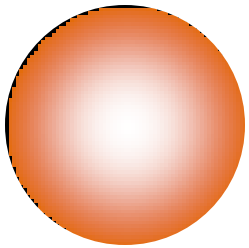
Measurement of proton spin structure at RHIC-PHENIX

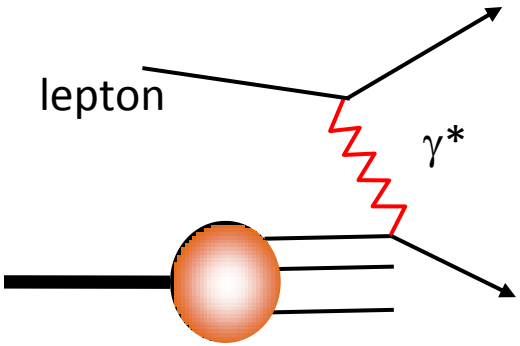
Kensuke Okada (RBRC)
for the PHENIX collaboration
WWND2009
February 5, 2009

The proton



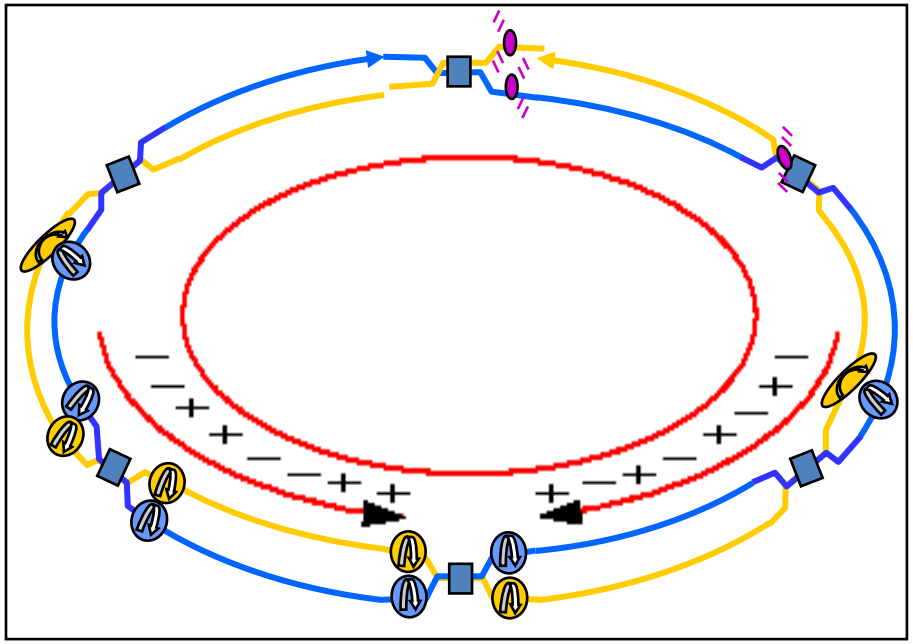
The most fundamental hadron.
Spin ½

What is the origin of the spin?



Deep inelastic scattering (DIS) experiments has led the field.

RHIC : the polarized *p+p* collider



The polarization is kept during the acceleration and at the store.
Any polarization direction can be set at the interaction points (STAR, PHENIX).
Alternative spin pattern for bunches to reduce the time dependent systematic.

Gluon interaction in leading order
High Q^2 ($\sqrt{s}$ is up to 500GeV)

Accumulated data (PHENIX)

Longitudinal polarization

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^4L)
2003 (Run 3)	200	.35 pb^{-1}	27	1.5 nb^{-1}
2004 (Run 4)	200	.12 pb^{-1}	40	3.3 nb^{-1}
2005 (Run 5)	200	3.4 pb^{-1}	49	200 nb^{-1}
2006 (Run 6)	200	7.5 pb^{-1}	57	690 nb^{-1}
2006 (Run 6)	62.4	.10 pb^{-1}	48	5.3 nb^{-1}

Transverse polarization

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^2L)
2001 (Run 2)	200	.15 pb^{-1}	15	3.4 nb^{-1}
2005 (Run 5)	200	.16 pb^{-1}	47	38 nb^{-1}
2006 (Run 6)	200	2.7 pb^{-1}	51	700 nb^{-1}
2006 (Run 6)	62.4	.02 pb^{-1}	48	4.6 nb^{-1}
2008 (Run 8)	200	5.2 pb^{-1}	46	1100 nb^{-1}

PHENIX Detector

Philosophy (initial design):

- ✓ **High rate capability & granularity**
- ✓ **Good mass resolution & particle ID**
- ➢ **Sacrifice acceptance**

π^0, γ, η

Electromagnetic Calorimeter, MPC

$\pi^{\pm}$, e, $J/\psi \rightarrow e^+e^-$

Drift Chamber
Ring Imaging Cherenkov Counter
Electromagnetic Calorimeter

μ, $J/\psi \rightarrow \mu^+\mu$

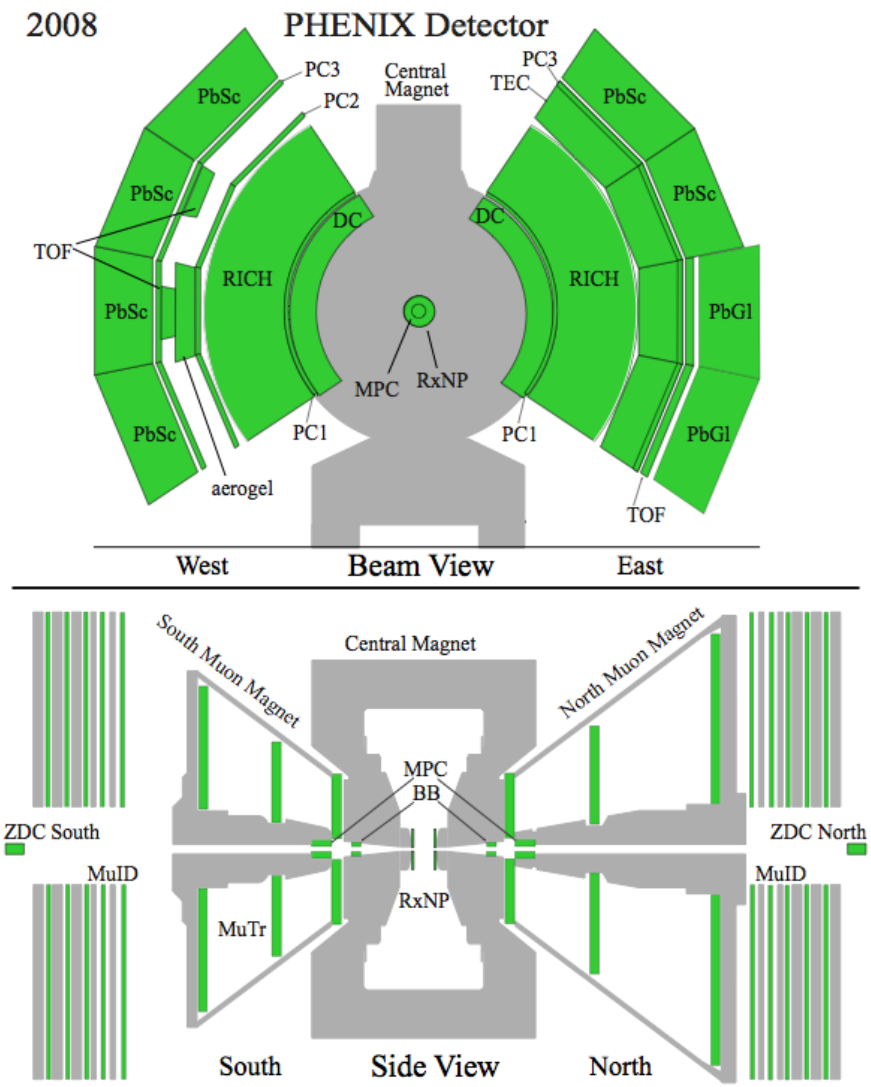
Muon Id/Muon Tracker

Relative Luminosity

Beam Beam Counter (BBC)
Zero Degree Calorimeter (ZDC)

Local Polarimetry – ZDC

Spin direction monitoring



Unpolarized Cross Section

Unpolarized = spin averaged

Before going to asymmetry measurements,
we need to confirm the applicability of pQCD factorization.

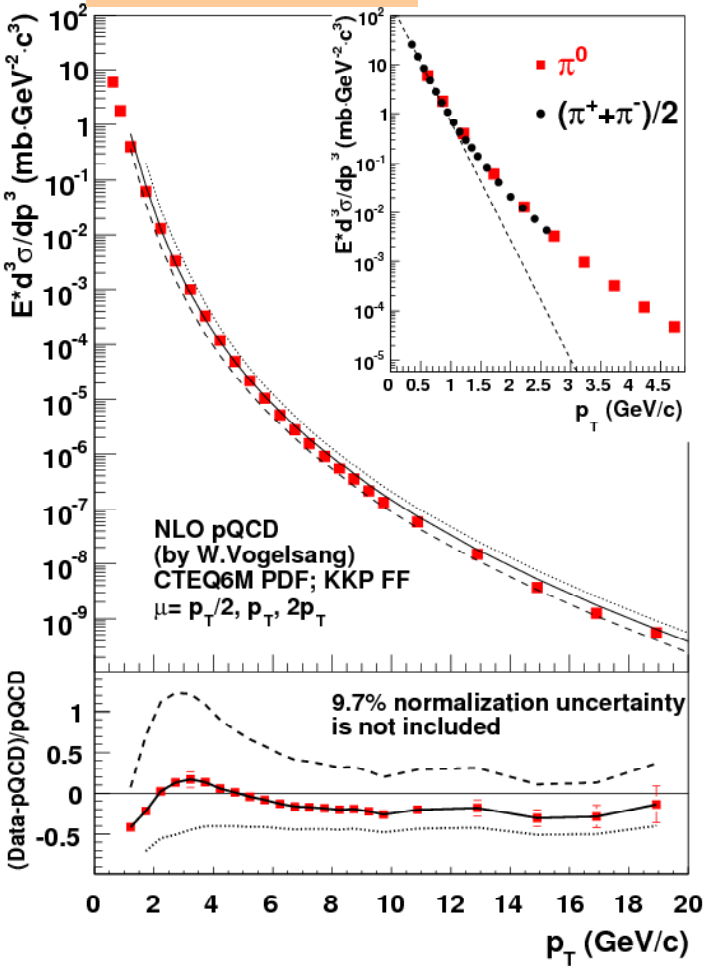
- pQCD calculation is the baseline (for example sensitive x region)
- Is the PDF measured by DIS experiments valid for *p+p* collisions?

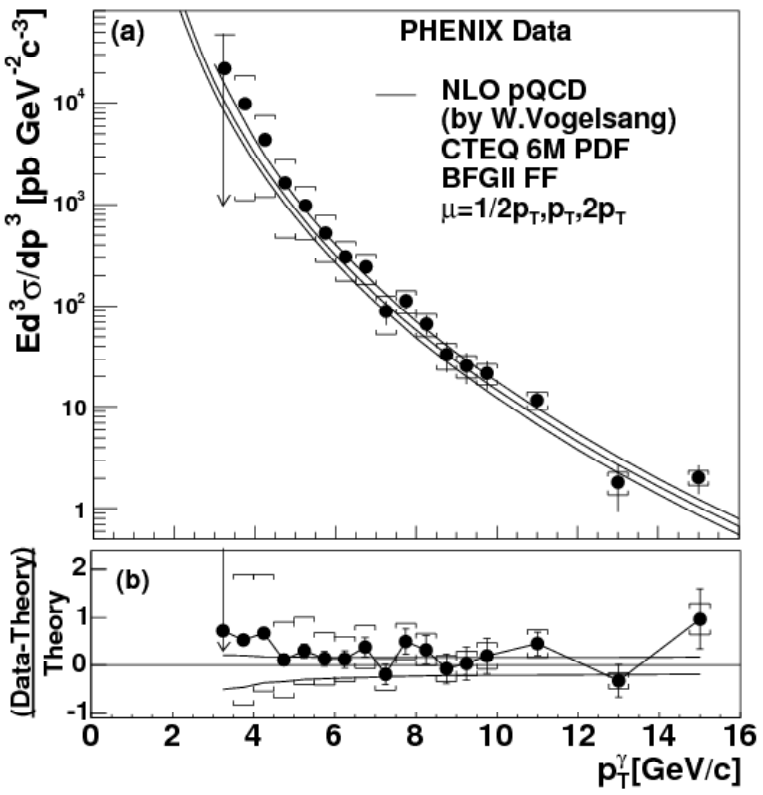
Cross section measurements

$pp \rightarrow \pi^0 X$:
PRD76,051106

Sqrt(s)=200GeV
Mid rapidity (|η|<0.35)

$pp \rightarrow \gamma X$:
PRL 98, 012002





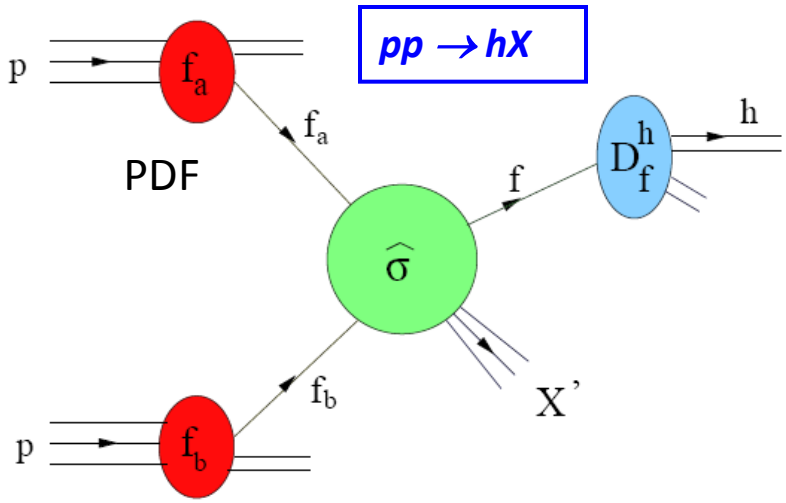
And also eta, h±, single electron (from charm)

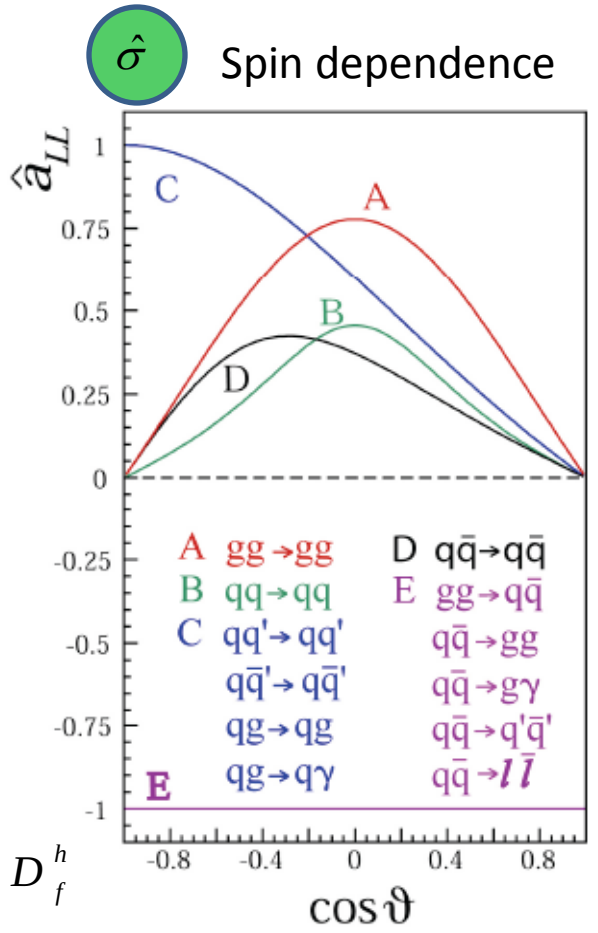
All measurements support the pQCD calculation.

pQCD our theory baseline is OK!

Longitudinal spin structure

Probing ΔG





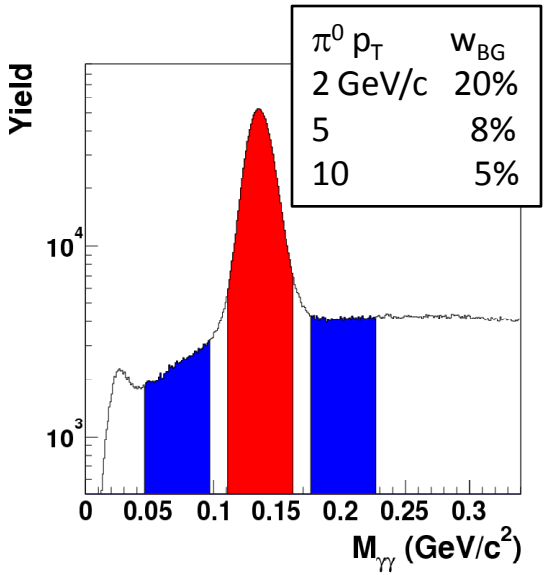
$$A_{LL} = \frac{d\sigma^{++} - d\sigma^{+-}}{d\sigma^{++} + d\sigma^{+-}} = \frac{\sum_{a,b} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \cdot \hat{a}_{LL}^{f_a f_b \to fX} \otimes D_f^h}{\sum_{a,b} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to fX} \otimes D_f^h}$$

Double longitudinal spin asymmetry A_{LL} is sensitive to ΔG

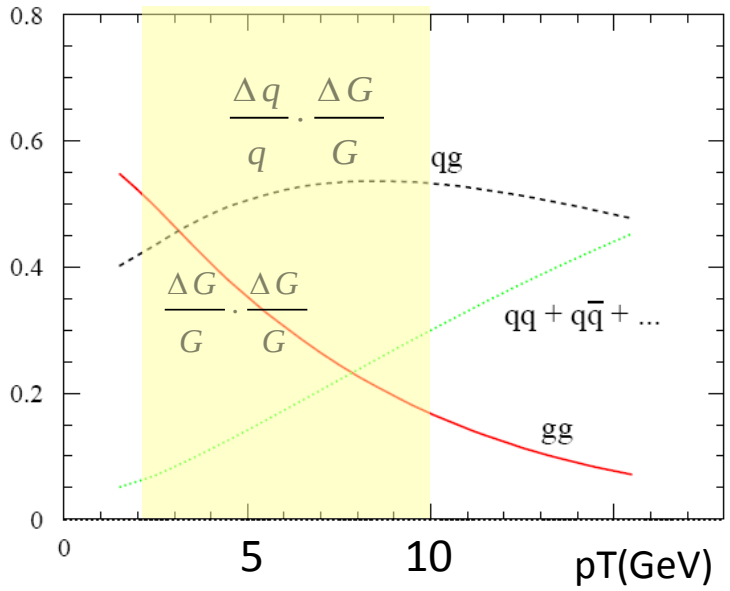
π^0 A_{LL}

The most abundant probe in PHENIX

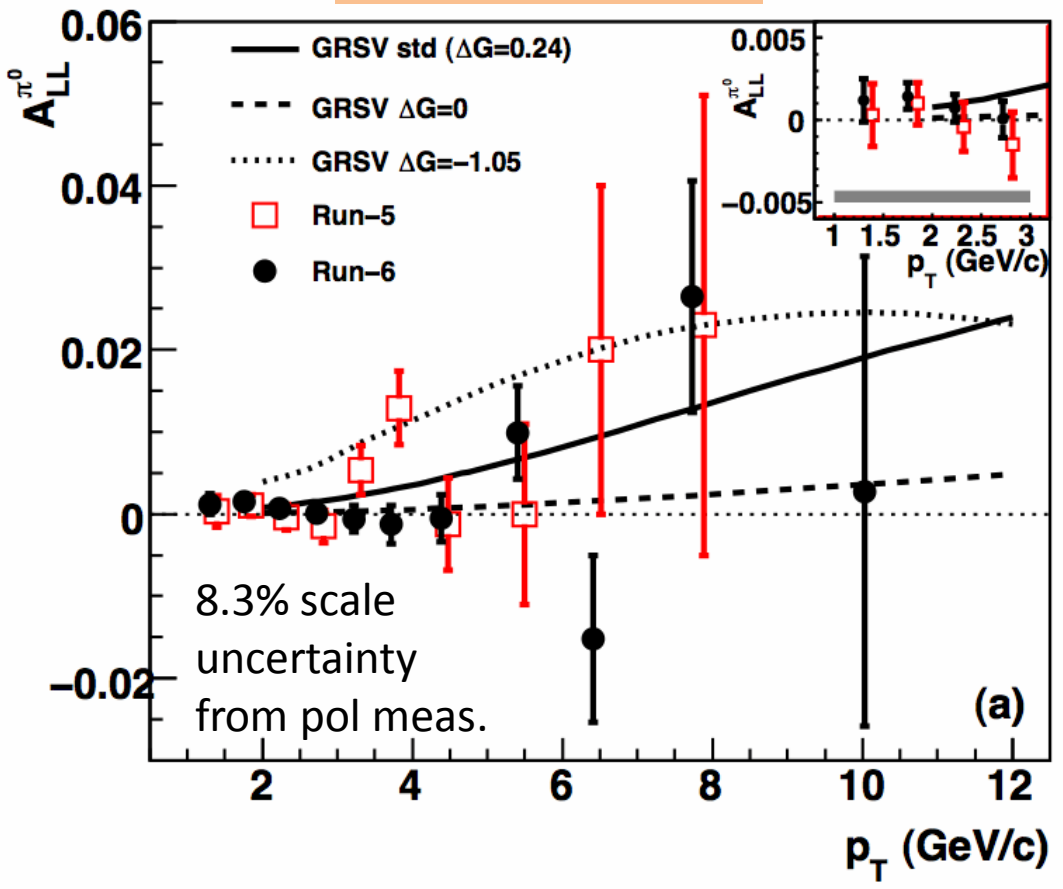
(triggering + identification capability)



$$A_{LL}^{\pi 0} = \frac{A_{LL}^{\pi 0+BG} - w_{BG} A_{LL}^{BG}}{1 - w_{BG}}$$



arXiv:0810.0694

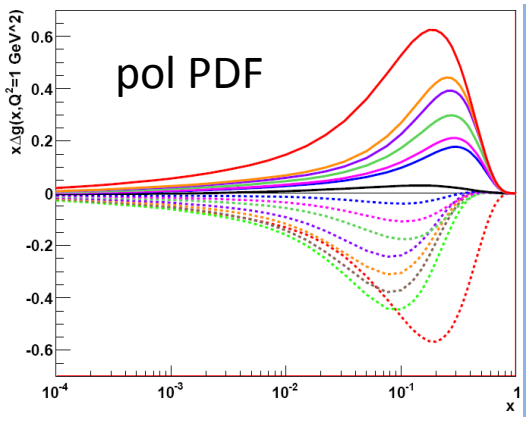


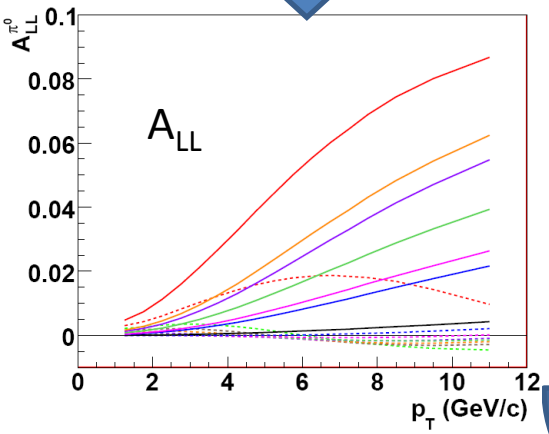
From A_{LL} to ΔG (with GRSV model)

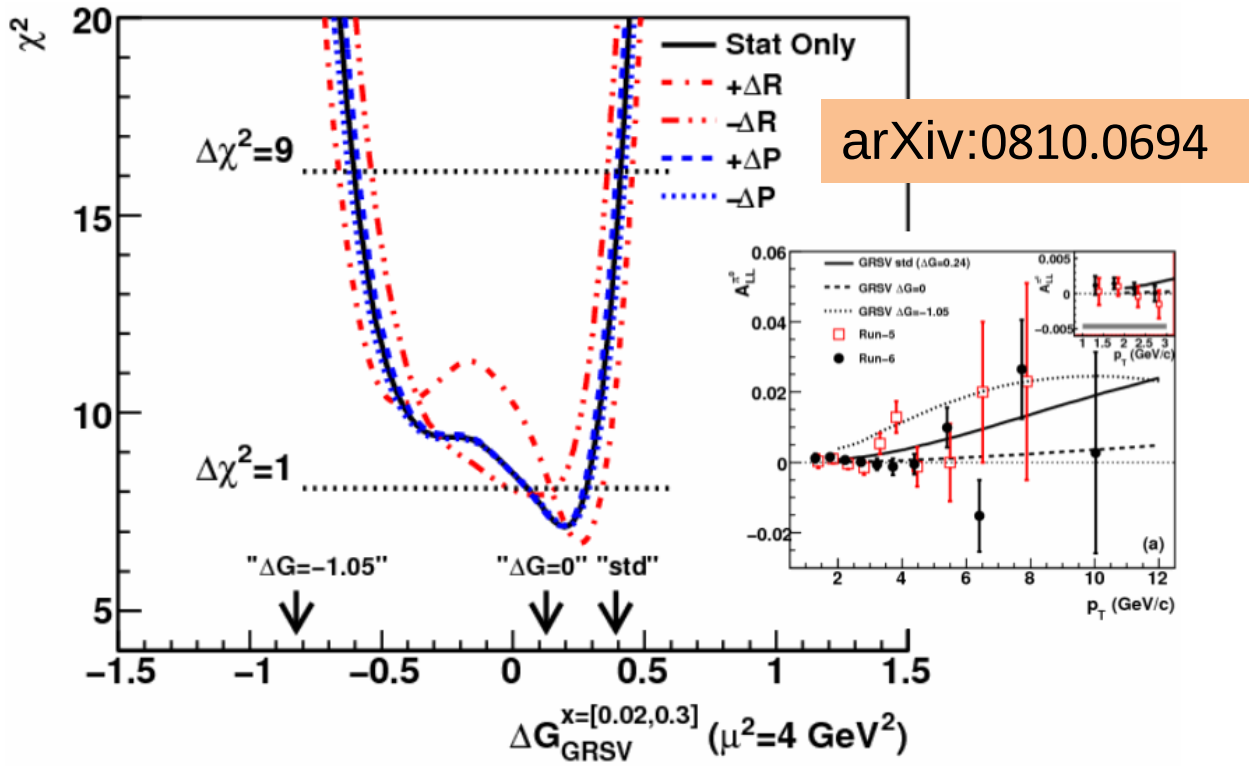
Generate $\Delta g(x)$ curves for different $\Delta G = \int_0^1 g(x)dx$ (with DIS refit)

Calculate A_{LL} for each ΔG

Compare A_{LL} data to curves (produce χ^2 vs ΔG)







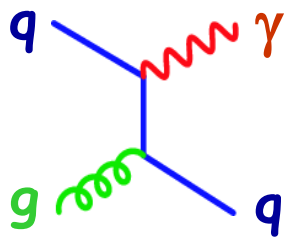
arXiv:0810.0694

Stat. error : $\Delta G^{x=[0.02,0.3]}_{GRSV}(\mu^2 = 4\ GeV^2) = 0.2 \pm 0.1\ (1\sigma)$ and $0.2^{+0.2}_{-0.8}\ (3\sigma)$

Syst. exp .error : ± 0.1

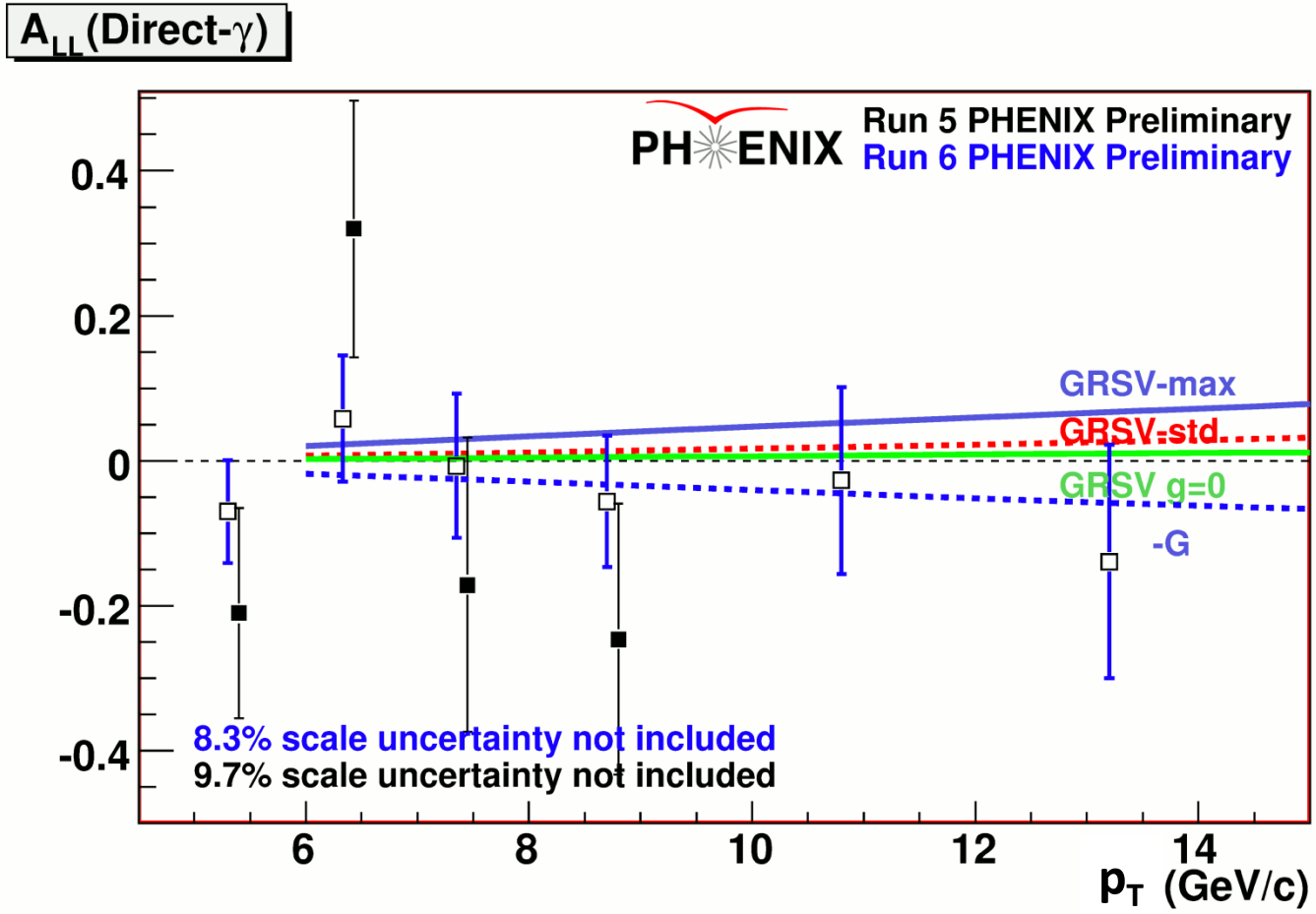
The gluon contribution is not large.

Direct photon A_{LL}



$$\frac{\Delta q}{q} \cdot \frac{\Delta G}{G}$$

clean channel
sensitive to the sign

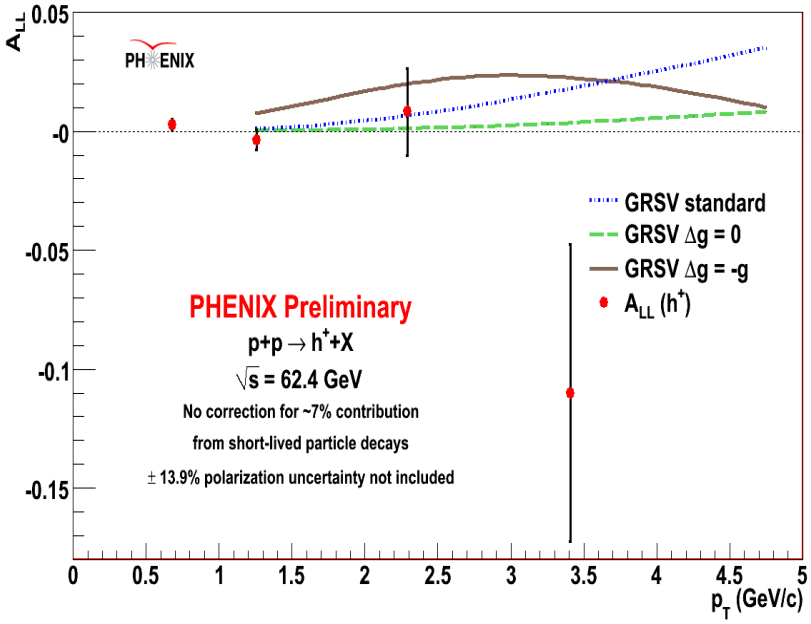


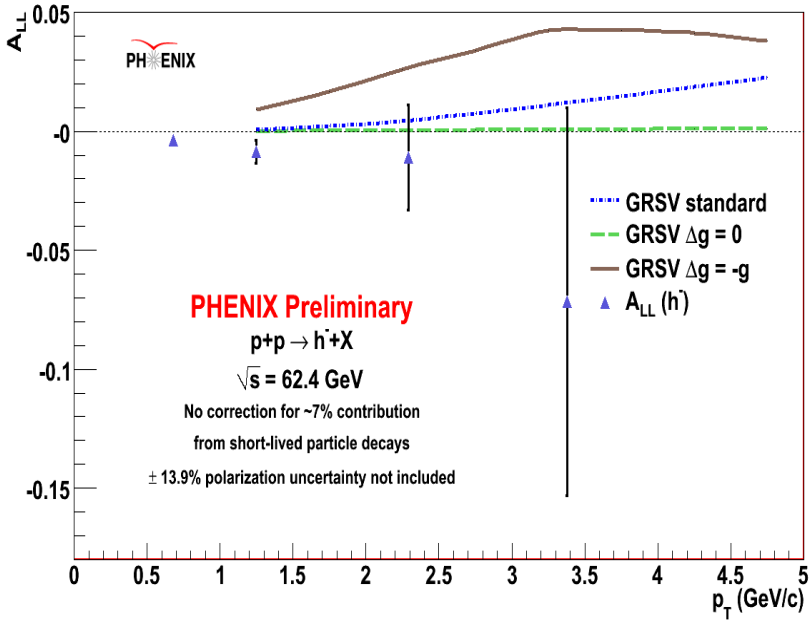
need more data

Other probes to access ΔG

charged pions : u,d quark difference
eta : an additional information
heavy flavor : the gluon fusion process

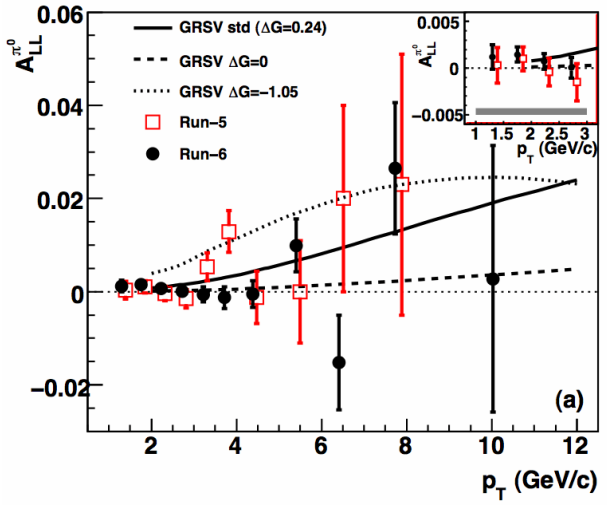
$h^{\pm}$ A_{LL} at √=62GeV

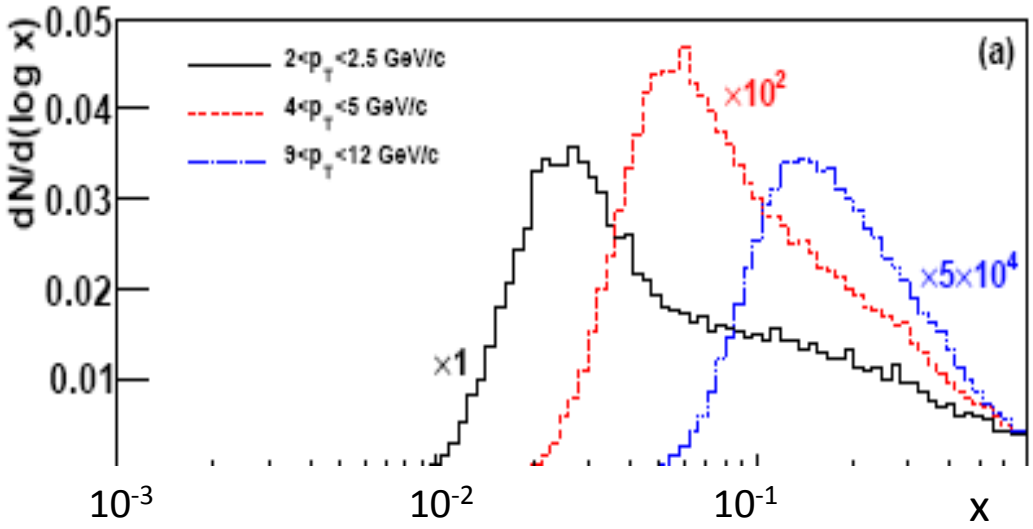




Issue 1

A poor resolution to x range in the inclusive measurements.
It's impossible to check the x-dependence.

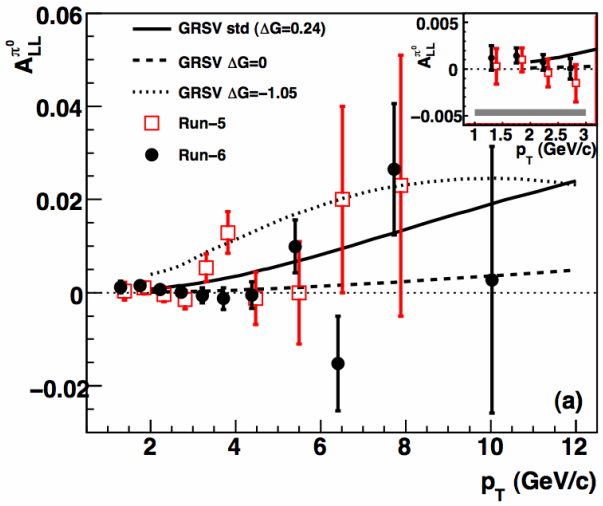


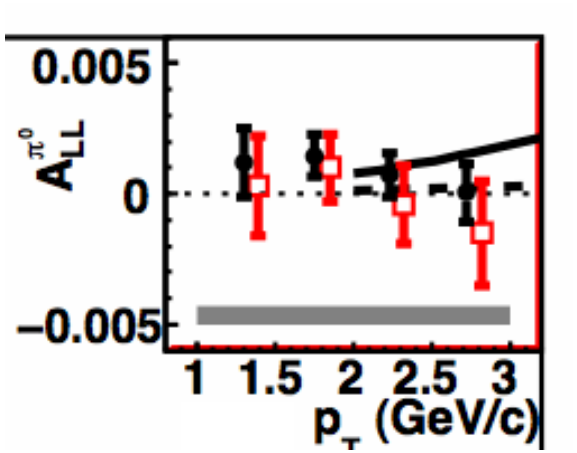


Multi particles for the x mapping. (jet+jet, photon+jet)
Other collision energies (higher √s lower the x)

Issue 2

Very small asymmetry





Systematic uncertainty ~0.1%

Statistics limit from the experimental data acquisition.
Systematic uncertainty on the relative luminosity measurement.
(= relative A_{LL})

The next step

direct photon, charged pions

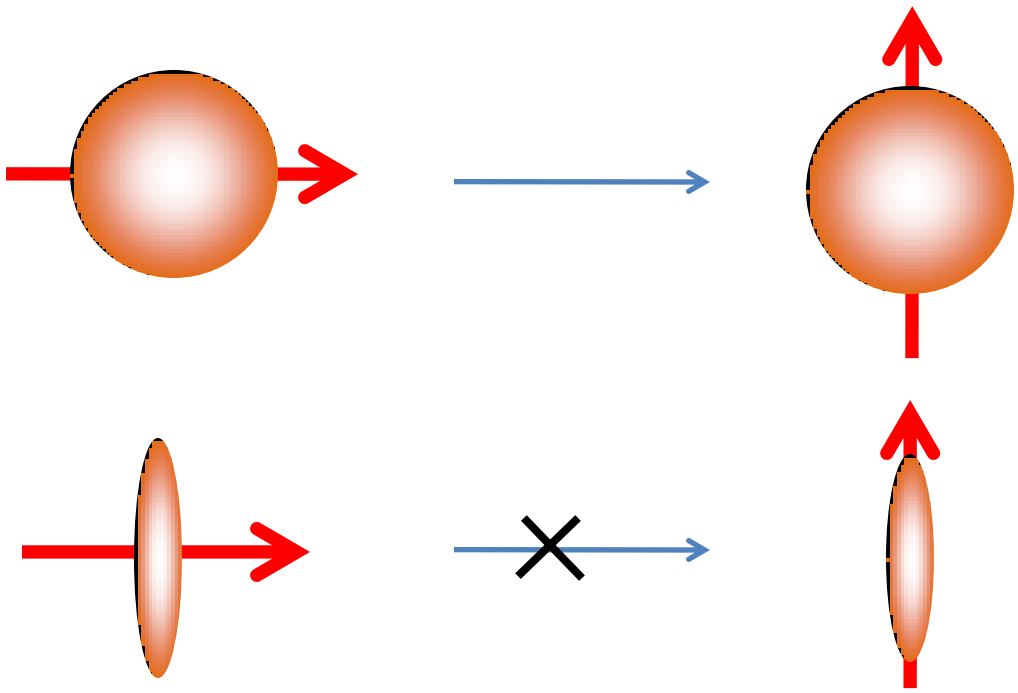
Explore the other kinematical regions

- **$\sqrt{s}$=500GeV small-x. Along with the W-program.**
- **Forward region for small-x.**
- **Mapping x by using away side particles.**

In the beam use proposal (for ~5 year plan),
we request 25/pb recorded with 70% pol at $\sqrt{s}$=200GeV
(~10x in terms of the figure of merit (LP^4))

Transverse spin structure

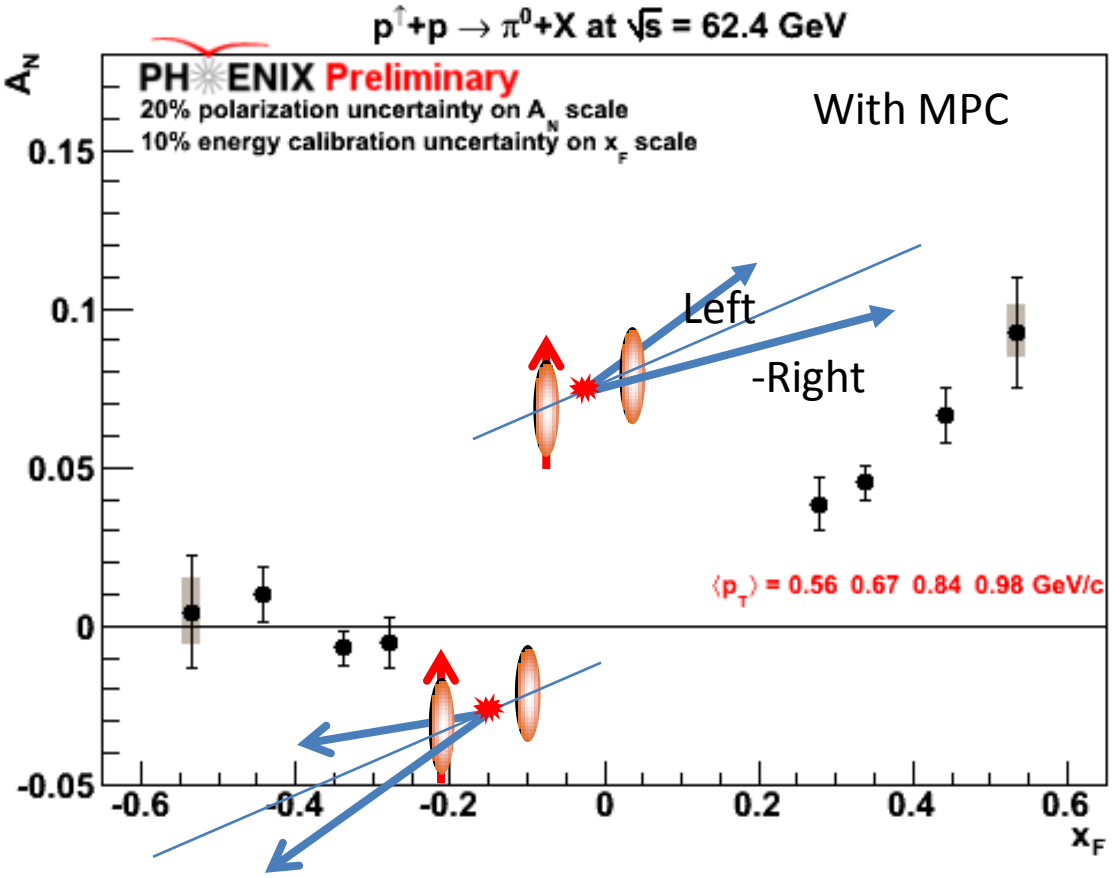
Transverse spin structure



The transverse spin structure is not a rotation of the helicity structure.
(true only for non-relativistic.)
Global picture including both is one way theorists try to.

Single spin asymmetry A_N

- Naive pQCD (in a collinear picture) predicts $A_N \sim m_q/\sqrt{s} \sim 0$



However, large A_N observed in forward pions.

(also confirmed at PHENIX)

Proposed mechanisms

- Sivers
- Collins
- twist-3 process
- ...

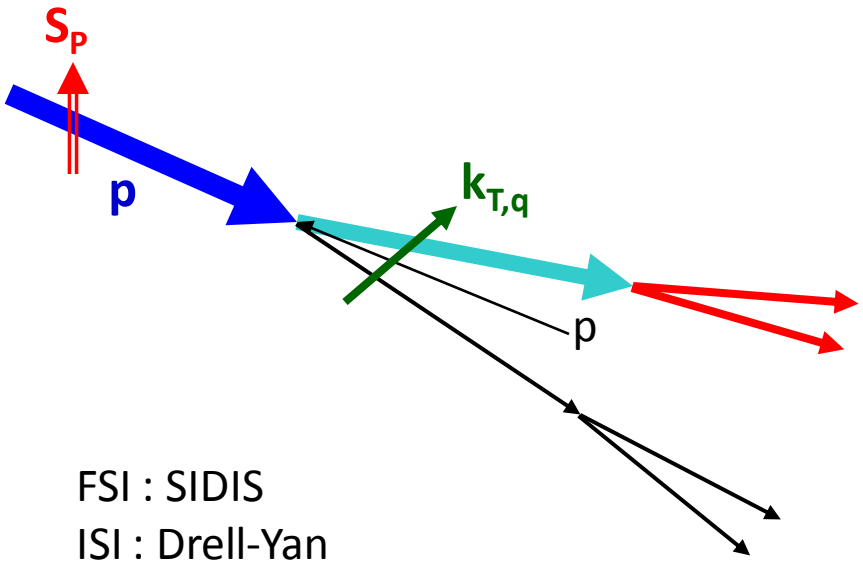
Very hot topic recently

Possible mechanisms (ex.)

Sivers mechanism:

correlation between proton spin & parton k_T

quark, gluon motion in the polarized proton.

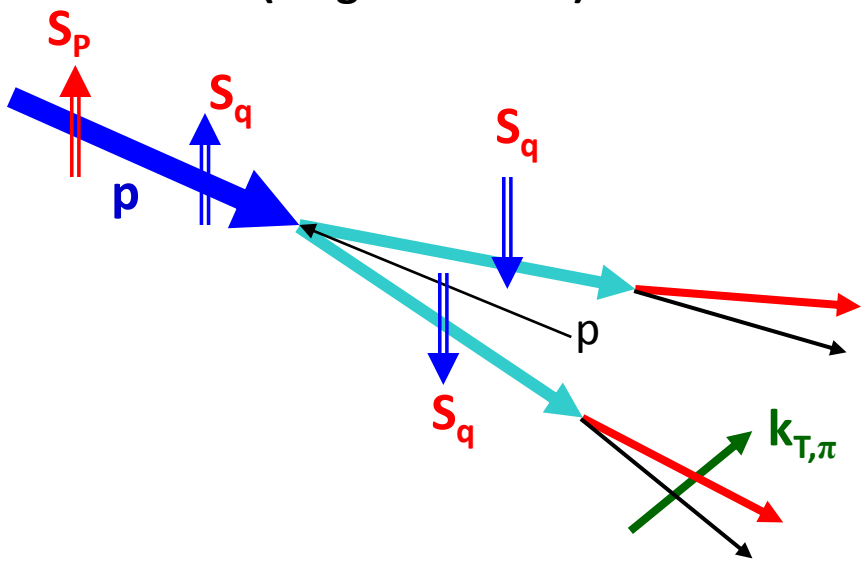


FSI : SIDIS
ISI : Drell-Yan

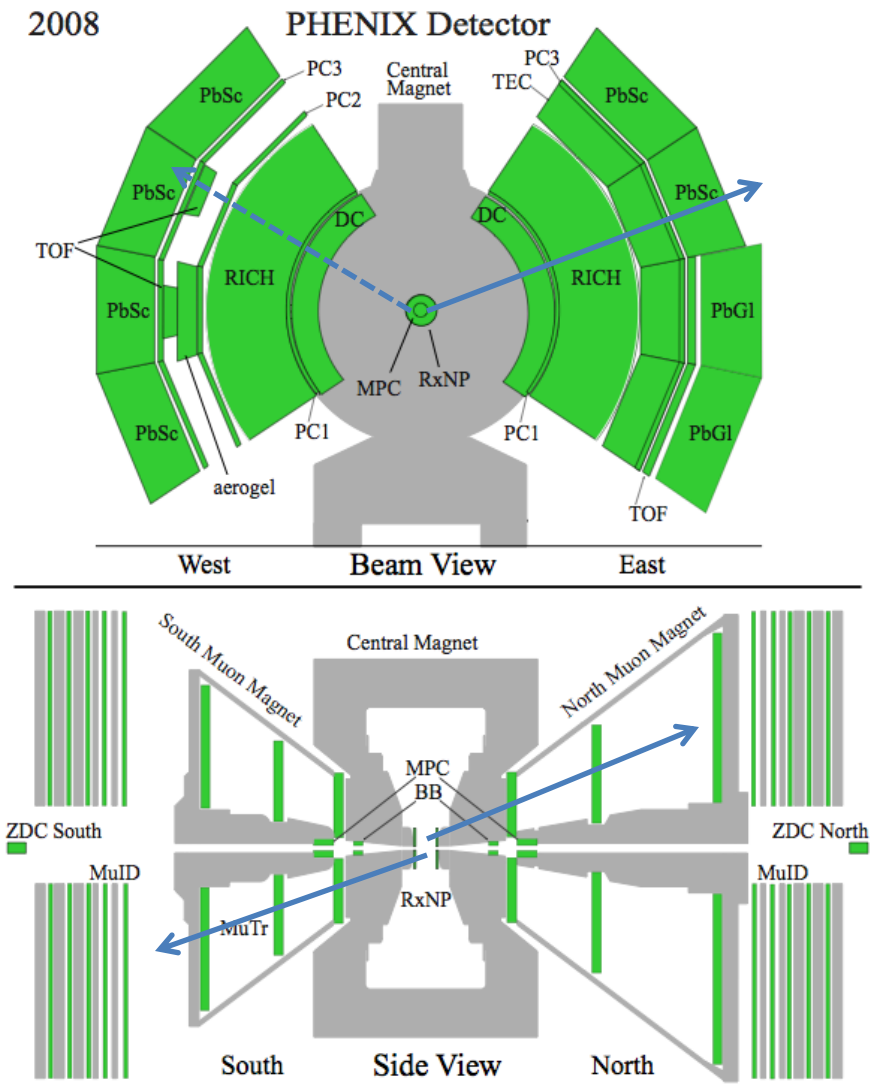
Collins mechanism:

Transversity (quark polarization) × jet fragmentation asymmetry

quark polarization, needs an analyzer to be observed. (no gluon effect)



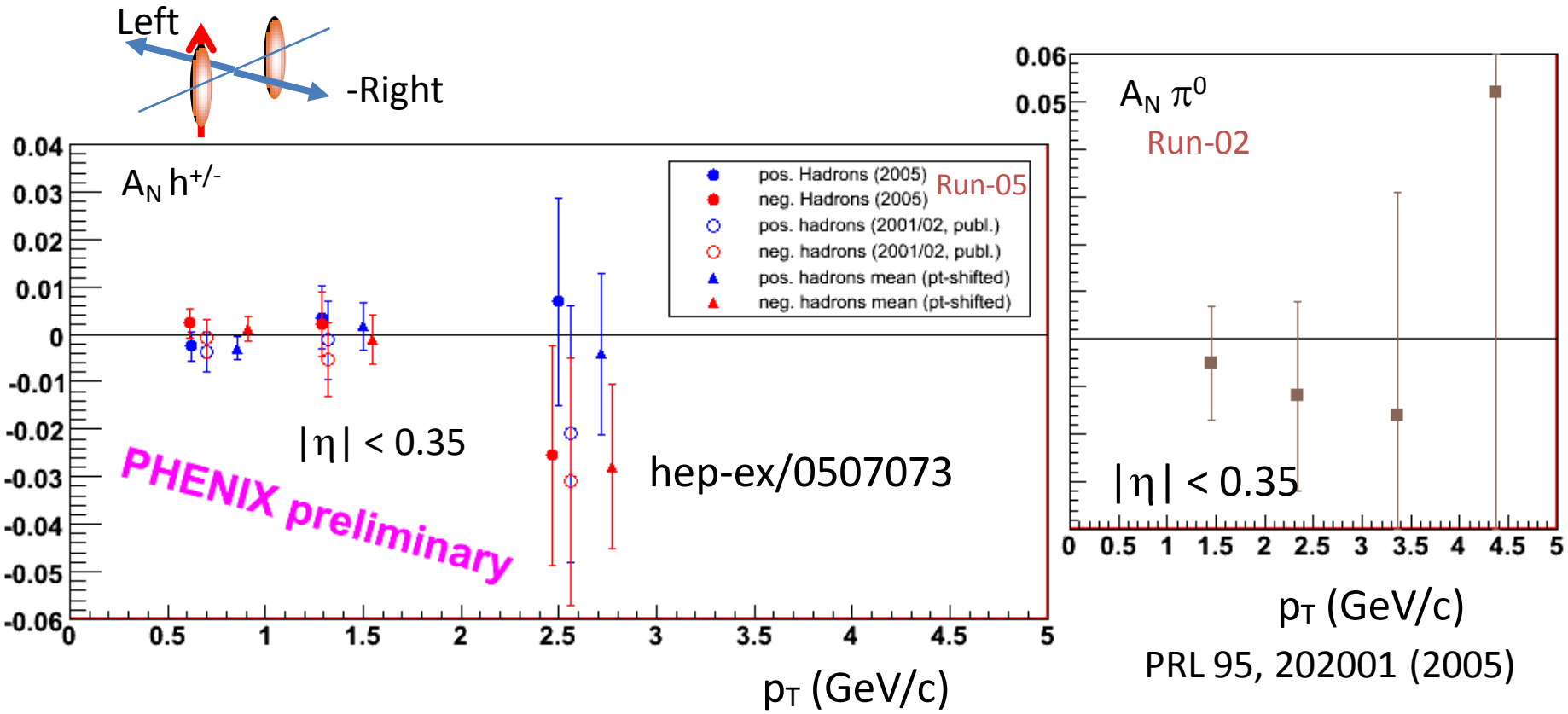
Looking for evidences



MPC pi0 result (Run6 sqrt(s)=62.4GeV) is already shown.

Other signals?

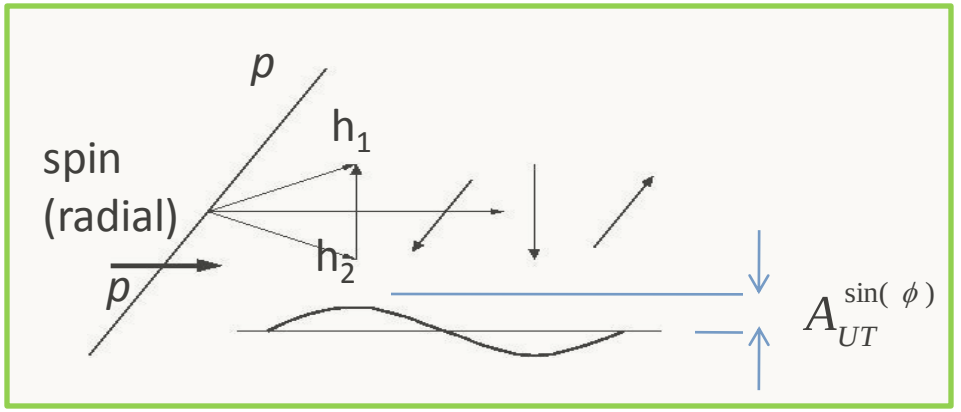
Midrapidity hadron A_N

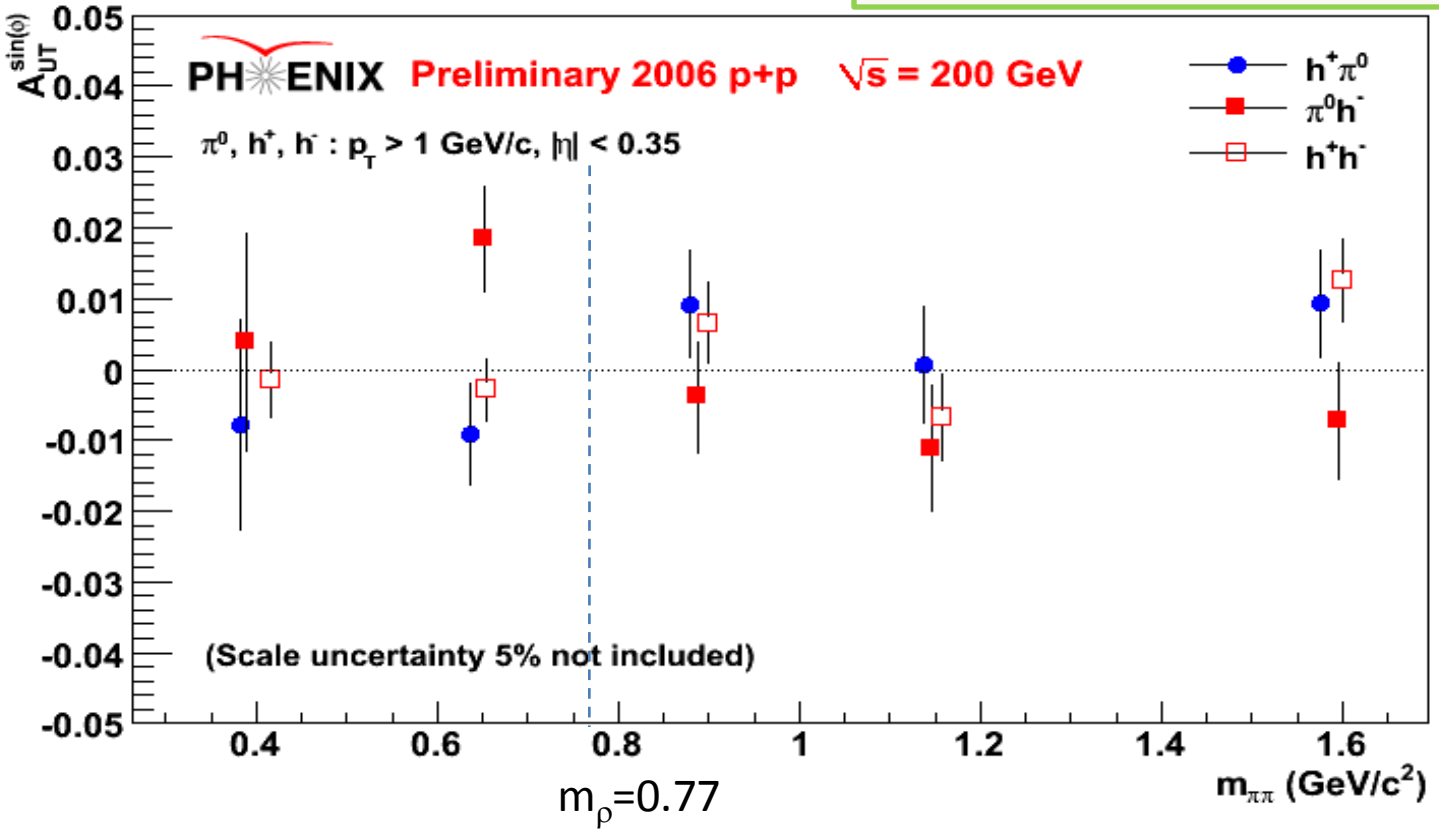


- A_N is zero within 1%
- It constrains Sivers distribution function for gluons not very large.
  (Anselmino et al., PRD74, 094011 (2006))
- Updated π^0 analysis with >10x smaller stat. error underway.

Interference FF as an analyzer

Transversity *IFF
2 hadrons in the central arm.





m_ρ=0.77

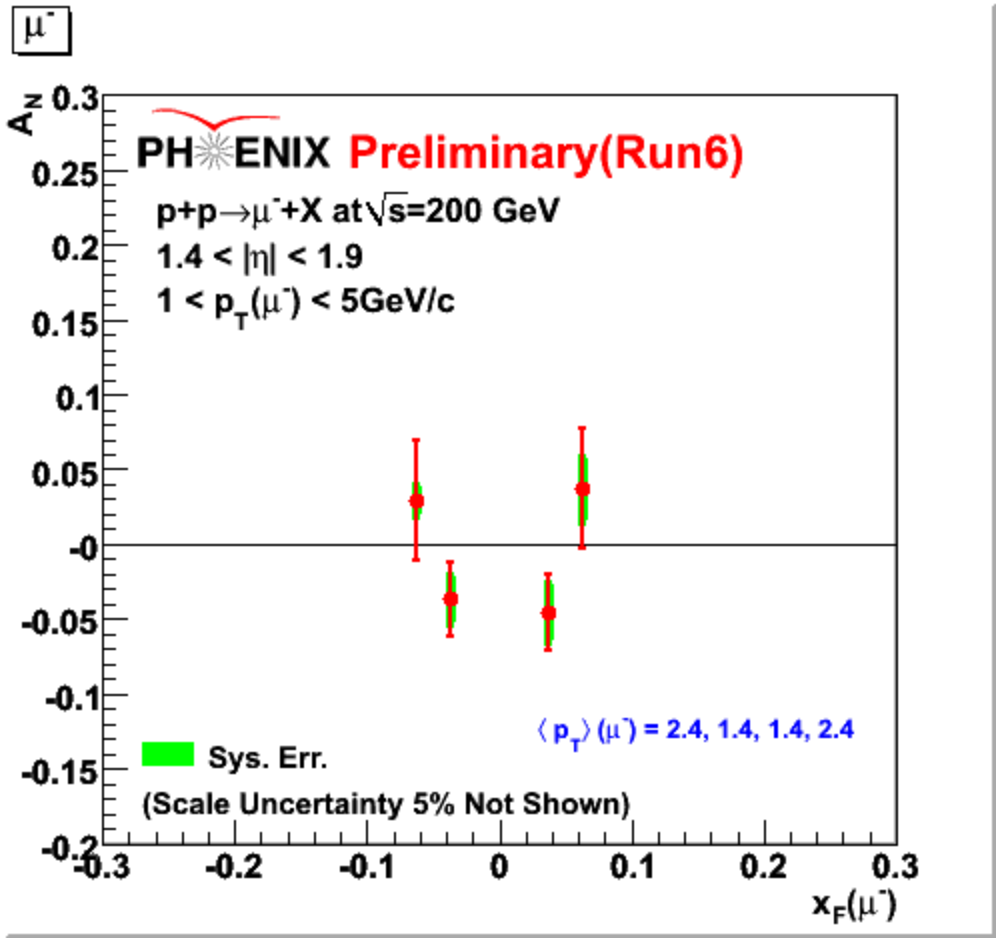
It's consistent with zero.

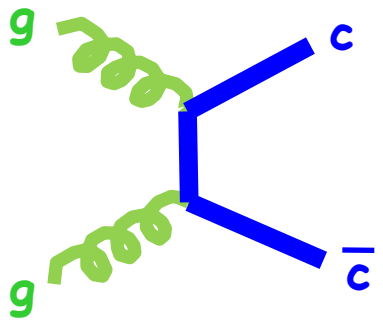
IFF from e+e collider data

The transversity will be constrained.

open charm A_N

gluon fusion process
sensitive to the gluon Sivers effect.



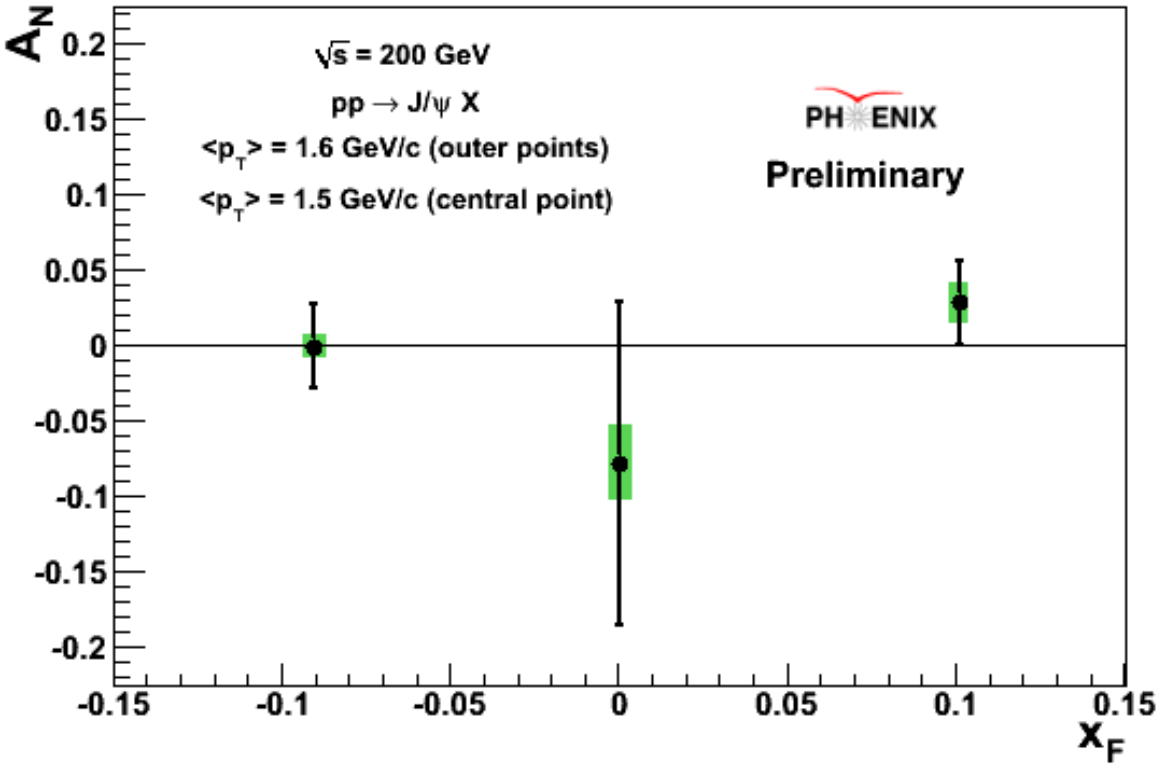


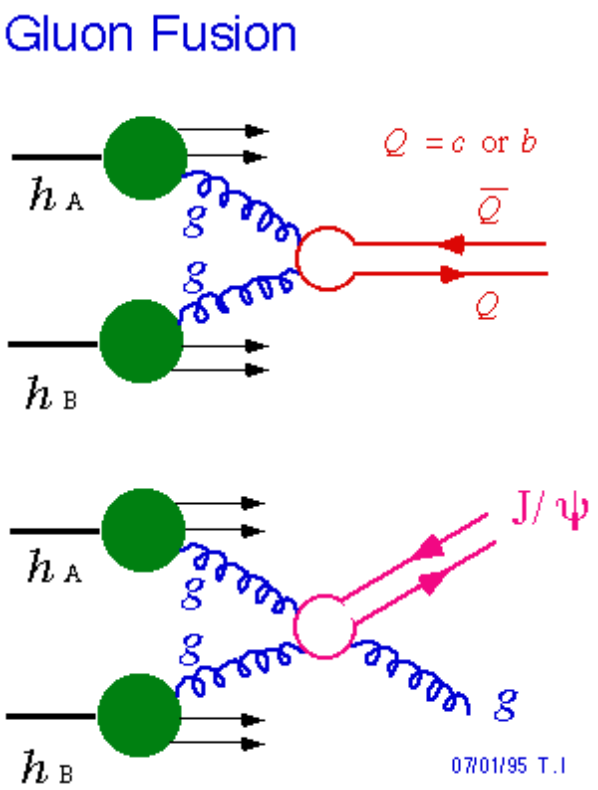
$c \rightarrow \mu, e$

It's consistent with zero.
Consistent with the small gluon Sivers.
An analysis on the electron channel is on going.

J/Ψ A_N

J/Ψ's are detected via di-lepton decay.





It is also sensitive to the production mechanism (PRD 78,014024)
The SSA survives in the color singlet model in *p+p* collisions.

Other probes

—Di-jet angle via 2 particle correlations : kT asymmetry

Central arm – Central arm

Central - Forward

Calculations based on observed Sivers effect in SIDIS.

STAR published a di-jet result (small <~1%) (PRL 99,142003)

A cancellation between (PRD 75, 075029)

ISI vs. FSI and

u-quark and d-quark ← There is a possibility to decompose by the charge of the leading hadron.

—Sivers effect in Drell-Yan process (PLB536,43,… , arXiv:0901.3078)

$$f_{1T}^{\perp}(x, k_T, \zeta)\big|_{\mathrm{DIS}} = -f_{1T}^{\perp}(x, k_T, \zeta)\big|_{\mathrm{DY}}.$$ FSI vs. ISI

A fundamental test of the QCD.

Direct photon (forward) + jet (mid-rapidity) :

The same trick with larger cross section. (PRL 99,212002)

The next step

—**It's not clear how large the asymmetry is (that's why we measure.)**
This is a difficulty for the planning.

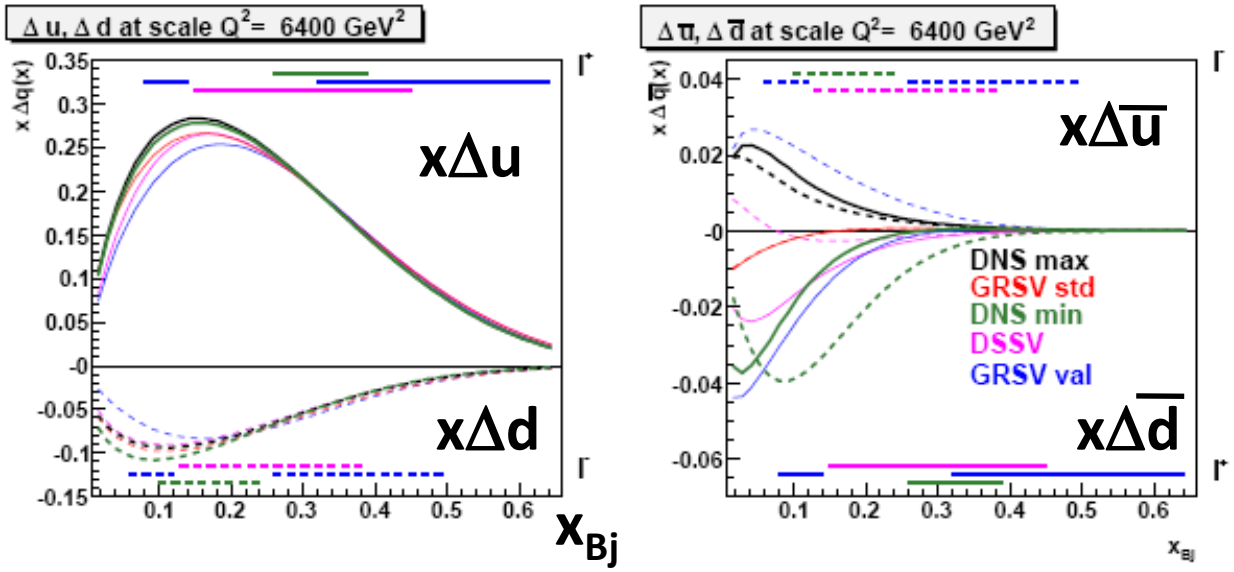
—**Drell-Yan process is the cleanest and the size of non-zero asymmetry is predicted by QCD from SIDIS results.**
(It's a fundamental test of QCD.) ~250/pb is required.

Direct photon + jet process is more reachable.
(With a forward photon detector, large enough to eliminate the pi0 decay photons.)

—**Large improvements on statistical precision to come from Run8 data.**
(It's our largest transverse data set.)

W program in √s=500GeV

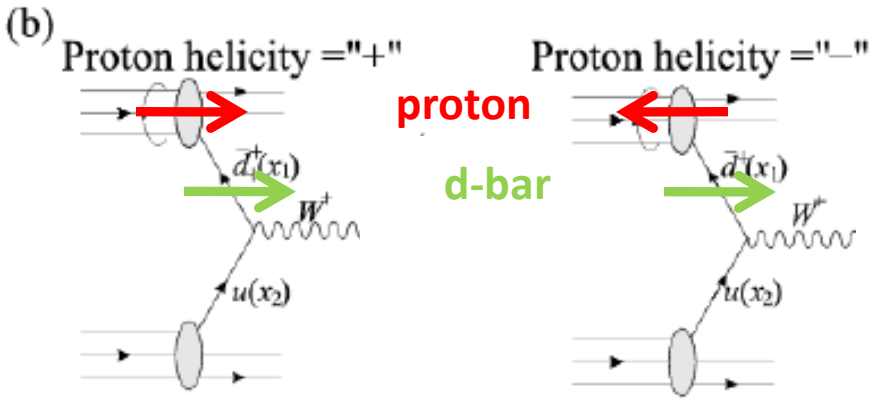
(Anti-) quark components of the proton spin



From Semi Inclusive Deep Inelastic Scattering (SIDIS) relying on the fragmentation models

W program at RHIC d-bar+u →W+
u-bar+d →W-

d-bar, u-bar is always positive helicity



W+ A_L: Longitudinal single spin asymmetry information of d-bar in the proton

Central W→e channel

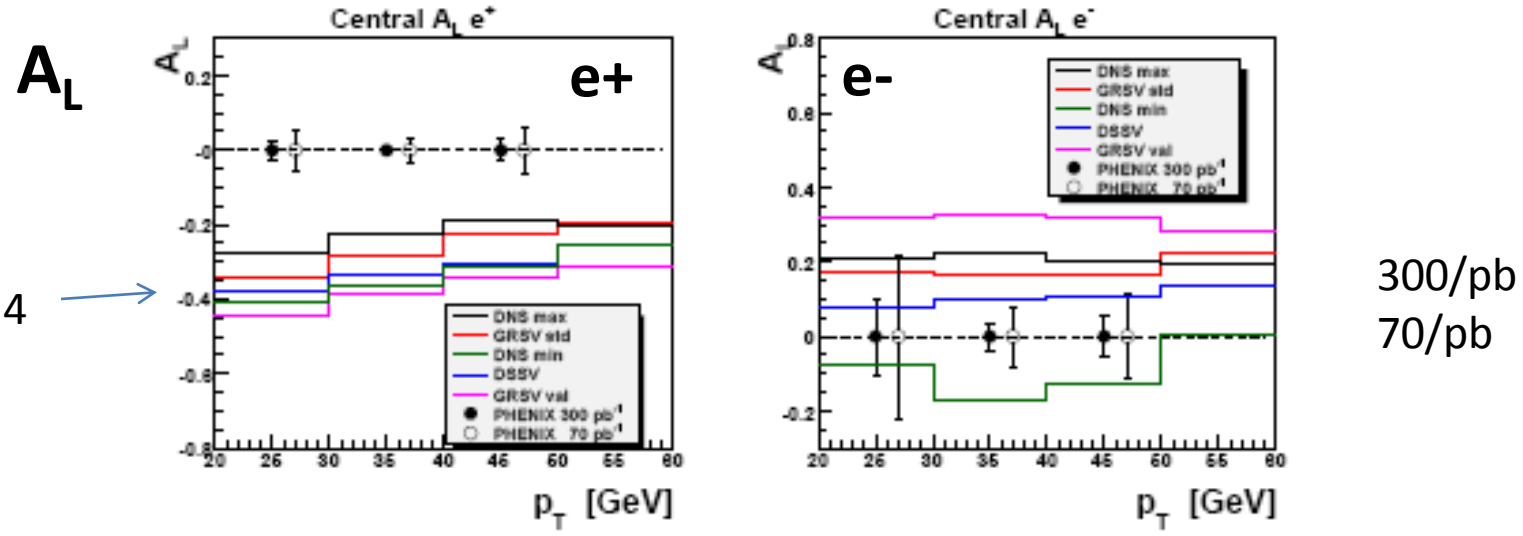


Figure 17: *Simulated asymmetries in the PHENIX central arms for $W^+ \rightarrow e^+\nu$ (left plot) and $W^- \rightarrow e^-\bar{\nu}$ as functions of p_T. The data has been obtained for GRSV standard, GRSV valence [45], DSSV [14], and DNS [47] using a maximal and minimal sea polarization scenario in RHICBOS [58] for 300 pb^{-1} (full symbols) and 70 pb^{-1} (open symbols) assuming 70% beam polarization.*

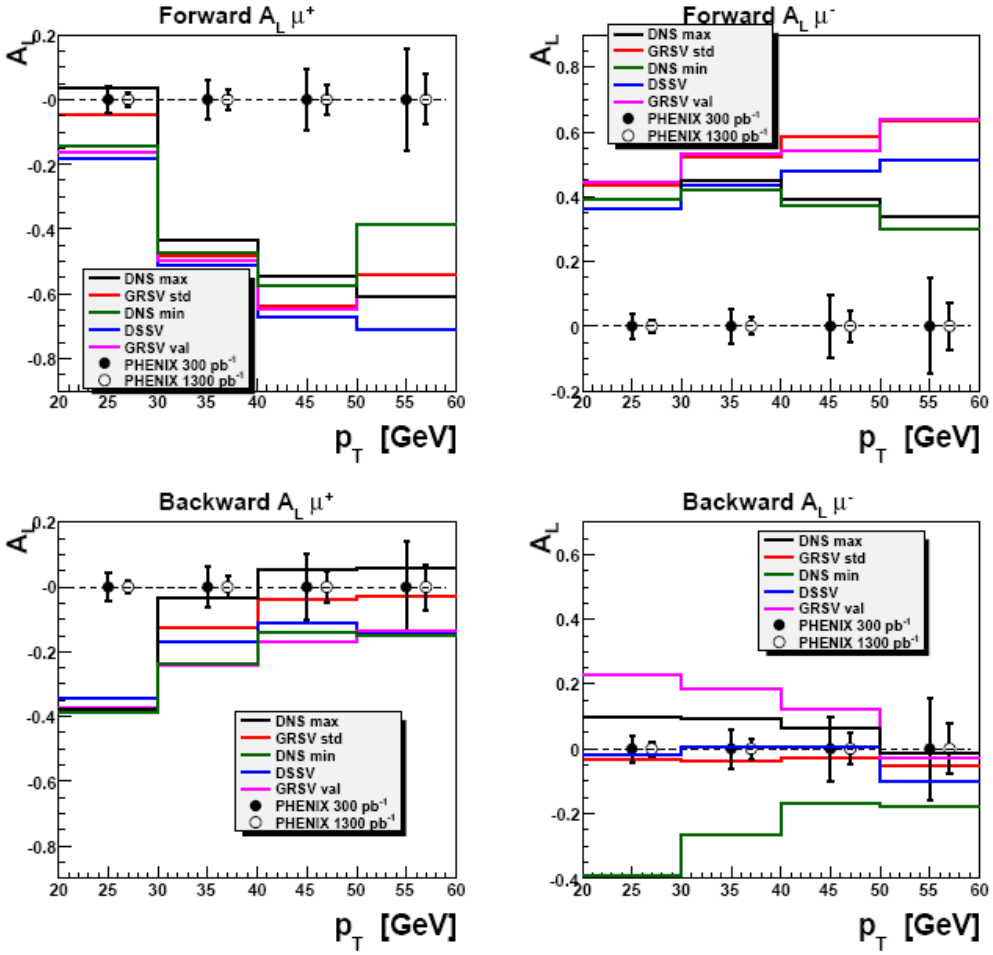
— Estimation for the near future (Run9)

3 weeks physics run (preparation is about 5 weeks)
7.5/pb/week *3 = 22.5/pb (recorded)

420e+,
70e- → δA_L=0.07 (with 50% pol)

The first non-zero asymmetry from the PHENIX Central Arm is expected!

Forward W→μ channel



300/pb
1300/pb

It's more sensitive to d-bar helicity.
The high momentum μ trigger will be ready by 2010.

Others related to the spin

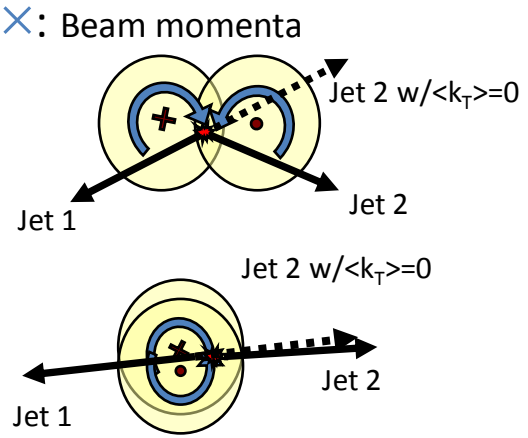
Others related to the spin

- **Very forward (<4mrad) neutron single spin asymmetry … non-zero!**

- **Jet kT asymmetry** new data (run5+6)
  (a probe of quark orbital angular momentum?)

- **Spin transfer analysis**
  with self-analyzing decay channel (Λ)
  Access to strange quark components?
  It can be a good tool. But no good trigger.
  (new data)

  Can J/Ψ be an analyzer?



Summary


In the longitudinal spin program, the primary goal is to find the gluon spin component in the proton.
For now, the measurement tells the gluon carries a small fraction of the missing spin component.
Our measurement is limited in a relatively large x, is insensitive to the shape of pol-PDF.

In the transverse spin program, experimental results leads the field (including pol-DIS).
For a few years, we need to collect more evidence on the table.

The W program (single helicity asymmetry in $\sqrt{s}$=500GeV) is about to start.
It will be the first non-zero spin asymmetry signal in the PHENIX central arm.

There are many observables related to the spin.
Which one do you bet?