Probing multi-gluon correlations in pp collisions

Yuji Koike

Department of Physics, Niigata University, Ikarashi, Niigata 950-2181, Japan

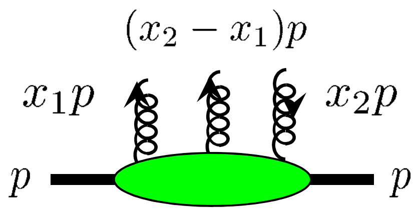
Abstract:

· We derived the contribution of the 3-gluon correlation functions to the polarized cross section for $p^{\uparrow}p \to DX$, $p^{\uparrow}p \to \gamma X$ and $p^{\uparrow}p \to \ell^{+}\ell^{-}X$.
· There are two independent twist-3 three-gluon correlation functions in the polarized nucleon due to the different color contractions; $O(x_1, x_2)$ and $N(x_1, x_2)$.
· SSA occurs as a pole contribution which is written in terms of four independent functions $O(x, x)$, $N(x, x)$, $O(x, 0)$ and $N(x, 0)$.

- Numerical calculation for $p^{\uparrow}p \to DX$ and $p^{\uparrow}p \to \gamma X$.

· Rising behavior of A_N for $p^{\uparrow}p \to DX$ at $x_F > 0$ as in the case of the SGP contribution from the quark-gluon correlation function for $p^{\uparrow}p \to \pi X$.
· For $p^{\uparrow}p \to \gamma X$, $A_N \simeq 0$ at $x_F > 0$ regardless of the magnitude of the 3-gluon correlation functions.
· A_N at $x_F < 0$ is sensitive to small-x behavior of 3-gluon correlation function for the two processes.
⋆ Two processes are useful to get costraint on magnitude and shape of 3-gluon correlation functions.

$\star$ Twist-3 "three-gluon" correlation functions



cf. Beppu-Koike-Tanaka-Yoshida (PRD 82('10)054005)

See also, Belitsky-Ji-Lu-Osborne, PRD63,094012(2001)
Braun-Manashov-Pirnay, PRD80,114002(2009).

- Hermiticity, PT-invariance, Permutation symmetry

$$O^{\alpha\beta\gamma}(x_1,x_2) = -gi^3 \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} e^{i\lambda x_1} e^{i\mu(x_2-x_1)} \langle pS| d^{bca} F_b^{\beta n}(0) F_c^{\gamma n}(\mu n) F_a^{\alpha n}(\lambda n)|pS\rangle$$

$$= 2iM_N \left[O(x_1,x_2) g^{\alpha\beta} \epsilon^{\gamma pnS} + O(x_2, x_2 - x_1) g^{\beta\gamma} \epsilon^{\alpha pnS} + O(x_1, x_1 - x_2) g^{\gamma\alpha} \epsilon^{\beta pnS} \right]$$

$$N^{\alpha\beta\gamma}(x_1,x_2) = -gi^3 \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} e^{i\lambda x_1} e^{i\mu(x_2-x_1)} \langle pS| if^{bca} F_b^{\beta n}(0) F_c^{\gamma n}(\mu n) F_a^{\alpha n}(\lambda n)|pS\rangle$$

$$= 2iM_N \left[N(x_1,x_2) g^{\alpha\beta} \epsilon^{\gamma pnS} - N(x_2, x_2 - x_1) g^{\beta\gamma} \epsilon^{\alpha pnS} - N(x_1, x_1 - x_2) g^{\gamma\alpha} \epsilon^{\beta pnS} \right].$$

$F_a^{\alpha n} \equiv F_a^{\alpha\mu} n_\mu$ $\qquad$ n: lightlike vector satisfying $p \cdot n = 1$.

$\epsilon^{\gamma pnS} \equiv \epsilon^{\gamma\mu\nu\lambda} p_\mu n_\nu S_\lambda$ etc.

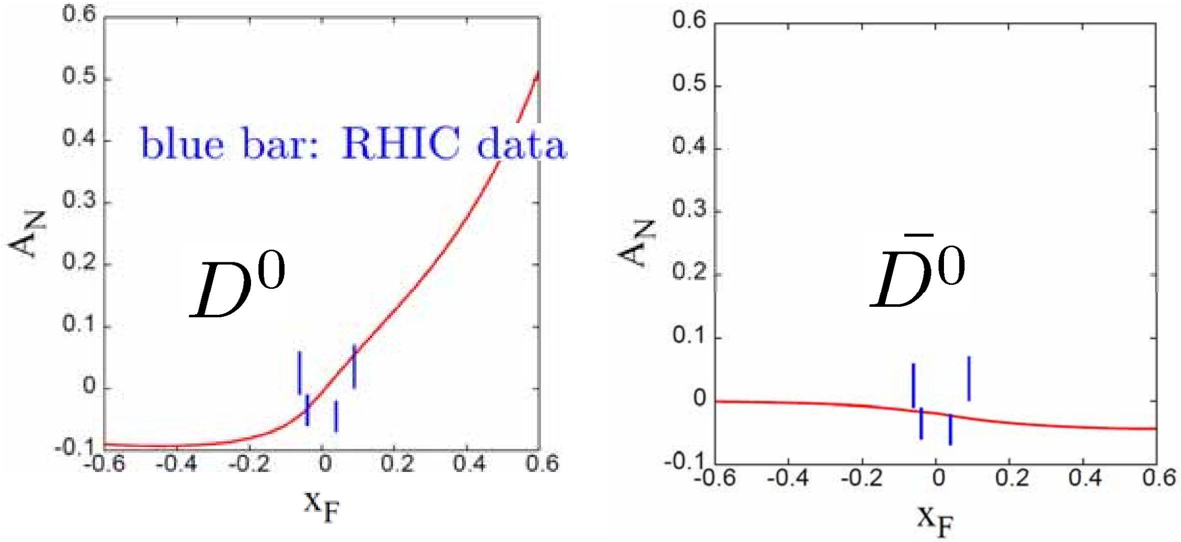
- Only two independent scalar functions due to the different color structures:

$$O(x_1,x_2) = O(x_2,x_1), \qquad O(x_1,x_2) = O(-x_1,-x_2),$$

$$N(x_1,x_2) = N(x_2,x_1), \qquad N(x_1,x_2) = -N(-x_1,-x_2).$$

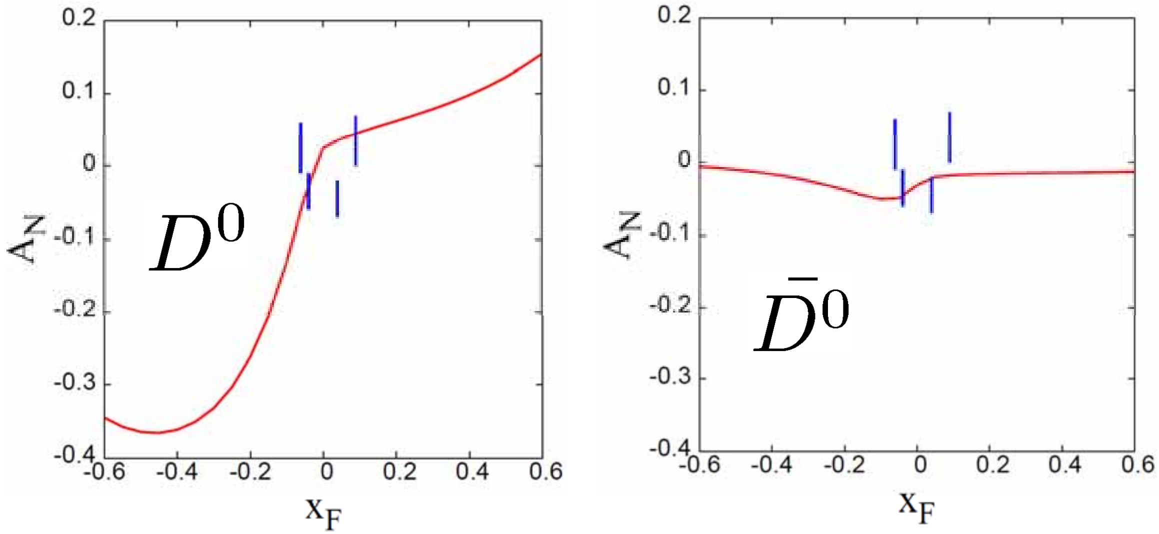
Model 1:
$O(x,x) = 0.002xG(x)$

@ $\sqrt{S} = 200$ GeV, $P_T = 2$ GeV



· Change of relative signs between $\{O(x,x), O(x,0)\}$ and $\{N(x,x), N(x,0)\}$ gives opposite prediction for D and $\bar{D}$ mesons.

Model 2:
$O(x,x) = \frac{1}{4} \times 0.002\sqrt{x}G(x)$



· A_N at $x_F < 0$ strongly depends on the small-x behavior of 3-gluon correlation function.

$\star$ Three-gluon contribution to the direct photon production: $p^{\uparrow}(p)+p(p) \to \gamma(q)+X$.

(YK, S.Yoshida, in preparation)

$$
\begin{aligned}
E_\gamma \frac{d\sigma}{d^3q} \quad = \quad & \frac{4\alpha_{em}\alpha_s M_N \pi}{S} \sum_a \int \frac{dx'}{x'} f_a(x') \int \frac{dx}{x} \delta(\hat{s}+\hat{t}+\hat{u}) \epsilon^{qpnS_\perp} \frac{1}{\hat{u}} \\
& \times \left[\delta_a \left(\frac{d}{dx} O(x,x) - \frac{2O(x,x)}{x} + \frac{d}{dx} O(x,0) - \frac{2O(x,0)}{x} \right) \right. \\
& \quad \left. - \frac{d}{dx} N(x,x) + \frac{2N(x,x)}{x} + \frac{d}{dx} N(x,0) - \frac{2N(x,0)}{x} \right] \left(\frac{1}{N} \left(\frac{\hat{s}}{\hat{u}} + \frac{\hat{u}}{\hat{s}} \right) \right)
\end{aligned}
$$

$\uparrow$

$\delta_a = 1$ for a =quark, $\delta_a = -1$ for a =anti-quark.

$\hat{s} = (xp + x'p')^2$, $\hat{t} = (xp - q)^2$, $\hat{u} = (x'p' - q)^2$

The same as twist-2 cross section
(also from master formula!)

· This differs form the previous study (X. Ji, Phys.lett.B289 ('92)137).

· Contribute in the combination of $O(x,x) + O(x,0)$ and $N(x,x) - N(x,0)$ as in $m_c \to 0$ for $p^{\uparrow}p \to DX$.

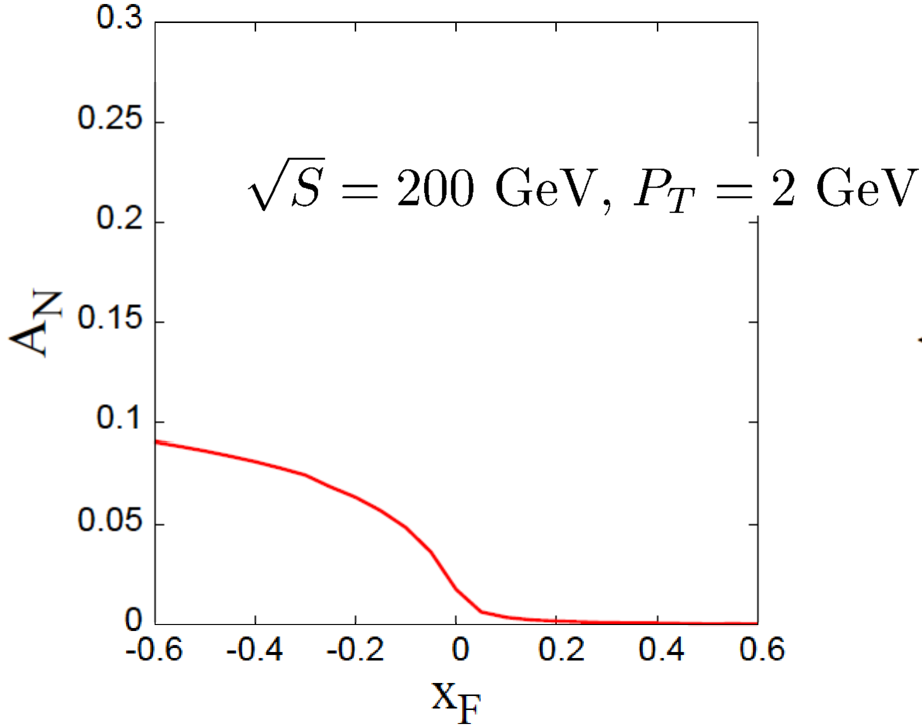
· $O(x,x) + O(x,0) = -(N(x,x) - N(x,0)) \to$ quarks in the unpolarized nucleon are active. $\to$ Large A_N^γ.

· $O(x,x) + O(x,0) = N(x,x) - N(x,0) \to$ quarks in the unpolarized nucleon are NOT active. $\to$ Small A_N^γ.

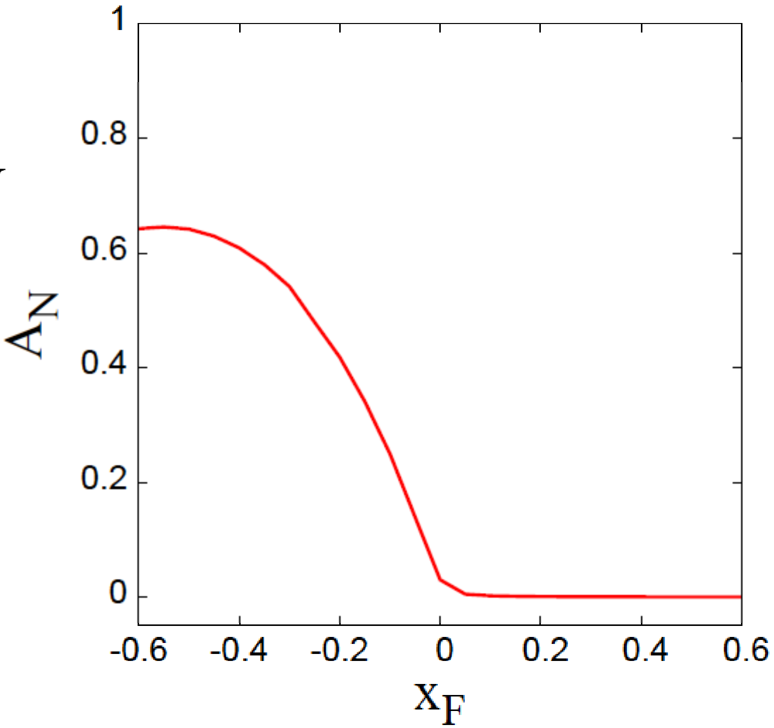
Change sign for N as $N(x,x) \to -N(x,x)$ and $N(x,0) \to -N(x,0)$.

$\to$ Quark contribution from the unpolarized nucleon is active, while anti-quark contribution is cancelled.

Model 1': $O(x,x) = 0.002 \times xG(x)$
$O(x,x) = O(x,0) = -N(x,x) = N(x,0)$



Model 2': $O(x,x) = 0.0005\sqrt{x}G(x)$
$O(x,x) = O(x,0) = -N(x,x) = N(x,0)$



· $A_N \sim 0$ at $x_F > 0$ regardless of magnitude of the 3-gluon correlation functions.

· Behavior at $x_F < 0$ is sensitive to small x behavior similarly to $pp \to DX$.

$\star$ Three-gluon contribution to $p^{\uparrow}p \to \gamma^* X$. (YK, S.Yoshida, in preparation)

$$\frac{d\sigma}{dQ^2 dy d^2 q_\perp} = \frac{2\pi M_N \alpha_{em}^2 \alpha_s}{3\pi S Q^2} \int \frac{dx}{x} \int \frac{dx'}{x'} \delta(\hat{s}+\hat{t}+\hat{u}-Q^2) \epsilon^{qpnS_\perp} \frac{1}{\hat{u}} \sum_a e_a^2 f_a(x')$$

$$\times \Big[\delta_a \Big(\frac{d}{dx} O(x,x) - \frac{2O(x,x)}{x} \Big) \hat{\sigma}_1 + \Big(\frac{d}{dx} O(x,0) - \frac{2O(x,0)}{x} \Big) \hat{\sigma}_2 + \frac{O(x,x)}{x} \hat{\sigma}_3 + \frac{O(x,0)}{x} \hat{\sigma}_4$$

$$- \Big(\frac{d}{dx} N(x,x) - \frac{2N(x,x)}{x} \Big) \hat{\sigma}_1 + \Big(\frac{d}{dx} N(x,0) - \frac{2N(x,0)}{x} \Big) \hat{\sigma}_2 - \frac{N(x,x)}{x} \hat{\sigma}_3 + \frac{N(x,0)}{x} \hat{\sigma}_4 \Big]$$

$$\hat{\sigma}_1 = \frac{2}{N} \left(\frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}} + \frac{2Q^2 \hat{t}}{\hat{s}\hat{u}} \right) \qquad \hat{\sigma}_3 = -\frac{1}{N} \frac{4Q^2(Q^2+\hat{t})}{\hat{s}\hat{u}}$$

$$\hat{\sigma}_2 = \frac{2}{N} \left(\frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}} + \frac{4Q^2 \hat{t}}{\hat{s}\hat{u}} \right) \qquad \hat{\sigma}_4 = -\frac{1}{N} \frac{4Q^2(3Q^2+\hat{t})}{\hat{s}\hat{u}}$$

· At $Q^2 \neq 0$, hard cross sections for $\{O(x,x), N(x,x)\}$ differ from those for $\{O(x,0), N(x,0)\}$ as in $ep^{\uparrow} \to eDX$.

· As $Q^2 \to 0$, this agrees with the result for the direct-photon production.

· Sum of the above result and that from the quark-gluon correlation functions gives the complete twist-3 cross section for Drell-Yan and direct-photon processes.

For q-g correlations, see
SGP: Ji-Qiu-Vogelsang-Yuan, PRD73('06), YK-Tanaka,PLB646('07)
Hard pole+SFP: Kanazawa-YK,arXiv:1105.1036 [hep-ph]