中国科学院高能物理研究所
Institute of High Energy Physics
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CEPC vacuum chamber production line

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Content

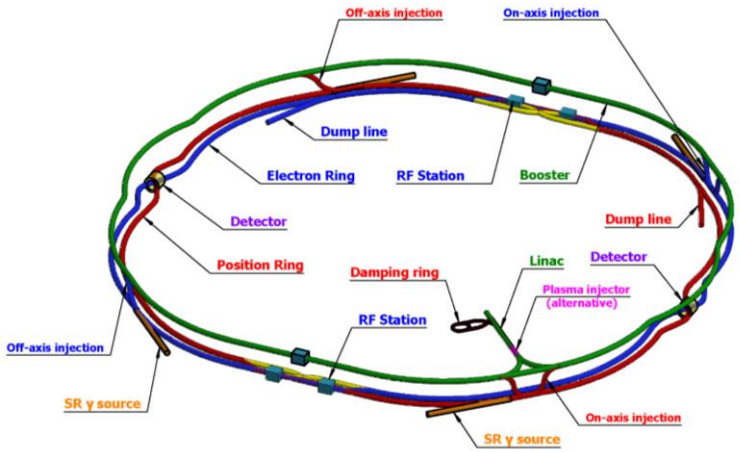
- Preview of CEPC vacuum system
- Production line development of NEG coating/ Spray for heating film in EDR
- Prototype of thermal-spray heating layer and testing
- Summary

Preview of CEPC vacuum system

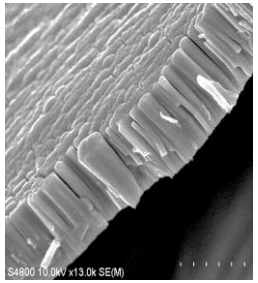
Machine and Vacuum Parameters

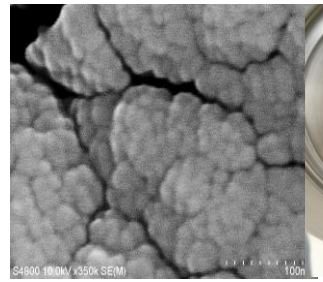
	E	I	ρ
	Gev	A	m
Higgs	120	0.0167	10700
W	80	0.084	10700
Z	45.5	0.803	10700
tt	180	0.0033	10700

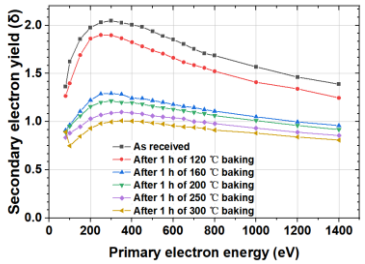
Accelerator	length/m
LINAC	1,601+335
Damping ring	147
Booster	100,000
Collider	200,000
Transport line	4,680
Total length/m	*306,763*



◆ Technical developments in TDR

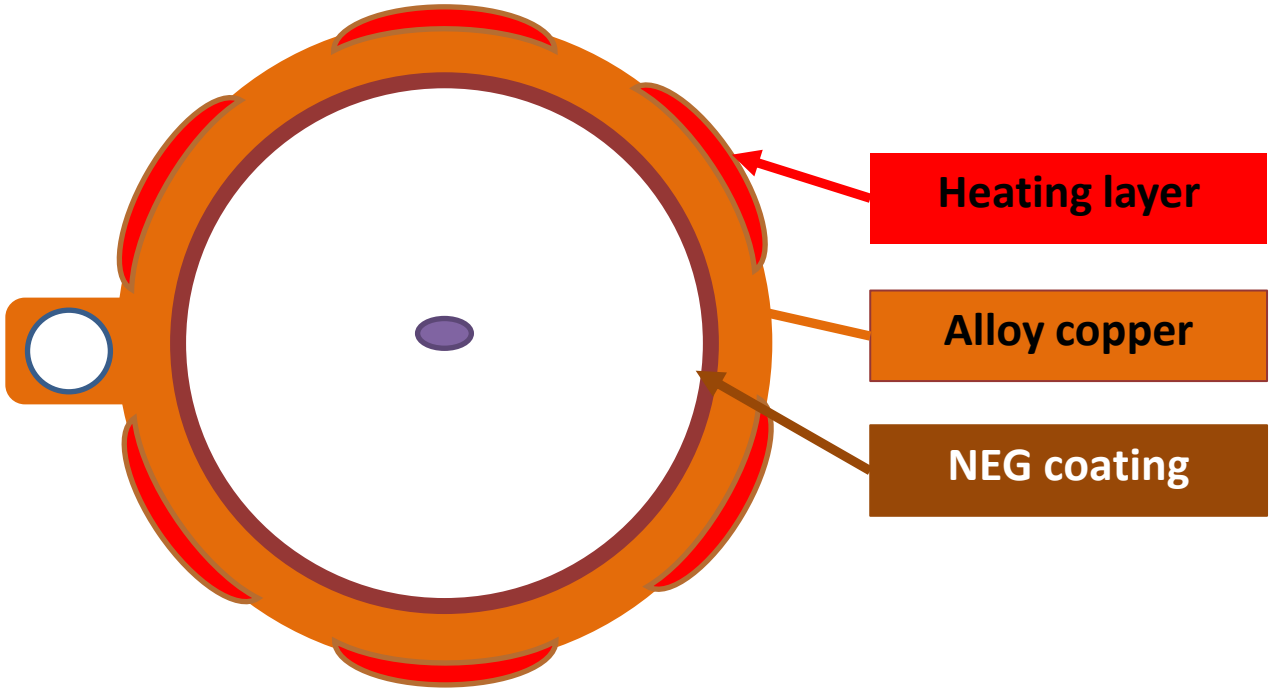


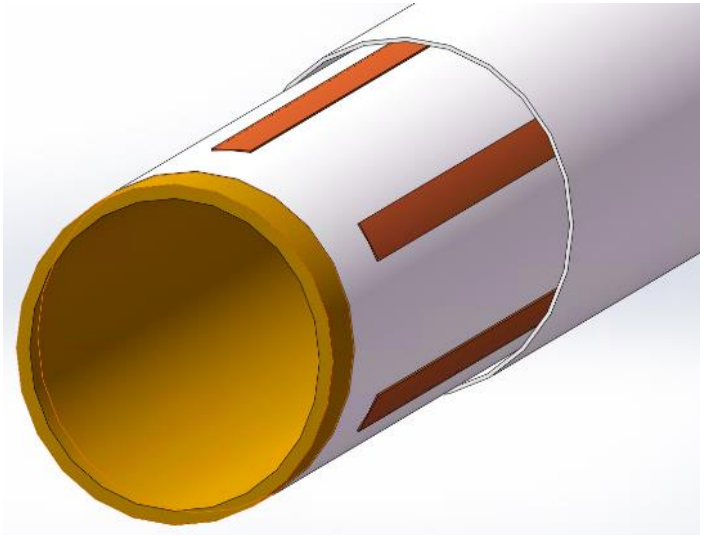




Those prototypes have a good application in HEPS.

Structure of vacuum chamber for CEPC collider rings





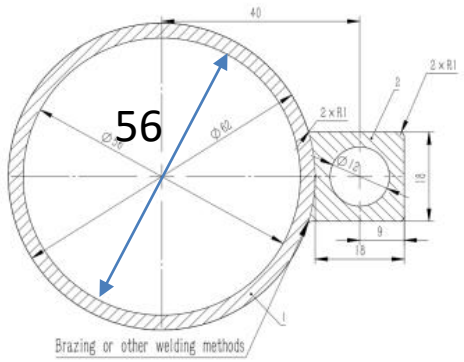
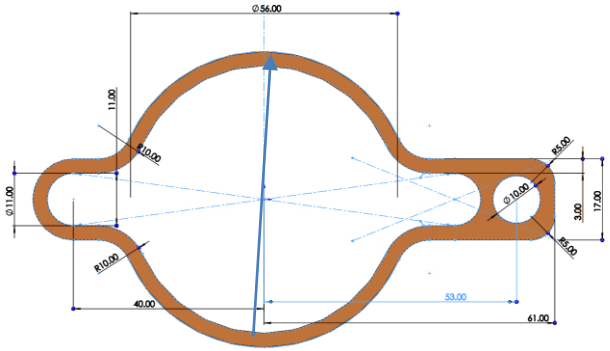
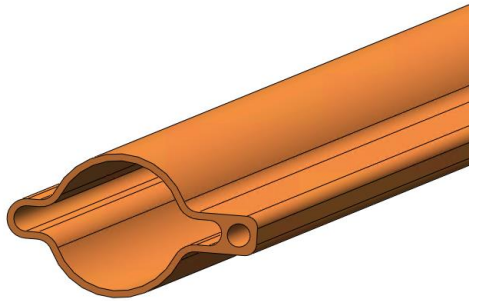


Figure 4.3.6.2: Copper dipole vacuum chamber

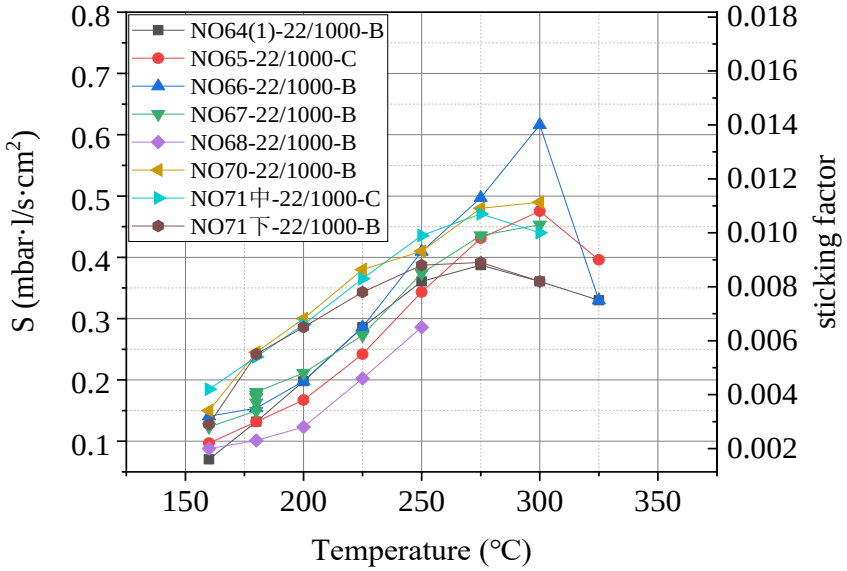


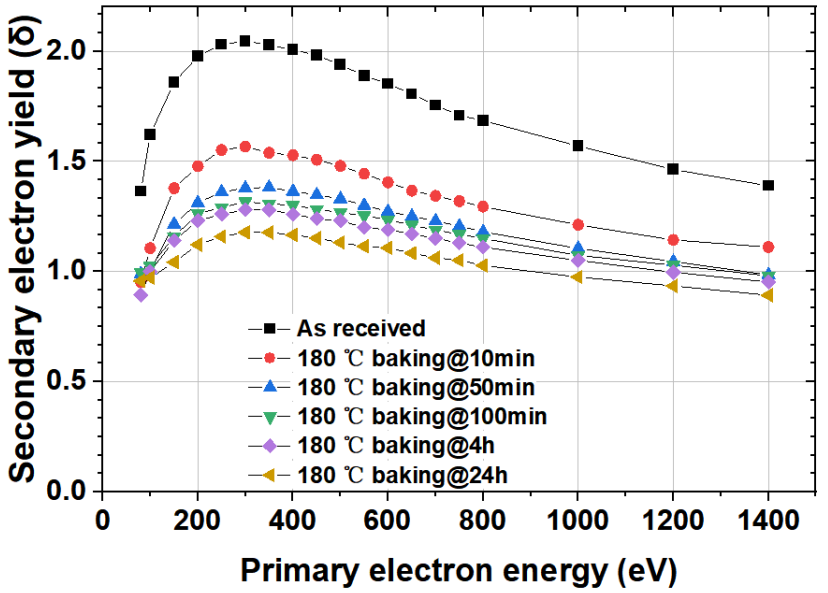


VC with photon absorber

Benefits from NEG coating

- 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.



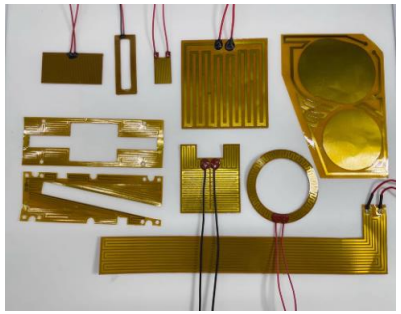


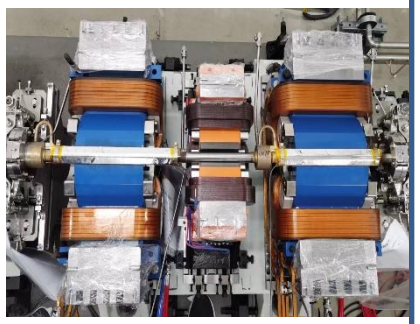
VC baking & Why spray heating film

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:

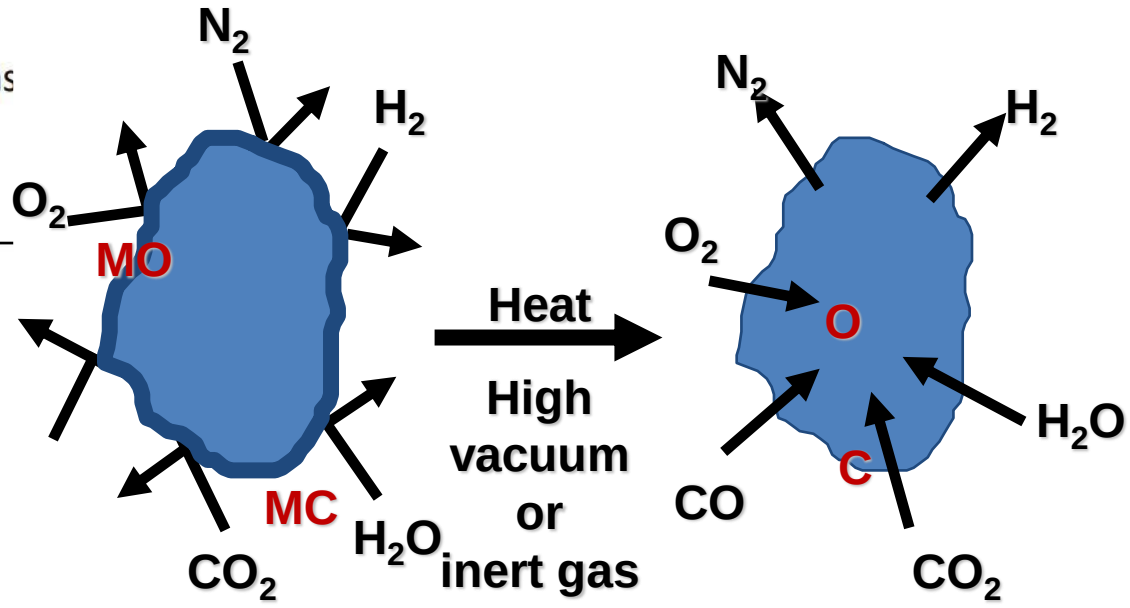
- If not baked (not heated) in-situ water is the dominant gas specie.

$$q_{H_2O} \approx \frac{3 \times 10^{-9}}{t[h]} \left[\frac{mbar\ l}{s\ cm^2}\right]$$

- 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***

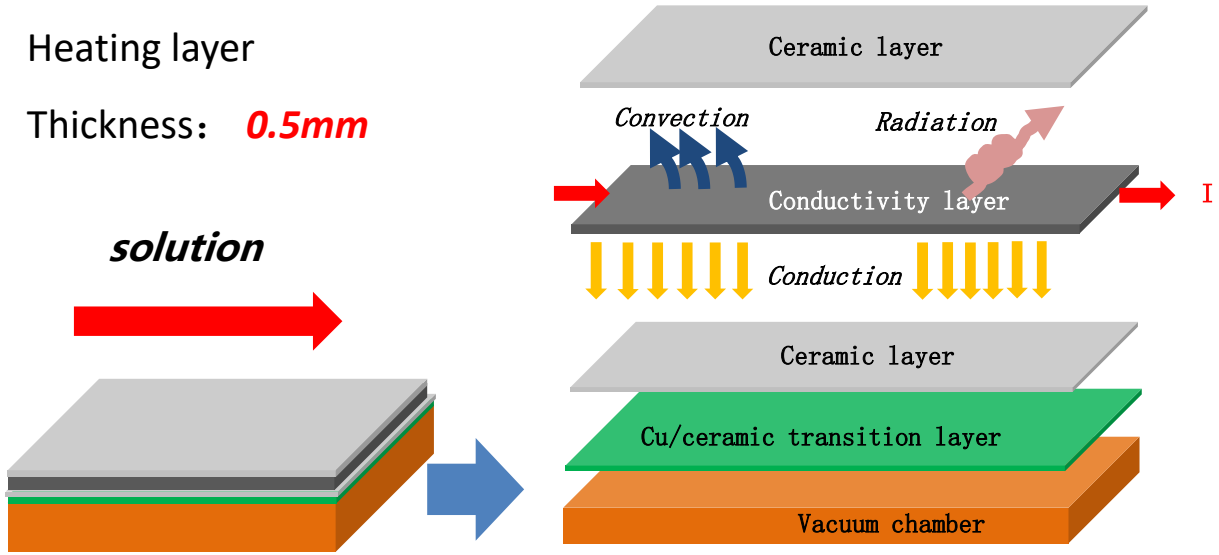
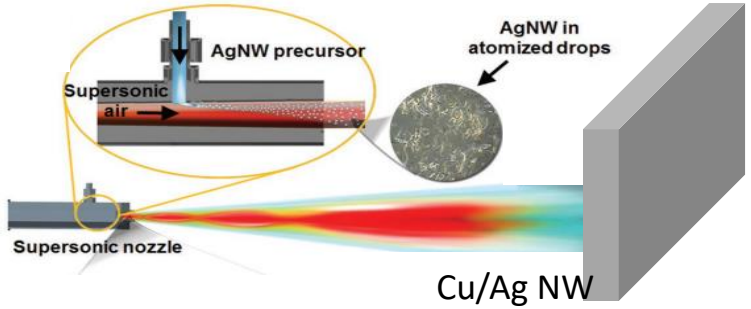
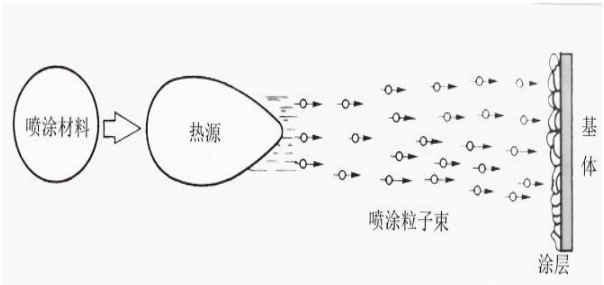


图 2.4 Oerlikon Metco UniCoatPro 大气等离子喷涂设备：(a)控制部分；(b)喷涂部分



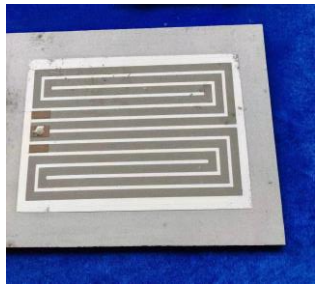
Cu/Ag NW

Processing of spray

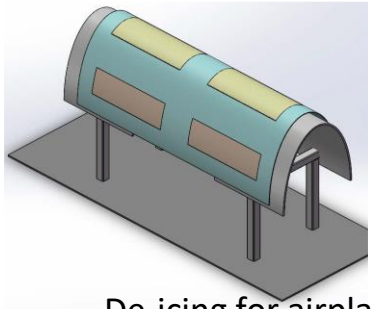


Plasma spraying

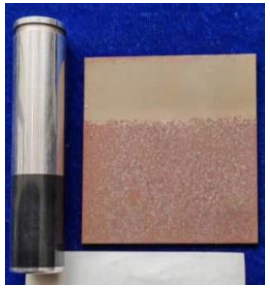
■ Related commercial products



Electric heating circuit



De-icing for airplane



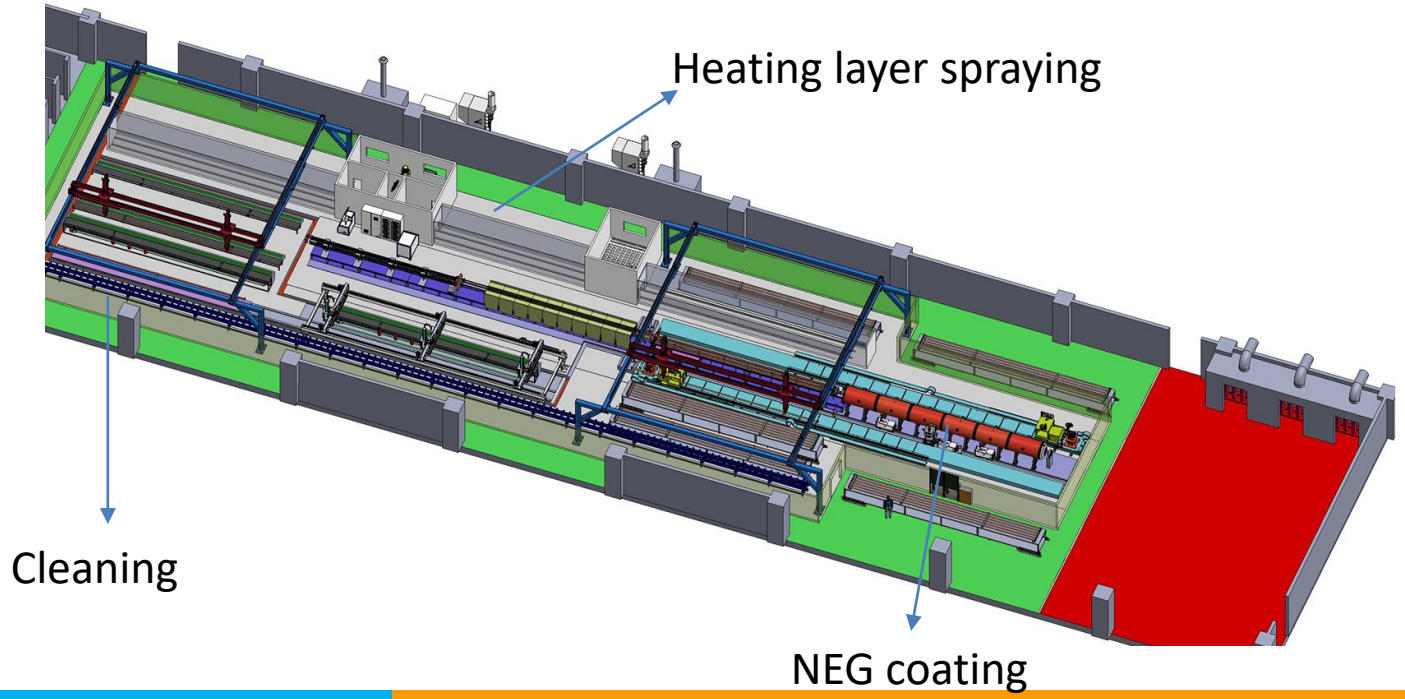
Preview of NEG coating/ Spray for heating film production line

■ 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.
- The full quantity of vacuum chambers for the collider will be manufactured within five years, utilizing two production lines operating at a combined capacity of 4,500 units per year.

■ Advantages

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



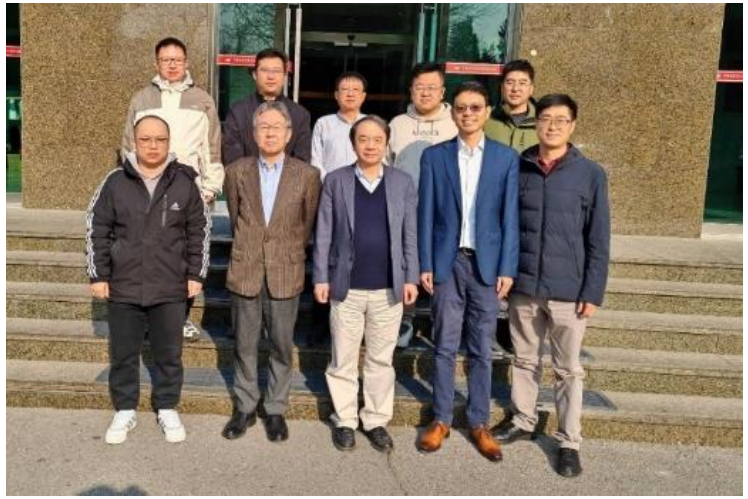
Items	Specifications
Dimension	• L 11400-d56-D62
Weight	• 50~100kg
NEG coating	• Thickness：200nm±30% • SEY<1.1 • S、Q、life-times
Spraying heating	• Thickness<0.5mm • Heating temperature <300℃

Critical Step in the Production Line

◆ **Important nodes and progresses**

✓ Technical scheme review	2024.10
✓ Procurement bidding	2024.12
✓ Process Review prior to Manufacturing	2025.6
✓ Most of components have been manufactured	2025.11
✓ The production line will be conditioned	2026.3

Manufacturer visit



Project kicker off

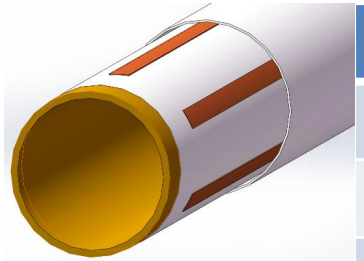
Process Review prior to Manufacturing

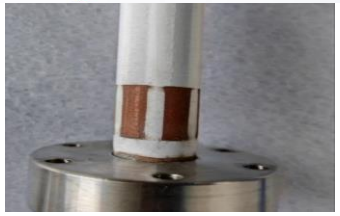
Production line composition

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

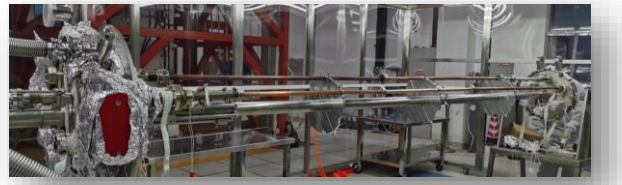
Procedure of NEG coating & spraying of production line

- Spraying (Air plasma spraying)
  - Sandblasting
  - Spraying_Isolation_layer
  - Spraying_Conductivity-layer
  - Spraying_Isolation-layer
  - Spraying_Contactor-layer
- Cleaning
  - Outside
  - Inside
- 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



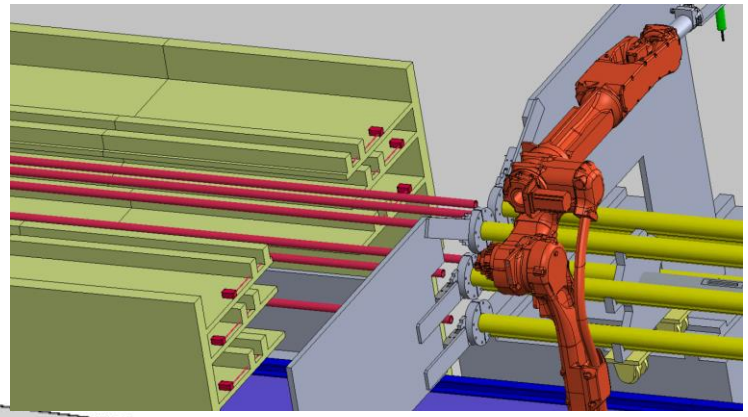


Function	Materials	Thichness/um
Transition-layer	MCrAlY alloy	50~100
Isolation-layer	Al2O3 cermic	~200
Conductivity-layer	NiCr alloy	50~100
Isolation-layer	Al2O3 cermic	~200
Contactor-layer	Copper	~50

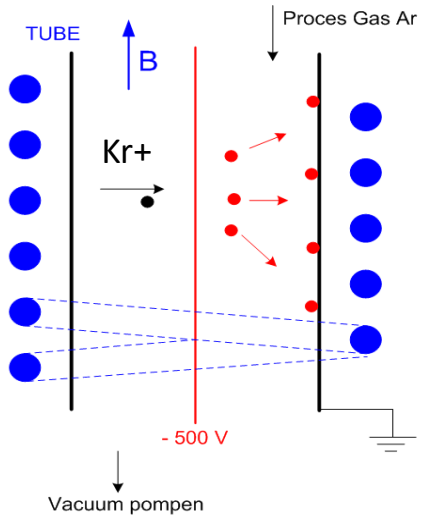


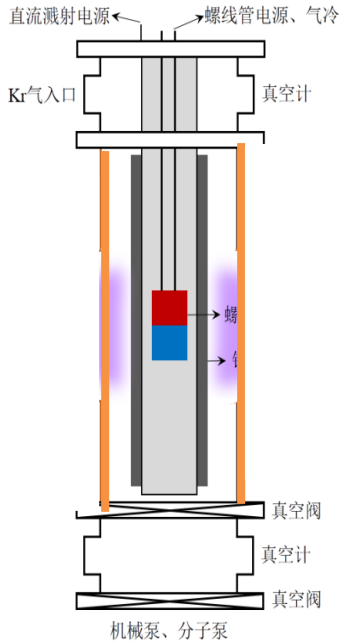
Layout & composition of NEG coating facility

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

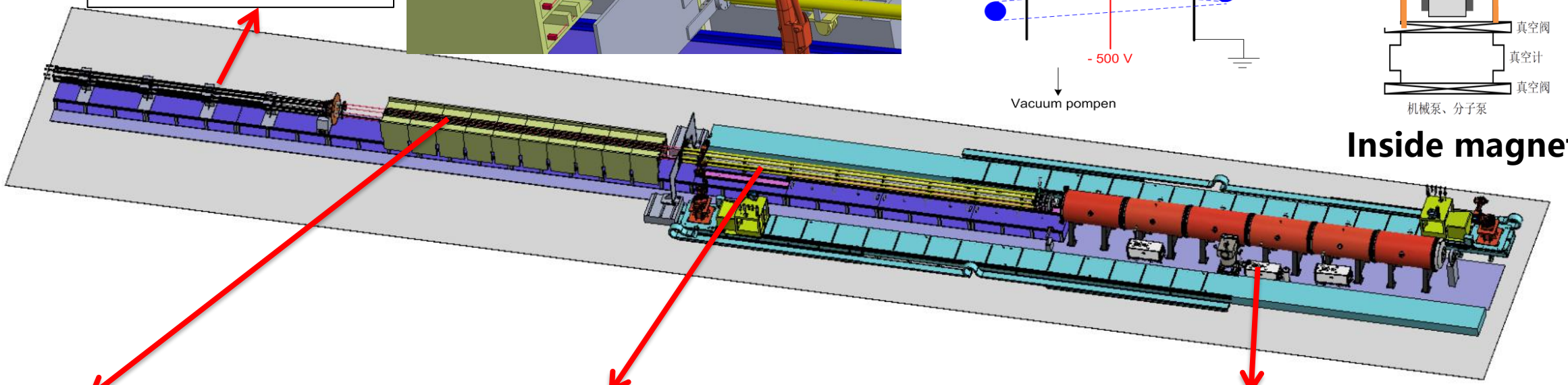


DCMS for NEG coating

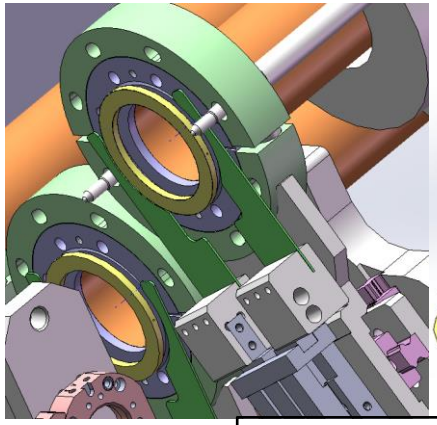


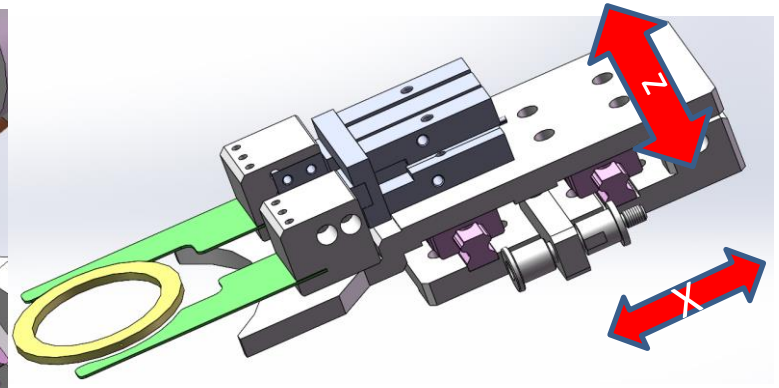


Inside magnet

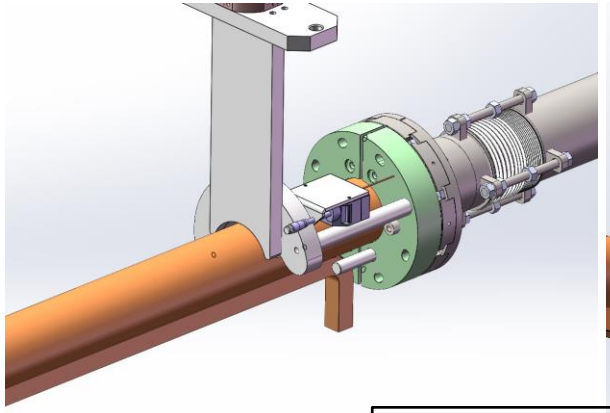


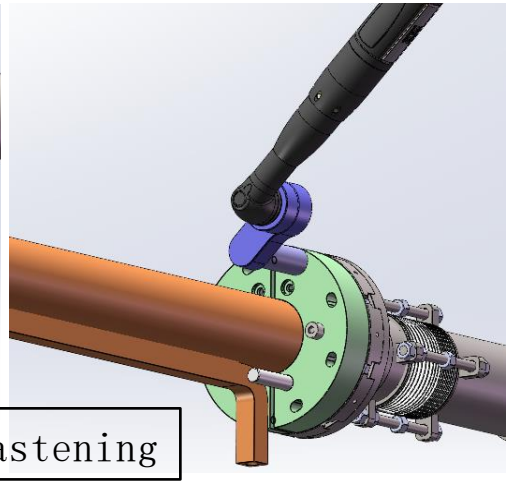
Vacuum chamber automatic assembly



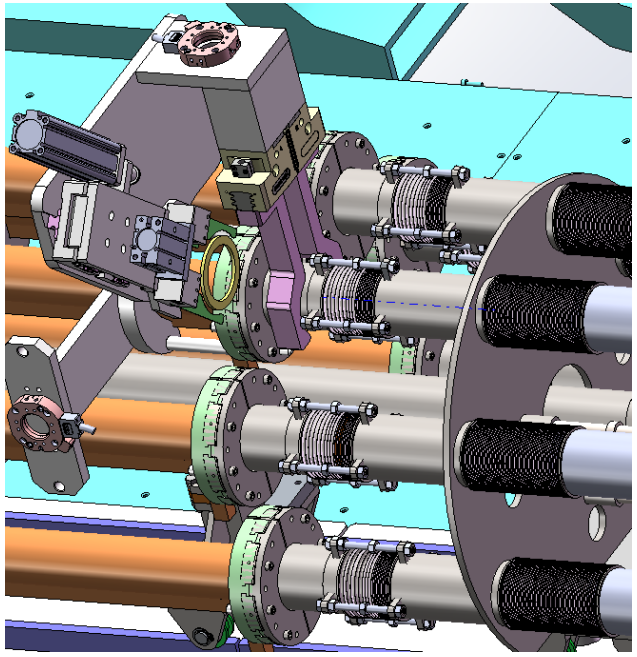


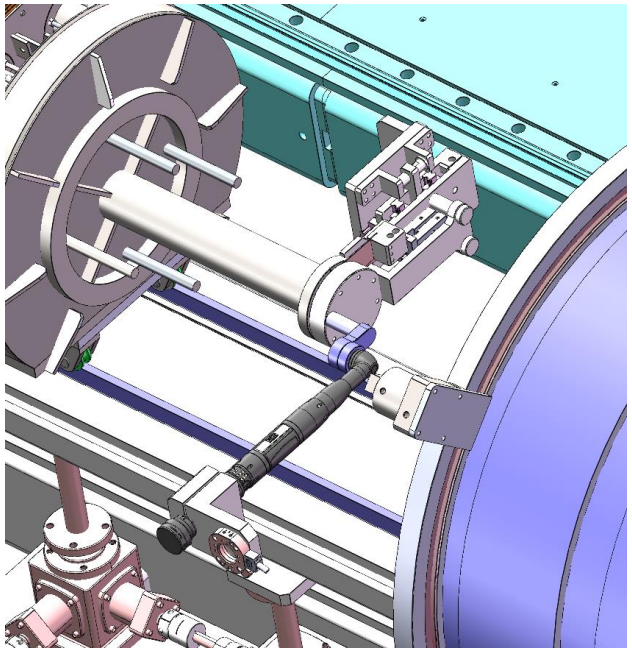
Sealing gasket installation

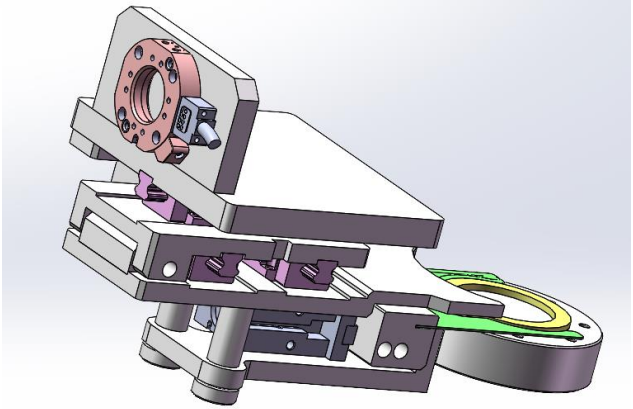




Flanges fastening

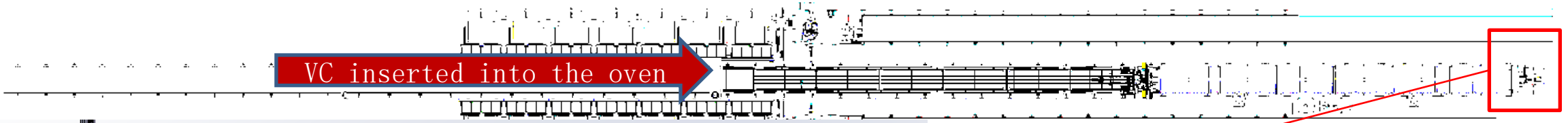


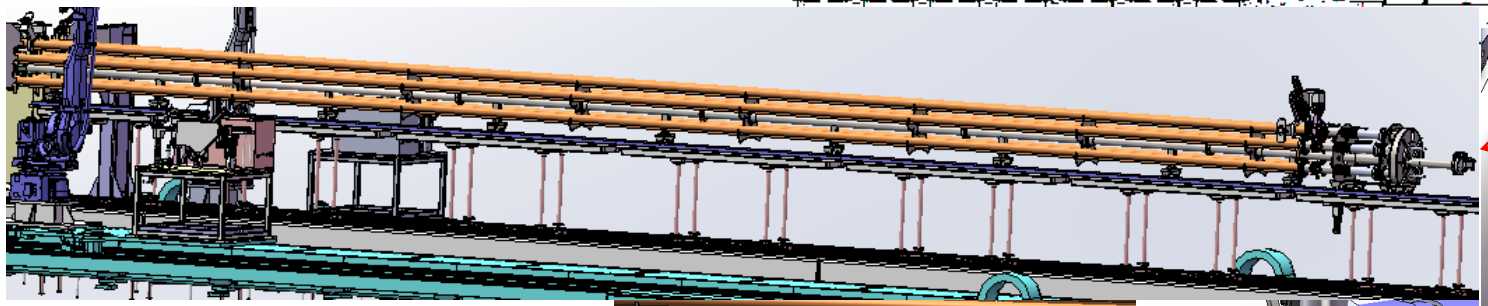


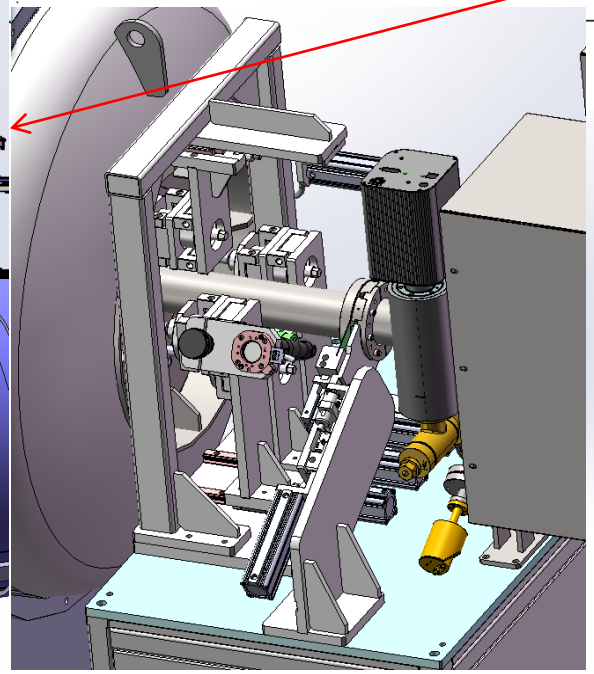


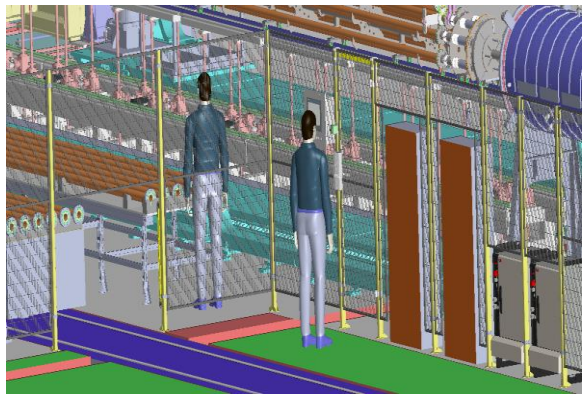
Vacuum chamber automatic assembly

- 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;

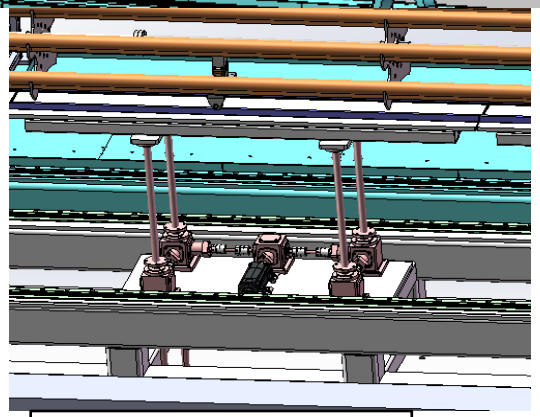


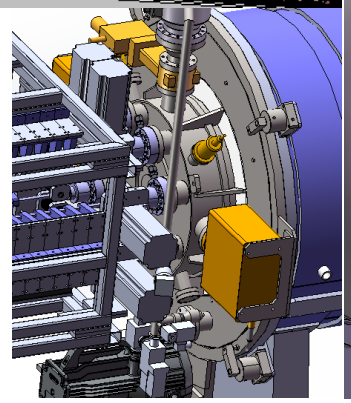




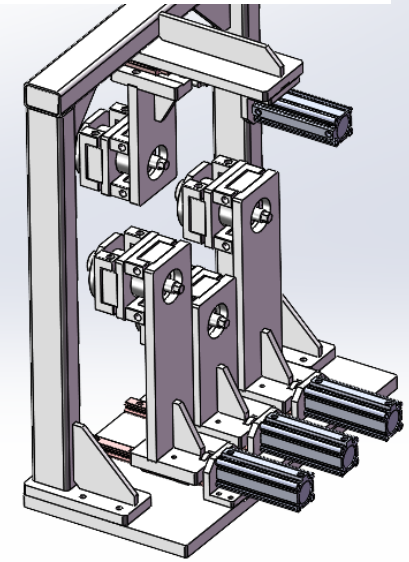


Safety insurence





VC & cathode support



UHV system for NEG coating

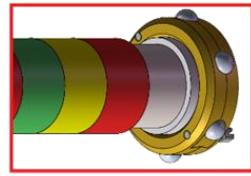
Prototype of cathode for NEG coating

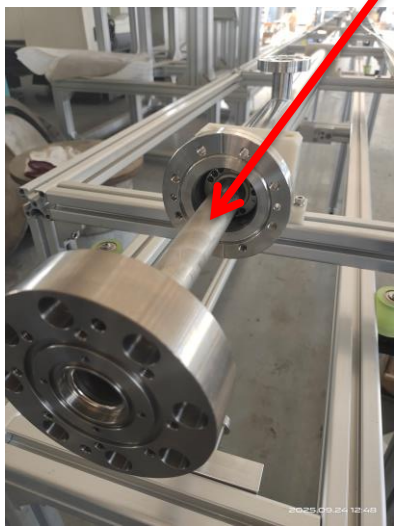
Motor for magnets driven

23000mm(23 meters)

~12000mm(12 meters)

Magnetron Cathode





- After testing and conditioning, the cathode achieves a stable DCMS plasma discharge under 367 V and 1.1 A.

Manufacturing progress of production line

- The oven for NEG coating, which provides a low vacuum environment and baking capabilities, is under manufacturing.



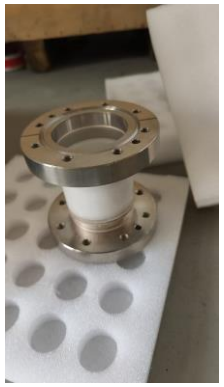



- The 12-meter cathode prototype for NEG coating is under manufacturing.



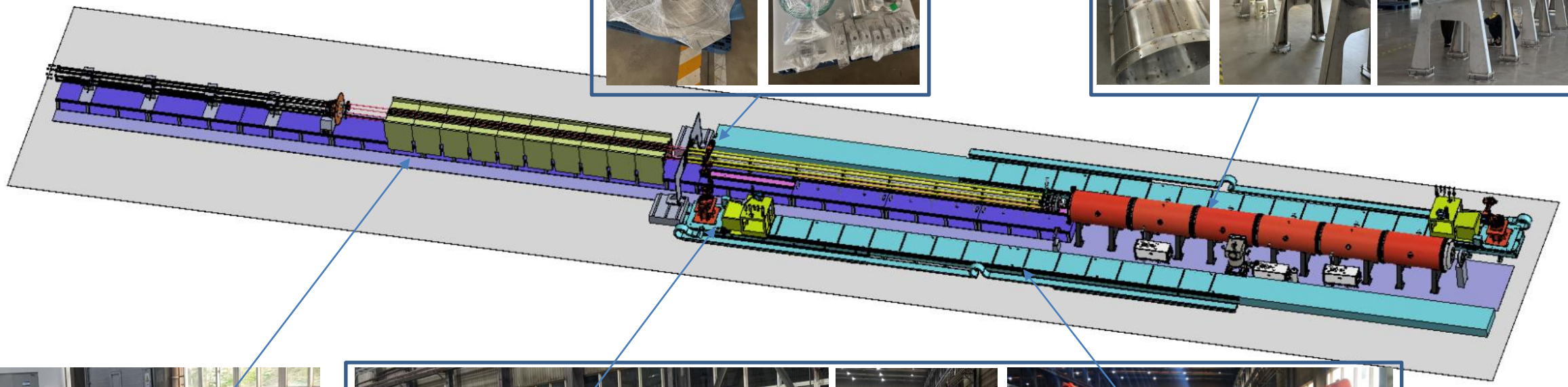




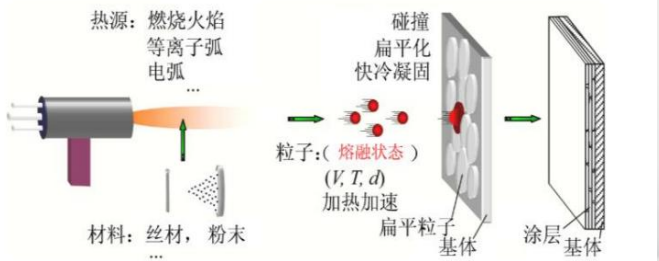



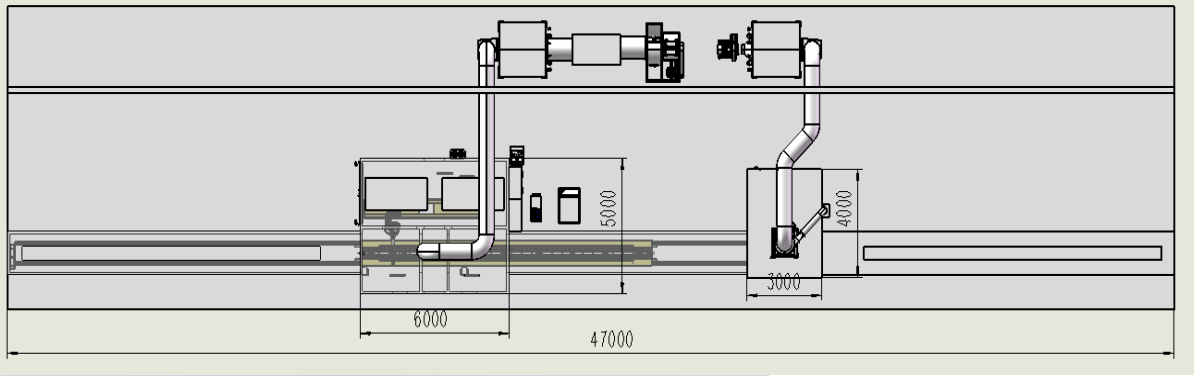

Manufacturing progress of production line

- The main components of vacuum oven for NEG coating have been manufactured and under are now being assembled.



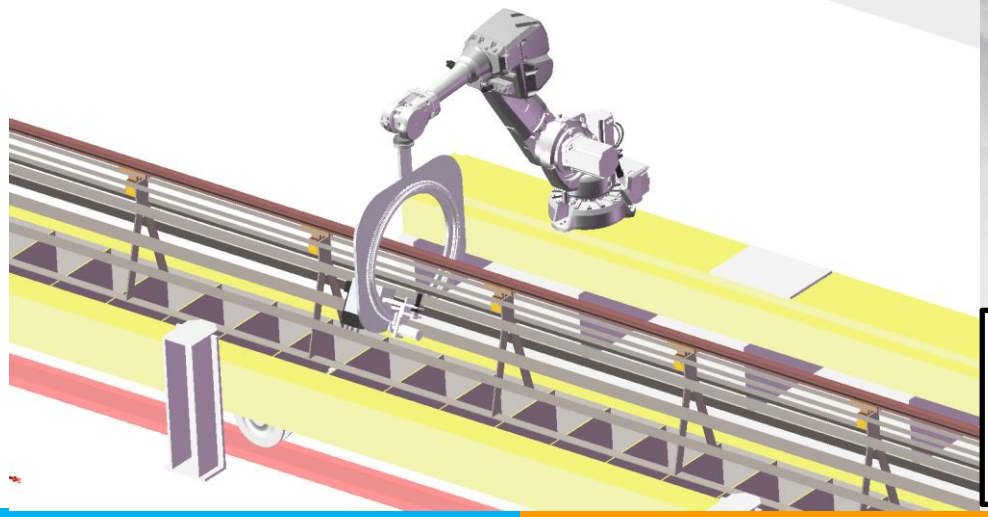
Plasma Spraying system





Plasma Spraying
& Laser etching room

Sandblasting room

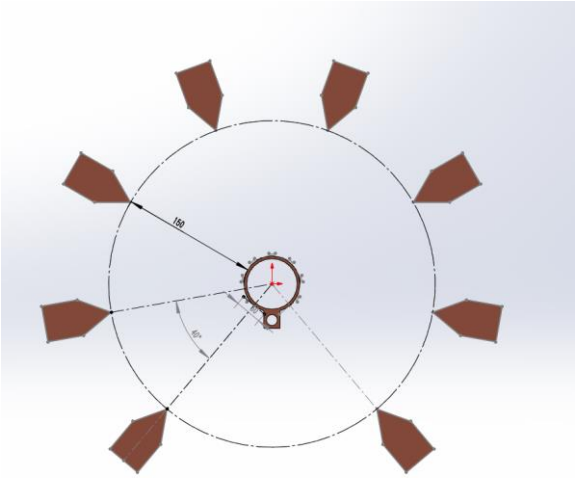


The vacuum chamber will be transferred by motorized conveyance to the coating station, where a robotic arm will execute multi-layer deposition using an automated spray gun.

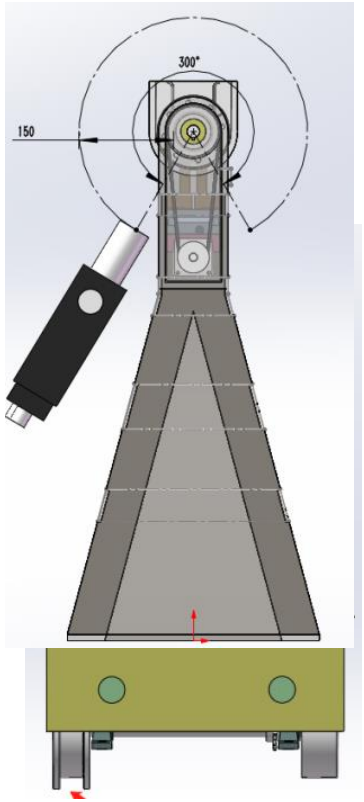
Heating coating spraying

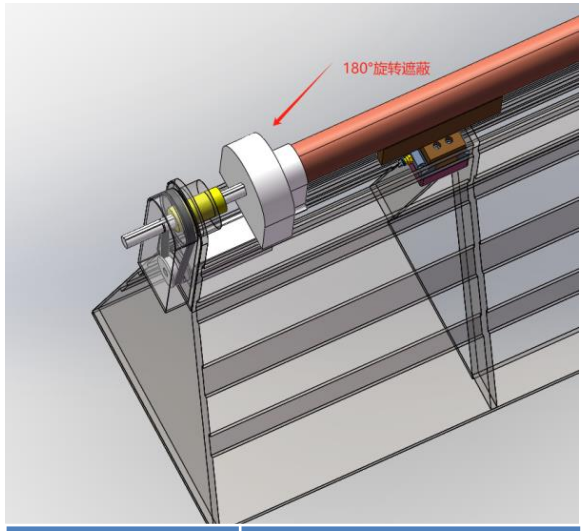
◆ The processing step for the heating coating spraying

Sandblasting → **Plasma Spraying** → **Etching by laser**

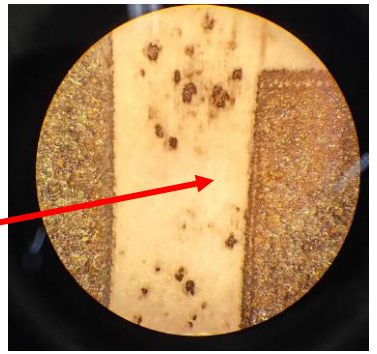


名称	参数
喷砂枪数量	8把
喷砂距离	150~180mm
喷枪喷砂有效区域	≤φ30mm
砂料	白刚玉或棕刚玉
喷枪口径	8mm
喷砂压力	0.25-0.6MPa（可调）
砂流调整范围	1~3KG/min



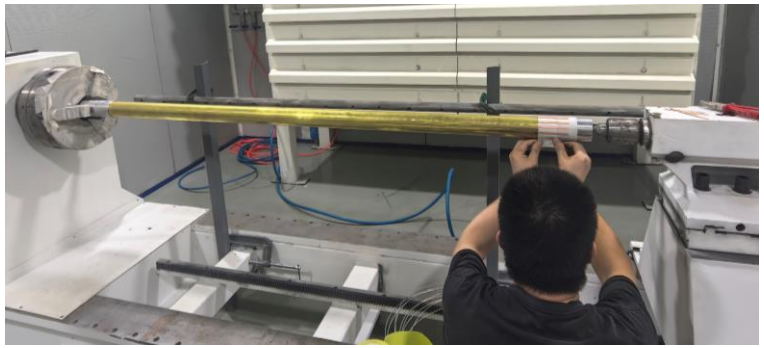


项目	参数
驱动方式	旋转气缸驱动
遮蔽材质	不锈钢
轴向可调节范围	100mm

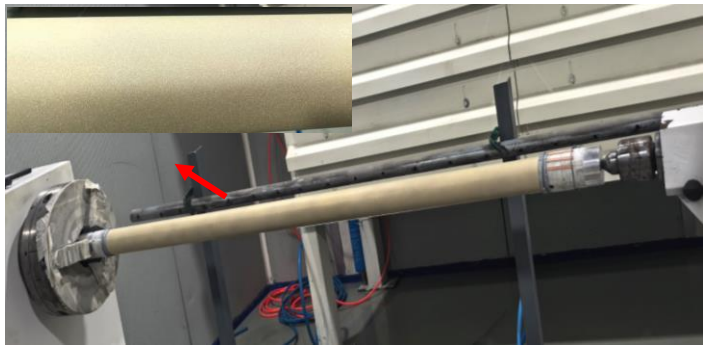


Length of 1.5m prototype of Spraying

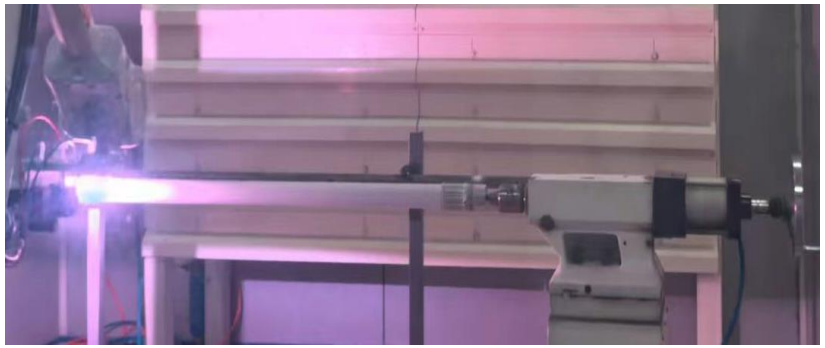
- A 1.5-meter prototype has been developed to validate key process steps that will be implemented in the production line.



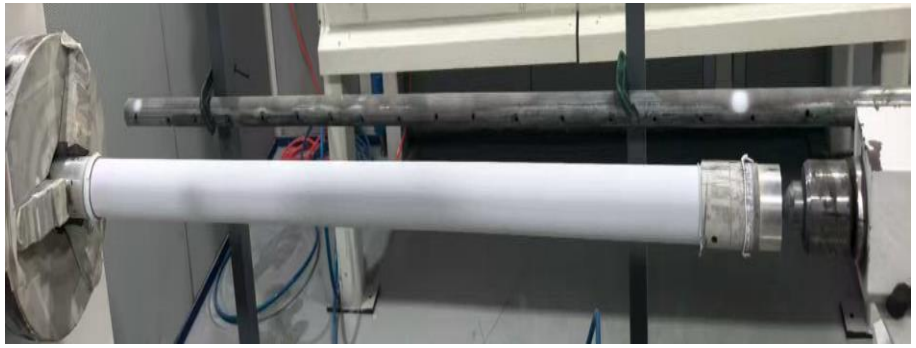
Installation



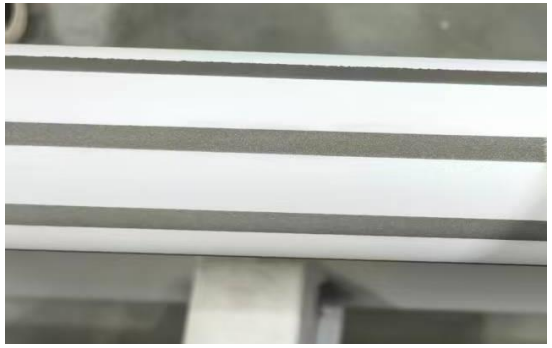
Sandblasting



Spraying



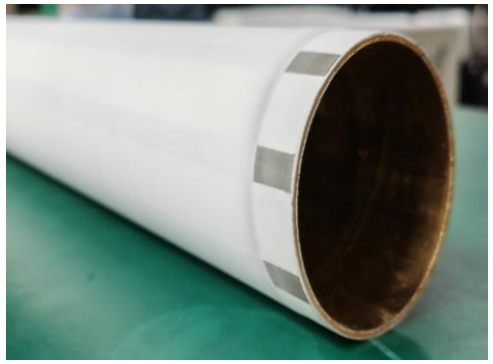
Spraying_Isolation-layer

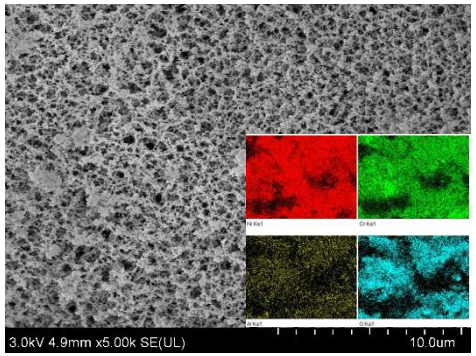


Spraying_Conductivity-layer

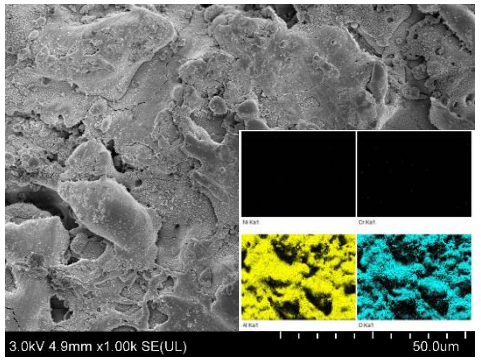
Spraying_Isolation_layer

Elements and thickness of thermal-spray heating layer

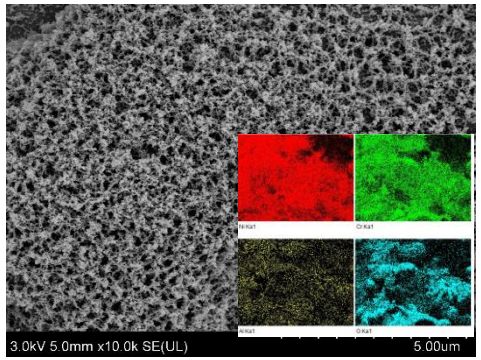




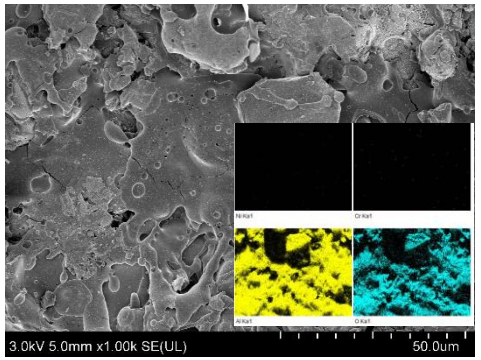
NiCr Conductivity-layer



Al_2O_3 isolation layer

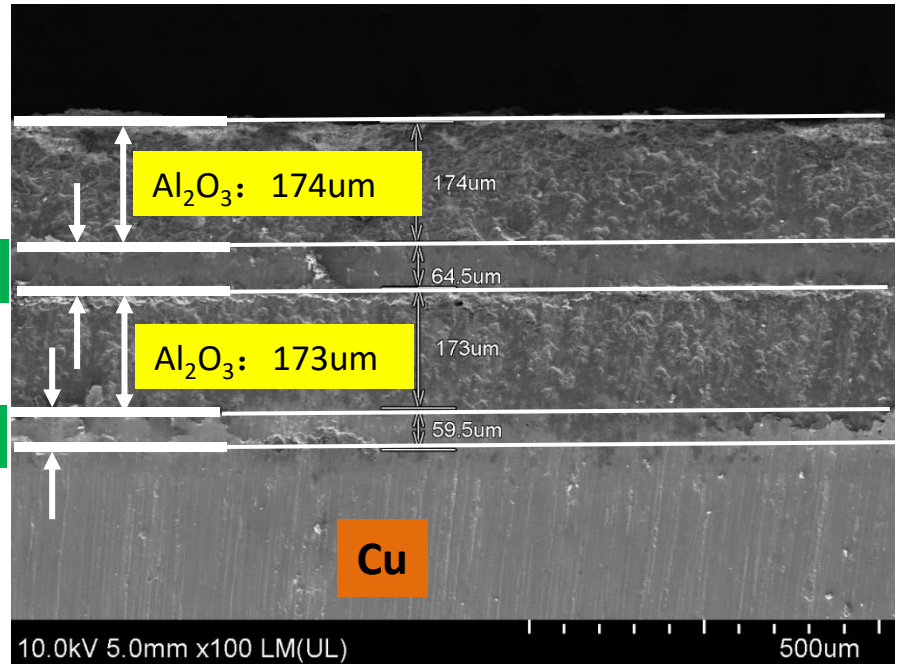


NiCr Transition-layer



Al_2O_3 isolation layer

Thickness

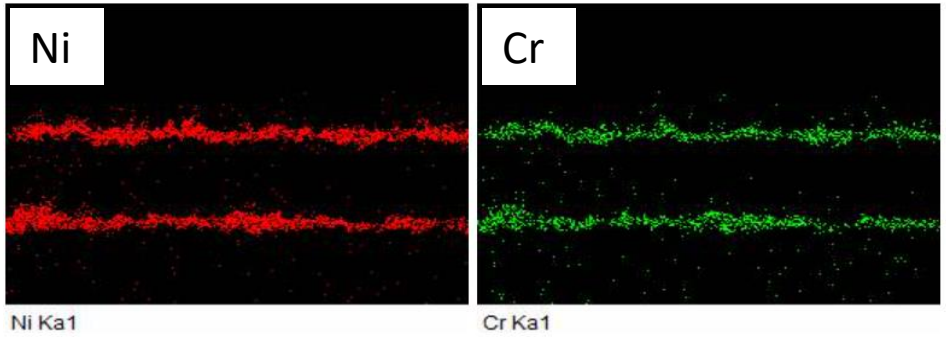


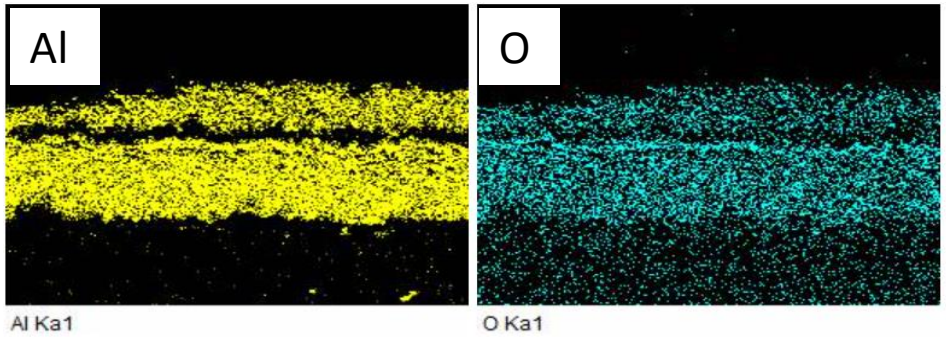
NiCr：64.5um

NiCr：59.5um

=471um

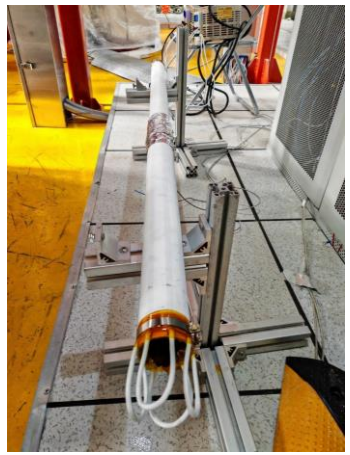
＜0.5mm

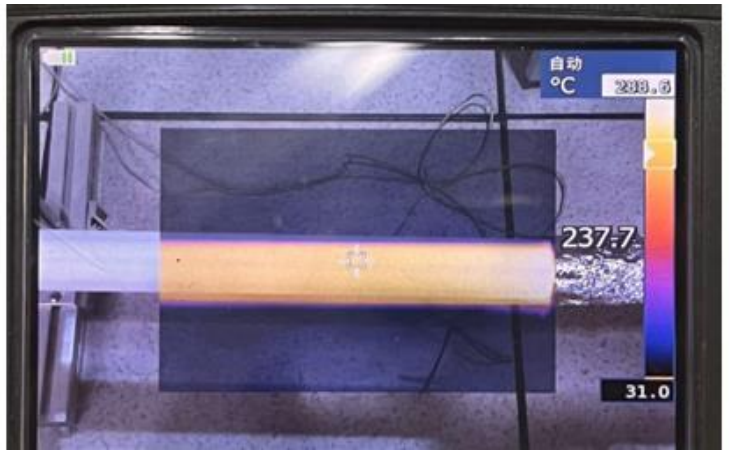


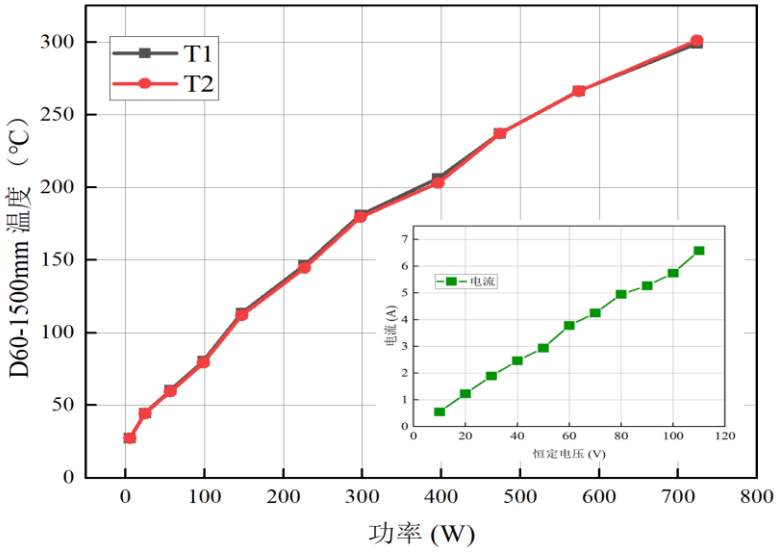


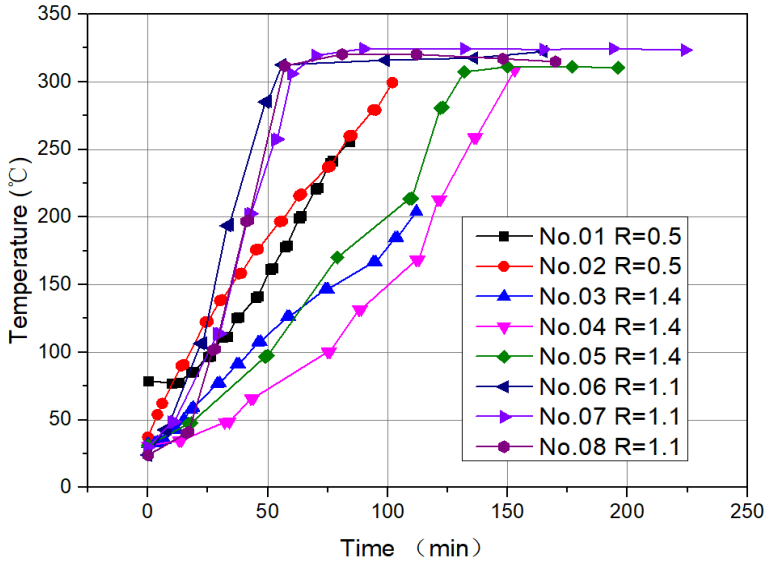
Prototype of thermal-spray heating layer and testing

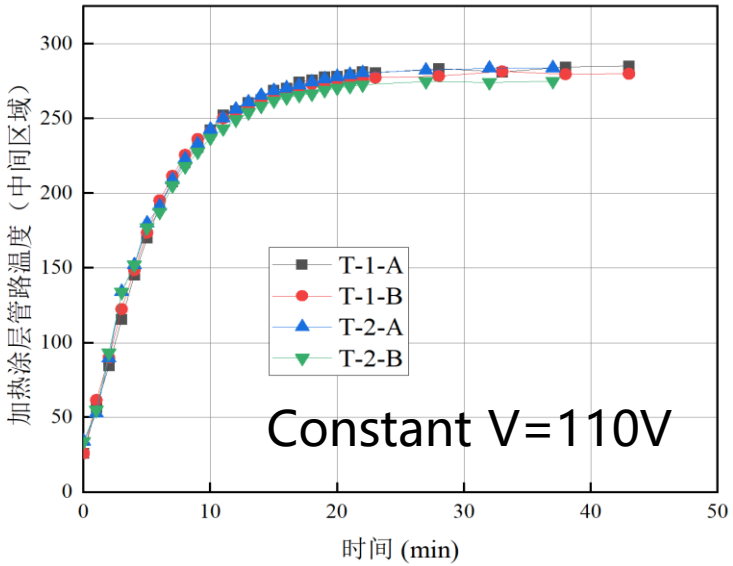
Dimension: L1500*D60 Substrate: copper











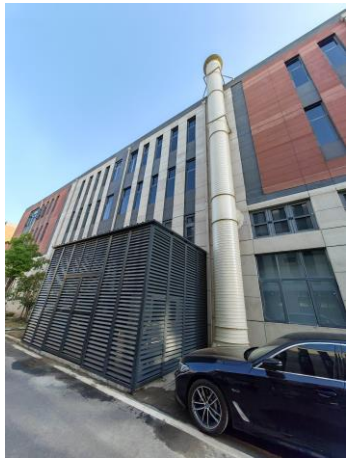
Several ten times reheating tests which shows a good lifetimes and performance

D60-1500 mm

Plasma spraying devices

- The spraying system is similar to the system detailed in the following pictures.



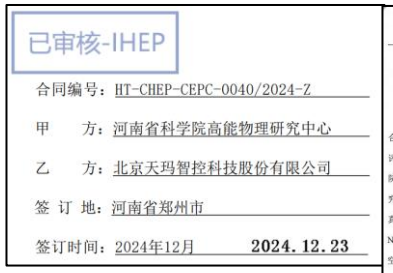
Summary

- The production line for vacuum chamber NEG coating and thermally sprayed heating layers is currently under installation and will be commissioned by March 2026.
- It is capable of handling vacuum chambers with a minimum dimension of 56 mm and a maximum length of 11.5 meters for NEG coating applications. There are no dimensional restrictions for the thermal-sprayed heating layer process.
- Additionally, a 1.5-meter prototype of the thermally sprayed heating layer has been fabricated, with relevant performance tests successfully completed.

Thanks for your attention!

里程碑

一、CEPC真空盒NEG镀膜与加热层喷涂批量生产方法研究装置项目


已审核-IHEP

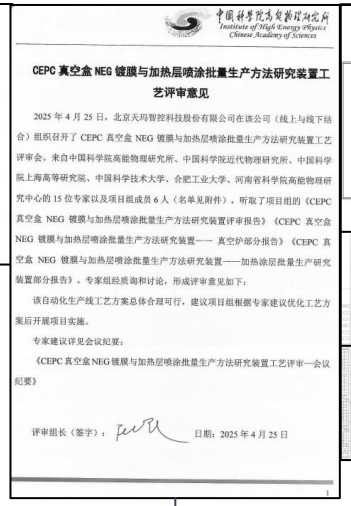
合同编号：HT-CHEP-CEPC-0040/2024-Z

甲　方：河南省科学院高能物理研究中心

乙　方：北京天玛智控科技股份有限公司

签 订 地：河南省郑州市

签订时间：2024年12月　2024.12.23


中国科学院高能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences

CEPC 真空盒 NEG 镀膜与加热层喷涂批量生产方法研究装置工艺评审意见

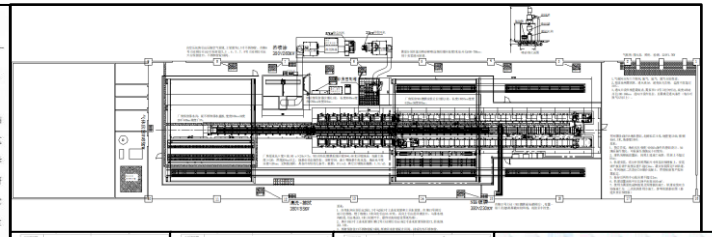
2025 年 4 月 25 日，北京天玛智控科技股份有限公司在该公司（线上与线下结合）组织召开了 CEPC 真空盒 NEG 镀膜与加热层喷涂批量生产方法研究装置工艺评审会。来自中国科学院高能物理研究所、中国科学院近代物理研究所、中国科学院上海高等研究院、中国科学技术大学、合肥工业大学、河南省科学院高能物理研究中心的 15 位专家以及项目组成员 6 人（名单见附件），听取了项目组的《CEPC 真空盒 NEG 镀膜与加热层喷涂批量生产方法研究装置评审报告》《CEPC 真空盒 NEG 镀膜与加热层喷涂批量生产方法研究装置——真空炉部分报告》《CEPC 真空盒 NEG 镀膜与加热层喷涂批量生产方法研究装置——加热涂层批量生产研究装置部分报告》。专家组经质询和讨论，形成评审意见如下：

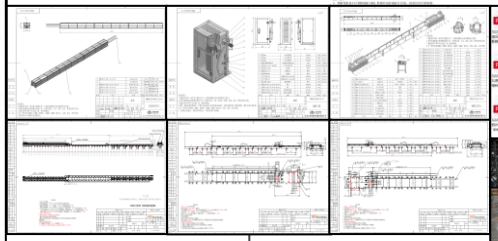
该自动化生产线工艺方案总体合理可行，建议项目组根据专家建议优化工艺方案后开展项目实施。

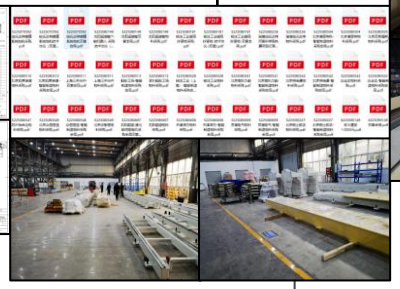
专家建议评见会议纪要：

《CEPC 真空盒NEG 镀膜与加热层喷涂批量生产方法研究装置工艺评审—会议纪要》

评审组长（签字）：　日期：2025 年 4 月 25 日







项目启动

2025年1月

项目于2024年12约23日签订合同，2025年初正式启动。

2025年4月

工艺评审：详细设计后，组织了工艺评审，获得15位专家认可并通过。

2025年6月

设计出图：按评审意见优化方案后，确定了最终实施方案及加工图纸等。

2025年8月

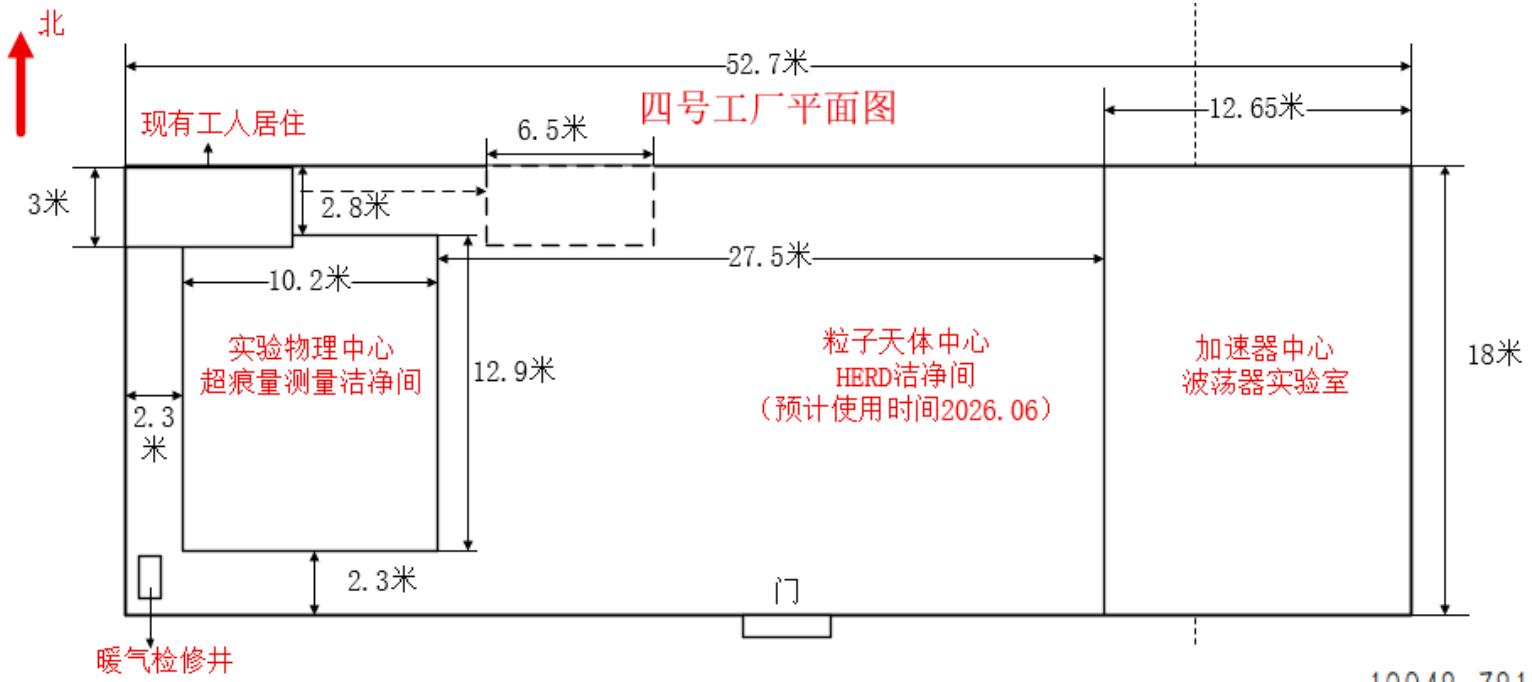
物料采购：根据项目明细，进行加工件、电气元件，非标地轨等采购。

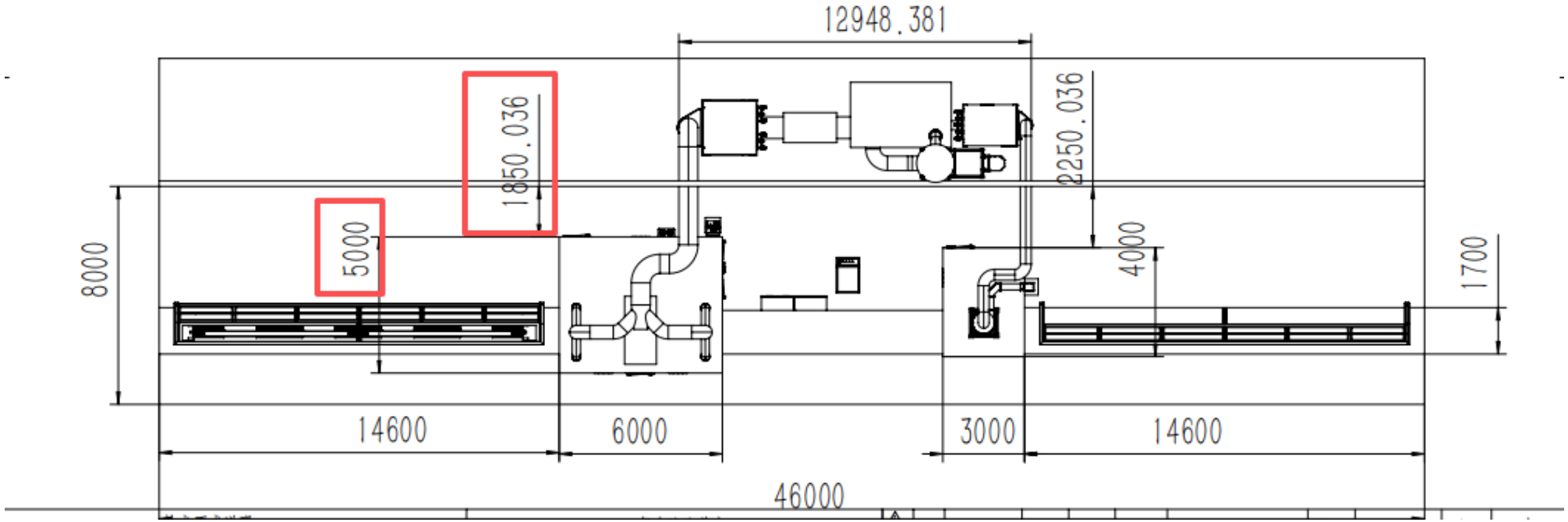
2025年10月

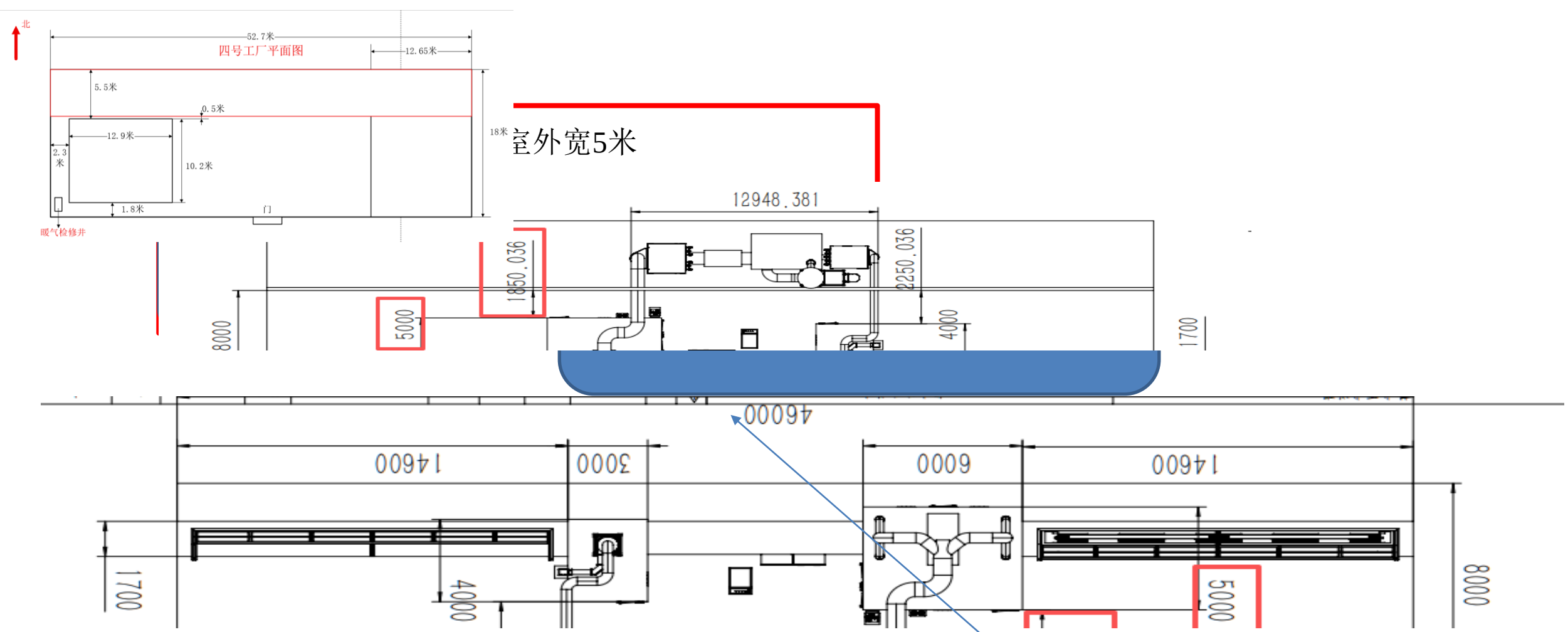
结构安装：安装非标地轨、第七轴地轨机器人及其它机械结构。

2025年12月

电气连接：连接研究装置气路、电路，包括磁开、传感器，驱动器，配电柜等。

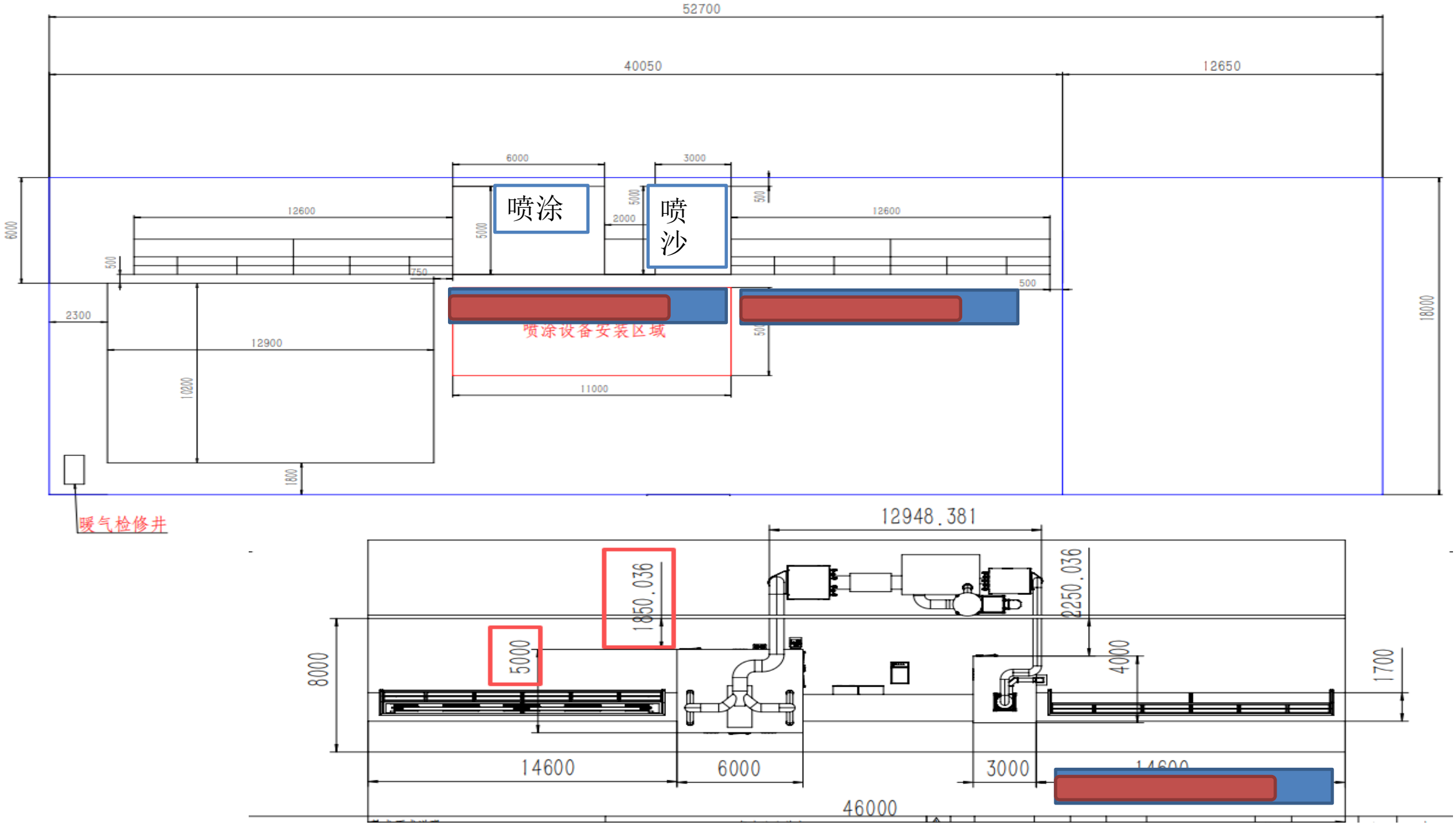

北
四号工厂平面图
现有工人居住
52.7米
6.5米
12.65米
3米
2.8米
27.5米
10.2米
实验物理中心
超痕量测量洁净间
12.9米
粒子天体中心
HERD洁净间
（预计使用时间2026.06）
加速器中心
波荡器实验室
18米
2.3
米
2.3米
门
暖气检修井


12948.381
1850.036
2250.036
5000
8000
4000
1700
14600
6000
3000
14600
46000



原喷涂系统设计总长46米，可为11.5米长真空盒进行外壁加热层喷涂。考虑到所内道路运输，北大厅内部空间有限，可喷涂的工作长度将压缩至7米。这样调整后室内占地长度也将压缩为37米，以匹配北大厅场地。从技术角度7米已经足够验证技术难度与工艺各项参数。

综合以上考虑，喷涂设备室外占地尺寸为长×宽：13×5 m^2，室内占地为长×宽：37×5m^2。图2红色方框为喷涂设备拟占用空间。


52700
40050
12650
6000
3000
喷涂
喷沙
12600
12600
5000
2000
5000
500
500
6000
750
500
2300
12900
10200
1800
喷涂设备安装区域
11000
18000
暖气检修井
12948.381
1850.036
2250.036
5000
8000
4000
1700
14600
6000
3000
14600
46000