Preliminary concept design of EicC accelerator

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28-29 June 2019, Jeju • Korea
Outline

1. HIAF introduction and status
2. EIC proposals in the world
3. Concept design of EicC accelerator
4. Interaction region and luminosity concept
5. Cost estimation and schedule
6. Summary
HIAF introduction and status

High-Intensity Heavy Ion Accelerator Facility - HIAF
Next-generation high intensity facilities are required for advances in nuclear physics and related research fields:

- To explore the limit of nuclear existence
- To study exotic nuclear structure
- Understand the origin of the elements
- To study the properties of High Energy and Density Matter

Fascinating and crucial questions

Next-generation facilities are being constructed or proposed worldwide:

- SPIRAL2 at GANIL in Caen, France
- FAIR at GSI in Darmstadt, Germany
- FRIB at MSU in the U.S.
- NICA at JINR, Dubna, Russia
- EURISOL in Europe

HIAF in China
These tunnels will be built in a cut and cover method and will be filled with 5 m overlay of soil. This conforms to the requirements of radiation safety.
HIAF introduction and status

Unprecedented parameters and unique features:

**Highest beam Intensity** (Comparison with HIRFL):
- Primary beam intensity increases by $x \ 1000 - x \ 10000$
- Secondary beam intensity increases by up to $x \ 10000$
- Highest heavy ion beam intensity in the world

**Precisely-tailored beams - Precision frontiers**
- Beam cooling (Electron, Stochastic, laser; high quality, very small spot)
- Beam compression (Ultra-short bunch length: 50-100ns)
- Super long period slow extraction (Super long, high energy, quasi-continuous beam)

**Versatile operation modes:**
- Parallel operation, beam splitting (increase of target time, high integrated luminosity)

Parallel mode

BRing-N Switch iLinac Switch Chopper SECR
# HIAF introduction and status

## Heavy ion beam intensity

<table>
<thead>
<tr>
<th>Ions</th>
<th>Energy</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SECR</strong></td>
<td>14 keV/u</td>
<td>0.05-0.1 pmA</td>
</tr>
<tr>
<td>238U^{35+}</td>
<td>17 MeV/u</td>
<td>0.028-0.05 pmA</td>
</tr>
<tr>
<td><strong>iLinac</strong></td>
<td>0.8 GeV/u</td>
<td>~2.0×10^{11} ppp</td>
</tr>
<tr>
<td>238U^{35+}</td>
<td>2.3 GeV/u</td>
<td>~1.0×10^{12} ppp</td>
</tr>
<tr>
<td><strong>BRing-N</strong></td>
<td>0.84 GeV/u(A/q=3)</td>
<td>~10^{9-10} ppp</td>
</tr>
<tr>
<td>238U^{35+}</td>
<td>5.8 GeV/u</td>
<td>~5.0×10^{11} ppp</td>
</tr>
<tr>
<td>238U^{92+}</td>
<td>7.3 GeV/u</td>
<td>~5.0×10^{11} ppp</td>
</tr>
<tr>
<td><strong>BRing-S</strong></td>
<td>0.8 GeV/u(238U^{92+})</td>
<td>~10^{11-12} ppp</td>
</tr>
<tr>
<td><strong>SRing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RIBs: neutron-rich, proton-rich</td>
<td>0.84 GeV/u(A/q=3)</td>
<td>~10^{9-10} ppp</td>
</tr>
<tr>
<td>Fully stripped heavy ions H-like, He-like heavy ions</td>
<td>0.8 GeV/u(238U^{92+})</td>
<td>~10^{11-12} ppp</td>
</tr>
</tbody>
</table>
# HIAF introduction and status

## Heavy ion beam intensity

### The highest pulse heavy ion beam intensity in the world

<table>
<thead>
<tr>
<th>Institute</th>
<th>Machine</th>
<th>Planned Intensity</th>
<th>Achieved Intensity</th>
<th>Ion species</th>
<th>Repetition rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BNL</td>
<td>AGS Booster</td>
<td>$5 \times 10^9$</td>
<td></td>
<td>Au$^{32+}$</td>
<td></td>
</tr>
<tr>
<td>CERN</td>
<td>LEIR</td>
<td>$9 \times 10^8$</td>
<td></td>
<td>Pb$^{54+}$</td>
<td></td>
</tr>
<tr>
<td>JINR</td>
<td>NICA Booster</td>
<td>$4 \times 10^9$</td>
<td></td>
<td>Au$^{32+}$</td>
<td></td>
</tr>
<tr>
<td>GSI</td>
<td>SIS18</td>
<td>$1.0 \times 10^{11}$</td>
<td>$3 \times 10^{10}$</td>
<td>U$^{28+}$</td>
<td>2.7Hz</td>
</tr>
<tr>
<td>FAIR</td>
<td>SIS100</td>
<td>$4.0 \times 10^{11}$</td>
<td></td>
<td>U$^{28+}$</td>
<td></td>
</tr>
<tr>
<td>IMP</td>
<td>HIAF-BRing-N</td>
<td>$2.0 \times 10^{11}$</td>
<td></td>
<td>U$^{35+}$</td>
<td>5-10Hz, 10-20Hz</td>
</tr>
<tr>
<td>IMP</td>
<td>HIAF-BRing-S</td>
<td>$1.0 \times 10^{12}$</td>
<td>$2.0 \times 10^{12}$</td>
<td>U$^{35+}$</td>
<td></td>
</tr>
</tbody>
</table>
Experiment terminals

External target station
High Energy Density Physics
Nuclear Matter study-CEE
Hypernuclear
High energy irradiation

BRing-S
BRing-N

HFRS

SRing
MRing

e-ion recombination spectroscopy

Ion-Ion Merging

iLinac-100
iLinac-25

SECR

Low energy irradiation

RIBs physics station
High precision spectrometer ring

Low energy nuclear structure terminal
HIAF introduction and status

Unique feature-1

Multi-function storage ring

Key devices
- Electron cooling
- Stochastic cooling
- Two TOF detectors
- Electron target

Operation modes
- Isochronous mode
- Normal Mode
- Internal-target Mode
- Ion-ion merging Mode

Experiment programs
- Gas-jet target experiments
- DR experiments
- IMS & SMS
- Ion-ion merging experiments

Precision frontiers machine for in-ring experiments
**HIAF introduction and status**

Isochronous mode with two TOF

**HIRFL-CSRe**

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

\[\gamma = \gamma_{\text{rev}} = 1.395\]

Beams: $^{58}\text{Ni}$, $^{78}\text{Kr}$, $^{86}\text{Kr}$ and $^{112}\text{Sn}$

43 masses are measured

Measured for the first time: 16

Precision improved: 27

Precision achieved: $\Delta M/M \sim 10^{-7}$

Demonstrated the TOF mode first time in the world

**HIAF-SRing**

$\Delta M/M \sim 10^{-7} - 10^{-8}$
Spontaneous electron–positron pair production

A fundamental question of QED—spontaneous electron-positron pair creation in supercritical Coulomb fields

Theory prediction: occur in the collisions of two very heavy ions with the total atomic number $Z_1 + Z_2 \geq 173$.

Failed to observe in fixed target experiments due to the interference of extranuclear electrons.
HIAF introduction and status

First figure-8 shape ring for ion-ion merging: pair production

Unique features:
- “8” shape ring
- Coasting beam merging with itself scheme
- Based on SRing
- Sharing the injection and cooling system
- No powerful RF system

Advantages:
- No electron-electron correlation
- Ultra-low background signals
- Small angle collision provides the energy (6~8MeV/u) to cross column barrier

Bare heavy nuclei, e.g. $^{238}$U$^{92+}$, $Z_1 + Z_2 = 184 \geq 173$
## Schedule

<table>
<thead>
<tr>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **2019**
  - Project Start
  - Site Preparation

- **2020**
  - Site Preparation
  - Mechanical, Electrical, and Plumbing (MEP) installation

- **2021**
  - MEP Installation
  - Civil Works

- **2022**
  - Civil Works
  - MEP Installation

- **2023**
  - MEP Installation
  - Structural Works

- **2024**
  - Structural Works
  - Electrical Works

- **2025**
  - Electrical Works
  - Commissioning

- **2026**
  - Commissioning
  - Operational readiness

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**Key Milestones**

- **2020-07-31**: Start of commissioning
- **2020-12-31**: Full commissioning
- **2021-03-31**: Operational readiness
HIAF introduction and status

New campus
HIAF introduction and status

Present status

HIAF园区主要建筑平面布置图
HIAF introduction and status

Present status

[Images of natural landscapes and construction sites]
HIAF introduction and status

Present status
Outline

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HERA: First EIC machine in the world

A Ring-Ring (polarized) Lepton-Proton collider with 320 GeV CM energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>Proposal</td>
</tr>
<tr>
<td>1984</td>
<td>Start construction</td>
</tr>
<tr>
<td>1991</td>
<td>Commissioning, first Collisions</td>
</tr>
<tr>
<td>1992</td>
<td>Start Operations for H1 and ZEUS, 1st exciting results with low luminosity</td>
</tr>
<tr>
<td>1994</td>
<td>Install East Spin Rotators</td>
</tr>
<tr>
<td>1996</td>
<td>Install 4th Interaction region for HERA-B</td>
</tr>
<tr>
<td>1999</td>
<td>High Luminosity Run with electrons</td>
</tr>
<tr>
<td>2000</td>
<td>High efficient luminosity production:100 /pb/y</td>
</tr>
<tr>
<td>2001</td>
<td>Install luminosity upgrade, Spin Rotators for H1 and ZEUS</td>
</tr>
<tr>
<td>2003</td>
<td>Longitudinal polarization in high energy collisions</td>
</tr>
<tr>
<td>2007</td>
<td>End of a highly successful program</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Lepton</th>
<th>Proton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>27.5</td>
</tr>
<tr>
<td>Intensities</td>
<td>mA</td>
<td>60</td>
</tr>
<tr>
<td>Magnetic field</td>
<td>T</td>
<td>0.15</td>
</tr>
<tr>
<td>Acc. voltage</td>
<td>MV</td>
<td>130</td>
</tr>
<tr>
<td>e-polarization</td>
<td>%</td>
<td>50 to 70</td>
</tr>
</tbody>
</table>

Final luminosity (1.5 to 5)x10^{31} cm^{-2}s^{-1}

Tunnel: 5.2 m diameter
EIC proposals in the world

- Energy ~ 10^2
- Beam intensity ~ 1000
- Energy deposition rate ~ 1000 to 10000

RHIC ➔ eRHIC
CEBAF ➔ JLEIC
LHC ➔ LHeC
FAIR ➔ ENC
HIÅF ➔ EICc
HERA

Roadmap for EIC proposals:

- RHIC ➔ eRHIC
- CEBAF ➔ JLEIC
- HERA
- HIÅF ➔ EICc
- FAIR ➔ ENC
- LHC ➔ LHeC
The High-Energy/Nuclear Science of LHeC

**Overarching Goal: lepton-proton at the TeV Scale**
- Hunt for quark substructure & high-density matter (saturation)
- High precision QCD and EW studies and possible implications for GUT

The Nuclear Science of eRHIC/MEIC

**Overarching Goal: Explore and Understand QCD:**
- Map the spin and spatial structure of quarks and gluons in nucleons
- Discover the collective effects of gluons in atomic nuclei
  
  *(role of gluons in nuclei & onset of saturation)*

The Nuclear Science of EicC

**Overarching Goal: Explore Hadron Structure**
- Map the spin and spatial structure of valence & sea quarks in nucleons
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Machine Design Goal

Present baseline:

- **Energy**: 3.5 GeV/electron, 20 GeV/proton  **First phase-EicC-1**
  5-10 GeV/electron, 60-100 GeV/proton  **Second phase-EicC-2**

- **Ions**: Polarized light ions (p, d, $^3$He), unpolarized heavy ions up to Uranium
  High polarization for both beams, 80% for electron, and 80% for proton

- **Layout**: Ring-Ring collision mode
  New figure “8” shape ring for ion
  Racetrack shape for electron
  Electron injector based on SRF Linac-Ring

- **Cooling strategy**:
  Conventional DC cooling for pre-cooling
  Bunched electron cooling for high energy stage based ERL

- **Luminosity**:
  $(2-4) \times 10^{33}$ cm$^{-2}$s$^{-1}$  **First phase-EicC-1**
  $1 \times 10^{34}$ cm$^{-2}$s$^{-1}$  **Second phase-EicC-2**
The preliminary concept design of EicC

The whole layout of EicC

**EIC-I:** 20 GeV p + 3.5 GeV e
\[ \sqrt{s} = 16.7 \text{ GeV} \]

**EIC-II:** 100 GeV p + 5 GeV e
\[ \sqrt{s} = 45.0 \text{ GeV} \]

- **EicC-I**
  - High energy ion collision ring
  - High energy density study
  - 7.6 GeV/u(U^{34+})
  - \(5.0 \times 10^{12}\) ppp, 50-100 ns
  - C: 1.5-2.0 km

- **EicC-II**
  - High energy ion collision ring
  - 60-100 GeV
  - C: 1.5-2.0 km

- **Hiaf-I**
  - SRF Linac-ring, 3.5-10 GeV

- **Hiaf-II**
  - Polarized proton

- **HeRing**
  - 5-10 GeV
  - C: 1.5-2.0 km

- **EpRing**
  - 20 GeV, C: 1347 m Polarized proton
The whole layout of EicC-1

**Main changes**
- Figure-8 shape ion collider with four long straight sections
- Two interaction points for detectors, electron cooling, RF system
- The high luminosity $2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$, $4 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

**EicC-I New construction**
- polarized ion source
- Siberia snake/DC cooler for BRing
- pRing
  - Superconducting, 4T
  - Partial sharing the tunnel with BRing

Electron injector:
- SRF Linac-ring
  - 3.5 GeV, Top-up
- Polarized electron

Polarized proton

**Interaction regions**
- Bunched cooler
  - 14 MeV
  - ERL circulator
- e injectors
  - SRF Linac-ring
  - eRing
- Racetrack shape
- DC cooler
- Siberia snake
- Polarized ion source

pRing
- 3.5 GeV
- C: 822 m
- Polarized proton

Electron injector:
- SRF Linac-ring
  - 3.5 GeV, Top-up
- Polarized electron

pRing
- 3.5 GeV
- C: 1347 m
- Polarized proton

**BRing**
- HFRS
- SRing
- MRing

**eRing**
- 3.5 GeV
- C: 822 m
- Polarized electron

**Interaction region**

**Interaction region**
Ion Collider Layout and Optics - pRing

- FD type lattice cell in arcs - not standard FODO, dynamic vacuum effects
- Dedicated Chromaticity Compensation Blocks (CCB) in arcs
- Long straight sections for two IPs, RF, cooler

Circumference: 1350m
Rigidity: 87Tm
Electron Collider Layout and Optics- eRing

- FODO-cell arcs, racetrack shape
- Dedicated Chromaticity Compensation Blocks (CCB) in arcs

Circumference: 820 m
Rigidity: 11.2 Tm

The whole layout of the electron collider-eRing

Optics of the whole electron collider-eRing
Outline

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IR design requirements:

- Small $\beta^*$ for high luminosity
- Limited IR chromaticity contributions
- Large detector acceptance
  - Large quadrupole aperture
- Accommodate spectrometer in the low-$\beta$ optics
- No accelerator magnets +/-7.0 m
- Avoid synchrotron radiation:
  - no electron bends on the forward side
  - absorb SR far from IP
  - need mask against backscattered SR photons
- Accommodate spin rotators, spin matching
- Space for luminosity monitor, neutron detector, “Roman Pots”
Interaction Regions Layout

- Two interaction points and 7m free straight section for each point
- 50 mrad crossing angle
- Two Mirror-symmetric Interaction Regions

**Schematic layout of the interaction region**

Forward hadron detection

Forward electron detection
Interaction Region Optics - pRing

- Symmetric optic design and no dispersion at IPS
- Two Interaction Regions based on Final Focusing Blocks (FFB)
- Three CCBs with dispersion suppression and chromaticity compensation
Interaction Region Optics - eRing

- IR design feature similar to proton
  - Symmetric optic design and no dispersion at IPS
  - Two Interaction Regions based on Final Focusing Blocks (FFB)
  - Three CCBs with dispersion suppression and chromaticity compensation
Luminosity concept

EicC-1: 25GeV p + 3.5GeV e
\[ \sqrt{S} = 18.7\text{GeV} \]

Luminosity:
- \[ 2.0 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \]
- \[ 4.0 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \]
Basic strategy and design principles

Limitation of the state-of-art

- The stored beam currents are up to 0.5A for protons or ions and 3A for electrons
- The hadron beam-beam tune-shift is limited to 0.03/interaction point
- The direct space-charge tune-shift of ion beams is limited to 0.06

\[ L = \frac{N_p N_e f_c}{4\pi \sigma_x \sigma_y} H \]

\[ N_p f_c \propto I_p \]
\[ N_e f_c \propto I_e \]

\[ L \propto \frac{I_p I_e}{f_c} \]

\[ \sigma_x \sigma_y \text{ also increase, but smaller impaction than } f_c \]

Strategy of EicC-1

- More particles in a single bunch.
- A lower collision frequency.
- Crab-crossing
- Adjust emittance simultaneously due to IBS.
The main challenge of EicC is IBS

\[ \frac{1}{\tau} \propto \frac{N_p}{\varepsilon_x \varepsilon_y \sigma_{dp/p} \sigma_s} \]

Volume of 6 phase space

If \( N_p \) increase \( m \) times, let IBS rate keep constant, Then

\[ \varepsilon_x \propto m^3, \quad \varepsilon_y \propto m^3, \quad \sigma_{dp/p} \propto m^6, \quad \sigma_s \propto m^6 \]

Luminosity

\[ L = \frac{N_p N_e f_c}{4\pi \sigma_x \sigma_y} H \propto mm \frac{1}{m} \frac{1}{m^3} = \sqrt{m} \]
## Basic strategy and design principles

<table>
<thead>
<tr>
<th></th>
<th>Old</th>
<th>New</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>particle</strong></td>
<td>p</td>
<td>e</td>
</tr>
<tr>
<td>circumference(m)</td>
<td>1350</td>
<td>876</td>
</tr>
<tr>
<td>energy(GeV)</td>
<td>25</td>
<td>3.5</td>
</tr>
<tr>
<td>Bp(T·m)</td>
<td>87</td>
<td>11.7</td>
</tr>
<tr>
<td>$f_{\text{collision}}$(MHz)</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>particles per bunch($\times 10^{10}$)</td>
<td>0.5</td>
<td>2.6</td>
</tr>
<tr>
<td>$\varepsilon_x$, $\varepsilon_y$(nm·rad, rms)</td>
<td>100/60</td>
<td>10</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$ (m)</td>
<td>0.024/0.012</td>
<td>0.24/0.072</td>
</tr>
<tr>
<td>bunch length(m)</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>dp/p</td>
<td>5e-4</td>
<td></td>
</tr>
<tr>
<td>Beam-Beam Parameter $\xi_y$</td>
<td>0.002</td>
<td>0.007</td>
</tr>
<tr>
<td>Laslett tune shift</td>
<td>0.01</td>
<td>—</td>
</tr>
<tr>
<td>energy loss per turn(MeV)</td>
<td>—</td>
<td>0.32</td>
</tr>
<tr>
<td>total SR power(MW)</td>
<td>—</td>
<td>1.0</td>
</tr>
<tr>
<td>SR linear power density(kW/m)</td>
<td>—</td>
<td>3.7</td>
</tr>
<tr>
<td>current(A)</td>
<td>0.6</td>
<td>3.1</td>
</tr>
<tr>
<td>crossing angle(mrad)</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>hourglass</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Luminosity(cm$^{-2}$s$^{-1}$)</td>
<td>$0.5 \times 10^{33}$</td>
<td>$2.0 \times 10^{33}$</td>
</tr>
</tbody>
</table>

Luminosity increases by 4 times
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# EicC-1 cost estimation

<table>
<thead>
<tr>
<th>Items</th>
<th>1st phase (MRMB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIAF update</td>
<td>560</td>
</tr>
<tr>
<td>eLinac</td>
<td>550</td>
</tr>
<tr>
<td>eRing</td>
<td>600</td>
</tr>
<tr>
<td>pRing</td>
<td>800</td>
</tr>
<tr>
<td>Beam transfer line</td>
<td>400</td>
</tr>
<tr>
<td>Experiment setups</td>
<td>1000</td>
</tr>
<tr>
<td>Cryogenics</td>
<td>450</td>
</tr>
<tr>
<td>Civil engineering</td>
<td>550</td>
</tr>
<tr>
<td>Tunnel construction</td>
<td>600</td>
</tr>
<tr>
<td>Contingency cost</td>
<td>500</td>
</tr>
<tr>
<td><strong>Total of facility</strong></td>
<td><strong>6010</strong></td>
</tr>
</tbody>
</table>
Schedule of EicC-1

| 20~ | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|-----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| **Critical Points** | | | | | | | | | | | | | | | | | |
| Proposal | | | | | | | | | | | | | | | | | |
| **HIAF construction** | | | | | | | | | | | | | | | | | |
| Design R&D | | | | | | | | | | | | | | | | | |
| Idea design | | | | | | | | | | | | | | | | | |
| Conceptual design | | | | | | | | | | | | | | | | | |
| Key technologies R&D | | | | | | | | | | | | | | | | | |
| **Construction and Installation** | | | | | | | | | | | | | | | | | |
| Civil construction | | | | | | | | | | | | | | | | | |
| Equipment construction, Fabrication | | | | | | | | | | | | | | | | | |
| Installation | | | | | | | | | | | | | | | | | |
| **Commissioning** | | | | | | | | | | | | | | | | | |
| eLinac, eRing, pRing commissioning | | | | | | | | | | | | | | | | | |
| Combined commissioning | | | | | | | | | | | | | | | | | |
| Start of operation | | | | | | | | | | | | | | | | | |

**Design report preparation, submission, approval**

**Detailed design & prototype**
Campus for EicC
1. HIAF introduction and status
2. EIC proposals in the world
3. Concept design of EicC-1 accelerator
4. Interaction region and luminosity concept
5. Cooling strategy and design
6. Summary
Based on the HIAF accelerator complex, a concept design of EicC-1 accelerator design was presented. The new design mainly focused on the scientific requirements, such as luminosity, interaction region.

This is a preliminary concept design and provides a basis for performance evaluation, technical risk assessment and cost estimation.

The design will be further optimized and improved. More details should be investigated, especially cooling scheme and stimulation studies.

The polarization issue is not covered by this presentation, for polarization in BRing, the Siberia Snakes will be used and figure 8 shape ring for ion collider ring-pRing.

A series of beam dynamics and technical challenges for EicC. Prototypes of key technologies or components will be developed step by step.
Thanks for your attention!
Cooling strategy

Cooling

- Small emittance and short bunch (with strong SRF)
- Enabling ultra strong final focusing and crab crossing
- Suppressing IBS, expanding high luminosity lifetime

Two stages cooling scheme:

- **Pre-Cooling**: Booster-BRing-N, 2GeV, Conventional DC cooler
- **Collision cooling**: Proton collider-PRing, 25 GeV, ERL bunched cooler
Cooling strategy

Pre-cooling design:

- Pre-Cooling: Booster-BRing-N, 2GeV, Conventional DC cooler

Such a cooler is technically well developed and readily available.
## Cooling strategy

### Collision cooler design:

- **Collision cooling**: Proton collider-pRing, 25 GeV, ERL bunched cooler

### Sketch of EicC collision cooling design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gun type</td>
<td>NCRF</td>
</tr>
<tr>
<td>RF frequency</td>
<td>700 MHz</td>
</tr>
<tr>
<td>RMS energy spread</td>
<td>$5 \times 10^{-4}$</td>
</tr>
<tr>
<td>PRF</td>
<td>2 MHz</td>
</tr>
<tr>
<td>RMS bunch length</td>
<td>200 ps</td>
</tr>
<tr>
<td>Charge /bunch</td>
<td>4 nC</td>
</tr>
<tr>
<td>Cryostat number</td>
<td>1</td>
</tr>
<tr>
<td>Inject energy</td>
<td>2 MeV</td>
</tr>
<tr>
<td>Cryostat length</td>
<td>1.5m</td>
</tr>
<tr>
<td>Cooling energy</td>
<td>14 MeV</td>
</tr>
<tr>
<td>Circumference of circulating ring</td>
<td>160m</td>
</tr>
<tr>
<td>Transverse rms normalized emittance</td>
<td>$2.5\pi$ mm mrad</td>
</tr>
<tr>
<td>Bunch frequency in circulating ring</td>
<td>30 MHz</td>
</tr>
</tbody>
</table>
Transverse IBS rate

Longitudinal IBS rate

EicC luminosity parameters

<table>
<thead>
<tr>
<th></th>
<th>p</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference(m)</td>
<td>1350</td>
<td>820</td>
</tr>
<tr>
<td>energy(GeV)</td>
<td>25</td>
<td>3.5</td>
</tr>
<tr>
<td>Bp(T·m)</td>
<td>87</td>
<td>11.7</td>
</tr>
<tr>
<td>$f_{\text{collision}}$(MHz)</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>particles per bunch($\times 10^{11}$)</td>
<td>1.04</td>
<td>6.25</td>
</tr>
<tr>
<td>$\epsilon_x, \epsilon_y$(nm·rad, rms)</td>
<td>300/180</td>
<td>60</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$(m)</td>
<td>0.04/0.02</td>
<td>0.2/0.06</td>
</tr>
<tr>
<td>bunch length(m)</td>
<td>0.035</td>
<td>0.02</td>
</tr>
<tr>
<td>dp/p</td>
<td>8.5e-4</td>
<td></td>
</tr>
<tr>
<td>Beam-Beam Parameter $\xi_y$</td>
<td>0.011</td>
<td>0.04</td>
</tr>
<tr>
<td>Laslett tune shift</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>energy loss per turn(MeV)</td>
<td>—</td>
<td>0.32</td>
</tr>
<tr>
<td>total SR power(MW)</td>
<td>—</td>
<td>1.0</td>
</tr>
</tbody>
</table>

- The IBS growth rate is estimated around $1.2 \text{ h}^{-1}$
- A beam cooling rate should be the same as IBS growth rate, to suppress the emittance growth in operation.
EicC proton beam cooling

Operation without cooling

Operation with cooling
The cooling rates $1/T_c$ are normalized by $Z^2/A$ to an electron density $n_e$ of $10^8$ cm$^{-3}$

$$\frac{1}{T_c} = \frac{4e_r r_p n_e \eta_c c}{\gamma^2} \left( \frac{1}{\beta^2 \theta_\perp^2 + \beta^2 \theta_\parallel^2 + \gamma^2 \theta_e^2} \right)^{3/2} \frac{Z^2}{A} \ln \xi \propto n_e Z^2 \frac{1}{A \gamma^2 \beta^3}$$
The bunched beam cooling based on ERL design relies on adapting several new concepts/schemes and integrating an array of cutting-edge accelerator technologies for delivering high performance to meet the cooling needs. A successful demonstration of these new concepts/schemes and development of various key supporting technologies are still very challenging. In this case, this cooling scheme is a big risk of EicC-1.

An alternative design without ERL collision cooling is also under active evaluation for high integrated luminosity with fast cycling mode and it provides a backup approach.
Operation mode and integrated luminosity

- The normal integrated luminosity mode

<table>
<thead>
<tr>
<th></th>
<th>LHC</th>
<th>RHIC</th>
<th>HERA</th>
<th>EicC-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection</td>
<td>20 min</td>
<td>1 min</td>
<td>20 min</td>
<td>1-2s</td>
</tr>
<tr>
<td>Acceleration</td>
<td>18 min</td>
<td>130 s</td>
<td>30 min</td>
<td>4s</td>
</tr>
<tr>
<td>Collision</td>
<td>~ 15 h</td>
<td>~ 8 h (Max 10 h)</td>
<td>~ 10 h</td>
<td>~ 2 h</td>
</tr>
<tr>
<td>Ions</td>
<td>p-p</td>
<td>Au-Au</td>
<td>p-e</td>
<td>p-e</td>
</tr>
</tbody>
</table>
The new integrated luminosity scenario
transverse

in principle, a fast cooling is necessary for low luminosity mode ($t_{\text{cooling}} < 1000 \text{ sec}$) and high luminosity ($t_{\text{cooling}} < 100 \text{ sec}$)

the big challenge!

longitudinal

energy scaling from Recycler 8.9 GeV/c p cooling: $t_{\text{cooling}} =3000 \text{ sec}$
Cooling strategy

<table>
<thead>
<tr>
<th>电子束能量</th>
<th>10.89 MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>电子束团长度</td>
<td>20 mm</td>
</tr>
<tr>
<td>电子束团动量分散</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>电子束团半径</td>
<td>2 mm</td>
</tr>
<tr>
<td>电子束团发射度</td>
<td>0.04 urad</td>
</tr>
<tr>
<td>电子束团峰值流强</td>
<td>4.7 A</td>
</tr>
<tr>
<td>电子束团密度</td>
<td>$1.7 \times 10^{14} \text{cm}^{-3}$</td>
</tr>
<tr>
<td>Parameter</td>
<td>p</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>circumference (m)</td>
<td>1200</td>
</tr>
<tr>
<td>energy (GeV)</td>
<td>60</td>
</tr>
<tr>
<td>$B \rho$ (T·m)</td>
<td>203</td>
</tr>
<tr>
<td>$f_{\text{collision}}$ (MHz)</td>
<td>500</td>
</tr>
<tr>
<td>particles per bunch ($\times 10^{10}$)</td>
<td>1</td>
</tr>
<tr>
<td>$\epsilon_x, \epsilon_y$ (nm·rad, rms)</td>
<td>10/2</td>
</tr>
<tr>
<td>$\beta_x^<em>/\beta_y^</em>$ (m)</td>
<td>0.05/0.01</td>
</tr>
<tr>
<td>bunch length (m)</td>
<td>0.012</td>
</tr>
<tr>
<td>Beam-Beam Parameter $\xi_y$</td>
<td>0.01</td>
</tr>
<tr>
<td>Laslett tune shift</td>
<td>0.06</td>
</tr>
<tr>
<td>energy loss per turn (MeV)</td>
<td>—</td>
</tr>
<tr>
<td>total SR power (MW)</td>
<td>—</td>
</tr>
<tr>
<td>SR linear power density (kW/m)</td>
<td>—</td>
</tr>
<tr>
<td>current (A)</td>
<td>0.8</td>
</tr>
<tr>
<td>crossing angle (mrad)</td>
<td>50</td>
</tr>
<tr>
<td>hourglass</td>
<td>0.88</td>
</tr>
<tr>
<td>Luminosity (cm$^{-2}$s$^{-1}$)</td>
<td>$1.1 \times 10^{34}$</td>
</tr>
</tbody>
</table>
$10 \text{ sec} < t_{\text{cooling}} < 100 \text{ sec}$ is needed for 60 GeV EIC!

$$\frac{1}{\tau_{\text{cool}}} \propto Z^2 \frac{n_e L_c}{A \beta^3 \gamma^5 \theta_{\text{rel}}^3}$$
<table>
<thead>
<tr>
<th>Parameter</th>
<th>p</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>circumference (m)</td>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td>energy (GeV)</td>
<td>60</td>
<td>5</td>
</tr>
<tr>
<td>$B_p (T \cdot m)$</td>
<td>203</td>
<td>16.7</td>
</tr>
<tr>
<td>$f_{\text{collision}} (MHz)$</td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td>particles per bunch ($\times 10^{10}$)</td>
<td>0.5</td>
<td>3.2</td>
</tr>
<tr>
<td>$\epsilon_x, \epsilon_y (nm \cdot \text{rad, rms})$</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>$\beta^<em>_x / \beta^</em>_y \text{ (m)}$</td>
<td>0.02/0.01</td>
<td>0.2/0.1</td>
</tr>
<tr>
<td>IBS rate</td>
<td>0.0003(H,V),0.0018(L)</td>
<td>—</td>
</tr>
<tr>
<td>bunch length (m)</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>$dp/p$</td>
<td>3e-4</td>
<td></td>
</tr>
<tr>
<td>Beam-Beam Parameter $\xi_y$</td>
<td>0.0015</td>
<td>0.01</td>
</tr>
<tr>
<td>Laslett tune shift</td>
<td>0.005</td>
<td>—</td>
</tr>
<tr>
<td>energy loss per turn (MeV)</td>
<td>—</td>
<td>0.33</td>
</tr>
<tr>
<td>total SR power (MW)</td>
<td>—</td>
<td>1.3</td>
</tr>
<tr>
<td>SR linear power density (kW/m)</td>
<td>—</td>
<td>5.2</td>
</tr>
<tr>
<td>current (A)</td>
<td>0.6</td>
<td>3.9</td>
</tr>
<tr>
<td>crossing angle (mrad)</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>hourglass</td>
<td></td>
<td>0.75</td>
</tr>
<tr>
<td>Luminosity (cm$^{-2}$s$^{-1}$)</td>
<td></td>
<td>$0.5 \times 10^{33}$</td>
</tr>
</tbody>
</table>