Electron-Ion Collider in the US

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Hard Probes, Aix-les-Bains, Oct 4, 2018
## Electron-Ion Colliders around the world

<table>
<thead>
<tr>
<th></th>
<th>HERA @DESY</th>
<th>LHeC</th>
<th>VLHEeP</th>
<th>eRHIC@BNL</th>
<th>JLEIC@JLAB</th>
<th>HIAF@CAS</th>
<th>ENC@GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{CM} ) (GeV)</td>
<td>320</td>
<td>800-1300</td>
<td>1000-9000</td>
<td>30-140</td>
<td>20-100 ( \times ) 140</td>
<td>12-65</td>
<td>14</td>
</tr>
<tr>
<td>Proton ( x_{\text{min}} )</td>
<td>( 10^{-5} )</td>
<td>( 5 \times 10^{-7} )</td>
<td>( 10^{-7-8} )</td>
<td>( 2 \times 10^{-5} )</td>
<td>( 5 \times 10^{-5} )</td>
<td>( 3 \times 10^{-4} )</td>
<td>( 5 \times 10^{-3} )</td>
</tr>
<tr>
<td>Ion type</td>
<td>p</td>
<td>p to HI</td>
<td>p to HI</td>
<td>p to HI</td>
<td>p to HI</td>
<td>p to HI</td>
<td>p to (^{40})Ca</td>
</tr>
<tr>
<td>Ion polarization</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>p, d, (^{3})He,(^{6})Li</td>
<td>p,d,(^{3})He,(^{6})Li</td>
<td>p,d,(^{3})He</td>
<td>p,d</td>
</tr>
<tr>
<td>L ((/\text{cm}^2/\text{s}))</td>
<td>(2 \times 10^{31} )</td>
<td>(10^{34} )</td>
<td>(10^{28-29} )</td>
<td>(10^{33-34} )</td>
<td>(10^{33-34} )</td>
<td>(10^{33-35} )</td>
<td>(10^{32} )</td>
</tr>
<tr>
<td>IP</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>When</td>
<td>1992-2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Upgrade</td>
<td>Upgrade</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>to HIAF</td>
<td>to FAIR</td>
</tr>
</tbody>
</table>

US Based EIC at most 1 will be built

+FCCeh
Uniqueness of US EIC among all DIS Facilities

All DIS facilities in the world.

However, if we ask for:

- high luminosity & wide reach in $\sqrt{s}$
- polarized lepton & hadron beams
- nuclear beams

EIC is a unique facility ...
History of US EIC

NSAC 2007 Long-Range Plan:

“An Electron-Ion Collider (EIC) with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier. EIC would provide unique capabilities for the study of QCD well beyond those available at existing facilities worldwide and complementary to those planned for the next generation of accelerators in Europe and Asia.”

2013 EIC White Paper

NSAC 2015 Long-Range Plan: RECOMMENDATION III

We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB.

National of Academy of Sciences : 2018 Assessment of US EIC

In summary, the committee finds a compelling scientific case for such a facility. The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would advance accelerator science and technology in nuclear science; it would as well benefit other fields of accelerator-based science and society, from medicine through materials science to elementary particle physics.
Findings of the NAS committee

Main Findings

• **Finding 1:** An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:
  — How does the **mass** of the nucleon arise?
  — How does the **spin** of the nucleon arise?
  — What are the **emergent properties** of dense systems of gluons?

• **Finding 2:** These three high-priority science questions can be answered by an EIC with **highly polarized beams** of electrons and ions, with **sufficiently high luminosity** and sufficient, and variable, center-of-mass **energy**.

Further findings

• **Finding 3:** An EIC would be a unique facility in the world and would maintain U.S. leadership in nuclear physics.

• **Finding 4:** An EIC would maintain U.S. leadership in the accelerator science and technology of colliders and help to maintain scientific leadership more broadly.

• **Finding 5:** Taking advantage of existing accelerator infrastructure and accelerator expertise would make development of an EIC cost effective and would potentially reduce risk.

• **Finding 6:** The current accelerator R&D program supported by DOE is crucial to addressing outstanding design challenges.

• +3 more
Progress in pQCD Theory (~1980-~2010)

Parton Distribution Functions:
Longitudinal only—
No way to interpret nucleon partonic structure in rest frame

3D (Transverse) Structure
TMD’s, GPD’s—
Now we know what to measure to understand the 3D structure of nucleons

Transverse Momentum Dependent Distributions (TMD): $k_t$
Generalized Parton Distributions (GPD): $b_t$
QCD at Extremes: Parton Saturation

HERA discovered a dramatic rise in the number of gluons carrying a small fractional longitudinal momentum of the proton (i.e. small-$x$).

This cannot go on forever as $x$ becomes smaller and smaller: parton recombination must balance parton splitting.

i.e. Saturation—unobserved at HERA for a proton. (expected at extreme low $x$ and high $Q^2$)

In nuclei, the interaction probability geometrically enhanced by $A^{\frac{2}{3}}$?

Will nuclei saturate faster as color leaks out of nucleons?

The Electron-Ion Collider
US-Based EIC Proposals

Jefferson Lab
Newport News, VA

2002 JLab Concept
Needed Collision Energy and Luminosity

EIC Whitepaper and NAS report

• (Center of mass) Energy Range $\sim 20$ to $\sim 100$ GeV, upgradable to $\sim 140$ GeV.
• Luminosity: $\sim 10^{33-34}$ cm$^{-2}$ s$^{-1}$
• Highly polarizable electron and proton/light-ion beams ( $> 70\%$)

AND

• Ion beams from deuteron to heavy nuclei (e.g. lead)
• Possibility of having more than one interaction point.
current data for Collins and Sivers asymmetry:

- COMPASS \( h^\tau; P_{hT} < 1.6 \text{ GeV} \)
- HERMES \( x^0, K; P_{hT} < 1 \text{ GeV} \)
- JLab Hall-A \( \pi^\tau; P_{hT} < 0.45 \text{ GeV} \)
- JLab 12 (upcoming)
- RHIC 500 GeV \(-1 < \eta < 1 \text{ Collins}\)
- RHIC 200 GeV \(-1 < \eta < 1 \text{ Collins}\)
- RHIC 500 GeV \(1 < \eta < 4 \text{ Collins}\)
- STAR W bosons
- STAR-pp DY \( \sqrt{s} = 500 \text{ GeV}\)

**EIC \( \sqrt{s} = 100 \text{ GeV}, y = 0.95 \)**

**upgrade EIC \( \sqrt{s} = 140 \text{ GeV}, 0.95 \leq y \leq 0.95 \)**

**EIC \( \sqrt{s} = 20 \text{ GeV}, y = 0.05 \)**
Luminosity Needs from the EIC whitepaper

<table>
<thead>
<tr>
<th>Physics</th>
<th>WP reference</th>
<th>eP low (~20 GeV)</th>
<th>eP medium (~40 GeV)</th>
<th>eP high (~65-100 GeV)</th>
<th>eP Phase II (140 GeV)</th>
<th>eD or e3He</th>
<th>eCa</th>
<th>eAu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gluon Spin (UL)</td>
<td>Table 2.1</td>
<td></td>
<td></td>
<td>(10)</td>
<td>(10)</td>
<td></td>
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<tr>
<td>Quark TMD (LL+LT)</td>
<td>Fig 2.15, 2.16</td>
<td>10+10</td>
<td></td>
<td>(10+10)</td>
<td>(10+10)</td>
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<tr>
<td>Gluon TMD (LL+LT)</td>
<td>Fig 2.17</td>
<td></td>
<td></td>
<td>100+100</td>
<td></td>
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<td></td>
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<tr>
<td>DVCS/VM (LL+LT)</td>
<td>Fig. 2.21, 2.26</td>
<td>100+100</td>
<td></td>
<td>(100+100)</td>
<td></td>
<td></td>
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<tr>
<td>DVCS eD (LL+LT)</td>
<td>Sec. 2.4.6</td>
<td></td>
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</tr>
<tr>
<td>Saturatio n(UU)</td>
<td>Fig. 3.16, 3.17,3.18,3.20 etc.</td>
<td></td>
<td>(10)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

luminosity in $\text{\ fb}$. Datasets in () indicates can be concurrently taken with another dataset. Blank entry does not mean there is no interest; merely that WP does not discuss explicitly.
EIC Users Group

Formed 2016, currently: 822 members
173 institutions, 30 countries
EIC write-ups & Lab brochures

- Recent EIC write-up in CERN Courier:
  Article written by Elke Aschenauer (BNL) and Rolf Ent (JLab)

- EIC fact-sheet:

- EIC brochure:
EIC Realization Imagined

With a formal NSAC/LRP recommendation, and a very positive NAS committee report what can we speculate about the EIC timeline?

- DOE project “CD0” (Establish Mission Need) will be after the NAS study: 2019.

- EIC construction has to start after FRIB completion, with FRIB construction anticipated to start ramping down near or in FY20.

→ **Most optimistic** scenario would have EIC construction start (CD3) in FY21, perhaps more realistic FY22-23 timeframe

→ Best guess for EIC completion assuming formal NSAC/LRP recommendation would be 2025-2030 timeframe