The Electron-Ion Collider

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UK Nuclear Physics Community Meeting,
University of Warwick,
5th January 2018
Electron-Ion Collider

World’s first polarized electron–proton/light ion and electron–Nucleus collider.

For e–N collisions at the EIC:
✓ Polarized beams: e, p, d/\(^3\)He
✓ e beam 3 – 10 (18) GeV
✓ Luminosity \(L_{\text{ep}} \sim 10^{33-34} \text{ cm}^{-2}\text{s}^{-1}\)
✓ 20 – 100 (140) GeV Variable CoM

For e–A collisions at the EIC:
✓ Wide range of nuclei
✓ Luminosity per nucleon same as e–p
✓ Variable centre of mass energy

Two proposals for realisation of the science case:

**JLEIC @ Jefferson Lab**

**eRHIC @ Brookhaven National Lab**

Design in flux: physics case evolving, machine and detector design developing.
Some questions for the EIC

What is the full composition of nucleon spin? How much do sea quarks and glue contribute?

What is the quark-gluon origin of the nuclear force?

How do hadrons and nuclei emerge from quarks and gluons? What is the nature of confinement?

How does colour charge propagate through nuclear matter?

What is the origin of nucleon mass and what is the role of glue in it?

Where does gluon saturation set in?


Physics case still evolving!
EIC timeline

- **2007 Nuclear Physics Long Range Plan:** “The EIC is embodying the vision of reaching the next QCD frontier”


- **2015 Nuclear Physics Long Range Plan:** “high-energy, high-luminosity polarised EIC as the highest priority for new facility construction following completion of FRIB”

- **2016 EIC Users Group acquires formal charter, representatives (including one for Europe) are elected to the board. Bi–annual meetings in the US.**

- **2017 First European meeting of EICUG held in Trieste, Italy, in July.**

- **2017 National Academies of Science, Engineering and Medicine review of the science case. Expect report in spring 2018.**

- **Indications of a favourable result, CD0 stage ~ 2019.**

- **Construction: ~ some time in the 2020s!**
First UK EIC meeting

Workshop on Physics & Engineering Opportunities at the Electron-Ion Collider 2016

13 - 14 October 2016, Ross Priory on Loch Lomond, Scotland

https://ukeicworkshop2016.wordpress.com
Current UK interest

UNIVERSITY OF GLASGOW

THE UNIVERSITY OF LIVERPOOL

THE UNIVERSITY OF EDINBURGH

The Cockcroft Institute of Accelerator Science and Technology

John Adams Institute for Accelerator Science

UNIVERSITY OF BIRMINGHAM

Science & Technology Facilities Council

Daresbury Laboratory

Plus some tentative interest from other groups…
“Precision Central Silicon Tracking & Vertexing for the EIC”
Peter Jones, Laura Gonella, Paul Newman, Phil Allport, …
Proposal to the EIC detector advisory committee in June 2016, for EIC generic detector R&D.

Successful collaboration of nuclear, particle and instrumentation groups, synergies with existing R&D projects.

“Challenges for next-generation DIS facilities”: proposal for the Horizon-2020 European Integrating Initiative in Hadron Physics.
Spokesperson: Daria Sokhan
Glasgow, Birmingham, Edinburgh, INFN, Saclay, CNRS, …
A collaborative European effort focussed on EIC detector R&D and simulations.

R&D in ERL technology: synergies with currently funded projects (UK–FEL), direct relevance for EIC.
3 new PhD projects funded, start 2018 (Cockcroft)
Strong, existing connections to both JLab and BNL.
Several accelerator SOIs in preparation

Community document on the UK interest in the EIC: just started
Summary

Electron–Ion Collider is a becoming the highest priority for US nuclear physics.

The EIC Community: 732 members, 169 institutes, 29 countries.  
http://www.eicug.org

The US EIC leadership is extremely positive about UK, and other European, involvement and significant contributions, e.g.:

- Funding has been granted to the Birmingham project on tracking R&D.
- Concrete accelerator projects have been initiated with both JLab and BNL.

Enthusiastic involvement of European colleagues, e.g.: EIC featured in the 2017 NuPECC Long Range Plan:

“NuPECC highly recognises the science of the EIC project …representing an opportunity for a major step forward in the field of hadron physics.”

“The large communities working on hadron structure both in Europe and the US are working towards and eagerly waiting for the approval of the first polarised Electron-Ion Collider.”

Scale of UK interest is ramping up: requests for funds from international sources, work towards accelerator and nuclear/detector physics SOIs.

Involvement has already started, the EIC project is much closer than the horizon!
Thank you
Back-up
Are there differences for light and heavy quarks?

- How does the nuclear environment affect the quark-gluon distributions and their interactions inside nuclei?
- How does matter respond to a fast moving colour charge?
- Are there differences for light and heavy quarks?
Interpretations of the nucleon

What do spatial distributions tell us?

**Bag Model**: Gluon field distribution is wider than the fast moving quarks.

Gluon radius > Charge Radius

**Constituent Quark Model**: Gluons and sea quarks hide inside massive quarks.

Gluon radius ~ Charge Radius

**Lattice Gauge theory** (with slow moving quarks), gluons more concentrated inside the quarks:

Gluon radius < Charge Radius

Need transverse images of the quarks and gluons in confinement: form factors

Courtesy of A. Deshpande
The puzzle of nucleon spin

Gluons carry a sizeable fraction of nucleon momentum and give rise to transverse momentum of quarks. What is their contribution to nucleon spin? How do sea quarks contribute?

\[ J_q = \frac{1}{2} \Delta \Sigma + L_q + J_g \]

3D imaging of hadrons across the widest range of scales.
Runaway growth of glue at low-x:

“…A small color charge in isolation builds up a big color thundercloud….”

F. Wilczek, in “Origin of Mass” Nobel Prize, 2004

But somewhere it must saturate…

Possible effective theory for the saturated phase: Colour Glass Condensate.


Physics case has already evolved far beyond it!
What will the EIC be able to do?

- Tomography (p/A)
- Transverse Momentum Distribution and Spatial Imaging
- Spin and Flavor Structure of the Nucleon and Nuclei
- Parton Distributions in Nuclei
- QCD at Extreme Parton Densities - Saturation

Luminosity (cm$^{-2}$ sec$^{-1}$)

Integrated Luminosity [fb$^{-1}$/yr]

$\sqrt{s}$ (GeV)

$\text{year} = 10^7$ sec
Runaway glue

- Nucleon probed at low $Q^2$, high $x$.

- Nucleon probed at large $Q^2$, low $x$.

- Gluons are charged under colour: can generate (and absorb) other gluons.

- Nucleon probed at high energies, time dilation of strong interaction processes: gluons appear to live longer, emitting more and more gluons. Runaway growth! Runaway growth?
Can we reach saturation at EIC?

Saturation regime would be accessible at much lower energy in e-A collisions than e-p. You do not need a TeV collider!

Saturation scale:

\[(Q_s^A)^2 \approx cQ_0^2 \left[ \frac{A}{x} \right]^{1/3}\]

\[L \sim (2m_N x)^{-1} > 2 R_A \sim A^{1/3}\]
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A sign of gluon saturation

A powerful signature is diffractive cross-sections:

\[ \sigma_{\text{diff}} \propto [g(x, Q^2)]^2 \]

Saw ~10% diffractive events at HERA.

Courtesy of A. Deshpande
Gluon saturation

Modified transverse gluon distributions?

Fraction of diffractive events in eAu over that in ep

With Saturation

Without Saturation

Courtesy of A. Deshpande
Saturation/CGC: What to measure?

Many ways to get to gluon distribution in nuclei, but diffraction most sensitive:

\[ \sigma_{\text{diff}} \propto [g(x, Q^2)]^2 \]

At HERA

ep: 10-15% diffractive

At EIC eA, if Saturation/CGC

eA: 25-30% diffractive
EIC Reach: electron / heavy-ion

What do we want from the machine?

- Parton imaging in 3D: high luminosity, $10^{33-34}$ cm$^{-2}$ s$^{-1}$ and above.

- Wide coverage of phase space from low to high x and up to high $Q^2$: variable centre of mass energy.

- Spin structure: high polarisation of electrons (0.8) and light nuclei (0.7).

- Studies of hadronisation, search for saturation at high gluon densities: a wide range of ion species up to the heaviest elements (p -> U).

- Flavour tagging: large acceptance detectors with good PID capabilities.
High luminosity reached through small beam size (small emittance through cooling and low bunch charge with high repetition).

High polarisation through figure-of-8 design (net spin precession is zero, spin controlled with small magnets)
Interaction Region

Possible to get ~100% acceptance for the whole event

Central Detector/Solenoid

Dipole

Forward (Ion) Detector

ZDC

Particles Associated with Initial Ion

Particles Associated with struck parton

Scattered Electron

Dipole

 Ion beamline

Electron beamline

Forward hadron spectrometer

(low-Q² electron detection and Compton polarimeter)
The JLEIC options

Courtesy of F. Pilat
**eRHIC**

- Exploit current 275 GeV proton collider by adding 18 GeV electron accelerator in the same tunnel.

- High luminosity requires novel technologies of coherent electron cooling.

- 20 - 140 GeV CoM energies

- Two designs under consideration for electrons: ERL (energy recovery LINAC) and high intensity electron storage ring.
GPD opportunities at the EIC: I

**DVCS**

- Nucleon tomography at low x: sea quarks and gluons. Gluon distributions accessible via a log dependence of GPDs on $Q^2$.
- Access phase of the Compton amplitude through beam-charge asymmetry (using electron and positron beams) or Rosenbluth separation of cross-sections at different electron energies.

**TCS**

- Asymmetries carry similar information to beam-charge asymmetry in DVCS, without need for positron beams.

**DVMP**

- Flavour-separation of contributions from $q$ and $\bar{q}$ and from gluons.
- $J/\Psi$ production direct access to gluon GPDs.
- Vector meson production allows separation of cross-sections for longitudinal, $\sigma_L$, and transverse, $\sigma_T$, photon polarisation.
- $\pi^+\pi^-$ production is sensitive to differences in $q$ and $\bar{q}$ distributions.
**GPD opportunities at the EIC: II**

**DDVCS**
- Direct access to $x$-dependence of GPDs.

**Measurements on other hadrons**
- Could potentially measure DVCS/DVMP off the virtual pion.
- Light nuclei (He, deuteron) allow measurements off the neutron: flavour separation of GPDs.
- Nuclear DVCS /DVMP: tomography of the nucleus, parton saturation.
- Scattering and $J/\Psi$-production off nuclei with multi-nucleon knockout: short-range correlations, contribution of glue.

*Wide range of $Q^2$ in the valence region will complement valence measurements: can observe scaling violations.*