CEPC linac/DR EDR plan

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2024.02.28

On behalf of linac group, Institute of High Energy Physics, CAS

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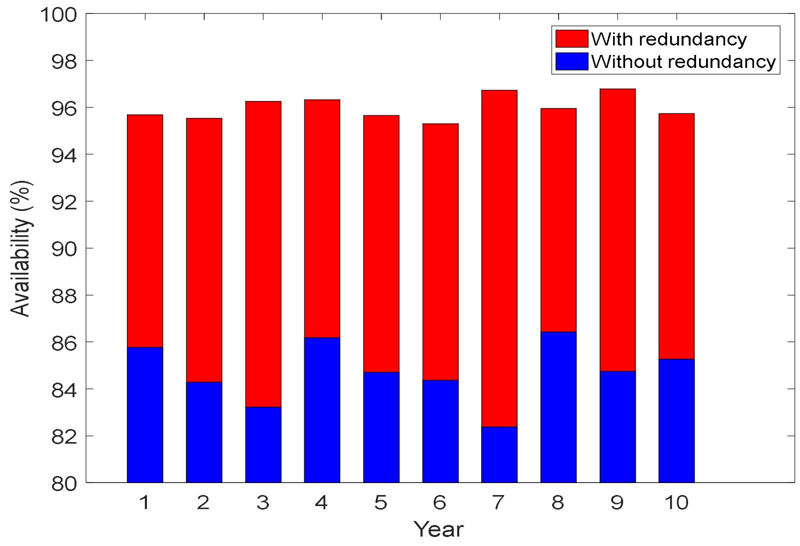
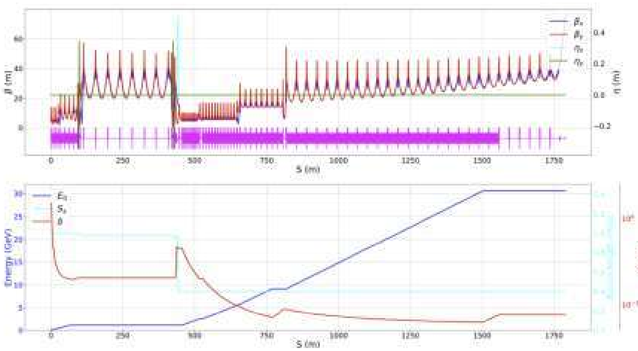
Physical design of LINAC in EDR

Meng Cai

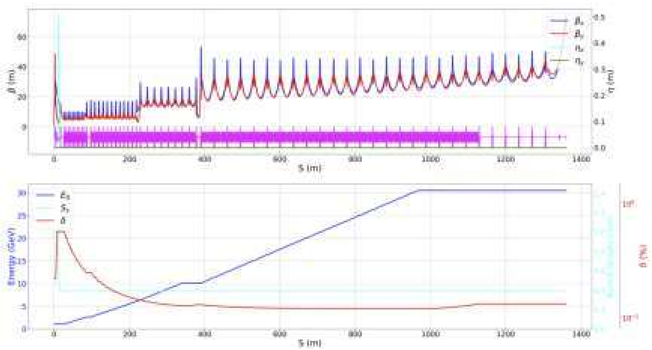
- TDR finished: Start to end simulations with errors have been conducted for both electron and positron beams with qualities satisfying design requirements
- In EDR:
  - Optimization of the physics design, especially double-bunch acceleration simulation will be done
  - Availability analysis of the Linac
    - During the CDR phase, there is a preliminary analysis, which will be further analyzed

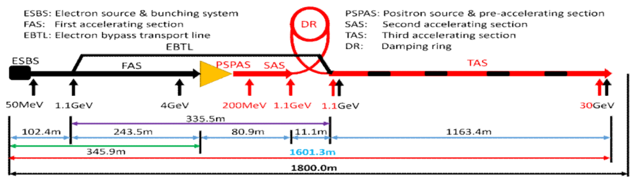


e- in linac



e+ in linac





Double-bunch-per-pulse experiment in EDR

- This is the proposed operation modes of CEPC, the pulse repetition rate of the linac is 100Hz. For Z mode, **double bunch per pulse** is needed

	tt(180GeV)	Higs(120GeV)	W(80GeV)	Z(45.5GeV)
Pulse repetition rate(Hz)	100	100	100	100
Bunch number per pulse	1	1	1	2

- double-bunch acceleration
  - The accelerators that achieve double-bunch acceleration are KEKB (high bunch charge) and the Swiss FEL (low bunch charge)
  - SuperKEKB is currently reattempting double-bunch acceleration operation mode. There are **still significant challenges**, especially with high bunch charge

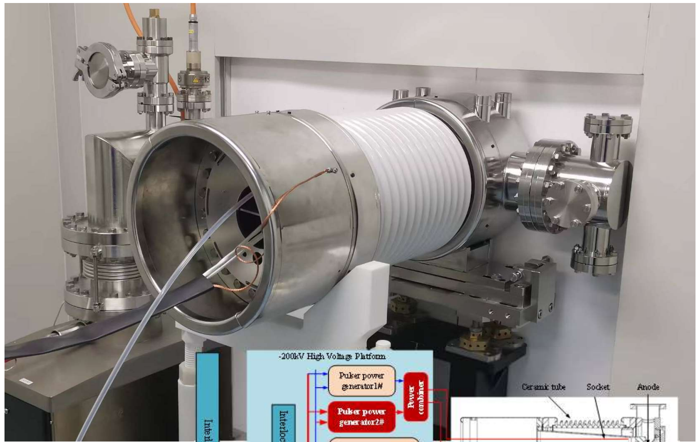
Double-bunch-per-pulse experiment on HEPS Linac

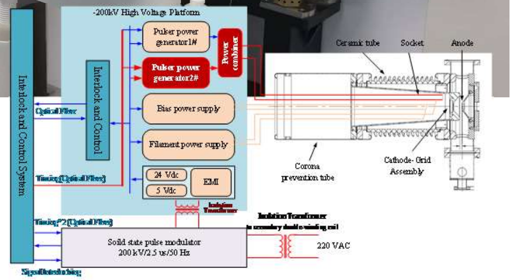
- The HEPS linac is a 500-MeV S-band normal conducting linear accelerator
- A maximum bunch charge of 8 nC at the exit of the Linac can be routinely achieved
- There is still time for Linac based machine studies before commissioning the HEPS storage ring
- With minor modification, the HEPS Linac could be used for double-bunch-per-pulse experiments

Double-bunch-per-pulse experiment on HEPS Linac

Modification and upgrade for the Double-bunch-per-pulse experiment

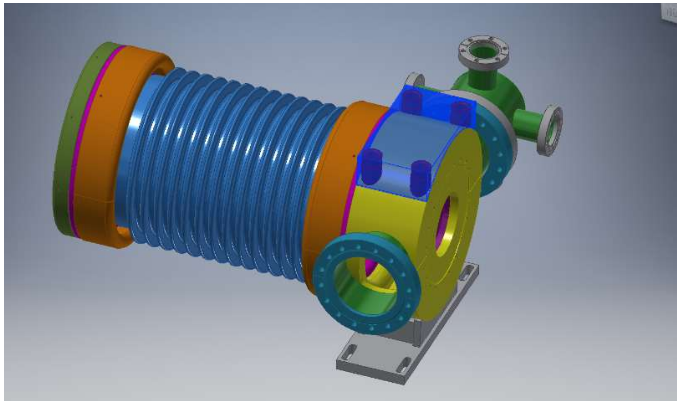
- The e-Gun
  - Only one pulser are currently installed
  - Additional pulser is needed for the double-bunch experiment
- Timing upgrade
  - One additional high precision timing module is needed for the second pulser
- Beam diagnostics
  - Current beam diagnostics can only be used for single-pass long separation pulses
  - A new system need to be developed for pulses with separation about 77 ns



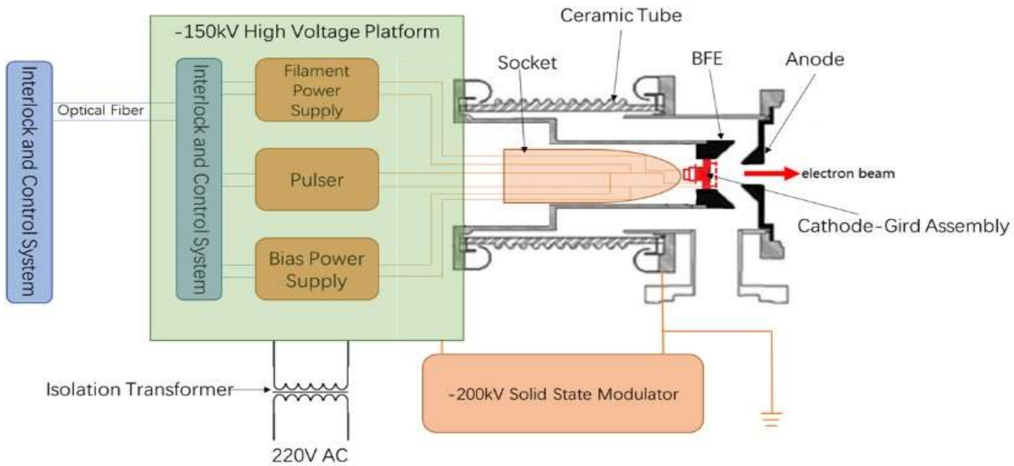


Sources-TDR finished

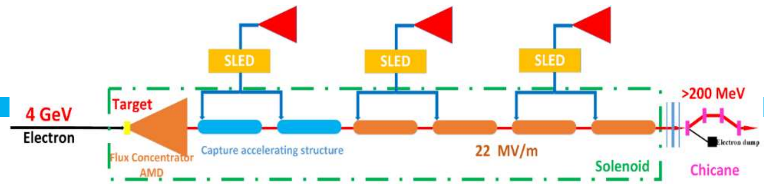
- Electron source
  - Traditional thermionic triode gun
  - Mature technology
- Design parameters of the TDR
  - 1.5 nC bunch charge for electron injection
  - 10 nC bunch charge for positron production
- The HEPS and BEPCII design can meet our requirement



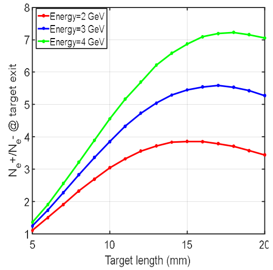
Parameter	Unit	Value
Type	-	Thermionic Triode Gun
Cathode	-	Dispenser cathode
Beam current	A	> 10
High voltage of anode	kV	150
Bunch charge 1	nC	3.3 (e^- injection)
Bunch charge 2	nC	11 (e^+ production)
Repetition rate	Hz	100
Pulse duration	ns	1

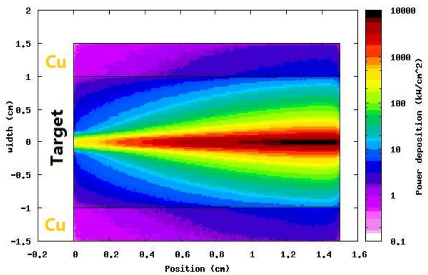


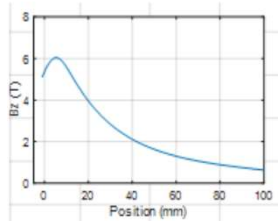
Sources-TDR finished

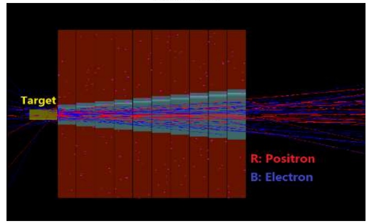


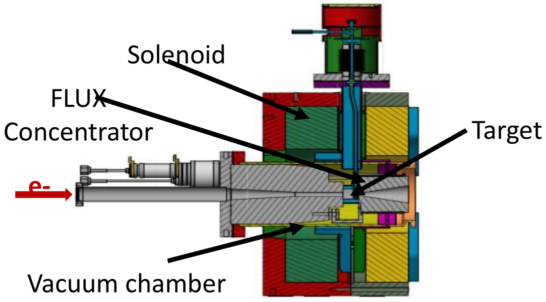
- Positron source
  - Incident electron beam:4GeV/10nC/100Hz, Beam power 4kW
  - Fixed Target (tungsten,15mm thickness , Beam size: 0.5 mm)
  - Energy deposition: 0.784 GeV/e- @ FLUKA, 784 W → water cooling
  - We have made a prototype of the flux concentrator and it's power supply and successfully high power tested
- For the beam energy is high, under normal circumstances, there is no problem. We will research on the protection method of positron conversion target under extreme conditions







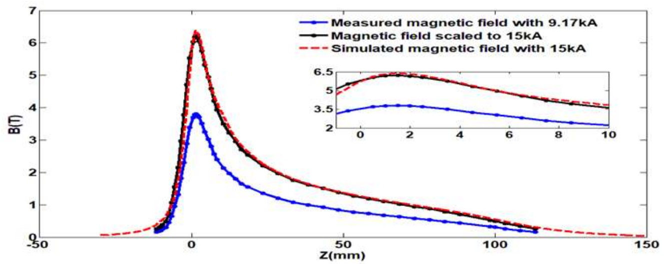




Design of positron converter device

The FLUX conentrator

The 15kA solid-state modulator

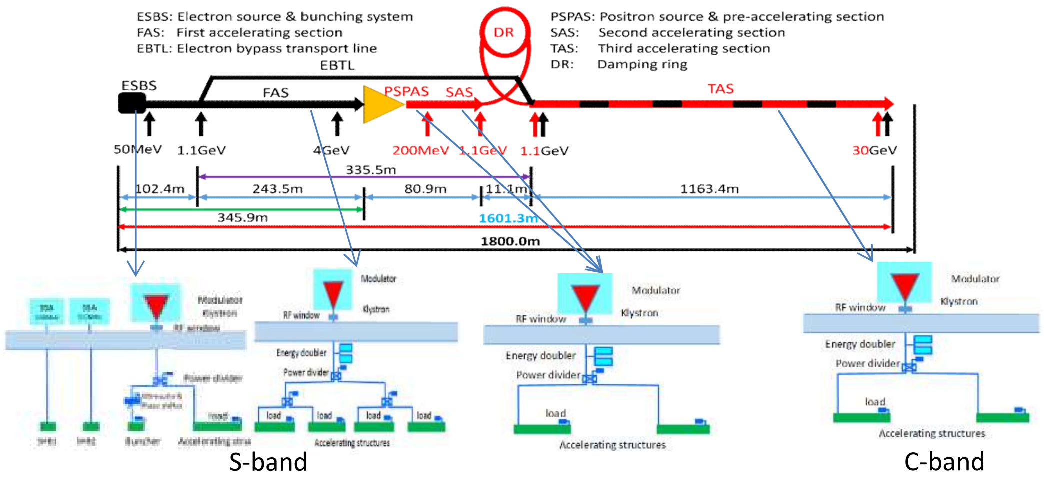


Test of the peak pulse magnetic field

RF system

- RF distribution of the 30 GeV linac
  - S-band, 80 MW klystron, the number of S-band Acc. Structure is 93, big hole s-band structure after the positron source is 16. the number of pulse compressor is 33
    - 1-1(ESBS), 1 accelerating structure, 22MV/m
    - 1-4 (FAS), 21 sets, 84 standard accelerating structures, with pulse compressor, 22MV/m
    - 1-2(PSPAS), 8 sets, 16 big hole accelerating structures, 22MV/m, with pulse compressor
    - 1-2(SAS), 4 sets, 8 accelerating structures, 27MV/m , with pulse compressor
  - C-band, 50 MW klystron, C-band structures: 470, with 235 pulse compressors
    - 1.1GeV-30GeV, 1-2(TAS), 235 sets, 470 accelerating structures, ~40MV/m,

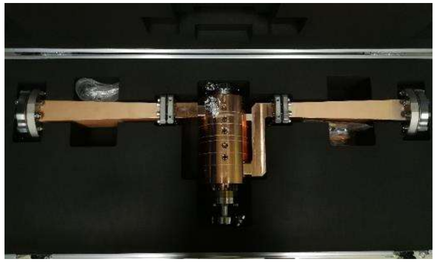
Parameter	Unit	S-band		C-band
Frequency	MHz	2860		5720
Length	m	3.1	2.0	1.8
Cavity mode		2π/3		3π/4
Aperture	mm	19~26	25	12~16
Gradient	MV/m	22/27	22	40~45
Cells (include coupler cells)		86	55	89
Number of Acc. Stru.		93	16	470
Number of Klystron		33		236
Klystron Power	MW	80		50



Bunching cavities and S-band RF system-TDR finished

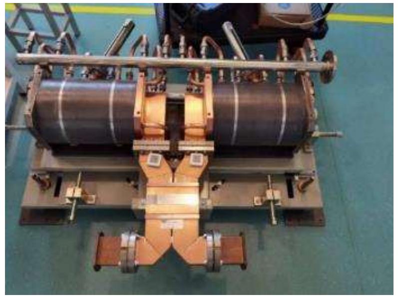
- The SHBs & buncher
  - Traditional cavity structure
    - Re-entrant SW for SHBs
    - TW/CI for buncher
- The same as HEPS only the frequency is a little deference

SHBs for HEPS



Buncher for HEPS

- S-band RF system
  - The prototype for CEPC was tested and the average gradient has reached 33 MV/m at high power test (with SLED)
- The S-band RF system successfully used in HEPS project and the gradient with beam reached 26MV/m



HEPS pulse compressor

For bunching cavities and S-band RF system, the technology is mature now for us.

C-band RF system-TDR finished

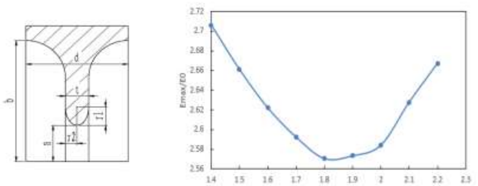
- The situation of other labs
  - The maximum average gradient with beam is about 40MV/m

	IHEP	SARI	RIKEN	INFN	PSI
Frequency(MHz)	5712	5712	5712	5712	5712
Mode	$3\pi/4$	$4\pi/5$	$2\pi/3$	$2\pi/3$	$2\pi/3$
Length (m)	1.8	1.8	2	1.4	2
Gradient at high power test bench(MV/m)	-	50[1]	50.1[2]	36[3]	52[4]
Operating gradient with beam (MV/m)	-	41.7(maximum, private talk)	41.4	36	28

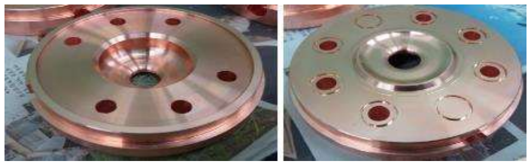
1. W. Fang, et al. THE C-BAND TRAVELING-WAVE ACCELERATING STRUCTURE FOR COMPACT XFEL AT SINAP . NIMA 2016
2. T. Sakurai, et al. C-band disk-loaded-type accelerating structure for a high acceleration gradient and high-repetition-rate operation. PHYSICAL REVIEW ACCELERATORS AND BEAMS 20, 042003 (2017)
3. D. Alesini, et al. HIGH POWER TEST RESULTS OF THE SPARC C-BAND ACCELERATING STRUCTURES. IPAC 2014
4. F. Loehl, et al. STATUS OF THE SWISSFEL C-BAND LINEAR ACCELERATOR. FEL 2013

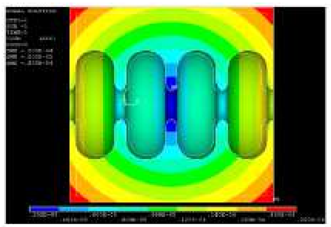
C-band accelerating structure

- The R&D of C-band accelerating structure at IHEP
  - The beam dynamics of linac based on this design
  - Constant gradient, 3π/4 mode, 1.8 meters long (Including mechanical length, Effective length is about 1.7m)
    - Round cavity shape
    - Racetrack symmetrical magnetic coupling
- **No high power test and beam testing**

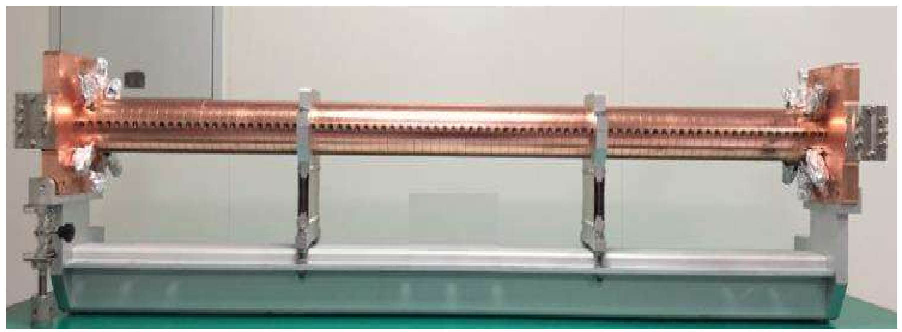


Cavity shape





The deformation caused by temperature variation



C-band accelerating structure

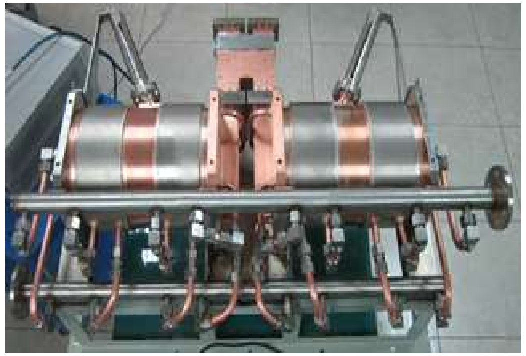
- The design parameters between different lab
  - Mode :3π/4, 2π/3, 4π/5
  - Length
  - Disc thickness
- Though the phase advance is deferent, the other key parameters is similar

	IHEP	Spring8	SINAP[1]
Frequency: f（MHz）	5712	5712	5712
No. of Cells	87+2	100 regular cells +2 coupler	89+2
Phase advance	3π/4	2π/3	4π/5
Total length(m)	1.8	2	1.784
Length of cell : d (mm)	19.675	17.495	20.994
Disk thickness: t (mm)	4.5	4	5
Average aperture: 2a (mm)	14.04	15.938~12.107	15
Average diameter : 2b (mm)	45.6	43.196~41.869	-
Shunt impedance(average) : Rs (MΩ/m)	66.05	66	62
Quality factor : Q	11358~11186	9300/8900(measured)	10470
Group velocity: Vg/c (%)	2.8% ~ 0.96%	2.3%(average)	1.7%(average)
Filling time : t_f (ns)	350	290	330
Attenuation factor : τ	0.56	0.59	0.585
Epeak/E0	2.57	2.6	2.6

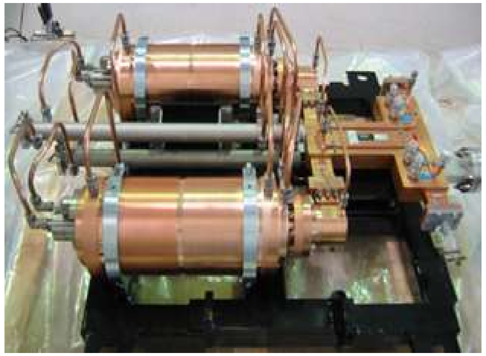
1. W. Fang, et al. THE C-BAND TRAVELING-WAVE ACCELERATING STRUCTURE FOR COMPACT XFEL AT SINAP

C-band RF system-what EDR can do

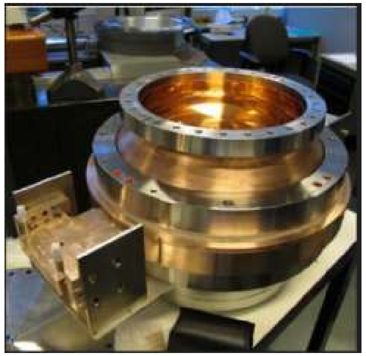
- The model selection of the pulse compressor(PC)
  - SLAC type (Two cavities)
  - BOC type
  - Spherical type



Two cavities PC



SACLA C-band PC



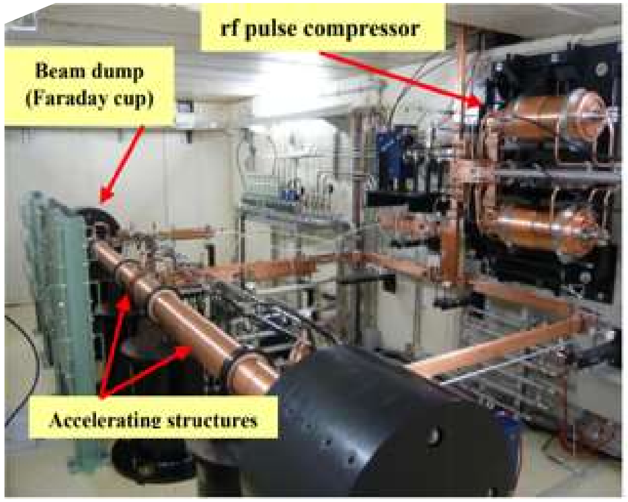
BOC type PC

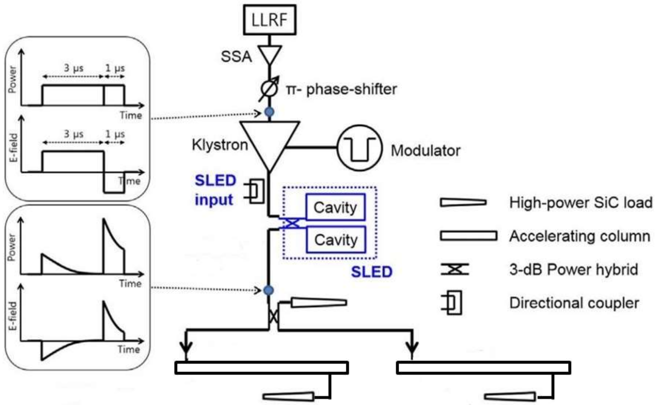
Spherical PC（Xband of SLAC）

- **No direct high power experience for us**

C-band RF system-what EDR can do

- This is a high power test bench of Spring-8 before their mass-production
- We hope we can establish the C-band test bench and test the components. With pulsed compressor, waveguides, directional couplers, loads, bend and straight waveguides, etc.
- It is a complete unit and should cooperation with C-band power source

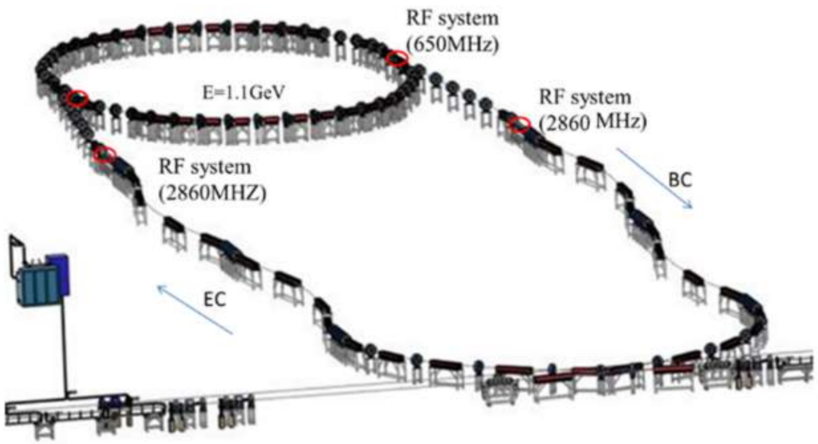


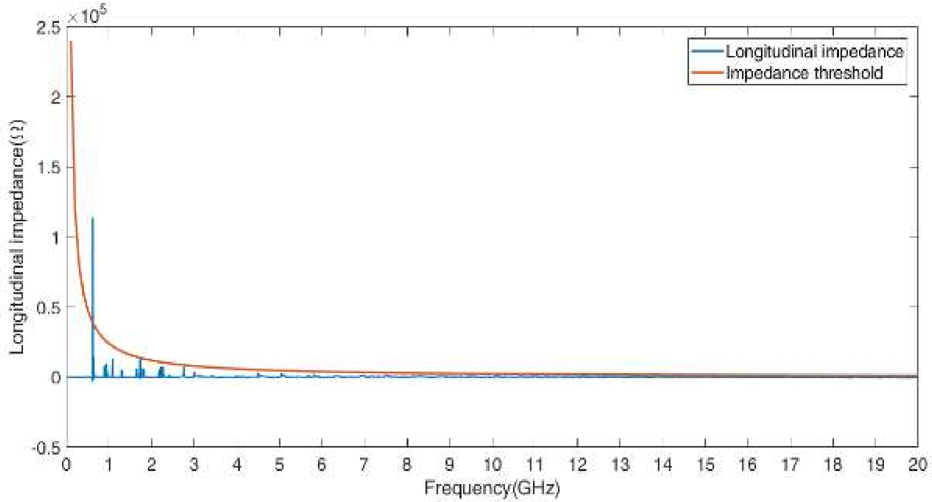


Damping Ring RF cavity-TDR completed

D. Wang, Y.D. Liu, X.H. Cui

- The total cavity voltage requirement is 2.5MV
- 5 cell cavity aperture is decided by impedance、HOM and instability threshold
  - Taking into account the simulation results for impedance threshold and HOM power, the 5-cell cavity with a 90 mm aperture is considered the best choice

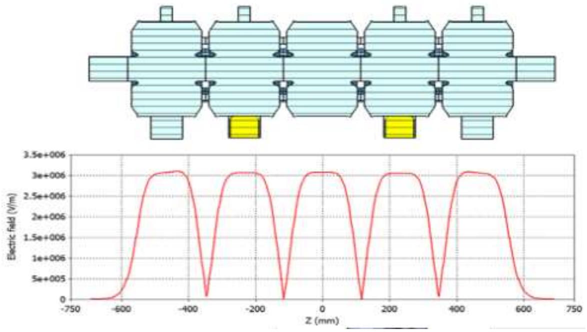


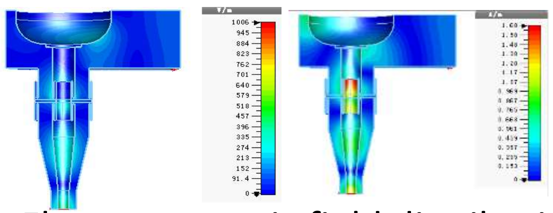


Damping Ring RF cavity-TDR completed

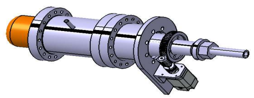
- The design of the 650MHz 5 cell cavity finished
  - RF cavity design
  - Input coupler and doorknob design
  - Vacuum design
  - Mechanical design

	Unit	Value
Beam tube aperture	mm	90
Cell length	mm	5*230.61
π-mode frequency	MHz	650.0
Q0		31633
Shunt impedance	MΩ	32.4
R/Q	Ω	1023
Accelerating voltage per cavity	MV	1.25
Accelerating gradient E0	MV/m	1.08
Esmax/E0	-	4.62
Dissipated cavity power (20% margin)	kW	58 (84*)

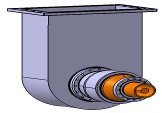




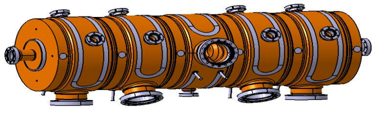
Electromagnetic field distribution



Tunner

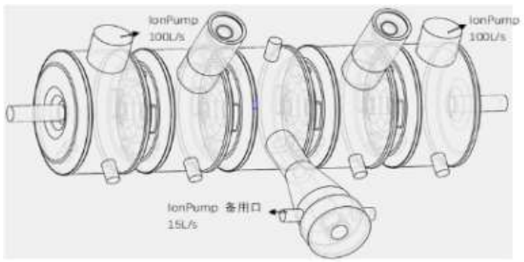


Coupler



Cavity

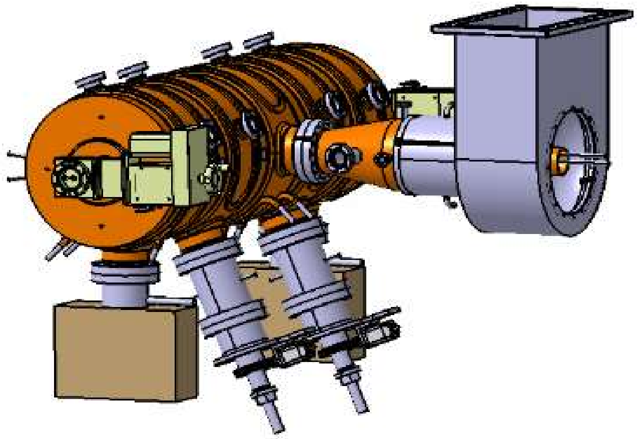
Mechanical design



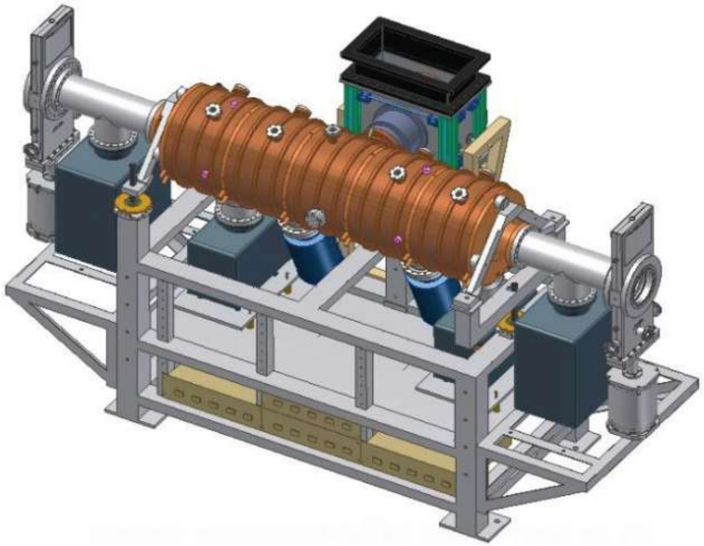
Ion pump distribution

Damping Ring RF cavity-what EDR can do

- Further optimize the 5 cell cavity design
- If possible, we hope have fund to process the DR normal conducting 5 cell cavity. And finished the cold test of the cavity
- After the machining of the cavity completed, use PAPS (a test bench of IHEP at Huairou) test bench to do the high-power test of the DR normal conducting 5 cell cavity



Mechanical design



经费需求

双束加速实验系统升级（48.6万元）

	数量（套）	单价	总价	说明
电子枪及定时	2		18.6	
束测	2	15	30	

	数量	总价	说明
pulse发生器	1	11	1kV/1.5ns/50Hz
功率合成器	2	1.5	SMA 500MHz to 2.5GHz
高压同轴馈线	3	0.6	3根SMA连接器
控制和联锁通道	1	0.5	
阴栅高压连接器插件阻抗优化		5	
总计		18.6	

C波段微波系统套（420万元）

	数量	单价	总价	说明
加速结构及二层支架	2	60	120	含材料费及安装测试费等
脉冲压缩器、波导、功分器、负载等		150	150	
真空设备		40	40	离子泵、真空规，角阀等
其它辅助设备	1	40	40	支架、水路、线缆、安装
性能诊断	1	70	70	暗电流测试，打火测试等

DR 常温腔（525万元）

	数量（套）	单价	总价	说明
腔体（包含耦合器和调谐器）	1	350	350	
波导及环形器	1	90	90	
真空和水冷	1	45	45	
控制	1	40	40	

主要参加人员

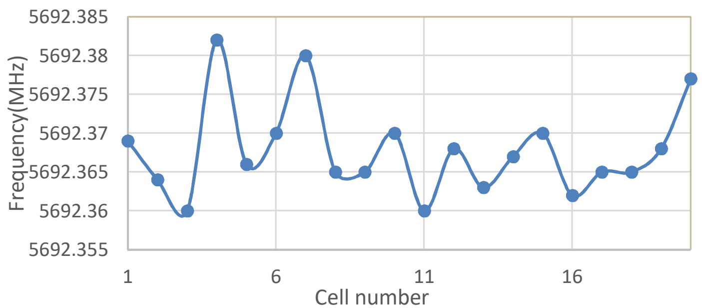
	姓名	主要负责	职称
1	李京祎	双束加速实验	研究员
2	孟才	双束加速实验调束实验	研究员
3	隋艳峰	双束加速束测升级	研究员
4	何大勇	双束加速电子枪升级	高级工程师
5	刘劲东	双束加速电子枪升级及C波段测试台控制	工程师
6	张敬如	C波段加速结构的设计及高功率实验总协调	研究员
7	施华	DR 5 cell腔体的设计加工及高功率实验	副研究员
8	贺祥	微波传输部分的设计及高功率实验	高级工程师
9	马新朋	微波信号源	副研究员
10	甘楠	微波低电平	副研究员
11	肖欧正	DR 5 cell腔体耦合器的设计和高功率实验	副研究员
12	李飞	C波段高功率测试功率源调制器	工程师
13	周祖圣	C波段高功率测试平台功率源	研究员
14	李小平	DR 5 cell腔体的高功率实验	研究员
15	王辉	测试台的总体机械设计	高级工程师
16	邓秉林	C波段和DR高功率测试台的真空及支架	高级工程师

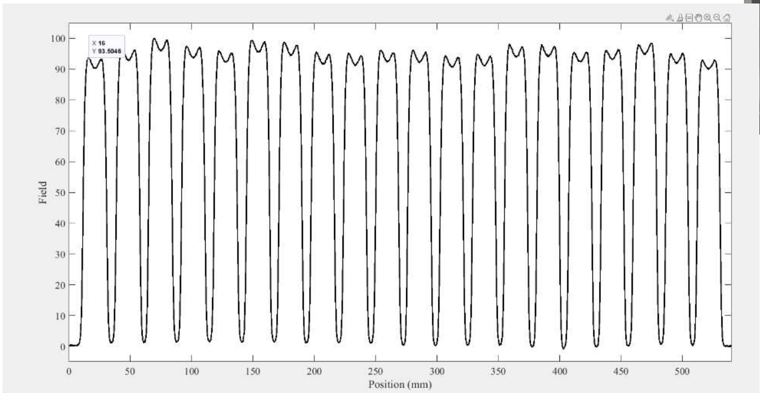
时间节点

- 双束加速实验系统升级
  - 2024.2-2024.12.31，完成系统改造并进行实验
  - 2025.1.1-2025.12.31
- C波段微波系统
  - 2024.2-2024.12.31，完成系统设计，加速管和脉冲压缩器的的设计，完成无氧铜材料的采购
  - 2025.1.1-2025.12.31，完成加速管和脉冲压缩器的加工调试，搭建高功率测试台，完成高功率测试（功率源可用的情况下）
- DR 常温腔
  - 2024.2-2024.12.31，细化设计并完成招标，对厂家的工艺评审，并完成腔体的加工；细化耦合器、调谐器的设计并完成加工
  - 2025.1.1-2025.12.31，完成腔体的组装、冷测和调试，完成高功率测试台搭建并进行高功率实验，完成测试报告和相关文章

低温平行耦合加速结构的现状

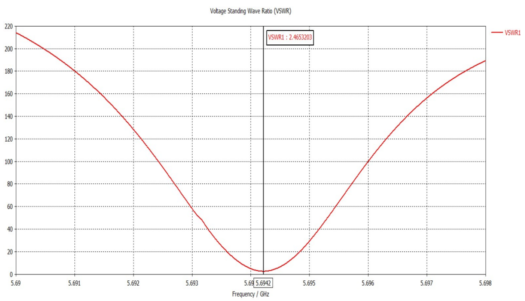
- I号在低温试验时遇到各腔频率变化不一致的问题
- II号结构的测试结果
  - 调试完成后实验室冷测结果，±11kHz

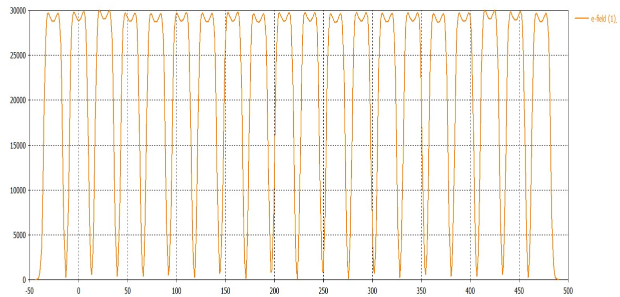




整体氦罩10分钟检漏，漏率小于$4E^{-11}$Torr*l/S

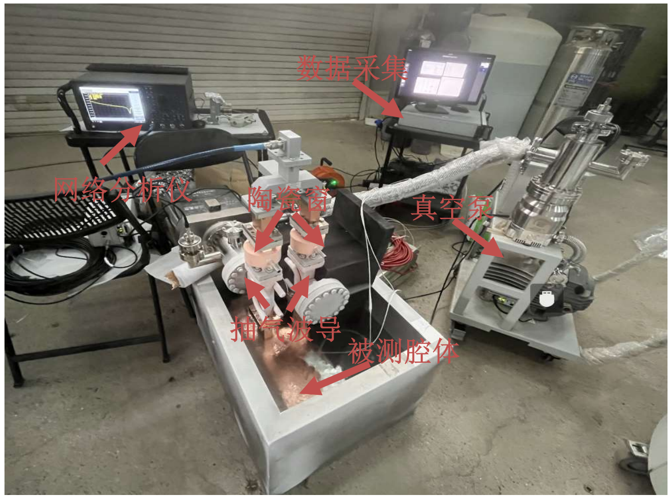
真空检漏

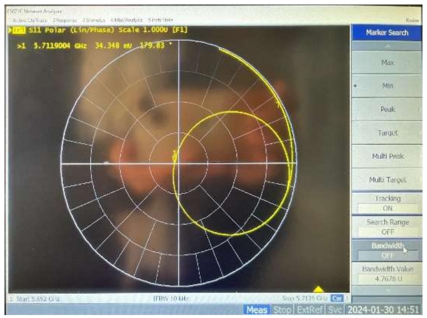


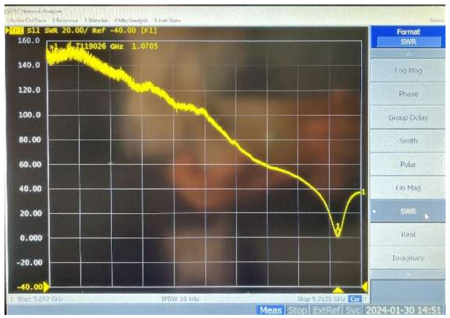


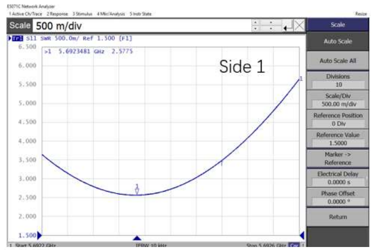
低温平行耦合加速结构的现状

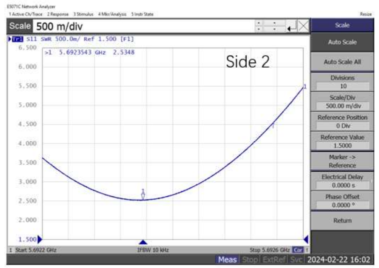
- 低温实验结果
  - 在真空状态，温度在77k时，频率稳定在5711.902MHz，驻波比1.07，此时测得的Q_0为32116，恢复常温后的Q_0为12355
  - 恢复常温后测试了极限真空
    - 整个系统抽极限真空48小时，在一台70L离子泵工作的情况下，泵口真空度=2.7E-8 Mbar,离子泵电流Ip=35uA.
    - 如果用2台100L离子泵抽，真空度低于1.35E-8 Mbar，使加速结构中心真空度维持在 5E-8 Mbar。达到高功率情况下的真空指标







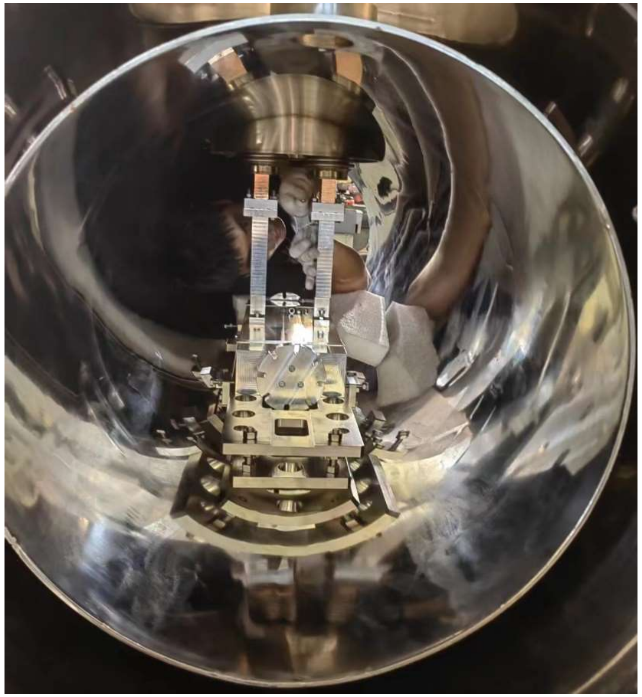




恢复常温后的复测

低温恒温器现状

- The test cryostat has been completed and transported to IHEP
- Assembly of the cavity and cryostat has been completed within 15 days



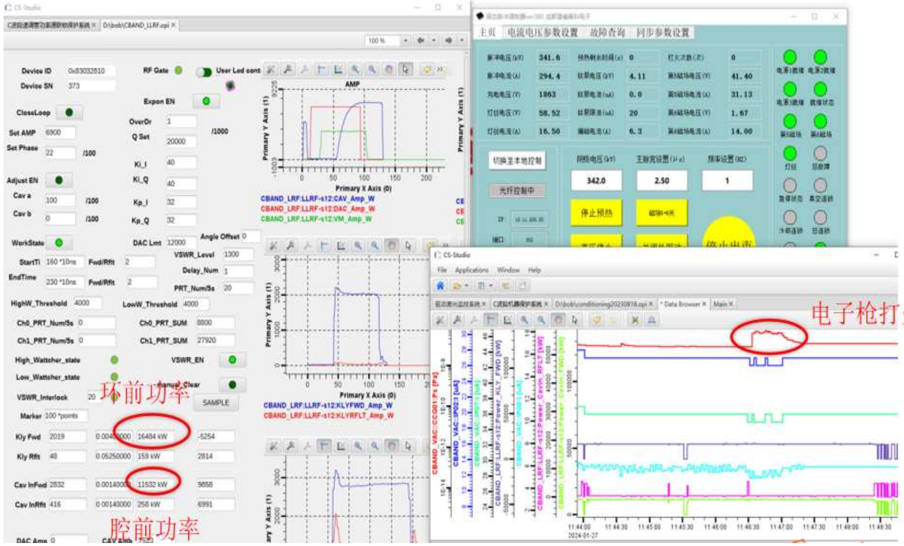
低温恒温器现状

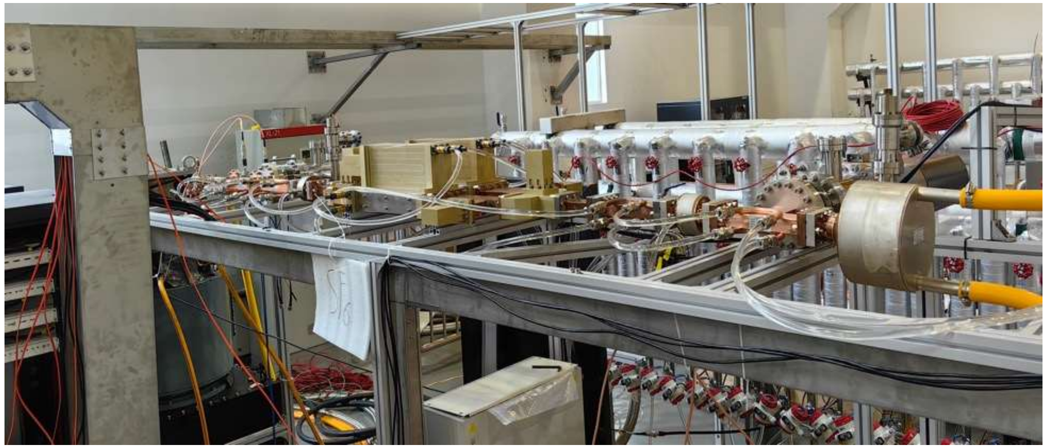
序号	工作内容	2.25	2.26	2.27	2.28	2.29	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	3.11	3.12
1	出厂运输	■																
2	恒温器零部件检查		■															
3	低温管道真空复测		■															
4	组装腔体滑动工装		■	■														
5	调节铜腔机械位移			■														
6	安装法拉第筒，适配信号线				■													
7	波导组件安装适配				■													
8	建立腔体真空				■	■												
9	组装液位计，压力传感器工装					■												
10	安装温度传感器					■												
11	封恒温器内氮池						■	■										
12	氮池负压检漏							■										
13	安装恒温器feedthrough								■									
14	内筒支撑等组装								■	■								
15	绝热材料包扎									■	■							
16	建立恒温器隔热真空										■	■						
17	低温阀门调试											■						
18	模组运输，真空监测												■	■				
19	控制系统接入														■	■	■	■

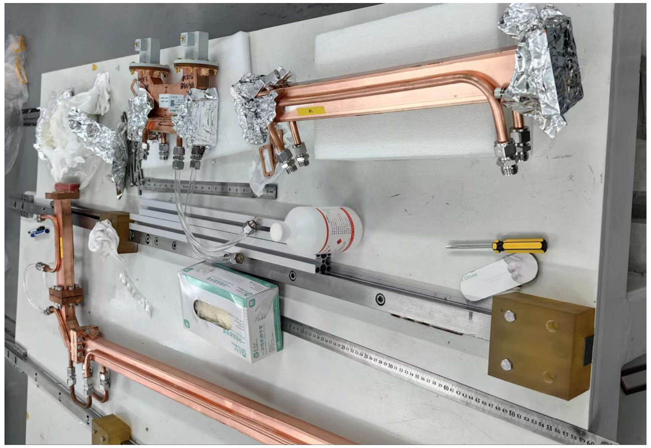
C波段测试平台进展

李晓

- 2023.10开始高功率联调
- 2023.11开始电子枪高功率老练
  - 更换环形器
  - 更换波导窗
- 预计2024.03入腔功率达到15MW







Thank you for your attention!