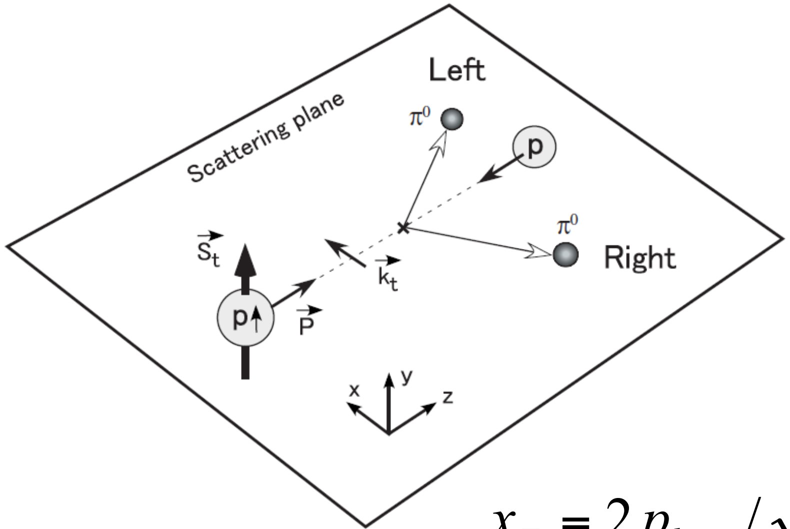
Transverse spin results from PHENIX

Vipuli Dharmawardane
for the PHENIX collaboration
New Mexico State University

Narrated by Anselm Vossen, UIUC

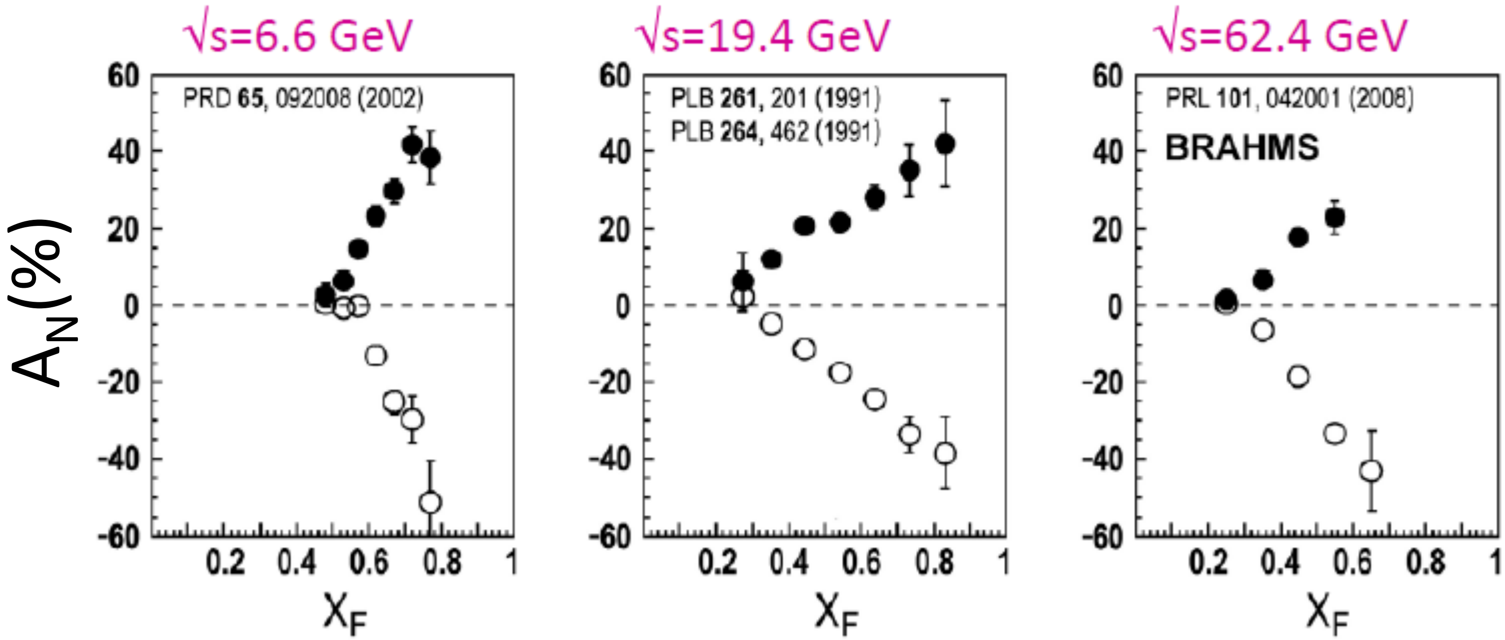
Transverse SSAs in pp scattering



In the parton model A_N is expected to be small

A_N is suppressed by $m_q \alpha_s / P_\perp$

$$x_F = 2 p_{long} / \sqrt{s}$$



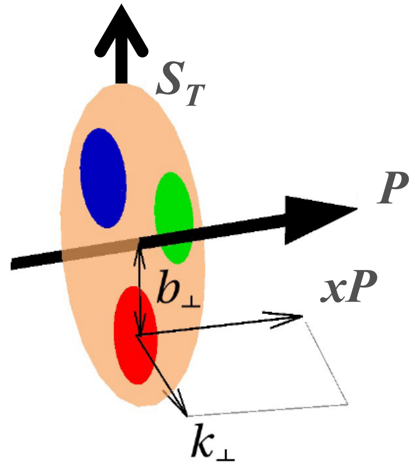
Mechanisms in QCD

I. Transverse momentum dependent (TMD) functions approach Sivers function, Collins function ...

II. Collinear factorization approach

At high transverse momenta : two twist-3 correlation functions

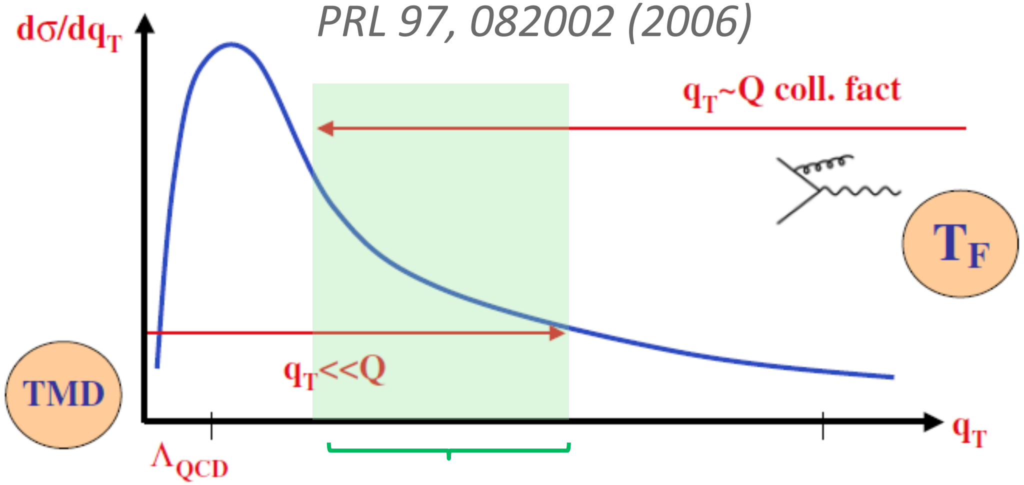
1. Quark-gluon correlation function $T_{q,F}$
2. Two independent trigluon correlation functions $T_G^{(f)}, T_G^{(d)}$



k⊥ is integrated ⇨ represent integrated spin dependence of the partons transverse motion

Are the two mechanisms related?

PRL 97, 082002 (2006)



• $T_{q,F}, T_G^{(f)}$ related to a moment in k⊥ of the corresponding quark/gluon Sivers function

Case study : Drell-Yan

In the overlap region both approaches give the same answer/physics

Processes sensitive to Sivers $PP^{\uparrow} \rightarrow \pi X$

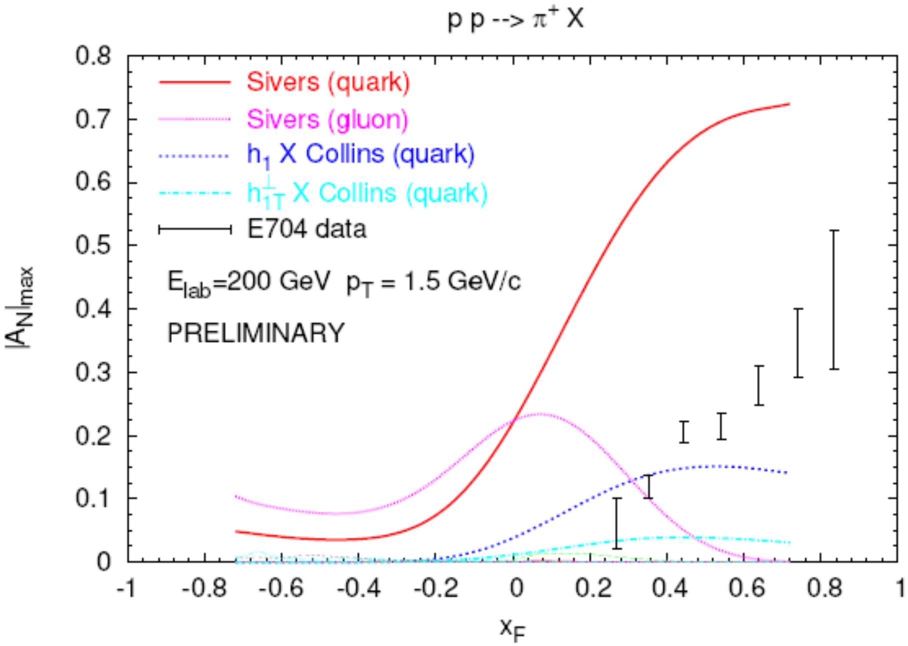
Asymmetries contain mixture of contributions from

- Sivers
- Transversity x Collins etc.

PRD 73,014020 (2006)

Different kinematics/probes sensitive to different contributions

Maximized contributions

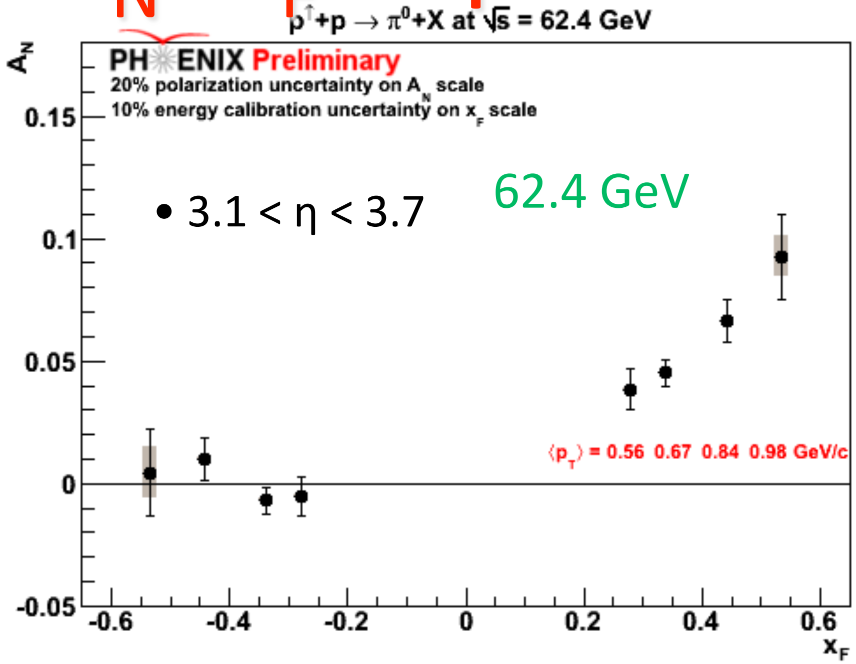


$PP^{\uparrow} \rightarrow \pi X$: largest contributions to A_N come from Sivers mechanism

- Quark Sivers large at large X_F
- Sensitive to gluon Sivers $X_F \approx 0$
- A_N at large x_F is mainly driven by valence quark properties: $x > x_F$

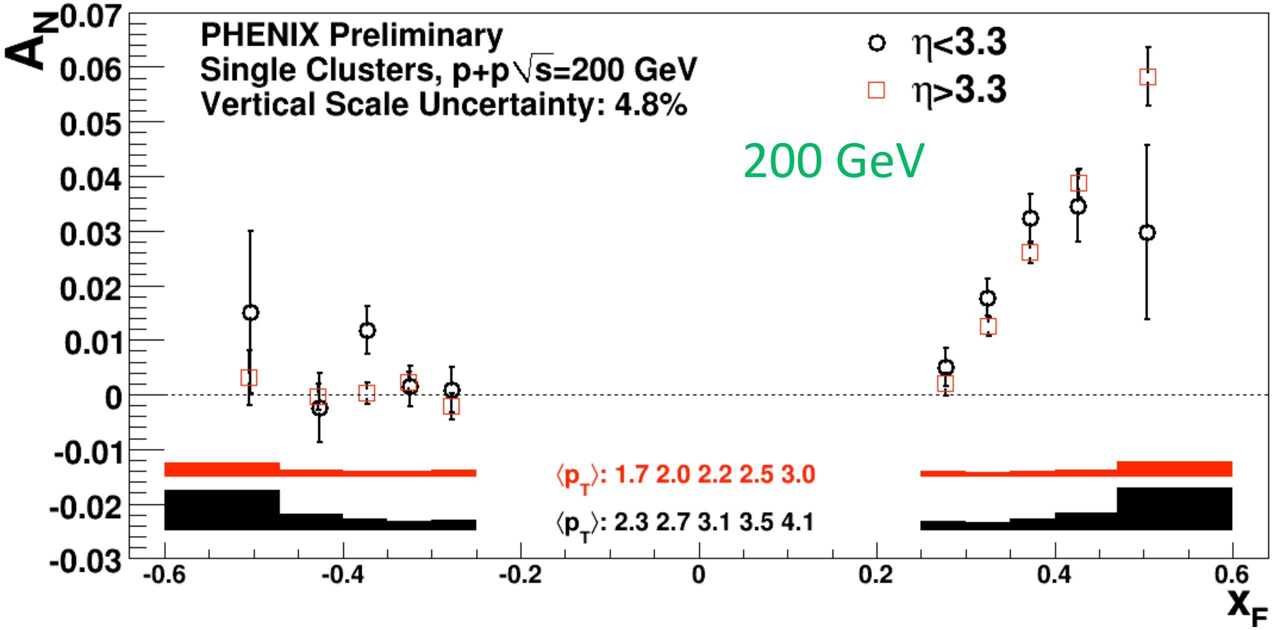
A_N: X_F dependence

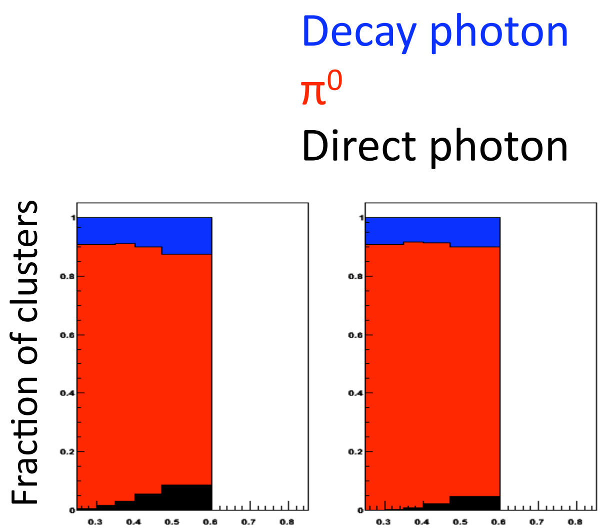
$PP^{\uparrow} \rightarrow \pi^0 X$



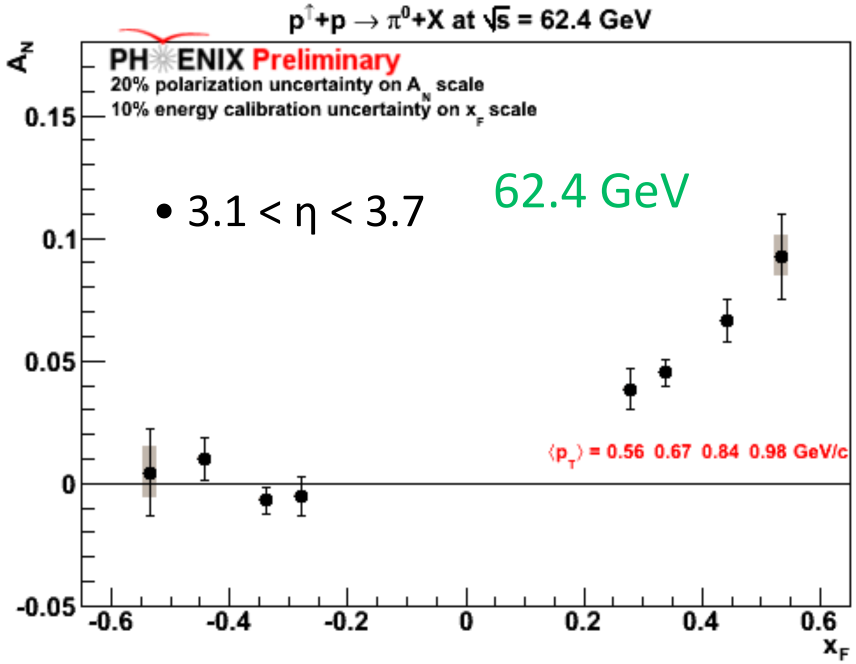
A_N at X_F >0 grows with increasing X_F

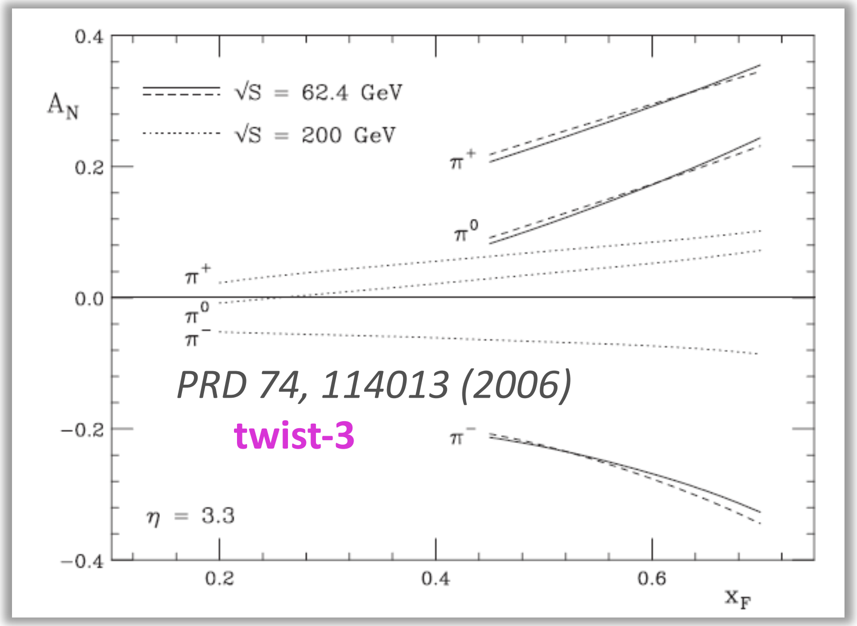
200 GeV results:
Yields dominated by π^0's but also get contributions from : Direct photons, Decay photons ,etc.

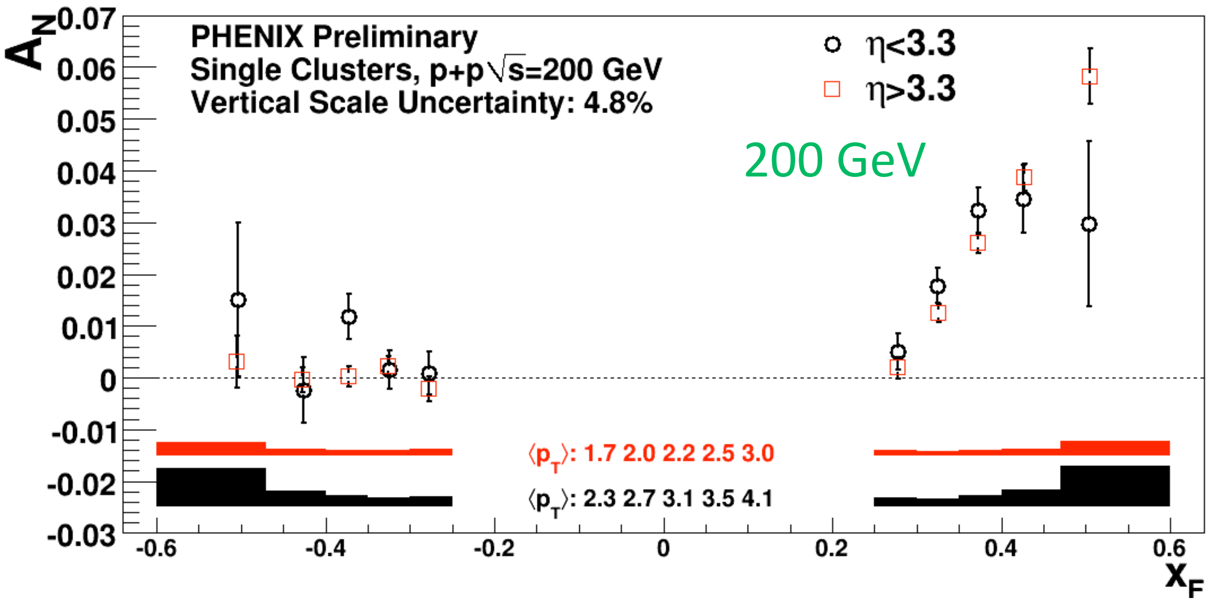




X_F dependence: Twist-3 comparison $PP^{\uparrow} \rightarrow \pi^0 X$





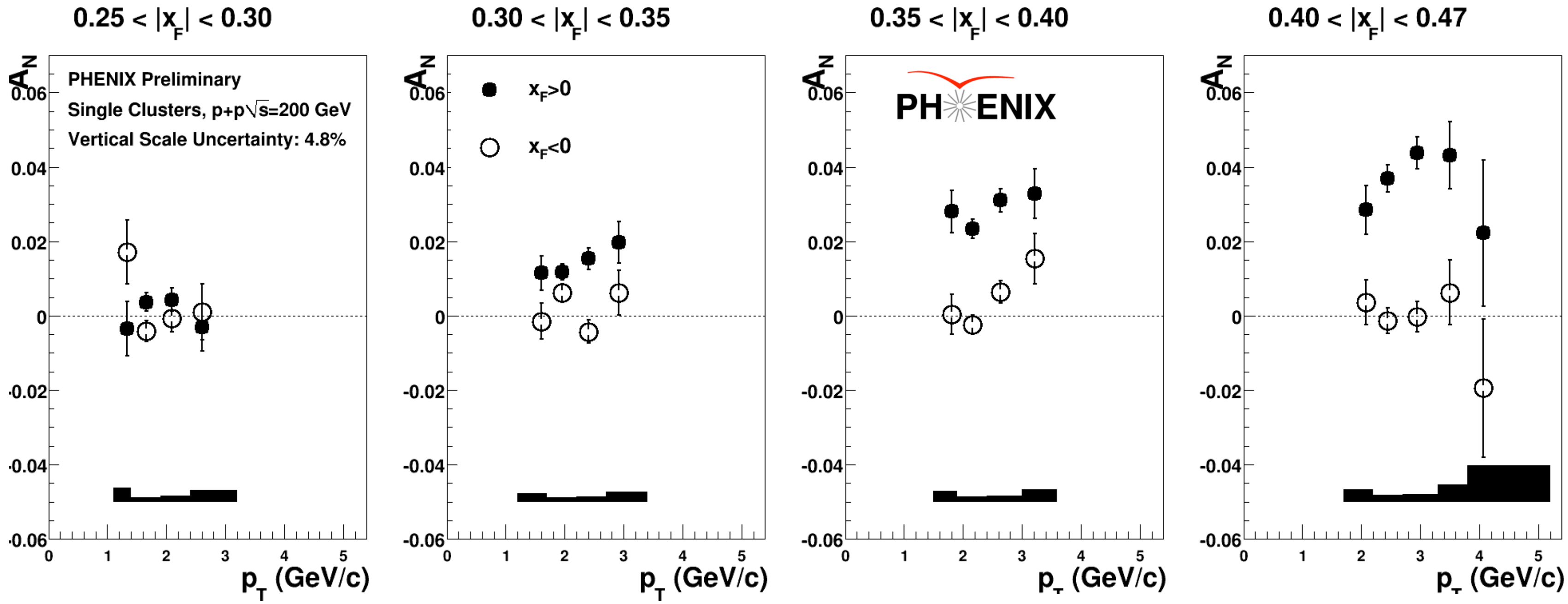


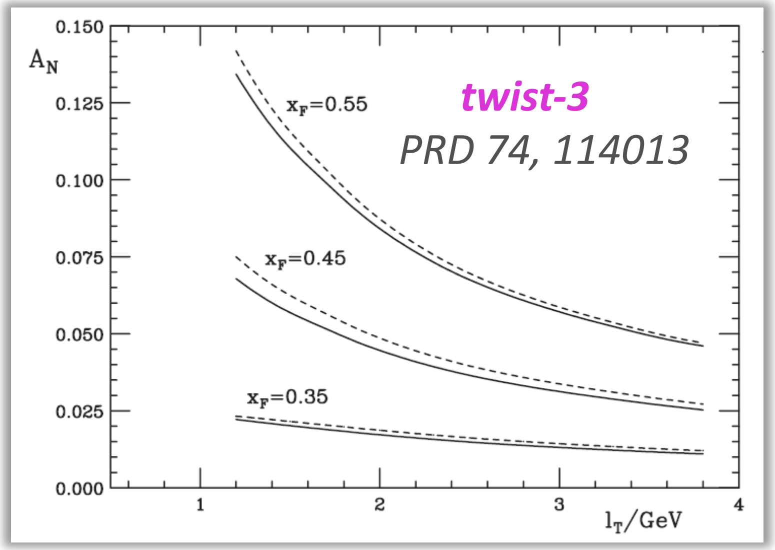
<u>twist-3 calculations:</u>

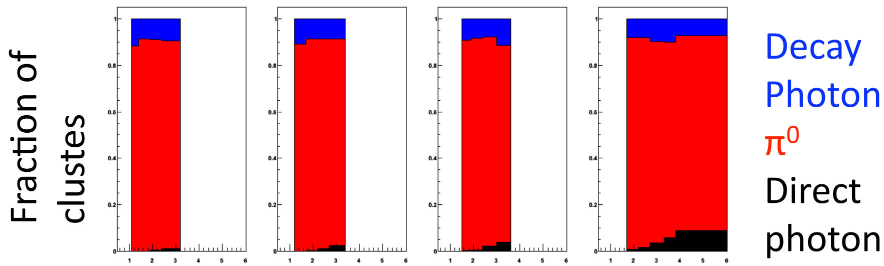
Non-pertubative effects→ predictions are based on a model / a fit to low energy data

X_F dependence consistent with predictions

A_N in X_F bins: P_T dependence $PP^{\uparrow} \rightarrow \pi^0 X$



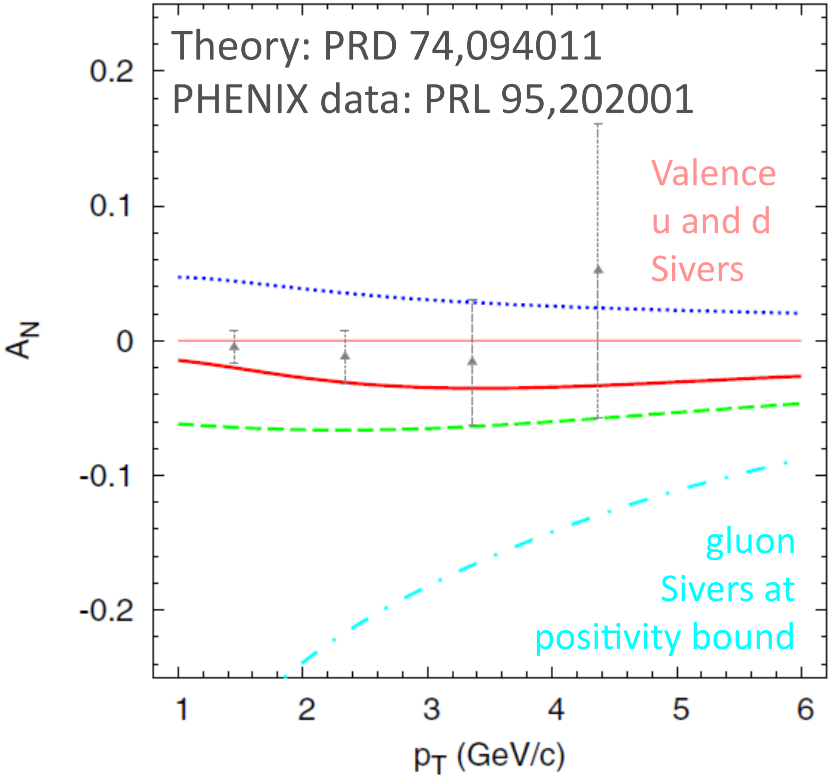




Measured A_N @ fixed X_F bins :

<u>Rising P_T dependence is not explained</u>

Processes sensitive to gluon Sivers



maximized sea and valence quark Sivers

+

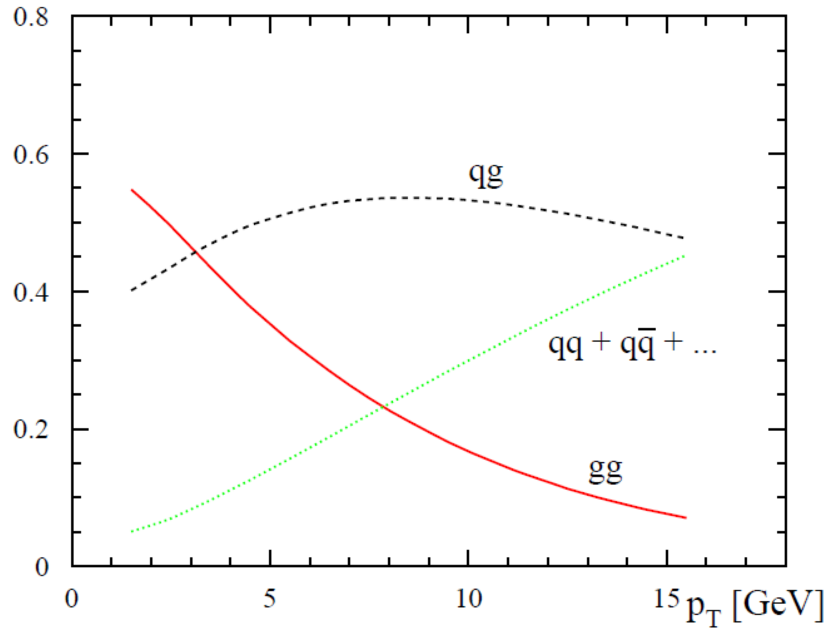
gluon Sivers when sea +valence quark Sivers at positivity bound →largest gluon Sivers compatible with PHENIX data

gluon Sivers parameterized within one sigma from PHENIX π^0 results

midrapidity

$PP^{\uparrow} \rightarrow \pi^0 X$

At small P_T → small x gluons dominate



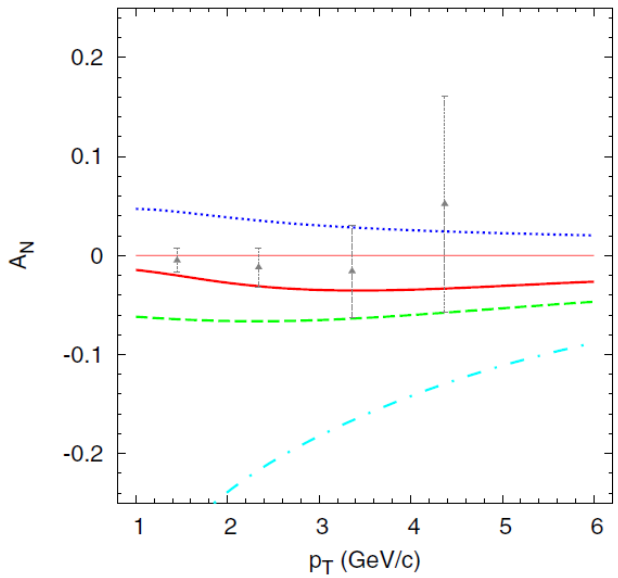
Processes sensitive to gluon Sivers

~20x better statistics

PHENIX

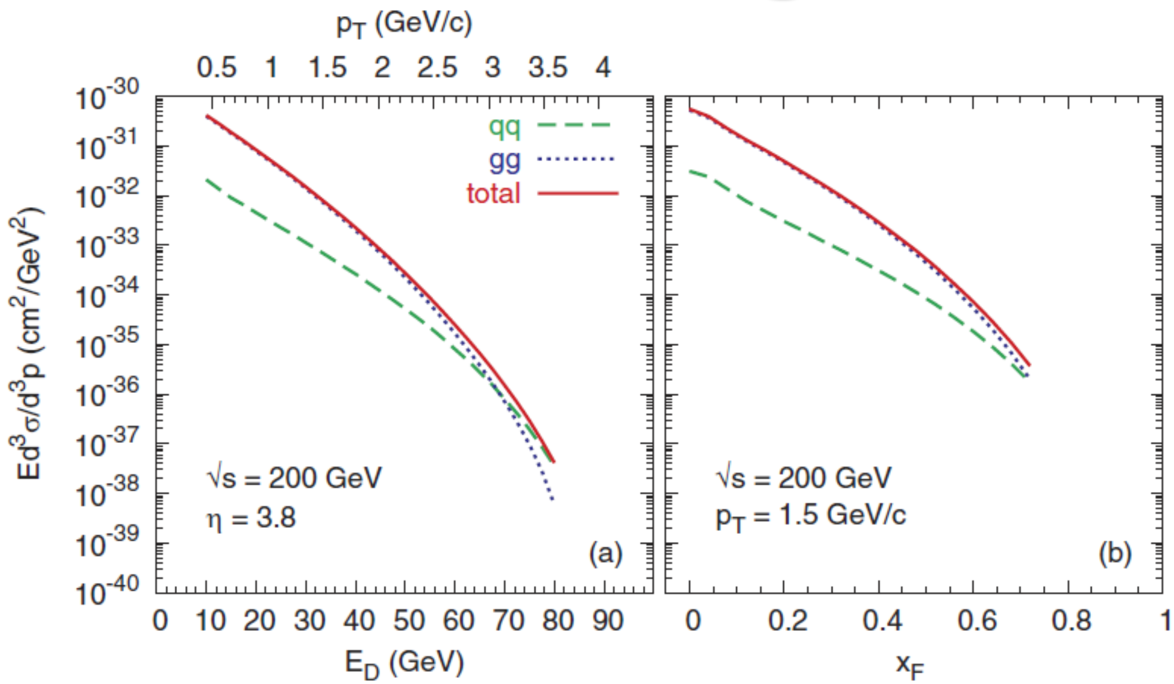
midrapidity

$PP^{\uparrow} \rightarrow \pi^0 X$



New results will impose better constraints on gluon sivers

Constraints on gluon Sivers *PRD 70,074025*



$pp^{\uparrow} \to DX$

@LO

$$gg \to c\bar{c}$$

$$q\vec{q} \to c\bar{c}$$

Cross section for gluon fusion process dominates

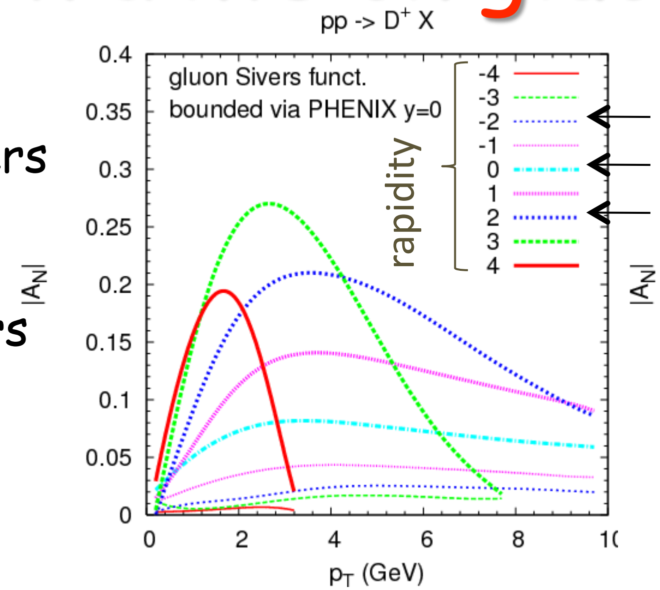
Gluons cannot carry transverse spin ⇨ $gg \to c\bar{c}$ unpolarized final quarks

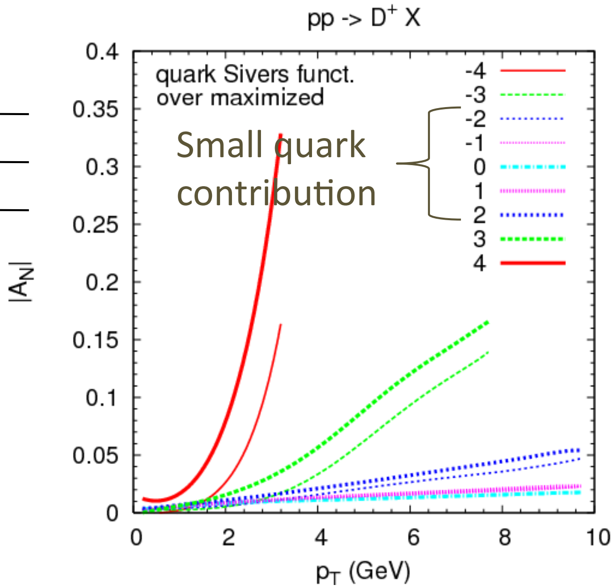
$pp^{\uparrow} \to DX$ can only be generated by the Sivers mechanism
→Possible to isolate gluon Sivers

Constraints on gluon Sivers

PRD 70,074025

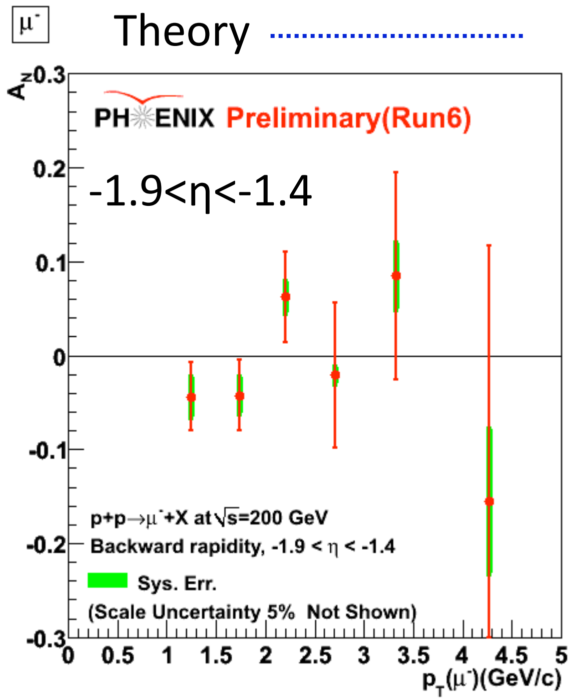
- Quark Sivers set to zero
- Gluon Sivers set to max



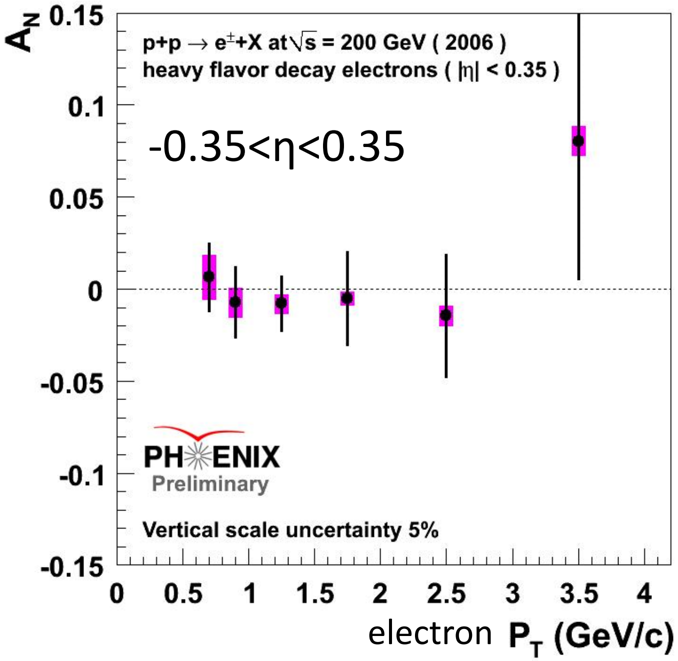


- Quark Sivers set to max
- Gluon Sivers set to zero

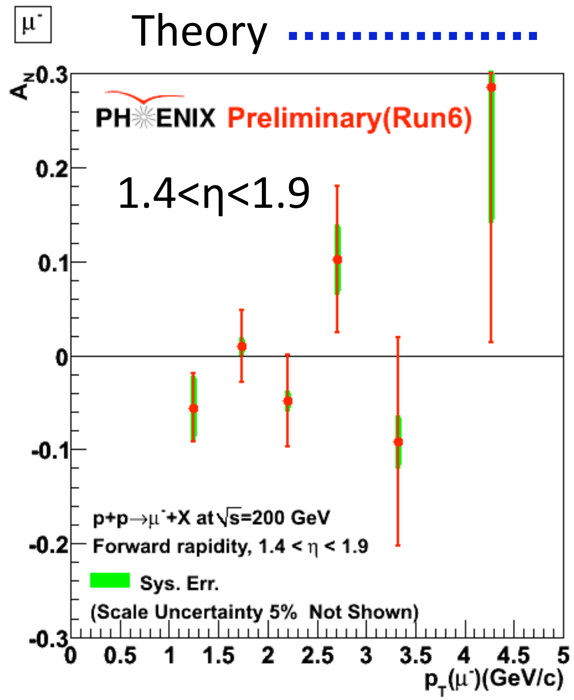
Theory



Theory

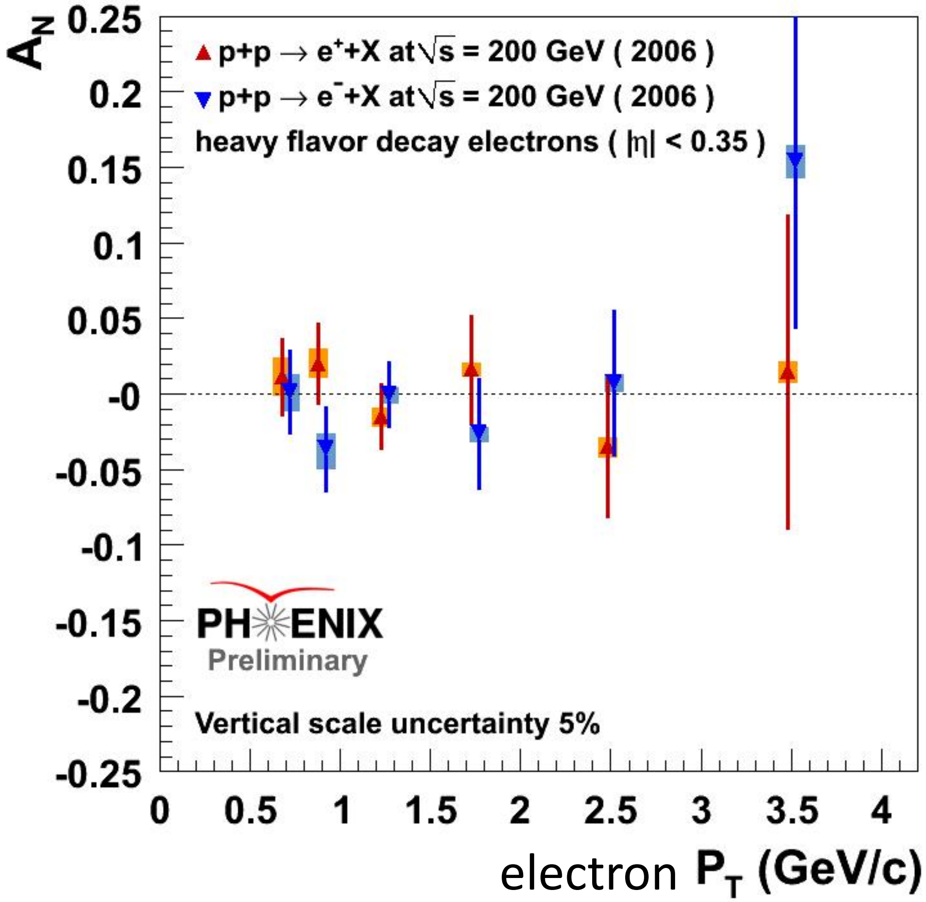


Theory

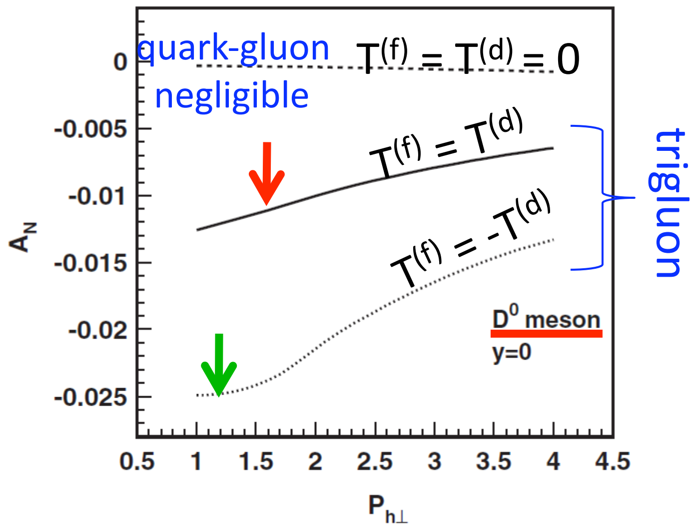


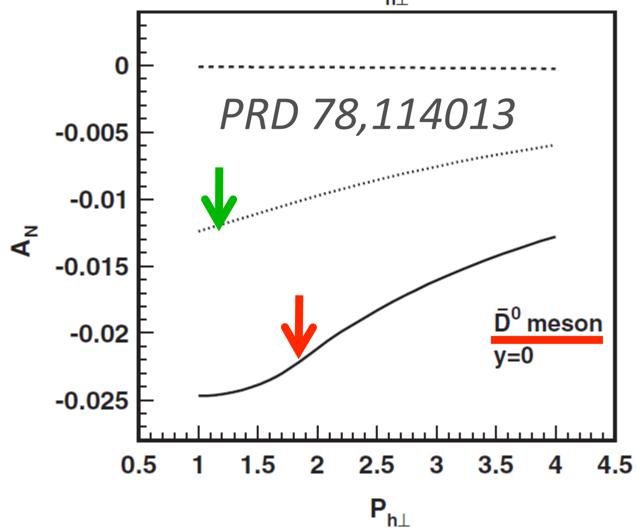
Constraints on trigluon correlations

Single Sivers function → A_N for $D = \bar{D}$



model trigluon correlation functions using ordinary unpolarized gluon distribution function : A rough estimate



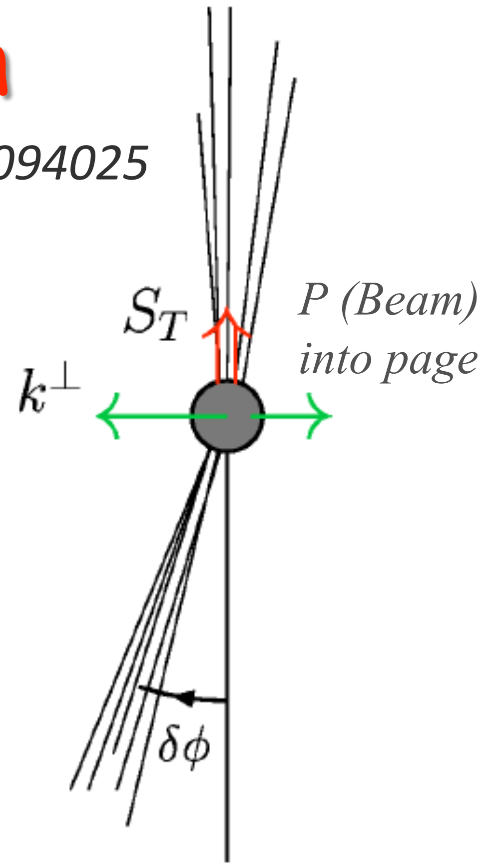


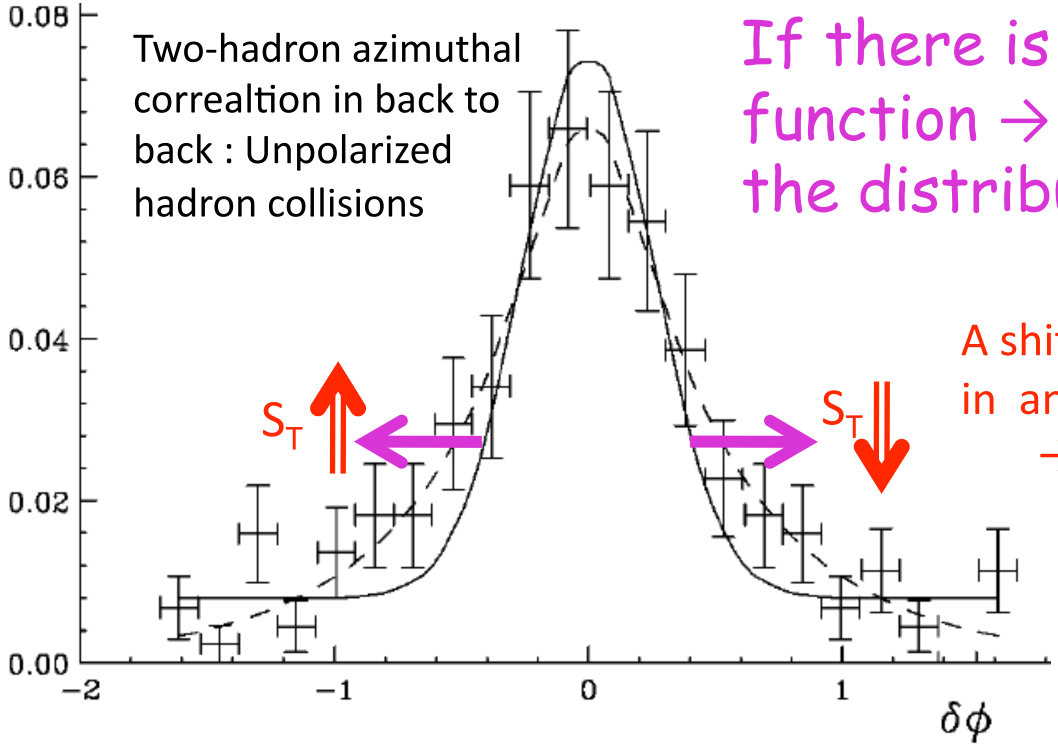
- Need to translate muon/electron kinematics to D meson kinematics : simulations underway
- $T^{(f)}$ is related to Sivers , disentangle $T^{(f)}$ and $T^{(d)}$

Accessing Sivers function

- If Sivers exist →a preference for partons to have a component of k⊥ to one side
- left right imbalance in K⊥ of the partons will affect the dø distribution of jets nearly opposite to the first jet

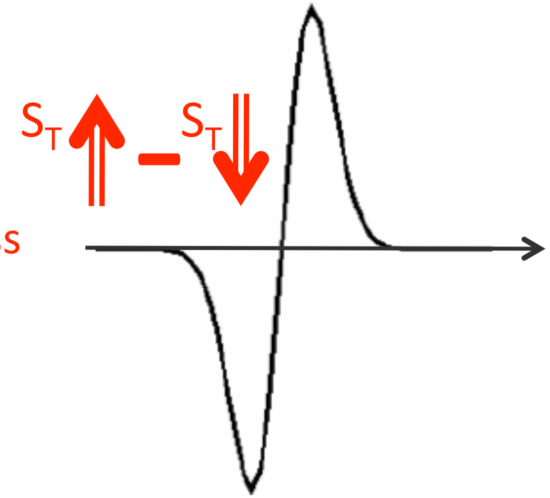
PRD 69,094025





If there is Sivers function → a shift in the distribution

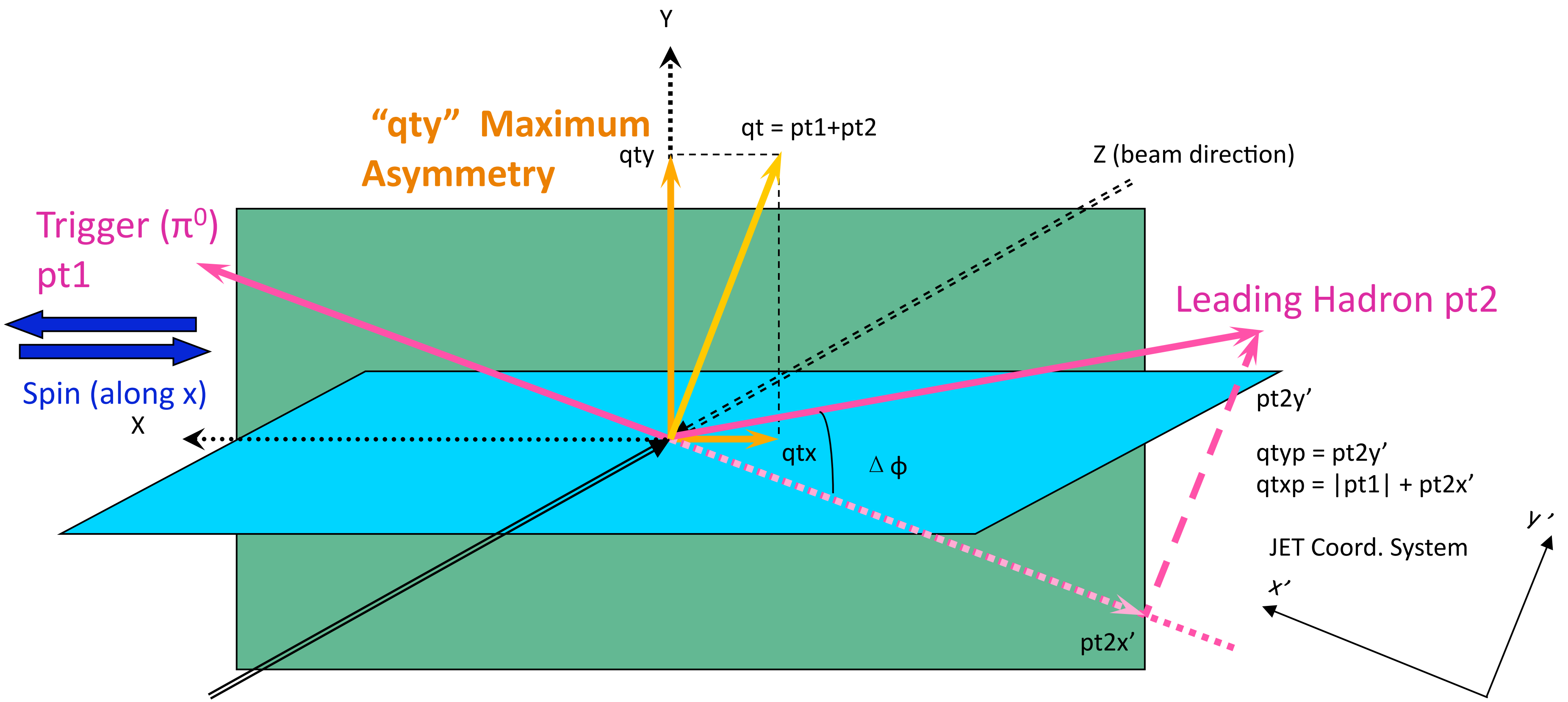
A shift will result in an asymmetry
→ direct access to Sivers



Accessing Sivers function

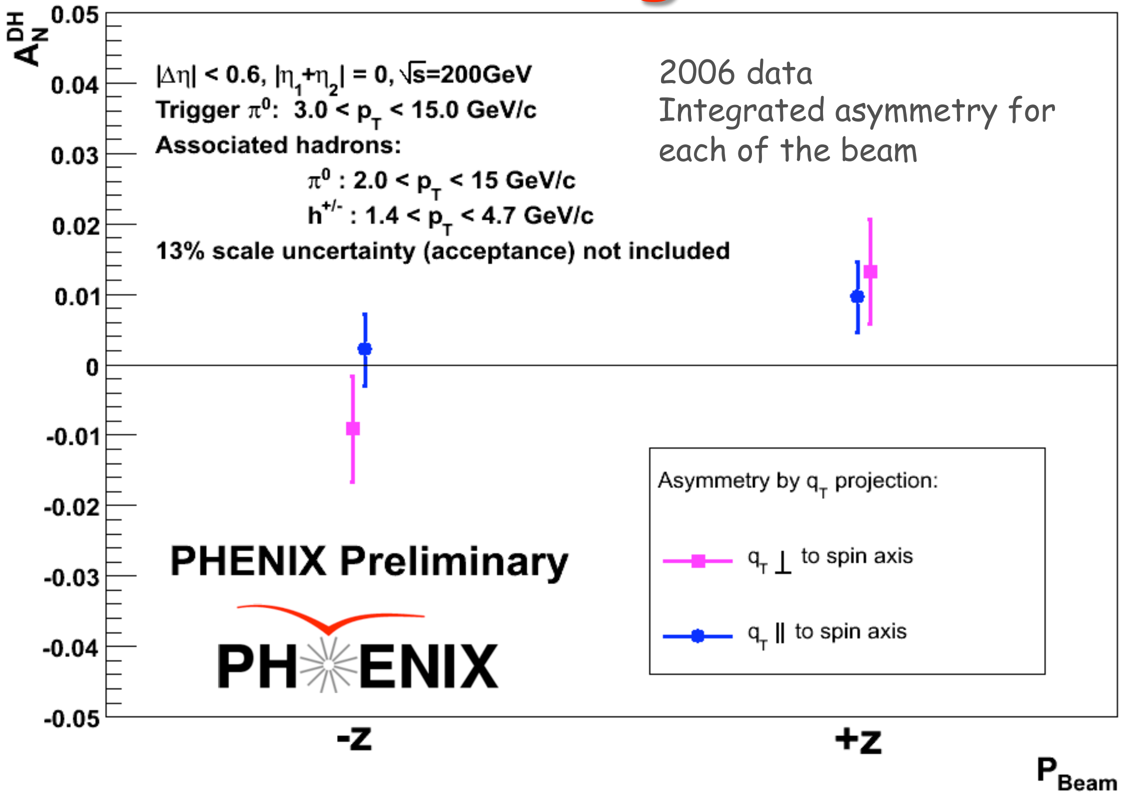
$PP^{\uparrow} \rightarrow h_1 h_2 X$ back-to-back instead of dijets :

Possible to access the same physics



Measure the sum of two leading back-to-back hadrons' transverse momentum as qt

Accessing Sivers function



A_N for $q_T \perp$ is Sivers asymmetry

A_N for $q_T ||$ should be zero: only a cross check

A_N is expected to be small at midrapidity

PRD75,074019

- Sivers function is process dependent
- processes due to initial-state and final-state interactions expected to give asymmetries opposite in sign
- Both initial-state and final-state interactions contribute to the Sivers asymmetry for dijet production

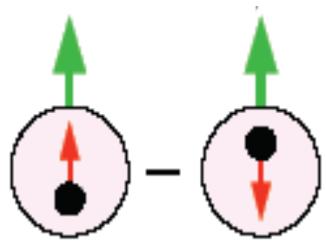
Similar analysis possible in different combinations of rapidity

η_{min}	-3.7	-2.0	-0.35	1.4	3.1
η_{max}	-3.1	-1.4	+0.35	2.0	3.9

Works in progress…

Transversity dq(x)

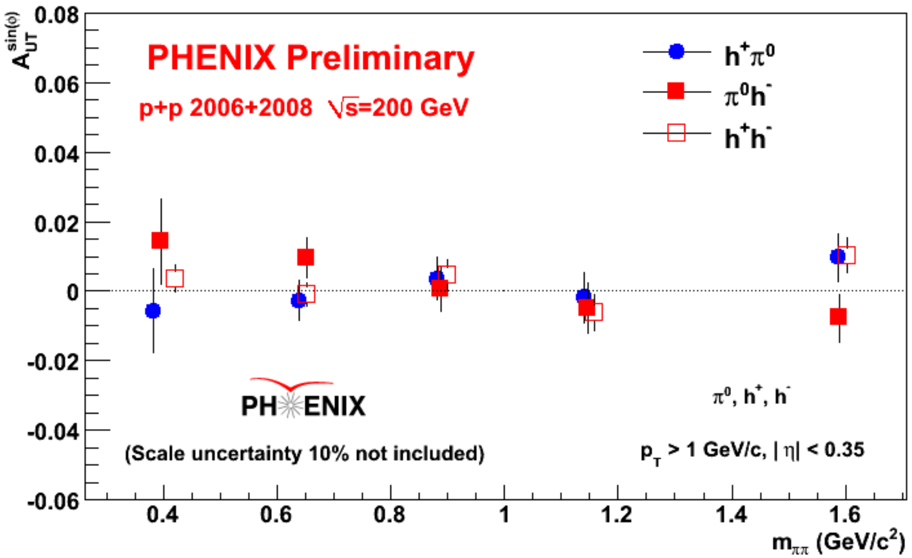
Transverse spin information at leading twist

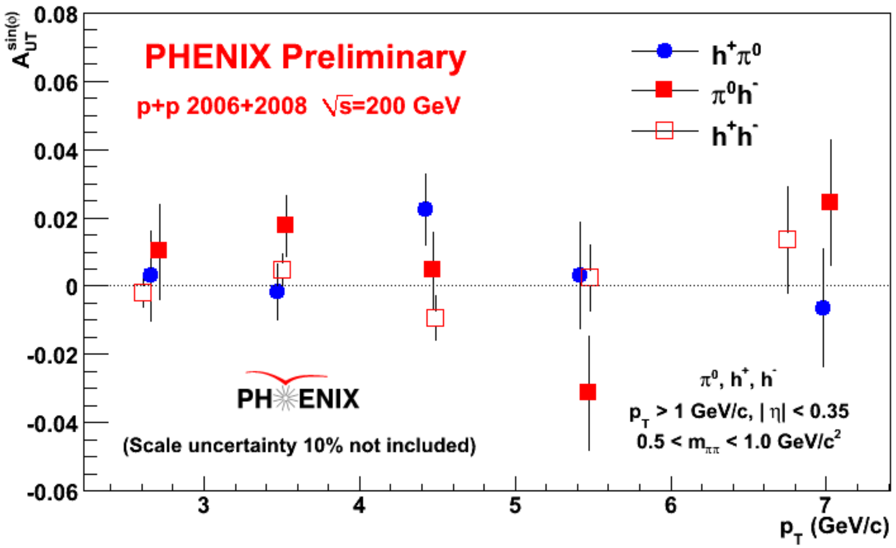


$$A_{UT,\phi}^{h_1,h_2} = \frac{\sigma_\phi^{\uparrow} - \sigma_\phi^{\downarrow}}{\sigma_\phi^{\uparrow} + \sigma_\phi^{\downarrow}}$$

Measure dq X Interference Fragmentation functions

Transversity extraction will become possible with Interference Fragmentation Function - BELLE has shown first observation of IFF asymmetries





Exploring analysis with hadrons in forward region

Summary and Outlook

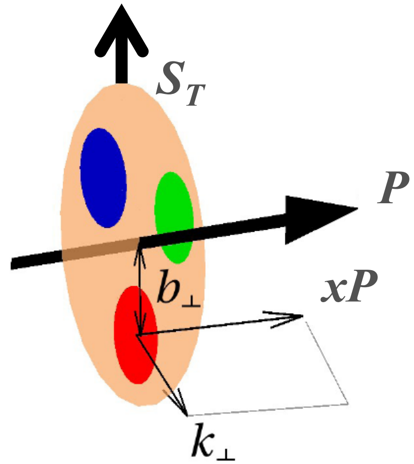
- Good physics program to study the transverse spin structure of the nucleon at PHENIX
  - Non-zero single spin asymmetries in forward region
  - Different channels to understand different contributions to large asymmetries
  - Central rapidity results: constraints on gluon Sivers

- Outlook
  - Measure di-hadron back-to-back asymmetries with large rapidity combinations
  - Explore IFF at forward rapidities
  - Check process dependence of Sivers mechanism: measure Drell-Yan Sivers A_{Siv} (Drell-Yan) = -A_{Siv} (DIS)

BACKUP SLIDES

Mechanisms in QCD

I. Transverse momentum dependent (TMD) functions approach



Sivers function:

- TMD distributions of unpolarized partons in a transversely polarized nucleon
- correlation between the transverse spin of the nucleon and parton k⊥

Collins function:

- TMD fragmentation function
- Correlation between the transverse spin of a fragmenting quark and the transverse momentum of the hadron

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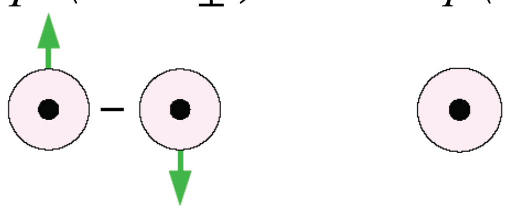
Sivers effect

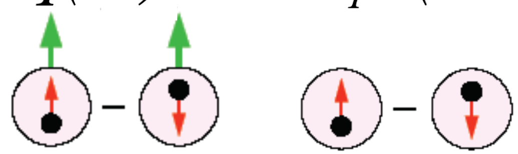
$$f_{1T}^{\perp q}(x,k_\perp) \otimes D_1^q(z)$$



Sivers function unpol FF

Quark transverse polarization x Collins fragmentation function

$$\delta q(x) \otimes H_1^{\perp q}(z,k_\perp)$$



Transversity Collins function

Mechanisms in QCD

II. Collinear factorization approach

At high transverse momenta : two twist-3 correlation functions

1. Quark-gluon correlation function $T_{q,F}$
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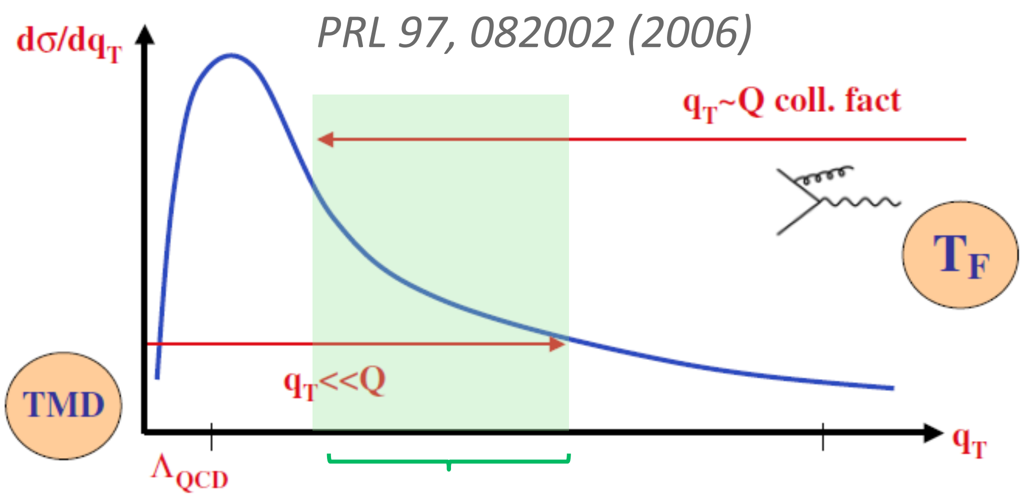
Parton's transverse momentum k⊥ is integrated ⇨ represent integrated spin dependence of the partons transverse motion

Are the two mechanisms related?

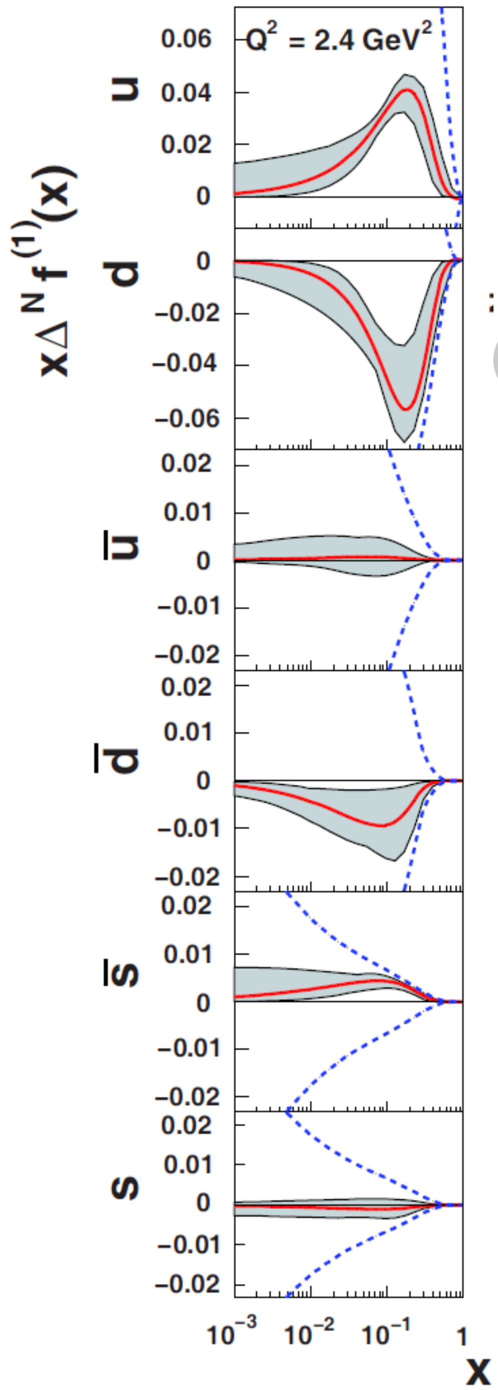


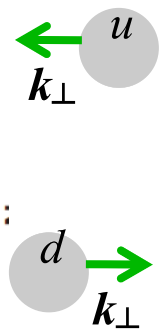
• $T_{q,F}, T_G^{(f)}$ related to a moment in k⊥ of the corresponding quark/gluon Sivers function

Case study : Drell-Yan

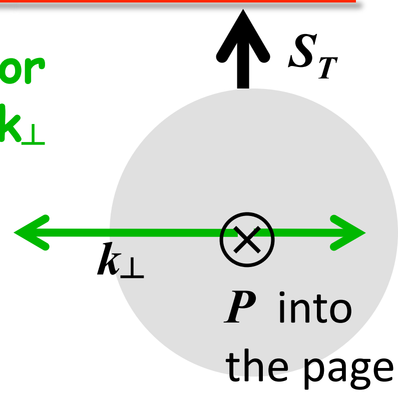
In the overlap region both approaches give the same answer/physics

Phenomenology of Sivers function





If Sivers exist →a preference for partons to have a component of $k_\perp$ to one side



Orbital angular momentum of partons is needed for a non vanishing Sivers effect *PLB530,99*

→no quantitative relation yet

The sum of the transverse momenta due to the Sivers mechanism from all partons combined should vanish

$$\sum_a \langle k_\perp^a \rangle = 0$$

PRD 69, 091501

Eur. Phy J A39,89(2009)

Analysis of SIDIS data

The sum rule is almost saturated by *u* and *d* quarks

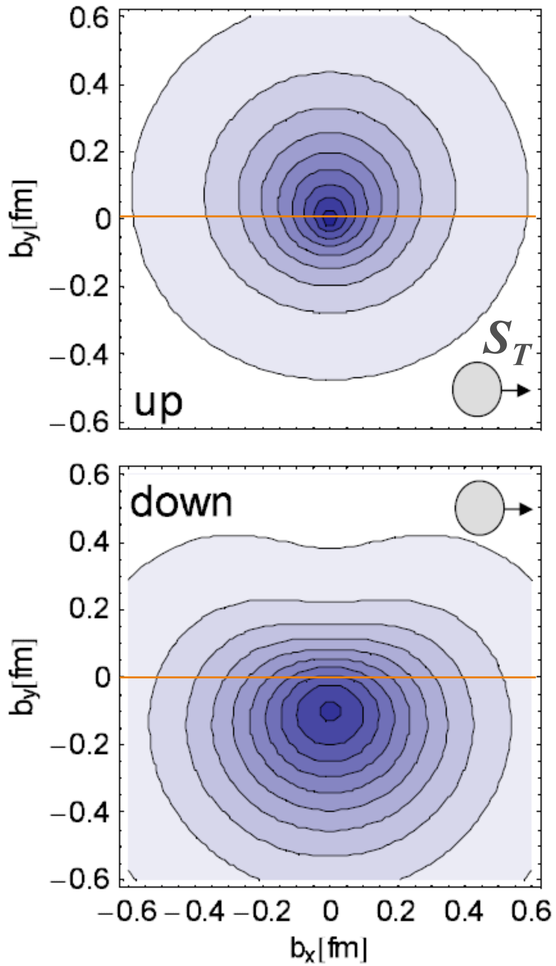
Gluon Sivers function should be small

$$-10 \leq \langle k_\perp^g \rangle \leq 48\,(\mathrm{MeV}/c)$$

Phenomenology of Sivers function

Distortion of quark densities as origin of asymmetry

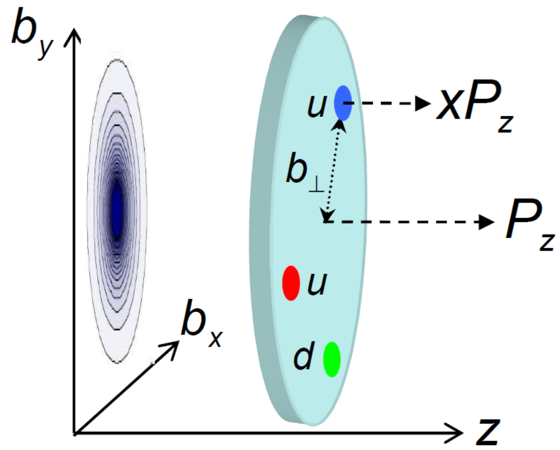
Nucl. Phys. A735,185



Lattice calculations

quark densities of unpolarized quarks in a transversely polarized nucleon in impact parameter space

PRL 98,222001
Hep-lat:0912.5483



Hope to see similar lattice calculations for $k_\perp$ densities in the transverse momentum plane soon……

Gluon Sivers and J/ψ production mechanisms

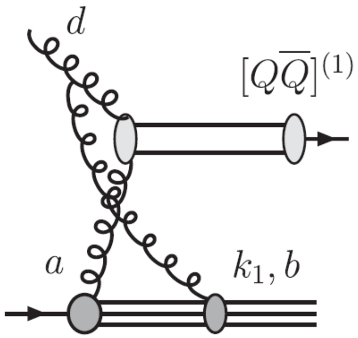
J/ψ production mechanisms not well understood

<u>pp scattering</u>

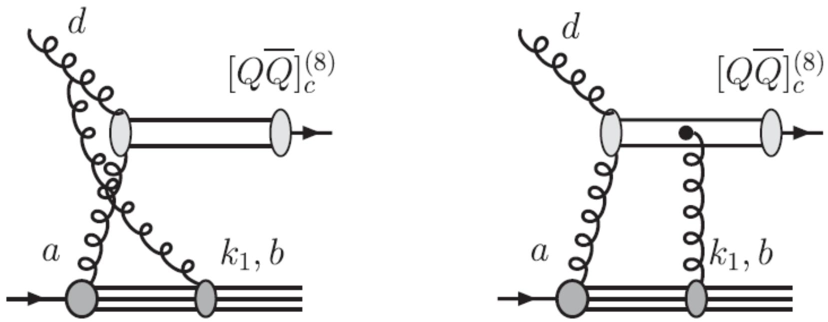
→ non-zero A_N due to gluon Sivers expected only in <u>color-singlet model</u> : Only initial state interactions

→zero A_N due to gluon Sivers in <u>color octet model</u> : cancellation of initial and final state interactions

PRD 78,014024



Color singlet model
Only initial state interactions



Color octet model
initial and final state interactions

Opportunity to understand J/ψ production mechanisms