

Nucleon Structure with charge correlation at EIC

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H.C., Liu, Petriello, arXiv:2605.15280

H.C., Petriello, Phys.Rev.D 114 (2026) 3, 036023-

H.C., Kang, Padilla, Penttala, arXiv:2606.12064

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- 1 The concept and features of the one point charge correlation
- 2 Numerical result
- 3 Conclusion and Outlook

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Proton Structure

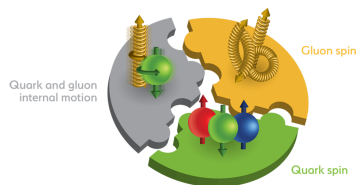
Leading Quark TMDPDFs  Nucleon Spin  Quark Spin

		Quark Polarization		
		Un-Polarized (U)	Longitudinally Polarized (L)	Transversely Polarized (T)
Nucleon Polarization	U	$f_1 = \text{Unpolarized}$		$h_1^\perp = \text{Boer-Mulders}$
	L		$g_1 = \text{Helicity}$	$h_{1L}^\perp = \text{Worm-gear}$
	T	$f_{1T}^\perp = \text{Sivers}$	$g_{1T}^\perp = \text{Worm-gear}$	$h_1^\perp = \text{Transversity}$ $h_{1T}^\perp = \text{Pretzelosity}$

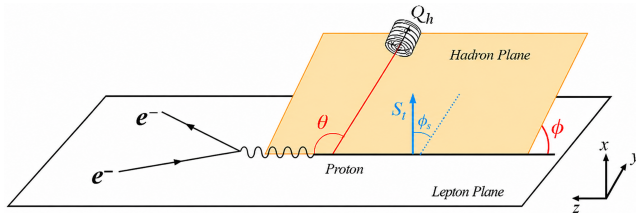
[Boussarie et al.](2023)

Major focus of the EicC, EIC

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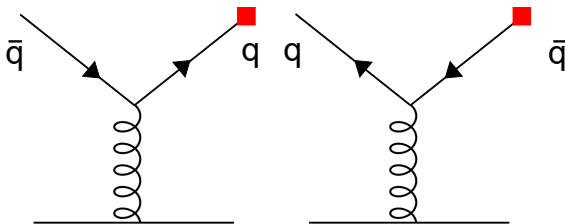
Definition of Charge Correlation



Measurement in DIS

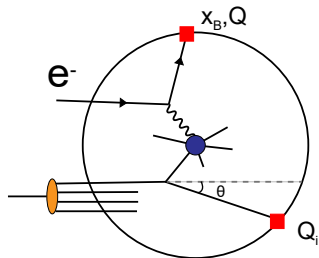
$$\Sigma(\vec{n}, x_B, Q^2) = \sum_h \int d\sigma_{ep^\uparrow \rightarrow eh+X} Q_h \delta(\vec{n} - \vec{n}_h)$$

Only need charge and angular directions of charged tracks , no jet/hadrons, no energy

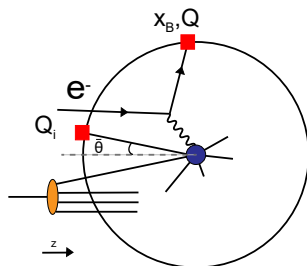


The charge conservation ensures that the resulting contribution to the QC vanishes upon summing over q and $\bar{q}$ [Riembau, Son](2024), [Monni, Vita, Xu, Zhu](2025)

TMD region and Target Fragmentation Region



In TFR $\theta \ll 1$

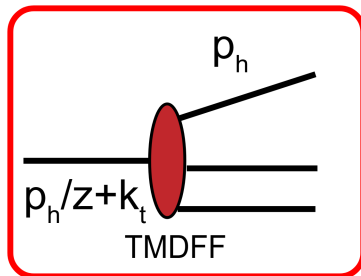
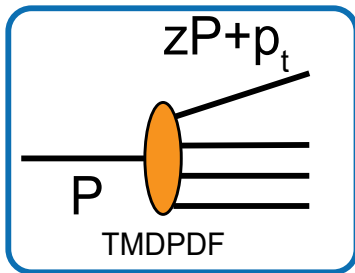
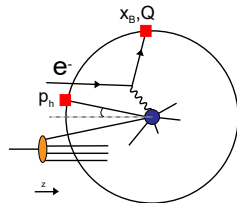


In TMD region $\bar{\theta} = \pi - \theta \ll 1$

Factorization in TMD region

I. SIDIS

$$d\sigma_{un} = H \boxed{f_q} \otimes S \otimes \boxed{D_{h/q}}$$



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II. Charge Correlators

$$\Sigma_{un} = \sum_h Q_h \int d\sigma_{un} \delta(\vec{n} - \vec{n}_h)$$

$$\Sigma_{un} = H \boxed{f_q} \otimes S \otimes \boxed{J_q}$$

$$J_q(k_t) \equiv \sum_a \int_0^1 dz Q_a D_{a/f}(z, k_t)$$

$$J_q = -J_{\bar{q}}$$

$$\begin{aligned} J_q &= \sum_{h,i} \int dz_h Q_h \int_{z_h}^1 \frac{dz}{z} D_{h/i} \left(\frac{z_h}{z} \right) \\ &\quad \times \mathcal{I}_{i/q}(z, k_t) \\ &= \sum_{h,i} \int dz_h Q_h D_{h/i}(z_h) \int dz \mathcal{I}_{i/f}(z, k_t) \\ &= \sum_i \int dz Q_i \mathcal{I}_{i/q}(z, k_t) \end{aligned}$$

QC jet functions known up to N⁴LO [Monni, Vita, Xu, Zhu](2025)

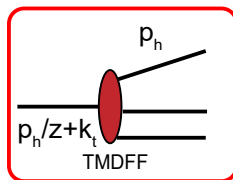
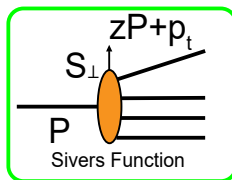
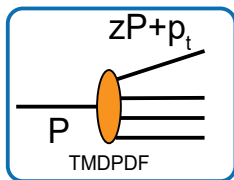
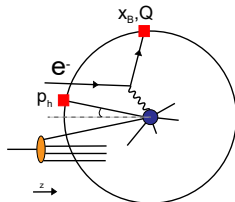
Factorization in TMD region

I. SIDIS

$$d\sigma_{pol} = F_{UU} + |S_{\perp}| \sin(\phi - \phi_S) F_{UT}^{\sin(\phi - \phi_S)}$$

$$F_{UU} = H \boxed{f_q} \otimes S \otimes \boxed{D_{h/q}}$$

$$F_{UT} = H \boxed{f_{1T,q}^{\perp}} \otimes S \otimes \boxed{D_{h/q}}$$



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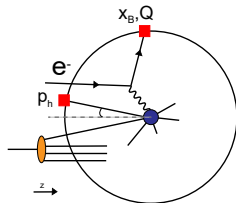
II. Charge Correlators

$$\Sigma_{pol} = \sum_h Q_h \int d\sigma_{pol} \delta(\vec{n} - \vec{n}_h)$$

$$\Sigma_{pol} = \Sigma_{UU} + |S_{\perp}| \sin(\phi - \phi_S) \Sigma_{UT}^{\sin(\phi - \phi_S)}$$

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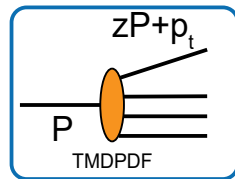
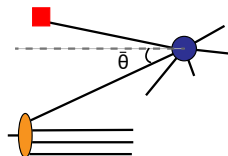


$$A^{\text{Sivers}}(\theta) = \frac{\Sigma_{UT}(\theta)}{\Sigma_{UU}(\theta)}$$

Transverse Moment Dependent PDFs

$$d\sigma_{un} = H[f_q] \otimes S \otimes D_{h/q}$$

- Major tool for structure studies
- Extra non-perturbative object



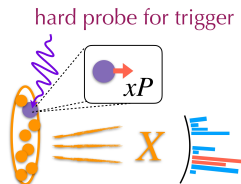
Operator Definition of Nucleon Charge Correlator

To Describe the distribution in TFR, we follow the procedure in Nucleon Energy Correlator [Liu,Zhu](2023) and define the Nucleon Charge Correlator

$$f_{q,QC}(x, \vec{n}) = \int \frac{dy^-}{4\pi} e^{-ixP^+ \frac{y^-}{2}} \langle P | \bar{\chi}_n \left(\frac{y^-}{2} n^\mu \right) \frac{\gamma^+}{2} \hat{Q}(\vec{n}) \chi_n(0) | P \rangle$$

$$Q(\vec{n}) = \lim_{r \rightarrow \infty} r^2 \int_{-\infty}^{\infty} dt n^i J_i(t, r\vec{n})$$

- Charge correlator in the forward region
- Purely collinear object, insensitive to soft radiations



Factorization in TFR

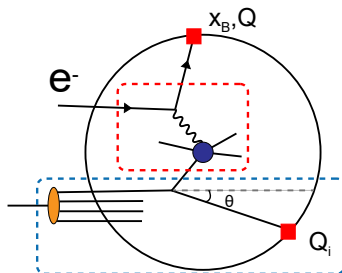
When $\theta \ll 1$

$$\Sigma(\theta) = \sum_{i=q,g} \int \frac{dz}{z} \hat{\sigma}_i \left(\frac{x_B}{z}, Q^2 \right) f_{i,QC}(z, \theta)$$

This is a DIS type factorization.

The Nucleon Charge Correlators satisfy the DGLAP equation as PDF.

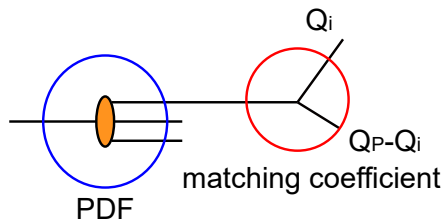
Comparing with NEC in a charged subset, QC don't need to consider energy and expect to get lower uncertainty.



Factorization in TFR

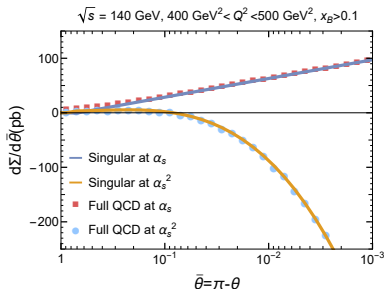
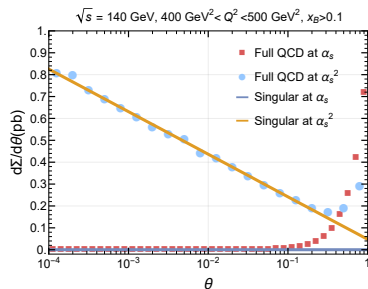
When $\theta \ll 1$ but still large enough that $\theta Q \gg \Lambda_{\text{QCD}}$ we can further separate the previous collinear region into the **hard collinear mode** where $p_t \sim \theta Q$ and the **SCET_{II} mode** where $p_t \sim \Lambda_{\text{QCD}}$ and factorize $f_{i,\text{QC}}$ as

$$f_{i,\text{QC}}(x, \theta) = \int \frac{dz}{z} I_{ij} \left(\frac{x_B}{z}, \theta \right) f_j(z)$$



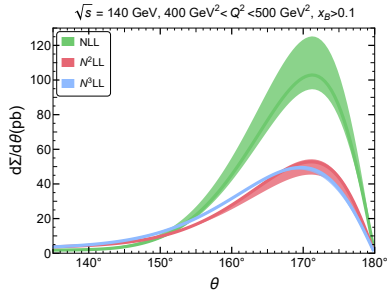
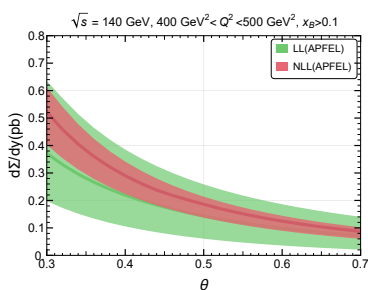
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Validity of SCET



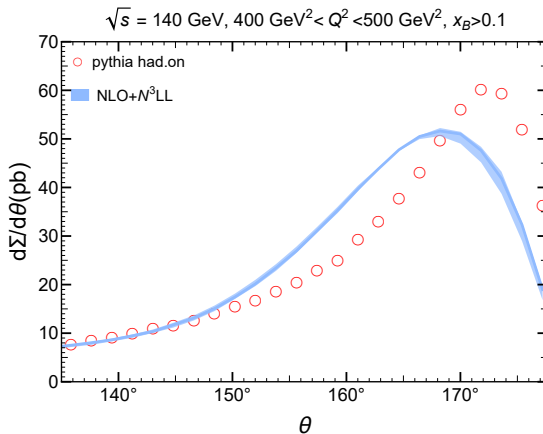
The two calculations agree very well in TMD region and TFR.
Potentially dangerous soft gluon splitting $g \rightarrow q\bar{q}$ singular contribution cancels after the charge-conjugate integration at this order.

Resummation



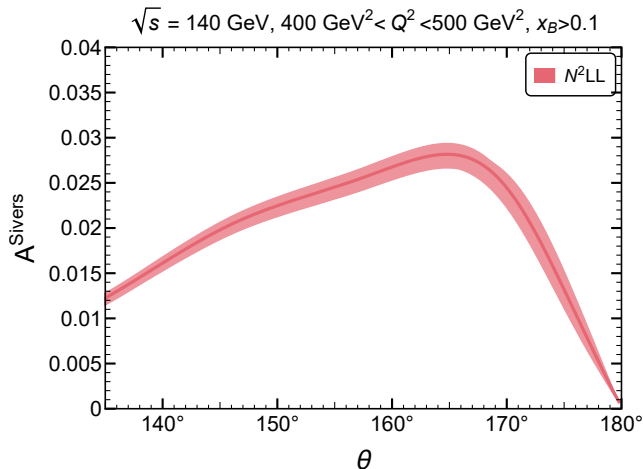
The perturbative series stabilizes as the logarithmic accuracy is increased, and the scale uncertainty is correspondingly reduced

Resummation



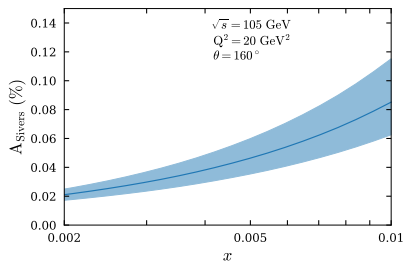
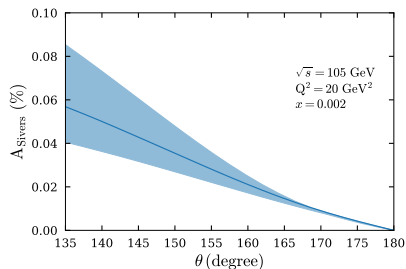
The resummed result accounting for the effects of large logarithms to all orders correctly captures the behavior of PYTHIA in this region.

Sivers Asymmetry



The QC probe predicts a sizeable Sivers asymmetry.

Sivers Asymmetry in small- x



We could also probe the Sivers Asymmetry in small x region.

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Conclusions

- (1) The charge correction is introduced.
- (2) Factorization in both TFR and TMD region is introduced.
- (3) The charge correction could be used to probe Sivers function.
- (4) The logic of the QC is more broadly applicable to other similar observables.

The relation between Nucleon QC and fracture function?

Hadron-in-jet measurements?

Thank You!

To calculate the TFR result, we are actually using

$$\Sigma(\theta, \phi) = \sum_i \int d\sigma_{ep \rightarrow e+i+X} Q_i \Theta(\theta - \theta_i) \delta(\phi - \phi_i)$$

and taking derivative.

When $\theta Q \gg \Lambda_{QCD}$ have α_s^0 level contribution from SCET_{II} region and have

$$f_{i,QC}^{(0)}(z, \theta) = (Q_P - Q_i) f(z)$$

In the TMD region

$$\frac{d\Sigma_{UT}^{\sin(\phi_h - \phi_s)}(\theta)}{d\theta} = \sigma_0 H(Q^2, \mu) \sum_f Q_f^2 \int \mathbf{q}_T d\mathbf{q}_T \int_0^\infty \frac{b^2 db}{4\pi} J_1(b|\mathbf{q}_T|) \\ \times f_{1T,f/p}(x_B, b, \mu, \nu) S(b, \mu, \nu) J_{f,Q}(b, \mu, \nu) \delta\left(\frac{2|\mathbf{q}_T|}{Q} - \bar{\theta}\right)$$

$$\frac{d\Sigma(\theta)}{d\theta} = H(Q^2, \mu_H) \sum_f Q_f^2 \int d^2\mathbf{q}_T \frac{d^2\mathbf{b}}{(2\pi)^2} \\ \times \exp[-i\mathbf{q}_T \cdot \mathbf{b}] U_{tot} B_{f/p}(x_B, b, \mu_B, \nu_B) \\ \times S(b, \mu_S, \nu_S) J_{f,Q}(b, \mu_J, \nu_J) \delta\left(\frac{2|\mathbf{q}_T|}{Q} - \bar{\theta}\right)$$

$$\begin{aligned}
 \Sigma = & Q_q \int \frac{d^3 p_q}{p_q^0} \frac{d^3 p_{q'}}{p_{q'}^0} \frac{d^3 p_{\bar{q}'}}{p_{\bar{q}'}^0} \delta^4(p + q - p_q - p_{q'} - q_{\bar{q}'}) \delta(\theta - \theta_q) |M_{\gamma q \rightarrow qq' \bar{q}'}|^2 \\
 & + Q_{q'} \int \frac{d^3 p_q}{p_q^0} \frac{d^3 p_{q'}}{p_{q'}^0} \frac{d^3 p_{\bar{q}'}}{p_{\bar{q}'}^0} \delta^4(p + q - p_q - p_{q'} - q_{\bar{q}'}) \delta(\theta - \theta_{q'}) |M_{\gamma q \rightarrow qq' \bar{q}'}|^2 \\
 & - Q_{q'} \int \frac{d^3 p_q}{p_q^0} \frac{d^3 p_{q'}}{p_{q'}^0} \frac{d^3 p_{\bar{q}'}}{p_{\bar{q}'}^0} \delta^4(p + q - p_q - p_{q'} - q_{\bar{q}'}) \delta(\theta - \theta_{\bar{q}'}) |M_{\gamma q \rightarrow qq' \bar{q}'}|^2
 \end{aligned}$$

When q is hard , q' and $\bar{q}'$ are soft, from Eq.95 in hep-ph/9908523

$$|M_{\gamma q \rightarrow qq' \bar{q}'}|^2 \sim (4\pi\mu^{2\epsilon}\alpha_s)^2 T_R \sum_{i,j} |M_{\gamma q \rightarrow q}|_{ij}^2 \Gamma^{ij}(p_{q'}, p_{\bar{q}'})$$