Overview of Electron-ion collider in China

Jinlong Zhang (张金龙), Shandong University

On behalf of the EicC working group
Deeply Inelastic Scattering

Precision microscope with superfine control

\[ Q^2 : \text{Resolution/scale} \]
\[ y : \text{Scattering inelasticity} \]
\[ x : \text{Momentum fraction of struck quark} \]
\[ s : \text{center of mass energy} \]

\[ Q^2 = sxy \]

- **Inclusive events**: \( e + p/A \rightarrow e' + X \)
  Detect the scattered lepton only

- **Semi-Inclusive events**: \( e + p/A \rightarrow e' + h(\pi, K, p, jet, etc) + X \)
  Detect the scattered lepton + identified hadrons/jets

- **Exclusive events**: \( e + p/A \rightarrow e' + p'/A' + h(\pi, K, p, jet, etc) \)
  Detect everything
- How does the spin of proton arise?
- How does the mass of proton arise?
- How does gluon bind quarks and gluons inside proton?
- What are the emergent properties of dense gluon system?
- Can we map the quark and gluon inside the proton in 3D?
Proposed Electron-ion colliders

- LHC ➔ LHeC
- FAIR ➔ ENC
- RHIC ➔ eRHIC/EIC
- HIAF ➔ EicC
Electron-ion colliders in China

HIAF under construction

Location: Huizhou, south coast of China

HIAF ➔ EicC: Take use of facility under construction
HIAF - High Intensity heavy-ion Accelerator Facility

- Funded 2.5 billion RMB, under construction
- for atomic physics, nuclear physics, applied research in biology and material science etc.
- Upgrades to EicC taken into consideration during the design stage

Booster Ring:
- Circumference: 569 m
- Rigidity: 34 Tm
- A accumulation
- Colling & acceleration
- Two-plane painting injections scheme
- Fast ramping rate operation

Superconducting Ion Linac:
- Length: 180 m
- Energy: 17 MeV/u (U^{34+})
- CW and pulsed modes
Layout of EicC

Need to be built for the EicC

- Polarized electron injector + racetrack eRing + Figure 8 pRing
- 2 interaction regions
- 3.5 GeV (e) x 20 GeV (p)

HIAF under construction
EicC Parameters

- EicC covers the kinematic region between JLab experiments and US-EIC.
- EicC complements the ongoing scientific programs at JLab and future EIC project.
- EicC focus on moderate $x$ and sea-quark for spin, exotic hadrons and nuclear modification.
- EicC can systematically study $\Upsilon$ near threshold and shed lights on proton mass origin.
Published in the Frontiers of Physics Journal (open access)

100+ physicists from 46 institutes
Highlighted physics topics

1D spin structure of nucleon

3D and 2+1D tomography of nucleon

Partonic structure of nucleus

Proton mass

Exotic hadron states
1D spin structure of nucleon

\[ \langle S_p \rangle = \frac{1}{2} = \frac{1}{2} \Delta \Sigma + \Delta G + L_q + L_g \]

Jaffe-Manohar 1990

\( \Delta \Sigma \) Quark spin \quad \Delta G \) gluon spin \quad L_{q,g} \) Orbital angular momentum

NLO EicC SIDIS projection:
- Pion(+/-), Kaon(+/-)
- ep: 3.5 GeV x 20 GeV
- eHe-3: 3.5 GeV x 40 GeV
- Pol.: e(80%), p(70%), He-3(70%)
- Lumi: ep 50 fb\(^{-1}\), eHe-3 50 fb\(^{-1}\)

Significantly reduce uncertainties of spin contribution from the sea
3D spin structure at momentum space

Access to quark Sivers function, especially the strange quark Sivers via SIDIS

LO analysis of EicC projection
- Pion(+/−), Kaon(+/−)
- ep: 3.5 GeV × 20 GeV
- eHe-3: 3.5 GeV × 40 GeV
- Lumi: ep 50 fb⁻¹, eHe-3 50 fb⁻¹
- Stat. Error vs Sys. Error

<table>
<thead>
<tr>
<th>Nucleon Polarization</th>
<th>TMDs</th>
<th>Quark Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unpolarized (U)</td>
<td>Longitudinally polarized (L)</td>
</tr>
<tr>
<td>U</td>
<td>f₁</td>
<td>Unpolarized</td>
</tr>
<tr>
<td>L</td>
<td>g₁L</td>
<td>Helicity</td>
</tr>
<tr>
<td>T</td>
<td>f₁T</td>
<td>Sivers</td>
</tr>
<tr>
<td></td>
<td>h₁T</td>
<td>Transversity</td>
</tr>
</tbody>
</table>

- Nucleon spin
- Quark spin
GPDs

- Spatial distribution of partons encoded in GPDs
- GPD is related to quark angular momentum [Ji, 95]
- Access to GPDs via exclusive reactions DVCS, DVMP, etc
- Flavor separation and sea quark GPD in DVMP

Extraction of CFF with neutral network methods [Kumericki, 19]

Only this azimuthal angular modulation
Understanding Proton Mass

Mass decomposition [Ji, 95]

\[ M = M_q + M_m + M_g + M_a \]

- \( M_q \) : quark energy
- \( M_m \) : quark mass (condensate)
- \( M_g \) : gluon energy
- \( M_a \) : trace anomaly

- \( M_q \) and \( M_g \) : constrained by PDFs
- \( M_m \) via \( \pi N \) scattering
- \( M_a \) via threshold production of \( J/\psi \) (8.2 GeV, JLab) and \( \Upsilon \) (12 GeV)
- Threshold requires low CoM energy (low \( y \) at EIC)
- Complementarity between EicC (and EIC) and Lattices.

Lattice QCD, Yang et al 2018
Partonic structure of nucleus

- Use heavy nuclei to study parton energy loss in cold nuclear medium
- Hadronization inside and outside medium. (Nucleus as a lab at the fm scale)
- Medium modification of light meson and heavy meson in SIDIS.
- Precision study of nuclear PDFs with heavy ion beams.

With only a few hours of running
- Complementary to $e^+e^-$ and $pp$ collisions.
- Larger acceptance, exotic hadrons produced at middle rapidity.
- Heavy-flavor exotic hadrons, in particular to charmonium-like states and hidden charm pentaquarks.
- Polarization helps to determine the quantum numbers.
Towards Conceptual Design Reports

Volume I: Accelerator

Contents
1 Overview of EicC
1.1 The Science Goals and the Requirements for EicC
1.2 EicC Design Concept
1.3 Beam Parameters and Luminosity
1.4 Ion Accelerator Complex Design
1.5 Electron Accelerator Complex Design
1.6 Staged Electron Cooling for Ions
1.7 The Interaction Region Design
1.8 Overview Summary

2 Beam Dynamics Design
2.1 EicC Collision Scheme
2.2 Luminosity lifetime
2.3 Collective Effects and Beam Stabilities
2.4 Space Charge Effects
2.5 Beam-Beam Effects
2.6 Intra-beam Scattering

3 Ion Accelerator Complex
3.1 Introduction
3.2 Formation of EicC Ion Beams
3.3 Polarized Ion Source
3.4 iLinac
3.5 Booster Ring
3.6 pRing
3.7 Beam Synchronization
3.8 Polarization and Polarimetry

4 Electron Accelerator Complex
4.1 Introduction
4.2 Polarized Electron Source
4.3 Electron Injector
4.4 eRing
4.5 Synchrotron Radiation and Beam Parameters
4.6 Polarization and Polarimetry

5 Electron Cooling
5.1 Introduction
5.2 Medium Energy Electron Cooler
5.3 ERL Based High Energy Electron Cooler
5.4 Novel cooling scheme development

Volume II: Physics and Detectors

Contents
1 EicC Physics
1.1 One-dimensional spin structure of nucleons
1.2 Three-dimensional tomography of nucleons
1.2.1 TMDs
1.2.2 GPDs
1.3 Nucleon mass
1.4 Partonic structure of nucleus
1.5 Exotic hadronic states
1.6 Structure of light pseudoscalar mesons

2 Physics requirements and detector concept
2.1 Physics requirements
2.1.1 Particle multiplicity and event rate
2.1.2 Scattered electron
2.1.3 Charged hadron identification
2.1.4 Small angle detection
2.2 Detector concept

3 Tracking system
3.1 Vertex detector
3.2 Time projection chamber
3.3 All silicon tracker
3.3.1 All silicon tracker layout
3.3.2 Detector simulation and reconstruction
3.3.3 Tracking and vertexing performance
3.4 Endcap disk

4 PID system
4.1 Detector consideration
4.2 Time of flight detector
4.2.1 MRPC
4.2.2 DIRC-based TOF
4.3 Cherenkov detector
4.3.1 DIRC
4.3.2 Module RICH

5 Calorimetry
5.1 Design consideration
5.2 Scintillation-type ECal
5.2.1 Module design and simulation
5.2.2 Energy and spatial resolution
5.2.3 Detector layout
5.3 Crystal EMCal
5.4 HCal
Conceptual design of the EicC detector

A general purpose detector with:
- Vertex detector;
- Tracking detector;
- Particle Identification detector (ToF & RICH);
- Calorimeter (EM & Hadron)

Detailed full Geant4 simulation is ongoing
Detector R&D

Clean room (200 m²) for detector assembling

Micromegas 25cm x 25cm

GEM 1m x 0.5m

sTGC @SDU

ALICE style ITS2 MAPS pixel detector

DIRC prototype @IMP

Shashlik and W-powder+SciFi EMCal

Clean room (200 m²) for detector assembling
- HIAF construction is near complement
- Aiming to finish EicC CDR by 2023
- Hope to get support in the next 5-year-plan and first collision in 2032
Summary

- Electron-ion collider in China — EicC
  - Focused on sea-quark/gluon at moderated/large-x region
  - Complements EICs at higher energies
- Conceptual design report by 2023
  - Geant4 simulations and detector R&D
- More physics topics under development


Thanks for your attention and welcome to join us!