Space Charge 2026

7th ICFA Beam Dynamics Mini-Workshop

High-intensity challenges and progress in the HIAF project

Jiancheng Yang (杨建成), Ruihu Zhu (朱瑞虎)

On behalf of the HIAF Project Team

Institute of Modern Physics (IMP) , Chinese Academy of Sciences (CAS)

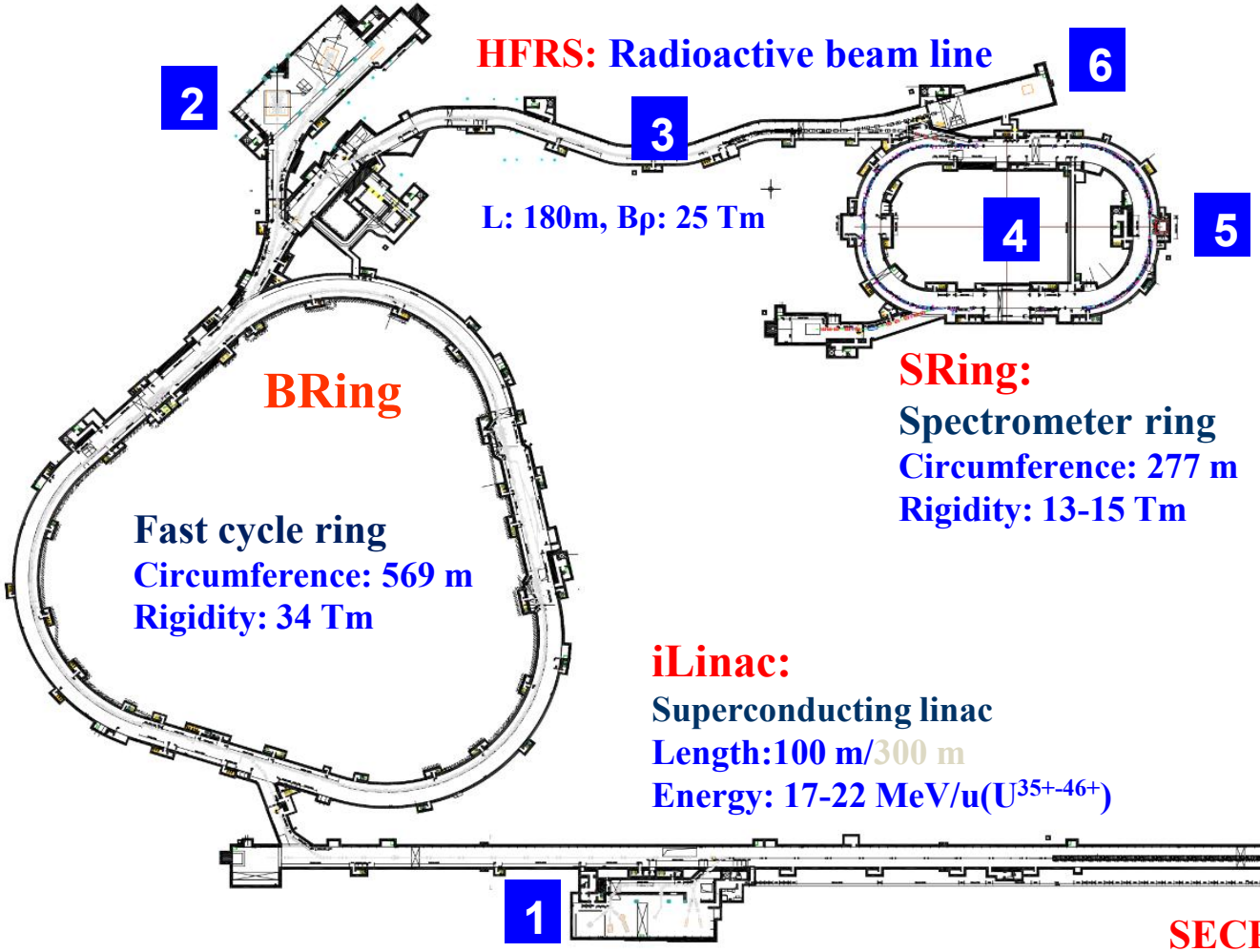
University of Oxford, Sep. 30th, 2026

Outline

1. General introduction
2. Challenges and innovations
3. Construction and commissioning
4. Outlook

General introduction

The whole layout: accelerator components and experimental terminals



Experimental 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

General introduction

Features:

High current low energy CW and the highest intensity high energy pulse

	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+})	1100 (U^{92+})
Magnetic rigidity(Tm)	---	---	34	25	15
Beam intensity of U	**1.7 emA (U^{35+})**	**1.0 emA (U^{35+})**	**2×10^{11}ppp (U^{35+}) 6×10^{11}pps (U^{35+})**	-------	**(0.5-1) $\times10^{12}$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)

General introduction

Time schedule

7-year construction period since 2019



Civil construction began



Key prototype
Equipment bidding



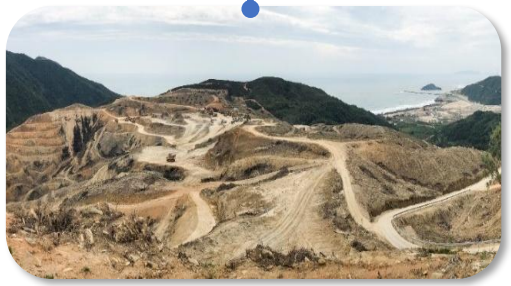
Testing
Auxiliary system

Beam commissioning
Equipment operation



2019 2020 2021 2022 2023 2024 2025

First key equipment



Batch processing



Installation
Offline commissioning



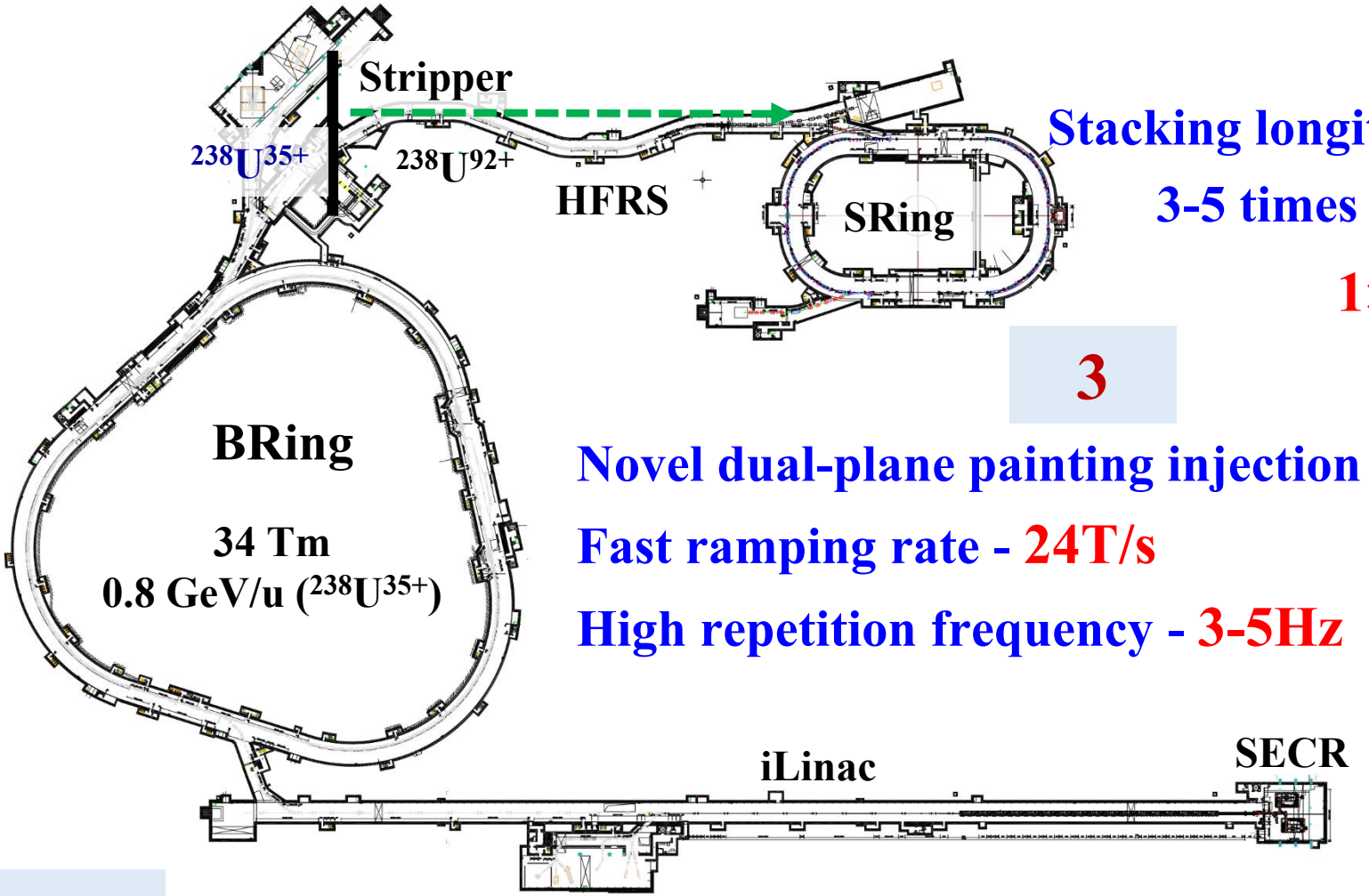
Achieve design parameters
@2025.11

Outline

1. General introduction
2. **Challenges and innovations**
3. Construction and commissioning
4. Perspectives

High intensity ion beam

How to achieve the unprecedented heavy ion intensity



4

Stacking longitudinally from BRing to SRing

3-5 times barrier bucket technology

1×10^{12}ppp ($^{238}U^{92+}$)

3

Novel dual-plane painting injection scheme - 2.0×10^{11} ppp

Fast ramping rate - 24T/s

High repetition frequency - 3-5Hz

1

Fourth generation high current ion source – 1.7 emA U^{35+}

2

High current superconducting linac -1emA U^{35+}

Major Challenges

World's most intense pulsed heavy-ion beams

Institute	Machine	Planned	Achieved	Ion
BNL	AGS Booster		5×10^{9}	Au^{32+}
CERN	LEIR		9×10^{8}	Pb^{54+}
JINR	NICA Booster	4×10^{9}	/	Au^{32+}
GSI	SIS18	1.0×10^{11}	$\sim 4\times10^{10}$	U^{28+}
FAIR	SIS100	4.0×10^{11}	/	U^{28+}
IMP	**HIAF-BRing**	**$>1.0\times10^{11}$**	**/**	**U^{35+}**
IMP	**HIAF-SRing**	**$>5.0\times10^{11}$**	**/**	**U^{92+}**
IMP	**HIRFL-CSR**	**1.0×10^{9}**	**1.0×10^{8}**	**U^{74+}**

Challenge-1: Beam dynamics

↓ leads to

- **Nonlinear effects**
- **Space charge effects**
- **Collective effects**
- **Dynamic vacuum**

↓ limits

Challenge-2 Technology aspect

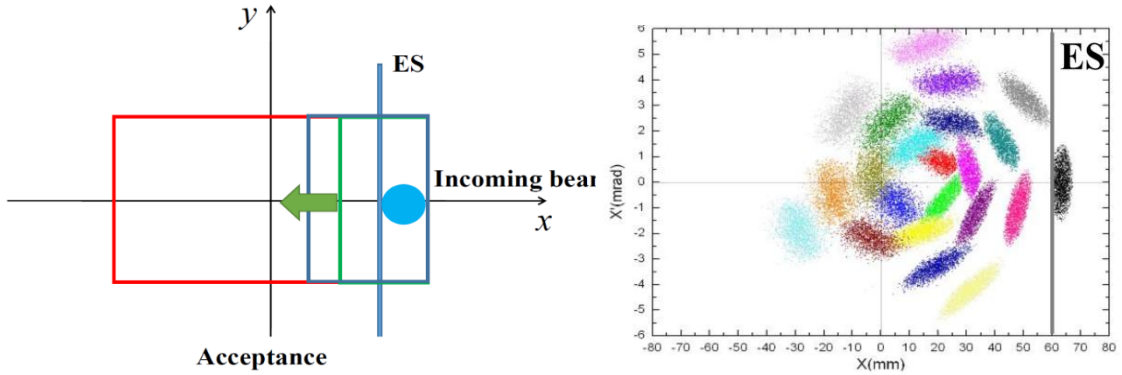
→

- **Beam production**
- **Low energy manipulation**
- **Fast ramping acceleration**

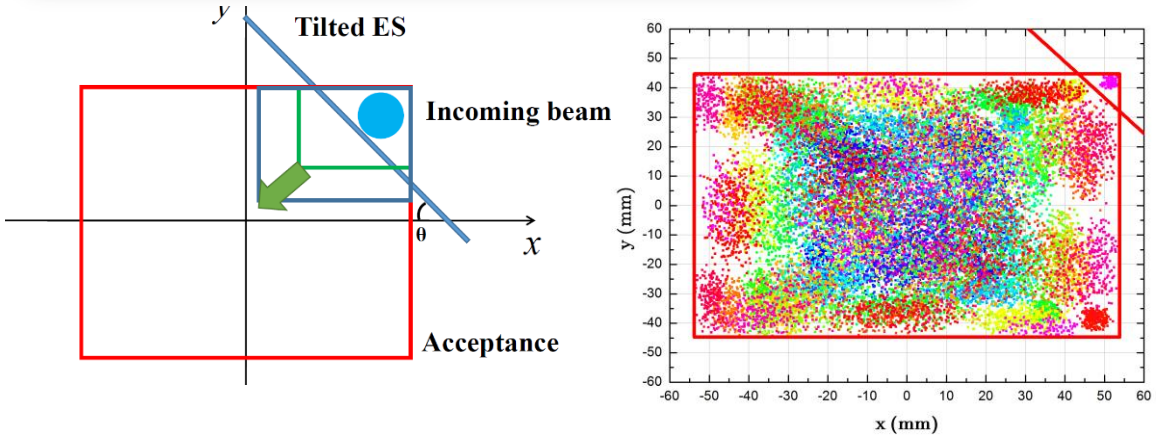
→ Beam intensity, Beam quality

Beam dynamics and challenges

Novel dual planes painting injection

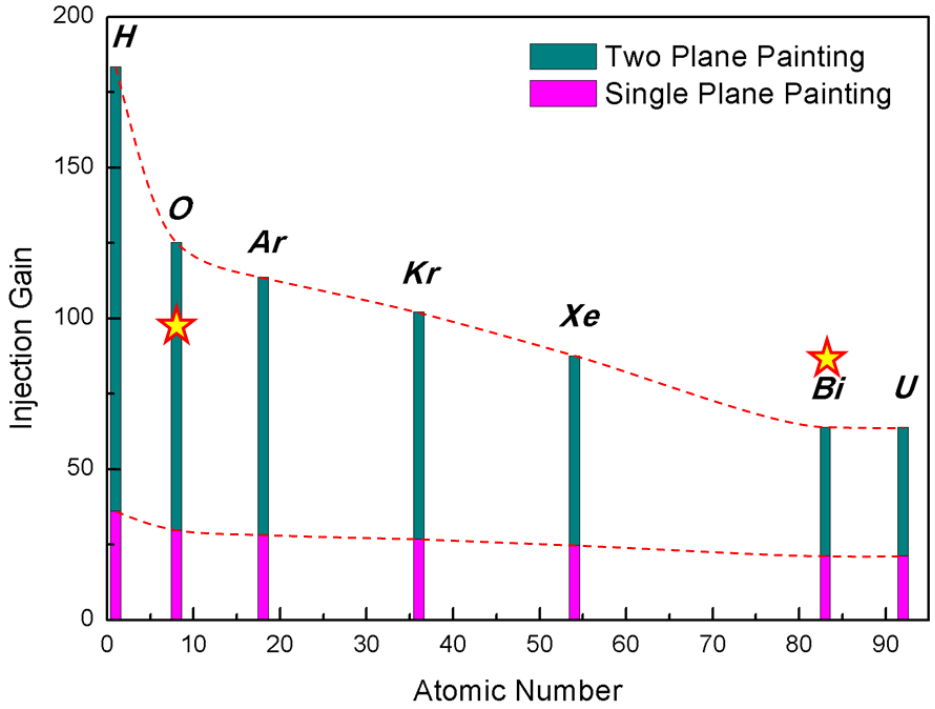


Conventional multi-turn injection



Dual planes painting injection

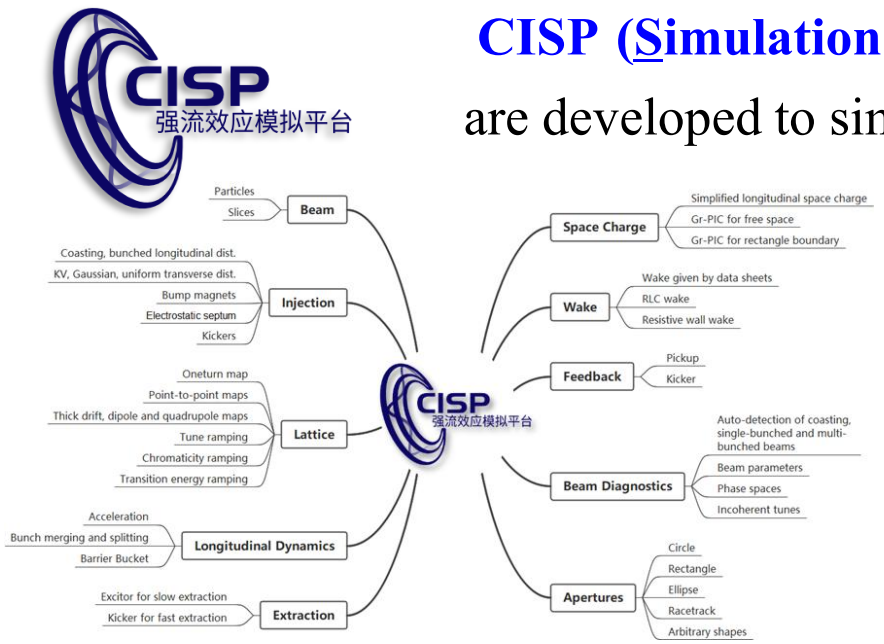
Both the horizontal and vertical painting simultaneous using the tilted E-Septum

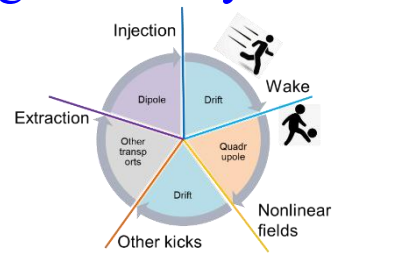


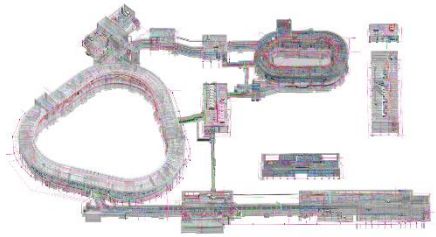
2.0×10^{11} with two planes painting, **nearly 10 times over the conventional multi-turn injection**

Beam dynamics and challenges

CISP (Simulation Platform for Collective Instabilities) and its GPU version are developed to simulate high intensity effects and their coupling effects



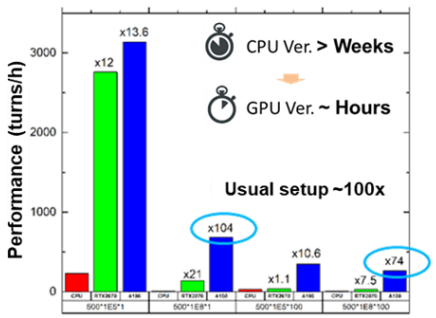


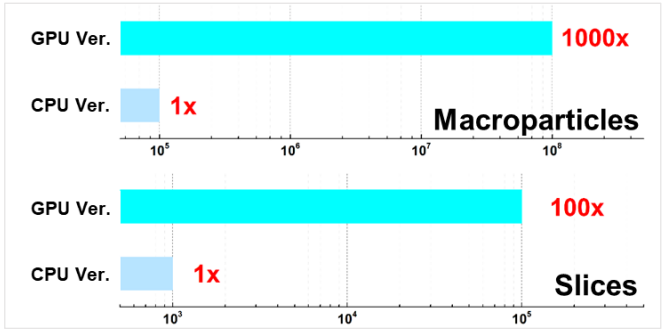


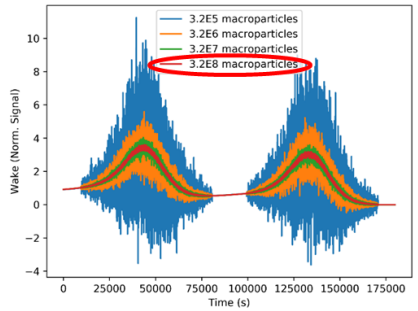
- To perform 1:1 end-to-end multi-dynamics coupling simulations

- All effects are included in a single simulation to get closer to the actual accelerators

CISP-GPU: accelerated parallel computing of all beam dynamics.





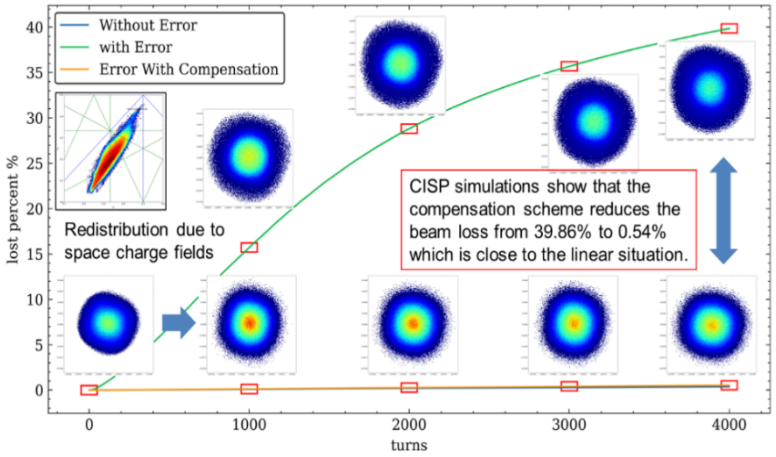


Higher performance → Much higher accuracy

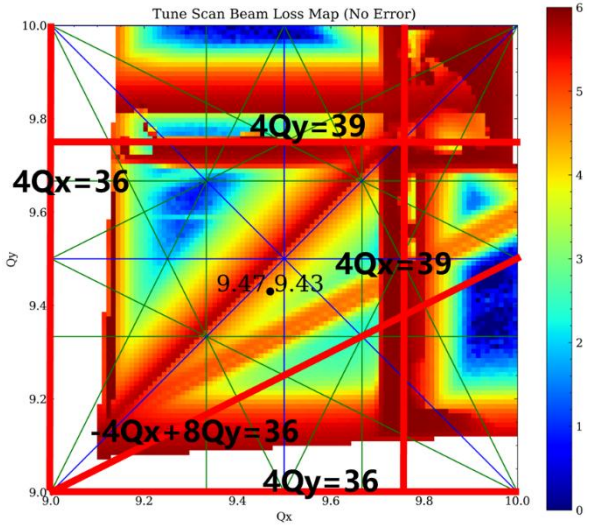
- ~10^8 macroparticles and 10^5 beam slices
- Study the interaction between ultra-short wakes and ultra-long bunches, also many other multi-dynamics coupling effects

High intensity beam dynamics investigation

Nonlinear effect and space charge

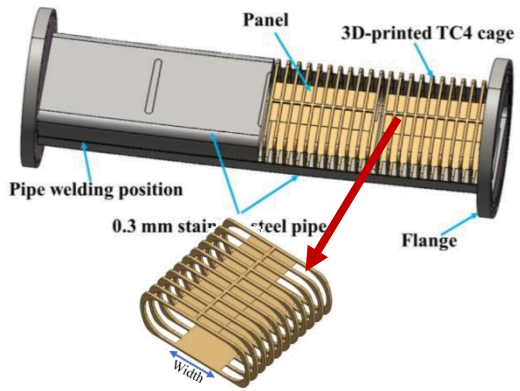


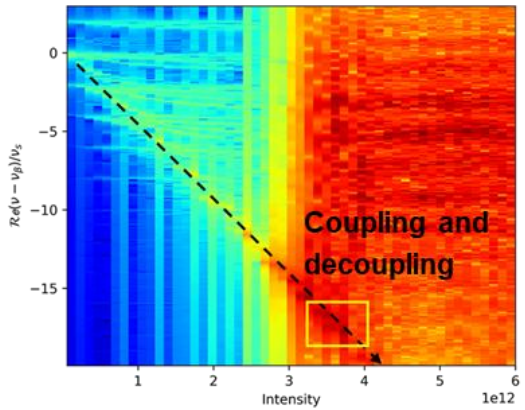
Resonances driven by high order field errors with space charge were corrected to reduce the beam loss



Work point was optimized to avoid the beam loss of structural resonances

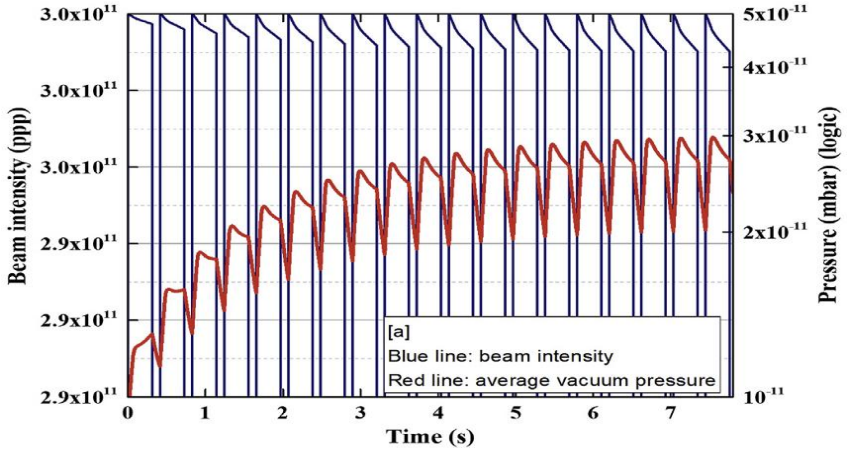
Collective instability





Transverse mode coupling of Titanium alloy cage supported vacuum chamber were investigated and compensated

Dynamic vacuum effect



Beam intensity is 3E11 ppp at the equilibrium state the drop of vacuum pressure is acceptable

Key technologies and challenges



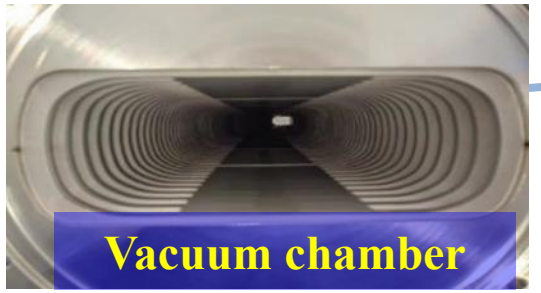
Full energy storage PS

38kA/s, 3Hz



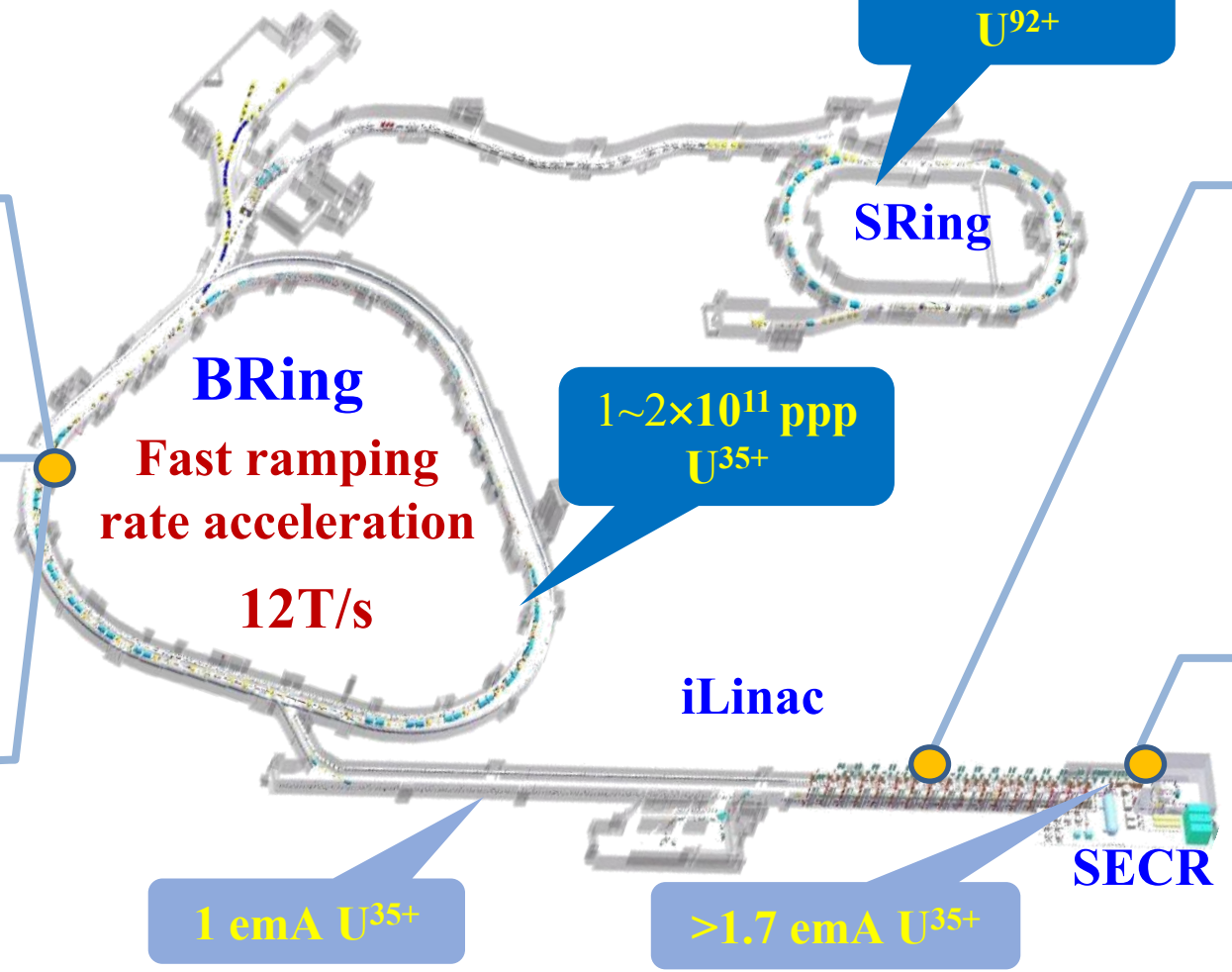
Magnetic alloy core RF

70kV, 35 kV/m



Vacuum chamber

0.3 mm, <7×10-12 mbar





SRF Linac

mA level heavy ion beam



SC-ECR ion source

Fourth generation superconducting ECR source

Outline

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3. **Construction and commissioning**
4. Perspectives

Project Construction

Civil construction

Occupies **80 acres**, total construction area **58,000 m²**,


BRing building


SRing building


Cryo center


Testing&Assembly hall


Linac building


Central control building

10 above-ground building and a 2-kilometer-long underground tunnel at a depth of 13 meters

Project Construction

Tunnel installation

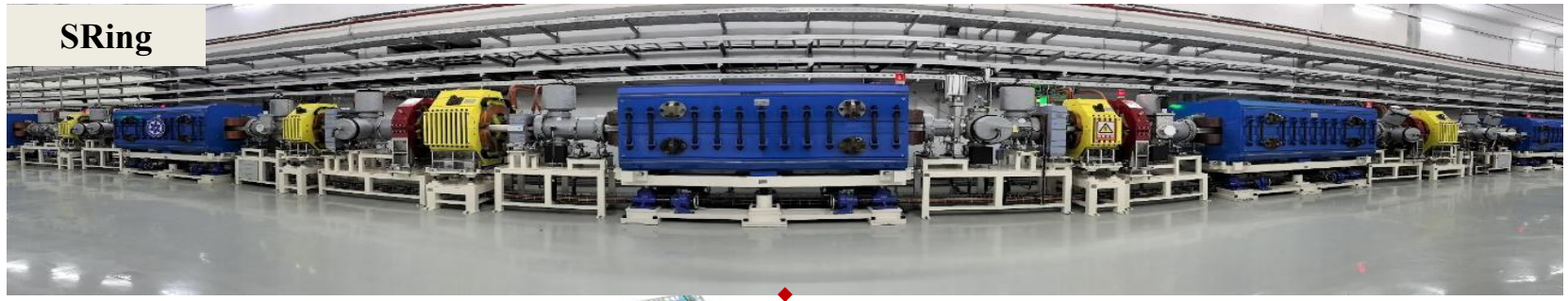
Full Digital Instruction

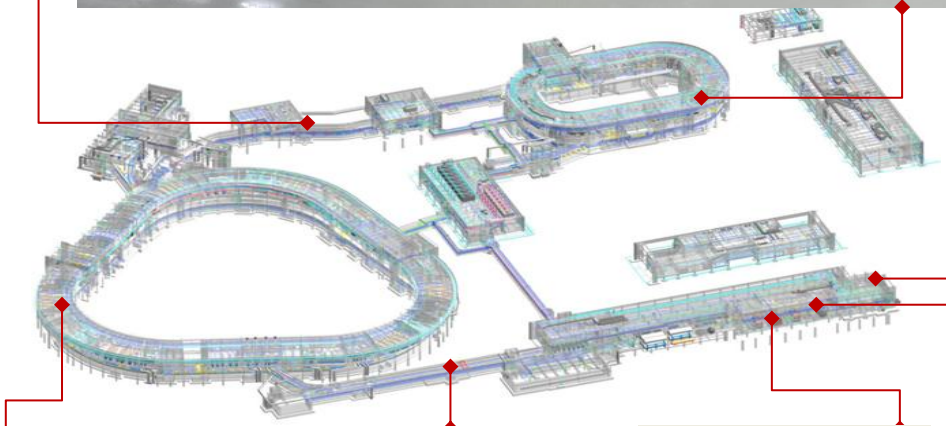
HiRIBL (HFRS)



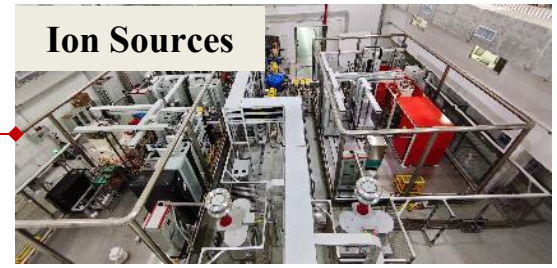


SRing





Ion Sources



BRing



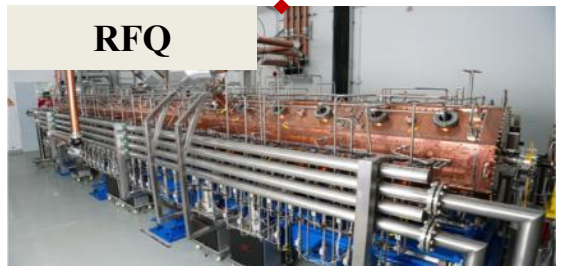
BRing Injection Line



iLinac



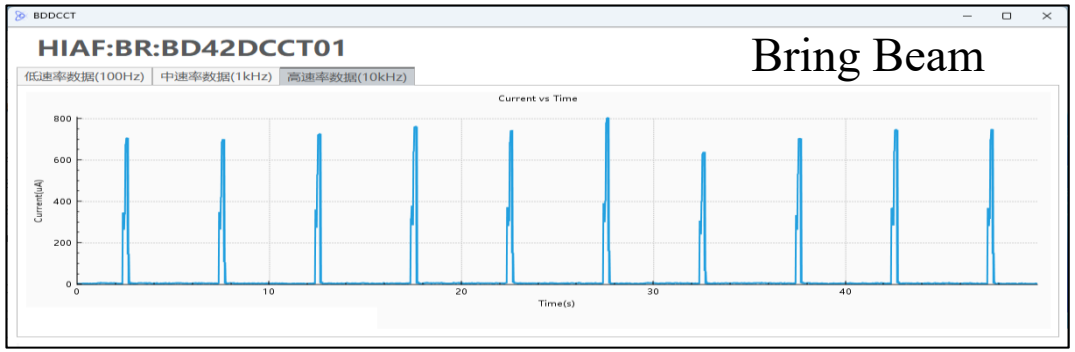
RFQ



The period for a 2-kilometer beam line has been shortened from 2-3 years to 8 months

Beam Commissioning

The commissioning, including its 2-kilometer-long beamline, was completed in just 16 hours, setting a new speed record for large-scale scientific facilities





Heavy-ion Accelerator Fires Up



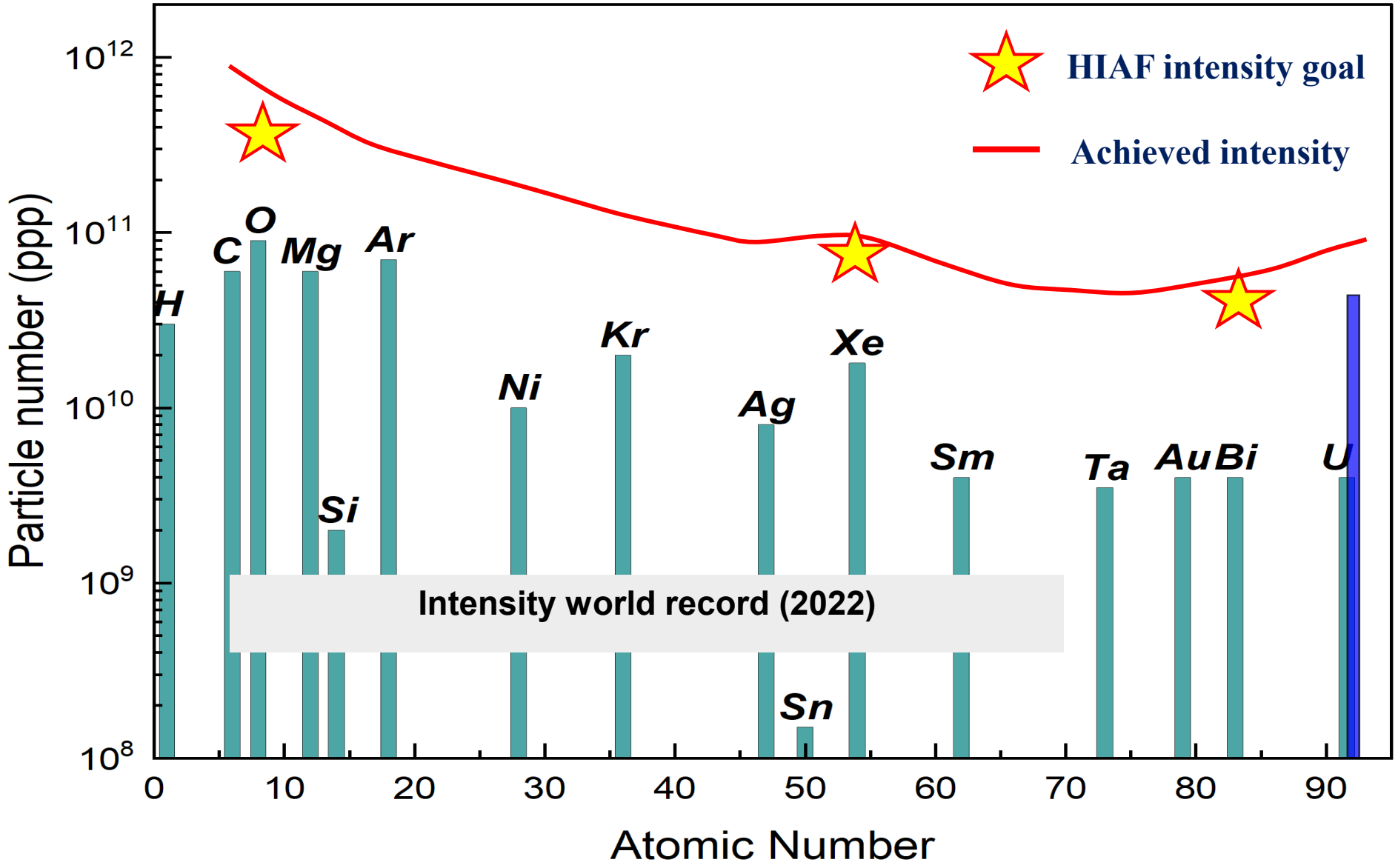
Heavy-ion accelerator fires up

An accelerator that will produce the world's most intense pulses of heavy ions generated its first beam on 28 October. When fully operational, China's High Intensity heavy-ion Accelerator Facility (HIAF), nestled among the mountains of southern Guangdong province, will send pulses of exotic, short-lived ions into fixed targets or into a storage ring to support research on the properties of atomic nuclei and how stars forge heavy elements, as well as material sciences and biomedicine. The research center, which joins the ranks of similar facilities worldwide, represents a $420 million investment by the Chinese Academy of Sciences's Institute of Modern Physics. Institute officials say HIAF will be open to foreign researchers. —Dennis Normile

Science, 6 NOVEMBER 2025, P.559

***Science* magazine promptly reported the successful commissioning**

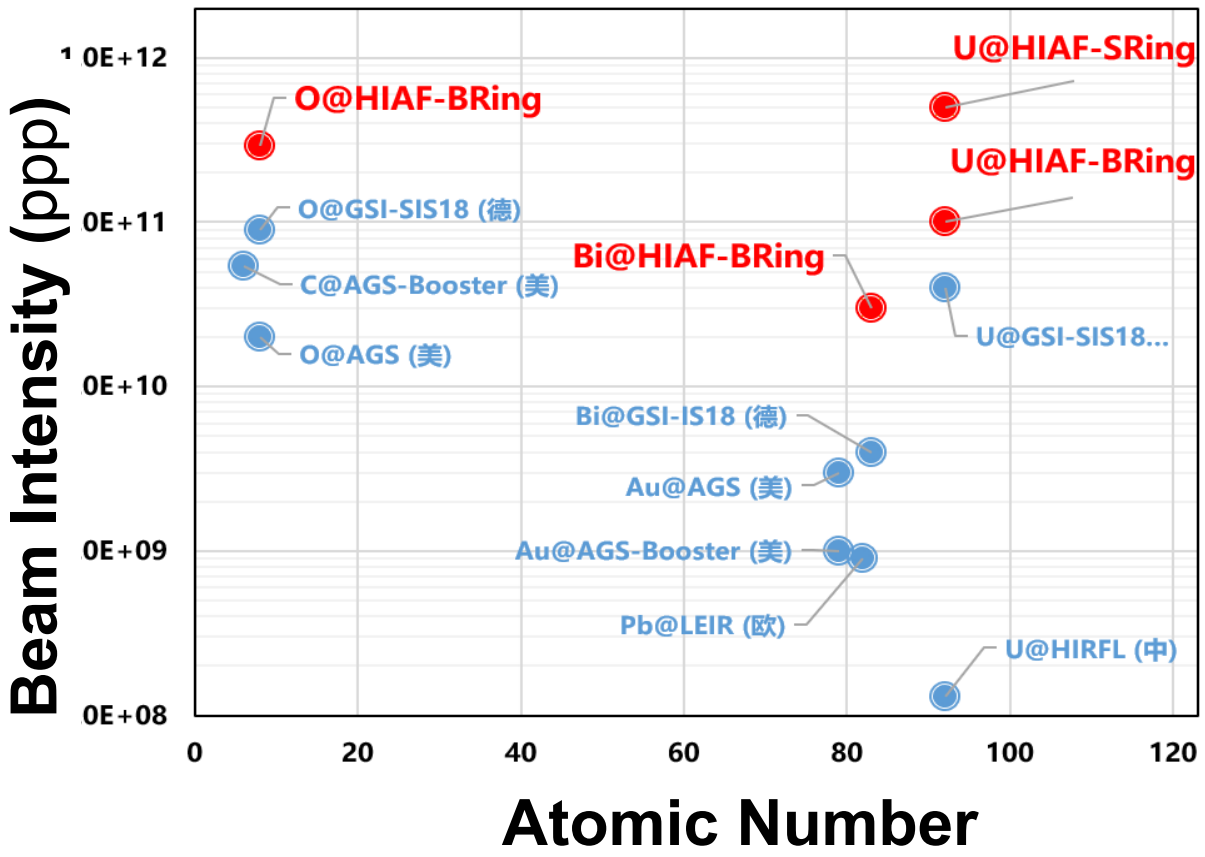
New High Energy heavy-ion Beam Intensity Record



Outlook

Ongoing efforts are focused on

- Beam dynamics study and machine performance improvement
- New techniques implementation for higher intensity
- Reliable and high efficiency operation for users



World first class performance for researchers worldwide


We appreciate the strong collaboration and support from the international scientific community during the construction of the HIAF
IMP
Thanks for your attention!