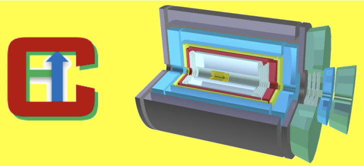
Updates on the Scientific Opportunities with EicC

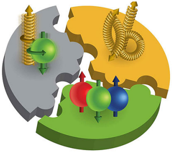
Bo-Wen Xiao
On behalf of EicC CDR Working Group

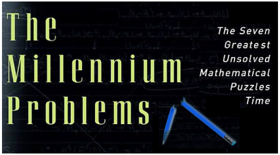
School of Science and Engineering,
The Chinese University of Hong Kong, Shenzhen

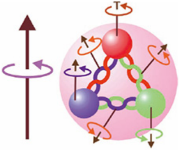
Special thanks to all the contributors



Ultimate Questions and Challenges in QCD







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

EICs: keys to unlocking these mysteries! Many opportunities will be in front of us!

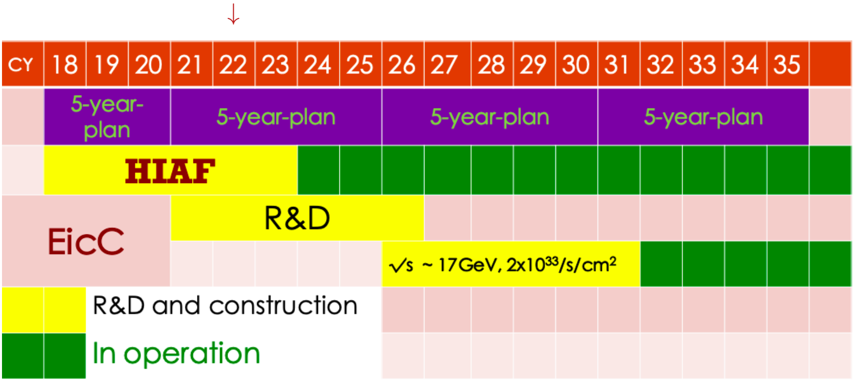
Proposed EIC Facilities Across the Globe

- 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

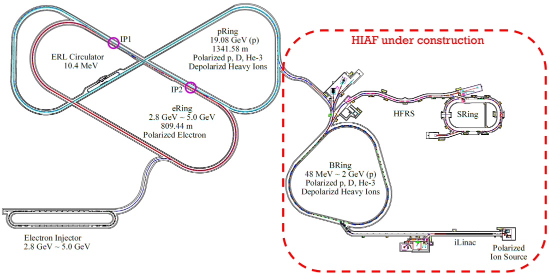
- Based on High-Intensity Heavy Ion Accelerator Facility (HIAF) which is currently under construction in Huizhou (惠州).
- HIAF total investment: 2.5 billion RMB.

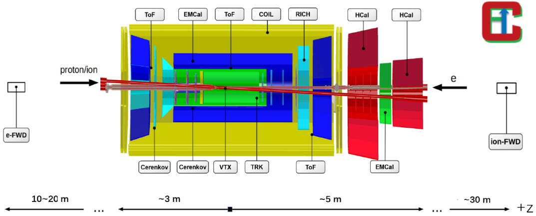
EicC Preliminary Timeline



- 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





Detailed full Geant4 simulation is ongoing!

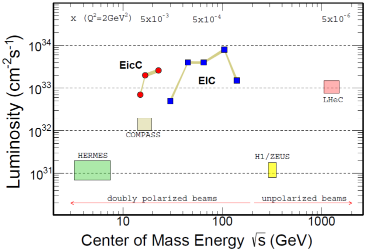
EicC accelerator includes

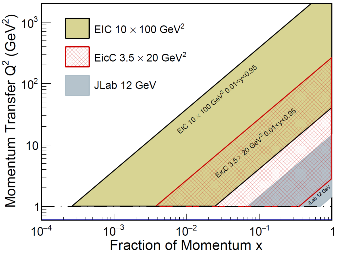
- Based on HIAF (right)
- pRing (8-shape)
- Energy Recovery Linac
- Electron Polarized Source and Injector.
- eRing (racetrack)
- Two IPs reserved.

A general purpose detector with 4 components:

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

Kinematics



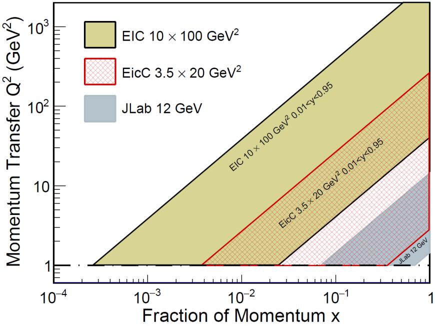


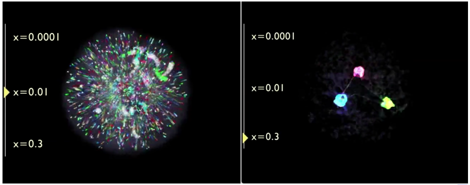
Facility	CoM energy	lum./10^{33}cm^{-2}s^{-1}	Ions	Polarization
EicC	15 - 20	2 - 3	$p \rightarrow$U	e^-, p, and light nuclei
EIC-US	30 - 140	2 - 15	$p \rightarrow$U	e^-, p, ^{3}He, Li

- EicC covers the kinematic region between JLab experiments and US-EIC.
- EicC complements the ongoing scientific programs at JLab and future EIC project.
- EicC can systematically study Υ near threshold and shed lights on proton mass origin.

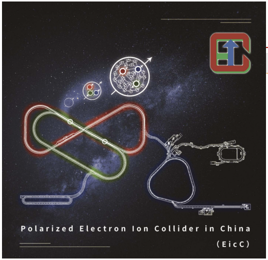
Kinematic Coverage

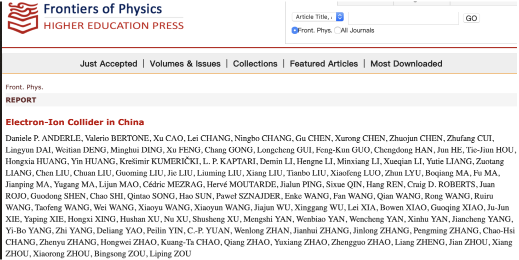
EicC focus on moderate x and sea-quark region





EicC white paper





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REPORT

Electron-Ion Collider in China

Daniele P. ANDERLE, Valerio BERTONE, Xu CAO, Lei CHANG, Ningbo CHANG, Gu CHEN, Xurong CHEN, Zhuojun CHEN, Zhufang CUI, Lingyun DAI, Weitian DENG, Minghui DING, Xu FENG, Chang GONG, Longcheng GUI, Feng-Kun GUO, Chengdong HAN, Jun HE, Tie-Jiun HOU, Hongxia HUANG, Yin HUANG, Krešimir KUMERIČKI, L. P. KAPTARI, Demin LI, Hengne LI, Minxiang LI, Xueqian LI, Yutie LIANG, Zuotang LIANG, Chen LIU, Chuan LIU, Guoming LIU, Jie LIU, Liuming LIU, Xiang LIU, Tianbo LIU, Xiaofeng LUO, Zhun LYU, Boqiang MA, Fu MA, Jianping MA, Yugang MA, Lijun MAO, Cédric MEZRAG, Hervé MOUTARDE, Jialun PING, Sixue QIN, Hang REN, Craig D. ROBERTS, Juan ROJO, Guodong SHEN, Chao SHI, Qintao SONG, Hao SUN, Paweł SZNAJDER, Enke WANG, Fan WANG, Qian WANG, Rong WANG, Ruiru WANG, Taofeng WANG, Wei WANG, Xiaoyu WANG, Xiaoyun WANG, Jiajun WU, Xinggang WU, Lei XIA, Bowen XIAO, Guoqing XIAO, Ju-Jun XIE, Yaping XIE, Hongxi XING, Hushan XU, Nu XU, Shusheng XU, Mengshi YAN, Wenbiao YAN, Wencheng YAN, Xinhu YAN, Jiancheng YANG, Yi-Bo YANG, Zhi YANG, Deliang YAO, Peilin YIN, C.-P. YUAN, Wenlong ZHAN, Jianhui ZHANG, Jinlong ZHANG, Pengming ZHANG, Chao-Hsi CHANG, Zhenyu ZHANG, Hongwei ZHAO, Kuang-Ta CHAO, Qiang ZHAO, Yuxiang ZHAO, Zhengguo ZHAO, Liang ZHENG, Jian ZHOU, Xiang ZHOU, Xiaorong ZHOU, Bingsong ZOU, Liping ZOU

- 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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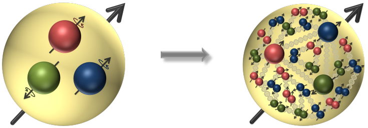
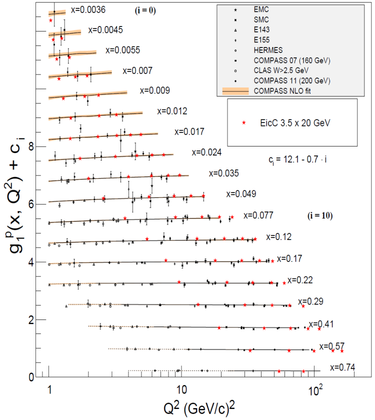
  2. EicC Physics Highlights (Several Physics Goals)
  3. Accelerator Conceptual Design
  4. Detector Conceptual Design

EicC Conceptual Design Report Efforts

Accelerator	Physics	Detector
1) EicC Accelerators	1) 1D spin	1) Vertexing + tracking
2) Ion Sources	2) 3D spin (TMDs + GPDs)	2) PID
3) Ion Machine	3) Exotic states	3) Calorimetry
5) Electron Machine	4) EHM and proton mass	4) IR + Magnet
5) Polarization	5) Cold nuclear medium effect	5) Luminosity and polarimetry
6) Electron cooling	6) LQCD	6) Far Forward detector
7) IR	7) DSE	7) DAQ
8) Common System	8) New ideas: (1) Jets (2) Heavy flavor observable (3) Fragmentation function	8) Simulations
		Software: EicCRoot **Southern Nuclear Science Computing Center.**
HIAF → EicC		
EicC CDR Volume I	**EicC CDR** Volume II	

Understanding Nucleon Spin





Jaffe-Manohar decomposition

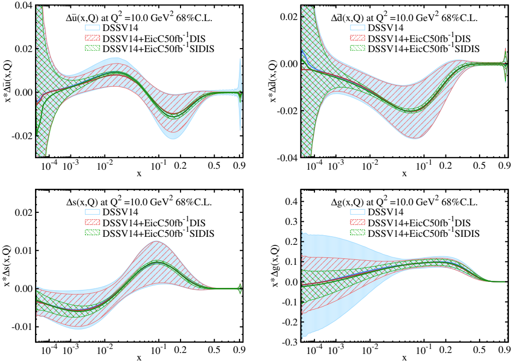
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma + L_q}_{\text{Quark}} + \underbrace{\Delta G + L_g}_{\text{Gluon}}$$

- 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 $\Delta G \simeq 0.25$

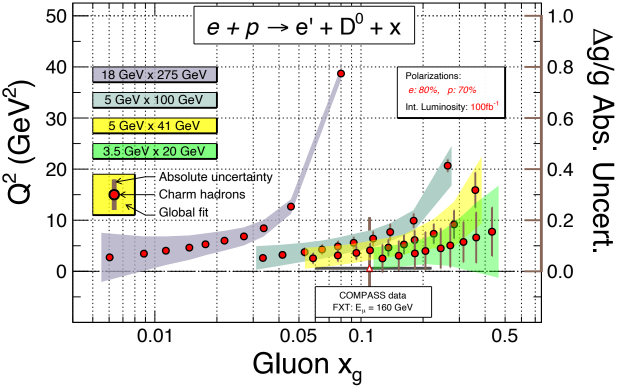
Spin flavor Structure at EicC

NLO EicC SIDIS projection

- $\pi^{\pm}$ and $K^{\pm}$ mesons
- ep: 3.5 GeV $\times$ 20 GeV
- eHe^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

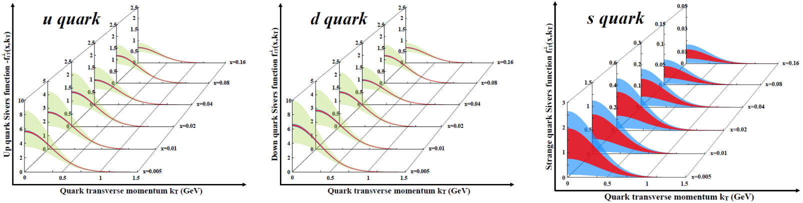
Access to quark Sivers function, especially the strange quark Sivers via SIDIS.

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

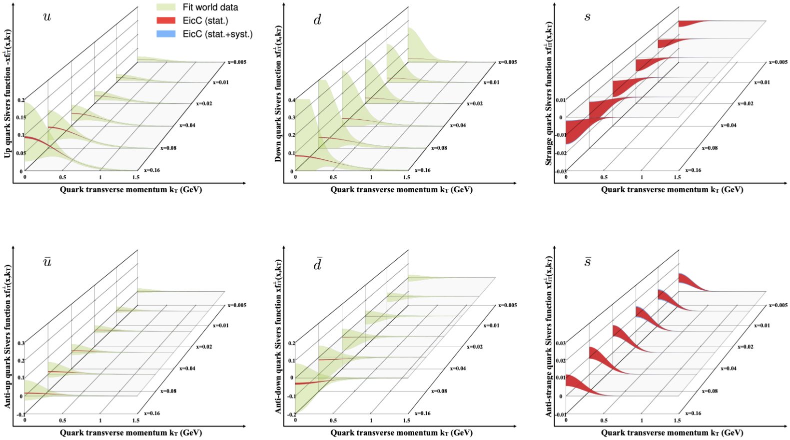
TMDs		Quark Polarization: Unpolarized (U)	Quark Polarization: Longitudinally polarized (L)	Quark Polarization: Transversely polarized (T)
Nucleon Polarization	U	f_1 unpolarized		$h_1^{\perp}$ Boer-Mulders
	L		g_{1L} helicity	$h_{1L}^{\perp}$ longi-transversity
	T	$f_{1T}^{\perp}$ Sivers	g_{1T} trans-helicity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

Nucleon spin — Quark spin

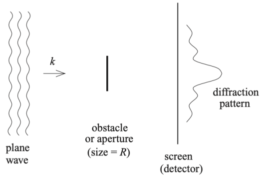


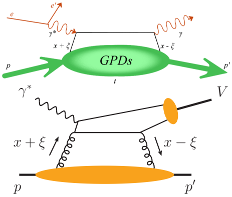
EicC's Impact on Sivers

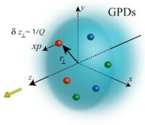
Recent EicC impact studies ▸ arXiv:2208.14620



3D Imaging: GPD from DVCS and DVMP







Ji Sum Rule[Ji, 97]:

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

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

- 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

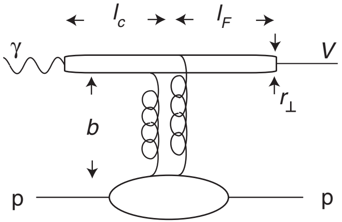
M_m : quark mass (condensate)

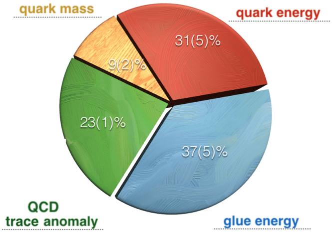
M_g : gluon energy

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.

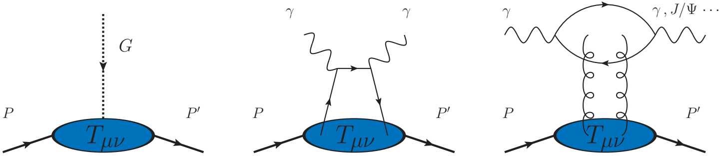
[Kharzeev, *et al*, 99; Brodsky *et al*, 01]





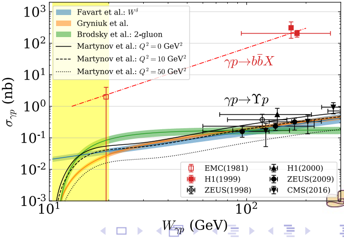
[χQCD, Yang, *et al*, 18]

Measuring Gravitational Form Factors

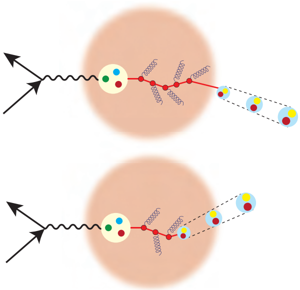


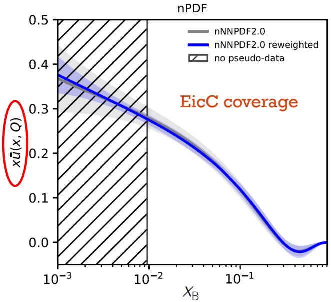
- Intuitively, one can use graviton (spin 2), similar to charge form factor, to probe the mass properties of proton (GFF). But gravity is too weak.
- [Ji, 97] Use two photons (spin 1) in DVCS to study GPDs, which are related to GFF. Two different channels can probe quark and gluon parts, respectively.

- 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], [Roberts, *et al*, 21] π, K
- Synergy between EICs and theory including lattice.



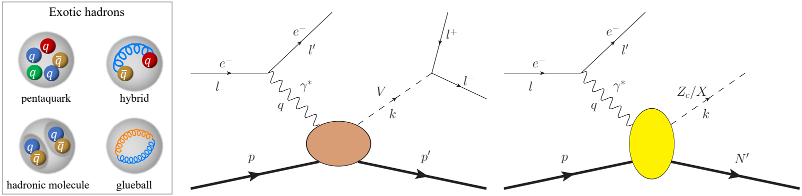
Quark-gluons in cold nuclear medium





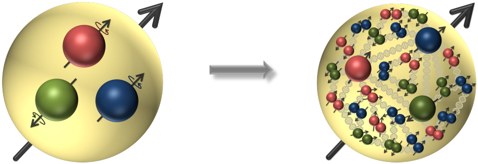
- Use heavy nuclei to study parton energy loss in cold nuclear medium
- Hadronization inside and outside medium. (Nucleus as a lab at the fm scale)
- Medium modification of light meson and heavy meson in SIDIS.
- Precision study of nuclear PDFs with heavy ion beams.

Exotic States



- Complementary to e^+e^- and pp colliders. (reduce ambiguity / background)
- 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. Understand mass in general!
- EIC and EicC are complementary to each other in physics goals.