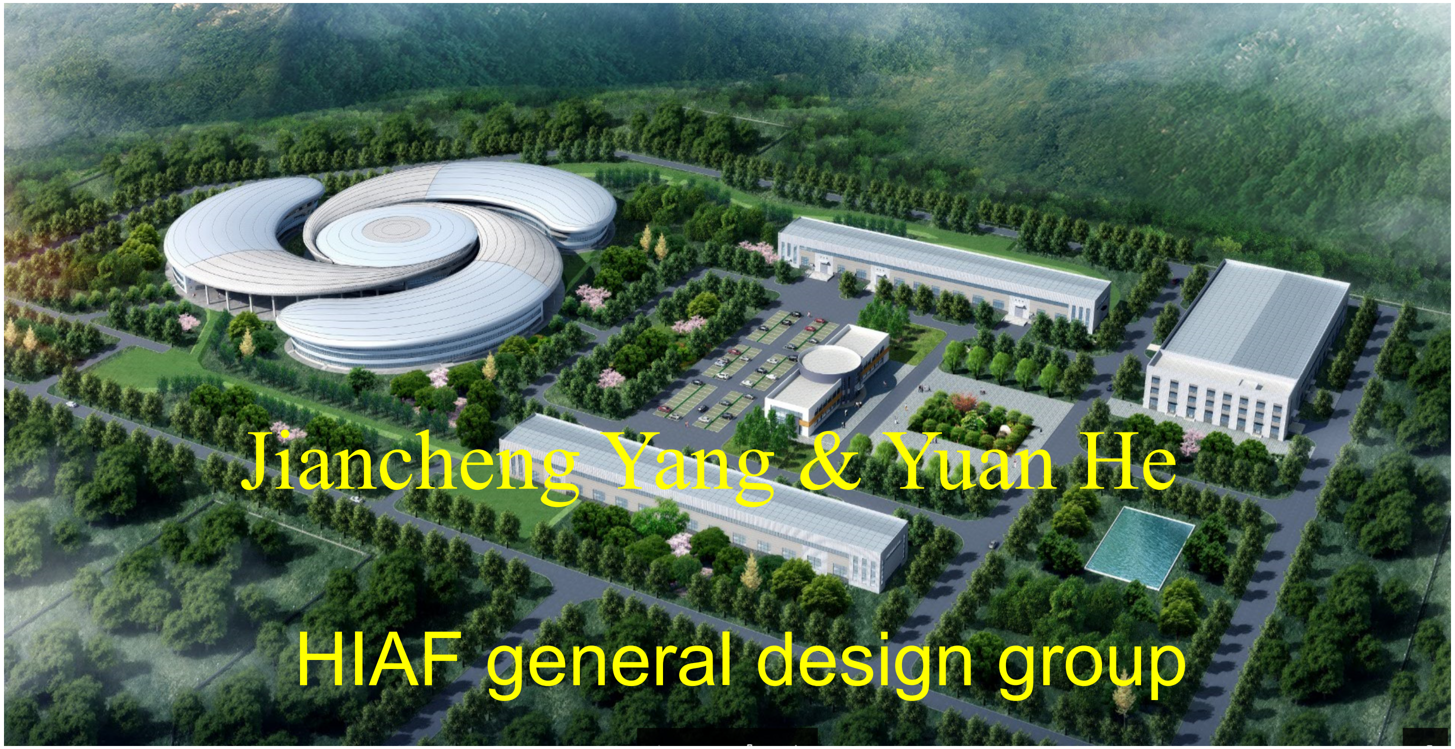
Progress and new developments of accelerator

High-Intensity Heavy Ion Accelerator Facility-HIAF



Jiancheng Yang & Yuan He

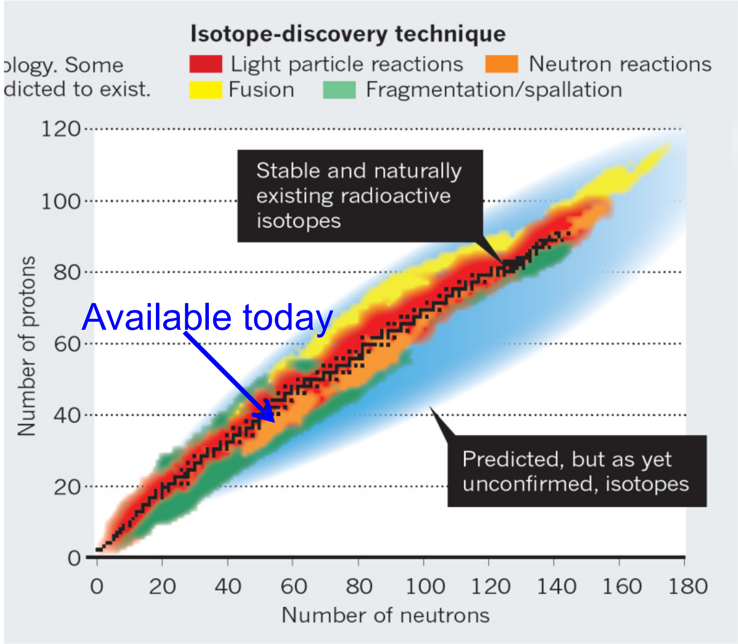
HIAF general design group

Outline

1. Background and science motivations
2. General description of project
3. Design concept and unique features
4. Innovative technologies and developments
5. Summary

HIAF: background and motivation

Next-generation high intensity facilities are required for advances in nuclear physics and related research fields:



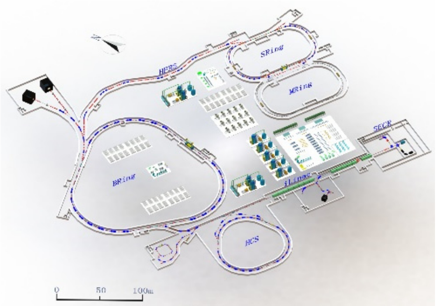
Fascinating and crucial questions

- To explore the limit of nuclear existence
- To study exotic nuclear structure
- Understand the origin of the elements
- To study the properties of High Energy and Density Matter

……

Next-generation facilities being constructed or proposed worldwide:

- SPIRAL2 at GANIL in Caen, France
- FAIR at GSI in Darmstadt, Germany
- FRIB at MSU in the U.S.
- NICA at JINR, Dubna, Russia
- EURISOL in Europe



High Intensity Heavy-ion Accelerator Facility

HIAF in China

HIAF: background and motivation

HIAF: One of 16 large-scale research facilities proposed in China in order to boost basic science, next-generation high intensity facility for advances in nuclear physics and related research fields.

The HIAF project:

- Proposed by IMP in 2009.
- Approved in principle by the central government in the end of the 2012.
- The final approval was in the December of 2015
- **Final preparation for starting of construction are under way and will start in coming few months**

Science motivations:

※ High intensity radioactive beams to investigate the structure of exotic nuclei, nuclear reactions of astrophysics and to measure the mass of nuclei with high precision.

※ High charge state ions for a series of atomic physics programs.

※ Quasi-continuous beam with wide energy range for applied science.

※ High energy and intensity ultra-short bunched ion beams for high energy and density matter research.

※ Spontaneous electron–positron pair production

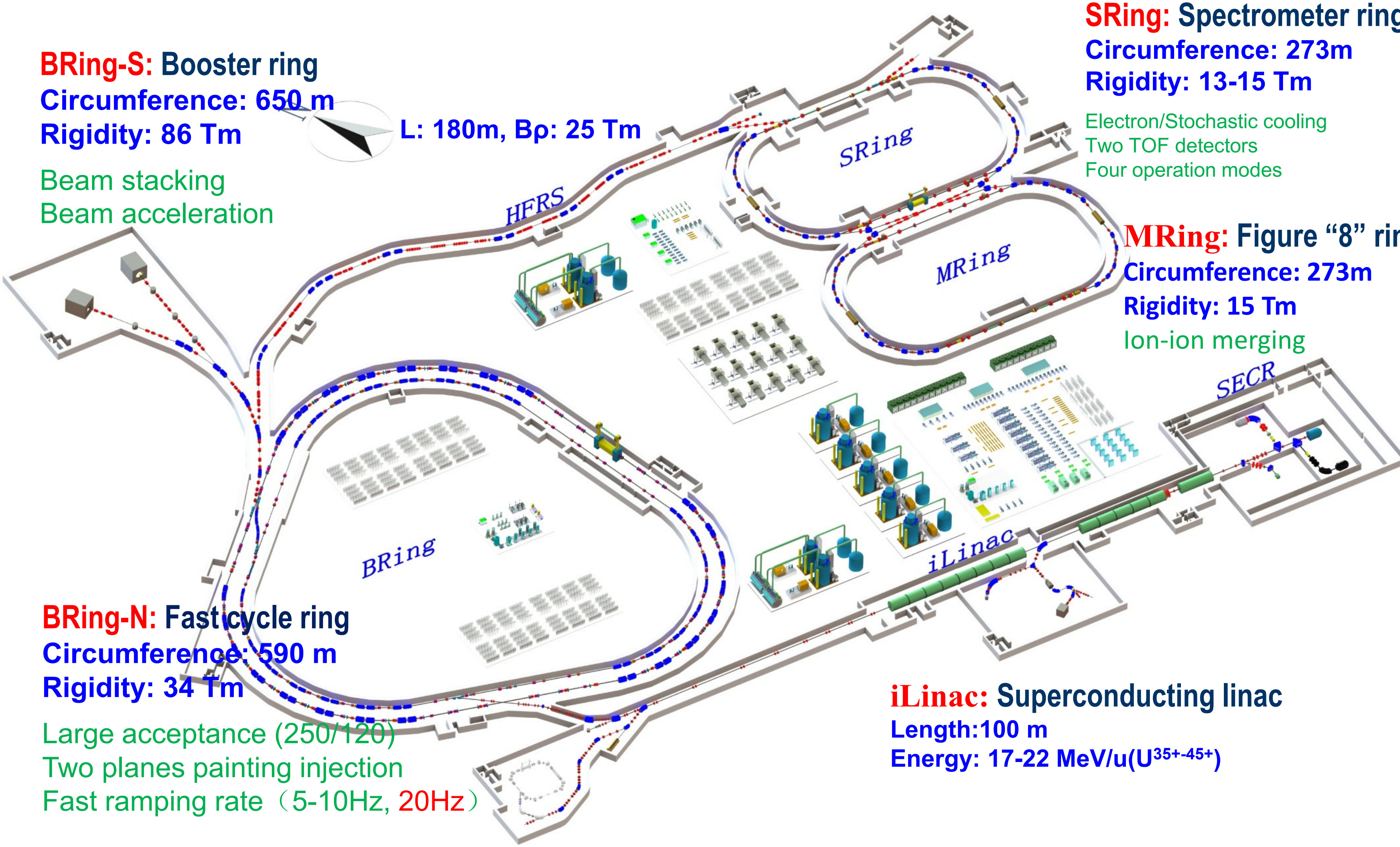
Main accelerator components

BRing-S: Booster ring
Circumference: 650 m
Rigidity: 86 Tm
Beam stacking
Beam acceleration

L: 180m, Bρ: 25 Tm

SRing: Spectrometer ring
Circumference: 273m
Rigidity: 13-15 Tm
Electron/Stochastic cooling
Two TOF detectors
Four operation modes

MRing: Figure "8" ring
Circumference: 273m
Rigidity: 15 Tm
Ion-ion merging



BRing-N: Fast cycle ring
Circumference: 590 m
Rigidity: 34 Tm
Large acceptance (250/120)
Two planes painting injection
Fast ramping rate（5-10Hz, 20Hz）

iLinac: Superconducting linac
Length:100 m
Energy: 17-22 MeV/u($U^{35+-45+}$)

These tunnels will be built in a cut and cover method and will be filled with 5 m overlay of soil. This conforms to the requirements of radiation safety.

Facility for world class experiments

Unprecedented parameters and unique features:

Highest beam Intensity （Comparison with HIRFL）：

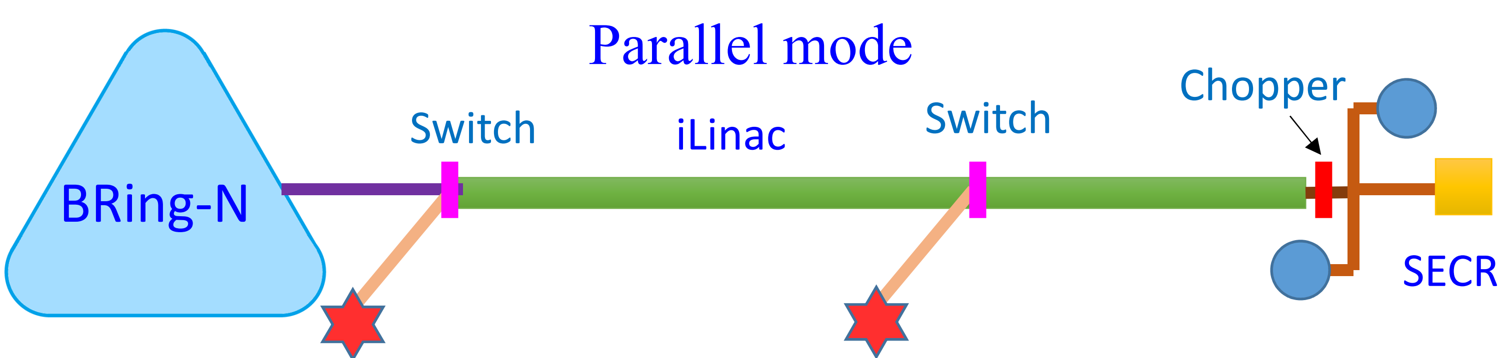
- **Primary beam intensity increases by x 1000 - x 10000**
- **Secondary beam intensity increases by up to x 10000**
- **Highest heavy ion beam intensity in the world**

Precisely-tailored beams - Precision frontiers

- **Beam cooling (**Electron, Stochastic, laser; high quality, very small spot **)**
- **Beam compression (**Ultra-short bunch length: 50-100ns**)**
- **Super long period slow extraction (**Super long, high energy, quasi-continuous beam **)**

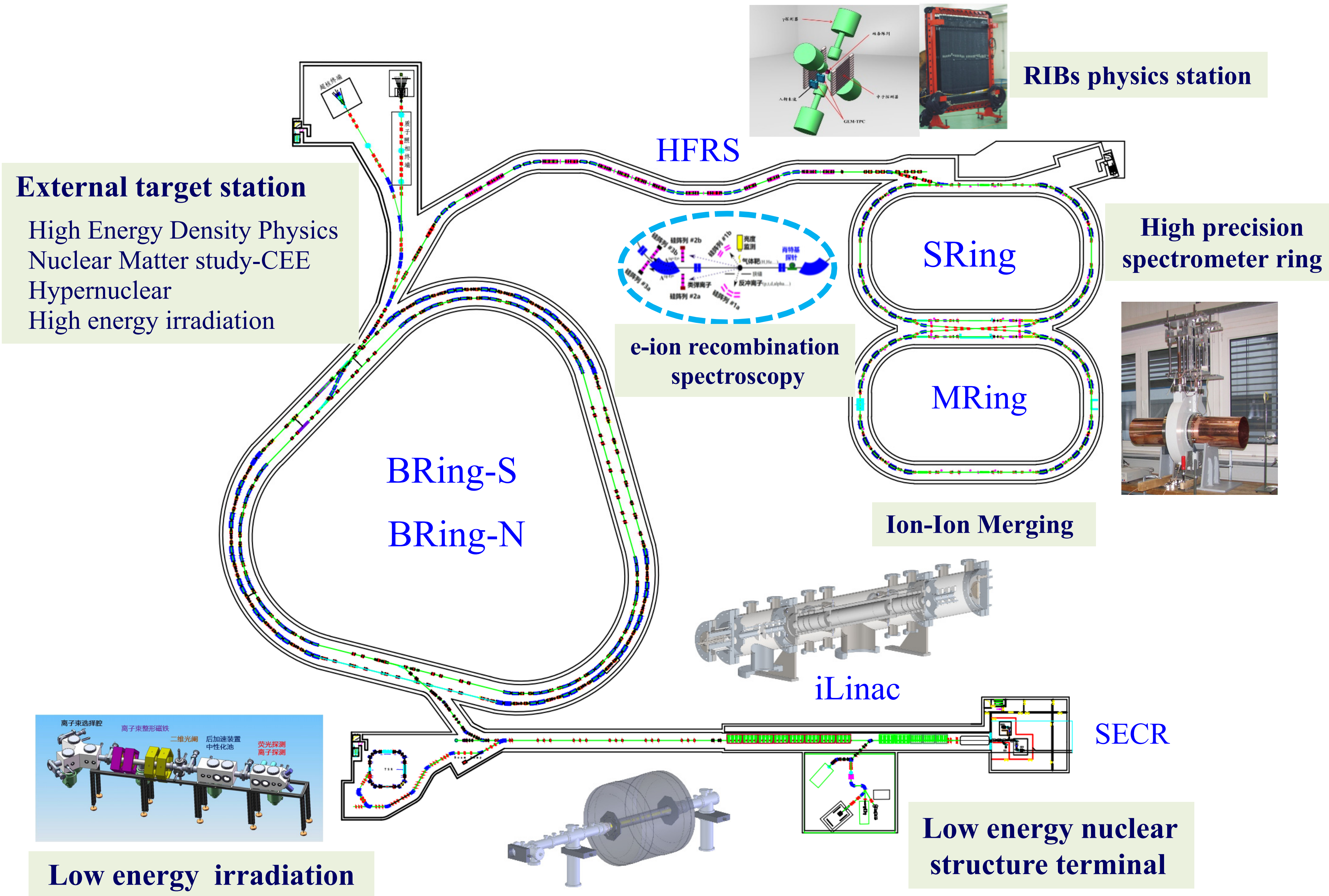
Versatile operation modes:

- **Parallel operation, beam splitting (** increase of target time, high integrated luminosity)



Experiment terminals

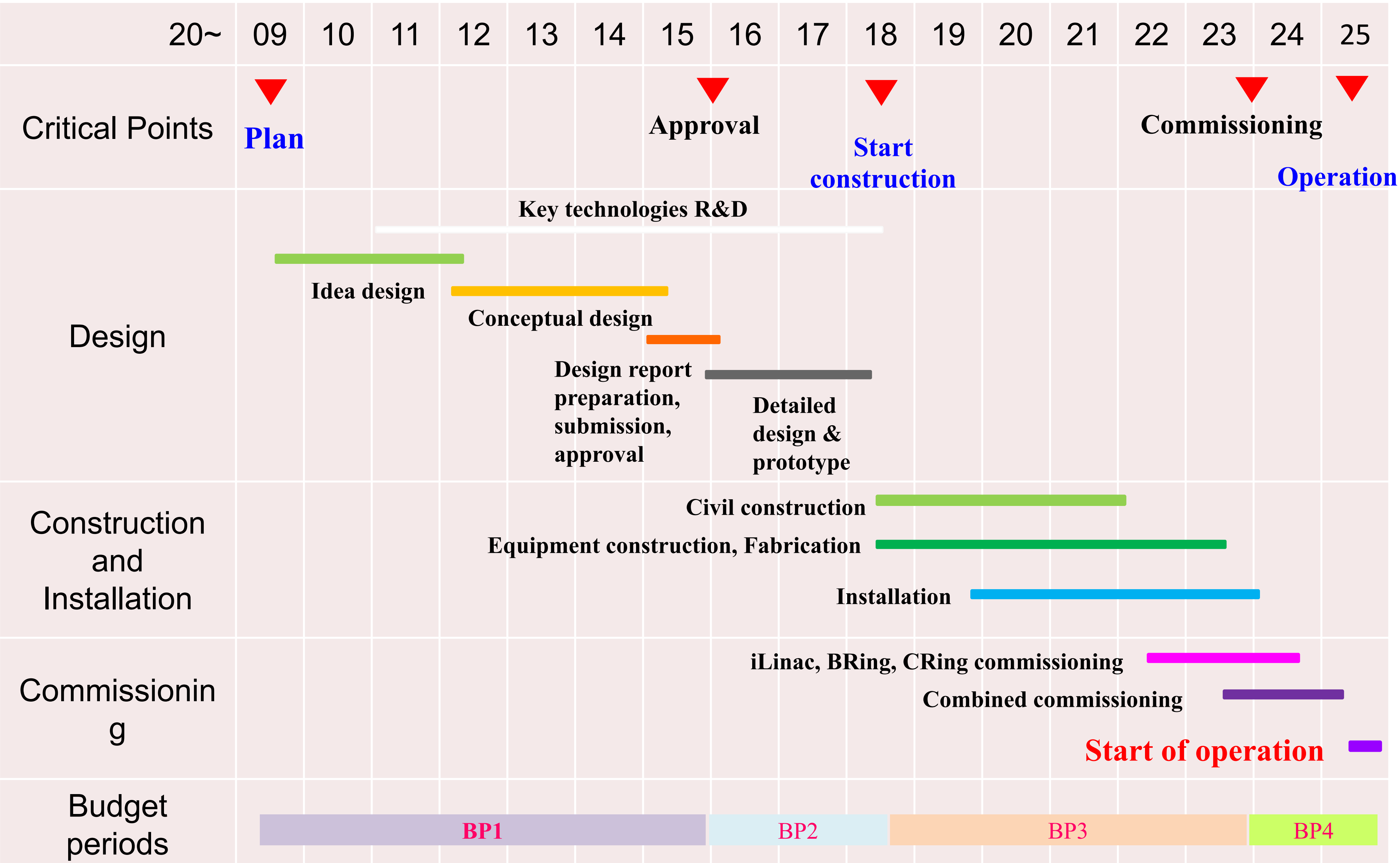
HIAF



Budget

Items	1st phase (MRMB)
iLinac	360
BRing	350
Beam transfer line	50
Experiment setups	240
Cryogenics	80
Civil engineering	190
Tunnel construction	160
Contingency cost	100
Total of facility	1530 (central government)
Infrastructure & common systems	1000 (local government)
Total	2530

Schedule



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Critical Points
Plan
Approval
Start construction
Commissioning
Operation
Design
Key technologies R&D
Idea design
Conceptual design
Design report preparation, submission, approval
Detailed design & prototype
Construction and Installation
Civil construction
Equipment construction, Fabrication
Installation
Commissioning
iLinac, BRing, CRing commissioning
Combined commissioning
Start of operation
Budget periods
BP1
BP2
BP3
BP4

New campus

HIAF site

惠州市
广州市
广汕铁路
广九铁路
佛山市
东莞市
惠州机场
京港澳高速
环大亚湾新区
惠东站
惠州南站
惠州港
汕尾市
江门市
中山市
深圳市
香港
珠海市
澳门
HIAF site

十里银滩
"十二五"装置
惠州核电优选
HIAF
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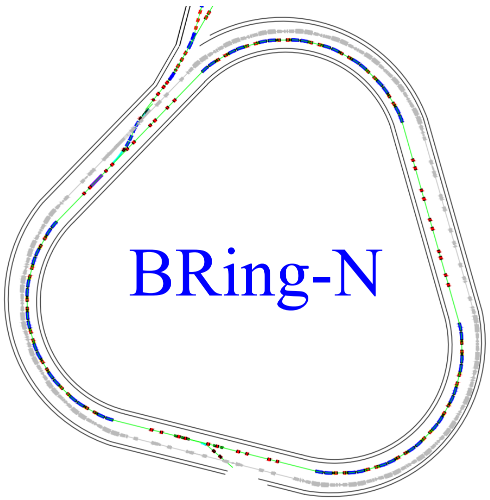
9.71 公里
Google earth

Design concept and unique features

- Unprecedented heavy ion beam intensity
- Multi-function storage ring
- Figure-8 shape ion-ion merging ring

Unprecedented heavy ion beam intensity

Concepts for approaching the highest heavy ion intensity

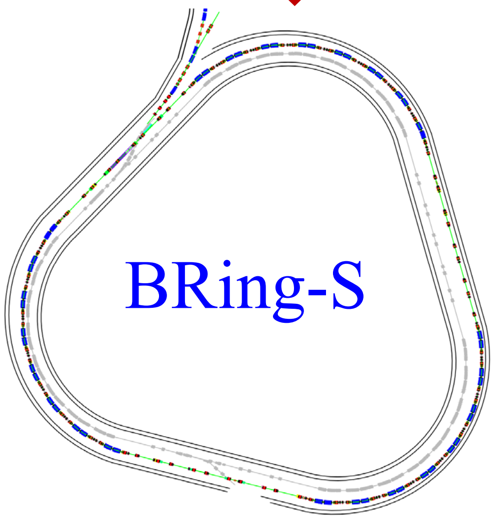


BRing-N

Novel two planes painting injection scheme - 2.0×10^{11} ppp

Fast ramping rate operation mode- 3-5 Hz

Barrier bucket stacking longitudinal



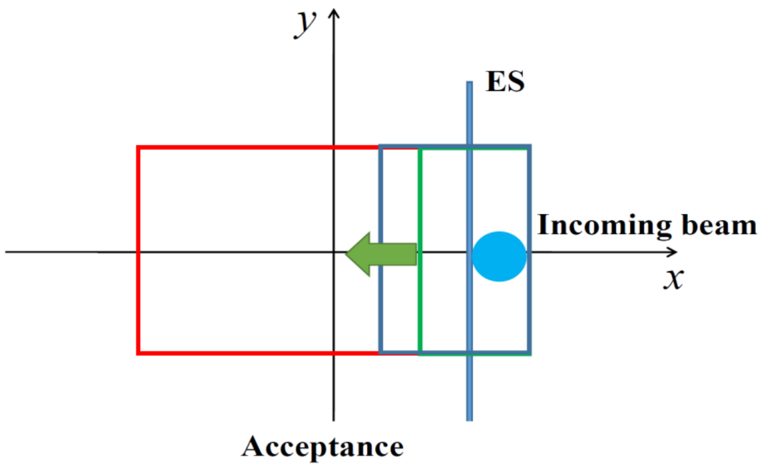
BRing-S

Innovative timing system of RF synchronization

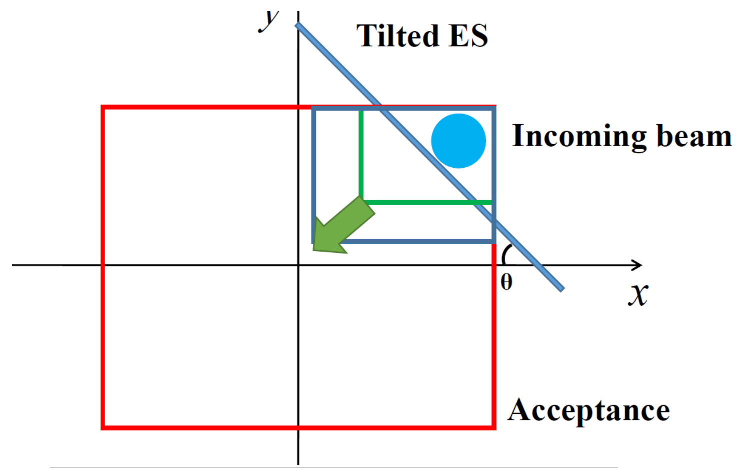
5 times increase of intensity

1.0×10^{12} ppp

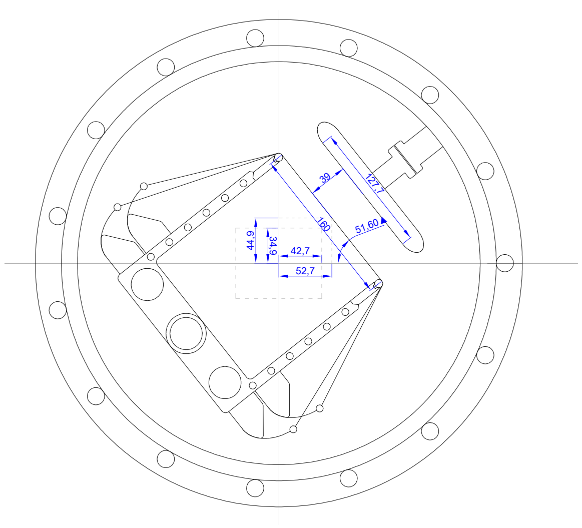
Two planes painting injection

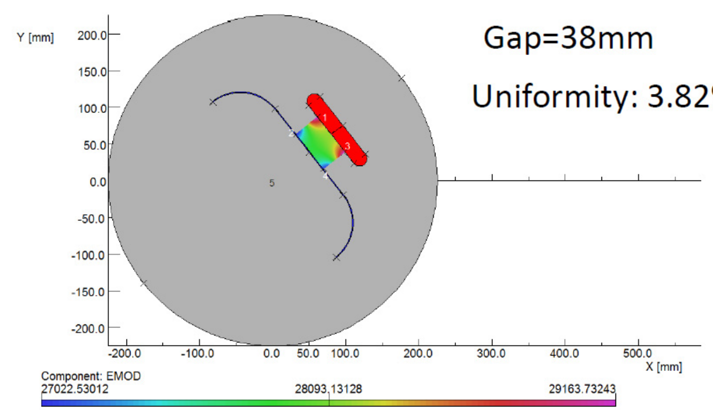


Conventional multi-turn injection



Two-plane painting multiturninjection





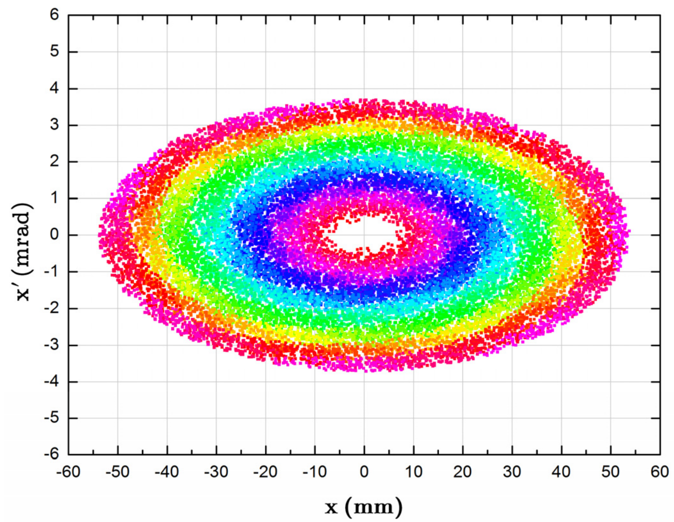
Gap=38mm

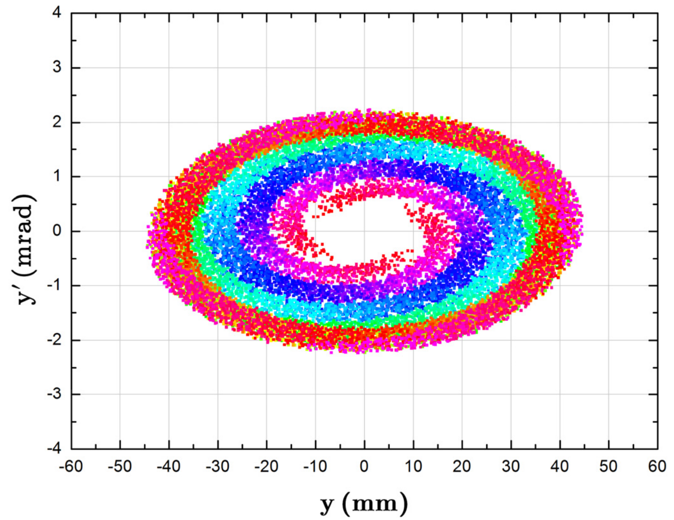
Uniformity: 3.82%

Simultaneous injection in H and V planes using **tilted septum**

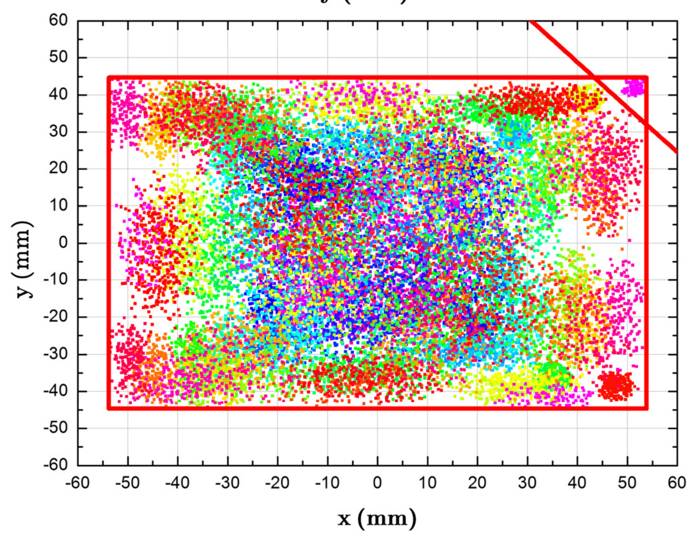
Unprecedented heavy ion beam intensity

Simulation results





Ions	Plane	Injection turns	Single injection
$^{238}U^{35+}$	H	33	3.3×10^{10}
	V	16	1.6×10^{10}
	H+V	**150**	$\mathbf{2.0\times10^{11}}$



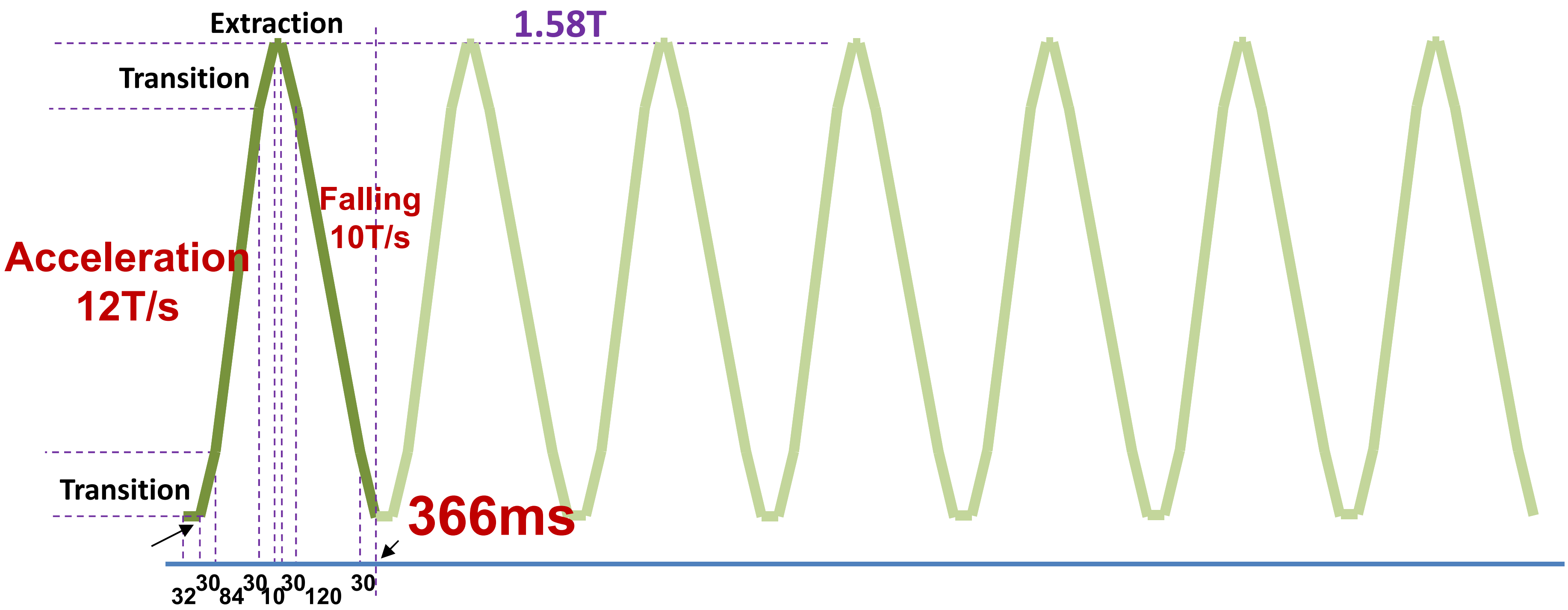
Conclusions:

- The beam intensity could reach 2.0×10^{11} with two planes painting, nearly 10 times over the conventional single-plane injection.

Fast ramping rate mode of BRing-N

Why？

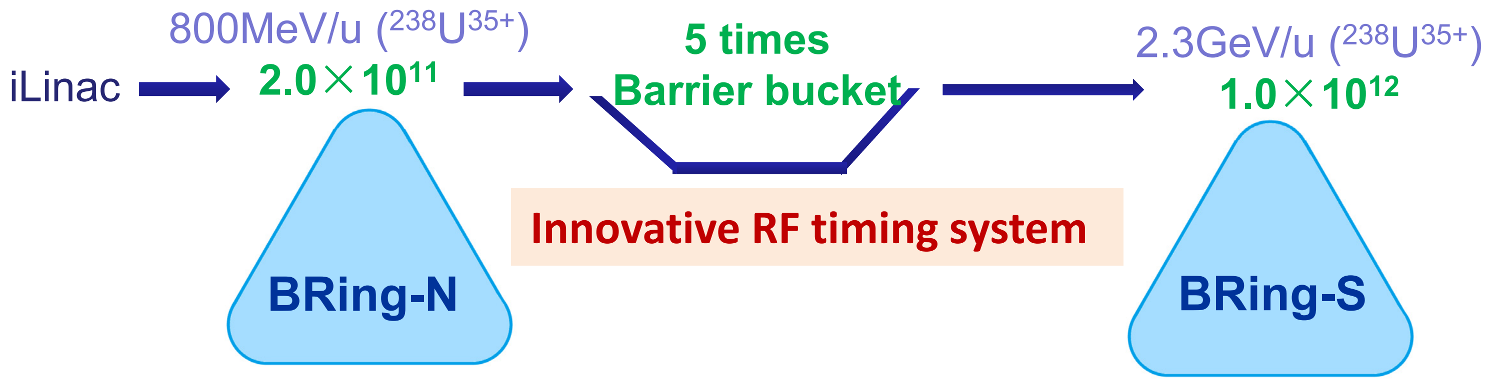
Due to **space charge** and **dynamic vacuum** effect, beam should be launched to the high energy as soon as possible.



Repetition rate：3-5 Hz, 5-10Hz

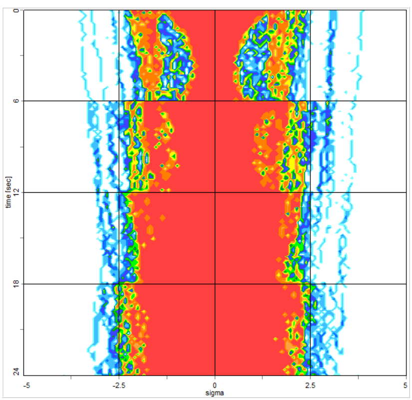
Unprecedented heavy ion beam intensity

Barrier bucket stacking

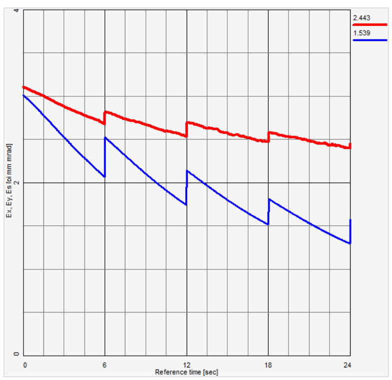


Challenges:

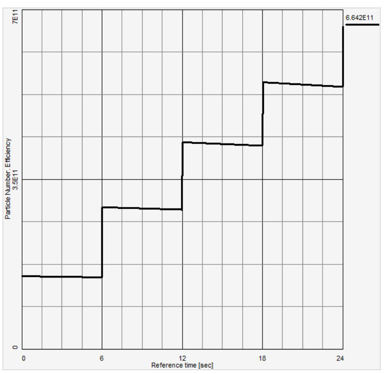
- Fast e-cooling for high energy heavy ion
- High intensity effect of barrier bucket stacking



Momentum spread



Emittance



Intensity

5 times increase of beam intensity through barrier bucket

Unprecedented heavy ion beam intensity

HIAF

Basic beam parameters

	Ions	Energy	Intensity
SECR	$^{238}U^{35+}$	14 keV/u	0.05-0.1 pmA
iLinac	$^{238}U^{35+}$	17 MeV/u	0.028-0.05 pmA
BRing-N	$^{238}U^{35+}$	0.8 GeV/u	~2.0×10^{11} ppp
BRing-S	$^{238}U^{35+}$	2.3 GeV/u	~1.0×10^{12} ppp
	$^{238}U^{76+}$	5.8 GeV/u	~5.0×10^{11} ppp
	$^{238}U^{92+}$	7.3 GeV/u	~5.0×10^{11} ppp
SRing	RIBs: neutron-rich, proton-rich	0.84 GeV/u(A/q=3)	~10^{9-10} ppp
	Fully stripped heavy ions H-like, He-like heavy ions	0.8 GeV/u($^{238}U^{92+}$)	~10^{11-12} ppp

Unprecedented heavy ion beam intensity

The highest pulse heavy ion beam intensity in the world

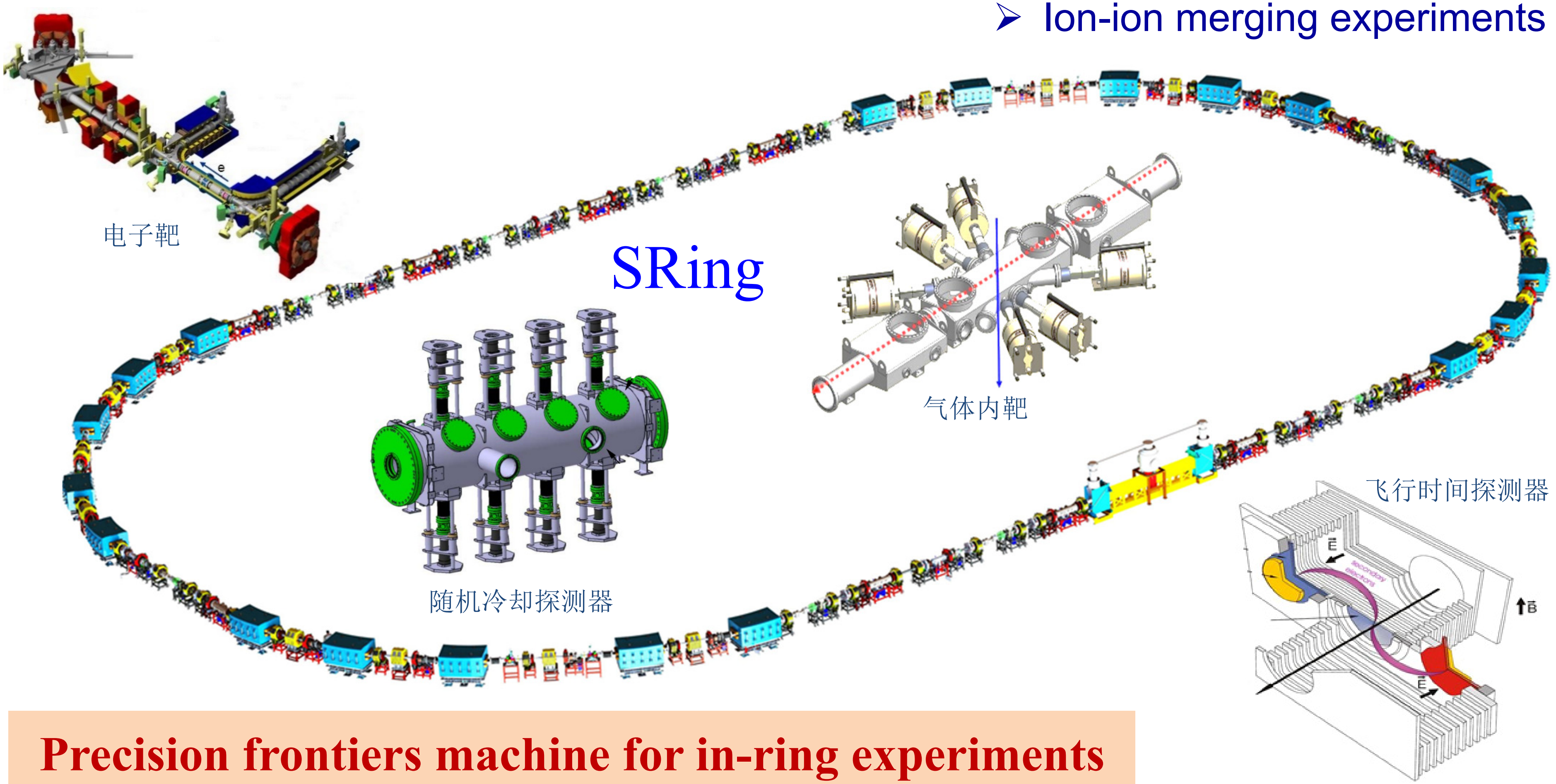
Institute	Machine	Planned Intensity	Achieved Intensity	Ion species	Repetition rate
BNL	AGS Booster		5×10^{9}	Au^{32+}	
CERN	LEIR		9×10^{8}	Pb^{54+}	
JINR	NICA Booster	4×10^{9}		Au^{32+}	
GSI	SIS18	1.0×10^{11}	3×10^{10}	U^{28+}	2.7Hz
FAIR	SIS100	4.0×10^{11}		U^{28+}	
IMP	HIAF-BRing-N	2.0×10^{11}		U^{35+}	5-10Hz, 10-20Hz
IMP	HIAF-BRing-S	1.0×10^{12} 2.0×10^{12}		U^{35+}	

Multi-function storage ring

Key devices
- Electron cooling
- Stochastic cooling
- Two TOF detectors
- Electron target

Operation modes
- Isochronous mode
- Normal Mode
- Internal-target Mode
- Ion-ion merging Mode

Experiment programs
- Gas-jet target experiments
- DR experiments
- IMS & SMS
- Laser cooling
- Ion-ion merging experiments

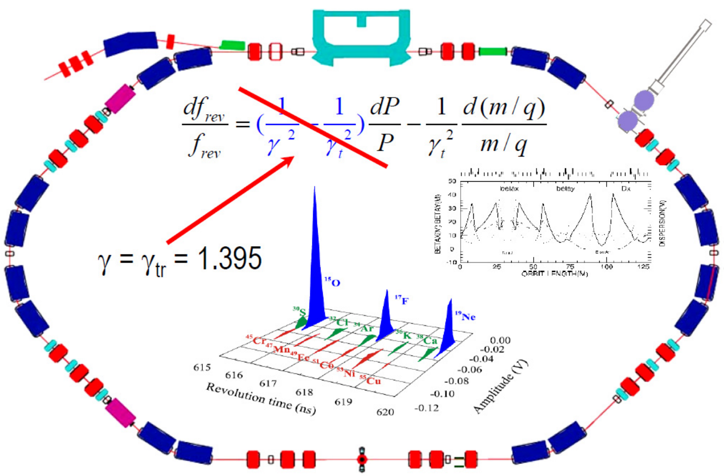


Precision frontiers machine for in-ring experiments

Multi-function storage ring

Isochronous mode with two TOF

HIRFL-CSRe



Beams: ^{58}Ni, ^{78}Kr, ^{86}Kr and ^{112}Sn

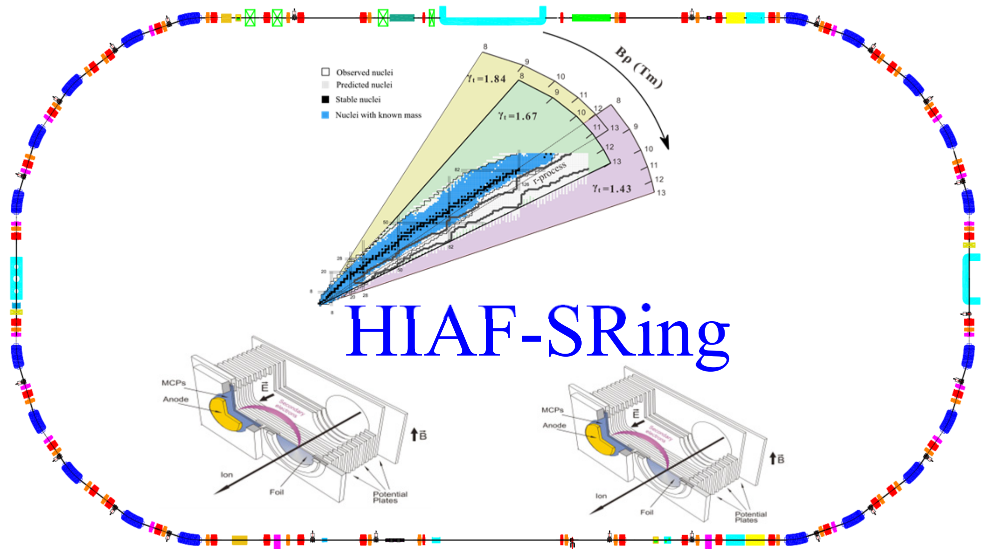
43 masses are measured

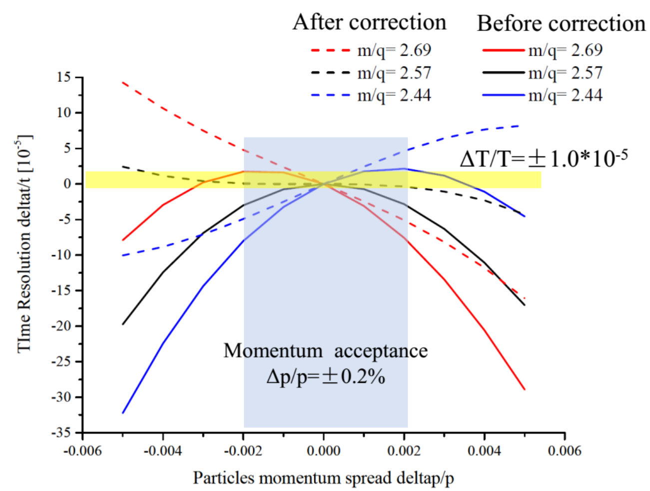
Measured for the first time: 16

Precision improved: 27

Precision achieved: $\Delta M/M \sim 10^{-7}$

Demonstrated the TOF mode first time in the world

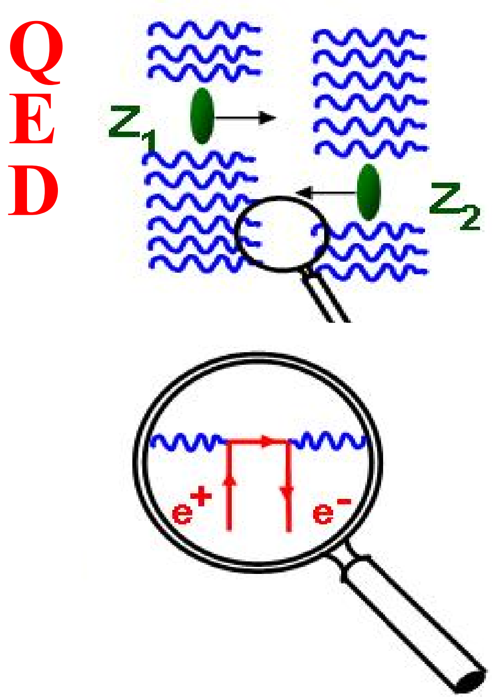


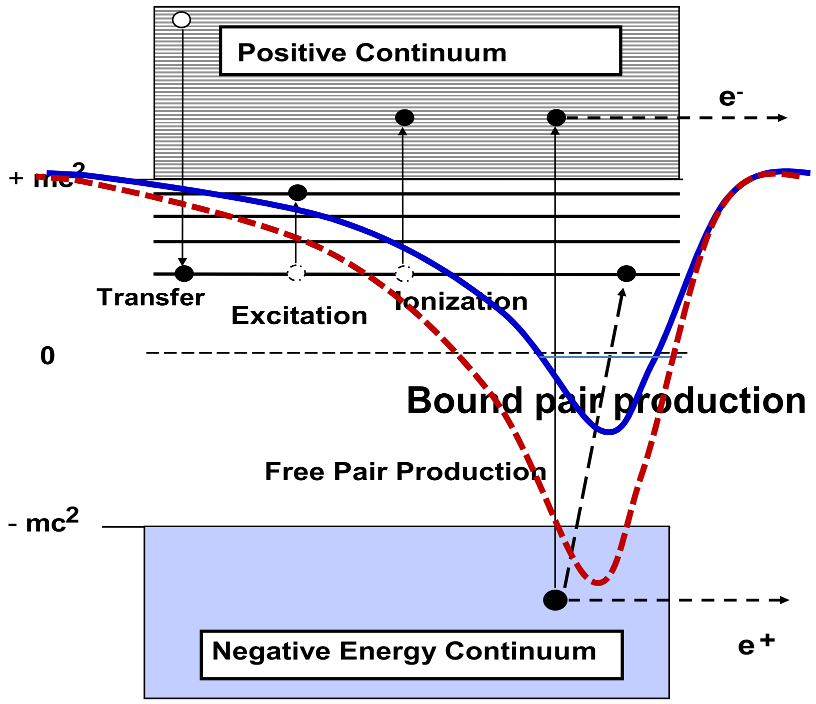


$\Delta M/M \sim 10^{-7}-10^{-8}$

Figure-8 shape ring for ion-merging

Spontaneous electron–positron pair production





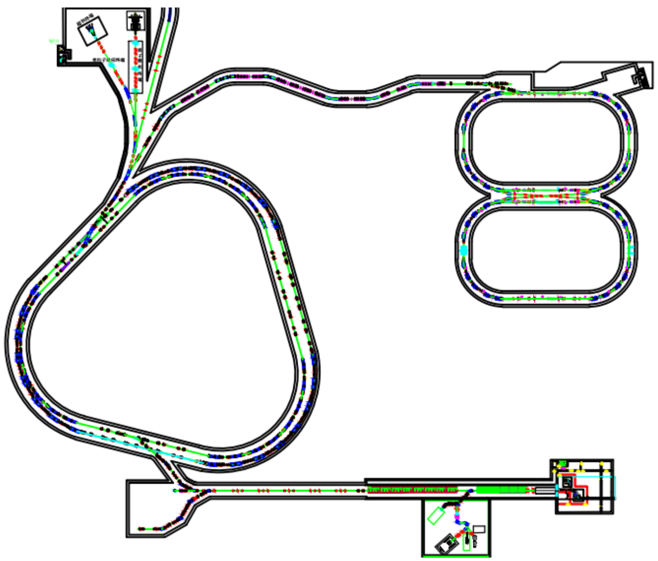
- A fundamental question of QED-spontaneous electron-positron pair creation in supercritical Coulomb fields
- Theory prediction: occur in the collisions of two very heavy ions with the total atomic number $Z1 + Z2 \geq 173$.
- Failed to observe in fixed target experiments due to the interference of extranuclear electrons.

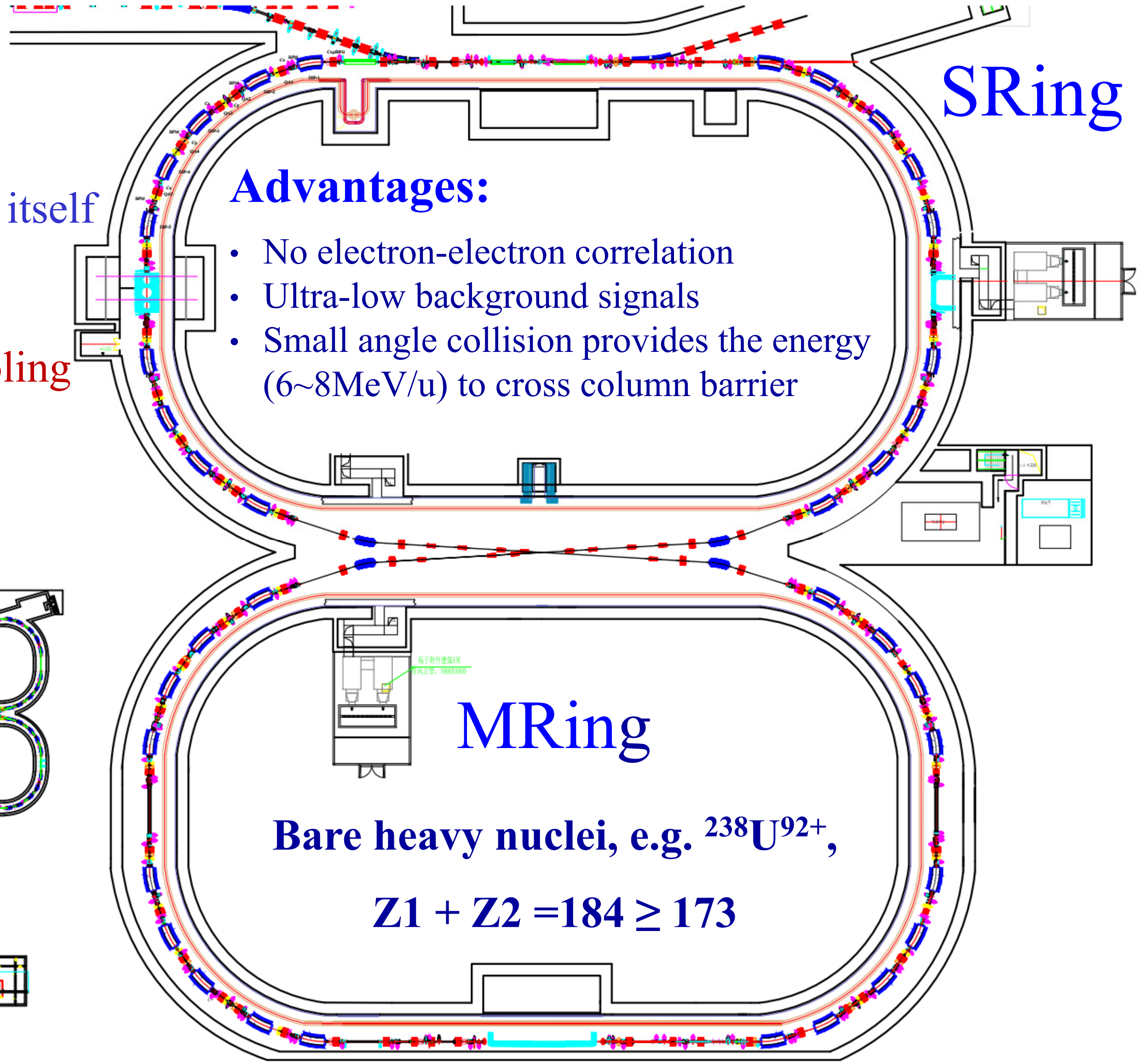
Figure-8 shape ring for ion-merging

First ion-ion merging facility in the world

Unique features:

- “8” shape ring
- Coasting beam merging with itself scheme
- Based on SRing
- Sharing the injection and cooling system
- No powerful RF system





Advantages:

- No electron-electron correlation
- Ultra-low background signals
- Small angle collision provides the energy (6~8MeV/u) to cross column barrier

Bare heavy nuclei, e.g. $^{238}U^{92+}$,

$Z1 + Z2 = 184 \geq 173$

Figure-8 shape ring for ion-merging

HIAF

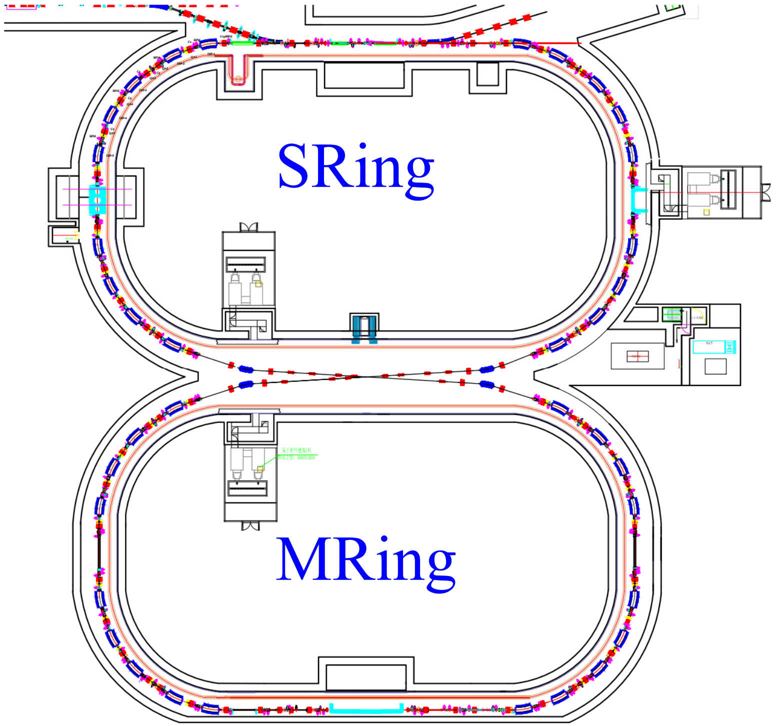
Merging beam parameters - First phase

Parameter	Value
Ion	$^{238}U^{92+}$
Energy(MeV/u)	637(800)
Circumference(m)	483.8
Frequency(MHz)	0.50(0.52)
Crossing angle(◦)	6.8
CM energy(MeV/u)	6(8)
Particle number	**7(8)$\times 10^{10}$**
$\varepsilon_{x,rms}/\varepsilon_{y,rms}$ (π mm mrad)	1/1
β^*_x/β^*_y(m)	1/0.03
$\sigma_{x,rms}/\sigma_{y,rms}$ (mm)	1/0.173
Laslett tune shift	-0.1(-0.077)
Hourglass factor	0.9
Luminosity($cm^{-2}s^{-1}$)	**4.4(5.4) $\times 10^{23}$**

Figure-8 shape ring for ion-merging

Merging beam parameters – **Update- 1000 times**

Parameter	Value
Ion	$^{238}U^{92+}$
Energy(MeV/u)	4300
Circumference(m)	472.7
Frequency(MHz)	0.624
Crossing angle(∘)	1.93
CM energy(MeV/u)	8
Particle number	**3×10^{12}**
$\varepsilon_{x,rms}/\varepsilon_{y,rms}$ (π mm mrad)	1/1
β^*_x/β^*_y(m)	0.1/0.02
$\sigma_{x,rms}/\sigma_{y,rms}$ (mm)	0.316/0.141
Laslett tune shift	-0.08
Hourglass factor	0.9
Luminosity($cm^{-2}s^{-1}$)	**4.1×10^{26}**



Update-1： SC magnet to 4T

Update-2： New interaction section with small cross angle