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中国科学院高能物理研究所
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CEPC Vacuum system development progress

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- Collider rings, Booster ring, Linac Vacuum
- **Production line development of NEG coating/ Spray for heating film in EDR**
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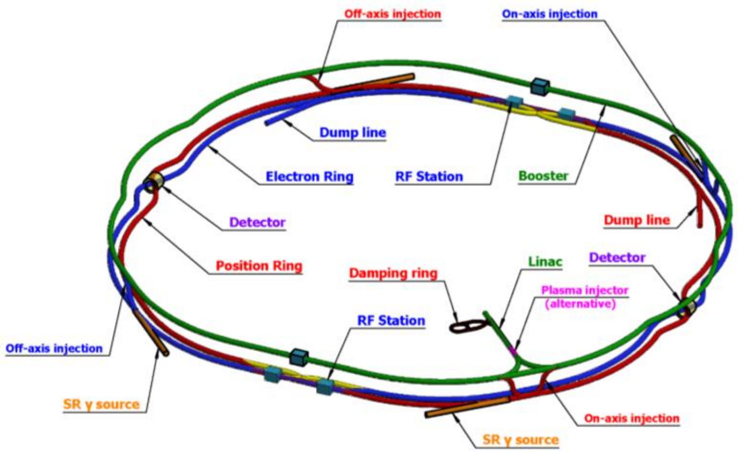
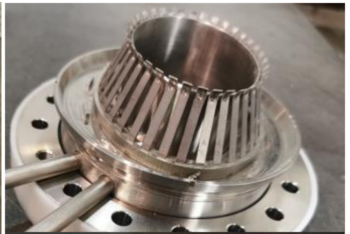
Preview of CEPC vacuum system

Machine and Vacuum Parameters

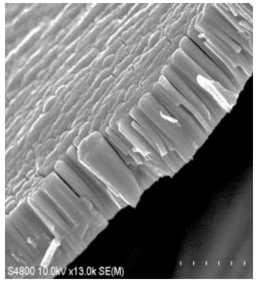
	E	I	ρ
	Gev	A	m
Higgs	120	0.0167	10700
W	80	0.084	10700
Z	45.5	0.803	10700
tt	180	0.0033	10700

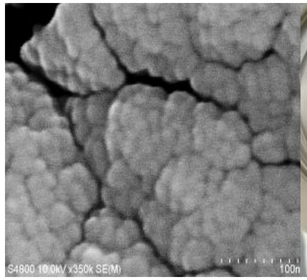
Accelerator	**length/m**
LINAC	1,601+335
Damping ring	147
Booster	100,000
Collider	200,000
Transport line	4,680
Total length/m	*306,763*

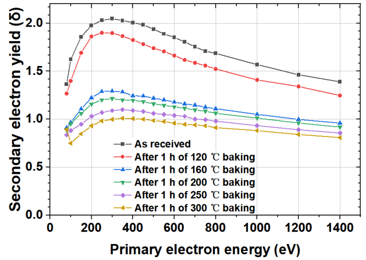




◆ Technical developments in TDR







Those prototypes have a good application in HEPS.

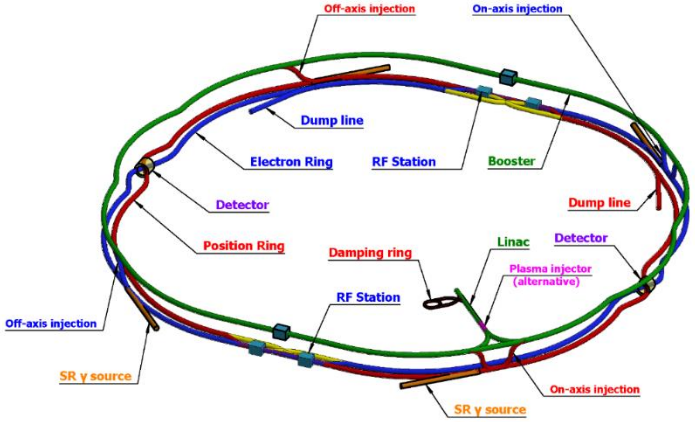
Vacuum requirements and configuration

	Energy	Material	Cross Section/mm	Length/m	Dynamic pressure /Torr
LINAC	30 GeV	Stainless steel, copper	Φ20~30	1,601+ 335 (BTL)	Acc $<2\times10^{-7}$ E-gun$<2\times10^{-8}$
Damping ring	1.1 GeV	Extruded aluminum 6061	Φ30/Al 6061	147	$<2\times10^{-8}$
Booster	30 to 180 GeV	Extruded aluminum 6061	Φ56/thickness of 2mm	100,000	$<3\times10^{-8}$ tt$<4\times10^{-8}$
Collider	45.5~180 GeV	Extruded copper, NEG film SEY<1.2	Φ56/thickness of 2mm	100,000×2	Z$<8\times10^{-10}$ tt$<1\times10^{-8}$
MDI	45.5~180 GeV	Copper/tungsten alloy, NEG film	Φ20	12	$<3\times10^{-9}$
LTB	30 GeV	Stainless steel	Φ56	3,000	$<1\times10^{-7}$
BTC(CTB)	6 GeV	Stainless steel	Φ56	240×6	$<1\times10^{-7}$
DL	1.1 GeV	Stainless steel	Φ30	240	$<1\times10^{-7}$

Layout & configuration of Collider

	Classification	*length/m*
collider	Arc beam pipe	78752
	Straight section beam pipe	**8456**
	RF Substitute pipe	**1192**
	RF system	352
	Insertion and extraction	286
	Manifold for SIP	**1333**
	Bellows	**2082**
	BPM	300
	Manifold for Gauge & RGA	**247**
	Detector 1	12
	Detector 2	12
	Collider section	**7000**
	Total length	**100000**

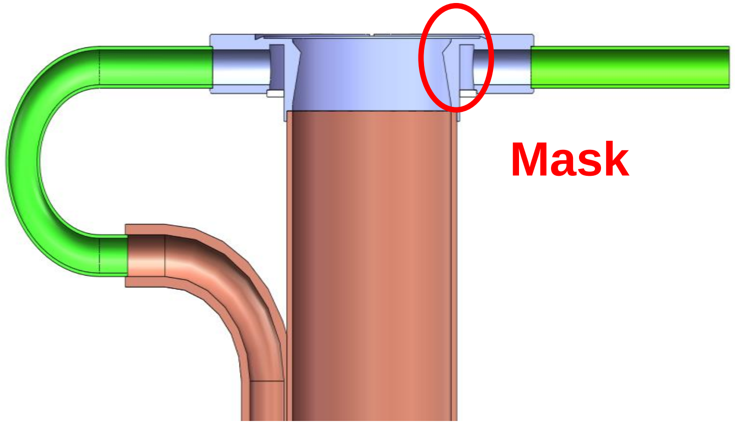
Parameter	e^+ & e^-
Energy [GeV]	45.5~180
Beam current [A]	0.0033~1.39
Circumference [m]	100,000 × 2
Bending radius [m]	10,700
Beam pipe material	Extruded copper (water-cooled) NEG coating
Beam pipe shape (mm)	Φ56/thickness of 2mm
Pump type in arcs	SIP



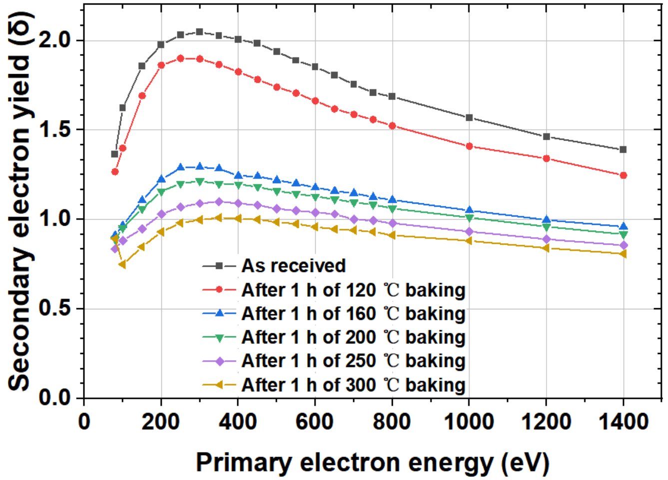
Modes	E (Gev)	Beam gas scattering lifetime (h)	Vacuum requirement (Torr)
Higgs	**120**	**10**	**2×10^{-9}**
W	80	5	1.5×10^{-9}
Z	45.5	3	8×10^{-10}
tt	180	15	1×10^{-8}

Collider rings Vacuum requirements and configuration

- Good beam lifetime must be achieved soon after the initial start-up with a stored beam.
- The vacuum system must be capable of quick recovery after sections are exposed to air for maintenance or repairs.
- The chamber wall must be as smooth as possible to minimize electromagnetic fields induced by the beam.
- NEG coating of 200nm is employed to suppress e-cloud of positron ring and absorb residual gases simultaneously. SEY will blow 1.2 after 24h activation of 180℃ and could even lower under higher activation temperature.
- Similar to positron ring, NEG coating is proposed to vacuum chamber of electron storage ring to absorb extra gas load.



On-line mask



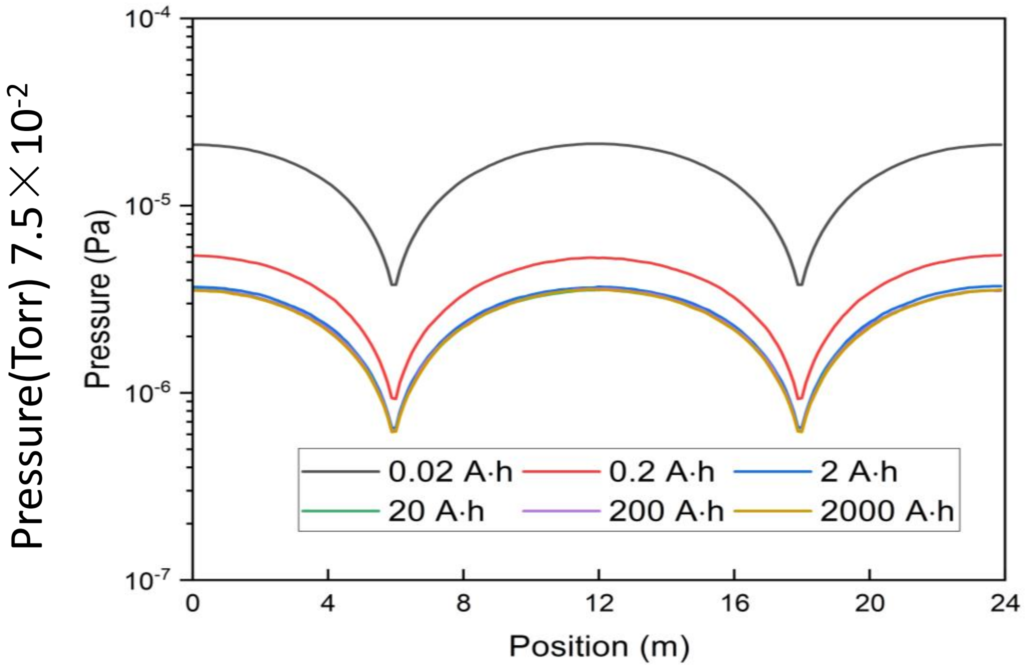
NEG coating


RF shielding bellows

Layout & configuration of Booster

- Booster will work in four modes of higgs, W, Z, tt under 30MW and 50MW alternatively. 50MW is given to calculate the vacuum parameters as it has the highest energy and gas load.
- The main pumping process will then be followed by ion pumps distributed around the circumference at intervals of about 12 m.

Parameter	e^+ & e^-
Energy [GeV]	30~180
Beam current [A]	0.11~14.4 $\times 10^{-3}$
Circumference [m]	100,000
Bending radius [m]	11,380.8
Beam pipe material	Extruded Al
Beam pipe shape (mm)	Φ56/thickness of 2mm
Pump type in arcs	SIP
Dynamic pressure /Torr	$<3\times10^{-8}$ tt$<4\times10^{-8}$



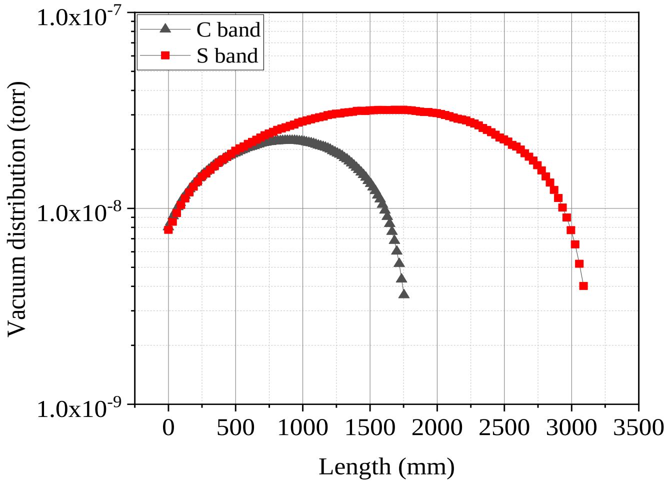
	Classification	*length/m*
booster	arc beam pipe	78428
	Straight section beam pipe	17010
	RF Substitute pipe	384
	RF system	96
	insertion and extraction	198
	Manifold for SIP	1250
	Bellows	850
	BPM	240
	Manifold for Gauge & RGA	1544
	total length	**100000**

Linac vacuum system

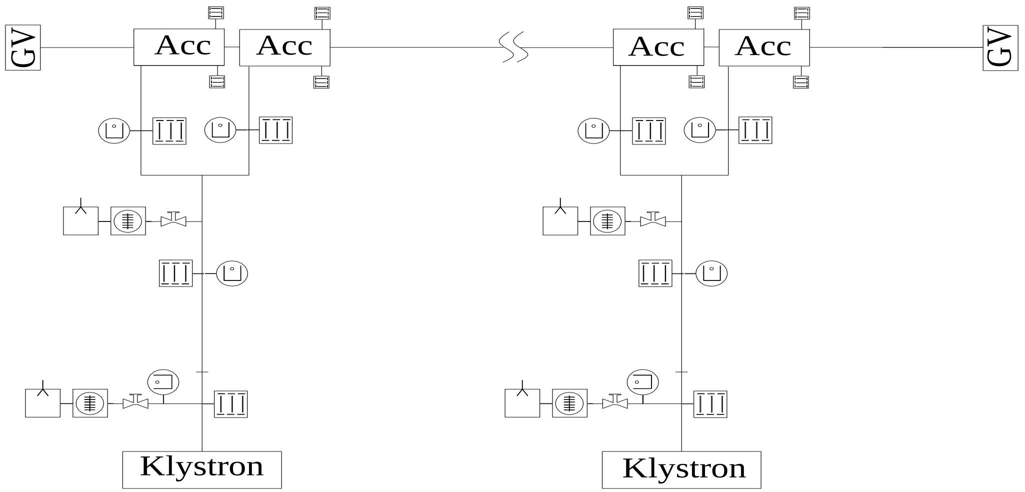
- The Linac vacuum system with a length of 1936m is divided into 59 sections. it consists of electron gun, bunching system, accelerating structures .
- Sputter ion pumps: 3431; Vacuum gauges: 1352; Gate valves: 60

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



The static pressure distribution of a accelerator structure

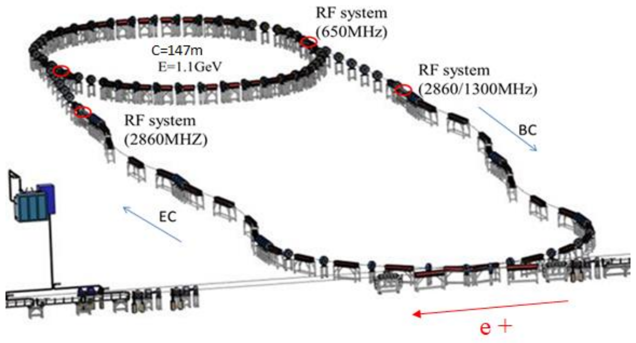


Vacuum diagram of klystron and accelerator structures

Layout of Damping ring, Transport line

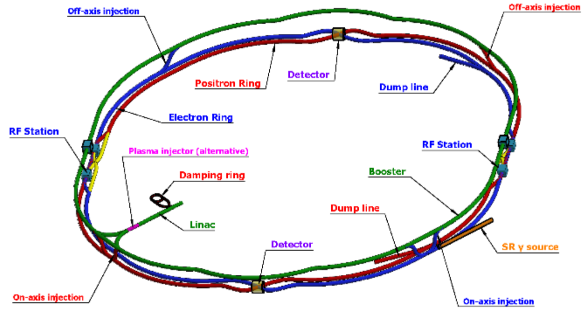
	Classification	length/m
DR	arc beam pipe	119.0
	Straight section beam pipe	14.0
	RF Substitute pipe	0.0
	RF system	3.0
	insertion and extraction	2.8
	Manifold for SIP	1.5
	Bellows	1.5
	BPM	4.0
	Manifold for Gauge & RGA	1.5
	total length	147.3

Parameter	e^+ & e^-
Energy [GeV]	1.1
Beam current [A]	0.012~0.024
Circumference [m]	147
Bending radius [m]	2.87
Beam pipe material	Extruded Al
Beam pipe shape (mm)	Φ30/thickness of 1
Pump type in arcs	SIP
Dynamic pressure /Torr	2×10^{-8}



	Classification	length/m	Note
transport line	linac to booster	3000	e- & e+ 1500 m
	booster to colider	960	On axis： e- & e+ 240 m Off axis: e- & e+ 240 m
	colider to booster	480	e- & e+ 240 m
	damping ring	240	In & ex 120 m
	total length	4680	

Parameter	e^+ & e^-
Linac to Damping Ring	
Energy (GeV)	1.1 GeV
Linac to Booster	
Energy (GeV)	30 GeV
Booster to Collider	
Energy (GeV)	45 GeV~180 GeV
Dynamic Pressure (Torr)	2e-8



Damping ring vacuum system

- For the DR, with values of E = 1.1 GeV, I = 0.012~0.024 A, and ρ = 2.87 m, these equations give a total synchrotron radiation power of P_{SR} = 1.08 kW and a linear power density of P_L = 60.1 W/m.

The gas load under different beam energy and beam density

Mode	E	I	PSD	P_L	Q_{gas}	Q_{LSR}	P_{ave}
	Gev	*A*	*Molecules/photon*	*W/m*	*Torr·L/s*	*Torr·L/s·m*	*Torr*
	1.1	0.024	2.00E-06	60.1	1.28E-06	7.09E-8	1.78E-08

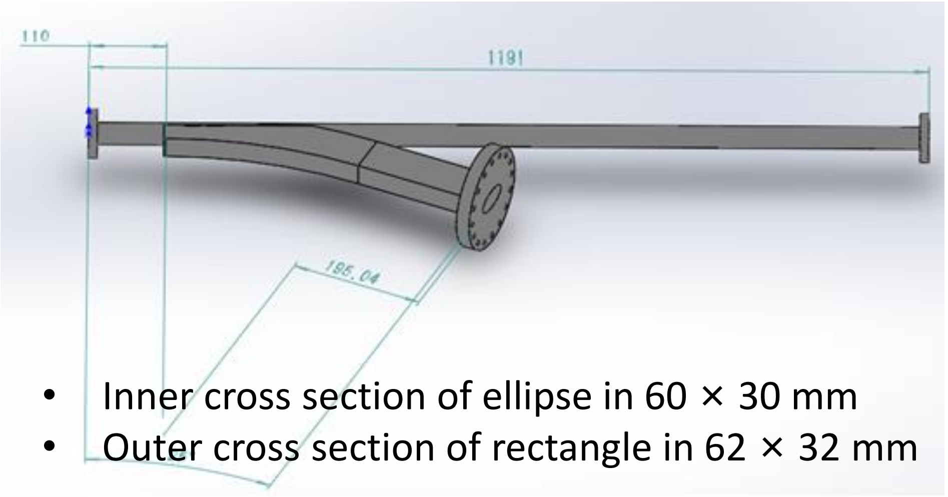
  - With an effective pumping speed of 15 L/s and a distribution of 2 meters sputtering ion pumps, the vacuum value of 1.78×10^{-8} Torr will be reached.

- Due to the beam current of damping ring is low enough, SEY of aluminium vacuum chamber which do not need NEG coating or TiN coating could meet the requirement of physics.

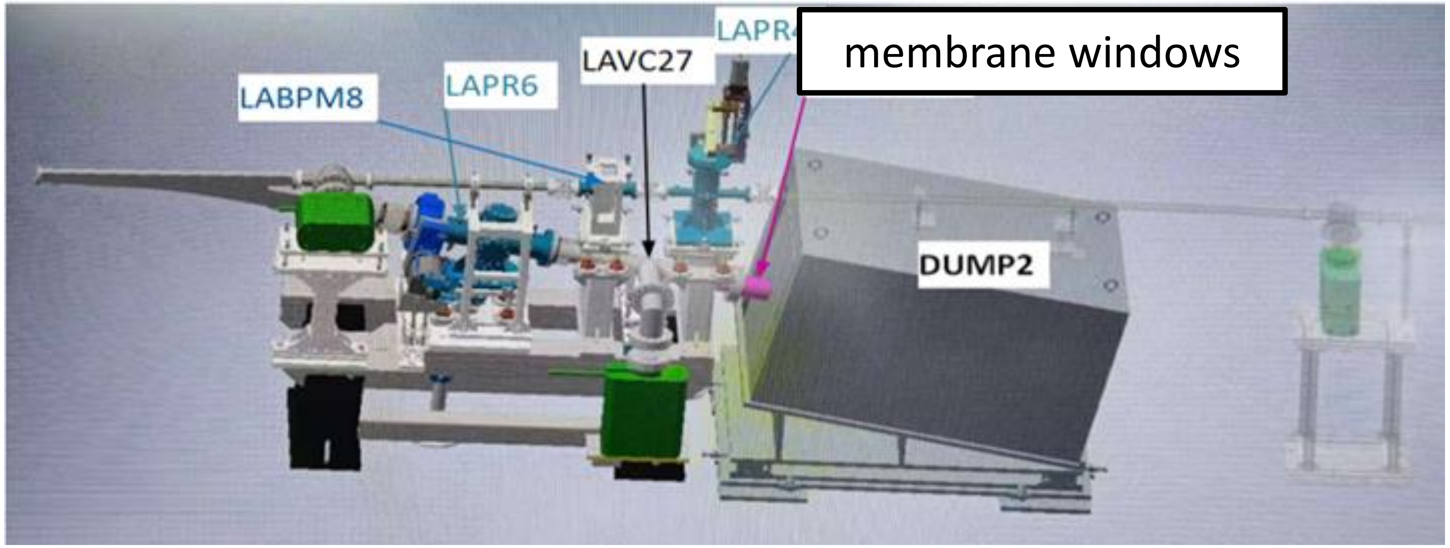
- RF shielding Bellows with spring and contact fingers made of stainless steel will be employed to absorb the extension and the misalignment of vacuum chambers and other vacuum devices during installation.

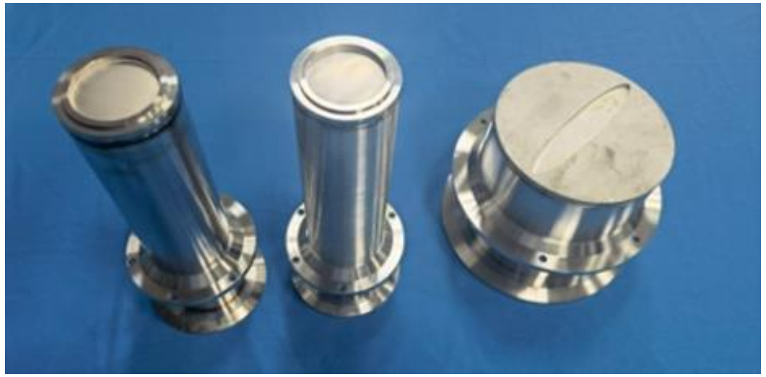
Protypes of Dump chamber and membrane window

◆ 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





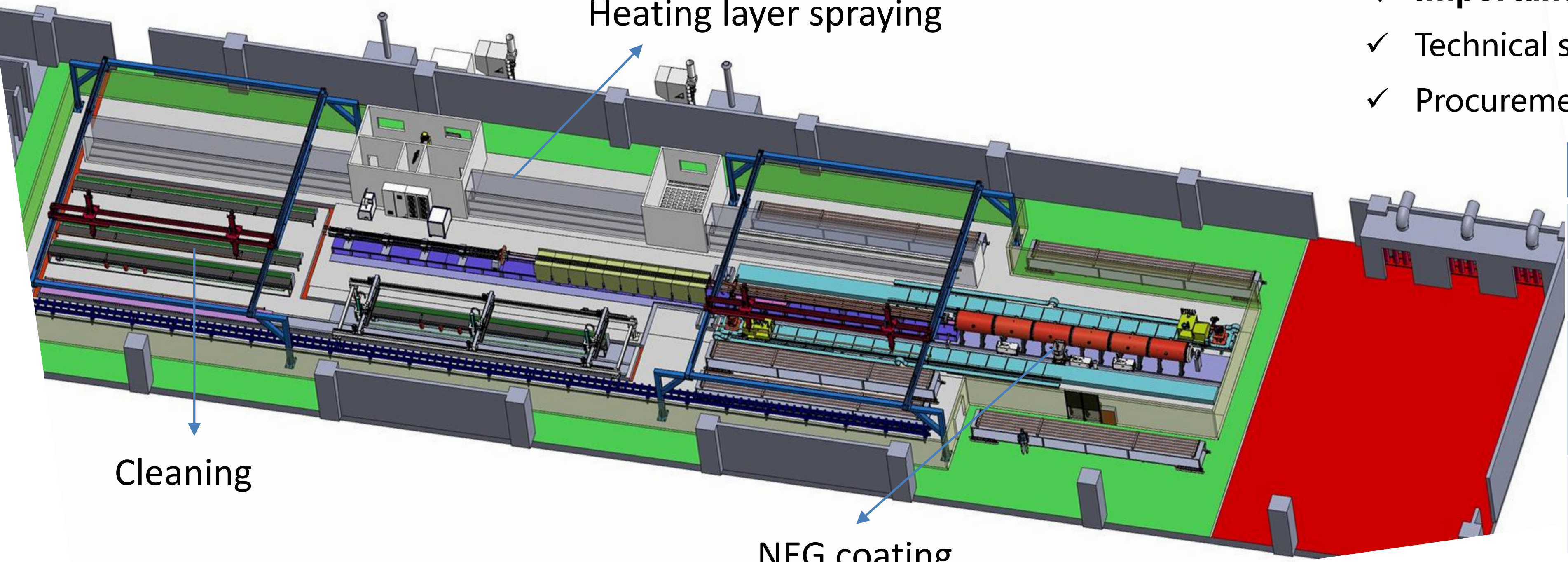
◆ Membrane windows

- 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 $\times 10^{-10}$ Torr。

CEPC vacuum chamber production line

- Requirement
  - Due to the difference in length, two production lines will be used to complete the production of vacuum chambers for the CEPC collider. The quantity of NEG coating and spraying facilities for the two lines varies to match the production speed.
  - With two production lines, the all vacuum chambers of collider will be finished in 5 years.
- Advantages

More stable process, less manpower, less NEG coating facility, more adaptive capacity in production, etc.



- **Important nodes and progress**
  - ✓ Technical scheme review 2024.10
  - ✓ Procurement bidding 2024.12

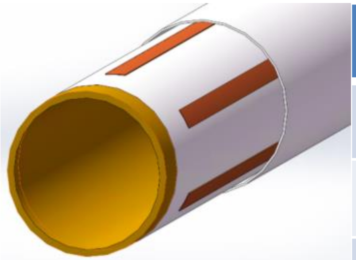
Items	Specifications
Dimension	• L 11400-d56-D62
Weight	• 50~100kg
NEG coating	• Thickness：200nm±30% • SEY<1.1 • S、Q、life-times
Spraying heating	• Thickness<0.5mm • Heating temperature <300℃

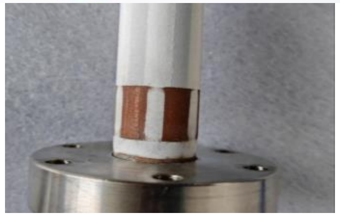
Production line composition

Classification	Sub-devices	Parameters	Note
Electron-beam welder	• Electron-beam gun • Power supply • Vacuum chamber	• Meets the Length of 11.4m vacuum chamber • 6 working position	Design and manufacturing
Brazing	• Mechanical holder • Power supply	• 350℃ • 11.4m long	Low temperature brazing in air by conductivity heating, expecting stead by double hole copper tube
Heating film spraying facility	• Electron-beam gun • Power supply • Controller • Mechanical Structure	• Meets the Length of 11.4m vacuum chamber • Multilayer Spray • Ceramic and conductivity layer	R&D
NEG coating tower	• Pumping system • Vacuum measurement • Power supply • Vacuum chambers • Discharge Gas • Cathode、controller	• Meets the Length of 11.4m vacuum chamber • 6 working position • Background vacuum <5e-7Pa • Baking temperature 200℃	Developing to be more fitted the production line
Measurement and testing	• Dimension measurement • Leakage testing	• Dimension measurement 11.5m/0.1mm • Leakage testing 1e-10 mbar·L/s	Design and manufacturing
Cleaning	• rinsing	• deionized water rinsing	Design and manufacturing
Production line auxiliary equipment	• Moving band • robot arm system • controller	• Meets the Length of 11.4m vacuum chamber	Design and manufacturing

Procedure of NEG coating, spraying

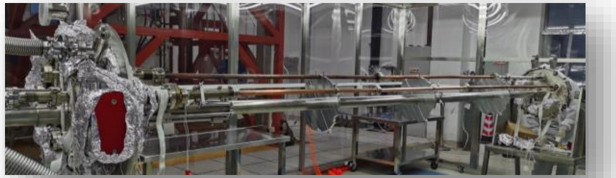
- **Spraying**
  - Sandblasting
  - Spraying_Isolation_layer
  - Spraying_Conductivity-layer
  - Spraying_Isolation-layer
  - Spraying_Contactor-layer
- **Cleaning**
  - Outside
  - Inside

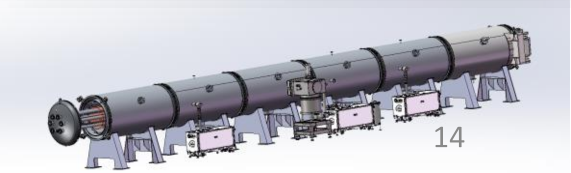




Function	Materials	Thichness/um
Transition-layer	MCrAlY alloy	50~100
Isolation-layer	Al2O3 cermic	~150
Conductivity-layer	NiCr alloy	~100~200
Isolation-layer	Al2O3 cermic	~150
Contactor-layer	Copper	~50

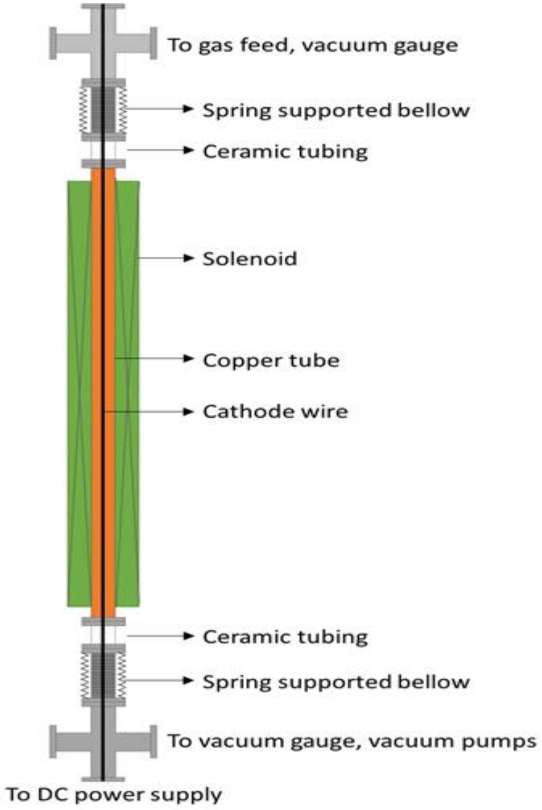
- **NEG coating**
  - vacuum chambers, cathodes assembling by mechanical arms (flanges sealing).
  - Leakage testing.
  - Deliver the assembles to vacuum oven/ baking/ NEG coating;
  - Disassembly the vacuum chambers





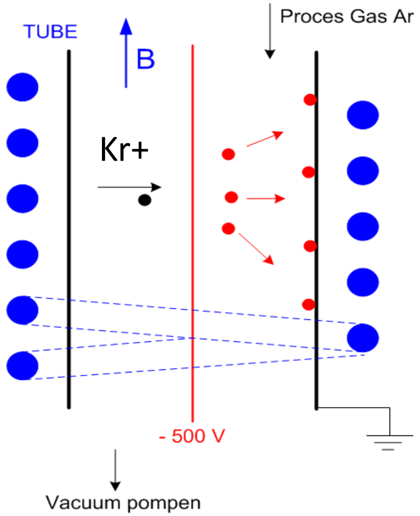
NEG coating mechanism & method

- HEPS, LHC, MAX IV, SIRIUS, APS_U etc.

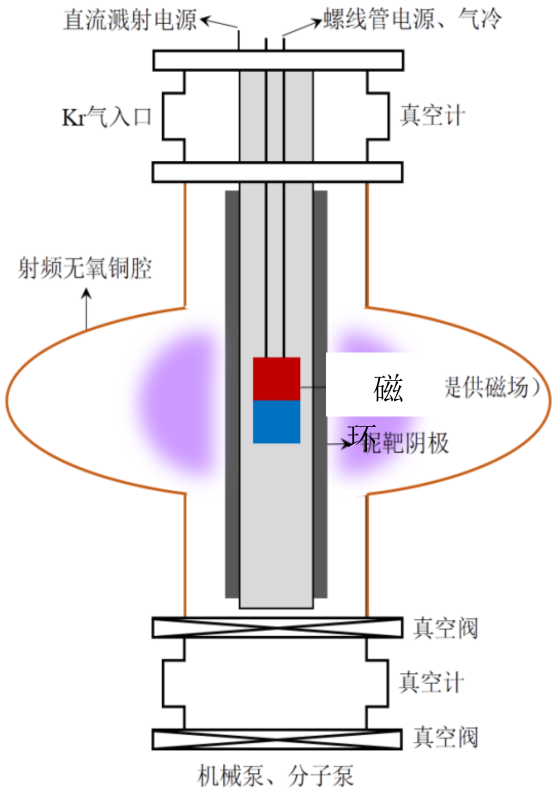


Outside magnet (solenoid)

Cathode wire



- CSNS, BEPCII vacuum chambers;
- Nb coating;

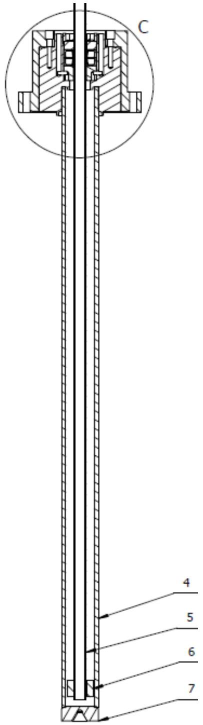


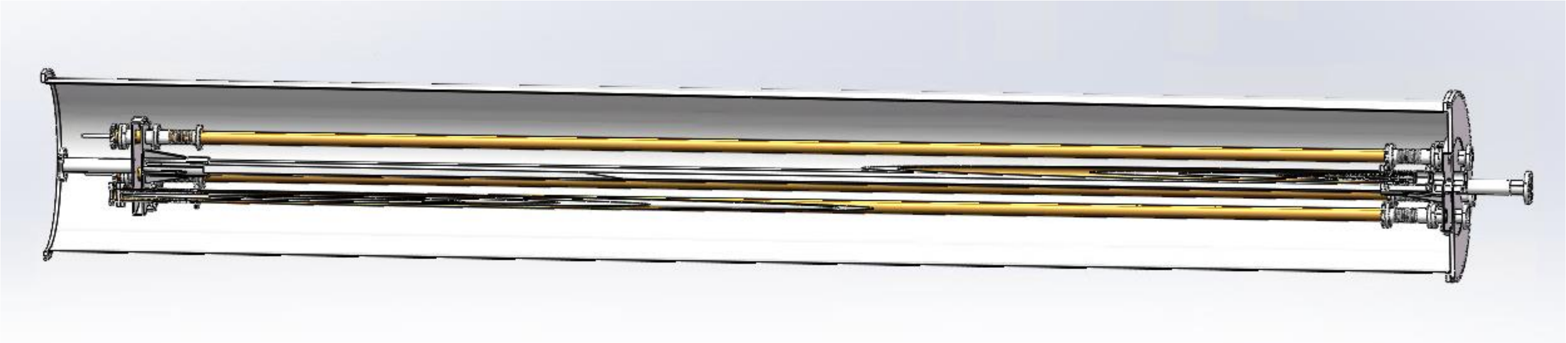
Inside magnet

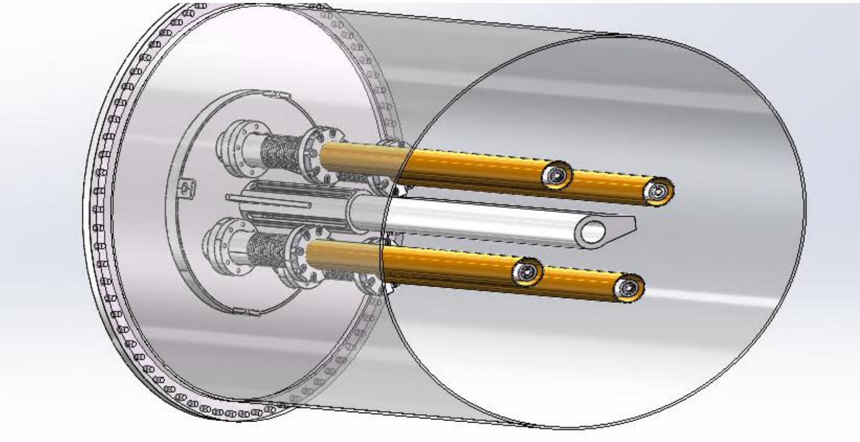
Magnetron sputtering cathode

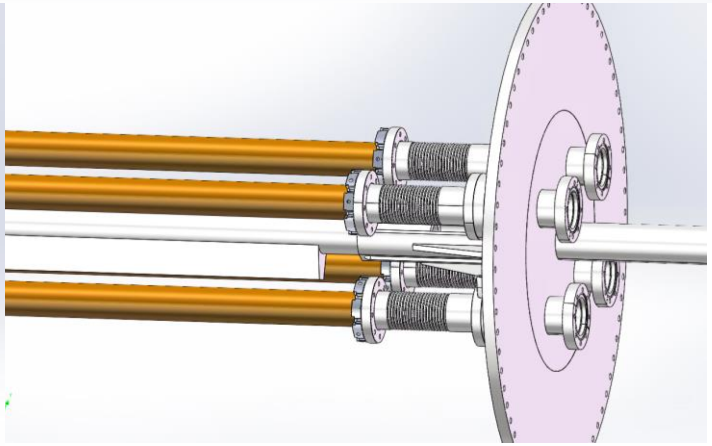
Massive production of NEG coating for CEPC——Upgrade plan

- Due to the diameter of CEPC is D56, we plan to replace the cathode wire with a magnetron sputtering cathode
- Permanent magnet instead of the solenoid which supplies magnetic field for DCMS;
- By combining the low vacuum chamber outside of the vacuum chambers to be coated with NEG, the high vacuum process is simplified;



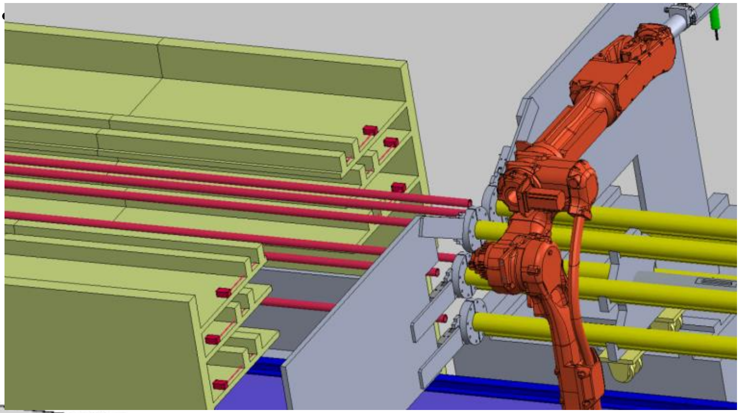


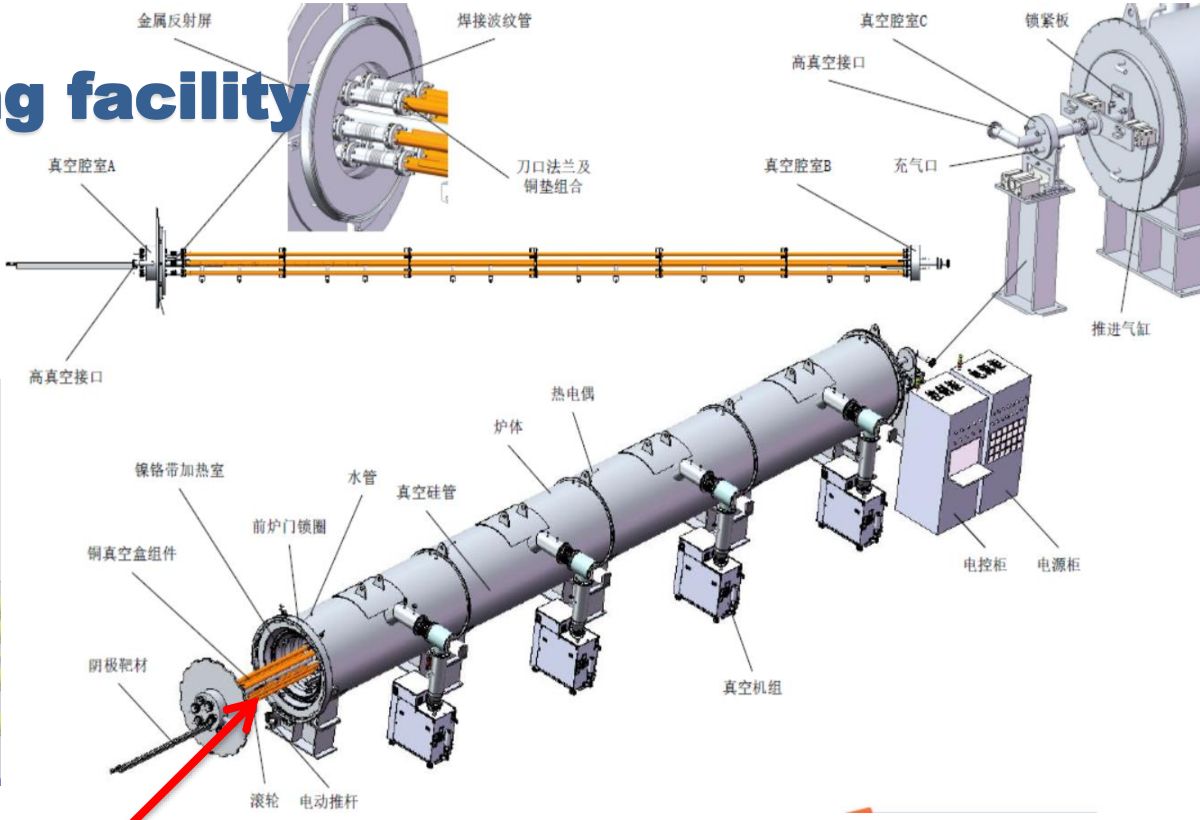


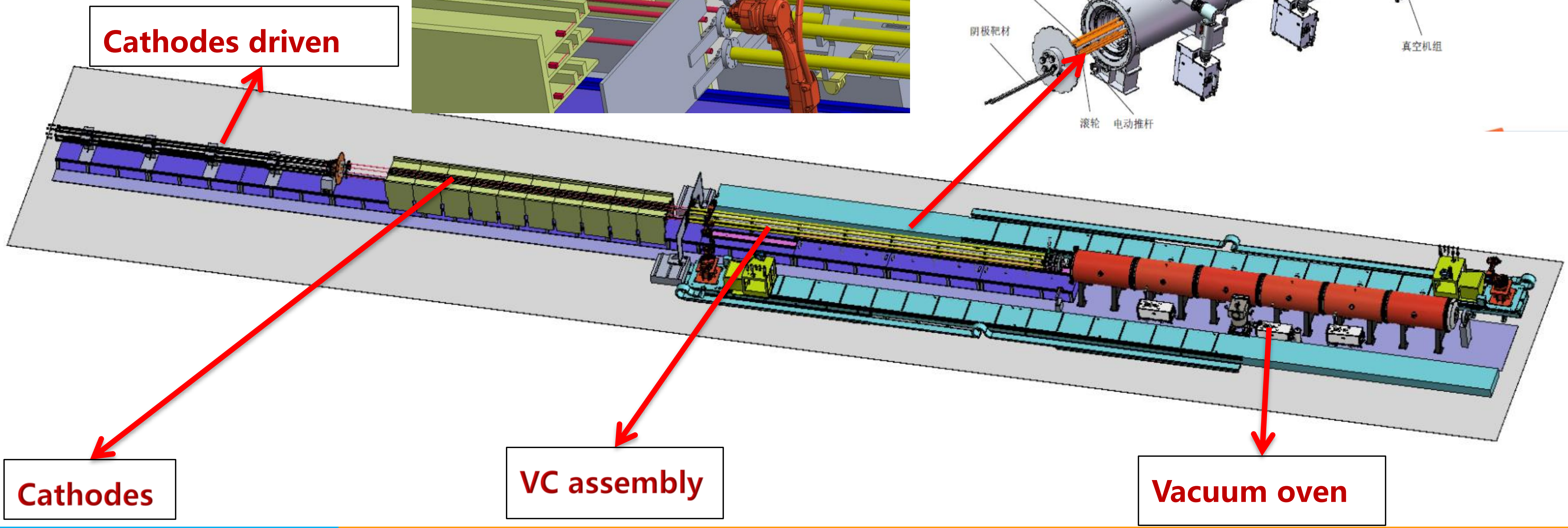


layout & composition of NEG coating facility

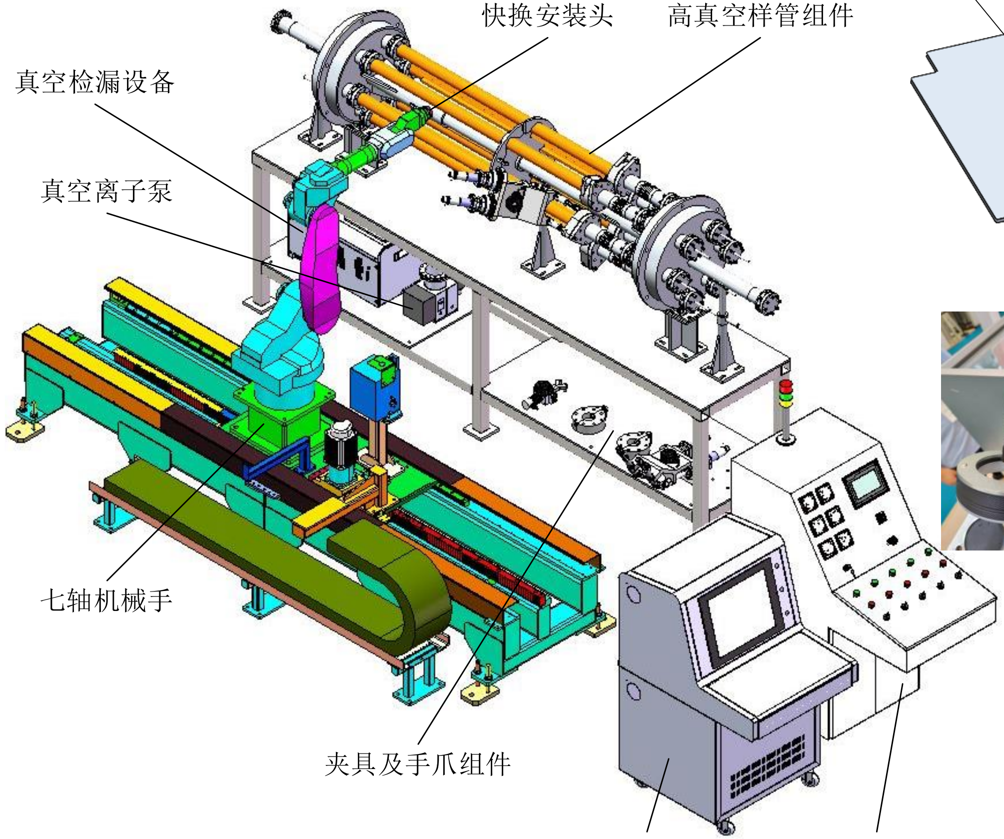
- NEG coating, VC assembly and disassembly with automatic robot arms.



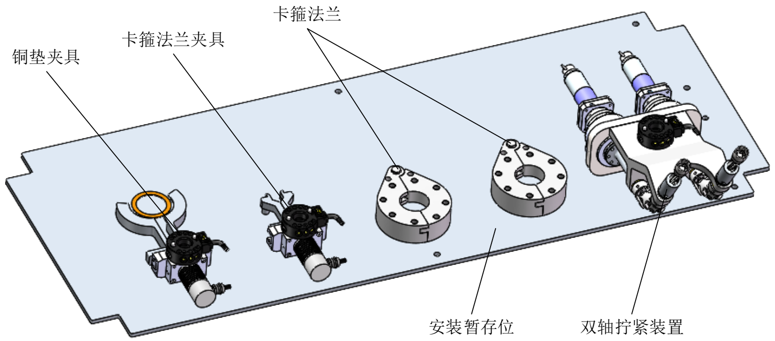


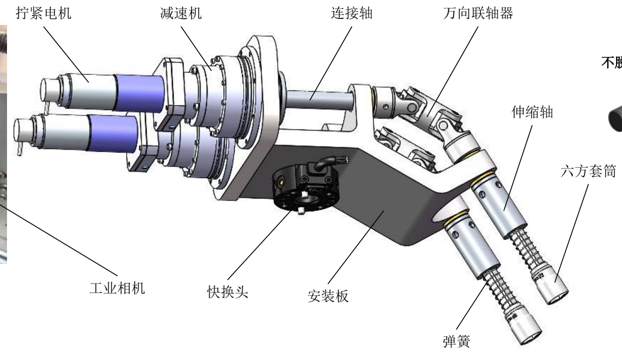


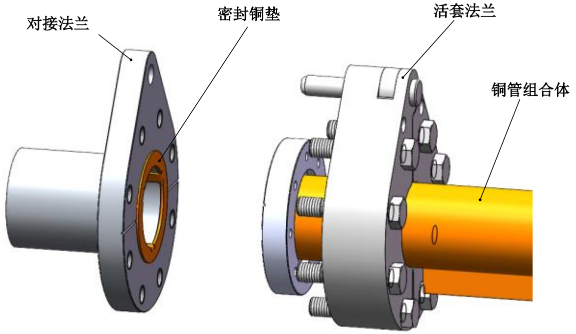
Prototype of vacuum chambers assembly

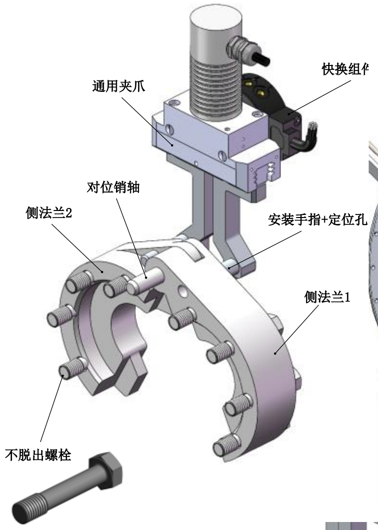


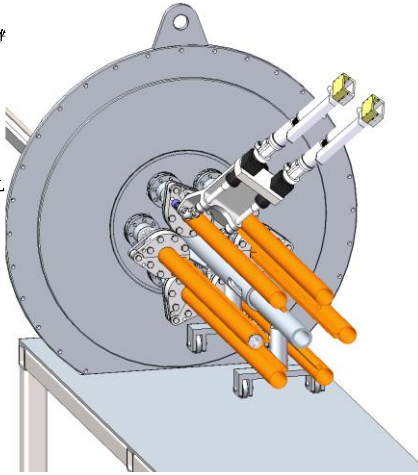
设备总尺寸：~5100×2500×1700mm。

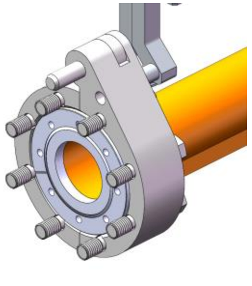


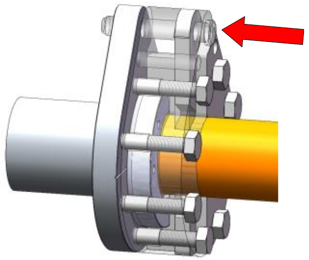








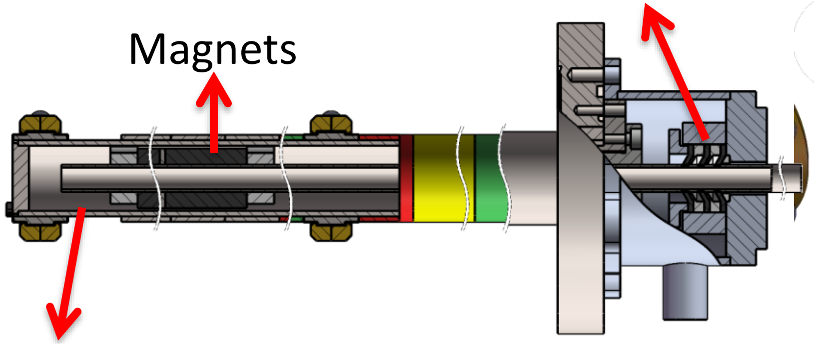




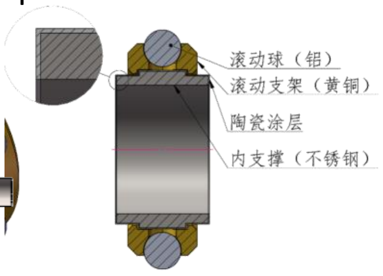
Prototype of cathode for NEG coating

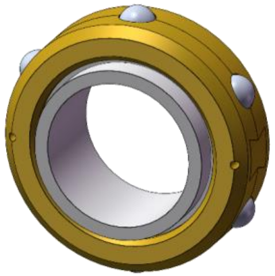
dynamic sealing for water pipe

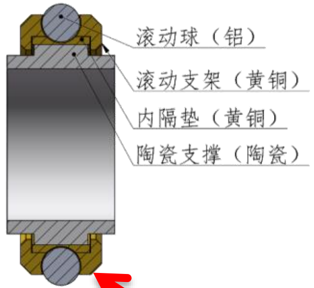
Magnets

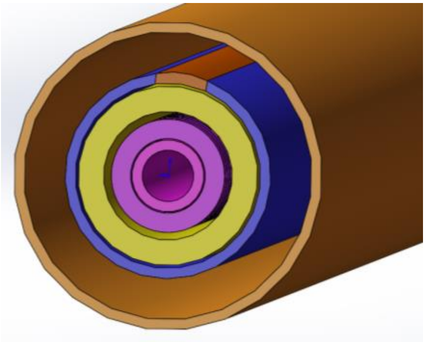


Water cooling pipe





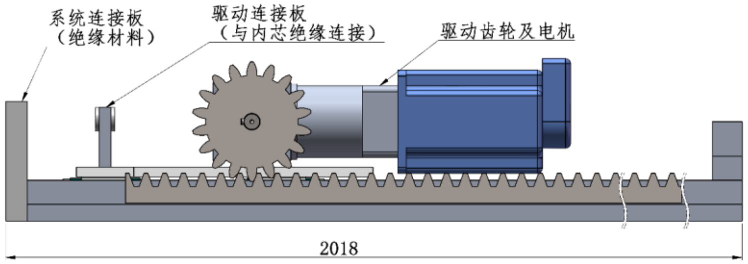




Isolating and supporting ring

~12000mm(12 meters)

Magnetron Cathode



Motor for magnets driven

- The magnets will be driven by motor when NEG coating

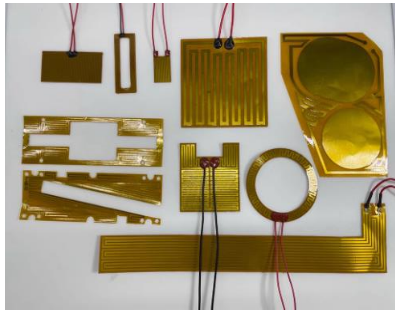
23000mm(23 meters)

VC baking & Why spray heating film

The baking is the most crucial procedure in achieving ultra-high vacuum

- ☐ Necessity:
- ✓ In order to meet the ultra-high vacuum requirement of achieving a dynamic vacuum level of 3.0E-10 mbar.
- ✓ NEG coating reactivation


Too thick




Lifetime is very short under SR of CEPC

For metals:

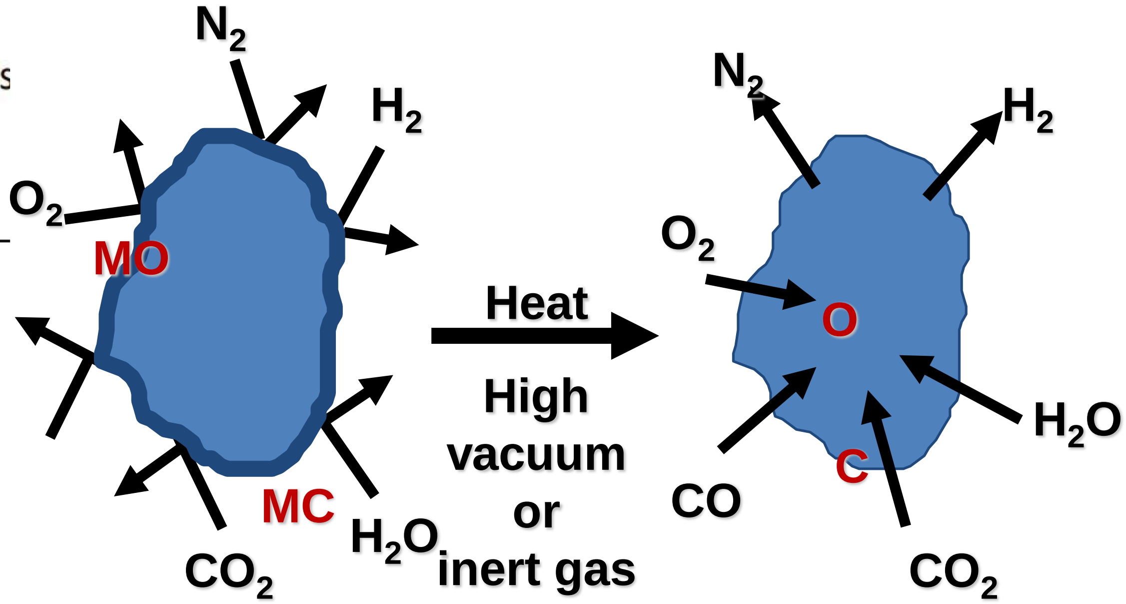
- If not baked (not heated) in-situ water is the dominant gas specie.

$$q_{H_2O} \approx \frac{3\times10^{-9}}{t[h]}\left[\frac{mbar\ l}{s\ cm^2}\right]$$

- If baked (heated above ~120^{0}C) in-situ hydrogen H_2 is the dominant gas

Outgassing rates $q\left[\frac{torr\ l}{s\ cm^2}\right]$ at 20^{0}C:

Austenitic stainless steel not baked, after 10 h pumping	3x10 ^{10} (main gas: H_2O)
Austenitic stainless steel baked in-situ for 24 h at 150^{0}C	2x10^{-12} (main gas: H_2)
OFS copper baked in-situ for 24 h at 200^{0}C	~10^{-14} (main gas: H_2)



Spraying for heating film

- Multilayer heating film will be coated outside of the vacuum chamber which composited by ceramic and conductivity layer
- The heating temperature could reach 250℃

Heating layer

Thickness: ***0.5mm***

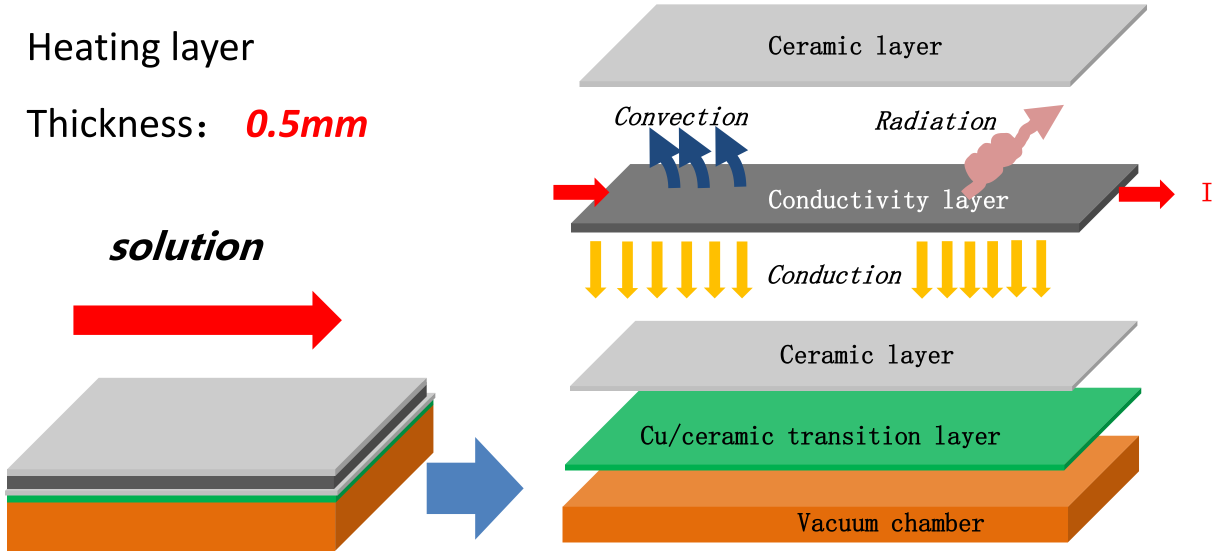
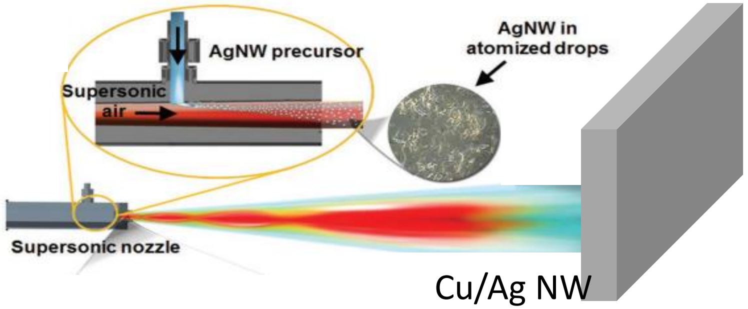
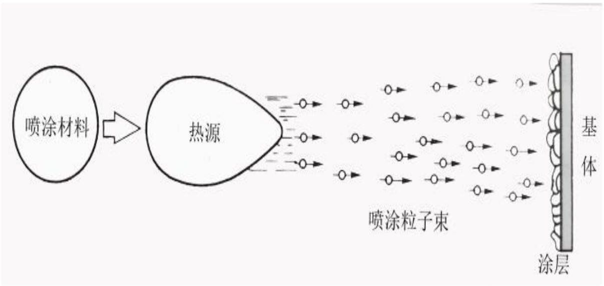


图 2.4 Oerlikon Metco UniCoatPro 大气等离子喷涂设备：(a)控制部分；(b)喷涂部分

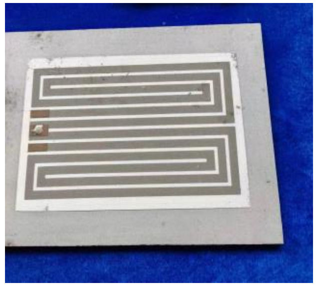


Processing of spray

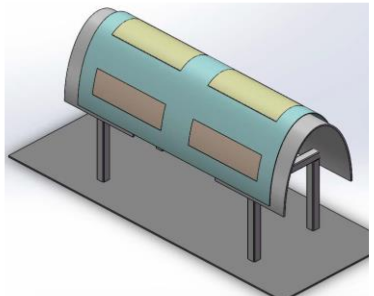


Plasma spraying

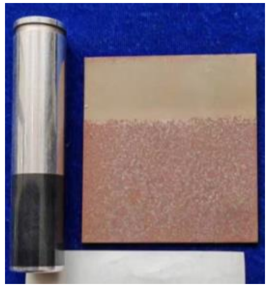
■ Related commercial products



Electric heating circuit



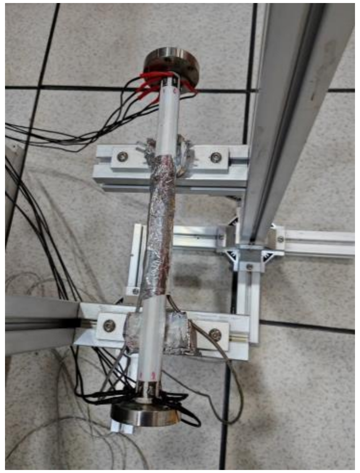
De-icing for airplane

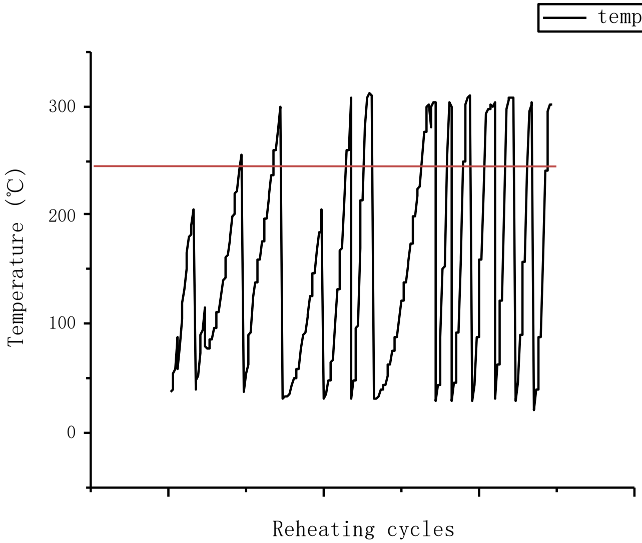


Spraying for heating film

Prototype of Spraying heating film and tests

Reheating test more than 12 times

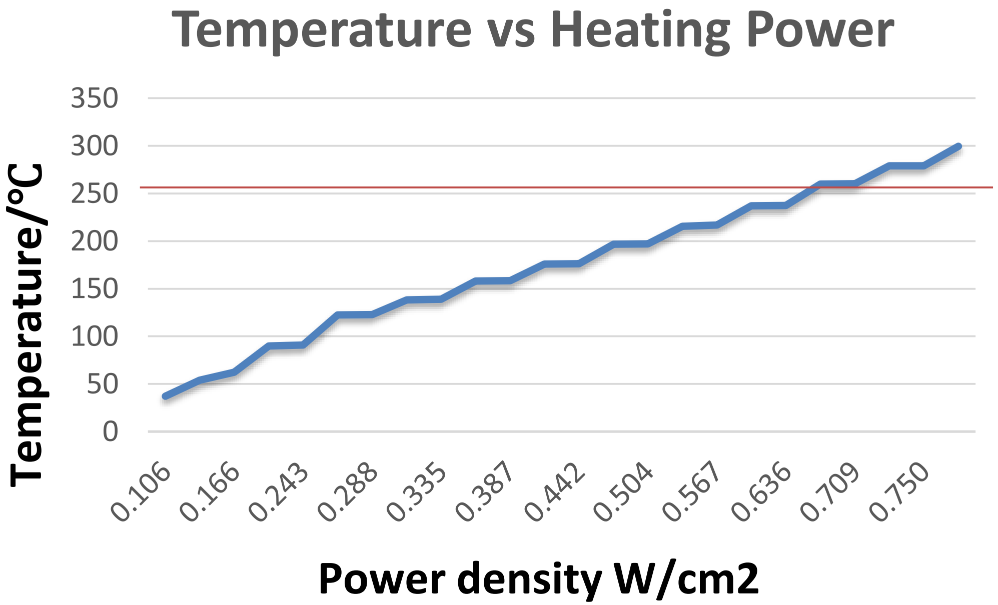




Adhesion test in ultrasonic resining

Dimension: L400*D24   Substrate: copper

Function	Materials	Thichness/um
Transition-layer	MCrAlY alloy	50~100
Isolation-layer	Al2O3 cermic	~150
Conductivity-layer	NiCr alloy	~100~200
Isolation-layer	Al2O3 cermic	~150
Contactor-layer	Copper	~50



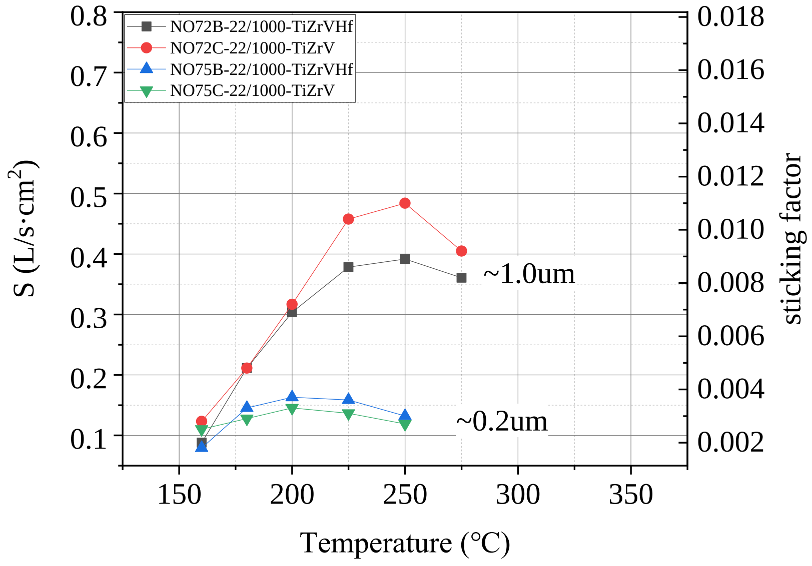
NEG coating optimization in EDR

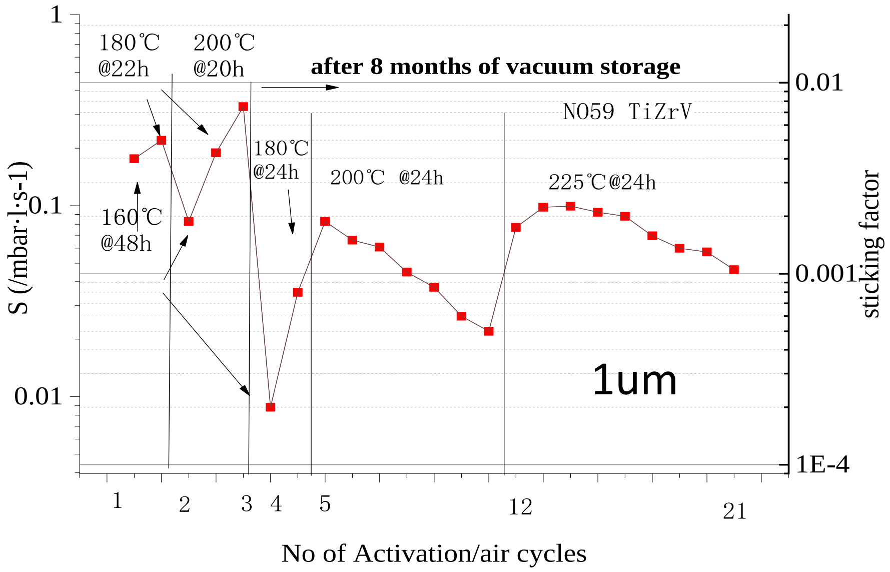
☐ *Impedence*

Round pipe of Copper (2~3mm) with NEG coating (200nm)

Strictly control on the coating thickness for impedance source to restrain the instability!【1】

☐ *Reactivation life-times*





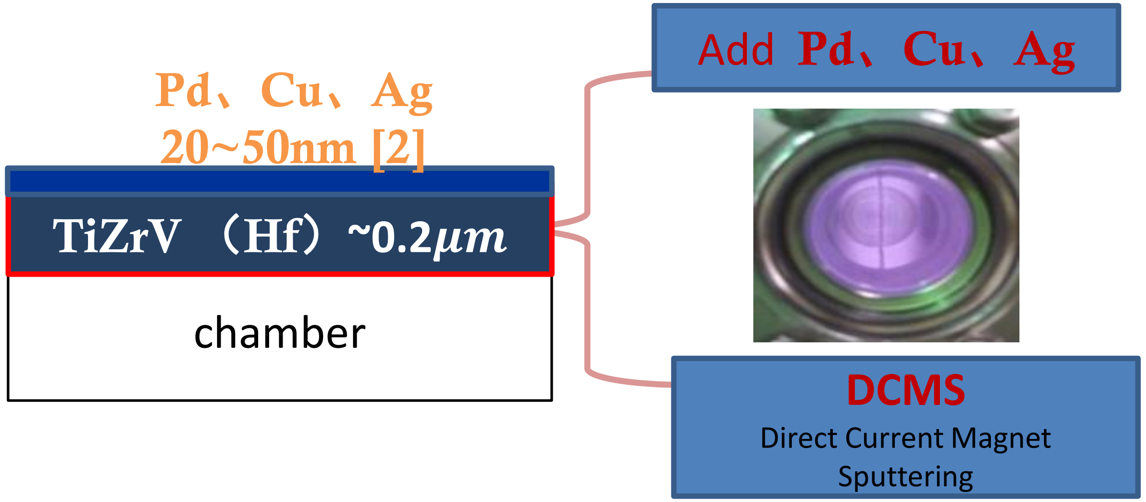
Problems: 200nm NEG coating, pumping performance (pumping speed and life) rapidly decreased

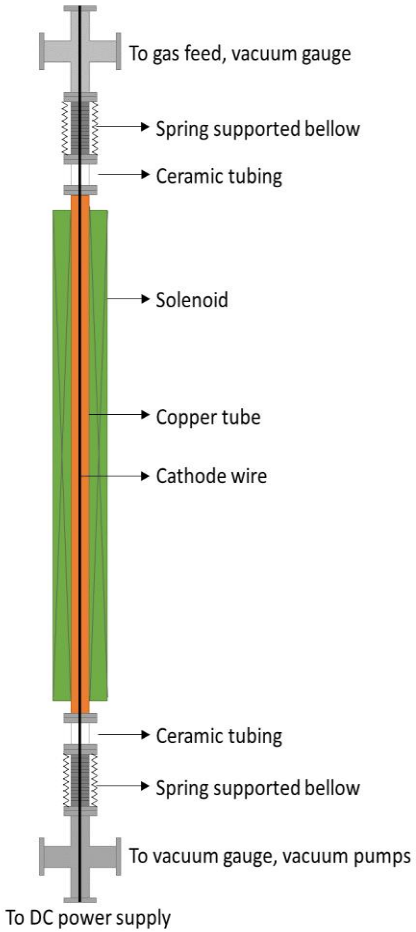
【1】Liu Yu Dong .Modification suggestion of vacuum chamber for the collider ring. 2021/3/25

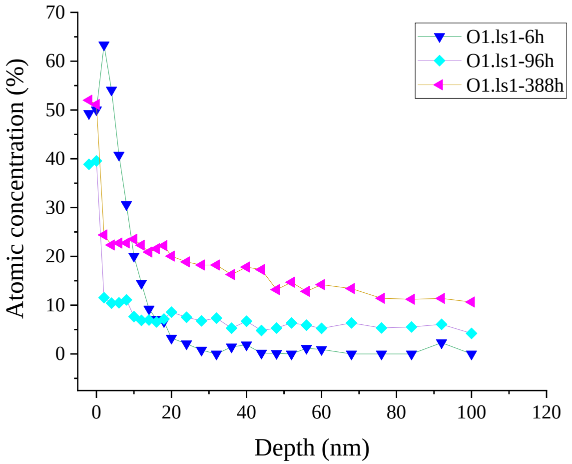
NEG coating optimization _ Next step

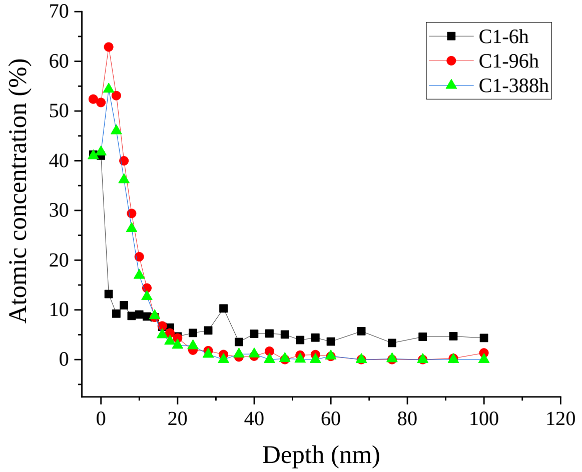
- Multilayer NEG coating: improve lifetimes, conductivity.

The application of a thin palladium (Pd) layer to a getter film has been proposed as a means of preventing oxidation of the getter layer so as to address the issue of limited operational lifespans.[1]





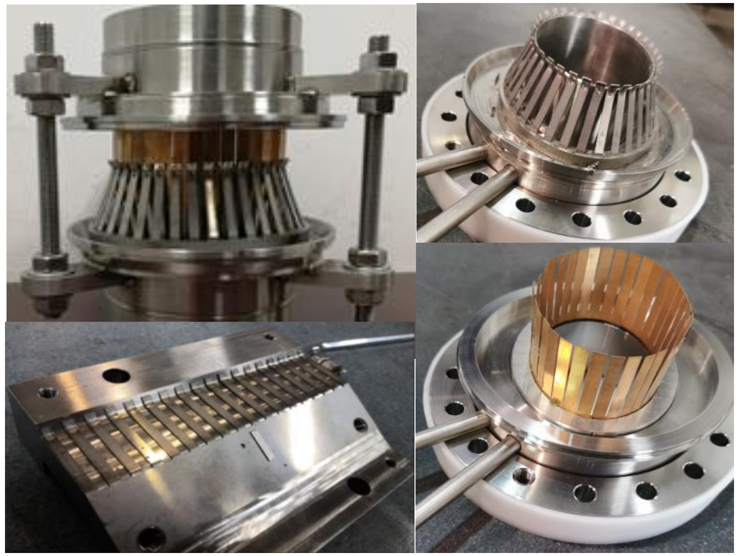




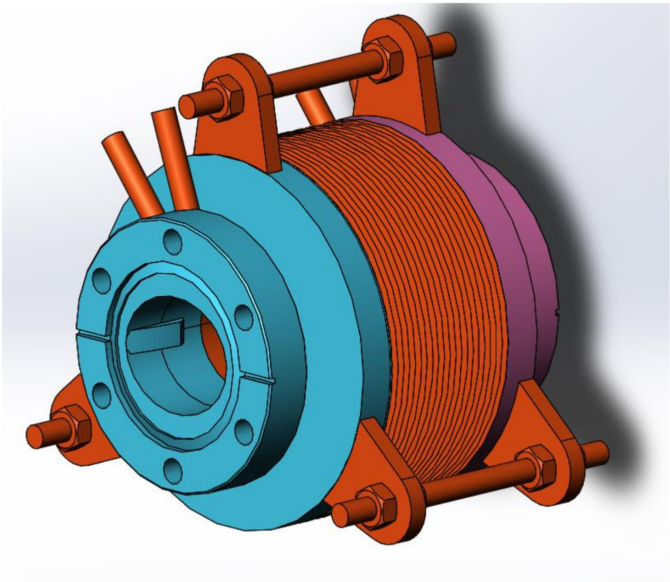
[1] C. Benvenuti, P. Chiggiato, F. Cicoira, Y. L'Aminot, V. Ruzinov, Vacuum properties of pallium thin film coatings, Vacuum 73 (2004) 139–144.
[2] JIN X, TANIMOTO Y, UCHIYAMA T, et al. Synchrotron radiation-stimulated desorption from Pd or Pd/TiZrV coated copper tubes [J]. Vacuum, 2021, 192(110445.

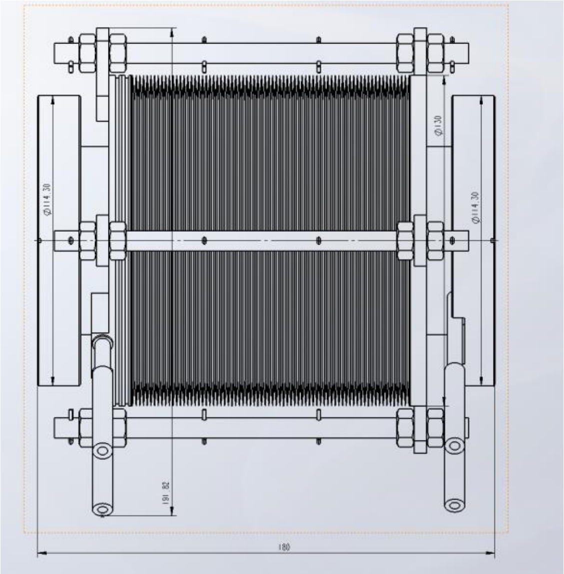
Full-scaled size RF shielding bellows development

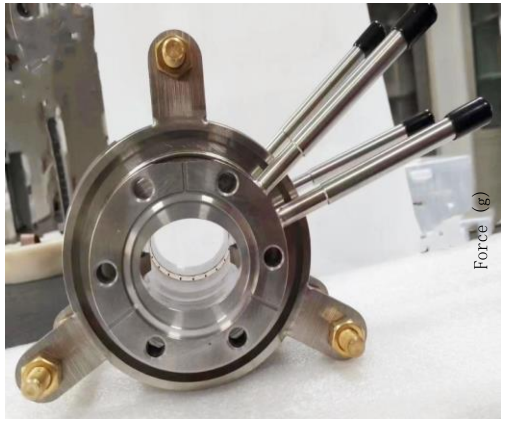
- RF shielding Bellows for ultra Expansion/contraction： Ultra Expansion/contraction RF bellows to meet the 11.5m long vacuum chambers.

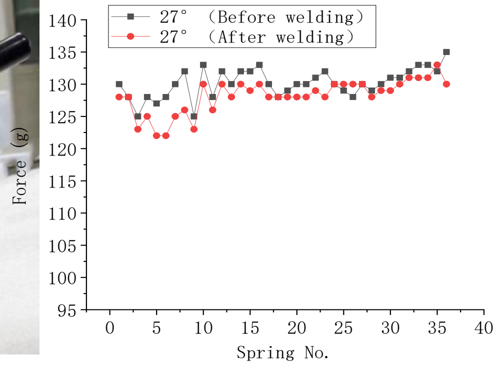


- Mask is designed on the upstream of RF bellows to absorb the SR
- The all RF bellows were produced by local company in China, and massive used in HEPS.









Prototypes in TDR & HEPS

Conclusion

- Vacuum chambers with Al, Copper alloy materials have been conducted in BEPC II, HEPS, and also NEG coating have been applicated in HEPS with thickness of 1 um, For CEPC, 0.2 um NEG coating is a curial technology, due to its short time life-cycles.
- Production line of vacuum chambers NEG coating and spraying heating will be R&D in 2 years;
- ✓ NEG coating by magnetron sputtering cathode method R&D will be carried out to adapt the production line;
- ✓ Prototype of Spraying heating film and tests have been carried out, which shows a good results;
- NEG coating optimization for low impedance film, Spraying for heating film plan to be carried out ;

Acknowledgement

- **A significant amount of work has been completed in the CDR and TDR, and I would like to thank all those who have contributed to these efforts.**
- **Thanks for the HEPS, FCC-ee project;**

Thanks for your attention