A Menu for Spin Physics at RHIC II

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RBRC & BNL Nuclear Theory

RHIC II Science Workshop 11/19

Main focus of this talk :

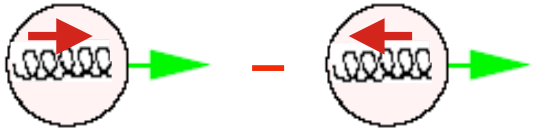
What will (likely) be the compelling questions in spin physics in the RHIC II era ?

What could be the corresponding key measurements at RHIC II ?

What would it take to do those ?

***Disclaimer : this talk will not have complete answers …**

Cornerstones of present RHIC spin program:

- **Gluon polarization** $\Delta g(x) =$  $-$

  gluons key contributors to the proton spin ?

- **$u, \bar{u}, d, \bar{d}$ polarizations from W production**

  important insights into dynamics in nucleon sea

- **Transverse-spin phenomena in QCD**

  transversity, single-spin asymmetries, orbital ang. mom., …

- **Elastic pp scattering**

  cross sections and spin asymmetries in new kinematic domain

The "baseline" RHIC spin program will provide important information on each of these topics, advancing our understanding of QCD and Nucleon structure.

Sustained running at high polarization and luminosity will be benefitial :

→ **Increased statistics**

- **rare probes**
- **more detailed measurements / wider kinematics**
- **can exploit the detector upgrades expected over next few years**
- **can explore other "genuinely new things"**

Gluon polarization

- **a particular strength of RHIC :**
  can probe $\Delta g(x)$ in various channels

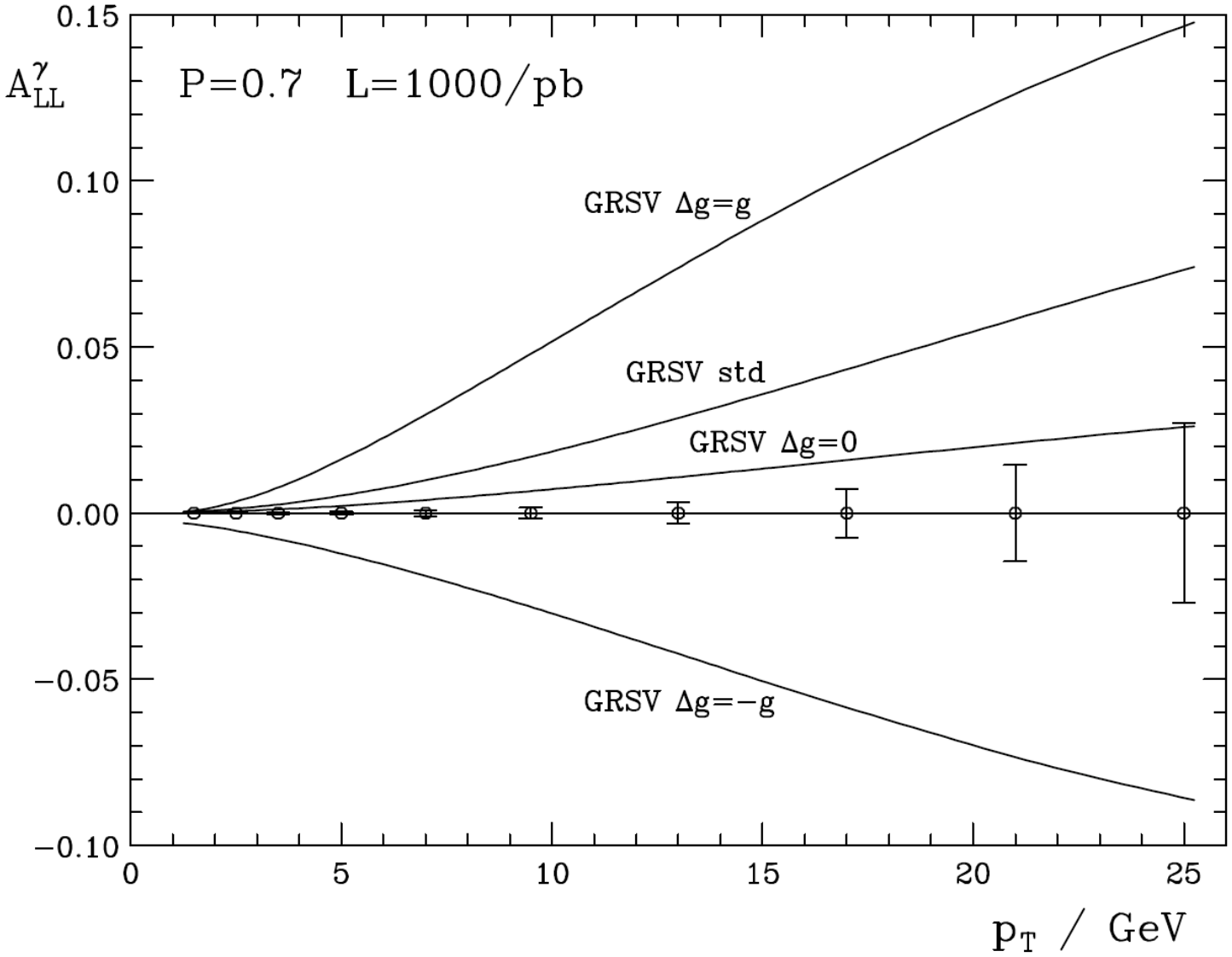
- **typically, high-p_T photons, hadrons, jets, heavy fl.**

$$x_g \sim 2\,p_T/\sqrt{s}$$

$0.025 < x_g < 0.3$ @ $\sqrt{s} = 200$ GeV

$0.01 < x_g < 0.1$ @ $\sqrt{s} = 500$ GeV

- **perhaps, determine unpolarized gluon distrib.?**



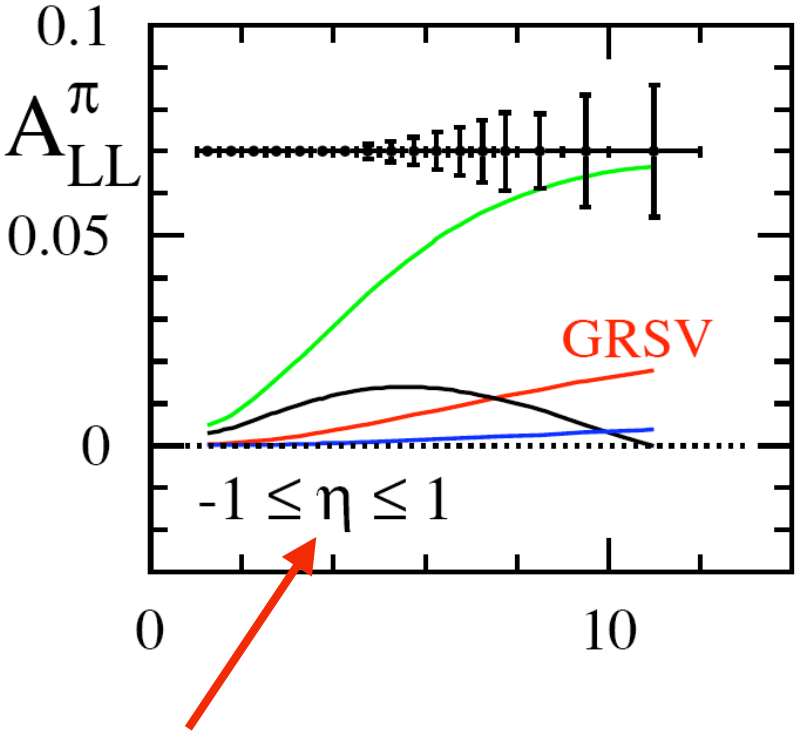
$\sqrt{s} = 200$ GeV $\quad |\eta| < 0.38$

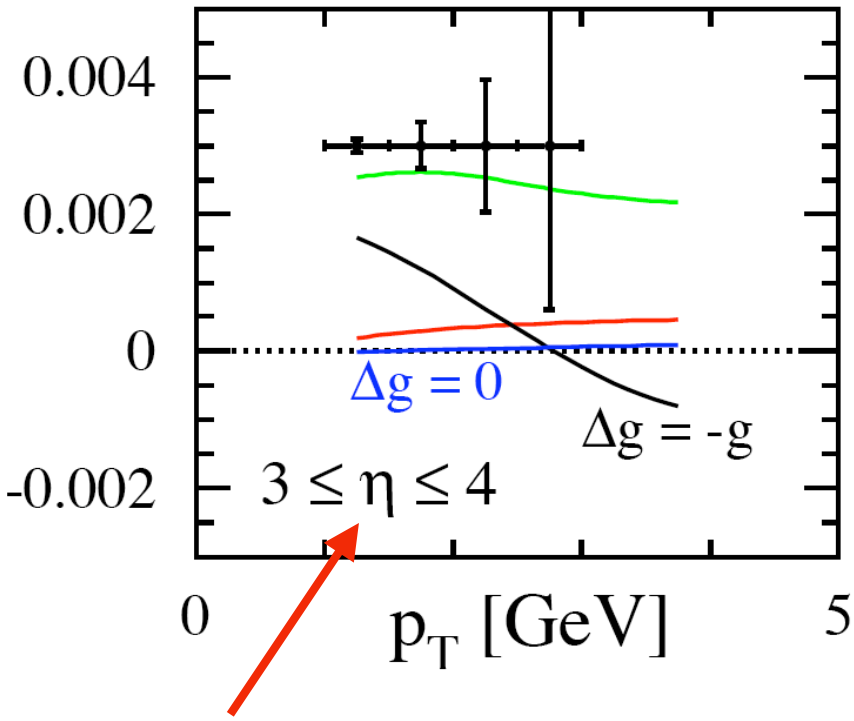
- how well are we going to get the integral ?
- $\langle S_g \rangle = \int_0^1 dx\, \Delta g(x, Q^2) \propto \frac{1}{\alpha_s(Q^2)}$ in QCD

  is that testable ?
- may gain more information at small x with the help of planned forward detector upgrades
- this will require good statistics

Jäger, Stratmann, WV

L = 7/pb, P = 0.4

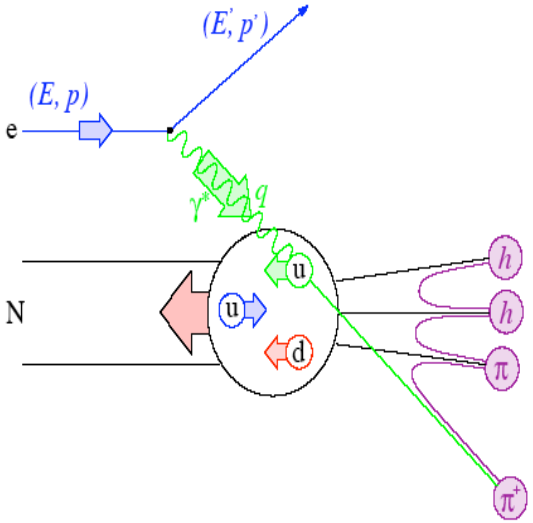




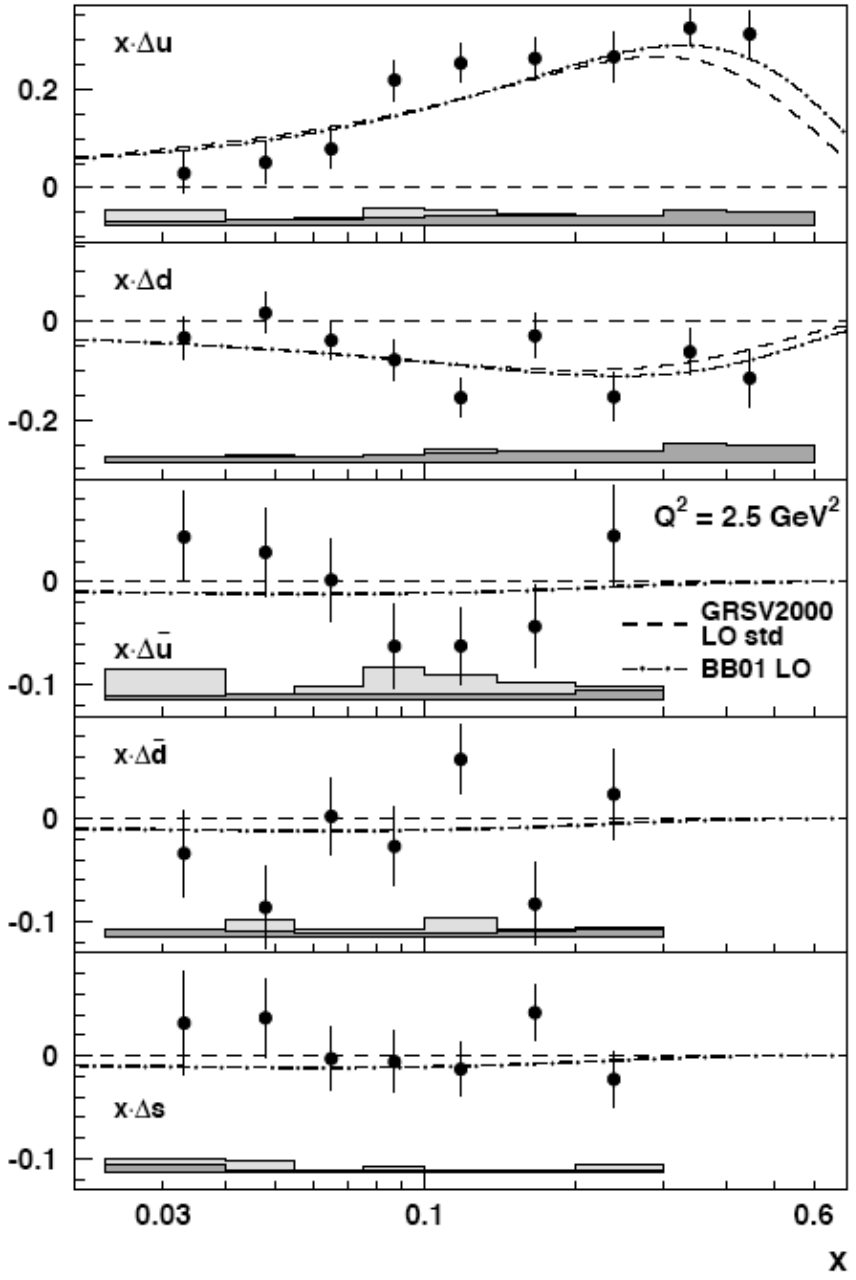
(Sea) Quark polarizations

Current status

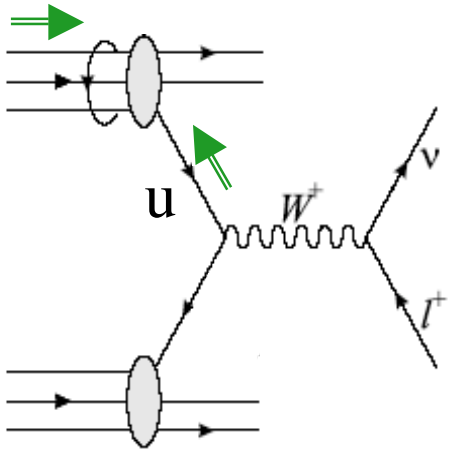
(HERMES)



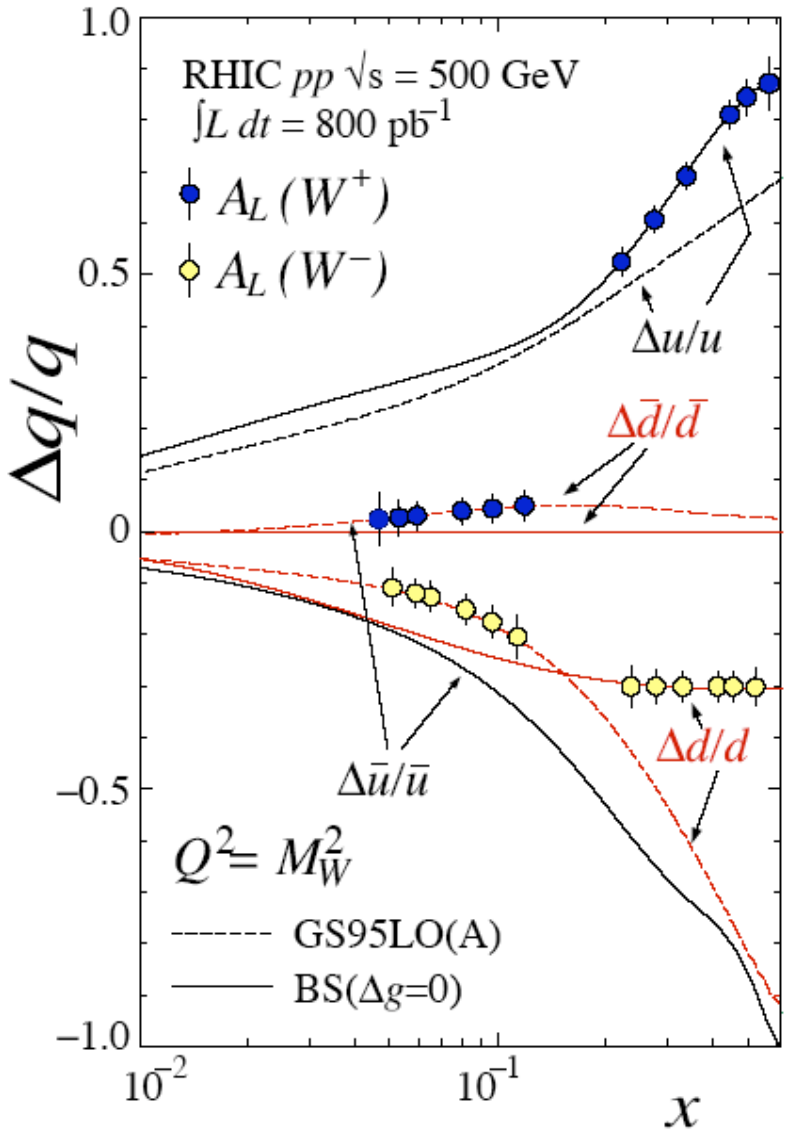
π^-, $K^{\pm}$, ...



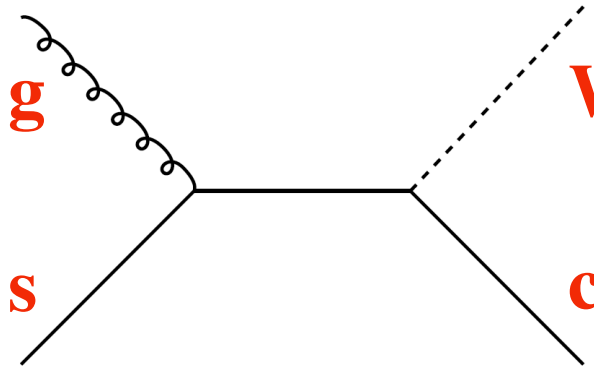
(large theoretical uncertainties)


u
W^+
ν
l^+

unpol.


RHIC pp √s = 500 GeV
$\int L\,dt$ = 800 pb^{-1}
$A_L\,(W^+)$
$A_L\,(W^-)$
$\Delta u/u$
$\Delta\bar{d}/\bar{d}$
$\Delta\bar{u}/\bar{u}$
$\Delta d/d$
$Q^2 = M_W^2$
GS95LO(A)
BS(Δg=0)
$\Delta q/q$
1.0
0.5
0
−0.5
−1.0
10^{-2}
10^{-1}
x

- can one determine strange quark polarization ?
- remember, deviation from Ellis-Jaffe sum rule is related to strange quarks
- associated W+charm production a possibility ?



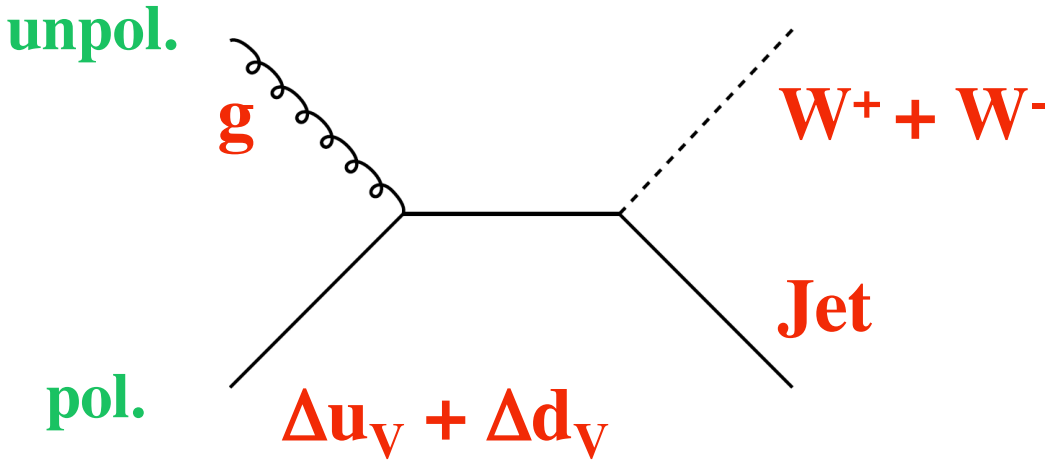
"D-tagged W's"

s vs. $\bar{s}$?

Ji, Kretzer,Saito, Soffer, Ming, Sudoh, Yokoya

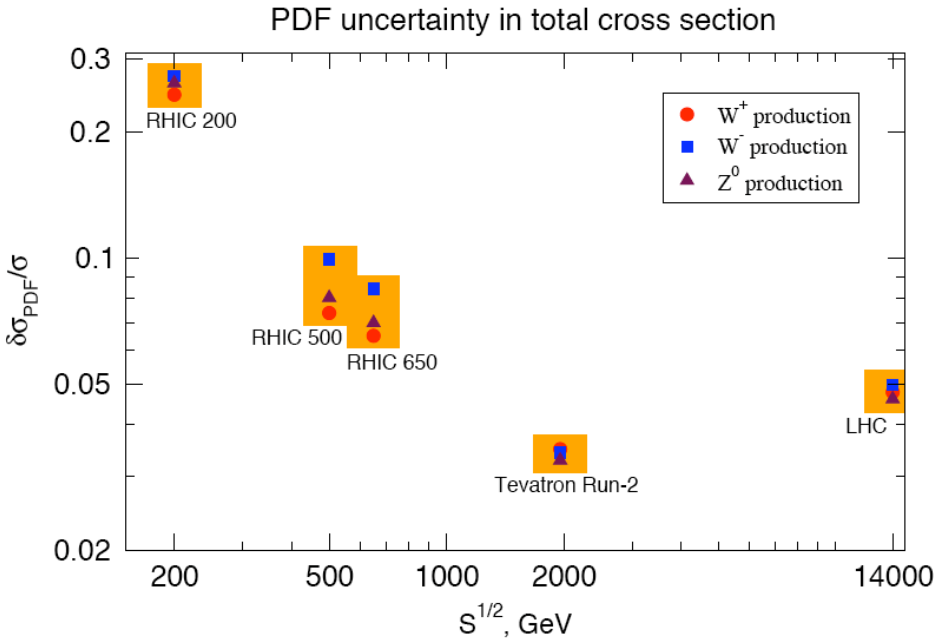
- total cross section ~ few pb : again a question of statistics (& energy ?)
- complementary to νp elastic scattering ?

- **associated W+jet production ?**

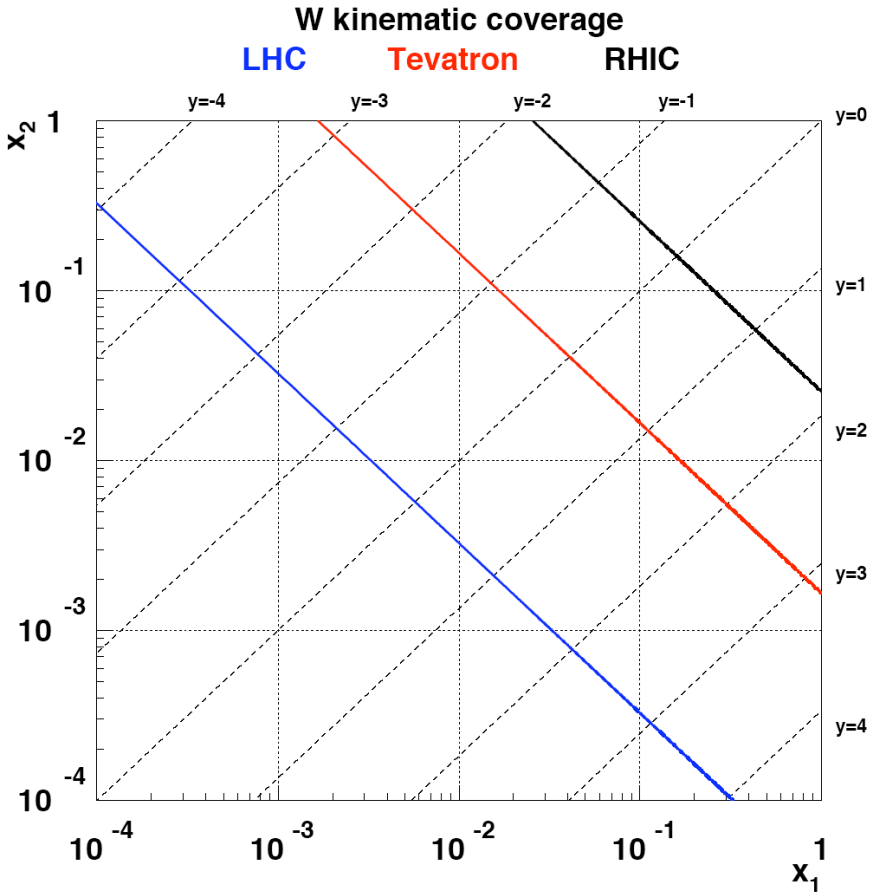


- **opportunities for unpolarized physics ?**

Nadolsky, Yuan



(courtesy B. Surrow)

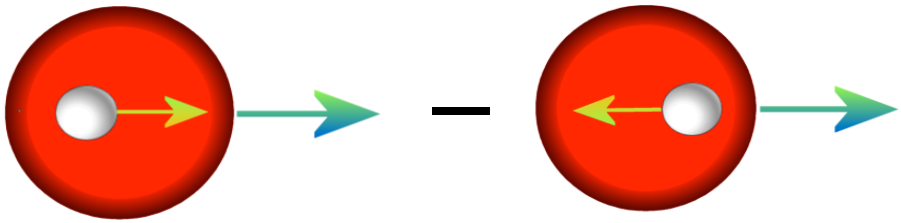


→ **Sea quarks at large x**

Transversity

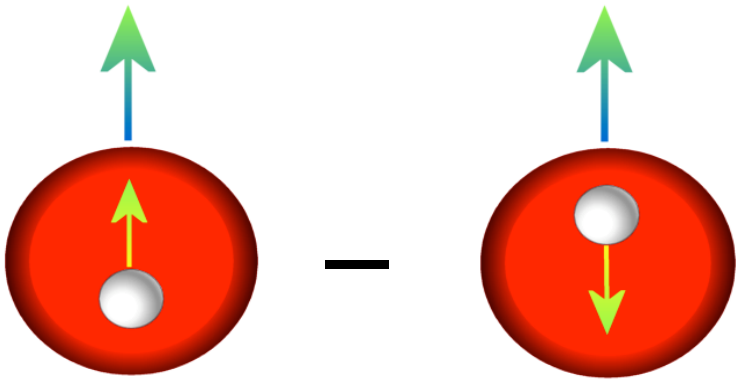
Helicity :

$$\Delta q(x) = \quad - \quad$$



Transversity :

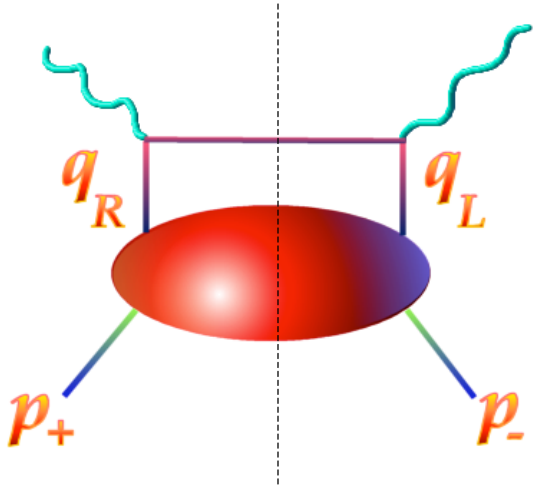
$$\delta q(x) = \quad - \quad$$



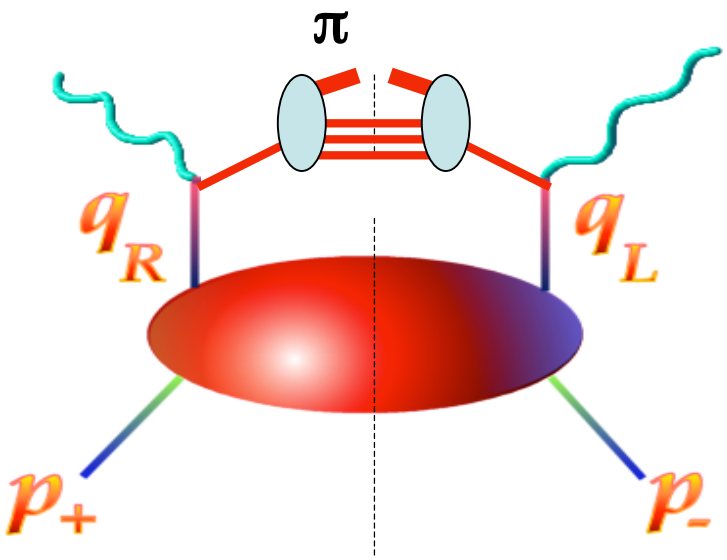
- **the unknown "leading-twist" distribution functions**
- **the physics involved:** relativistic / dynamical effects, helicity-flip, χSB, nucleon tensor charge $\langle P | \bar{q}\, i\sigma^{\mu\nu}\gamma^5\, q | P \rangle$, …

- **Hard to measure :**

  * not in inclusive DIS:



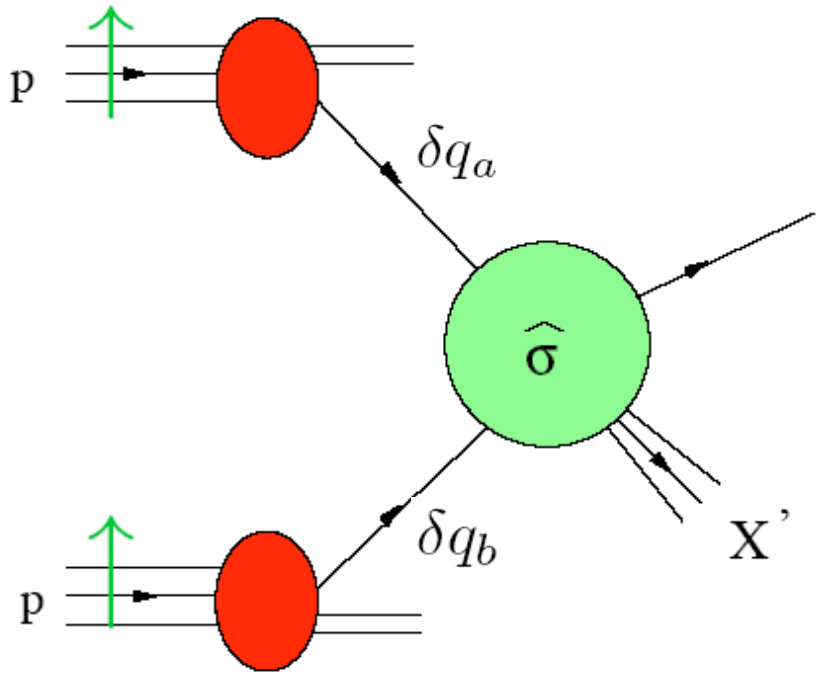
  * helicity-flip from final-state effect :



"Collins effect"

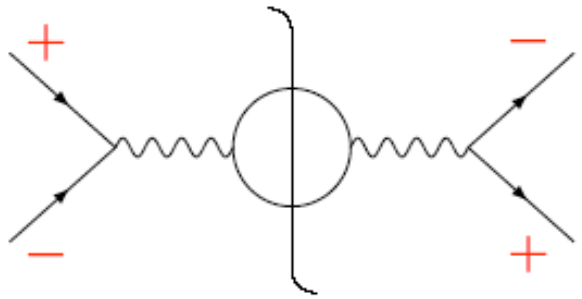
  * initial studies done by HERMES and COMPASS, limited inform.

- **The most straightforward (and clear-cut) probe :**

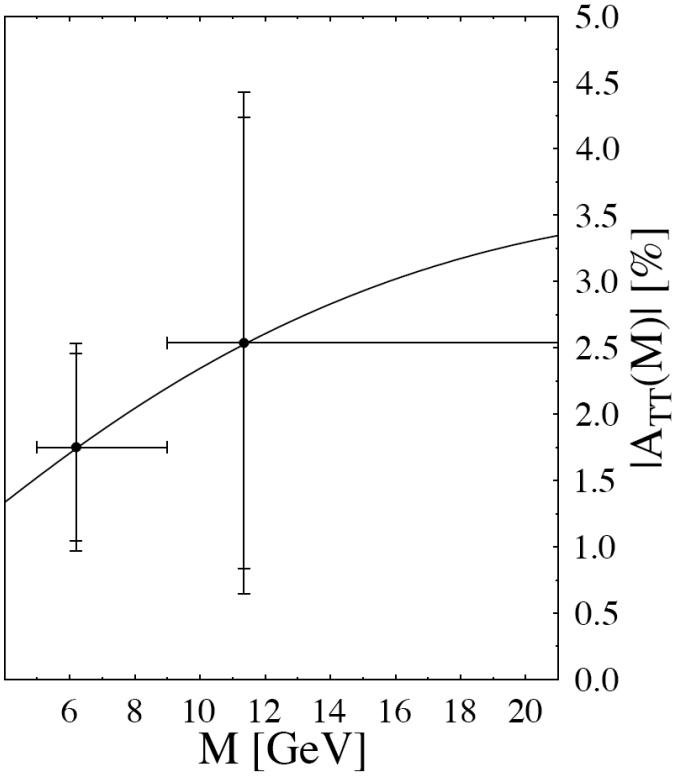


$$A_{TT} = \frac{d\sigma^{p^{\uparrow}p^{\uparrow}} - d\sigma^{p^{\uparrow}p^{\downarrow}}}{d\sigma^{p^{\uparrow}p^{\uparrow}} + d\sigma^{p^{\uparrow}p^{\downarrow}}}$$

- **In particular : Drell-Yan**



- **note, dedicated program on Drell-Yan in $p^{\uparrow}\bar{p}^{\uparrow}$ is proposed at GSI**
- **expectations for RHIC :**



√S = 200 GeV

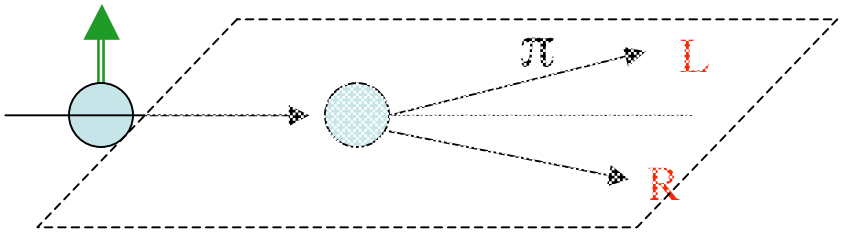
L = 320/pb

P = 0.7

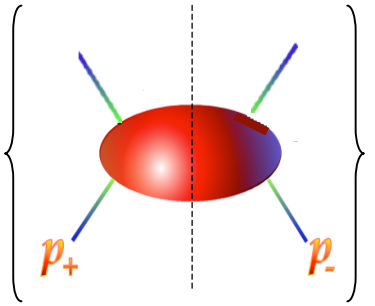
O. Martin et al.

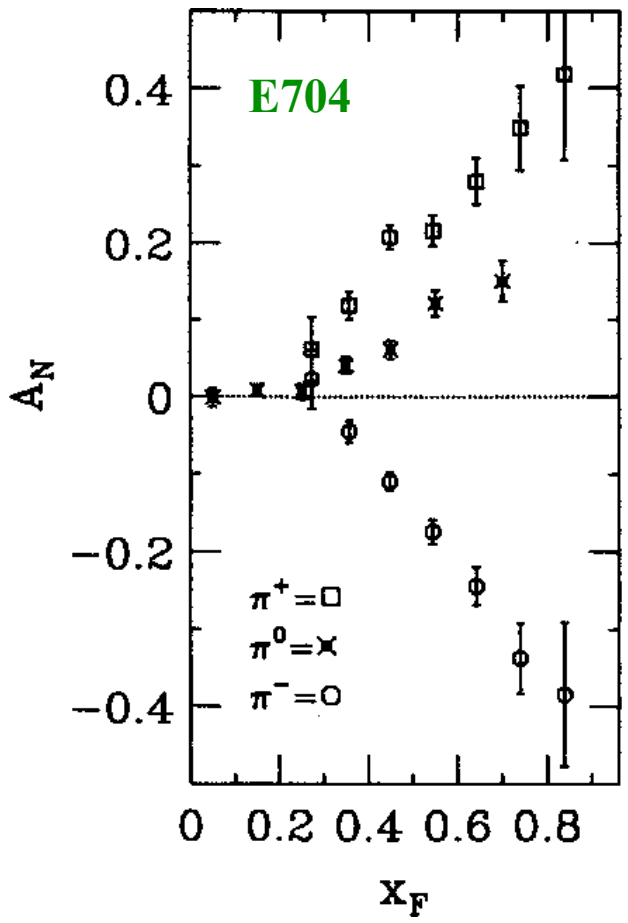
- **detector coverage and statistics important**
- **also: A_{TT} for prompt photons, jets, …**

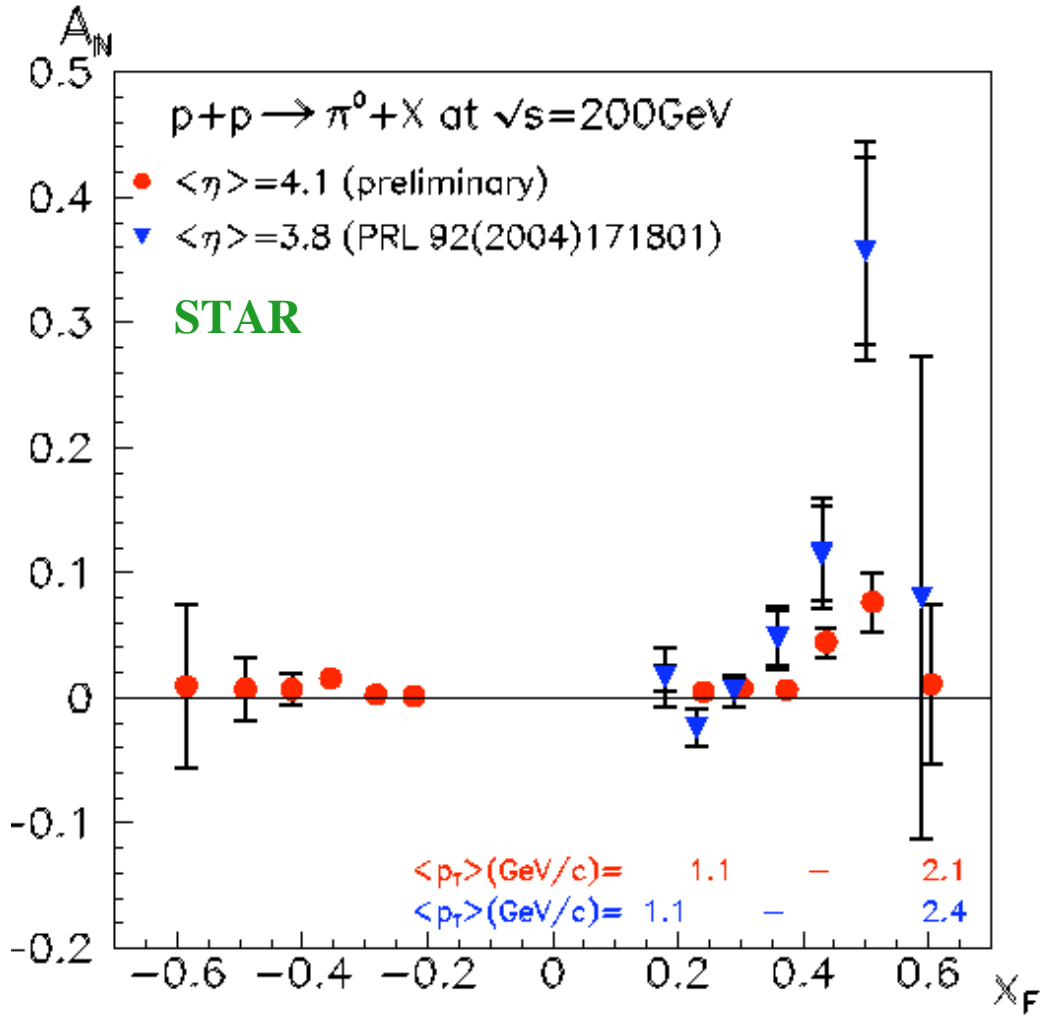
Single-spin asymmetries



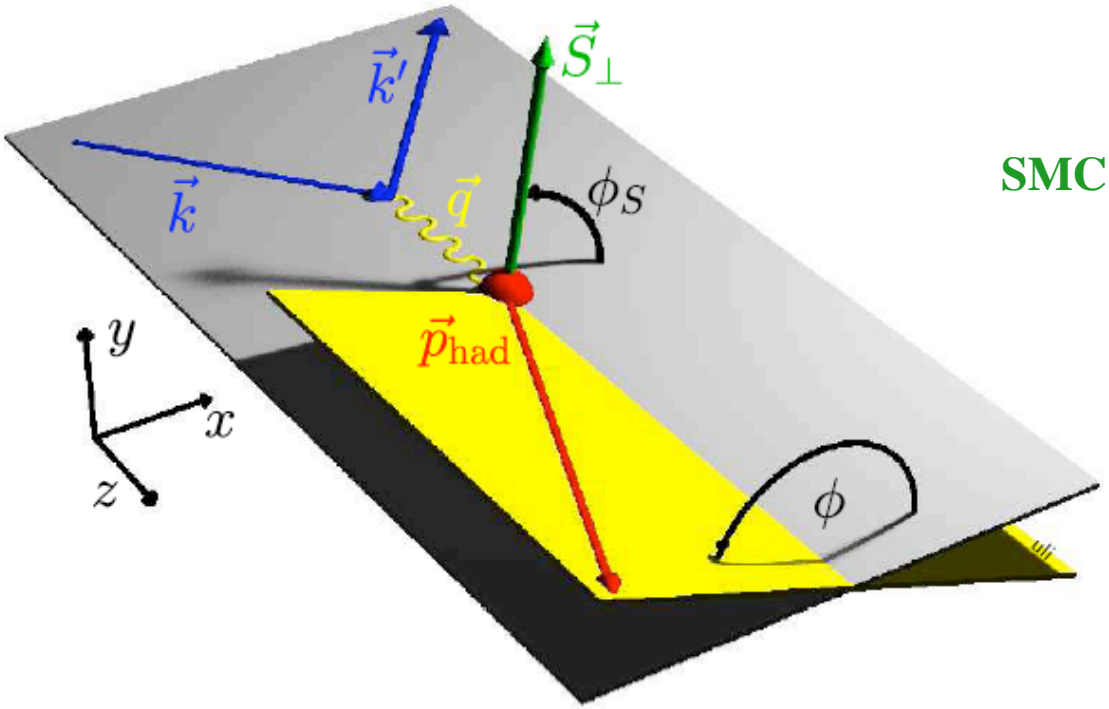
$$A_N = \frac{L-R}{L+R} \sim \mathbf{Im}$$







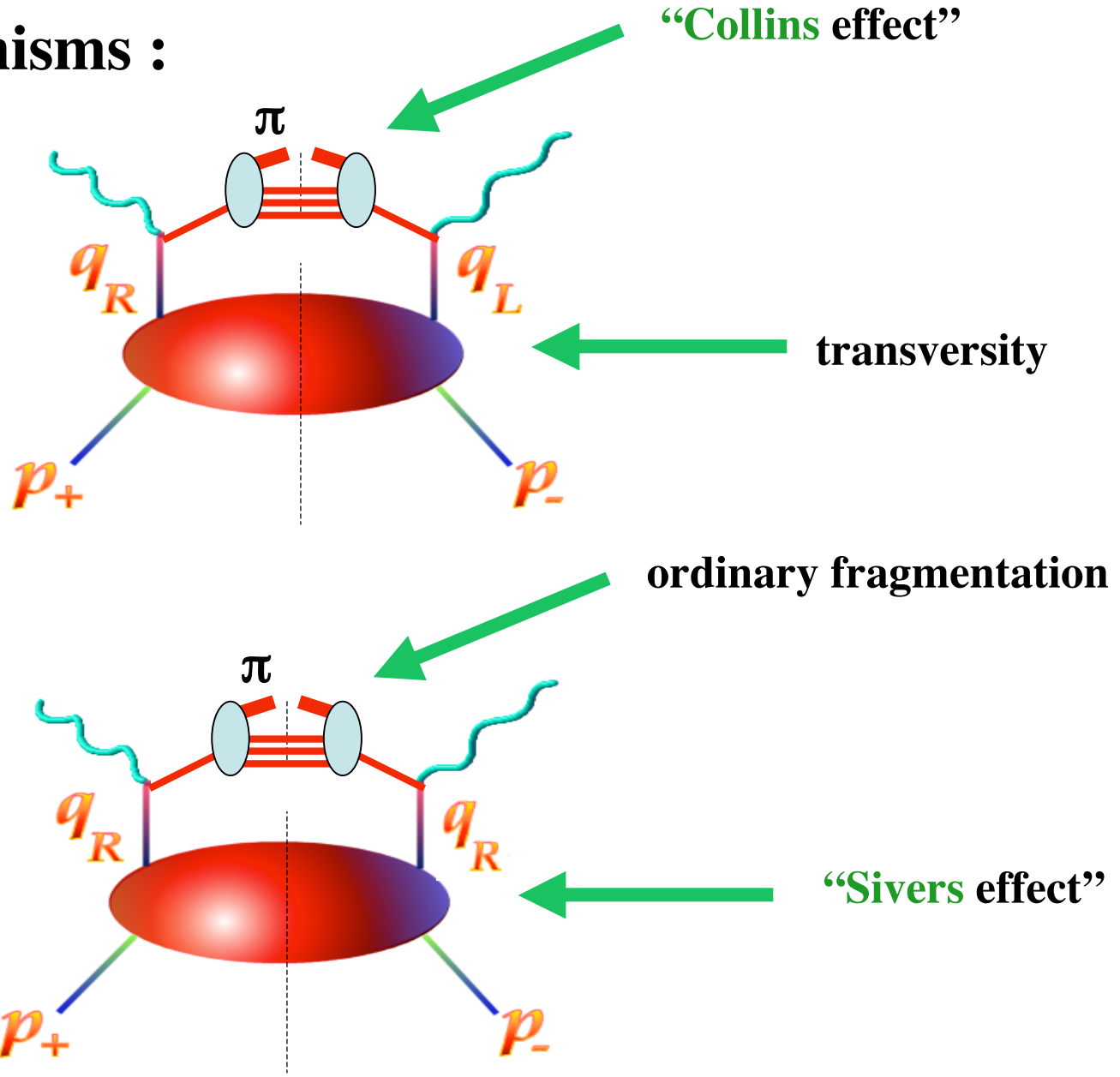
Related effects in lepton scattering $\mathbf{e p^{\uparrow} \to e \pi X}$



SMC, HERMES, COMPASS

$$\mathbf{A_N} \sim \sin(\phi - \phi_\mathbf{S}) \, , \, \sin(\phi + \phi_\mathbf{S})$$

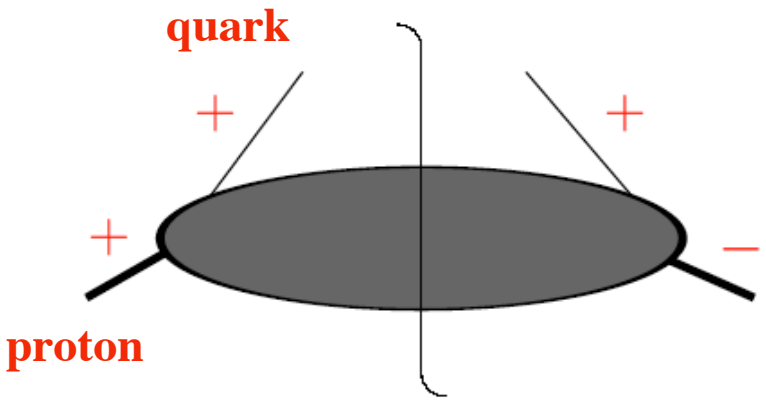
Possible mechanisms :



- **Both could be involved in A_N for $pp \rightarrow \pi X$**

The physics of the Sivers function :

- **access to orbital angular momentum :**



Probes overlap of proton wave fcts. with $J_z = \pm 1/2$

→ requires quark transverse momentum

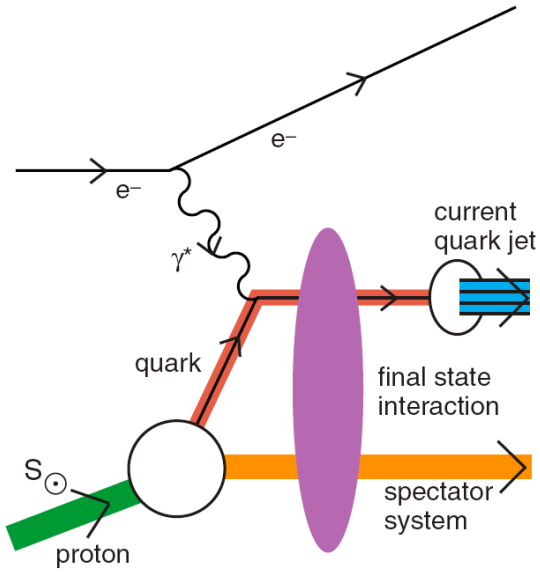
- **in fact, connected to GPD's & spatial distributions of partons**

Burkardt

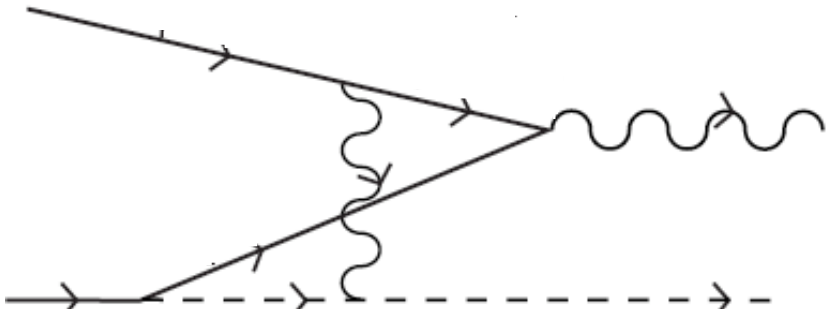
- **origin of the phase :**
  from Wilson lines in gauge-invariant definition of function

Brodsky,Hwang,Schmidt; Collins; Belitsky,Ji,Yuan; Boer,Mulders,Pijlman

DIS :



Drell Yan :



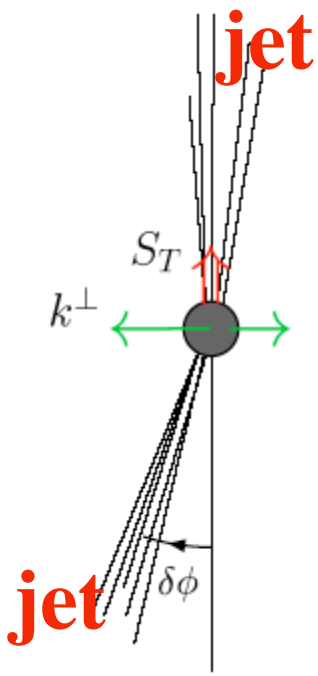
→ **Sivers functions in DIS and DY come with opposite sign**

→ **leads to predictions that are testable at RHIC**

Possibilities for RHIC : the physics of correlations

- single-spin azimuthal asymmetries in Drell-Yan
- back-to-back jet correlations

Boer, WV



- description of A_N for $pp \to \pi X$ is somewhat more involved and offers further insights

Qiu, Sterman, …

- we are likely only in early stages of this area

From polarized Hadron colliders to "polarized Parton colliders" …

- **polarization is a valued tool in searches for New Physics :**
  linear collider, parity violation in $\vec{e}e \rightarrow ee$, $\vec{e}p \rightarrow ep$
- **ideas have been around for RHIC for a long time**

  Tannenbaum; Craigie, Hidaka, Ratcliffe; Bourrely, Guillet, Soffer; Taxil, Virey
- **possibilities at RHIC need to be seen in LHC context**
- **potential benefits of polarization are**
  - **“elimination” of (QCD) backgrounds**
  - **sensitivity to couplings that violate symmetries (parity)**

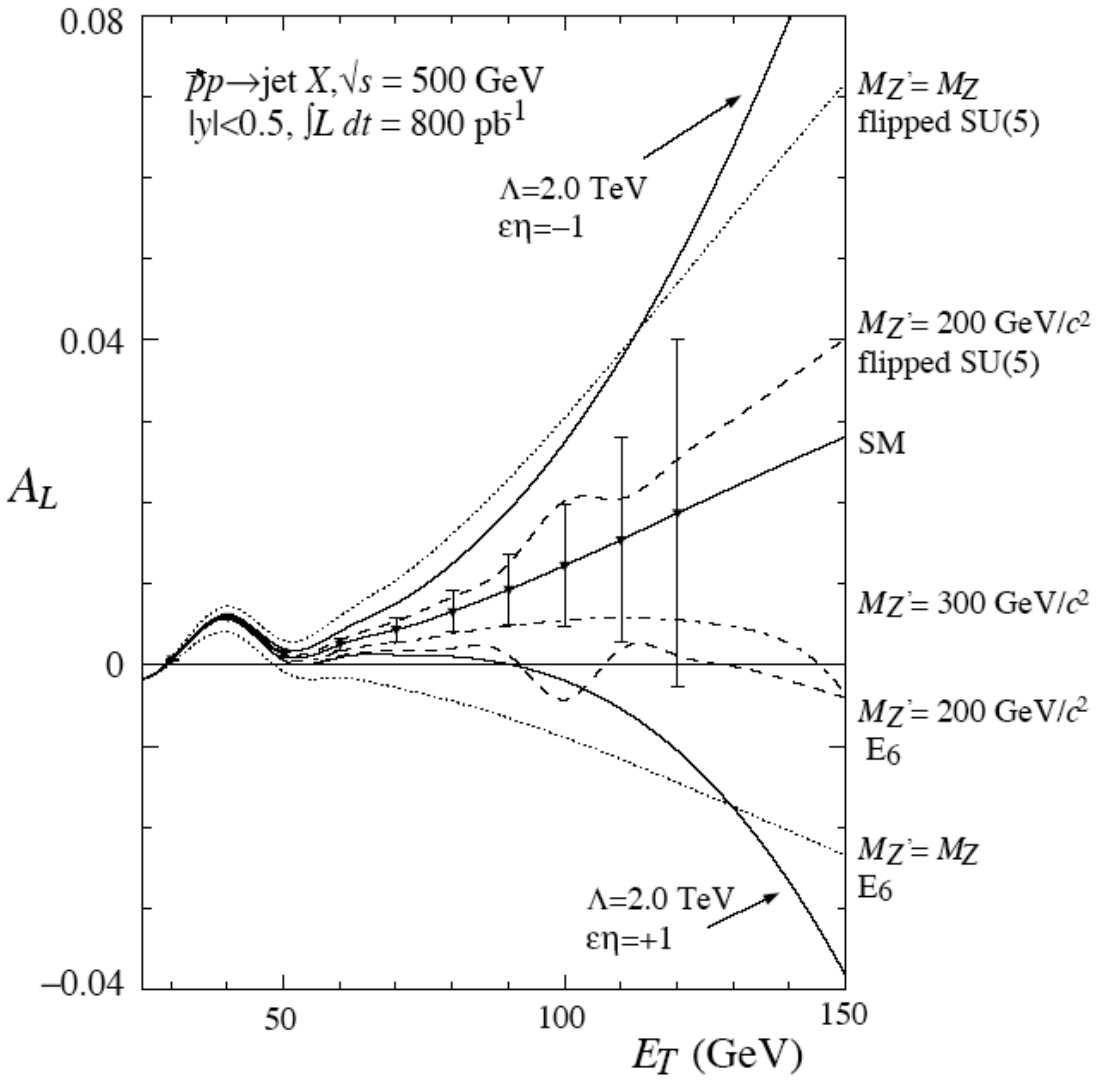
- PV at the shortest distances at RHIC :

pp → jet X

$$A_L^{PV} \equiv \frac{(d\sigma^{\leftarrow}/dE_T) - (d\sigma^{\rightarrow}/dE_T)}{(d\sigma^{\leftarrow}/dE_T) + (d\sigma^{\rightarrow}/dE_T)}$$

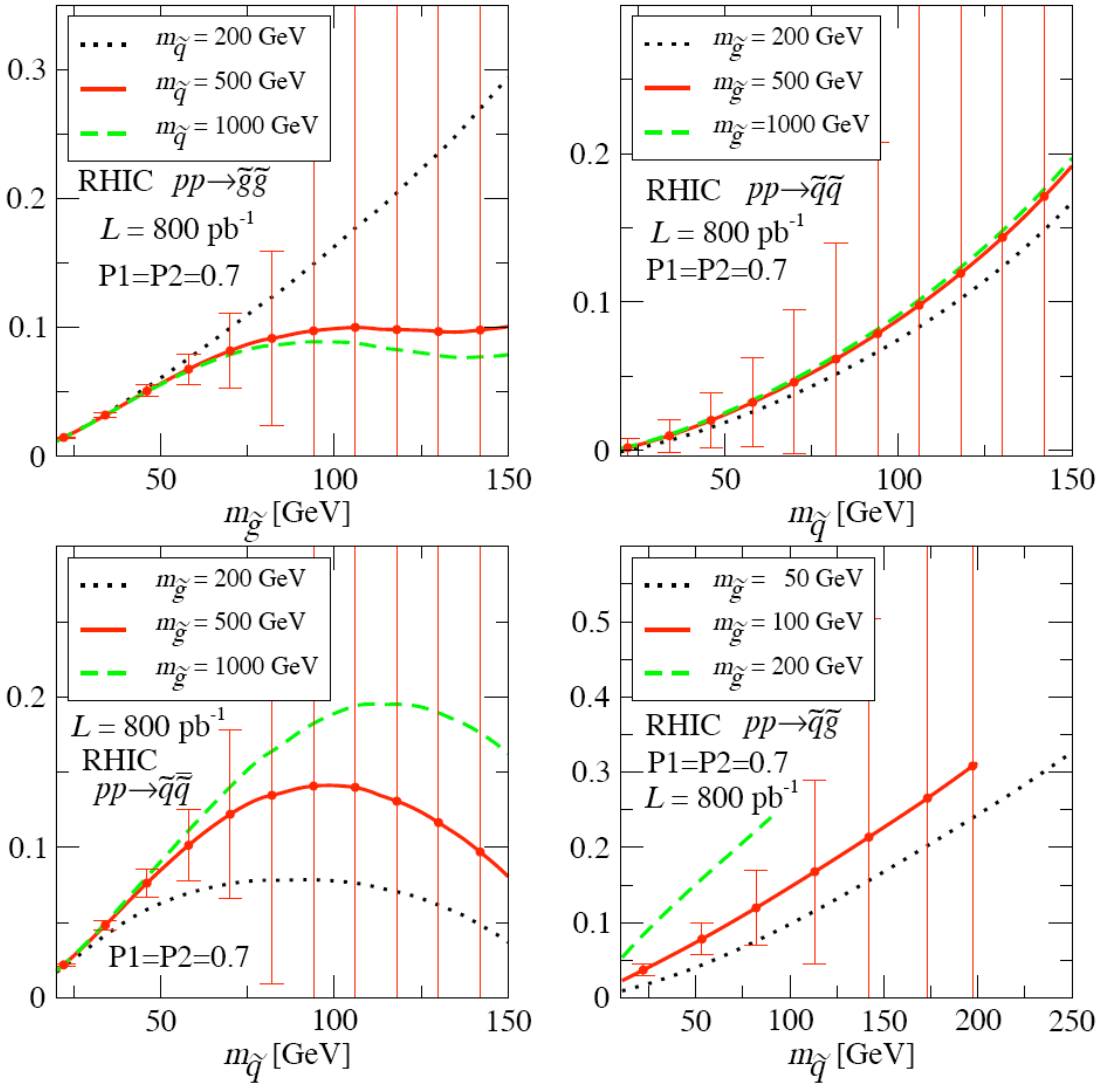
generic contact interaction:

$$\sim \frac{g^2}{\Lambda^2}\, \bar{\Psi}\Gamma_\mu\Psi\ \bar{\Psi}\Gamma^\mu\Psi$$



Bourrely, Guillet, Soffer; Tannenbaum; Taxil, Virey

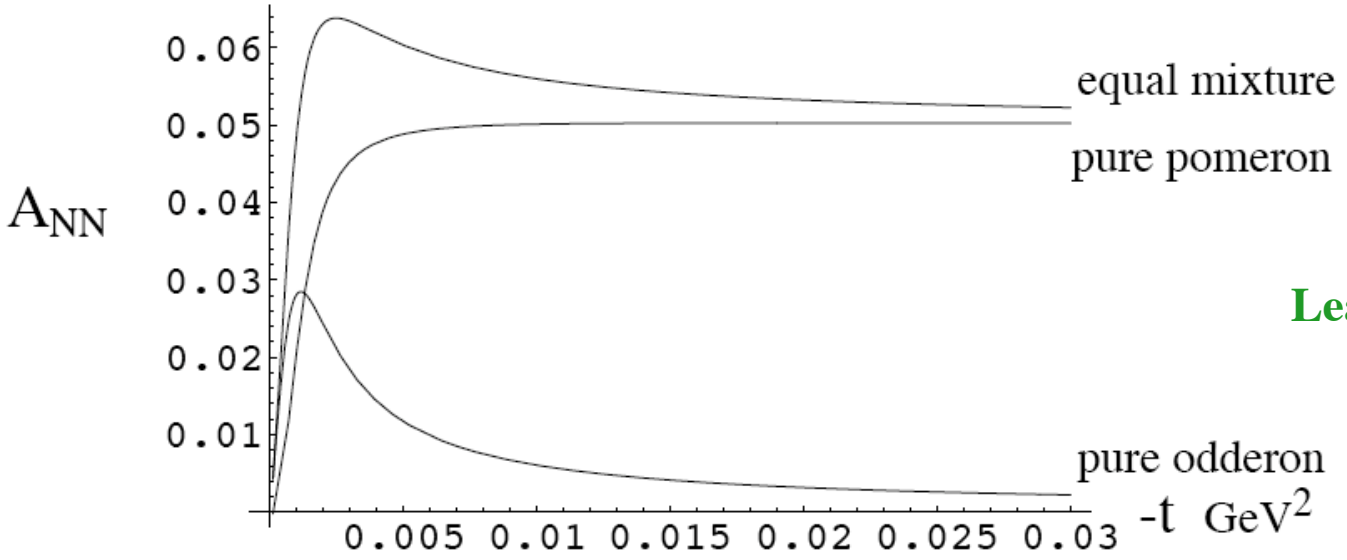
Non-MSSM Squark and Gluino production



Gehrmann, Maitre, Wyler

Elastic scattering

- **in some sense, the most fundamental hadronic reactions, but among the most difficult to understand**
- **an exciting beginning now at RHIC**
- **topics for the future ?**



Leader, Trueman

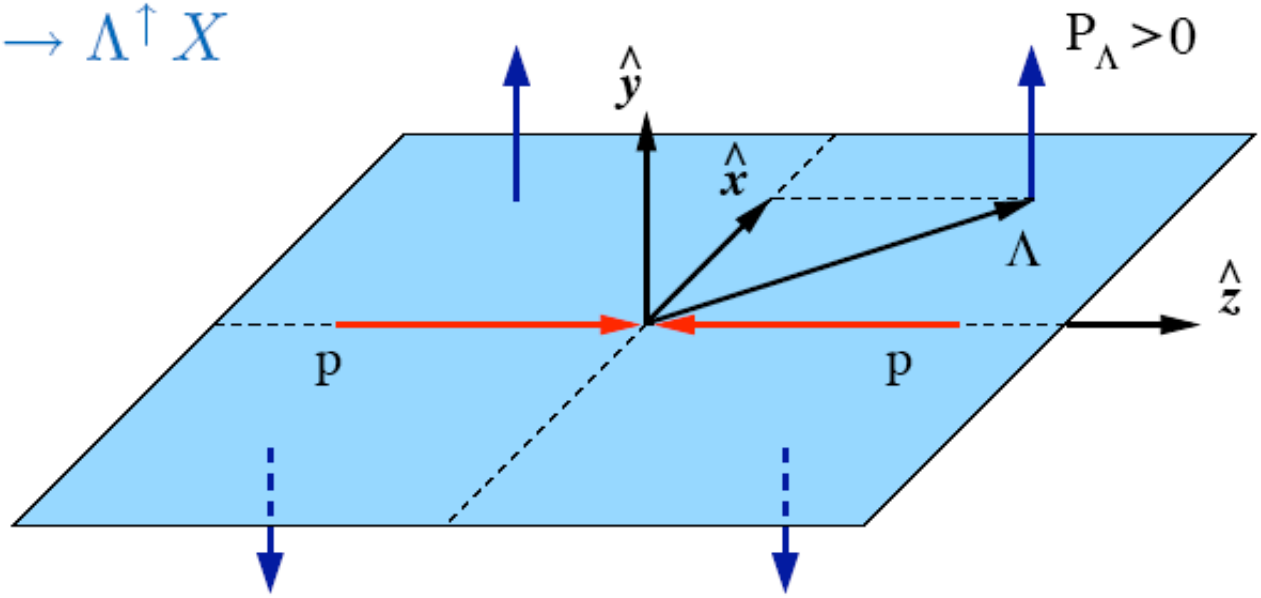
- **generally, reach out to larger -t ?**

Spin Physics at RHIC $\neq$ polarized pp

- **example : polarization as probe of dynamics in dA scattering**

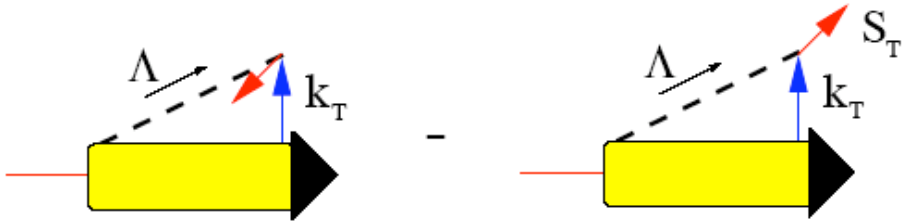
$p\,p \rightarrow \Lambda^{\uparrow} X$

Boer, Dumitru



Anselmino, Boer, d'Alesio, Murgia : **explain in terms of**

$D_{1T}^{\perp} =$



$$\sim \vec{S}_T \cdot (\vec{q} \times \vec{k}_T)$$

odd in k_T

Do this in pA collisions. Λ polarization will be proportional to

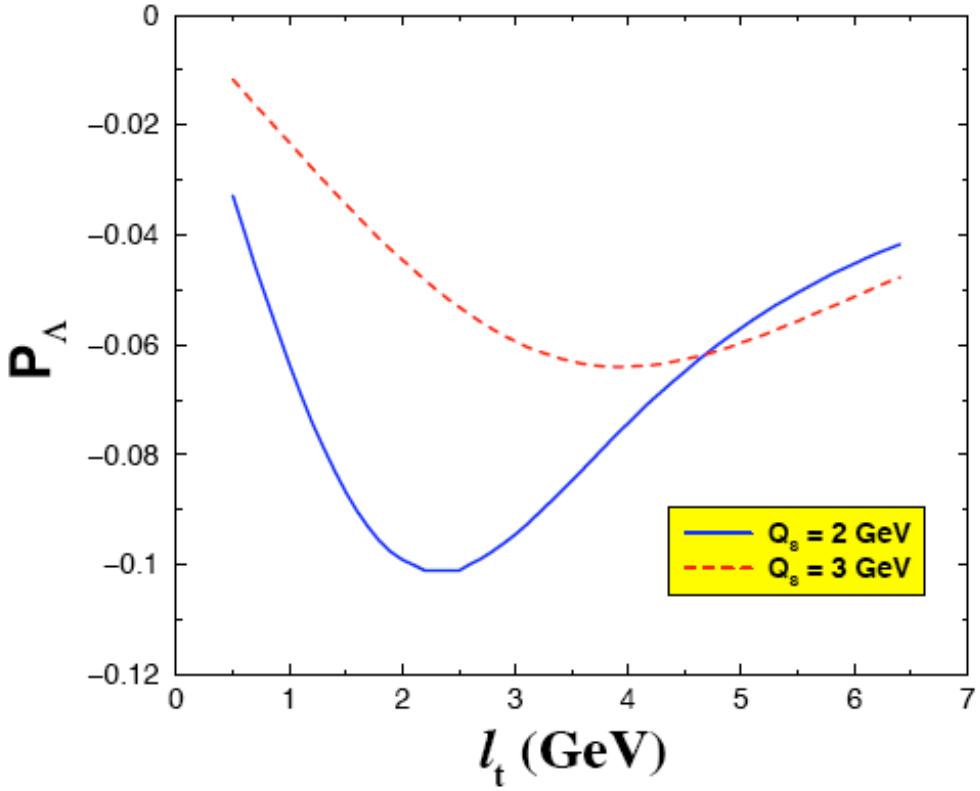
$$\hat{\sigma}\left(\mathbf{p}_{\mathbf{T}}^{\Lambda}+\mathbf{k}_{\mathbf{T}}\right)-\hat{\sigma}\left(\mathbf{p}_{\mathbf{T}}^{\Lambda}-\mathbf{k}_{\mathbf{T}}\right)$$

~ derivative of partonic cross section in quark transv. mom.

LT : peaked at small q_T

CGC : peaked at $q_T \sim Q_s$

Boer, Dumitru



Instead of Conclusions :

Some questions (of many…)

- **how well can one get the gluon spin contribution ?**
- **is there an independent way of determining strange quark polarization ?**
- **how large is transversity in the nucleon ?**
- **can we learn about parton orbital angular momentum from the Sivers functions ?**
- **can one verify the non-universality of the function ?**
- **can one use polarized pp to find New Physics ? Which ?**
- **can one use polarization to probe high-density effects ?**