Session 5

Application Oriented Research
High Average Current

Review of requirements and challenges

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Electron–ion collider on the horizon

28 September 2018

The National Academy of Sciences in the US finds a compelling scientific case for an advanced collider that would reveal how visible matter emerges from fundamental quarks and gluons.

Protons and neutrons, the building blocks of nuclear matter, constitute about 99.9% of the mass of all visible matter in the universe. In contrast to more familiar atomic and molecular matter, nuclear matter is also inherently complex because the interactions and structures in nuclear matter are inextricably mixed up: its constituent quarks are bound by gluons that also bind themselves. Consequently, the observed properties of nucleons and nuclei, such as their mass and spin, emerge from a complex, dynamical system governed by quantum chromodynamics (QCD). The quark masses, generated via the Higgs mechanism, only account for a tiny fraction of the mass of a proton, leaving fundamental questions about the role of strongly interacting degrees of freedom in setting the scale of the nuclear mass hierarchy.
Two proposed machine designs for an EIC build on existing U.S. accelerator facilities with some of the required elements in place.
BNL Low Energy RHIC electron Cooling (LEReC)

**Energies** $E$ : 1.6, 2.0 MeV

**Luminosity gain** : 4×

**1st bunched beam electron cooler**

### Final goal | Achieved in gun
---|---
Iave | 30-50 | 30
Lifetime | >24 hrs | >100 hrs
QE | >5% | 5.6 %
$\delta p/p$ | $< 1.5 \times 10^{-3}$ | $1.0 \times 10^{-3}$
$\epsilon_n$ | $< 3.5 \mu$rad | Hor = 1.7 \mu rad; Ver = 1.7 \mu rad

**Courtesy of Erdong Wang**
BNL Coherence electron cooling-Pop

CeC “kicker”
CeC modulator
Dog-leg: 3 dipoles 6 quads
Low energy transport beam-line with 5 solenoids
Bunching RF cavities
1.25 MV SRF photo-gun and cathode manipulation system

Common section with RHIC

High power beam dump
1 dipole, 2 quads
Low power beam dump

SRF 113MHz electron gun

<table>
<thead>
<tr>
<th>Metric</th>
<th>Design Goal</th>
<th>Achieved</th>
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</thead>
<tbody>
<tr>
<td>Charge per electron bunch</td>
<td>0.5-5 nC</td>
<td>0.1-10.7 nC</td>
</tr>
<tr>
<td>Peak current</td>
<td>100 A</td>
<td>50-100 A</td>
</tr>
<tr>
<td>Bunch duration, psec</td>
<td>10-50</td>
<td>12</td>
</tr>
<tr>
<td>Normalized beam emittance</td>
<td>&lt; 5 mm mrad</td>
<td>3 - 5 mm mrad</td>
</tr>
<tr>
<td>FEL wavelength</td>
<td>13 μm</td>
<td>31 μm</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>78.17 kHz</td>
<td>78.17 kHz</td>
</tr>
<tr>
<td>CW beam</td>
<td>&lt;400 μA</td>
<td>150 μA</td>
</tr>
</tbody>
</table>

Courtesy of Erdong Wang
JLEIC Baseline: strong cooling

ERL cooler (20-55 MeV) + Multi-turn circulator ring

(400kV) Magnetized source
Cathode field 0.05 T

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
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<tbody>
<tr>
<td>Bunch charge</td>
<td>3.2 nC</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>43.3 MHz</td>
</tr>
<tr>
<td>( \text{I}_{\text{ave}} )</td>
<td>140 mA</td>
</tr>
<tr>
<td>Bunch length ( \text{ps rms} )</td>
<td>24</td>
</tr>
<tr>
<td>Energy spread ( \text{p-p} )</td>
<td>(6 \times 10^{-4})</td>
</tr>
<tr>
<td>Normalized emittance (uncorrelated)</td>
<td>10 mm-mrad</td>
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</table>
Electron beam is being used inside cooling solenoid where it suffers an azimuthal kick when it enters. This kick is cancelled by an earlier kick at exit of cathode solenoid.

Electrons born in strong uniform $B_z$

Upon exit of Cathode Solenoid

Upon entering Cooling Solenoid

Cartoon of the proposed JLEIC magnetized beam injector

Courtesy of Riad Suleiman

Courtesy of Steve Benson
Some of the challenges for the electron source required by proposed cooling schemes

conventional (magnetized beam)  
coherent (FEL-based)  
micro-bunching

Beam challenges

• Bunch charge \( \sim 1 \text{ to } 5 \text{ nC} \)
• Average current \( \sim 10 \text{ to } 100 \text{ mA} \text{ CW} \)
• Energy spread \(< 10^4 \text{ p-p} \)
• Top-hat longitudinal bunch shape

Gun operability challenges

• Photocathode lifetime \( \sim 10 \text{ kC / cathode} \)
• One cathode per day, changeout in a few minutes
• Cathode gradient \( \sim 10 \text{ MV/m} \)
The quest for robust high current photocathodes

Synthesis and x-ray characterization of Cesium Telluride photocathodes

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Collider-Accelerator Department, Brookhaven National Laboratory

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Thermal Degradation of Alkali Antimonide Cathodes

Zihao Ding, Siddharth Karkare, Jun Feng, Daniele Filippetto, Matthew Johnson, Steve Virostek, Fernando Sannibale, James Nasiatka, Mengjia Gaowei, John Sinsheimer, Erik Muller, John Smedley, and Howard Padmore

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Finding the perfect balance between lifetime and QE