Updates on the Scientific Opportunities with EicC

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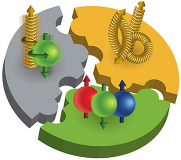
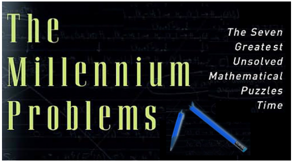
Special thanks to all the contributors

Ultimate Questions and Challenges in Quantum Chromodynamics

To understand the most fundamental composition and dynamics of the physical world, we have to understand QCD!

- 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 keys to unlocking these mysteries!

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.

EicC Preliminary Timeline

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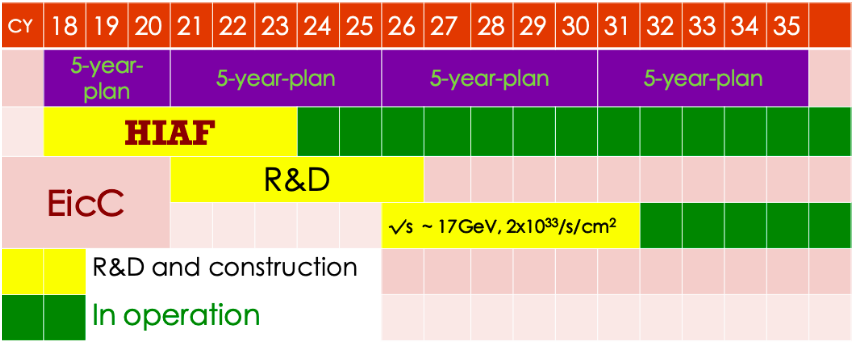
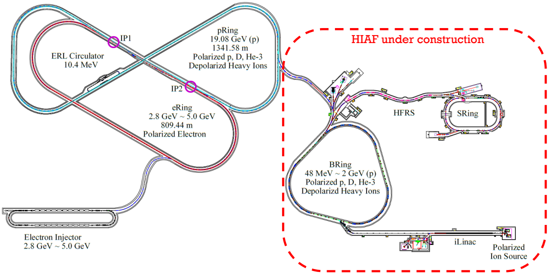
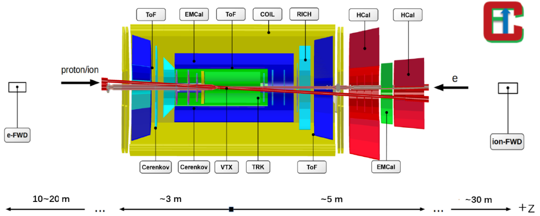


- HIAF is half way through the construction.
- Tech driven schedule: it is like a wish list to be blessed by the funding agency.
- 21-25: Simulations and detector R&D.
- 2026, hope to get supported by the next five-year plan.
- 2032, in operation if everything goes through.

Conceptual Design for Accelerator and Detector





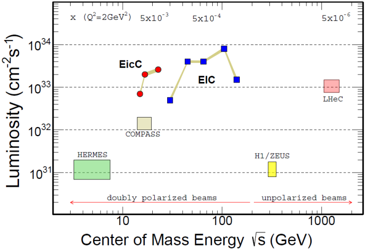
EicC accelerator includes

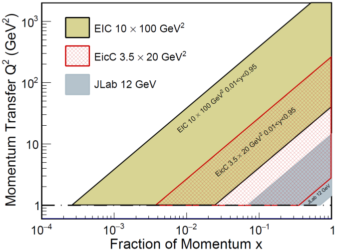
- Based on HIAF (right)
- pRing (8-shape)
- Energy Recovery Linac
- Electron Polarized Source and Injector.
- eRing (racetrack)
- Two IPs reserved.

A general purpose detector with 4 components:

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

Kinematics

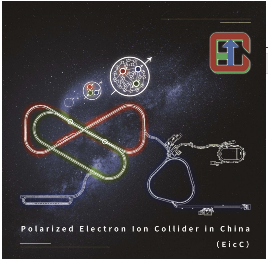




Facility	CoM energy	lum./10^{33}cm^{-2}s^{-1}	Ions	Polarization
EicC	15 - 20	2 - 3	$p \to$U	e^-, p, and light nuclei
EIC-US	30 - 140	2 - 15	$p \to$U	e^-, p, ^{3}He, Li

- 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.

EicC white paper



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REPORT

Electron-Ion Collider in China

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- The white paper effort is lead by a team of 20 conveners and contains contributions from more than 100 authors from 46 institutions across the globe.
- Peer-reviewed and Accepted for Publication in “Frontiers of Physics".
  ▸ Click to Download ▸ arXiv:2102.09222
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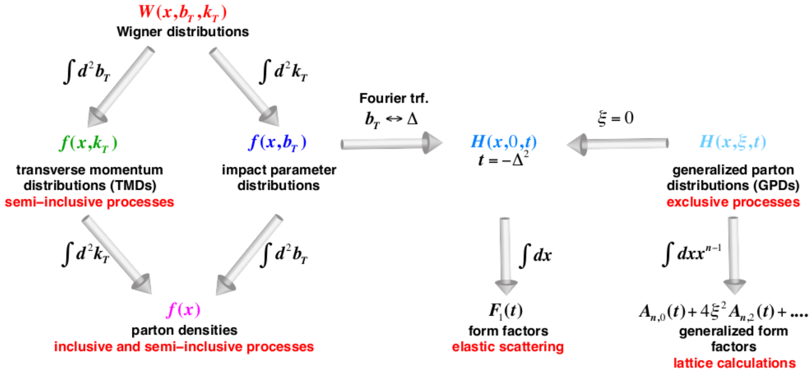
  3. Accelerator Conceptual Design
  4. Detector Conceptual Design

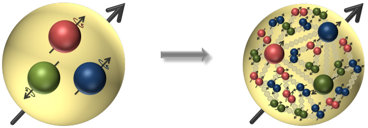
EicC Physics Goals

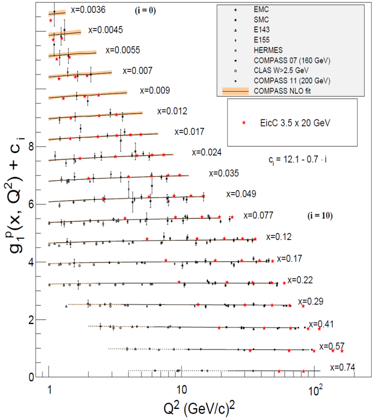
3D Tomography of Proton

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



Understanding Nucleon Spin





Jaffe-Manohar decomposition

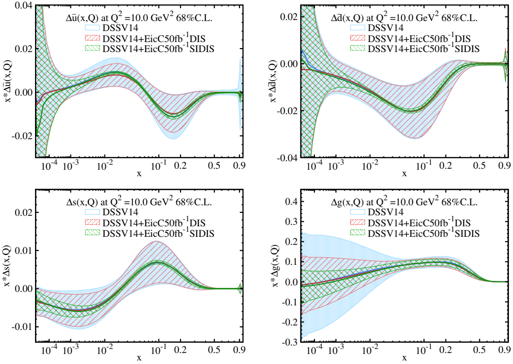
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{\text{Quark}} + \underbrace{\Delta G + L_g}_{\text{Gluon}}$$

- 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 $\Delta G \simeq 0.25$

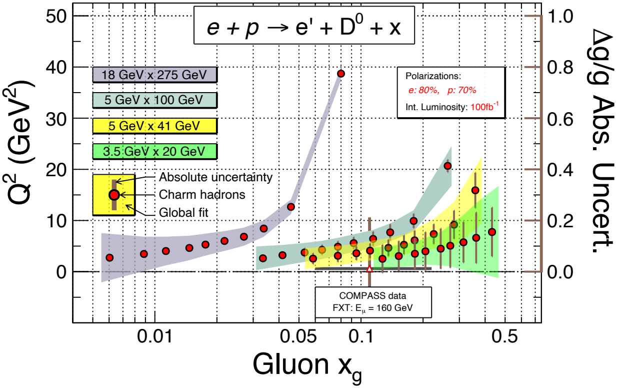
Spin flavor Structure at EicC

NLO EicC SIDIS projection

- $\pi^{\pm}$ and $K^{\pm}$ mesons
- ep: 3.5 GeV $\times$ 20 GeV
- $e\mathrm{He}^3$: 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.
- The position of each data point is according to the mean value of x_g and Q^2.
- The uncertainty for the data points is shown on the right side of the plot.
- The colored band represents the uncertainty calculated using NNPDF PDFs.
- The red triangle marker shows the existing measurement from COMPASS.

Probing 3D Distributions in Momentum Space with SIDIS

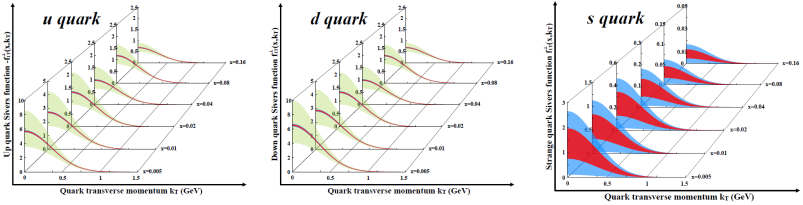
Access to quark Sivers function, especially the strange quark Sivers via SIDIS.

LO analysis of EicC projection

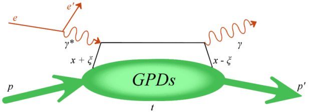
- $\pi^{\pm}$ and $K^{\pm}$ mesons
- ep: 3.5 GeV $\times$ 20 GeV
- $e\mathrm{He}^3$: $3.5\times 40/3$ GeV
- Luminosity 50 fb^{-1}
- Stat. Error vs Sys. Error

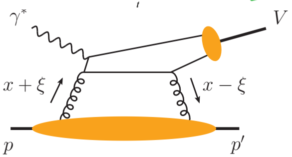
TMDs		Quark Polarization		
		Unpolarized (U)	Longitudinally polarized (L)	Transversely polarized (T)
Nucleon Polarization	U	f_1 unpolarized		$h_1^{\perp}$ Boer-Mulders
	L		g_{1L} helicity	$h_{1L}^{\perp}$ longi-transversity
	T	$f_{1T}^{\perp}$ Sivers	g_{1T} trans-helicity	h_1 transversity; $h_{1T}^{\perp}$ pretzelosity

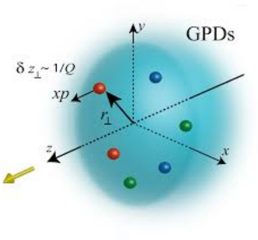
Nucleon spin — Quark spin



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.

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

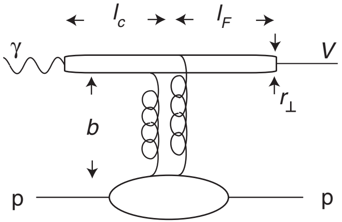
M_m : quark mass (condensate)

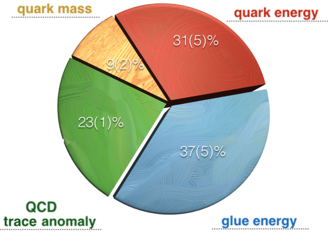
M_g : gluon energy

M_a : trace anomaly

- 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 $y \equiv q \cdot p / k \cdot p$ at EIC).
- Complementarity between EicC (and EIC) and lattice.

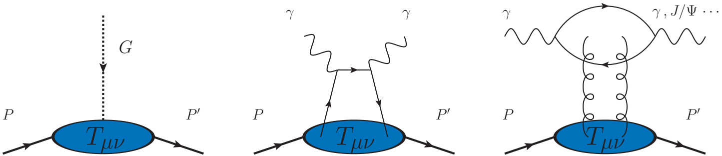
[Kharzeev, *et al*, 99; Brodsky *et al*, 01]





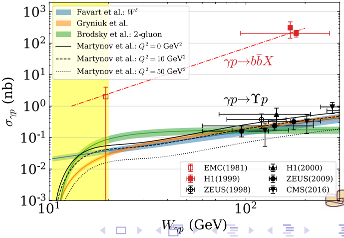
[χQCD, Yang, *et al*, 18]

Measuring Gravitational Form Factors

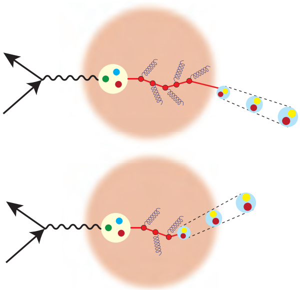


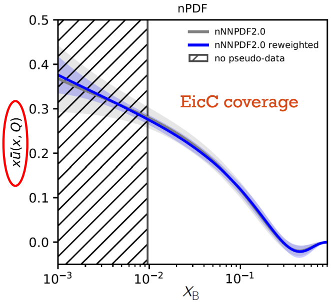
- Intuitively, one can use graviton (spin 2), similar to charge form factor, to probe the mass properties of proton (GFF). But gravity is too weak.
- [Ji, 97] Use two photons (spin 1) in DVCS to study GPDs, which are related to GFF. Two different channels can probe quark and gluon parts, respectively.

- Strong impact of recent GlueX data on extraction of mass radius. [Kharzeev, 21], [Wang, *et al*, 21], [Ji, 21] [Guo, *et al*, 21], [Sun, *et al*, 21]
- Synergy between EICs and theory including lattice.



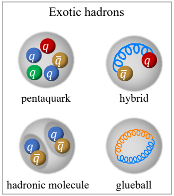
Quark-gluons in cold nuclear medium

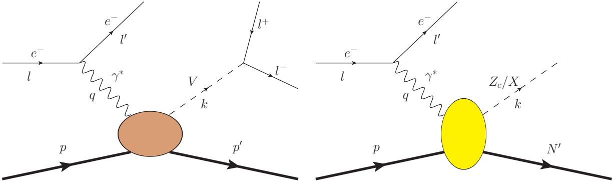




- Use heavy nuclei to study parton energy loss in cold nuclear medium
- Hadronization inside and outside medium. (Nucleus as a lab at the fm scale)
- Medium modification of light meson and heavy meson in SIDIS.
- Precision study of nuclear PDFs with heavy ion beams.

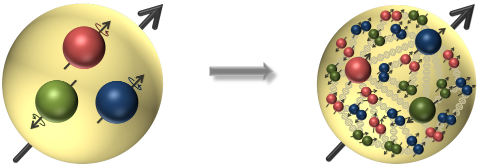
Exotic States

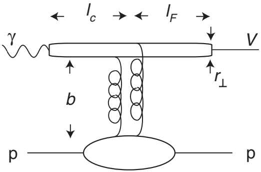




- Complementary to e^+e^- and pp collisions.
- Larger acceptance, exotic hadrons produced at middle rapidity.
- Heavy-flavor exotic hadrons, in particular to charmonium-like states and hidden charm pentaquarks.
- Polarization helps to determine the quantum numbers.

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 (Δg/g and 3D).
- EicC can tackle the issue of the trace anomaly contribution to the proton mass at the Υ threshold. Understand mass in general!
- EIC and EicC are complementary to each other in physics goals.