Dijet Azimuthal Anisotropy in High Energy DIS

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Outline

- **Short introduction**
- **Dijets in DIS and TMD**
- **JIMWLK-B for $h_\perp^{(1)}$**
- **Dijet azimuthal anisotropy**
- **Outlook and Conclusions**

Weizsäcker-Williams gluon distribution: linearly polarized gluons in unpolarized target

P. Mulders and J. Ridrigues Phys.Rev. D63 (2001) 094021
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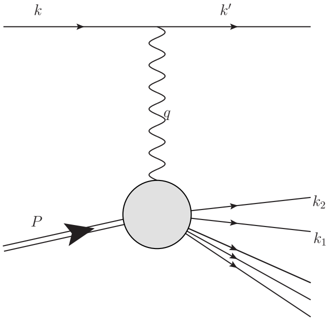
- WW Linearly polarized gluon distribution contributes with $\cos(2\phi)$ azimuthal angular dependence
- It can be directly probed in DIS dijet production
- Small x behaviour is largely unknown
- JIMWLK-B renormalization group equation to analyze the magnitude of azimuthal anisotropy

Dijet production in DIS



- DIS dijet production: $\gamma^* A \quad \to \quad q\, \bar{q}\;\; X$
- In color dipole model this is related to

$$\frac{d\sigma^{\gamma^* A \to q\bar{q}X}}{d^3k_1 d^3k_2} \propto \int d^2x_1 d^2y_1 d^2x_2 d^2y_2$$
$$\exp\left(-ik_1(x_1 - y_1) - ik_2(x_2 - y_2)\right)$$
$$\cdots \Big[1 + \frac{1}{N_c}\Big(\langle \mathrm{Tr}\, U(x_1)U^\dagger(y_1)U(y_2)U^\dagger(x_2)\rangle$$
$$-\langle \mathrm{Tr}\, U(x_1)U^\dagger(x_2)\rangle - \langle \mathrm{Tr}\, U(y_1)U^\dagger(y_2)\rangle\Big)\Big]$$

- In principal can be computed without any further simplifications, but no direct relation to WW distribution
- In correlation limit (almost back-to-back jets) $\mathbf{P} = (\mathbf{k}_1 - \mathbf{k}_2)/2$ is much larger than $\mathbf{q} = \mathbf{k}_1 + \mathbf{k}_2$, so that for conjugate variables, $u \ll v$, where $\mathbf{u} = \mathbf{x}_1 - \mathbf{x}_2$ and $\mathbf{v} = (\mathbf{x}_1 + \mathbf{x}_2)/2$. Expand in u.

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Weizsäcker-Williams gluon distribution

- In correlation limit, reduction to 2 point functions

$$xG^{ij}_{WW}(\mathbf{k}) = \frac{8\pi}{S_\perp}\int \frac{d^2x}{(2\pi)^2}\frac{d^2y}{(2\pi)^2} e^{-\mathbf{k}\,(\mathbf{x}-\mathbf{y})}\langle A^i_a(\mathbf{x})A^j_a(\mathbf{y})\rangle, \quad A^i(\mathbf{x}) = \frac{1}{ig}U^\dagger(\mathbf{x})\partial_i U(\mathbf{x})$$

- Decomposition to conventional and traceless contribution

$$xG^{ij}_{WW} = \frac{1}{2}\delta^{ij} x\, G^{(1)} - \frac{1}{2}\left(\delta^{ij} - 2\frac{q^i q^j}{q^2}\right) x\, h^{(1)}_\perp$$

- Contribution to azimuthal anisotropy of dijet production

$$E_1 E_2 \frac{d\sigma^{\gamma^*_L A\to q\bar{q}X}}{d^3k_1 d^3k_2 d^2b} = \alpha_{em} e_q^2 \alpha_s \delta\left(x_{\gamma^*} - 1\right) z^2(1-z)^2 \frac{8\epsilon_f^2 P_\perp^2}{(P_\perp^2 + \epsilon_f^2)^4}$$

$$\times\left[xG^{(1)}(x,q_\perp) + \underline{\cos(2\phi)}\; xh^{(1)}_\perp(x,q_\perp)\right].$$

z is long. momentum fraction of photon carried by quark $\qquad \epsilon_f^2 = z(1-z)Q^2$

Physical interpretation

- Conventional WW: probability distribution

$$\delta_{ij} = \varepsilon_{+}^{*i}\varepsilon_{+}^{j} + \varepsilon_{-}^{*i}\varepsilon_{-}^{j}$$

- Gluon helicity: difference of probability distributions

$$i\epsilon_{ij} = \varepsilon_{+}^{*i}\varepsilon_{+}^{j} - \varepsilon_{-}^{*i}\varepsilon_{-}^{j}$$

- $h^{(1)}$: transverse spin correlation function of gluons in two orthogonal polarization states

$$2\frac{q^i q^j}{q^2} - \delta^{ij} = i(\varepsilon_{+}^{*i}\varepsilon_{-}^{j} - \varepsilon_{-}^{*i}\varepsilon_{+}^{j})$$

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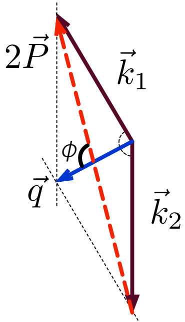
Correlations limit results for $\gamma^*_{\|,\perp}$

$$E_1E_2\frac{d\sigma^{\gamma_L^* A\to q\bar{q}X}}{d^3k_1d^3k_2d^2b} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z^2(1-z)^2\frac{8\epsilon_f^2P_\perp^2}{(P_\perp^2+\epsilon_f^2)^4}\times\left[xG^{(1)}(x,q_\perp)+\underline{\cos(2\phi)}\;xh_\perp^{(1)}(x,q_\perp)\right]$$

$$E_1E_2\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{d^3k_1d^3k_2d^2b} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z(1-z)\left(z^2+(1-z)^2\right)\frac{\epsilon_f^4+P_\perp^4}{(P_\perp^2+\epsilon_f^2)^4}$$
$$\times\left[xG^{(1)}(x,q_\perp)-\frac{2\epsilon_f^2P_\perp^2}{\epsilon_f^4+P_\perp^4}\;\underline{\cos(2\phi)}\;xh_\perp^{(1)}(x,q_\perp)\right]$$

- Jets are almost back-to-back.
- Azimuthal anisotropy is in ϕ: angle between **P** and **q**.
- Is $h_\perp^{(1)}$ important at small x?



$$2\vec{P} = \vec{k}_1 - \vec{k}_2$$
$$\vec{q} = \vec{k}_1 + \vec{k}_2$$

NUMERICS

- MV initial conditions at $Y = \ln x_0/x = 0$

$$S_{\text{eff}}[\rho^a] = \int dx^- d^2x_\perp \, \frac{\rho^a(x^-, x_\perp)\,\rho^a(x^-, x_\perp)}{2\mu^2}$$

for

$$U(x_\perp) = \mathbb{P}\exp\left\{ig^2 \int dx^- \frac{1}{\nabla_\perp^2} t^a \rho^a(x^-, x_\perp)\right\}$$

- Quantum evolution at $Y > 0$ is accounted for by solving JIMWLK-B using Langevin method

$$\partial_Y U(z) = U(z)\frac{i}{\pi}\int d^2u \frac{(z-u)^i \eta^i(u)}{(z-u)^2} - \frac{i}{\pi}\int d^2v \, U(v)\frac{(z-v)^i \eta^i(v)}{(z-v)^2} U^\dagger(v)U(z)\,.$$

The Gaussian white noise $\eta^i = \eta^i_a t^a$ satisfies $\langle \eta^a_i(z)\rangle = 0$ and

$$\langle \eta^a_i(z)\, \eta^b_j(y)\rangle = \alpha_s\, \delta^{ab}\delta_{ij}\delta^{(2)}(z-y).$$

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J.-P. Blaizot, E. Iancu and H. Weigert, Nucl. Phys. A713, 441 (2003)
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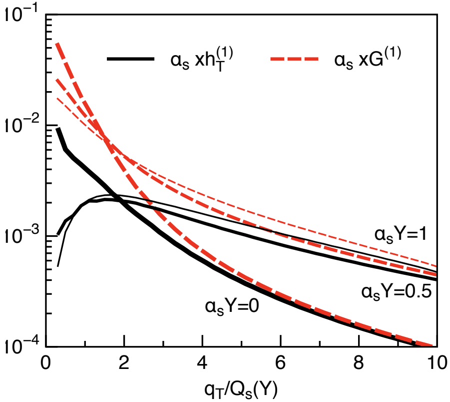

- at large $q_\perp$, saturation of positivity bound $h_\perp^{(1)} \to G^{(1)}$, as also was found in pert. twist 2 calculations of small x field of fast quark
- at small $q_\perp$, $h_\perp^{(1)}/G^{(1)} \to 0$
- both functions decrease fast as functions of $q_\perp$ ($q_\perp^{-2}$ in MV): best measured when $q_\perp \approx Q_s$. Nuclear target!

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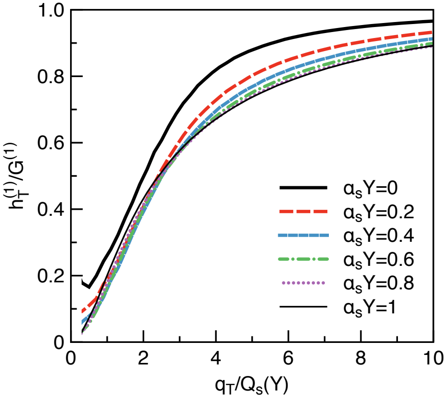

- Fast departure from MV
- Slow evolution at small x
- $h_\perp^{(1)}$ is large at small x
- Note: $q_\perp$ is scaled by $Q_s(Y)$: ratio at fixed $q_\perp$ decreases with rapidity. Emission of small x gluons reduces degree of polarization.

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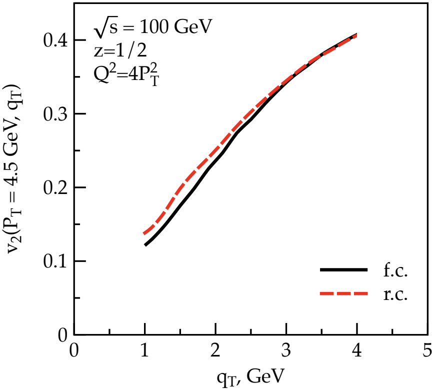
Second harmonics of azimuthal anisotropy: $q_\perp$-dependence

- By analogy to HIC

$$v_2(P_\perp, q_\perp) = \langle \cos 2\phi \rangle$$

- Fixed coupling results ("f.c.") are for $\alpha_s = 0.15$
- At this $P_\perp$ not very significant dependence on prescription
- Increase of v_2 is due to increasing $h_\perp^{(1)}(q_\perp)/G^{(1)}(q_\perp)$



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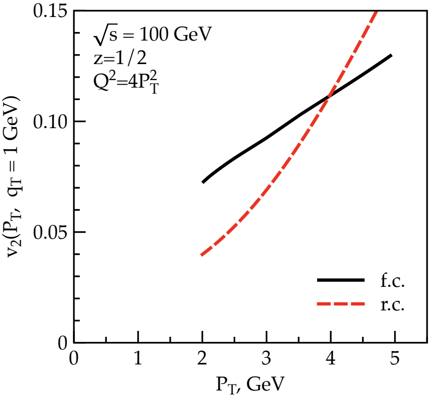

- Fixed coupling results significantly different from running coupling results
- Large azimuthal anisotropy in both cases
- Increasing $P_\perp$ increases x and suppresses evolution effects driving v_2 towards its MV value

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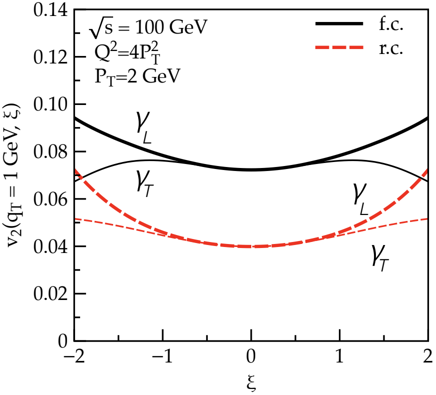
- To probe longitudinal structure

$$\xi = \ln \frac{1-z}{z}$$

- Long-range "rapidity" correlation
- Mild increase for large ξ because asymmetric dijets probe target at larger values of x



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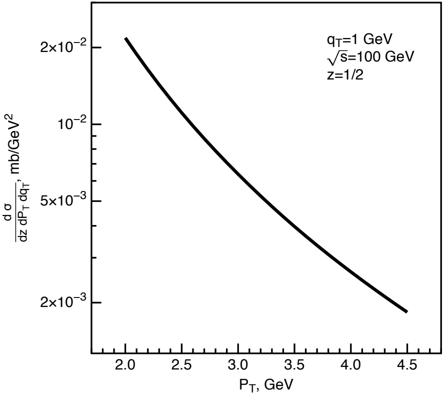
Cross-section for signal

- Cross-section summed with respect to γ^* polarizations and integrated over angles
- $\sqrt{s}$ is given for $\gamma^* A$ CM

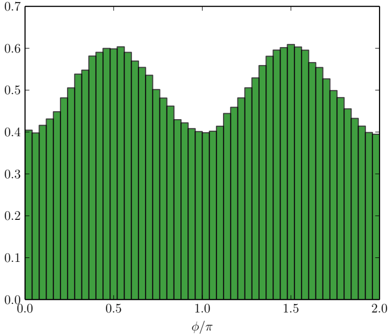


A. Dumitru, and V. S. work in progress

Outlook

- To provide realistic prediction for EIC: Monte-Carlo event generator with Pythia afterburner in collaboration with A. Dumitru and T. Ulrich
- Sudakov resummation effects might be important for azimuthal anisotropy: work in progress
- More general kinematics which would include quadrupole
- Measuring $h^{(1)}$ may require jet reconstruction and associated complications

  Need for nuclear target and larger Q_s?! Access to higher transverse momenta; which simplifies jet reconstruction



A. Dumitru, V. S. and T. Ulrich work in progress

Conclusions

- In correlations limit, DIS dijets to probe WW gluon distribution
- Gluon distribution has two distinct contributions: isotropic conventional WW $xG^{(1)}$ and $\cos(2\phi)$ anisotropic with amplitude $xh^{(1)}$ – interference of gluons in orthogonal polarizations
- MV model gives large relative anisotropy at large momentum, both $G^{(1)}$ and $h_{\perp}^{(1)}$ are proportional to $1/q_{\perp}^{2}$
- JIMWLK-B: $h^{(1)}$ grows as fast as $G^{(1)}$
- Not significant dependence on prescription for α_s
- Long-range in "rapidity"
- Survives in MC events summed over polarization and different distributions of q, z, $P_{\perp}$, $q_{\perp}$ etc.