JLEIC Design Update (Oct. 2018)

Rik Yoshida for the JLEIC Collaboration

Oct 22, 2018, INT, Seattle
• Extensive center-of-mass energy range, from \( \sim 20-100 \text{ GeV} \), upgradable to \( \sim 140 \text{ GeV} \), to map the transition in nuclear properties from a dilute gas of quarks and gluons to saturated gluonic matter.

• Ion beams from deuterons to the heaviest stable nuclei.

• Luminosity on the order of 100 to 1,000 times higher than the earlier electron-proton collider Hadron-Electron Ring Accelerator (HERA) at Deutsches Elektronen-Synchrotron (DESY), to allow unprecedented three-dimensional (3D) imaging of the gluon and sea quark distributions in nucleons and nuclei.

• Spin-polarized (\( \sim 70 \% \)) electron and proton/light-ion beams to explore the correlations of gluon and sea quark distributions with the overall nucleon spin. Polarized colliding beams have been achieved before only at HERA (with electrons and positrons only) and Relativistic Heavy Ion Collider (RHIC; with protons only).

• One or more interaction regions, which integrate the detectors into the collider and preserve the extensive kinematic coverage for measurements.

• \( \sqrt{s_{ep}} \) range \( \sim 20 \text{ to } \sim 100 \text{ GeV} \), upgradable to \( \sim 140 \text{ GeV} \)

• Ion beams from D to heaviest stable nuclei

• 100 to 1000 times HERA luminosity—will discuss what this means

• At least \( \sim 70\% \) polarization for electrons, protons and light ions

• One or more IR with integrated detector with high acceptance
Fundamental concept unchanged

This update:
• Increase $\sqrt{s}$ range by increasing ion ring dipoles from $3T \to 6T$.
• Keep the land footprint of the design the same.
• The luminosity performance satisfies the requirements.
• IR design retains high acceptance.
• Polarization remains high.
• Relatively small design changes.

Update History:
2015
arXiv:1504.07961

2017

2018
Document
Under development
JLEIC Design Update (Oct. 2018)

beam energy range:
\[ E_e: \ 3 \text{ to } 12 \text{ GeV} \ (\text{same as before}) \]
\[ E_p: \ 30 \text{ to } 200 \text{ GeV} \ (\text{enabled by } 3T \rightarrow 6T \text{ dipoles}) \text{ upgradable to } 400 \text{ GeV} \ (\text{use HE-LHC/FCC development — } 12T \text{ dipoles}) \]

JLEIC Energy: \( \sqrt{s} = 20 \text{ to } 100 \text{ GeV} \text{ upgradable to } 140 \text{ GeV} \)

Most of the design remains the same

- **Electron complex** (unchanged)
  - CEBAF
  - Electron collider ring

- **Ion complex** (mainly incremental changes)
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring (3T \( \rightarrow \) 6T dipoles)

- Fully integrated high-acceptance IR (being re-optimized for higher energies)

  - **detector**
    - 2 IRs with same acceptance

- DC and bunched beam **coolers** (incremental changes + no BBC concept)
High luminosity: multi-phased cooling

- DC cooling for emittance reduction
- BBC cooling for emittance preservation against intra-beam scattering

<table>
<thead>
<tr>
<th>Ring</th>
<th>Functions</th>
<th>Kinetic energy (GeV / MeV)</th>
<th>Cooler type</th>
</tr>
</thead>
<tbody>
<tr>
<td>booster ring</td>
<td>Accumulation of positive ions</td>
<td>Proton: 0.1 (injection)</td>
<td>DC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead ion: 0.054</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintain emitt. during stacking</td>
<td>Electron: 6.0 (proton)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DC</td>
</tr>
<tr>
<td>collider ring</td>
<td>Maintain emitt. during stacking</td>
<td>Proton: 11 (injection)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead ion: 3 (injection)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-cooling for emitt. reduction</td>
<td>Electron: 6.0 (lead)</td>
<td>DC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maintain emitt. during collision</td>
<td>Up to 200</td>
<td>BBC/ERL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 78.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Up to 109</td>
<td></td>
</tr>
</tbody>
</table>

4.3 MeV DC Cooler @Fermilab
Bunched Beam Cooling

**Enabling technologies:**
- Fast kickers, risetime <1 nsec
- Magnetized source ~75mA

**Diagram:**
- Top ring: CCR
- Bottom ring: ERL

**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Energy</td>
<td>[MeV]</td>
<td>20–110</td>
</tr>
<tr>
<td>Charge</td>
<td>[nC]</td>
<td>3.2</td>
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<tr>
<td>CCR pulse frequency</td>
<td>[MHz]</td>
<td>476.3</td>
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<tr>
<td>Gun frequency</td>
<td>[MHz]</td>
<td>43.3</td>
</tr>
<tr>
<td>Bunch length (tophat)</td>
<td>[cm, °]</td>
<td>3 / 23</td>
</tr>
<tr>
<td>Thermal (Larmor) emittance</td>
<td>[mm-mrad]</td>
<td>&lt;19</td>
</tr>
<tr>
<td>Cathode spot radius</td>
<td>[mm]</td>
<td>3.1</td>
</tr>
<tr>
<td>Cathode field</td>
<td>[T]</td>
<td>0.05</td>
</tr>
<tr>
<td>Normalized hor. drift emittance</td>
<td>[mm-mrad]</td>
<td>36</td>
</tr>
<tr>
<td>rms Energy spread (uncorr.)*</td>
<td></td>
<td>3×10^{-4}</td>
</tr>
<tr>
<td>Energy spread (p-p corr.)*</td>
<td></td>
<td>&lt;6×10^{-4}</td>
</tr>
<tr>
<td>Solenoid field</td>
<td>[T]</td>
<td>2</td>
</tr>
<tr>
<td>Electron beta in cooler</td>
<td>[cm]</td>
<td>37.6</td>
</tr>
<tr>
<td>Solenoid length</td>
<td>[m]</td>
<td>4×15</td>
</tr>
<tr>
<td>Bunch shape</td>
<td></td>
<td>beer can</td>
</tr>
</tbody>
</table>
High polarization: Figure-8

- **Figure-8 concept**: spin precession in one arc is exactly cancelled in the other

- **Spin stabilization by small fields**: \(~3 \text{Tm vs.} \sim 400 \text{Tm}\) for deuterons at 100 GeV
  - Criterion: induced spin rotation \(\gg\) spin rotation due to orbit errors

- **Highly polarized deuteron beams will run in JLEIC**

- **3D spin rotator**: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring

- No effect on the orbit

- Adiabatic spin flips

- **Spin tracking** in progress

<table>
<thead>
<tr>
<th>E- energy (GeV)</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Pol. Lifetime (hours)</td>
<td>66</td>
<td>5.2</td>
<td>2.2</td>
<td>1.3</td>
<td>0.8</td>
</tr>
</tbody>
</table>

- Polarization for proton, light ions (incl. deuterons), electrons \(>80\%\).
In HERA-2, ~600 pb\(^{-1}\) of integrated luminosity was delivered (to ZEUS) over ~1000 days of running.

The means that HERA-2 delivered ~0.6 pb\(^{-1}\)/day or ~4 pb\(^{-1}\)/week of integrated luminosity during “running”. There were two collider experiments, so inflate this a little to 6 pb\(^{-1}\)/week.

6 pb\(^{-1}\)/(one week in seconds) = \(10^{31}\) cm\(^{-2}\)s\(^{-1}\)

This is the average luminosity of HERA while running.

We would like to have 100 – 1000 times HERA luminosity: So the aim for the EIC is 0.6 fb\(^{-1}\) to 6 fb\(^{-1}\)/week of running. Or average luminosity (while running) of \(10^{33}\) to \(10^{34}\) cm\(^{-2}\) s\(^{-1}\)

average while running (not instant, not peak, etc.)

Average luminosity (while running) is quoted for JLEIC.
Average luminosity during running (operational inefficiency taken into account): i.e.
Integrated luminosity = Av. Lumi × Time of running

Luminosity 100 to 1000 time that of HERA over the energy range

Note good perf. w DC only
Average luminosity during operation: i.e.
Integrated luminosity = Av. Lumi × Time

Note: Total of ~640 fb⁻¹
- $10^{34}$ cm⁻²s⁻¹ ➔ 6 fb⁻¹/week,
  ( >100 fb⁻¹/year)
- $10^{33}$ cm⁻²s⁻¹ ➔ 0.6 fb⁻¹/week,
  ( >10 fb⁻¹/year)

Table 1.1: EIC White Paper Luminosity Needs. Units are integrated luminosity in fb⁻¹. Values in parentheses can be acquired concurrently with other measurements. Blank entry does not mean there is no interest; rather that the White Paper does not discuss these measurements explicitly. Polarizations are indicated as unpolarized (U), transverse (T), and Longitudinal (L).
JLEIC SUMMARY

- The basis of the design (ring-ring, high luminosity by high rep-rate, high polarization with Figure-8, full event coverage, and minimization of technical risk) has remained constant since 2005.

- The energy reach is $\sqrt{s} = 20$ to $100$ GeV upgradable to $140$ GeV, using 12 T magnet technology being developed for CERN projects HE-LHC and FCC.

- The design delivers average luminosity of $10^{33-34}$ cm$^{-2}$ sec$^{-1}$ in the almost the entire energy range with only DC cooling.

- The figure-8 design achieves $>80\%$ polarization for both light ions (including deuteron) and electrons.

- A pre-CDR with a full description is under preparation. There may be a minor update to the parameters upon its release.

- The overall design risk is low in most areas.

- Technology demonstration is needed primarily for the bunched beam electron cooling; However, very good performance can be achieved with only DC cooling.