中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

HIAF

Status of the HIAF Accelerator Facility in China

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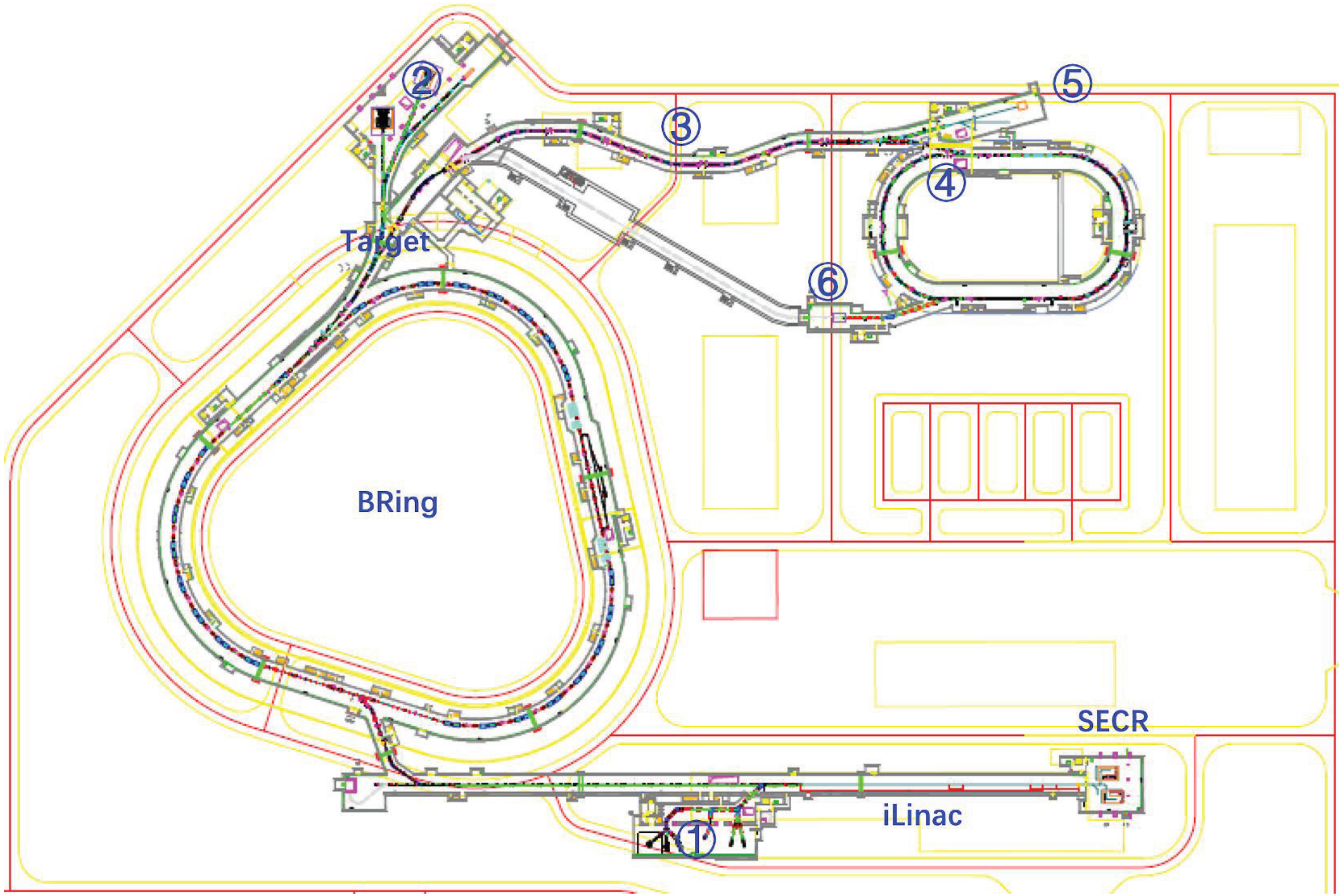
on behalf of the HIAF project team

RuPAC – 2021, 28th, Sept

Content

I. Introduction of the HIAF project

■ **High Intensity heavy-ion Accelerator Facility (HIAF)**



- **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

I. Introduction of the HIAF project

■ HIAF main parameters

	SECR	iLinac	BRing	HFRS	SRing
Length / circumference (m)	---	114	569	192	277
Final energy of U (MeV/u)	0.014 (U^{35+})	17 (U^{35+})	835 (U^{35+})	800 (U^{92+})	800 (U^{92+})
Max. magnetic rigidity (Tm)	---	---	34	25	15
Max. beam intensity of U	50 pμA (U^{35+})	28 pμA (U^{35+})	2×10^{11}ppp (U^{35+})	-------	10^{10}ppp (U^{92+})
Operation mode	DC	CW or pulse	fast ramping (12T/s, 3Hz)	Momentum-resolution 1100	DC, deceleration
Emittance or Acceptance (H/V, π·mm·mrad, dp/p)		5 / 5	200/100, 0.5%	±30mrad(H)/±15 mrad(V), ±2%	40/40, 1.5% (normal mode)

HIAF construction bird-view

I. Introduction of the HIAF project

■ HIAF goal

To provide highest intensity heavy ion beam

AGS booster	BNL	5×10^{9}	Au^{31+}	
LEIR	CERN	1×10^{9}	Pb^{54+}	
SIS18	**GSI**	**1.5×10^{11}**	**U^{28+}**	**2.7 Hz**
SIS100	GSI	6×10^{11}	U^{28+}	<1 Hz
NICA	JINR	4×10^{9}	Au^{32+}	
HIAF	**IMP**	**2×10^{11}**	**U^{35+}**	**3-10 Hz**

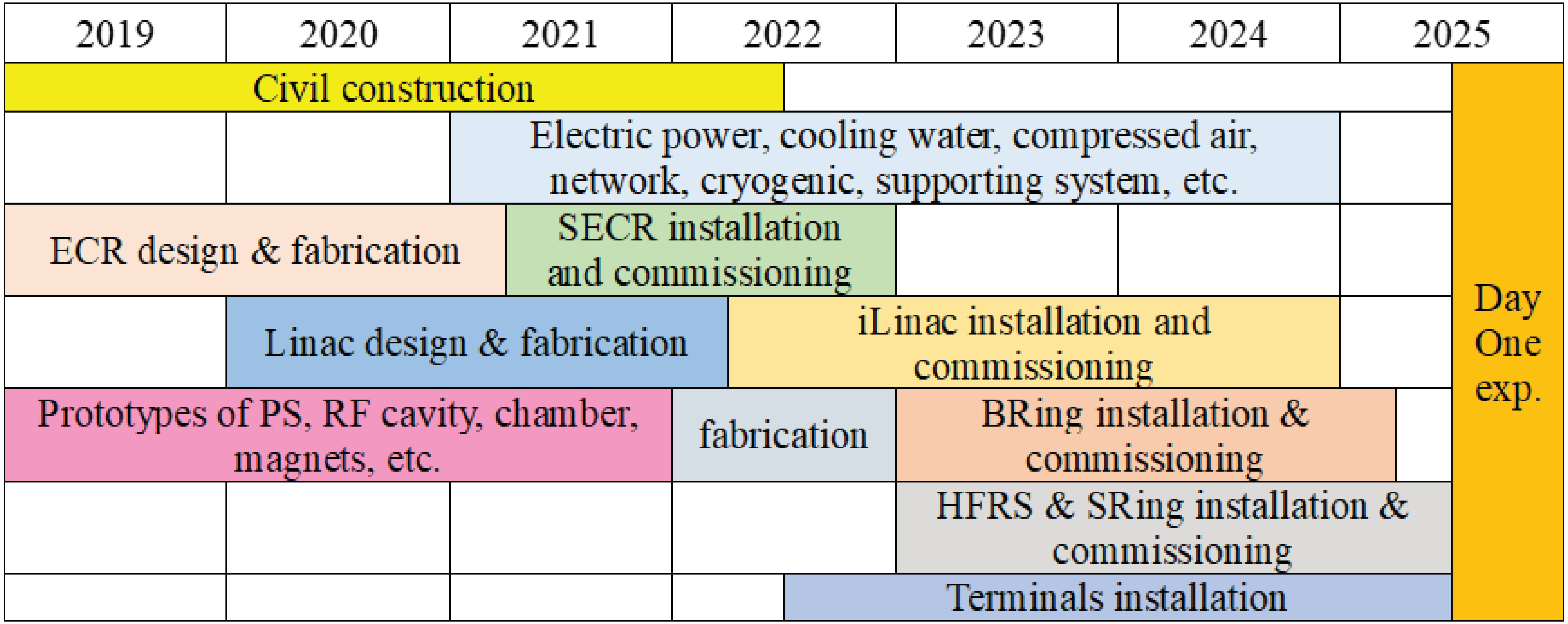
How to reach the goal:

- 4^{th} generation ECR ion source and superconducting Linac;
- Two phase painting injection to increase the injection efficiency and overcome space charge limit;
- Fast ramping rate (12T/s) for minimum ionization beam loss and dynamic vacuum effect

I. Introduction of the HIAF project

■ HIAF construction time schedule

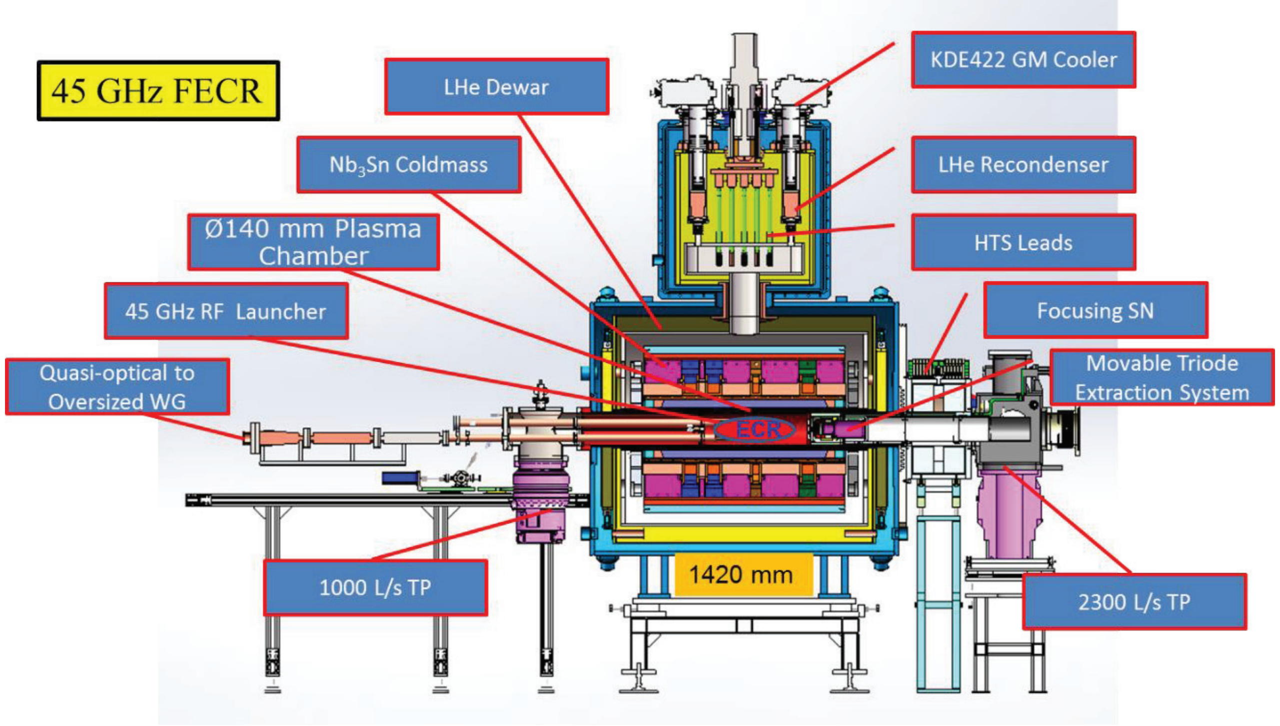
Day-one experiments will be started in mid 2025

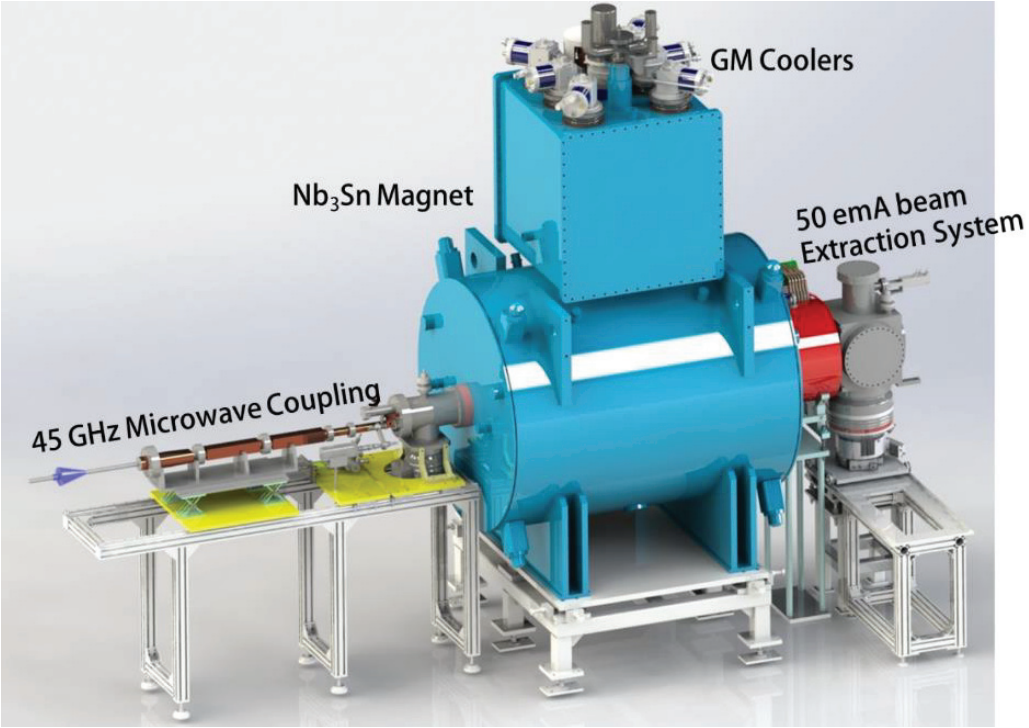


- The first ion beam provided by SECR in the end of 2022;
- The first ion beam extracted from iLinac in the end of 2024;
- The first ion beam injected, accelerated and extracted from BRing in April 2024

II. 4th generation ECR ion source

45 GHz superconducting ECR ion source structure





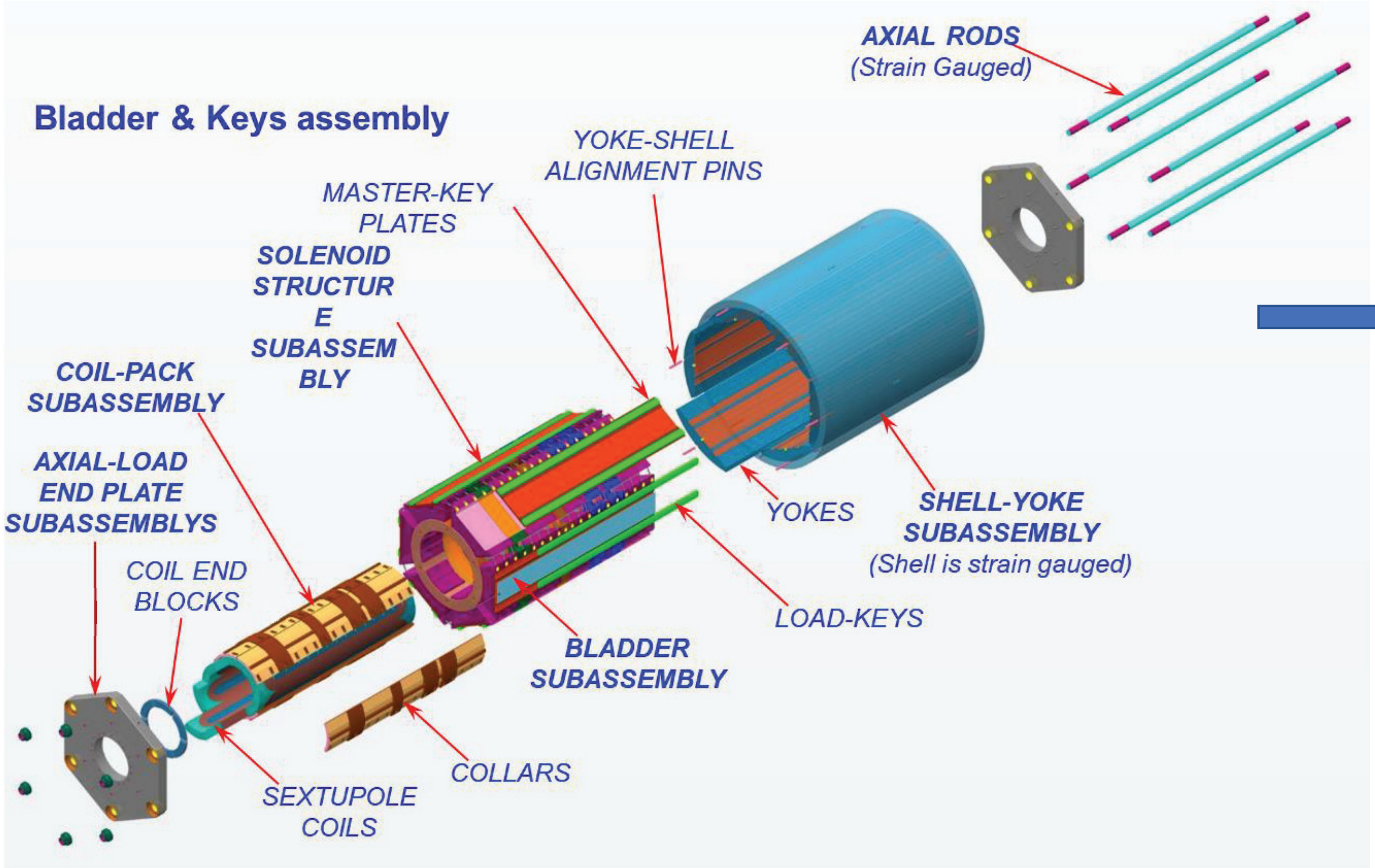
Challenges:

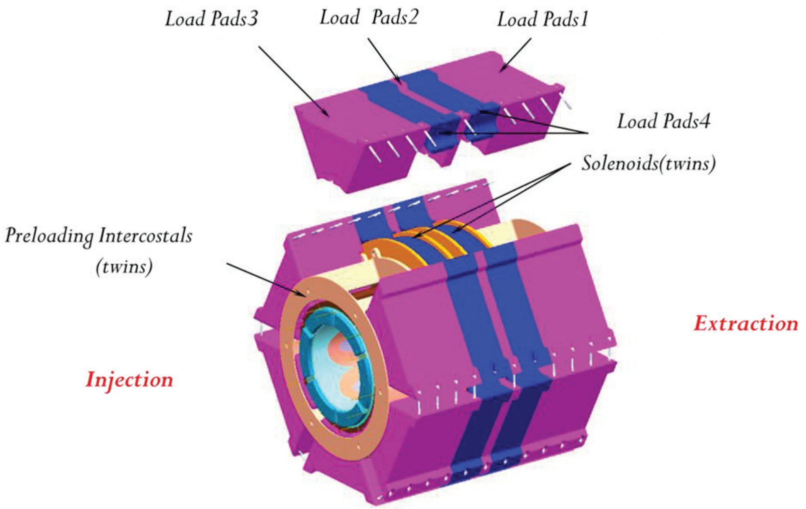
- Reliable SC-magnet for 45 GHz plasma confinement
- Effective coupling to the plasma of 20 kW/45 GHz microwave power
- 20 kW microwave heated plasma operation reliability and stability
- Extraction, transportation and beam quality control

II. 4th generation ECR ion source

- **Nb$_3$Sn magnet development**

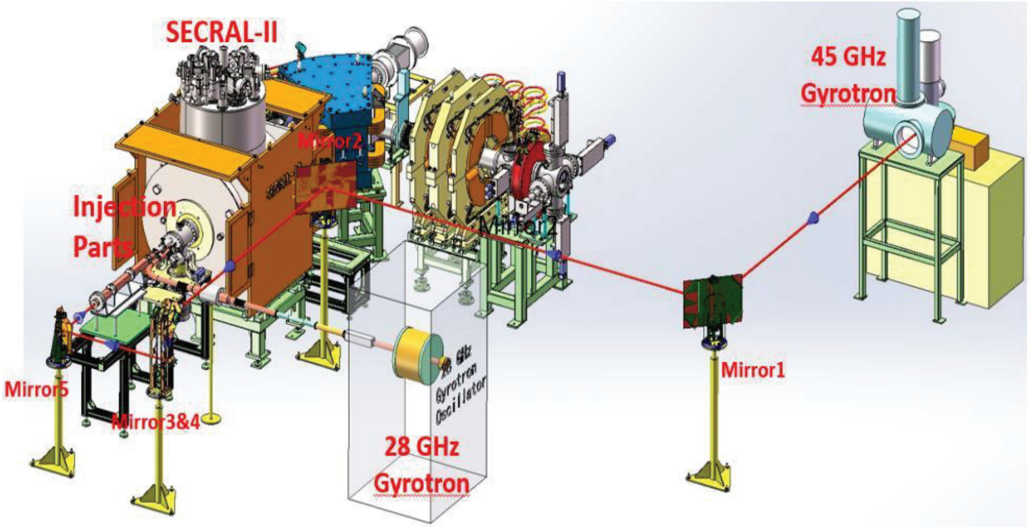
The coldmass mechanical structure was designed by collaboration with ATAP magnet group at LBNL (2015~2016)

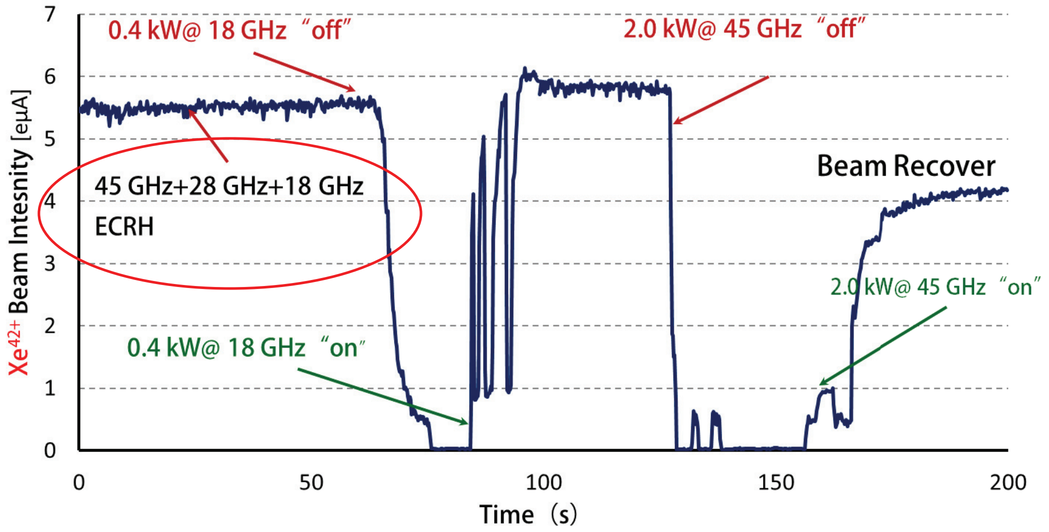


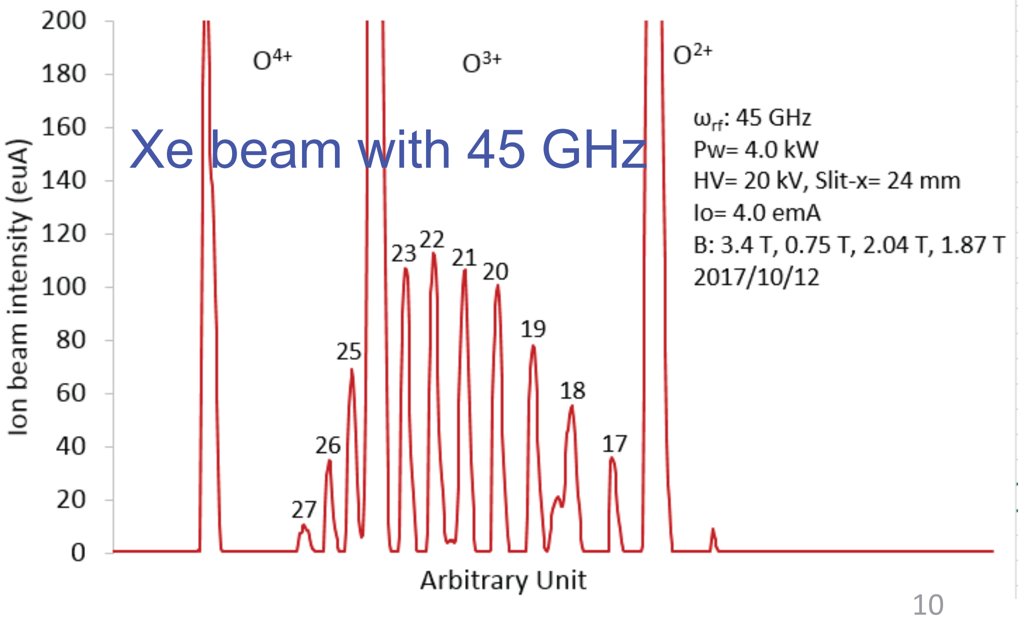


½ length prototype

■ 45 GHz microwave coupling



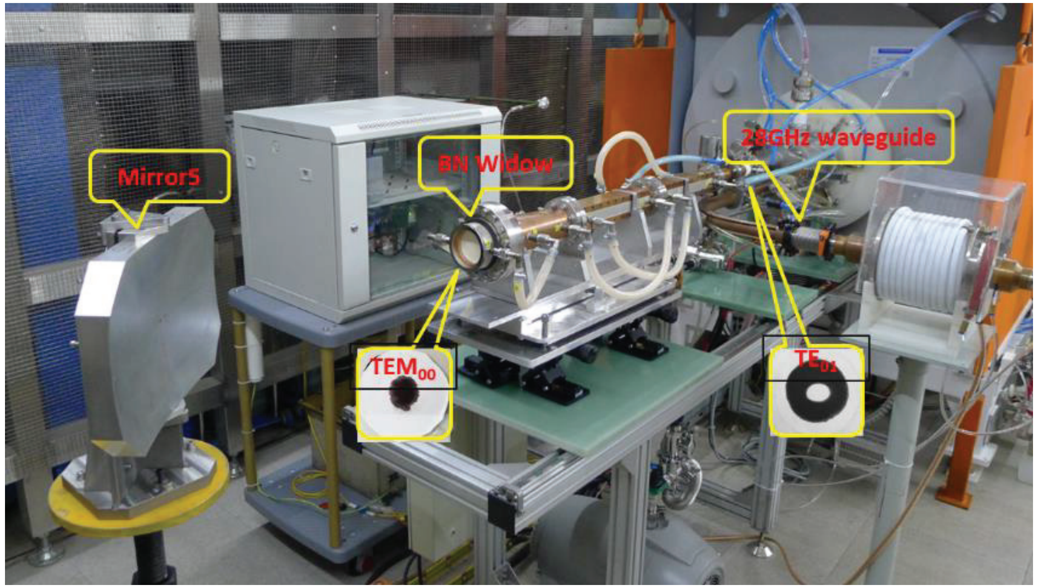


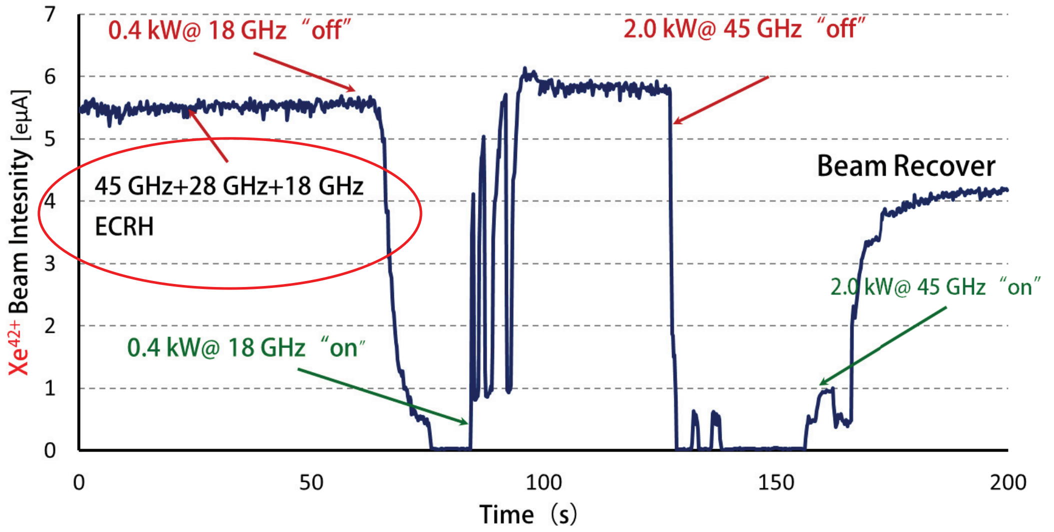


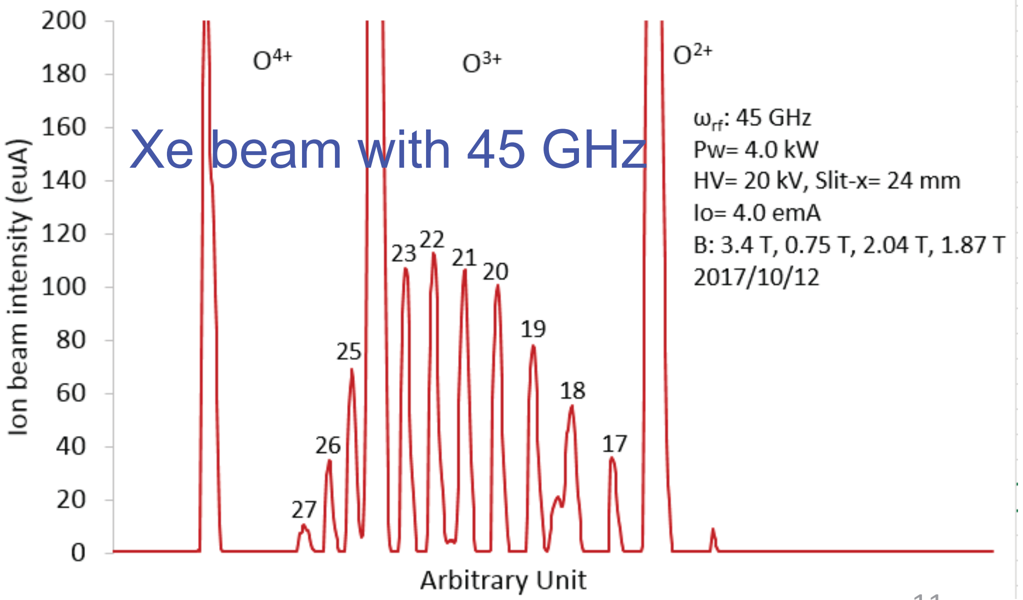
- 45 GHz/20 kW microwave transmission system based on Quasi-optical design
- First 45 GHz ECR plasma with SECRAL-II ion source
- Efficient transmission and coupling demonstrated

II. 4th generation ECR ion source

■ 45 GHz microwave coupling



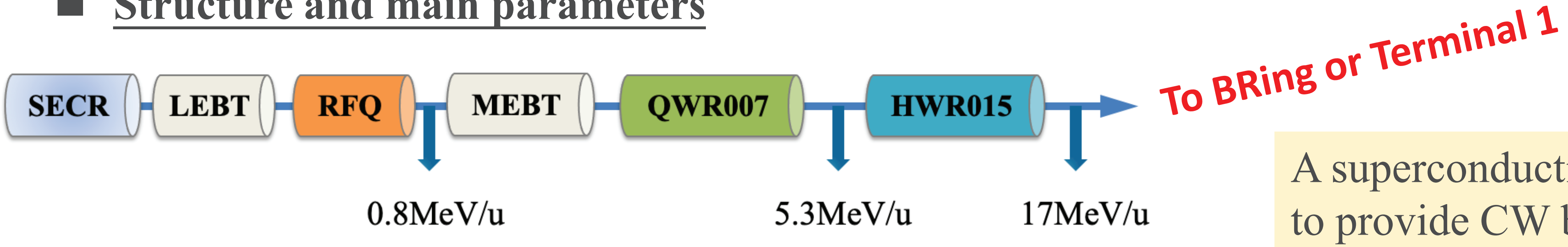


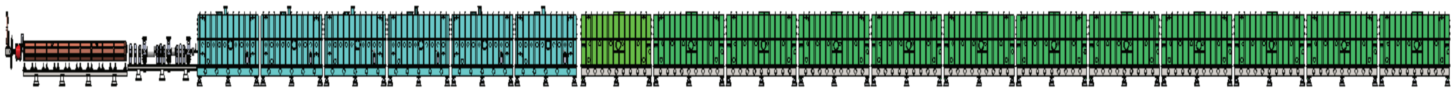


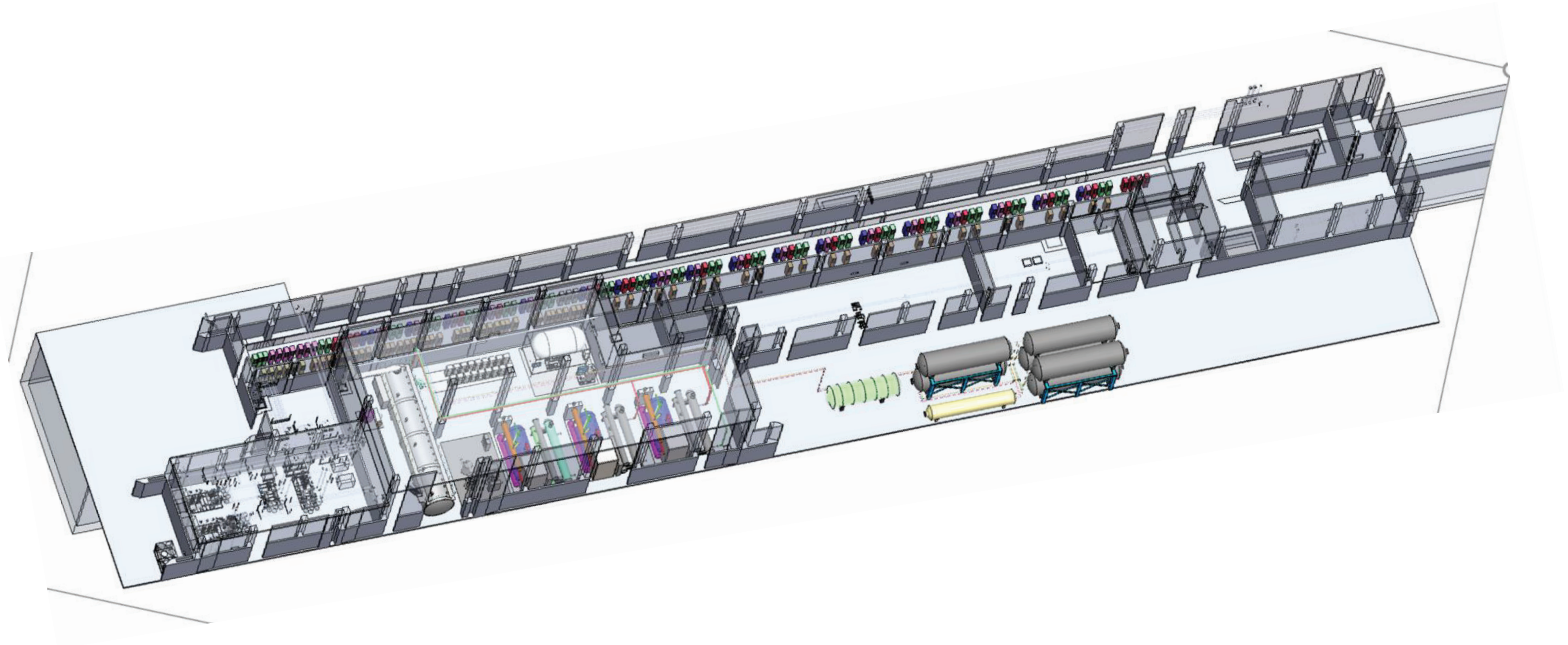
- 45 GHz/20 kW microwave transmission system based on Quasi-optical design
- First 45 GHz ECR plasma with SECRAL-II ion source
- Efficient transmission and coupling demonstrated

III. Superconducting heavy ion linac

- **Structure and main parameters**



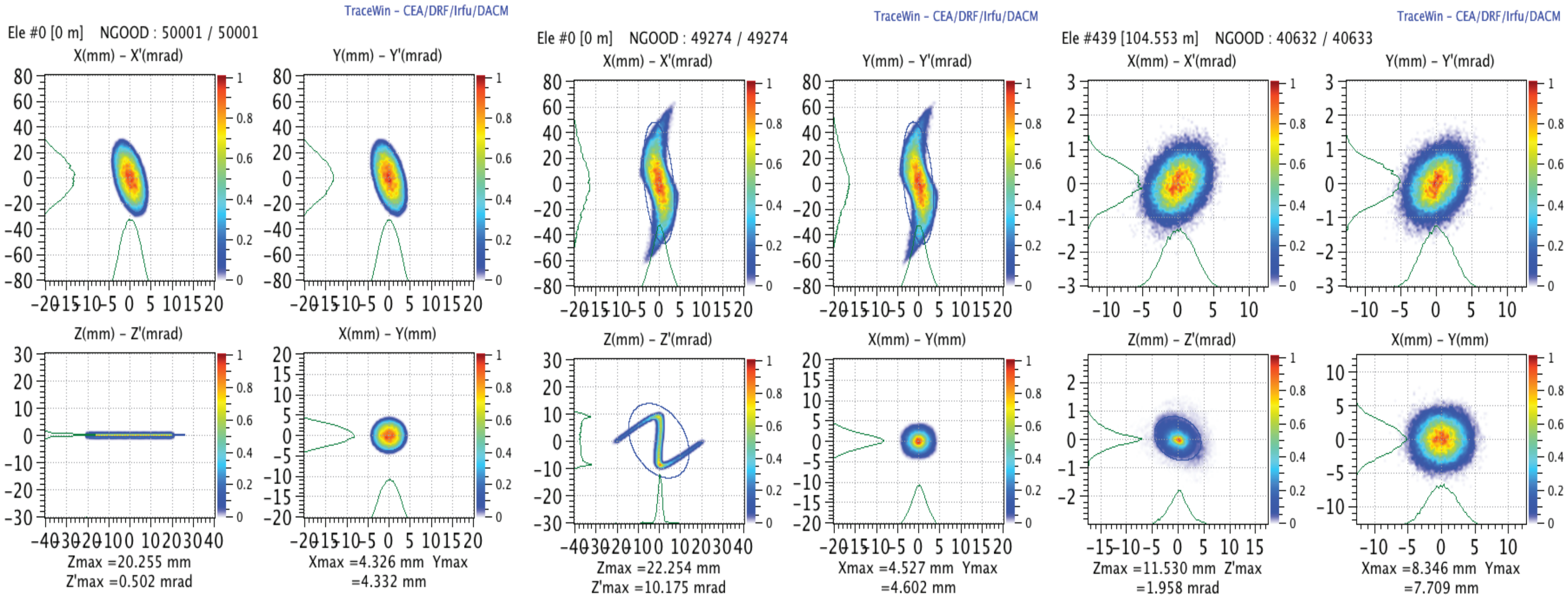




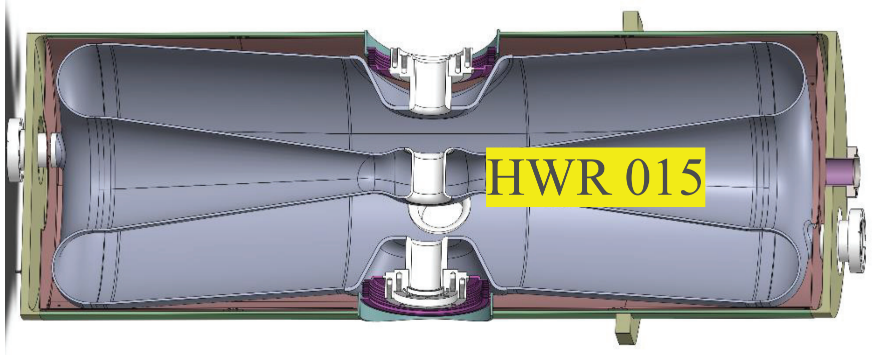
A superconducting linac is used, in order to provide CW beam for terminal 1

Parameters	Target	unit
Ion	$^{238}U^{35+}$	-
Energy	17	MeV/u
Current	2	emA
Emittance	5.0	π.mm.mrad
dp/p	0.2%	
Mode	CW & Pulse	

iLinac design

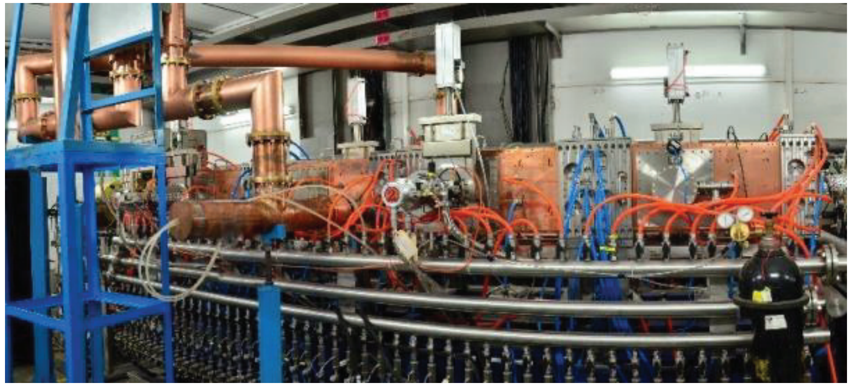


3HB RFQ entrance SC exit

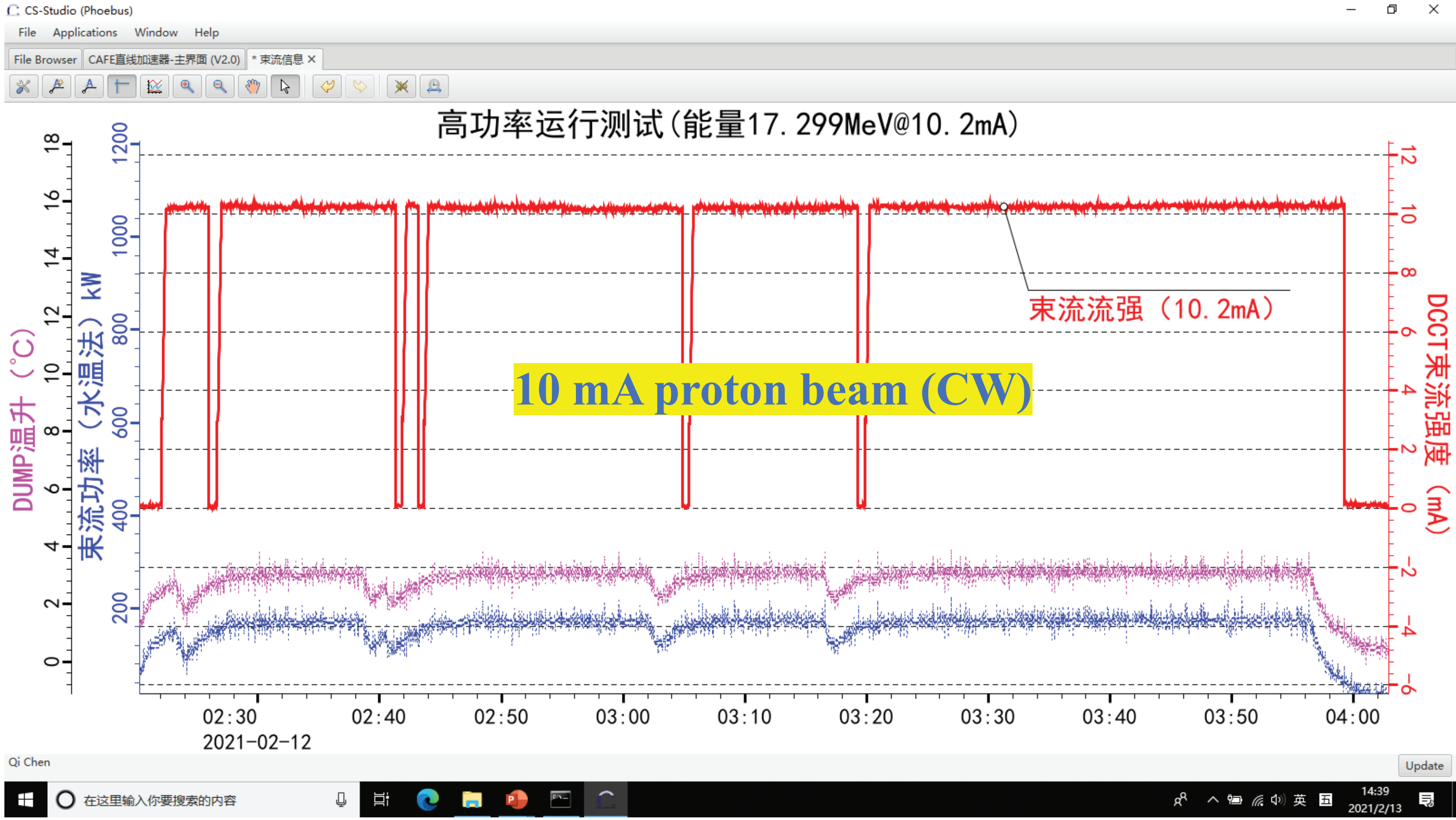


III. Superconducting heavy ion linac

■ **iLinac is designed based on the experience of ADS prototype**

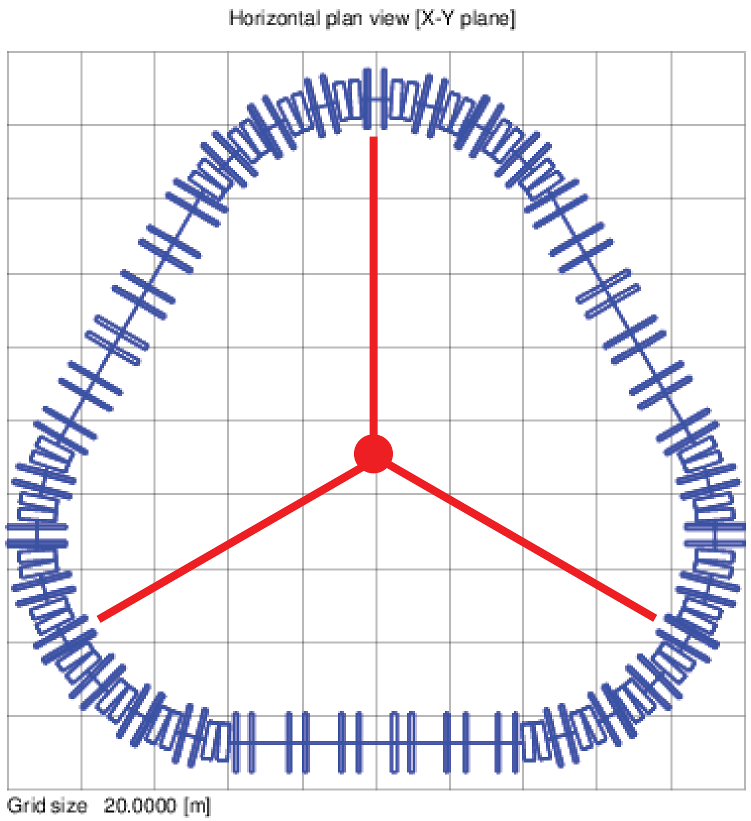


ADS RFQ and cavities

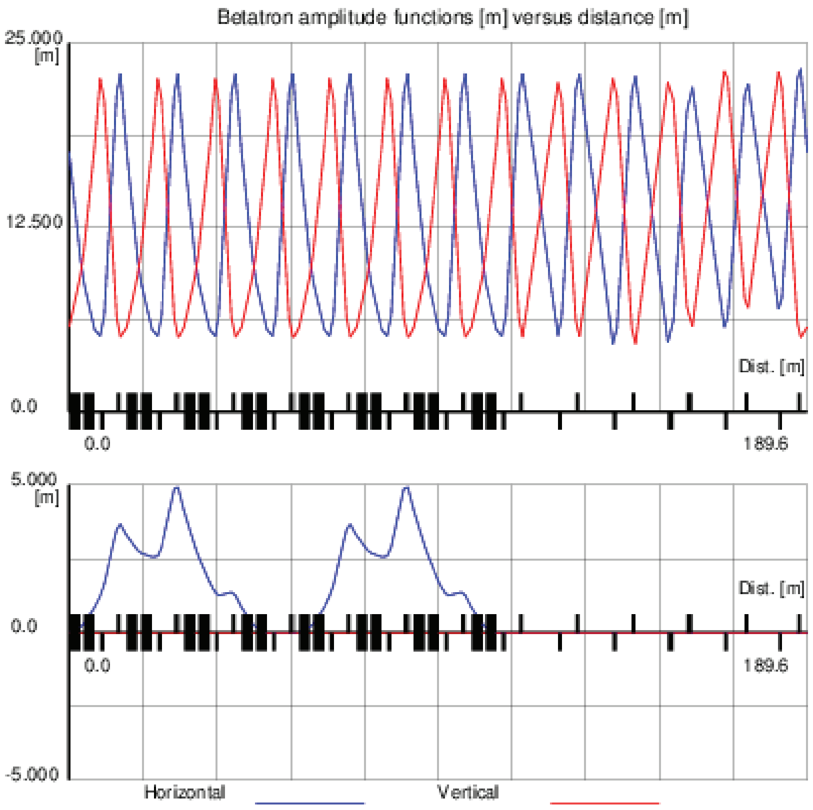


IV. Booster synchrotron

■ BRing Lattice structure



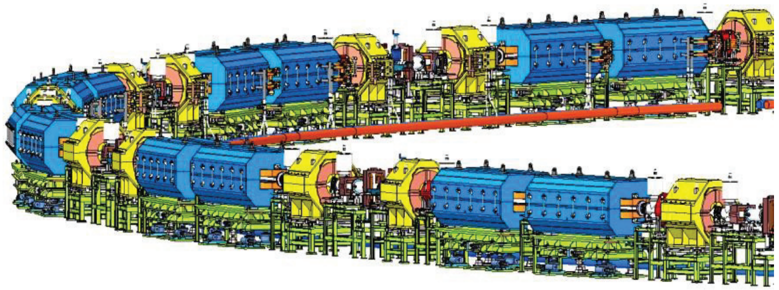
Parameters	value
Circumference	569.09 m
Qx / Qy	9.47 / 9.43
γ_{tr}	7.635
Magnetic rigidity	34 Tm
Ramping rate	12 T/s
Acceptance	200 / 100 π.mm.mrad
Dipoles	48
Quadrupoles	78



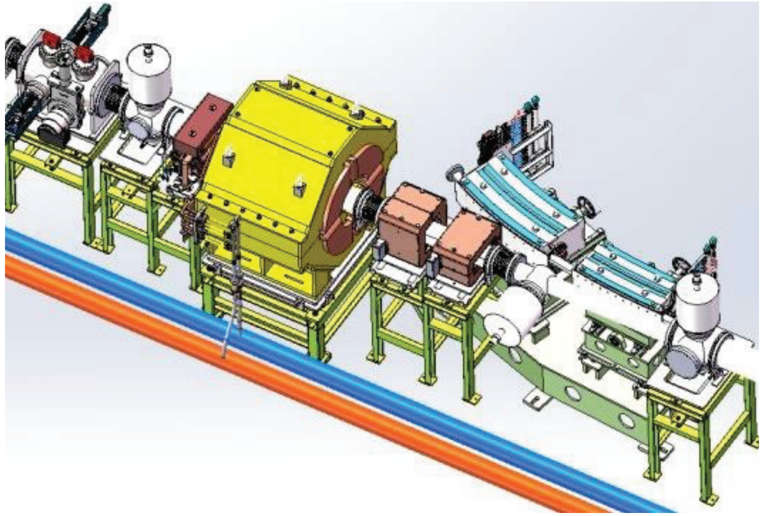
- ➢ Three-folding symmetry lattice with DBA structure
- ➢ Operation below energy transition
- ➢ 4-D painting injection, fast ramping and ceramic-lined thin-wall vacuum chamber

IV. Booster synchrotron

■ BRing Lattice structure

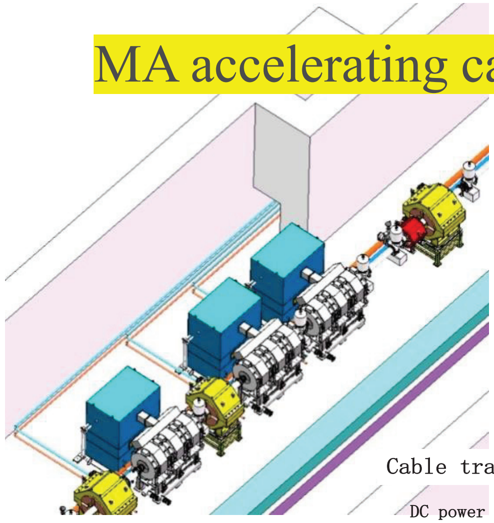


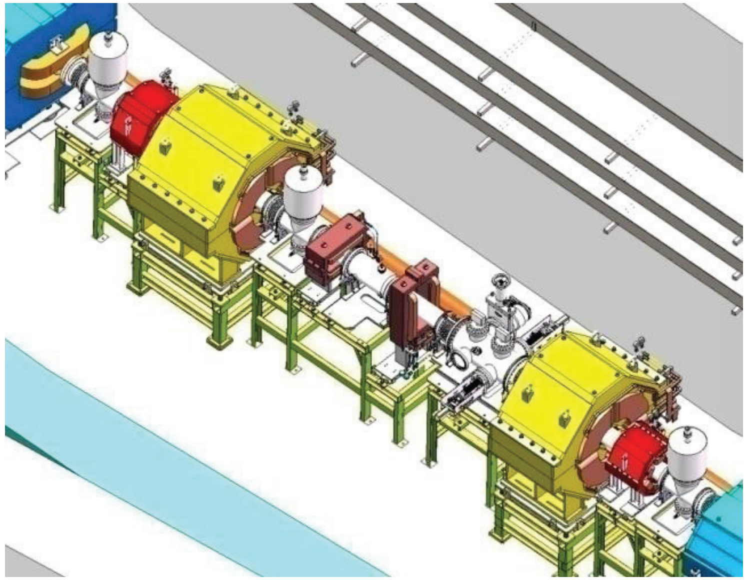
Bending section



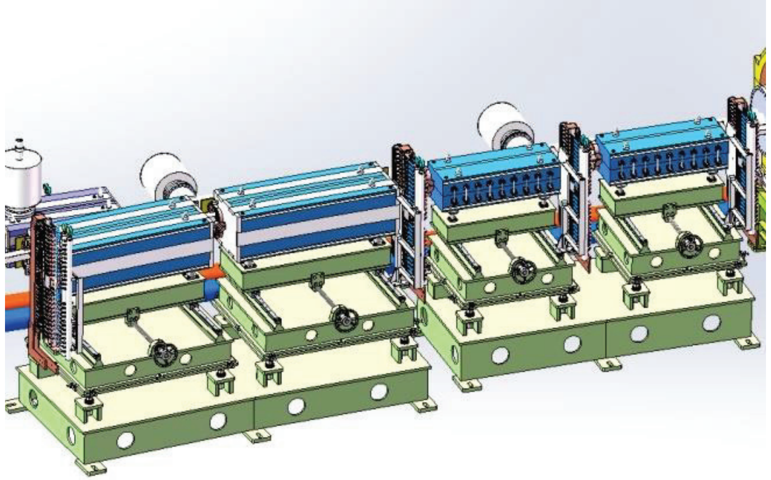
Septum for multi-turn injection

MA accelerating cavities

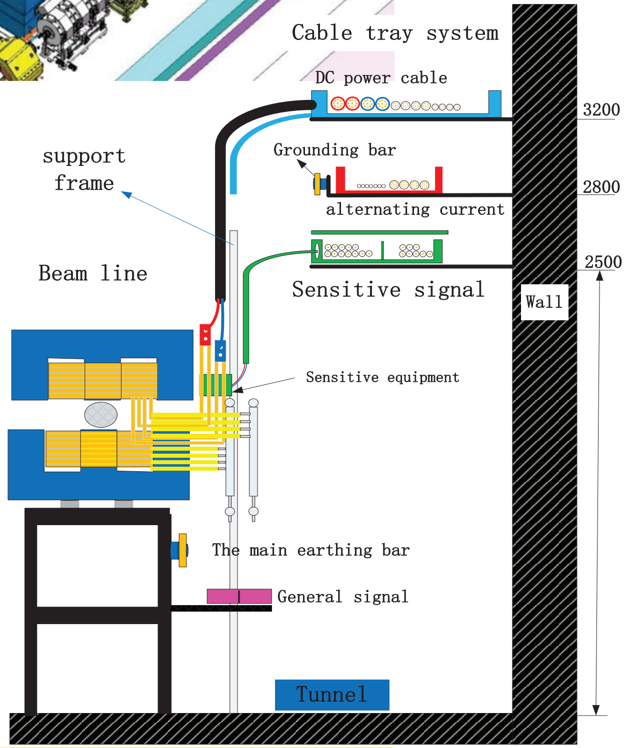




Straight section

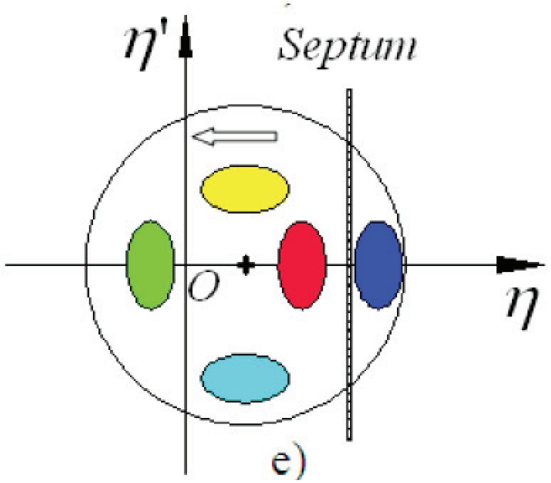


Septum for extraction

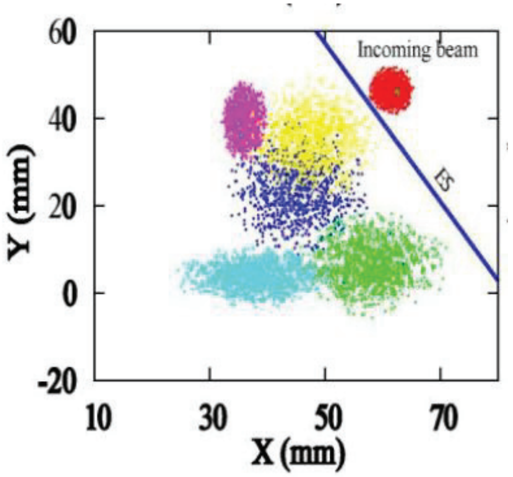


Cable and water pipe

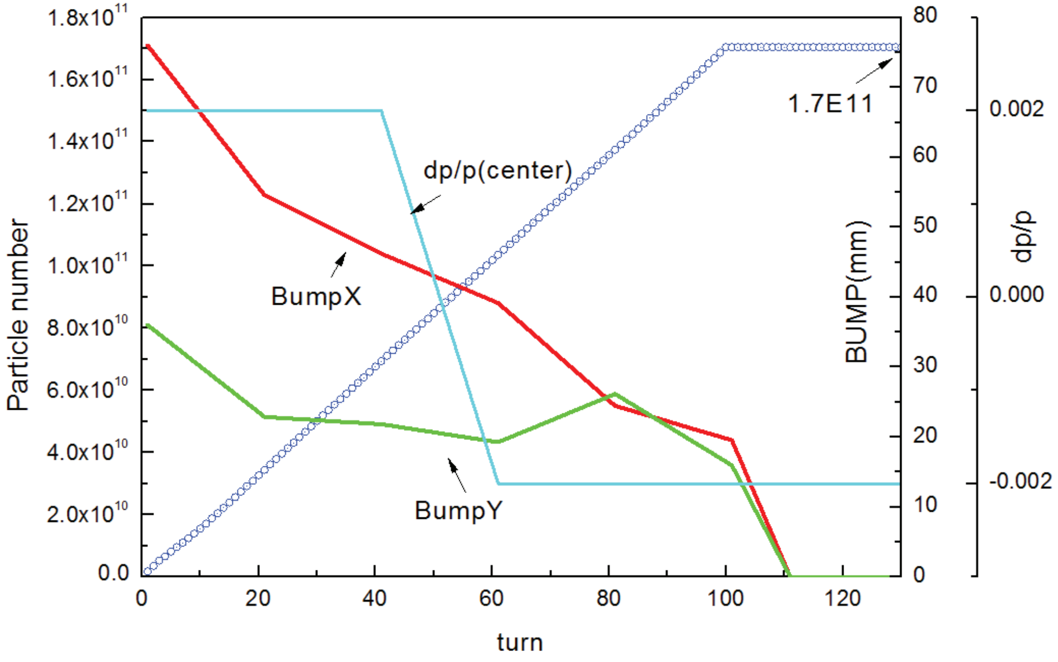
4-D painting injection

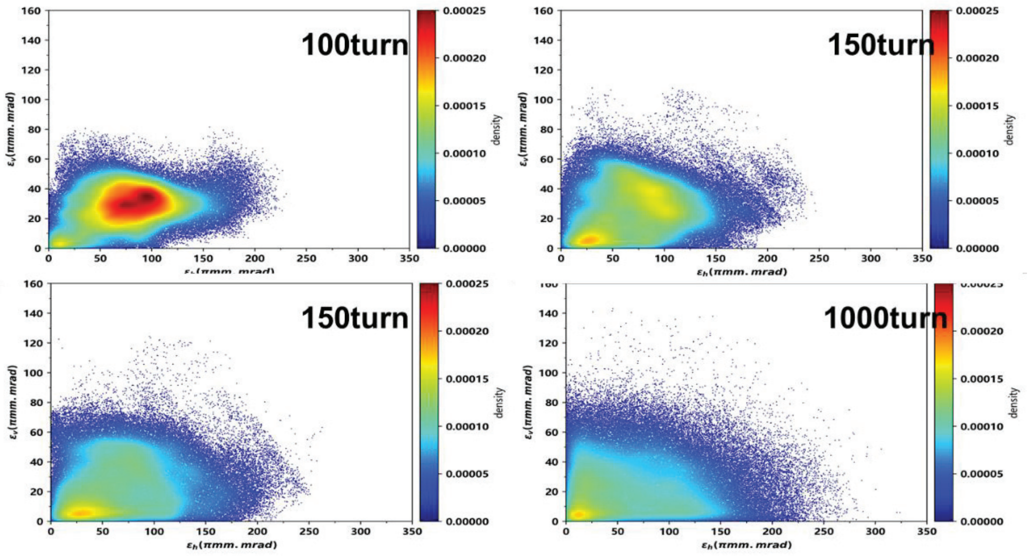


Horizontal multi-turn injection



Horizontal & vertical multi-turn injection

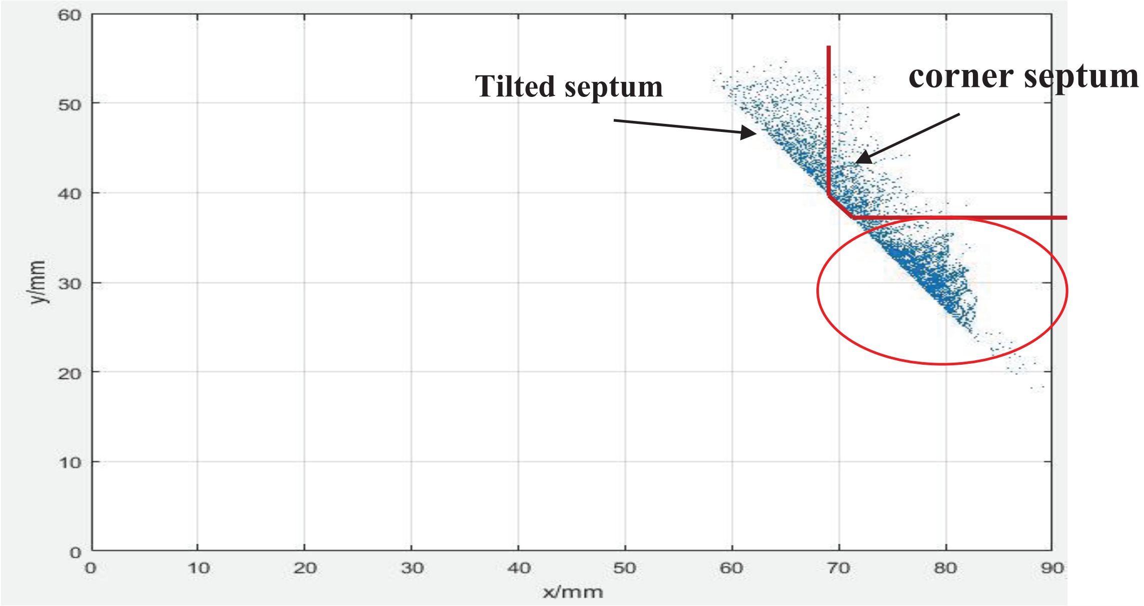


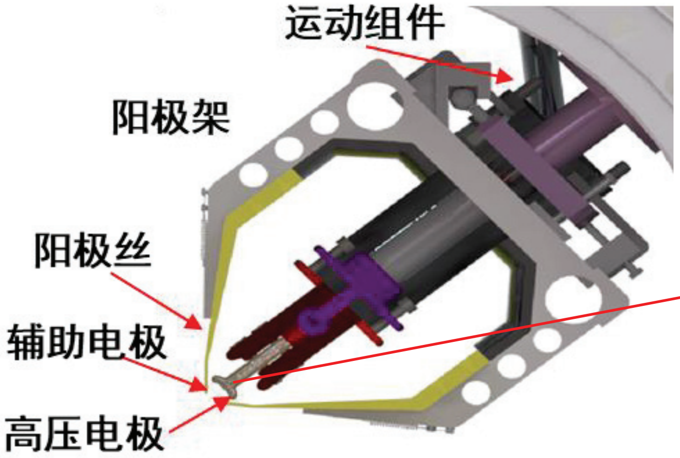


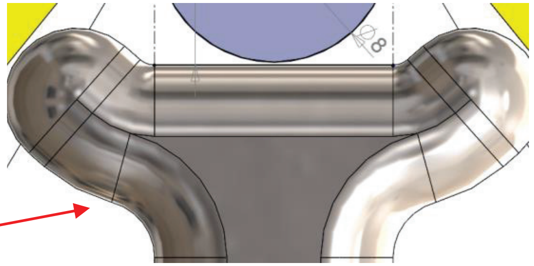
- Use the vertical space, increase the accumulation gain factor
- Increase the magnet gap, expensive
- Different bump curve, flat distribution

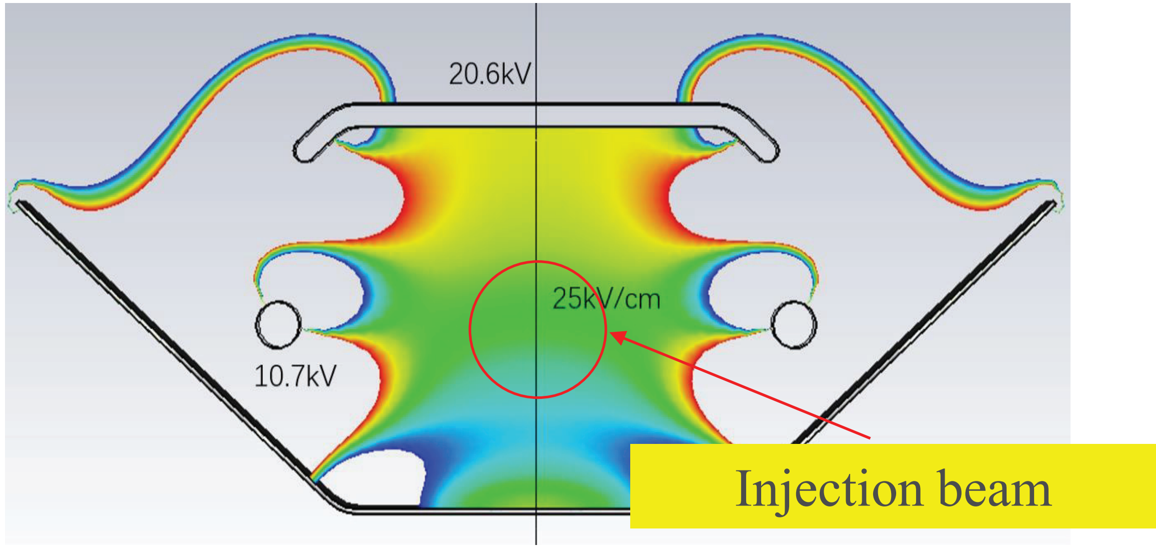
IV. Booster synchrotron

4-D painting injection



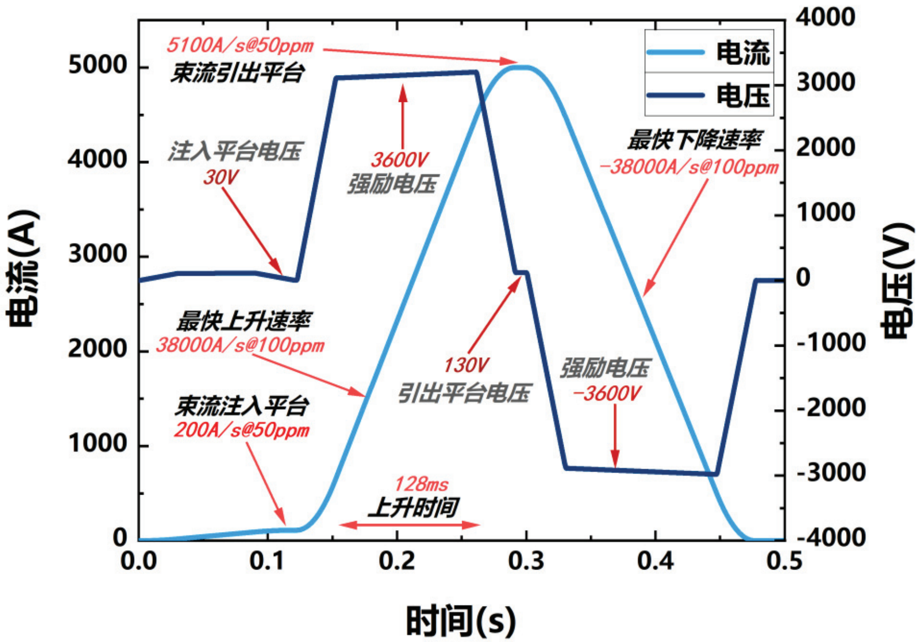




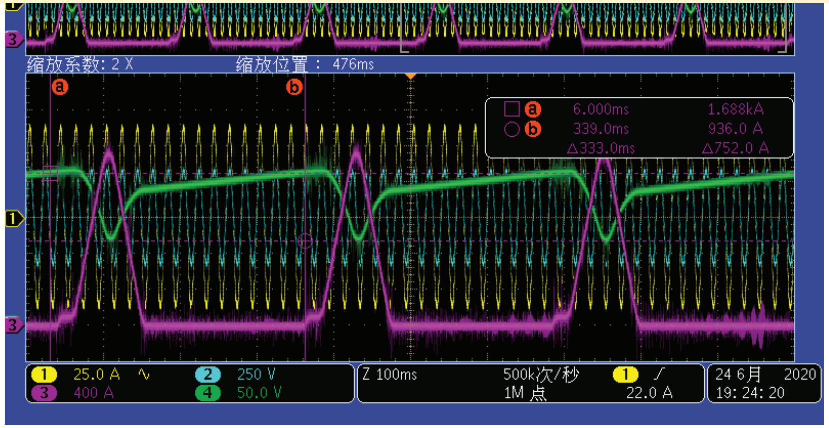


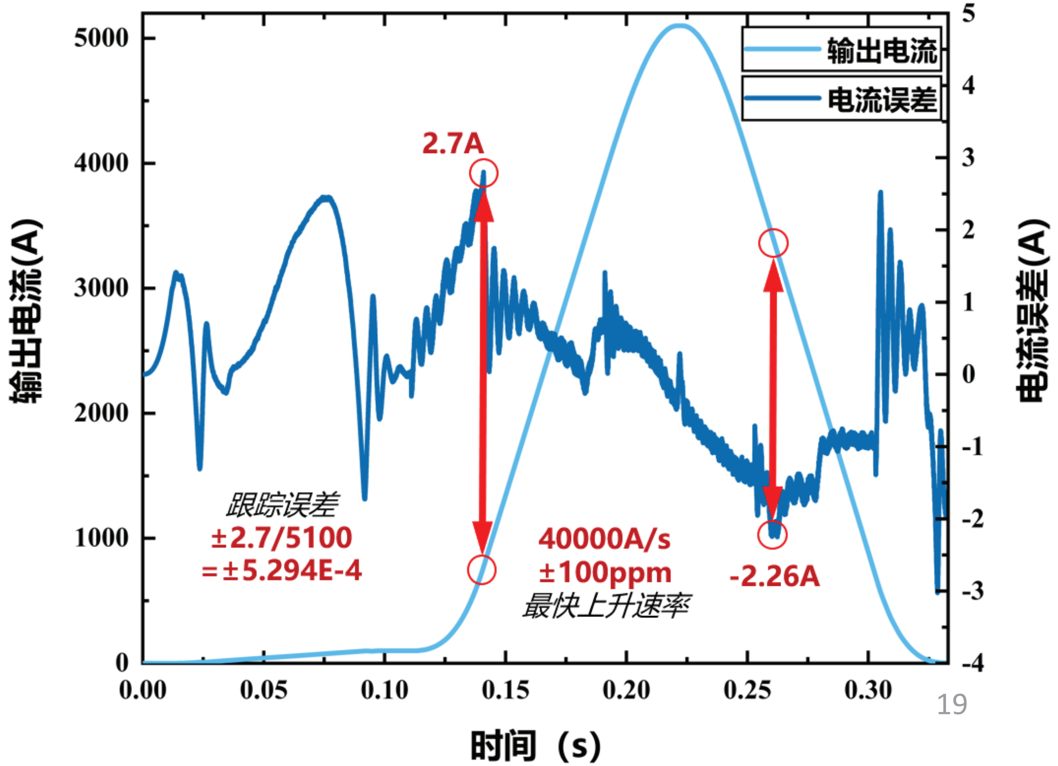
- Use the vertical space, increase the accumulation gain factor
- Increase the magnet gap, expensive
- Special electrostatic septum, decrease the beam loss --- corner septum

- Prototypes of BRing --- dipole power supply



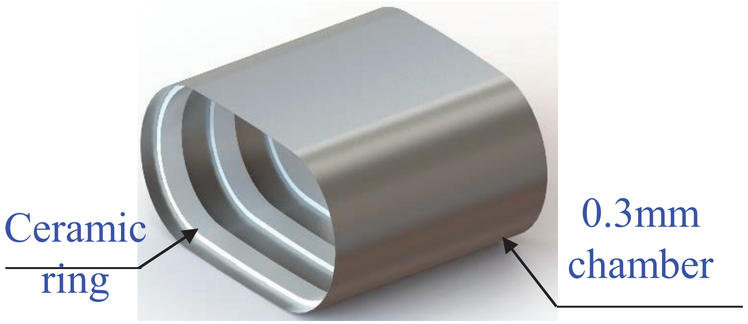
> Fast ramping up to 40 kA/s





IV. Booster synchrotron

■ Prototypes of BRing --- ceramic-lined thin-wall vacuum chamber



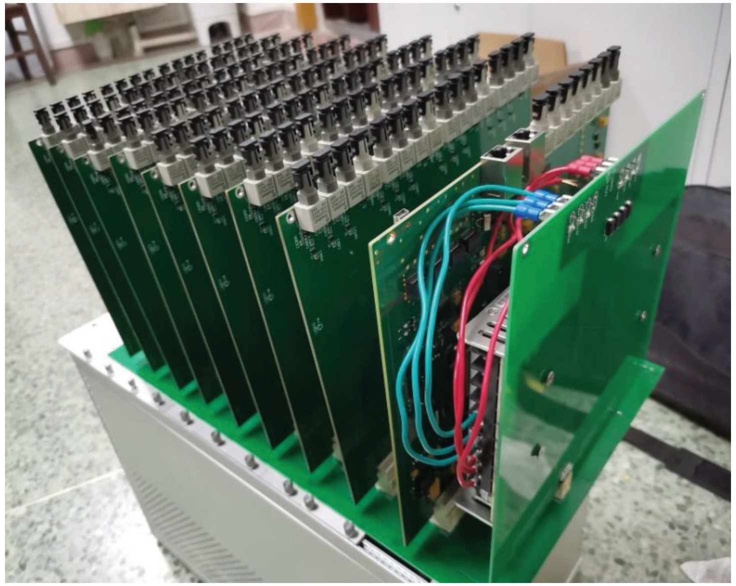
- ➢ Reduce the eddy currents because of 0.3 mm wall
- ➢ Coated with a 1 μm Au film to recue the beam impedance

IV. Booster synchrotron

- Prototypes of BRing

Dipole magnet

MA ring for RF station

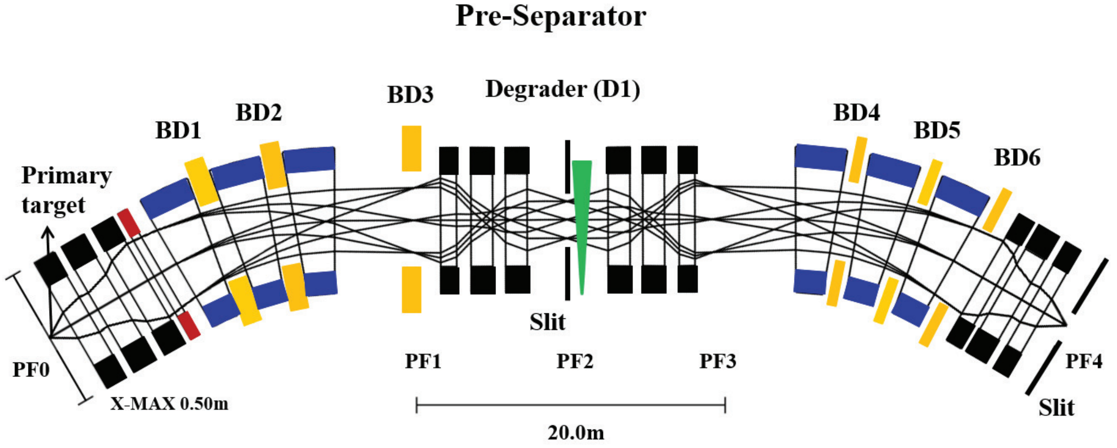


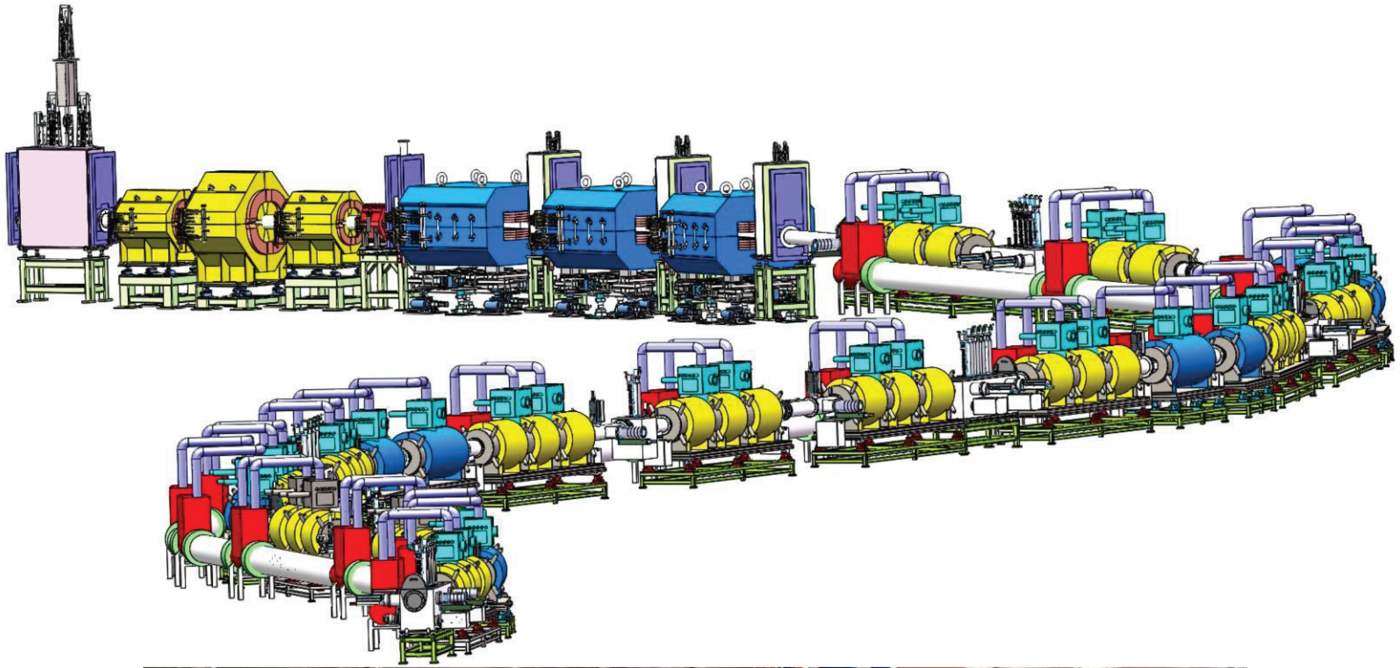
Cards for protection

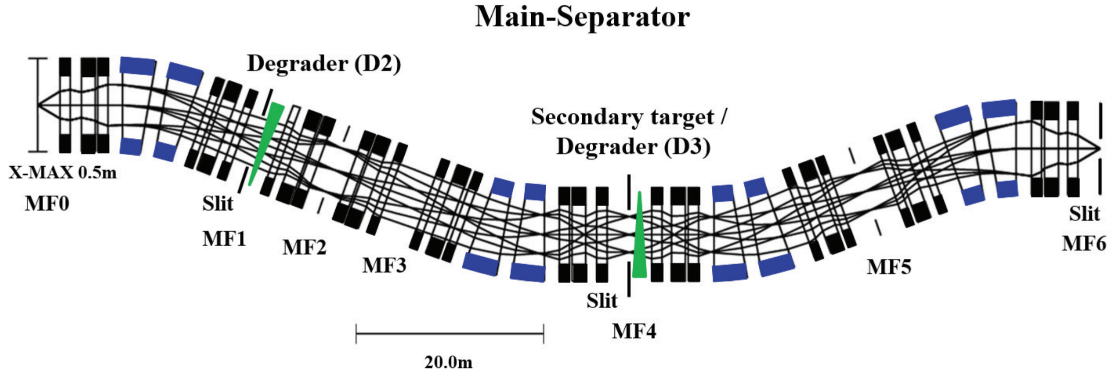
- 17 dipole magnets have been made at IMP workshop
- MA ring with a diameter of 780 mm was tested in laboratory
- Circuit cards for the machine protection were tested in CSR at IMP

V. Experimental terminals

■ High energy fragment separator (HFRS)





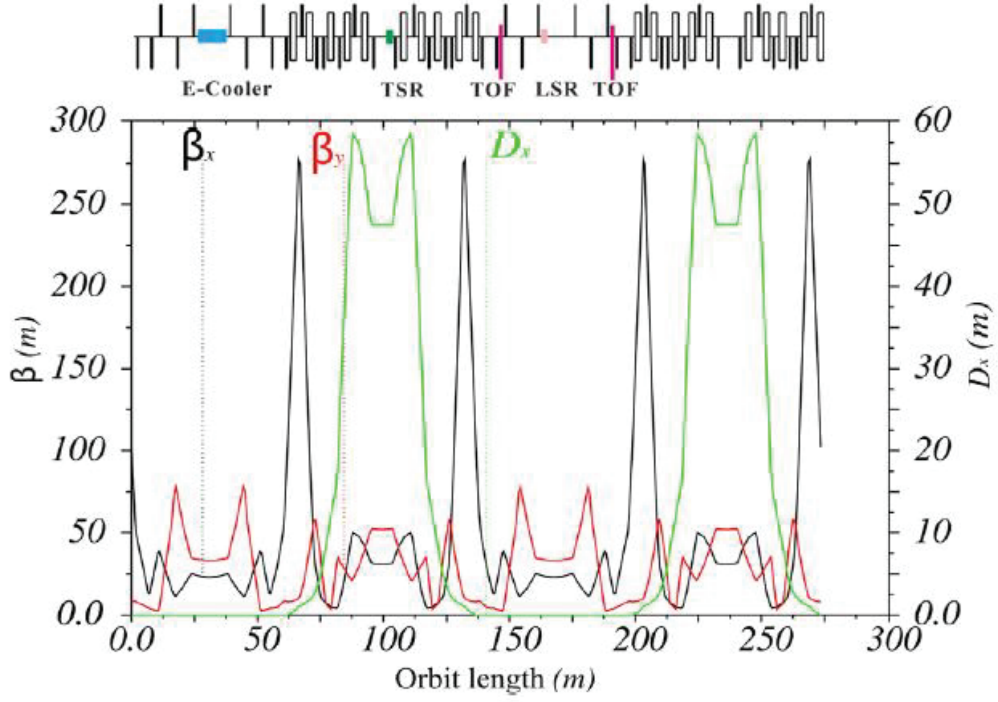


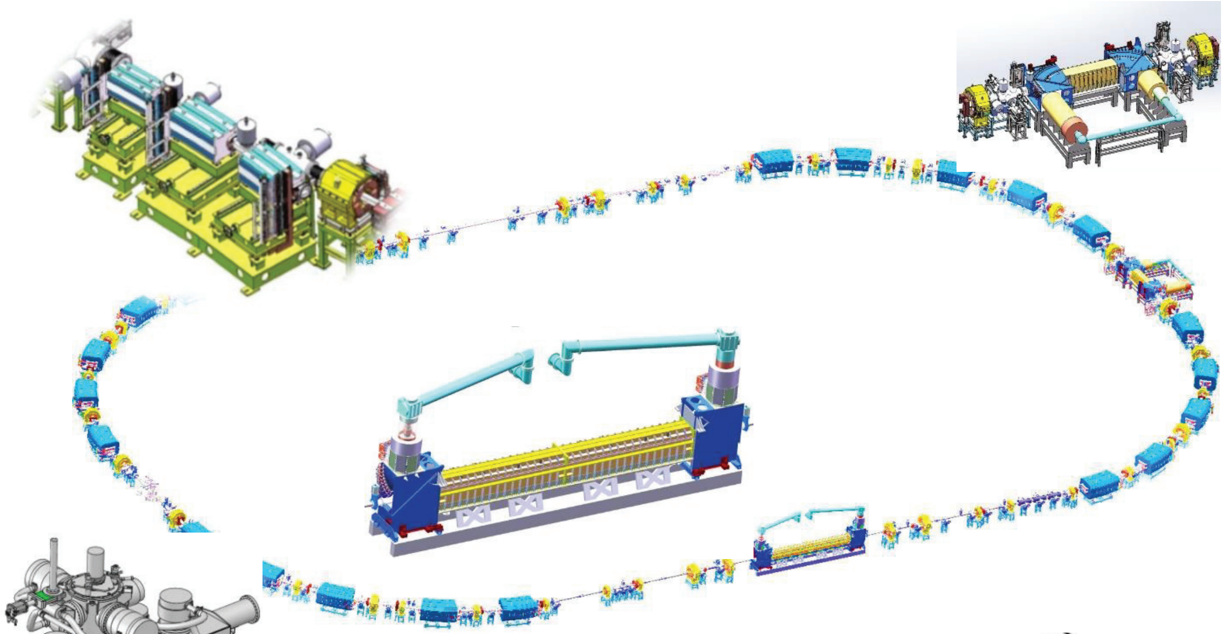
Main parameters of the HFRS.

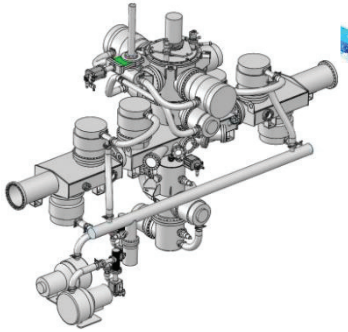
Max. magnetic rigidity/Tm	Beam spot size at target/mm	Angular acceptance/mrad	Momentum acceptance	First order Momentum resolution
25	x= ± 1; y= ± 2	x'= ± 30; y'= ± 15	± 2.0%	1100 (emittance = 30π·mm·mrad and x= ± 1mm)

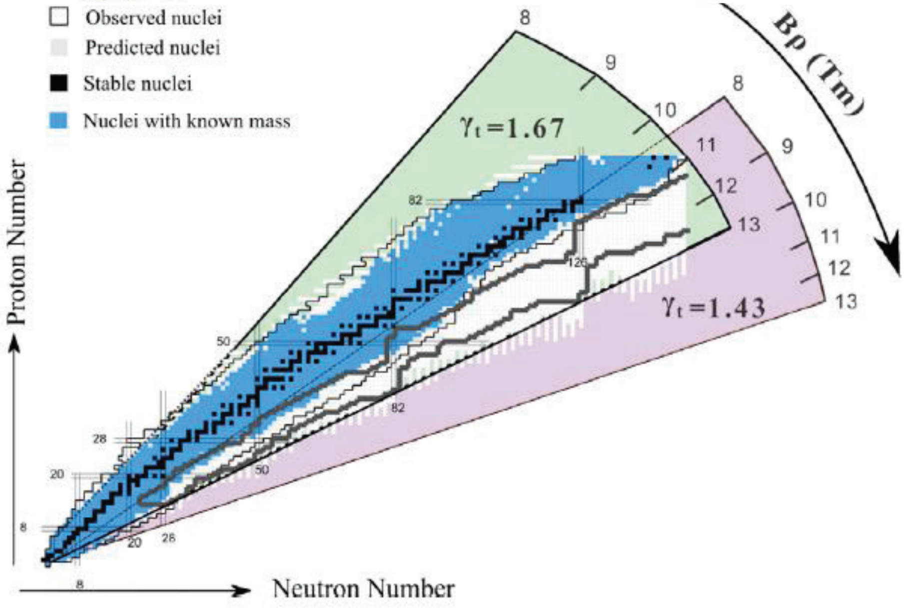
V. Experimental terminals

■ Spectrometer Ring





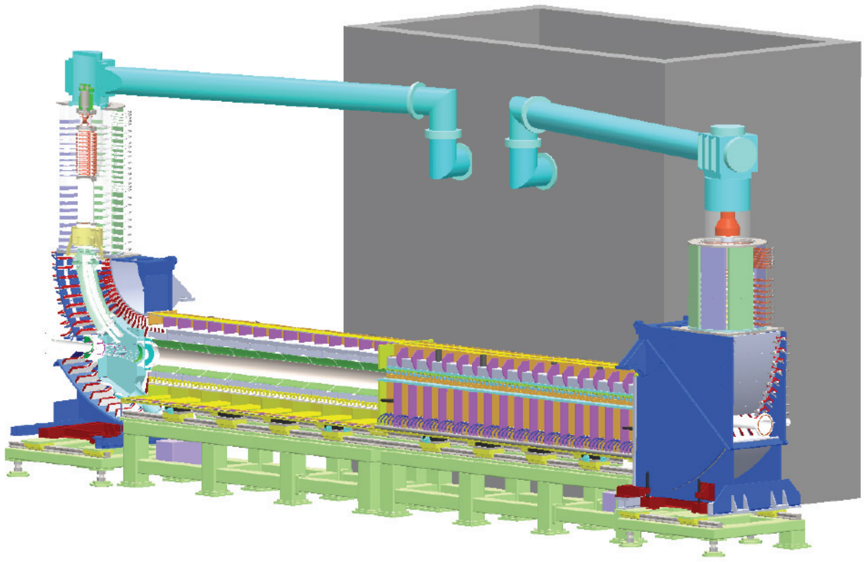




Operation modes	Isochronous mode	Normal mode	Internal Target mode
Energy range	400 ~ 800 MeV/u	400 ~ 800 MeV/u	< 3.6 GeV (proton) < 1.5 GeV/u (12C6 +) < 0.8 GeV/u (238U92 +
Magnetic rigidity range	8 ~ 13 Tm	8 ~ 13 Tm	< 15 Tm
Beam quality (2σ)	$\Delta p/p \leq \pm 3.6 \times 10^{-3}$ $\varepsilon_x/\varepsilon_y \leq 40\pi$ mm·mrad	$\Delta p/p \leq \pm 1.5 \times 10^{-2}$ $\varepsilon_x/\varepsilon_y \leq 40\pi$ mm·mrad	$\Delta p/p \leq \pm 1.5 \times 10^{-2}$ $\varepsilon_x/\varepsilon_y \leq 40\pi$ mm·mrad
Bunch length (μs, 2σ)	0.71	0.26	0.71

■ Electron cooler in SRing

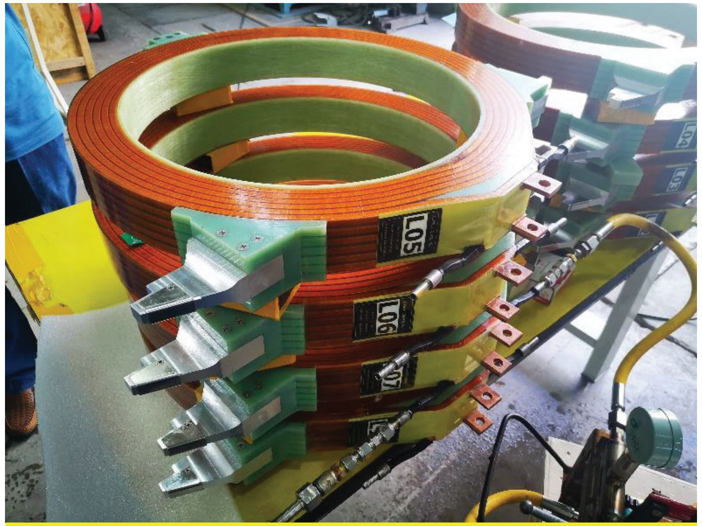
Based on the 300 keV cooler made by BINP



450 keV DC magnetized electron cooler

Energy	450 keV
Maximum current	2.0 A
Magnetic field	1500 Gs
Cooling length	7.4 m

Collector



coils

gun

VI. Summary

- The HIAF is only one project of heavy ion accelerator supported in China
- The day-one experiment is planned to be done in 2025. The nuclear physics is the main goal of the HIAF project. The day-one experiment may be done in HFRS or SRing.
- SECR and iLinac will be developed based on the experience of the present devices at IMP
- The dipole power supply, the ceramic-lined thin-wall vacuum chamber, the corner septum and the MA RF cavities are the key technologies of BRing. Now we already have some good results.
- Today, the civil construction is done as the time schedule.

Thanks for your attention!