Latest HERMES Results on the Helicity Substructure of the Nucleon

Riccardo Fabbri

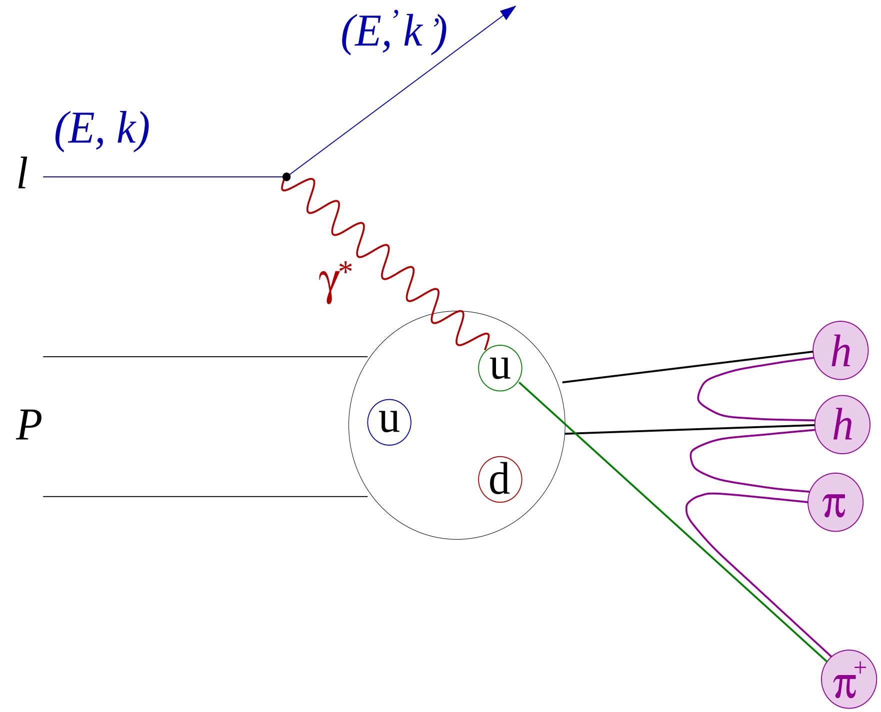
on behalf of the *HERMES* Collaboration

$\mathcal{HADRON}07$ ***Frascati*, 11 October 2007**

- **Spin Structure of the Proton**
- **The HERMES Experiment**
- **Inclusive Spin Structure Function g_1**
- **Gluon Polarization**
- **Summary and Outlook**

Spin Structure of the Proton

- Proton structure investigated via short-wavelength virtual photons emitted by incident high energetic leptons: as in Deep Inelastic Scattering



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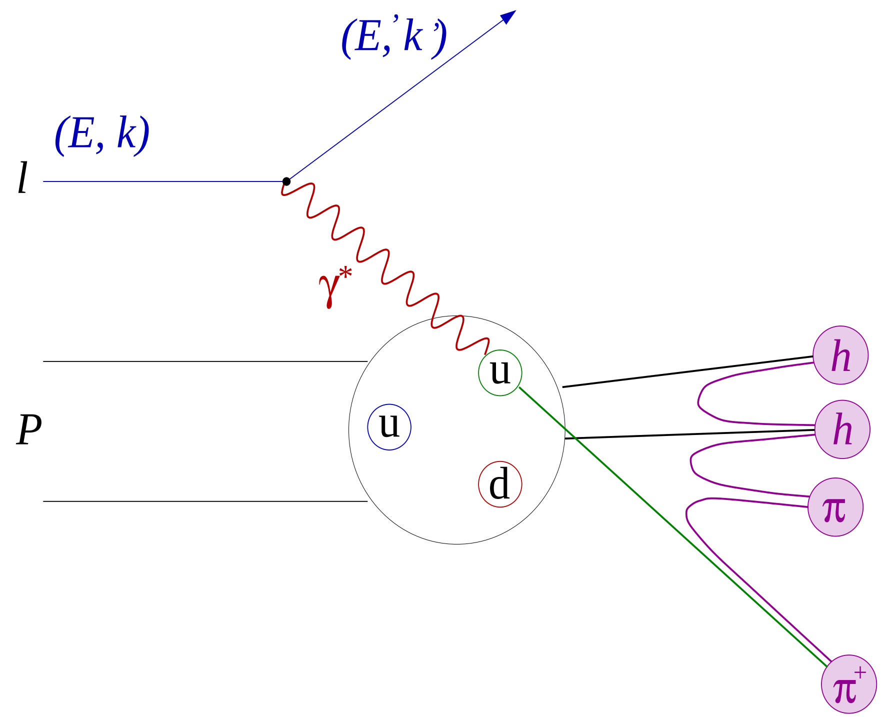

- **Polarized DIS gives access to polarization of proton constituents**

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

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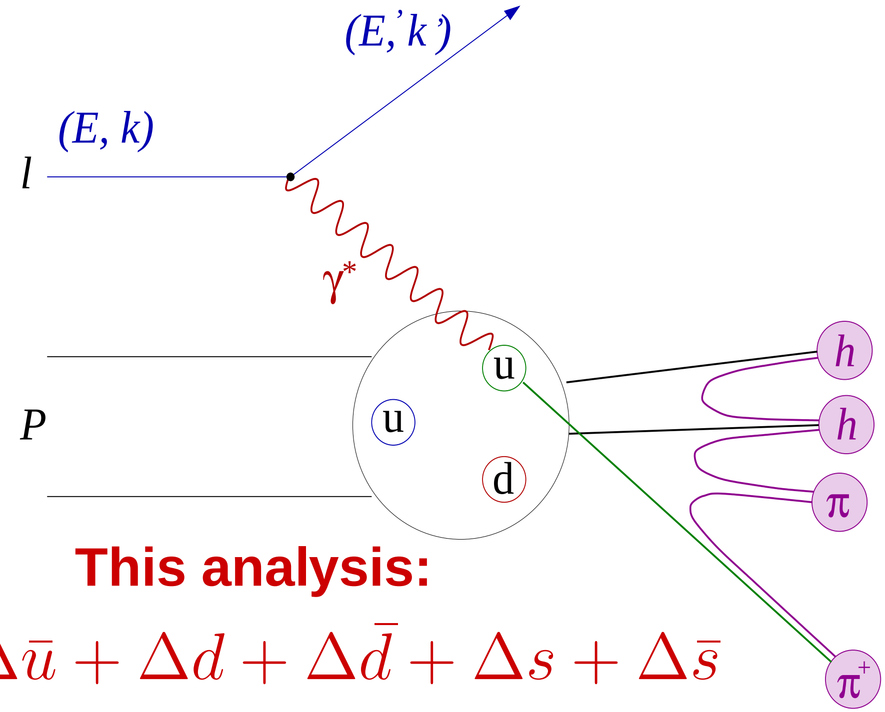

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This analysis:

$\Rightarrow$ **all quarks spin:** $\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$

$\Rightarrow$ **strange-quark spin:** $\Delta S = \Delta s + \Delta\bar{s}$

$\Rightarrow$ **gluon spin:** ΔG

RUN I data: 1996-2000

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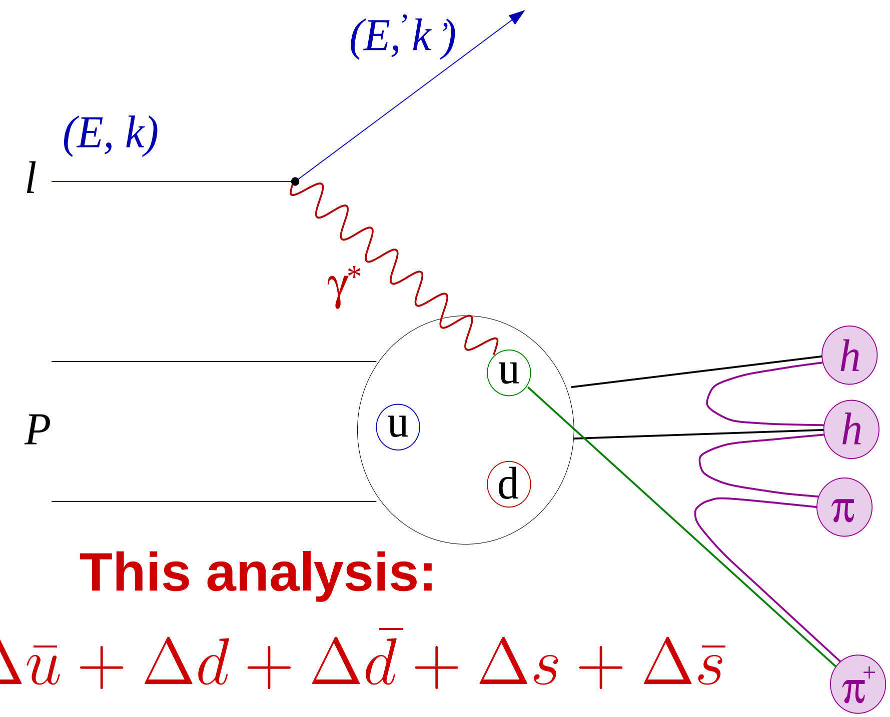

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- Relevant variables used in this analysis:

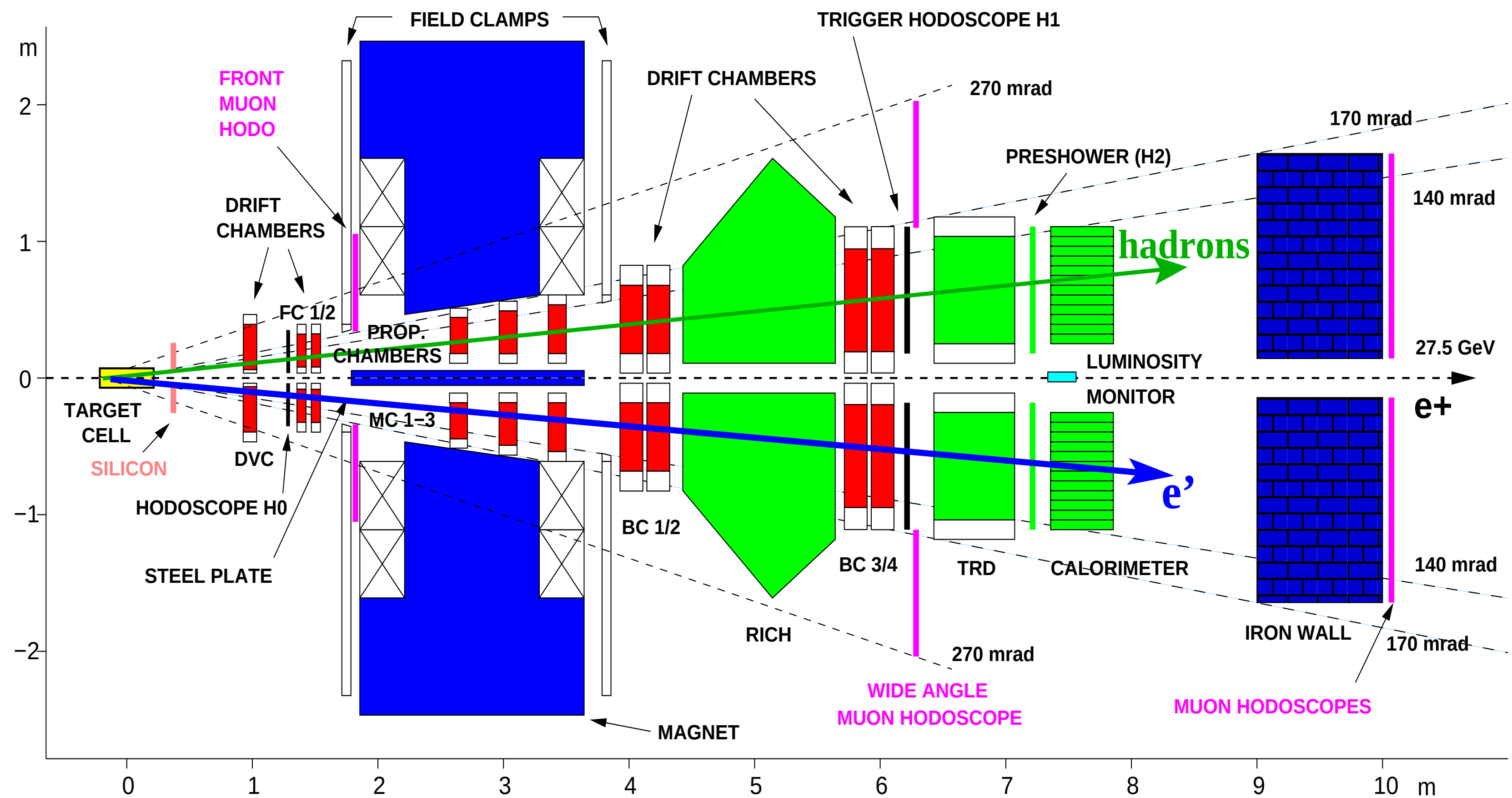
$\longrightarrow Q^2 = -q^2 = -(k - k')^2$ $\qquad \longrightarrow x \stackrel{lab}{=} \frac{Q^2}{2m_P \cdot \nu}$

$\longrightarrow \nu \stackrel{lab}{=} E - E'$ $\qquad \longrightarrow z \stackrel{lab}{=} E_{had}/\nu$

The HERMES Experiment at DESY

$\vec{e}^{+}/\vec{e}^{-}$

27.6 GeV



- **Gas storage target cell: longitudinally polarized H & D with $P_L \approx 80\%$**
- **Forward spectrometer:** $40\ mrad < \theta < 220\ mrad$
- **Tracking chambers:** $\Longrightarrow \delta p/p \approx 2\%$, $\delta\theta \leq 1\ mrad$
- **PIDs:** e/h **separation efficiency** $> 98\%$, $\pi^{\pm}/K^{\pm}/p$ **ID:** $2 < p < 15$ **GeV**

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  $\Rightarrow$ **polarized counterpart of unpolarized F_1:**

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- **How to access g_1?**

  $\Rightarrow$ **consider asymmetry $A_\parallel$ for inclusive process $\vec{e}^{\,\pm} N^{\Rightarrow} \rightarrow e^{\pm} X$ (both beam and target longitudinally polarized):**

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Kinematic factors

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world data parameterizations

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- **g_1 can be measured through measured inclusive $A_\parallel$ asymmetry!**

$g_1^{p,d}$ HERMES Results and World Data

$\vec{e}^{\,\pm} p^{\Rightarrow} \to e^{\pm} X \qquad \vec{e}^{\,\pm} d^{\Rightarrow} \to e^{\pm} X$

$\underline{\mathcal{FINAL\ RESULTS}}$

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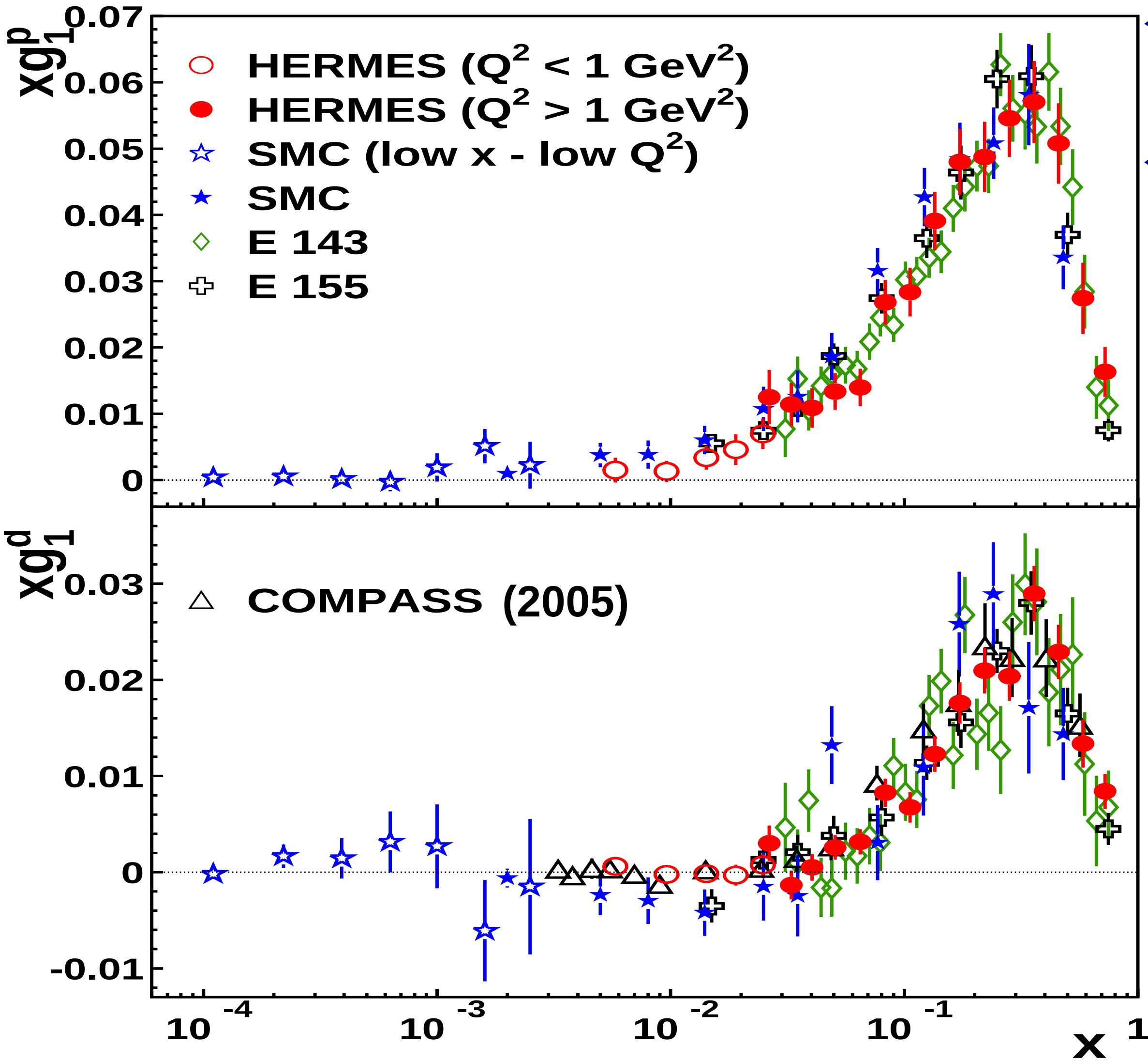

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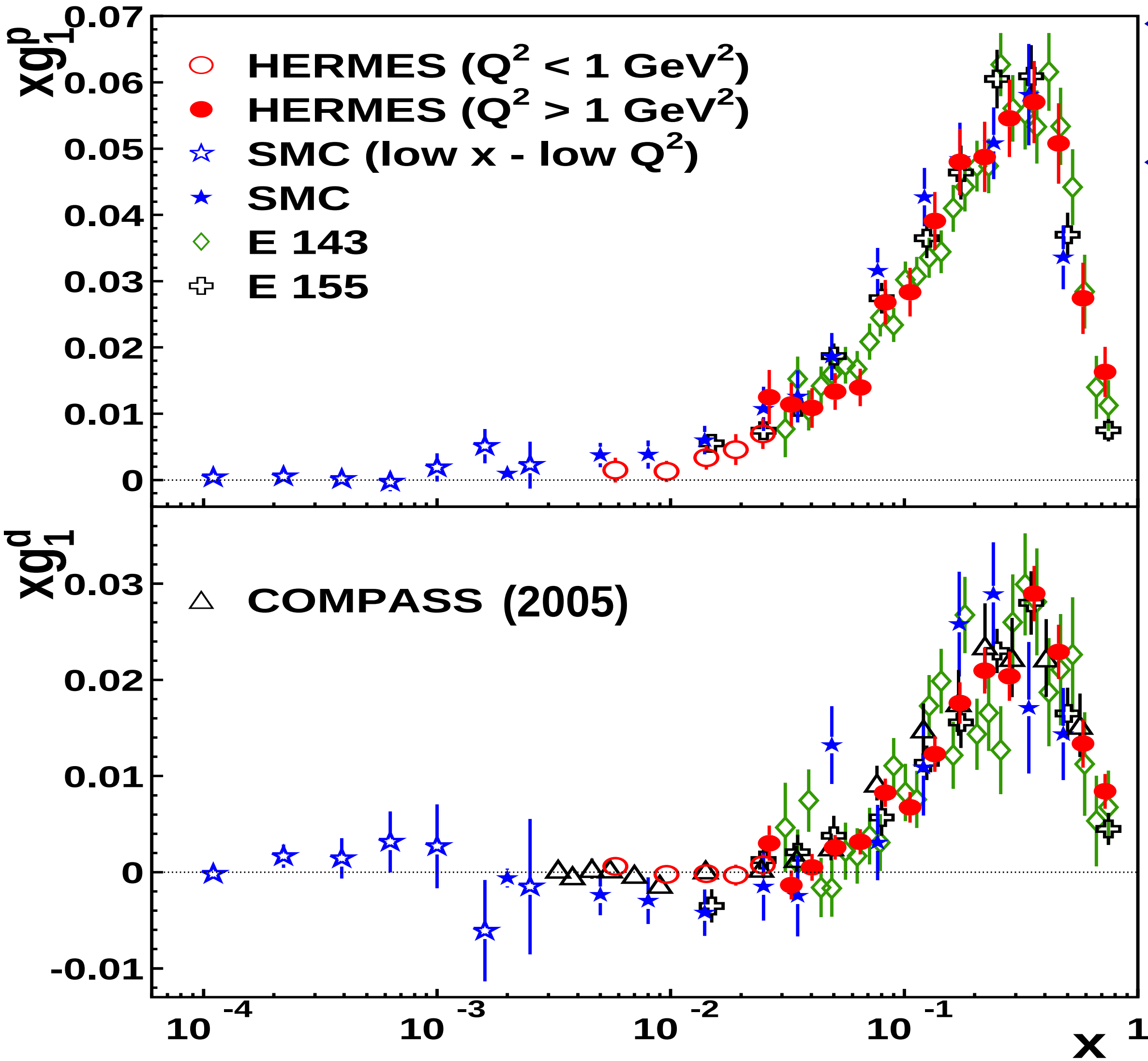

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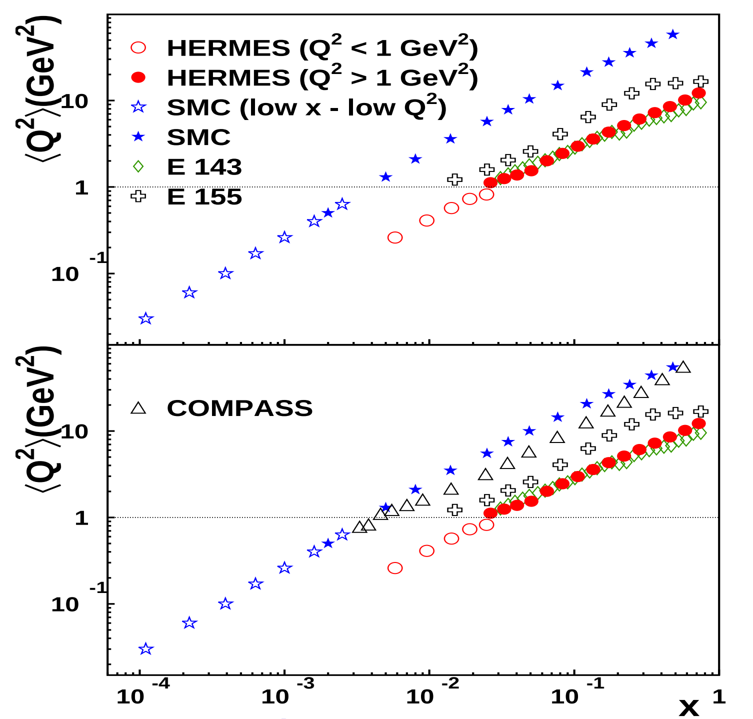
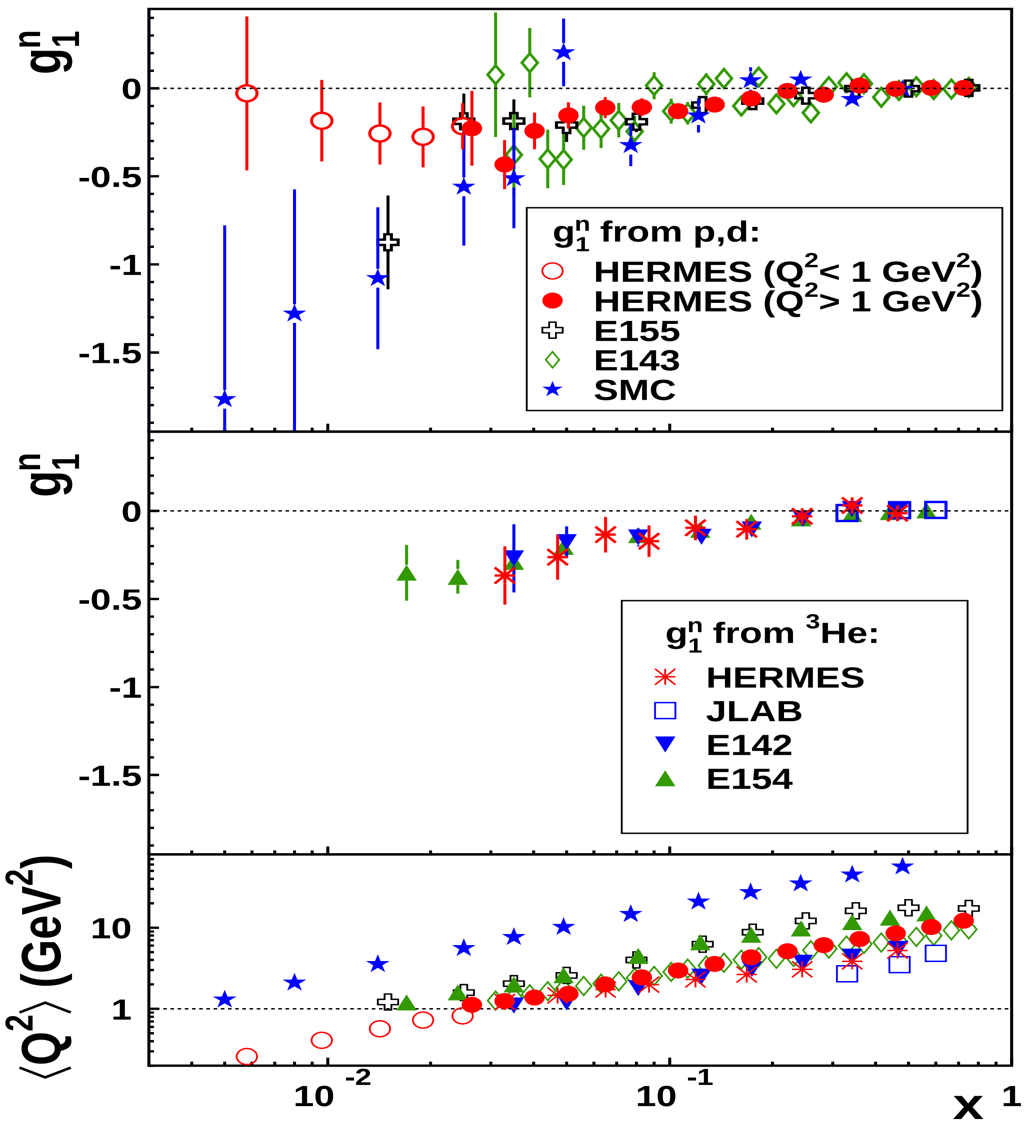


Extraction of g_1 for Neutron

- Using extracted g_1 from proton and deuterium targets:

$$g_1^d = \frac{1}{2}(1 - \frac{3}{2}\omega_D)(g_1^p + g_1^n)$$



$\Rightarrow$ D-state correction:

$$\omega_D = 0.05 \pm 0.01$$

Most precise extraction of g_1^n

(in intermediate x-range)

Quark Helicity Extraction

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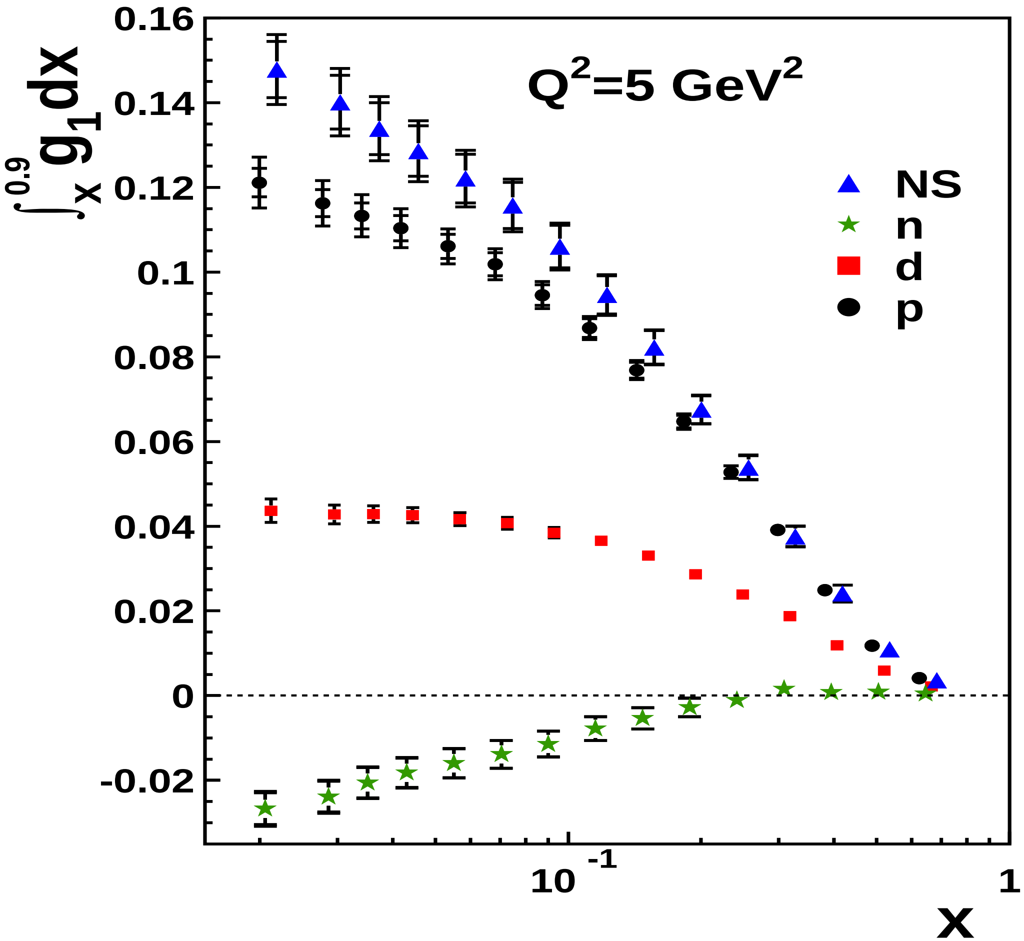

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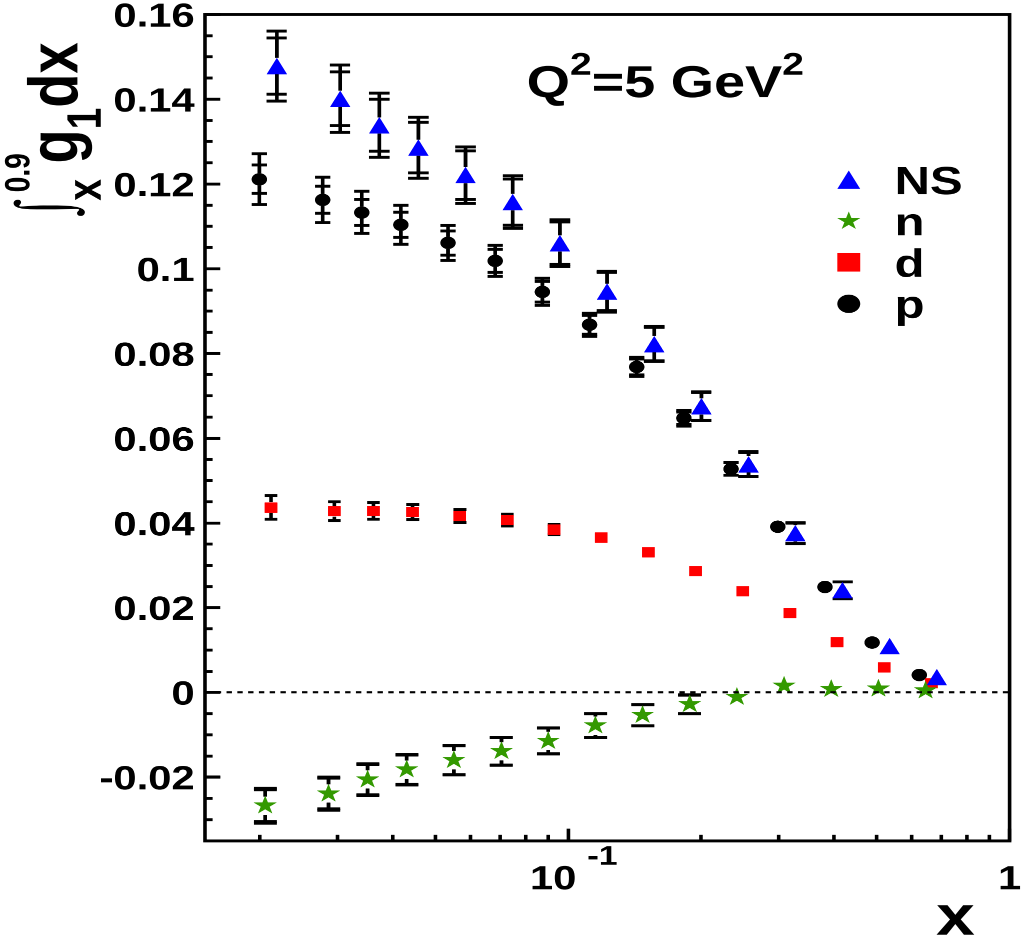

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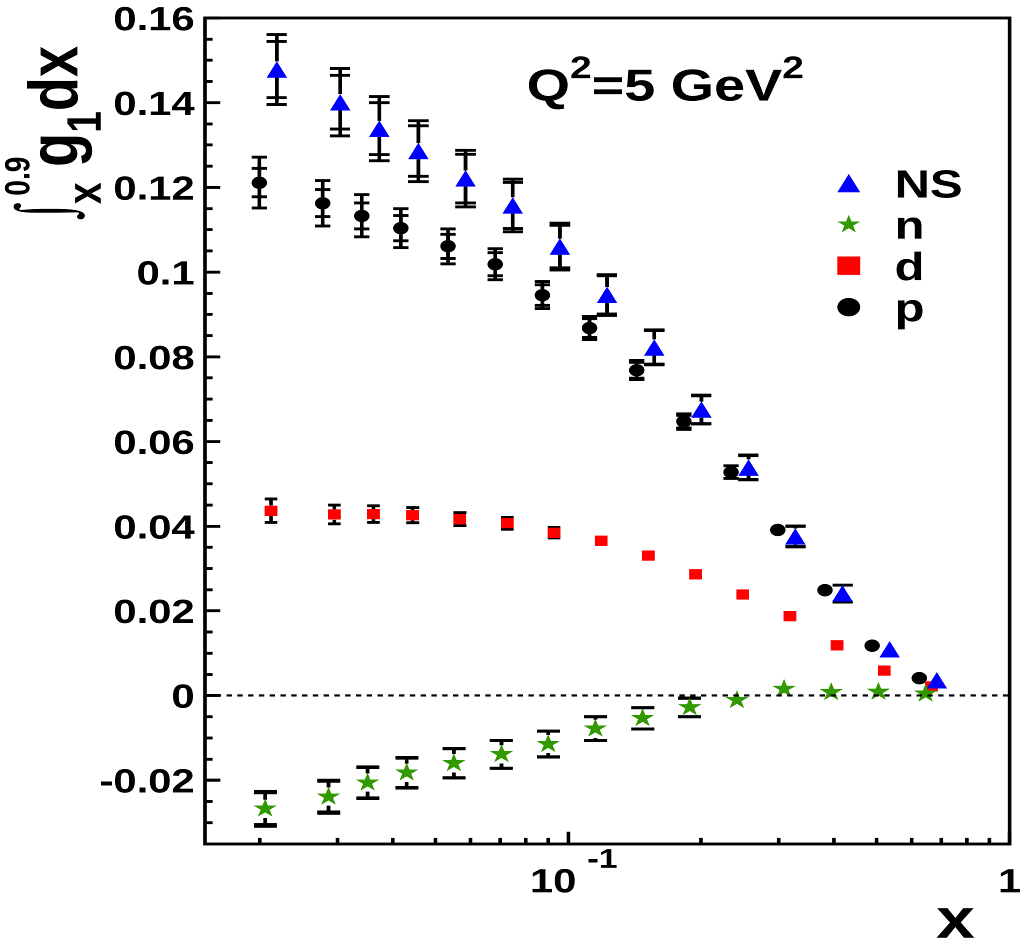

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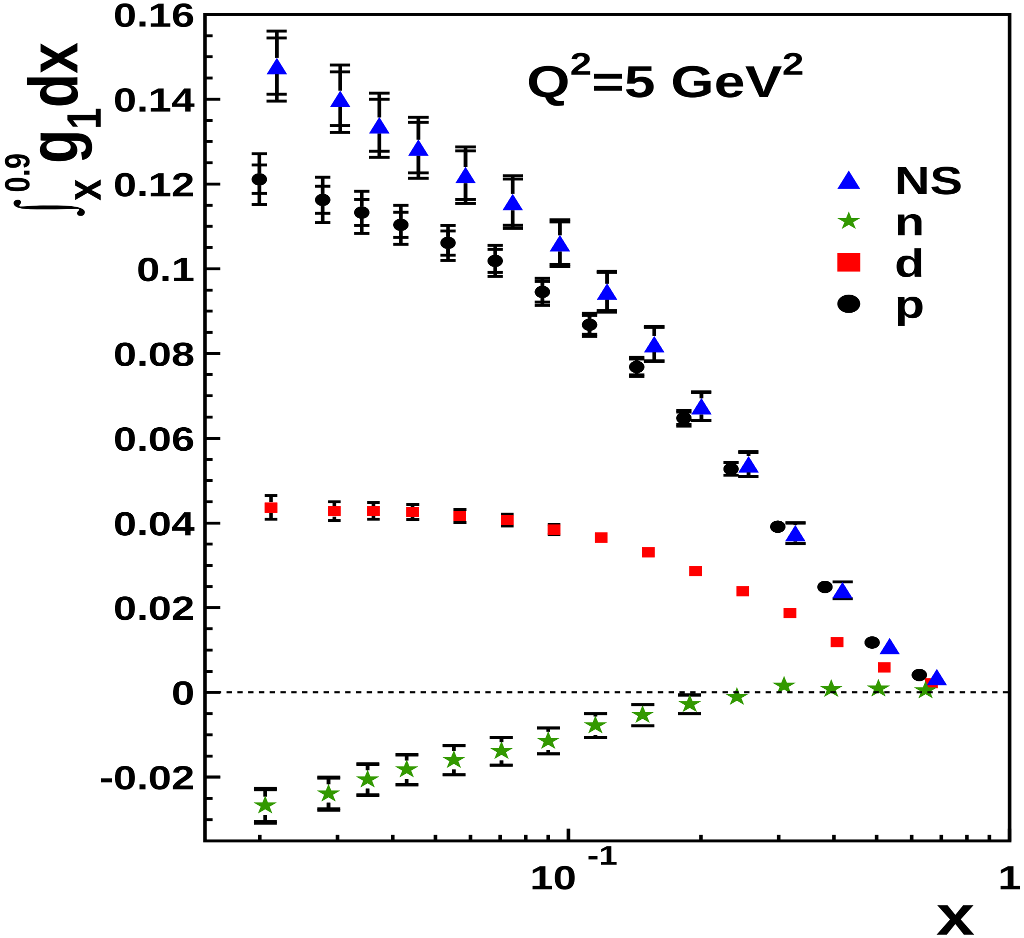

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✗ **Precise measurement of** $\Delta\Sigma$**:**

$\Delta\Sigma = 0.330 \pm 0.025(exp) \pm 0.011(theo.) \pm 0.028(evol.)$

at NNLO ($\mathcal{O}(\alpha_S^2)$**)**

Extraction of the Strange-Quark Helicity

- **Using g_1 data + observed Γ_1^d saturation:**

$$\Rightarrow \Delta s + \Delta\bar{s} = 1/3 \cdot (a_8 - a_0)$$

$$\Rightarrow \boxed{\Delta s + \Delta\bar{s} = -0.085 \pm 0.008 \pm 0.0013 \pm 0.009} \qquad [Q^2 = 5.0 \text{ GeV}^2]$$

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- **Using semi-inclusive $A_1^{\pi^\pm,\, K^\pm}$ asymmetry data + 'Purity' method**
  $\Rightarrow$ **HERMES 5-flavour extraction of quark polarization [PRD71 012003 (2005)]**
  $\Rightarrow \Delta u/u$, $\Delta d/d$, $\Delta \bar{u}/\bar{u}$, $\Delta \bar{d}/\bar{d}$, $\Delta s/s$; **only assumption:** $\Delta \bar{s}/\bar{s} = 0$
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  - $\Rightarrow$ **extract isoscalar $\Delta s + \Delta \bar{s}$ using an isoscalar target: deuterium**
  - $\Rightarrow$ **no dependence on MC; using only CTEQ6 LO unpolarized PDFs**
  - $\Rightarrow \boxed{\Delta s + \Delta \bar{s} = 0.006 \pm 0.029 \pm 0.007}$ $[0.02 < x < 0.60,\ Q^2 = 2.5$ GeV$^2]$

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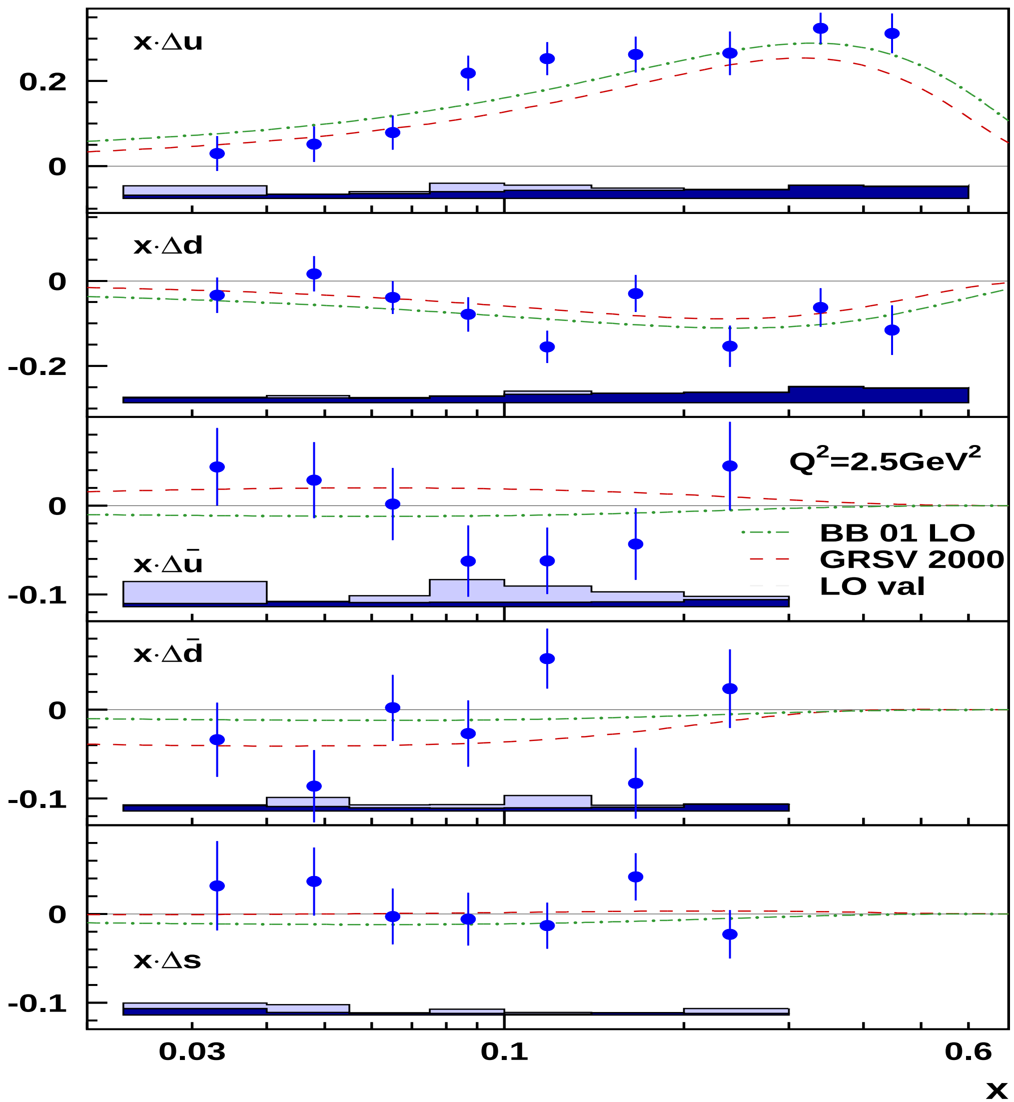
- **How to reconcile strange quark results between g_1 analysis and semi-inclusive analyses? $\Rightarrow$ substantial negative polarization at small x?**

ΔS from Different HERMES Analyses

From 'Purity' analysis:



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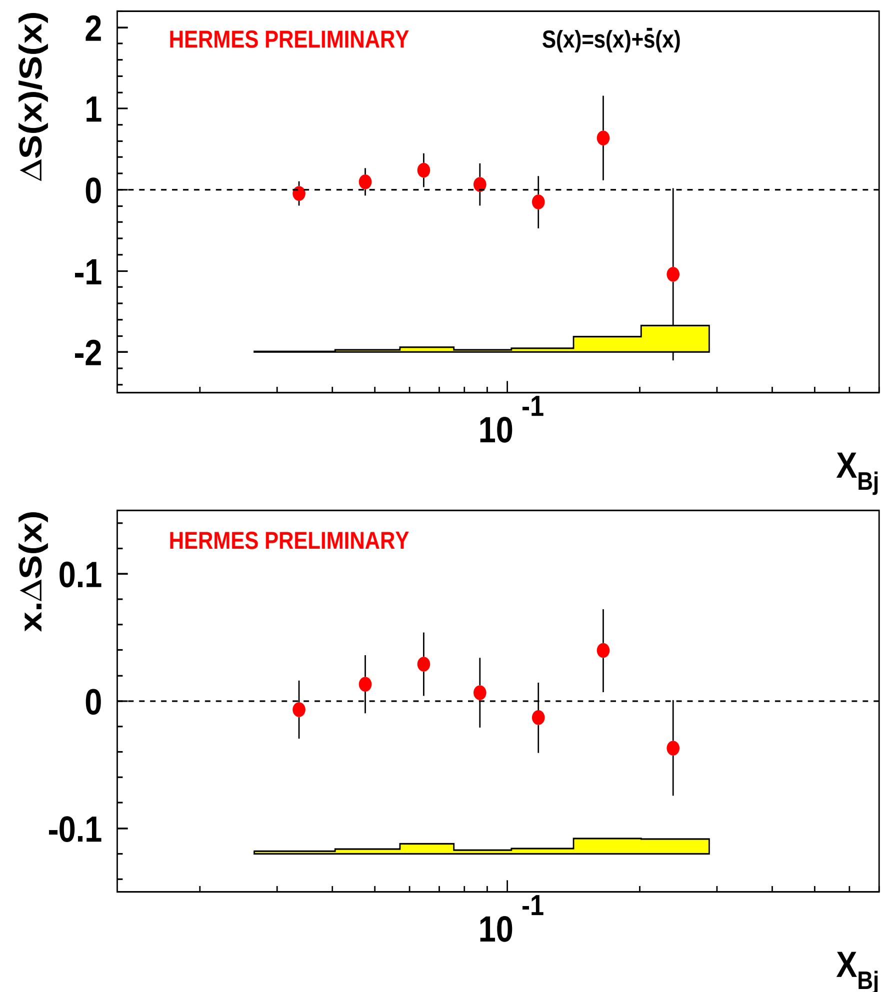

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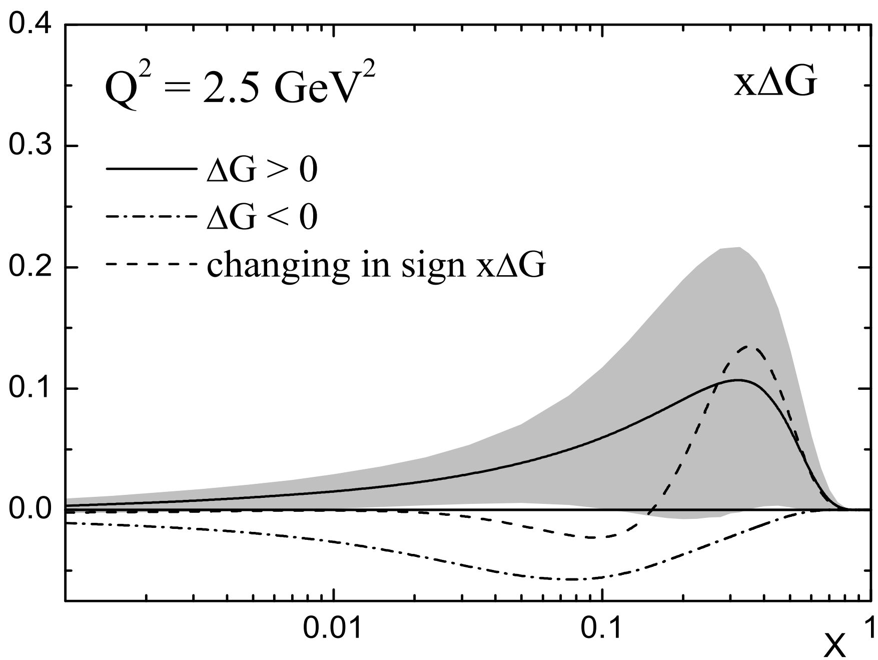

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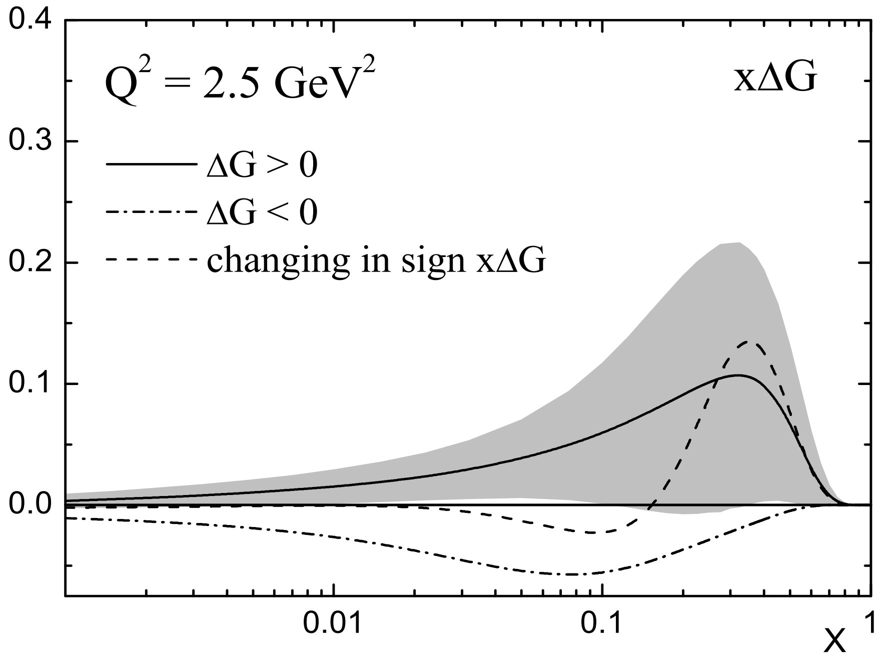
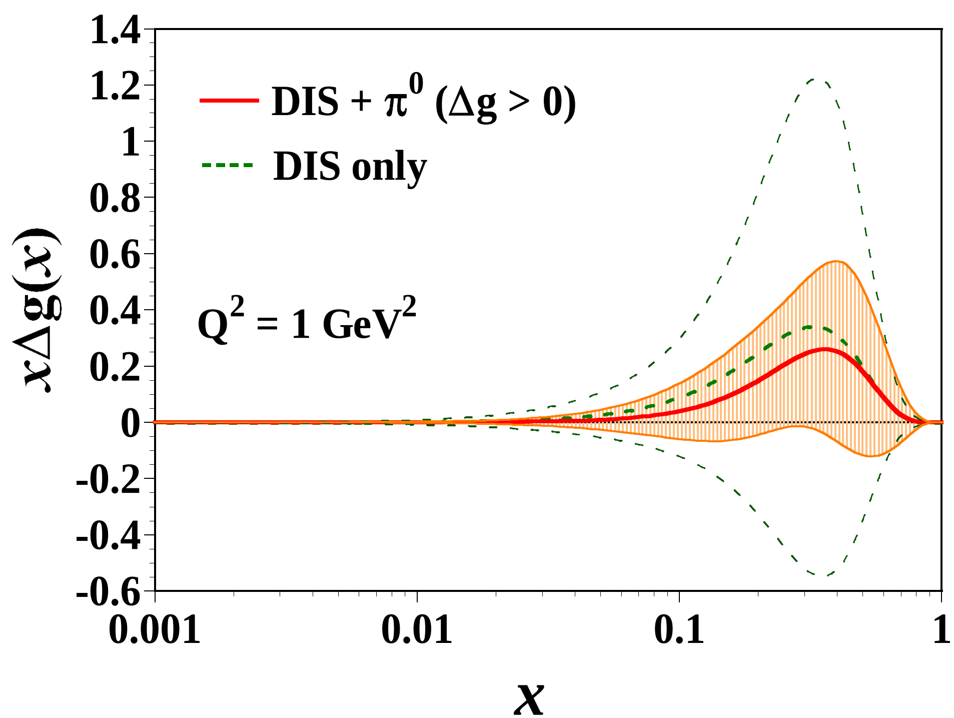
— including π^0 asymmetry data: e.g. AAC Coll., 2006

[Note: w/o CLAS + new COMPASS data]





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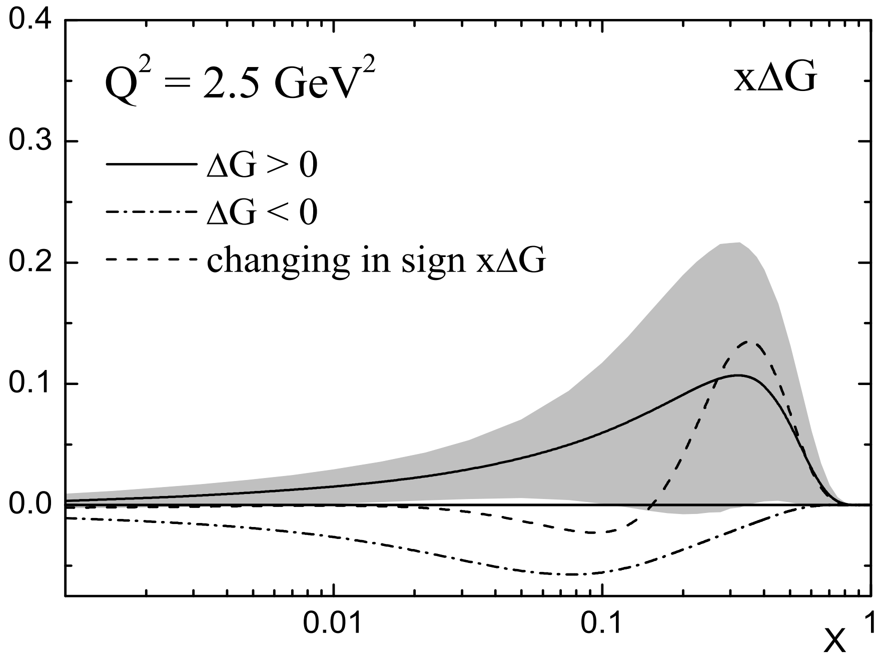
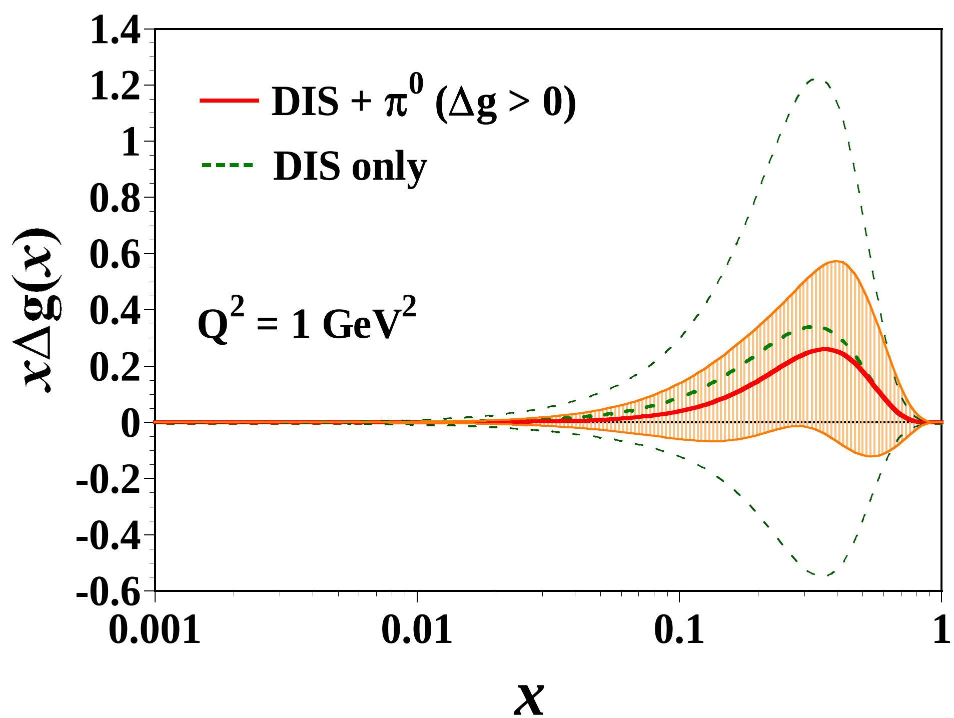


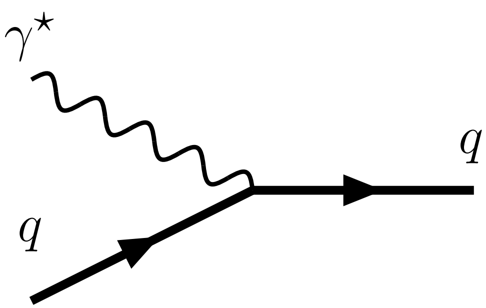


- **Or ....**

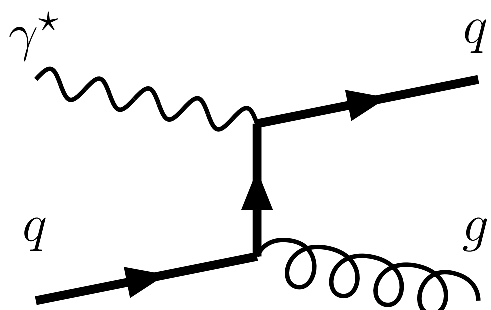
Gluon Polarization

❖ **Alternatively: access spin observables with direct gluon contribution as in charged hadron prod. in polarized lepton scattering (at NLO)**

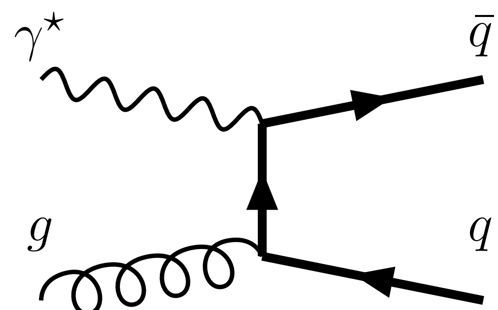
Examples of subprocesses involved:



$\mathcal{O}(\alpha_S^0)$ **LO DIS**



$\mathcal{O}(\alpha_S^1)$ **QCD Compton**



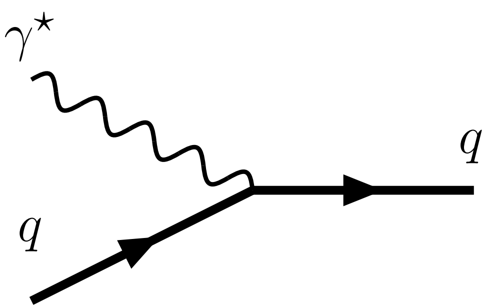
$\mathcal{O}(\alpha_S^1)$ **PGF**

... + channels involving $\gamma^\star$ hadronic wave function

Gluon Polarization

- **Alternatively: access spin observables with direct gluon contribution as in charged hadron prod. in polarized lepton scattering (at NLO)**

Examples of subprocesses involved:



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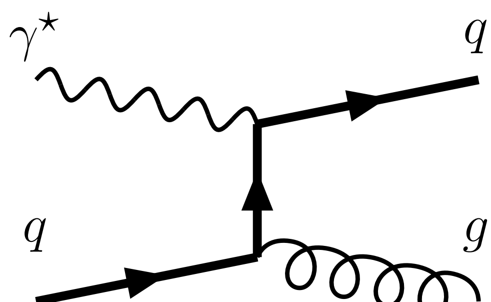

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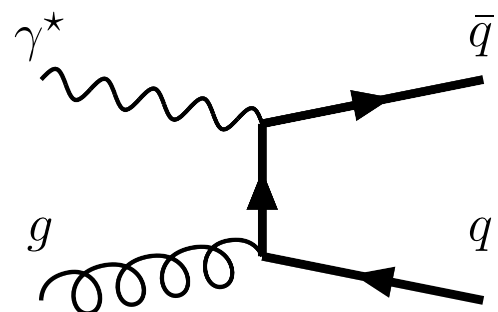

$\mathcal{O}(\alpha_S^1)$ **PGF**

... + channels involving $\gamma^\star$ hadronic wave function

- **Choose proper process to enhance gluon contribution**
  - **detection of high-p_T hadrons $\Rightarrow$ this analysis**

Enhancing gluon contribution

- Consider the process with veto on scattered lepton in acceptance:

$$\vec{e} + \vec{p} \longrightarrow h^{\pm} X \qquad \vec{e} + \vec{d} \longrightarrow h^{\pm} X$$

$\Rightarrow$ **most of our data**

$\Rightarrow$ p_T **defined with respect to beam direction**

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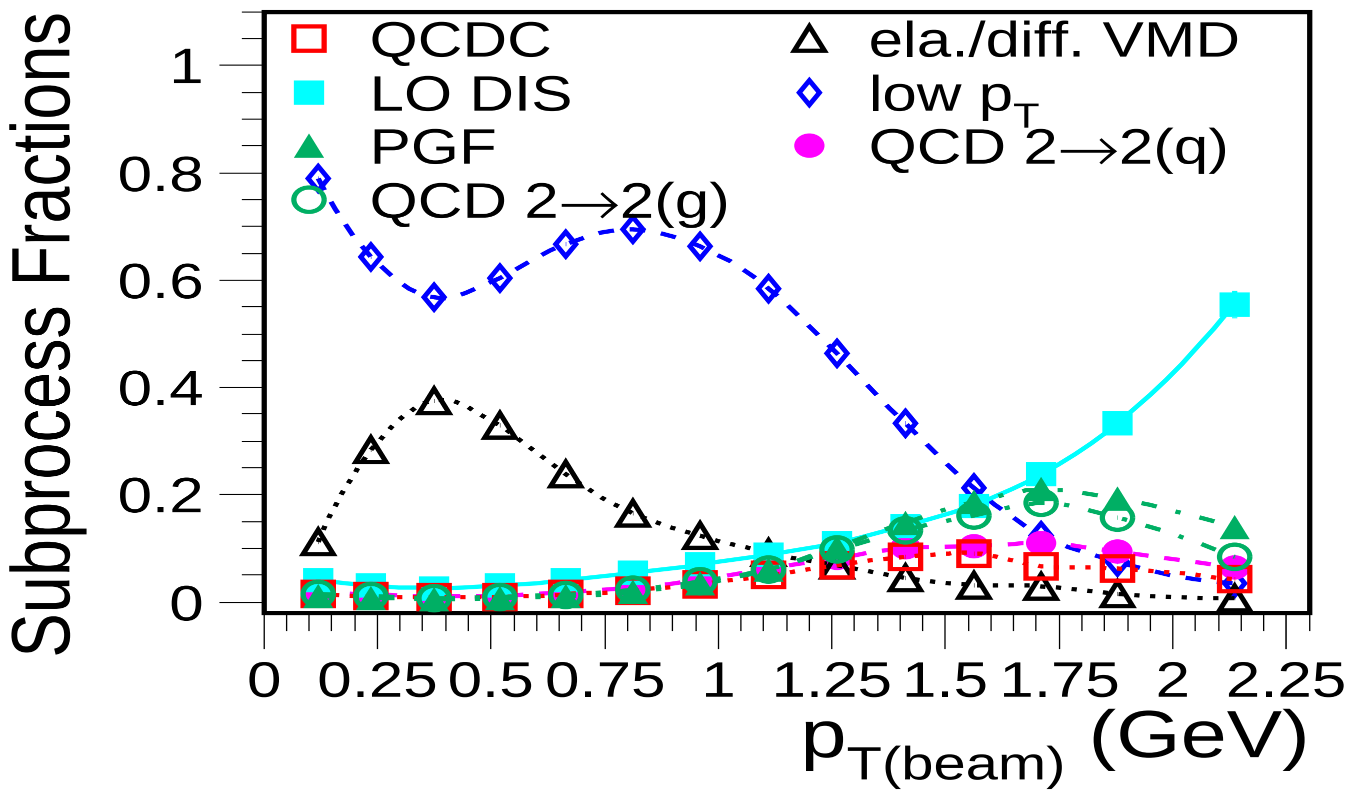
- **Using tuned PYTHIA 6.2 simulation:**



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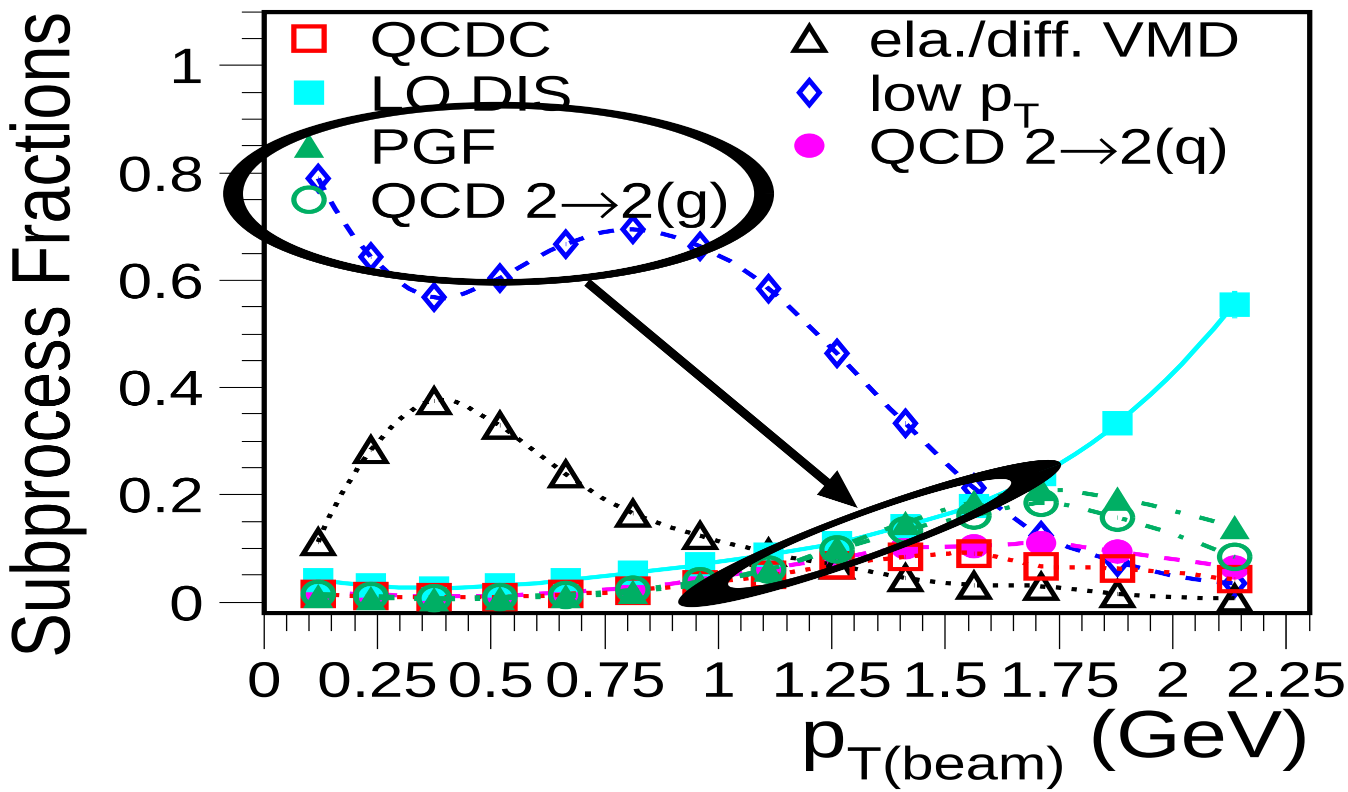

- **Gluon tagging contributions enhanced at high p_T values**

Measured Observable

- **Consider the experimental asymmetry** $A_{\parallel} = \frac{N_h^{\overrightarrow{\Leftarrow}} L^{\overrightarrow{\Rightarrow}} - N_h^{\overrightarrow{\Rightarrow}} L^{\overrightarrow{\Leftarrow}}}{N_h^{\overrightarrow{\Leftarrow}} L_P^{\overrightarrow{\Rightarrow}} + N_h^{\overrightarrow{\Rightarrow}} L_P^{\overrightarrow{\Leftarrow}}}$

  $\Rightarrow N_h^{\overrightarrow{\Leftarrow}} (N_h^{\overrightarrow{\Rightarrow}})$: **Nr. hadrons with beam/target helicity (anti)aligned**

  $\Rightarrow L^{\overrightarrow{\Leftarrow}} (L^{\overrightarrow{\Rightarrow}})$: **Luminosity with beam/target helicity (anti)aligned**

  $\Rightarrow L_P$: **Luminosity weighted with beam & target polarization**

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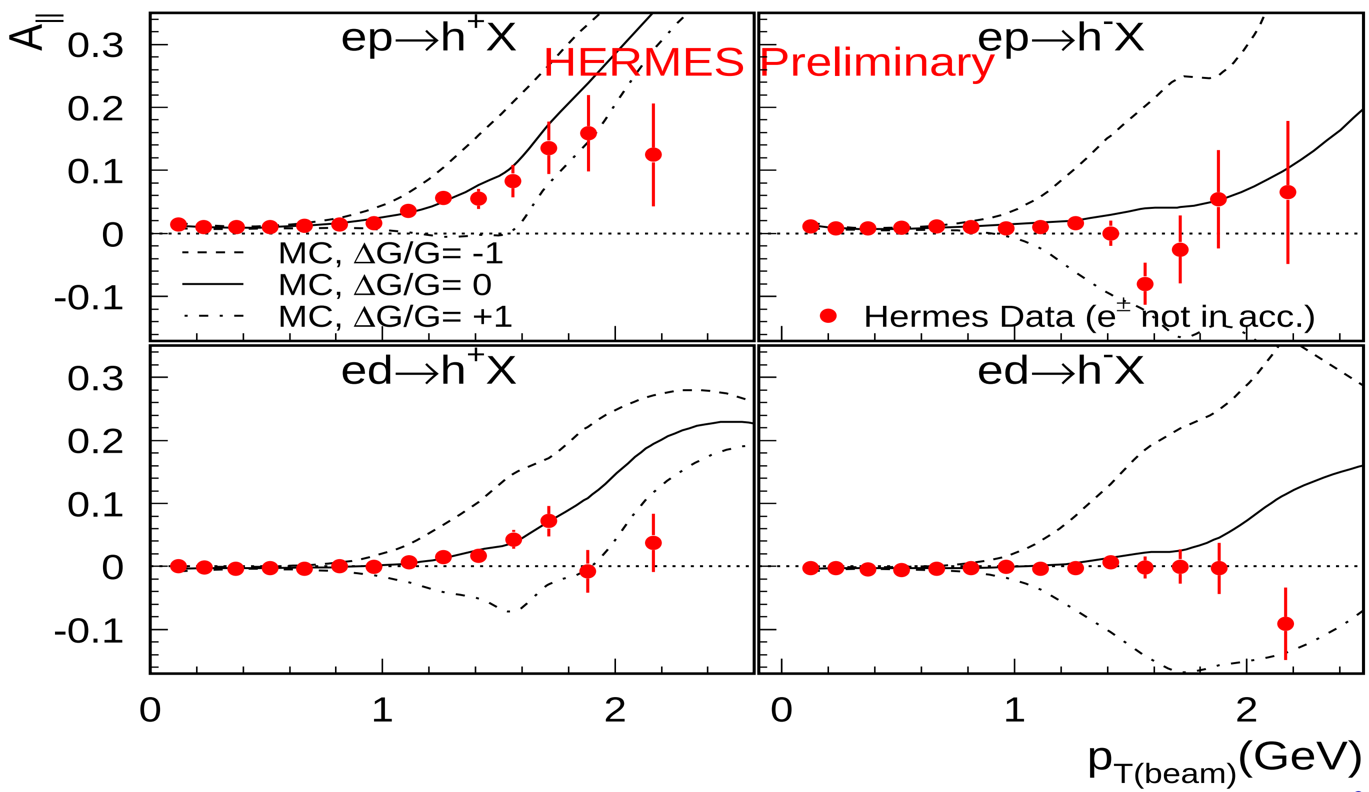

- **Systematics dominated by beam/target pol.uncertainty:** 3.9%

Extraction of the Gluon Polarization

- **Extracted asymmetry expressed in terms of asymmetry by contributing i subprocesses (DIS, PGF, QCDC, soft & hard VM)**

$$A_{\|}(p_T) = \sum_{i \in Bg} R_i(p_T) \cdot \langle A_{\|}^i \rangle (p_T) + \sum_{i \in Sg} R_i(p_T) \cdot \langle A_{\|}^i \rangle (p_T)$$

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PYTHIA events (→ $\frac{1}{N^i}$)

qq, qg, **... xsec asym.** (→ $a_{\|,k}^i$)
$\Rightarrow$ **calculable**

γ **pol/unpol PDF** (→ $\frac{\Delta f_k^\gamma}{f_k^\gamma}$)

nucleon pol/unpol PDF (→ $\frac{\Delta f_k^N}{f_k^N}$)

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II: <u>Fit Method</u> (functional form for $\frac{\Delta g(x)}{g(x)}$ plugged into $A_{\parallel}^{Sg}$ and then fit to $A_{\parallel}^{meas.}$)

$\downarrow$ **for syst.studies** $\downarrow$

$$\frac{\Delta g(x)}{g(x)} = x(1 + p_1(1-x)^2) \quad \textbf{and} \quad x(1 + p_1(1-x)^2) + p_2(1-x)^3$$

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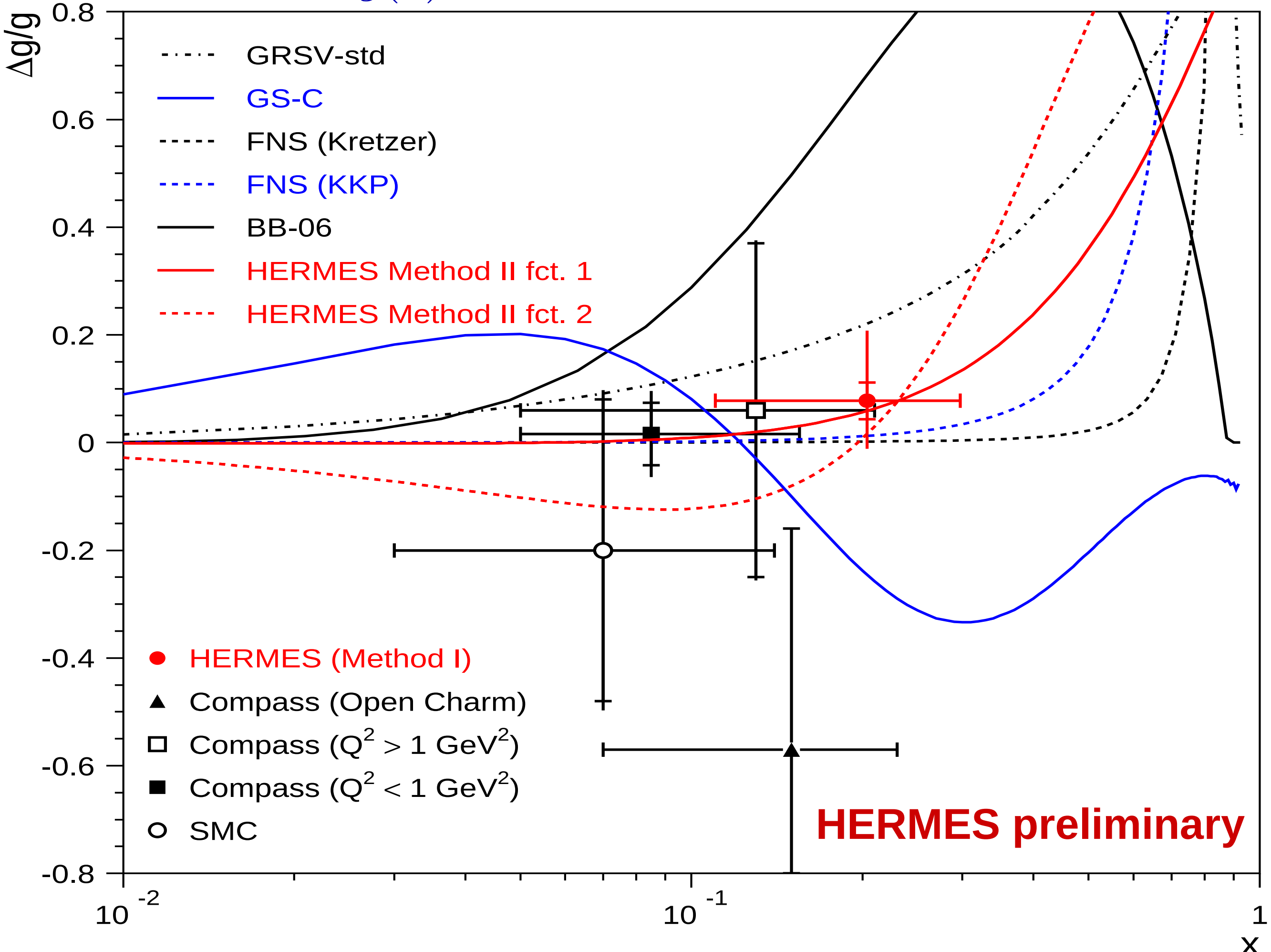

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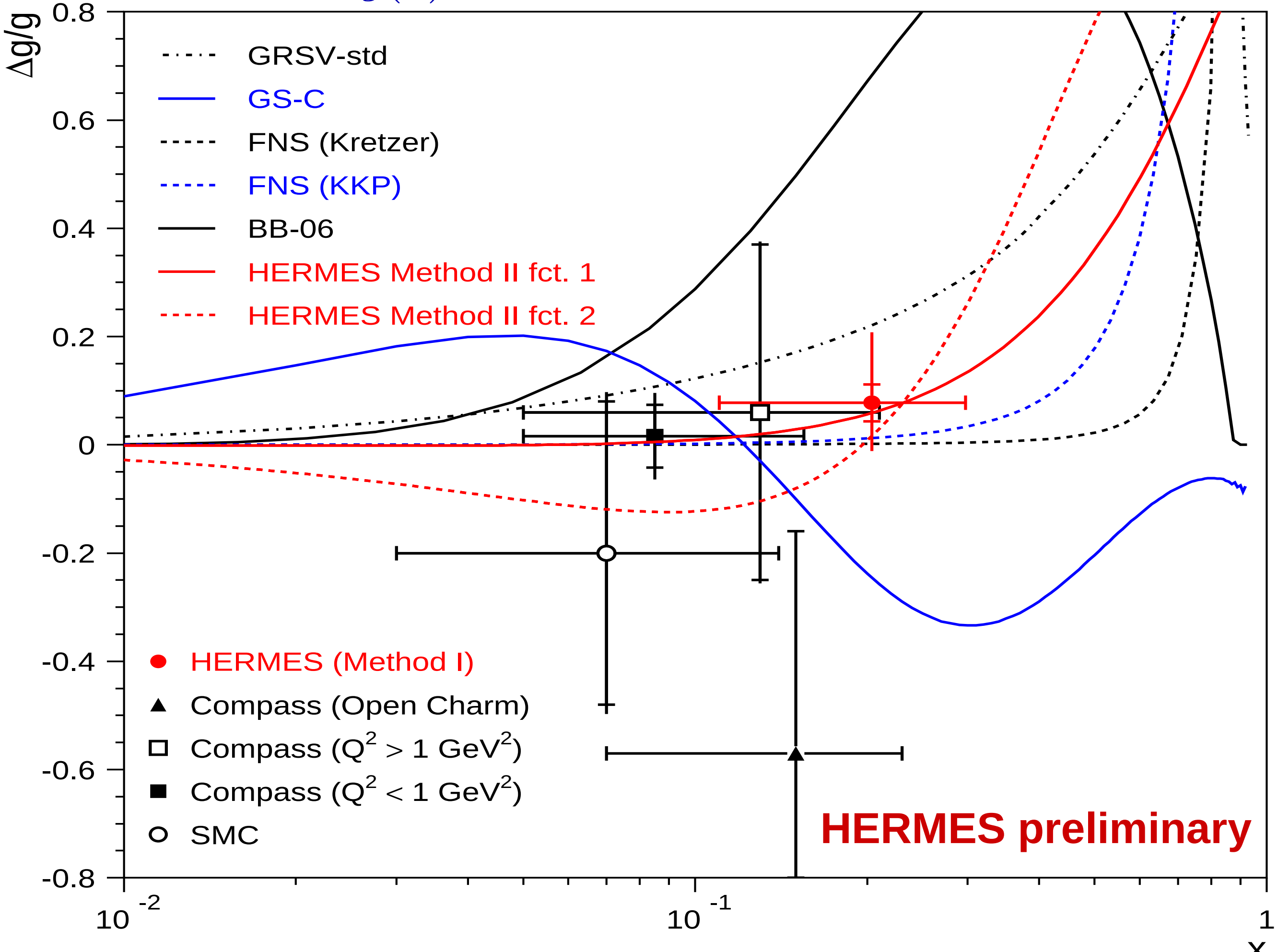

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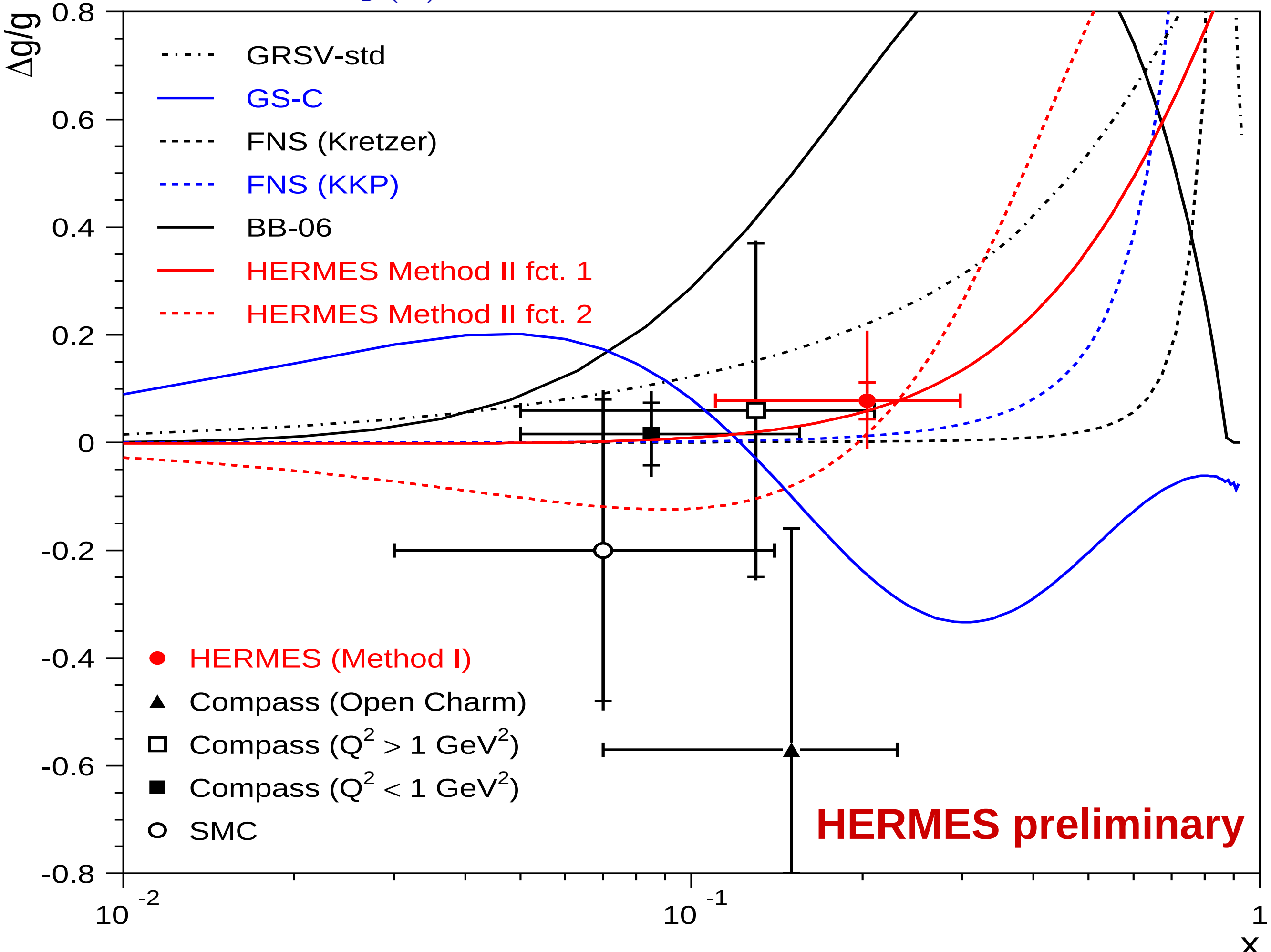

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- ✗ **diff. γ & N pdf param.**
- ✗ **PYTHIA par. change**
- ✗ **scale factor varied by factors 1/2 and 2**

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$\Longrightarrow$ **proton data precision comparable with CERN and SLAC**

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- **Finalization of the** ΔS **&** ΔG **analyses for publication is on-going**

BackUp Slides

The Purity Method

- Measure cross-section asymmetry A_1 for different identified hadrons

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(Q^2,z)}{\sum_q e_q^2 q(x,Q^2) D_q^h(Q^2,z)}$$

$$= \sum_q \mathcal{P}_q^h(x,Q^2,z) \frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

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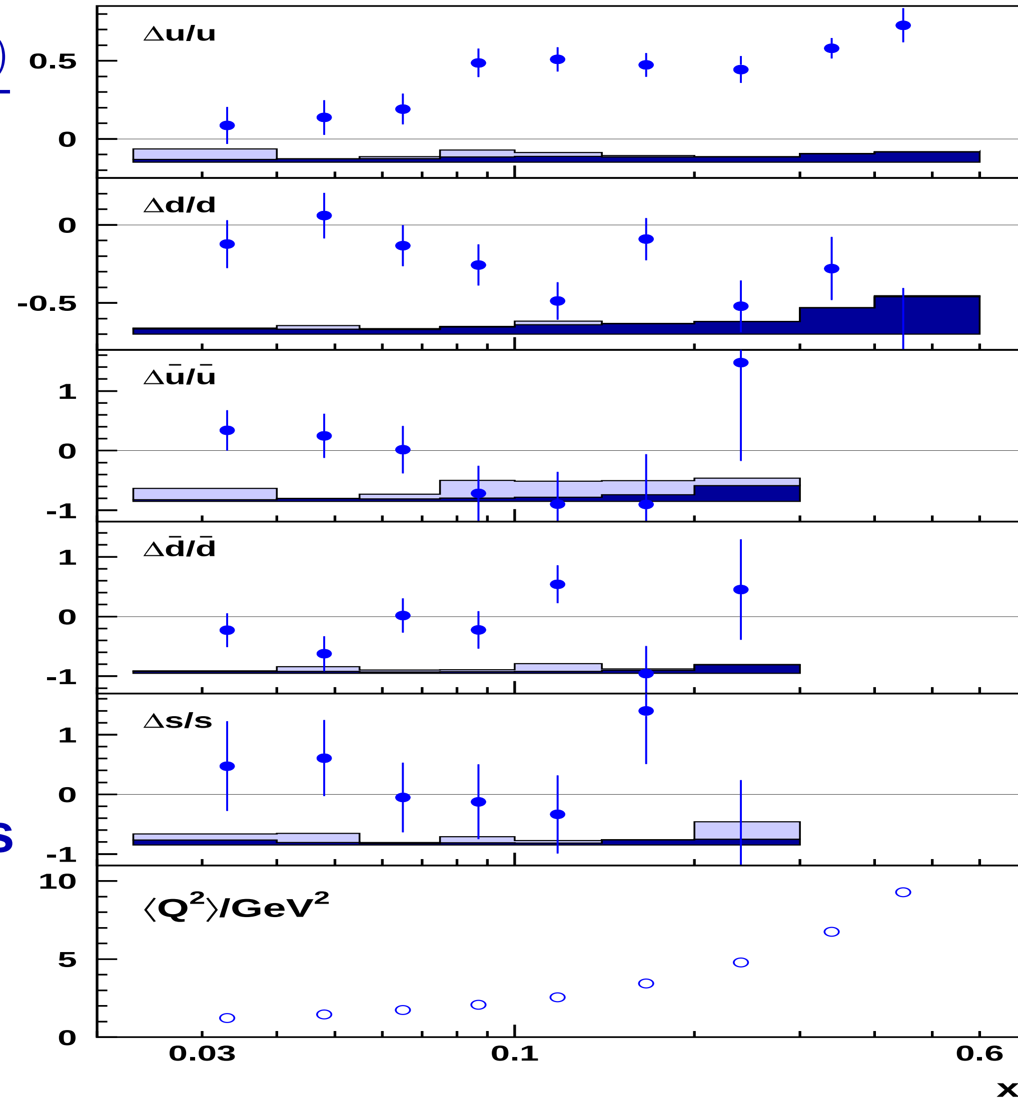


- Extract purities in the frame of LUND fragmentation model

Tune to π, K HERMES multiplicities

- Extract quarks polarization

Isoscalar Method Formalism: I

$$\vec{e}^{\pm} d^{\Rightarrow} \to e^{\pm} X \qquad \vec{e}^{\pm} d^{\Rightarrow} \to e^{\pm} K^{\pm} X$$

- **Measure inclusive asymmetry A_1 and kaons asymmetry $A_1^{K^{\pm}}$**

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \qquad A_1^K = \frac{\sigma^K_{1/2} - \sigma^K_{3/2}}{\sigma^K_{1/2} + \sigma^K_{3/2}}$$

- **After some algebra, asymmetries expressed in terms of PDFs and fragmentation functions**

$$A_1(x,z) = \frac{5\Delta Q(x) + 2\Delta S(x)}{5Q(x) + 2S(s)} \qquad A_1^K(x,z) = \frac{\Delta Q(x)\mathcal{D}^K_Q(z) + 2\Delta S(x)\mathcal{D}^K_S(z)}{Q(x)\mathcal{D}^K_Q(z) + 2S(x)\mathcal{D}^K_S(z)}$$

$\Rightarrow \mathcal{D}^K_Q = 4 \cdot (\mathcal{D}^{K^+}_u + \mathcal{D}^{K^-}_u) + (\mathcal{D}^{K^+}_d + \mathcal{D}^{K^-}_d) \qquad \mathcal{D}^K_S = (\mathcal{D}^{K^+}_s + \mathcal{D}^{K^-}_s)$

$\Rightarrow \mathcal{D}^{K^{\pm}}_q$ **= probability that struck quark q fragments into detected $K^{\pm}$**

$\Rightarrow$ **Charge conjug. invariance assumed:** $(\mathcal{D}^{K^+}_q + \mathcal{D}^{K^-}_q) = (\mathcal{D}^{K^+}_{\bar{q}} + \mathcal{D}^{K^-}_{\bar{q}})$

$\Rightarrow \Delta Q(x) \equiv \Delta u + \Delta d + \Delta \bar{u} + \Delta \bar{d} \qquad \Delta S(x) \equiv \Delta s + \Delta \bar{s}$

Isoscalar Method Formalism: II

$$A_1(x,z) = \frac{5\Delta Q(x)+2\Delta S(x)}{5Q(x)+2S(s)} \qquad A_1^K(x,z) = \frac{\Delta Q(x)\mathcal{D}_Q^K(z)+2\Delta S(x)\mathcal{D}_S^K(z)}{Q(x)\mathcal{D}_Q^K(z)+2S(x)\mathcal{D}_S^K(z)}$$

- **Taking $S(x)$ & $Q(x)$ from CTEQ6L, we are left with 2 Eqs & 4 unknowns**

  $\Rightarrow$ **additional information needed**

- **Fragmentation functions obtained directly from unpolarized DIS data**

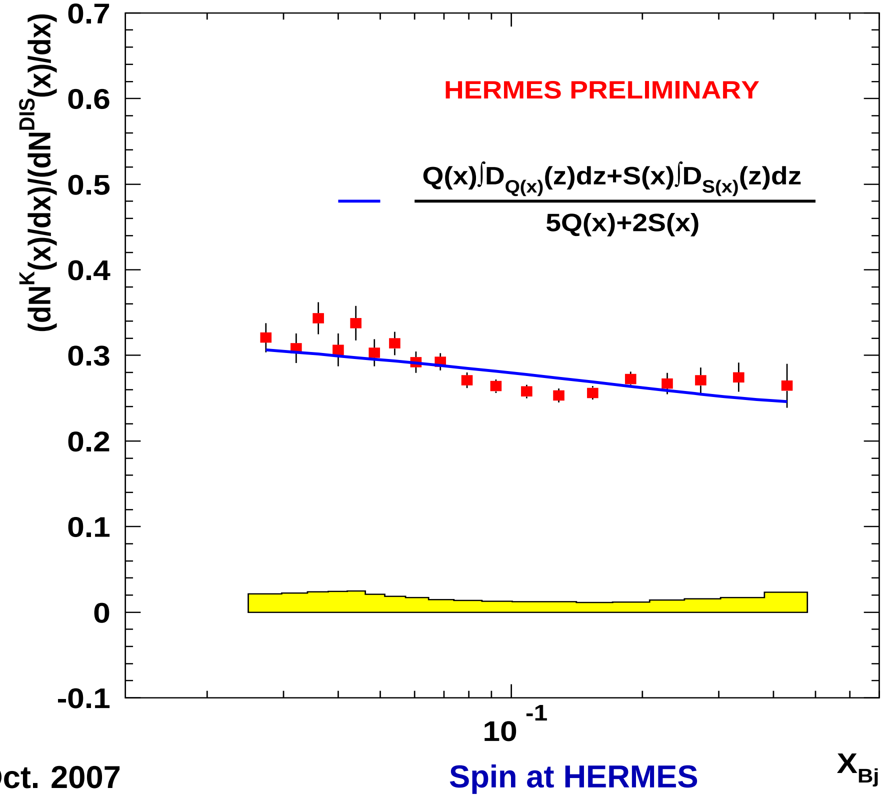
$$\frac{dN^{K\pm}(x)/dx}{dN^{DIS}(x)/dx} = \frac{Q(x)\int \mathcal{D}_Q^K(z)dz+S(x)\int \mathcal{D}_S^K(z)dz}{5Q(x)+S(x)}$$

- **CTEQ6 LO used in fit to extract fragm. function constants**

  $\Rightarrow \int \mathcal{D}_Q^K(z)dz = 1.20 \pm 0.06 \pm 0.03$

  $\Rightarrow \int \mathcal{D}_S^K(z)dz = 2.86 \pm 0.72 \pm 0.30$

  $\Rightarrow$ **at** $0.2 < z < 0.8$



ΔG: subprocess asymmetries

Average asymmetry of i-subprocess

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qq, qg, ... xsec asym.

$\Rightarrow$ calculable

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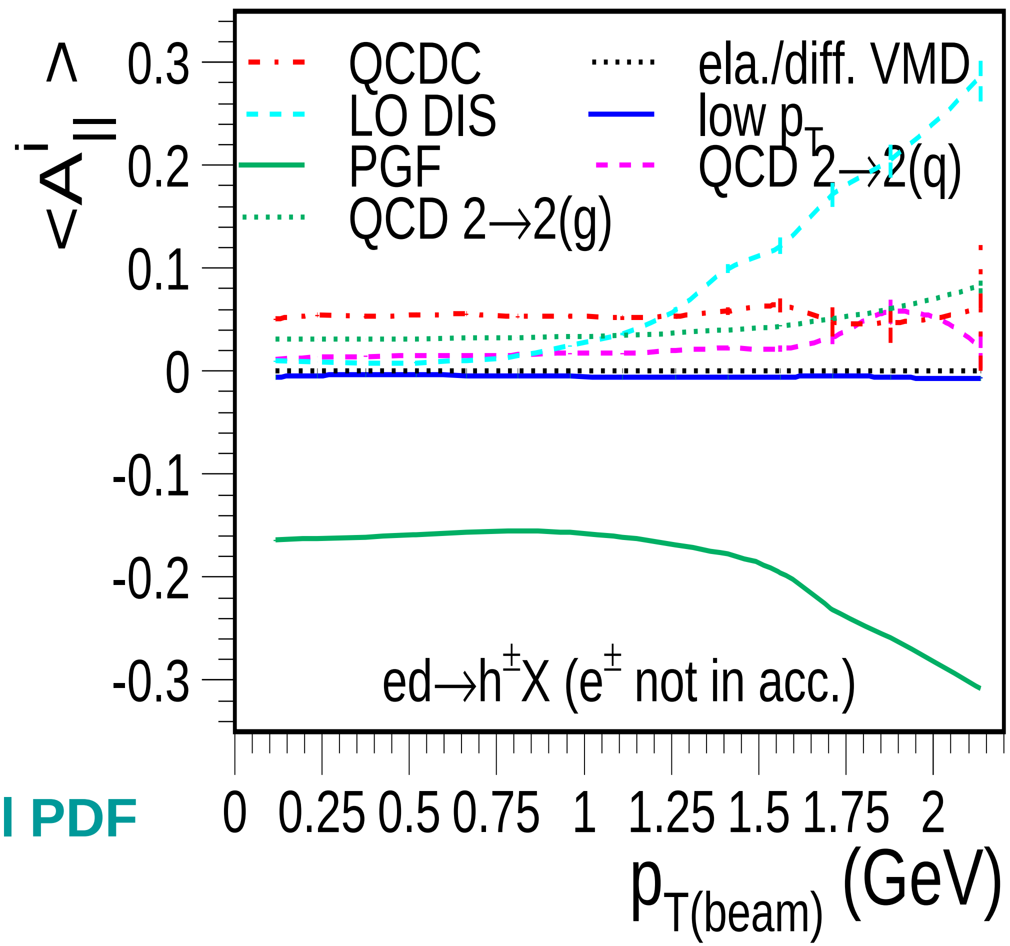

ΔG: Model Systematics

PDF parameterizations (for cross-section calculation):

Type	Standard	Alternative
Unpolarized N PDFs	CTEQ5L	GRV98
Unpolarized γ PDFs	SS	GRS

PDF parameterizations (for subprocess asymmetry calculation):

Type	Standard	Alternative
Unpolarized N PDFs	GRV98	GRV94/CTEQ5L
Unpolarized γ PDFs	GRS	GRS
Polarized N PDFs	GRSV	GS-B, BB-06
Polarized γ PDFs:	1/2(max-min) scenario of GRS	max/min scenario of GRS

Pythia parameters:

Type	Standard	Alternative
PARP(91/99): initial γ/N parton k_T	0.4 GeV	1σ from χ^2_{min}
PARJ(21): fragmenting parton p_T	0.4 GeV	1σ from χ^2_{min}
PARP(90): cutoff for switching on soft VMD	0.16	0.14-0.18