Dijet and single-jet Sivers measurements at EIC

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PHYS. REV. D 98, 034011 (2018)

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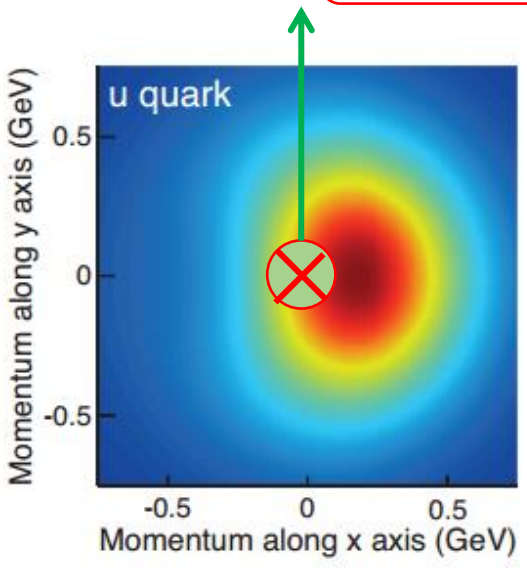
Jets for 3D Imaging online workshop
November 25, 2020

Sivers function

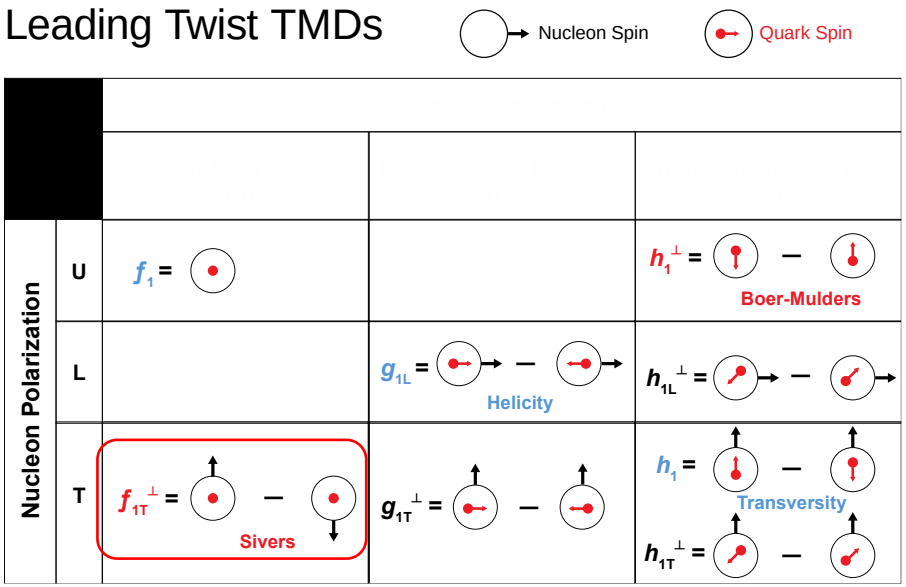
- EIC: polarized collider to have full access to the nucleon dynamics.
- Transverse Momentum Dependent (TMD) parton distributions provide useful tools to image the nucleon 3D structure in momentum space.
- Sivers function describes the correlation of k_T and S_T.

$$\hat{f}_{a/p^\uparrow}(x,k_\perp) = f_{a/p}(x,k_\perp) + \frac{1}{2}\Delta^N f_{a/p^\uparrow}(x,k_\perp)\ \vec{S}\cdot(\hat{\vec{P}}\times\hat{\vec{k}}_\perp)$$



EIC White paper

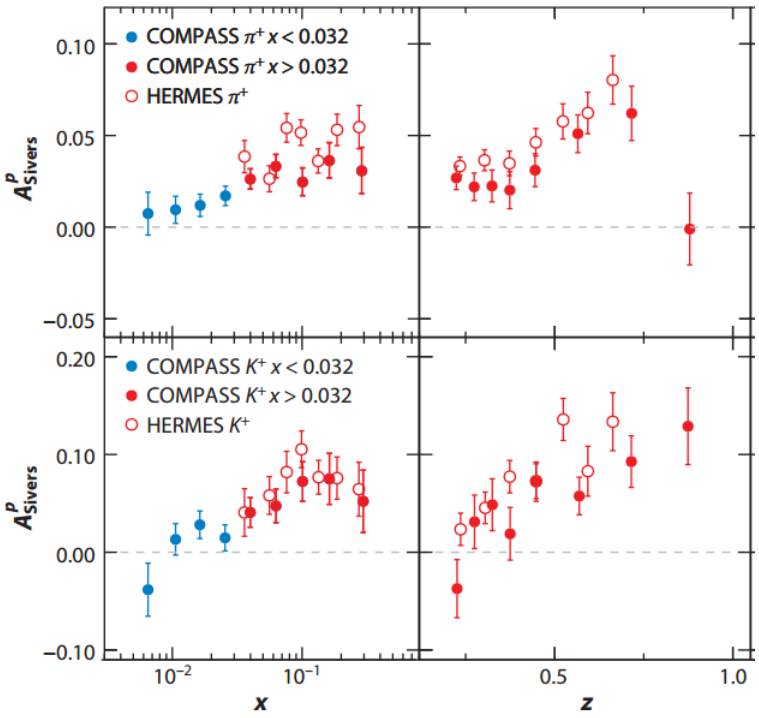
Leading Twist TMDs



Similar for gluons

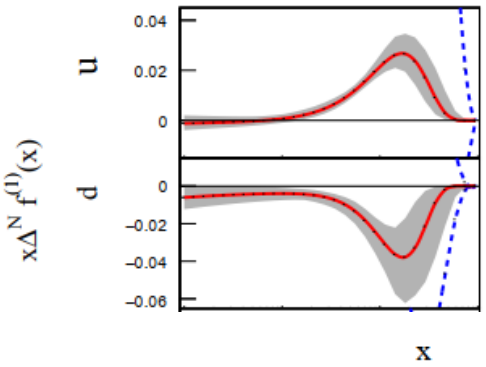
Previous approach to measure Sivers function in ep collisions

M. Perdekamp, et. al., Ann.Rev.Nucl.Part.Sci. 65 429 (2015)



PRL 103, 152002 (2009) HERMES data
PLB 717, 383 (2012) COMPASS data

Anselmino et. al. JHEP 04, 046 (2017)



- Accessed with SIDIS measurements.
- Sizable Sivers effect.
- u, d quark Sivers with opposite sign.
- Subject to large uncertainty.

Previous approach to measure Sivers function in ep collisions

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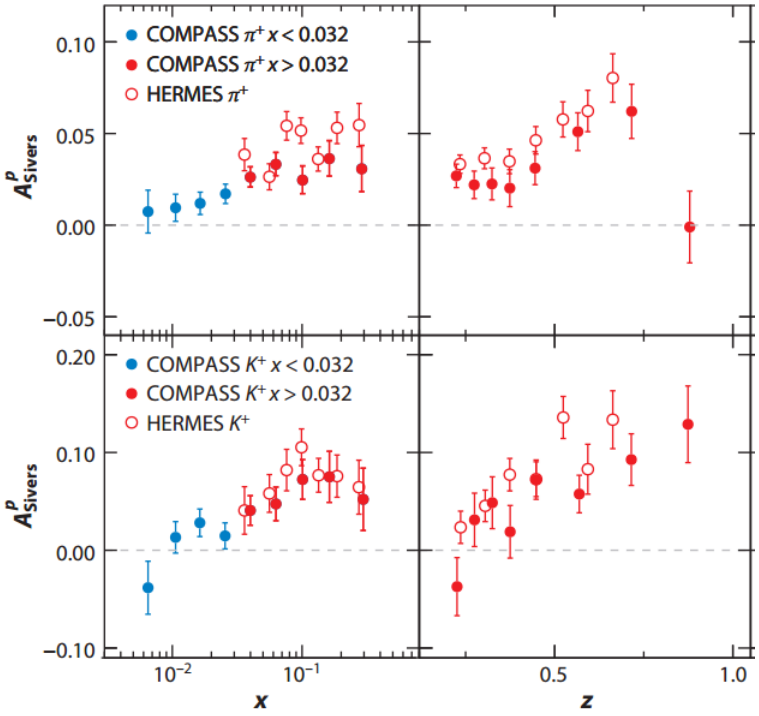
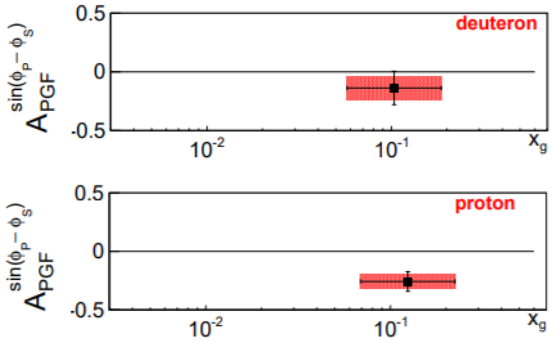


PRL 103, 152002 (2009) HERMES data
PLB 717, 383 (2012) COMPASS data

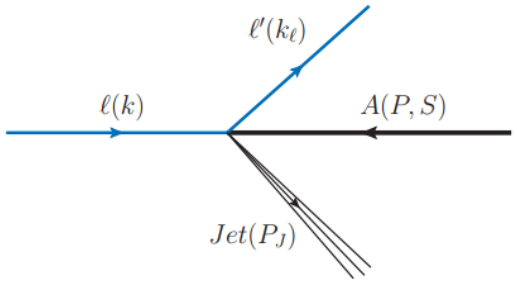
$ep^{\uparrow} \rightarrow e\, h_1 h_2 X$ COMPASS PLB722, 854 (2017)



- Accessed with SIDIS measurements.
- Sizable Sivers effect.
- u, d quark Sivers with opposite sign.
- Subject to large uncertainty.
- Limited knowledge to gluon Sivers.

Accessing quark Sivers function with single jets

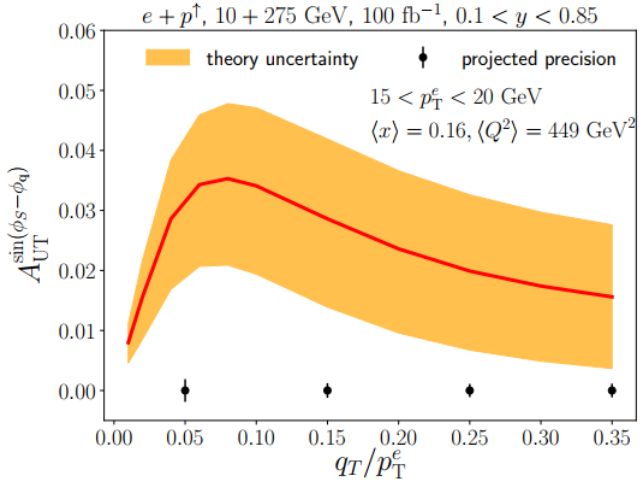
XH Liu et. al. ***PRL*** **122, 192003 (2019)**



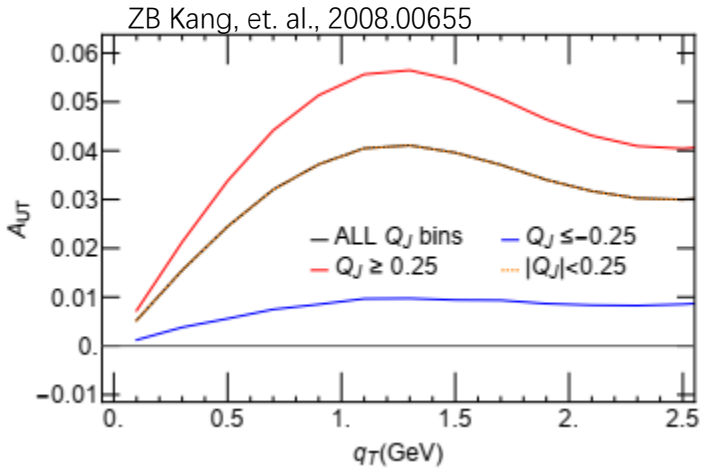
- Lepton Jet correlation in ep cms frame
- Can be well measured at the EIC
- Jet charge for flavor separation

$$Q_\kappa^i = \sum_h Q_\kappa^h \equiv \sum_{h\in \text{jet}} z_h^\kappa Q_h$$

M. Arratia, et. al., PRD102, 074015 (2020)

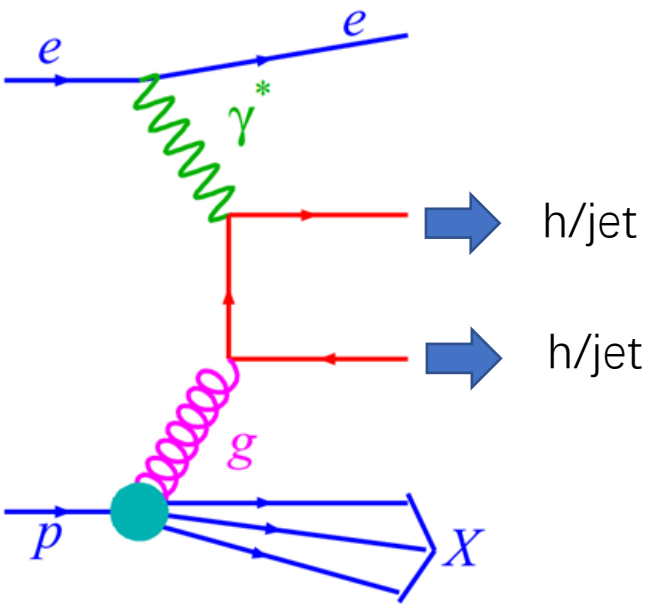


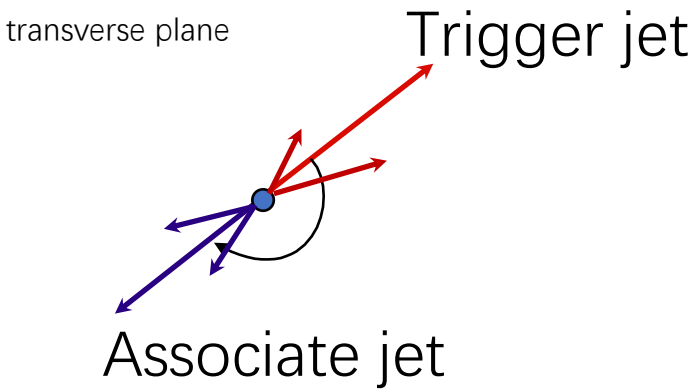
ZB Kang, et. al., 2008.00655



Accessing gluon Sivers function with Dijets

- Photon-Gluon Fusion (PGF) process as good proxy to the underlying gluon distribution
- Back-to-back dihadron/dijet can map initial gluon kinematics
- Similar ideas applied to eA saturation physics





Two gluon distributions

- Two different gauge invariant gluon definitions
- Weizsacker-Williams (WW) gluon distribution

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

- Color dipole gluon distribution

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

- Unique opportunity to explore the WW gluon distribution at the EIC

	Inclusive	Single Inc	DIS dijet	γ +jet	dijet in pA
xG_{WW}	×	×	√	×	√
xG_{DP}	√	√	×	√	√

× ⇒ Do Not Appear. √ ⇒ Apppear.

Dominguez, et. al., PRD83, 105005 (2011)

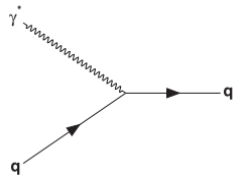
Simulation framework

PYTHIA
event generator

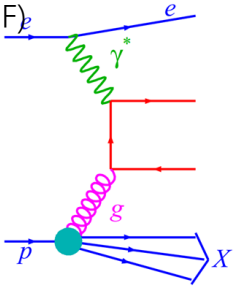
Beam energy

Partonic flavor, kinematic info

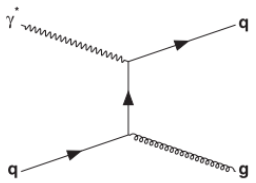
Leading order DIS (LODIS)



Photon-gluon fusion (PGF)



QCD compton (QCDC)



Sivers weight event-by-event（signal、background）

$$w = \frac{\Delta^N f_{a/p^\uparrow}(x, k_\perp, Q^2)}{2 f_{a/p}(x, k_\perp, Q^2)}$$

hadronization

SSA in final state observable

Weighting events in a final state observable

$$A_{UT} = R_g \frac{\Sigma_i^{N_g} w_i}{N_g} + R_q \frac{\Sigma_i^{N_q} w_i}{N_q}$$

$$\delta A_{UT} = \sqrt{\frac{1}{PN^2} - \frac{A_{UT}^2}{N}}$$

Inputs to the model calculation

$$\Delta^N f_{a/p^\uparrow}(x,k_\perp) = 2\mathcal{N}_a(x) f_{a/p}(x,k_\perp) h(k_\perp)$$

$$w = \frac{\Delta^N f_{a/p^\uparrow}(x,k_\perp,Q^2)}{2 f_{a/p}(x,k_\perp,Q^2)}.$$

$$A_{UT} = R_g \frac{\Sigma_i^{N_g} w_i}{N_g} + R_q \frac{\Sigma_i^{N_q} w_i}{N_q}$$

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

u, d and sea quarks

Gluon Sivers:

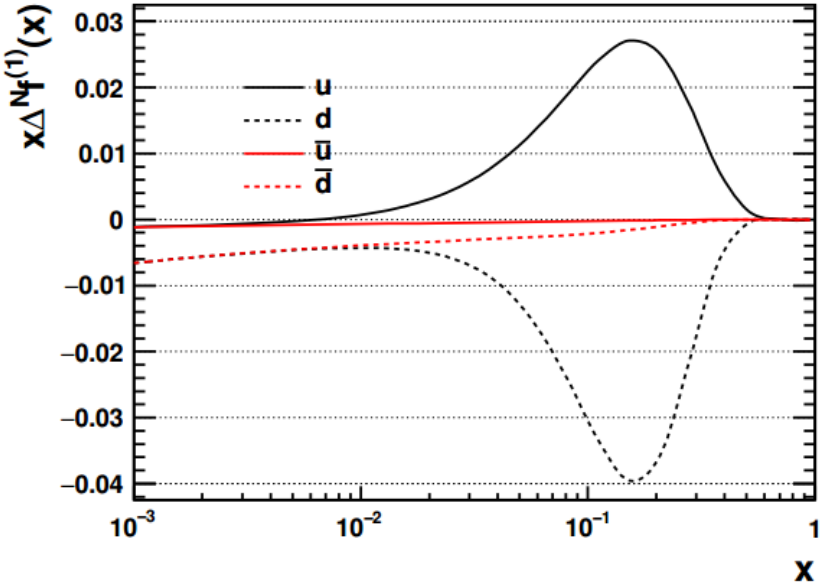
(1) GPM fit (g SIDIS1 set)

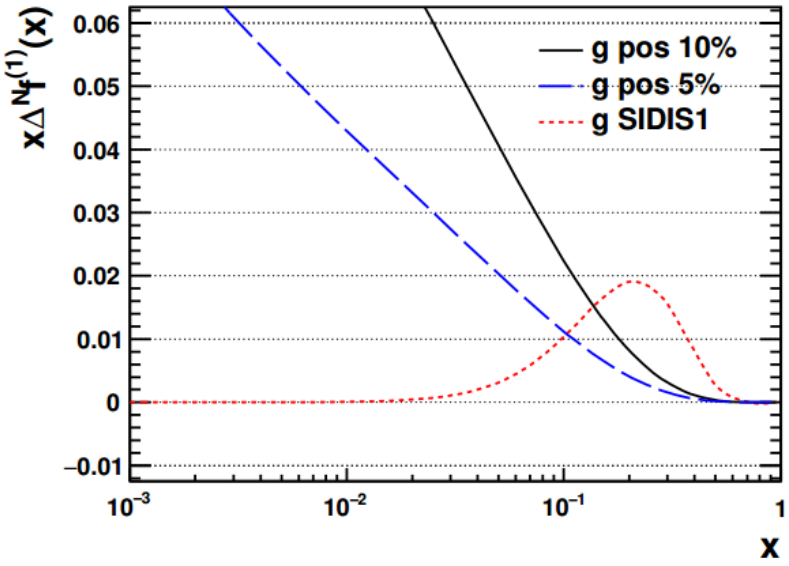
Alesio et. al. JHEP 09, 119 (2015)

(2) Positivity bound ansatz (g pos set)

Anselmino et. al. PRD 70, 074025 (2004)

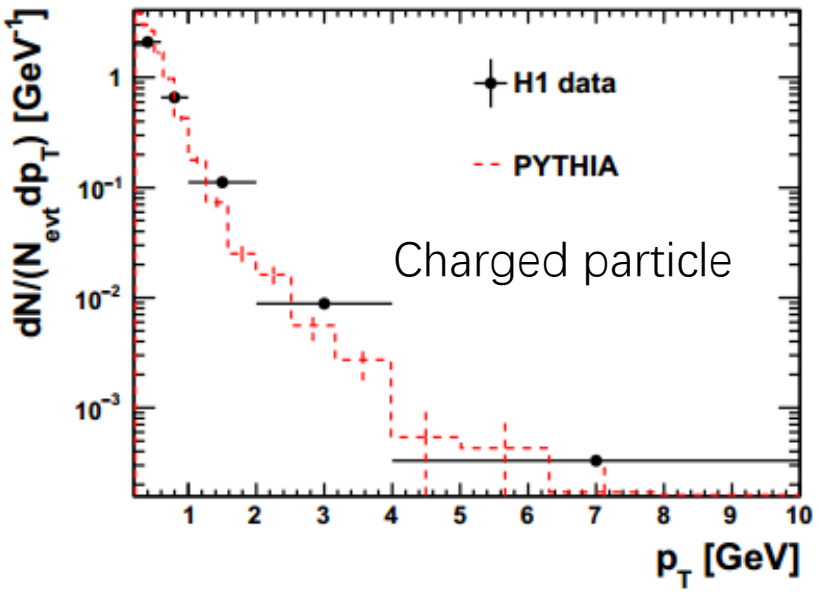
$$f_{1T}^{\perp g} = -\frac{2\sigma M_p}{k_\perp^2 + \sigma^2} f_g(x,k_\perp), \qquad \sigma = 0.8 \text{ GeV}$$

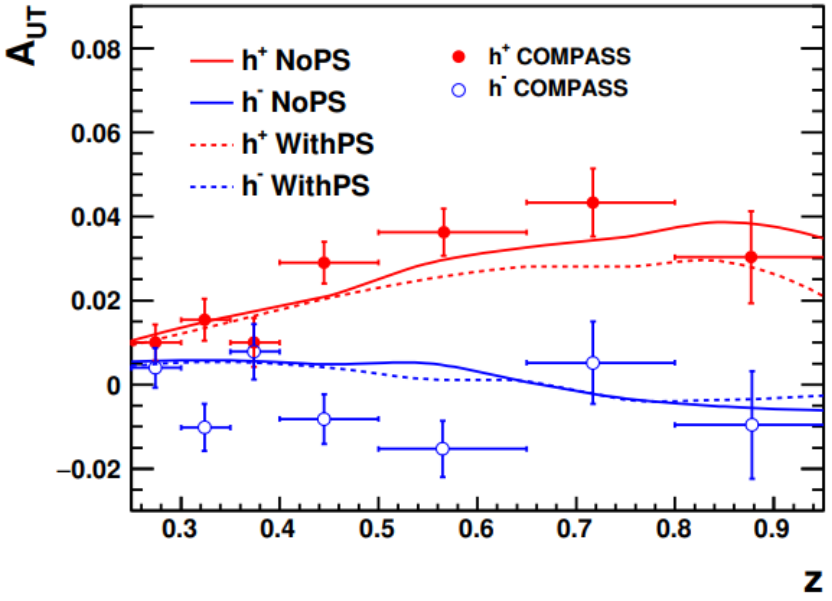




Comparing to experimental data

- The unpolarized data can be described by our tuned PYTHIA
- The quark Sivers data is consistent with event weighted single spin asymmetry



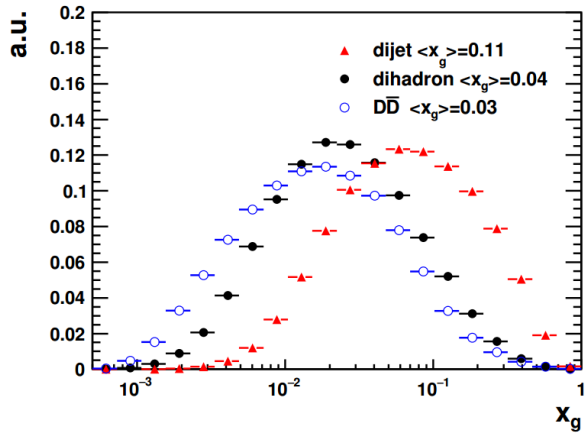


EIC setup for gluon Sivers study

ep$^{\uparrow}$ 18x275 GeV
$\sqrt{s}$ =141 GeV
L_{int}=10 fb^{-1}
0.01<y<0.95
Q^2>1 GeV^2

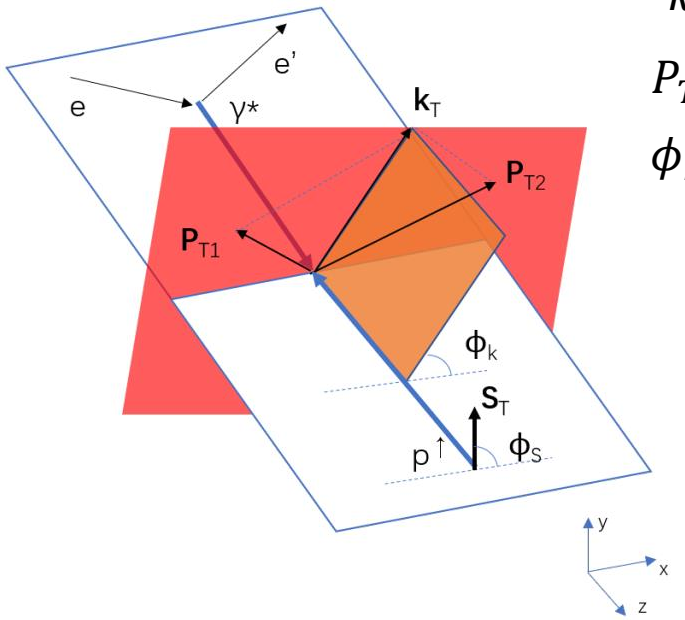
Final state observables

1. **Open charm pair**
2. **Charged hadron pair**
3. **Dijet pair**



Single Spin Asymmetry (SSA)

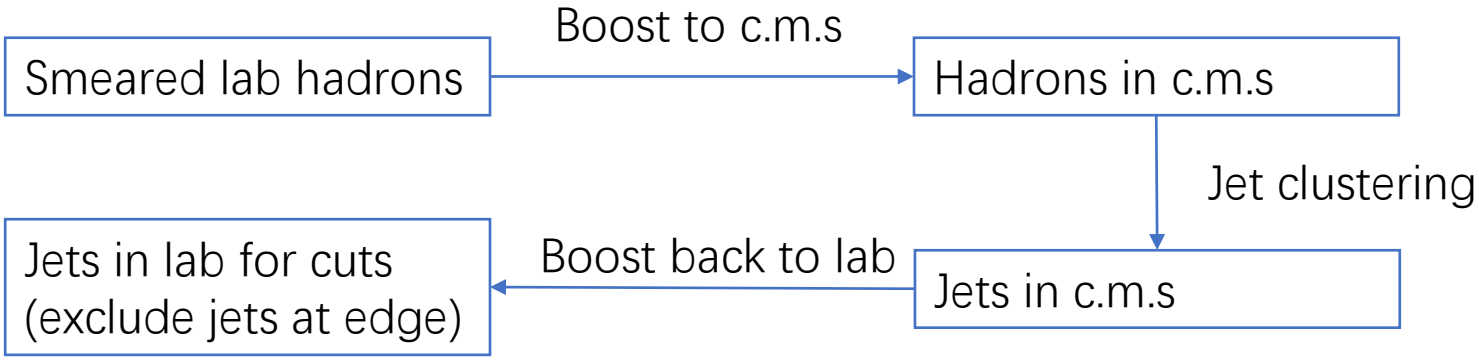
$$A_{UT} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} \propto \frac{\Delta^N f_{g/p^{\uparrow}}(x, k_{\perp})}{f_1^g(x_g, k_{\perp})}$$



Angular definition

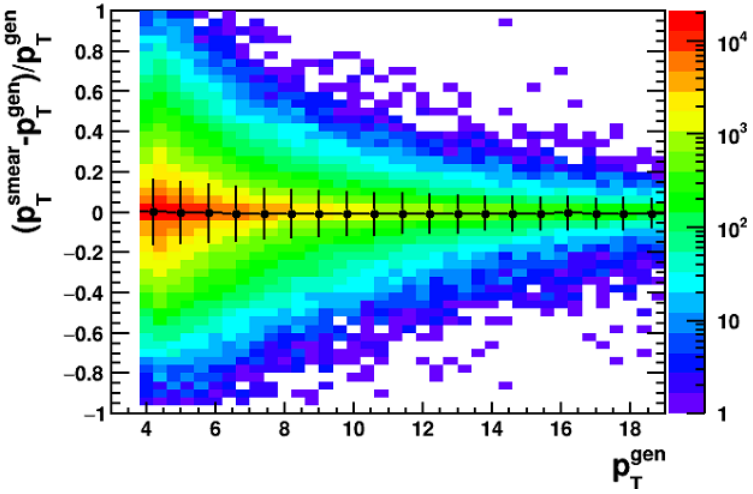
$$\vec{k}_T = \vec{P}_{T1} + \vec{P}_{T2}$$
$$P_T = |\vec{P}_{T1} - \vec{P}_{T2}|/2$$
$$\phi_{kS} = \phi_k - \phi_S$$

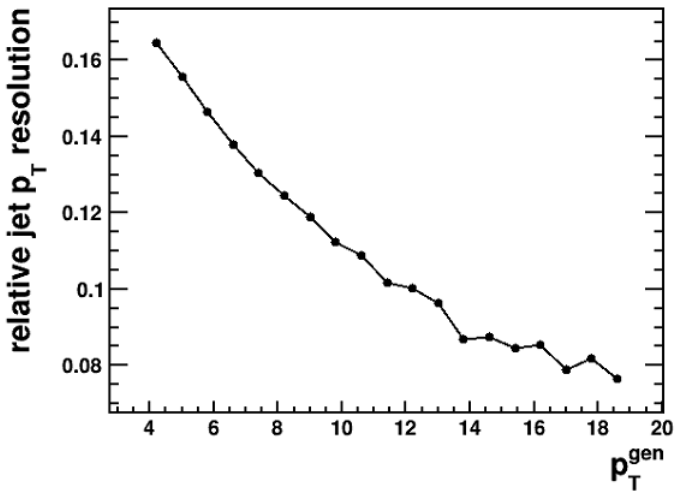
Jet reconstruction



Jet constituent: all final, p_T^{Lab}>0.25 GeV, $|\eta^{Lab}|$<3.5
Jet find in c.m.s frame, anti-kt R=0.8, p_T^{jet1}>4.5 GeV, p_T^{jet2}>4 GeV
Jet cut: $|\eta_{jet}{}^{Lab}|$<2.5

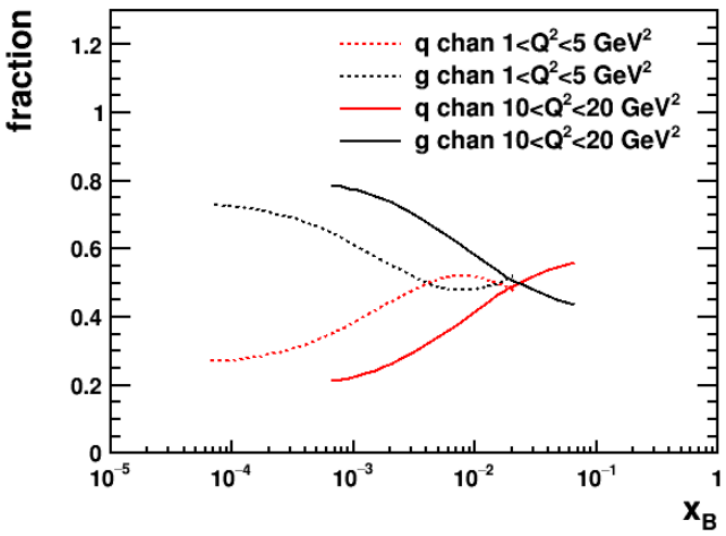
Jet p_T resolutions

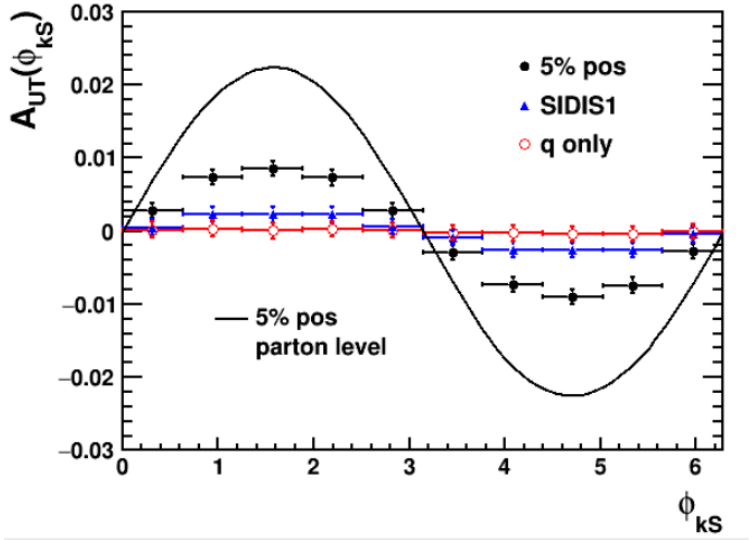




Dijet projection on gluon SSA

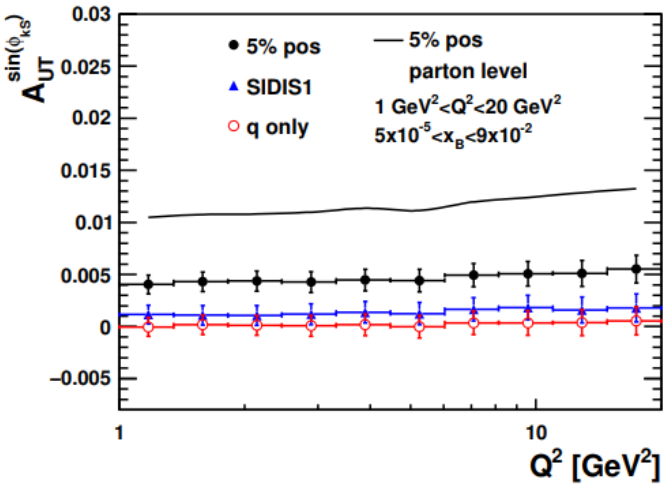
- Subject to the quark background contamination
- Stronger correlation between final state observable to parton level kinematics
- Resolution down to 5% positivity bound gluon Sivers size

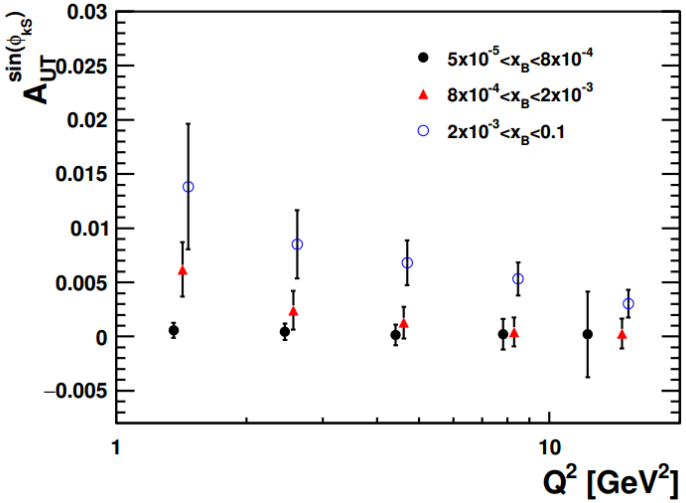


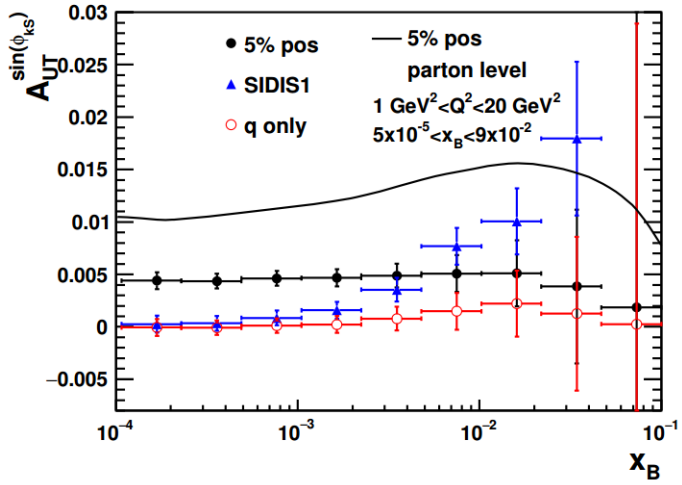


Dijet projection on gluon SSA

- Large statistics allow to explore gluon SSA in multidimensional analysis.

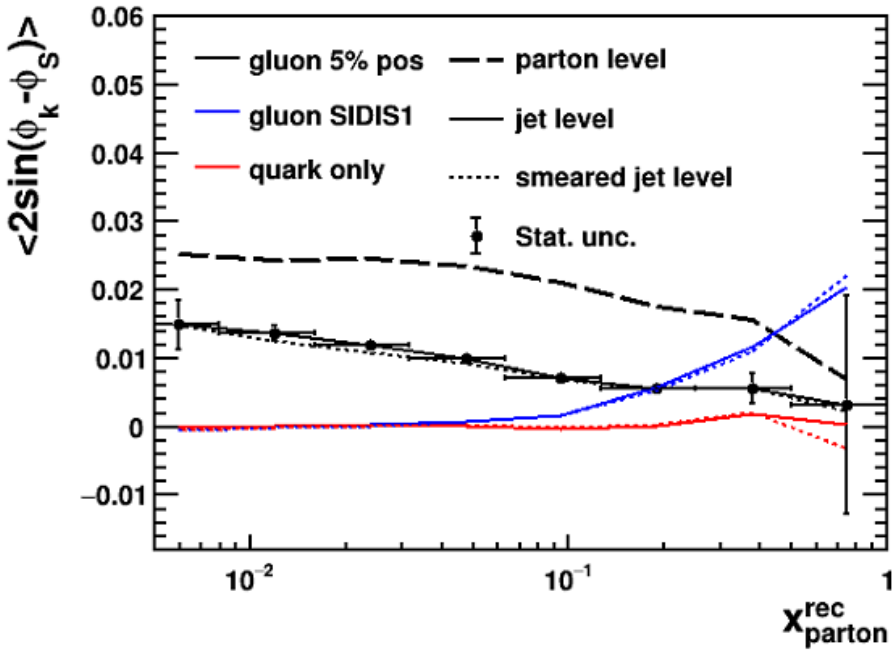


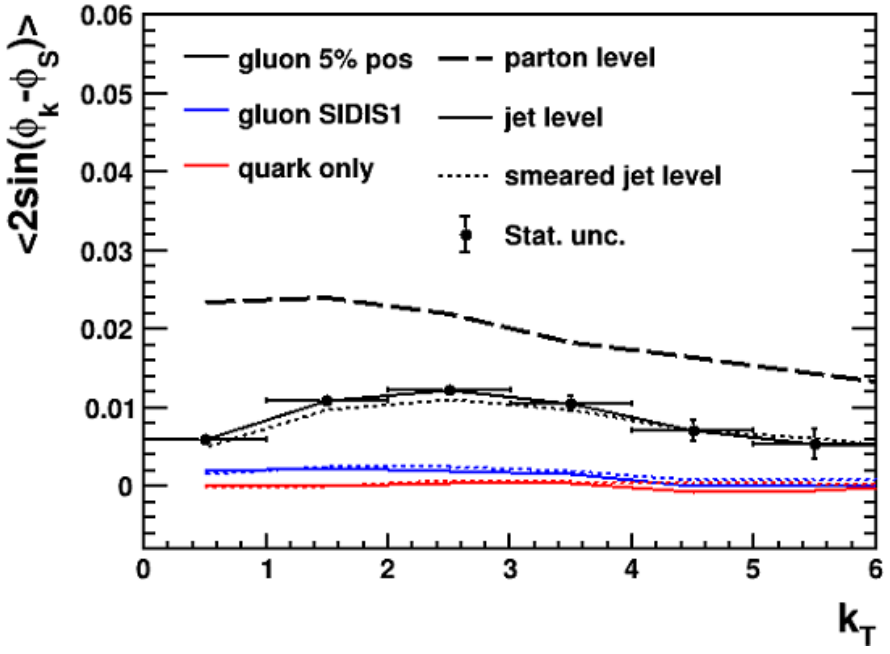




Dijet projection on gluon SSA

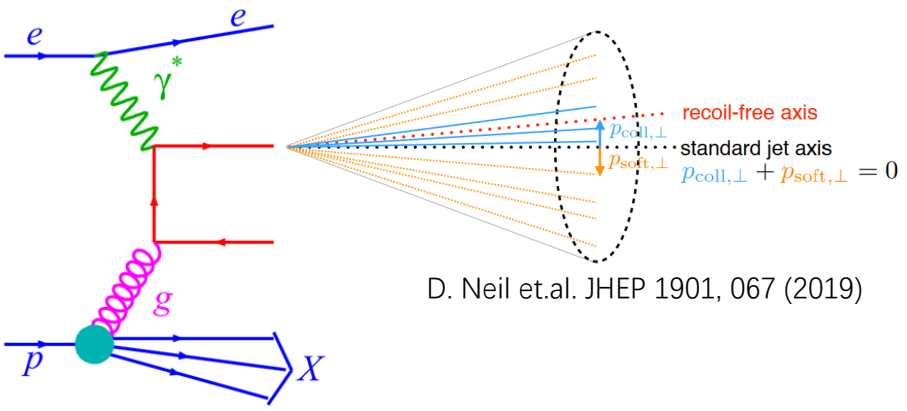
- Can be measured with EIC detector design
- Control underlying gluon kinematics
- Map initial gluon Sivers behavior
- Still suffer from sizable dilution effect



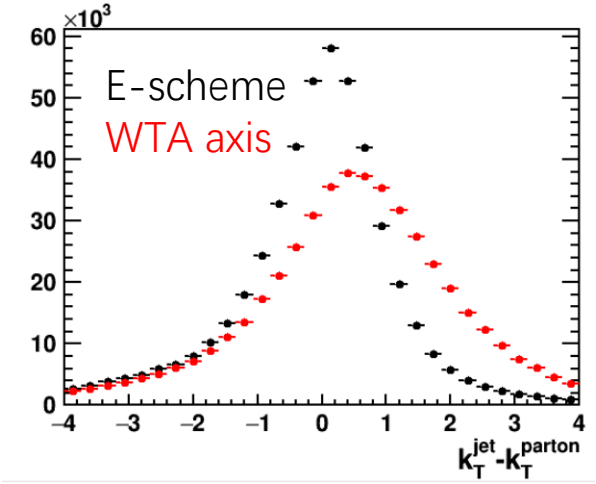


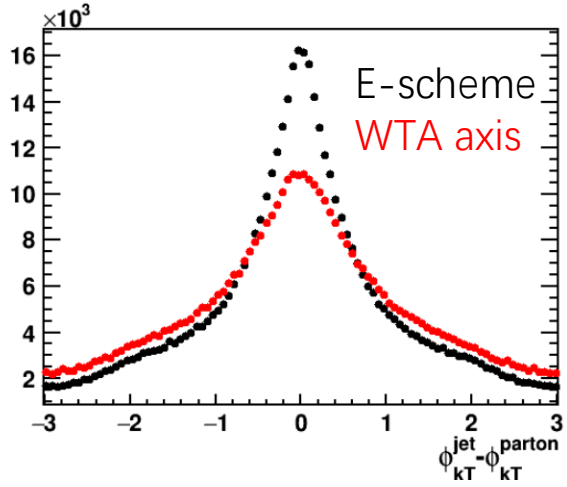
Winner takes all (WTA) jet axis

- Jet k_T angular correlation to parton gets broadening in WTA than in E-scheme
- Jet k_T value gets shifted and broadened in WTA



D. Neil et.al. JHEP 1901, 067 (2019)



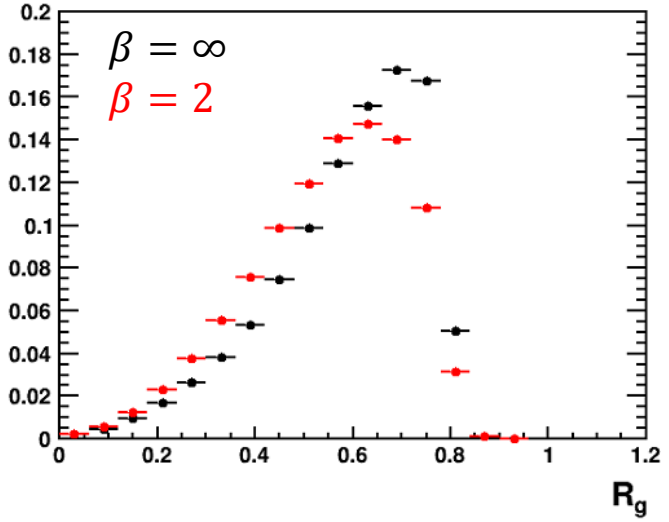


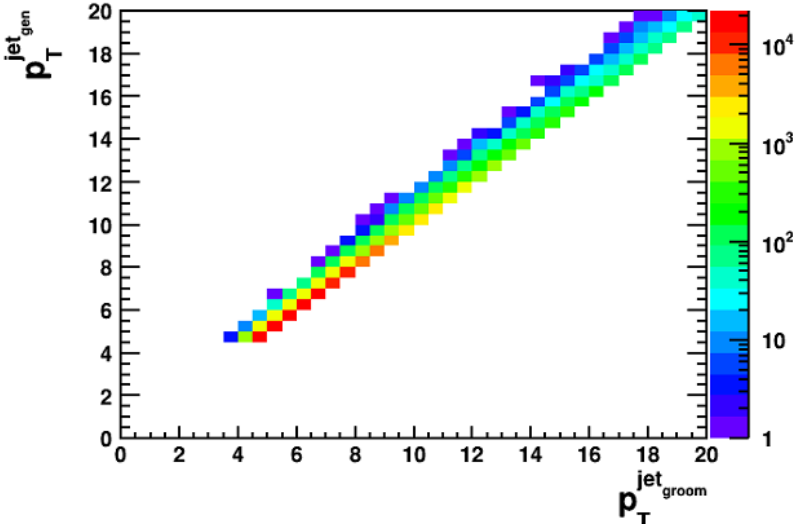
Groomed jet

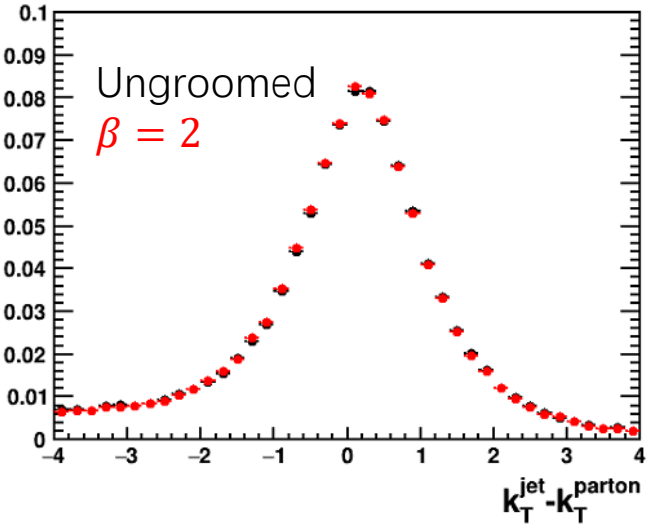
$$\frac{\min[p_{T1}, p_{T2}]}{p_{T1} + p_{T2}} > z_{\text{cut}} \left(\frac{\Delta R_{12}}{R}\right)^{\beta}$$

$$z_g = 0.1, \beta = 0.2$$

- The groomed radius shows only small shift
- Groomed jet kinematics changes little







Summary

- Jets are important probes to explore the Sivers effect at the future EIC.
- Quark Sivers evolution and its flavor dependence can be investigated with the single jets.
- Dijets at the EIC are unique observables to explore the gluon Sivers effect in deep inelastic scattering.
- Sizable dilution effect may call for more sophisticated unfolding technique to fully map the Sivers distribution.