Effects of $\Delta g(x)$ on the π^0 spin asymmetry at RHIC

K. Sudoh (RIKEN)

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hep-ph/0403102, with M. Hirai

I. **Introduction**

II. **Inclusive π^0 Production in $\vec{p}\vec{p}$ Collisions**

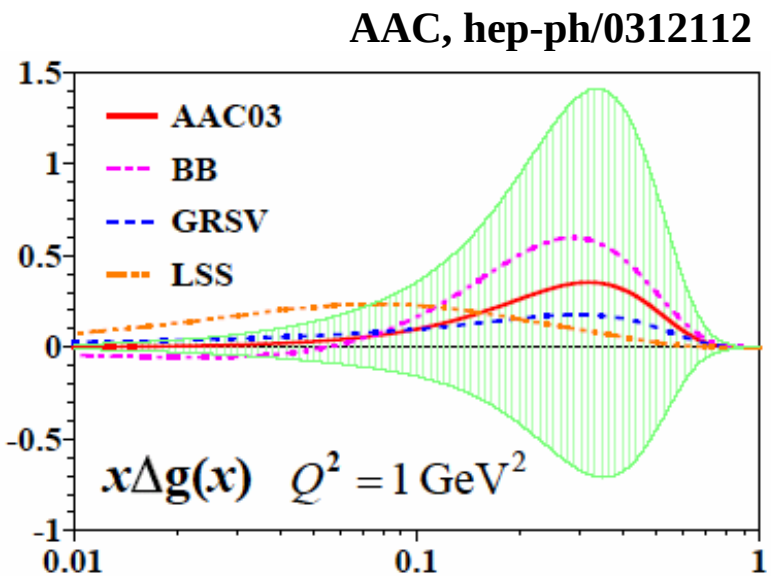
$$\vec{p} + \vec{p} \rightarrow \pi^0 + X$$

III. **Correlation to $\Delta g(x)$**

IV. **Summary**

I. Introduction

- **Uncertainty of the polarized gluon distributions $\Delta g(x)$ is still large, since the gluon contribution appears in NLO in polarized DIS.**



➡ **RHIC has started!!**

- **The π^0 spin asymmetry A_{LL}^{π} has been measured by the PHENIX.**
  - **The data suggest significant negative asymmetry!!!**

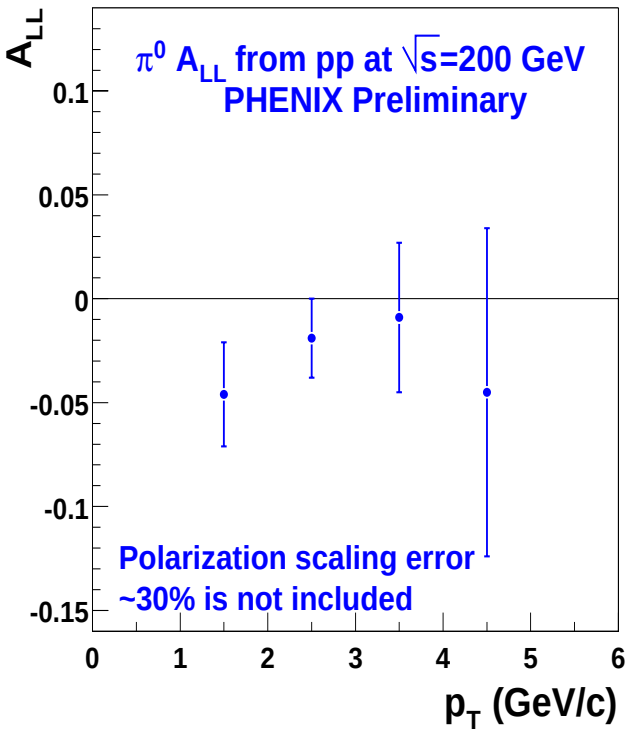
Effects of $\Delta g(x)$ on the π^0 spin asymmetry

Negative Asymmetry

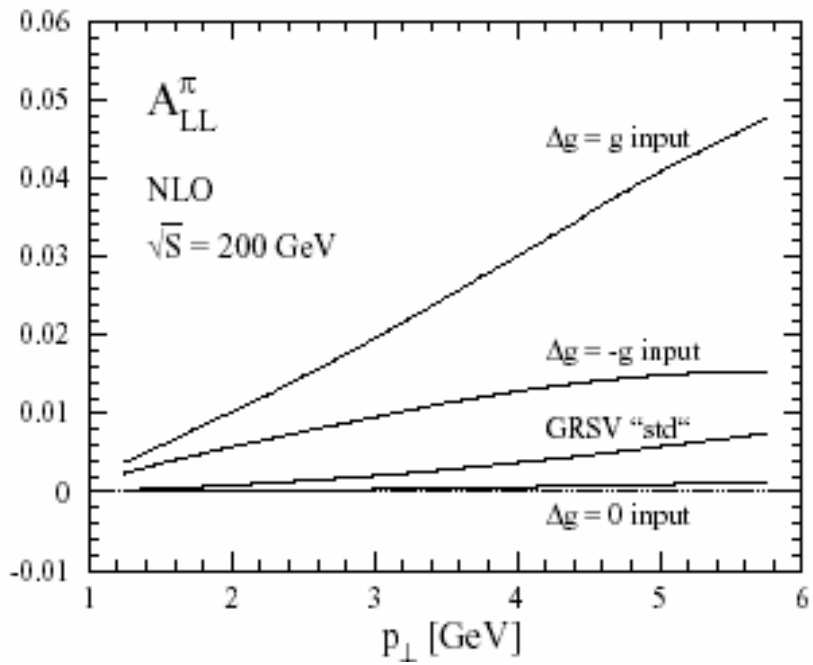
- **Comparison A_{LL}^{π} with the PHENIX data**

$$\sqrt{s} = 200 \text{ GeV}, \quad |\eta| \le 0.38$$

- **pQCD prediction indicates positive asymmetry.**



A. Bazilevsky, talk at Spin-03, Dubna



B. Jagar *et al.*, PRL92, 121803 (2004)

Inclusive π^0 Production @RHIC

- **Subprocesses for π^0 production**
  - ***O*(α_s^2) 2→2 tree-level channels in LO**

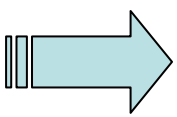
$$gg \to q(g)X, \quad qg \to q(g)X, \quad qq \to qX,$$
$$q\bar{q} \to q(g,q')X, \quad qq' \to qX, \quad q\bar{q}' \to qX$$

  - **Dominant contribution:**

$gg \to q(g)X$: **in small p_T**

$qg \to q(g)X$: **in large p_T**

- **π^0 spin asymmetry is sensitive to $\Delta g(x)$.**



Determined by a balance between *gg* and *qg* contributions.

Double Spin Asymmetry

Longitudinal Double Spin Asymmetry:

$$A_{LL}^{\pi^0} \equiv \frac{[d\sigma_{++} - d\sigma_{+-}]/dp_T}{[d\sigma_{++} + d\sigma_{+-}]/dp_T} = \frac{d\Delta\sigma/dp_T}{d\sigma/dp_T}$$

$$\frac{d\Delta\sigma}{dp_T} \equiv \frac{1}{2}\left[\frac{d\sigma_{++}}{dp_T} - \frac{d\sigma_{+-}}{dp_T}\right] \qquad : \quad |\eta| \le 0.38, \quad Q^2 = p_T^2$$

$$= \sum_{a,b,c} \int d\eta \int dx_a \int dx_b \int dz \;\; \Delta f_a(x_a, Q^2)\Delta f_b(x_b, Q^2) \frac{d\Delta\hat{\sigma}}{dp_T d\eta} D_c^{\pi}(z, Q^2)$$

PDF and FF: Determined using experimental data

Amplitude: Calculable in pQCD

Where does the inconsistency come from?

Where does ambiguity come from?

- **Fragmentation function: $D^{\pi}(z)$**
  - **Unpolarized π^0 cross section by the PHENIX is consistent with pQCD calculation.**

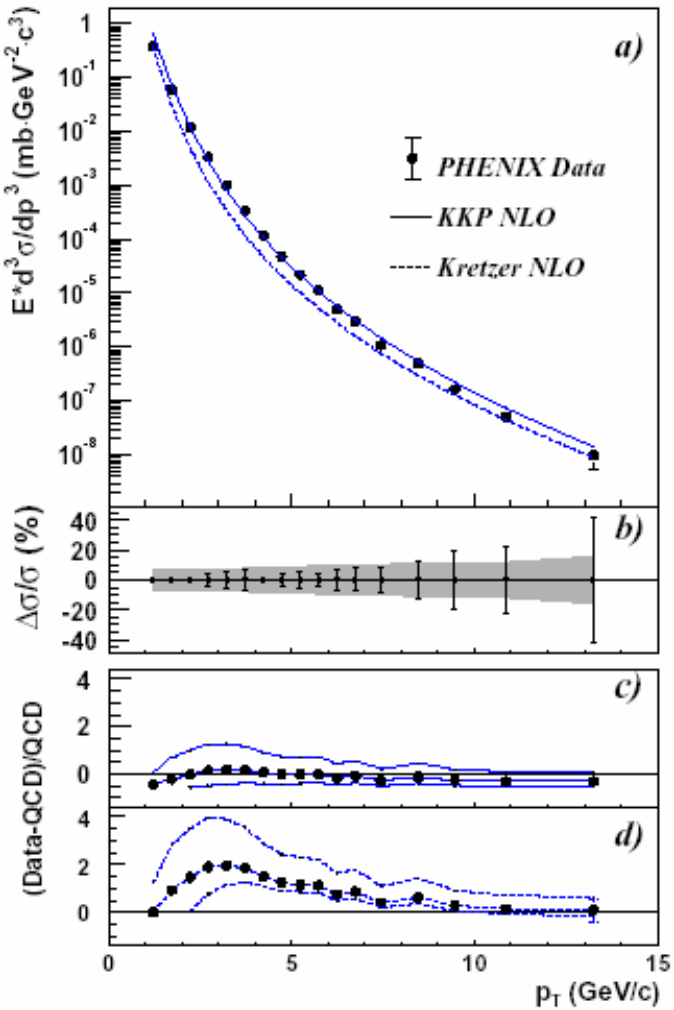
$$\sqrt{s} = 200 \text{ GeV}, \quad |\eta| \leq 0.35$$

  - **Determined from e^+e^- data**

- **Pol. quark distribution: $\Delta q(x)$**
  - **Flavor blind reaction**
  - **Depends on the sum $\Delta q(x)+\Delta\bar{q}(x)$.**

Ambiguity comes from $\Delta g(x)$

PHENIX Collab. PRL91, 241803 (2003)



Modification of $\Delta g(x)$

Can we obtain negative asymmetry by modifying $\Delta g(x)$?

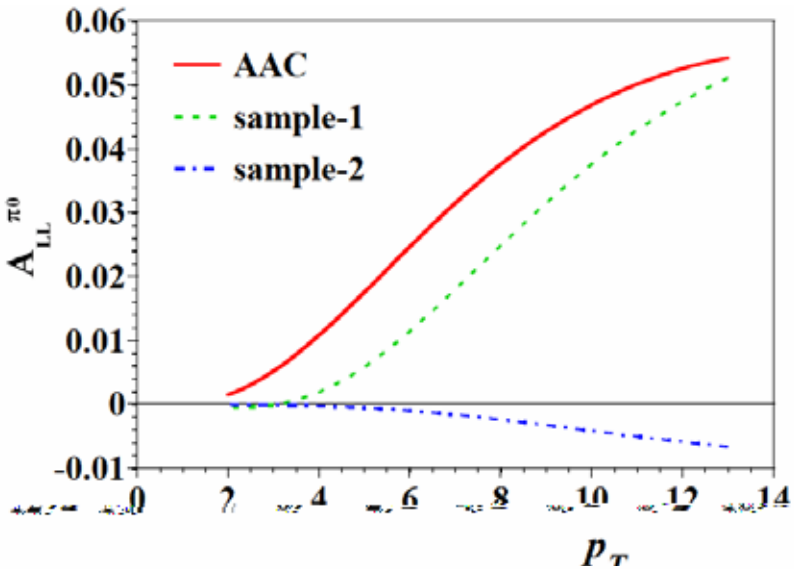
3 configurations of $\Delta g(x)$ within their uncertainty

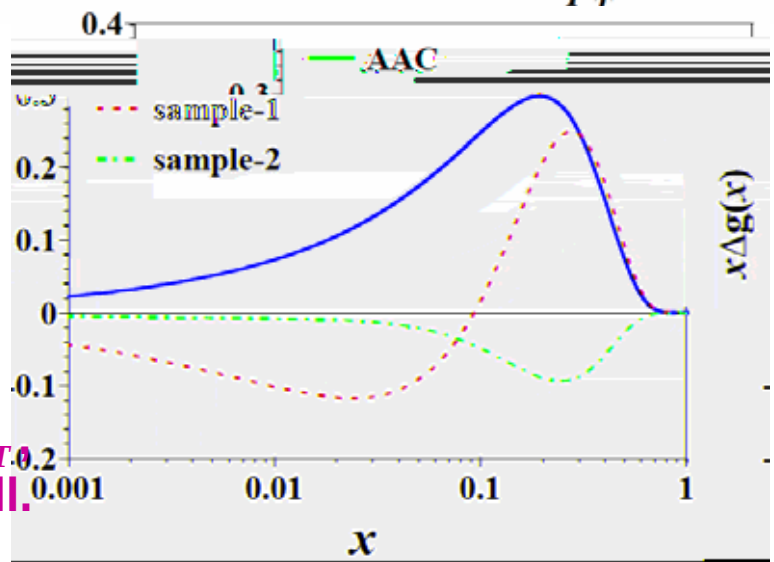
- **Scen.1 standard Δg**
  - **global analysis with pol. DIS**
  - **A_{LL} does not become negative.**
- **Scen.2 Δg with a node**
  - **possibility gg<0 ($\Delta g(x_a)$・$\Delta g(x_b)$<0)**
  - **$|x_a - x_b|$ is small in η<0.38**
- **Scen.3 negative Δg**
  - ***gg>0, qg<0***
  - **$|\Delta g(x)|$ is small in low x**
  - **$|\Delta g(x)|$ is large in high x**

$\Delta g(x)$ has Q^2 dependence by DGLAP equation.

A_{LL}^{π} with modified $\Delta g(x)$

- **AAC $\Delta g(x)$**
  - Both *gg* and *qg* >0
  - A_{LL} is positive and increases with p_T
- **Sample-1**
  - In low p_T
    - Both *gg* and *qg* <0
    - Slight negative A_{LL} in η<0.38
  - In large p_T
    - Both *gg* and *qg* >0
    - A_{LL} becomes large positive
- **Sample-2**
  - *gg*>0, *qg*<0, A_{LL}<0 in whole p_T
  - $|A_{LL}|$ becomes larger to negative

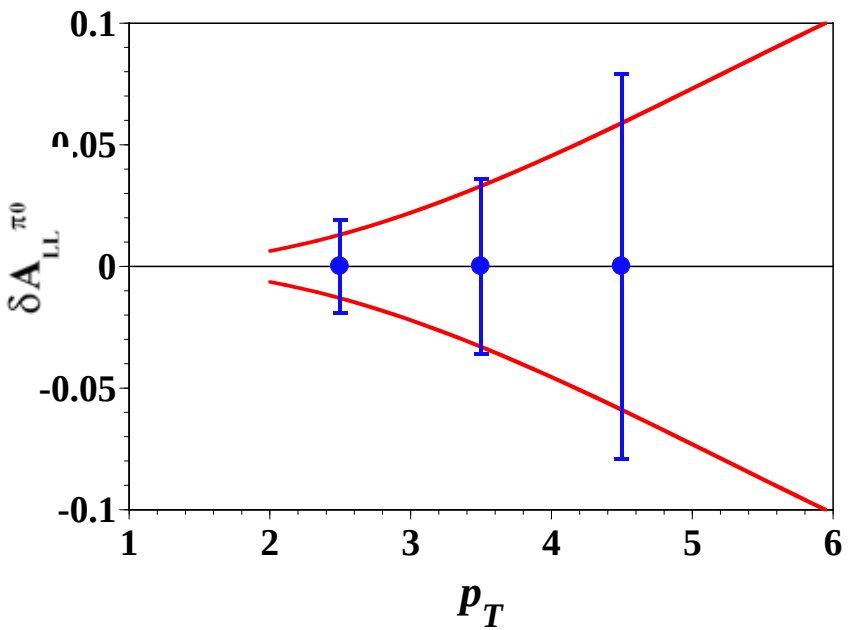


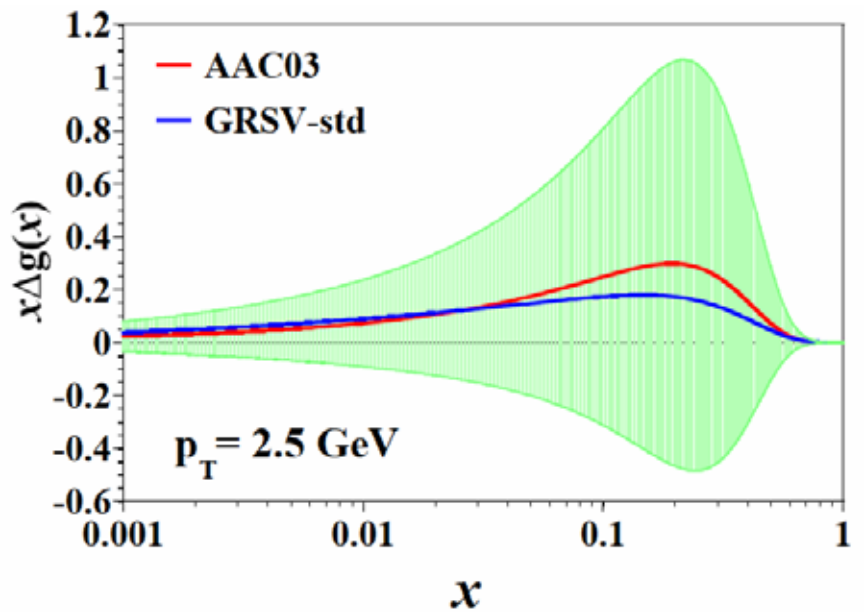


Difficult to obtain sizable asymmetry in low p_T since partonic cross section itself is too small.

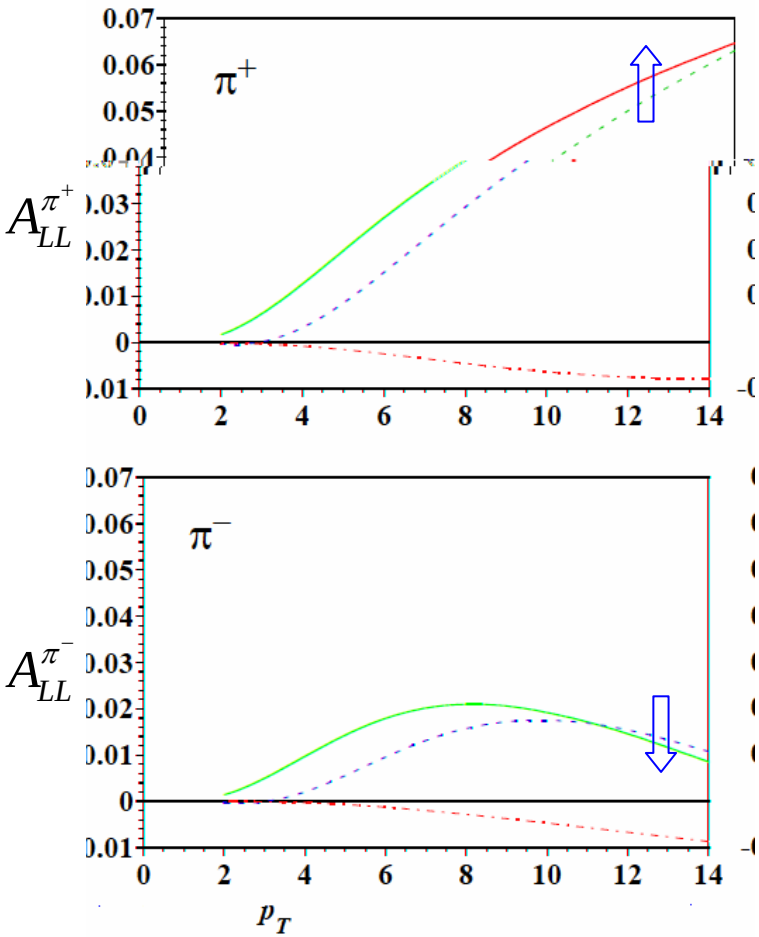
Uncertainty of A_{LL}^{π}

- Comparison A_{LL} uncertainty with errors of PHENIX data
- A_{LL} uncertainty comes from the gluon uncertainty
- The same constriction as the polarized DIS data





Charged Pion Asymmetry



qg process dominates in large p_T

$$\Delta g \left\{ (\Delta u + \Delta d) D_g^{\pi^+} + \Delta u \cdot D_u^{\pi^+} + \Delta d \cdot D_d^{\pi^+} \right\}$$

positive

negative

$$\Delta g \left\{ (\Delta u + \Delta d) D_g^{\pi^-} + \Delta u \cdot D_u^{\pi^-} + \Delta d \cdot D_d^{\pi^-} \right\}$$

cf. $D_g^{\pi^+} = D_g^{\pi^-}$, $D_u^{\pi^+} > D_u^{\pi^-}$, $D_d^{\pi^+} < D_d^{\pi^-}$

$$D_a^{\pi^0} = \left(D_a^{\pi^+} + D_a^{\pi^-} \right) / 2$$

π^+ is more promising than π^-.

Neutral π^0 vs. Charged $\pi^+\pi^-$

$$A_{LL} \quad \frac{g}{g} \quad \frac{\left(u \quad d \right) D_g^{\pi} \quad u \; D_u^{\pi} \quad d \; D_d^{\pi}}{\left(u \quad d \right) D_g \quad u \; D_u \quad d \; D_d}$$

IV. Summary

- **Correlation between π^0 spin asymmetry and $\Delta g(x)$ is studied.**

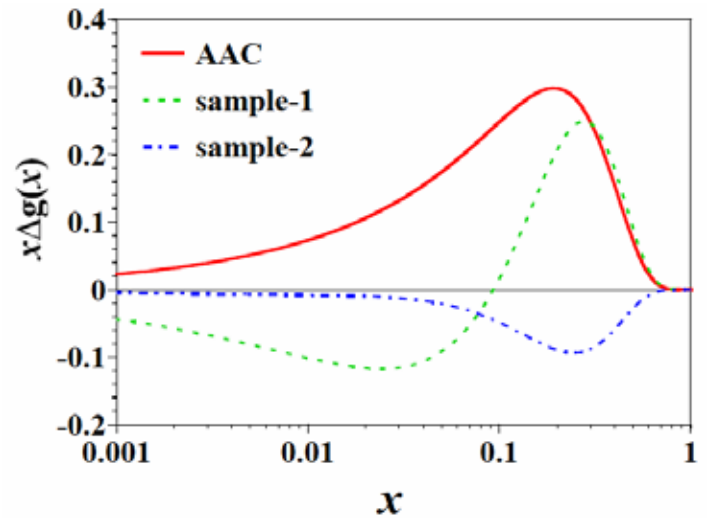
  ★ **It is extremely difficult to derive sizable A_{LL} in a few % level in low p_T .**

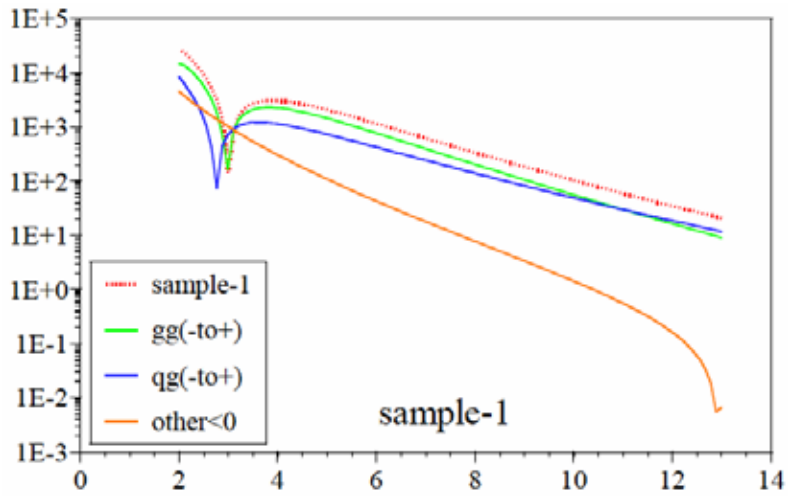
  - **Slight negative asymmetry at low p_T can be obtained.**
  - **It is premature to conclude that pQCD is not applicable to π^0 asymmetry.**
  - **Existence of $\Delta g(x)$ which keeps A_{LL} to be negative in whole p_T.**

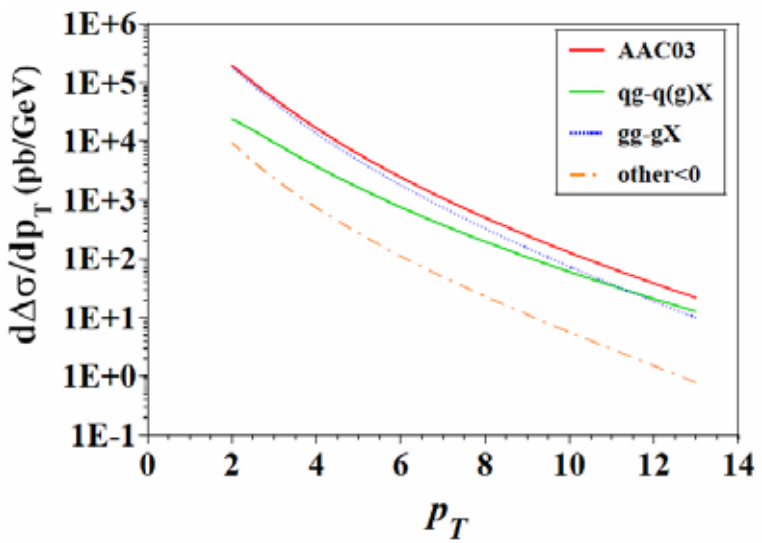
- **PHENIX data motivate us to modify $\Delta g(x)$ drastically?**
  - **Negative asymmetry suggests negative polarization of $\Delta g(x)$.**

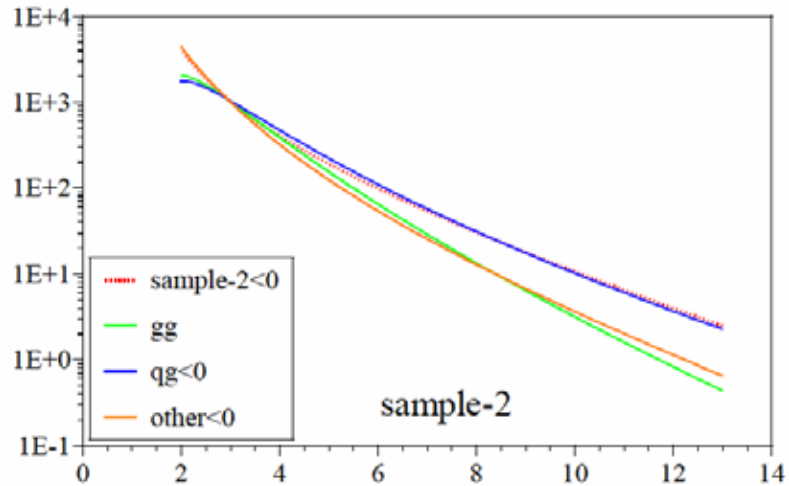
⇒ **Precise data in wide p_T regions is needed to determine the gluon spin content.**

Polarized Cross Section

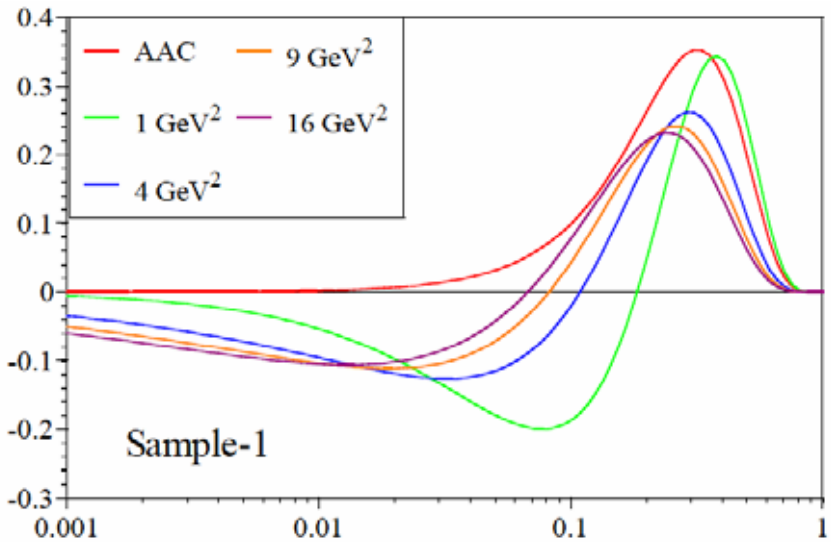


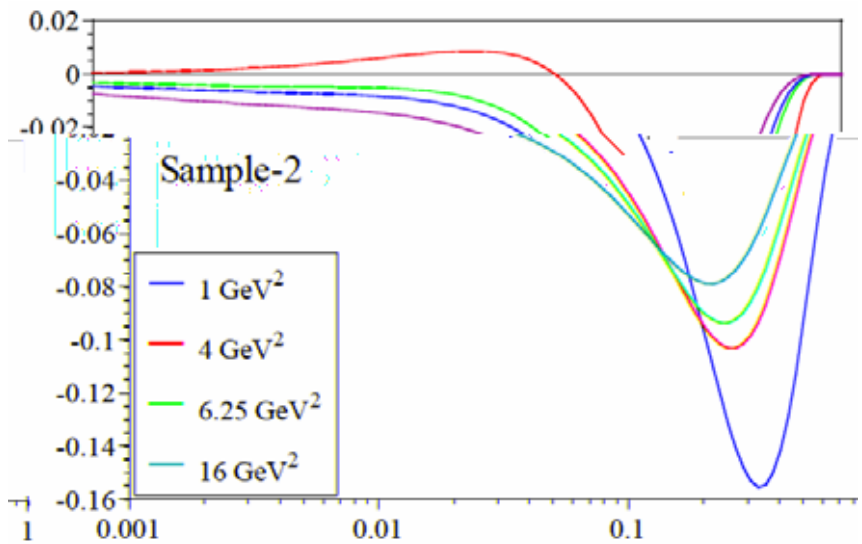




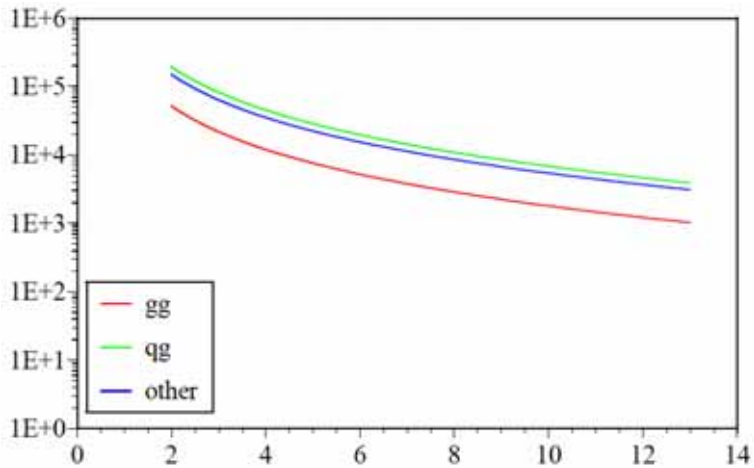


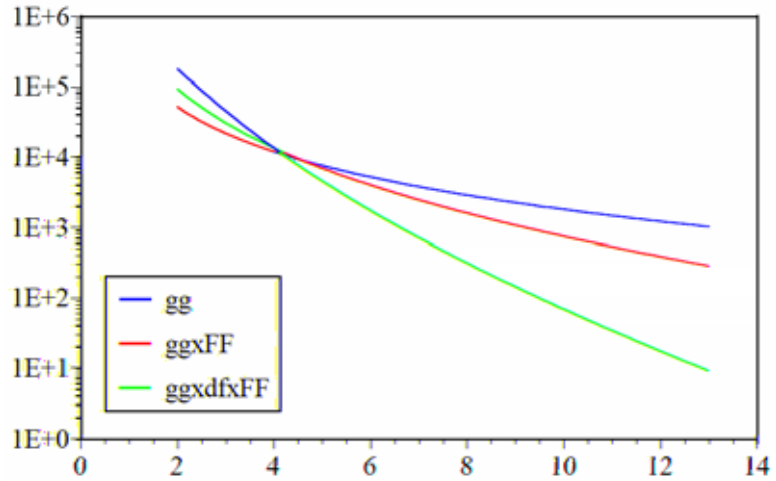
Q^2 evolved $\Delta g(x,Q^2)$

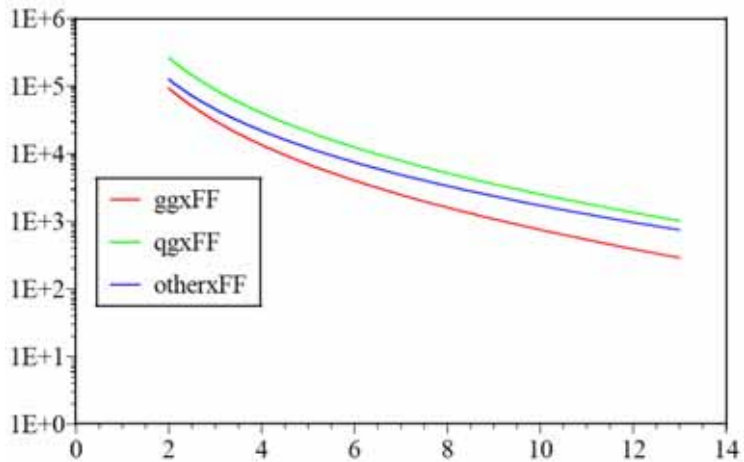




gg vs. *qg*


1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
0
2
4
6
8
10
12
14
gg
qg
other


1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
0
2
4
6
8
10
12
14
gg
ggxFF
ggxdfxFF


1E+6
1E+5
1E+4
1E+3
1E+2
1E+1
1E+0
0
2
4
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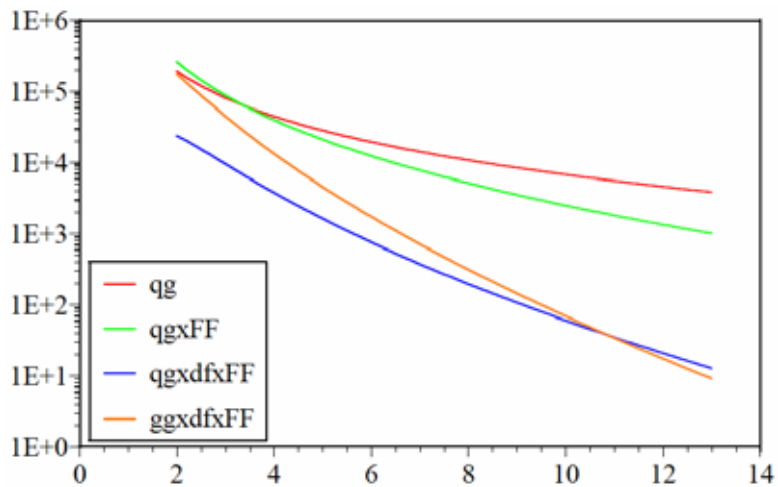
8
10
12
14
ggxFF
qgxFF
otherxFF


1E+6
1E+5
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1E+3
1E+2
1E+1
1E+0
0
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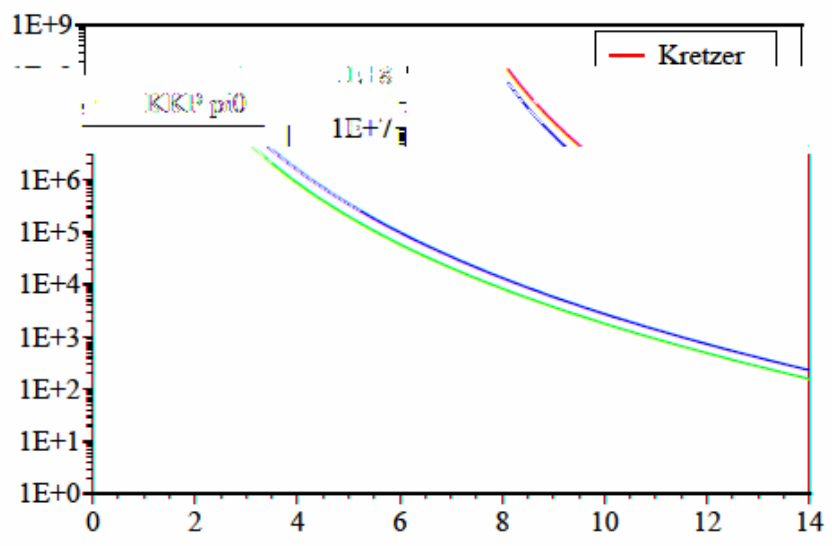
8
10
12
14
qg
qgxFF
qgxdfxFF
ggxdfxFF

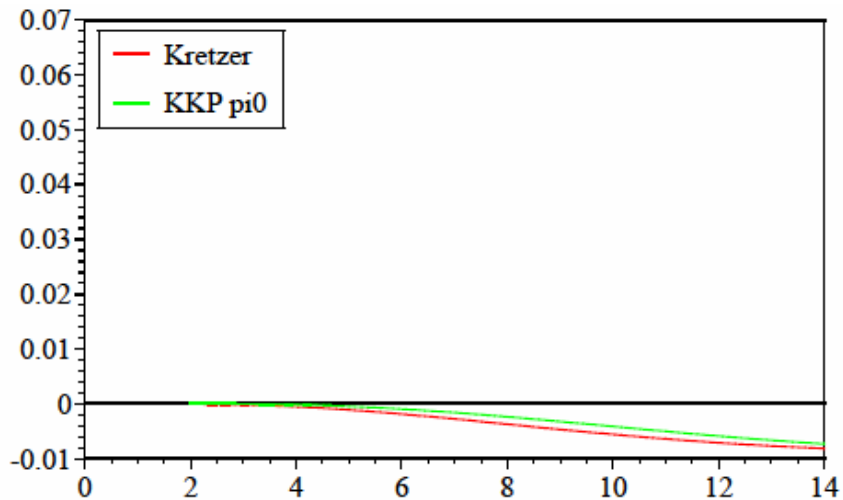
FF Dependence

Model dependence of fragmentation functions:
Kretzer and KKP for π^0 production

Unpolarized cross section



Asymmetry with sample-2 $\Delta g(x)$



p_T (GeV)

Ambiguity of FFs is not so large.

Negative Asymmetry

- **Comparison A_{LL}^{π} with the PHENIX data**

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

- **pQCD prediction indicates positive asymmetry.**