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QCD evolution of the gluon Sivers function in heavy flavor dijet production at the EIC

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EIC opportunities for Snowmass (online)
Jan 24, 2021

Reference: Zhong-bo Kang, Jared Reiten, Ding Yu Shao, John Terry arXiv:2012.01756

Gluon Sivers function (GSF)

- **Gauge link dependent gluon TMDs**

$$\Gamma^{[U,U']\mu\nu}(x,p_T;n) = \int \frac{d\xi\cdot P d^2\xi_T}{(2\pi)^3} e^{ip\cdot\xi}\langle P,S|F^{n\mu}(0)\, U_{[0,\xi]}F^{n\nu}(\xi)U'_{[\xi,0]}|P,S\rangle\Big|_{\mathrm{LF}}$$

- **GSF: T-odd object; two gauge links; process dependence more involved**
- **For any process GSF can be expressed in terms of two functions:**

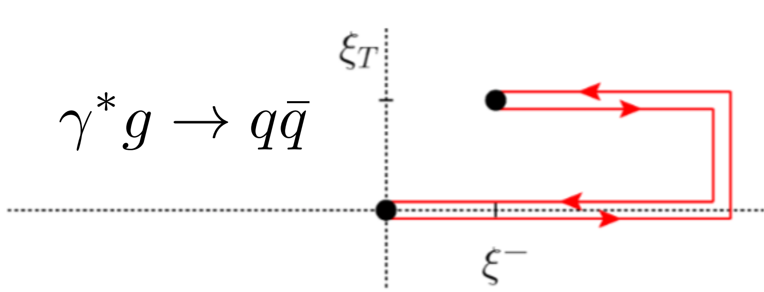
(Buffing, Mukherjee, Mulders'13)

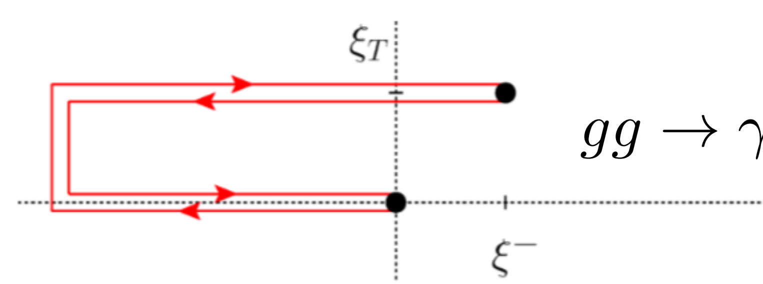
$$f_{1T}^{\perp g[U]}\left(x,\mathbf{k}_\perp^2\right) = \sum_{c=1}^{2} C_{G,c}^{[U]} f_{1T}^{\perp g(Ac)}\left(x,\mathbf{k}_\perp^2\right)$$

calculable for each channel

- $f_{1T}^{\perp g(f)}$ **f-type, C-even**
- $f_{1T}^{\perp g(d)}$ **d-type, C-odd**

$\gamma^* g \to q\bar{q}$





$gg \to \gamma\gamma$

$$f_{1T}^{\perp g[e\,p^\uparrow \to e'\,Q\bar{Q}\,X]}(x,p_T^2) = -f_{1T}^{\perp g[p^\uparrow\,p\to\gamma\,\gamma\,X]}(x,p_T^2)$$

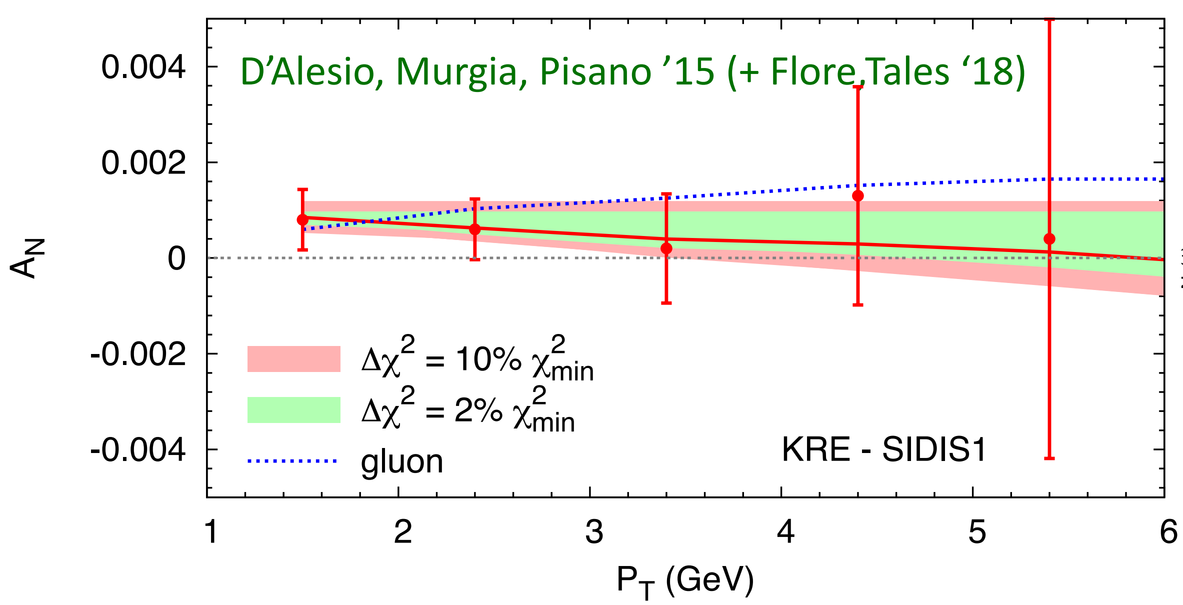
Gluon Sivers function (GSF)

- **Theory constrain from Burkardt's sum rule: sum of the transverse momenta of quarks and gluons in a transversely polarized nucleon is zero**
- **Various pp scattering processes suggested to probe GSF** see a review (Boer, Lorce, Pisano, Zhou '15)

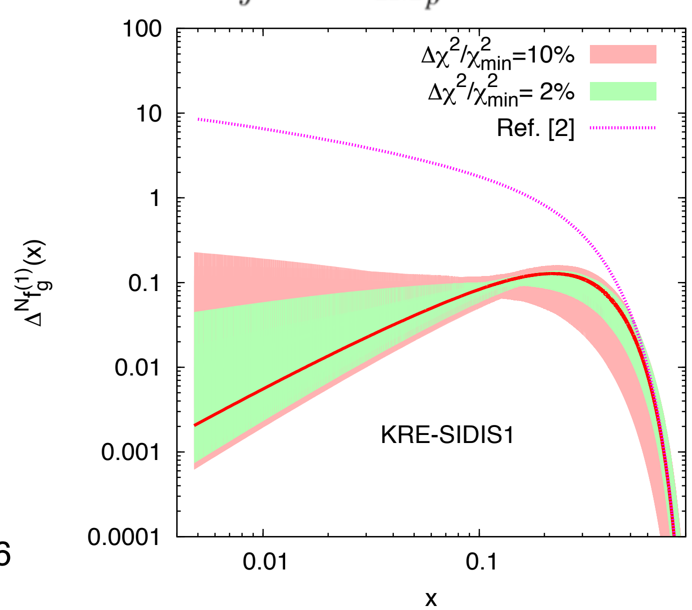
$p^\uparrow p \to \text{jet}\,\text{jet}X \qquad p^\uparrow p \to DX \qquad p^\uparrow p \to \gamma X \qquad p^\uparrow p \to \gamma\text{jet}X \qquad p^\uparrow p \to \text{jet}X \qquad p^\uparrow p \to \pi\text{jet}X$

$p^\uparrow p \to \eta_{c/b}X \qquad p^\uparrow p \to Q\bar{Q}X \qquad p^\uparrow p \to D^0\overline{D}^0X \qquad p^\uparrow p \to J/\psi\gamma X \qquad p^\uparrow p \to J/\psi J/\psi X$

$$A_N(p^\uparrow p \to \pi X)$$



$$\Delta^N f^{(1)}_{g/p^\uparrow}(x) \equiv \int d^2\boldsymbol{k}_\perp \frac{k_\perp}{4M_p}\Delta^N f_{g/p^\uparrow}(x,k_\perp) = -f_{1T}^{\perp(1)g}(x)$$



first estimate of the GSF (within the generalized parton model)

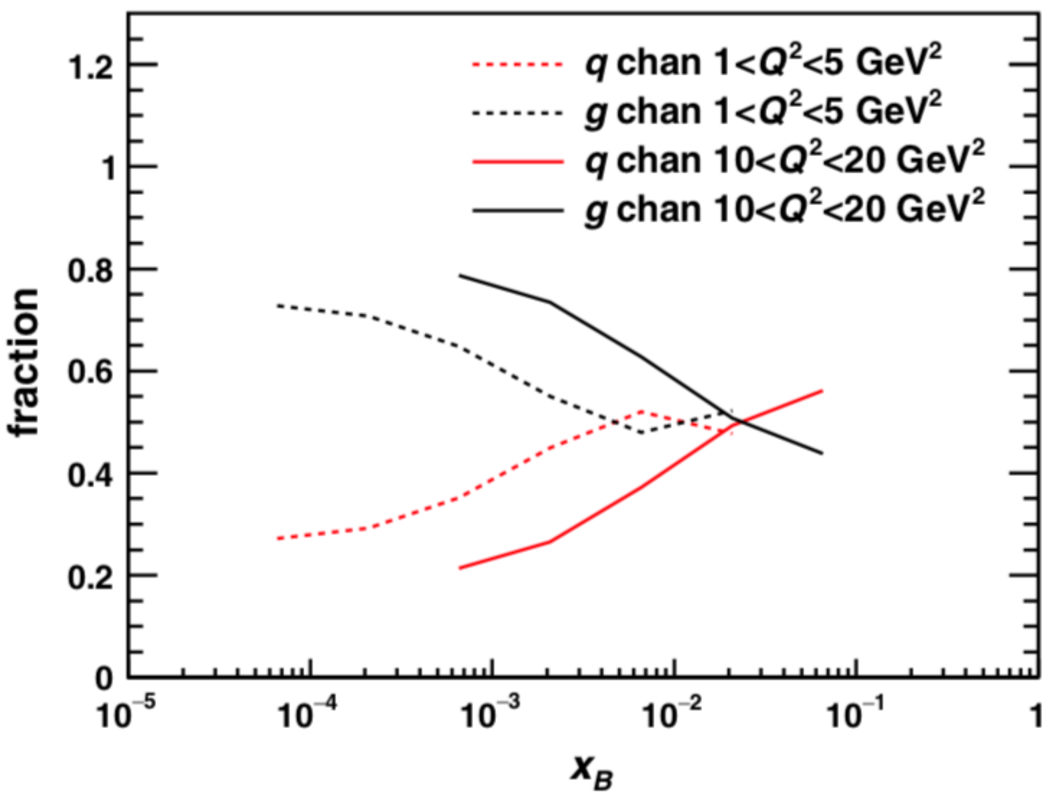
Limited knowledge to the gluon Sivers function

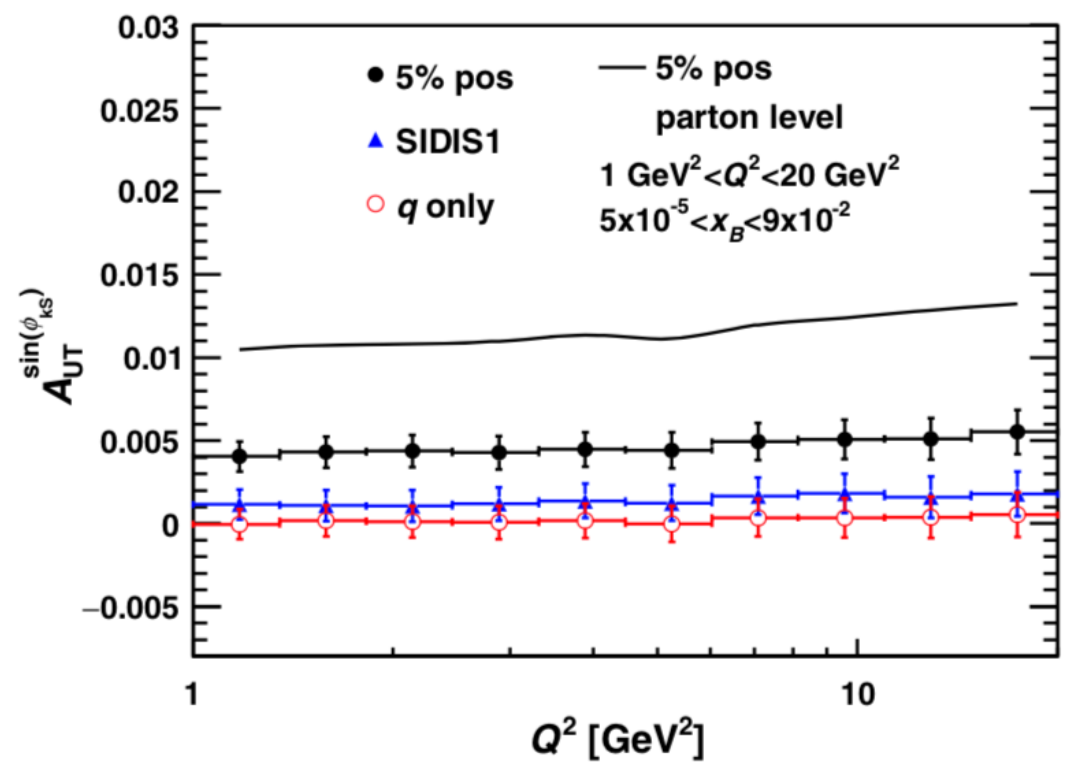
GSF and spin asymmetry in di-jet at the EIC

At the EIC , accessing of GSF via high-p_T dihadron, open di-charm, di-D-meson and dijet has been investigated using PYTHIA and reweighing methods in Zheng, Aschenauer, Lee, Xiao, Yin '18

- **They find that dijet process is the most promising channel**

At the LO di-jet production in DIS involves two processes: $\gamma^* q \to qg \qquad \gamma^* g \to q\bar{q}$

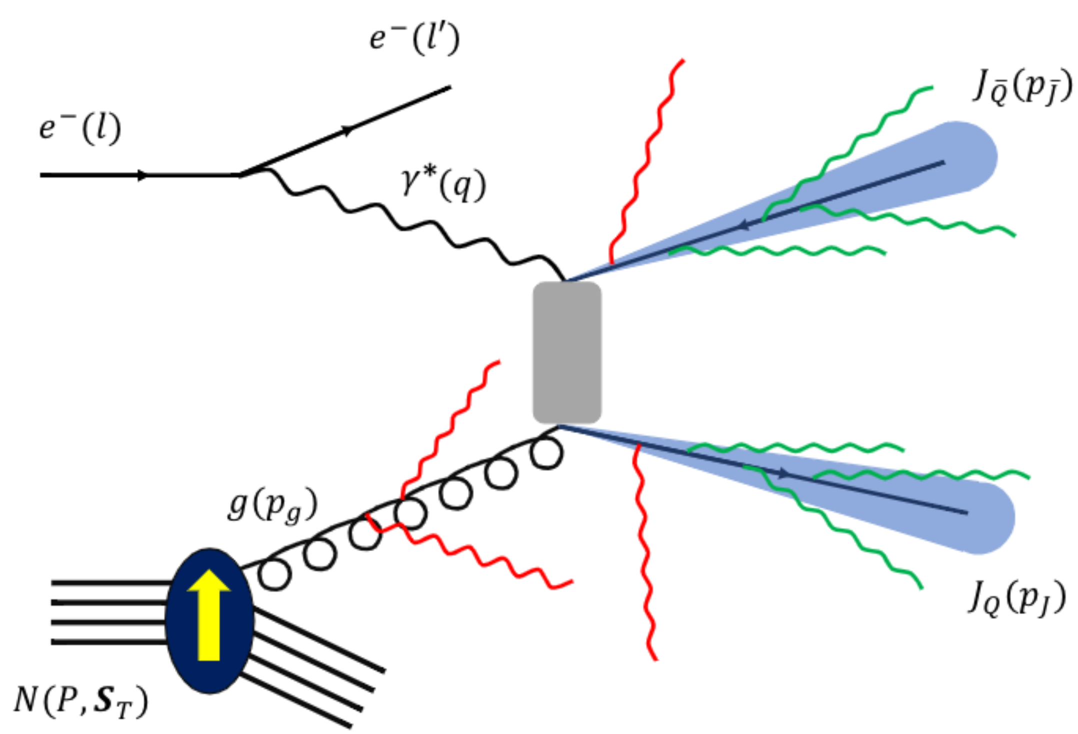


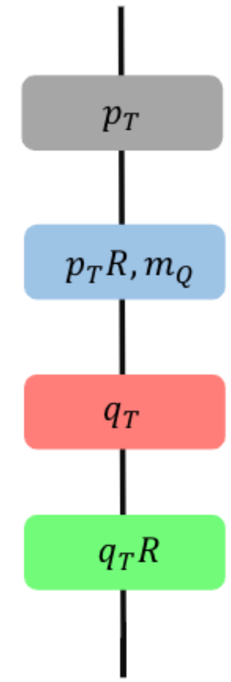


- **Using jets inner information to distinguish different TMDs**
  - **Jet substructure (e.g. jet charge "different quark flavor TMDs"** Kang, Liu, Mantry, DYS '20 PRL**)**
  - **Heavy-flavor (HF) dijet processes, where q-channel starts to contribute beyond the LO** (Kang, Reiten, DYS, Terry 2011.01756)

TMD factorization for heavy-flavor dijet production in DIS

(Kang, Reiten, DYS, Terry 2011.01756)





$$q_T \ll p_T$$

$$m_Q \lesssim p_T R \ll p_T$$

Construction of the theory formalism

- **Multiple scales in the problem**
- **Rely on effective field theory: SCET**

$$d\sigma^{UU} \sim H(Q, p_T) J_Q(p_T R, m_Q) J_{\bar{Q}}(p_T R, m_Q) S(\boldsymbol{\lambda}_T) f_g(\boldsymbol{k}_T) S^c_Q(\boldsymbol{l}_{QT}) S^c_{\bar{Q}}(\boldsymbol{l}_{\bar{Q}T}) \delta^{(2)}(\boldsymbol{k}_T + \boldsymbol{\lambda}_T + \boldsymbol{l}_{QT} + \boldsymbol{l}_{\bar{Q}T} - \boldsymbol{q}_T)$$

- **Hard and soft functions are the same as light-jet cases, since $p_T \gg m_Q$**
- **Jet and collinear-soft functions are new, which receive finite quark mass correction**

RGE and resummation

Anomalous dimension for the HF quark jet function:

$$\Gamma^{jQ}(\alpha_s) = -C_F\gamma^{\text{cusp}}(\alpha_s)\ln\frac{m_Q^2+p_T^2R^2}{\mu^2} + \gamma^{jQ}(\alpha_s) \qquad \gamma_0^{jQ} = 2C_F\left(3 - \frac{2m_Q^2}{m_Q^2+p_T^2R^2}\right)$$

Anomalous dimension for the HF collinear-soft function

$$\Gamma^{csQ}(\alpha_s) = C_F\gamma^{\text{cusp}}(\alpha_s)\ln\frac{R^2\mu_b^2}{\mu^2} + \gamma^{csQ}(\alpha_s) \qquad \gamma_0^{csQ} = -4C_F\left[2\ln\left[-2i\cos(\phi_b-\phi_J)\right] - \frac{m_Q^2}{m_Q^2+p_T^2R^2} - \ln\frac{m_Q^2+p_T^2R^2}{p_T^2R^2}\right]$$

Heavy quark mass will contribute the RG evolution between jet and collinear-sot function different from the case for the inclusive HF quark jet production Dai, Kim, Leibovich '18**.**

Resummation formula:

$$\begin{aligned}\frac{d\sigma^{UU}}{dQ^2dyd^2\boldsymbol{q}_Tdy_Jd^2\boldsymbol{p}_T} =& H(Q,p_T,y_J,\mu_h)\int_0^\infty\frac{bdb}{2\pi}J_0(b\,q_T)f_{g/N}(x_g,\mu_{b*})\\ &\times\exp\left[-\int_{\mu_{b*}}^{\mu_h}\frac{d\mu}{\mu}\Gamma^h(\alpha_s) - 2\int_{\mu_{b*}}^{\mu_j}\frac{d\mu}{\mu}\Gamma^{jQ}(\alpha_s) - 2\int_{\mu_{b_*}}^{\mu_{cs}}\frac{d\mu}{\mu}\Gamma^{csQ}(\alpha_s)\right]\\ &\times\exp\left[-S_{\text{NP}}(b,Q_0,n\cdot p_g)\right]\end{aligned}$$

Typical scales: $\mu_h \sim p_T, \quad \mu_j \sim Rp_T, \quad \mu_{cs} \sim R\mu_{b*}$

Numerical results

Anti-k_T, R=0.6

c-jets: $5\,\mathrm{GeV} < p_T < 10\,\mathrm{GeV}, \quad |\eta_J| < 4.5,$

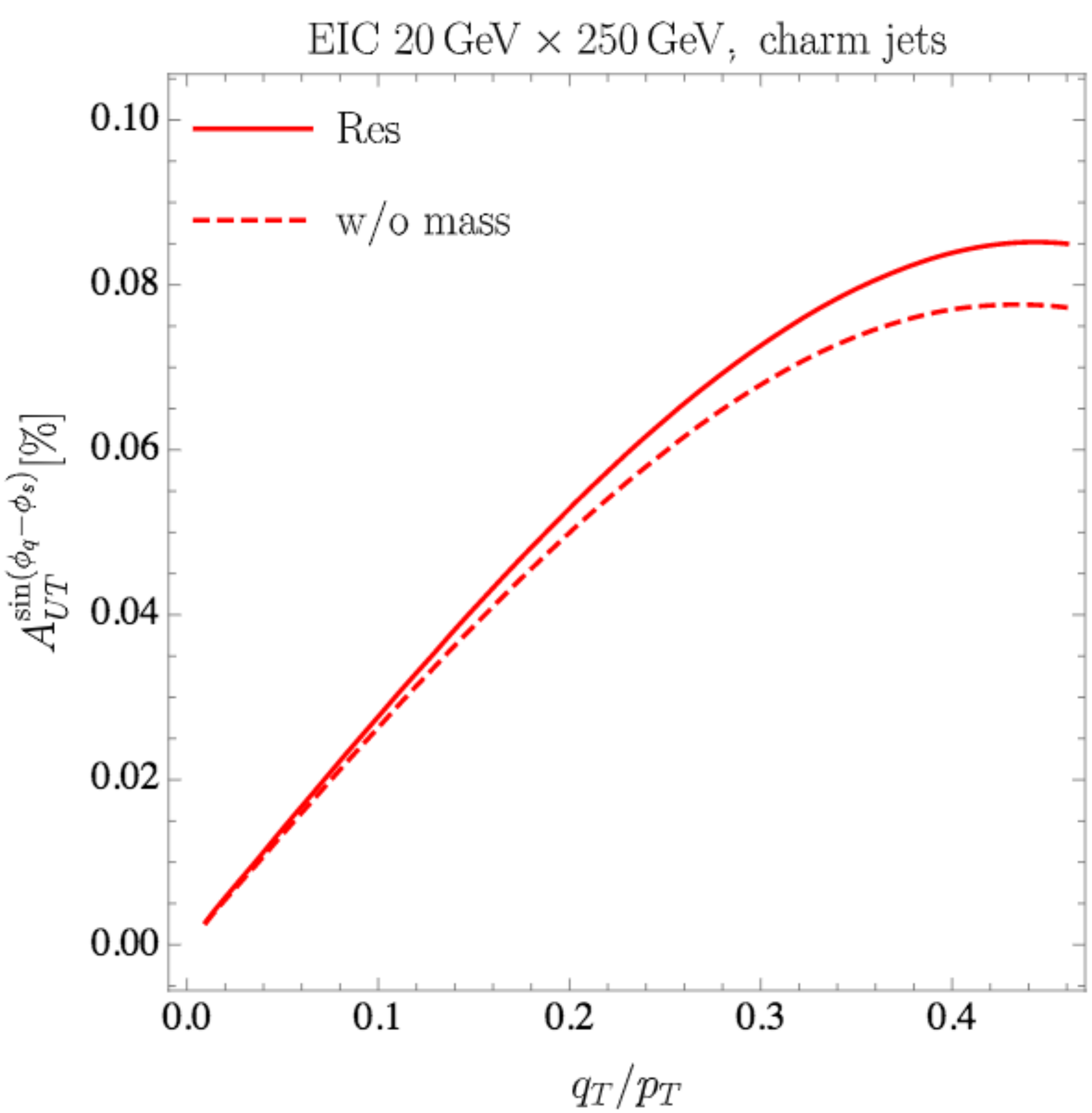
b-jets: $10\,\mathrm{GeV} < p_T < 15\,\mathrm{GeV}, \quad |\eta_J| < 4.5,$

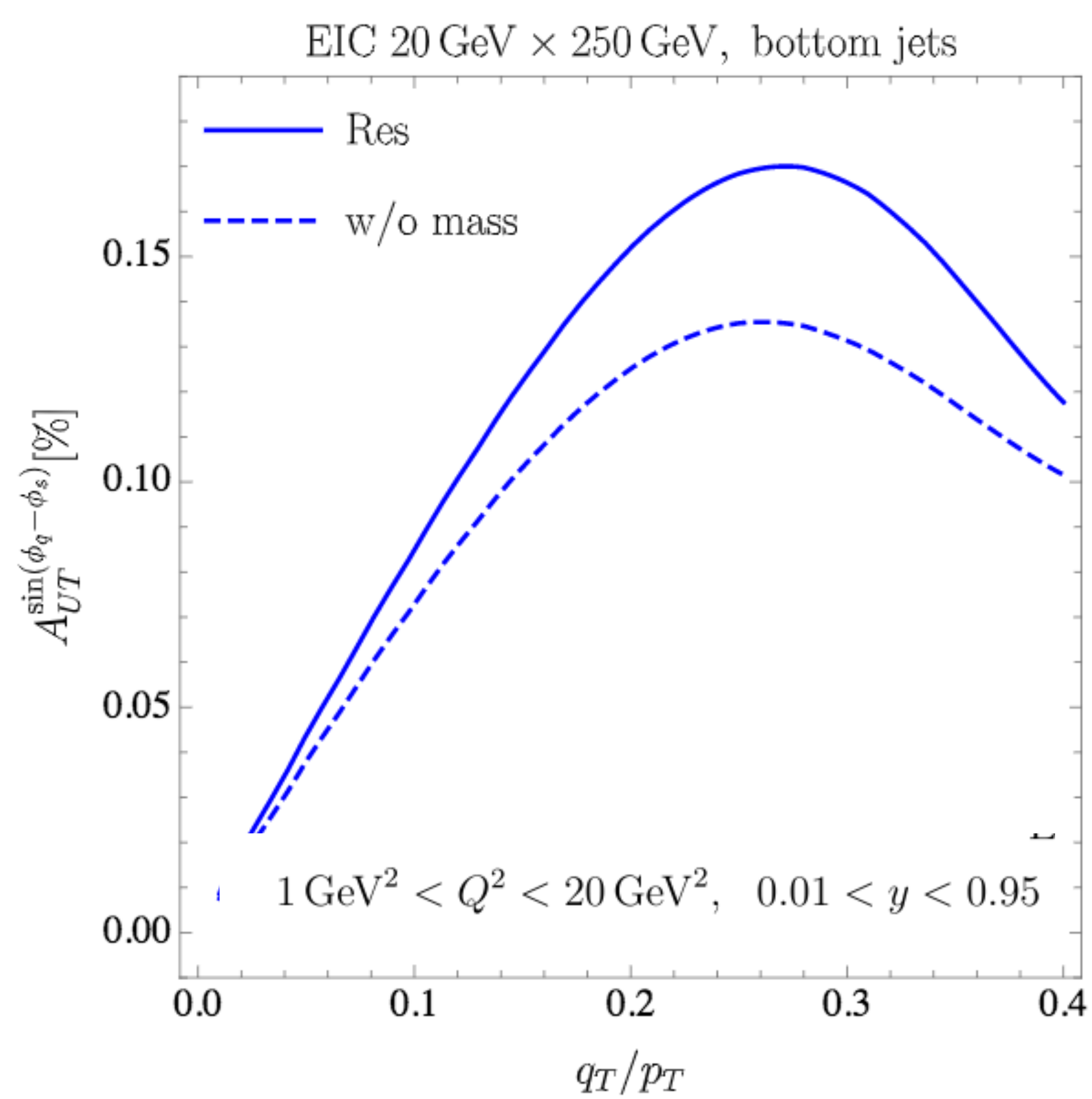
$$d\sigma(\boldsymbol{S}_T) = d\sigma^{UU} + \sin(\phi_q - \phi_s) d\sigma^{UT}$$

$$A_{UT}^{\sin(\phi_q-\phi_s)} = \frac{d\sigma^{UT}}{d\sigma^{UU}}$$

GSF: SIDIS1 set

D'Alesio, Murgia, Pisano '15 (+ Flore,Tales '18)





Conclusion

- **We develop the TMD factorization formalism for heavy flavor dijet production in electron polarized proton collisions.**

- **We consider heavy flavor mass correction in the collinear-soft and jet functions, as well as the associated evolution equations.**

- **We generate a prediction for the gluon-Sivers asymmetry for charm and bottom dijet production at the future EIC.**

- **After comparing our theoretical prediction with and without considering the heavy-flavor mass effects, we find that these effects can give sizable corrections to the predicted asymmetry.**

Thank you