Progress of HIRFL-CSR
(Institute of Modern Physics, CAS)

• Introduction
• CSR Progress
• Experiment at CSR
HIRFL Layout

- ECR Ion Source
- SFC $K=69(72)-10$ AMev
- SSC $K=450 -100$ AMev
- CSRm Quasi-synchrotron
- CSRe: Accel. & Deccel.
  And High Sensitive
  (measure 1 atom of $^{238}$U)
  & Accuracy ($\sim 10^{-6}$)
  Spectrometer
Structure of Matter

Gravitation force
- general relativity

Electromagnetic force
- QED
- Electroweak force
- Standardmodell

Weak force
- Standardmodell

Strong force
- QCD

Research with ion beam:
- Material research
- Health research
- Dense plasma
- Atomic process
- Nucleus structure
- Hadron structure
- High temperature high density nuclear matter

Galaxy: $10^{21}$ m
Matter: $10^{-1}$ m
Crystal: $10^{-9}$ m
Atom: $10^{-10}$ m
Atom nucleus: $10^{-14}$ m
Nucleon: $10^{-15}$ m
Electron: $<10^{-18}$ m
Quark: $<10^{-18}$ m
DNA: $10^{-8}$ m
LECR3

RF: 14.5, 18 GHz, 800-1000 W
Extract: φ 8mm, 20-25kV
Slit: 10-15 mm
Faraday-cup: -150 V

\[
\begin{align*}
\text{Ar}^{11+} &\quad 240 \text{ } \mu\text{A}, \text{Ar}^{14+} 30 \text{ } \mu\text{A} \\
\text{Ar}^{8+1m} &\quad \text{Ar}^{11+} 325 \text{ } \mu\text{A} \text{ at } 18\text{GHz} \\
\text{Xe}^{20+} &\quad 160 \text{ } \mu\text{A}, \text{Xe}^{26+} 95 \text{ } \mu\text{A}, \text{Xe}^{30+} 7 \text{ } \mu\text{A} \\
\text{Ni}^{12+} &\quad 75 \text{ } \mu\text{A}, \text{Ni}^{13+} 57 \text{ } \mu\text{A}, \text{Ni}^{15+} 31 \text{ } \mu\text{A} \\
\text{Fe}^{11+} &\quad 210 \text{ } \mu\text{A}, \text{Fe}^{12+} 175 \text{ } \mu\text{A}, \text{Fe}^{13+} 141 \text{ } \mu\text{A}, \text{Fe}^{16+} 25 \text{ } \mu\text{A}
\end{align*}
\]
SFC & SSC

$K_{SSC} = 450$
$\sim 10^{11}$ pps (Kr——Xe)
$\sim 10^{10}$ pps (>Xe)

$K_{SFC} = 70$

$(Z<30, \ E \sim 5\text{MeV/A})$

$I: \sim 3 \times 10^{13}$ pps (C—Ne)
$>5 \times 10^{12}$ pps (Mg—Ar)
$>1 \times 10^{12}$ pps (Ca—*Zn,*Ge,*Kr)
Rebuncher between SFC and SSC
Unique Features of SECRAL

- **Axial solenoid coils are located inside of Sextupole**
  - Decrease interaction force
  - The ion source more compact
  - Reduce the stored energy
  - Reduce stray field

- **Cold iron structure as field booster and clamp**

- **Sextupole with curved saddle-shaped coils**
  - More convenient for clamp of the coils

- **Three solenoid coils are energized by same direction current**

<table>
<thead>
<tr>
<th>Ion</th>
<th>Current (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{64}\text{Ni}^{17+}$</td>
<td>50</td>
</tr>
<tr>
<td>$^{86}\text{Kr}^{25+}$</td>
<td>50</td>
</tr>
<tr>
<td>$^{132}\text{Xe}^{30+}$</td>
<td>50</td>
</tr>
</tbody>
</table>
Main Physics Goals at CSR

- Radioactive Ion Beam Physics
- Nuclear Reactions in Energy $\leq 1.1 \text{ GeV/u}$ HI & $< 2.8 \text{ GeV Proton}$
- High Charge State of Atomic Physics
- High Energy Density (high T & D Plasma)
- Applications
  - Astrophysics (Key Point)
  - *Irradiative Biology (Cancer Therapy)
# CSR Main Performances

<table>
<thead>
<tr>
<th>Ion Species</th>
<th>CSRm</th>
<th>CSRe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion Species</td>
<td>P,C-U</td>
<td>P,C-U, RIB,HCl, Molecular &amp; Cluster</td>
</tr>
<tr>
<td>Energy (MeV/u)</td>
<td>2350, 2800 (P)</td>
<td>2000 (P)</td>
</tr>
<tr>
<td>(B&lt;sub&gt;max&lt;/sub&gt;=1.4 1.6 T)</td>
<td>900, 1100 (12C&lt;sup&gt;6+&lt;/sup&gt;)</td>
<td>620, 760 (12C&lt;sup&gt;6+&lt;/sup&gt;)</td>
</tr>
<tr>
<td></td>
<td>420, 520 (238U&lt;sup&gt;72+&lt;/sup&gt;)</td>
<td>400, 500 (238U&lt;sup&gt;≠90+&lt;/sup&gt;)</td>
</tr>
<tr>
<td>ΔP/P</td>
<td>&lt;10&lt;sup&gt;-4&lt;/sup&gt;</td>
<td>&lt;10&lt;sup&gt;-5&lt;/sup&gt;</td>
</tr>
<tr>
<td>δP/P (entrance)</td>
<td>±0.15%</td>
<td>±0.25~0.5%</td>
</tr>
<tr>
<td>Emmitance</td>
<td>≤ 5 π mm-mrad</td>
<td>≤ 1 π mm-mrad</td>
</tr>
</tbody>
</table>
Time Schedule & Budget

Time Schedule:

• 2000.4—2001.7 Building Construction
• —— 2001.7 Key Samples
• 2001.4—2004.10 Fabrication
• 2002.6—2004.12 Assembling, Testing
• 2003.9—2004.12 CSRm Install & Commission
• 2004.1—2005.4 CSRe Install & Commission

Budget: 293.5 Million Yuan + 50 Million Yuan
<table>
<thead>
<tr>
<th>Sub-System</th>
<th>Progress (Money pay)</th>
<th>Progress (Contracts)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td>90%</td>
<td>99%</td>
<td>Good</td>
</tr>
<tr>
<td>Power Supplier</td>
<td>89%</td>
<td>98%</td>
<td>Good</td>
</tr>
<tr>
<td>UHV</td>
<td>90%</td>
<td>99%</td>
<td>Good, Uncertainly</td>
</tr>
<tr>
<td>E-Cooler</td>
<td>99%</td>
<td>100%</td>
<td>Better</td>
</tr>
<tr>
<td>RF</td>
<td>86%</td>
<td>99%</td>
<td>Good</td>
</tr>
<tr>
<td>Inject &amp; Extract</td>
<td>72%</td>
<td>85%</td>
<td>Weak, Speed Up</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>88%</td>
<td>96%</td>
<td>Good</td>
</tr>
<tr>
<td>Control</td>
<td>86%</td>
<td>96%</td>
<td>Good</td>
</tr>
<tr>
<td>Alignment</td>
<td>99%</td>
<td>100%</td>
<td>Good</td>
</tr>
<tr>
<td>Internal Target</td>
<td>99%</td>
<td>100%</td>
<td>Good</td>
</tr>
</tbody>
</table>
1, Magnet

![Magnet Images]

- $B_0 = 1.46235\, T$ calculated
- $B_0 = 1.44740\, T$ measured

![Graph showing magnetic field distribution]
## Power Supplier

Total Net Power: >12MW

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-term stability</td>
<td></td>
</tr>
<tr>
<td>2570A</td>
<td>$9.8 \times 10^{-6}$</td>
</tr>
<tr>
<td>2000A</td>
<td>$3.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>Current ripple (570A)</td>
<td></td>
</tr>
<tr>
<td>100HZ</td>
<td>$1.9 \times 10^{-6}$</td>
</tr>
<tr>
<td>300HZ</td>
<td>$5.6 \times 10^{-7}$</td>
</tr>
<tr>
<td>600HZ</td>
<td>$6.8 \times 10^{-7}$</td>
</tr>
<tr>
<td>900HZ</td>
<td>$8.4 \times 10^{-8}$</td>
</tr>
<tr>
<td>Repetition</td>
<td>$7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Cycle-to-cycle repetition</td>
<td>$3.2 \times 10^{-5}$</td>
</tr>
</tbody>
</table>
3. Vacuum (~300 m²)
4, Electron Cooler at CSRm

Horizontal angle magnet field at cooling section
- after assembling
- after alliments of coils

Vertical angle at cooling section
- after assembling
- after alliments of coils
## 5, RF System

<table>
<thead>
<tr>
<th></th>
<th>CSRm</th>
<th></th>
<th>CSRe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accel.</td>
<td>RF Stack</td>
<td>Accel. &amp; Capture</td>
</tr>
<tr>
<td>Harmonic</td>
<td>1</td>
<td>16,32,64</td>
<td>1</td>
</tr>
<tr>
<td>$f_{\text{min}}/f_{\text{max}}$ (MHz)</td>
<td>0.24/1.71</td>
<td>6.0/14.0</td>
<td>0.5/2.0</td>
</tr>
<tr>
<td>$HV_{\text{rf}}(n\times kv)$</td>
<td>1×7.0</td>
<td>1×20.0</td>
<td>2×10.0</td>
</tr>
</tbody>
</table>
CSRm Alignment

Accuracy: 0.1~0.3 mm
CSR Inject Line
CSRm Installation
CSRe Key Setup

300 KV E_Cooler

Dipole (~34T)

Gas Jet Target

\[ N_2 \quad 2 \times 10^{13}/\text{cm}^2 \]

\[ \text{Ne} \quad \sim 2 \times 10^{13}/\text{cm}^2 \]

\[ \text{Ar} \quad 7 \times 10^{13}/\text{cm}^2 \]
Commission

- Inject Beam from SSC-CSR was Installed and Beam commission to entry of CSRm
- CSRm has Installed about end of Feb. 2004 and Beam Commission: 2004.7 ~2004.12
- CSRe is Installed before end of 2004 and Beam Commission: 2005.2~2005.4
- First test experiment 2005 ~
Experiment at CSR

- **SFC**: several to 10 AMeV
- **SSC**: tens to 100 AMeV
- **CSRm**: 1.1 AGeV($^{12}$C$^{6+}$), 2.8 GeV(p)
- **CSRe**: 0.76 AGeV($^{12}$C$^{6+}$)

North

- CSRm Internal Target
- CSRe Internal Target
- Cancel Therapy
- High Energy Density

External Target

Building 2#
Detectors at CSR

• CSRe Detector (high accuracy HI, RIB, Atom…)
  – e, x, γ, HI, Laser…
  – Internal target (Cluster Jet),

• RIB Detector
  – Charged Particles, neutron, γ
  – External Target,

• CSRm Detector
  – Mini-4π detector (wasa)
  – Internal (pellet, polarization) or solid foil target,

• High Energy Density Matter
• Irradiate Experiment (Cancer Therapy)
HIRFL–CSR Operation Feature

- Multi-Exp. (＞90% HIRFL + ＜0.1% CSRm, ＜0.01% CSRe)
- Energy range (5MeV/u~1100MeV/u)
- Many beam species (Ion, RIB, HCI)
- Multi-field (nuclear, atom, irradiation, biology)
- Operation modes:
  - CSRm + external target
  - CSRm+RIBLL-II + external target
  - CSRm+CSRe + internal target (high accuracy)
  - CSRm+RIBLL-II+CSRe + internal target (high accuracy)
  - CSRm+CSRe+E_Cooler + laser (high accuracy)
  - ...

Experiment in CSRe

• Reaction measurement
  – Internal solid target + (300keV) e-cooler
    (E<547MeV/u, A<40 balance ?)
  – $\gamma$ measured by Campton telescope
  – Particle, neutron, measured in downstream

• Nuclear Shape measurement
  – RFQ internal target (RIB possible) ?
  – Measurement >800 MeV Proton scattering as Fraunhofer diffraction
  – Charged particle Radius measured by using laser spectroscopy
CSRe Detector
- Neutron Wall ($\delta E/E \sim 5\%$ for 1 GeV neutrons)

$$\frac{\delta T_n}{T_n} = \gamma (\gamma + 1) \left[ (\delta l / l)^2 + (\delta t / t)^2 \right]^{1/2}$$

**Efficiency Curve**

**Peddle**
- Width: 80
- Thickness: 70
- Length: 1440

**Scintillator:** 10 mm for each layer

**Iron:** 4 mm for each layer

**Width8_Thickness7 cut=500 photons**

**1120**

**1440**

**1440**

**1120**

**PMT**

**lightguide**

**Neutron**
• Preliminary physics program at CSRm

  – Rare decay modes of mesons
    Such as η, ω, η', K⁺, K⁻, φ, ρ

  – Studies on N*
    Such as N*(1440), N*(1535), N*(1650)

  – Search for multi-quark states
    Such as
    double ω,d*(2165-2186) → pn or ppπ⁻ di-baryon states
    p+d→Λ+(Θ⁺=K⁰+p) or Λ+(Θ⁺=K⁺+n) pentaquark

  – polarization (close to threshold)
CSRm Internal Experiment

- Setup
  - Pellet Target
  - Forward detector (4°~18°)
  - Central detector (20°~160°)

C Solid foil Target
L~ $6 \times 10^{10} \times 10^{17} \times 1.8 \times 10^6$—$10^{34}$
Pellet Target (p, d)

Most Advanced internal target

Pellet frequency (max): 70 kHz

Pellet diameter: <40 µm

Effective target thickness: \(10^{15} \sim 10^{16}\) atoms/cm\(^2\)

Proton beam lifetime (@\(3 \times 10^{15}\) atoms/cm\(^2\)): at 550/1360 MeV 5/10 min

Luminosity (@ \(3 \times 10^{15}\) atoms/cm\(^2\), \(1 \times 10^{10}\) p stored): \(10^{32}\) cm\(^{-2}\)s\(^{-1}\)

Employed by WASA @ CELSIUS TLS Lab., Uppsala, Sweden
HIRFL Future Development

- RIB Production by $50\text{MeV}\ e(+C\rightarrow\gamma)+^{238}\text{U}$
- Linac: 10 Mev/u
- RFQ internal target
- LIS + HV + Booster
  Feature: RIB+RIB
  Wide E @ T1/2 range
  high beam quality
  favor beam intensity
- Cancer Therapy Setup
Thank You!
Forward Detector (4°~ 18°)

Detectors:

- **Tracking detector:**
  totally 1600 fibers (φ2 × 400), angular resolution: 0.2 deg.

- **Timing & trigger detector:**
  2 layers of BC408 sheets & 10 sheets/layer, sheet size: 5 × 40 × 400, σ_t~300 ps

- **Hadron calorimeter:**
  sampling type. (1mm Fe + 4 mm BC408) × 70; 8 layers & 25 paddles/layer.
  Paddle size: 50 (T) × 40 (W) × 1000 (L), δE/E~7% (E=370 MeV protons)

- **Cherenkov detector:**
  threshold type, for detecting high energy charged particles

Particle identification methods:

- Lower energy charged particles ⇒ ΔE-E  (E_{proton} < 370 MeV)
- Higher energy charged particles ⇒ Cherenkov light
Central Detector \( (20^\circ \sim 160^\circ) \)

**Detectors:**

- **Tracking detector**
  TPC: inner \( \phi \) 82 mm, outer \( \phi \) 406 mm, length of 400 mm, \( \sigma_{x,y} < 1.0 \) mm, \( \delta E/E \sim 6\% \)

- **Scintillator barrel:**
  \( \phi \)460; 146 plastic scintillator bars with size of \( 8 \times 10 \times 410 \), \( \sigma_t < 500 \) ps

- **Electromagnetic calorimeter**
  \(~1200\) CsI(Tl) crystals, length of 20\~30 cm, each crystal covers the angles of both \( \Delta \theta \) and \( \Delta \phi \) around \( 7^\circ \), \( \delta E/E < 3\% \) (1 GeV photons).

- **Superconducting Solenoid**
  inner diameter \(~1300\) mm; axial magnetic field at the center \( 1.37 \) T.

**Particle identification methods:**

- Charged particles \( \Rightarrow \) \( dE/dx \ vs \ B\rho \) up to \( p \sim 400\sim 500 \) MeV/c
- \( \pi^0 \) and Photon \( \Rightarrow \) EMC
Identification Z by RIS?

1st and 2nd Ionization Potential
Possible Excitation & Ionization RIS

continuum

Third step (Ionization)

second step excitation

First step excitation

two step excitation + final step photoionization

field ionization

Rydberg states

Energy Lifetime ?

autoionization state

Energy Lifetime ?

three step excitation + field ionization

three step excitation + autoionization
Key Point of Identify Z by RIS

• Strong Laser with $10^{15-17}/p$ for excitation cross section about $10^{-15-17}/cm^2$
• Maintain SHE in a small location $\rightarrow$ RFQ
• Precise excitation level $\rightarrow$ QED Calc.
• Half-lives of excitation state
• 1st or/both 2nd ionization
• Laser photo energy $> 6eV$ ?
Pulsed Ti:Sa Laser System
(Tunable pulse width >50ps & >10ps between each pulse)

Fs Laser oscillation
30fs/400mW/800nm

pump, 532nm
Verdi或Millennia

Expended
50~500ps/1nJ

Ti : Sa
400mJ/800nm, 30Hz

Amplifier
30Hz, 2mJ

pump, 100mJ/532nm
30Hz.

pump 1500mJ/532nm
10Hz.

Ti : Sa
400mJ/800nm, 30Hz

F freq. Double。BBO
800→400nm(400mJ)

~20mJ/200nm

Parameter Amplifier
(~ 10mJ)
200nm→230~450nm

~140mJ/200nm

Delay I

~40mJ/200nm

Parameter Amplifier
(~ 20mJ)
200nm→230~450nm

Delay II
Pulsed Laser Assemble
RIBLL Upgrade for SHE

Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>RIBLL</th>
<th>SHIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \Omega$</td>
<td>&gt;7msr</td>
<td>~1.7msr</td>
</tr>
<tr>
<td>$\Delta P/P$</td>
<td>~10%</td>
<td>~10%</td>
</tr>
<tr>
<td>$B_{\rho \text{max}}$</td>
<td>~4.2Tm</td>
<td>~1.2Tm</td>
</tr>
<tr>
<td>$A/ \Delta A$</td>
<td>~300</td>
<td>~300</td>
</tr>
</tbody>
</table>
6. Inject & Extract

4 Sets

4 Sets
7, Control:(> 96% Digit)
(Home Make >75%)

• Web + Internet + DB
• CPCI(PXI), Fast Ethernet, RS485, …
• Multifunction, Arbitrary wave generator (Processor Embed)
8, Diagnostic

Horizontal/vertical Slits

Double Single Wire

Faraday-Cup

45° Viewing Screen