



Development of an electron cooler for HIAF facility in China

Lijun Mao

Institute of Modern Physics, CAS

2025/10/27

□ HIAF Introduction



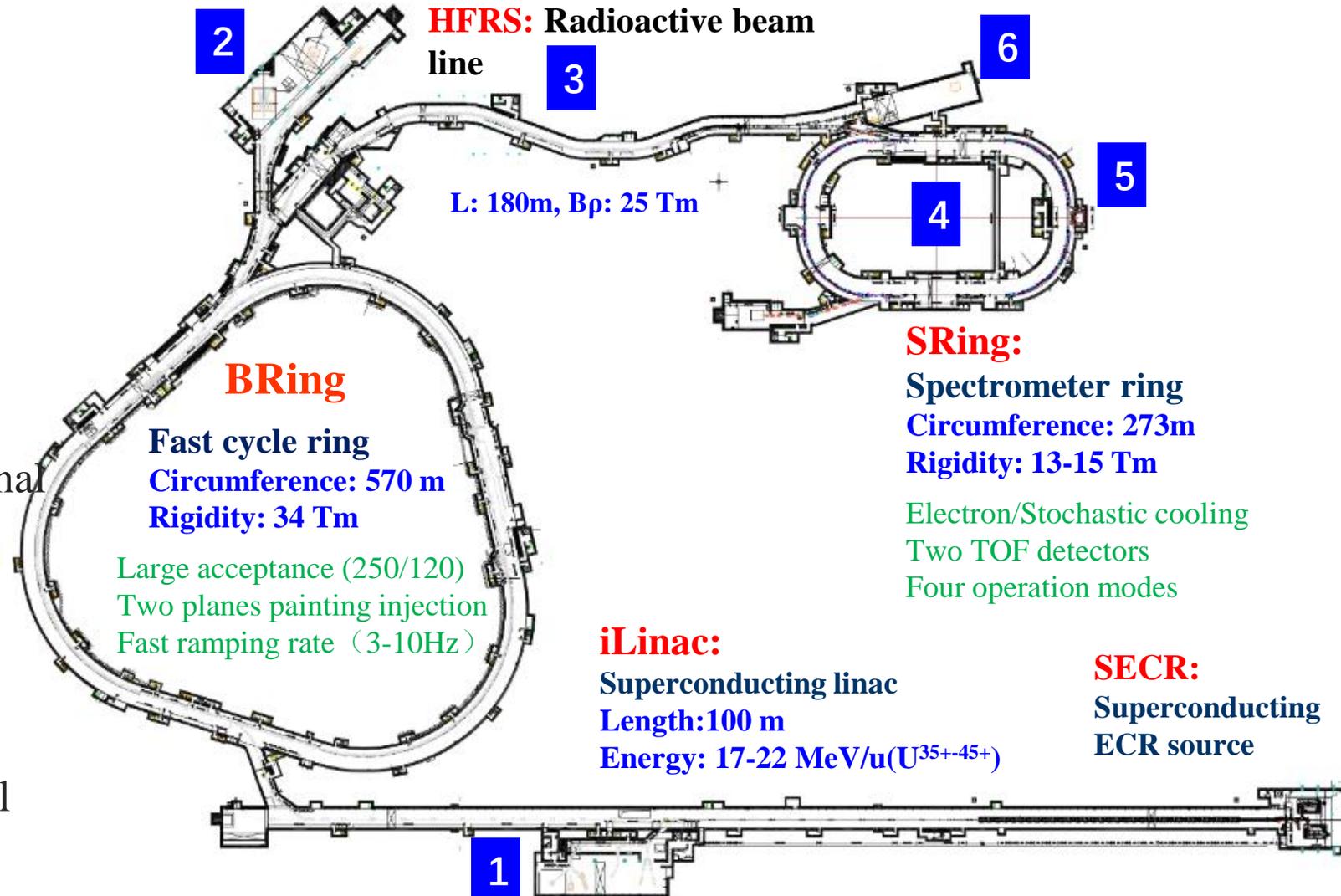
- HIAF (High Intensity heavy-ion Accelerator Facility)

• Accelerators

- super conduction ECR ion source
- + super conducting CW Linac
- + fast ramping synchrotron

• Terminals

- ① Low energy nuclear structure terminal
- ② High energy experimental terminal
- ③ High energy fragment separator
HFRS
- ④ High precision spectrometer ring
SRing
- ⑤ Electron ion recombination terminal
- ⑥ Radioactive ion beam physics terminal



□ HIAF Introduction



- HIAF: **proposed** in 2011, **approved** in 2015, **Budget** ~400 million USD, **start** civil construction in Dec. 2018, **installation finished** in Sept. 2025, located in **Huizhou**.



December. 2018



ECR ion source



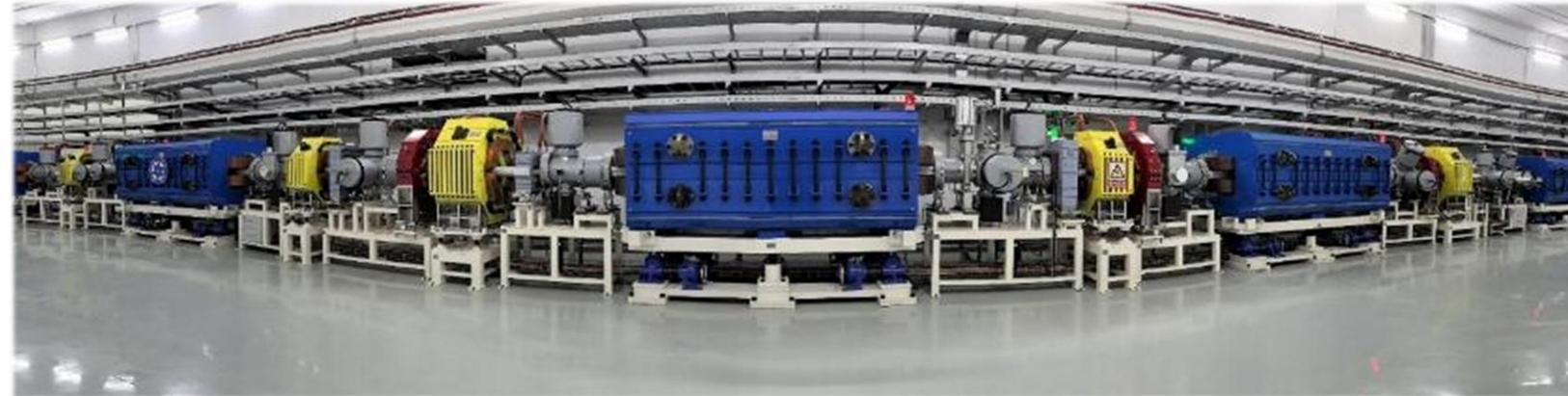
RFQ



iLinac



September. 2025



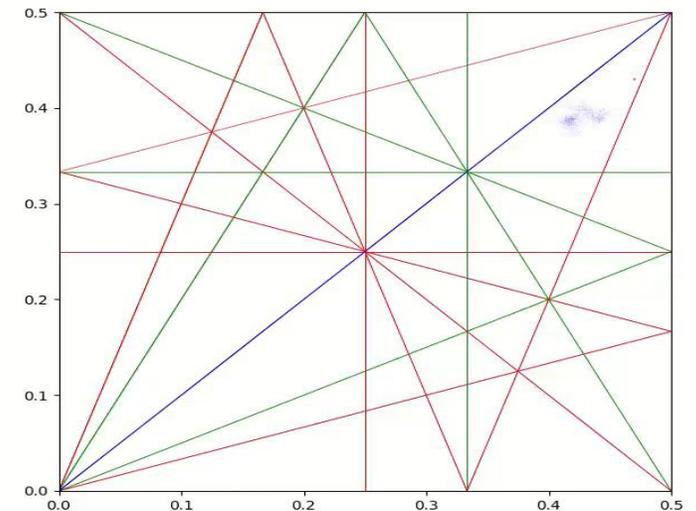
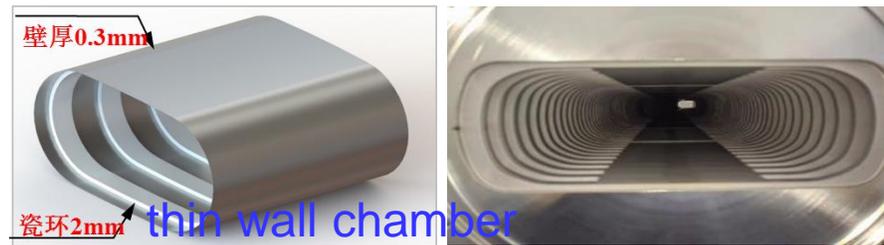
Fast ramping synchrotron

□ HIAF Introduction



- Fast ramping synchrotron

- the **dipole** magnetic field ramping rate is up to **12 T/s**
- corresponding the PS for dipoles must be ramping with **40 kA/s**
- the maximum RF voltage is **240 kV** for required energy
- the vacuum chamber thickness is reduced to **0.3 mm** to avoid eddy current



Electron cooling is **NOT** necessary for beam accumulation in BRing

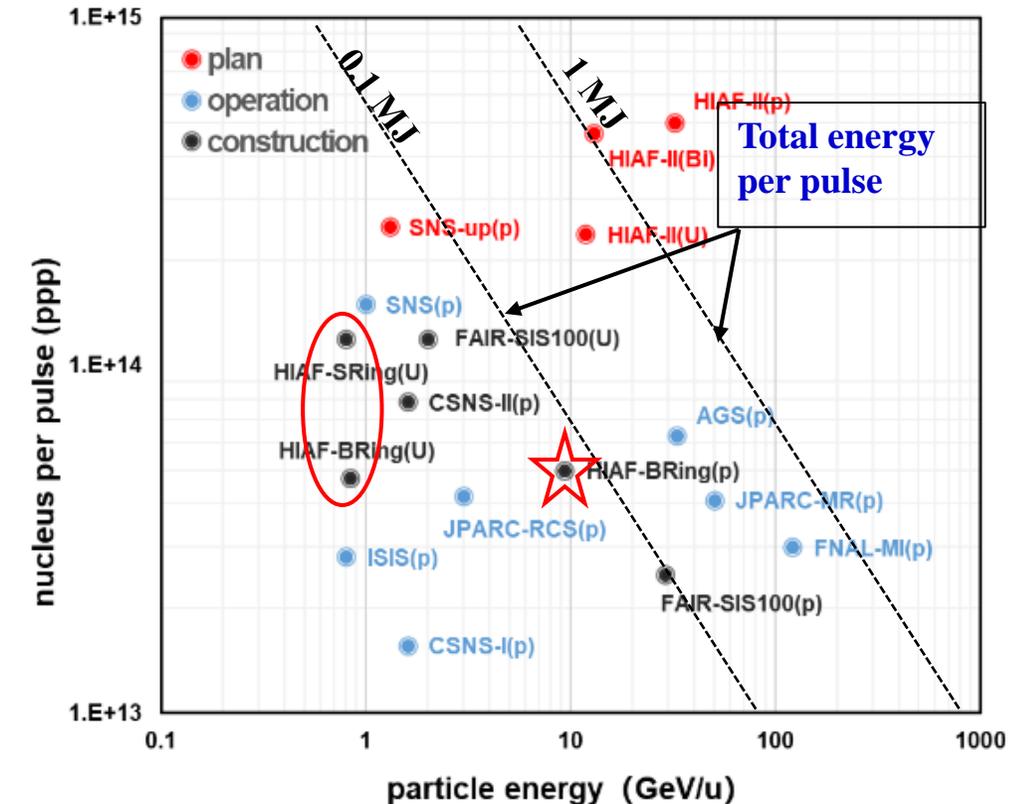
TUNE spread

□ HIAF parameters



- HIAF is aimed to provide the ultra-high intensity heavy ion bunches ($\sim 10^{11}$ ppp)
- Improve the average power as much as possible (operation cycle ~ 3 Hz)

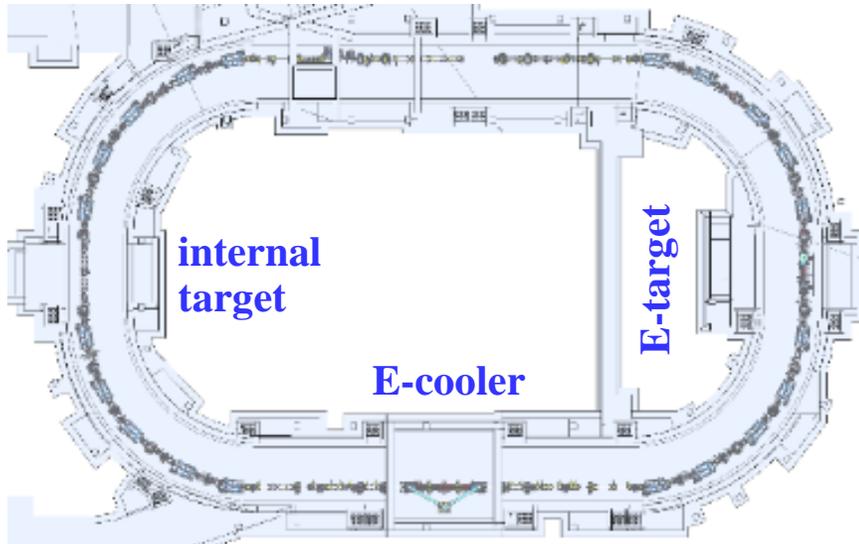
	iLinac	BRing	SRing	FAIR
Length / circumference (m)	114	569	277	1080
Final energy of U (MeV/u)	17 (U ³⁵⁺)	835 (U ³⁵⁺)	835 (U ⁹²⁺)	2700 (U ²⁸⁺)
Max. magnetic rigidity (Tm)	---	34	15	100
Max. beam intensity of U	28 pμA (U ³⁵⁺)	1×10^{11} ppp (U ³⁵⁺)	$(2 \sim 4) \times 10^{11}$ pp p (U ⁹²⁺)	4×10^{11} ppp (U ²⁸⁺)
Operation mode	CW or pulse	fast ramping (12T/s, 3Hz)	DC	0.5



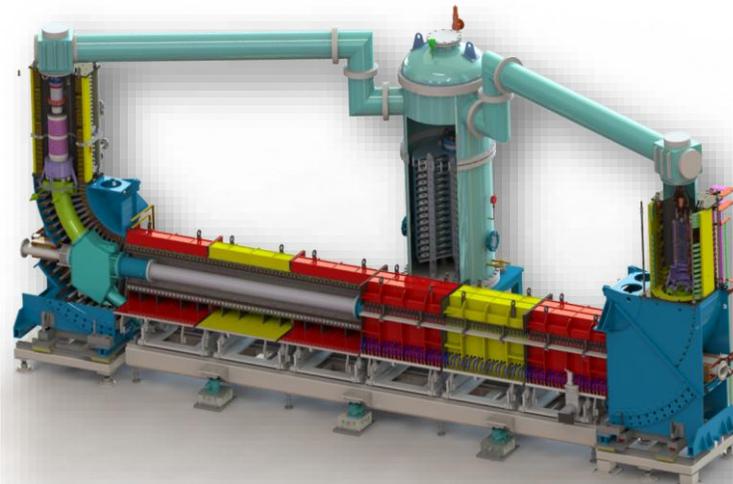
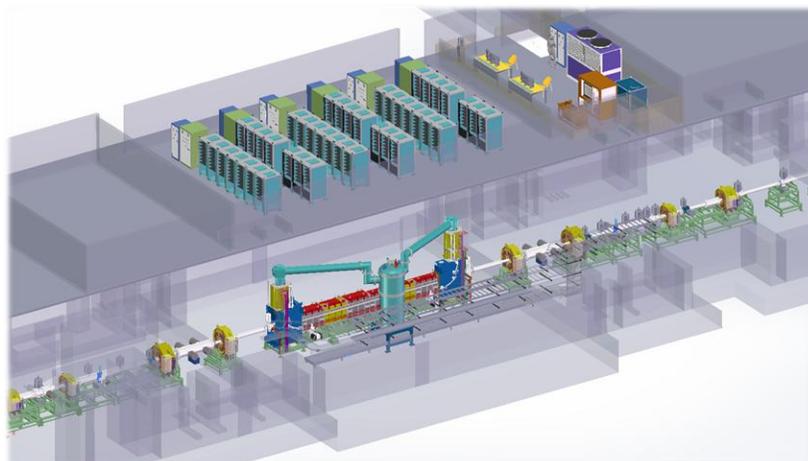
□ Electron Cooling System in HIAF



- A 450 keV classical magnetized DC e-cooler is needed to **reduce** the phase volume and **compensate** energy loss for internal target experiments

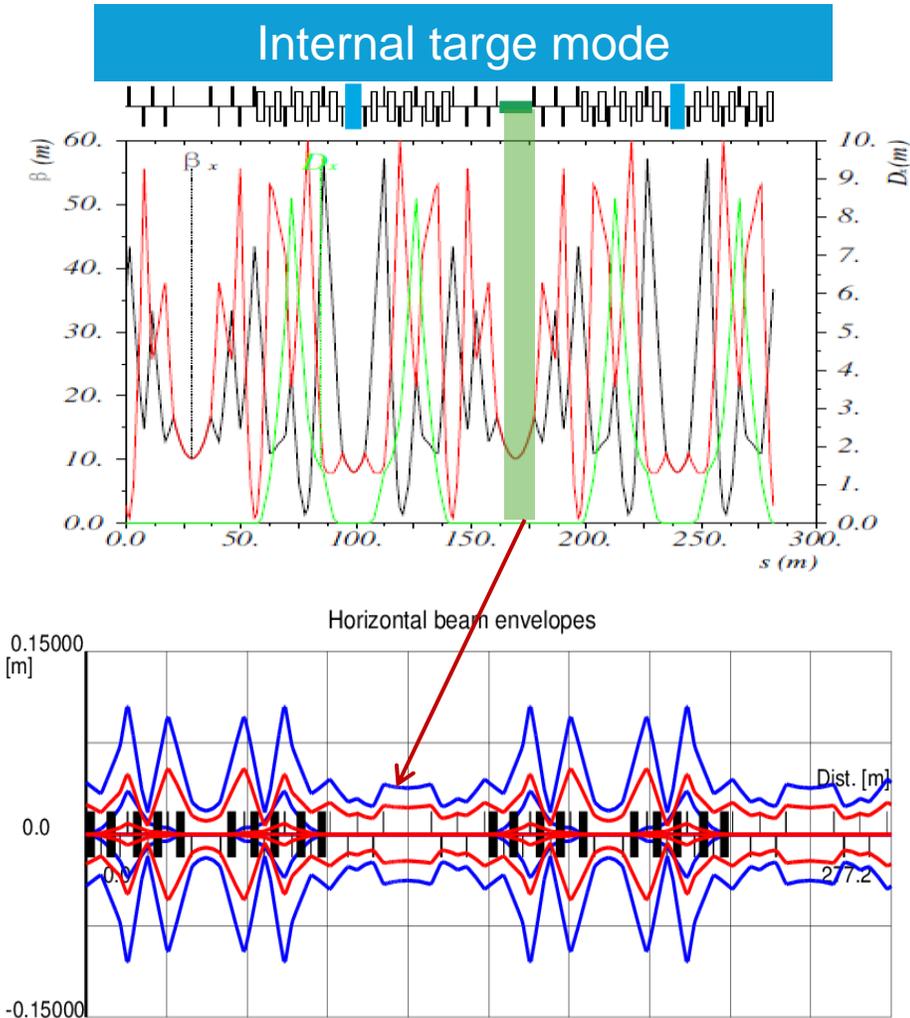


- **High voltage system:** based on cascade transformer, 15 modulates, each for 40 kV, operated at 450 kV (total 600 kV)
- **magnetic system:** 6 individual sections, 22 coils for each
- **Bending section:** toroid with electrostatic plate
- **Gun and collector:** thermionic gun with oxide cathode and collector cup cooling by oil

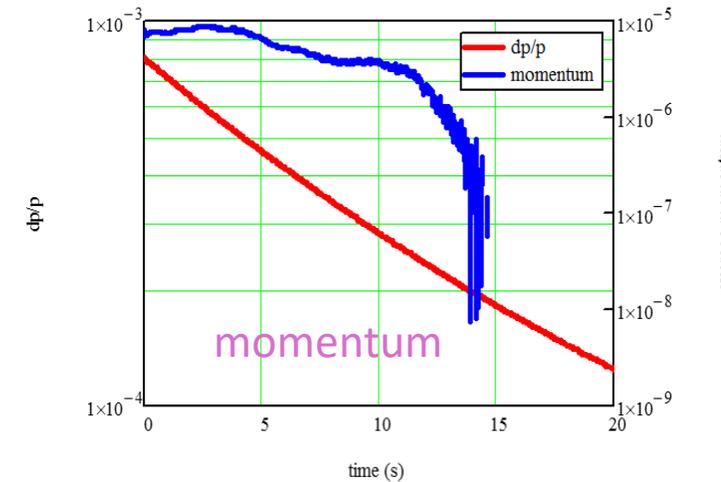
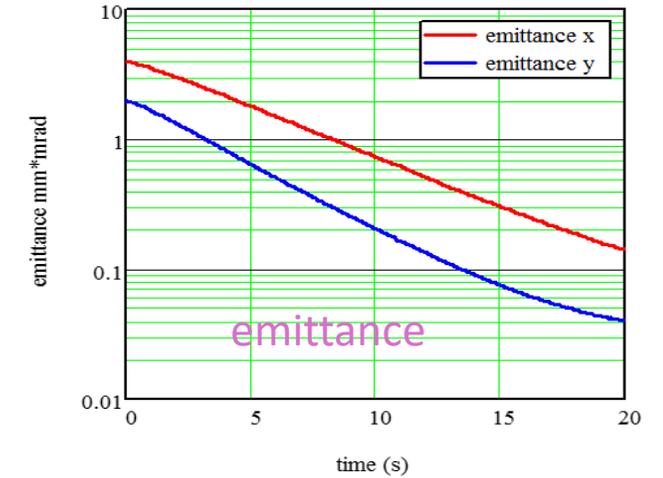


Cooler parameters

- SRing was designed for **isochronous**, **normal** and **internal target** modes
- Cooling is working at **internal target** mode



Particle	$^{238}\text{U}^{92+}$
Ion energy	800 MeV/u
Particle number in the ring	1×10^9
Initial emittance H/V (RMS)	$4.0/2.0 \pi \cdot \text{mm} \cdot \text{mrad}$
Initial momentum spread (RMS)	8.0×10^{-4}
Electron energy	438.8 keV
Electron current	2.0 A
Electron beam radius	30 mm
Effective cooling length	7.4 m (2.6% of the ring)
Longitudinal magnetic field at the cooling section	0.15 T
Magnetic field homogeneity	1×10^{-4}
Electron beam temperature (transverse/ longitudinal)	$0.5 \text{ eV} / 3.0 \times 10^{-5} \text{ eV}$

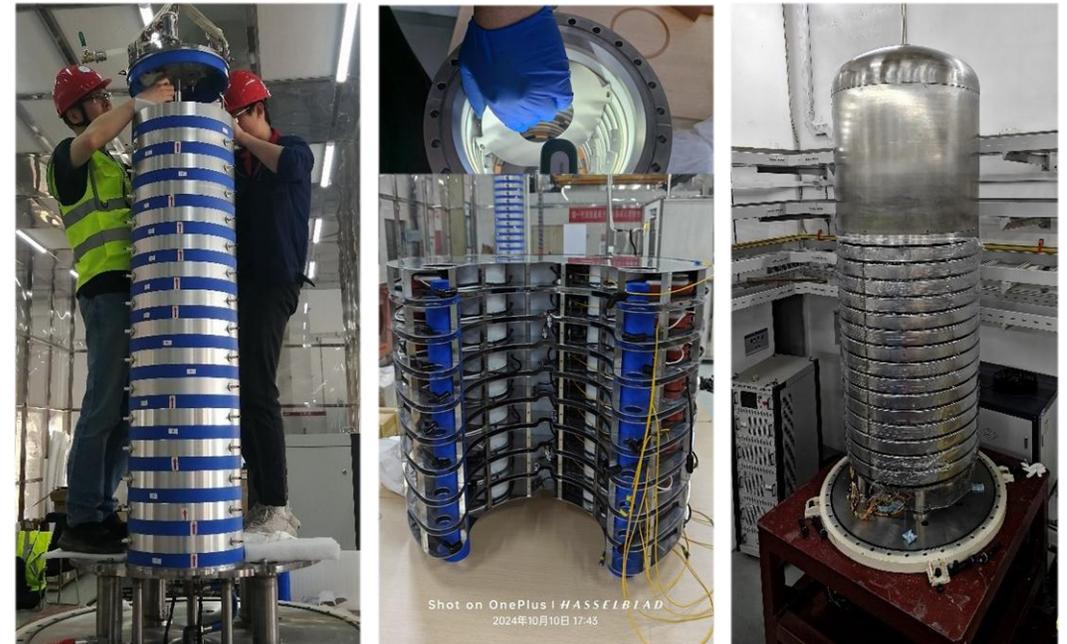


□ General design and timetable



- 2019, first contract for electron gun and collector
- 2020, first coil for the cooling section, setup for coil axis measurement
- 2021, gun and collector test, transformer manufacture,
- 2022, first cooling section, test of HV sections and **repair them several times**
- 2023, test of high voltage system, measure the longitudinal magnetic field
- 2024/25, installation step by step, get the **first electron beam**

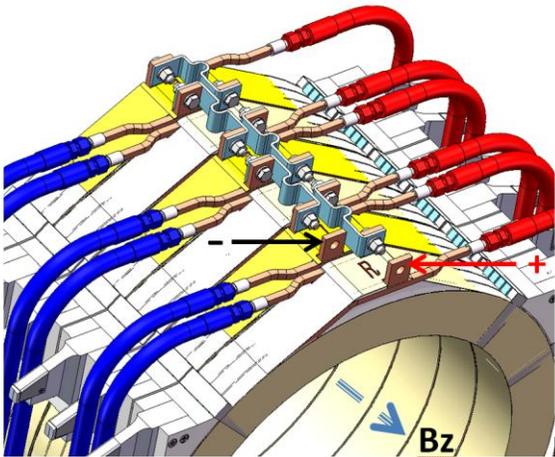
Parameters	value
Straight section	16.0m
Cooler length	11.2 m
Cooler height	5.0 m
Effective length	7.4 m (2.6%)
Cathode radius	15 mm
HV ripple	5.0×10^{-5}
Field homogeneity	1.0×10^{-4}
E-current	2.0 A
vacuum	$<2.0 \times 10^{-11}$ mbar



assembling, disassembling, re-assembling,...

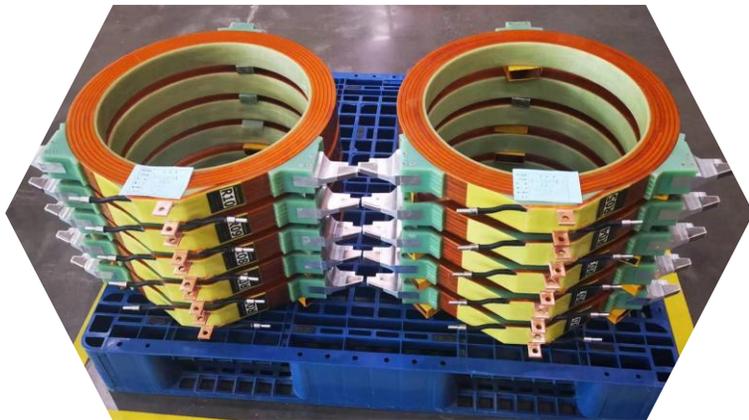
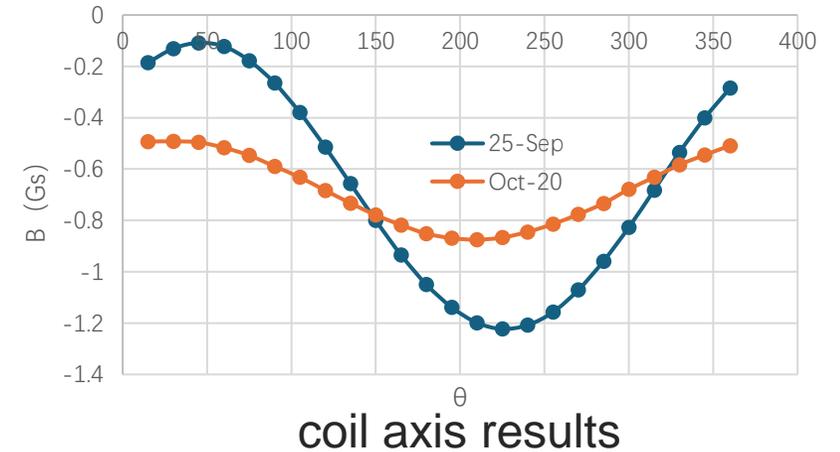
□ Cooling Section

- Coils, correctors and magnetic field homogeneity
 - clockwise and anticlockwise pancakes are alternately arranged, compensate transverse field
 - measure the magnetic field axis for each coil, optimal combination of coils based the results

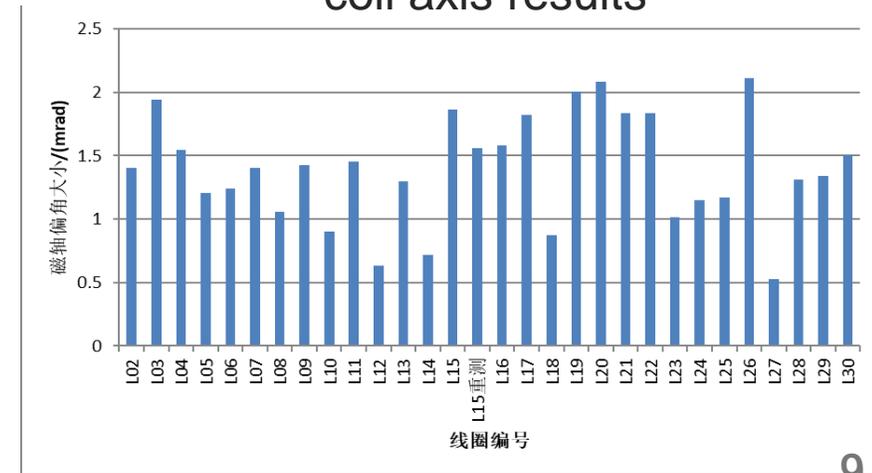


left and right coils

- Use alignment to ensure the Hall sensor is **centered** within the coil and **perpendicular** to the coil plane
- measure the **transverse** field component



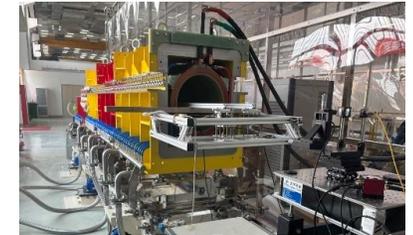
coil axis measure setup



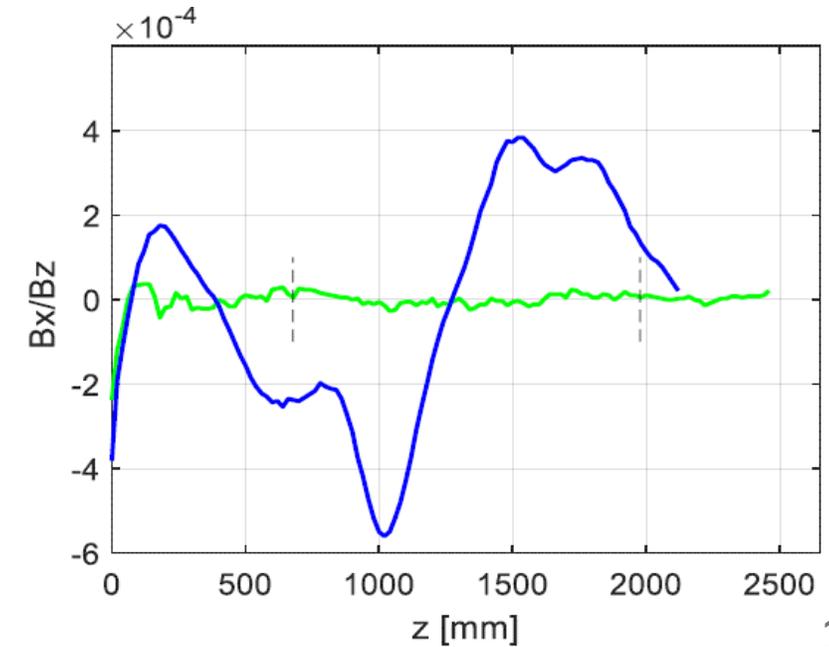
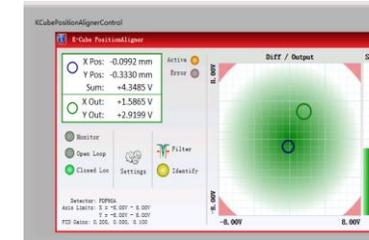
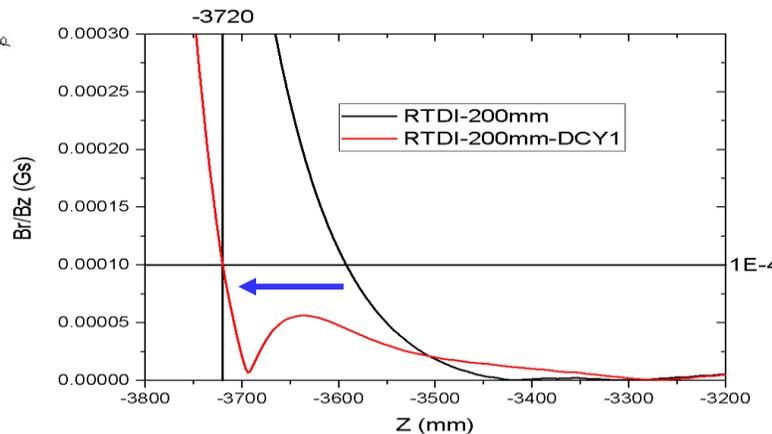
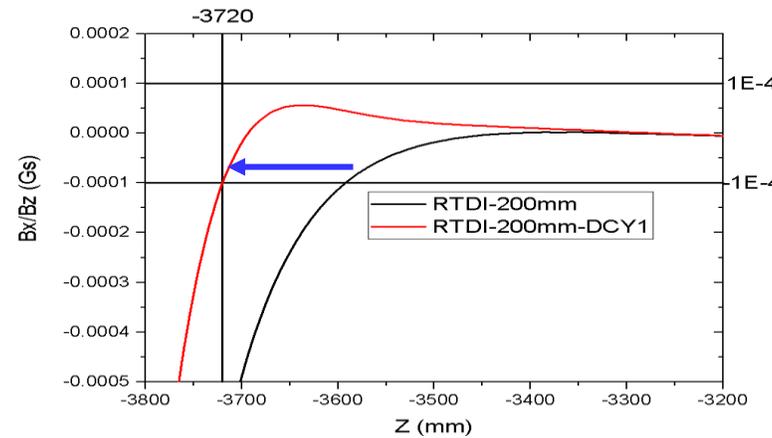
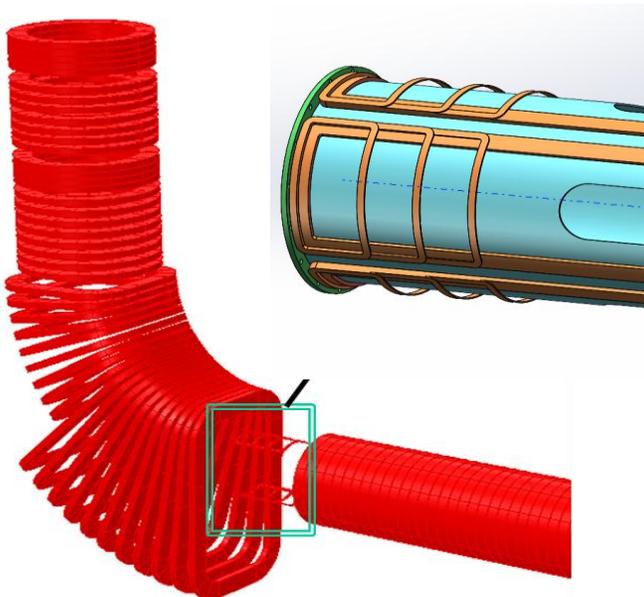
□ Cooling Section



- Coils, correctors and magnetic field homogeneity
 - compensation coils at the end to modify the transverse magnetic field
 - use compass method to measure the homogeneity in the cooling section
 - change the position of each unit, adjustment of coils in the central unit



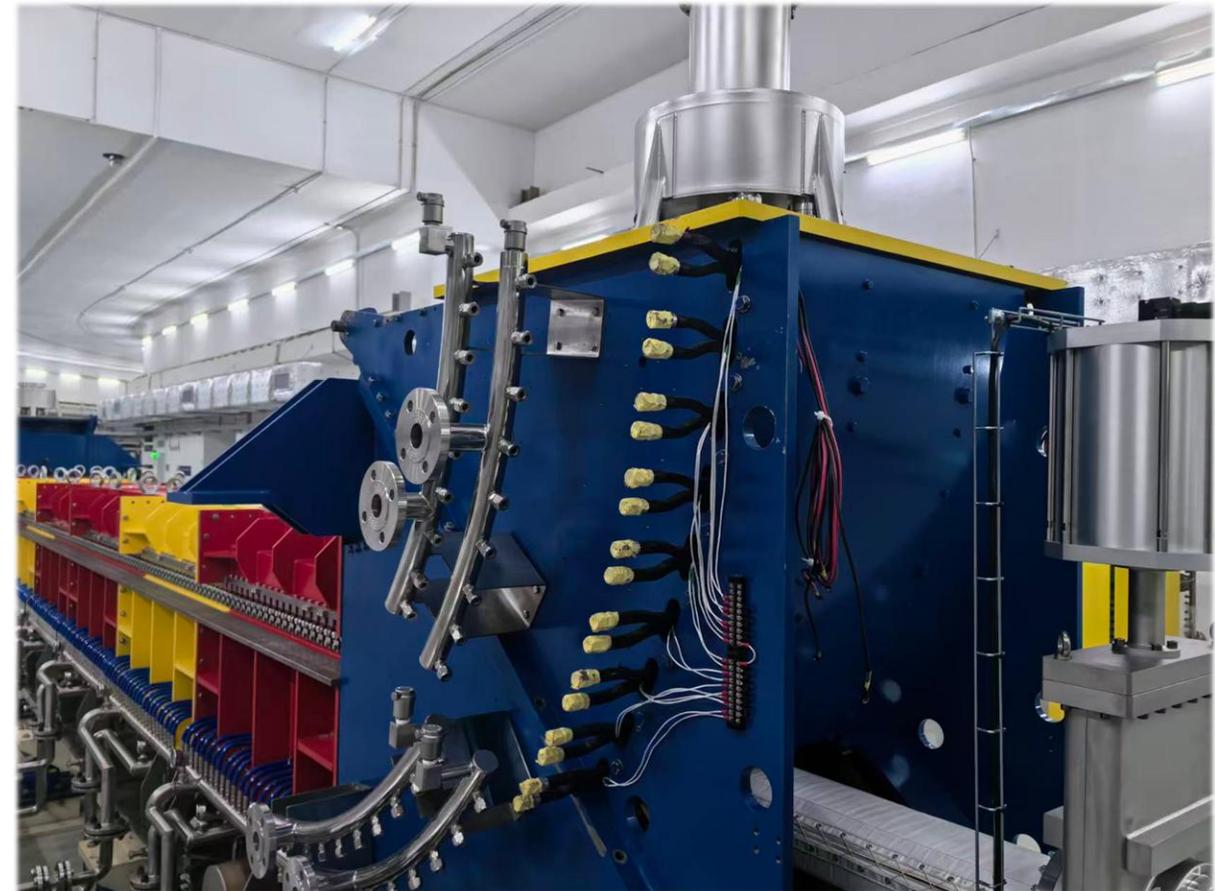
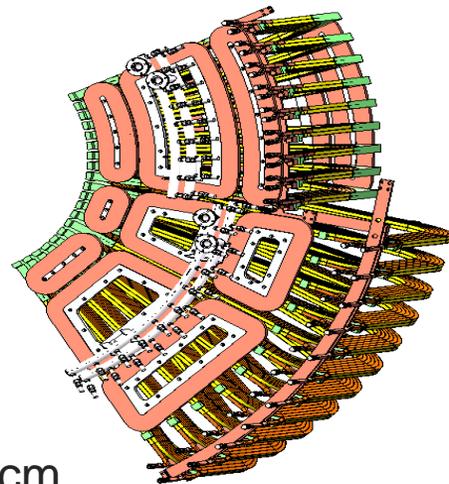
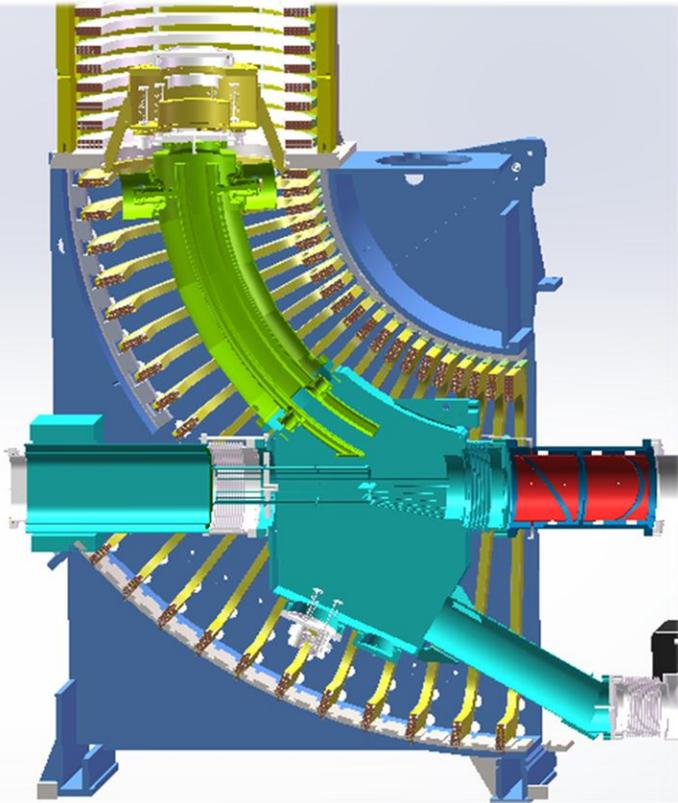
- compensate the toroid field, extend the effective cooling section



□ Toroid and Bending



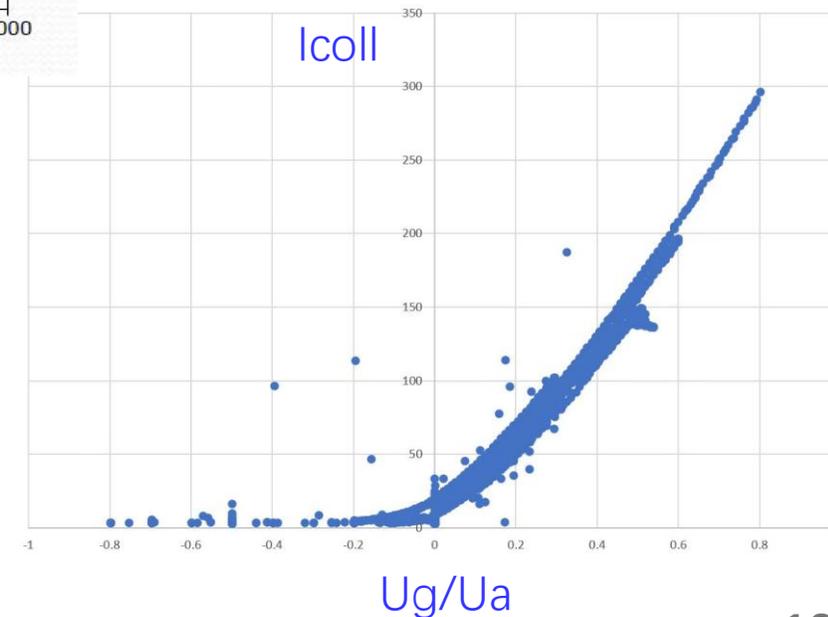
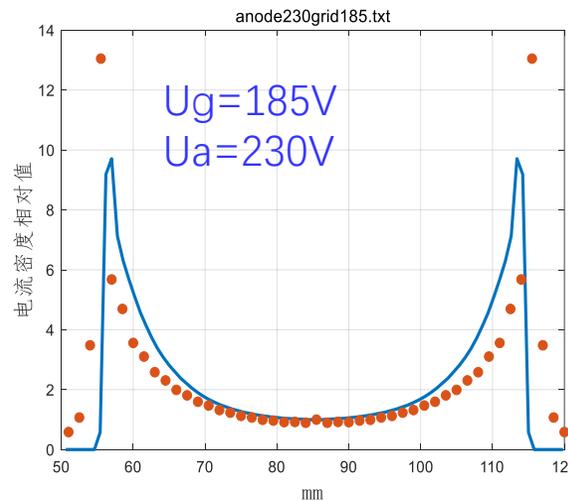
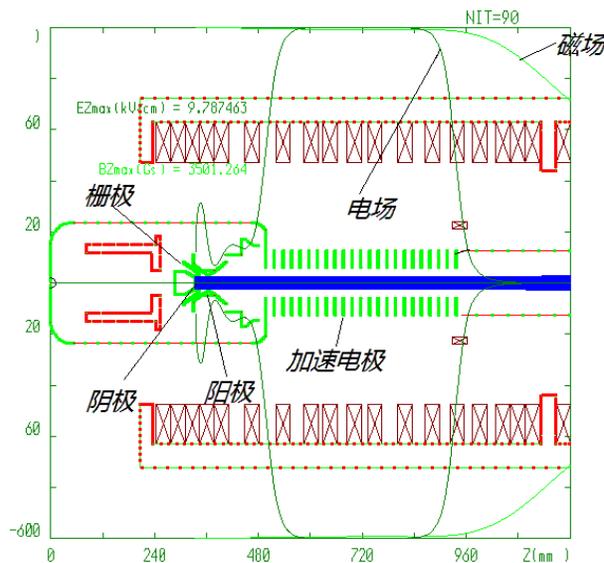
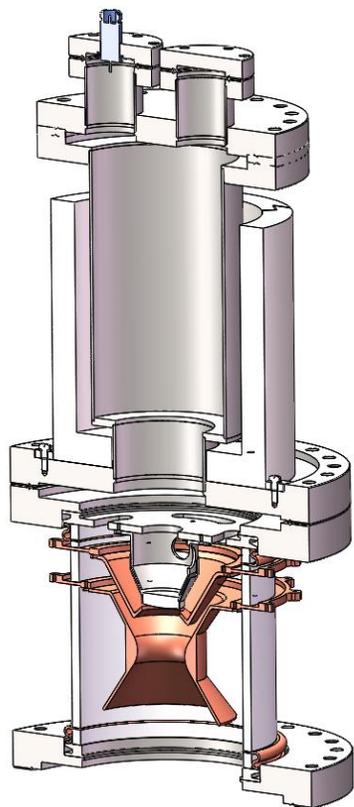
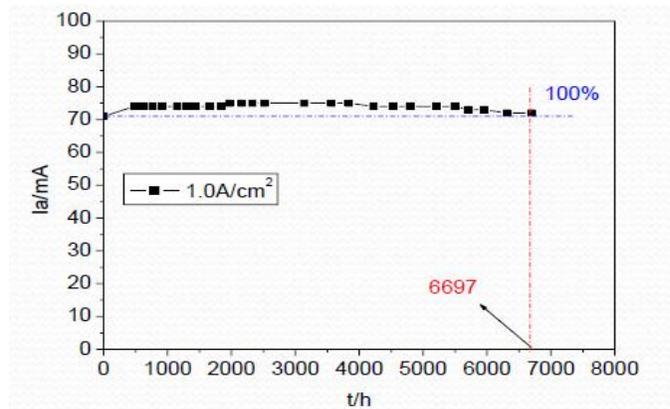
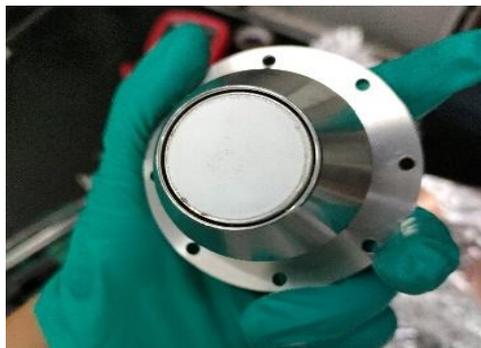
- **U-shape** cooler, toroid provides longitudinal guiding field for electrons
- Electrostatic plate provide a compensation of centrifugal force $=mV^2/R$
- Coils are used to make an electron beam position correction



maximum bending field is 10 kV/cm

□ Gun and Collector

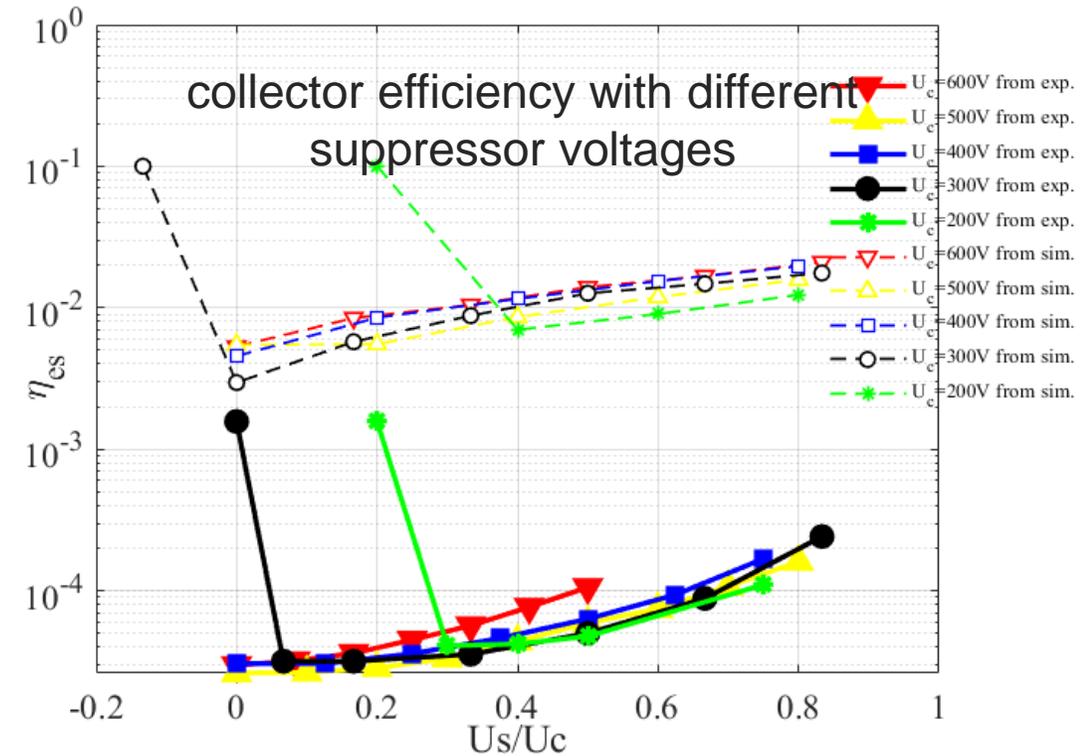
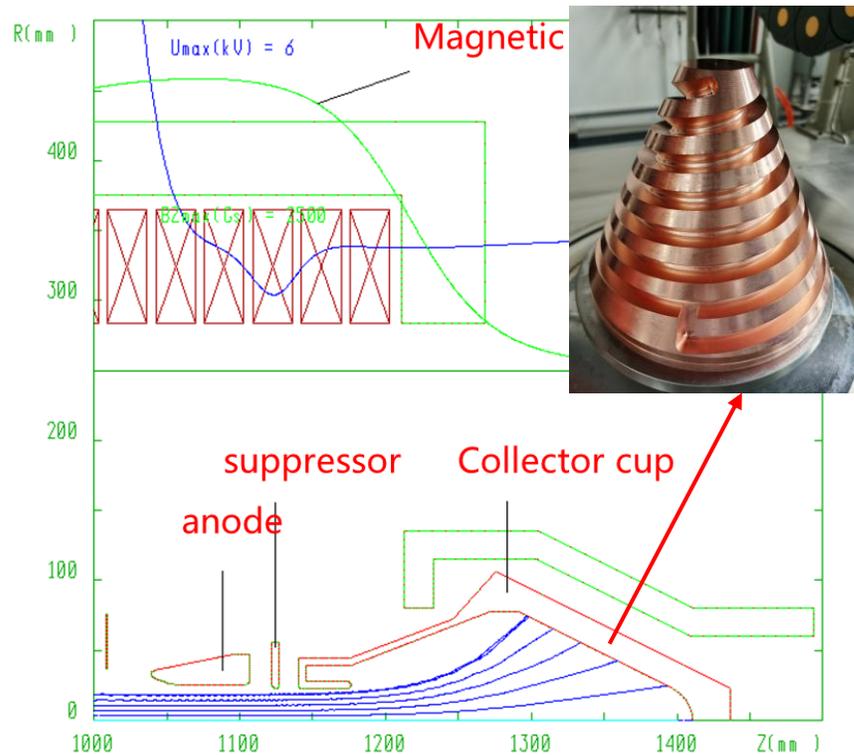
- **oxide cathode** can provide electrons with the density of 1.0 A/cm^2
- grid electrode is used to make a ‘hollow’ electron beam
- **perveance** has **NOT** met the design value



□ Gun and Collector

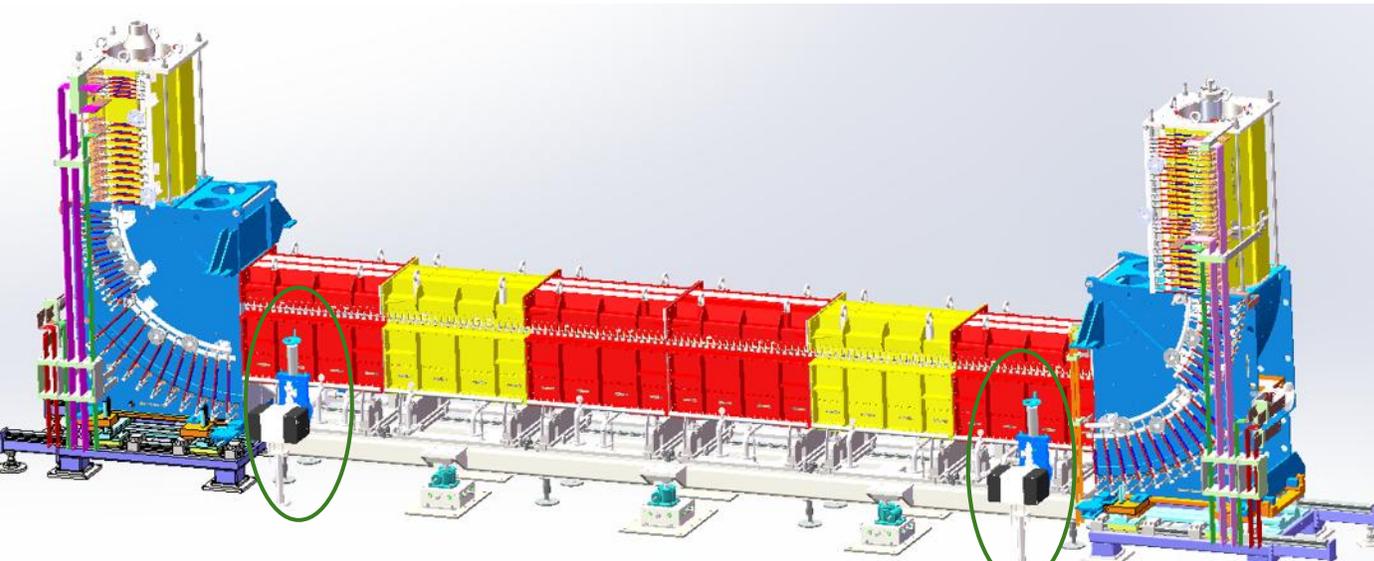


- collector in a decreasing magnetic field, guiding electrons to the surface
- suppressor electrode serves to block secondary electron emission
- oil cooling is used for the collector cup (separate to the oil cooling of HV system)

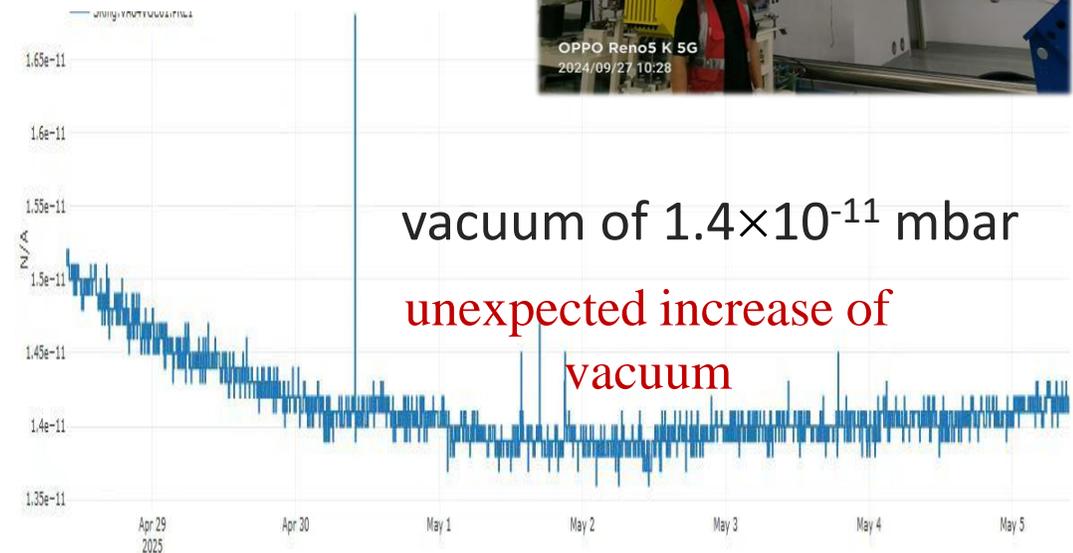


□ Vacuum system

- cooling section is divided into 3 vacuum chambers, with NEG coating
- 2 ion pumps installed in the cooling section
- titanium pumps in toroid and end of acc. tube

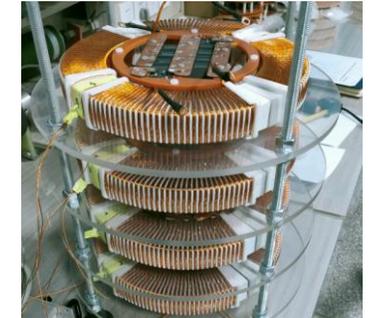
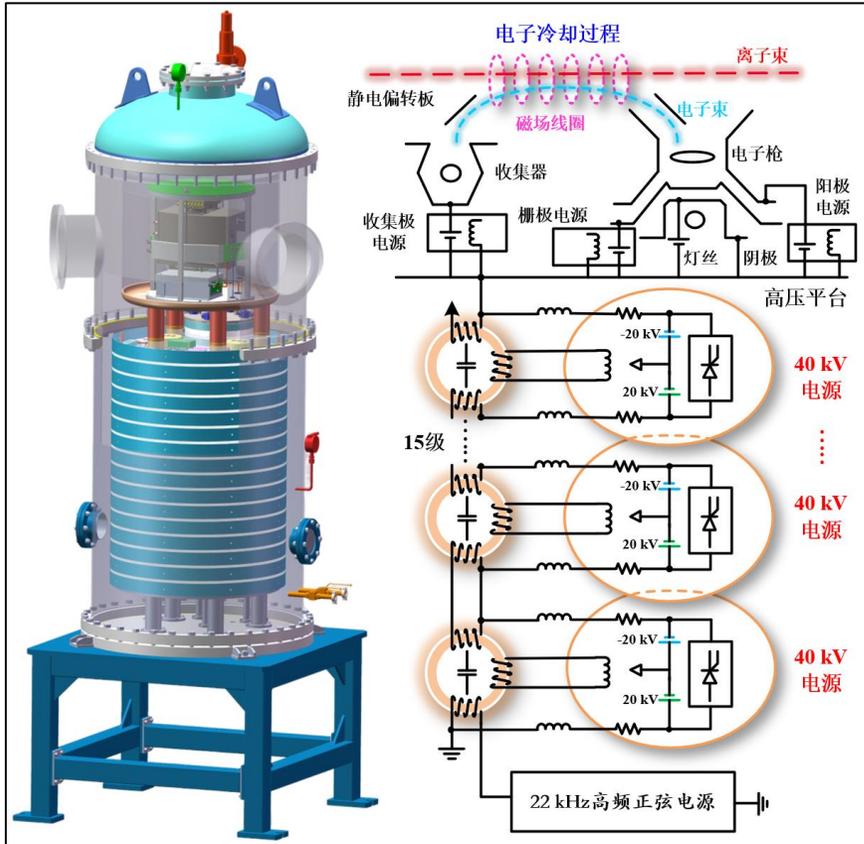


Titanium pumps



High Voltage System

- Cascade transformer frequency is around 20 kHz
- 15 sections with the output voltage of -40 kV for each one

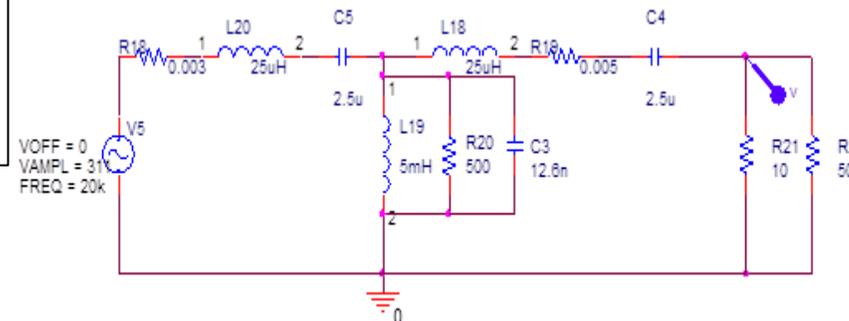


capacitors

$$f = \frac{1}{2\pi\sqrt{LC}} = 20\text{kHz}$$

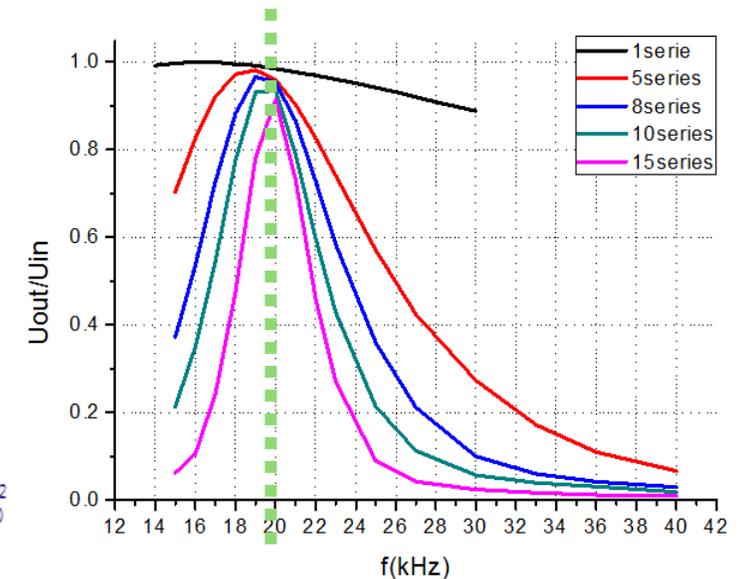
$$L_m = 5\text{mH} \quad C_0 = 12.6\text{nF},$$

$$L_s = 25\mu\text{H} \quad C_1 = 2.5\mu\text{H}$$



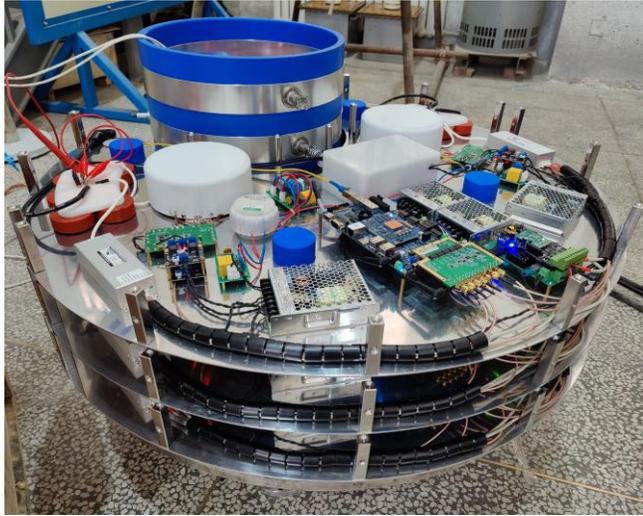
coils

transformer

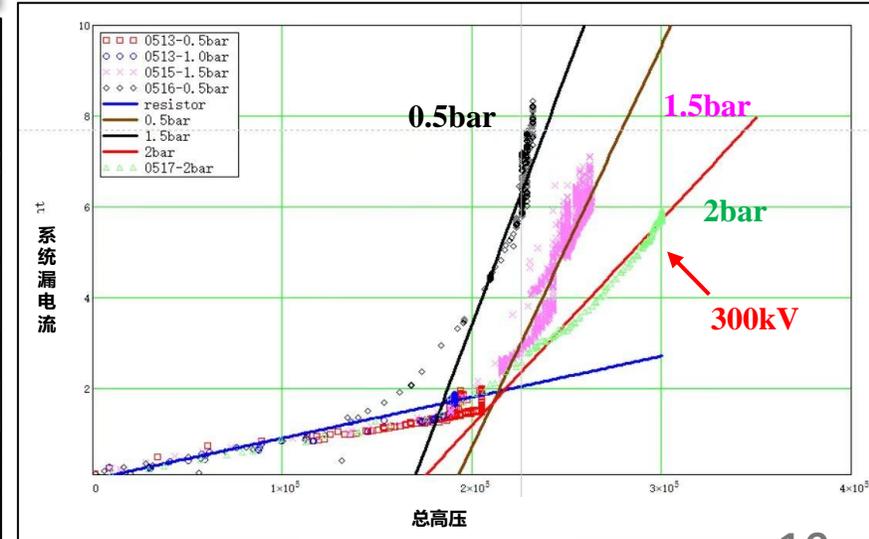
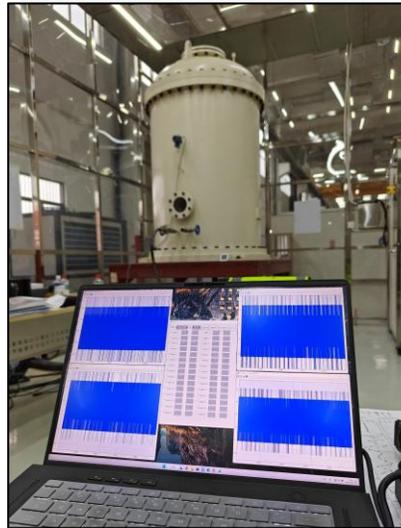
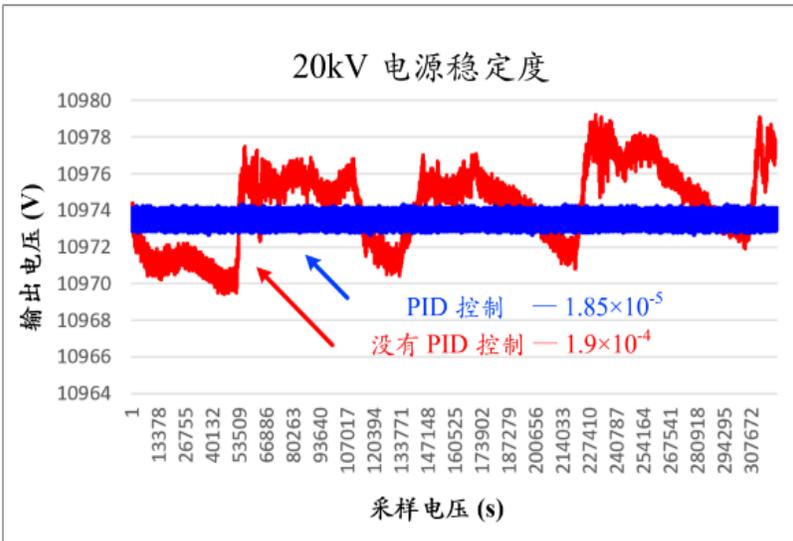


High Voltage System

- PID control obtain the RMS stability about 10^{-5}

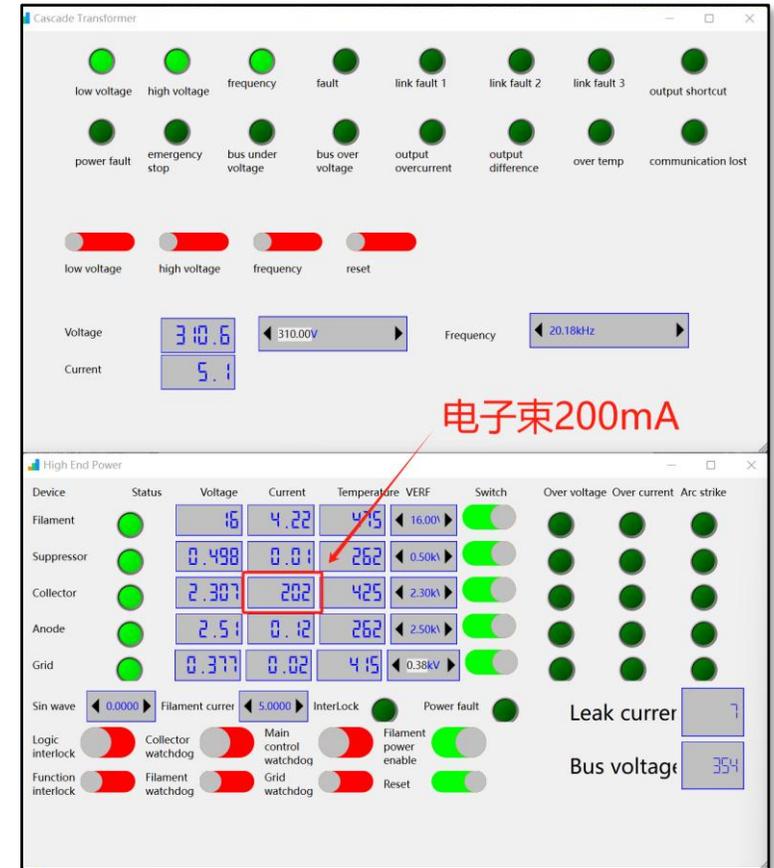


PS for gun & collector



Electron Beam Commissioning

- The High voltage operated in **405 kV** with the SF6 at **0.2 MPa**
- The output electron beam is up to **350 mA**



□ HIAF Electron Cooler in Tunnel



□ Conclusion

- A traditional magnetized DC electron cooler, following the design of coolers installed in CSRm, CSRe, COSY...
- The voltage up to 400 kV and electron beam around 350 mA was obtained in the machine.
- The vacuum problems should be solved recently, the voltage and electron beam current should be increased carefully step by step.
- Thanks Dr.Parkhomchuk and BINP colleagues for their long-term support!

Thanks for your attention!

