# HIRFL–CSR PROPOSAL

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**CSR, a new accelerator complex planed at the Heavy Ion Research Facility in Lanzhou(HIRFL), is a multipurpose Cooling Storage Ring system, and consists of a main ring(CSRm) and a experimental ring(CSRe). The existing two cyclotrons SFC(K=69) and SSC(K=450) of HIRFL will be used as its injectors. The heavy ion beams from the two injectors will be accumulated, cooled and accelerated in the main ring, and then extracted fast to produce radioactive ion beams(RIBs) or highly charged state heavy ions. After that, the secondary beams (RIBs or highly charged state ions) can be accepted by the experimental ring for internal target experiments. The details on HIRFL–CSR proposal will be reported in this paper.**

## 1 Introduction

Since its inception, Heavy Ion Research Facility of Lanzhou (HIRFL) has opened a new field of heavy ion physics and its applications at intermediate energy domain in China. Recently, it is proposed to upgrade the HIRFL with a multifunctional Cooling Storage Ring (CSR) forming a HIRFL–CSR accelerator system. This will greatly enhance the performances of HIRFL for the first decade of next century, particularly for studies by using Radioactive Ion Beams (RIBs), and to meet the emerging nuclear physics needs. The details on HIRFL–CSR proposal will be reported in this paper.

## 2 General Descriptions

### *2.1 Outline*

CSR is a multipurpose Cooling Storage Ring system shown in Figure 1, and consists of a main ring(CSRm) and a experimental ring(CSRe). The existing two cyclotrons SFC(K=69) and SSC(K=450) of HIRFL will be used as its injectors. The heavy ion beams from the two injectors will be accumulated, cooled and accelerated in the main ring, and then extracted fast to produce radioactive ion beams(RIBs) or highly charged state heavy ions. After that, the secondary beams (RIBs or highly charged state ions) can be accepted by the experimental ring for internal target experiments.

Two electron coolers located in the long straight sections of CSRm and CSRe respectively, will be used for beam accumulation and providing high quality beams for internal target experiments.

CSR intends to provide internal and external target beams for many physical experiments. Two internal targets in the long straight sections of CSRm and CSRe will be used for RIBs physics and highly charged state atomic physics. Two external targets of CSRm will be used for cancer therapy study and the researches on the properties of nuclear matter under extreme conditions.

The whole complex of CSR will be arranged under the ground (from point A).

### *2.1 Production of Secondary Beams*

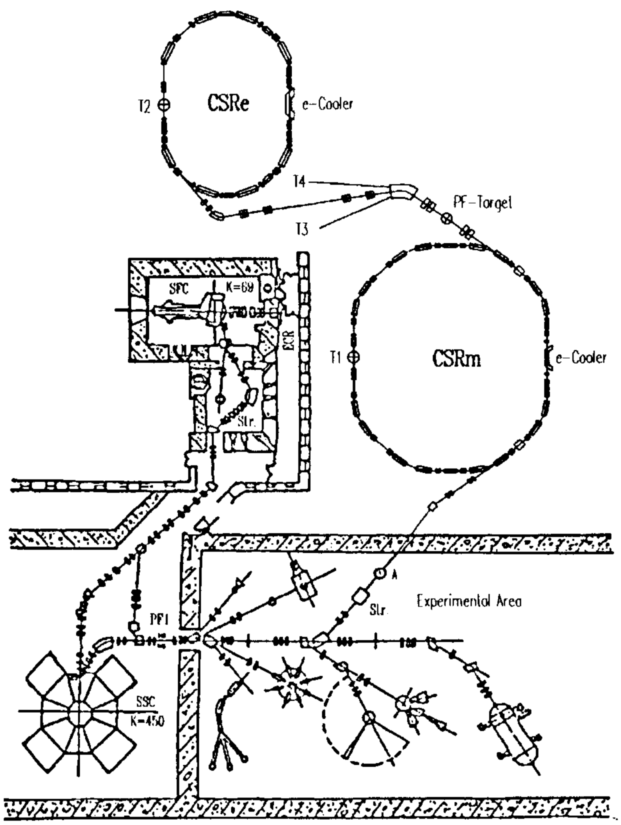
RIBs (Radioactive Ion Beams) will be produced by heavy ion projectile fragmentation(PF) method[1]. The heavy ions from present HIRFL system will be injected into the main ring for accumulating, cooling and accelerating to higher energies(200—400MeV/u), and then extracted fast to bombard a primary target to produce radioactive beams. Finally, the produced RIBs will be fed into the experimental ring for physical experiments.

Highly charged state ions (fully stripped heavy ions, or those ions with one or two electrons) are demanded for atomic physical researches. HIRFL–CSR will provide those heavy ion beams by multiple stripping shown in below figure.

| SFC(k=69) —\|-→ (str.) | SSC(k=450) —\|—-→ (str.) | CSRm ——\|—-→ (str.) | CSRe |
|---|---|---|---|
| $^{238}U^{30+}$ | $^{238}U^{37+}$ | $^{238}U^{72+}$ | $^{238}U^{90+}$ |
| 0.96MeV/u | 10MeV/u | 250MeV/u | 250MeV/u |

### *2.2 Injectors*

HIRFL consists of two cyclotrons, the main accelerator SSC(Separated Sector Cyclotron, K=450)with the mean extraction radius of 3.207m, and the SSC's injector SFC(Sector-Focusing Cyclotron, K=69) with the mean extraction radius of 0.75m. Light heavy ions($Z \leq 10$) from SFC have enough energy to be fully stripped through a stripper, then those beams with intensity of $10^{12\sim13}$pps can be injected into CSR directly and accelerated to the maximum energies. As for the heavy ions($Z > 10$), they must be accelerated by SSC and then pass through a stripper for fully or highly charged state




$T_1$, $T_2$ : internal target; $T_3$, $T_4$ : external target.

Figure 1: The overall layout of HIRFL–CSR.

stripping before injected into CSRm. The intensity of heavy ion beam from SSC is about of $10^{9\sim12}$pps. The beam parameters of SFC and SSC as the two injectors of CSR are shown in table 1.

Table 1: Beam parameters of the injectors of CSRm.

| | | |
|---|---|---|
| SFC: | | |
| | Ion species | C—Ne |
| | Energy | 5.0~8.0 MeV/u |
| | Intensity | $10^{12\sim13}$ pps |
| | Instant Intensity(1us) | $10^{7\sim8}$ |
| | Momentum spread | $\sim \pm 0.1\%$ |
| | Emittance | $\sim 25\ \pi$ mm.mrad |
| SSC: | | |
| | Ion species | C—U |
| | Energy | 5 ~100 MeV/u |
| | Intensity | $10^{9\sim11}$ pps |
| | Instant Intensity(1us) | $10^{4\sim6}$ |
| | Momentum spread | $\sim \pm 0.075\%$ |
| | Emittance | $\sim 8\ \pi$ mm.mrad |

### 2.3 Beam Accumulation

While heavy ion beams from the injectors are injected into CSRm, the beam lifetime should be long enough for the beam accumulation of CSRm. Referring to the actually measured spectra[2,3] of residual gases, the average pressure of CSR is assumed to be $1.0 \times 10^{-10}$ torr, with the residual gas composition of 85% $H_2$ and 15% $(N_2, CO)$. According to the calculation[4], the REC (Radiative electron capture) process in the electron cooler restricts the lifetimes of light heavy ions (C–Kr) injected into CSRm, the electron capture mechanism dominates the lifetimes of heavy ions (Xe–U), and the beam loss caused by Coulomb scattering can be negligible. In conclusion, the beam lifetimes ( 15 s) are longer than the time that CSRm need for beam accumulation ($\sim$ 4 s).

The multiple single-turn injection (cooling accumulation[5]) will be used for CSRm to accumulate the heavy ions up to $10^{6-10}$ in a short duration of ~4 seconds. RF cavities will be used for capturing the injected beam into a stationary RF bucket, and simultaneously, electron cooling will be utilized to reduce the beam emittance in order to open the free space in the bucket for successive events of the beam injection. This method is more simple and could avoid any increase of the transverse and longitudinal beam emittance, compared with the multi-turn injection[5] and RF stacking method[5]. Table 2 is the accumulation parameters of three typical ions.

Table 2: Parameters of accumulation in CSRm.

| Ions | O | Ar | U |
|---|---|---|---|
| Injection energy(Mev/u) | 8.5 | 25 | 10 |
| Lifetime (s) | 2796 | 759 | 16 |
| Injection current(pps) | $8 \times 10^{13}$ | $2.0 \times 10^{12}$ | $5.0 \times 10^{9}$ |
| Circulation frequency(MHz) | 0.285 | 0.483 | 0.309 |
| Particles/turn | $2.8\times10^{8}$ | $4.1\times10^{6}$ | $1.6\times10^{4}$ |
| Repetition cycle(ms) | 20 | 40 | 20 |
| Injection period(s) | 4 | 4 | 4 |
| Particles accumulated | $2.8\times10^{10}$ | $2.1\times10^{8}$ | $1.6\times10^{6}$ |

### 2.4 Basic Parameters

The main parameters of CSR are listed in table 3, and Figure 2 shows the energy range of HIRFL–CSR.

In the energy range of CSRe, fully stripped ion as heavy as Tantalum could be obtained in HIRFL–CSR system, and the highest charged state for Uranium is about 90+.

Table 3: Main parameters of CSR.

| Ring | CSRm | CSRe |
|---|---|---|
| Circumference (m) | 141.051 | 94.034 |
| Average radius (m) | 22.449 | 14.9674 |
| $B\rho_{max}/B\rho_{min}$ (T.m) | 10.584/0.64 | 6.4/0.91 |
| $B_{max}$ (T) | 1.4 | 1.4 |
| Ramping rate (T/s) | 1.5 | 1.5 |
| Acceptance | | |
| $\varepsilon_{\perp}$ ($\pi$mm.mrad) | 25 | 40 |
| $\Delta p/p$ (%) | 1.5 | 1.0 |
| E-cooler section | | |
| $E_{emax}$ (KeV) | 165 | 165 |
| length (m) | 2.7 | 2.7 |
| RF–system | | |
| harmonic number | 1 | 1 |
| $f_{max}/f_{min}$ (MHz) | 2.0/0.2 | 2.3/0.45 |
| voltages(n×KeV) | 2×7 | 4×7 |
| Vacuum (Torr) | $1 \times 10^{-10}$ | $1 \times 10^{-10}$ |

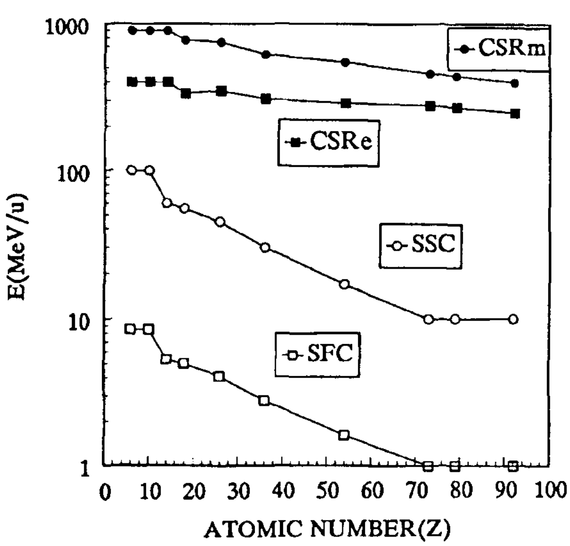



Figure 2: The energy range of HIRFL–CSR.

### 2.5 Continuous Beam Operation Mode

CSR is a double ring system. In every operation cycle, the stable nuclei beams from the injectors are accumulated, cooled and accelerated in the main ring(CSRm), then extracted fast to produce RIBs or highly charged state ions. The experimental ring(CSRe) can obtain the secondary beams once of every operation cycle. The accumulation duration of multiple single-turn injection is about 4 seconds. Considering the ramping rate of magnetic field in the dipole magnets to be 1.5 T/s, the acceleration time of CSRm will not be exceeded 1 second. Thus the total time of the cycle is about 5 seconds. Figure 3 shows the magnetic field exciting procedure of the two rings.

In every cycle, the circulating beams in CSRe can be used for bombarding the internal target continuously. Therefore, the continuous beams at the internal target of CSRe could be obtained, and the experimental luminosity, in this case, is higher than that of pulse beam storage ring system. Figure 4 shows the time structure of CSR two rings in such a continuous beam operation mode.

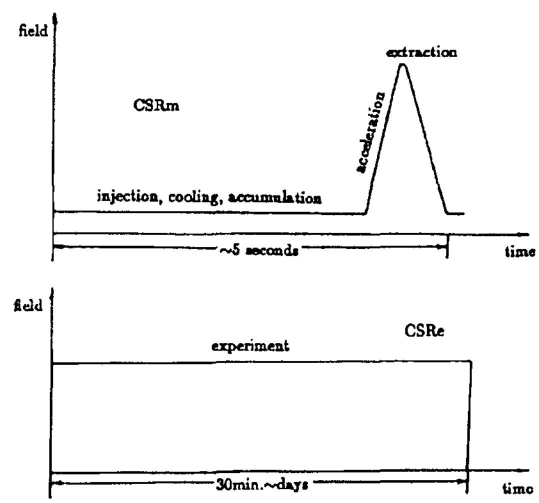



Figure 3: Magnetic field exciting period of CSR.

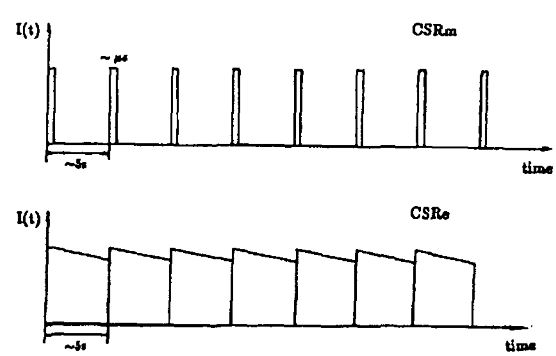



Figure 4: The time structures of CSR beams.

## 3 Lattice

As shown in Figure 1, the circumference of the main ring(CSRm) is 141.051m. Its average radius is 7 times of SSC's mean extraction radius, and 30 times of SFC's. The circumference of the experimental ring(CSRe) is 94.034m.

CSRm is a race-track shape with four similar bending cells (29.552m) and two long straight sections(11.422m). Each bending cell is a dispersion suppressor and consists of 4 dipoles and 8 quadrupoles. An electron-cooler and an internal target are arranged respectively in the two long straight sections.

CSRe consists of two dispersion suppressors (31.537m) and two long straight sections (15.479m). In each suppressor, there are 4 dipoles and 8 quadrupoles. An electron-cooler and an internal target are also arranged in the two long straight sections.

The lattice (magnetic focusing structure) parameters of CSR are shown in table 4. Figure 5, Figure 6 are the distributions of $\beta$-functions and dispersions for CSRm and CSRe.

Table 4: Lattice parameters of CSR.

| | CSRm |
|---|---|
| Betatron tune values ($Q_h/Q_v$) | 3.4516/2.8893 |
| Natural chromaticity ($Q_h'/Q_v'$) | -4.907/-3.988 |
| Transition gamma ($\gamma_{tr}$) | 4.359 |
| Max. $\beta$ amplitude ($\beta_h/\beta_v$) | 19.55 m/14.535 m |
| Max. dispersion ($D_x$) | 5.373 m |
| $\beta_h/\beta_v$ at target point | 1.5 m/1.15 m |
| $\beta_h/\beta_v$ in e-cooler | 7.311 m/8.981 m |
| $\beta_h/\beta_v$ at injection point | 5.486 m/9.216 m |
| $D_x$ at injection point | 0.973 m |
| | **CSRe** |
| Betatron tune values ($Q_h/Q_v$) | 2.4666/2.5659 |
| Natural chromaticity ($Q_h'/Q_v'$) | -2.0223/-4.3069 |
| Transition gamma ($\gamma_{tr}$) | 2.196 |
| Max. $\beta$ amplitude ($\beta_h/\beta_v$) | 14.872m/14.83 m |
| Max. dispersion ($D_x$) | 6.972m |
| $\beta_h/\beta_v$ at target point | 2.3 m/1.1 m |
| $\beta_h/\beta_v$ in e-cooler | 8.1 m/7.1 m |
| $\beta_h/\beta_v$ at injection point | 8.3 m/9.5 m |
| $D_x$ at injection point | 4.8m |

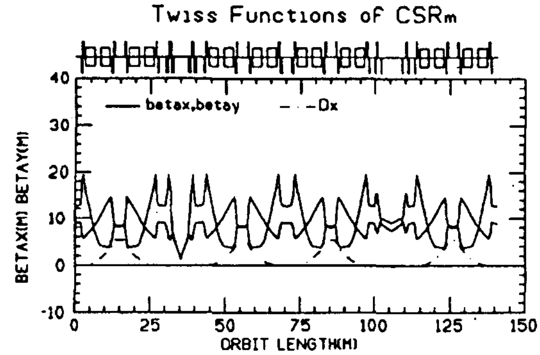



Figure 5: The distributions of $\beta$ and $D_x$ for CSRm.

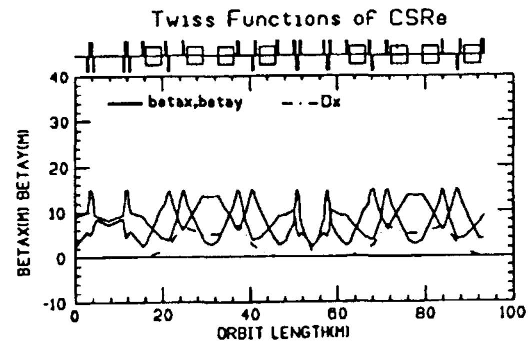



Figure 6: The distributions of $\beta$ and $D_x$ for CSRe.

## 4 Schedule

For this proposal, all optimizing design and study are now under progress.

The total budget of CSR is about 250 million chinese yuan. The whole duration of it is indented to be seven years, two years for design and five years for construction.

### References

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