STATUS AND UPGRADES OF HIRFL*

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Abstract

The Heavy Ion Research Facility at Lanzhou (HIRFL) is the only one large scale heavy ion accelerator complex that uses cyclotron (SFC and SSC) as injector, synchrotron (CSRm) for accumulation and post acceleration, storage ring (CSRe) for in-ring experiments in Asia. To reach the increasing requirements from nuclear physics, atomic physics, interdisciplinary science and their applications, many upgrading plans were launched or scheduled. The present status and recent upgrading plans of HIRFL will be introduced in this paper. For the upgrading plans, the development of new linac injector for HIRFL and the plans to improve the performance of experiments will be discussed in detail.

INTRODUCTION

HIRFL is the only one large scale heavy ion accelerator complex that uses cyclotron (SFC and SSC) as injector, synchrotron (CSRm) for accumulation and post acceleration, storage ring (CSRe) for in-ring experiments in Asia[1-5]. The layout of HIRFL is shown in Fig.1. For CSRm, both multi-turn injection and charge exchange injection methods are used with strong support from cross-section-variable electron cooling during beam accumulation; and both fast and slow extracted[6] beams are available for experiments and transmission to CSRe.

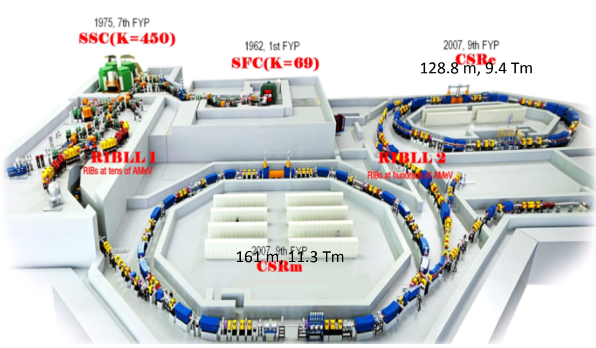

Figure 1: Layout of HIRFL

The operation time is 7,272 h in 2014, while beam time for experiments counts 5,199.5 h. The distribution of operation time is shown in Fig.2. The distribution of experiment time among researches is shown in Fig.3.

In 2014, about 25 kinds of ions, with different charge states and energies, were provided by HIRFL accelerator complex (See Table 1). Among them about 10 beams were provided for the 1st time (green background), 6 beams (marked by *) were supplies for ring experiments.

Table 1: Typical Beams Supplied in 2014

No.	SFC			SSC	
	Ion	Energy MeV/u	Current eμA	Energy MeV/u	Current eμA
1*	$^{78}Kr^{19+/28+}$	4	4.2		
2	H_2^+	10	4		
3	$^{40}Ar^{11+}$	4.8	3.2		
4*	$^{16}O^{6+}$	7	8.5		
5	$^{12}C^{4+/6+}$	7	2.3	80.55	0.17
6	$^{40}Ar^{12+/17+}$	6.17	5	70	0.45
7	$^{16}O^{6+/8+}$	6.17	5.9	70	0.45
8	$^{12}C^{4+/6+}$	5.361	2.8	60	0.24
9	$^{209}Bi^{31+}$	0.911	0.6	9.5	0.04
10	$^{58}Ni^{19+/25+}$	6.17	1.2	70	0.07
11	$^{32}S^{9+}$	3.9	1.7		
12	$^{40}Ar^{9+/15+}$	2.794	3	30	0.05
13	$^{20}Ne^{7+}$	6.17	3.8		
14	$^{16}O^{6+}$	7.5	2		
15	$^{22}Ne^{8+}$	7.5	2.2		
16	$^{86}Kr^{17+/26+}$	2.345	4.5	25	0.13
17	$^{12}C^{4+/6+}$	4.906	5	54.5	0.35
18*	$^{36}Ar^{15+}$	8.5	1.9		
19	$^{14}N^{4+}$	4.5	2.8		
20	$^{40}Ca^{12+}$	5	2		
21*	$^{12}C^{3+}$	4.2	5		
22*	$^{12}C^{4+}$	7	10		
23	$^{40}Ca^{12+}$	4.825	2		
24	$^{209}Bi^{31+}$	0.911	0.3	9.5	0.01
25*	$^{58}Ni^{19+}$	6.3	1.2		

*For ring experiments

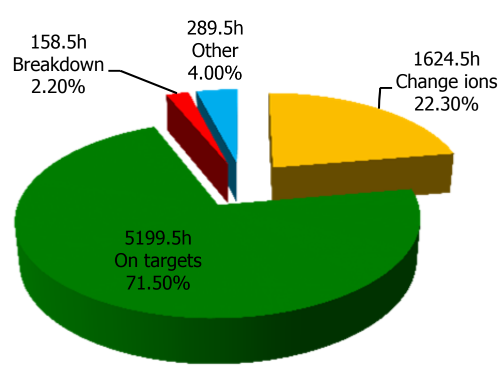

Figure 2: Distribution of operation time

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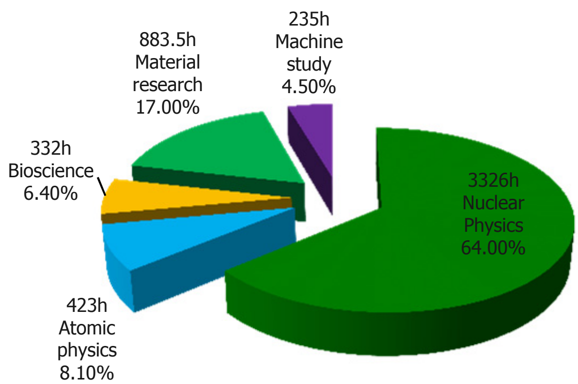

Figure 3: Distribution of experiment time

ACTIVITIES OF UPGRADING

To keep the high level performance of HIRFL, continuous upgrading is necessary. The upgrading of HIRFL includes following aspects: New high intensity heavy ion injectors, various heavy ion cooling methods, new setups for experiments and improvement of the dynamic vacuum condition of rings.

New Injectors for CSRm

The cyclotron injectors were not built on the requirements of HIRFL-CSR project, especially for heavier ions, beam energy and intensity is rather lower for sufficient lifetime in the ring for accumulation. New high intensity heavy ion linac's are planned to be constructed instead of cyclotrons to provide better injection beam and increase the beam time by a large scale. Figure 4 shows the new layout of HIRFL with new injectors.

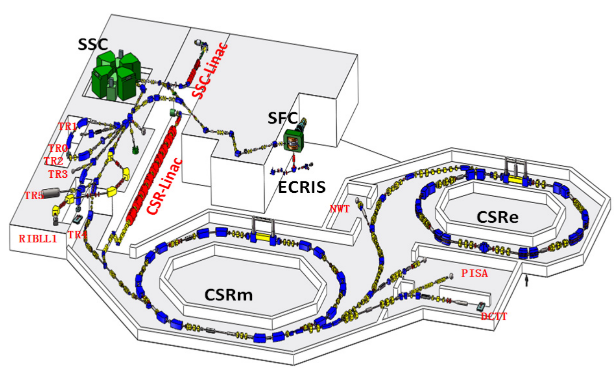

Figure 4: Layout of HRFL with new injectors.

The low energy linac injector for SSC, SSC-Linac, is designed and being constructed (Fig.5) [7-12]. The frequency of RFQ cavity is designed to 53.667 MHz. Due to the matching condition of SSC, the designed energy is fixed to 0.58 and 1.025 MeV/u (6.0 and 10.7 MeV/u after SSC, respectively). The ECR to RFQ section is commissioned in 2014 with good performance (Fig.6)[13]. A new evaporation cooling non-superconducting high magnetic field ECR source has been developed for beam testing. During beam testing transverse coupling due to solenoid field and hollow beam formation (right-down of Fig.6) due to space charge effects are investigated [14], the LEBT is redesigned and rebuilt.

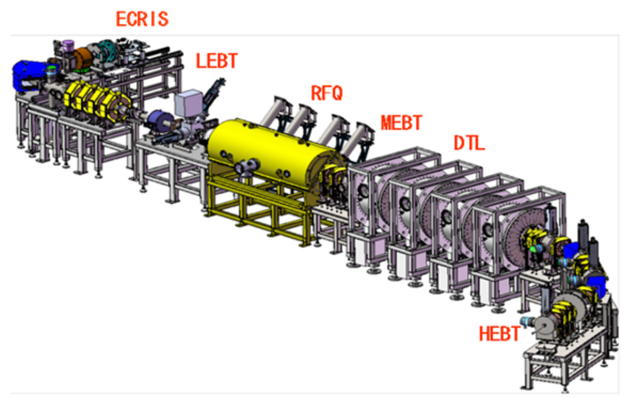

Figure 5: Layout of SSC-Linac.

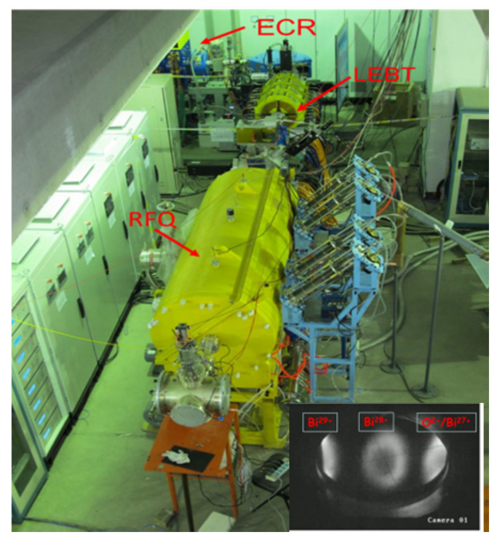

Figure 6: SSC-Linac testing platform.

The heavy ion linac injector for CSRm[15], CSR-Linac is being designed, which will provide >3.5 MeV/u pulsed high intensity heavy ion beams directly.

Heavy Ion Beam Cooling Technology

Electron cooling is used in HIRFL[16-19] for both CSRm and CSRe. The cross-sections of electron beams are variable for optimization the cooling efficiency. In addition to routine operation for beam accumulation and preparation for experiments, the electron cooler of CSRm is also used as internal target for atomic physics research. Recently, according to the requirement of nuclear physics research of short lived isotopes, new local injection orbit of CSRe is investigated to enable electron cooling on right after single turn injection.

For the purpose of cooling of large momentum spread secondary beam in CSRe, stochastic cooling is being developed at HIRFL [20-21]. The setup of stochastic cooling at CSRe and some of the hardware is shown in Fig.7. Most of the hardware will be ready by the end of 2015. It's expected to reduce cooling time of high energy

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secondary beam in SMS (Schottky Mass Spectrometry) experiments.

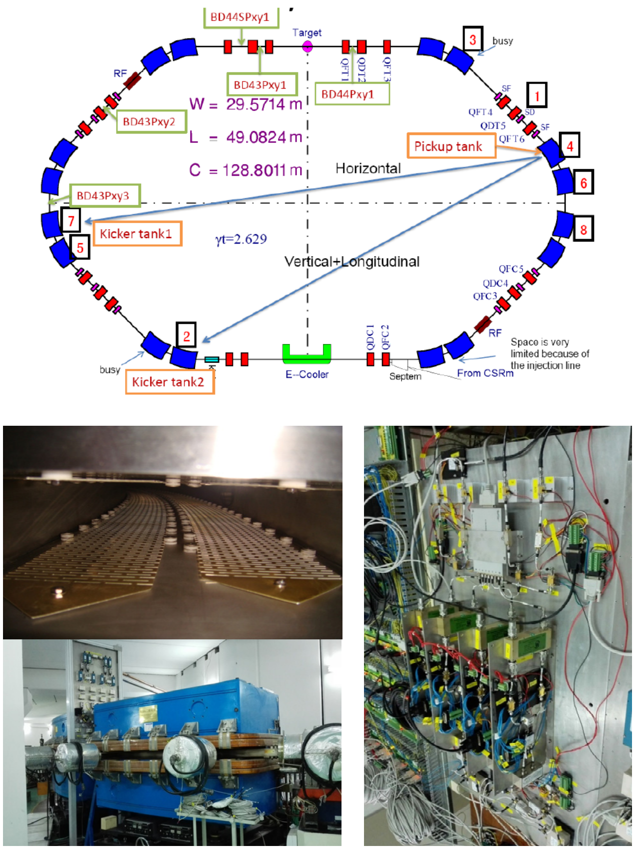

Figure 7: Layout of stochastic cooling at CSRe and some components.

Another cooling method – the laser cooling is being investigated at CSRe (Fig.8). Cooling of 122 MeV/u $^{12}C^{3+}$ beam is focused on at present. Some preparation experiments were committed [22-24], the multi-harmonic RF buncher, UV-sensitive Channeltron and Resonant Schottky were tested. The investigation of laser cooling at CSRe will be helpful for future ring projects at cooling of relativistic ion beam.

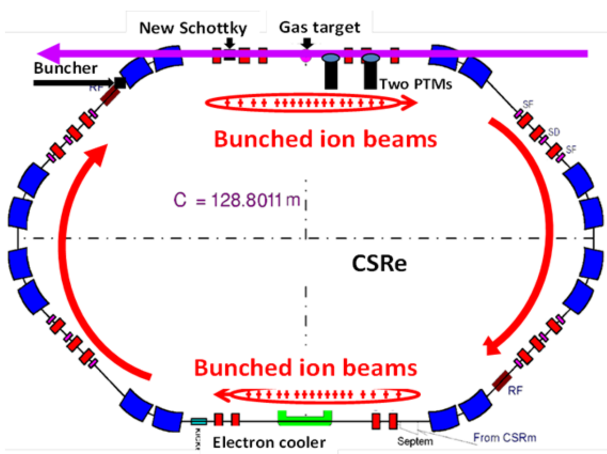

Figure 8: Layout of laser cooling at CSRe.

Mass Spectrometry at CSRe

At CSRe, in addition to normal storage ring mode and internal target mode, isochronous mode mass spectrometry (IMS) is designed and operated for precise atomic mass measurement successfully [25-31]. With relative high momentum acceptance (0.6%) of CSRe-ISO mode, the overall mass resolution power can reach about 300,000 based on the high intrinsic resolution (30 ps) of TOF detector and new charge resolution method. The online data processing software is very important for optimization of ISO mode of CSRe and experiment setup. It will be improved by high performance GPU computing technology to realize online pulse by pulse data analyses. Recently, new velocity resolved double-TOF IMS is installed and tested. The layout of TOFs at CSRe is shown in Fig.9. New isochronous mode is designed to reduce the dispersion at locations of TOFs. The SMS is expected to be realized at CSRe when the stochastic cooling is ready.

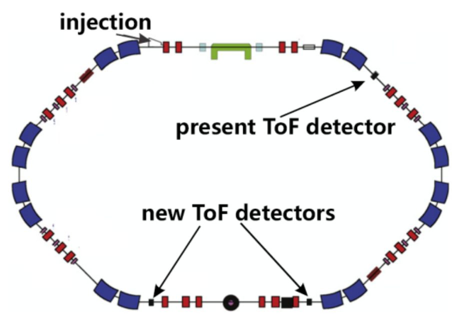

Figure 9: Layout of TOFs at CSRe.

Beam Collimation

To maintain extra-low and stable vacuum pressure at heavy ion synchrotrons and storage rings, the vacuum collimation of beam loss is necessary. It's considered in the design of FAIR project at Darmstadt, Germany [32-35]. For the research and application at HIRFL and newly approved HIAF project, a new simulation program is developed independently at IMP[36]. Test experiments will be committed at CSRm. One of the simulation results of beam loss distribution and collimation efficiency study at CSRm is shown in Fig. 10. The collimation efficiency at present layout and design of CSRm can only reach 60%. Higher efficiency is expected for HIAF project, if it's considered during lattice design.

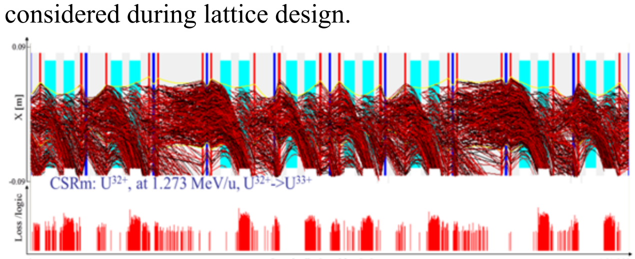

Figure 10: One of the simulation results of dynamic vacuum collimation.

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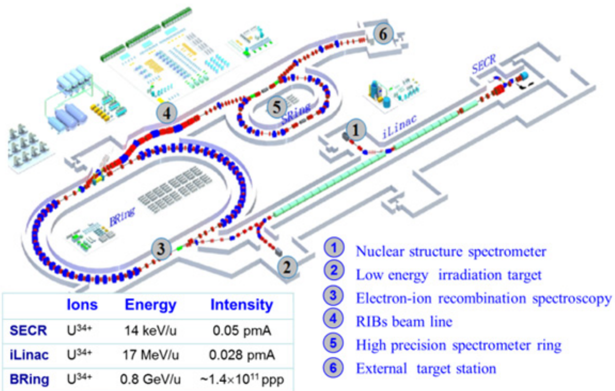
NEW PROJECT – HIAF

To further enhance the basic research ability in heavy ion science of China, one of the national critical infrastructure facilities - High Intensity Heavy Ion Accelerator (HIAF) is planned [37-39]. Layout and some parameters of HIAF are shown in Figure 11. Based on present HIRFL facility, HIAF will significantly improve the intensity and energy of heavy ion beams for front edge nuclear physics and interdisciplinary science researches. A post phase project is also planned.



	Ions	Energy	Intensity
SECR	U^{34+}	14 keV/u	0.05 pmA
iLinac	U^{34+}	17 MeV/u	0.028 pmA
BRing	U^{34+}	0.8 GeV/u	~1.4×10^{11} ppp

Figure 11: Layout and major parameters of HIAF project.

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