Chinese Academy of Sciences
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中国科学院
CHINESE ACADEMY OF SCIENCES

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HIRFL Status and Development

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On behalf of Institute of Modern Physics (IMP)
Chinese Academy of Sciences (CAS)

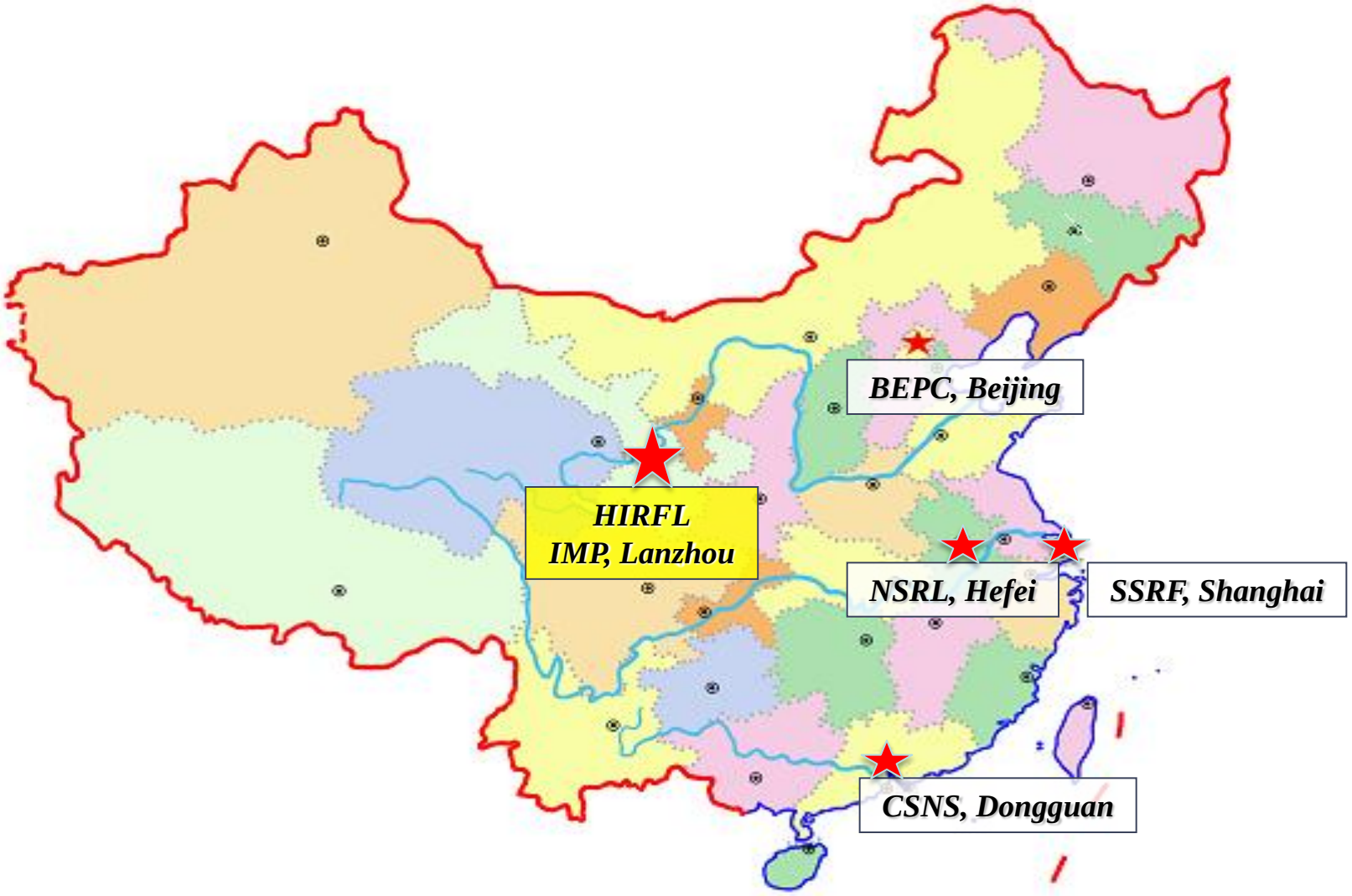
Outline

- Brief Introduction of IMP
- Status of HIRFL
- Upgrade Projects at HIRFL
- Brief introduction of future projects of IMP

Outline

- Brief Introduction of IMP
  - Location
  - Scientific activities
  - Manpower and Budget
- Status of HIRFL
- Upgrade Projects at HIRFL
- Brief introduction of future projects of IMP

Location of Lanzhou



Bird's eye view of IMP

One of the nuclear physics and heavy ion application research centers
Operating the biggest Heavy Ion Accelerator Facility in China, National Lab.

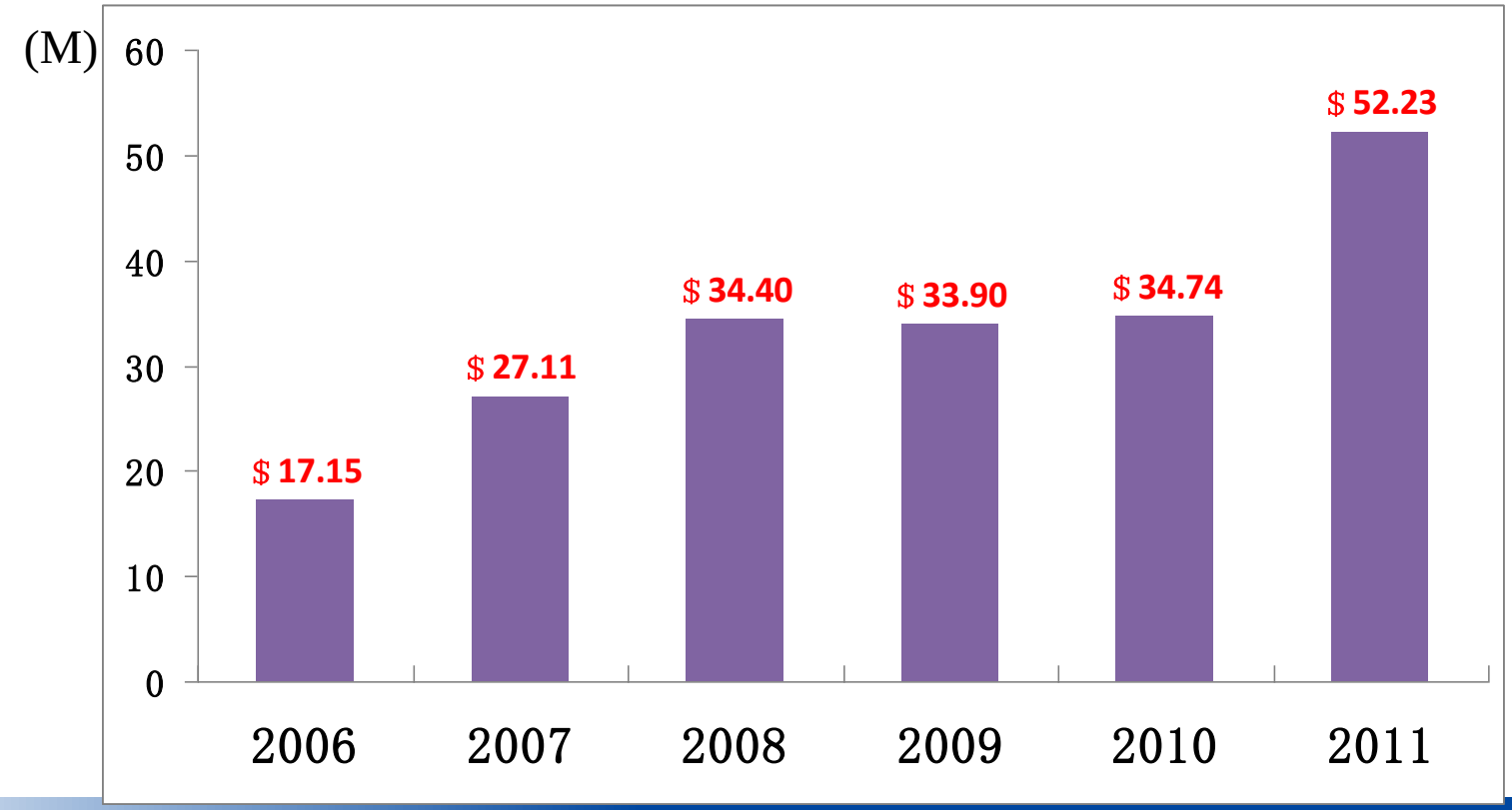
Scientific Activities in IMP

- Fundamental researches on nuclear & atomic physics
  - Reactions with exotic nuclei: elastic scattering, (p, γ), total cross-section, …
  - Nuclear spectroscopy: **mass measurement**, γ-spectroscopy, β-delayed n-emission, 2p-emission, …
  - Properties of nuclear matter: high density behavior of asymmetric nuclear matter
  - Chemistry of super-heavy elements, and synthesis of new isotopes
  - Key reactions in stellar evolution
  - Spallation & nuclear data for ADS project
  - HED physics, hadron physics
  - HCI interaction with laser, electron, molecular, and surface
- Applications with heavy ions
  - Material: nano-tech., nuclear energy structural material, …
  - Radio-biology: **tumor therapy**, mutation breeding, …
- Detector development
  - Si detectors: Si(Au), Si(Li), Si-strip
  - Scintillator detectors: CsI, LaBr, plastic sci., liquid sci. …
  - Gaseous detectors: IC, TPC, PPAC, MWPC, MWDC, MicroMeGAS, GEM, …
- **Key technique development related to HI Accelerator and ADS**

Manpower and Budget

Total manpower now: 733 (+211) permanent staffs
+ 20 Post-docs
+ 150 temporary
+ 240 graduate students

Budget in 2012: ~70M$ (expected)



Outline

- Brief Introduction of IMP
- Status of HIRFL
  - Facility introduction
  - Operation statistics
  - Operation Highlights
- Upgrade Projects at HIRFL
- Brief introduction of future projects of IMP

Heavy Ion Research Facility in Lanzhou

SSC(K=450), in 1988

100 AMeV (H.I.), 110 MeV (p)

SFC (K=69), in 1964

10 AMeV (H.I.), 17~35 MeV (p)

CSRe, in 2007

Mass Spectrometer

RIBLL1, in 1998

RIBs at tens of AMeV

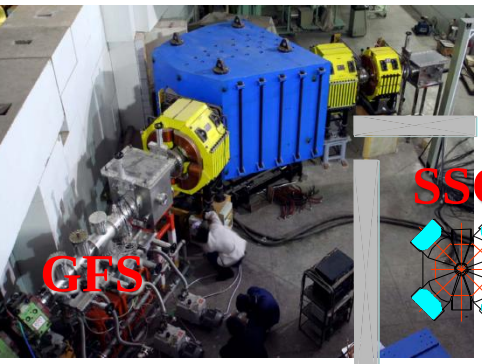
RIBLL2, in 2007

RIBs at hundreds of AMeV

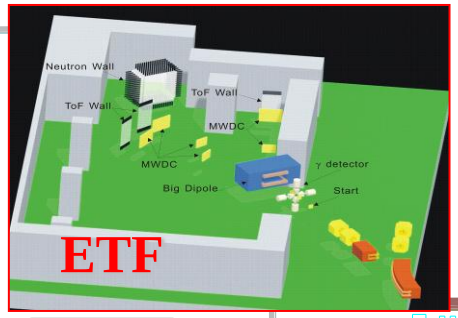
CSRm, in 2006

1000 AMeV (H.I.), ≤ 2.8 GeV (p)A

Experimental Areas



SSC



Mass measurement
ToF target

SFC

CSRe

Medial energy
Exp. area

Low energy
Exp. area

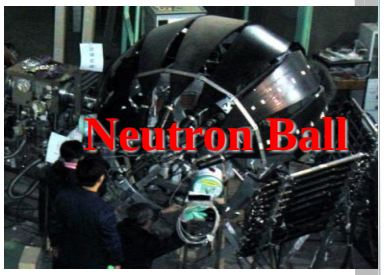
External
target

RIBLL2

Internal target

E-cooler

PISSA



RIB1
Exp. area

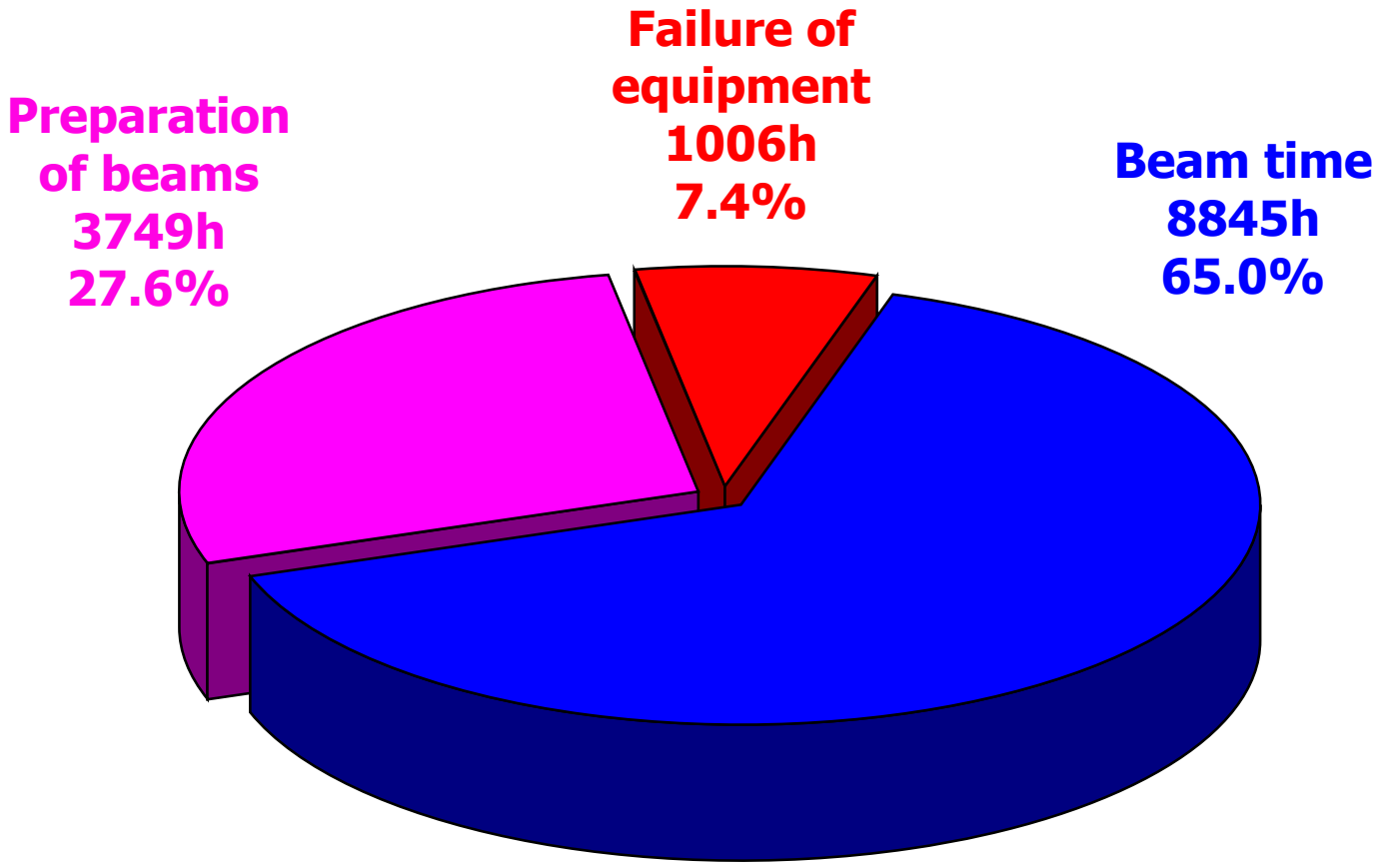
RIBLL1

CSRm

Cancer
therapy

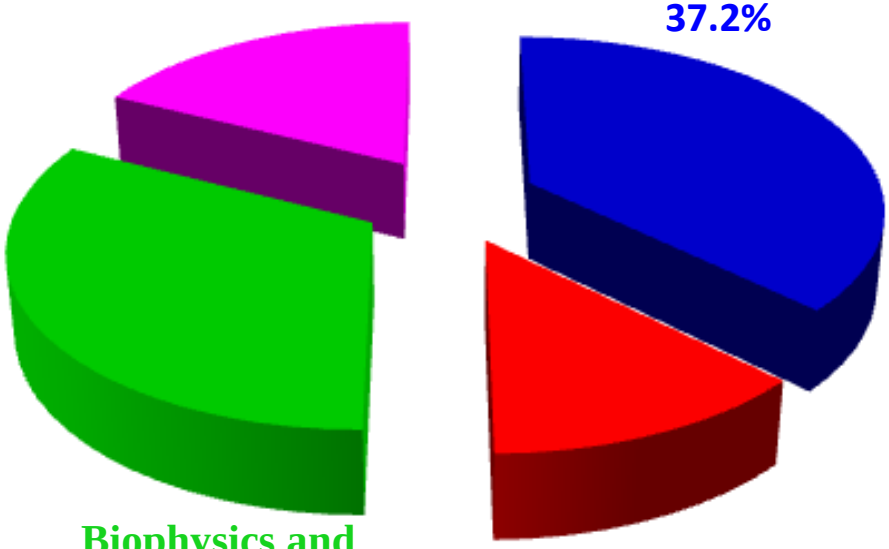
Operation Status

Total operation time: 13600 hours; 7893 hours for CSR (58%)

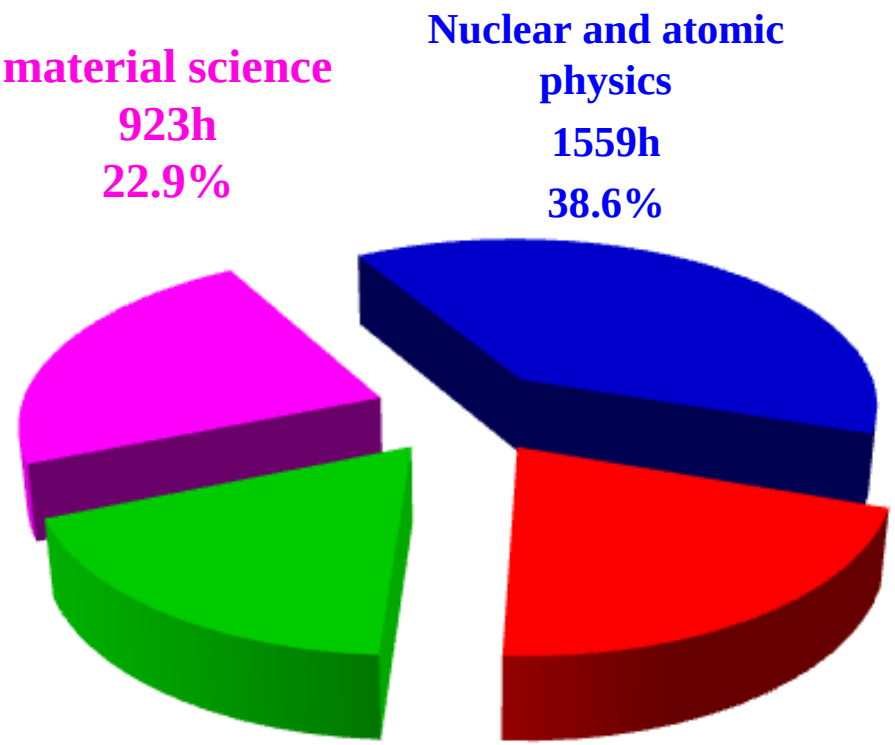


Operation time distribution in 2010.09 - 2012.04

Operation Status



2010.9-2011.7



2011.9-2012.4

Operation Status

序号	束流种类	SFC		SSC		CSR		调束时间
		能量 (MeV/u)	流强 (μA)	能量 (MeV/u)	流强 (μA)	能量 (MeV/u)	流强 (μA)	
1	$^{209}Bi^{31+}$	0.91	0.8	9.5	0.05	/	/	10.09.16
2	$^{12}C^{4+/6+}$	7.0	10	/	/	165~270	1200	10.10.15
3	$^{12}C^{4+/6+}$	7.0	13	/	/	80~430	1600	10.11.07
4	$^{12}C^{4+/6+}$	4.91	7.8	54.5	0.6	/	/	10.12.09
5	$^{209}Bi^{31+}$	0.91	0.35	9.5	0.02	/	/	10.12.21
6	$^{209}Bi^{31+}$	1.5	1.5	/	/	/	/	10.12.31
7	$^{209}Bi^{41+}$	2.6	0.3	/	/	/	/	11.01.07
8	$^{209}Bi^{38+}$	2.25	0.7	/	/	/	/	11.01.08
9	$^{209}Bi^{36+}$	2.0	1.8	/	/	170	10	11.01.10
10	$^{64}Ni^{19+}$	4.98	2.5	/	/	/	/	11.01.19
11	$^{58}Ni^{19+}$	6.3	1.5	/	/	463.3	350	11.02.12
12	$^{209}Bi^{36+}$	2.0	1.8	/	/	170	60	11.02.25
13	$^{86}Kr^{17+/26+}$	2.35	2.2	25	0.1	/	/	11.02.28
14	$^{12}C^{4+/6+}$	7	2.5	80.55	0.1	/	/	11.03.07
15	$^{64}Ni^{19+}$	4.98	2.5	/	/	/	/	11.03.19
16	$^{36}Ar^{8+/8+}$	2.073	5	22	0.8	/	/	11.04.03
17	$^{36}Ar^{8+/14+}$	2.073	5	22	0.2	/	/	11.04.09
18	$^{40}Ar^{12+/16+}$	6.17	4.5	70	0.17	/	/	11.04.14
19	$^{58}Ni^{19+/25+}$	6.17	2.5	70	0.06	/	/	11.05.05
20	$^{12}C^{4+/6+}$	7	4.2	80.55	0.35	/	/	11.05.11
21	$^{12}C^{4+/6+}$	7	7~9	/	/	165~350	2000	11.05.21
22	$^{12}C^{4+/6+}$	7	3.5	80.55	0.25	/	/	11.07.13
23	H_2/H	10	4	/	/	400		11.07.22

2010.09 – 2011.08

C, Bi, Ni, Kr, Ar, H2

Newly accelerated nuclei:
209Bi36+ 170 MeV/u
H2+/H+ 400 MeV/u

Operation Status

序号	束流种类	SFC		SSC		CSR		调束时间
		能量 (MeV/u)	流强 (μA)	能量 (MeV/u)	流强 (μA)	能量 (MeV/u)	流强 (μA)	
1	$P(H_2/H)$	10	7	/	/	400	7/20	11.09.08
2	$^{238}U^{32+}$	1.22	1	/	/	100	160	11.09.21
3	$^{40}Ar^{8+/16+}$	2.35	3.5	25	0.15	/	/	11.10.14
4	$^{209}Bi^{31+}$	0.91	0.35	9.5	0.02	/	/	11.10.16
5	$^{12}C^{4+/6+}$	7	6~7	/	/	165~350	600	11.11.11
6	$^{12}C^{4+/6+}$	4.91	6	54.5	0.6	/	/	11.11.20
7	$^{22}Ne^{7+/10+}$	6.17	8~12	/	/	70	3500/1500	11.12.07
8	$^{18}O^{6+/8+}$	5.36	8	60	*	/	/	11.12.10
9	$^{86}Kr^{20+/28+}$	3.63	4	/	/	264~435	700	11.12.21
10	$^{18}O^{6+/8+}$	5.36	8	60	0.4	/	/	12.01.11
11	$^{84}Kr^{17+/26+}$	2.35	5	25	0.25	/	/	12.01.22
12	$^{19}F^{7+}$	6.6	1.6	/	/	/	/	12.02.14
13	d	10	5	/	/	/	/	12.02.19
14	$^{12}C^{4+/6+}$	7	7	/	/	200~400	1000	12.02.25
15	$^{40}Ca^{12+}$	5.17	2.5	/	/	/	/	12.03.14
16	$^{40}Ca^{13+/18+}$	6.96	2	80	/	/	/	12.03.17
17	$^{40}Ca^{12+/18+}$	6.17	2.2	70	0.08	/	/	12.03.26
18	$^{12}C^{4+/6+}$	7	2.9	80.55		/	/	12.03.28
19	$^{12}C^{4+/6+}$	7	8	/	/	165~350	2000	12.04.20

2011.09 – 2012.04

H2, U, Bi, C, Ne, O, Kr, F, D, Ca

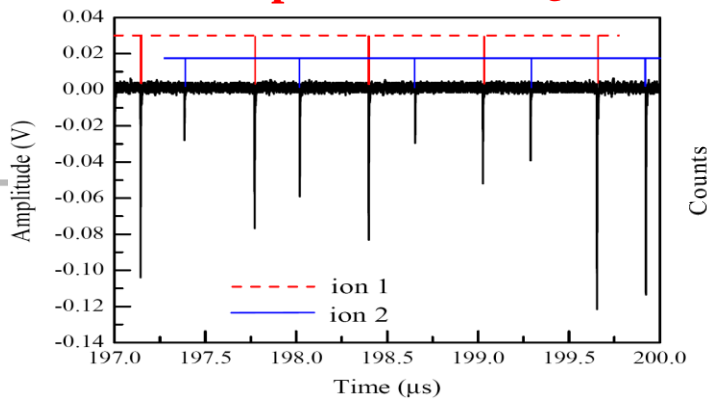
Newly accelerated nuclei:
238U32+, 100 MeV/u, 1E7 ppp
D+, 10 MeV/u

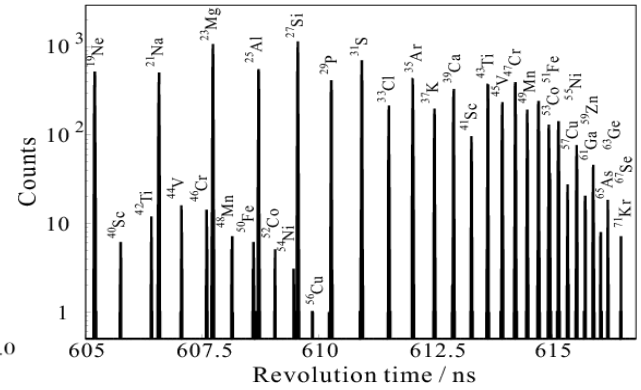
Mass measurements at HIRFL

Isochronous Mass Spectrometry (IMS)

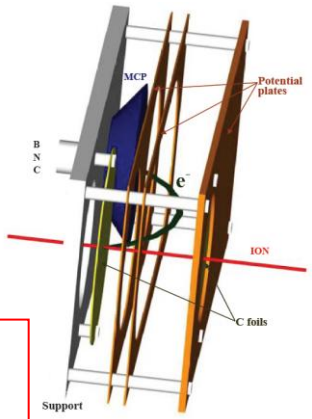
the revolution time depends on M/Q of nucleus only

In operation from 2008





Time detector

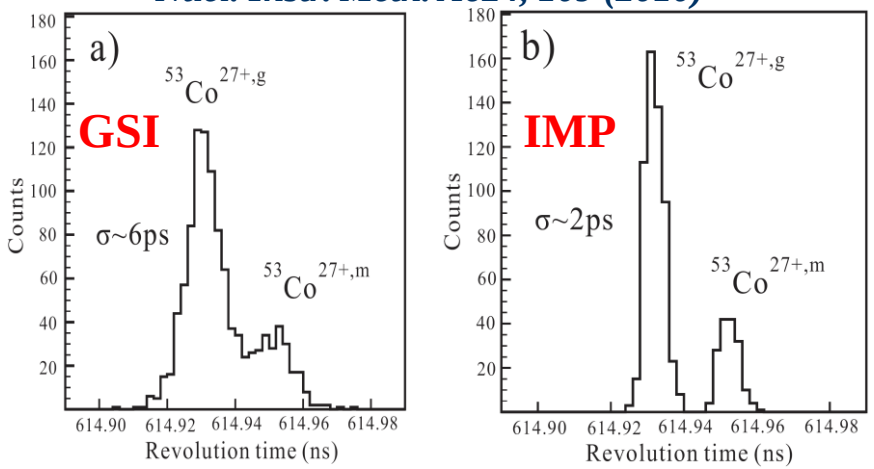


$$\frac{df}{f} = -\frac{1}{\gamma_t^{\,2}}\frac{d(m/q)}{(m/q)} + \left(1 - \frac{\gamma^2}{\gamma_t^{\,2}}\right)\frac{dv}{v}$$

Mass Measurement Experiments

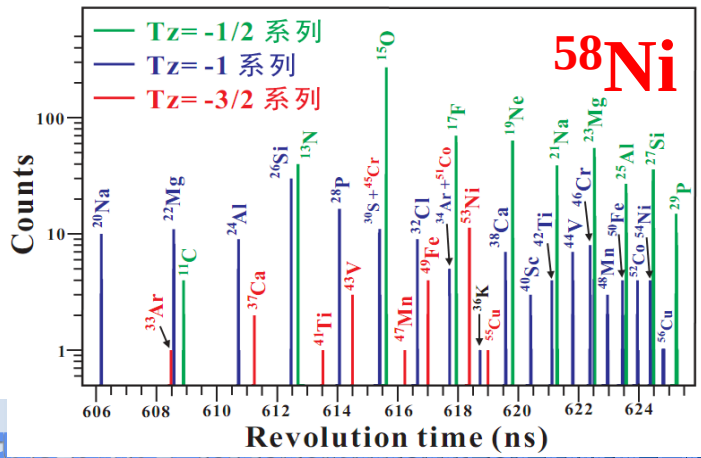
- 1st： ^{78}Kr projectile fragmentation
  - 2009.10 Data analysis finished
- 2nd：^{58}Ni projectile fragmentation
  - 2011.02 Data analysis finished
- 3rd：^{86}Kr projectile fragmentation
  - 2012.01 Data analysis in progress

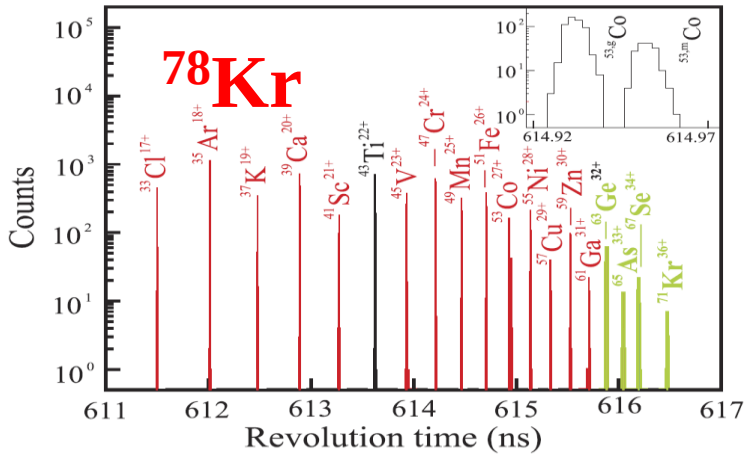
Nucl. Instr. Meth. A624, 109 (2010)



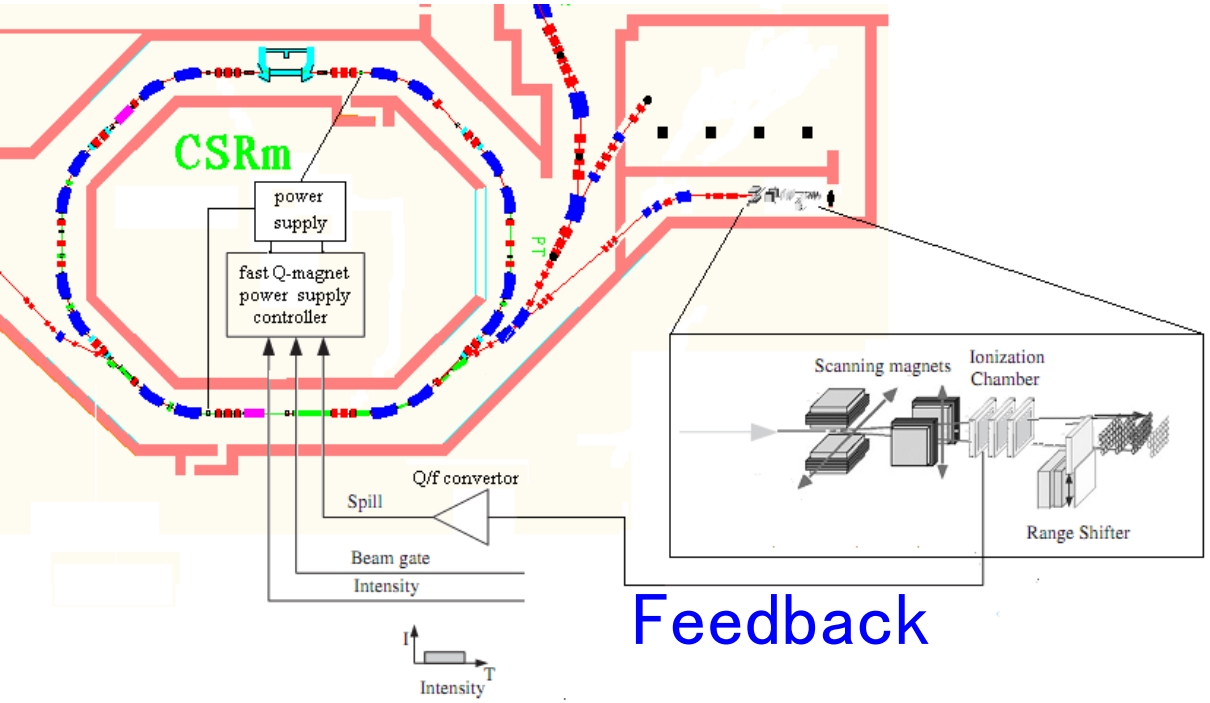
PRL 106, 112501 (2011) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2011

Direct Mass Measurements of Short-Lived $A = 2Z - 1$ Nuclides ^{63}Ge, ^{65}As, ^{67}Se, and ^{71}Kr and Their Impact on Nucleosynthesis in the *rp* Process

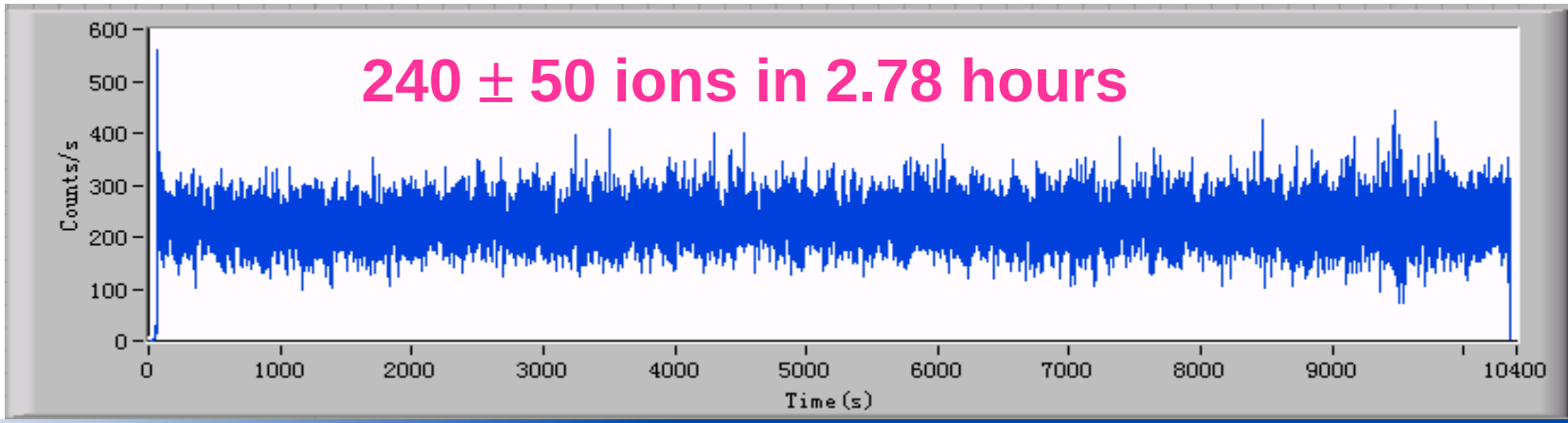




Cancer Therapy Terminal

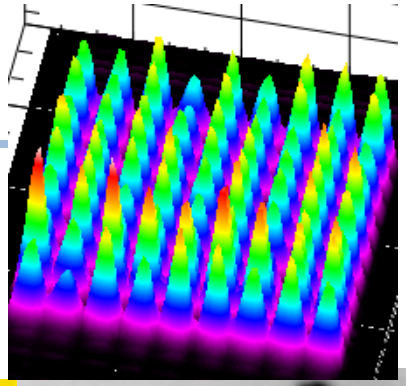


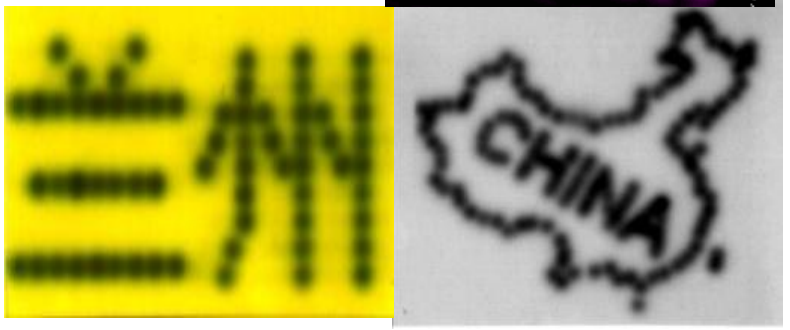
- 1/3 resonance slow extraction
- RF-Knockout exciting
- Feedback of extraction rates with fast Qs

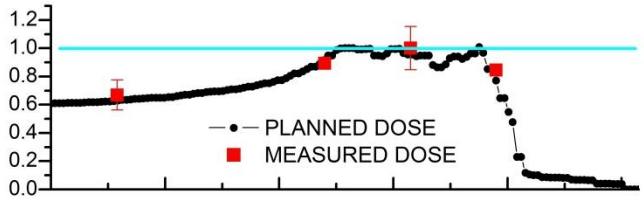


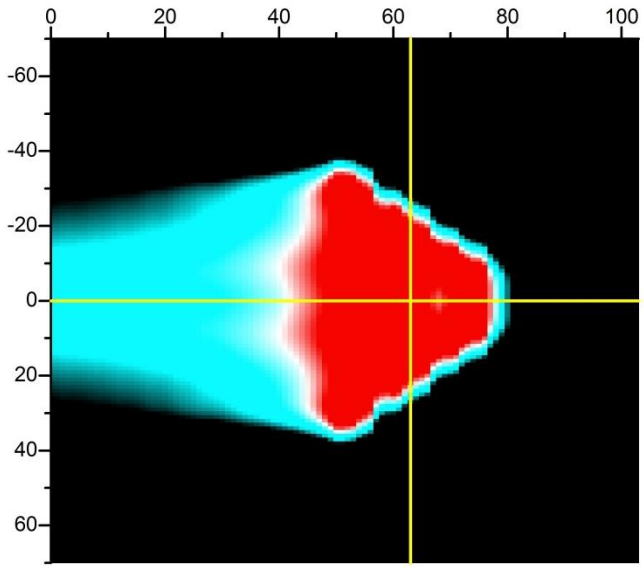
3D Dose Conformal Plan

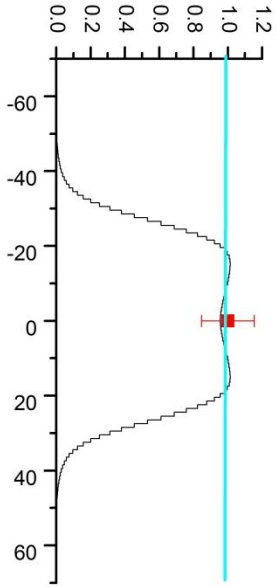
- Active energy variation
- Spot scanning
- Intensity modulation

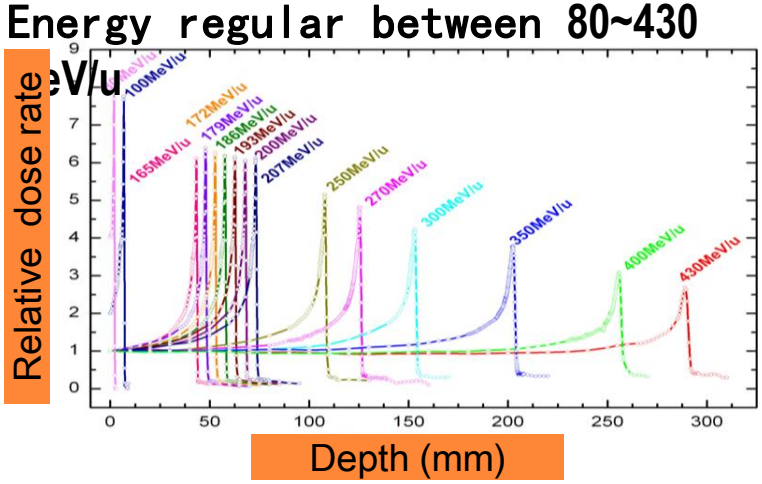




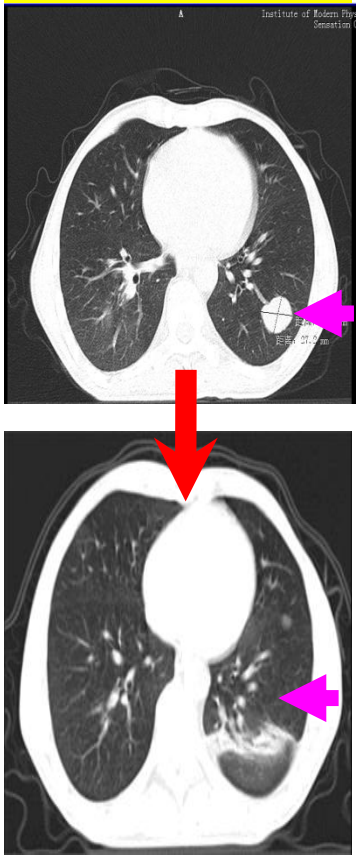
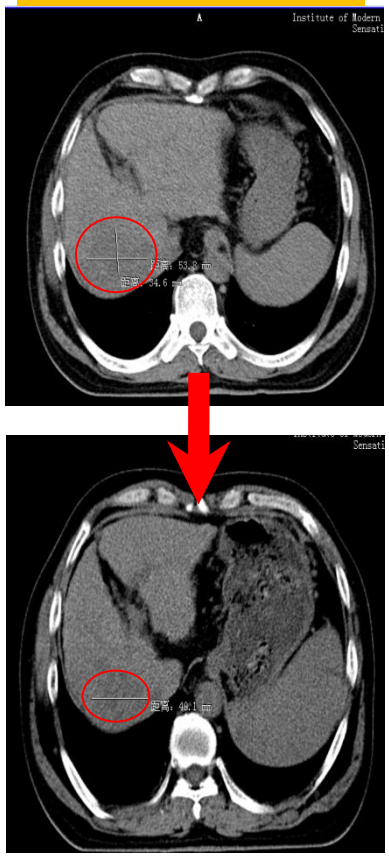
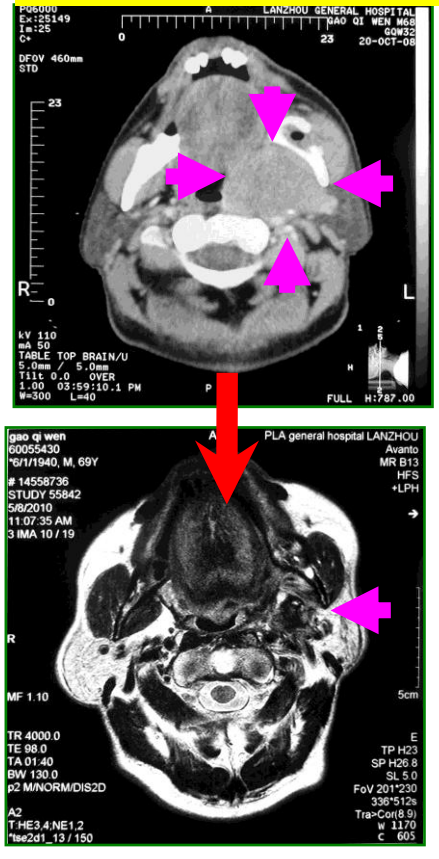
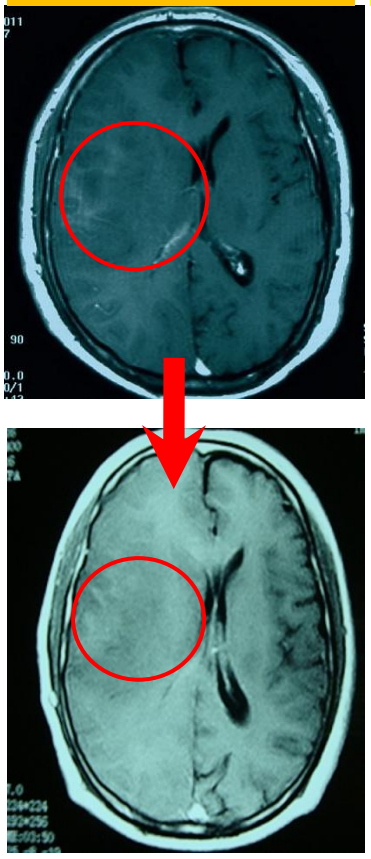
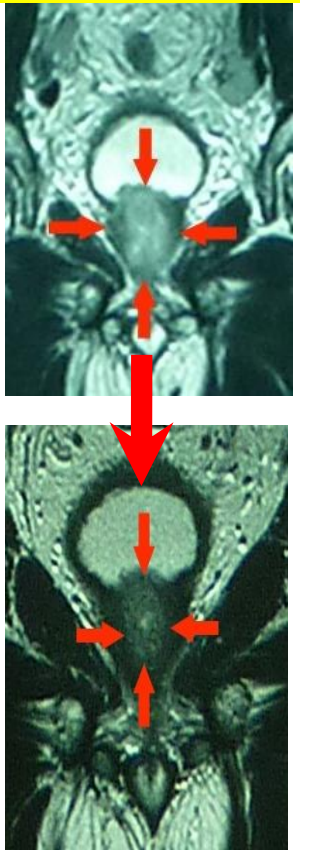




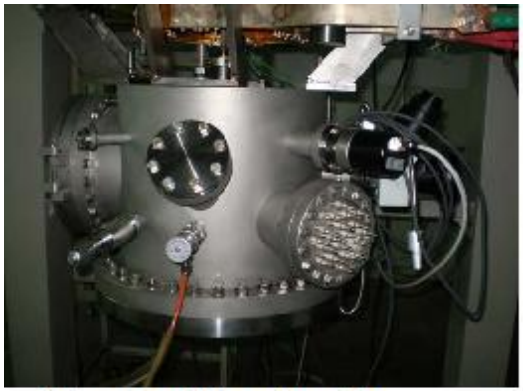




Deep tumor treatment experiments

Metastatic lung cancer	Primary liver cancer	Cell Carcinoma of salivary gland	Cerebral Glioma	Prostate cancer
				
5 months	4 weeks	14 months	0 day	1 month
disappear	Shrink 30%	disappear	Shrink 10%	Shrink 30%

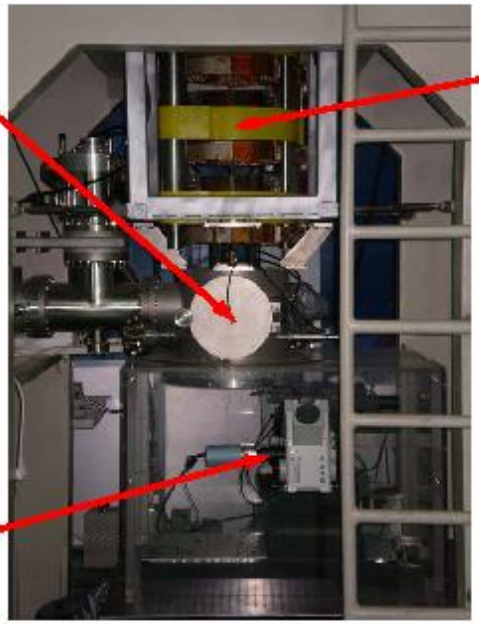
New Micro-Beam irradiation terminal



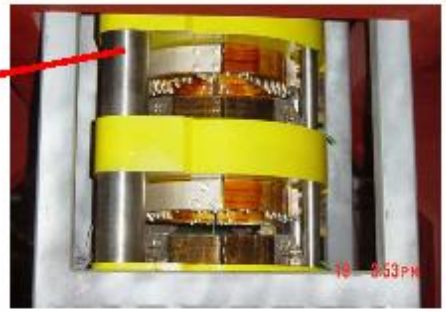
Vacuum Chamber for material irradiation

Microbeam facility on the first floor

(upper part)



Inverted microscope for cell irradiation



Quadrupole triplet, Φ15mm
L = 100mm, G = 123 T/m

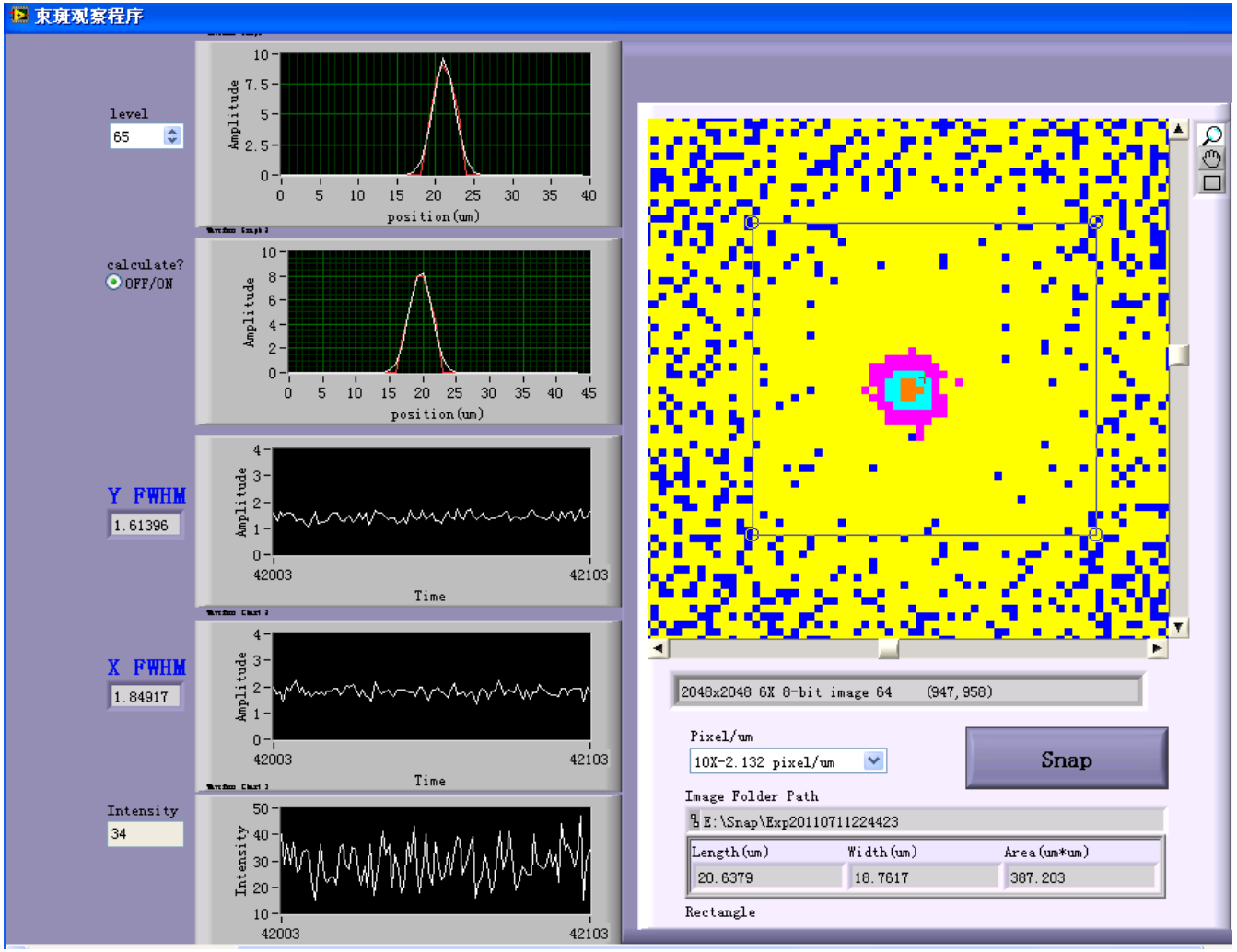
Facility in the cellar

(lower part)

High Energy (100 MeV/u)

Vertical irradiation

New Micro-Beam irradiation terminal



$^{12}C^{6+}$ 80.55MeV/u

Ion hitting rate:
1~1200/s

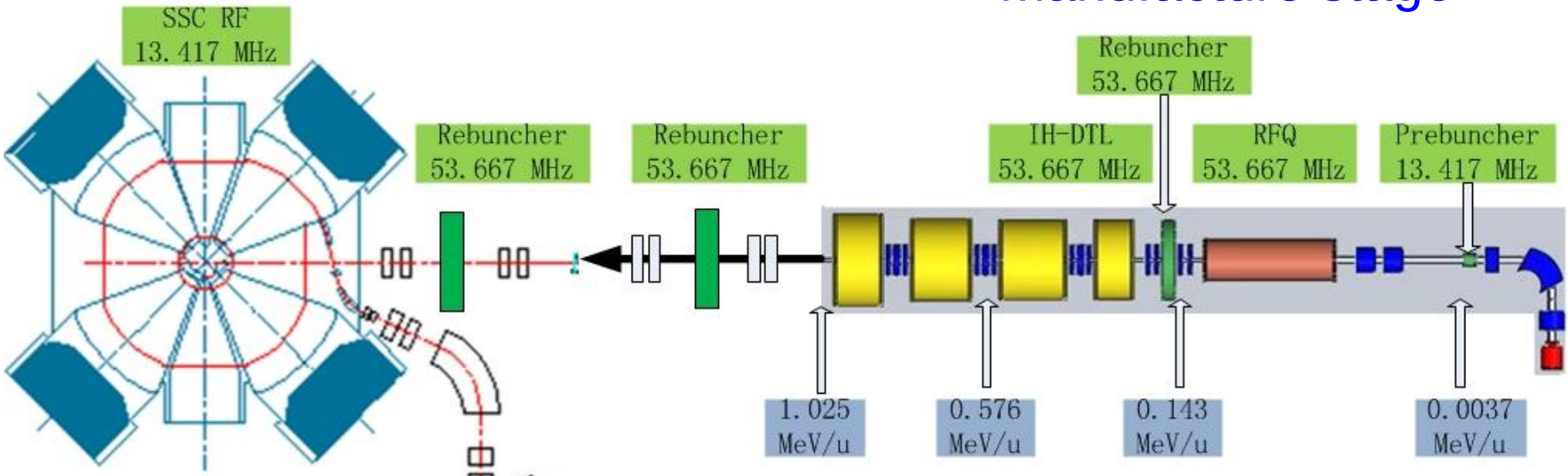
FWHM beam spot:
<2μm in air and
<1μm in vacuum

Outline

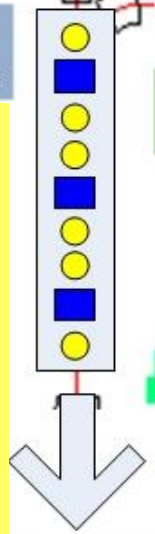
- Brief Introduction of IMP
- Status of HIRFL
- Upgrade Projects at HIRFL
  - New injector cyclotron: SSC-LINAC
  - New injector for synchrotron: CSR-LINAC
  - Stochastic Cooling in CSRe
  - Molecular injector for CSRe
- Brief introduction of future projects of IMP

New injector for SSC

Next 2~3 years
Prototypes and manufacture stage



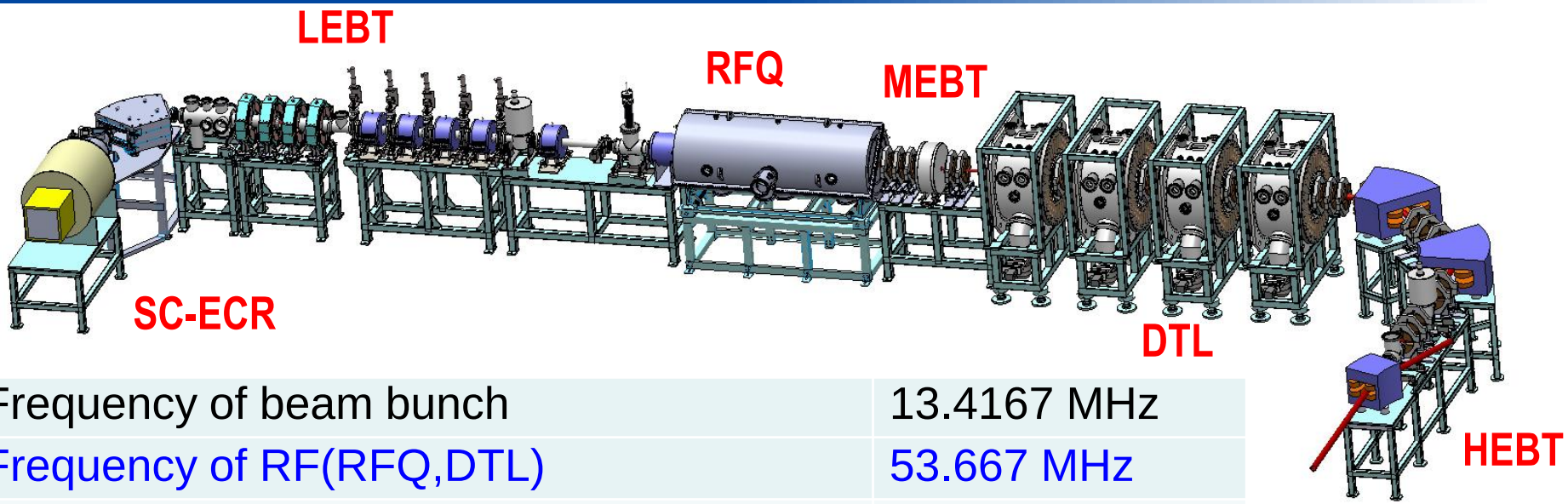
H=8 for light ions of 5.97 MeV/u
H=6 for heavy ions of 10.65 MeV/u



1. 1 MeV/u beam for SSC→10MeV/u for CSRm→500MeV/u ^{238}U
2. Beam intensity: >0.5 puA for 238U at Linac.
   >1 puA for Ni, Fe, etc.
3. Parallel operation with SFC and Linac-SSC.

Ions	$^{48}Ca^{7+}$, $^{59}Ni^{9+}$, $^{70}Zn^{10+}$ $^{86}Kr^{14+}$, $^{136}Xe^{22+}$, $^{238}U^{37+}$	
A/q	~7	~6.43
E_{inj} (MeV/u)	0.576	1.02
RF freq (MHz) (6.5~14)	13.417	13.417
h	8	6
Kb (450)	294	417
E_{ext} (MeV/u)	5.97	10.65

Layout of SSC-LINAC



Frequency of beam bunch	13.4167 MHz
Frequency of RF(RFQ,DTL)	53.667 MHz
Design A/q	≤7
Beam intensity	>0.5 pμA
Extraction voltage of SC-ECR	26.1kV(A/q=7)
Emittance of SC-ECR (90%normalized)	0.6 π.mm.mrad
Injection energy RFQ	3.73keV/u
Extraction energy of RFQ	0.143MeV/u
Injection energy of DTL	0.143MeV/u
Extraction energy of DTL	1.025 MeV/u
Duty factor	100%

Progress of Prototypes

4-rod RFQ

cavity coated

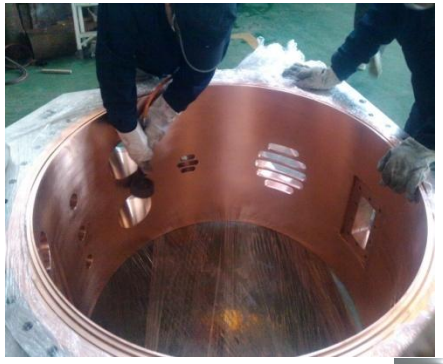
4-rod RFQ

electrode

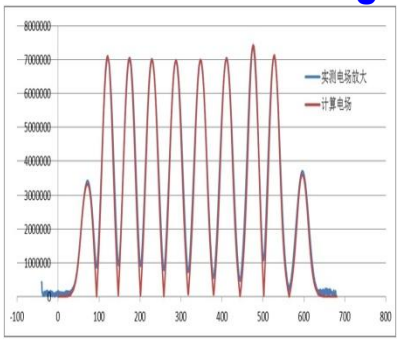
Aluminum DTL1 prototype

IH-DTL1

cavity coated



DTL testing



4 gaps spiral DTL

rebuncher

60 kW

53.667 MHz

Solid state AMP

Budget and Schedule of SSC-LINAC

Budget estimated	
SECR	$3,894k
RF system	$5,210k
Beam Diagnosis	$356k
Vacuum system	$509k
Magnet system	$1,215k
PS system	$927k
Control system	$781k
Water cooling	$710k
Installation and alignment	$78k
Civil construction	$0k
Dose control	$195k
SUM	$13,879k

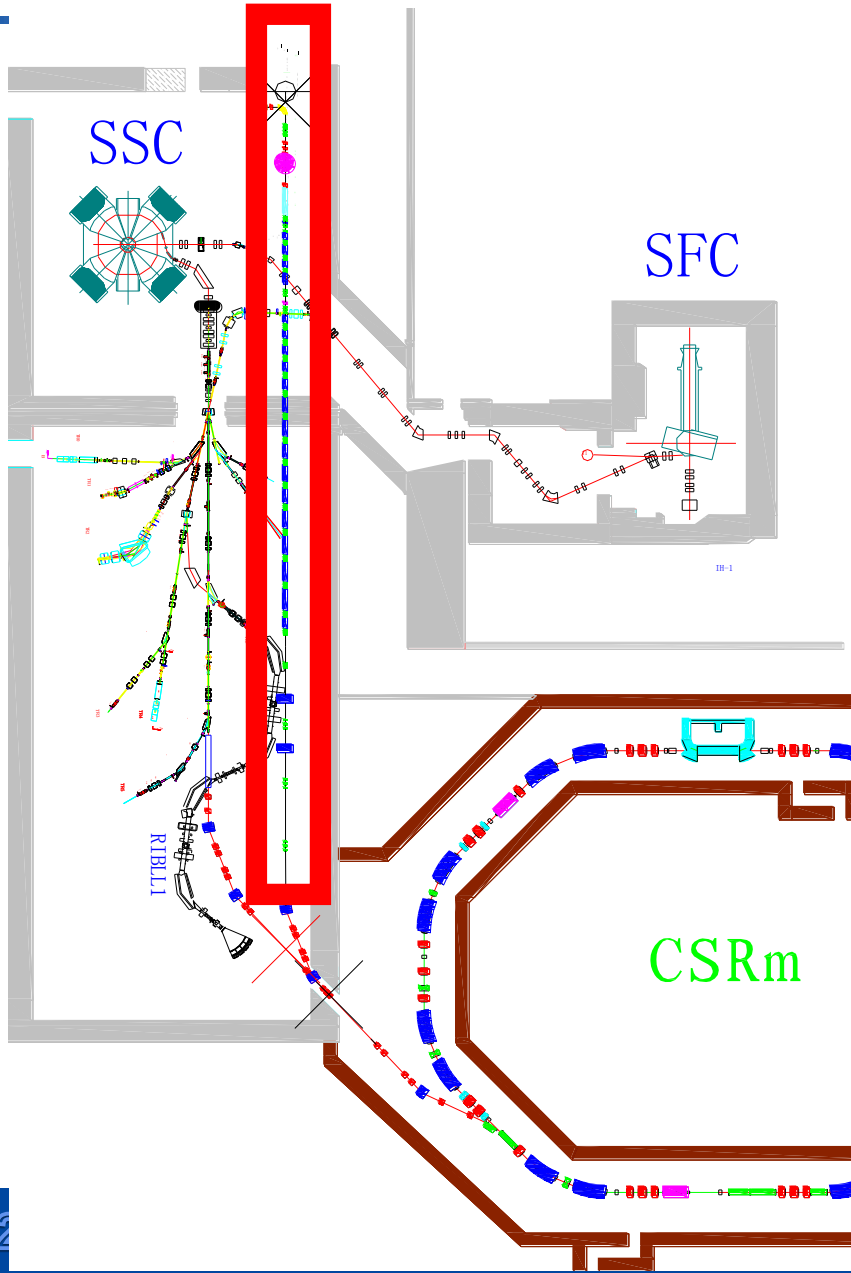
Scheduled milestones	
Stage 1: ECR to DTL1	
Jun. 2012	Final version of design
Dec. 2012	Components finished Testing platform installation starts
Mar. 2013	Commissioning offline starts
Jun. 2013	Commissioning offline finished
Stage 2: ECR to SSC	
Mar. 2014	Components finished, installation starts
Aug. 2014	Commissioning starts
Dec. 2014	Commissioning finished

CSR-LINAC

Next 3~5 years
Concept design

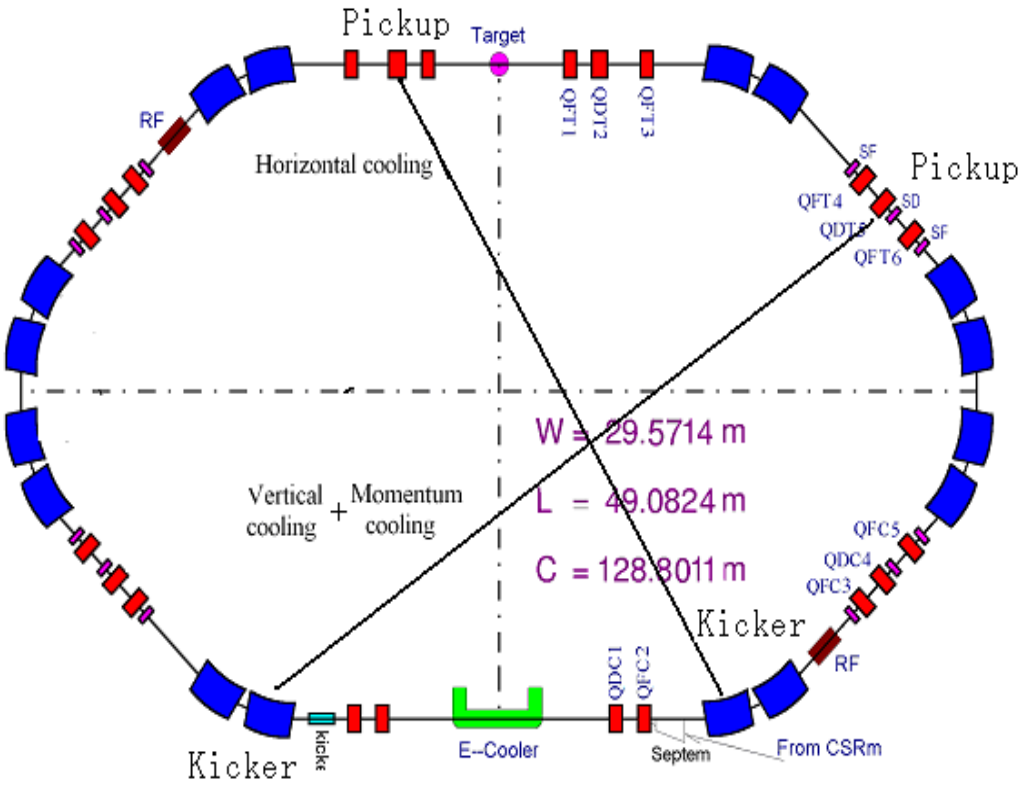
1. 10 MeV/u beam for CSRm.
2. Beam intensity: >0.5 puA for 238U.
3. Parallel operation with SFC, SFC+SSC and Linac+CSR.
4. Low duty factor <1%

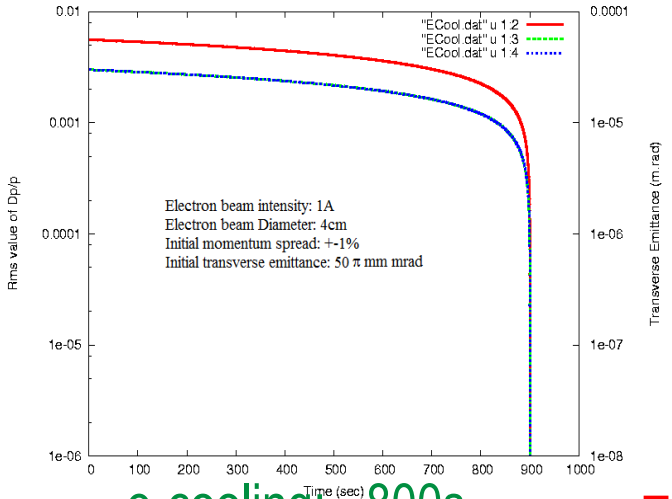
Element	Length [cm]	Frequency [MHz]	Energy [MeV/u]
LEBT	920	0→13.4167	0.00373
RFQ	252	53.6667	0.143
MEBT1	175	53.6667	0.143
DTL1	480	53.6667	1.025
MEBT2	400	161	1.025
DTL2	3000	161	10
HEBT	3300	161	10



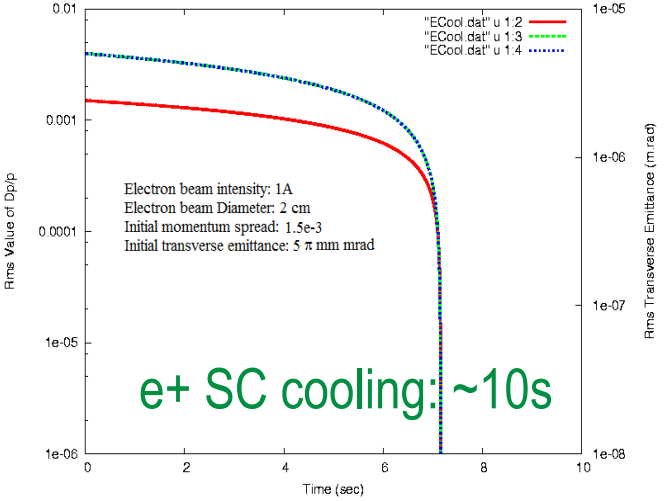
Stochastic Cooling at CSRe

Next 2~3 years
Design and prototype stage





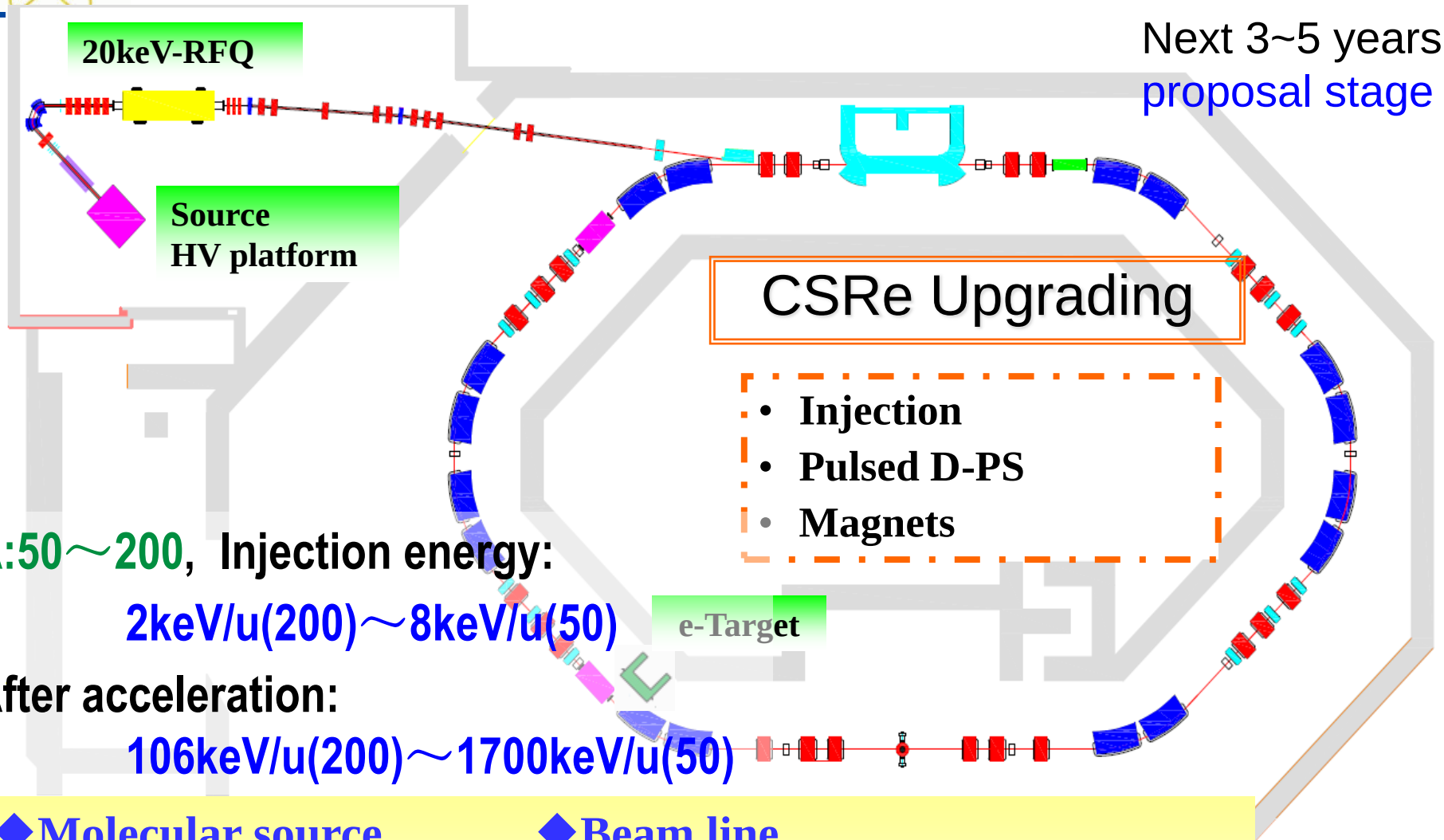
e-cooling: ~800s
For RIBs cooling



e+ SC cooling: ~10s

Prototype

Molecules ion research platform at CSRe



Next 3~5 years
proposal stage

A:50～200, Injection energy:

2keV/u(200)～8keV/u(50)

After acceleration:

106keV/u(200)～1700keV/u(50)

- ◆Molecular source
- ◆150keV HV platform
- ◆High A/Q RFQ
- ◆Beam line
- ◆Diagnosis system of nA beam
- ◆Superconductive e-target

Outline

- Brief Introduction of IMP
- Status of HIRFL
- Upgrade Projects at HIRFL
- Brief introduction of future projects of IMP
  - HITFiL
  - C-ADS
  - HIAF

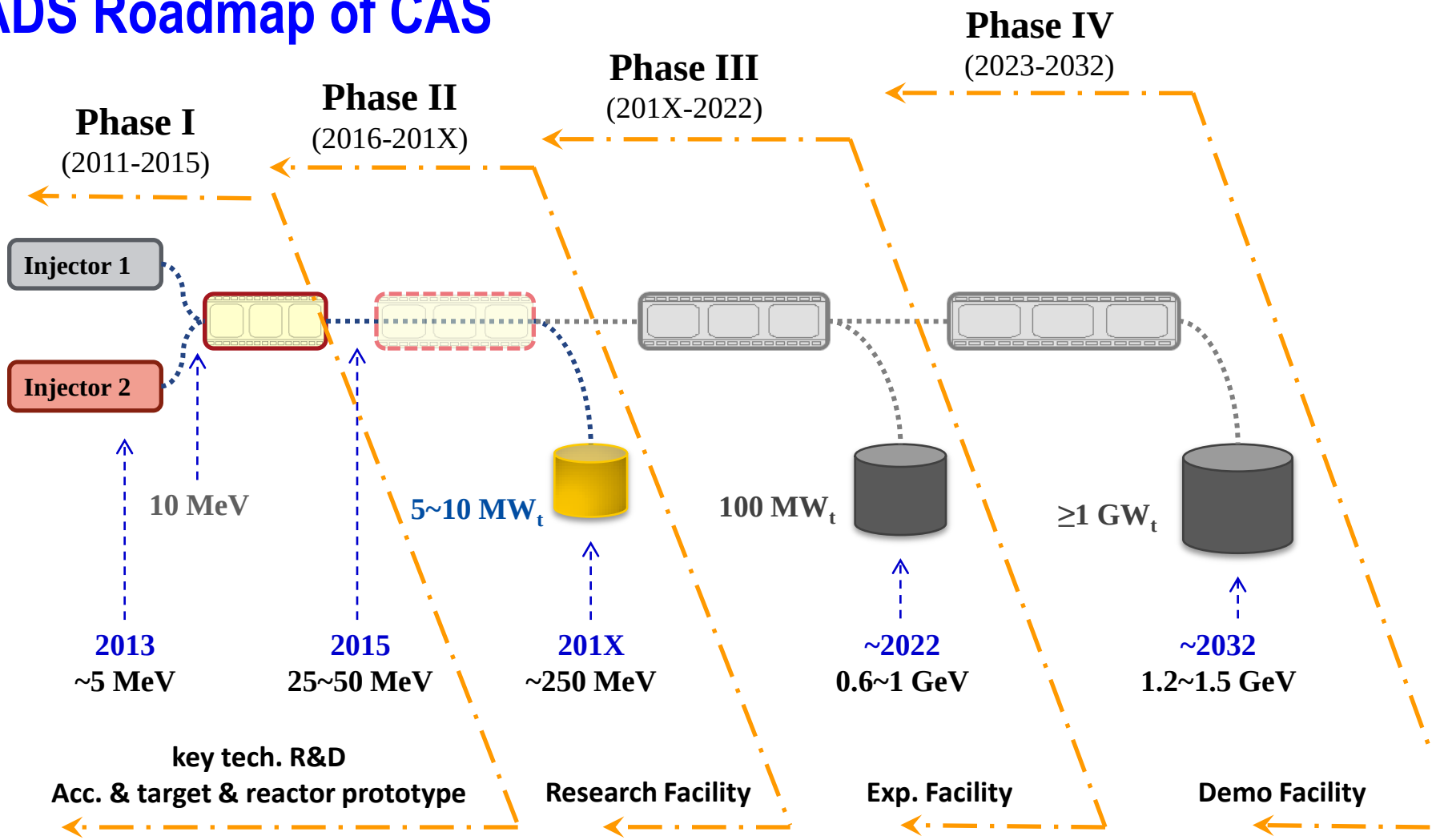
Heavy Ion Therapy Facility in Lanzhou

Manufacturing

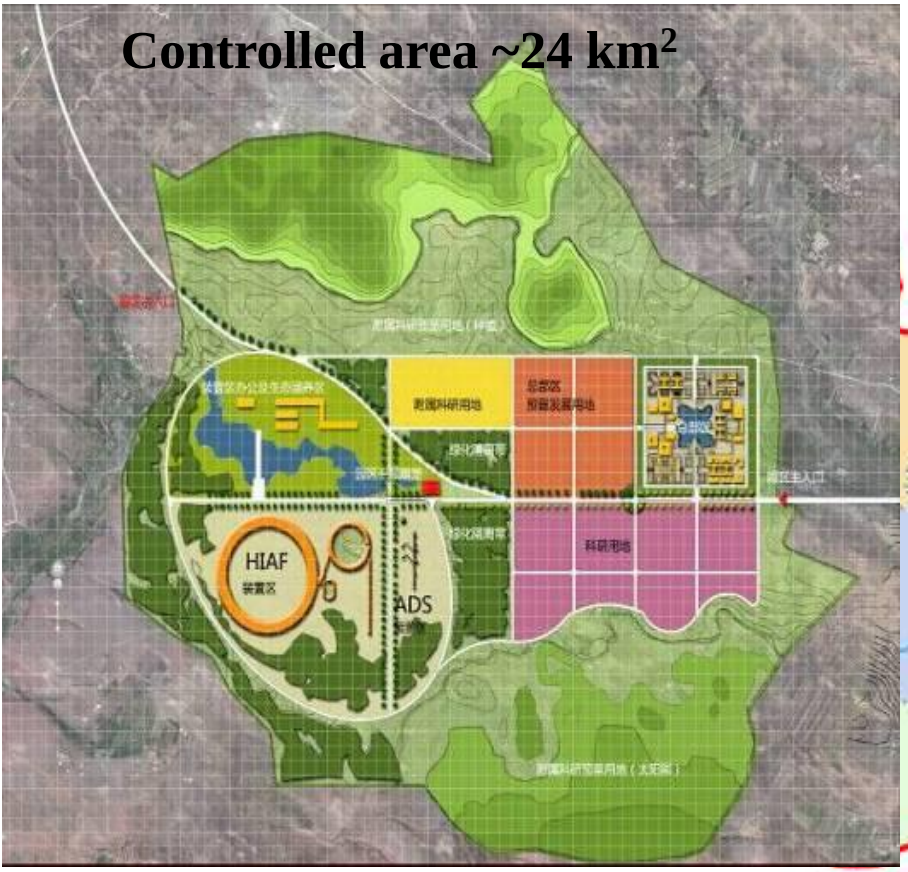
Install In Next 2~5 years

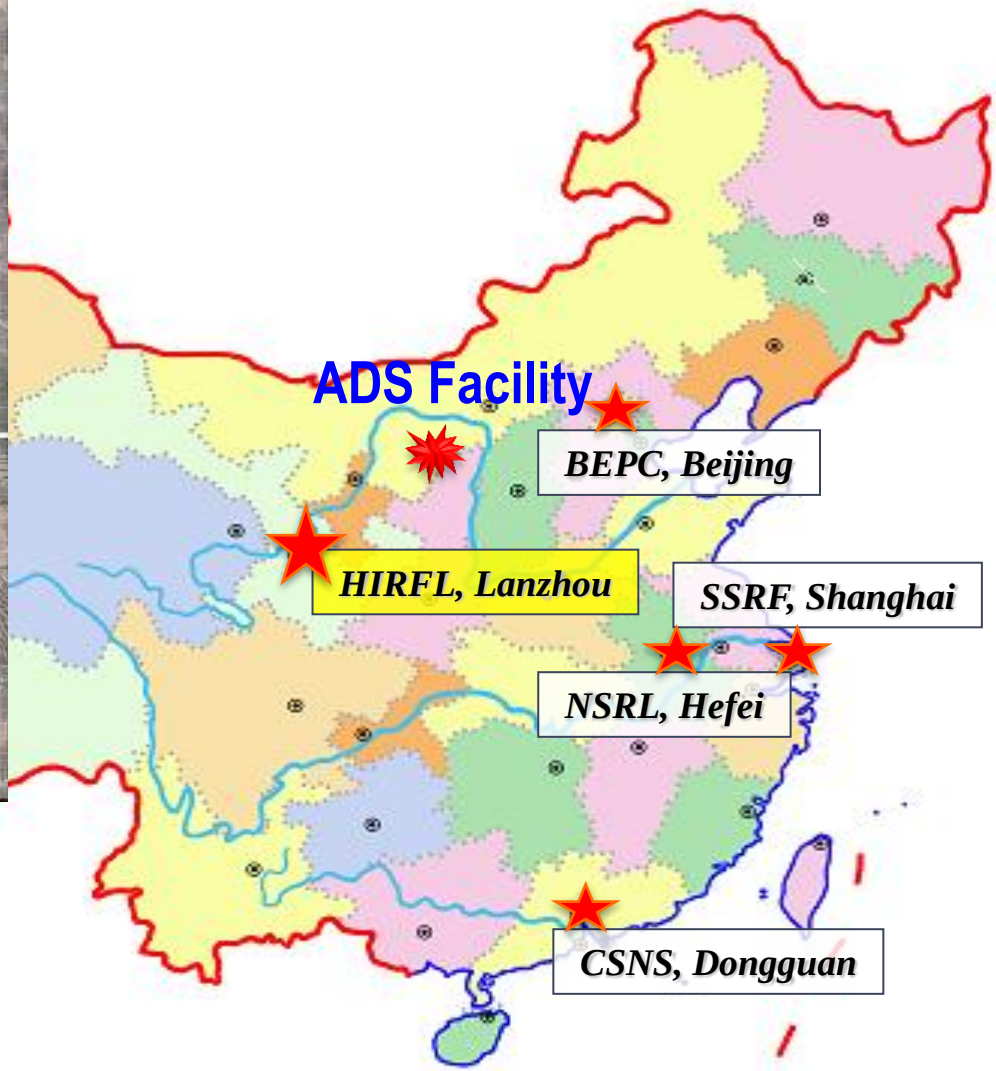
Chinese ADS Project

C-ADS Roadmap of CAS



Site Candidate of CIADS



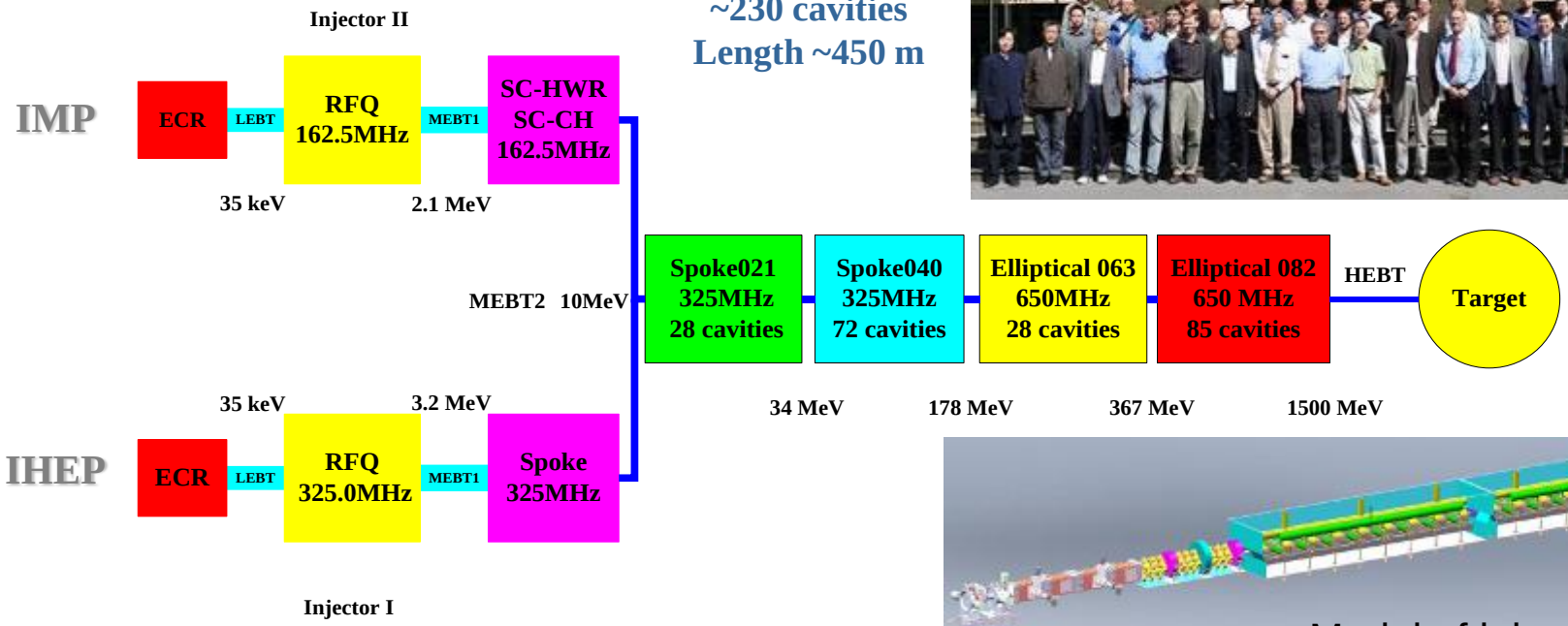


Progress of sc proton linac for C-ADS

Initial physical design of ADS Accelerator（IHEP、IMP）

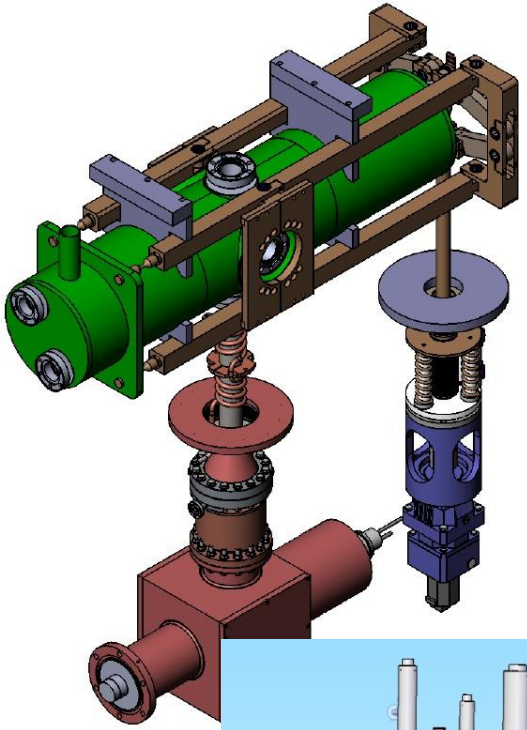
- Apr.27, 2011 Initial Review of the ADS Accelerator Design
- Sept.19, 2011 International Review of ADS Accelerator Design

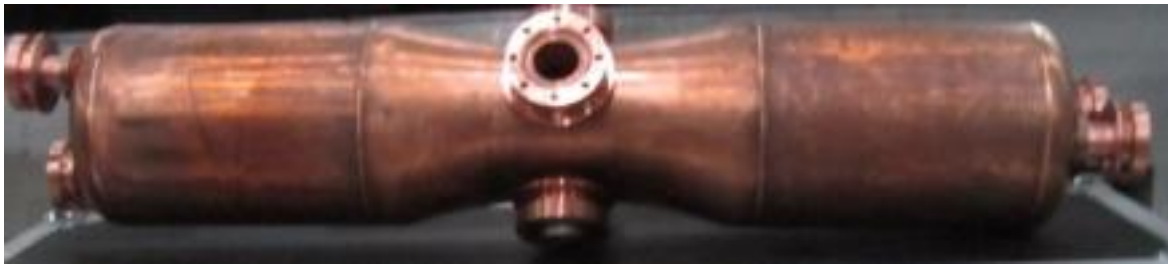
Approved by review committee



Model of injector II

Fabrication of Sc-HWR for C-ADS





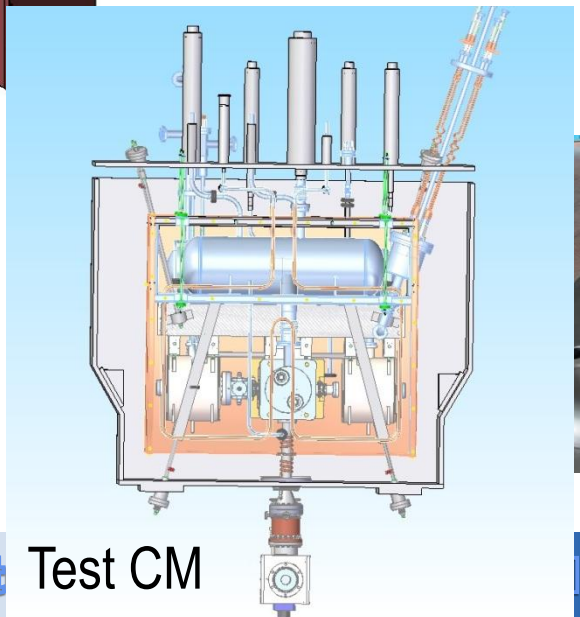
Copper Model

Outer conductor

Inner conductor

Top covers

Outer conductor



Test CM

Future Facility: HIAF

Budget planned: ~2.0B RMB (2013-2019)

Accelerator Components

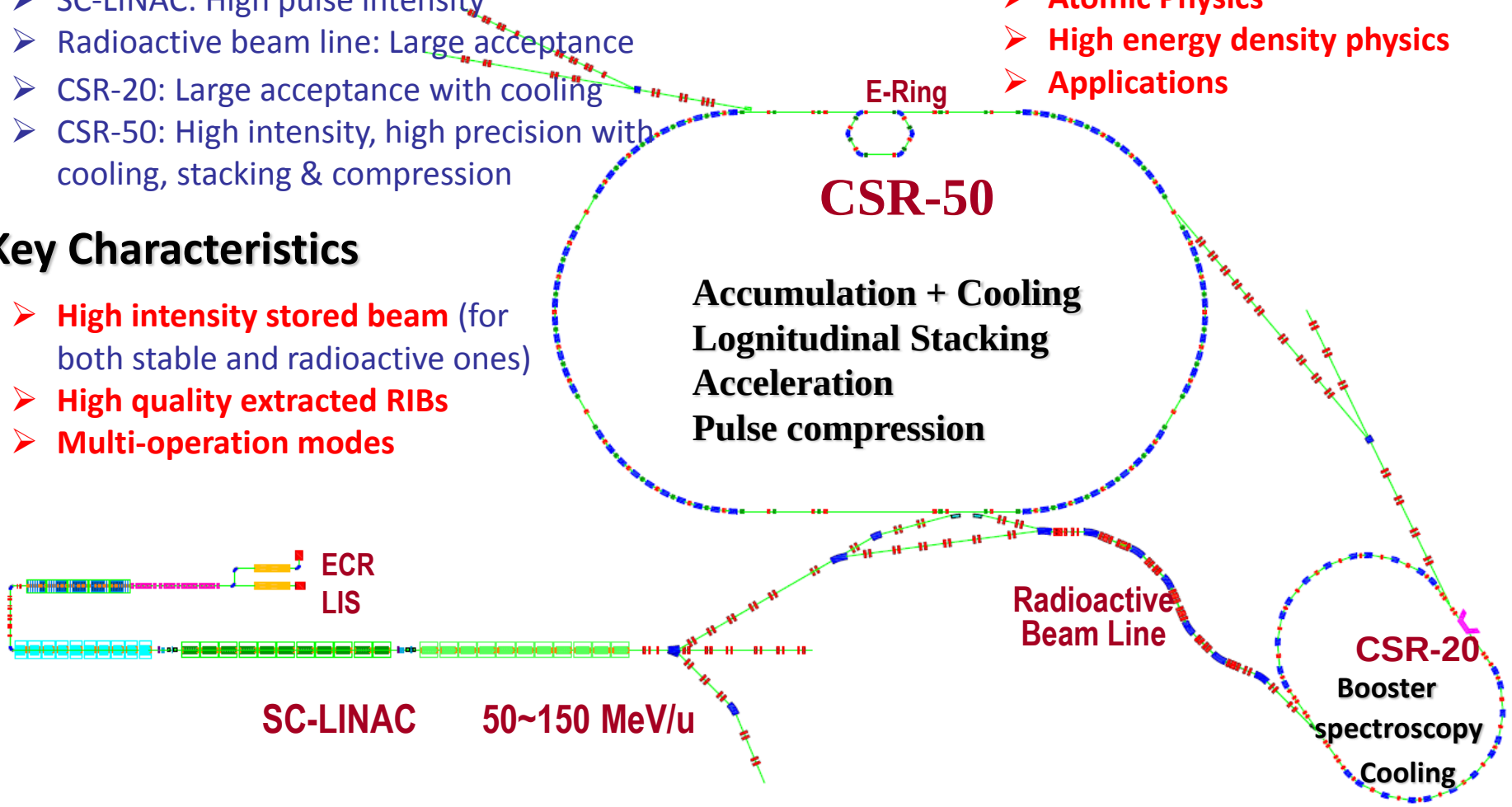
- Ion sources: High intensity
- SC-LINAC: High pulse intensity
- Radioactive beam line: Large acceptance
- CSR-20: Large acceptance with cooling
- CSR-50: High intensity, high precision with cooling, stacking & compression

Key Characteristics

- **High intensity stored beam** (for both stable and radioactive ones)
- **High quality extracted RIBs**
- **Multi-operation modes**

Motivation

- **Nuclear physics and astrophysics**
- **Atomic Physics**
- **High energy density physics**
- **Applications**



Future Facility: HIAF

SC-LINAC

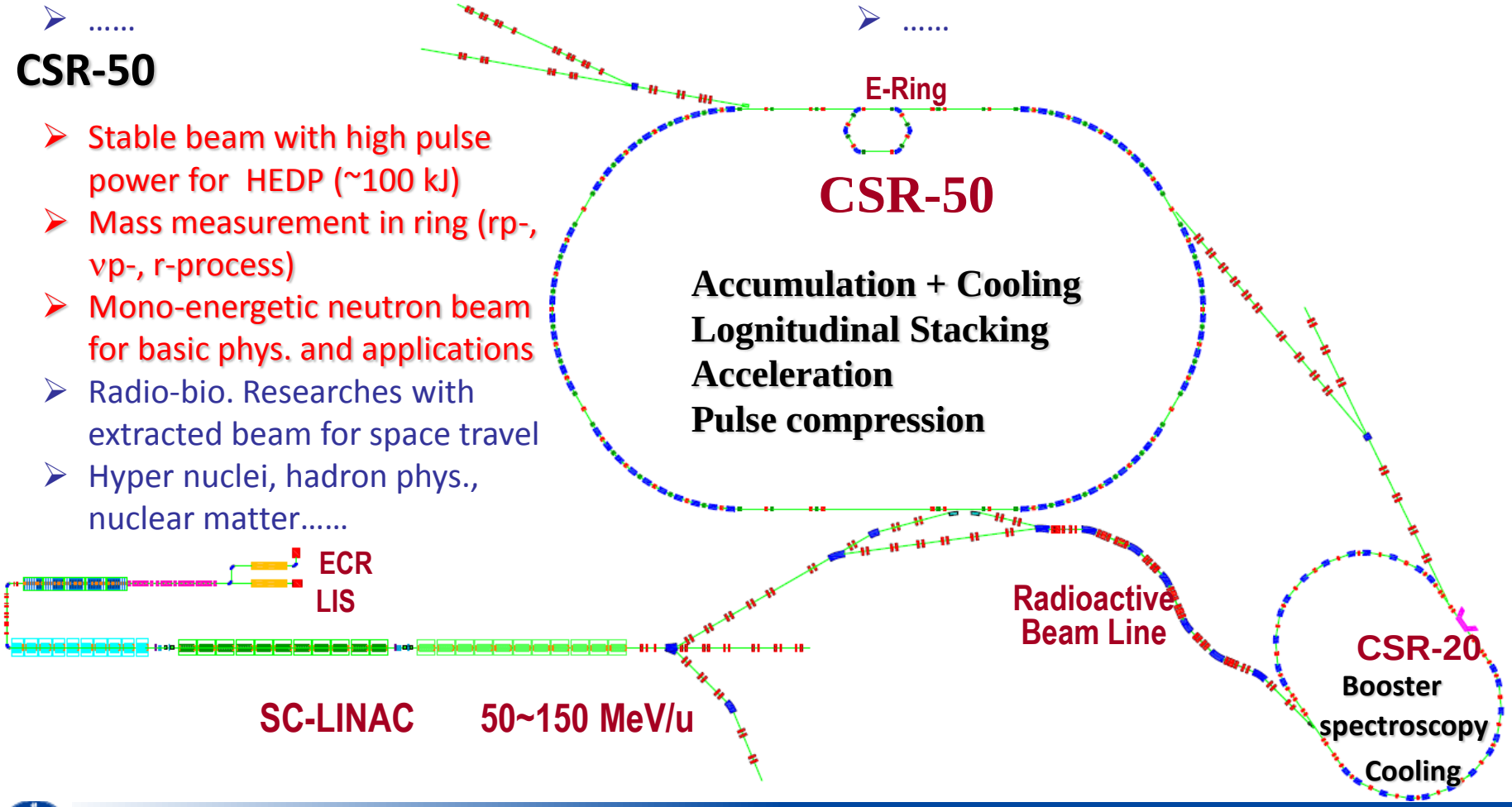
- RIB Physics in general and SHN
- Material irradiation
- ……

CSR-20

- High quality RIB extracted (EoS…)
- High precision inner-ring reaction exp.
- ……

CSR-50

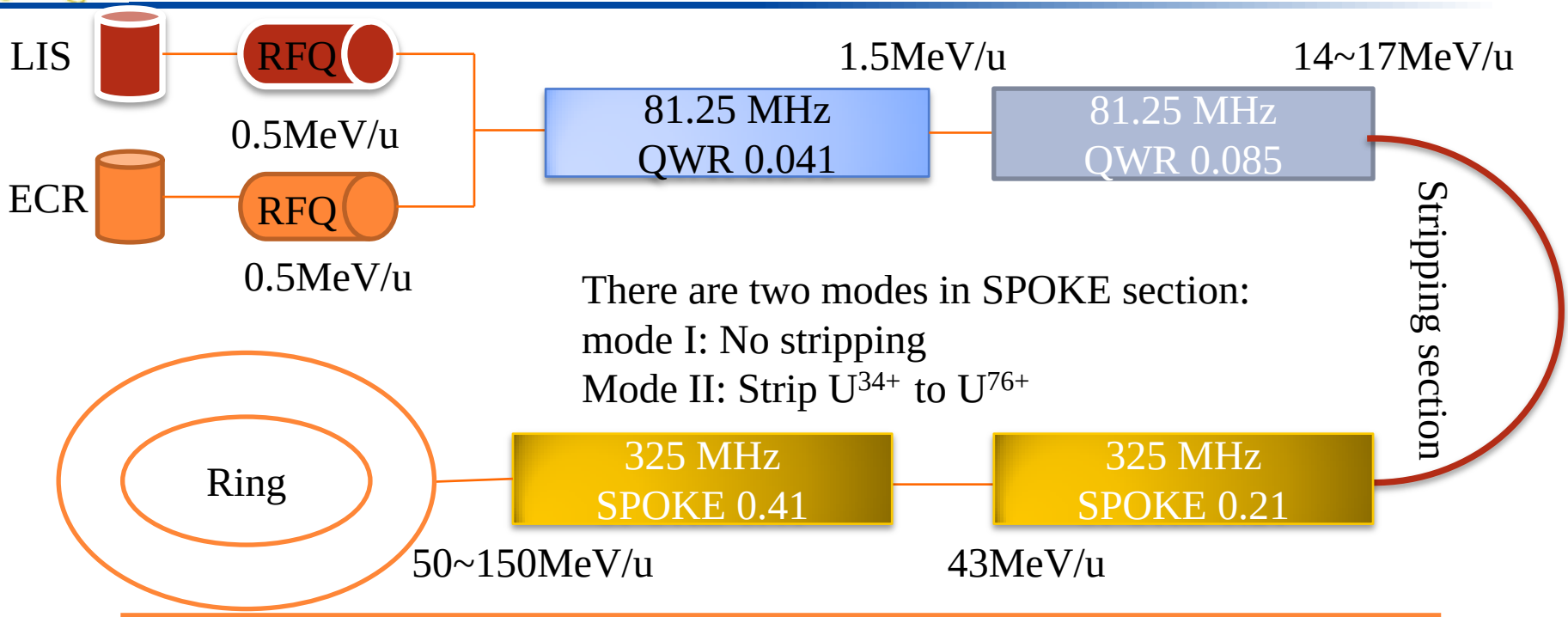
- Stable beam with high pulse power for HEDP (~100 kJ)
- Mass measurement in ring (rp-, νp-, r-process)
- Mono-energetic neutron beam for basic phys. and applications
- Radio-bio. Researches with extracted beam for space travel
- Hyper nuclei, hadron phys., nuclear matter……



Beam Specifications of HIAF

Machines		Ions	Energy	Intensity
Ion Sources	ECR	$^{18}O^{6+}$	30 keV	1.5 pmA
		U^{34+}	30 keV	0.05 pmA
	LIS	U^{34+}	30 keV	0.5 pmA
SC-LINAC (0.5Hz, 1ms)		$^{18}O^{6+}$	150 MeV/u	1.0 pmA
		U^{34+}	50 MeV/u	0.04-0.4 pmA
		U^{76+}	150 MeV/u	0.008-0.08 pmA
CSR-20 (Booster)		$^{18}O^{8+}$	1.9 GeV/u	4.0×10^{12} (Painting)
		U^{34+}	350 MeV/u	$0.5\text{-}6.0\times10^{11}$ ppp
		U^{76+}	1.2 GeV/u	$0.1\text{-}1.2\times10^{11}$ ppp
CSR-50		$^{17}N^{7+}$	5.3 GeV/u	6.0×10^{10}
		U^{34+}	1.4 GeV/u	$0.2\text{-}2.4\times10^{12}$ ppp
		U^{76+}	4.0 GeV/u	$0.2\text{-}2.4\times10^{12}$ ppp
		U^{92+}	5.0 GeV/u	$0.16\text{-}2.0\times10^{12}$ ppp

Concept of LINAC for HIAF



HIAF-linac main parameters		
Particle species	$^{238}U^{34+}$, $^{208}Pb^{30+}$, $^{28}Si^{10+}$, $^{9}Be^{3+}$, $^{18}O^{6+}$	
Design beam current	20	mA
Operation frequency	81.25/325	MHz
Duty factor	~1%	
Stripping energy	14~17	MeV/u

Thanks for your attention and welcome to Lanzhou !!

Lanzhou, the only city that the Yellow River goes through, is the capital of Gansu province, covers an area of 13.086 square kilometers and has a population of 2.83million (1.48 million in the city zone). The 2,000-year-old town once functioned as a garrison of strategic importance on the Silk Road .