Nucleon Polarized Parton Distribution Functions

G. K. Mallot
CERN/PH

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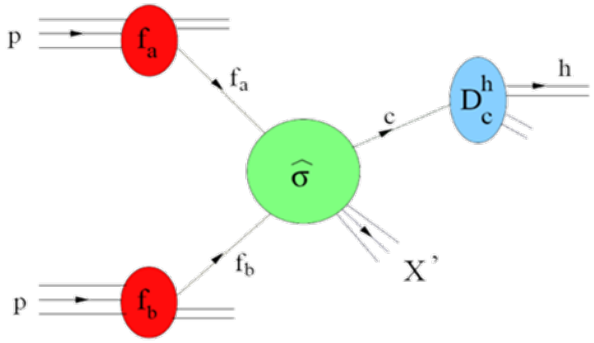
Quarks, Gluons & the Nucleon

- Baryons make up all of the visible matter.
  - How are they made up from quarks and gluons?

- In QCD many cross-sections factorize in
  - calculable hard part and
  - universal soft part (PDFs)



- Experimental findings:
  - Quarks & gluons share longitudinal momentum 50/50
  - Quark spins carry only about 30% of the nucleon spin

Spin Structure: a Global Endeavour

- polarized DIS (long. double spin asymmetries):
  - fixed-target (FT) lepton–nucleon scattering

EMC     Jefferson Lab

  - lepton-nucleon collider (HERA unpol., future EIC)

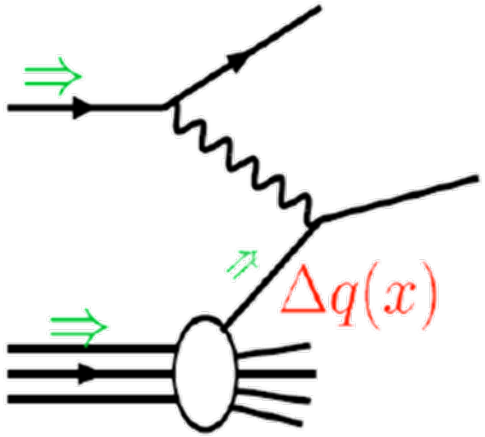
- polarized semi-inclusive DIS

EMC    Jefferson Lab

- polarized pp collisions (RHIC)

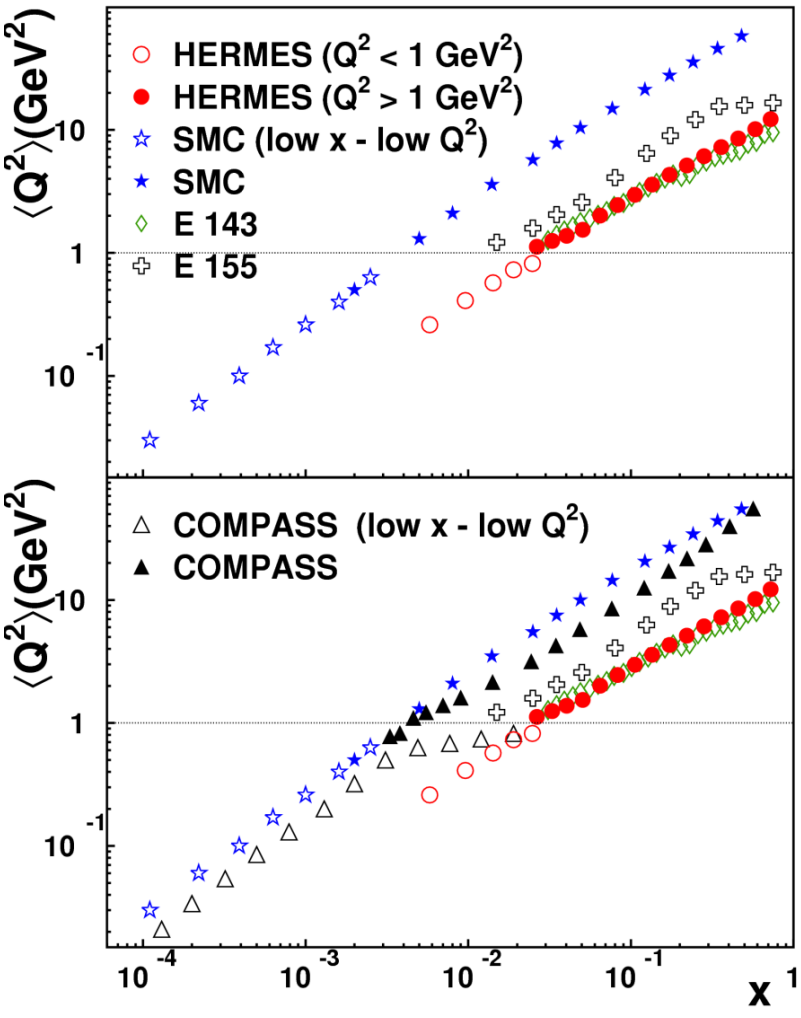
 

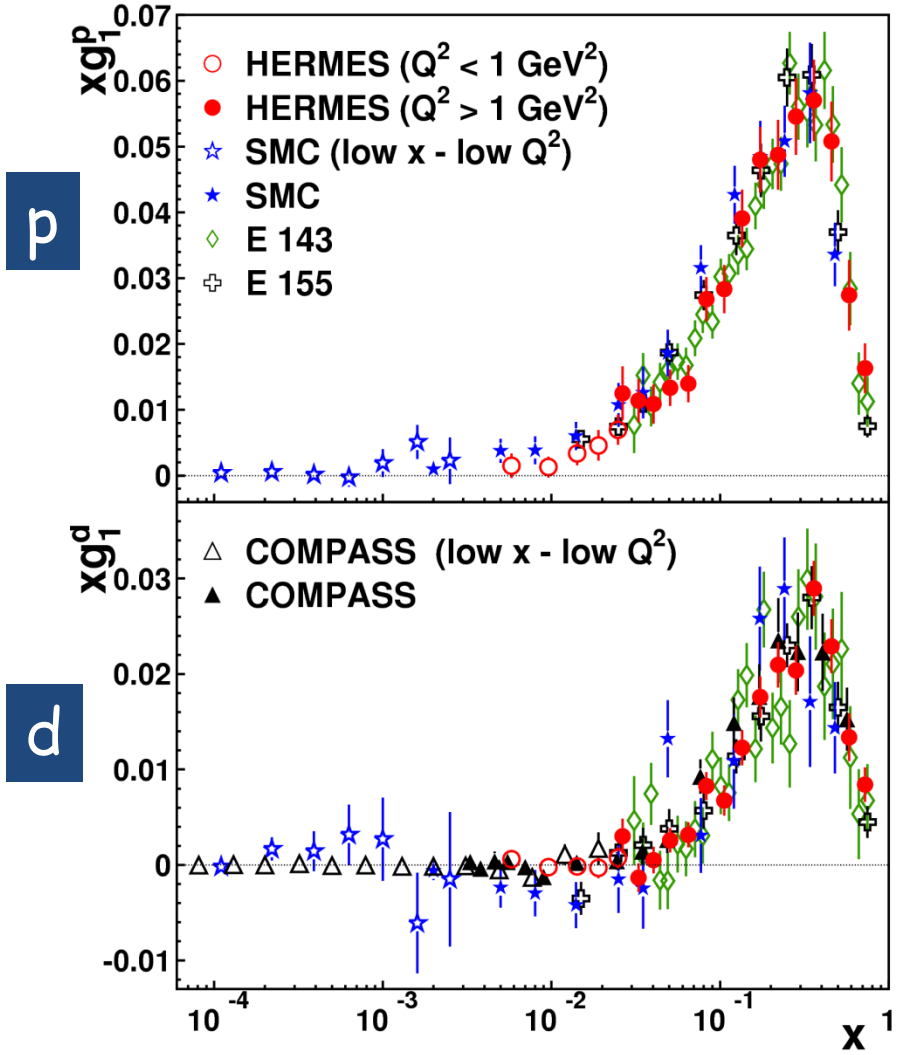
DIS



$$g_1(x) = \frac{1}{2} \sum_i e_i^2 \left\{ q_i^+(x) - q_i^-(x) \right\}$$

World Data on $xg_1(x,Q^2)$

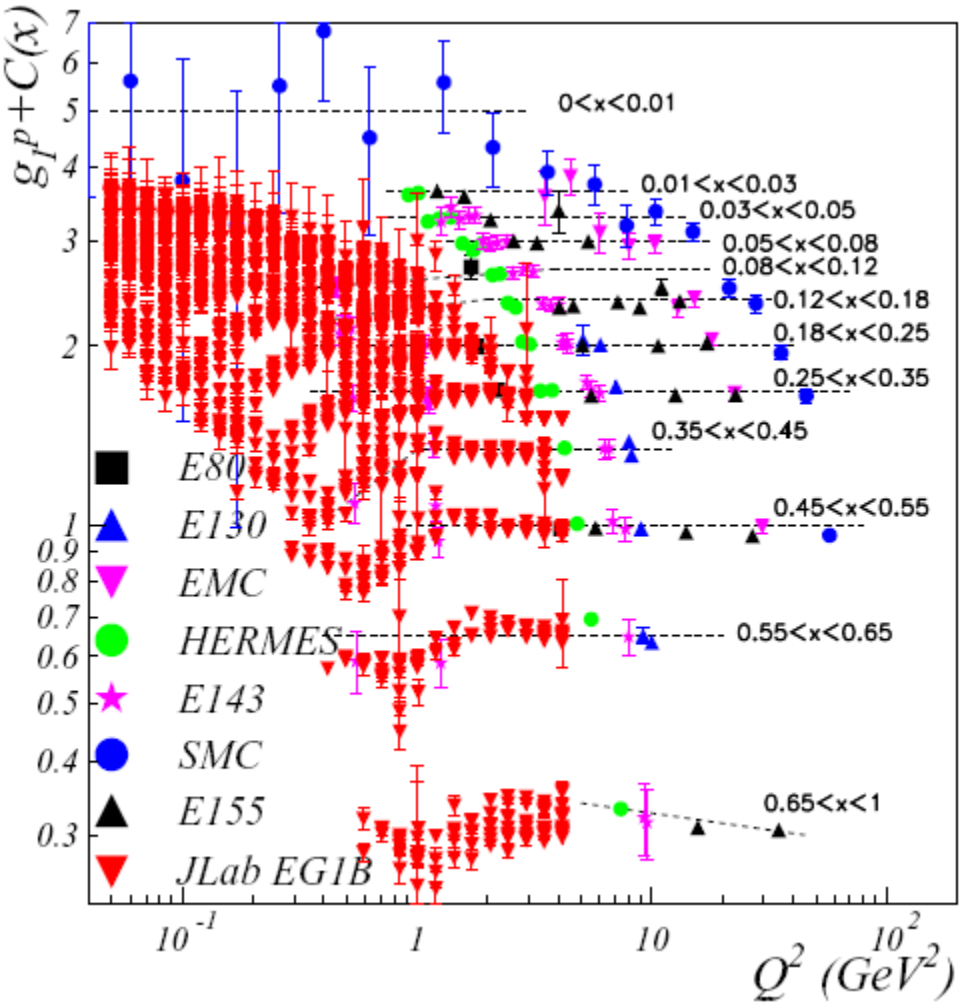




CLAS Proton data

- very precise CLAS data (EG1)
- mostly resonance region
- low Q^2, W
- used to determine higher twist terms

(Leader et al., PRD75, 074027, 2007)



from V. Burkhard, arXiv:0711.1703v2

QCD Analysis of data

NLO DGLAP:

$$\frac{\mathrm{d}}{\mathrm{d}\ln Q^2}\Delta q^{\mathrm{ns}} = \Delta\mathcal{P}^{\mathrm{ns}}_{qq} \otimes \Delta q^{\mathrm{ns}}$$

$$\frac{\mathrm{d}}{\mathrm{d}\ln Q^2}\begin{pmatrix} \Delta q^{\mathrm{s}} \\ \Delta g \end{pmatrix} = \begin{pmatrix} \Delta\mathcal{P}^{\mathrm{s}}_{qq} & \Delta\mathcal{P}^{\mathrm{s}}_{qg} \\ \Delta\mathcal{P}^{\mathrm{s}}_{gq} & \Delta\mathcal{P}^{\mathrm{s}}_{gg} \end{pmatrix} \otimes \begin{pmatrix} \Delta q^{\mathrm{s}} \\ \Delta g \end{pmatrix}$$

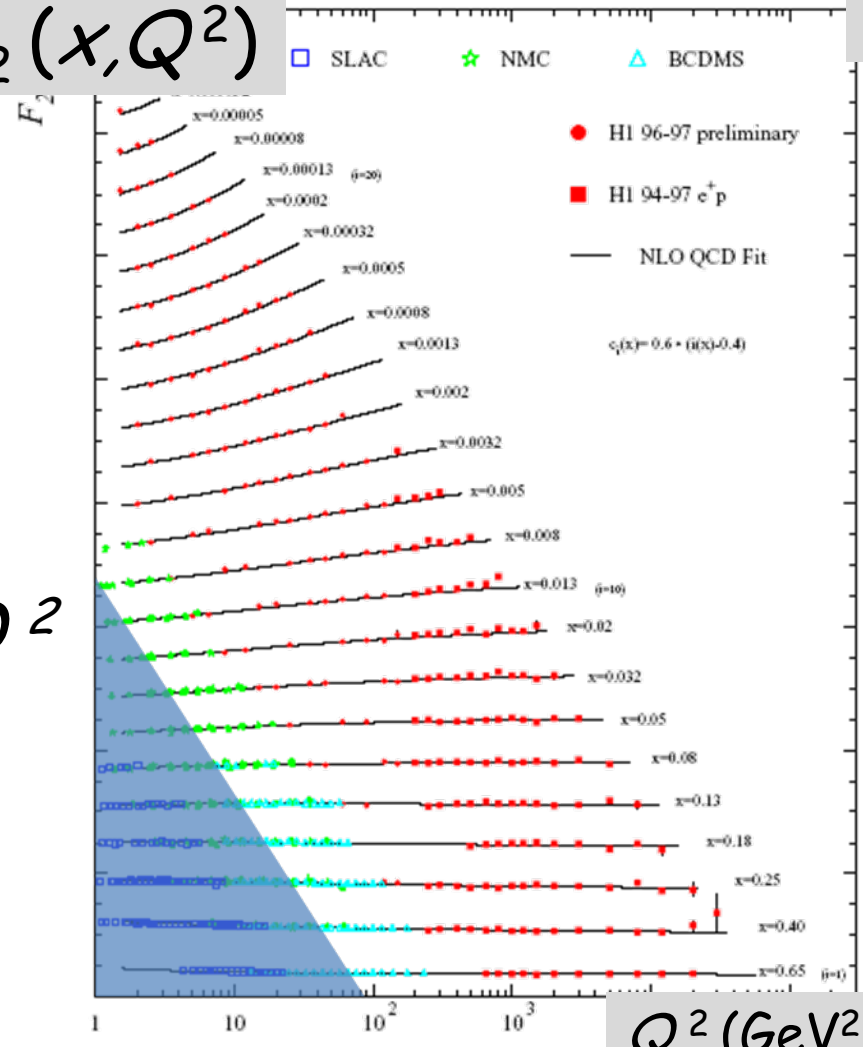
- choose renormalization scheme ($\overline{\mathrm{MS}}$, AB, jet, …) and Q_0^2
- optionally fix non-singlet moments from hyperon decays
- choose PDF parametrizations for non-singlet and singlet quark and for gluon
- fit to g_1 or A_1 data
- functional form of PDFs may bias error bands (and more)
- NNLO, higher twist, …

QCD analysis of pol. DIS data

- extra problems in polarized case:
  - no positivity constraint for PDFs
  - no momentum sum rule
- non-singlet distributions well determined
- singlet quark distribution rather well determined
- however, anti-quark and strange distributions still have large uncertainties
- gluon distribution has still large uncertainties, information only from scaling violations

DIS: Unpolarized vs Polarized

$F_2(x,Q^2)$

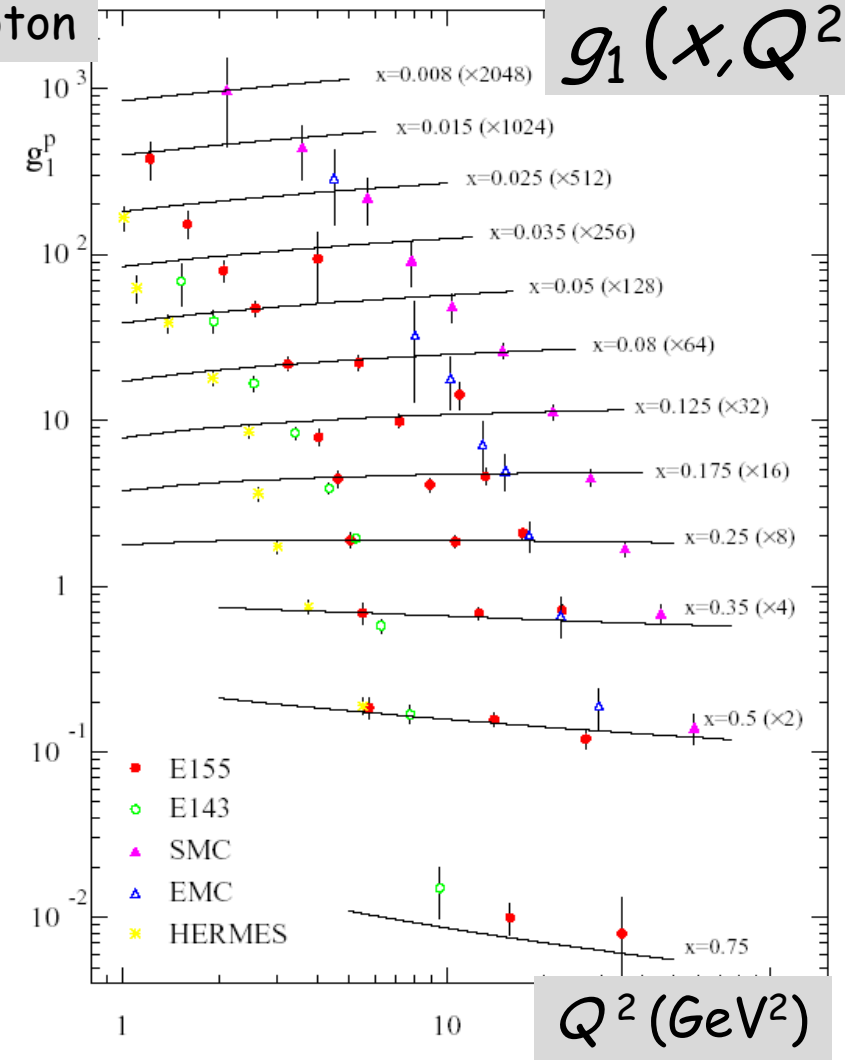


Q^2

$Q^2\,(GeV^2)$

proton

$g_1(x,Q^2)$

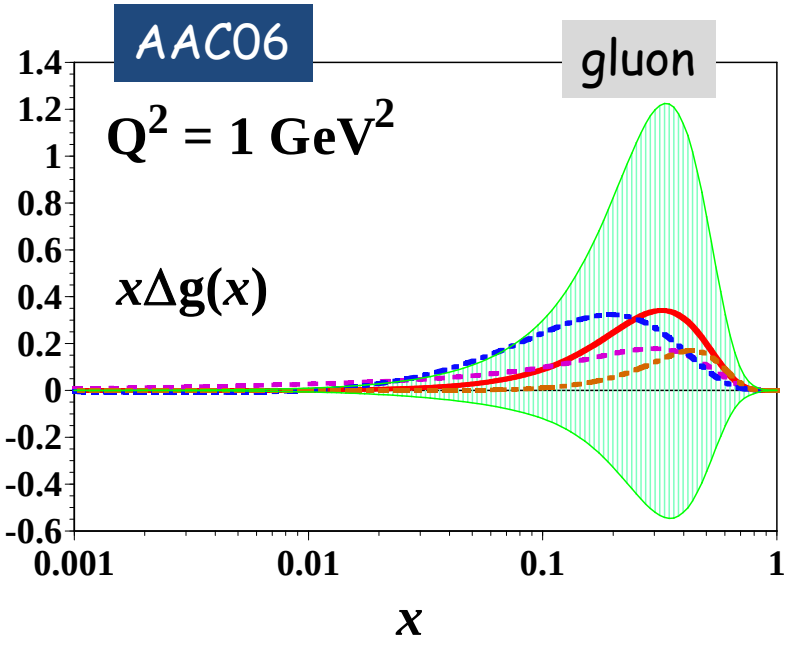


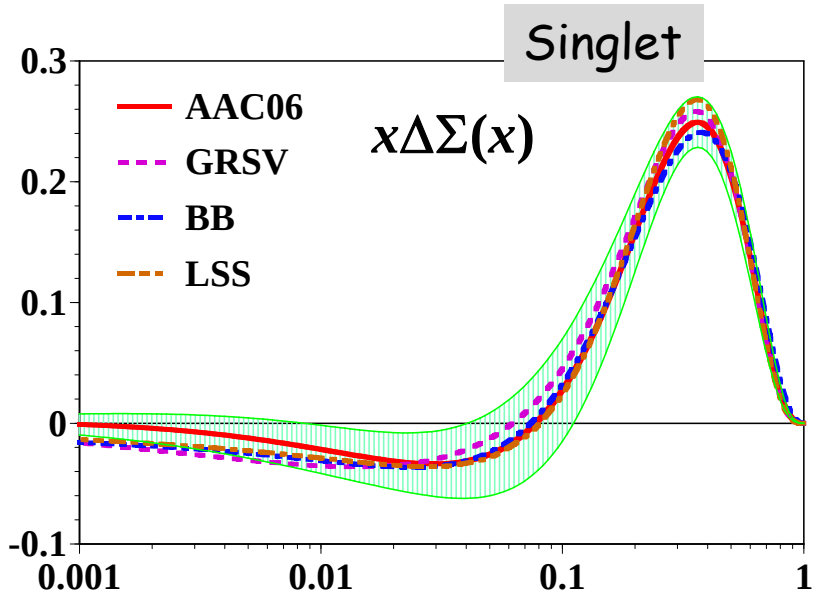
$Q^2\,(GeV^2)$

QCD analyses

- many groups performing World Data fits
- AAC06, LSS06,BB02, GRSV01, …; exp: COMPASS06, …
- most recent DSSV08, AAC08
- most complete DSSV08

→ later

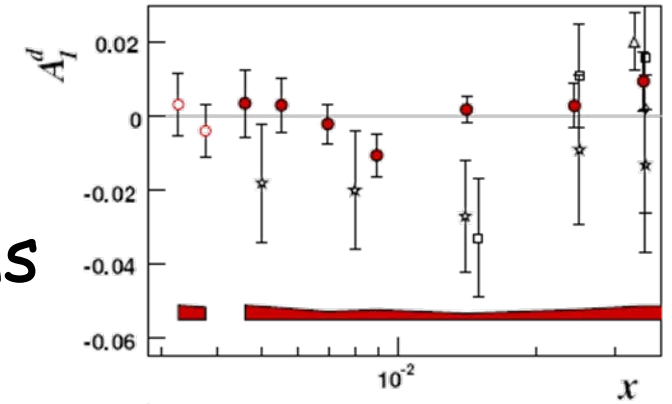


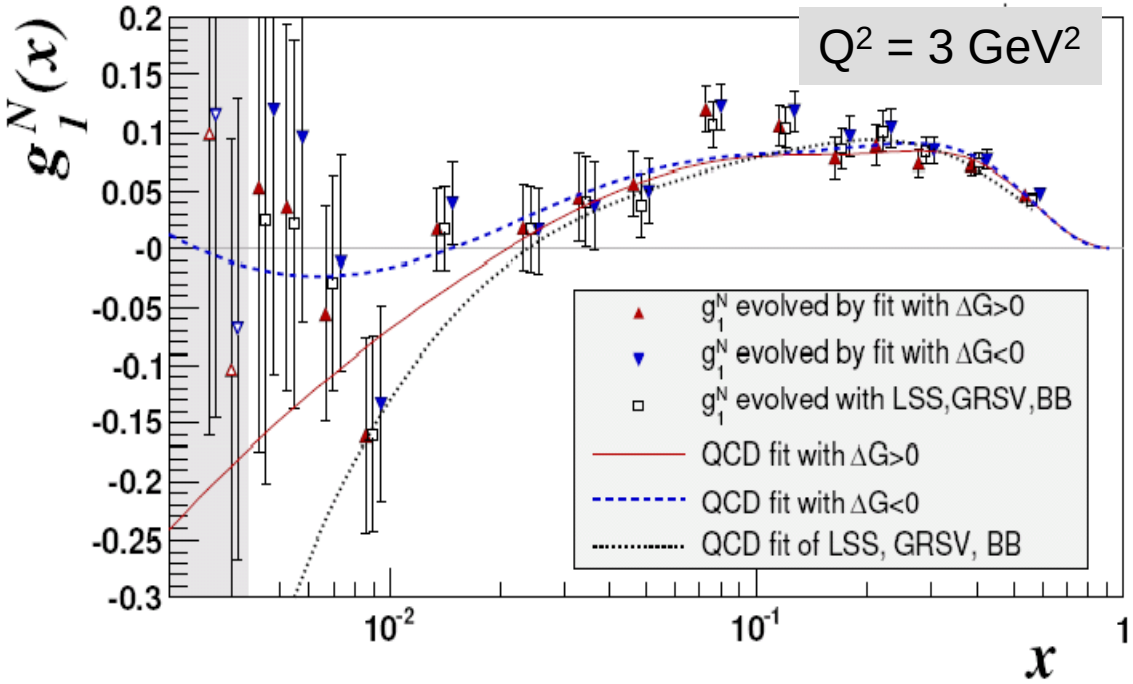


note: errors of AAC account for simultaneous deviation of all parameters

COMPASS deuteron g_1

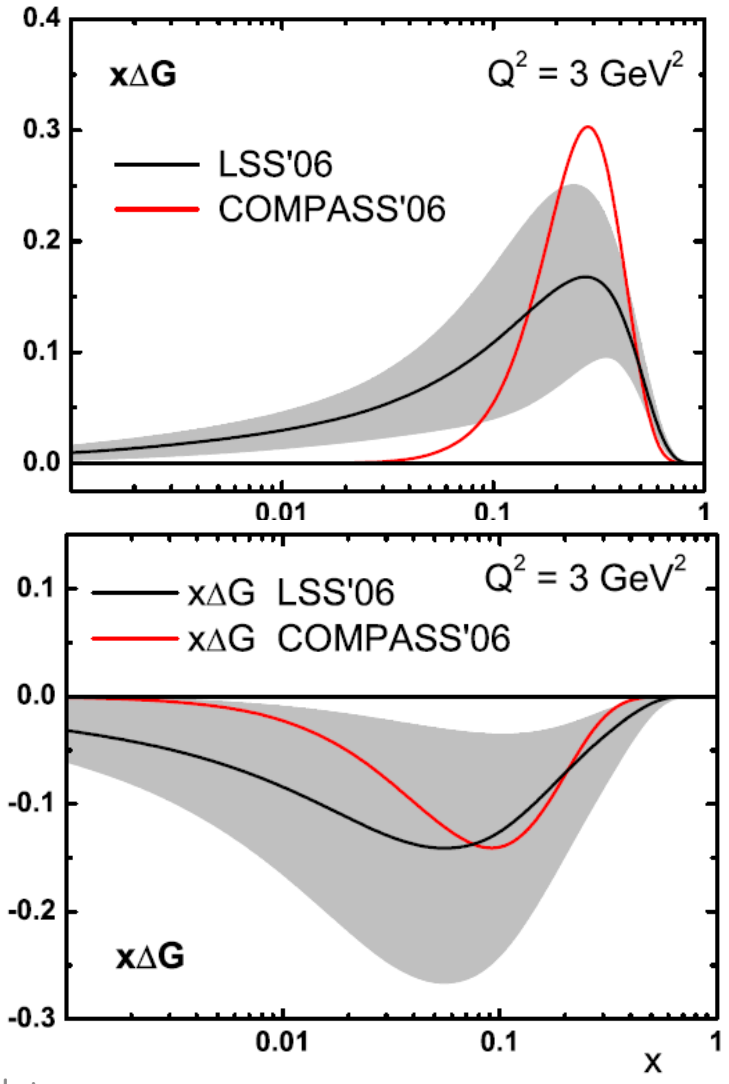
- about 6 times more precise at low x than SMC
- find +ve and –ve ΔG solutions



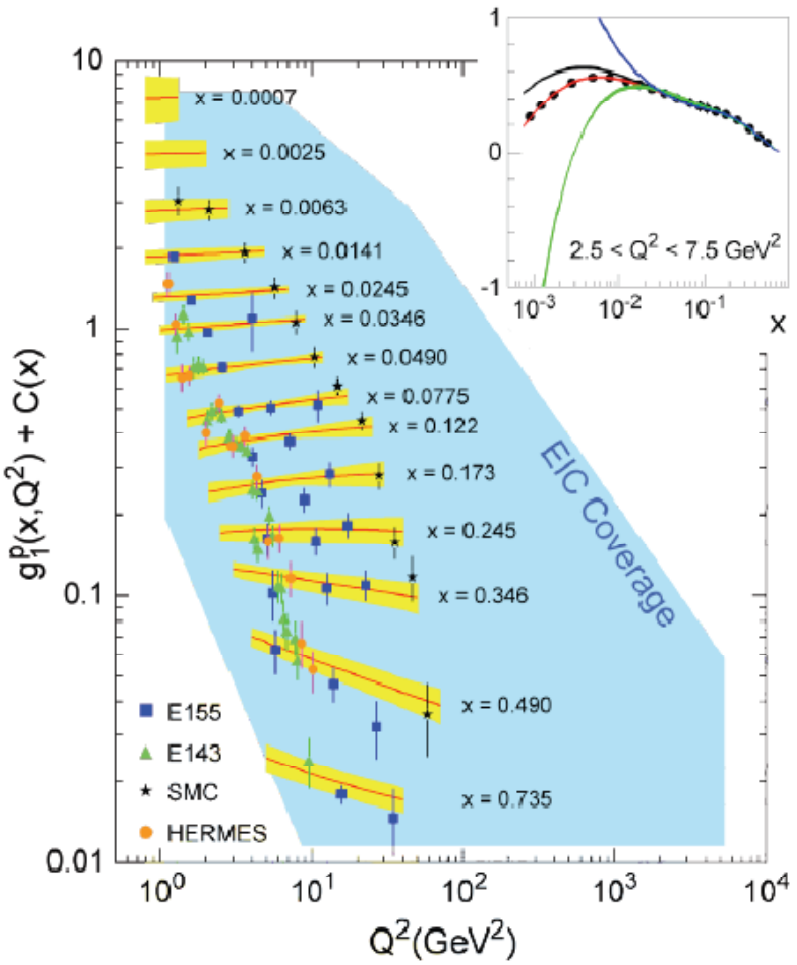


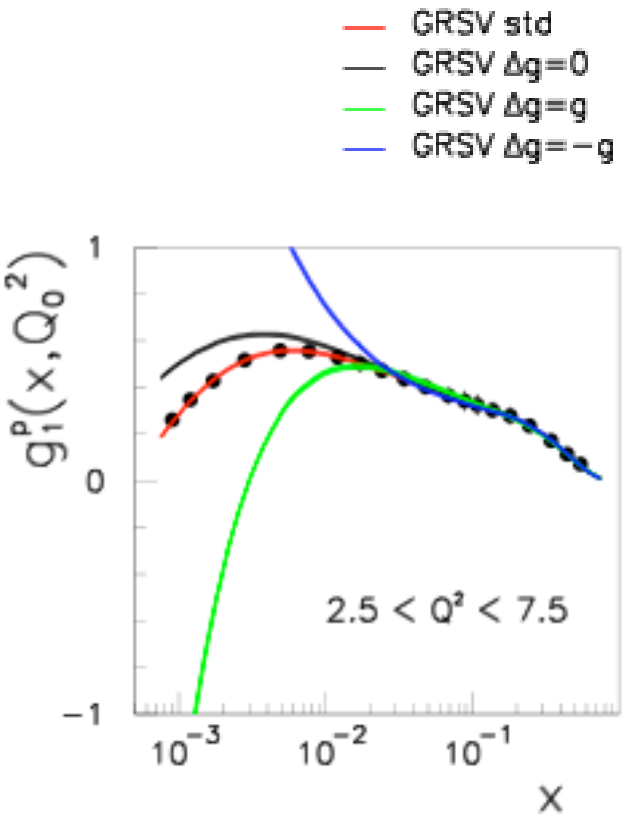
LSS06 / COMPASS06

- Compass and LSS06 find two solutions with small $\Delta G > 0$ and $\Delta G < 0$
- LSS06 includes HT and CLAS data
- How to tell sign of ΔG?

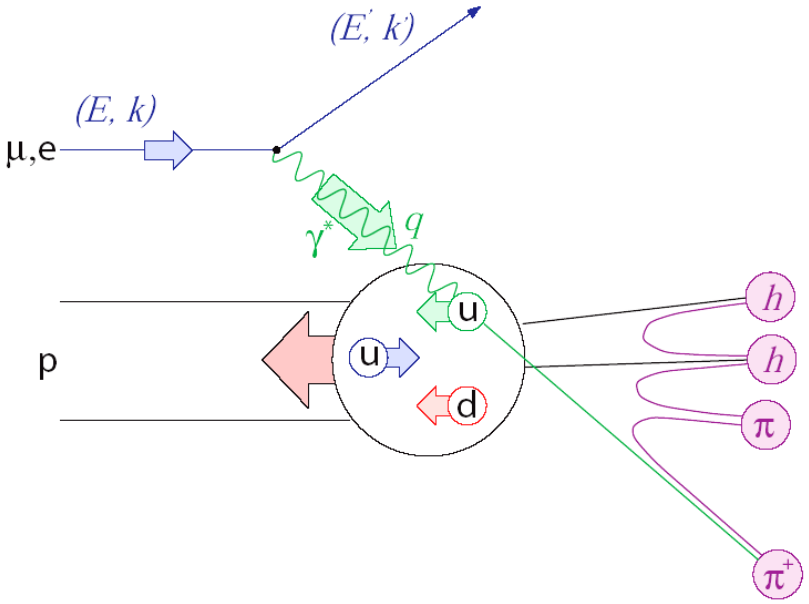


Range of a Future EIC at BNL

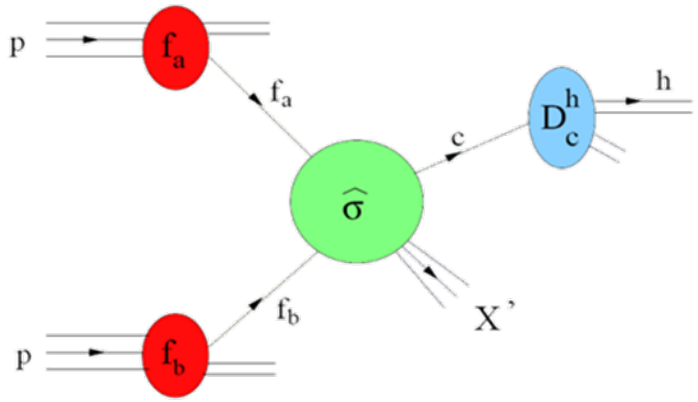




(SI)DIS

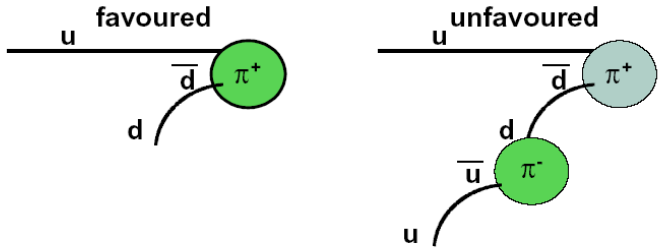


Flavour-tag: Semi-inclusive DIS



D_q^h from quark q into hadron h

$z = \frac{E_h}{\nu}$ energy fraction carried by h



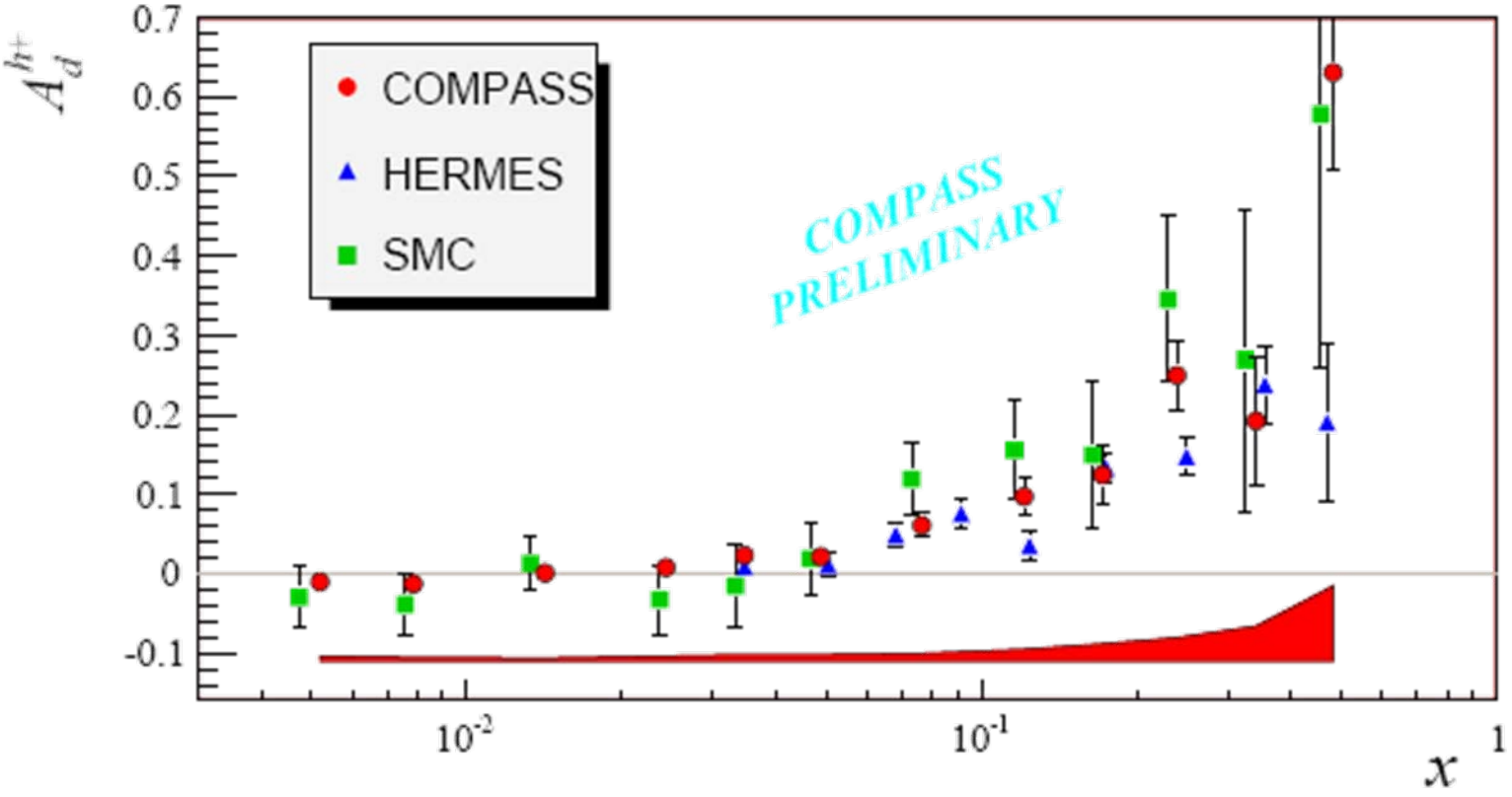
Factorization!

$$D_u^{\pi^+} \underset{\text{CC}}{=} D_{\bar{u}}^{\pi^-} \underset{\text{IS}}{=} D_{\bar{d}}^{\pi^+} \underset{\text{CC}}{=} D_d^{\pi^-}$$
$$D_d^{\pi^+} = D_{\bar{d}}^{\pi^-} = D_{\bar{u}}^{\pi^+} = D_u^{\pi^-}$$

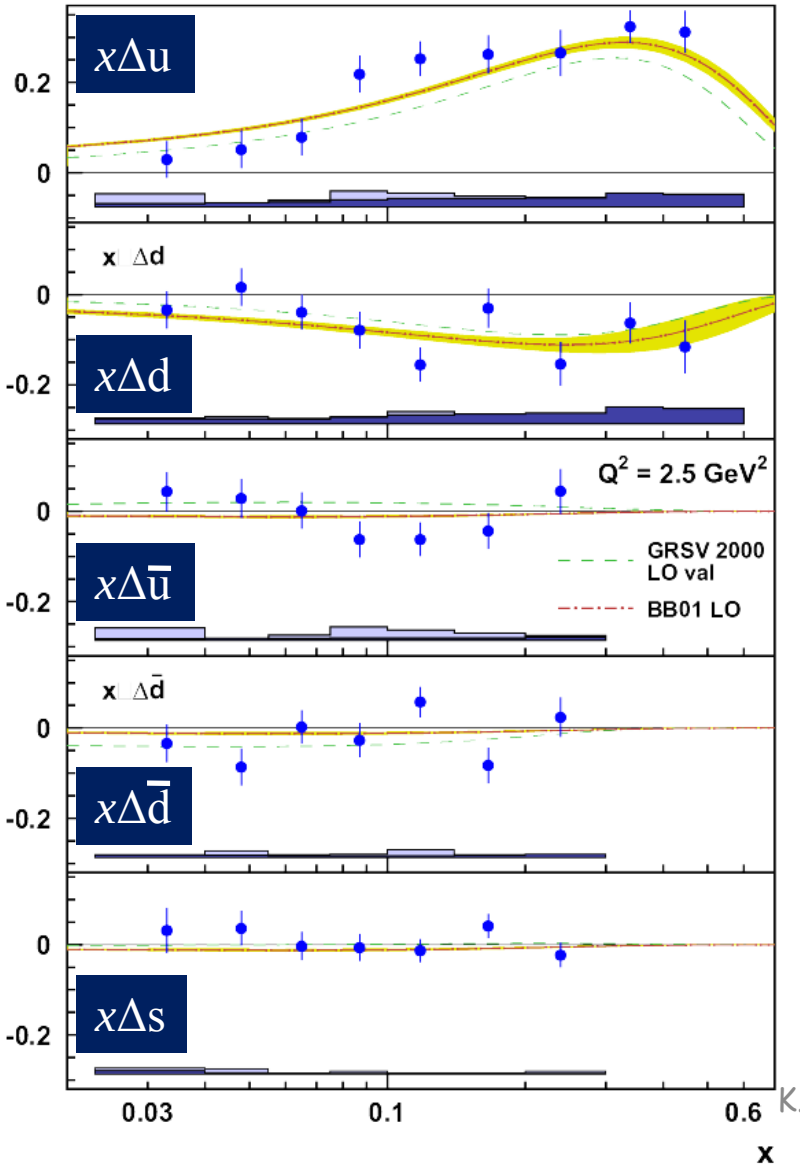
$$\frac{1}{\sigma_0}\frac{d\sigma^h}{dz} = \frac{\sum_f e_f^2\ q_f(x,Q^2)\cdot D_f^h(z,Q^2)}{\sum_f e_f^2\ q_f(x,Q^2)}$$

Semi-inclusive asymmetries

- E.g.: Asymmetries with an additional positive hadron A^{h+} (deuteron)



Flavour separated PDF



Asymmetries can in LO be related to Δq by

$$\vec{\mathcal{A}} = \mathcal{P}\vec{\mathcal{Q}}$$

where

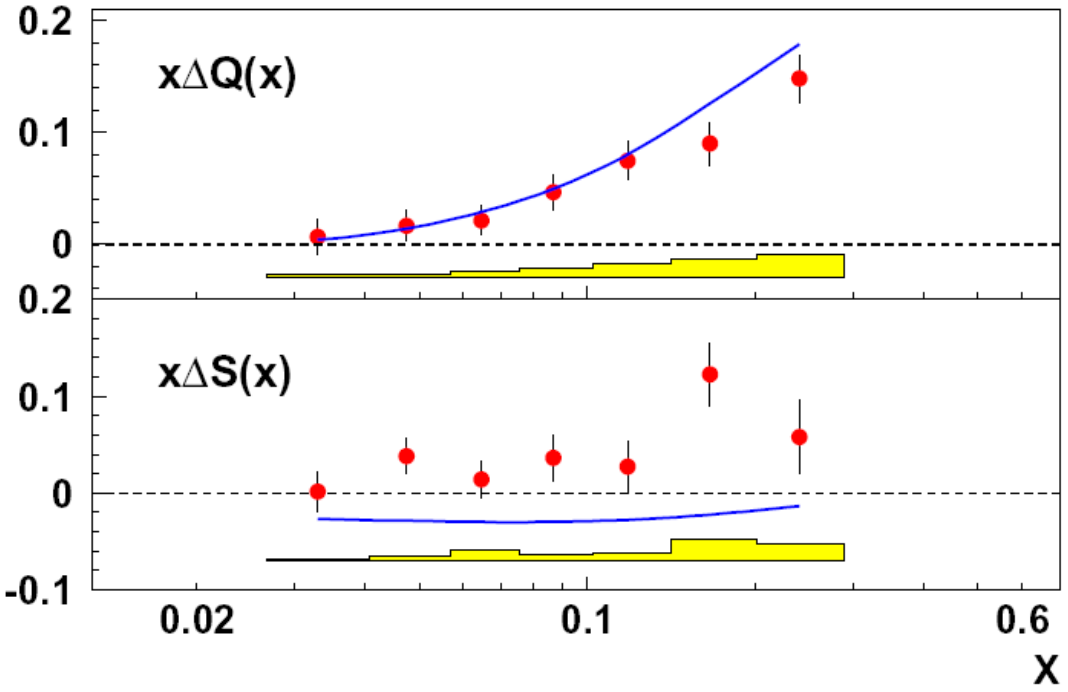
$$\vec{\mathcal{A}} = (A_{1,t}^{h}, \ldots)$$
$$\vec{\mathcal{Q}} = (\Delta q_f, \ldots)$$

$$\mathcal{P}_f^h = \frac{e_f^2 q_f(x) \int dz D_f^h}{\sum_i e_i^2 q_i(x) \int dz D_i^h(z)}$$

Strange quark sea

- semi-inclusive data incl. kaon $A_{\parallel,d}^{K^{\pm}}(x)$
- $\Delta Q = \Delta q + \Delta\bar{q}$
- $\Delta S = 0.037 \pm 0.019 \pm 0.027$
- range $0.02 < x < 0.6$
  $Q^2 = 2.5\ GeV^2$
- $\Delta S < 0$ expected from incl. data

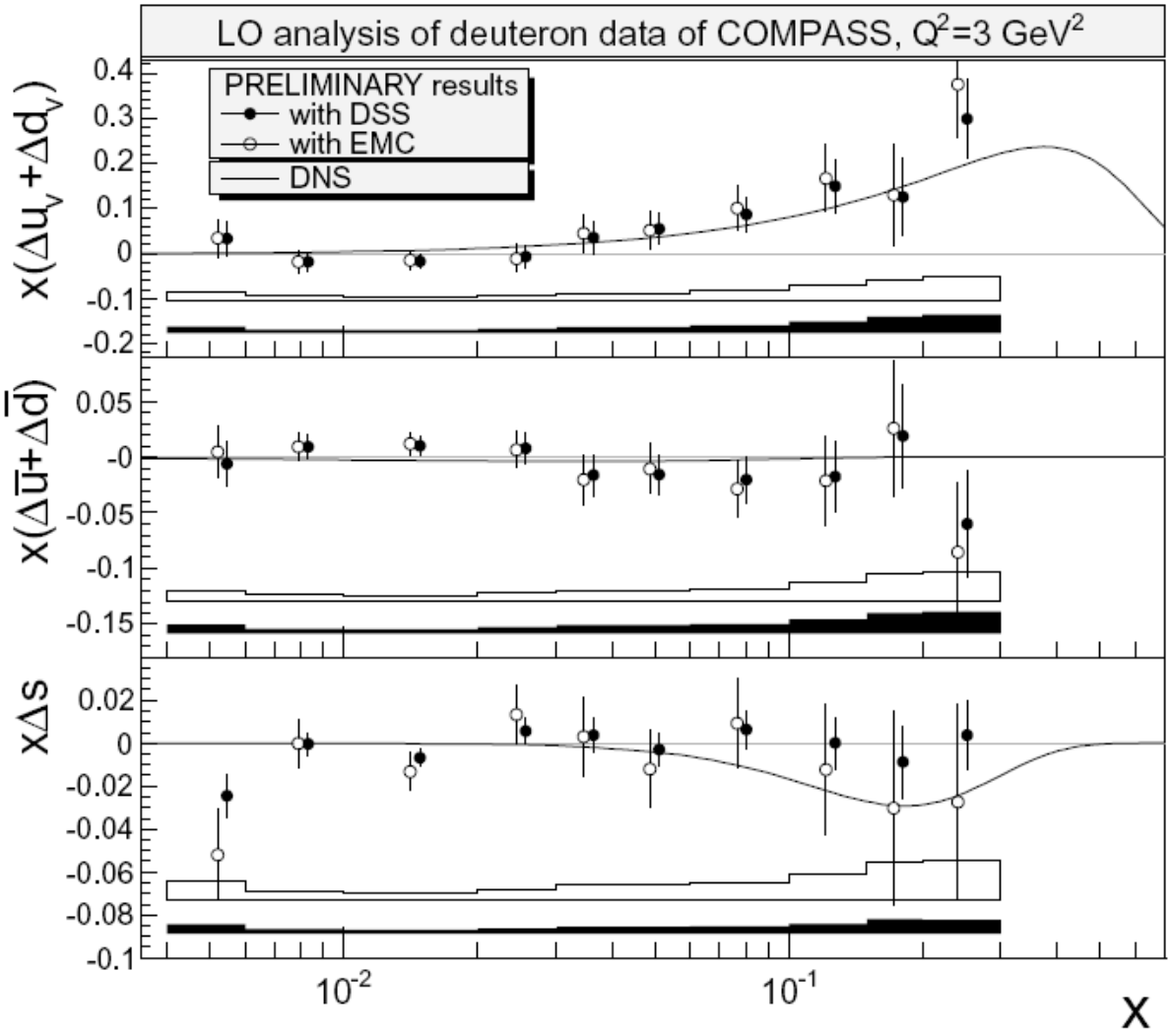
$Q^2 = 2.5\ GeV^2$



PDF from SIDIS (LO)

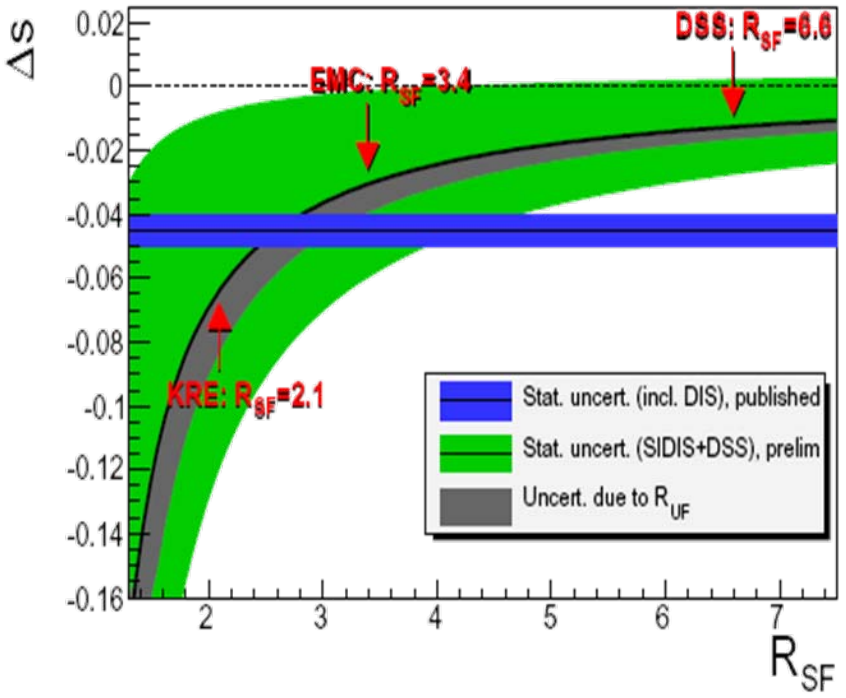
EMC and DSS FF

- $\Delta u_v + \Delta d_v$, Δu -bar+Δd-bar insensitive to FF
- Δu+Δd-bar consistent with 0
- Δs and errors 2-3 times larger with EMC with DSS FF

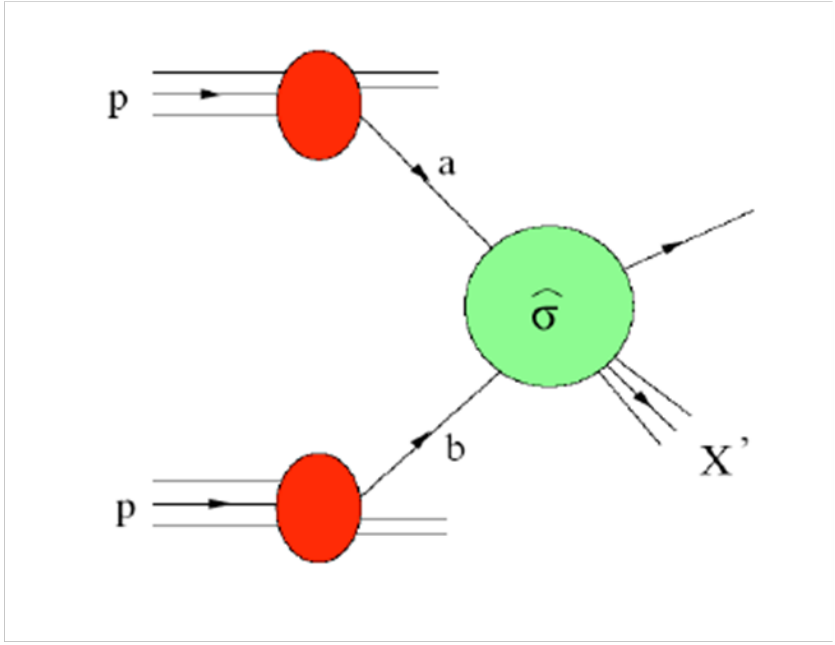


Dependence of Δs on FF

- Compass data 0.004 < x < 0.3 from kaon A_1 a
- $R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$
- first moment
  $\Delta s = -0.01 \pm 0.01 \pm 0.01$
  $(= \Delta\bar{s})$
- 0.004 < x < 0.3,
  Q^2 = 3 GeV^2 and
  DSS 2007 FF

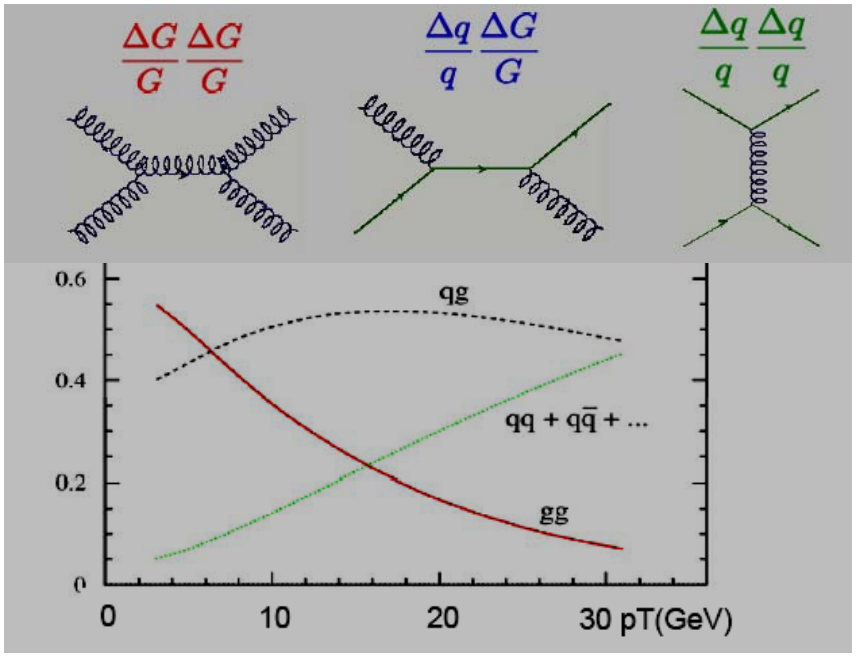


pp

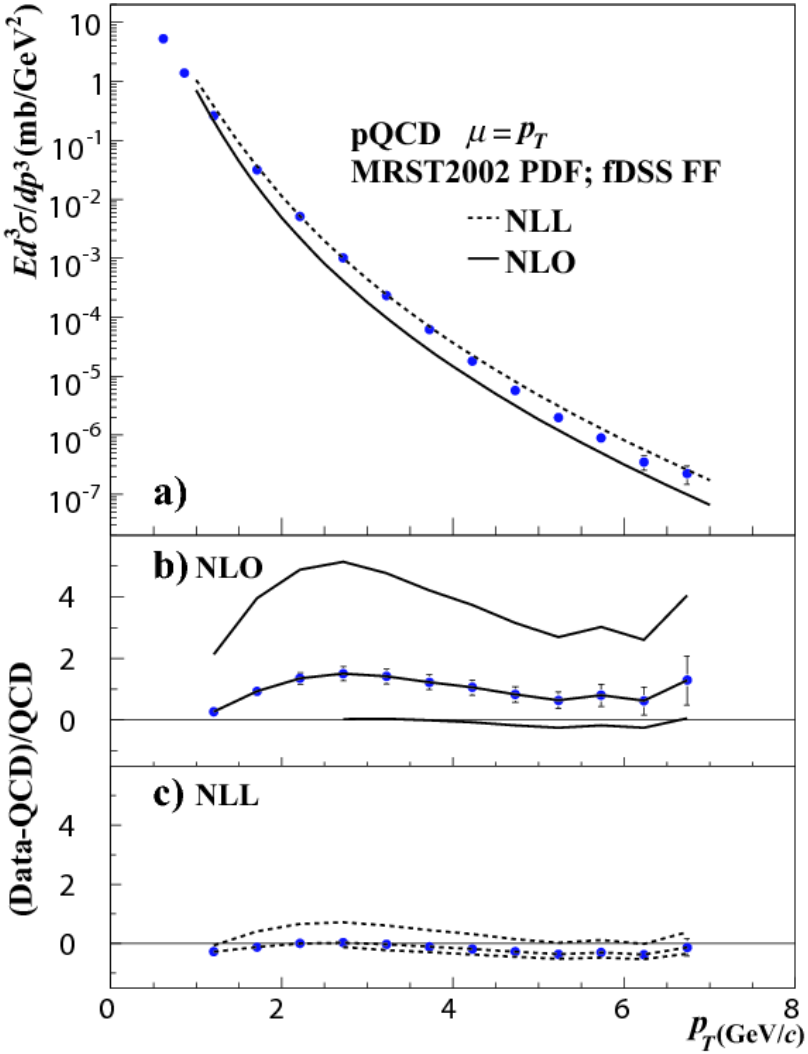


at RHIC

Inclusive π^0 Cross-section

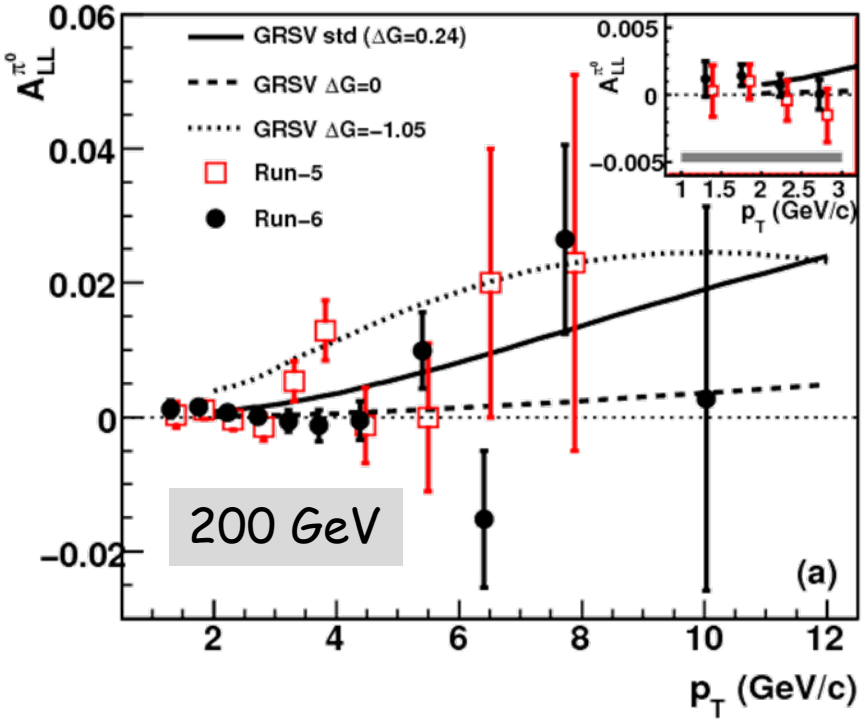


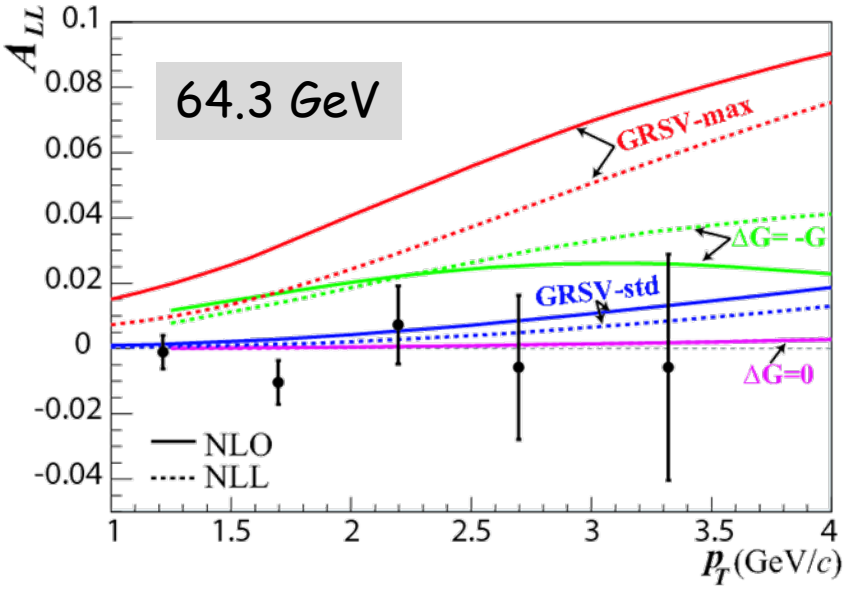
- Excellent agreement of NLL with data



$A_{LL}^{\pi^0}$ $\sqrt{s}$=200 and 64.2 GeV

PHENIX





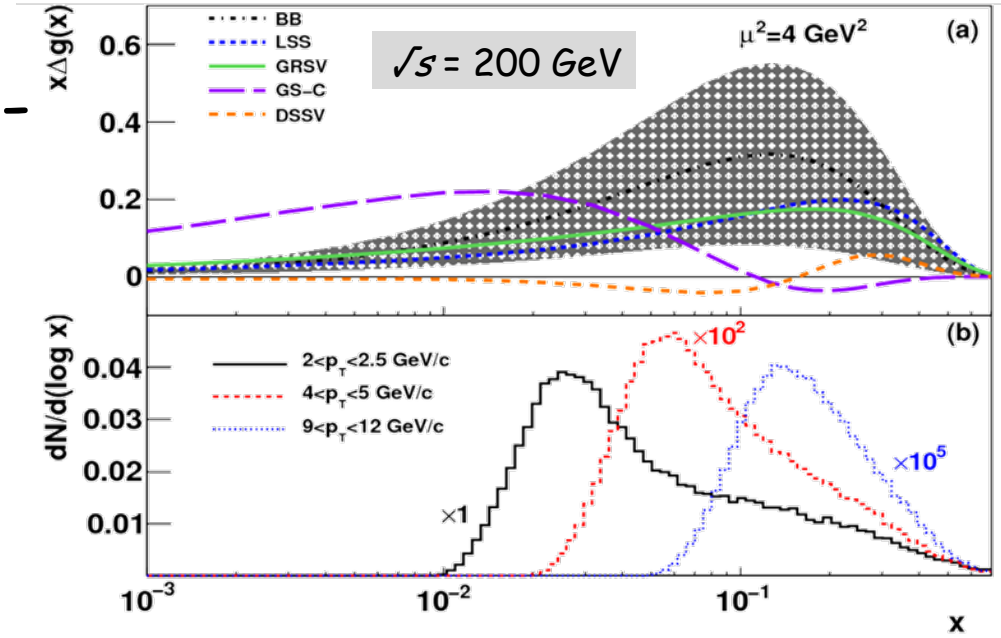
from: K. Nakano, Spin 2008

- big improvement with Run6
- π^0 data incompatible with large ΔG
- rather strong NLL effect in 64.2 GeV

Sensitivity to x_g $A_{LL}^{\pi^0}$

- no x_g info on event-by-event basis

$$\langle x \rangle \approx \frac{2 p_T}{\sqrt{s}}$$

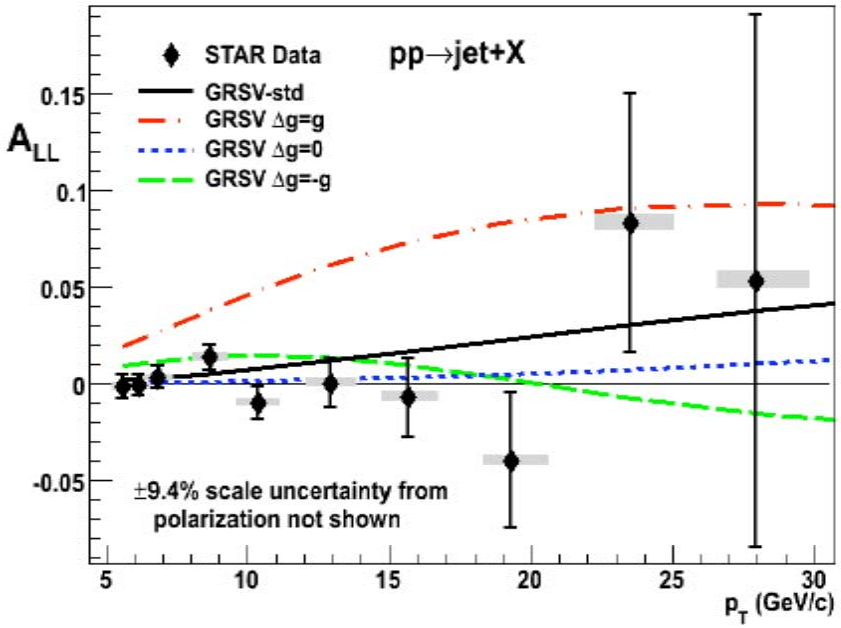


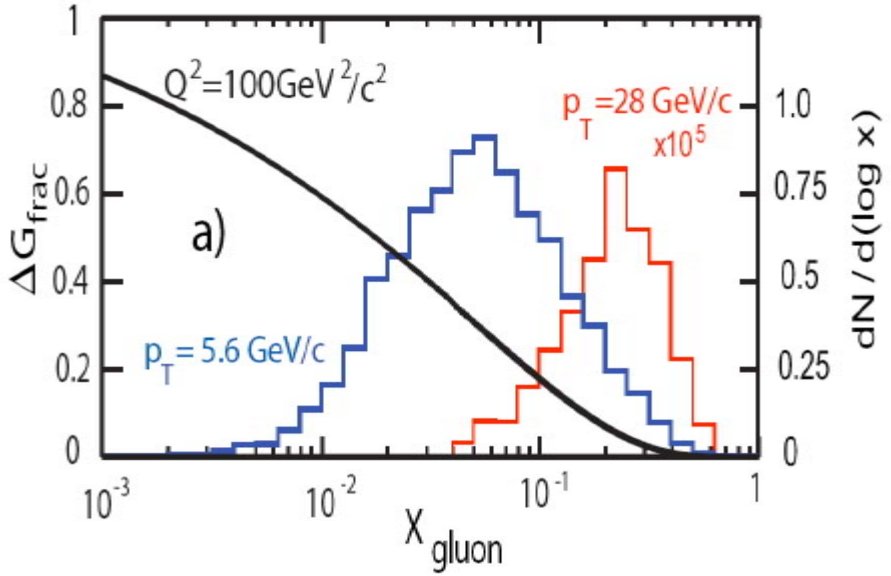
from: K. Nakano, Spin 2008

- $\sqrt{s}$ = 200 GeV: 0.02 < x_g < 0.3
- $\sqrt{s}$ = 62.4 GeV: 0.06 < x_g < 0.4
  - slightly higher x_g, better statistics

pp → jet + X

- 2005 inclusive data: 2 pb^{-1}, ~50% pol. $x \approx \frac{2p_T}{\sqrt{s}}$





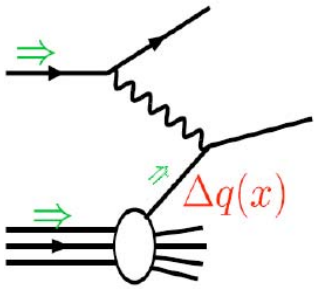
PRL 100, 232003 (2008)

- 2006 di-jet data in progress: $M = \sqrt{x_1 x_2 s}$

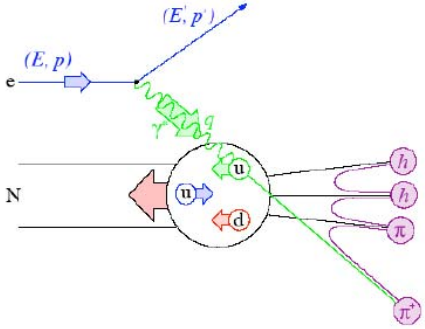
DSSV08: De Florian, Sassot, Stratmann, Vogelsang; PRL 101 (2008) 072001

Global Analysis

DIS



SIDIS



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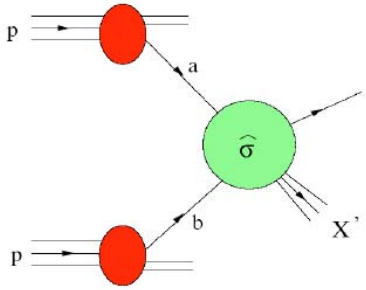
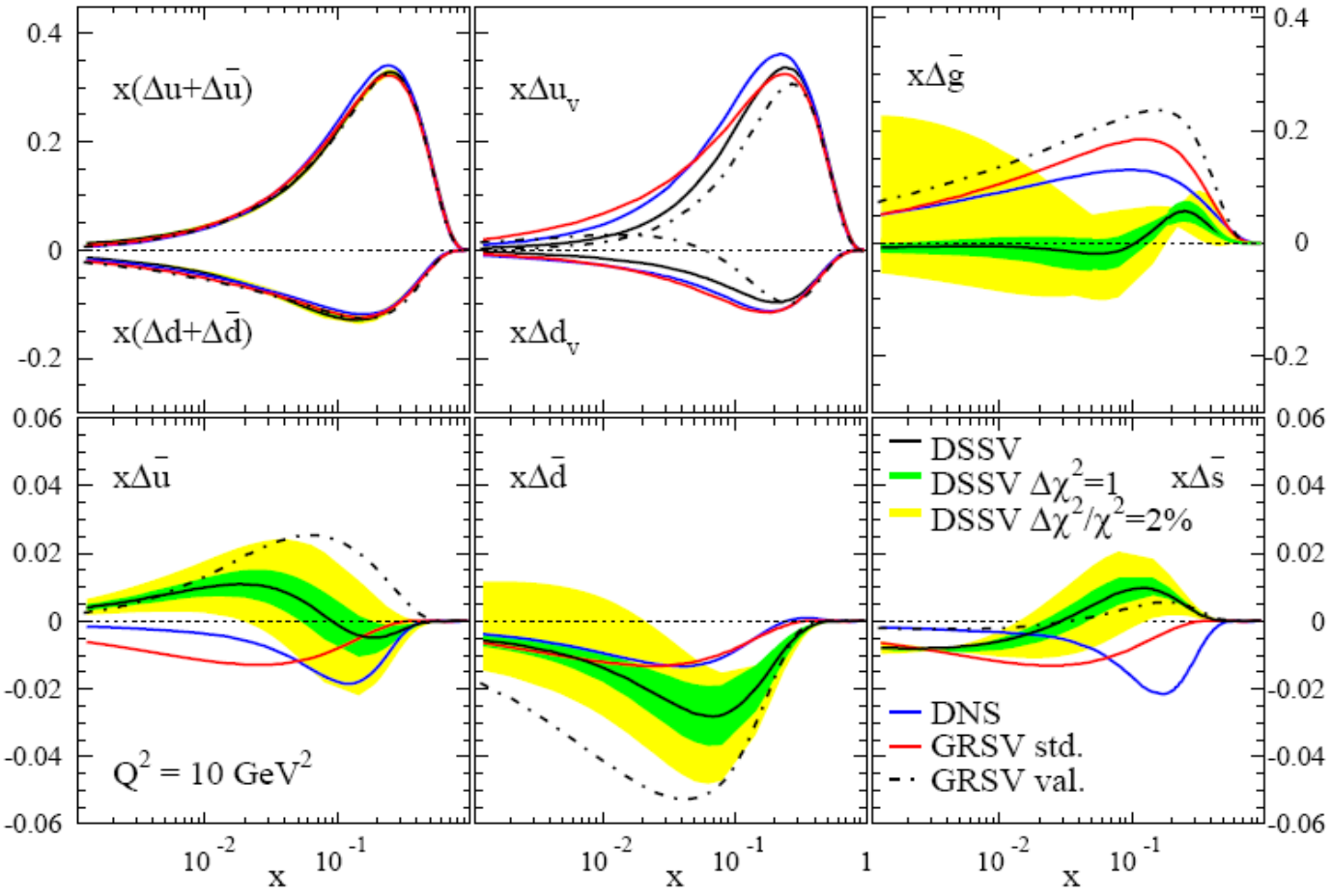


Global Analysis of (SI)DIS and pp

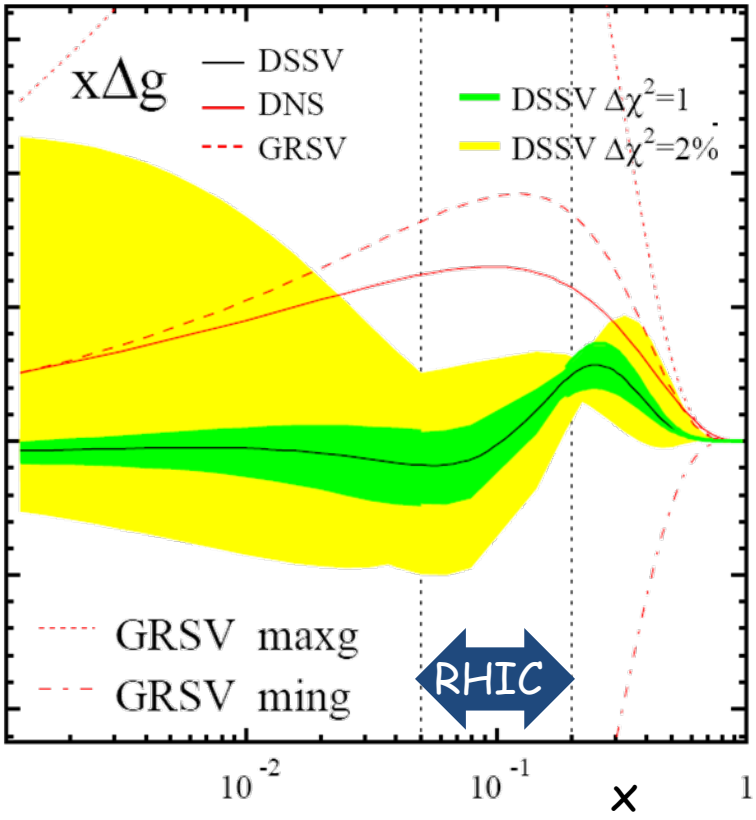
- Data: EMC, SLAC-Exxx, SMC, HERMES, COMPASS, Hall-A, CLAS, PHENIX, STAR
- NLO/NLL, $\overline{\text{MS}}$, Q^2_0=1 GeV^2, $\varepsilon_{SU(2,3)}$ fitted
- Fragmentation functions from new DSS fit (**PRD75 (2007) 114010 ; D76 074033**)

DSSV08 PDFs

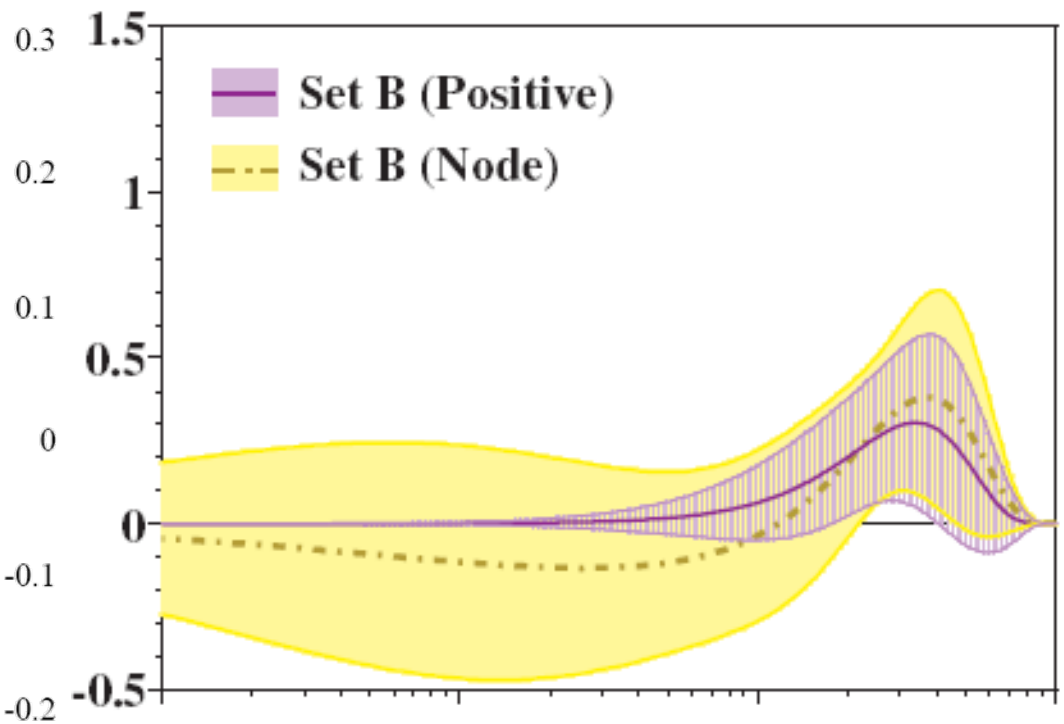

x(Δu+Δū)
x(Δd+Δd̄)
xΔu_v
xΔd_v
xΔḡ
xΔū
xΔd̄
xΔs̄
DSSV
DSSV Δχ²=1
DSSV Δχ²/χ²=2%
DNS
GRSV std.
GRSV val.
Q² = 10 GeV²
x

DSSV08 & AAC08 gluon PDFs

- DSSV08

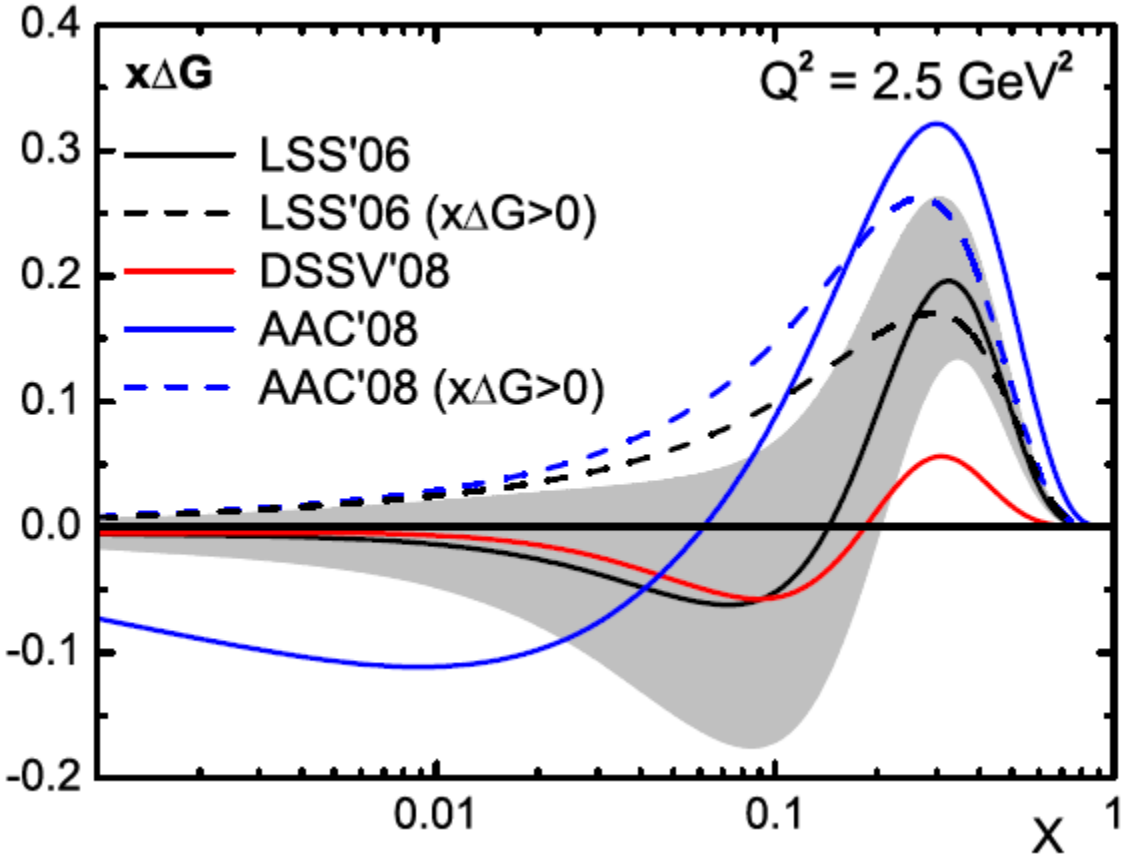


AAC08



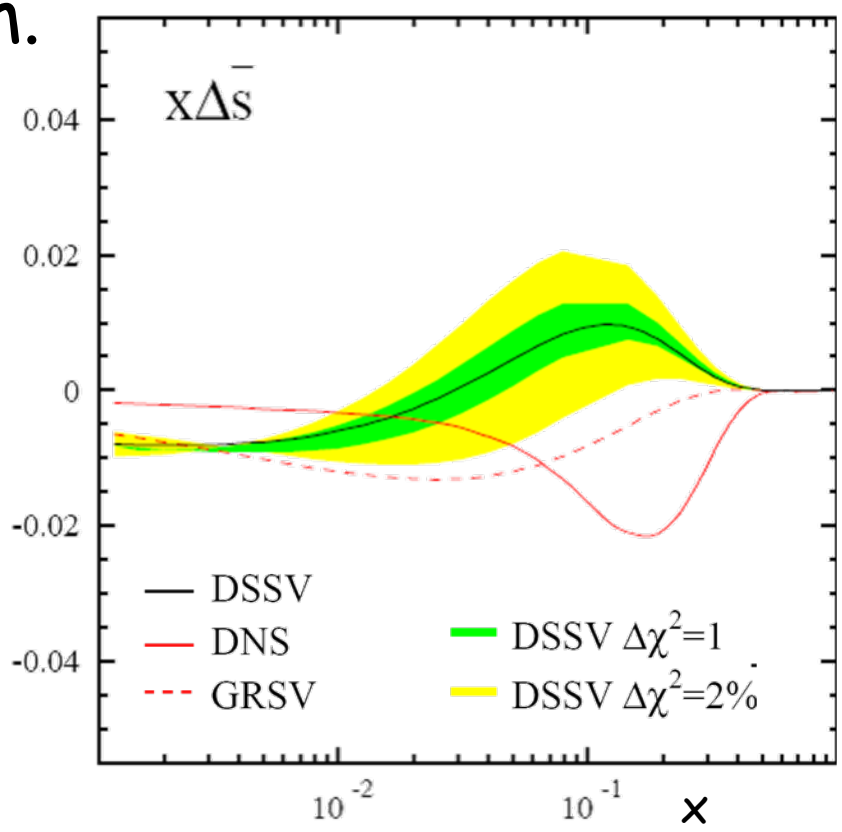
M. Hirai, S. Kumano arXiv:0808.0413v1

Comparison of gluon PDFs



Δs

- Δs positive at large x (Hermes SIDIS)
- Compass kaon asymm. not yet included
- first moment < 0 from DIS
- node in strangeness distribution



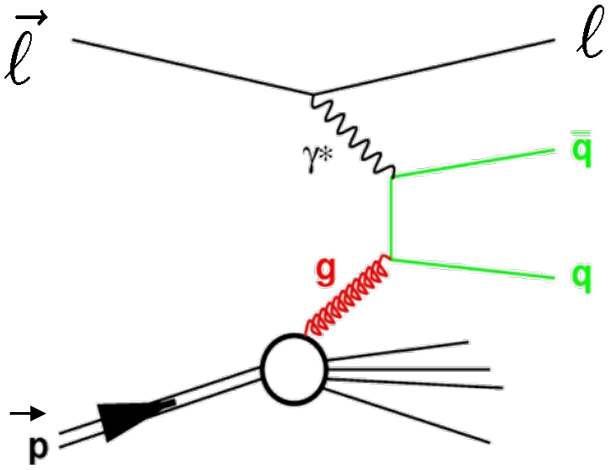
PDF first moments (DSSV08)

	$x_{\min} = 0$	$x_{\min} = 0.001$	
	best fit	$\Delta\chi^2 = 1$	$\Delta\chi^2/\chi^2 = 2\%$
$\Delta u + \Delta\bar{u}$	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	$0.366\ ^{+0.015}_{-0.018}$	$0.366\ ^{+0.042}_{-0.062}$

EMC (1988):

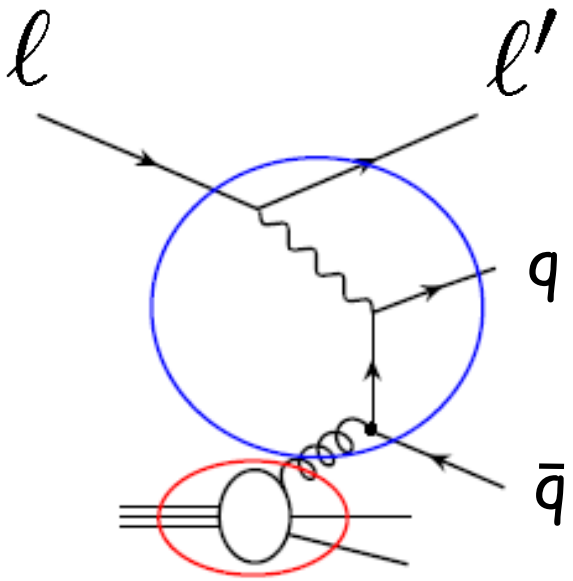
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.12 \pm 0.17$$
$$\Delta s = -0.19 \pm 0.06$$

Δg/g from FT hadrons



Hadron production in DIS via PGF

Principle: Gluon polarization enters via photon-gluon fusion (PGF)



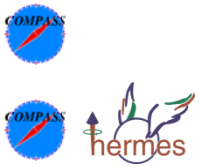
$$A_{\parallel} = R_{pgf} \langle \hat{a}_{pdf} \rangle \left\langle \frac{\Delta g}{g} \right\rangle$$

- measure $A_{\parallel}$
- calculate R_{pgf} ,$\langle \hat{a}_{pgf} \rangle$ and background by Monte Carlo

Analysed channels

analysed data sets:

- high-p_T hadron pairs (no ID, pions/kaons)
  - $Q^2 > 1$ GeV^2 — LEPTO
  - $Q^2 < 1$ GeV^2 or unmeasured — PYTHIA



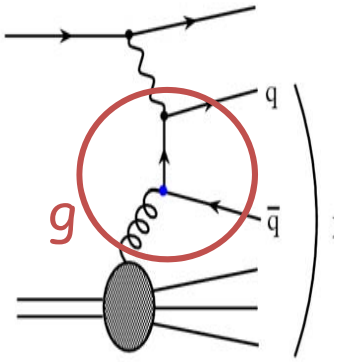
- high-p_T single hadron
  - small Q^2 or unmeasured — PYTHIA

- single charmed meson
  - quasi-real photons — AROMA, RAPGAP

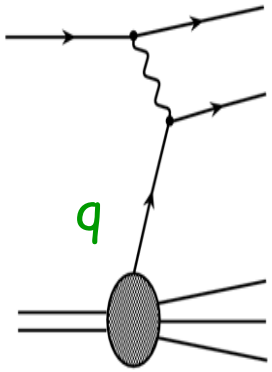
All analyses in LO till now (plus parton showers)

Δg/g from FT hadrons

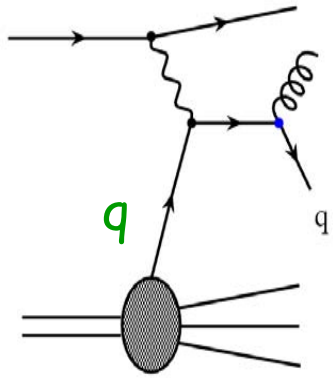
all Q^2



Photon Gluon Fusion ~ 30%



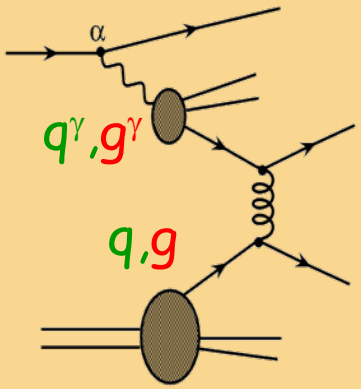
Leading Order



QCD Compton

+

$Q^2 < 1\ GeV^2$



Resolved γ ~50%

$$A_{LL}^{2h} = R_{pgf} a_{LL}^{pgf} \frac{\Delta g}{g}(x_g) + R_{LO} D A_1^{LO}(x_{Bj}) + R_C a_{LL}^{C} A_1^{LO}(x_C)$$

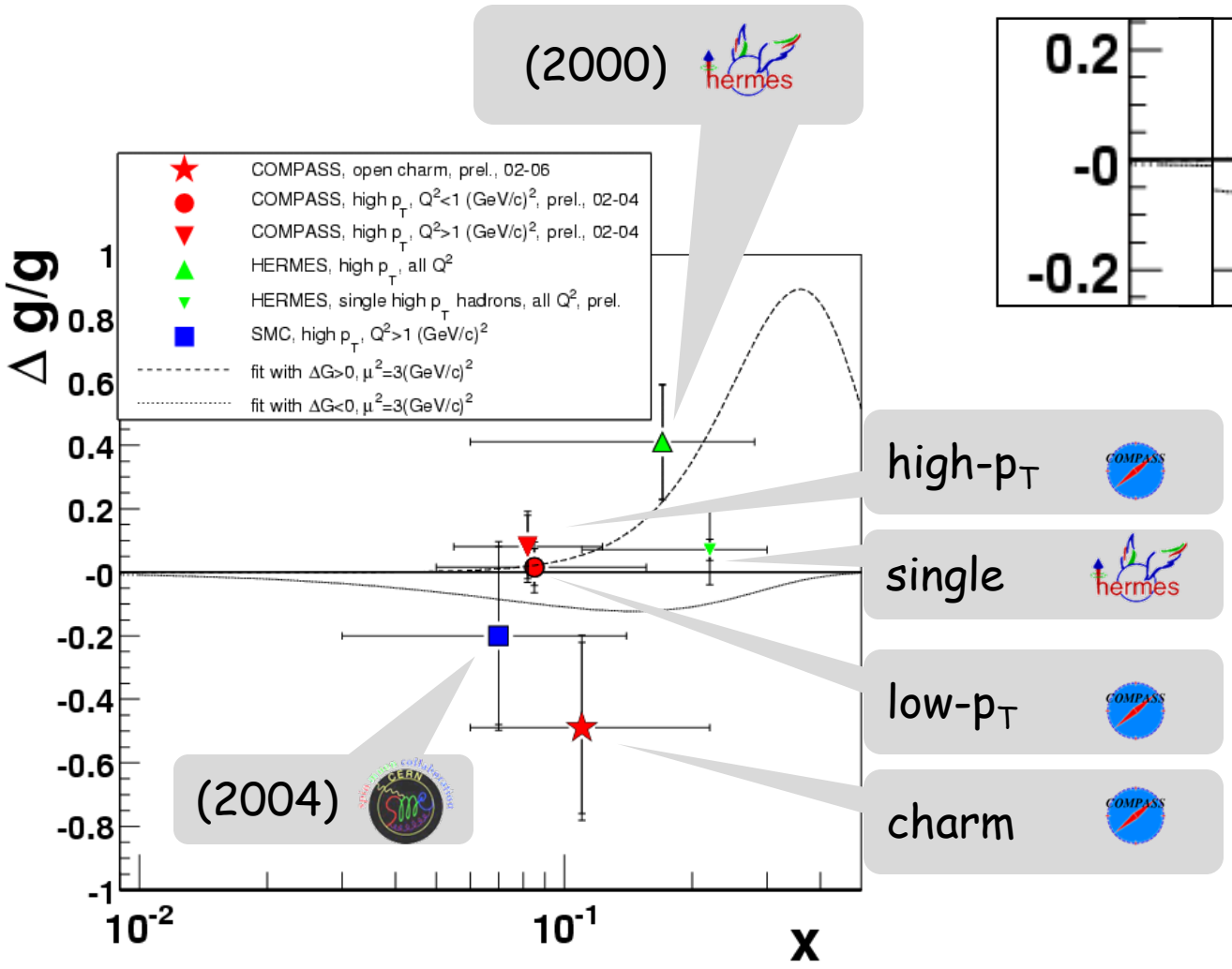
use also inclusive A_{LL}

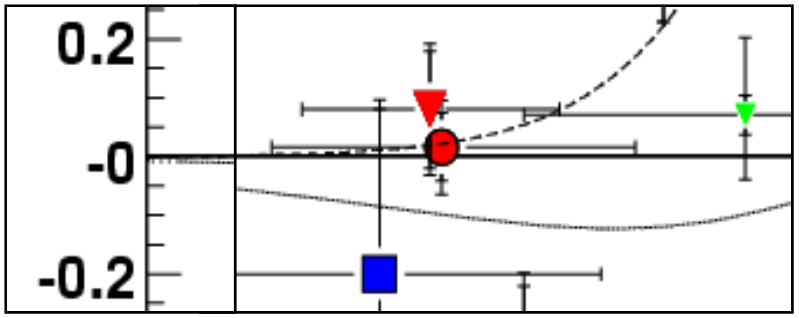
Δg/g from open charm

- cleanest process
  - no or little physics background (LO, QCDC)
- observe asymmetry in D meson production
  - statistics limited
  - only one D meson via $D \rightarrow \pi K$ (BR ~ 4%)
  - combinatorial background large
  - drastically reduced when looking to D* decay in coincidence with slow pion

$$D^* \rightarrow D^0 + \pi_s \rightarrow K + \pi + \pi_s$$

Δg/g from FT hadrons (LO)





data points at different scales ~ 1 - 10 GeV^2

Summary

- All results point to small $\Delta g/g$
- The strange sea is strange
- First global analysis of DIS, SIDIS and pp
- Very precise data for hadron production in FT
  - These data must be included in the gobal analyses
  - However, the full NLO description needs to be worked out first (in progress)

Details during this session and in the plenary talks by D. Hasch and W. Vogelsang on Wednesday morning