Future Facilities and Experiments

Summary

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University of South Carolina

Yulia Furletova
Thomas Jefferson National Accelerator Facility
Polarized Drell-Yan at Fermi Lab

Andrew Chen

**Polarized Drell-Yan**

\[ p_{\text{beam}} \rightarrow f^{1+}(x_1) \]

\[ q_{\text{beam}} \rightarrow \gamma^* \rightarrow f^{1-}(x_2) \]

**E1039 Seaquest Experiment**

\[
A_N^{DY} \propto \frac{\sum_q e_q^2 [f_1^q(x_1) \cdot f_{1T}^q(x_2) + 1 \leftrightarrow 2]}{\sum_q e_q^2 [f_1^q(x_1) \cdot f_1^q(x_2) + 1 \leftrightarrow 2]}
\]

A fixed target Drell-Yan Experiment with polarized target isolates sea quark Sivers TMD to target!

Proton beam on NH\(_3\), ND\(_3\) polarized targets

Measurements of \(A_N\), \(A_Q\) (tensor charge)
STAR Forward Rapidity Upgrade

Kenneth Barish

Forward Instrumentation for STAR Upgrade (I)

<table>
<thead>
<tr>
<th>Detector</th>
<th>pp and pA</th>
<th>AA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECal</td>
<td>~10%/\sqrt{E}</td>
<td>~20%/\sqrt{E}</td>
</tr>
<tr>
<td>HCal</td>
<td>~60%/\sqrt{E}</td>
<td>---</td>
</tr>
<tr>
<td>Tracking</td>
<td>charge separation, photon suppression</td>
<td>0.2&lt;p_T&lt;2 GeV/c with 20-30% 1/p_T</td>
</tr>
</tbody>
</table>

- Comprehensive TMD physics
- Gluon polarization
- pA physics
  - nuclear PDFs (gluon PDFs, sea quark PDFs)
- final-state effects
- saturation (di-hadron correlations, forward γ+jet)

STAR unique kinematics: from high to low x at high Q^2
Spin Physics with sPHENIX

Alexander Bazylevsky

Jet
Di-Jet
Photon and $\gamma$-jet
Hadrons
Hadrons in jet and di-h
Heavy Flavor
h-h, $\gamma$-h, jet-jet, $\gamma$-jet

Gluon polarization $\Delta G$
Transversity
Sivers effect (through Twist-3)
TMD factorization (breaking)

$\sqrt{s}=200$ GeV $|\eta|<1.1$
L=700 pb$^{-1}$ $P=0.6$
Theory curve and band: NNPDF

Jet
Pions
Dir. photons

High-precision $\Delta G$ measurements (at $x>0.05$, $\Delta G_{dx}$-integral precision improvement by a factor of 4
Multiple channels
Complementary to future EIC
The SPD Project at NICA

Roumen Tsenov

The Nuclotron based Ion Collider fAcility (JINR, Dubna)

Physics Highlight: Nucleon Spin Structure
- Drell-Yan Production
- Direct Photons
- Nucleon PDFs via $J/\psi$ Production

<table>
<thead>
<tr>
<th>Ring circumference, m</th>
<th>503.04</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>heavy ions</strong></td>
<td></td>
</tr>
<tr>
<td>energy range for $Au^{79+}$: $\sqrt{s_{NN}}$, GeV</td>
<td>4 - 11</td>
</tr>
<tr>
<td>r.m.s. $\Delta p/p$, $10^{-3}$</td>
<td>1.6</td>
</tr>
<tr>
<td>Luminosity for $Au^{79+}$, cm$^{-2}$ s$^{-1}$</td>
<td>$1 \times 10^{27}$</td>
</tr>
<tr>
<td><strong>polarized particles</strong></td>
<td></td>
</tr>
<tr>
<td>max. $\sqrt{s}$ for polarized $p$, Gev</td>
<td>27</td>
</tr>
<tr>
<td>Luminosity for $p$, cm$^{-2}$ s$^{-1}$</td>
<td>$1 \times 10^{32}$</td>
</tr>
</tbody>
</table>
3D Nucleon Structure with the Solenoidal Large Intensity Device (SoLID) at JLab

Zhiwen Zhao

Projected Uncertainties

Lumi $\sim 1e^{37}/cm^2/s$ (open geometry)

- 3D hadron structure
- TMD (SIDIS on both neutron and proton)
- GPD (TCS, DEMP)
- Gluon and nucleon mass
- $J/\psi$ production at threshold
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?**

### Unique Features

- **polarized electron, proton, and light ion beams (>70%)**
- **$L=10^{33-34} \text{ cm}^{-2}\text{s}^{-1} (ep)$**
- **variable CM energy: 20–100 (140) GeV**

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**National Academy of Sciences Review of Science Merit (2018)**

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**Ep Facilities & Experiments:**

- **Past Colliders**
- **Collider Concepts**
- **Past Fixed Target**
- **Ongoing Fixed Target**
- **EIC Project**
Electron-Ion Collider Designs

Joined R&D programs (cooling, Interaction Region design, backgrounds)
Both labs are working on design optimizations

**eRHIC**

Exploiting existing Hadron complex RHIC
- p: 275 GeV
- Adding ion complex
- e: 5-18 GeV
- $\sqrt{s} \sim 29-141$ GeV
- $L \sim 1 \times 10^{34}$ cm$^{-2}$s$^{-1}$

**JLEIC**

- Exploring existing Electron complex CEBAF
  - e: 3-12 GeV
  - Adding Ion complex
  - p: 20-100(400) GeV
  - $\sqrt{s} \sim 20-65$ (140) GeV
  - $L \sim 4 \times 10^{34}$ cm$^{-2}$s$^{-1}$

**Figure-8:** High polarization (~80%)

- Wide range of nuclear beams D to U,
- High beam polarizations for hadrons and electrons
- Integration of detector and IR
Hadron-Beam Polarimetry at Colliders

Haixin Huang

Polarized Hydrogen Jet Polarimeter (HJet): absolute polarization, but slow

Proton Carbon Polarimeter (pC): very fast and high precision, measures polarization profile and lifetime, but needs to be normalized to HJet

\[ P_{\text{beam}} = P_{\text{target}} \frac{\varepsilon_{\text{beam}}}{\varepsilon_{\text{target}}} \]

\( \varepsilon \): measured left/right asymmetry

EIC Challenges

- increased bunch frequency and number → lose data with highest stat. and analyzing power
- background effect

Mitigations
Spin Physics at EIC

Daniel Boer

- Electroweak Structure Functions, quark and gluon TMDs, GTMDs, and GPDs
- Polarized deuteron
- Specific spin effects probed with particular final states
  - Heavy Quarks: gluon TMDs
  - As and di-hadrons: polarization dependent fragmentation functions
- Synergy and interplay with results from pp and e^+e^- collisions
Spin Physics at EIC

Wim Cosyn

Physics with Light Ions (neutron structure, nucleon interactions in QCD, imaging nuclear bound states)

Neutron Structure with Spectator Tagging

\[ t = (p_R - p_D)^2 \]

Neutron spin structure with tagged DIS \( e^+ D \rightarrow e' + p\text{(recoil)} + X \)

EIC simulation, \( s_{eN} = 2000 \text{ GeV}^2 \), \( L_{\text{int}} = 100 \text{ fb}^{-1} \)

Nuclear binding eliminated through on-shell extrapolation in recoil proton momentum

\[ Q^2 = 10–16 \]

\[ 2.5–4 \]

\[ 4–6 \]

\[ 6–10 \]

\[ 16–25 \]

\[ 25–40 \]

\[ 40–63 \]

Error estimates include extrapolation uncertainty
Spin Physics at EIC

Rick Yoshida

World Data on $F_2^p$  World Data on $g_1^p$  World Data on $h_1^p$

Similar for $F_2^n$

Similar for $g_2^p$, $g_2^n$ (and $b_1^d$)

$F_{UT} \sin(f_h f_S)(x, Q^2) + C(x) \propto h_1$

Note: need to update plots for COMPASS data

An EIC makes it possible!

momentum  spin  transverse spin ~ angular momentum
Study the polarized and unpolarized hadronic structure of the photon

- In QCD, the photon can be considered a superposition of a bare photon state and a hadronic state
- Want to characterize the polarized and unpolarized structure of this hadronic state (photon PDFs)
- EIC cross section data will allow very precise extractions of these PDFs and give access to the polarized structure for the first time

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Spin Physics at EIC

Salvatore Fazio

Studies of GPDs

Current DVCS data at colliders:
- ZEUS- total xsec
- H1- total xsec
- H1- d:x/dt
- H1- A_{CU}

Current DVCS data at fixed targets:
- COMPASS- d:x/dt, A_{CSU}, A_{CST}
- JLAB12- d:x/dt, A_{LU}, A_{UL}, A_{LL}

Planned DVCS at fixed targ.:
- COMPASS- d:x/dt, A_{CSU}, A_{CST}
- JLAB12- d:x/dt, A_{CU}, A_{LL}
- CLAS- A_{LU}, A_{UL}, A_{LL}

EIC $\sqrt{s} = 140$ GeV, $0.01 \leq y \leq 0.95$

EIC $\sqrt{s} = 45$ GeV, $0.01 \leq y \leq 0.6$

Different assumptions for E

Imaging Gluons in Nuclei

Diffractive physics in eA

Measure spatial gluon distribution in nuclei

Reaction: $e + Au \rightarrow e' + Au' + J/\psi, \varphi, \rho$

Momentum transfer $t = |p_{Au} - p_{Au'}|^2$

Physics requires forward scattered nucleus needs to stay intact

Veto breakup through neutron detection
Liang Zhang

The Gluon Sivers Function can be uniquely accessed at EIC.

Dihadron and dijet methods are statistically more favored than open charm production.
3D Nucleon Structure from JLab to EIC

Harut Avakian  

Evolution and $k_T$-dependence of TMDs

- Large acceptance of CLAS12 allows studies of $P_T$ and $Q^2$-dependence of SSAs in a wide kinematic range
- Comparison of JLab12 data with HERMES, COMPASS and EIC will pin down transverse momentum dependence and the non-trivial $Q^2$ evolution of TMD PDFs in general, and Sivers function in particular.
Spin Physics at JLab and EIC

Alessio DelDotto

Neutron Spin Structure from (polarized) spectator (SI)DIS on $^3$He target

$g_1$: n data needed for $x<0.04$ and $x>0.4$; $Q^2>1$ at very small $x$

- $A-1=D \rightarrow g_1^p$ (test of FSI)
- $A-1=pp \rightarrow g_1^n$

Studies of kinematic coverage, detector requirements, and projected uncertainties are ongoing.

James Maxwell

Search for Exotic Glue in Nuclei

double-helicity structure function $\Delta(x,Q^2)$

- In nuclei: from gluons not associated with individual nucleon
- DIS with Unpolarized e beam on transversely polarized nuclear target with spin $\geq 1$
- Clever choice of target polarization direction to cancel out contributions from tensor structure functions $b_1, b_2$
- Various extraction methods (vector and tensor polarizations)
- $^{14}$NH$_3$ target in Hall C
- EIC: $^6$Li (P:88%), $^{23}$Na (77%)
**Electron-Ion Collider in China (EICC)**

Xurong Chen

**EicC-I New construction**
- polarization ion source
- Siberia snake for FRing
- e injector
- SRF Linac-ring
- 4~5 passes
- eRing
- 3~4A SR

**EicC-I**
- 20GeV p + 3.5GeV e
- $\sqrt{s}=16.7\text{GeV}$

**EicC-II**
- 60GeV p + 5GeV e
- $\sqrt{s}=34.6\text{GeV}$

**Center of Mass Energy $\sqrt{s}$ (GeV)**

**Luminosity (cm$^{-2}$s$^{-1}$)**

**C-I: will be constructed at $\sqrt{s} \sim 15 \sim 20$ GeV region**

1) Focus on nuclear physics
2) B-quark hadron production

\[ L \sim 10^{33} \text{ cm}^{-2}\text{s}^{-1} - 10^{35} \text{ cm}^{-2}\text{s}^{-1} \]
Many thanks to all speakers and contributors!