Impact of the triple-gluon correlation functions on the single spin asymmetries in pp collisions

Shinsuke Yoshida (Niigata Univ)

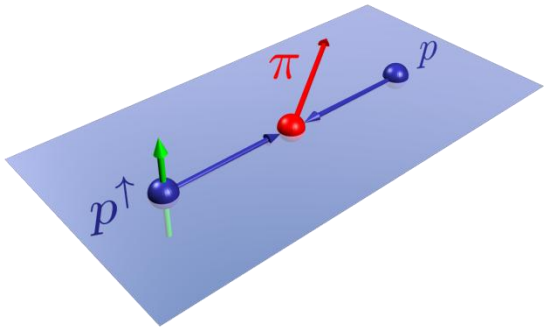
based on work with Yuji Koike

Large single spin asymmetry

single spin asymmetry(SSA)

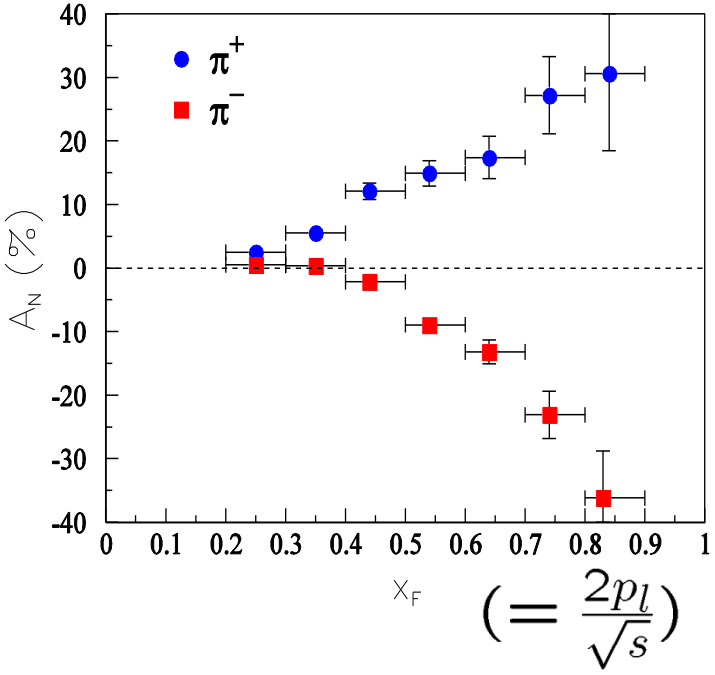
$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

"single spin" means only one particle is polarized.



FNAL-E704($p^{\uparrow}p \to \pi X$) P.L.B264('91) 462
P.L.B261('91) 201

$\sqrt{s} = 20$ GeV



Conventional twist-2

$$A_N \sim \alpha_s(\frac{m_q}{\sqrt{s}}) \sim 0 \text{ (Kane } et\ al. \text{ ('78))}$$

What is origin of SSA !!

Factorization formalism beyond conventional twist-2

Two formalisms exist
- TMD(Tranverse Momentum Dependent) factorization
- collinear factorization

frameworks	TMD factorization "T-odd" functions (Sivers, Collins etc)	Collinear factorization Twist-3 (Qiu-Sterman, Eguchi-Koike-Tanaka,,,)
$q_\perp$	$Q \gg q_\perp \geq \Lambda_{\rm QCD}$ NP, intrinsic-$k_\perp$	$q_\perp \sim Q \gg \Lambda_{\rm QCD}$ P, hard scattering
complex phase	NP	P
helicity-flip	NP	NP

Purpose of this talk

We study the effect of multi-gluon correlations inside the transeversely polarized proton.

This is represented by 3-gluon correlation functions.

$pp^\uparrow \to DX$

- Heavy quark production is sensitive to gluons inside the proton.
- The mesurement of A_N for this process is ongoing at RHIC.
- We will extract magnitude of the 3-gluon correlation functions from the preliminary data.

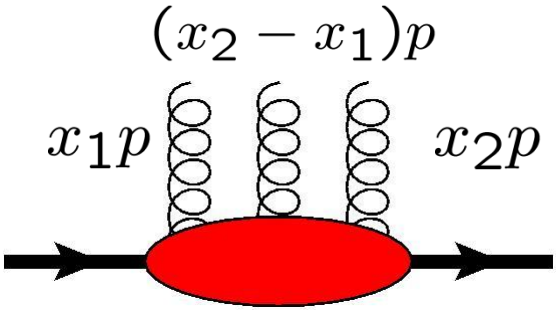
$pp^\uparrow \to \gamma X$

- Cross section formula was derived by Ji. We will reexamine this with our framework (developed for $ep^\uparrow \to eDX$).

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

- We present numerical estimate based on the study of $pp^\uparrow \to DX$.

Triple-gluon correlation functions for $p^\uparrow$



cf. Beppu-Koike-Tanaka-Yoshida (PRD 82('10)054005) and the talk by K. Tanaka.

$$\left\{ \begin{array}{c} O^{\alpha\beta\gamma} \\ N^{\alpha\beta\gamma} \end{array} \right\} = \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} e^{i\lambda x_1} e^{i\mu(x_2-x_1)} \langle PS_\perp | \left\{ \begin{array}{c} d_{bca} \\ if_{bca} \end{array} \right\} (-i) F_b^{\beta n}(0) i F_c^{\gamma n}(\mu n) i F_a^{\alpha n}(\lambda n) | PS_\perp \rangle$$

$$= 2iM_N [g_\perp^{\alpha\beta} \epsilon^{\gamma pnS} \left\{ \begin{array}{c} O(x_1, x_2) \\ N(x_1, x_2) \end{array} \right\} + g_\perp^{\beta\gamma} \epsilon^{\alpha pnS} \left\{ \begin{array}{c} O(x_2, x_2 - x_1) \\ N(x_2, x_2 - x_1) \end{array} \right\} + g_\perp^{\gamma\alpha} \epsilon^{\beta pnS} \left\{ \begin{array}{c} O(x_1, x_1 - x_2) \\ N(x_1, x_1 - x_2) \end{array} \right\}$$

Two independent correlation functions

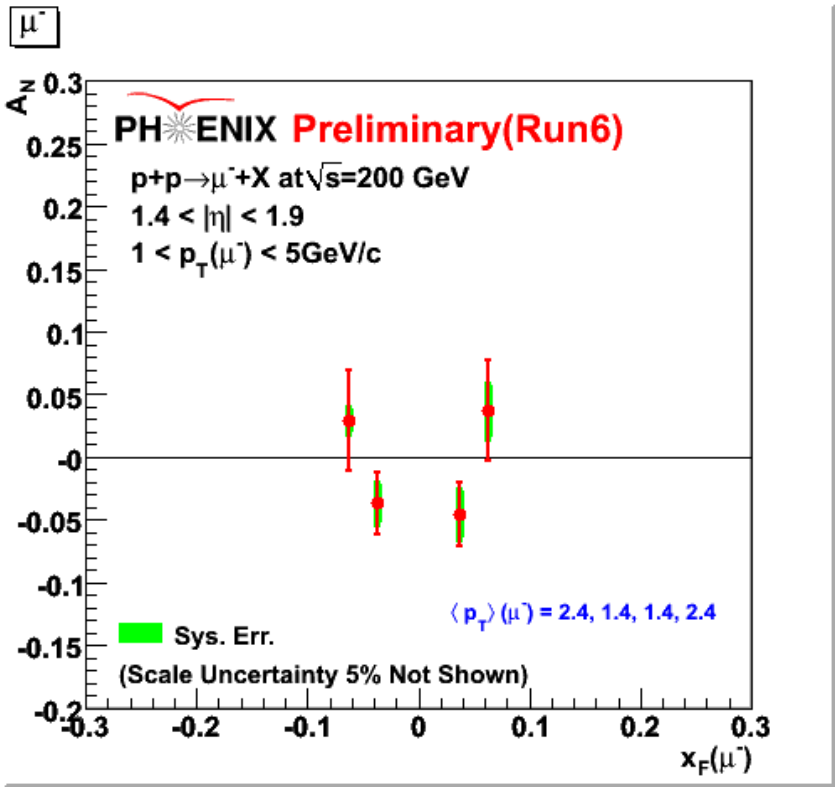
All three terms with the above coefficient tensors are required because of the Bose statistics of gluon and PT-invariance.

D-meson production

$$pp^{\uparrow} \to DX$$

Experimental data

preliminaty data

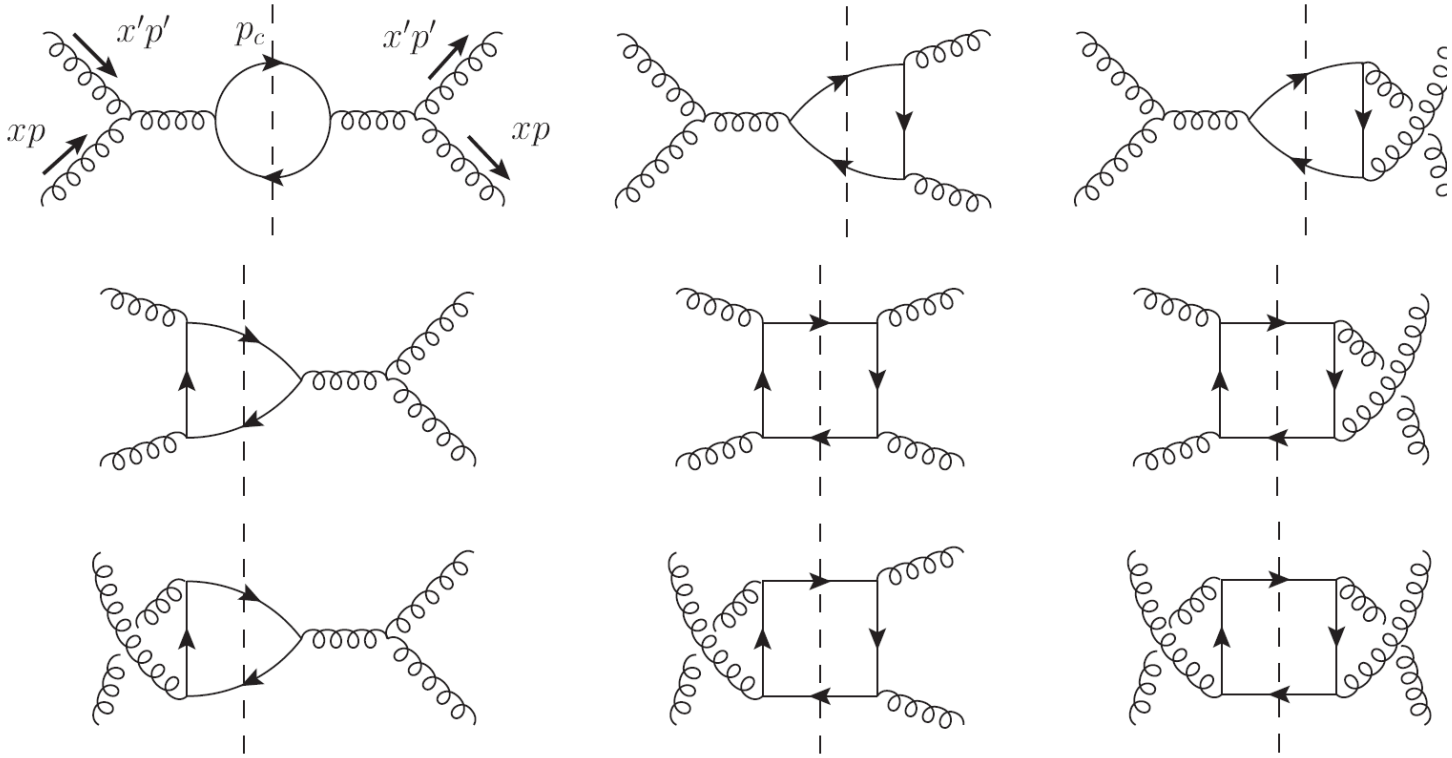


This suggests $-0.1 \leq A_N \leq 0.1$ in the range of $-0.1 \leq x_F \leq 0.1$

We derive cross section formula and present a simple model estimate.

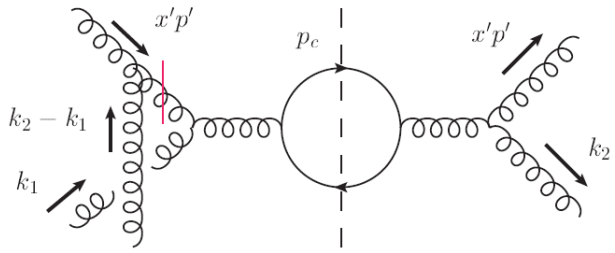
Leading order diagrams

Twist-2(unpolarized cross section)

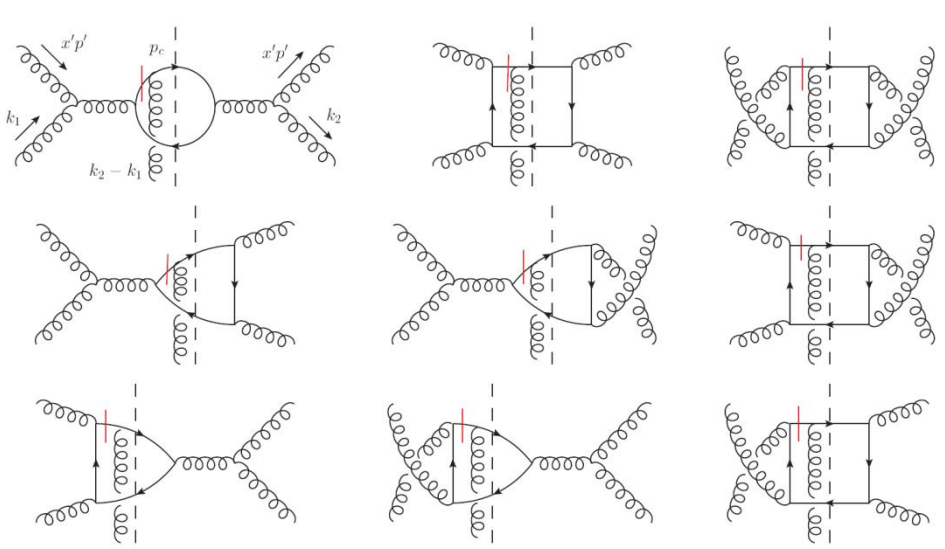


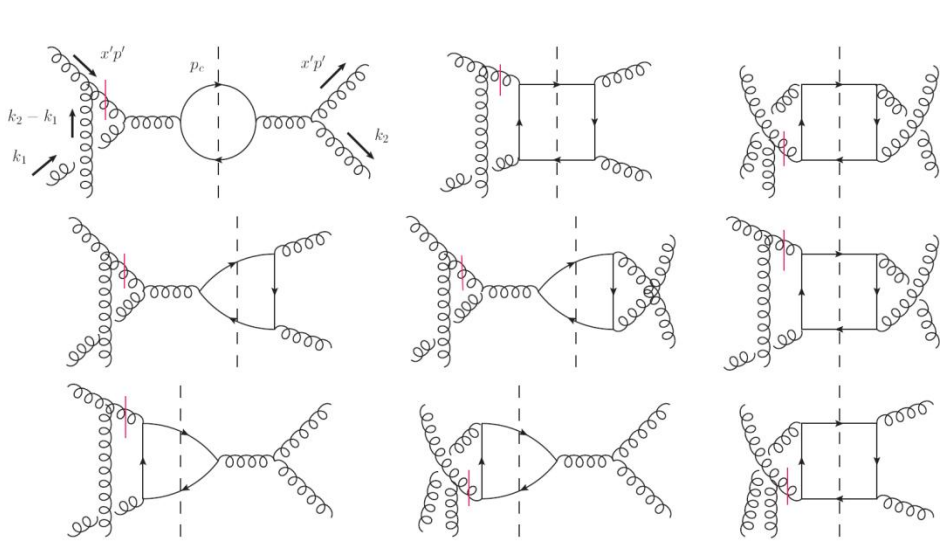
Twist-3(polarized cross section)

To produce nonzero A_N, the partonic hard part give a complex phase as pole of internal propagator.



$$\frac{1}{(k_2-k_1+x'p')^2+i\epsilon} = P\frac{1}{(k_2-k_1+x'p')^2} - i\pi\delta((k_2-k_1+x'p')^2)$$





Final state interaction + mirrors Initial state interaction

These diagrams give pole contribution at $x_1 = x_2$

Factorization formula for polarized cross section

cf. for $ep^{\uparrow} \to eDX$ (Beppu-Koike-Tanaka-Yoshida (PRD 82('10)054005) and the talk by K. Tanaka.)

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h} = \frac{\alpha_s^2}{S}\sum_a \int \frac{dx'}{x'}G(x')\int \frac{dz}{z^2}D_a(z)\int \frac{dx_1}{x_1}\int \frac{dx_2}{x_2} \times \left.\frac{\partial S^{abc}_{\alpha\beta\lambda}(k_1,k_2,x'p',p_c)p^\lambda}{\partial k_2^\gamma}\right|_{k_i=x_i p} M^{\alpha\beta\gamma}_{F,abc}(x_1,x_2), \quad (\alpha,\ \beta,\ \gamma = \perp)$$

$$M^{\alpha\beta\gamma}_{F,abc}(x_1,x_2) = \frac{N d_{bca}}{(N^2-4)(N^2-1)}O^{\alpha\beta\gamma}(x_1,x_2) - \frac{i f_{bca}}{N(N^2-1)}N^{\alpha\beta\gamma}(x_1,x_2)$$

$$\begin{Bmatrix} O^{\alpha\beta\gamma} \\ N^{\alpha\beta\gamma} \end{Bmatrix} = \int \frac{d\lambda}{2\pi}\int \frac{d\mu}{2\pi}e^{i\lambda x_1}e^{i\mu(x_2-x_1)}\langle PS_\perp|\begin{Bmatrix} d_{bca} \\ i f_{bca} \end{Bmatrix}(-i)F_b^{\beta n}(0)iF_c^{\gamma n}(\mu n)iF_a^{\alpha n}(\lambda n)|PS_\perp\rangle$$

$$= 2iM_N[g_\perp^{\alpha\beta}\epsilon^{\gamma pnS}\begin{Bmatrix} O(x_1,x_2) \\ N(x_1,x_2) \end{Bmatrix} + g_\perp^{\beta\gamma}\epsilon^{\alpha pnS}\begin{Bmatrix} O(x_2,x_2-x_1) \\ N(x_2,x_2-x_1) \end{Bmatrix} + g_\perp^{\gamma\alpha}\epsilon^{\beta pnS}\begin{Bmatrix} O(x_1,x_1-x_2) \\ N(x_1,x_1-x_2) \end{Bmatrix}$$

Cross section formula for $pp^{\uparrow} \to DX$

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h} = \frac{\alpha_s^2 M_N \pi}{S}\sum_a \int \frac{dx'}{x'}G(x')\int \frac{dz}{z^2}D_a(z)\int \frac{dx}{x}\delta(\tilde{s}+\tilde{t}+\tilde{u})\frac{\epsilon^{p_c p n S_\perp}}{\tilde{u}}$$

$$\times\Big[\delta_a\Big\{\Big(\frac{d}{dx}O(x,x)-\frac{2O(x,x)}{x}\Big)\hat{\sigma}^{O1}+\Big(\frac{d}{dx}O(x,0)-\frac{2O(x,0)}{x}\Big)\hat{\sigma}^{O2}+\frac{O(x,x)}{x}\hat{\sigma}^{O3}+\frac{O(x,0)}{x}\hat{\sigma}^{O4}\Big\}$$

$$+\Big\{\Big(\frac{d}{dx}N(x,x)-\frac{2N(x,x)}{x}\Big)\hat{\sigma}^{N1}+\Big(\frac{d}{dx}N(x,0)-\frac{2N(x,0)}{x}\Big)\hat{\sigma}^{N2}+\frac{N(x,x)}{x}\hat{\sigma}^{N3}+\frac{N(x,0)}{x}\hat{\sigma}^{N4}\Big\}\Big]$$

$\delta_c = 1,\ \delta_{\bar{c}} = -1$

Receives contribution from $O(x,x), O(x,0), N(x,x), N(x,0)$ as in the case of $ep^{\uparrow} \to eDX$

$\longleftrightarrow$ Kang-Qiu-Vogelsang-Yuan (PRD 78('08)114013)

Partonic hard cross sections for $\{O(x,x), N(x,x)\}$ differ from those for $\{O(x,0), N(x,0)\}$. we can not combine these functions.

We present a simple model estimate.

assumption

$$O(x,x) = O(x,0) = N(x,x) = -N(x,0) \qquad \text{maximize } A_N^D$$

We use the following two ansatz with constant K_G, K'_G in order to see the behavior of A_N

$$\begin{cases} O(x,x) = K_G \times xG(x) \\ O(x,x) = K'_G \times x^{\frac{1}{2}} G(x) \end{cases}$$

$G(x)$:unpolarized gluon distribution function

Gluck, Jimenez-Delgado, Reya Eur.phys.J.C53(2008)

We determine K_G, K'_G so that A_N is consistent with the preliminary data.

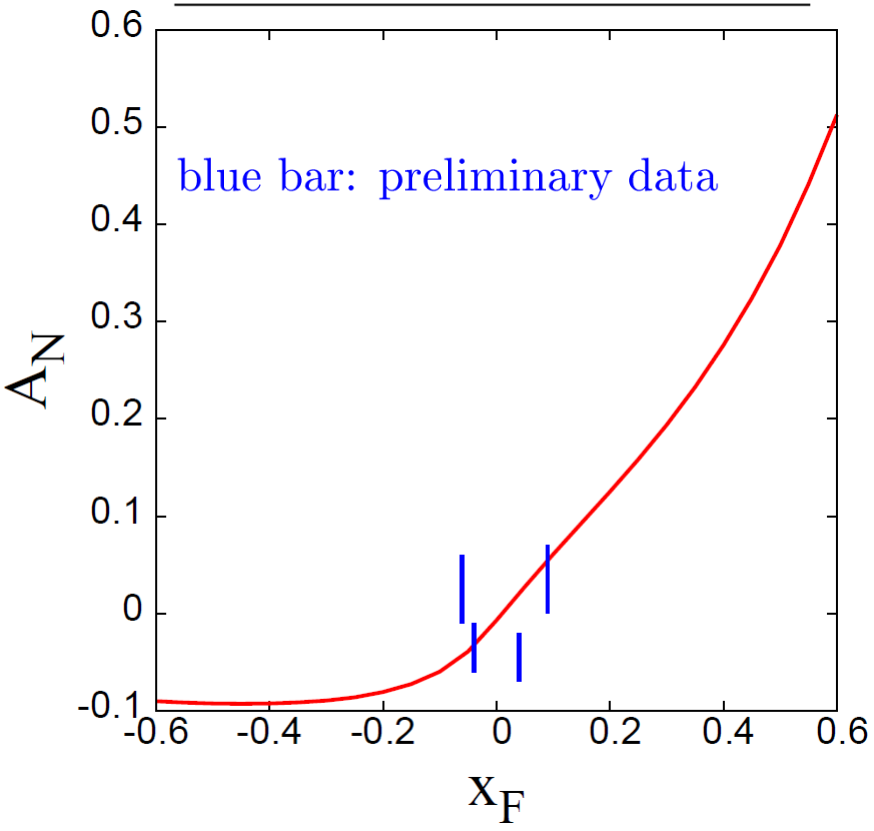
Numerical estimate

parameterization

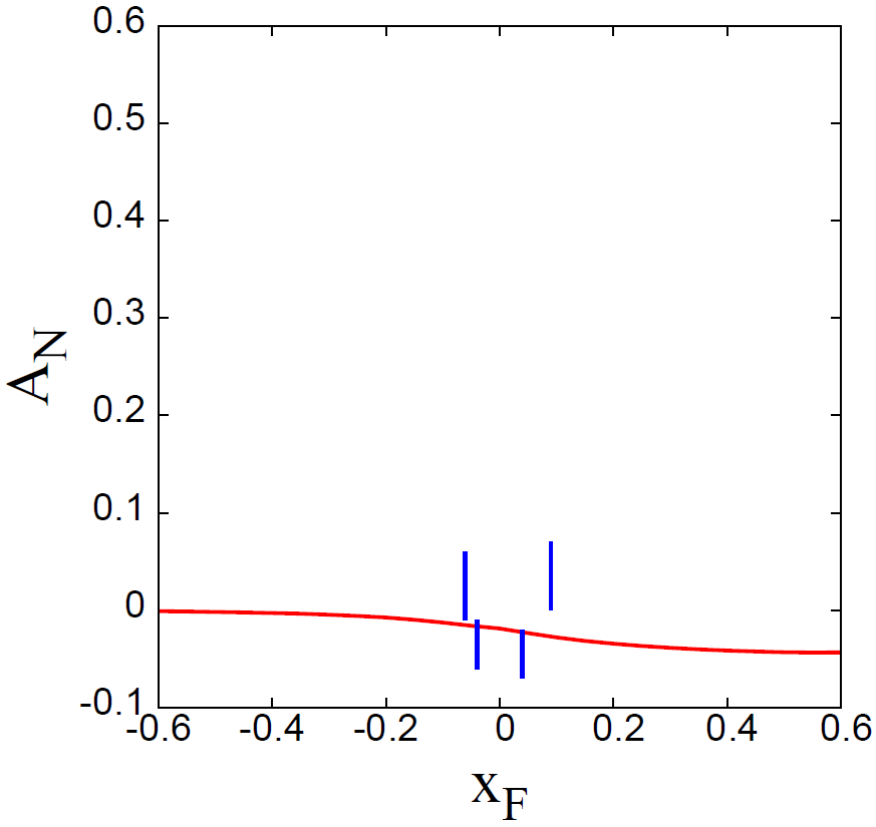
$$O(x,x) = 0.002 \times xG(x)$$

$$\sqrt{s} = 200GeV \quad P_T = 2GeV$$

D^0-meson production



$\bar{D}^0$-meson$(O(x,x) \to -O(x,x))$

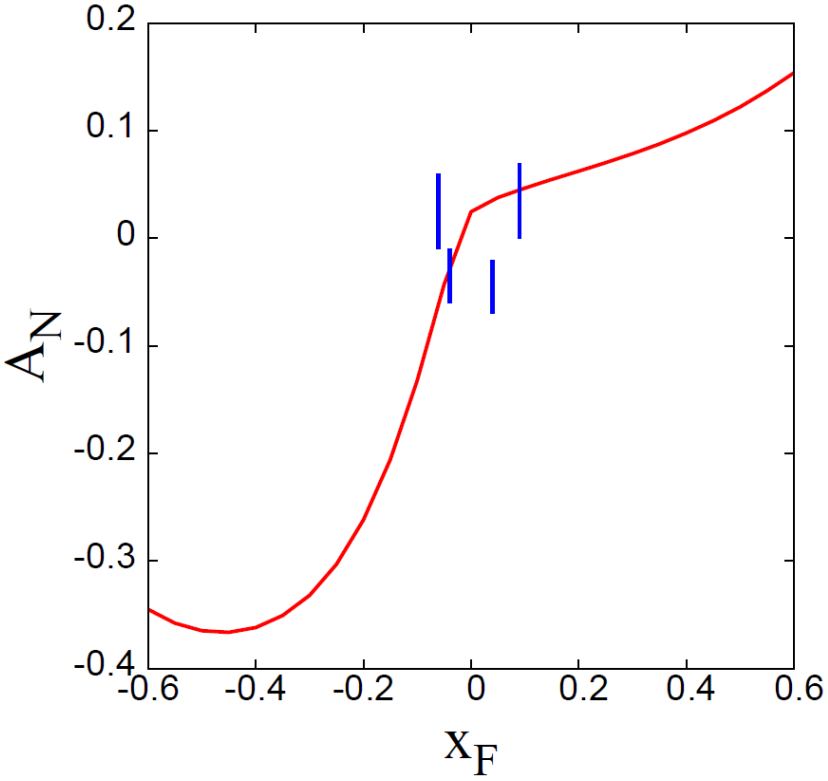


parameterization

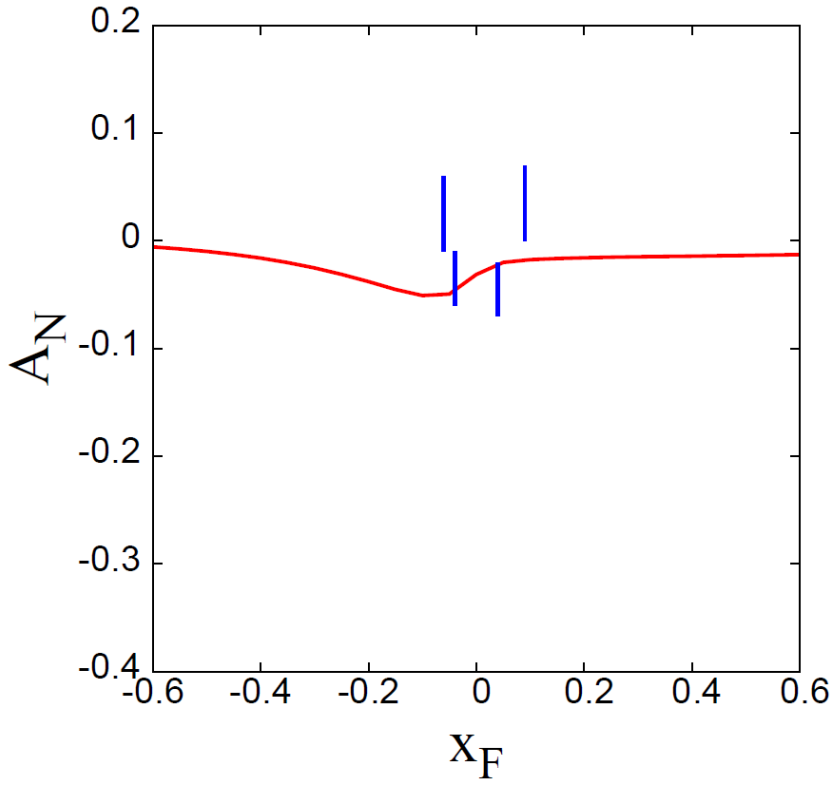
$$O(x,x) = \frac{1}{4} \times 0.002 \times x^{\frac{1}{2}} G(x)$$

$$\sqrt{s} = 200GeV \quad P_T = 2GeV$$

D^0-meson production



$\bar{D}^0$-meson$(O(x,x) \to -O(x,x))$



Behavior at negative x_F drastically changes.

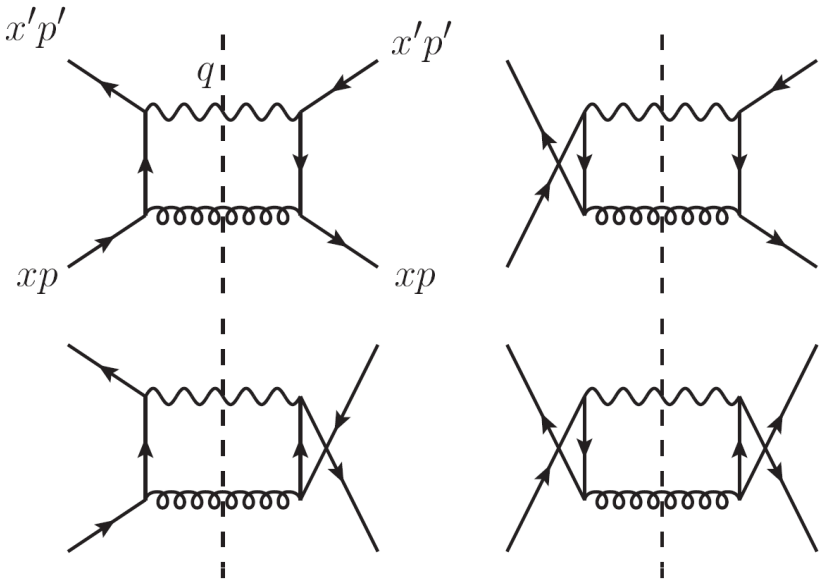
A_N at negative x_F strongly depends on small-x behavior of 3-gluon correlation function.

Direct photon production

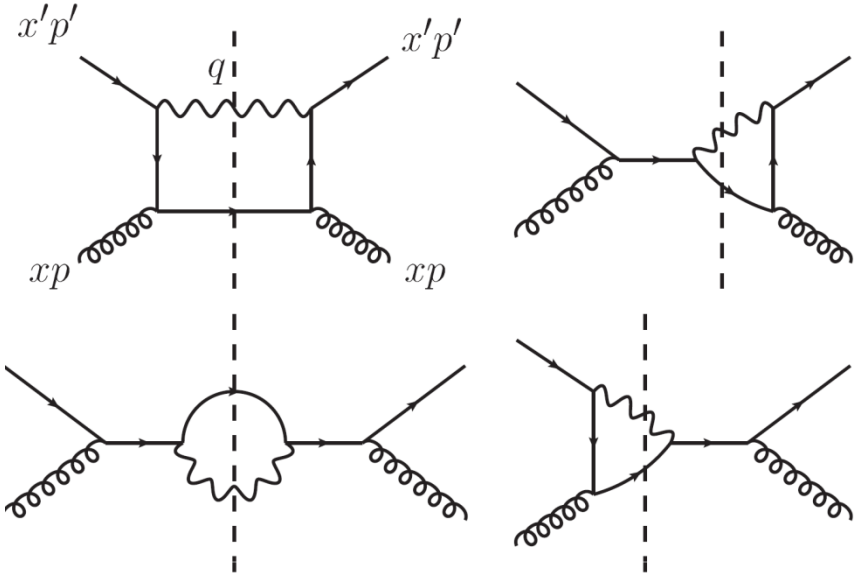
$$pp^{\uparrow} \to \gamma X$$

Leading order diagrams

Twist-2(unpolarized cross section)



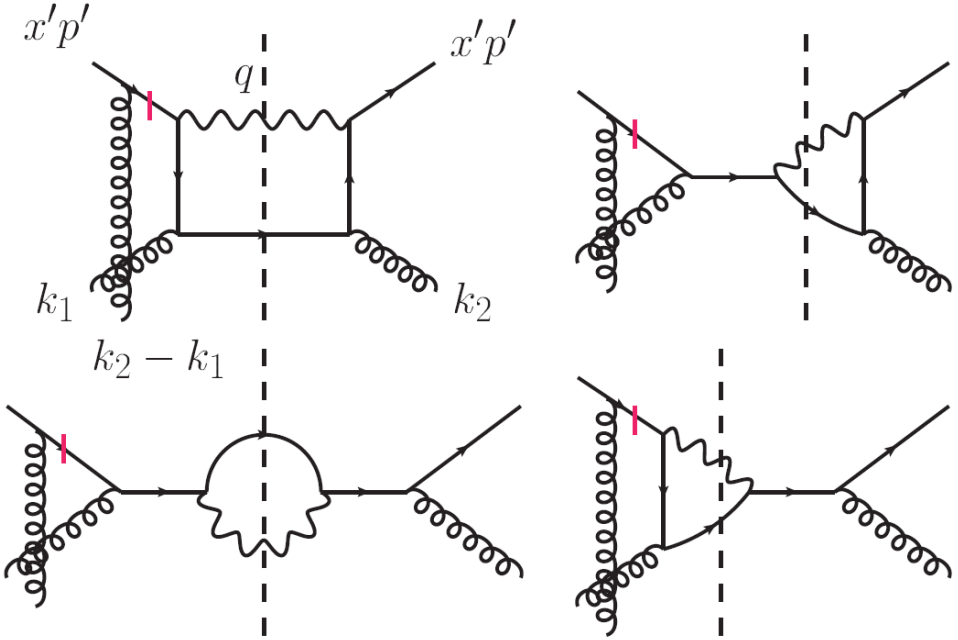
$q\bar{q} \to \gamma g$



$gq \to \gamma q$

Twist-3(polarized cross section)

initial state interaction



+ mirrors

These diagrams give pole contribution at the $x_1 = x_2$

Cross section formula for $pp^{\uparrow} \to \gamma X$

$$E_\gamma \frac{d\sigma}{d^3q} = \frac{\alpha_{em}\alpha_s M_N \pi}{S} \sum_a \int \frac{dx'}{x'} f_a(x') \int \frac{dx}{x} \delta(\hat{s}+\hat{t}+\hat{u}) \epsilon^{qpnS_\perp} \frac{1}{\hat{u}}$$

$$\times \Big[\delta_a \Big(\frac{d}{dx} O(x,x) - \frac{2O(x,x)}{x} + \frac{d}{dx} O(x,0) - \frac{2O(x,0)}{x} \Big)$$

$$- \frac{d}{dx} N(x,x) + \frac{2N(x,x)}{x} + \frac{d}{dx} N(x,0) - \frac{2N(x,0)}{x} \Big] \Big(\frac{2}{N} (\frac{\hat{s}}{\hat{u}} + \frac{\hat{u}}{\hat{s}}) \Big)$$

This differs form the previous study.

X. Ji Phys.lett.B 289 (1992)

We obtained two parameterization by study of $pp^{\uparrow} \to DX$

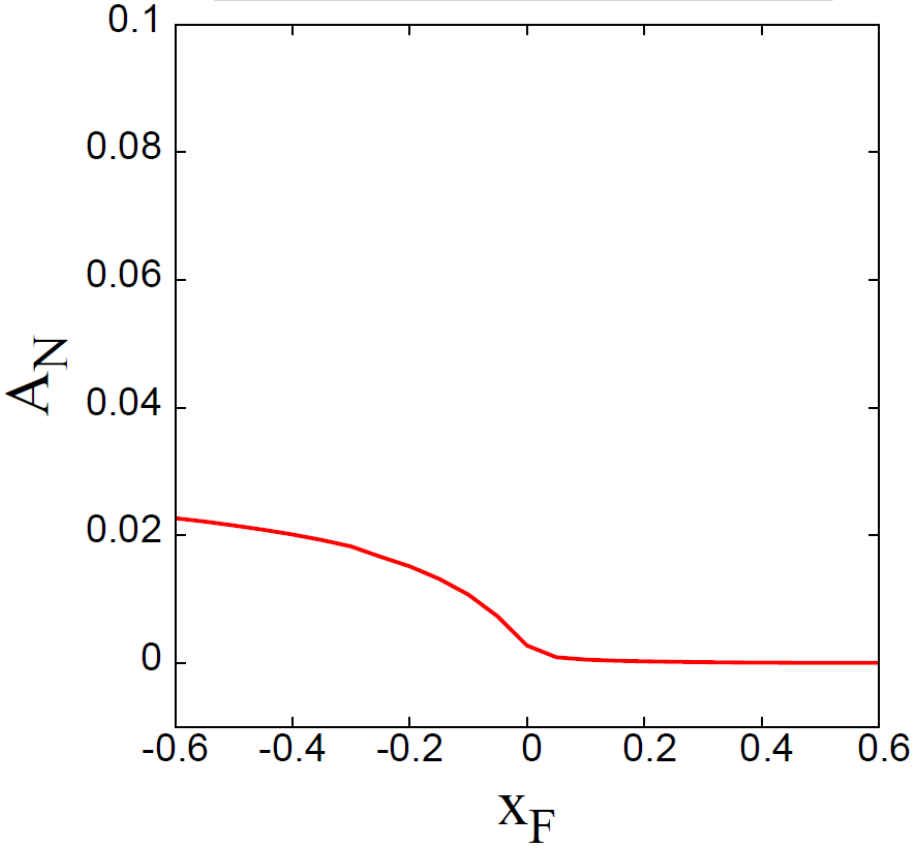
$$\begin{cases} O(x,x) = 0.002 \times xG(x) \\ O(x,x) = 0.0005 \times x^{\frac{1}{2}} G(x) \end{cases}$$

We present numerical estimate based on these parameterization.

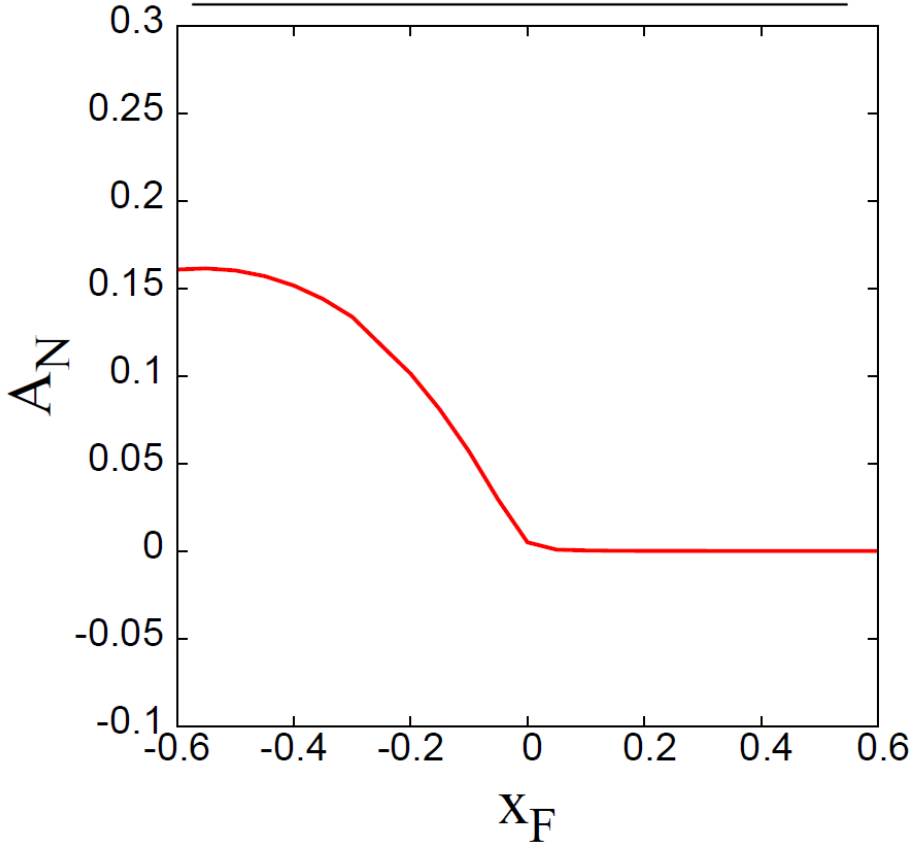
Numerical estimate

$$\sqrt{s} = 200GeV \quad P_T = 2GeV$$

$O(x,x) = 0.002 \times xG(x)$



$O(x,x) = 0.0005 \times x^{\frac{1}{2}} G(x)$



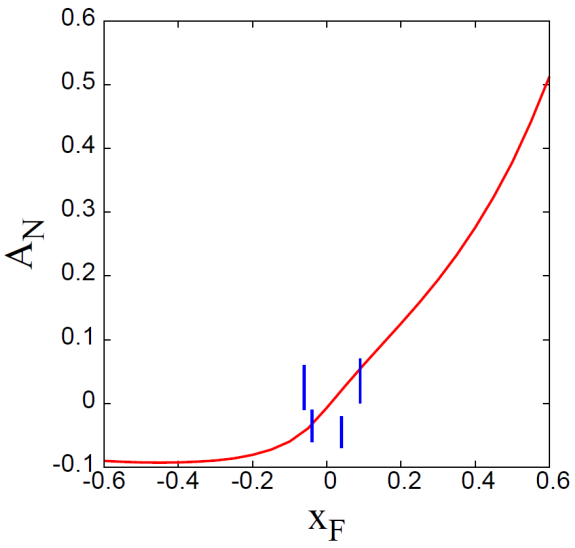
· $A_N \sim 0$ at $x_F > 0$ regardless of magnitude of the 3-gluon correlation functions.

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

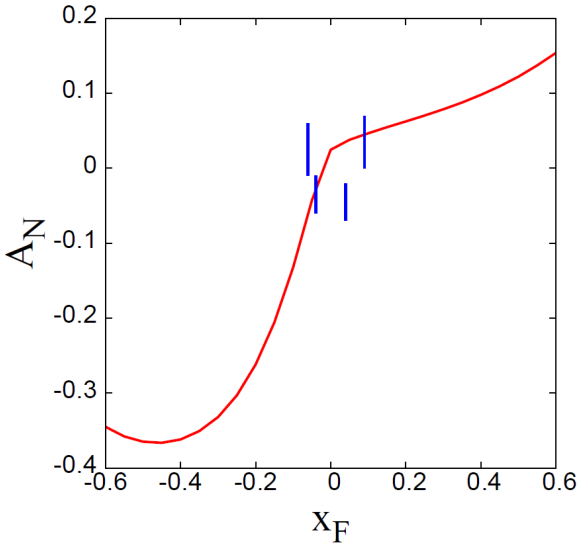
$$\sqrt{s} = 200GeV \qquad P_T = 2GeV$$

$pp^{\uparrow} \rightarrow DX$

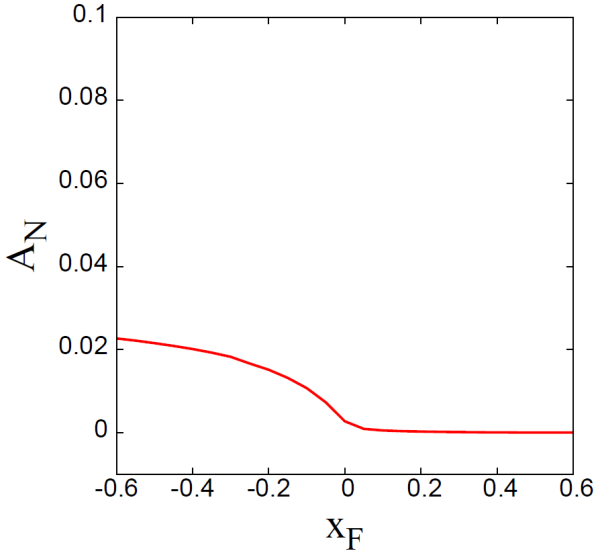
$O(x,x) = 0.002 \times xG(x)$

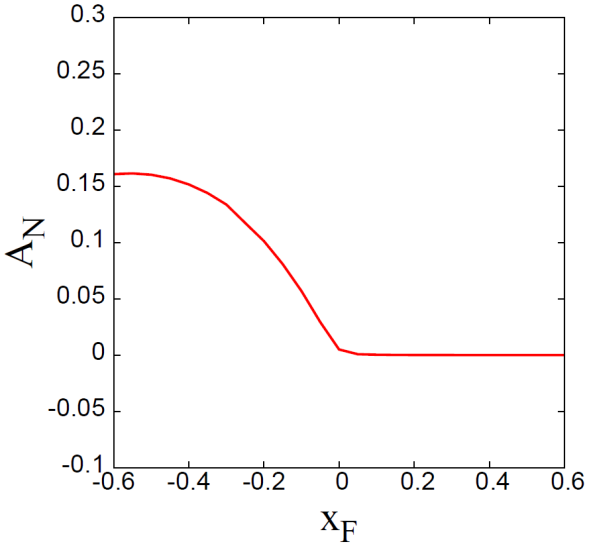


$O(x,x) = 0.0005 \times x^{\frac{1}{2}}G(x)$



$pp^{\uparrow} \rightarrow \gamma X$





Summary

· We derived the contribution of the 3-gluon correlation functions to the polarized cross section for $pp^\uparrow \to DX$ and $pp^\uparrow \to \gamma X$.

· Our cross section formula for $pp^\uparrow \to \gamma X$ differs from the previous study.

· A_N for $pp^\uparrow \to DX$ at $x_F > 0$ is sensitive to the magnitude of 3-gluon correlation function.

· For $pp^\uparrow \to \gamma X$, $A_N \simeq 0$ 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 both two processes.

$\star$ Two processes impose a costraint on magnitude and shape of 3-gluon correlation functions.