QCD Evolution of the Gluon Sivers Function in Heavy Flavor Dijet Production at the Electron-Ion Collider (2012.01756)

John Terry (johndterry@physics.ucla.edu)

UCLA

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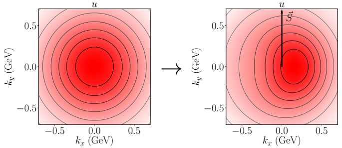
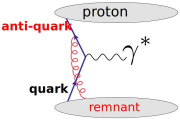
The Sivers Function

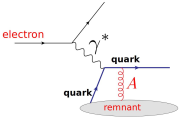
Can access the intrinsic transverse momentum of quarks in transversely polarized hadrons by fitting experimental data.

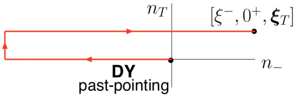


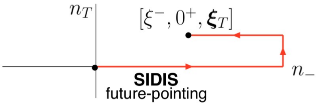
(Echevarria, Kang, JT 2020)

$$f_{1T}^{\perp\, DY}(x, p_\perp) = -f_{1T}^{\perp\, SIDIS}(x, p_\perp)$$

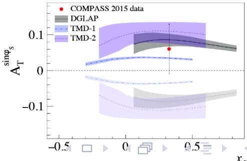








- (Collins 02)
- (Boer-Mulders-Pijlman 03)
- (Collins-Metz 04)
- (Kang-Qiu 09)

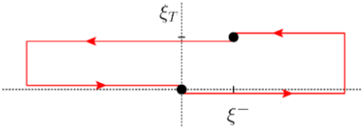


Process dependence for the gluon Sivers function

Two types of gluon Sivers functions. See (Dominguez, Xiao, Yuan 2011) and (Buffing, Mukherjee, Mulders 2013).

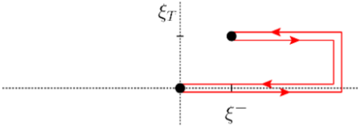
Dipole (d-type)

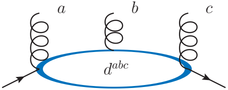
Measurable in $pp^{\uparrow} \to \gamma$ Jet ($qg \to \gamma q$)



Weizscker-Williams (f-type)

Measurable in $ep^{\uparrow} \to Q\bar{Q}$ ($\gamma g \to Q\bar{Q}$)





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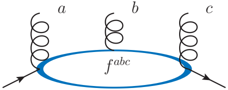
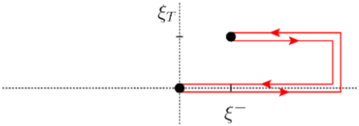
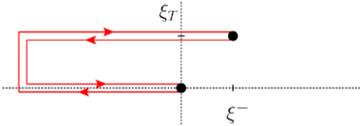


See for instance (Boer, Echevarria, Mulders, Zhou 2015).

Modified universality for the gluon Sivers (Boer, Mulders, Pisano, Zhou 2016)



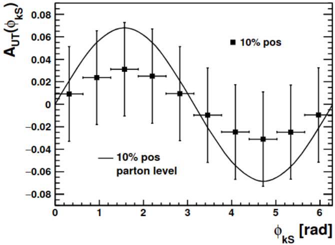


$$f_{1T}^{\perp[ep^{\uparrow} \to e' Q\bar{Q}X]}(x, p_{\perp}) = -f_{1T}^{\perp[pp^{\uparrow} \to \gamma\gamma X]}(x, p_{\perp})$$

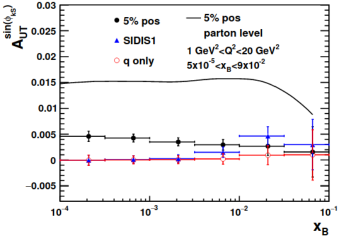
Gluon Sivers Function at the EIC

Feasibility of measuring the gluon Sivers asymmetry was examined in (Zheng, Aschenauer, Lee, Xiao, Yin 2018) using a Pythia reweighting analysis $\mathcal{L}_{int} = 10\, fb^{-1}$.

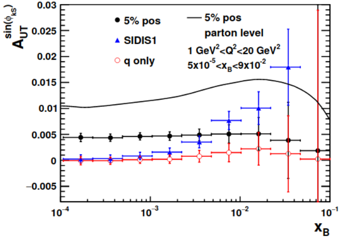
Open charm ($D \to K\pi$ pair)

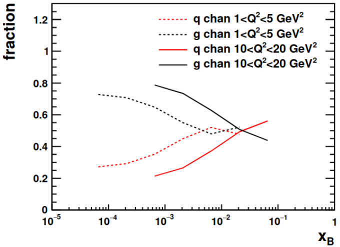


Di-hadron production

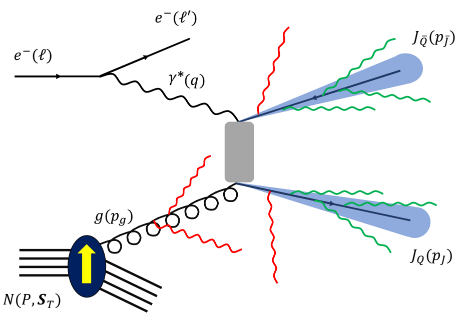


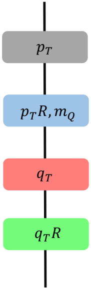
Dijet ($\gamma g \to qg$, $\gamma q \to qg$)





Imbalance for heavy flavor dijet production(Kang, Reiten, Shao, JT 2020)





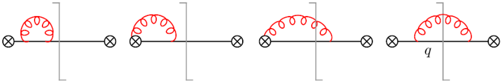
$$\frac{d\boldsymbol{\sigma}^{UU}}{dQ^2 dy d^2\boldsymbol{p}_T dy_J d^2\boldsymbol{q}_T} \sim H(Q,p_T) S(\boldsymbol{\lambda}_T) f_{g/N}(x,k_T) J_{\mathcal{Q}}(p_T R, m_{\mathcal{Q}}) S^c_{\mathcal{Q}}(\boldsymbol{l}_{\mathcal{Q}T}, R, m_{\mathcal{Q}}) J_{\bar{\mathcal{Q}}}(p_T R, m_{\mathcal{Q}}) S^c_{\bar{\mathcal{Q}}}(\boldsymbol{l}_{\bar{\mathcal{Q}}T}, R, m_{\mathcal{Q}}) \delta^{(2)}(\boldsymbol{\lambda}_T + \boldsymbol{k}_T + \boldsymbol{l}_{\mathcal{Q}T} + \boldsymbol{l}_{\bar{\mathcal{Q}}T} - \boldsymbol{q}_T)$$

$H(Q, p_T)$ and $S(\boldsymbol{\lambda}_T)$ are the same as light flavor dijet production since $m_{\mathcal{Q}} \ll p_T$.

The functions $S^c_{\mathcal{Q}}(\boldsymbol{l}_{\mathcal{Q}T}, R, m_{\mathcal{Q}})$ and $J_{\mathcal{Q}}(p_T R, m_{\mathcal{Q}})$ are sensitive to the mass.

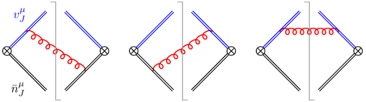
Perturbative ingredients at NLO, see also (Kim 2020)

Mass dependent jet function



$$\Gamma^{j\mathcal{Q}}(\alpha_s) = -C_F \gamma^{\text{cusp}}(\alpha_s) \ln \frac{m_{\mathcal{Q}}^2 + p_T^2 R^2}{\mu^2} + \frac{\alpha_s C_F}{2\pi}\left(3 - \frac{2m_{\mathcal{Q}}^2}{m_{\mathcal{Q}}^2 + p_T^2 R^2}\right)$$

Mass dependent collinear soft function



$$v_J^\mu = \frac{\omega_J}{m_{\mathcal{Q}}} \frac{n_J^\mu}{2} + \frac{m_{\mathcal{Q}}}{\omega_J} \frac{\bar{n}_J^\mu}{2}\,, \qquad v_J^2 = 1$$

$$\Gamma^{cs\mathcal{Q}}(\alpha_s) = C_F \gamma^{\text{cusp}}(\alpha_s) \ln \frac{R^2 \mu_b^2}{\mu^2} - \frac{\alpha_s C_F}{\pi}\left[2 \ln(-2ic_{bJ}) - \frac{m_{\mathcal{Q}}^2}{m_{\mathcal{Q}}^2 + p_T^2 R^2} - \ln \frac{m_{\mathcal{Q}}^2 + p_T^2 R^2}{p_T^2 R^2}\right]$$

Demonstrates RG consistency at NLL. (Castillo, Echevarria, Makris, Scimemi 2020)

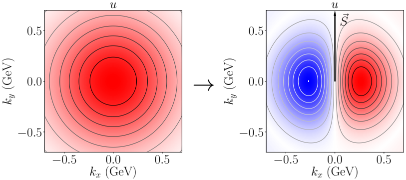
$$\Gamma^h + \Gamma^s + \Gamma^{fg} + 2\Gamma^{jq} + \Gamma^{csq} + \Gamma^{cs\bar{q}} = 0\,.$$

We find

$$2\Gamma^{j\mathcal{Q}} + \Gamma^{cs\mathcal{Q}} + \Gamma^{cs\bar{\mathcal{Q}}} = 2\Gamma^{jq} + \Gamma^{csq} + \Gamma^{cs\bar{q}}$$

Spin Dependent Resummation

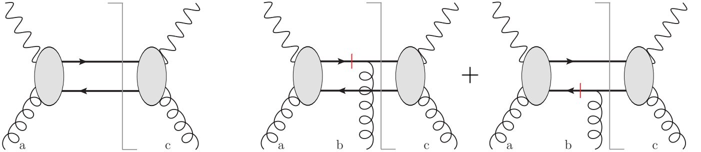
Replace TMDPDF with the gluon Sivers function



$$f\left(x, k_T, \mu, \zeta\right) \rightarrow \frac{1}{M}\varepsilon_{\alpha\beta}\, S_T^{\alpha}\, k_T^{\beta}\, f_{1T}^{\perp,f}\left(x, k_T, \mu, \zeta\right).$$

$$\Gamma^{f\perp} = \Gamma^{f} \qquad \gamma_V^{f\perp} = \gamma_V^{f}$$

Need to consider additional gauge link attachment for the spin dependent cross section



$$= C_u\, \delta^{ac}\, h(Q, y, p_T, y_J, \mu_h) \qquad = \left(C_1^{\perp} + C_2^{\perp}\right)\left(-i f^{abc}\right) h(Q, y, p_T, y_J, \mu_h)$$

$$C_u = C_1^{\perp} + C_2^{\perp} \rightarrow \Gamma^{h\perp} = \Gamma^{h}$$

Unpolarized Cross Section

Perturbative evolution

$$S_{\text{pert}} = \exp\left[\int_{\mu_{b*}}^{\mu_h} \frac{d\mu}{\mu}\left(\Gamma^s + \Gamma^{fg}\right) + 2\int_{\mu_j}^{\mu_h} \frac{d\mu}{\mu}\Gamma^j \mathcal{Q} + \int_{\mu_{cs}}^{\mu_h}\frac{d\mu}{\mu}\left(\bar{\Gamma}^{cs}\mathcal{Q} + \bar{\Gamma}^{cs}\bar{\mathcal{Q}}\right)\right]$$

Mass dependence does not vanish in the cross section

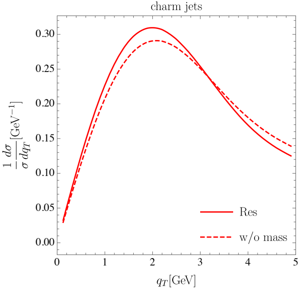
$$\mu_j = p_T R, \quad \mu_{cs} = \mu_{b_*} R\,.$$

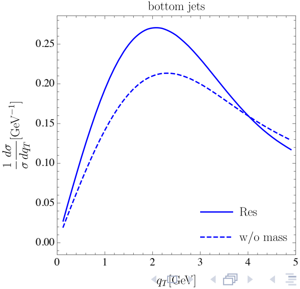
Unpolarized phenomenology

$$S_{\text{NP}}\left(b, Q_0, n\cdot p_g\right) = g_1 b^2 + \frac{g_2}{2}\frac{C_A}{C_F}\ln\frac{n\cdot p_g}{Q_0}\ln\frac{b}{b_*}\,.$$ (Sun, Isaacson, Yuan, Yuan 2014)

$$\text{charm}: \quad 5\,\text{GeV} < p_T < 10\,\text{GeV}, \qquad \text{bottom}: \quad 10\,\text{GeV} < p_T < 15\,\text{GeV},$$

$|y_J| < 4.5$, see (Aschenauer, Baker et al 2014)





Phenomenology

Non-perturbative collinear parameterization

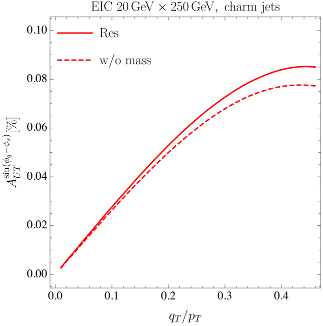
$$f_{1T,g/N}^{\perp f}(x,\mu) = N_g \frac{4\rho\sqrt{2e\rho(1-\rho)g_1}}{M_{\mathrm{proton}}} x^{\alpha_g}(1-x)^{\beta_g} \frac{(\alpha_g+\beta_g)^{\alpha_g+\beta_g}}{\alpha_g^{\alpha_g}\,\beta_g^{\beta_g}} f_{g/N}(x,\mu)\,,$$

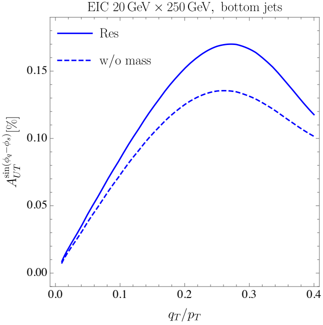
Parameters from (D'Alesio, Murgia, Pisano 2015)

$$N_g = 0.65, \quad \alpha_g = 2.8, \quad \beta_g = 2.8, \quad \rho = 0.5, \quad M_{\mathrm{proton}} = 1\,\mathrm{GeV}\,,$$

For the TMD

$$S_{\mathrm{NP}}^{\perp}(b, Q_0, n\cdot p_g) = g_1\rho\, b^2 + \frac{g_2}{2}\frac{C_A}{C_F}\ln\frac{n\cdot p_g}{Q_0}\ln\frac{b}{b_*}\,,$$





Conclusion

- We have developed a factorization and resummation formalism for heavy flavor dijet production at the EIC.
- We considered mass corrections to the collinear-soft, the exclusive jet function, as well as the resummed factorized expression.
- Using our theoretical framework we generate a prediction for heavy flavored dijet production at the EIC and find sizeable corrections to the projected asymmetry.
- Over the large kinematic regions at the EIC, these mass corrections may prove important for global analyses of the gluon Sivers function.

Thank you!