Status of HIAF project

(High-Intensity Heavy Ion Accelerator Facility)

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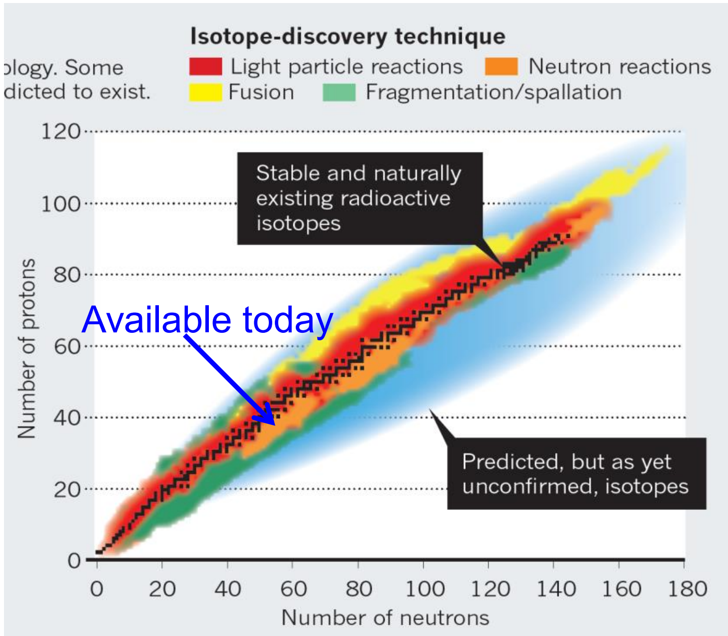
Outline

1. Background and motivations
2. General description
3. Dynamics challenges & studies
4. Technical challenges and R&D
5. Present status
6. Summary and perspective

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

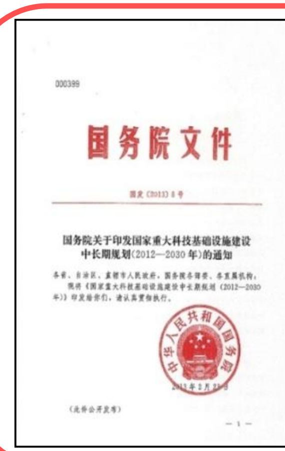
HIAF in China

HIAF: background and motivation

HIAF: One of 16 large-scale research facilities proposed in China in order to boost basic science, now under design optimization and technical R&D

The HIAF project:

- Proposed by IMP in 2009.
- Approved in principle by the central government in the end of the 2012.
- Design Report(v1.0) was published in July 2014



国务院文件

国务院关于印发国家重大科技基础设施建设中长期规划（2012—2030年）的通知

（一）海底科学观测网
（二）高能同步辐射光源验证装置
（三）加速器驱动嬗变研究装置
（四）综合极端条件实验装置
（五）强流重离子加速器
（六）高效低碳燃气轮机试验装置
（七）高海拔宇宙线观测站
（八）未来网络试验设施
（九）空间环境地面模拟装置
（十）转化医学研究设施
……

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 energy and intensity ultra-short bunch heavy ion beams for high energy and high density matter research.

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

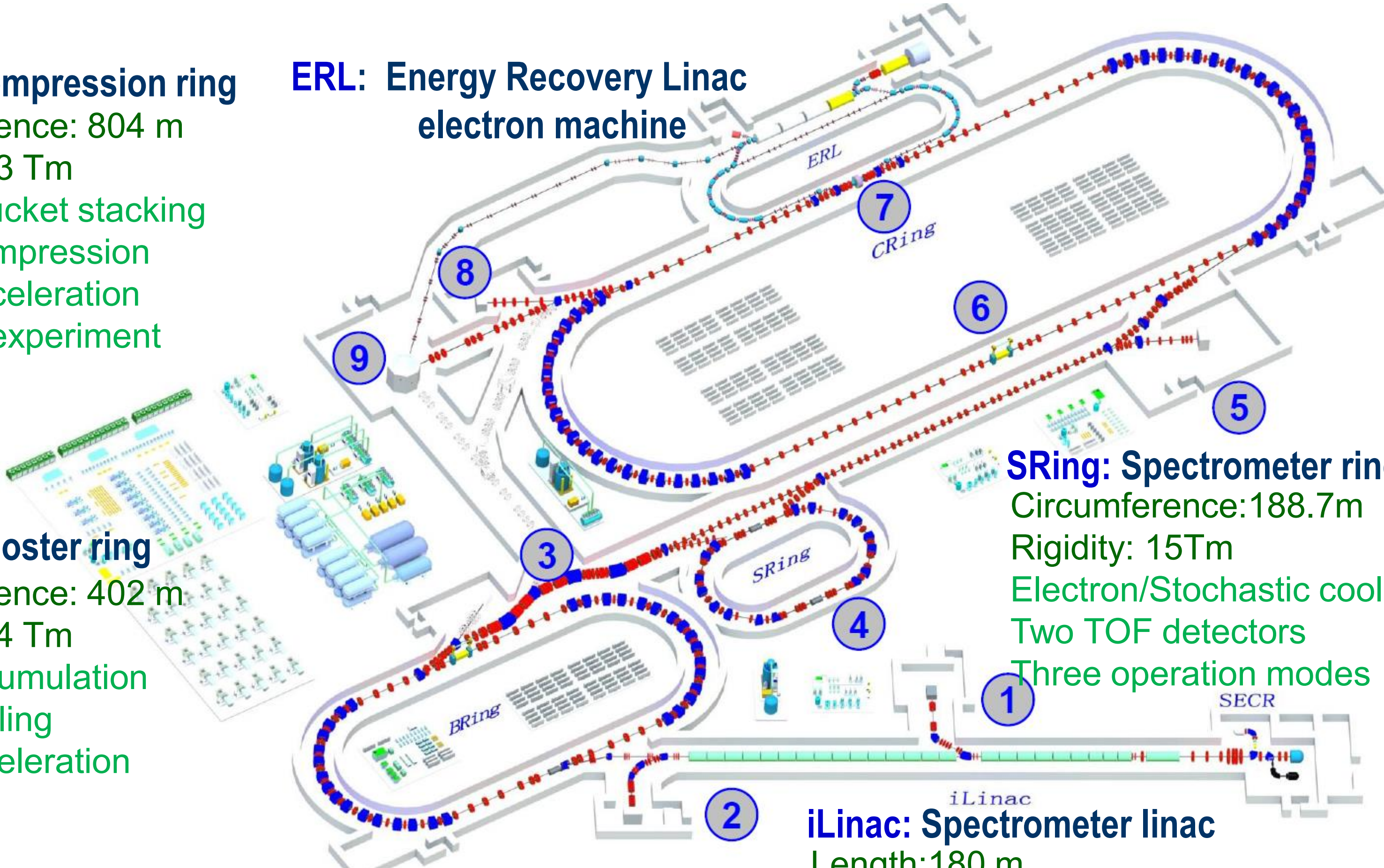
※ Quasi-continuous ion beam (slow extraction) with wide energy range for applied science.

HIAF: Multi-purpose facility

with unprecedented parameters

CRing: Compression ring
Circumference: 804 m
Rigidity: 43 Tm
- Barrier bucket stacking
- Beam compression
- Beam acceleration
- In-beam experiment

ERL: Energy Recovery Linac electron machine



BRing: Booster ring
Circumference: 402 m
Rigidity: 34 Tm
- Beam accumulation
- Beam cooling
- Beam acceleration

SRing: Spectrometer ring
Circumference:188.7m
Rigidity: 15Tm
- Electron/Stochastic cooling
- Two TOF detectors
- Three operation modes

iLinac: Spectrometer linac
Length:180 m
Energy: 25MeV/u(U^{34+})

1. Nuclear structure spectrometer
2. Low energy irradiation target
3. RIBs beam line
4. High precision spectrometer ring
5. External target station
6. Electron-ion recombination spectroscopy
7. Electron-Nucleus Collision (ENC)
8. High Energy Density Physics target
9. High energy irradiation target

HIAF: Multi-purpose facility

with unprecedented parameters

Advantages:

Unprecedented beam Intensity(Comparison with HIRFL):

- Primary beam intensity increases by x 1000 - x 10000
- secondary beam intensity increases by up to x 10000

Precisely-tailored beams

- 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*)

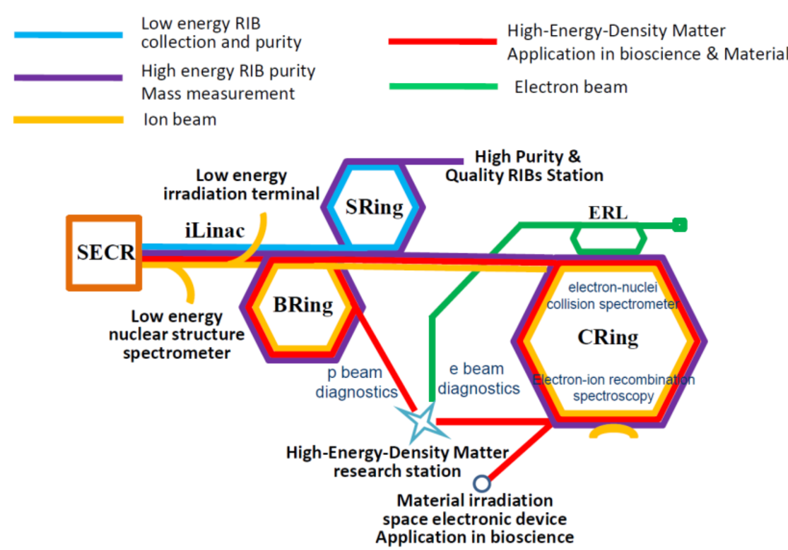
Wide beam Energy:

- heavy-ion energy : x 10 - x 15

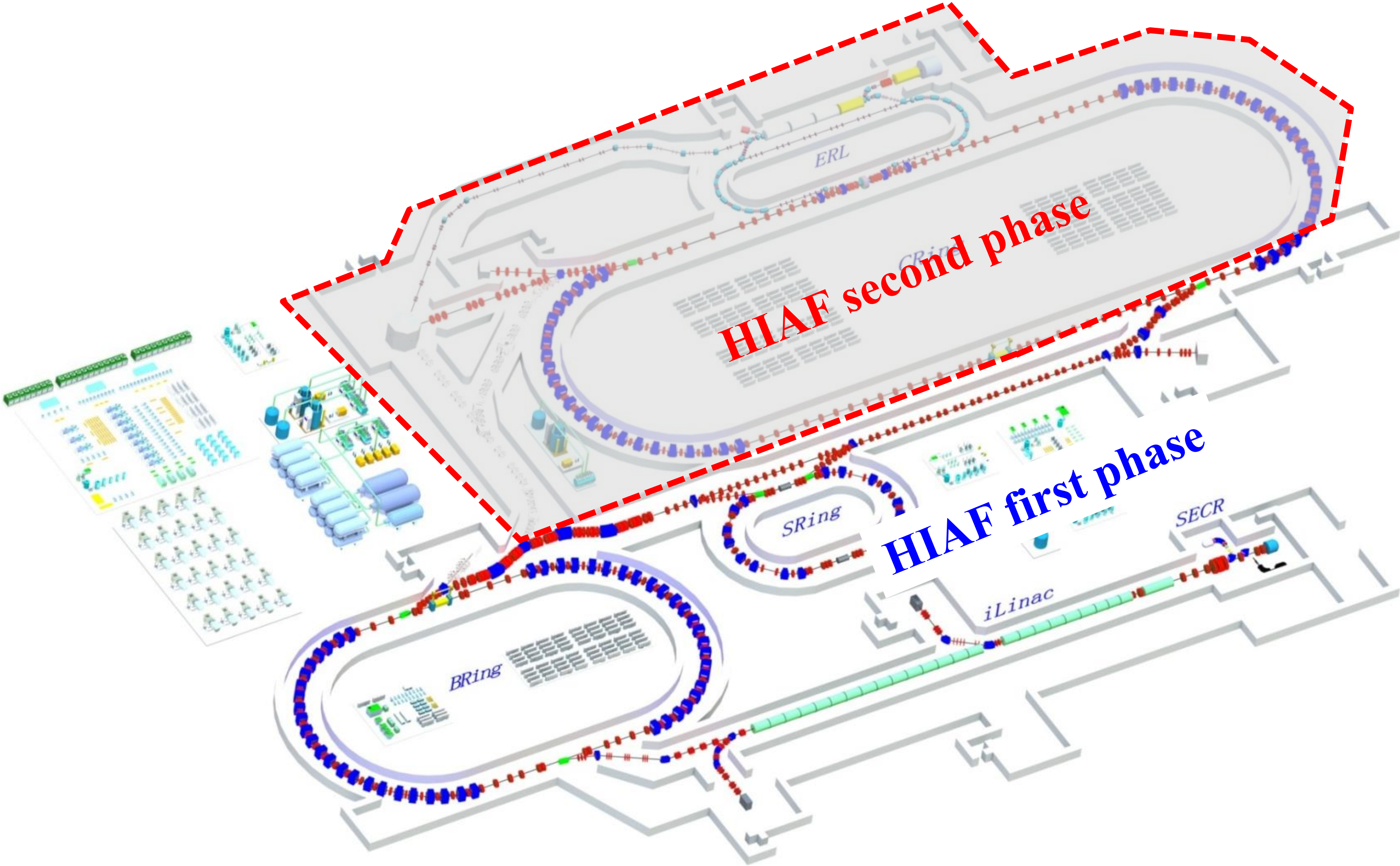
Versatile operation modes:

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

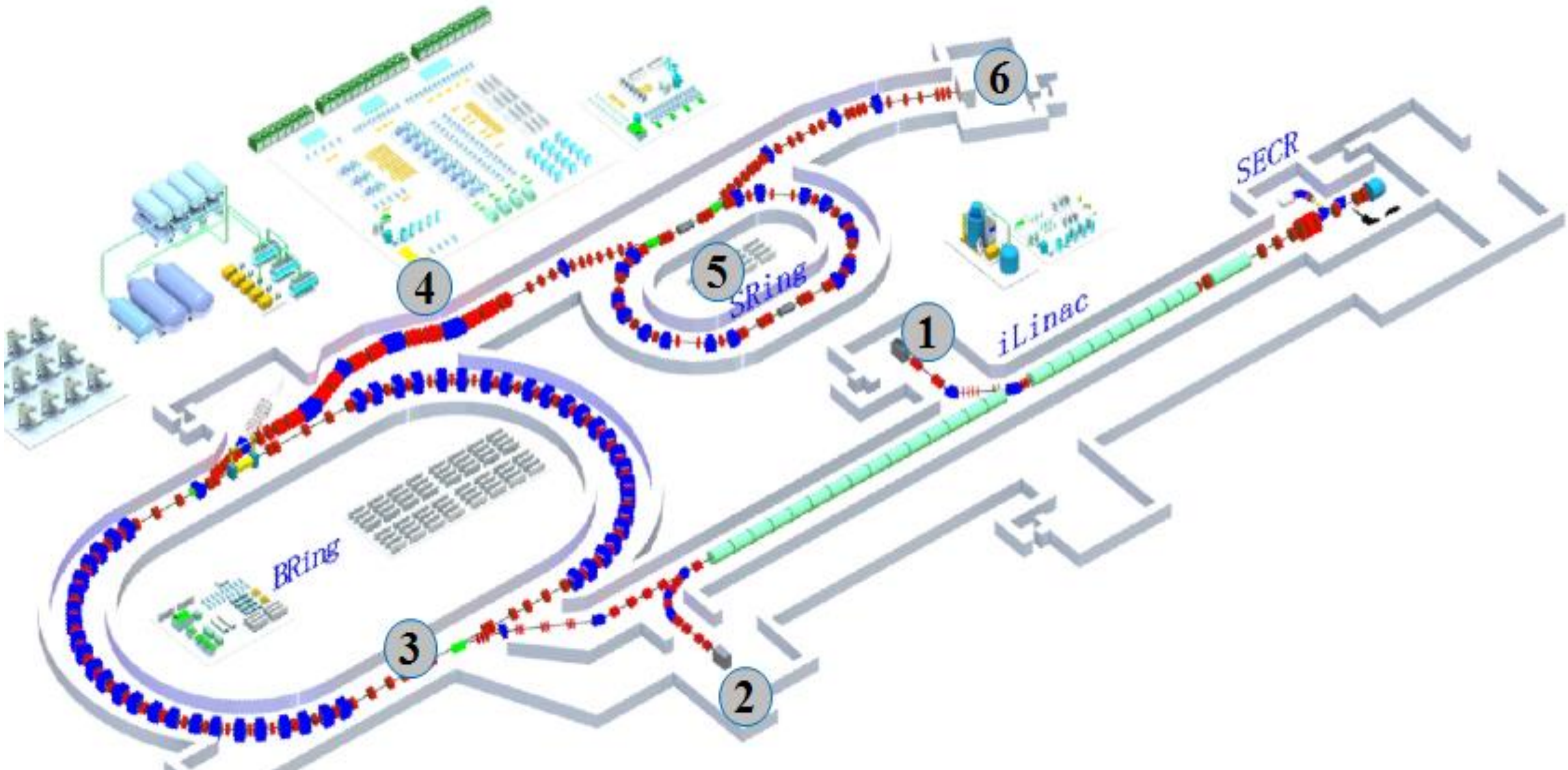
	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	25 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	~1.4×10^{11} ppp
CRing	U^{34+}	1.1 GeV/u	~5.0×10^{11} ppp
	U^{92+}	4.1 GeV/u	~2.0×10^{11} ppp



Two phase plan of HIAF



First phase of HIAF



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1. Nuclear structure spectrometer
2. Low energy irradiation target
3. Electron-ion recombination spectroscopy
4. RIBs beam line
5. High precision spectrometer ring
6. External target station

New version of HIAF first phase

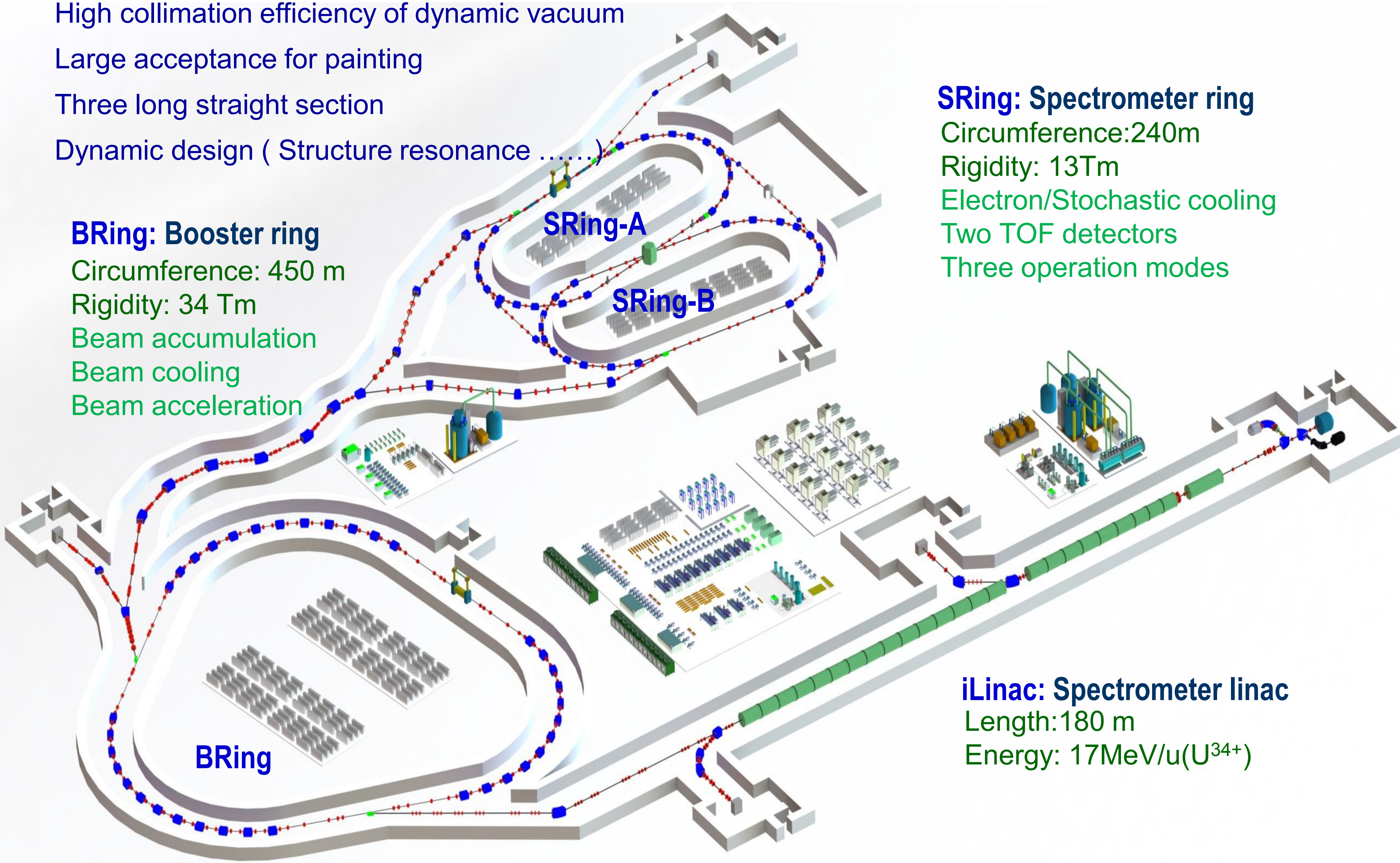
Advantages:

High collimation efficiency of dynamic vacuum

Large acceptance for painting

Three long straight section

Dynamic design (Structure resonance ……)



SRing new layout

Advantages:

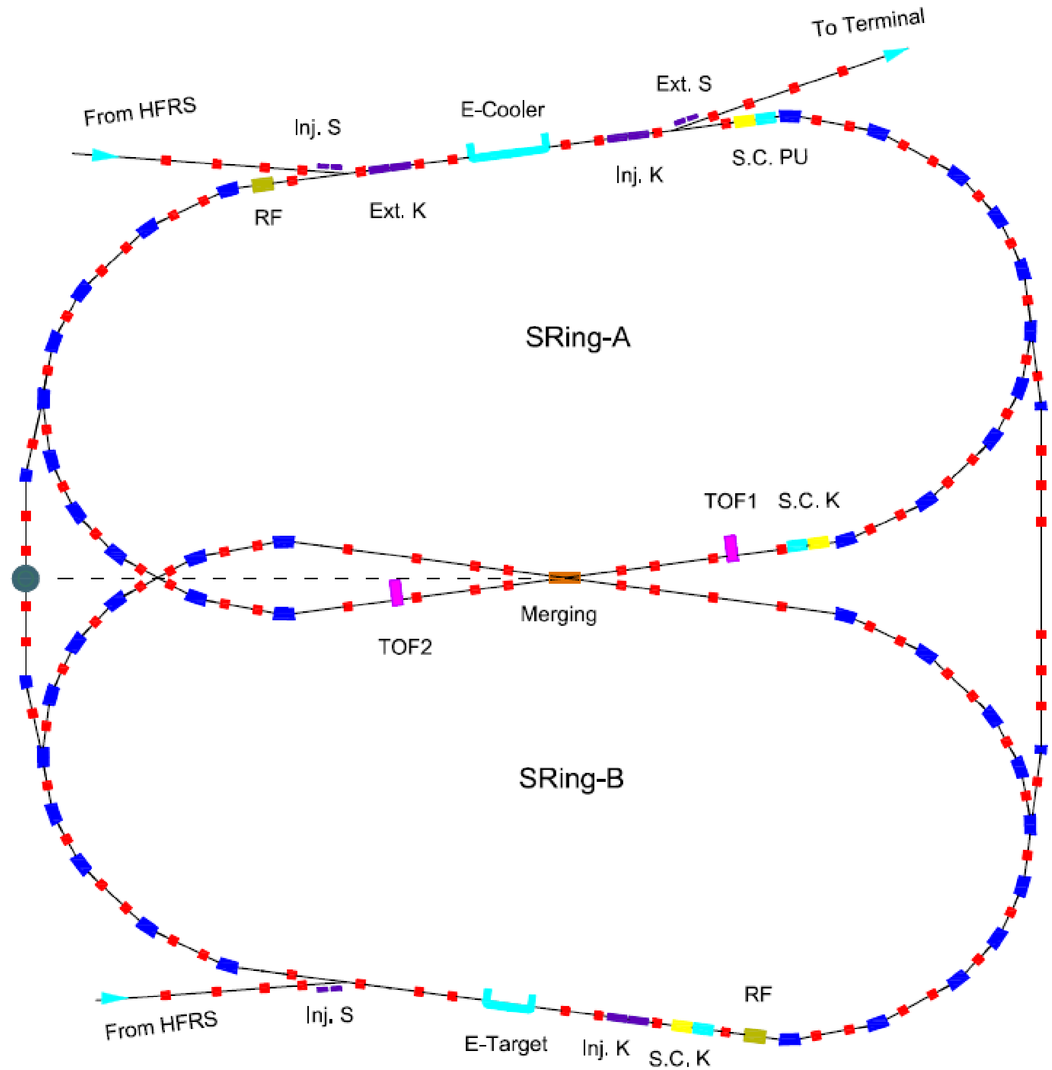
Two identical layout rings

Same type magnets, hardware system …

The simple cross merging scheme

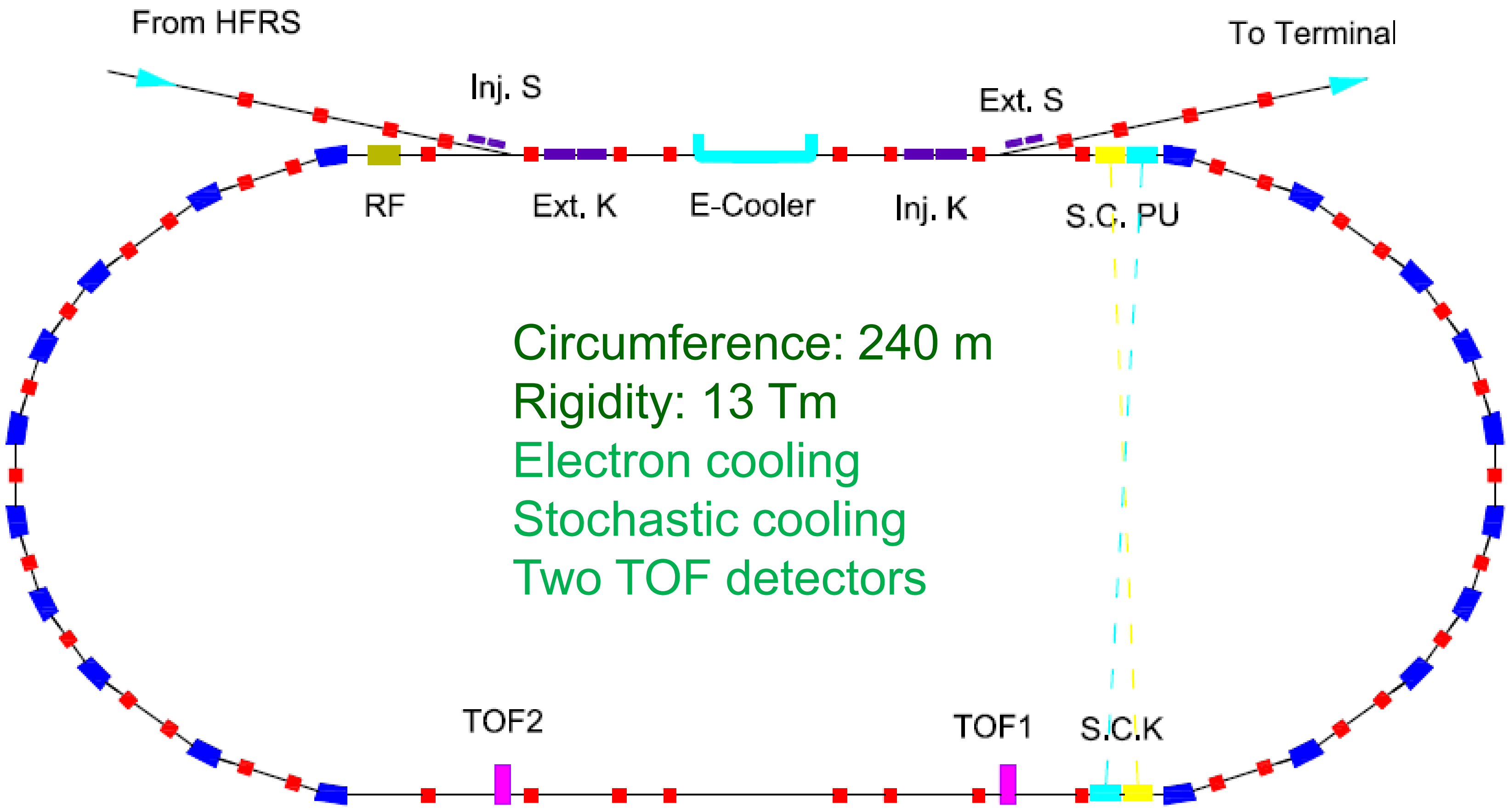
SRing-A is the same ring with Sring

In the case, the budget is not enough, we still can keep all the functions of SRing. This design maintain a well defined path for future upgrade



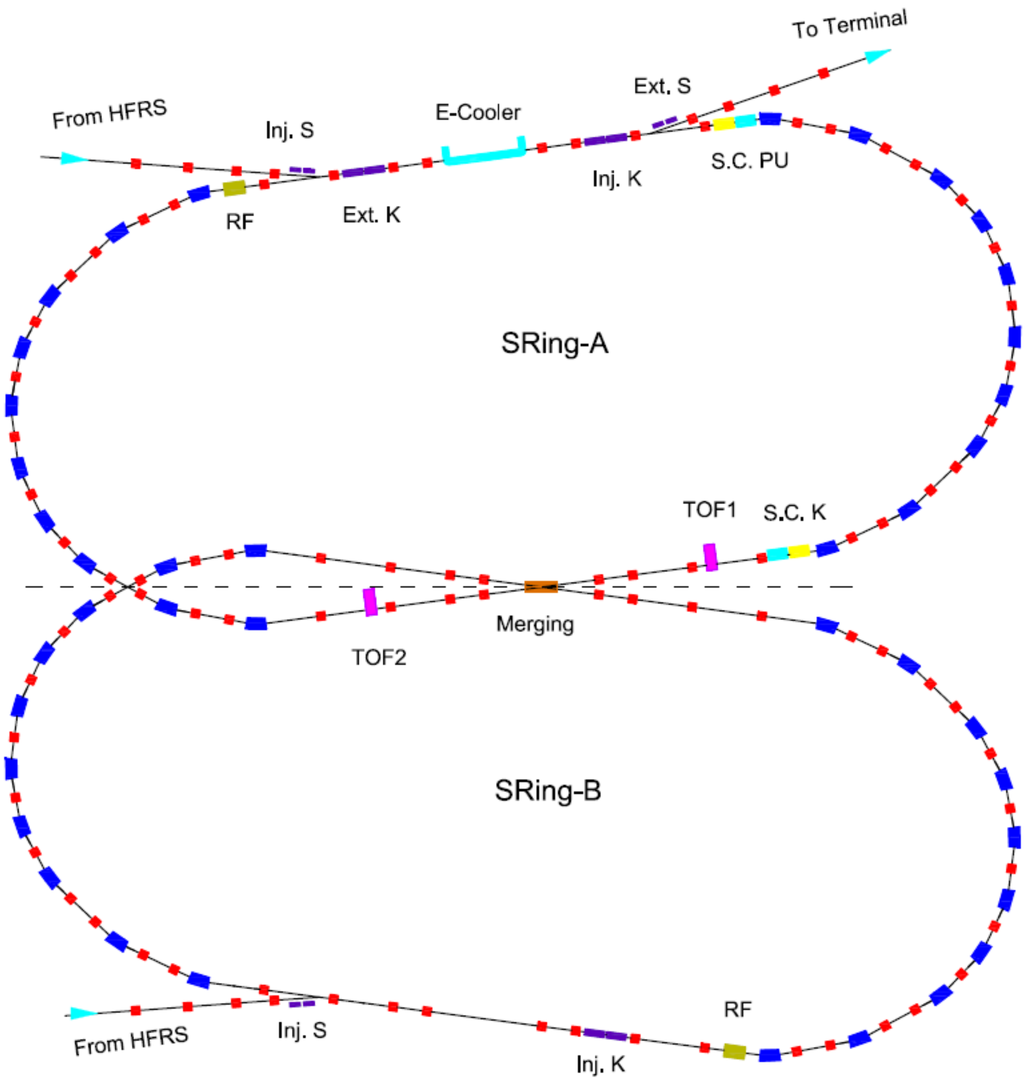
SRing operation modes

Mode 1: For RIBs researches

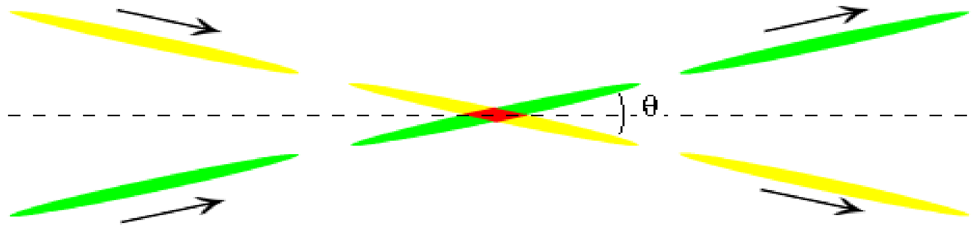


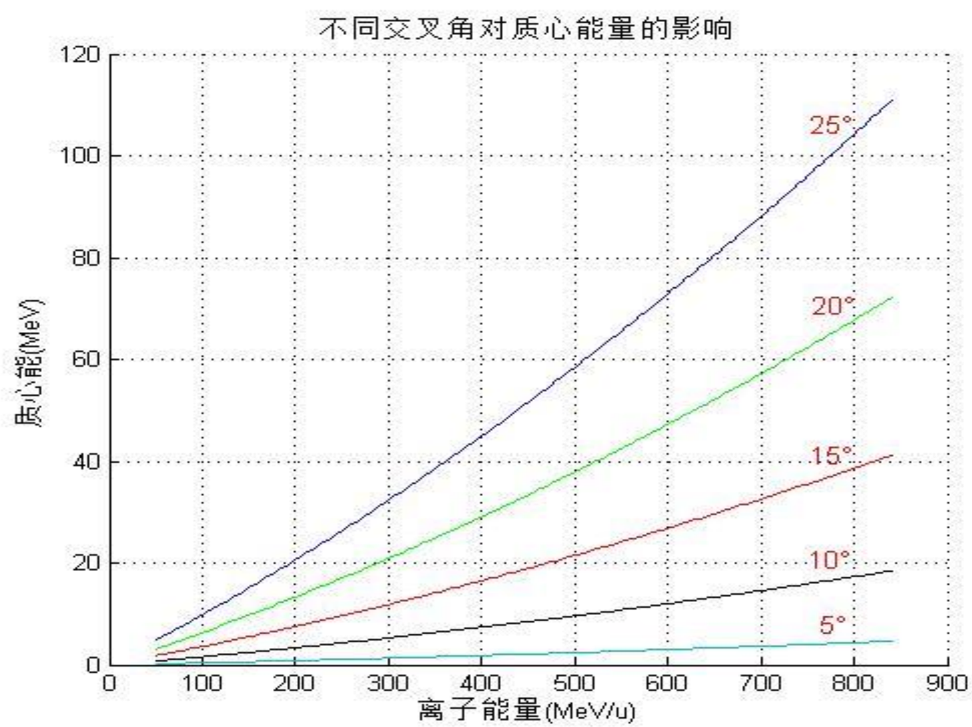
SRing new layout

Mode2: merging ion beams



Cross merging scheme





SRing new layout

Collision beam parameters

Ion	$^{238}U^{92+}$	$^{238}U^{92+}$
C (m)	240	240
RF Frequency (MHz)	10.5	10.5
Collision frequency MHz)	10.5	
Rms Beam length (m)	0.6	0.6
Particle number per bunch ($\times 10^9$)	6.4	6.4
ε_x(mm·rad)	10	10
ε_y(mm·rad)	10	10
β^*_x (m)	0.002	0.002
β^*_y (m)	0.002	0.002
Beam current（A）	1	1
Laslett tune shift	0.1	0.1
cross angle (°)	15	
Luminosity ($cm^{-2}s^{-1}$)	3.2×10^{25}	

Beam dynamics challenges & studies

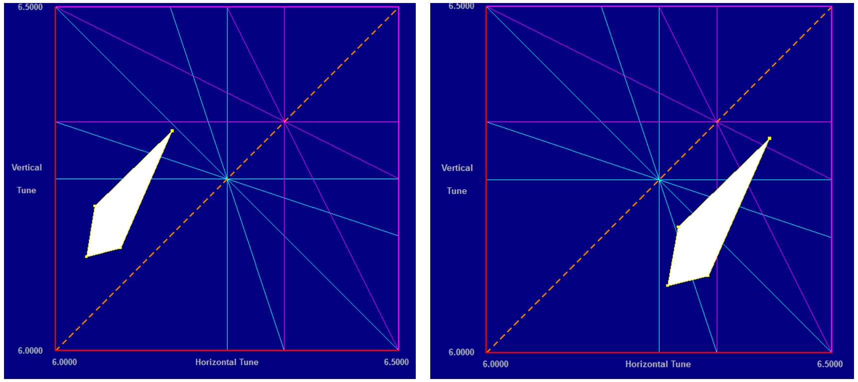
Topics:

- Space charge limit and optimized working point
- Control of the dynamic vacuum pressure
- Design and simulation of two-plane painting injection
- Longitudinal barrier bucket stacking of high intensity beam
- Ultra-short bunch compression

Space charge effect

$$N_{SCL} = \frac{A}{Z^2} \cdot \frac{-\Delta Q_y^{sc} \cdot \pi \cdot \beta^2 \cdot \gamma^3 \cdot B_f}{g1 \cdot r_p} \cdot \frac{\varepsilon_y + \sqrt{\varepsilon_x \cdot \varepsilon_y}}{2}$$

Ions	Energy (MeV/u)	SCL intensity
p	70	2.1×10^{13}
$^{12}C^{6+}$	75	7.5×10^{11}
$^{16}O^{8+}$	50	3.6×10^{11}
$^{78}Kr^{29+}$	40	1.1×10^{11}
$^{238}U^{34+}$	17	9.6×10^{10}
$^{238}U^{34+}$	25	1.4×10^{11}
$^{238}U^{34+}$	50	3.0×10^{11}



Two work points are considered: (6.17,6.32) and (6.41,6.31)

Unique challenges:

- Long storage time at injection energy

  The incoherent tune shift is tolerable for relatively short "waiting time"(～ms), but how much is it for the accumulation time in the presence of electron cooling (～10s) ?

  Long-term 3D particle tracking studies are in progress to find the tolerable tune shift

- High intensity beam accumulation with fast electron cooling

  Effective electron cooling: angle between electron and ion beams, hollow electron beam

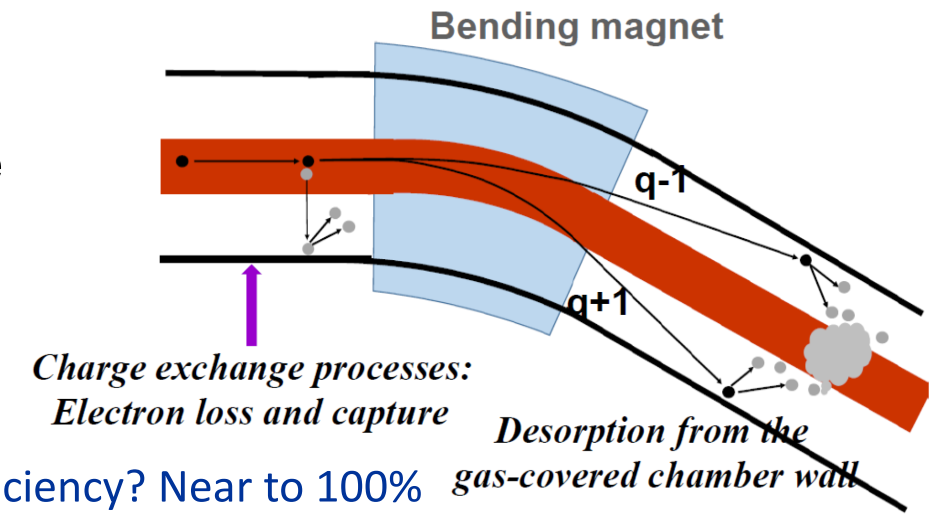
  Beam dynamics simulation code is under development in cooperation with BINP

Dynamic vacuum

Beam loss mechanism:

Charge exchange of intermediate charge state ions ($^{238}U^{34+}$) **due to collision**

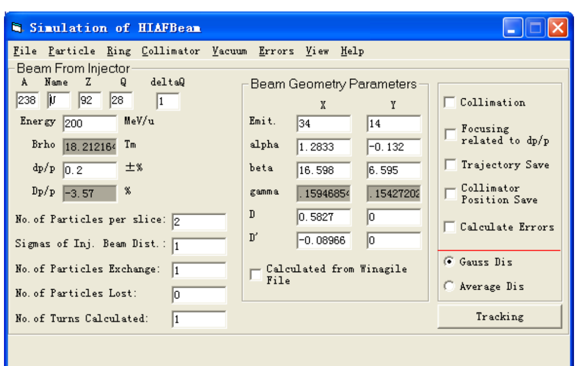
$$U^{34+} + X \rightarrow U^{35+} + X + e$$



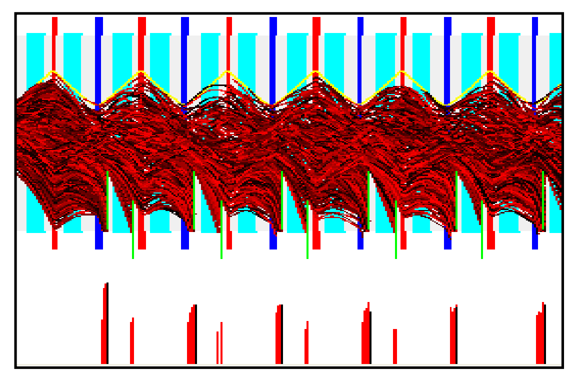
Challenges:

- How to get the high collimation efficiency? Near to 100%
- How to optimize the lattice for different types of particles?
- How to design the collimator? the mechanical design, control system, vacuum system test.

A dedicated dynamic vacuum simulation code-HIAF-DYSD has been developed for the optimization of dynamics design.

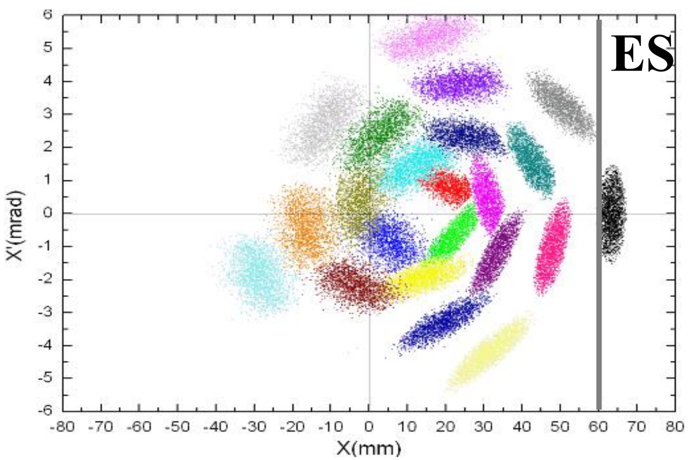


Simulation Code HIAF-DYSD

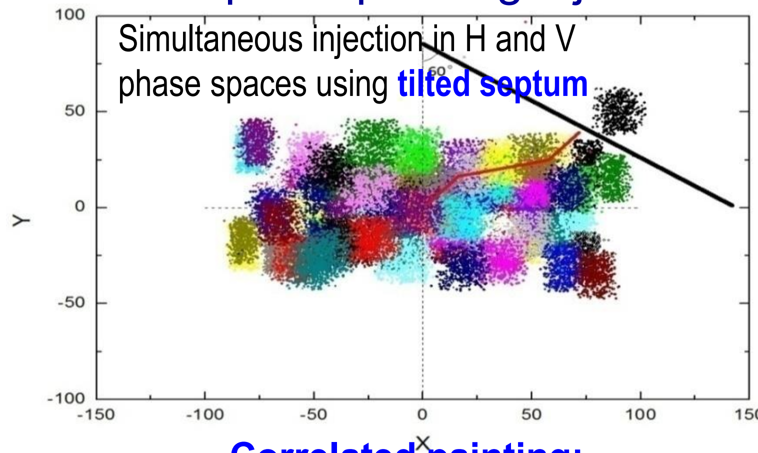


Two-plane painting injection

conventional multiturn injection



Two-plane painting injection



Correlated painting:
Two groups of orbit bump for both horizontal and vertical

Challenges:

- **Many beam dynamics issues should be studied carefully**
  ring lattice, injection optics match, septum angle
- **The first time to adopt the tilted septum injection in the world**

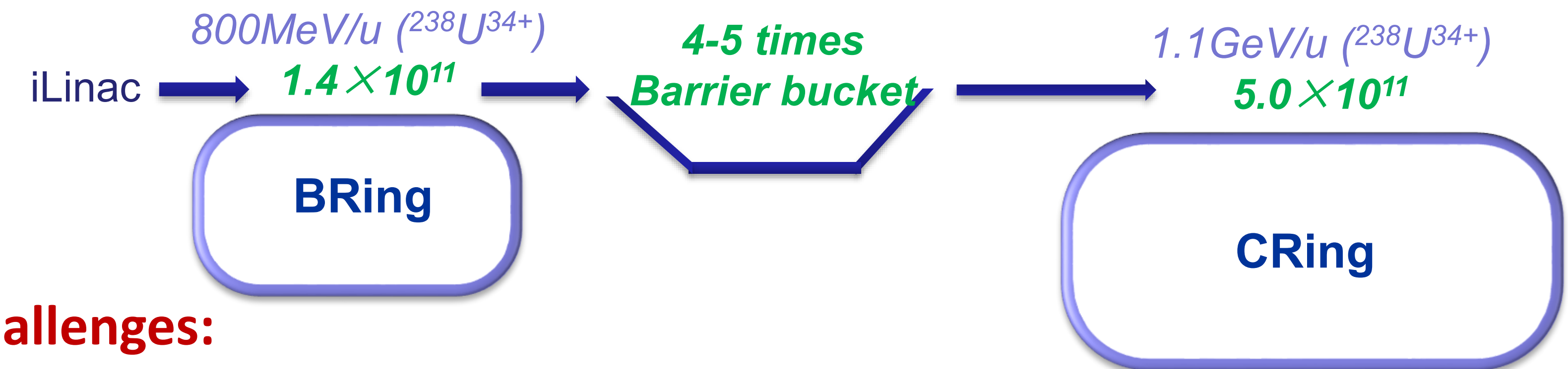
The dynamics design of two-plane injection has been finished for BRing

Ions	Energy (MeV/u)	Injection current (pmA)	Plane	Injection turns	Single injection	Number of injection	intensity
			H	33	3.3×10^{10}	10	3.3×10^{11}
$^{238}U^{34+}$	25	0.028	V	16	1.6×10^{10}	20	3.3×10^{11}
			H+V	**150**	**1.6×10^{11}**	**2**	**3.3×10^{11}**

Barrier bucket stacking

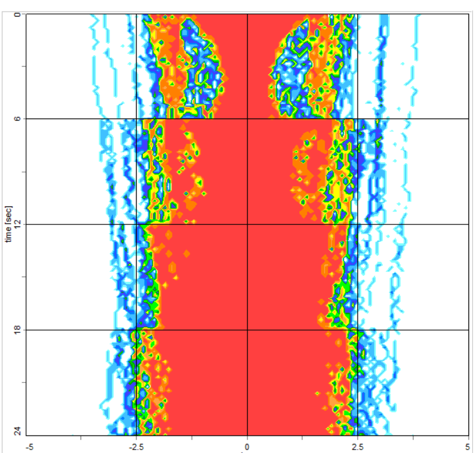
Goals:

4-5 times increase of beam intensity through barrier bucket

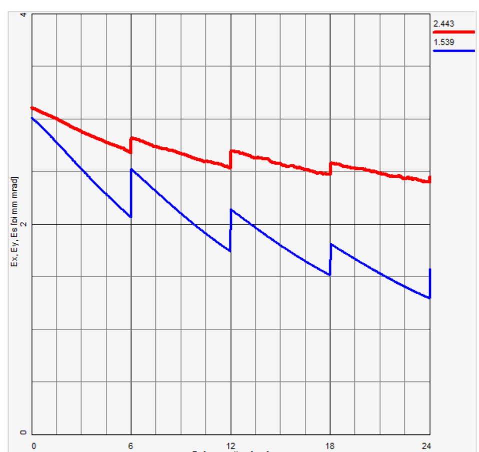


Challenges:

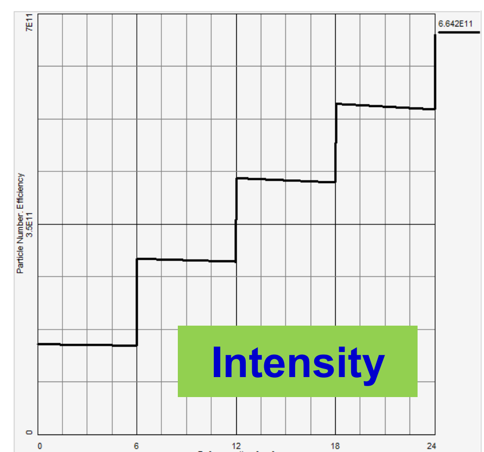
- Fast e-cooling for high energy heavy ion
- High intensity effect of barrier bucket stacking



Momentum spread



Emittance

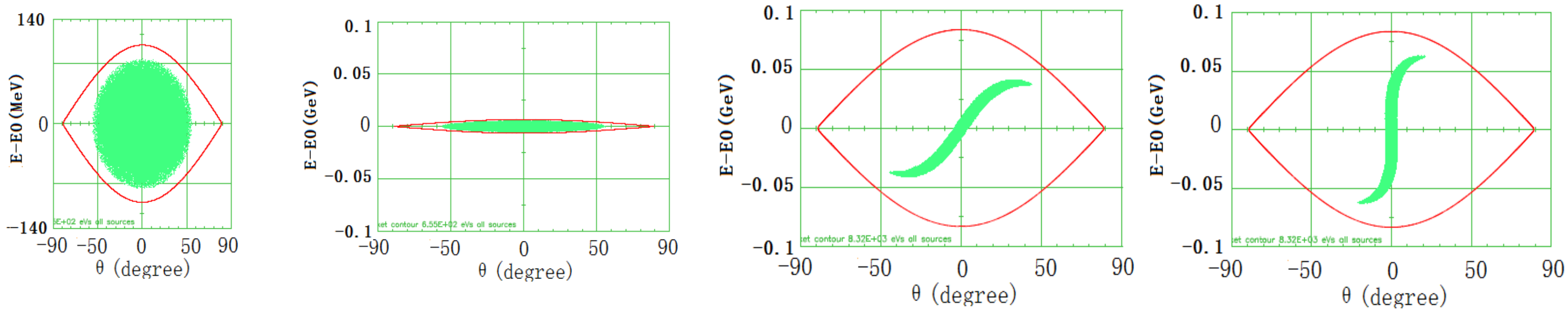


Ultra short beam compression

Goals:

To get the ultra-short bunch length for High Energy Density Physics

The short bunch can be obtained by fast bunch rotation



Challenges:

- Efficient e-cooling to reduce the momentum spread
- Control of the beam loss during bunch rotation
- Magnetic alloy compression cavity design and fabrication

The preliminary design of the beam compression scheme has been completed. Two methods: K-V envelope equation and PIC code of ESME are used for simulation.

Technical challenges and R&D

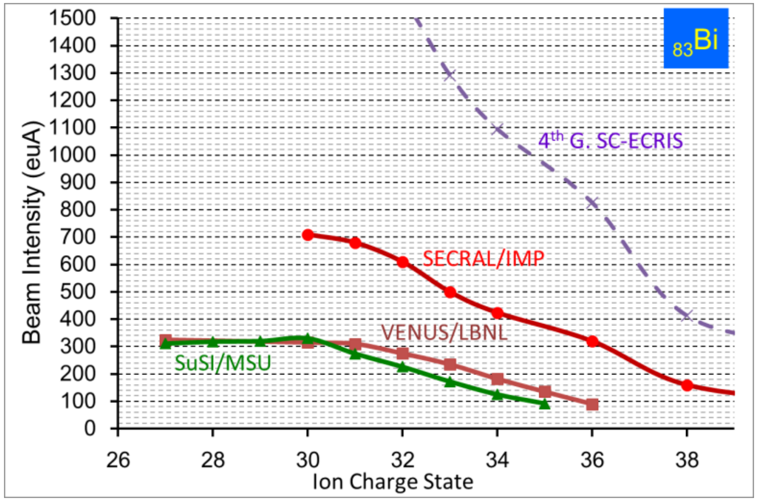
- ※ Superconducting ECR
- ※ Superconducting Linac
- ※ Dynamic vacuum collimator
- ※ Superconducting magnet
- ※ Electron cooling
- ※ Stochastic cooling

Superconducting ECR

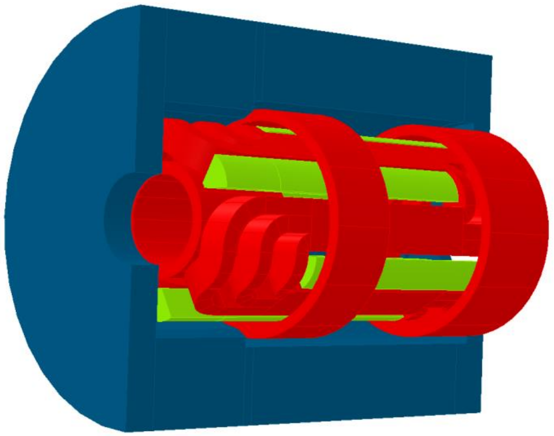
None of existing highly charged ion sources can meet HIAF requirements for the moment

But the 4th Generation ECRIS seems to provide a feasible solution

Ion	Bi^{30+}	U^{34+}
HIAF Beam Intensity (euA)	1500	1700
World Record Intensity (euA)	422	400
3rd Generation Sources	SECRAL/24 GHz	
Gain for HIAF	3.6	4.2



Intense heavy ion beam production

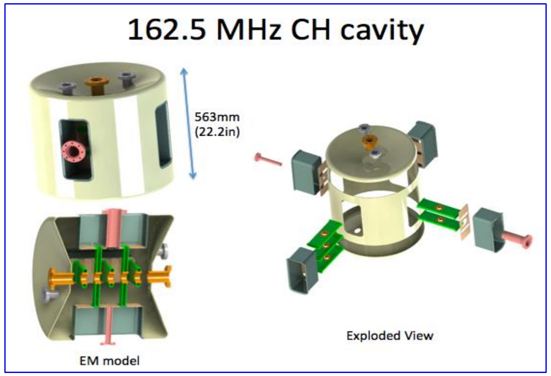


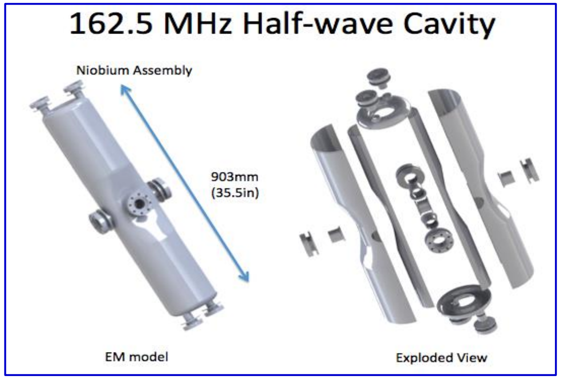
- New magnet configuration based on the traditional Ioffe-bar layout can minimize the highest field inside the magnet coils, and maximize the efficient field inside the plasma chamber.
- Possible utilizing the matured NbTi technique instead of the cutting edge Nb_3Sn technique will be more cost efficient and technical feasible.

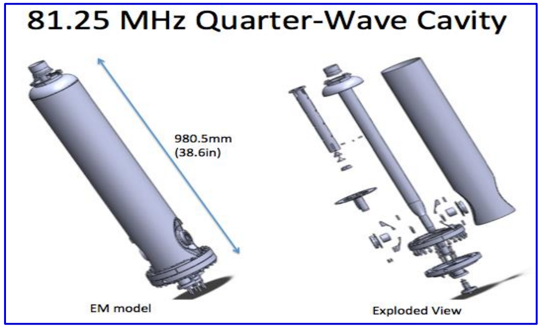
Details in L.T. Sun's presentation!

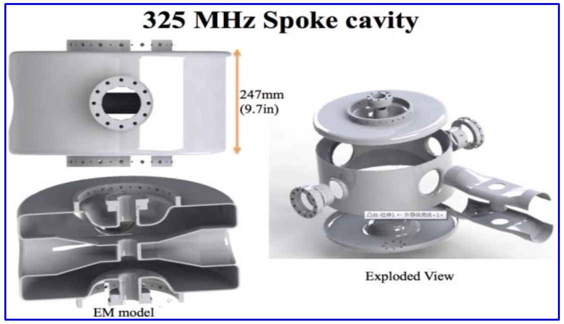
Challenges of iLinac

- **Highest peak current pulse for superconducting ion linac in the world,** the peak current is four times higher than at FRIB (CW mode)
- **Low-Beta SRF cryomodules design and prototype development.** There are four types of superconducting cavities developed at IMP









- **The average uncontrolled beam loss should be limited to below 1 W/m level**

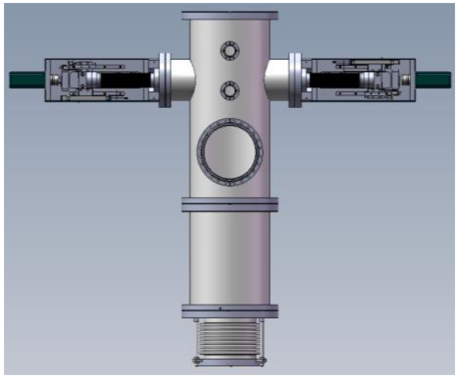
R&D of Dynamic vacuum

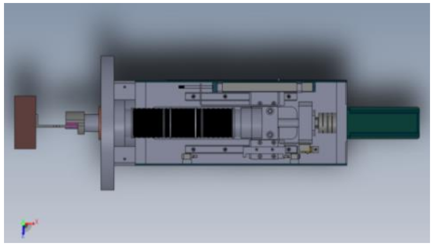
Collimator prototype development

First step - Test platform

Desorption measurement
Control system and vacuum system test
Install at PISA or E-point

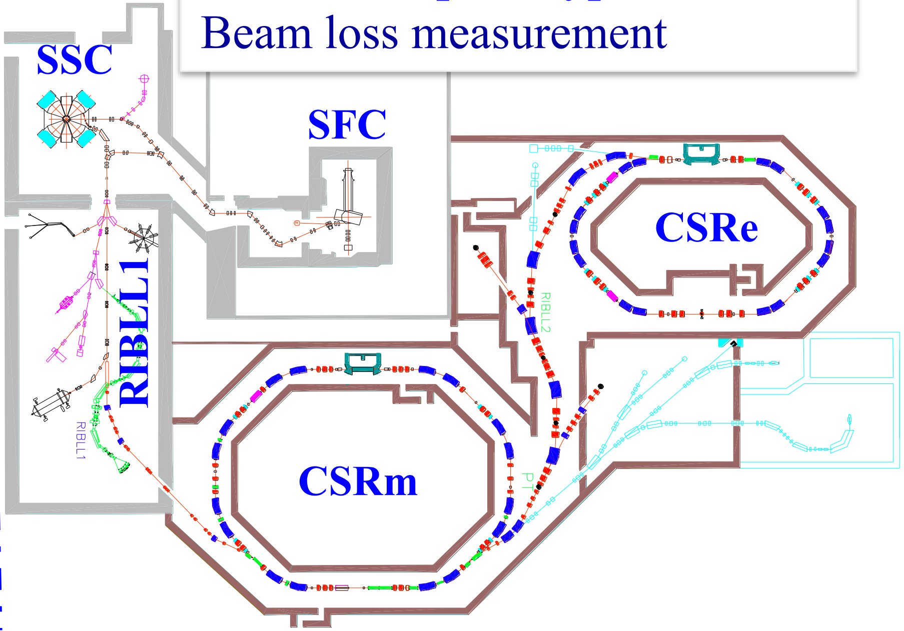
The mechanical design has been finished



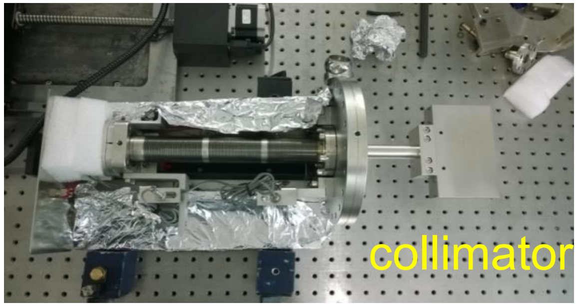


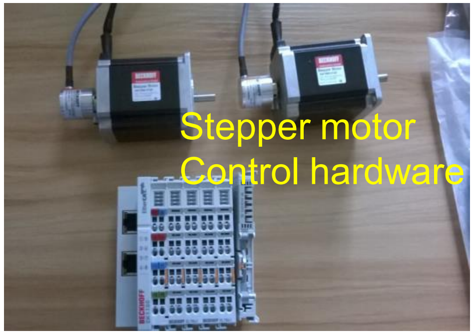
Second step – Collimator prototype of CSRm

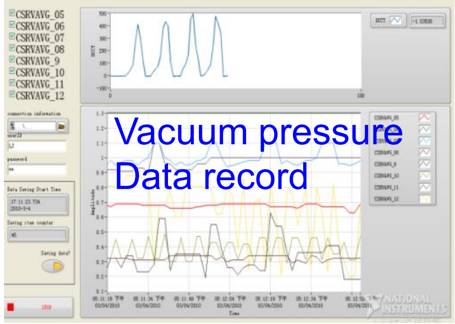
Beam loss measurement



Fabrication of hardware components





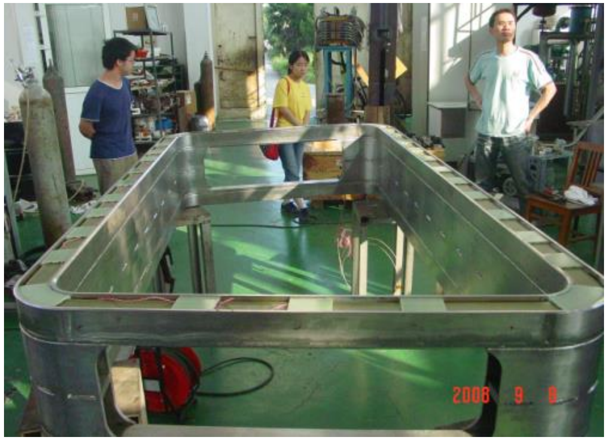


Super-ferric dipole with warm iron yoke

BRing, CRing and SRing

Features and design proposal:

- Big gap — Superconducting coil
- Big good field region — Warm iron
- Fast-cycling magnet（small inductance）— large operation current， liquid helium inner cooling superconducting cable
- Type of cooling — Forced flow cooling with super-critical helium/two-phase helium



- Superconducting solenoids: 3T, 5T, 7T for Penning trap
- The superconducting dipole prototype for the super-FRS has been fabricated and tested at IMP, and it has been already transferred to GSI

R&D of SC magnet for HIAF

Fabrication

Fabrication of superconducting cable

Fabrication of coil case

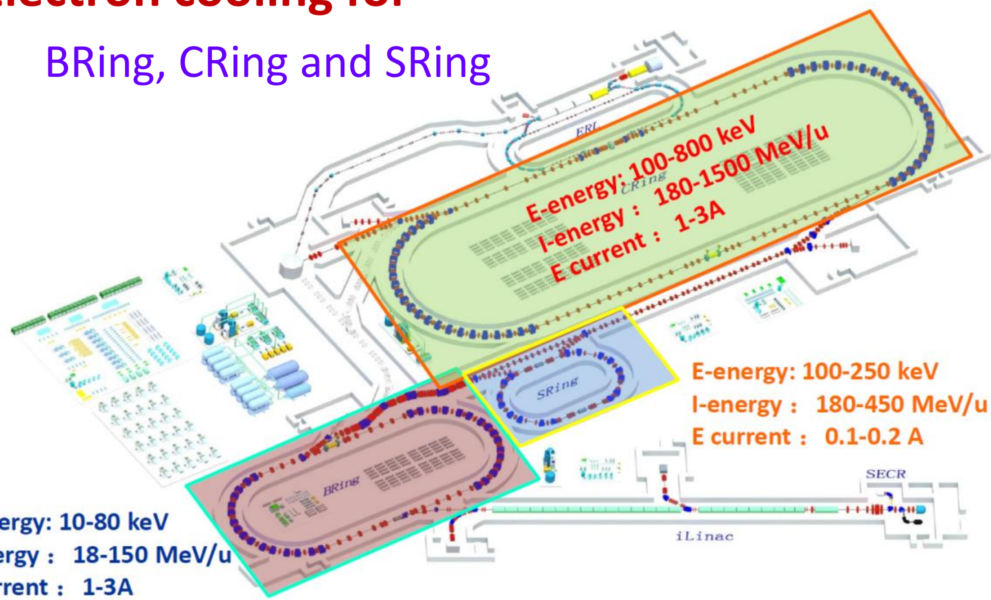
Fabrication of cryostat

- A new type of superconducting cable is designed and fabricated
- The coil case fabrication has been finished
- The current leads and cooling system are still under design
- The quench protection system will be established in the next step

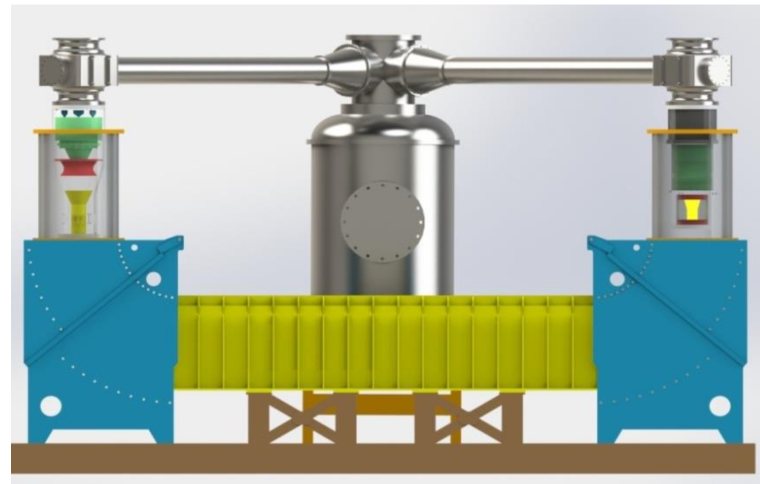
Electron cooling

Electron cooling for

BRing, CRing and SRing



Sketch of the magnetized Electron cooling system for HIAF



Well-established electron cooling of existing facility-HIRFL

CSRm e-cooler

E-energy: 4-35keV
I-energy :7-50MeV/u
E current :1-3A

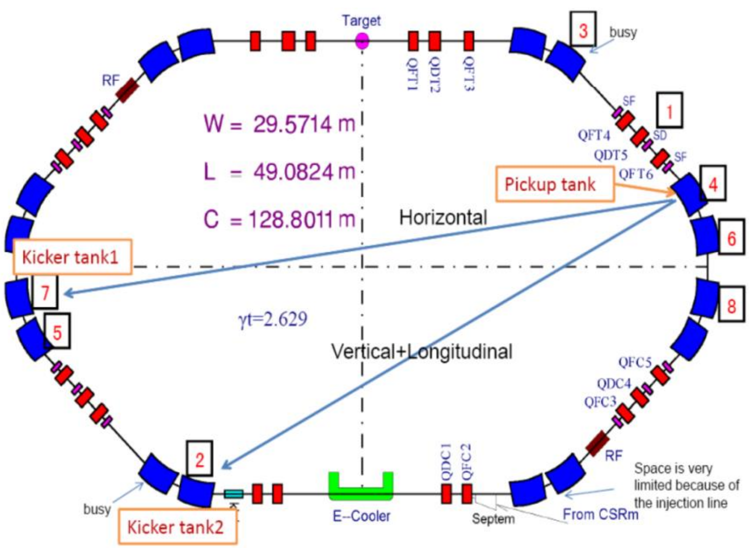
CSRe e-cooler

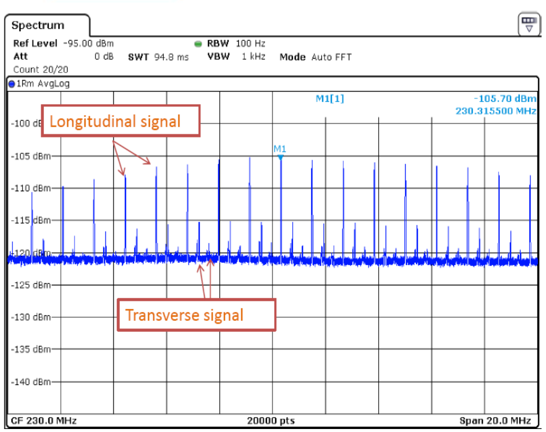
E-energy:10-300keV
I-energy:25-500MeV/u
E-current:1-3A

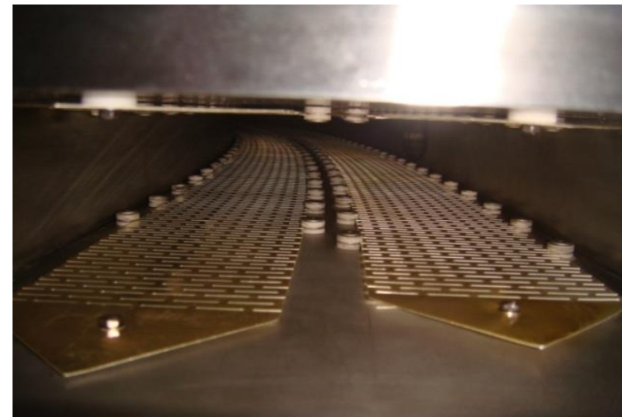
The hollow e-beam can be obtained in both of two e-coolers to partially solve the problem due to the space charge effect and reduce the effect of recombination between the ions and the e-beam. The intensity gain factor of C beam is more than 300.

Stochastic cooling of CSRe

A novel type of 2.76 m long slotted pick-up was developed (in cooperation with CERN and GSI) for CSRe stochastic cooling. The key components have been fabricated and installed in CSRe, the tuning of machine for stochastic cooling will start next year.





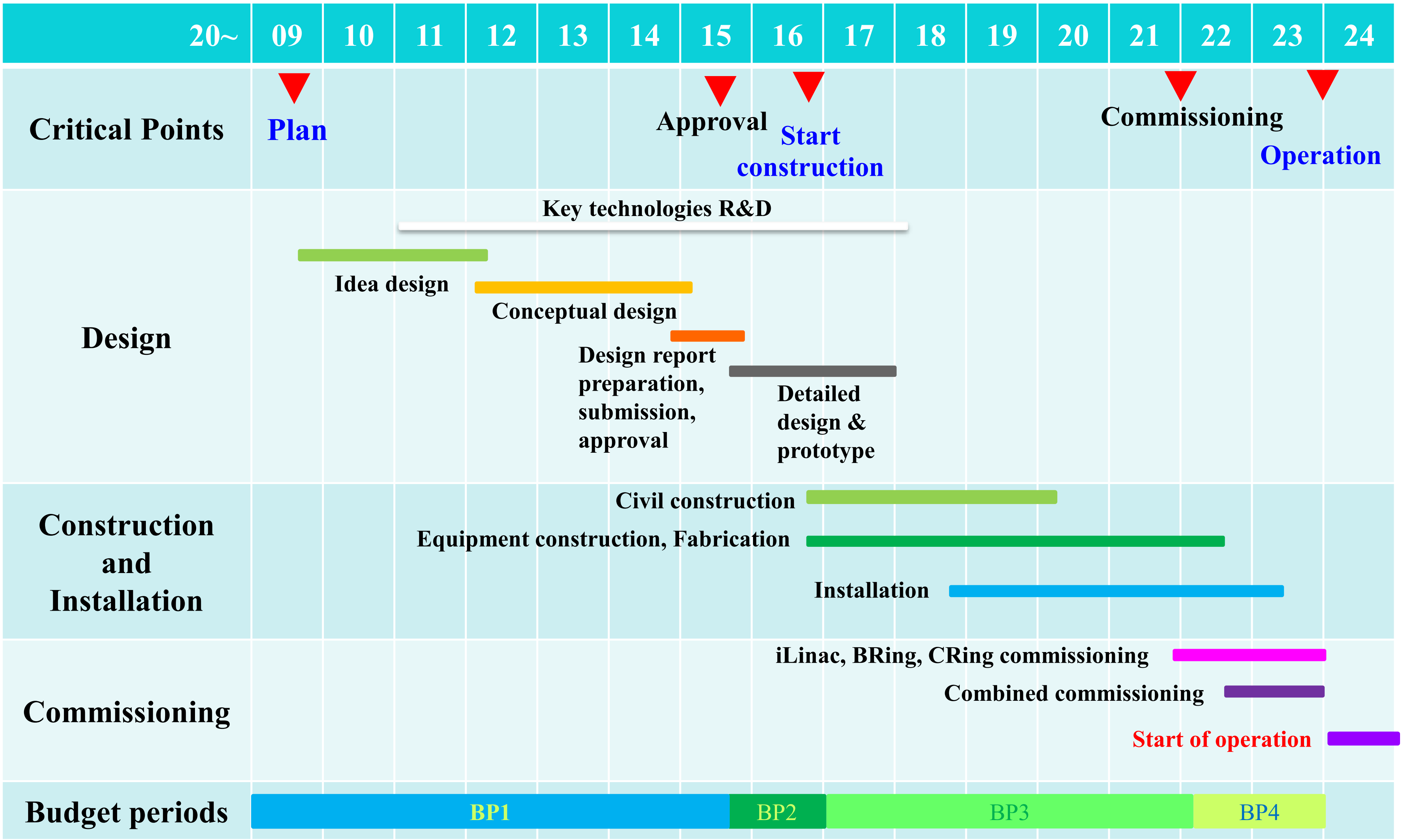


The beam test ($^{117}Sn^{50+}$, 253 MeV/u) results show it is a well-suited structure for CSRe stochastic cooling.

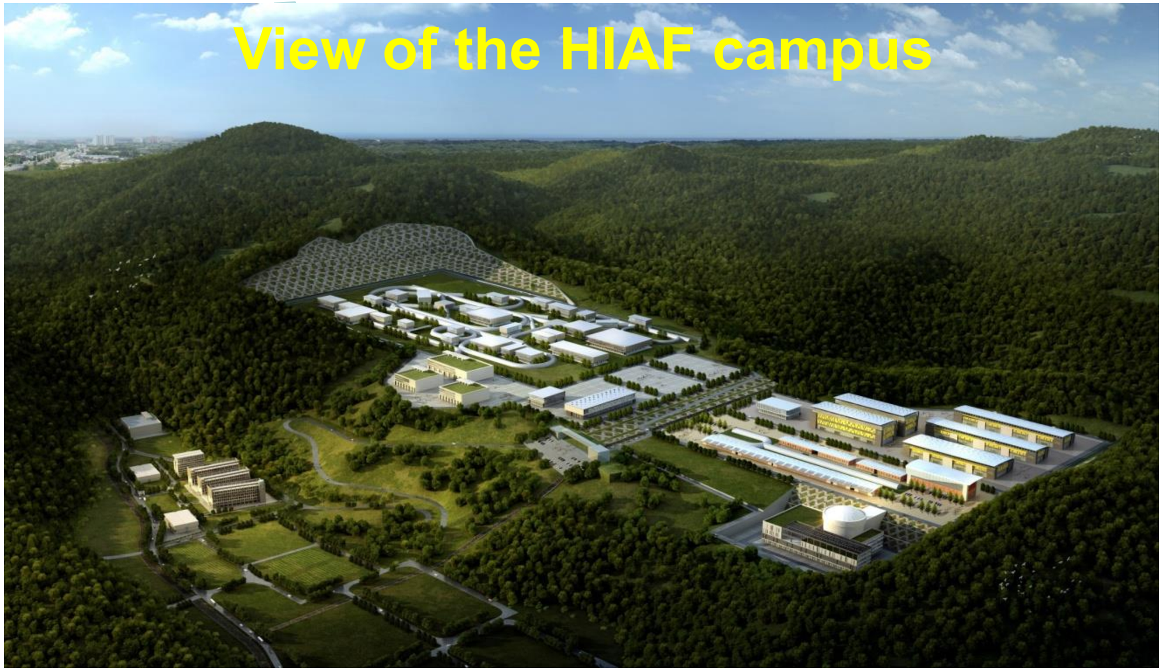
Budget of HIAF (1^{st} phase)

Items	1^{st} phase (MRMB)
iLinac	460
BRing	350
CRing	
eLinac	
ERing	
High energy electron cooling	
Beam transfer line	50
Experiment setups	230
Cryogenics	80
Civil engineering	70
Tunnel construction	160
Contingency cost	100
Total of facility	1500 (central government)
Land & infrastructure	1400 (local government)
Total	**2900**

Schedule for the HIAF (1st phase)



Site of HIAF project-new campus



Summary

◆ We have got the final approval from the central government.

◆ The machine studies are now mainly focused on beam dynamics design optimization and key technical R&D.

- A number of beam dynamics issues has been investigated and some issues should be studied carefully:
  - Long-term 3D particle tracking studies to find the tolerable tune shift
  - Optimization of the two-plane painting injection scheme
  - Simulation of barrier bucket stacking with high intensity effects.
  - Design of ENC optics with high luminosity

- A number of key technical R&D issues are in progress:
  - Superconducting magnet
  - Tilted electrostatic septum
  - Dynamic vacuum collimator
  - Magnetic alloy compression cavity
  - Electron & stochastic cooling

Thanks for your attention!