Overview of the PHENIX transverse and longitudinal spin physics program

M. Sarsour

Georgia State University

for the PHENIX Collaboration

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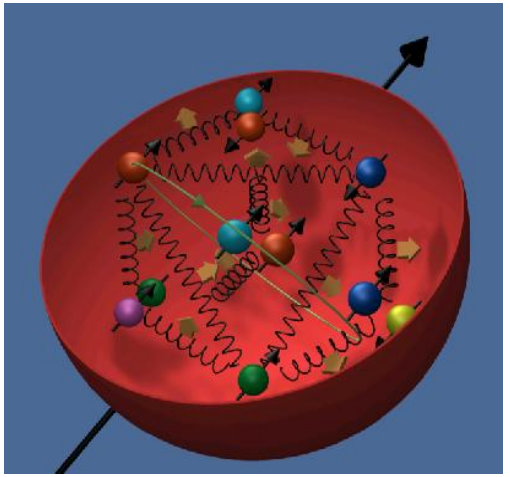
Outline :

1. ***Introduction***
2. ***Experimental setup***
3. ***Recent results from transverse spin program***
4. ***Recent results from longitudinal spin program***
5. ***Summary & Outlook***



Proton Spin Structure

Origin of the proton spin?

Recent fits show it is small
~ 0.33 from recent fits

Poorly Constrained

Very little is known

$$\langle S_z^p \rangle = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z^q \rangle + \langle L_z^g \rangle$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}$$

Poorly Constrained

- $\vec{p}\vec{p}$ ***at RHIC*** $\Rightarrow$ ***New QCD lab: strongly interacting probes***
- ***High*** $\sqrt{s}$ ***make NLO pQCD analysis more reliable***
- ***PHENIX spin program:***
  - ***Longitudinal spin program*** $\Rightarrow$ ***Gluon polarization distribution + Anti-quark sea polarization***
  - ***Transverse spin program*** $\Rightarrow$ ***sensitivity to*** $\langle L_z \rangle$ ***+ Transversity***

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See Stephen Pate's talk after this talk

Probing ΔG in polarized pp collisions –

Inclusive A_{LL} measurements (π^o, η, $\pi^{\pm}$, J/ψ, …)

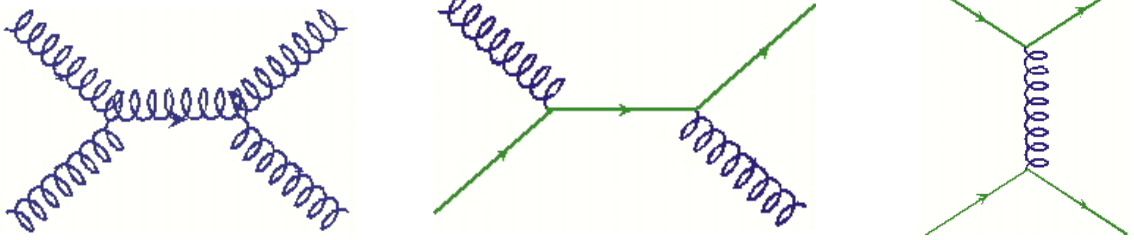
❑ ***Δσ - very small (difficult to measure) ⇒ measure asymmetries instead ⇔ most of systematic effects cancel out***

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}} = \frac{\sum_{a,b,c=q,\bar{q},g} \Delta f_a \otimes \Delta f_b \otimes \Delta\hat{\sigma} \otimes D_{\pi/c}}{\sum_{a,b,c=q,\bar{q},g} f_a \otimes f_b \otimes \hat{\sigma} \otimes D_{\pi/c}}$$

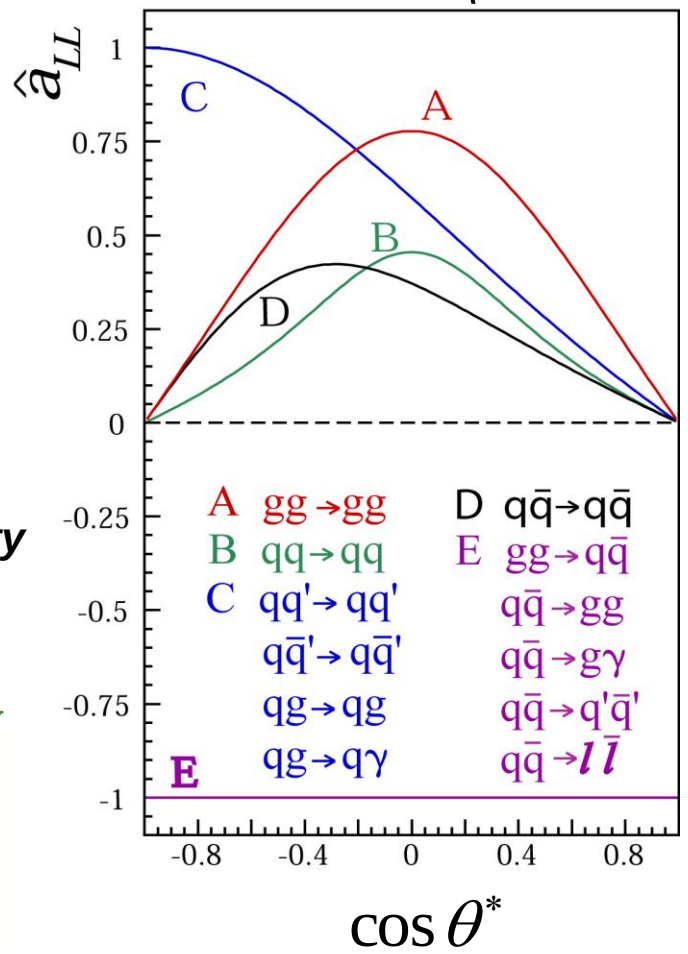
$$A_{LL} \cong a_{gg}\Delta g^2 + b_{gq}\Delta g\Delta q + c_{qq}\Delta q^2$$

Where a_{gg}, b_{qg} and c_{qq} depend on p_T, process and rapidity

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



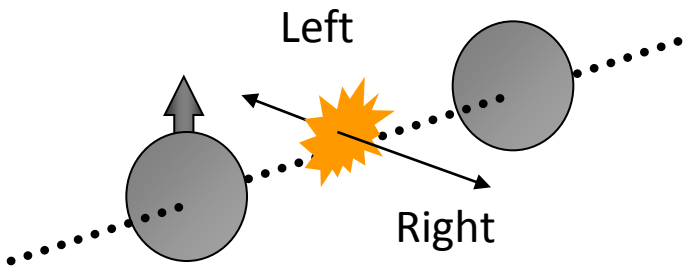
$\theta = 90^o \Rightarrow \eta = 0$



❑ ***Good tool to study the gluon polarization but with no direct parton kinematics reconstruction... To be used in a global analysis to obtain ΔG.***

As boost and rotations don't commute, transverse spin structure is studied independently –

Inclusive A_N measurements



$$A_N = \frac{1}{P}\frac{\sigma_L^{\pi} - \sigma_R^{\pi}}{\sigma_L^{\pi} + \sigma_R^{\pi}}$$

❖ ***Small A_N is expected at high energies*** (Kane, Pumplin, Repko, PRL 41, 1689–1692 (1978))

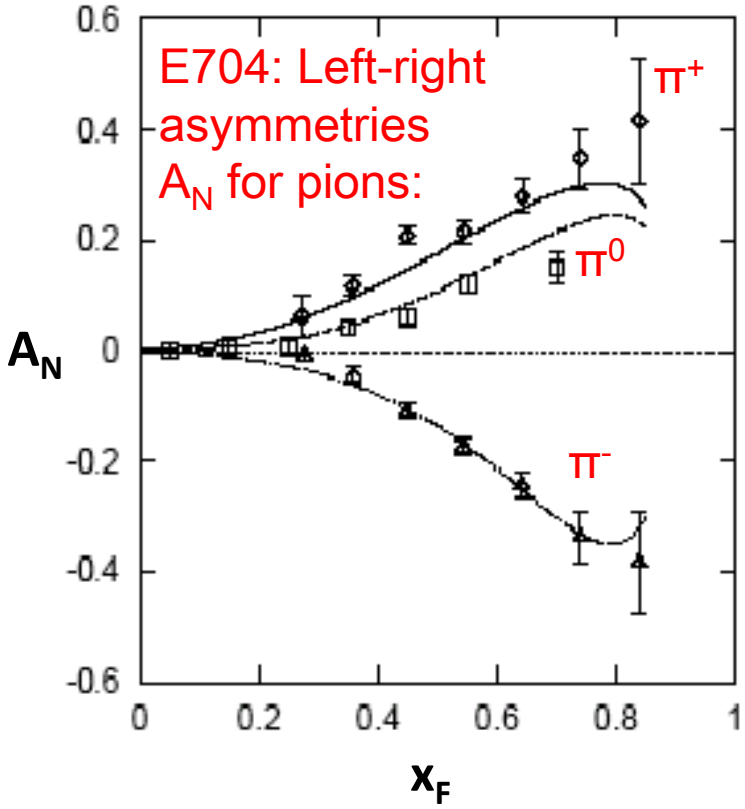
$$A_N \propto \frac{m_q}{\sqrt{s}}$$

A_N O(10^{-4}) Theory

❖ ***Large A_N is seen*** (E704, Fermi National Laboratory, 1991)

$$p p^{\uparrow} \rightarrow \pi + X$$
$$\sqrt{s} = 20\,\mathrm{GeV}$$

A_N O(10^{-1}) Measured



Origin of Single Spin Asymmetries?

1. **Transversity quark distributions and Collins or Interference fragmentation**

   Correlation between proton and quark spin and spin dependent fragmentation

$$\propto \delta q(x) \cdot H_1^{(\perp,<)}(z_2, k_\perp^2)$$

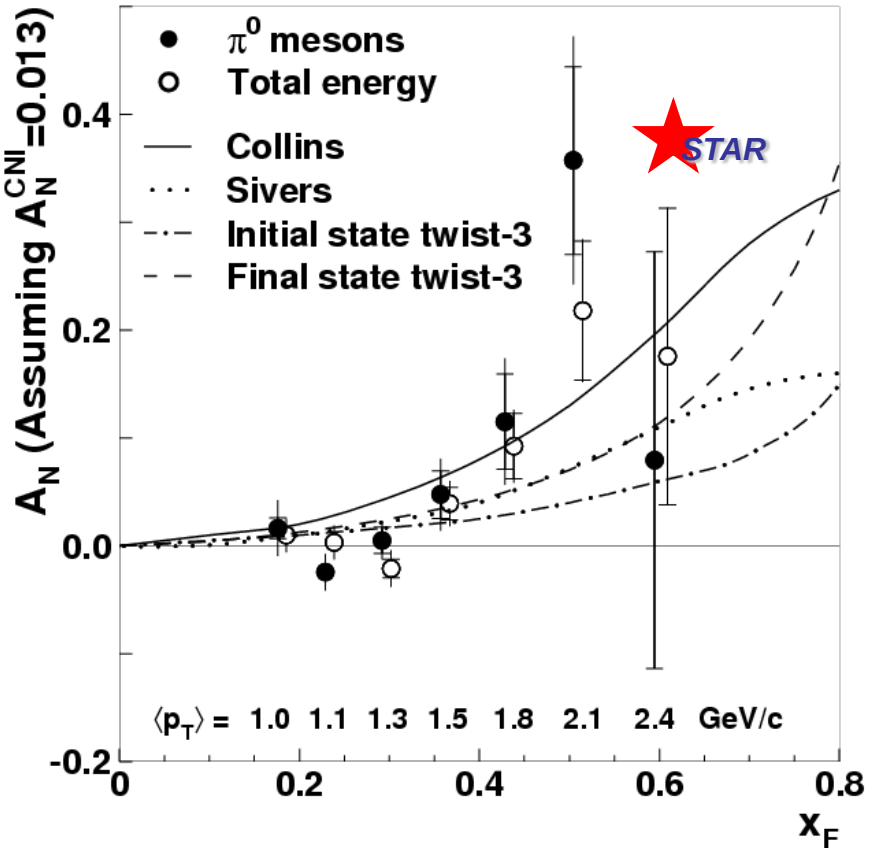
2. **Sivers quark distribution**

   Correlation between proton-spin and transverse quark momentum

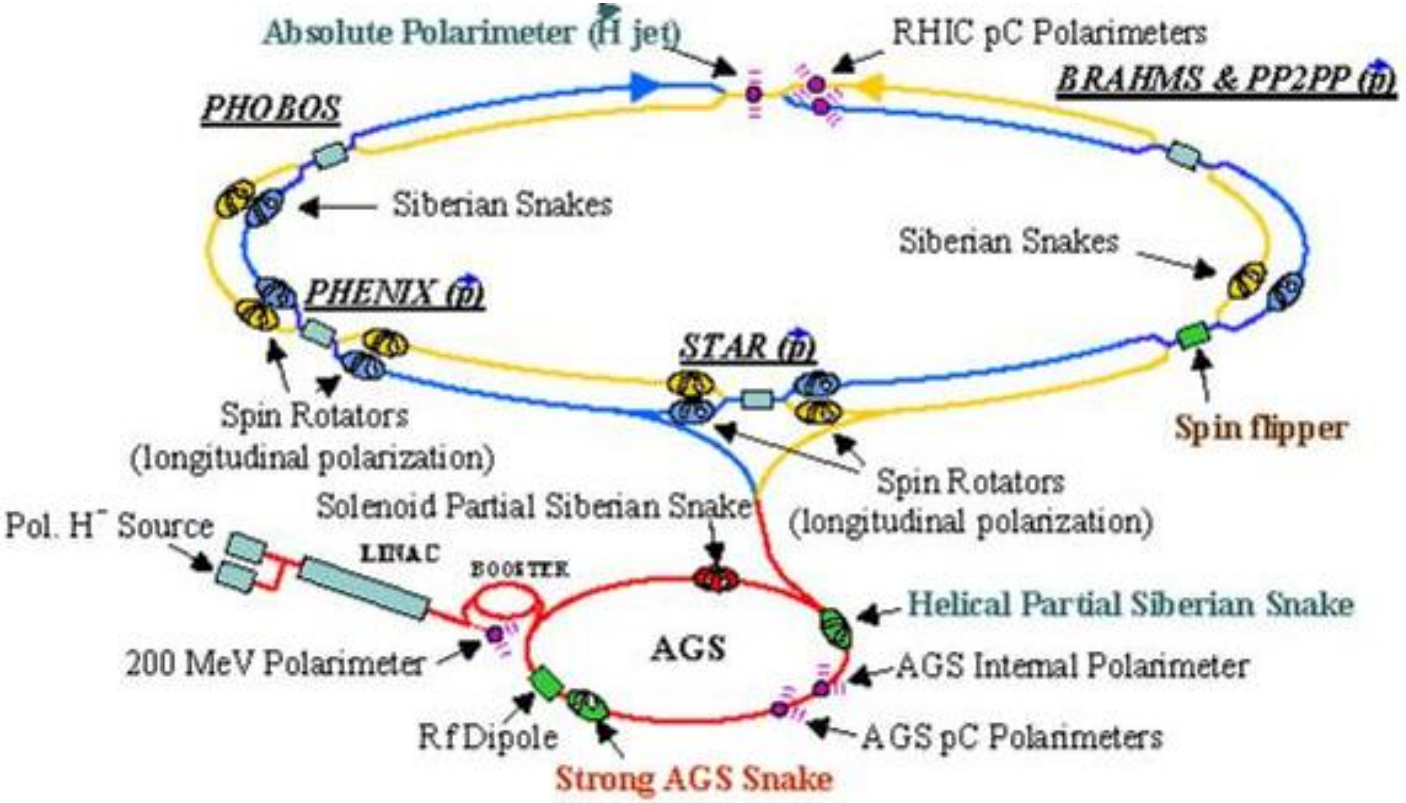
$$\propto f_{1T}^{\perp q}(x, k_\perp^2) \cdot D_q^h(z)$$

3. **Higher Twist Contributions**

   Equivalent to Sivers at small k_T



Polarized Protons at RHIC



RHIC RUN	√s [GeV]	L_{Rec} [pb^{-1}] / Long.	Pol. [%]	L_{Rec} [pb^{-1}] / Trans.	Pol. [%]
2003	200	0.35	27	-	-
2004	200	0.12	40	-	-
2005	200	3.4	49	0.16	47
2006	200	7.5	57	2.7	51
2006	62.4	0.08	48	0.02	48
2008	200	-	-	5.2	46
2009	200	14	55	-	-
2009	500	16	35	-	-

PHENIX Detector Layout

Philosophy (initial design):

- High rate capability & fine granularity
  - ➢ Good mass resolution & particle ID
  - ○ Sacrifice acceptance

π^0, η, γ

Electromagnetic Calorimeter (PbSc/PbGl)
($|\eta|<0.35$, $\varphi = 2 \times \pi/2$)

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

Drift Chamber (DC)
Ring Imaging Cherenkov Detector (RICH)
Electromagnetic Calorimeter (PbSc/PbGl)

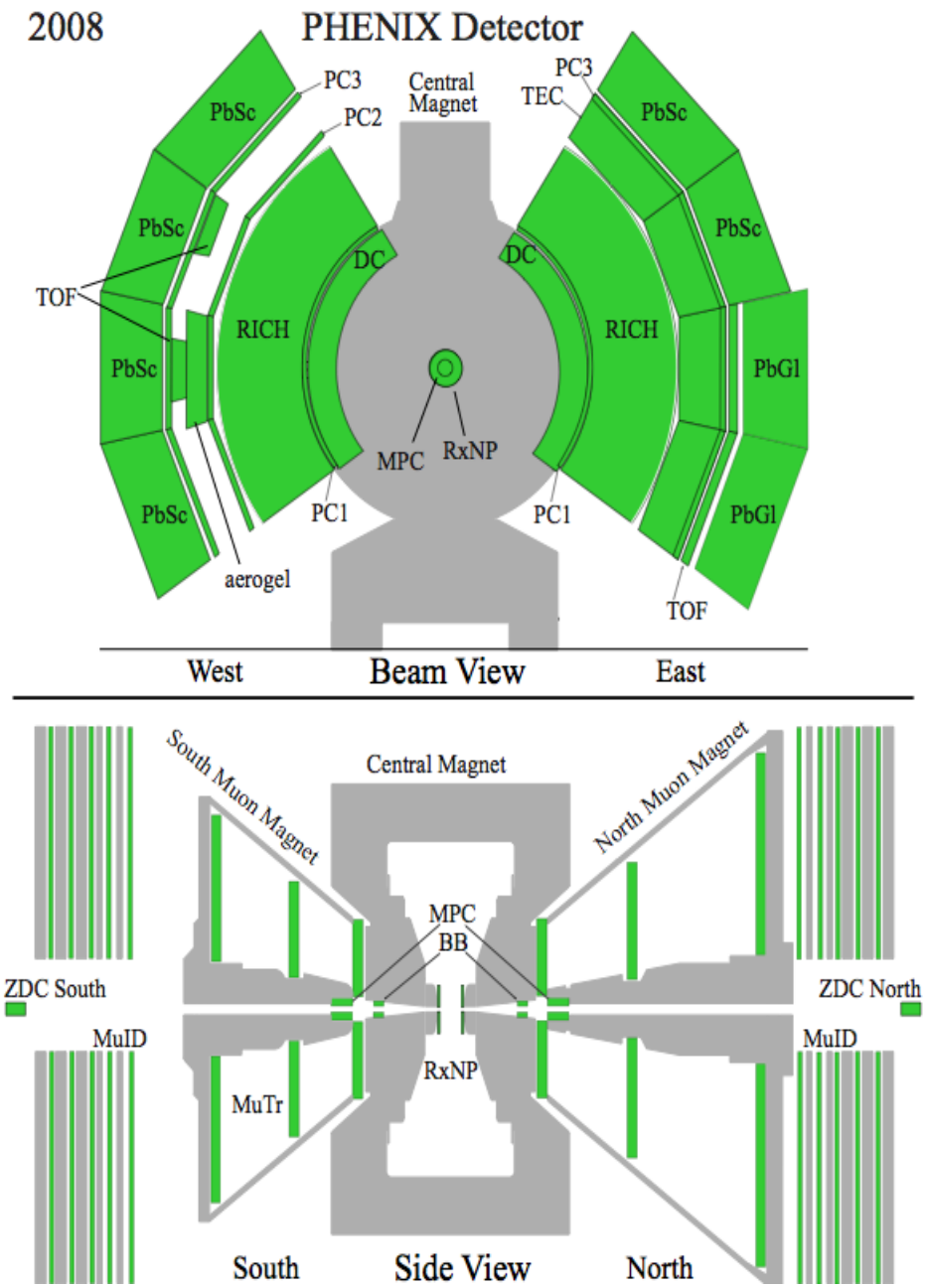
μ, $J/\psi \rightarrow \mu^+\mu^-$

Muon Id/Muon Tracker ($1.2<|\eta|<2.4 + 2\pi$)

π^0, η MPC ($3.1<|\eta|<3.9 + 2\pi$)

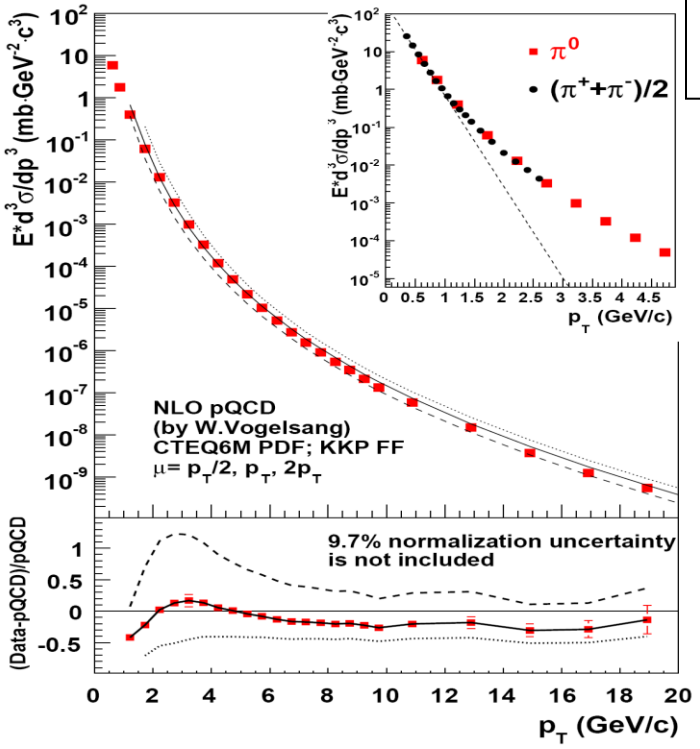
Relative Luminosity

Beam Beam Counter (BBC) ($3.0< \eta<3.9$)
Zero Degree Calorimeter (ZDC)

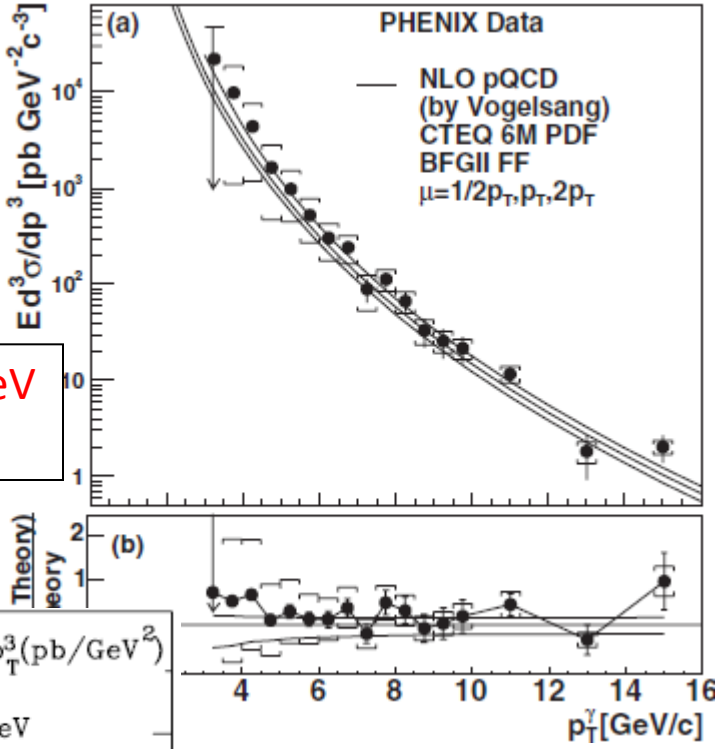


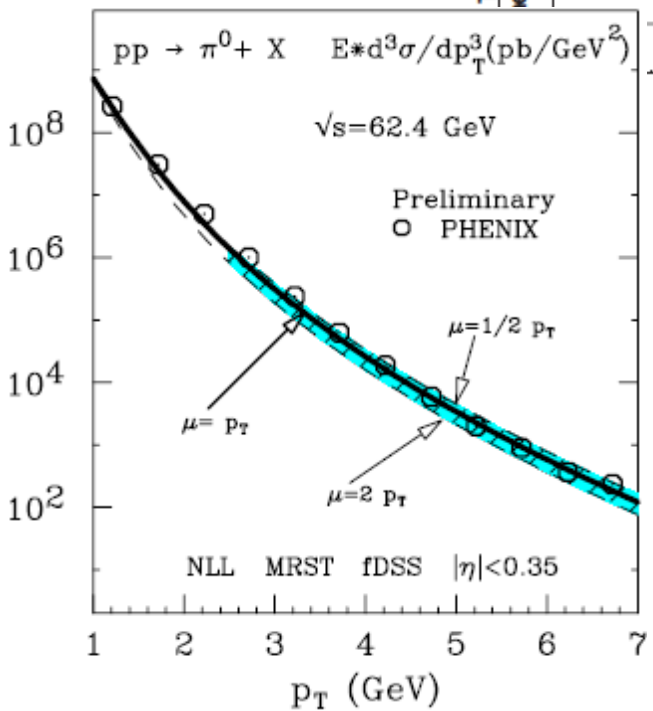
Cross Sections from PHENIX and pQCD

π^0 @ 200 GeV
PRD**76**, 051106



Direct γ @ 200 GeV
PRL**98**, 012002



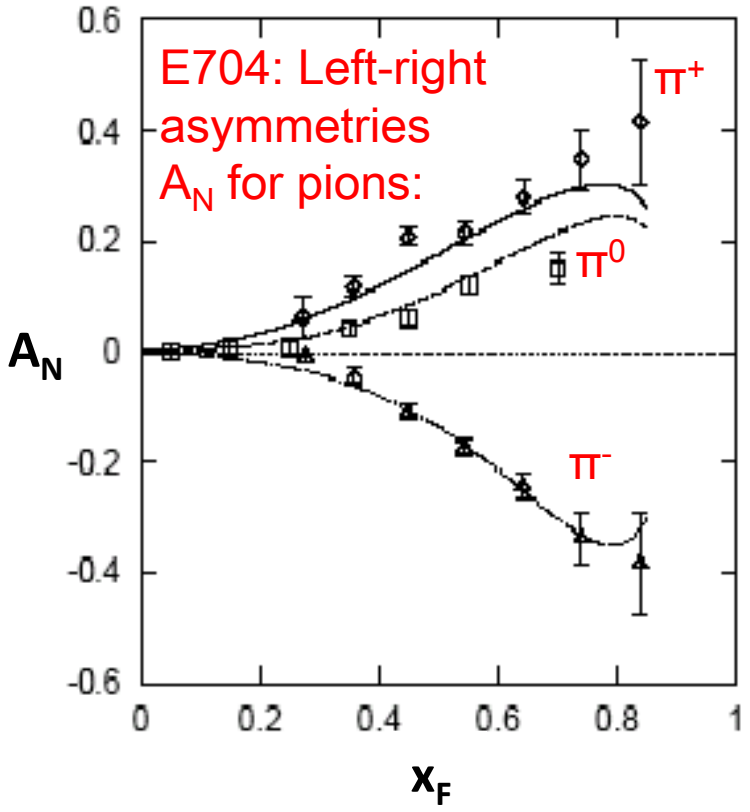


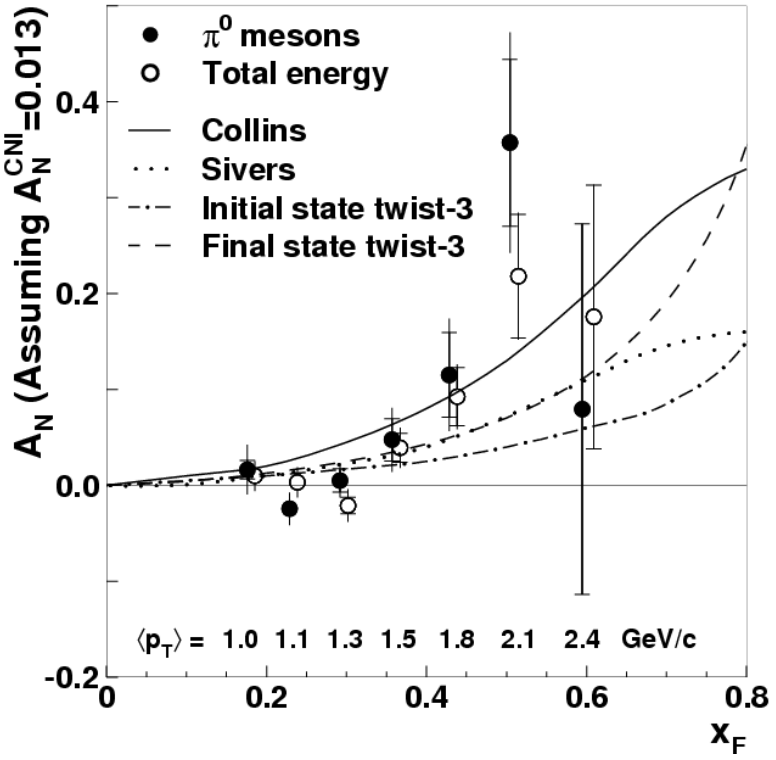
Consistent with NLO pQCD calculations ⇒ ***pQCD suitable framework for treating polarization observables in these kinematics***

Transverse spin program at PHENIX

PHENIX Strategy:

Measure several observables at different rapidity ranges , each sensitive to different transverse spin effect





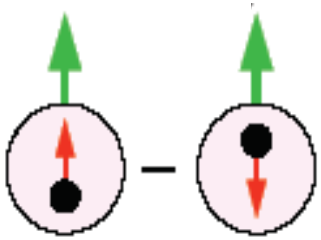
Transverse spin program at PHENIX -

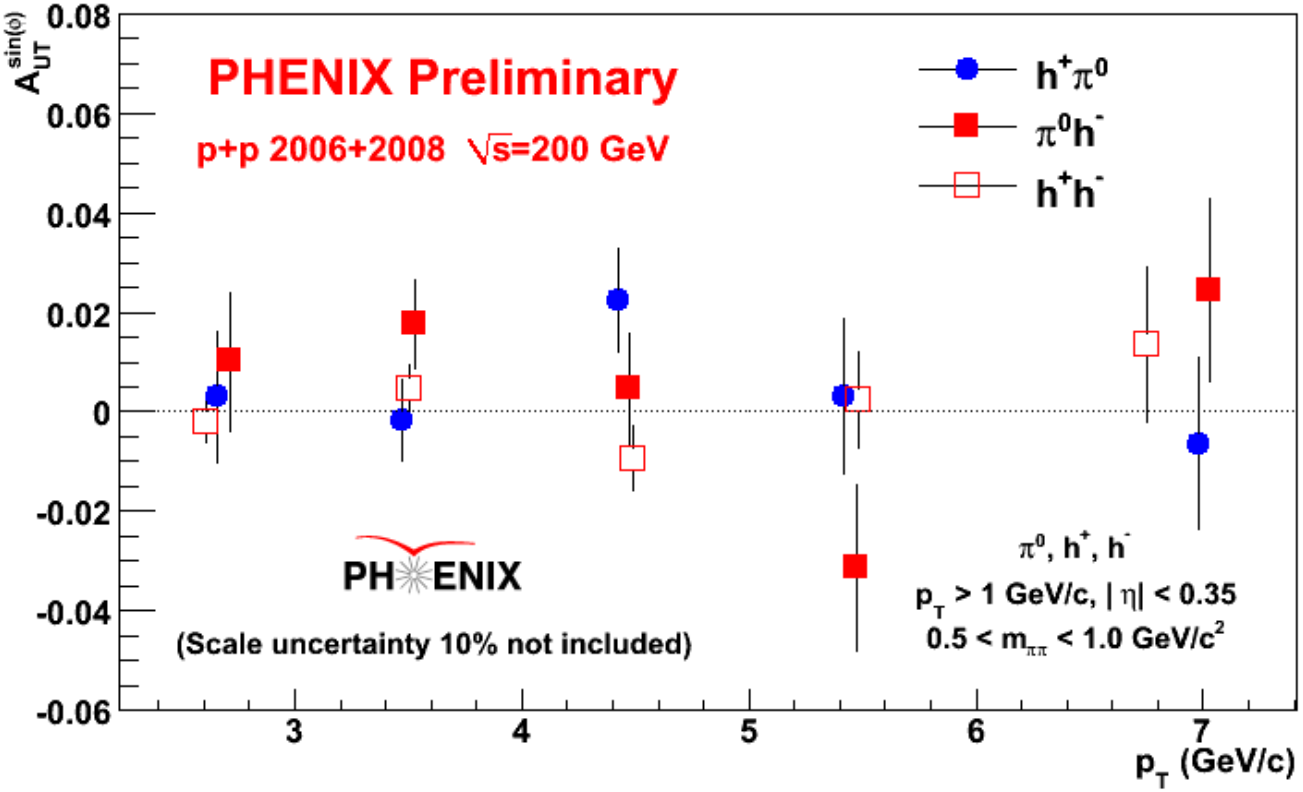
Transversity δq(x)

Transverse spin information at leading twist

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

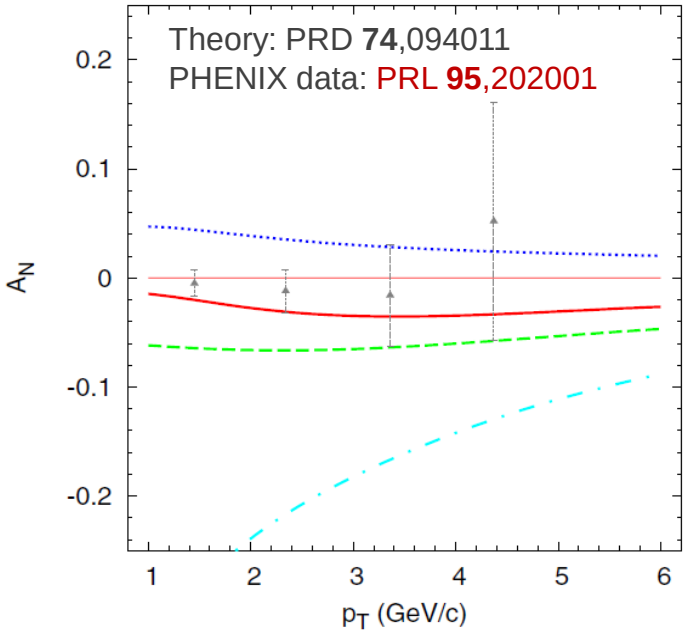
Measure δq X Interference Fragmentation functions





No significant asymmetries seen at mid-rapidity

Transverse spin program at PHENIX -
Sensitivity to gluon Sivers



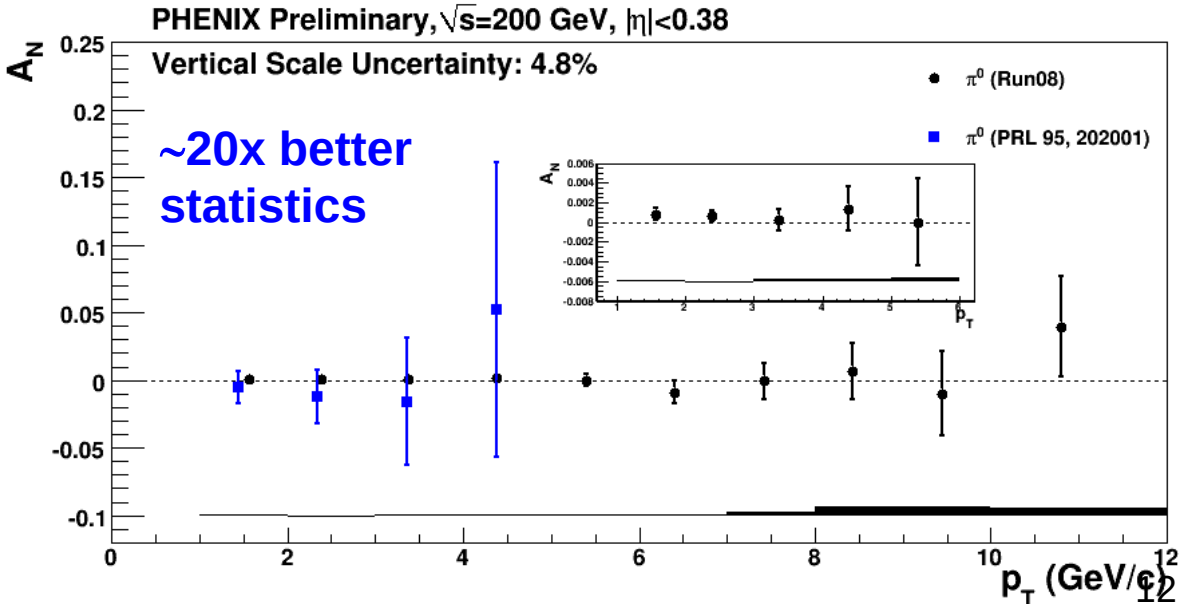
maximized sea and valence quark Sivers

+

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

New results will impose better constraints on gluon sivers

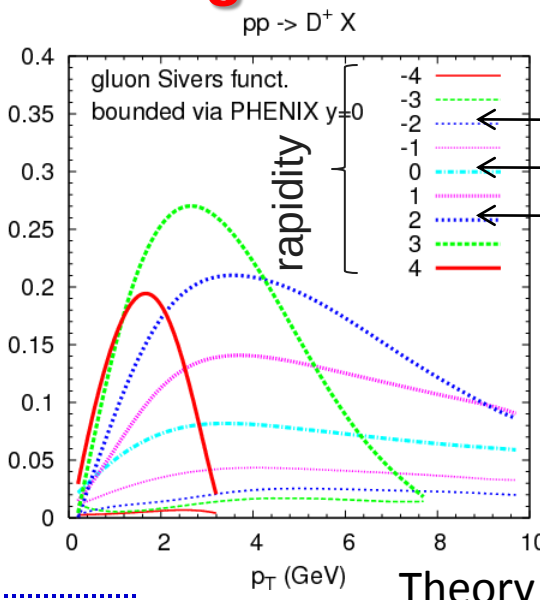


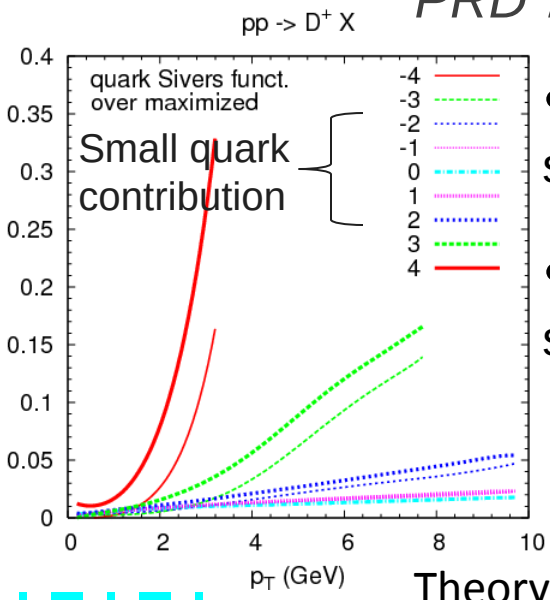
Transverse spin program at PHENIX -

Constraints on gluon Sivers?

PRD 70,074025

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





- Quark Sivers set to max
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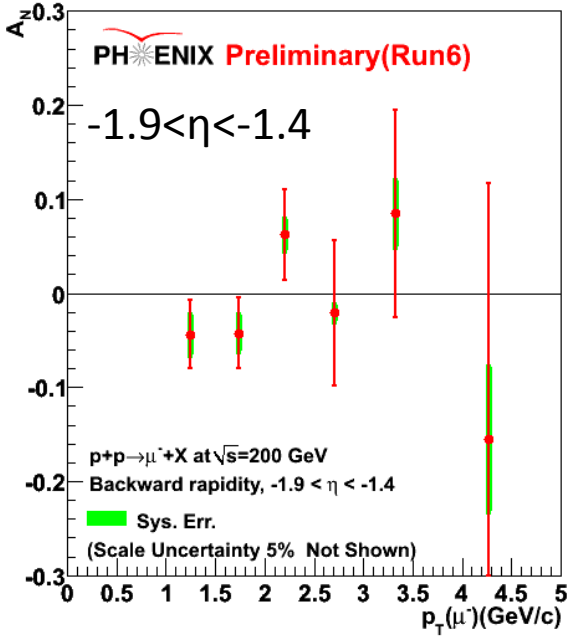
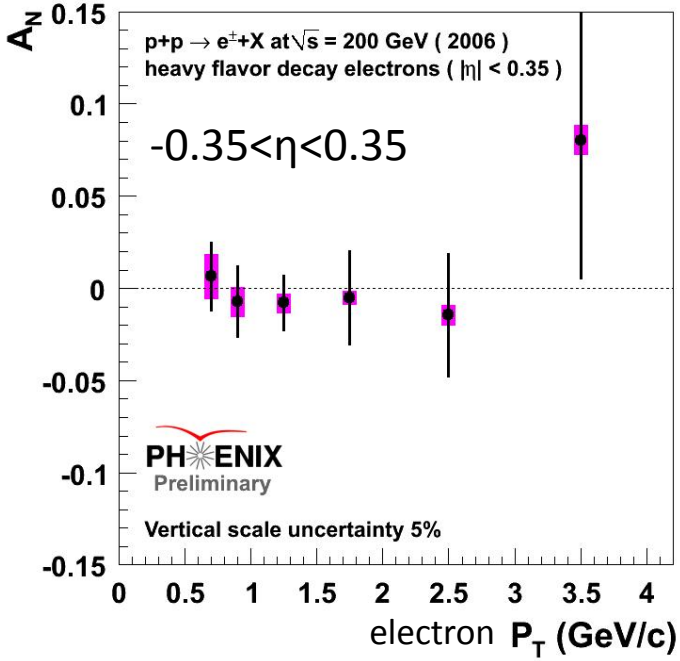
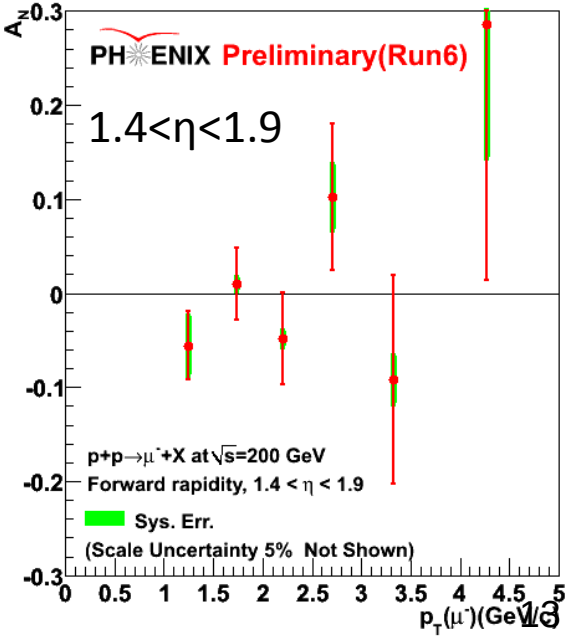
Theory ..... Theory - - - - Theory .....

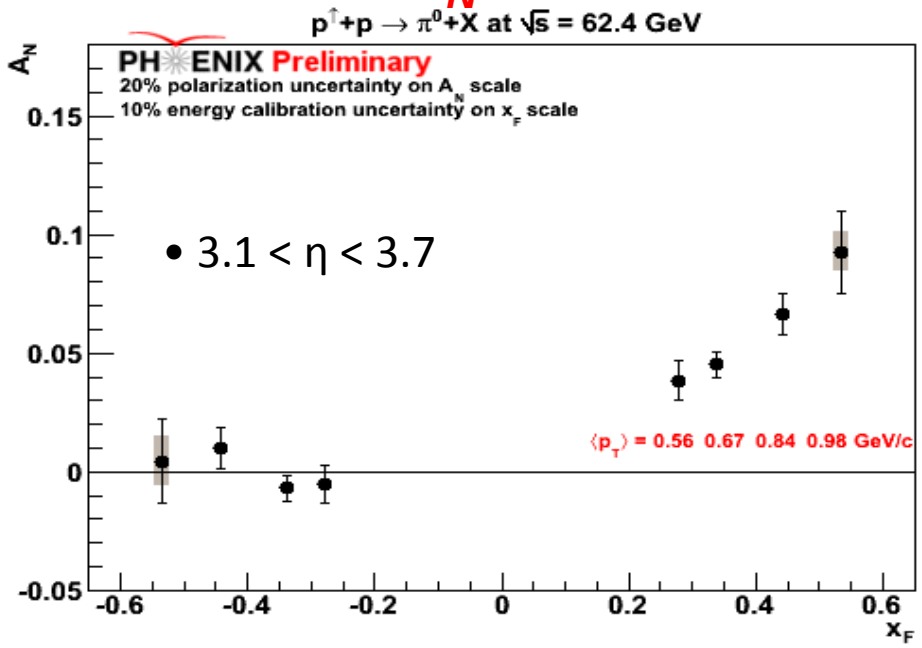




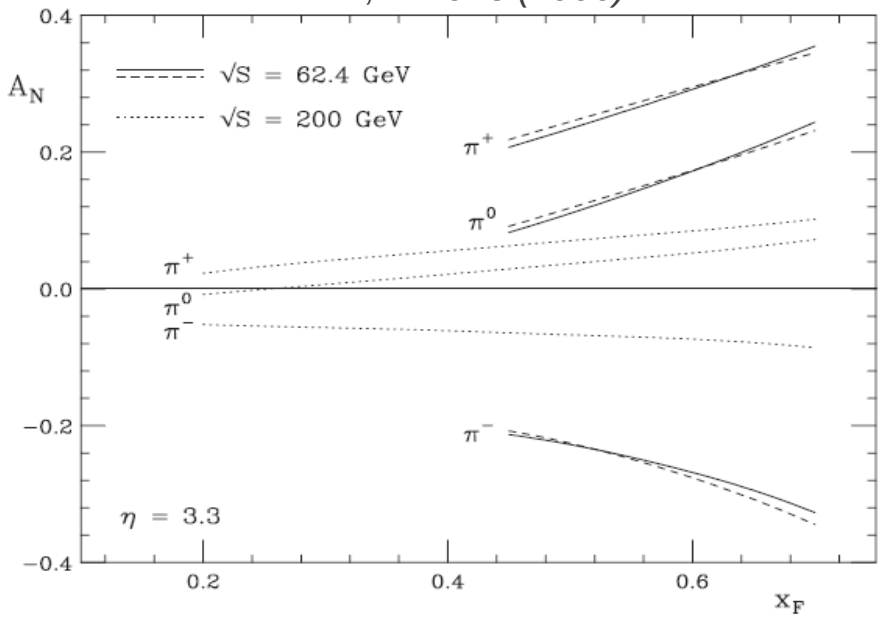


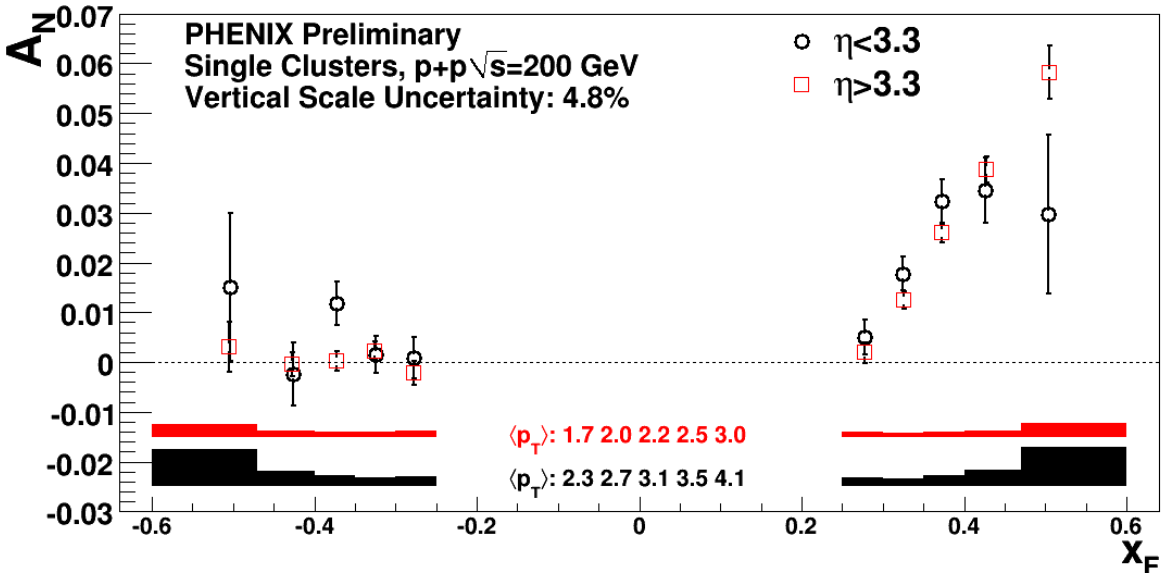
Transverse spin program at PHENIX -

Forward π^0 A_N in MPC



*PRD **74**, 114013 (2006)*





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

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

X_F dependence consistent with predictions

Longitudinal spin program at PHENIX

PHENIX Strategy:

Measure several observables covering different kinematic regimes & different systematics

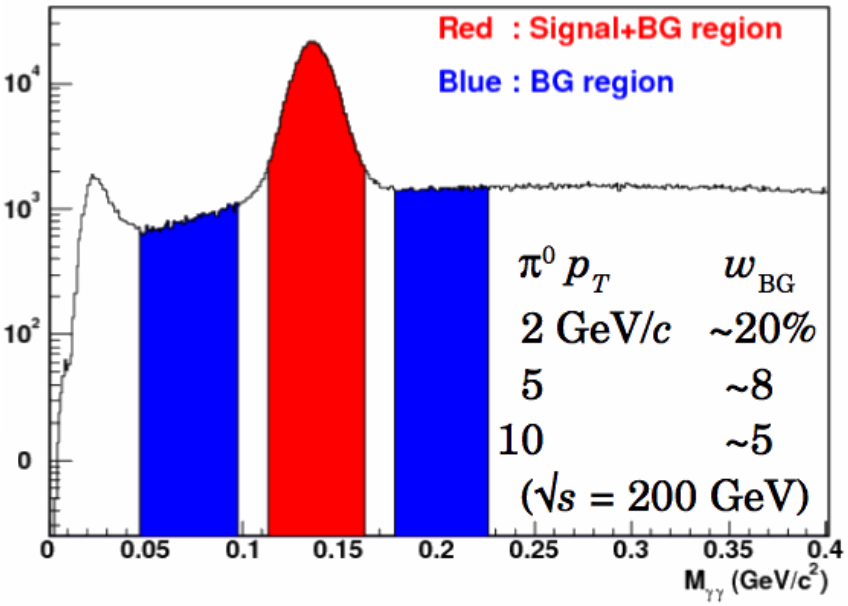
Extend the covered x-range (running @ $\sqrt{s}$ = 62.4 and 500 GeV

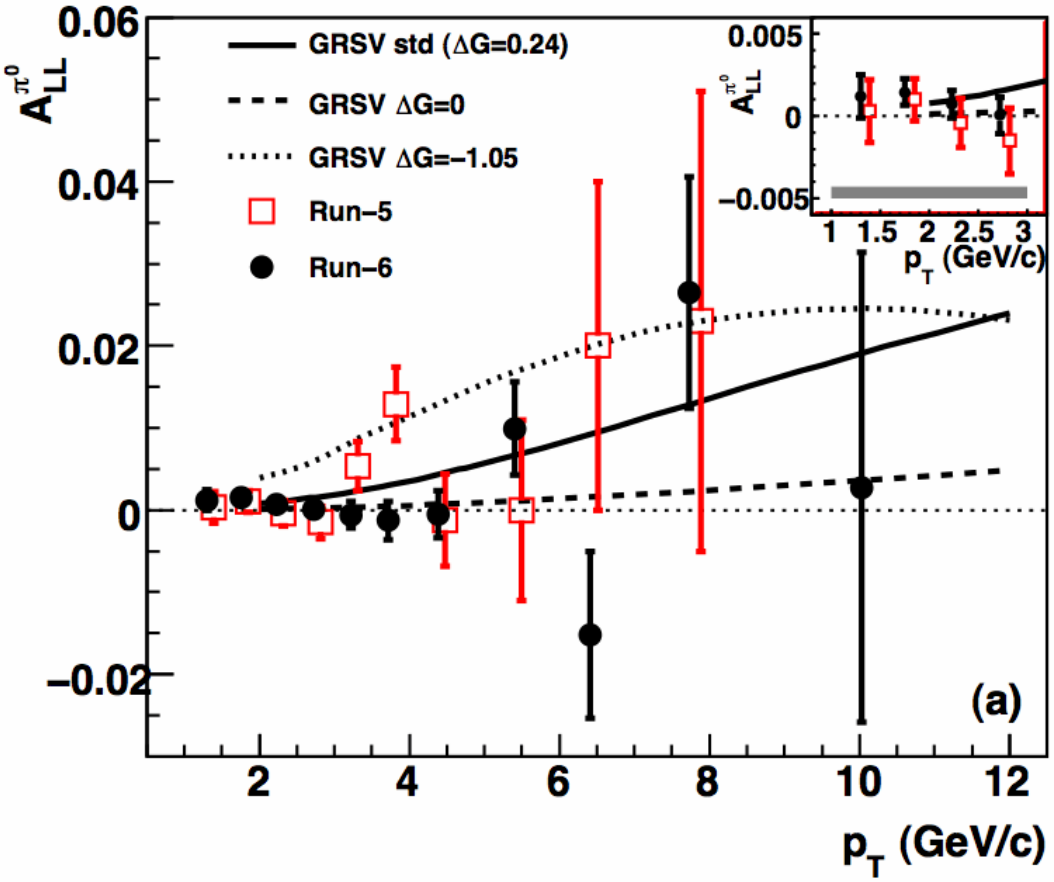
Longitudinal spin program at PHENIX -

Measurement of π^0 A_{LL}

Most dominant statistically:

- Large cross section
- finely segmented EMCal
- high p_T photon trigger





$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

$$= \frac{1}{P_B P_y} \frac{N_{++} - R N_{+-}}{N_{++} + R N_{+-}}, R = \frac{L_{++}}{L_{+-}}$$

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

2005: PRD **76**, 051106

2006: PRL **103**, 012003

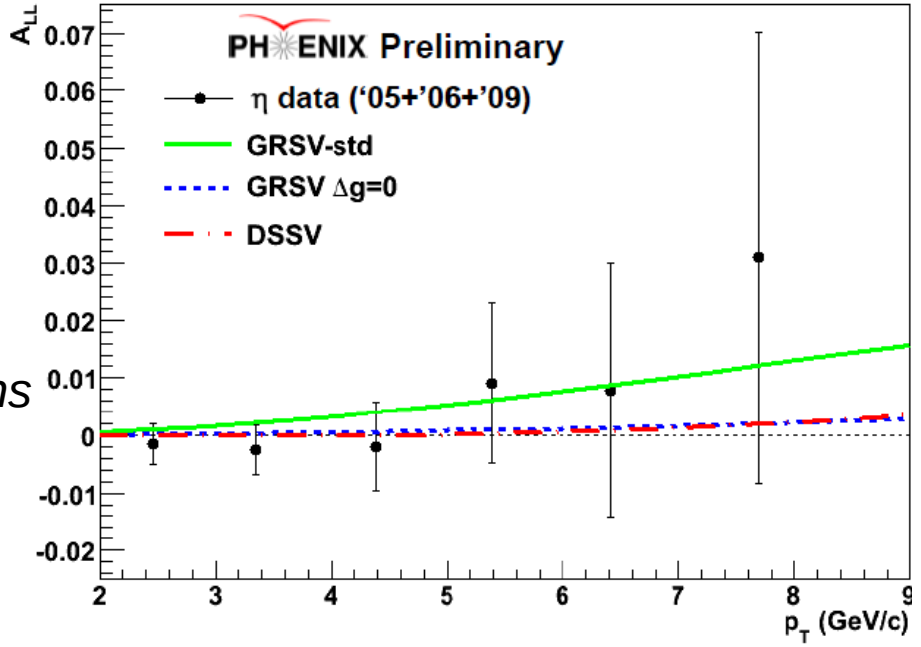
Longitudinal spin program at PHENIX - Other probes

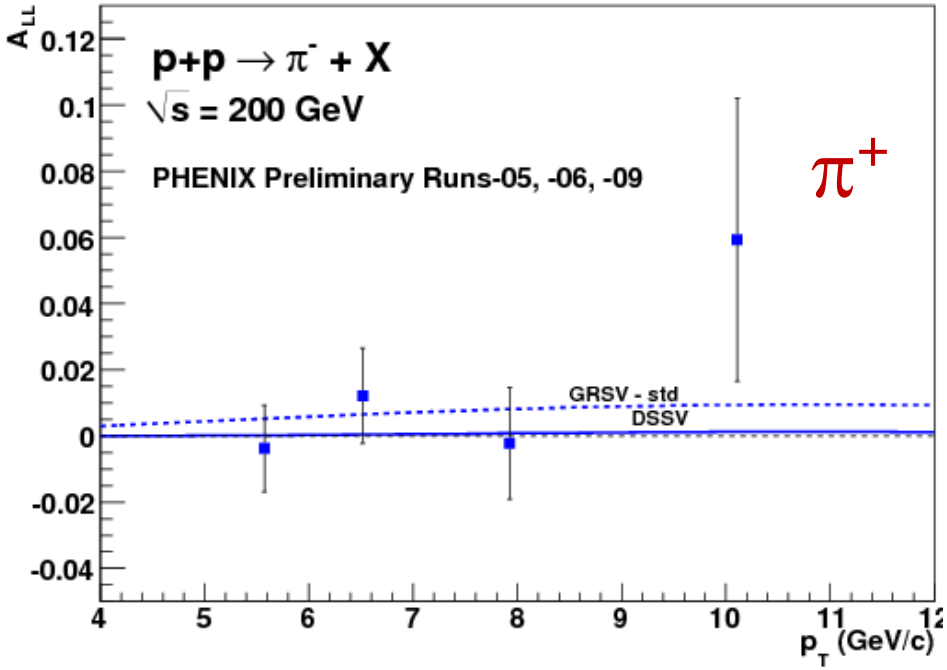
- **η at 200 GeV**
  - *Analysis similar to π^0*
  - *Fractional sub process differ somewhat*
  - *Independent confirmation of ΔG*
- **Charged pion ($\pi^{\pm}$) at 200 GeV**

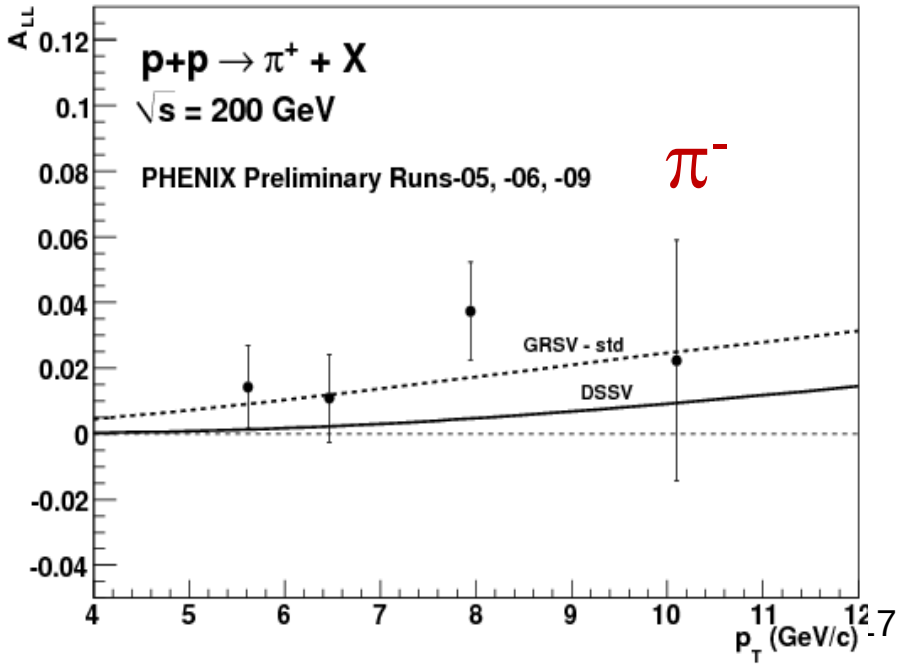
Preferred fragmentation $u \to \pi^+$ and $d \to \pi^-$;
$\Delta u > 0$ and $\Delta d < 0$ $\Rightarrow$ different qg contributions
for π^+, π^0, π^- **$\Rightarrow$ access sign of ΔG**

$$A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-} \Rightarrow \Delta G > 0$$

$$A_{LL}^{\pi^+} < A_{LL}^{\pi^0} < A_{LL}^{\pi^-} \Rightarrow \Delta G < 0$$

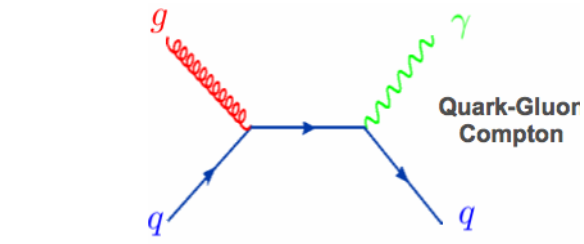




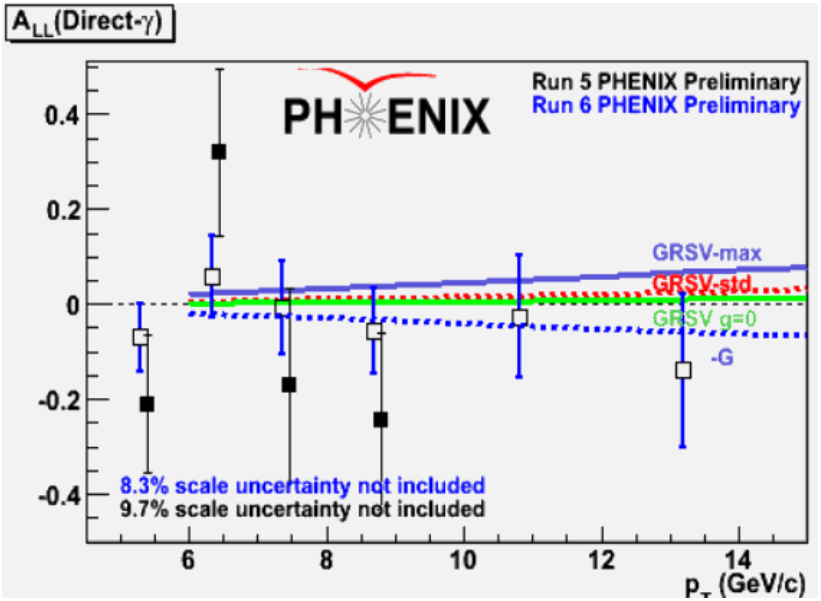


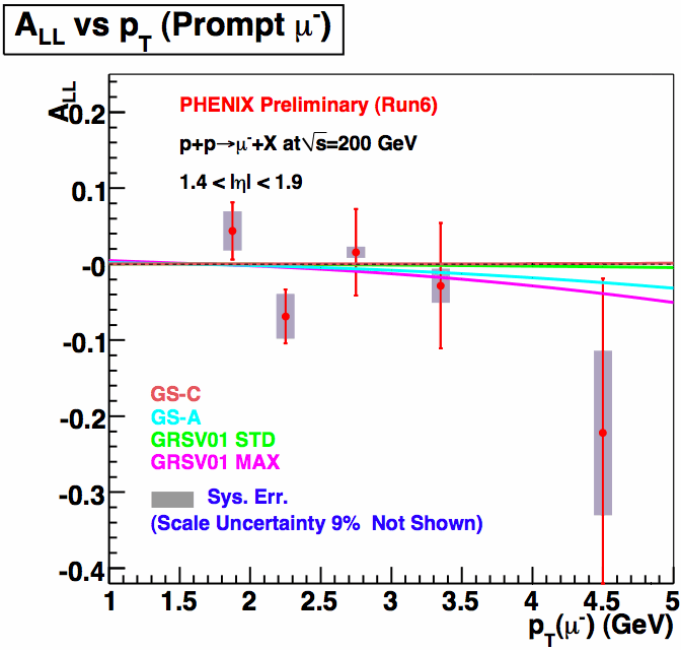
Longitudinal spin program at PHENIX - Other probes

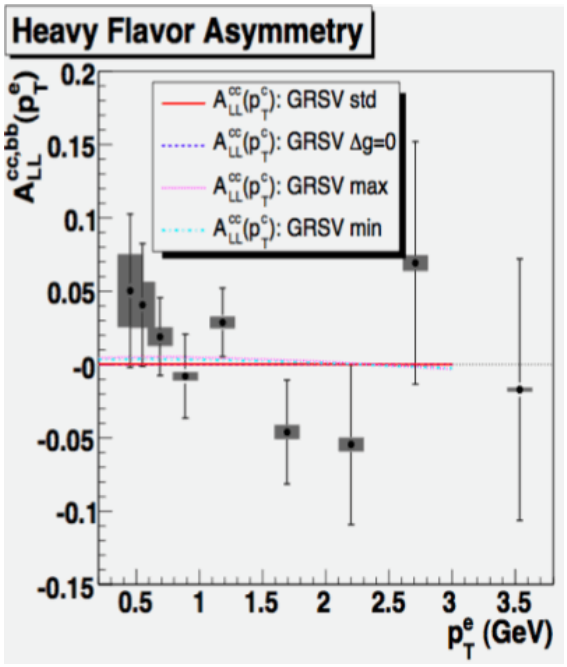
- **Direct photon A_{LL} at 200 GeV**



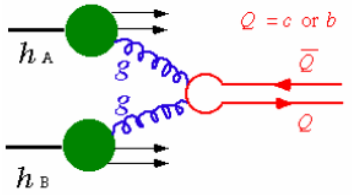
  - *quark gluon scattering dominates*
  - *clean channel, linear in ΔG*
  - *higher statistics needed*







- **Heavy Flavor**



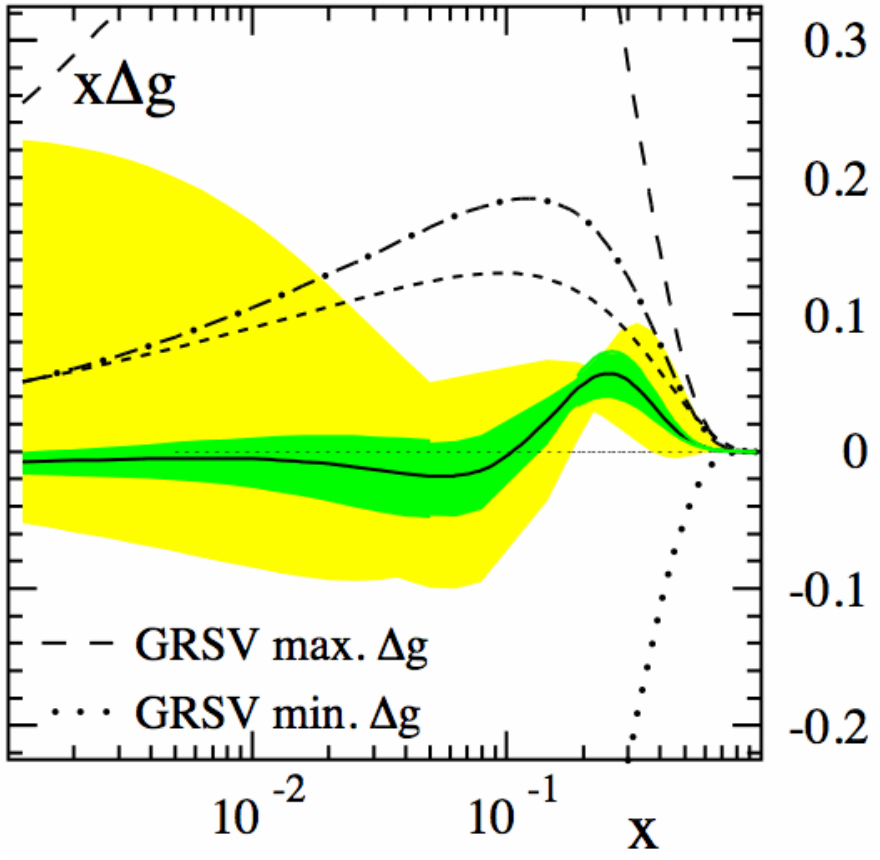
  - *Production dominated by gluon gluon fusion*
  - *Distinct process from light quark processes*
  - *Future luminosity and detector upgrades will significantly improve*

Longitudinal spin program at PHENIX –
Constraining ΔG

- Recent Global Fit (DSSV). PRL **101**, 072001(2008)
- First truly global analysis of polarized DIS, SIDIS and pp results
- PHENIX $\sqrt{s}$ = 200 and 62 GeV data used
- RHIC data significantly constrain ΔG in range 0.05<*x*<0.3

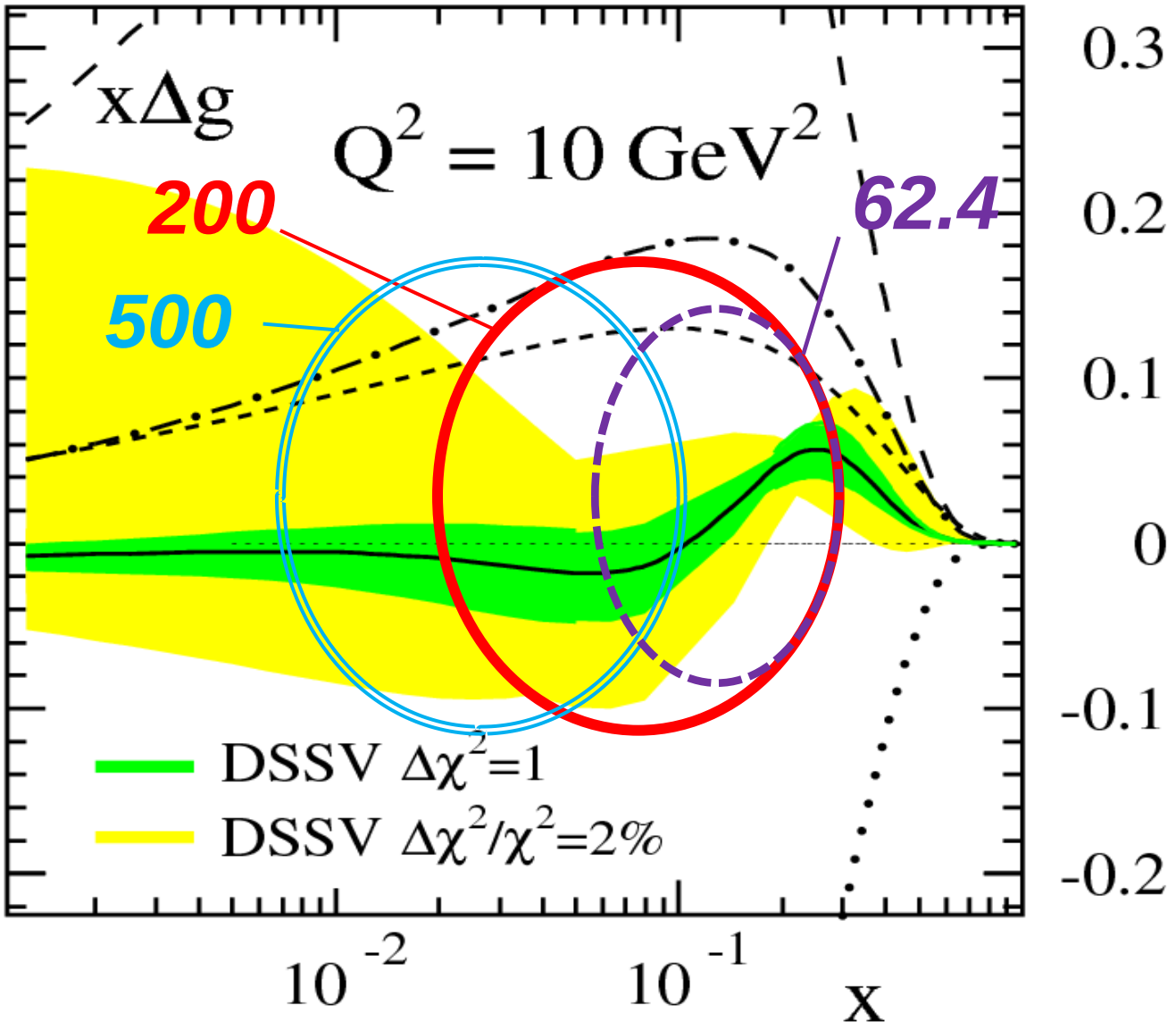
TABLE II. First moments $\Delta f_j^{1,[x_{\min}\to 1]}$ at $Q^2 = 10$ GeV^2.

	$x_{\min} = 0$ best fit	$x_{\min} = 0.001$ $\Delta\chi^2 = 1$	$x_{\min} = 0.001$ $\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	0.813	$0.793^{+0.011}_{-0.012}$	$0.793^{+0.028}_{-0.034}$
$\Delta d + \Delta\bar{d}$	−0.458	$-0.416^{+0.011}_{-0.009}$	$-0.416^{+0.035}_{-0.025}$
$\Delta\bar{u}$	0.036	$0.028^{+0.021}_{-0.020}$	$0.028^{+0.059}_{-0.059}$
$\Delta\bar{d}$	−0.115	$-0.089^{+0.029}_{-0.029}$	$-0.089^{+0.090}_{-0.080}$
$\Delta\bar{s}$	−0.057	$-0.006^{+0.010}_{-0.012}$	$-0.006^{+0.028}_{-0.031}$
Δg	−0.084	$0.013^{+0.106}_{-0.120}$	$0.013^{+0.702}_{-0.314}$
$\Delta\Sigma$	0.242	$0.366^{+0.015}_{-0.018}$	$0.366^{+0.042}_{-0.062}$



❖ ***ΔG is very small in the probed x-range but very large uncertainty at lower x***

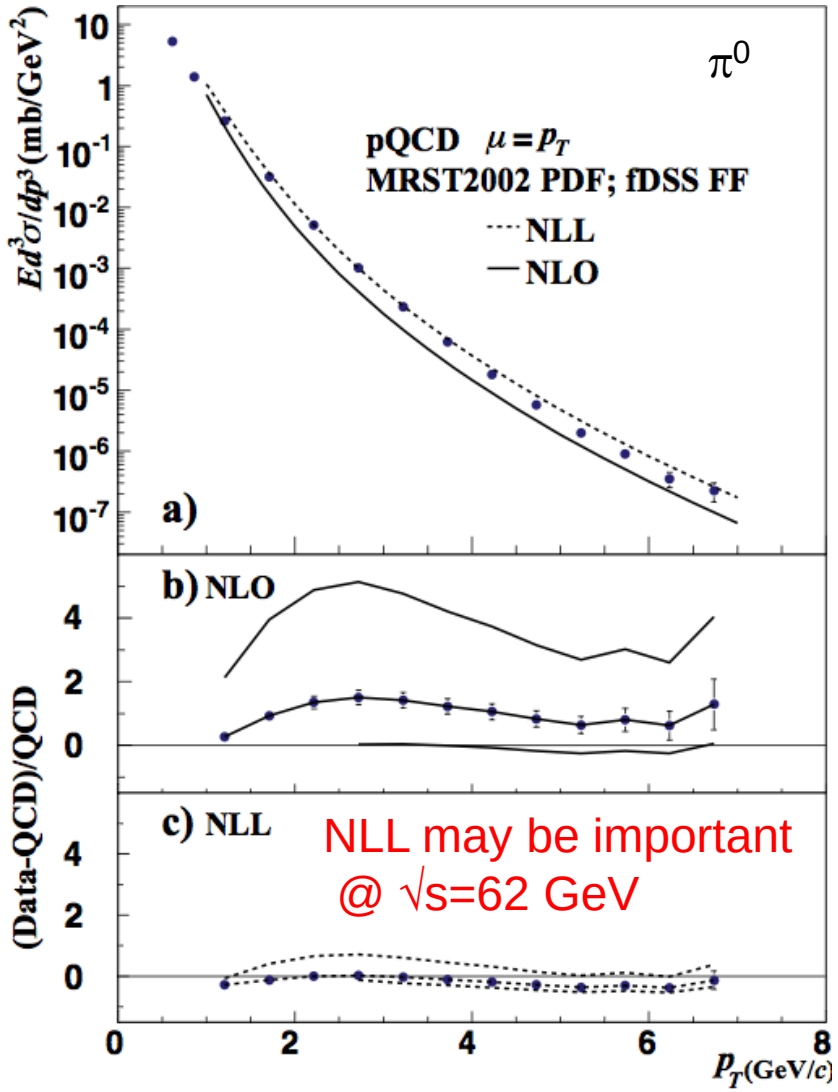
Longitudinal spin program at PHENIX –
Extending the covered *x* range



Longitudinal spin program at PHENIX –

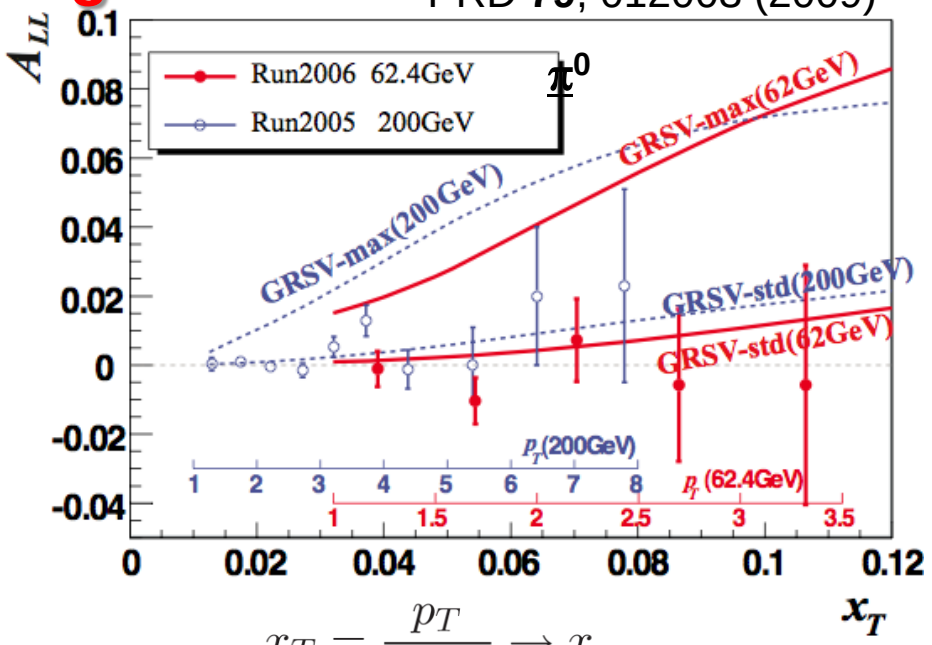
Extending the coverage to higher *x*

PRD **79**, 012003 (2009)



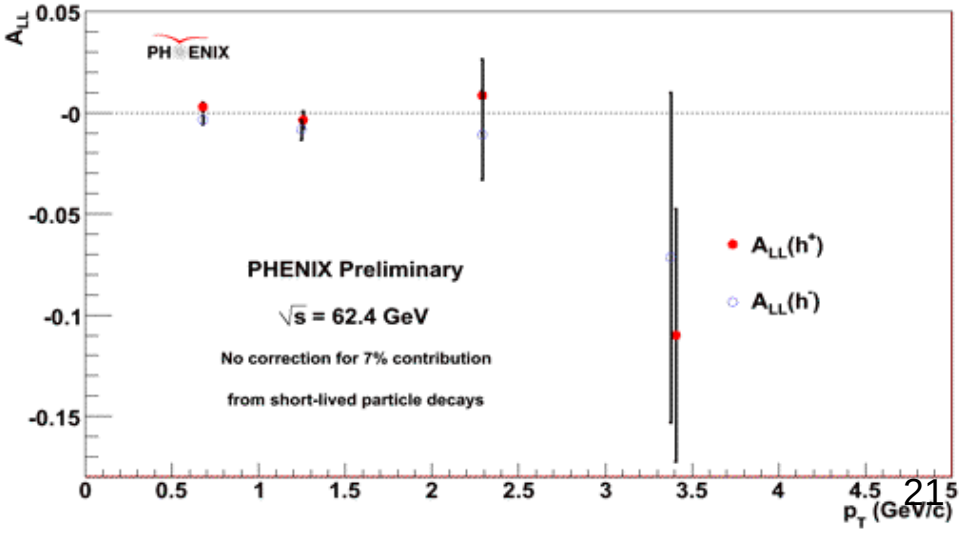
NLL may be important @ √s=62 GeV

PRD **79**, 012003 (2009)



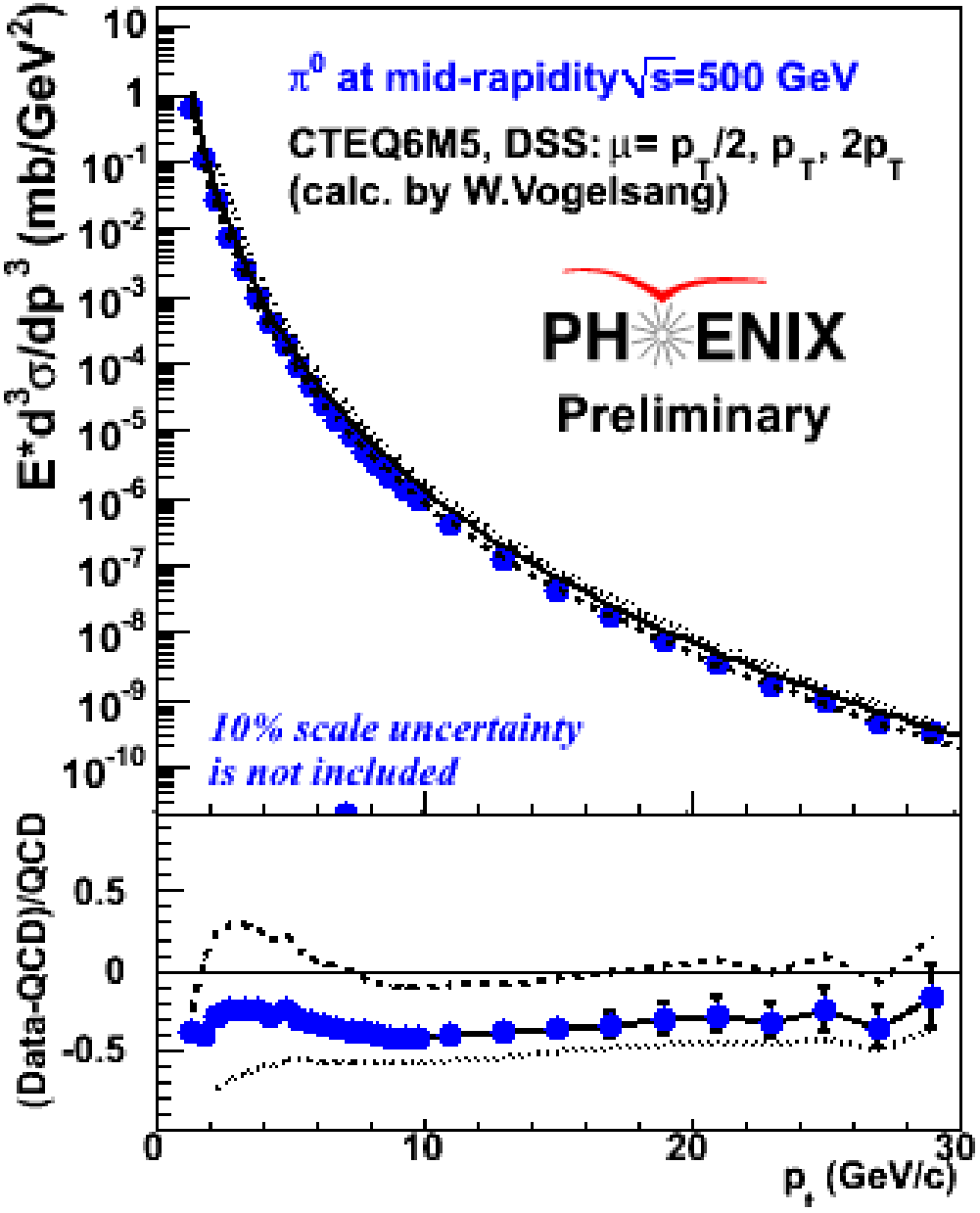
$$x_T = \frac{p_T}{\sqrt{s}/2} \rightarrow x$$

Charged hadrons



Longitudinal spin program at PHENIX -

Extending the coverage to lower *x*



Summary & Outlook

- **NLO pQCD describes hadron cross sections at RHIC**
  - *π^0 at mid-rapidity @ different $\sqrt{s}$= 62.4, 200, and 500 GeV*
  - *Direct γ at mid-rapidity @ $\sqrt{s}$= 200 GeV*
- **PHENIX transverse spin program**
  - *Different channels to understand different contributions to large SSA's*
  - *Large SSA's measured at forward rapidities while none observed at midrapidity rapidities*
- **PHENIX longitudinal spin program**
  - *PHENIX inclusive π^0 A_{LL} data offer a significant constraint on ΔG in the x_g range ~0.02−0.3. $\Delta G \sim 0$ in this x_g range*
  - *Other PHENIX A_{LL} data are available:*
    - *η & $\pi^{\pm}$ expected to be included in global analysis.*
    - *γ, e, μ, J/ψ need more stats*
- **Outlook**
  - **FVTX upgrade + MPC:** *Extending x_g-range by moving to forward rapidities*
  - **VTX+FVTX+FOCAL upgrade:** *Map ΔG vs. x_g by using more exclusive channels*

$$pp \to \gamma + jet \text{ and } pp \to jet + jet$$

BACK UP SLIDES

PHENIX Upgrades

- Vertex Detectors (2011-2012)

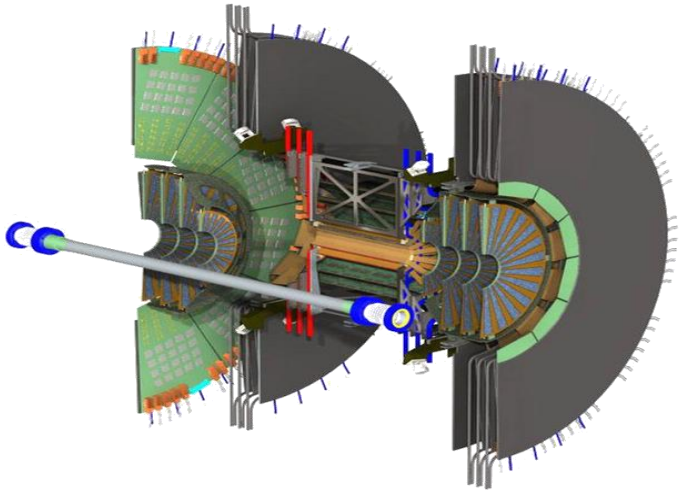
Large acceptance precision tracking

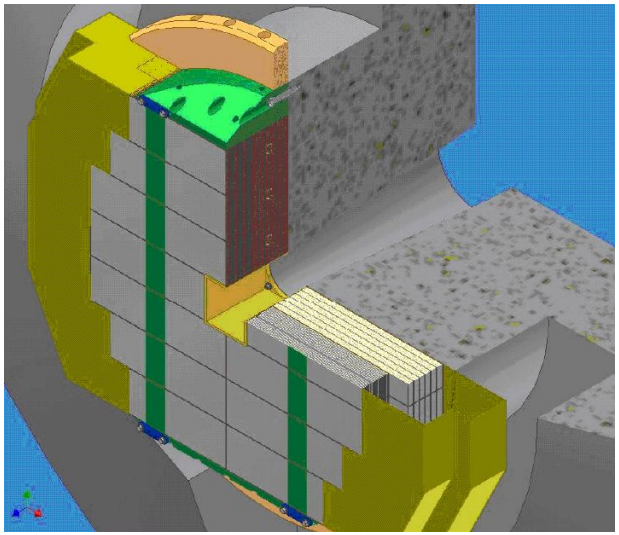
  - Heavy flavor tagging
  - Jets
  - Drell-Yan
  - Electrons from charm decays and beauty decays separately
  - c,b-Jet Correlations

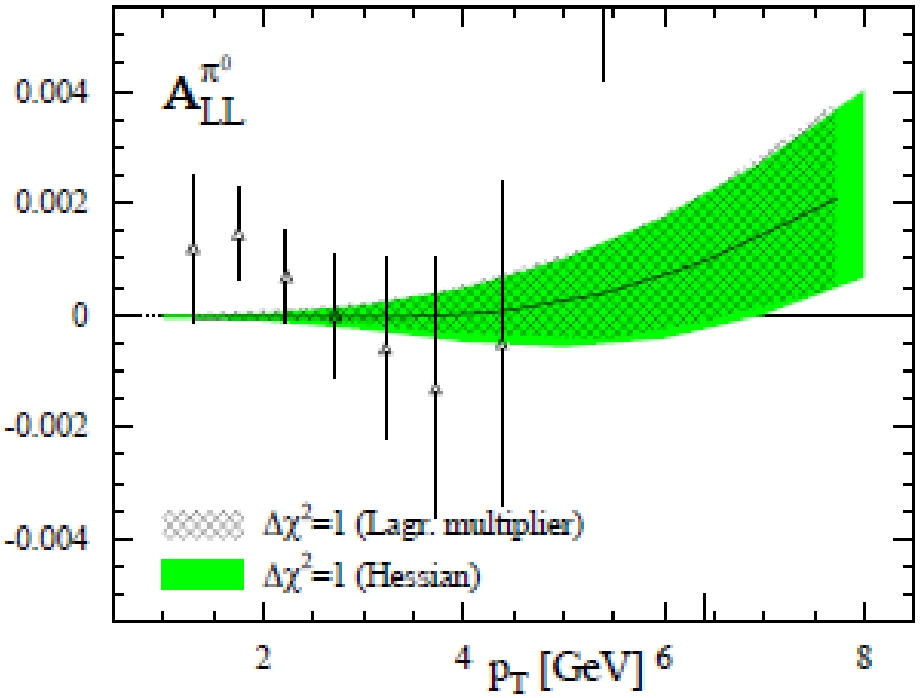
- Forward Calorimetery (2012-2013)

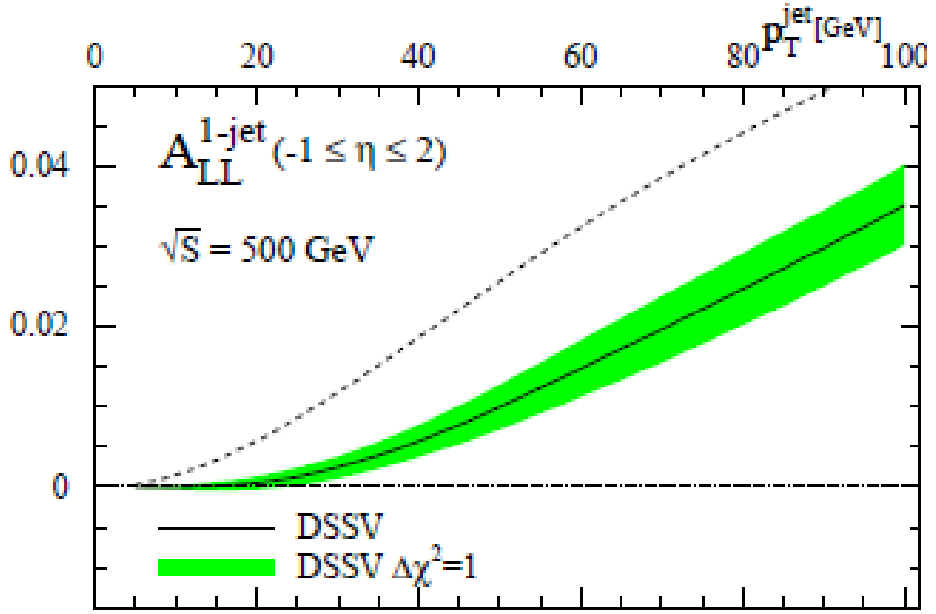
Proposed PHENIX Upgrade (1 < eta < 3)

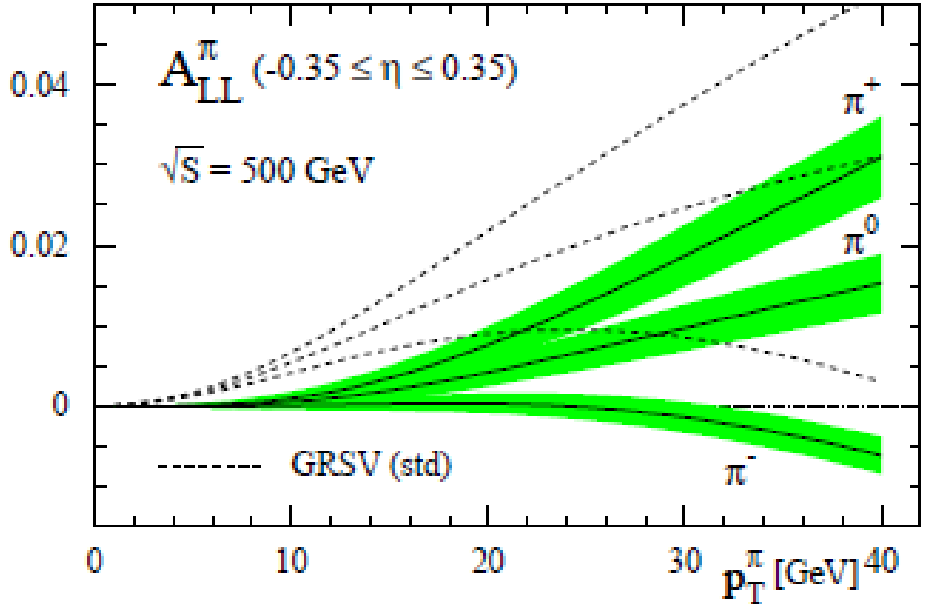
  - π^0, Direct γ, γ-Jet
  - Drell-Yan

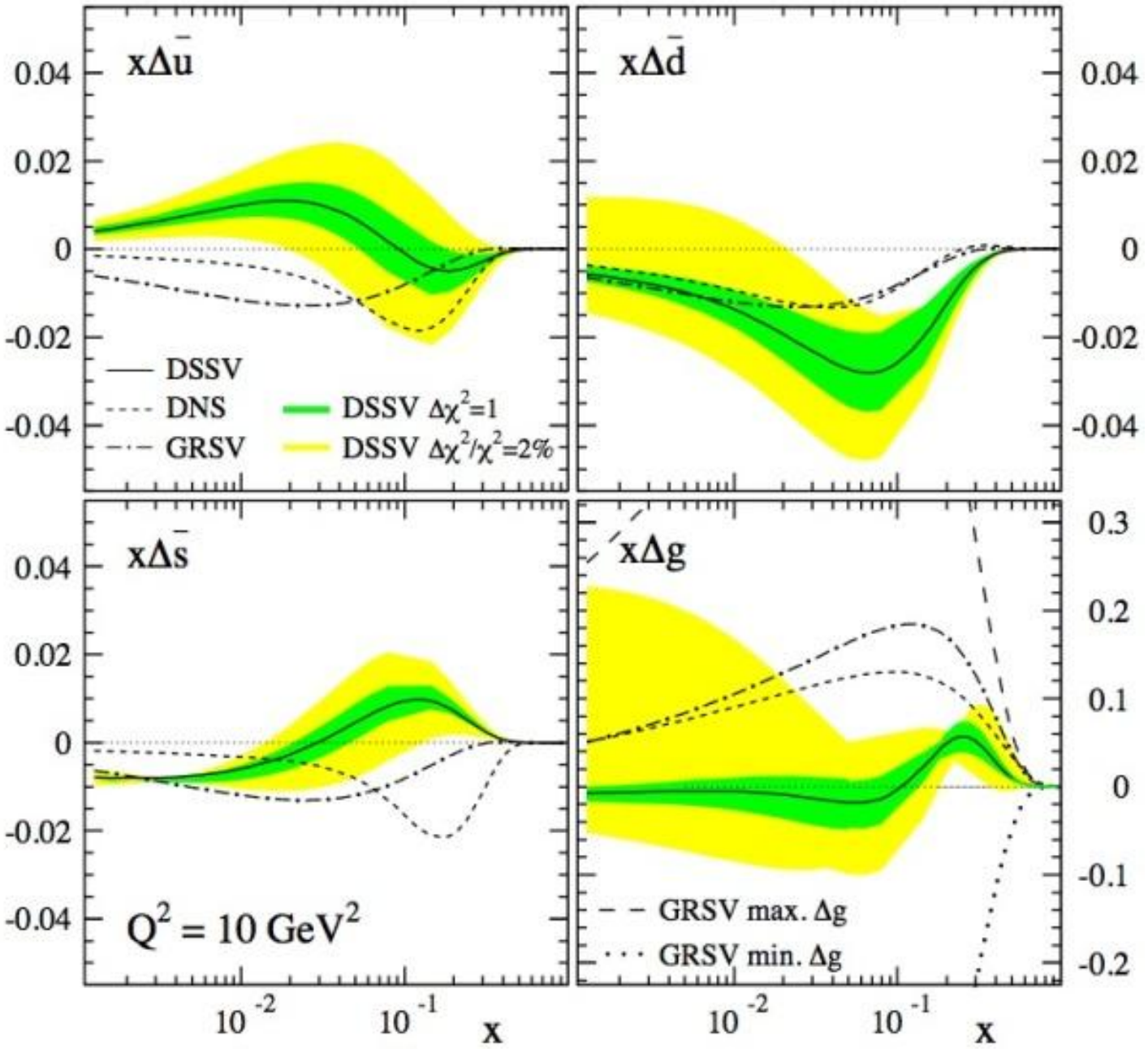





$A_{LL}^{\pi^0}$
0.004
0.002
0
-0.002
-0.004
$\Delta\chi^2$=1 (Lagr. multiplier)
$\Delta\chi^2$=1 (Hessian)
2
4
p_T [GeV]
6
8


p_T^{jet} [GeV]
0
20
40
60
80
100
$A_{LL}^{1\text{-jet}}$ ($-1 \le \eta \le 2$)
$\sqrt{S}$ = 500 GeV
0.04
0.02
0
DSSV
DSSV $\Delta\chi^2$=1


A_{LL}^{π} ($-0.35 \le \eta \le 0.35$)
$\sqrt{S}$ = 500 GeV
π^+
π^0
π^-
0.04
0.02
0
GRSV (std)
0
10
20
30
p_T^{π} [GeV]
40


xΔū
xΔd̄
xΔs̄
xΔg
DSSV
DNS
GRSV
DSSV Δχ²=1
DSSV Δχ²/χ²=2%
Q² = 10 GeV²
GRSV max. Δg
GRSV min. Δg
x
x