



THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

STRONG-2020

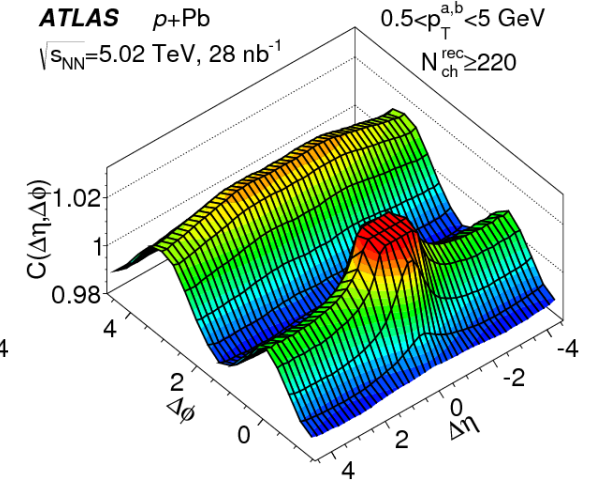
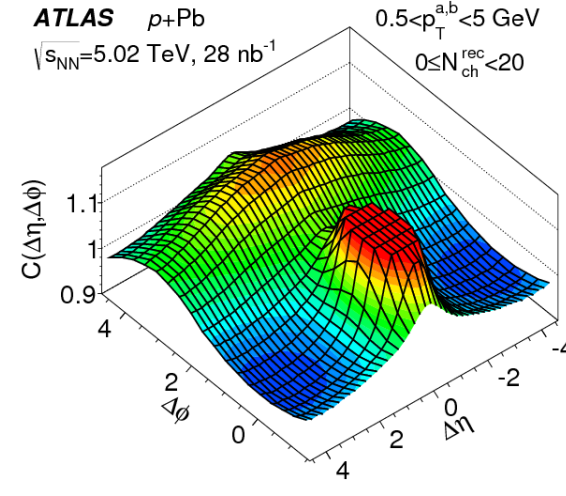
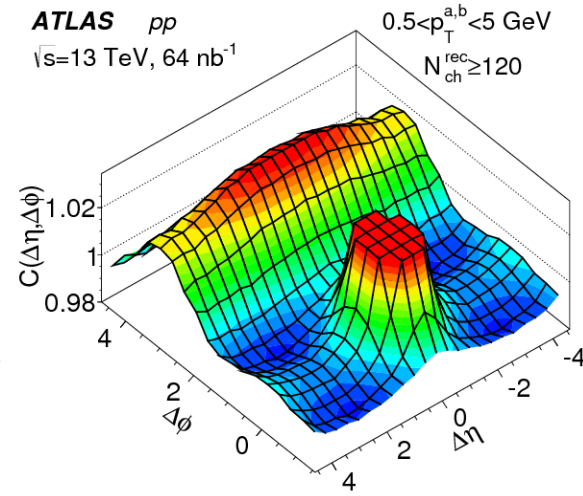
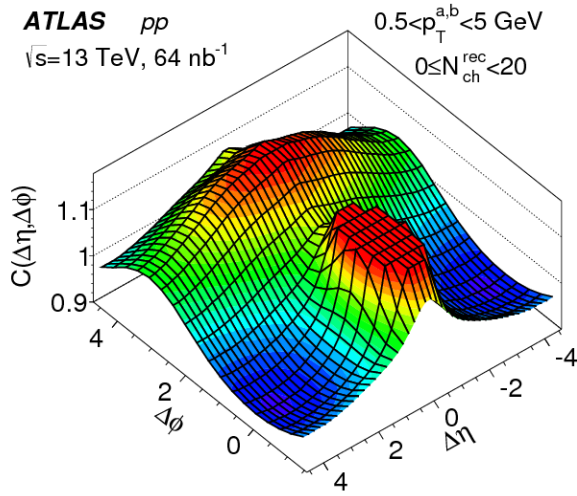
**SURFACING ODD HARMONICS IN TWO PARTICLE CORRELATIONS
WITHIN THE COLOR GLASS CONDENSATE APPROACH**

Víctor Vila

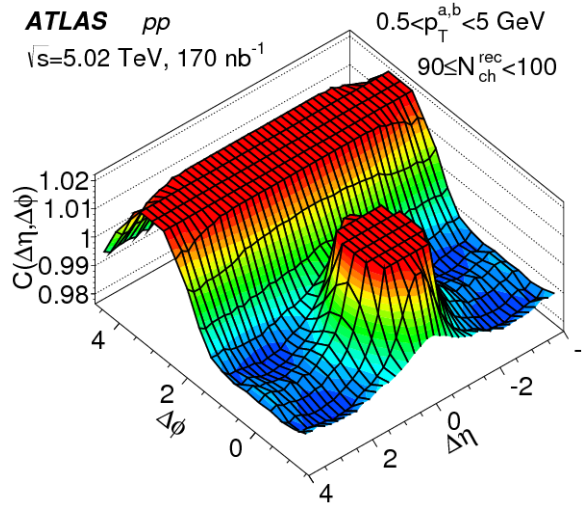
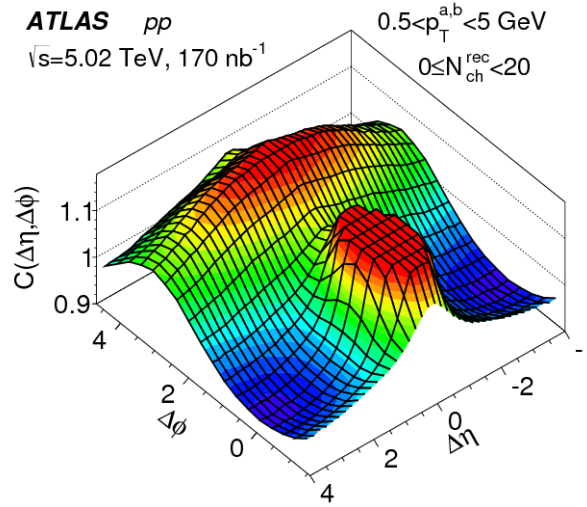
[in collaboration with Cyrille Marquet and Anderson Kendi]

Diffraction and Low-x 2022, 24-30 September 2022

Corigliano Calabro, Cosenza



ATLAS Collaboration, "Measurements of long-range azimuthal anisotropies and associated Fourier coefficients for pp collisions at $s^{1/2}=5.02$ and 13 TeV and $p+Pb$ collisions at $s_{NN}^{1/2}=5.02\text{ TeV}$ with the ATLAS detector", ATLAS-CONF-2016-026 [arXiv:1609.06213 [nucl-ex]].



- ➔ One of the **main unveilings** of the **CMS** collaboration.
- ➔ First noticed in **relativistic heavy-ion** data from **RHIC**.
- ➔ An **incentive** to seek the **origin of particle correlations**.

➔ Mechanisms behind the ridge in pp , pA and AA collisions:

- **HICs:** collective behaviour of the gluons cloud's final state.
- **Small systems:** hydrodynamical evolution logic consistent with data.

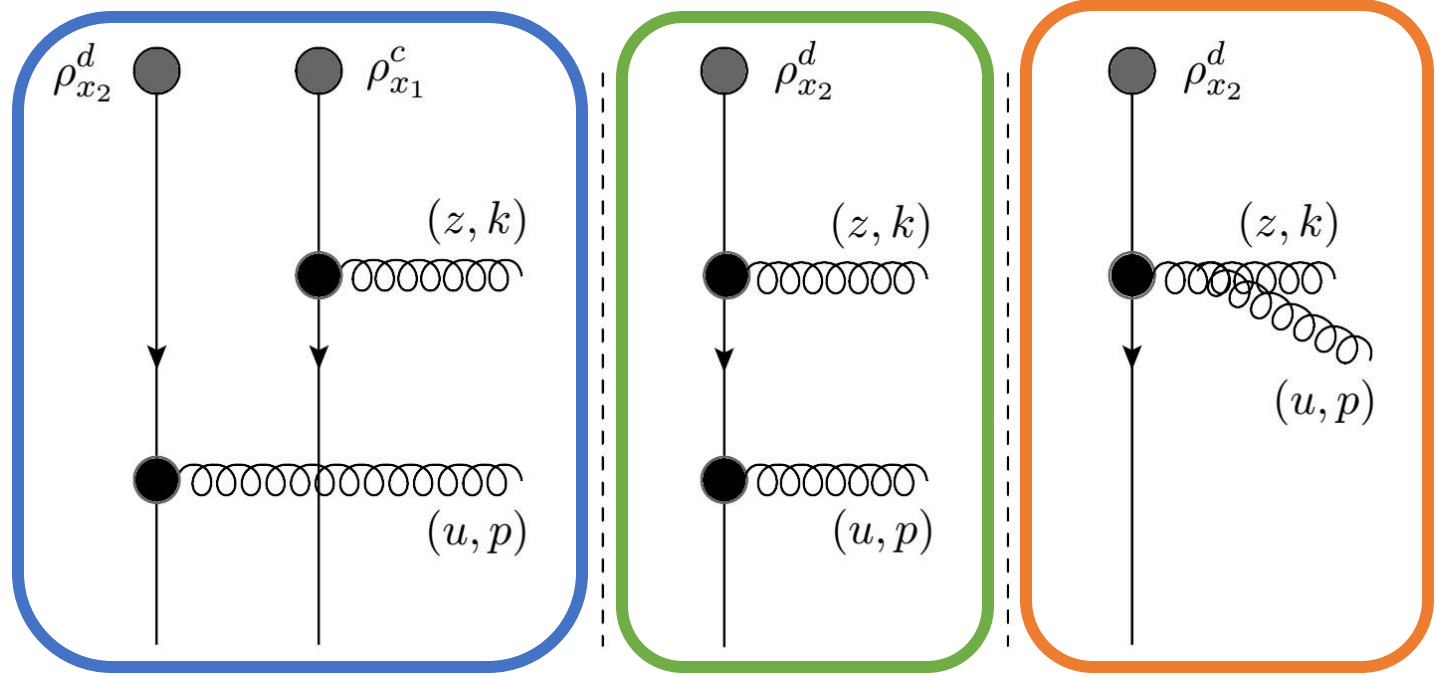
■ **Particle correlations: roots in the very early stages of the collision.**

■ **Glasma graph approximation — Dilute-dilute limit of the CGC framework:**

- Extremely effective.
- Anisotropic distribution of particles motivates decomposition in Fourier harmonics with the corresponding coefficients v_n :
 - Rise of even Fourier harmonics.
 - **ABSENCE OF ODD AZIMUTHAL HARMONICS.**

$$A_{ij}^{ab}(k, p) = \int_{u, z} e^{ik \cdot z + ip \cdot u} \left\{ \int_{x_1, x_2} \left\{ f_i(z - x_1) [S_z - S_{x_1}]^{ac} \rho_{x_1}^c \right\} \left\{ f_j(u - x_2) [S_u - S_{x_2}]^{bd} \rho_{x_2}^d \right\} \right. \\
 - \frac{1}{2} \int_{x_1} f_i(z - x_1) f_j(u - x_1) \left\{ [S_z - S_{x_1}] \bar{\rho}_{x_1} [S_u^\dagger + S_{x_1}^\dagger] \right\}^{ab} \\
 \left. + \int_{x_1} f_i(z - u) f_j(u - x_1) \left\{ [S_z - S_u] \bar{\rho}_{x_1} S_u^\dagger \right\}^{ab} \right\},$$

A. Kovner and M. Lublinsky, "Angular Correlations in Gluon Production at High Energy", Phys.Rev. D83 (2011) 034017 [arXiv:1012.3398 [hep-ph]].



$$\frac{dN}{d^2pd^2kd\eta d\xi} = \left\{ \sigma^4 + \sigma^3 + \sigma^2 \right\}_{P,T}$$

A. Kovner and M. Lublinsky, "Angular Correlations in Gluon Production at High Energy", Phys.Rev. D83 (2011) 034017 [arXiv:1012.3398 [hep-ph]].

$$\sigma^4 = \int_{u,z,\bar{u},\bar{z}} e^{ik \cdot (z-\bar{z}) + ip \cdot (u-\bar{u})} \int_{x_1, x_2, \bar{x}_1, \bar{x}_2} f(\bar{z} - \bar{x}_1) \cdot f(z - x_1) f(\bar{u} - \bar{x}_2) \cdot f(u - x_2) \\ \times \left\{ \rho_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \rho_{\bar{x}_1} \right\} \left\{ \rho_{x_2} [S_u^\dagger - S_{x_2}^\dagger] [S_{\bar{u}} - S_{\bar{x}_2}] \rho_{\bar{x}_2} \right\}$$

$$\sigma^3 = \int_{u,z,\bar{u},\bar{z}} e^{ik \cdot (z-\bar{z}) + ip \cdot (u-\bar{u})} \int_{x_1, \bar{x}_1, x_2(\bar{x}_2)} \\ - \frac{1}{2} f(\bar{z} - \bar{x}_1) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_2) \\ \times \text{Tr} \left\{ \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} [S_{\bar{u}}^\dagger + S_{\bar{x}_1}^\dagger] [S_u - S_{x_2}] \bar{\rho}_{x_2} \right\} \\ + \frac{1}{2} f(\bar{z} - \bar{x}_1) \cdot f(z - x_1) f(\bar{u} - \bar{x}_2) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ \bar{\rho}_{\bar{x}_2} [S_{\bar{u}}^\dagger - S_{\bar{x}_2}^\dagger] [S_u + S_{x_1}] \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} \right\} \\ + f(\bar{z} - \bar{u}) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_2) \\ \times \text{Tr} \left\{ \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{u}}] \bar{\rho}_{\bar{x}_1} S_{\bar{u}}^\dagger [S_u - S_{x_2}] \bar{\rho}_{x_2} \right\} \\ - f(\bar{z} - \bar{x}_1) \cdot f(z - u) f(\bar{u} - \bar{x}_2) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ \bar{\rho}_{\bar{x}_2} [S_{\bar{u}}^\dagger - S_{\bar{x}_2}^\dagger] S_u \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} \right\}$$

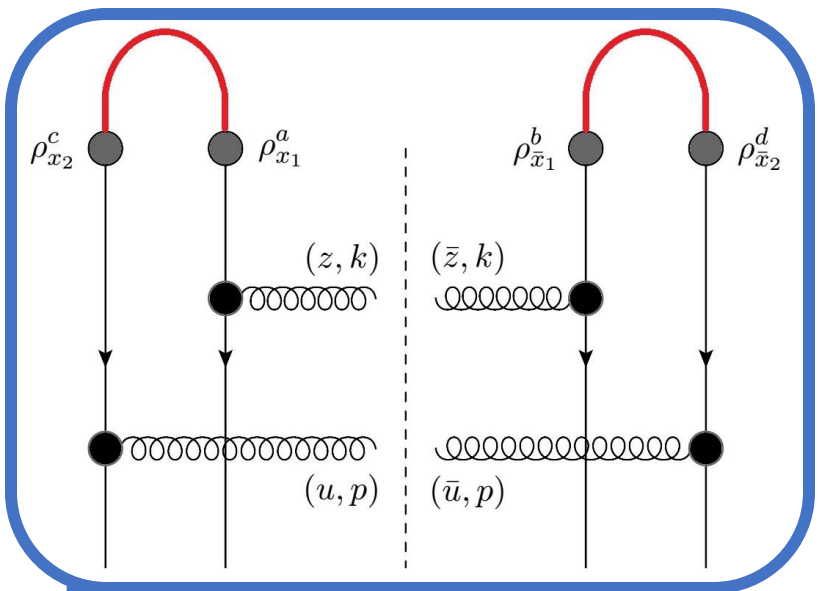
$$\sigma^2 = \int_{u,z,\bar{u},\bar{z}} e^{ik \cdot (z-\bar{z}) + ip \cdot (u-\bar{u})} \int_{x_1, \bar{x}_1} \\ \frac{1}{4} f(\bar{z} - \bar{x}_1) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ [S_u + S_{x_1}] \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} [S_{\bar{u}}^\dagger + S_{\bar{x}_1}^\dagger] \right\} \\ + f(\bar{z} - \bar{u}) \cdot f(z - u) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ S_u \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{u}}] \bar{\rho}_{\bar{x}_1} S_{\bar{u}}^\dagger \right\} \\ - \frac{1}{2} f(\bar{z} - \bar{x}_1) \cdot f(z - u) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ S_u \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} [S_{\bar{u}}^\dagger + S_{\bar{x}_1}^\dagger] \right\} \\ - \frac{1}{2} f(\bar{z} - \bar{u}) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \\ \times \text{Tr} \left\{ [S_u + S_{x_1}] \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{u}}] \bar{\rho}_{\bar{x}_1} S_{\bar{u}}^\dagger \right\}$$

$$\begin{aligned}
 \langle \hat{\rho}_{x_2}^c \hat{\rho}_{x_1}^a \hat{\rho}_{\bar{x}_2}^d \hat{\rho}_{\bar{x}_1}^b \rangle_P &= \langle \hat{\rho}_{x_2}^c \hat{\rho}_{x_1}^a \rangle_P \langle \hat{\rho}_{\bar{x}_2}^d \hat{\rho}_{\bar{x}_1}^b \rangle_P + \langle \hat{\rho}_{x_2}^c \hat{\rho}_{\bar{x}_2}^d \rangle_P \langle \hat{\rho}_{x_1}^a \hat{\rho}_{\bar{x}_1}^b \rangle_P \\
 &+ \langle \hat{\rho}_{x_2}^c \hat{\rho}_{\bar{x}_1}^b \rangle_P \langle \hat{\rho}_{x_1}^a \hat{\rho}_{\bar{x}_2}^d \rangle_P
 \end{aligned}$$

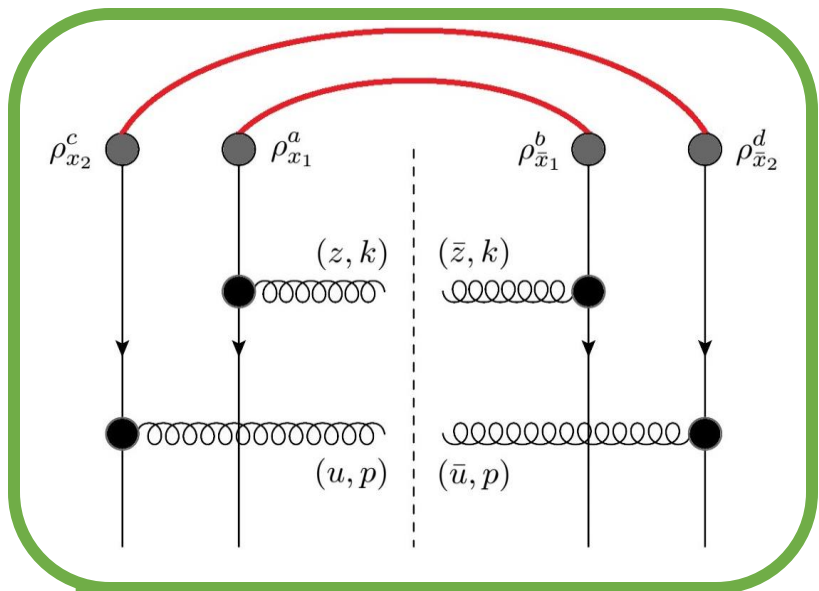
$$\langle \hat{\rho}_{x_1}^a \hat{\rho}_{x_2}^b \rangle_P = \delta^{ab} \mu^2 \delta^{(2)}(x_1 - x_2)$$

MV MODEL PROJECTILE AVERAGING

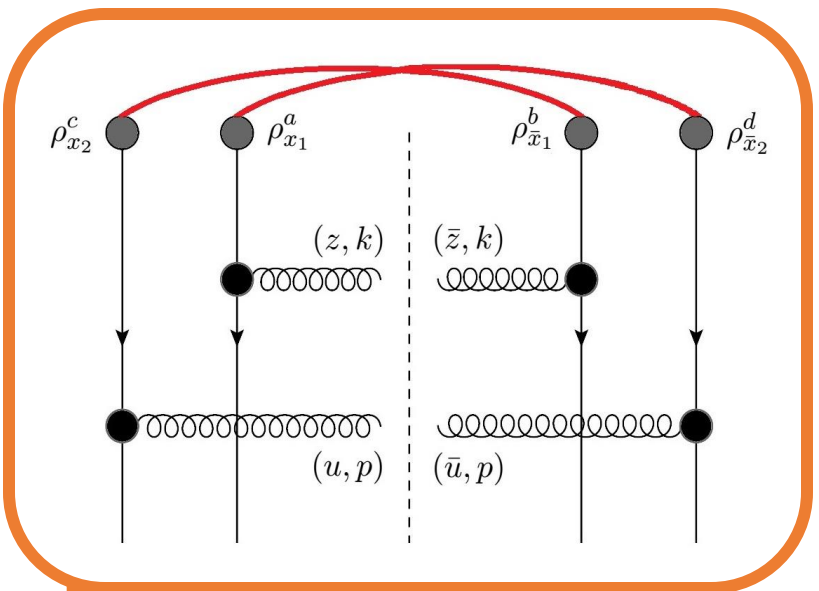
T. Altinoluk, N. Armesto, A. Kovner and M. Lublinsky, "Double and triple inclusive gluon production at mid rapidity: quantum interference in p-A scattering", Eur.Phys.J. C78 (2018) 9, 702 [arXiv:1805.07739 [hep-ph]].



$\sigma^4(i)$



$\sigma^4(ii)$



$\sigma^4(iii)$

$$\sigma^2 = \int_{u, z, \bar{u}, \bar{z}} e^{ik \cdot (z - \bar{z}) + ip \cdot (u - \bar{u})} \int_{x_1, \bar{x}_1} \quad [A. Kendi, C. Marquet and V. Vila, "in preparation"]$$

$$\frac{1}{4} f(\bar{z} - \bar{x}_1) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \times \text{Tr} \left\{ [S_u + S_{x_1}] \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} [S_{\bar{u}}^\dagger + S_{\bar{x}_1}^\dagger] \right\}$$

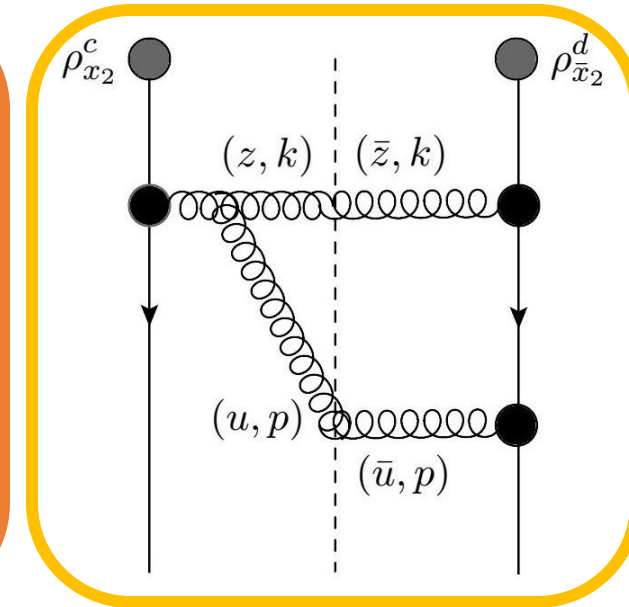
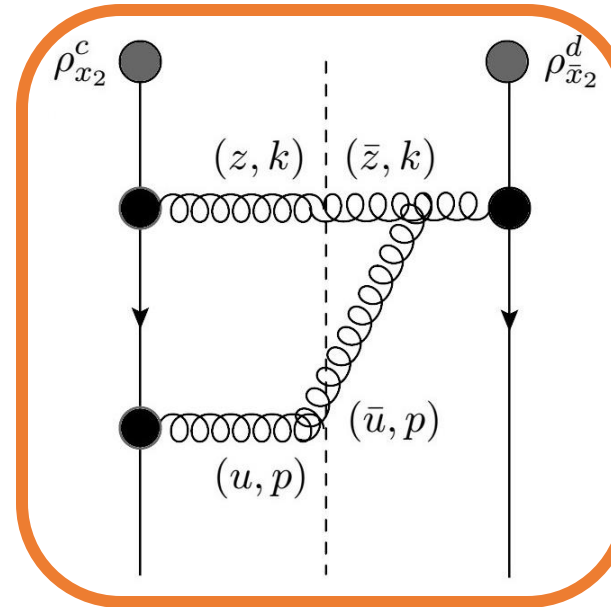
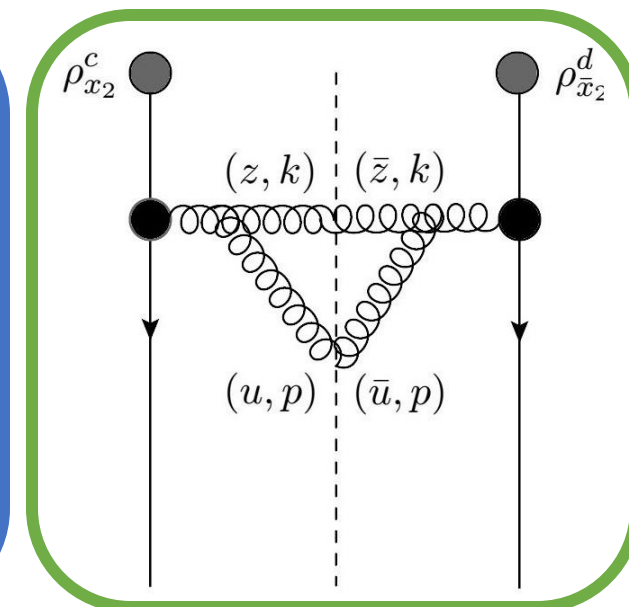
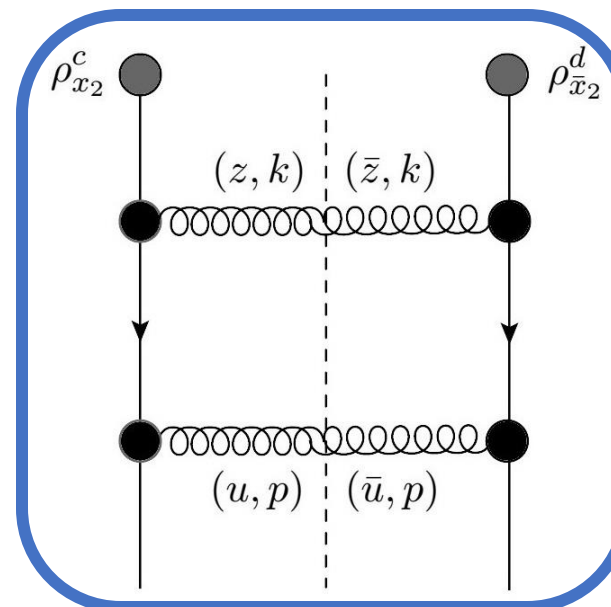
$$+ f(\bar{z} - \bar{u}) \cdot f(z - u) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \times \text{Tr} \left\{ S_u \bar{\rho}_{x_1} [S_z^\dagger - S_u^\dagger] [S_{\bar{z}} - S_{\bar{u}}] \bar{\rho}_{\bar{x}_1} S_{\bar{u}}^\dagger \right\}$$

$$- \frac{1}{2} f(\bar{z} - \bar{x}_1) \cdot f(z - u) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \times \text{Tr} \left\{ S_u \bar{\rho}_{x_1} [S_z^\dagger - S_u^\dagger] [S_{\bar{z}} - S_{\bar{x}_1}] \bar{\rho}_{\bar{x}_1} [S_{\bar{u}}^\dagger + S_{\bar{x}_1}^\dagger] \right\}$$

$$- \frac{1}{2} f(\bar{z} - \bar{u}) \cdot f(z - x_1) f(\bar{u} - \bar{x}_1) \cdot f(u - x_1) \times \text{Tr} \left\{ [S_u + S_{x_1}] \bar{\rho}_{x_1} [S_z^\dagger - S_{x_1}^\dagger] [S_{\bar{z}} - S_{\bar{u}}] \bar{\rho}_{\bar{x}_1} S_{\bar{u}}^\dagger \right\}$$

$$\left\langle \hat{\rho}_{x_1}^a \hat{\rho}_{\bar{x}_1}^b \hat{\rho}_{\bar{x}_2}^c \right\rangle_P = 0$$

MV MODEL PROJECTILE AVERAGING



$$\tilde{D}(\bar{u}, u) = \left\langle \frac{1}{N^2 - 1} \text{Tr} \left[S^\dagger(\bar{u}) S(u) \right] \right\rangle_T$$

$$\tilde{Q}(\bar{u}, u, z, \bar{z}) = \left\langle \frac{1}{N^2 - 1} \text{Tr} \left[S^\dagger(\bar{u}) S(u) S^\dagger(z) S(\bar{z}) \right] \right\rangle_T$$

AEA

LARGE N_c

$$\tilde{D}(\bar{u}, u) = D^2(\bar{u}, u)$$

$$\tilde{Q}(\bar{u}, u, z, \bar{z}) \approx D^2(\bar{u}, u) D^2(z, \bar{z}) + D^2(\bar{u}, \bar{z}) D^2(u, z)$$

$$\sigma^{4(ii)} = \int_{u, z, \bar{u}, \bar{z}} e^{ik \cdot (z - \bar{z}) + ip \cdot (u - \bar{u})} \int_{x_1, x_2} f(\bar{z} - x_1) \cdot f(z - x_1) f(\bar{u} - x_2) \cdot f(u - x_2)$$

$$\times (N^2 - 1)^2 \mu^4 \left\{ \tilde{D}(z, \bar{z}) \tilde{D}(u, \bar{u}) - \tilde{D}(z, \bar{z}) \tilde{D}(u, x_2) - \tilde{D}(z, \bar{z}) \tilde{D}(x_2, \bar{u}) \right.$$

$$+ \tilde{D}(z, \bar{z}) - \tilde{D}(x_1, \bar{z}) \tilde{D}(u, \bar{u}) + \tilde{D}(x_1, \bar{z}) \tilde{D}(u, x_2) + \tilde{D}(x_1, \bar{z}) \tilde{D}(x_2, \bar{u})$$

$$- \tilde{D}(x_1, \bar{z}) - \tilde{D}(z, x_1) \tilde{D}(u, \bar{u}) + \tilde{D}(z, x_1) \tilde{D}(u, x_2) + \tilde{D}(z, x_1) \tilde{D}(x_2, \bar{u})$$

$$\left. - \tilde{D}(z, x_1) + \tilde{D}(u, \bar{u}) - \tilde{D}(u, x_2) - \tilde{D}(x_2, \bar{u}) + 1 \right\}$$

$$\sigma^{4(ii)} = \int_{u, z, \bar{u}, \bar{z}} e^{ik \cdot (z - \bar{z}) + ip \cdot (u - \bar{u})} \int_{x, \bar{x}} f(\bar{z} - x) \cdot f(z - x) f(\bar{u} - \bar{x}) \cdot f(u - \bar{x})$$

$$\times (N^2 - 1)^2 \mu^4 \left\{ \left[D^2(z, \bar{z}) - D^2(z, x) - D^2(x, \bar{z}) + 1 \right] \right.$$

$$\left. \times \left[D^2(u, \bar{u}) - D^2(u, \bar{x}) - D^2(\bar{x}, \bar{u}) + 1 \right] \right\}$$

$$f(x - y) = \frac{g_s}{2\pi} \frac{(x - y)^i}{(x - y)^2} = \frac{g_s}{2\pi} \int \frac{d^2 q}{2\pi i} \frac{q^i}{q^2} e^{iq \cdot (x - y)}$$

$$D(r) = \int \frac{d^2 q}{\pi} e^{-iq \cdot r} \frac{1}{Q_s^2} e^{-\frac{q^2}{Q_s^2}}$$

$$D^2(r) = \int \frac{d^2 q}{2\pi} e^{-iq \cdot r} \frac{1}{Q_s^2} e^{-\frac{q^2}{2Q_s^2}}$$

**FOURIER TRANSFORMATION
OF THE WEIZSACKER-
WILLIAMS FIELDS AND
THE GBW MODEL FOR THE
DIPOLES**


$$\begin{aligned} \sigma^{4([i+iii].I)} &\approx \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp \frac{2\pi}{Q_s^2} e^{-\frac{(k+p)^2}{4Q_s^2}} \\ &\times \left[\frac{2 \left(k^4 + p^4 + 2(k \cdot p)^2 \right)}{k^2 p^2 (k-p)^4} + \frac{8Q_s^2 (k+p)^4}{k^2 p^2 (k-p)^6} \right. \\ &\left. + \frac{64Q_s^4 \left(k^4 + 4(k \cdot p)^2 + p^4 + 8(k \cdot p)(k^2 + p^2) + 14k^2 p^2 \right)}{k^2 p^2 (k-p)^8} \right] \\ &+ \{(p \rightarrow -p)\} \end{aligned}$$

$$\begin{aligned} \sigma^{4([i+iii].II)} &\approx \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp (2\pi)^2 \left[\delta^{(2)}(k+p) + \delta^{(2)}(k-p) \right] \\ &\times \frac{4}{k^{12}} e^{-\frac{k^2}{Q_s^2}} \left(k^4 + k^2 e^{\frac{k^2}{2Q_s^2}} Q_s^2 + 4e^{\frac{k^2}{2Q_s^2}} Q_s^4 \right)^2 \end{aligned}$$

$$\begin{aligned} \sigma^{4(ii)} &= \alpha_s^2 (4\pi)^2 (N^2 - 1)^2 \mu^4 S_\perp^2 \\ &\times e^{-\frac{k^2}{2Q_s^2}} \left\{ \frac{2}{k^2} - \frac{1}{k^2} e^{\frac{k^2}{2Q_s^2}} + \frac{1}{2Q_s^2} \left[\text{Ei} \left(\frac{k^2}{2Q_s^2} \right) - \text{Ei} \left(\frac{k^2 \lambda}{2Q_s^2} \right) \right] \right\} \\ &\times \{(k \rightarrow p)\} \end{aligned}$$

■ THE FULLY CORRELATED PIECE ENCAPSULATING TWO EFFECTS:

 **BOSE ENHANCEMENT OF GLUONS IN THE WAVE FUNCTION OF THE INCOMING HADRONS**

 **HANBURY-BROWN-TWISS INTERFERENCE EFFECT IN THE EMISSION OF GLUONS**

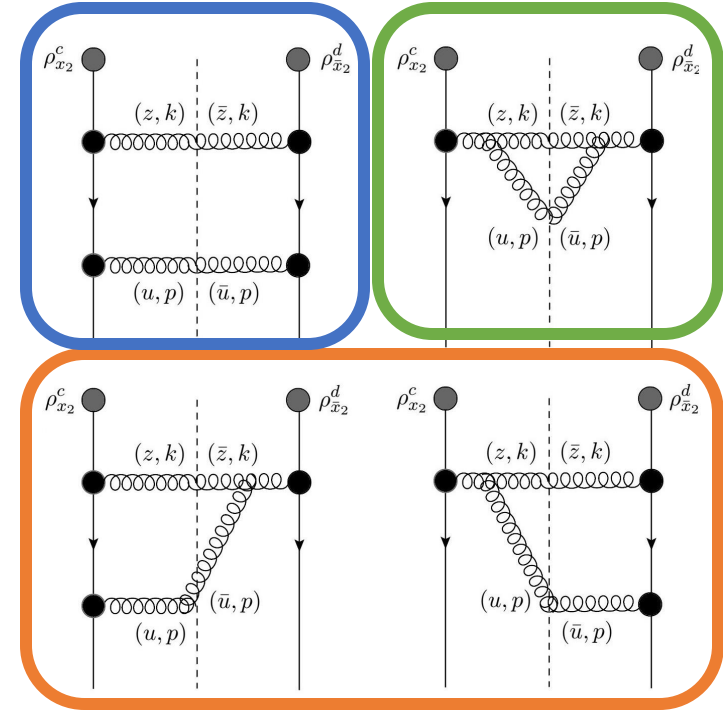
[A. Kendi, C. Marquet and V. Vila, "in preparation"]

THE UNCORRELATED PIECE CORRESPONDING TO THE SQUARE OF THE SINGLE INCLUSIVE GLUON PRODUCTION CROSS-SECTION

$$\sigma^{2(i)} = \alpha_s^2 (4\pi)^2 N^3 \mu^2 S_\perp \frac{1}{k^6 p^6} e^{-\frac{k^2+p^2}{2Q_s^2}} \times \left[k^4 + e^{\frac{k^2}{2Q_s^2}} k^2 Q_s^2 + 4e^{\frac{k^2}{2Q_s^2}} Q_s^4 \right] \left[\left(2e^{\frac{p^2}{2Q_s^2}} - 1 \right) p^4 + e^{\frac{p^2}{2Q_s^2}} p^2 Q_s^2 + 4e^{\frac{p^2}{2Q_s^2}} Q_s^4 \right]$$

$$\sigma^{2(ii)} = \alpha_s^2 (4\pi)^2 N^3 \mu^2 S_\perp \left\{ \frac{1}{(2\pi)^2 Q_s^4} e^{-\frac{k^2+p^2}{2Q_s^2}} \int_{s_1, s_2} \frac{1}{s_1^2} \frac{1}{(s_1 - s_2)^2} e^{-\frac{s_1^2 + 2k \cdot s_1}{2Q_s^2}} e^{-\frac{s_2^2 - 2p \cdot s_2}{2Q_s^2}} \right. \\ \left. + \frac{1}{2\pi^2 Q_s^4} e^{-\frac{k^2+p^2}{2Q_s^2}} \int_{s_1, s_2} \frac{s_1^i}{s_1^2} \frac{1}{s_2^2} e^{-\frac{2s_1^2 + 2(k-p) \cdot s_1}{2Q_s^2}} e^{-\frac{s_2^2 - 2(s_1-p) \cdot s_2}{2Q_s^2}} \right. \\ \left. + \frac{1}{(k+p)^2} \left[1 + \frac{1}{2} \frac{2^3 Q_s^2}{(k+p)^2} + \frac{1}{2} \frac{2^6 Q_s^4}{(k+p)^4} \right] \right\}$$

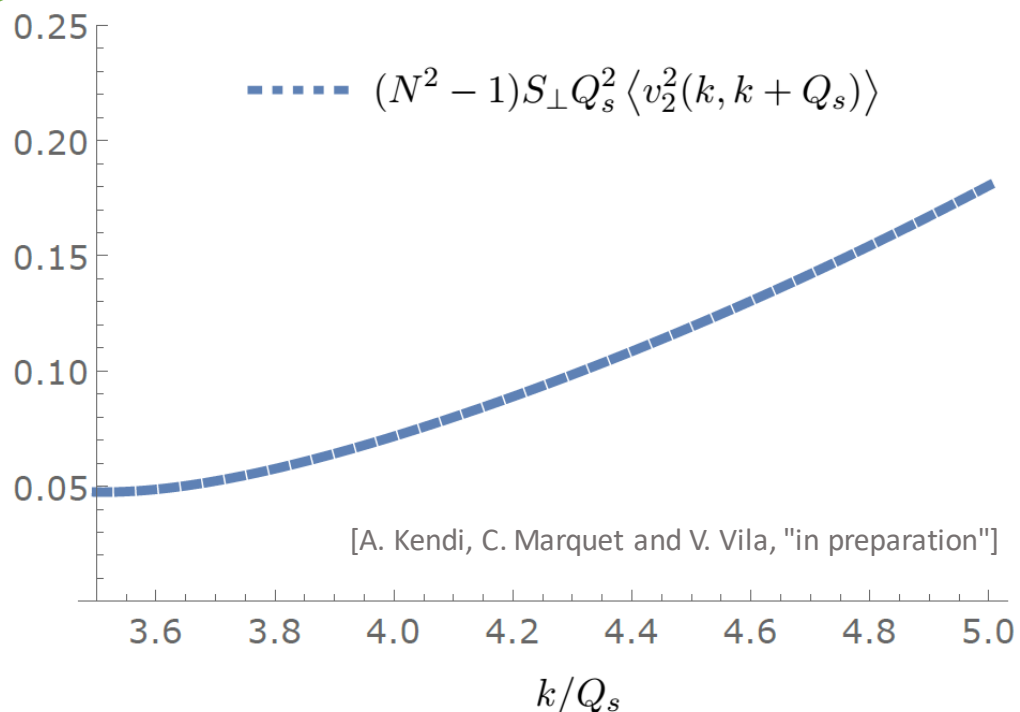
$$\sigma^{2[(iii)+(iv)]} = \alpha_s^2 (4\pi)^2 N^3 \mu^2 S_\perp \left\{ \frac{1}{(2\pi)^2 Q_s^4} e^{-\frac{k^2+p^2}{2Q_s^2}} \int_{s_1, s_2} \left[\left(\frac{s_1^i}{s_1^2} + \frac{k^i}{k^2} \right)^2 \left(\frac{s_2^j}{s_2^2} + \frac{p^j}{p^2} \right) - \frac{1}{k^2} \frac{p^j}{p^2} \right] \right. \\ \left. \times e^{-\frac{s_1^2 + 2k \cdot s_1}{2Q_s^2}} e^{-\frac{s_2^2 - 2p \cdot s_2}{2Q_s^2}} \right. \\ \left. + \frac{1}{k^2} \frac{p \cdot (k+p)}{p^2 (k+p)^2} \left(e^{-\frac{(k+p)^2}{4Q_s^2}} - 1 \right) \right\}$$



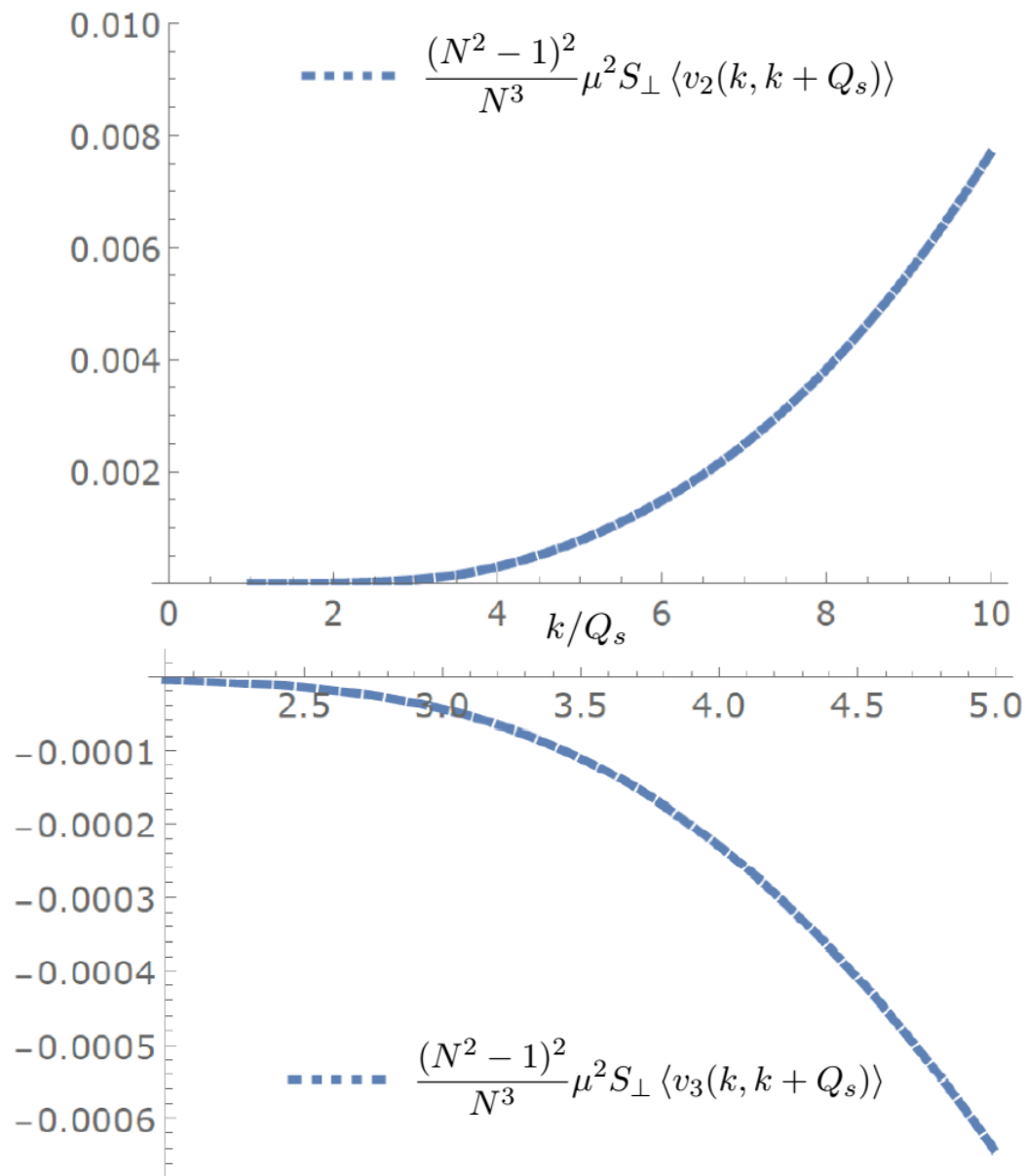
[A. Kendi, C. Marquet and V. Vila, "in preparation"]

$$v_n^2(k, p) = \frac{\int d\phi_k d\phi_p e^{in(\phi_k - \phi_p)} \frac{d^2 N^{(2)}}{d^2 k d^2 p}}{\int d\phi_k d\phi_p \frac{d^2 N^{(2)}}{d^2 k d^2 p}}$$

$$\begin{aligned} \sigma^{4([i+iii].1)} &\approx \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp \frac{2\pi}{Q_s^2} e^{-\frac{(k+p)^2}{4Q_s^2}} \\ &\times \left[\frac{2(k^4 + p^4 + 2(k \cdot p)^2)}{k^2 p^2 (k-p)^4} + \frac{8Q_s^2 (k+p)^4}{k^2 p^2 (k-p)^6} \right. \\ &\left. + \frac{64Q_s^4 (k^4 + 4(k \cdot p)^2 + p^4 + 8(k \cdot p)(k^2 + p^2) + 14k^2 p^2)}{k^2 p^2 (k-p)^8} \right] \\ &+ \{(p \rightarrow -p)\} \end{aligned}$$



- BOSE CORRELATIONS REGIME: VERY WEAKLY DEPENDENCE ON THE MOMENTUM
- SLOW INCREASE TOWARDS LARGE MOMENTA
- BOSE CORRELATED PART SCALES WITH THE SAME POWER OF MOMENTUM AS UNCORRELATED PIECE



$$\sigma^{2[(iii)+(iv)]} = \alpha_s^2 (4\pi)^2 N^3 \mu^2 S_{\perp} \left\{ \frac{1}{(2\pi)^2 Q_s^4} e^{-\frac{k^2+p^2}{2Q_s^2}} \int_{s_1, s_2} \left[\left(\frac{s_1^i}{s_1^2} + \frac{k^i}{k^2} \right)^2 \left(\frac{s_2^j}{s_2^2} + \frac{p^j}{p^2} \right) - \frac{1}{k^2} \frac{p^j}{p^2} \right] \right.$$

$$\times e^{-\frac{s_1^2+2k \cdot s_1}{2Q_s^2}} e^{-\frac{s_2^2-2p \cdot s_2}{2Q_s^2}}$$

$$\left. - \frac{1}{k^2} \frac{p \cdot (k+p)}{p^2 (k+p)^2} \left(e^{-\frac{(k+p)^2}{4Q_s^2}} - 1 \right) \right\}$$

- THE STUDIED PIECE REVEALS BOTH EVEN AND ODD HARMONICS
- SAME PATTERN AS THE BOSE CORRELATED PIECE FOR v_2
- ODD HARMONICS SURFACING FROM THIS SMALL CONTRIBUTION
- TO BE COMPLETED WITH THE REMAINING PIECES (WORK IN PROGRESS)

[A. Kendi, C. Marquet and V. Vila, "in preparation"]

- ➔ We calculate the **double inclusive gluon production cross-section** within the approach of the **dense-dilute CGC** via going beyond the Glasma Graph approximation.
- ➔ We **retrieve** the contribution that is responsible for **independent production of two gluons** as well as the **single inclusive spectrum**.
- ➔ **As a novelty, we provide the quantum correction accounting for the two gluons being correlated in the incoming wave function.**
- ➔ The **numerical evaluation** of the **Bose type contribution** for the **two-gluons independent production configuration** confirms the already studied **behaviour** of v_2 .
- ➔ **One of the pieces of the quantum correction σ^2 reveals the presence of both even and odd azimuthal harmonics [full numerical evaluation still in progress].**

THANK YOU VERY MUCH FOR YOUR ATTENTION!

$$\begin{aligned}
 Q_1 = & \alpha_s^2 (4\pi)^2 (N_c^2 - 1) \mu^4 S_\perp \frac{1}{\pi Q_s^2} e^{-(k_2 - k_3)^2 / 2Q_s^2} \left\{ \left[\frac{1}{2} + \frac{2^2 Q_s^2}{(k_2 + k_3)^2} + \frac{2^4 Q_s^4}{(k_2 + k_3)^4} \right] \frac{1}{k_2^2 k_3^2} \frac{(k_2 - k_3)^4}{(k_2 + k_3)^4} \right. \\
 & \left. + Q_s^4 \frac{2^6}{(k_2 + k_3)^8} \left[1 + (k_2^i - k_3^i) \left(\frac{k_2^i}{k_2^2} - \frac{k_3^i}{k_3^2} \right) \right] \right\} + (k_3 \rightarrow -k_3)
 \end{aligned}$$

T. Altinoluk, N. Armesto, A. Kovner and M. Lublinsky, "Double and triple inclusive gluon production at mid rapidity: quantum interference in p-A scattering", Eur.Phys.J. C78 (2018) 9, 702 [arXiv:1805.07739 [hep-ph]].

$$\begin{aligned}
 \sigma^{4([i+iii].1)} \approx & \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp \frac{(2\pi)^2}{2\pi Q_s^2} e^{-\frac{(k+p)^2}{2 \cdot 2Q_s^2}} \\
 & \times \left[\frac{2 \left(k^4 + p^4 + 2(k \cdot p)^2 \right)}{k^2 p^2 (k - p)^4} + \frac{2 \cdot 4Q_s^2 (k + p)^4}{k^2 p^2 (k - p)^6} \right. \\
 & \left. + \frac{4 \cdot 16Q_s^4 (k^4 + 4(k \cdot p)^2 + p^4 + 8(k \cdot p)(k^2 + p^2) + 14k^2 p^2)}{k^2 p^2 (k - p)^8} \right] \\
 & + \{(p \rightarrow -p)\}
 \end{aligned}$$

[A. Kendi, C. Marquet and V. Vila, "in preparation"]

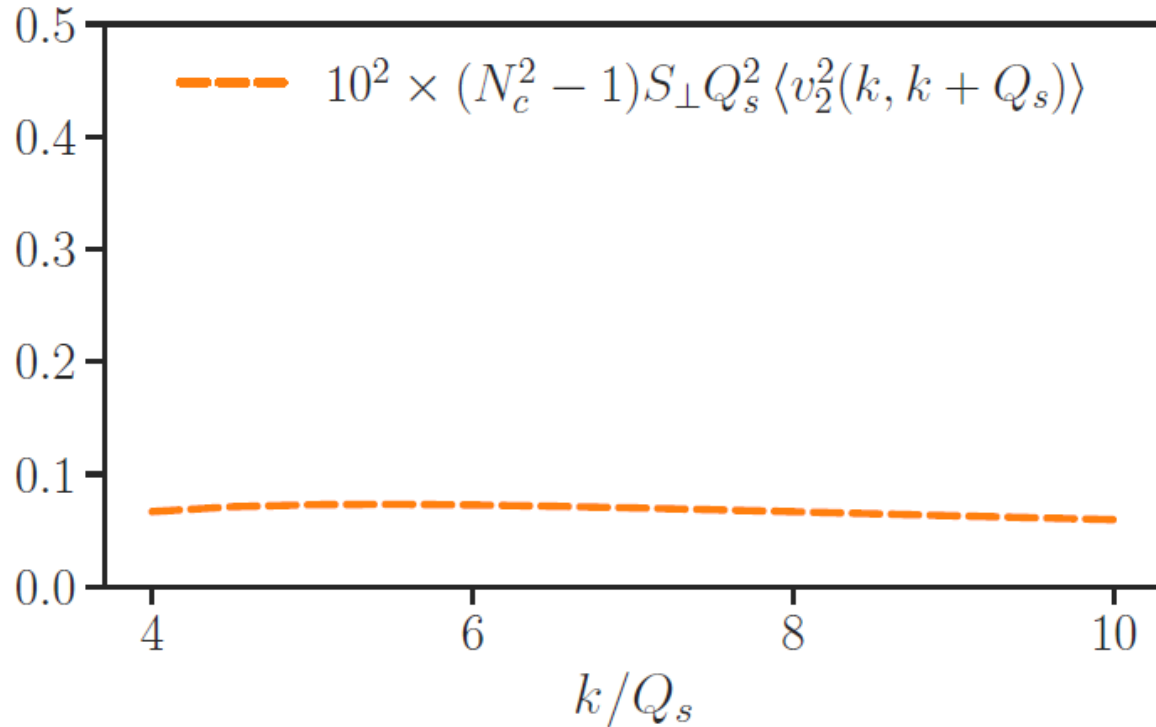
$$Q_2 = \alpha_s^2 (4\pi)^2 (N_c^2 - 1) \mu^4 S_\perp (2\pi)^2 \left[\delta^{(2)}(k_2 + k_3) + \delta^{(2)}(k_2 - k_3) \right] \frac{1}{2} \frac{Q_s^4}{k_2^8}$$

T. Altinoluk, N. Armesto, A. Kovner and M. Lublinsky, "Double and triple inclusive gluon production at mid rapidity: quantum interference in p-A scattering", Eur.Phys.J. C78 (2018) 9, 702 [arXiv:1805.07739 [hep-ph]].

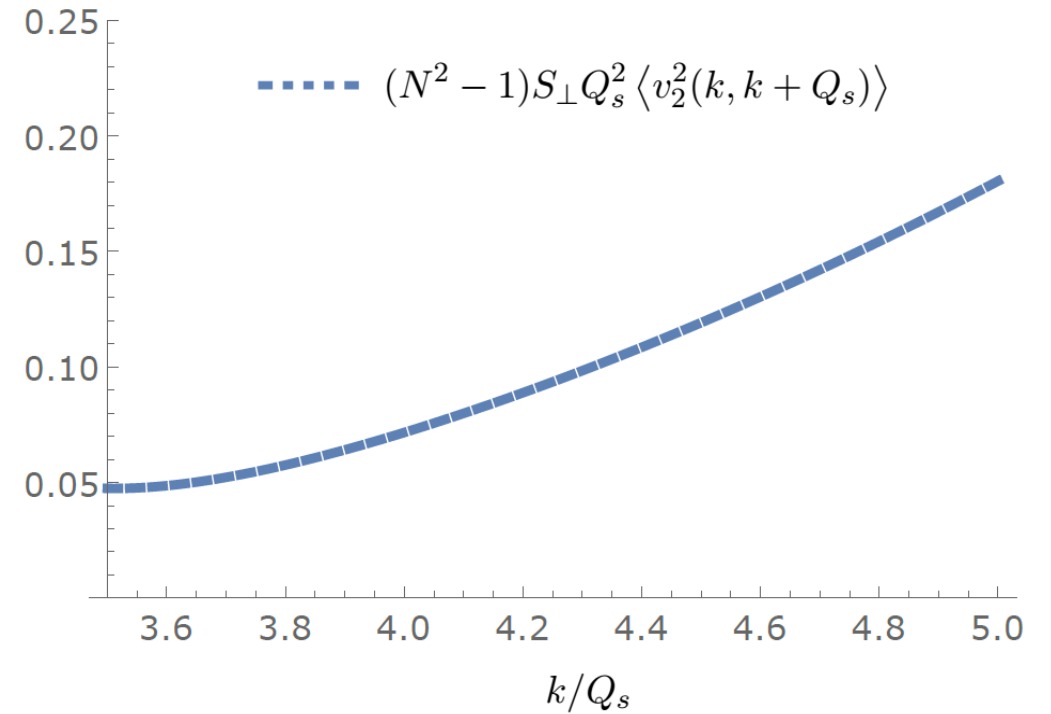
$$\sigma^{4([i+iii].11)} \approx \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp (2\pi)^2 \left[\delta^{(2)}(k + p) + \delta^{(2)}(k - p) \right] \\ \times \frac{4}{k^{12}} e^{-\frac{k^2}{Q_s^2}} \left(k^4 + k^2 e^{\frac{k^2}{2Q_s^2}} Q_s^2 + 4e^{\frac{k^2}{2Q_s^2}} Q_s^4 \right)^2$$

[A. Kendi, C. Marquet and V. Vila, "in preparation"]

$$\sigma^{4([i+iii].11)} \approx \alpha_s^2 (4\pi)^2 (N^2 - 1) \mu^4 S_\perp (2\pi)^2 \left[\delta^{(2)}(k + p) + \delta^{(2)}(k - p) \right] \frac{2}{2} \frac{4Q_s^4}{k^8}$$



T. Altinoluk, N. Armesto, A. Kovner and M. Lublinsky, "Double and triple inclusive gluon production at mid rapidity: quantum interference in p-A scattering", Eur.Phys.J. C78 (2018) 9, 702 [arXiv:1805.07739 [hep-ph]].



[A. Kendi, C. Marquet and V. Vila, "in preparation"]