IMPACT OF SIVERS EFFECT ON TRANSVERSITY MEASUREMENTS

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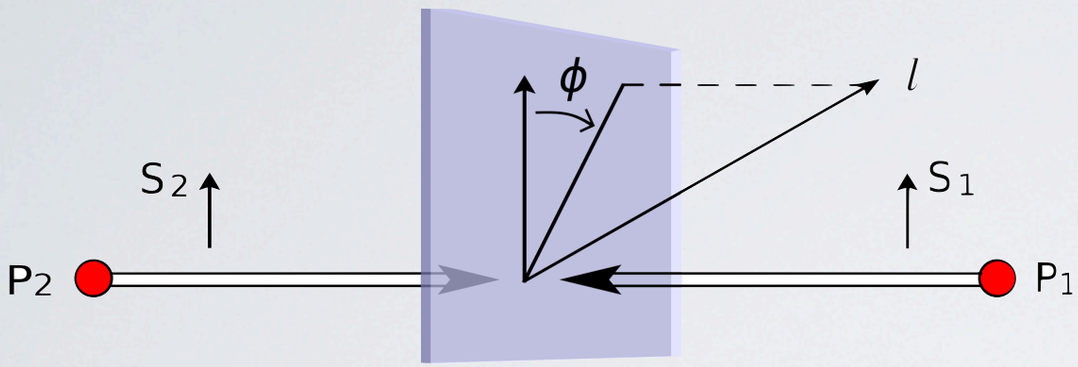
POLARIZED DRELL-YAN

collinear treatment



$$A_{TT} \equiv \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}} \propto h_1^q h_1^{\bar{q}} \cos 2\phi$$

At RHIC $\sqrt{s} = 500\mathrm{GeV}$

A_{TT}^{DY} (q_T integrated) ~1% Q=5-20 GeV

Martin et al. PR D60, 117502 (1999)

$A_{TT}^{DY}(q_T)$ ~3% q_T=1 GeV Q=5 GeV

Kawamura et al. NP B777, 203 (2007)

TRANSVERSITY

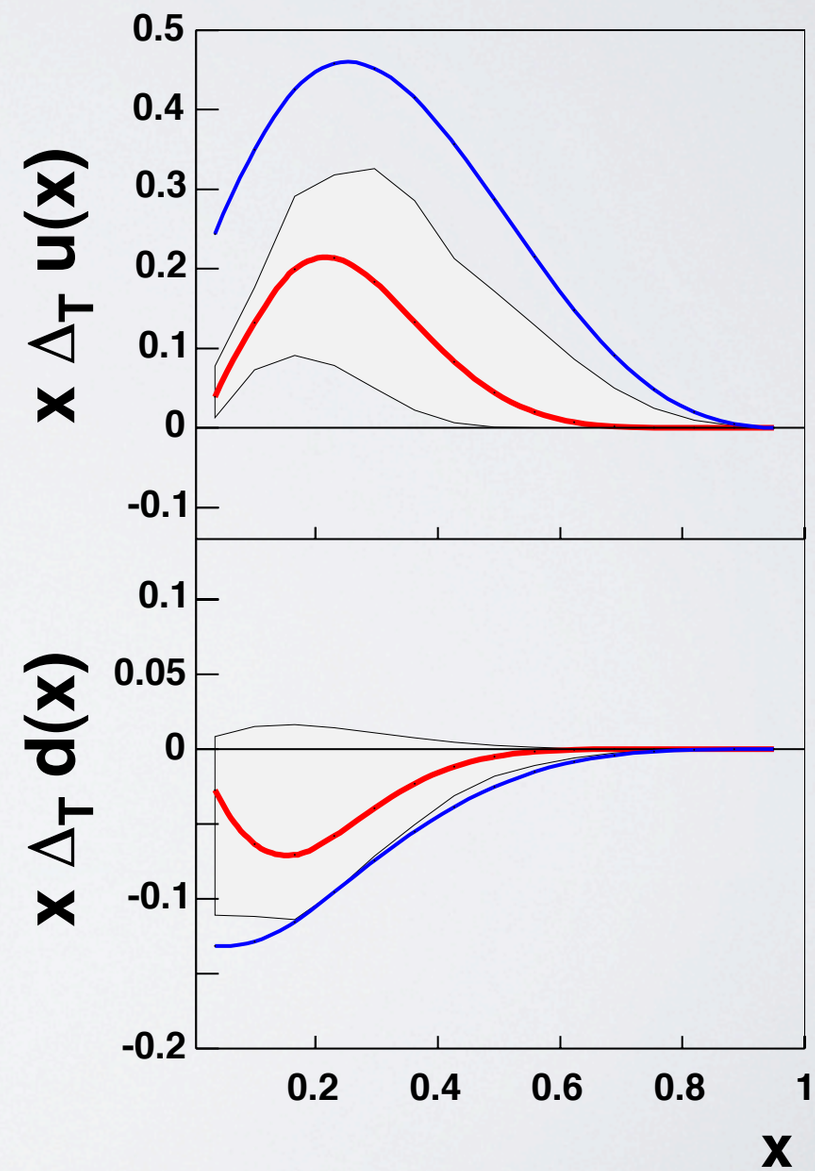
Soffer bound $|h_1(x,\mu^2)| \leq \frac{1}{2}[f_1(x,\mu^2) + g_1(x,\mu^2)]$

first extraction

Anselmino et al. PR D75 054032 (2007)

$$A_{TT}^{DY} < 1\%$$

$$A_{TT}^{DY}(q_T) \sim 1\%$$



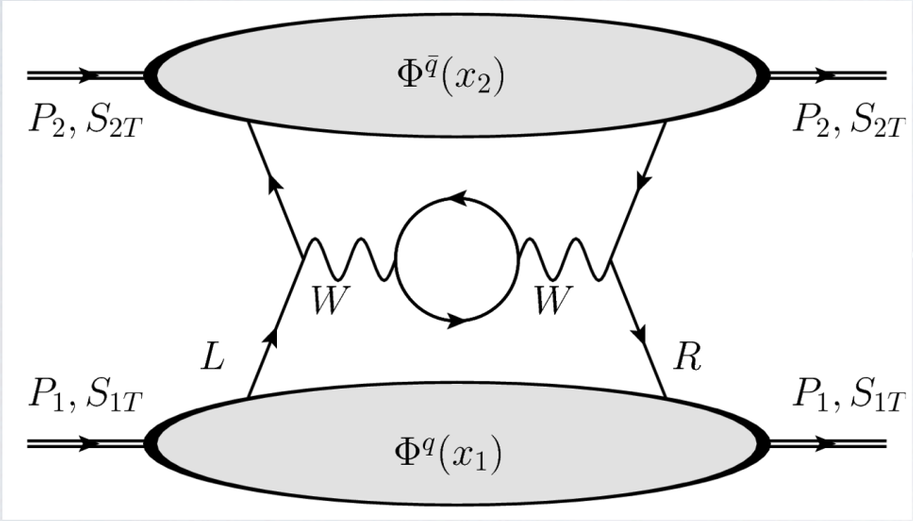
background study important

POLARIZED W PRODUCTION

collinear treatment

$$A_{TT}^{W}(l_T) = 0$$

Bourrely & Soffer NP B423 329 (1994)



$$\Phi(x) = \frac{1}{2}\left\{ f_1(x)\not{n}_+ + \lambda g_1(x)\gamma_5\not{n}_+ + h_1(x)\frac{\gamma_5[\not{S}_T, \not{n}_+]}{2} \right\} + \cdots$$

→ allows for new physics studies

$$A_{TT}^{W}(l_T) \sim 1\%$$

if W-boson has 4% right-handed coupling

Boer & WDD PRL 105 071801(2010)

→ background study important

TMD EFFECTS

Sivers & worm-gear

Sivers function: correlation between k_T and S_T

$$\mathcal{P}_R^q(x,\mathbf{k}_T) + \mathcal{P}_L^q(x,\mathbf{k}_T) = f_1^q(x,k_T) + \sin(\phi_{\mathbf{k}_T} - \phi_{\mathbf{S}_T})\frac{|\mathbf{k}_T||\mathbf{S}_T|}{M_p} f_{1T}^{\perp q}(x,k_T).$$

worm-gear distribution: longitudinal polarization of quarks inside a transversely polarized proton

$$\mathcal{P}_R^q(x,\mathbf{k}_T) - \mathcal{P}_L^q(x,\mathbf{k}_T) = g_{1L}^q(x,k_T)\lambda - g_{1T}^q(x,k_T)\frac{\mathbf{k}_T \cdot \mathbf{S}_T}{M_p}$$

TMD EFFECTS

in the Collins-Soper frame

correlation between q_T and the proton spins

$$
\begin{aligned}
\frac{d\sigma^{(2)}(h_1 h_2 \to \ell\bar{\ell}X)}{d\Omega dx_1 dx_2 d^2\mathbf{q}_T} = \frac{\alpha^2}{3Q^2} \sum_{a,\bar{a}} \Big\{ \cdots \\
+\frac{K_1(y)}{2} \, |_{1T}| \, |S_{2T}| \, \cos(2\phi_{q_T} - \phi_{S_1} - \phi_{S_2}) \, \mathcal{F}\left[\hat{h}\cdot p_T \, \hat{h}\cdot k_T \, \frac{f_{1T}^{\perp}\bar{f}_{1T}^{\perp} - g_{1T}\bar{g}_{1T}}{M_1 M_2} \right] \\
-\frac{K_1(y)}{2} \, |S_{1T}| \, |S_{2T}| \, \cos(\phi_{q_T} - \phi_{S_1}) \, \cos(\phi_{q_T} - \phi_{S_2}) \, \mathcal{F}\left[p_T\cdot k_T \, \frac{f_{1T}^{\perp}\bar{f}_{1T}^{\perp}}{M_1 M_2} \right] \\
-\frac{K_1(y)}{2} \, |S_{1T}| \, |S_{2T}| \, \sin(\phi_{q_T} - \phi_{S_1}) \, \sin(\phi_{q_T} - \phi_{S_2}) \, \mathcal{F}\left[p_T\cdot k_T \, \frac{g_{1T}\bar{g}_{1T}}{M_1 M_2} \right] \\
+K_2(y) \, \lambda_1 \, |S_{2T}| \, \sin(\phi_{q_T} - \phi_{S_2}) \, \mathcal{F}\left[\hat{h}\cdot k_T \, \frac{g_1 \bar{f}_{1T}^{\perp}}{M_2} \right] \\
+K_2(y) \, |S_{1T}| \, |S_{2T}| \, \sin(2\phi_{q_T} - \phi_{S_1} - \phi_{S_2}) \, \mathcal{F}\left[\hat{h}\cdot p_T \, \hat{h}\cdot k_T \, \frac{f_{1T}^{\perp}\bar{g}_{1T}}{M_1 M_2} \right] \\
-K_2(y) \, |S_{1T}| \, |S_{2T}| \, \cos(\phi_{q_T} - \phi_{S_1}) \sin(\phi_{q_T} - \phi_{S_2}) \, \mathcal{F}\left[p_T\cdot k_T \, \frac{f_{1T}^{\perp}\bar{g}_{1T}}{M_1 M_2} \right] + \begin{pmatrix} 1 \longleftrightarrow 2 \\ p \longleftrightarrow k \end{pmatrix} \Big\}
\end{aligned}
$$

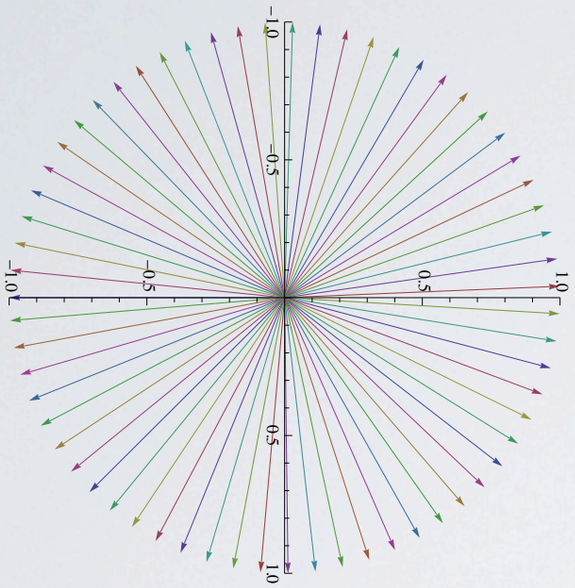
In the CS frame lepton distribution isotropic!

no background for transversity study?

Boer, PRD 60 (1999), 014012

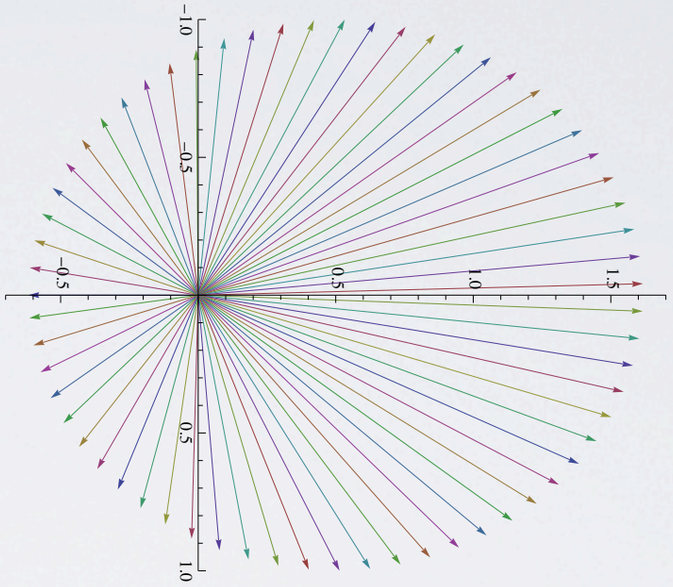
TMD EFFECTS

in the lab frame



CS frame

boost



lab frame

lab frame: correlation between q_T and l_T

→ transversity and TMD effects same signature!

TMD EFFECTS

in the lab frame

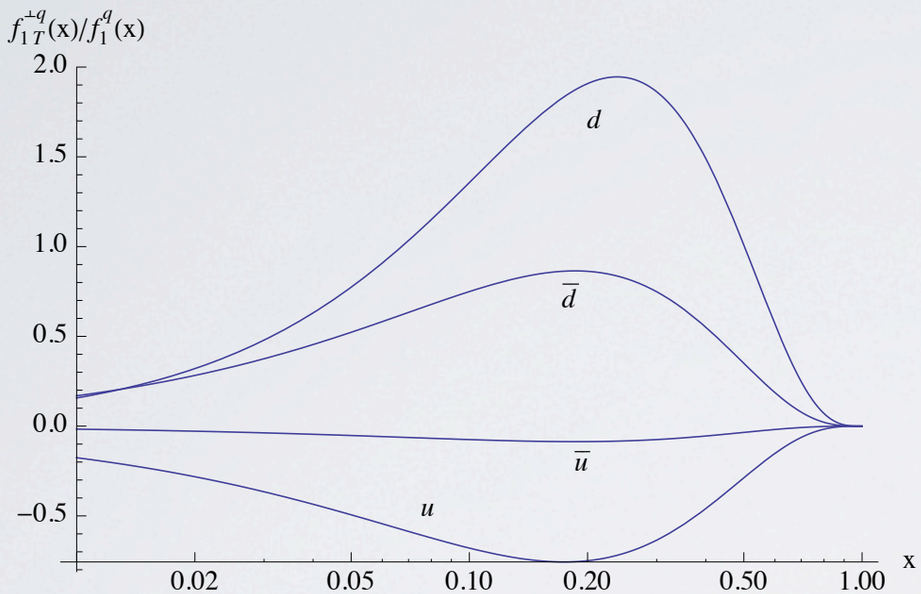
Drell-Yan:
in principle, non-zero spin asymmetry
≠ non-zero transversity!

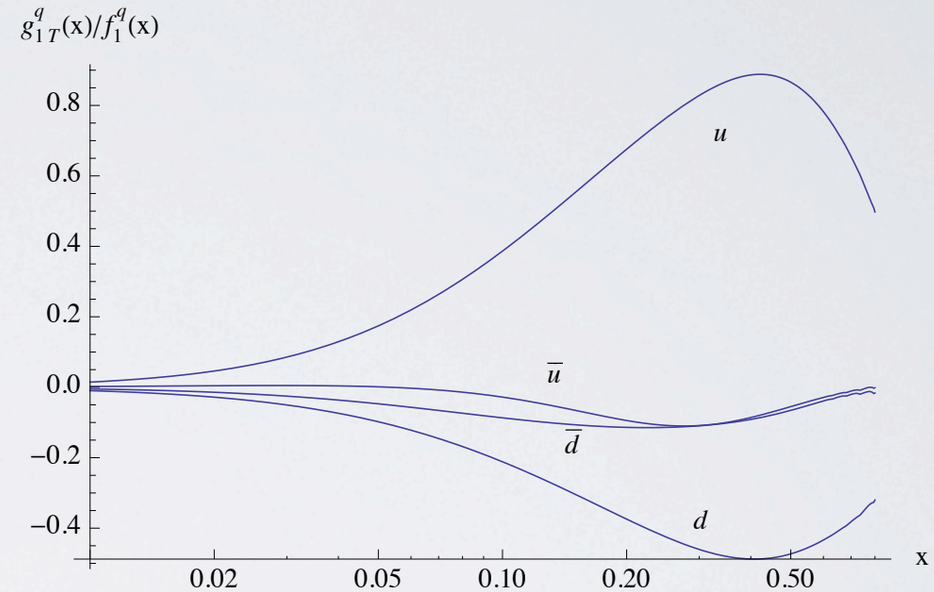
W production:
in principle, non-zero spin asymmetry
≠ new physics!

will show here that TMD effects in the lab frame are small

SIVERS & WORM GEAR

extraction from experiment & model prediction





$$f_{1T}^{\perp q}(x,k_T) = \frac{1}{\pi\langle k_T^2\rangle_{\rm S}} e^{-k_T^2/\langle k_T^2\rangle_{\rm S}} f_{1T}^{\perp q}(x)$$

$$g_{1T}^{q}(x,k_T) = \frac{1}{\pi\langle k_T^2\rangle_{\rm WG}} e^{-k_T^2/\langle k_T^2\rangle_{\rm WG}} g_{1T}^{q}(x)$$

extraction by Anselmino et al.
Eur. Phys. J. A39, 89 (2009)

through Wandzura-Wilczek approximation

$$g_{1T}^{q(1)}(x) \approx x\int_x^1 dy \frac{g_1^q(y)}{y}$$

in terms of the DSSV helicity distribution
(de Florian et al. PRL 101, 072001 (2008))

DRELL-YAN

spin asymmetries due to TMD effects in the lab frame

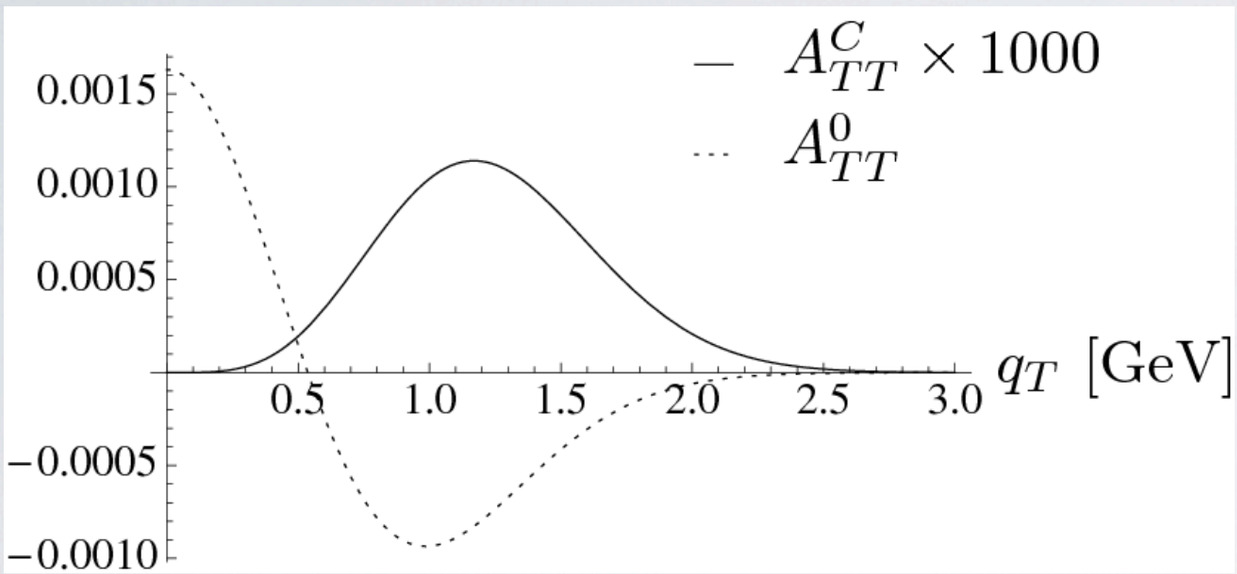
$$\sigma^S \equiv \frac{1}{4}\left(\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}\right) \qquad \sigma^A \equiv \frac{1}{4}\left(\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}\right)$$

$$A^0_{TT}(q_T, Q, Y) \equiv \frac{\int_0^{2\pi} d\phi_l \int d\phi_q \int dy\, \sigma^A}{\int_0^{2\pi} d\phi_l \int d\phi_q \int dy\, \sigma^S}$$

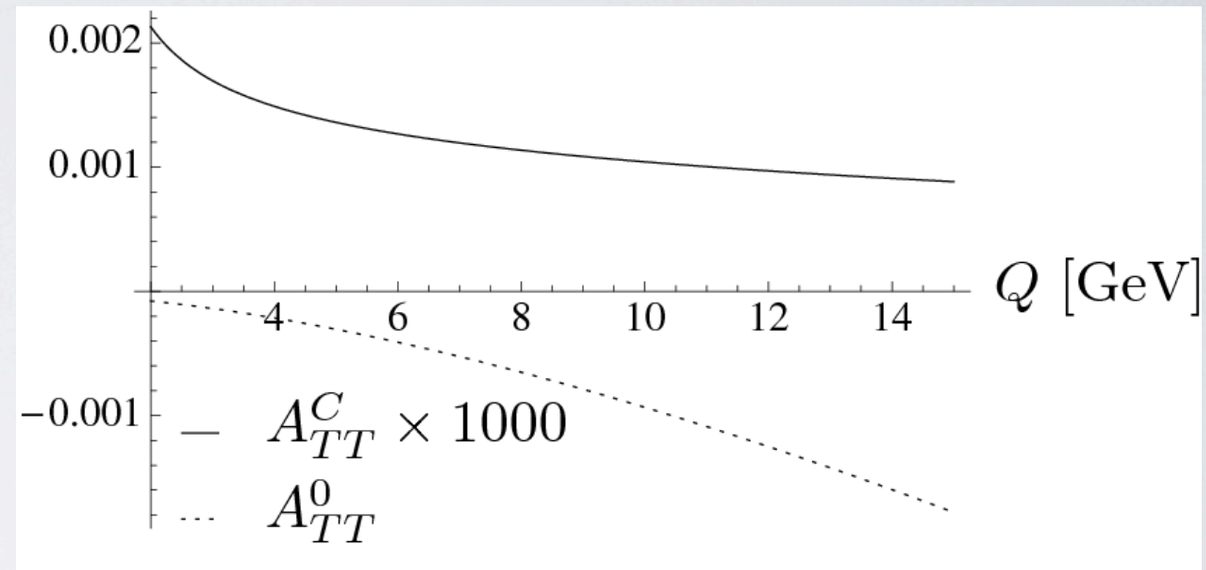
$$A^C_{TT}(q_T, Q, Y) \equiv \frac{\left(\int_{-\pi/4}^{\pi/4} - \int_{\pi/4}^{3\pi/4} + \int_{3\pi/4}^{5\pi/4} - \int_{5\pi/4}^{7\pi/4}\right) d\phi_l \int d\phi_q \int dy\, \sigma^A}{\int_0^{2\pi} d\phi_l \int d\phi_q \int dy\, \sigma^S}$$

DRELL-YAN

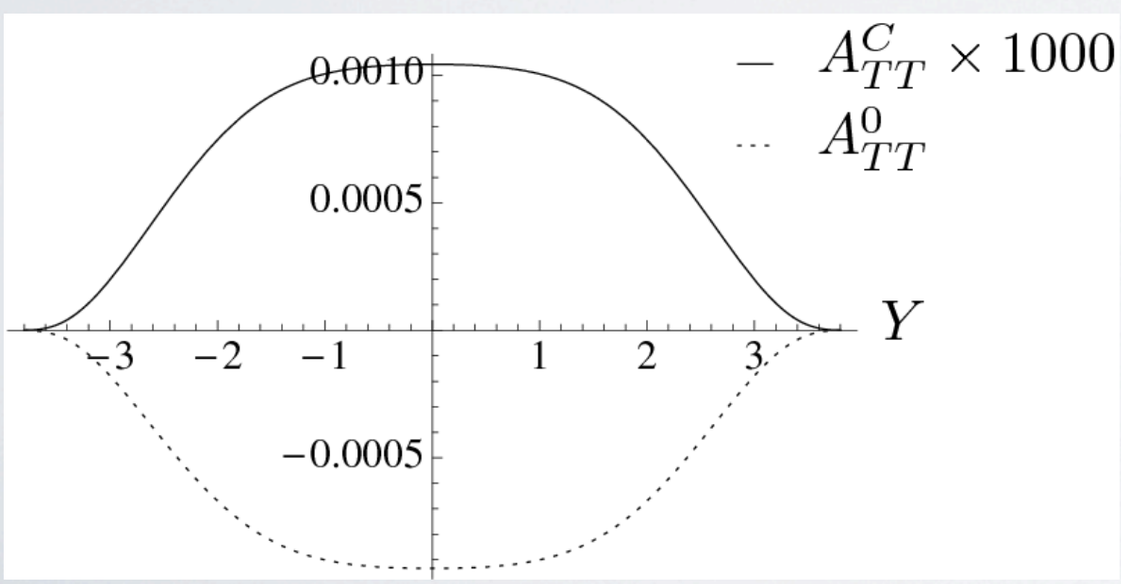
spin asymmetries due to TMD effects in the lab frame



$Q = 10\text{GeV}$ and $Y = 0$



$q_T = 1\text{GeV}$ and $Y = 0$



$Q = 10\text{GeV}$ and $q_T = 1\text{GeV}$

double Sivers effect asymmetries at RHIC

$\sqrt{s} = 500\text{GeV}$

W PRODUCTION

spin asymmetries due to TMD effects in the lab frame

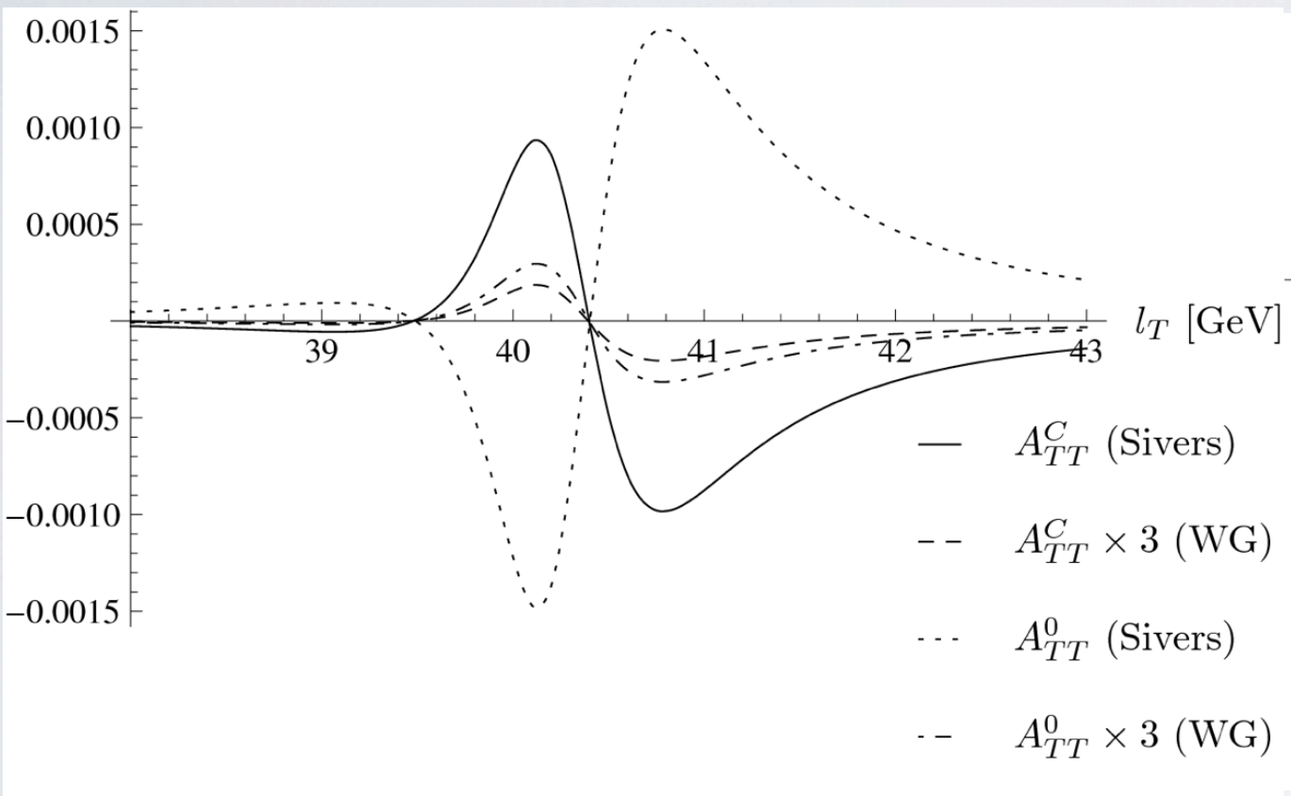
$$\sigma^S \equiv \frac{1}{4}\left(\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow} + \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}\right) \qquad \sigma^A \equiv \frac{1}{4}\left(\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow} + \sigma^{\downarrow\downarrow}\right)$$

$$A^0_{TT}(l_T, Y_l) \equiv \frac{\int_0^{2\pi} d\phi_l \int dY_{\bar{l}} \int d\bar{l}_T \int d\phi_{\bar{l}}\, \sigma^A}{\int_0^{2\pi} d\phi_l \int dY_{\bar{l}} \int d\bar{l}_T \int d\phi_{\bar{l}}\, \sigma^S}$$

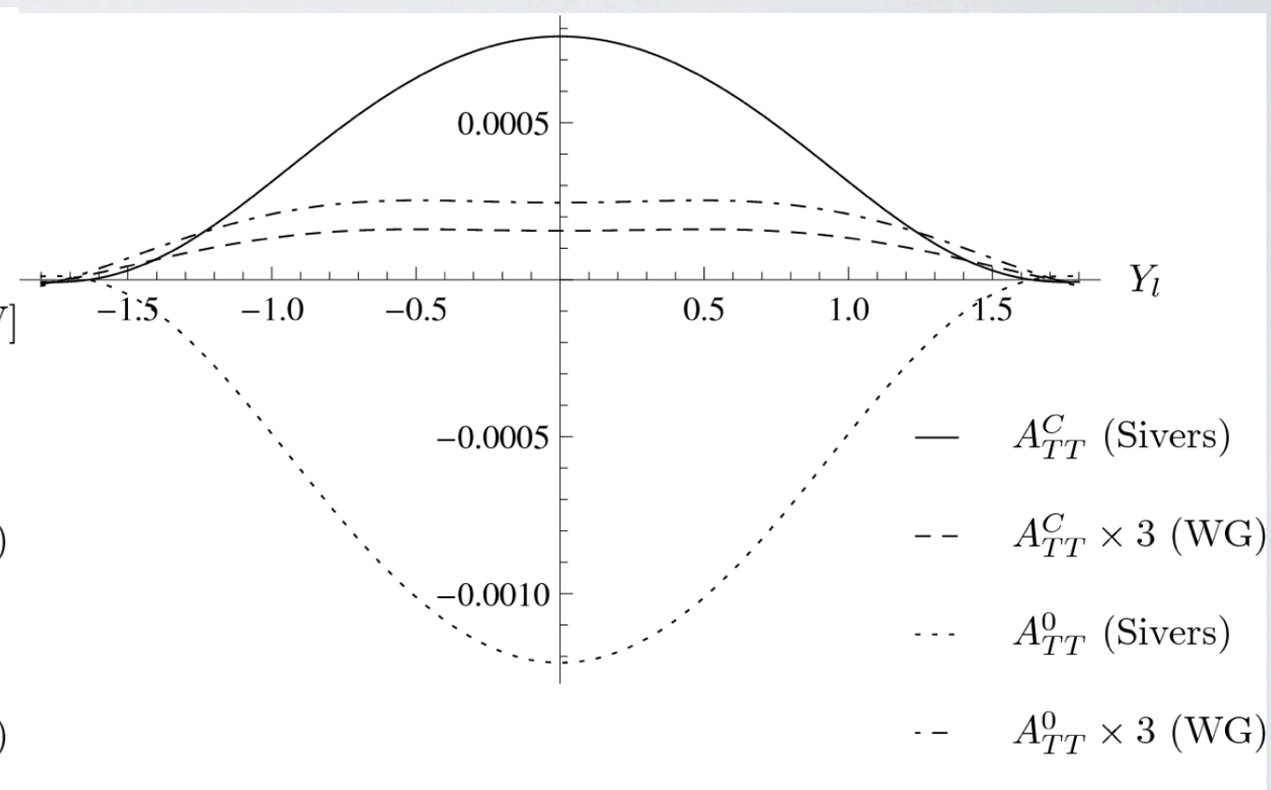
$$A^C_{TT}(l_T, Y_l) \equiv \frac{\left(\int_{-\pi/4}^{\pi/4} - \int_{\pi/4}^{3\pi/4} + \int_{3\pi/4}^{5\pi/4} - \int_{5\pi/4}^{7\pi/4}\right) d\phi_l \int dY_{\bar{l}} \int d\bar{l}_T \int d\phi_{\bar{l}}\, \sigma^A}{\int_0^{2\pi} d\phi_l \int dY_{\bar{l}} \int d\bar{l}_T \int d\phi_{\bar{l}}\, \sigma^S}$$

W PRODUCTION

spin asymmetries due to TMD effects in the lab frame



$Y_l = 0$



$l_T = 40\mathrm{GeV}$

W^+ production at RHIC $\sqrt{s} = 500\mathrm{GeV}$

CONCLUSIONS

TMD effects in the lab frame

- Drell-Yan:
  - $A_{TT}^{C}(q_T)$ due to TMD effects negligibly small
  - transversity can safely be determined from $A_{TT}^{C}(q_T)$ in the lab frame
  - $A_{TT}^{0}(q_T)$ can be used as a cross-check
- W production:
  - $A_{TT}^{C,0}(l_T)$ due to TMD effects ~ 0.1%
  - integrated asymmetry negligibly small
    → no background for new physics studies