Oct.02, 2009, Talk at Argonne lab

Status and Development of Heavy Ion Research Facility at IMP

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Chinese Academy of Science (CAS)

Lanzhou, China

Chinese Academy of Sciences

- **More than 90 institutes and scientific centers for basic science research and applied science research.**
- **More than 40000 staff**
- **Budget per year more than 3 Bil. USD**
- **Most of large-scale scientific facilities in China are located in CAS.**

Outline

- Brief Introduction of IMP
- HIRFL Accelerator Complex
- Research and Physics Program
- Near-future Development

Where Lanzhou is located

How to go to Lanzhou?

Convenient transportation:
Many flights are available for travel to Lanzhou

Lanzhou, the geometry center of China, is famous for her long time history (2000 years), the special geometry position and her special local products.

IMP is located in Lanzhou city

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 .

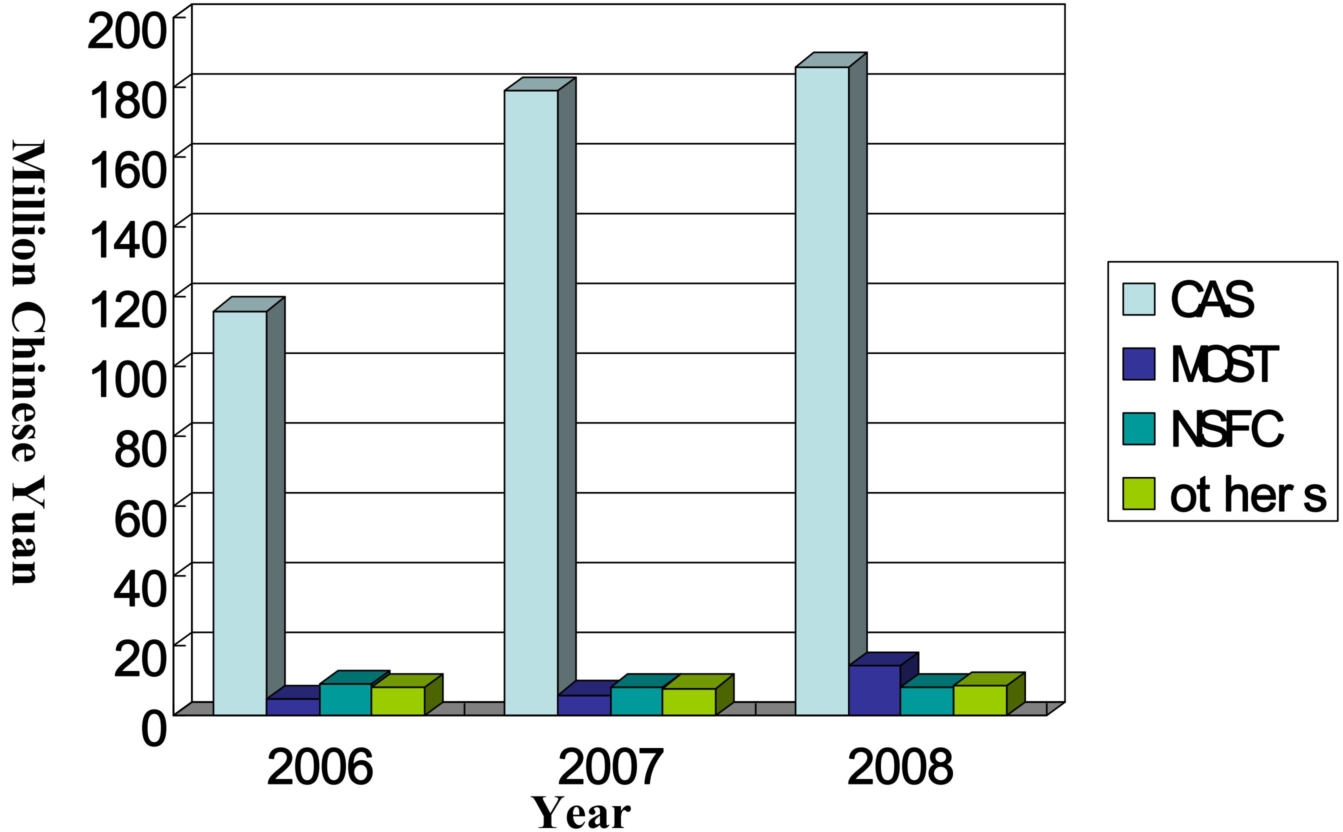

IMP

IMP Basic Information

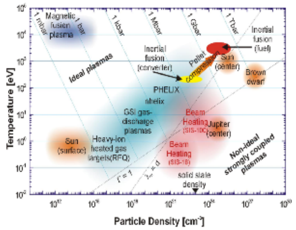
- **IMP was founded in 1957 in Lanzhou and affiliated with Chinese Academy of Sciences.**
- **The biggest nuclear physics research center in China**
- **653 permanent staff, 230 PHD and master Students.**
- **Total budget a year: 150~200 M C¥ (25~30 M$)**
- **National lab of Heavy Ion Research Facility (HIRFL)**

FY Budget for IMP and NLHIRFL

- Chinese Academy of Sciences
- Ministry of Science and Technology
- National Development and Reform Commission
- Ministry of Finance
- National Natural Science Foundation of China
- Local government



Research Fields at IMP



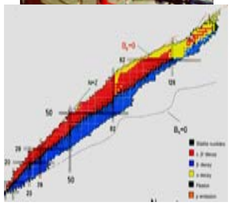
Basic researches on High Energy Density matter Physics, Heavy ion Inertial Fusion (future plan)

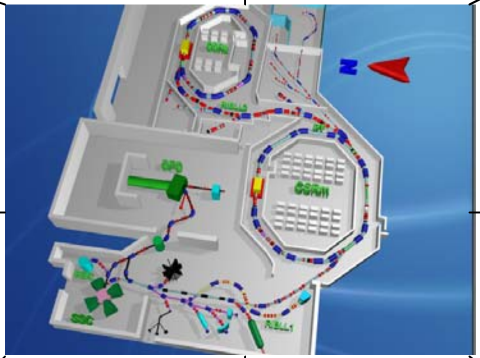
Biophysics,

Heavy Ion Therapy

Heavy Ion Accelerators,

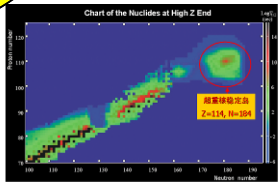
Operation and Development





RIB Physics, Astrophysics

Nuclear Structure and properties, Superheavy Nuclei and Elements

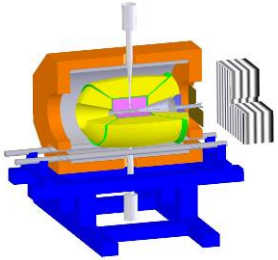


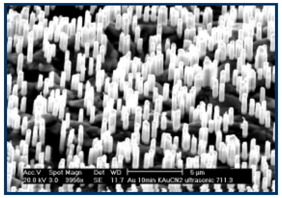
Hadron-nucleon Physics

Irradiation

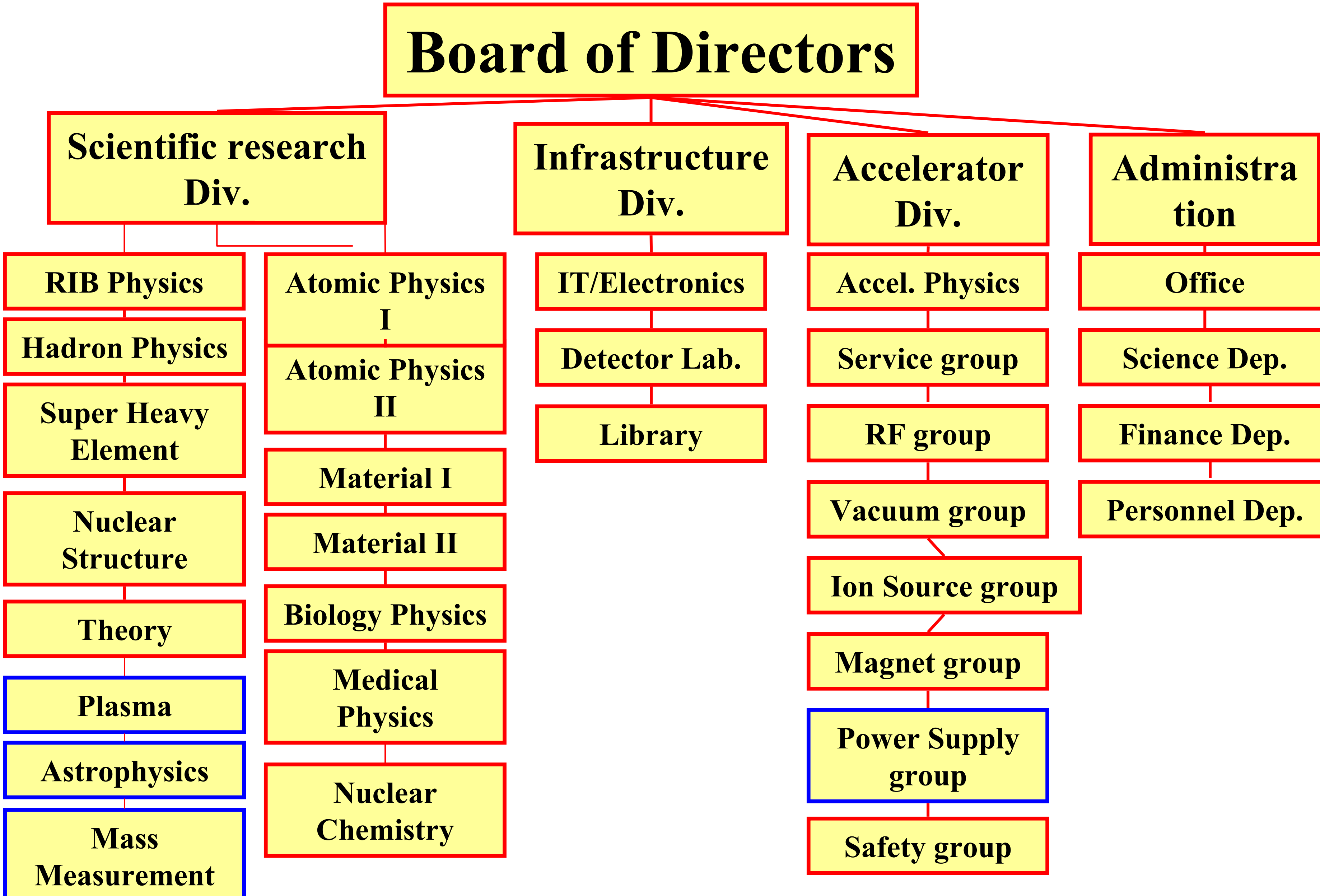
Material Sciences

Highly Charged Atomic Physics

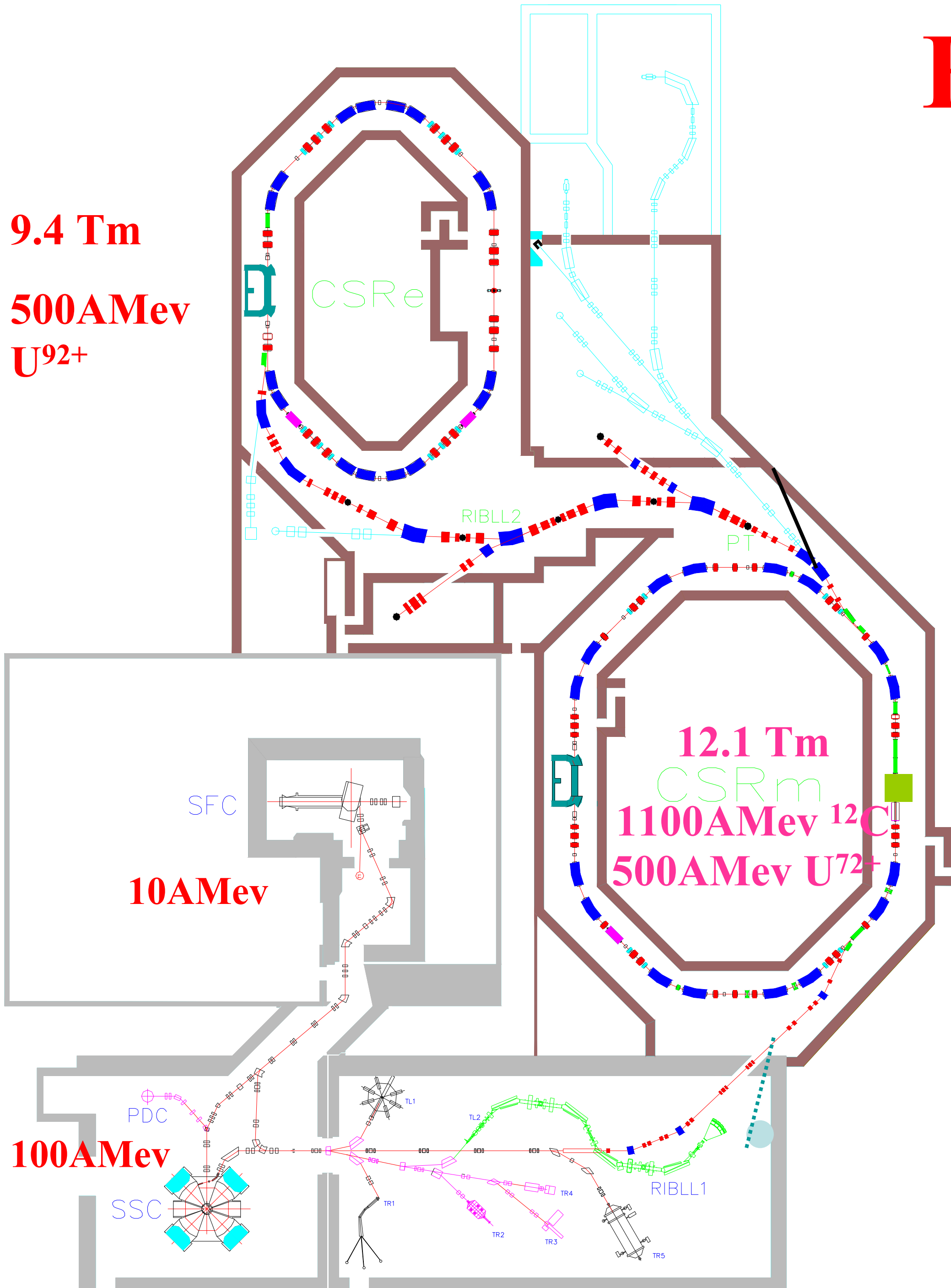




Management Structure of IMP



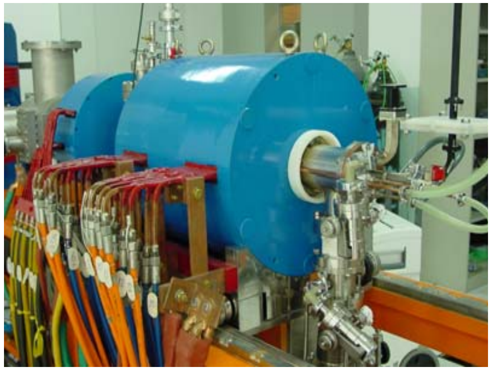
HIRFL Accelerator Complex and Development



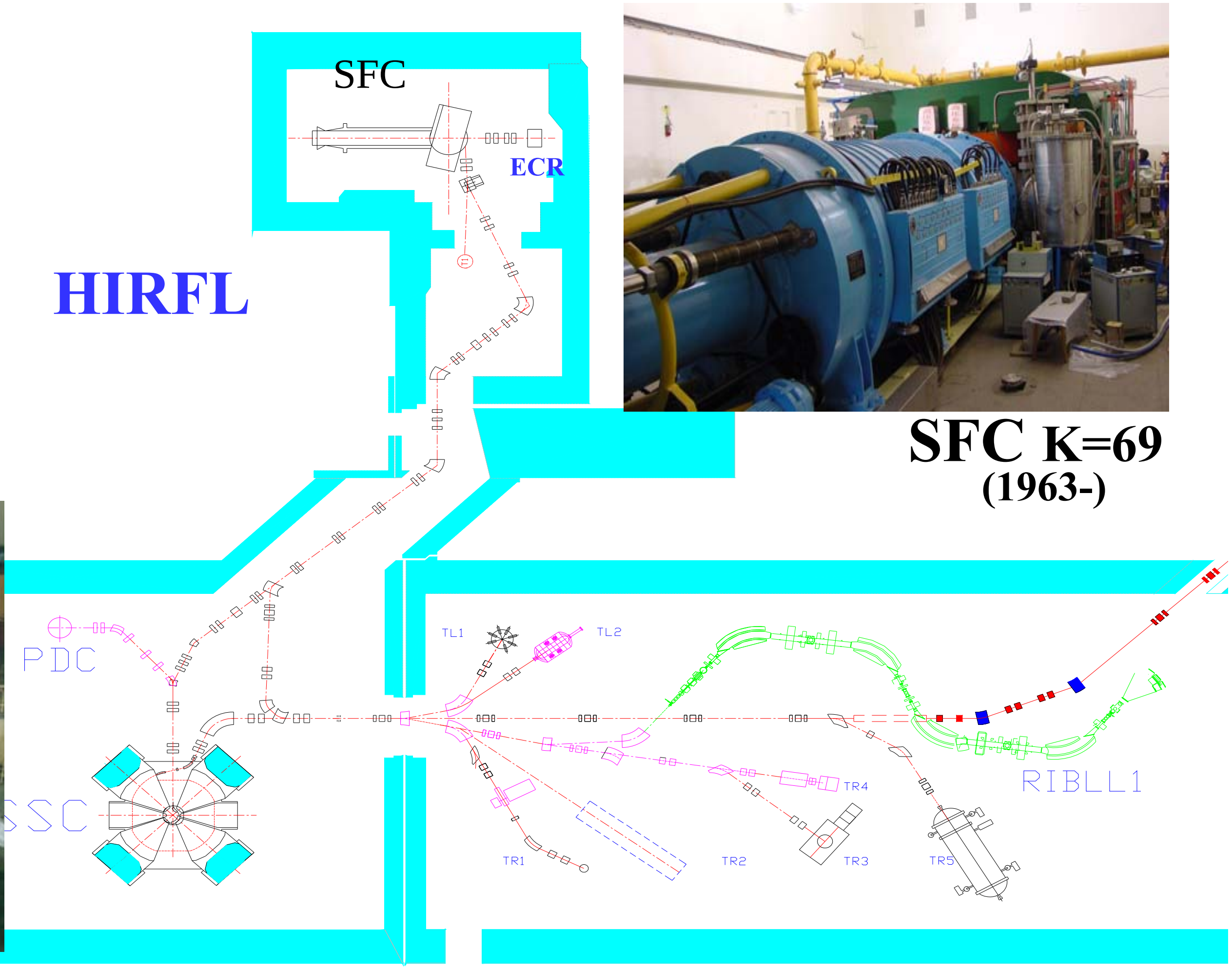
HIRFL Layout

- ECR Ion Source
- SFC K=69--10AMev
- SSC K=450 –100AMev
- **CSRm: Synchrotron**
  - Intensity: 10^{8-9} pps ,
  - Circumference: 162 m
- **CSRe: Storage ring**
  - Accel. & Deccel.
  - Intensity: 10^{8-10} pps
  - Circumference: 128 m
  - RIB, internal target
  - High Resolution Spectrometer
- CSR budget:42 M$; 2000-2007

HIRFL Cyclotrons

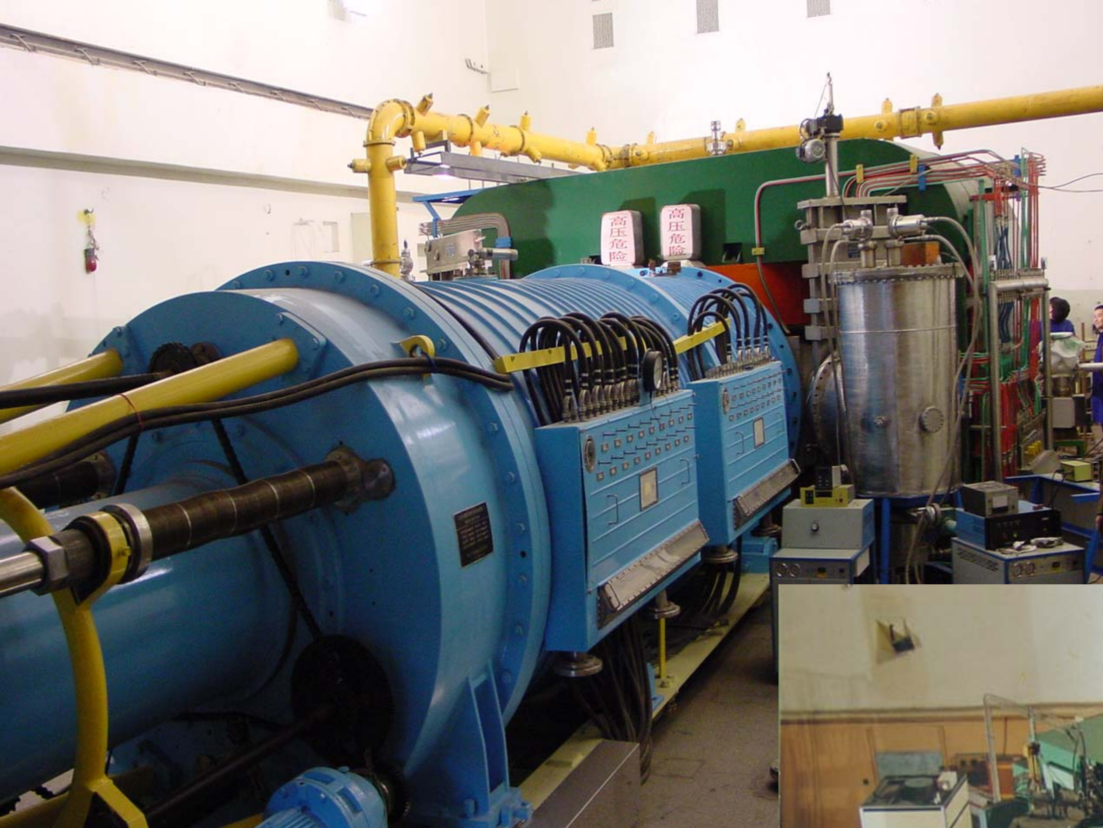


ECR



SFC K=69
(1963-)

SSC k=450 (1988-)



SFC & SSC

$K_{SSC} = 450$

E:10-100MeV/u

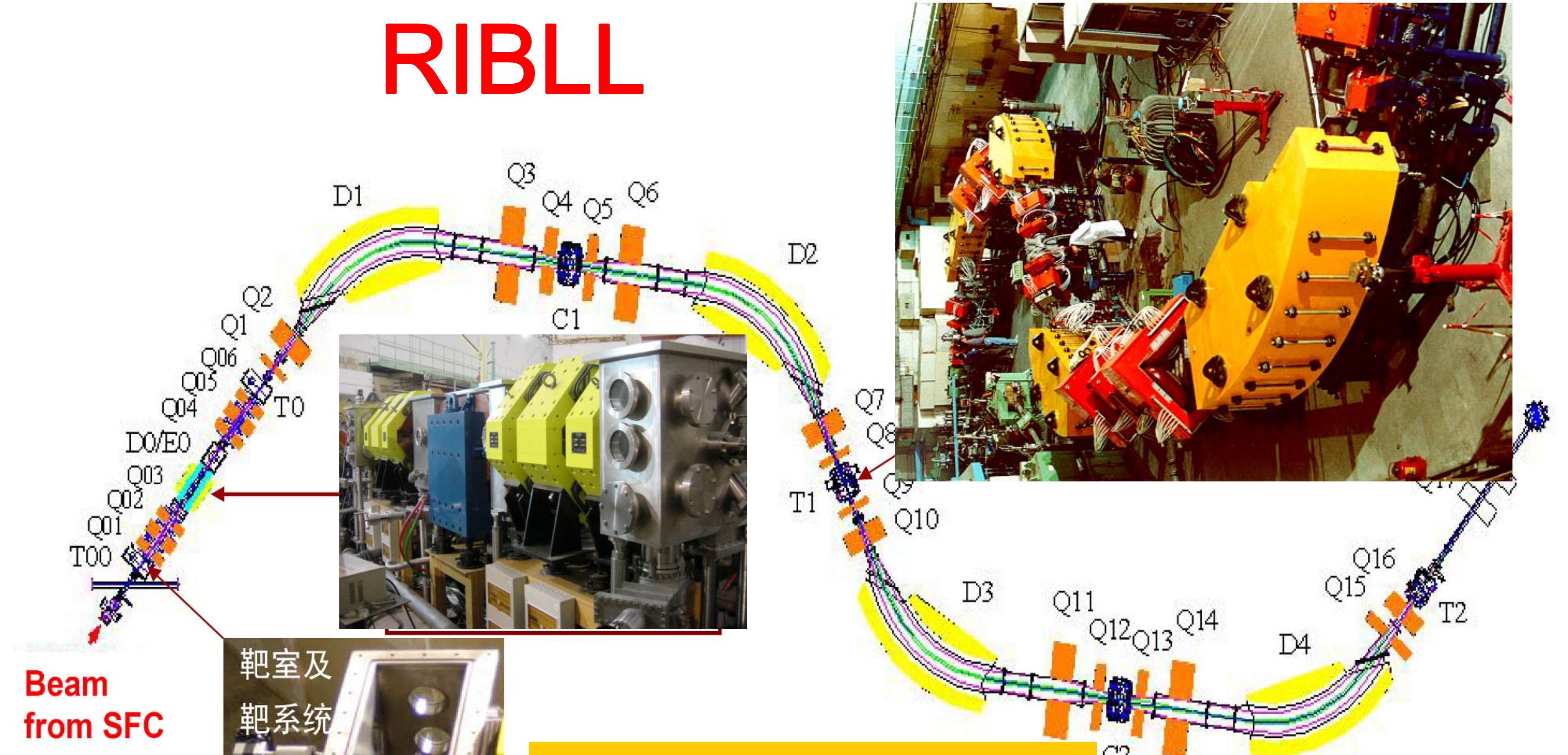
10^{10} ~10^{11}pps(C——Bi)

$K_{SFC} \sim 69$

E: 0.2-10MeV/u

10^{12} ~10^{13}pps (C—U)

RIBLL



Main Parameters

	RIBLL	SHIP
ΔΩ	>7msr	~1.7msr
ΔP/P	~10%	~10%
$B\rho_{max}$	~4.2Tm	~1.2Tm
A/ ΔA	~300	~300

Typical beams provided by SFC and SSC in recent years

Ion Beams	E (MeV/A)		Beam Intensity (eμA)
	SFC	SSC	
$^{129}Xe^{27+}$	3.0	/	6.0-7.0
$^{208}Pb^{27+}$	1.1	/	0.8-1.0
$^{40}Ca^{12+}$	5.8	/	1.0
$^{20}Ne^{7+}$	7.2	/	10-12
$^{12}C^{4+}$	7.0	/	10-15
$^{26}Mg^{8+}$	6.54	/	2.0
$^{16}O^{6+}$	7.99	/	7-12
$^{40}Ar^{8+}$	2.35	/	8-15
$^{78}Kr^{19+}$	4.0		7-9
$^{238}U^{26+}$	0.81	/	0.33
$^{12}C^{4+/6+}$	7.0	80.5	0.2-0.5
$^{12}C^{5+/6+}$	8.2	100	0.2-0.3
$^{32}S^{11+/16+}$	7.1	82	0.2-0.3
$^{26}Mg^{8+/12+}$	6.17	70	0.3-0.4
$^{40}Ar^{12+/17+}$	7.1	82	0.1-0.3
$^{209}Bi^{31+}$	0.88	9.8	0.08
$^{22}Ne^{7+/10+}$	6.17	70	0.2-0.5
$^{58}Ni^{13+/22+}$	4.5	50	0.1-0.2
$^{129}Xe^{27+}$	1.8	19.5	0.6-0.75
$^{36}Ar^{8+}$	2.07	22	2.5-3.5

HIRFL Operation in 2008-2009

HIRFL operation time distribution in Sept.2008-July 2009

Operation time distribution	Time (hours)	Percentage
Total operation time	6922	100%
Beam time	5218	75.4%
Preparation of beams	931	13.4%
Failure of equipments	773	11.2%

HIRFL beam time distribution in 2008-2009

Beam time distribution	Time (hours)	Percentage
Total beam time	5218	100%
Nuclear physics, material science	2730	53.2%
Biophysics and therapy research	1205	23.1%
Machine study and improvement	1283	23.7%

5218 hours beam time: 50.5% beam delivered by CSR, the others by SFC or SSC

IMP ECR Source Development

Kr^{27+}, Xe^{33+}, Au^{35+}, U^{41+}

50-100 μA

IMP SECRL (18-28 GHz)

Bz 3.7 , Br 2.0T

2002-2007

O^{7+} 140μA, Ar^{11+} 185μA

Kr^{19+}50μA, Xe^{26+}50 μA

Ca^{11+}130 μA, Fe^{13+}65 μA

Zn^{13+}50 μA, Pb^{30+} 8 μA

Ar^{9+} 320μA, Ar^{11+}80μA

Kr^{15+}100μA,Kr^{17+}70 μA

IMP 10GHz LECR1

Bz 1.0T, Br 0.7T

1990-1995-1996

IMP 14.5-18 GHz LECR2,3

Bz 1.5-1.7T, Br 1.0T

1999, 2001

O^{7+} 300μA, Ar^{11+} 325μA

Ar^{8+} 1.1 mA, Xe $^{26+}$ 95 μA

Fe $^{13+}$ 141 μA, Ar^{17+} 0.6 uA

Pb $^{40+}$ 0.2 μA, U^{32+} 8 μA

Fully Superconducting ECR Ion Source

$n_e \sim \omega^2_{rf}$; $I \sim \omega^2_{rf}$; $B_{ecr} = \omega_{rf} m/q$

$B_{inj} \sim 3\text{-}4\ B_{ecr}$; $B_{rad} > 2\ B_{ecr}$

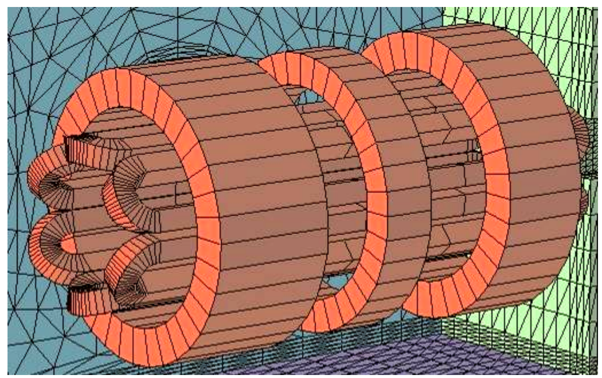
High B, ω_{rf}, P_{rf}

$B > 4$ T, $\omega_{rf} \sim 28\text{-}56$ GHz,

$P_{rf} \sim 5\text{-}10$ kW

SERSE in Catania (14.5-28 GHz)

Conventional Structure



VENUS in Berkeley (18-28 GHz)

Advantage:

- ✓ Higher sextuple field;
- ✓ Larger plasma chamber;

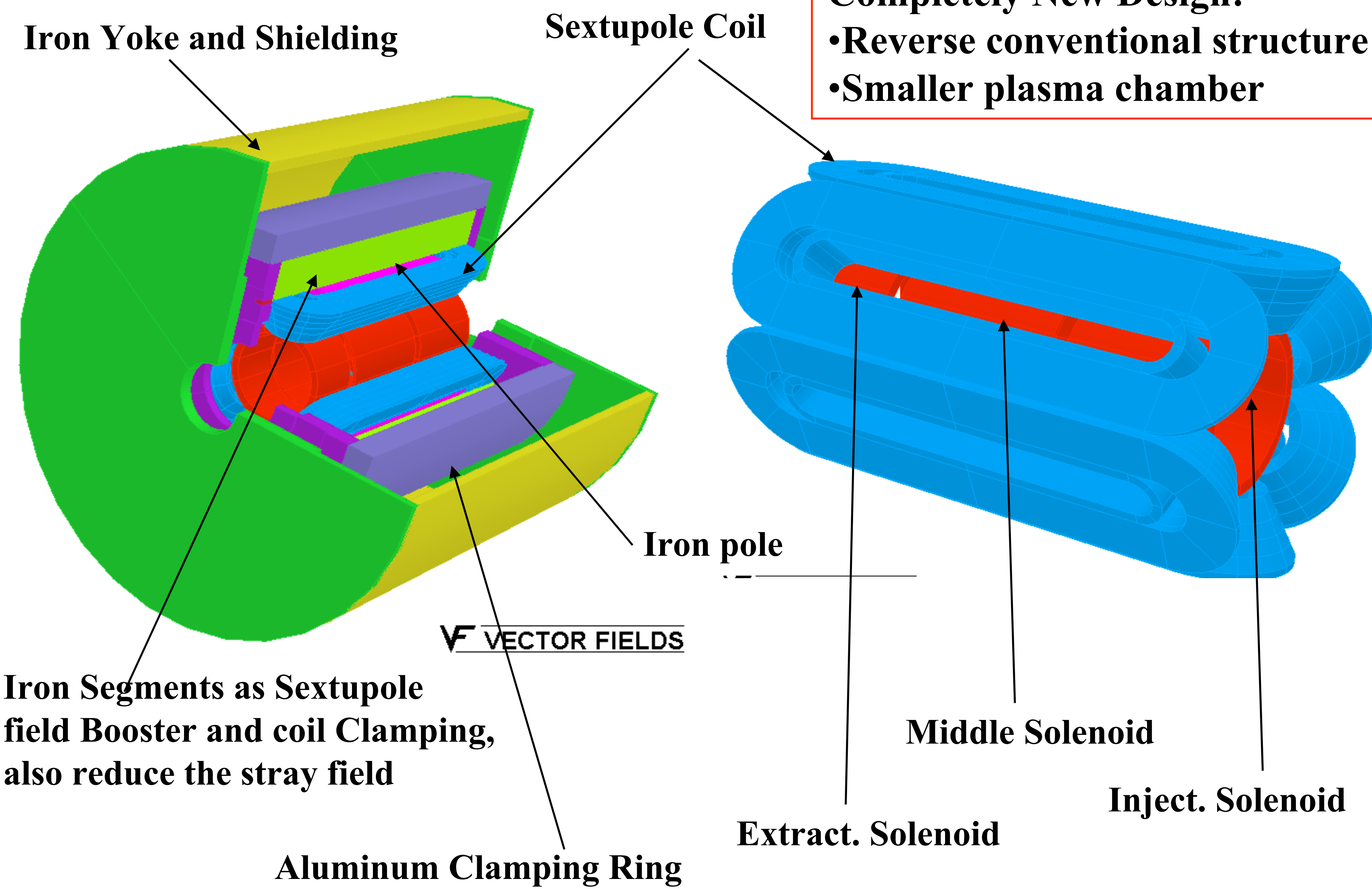
Disadvantage:

- Very strong interaction forces;
- Much longer sextupole and bigger source body

MS-ECRIS, RIKEN SC-ECR, SuSi…

SECRAL Magnet Concept and Superconducting Coil Configuration

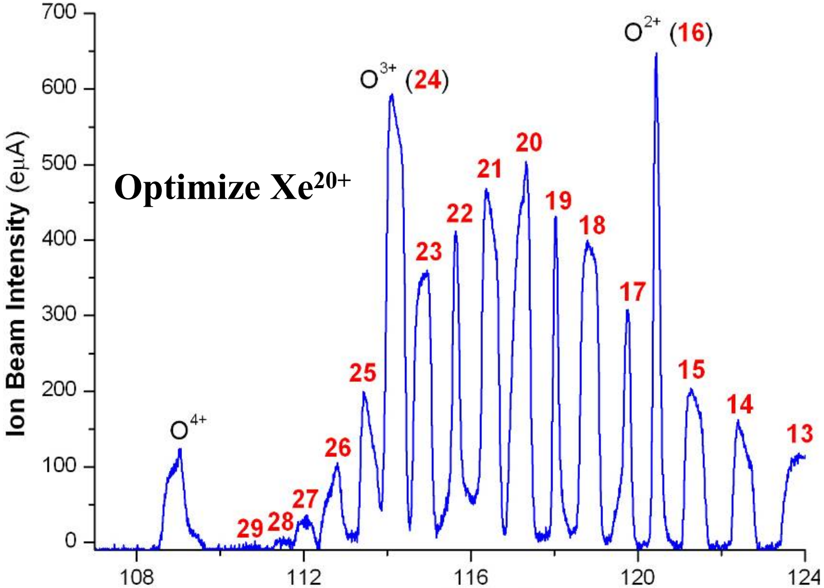
Completely New Design!
- **Reverse conventional structure**
- **Smaller plasma chamber**

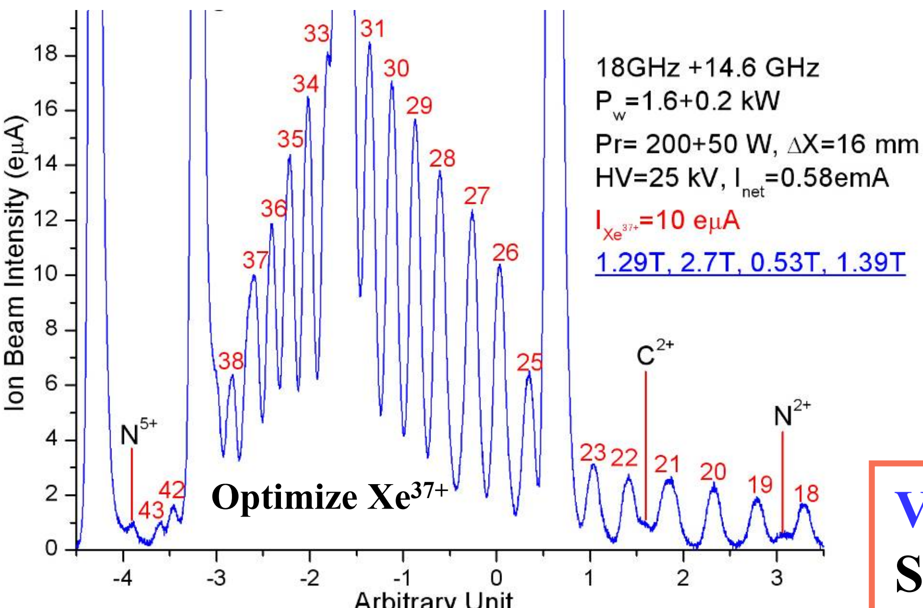


SECRAL at the Axial Injection Beam Line of IMP Cyclotron (since2007. 05)

24GHz+18GHz

SECRAL performance in production of highly charged heavy ions demonstrates ECRIS optimized design plays more important role besides frequency scaling and rf power effects



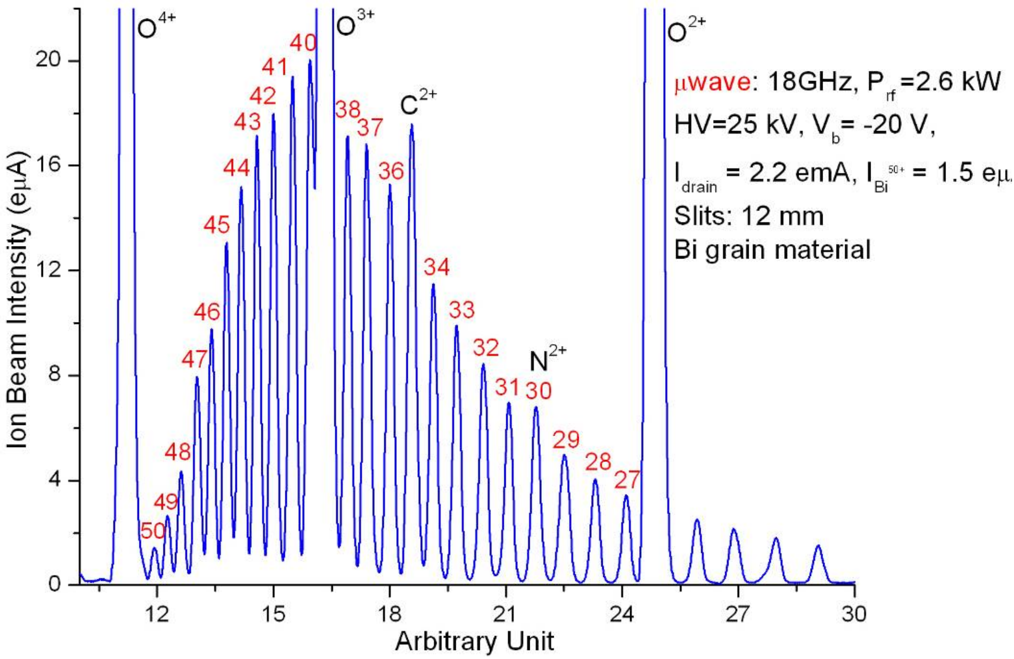


Xe	SECRAL 18GHz or 18+14.5GHz (eμA)	VENUS 28GHz or 28+18GHz (eμA)
20	505	320
27	306	270
30	101	116
31	68	67
34	21	41
35	16	28
37	10	12
38	6.6	8
42	1.6	0.5
43	1	
44	0.16	

VENUS: 6-9 kW, B_{inj}≥3.3 T, B_{ex}=2.1 T

SECRAL: 1.8-3.2kW, B_{inj}=2.7 T, B_{ex}=1.4 T

SECRAL performance in production of highly charged heavy ions demonstrate ECRIS optimized design plays more important role besides frequency scaling and rf power effect

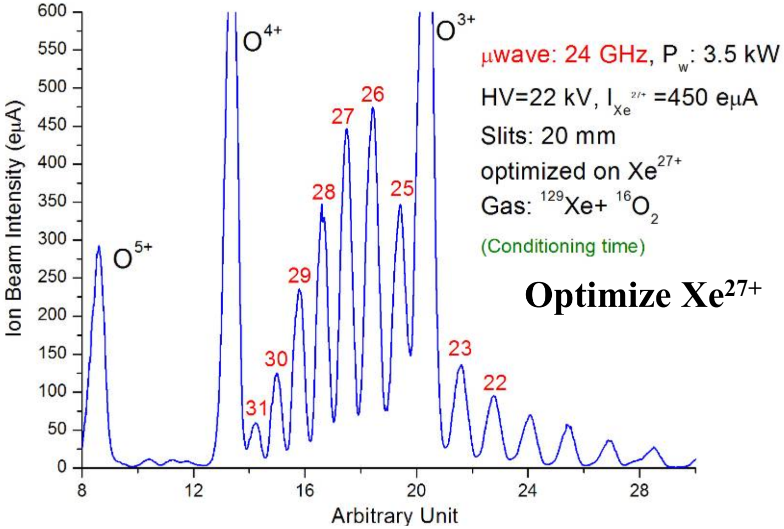


SECRAL produced 1.5 eμA Bi^{50+}, 18GHz, stainless steel chamber.

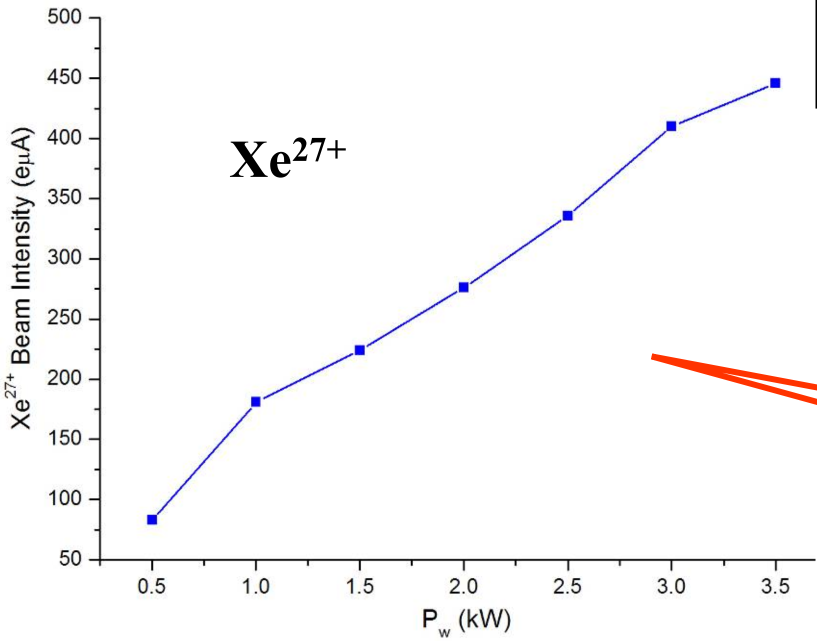
Better results for highly charged Bi beam should be produced by 18+14.5GHz+Al chamber.

^{209}Bi	SECRAL 18GHz Max. power 2.6kW (eμA)	VENUS 28GHz Max. power >4.5kW (eμA)
28	214	240
30	191	225
41	22	15
43	17.3	11.5
44	15.2	7.7
46	10	3.6
47	8	2.4
48	4.3	1.4
49	2.6	1.0
50	1.5	0.5

Preliminary Test Results of SECRAL at 24GHz—Xe beam



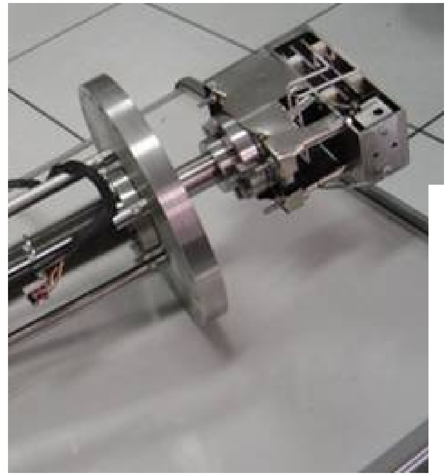
IONS	SECRAL 18GHz <3.2kW (eμA)	SECRAL 24GHz 3.5kW (eμA)	VENUS 28GHz or 28+18GHz >6kW (eμA)
Xe 26+	410	480	290
27+	306	455	270
28+		350	222
30+	101	152	116
31+	68	85	67



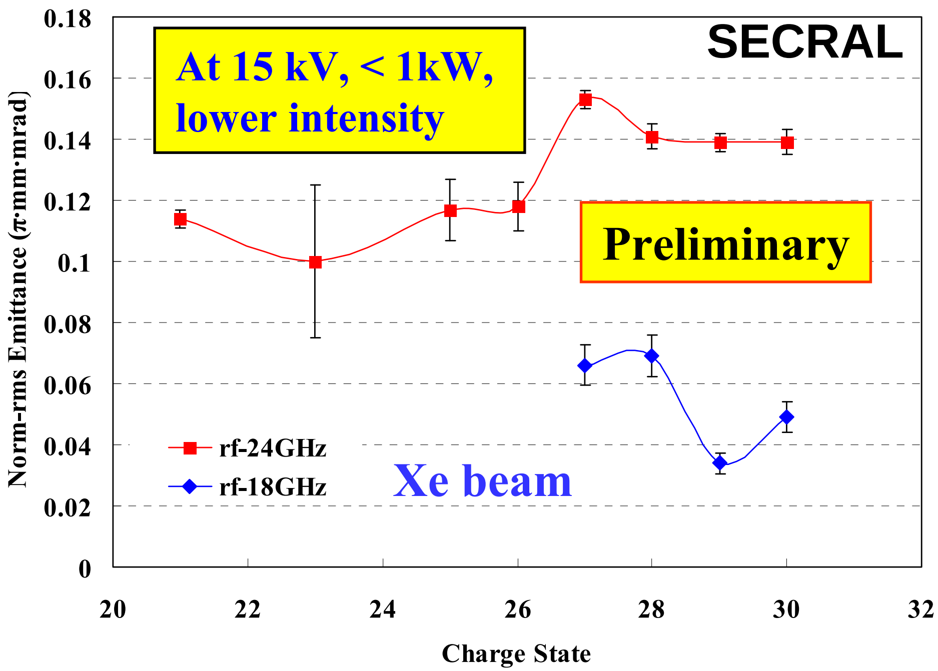
22kV extrac. Volt. 24GHz , 3.5 kW, magnet 94%, B_{inj}=3.5 T, B_{rad}=1.75T

Xe^{27+} keep increasing with 24GHz rf power, not saturate

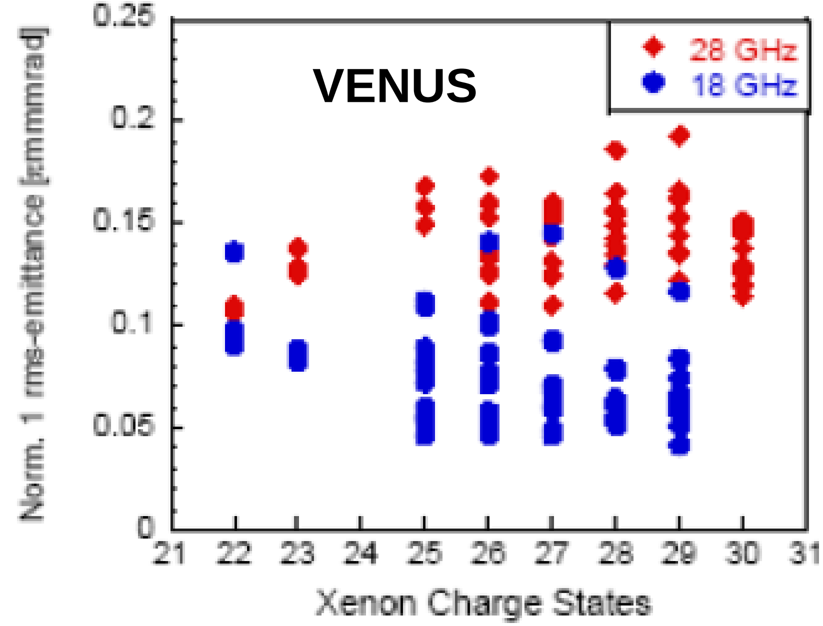
Beam Emittance Measurement at SECRAL



IMP Allison-type emittance scanner.
Located after the analyzing magnet



VENUS emittance



From D.Leitner talk at Cycllotron07

SECRAL Operation for HIRFL Accelerator

- **Beams operated for accelerator:**

  $^{209}Bi^{31+}$, $^{129}Xe^{27+}$, $^{78}Kr^{19+}$, $^{58}Ni^{19+}$

  At 18GHz, **typical rf power 1.3-2.0 kW, extraction voltage 10-22kV**

  Beam intensity during operation:

  120-150 eμA for Bi,Xe,Kr (V>15kV), 50-70 eμA Ni^{19+}(9.8kV)

- **Total beam time from SECRAL for HIRFL: >2000 h**

- SECRAL great contribution to HIRFL in terms of intensity and energy

  SFC Xe beam intensity increased by factor 10

  SSC Xe beam intensity increased by factor 50

  CSRm accelerated Xe^{27+} beam to 235 MeV/u, accumulated beam intensity up to 500 eμA (1×10^8 pps); $Bi^{31+}$and Ni^{19+} not available before

- **With ^{78}Kr beams at CSRe, 3 new nuclides (^{63}Ge,^{65}As,^{67}Se) were identified firstly $\Delta m/m<10^{-6}$**

- SECRAL with an innovative magnet structure and unique features may open a new way for developing high performance and compact SC-ECR ion source.

- SECRAL preliminary results at 24GHz are promising and exciting although commissioning time is too short. Better results should be coming up.

- Unfortunately the high temperature oven not ready, Uranium beam not yet tested at SECRAL

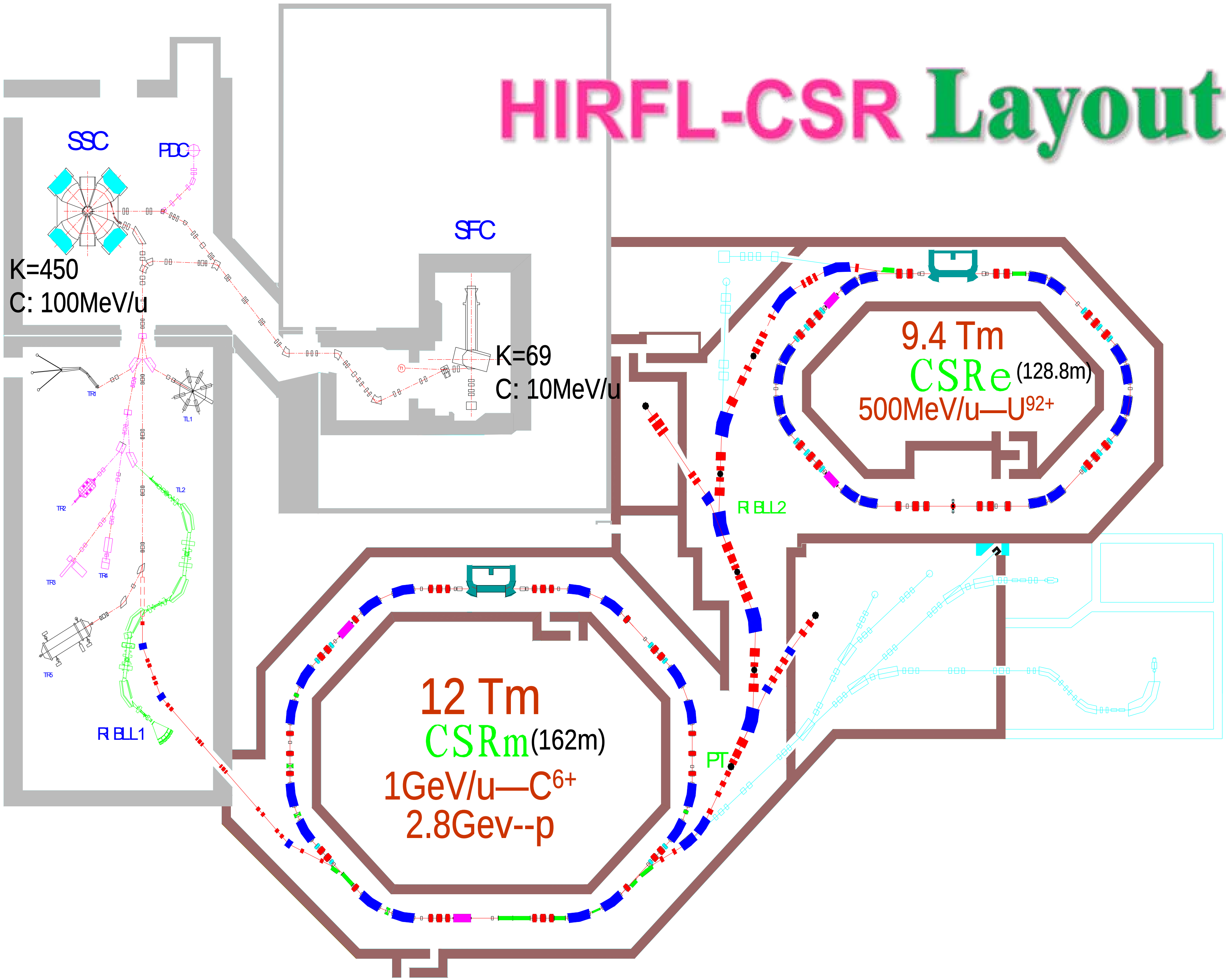
	Q	SECRAL *18 GHz* *<3.2 kW* *eμA*	SECRAL 24GHz *3-4 kW* *eμA*	VENUS *28 GHz* *6-9kW* *eμA*
^{16}O	6+	2300		2860
	7+	810		850
^{40}Ar	12+	510	650	860
	14+	270	440	514
	16+	73	149	270
	17+	8.5	14	36
^{129}Xe	20+	505		320
	27+	306	455	270
	30+	101	152	116
	31+	68	85	67
	34+	21		40
	35+	16		28
	37	10		12
	42+	1.5		0.5
	43+	1		
^{209}Bi	28+	214		240
	30+	191		225
	41+	22		15
	44+	15		7.7
	48+	4.2		1.4
	50+	1.5		0.5

HIRFL-CSR Commissioning and Operation

1998	Project approved
2000-2005	Construction
2006-2007	Commissioning
2008 - present	Operating

Total budget of the HIRFL-CSR project: 42M$

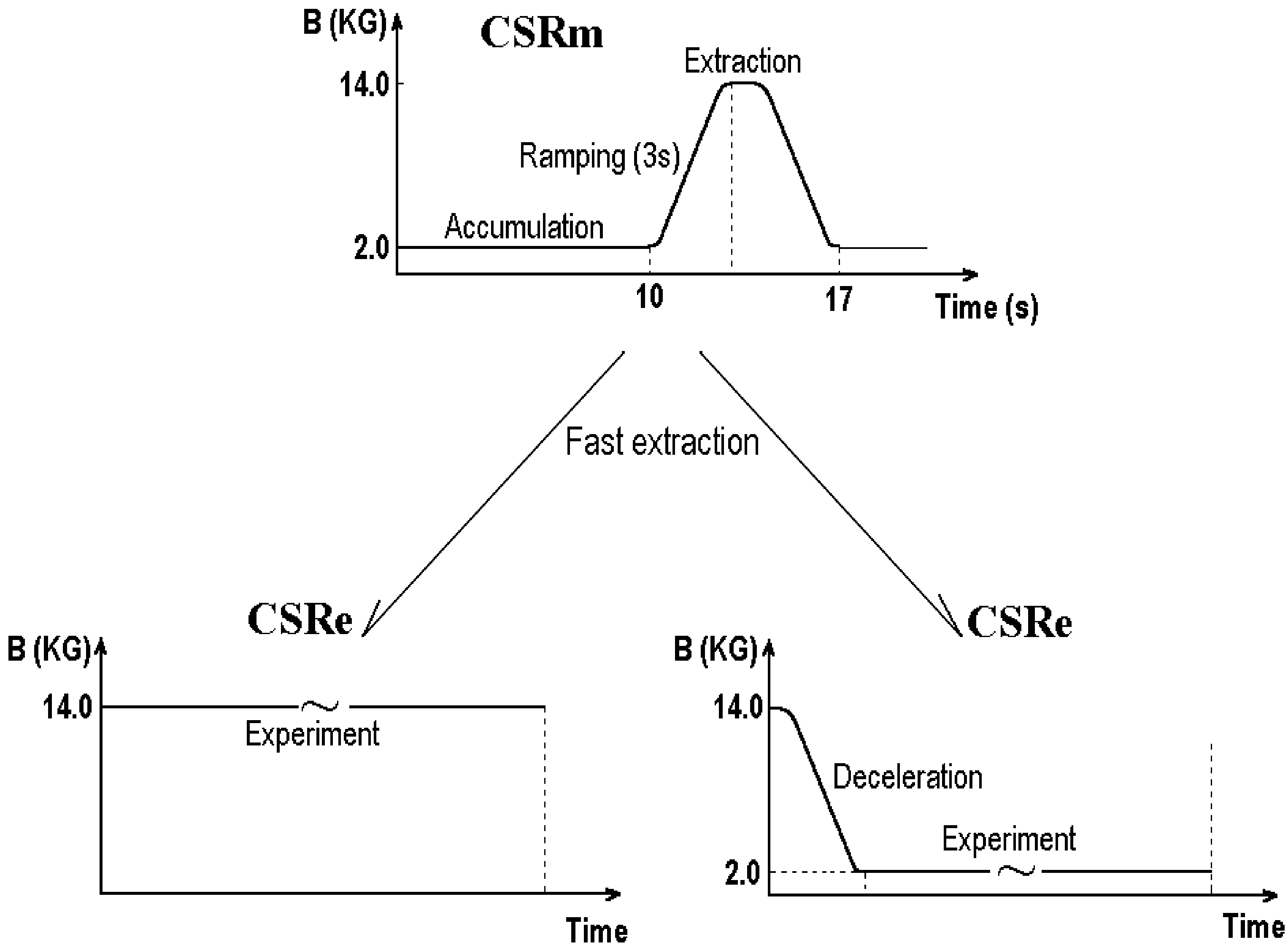
HIRFL-CSR Layout



CSR Main Performances

	CSRm	CSRe
Ion Species	P,C-U	P,C-U, RIB,HCI, Molecular & Cluster
Energy (MeV/u) (B_{max}=1.4~1.6 T)	2350~2800 (P) 900~1100 ($^{12}C^{6+}$) 420~520 ($^{238}U^{72+}$)	2000(P) 620~760 ($^{12}C^{6+}$) 400~500 ($^{238}U^{92+}$)
$\Delta P/P$	$<10^{-4}$	$<10^{-5}$
Emmitance	$\leq 5\pi$ mm-mrad	$\leq 1\pi$ mm-mrad

CSR Operation Scheme



CSRm *Injection* Scheme

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

SFC + CSRm

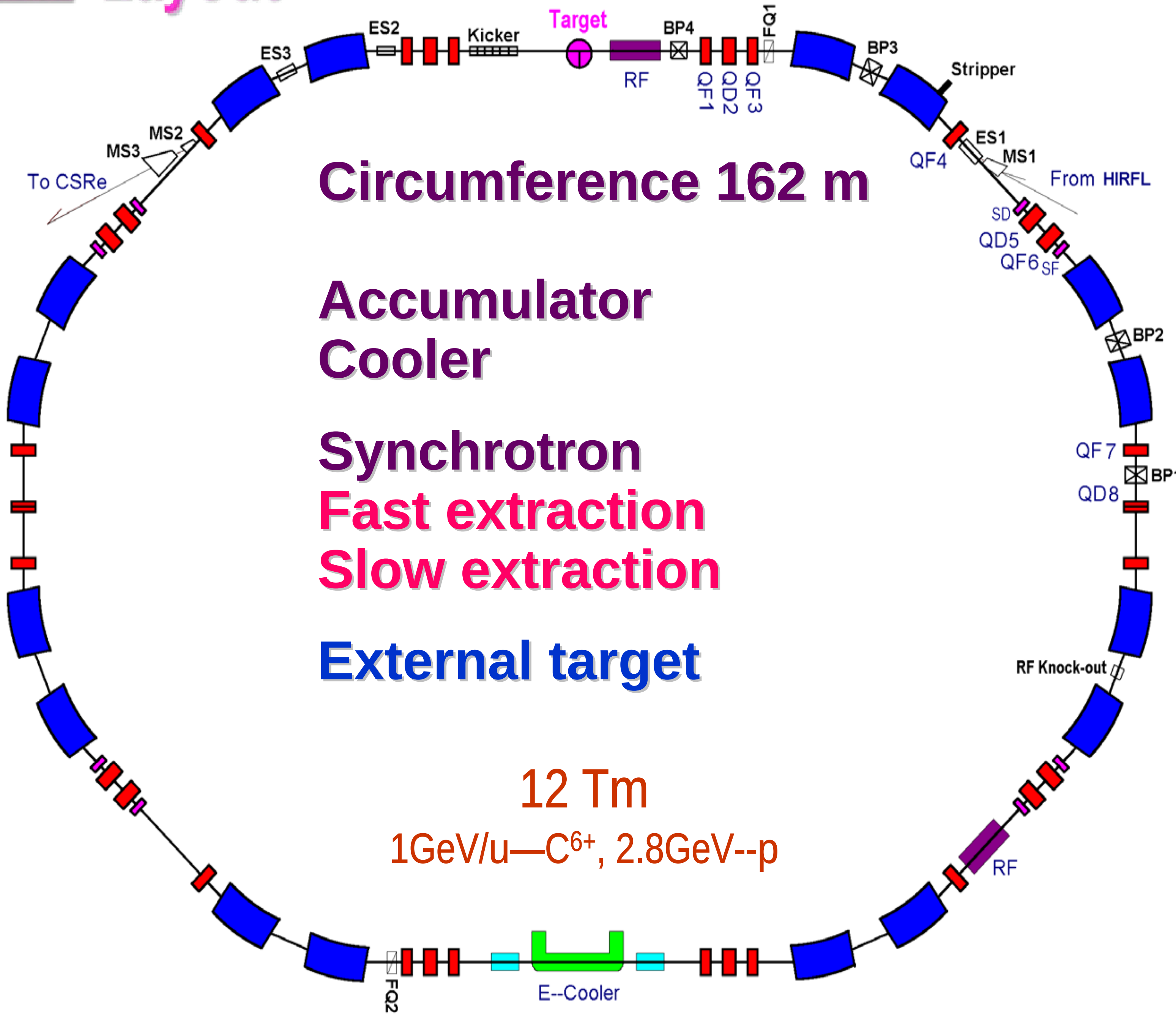
Stripping Injection + E-cooling →→ $I=10^{8\sim9}$

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

SFC + SSC + CSRm

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

CSRm Layout



Circumference 162 m

Accumulator
Cooler

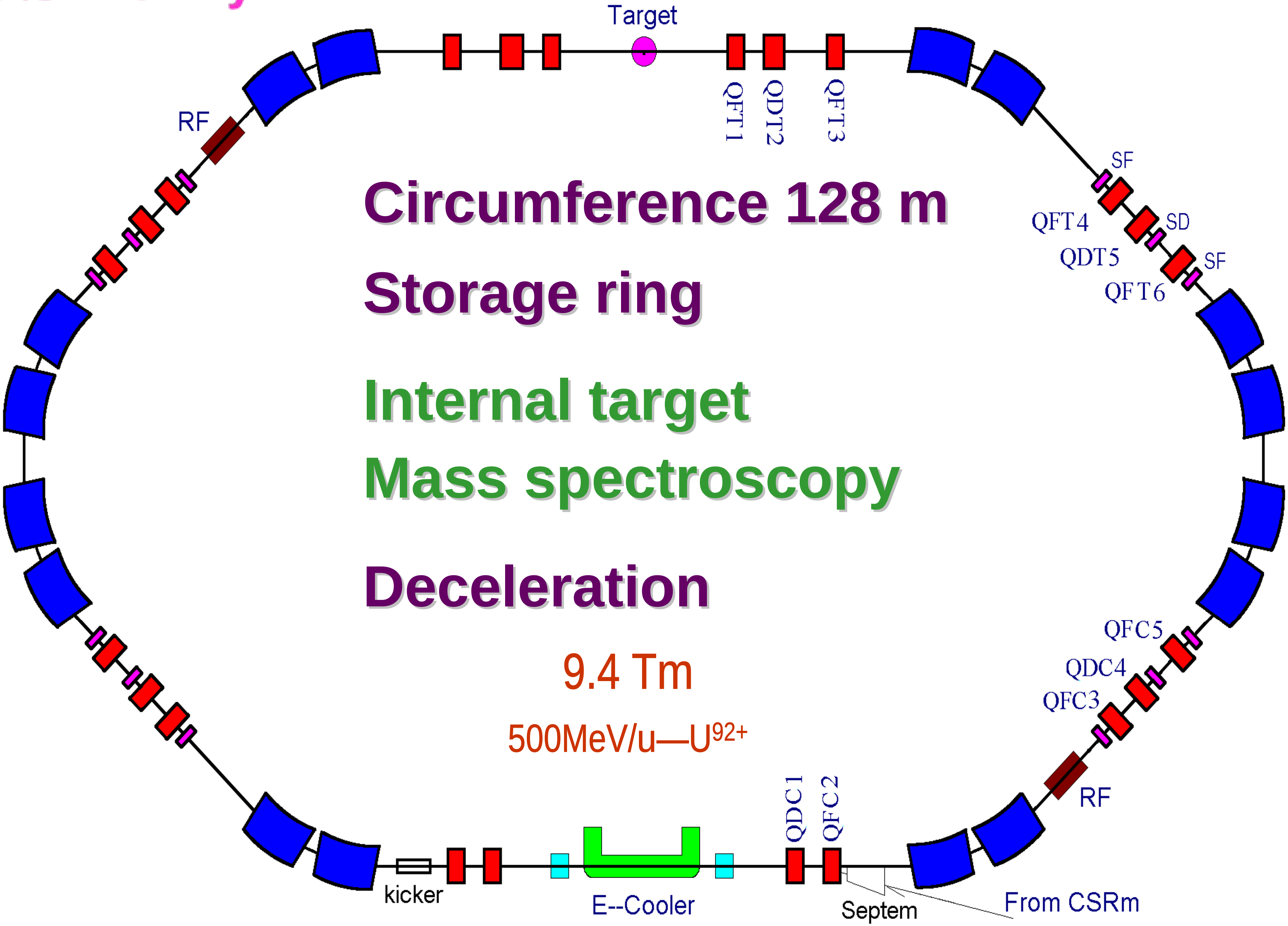
Synchrotron
Fast extraction
Slow extraction

External target

12 Tm

1GeV/u—C^{6+}, 2.8GeV--p

CSRe layout



Circumference 128 m

Storage ring

Internal target

Mass spectroscopy

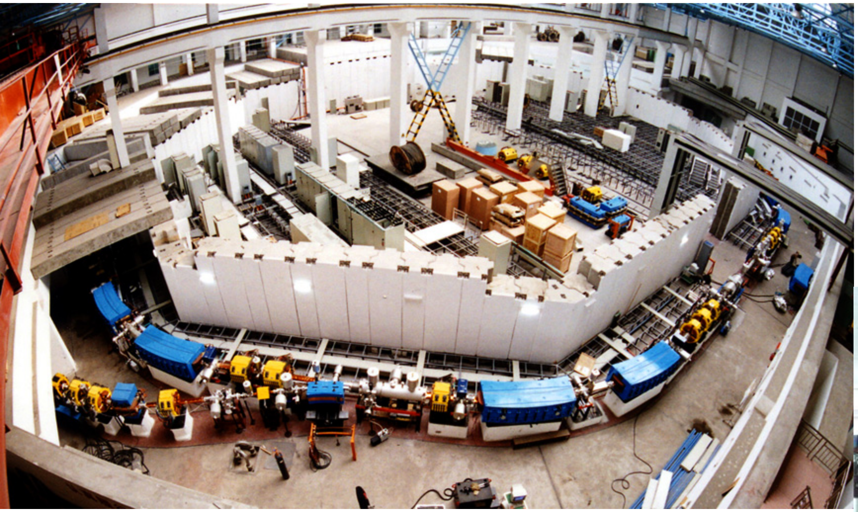
Deceleration

9.4 Tm

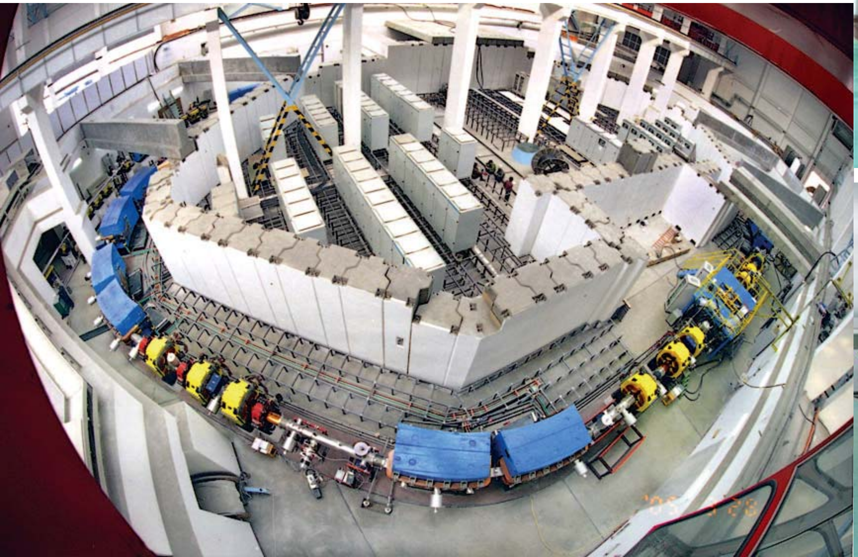
500MeV/u—U^{92+}

HIRFL-CSR

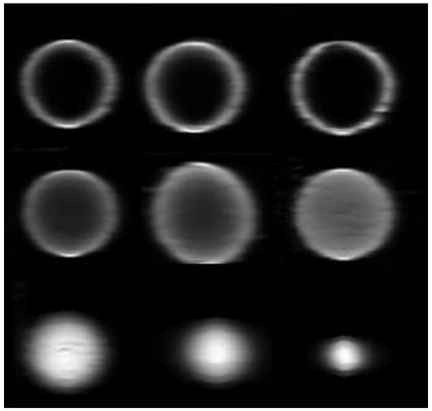
- More than 80% CSR components built by IMP.
- GSI colleagues were invited as consultants and gave a lot advices.

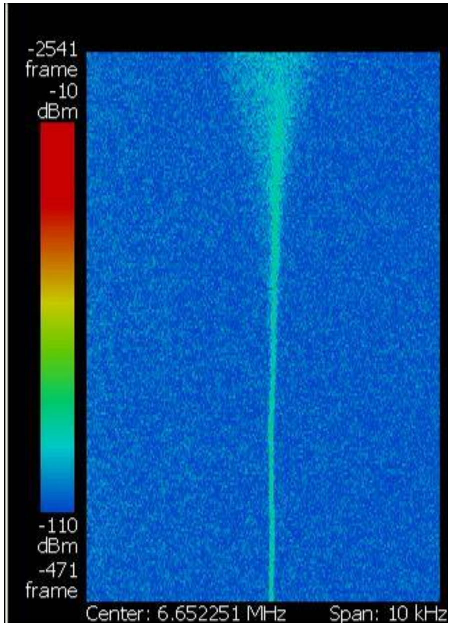







Electron coolers (BINP-IMP)





ΔP/P

7×10^{-4}

↓

2.5×10^{-5}

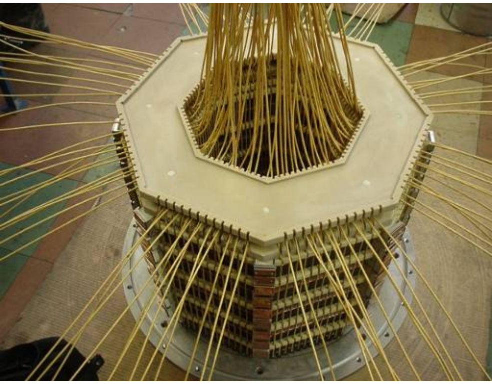

CSRe Channel
Internal Target
e-cooler
300kV
RF
RF STATION

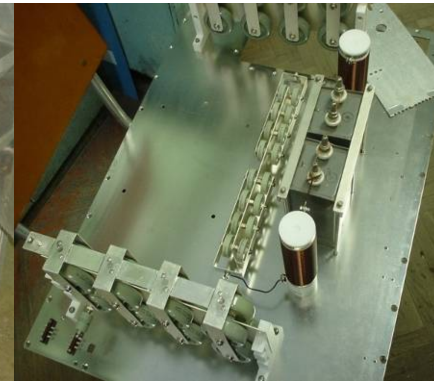
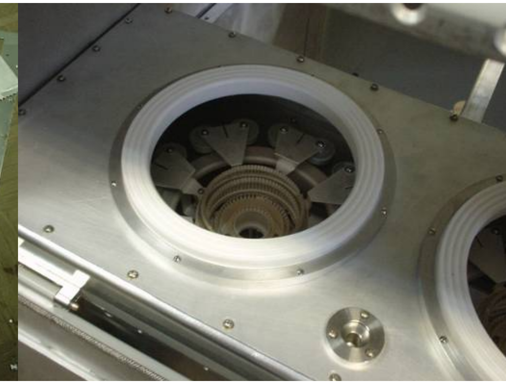
UHV System of CSR

Bake-out temperature: 250°C,

CSR reached vacuum: **5×10^{-12} mbar**

CSR RF System (IMP-BINP)



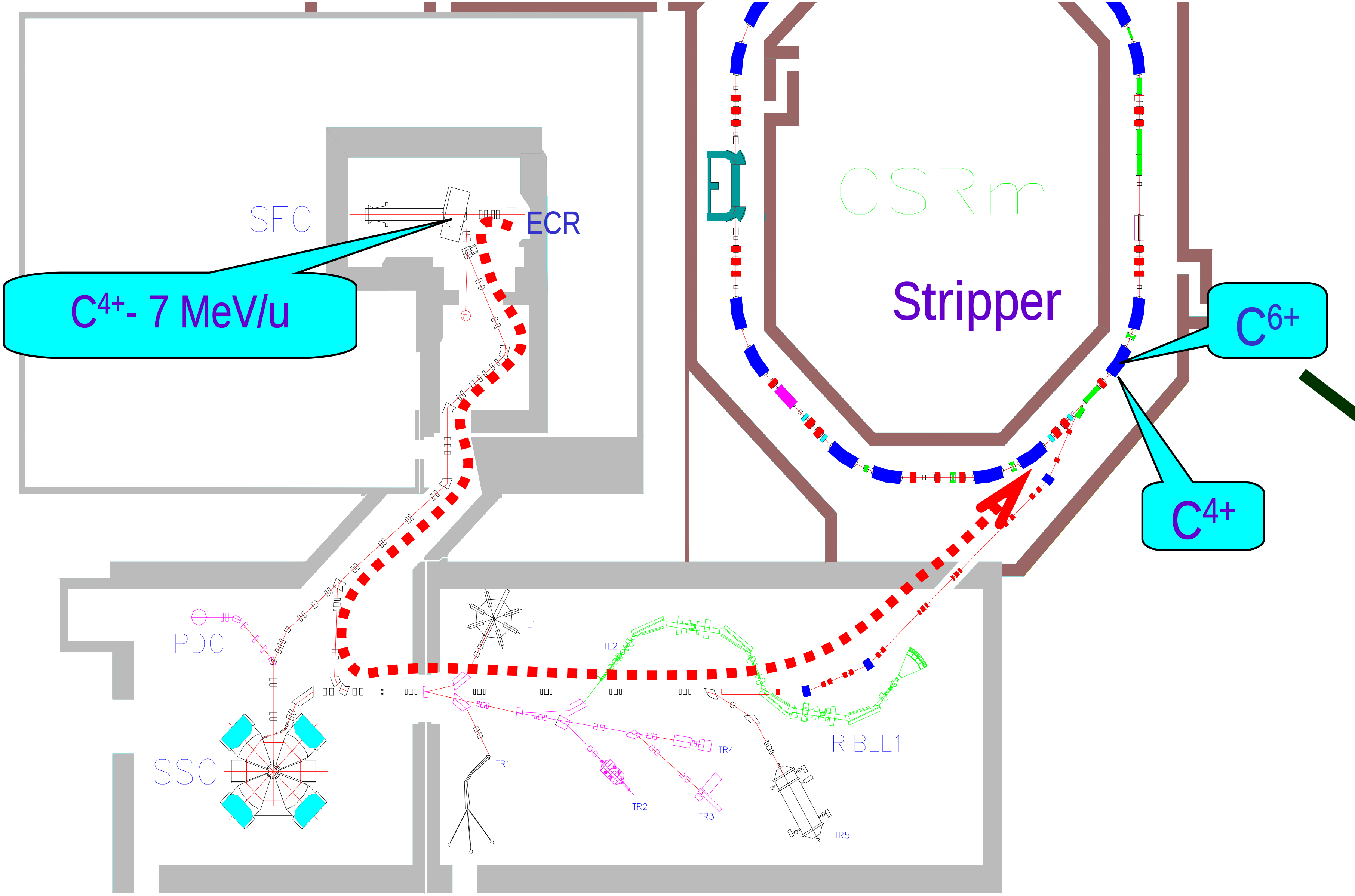
RF-station for acceleration CSR m by BINP

f = 0.24 ~ 1.81 MHz, V_m= 9 kV

RF for beam deceleration CSRe
Designed and built by IMP

Scheme *of the stripping injection in CSRm*

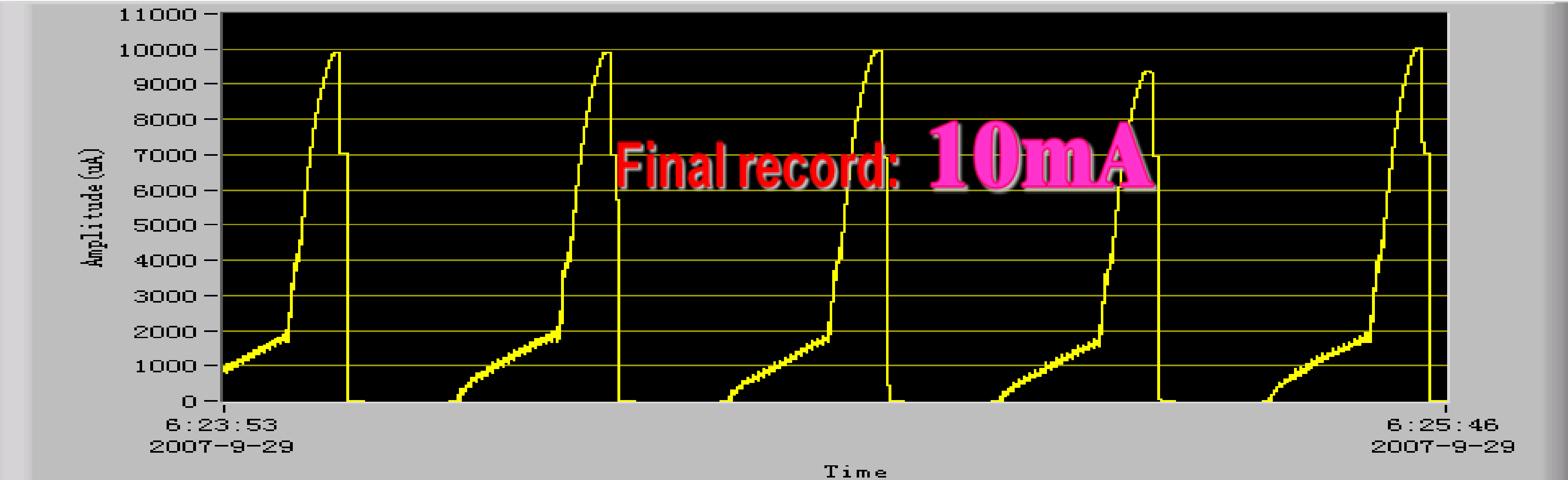
2006.01

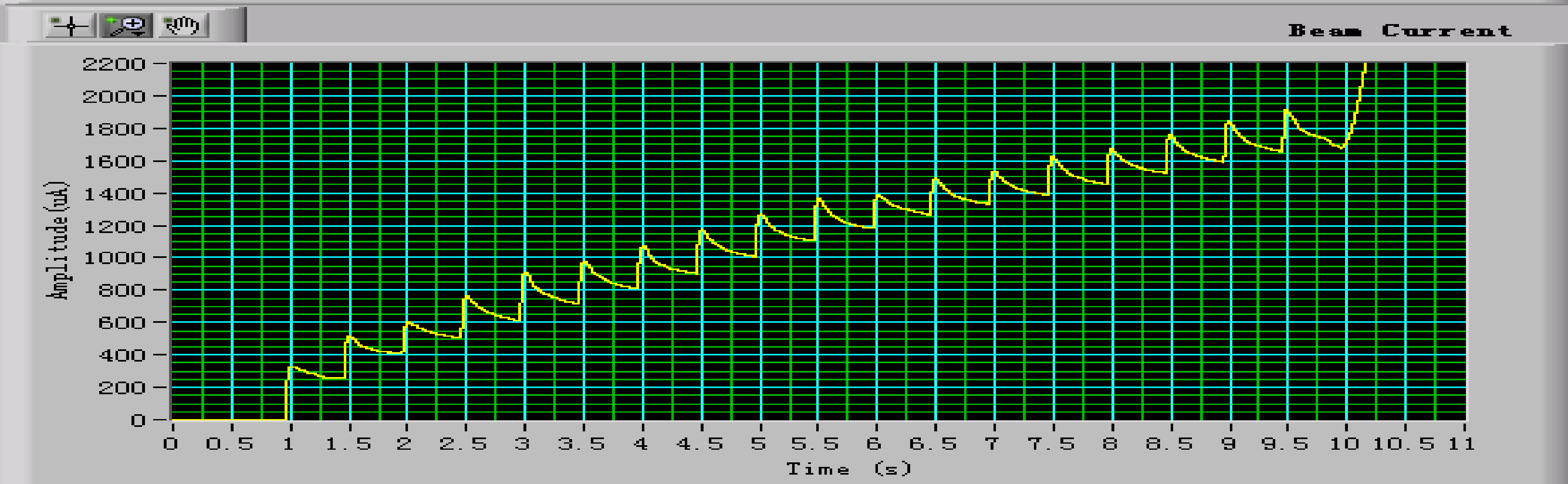


C^{6+}-600MeV/u Ramping in CSRm

07/09/29
06:25

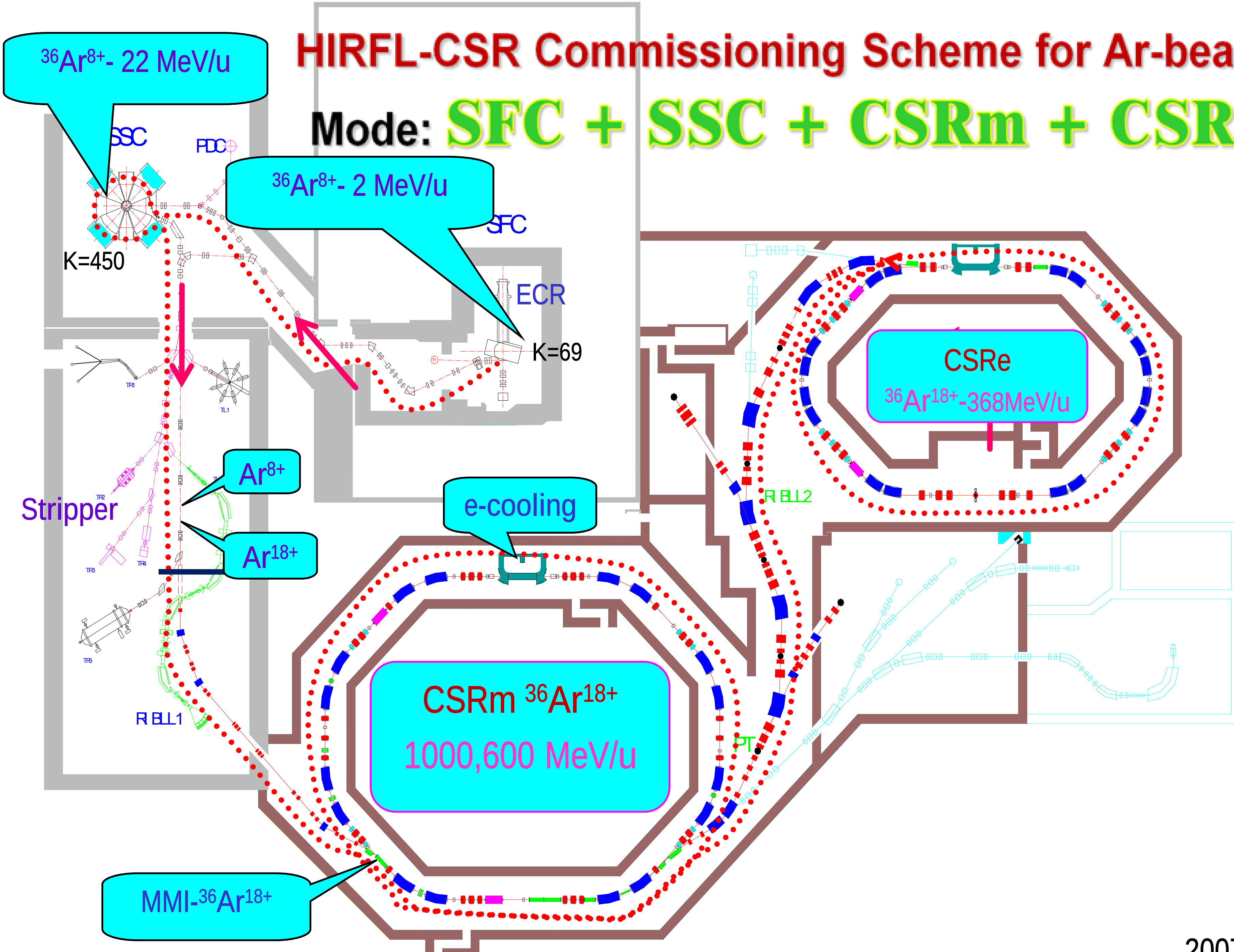
SFC-$^{12}C^{4+}$-7MeV/u, $I_{inj.}$= 11uA, STI, 1800uA in 10s, 10000uA on top, 7×10^9





HIRFL-CSR Commissioning Scheme for Ar-beam

Mode: SFC + SSC + CSRm + CSRe

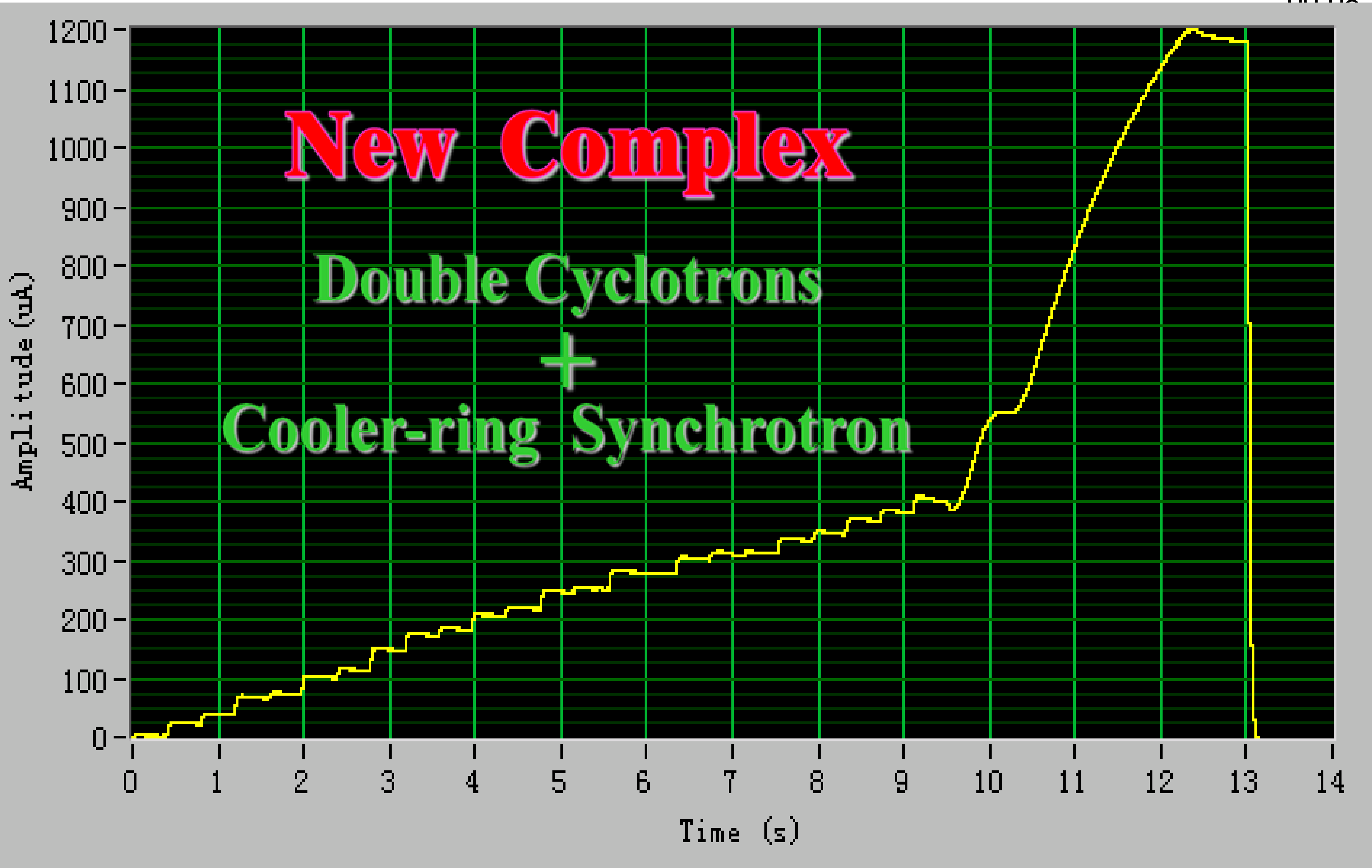


2007/12

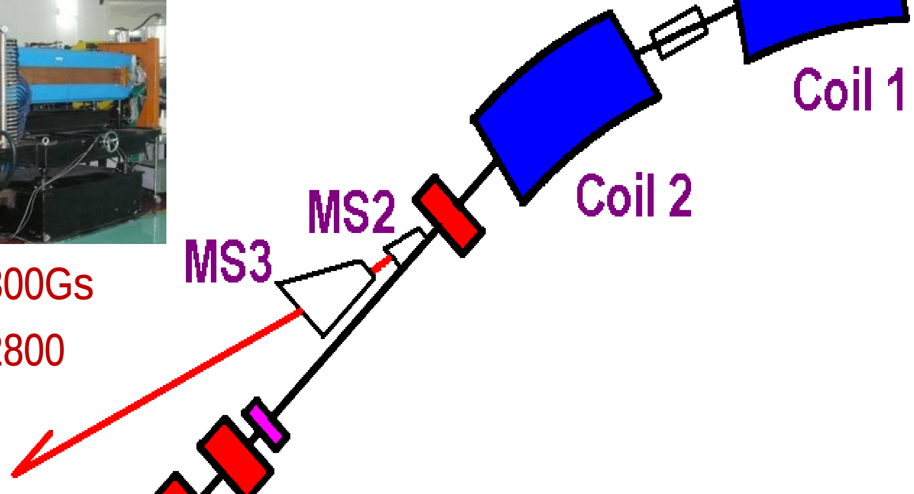
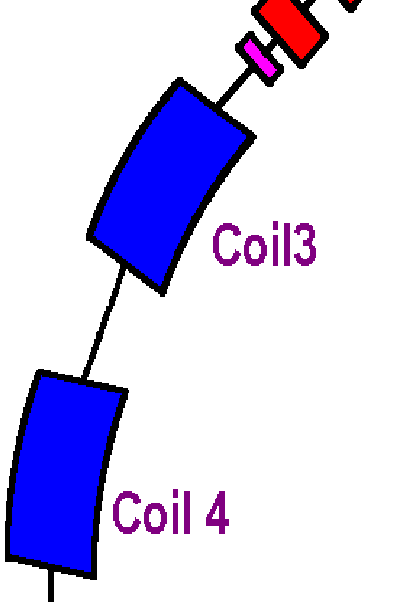
MMI + Ramping ($^{36}Ar^{18+}$--22~368MeV/u) in CSRm

Final record: 1.2mA, 4×10^8

07/12/10 00:08

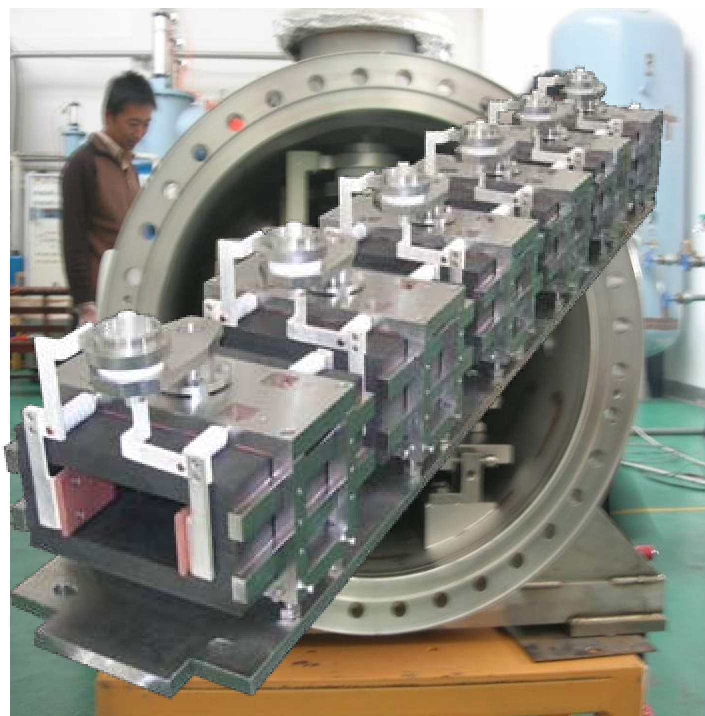


Fast extraction section of CSRm

MS2: 2900A, 4300Gs

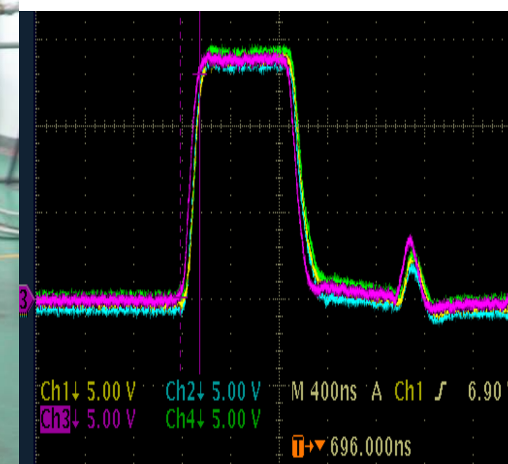
MS2: 2900A, 12800



I_{max} = 2700A

$V_{max.}$= 60 kV

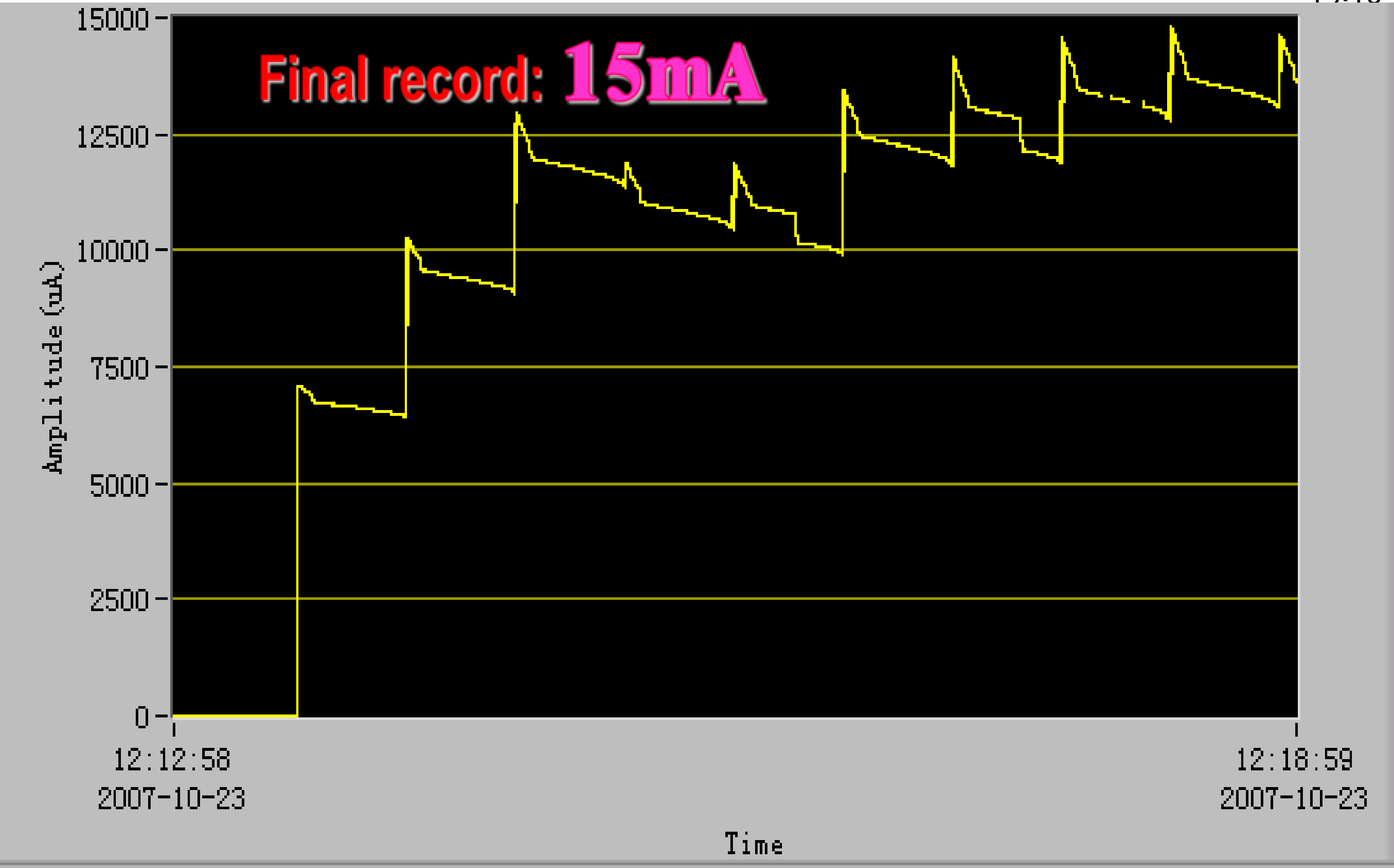
Rising time: **150ns**



Multi-time Injection for CSRe 1st Commissioning

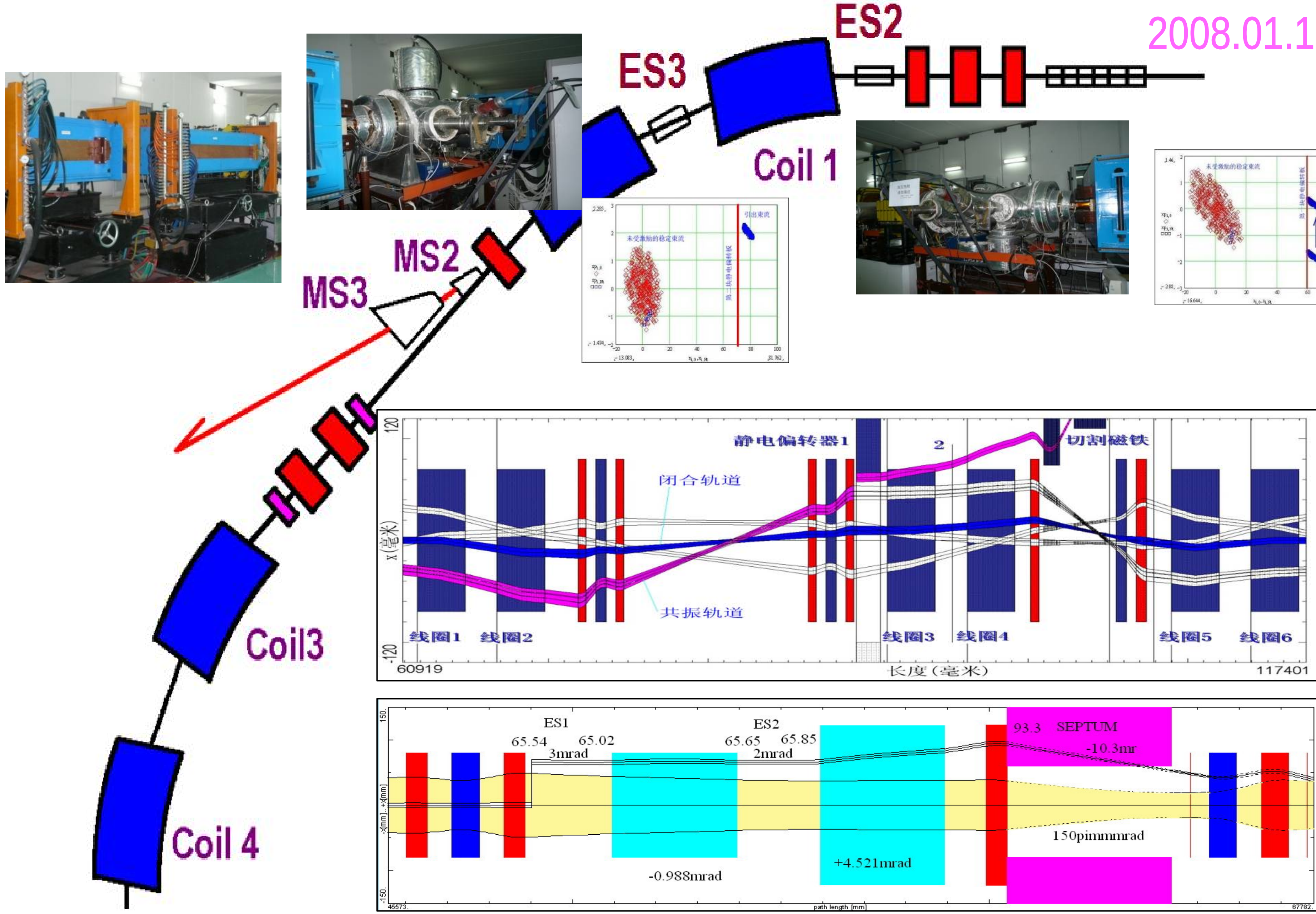
$^{12}C^{6+}$-660MeV/u

07/10/23 12:18



Slow extraction of 1/3 Resonance in CSRm

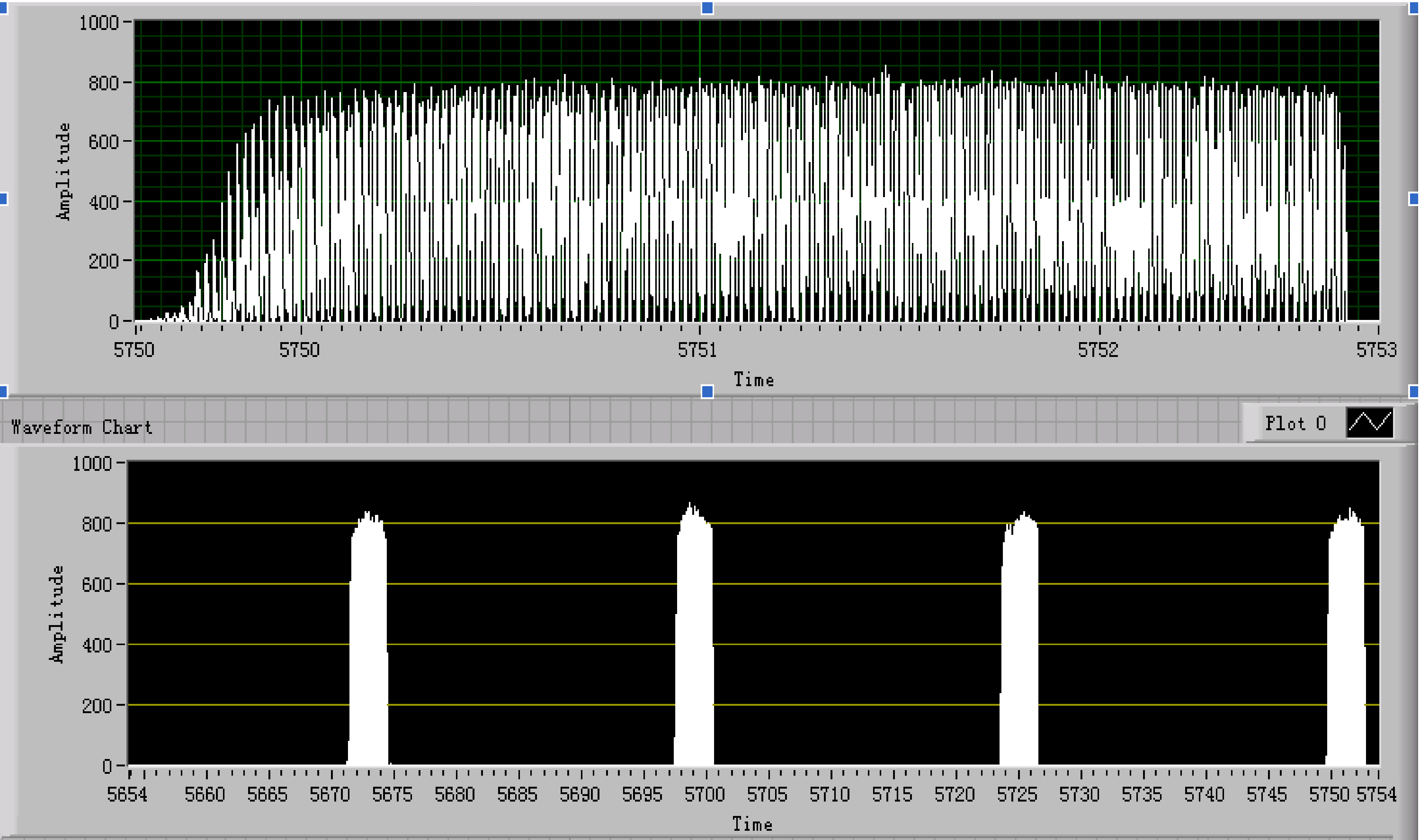
2008.01.10



Slow extraction for $^{12}C^{4+}$-300MeV/u in CSRm

From Scintillation Crystal

2008.05.21 03:31



Summarize: CSR Beam Status

Ions : $^{12}C^{6+}$, $^{36}Ar^{18+}$, $^{78}Kr^{28+}$, $^{129}Xe^{27+}$

Energy: 1GeV/u for C & Ar in CSRm

Intensity:

10mA (7×10^{9}) for ^{12}C-600MeV/u in CSRm

1.2mA (4×10^{8}) for ^{36}Ar-368MeV/u in CSRm

0.5mA (7×10^{7}) for ^{78}Kr-487 MeV/u in CSRm

0.5mA (1×10^{8}) for ^{129}Xe-235MeV/u in CSRm

15mA (8×10^{9}) for ^{12}C-660MeV/u in CSRe

Fast -extraction: Single-turn beam injection into CSRe;

RIB beams produced at RIBLL2.

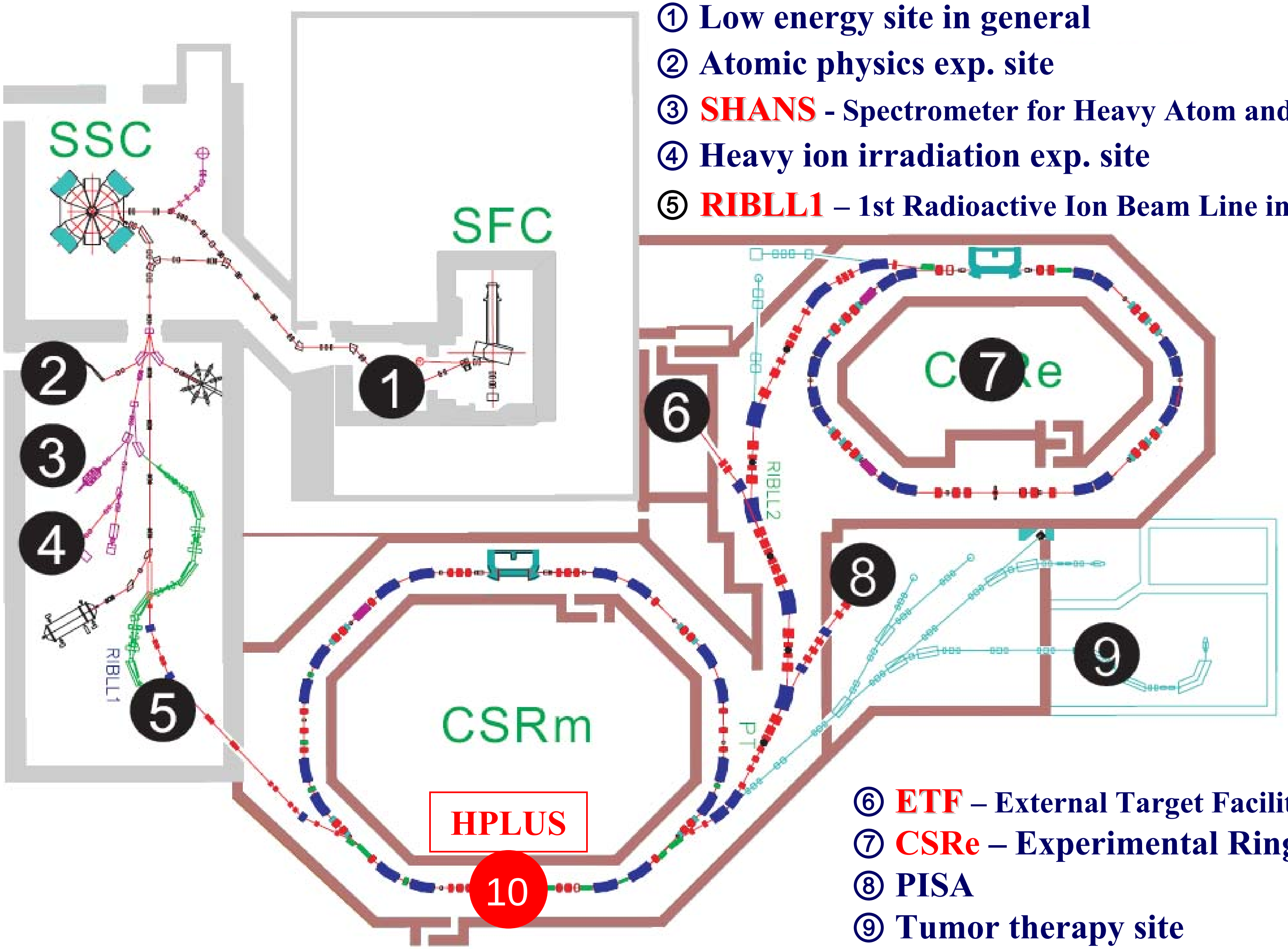
Slow-extraction: 3 s for C-300MeV/u from CSRm; Actively E variation ;

For external-target experiments and ion therapy.

Experiments: RIB beams from RIBLL2; Isochronous mode in CSRe and short-live nuclei mass measurement, $\Delta M/M \sim 10^{-6}$; 8 patients treatment.

Research and Physics Programs

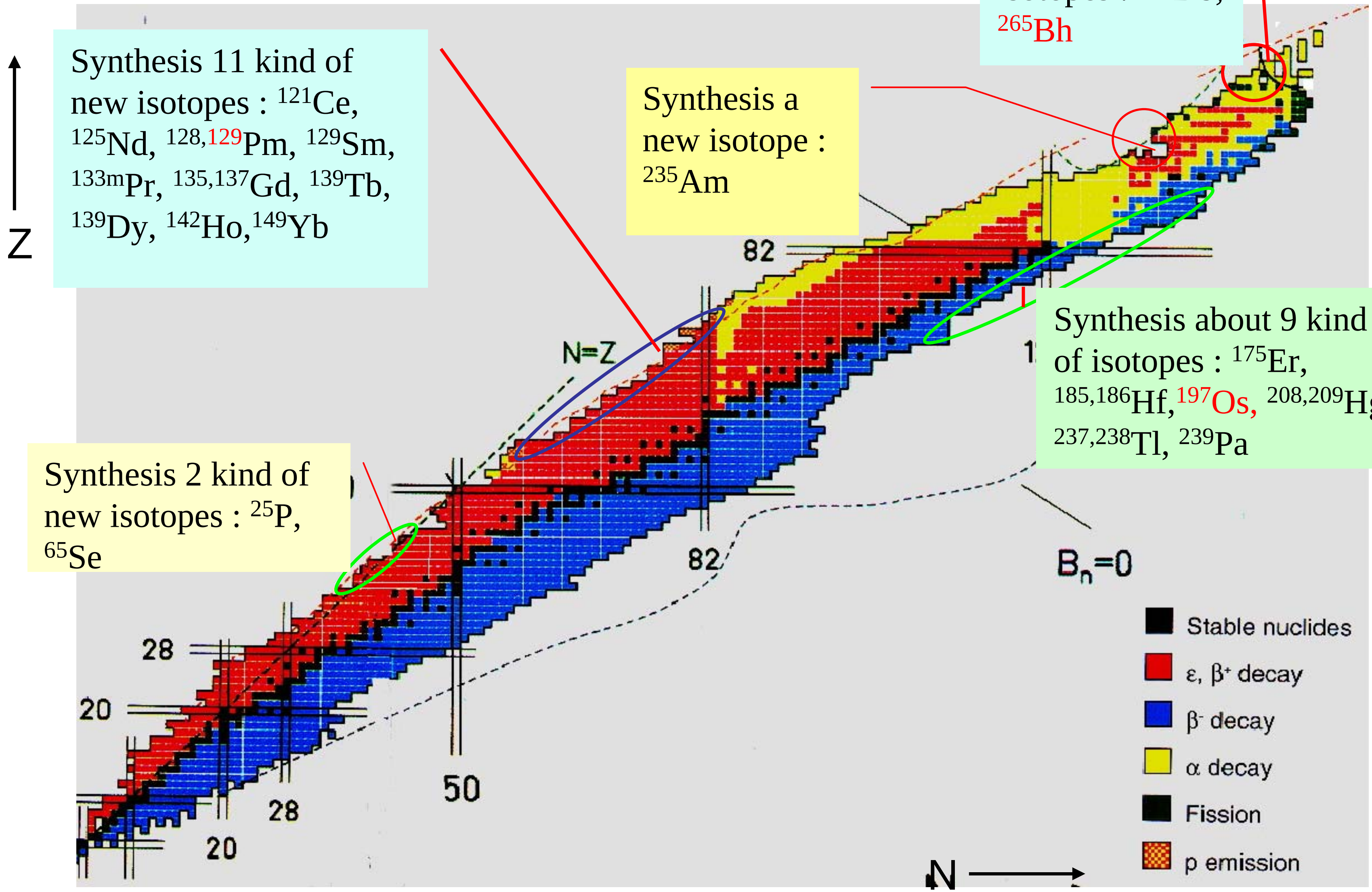
HIRFL: Exp. Setups



① Low energy site in general
② Atomic physics exp. site
③ SHANS - Spectrometer for Heavy Atom and Nuclear Structure
④ Heavy ion irradiation exp. site
⑤ RIBLL1 – 1st Radioactive Ion Beam Line in Lanzhou

⑥ ETF – External Target Facility at CSR
⑦ CSRe – Experimental Ring
⑧ PISA
⑨ Tumor therapy site

25 New Isotopes



Synthesis 2 kind of heavy isotopes : ^{259}Db, ^{265}Bh

Synthesis 11 kind of new isotopes : ^{121}Ce, ^{125}Nd, ^{128,129}Pm, ^{129}Sm, ^{133m}Pr, ^{135,137}Gd, ^{139}Tb, ^{139}Dy, ^{142}Ho, ^{149}Yb

Synthesis a new isotope : ^{235}Am

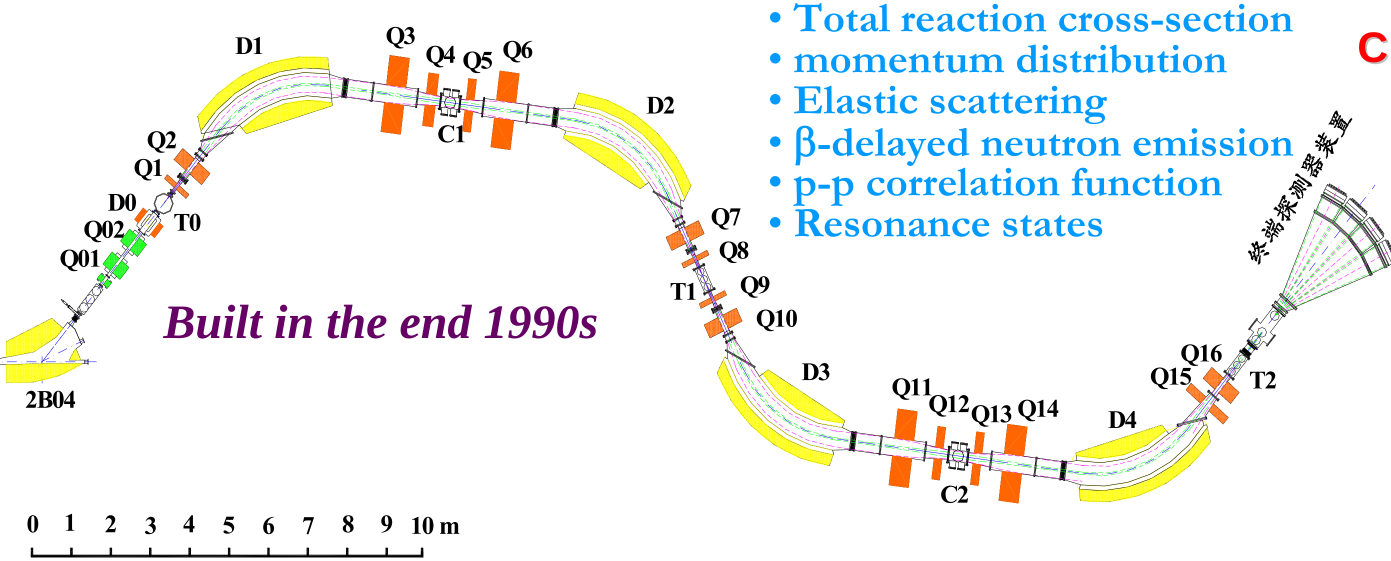
Synthesis about 9 kind of isotopes : ^{175}Er, ^{185,186}Hf, ^{197}Os, ^{208,209}Hg, ^{237,238}Tl, ^{239}Pa

Synthesis 2 kind of new isotopes : ^{25}P, ^{65}Se

IMP synthesis more than 25 new isotopes in the past years.

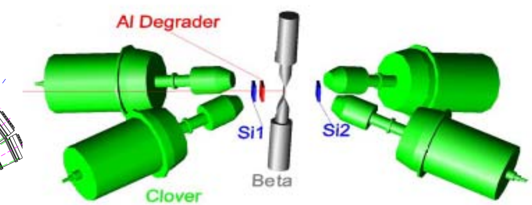
RIBLL 1: *1st Radioactive Beam Line in Lanzhou*

- Total reaction cross-section
- momentum distribution
- Elastic scattering
- β-delayed neutron emission
- p-p correlation function
- Resonance states



Built in the end 1990s

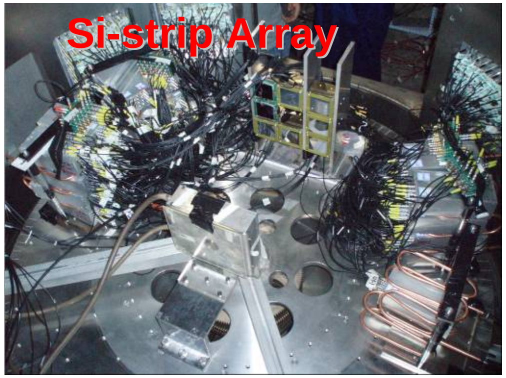
Clover det. for γ detection



The main characteristics of the RIBLL

Angular acceptance (mrad)	Horizontal	50
	Vertical	50
Momentum acceptance $\Delta P/P$		10%
Maximum magnetic rigidity $B\rho_{max}$ (Tm)		4.2
Magnetic rigidity resolution $\Delta B\rho/B\rho$		6×10^{-4}
Charge resolution $Q/\Delta Q$		50–100
Mass resolution $A/\Delta A$		~300
Beam incident angle		0–5°
Minimum measurable RIB life time τ (μs)		<1

Equipped with

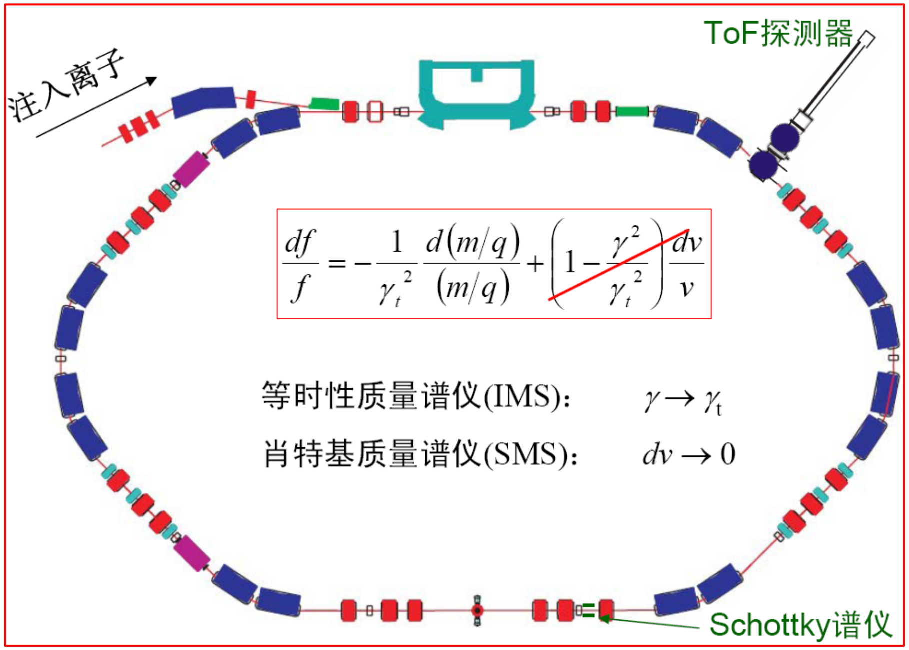


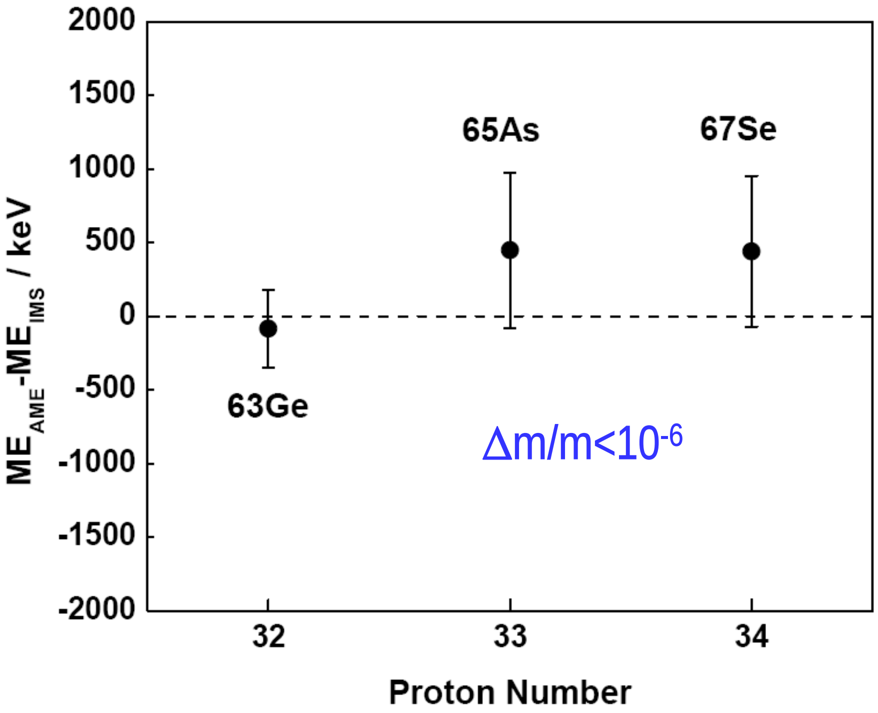
Mass & Decay Measurement at CSRe

RIBLL2 + CSRe

Isochronous mass spectrometer

481MeV/u ^{78}Kr → ^{9}Be → RIB

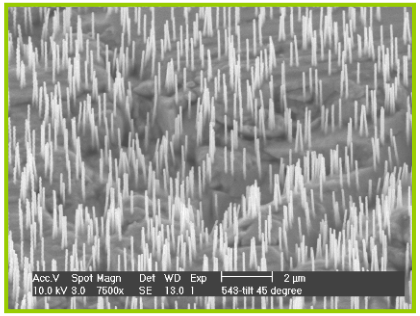




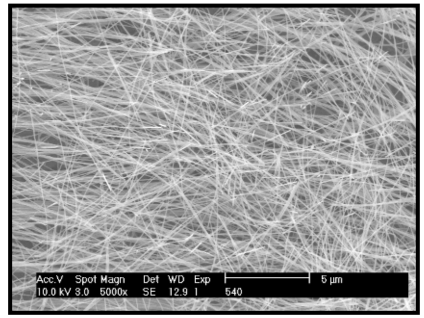
- The end of 2007: test run
- The end of 2008: 1st physics run

Nanowires made by Heavy-ion irradiation Collaborated with GSI

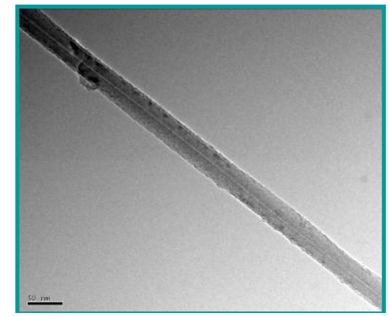
New diagnostic probe



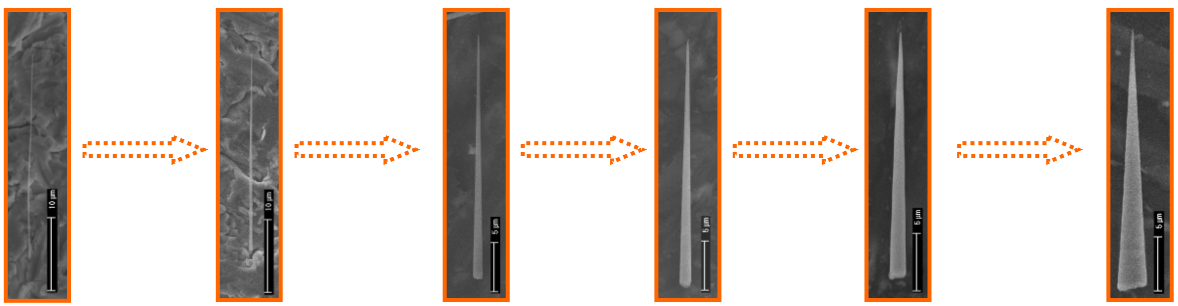
rod

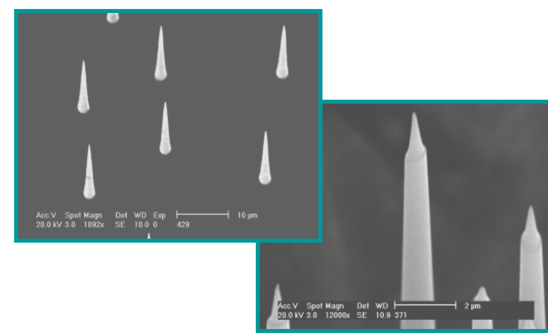


wire

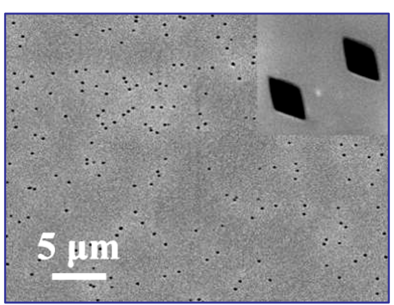


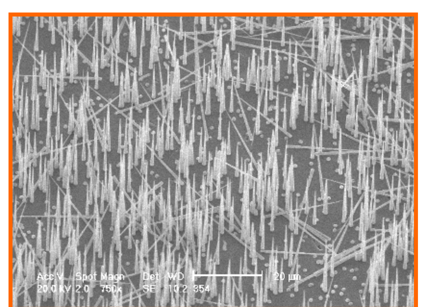
15nm diameter wire

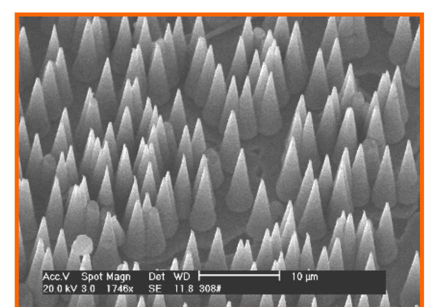




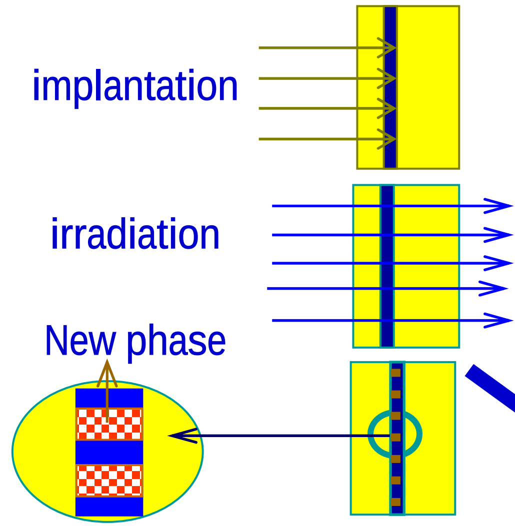
Needle

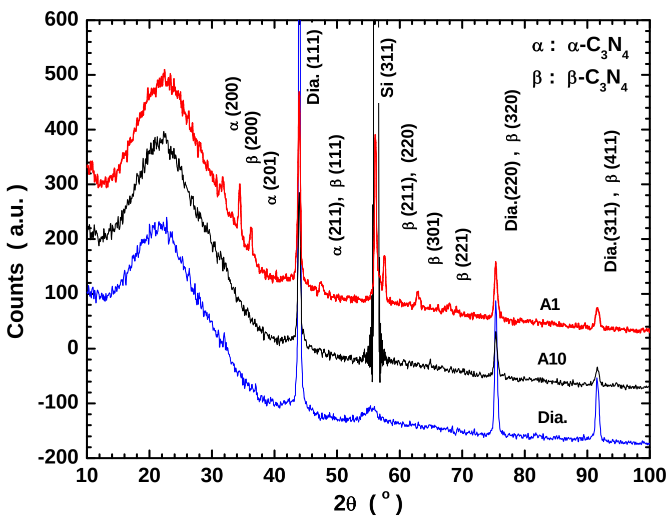


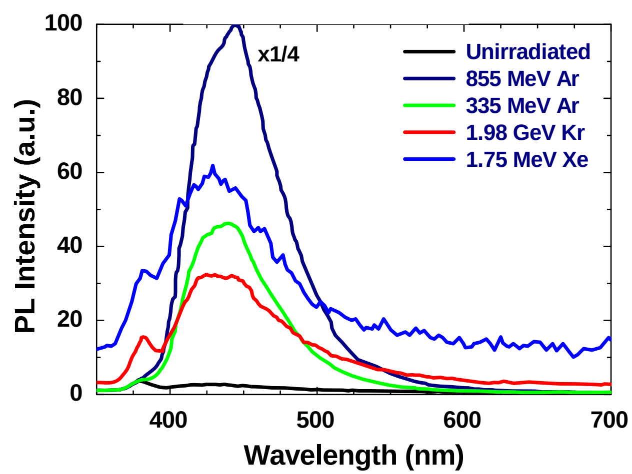


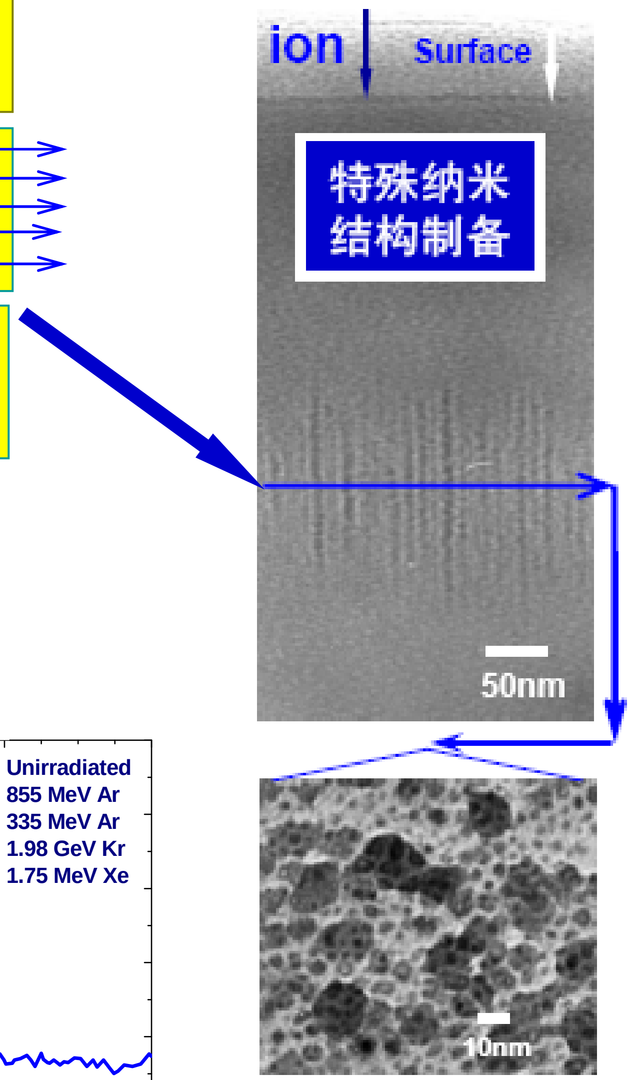


New material produced by heavy-ion irradiation



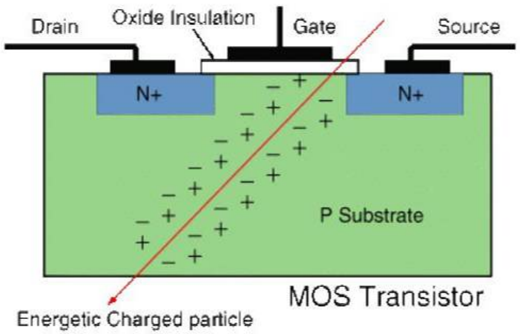


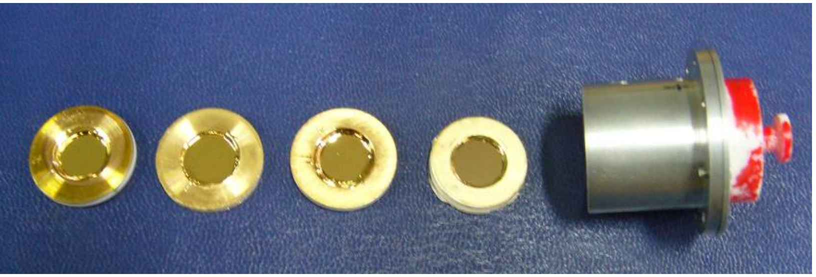


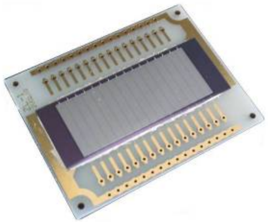


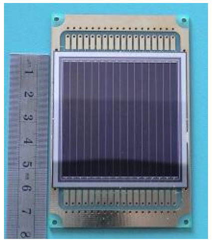
Charged Particle Detector and Single-particle Effect Study

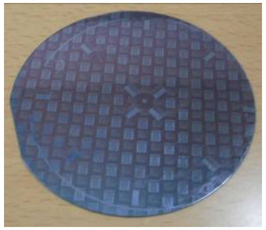
- Si and Si(Li) detectors for nuclear physics and space researches
- Stripped Si detectors under development
- Single-particle effect study in space application

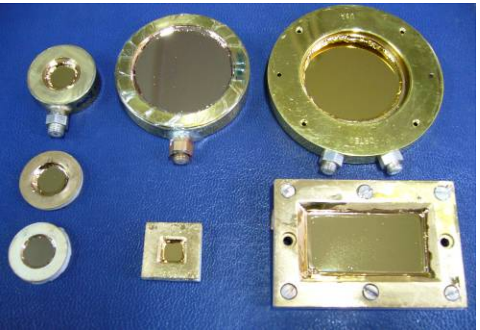










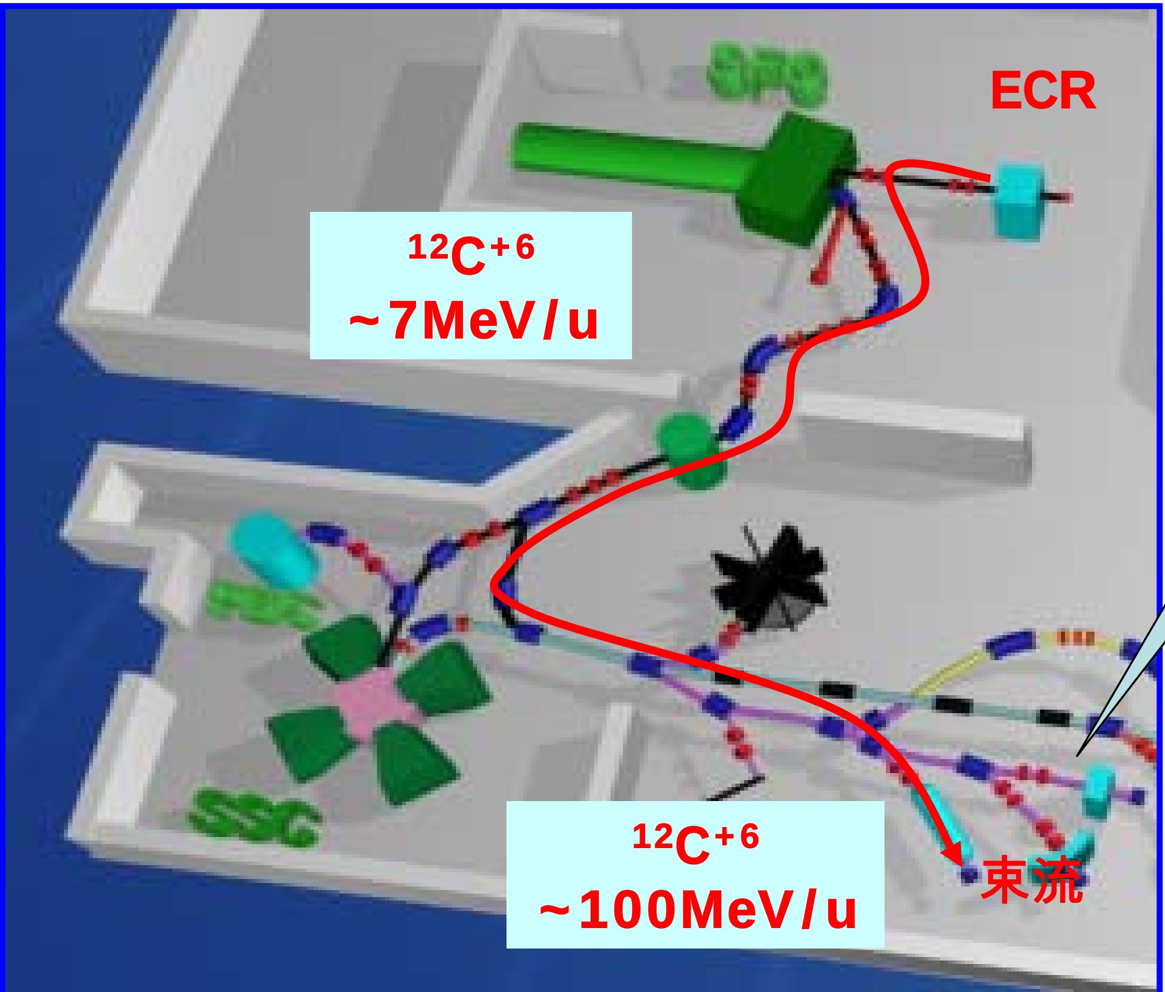


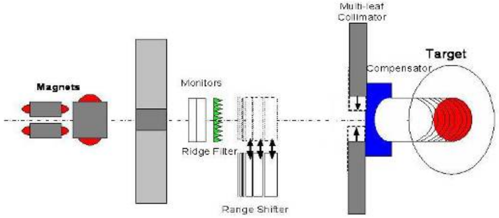
Heavy-Ion Cancer Therapy Center

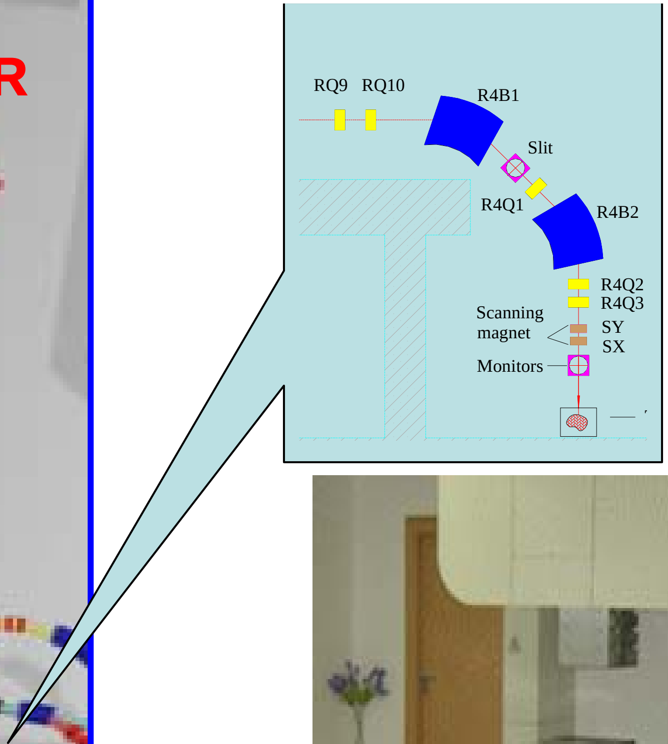
Clinical Trials for the shallow-seated Tumor therapy

3D conformal irradiation method

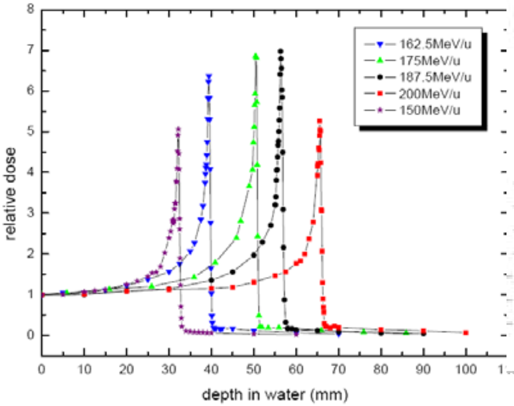
➢ **Double Cyclotron combination SFC+SSC**

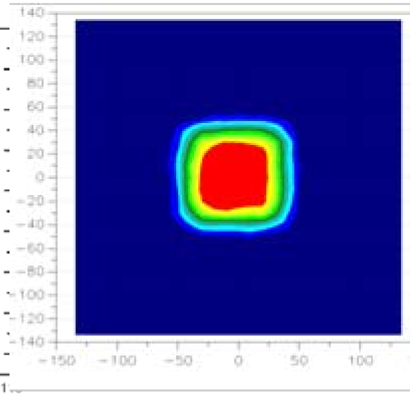


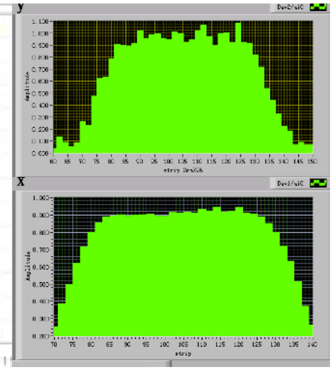


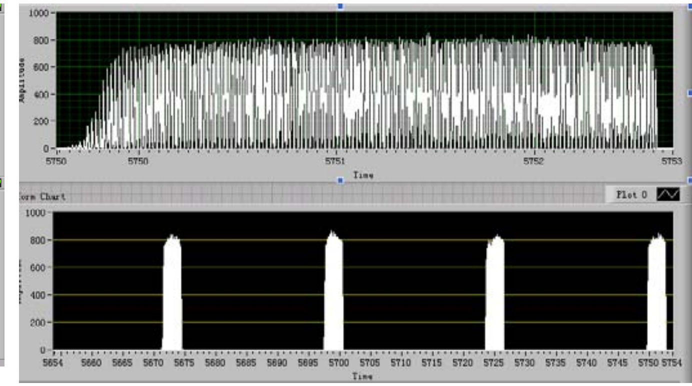


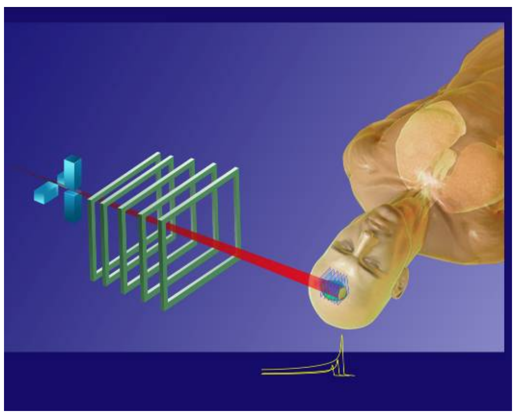
Deep-seated Tumor Therapy at HIRFL-CSR

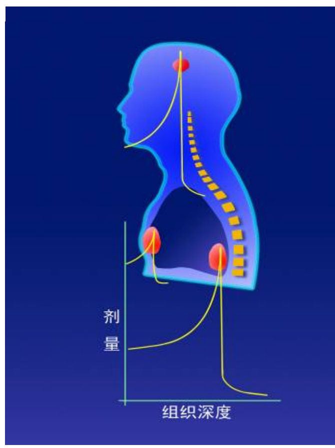


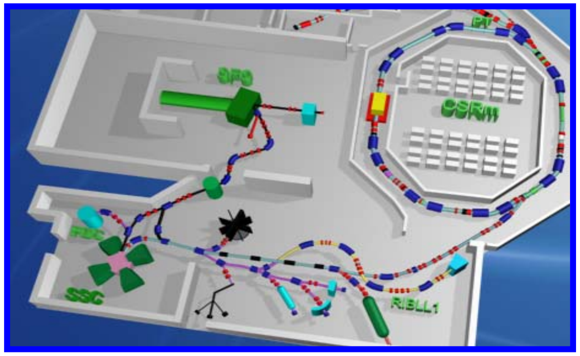












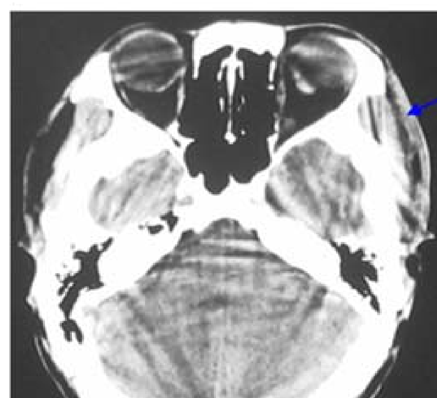
◎Collaborated with local hospitals

◎103 patients treated for ~10 kinds of shallow-seated tumors (SSC)

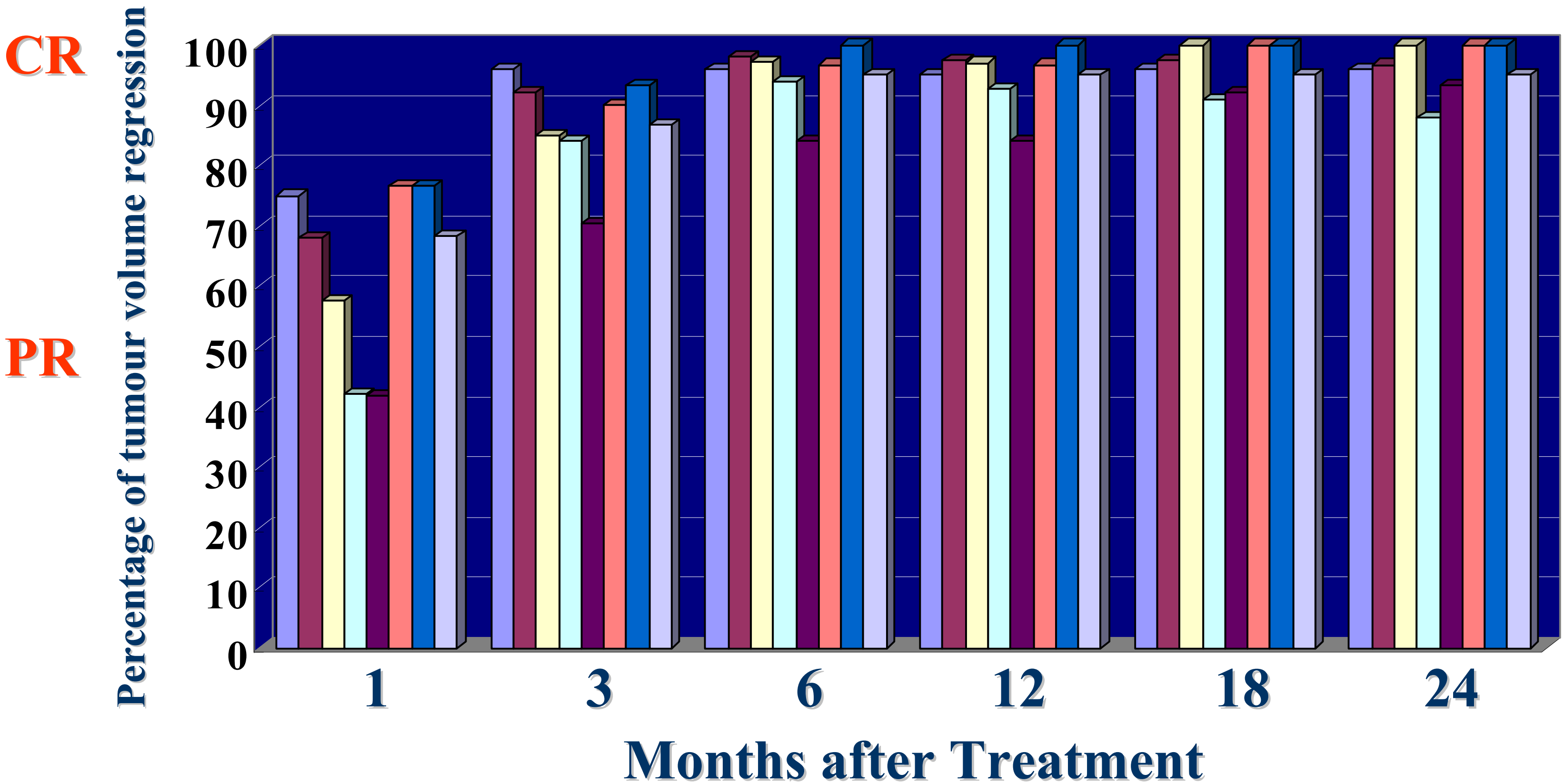
◎8 patients for deep-seated tumors by HIRFL-CSR

Treatment date	depth	N
Nov. 2006	1.6cm	4
Jan.2007	2.1 cm	9
March 2007	2.1 cm	14
August 2007	2.1 cm	9
Dec. 2007	2.1 cm	15
March 2008	2.1 cm	15
Sept. 2008	2.1 cm	16
March 2009	2.1 cm	21
April, July 2009	3~11 cm	8

Before | **After treatment 2-6 months**



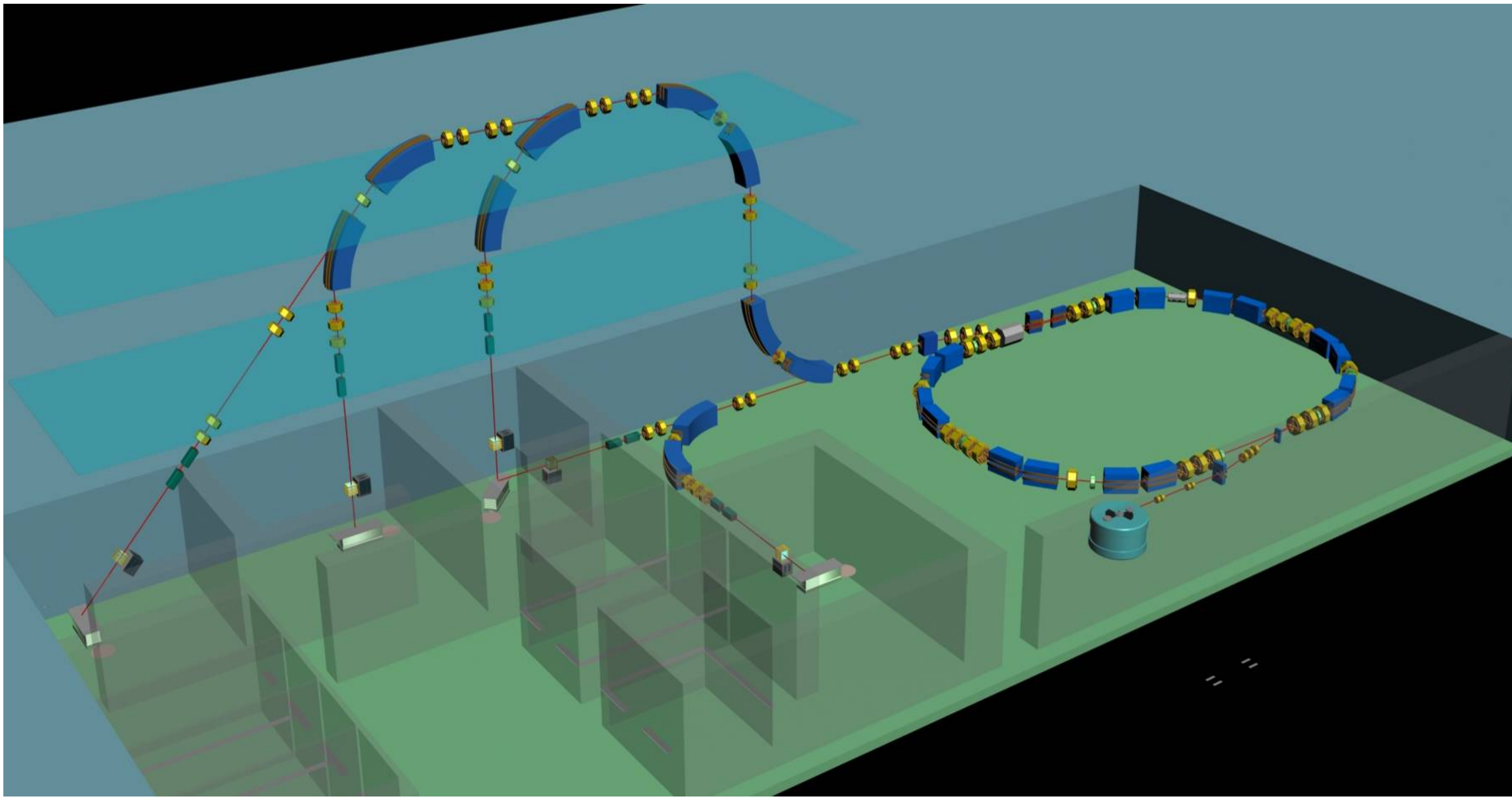
Local Control Rates Following Treatment of 79 Patients



- Squamous cell carcinoma (42-70.4GyE/4-10fr)
- Basal cell carcinoma (54.8-61.2GyE/6-11fr)
- Malignant skin melanoma (61-75GyE/6-7fr)
- Sarcoma (51-65.7GyE/6-11fr)
- Other skin lesions (30-60GyE/6-8fr)
- Lymphoma (40-54GyE/6-9fr)
- Adenocarcinoma (40-60GyE/6-9fr)
- Metastatic lymph nodes of carcinomas (40-70GyE/6-11fr)

Int J Mol Med, 2008,22(suppl.) :186

IMP Dedicated Ion Therapy Facility



80-420 MeV/u, C beam, 5×10^{8} pps, will be built in Lanzhou

Near-future Development

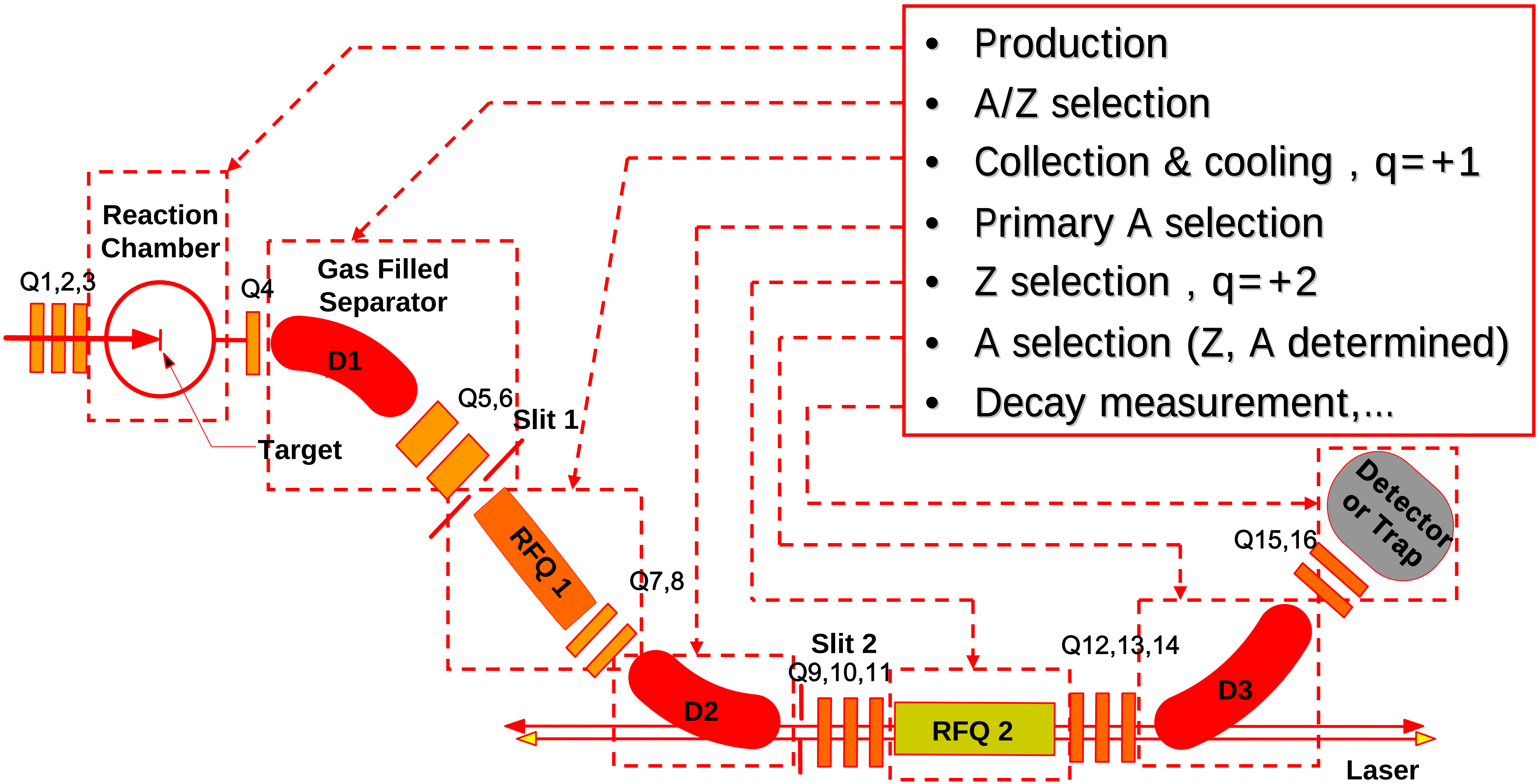
Present Status & Prospective of the Main Equipments for Nuclear Physics Experiment

During CSR construction, almost no budget for physics setups.

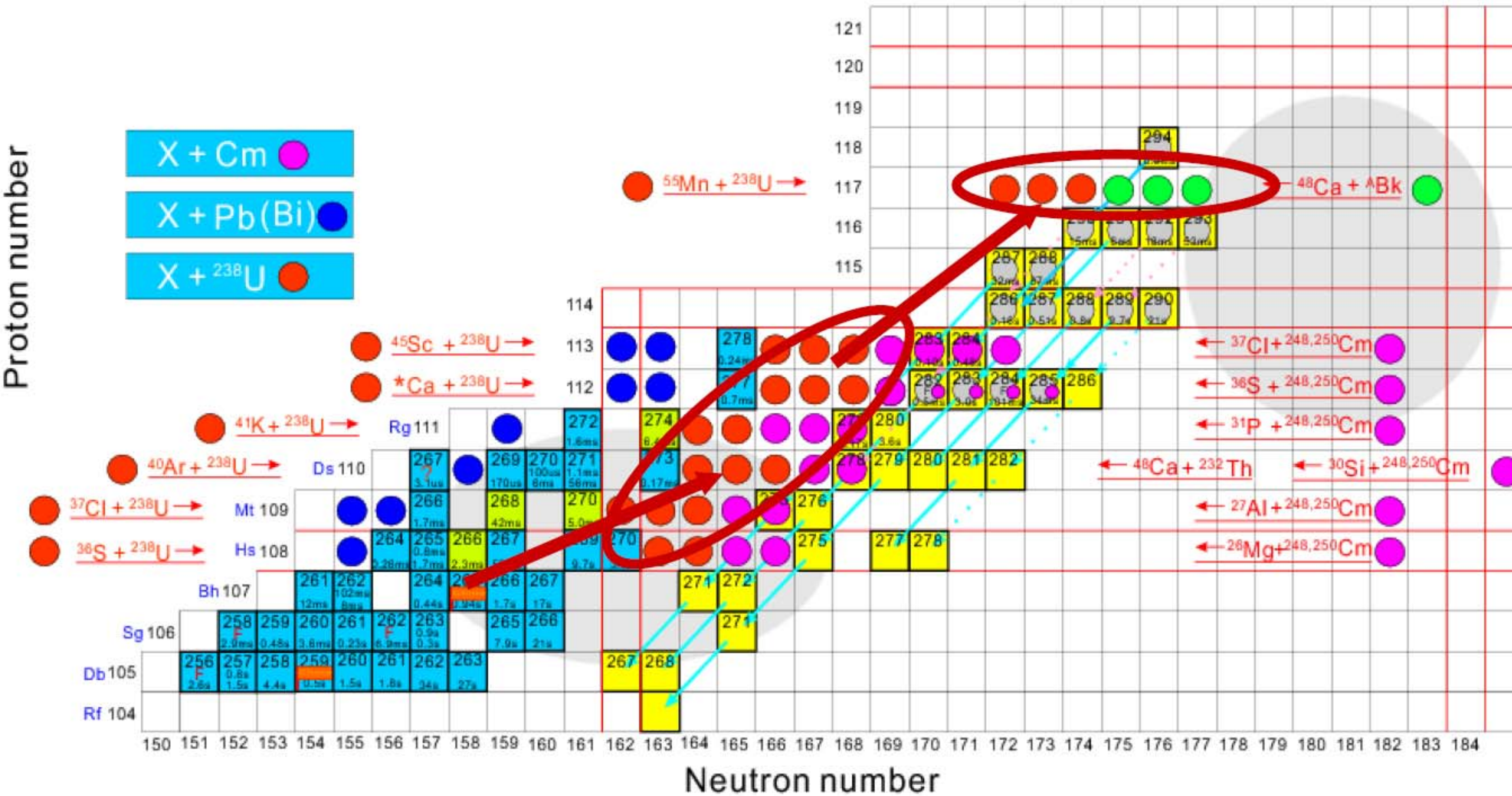
- **SHANS:** ***Spectrometer for Heavy Atom and Nuclear Structure***
- **CSRe:** ***Experimental Ring of CSR***
- **ETF:** ***External Target Facility at CSRm***

SHANS

Spectrometer for Heavy Atom and Nuclear Structure

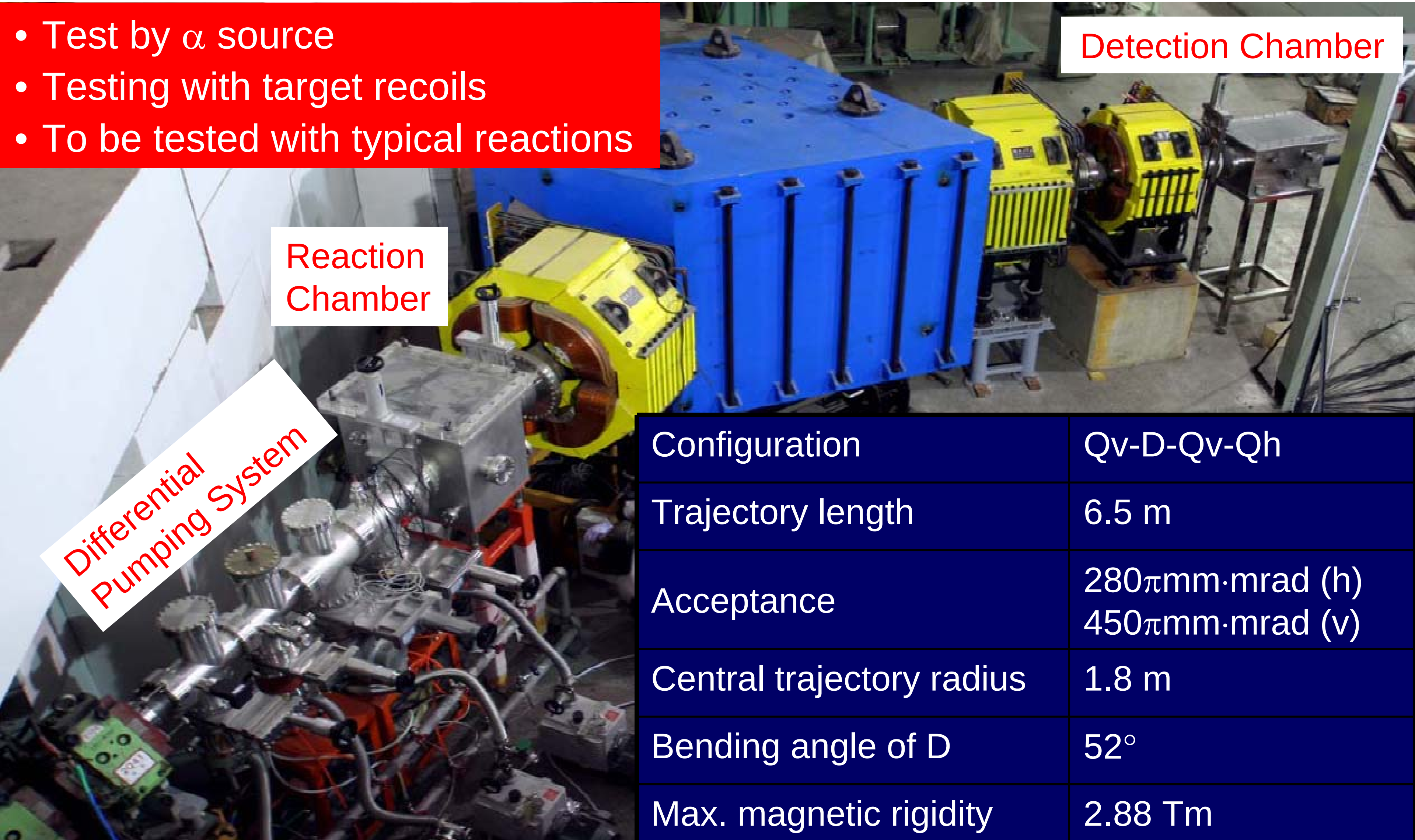


Future Plan for SHN at HIRFL



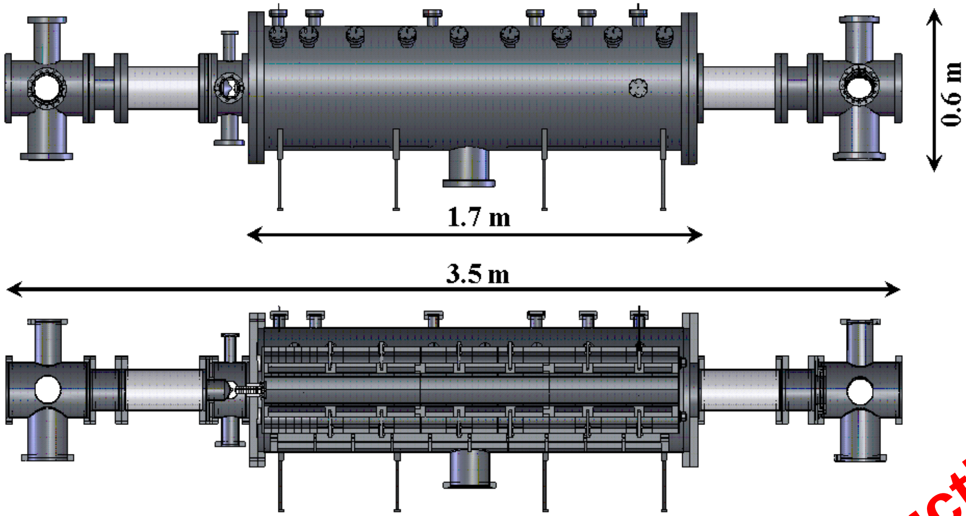
Gas-Filled Recoil Separator - GFRS

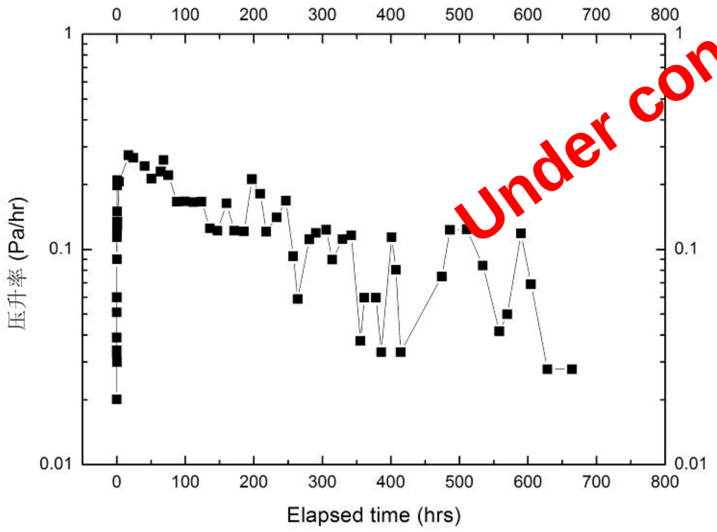
- Test by α source
- Testing with target recoils
- To be tested with typical reactions



Configuration	Qv-D-Qv-Qh
Trajectory length	6.5 m
Acceptance	280πmm·mrad (h) 450πmm·mrad (v)
Central trajectory radius	1.8 m
Bending angle of D	52°
Max. magnetic rigidity	2.88 Tm

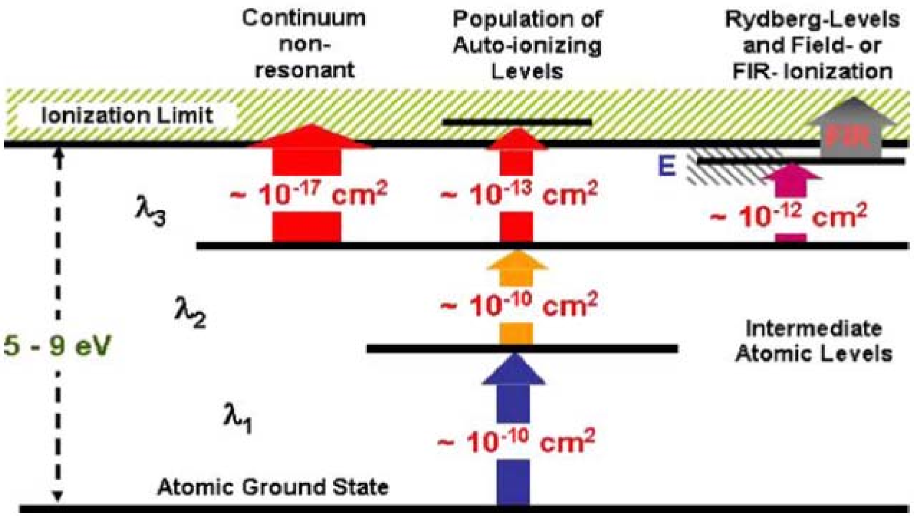
RFQ Cooler and Buncher

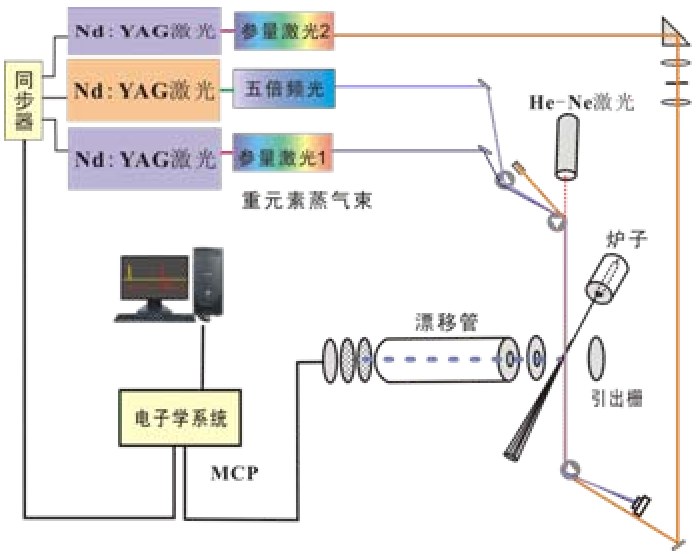




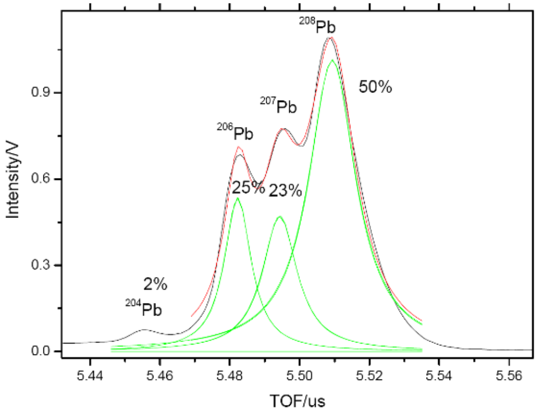
Under construction

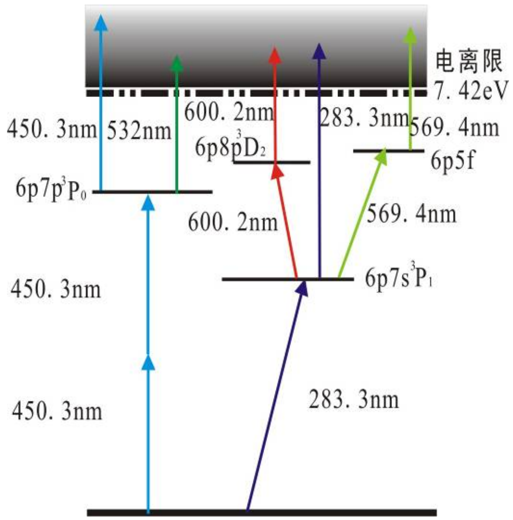
Laser Multi-step Resonant Ionization





No wave length scanning needed





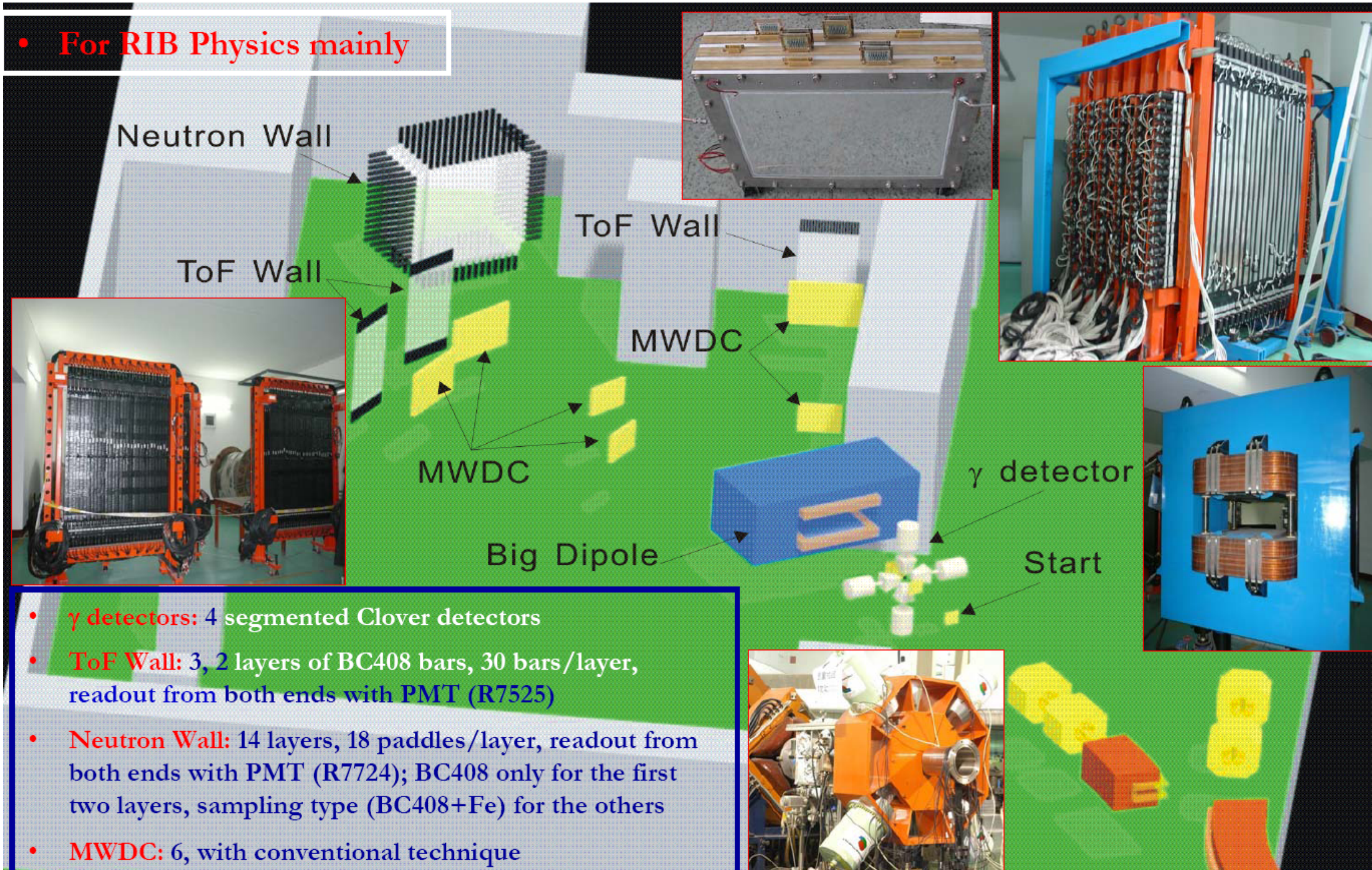
- Goal: SHE region

CSRe

- **Status of CSRe**
  - **ToF detector for mass measurement** **(running)**
  - **Schottky detectors for mass & decay measurement** **(under testing)**
  - **Electron cooler** **(running)**
  - **Cluster-jet target** **(testing)**

- **Recent nuclear physics exps. at CSRe**
  - **Mass measurement: IMS, SMS, ToF**
  - **Decay measurement: SMS**

ETF I: *External Target Facility, Phase I*

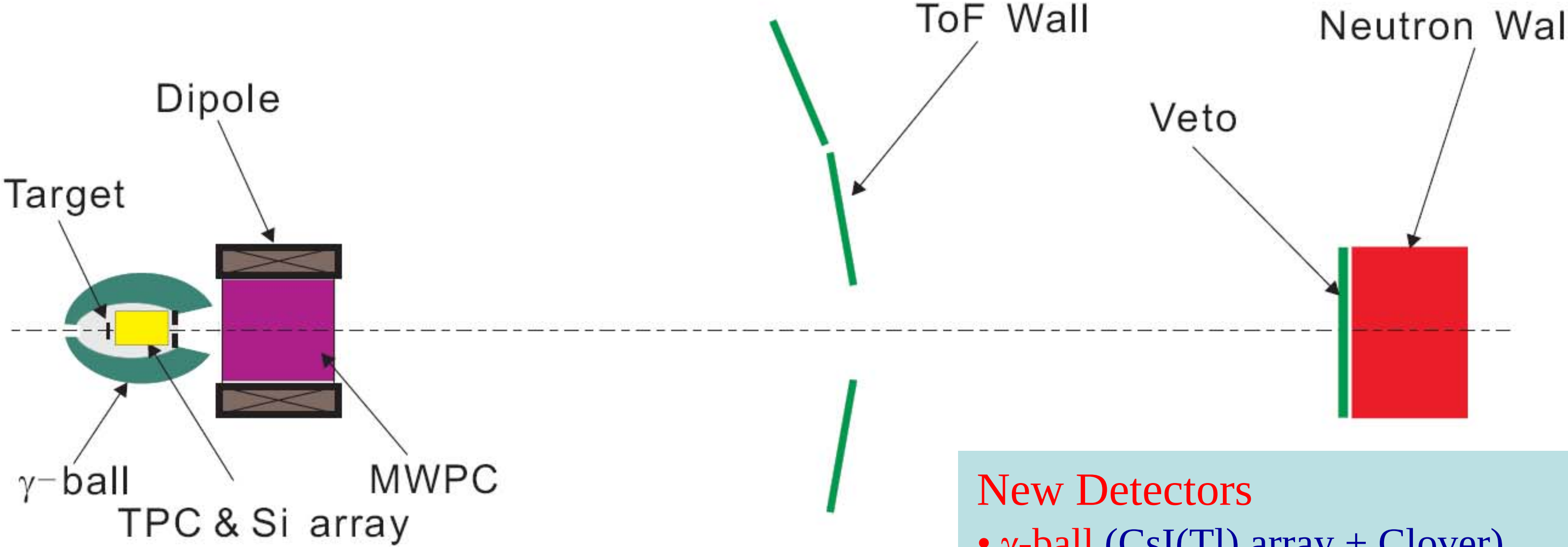


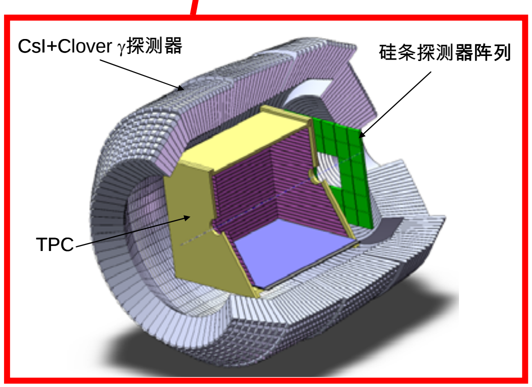
- For RIB Physics mainly

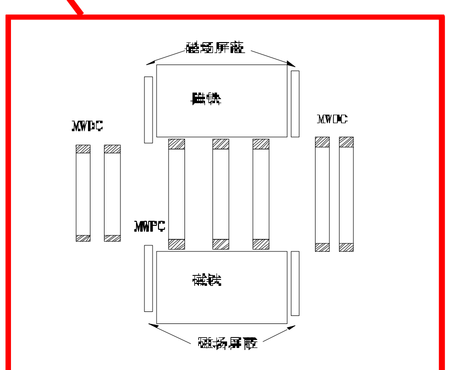
- γ detectors: 4 segmented Clover detectors
- ToF Wall: 3, 2 layers of BC408 bars, 30 bars/layer, readout from both ends with PMT (R7525)
- Neutron Wall: 14 layers, 18 paddles/layer, readout from both ends with PMT (R7724); BC408 only for the first two layers, sampling type (BC408+Fe) for the others
- MWDC: 6, with conventional technique

ETF II: External Target Facility, Phase II

To be constructed within 3 years







New Detectors

- γ-ball (CsI(Tl) array + Clover)
- TPC (at target region)
- Si-strip array (behind TPC)
- MWPC (inside dipole)

Possible Physics

- For RIB Physics
- For EoS of asymmetry nuclear matter
- For high baryon density matter

Research Topics Planned at CSR

- *Mass measurement of the short-lived nuclei at CSRe with ToF*
- *β-decay lifetime measurement at CSRe with Schottky spectrometry*
- *Halo nuclei, cluster structure of the weakly bound nuclei & neutron-cluster at ETF*
- *Deformed nuclei, γ-spectroscopy & new magic number at ETF*
- *Astrophysics related issues*
- *…*

Other topics

- **Atomic Physics with HCI —** **started**
- **Cancer therapy —** **started**
- **Plasma physics and HED physics —** **planned**
- **Proton/H.I. radiography —** **planned**
- **…**

Near-future Development of HIRFL

What is the most important for HIRFL near future:

- Increase beam intensity from SSC
- Increase injected beam intensity for CSR.

Three steps depending on financial support

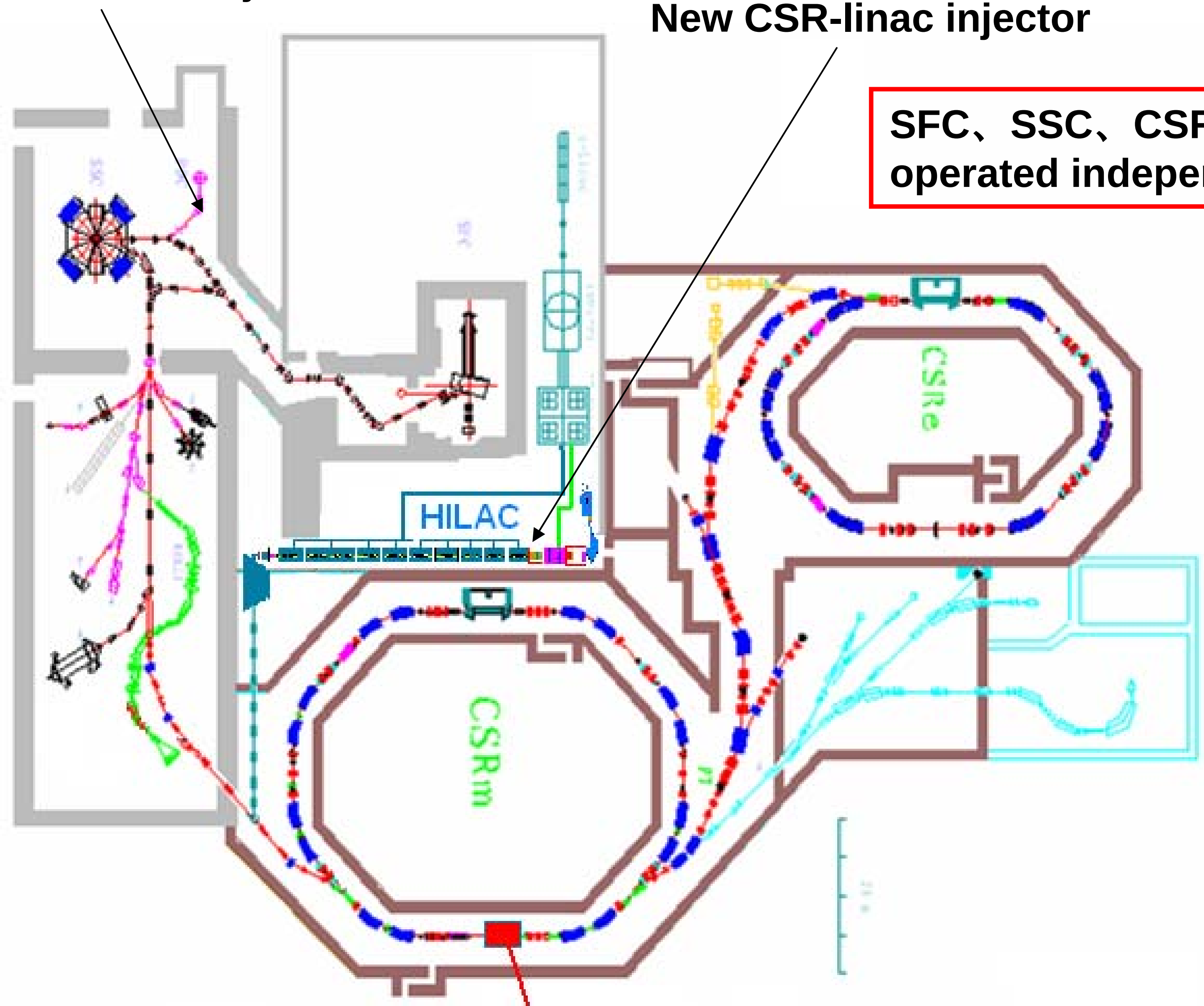
- Upgrade existing cyclotron system;
- Build a low energy fixed frequency linac as a new SSC injector instead of SFC;
- Build an intense heavy ion linac as a new injector for CSR

Build intense heavy ion linac injectors

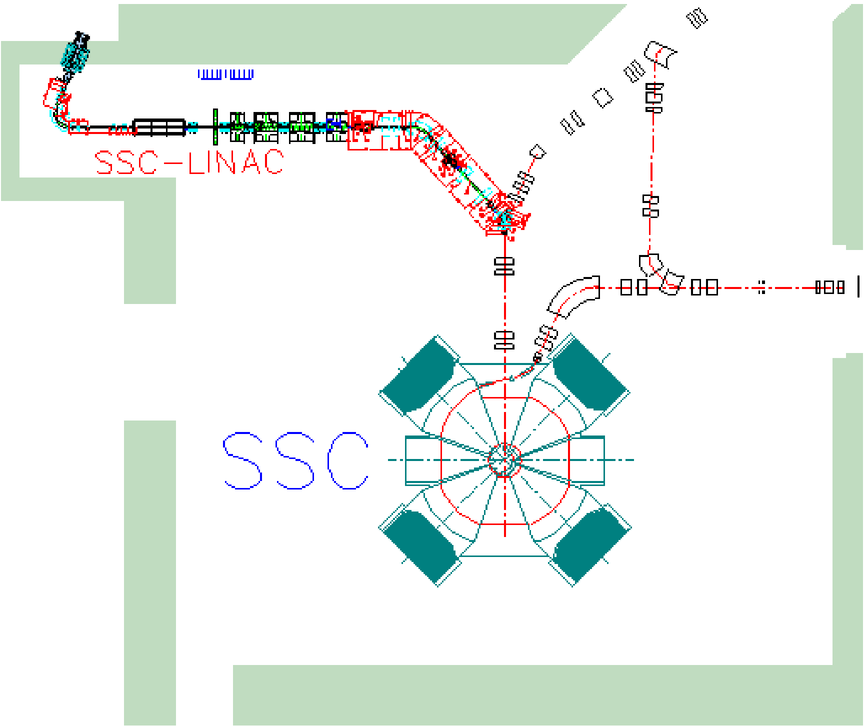
New SSC-linac injector

New CSR-linac injector

SFC、SSC、CSR can be operated independently.



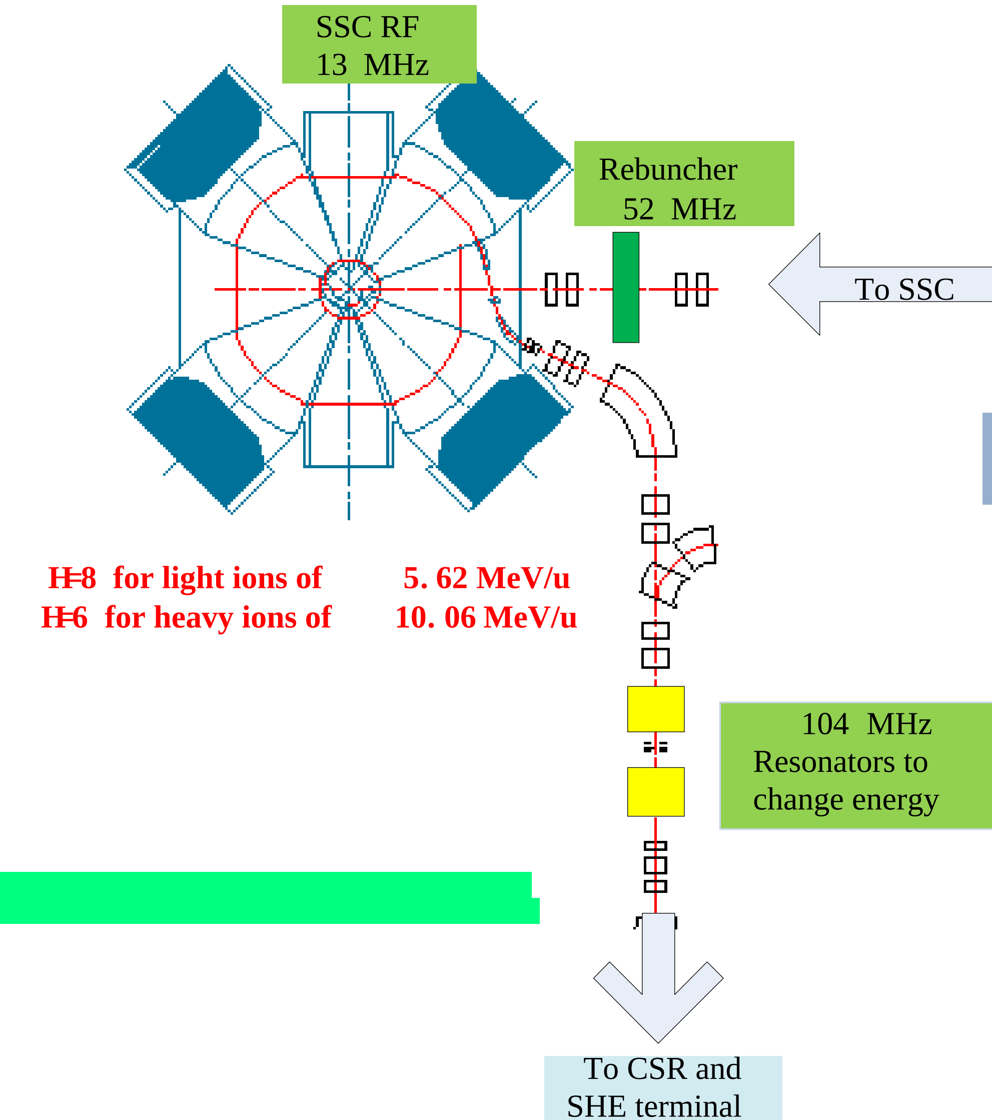
Build a low energy fixed frequency linac as a new SSC injector

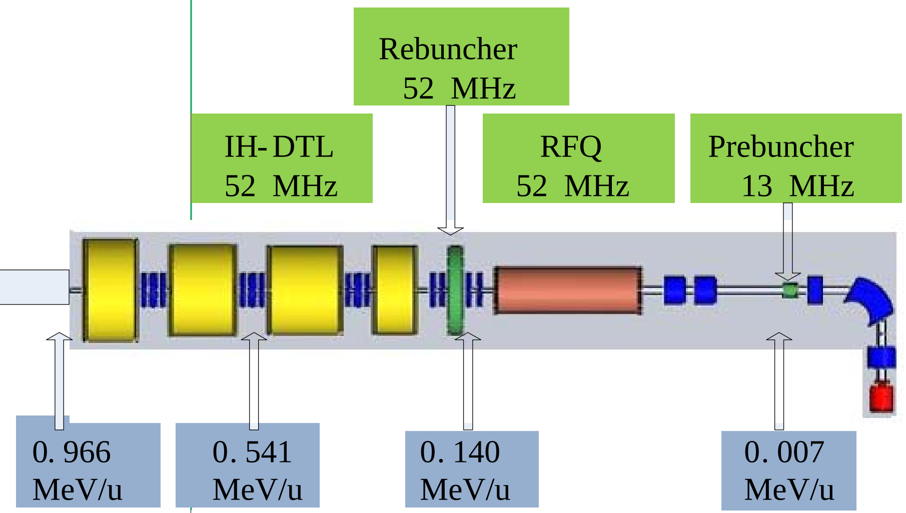


Items	value
Frequency	51.2 MHz
Mass to charge ratio	≦7
ECRIS extraction voltage	50 kV
ECRIS extraction emittance (normalized)	0.6
RFQ type	4-rod
DTL type	IH
Extraction energy of stage1	0.6 MeV
Extraction energy of stage2	1.0 MeV
Operation mode	cw

Expected Beam Intensity from Linc+SSC:
For Ca,Ni,Zn, 6MeV/u, 1-2 pμA, increased by a factor 2-4 compared to SFC;
For Kr, Xe, Pb, U, 10MeV/u, 0.5-1pμA, increased by a factor 10 compared to SFC+SSC

SSC-LINAC



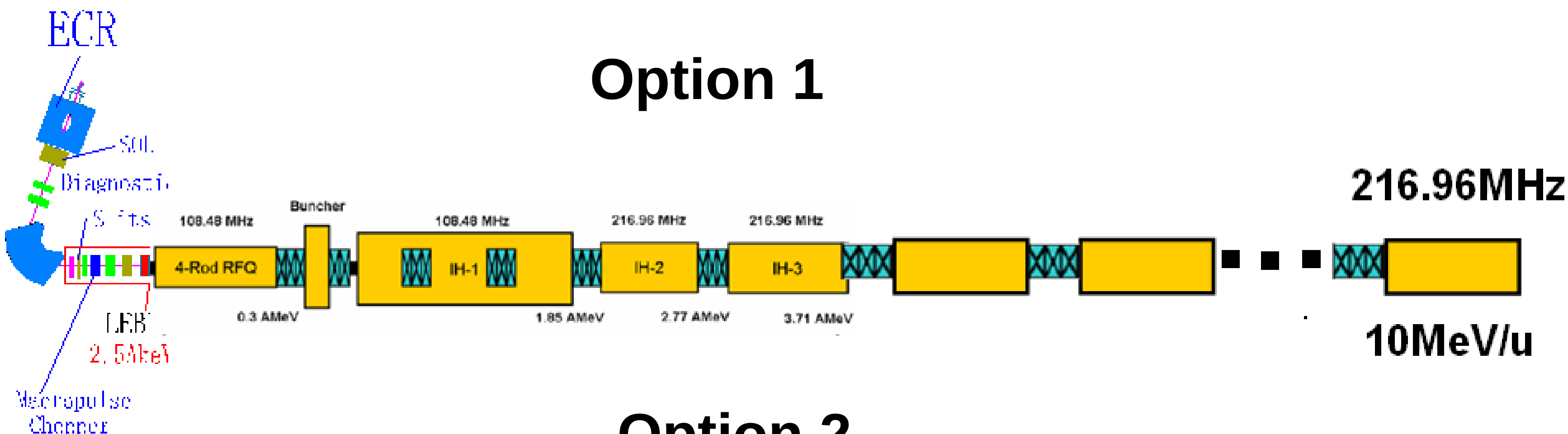


- Supply 5.0~6.2MeV/u ^{48}Ca, ^{56}Fe, ^{59}Ni, ^{70}Zn for SHE（Super Heavy Elements），1 - 2 pμA
- Supply 10MeV/u heavy ions for CSR,0.5-1pμA

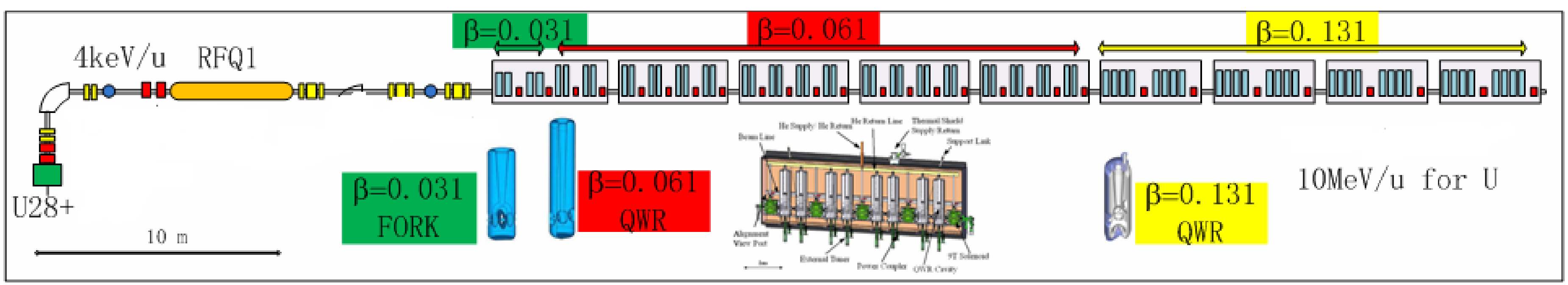
CSR-linac injector

Normal Conductor Linac
10MeV/u, A/Q 3-8.5, pulsed beam, 0.5-2 emA

Option 1



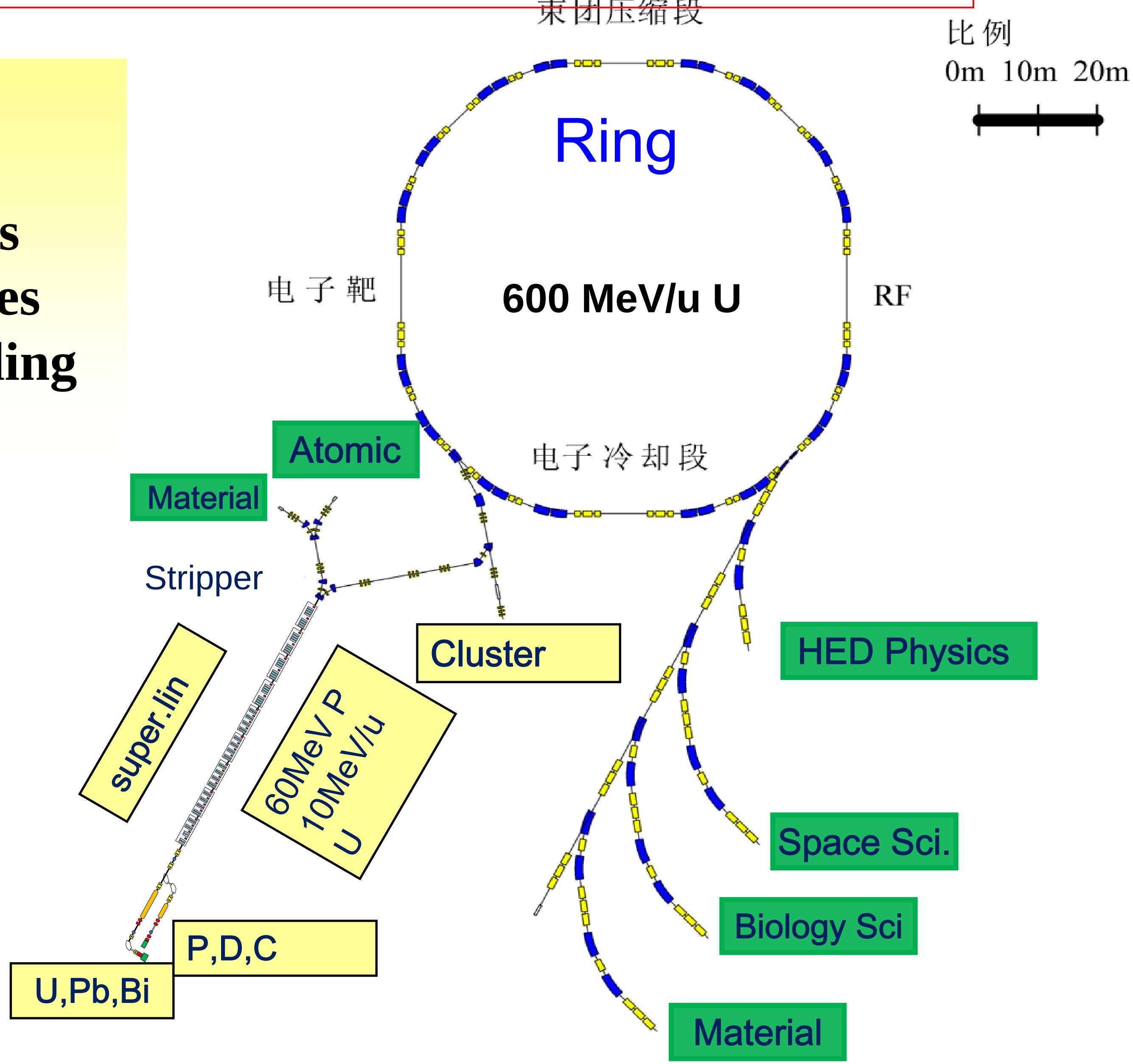
Option 2



Lanzhou Ion Application Facility (LIAF)

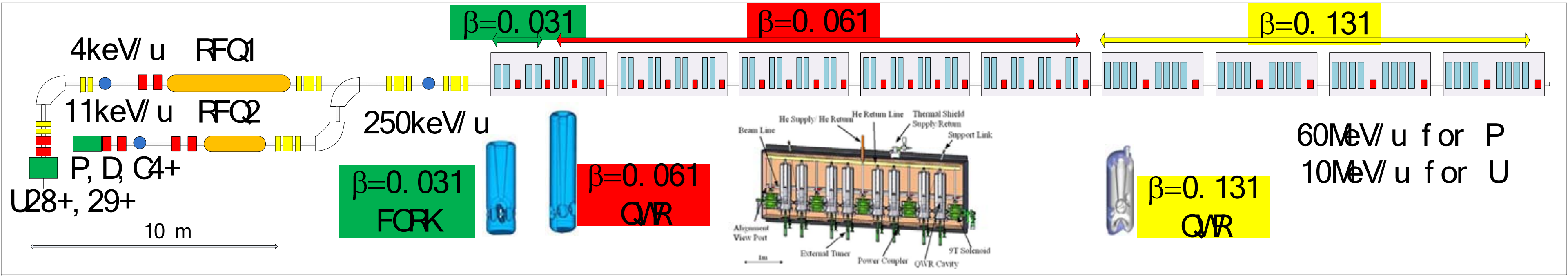
Focus on：

- **Biology effects**
- **Space industries**
- **Material sciences**
- **Mutation breeding**
- **Beam analysis**



Heavy Ion Superconducting LinAC（HI-SLAC）

Preliminary Design



IMP Accelerator Technology needed urgently R&D

- **Heavy ion normal conductor linac**

  (RFQ and IH linac)

- **Heavy ion superconducting linac**

We expect collaborations between IMP and Argonne lab on physics research and accelerator technology development.

Thanks for your attention!