Vacuum System Development of HEPS

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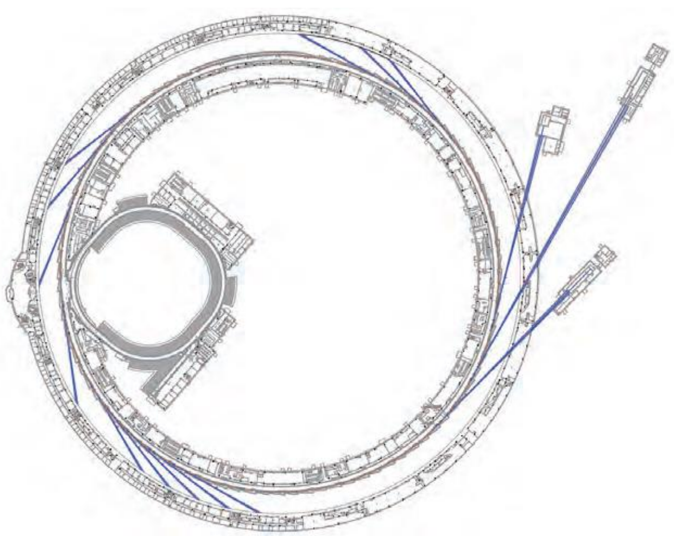
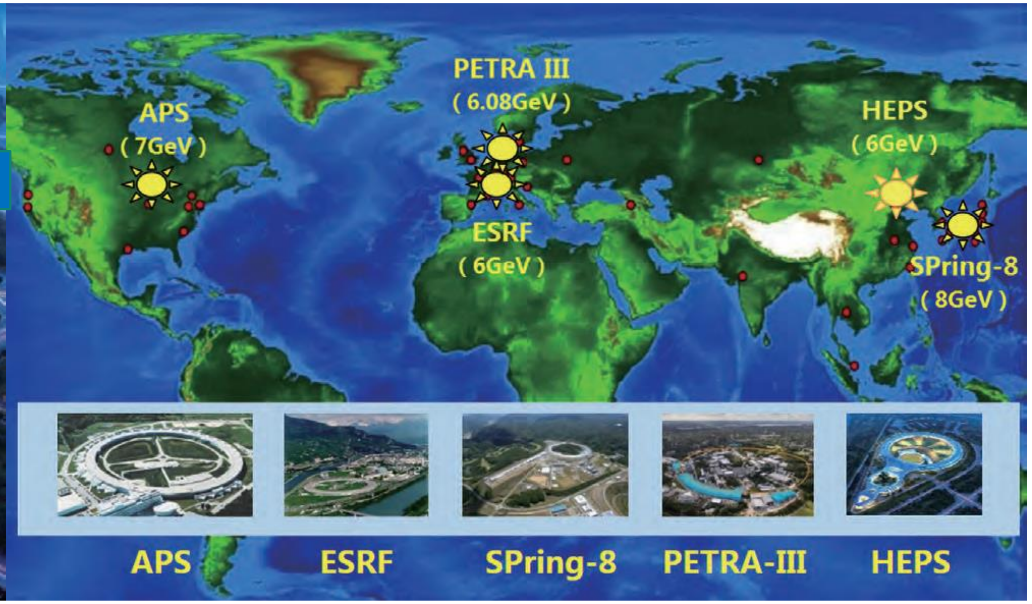
Haiyi Dong

◆High Energy Photon Source





◆ Storage ring vacuum chamber changes to much smaller from **3th Generation** To **4th Generation**

3th Generation **4th Generation**

1 Preview of HEPS vacuum system

Haiyi Dong

	Energy	Material	Cross Section/mm	Length /m	Dynamic pressure /Torr
LINAC	500 MeV	Stainless steel, copper	Φ30	49	Acc $<2\times10^{-7}$ E-gun$<2\times10^{-8}$
Booster	500 MeV to 6 GeV	Stainless steel	36×30 (H×V) ellipse / thickness of 0.7mm	454	$<3\times10^{-8}$
Storage Ring	6 GeV	Extruded copper, S.S, NEG film	ϕ22/thickness of 1mm	1360.4	$<3\times10^{-9}$
LTB	500 MeV	Stainless steel	ϕ30/thickness of 1mm	25	$<1\times10^{-7}$
BTS(STB)	6 GeV	Stainless steel	ϕ26/thickness of 1mm	105	$<1\times10^{-7}$

Facility	C(m).	E(GeV)/I(A) Ɛx(pm.rad)	Mag. Bore(mm)	Chamber Material	Baking Method
MAX-IV (Sweden)	528 (20cell-7BA)	3/0.5 330	25	OFS Cu (100% NEG Coating)	Ex-situ
SIRIUS (Brazil)	518.4 (20cell-5BA)	3/0.5 250	28	OFS Cu (100% NEG Coating)	In-situ
EBS (France)	844 (32cell-7BA)	6/0.2 135	26	SST/Al (Partial NEG Coating)	In-situ
APS_U (USA)	1100 (40cell-7BA)	6/0.2 60	26	OFS Cu/Al (Partial NEG Coating)	Ex-situ
HEPS	**1346 (48cell-7BA)**	**6/0.2** **35 [1]**	**26**	**CrZrCu (Partial NEG coating)**	**In-situ**

1 SR power and gas load

To estimate the desorption rate, we follow the approach of Grobner et al. [1983]. The effective gas load due to photodesorption is found to be

$$Q_{gas} = 24.2 E I \eta \ \text{[Torr·L/s]},$$

Where E is the beam energy in GeV, I the beam current in A, and η the photodesorption coefficient in molecules/photon. The photodesorption coefficient η is a property of the chamber that depends on several factors:

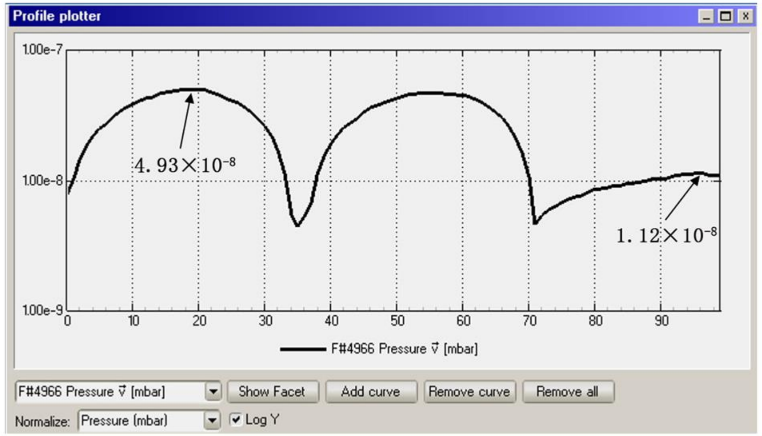
	E	I	ρ	Psr	PL	PSD	q_{th}	Q_{gas}	Q_{LSR}
	Gev	A	m	MW	W/m	molecules/photon	Torr·L/s·cm^2	Torr·L/s	Torr·L/s·m
Booster	6	0.015	28.52	60.32	336.8	2.00E-06	1.0E-11	4.36E-06	2.43E-08
Storage ring	6	0.2	53	432.82	1300.4	2.00E-06	2.5E-12	5.81E-05	1.74E-07

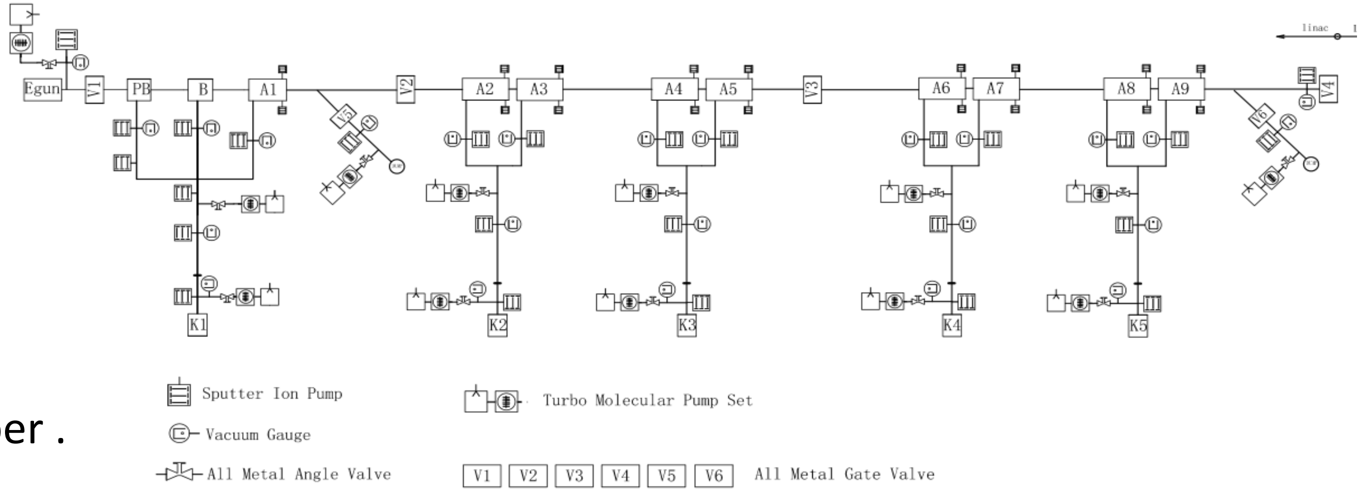
2 Layout of Linac vacuum system

Hong Song

- The Linac vacuum system with a length of 49m is divided into 6 sections. it consists of electron gun, bunching system, accelerating structures and Analyzer Magnet sections.
- Sputter ion pumps: 45; Vacuum gauges: 25; Gate valves: 6

Section	Static pressure /Torr	Dynamic pressure /Torr
E-gun	$<1\times10^{-9}$	$<2\times10^{-8}$
Buncher	$<5\times10^{-8}$	$<2\times10^{-7}$
Accelerating structure	$<5\times10^{-8}$	$<2\times10^{-7}$
AM	$<5\times10^{-8}$	$<5\times10^{-7}$
Waveguide	$<5\times10^{-8}$	$<5\times10^{-7}$

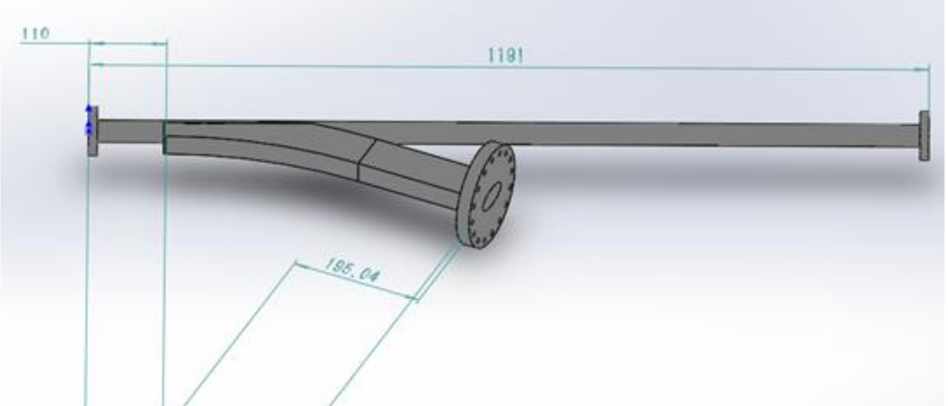




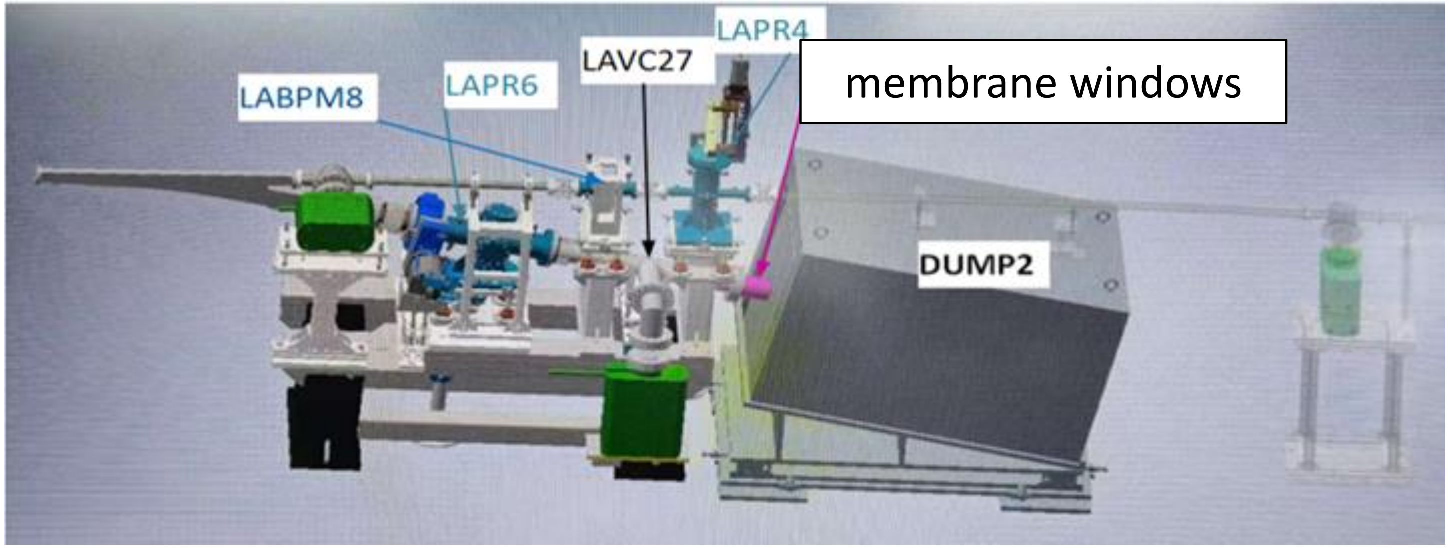
Most of the components are made of oxygen-free copper . The thermal outgassing rate is 1×10^{-11} Torr·l/s·cm^2.

Dump chambers and membrane windows for Linac

◆ The elliptical Ti thin membrane window of 170×10 mm with a thickness of 0.1 mm was welded on the s. s. plate with a diameter of 183 mm and a thickness of 5mm.



- Inner cross section of ellipse in 60 × 30 mm
- Outer cross section of rectangle in 62 × 32 mm

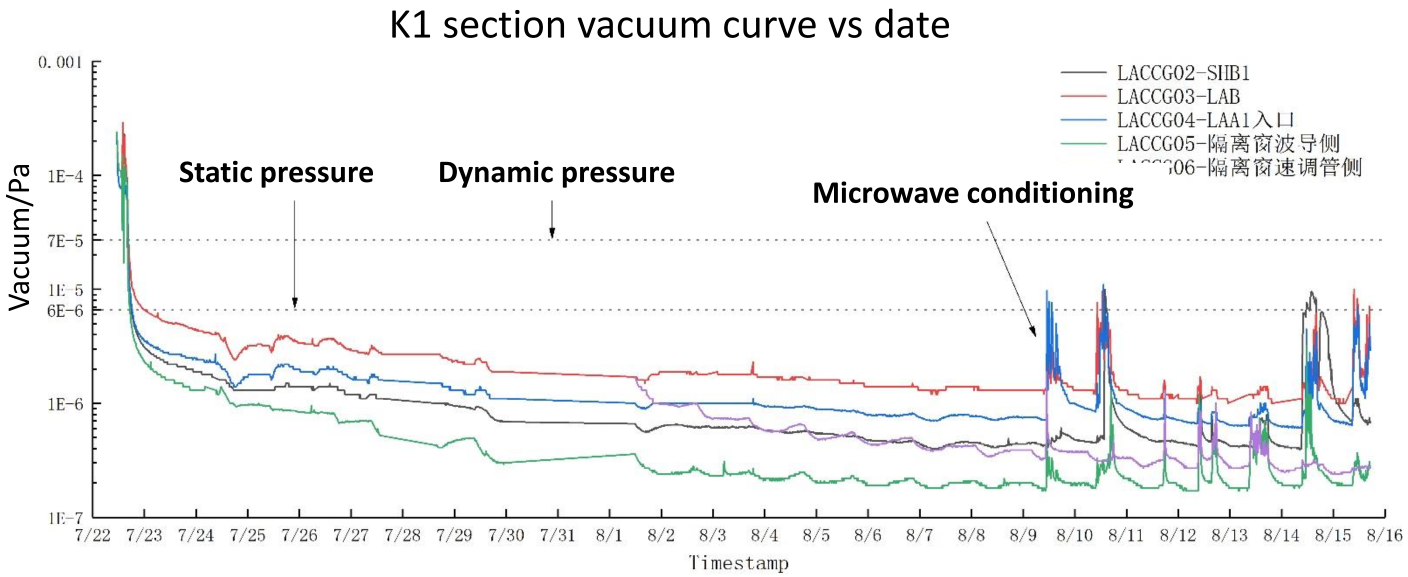


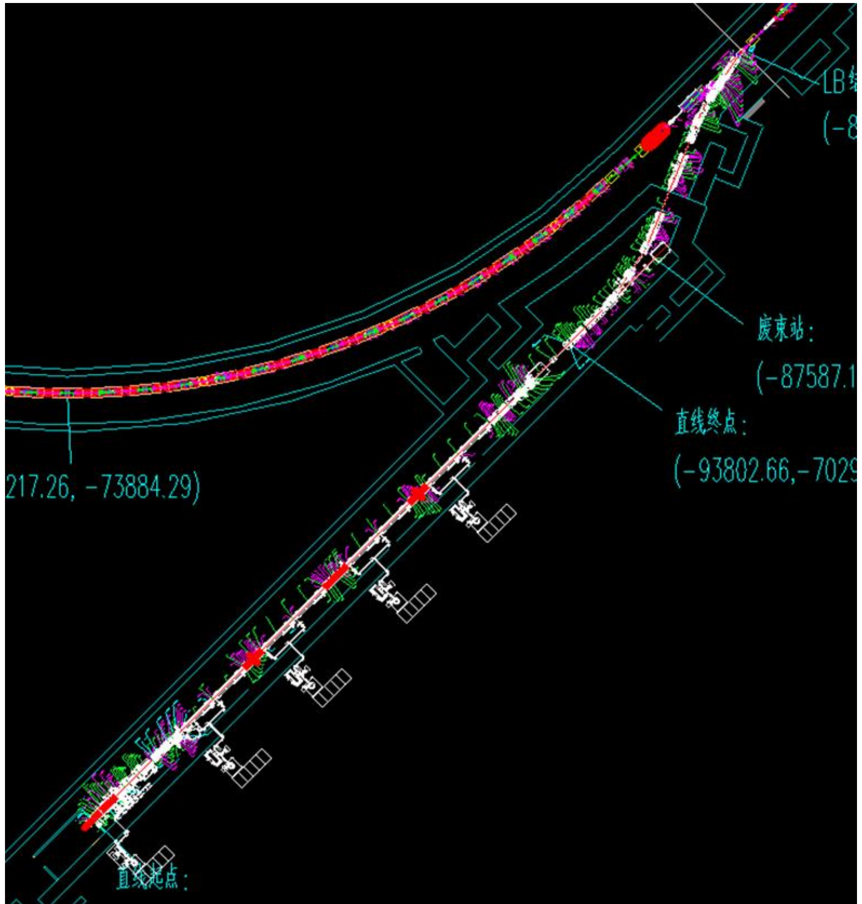
◆ Membrane windows

- The thickness of Ti window is 0.1mm
- Deformation test under vacuum: elliptical window is 0.4mm, circle window is 2.3mm;
- ultimate vacuum<5 $\times 10^{-8}$Pa。

2 Status of Linac

- The installation of all devices of Linac has been finished by July 2022,
- **The static pressure reached its design value .**

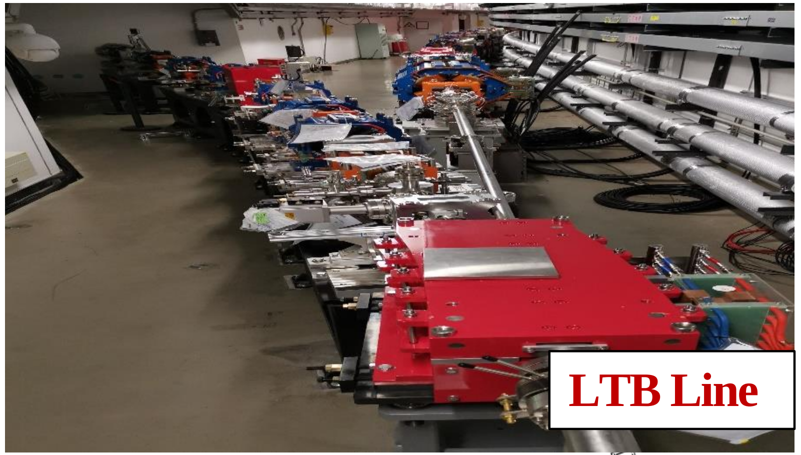


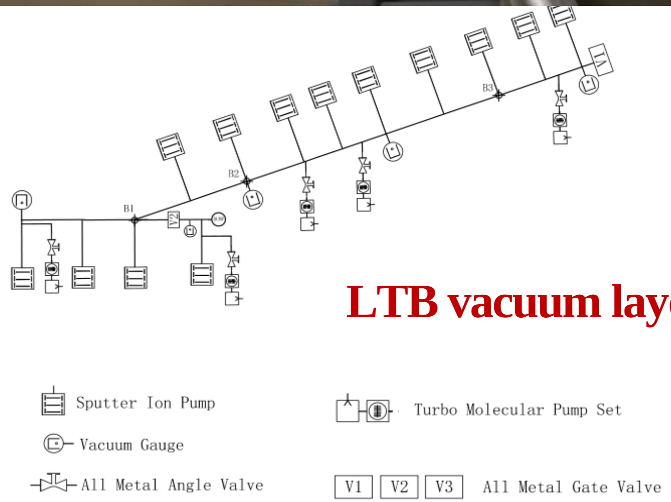


2 Introduction of transportation lines

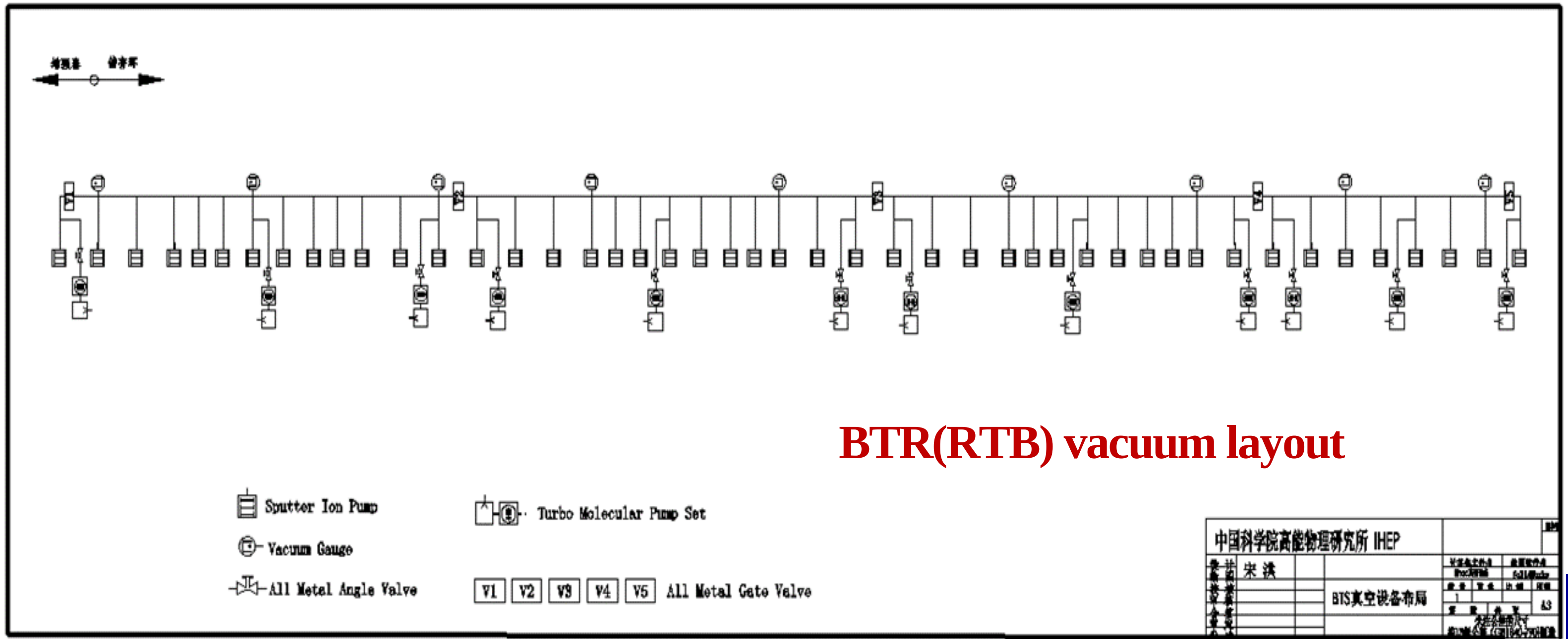
- There are three beam transport lines. One is used to transfer 500MeV electrons from linac to the booster (LTB), the other two lines are used to transfer 6GeV electrons from booster to storage ring (BTS), and storage ring to booster (STB).
- Thermal outgassing rate is 1×10^{-10} Torr·l/(s·cm^{-2}). The dynamic vacuum pressure < 1×10^{-7} Torr.

Section	Length/m	Average pressure /Torr	Maximum pressure /Torr	The distance of SIP
LTB	**25**	2.3×10^{-8}	3.3×10^{-8}	2.5m
BTS(STB)	**105**	2.7×10^{-8}	4.7×10^{-8}	1.8m





LTB vacuum layout

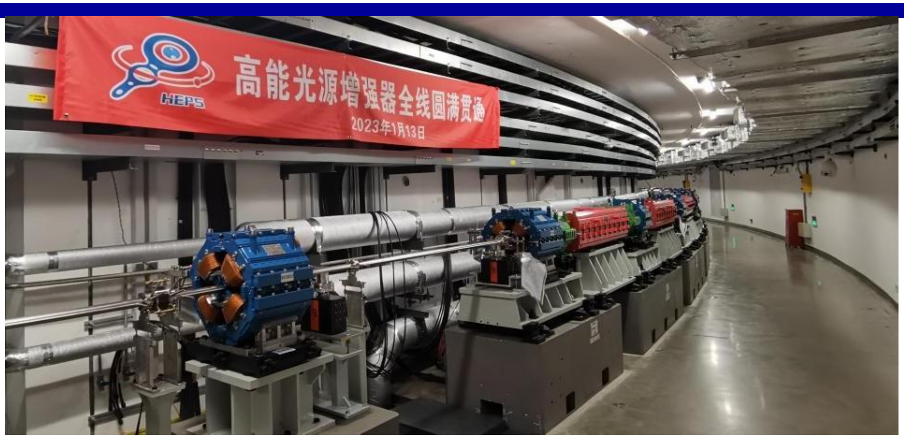


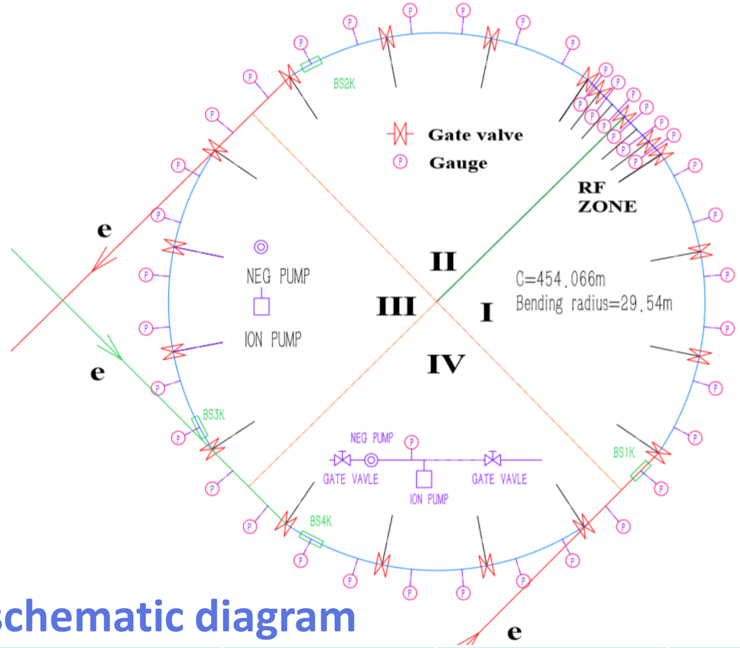
BTR(RTB) vacuum layout

3 Booster vacuum system

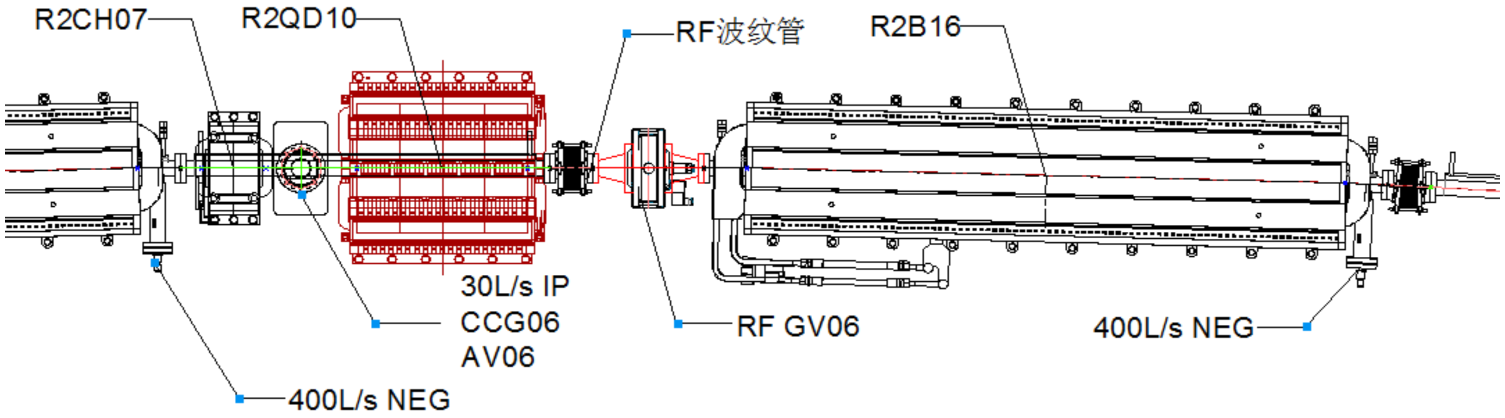
Pengcheng Wang

- The vacuum system is divided into 19 sections , 12 sections for the arc regions, 7 sections for the straight and RF regions. Each section has 2 rough pumping valves.The system is first pumped to 10^{-7} Torr by oil-free TMPs. The ion pumps and NEG pumps will be used as maintain pumps. Average pressure is 1.59×10^{-8} Torr

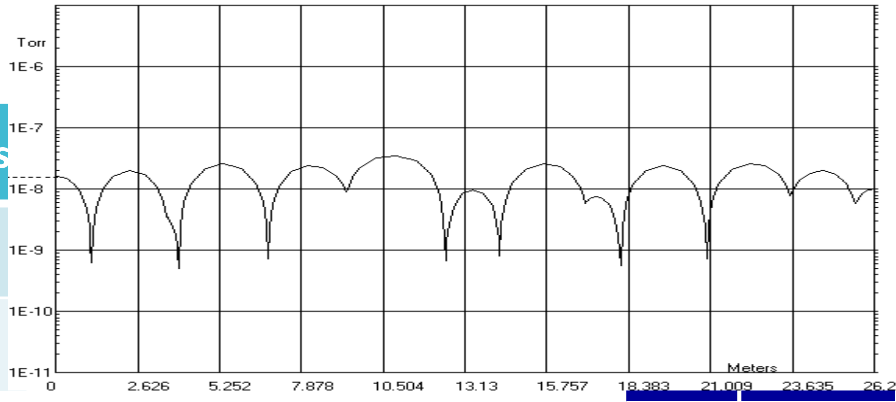




schematic diagram



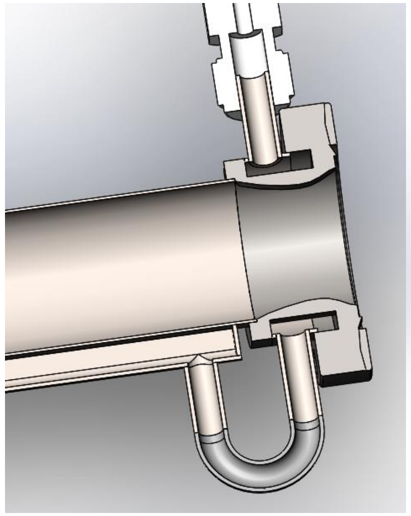
Item	Ion pump	NEG pump	Gate valve	Vacuum gauge	RGA	RF-shield Bellows
Quantity	140	84	19	38	16	152
Specification	30 L/s	400 L/s	All metal	CCG		Double fingers

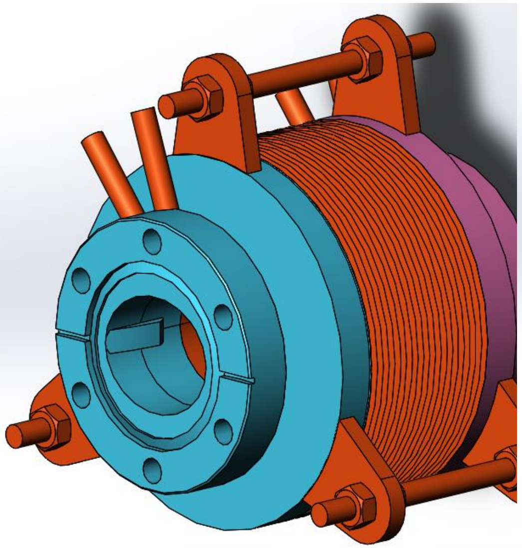


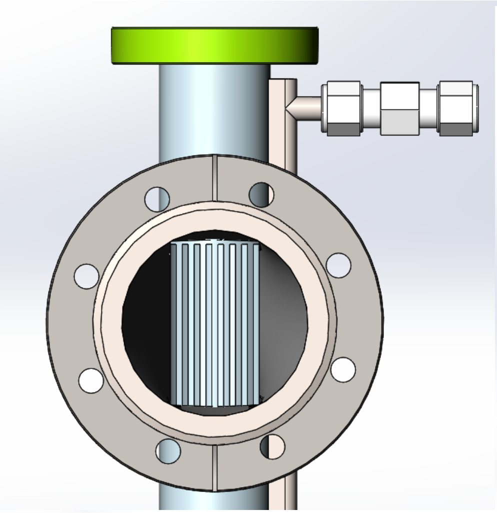
3 Booster vacuum requirements

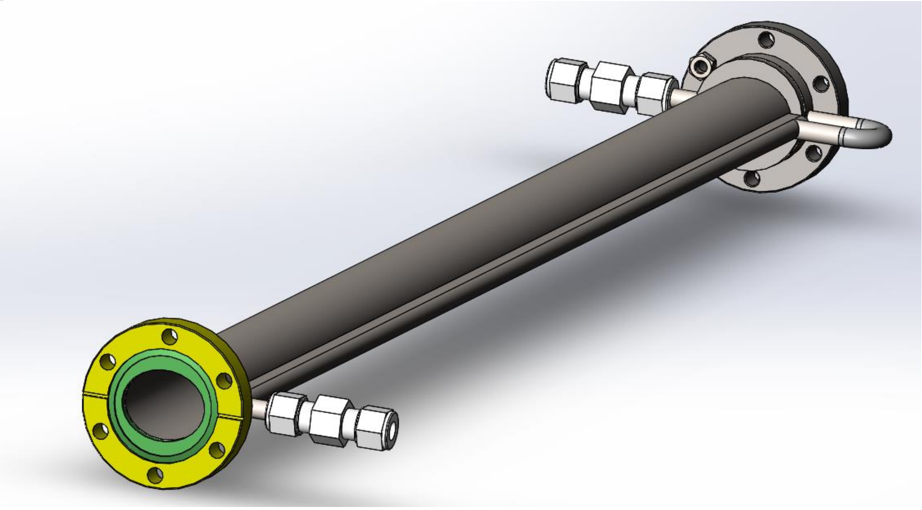
Jiaming Liu

- The in-line absorbers are used to prevent SR photons from falling on the bellows, BPM etc.



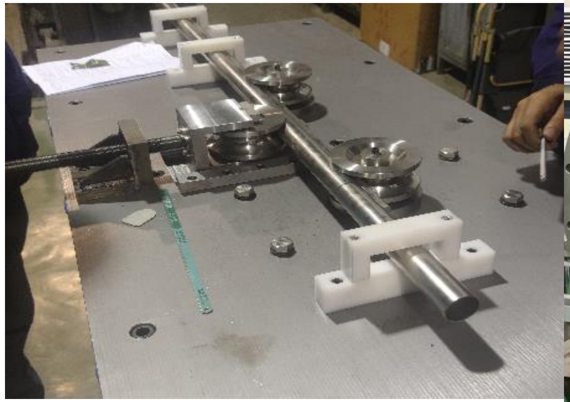


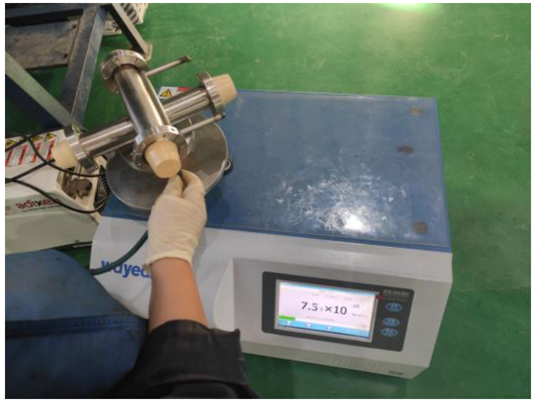


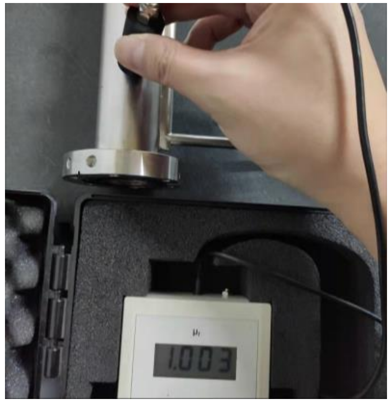


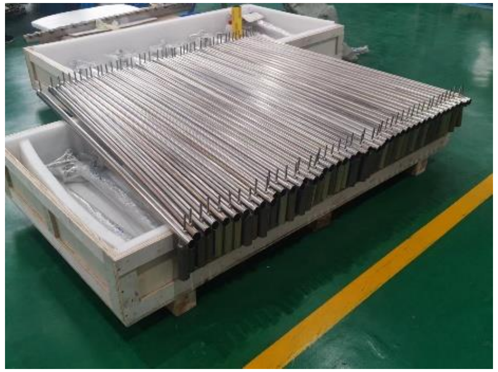
- In order to reduce the eddy current effect during the quick cycle of the magnets, the vacuum chambers will be made of thin-walled stainless steel. The inner surface of the vacuum chambers should be as smooth as possible to reduce the impedance.
- A cross-section of 36mm×30mm (H×V) ellipse with wall thickness of 0.7mm, length of 1.62m, bending radius of 28.52m. Permeability ≤1.02.
- The peak SR power of the booster reaches 0.34 kW/m, and the average power is about 1/4 of the peak power.

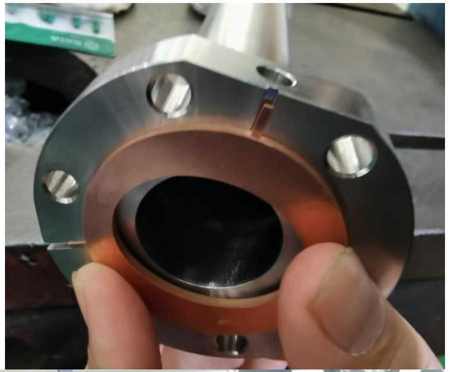
3 Processes of vacuum chamber produce

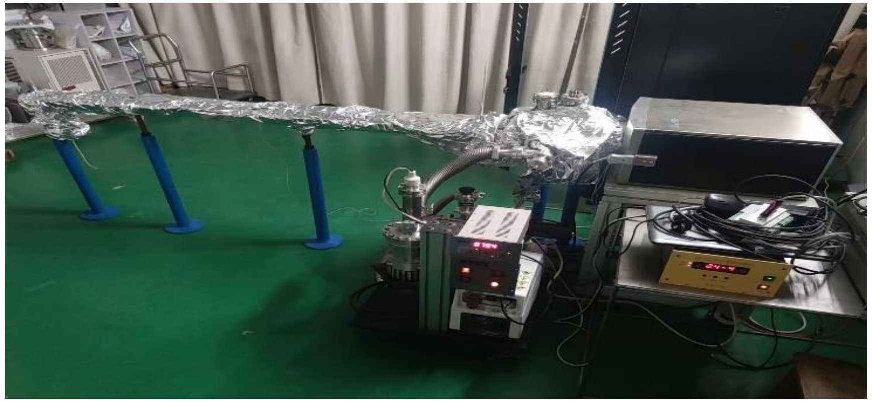


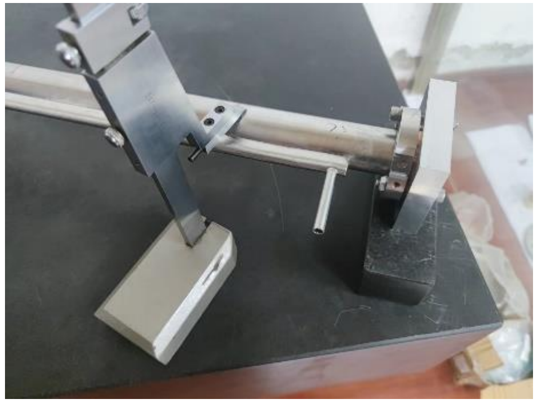










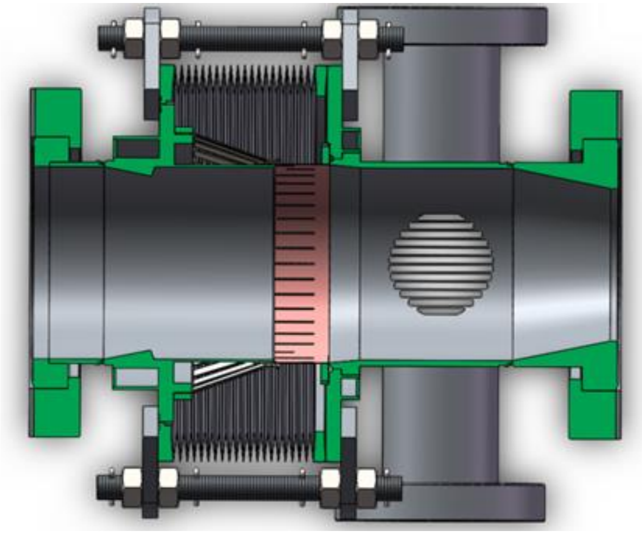


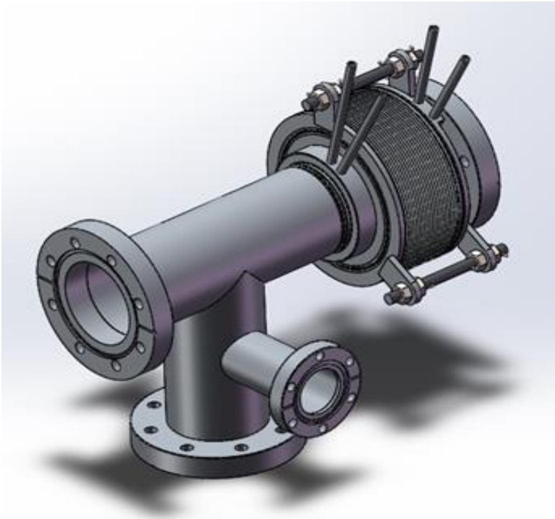
3 RF shielding bellows of booster

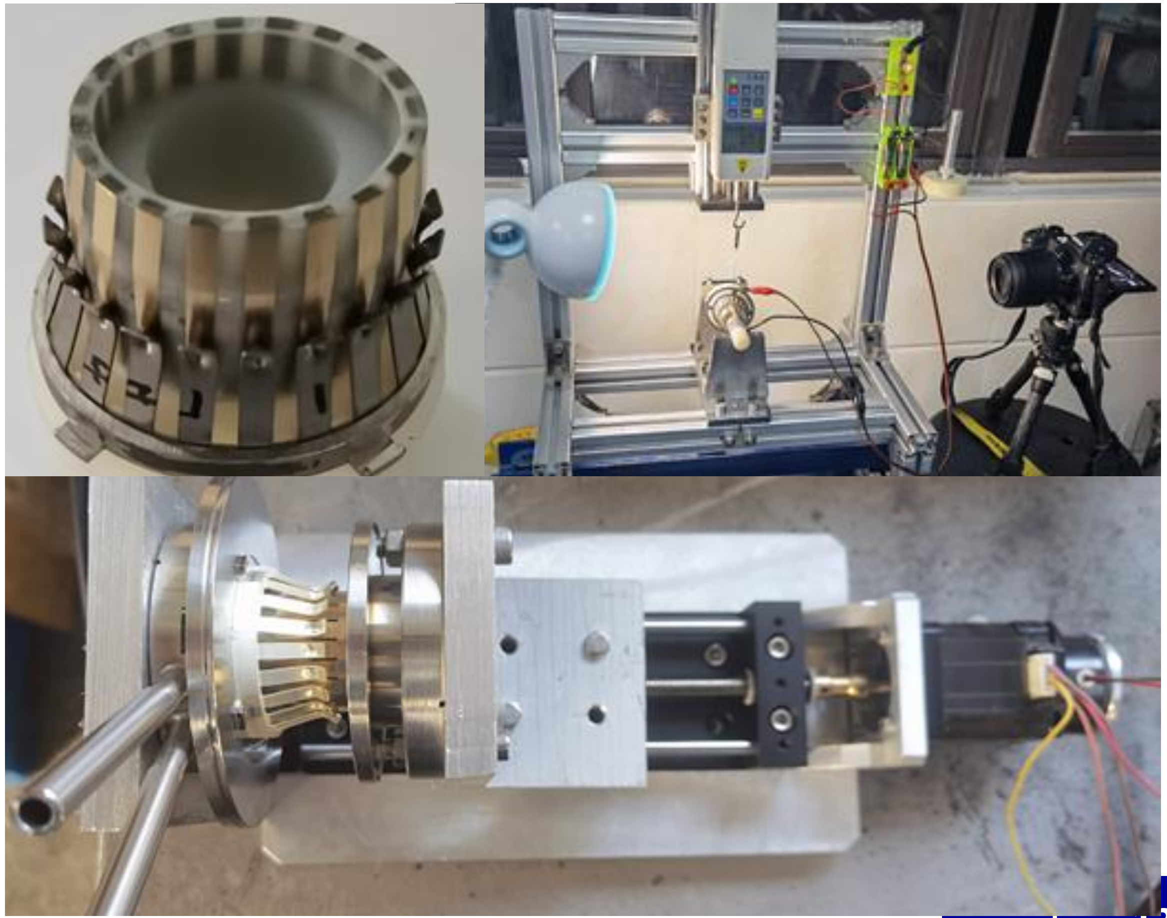
Jiaming Liu

Total length	Expansion	Contraction	Ellipse cross section	Contact pressure	Maximum radial offset
70-100mm	5mm	10mm	36mm×30mm	125±25g	2mm

- Mask is designed on the upstream of RF bellows to absorb the SR
- The all RF bellows of HEPS is produced by domestic company in China

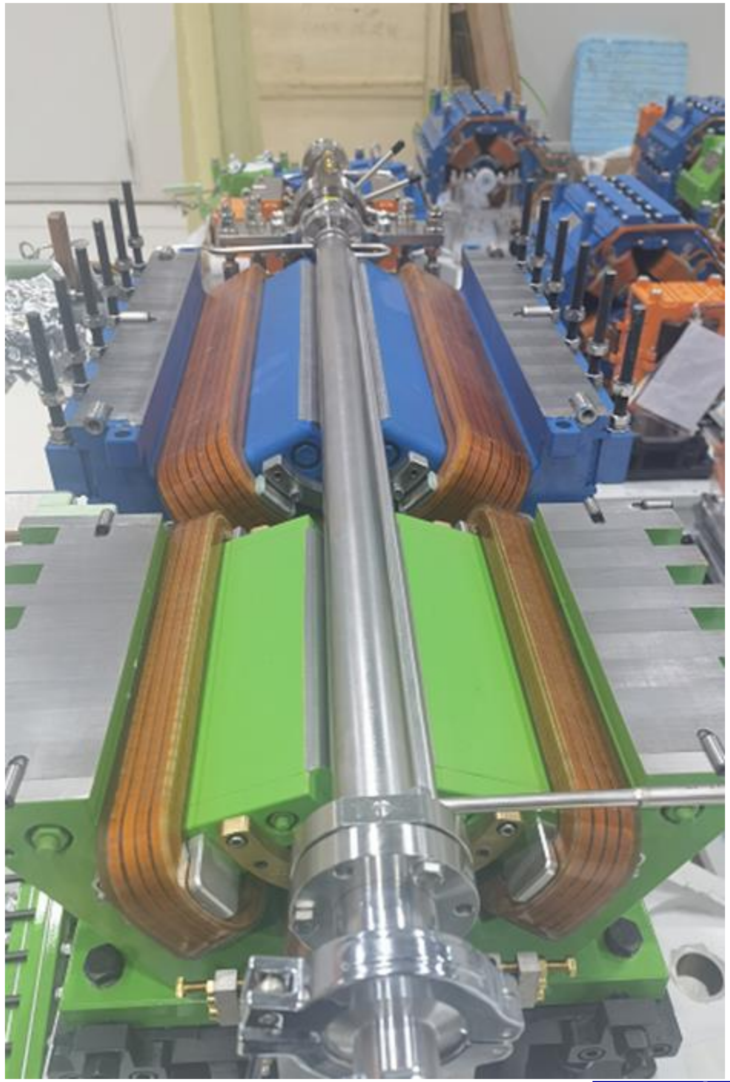


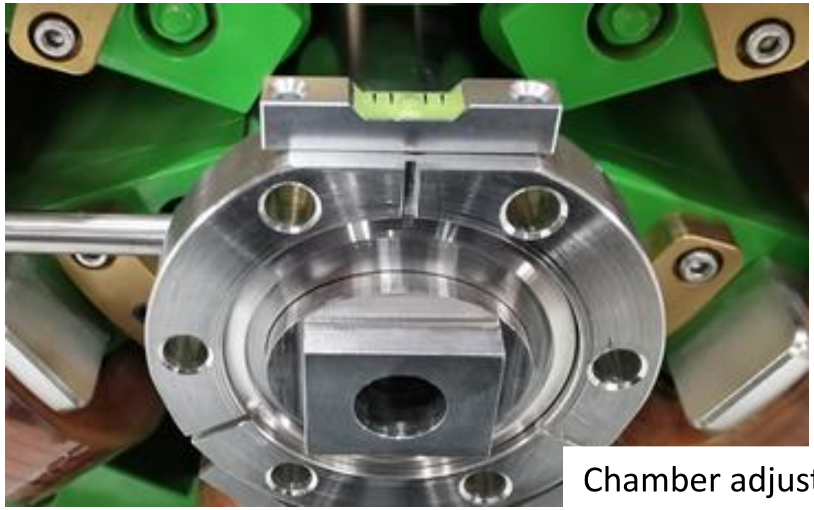




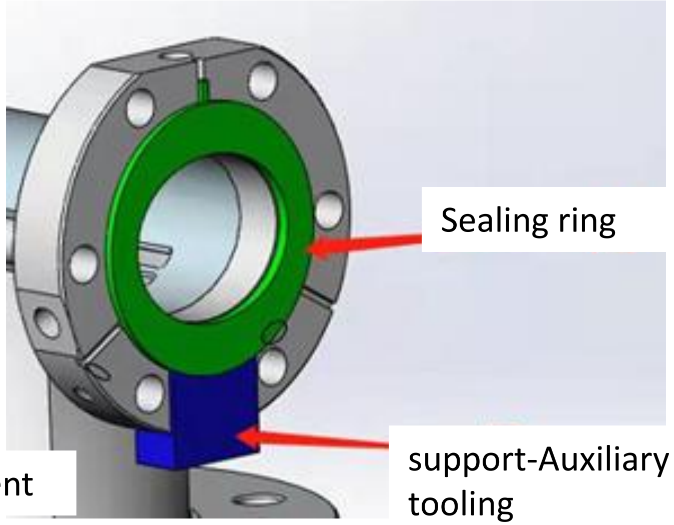
3 Booster vacuum components pre-installation at PAPS

Jiaming Liu xiaoyang Sun, Bangle Zhu





Chamber adjustment

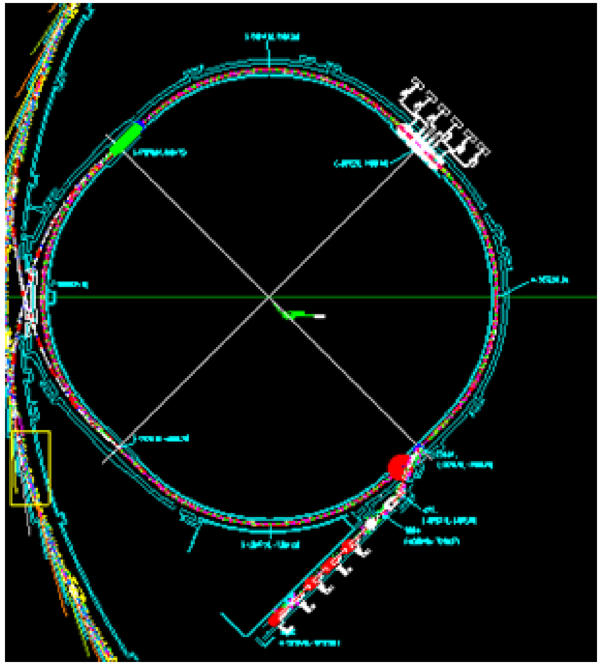


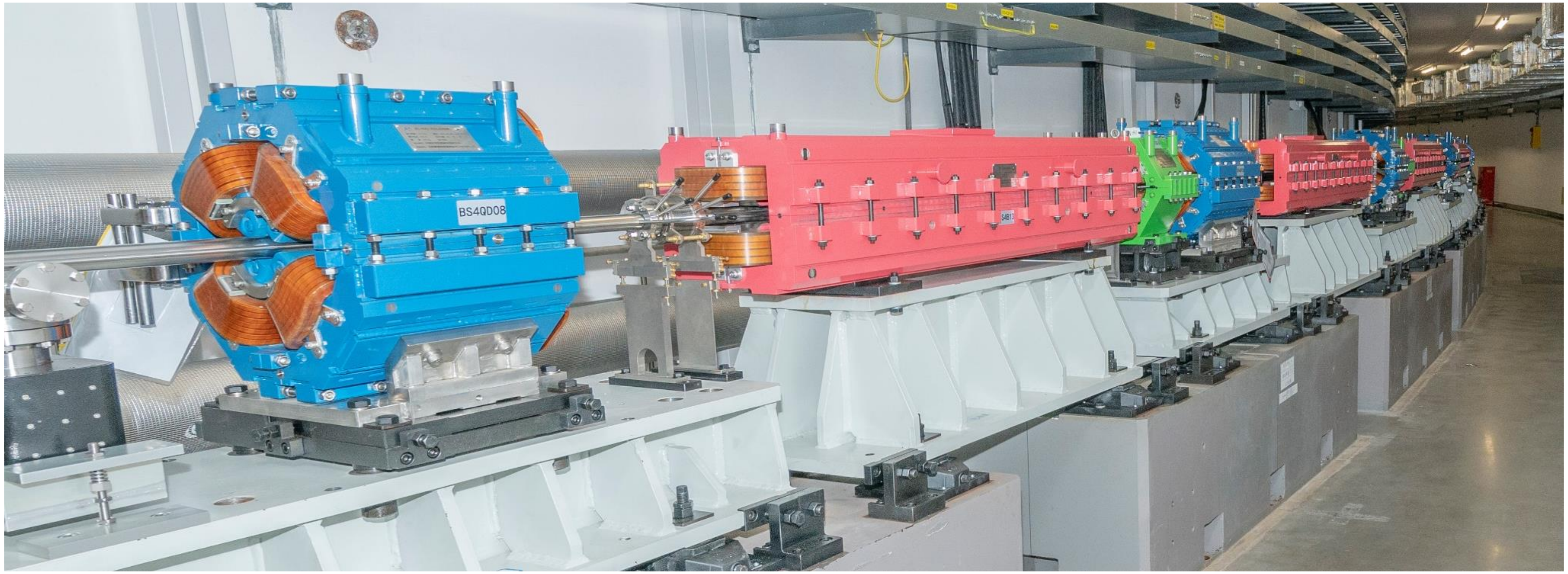
Sealing ring

support-Auxiliary tooling

3 Status of Booster

- The installation of all devices of booster has been finished so far.
- The last chamber of vacuum system have been installed by 23th Jan 2023, which is before Chinese New Year. The vacuum will be pumped down after cables are connected.

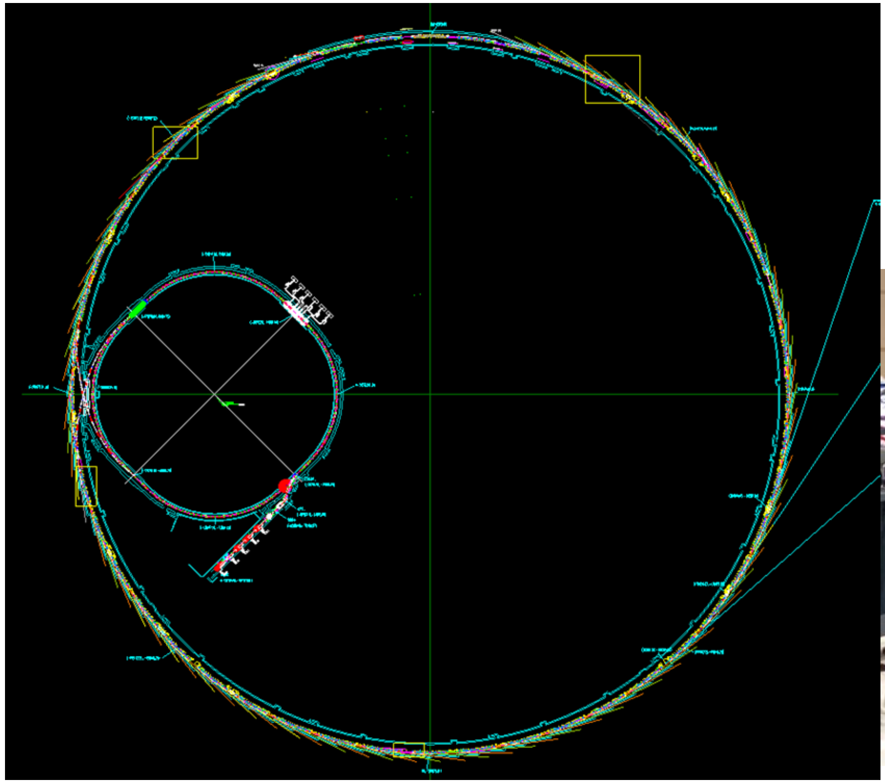


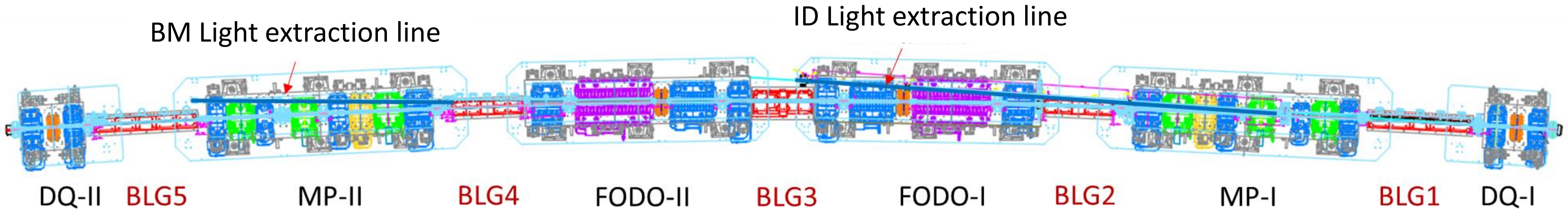


4. Storage ring Vacuum

Haiyi Dong

- The Circumference of **HEPS storage ring is 1360.4 m, and 24 double 7BA units** are applied in an achromatic Lattice design.
- The long linear section is located at the beginning of the **48 standard units** and is mainly used for mounting insertions, injection and extraction devices, RF and other equipment. RF shielding all-metal gate valves are installed on the two ends of the long linear section, which are divided into about **96 vacuum sections**.
- Each standard arc unit includes 18 vacuum chambers, the most of those will be NEG coating, and 14 RF shielded bellows, 4 photon absorbers, ion pumps, NEG pumps, vacuum gauges and valves.

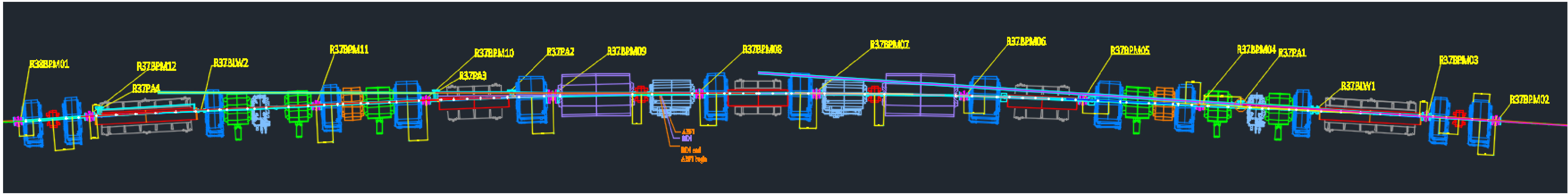


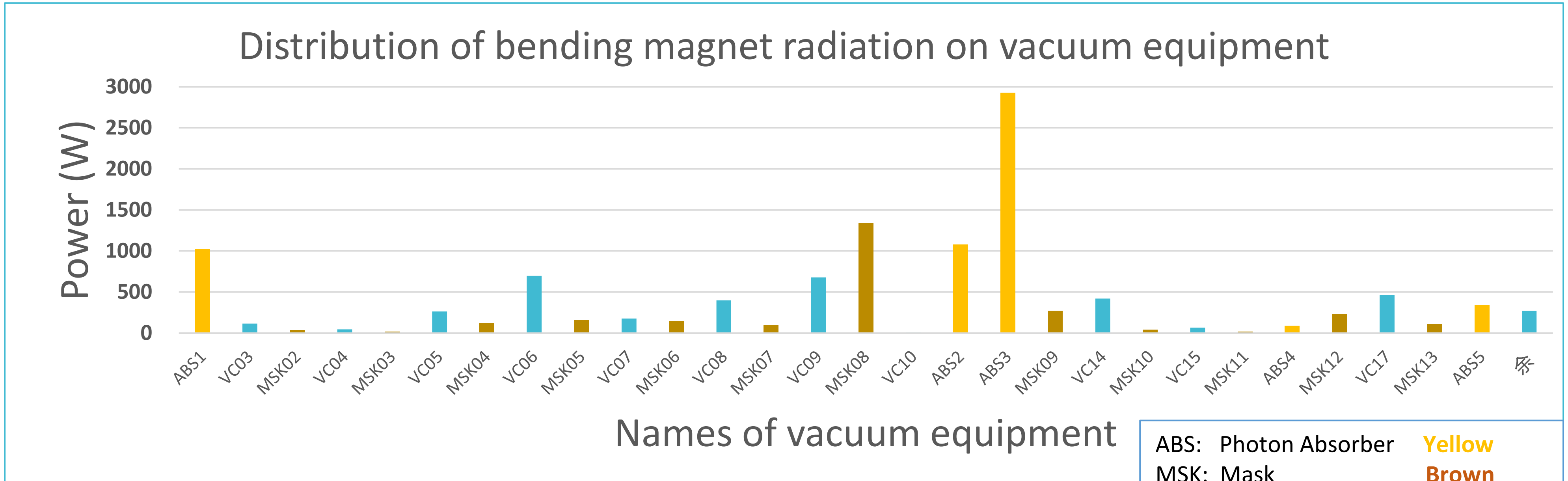


4. Storage ring Vacuum requirements

- A vacuum in the lower than 1×10^{-9} Torr is required when a beam is circulating in the storage ring. It can be shown that the beam lifetime would exceed 100 h if only losses due to Interactions between beam and gas.
- Good beam lifetime must be achieved soon after the initial startup with a stored beam.
- The system must be capable of quick recovery after the sections are vented for maintenance.
- The chamber wall is designed as smooth as possible to minimize the electromagnetic fields induced by the beam.
- Sufficient cooling to safely dissipate the heat load associated with both synchrotron radiation and higher-order-mode (HOM) losses.
- Capability to shield outer ring components from synchrotron radiation.

4. Distribution of SR power on the Storage Ring vacuum components



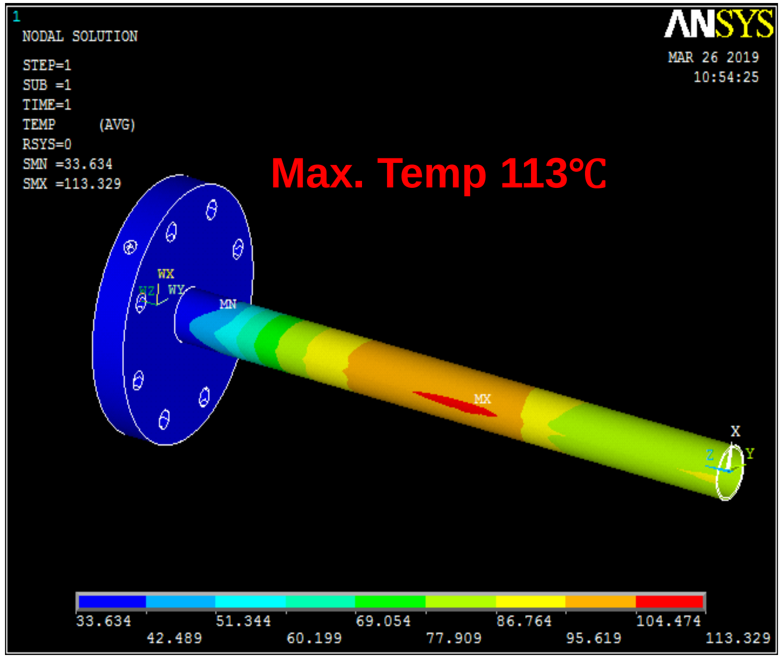


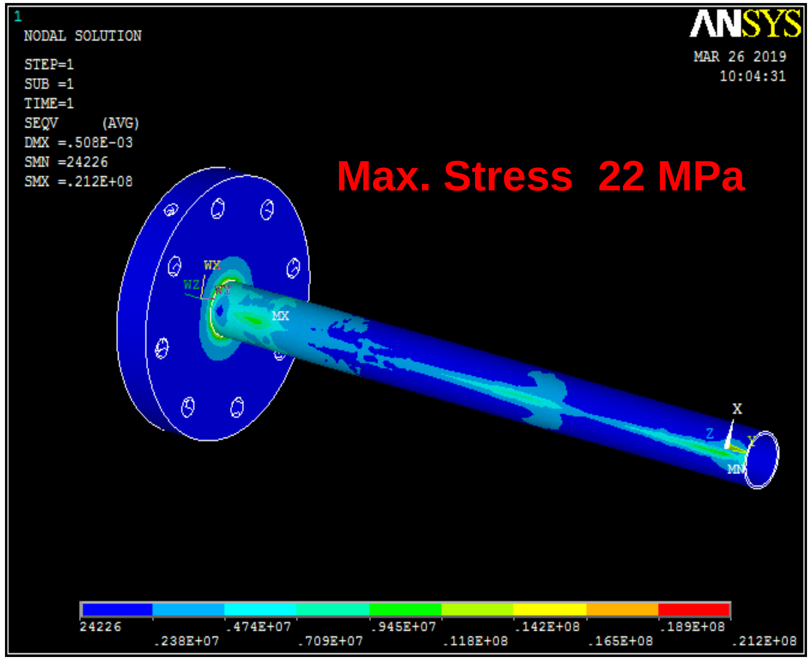
The power of each cell is 11.02kW, the total power of 48 cells is 529 kW.

4. FEA of the mask of a highest power density

Dizhou Guo

Positions	Power (W)	Length (mm)	Height (mm)	Area (mm^2)	Power density (W/mm^2)
I	297.92	101.24	0.2	20.25	14.71
II	839.11	164.77	0.2	33	25.46
III	129.6	19.18	0.2	3.84	33.79
IV	14.93	2.8	0.14	0.39	38.07
V	8.6	3	0.14	0.42	20.47



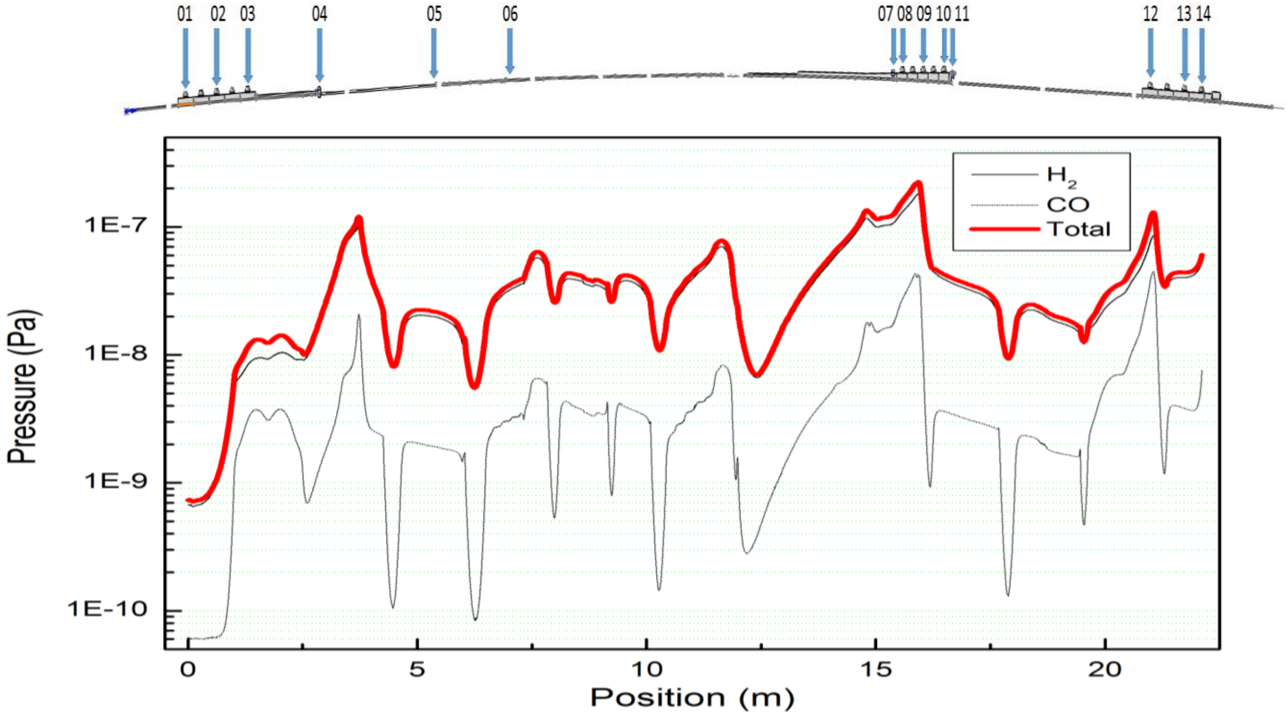


- SR Mask with a slope length of 300 mm (total of I To V) to reduce power density.
- The part of mask in the magnet is cooled by water-cooled pipes and the outer part by water-cooled jackets.
- As the total power does not decrease, the maximum temperature is still high.

4. Pumping system & vacuum distribution

- The circumference of the storage ring is divided into about 96 sectors by means of the RF all metal gate valves, which allow all vacuum work such as pumping down from atmosphere pressure, leak detecting, bakeout, and vacuum interlock protection, to be done in sections of manageable length and volume.
- Roughing down to approximately 10^{-7} Torr will be achieved by the oil free turbo-molecular pump group.
- **The main pumping is achieved with Non Evaporable Getter(NEG)-coated chambers, the ion pumps will be used to maintain pressure and pump off CH_4 and noble gases.**
- **CPMU, IVU and RF cavities will be pumped down by NEG pumps and ion pumps.**

1~14: ion sputtering pump

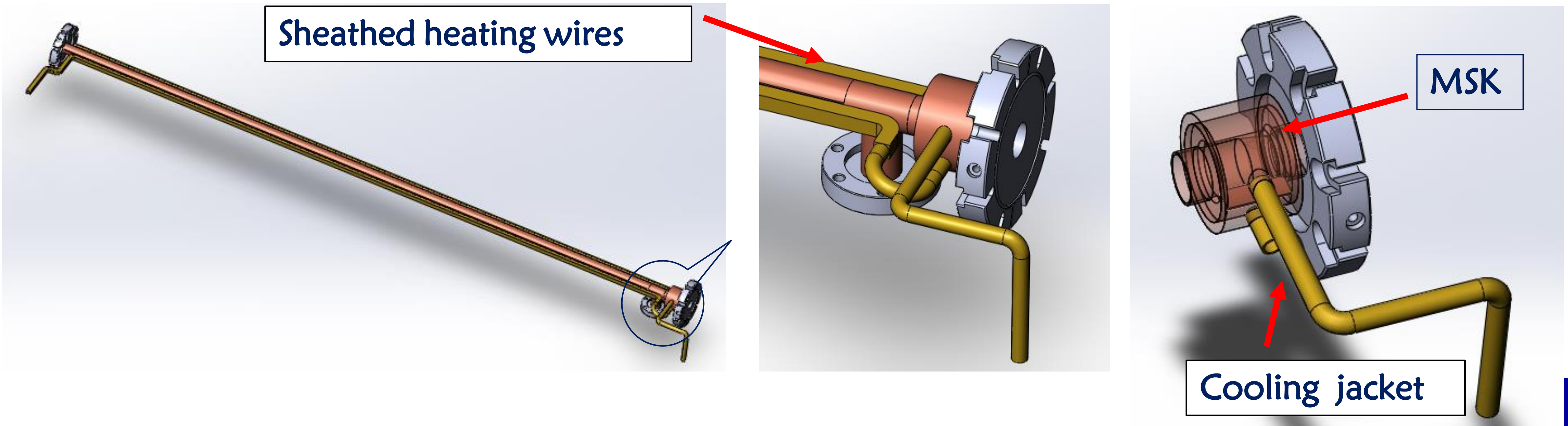


Pressure profile of a standard arc section @ 6GeV，200mA

- **Thermal outgassing rate: 2.5×10^{-12} mbar·L/s·cm^2**
- **Photo desorption rate: 1.95×10^{-6} moleculars/photon**
- **Pumping speeds: Ion pump 30 L/s;**
- **NEG film sticking factor H2 is 0.007, CO is 0.07**

4. Vacuum chambers requirements

- Cu-Cr-Zr (C18150) is chosen as the chambers material because of its higher thermal conductivity and higher resistance to softening due to the NEG activation temperature of 200 C°.
- Stainless steel (Inconel) material is used for fast corrector chambers and some chambers with ion pumps.
- The vacuum chambers have a 22 mm inside diameter with 1 mm wall thickness. The clearance between the chambers and the magnets poles is 1 mm (include 0.4mm heating tape).
- Distributed cooling channels are welded to the chambers to safely dissipate the SR power.
- All the chambers are produced with tight mechanical tolerances to avoid any interference with the magnet poles and coils.

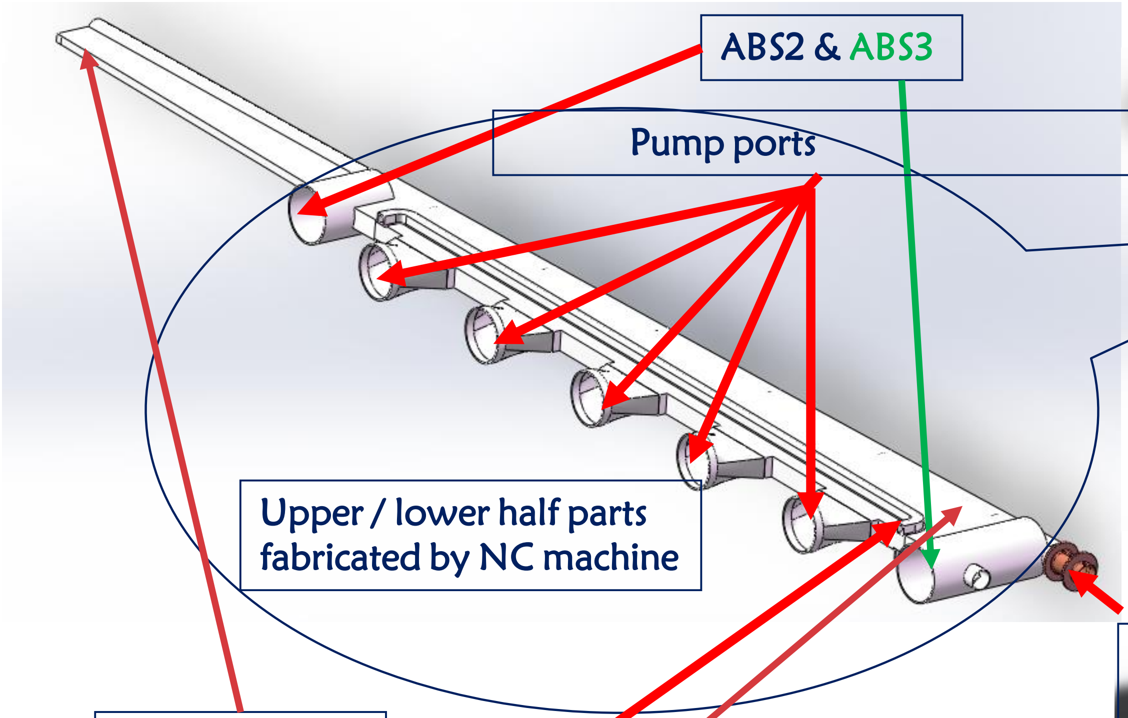


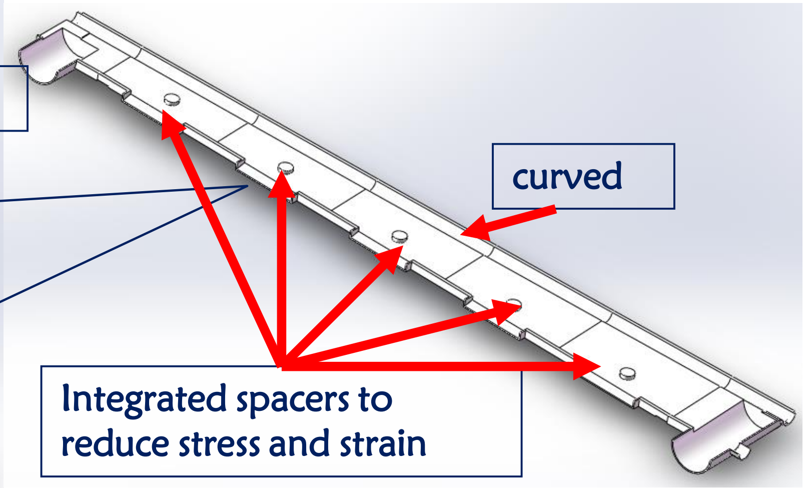
Vacuum chambers of a 7BA cell

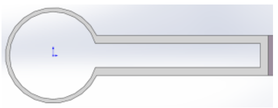
Number	Related magnets	Shape	Material	Length (mm)	Bending (°)	Flange types
VC1	QF1-FC1-QD1	φ24*1	C18150/Inconel625	956.9		Various
VC2	BLG1	Antechamber (part)	316LN (coating Cu)	1604.4	1.2372	CF63
VC3	QD2-SD1-ABF1	Antechamber/φ24*1	C18150 (Cu-Cr-Zr)	1155.3	0.0768	CF63/CF25
VC4	SF1	φ24*1	C18150	496.8		CF25/CF63
VC5	QF2-OCT1-SD2-QD3	φ24*1	C18150	1667.8		CF63
VC6	BLG2-QF3	φ24*1	C18150	1697.8	0.8375	CF63
VC7	BD1	φ24*1	C18150	1196.9	1.3671	CF63/CF25
VC8	FC2	φ24*1	Inconel625	221.3		CF25/CF25
VC9	ABF2	φ24*1	C18150	715.2	0.2756	CF25/CF63
VC10	QD4-BLG3-QD5	φ24*1	C18150	1666.7	1.3863	CF63
VC11	ABF3	Antechamber	C18150	705.2	0.3081	CF63
VC12	FC3	Antechamber	Inconel625	221.3		CF63
VC13	BD2	Antechamber	C18150	1168	1.3675	CF63/CF160
VC14	BLG4-QF4	Antechamber (part)	316LN (coating Cu)	1808.4	0.8142	CF160/CF63
VC15	QD6-SD3-OCT2-QF5	φ24*1	C18150	1555.8		CF63
VC16	SF2-ABF4-SD4-QD7	φ24*1	C18150	1647.1	0.1178	CF63/CF25
VC17	BLG5	Antechamber (part)	316LN (coating Cu)	1589.1	1.288	CF25/CF63
VC18	QD8-FC4-QF6	Antechamber/φ24*1	C18150/Inconel625	967.8		Various

Vacuum chamber design of VC14 (BLG4+QF4)

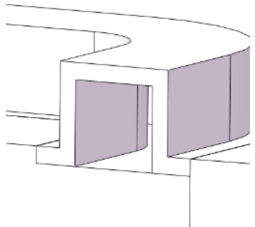
Dizhou Guo



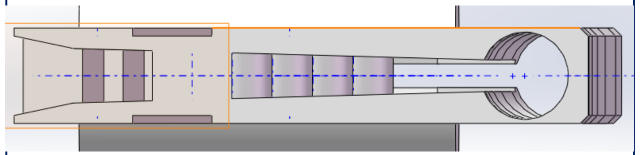




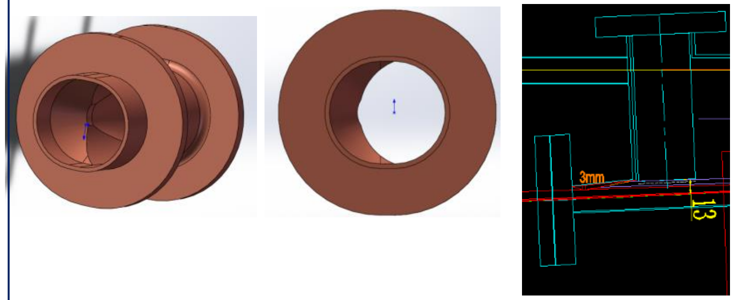
QF4 profile



Cooling water pipe



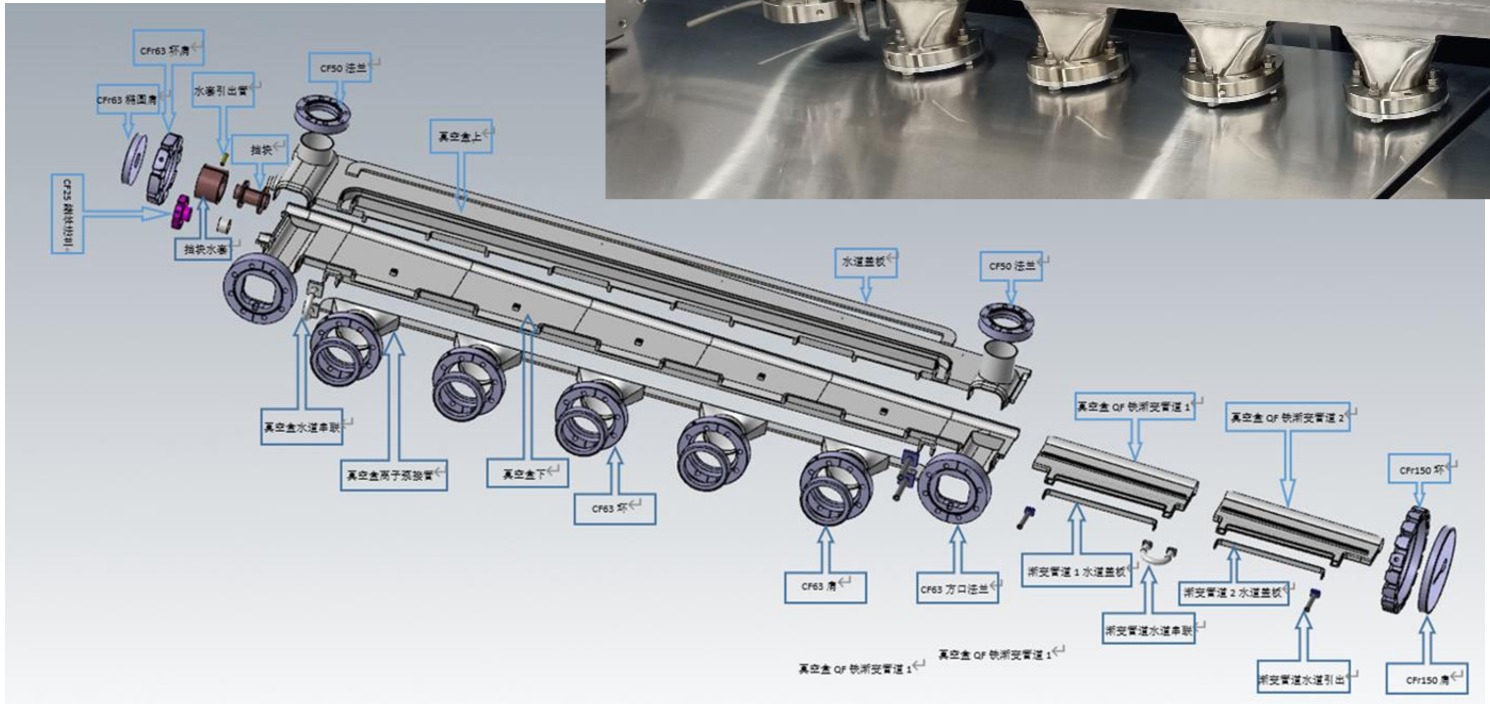
BLG4 profile

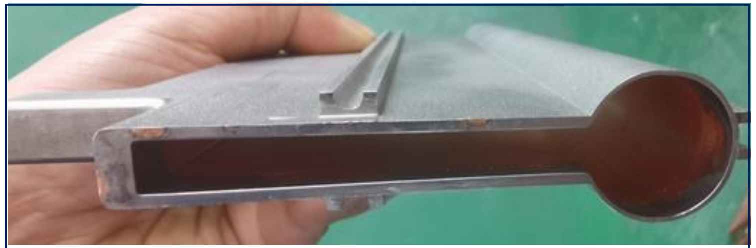


- Elliptical cross-section with mask to avoid stainless steel material from exposure to synchrotron radiation light.

Vacuum chamber design of VC14 (BLG4+QF4)

Dizhou Guo



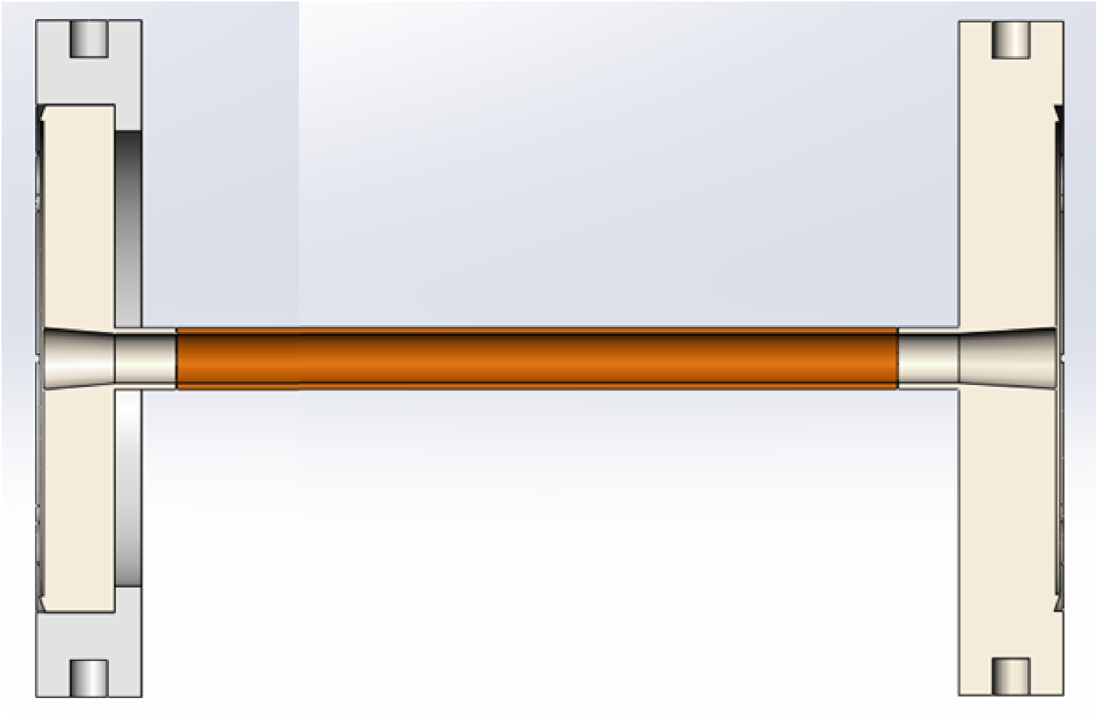


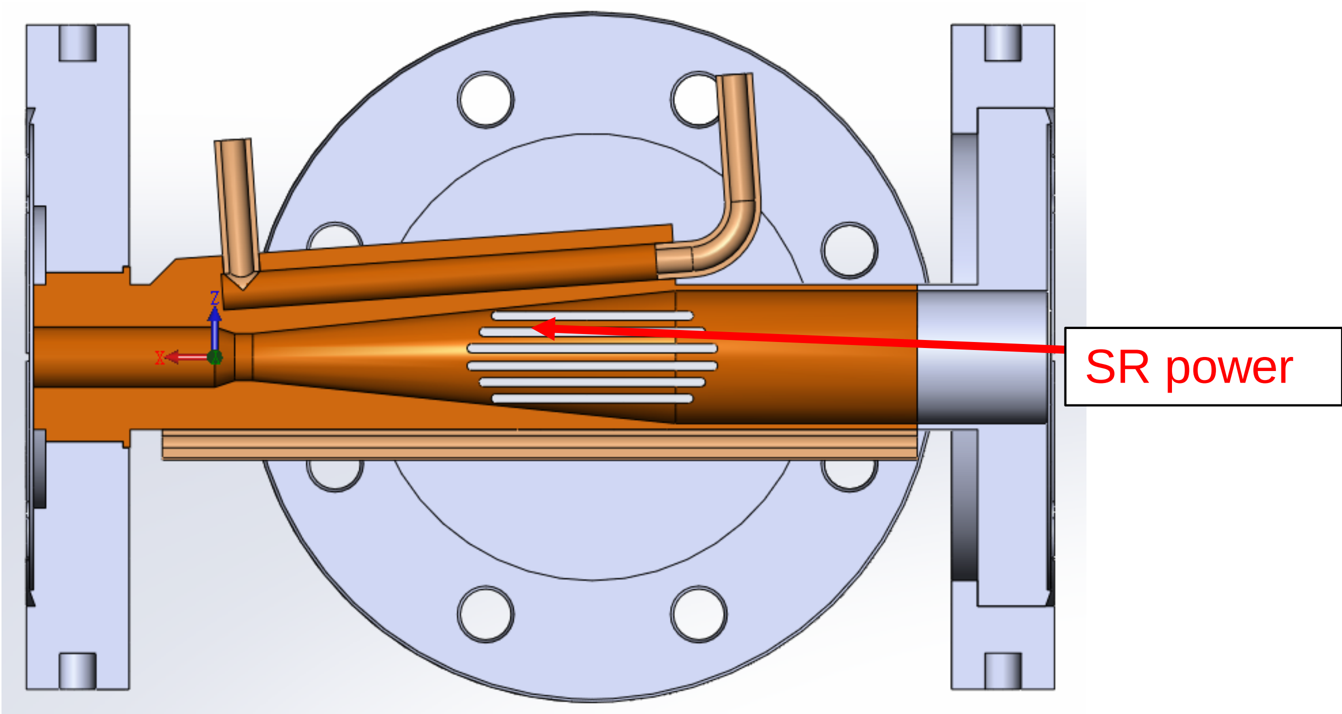
QF4 profile

- VC14 consisted by BLG4, QF4, mask, tapered pipe, antechamber, pump ports
- Cu film of 20 μm coated on the beam pipe of S.S, Permeability ≤1.02
- Laser welding, electron beam welding, argon arc welding are employed

Insertion vacuum chamber

Lei zhang



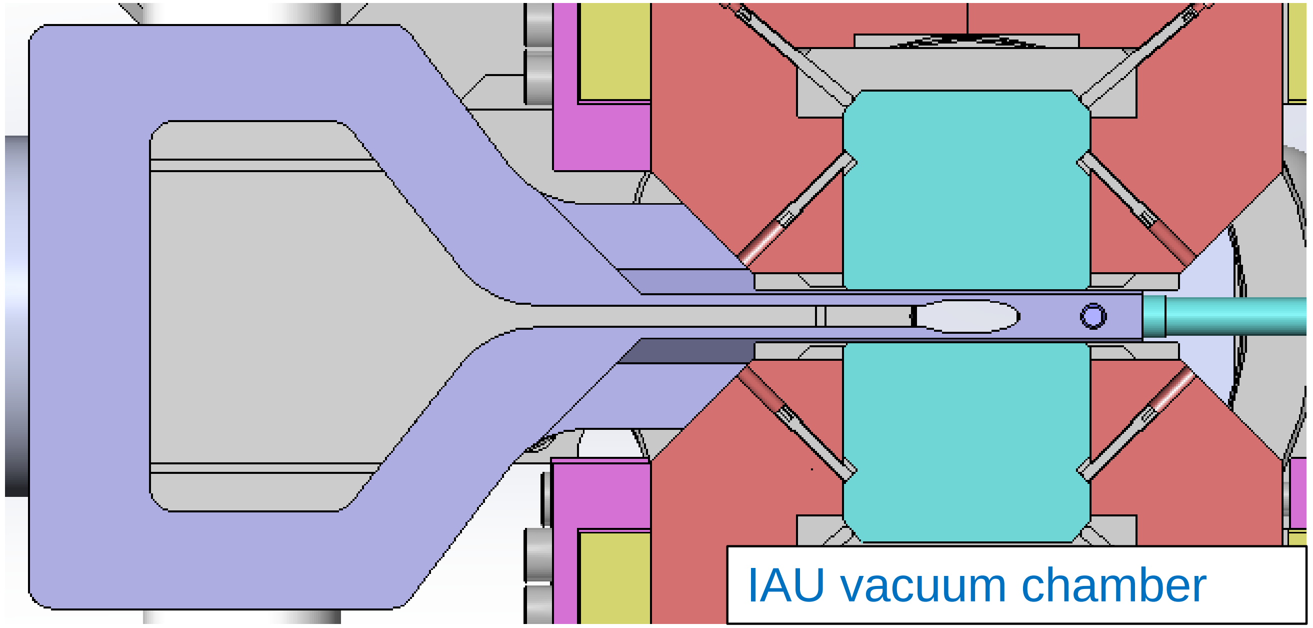


- Mango Wiggler vacuum chamber is made by extruded CuCrZr (C18150). The length is 2.4m, inner diameter is 8mm
- NEG coating, and no cooling pipe, due to low power of SR.

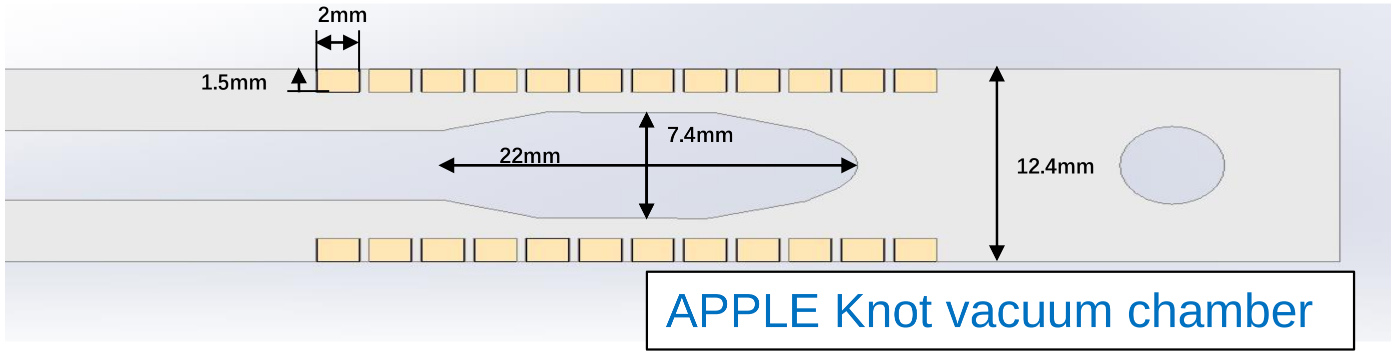
- Mango Wiggler upstream mask vacuum chamber is is made by extruded CuCrZr (C18150).). The length is 0.17m, inner diameter is varies from 7.8mm to 22mm.
- SR power si 3W/mm^2， NEG coating and water colling is applied.

Insertion vacuum chamber

Lei zhang



- IAU vacuum chamber is made by extruded Al6061, the length is 5.4m, elliptical beam aperture 7.4×22.

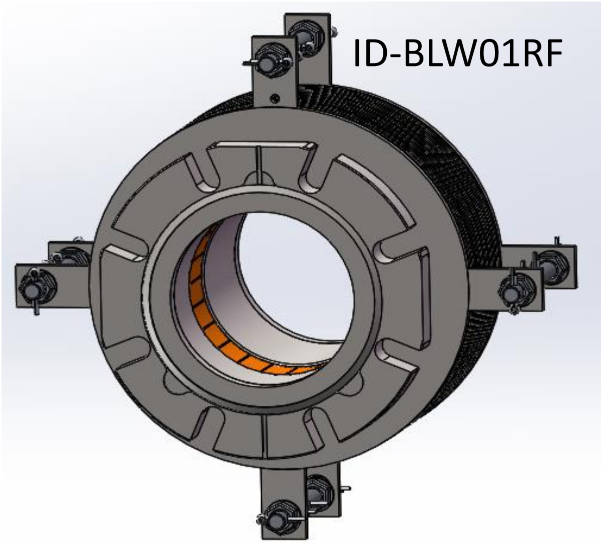


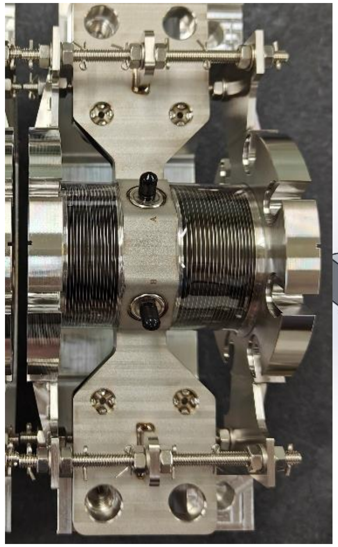
- APPLE Knot is the same as IAU vacuum chamber, which is made by extruded Al6061, the length is 5.4m, elliptical beam aperture 7.4×22.

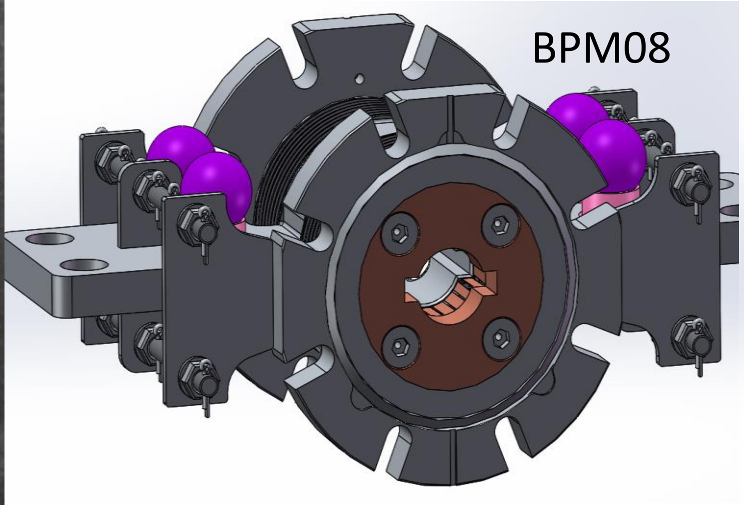
RF shielding bellows of storage ring

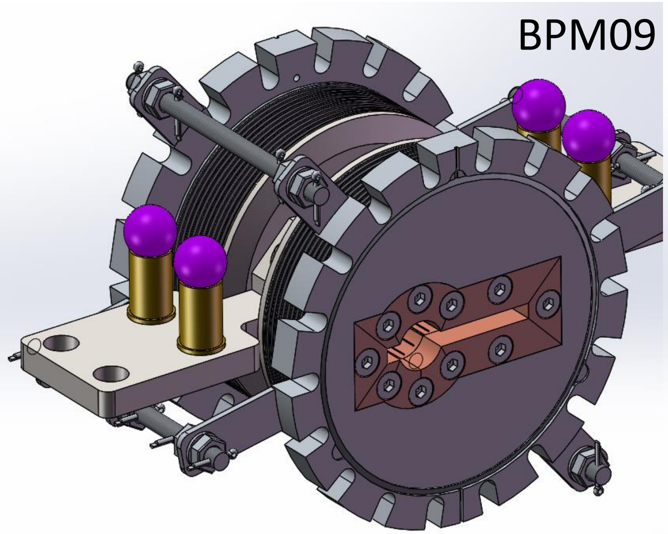
Xujian Wang

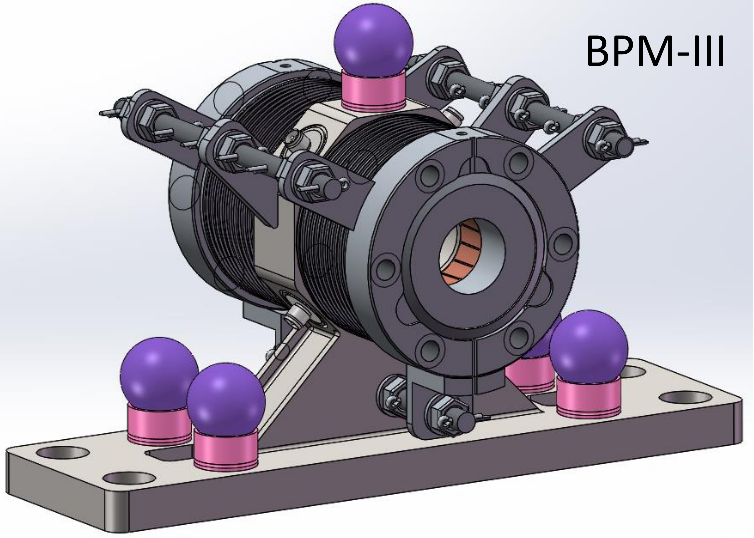
- Vacuum bellow modules are needed to compensate the mechanical misalignments of the vacuum chambers during installation and to absorb their thermal expansion during the bake-out. In order to reduce the beam impedance during operation with beams these modules are equipped with RF bridges to carry the image current.[1]
- **BPM and RF shielding bellow are constructed into a whole to save space.**







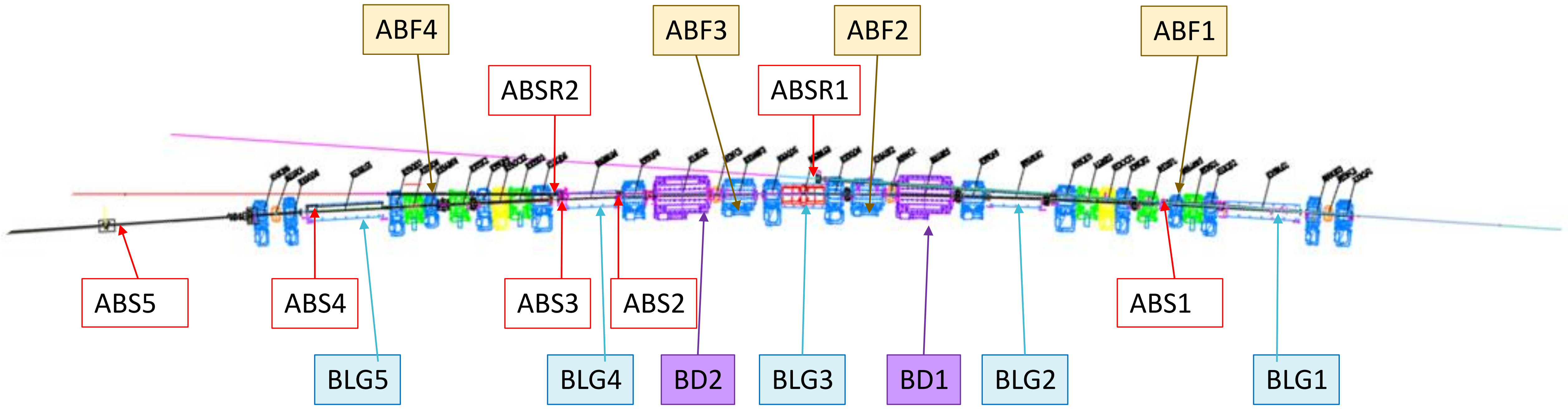




[1]IPAC2015-WEPHA005

Photon absorber Vs position of magnet

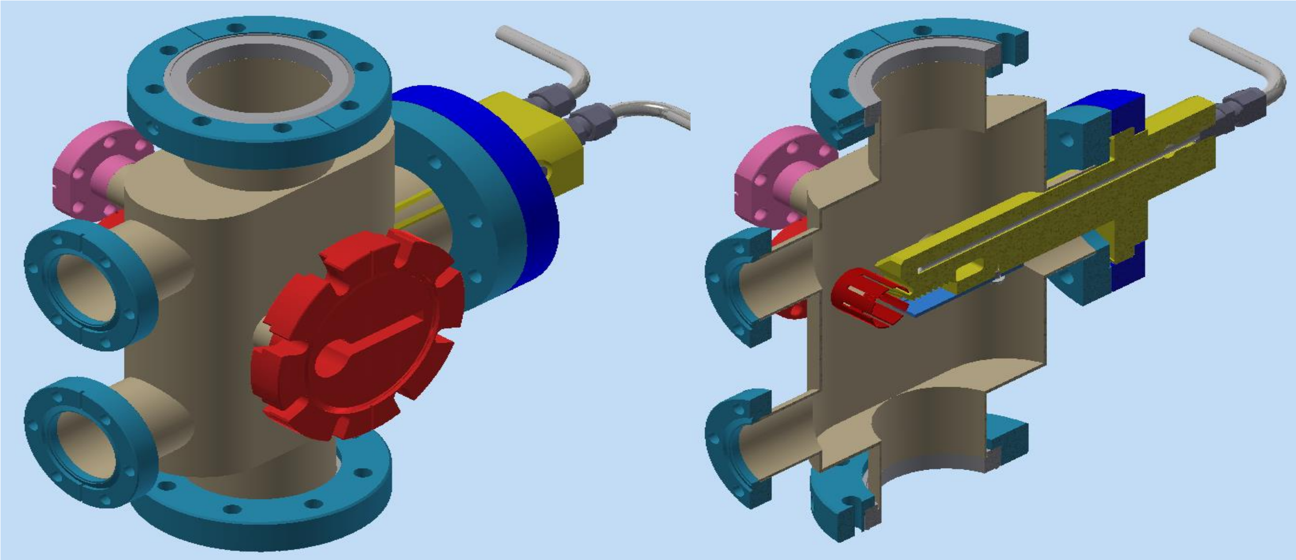
Qi Li

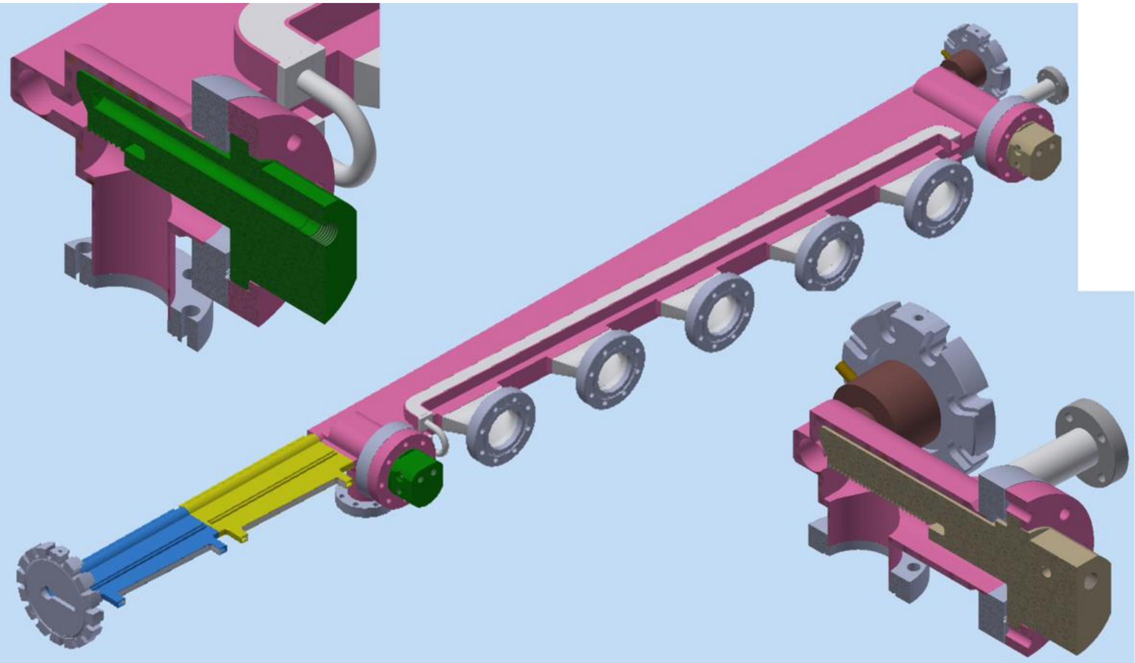


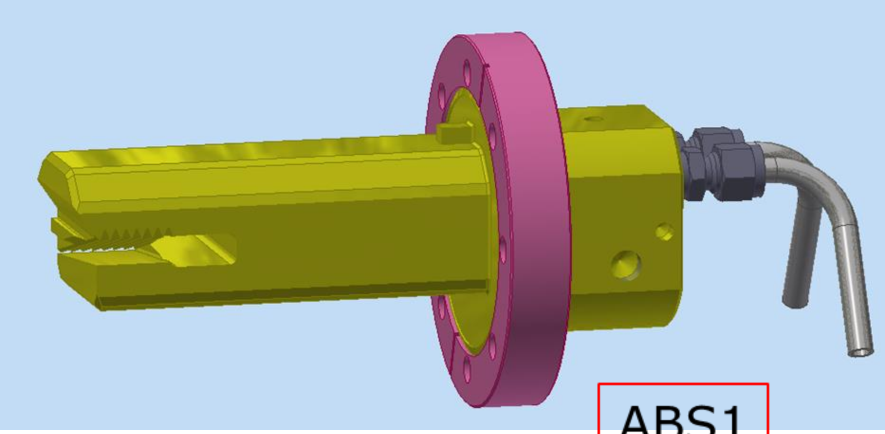
- About 41~48% of the synchrotron radiation power generated by the bending magnet is deposited on the photon absorber (ABS).
- Four photon absorbers were set up in the arc area of each unit, three of which were located at the exit of synchrotron radiation to extract the beam lines.
- Absorbers bear high power density synchronous light deposition, requiring good machining and installation accuracy.

Photon absorber models

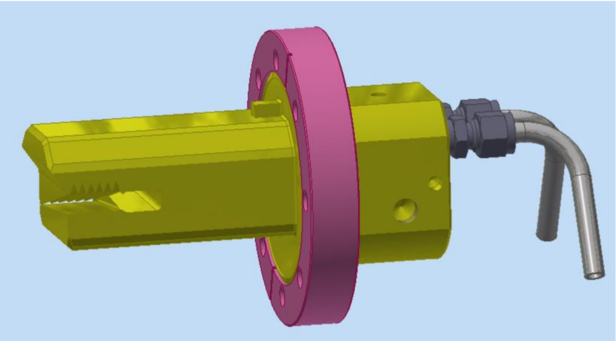
Qi Li



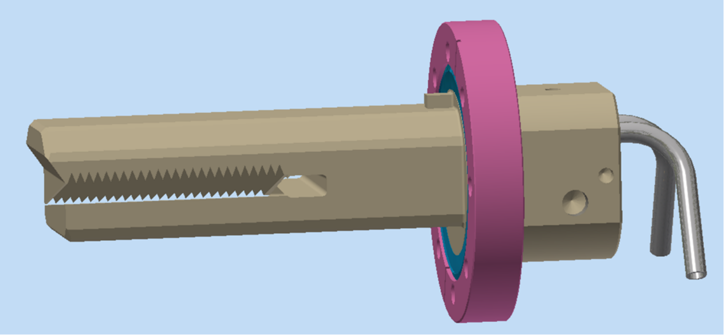




ABS1



ABS2



ABS3

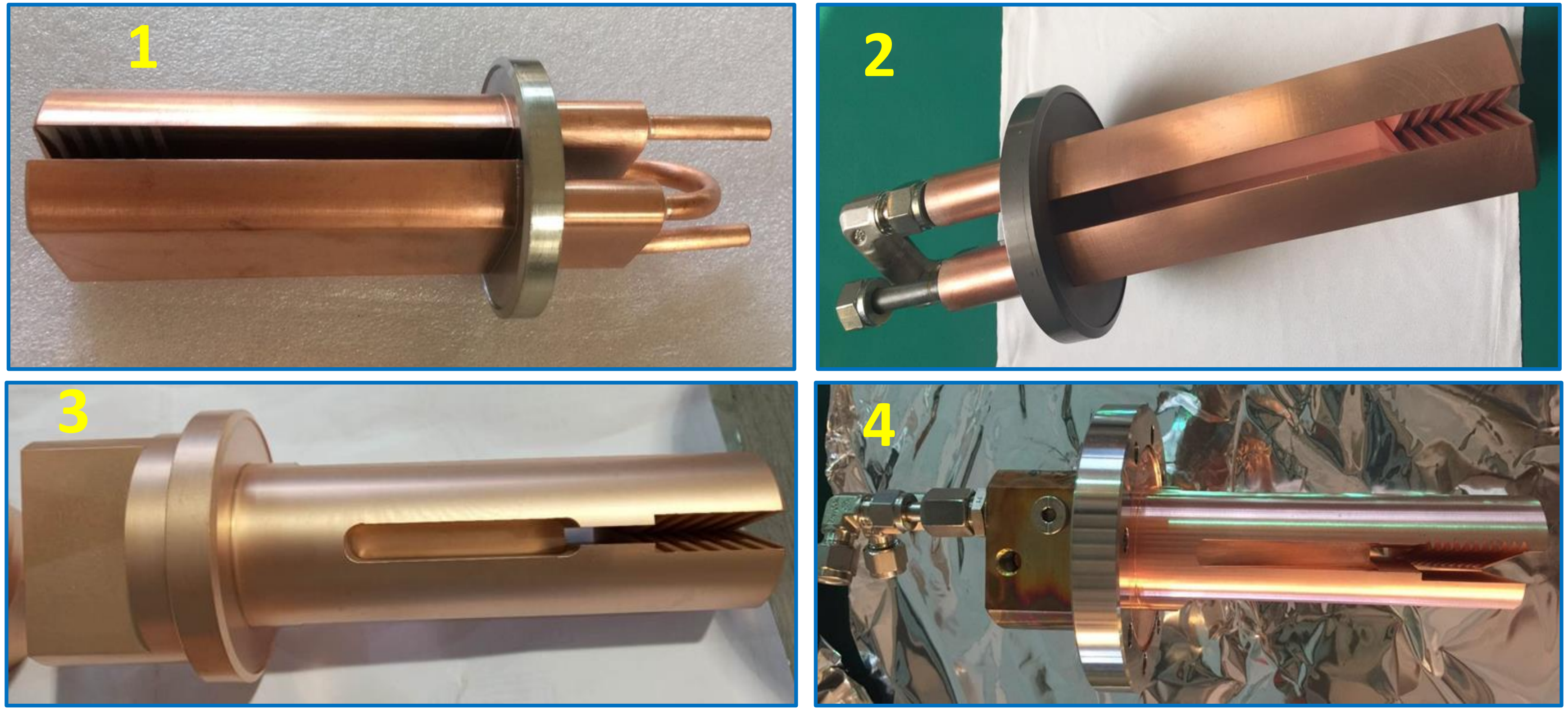
Photon absorber prototypes

Qi Li

1 **GlidCop-AL15** and SS316L flange brazing in a vacuum furnace.

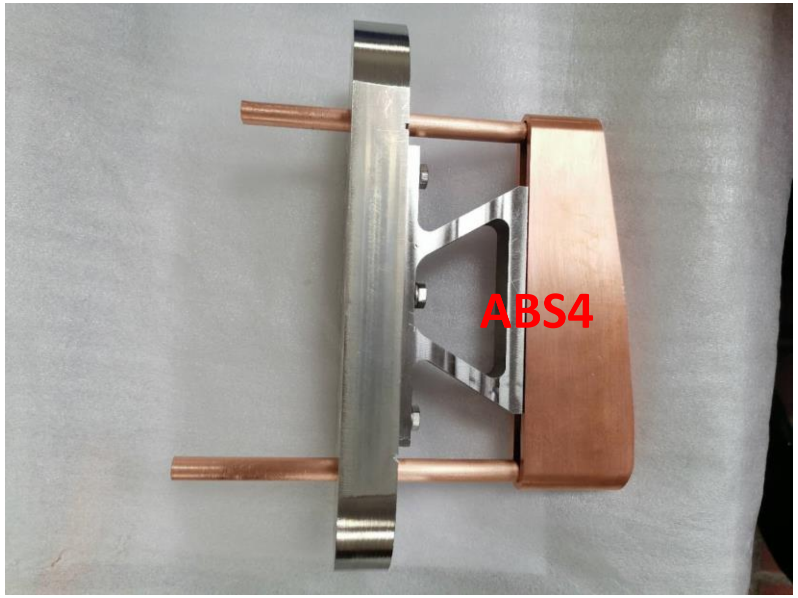
2 **GlidCop-AL15** and SS316L flange brazing in a hydrogen furnace.

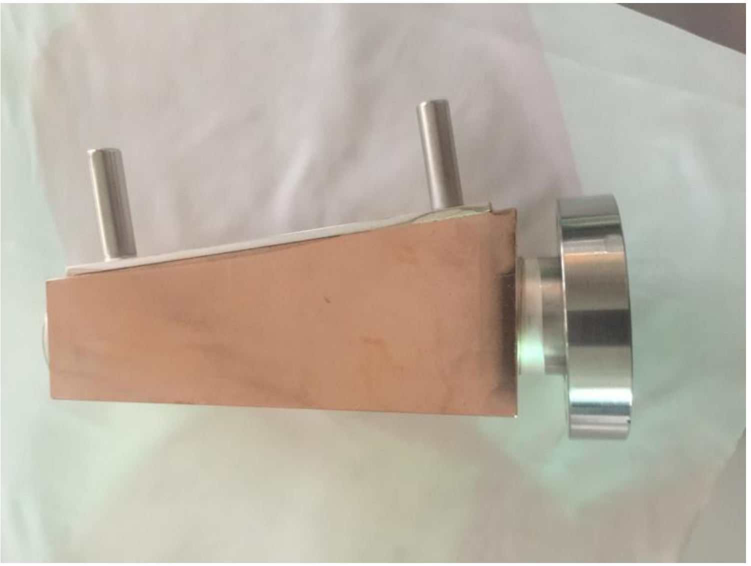
3 and 4 **CuCrZr copper** Integrating flange (no brazing).

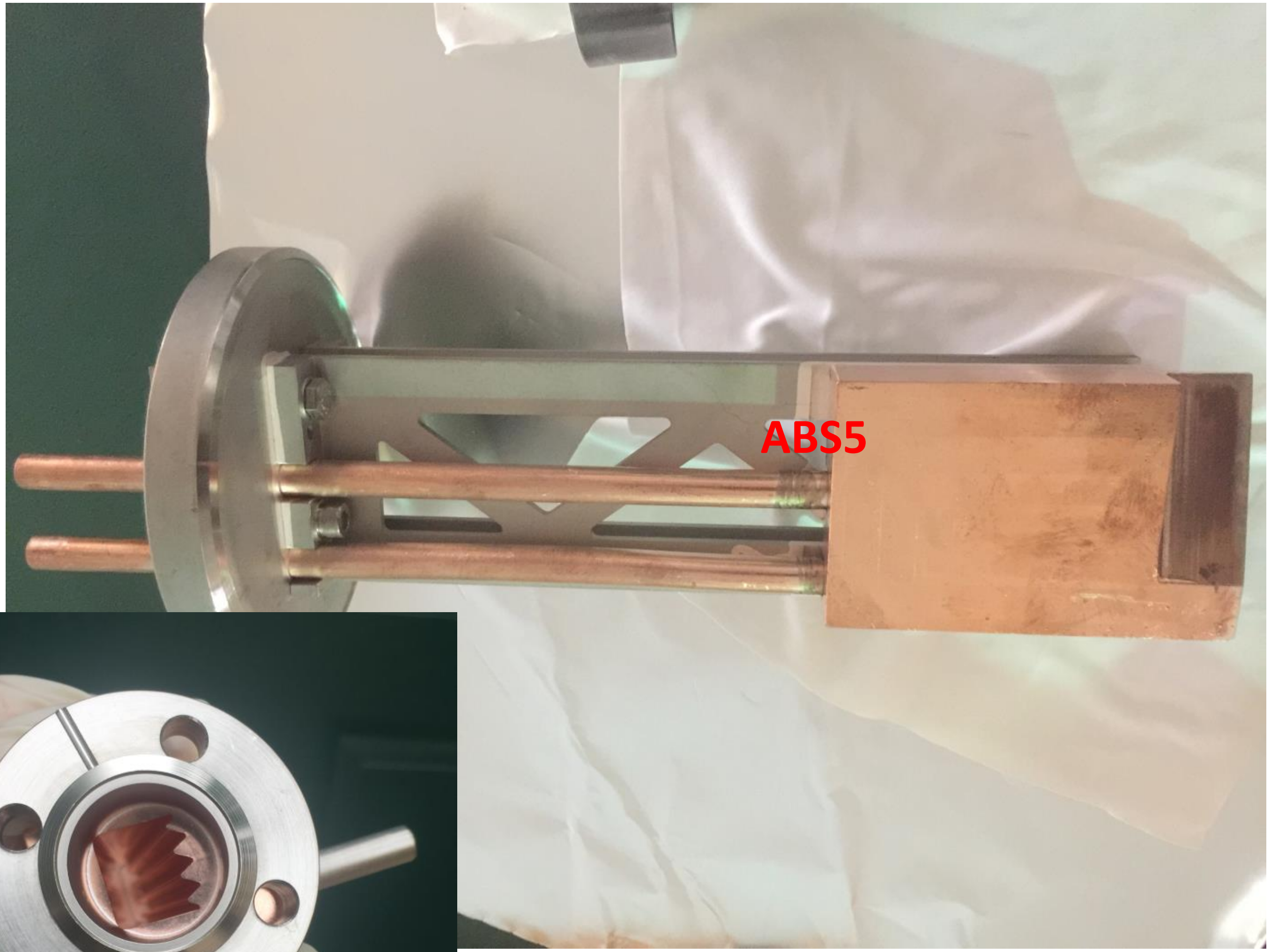


Photon absorber prototypes

Qi Li



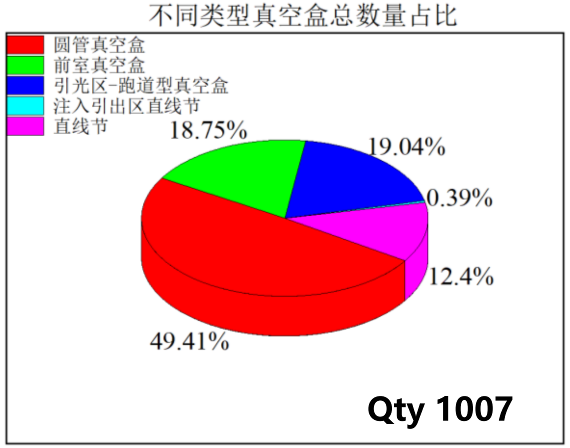


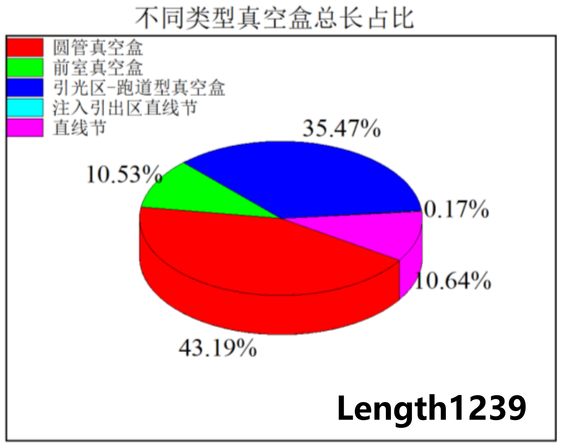


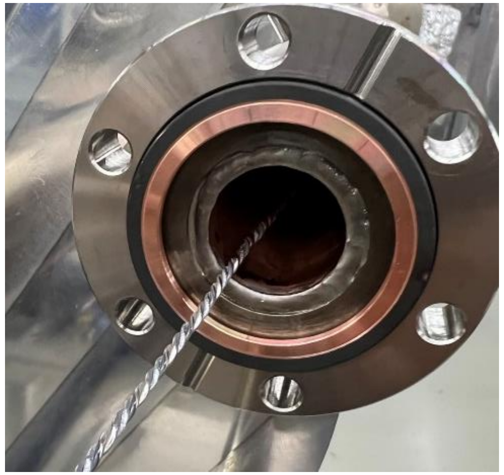
NEG coating of vacuum chamber

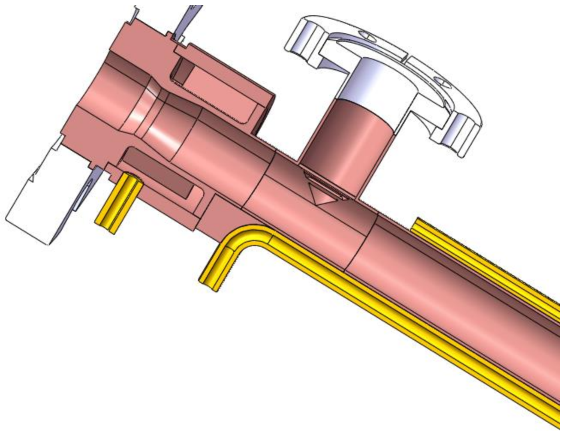
Yongsheng Ma, Fei Sun, Tao Huang

◆ There are 1007 and the total length of 1239m vacuum chambers will be NEG coating, include 22mm round chambers, Antechambers and racetrack.

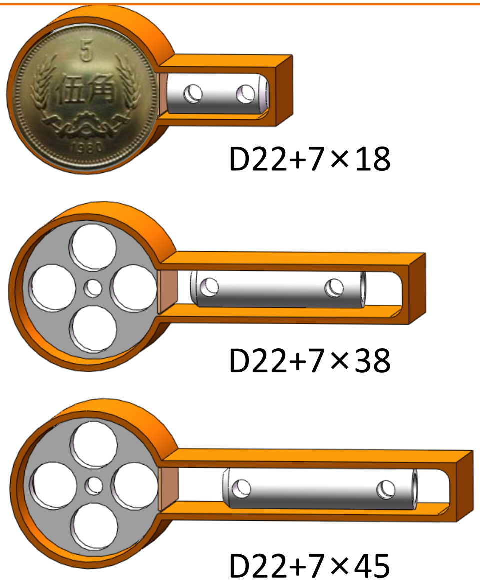




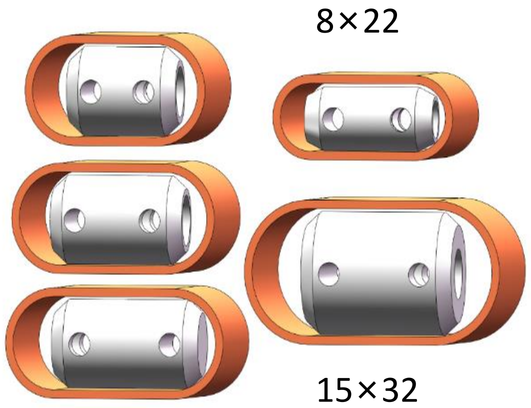




Antehchamber



Racetrack chamber

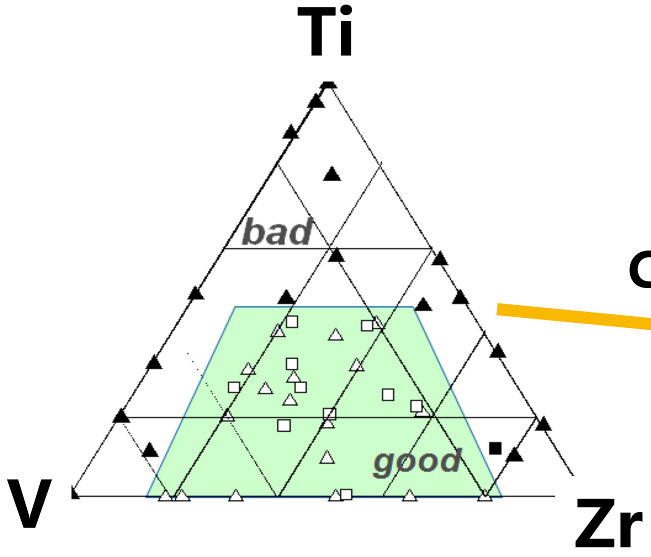


Specification of NEG coating

Yongsheng Ma, Fei Sun, Tao Huang

◆ Specification of NEG coating

Specification	Design value	attained
Pumping speed of H2 L/s.cm²	0.5	0.72
Activation temperature ℃	≤180	160
Capacity of CO mbar·L/s·cm²	$>1.0\times10^{-5}$	1.8×10^{-5}
Thermal degassing Torr·L/s/cm²	$\leq2.5\times10^{-12}$	$\leq2.5\times10^{-13}$

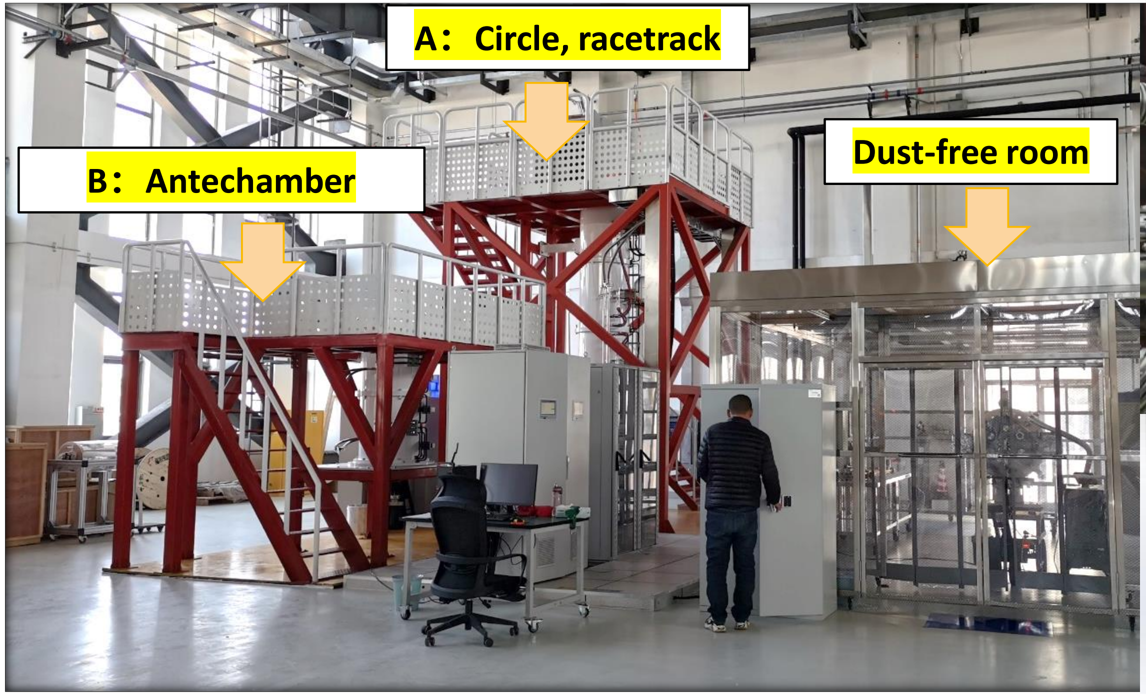


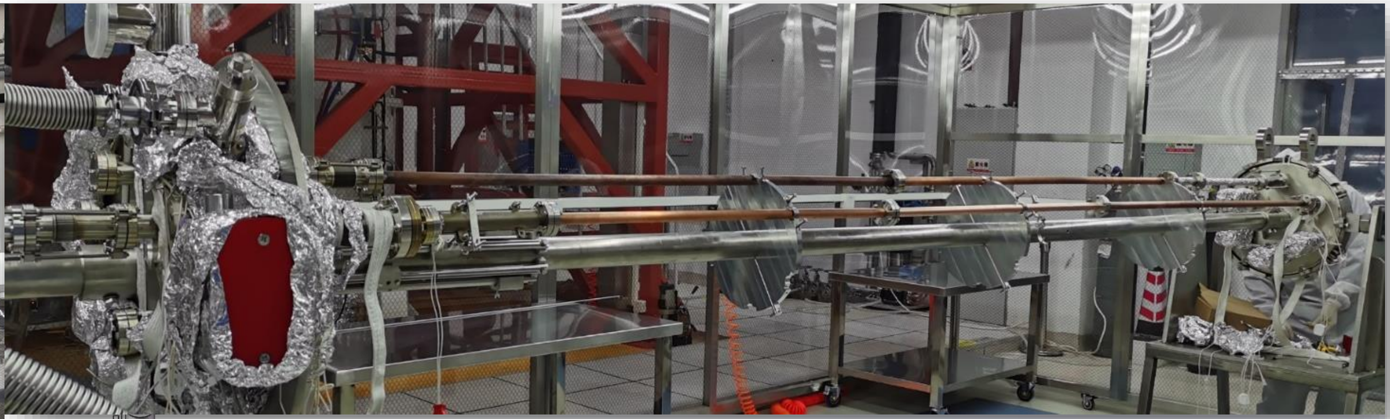
Cathode

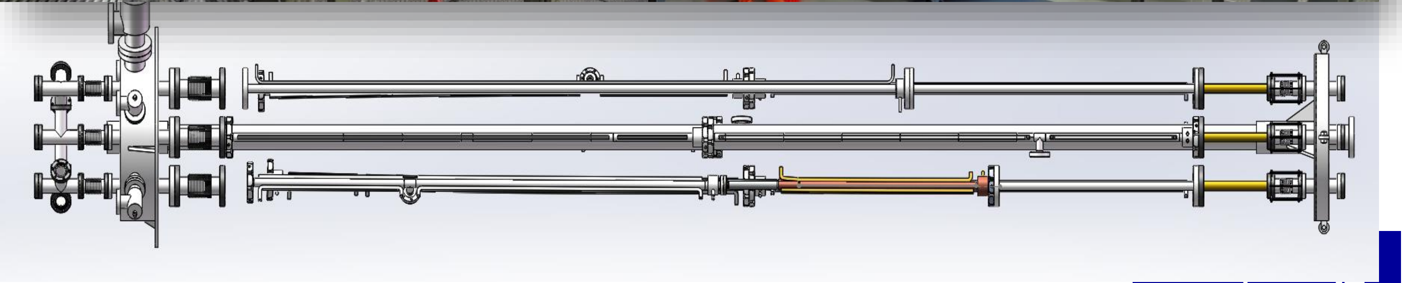
Massive NEG coating

Yongsheng Ma, Fei Sun, Tao Huang

- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.



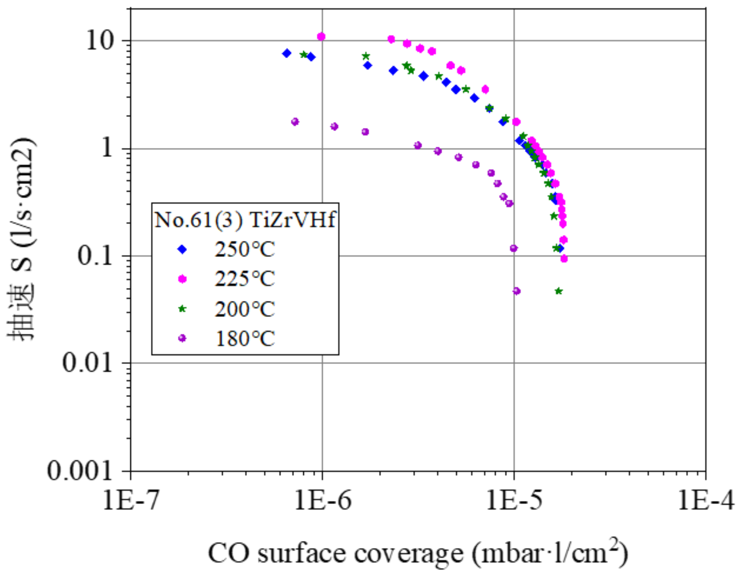


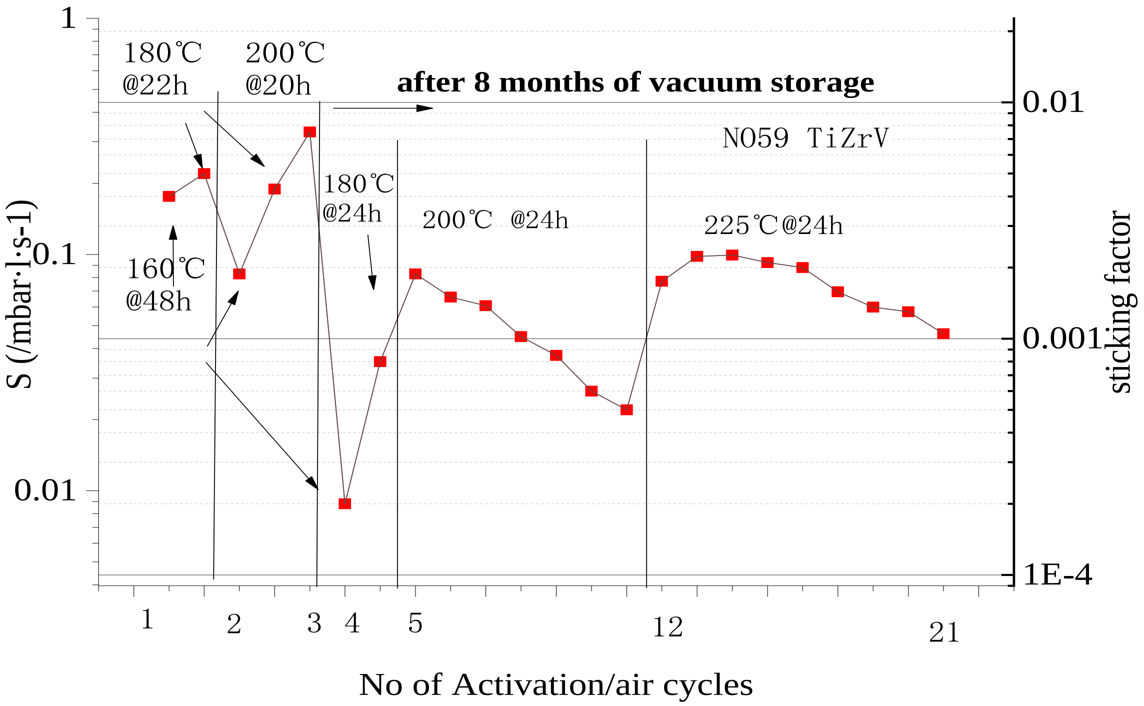


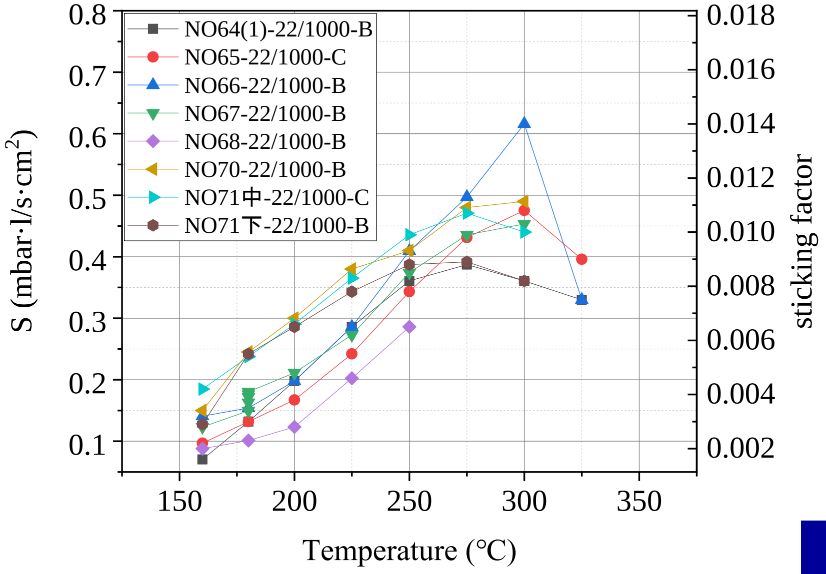
Results of massive NEG coating

Yongsheng Ma, Fei Sun, Tao Huang

- The discharge of antechamber is very difficult due to its height is only 7mm , the whole antechamber which length is 1200mm has been NEG coated by last year.
- The life times of NEG coating activation exceeded 21@225℃.
- The stability of massive NEG coating is very important due to time limit for storage ring installation.



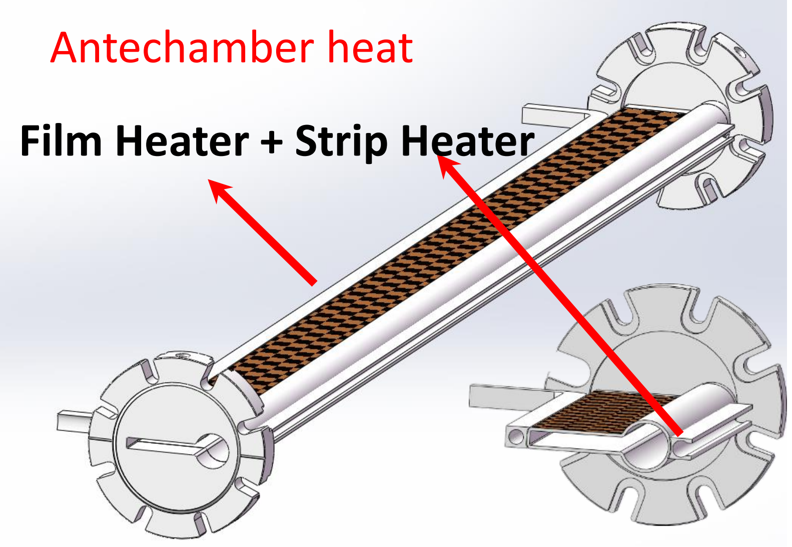


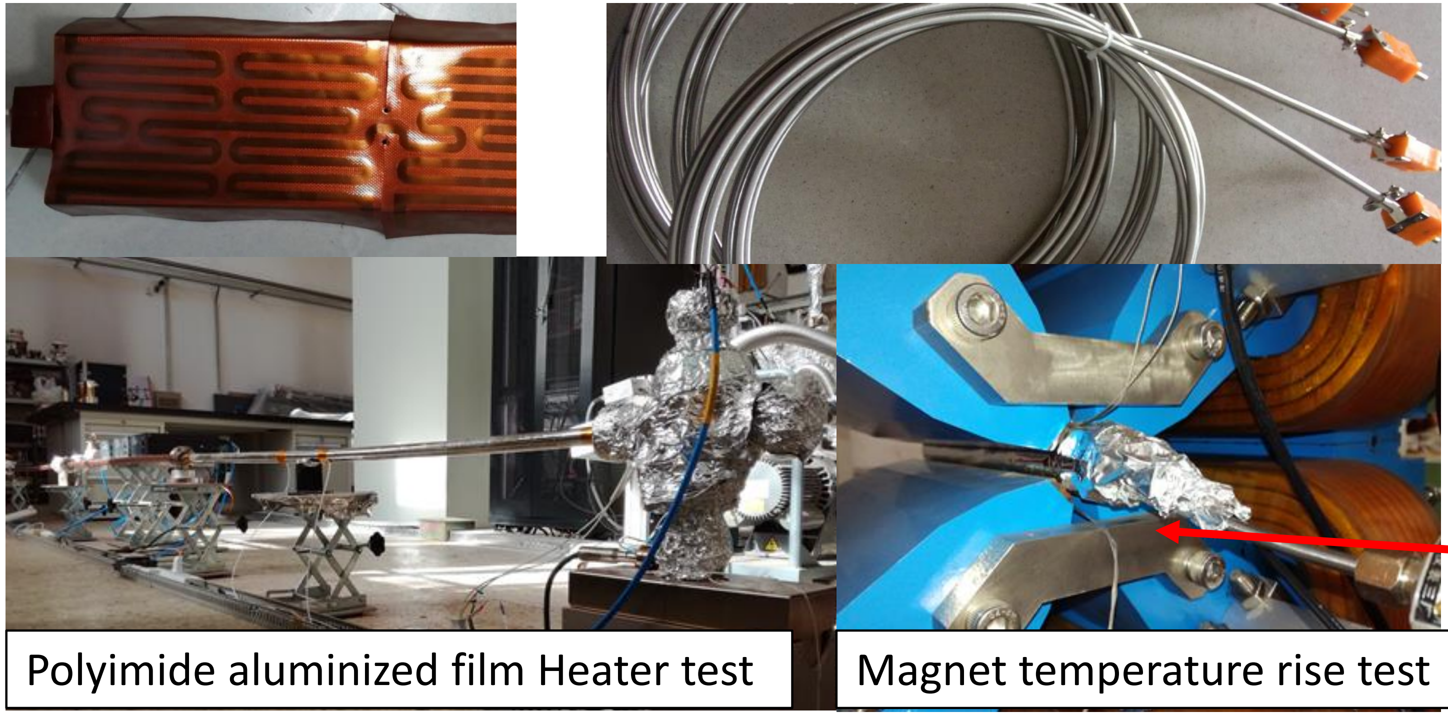


4 Bakeout experiments for NEG film activation

Baiqi Liu

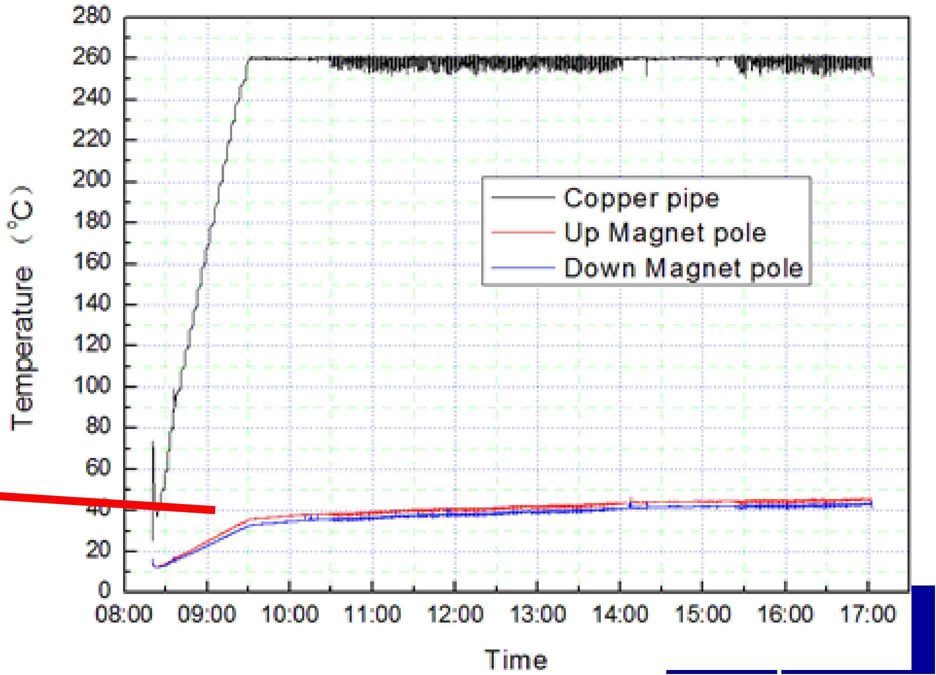
- Polyimide aluminized film Heaters (260℃) with a thickness of about 0.4mm were tested.
- For 260 ℃ baking temperature, if the gap between vacuum chamber and magnet pole increase from 0.5mm to 1mm, the rising temperature could reduce from 36.6 ℃ to 17.5 ℃.
- Strip Heater will be employed in most vacuum chamber heating, due to its easier to be installation and reliability. The temperature variation is 30℃.



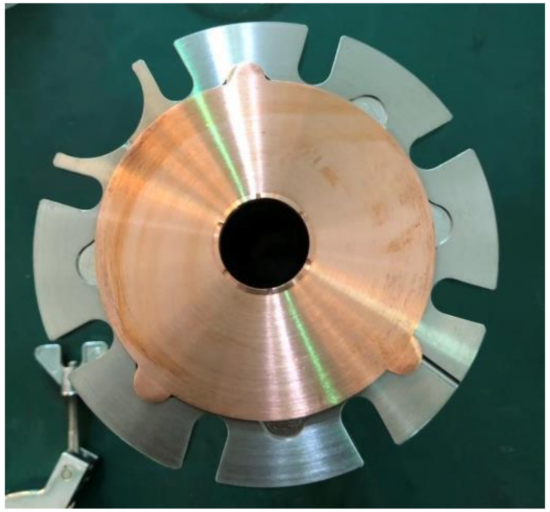


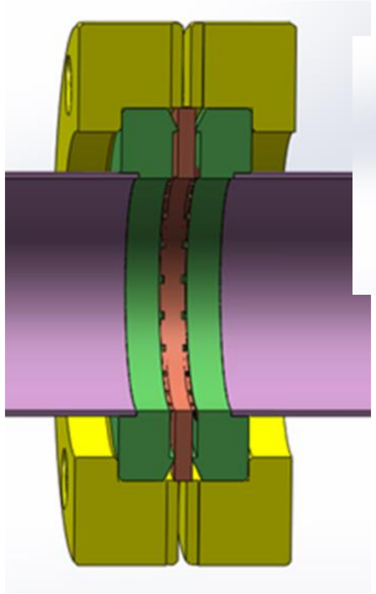
Polyimide aluminized film Heater test

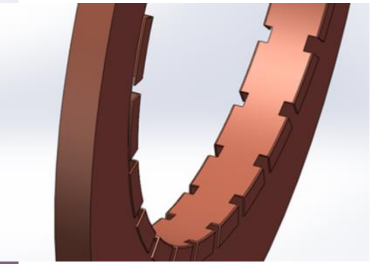
Magnet temperature rise test

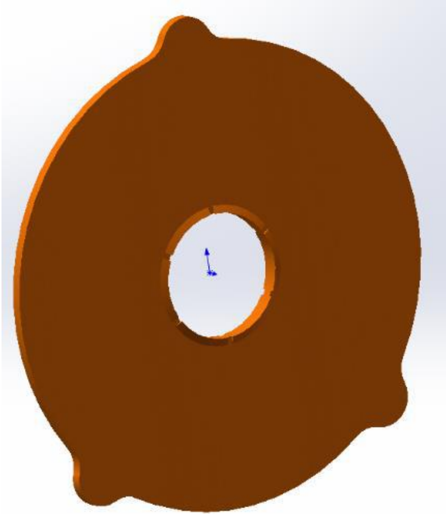


Tests of low impedance gaskets

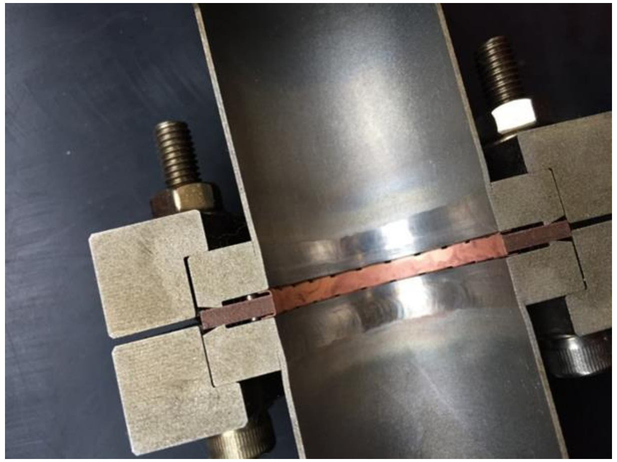




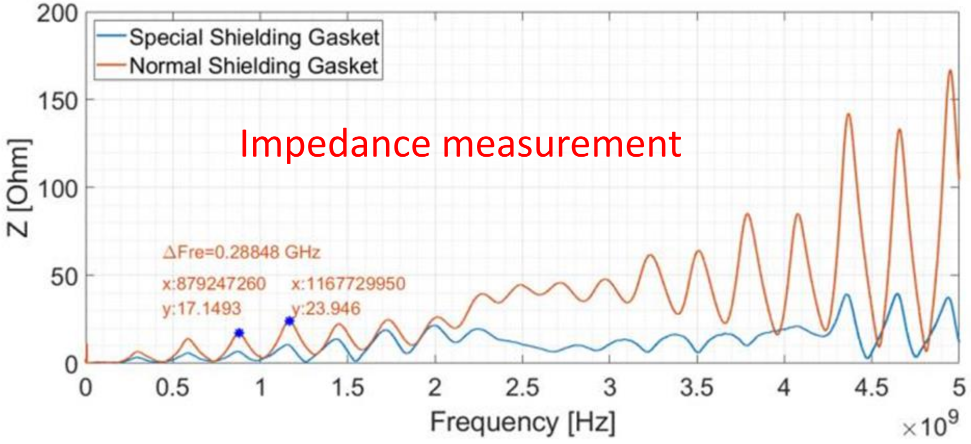




Copper gasket with contact fingers



Preload force /N	4
Leakage rate/mbar.L/s	< 1E-10
Baking temperature/°C	250
Baking time/h	24
Repeated Baking times	6
Repeat installation times	4



Several experiments indicate the contact fingers have a good contact with flange surface.

8. Summary

- The installation of all devices of Linac has been finished by July 2022, the static pressure has reached its design specifications.
- The membrane Ti windows have been applied in the dumps of linac.
- The installation and leak detection of the booster vacuum system have been completed and will be pumped down.
- Mass production of key equipment of storage ring will be soon finished.
- The vacuum chambers with the amount of 1007 and the total length of 1239m will be NEG-coated, which include the circle chambers of 22mm in diameter, Antechambers with a slit height of 7mm and racetrack chambers, many works need to be done.
- The installation of the storage ring devices began on 1th Feb 2023, it will take about one year to be finished.