Universality of unintegrated gluon distributions at small-x

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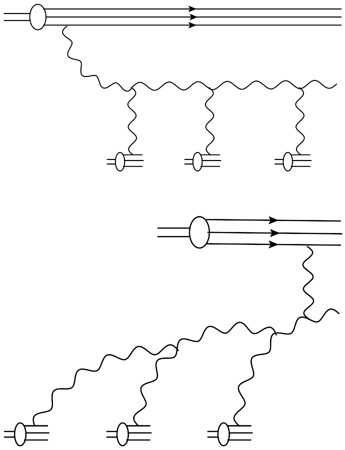
Factorization at Small x



- Resummation of multiple scatterings
- Particle production is sensitive to transverse momentum of partons in the nucleus
- Dense - dilute systems

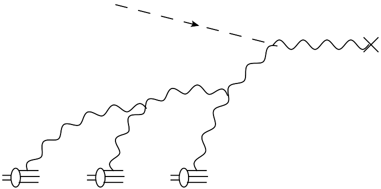
Two Different Gluon Distributions at Small-x

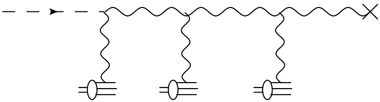
- Weizsäcker-Williams distribution
  - Explictly counts number of gluons in a physical gauge
- Fourier transform of dipole cross section
  - Widely used in k_t-factorized formulas for inclusive processes
  - Does not admit partonic interpretation

Weizsäcker-Williams Distribution

Can be calculated in specific models

- McLerran-Venugopalan
- Kovchegov-Mueller





Weizsäcker-Williams Distribution From DIS

- No such colorless current available in the lab
- Consider two-jet events in DIS
- Make separation between quark and antiquark small by taking correlation limit
- Singlet pair looks like a colorless object
- Octet pair looks like a gluon

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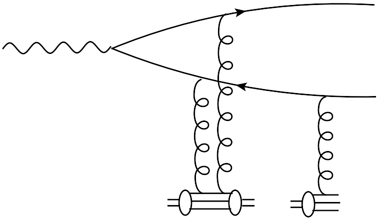

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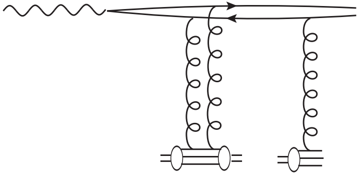

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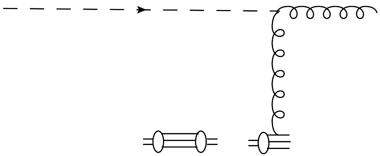
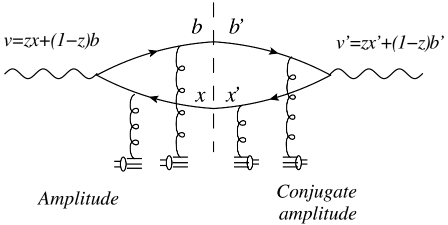


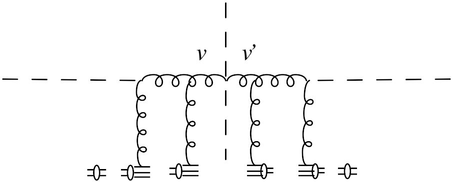
Dijet in DIS



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

$$Q_{x_g}(x,b;b',x') = \frac{1}{N_c}\left\langle \mathrm{Tr}U(b)U^\dagger(b')U(x')U^\dagger(x)\right\rangle_{x_g} \qquad S_{x_g}^{(2)}(x,b) = \frac{1}{N_c}\left\langle \mathrm{Tr}U(b)U^\dagger(x)\right\rangle_{x_g}$$

Dijet in DIS

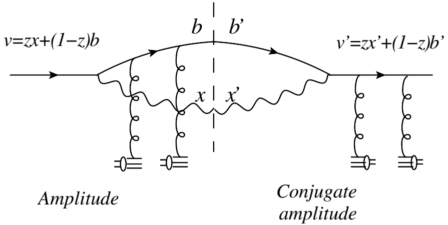


$$\frac{d\sigma^{\gamma_T^* A\to q\bar{q}+X}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \delta(x_{\gamma^*}-1)x_g G^{(1)}(x_g,q_\perp)H_{\gamma_T^* g\to q\bar{q}}$$

- Weizsäcker-Williams gluon distribution

$$x_g G^{(1)}(x_g,q_\perp) = -\frac{2}{\alpha_S}\int \frac{d^2v}{(2\pi)^2}\frac{d^2v'}{(2\pi)^2}\, e^{-iq_\perp\cdot(v-v')} \times \left\langle \mathrm{Tr}\left[\partial_i U(v)\right] U^\dagger(v')\left[\partial_i U(v')\right] U^\dagger(v)\right\rangle_{x_g}$$

Photon Emission in pA Collisions



$$\frac{d\sigma^{qA\to q\gamma X}}{d^3k_1 d^3k_2} = \alpha_{em} e_q^2 \delta(p^+ - k_1^+ - k_2^+) \int \frac{d^2x}{(2\pi)^2}\frac{d^2x'}{(2\pi)^2}\frac{d^2b}{(2\pi)^2}\frac{d^2b'}{(2\pi)^2}$$

$$\times\, e^{-ik_{1\perp}\cdot(x-x')} e^{-ik_{2\perp}\cdot(b-b')} \sum \psi^*(x-b)\psi(x'-b')$$

$$\times \Big[S_{x_g}^{(2)}(b,b') + S_{x_g}^{(2)}(zx+(1-z)b, zx'+(1-z)b')$$

$$- S_{x_g}^{(2)}(b, zx'+(1-z)b') - S_{x_g}^{(2)}(zx+(1-z)b, b') \Big]$$

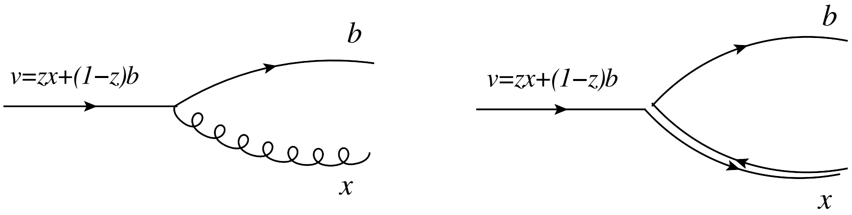
Photon Emission in pA Collisions

- The gluon distribution involved is the Fourier transform of the dipole cross section

$$\frac{d\sigma^{(pA\to\gamma q+X)}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \sum_f x_1 q(x_1) x_g G^{(2)}(x_g, q_\perp) H_{qg\to\gamma q}$$

$$x_g G^{(2)}(x_g, q_\perp) = \frac{q_\perp^2 N_c}{2\pi^2 \alpha_s} S_\perp \int \frac{d^2 r_\perp}{(2\pi)^2} e^{-iq_\perp \cdot r_\perp} S^{(2)}_{x_g}(0, r_\perp)$$

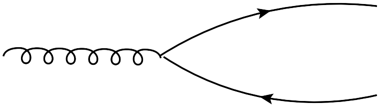
Dijet in pA Collisions, Quark Initiated

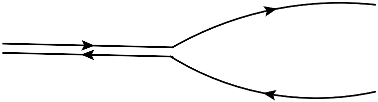


- Consider separately hard scattering in each part of the diagram
- When hard scattering hits the $q\bar{q}$ pair the WW distribution has to be convoluted with the multiple scattering of the quark line

$$\frac{d\sigma^{(pA\to qgX)}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \sum_q x_p q(x_p) \frac{\alpha_s^2}{\hat{s}^2} \left[\mathcal{F}_{qg}^{(1)} H_{qg\to qg}^{(1)} + \mathcal{F}_{qg}^{(2)} H_{qg\to qg}^{(2)} \right]$$

Dijet in pA Collisions, Gluon Initiated

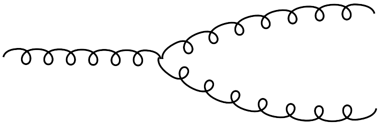


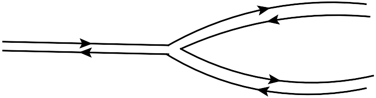


- Two different terms corresponding to different hookings of the hard scattering

$$\frac{d\sigma^{(pA\to q\bar{q}X)}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \sum_f x_p g(x_p) \frac{\alpha_s^2}{\hat{s}^2} \left[\mathcal{F}_{gg}^{(1)} H_{gg\to q\bar{q}}^{(1)} + \mathcal{F}_{gg}^{(2)} H_{gg\to q\bar{q}}^{(2)} \right]$$

Dijet in pA Collisions, Gluon Initiated





- Same as previous case + term with WW convoluted with two quark scatterings

$$\frac{d\sigma^{(pA\to ggX)}}{dy_1 dy_2 d^2P_\perp d^2q_\perp} = \sum_f x_p g(x_p) \frac{\alpha_s^2}{\hat{s}^2} \left[\mathcal{F}_{gg}^{(1)} H_{gg\to gg}^{(1)} + \mathcal{F}_{gg}^{(2)} H_{gg\to gg}^{(2)} + \mathcal{F}_{gg}^{(3)} H_{gg\to gg}^{(3)} \right]$$

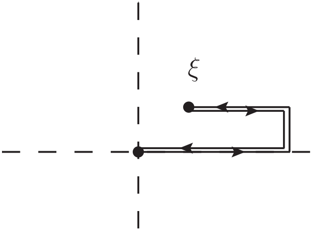
Conclusions

- A way of measuring the Weizsäcker-Williams distribution is proposed
- Different gluon distributions can be probed in different experiments
- Gluon distributions for more complicated processes can be built as convolutions of two basic universal blocks

Gauge Link Structure

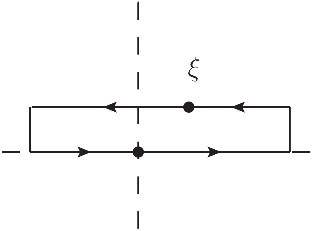
- Weizsäcker-Williams distribution

$$xG^{(1)}(x,k_\perp) = 2\int \frac{d\xi^- d\xi_\perp}{(2\pi)^3 P^+} e^{ixP^+\xi^- - ik_\perp\cdot\xi_\perp}$$
$$\times \langle P|\mathrm{Tr}\left[F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[+]\dagger}F^{+i}(0)\mathcal{U}^{[+]}\right]|P\rangle$$



- Fourier transform of dipole cross section

$$xG^{(2)}(x,k_\perp) = 2\int \frac{d\xi^- d\xi_\perp}{(2\pi)^3 P^+} e^{ixP^+\xi^- - ik_\perp\cdot\xi_\perp}$$
$$\times \langle P|\mathrm{Tr}\left[F^{+i}(\xi^-,\xi_\perp)\mathcal{U}^{[-]\dagger}F^{+i}(0)\mathcal{U}^{[+]}\right]|P\rangle$$



Correlation Limit

- Change variables:
  - Momentum variables

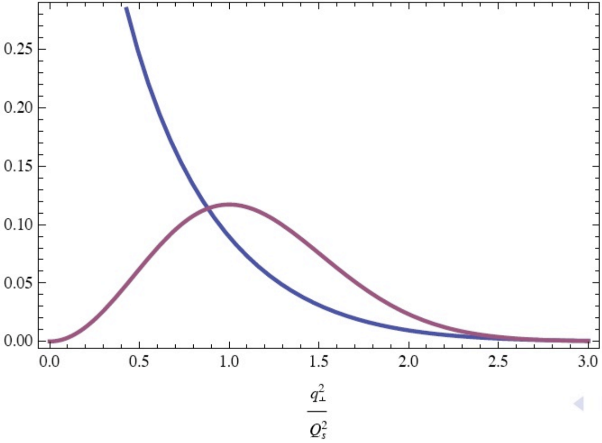
$$q_\perp = k_{1\perp} + k_{2\perp} \qquad P_\perp = (1-z)k_{1\perp} - zk_{2\perp}$$

  - Coordinate variables

$$v = zx + (1-z)b \qquad u = x - b$$

- Take $P_\perp \gg q_\perp$
- In Fourier transform take the leading term in expansion in terms of u and u'
- One hard scattering (sensitive to the inner structure) + multiple softer scatterings ($u = u' = 0$)

Comparison of Two Gluon Distributions



- Weizsäcker-Williams
- Dipole