- What is the impact of DY on small-x physics?

- What to blame if
  - No sign change
  - if we see a sign change but different magnitude/shape?

- What can we learn from Collider vs. fixed Target?

- What measurements are needed in the future?
- (or what analysis should be done on existing data? )
- What do we need to learn from current DY experiments (Compass, AnDY, E906) for the future generation of experiments?

# Still open: Jen-Chieh at 2010 DY workshop in Santa Fe

- Is there a Boer-Mulders sign change?
- Boer-Mulders different in protons and pions?
- Flavor dependence of DY?
- $k_t$ dependence:
  - x dependence?
  - flavor dependence?
  - difference between nucleons and mesons?
  - gluon/quark differences?

# What the Drell-Yan measurement can offer us at small-x?

May 12, 2011

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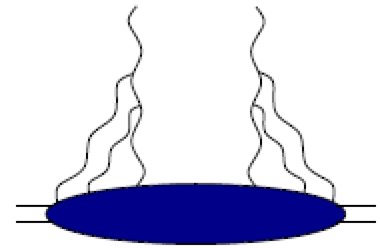
Bowen Xiao

# A Tale of Two Gluon Distributions

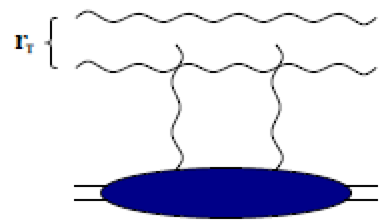
I. Weizsäcker Williams gluon distribution (MV model):

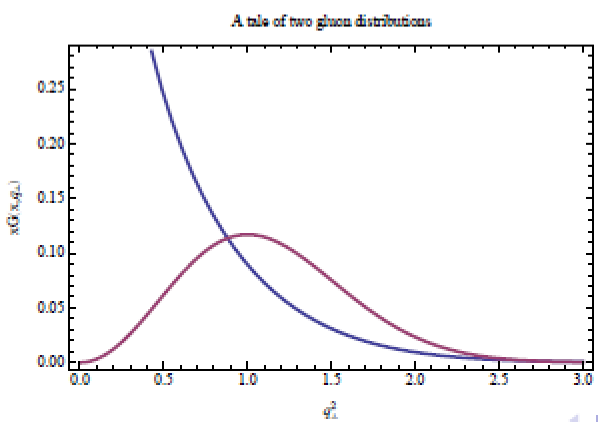
$$xG^{(1)} = \frac{S_\perp}{\pi^2 \alpha_s} \frac{N_c^2 - 1}{N_c} \times \int \frac{d^2 r_\perp}{(2\pi)^2} \frac{e^{-ik_\perp \cdot r_\perp}}{r_\perp^2} \left(1 - e^{-\frac{r_\perp^2 Q_s^2}{4}}\right) \Leftarrow$$



II. Color Dipole gluon distributions:

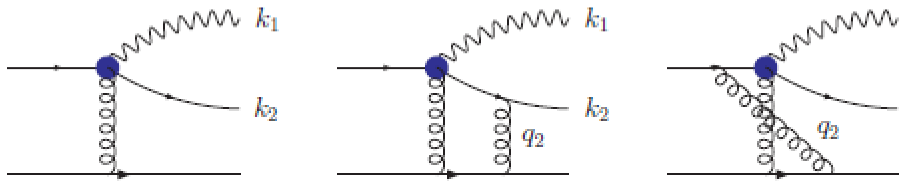
$$xG^{(2)} = \frac{S_\perp N_c}{2\pi^2 \alpha_s} \times \int \frac{d^2 r_\perp}{(2\pi)^2} e^{-ik_\perp \cdot r_\perp} \nabla_{r_\perp}^2 N(r_\perp) \Leftarrow$$



## $\gamma$+Jet in $pA$ collisions

The direct photon + jet production in $pA$ collisions. (Drell-Yan Process follows the same factorization.)




$(a)$ $(b)$ $(c)$

Dipole model approach:

$$\frac{d\sigma_{\text{DP}}^{pA\to\gamma^* q+X}}{dy_1 dy_2 d^2k_{1\perp} d^2k_{2\perp} d^2b} = \sum_f x_p q_f(x_p,\mu)\frac{\alpha_{e.m.}e_f^2}{2\pi^2}(1-z)F_{x_g}(q_\perp)$$
$$\times\left\{\left[1+(1-z)^2\right]\frac{z^2q_\perp^2}{\left[\tilde{P}_\perp^2+\epsilon_M^2\right]\left[(\tilde{P}_\perp+zq_\perp)^2+\epsilon_M^2\right]}\right.$$
$$\left.-z^2(1-z)M^2\left[\frac{1}{\tilde{P}_\perp^2+\epsilon_M^2}-\frac{1}{(\tilde{P}_\perp+zq_\perp)^2+\epsilon_M^2}\right]^2\right\},$$

Remarks:

- Direct photon measurement.
- Correlation.
- In addition, test the BK evolution equation.

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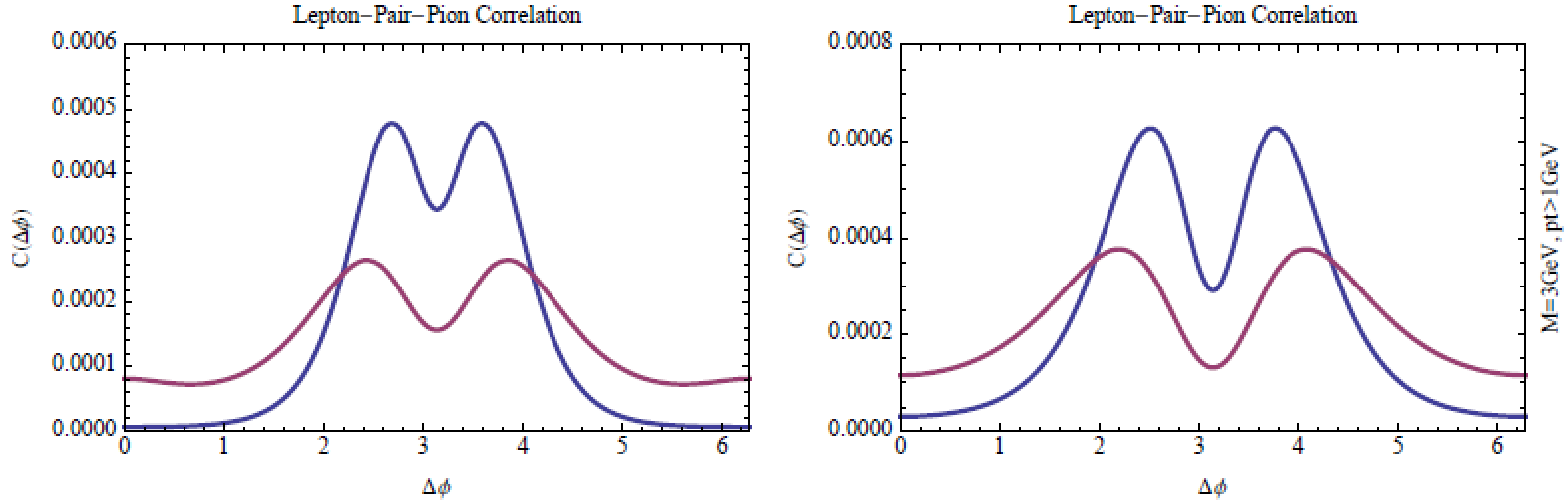
## Dilepton Pair + hadron correlation

Azimuthal angle correlation of $\gamma^* + \pi^0$ at forward rapidity 3.2:




Remarks:

- $p_{1\perp} > 1.5$Gev, $p_{2\perp} > 1.5$Gev and $M^2 = 1\text{GeV}^2$;
- $p_{1\perp} > 1$Gev, $p_{2\perp} > 1$Gev and $M^2 = 9\text{GeV}^2$;
- Suppression of away side peak at central *dAu* collisions.
- The unique double peak structure on the away side comes from the fact that $xG^{(2)} \propto q_\perp^2$ in the small $q_\perp$ limit.
- To avoid the contamination of $\rho$ and $J/\Psi$, better choice of kinematical region. Low Mass $M^2$ vs high mass?

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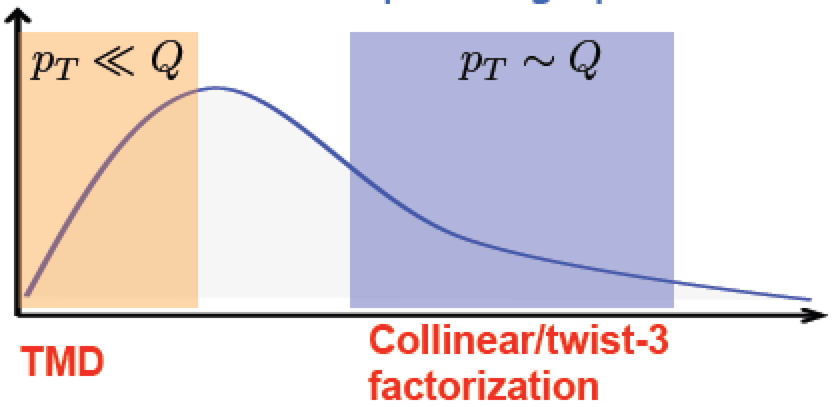
# Questions?

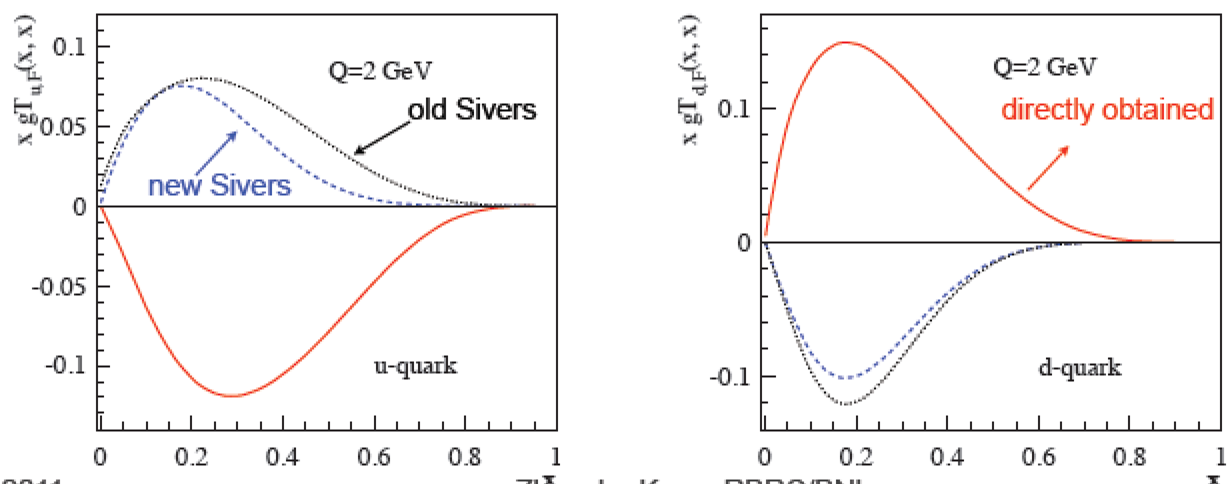
- What is the theoretical uncertainties of DY $A_N$ predictions?
  - How do they affect our goal of checking the sign change?
- What is the real impact of the measurement of sign change?
  - Is this issue only relevant to spin physics? How should be convey to outside community?
  - If we have sign change, what is the contribution we have made?
  - If we have not sign change, what does this mean? Is this really a big deal?

# "Sign mismatch" between SIDIS and pp

- Transition from low $p_T$ to high $p_T$



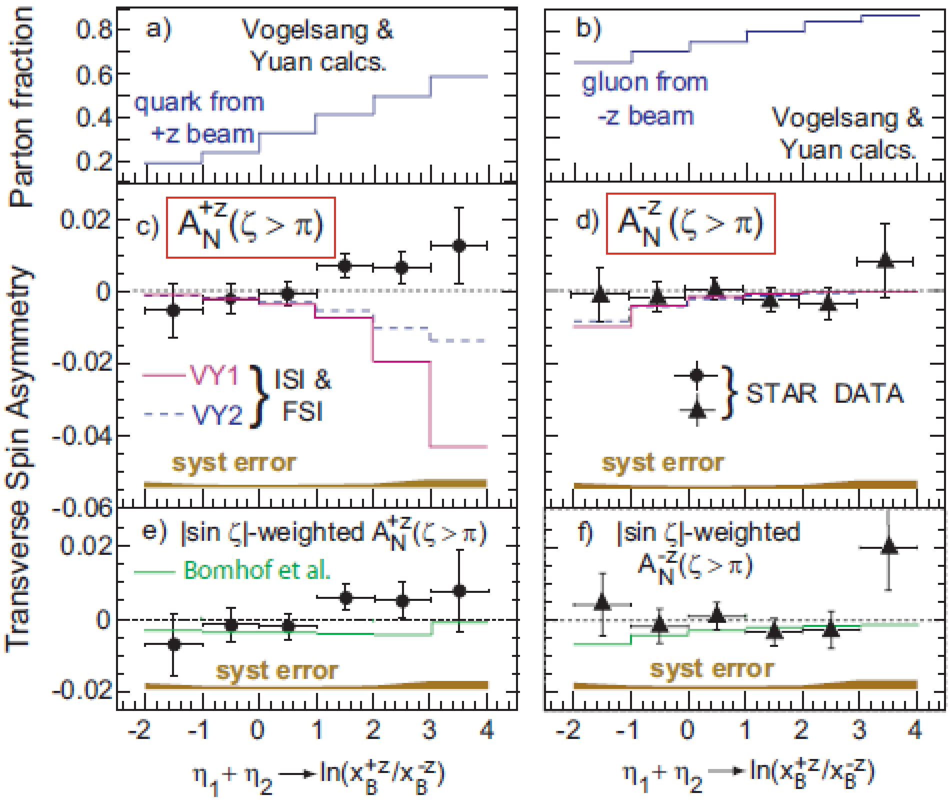

- Need to determine the sign and constrain $T_F(x,x)$



# Dijet asymmetry measurement

- The theory prediction here is using $T_F(x, x)$ from the first kt-moment of Sivers function from SIDIS

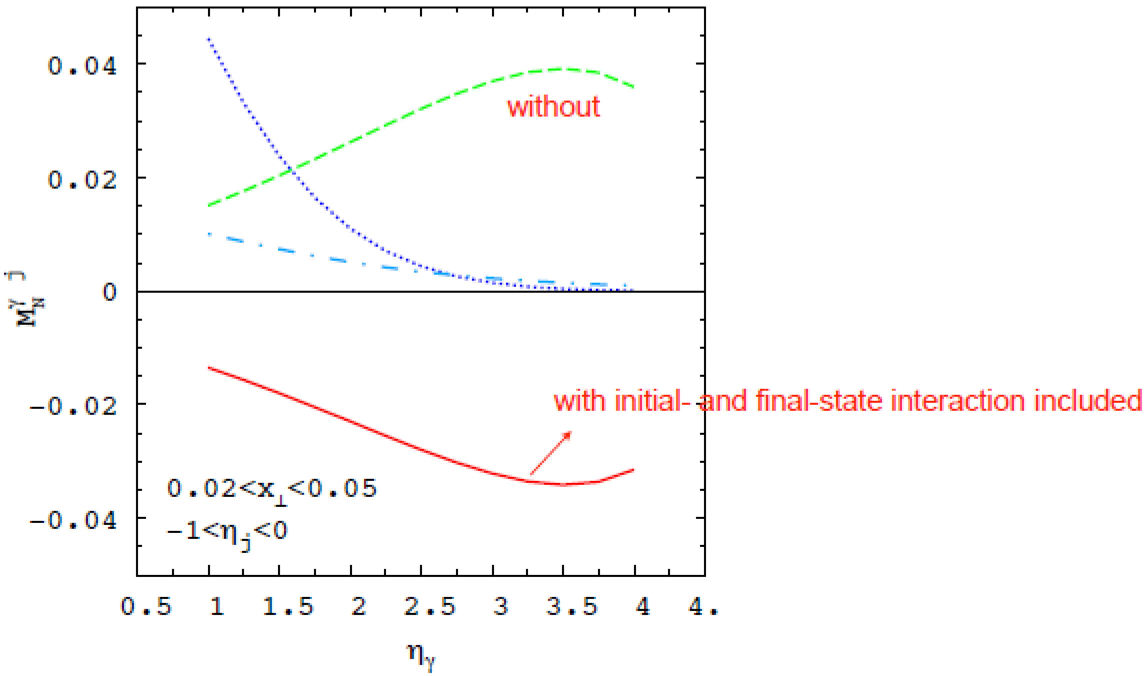
STAR, PRL 2007




- Also the problem of factorization breaking

# How could one probe the factorization breaking?

- Natural approach: use the prediction based on the generalized TMD factorization, compare with the experimental data, and look for the discrepancy
  - Prediction based on $T_F(x, x)$ from the first kt moment of Sivers function from SIDIS

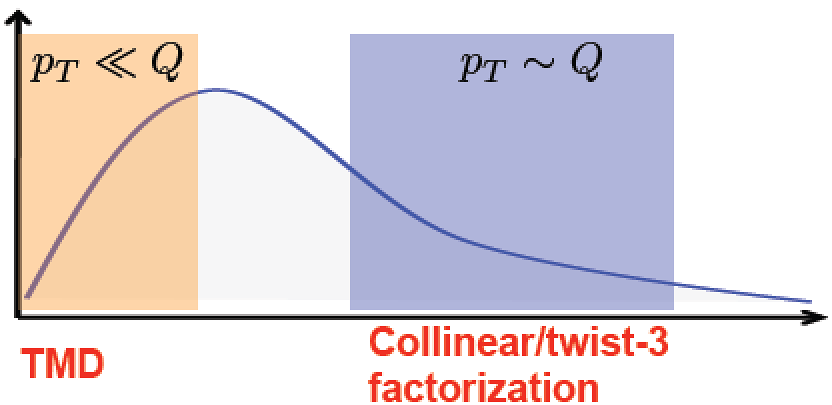



Bacchetta, Bomhof, D'Alesio, Mulders, Murgia, PRL 2007

# $T_F(x, x)$ is needed for Drell-Yan at high qt ~ Q

- For measure Sivers function, we need to use TMD factorization and try to restrict us in the region qt << Q

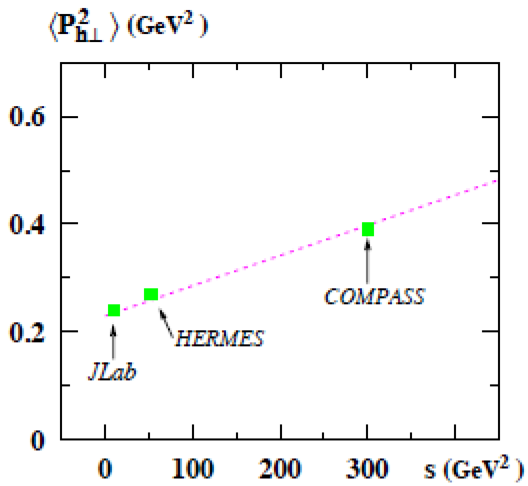
- At the same time, when qt ~ Q, we are then in the region of collinear factorization region, we thus really need $T_F(x, x)$ function to make correct prediction

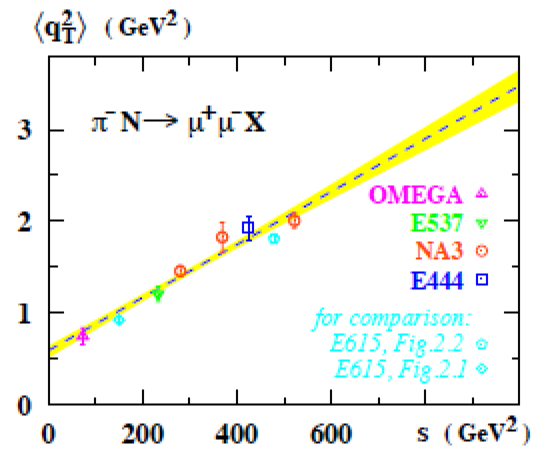


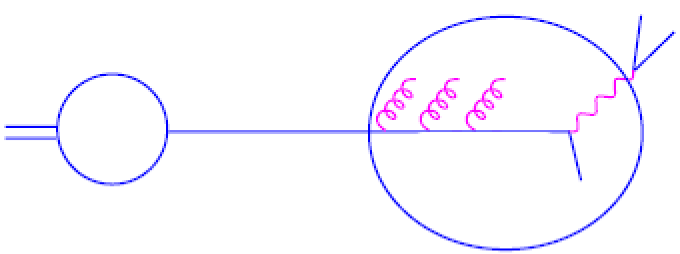
# How good is the Gaussian approximation?

- The Gaussian width will change as CM energy changes

Schweitzer, Teckentrup, Metz, 2010



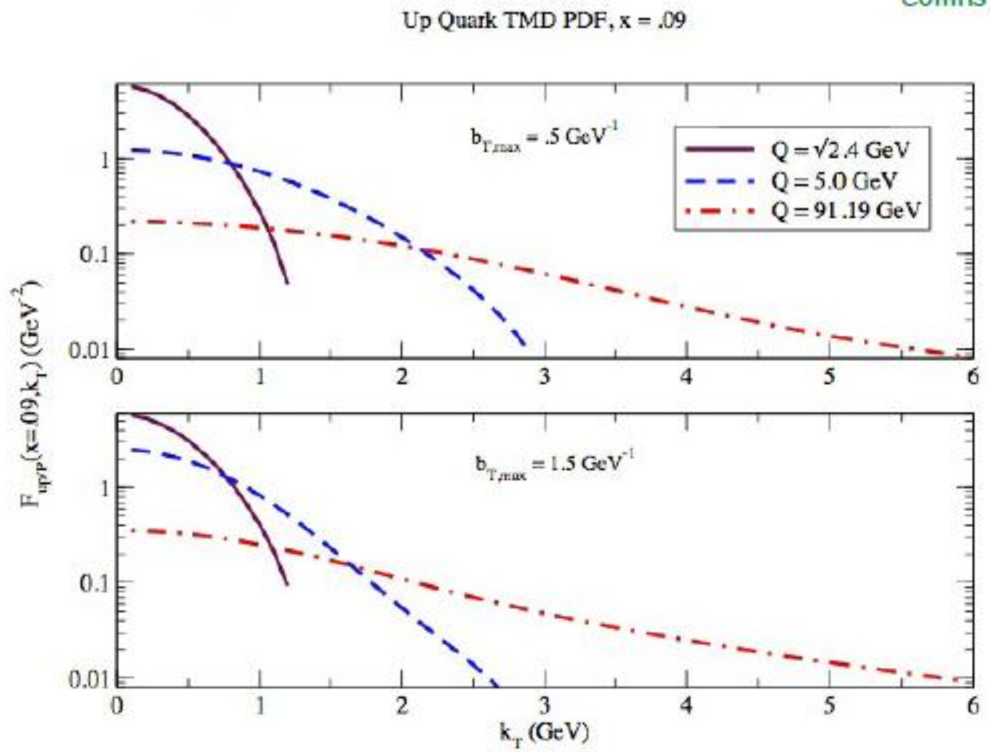



# It can not always be Gaussian: evolution is important

- Evolution for unpolarized PDFs

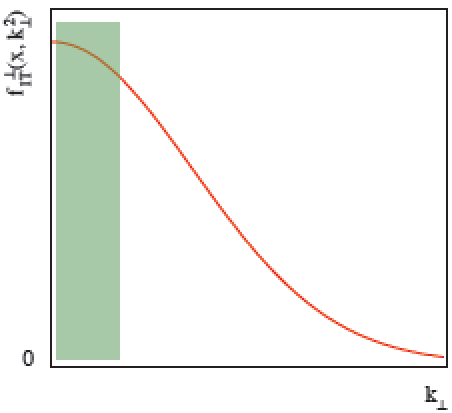
Aybat, Rogers, 2010
Collins, Soper, Sterman 1986

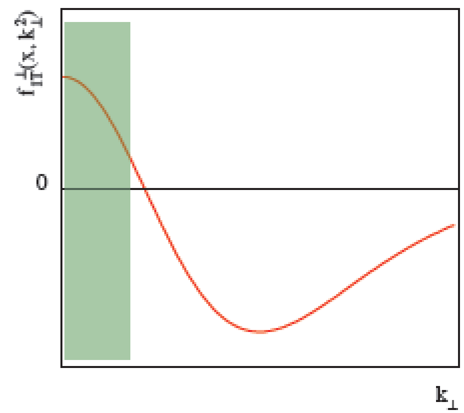



- More work to do on evolution of Sivers function Idilbi, Ji, Ma, Yuan, PRD, 2004

# What are the kt and x dependence?

- If we have a node, then ...




- If we measure $q_T$ distribution, if sign changes, but we need to be careful

- If we measure $x_F$ distribution, again, large $x_F$ and low $x_F$ region might have different sign

## Use spin to probe small-x physics

Kang, Yuan, in preparation

# Applications: simple TMD

Spin-average one:

$$\frac{d^4\sigma}{dQ^2dyd^2q_\perp} = \sigma_0 \sum_q e_q^2 \int d^2\vec{k}_{1\perp} d^2\vec{k}_{2\perp} d^2\vec{\lambda}_\perp \delta^{(2)}(\vec{k}_{1\perp} + \vec{k}_{2\perp} + \vec{\lambda}_\perp - \vec{q}_\perp)$$
$$\times q(z_1, k_{1\perp}, \zeta_1) \bar{q}(z_2, k_{2\perp}, \zeta_2) H(Q^2) (S(\lambda_\perp, \rho))^{-1} ,$$

Spin-dependent one:

$$\frac{d^4\Delta\sigma(S)}{dQ^2dyd^2q_\perp} = \sigma_0 \epsilon^{\alpha\beta} S_{\perp\alpha} q_{\perp\beta} \frac{1}{M_P} \int d^2\vec{k}_{1\perp} d^2\vec{k}_{2\perp} d^2\vec{\lambda}_\perp \frac{\vec{k}_{1\perp}\cdot\vec{q}_\perp}{q_\perp^2} \delta^{(2)}(\vec{k}_{1\perp} + \vec{k}_{2\perp} + \vec{\lambda}_\perp - \vec{q}_\perp)$$
$$\times q_T(z_1, k_{1\perp}, \zeta_1) \bar{q}(z_2, k_{2\perp}, \zeta_2) H(Q^2) (S(\lambda_\perp))^{-1} , \quad (4$$

Calculated from CGC

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