Diffractive dijet and Gluon Wigner Distributions

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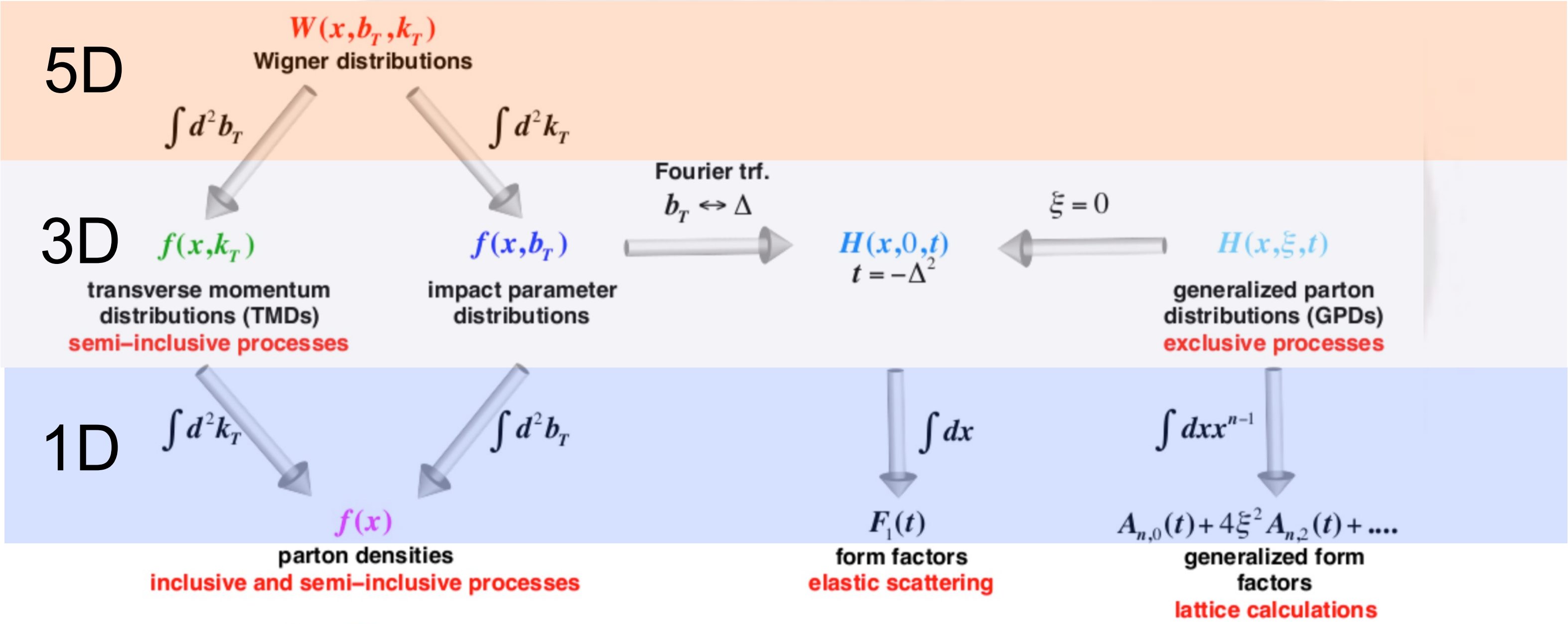
Diffractive Dijet to Probe Gluon Tomography

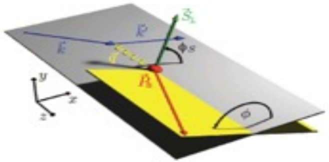
- Contribute to the key physics goals at the EIC
  - Spin/tomography of nucleon, e.g., probe the Gluon GPD
  - Gluon Orbital Angular Momentum
  - Small-x gluon saturation
  - …

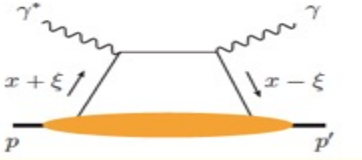
See, talks by Marquet and Hatta

Unified view of the Nucleon

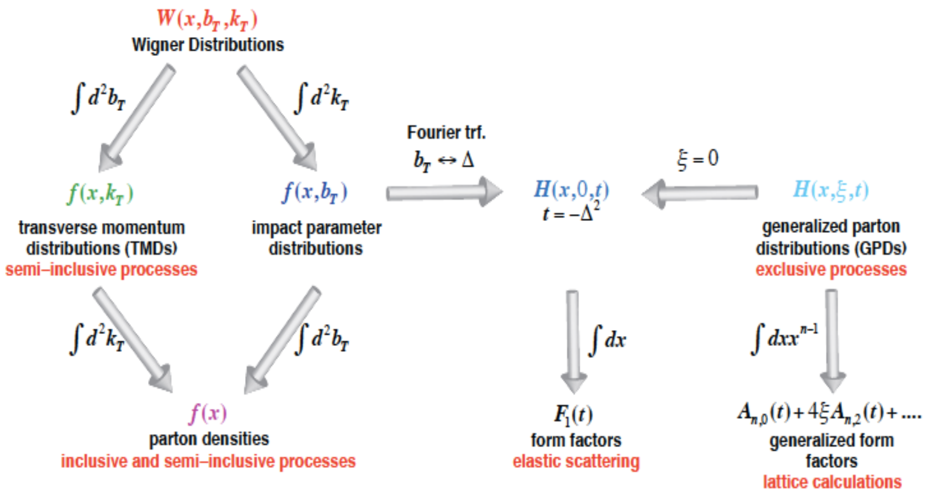
❑ Wigner distributions (Belitsky, Ji, Yuan)





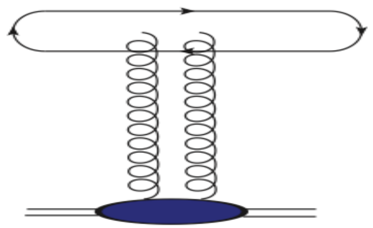


Small-x Approximation



Small-x

$$\frac{1}{N_c}\left\langle \mathrm{Tr}\left[U(R_\perp)\,U^\dagger(R'_\perp)\right]\right\rangle_x$$



Hatta-Xiao-Yuan,1601.01585
earlier: Mueller, NPB 1999

TMDs at small-x

- Consistency between the collinear TMD definitions and the small-x dipole calculations have been established
  - Dominguez-Marquet-Xiao-Yuan 2011
- They are the most studied subjects in small-x phenomenology: inclusive, semi-inclusive processes
- Unique predictions of the TMDs from small-x formalism
  - Significant linear polarization for the gluon (Metz-Zhou 2011)
  - Spin (of hadron) dependence offers nontrivial QCD dynamics (Zhou et al, 2015; Kovchegov et al, 2016-2023)

Small-x gluon distribution with TMD resummation

$$xG^{(1)}(x,k_\perp,\zeta_c=\mu_F=Q)$$

→ Hard scale entering TMD Factorization, e.g., Higgs

$$\Rightarrow -\frac{2}{\alpha_S}\int\frac{d^2x_\perp d^2y_\perp}{(2\pi)^4}e^{ik_\perp\cdot r_\perp}\mathcal{H}^{WW}(\alpha_s(Q))e^{-\mathcal{S}_{sud}(Q^2,r_\perp^2)}$$
$$\times\mathcal{F}^{WW}_{Y=\ln 1/x}(x_\perp,y_\perp)\ ,$$

Small-x evolution

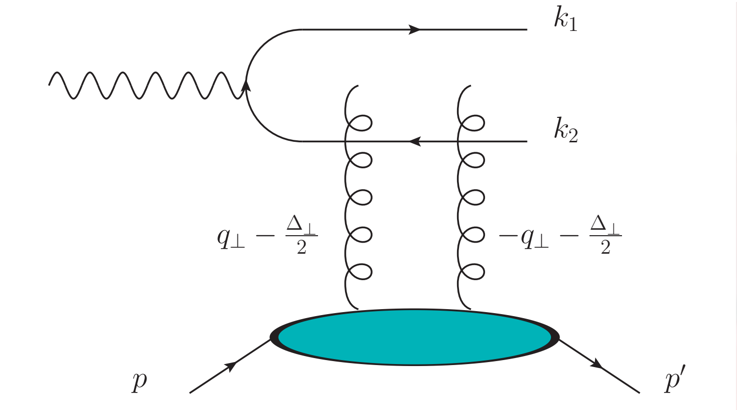
Pert. corrections

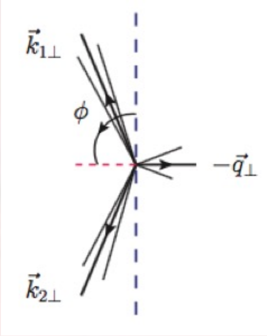
Sudakov resum.

Prediction Power!!

Directly measure the gluon Wigner distribution?

Hatta-Xiao-Yuan,1601.01585





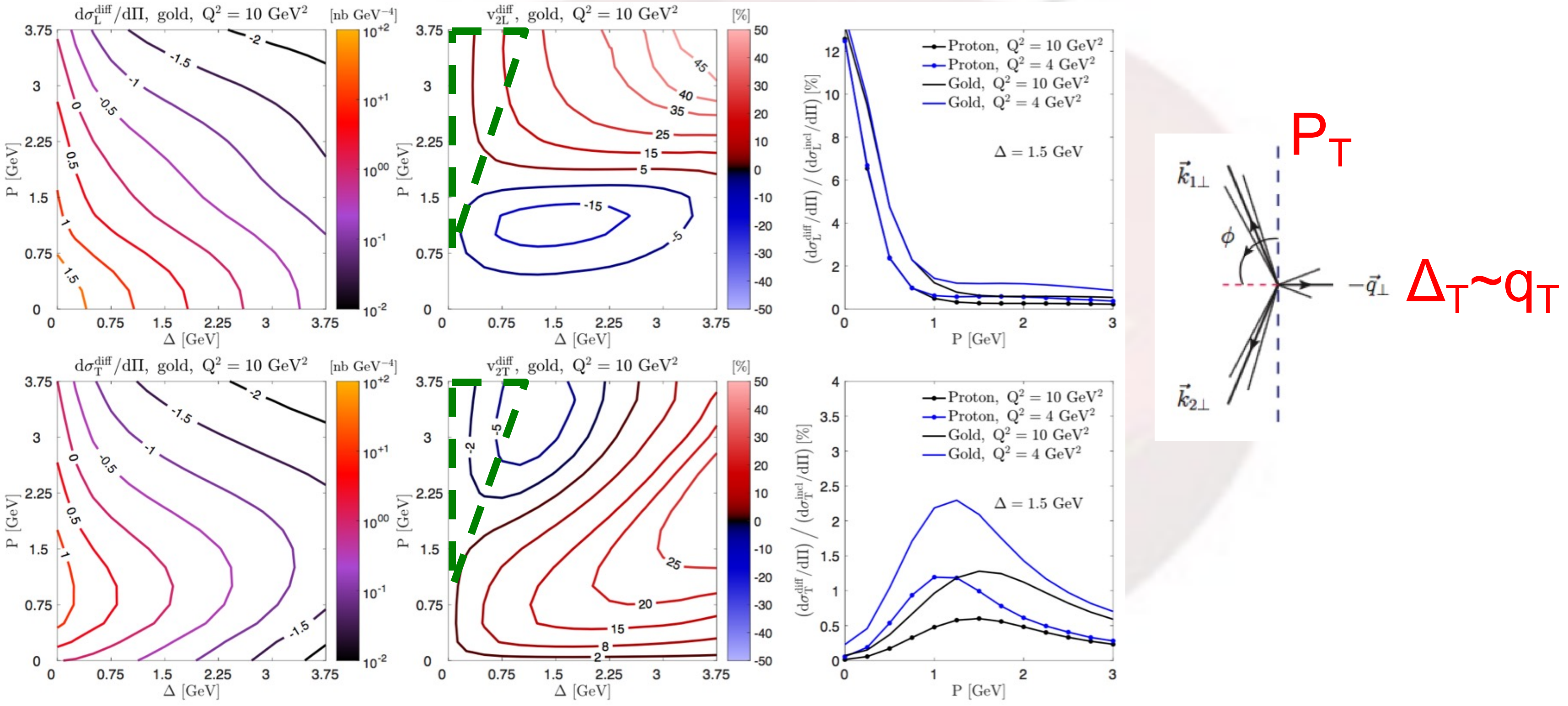
cos(2ϕ) anisotropy

- In the Breit frame, by measuring the recoil of final state proton, one can access Δ_T. By measuring jets momenta, one can approximately access q_T.
- The diffractive dijet cross section is proportional to the square of the Wigner distribution → nucleon/nucleus tomography

$$xW_g^T(x,|\vec{q}_\perp|,|\vec{b}_\perp|) + 2\cos(2\phi)xW_g^\epsilon(x,|\vec{q}_\perp|,|\vec{b}_\perp|)$$

Anisotropy ~ few %

This has generated a lot of interests…



CGC calculations: Mäntysaari-Mueller-Salazar-Schenke, 1912.05586, 1902.05087; Mäntysaari-Roy-Salazar-Schenke 2011.02464

However, life is more complicated, ☹

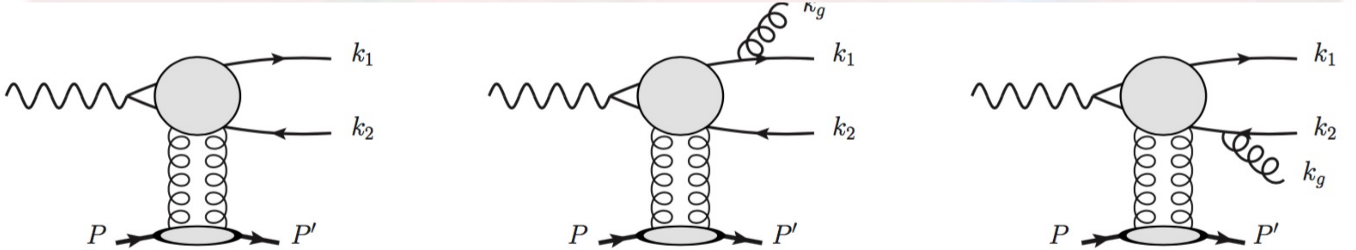
- Gluon radiation adds additional complications
  - Because final state jet carries color, soft gluon contribution will modify the intuitive and simple picture
  - Nontrivial azimuthal angular correlations can come from soft gluon radiation, Hatta-Xiao-Yuan-Zhou 2021
- On the other hand, gluon radiation offers a unique opportunity to study different perspective of gluon saturation, Iancu-Mueller-Triantafyllopoulos, 2112.06353
  - We may have a direct way to compute the so-called diffractive parton distributions

Soft gluon radiation

- Gluon radiation tends to be aligned with the jet direction

$$S_J(q_\perp) = \delta(q_\perp) + \frac{\alpha_s}{2\pi^2}\int dy_g \left(\frac{k_1\cdot k_2}{k_1\cdot k_g k_2\cdot k_g}\right)_{\vec{q}_\perp = -\vec{k}_{g\perp}}$$

$$S_{J0}(|q_\perp|) + 2\cos(2\phi) S_{J2}(|q_\perp|) + \cdots$$



Catani-Grazzini-Sargsyan, 1703.08468; Hatta-Xiao-Yuan-Zhou, 2010.10774

More broad context of quantum interference effects, Chen, Moult, Zhu, 2011.02492

Leading power contributions, explicit result at α_s

$$S_J(q_\perp) = S_{J0}(|q_\perp|) + 2\cos(2\phi) S_{J2}(|q_\perp|)$$

$$S_{J0}(q_\perp) = \delta(q_\perp) + \frac{\alpha_0}{\pi}\frac{1}{q_\perp^2}\,, \quad S_{J2}(q_\perp) = \frac{\alpha_2}{\pi}\frac{1}{q_\perp^2}\,,$$

where

$$\alpha_0 = \frac{\alpha_s C_F}{2\pi} 2\ln\frac{a_0}{R^2}\,, \quad \alpha_2 = \frac{\alpha_s C_F}{2\pi} 2\ln\frac{a_2}{R^2}\,.$$

In the small-R limit, <cos(2ϕ)> goes to 1

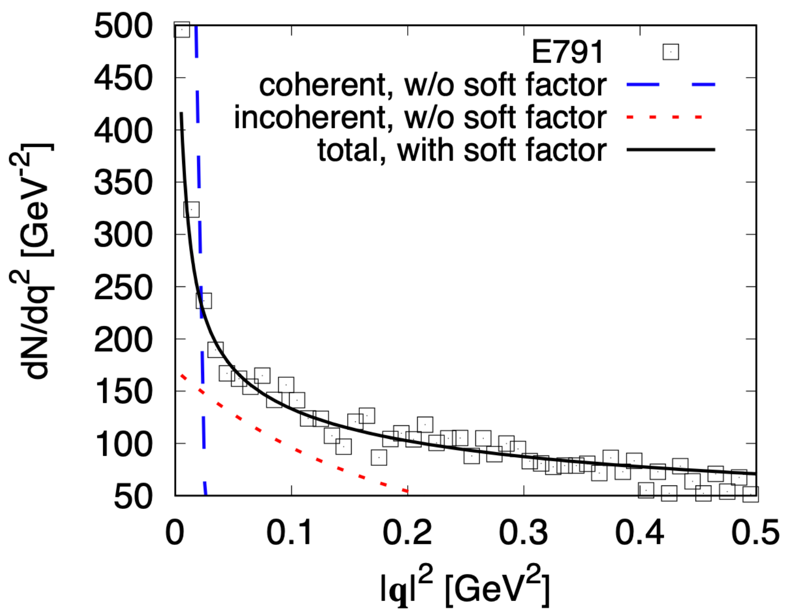
Additional gluon radiation contributions,

- In the momentum space, it will be a convolution
  - $q_T=k_{g1}+k_{g2}+\ldots$
  - Dominant contributions will be ϕ-independent
- It is convenient to perform resummation in Fourier-b space

$$\widetilde{S}_J(b_\perp) = \int d^2q_\perp e^{iq_\perp\cdot b_\perp} S_J(q_\perp)$$
$$= \widetilde{S}_{J0}(|b_\perp|) - 2\cos(2\phi_b)\widetilde{S}_{J2}(|b_\perp|) + \cdots$$

$$\widetilde{S}_{J0}(b_\perp) = 1 + \alpha_0 \ln(\mu_b^2/P_\perp^2)\ , \quad \widetilde{S}_{J2}(b_\perp) = \alpha_2$$

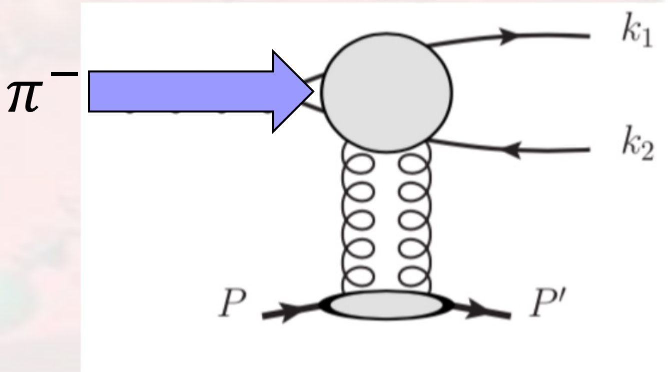
Soft gluon will affect the total transverse momentum distribution



Hatta et al, 1907.09491

E791: Pion (500 GeV) induced diffractive Dijet production on nuclear target

E791, PRL 2001



It also affects the angular distribution

$$\widetilde{S}_{J0}(b_\perp) = e^{-\Gamma_0(b_\perp)}\ , \quad \widetilde{S}_{J2}(b_\perp) = \alpha_2 e^{-\Gamma_0(b_\perp)} \quad \Gamma_0(b_\perp) = \int_{\mu_b^2}^{P_\perp^2} \frac{d\mu^2}{\mu^2}\alpha_0$$

EIC

Kinematics:

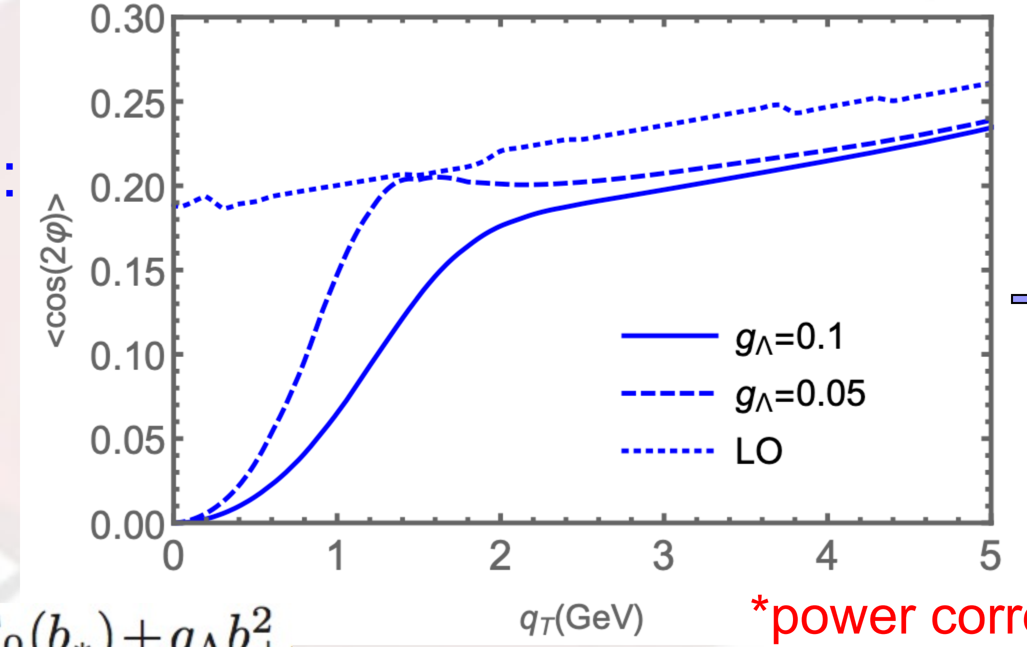
P_T~15GeV

R=0.4

$y_1=y_2$

Non-pert. input:

$$\Gamma_0(b_\perp) \Longrightarrow \Gamma_0(b_*) + g_\Lambda b_\perp^2$$

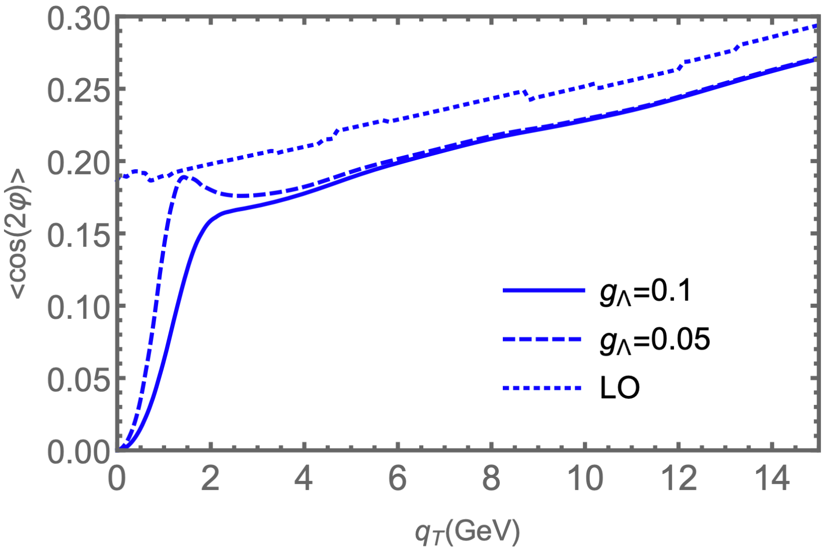


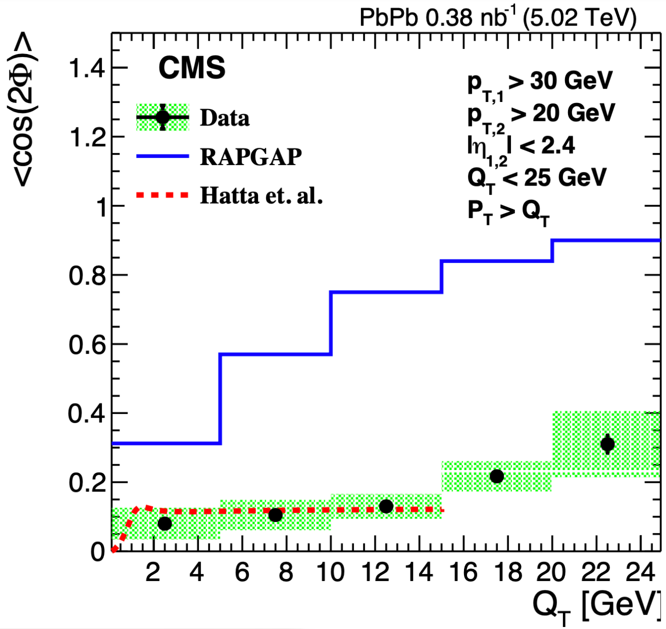
$\alpha_2/\alpha_0 \approx 0.14$

*power corrections included

Compare to recent CMS measurement

P_T~35GeV, R=0.4 ,y_1=y_2

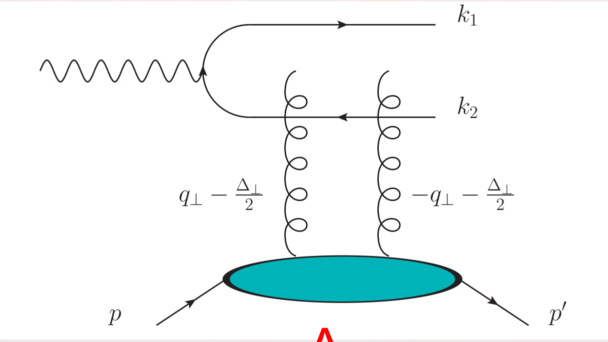




CMS, 2205.00045

Comments

- To avoid the soft gluon radiation contribution, we need to reconstruct nucleon/nucleus recoil momentum to study the tomography



Δ_T

Conclusion

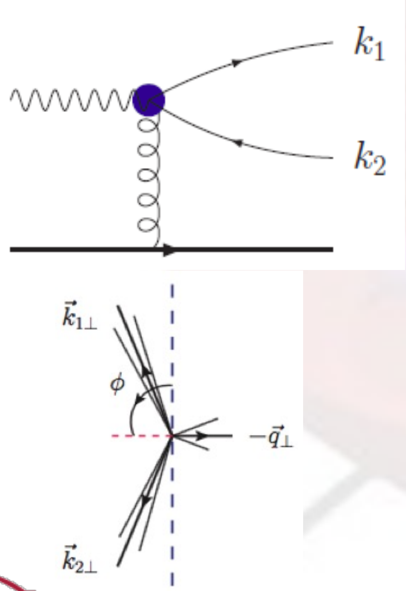
- Small-x physics provides a unique opportunity to explore nucleon tomography through parton Wigner distributions
  - Unified description with dipole amplitude starts to emerge
- Further developments are needed to explore the full potential of the future electron-ion collider
  - More processes to probe the dipole amplitudes, including its spin-dependence
  - Precision toward next-to-leading order computations!

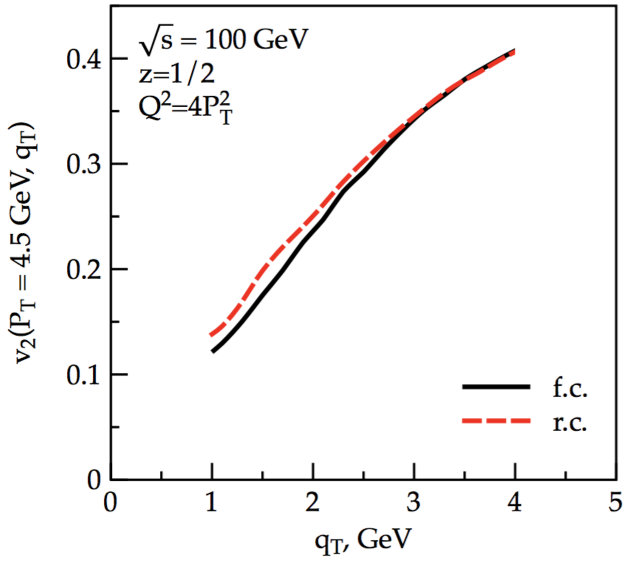
Discussions

- For jet measurements, we need tracking
  - Kinematic reach, more studies needed
- For exclusive observables, we need measurement on the recoiled nucleon
  - Detector requirement
  - Luminosity requirement
- …

Cos(2ϕ) anisotropy has been widely applied for EIC…

- Probe the linearly polarized gluon distribution calculation



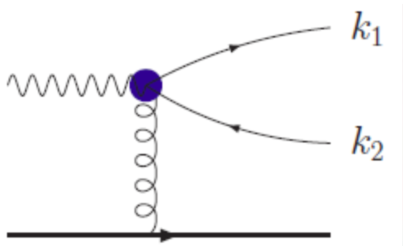


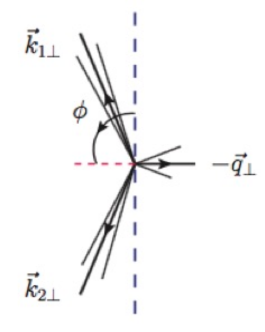
CGC calculation: Dumitru-Lappi-Skokov, 1508.04438

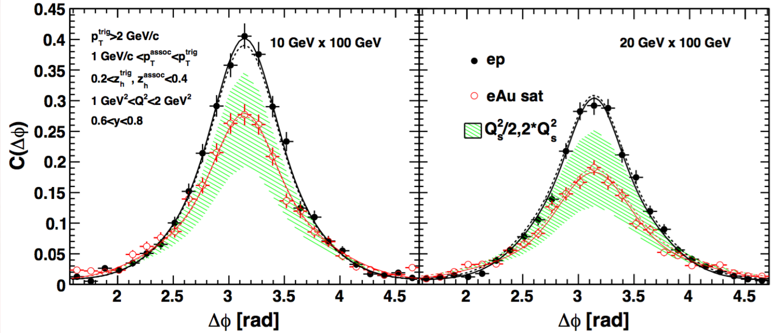
see also,
Boer-Brodsky-Mulders-Pisano 1011.4225
Metz-Zhou, 1105.1991
Boer et al., 1702.08195, 1605.07934
Mantysaari et al., 1902.05087, 1912.05586

Semi-inclusive process: DIS dijet probes gluon TMDs

$$\gamma_T^* A \to q(k_1) + \bar{q}(k_2) + X$$





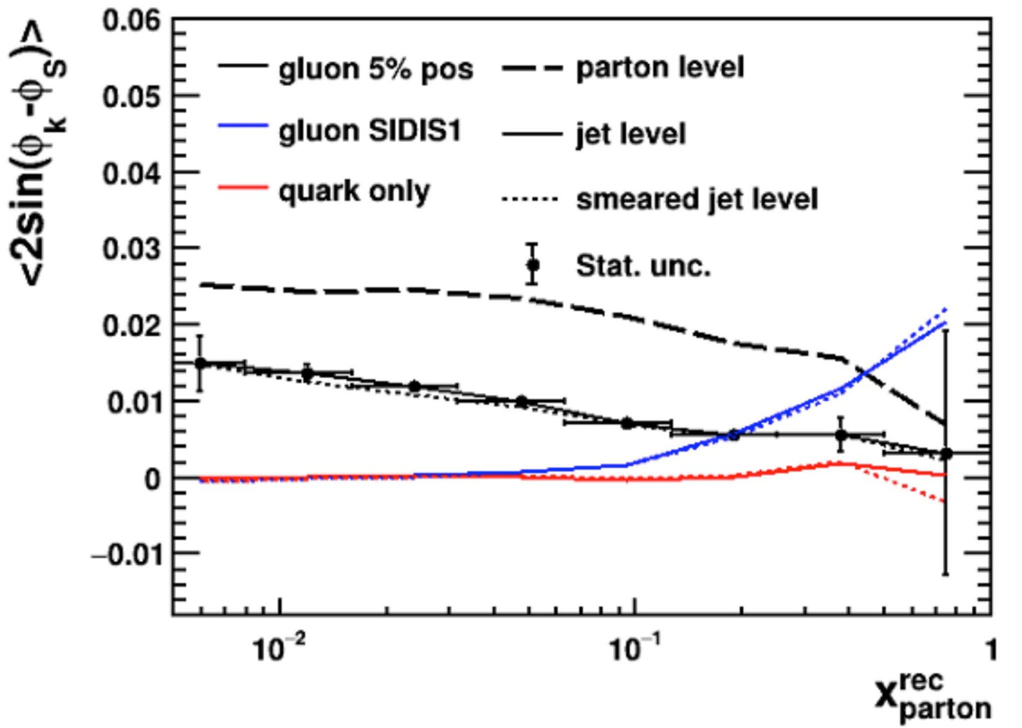


Zheng, et al., 1403.2413

- q_t-dependence measure the gluon distribution
  - Weizsacker-Williams gluon distribution in nucleus (CGC predictions)
- Various channels at the EIC: heavy flavor production, real and virtual photon

Dominguez-Marquet-Xiao-Yuan 2011

Gluon Sivers function at EIC



Kinematics:

- 18X275GeV,Q>1GeV Leading jet >4.5GeV, subleading jet >4 GeV, R=0.5, |η|<2.5

L. Zheng's talk at the jet workshop, see also, 1805.05290

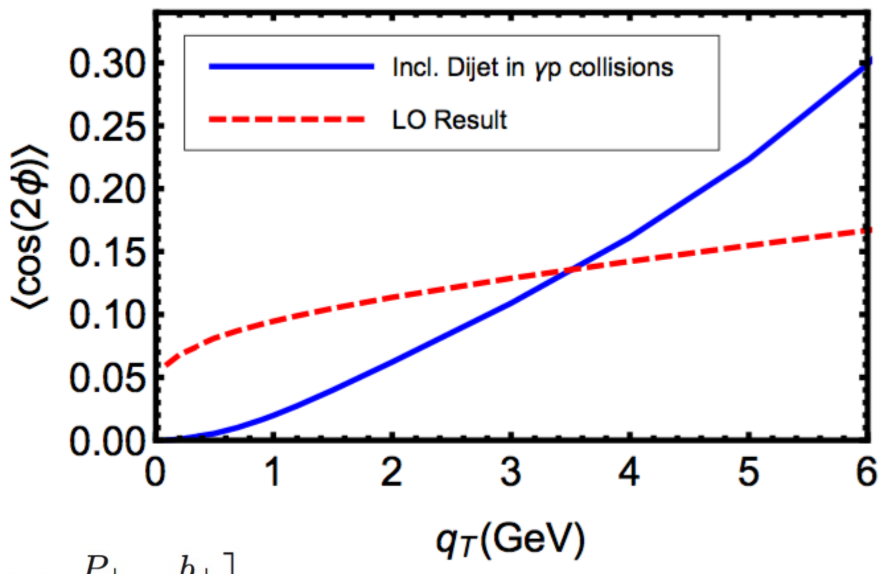
Impact to EIC measurements, photoproduction case ($Q^2=0$)

Kinematics:

$P_T \sim 15$GeV

R=0.4

$y_1=y_2$



There is no linearly Polarized gluon Contribution (Q^2=0

Non-pert. input:

$$S_{\rm NP}^{\gamma p} = \frac{C_A}{2C_F}\left[0.106\, b_\perp^2 + 0.42 \ln\frac{P_\perp}{Q_0}\ln\frac{b_\perp}{b_*}\right]$$

Scaled from quark TMD (fitted to DY data)