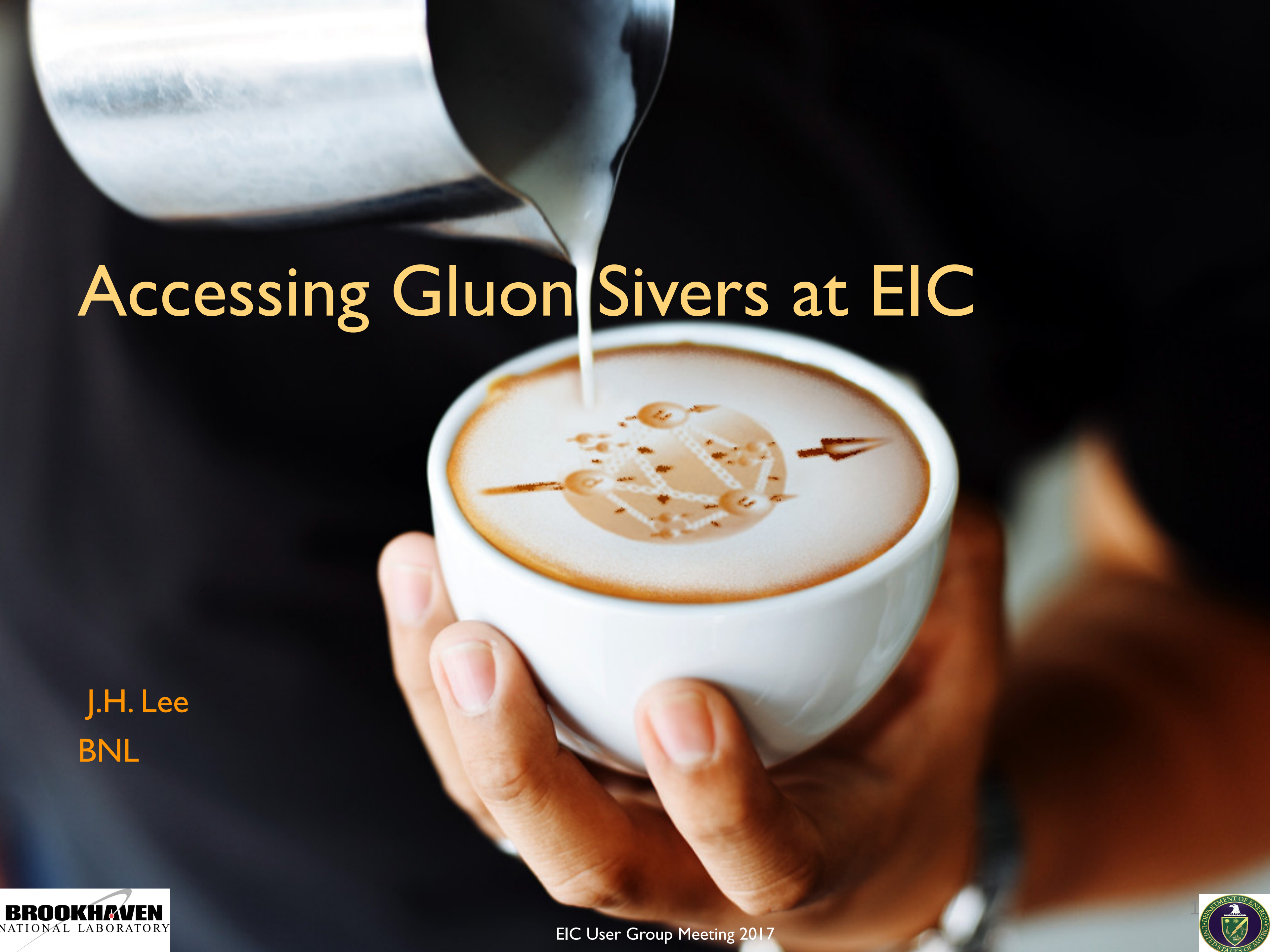

Accessing Gluon Sivers at EIC

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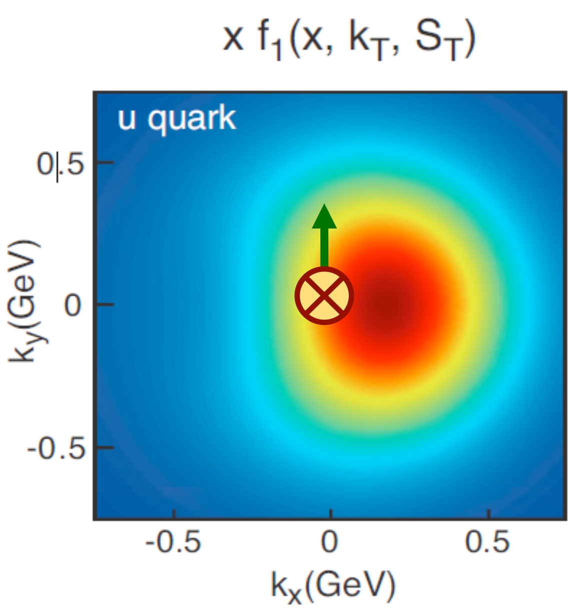
Nucleon Landscape

- Nucleon is a dynamical system of quarks and gluons
  - How partons are distributed in space and momentum inside the nucleon?
  - How are these **quark and gluon distributions correlated** with the over all nucleon properties, such as **spin** direction?
  - Spin as fundamental intrinsic property and also as a mechanism to do tomography of many body system of quarks and gluons
- EIC: polarized collider to have full access to the nucleon dynamics

3D imaging of partonic structure of nucleon

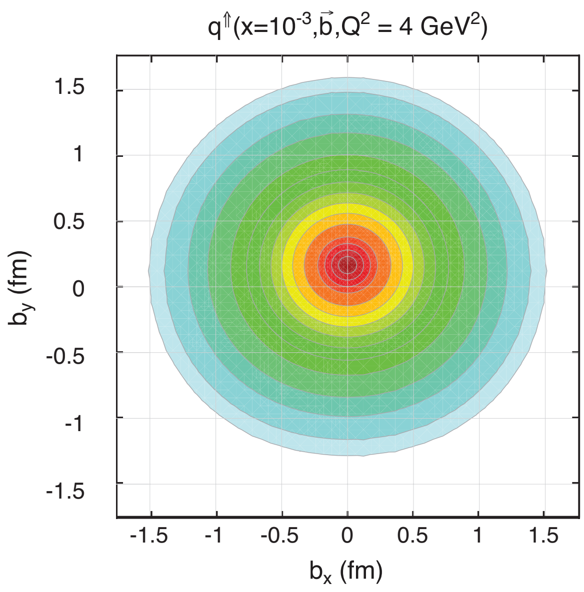
Transverse Momentum Dependent parton distributions (TMDs)

- confined motion in a nucleon (semi-inclusive DIS)
- 2+1D picture in momentum space (k_T)



Generalized Parton Distributions (GPDs)

- Spatial imaging of quarks and gluons (exclusive DIS)
- 2+1D picture in impact parameter space (b)



Sivers Function

Correlation of **nucleon's transverse spin** with **k_T of an unpolarized quark/gluon**: Can be viewed as partonic motion inside nucleon

polarized TMD parton distribution

$$\hat{f}_{a/p^\uparrow}(x,k_\perp) = f_{a/p}(x,k_\perp) - f_{1T}^{\perp a}(x,k_\perp)\frac{\vec{S}\cdot(\hat{\vec{P}}\times\vec{k}_\perp)}{M_p}$$

unpolarized TMD

Sivers function

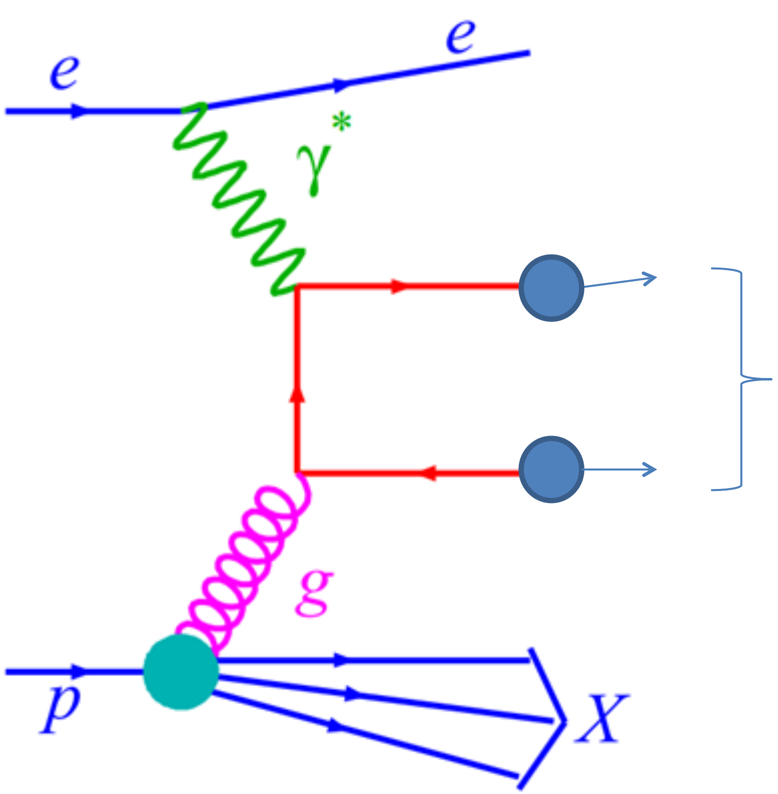
important link to physics of gluon saturation at small x

- "dipole" deformation
- measures spin-orbit correlations
- link to parton orbital motion (through models)
- reveals non-trivial aspects of QCD color gauge invariance

Due to the different gauge links involved in the processes, the gluon Sivers effect extracted from EIC would be an independent gluon Sivers function distinct from that obtained in pp collisions and can hardly be accessed in other collisions. **Gluon Sivers studies at EIC** will provide a unique test of the fundamental non-perturbative QCD effects and provide complementary information.

Accessing gluon dynamics in DIS

Photon-Gluon Fusion (PGF)



1. Photon-gluon fusion process
2. back-to-back jet/hadron pairs from the quark-antiquark
3. Reconstruct the gluon dynamics with the jet/hadron pair information

Gluon information can be extracted with the jet/hadron pairs from the quark-antiquark jet.

Back-to-back (correlation) limit:

$P_T' = |\mathbf{P}_T^{h1} - \mathbf{P}_T^{h2}|/2$

$k_T' = |\mathbf{P}_T^{h1} + \mathbf{P}_T^{h2}|$

$k_T' << P_T'$

Theoretical framework for the model calculation for Sivers function

TMD factorization at correlation limit

$$\frac{d\sigma_{\rm tot}^{\gamma^*+p^\uparrow\to h_1+h_2+X}}{dz_{h1}dz_{h2}d^2p_{h1\perp}d^2p_{h2\perp}} = C\int_{z_{h1}}^{1-z_{h2}}\sum_q dz_q\frac{z_q(1-z_q)}{z_{h2}^2z_{h1}^2}d^2p_{1\perp}d^2p_{2\perp}\hat{f}_{g/p^\uparrow}(x_g,k_\perp)$$
$$\times\,\mathcal{H}_{\rm tot}^{\gamma^* g\to q\bar{q}}(z_q,k_{1\perp},k_{2\perp})e_q^2D_{h1/q}(\tfrac{z_{h1}}{z_q},p_{1\perp})D_{h2/\bar{q}}(\tfrac{z_{h2}}{1-z_q},p_{2\perp})$$

Single Spin Asymmetry (SSA)

$$A_{UT}=\frac{d\sigma^\uparrow-d\sigma^\downarrow}{d\sigma^\uparrow+d\sigma^\downarrow}\propto\frac{\Delta^N f_{g/p^\uparrow}(x,k_\perp)}{2f_{g/p}(x,k_\perp)}$$

$$\hat{f}_{a/p^\uparrow}(x,k_\perp)=f_{a/p}(x,k_\perp)-f_{1T}^{\perp a}(x,k_\perp)\frac{\vec{S}\cdot(\hat{\vec{P}}\times\vec{k}_\perp)}{M_p}$$

$$f_{g/p}(x,k_\perp)=f_{g/p}(x)\frac{e^{-k_\perp^2/<k_\perp^2>}}{\pi\langle k_\perp^2\rangle}$$

$f_{1T}^{\perp a}(x,k_\perp)$ input for gluon Sivers:

- parameterization with data: barely known
- positivity constraint:

- Weight PYTHIA data at partonic level with the asymmetry accordingly for estimate

$$A_i=\frac{1}{N_i}\sum_{k=1}^{N_i}w_k \qquad w_k=\frac{\Delta^N f_{a/p^\uparrow}(x,k_\perp)}{2f_{a/p}(x,k_\perp)}$$

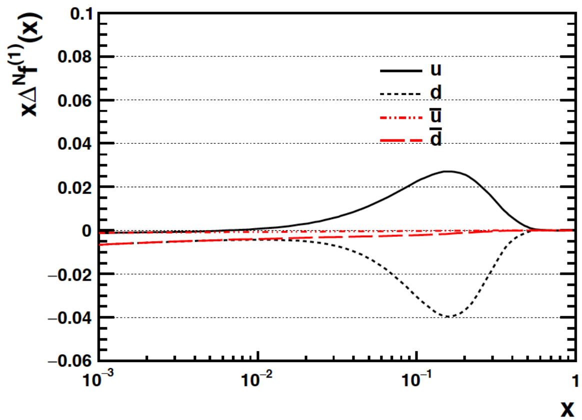
Sivers Function parametrization

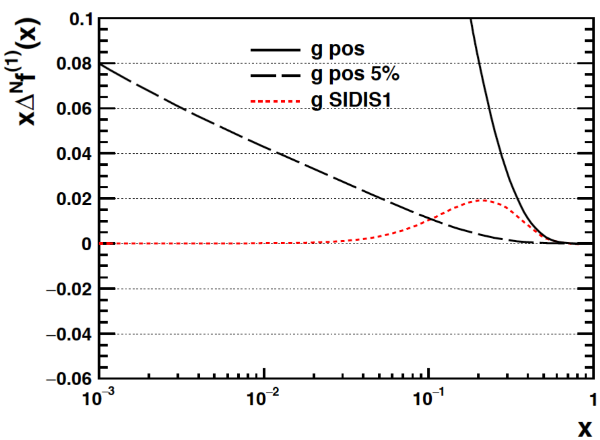
Quark Sivers: JHEP 04 (2017) 046 Anselmino et al.

Gluon Sivers: JHEP 09 (2015) 119 D'Alesio et al.

u,d + Kretzer FF ("SIDIS1")

Positivity bound ansatz: $f_{1T}^{\perp g} = -\frac{2\sigma M_p}{k_\perp^2 + \sigma^2} f_g(x, k_\perp), \quad \sigma = 0.8$

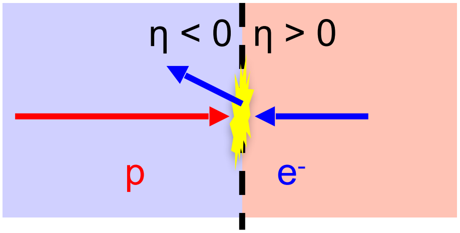


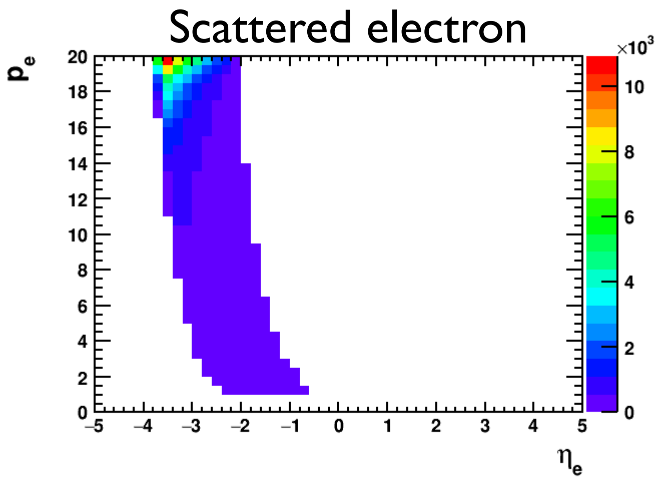


- Quark Sivers with only u and d contribution extracted from HERMES and COMPASS data.
- Gluon Sivers barely known: from a fit to RHIC π^0 A_N data with a large uncertainty
- Fitted gluon Sivers is much smaller than quark Sivers in a wide range of x.
- Gluon Sivers saturating the positivity bound is assumed.
- Stronger asymmetries for larger k_T'

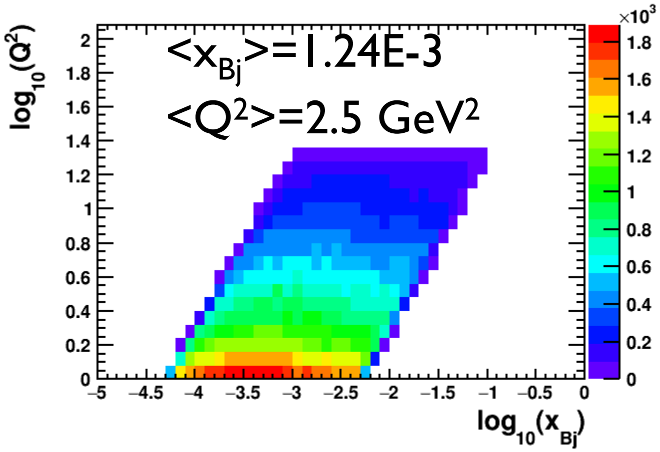
EIC setup for gluon SSA study

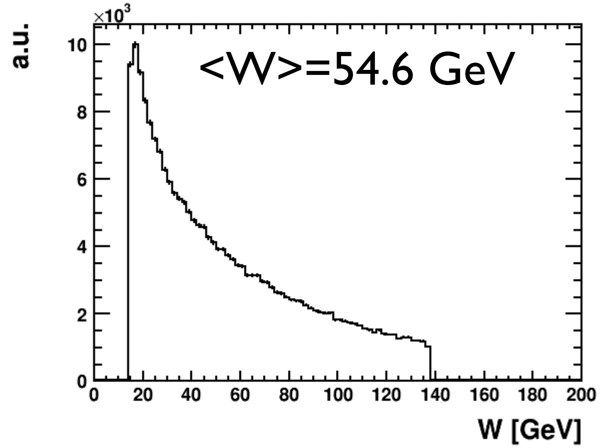
Kinematics:
$ep^{\uparrow}$ 20x250 GeV
$\sqrt{s}$=141 GeV
0.01<y<0.95
$1<Q^2<20$ GeV^2





Final state observables
1. D^0 pair (+single D^0)
2. Dihadron
3. Dijet
4. K^+K^-





Gluon tagging with D^0

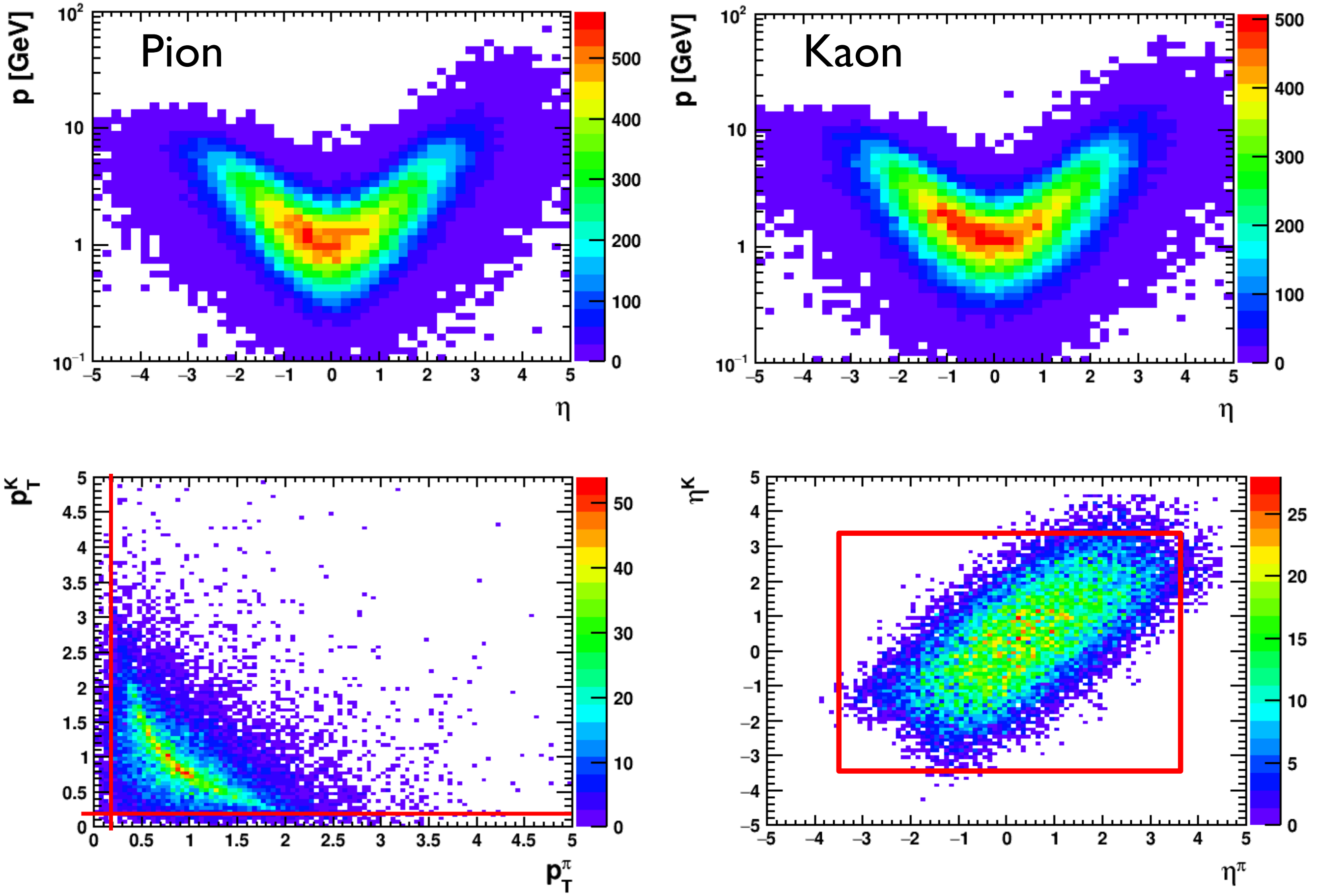
$$ep^{\uparrow} \rightarrow e'c\bar{c}X$$

$$D^0(c\bar{u}) \rightarrow \pi^+(u\bar{d})K^-(s\bar{u})$$

$$\bar{D}^0(\bar{c}u) \rightarrow \pi^-(\bar{u}d)K^+(u\bar{s})$$

Branching ratio: 3.9%

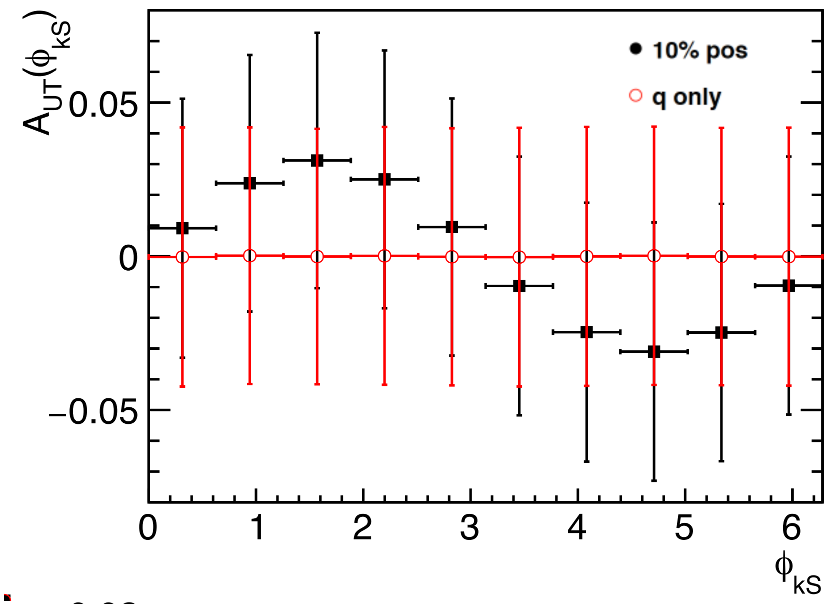
- Acceptance for PID is assumed to be $|\eta| < 3.5$
- Decay products from D^0 mesons are mostly less than 10 GeV within $|\eta|<1$
- Decay products $p_T>0.2$ GeV (94% survival)



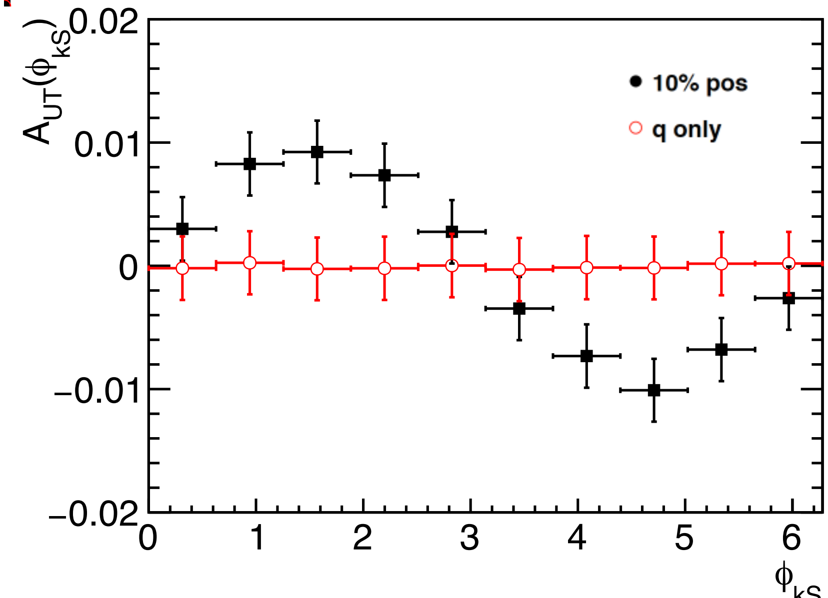
Projections for the SSA with D^0

$$ep^{\uparrow} \to e' c\bar{c} X$$

- ep 20x250 GeV
- $D^0 \to K\pi$ in acceptance
- $p_T > 0.2$ GeV, $z > 0.1$
- correlation limit: $k_T < 0.7 * P_T$
- $\langle x_g \rangle \sim 0.03$
- $\sigma_{DDbar} = 2.7 \times 10^{-3}$ nb
- Integrated luminosity 10 fb^{-1}: statistically challenging. Sensitive to a few % of positivity bound with D^0 (limited resolution)



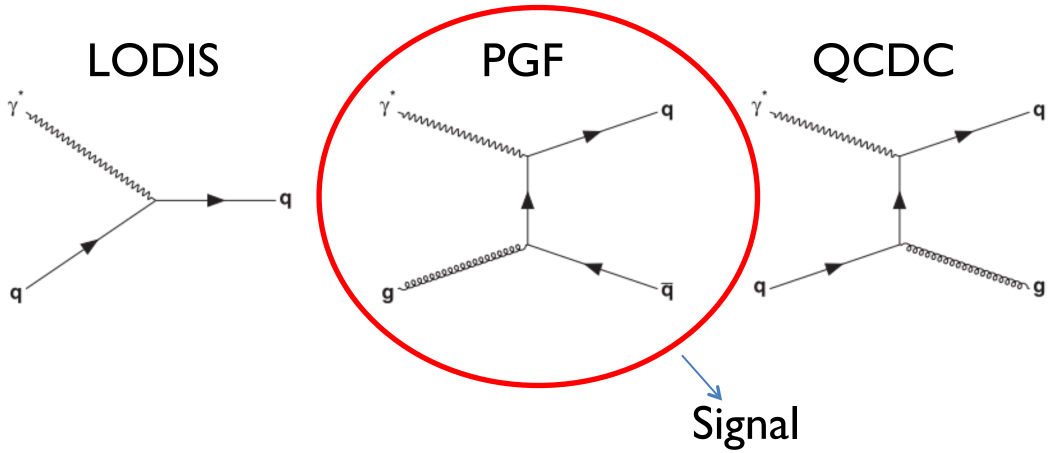
$D^0 D^0$bar+X



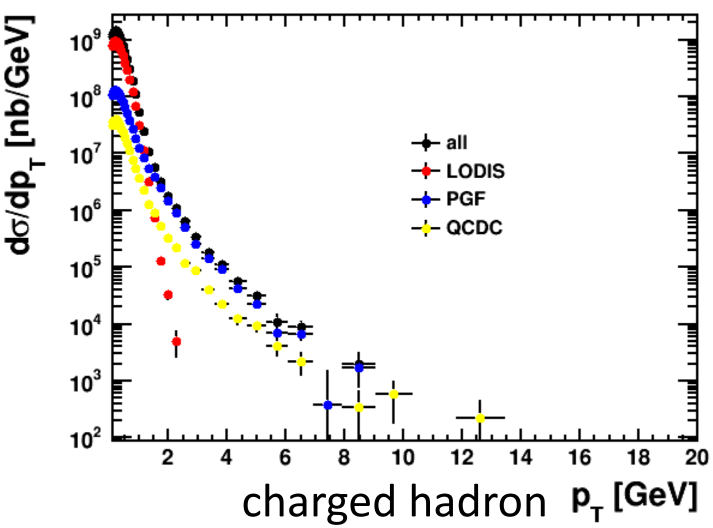
D^0+X

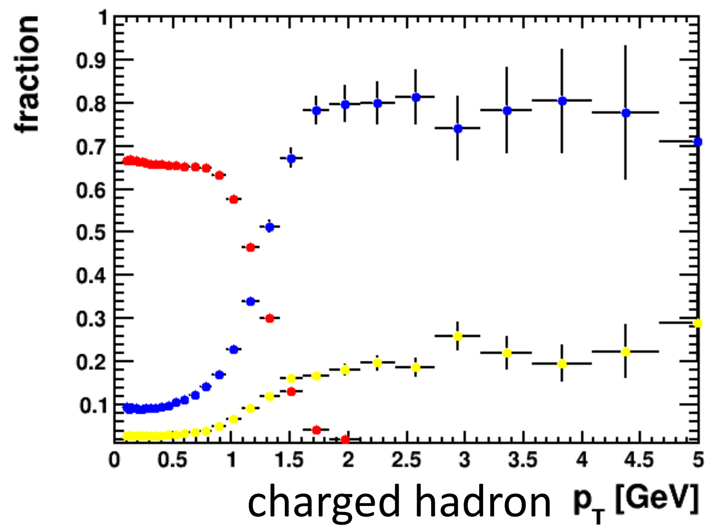
$$\delta A = \sqrt{\frac{1}{P^2 N} - \frac{A^2}{N}}$$ with P 70%

Gluon tagging with Dihadron and Dijet



p_T>1.7 GeV/c effectively enhances the gluon initiated process.





Dihadron selection

Kinematic cuts:

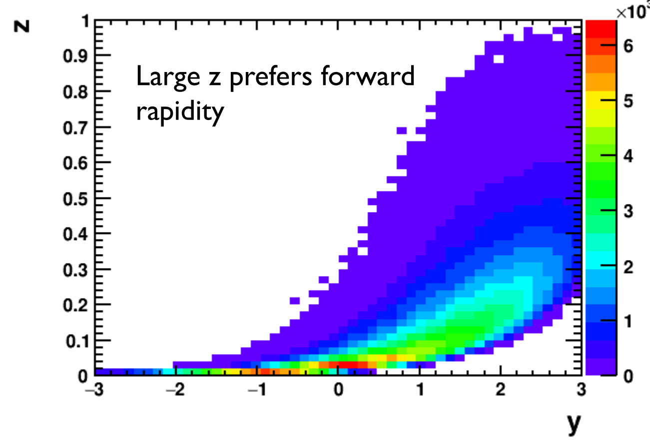
ep 20x250 GeV

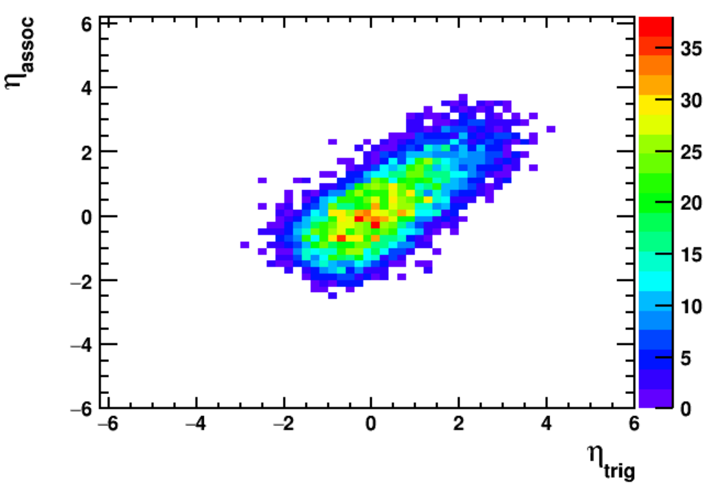
0.01<y<0.95

1<Q^2<20 GeV^2

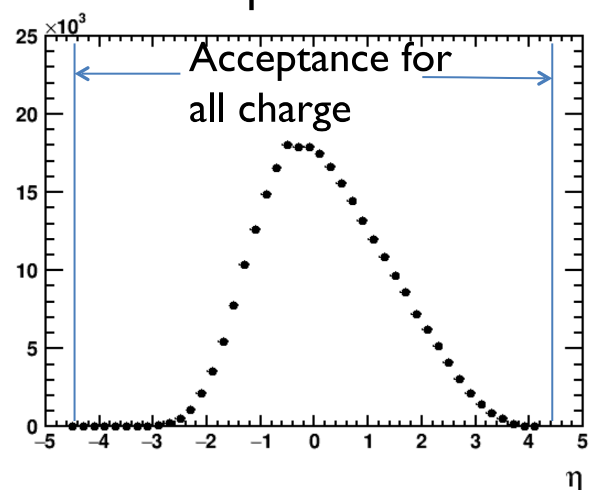
p_T>1.7 GeV, z_h>0.1, |η|<4.5

Back-to-back limit: $k_T' < 0.7P_T'$



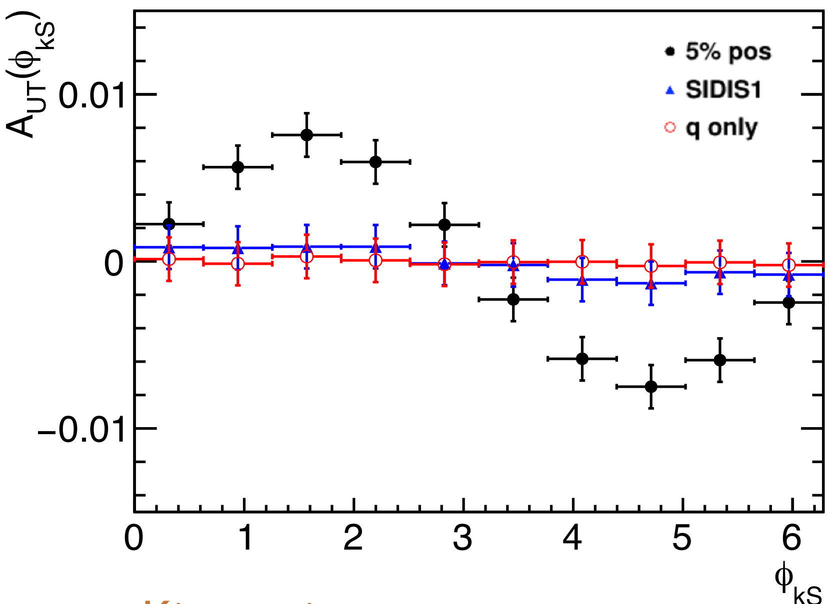


Hadron pair distribution

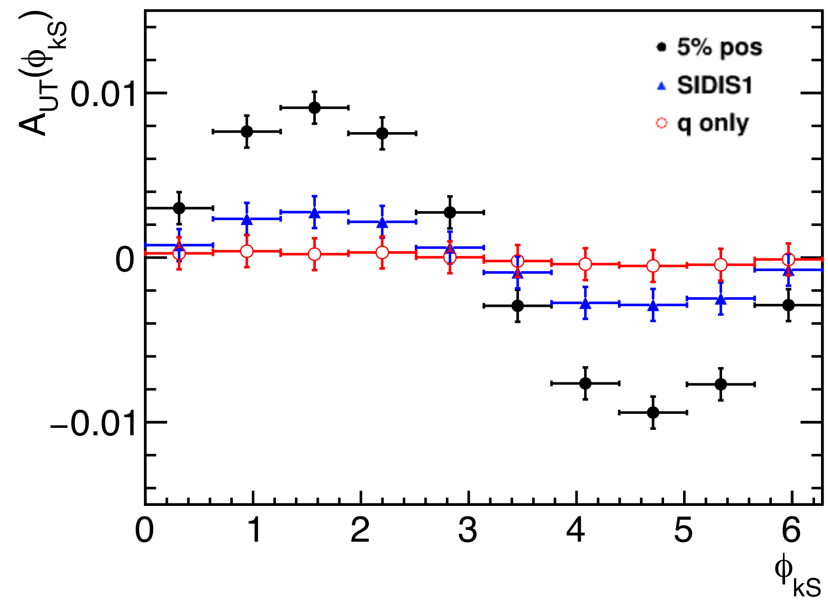


Projections on the SSA with Dihadron and Dijet

Dihadron



Dijet



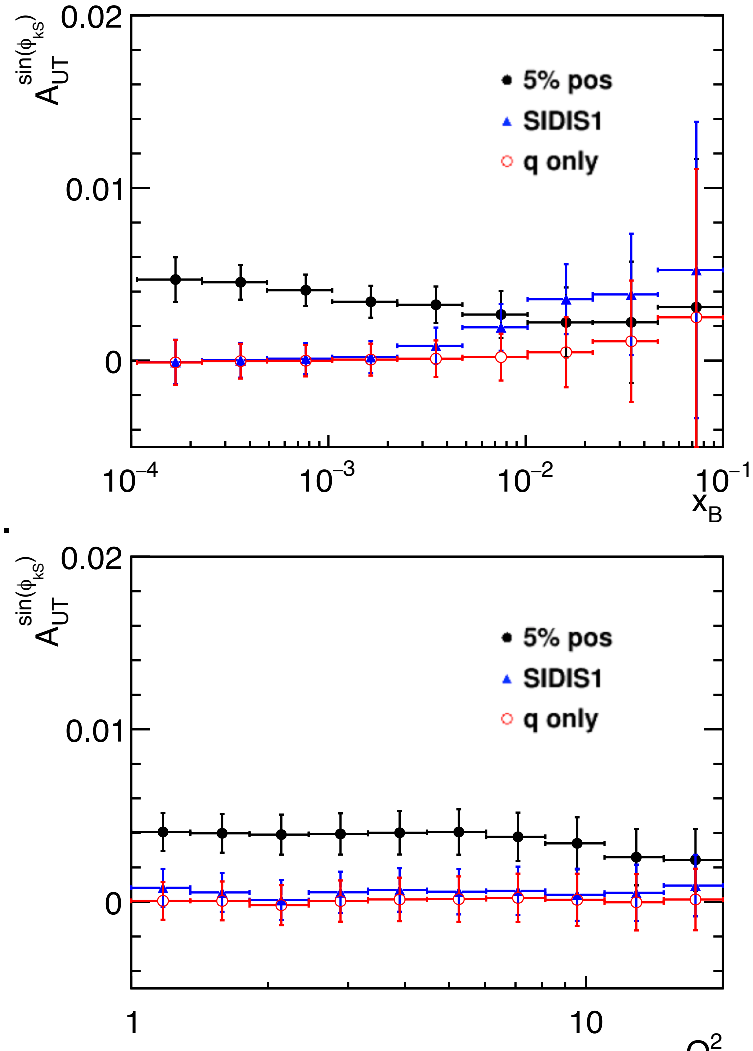
Kinematic cuts:

ep 20x250 GeV
$0.01<y<0.95$
$1<Q^2<20$ GeV^2
$|\eta|<4.5$
Dihadron: $p_T>1.7$ GeV, $z_h>0.1$
Dijet: $p_{Tjet1}>4.5$ GeV, $p_{Tjet2}>4$ GeV
Back-to-back limit: $k_T' < 0.7P_T'$

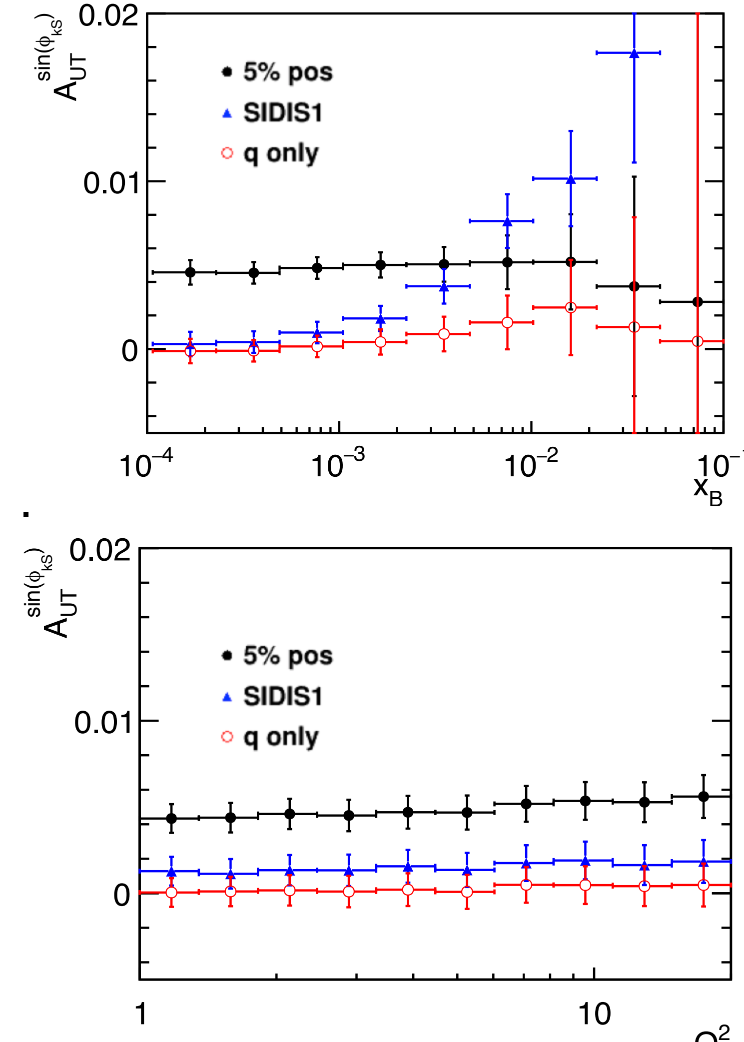
Integrated luminosity 10 fb^{-1}: sensitive to a few % of positivity limit

Jet @ EIC: see B. Page's Talk

Gluon SSA with Dihadron and Dijet



measured with dihadron



measured with dijet

Summary

- Gluon TMDs is ingredient of complete 3D imaging of nucleon, and can be uniquely measured at EIC by measuring gluon Sivers function
- Gluon Sivers can be accessible and constrained in a wide kinematic range via photon-gluon coupling - D^0, dihadron, dijet within EIC's machine and detector reach
  - complementary measurements will help reduce systematic uncertainties and enhance kinematic coverages - further study for optimizing parton kinematics reconstruction in progress