EIC@JLAB - a medium energy collider
taking nucleon structure beyond the valence region

Tanja Horn

THE CATHOLIC UNIVERSITY OF AMERICA

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Use CEBAF “as-is” after the 12-GeV Upgrade

- MEIC=EIC@JLAB
  - 4 possible IRs
  - 2 initial IRs
- ELIC=high-energy EIC@JLab
  - Limited by JLab site
  - $s=11000$ GeV$^2$

Electron energy: 3-11 GeV
Ion energy: 12-60 GeV

Talk by A. Bogacz
EIC@Jlab Kinematic Coverage

\[ x \sim \frac{Q^2}{ys} \]

\[ Q^2 \text{ (GeV}^2) \]

\[ x \]

\[ \text{HERA, } y=0.004 \quad \text{mEIC 3 on 20, } y=0.004 \]

- mEIC at JLab, 11 on 60 GeV
- JLab 12 GeV
- H1
- ZEUS

P. Nadel-Turonski
Luminosity

\[ \mathcal{L} \]

Detector limit

synchrotron radiation limits

electron current: \( I_e \sim \frac{R}{p_e^4} \)

For fixed ring size, luminosity scales with \( \gamma \)

space charge limits ion current

\[ L \sim \frac{1}{(\text{ring circumference})} \]

Luminosity scales with ion momentum if cooling can shrink the ion beam (\( \varepsilon_p \)):

cooling efficiency \( \sim \frac{1}{p_p^2} \)

A medium-energy ring-ring collider provides a high luminosity over a wide range in \( s \), not only at the end point

\[ \text{Luminosity } \propto I_e I_p \frac{p_p}{\varepsilon_p m_p} \]
The diagram shows the distribution of luminosity across different experiments and processes, with a focus on new physics region $Q^2/\Lambda$.

- **Luminosity** $[\text{cm}^{-2} \text{s}^{-1}]$
  - Different scales for luminosity ranges: $10^{32}$ to $10^{35}$

- **Processes** and experiments:
  - DIS
  - SIDIS
  - JETS
  - DIFF
  - EW
  - (M)EIC
  - MePHIC
  - HERMES
  - ENC@GSI
  - COMPASS

- **Variables**:
  - $s$ $[\text{GeV}^2]$
  - $x$ $\sim Q^2/\Lambda$

- **Experiments**:
  - COMPASS
  - JLAB6&12
  - HERMES
  - ENC@GSI
  - (M)EIC
  - MePHIC

- **Highlights**:
  - The diagram illustrates the spread of data from various experiments, focusing on the new physics region

- **Note**: The diagram is a visual representation of the scientific findings and experimental data collected from different research groups, emphasizing the exploration of nucleon structure beyond the valence region.
1) Gluon and sea quark (transverse) imaging of the nucleon
2) Nucleon Spin ($\Delta G$ vs. $\ln(Q^2)$, transverse momentum)
3) Nuclei in QCD (gluons in nuclei, quark/gluon energy loss)
4) QCD Vacuum and Hadron Structure and Creation
5) Electroweak Physics

### Energies, $s$, luminosity

<table>
<thead>
<tr>
<th></th>
<th>Energies</th>
<th>$s$</th>
<th>luminosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIC@Jlab</td>
<td>Up to 11 x 60</td>
<td>150-2650</td>
<td>Few x $10^{34}$</td>
</tr>
<tr>
<td>Future option</td>
<td>Up to 11 x 250</td>
<td>11000</td>
<td>$10^{35}$</td>
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- Basic consideration: Optimize for nucleon/nuclear structure in QCD
  - access to sea quarks/gluons (high luminosity for $x > 0.01$)
  - deep exclusive scattering at $Q^2 > 10$
e-p beyond 12 GeV: EIC@JLAB

- Hadrons in QCD are relativistic many-body systems, with a fluctuating number of elementary quark/gluon constituents and a very rich structure of the wave function.

- With JLab@12 GeV we study mostly the valence quark component, which can be described with methods of nuclear physics (fixed number of particles).

  → Talk by C. Weiss

- With an EIC@JLab we enter the region where the many-body nature of hadrons, coupling to vacuum excitations, etc., become manifest and the theoretical methods are those of quantum field theory.
(polarized) e-p at medium energies

- **Inclusive DIS**
  - Polarized: $\Delta G$ and $\Delta q+\Delta q$ from global fits (+ RHIC-spin, COMPASS, JLab 12 GeV)
  - Unpolarized: EMC effect, neutron structure from spectator tagging in D(e,e’p)X

- **Semi-inclusive DIS**
  - Unpolarized: Flavor decomposition: q ↔ q, u ↔ d, strangeness s, s
  - Polarized: TMDs: spin-orbit interactions from azimuthal asymmetries, $p_T$ dependence
  - Target fragmentation and fracture functions

- **Charm as direct probe of gluons**
  - $J/\psi$, exclusive: spatial distribution of gluons
  - $D \Lambda_c$, open charm (including quasi-real $D^0$ photoproduction for $\Delta G$)

- **Exclusive processes and GPDs**
  - Non-diffractive: sea quarks from light mesons
  - Diffractive: gluons from DVCS and $J/\psi$; DVCS on nuclei

Experimental requirements

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SIDIS - flavor decomposition

- Higher CM energies give
  - better coverage at small x
  - larger uncertainties at large x (>=0.1)

- Good particle ID range of $E_h=1-10$ GeV suited to relevant range of $z=E_h/\nu$

E. Kinney, J. Seele

100 days at $10^{33}$ cm$^{-2}$ s$^{-1}$ shown, curves are GRSV

Flavor decomposition in SIDIS nucleon/nuclear structure studies favors medium-energy EIC
SIDIS: $P_T$-dependence

Transverse motion through, e.g., spin-orbit interactions, “deformations”

Study for SSA transition from non-perturbative to perturbative regime. EIC will significantly increase the $P_T$ range.

In the perturbative limit $1/P_T$ behavior expected

100 days at $10^{33}$ cm$^2$ s$^{-1}$

H. Avakian
At $x \sim 0.1$ relative kaon rates higher, making it ideal place to study the Sivers asymmetry in Kaon production (in particular $K^-$).

Combination with CLAS12 data will provide almost complete $x$-range.
Polarized Transverse Momentum Distributions (TMDs)

... will greatly benefit from collider

- Particle identification at higher CM energies
  - favors more symmetric kinematics (hadron momenta < 10 GeV)

- Transverse “target” in collider has exceptional figure of merit
  - no beam current limitations (or holding fields)
  - no dilution (low background)
  - high transverse polarization
GPDs and Transverse Imaging

- Deep Exclusive Measurements:
  - Diffractive: transverse gluon imaging $J/\Psi$, $\rho^0$, DVCS
  - Non-diffractive: quark spin/flavor structure $\pi$, $K$, $\rho^+$

Describe correlation of longitudinal momentum and transverse position of quarks/gluons

Transverse quark/gluon imaging of nucleon
GPDs and Transverse Imaging

- Deep Exclusive Measurements:
  - Diffractive: transverse gluon imaging \( J/\Psi, \rho^0, \text{DVCS} \)
  - Non-diffractive: quark spin/flavor structure \( \pi, K, \rho^+ \)

- Experimental requirements:
  - High luminosity (non-diffractive)
  - Good momentum resolution, particle identification and low \( t \)-coverage

- \( \pi \) production, a good illustration of collider kinematics
Transverse imaging: gluons

- Transverse distribution of gluons from exclusive J/ψ
  - $x \leq 10^{-2}$ (HERA, H1, ZEUS, FNAL 82)
  - Large $x$ (fixed target)

- EIC Expectations
  - Cover region $10^{-2} < x < 0.3$
  - Valence structure
  - Hard process is $pp$ at LHC

- Exclusivity, $t$-resolution, recoil proton detection

EIC: gluon imaging up to valence region $x \sim 0.3$
Transverse imaging: gluons

Exclusive gamma $p \rightarrow J/\psi^+ p$: much wider angular spread of recoil proton at lower energies

- $-t \sim E_p^2(\theta-180^\circ)^2$

MEIC: better t-resolution at lower proton beam energies
Pushes for lower and more symmetric energies (to obtain sufficient $\Delta M_x$)

- Much more demanding in luminosity
- Physics closely related to JLab 6/12 GeV
  - Quark spin/flavor separations
  - Nucleon/meson structure
- Simulation for $\pi^+$ production assuming 100 days at a luminosity of $10^{34}$ with 5 on 50 GeV ($s=1000$)
  - V. Guzey, C. Weiss: Regge model
  - T. Horn: empirical $\pi^+$ parameterization

→ Tanja Horn, EICC meeting, Berkeley Dec. 2008
Non-diffractive: extension to quark imaging

Rate estimate for $K\Lambda$

Using an empirical fit to kaon electroproduction data from DESY and JLab assuming 100 days at a luminosity of $10^{34}$, with 5 on 50 GeV ($s = 1000$)

Pushes for lower and more symmetric energies (to obtain sufficient $\Delta M_x$) and luminosity > $10^{34}$

Consistent with back-of-the-envelope scaling arguments

Tanja Horn, David Cooper
- Detector offers very good acceptance
- It is well suited to symmetric kinematics
- **Particular attention has been paid to baryon recoil detection**
- Low-$Q^2$ tagger can be easily implemented
More symmetric kinematics improve detector acceptance (hermeticity), particle identification, and resolution (momentum and angular).

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Deep Exclusive – recoil baryon kinematics

\[ \frac{\delta t}{t} \sim \frac{t}{E_p} \rightarrow \text{lower } E_p \text{ better} \]

- Symmetric kinematics greatly improve acceptance (t-coverage)
- Forward detection needed to reach very low \(-t\)
  - Long magnet free space between IP and first beam quad
  - Spreader magnet for recoil protons
  - Calorimeter for recoil neutrons (angular information only)

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EIC@JLab Trigger Working Group

- JLab trigger development is being consolidated into a single project
  - Phase I: 6 GeV Hall B trigger (in use)
  - Phase II: 12 GeV triggers for Halls B (CLAS12) and D (GlueX)
  - Phase III: EIC trigger (working group established for EIC@JLab)

- Development of the advanced CLAS12 trigger and the high data rate GlueX trigger puts JLab at the forefront of this technology.

- The EIC trigger will be capable of handling high luminosities (> $10^{34}$ cm$^{-2}$ s$^{-1}$), event rates (0.1-1 MHz range), bunch crossing frequencies (GHz range), and detector occupancies (backgrounds).

- Features will include vertex determination from simple tracking, geometric matching between Cerenkovs and calorimeter, and shower shape analysis.
The main goal of the simulation working group is to provide:

- Event generators for various processes
- Fast Monte Carlo to explore acceptance and resolution requirements
- GEANT4 based Monte Carlo to study detector resolution and acceptance
- Event Reconstruction for GEANT based MC

GEANT4 MC will use the standard CLAS12 engine, GEMC.

- Flexible design uses external, implementation independent field map and detector geometry servers.
- Implementation of EIC detector into this framework will begin in November.
- Support for digitizations, etc provides data that can be used for full event reconstruction.
- Package will be maintained and developed together with CLAS12.
EIC@JLAB - further info

- EIC@JLAB webpage: http://eic.jlab.org
  - Overview and general information

- EIC@JLAB WIKI: https://eic.jlab.org/wiki
  - Ongoing project information
  - Working groups

- EIC@JLAB at the JLab Exclusive Reactions Workshop:
  - One-day workshop on EIC@JLAB science in May 2010

- Weekly project meetings at JLab
  - Fridays at 9:30am in ARC724 or F324/25

- Series of topical workshops starting in 2010
Summary

- The EIC@JLab is well suited for taking JLab beyond 12 GeV
  - Excellent tool to access nucleon/nuclear structure

- A medium energy collider is particularly appealing for measurements requiring *transverse targets* and/or good *resolution* and *particle id* (e.g., TMDs, GPDs).
  - These processes benefit from high *luminosity*, excellent *polarization*, and more *symmetric* collision kinematics.

- Matches *energy*, *luminosity*, and detector/IR for deep exclusive and SIDIS processes

- Rapidly Expanding User Community