Determination of $\Delta g(x)$ from π^0 production at RHIC

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(Asymmetry Analysis collaboration)

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Contents

- Introduction
- AAC analysis with DIS and π^0 production
  - Global analysis and uncertainty estimation
  - Spin components : $\Delta\Sigma$, Δg ?
  - Sign problem Δg
  - Small-x behavior of $\Delta g(x)$
- Large-x behavior from HERMES and COMPASS data
  - Positive $\Delta g(x)$ at large-x_{Bj}
- Summary

Introduction

- **Origin of the nucleon spin 1/2**
  - $1/2 = 1/2\ \Delta\Sigma + \Delta g + L_{q,g}$
  - Quark spin component from polarize DIS: $\Delta\Sigma = 0.1\text{-}0.3$
- **Orbital angular momentum $L_{q,g}$?**
  - $J_q = \Delta q + L_q$: Generalized PDF from DVCS
  - SSA: Sivers function ?
- **Δg is an important piece of the spin puzzle !**
  - Undetermined $\Delta g = 0.49 \pm 1.27$ (AAC03)
  - Experimental data from RHIC-Spin
    - Prompt photon, Jet, heavy quark production, et al.
  - π^0 production
    - PRL93, 202002 (2004)
    - RUN05

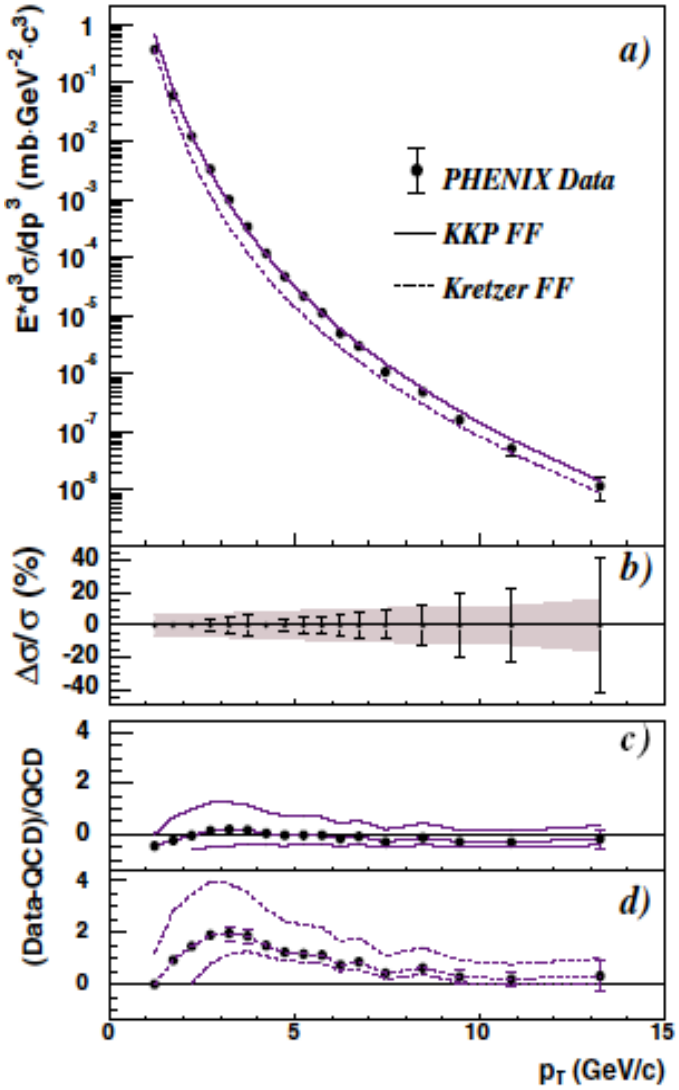
Spin asymmetry of π production

- **Cross section**

$$\frac{d\sigma^{pp\to\pi X}}{dp_T\,d\eta} = \sum_{a,b}\int_{\xi_1}^{1} dx_1 \int_{\xi_2}^{1} dx_2\; f_a^{A}(x_1)\, f_b^{B}(x_2)\, \frac{d\hat{\sigma}^{ab}}{dp_T\,d\eta}\, D^{\pi}(z)$$

  - gg→gg, gg→qq,qg→qg
  - qq→qq, qq'→qq'
  - qq→qq, qq→gg, gg→qq

- **Consistent with unpolarized data**
  - Fragmentation functions (FFs)
    - Determined by e^+e^- data
    - Ambiguity of $D_g^{\pi}(z)$



PRL91, 241803 (2003)

Initial distributions of polarized PDFs

- **Initial distribution at Q_0^2**
  - $\Delta f_i(x,Q_0^2) = \left[\delta_i x^{\nu_i} - \kappa_i\left(x^{\nu_i} - x^{\mu_i}\right)\right] f_i(x,Q_0^2), \quad \left(i = u_v, d_v, \bar{q}, g\right)$
  - Chose of the functional form is arbitrary
  - Source of model dependence

- **Constraint condition:** $\left|\Delta f(x)\right| \le f(x)$
  - Positivity condition:
    - Constraint of $\Delta f(x)$ at large x
    - Avoiding unphysical behavior for the asymmetry: $A_1(x) > 1$ $(x \to 1)$
  - Antiquark $SU_F(3)$ symmetry: $\Delta\bar{u}(x) = \Delta\bar{d}(x) = \Delta\bar{s}(x) = \Delta s(x) = \Delta\bar{q}(x)$
    - Fixed 1st moments: $\Delta u_v = 0.926$, $\Delta d_v = -0.341$
    - Fixed $\mu_{\bar{q}} = 1.0$: undetermined small-x behavior

AAC global analysis

- Added new data
  - DIS $A_1[=g_1*2x(1+R)/F_2]$
    - COMPASS(d), HERMES(p,d), J-Lab(n)
  - π^0 data
    - PHENIX RUN05 preliminary data
- Total # of data: 421
  - DIS: 413 ($Q^2 \geq 1GeV^2$)
  - π^0 : 8 ($1<p_T<10$ GeV, $\mu_{R,F}=p_T$)
- NLO analysis
  - $\overline{MS}$ scheme
  - π^0: K factor:$<K_{pol}>=1$, $<K_{unopl}>=1.6$
    - B. Jager, et al, PRD67,054005 (2000)
  - χ^2(/d.o.f.) = 370.47 (0.90)
    - DIS:359.29
    - π^0 : 11.18
- Q^2 dependence of pol-PDFs
  - DGLAP eq
  - $Q_0^2 = 1GeV^2$
- Minimizing χ^2

$$\chi^2 = \sum_i \frac{\left[A_{1,i}^{\exp}(x,Q^2) - A_{1,i}^{\text{theo}}(x,Q^2)\right]^2}{\sigma_{\exp}^2},$$

$$\left(\sigma_{\exp}^2 = \sigma_{sta}^2 + \sigma_{sys}^2\right)$$

  - Scaling error of π^0 data is not included
- Error estimation
  - Hessian method

$$\left[\delta\Delta f(x)\right]^2 = \Delta\chi^2 \sum_{i,j} \frac{\partial \Delta f(x)}{\partial a_i} H_{ij}^{-1} \frac{\partial \Delta f(x)}{\partial a_j}$$

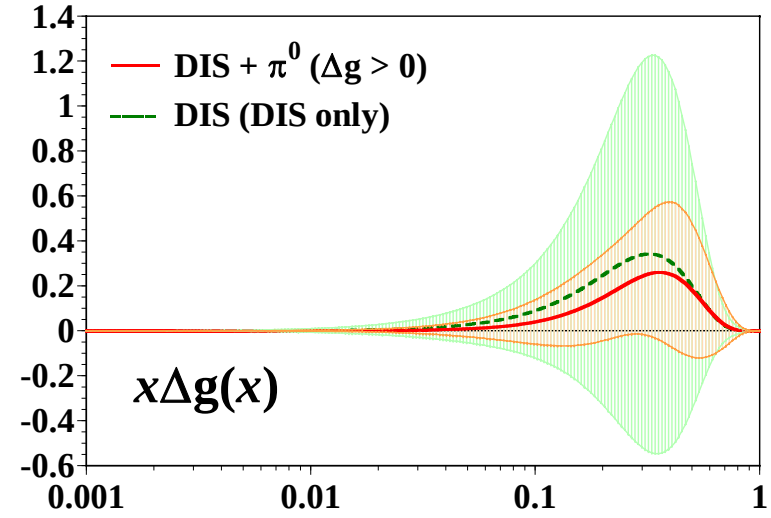
  - $\Delta\chi^2$ (N=11) = 12.64

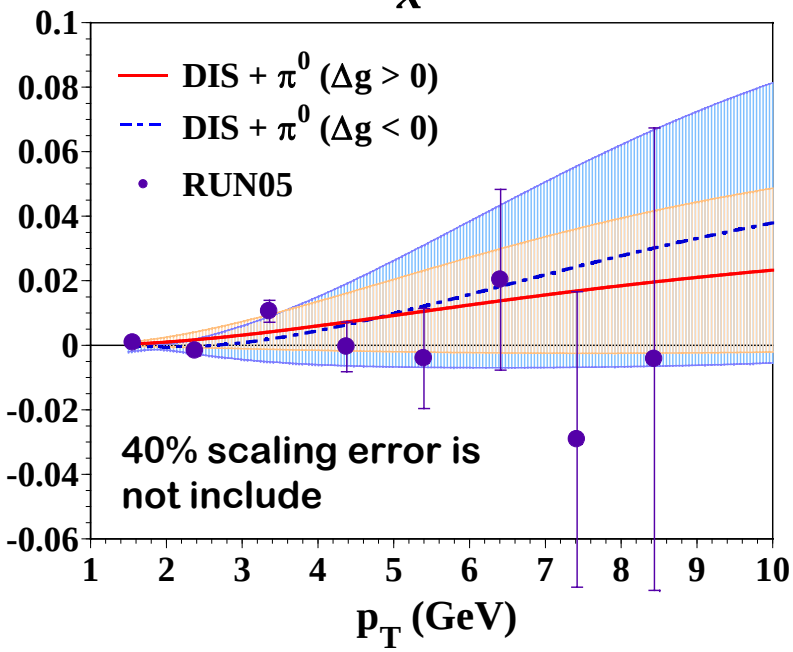
$$\int_0^{\Delta\chi^2} K(N,s)\, ds = 0.683\,(1\sigma)$$

Δg from DIS and π^0 data

- 1st moment Δg
  - 0.31 ± 0.32 (DIS+π^0)
  - 0.47 ± 1.08 (DIS only)
- Significant reduction of the Δg uncertainty
- Sign problem
  - gg process dominates
    - $\Delta\sigma \propto [\Delta g(x)]^2$
    - Positive or negative Δg?
    - $\chi^2_{\pi 0}$: 11.18($\Delta g>0$) vs. 11.05 ($\Delta g<0$)

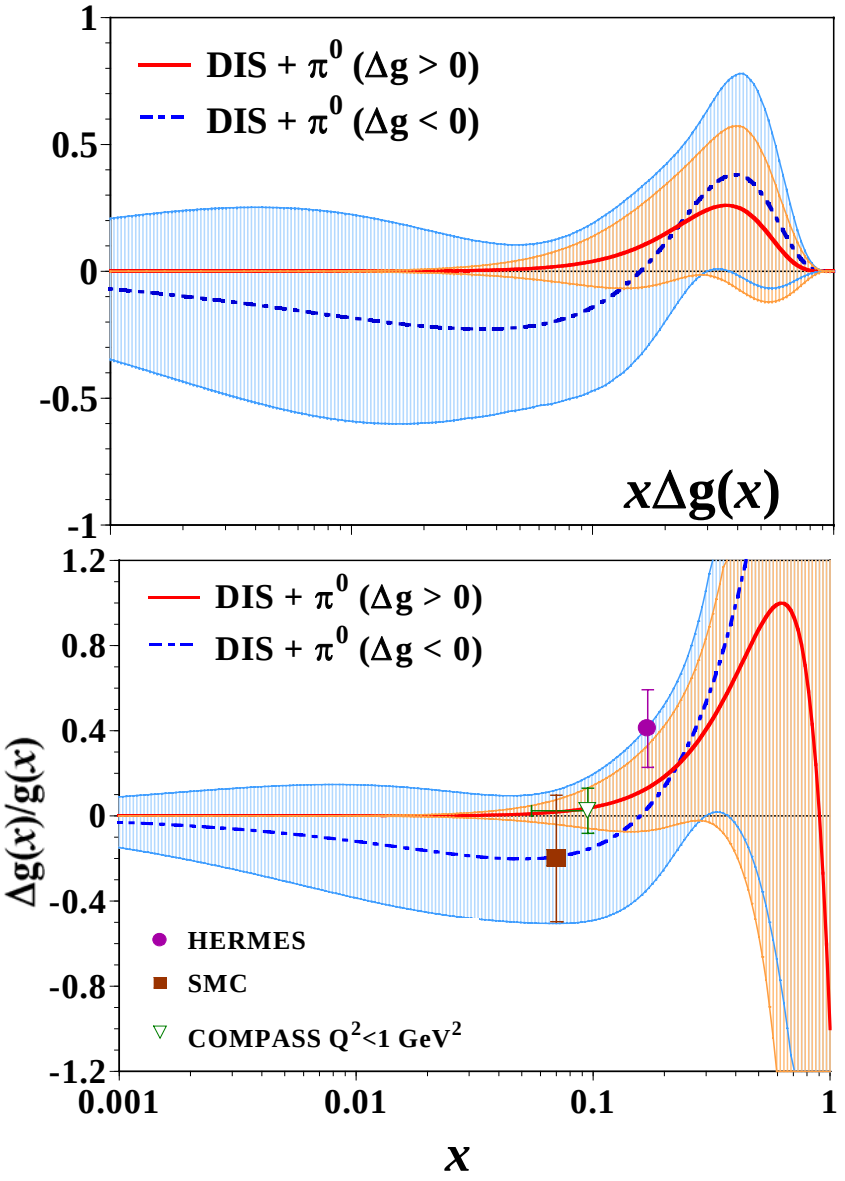
      (8 data points)





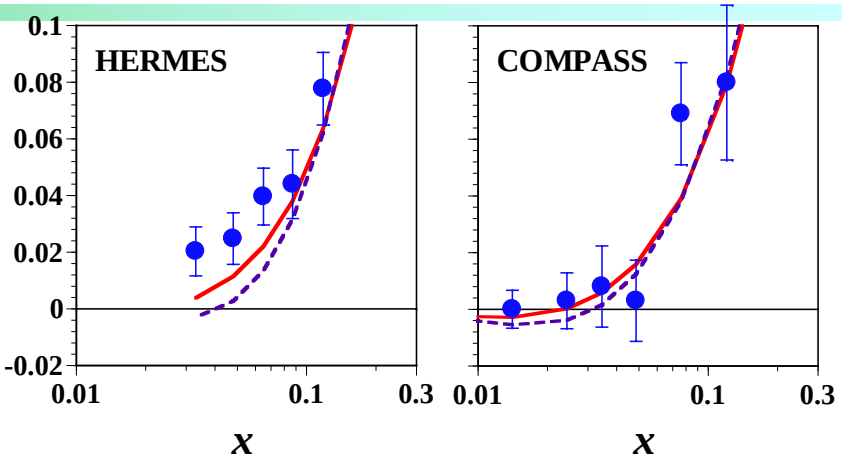
Small-x behavior of $\Delta g(x)$

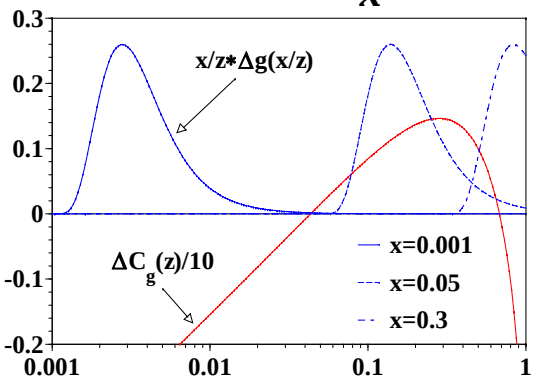
- 1st moment
  - $\Delta g>0$: 0.31 ± 0.32
  - $\Delta g<0$: -0.56 ± 2.16
- Consistent results
  - 1st moment ($0.1<x_{Bj}<1$)
    - $\Delta g>0$: 0.30 ± 0.30
    - $\Delta g<0$: 0.32 ± 0.42
  - DIS + π^0 data covered
- Huge uncertainty of $\Delta g<0$
  - Ambiguity of small-x behavior
  - No constraint on the behavior
- $\Delta g(x)$ is positive at large x



Large-x behavior of Δg(x)

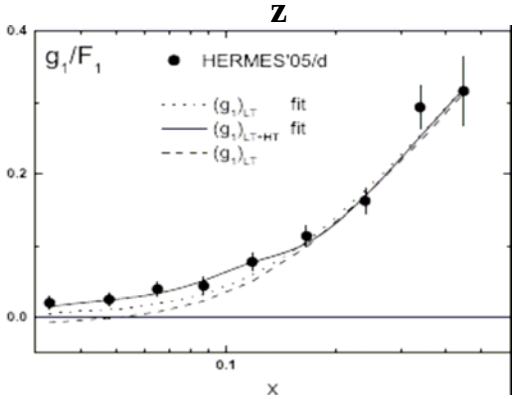
- **Positive Δg(x)/g(x) at large-x**
  - HERMES A_1^d
    - $0.03 < x_{Bj} < 0.07$, $1.2 < Q^2 < 1.7$
    - COMPASS-d: $4.5 < Q^2 < 8.6$
  - NLO gluon term
    - Positive contribution
    - Relative increasing for g_1^D
      - e_{uv}^2 : 4/9(P) → 2.5/9(D)
    - Positive Δg(x) at large-x
- **Other DOF for HERMES-d ?**
  - Higher Twist effects
    - LSS: PRD73(2006)034023
  - Antiquark $SU_F(3)$ asymmetry
    - D. de Florian, et al, PRD71(2005)094018

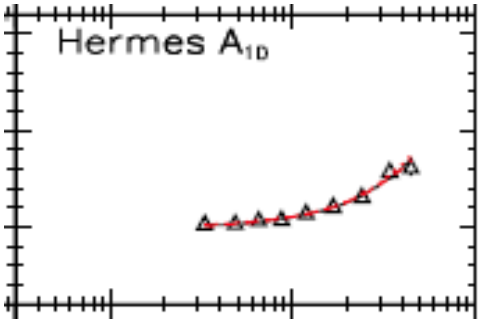




$$\Delta C_g(x) \otimes x\Delta g(x) = \int_x^1 \frac{dz}{z} \Delta C_g(z)\, x\Delta g\left(\frac{x}{z}\right)$$

$$\begin{cases} \Delta C_g(z): \mathbf{0.05} < z < \mathbf{0.2}, \\ \Delta g\left(x/z\right)_{x=0.05}: \mathbf{0.25} < x/z < \mathbf{1}. \end{cases}$$

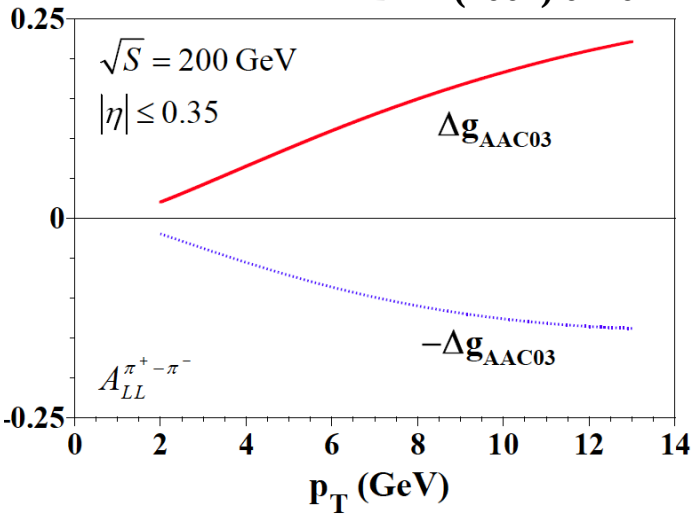


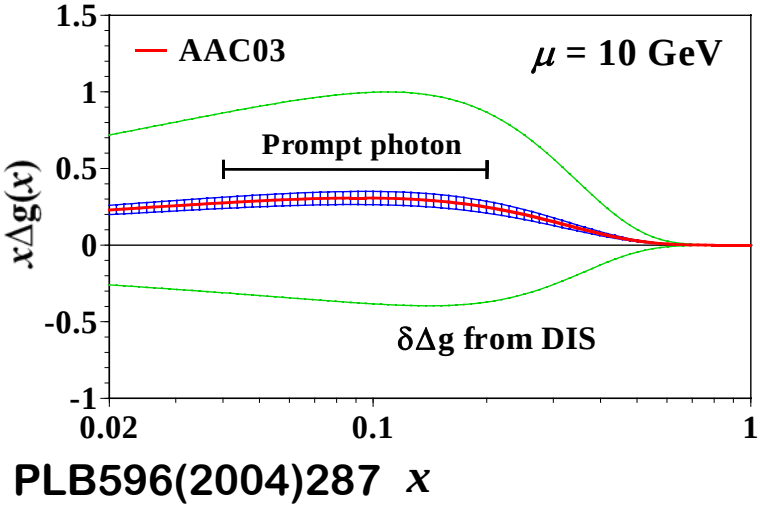


Other constraints from RHIC-Spin

- qg process dominates
  - $\pi^{\pm}$ production
    - Spin asymmetry: $A_{LL}^{\pi^+ - \pi^-} \equiv \frac{\Delta\sigma^{\pi^+} - \Delta\sigma^{\pi^-}}{\sigma^{\pi^+} - \sigma^{\pi^-}}$
      - Non $D_g^{\pi\pm}$ contribution $D_g^{\pi+} = D_g^{\pi-}$
    - L_{int}>10 pb^{-1}
  - Prompt photon production
    - Well known process
    - L_{int}> 100 pb^{-1}
- gg process dominates
  - Jet production
    - No ambiguity of FFs
  - Heavy flavor production

PRD 71 (2004) 014022





PLB596(2004)287

Summary

- **Polarized PDF from polarized DIS data**
  - $\Delta g = 0.47 \pm 1.08$ (DIS only)
    - $\Delta g(x)$ could not be determined well
  - Positive $\Delta g(x)$ at large-x
    - $A_1^d(x)$:HERMES,COMPASS data ($0.03 < x < 0.1$)
    - Positive NLO gluon term

- **π^0 production at RHIC-Spin**
  - $\Delta g = 0.31 \pm 0.32$ (DIS+π^0)
    - Significant reduction of its uncertainty
  - Sing problem:positive or negative Δg ?
    - $\Delta g = -0.56 \pm 2.16$
    - Ambiguity of the small-x behavior of $\Delta g(x)$
    - Need constraint on the behavior