Report on HIAF and CIADS Projects

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Outline

- ✓ **Background**
- ✓ **HIAF introduction**
- ✓ **CIADS introduction**
- ✓ **Progress of R & D related to the Projects**
- ✓ **Site of the Projects**

Background and motivation

HIAF: High Intensity heavy-ion Accelerator Facility

One of 16 large-scale research facilities proposed in China in order to boost basic science.

- Proposed by IMP in 2009.
- Put in the priority list by the central government in the end of the 2012.
- Design Report (v1.0) was published in July 2014
- **The final approval was on the 31st December of 2015**

Background and motivation

The 16 priority national Projects for Science and Technology for the 12th 5-year Plan in China

China Initiative Accelerator Driven System

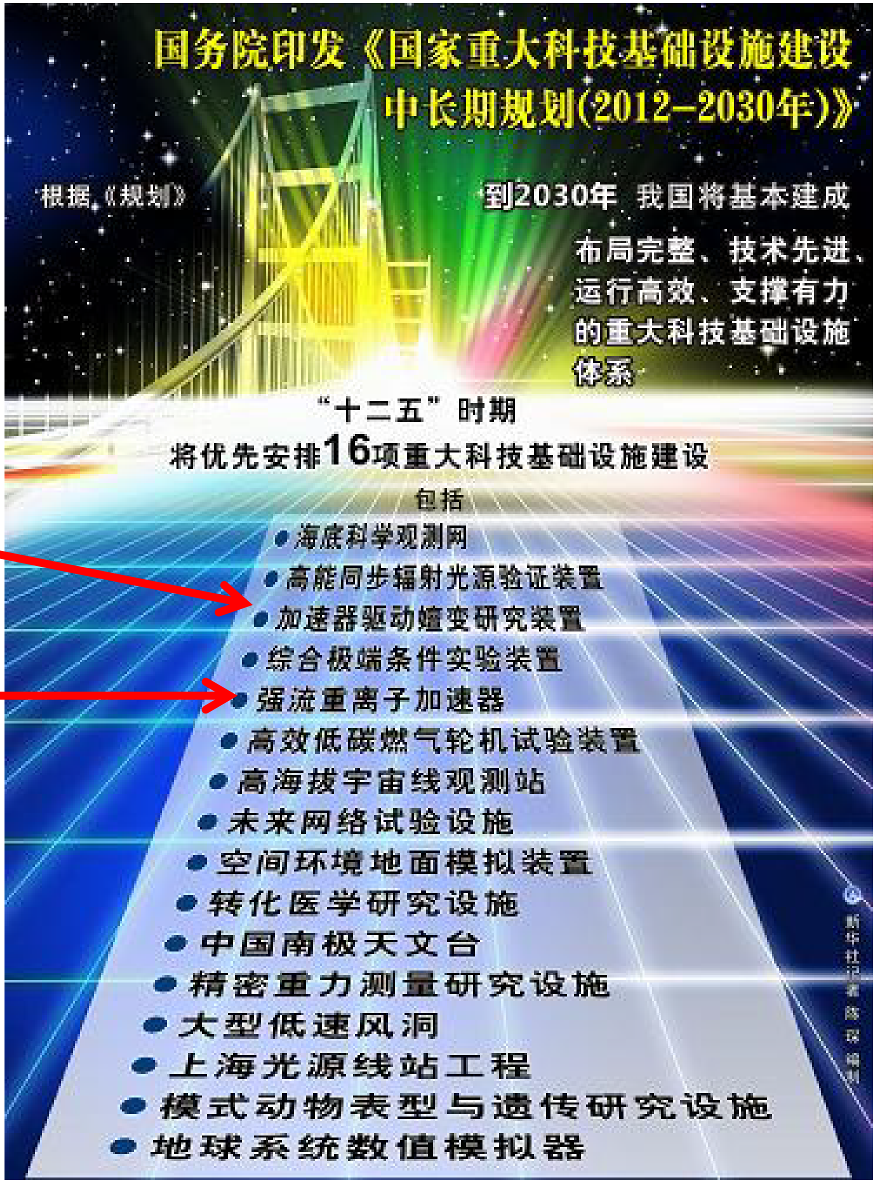
- **CIADS**

- **HIAF**

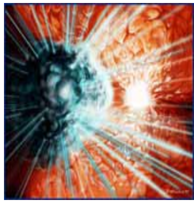
High Intensity heavy-ion Accelerator Facility

Official approval on the 31st Dec of 2015,

Red head documents are issued.

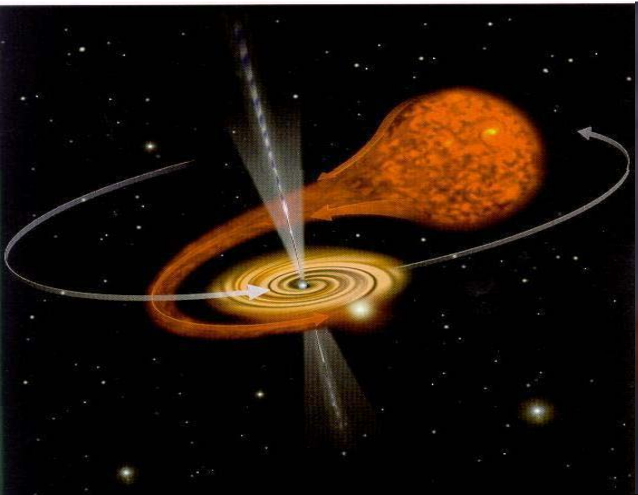


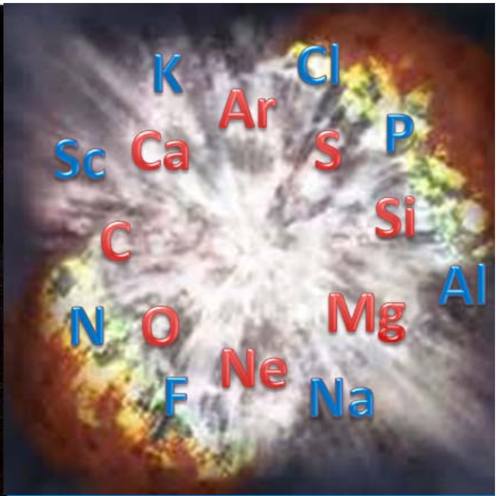
HIAF Introduction

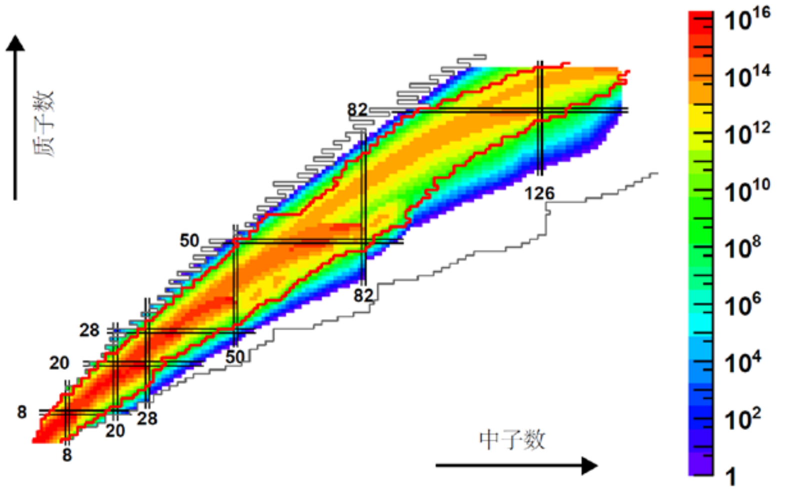


HIAF Scientific aims

- To explore the limit of nuclear existence
- To study exotic nuclear structure, to learn nuclear force
- To understand the origin of heavy elements in the universe
- To explore QED effects in strong Coulomb fields
- To learn the ultrafast dynamics in relativistic electromagnetic fields
- To study the properties of High Energy Density Matter
- To explore the heavy ion beams in material sciences





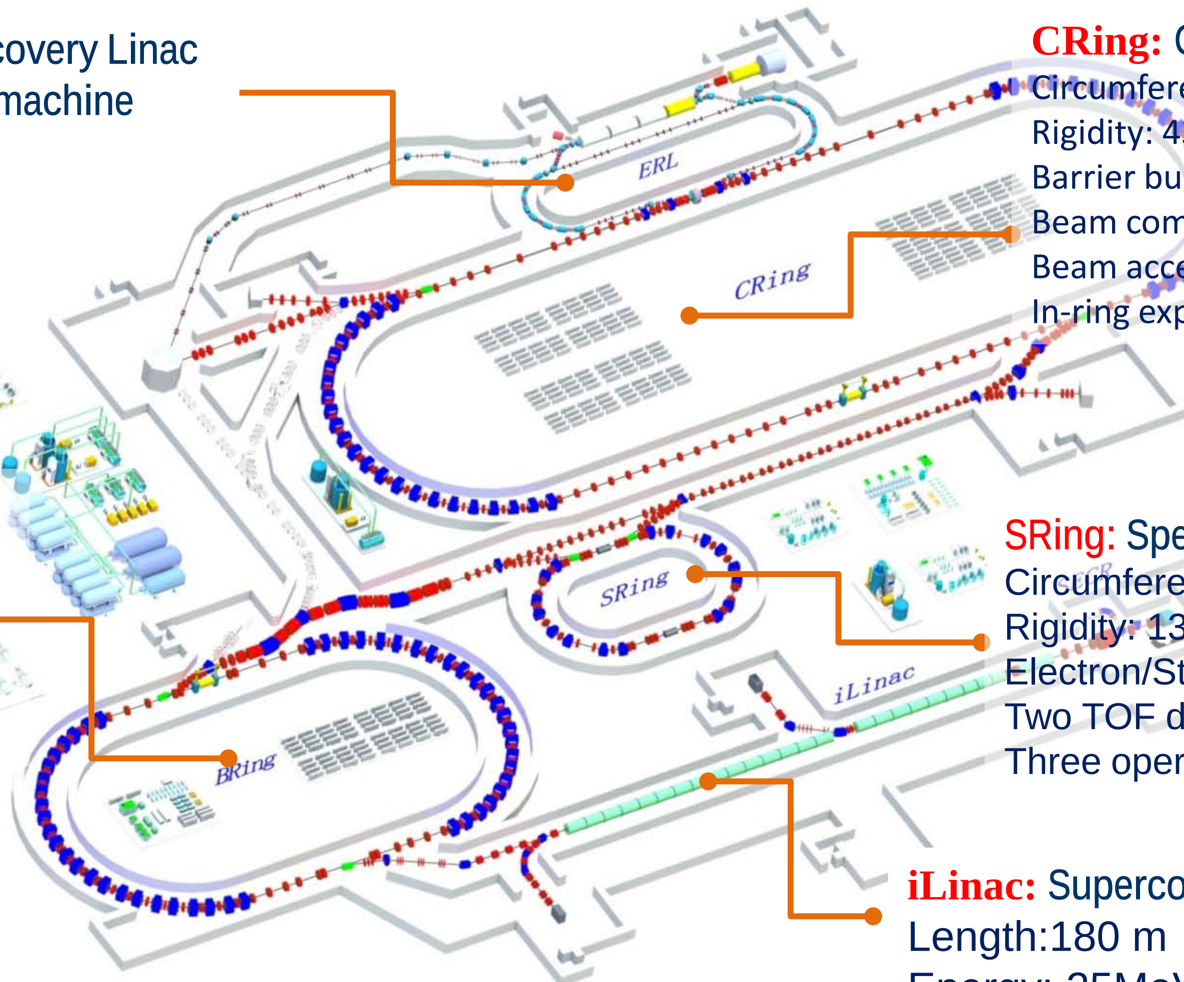


HIAF Introduction

HIAF: Multi-purpose facility

ERL: Energy Recovery Linac electron machine

CRing: Compression ring
Circumference: 880 m
Rigidity: 43 Tm
Barrier bucket stacking
Beam compression
Beam acceleration
In-ring experiment



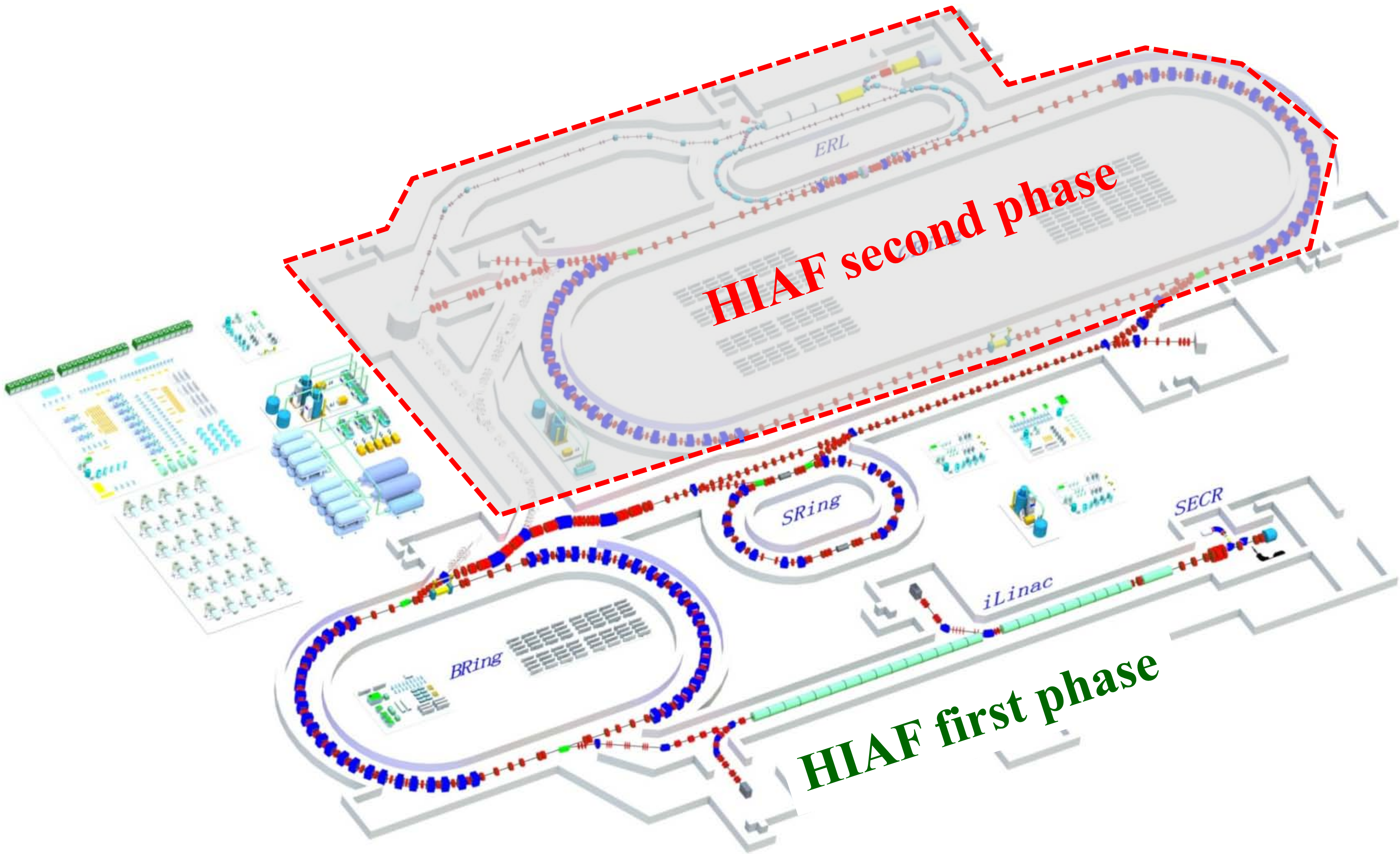
BRing: Booster ring
Circumference: 440 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration

SRing: Spectrometer ring
Circumference:250m
Rigidity: 13Tm
Electron/Stochastic cooling
Two TOF detectors
Three operation modes

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

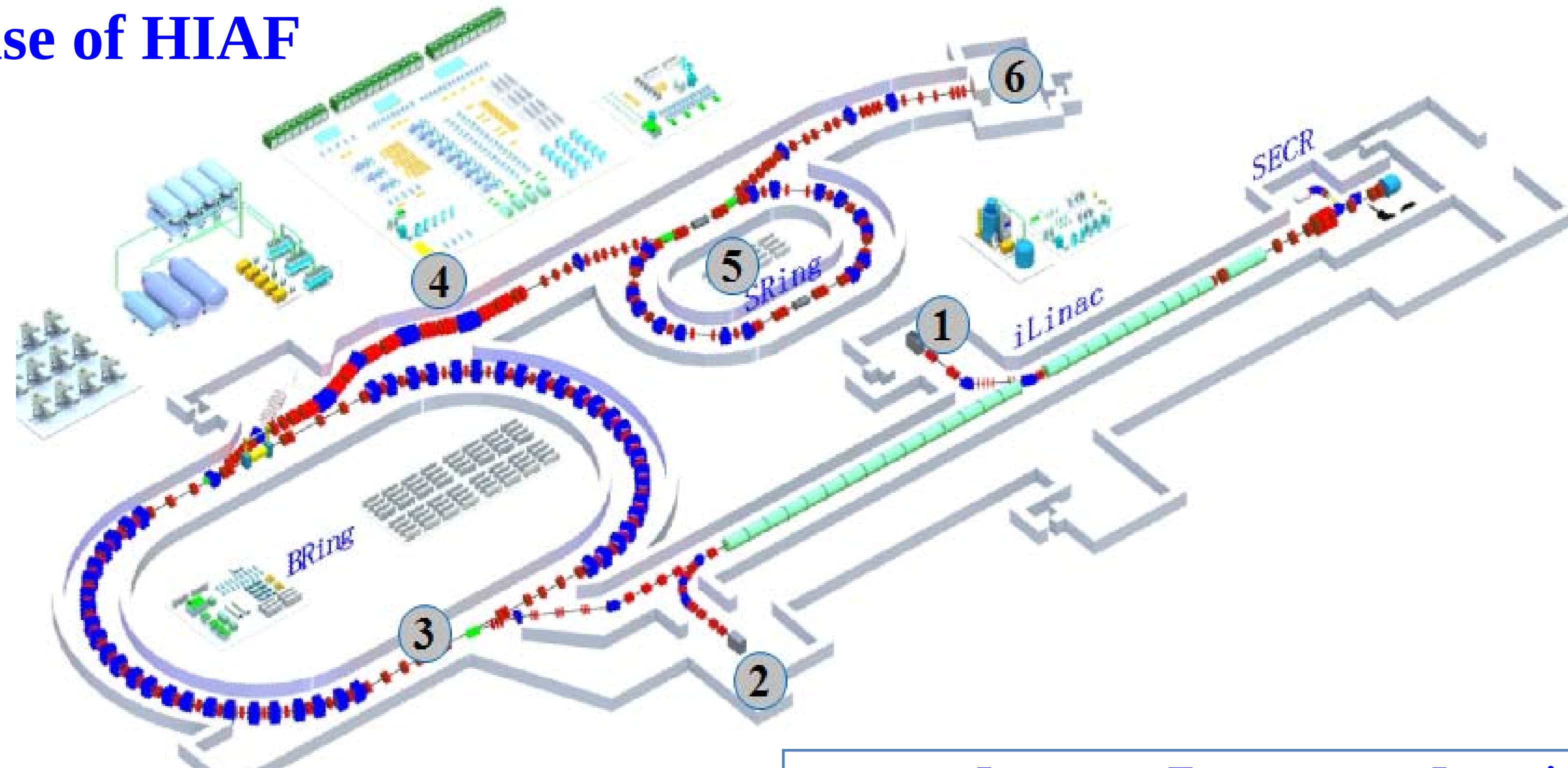
General description & status

Due to the approved budget, the HIAF project is divided into two phases.



General description & status

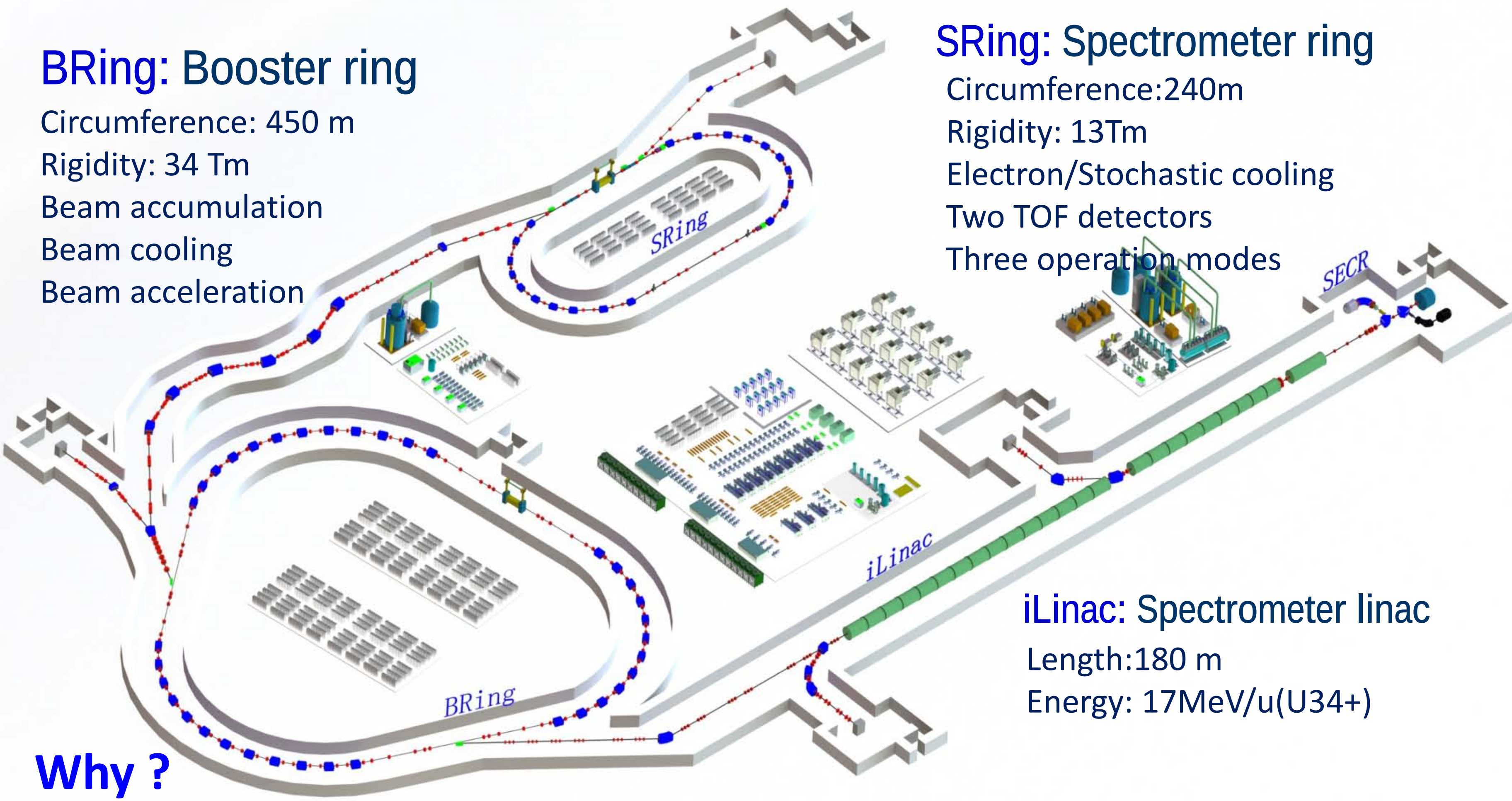
1st phase of HIAF



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

	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	17 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	~1.0×10^{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

New layout of HIAF first phase



BRing: Booster ring

Circumference: 450 m
Rigidity: 34 Tm
Beam accumulation
Beam cooling
Beam acceleration

SRing: Spectrometer ring

Circumference:240m
Rigidity: 13Tm
Electron/Stochastic cooling
Two TOF detectors
Three operation modes

iLinac: Spectrometer linac

Length:180 m
Energy: 17MeV/u(U34+)

Why ?

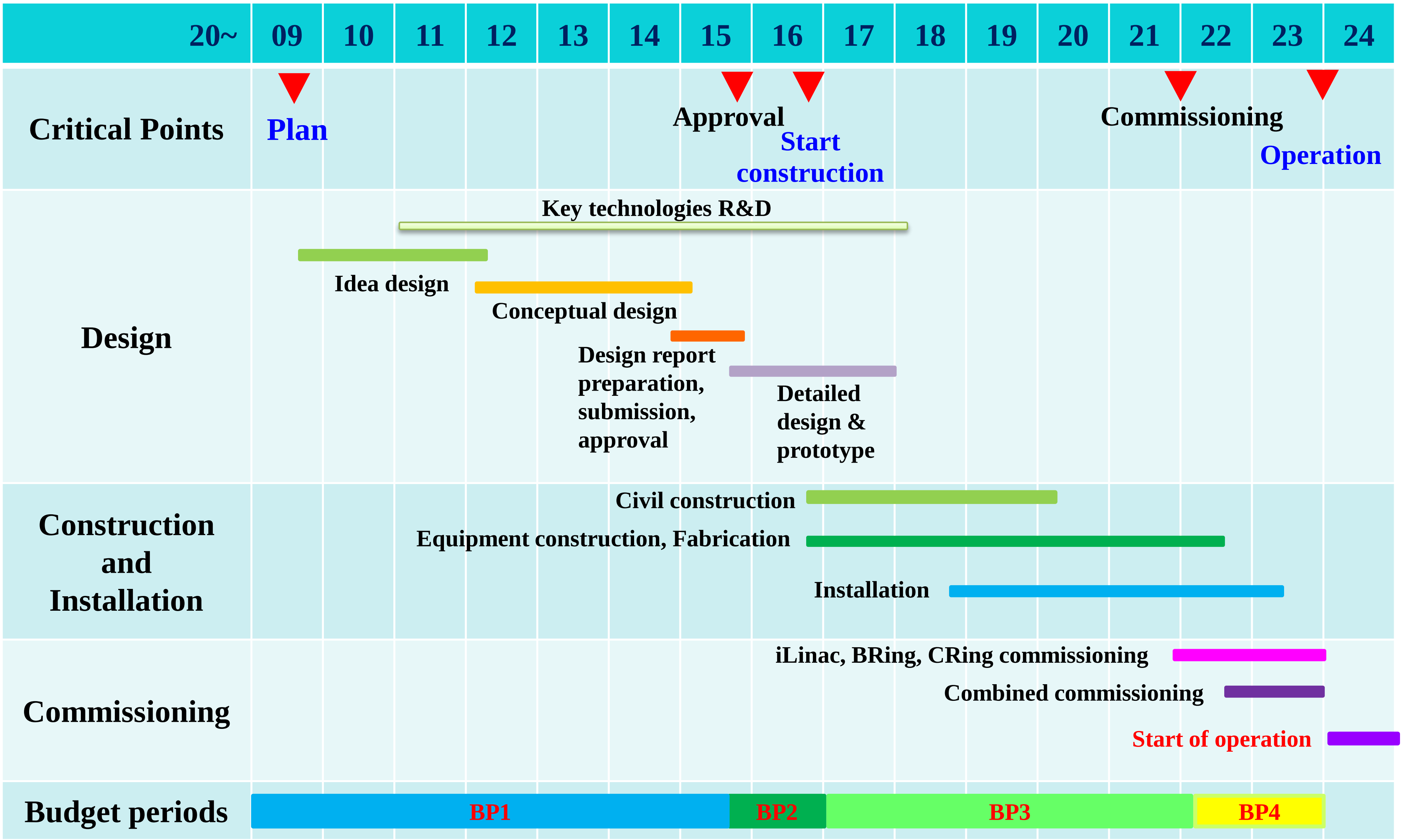
- Beam dynamic design optimization
- Challenge of injection and two extraction modes
- Nonlinear beam dynamics considerations

Budget of HIAF (1st phase)

Items	1st phase (MRMB)
iLinac	360
BRing	350
High energy electron cooling	
Beam transfer line	50
Experiment setups	240
Cryogenics	80
Civil engineering	190
Tunnel construction	160
Contingency cost	100
Total of facility	**1530(central govern.)**
Land & infrastructure	**1400 (local govern.)**
Total	**2930**

(1.5×10^9, 2.9×10^9, RMB)

Schedule for the HIAF (1^{st} phase)



CIADS Introduction

Nuclear energy is an inevitable strategic option to meet China energy demand in the future

- China is the largest energy consumer in the world and coal is the major resource for electricity production (79% in 2011)
- Nuclear power is a relatively clean energy without green-house gas emission
- Nuclear power started in the mid-1980s with Qinshan Nuclear Power Plant

Current status of China nuclear power

- 22 nuclear power reactors in operation, 18.056GWe (6^{th} in the world)
- Produced electricity: 104.8TW.h, 2.1% share in 2013, (5^{th} in the world)
- 27 units under construction, 26.756GWe, (1^{st} in the world)

The planned NP development in China (2011-2020)

- By 2015, the installed capacity reaches 40GWe and 18GWe under construction
- By 2020, the installed nuclear capacity will be increased to 58GWe (~7%), and 30GWe are under construction

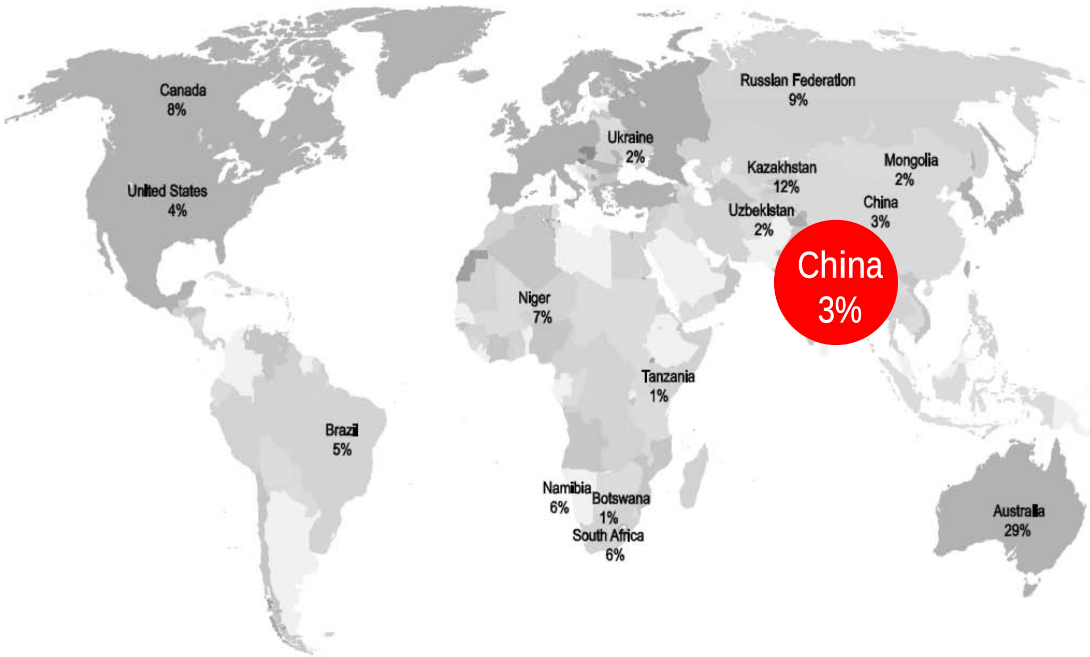
By 2050, 350~400GWe (~20%), comparable with the total NP capacity in the world (375GWe in 2014).

- **Management and safe disposal of nuclear waste**
- Fuel supply (Uranium~100 years for LWR)

"The ADS has the advantage that it can burn pure minor actinides while avoiding a deterioration of the core safety characteristics."

—— ADS and FR in Advanced Nuclear Fuel Cycles – A Comparative Study, NEA/OECD, 2002

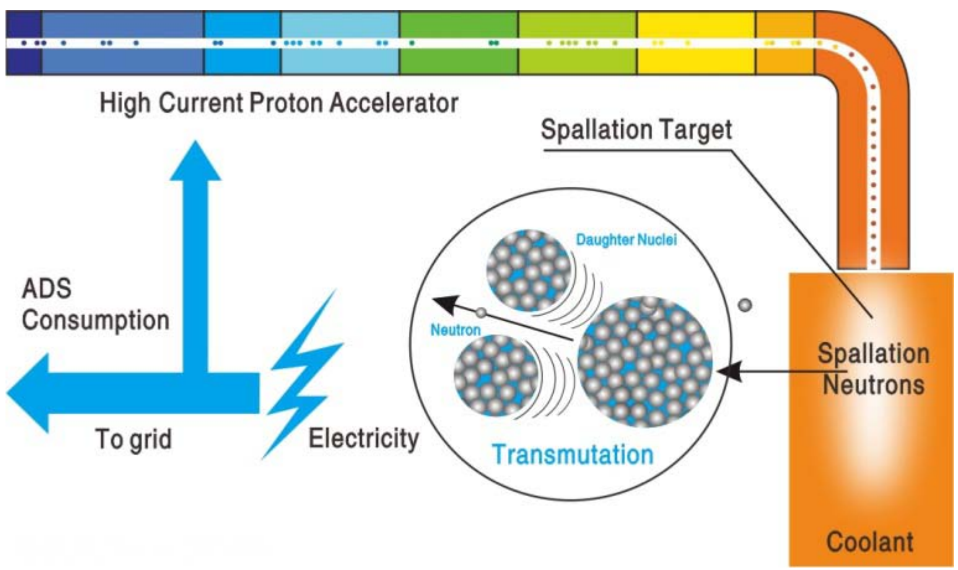
Accelerator **D**riven **S**ystem (**ADS**) is a promising path to resolve the problems



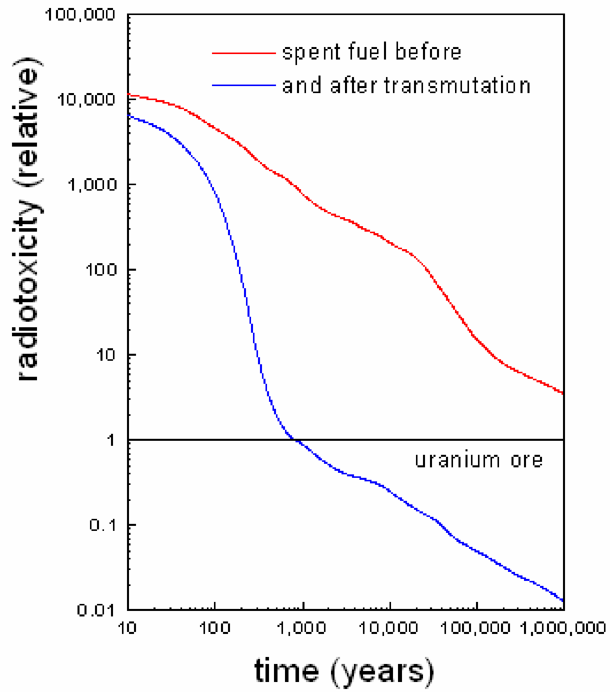
Global distribution of Uranium resources (Uranium 2014)

CIADS Introduction

- ADS was proposed for nuclear waste transmutation and nuclear power generation since late 1980s - early 1990's
- ADS consists of a high power proton accelerator, a spallation target, and a sub-critical core, which produces intensive, hard spallation neutrons by bombarding high energy protons on target to drive the sub-critical core



Schematic drawing of ADS

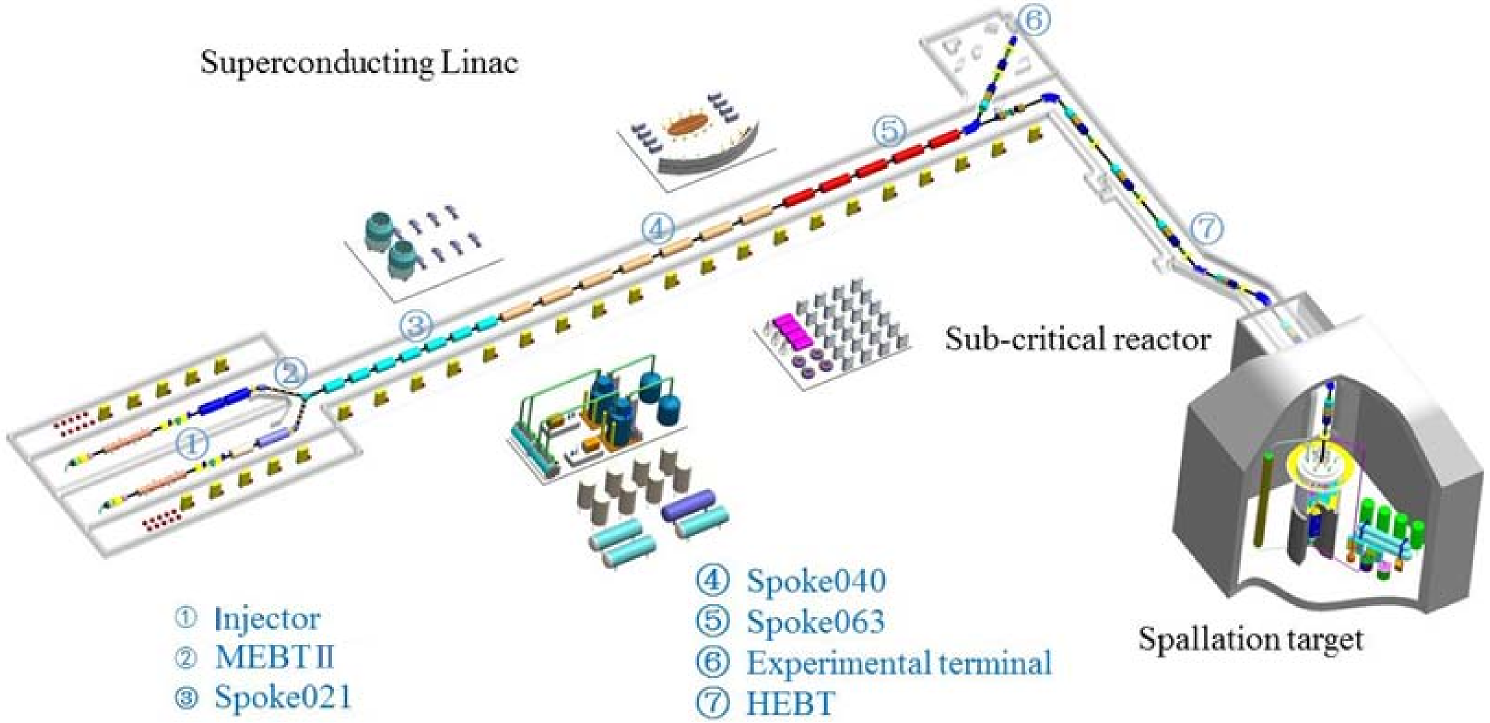


CIADS Introduction

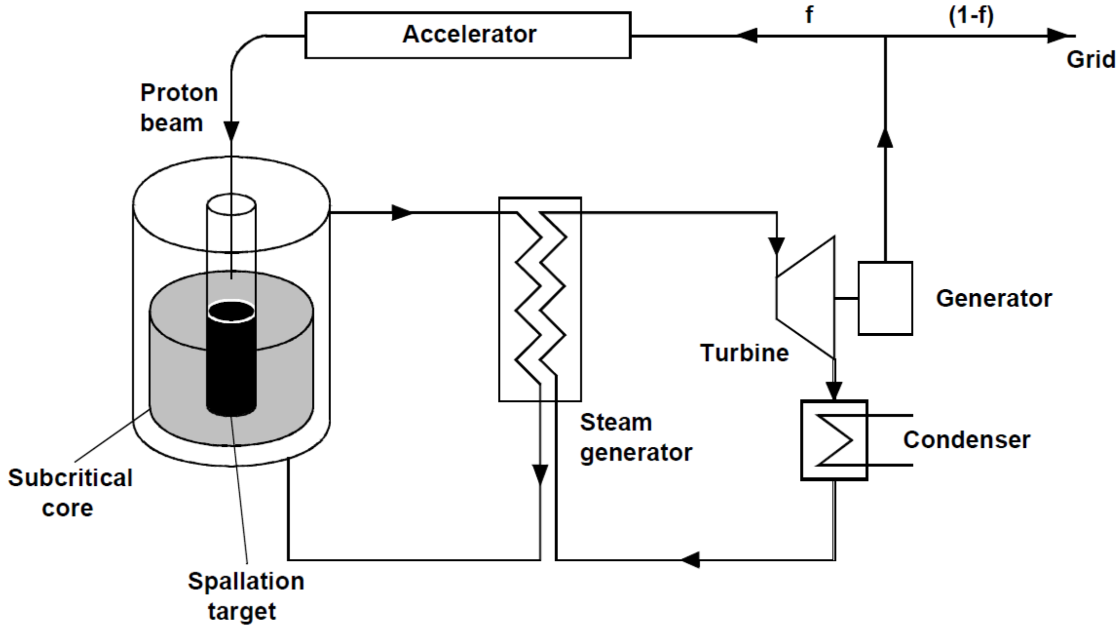
China Initiative Accelerator Driven System

The overall conceptual design of CIADS facility has been worked out

- LINAC: 250 MeV@10 mA with CW mode
- Spallation Target: granular flow spallation target, 2.5 MW
- Sub-critical core: 10 MWt, LBE cooled



- **ADS consists of high power proton accelerator, spallation target & subcritical core.**



ADS and FR in Advanced Nuclear Fuel Cycles — A Comparative Study, NEA/OECD, 2002

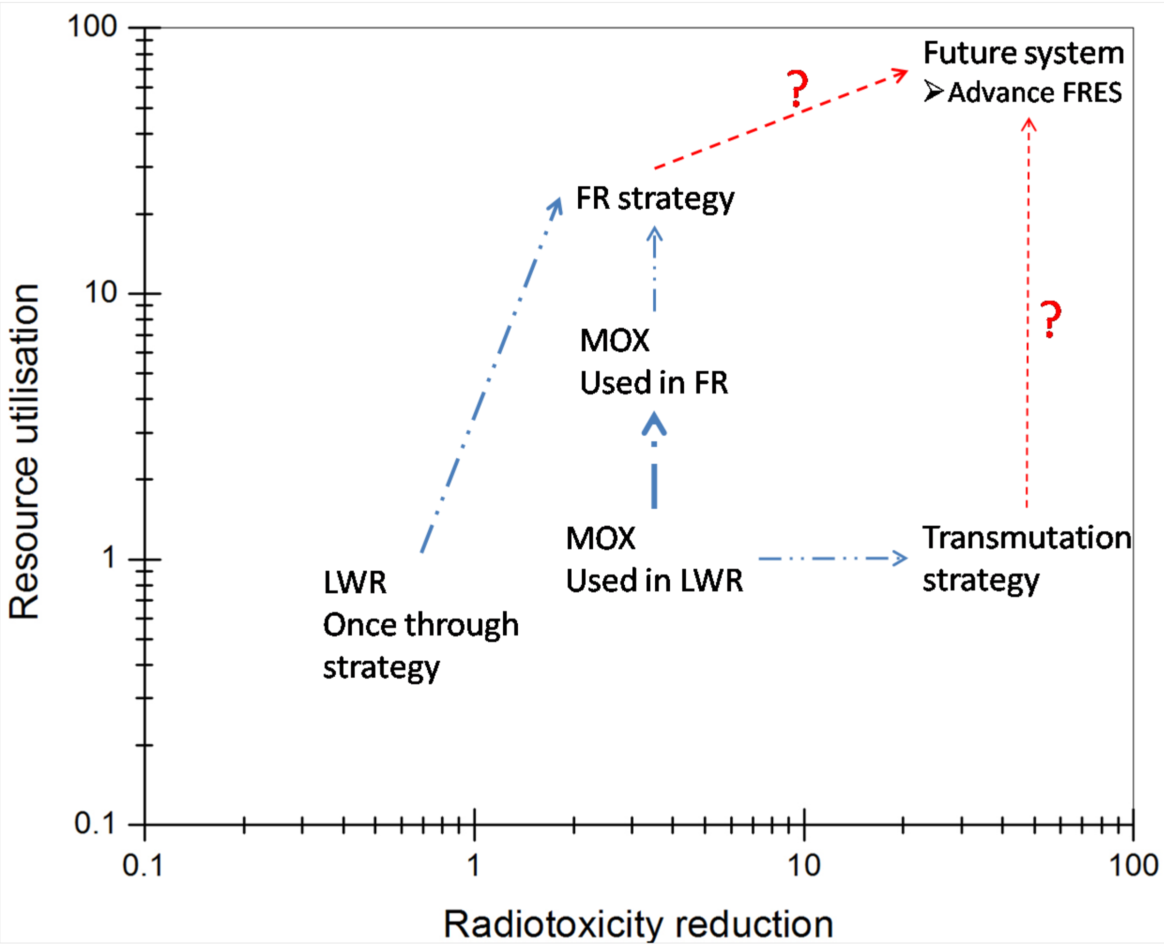
- Accelerator Driven System was proposed for:
  - **Nuclear waste transmutation (ADS)**
  - **Isotopes production (ex. Breed, ISOL, APT)**
  - **Energy Amplifier (ADTR)…**

Accelerator Driven Advanced Nuclear Energy System

ADANES Burner

ADANES - Perspectives of future

Paths to the future for nuclear fission energy

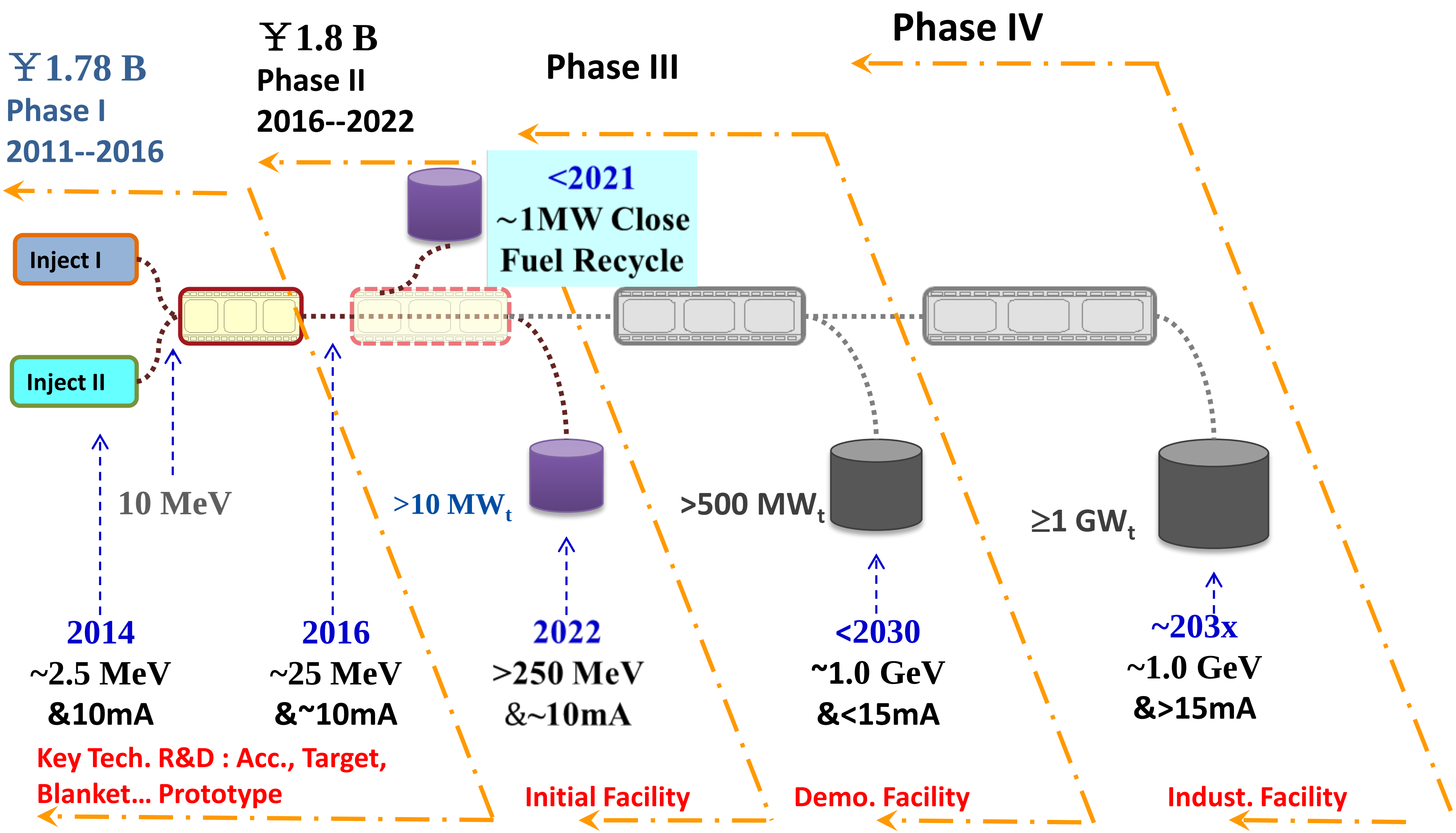


We proposed

ADANES:
Accelerator
Driven **A**dvanced
Nuclear **E**nergy
System

Fuel supply: $>10^3$ yr
Radiotoxicity: < 500 yr
Volume of NW: < 4%

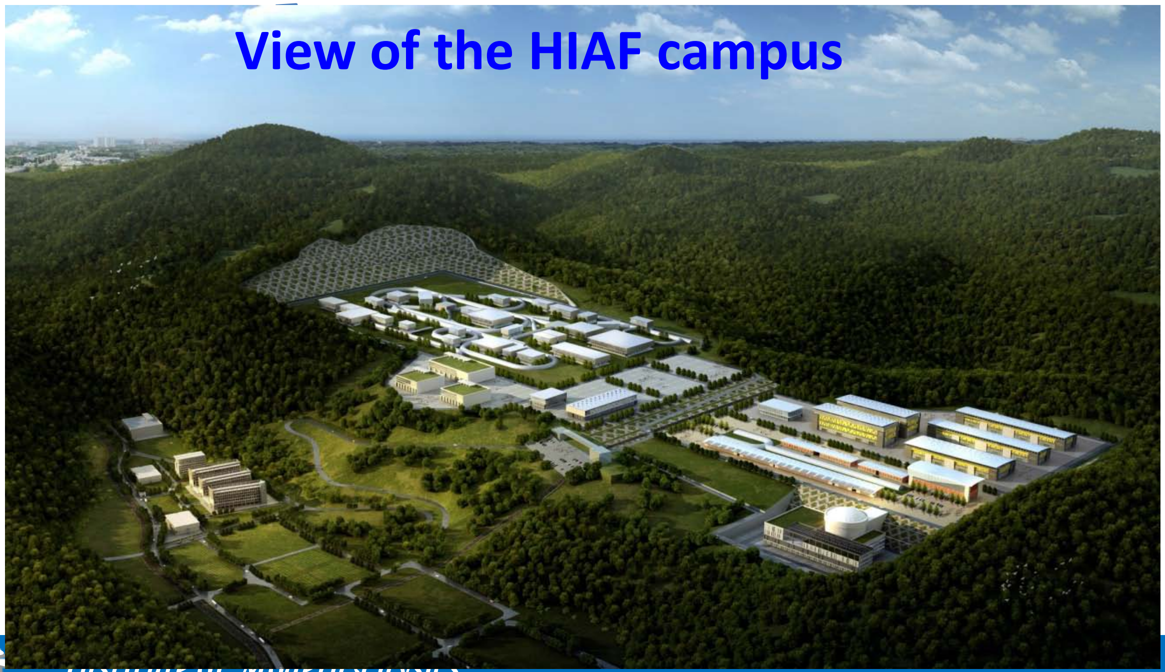
ADS/ADANES Roadmap



Site of HIAF & ADS projects

Huizhou
Guangdong Province(Canton)

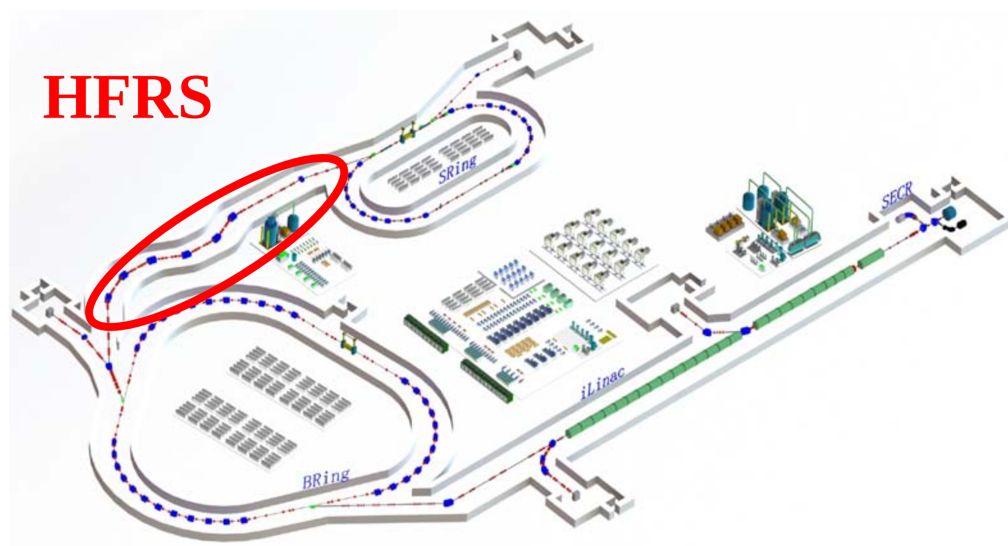
Site of HIAF & ADS projects

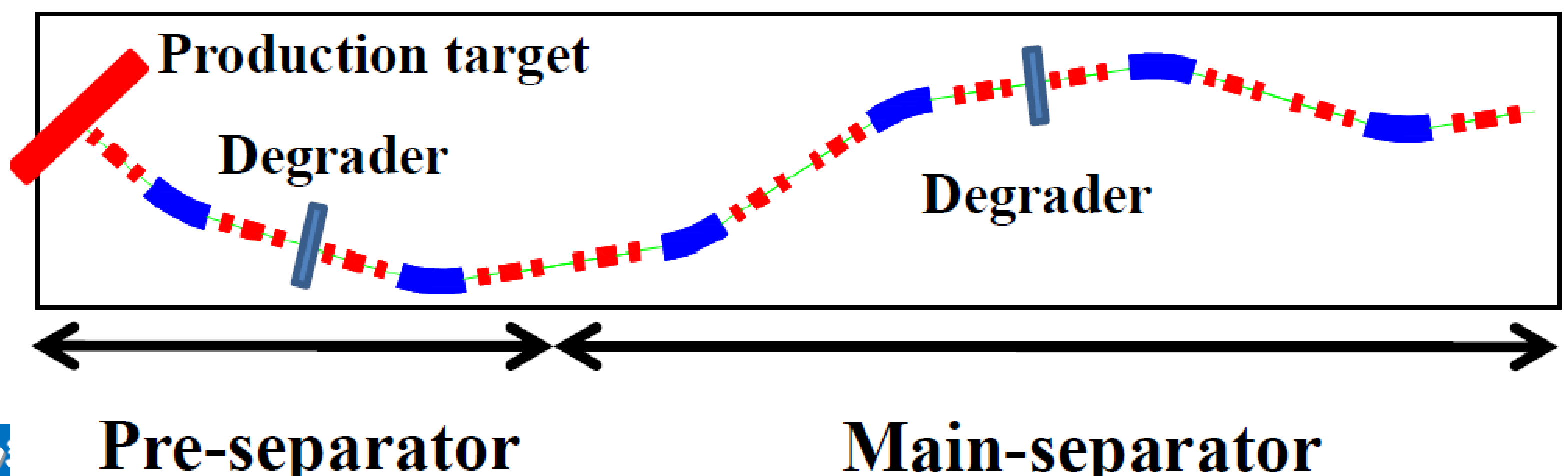


Introduction of HFRS

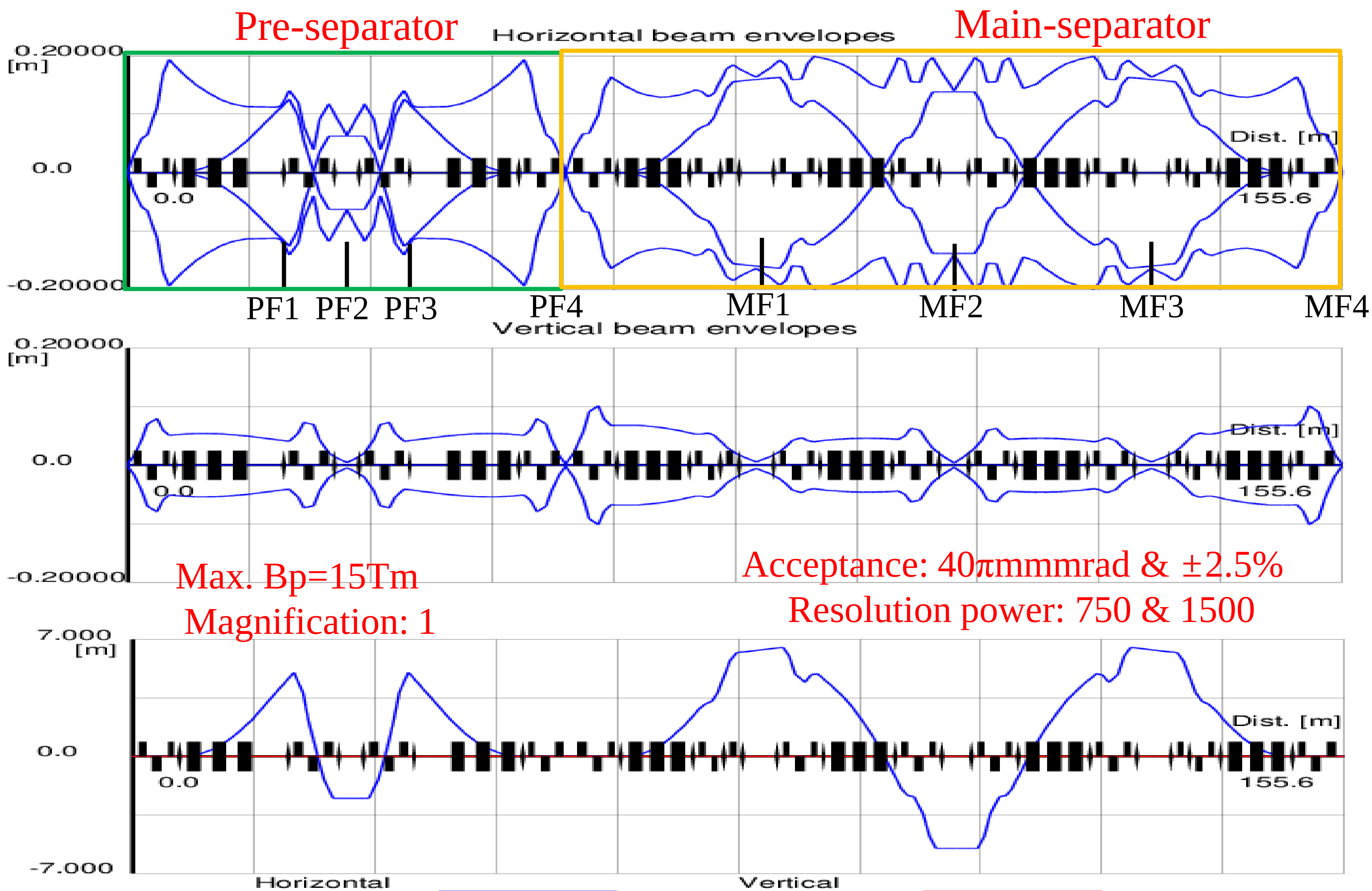
Layout of HFRS at HIAF

Projectile	Up to U with 800MeV/u
Method	Projectile fragmentation & Fission Bρ-ΔE-Bρ method
Max. magnetic rigidity	15Tm
Resolving power	1500
Acceptance x/y	40πmmmrad
Momentum acceptance	±2.5%
Angle acceptance	±40mrad (x) & ±20mrad (y)
Beam spot at target	±1mm(x) & ±2mm(y) (1 sigma)
Max. envelope	±200mm*±100mm
Total length	156m

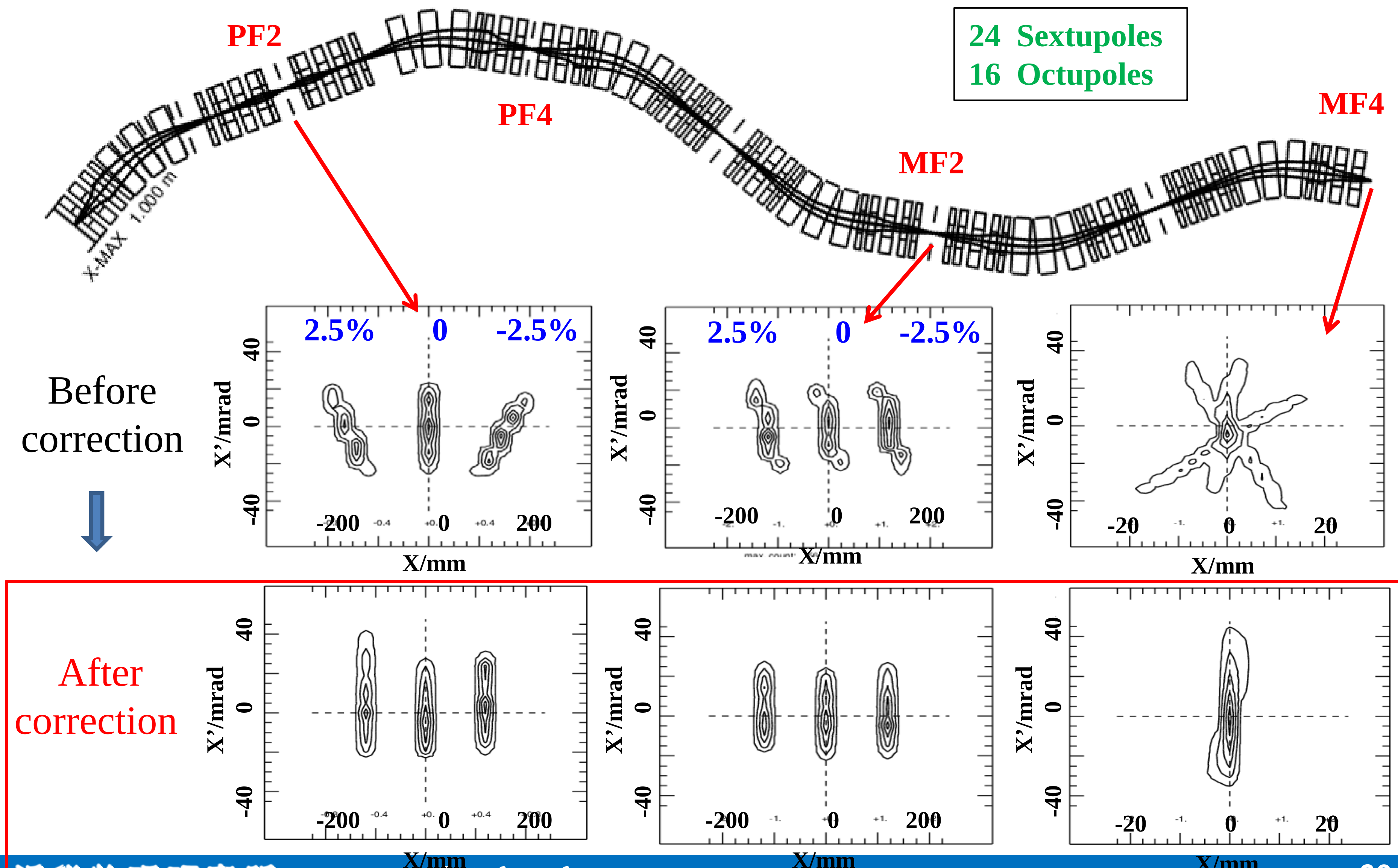




Beam optics of HFRS-1st order



High order beam optics of correction

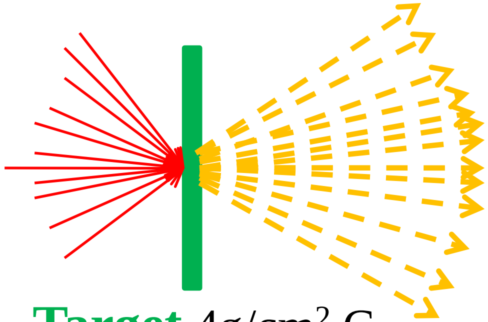


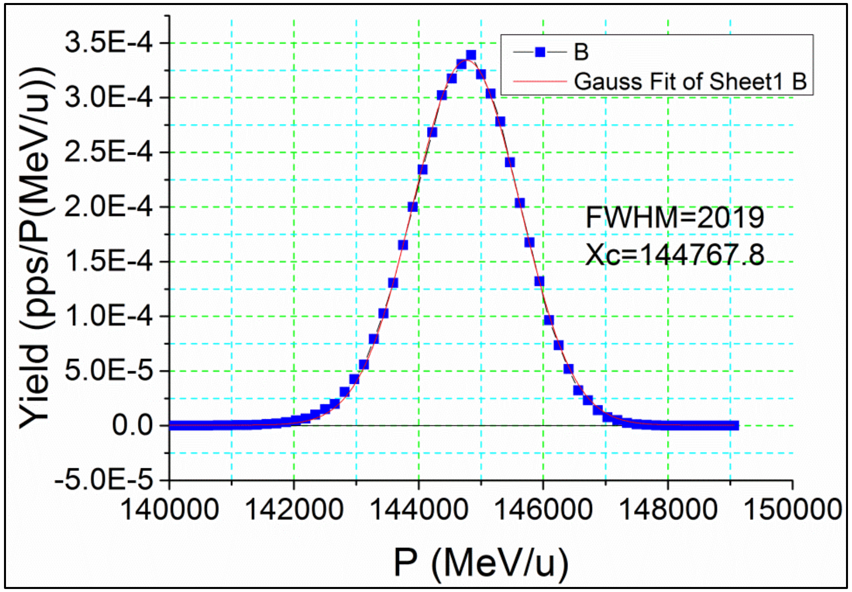
Simulations of RIB

- RIB: $^{100}Sn^{50+}$

Projectile

$^{124}Xe^{54+}$
1000MeV/u
3.33E10pps





Momentum distribution of $^{100}Sn^{50+}$ after target

PF2: 5.7 g/cm^2 Al degrader
MF2: 2.85 g/cm^2 Al degrader

⇩

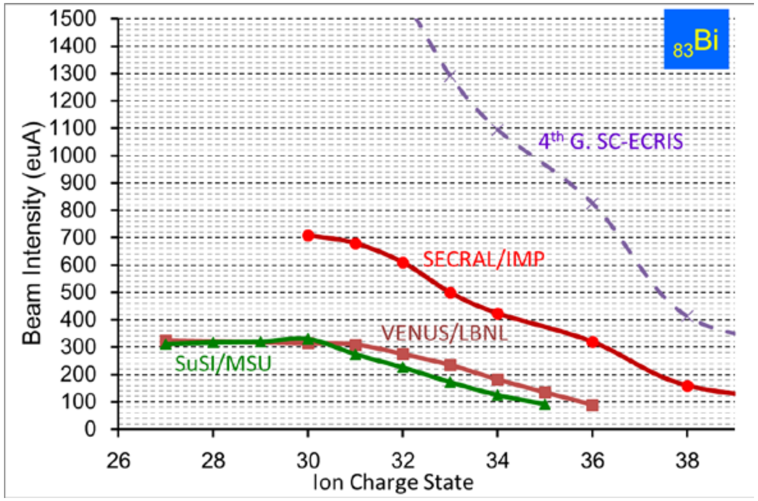
A. Production rate: 7.8e-3pps
B. Transmission: 19.48%
C. Purity: 28.2%

Superconducting ECR

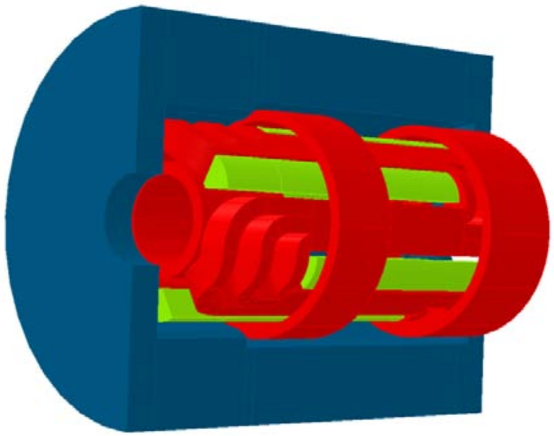
None of existing highly charged ion sources can meet HIAF requirements at present

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(720)**	**400**
3rd Generation Sources	**SECRAL/ 24 GHz**	
Gain for HIAF	**2.1**	**4.2**



Intense heavy ion beam production

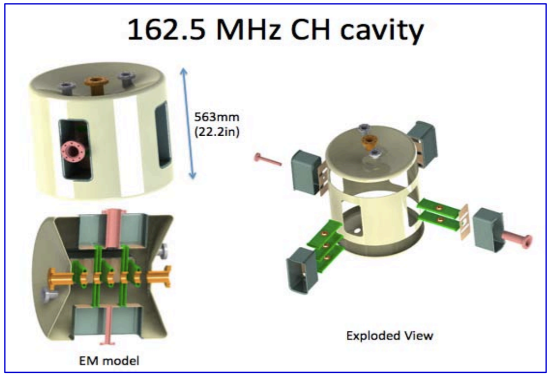


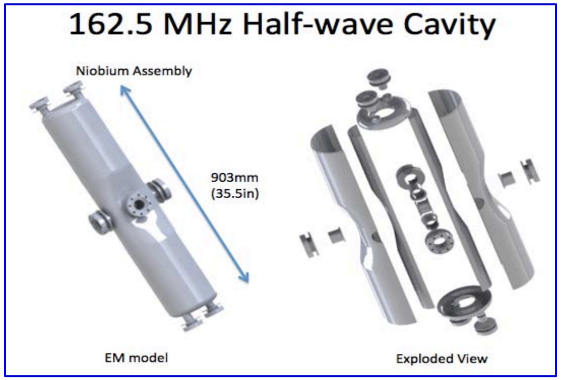
- New magnet configuration based on the traditional Ioffe-bar layout can minimize the highest field inside the magnet coils, and maximize the efficient field inside the plasma chamber.

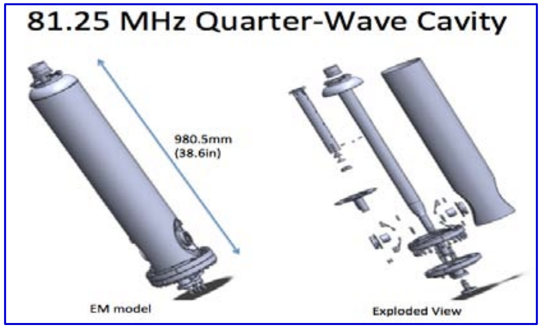
- Possible utilizing the matured NbTi technique instead of the cutting edge Nb_3Sn technique will be more cost efficient and technical feasible.

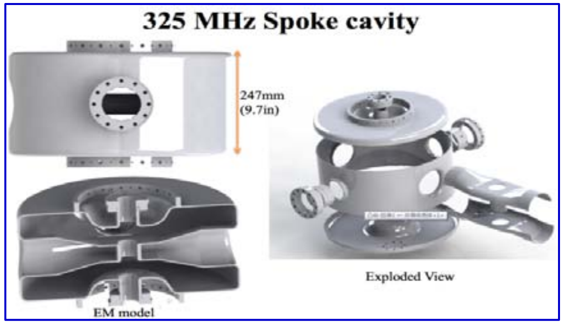
Development of iLinac

- Highest pulse current of 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





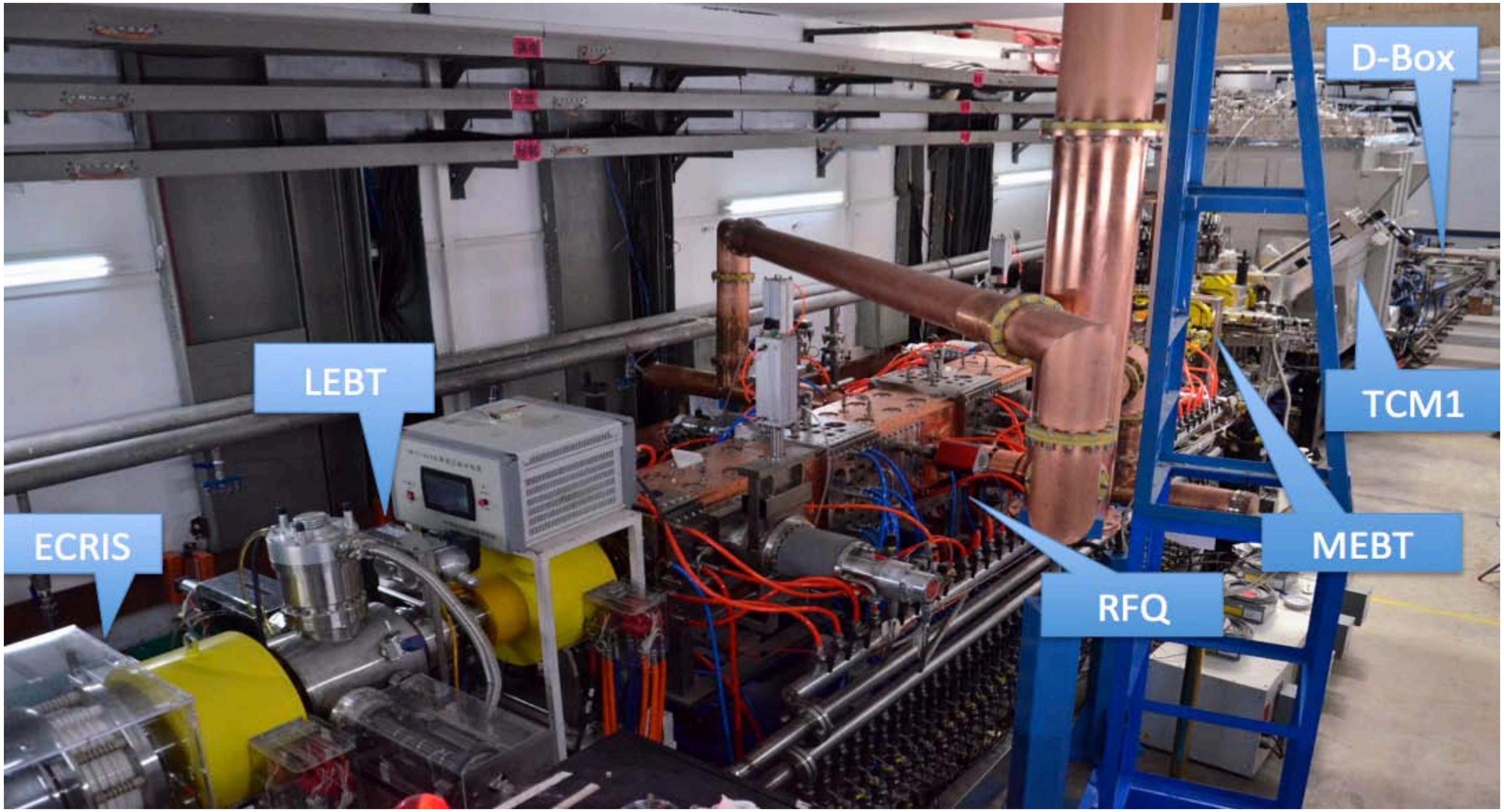




- The average uncontrolled beam loss should be limited to below 1 W/m level

Development of iLinac

The 2.5-MeV Demo of Superconducting LINAC

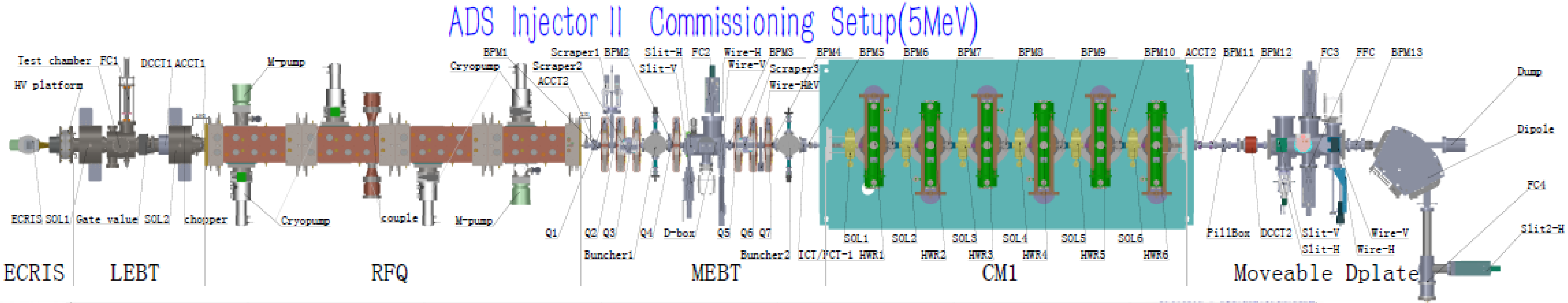


- RFQ operated successfully at 10 mA, CW mode, for many times. the record was 4.5 hours. The rms emittance is 0.2~0.3 pi.mm.mrad, transmission efficiency is 97%.
- MEBT and TCM operated at CW 10 mA 2.5 MeV for 1 hour. HWR operated successfully @ Ep=25MV/m, the design value.

Commissioning of 162.5-MHz CW RFQ

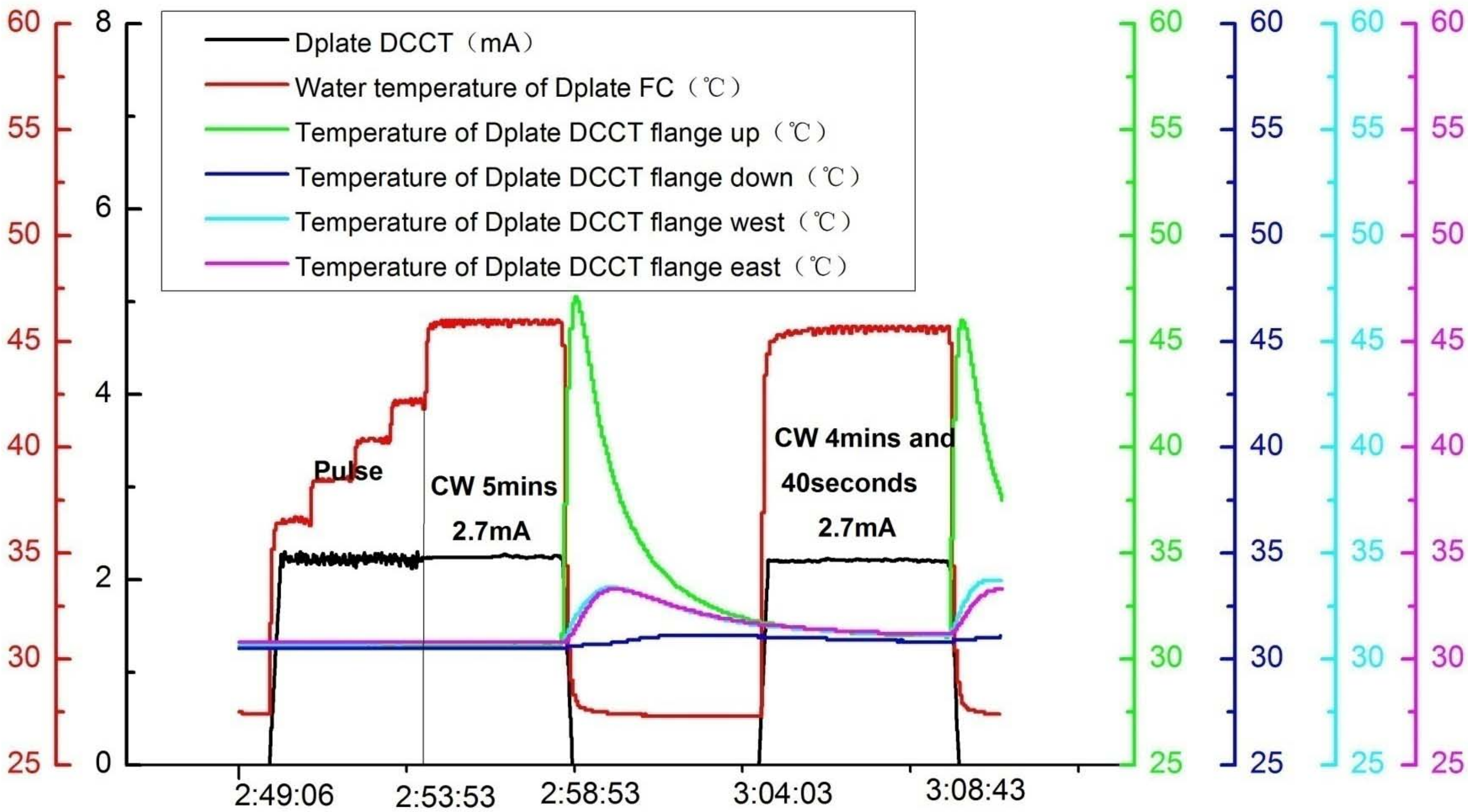
- June 6th, the first beam, energy is 2.15 MeV
- June 30th, 10 mA, CW beam, 4.5 hours, beam power 21.6 kW
- July 18th-19th, tested and peer reviewed by CAS
- July 24th, 18 mA, pulse beam, 37.8 kW, transmission 87%
- Total operation time is ~1000 hours including CW@10mA around 10 hours
- Record of non-trip operation is ~220 hours

Beam commissioning of MEBT & CM6



- Lattice settings of MEBT and CM6
- HWR Phase scan
- Tuning with 10 mA pulse beam and 2.7 mA CW beam

2.7 mA CW beam of MEBT & CM6



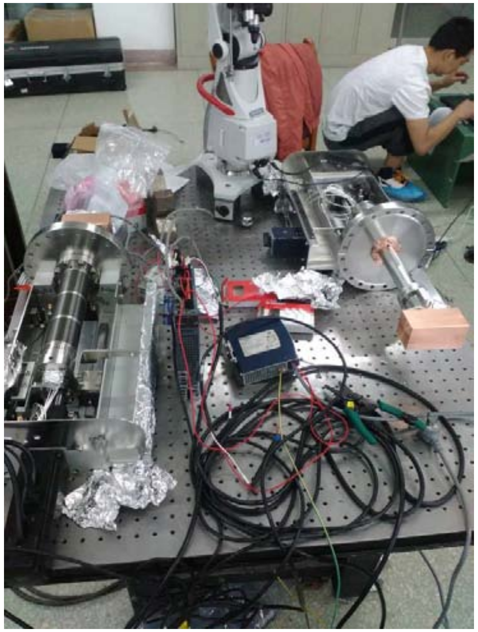
Dynamic vacuum

Collimator prototype development

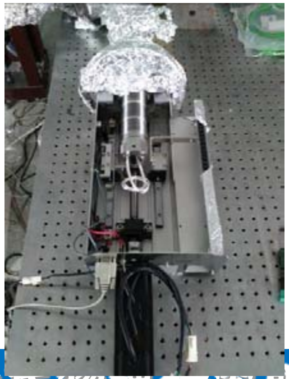
Chamber vacuum test

Collimator vacuum test

Mechanical test



Collimator Motion control test

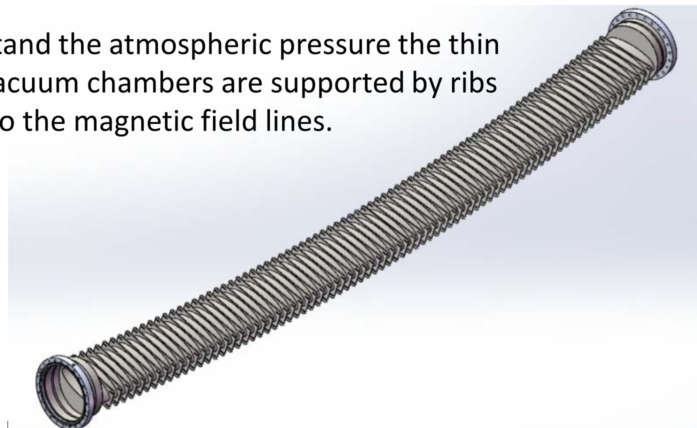


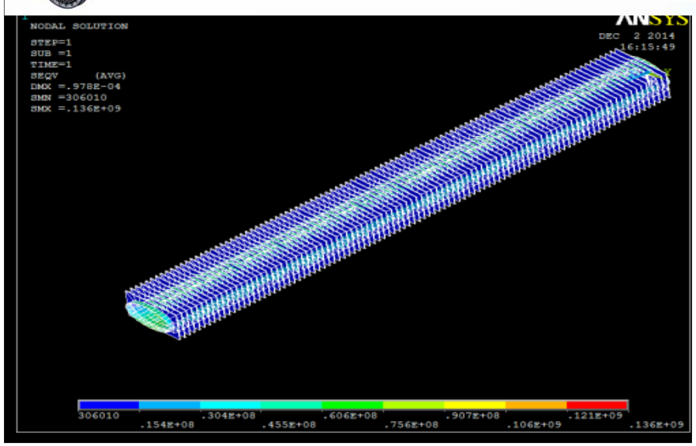
Beam test: Xe^{27+}

Thin wall vacuum chamber prototype

Due to high ramping rates, thin wall vacuum chambers are needed for all magnets to keep eddy currents at a tolerable level.

To withstand the atmospheric pressure the thin walled vacuum chambers are supported by ribs parallel to the magnetic field lines.





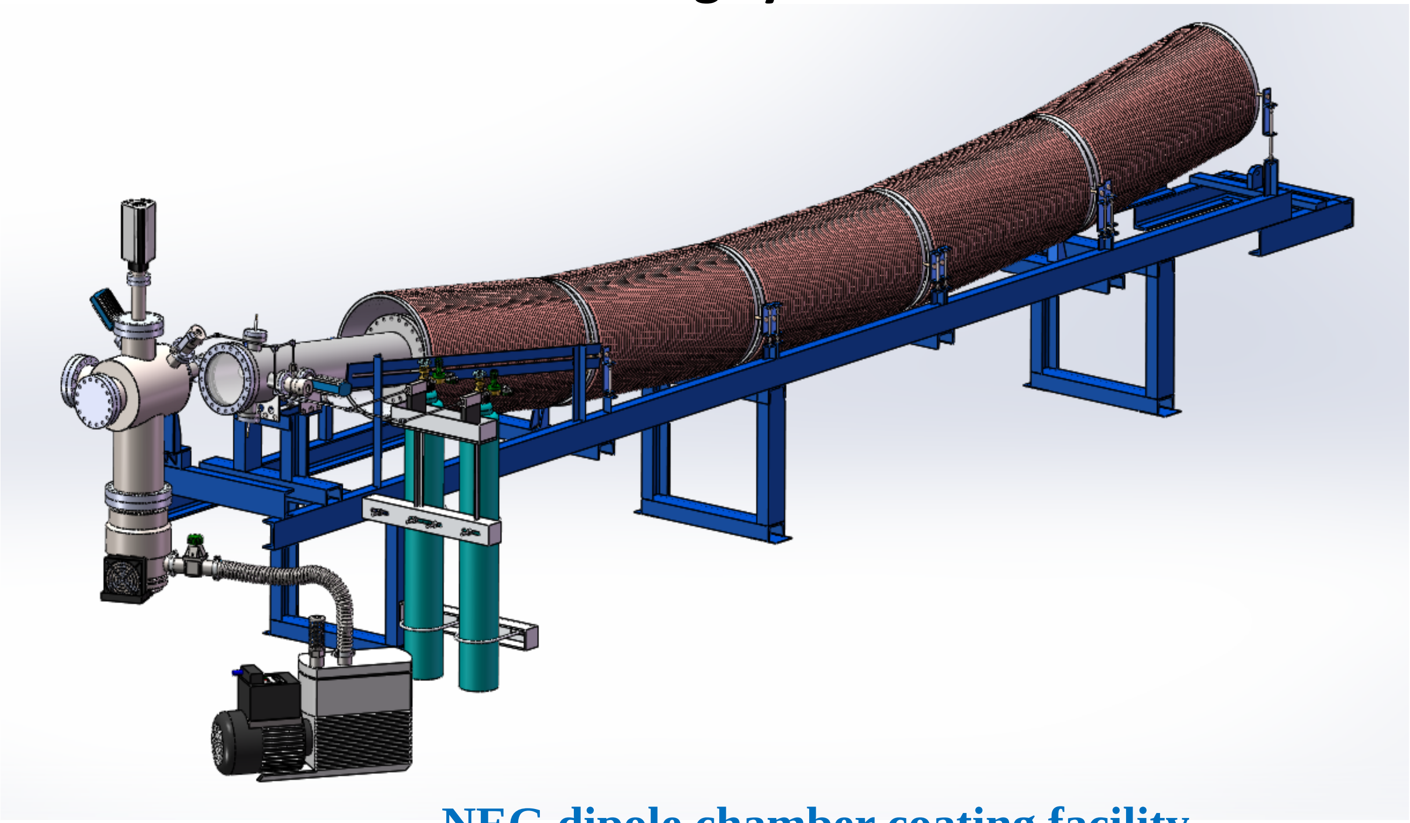
0.3 mm vacuum chamber design

0.3 mm vacuum chamber prototype

- 500mm, 1/5
- Elliptical aperture
- Stainless steel
- Ribs supporter parallel to the magnetic field lines

Vacuum chamber

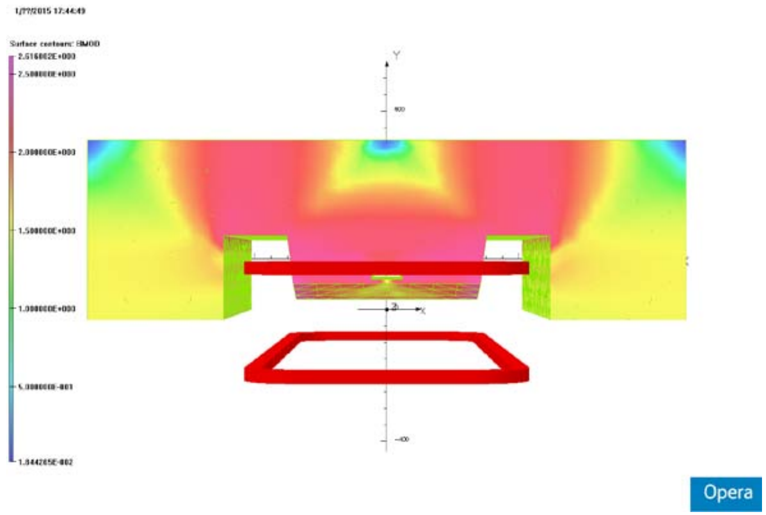
NEG coating system

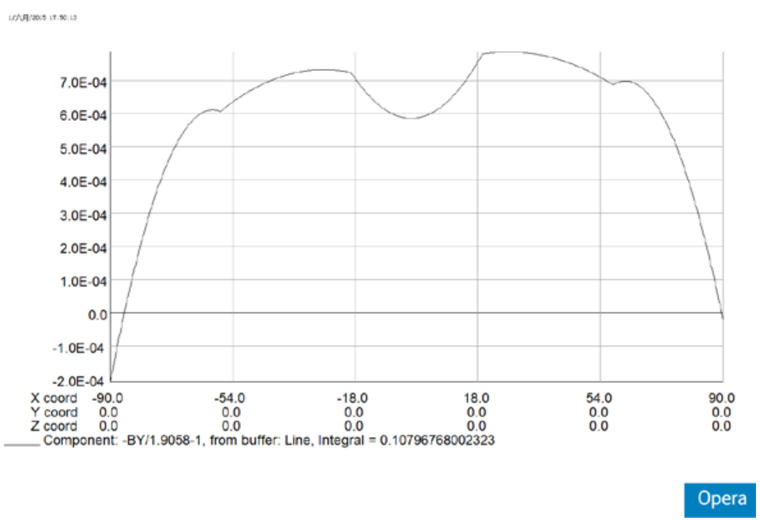


NEG dipole chamber coating facility

Non-Evaporable Getter thin films (NEG) is an excellent solution for conductance limited chambers, for the stabilization of the dynamic vacuum pressure. For this purpose, three is a proposal to develop the chamber coating facility. A dipole chamber coating facility has been designed for HIAF.

EM design





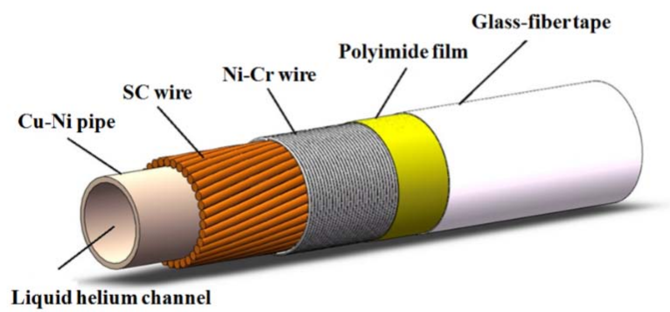
By (T)	2.0
Current（A）	11000
Total turns	4*3
Storage energy （MJ）	0.4
Inductance （mH）	7.6
Iron weight (Ton)	

R&D of SC magnet for HIAF

Low loss superconducting cable

Nuclotron Type Cable
CACC: Cable-around-conduit-conductor

- Cu-Ni pipe: inner radius 6 mm with thickness 0.5 mm
- NbTi superconducting wire: diameter 0.7 mm
- NiCr (0.3 mm) wire is close winded for overbanding
- One layer polyimide film (0.1 mm) is half wrapped
- Two layers of glass-fiber tape (0.1 mm) is then half wrapped



Superconducting cable parameters

strands	32
Twist pitch	120 mm
ID	6 mm
OD	10.2 mm

Advantages:

✓Good performance of mechanical stability
✓Lower eddy current loss
✓Good performance of cooling
✓Low critical current degrade

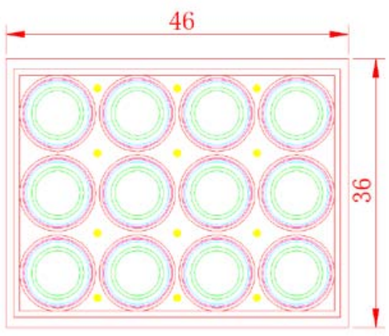
Disadvantages:

•Low engineer current density
•Expensive than rutherford cable
•Hard to bend and wind
•Difficult to make joints

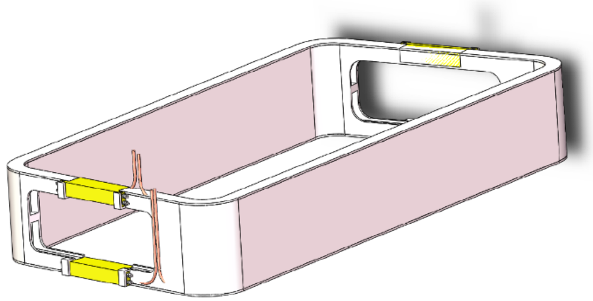
Supercritical or two-phase helium force-flow cooling

Superconducting dipole prototype

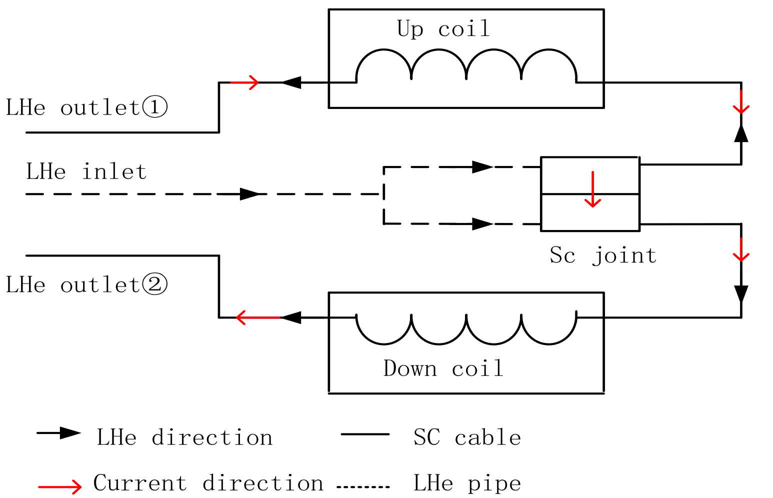
- Based on the Super-FRS dipole's design;
- Racetrack coil winded with nuclotron type cable;



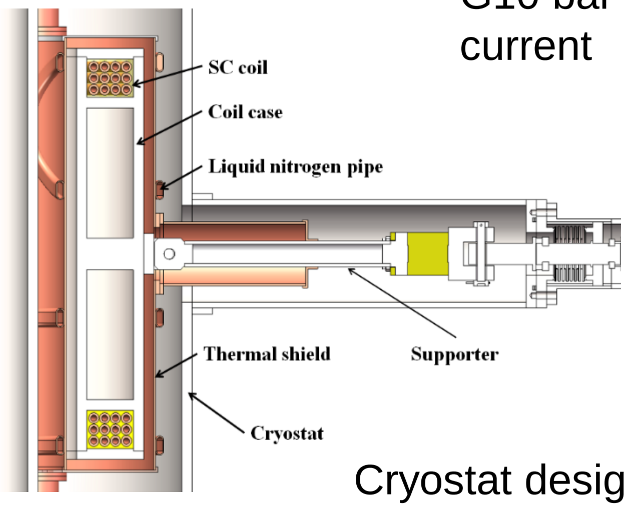
coil cross-section



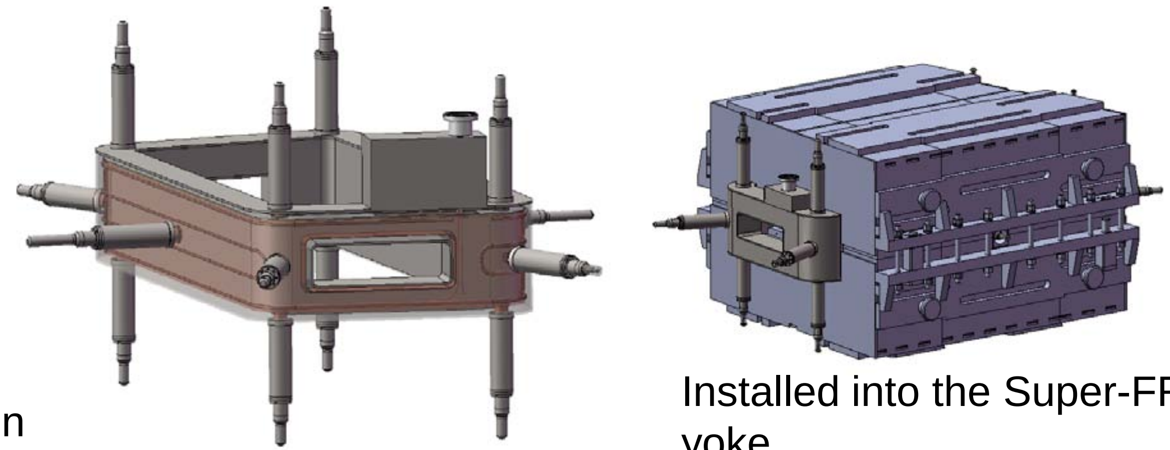
Coil case is broken with G10 bar to reduce eddy current



Electric and cooling circuit for the two coils

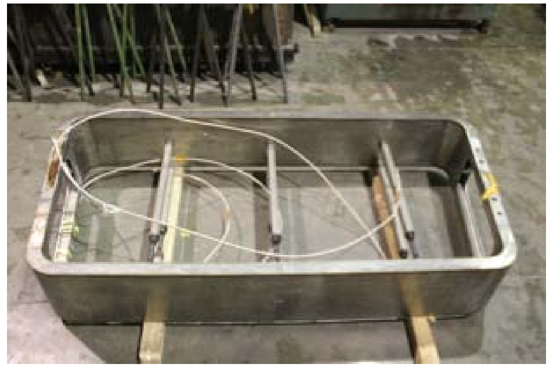


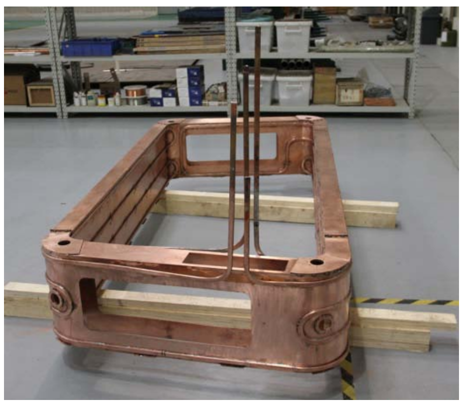
Cryostat design



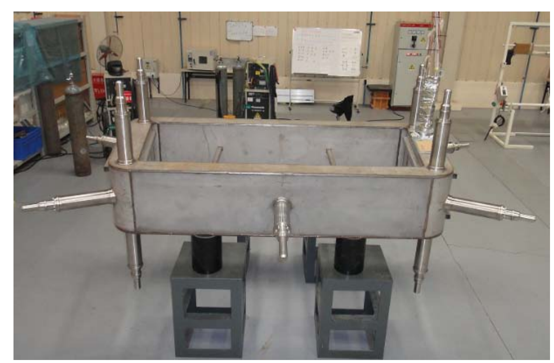
Installed into the Super-FRS yoke

Fabrication status





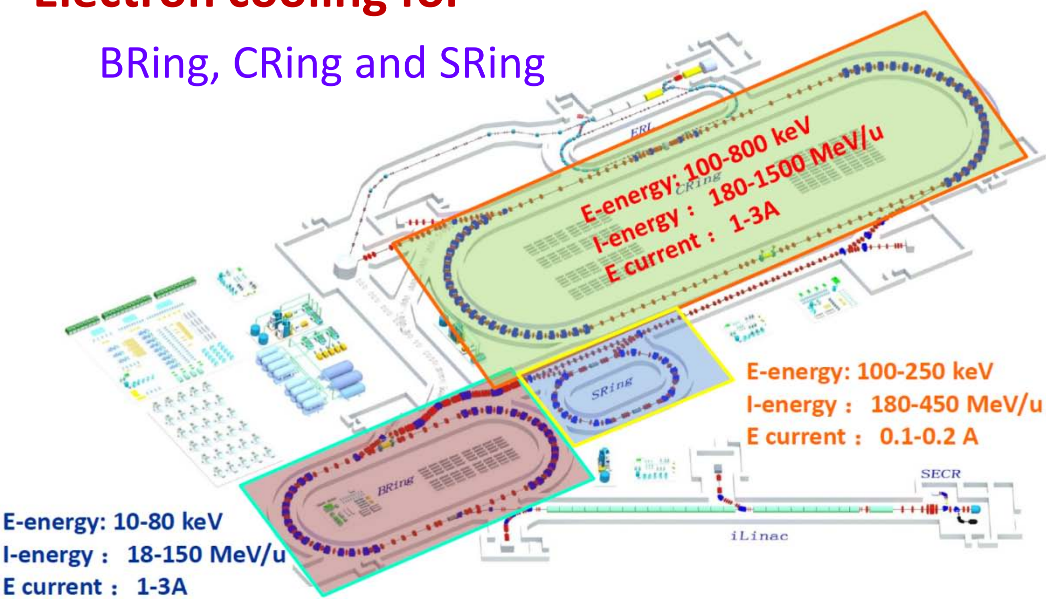
- ❖ Finished the coil winding and expoxy impregnation;
- ❖ The cryostat has been fabricated and assembled
- ❖ Waiting for the feeding box, cryogenic system, current leads and power supply to do cryogenic testing



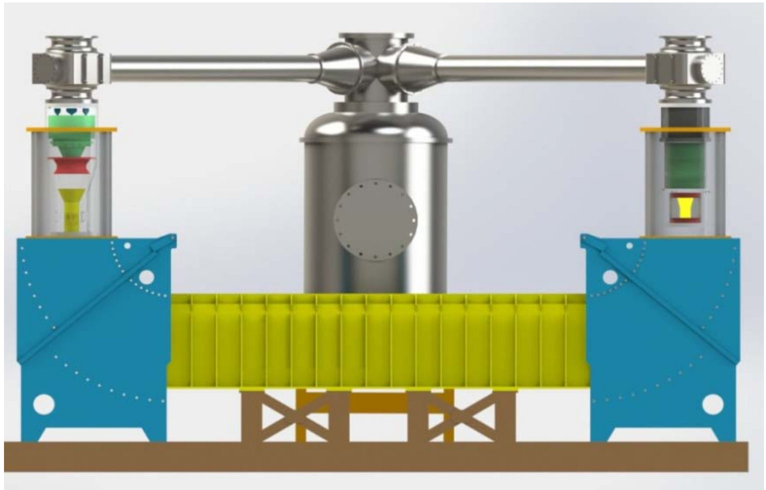
Electron cooling

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

Stochastic cooling at CSRe

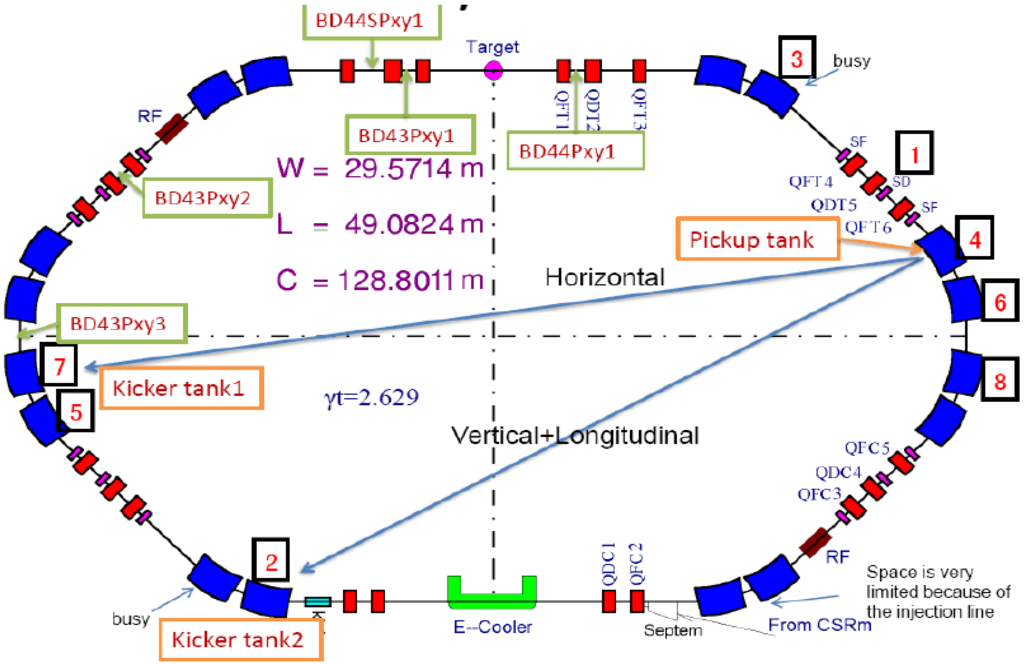
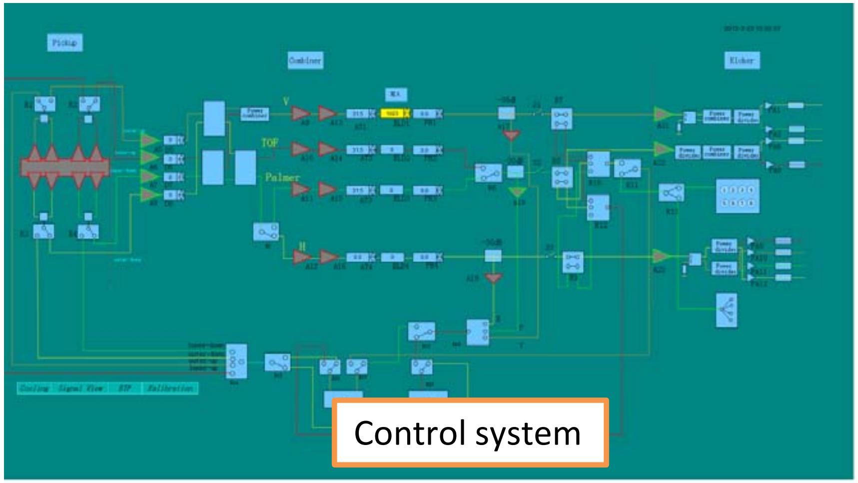


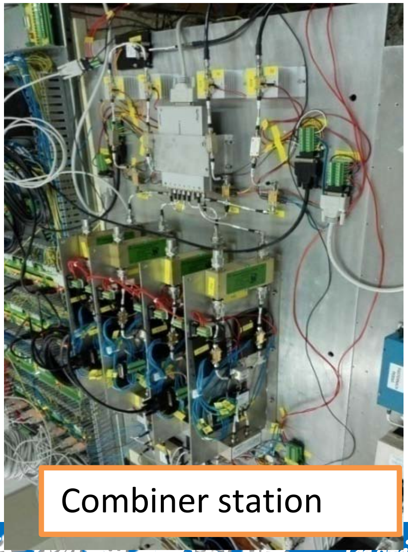
Figure 1 layout of the CSRe

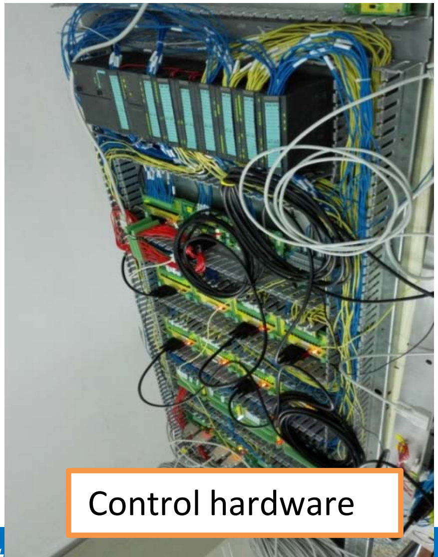
- Cooling ions: RI beam
- Energy range: 350MeV/u- 420 MeV/u
- Momentum spread after cooling: ± 5.0e-4
- Emittance after cooling : 5~10 π mm·mrad
- Bandwidth

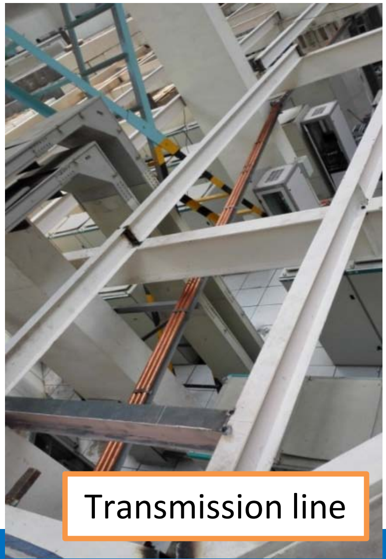
200 MHz-600 MHz@phase1, 200 MHz-1.2 GHz@phase2

Stochastic cooling at CSRe

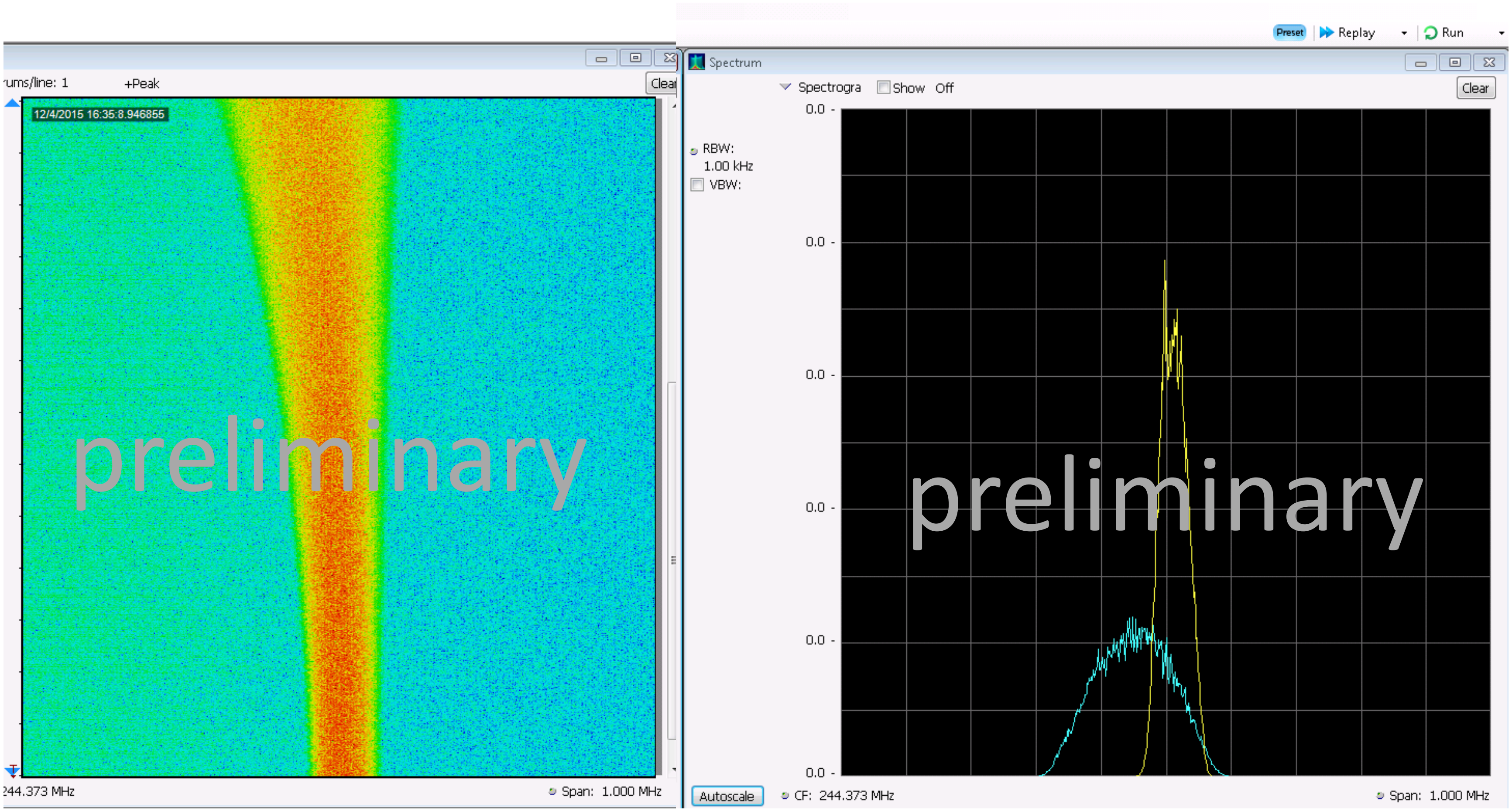








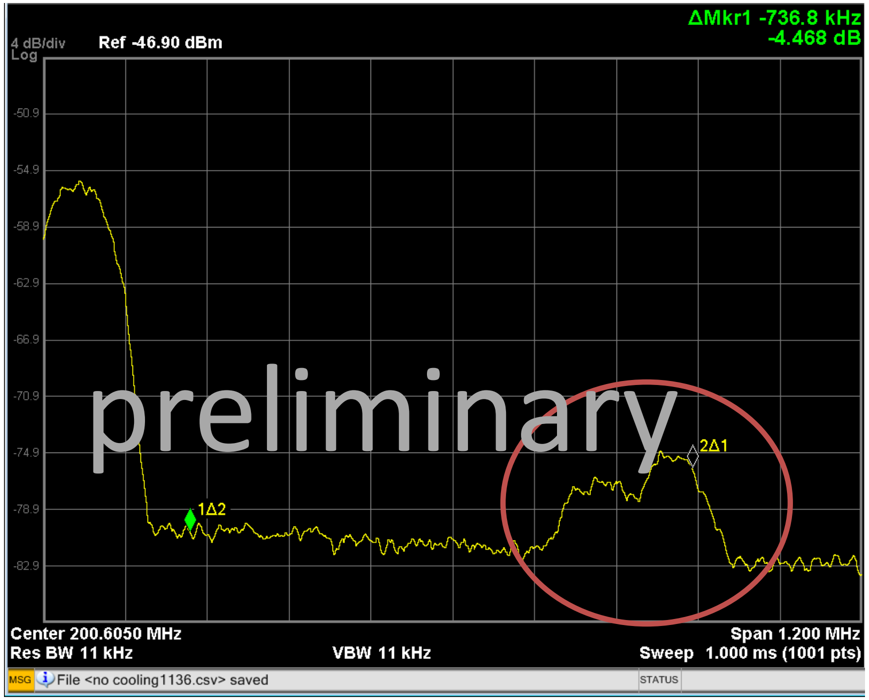
CSRe long. stochastic cooling

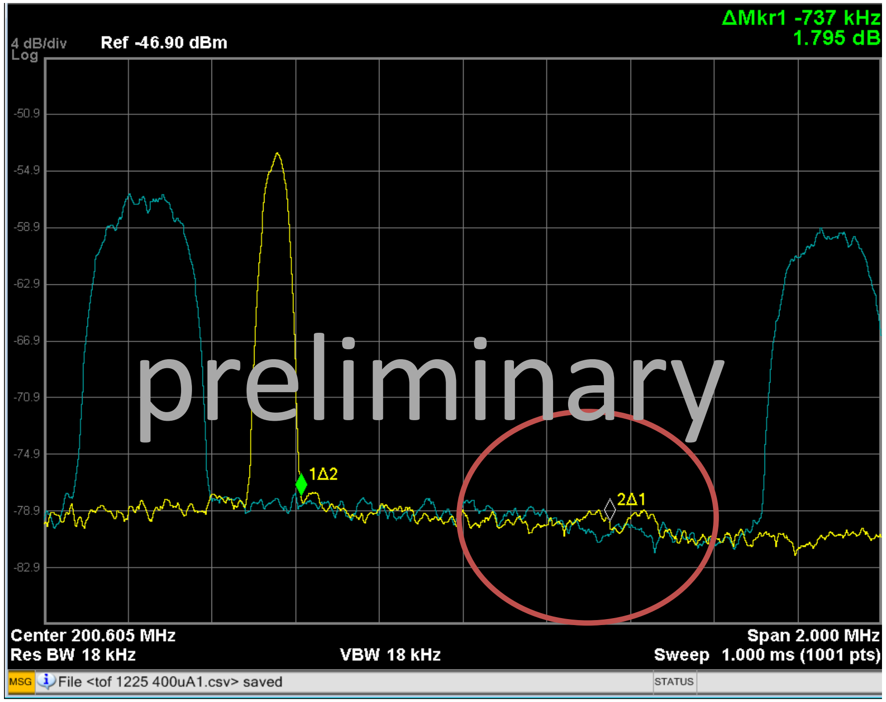


C6+， 380MeV/u，N=7.0e7

Δp/p（rms）： ± 8.0e-4 → ± 3.0e-4

CSRe transverse stochastic cooling



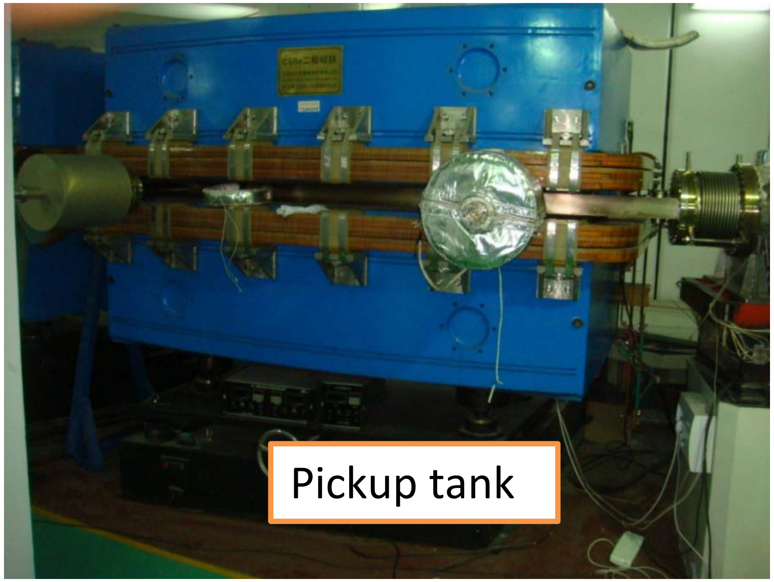


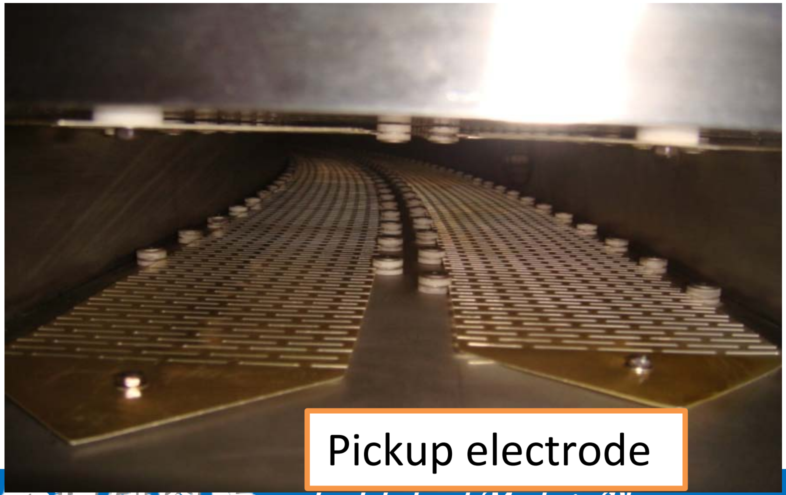
Injected beam, large sideband

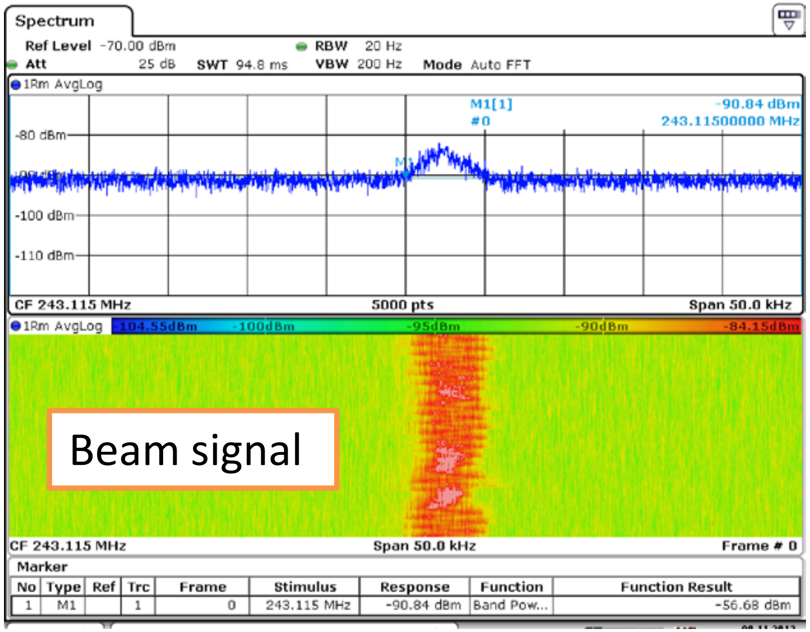
After cooling, sidebands disappear
Yellow line: after longitudinal and transverse cooling
Blue line: after heating only in longitudinal phase space

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

New possibilities

ADS + HIAF

Intense radioactive beam facility

The CAS Science city/park in Guangdong

HIAF and CIADS Projects

IMP-CAS, Lanzhou, China: H S Xu Y H Zhang, X H Zhou, X W Ma, Z G Hu, Y He, L Yang, G Q Xiao, ……

Y J Yuan, J C Yang, J X Wu, L J Mao, J X Wu, J W Xia, H W Zhao, W L Zhan, ……

GSI, Darmstadt, Germany

J-Lab, USA

MSU, USA

BINP Russia

TRIUMF, Canada

Juelich, Germany

France

……

Thank you for your attention!