Lanzhou Cooler Storage Ring Commissioning

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## History of CSR

Heavy-ion **Cooler Storage Ring** & Synchrotron in Lanzhou

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HIRFL-CSR Layout

12 Tm
1 GeV/u—C^{6+}

9.4 Tm
500 MeV/u—U^{92+}

128.8 m

K=450
C: 100 MeV/u

K=69
C: 10 MeV/u
Pre-accelerator system of CSR

- Superconducting ECR
  - 18GHz
  - K=69, R ~0.75 m

- SSC
  - C-100 MeV/u
  - U-10 MeV/u
  - K=450, R ~3.203 m

- SFC
  - C-10 MeV/u
  - U-1 MeV/u
  - K=450, R ~3.203 m

- CSRm
  - A< 40
  - A ≥ 40
Accumulator
Cooler
Synchrotron

Fast extraction
Slow extraction

External target
Internal target

12 Tm
P-2.8GeV, C^6+ 1GeV/u, U^{72+} - 500MeV/u
CSRm Tunnel
CSRe Layout

Storage ring
Internal target
Mass spectroscopy
Deceleration

9.4 Tm
500MeV/u — U^{92+}
Radioactive Ion Beam Line RIBLL2 between CSRm and CSRe

Double Separator

$$\Delta \frac{P}{P} = \pm 1\% , \text{ Emittance} = 25\pi \text{ mm-mrad}$$
RIBLL2 Tunnel

B:40T
HIRFL-CSR
Commissioning
2006---2007
Stripping Injection Scheme

C⁴⁺ - 7 MeV/u

2006.01
First stored beam signal from spectrum analyzer in CSRm

Bumping orbit, RF modulation (1.3Kv), Spe. Ana. in zero-span mode

Stripping injection 23Cy2 =7A  21D4 =0.5A

12C6+

January 23, 2006

5 times of RF in 10s
7MeV/u → 1 GeV/u (C^{6+}) Ramping

H = 2 → 1, \ f_i = 0.45 → 1.63 MHz, G = 11.3 Tm

Oct. 24, 2006
e-cooler
cooling for beam stacking

Hollow e-beam

$B_T/B_L < 5 \times 10^{-5}$
First e-cooling effect in CSRm

$C^6+ - 7\text{MeV/u}$, observed the longitudinal schottky signal from spectrum analyzer.
C$^{6+}$-600MeV/u Ramping in CSRm 07/09/29 06:25

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

10mA

Cooling stacking
Scheme of the MMI for Ar-beam in CSRm

- $^{36}\text{Ar}^{8+}$ - 2 MeV/u
- $^{36}\text{Ar}^{8+}$ - 22 MeV/u
- $\text{Ar}^{8+}$
- $\text{Ar}^{18+}$
- Stripper
- ECR
- CSRm
- MMI-$^{36}\text{Ar}^{18+}$
Bump section for CSRm Multi-turn injection

Orbits of the Multiple Multi-turn Injection

L = 2 m
V_{max} = 160 kV
Gap = 23 mm

Static-electric septum

Septum (Wolfram silk)

Beam

20007.03
MMI for Ar-beam in CSRm with e-cooling

SSC-Ar-22MeV/u, $I_{\text{inj.}} \sim 2\mu A$, DCCT~180uA, Period=2min., Gain ~90

07/04/25 06:00
MMI + Ramping in CSRm

07/12/10 00:08

$^{36}\text{Ar}^{18+} \rightarrow 22 - 368\text{MeV/u}$

1.2mA, $4 \times 10^8$

07/06/25 07:20

$^{129}\text{Xe}^{27+} - \rightarrow 235\text{MeV/u}$

0.5mA, $1 \times 10^8$
Fast extraction section of CSRm

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

$I_{\text{max}} = 2700\text{A}$
$V_{\text{max}} = 60\text{ kV}$
Rising time: 150ns
Fast-extraction from CSRm
Success

07.8.4
Storage-beam for CSRe 1st Commissioning

$^{12}{\text{C}}^+ - 600\text{MeV/u}$

First beam in CSRe
Multi-time Injection for CSRe 1st Commissioning

$^{12}\text{C}^+ - 600\text{MeV/u}$

15mA
HIRFL-CSR Commissioning Scheme for Ar-beam

Mode: SFC + SSC + CSRm + CSRe
Ar-beam in CSRm and CSRe

$^{36}\text{Ar}^{18+}$ - 368 MeV/u, Mode = Isochronous

CSRm $3 \times 10^8$

CSRe $1.2 \times 10^8$
E-cooling in CSRe

$^{6+}C$-400MeV/u, 1000uA, longitudinal schottky signal from spectrum analyzer

April, 2009

$\Delta P/P: \pm 1.5 \times 10^{-5}$

$\Delta P/P: \pm 1.6 \times 10^{-4}$
HIRFL-CSR
Operation & Experiments
2008---2010
HIRFL-CSR Control Room
Experiments-1

Mass Measurements for Radioactive Ion Beams (RIBs)

2008 & 2009

CSRm

78Kr^{28+}

481.88 MeV/u

CSRe

Isochronous mode

Secondary Beam

ToF

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

\[ \gamma = \gamma_t = 1.395 \]
Experiments for RIBs spectroscopy

CSRm, $^{78}$Kr$^{28+}$, 0.35mA, $7\times10^7$

CSRm, $^{78}$Kr$^{28+}$, 0.6mA, $1\times10^8$

Single particle signal at ToF target with isochronous mode in CSRe

RIBs signal spectrum at ToF target

During the experiment
For the 9 drop-line nuclei with the life-time of 100ms

A=2Z-1: \(^{63}\)Ge, \(^{65}\)As, \(^{67}\)Se, \(^{71}\)Kr
A=2Z-2: \(^{56}\)Cu, \(^{52}\)Co
A=2Z-3: \(^{43}\)V, \(^{49}\)Fe, \(^{53}\)Ni
Mass Resolution $\Delta M/M: 3 \times 10^{-6} \sim 1 \times 10^{-7}$
Radioactive Electron Capture (REC) experiment for atomic physics

Xe\(^{54+}\)-beam, 197MeV/u, crossed with the N\(_2\)-jet at internal target of CSRe
SFC-CSRm
Cancer therapy with c-beam
2008---2010
Slow extraction of 1/3 Resonance in CSRm
Slow extraction for $^{12}\text{C}^{6+}-200\text{MeV/u}$ in CSRm

DCCT beam signal in CSRm

AIC beam signal at therapy terminal
Uniform Scanning for Cancer Therapy

Target scanning in 2 dimensions

Dose distribution (3D & 2D)
Raster Scanning for Cancer Therapy

25 points

81 points
Varying-energy slow extraction for cancer therapy

Beam energy of each cycle can be changed

Bragg peaks in water with 5 energy spills
Cancer Therapy with CSRm (2008-2010)

Two batches: 8 patients
Summarize for CSR Beam Status

**Ion:** $^{12}\text{C}^6^+, \ 36\text{Ar}^{18^+}, \ 78\text{Kr}^{28^+}, \ 129\text{Xe}^{27^+}$

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

**Intensity:**
- 10mA ($7 \times 10^9$) for C-600MeV/u in CSRm
- 1.2mA ($4 \times 10^8$) for Ar-368MeV/u in CSRm
- 0.8mA ($2 \times 10^8$) for Kr-480MeV/u in CSRm
- 0.5mA ($1 \times 10^8$) for Xe-235MeV/u in CSRm
- 15mA ($8 \times 10^9$) for C-660MeV/u in CSRe

**Experiment:** RIBs mass-measurement, isochronous mode of CSRe, $\Delta M/M \sim 10^{-6}$

**Slow-extraction:** For external-target experiments and cancer therapy
Thanks