The 6th International Particle Accelerator Conference, IPAC15

Heavy ion accelerator in China-
Status and Initiative

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2015.05.08 , Richmond, Virginia, USA

Outlines

Status of existing facilities

Updates & New developments

Perspectives-New proposal

Heavy ion accelerator in China-

Status and Initiative

Status of existing facilities

Tandem in China

2×6MV Tandem
Peking University
introduced from Oxford University in the late 1980s
Ion species：most of heavy ions
Application：heavy ion irradiation, accelerator mass spectrometry

2x1.7MV Tandem
Beijing Normal University
Ion species：H, B, C, O, Al, Si, P
Research: ion beam analysis

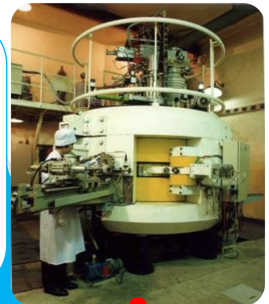
2x1.7MV Tandem
Institute of nuclear science and technology, Lanzhou university
Main purpose：research of ion collisions with atomic molecular gas, negative ions and solid surface interaction experiment

HI-13 Tandem
China Institute of Atomic Energy
put into operation officially in 1987, provide all kinds of ions except the inert gas

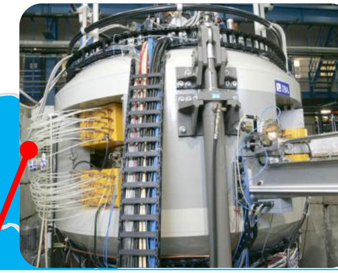
Low energy facilities

Cyclotron in China

CYCIAE-30 Cyclotron
China Institute of Atomic Energy
p-30MeV
Application: isotope production; delivered beam in 1994



Proton Therapy Center, Wanjie Corporation
proton-200MeV, outage now

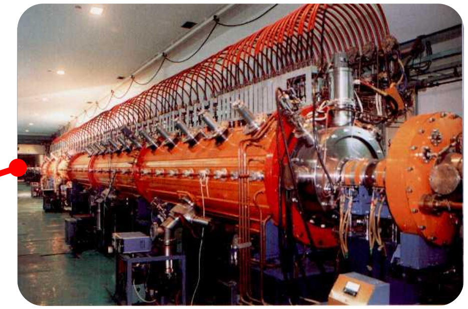


CS-30 isochronous cyclotron
Institute of Nuclear Science and Technology, Sichuan University
USA TCC Corporation, p--α, p-26MeV
Purpose: medical isotopes and industrial isotopes development and production

Ultra-sensitive Small Cyclotron Mass Spectrometer
Institute of Applied Physics
50KeV, built in 1998

Institute of Fluid Physics
proton-11MeV intensity : 50μA
delivered beam in 2013

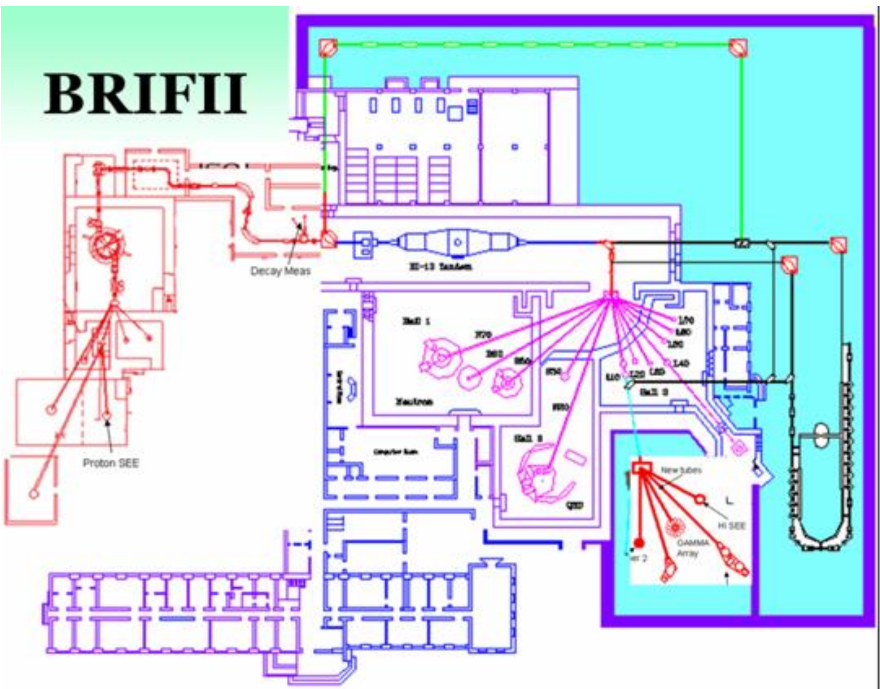
Linac in China



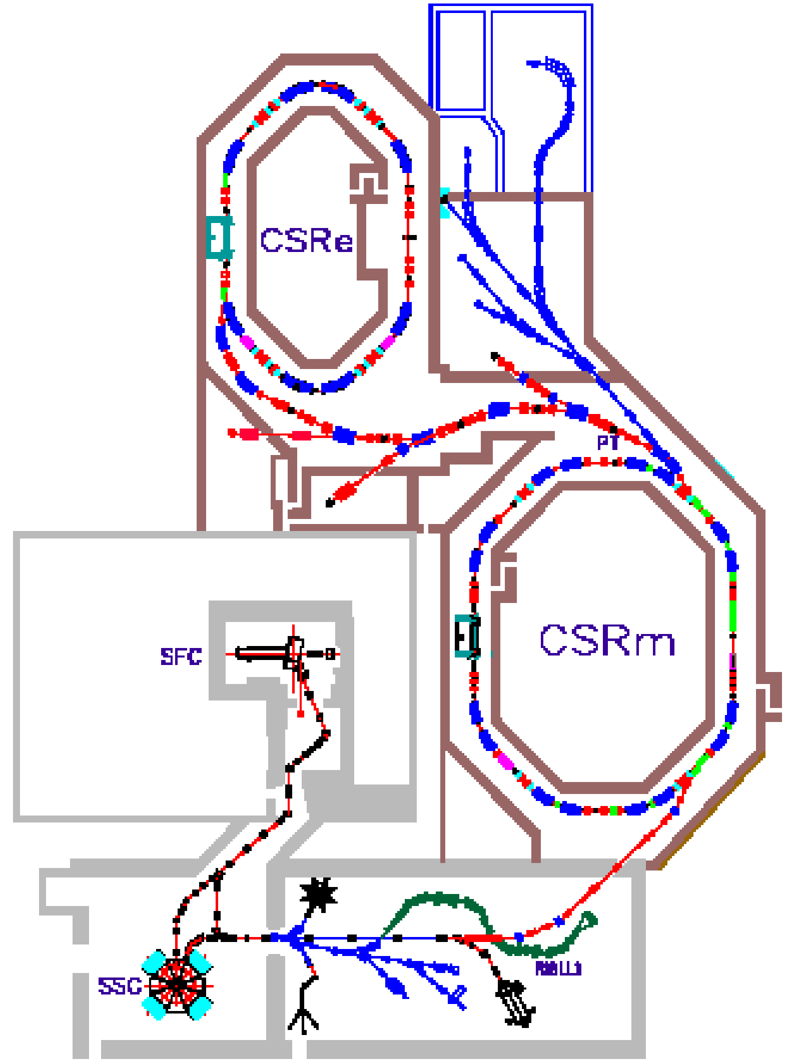
35MeV proton linac BPL
Institute of High Energy Physics
the first linac of China
built in the late 1980s and closed in 2003

ISR RFQ-1000
Peking University
overall separation ring high frequency quadrupole field RFQ, built in 1999
Ion species: O+, O-, N+   Duty ratio: 1ms/6ms
Energy: 1MeV   Frequency: 26MHz

Two major heavy ion facilities in China



Beijing
BRIF, BRIF II ,
Low E HI, RIB, 2014

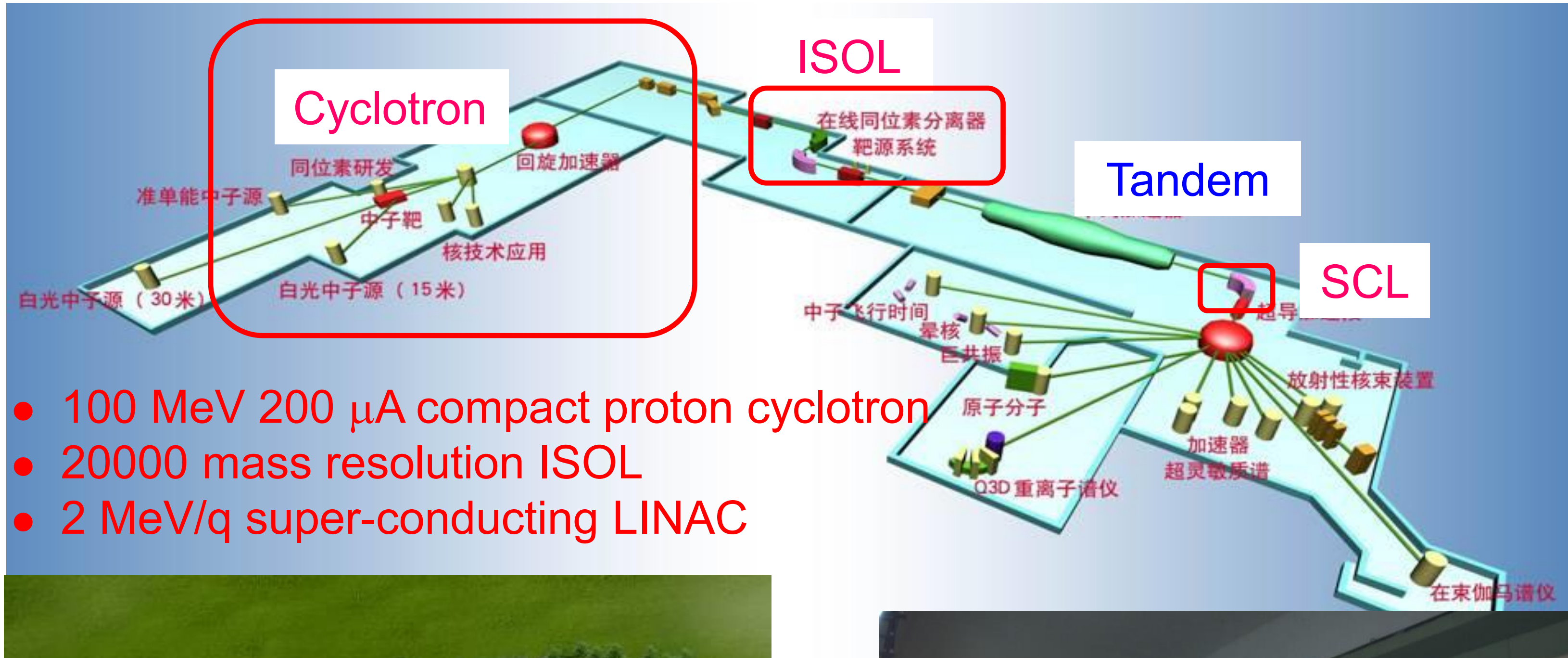


Lanzhou, HIRFL
Med E HI, RIB, 2008

Status of BRIFII

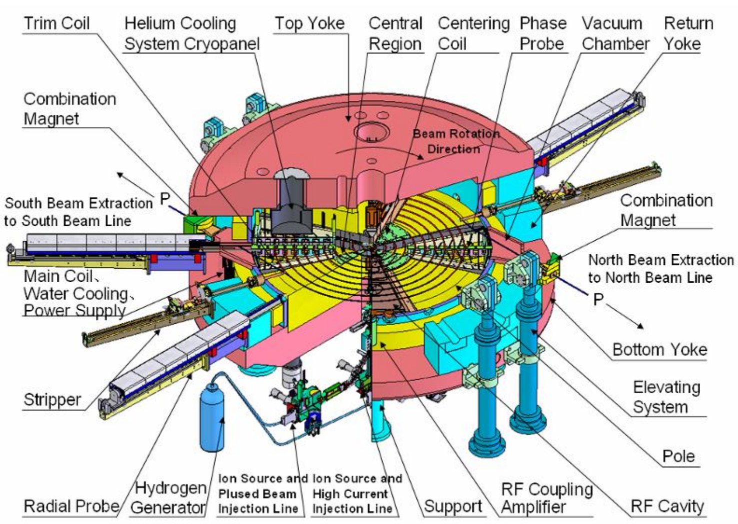
BRIF-(Beijing Rare Ion beam Facility)

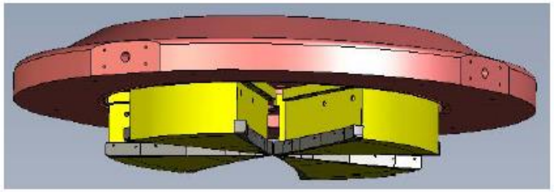
1987: Operation & Experiments 2001-2002: update to HI-15



- 100 MeV 200 μA compact proton cyclotron
- 20000 mass resolution ISOL
- 2 MeV/q super-conducting LINAC

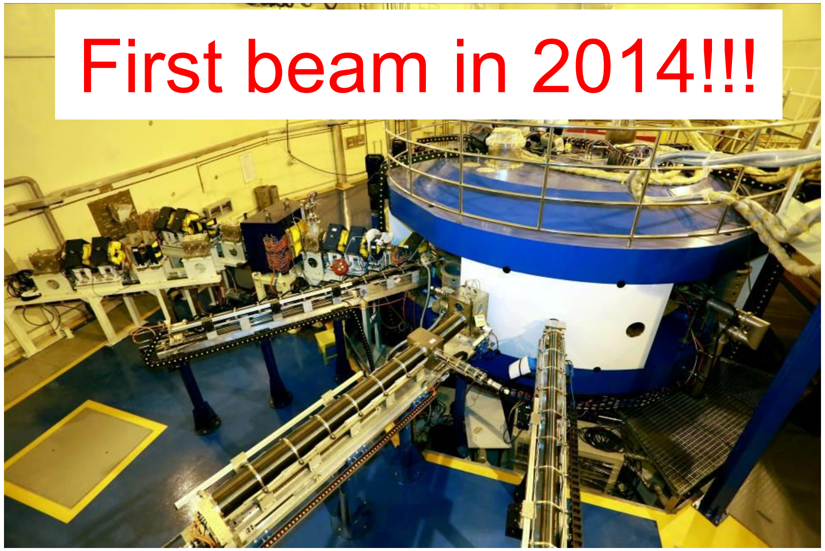
Status of BRIFII





Dia.: 6160 mm
Height: 2820 mm
Weight: 435 t

First beam in 2014!!!



Magnet design and fabrication

Introduction and status of HIRFL

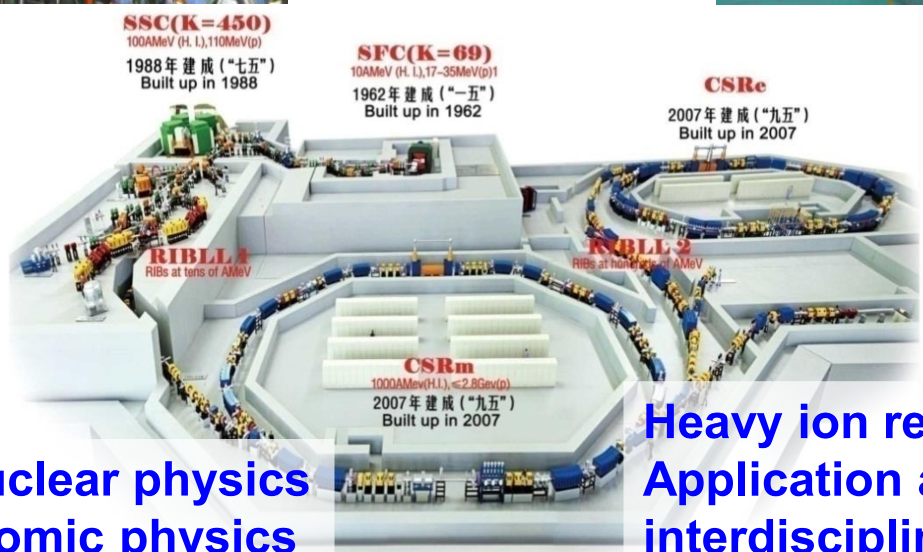
Heavy Ion Research Facility in Lanzhou (HIRFL)

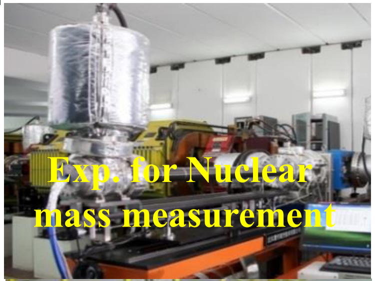
National Laboratory of Heavy Ion Accelerator in Lanzhou(1991)

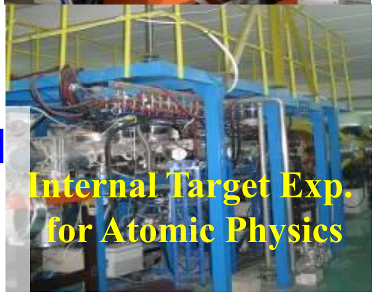
SSC (K=450)
100 AMeV (H.I.), 110 MeV (p)
1988

SFC (K=69)
10 AMeV (H.I.), 17~35 MeV (p)
1962

Main Setups

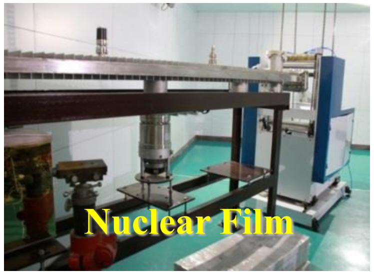


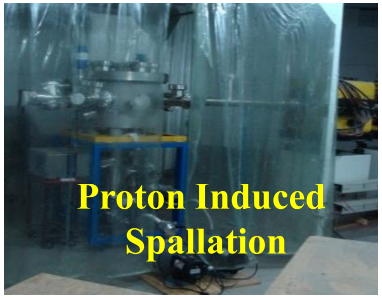




Nuclear physics
Atomic physics

Heavy ion related
Application and
interdisciplinary

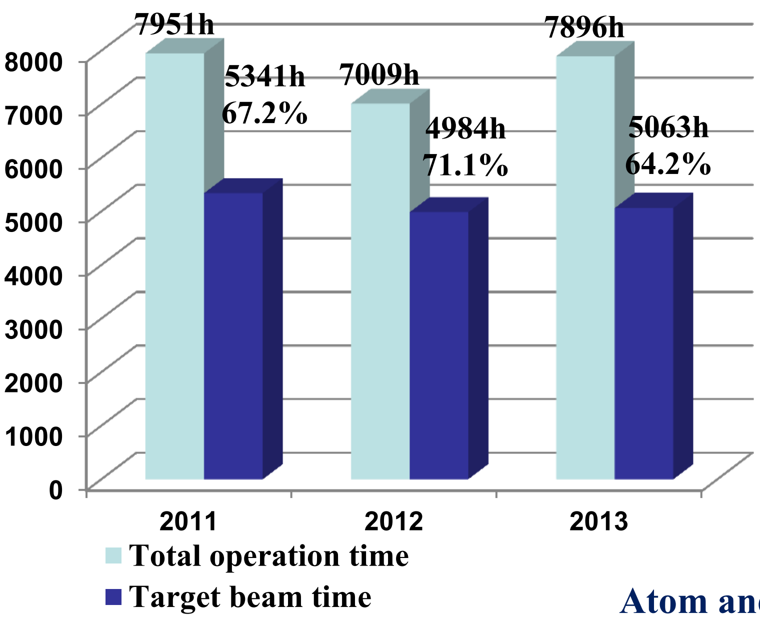


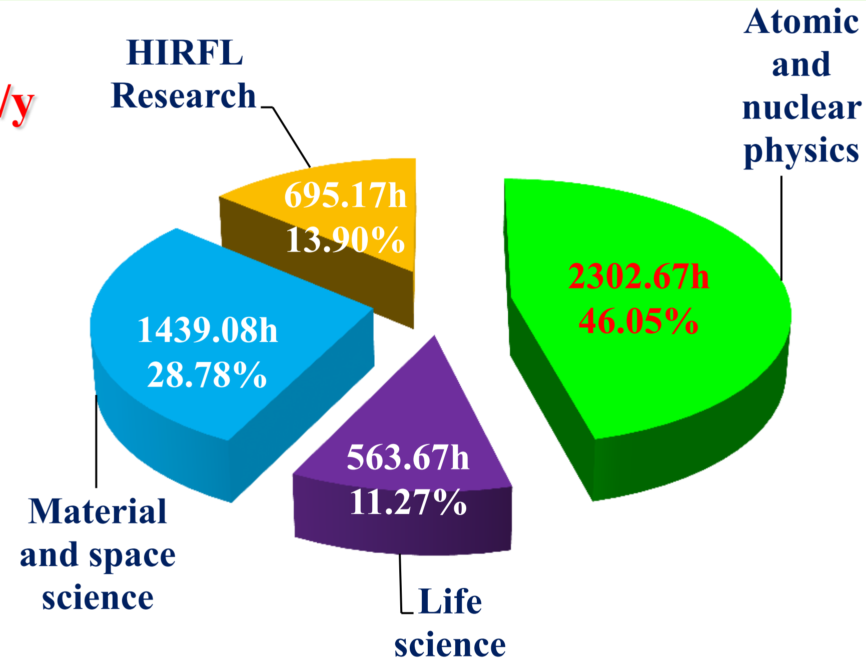


About 20 apparatuses for heavy-ion physics and applications

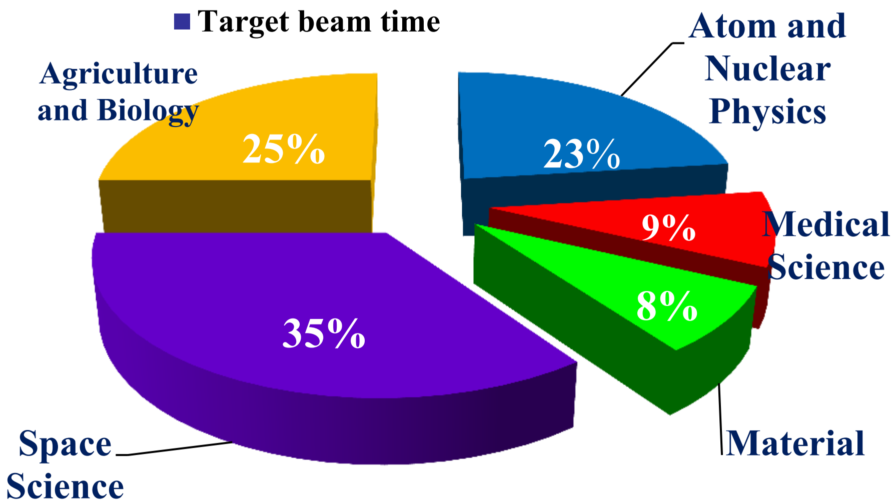
HIRFL status

Operation time >7000hrs/year, target time ~5000hrs/y, applied for beam time >14000hrs/y

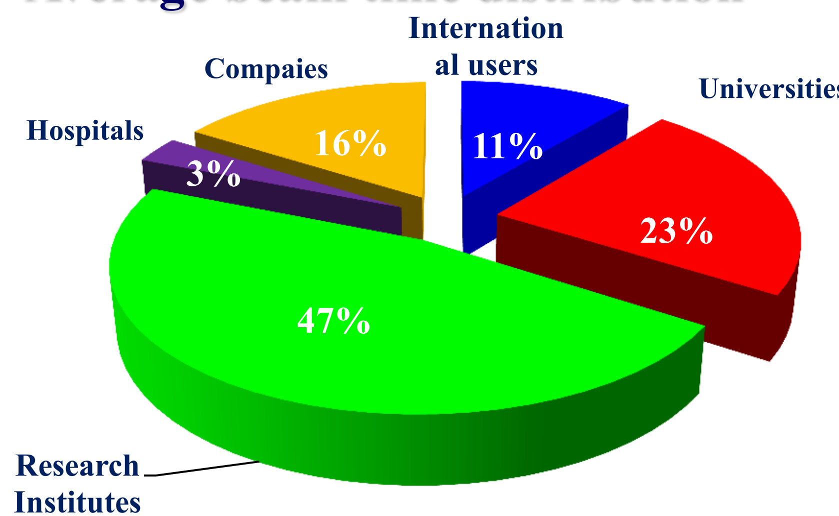




Average beam time distribution



Distribution in Research Fields

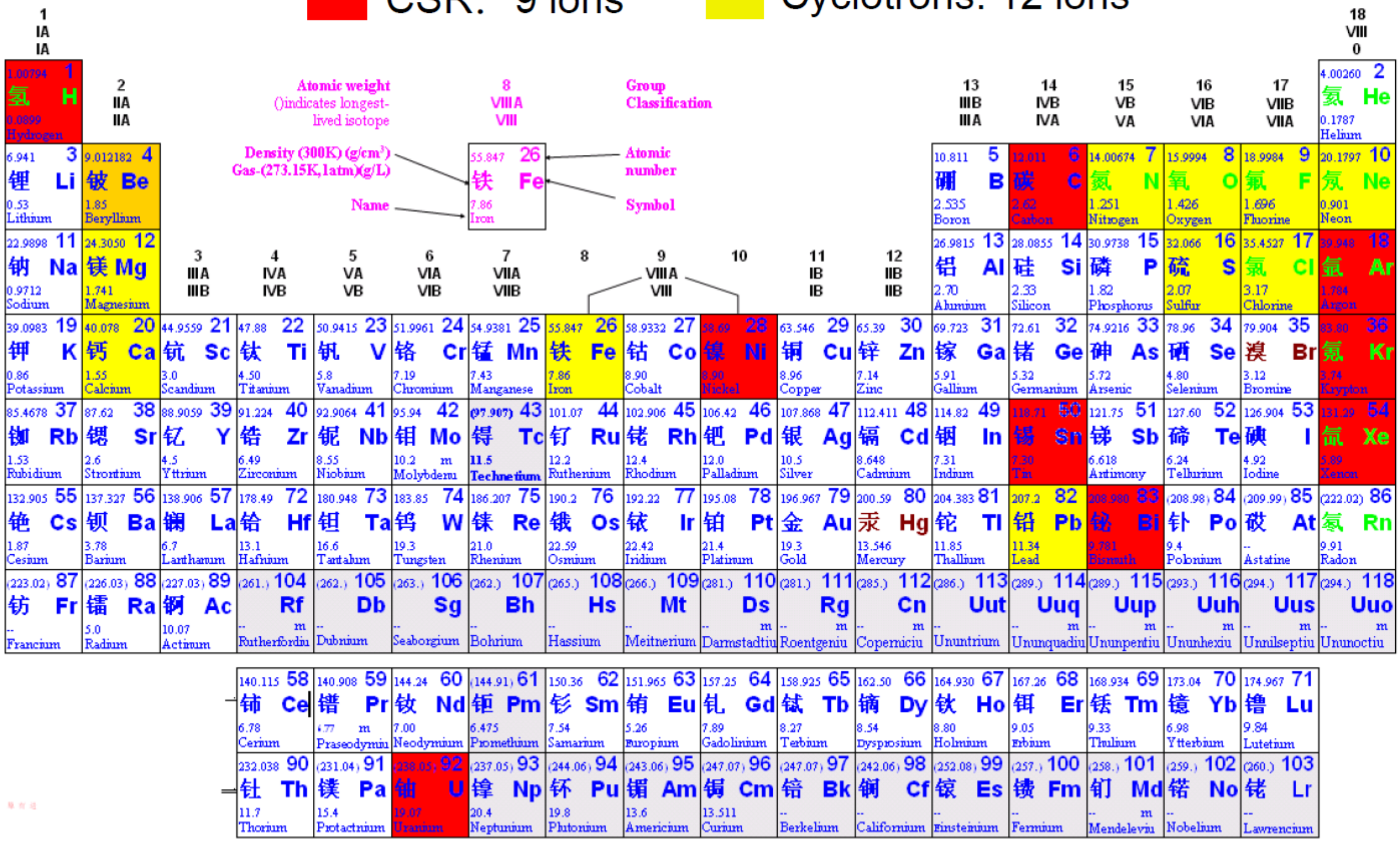


Distribution of ~200 Users Units

Typical beam

p ~ U, Total accelerated elements: 21

CSR: 9 ions   Cyclotrons: 12 ions



~23 different beam species (~10 new) provided by HIRFL every year

Typical beam

Ions	SFC		SSC		CSR	
	Energy AMeV	Intensity eμA	Energy AMeV	Intensity eμA	Energy AMeV	Intensity ppp
H_2^{1+}	10	7			400	1.40E+08
$^{9}Be^{3+}$	6.89	0.55				
$^{12}C^{5+/6+}$	8.47	2.7	100	0.4		
$^{12}C^{3+}$	4.2	8			122	1.70E+09
$^{12}C^{4+/6+}$	7	10			1000	1.00E+09
$^{14}N^{5+/7+}$	6.957	6	80	0.4		
$^{18}O^{6+/8+}$	6.17	5.9	70	0.45		
$^{18}O^{6+/8+}$	7	4			305.4	1.10E+09
$^{19}F^{7+}$	6.6	3				
$^{22}Ne^{7+/10+}$	6.17	9			70	2.70E+09
$^{26}Mg^{8+/12+}$	6.17	3.5	70	0.35		
$^{28}Si^{9+/14+}$	6.645	2.2	76	0.15		
$^{36}Ar^{8+}$	2.0725	16	22	3.3	368	3.90E+08
$^{35}Cl^{12+}$	6	1				
$^{32}S^{11+/16+}$	7.112	4.8	82	0.2		
$^{22}Ne^{7+/10+}$	6.17	9			70	2.70E+09
$^{40}Ca^{12+}$	5.625	3.5				
$^{58}Ni^{19+}$	6.3	2.4			463.36	8.30E+07
$^{58}Ni^{15+/24+}$	4.53	2.8	50	0.1		
$^{78}Kr^{19+/28+}$	4	4.2			487.9	9.50E+07
$^{86}Kr^{17+/26+}$	2.345	5	25	0.42		
$^{129}Xe^{27+}$	3	4.5			235	7.20E+07
$^{129}Xe^{27+}$	1.844	1.7	19.5	0.4		
$^{112}Sn^{26+/35+}$	3.7	2			392	1.70E+07
$^{208}Pb^{27+}$	1.1	1				
$^{209}Bi^{31+}$	0.911	0.7	9.5	0.06		
$^{209}Bi^{36+}$	2	2			170	1.20E+07
$^{238}U^{32+}$	1.22	1			100	4.40E+07

STI+MMI supporting by electron cooling

C, N, O, F, Ne, Ar, Ca, A<40, E = 7---10 MeV/u

SFC + CSRm

Stripping Injection + E-cooling →→ I=$10^{8\sim9}$

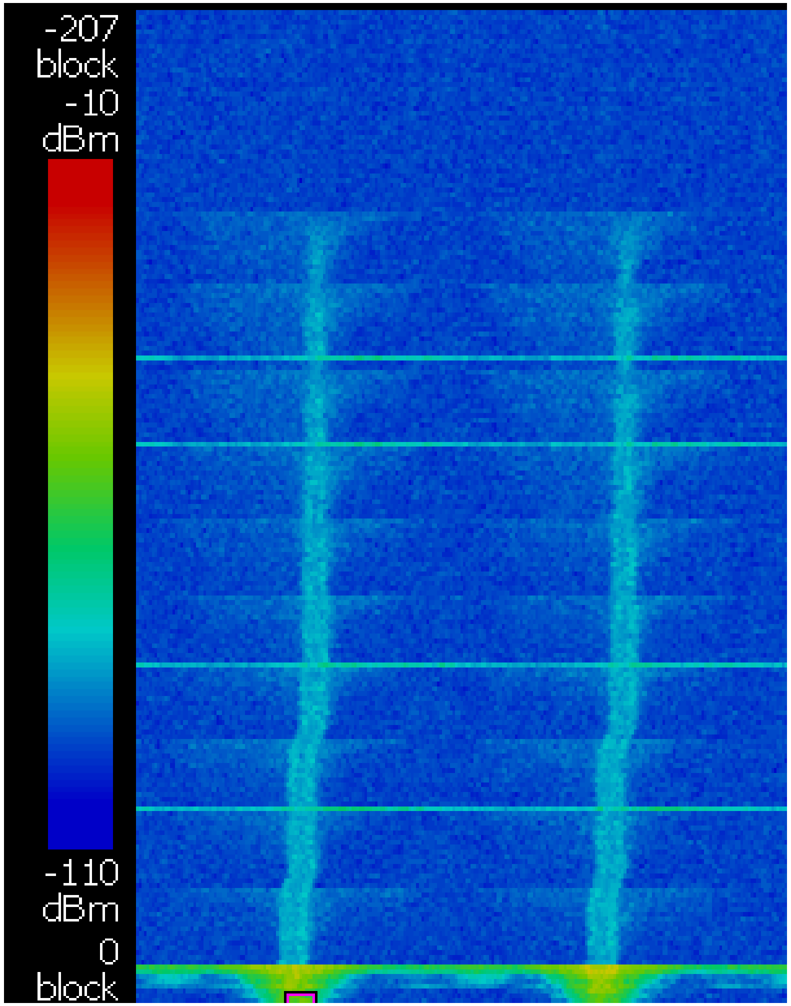
Ar, Kr, Xe, Ta, Au, Pu, U, A ≥ 40, E = 10---25 MeV/u

SFC + SSC + CSRm

Multiple Multi-turn Injection + E-cooling →→ I=$10^{7\sim8}$

e-cooling effect

C^{6+}-7MeV/u , observed the longitudinal schottky signal from spectrum analyzer



ΔP/P

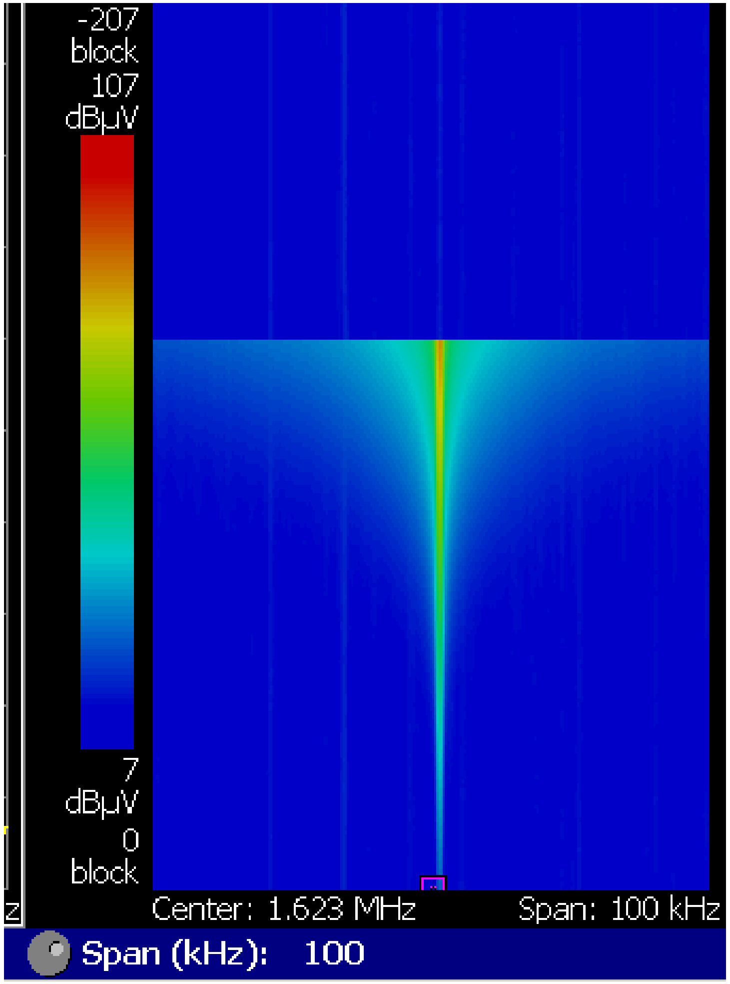
4×10^{-3}

↓

↓

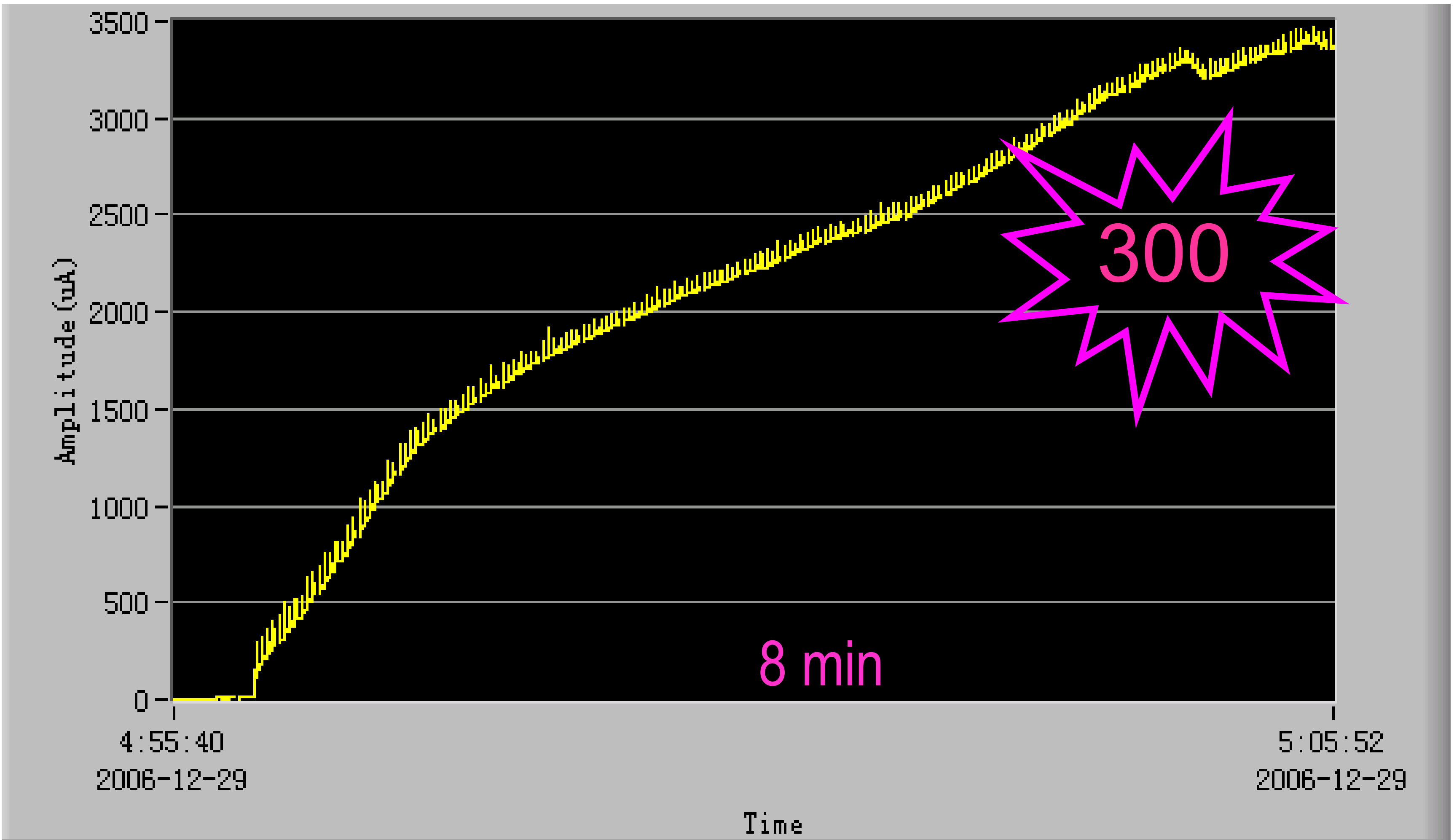
↓

2×10^{-4}



Beam Accumulation with e-cooing in CSRm

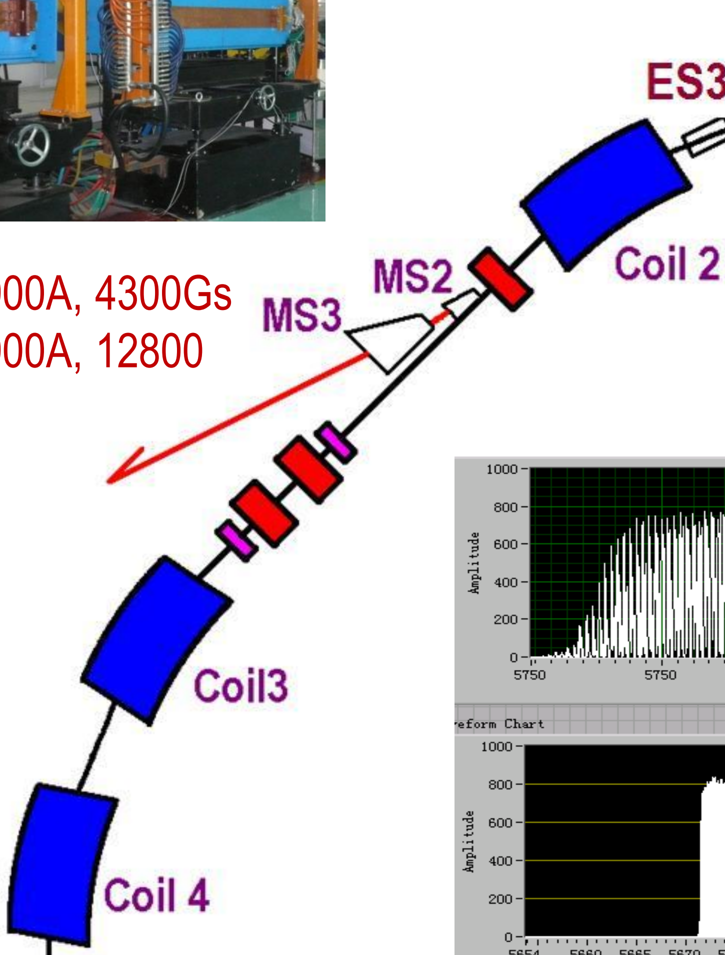
I_{inj}=10.2μA, Beam current: 3.2mA, 1.6×10^{10}, 8min., Gain=300



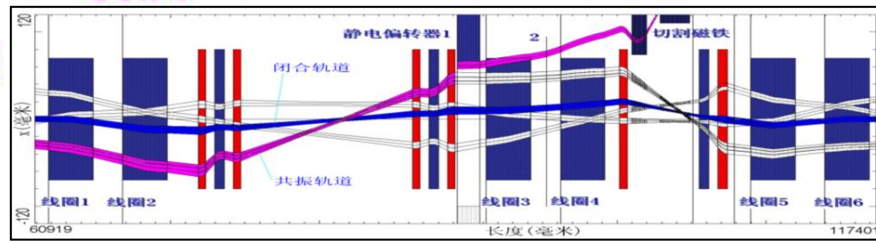
Slow extraction in CSRm

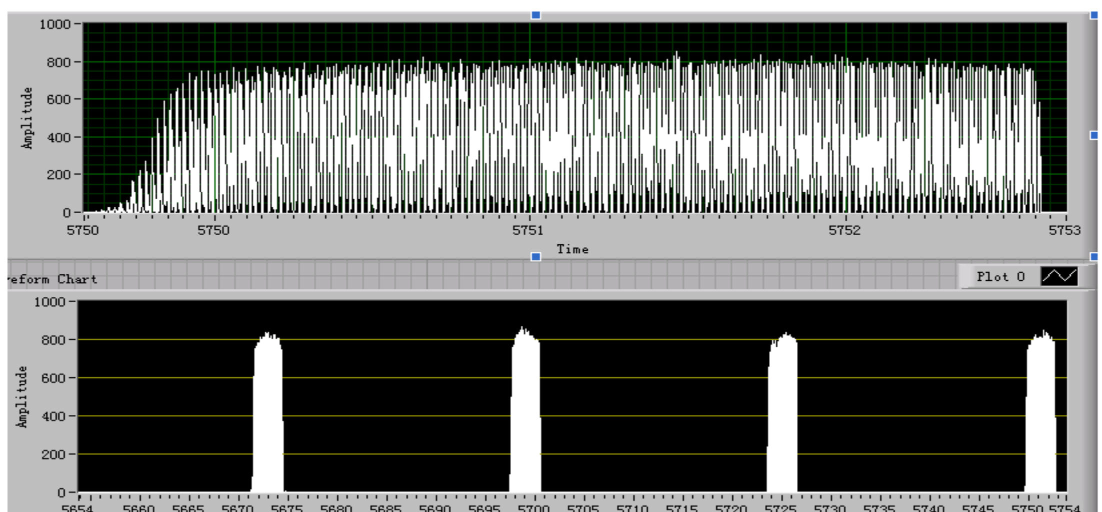
- 1/3 resonance
- RF-Knockout exciting
- Feedback with fast Qs

MS2: 2900A, 4300Gs
MS2: 2900A, 12800

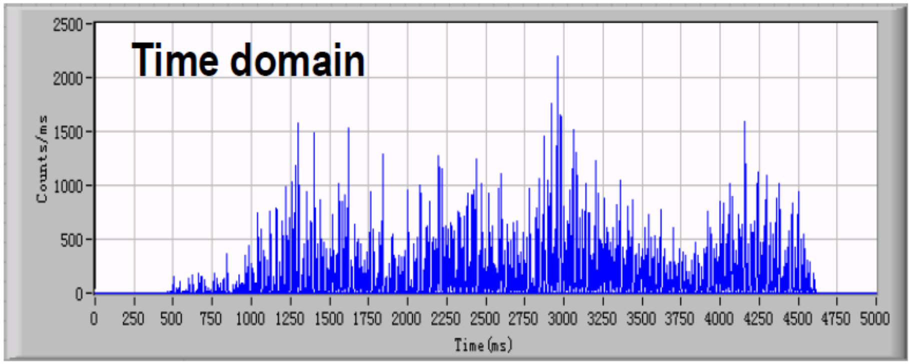


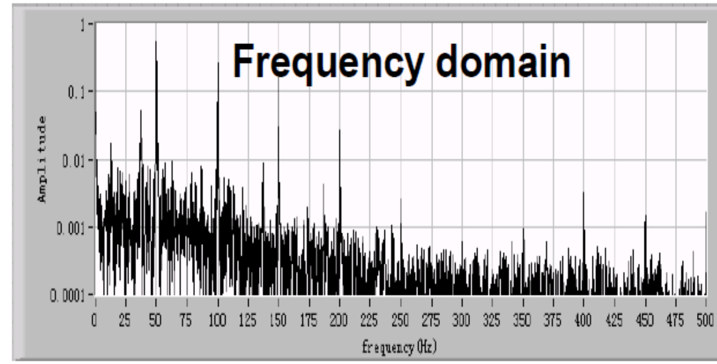
Electrostatic Septum





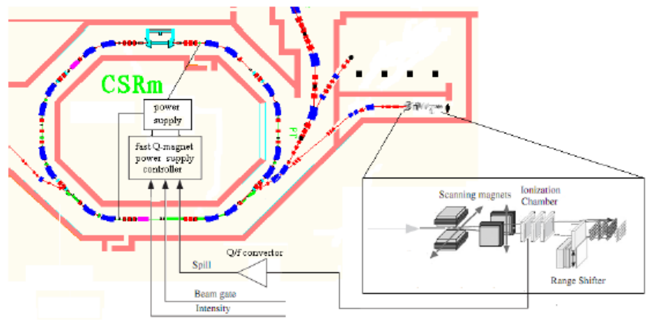
Improve the slow extr. beam quality through feedback





Feedback

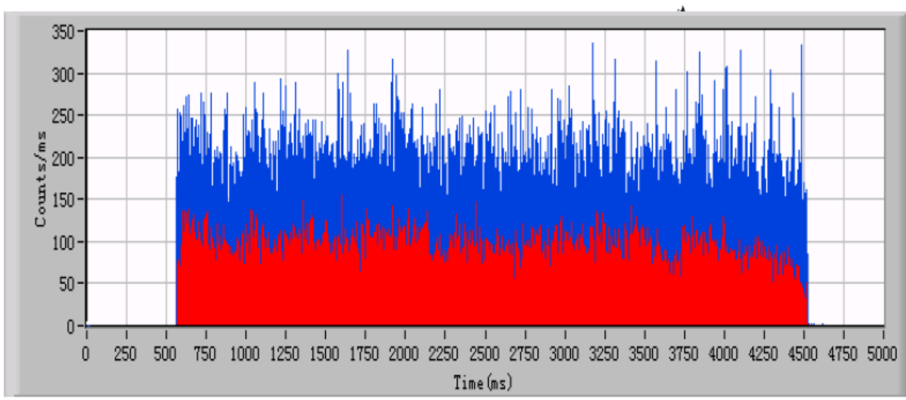
Get DC Beam

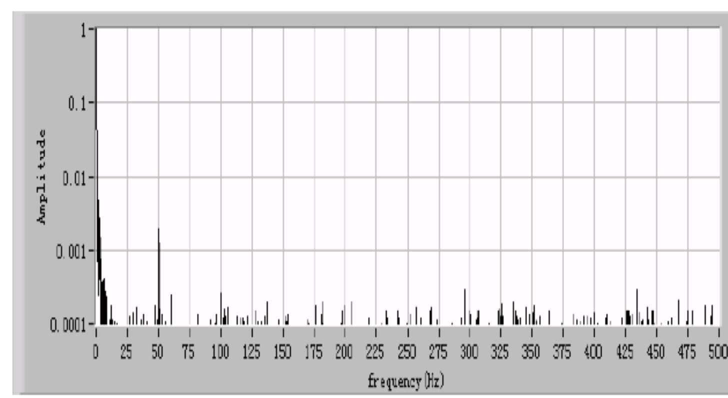


Feedback

50Hz ripple reduced 250 time

High order reduced 1000 tim

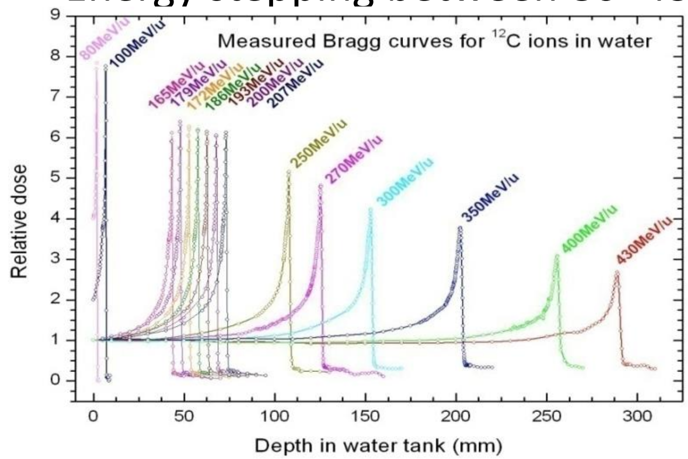




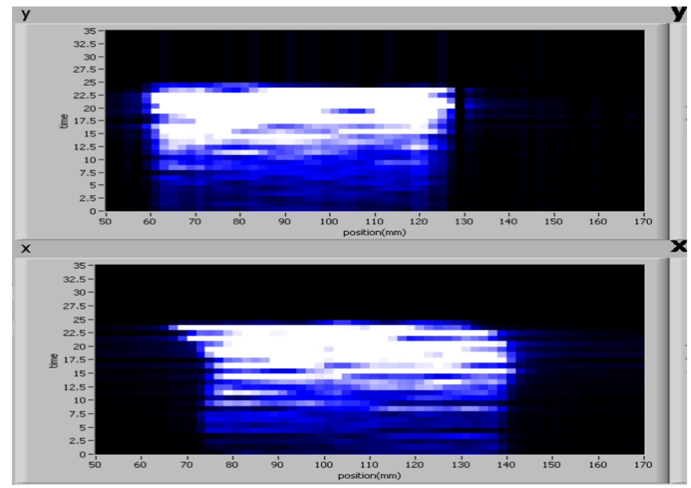
Cancer therapy technique: uniform and active spot scanning

Active energy variation

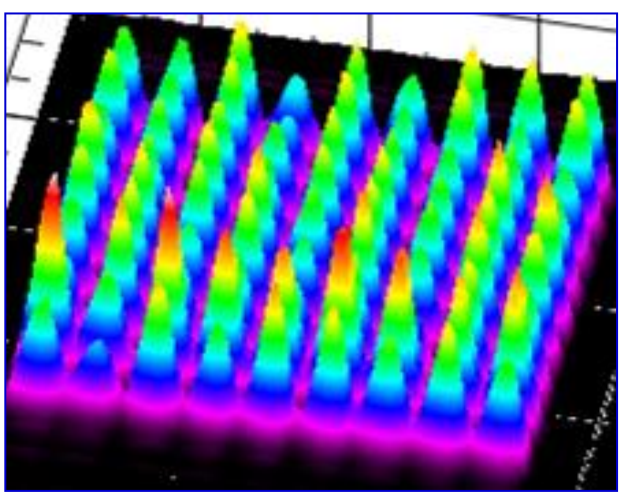
Energy stepping between 80~430



Spot scanning intensity-modulation

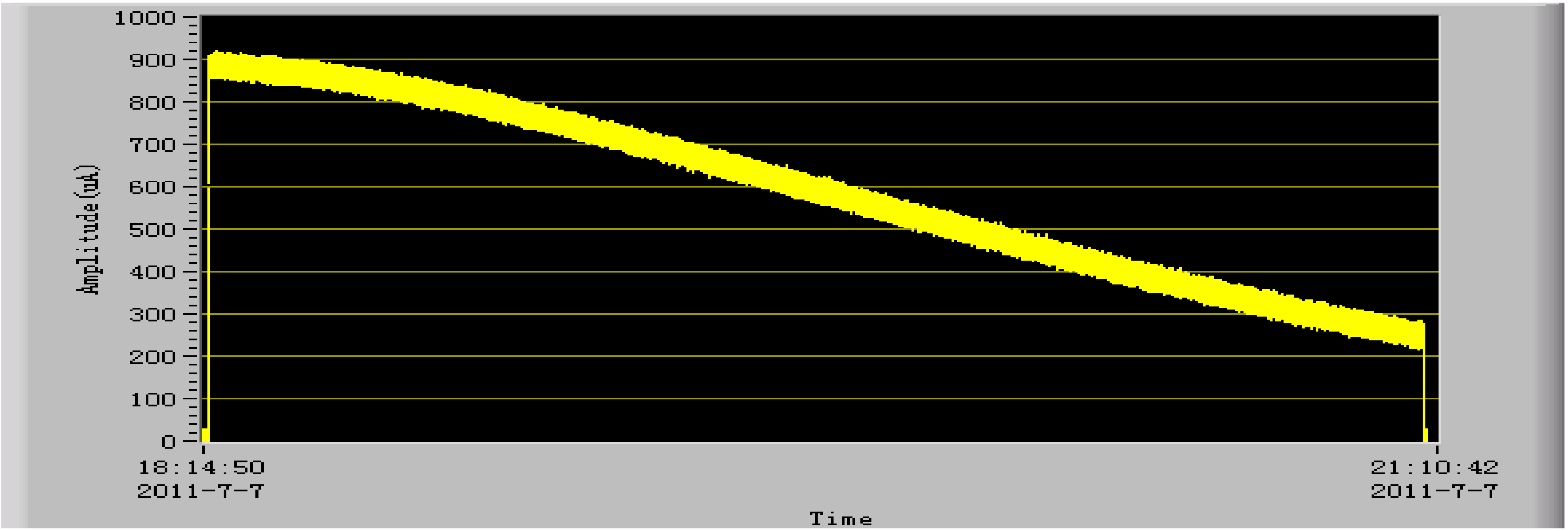


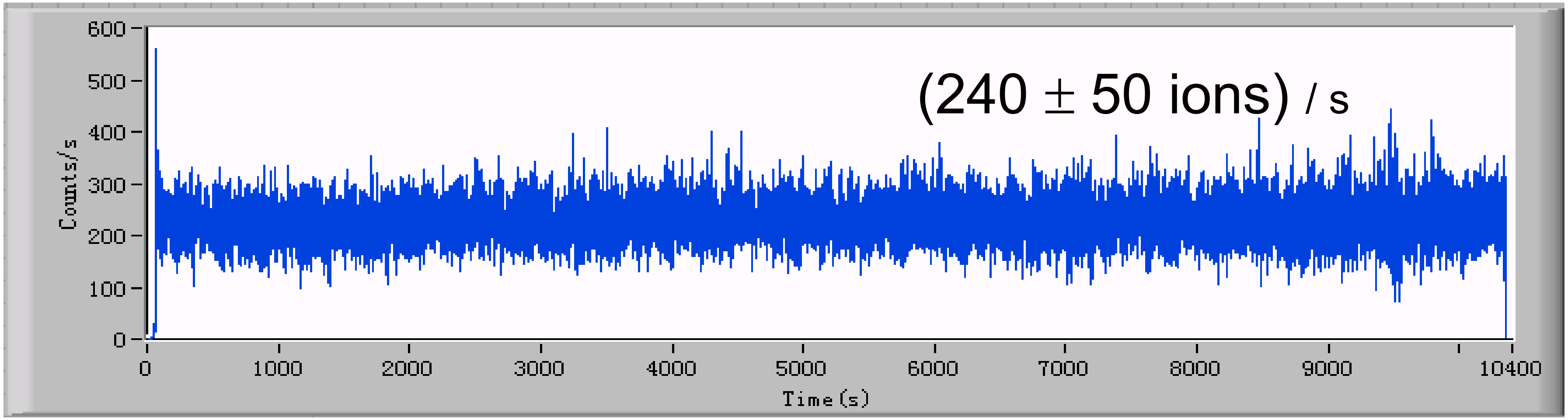
Pencil beam dose shaping



Writing and painting

Long pulse slow extraction from CSRm:10,000s



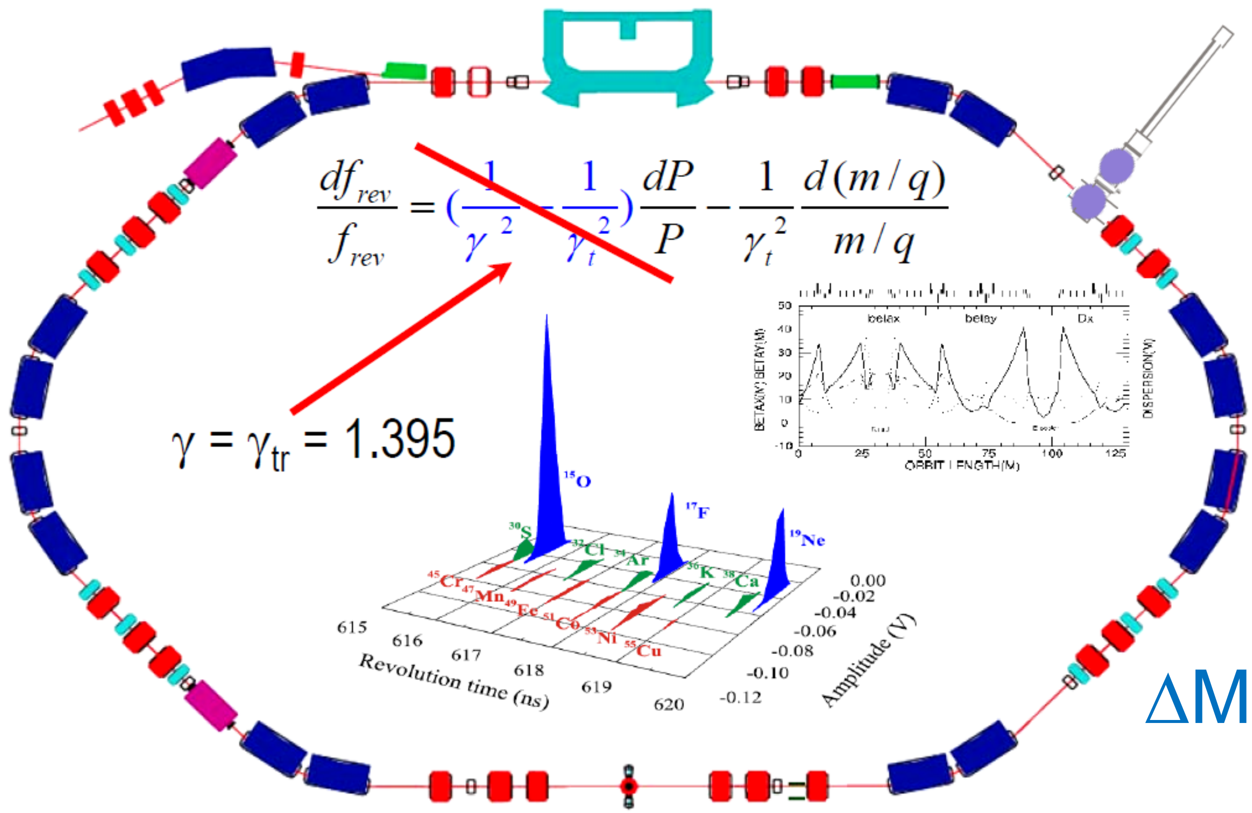


CSRe lattice: Isochronous mode

Mass measurement of short-life time nuclei in CSRe

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

Operation mode：SECR+SFC+CSRm+CSRe, 1.5 months/year

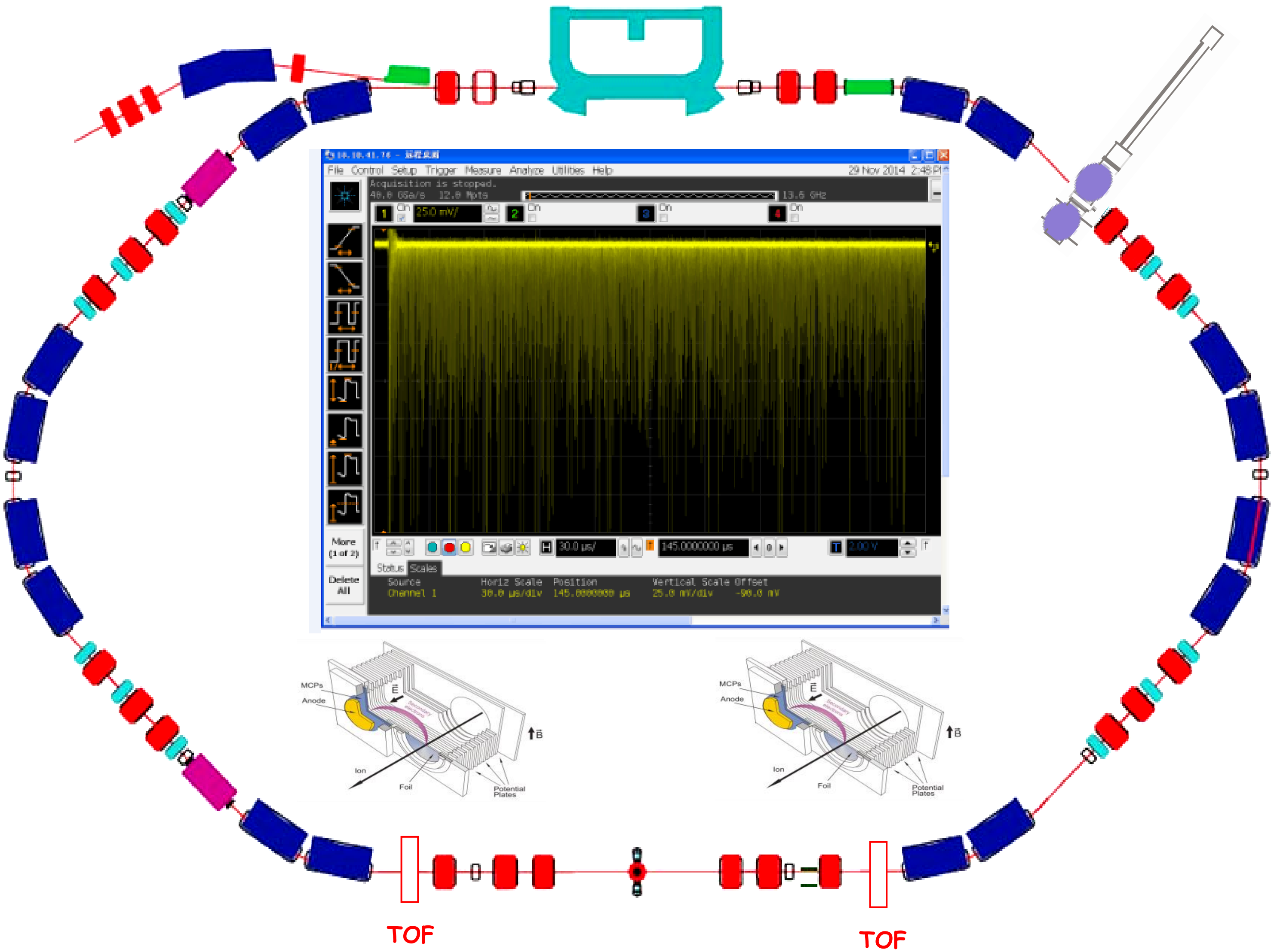


$$\frac{df_{rev}}{f_{rev}} = \left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)\frac{dP}{P} - \frac{1}{\gamma_t^2}\frac{d(m/q)}{m/q}$$

$\gamma = \gamma_{tr} = 1.395$

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

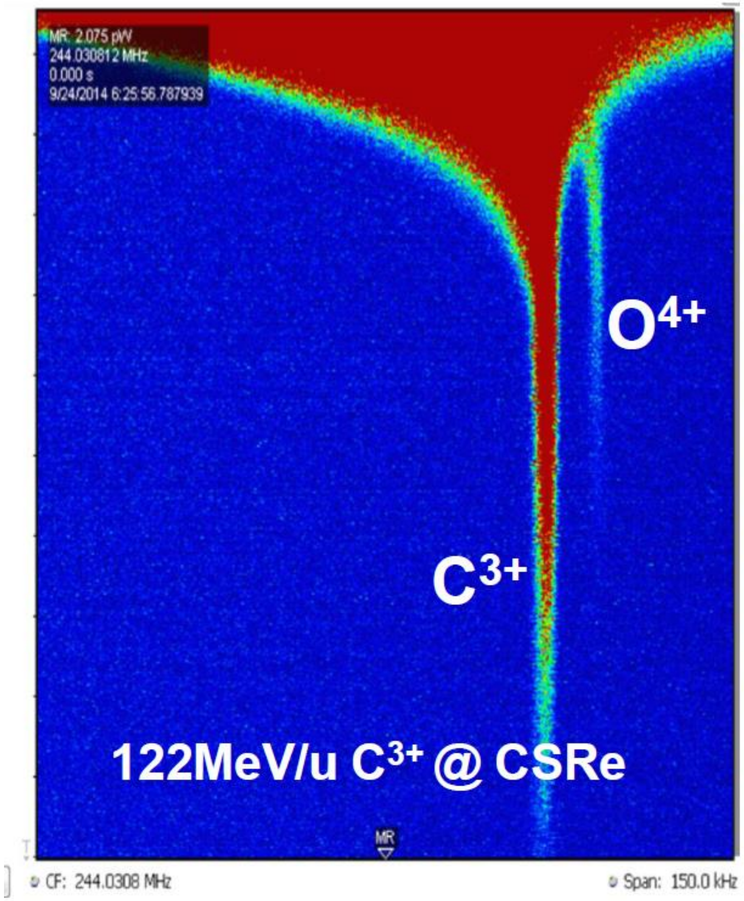
Two TOF isochronous mode, succeeded several days

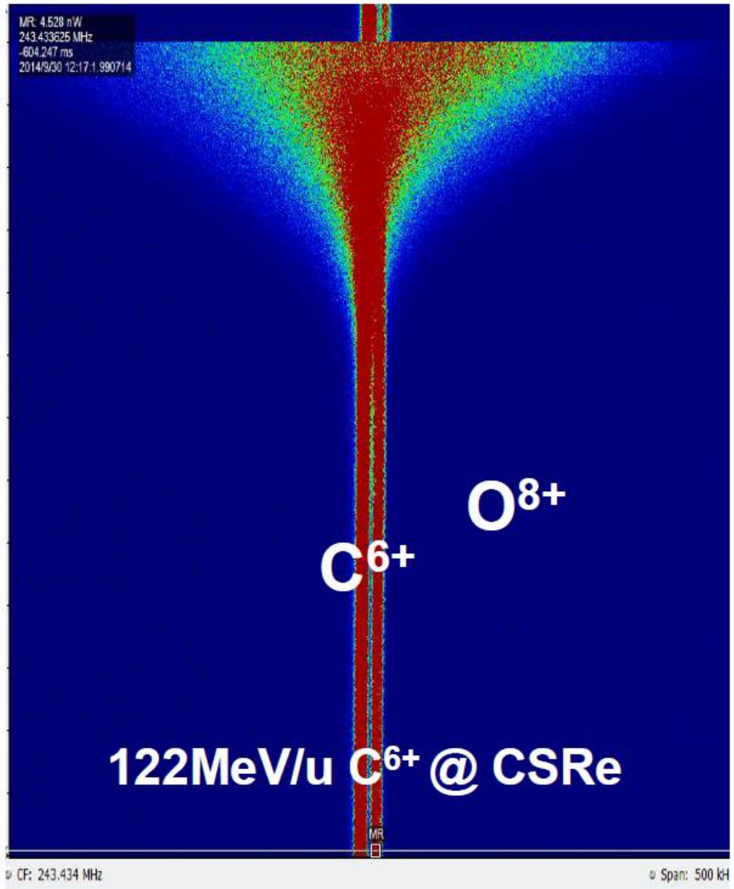


Powerful e-cooling effect at CSRe

The final momentum spread reached to below 10^{-5}

The two beams with same rigidity and same A/Z can be separated with small mass difference

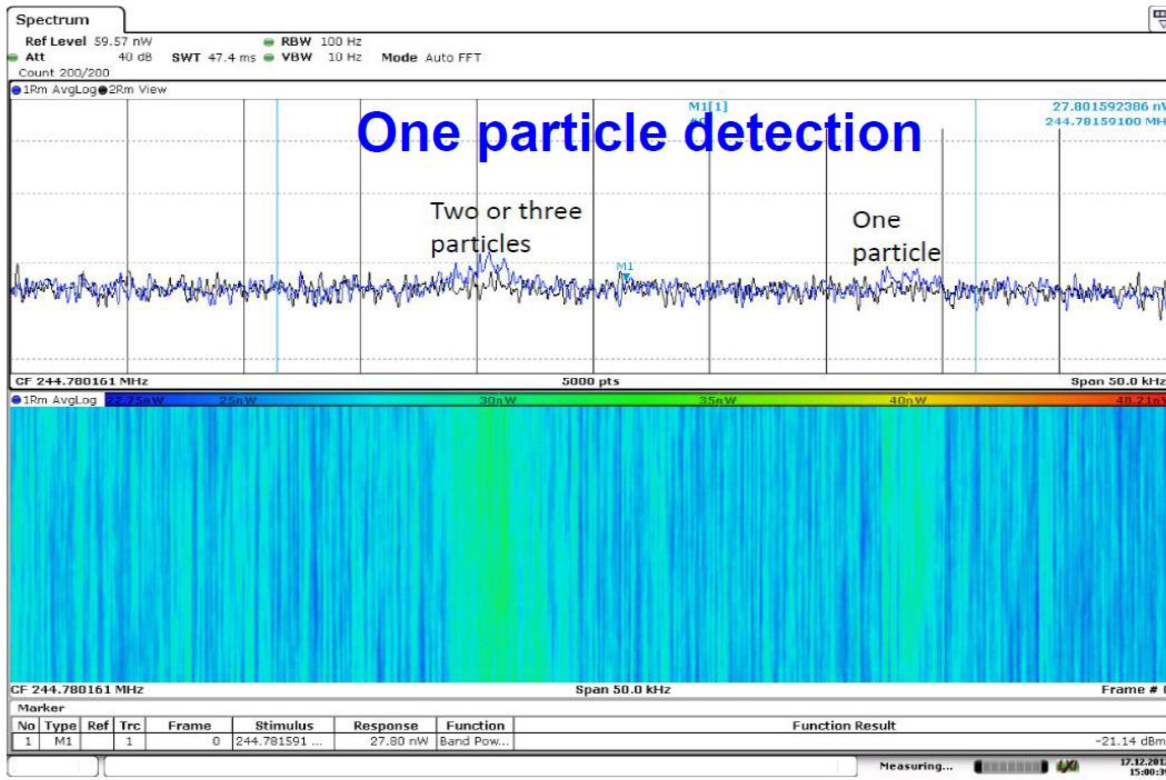




Resonant Schottky Pickup in CSRe

Cooperated with GSI, 2011-2013

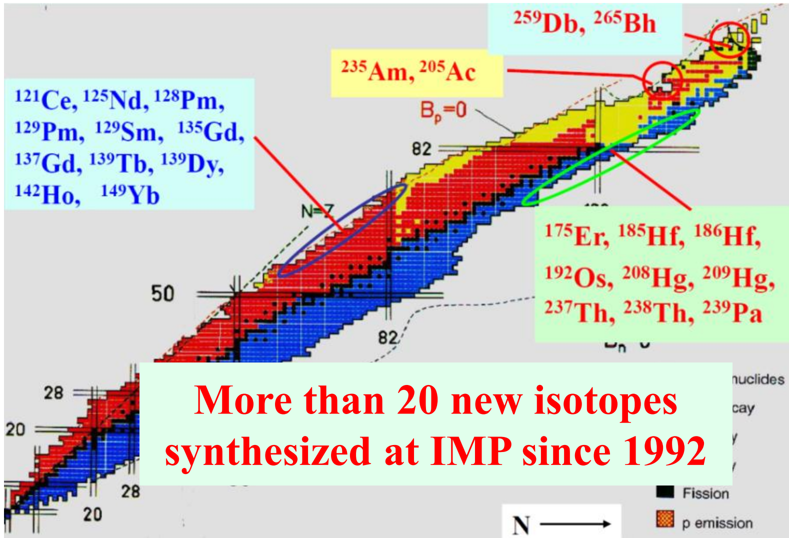
High sensitivity and High temporal resolution



$^{112}Sn^{50+}$ beam with an energy of 252.923 MeV/u

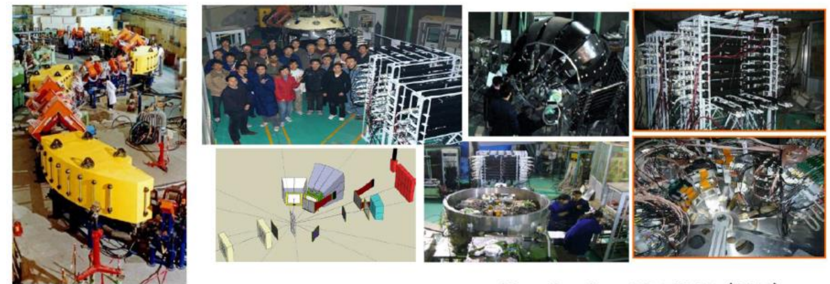
Introduction and status of HIRFL Highlights progress

Synthesis of New Isotopes



RIB physics

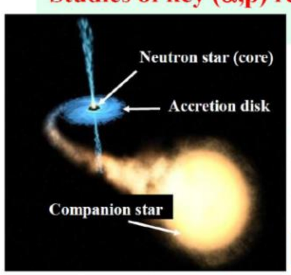
RIBLL Collaboration established in 2011, including >16 institutions

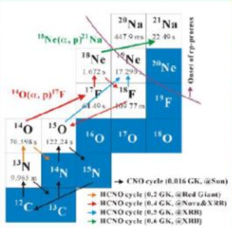


–Phys. Rev. Lett 112,162501（2014）
–Phys. Rev. C90, 014606(2014)
–Phys. Rev. C87, 024312（2013）
–Phys. Rev. C87, 044613（2013）
–Phys. Lett. B727, 126（2013）
–Phys. Rev. C84, 037603（2012）
–Phys. Rev. C85, 024621（2012）
–Phys. Rev. C81, 054317（2010）
–Phys. Rev. C82, 064316（2010）
–Phys. Rev. C80, 054315（2009）
–Phys. Rev. C80, 014310（2009）

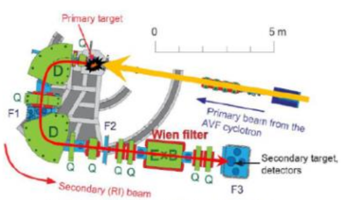
Nuclear Astrophysics

Studies of key (α,p) reactions in Type I X-ray bursts at RIBLL and CRIB





RIBLL1@IMP



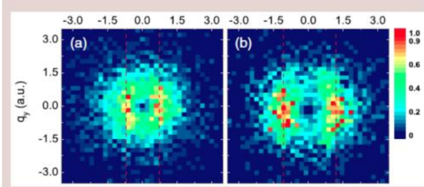
CRIB@University of Tokyo

Publications
1. J.J. He *et al.*, Eur. Phys. J. A47(2011)67
2. J.J. He *et al.*, Phys. Lett. B725(2013)287
3. J.J. He *et al.*, Phys. Rev. C88(2013)012801R
4. J. Hu *et al.*, Phys. Rev. C90(2014)025803
5. L.Y. Zhang *et al.*, Phys. Rev. C89(2014)015804
6. J.J. He *et al.*, Nucl. Instr. Meth. A680(2012)43
7. S.Z. Chen, Nucl. Instr. Meth. A735(2014)466

Atomic Physics

Two-center interference observed in a collision between H_2^+ projectile used as a double slit and helium target atoms using kinematically complete technique

IMP and MPIK collaboration

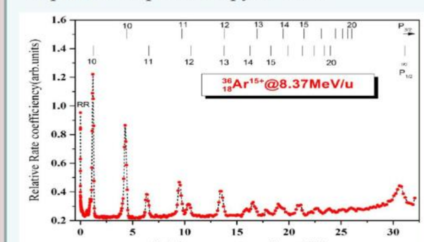


Momentum transfer pattern @ inter-nuclear distances

Theoretical optical interference patt

Dielectronic recombination spectroscopy at cooler storage ring

The resolution of dielectronic recombination spectroscopy is of 100meV. Paved the way to precision spectroscopy at CSR.



- Phys. Rev. Lett. 112, 023201 (2014)
- Phys. Rev. A 90, 022706 (2014)
- Nucl. Instr. Meth. A736, 75 (2014)
- Phys. Rev. A 87, 062510 (2013)
- Phys. Rev. A 86, 012709 (2012)
- Phys. Rev. A 84, 042710 (2011)

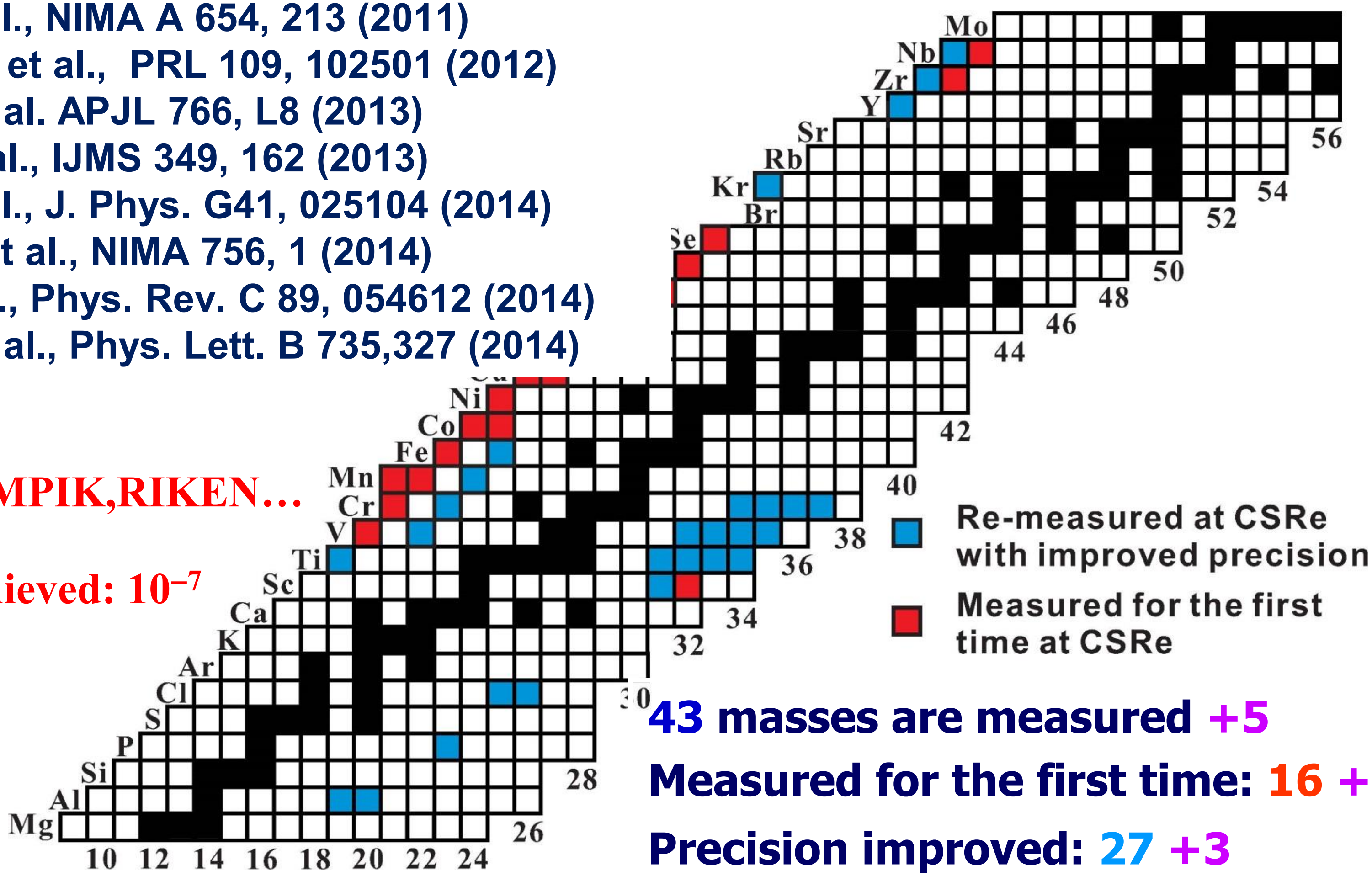
Mass Measurements

Primary Beams: ^{56}Ni, ^{78}Kr, ^{86}Kr, ^{112}Sn

1. B. Mei et al., NIMA A 624, 109 (2010)
2. X.L. Tu etal., PRL 106, 112501 (2011)
3. X.L. Tu et al., NIMA A 654, 213 (2011)
4. Y.H. Zhang et al., PRL 109, 102501 (2012)
5. X.L. Yan et al. APJL 766, L8 (2013)
6. H.S. Xu et al., IJMS 349, 162 (2013)
7. X.L. Tu et al., J. Phys. G41, 025104 (2014)
8. W. Zhang et al., NIMA 756, 1 (2014)
9. B. Mei et al., Phys. Rev. C 89, 054612 (2014)
10. P. Shuai et al., Phys. Lett. B 735,327 (2014)

IMP,GSI,MSU,MPIK,RIKEN…

Precision achieved: 10^{-7}



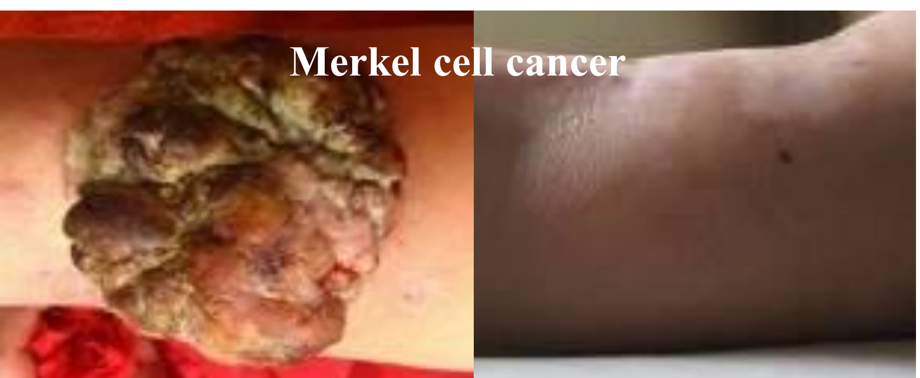
43 masses are measured +5

Measured for the first time: 16 +2

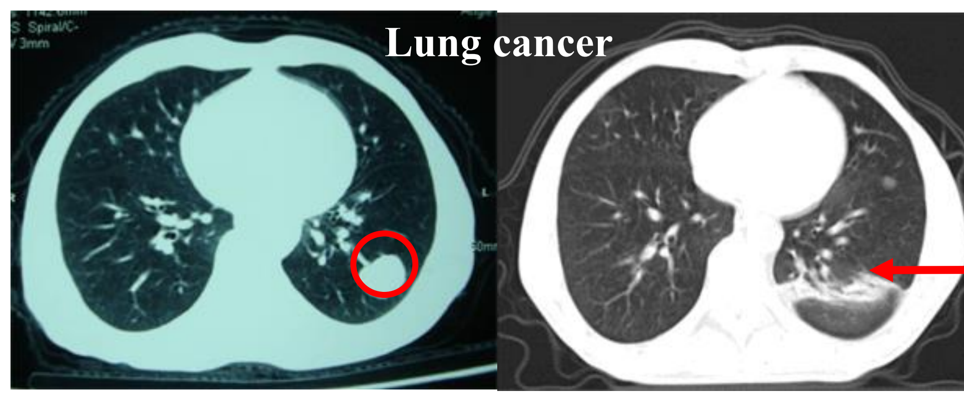
Precision improved: 27 +3

Heavy ion therapy

In collaboration with local hospitals
clinical trials for 213 patients of ~ 10 kinds of tumors have been performed



Before treatment | **18 months after irradiation with carbon ion beams**



Before treatment | **5 months after irradiation with carbon ion beams**

Heavy ion accelerator in China-

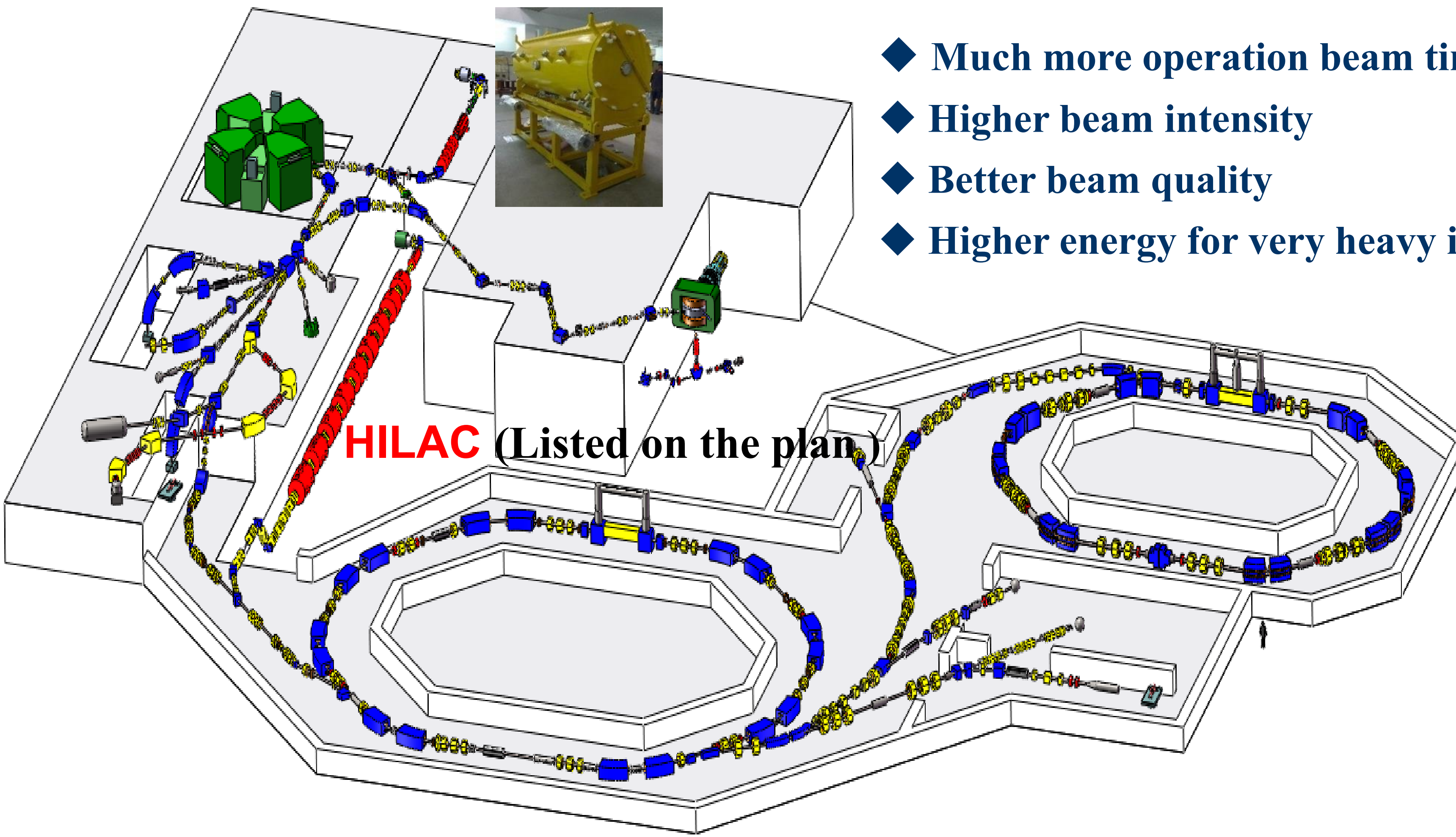
Status and Initiative

Updates & New Development

HIRFL Linac injector

● SSC LINAC & CSR LINAC

SSC-LINAC (under construction)

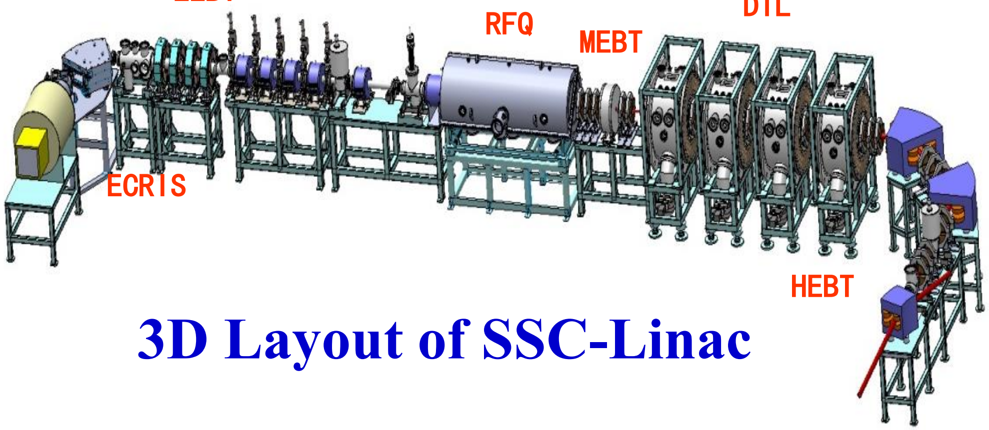


Motivations:

- Much more operation beam time
- Higher beam intensity
- Better beam quality
- Higher energy for very heavy ions

SSC-LINAC:

- CW injector for SSC
- ECR ion source + 4-rod type RFQ + quasi-KONUS IH-DTL
- Extraction energy:
  - 1.025MeV/u→10.7MeV/u(SSC)→CSRm
  - 0.576 MeV/u → 5.97 MeV/u(SSC)

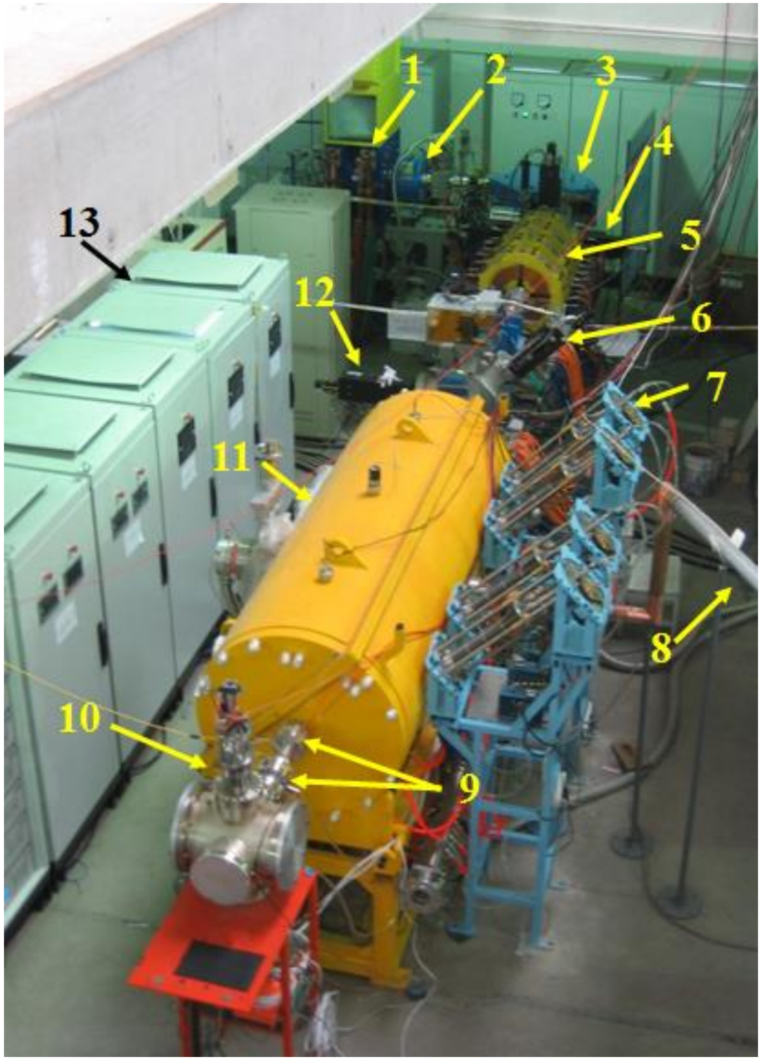


3D Layout of SSC-Linac

Main parameters of SSC-Linac

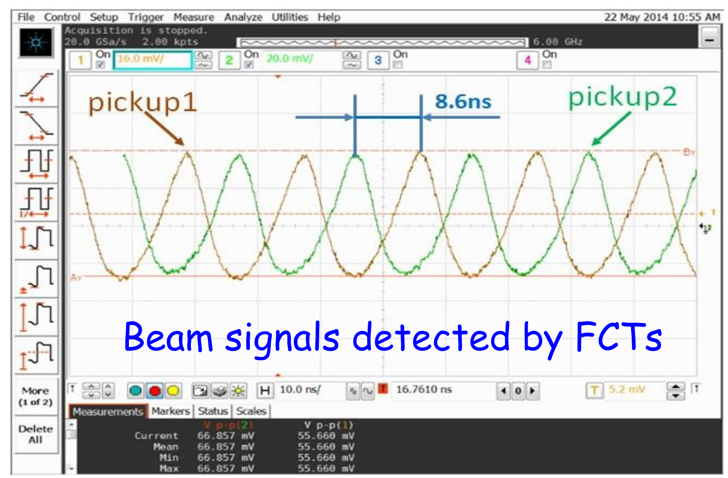
Design ion	$^{238}U^{34+}$
ECR ion source	
Extraction voltage	25kV
Max. axial B_{inj}	2.3 T
Frequency	18GHz
RFQ	4-rod
Frequency	53.667MHz
Input energy	3.728keV/u
Output energy	143keV/u
Gap voltage	70kV
RF power	35kW
Max. current	0.5emA
IH-DTL	KONUS
Frequency	53.667MHz
Input energy	0.143MeV/u
Output energy	1.025MeV/u

New development & progress SSC-LINAC



SSC-Linac: Test bench

CW RFQ beam commissioning



- **The 1st beam ($^{40}Ar^{8+}$) in May 2014**
- **E=142.8±0.21keV/u**
- **I_{cw}=198 eμA, Beam transmission efficiency of 94%**

New development & progress — Cancer Therapy Facility

Two demo facilities are under construction in Lanzhou city and Wuwei city in Gansu province, and more are under business discussion now

430MeV/u Carbon ions, 1×10^{9} particles/spill

Test center of Therapy Demo Facility

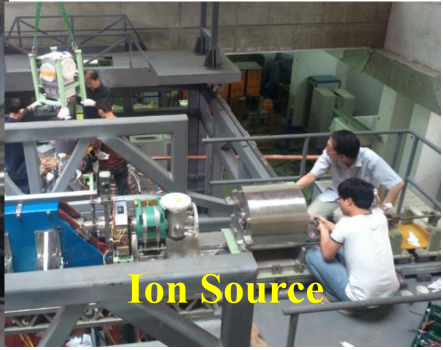
New hosipital at Lanzhou

New hospital at Wuwei


Treatment Planing System


Control System


Power Supply

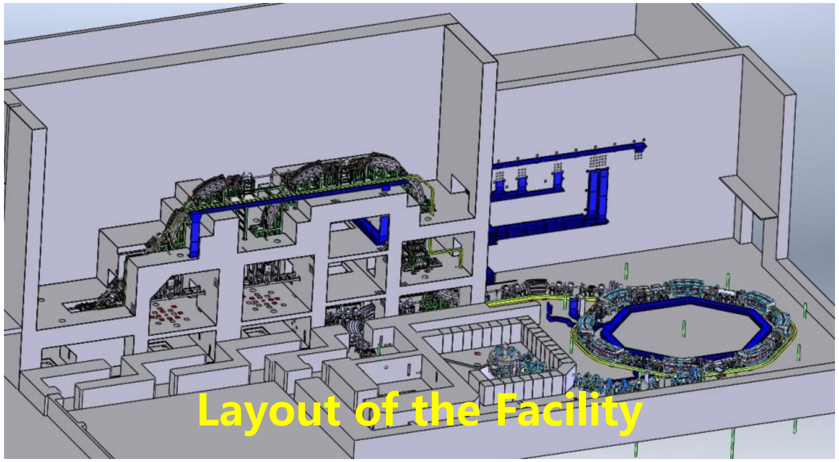

Ion Source


Beam Diagnostics

New Progresses of Therapy Demo Facility


RF Cavity

Therapy Terminal


Layout of the Facility


Radiation Protection System


Cyclotron Injectors Commissioning 12uA 7MeV/uC^{4+}


Synchrotron


QA System

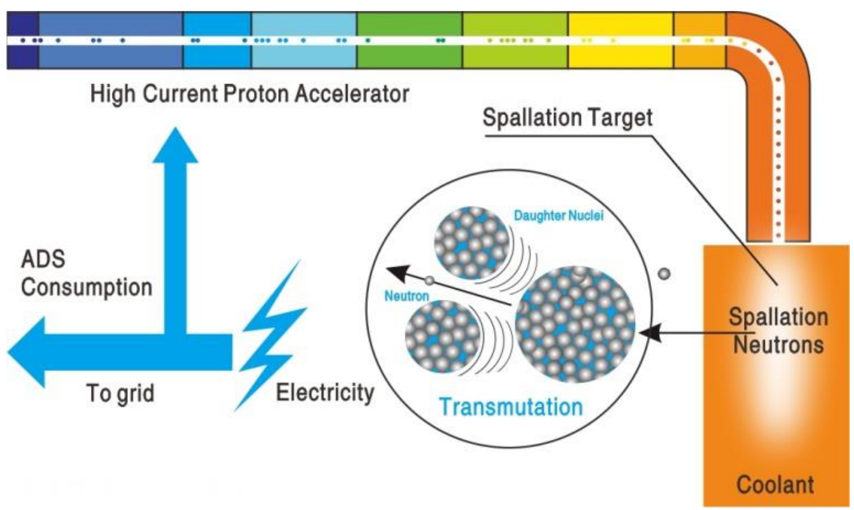
Important Issues for Sustainable NP Development

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

Accelerator **D**riven **S**ystem (**ADS**)

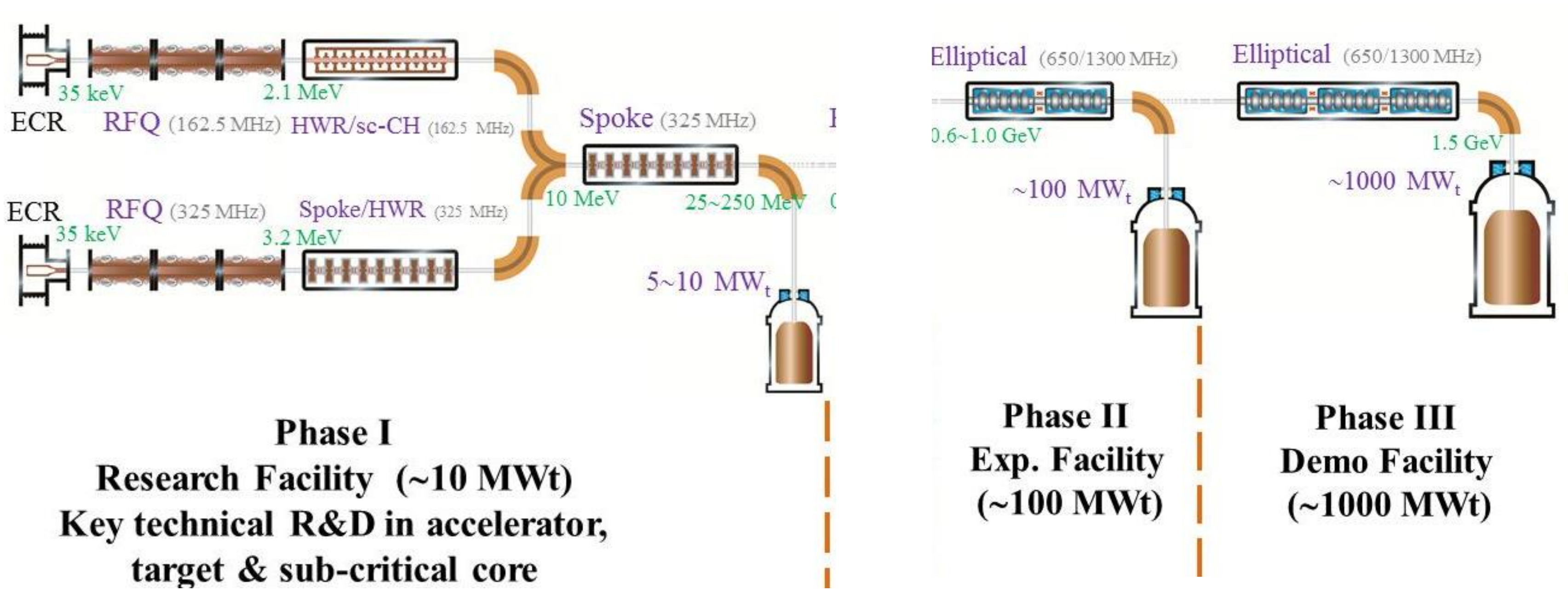
is a promising path to resolve the problems

- 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

Roadmap for developing ADS facilities in China proposed by CAS



Research Facility

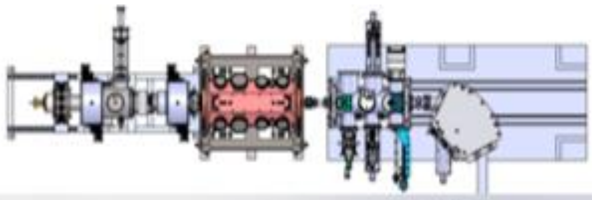
~10MWt ~ 2023

2016: Key technical R&Ds (¥1.78 Billion)

2023: CIADS (12th Five Year Plan, ¥1. 8 Billion)

Commissioning Plan of Demo Facility(LINAC)

1



- ECRIS + LEBT + 560keV RFQ prototype
- Validate LIS+LEBT+RFQ design. Learn experiences.
- Completed, 2013

2

- ECRIS + LEBT + RFQ + MEBT + TCM1, 2.5 MeV
- RFQ commissioning, validate CM design.
- Ongoing, beam commissioning in Sept. 2014

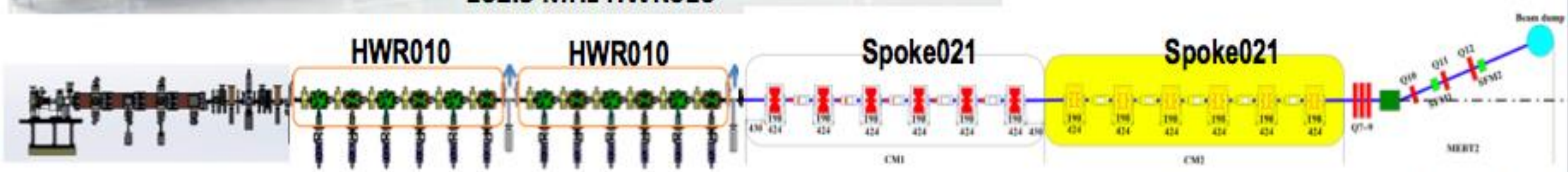
3

- ECRIS+LEBT+RFQ+MEBT+CM6, 5 MeV
- Beam commissioning in March 2015

4

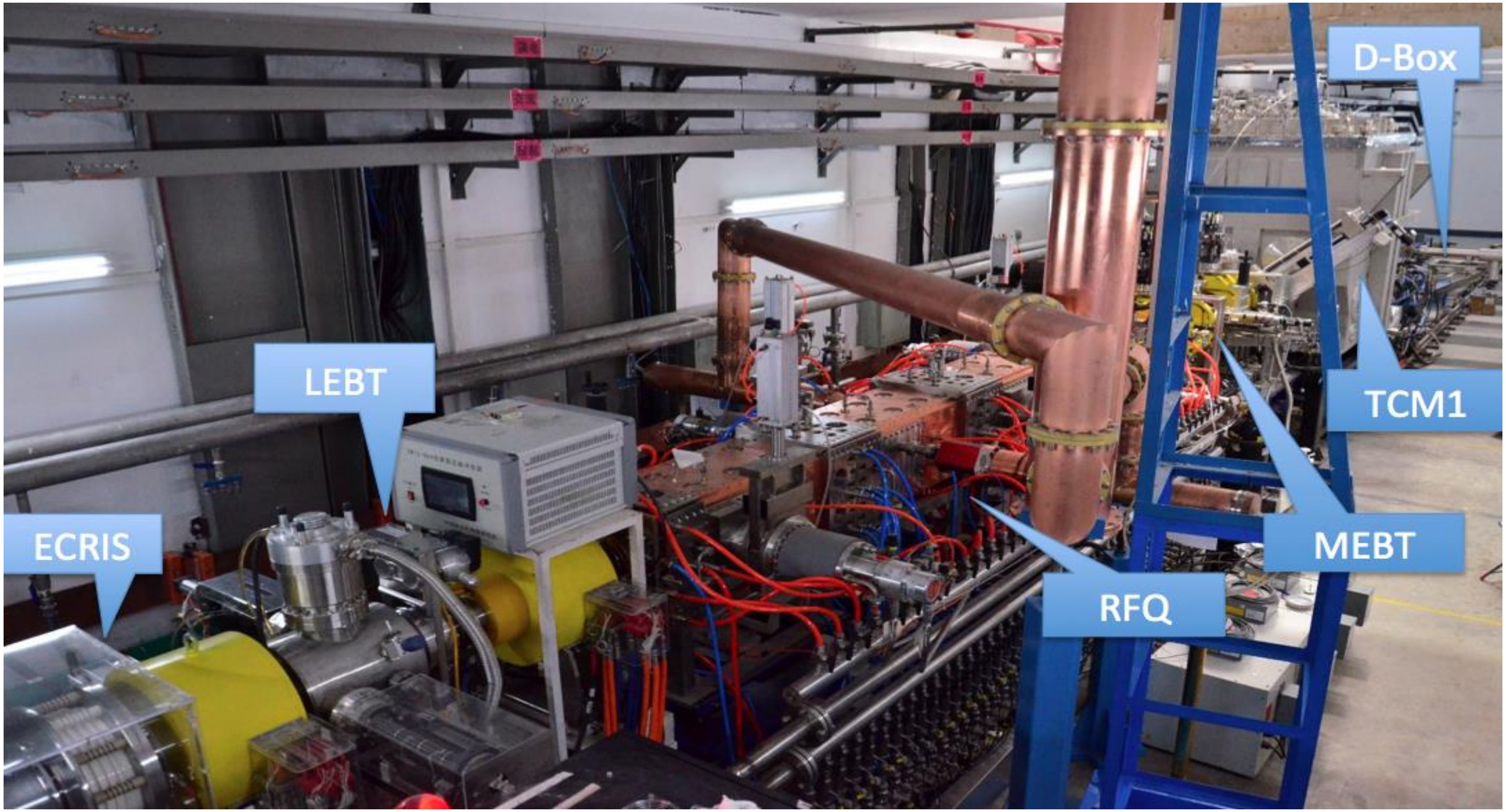
- ECRIS + LEBT + RFQ + MEBT + 2xCM6 +HEBT, 10 MeV
- Dec. 2015—Feb. 2016

5



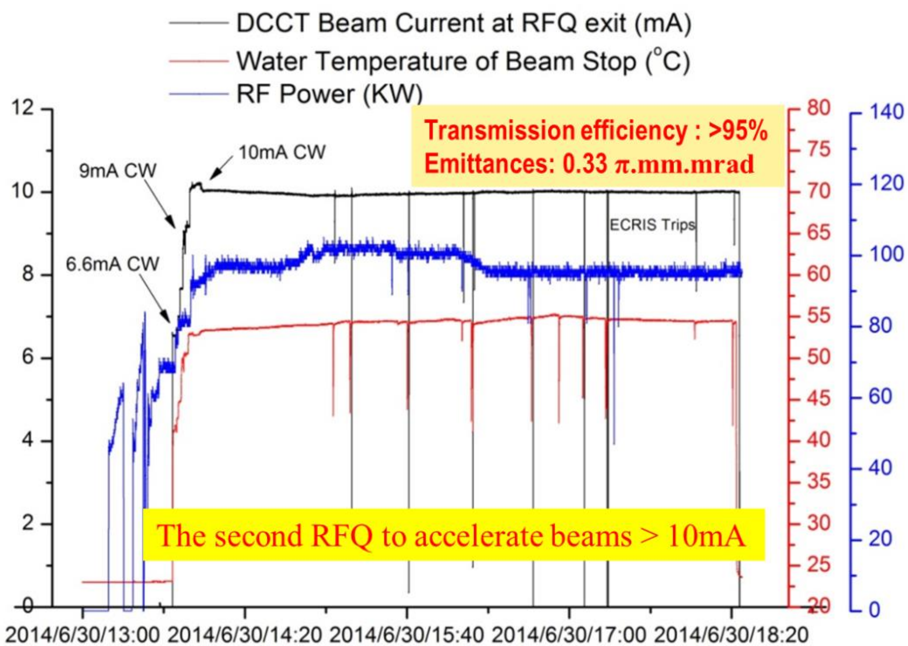
- ~25 MeV, Dec. Sept. 2016 - 2017

The 2.5-MeV Demo of Superconducting LINAC



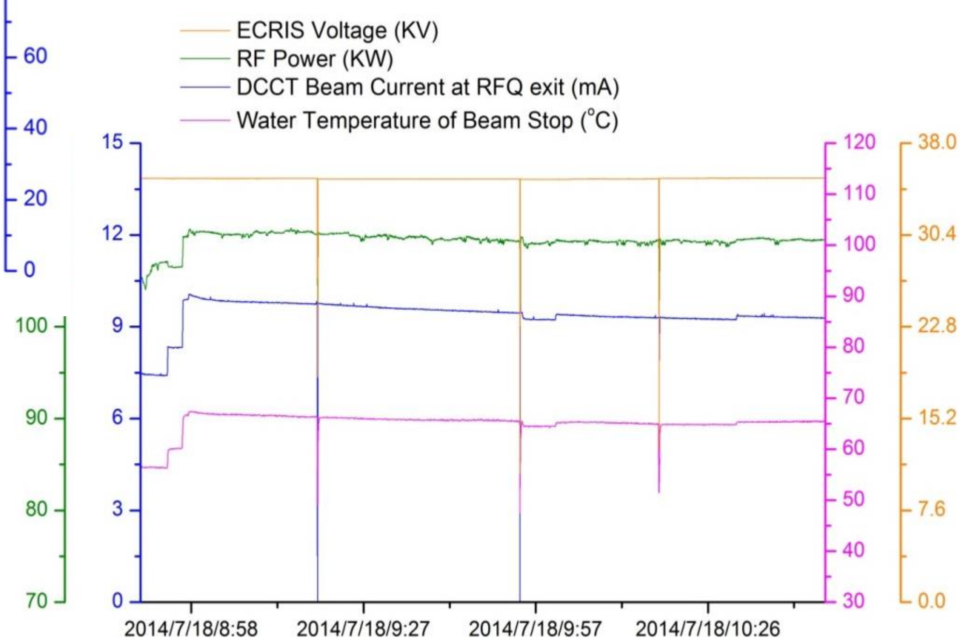
- RFQ operated successfully at 10 mA, CW mode, for many times. the record was 4.5 hours. The rms emittance is 0.2~0.3 pi.mm.mrad, transmission efficiency is 97%.
- MEBT and TCM operated at CW 10 mA 2.5 MeV for 1 hour. HWR operated successfully @ Ep=25MV/m, the design value.

On June 30 2014,
the acceleration of CW beam by RFQ @ 10 mA succeeded

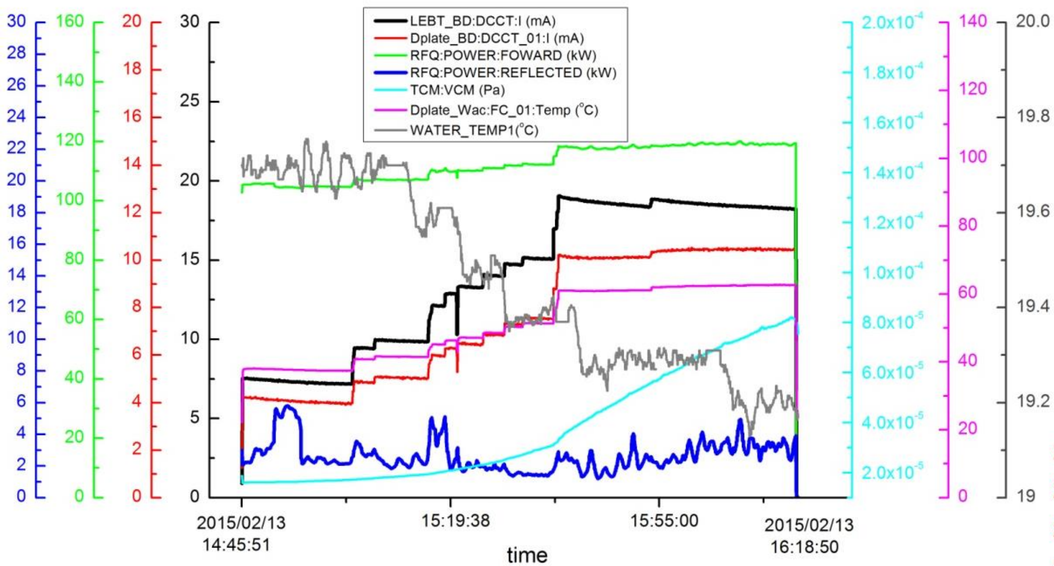


June 30 2014, CW beam@ 10 mA lasted for 4.5 hours

July 18 2014, CW beam @ 10 mA lasted for 2 hours.

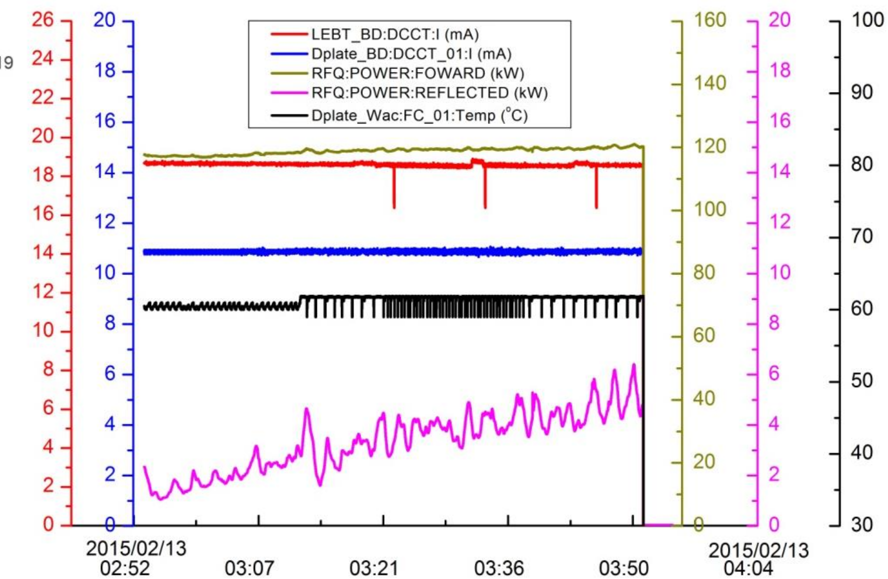


On Feb 13 2015,
the acceleration of CW beam by TCM1 @ 10 mA succeeded

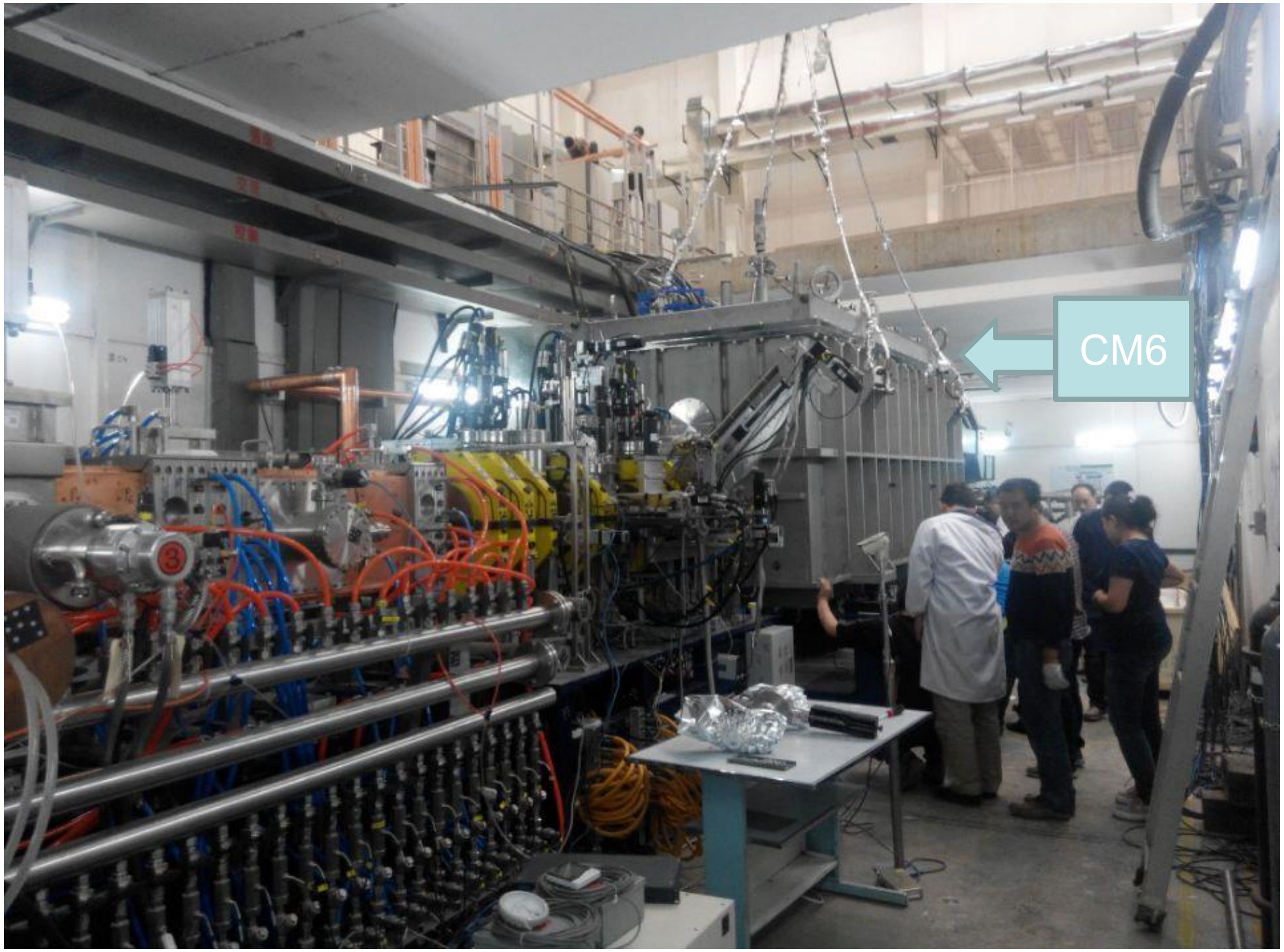


CW beam @ 10 mA lasted for 1 hour.

CW beam ramp from 4-10 mA while
10 mA lasted for 20 minites



CM6 was assembled online on April 29th 2015, cavity horizontal RF test will be performed in May and beam commissioning will be in June and July.



Heavy ion accelerator in China-

Status and Initiative

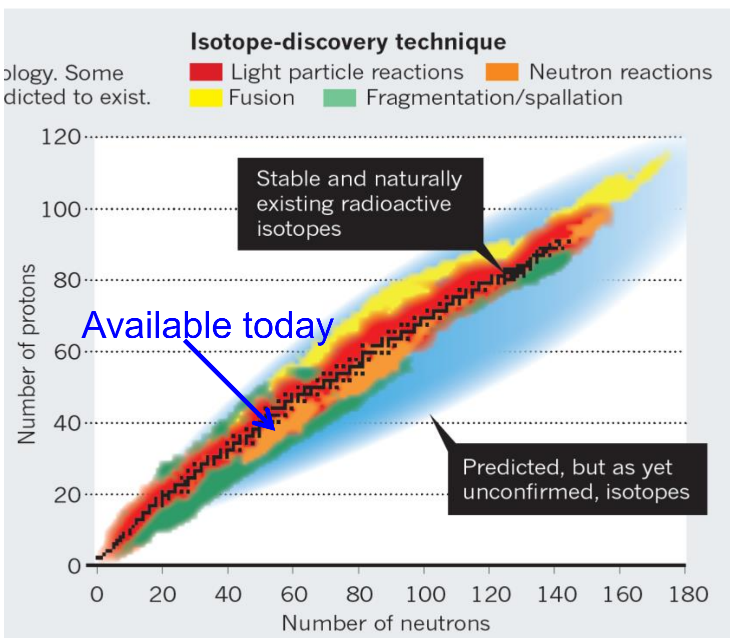
Perspective-New proposal

High Intensity heavy ion Accelerator Facility

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

- 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

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



Fascinating and crucial questions

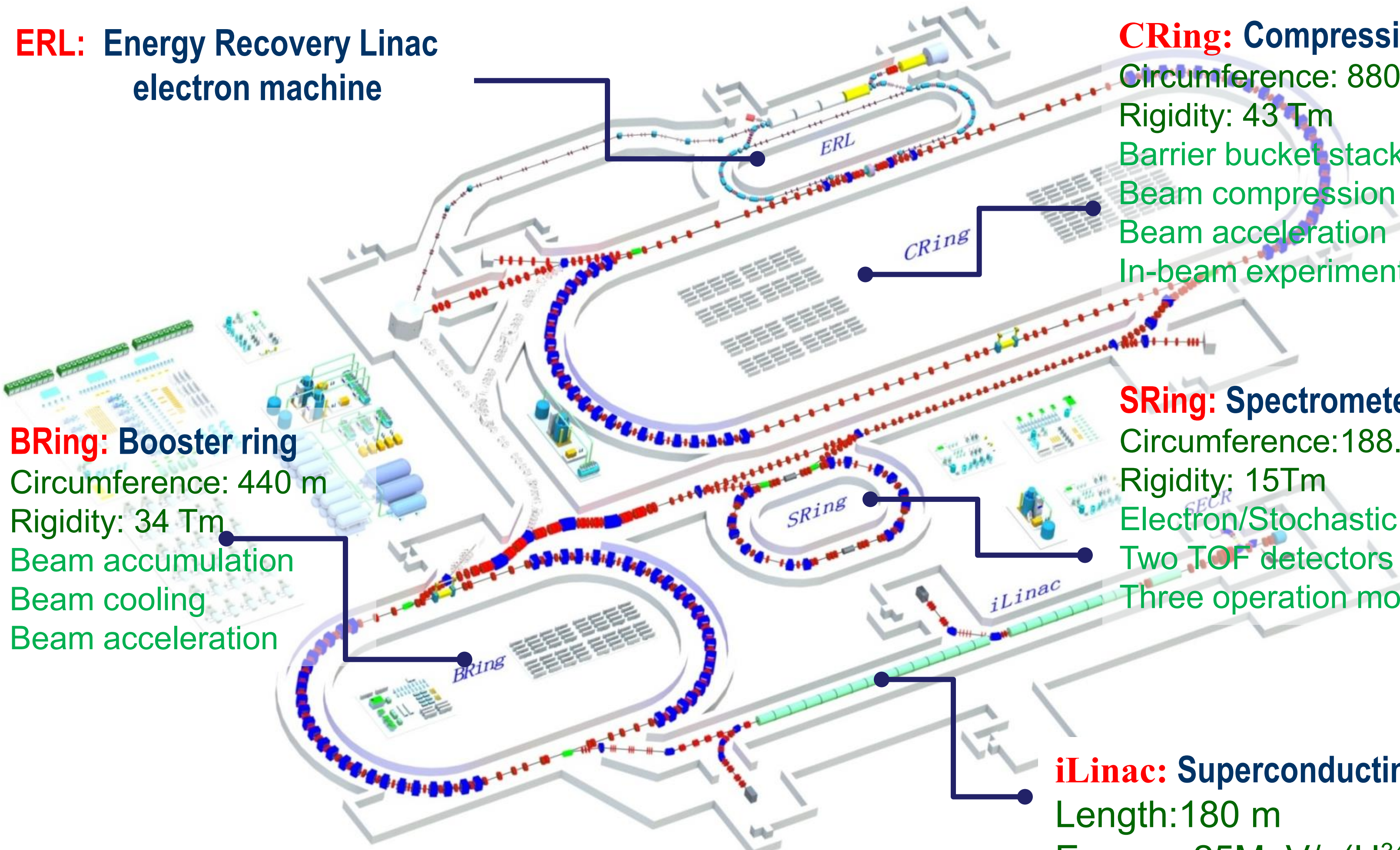
- *To explore the limit of nuclear existence*
- *To study exotic nuclear structure*
- *Understand the origin of the elements*
- *To study the properties of High Energy and Density Matter*

……

HIAF: Multi-purpose facility
with unprecedented parameters

ERL: Energy Recovery Linac electron machine

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



BRing: Booster ring
Circumference: 440 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: Superconducting linac
Length:180 m
Energy: 25MeV/u(U^{34+})

Perspective-New proposal   HIAF project in China

Multi-purpose facility with unprecedented parameters

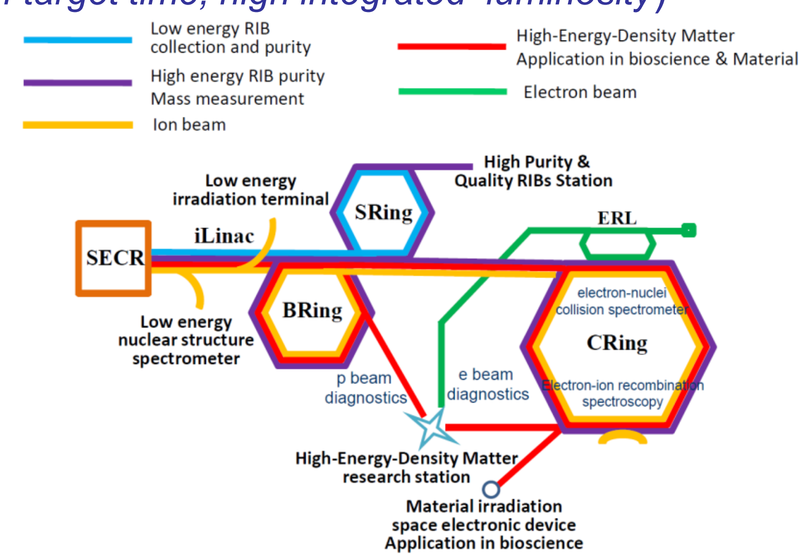
Unprecedented beam Intensity(Comparison with HIRFL):
- Primary beam intensity increases by x 1000 - x 10000
- secondary beam intensity increases by up to x 10000

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*)

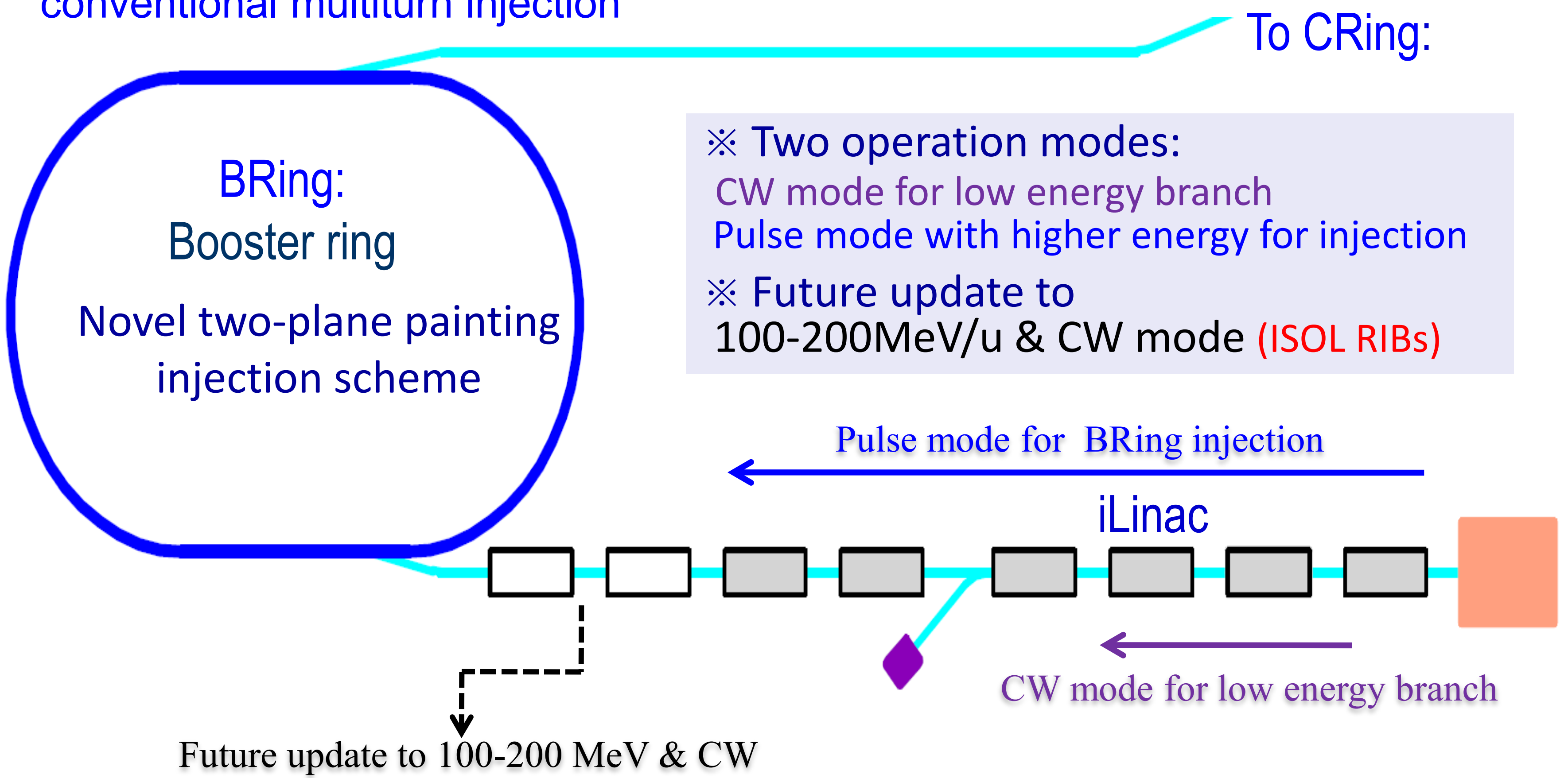
	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	25 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	~1.4×10^{11} ppp
CRing	U^{34+}	1.1 GeV/u	~5.0×10^{11} ppp
	U^{92+}	4.1 GeV/u	~2.0×10^{11} ppp



Unique feature-1

Superconducting Linac +Two-plane painting injection scheme
(Highly cost-effective accelerator layout to provide high intensity ion beam)

The first time to adopt two-plane painting injection for heavy ion in the world, the accumulation factor can reach nearly 150 for single injection, 5-10 over conventional multiturn injection



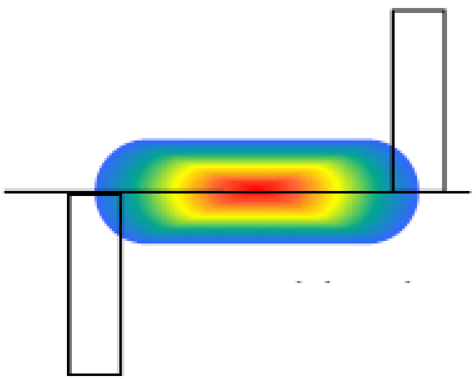
※ Two operation modes:
CW mode for low energy branch
Pulse mode with higher energy for injection

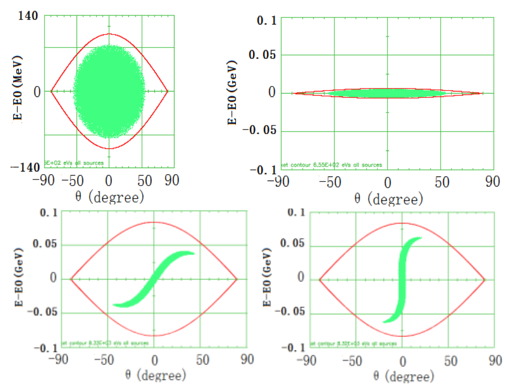
※ Future update to
100-200MeV/u & CW mode (ISOL RIBs)

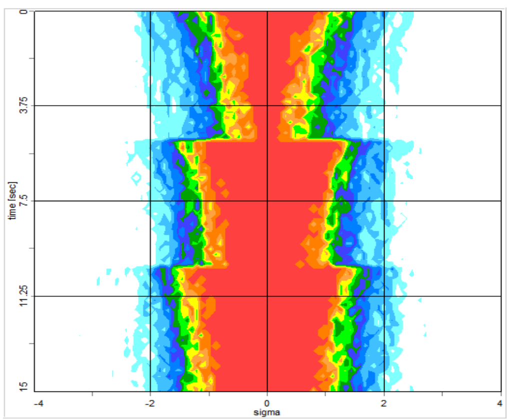
Unique feature-2

Barrier bucket + beam compression + beam cooling

Highly sophisticated scheme for high intensity ultra-short pulse ion beams







Barrier bucket stacking from BRing to CRing

4-5 times increase of beam intensity

5.0×10^{11} ppp (U^{34+})

Beam compression in CRing

5-6 times reduction of bunch length

50-100 ns

High energy electron cooling in CRing

4-5 times reduced beam size

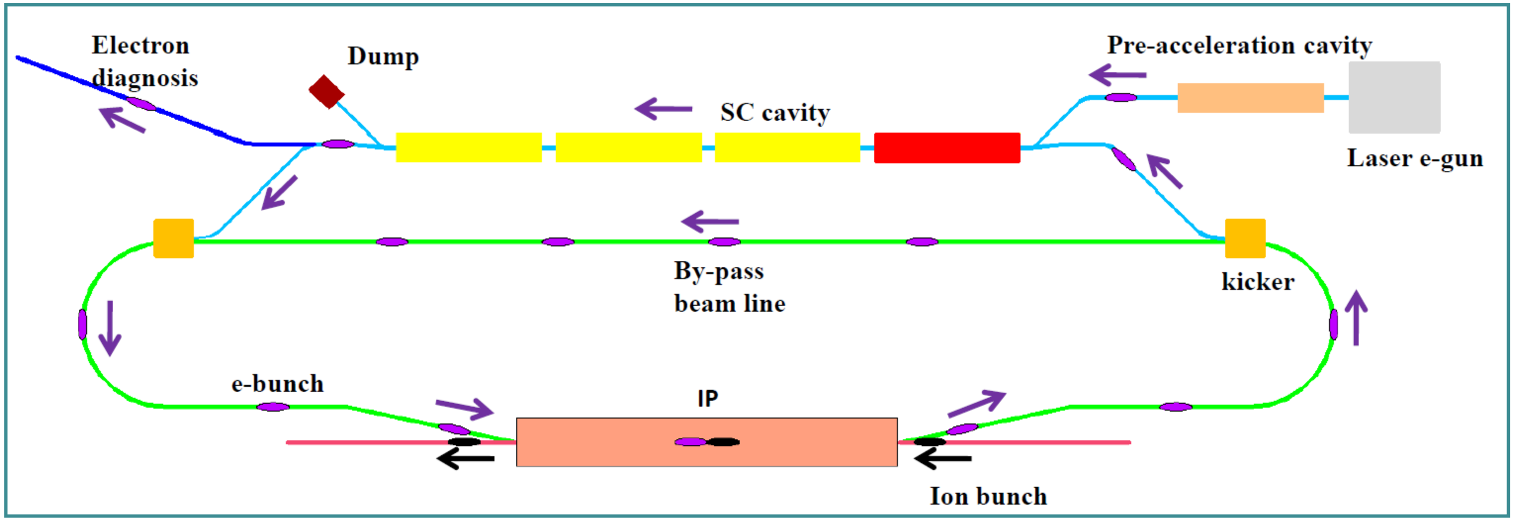
0.5-1.0 mm

Unique feature-3

Multifunction electron machine based on ERL technology

Two advanced technologies: Energy Recovery Linac & compact circulator ring

- ◎ Perfect solution for the high power beam dumping and low operational cost
- ◎ The compact circulator ring will reduce the required electron current from the cathode and ERL by a factor equal to the number of circulations



- Highly charged & ultra-short electron bunch for diagnosis of HEDP research
- High quality electron beam for ENC research
- Proof of principle test of the electron cooling of highly bunched ion beam

Beam dynamics challenges & studies

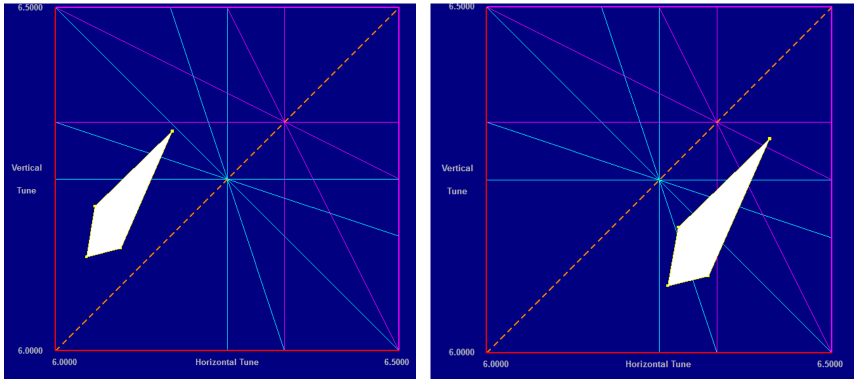
Topics:

- 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

HIAF dynamics Challenge & studies -1

Space charge effect

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)

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

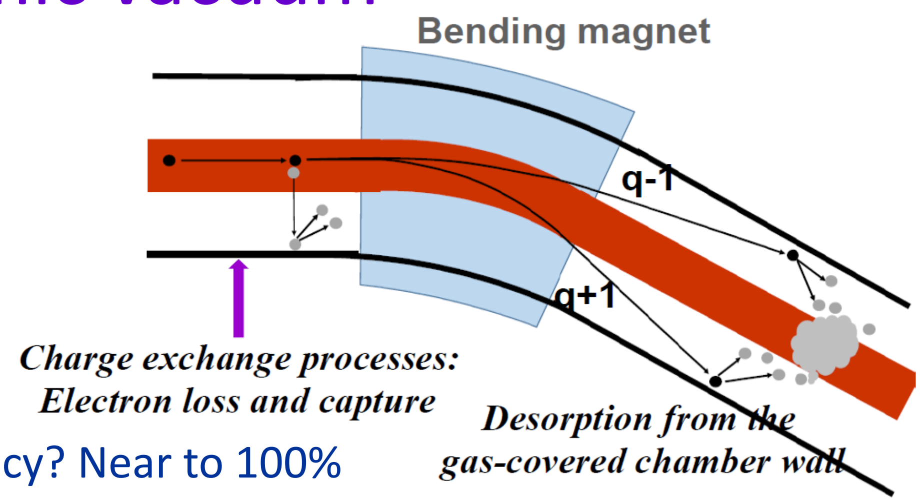
  Effective electron cooling: angle between electron and ion beams, hollow electron beam

  Beam dynamics simulation code is under development in cooperation with BINP

Developed simulation codes, studied the space charge effect and find the optimized work points.

HIAF dynamics Challenge & studies -2

Dynamic vacuum



Beam loss mechanism:

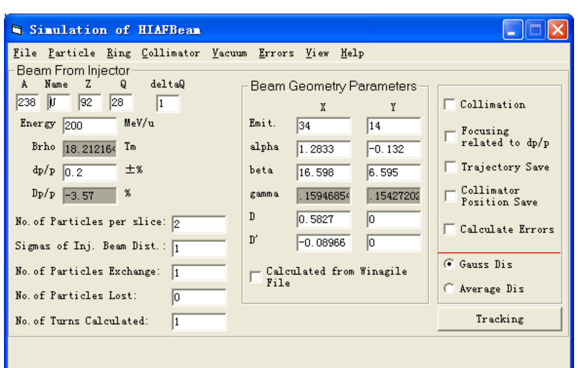
Charge exchange of intermediate charge state ions ($^{238}U^{34+}$) **due to collision**

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

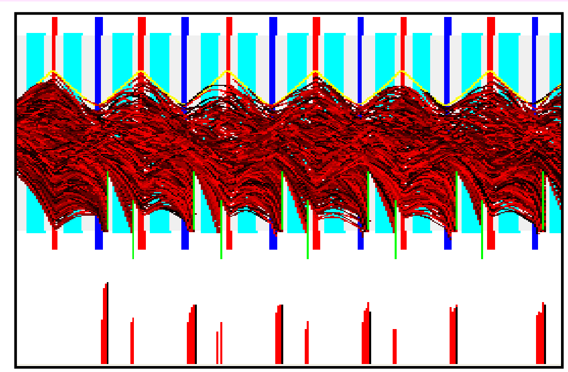
Challenges:

- 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.

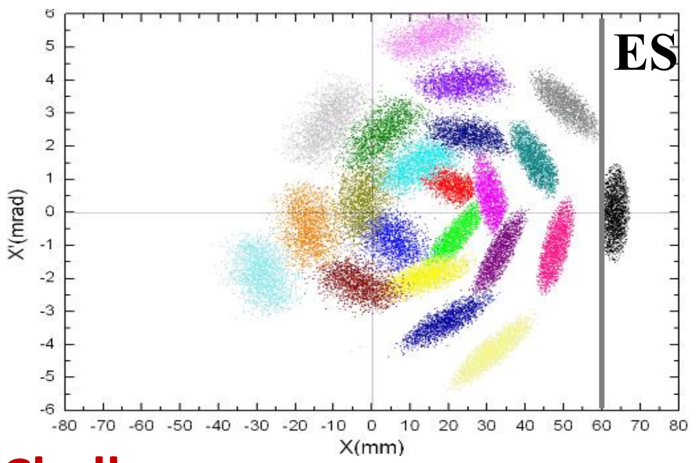


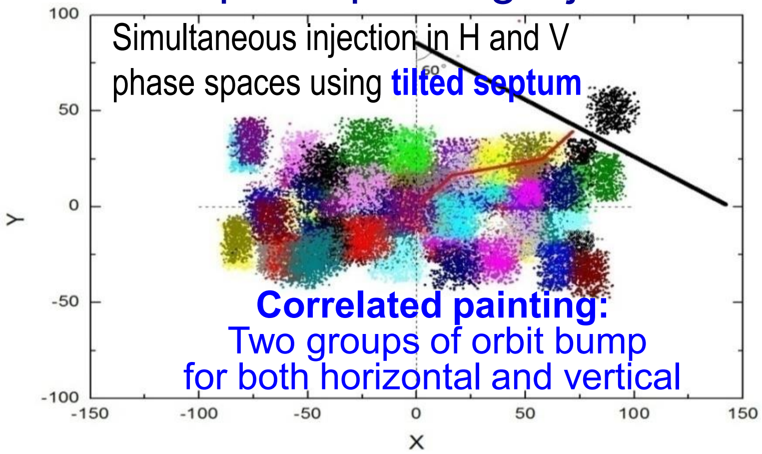
Simulation Code
HIAF-DYSD



HIAF dynamics Challenge & studies -3

Two-plane painting injection





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}**

HIAF dynamics Challenge & studies -4

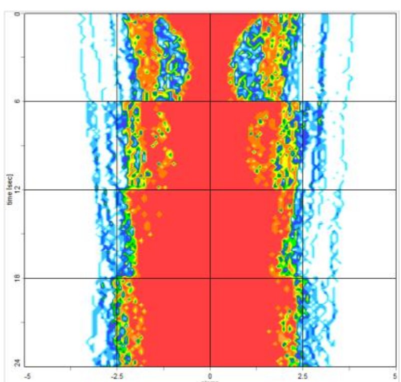
Barrier bucket stacking

Goals: **4-5 times increase of beam intensity through barrier bucket**

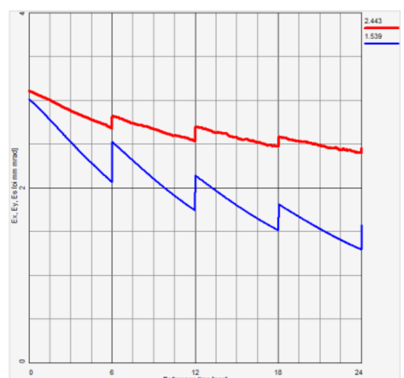
iLinac → *800MeV/u ($^{238}U^{34+}$)* ***1.4×10^11^*** BRing → ***4-5 times Barrier bucket*** → *1.1GeV/u ($^{238}U^{34+}$)* ***5.0×10^11^*** CRing

Challenges:

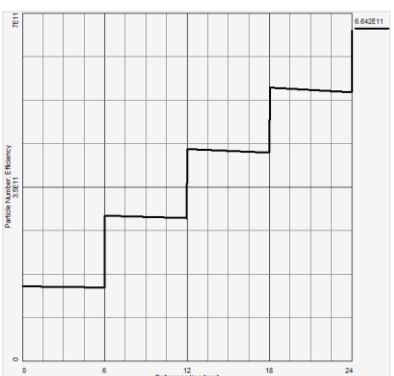
- Fast e-cooling for high energy heavy ion
- High intensity effect of barrier bucket stacking



Momentum spread



Emittance



Intensity

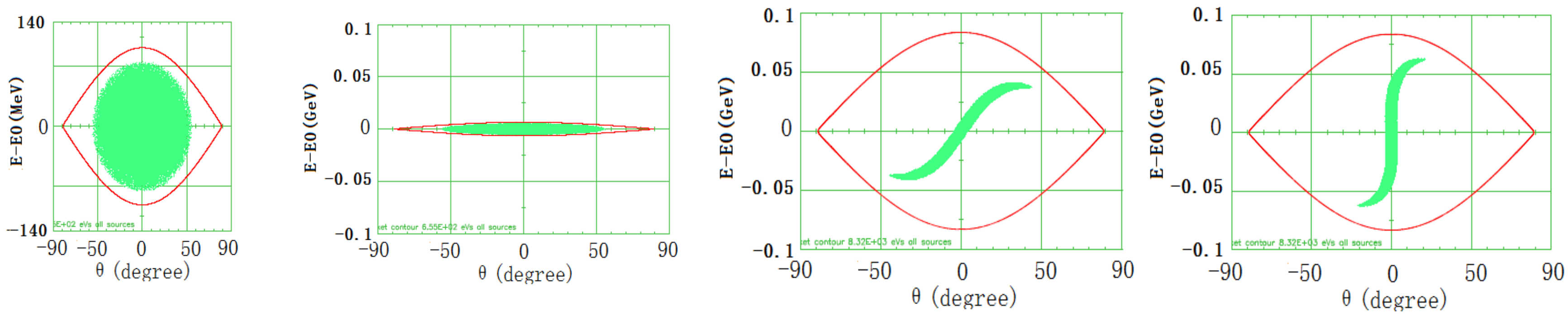
Beam dynamics design has been finished and under optimization

HIAF dynamics Challenge & studies -5

Ultra short beam compression

Goals: 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.

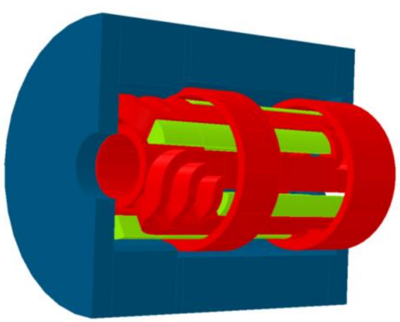
Technical challenges and R&D

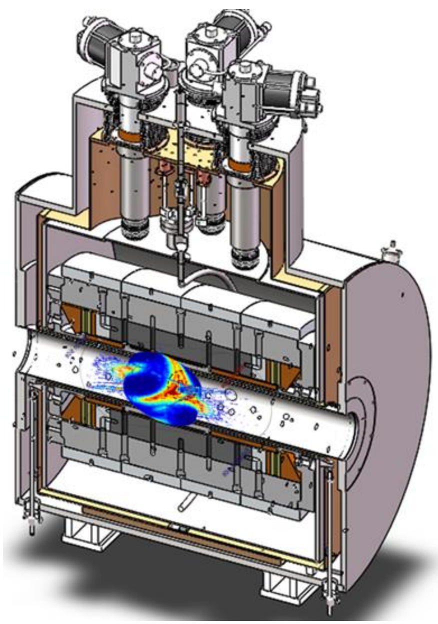
- ※ Superconducting ECR
- ※ Superconducting Linac
- ※ Dynamic vacuum collimator
- ※ Superconducting magnet
- ※ Electron cooling
- ※ Stochastic cooling

HIAF technical R&D-1

Superconducting ECR

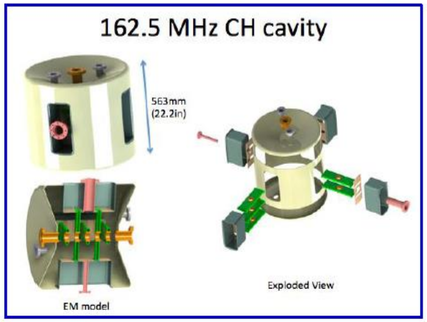
None of existing highly charged ion sources can meet HIAF requirements for the moment. Next generation (4^{th}) ECR source is under construction with the new magnet configuration and high RF frequency 40-50GHz.

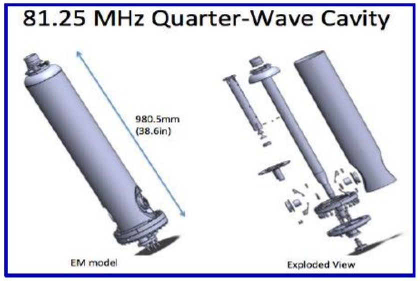




Superconducting linac

Several types of superconducting cavities has been developed at IMP for HIAF





HIAF technical R&D-2

Collimator prototype development

Two steps plan for collimator development and a prototype is under construction

First step: **Test platform**

Desorption measurement

Control system and vacuum system test

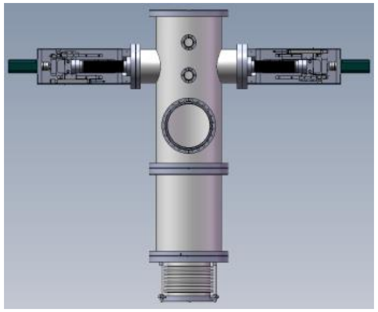
Install at PISA or E-point

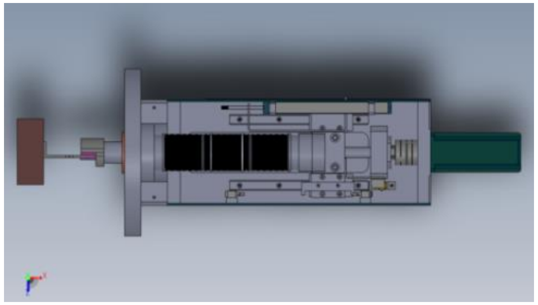
Second step

Collimator prototype of CSRm

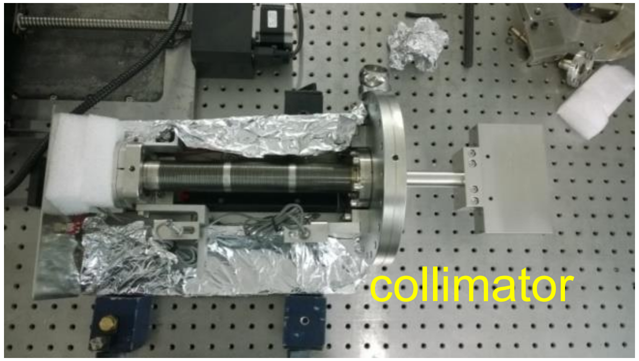
Beam loss measurement

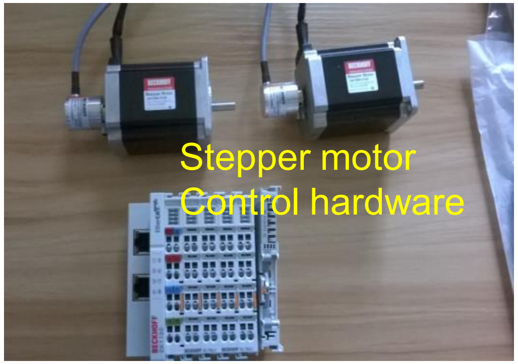
The mechanical design has been finished

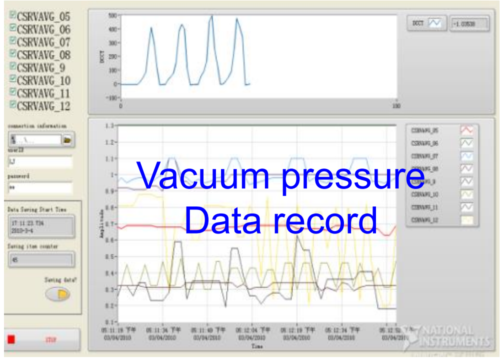




Fabrication of hardware components







HIAF technical R&D-4

Super-ferric dipole with warm iron yoke

- The dipole prototype for HIAF is under development in IMP. The fabrication has been finished and will be tested in few months.

Fabrication of superconducting cable

Fabrication of coil case

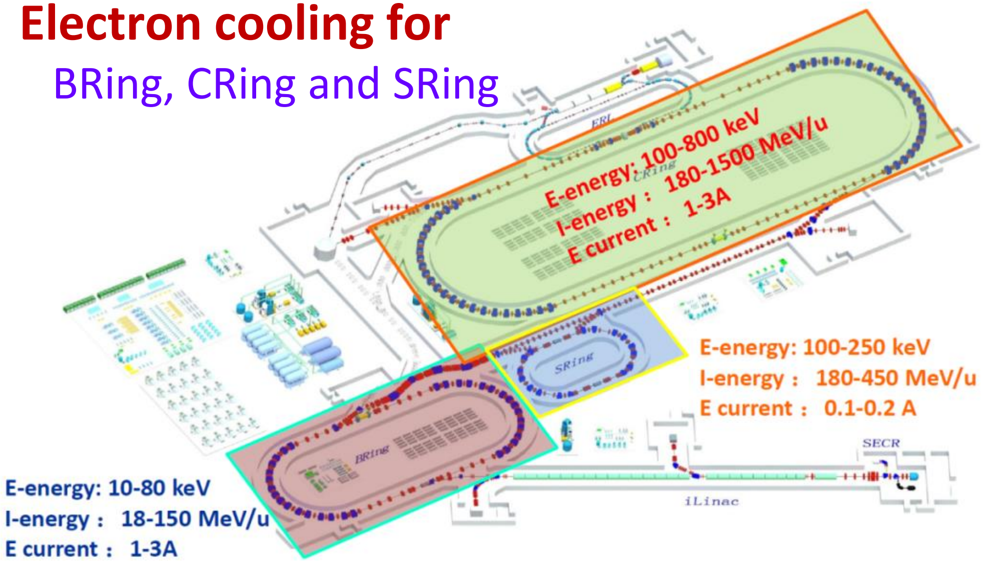
Fabrication of cryostat

HIAF technical R&D-5

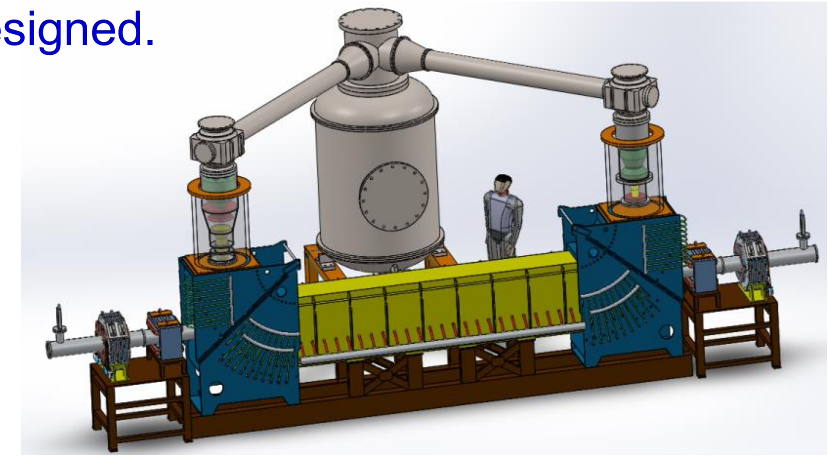
Beam cooling technique

Electron cooling for

BRing, CRing and SRing

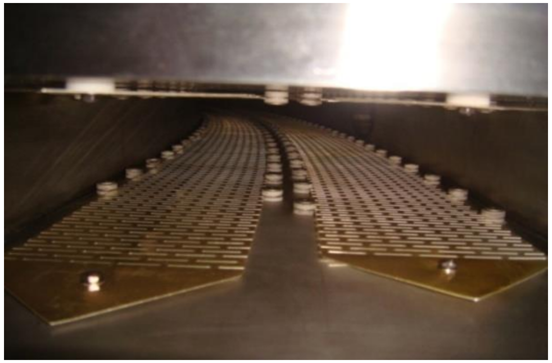


Based on well-established electron cooling of existing facility, new electron cooling device has been designed.



Stochastic cooling

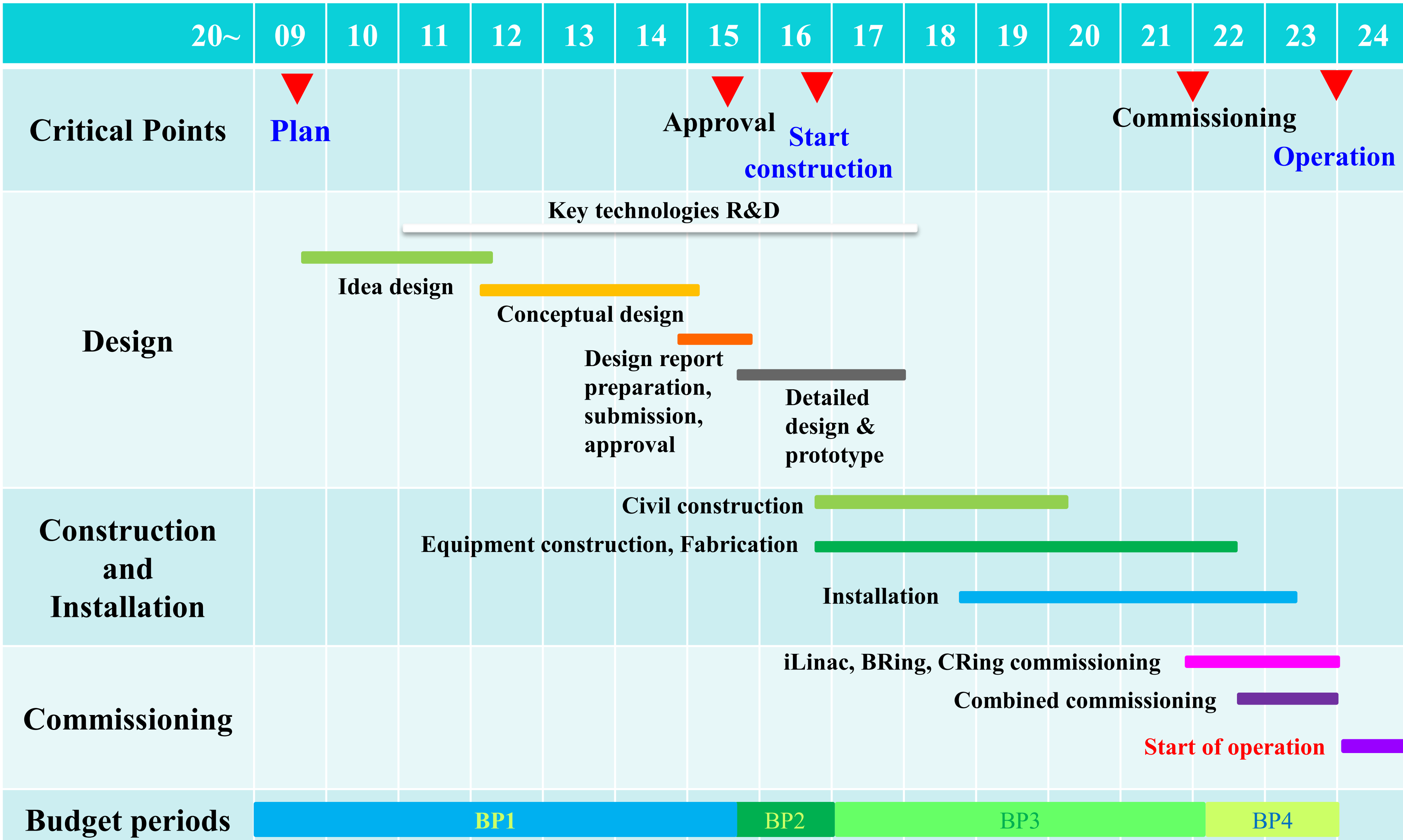
A novel type of 2.76 m long slotted pick-up was developed (in cooperation with CERN and GSI) for CSRe stochastic cooling. the tuning of machine will start next year.



Budget of HIAF (1st phase)

Items	1st phase (MRMB)
iLinac	550
BRing	320
CRing	370
eLinac	50
ERing	
High energy electron cooling	
Beam transfer line	50
Experiment setups	330
Cryogenics	205
Civil engineering	245
Tunnel construction	180
Contingency cost	70
Total of facility	2370 (central government)
Land & infrastructure	1400 (local government)
Total	**3770**

Schedule for the HIAF (1st phase)



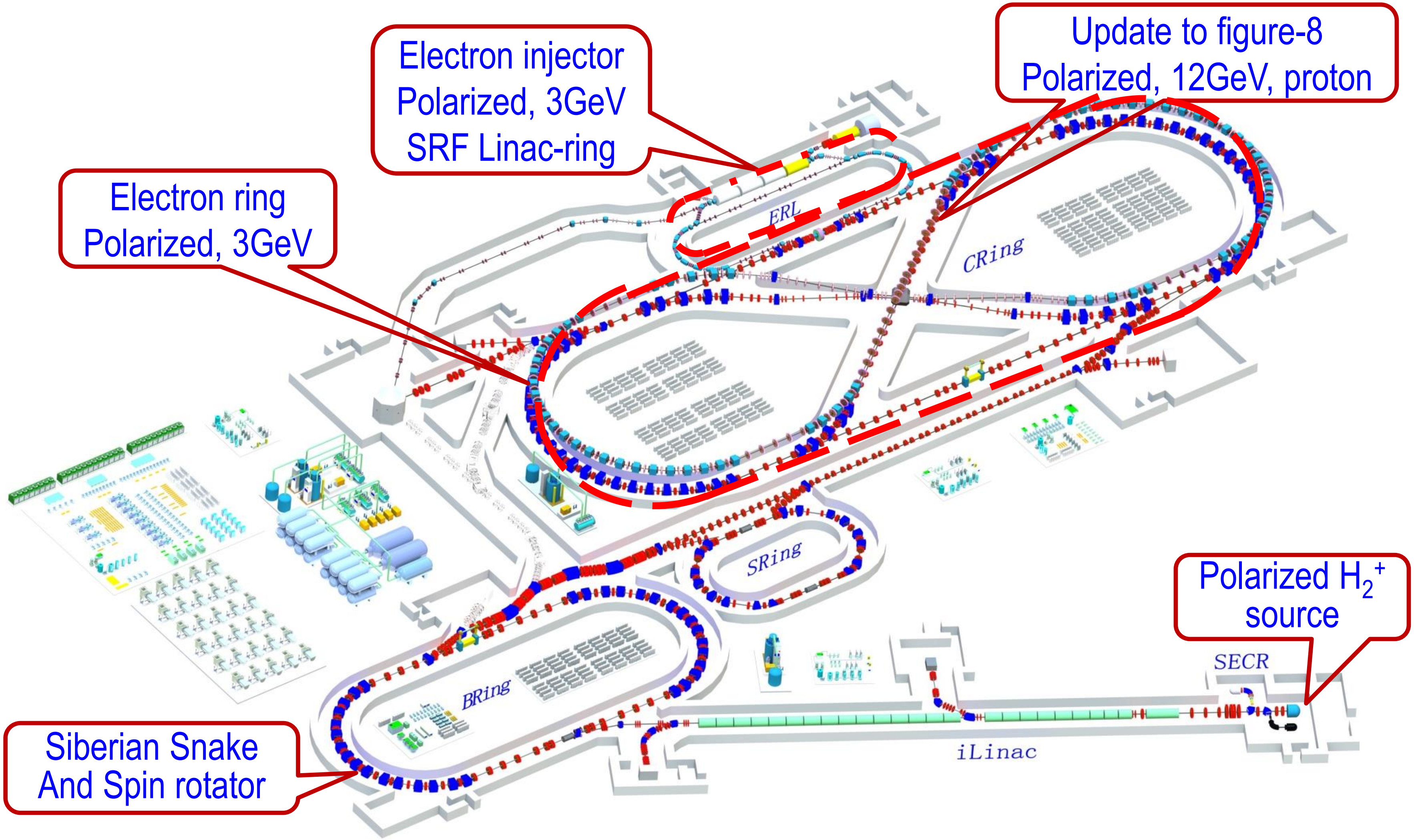
Site of HIAF project-new campus

Site of HIAF project-new campus

HIAF second phase-EIC

A High Luminosity Electron-Ion Collider

A New Experimental Quest to Study the Sea quark and Gluon



HIAF design of first phase maintains a well defined path for EIC

Thanks

for your attention