Linearly Polarized Gluon Distributions at Small-x

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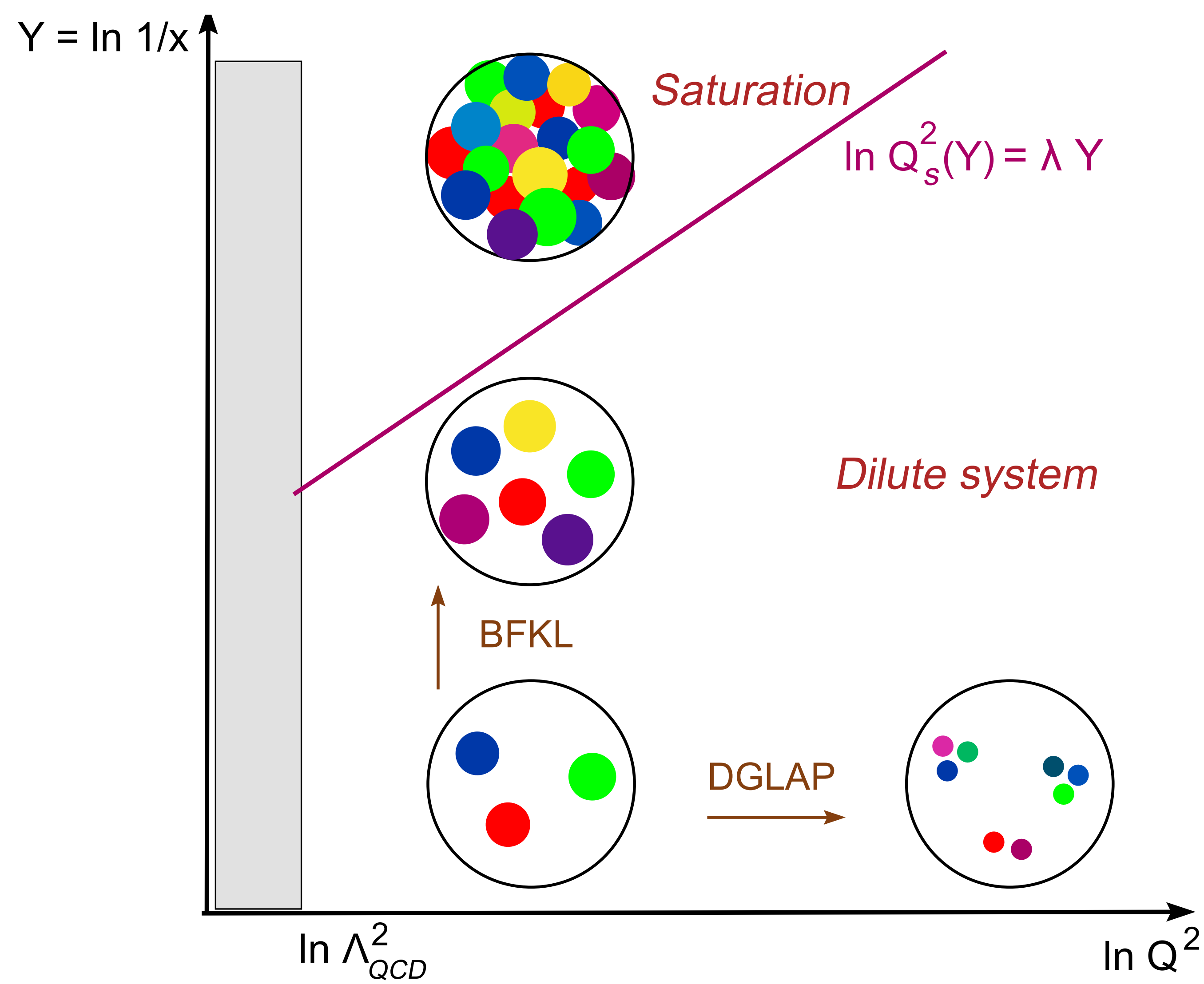
In collaboration with J.-W. Qiu, B.-W. Xiao, and F. Yuan, Phys.Rev. D85 (2012) 045003

DIS Workshop
Marseille, April 25, 2013

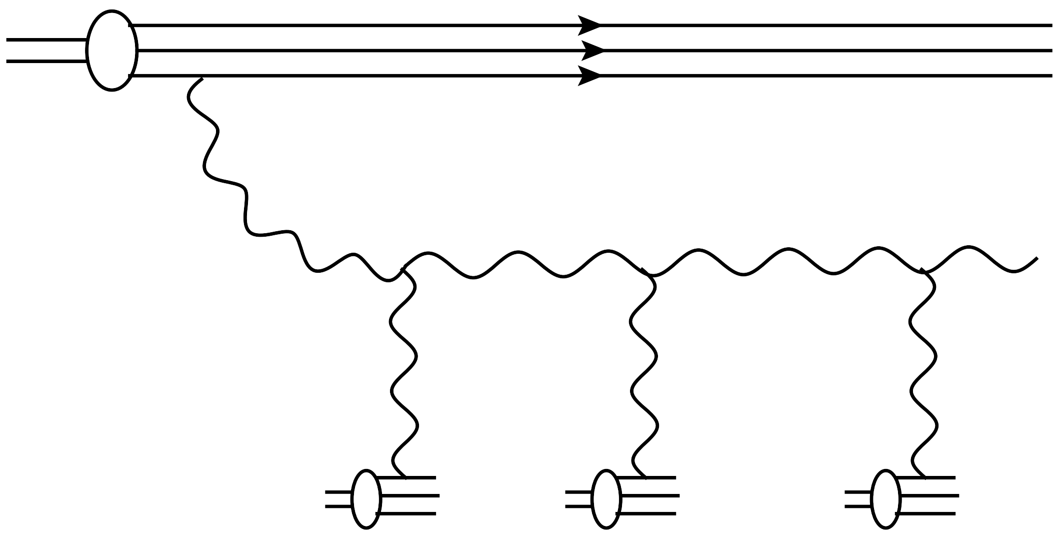
High densities at small-x

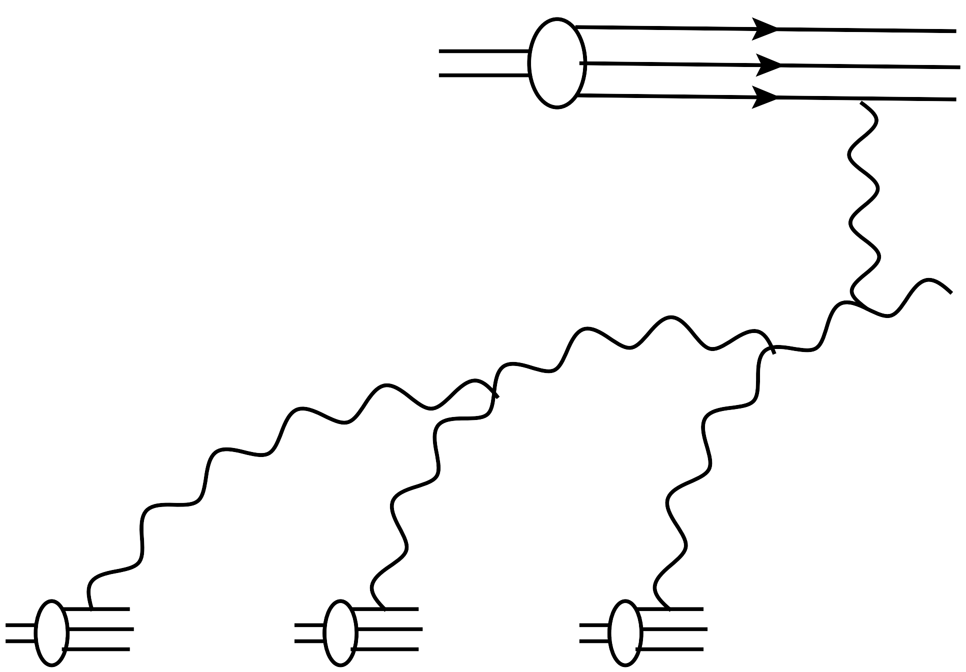
- Separation between dense/ dilute regimes given by saturation scale
- Non-linear evolution
- Collinear factorization does not apply for high-density regime
- Gluons are dominant



Factorization at small-x

- It is necessary to include transverse momentum dependence
- Partonic interpretation is not straightforward and possibly gauge dependent (gluons)
- Additional semi-hard scale: saturation scale

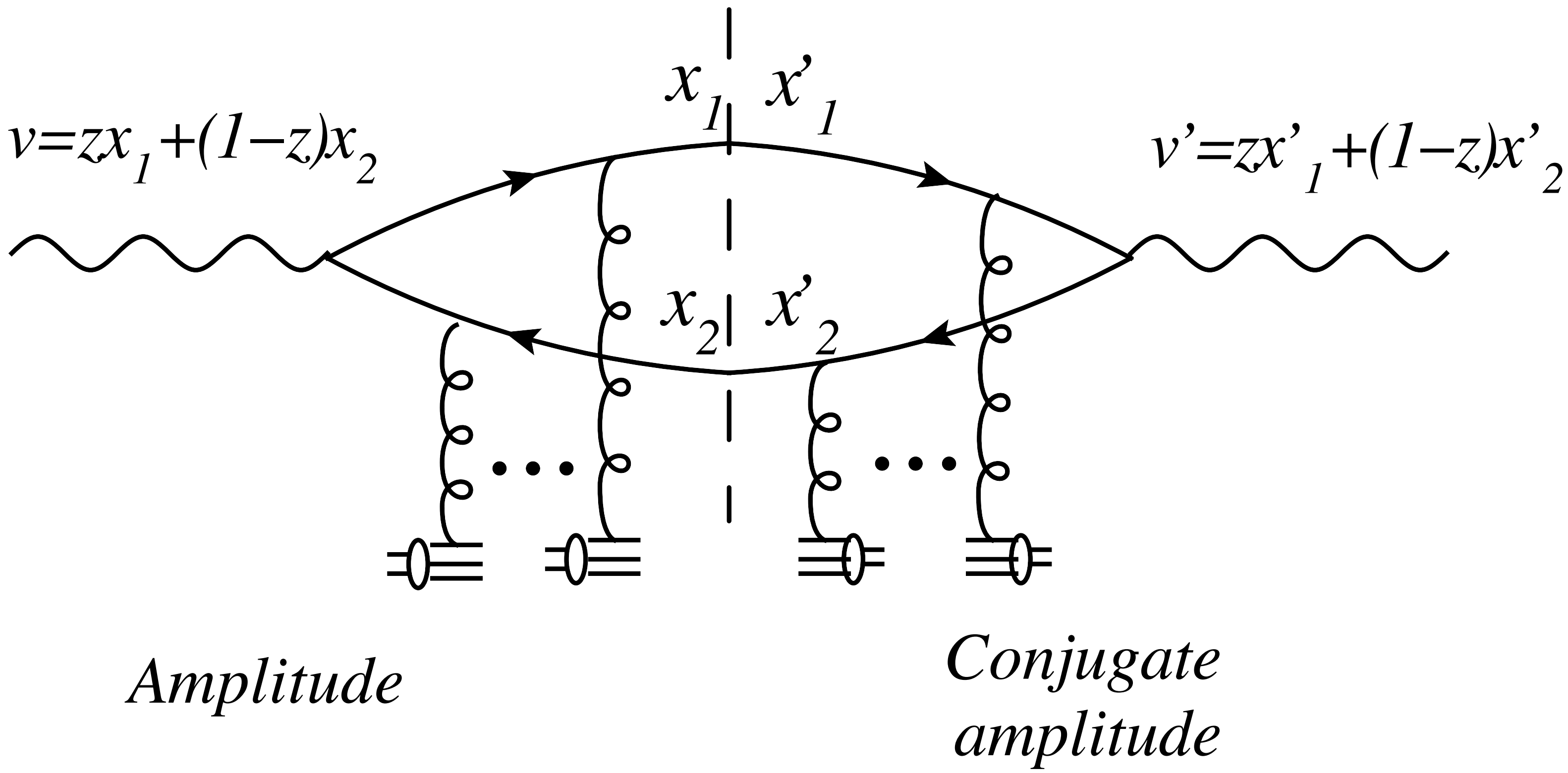




Multiple scatterings approach

- High energy probes propagating eikonally
- Target considered as a background field in a covariant gauge (appropriate for the small-x degrees of freedom)
- Multiple scattering can be resummed in terms of Wilson lines

Two-particle production in DIS

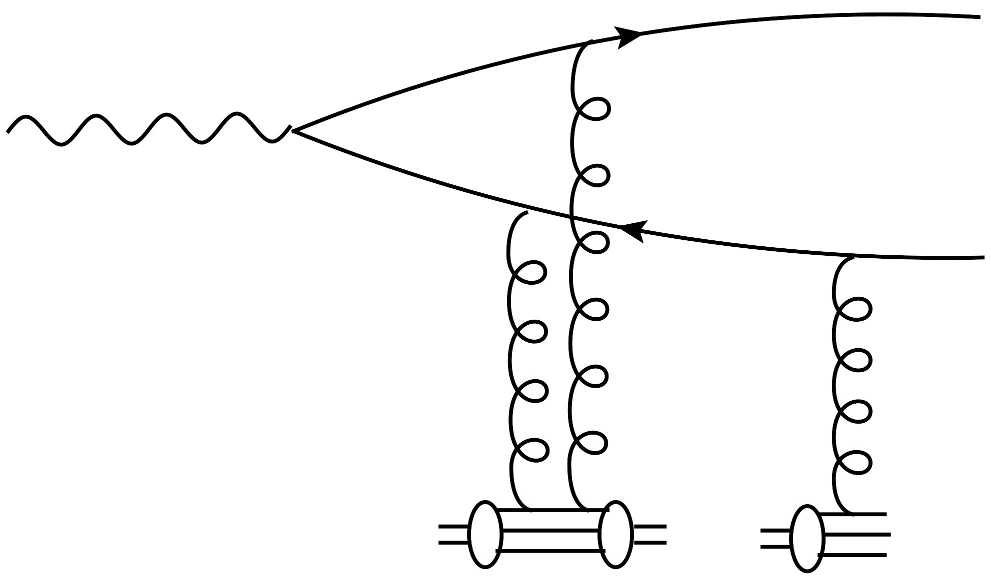


$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{d^3k_1 d^3k_2} = N_c \alpha_{em} e_q^2 \delta(p^+ - k_1^+ - k_2^+) \int \frac{d^2x_1}{(2\pi)^2}\frac{d^2x_1'}{(2\pi)^2}\frac{d^2x_2}{(2\pi)^2}\frac{d^2x_2'}{(2\pi)^2}$$
$$\times\, e^{-ik_{1\perp}\cdot(x_1-x_1')} e^{-ik_{2\perp}\cdot(x_2-x_2')} \sum \psi_T^*(x_1-x_2)\psi_T(x_1'-x_2')$$
$$\times \left[1 + Q_{x_g}(x_1,x_2;x_2',x_1') - S^{(2)}_{x_g}(x_1,x_2) - S^{(2)}_{x_g}(x_1',x_2')\right]$$

$$Q_{x_g}(x_1,x_2;x_2',x_1') = \frac{1}{N_c}\left\langle \mathrm{Tr} U(x_1)U^\dagger(x_1')U(x_2')U^\dagger(x_2)\right\rangle_{x_g} \qquad S^{(2)}_{x_g}(x_1,x_2) = \frac{1}{N_c}\left\langle \mathrm{Tr} U(x_1)U^\dagger(x_2)\right\rangle_{x_g}$$

Correlation limit

- Factorization requires a separation of scales
- Take momentum imbalance much smaller than individual transverse momenta
- In coordinate space this amounts to take a very small separation for the quark-antiquark pair



FD, C. Marquet, B.-W. Xiao, F. Yuan (2011)

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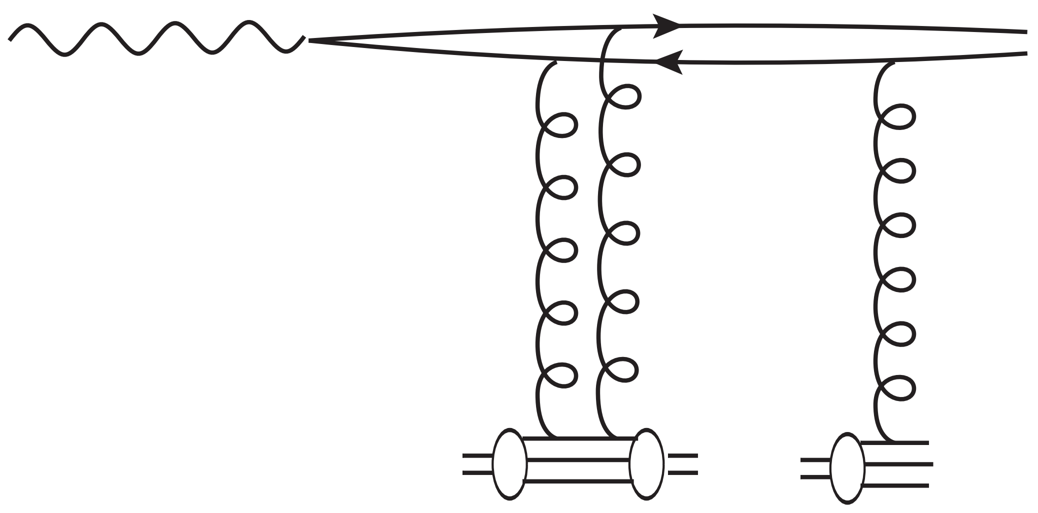

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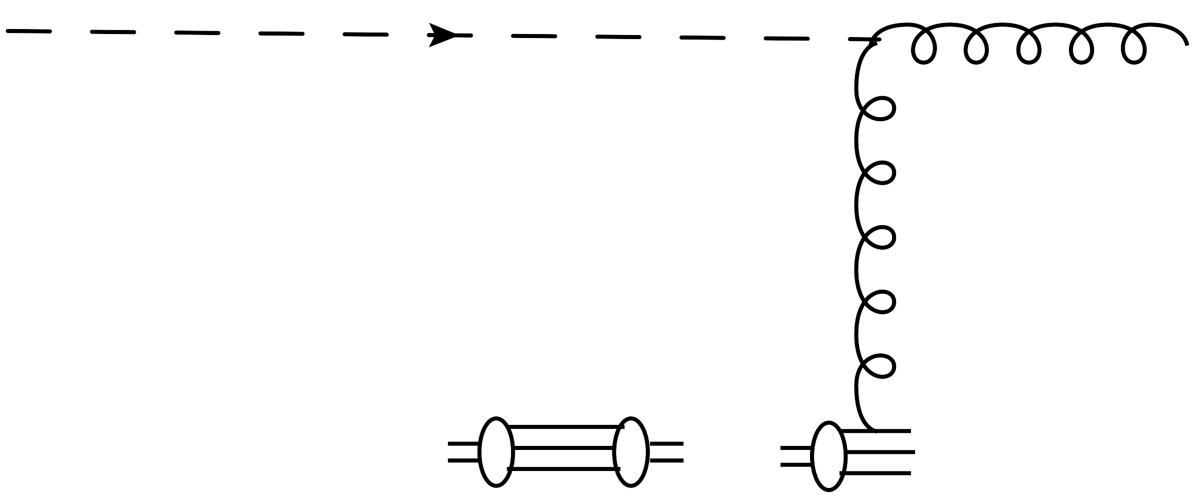

Looks like colorless current liberating a gluon

FD, C. Marquet, B.-W. Xiao, F. Yuan (2011)

Factorized form

$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z(1-z)\left(z^2+(1-z)^2\right)\left[\frac{\delta_{ij}}{(\tilde{P}_\perp^2+\epsilon_f^2)^2}-\frac{4\epsilon_f^2\tilde{P}_{\perp i}\tilde{P}_{\perp j}}{(\tilde{P}_\perp^2+\epsilon_f^2)^4}\right]$$
$$\times(16\pi^3)\int\frac{d^3v d^3v'}{(2\pi)^6}e^{-iq_\perp\cdot(v-v')}2\left\langle \mathrm{Tr}\left[F^{i-}(v)\mathcal{U}^{[+]\dagger}F^{j-}(v')\mathcal{U}^{[+]}\right]\right\rangle_{x_g}$$

Factorized form

$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \alpha_{em} e_q^2 \alpha_s \delta\left(x_{\gamma^*}-1\right) z(1-z)\left(z^2+(1-z)^2\right)\left[\frac{\delta_{ij}}{(\tilde{P}_\perp^2+\epsilon_f^2)^2} - \frac{4\epsilon_f^2 \tilde{P}_{\perp i}\tilde{P}_{\perp j}}{(\tilde{P}_\perp^2+\epsilon_f^2)^4}\right]$$

$$\times(16\pi^3)\int \frac{d^3v d^3v'}{(2\pi)^6} e^{-iq_\perp\cdot(v-v')} 2\left\langle \mathrm{Tr}\left[F^{i-}(v)\mathcal{U}^{[+]\dagger}F^{j-}(v')\mathcal{U}^{[+]}\right]\right\rangle_{x_g}$$

$$\frac{1}{2}\delta^{ij} xG^{(1)}(x,q_\perp) + \frac{1}{2}\left(\frac{2q_\perp^i q_\perp^j}{q_\perp^2} - \delta^{ij}\right) xh_\perp^{(1)}(x,q_\perp)$$

Factorized form

$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z(1-z)\left(z^2+(1-z)^2\right)\left[\frac{\delta_{ij}}{(\tilde{P}_\perp^2+\epsilon_f^2)^2}-\frac{4\epsilon_f^2\tilde{P}_{\perp i}\tilde{P}_{\perp j}}{(\tilde{P}_\perp^2+\epsilon_f^2)^4}\right]$$

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WW Unpolarized distribution

Factorized form

$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \alpha_{em}e_q^2\alpha_s\delta\left(x_{\gamma^*}-1\right)z(1-z)\left(z^2+(1-z)^2\right)\left[\frac{\delta_{ij}}{(\tilde{P}_\perp^2+\epsilon_f^2)^2}-\frac{4\epsilon_f^2\tilde{P}_{\perp i}\tilde{P}_{\perp j}}{(\tilde{P}_\perp^2+\epsilon_f^2)^4}\right]$$

$$\times(16\pi^3)\int\frac{d^3v d^3v'}{(2\pi)^6}e^{-iq_\perp\cdot(v-v')}2\left\langle \mathrm{Tr}\left[F^{i-}(v)\mathcal{U}^{[+]\dagger}F^{j-}(v')\mathcal{U}^{[+]}\right]\right\rangle_{x_g}$$

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$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \alpha_{em} e_q^2 \alpha_s \delta\left(x_{\gamma^*}-1\right) z(1-z)\left(z^2+(1-z)^2\right) \frac{\epsilon_f^4+\tilde{P}_\perp^4}{(\tilde{P}_\perp^2+\epsilon_f^2)^4}$$

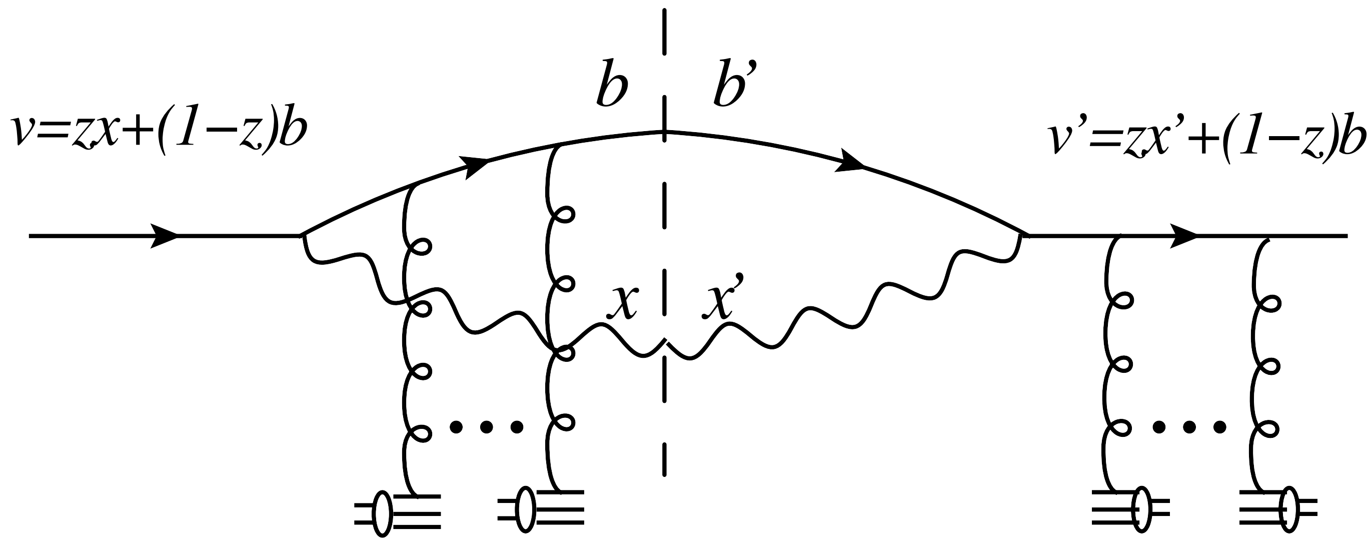
$$\times \left[xG^{(1)}(x,q_\perp) - \frac{2\epsilon_f^2 \tilde{P}_\perp^2}{\epsilon_f^4+\tilde{P}_\perp^4}\cos\left(2\Delta\phi\right) xh_\perp^{(1)}(x,q_\perp)\right]$$

$$\Delta\phi = \phi_{\tilde{P}_\perp} - \phi_{q_\perp}$$

Sensitive to the linearly polarized gluon distribution through the azimuthal dependence

A. Metz, J. Zhou (2011)

Drell-Yan in pA collisions



$$\frac{d\sigma^{pA\to\gamma^* q+X}}{dy_1 dy_2 d^2k_{1\perp} d^2k_{2\perp}} = \sum_f x_p q_f(x_p,\mu)\frac{\alpha_{em}e_f^2}{2\pi^2}(1-z)\,z^2 S_\perp F_{x_g}(q_\perp)$$
$$\times\left\{\left[1+(1-z)^2\right]\frac{q_\perp^2}{\left[\tilde{P}_\perp^2+\epsilon_M^2\right]\left[(\tilde{P}_\perp+zq_\perp)^2+\epsilon_M^2\right]} -\epsilon_M^2\left[\frac{1}{\tilde{P}_\perp^2+\epsilon_M^2}-\frac{1}{(\tilde{P}_\perp+zq_\perp)^2+\epsilon_M^2}\right]^2\right\}$$

$$F_{x_g}(q_\perp)=\int\frac{d^2r_\perp}{(2\pi)^2}e^{-iq_\perp\cdot r_\perp}\frac{1}{N_c}\left\langle \mathrm{Tr}U(0)U^\dagger(r_\perp)\right\rangle_{x_g}$$ Dipole amplitude

Factorized form

$$\left.\frac{d\sigma^{pA\to\gamma^* q+X}}{dy_1 dy_2 d^2k_{1\perp} d^2k_{2\perp}}\right|_{q_\perp \ll \tilde{P}_\perp} = \sum_f x_p q_f(x_p,\mu) x G^{(2)}(x_g,q_\perp)\left[H_{qg\to q\gamma^*} - \cos\left(2\Delta\phi\right) H^\perp_{qg\to q\gamma^*}\right]$$

Linearly polarized distribution is not independent

$$H_{qg\to q\gamma^*} = \frac{\alpha_s \alpha_{e.m.} e_f^2 \left(1-z\right) z^2}{N_c}\left\{\frac{1+\left(1-z\right)^2}{\left[\tilde{P}_\perp^2+\epsilon_M^2\right]^2} - \frac{2z^2\epsilon_M^2\tilde{P}_\perp^2}{\left[\tilde{P}_\perp^2+\epsilon_M^2\right]^4}\right\}$$

$$H^\perp_{qg\to q\gamma^*} = \frac{\alpha_s \alpha_{e.m.} e_f^2 \left(1-z\right) z^2}{N_c}\frac{2z^2\epsilon_M^2\tilde{P}_\perp^2}{\left[\tilde{P}_\perp^2+\epsilon_M^2\right]^4}$$

Factorized form

Dipole type gluon distribution

$$\left.\frac{d\sigma^{pA\to\gamma^* q+X}}{dy_1 dy_2 d^2k_{1\perp} d^2k_{2\perp}}\right|_{q_\perp \ll \tilde{P}_\perp} = \sum_f x_p q_f(x_p,\mu) xG^{(2)}(x_g,q_\perp)\left[H_{qg\to q\gamma^*} - \cos(2\Delta\phi)\, H^\perp_{qg\to q\gamma^*}\right]$$

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Conclusions

- Correlation limit leads to TMD-factorized expressions
- Azimuthal dependence gives access to linearly polarized gluon distributions
- As for the unpolarized case, there are two types of linearly polarized gluon distributions at small-x