EicC Status – White Paper

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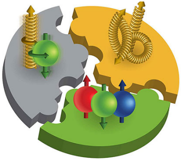
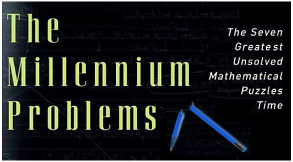
Special thanks to all the contributors and referees

Ultimate Questions and Challenges in Quantum Chromodynamics

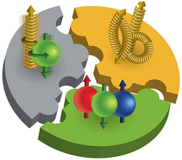


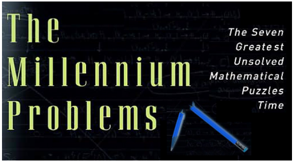


- How does the spin of proton arise? (Spin puzzle)
- What are the emergent properties of dense gluon system?
- How does the mass of the proton arise?
  (Mass gap, a hard million dollar question.)
- How does gluon bind quarks and gluons inside proton?
- Can we map the quark and gluon inside the proton in 3D?
- Proton radius puzzle.

EICs will be the key!

- The Hitchhiker's Guide to the Galaxy. Arguably the most profound sci-fi novel.
- "42" is the simple answer to the ultimate philosophical question of Life, the Universe, and Everything (By an enormous computer over 7.5 million yrs).
- Electron-Ion Colliders can be the answer to the ultimate questions in QCD!





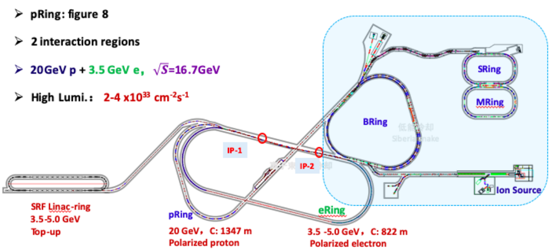
Proposed EIC Facilities Across the Globe

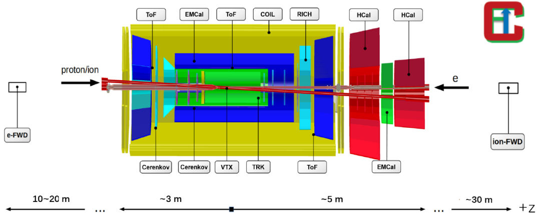
- Electron-Ion colliders will become the cutting-edge high-energy and nuclear physics research facilities in the near future.

Status of the polarized Electron Ion Collider in China

- Based on High-Intensity Heavy Ion Accelerator Facility (HIAF) which is currently under construction in Huizhou (惠州).
- HIAF total investment: 2.5 billion RMB.

Conceptual Design for Accelerator and Detector





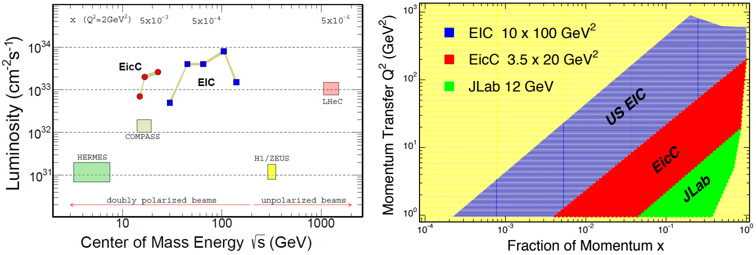
EicC accelerator includes

- Based on HIAF (right)
- pRing (8-shape)
- Electron Polarized Source and Injector.
- eRing (racetrack)
- Two IPs

A general purpose detector with 4 components:

- Vertex detector
- Tracking detector
- Particle Identification Detector (PID) (ToF & RICH)
- Calorimeter (EM & Hadron)

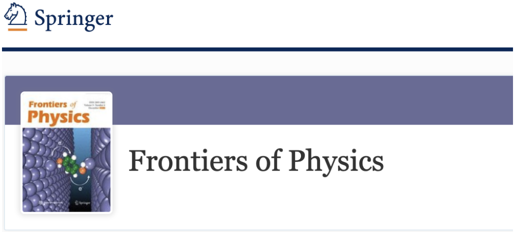
Kinematics



Facility	CoM energy	lum./10^{33}cm^{-2}s^{-1}	Ions	Polarization
EicC	15 - 20	2 - 3	$p \rightarrow$U	e^-, p, and light nuclei
EIC-US	30 - 140	2 - 15	$p \rightarrow$U	e^-, p, ^{3}He, Li

- 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 Υ near threshold and shed lights on proton mass origin.

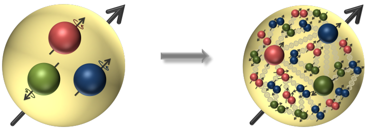
Status of the EicC white paper

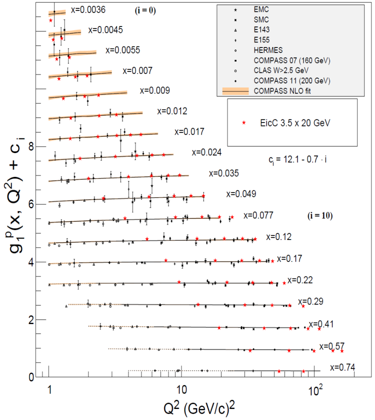


- The white paper effort is lead by a team of 20 conveners and it contains contributions from more than 100 authors across the globe.
- Completed and Submitted for Publication in “Frontiers of Physics".
- Currently under review. Scheduled to be published in December 2020.
- Contents:
  1. Executive Summary
  2. EicC Physics Highlights (Several Physics Goals)
  3. Accelerator Conceptual Design
  4. Detector Conceptual Design

EicC Physics Goals

Understanding Nucleon Spin





Jaffe-Manohar decomposition

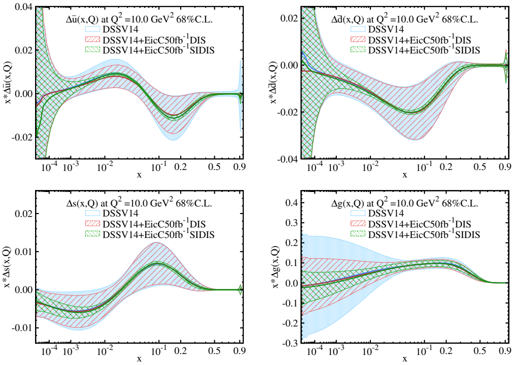
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{\text{Quark}} + \underbrace{\Delta G + L_g}_{\text{Gluon}}$$

- Quark spin $\Delta\Sigma$ is only 30% of proton spin. (g_1 structure func)
- $g_1(x, Q^2) = \frac{1}{2}\sum e_q^2\,[\Delta q + \Delta\bar{q}]$
- EicC: large acceptance and improvement at low-x.
- The rest of the proton spin must come from the gluon spin ΔG, quark and gluon OAM $L_{q,g}$.
- Orbital motions of quark and gluon are essential.
- [χQCD; Yang *et al*, 17]: Gluon $\Delta G \simeq 0.25$

Spin flavor Structure at EicC

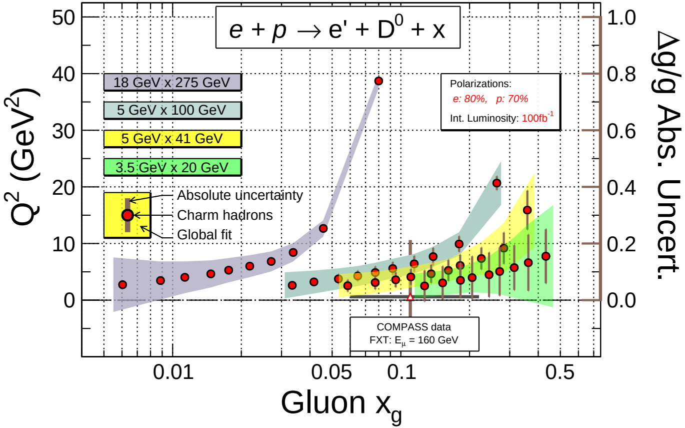
NLO EicC SIDIS projection

- $\pi^{\pm}$ and $K^{\pm}$ mesons
- *ep*: 3.5 GeV $\times$ 20 GeV
- *e*He^3: 3.5 GeV on 40 GeV
- Luminosity *ep* 50 fb^{-1}
- Polarization.: e(80%), p(70%), He^3(70%)
- High precision for sea quark helicity.
- Significantly reduce spin contribution from the sea.



Gluon Helicity at Moderate and Large x

By tagging D meson, EicC can access gluon helicity in moderate and high x regions.



Understanding Proton Mass

Mass decomposition [Ji, 95]

$$M = \underbrace{M_q + M_m}_{\text{Quark}} + \underbrace{M_g + M_a}_{\text{Gluon}}$$

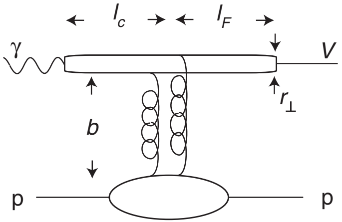
M_q : quark energy

M_m : quark mass (condensate)

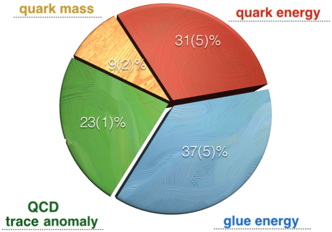
M_g : gluon energy

M_a : trace anomaly

[Kharzeev, *et al*, 99; Brodsky *et al*, 01]



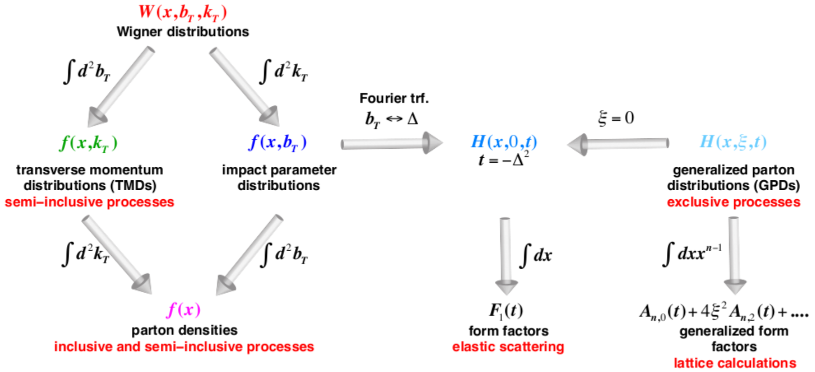
- M_q and M_g constrained by PDFs.
- M_m via πN low energy scattering.
- M_a via threshold production of J/Ψ (8.2 GeV; JLab) and Υ (12 GeV);
- Threshold requires low CoM energy. (Low y at EIC).
- Complementarity between EicC (and EIC) and lattice. Guideline



[χQCD, Yang, *et al*, 18]

3D Tomography of Proton

Wigner distributions [Belitsky, Ji, Yuan, 2004] ingeniously encode all quantum information of how partons are distributed inside hadrons.

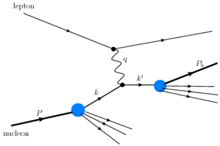


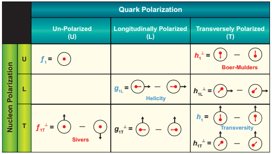
Probing 3D Distributions in Momentum Space with SIDIS

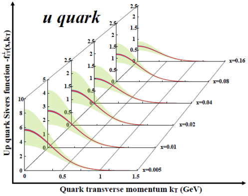
Access to quark Sivers function, especially the strange quark Sivers via SIDIS.

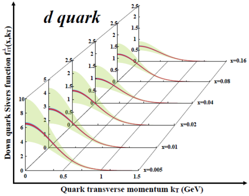
LO analysis of EicC projection

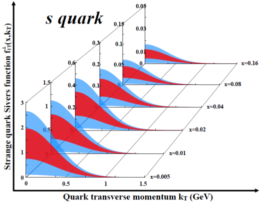
- $\pi^{\pm}$ and $K^{\pm}$ mesons
- *ep*: 3.5 GeV $\times$ 20 GeV
- $e\mathrm{He}^3$: $3.5\times\ 40/3$ GeV
- Luminosity 50 fb^{-1}
- Stat. Error vs Sys. Error



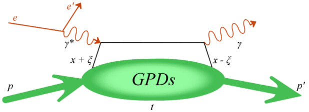


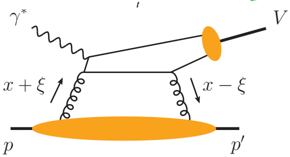






3D Imaging: GPD from DVCS and DVMP



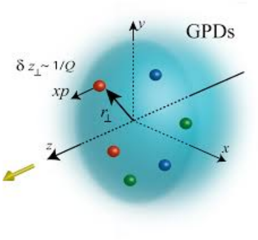


Ji Sum Rule[Ji, 97]:

$$\frac{1}{2} = J_q + J_g$$

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \frac{1}{2}\int dxx\,(H_q + E_q)\ ,$$

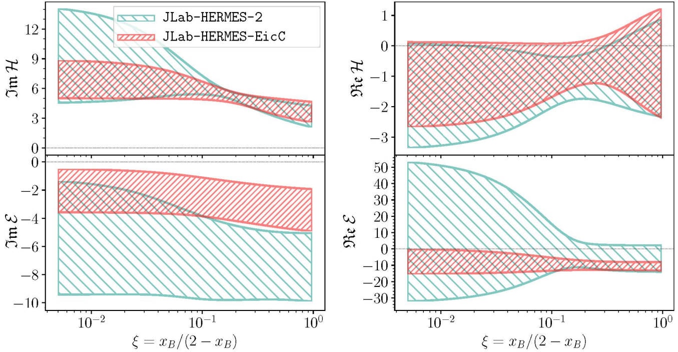
$$J_g = \frac{1}{4}\int dx\,(H_g + E_g)\ .$$



- Measure Compton Form Factors (CFF) which depends on GPDs.
- Allows us to access to spacial distributions (which are related to GPDs via FT) of (valence and sea) quarks in the nucleon.
- Obtain the information about the quark orbital motions L_q indirectly.
- Flavor separation and sea quark GPD in DVMP.

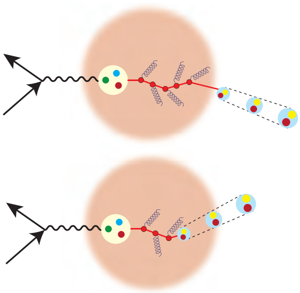
Projected Compton Form Factors

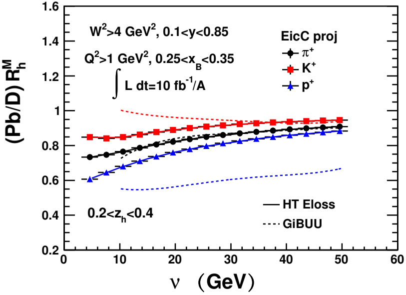
The extraction of CFF using neural network methods[Kumeriki, 19].



- Stats. error with $50\,fb^{-1}$, sys. error not included
- Reduced uncertainty in the sea quark region.

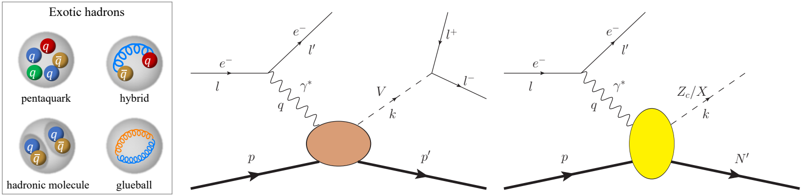
Quark-gluons in cold nuclear medium





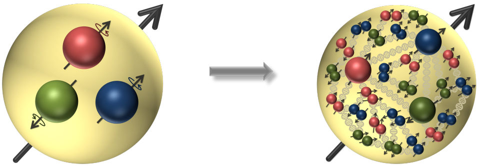
- Use heavy nuclei to study parton energy loss in nuclear medium and hadronization.
- Suppression of light meson and heavy meson in SIDIS.
- May use different hadrons to separate quark and gluon contributions.

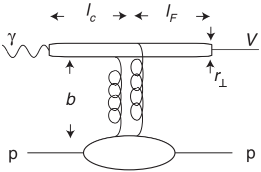
Exotic States



- 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.

Summary





- Fifty years ago, quark and gluon & their interaction discovered. On the other hand, still more questions than answers in QCD!
- Cutting-edge Electron-Ion Colliders will complete our 21st century view of the proton and render us 3D image of protons and heavy nuclei with unprecedented precision; significantly advance our understanding of strong interaction (QCD).
- EicC focuses on sea-quark/gluon at moderate/large-x region ($\Delta g/g$ and 3D).
- EicC can tackle the issue of the trace anomaly contribution to the proton mass at the Υ threshold.
- EIC and EicC are complementary to each other in physics goals.