Development of Electron Cooler Components for HIAF Accelerator

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II. Features of 450 keV e-cooler at HIAF-SRing

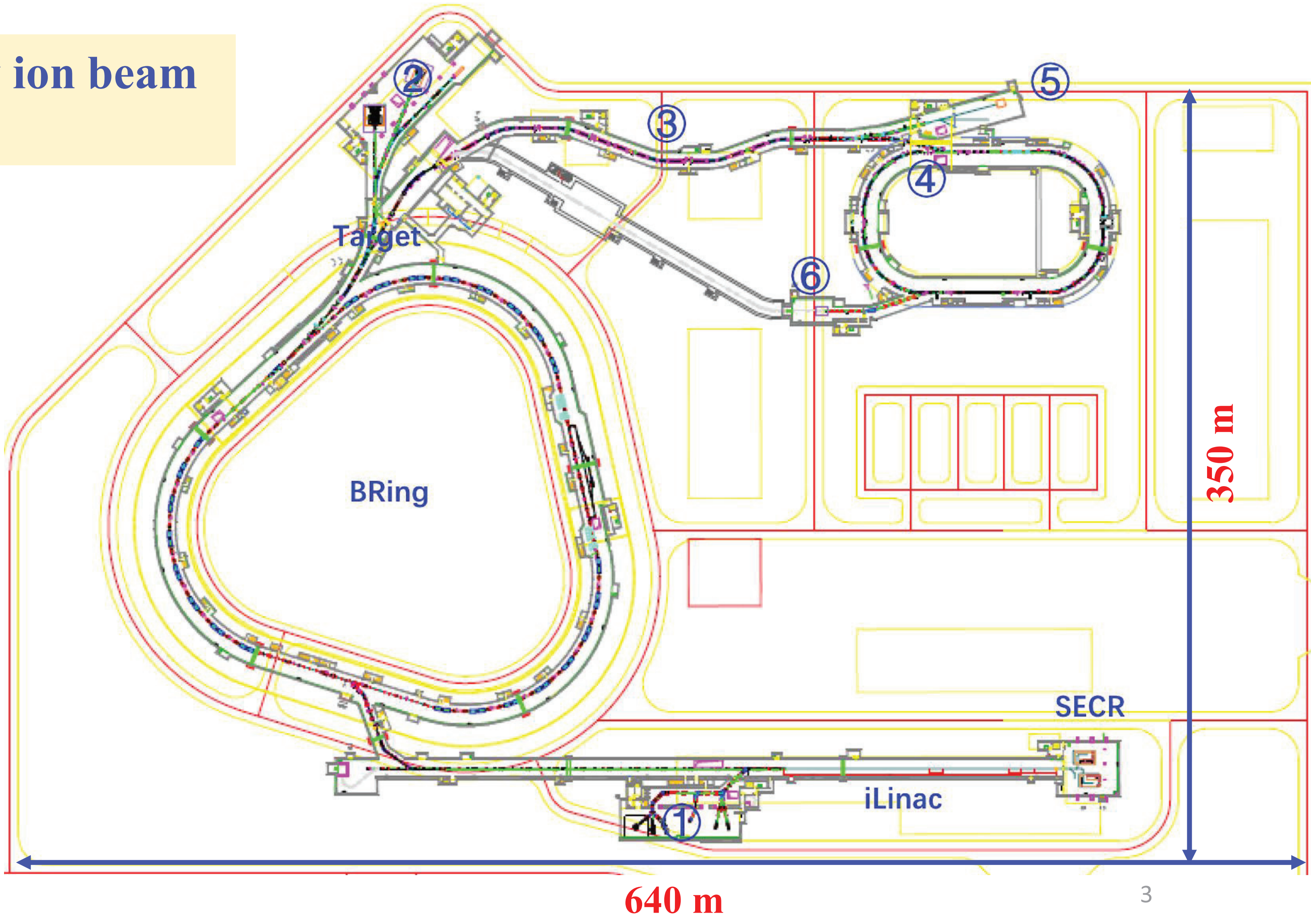
III. Technical challenges and developments at IMP

IV. Outlook

I. Introduction and motivation

■ High Intensity heavy-ion Accelerator Facility (HIAF)

To provide highest intensity heavy ion beam for nuclear and atomic physics



- **Experimental terminals**

① Low energy nuclear structure terminal
② Multi-function terminal
③ High energy fragment separator HFRS
④ **High precision spectrometer ring SRing**
⑤ Radioactive isotope beam terminal
⑥ High energy density physics terminal

The 450 keV electron cooler (DC, magnetized) will be installed in SRing

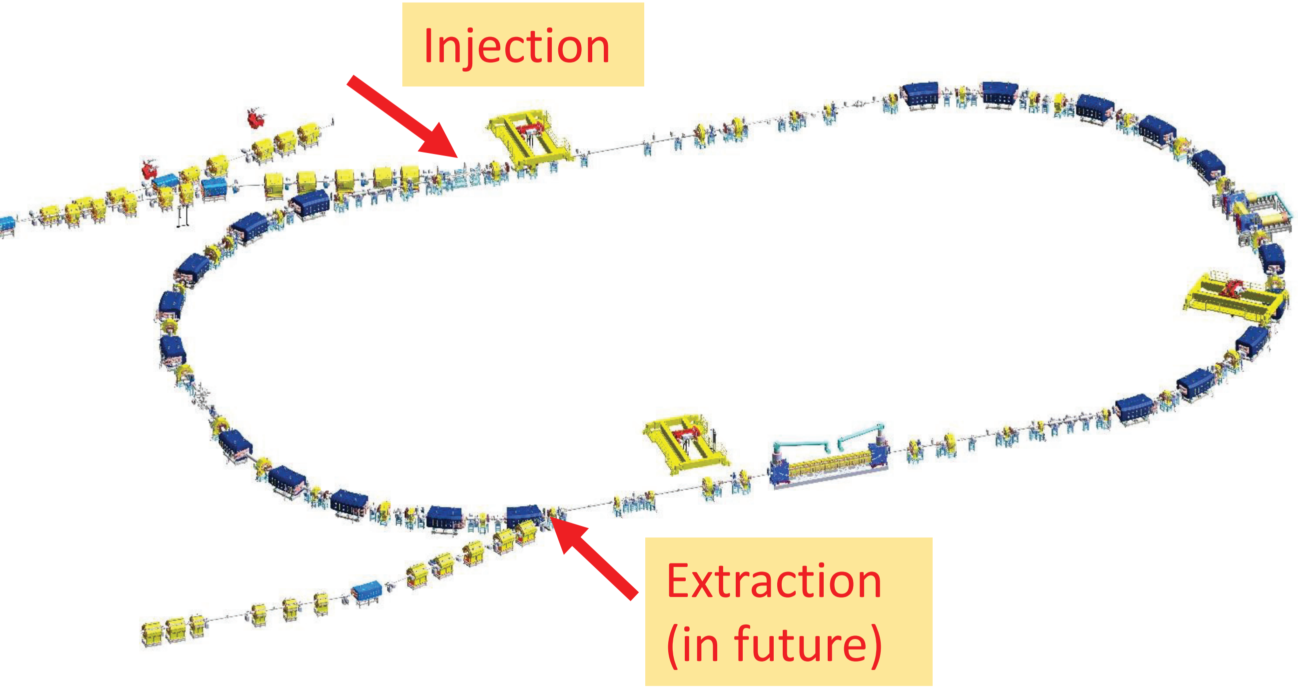
I. Introduction and motivation

HIAF construction bird-view

The first ion beam injected, accelerated and extracted from BRing in April 2024

I. Introduction and motivation

■ SRing and beam cooling



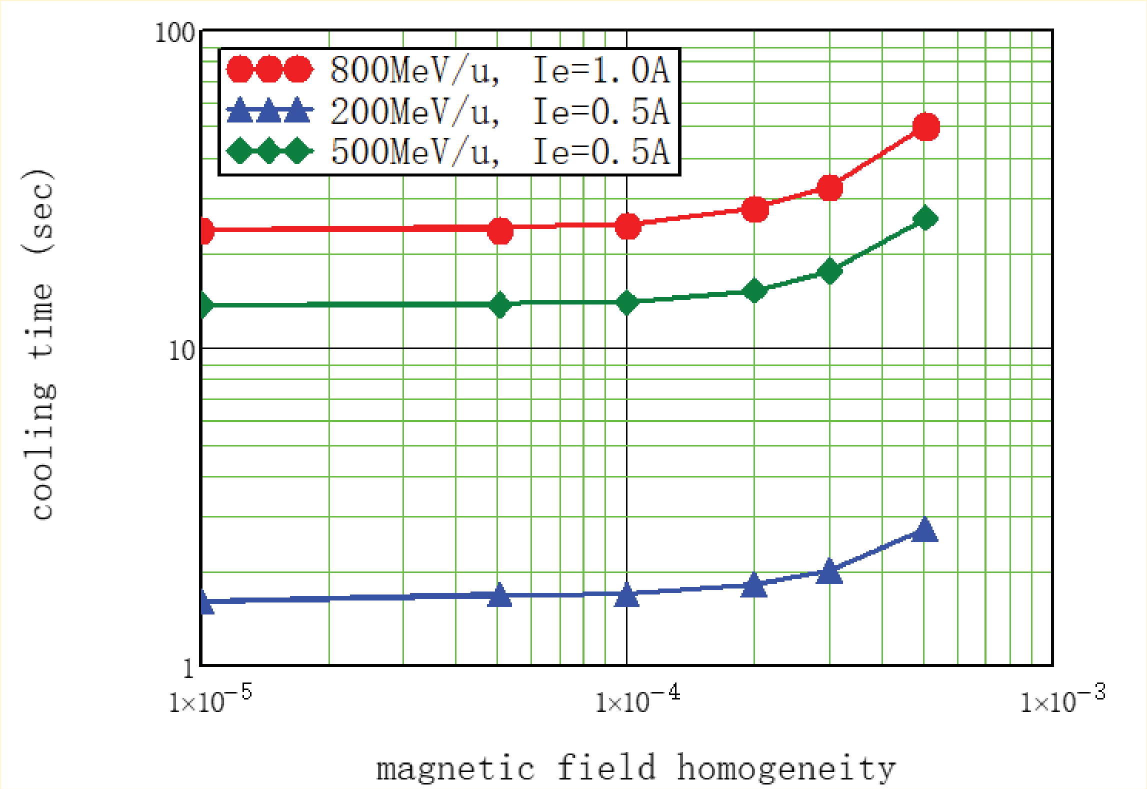
Circumference (m)	273.5			
Magnetic rigidity (Tm)	1.5-15			
Operation modes	Isochronous		Normal	Internal Target
Ion species	RIBs		RIBs or stable nuclei	Stable nuclei
Intensity (ppp)	1-10^3		10^{3-8}	10^{9-11}
Ion optics				
Transition energy γ_t	1.43	1.67	3.27	4.87
Tunes Q_x/Q_y	2.23/5.21		3.26/3.28	4.54/3.56
Natural chromaticity ξ_x / ξ_y	-7.26/-1.96	-3.59/-3.38	-2.84/-5.33	-7.56/-5.56
Transverse acceptance $\varepsilon_x/\varepsilon_y$ ($\Delta p/p$=0) (π mm·mrad)	80/40	150/40	580/40	450/40
Momentum acceptance $\Delta p/p$ ($\varepsilon_x/\varepsilon_y$=40/40 π mm·mrad)	±0.20%	±0.28%	±1.5%	±1.5%

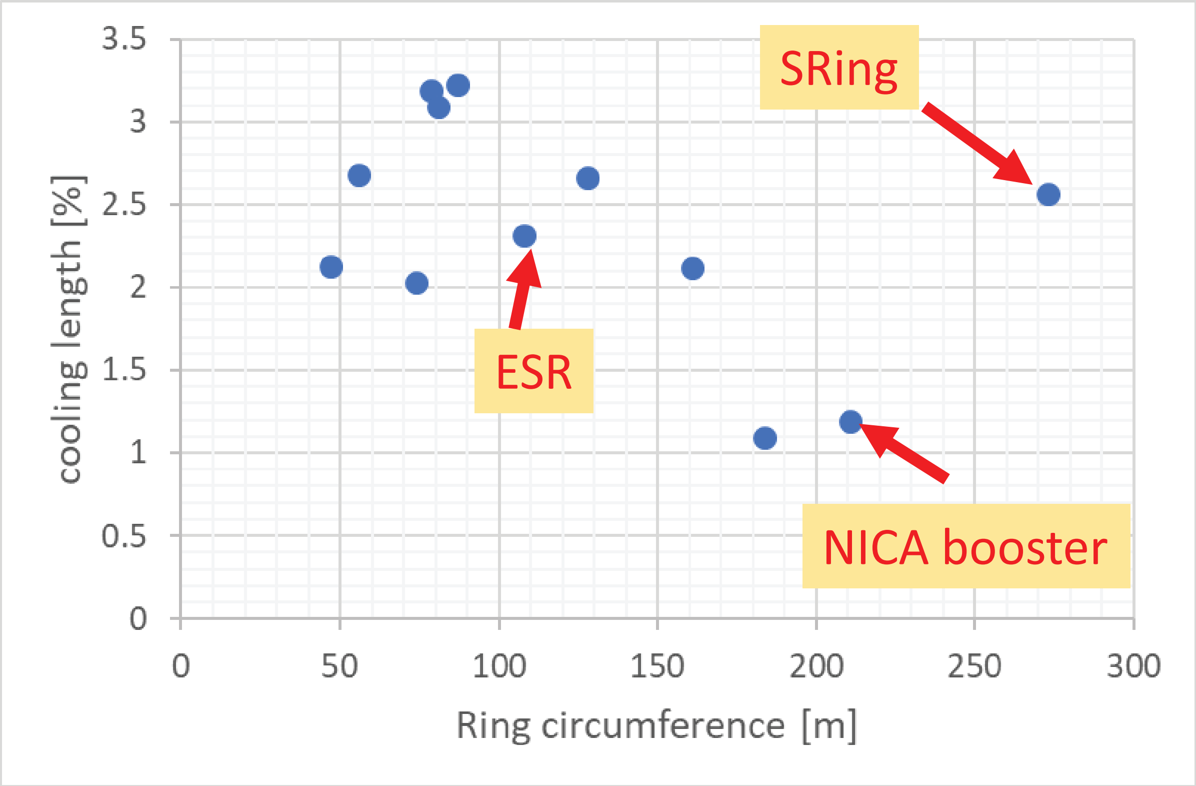
- Electron cooling is used to improve the quality of highly-charged, low-energy heavy ion beam for internal target experiments
- It is also used for the electron-ion recombination measurements together with the electron target
- Ion beam accumulation (with barrier bucket method) for extraction in future

II. Features of 450 keV e-cooler at HIAF-SRing

■ DC magnetized electron cooler based on the present 300 keV device developed by BINP in 2000

1 --- Long cooling section 7.4 m solenoid, magnetic field quality homogenity in cooling section < **10^{-4}**



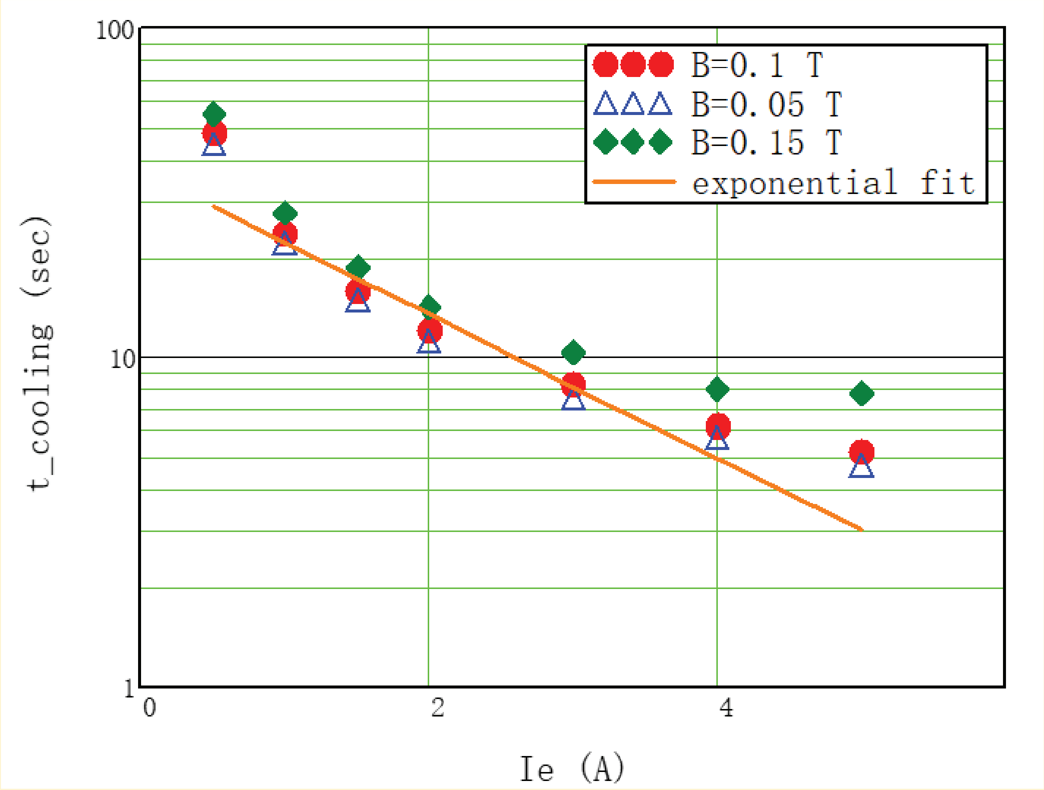


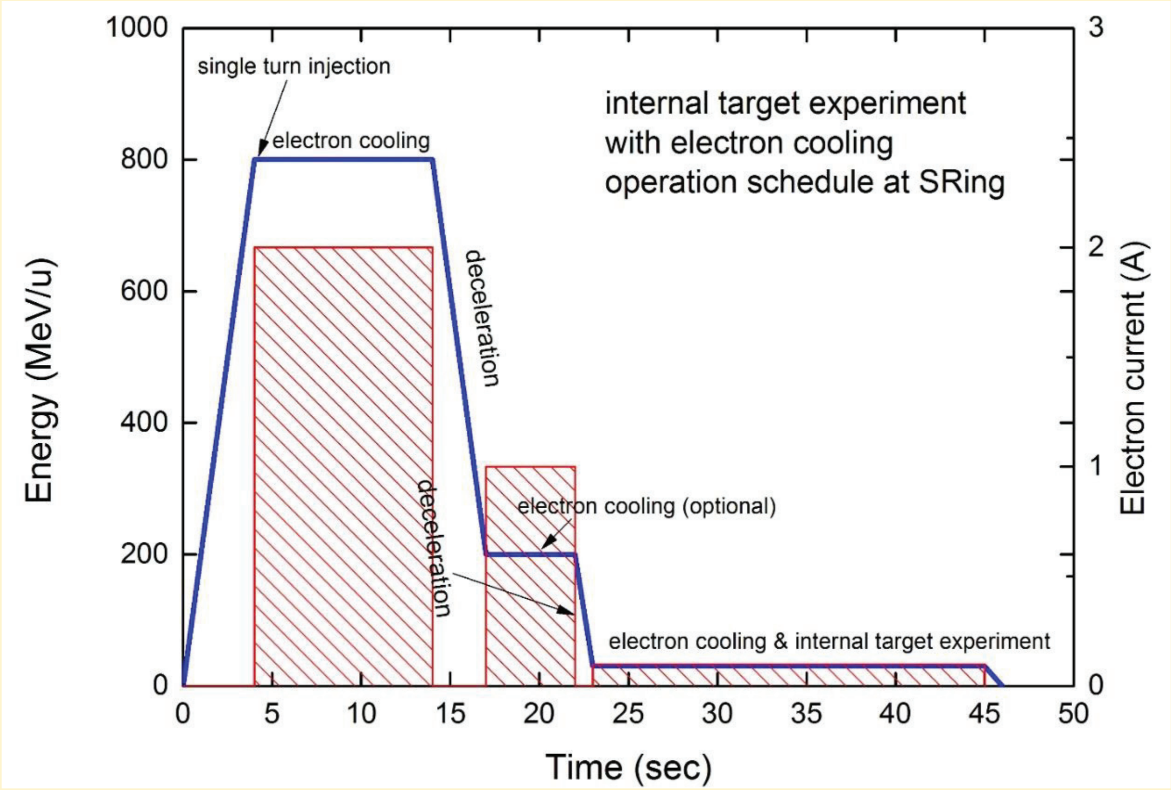
II. Features of 450 keV e-cooler at HIAF-SRing

- <u>DC magnetized electron cooler based on the present 300 keV device developed by BINP in 2000</u>

2 --- electron beam current up to 2.0 A

3 --- Deceleration operation, high voltage discharges **40~50 kV/s** (switch off the electron beam)



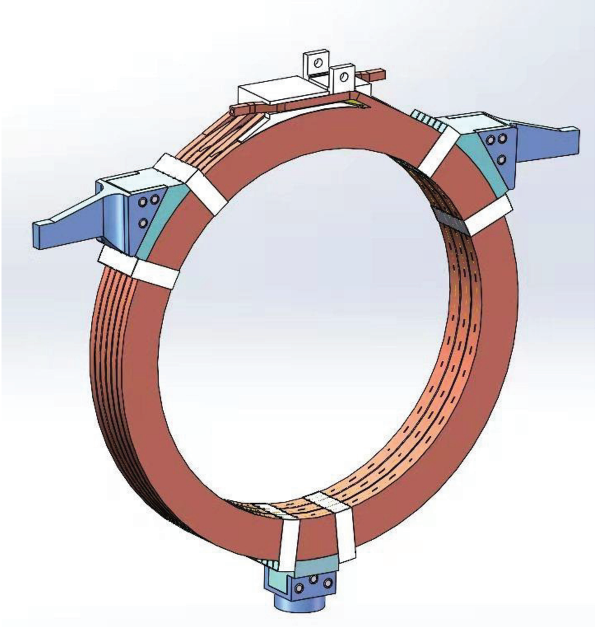


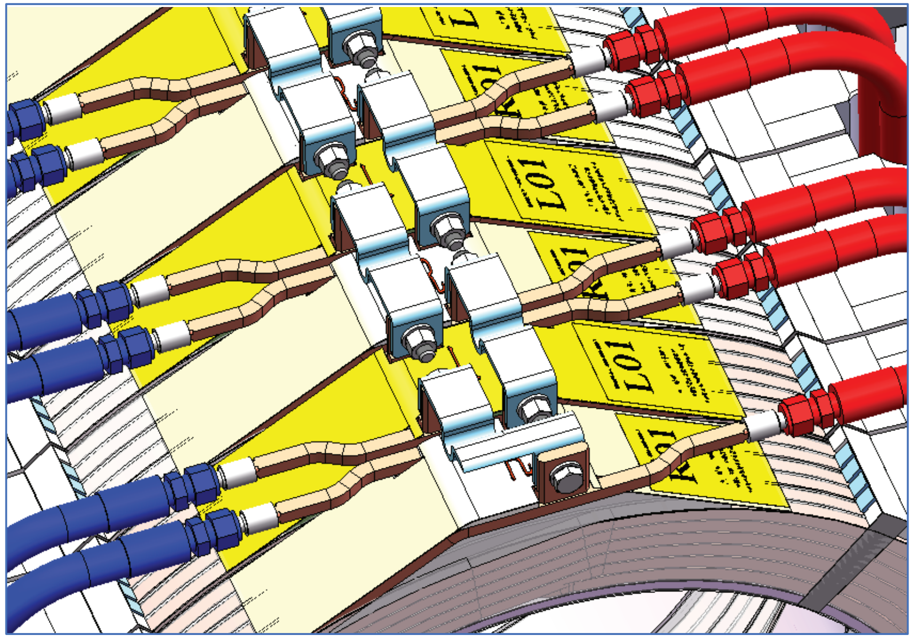
Simulated with U^{92+} beam

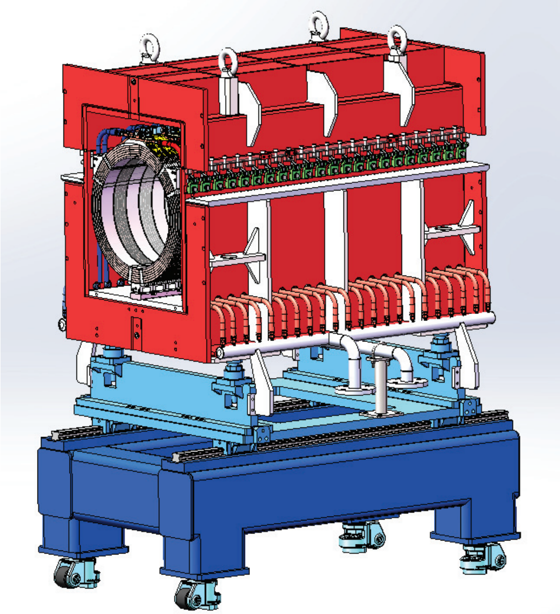
III. Technical challenges and developments at IMP

1. Coils and magnetic field measurement

Pancake coils connected in series --- CSR cooler used
Left-right winding coils to decrease the influence of the cross-bat commutation --- COSY cooler used





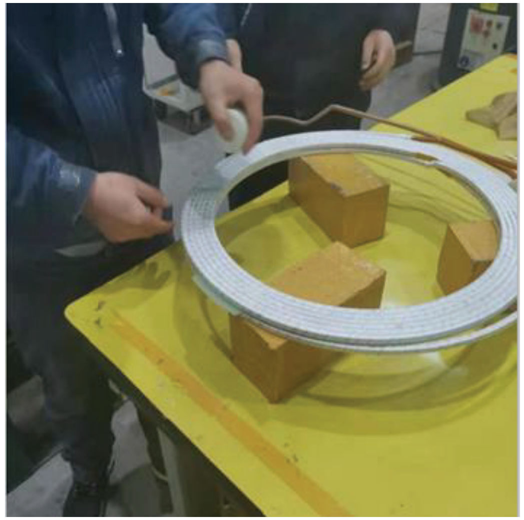
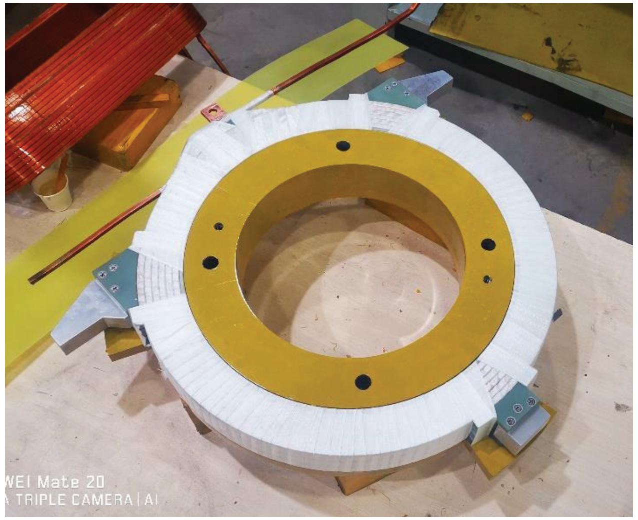
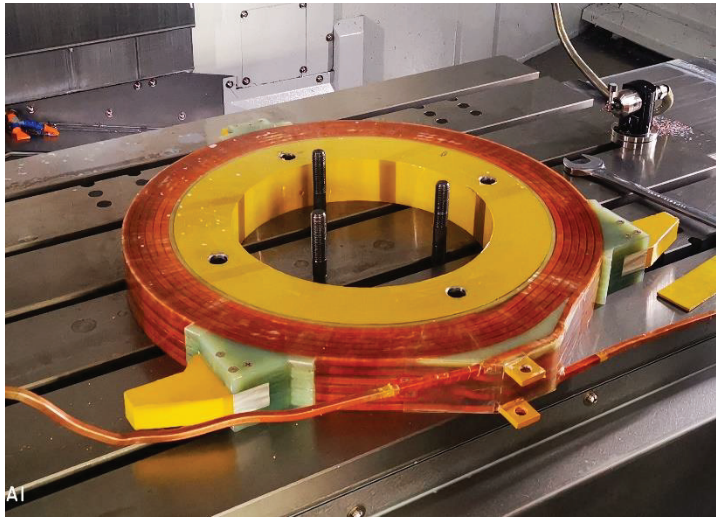
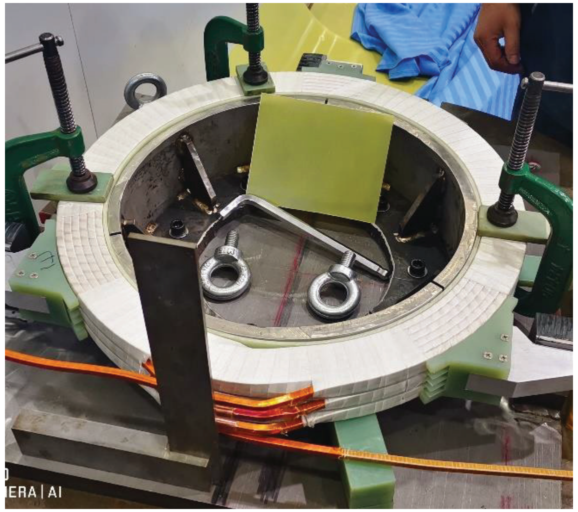
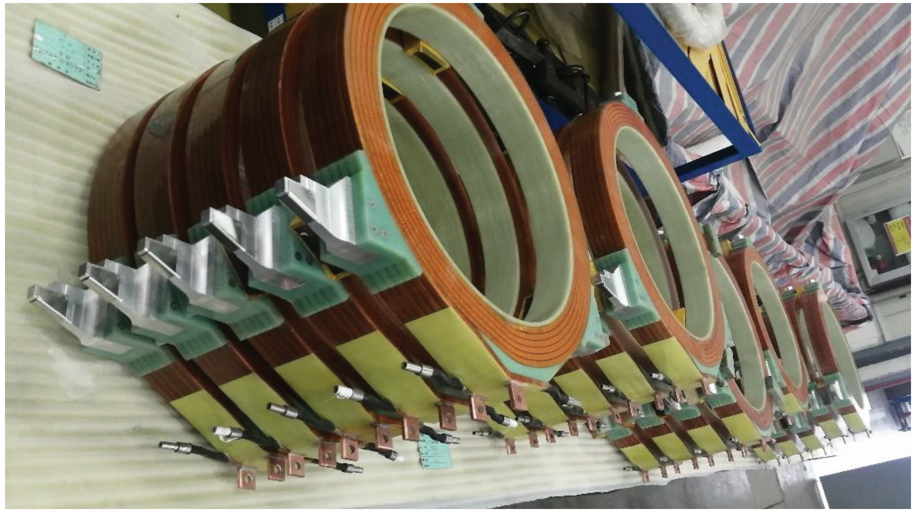


The coil size is the same as CSR cooler
Correction coil (for electron beam) is located inside of the solenoid

III. Technical challenges and developments at IMP

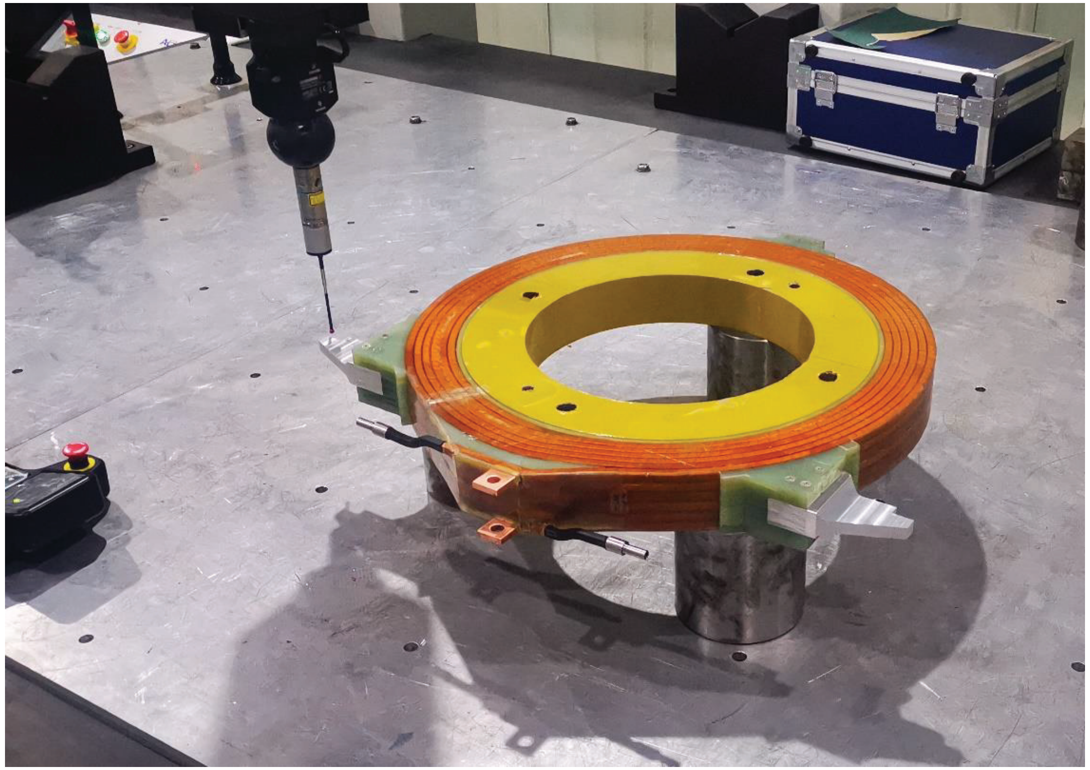
1. Coils and magnetic field measurement

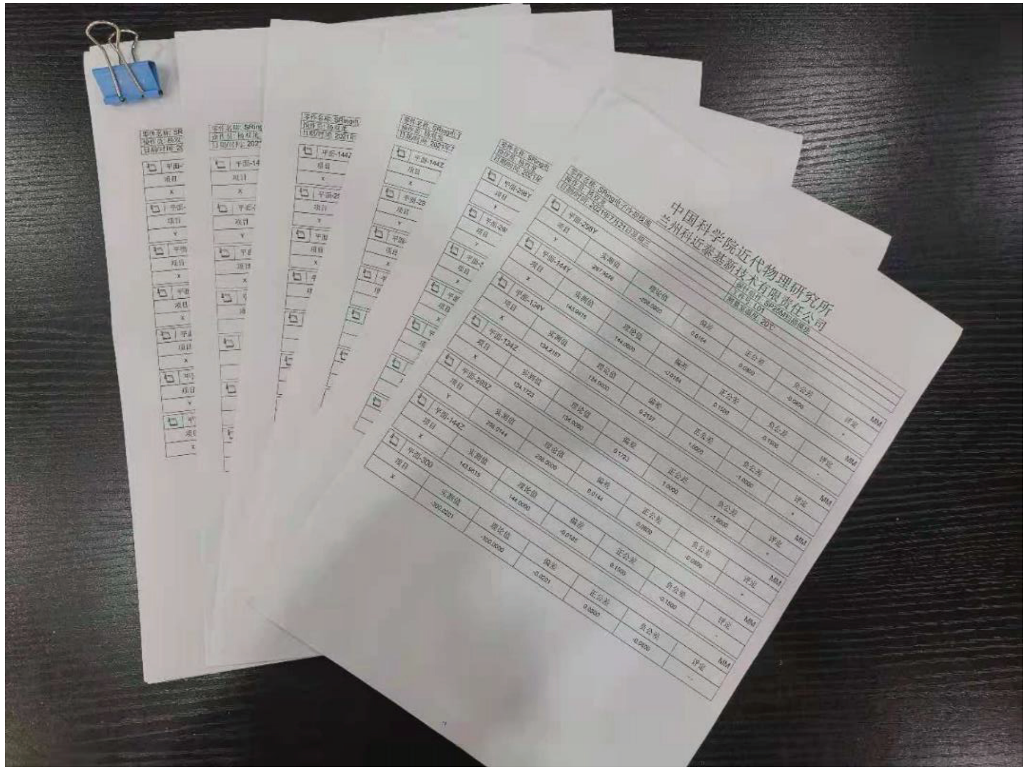
Coils have been manufacutred by workshop at Lanzhou

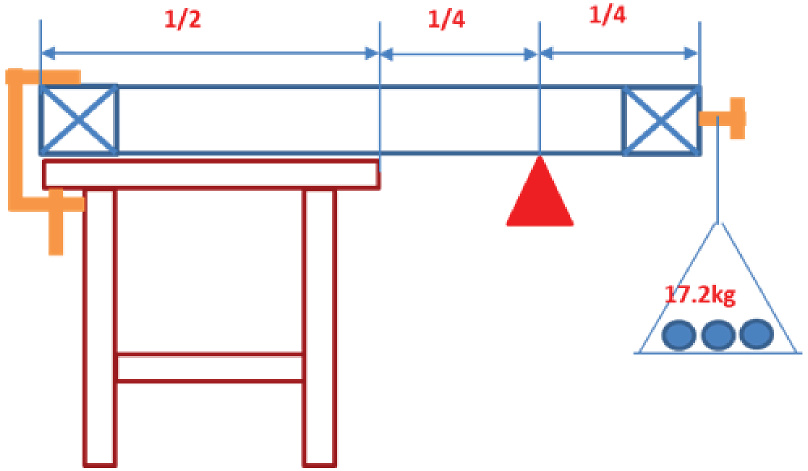

1. Coils and magnetic field measurement

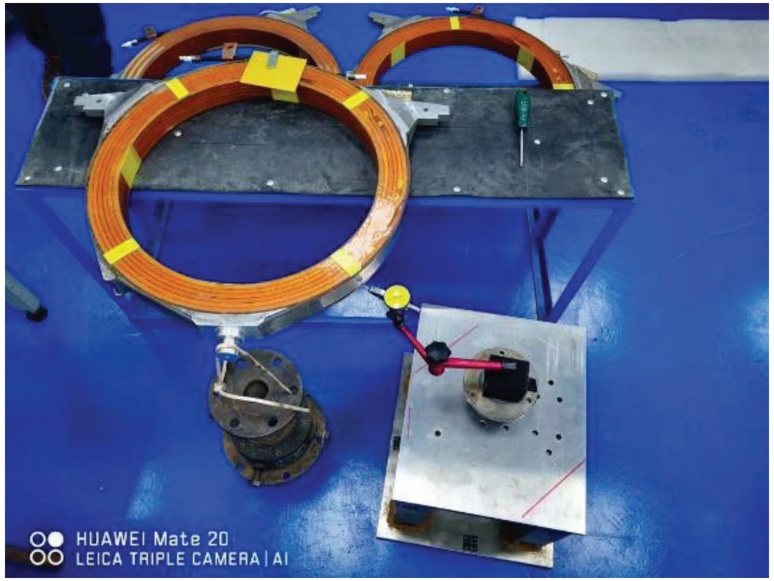
The position of coil supports is measured by a Coordination Measuring Machine



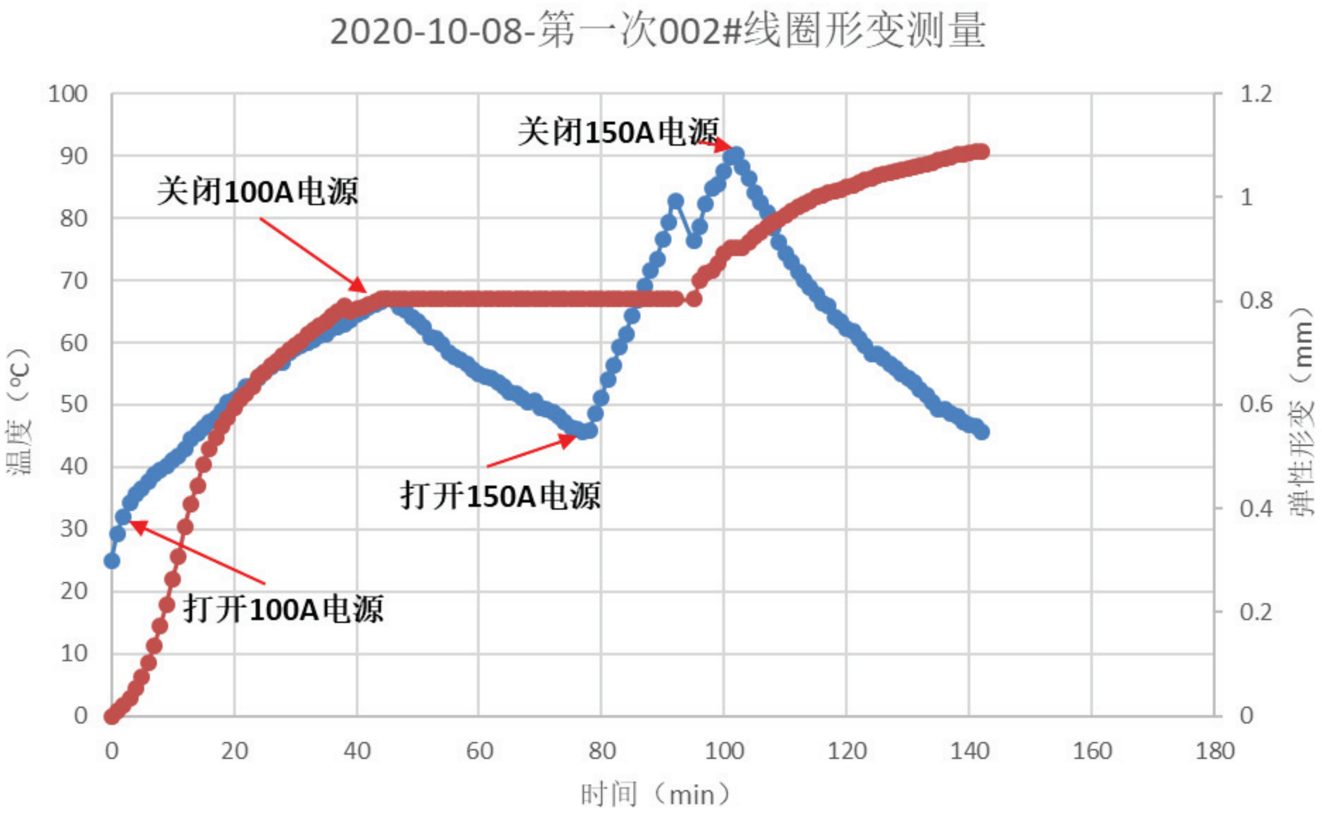


1. Coils and magnetic field measurement



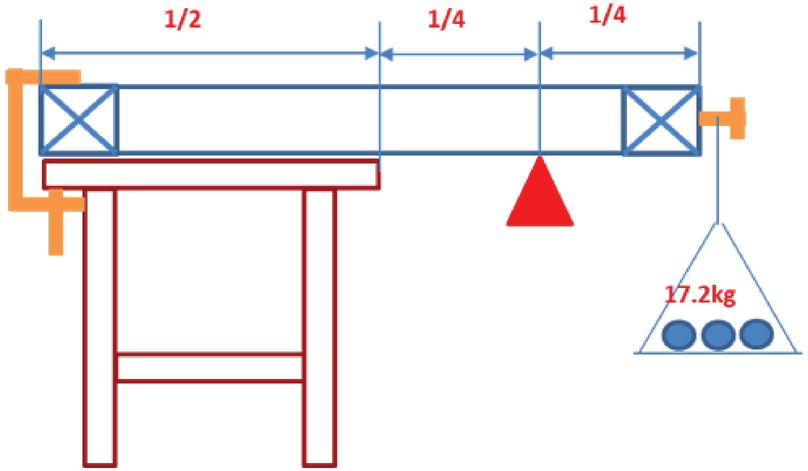


The deformation of coils depends on the temperature was measured <0.3 mm

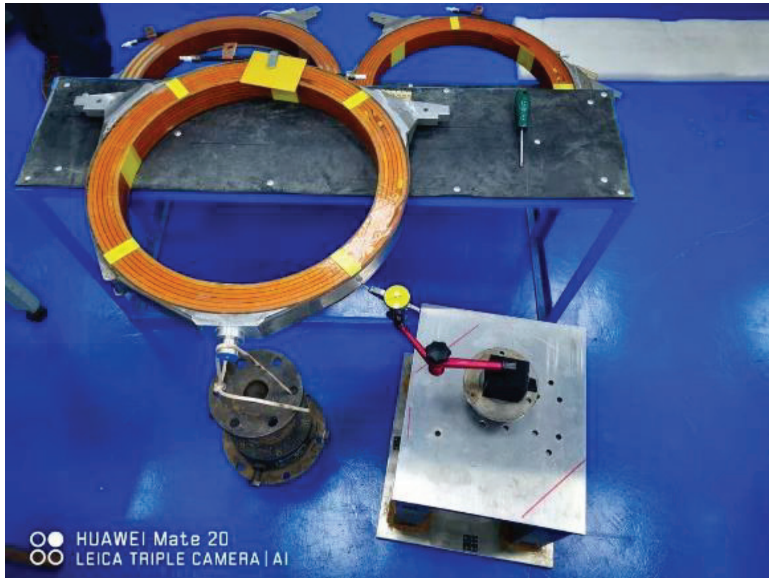


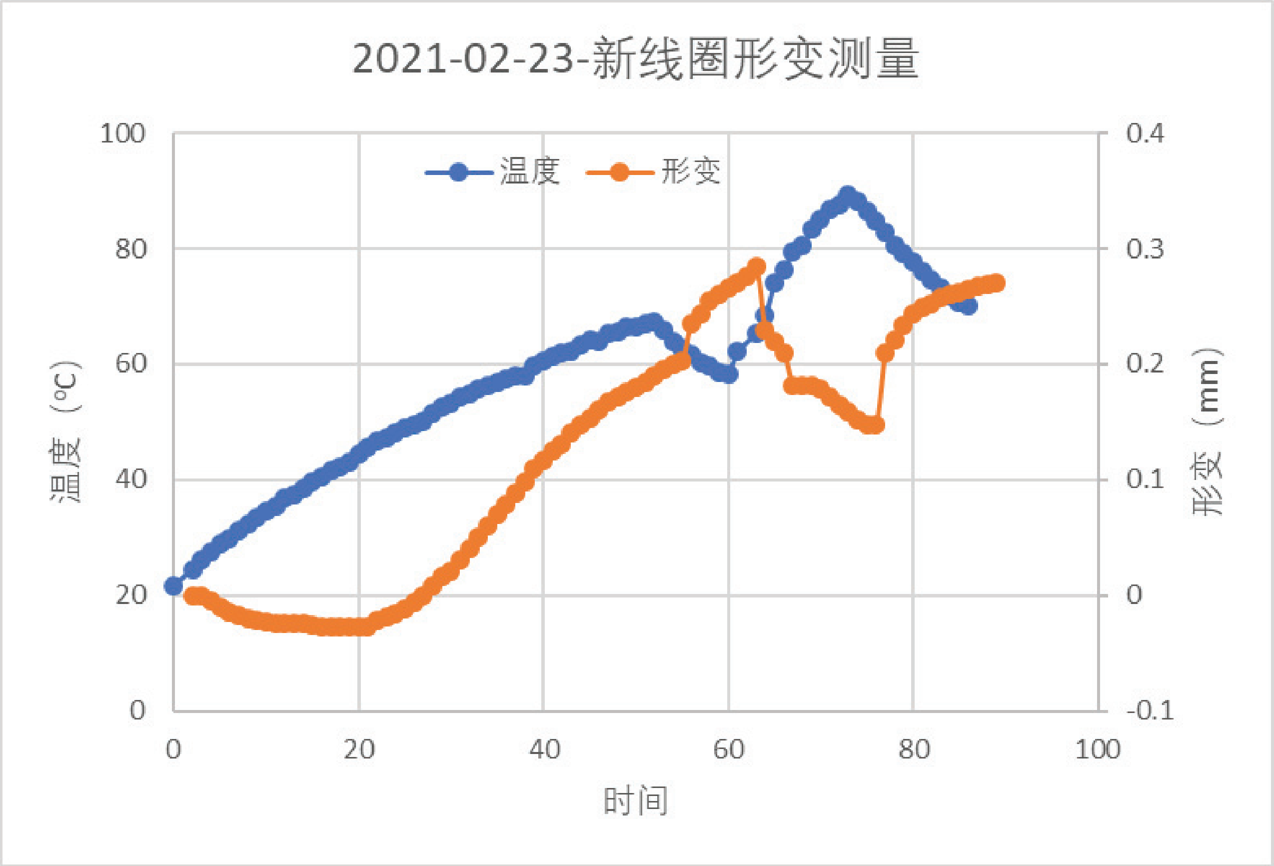
III. Technical challenges and developments at IMP

1. Coils and magnetic field measurement



The deformation of coils depends on the temperature was measured **<0.3 mm**

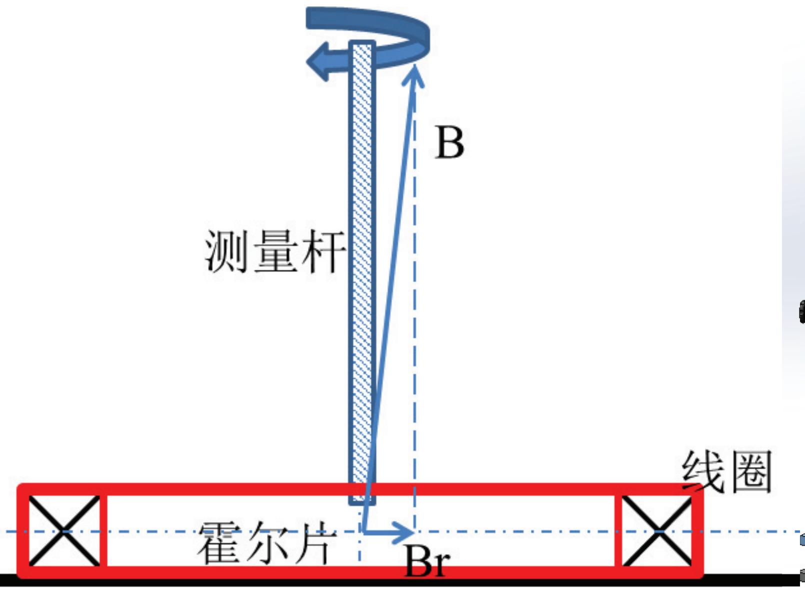


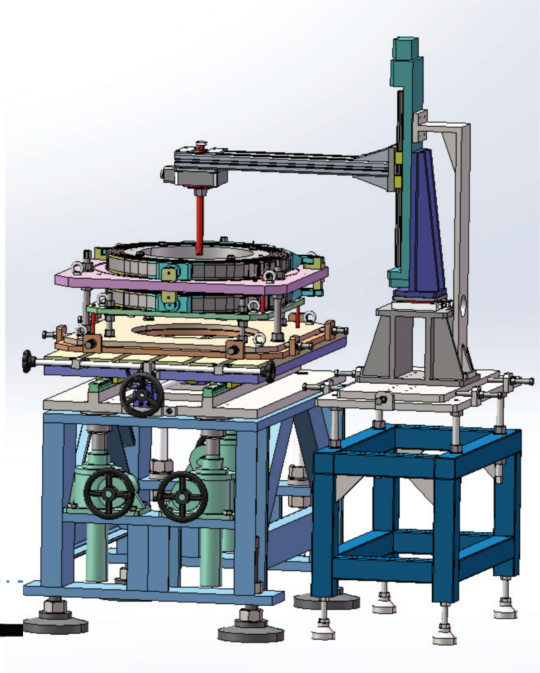


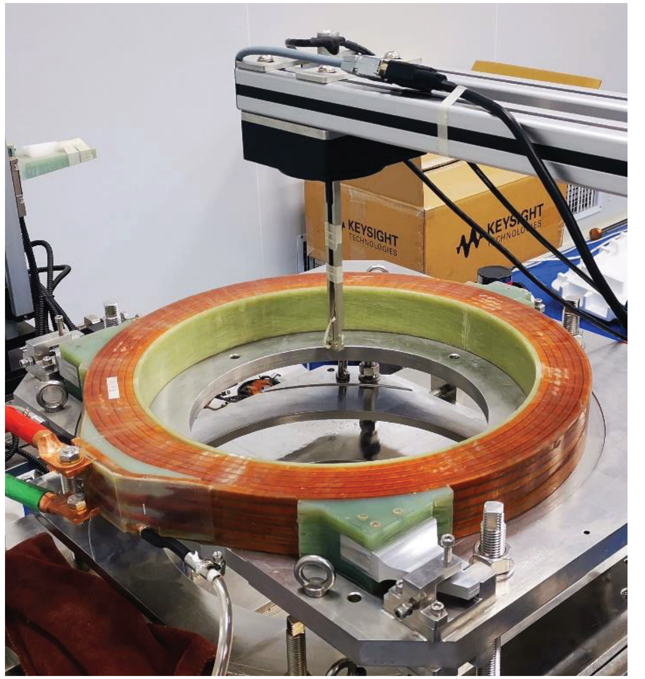
III. Technical challenges and developments at IMP

1. Coils and magnetic field measurement

The radial & axial magnetic field components are measured by different Hall probes

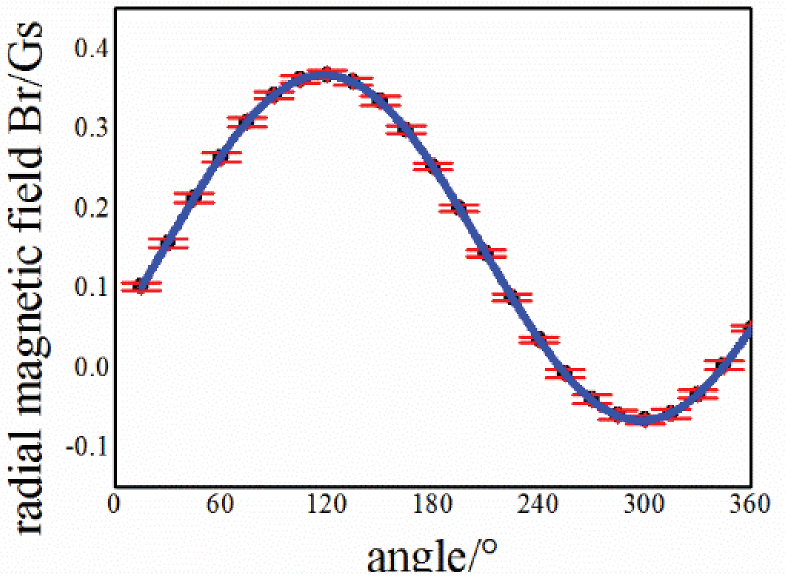


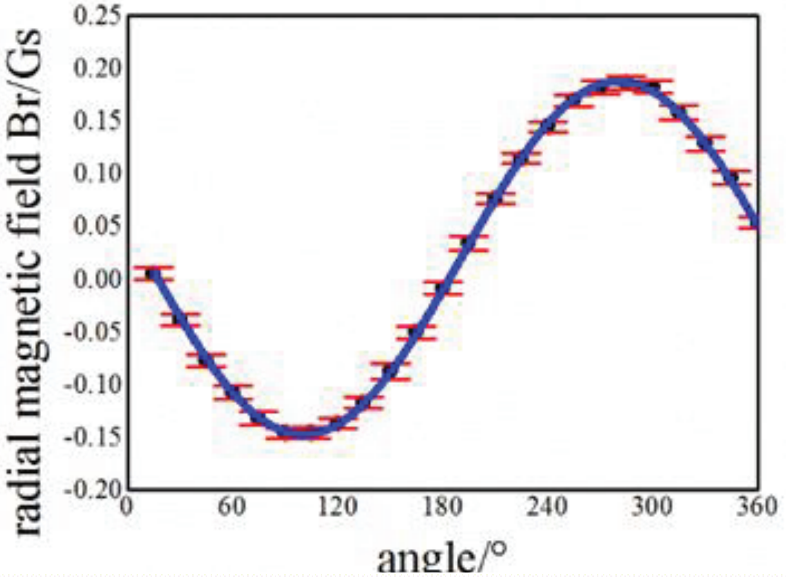


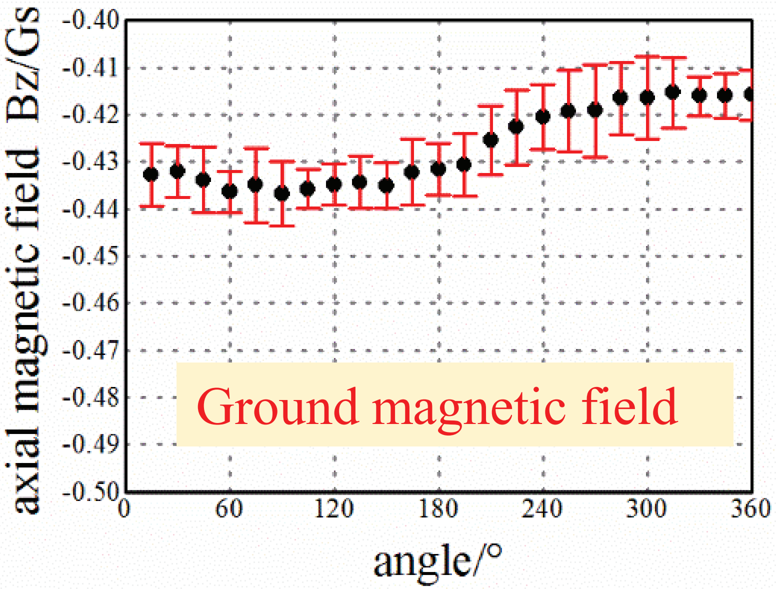


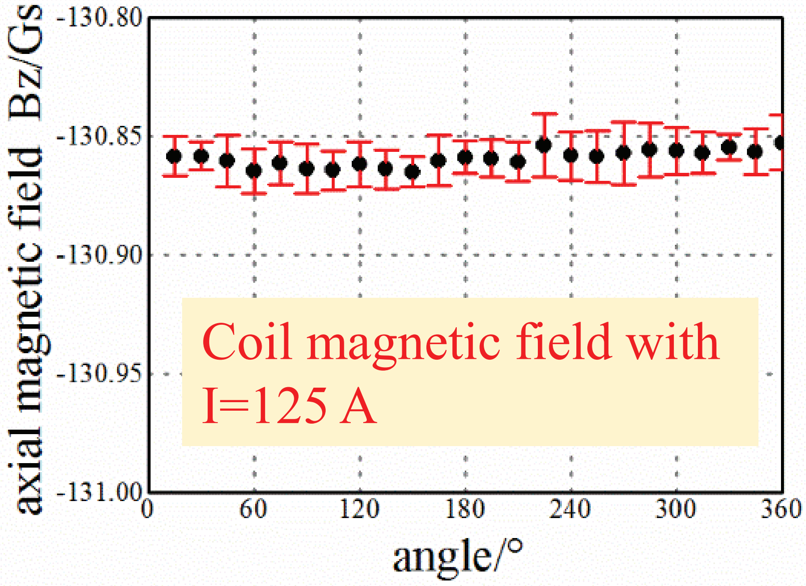
- It is used to measure the relative angle between magnetic field and the geometric symmetrical axis
- The angle less than 2.0 mrad is required

1. Coils and magnetic field measurement



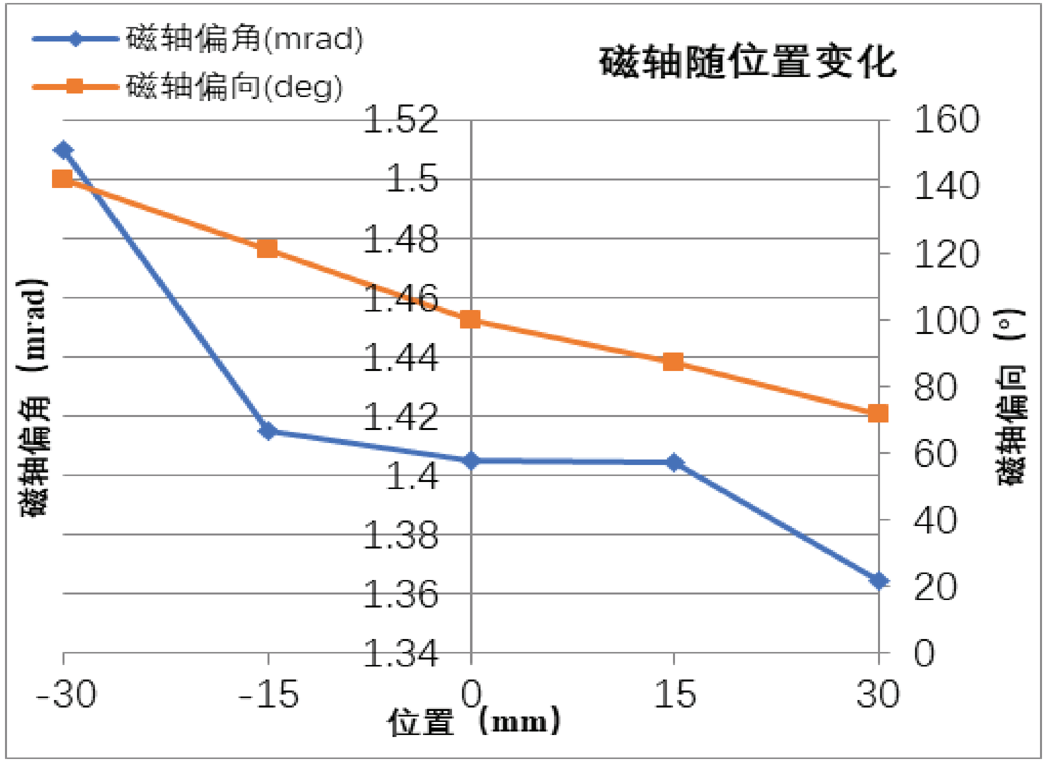


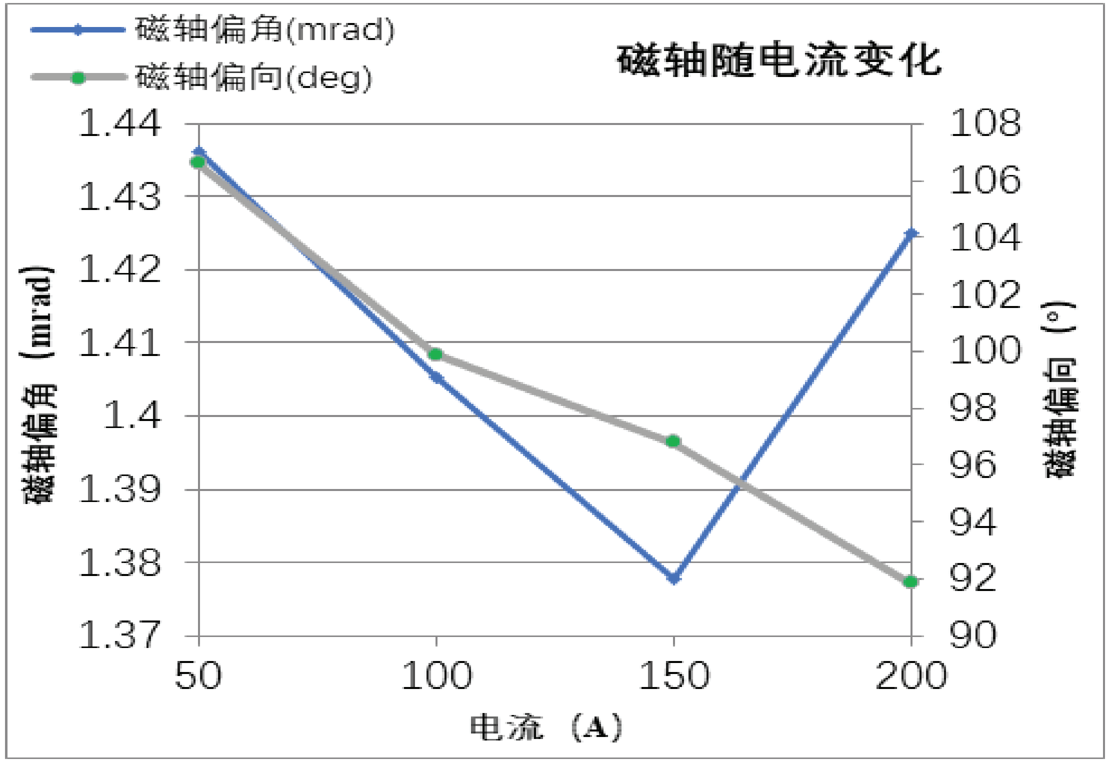




III. Technical challenges and developments at IMP

1. Coils and magnetic field measurement

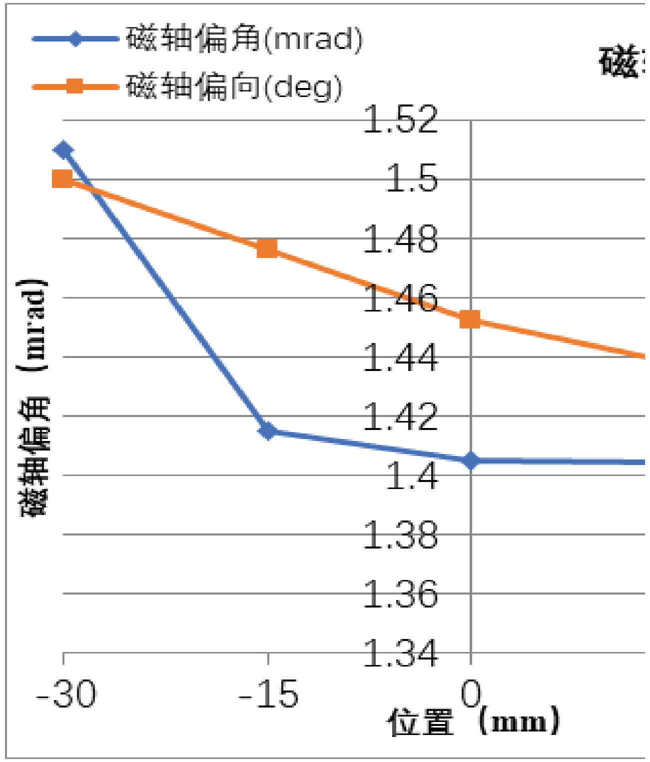




- The relative angle between magnetic field and the geometric symmetrical axis is measured by a rotating Hall probe
- The gap between coils are 1.5 mm, angle less than 2.0 mrad is required

III. Technical challenges and developments at IMP

1. Coils and magnetic field me

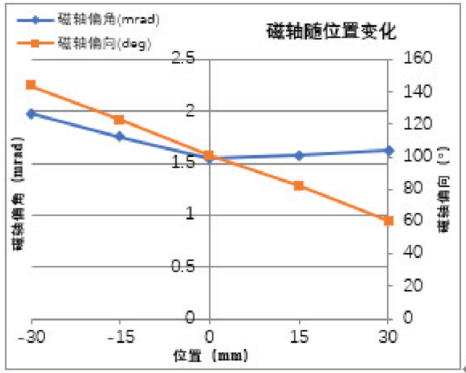


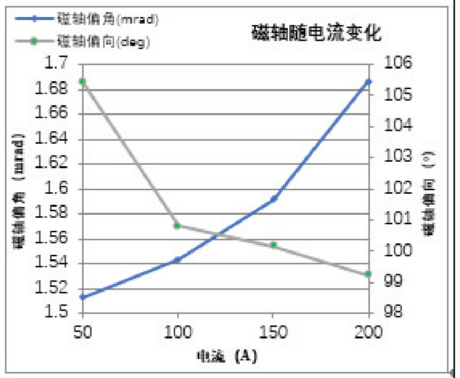
HIAF 电子冷却线圈磁轴偏角测量

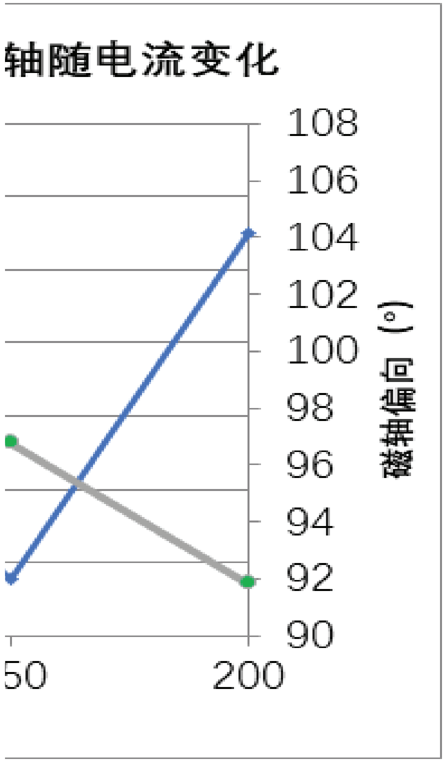
线圈编号	L04		
测量时间	20210924	测量人员	沙小平
数据文件夹	E:\测磁\测磁\1 单线圈\单线圈实际测量 1\2021 测磁\20210924		

测量结果

测量条件	磁轴偏角大小	磁轴偏角方向
50A	1.512474	105.4731
100A	1.542662	100.8222
150A	1.591624	100.159
200A	1.686206	99.21804
以下测量在 100A 电流下实施		
15mm	1.583273	82.31054
-15mm	1.750269	122.668
30mm	1.619564	60.15662
-30mm	1.974872	144.1285



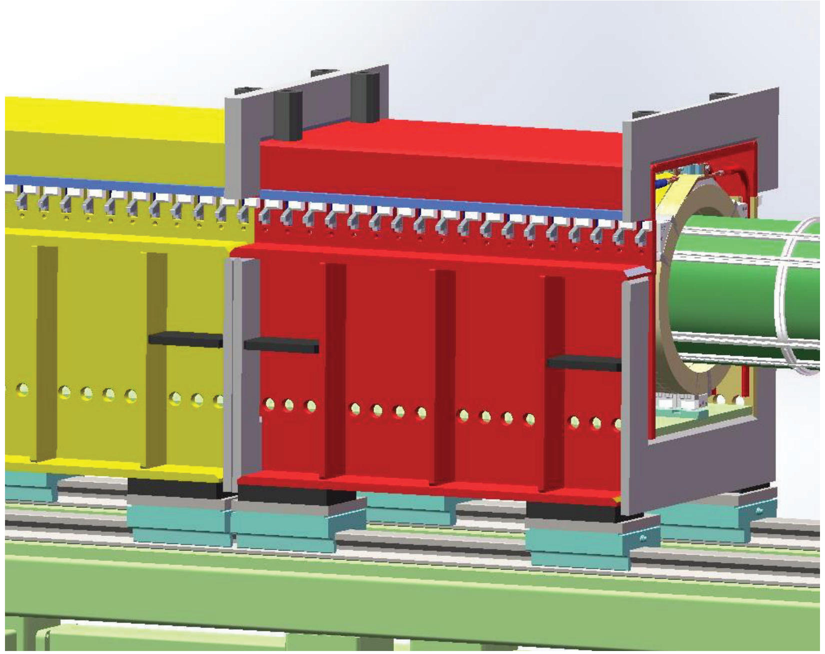


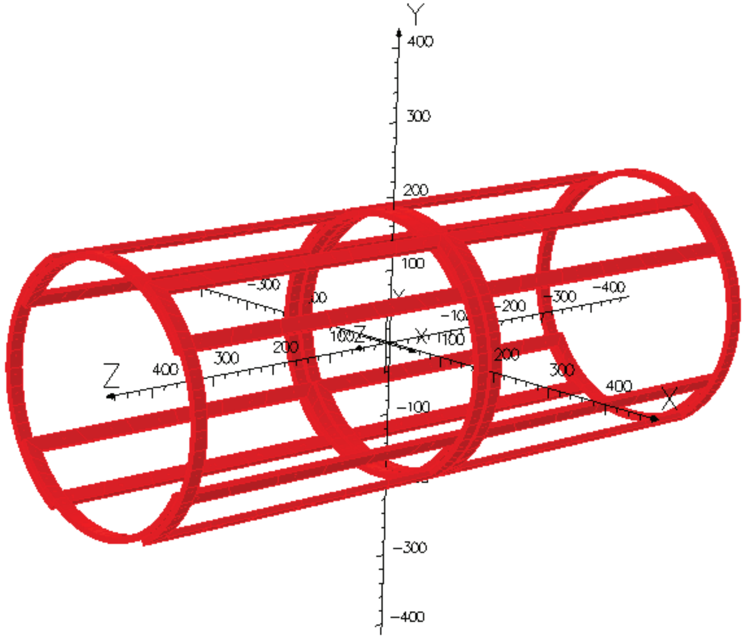


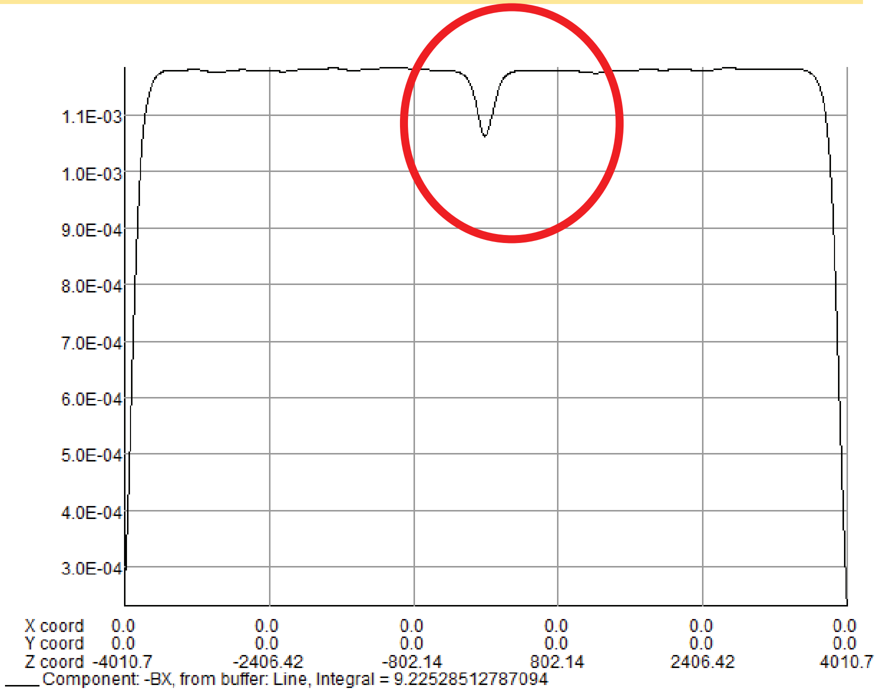
- ➢ The relative angle betwee … s is measured by a rotating Hall probe
- ➢ The gap between coils are

1. Coils and magnetic field measurement

The correction coils are located inside of the solenoid





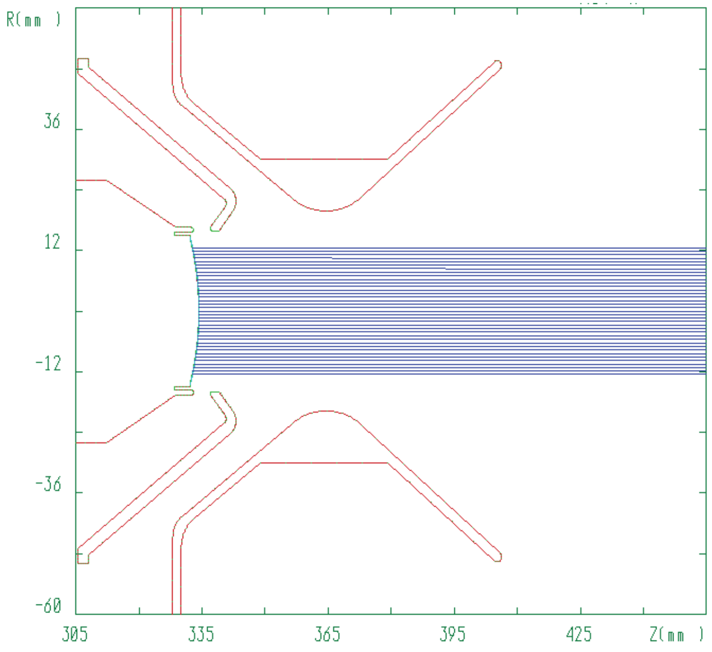


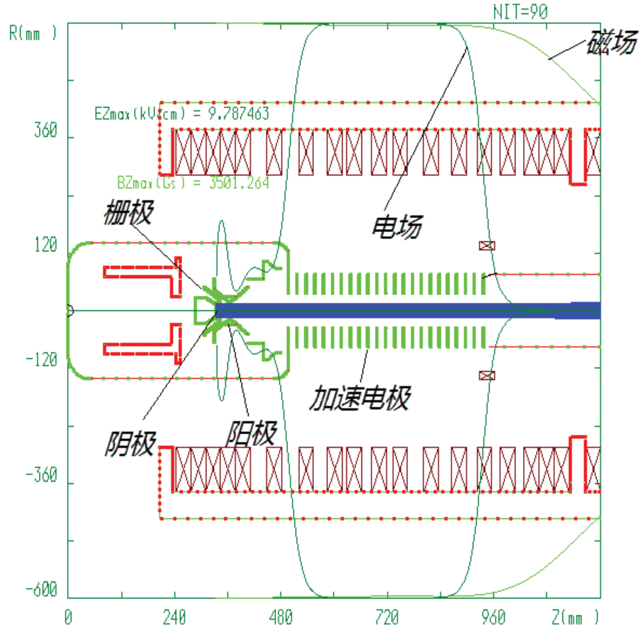
- The correction coils are divided in 2 groups (around 4 m for each group)
- It's difficult to reduce the field error at the gap between two correction coils
- To find a solution without cooling water

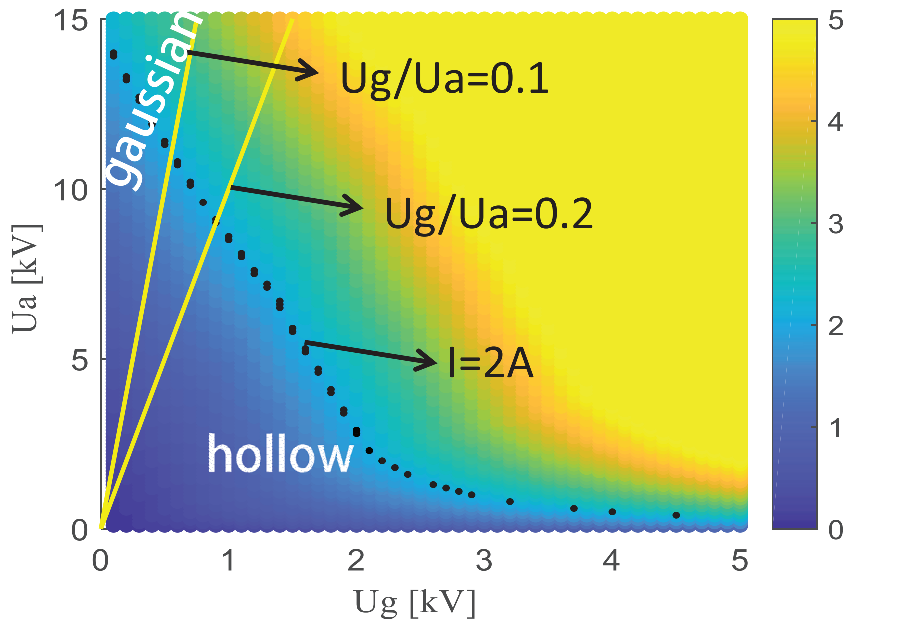
III. Technical challenges and developments at IMP

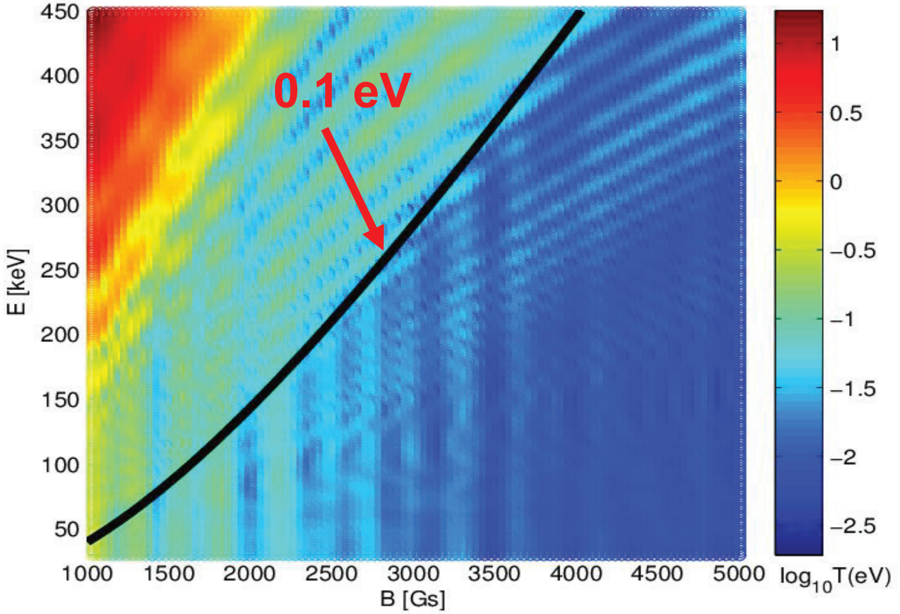
2. Gun and collector

The electron gun can provide electron beam up to 2.0 A





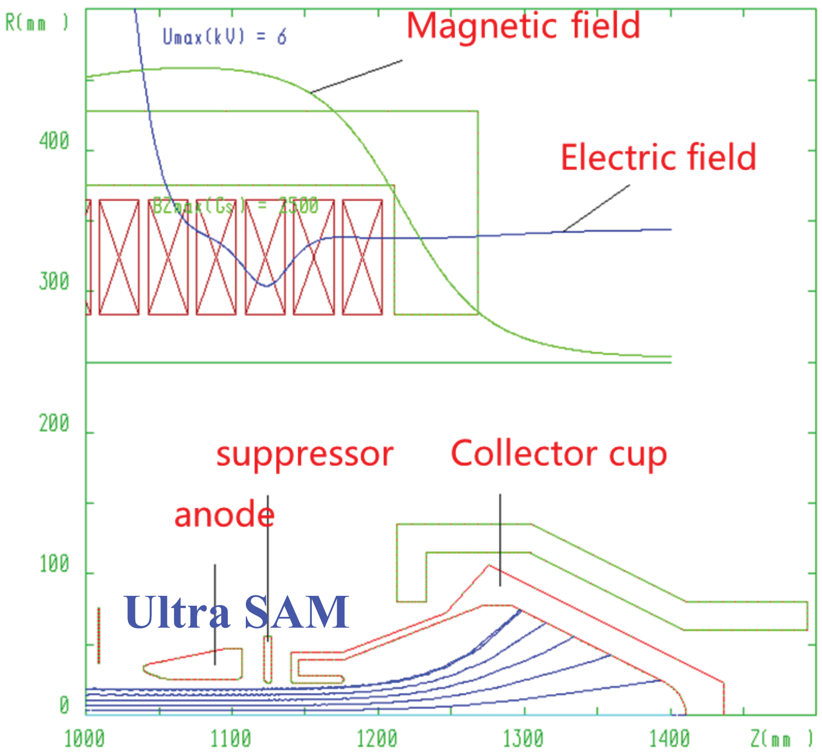


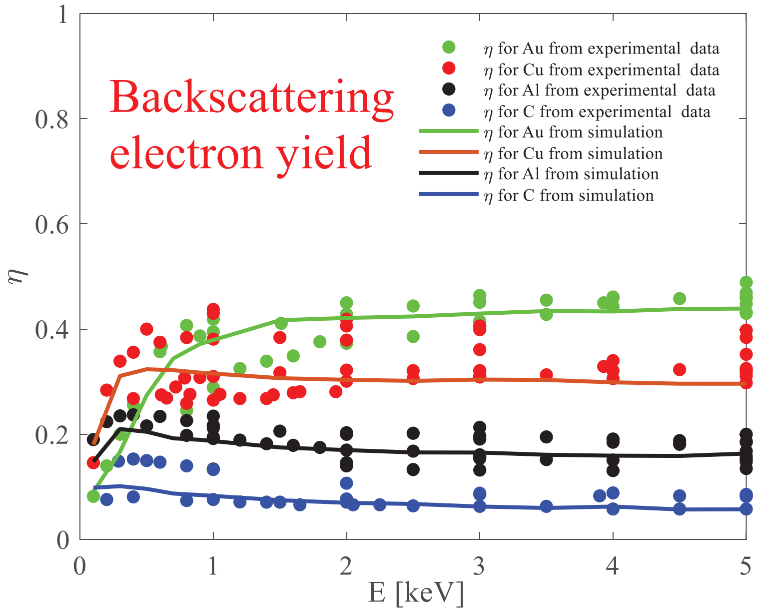


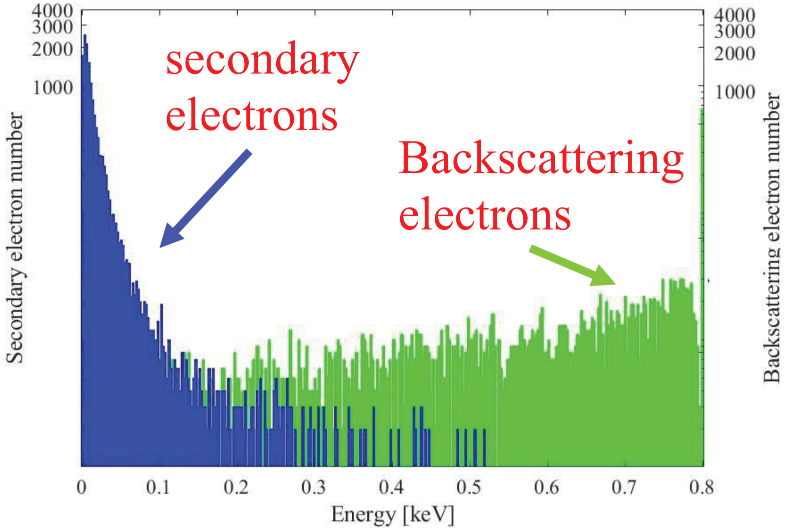
- ➢ Electron cooler gun is nearly the same as the CSR cooler gun
- ➢ The electron beam is accelerated in a high magnetic field and then expanded
- ➢ The calculated electron temperature is 0.1 eV after acceleration

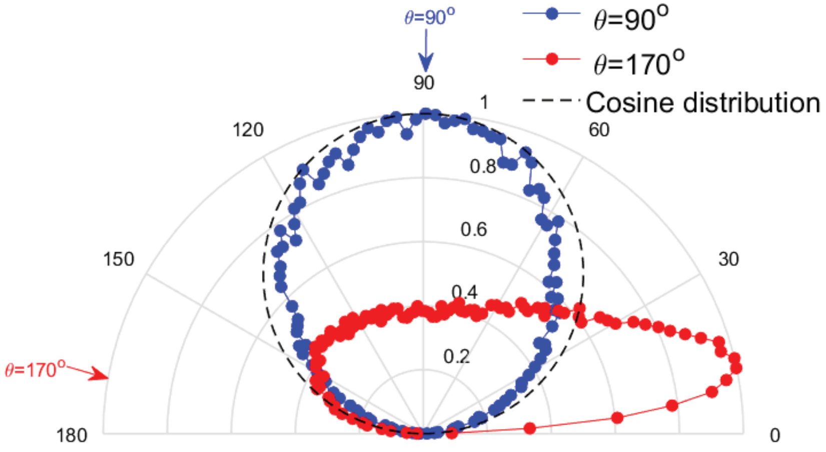
III. Technical challenges and developments at IMP

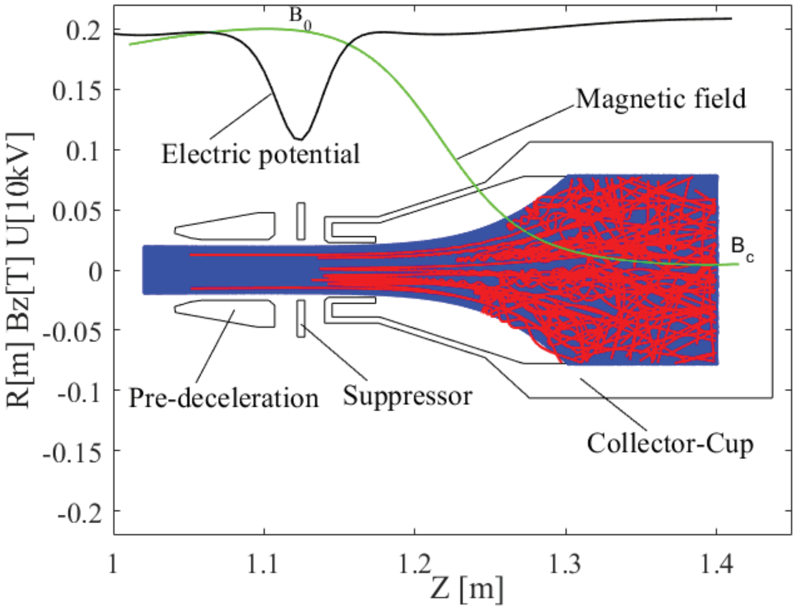
2. Gun and collector









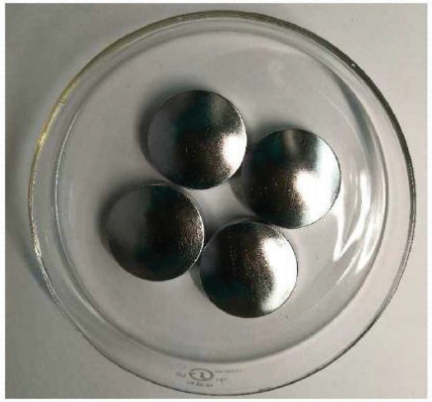


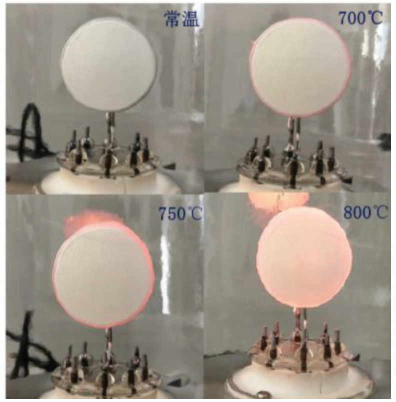
- ➢ Backscattering yield & secondary electron yield are calculated by a Monte-Carlo simulation code
- ➢ The energy spectrum shows backscattering electrons should be suppressed to improve the collection efficiency

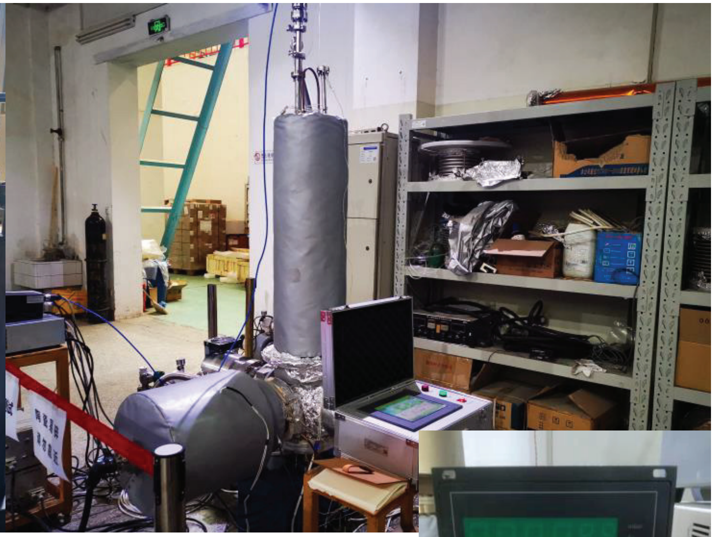
III. Technical challenges and developments at IMP

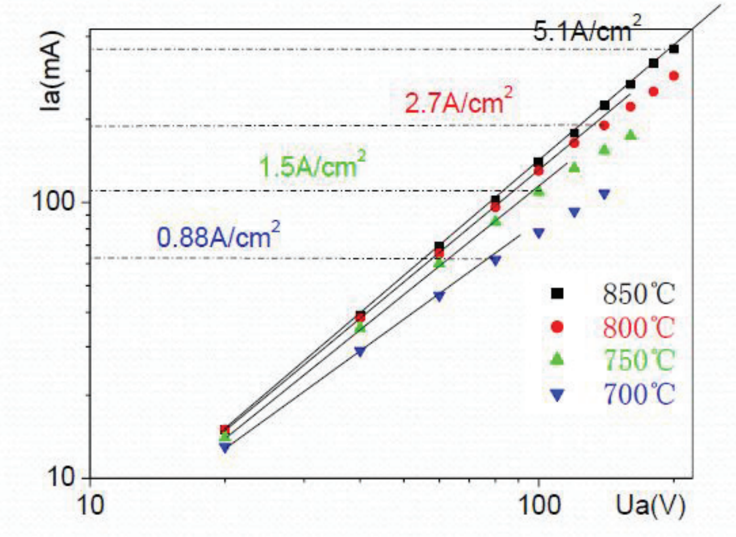
2. Gun and collector

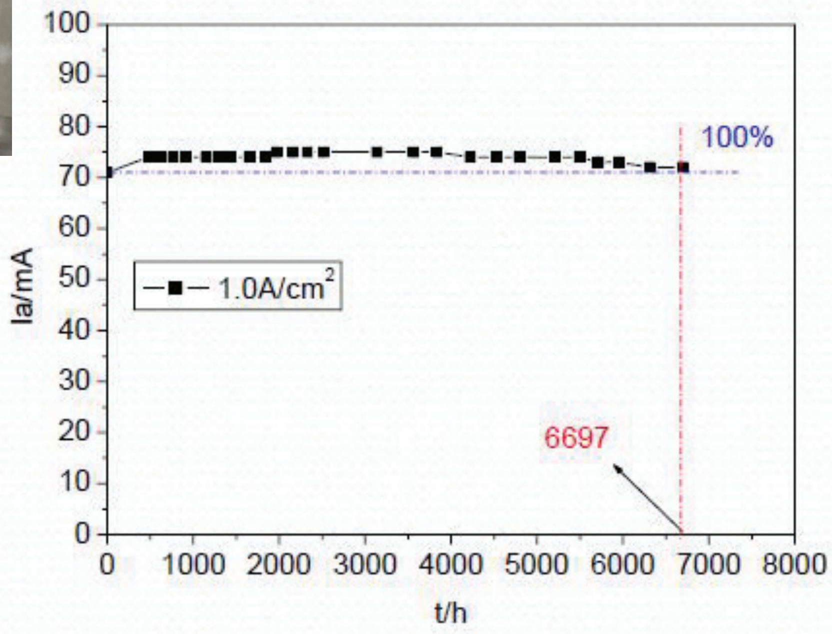
The oxide cathode is a cathode coated BaSrCa(CO3) on the surface of Ni base or W filament







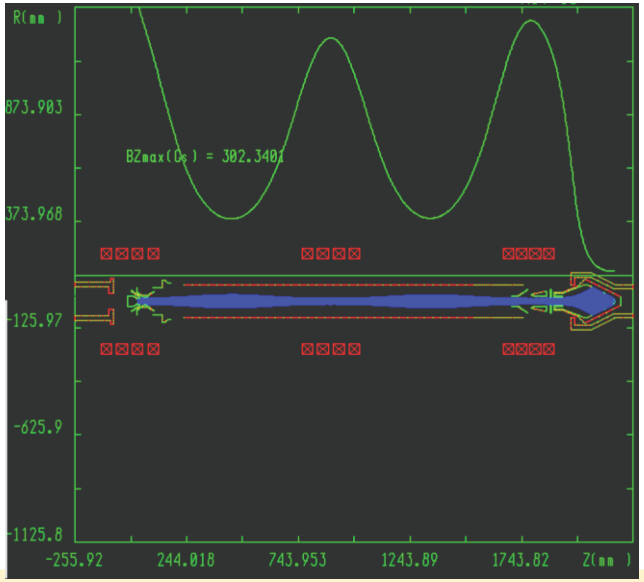




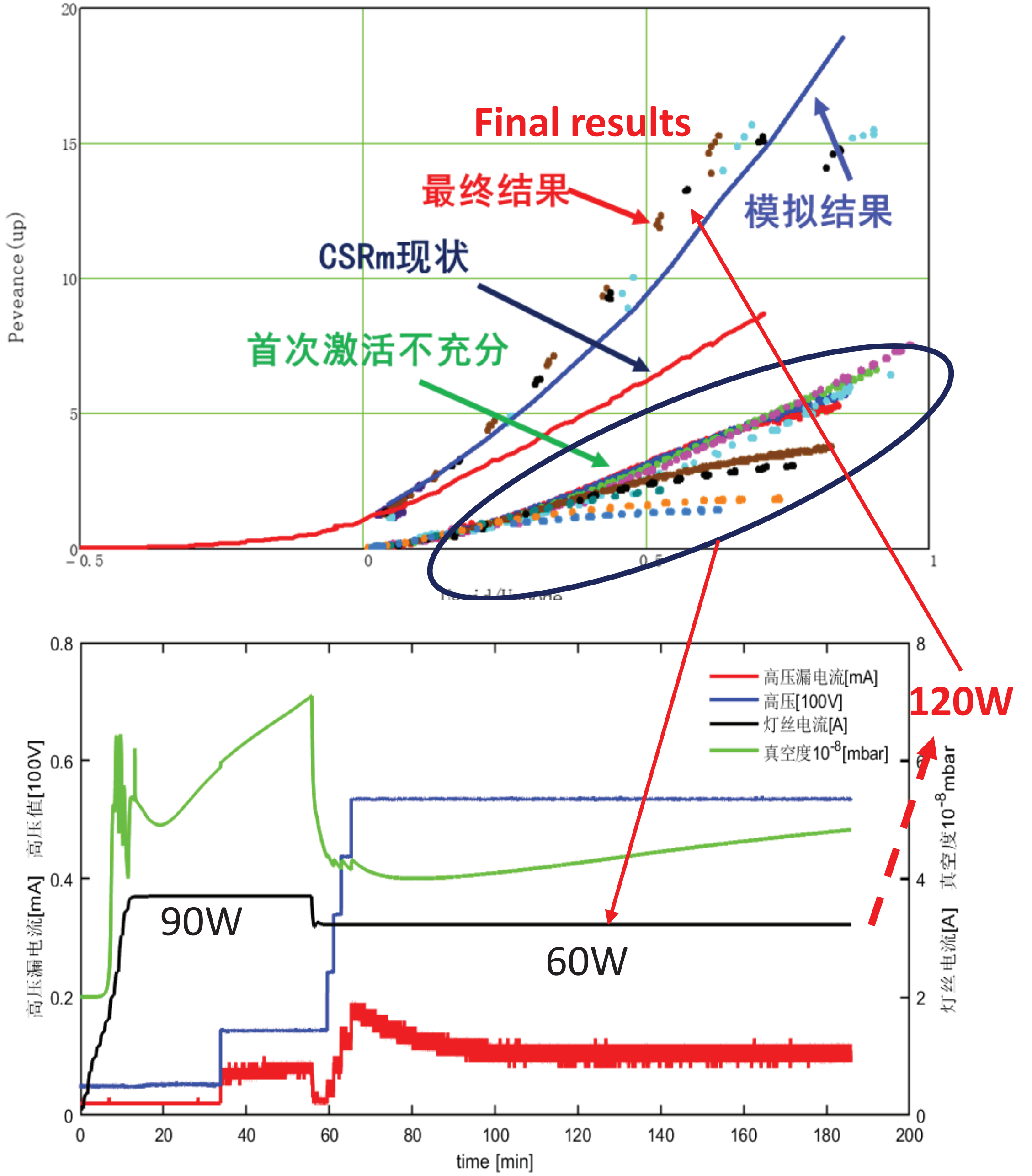
III. Technical challenges and developments at IMP

2. Gun and collector

Test bench for electron gun & collector



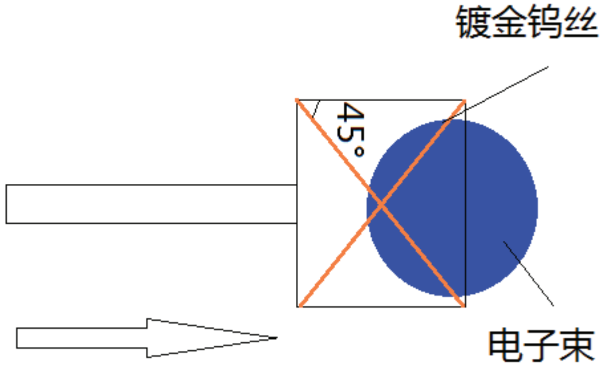
- Gun and collector are put in a straight line
- 3 group coils are used to control the electron motion
- Wire scanning is used to measure the electron beam profile

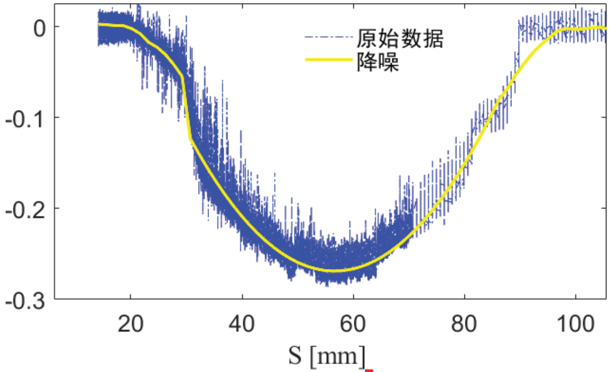


III. Technical challenges and developments at IMP

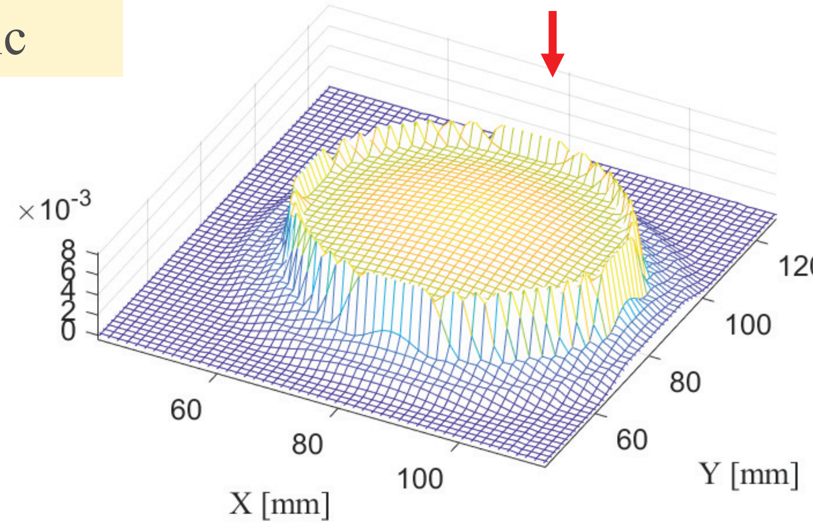
2. Gun and collector

Electron beam profile is measured by wire scanning

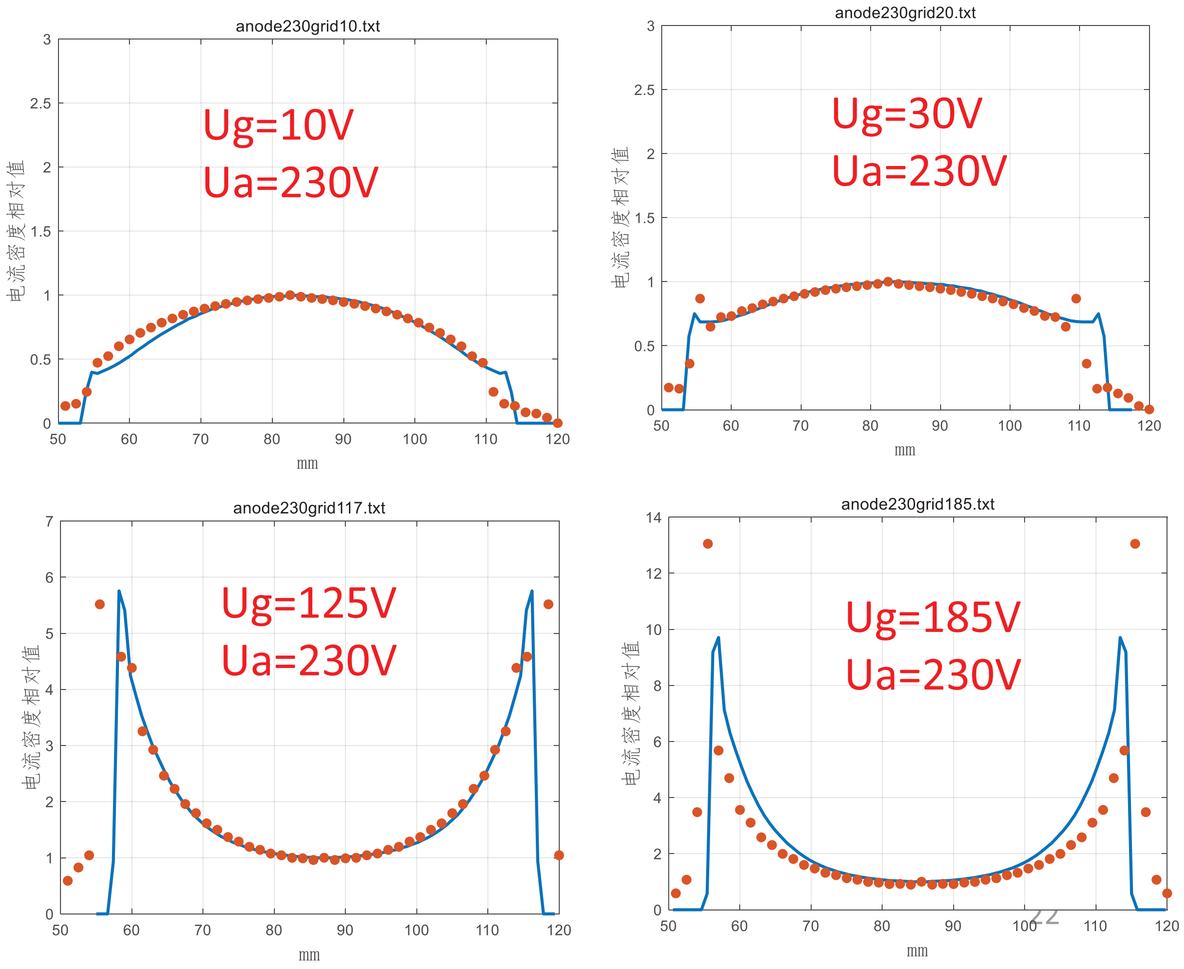




Radon Transform



The electron beam profile is symmetric

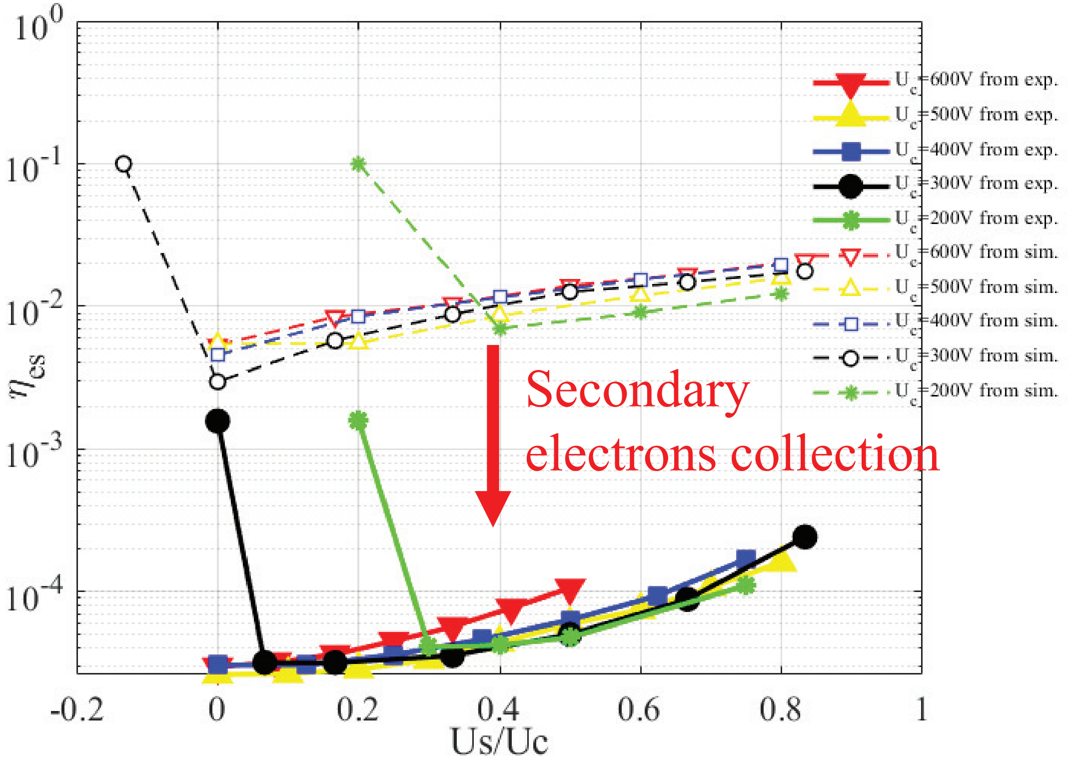


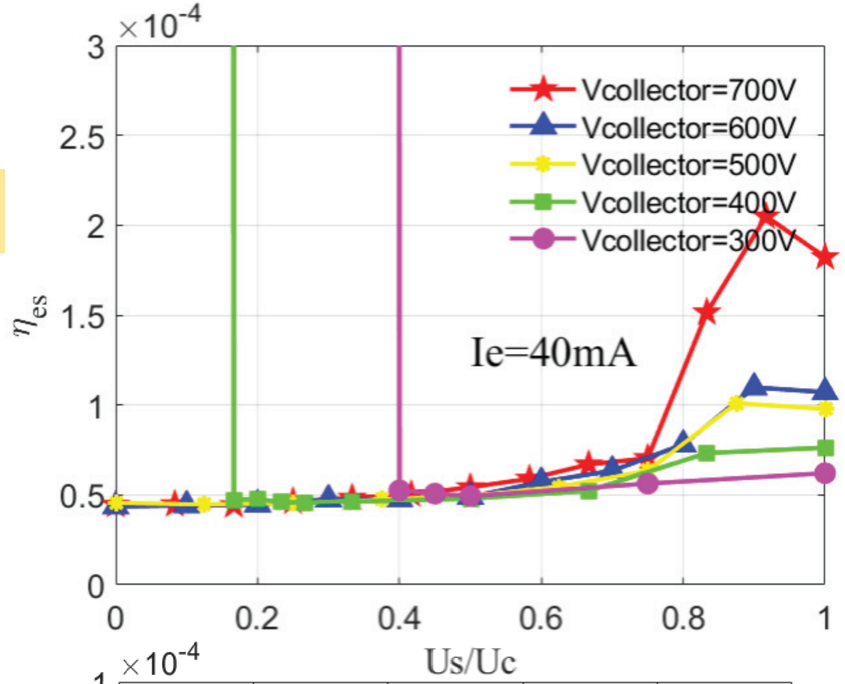
Measured electron beam profile vs. grid & anode voltage

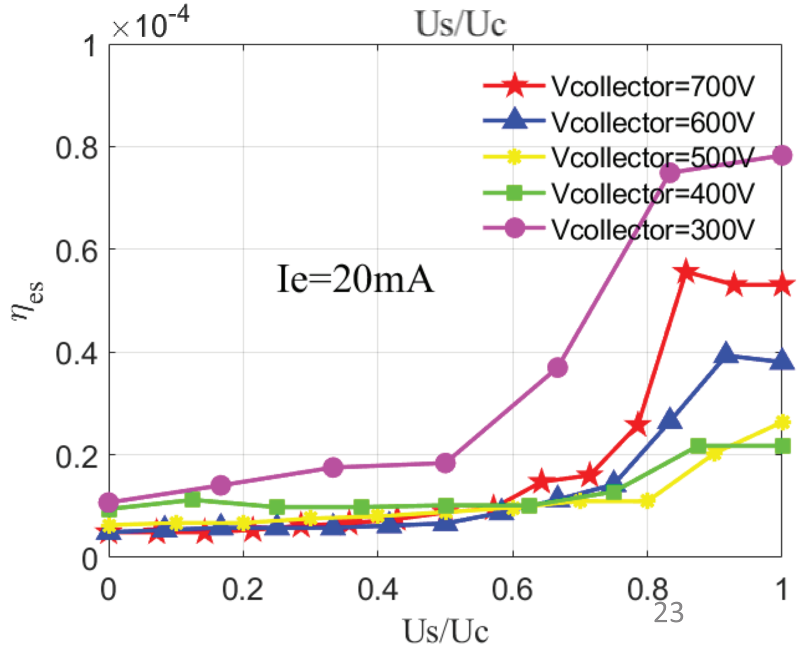
III. Technical challenges and developments at IMP

2. Gun and collector

The collection efficiency is measured with small electron beam current



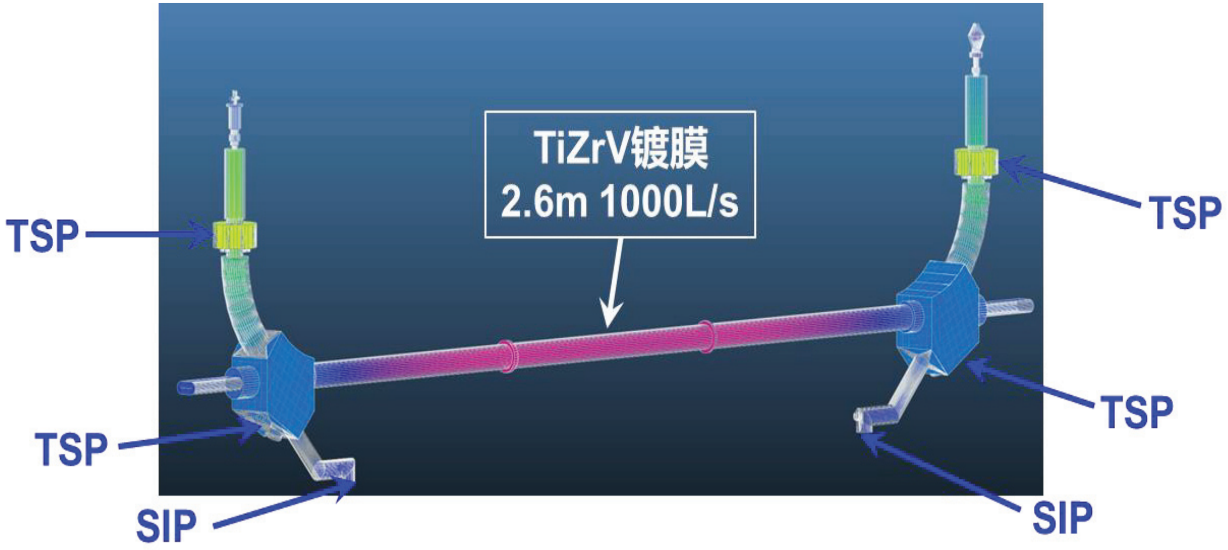




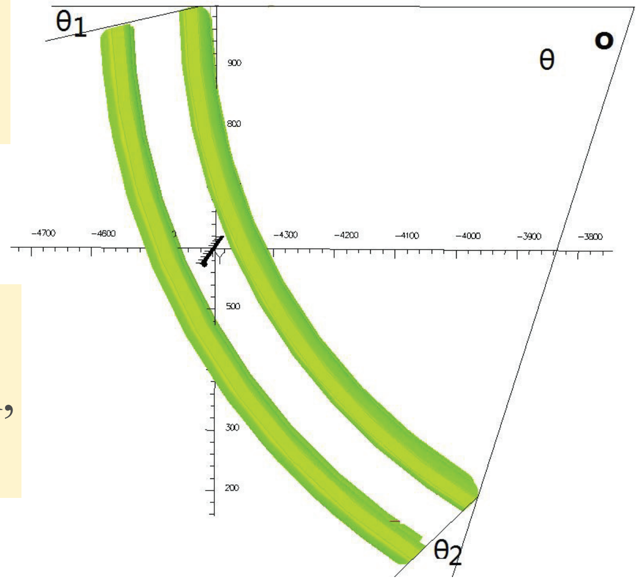
*the simulation didn't consider the collection of secondary electrons

III. Technical challenges and developments at IMP

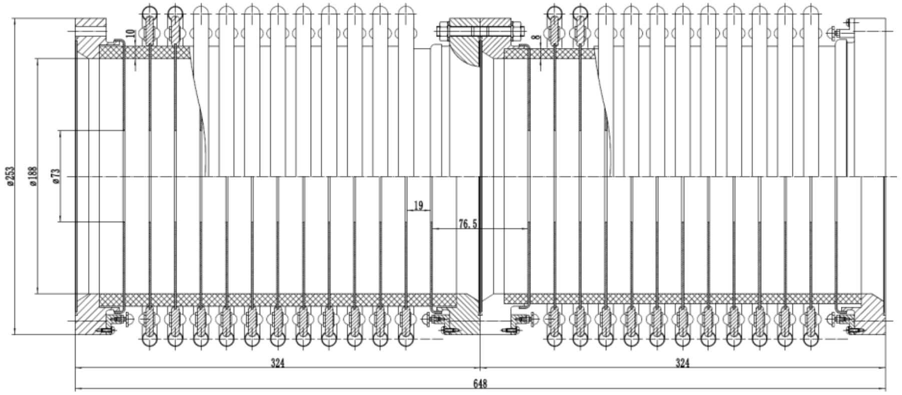
3. Other components

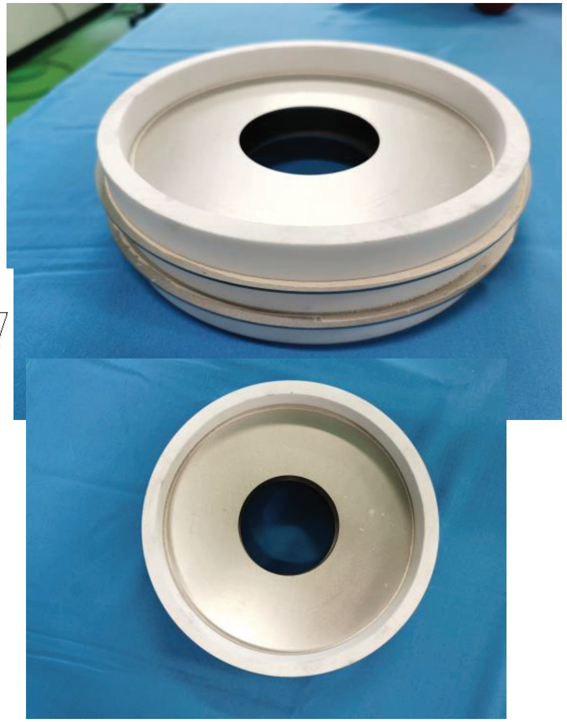


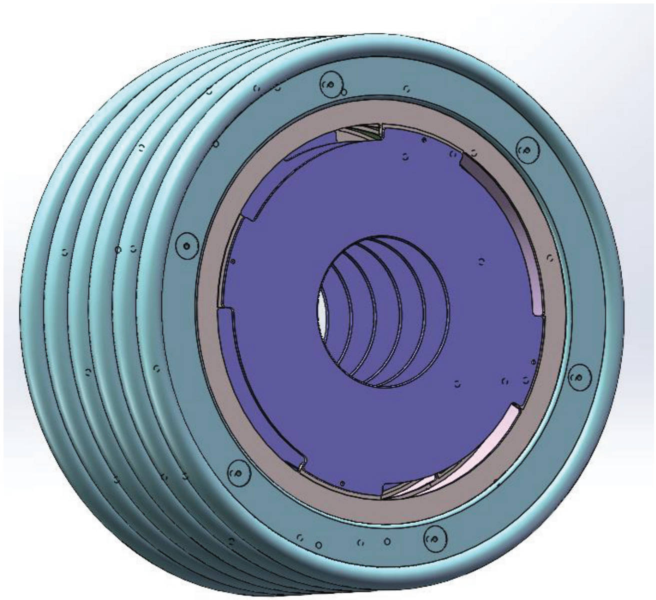
The vacuum chamber of cooling section NEG coating



The electrostatic plates, the design is finished (d_{gap}=10 cm, $\theta=15^{o}$)







Acceleration tube, with separated electrodes

IV. Outlook

- The HIAF electron cooler is a classical DC magnetized device based on the CSR cooler, which was designed by BINP in 2000
- All coils including cooling section, toroids, gun and collector sections are making by the workshop, we can get 10 coils for magnetic field measurement every month
- The gun and collector have been tested at IMP. The acceleration tube will be finished within 6 months
- The high voltage power supply is a big challenge for us. A new CSRe 300 kV high voltage platform was developed by BINP in 2019, it would be an available solution for SRing cooler
- **Thanks to Dr. Parkhomchuk, Reva, Skorobogatov and BINP group for the continuously support on the CSR cooler devices**

Thanks for your attention!