The Electron-Ion Collider

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On behalf of the EIC User Group

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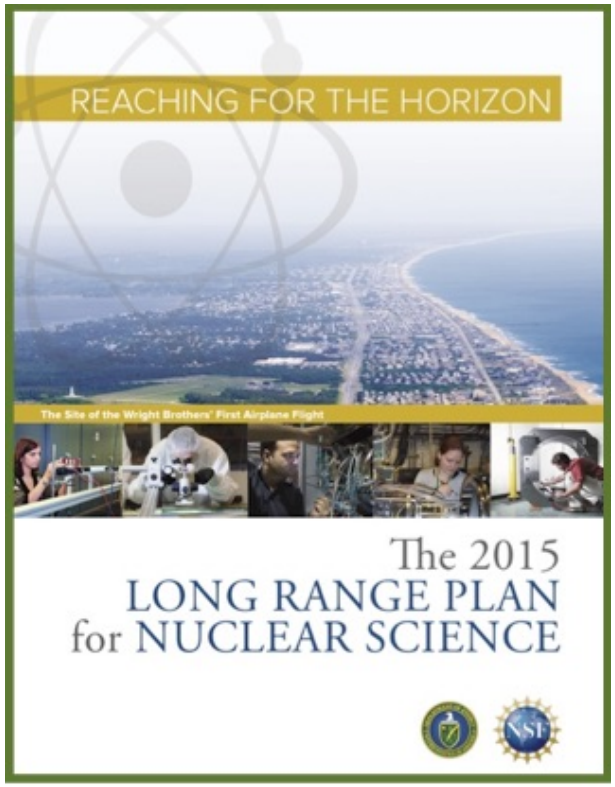
Electron Ion Collider

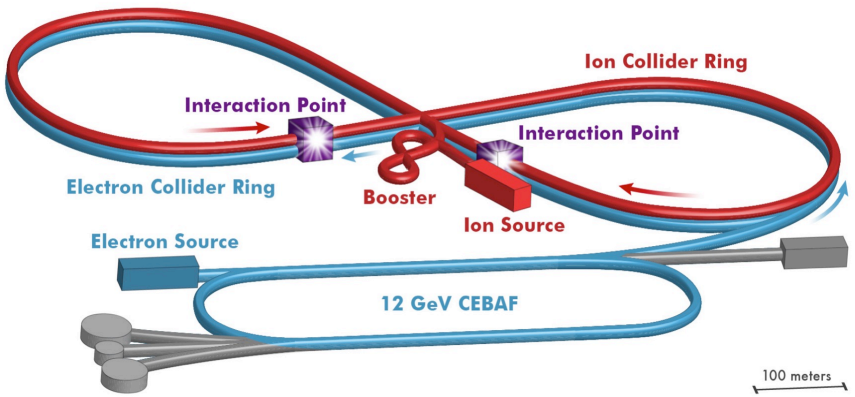
US 2015 Long Range Plan for Nuclear Science by NSAC:

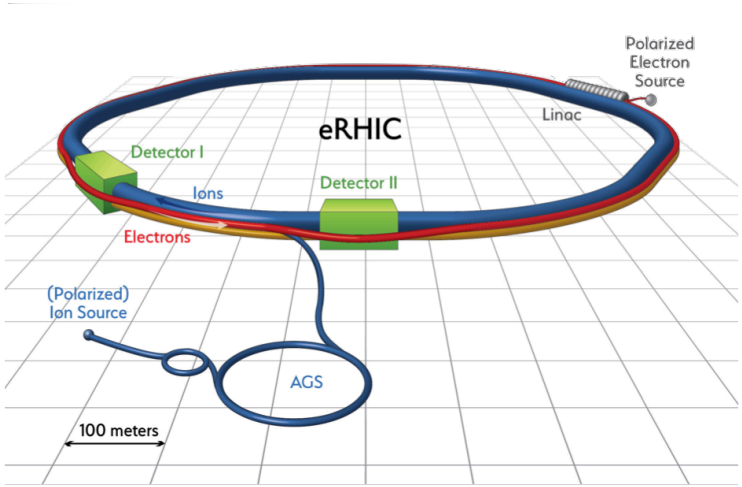


- "We recommend a high energy high luminosity polarized EIC as the highest priority for new facility construction following the completion of FRIB."
- The EIC will, for the first time, precisely image gluons in nucleons and nuclei. It will definitively reveal the origin of the nucleon spin and will explore a new quantum chromodynamics (QCD) frontier of ultra-dense gluon fields, with the potential to discover a new form of gluon matter predicted to be common to all nuclei. This science will be made possible by the EIC's unique capabilities for collisions of polarized electrons with polarized protons, polarized light ions, and heavy nuclei at high luminosity.

- Next Step: Independent assessment of EIC by the National Academies of Sciences, Engineering, and Medicine.

Electron Ion Collider





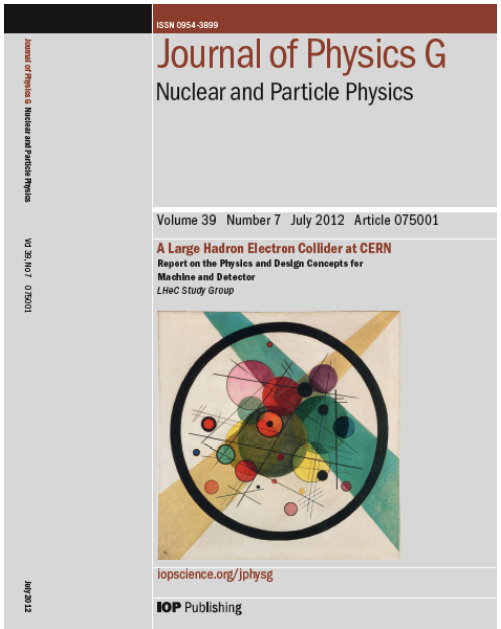
- Two proposed realization of EIC in US:
  JLEIC (Jefferson Lab) and eRHIC (Brookhaven).
- JLEIC: $\sqrt{s} = 20 \to 65 - 140\,\text{GeV}$ (Magnet technology choice).
- eRHIC: Up to $\sqrt{s} = 140\,\text{GeV}$.
- Polarized electron and light-ion beams.
- High-luminosity and high-precision.
- Also LHeC at CERN and HIAF at Lanzhou.

EIC User Group: EICUG.ORG

- 685 Users, 151 Institutes from 28 Countries. Series of EIC workshop.
- A lot of opportunities for contributions and participation!
- Website: eicug.org. To join: contact Dr. Abhay Deshpande (abhay.deshpande@stonybrook.edu)

Electron Ion Collider

arXiv:1108.1713



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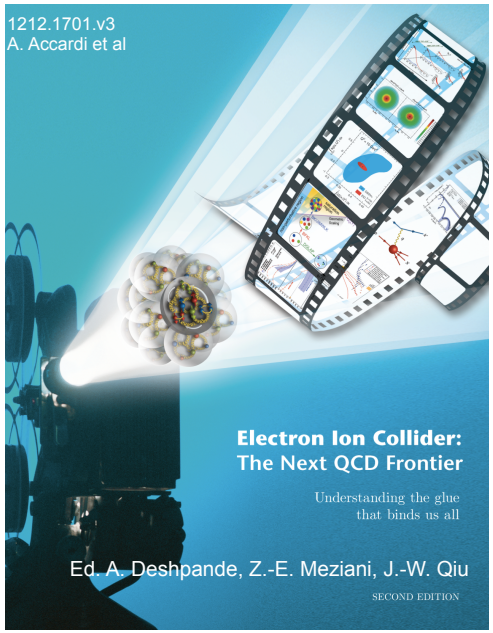
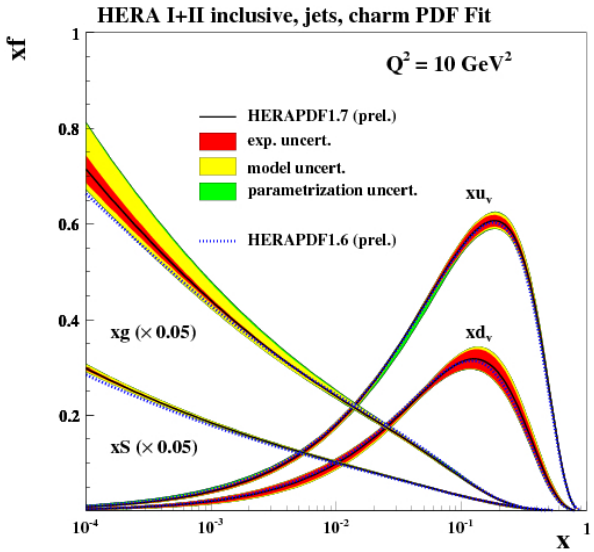


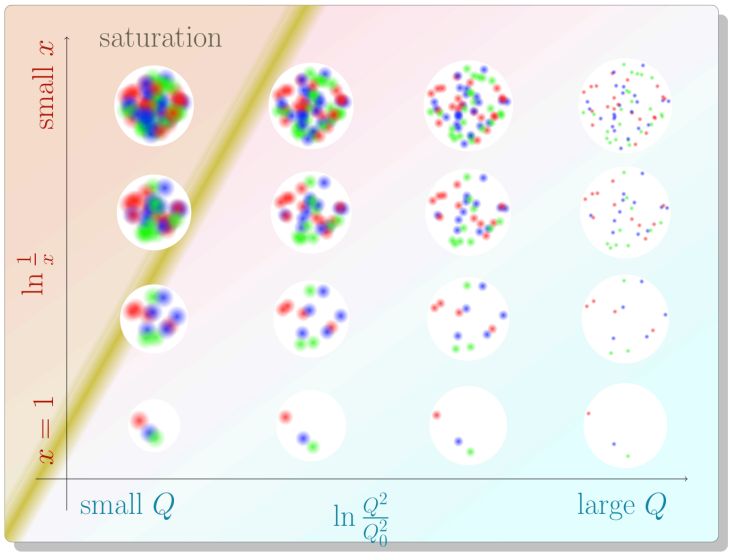
arXiv:1212.1701

- The proposed cutting-edge EIC can give us the opportunity to discover the gluon saturation phenomenon and understand proton spin puzzle.
- EIC will be a fantastic stereoscopic "camera" with extremely high resolution, which allows us to visualise protons and nuclei in a multi-dimensional fashion.

Saturation Physics (Color Glass Condensate)

QCD matter at extremely high gluon density [Mueller, Qiu, 86]





- Gluon density rises at low x.
- When too many gluons squeezed in a confined hadron, gluons start to overlap and recombine $\Rightarrow$ Non-linear QCD dynamics (BK equation) $\Rightarrow$ saturation in gluon distributions.
- Core ingredients: Multiple interactions (tree) + Small-x (high energy) evolution (loop)
- Introduce $Q_s(x)$ to separate the saturated dense regime from the dilute regime.
- Gluons at small-x carry typical transverse momentum of order $Q_s(x)$.

A Tale of Two Gluon Distributions

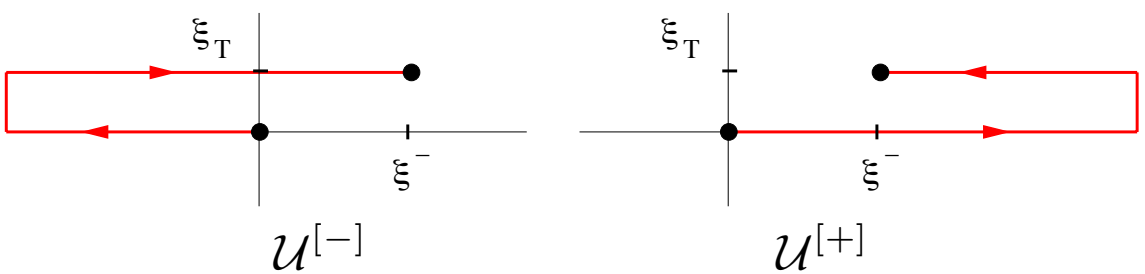
In terms of operators (TMD def. [Bomhof, Mulders and Pijlman, 06]), two gauge invariant gluon definitions: [Dominguez, Marquet, Xiao and Yuan, 11]

I. Weizsäcker Williams gluon distribution:

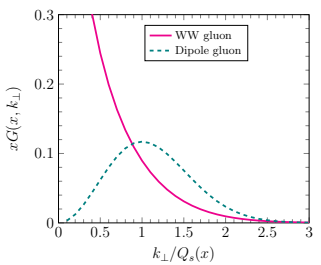
$$xG_{\rm WW}(x,k_\perp) = 2\int \frac{d\xi^- d\xi_\perp}{(2\pi)^3 P^+} e^{ixP^+\xi^- - ik_\perp\cdot\xi_\perp} \mathrm{Tr}\langle P|F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[\pm]\dagger}F^{+i}(0)\mathcal{U}^{[\pm]}|P\rangle.$$

II. Color Dipole gluon distributions:

$$xG_{\rm DP}(x,k_\perp) = 2\int \frac{d\xi^- d\xi_\perp}{(2\pi)^3 P^+} e^{ixP^+\xi^- - ik_\perp\cdot\xi_\perp} \mathrm{Tr}\langle P|F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[-]\dagger}F^{+i}(0)\mathcal{U}^{[+]}|P\rangle.$$

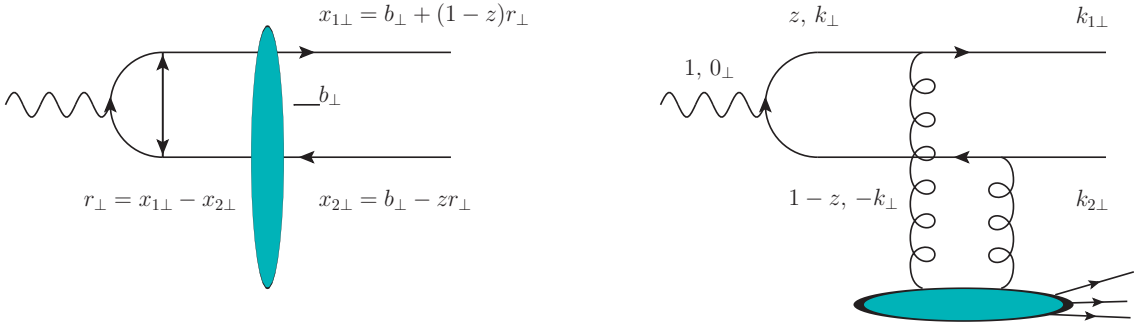


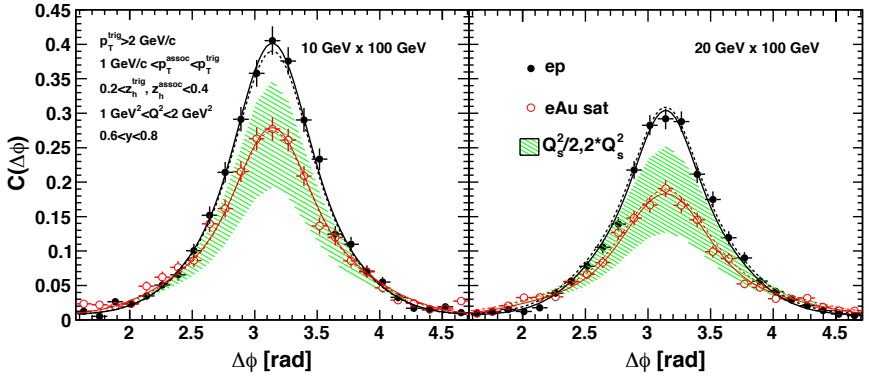
$\mathcal{U}^{[-]}$ $\mathcal{U}^{[+]}$



- The WW gluon distribution is the conventional gluon distributions.
- The dipole gluon distribution has no such interpretation.
- Two topologically different gauge invariant definitions.
- Appear in different physical processes, and both can be probed experimentally.

Dijet production in DIS

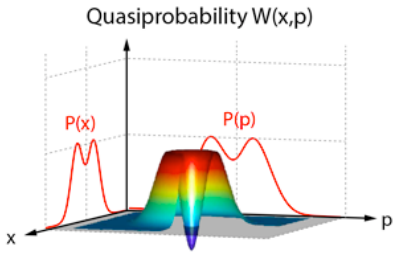


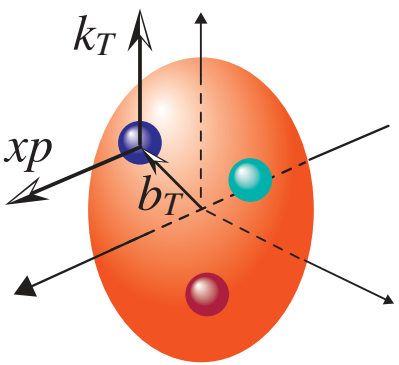


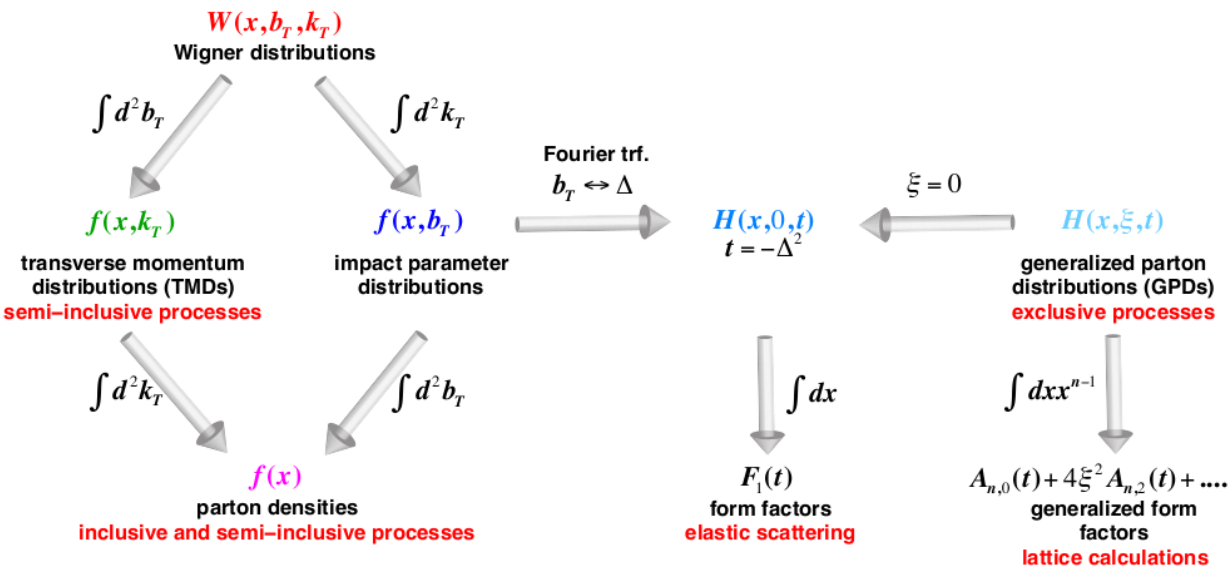
- Back-to-back correlation $C(\Delta\phi)$: [Zheng, Aschenauer, Lee and BX, 14]
- Unique golden measurement for the Weizsäcker Williams gluon distributions (gluon TMD at small-x) in proton and heavy nuclei.
- EIC will be a perfect machine to study gluon saturation inside protons/nuclei. [Dominguez, Marquet, Xiao and Yuan, 11]

3D Tomography of Proton

Wigner distributions ingeniously encode all quantum information of how partons are distributed inside hadrons. [Ji, 03; Belitsky, Ji, Yuan, 03]

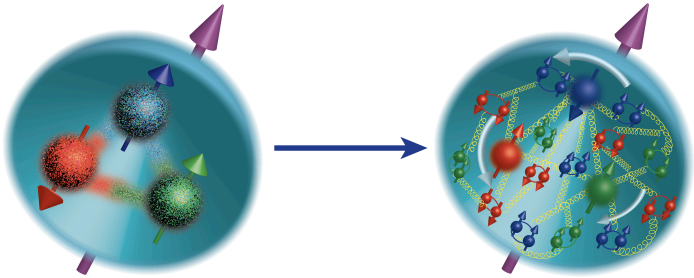






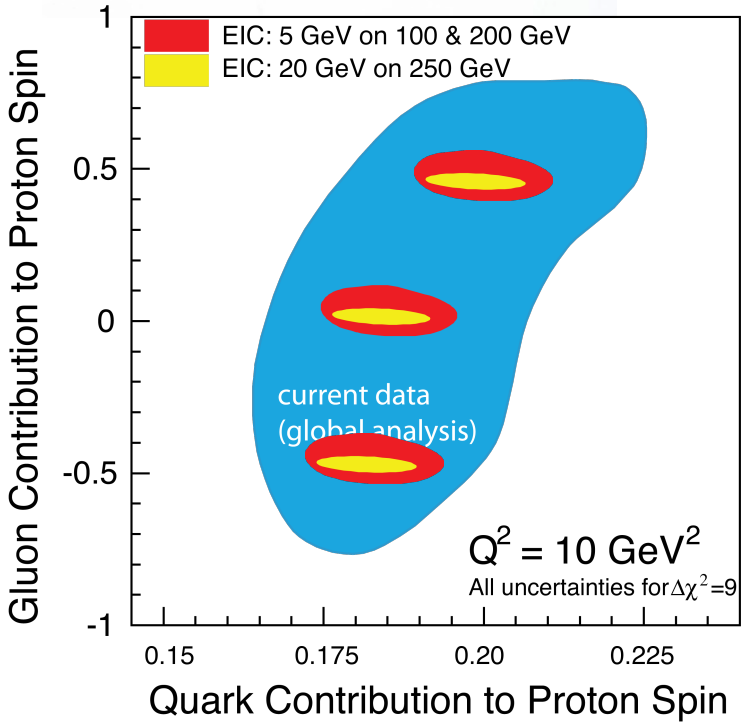
- Partons not only have longitudinal momentum, but must have transverse degrees of freedom as well.
- Small-x gluon distributions $\Leftrightarrow$ gluon Wigner distributions? [Ji, 03]
- Can we measure the gluon Wigner distribution at small-x? Yes, we can! Diffractive back-to-back dijet productions in DIS at EIC [Hatta, Xiao, Yuan, 16]

Understanding Nucleon Spin



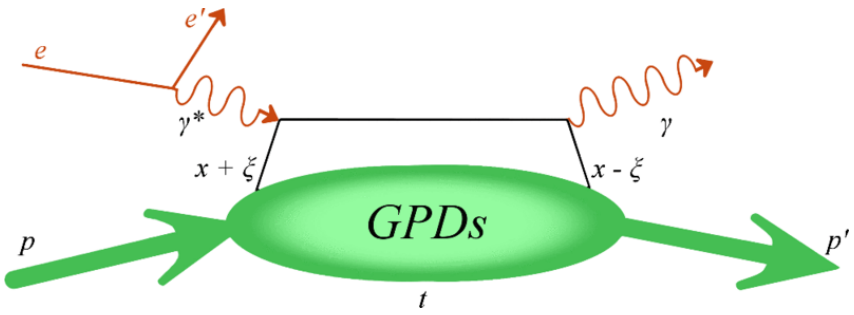
Jaffe-Manohar decomposition

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



- This is a complicated and challenging problem. (See Ji's gauge invariant decomposition and recent development.)
- Quark spin $\Delta\Sigma$ is only responsible for 30% of the proton spin.
- The rest of the proton spin must come from the gluon spin ΔG, quark and gluon OAM $L_{q,g}$.
- Current understanding is that orbital motions of quarks and gluons also contribute to the proton spin and they also give rise to a range of interesting phenomena.

Exclusive DIS (DVCS)

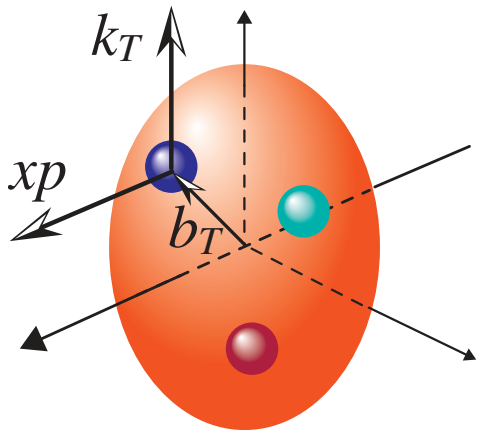


Ji Sum Rule:

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

$$J_q = \frac{1}{2}\Delta\Sigma + L_q = \frac{1}{2}\int dx x \left(H_q + E_q\right) ,$$

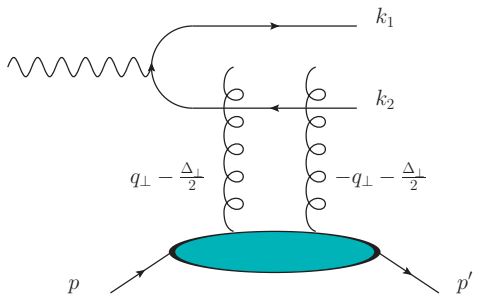
$$J_g = \frac{1}{4}\int dx \left(H_g + E_g\right) .$$

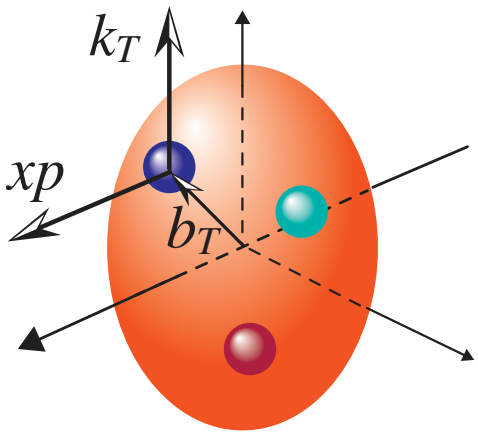


- Allows us to access to spacial distributions (which are related to GPDs via FT) of partons in the nucleon.
- Obtain the information about the quark orbital motions indirectly.

Gluon OAM at the EIC

Directly probing the gluon OAM at the EIC. (New exciting progress!)
[Ji, Yuan, Zhao, 16; Hatta, Nakagawa, Xiao, Yuan, Zhao, 16]





Wigner distribution and OAM
[Ji, Xiong, Yuan, 12; Hatta, 11; Lorce, Pasquini,11]

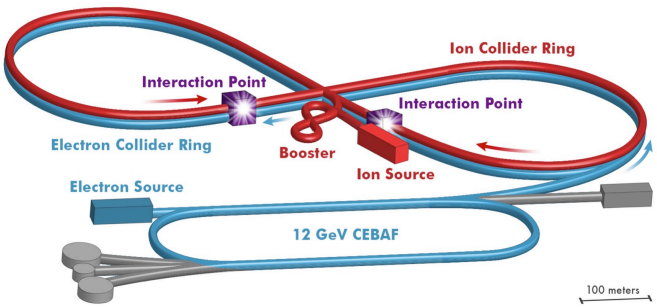
$$L_g = \int dx d^2b_\perp d^2k_\perp W_g(x, b_\perp, k_\perp)(b_\perp \times k_\perp).$$

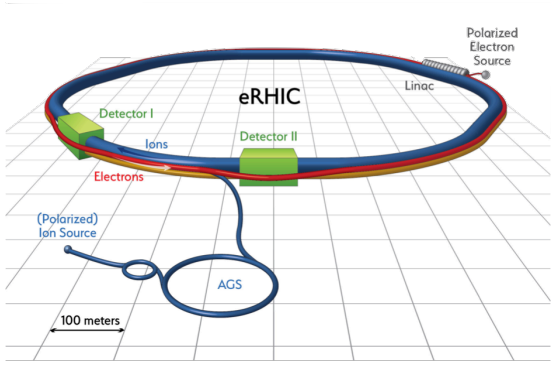
- The single spin asymmetry of this process is sensitive to L_g.
- First measurement of the gluon OAM in the proton spin sum rule!

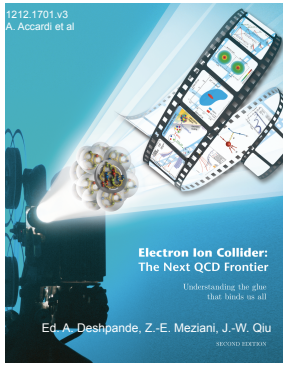
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g.$$

- Quark OAM seems to be more difficult to probe directly. Interesting development: [Bhatttacharya, Metz, Zhou, 17; Engelhardt, 17]

Summary







- The proposed cutting-edge EIC will be a superb "stereoscopic camera" , which allows us to depict 3D landscape of the internal structure of protons and heavy nuclei with unprecedented precision.
- It can give us the vital opportunity to discover the gluon saturation phenomenon and understand proton spin puzzle.
- It can also significantly advance our understanding of strong interaction and inspire deep theoretical insights about the non-perturbative quark and gluon physics which has been sketchy in our minds at present.