



Development of Equipment for Accelerator at HE Racing

Zhang Zhanjun

Beijing HE-Racing Technology Co., Ltd.

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Nanjing



Outline



Brief Introduction



Superconducting Cavities



Couplers



Accelerating Structure & RT Cavities



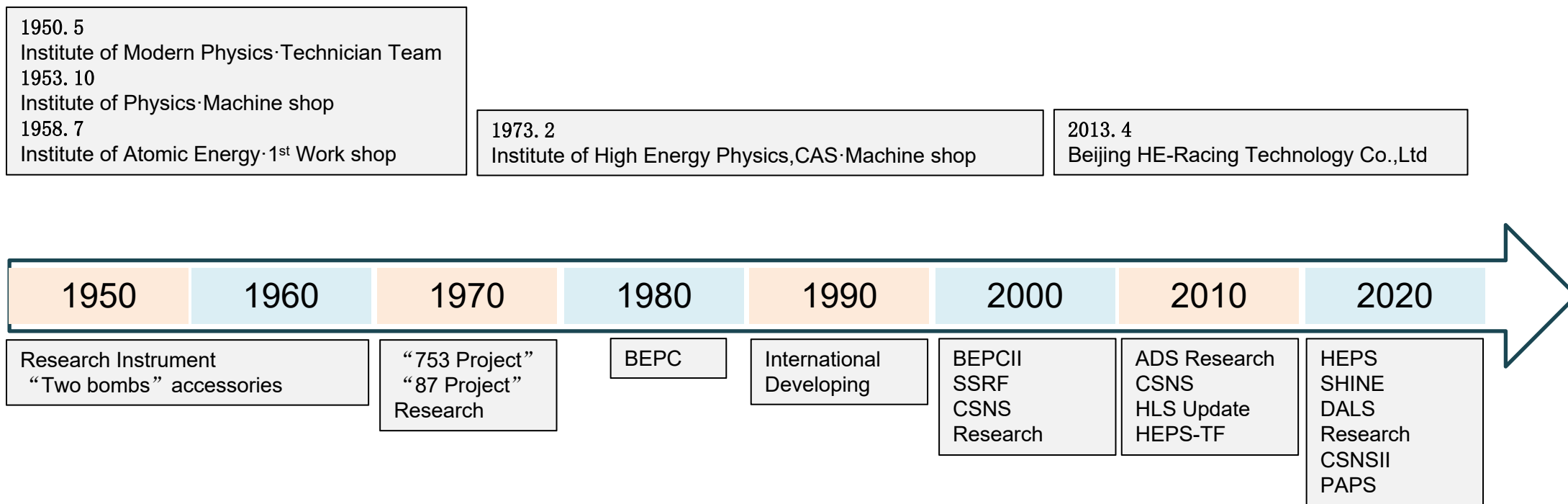
Cryomodules



Summary

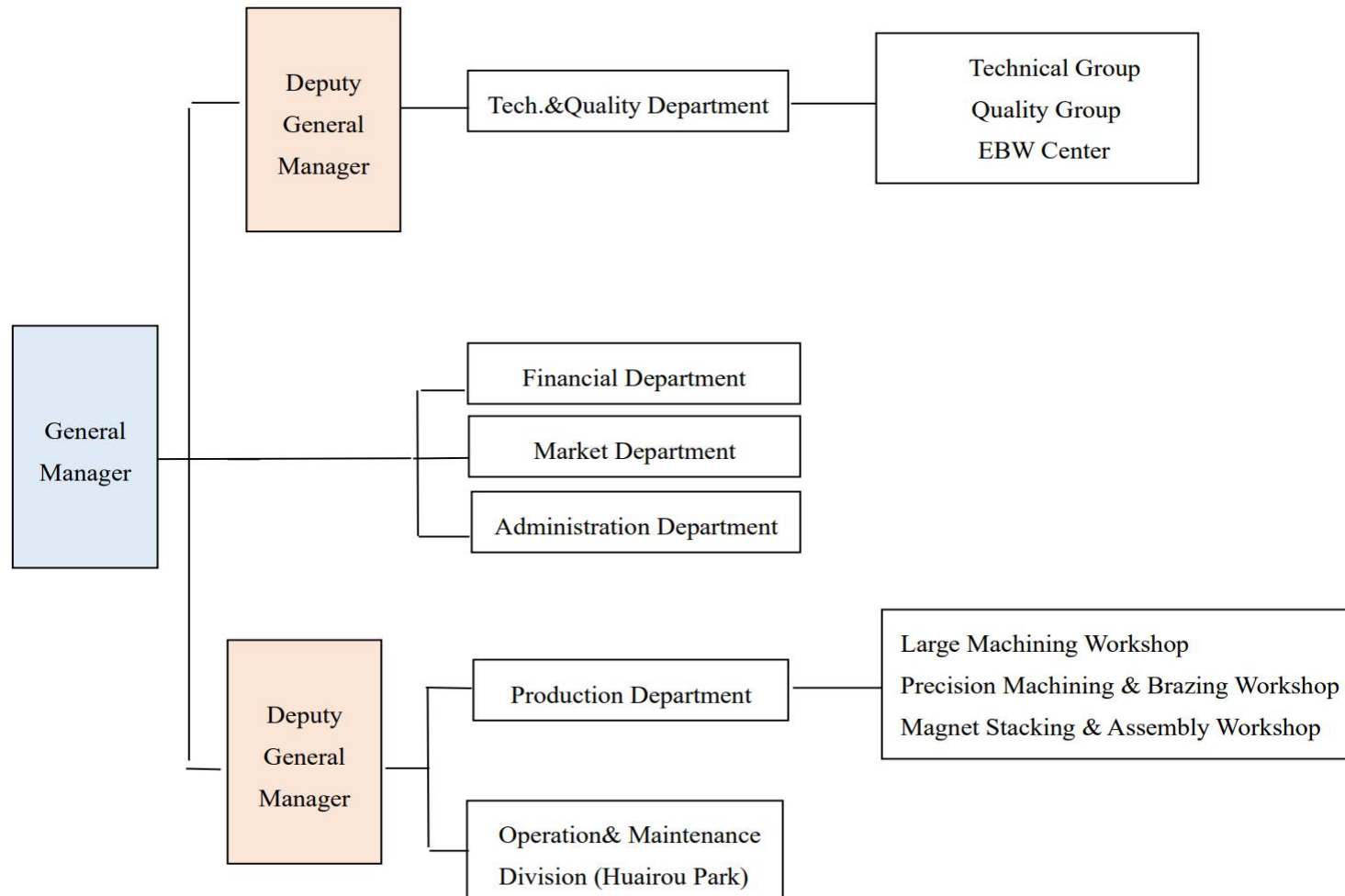
1. Brief Introduction

■ History



1. Brief Introduction

■ Organization Structure



1. Brief Introduction

■ Main Products:

- ◆ Magnets and Insertion Devices
- ◆ Accelerating structures, SLEDs
- ◆ Microwave devices
- ◆ RFQ and DTL
- ◆ Super-conducting Cavities
- ◆ Couplers
- ◆ Cryomodules, etc.

1. Brief Introduction

■ Project and Experience:

- ◆ BEPC/BEPCII, CSNS, SSRF, HEPS-TF, HLSII, THz, DCLS, SXFEL, CADS, SHINE, HEPS, DALIS, HALF, CSNSII...
- ◆ PLS/PLSII, PAL-FEL, PEFP, KEK-B, FIR/THz, RISP ...
- ◆ PEP-II, SPEAR3, NSLSII, CLS, ILC-ATF2, LCLSII...
- ◆ SPARK, LEG, E-XFEL, MAXIV, FERMI-Eletta, KIPAC-ADS ...

1. Brief Introduction

■ Machining Tools and Equipment:

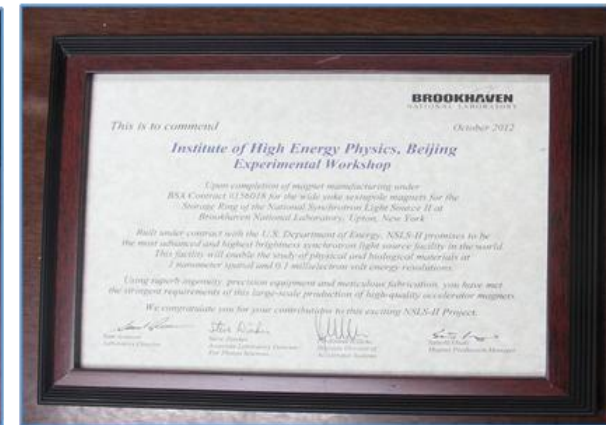
(Total >500 sets)

编号	设备名称	品牌	型号	主要技术指标 (行程 (精度)) mm	数量
1	加工中心	山崎马扎克	LGMazak	X/Y/Z:1050×510×560 (0.008)	1
2	加工中心	哈斯	VF6	X/Y/Z:1626×813×762 (0.01)	1
3	加工中心	沈阳机床	VMC 850E	X/Y/Z:850×510×540 (0.02)	3
4	车铣中心	山崎马扎克	LGMazak QTN	直径 Ø380×1033 (0.01)	1
5	车削中心	山崎马扎克	LGMazak Nexus	直径 Ø360×1063 (0.01)	1
6	车削中心	山崎马扎克	LGMazak Nexus	直径 Ø280×300 (0.01)	2
7	线切割	沙迪克	AQ550Ls	X/Y/Z:550×350×320 (0.003)	1
8	线切割	阿奇夏米尔	CA30	X/Y/Z:600×400×350 (0.002)	1
9	氢气炉	北方华创	MHF5060	Φ500×600 (1100℃、±5℃)	1
10	氢气炉	北方华创	MHF3040	Φ300×400 (1100℃、±5℃)	1
11	三坐标	海克斯康	Classical	X/Y/Z:900×1200×800 (0.0026)	1
12	检漏仪	INFICON	UL1000 Fab	最小检漏漏率: 5×10 ⁻¹² mbar•L/s	1
13	真空炉	兰州真空	ZRT-3580-14W5	Φ1150×1650 (1300℃、±5℃)	1
14	电子束焊机	泰克米特	LARA52	X/Y/Z: 3300×1000×1300	1
15	电子束焊机	狮达	THDW-9	X/Y/Z: 1050×500×700	1
16	四柱压力机	山东滕州	YQ32-200T	200T	1
17	网络分析仪	罗德施瓦茨	ZNB8	Max. 8.5GHz	1



1. Brief Introduction

■ Qualifications and Honors:



2. Superconducting Cavities

2.1 Cavities-Parameters List (>80 pieces)

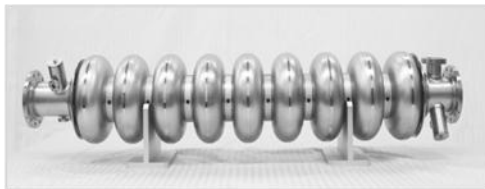
序号	科学装置	腔类型	频率 (MHz)	数量 (支)	测试梯度 (MV/m)	工作状态
1	HEPS-TF	QWR	166.6	2	19	垂测
2	HEPS	QWR	166	3	19	垂测
3	C-ADS	Spoke, $\beta=0.12$	325	4	11.5	带束运行
4	C-ADS	Spoke, $\beta=0.21$	325	5	12	带束运行
5	C-ADS	Spoke, $\beta=0.24$	325	1	11.2	垂测
6	C-ADS	双Spoke, $\beta=0.51$	325	1	16	垂测
7	CSNSII	双Spoke, $\beta=0.51$	325	1	11	垂测
8	RISP	Spoke, $\beta=0.51$	325	7	11	垂测
9	HALS	单cell 椭球腔	500	1	16	垂测 (4K)
10	HEPS	单cell 椭球腔	500	1	16	垂测 (4K)
11	CEPC	2 cell 椭球腔	650	1	24	垂测
12	CEPC	5 cell 椭球腔	650	1	12	垂测 (4K)
13	PAPS	2 Cell 椭球腔	650	3	36	垂测
14	PAPS&SHINE	单cell 椭球腔	1300	28	43	垂测
15	ILC R&D	9 cell 椭球腔	1300	1	24	垂测
16	PAPS	9 cell 椭球腔	1300	2	25	垂测
17	SHINE	9 cell 椭球腔	1300	8	25	水平
18	DALS	9 cell 椭球腔	1300	8	27	垂测

2. Superconducting Cavities

2.2 Cavities-Pictures



Spoke 024
第一支超导腔
(325MHz)



9 Cell 超导腔
第一支椭圆腔
(1.3GHz)



2 Cell 超导腔
5 Cell 超导腔
(650MHz)



双Spoke腔
(325MHz)



Spoke 051
SSR2超导腔
(325MHz)



QWR Cavity
HEPS超导腔
(166.7MHz)

2014

2015

2016

2017

2018

2019

2020

2021

Spoke 012
ADS 注入器超导腔
小批量生产



Spoke 021
ADS 主加速器超导腔
小批量生产



HEPS-TF超导腔
第一支QWR超导腔
(166.7MHz)



高Q值1.3GHz 9 Cell
高Q值1.3GHz 单 Cell



Cavity
HLS 超导腔
(500MHz)



SRF Cavities

2. Superconducting Cavities

2.2 Cavities-Pictures

PAPS
2Cell 椭球腔
(650MHz)



CSNSII
双Spoke 051
(325MHz)



HEPS
单Cell 椭球腔
(500MHz)



DALS
9Cell 高Q椭球腔 (1300MHz)



2021

SHINE
9Cell 高Q椭球腔
(1300MHz)



2022

HALF
单Cell 椭球腔
(500MHz)

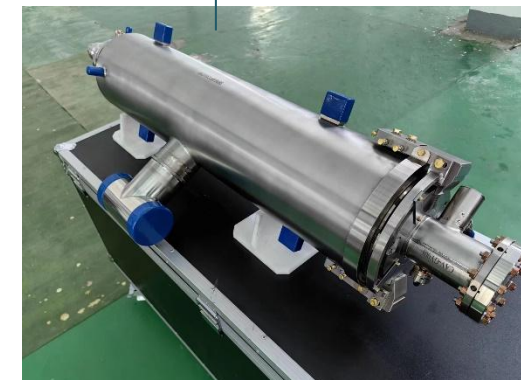


HEPS
QWR腔
(166MHz)



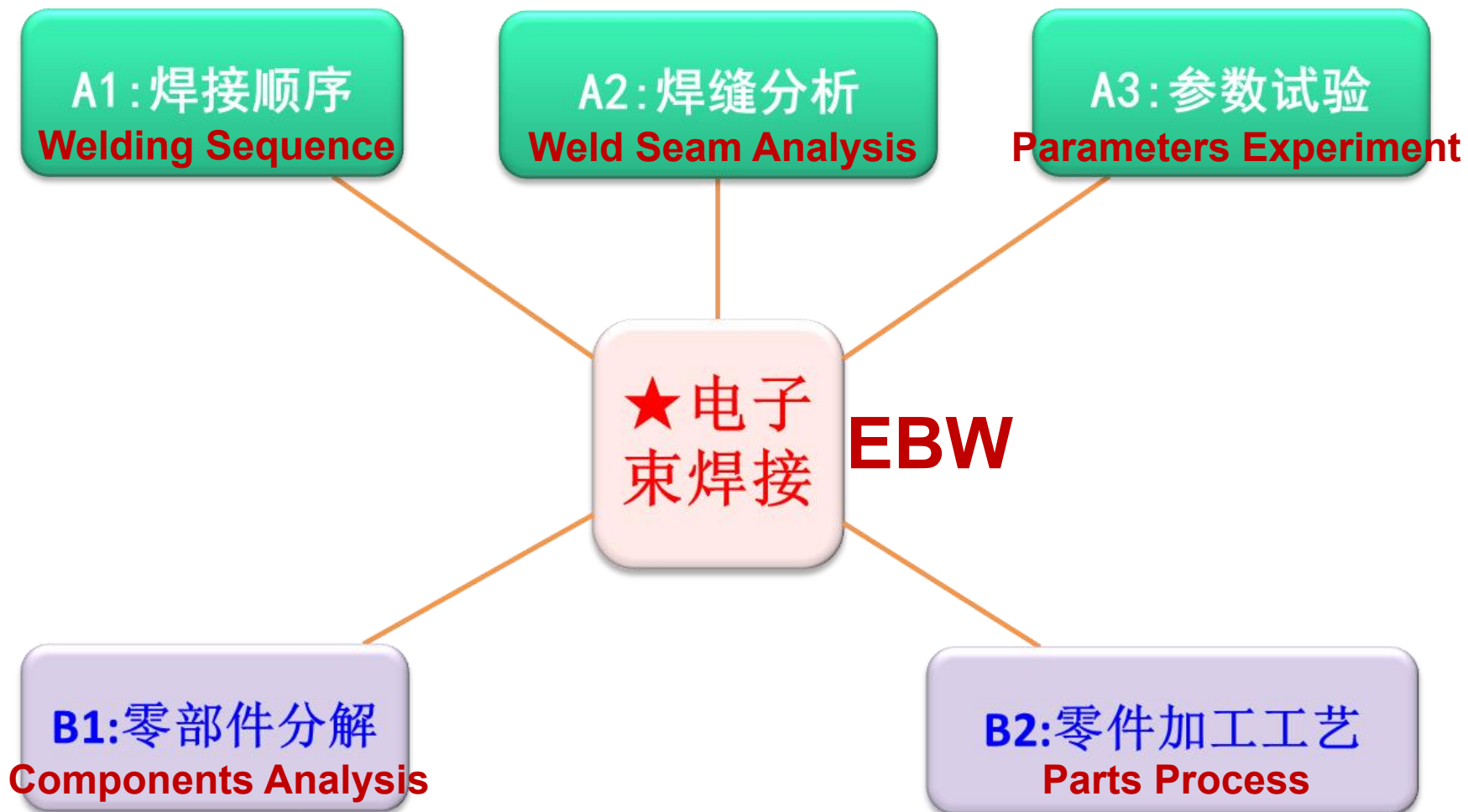
2023

SHINE
(1300MHz)



2. Superconducting Cavities

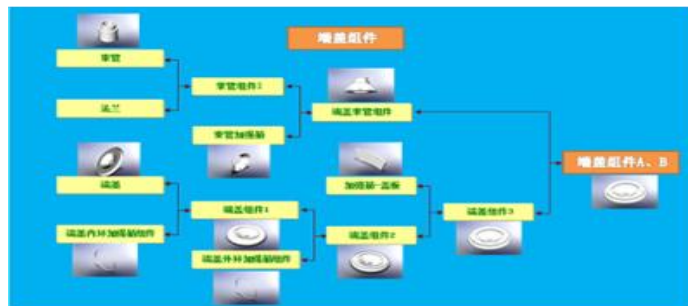
2.3 Cavities-Manufacture key Process (Five Elements)



2. Superconducting Cavities

2.3 Cavities-Manufacture key Process (Example: Spoke Cavities)

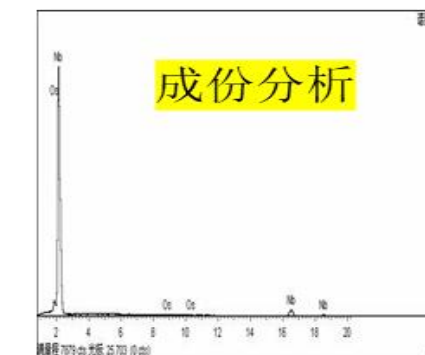
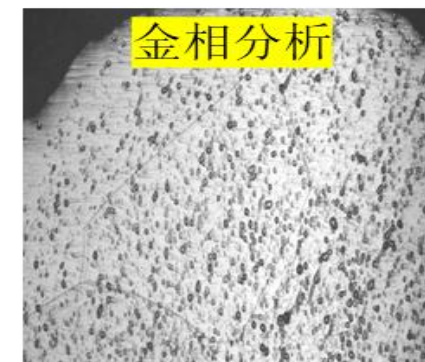
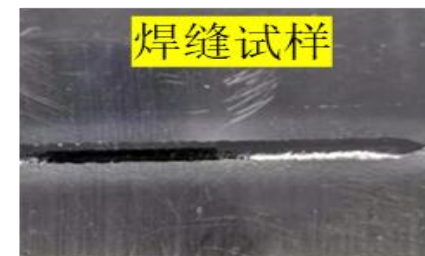
A1: 焊接顺序



A2: 焊缝分析

序号	零件/组件名称	零件/组件名称	焊缝类型	成型要求	焊缝数量	质量等级	组成材质	备注
1	端盖束管	束管加强筋	环焊缝	正面成型	2	★★	精铌+粗铌	
12	端盖束管组件	束管法兰	环焊缝	正面成型	2	★★	精铌+铌钛合金	
2, 3	端盖束管组件	端盖	环焊缝	正面成型	$(1+1) \times 2$	★★	精铌+精铌	
4, 5	端盖组件	加强筋外环	环焊缝	正面成型	$(1+1) \times 2$	★	精铌+粗铌	
6, 7	端盖组件1	加强筋内环	环焊缝	正面成型	$(1+1) \times 2$	★	精铌+粗铌	
8	端盖加强筋盖板	端盖螺母	环焊缝	正面成型	16×2	★★	铌钛合金+粗铌	注意安装位置
9	加强筋盖板组件	加强筋盖板组件	直线焊缝	正面成型	8×2	★★	粗铌+粗铌	注意安装位置
10, 11	加强筋盖板组件1	端盖组件2	直线焊缝	正面成型	$(1+1) \times 2$	★★	粗铌+粗铌	注意安装位置

A3: 参数试验



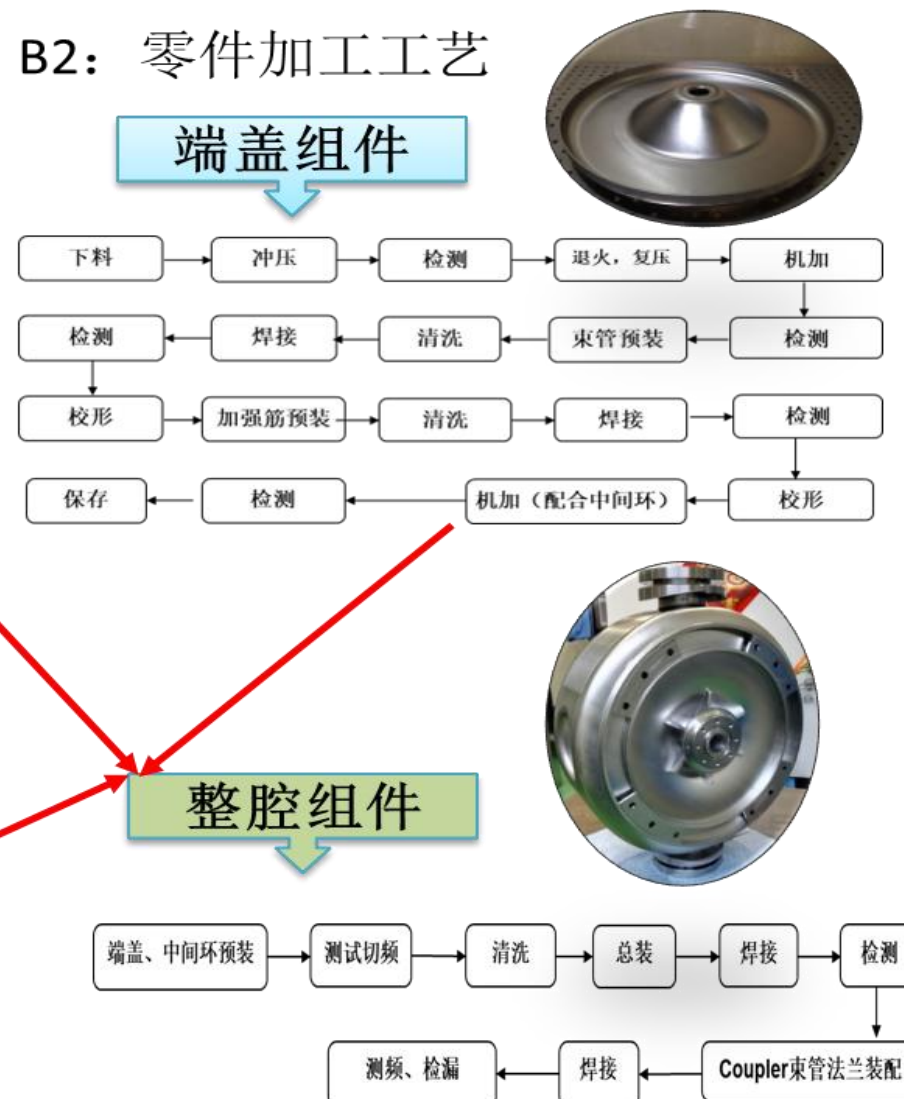
2. Superconducting Cavities

2.3 Cavities-Manufacture key Process (Example: Spoke Cavities)

B1: 零部件分解



B2: 零件加工工艺



2. Superconducting Cavities

2.4 Cavities-High performance 1.3GHz 9 Cell cavity

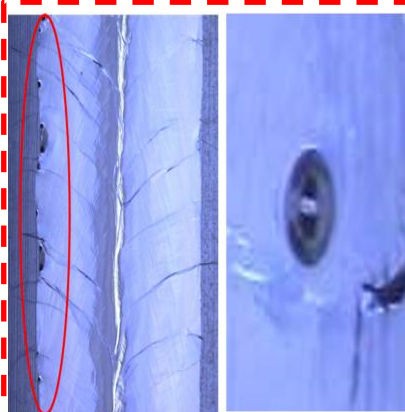
A. Improve welding quality--- **Eacc**

★Single cavity: **45MV/m**;

★ 9cell cavity: **24MV/m to 30-35MV/m**;

B. Improve surface quality--- **Ra1.6 to Ra0.4**;

C. Update equipment to increase efficiency--- **General welding,**
3days to 1.5 days/cavity;



焊缝（2016年）



焊缝（优化后）



腔碗（抛光前）



腔碗（抛光后）



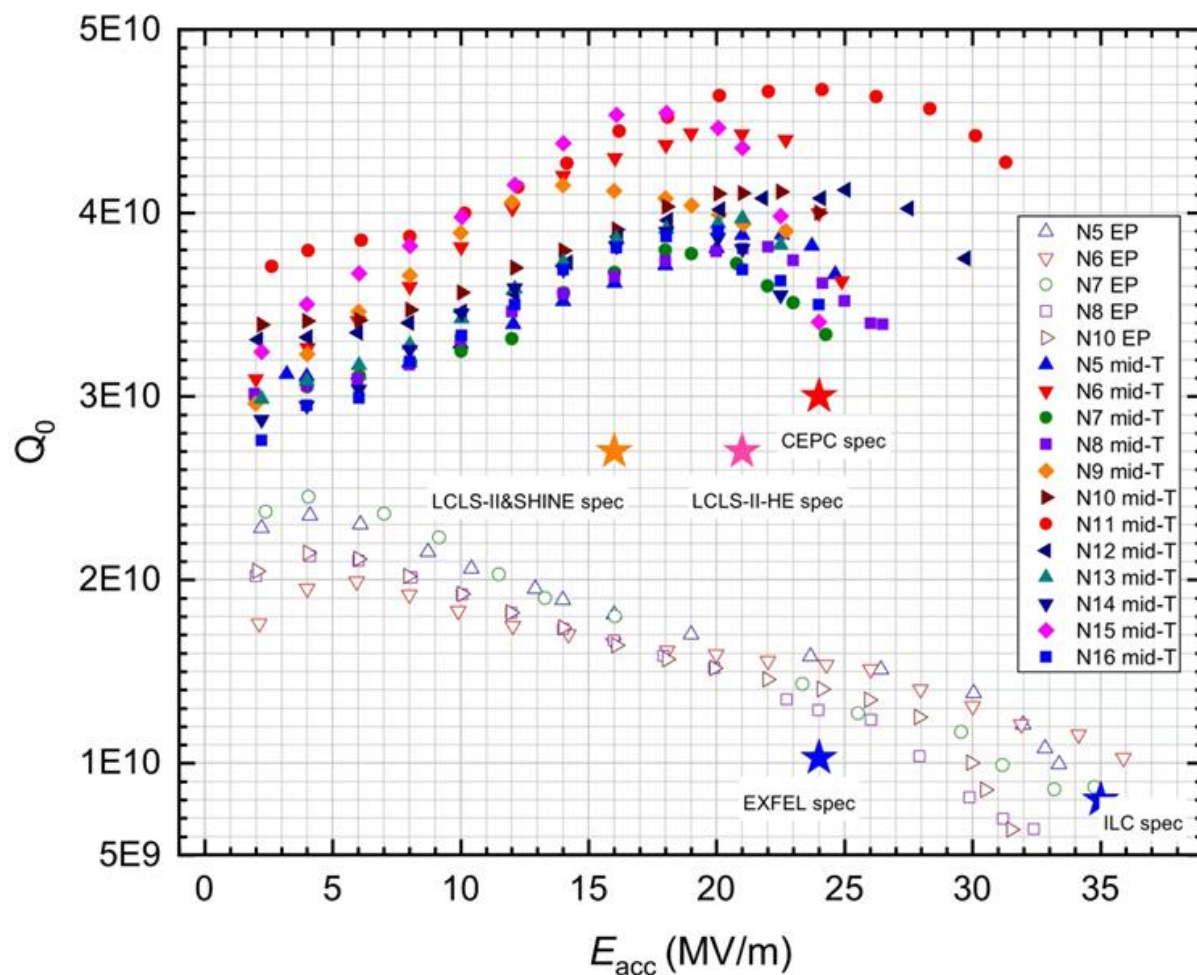
Cryotrap



N2 Cooling system

2. Superconducting Cavities

2.4 Cavities-High performance 1.3GHz 9 Cell cavity



9cell cavities test results (Jiyuan Zhai)



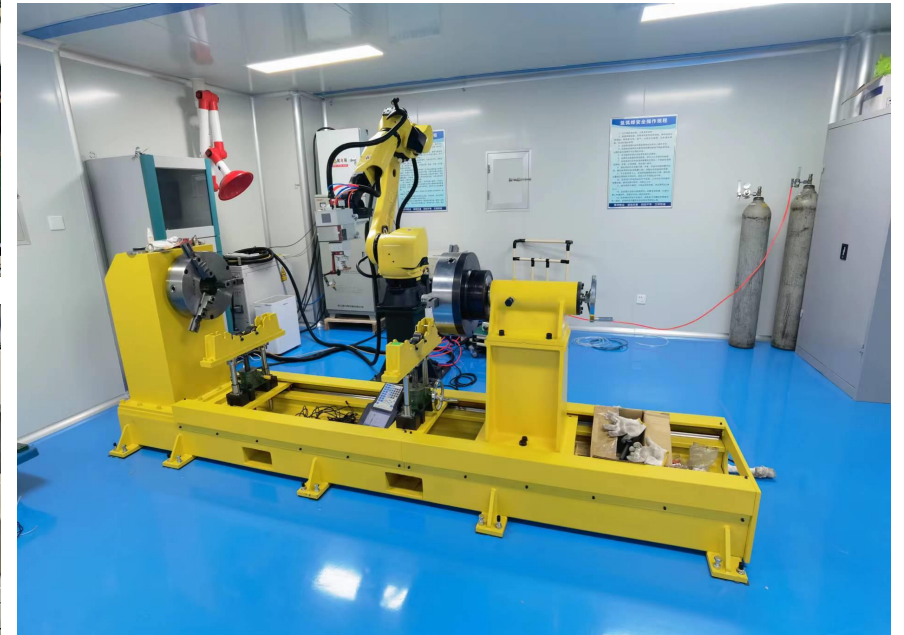
Technical Team (HERT)

2. Superconducting Cavities

2.5 Cavities- **Welding machine for mass production**



EBW machine (3 set)



Laser Welding machine

3. Couplers

3.1 Couplers-Parameters List (66 sets)

序号	科学装置	腔类型	频率 (MHz)	耦合器类型	数量	工作状态	功率指标
1	HALF	DTL (NC)	80	同轴单窗	2	运行	
2	IBS	HWR (SCC)	162.5	同轴单窗	2	测试	
3	C-ADS	HWR (SCC)	162.5	同轴单窗	2	运行	连续波15kW
4	HEPS-TF	QWR (SCC)	166.6	同轴单窗	2	测试	
5	HEPS	QWR (SCC)	166	同轴单窗	2	测试	行波250kW, 驻波100kW
6	CSNS	Spoke (SCC)	324	同轴单窗	2	测试	行波300kW, 占空比5%
7	C-ADS	RFQ (NC)	325	同轴单窗	8	运行	
8	C-ADS	Spoke (SCC)	325	同轴单窗	7	运行	连续波10kW
9	C-ADS	Buncher (NC)	325	同轴单窗	3	运行	连续波7kW
10	CSNS	RFQ (NC)	325	同轴单窗	5	运行	
11	BNCT	RFQ (NC)	325	同轴单窗	5	运行	95kW, 占空比80%
12	BEPCII	1 cell (SCC)	500	同轴单窗	4	运行	行波250kW, 驻波100kW
13	HEPS	5Cell (NC)	500	同轴单窗	2	测试	行波250kW, 驻波100kW
14	PAPS	20cell (SCC)	650	可调单窗	2	研制	
15	ILC R&D	9cell (SCC)	1300	可调双窗	2	测试	
16	SHINE	9cell (SCC)	1300	可调双窗	8	测试	连续波14kW; 驻波7kW
17	DALS	9cell (SCC)	1300	可调双窗	8	测试	连续波14kW; 驻波7kW

3. Couplers

3.2 Couplers-Pictures



325MHz-ADS



324MHz-CSNS



162.5MHz-CADS



325MHz-ADS



500MHz-BEPC II

2012

2013

2014

2015

2016

3. Couplers

3.2 Couplers-Pictures



1. 3GHz-自然基金



352MHz-BNCT



650MHz/1. 3GHz-CEPC



1. 3GHz-SHINE



166. 6MHz-HEPS TF

2017

2018

2019



3. Couplers

3.2 Couplers-Pictures



325MHz-RISP



500MHz-南方光源



324MHz-南方光源



166MHz-HEPS



1300MHz-DALS

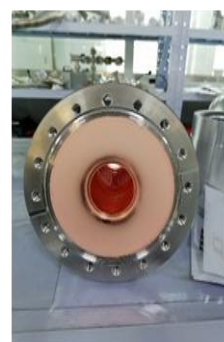
2020

2021

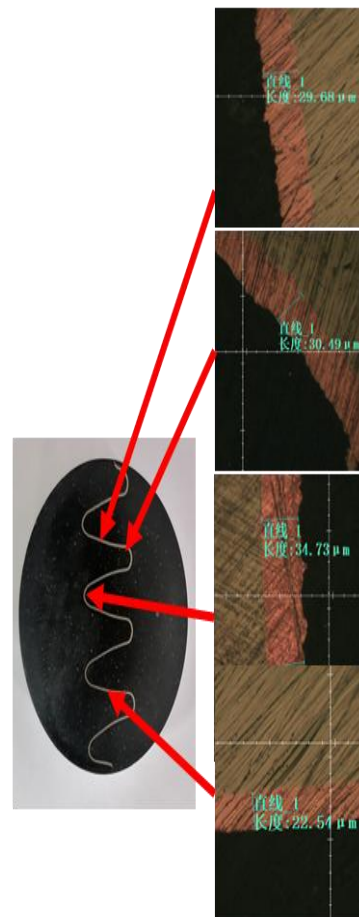
2022

3. Couplers

3.3 Couplers-Special process



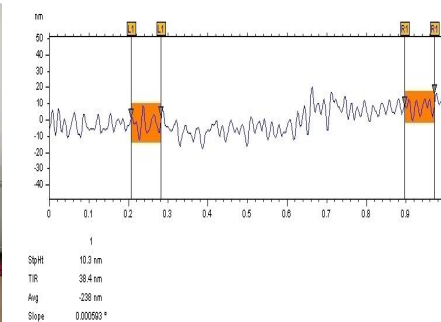
Thickness (um)							
peak	26	24	30	19	23	29	33
valley	29	33	29	27	34	35	35
slope	36	37	29	32	28	30	26
	32	28	36	22	28	30	28
pipe	36	35	37	35	35	32	31



Copper Plating



Ceramic Window Brazing



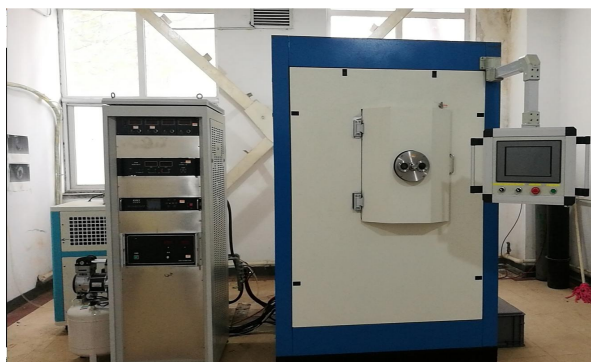
TiN Coating

3. Couplers

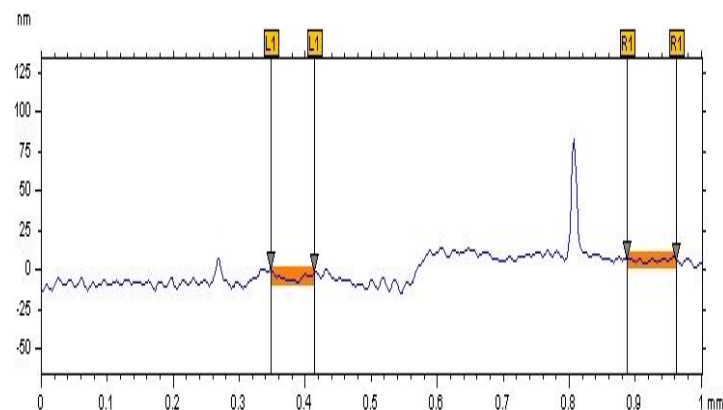
3.3 Couplers- TiN Thickness measurement



Samples

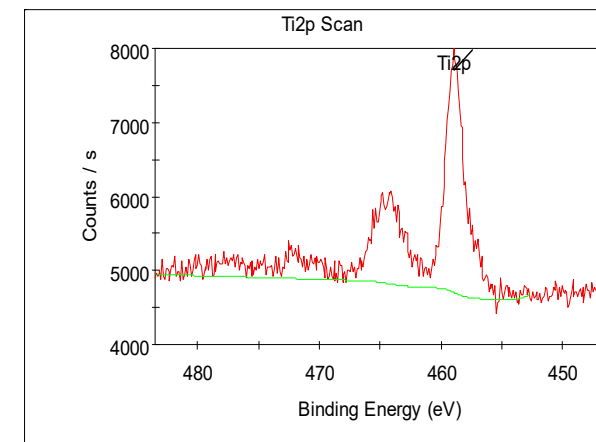


TiN Coating Oven

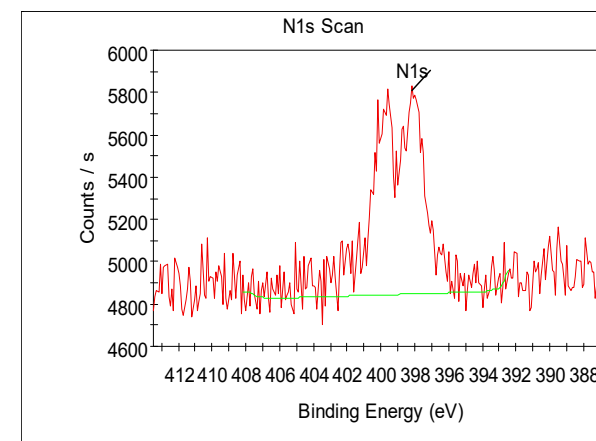


1
StpHt 10.8 nm
TIR 98.8 nm
Avg -1508 nm
Slope 0.000781 °

Thickness(10nm)



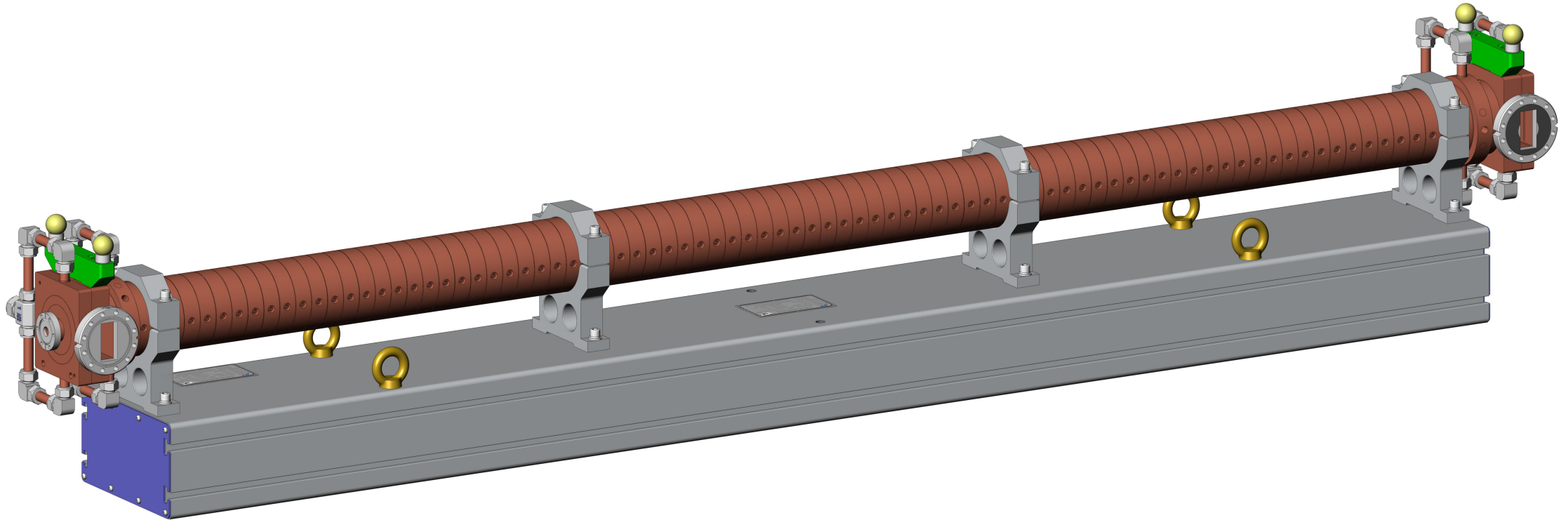
Ingredients of Ti



Ingredients of N

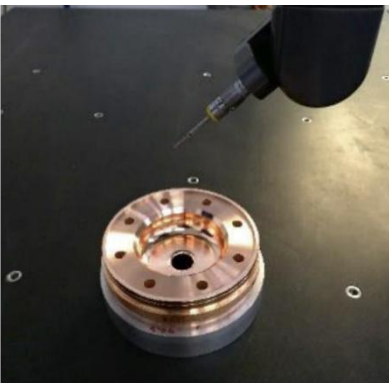
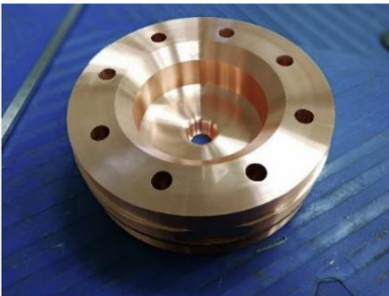
4. Accelerating Structure & RT Cavities

4.1 Accelerating Structure -3D model

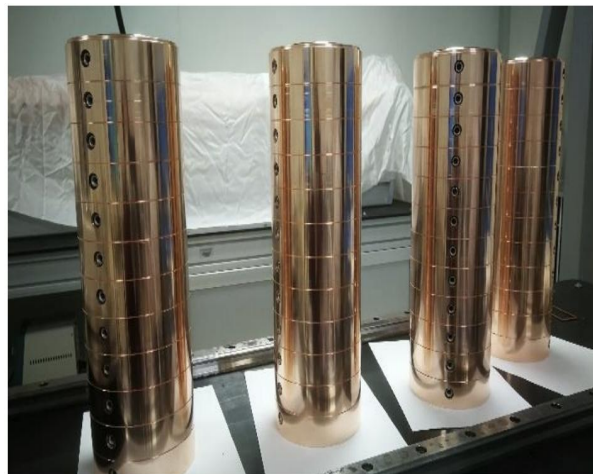


4. Accelerating Structure & RT Cavities

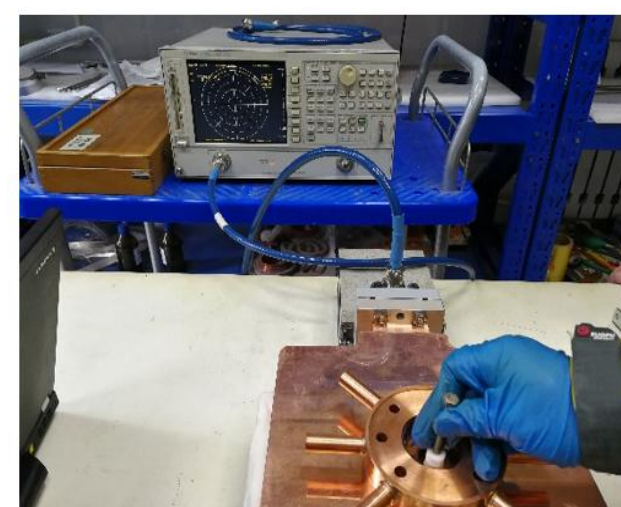
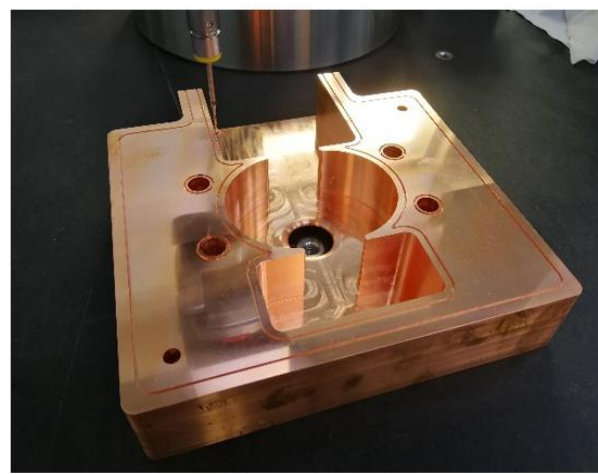
4.1 Accelerating Structure — Inner cooling structure



Machine & Inspection



Welding & Leakage test



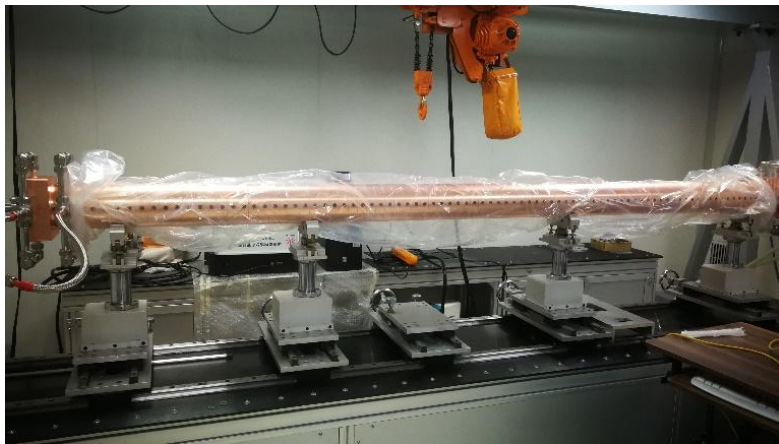
Coupler machining & RF test



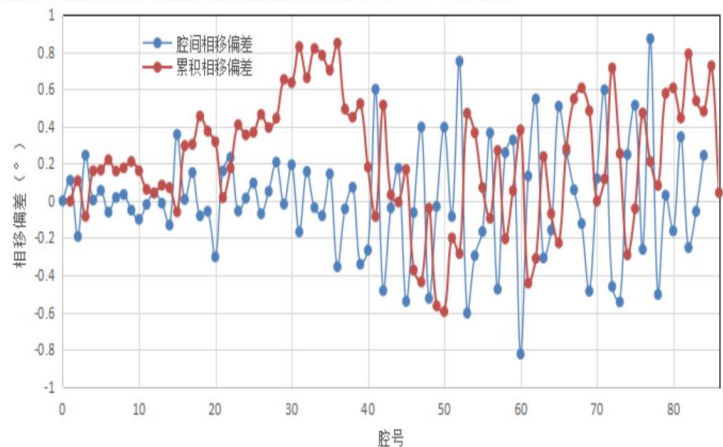
4. Accelerating Structure & RT Cavities

4.1 Accelerating Structure — RF test and tuning

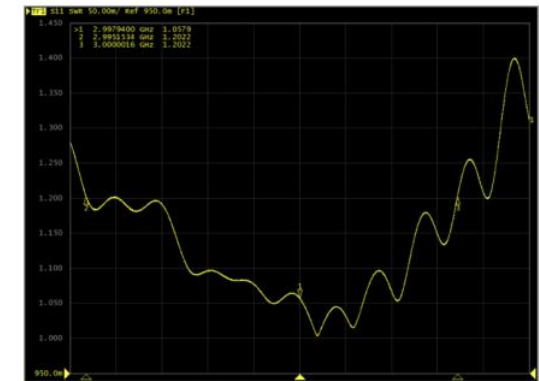
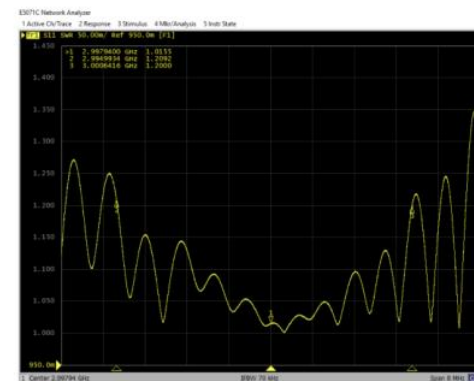
- 将根据采购方的要求，协助进行加速管的测试与调谐



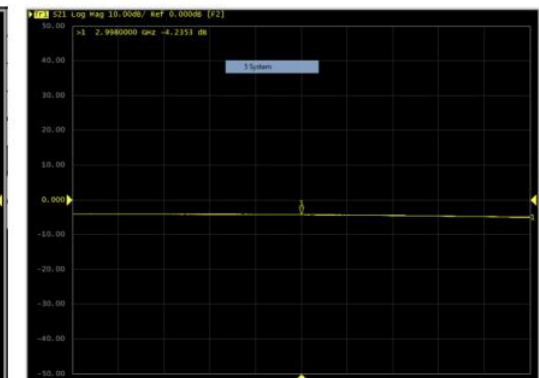
- 调整腔间相移和累积相移误差 $\pm 2^\circ$ 以内



- 完成输入/输出耦合器驻波比测试 (≤ 1.1)

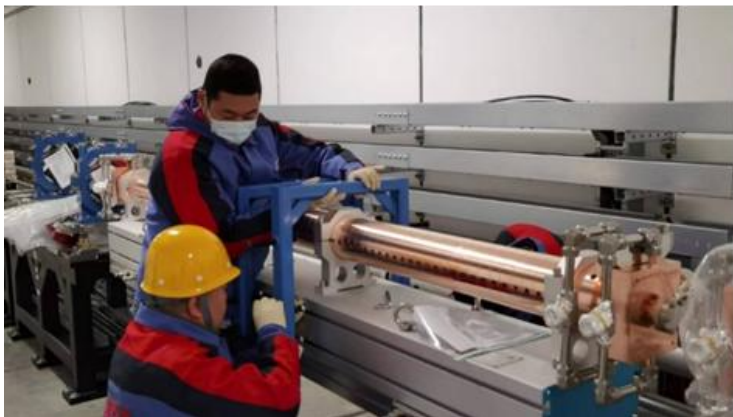
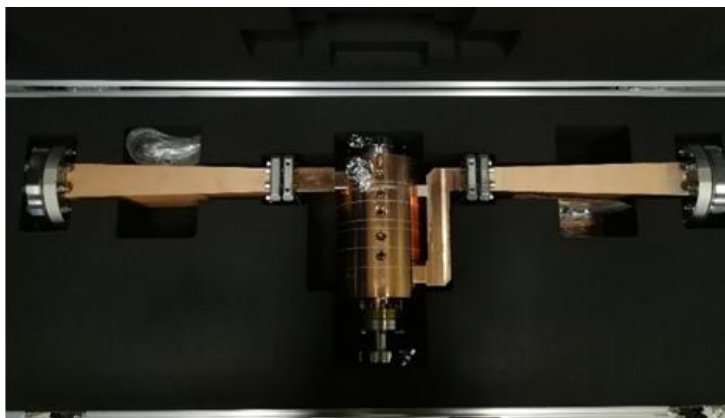


- 填充时间与衰减测试



4. Accelerating Structure & RT Cavities

4.1 Accelerating Structure — General assembly and alignment



4. Accelerating Structure & RT Cavities

4.1 Accelerating Structure —Pass acceptance (2022.4)



HEPS直线加速器加速结构通过测试验收

文章来源: | 发布时间: 2022-05-25 | 【打印】 【关闭】 | 浏览:

4月20日, 中科院高能所高能同步辐射光源 (HEPS) 直线加速器加速结构通过现场测试验收, 达到指标, 满足设计要求。

此次验收由HEPS工程指挥部组织, 对在隧道安装完成后的加速结构进行了现场验收。加速结构的实验室微波调试表明, 各项指标均与设计值吻合; 高功率老练到了22MV/m的加速梯度, 满足物理设计提出的20MV/m要求; 在直线隧道的安装完成后, 工作人员对每根加速管进行了校直, 均达到了物理设计对直线度的要求。

HEPS直线加速器加速结构由加速器中心直线组负责研制和测试, 由北京高能锐新科技有限责任公司加工制造, 总量为9根, 单根长度约3.1m, 其中1根用于聚束系统, 在进行聚束的同时将电子束加速到约50MeV, 其余8根用于主加速段, 将电子束由50MeV加速到500MeV。HEPS加速结构采用弧形腔, 具有更低的表面场强和场致发射, 从而具有更高加速梯度的潜力; HEPS加速结构采用内水冷方案, 使得它的内温度分布更加均匀; 直线加速器加速结构在国内首次采用了 $\lambda g/4$ 型双馈结构耦合器, 工作人员在保证性能优越的同时, 简化了加工工艺。



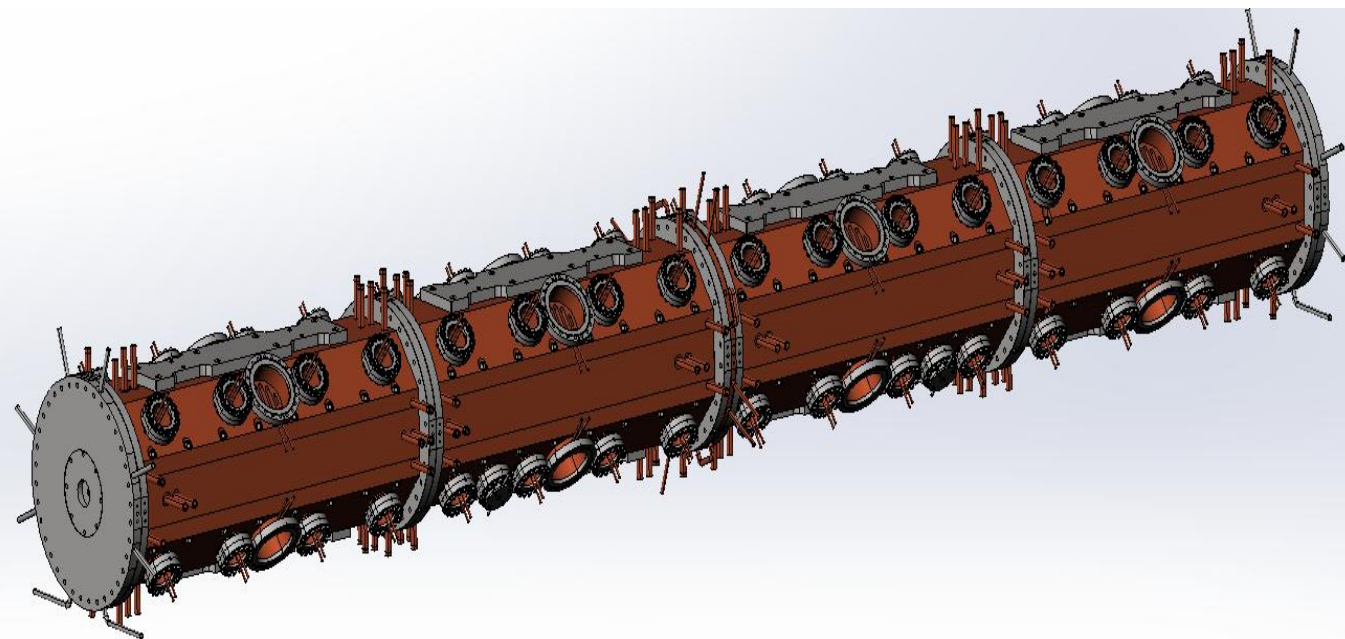
加速结构验收会现场



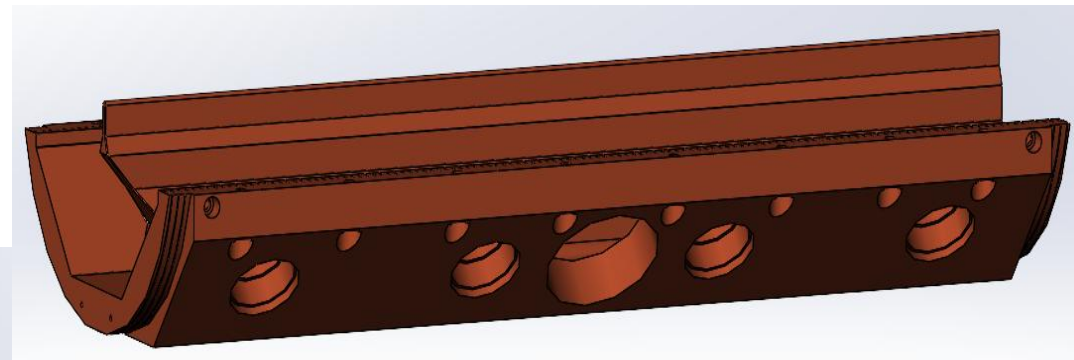
加速结构现场验收合影

4. Accelerating Structure & RT Cavities

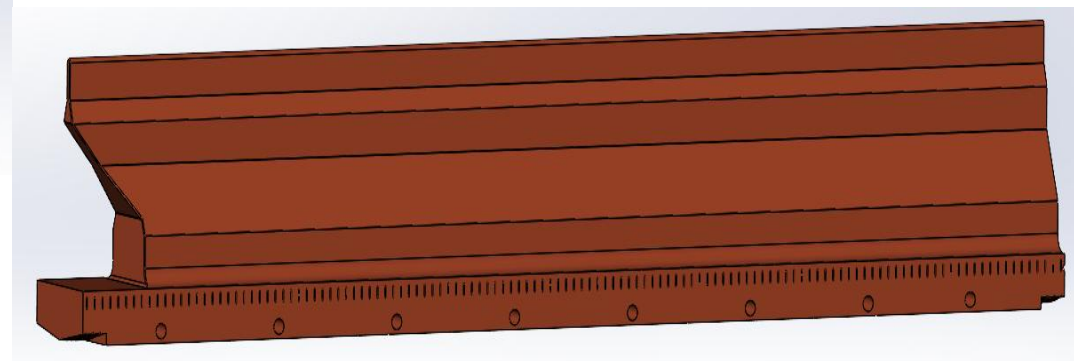
4.2 BNCT 180MHz RFQ-Structures



BNCT RFQ



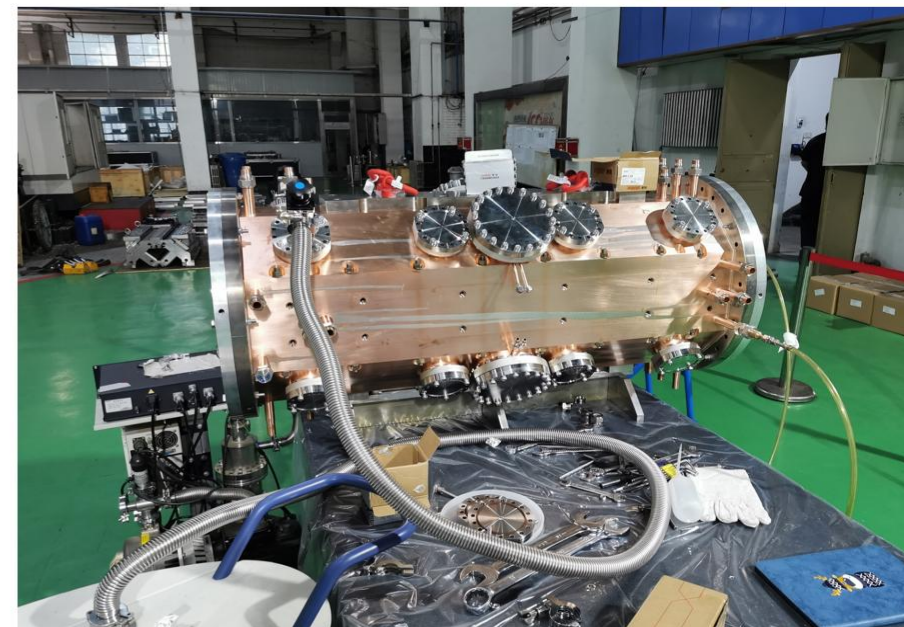
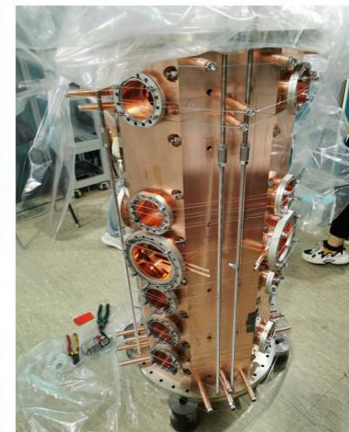
Vertical Pole



Horizontal Pole

4. Accelerating Structure & RT Cavities

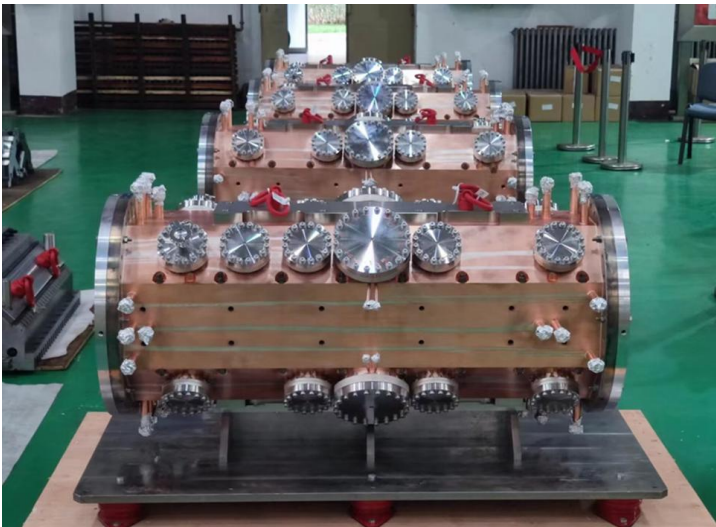
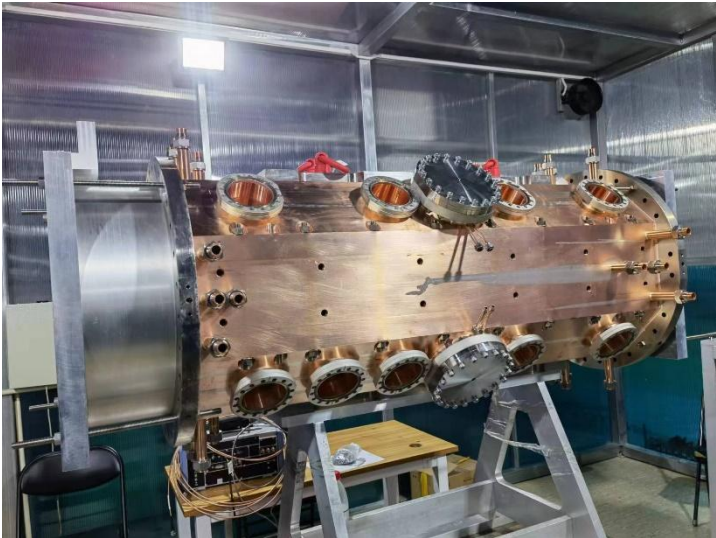
4.2 BNCT 180MHz RFQ-**Assemble, Brazing and Leakage test**



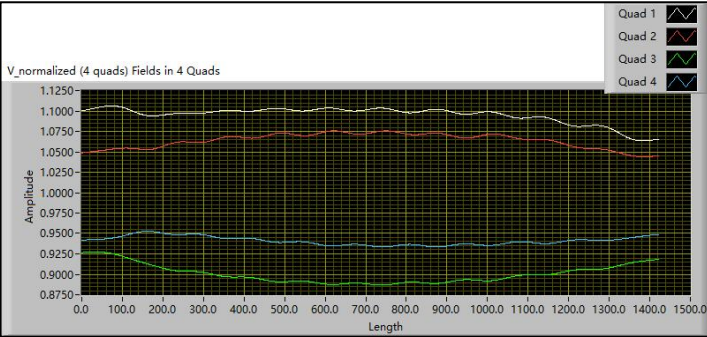
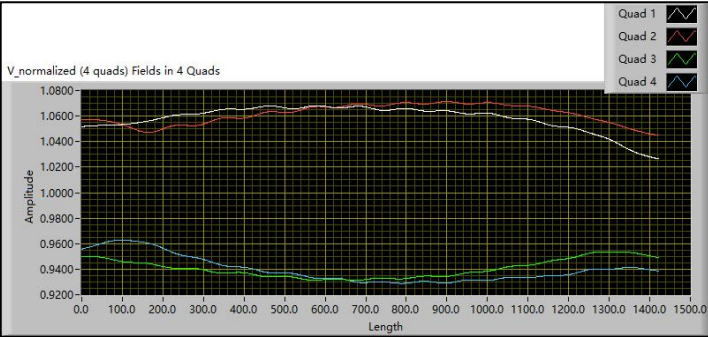
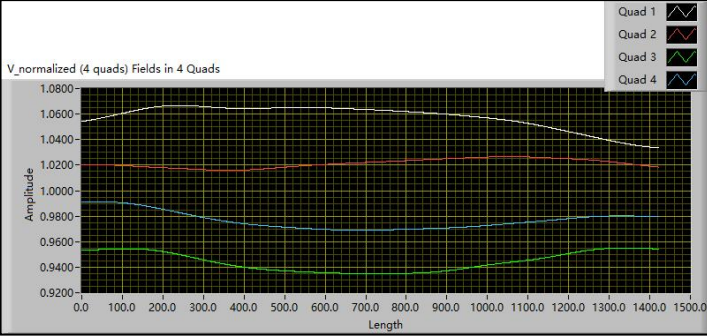
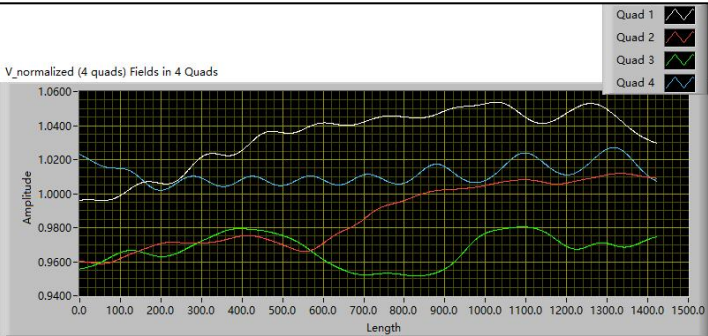
4. Accelerating Structure & RT Cavities



4.2 BNCT 180MHz RFQ-RF test

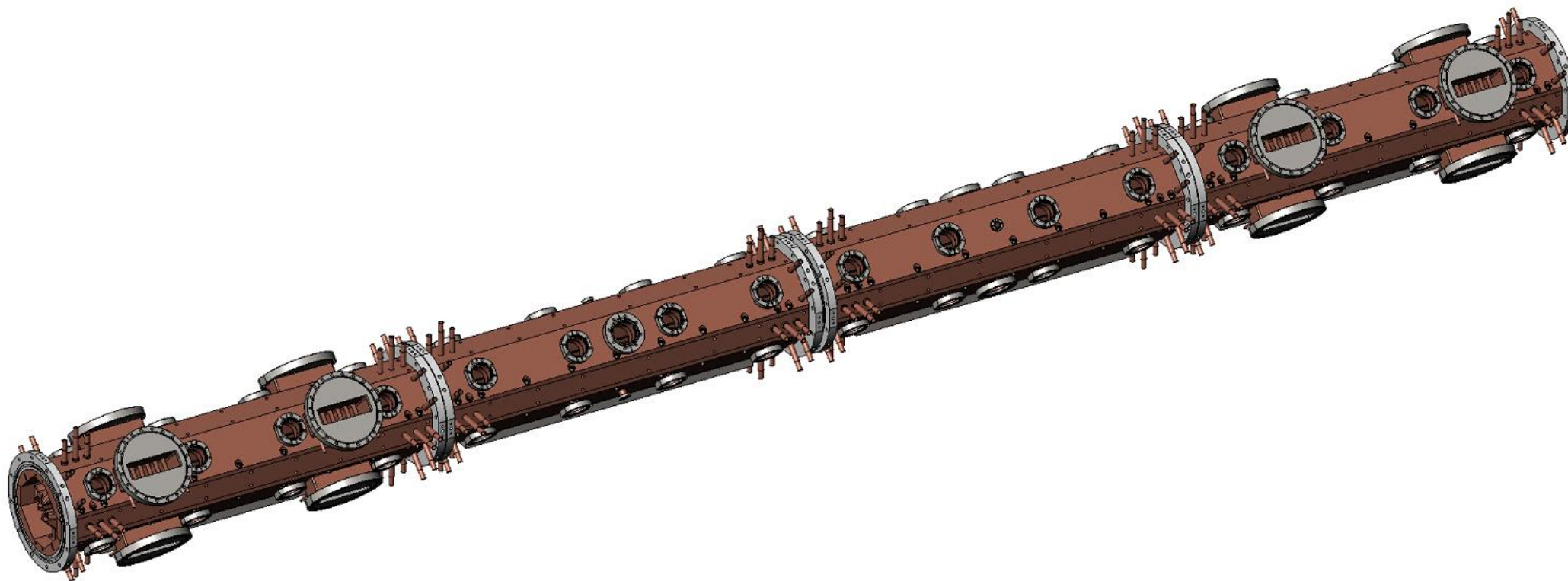


	Content	Section1	Section2	Section3	Section4
before brazing	f MHz	179.365	178.999	178.896	178.960
	field	15%	12.2%	7.6%	5%
after brazing	f MHz	179.341	179.089	178.907	178.952
	field	5.5%	6.8%	7.3%	10.6%
	Δf kHz	24	-90	-11	8



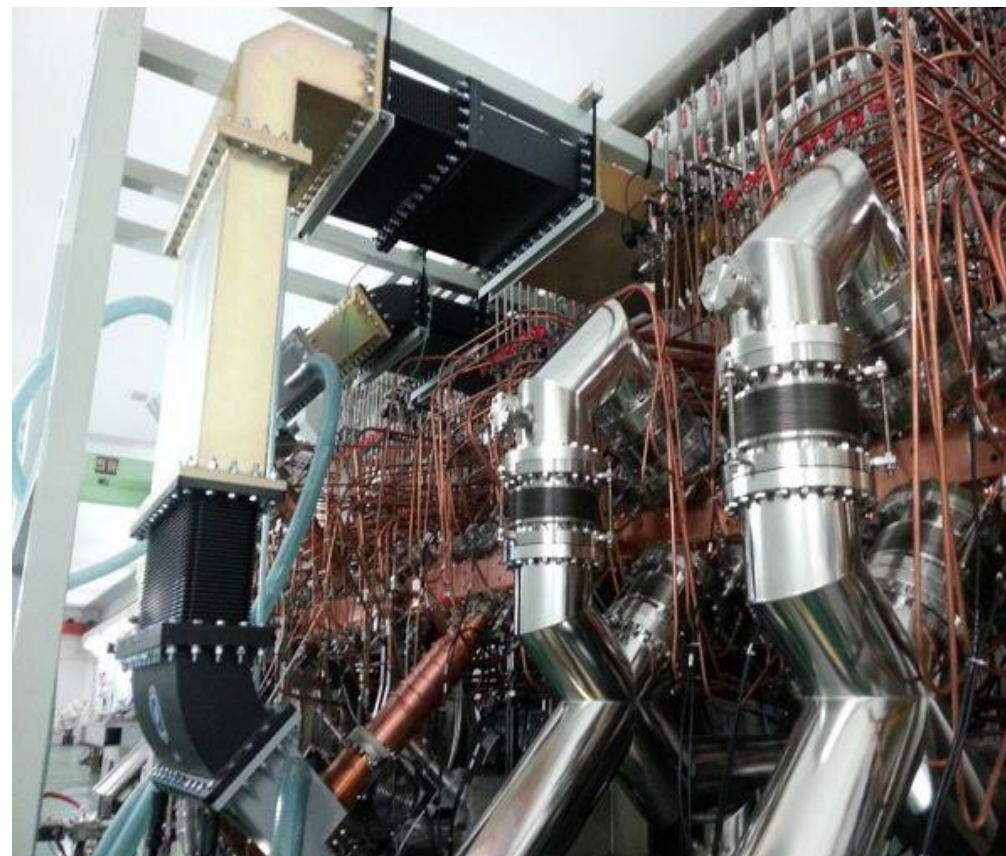
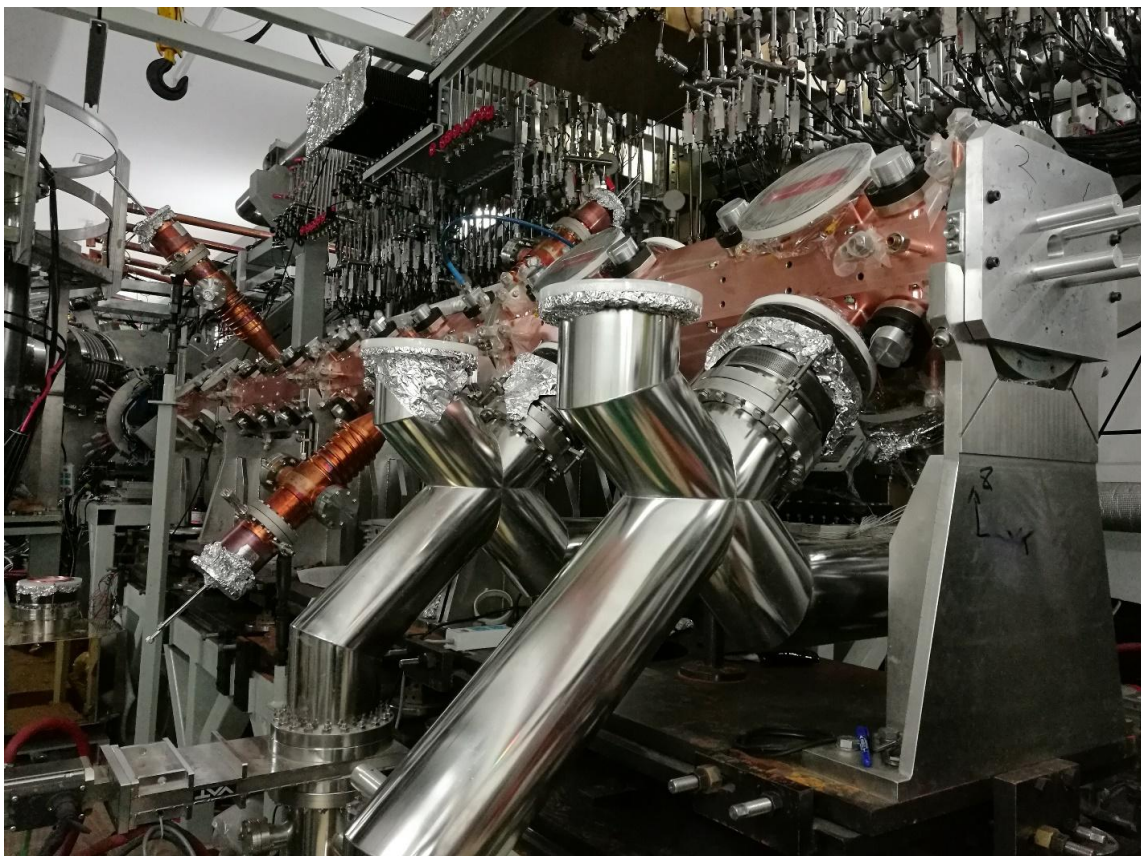
4. Accelerating Structure & RT Cavities

4.3 ADS Injecor I 325MHz RFQ-Structures



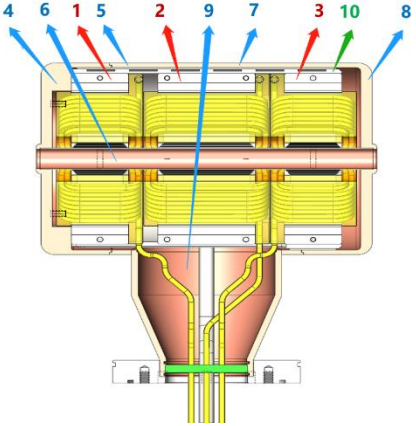
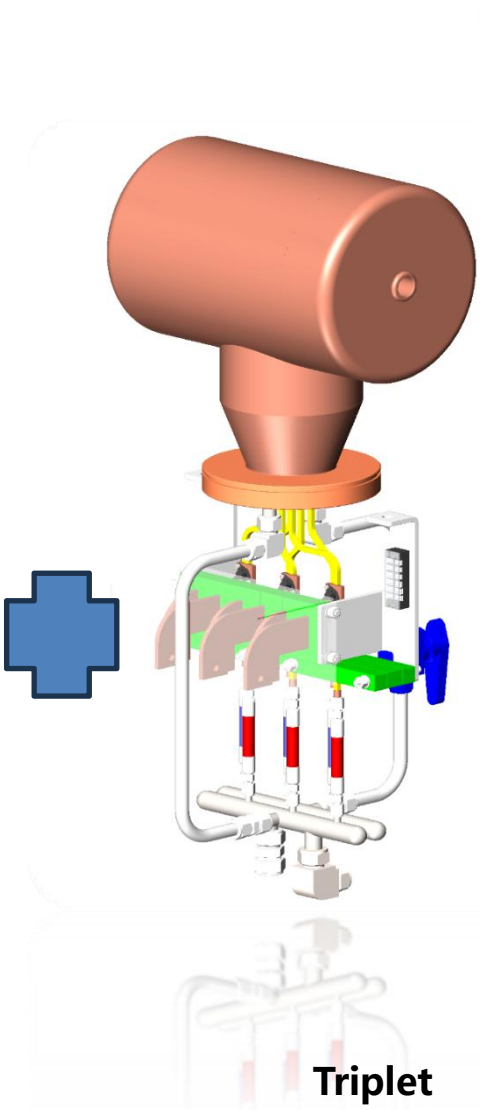
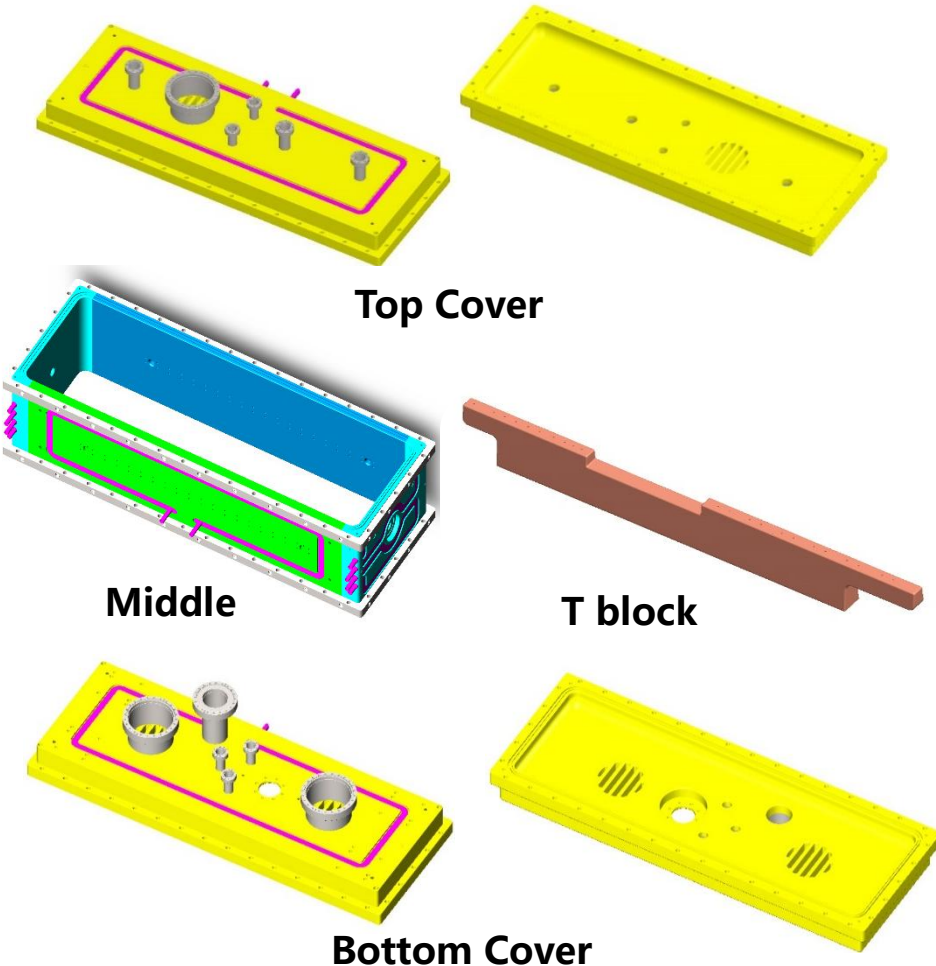
4. Accelerating Structure & RT Cavities

4.3 ADS Injecor I 325MHz RFQ-Cavity in tunnel

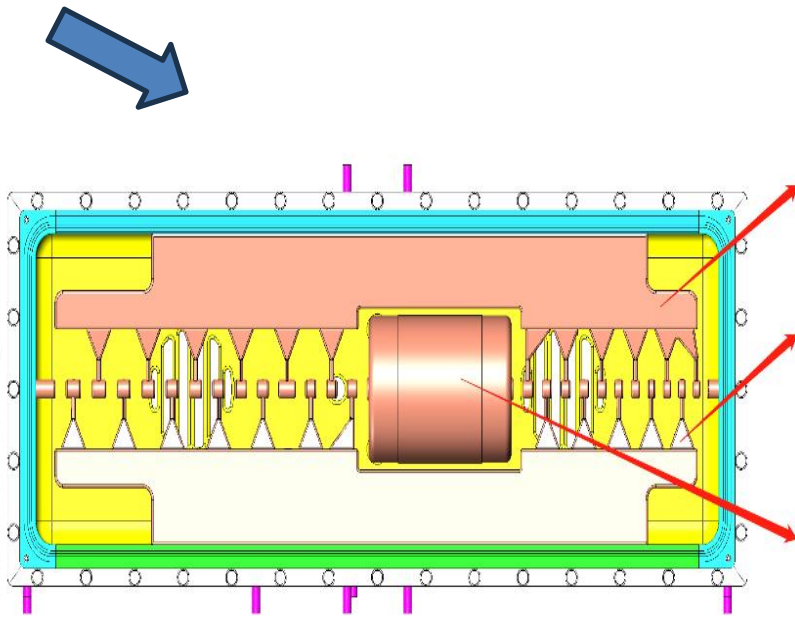


4. Accelerating Structure & RT Cavities

4.4 SESRI DTL-Structures



零部件序号	零部件名称
1	四极磁铁Q6
2	四极磁铁Q7
3	四极磁铁Q8
4	低能端盖
5	中间环一
6	束管
7	中间环二
8	高能端盖
9	支撑杆
10	外壳冷却水套

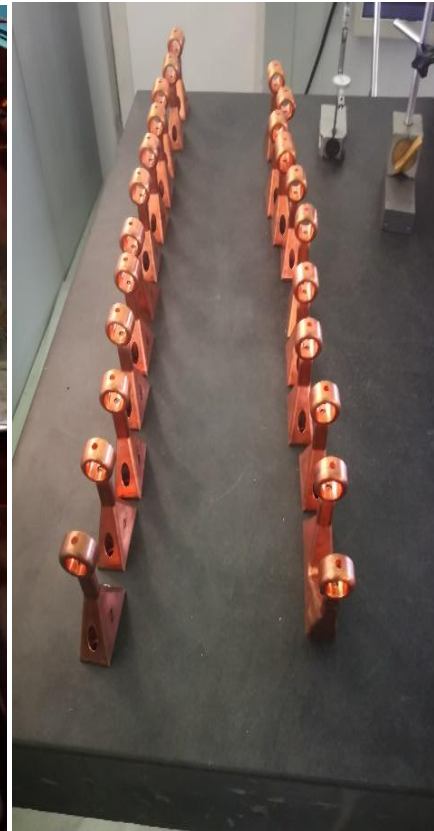


4. Accelerating Structure & RT Cavities

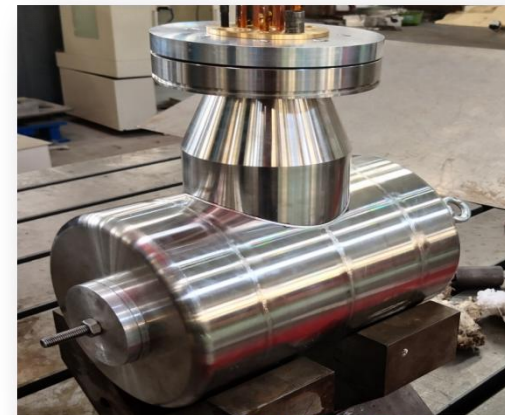
4.4 SESRI DTL-**Manufacture and test**



Cavity



Drift tubes

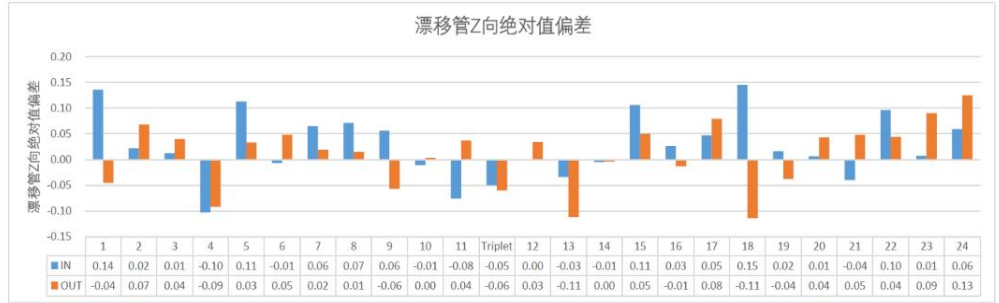


Triplet

4. Accelerating Structure & RT Cavities



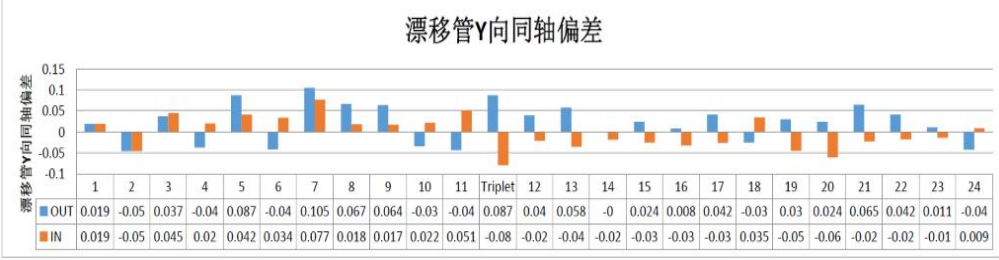
4.4 SESRI DTL-Assembly and alignment



漂移管Z向绝对值偏差 (激光跟踪仪检测)



漂移管X向同轴偏差 (激光跟踪仪检测)



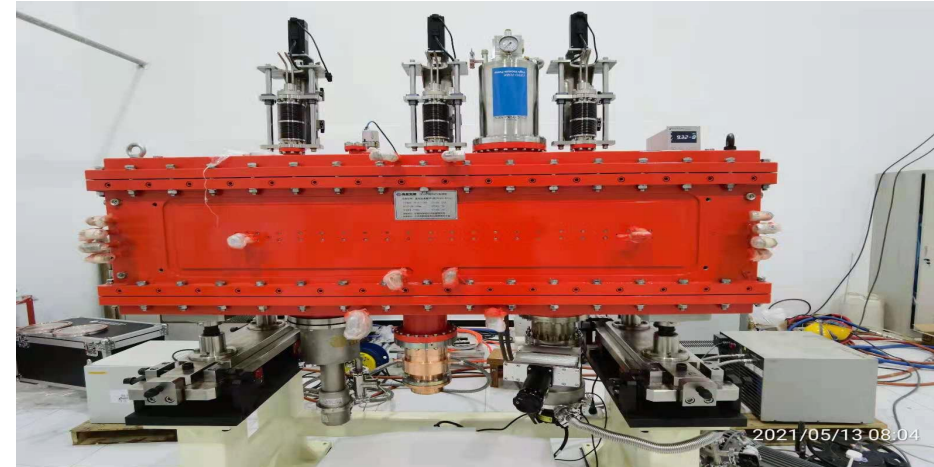
漂移管Y向同轴偏差 (激光跟踪仪检测)

4. Accelerating Structure & RT Cavities

4.4 SESRI DTL-General assembly



DTL1



DTL2



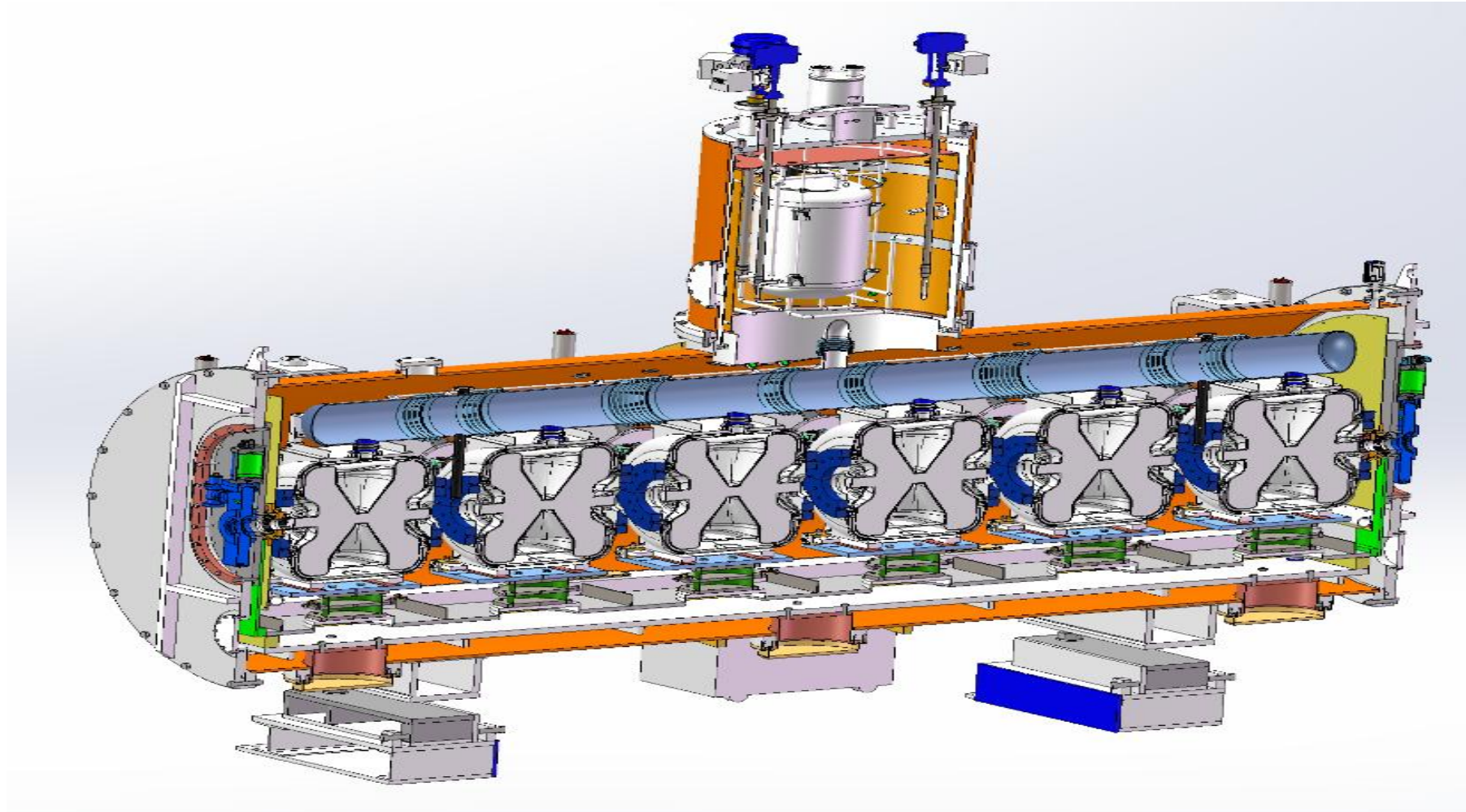
DTL3



Cavities in tunnel

5. Cryomodules

5.1 SSR2 cryomodule-3D model



5. Cryomodules

5.1 SSR2 cryomodule-Cavity string assembly



Cavity string



Cavity string on cold mass

5. Cryomodules

5.1 SSR2 cryomodule-General assembly



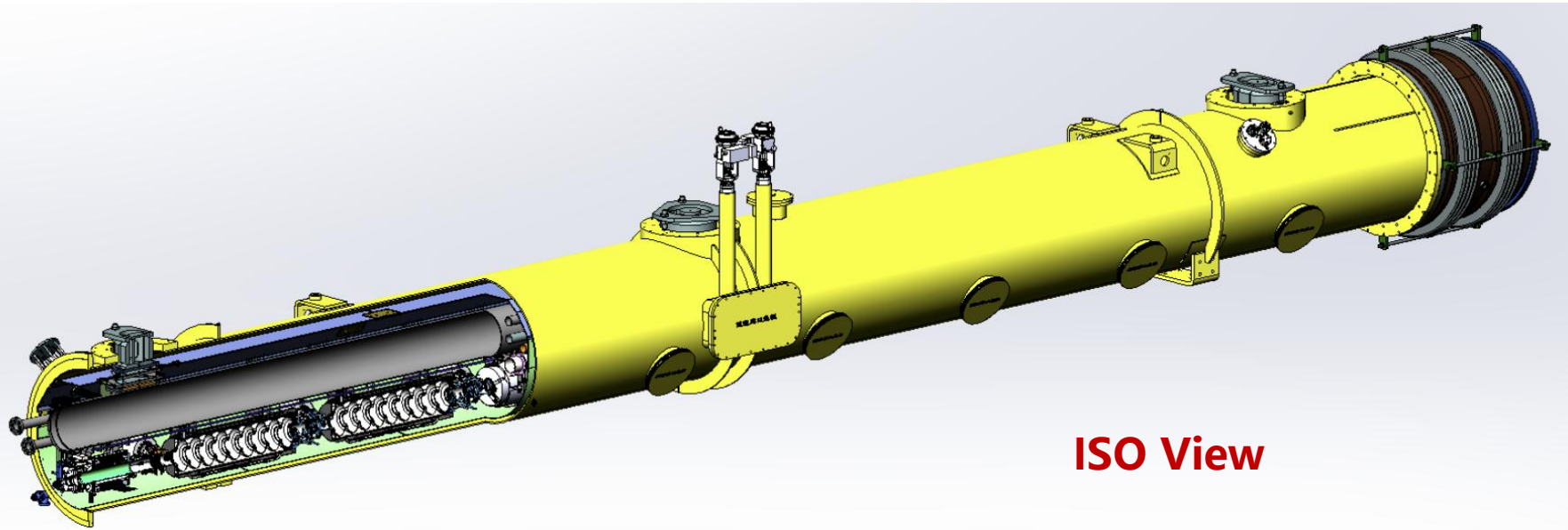
Cavity string alignment



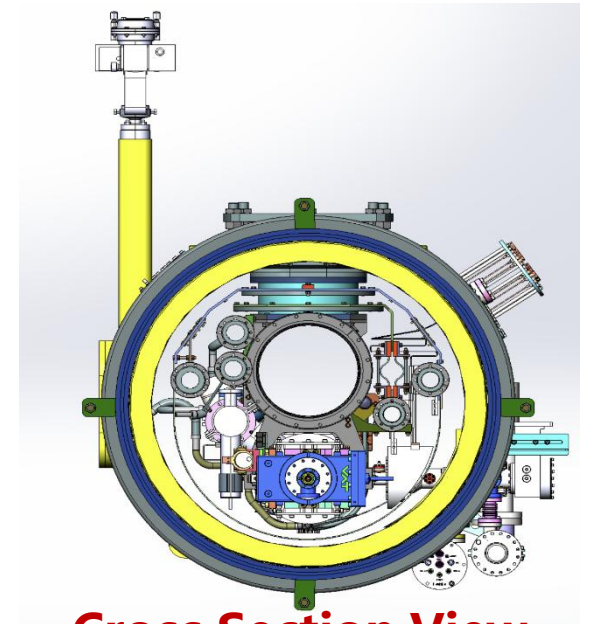
Cryomoduel complete

5. Cryomodules

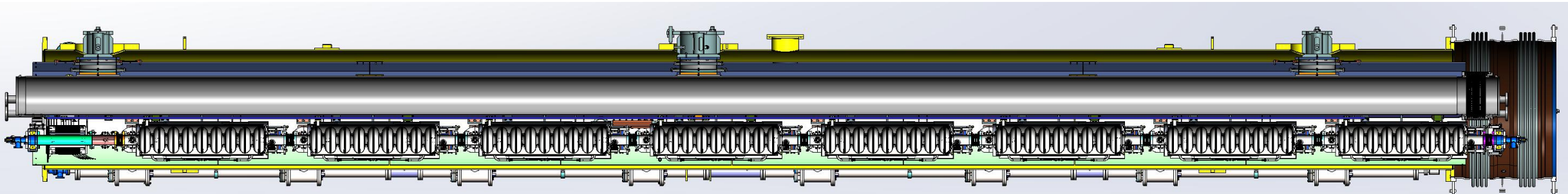
5.2 1.3GHz cryomodule-3D model



ISO View



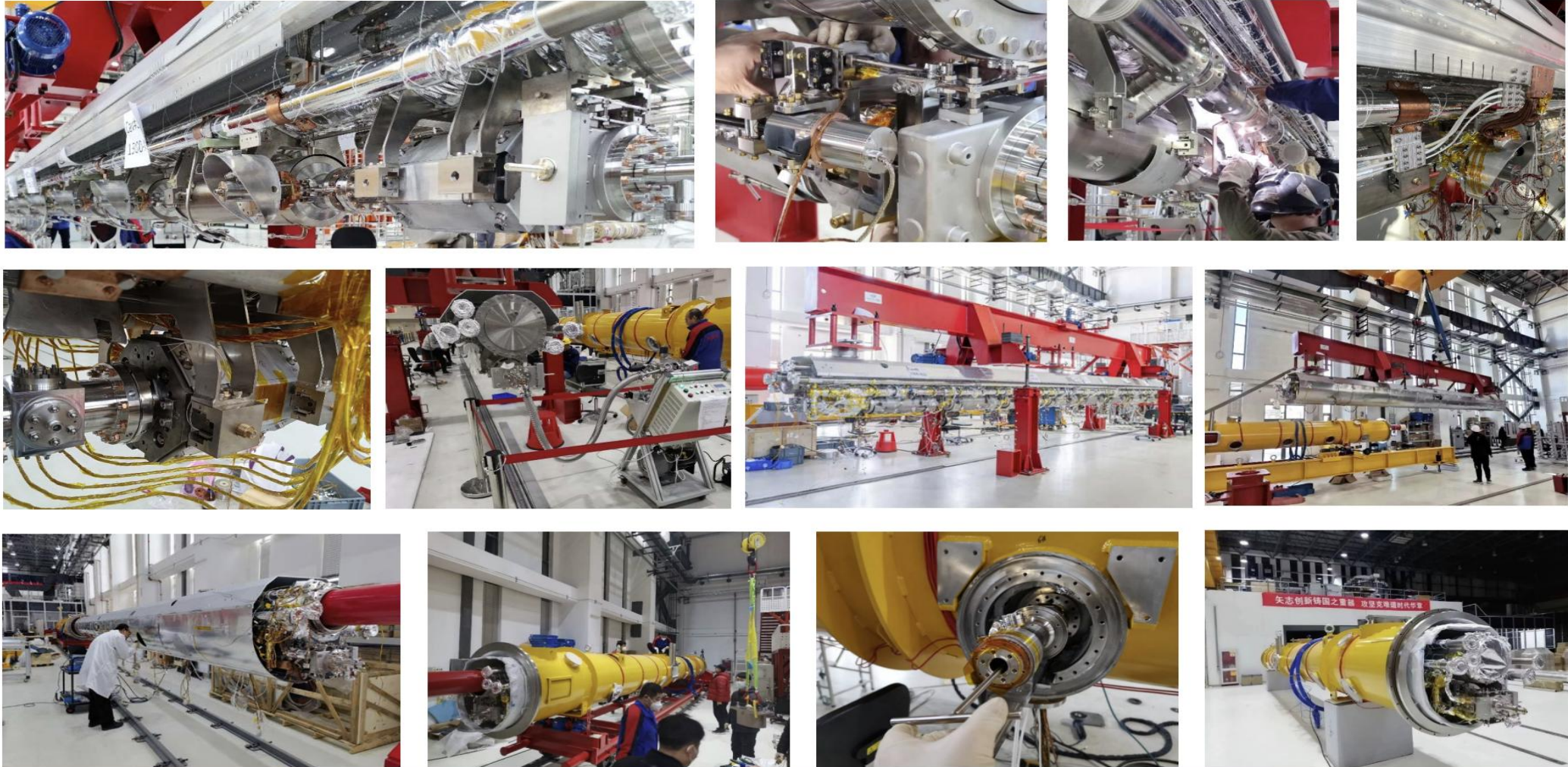
Cross Section View



LongitudinalSection View

5. Cryomodules

5.2 1.3GHz cryomodule-Assembly



Picture from (高品质因数1.3GHz超导腔及模组研制-翟纪元)

5. Cryomodules

5.2 1.3GHz cryomodule-General assembly



6. Summary



北京正负电子对撞机



上海光源



广东散裂中子源



ADS注入器



西安高亮装置



核反应堆次临界装置直线
加速器整机 (乌克兰)



大连光源



上海软线



浦项光源 (韩国)



HEPS直线加速结构



230MeV超导质子回旋加速器后端磁铁系统



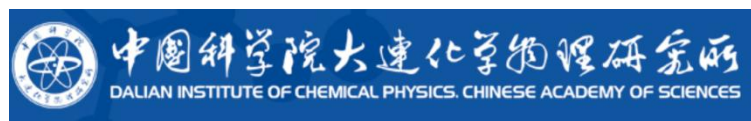
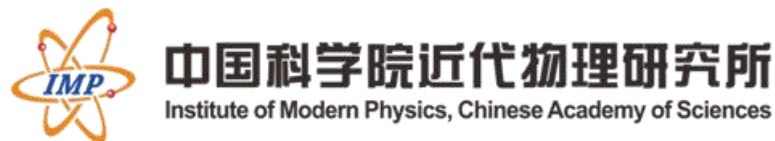
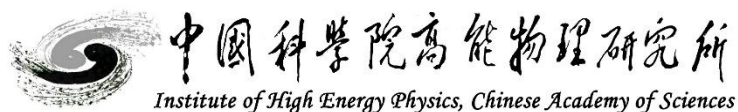
工业辐照加速器整机

6. Summary

- HERT full with the experience for accelerator key technology and components R&D and manufacture.
- HERT has Successfully developed the several prototype for SRF cavities and Couplers.
- HERT is willing to undertake more R&D work for CEPC Accelerator key technologies with domestic and international companies and institutes

一起向未来

Together for a Shared Future





Thanks for your attention!



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



北京高能锐新科技有限责任公司
Beijing HE-Racing Technology Co., Ltd.