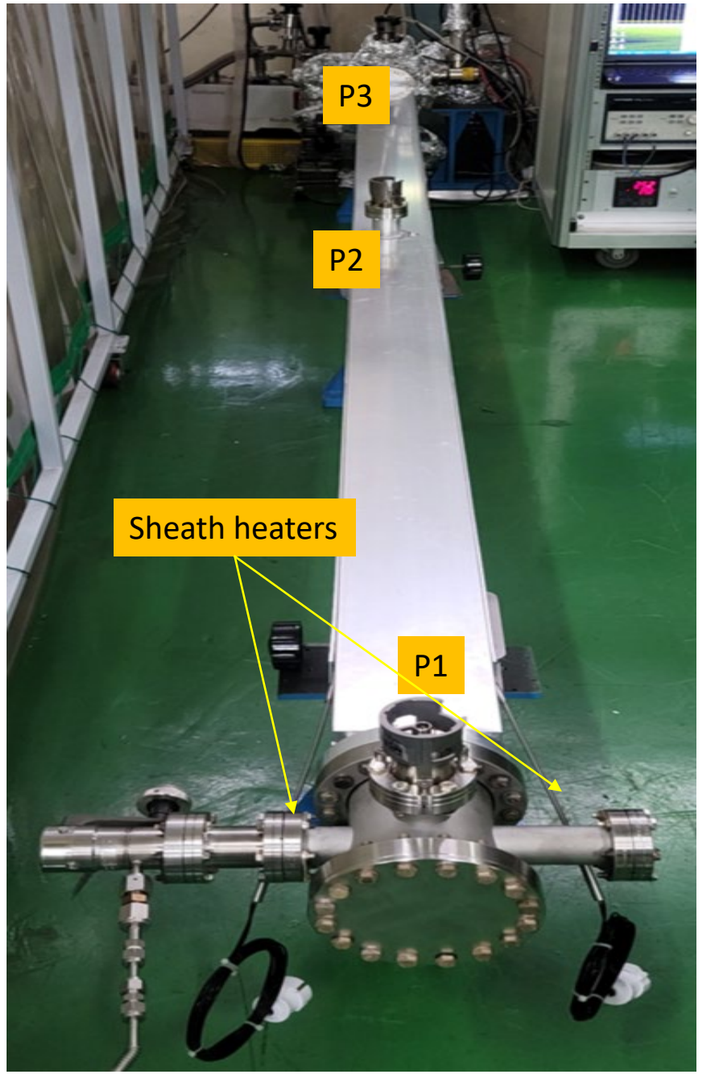


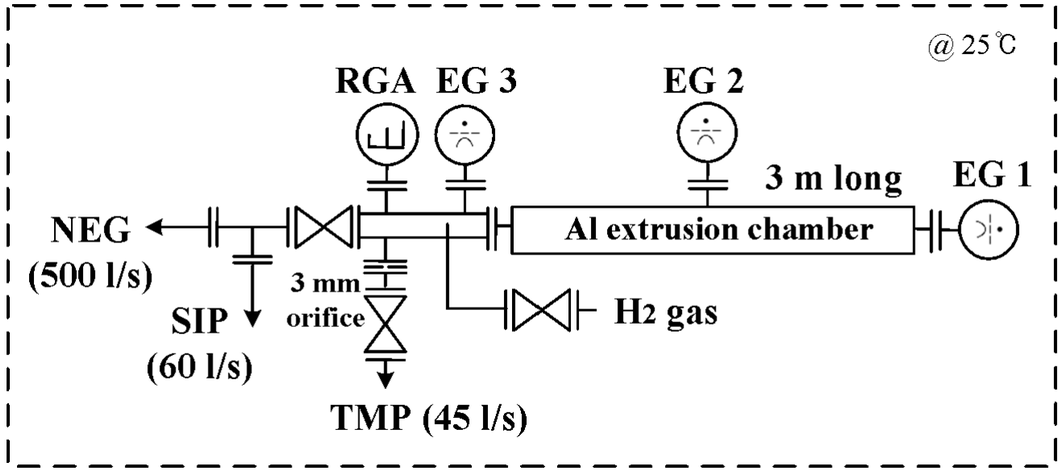


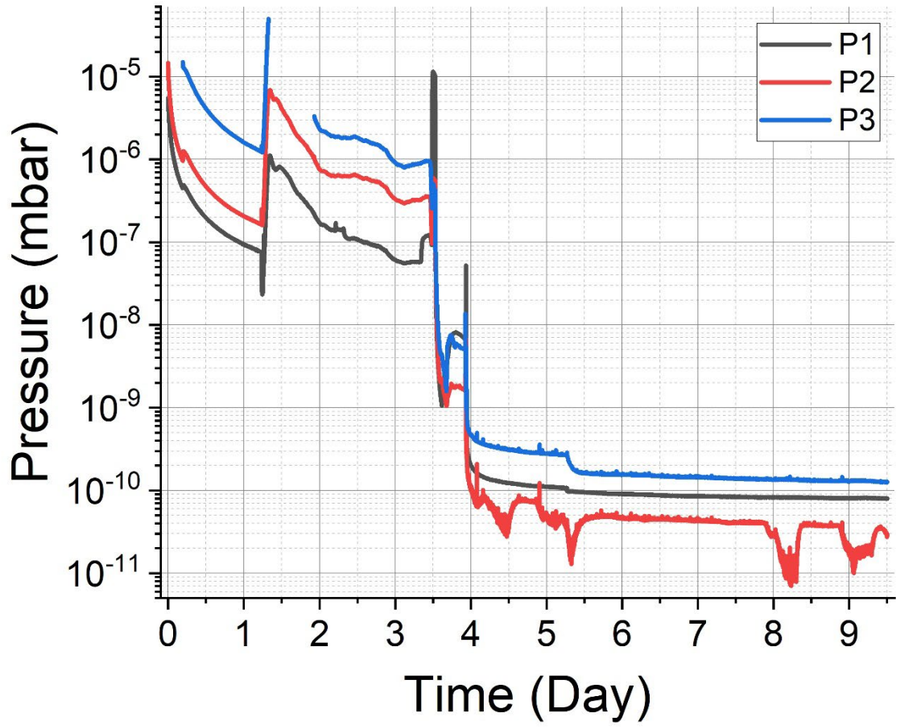
- Pumping speed has decreased by 30 % of H_2
- Pumping speed has decreased by 50 % of CO

Ultimate Pressure

- BO & NEG Act. : 180 ℃ - 48 h
- Sheath heater : 2 ea
- Extractor gauge : 3 ea







Summary

- We fabricated a prototype vacuum chamber for the Korea-4GSR Storage Ring and evaluated its vacuum characteristics.

- The thermal outgassing rate of the aluminum extruded chamber was measured using the rate-of-pressure rise method after 150℃, 48h bake-out is approximately 2×10^{-13} mbar l/s cm².

- We measured the pumping speed of the pill-type getters before assembling them into the chamber.

- Pumping speed of Pill-type getters after ultrasonic cleaning to reduce particles were also measured.

- We measured and evaluated the ultimate pressure of the Korea-4GSR Storage Ring prototype vacuum chamber.

Many thanks for your attention