Experimental Status of Spin DIS

Gerhard Mallot
CERN

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The Nucleon spin puzzle

- Nucleon spin:

$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + \langle L_z \rangle}$$

$$\Delta q = q^{\uparrow} - q^{\downarrow} + \bar{q}^{\uparrow} - \bar{q}^{\downarrow}$$

- quarks spins: $\Delta\Sigma = \Delta u + \Delta d + \Delta s$
- gluons spins: Δg
- orbital angular momentum of q & g: L_z
- Naïve: $\Delta\Sigma = 1$

EMC 1987:

$$\boxed{\Delta\Sigma = 0.12 \pm 0.17}$$

$$\Delta s = -0.19 \pm 0.06$$

Spin structure functions

- DIS with polarised beam and target

$$\sigma = \bar{\sigma} \pm \tfrac{1}{2}\Delta\sigma$$

  - longitudinal pol. $\Delta\sigma_{\parallel} = \sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}$
  - transverse pol. $\Delta\sigma_{\perp} = \sigma^{\Uparrow\rightarrow} - \sigma^{\Uparrow\leftarrow}$

- Structure functions

$$\begin{aligned} \bar{\sigma} &= a F_1(x,Q^2) + b F_2(x,Q^2) \\ \Delta\sigma &= \alpha g_1(x,Q^2) + \beta g_2(x,Q^2) \end{aligned}$$

- QPM

$$\begin{aligned} g_1(x,Q^2) &= \frac{1}{2}\sum e_f^2 \Delta q_f(x,Q^2) \\ F_1(x,Q^2) &= \frac{1}{2}\sum e_f^2 \; q_f(x,Q^2) \end{aligned}$$

Experimental technique

- Double spin asymmetries

$$A = \frac{\Delta\sigma}{2\bar{\sigma}} = \frac{A_{meas}}{P_t P_b f}$$

- target & beam polarisations: P_t, P_b
  dilution factor: f, fraction of polarisable nucleons

- depolarisation of virtual photon: D

$$\begin{aligned} g_1 &\simeq \frac{A_\parallel}{D} F_1 \\ g_2 &\simeq \frac{A_\perp}{d}\frac{F_1}{\gamma} - \frac{y}{2} g_1; \qquad \gamma = \frac{4x^2M^2}{Q^2} \end{aligned}$$

- virtual photon asymmetry

$$\begin{aligned} A_1 &= \frac{\sigma^{1/2} - \sigma^{3/2}}{\sigma^{1/2} + \sigma^{3/2}} \simeq \frac{g_1}{F_1} \\ A_2 &= \frac{\sigma_{LT}}{\sigma^{1/2} + \sigma^{3/2}} \simeq \frac{\gamma}{F_1}(g_1 + g_2) \end{aligned}$$

$$0 \le A_1 \le 1; \qquad |A_2| \le \sqrt{R}$$

The players

All started 1972 at SLAC with E80 and E130!

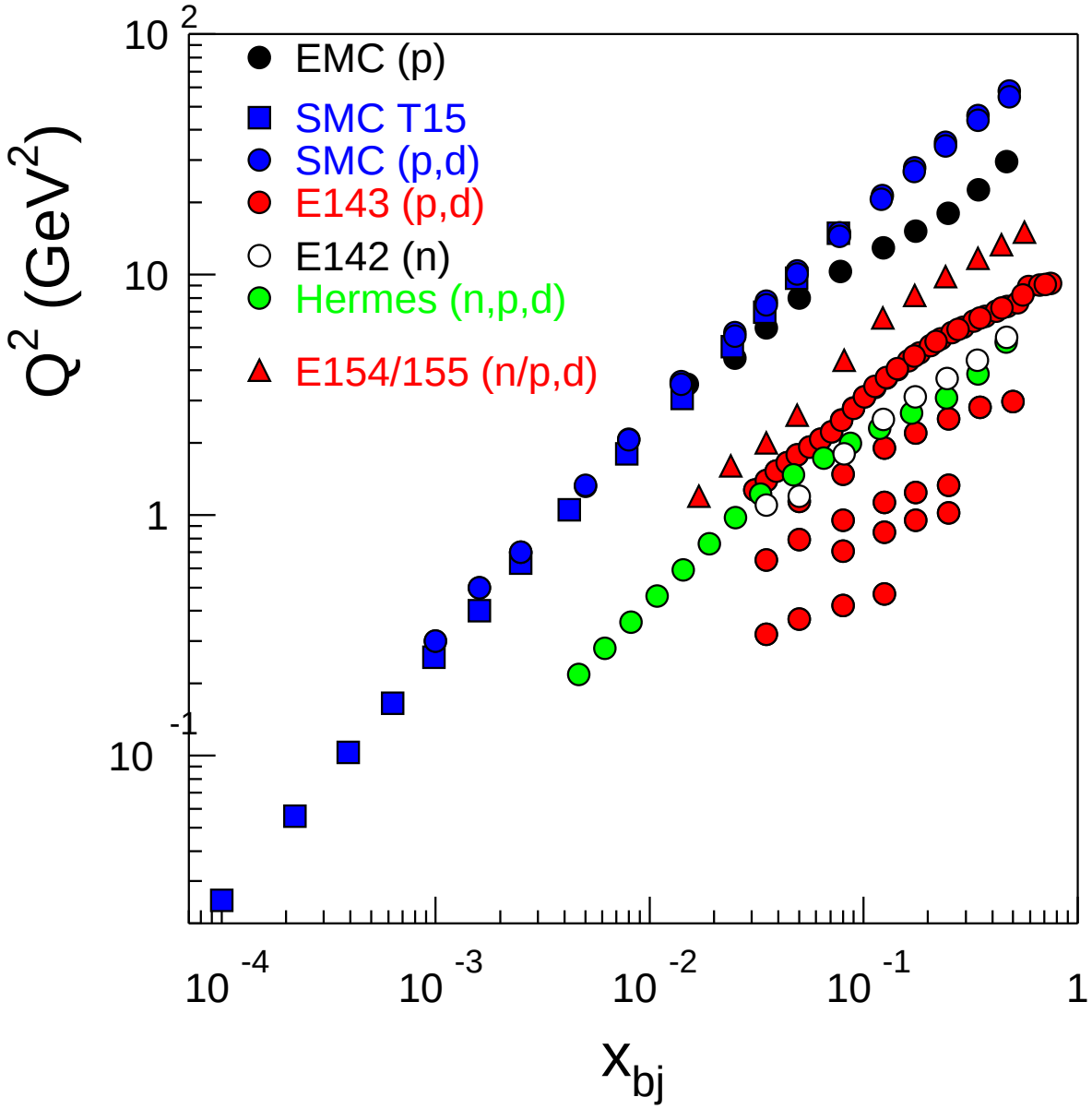
SMC 1992–1996
CERN μ^+ beam: 100–190 GeV
targets: butanol, ammonia
twin target

SLAC 1992–1999, E142, E143, E154, E155, E155x
SLAC e^-: 28–48 GeV
targets: ^{3}He, butanol, ammonia, ^{6}LiD
rapid change of beam polarisation

Hermes 1995–
Desy $e^\pm$: 27 GeV
targets: ^{3}He, H, D; internal gas storage cell
rapid change of target polarisation

COMPASS 2001–
CERN, μ^+: 100–190 GeV
targets: ^{6}LiD, NH_3 à la SMC
increased acceptance, particle ID

Kinematic ranges



Present status of A_1 and g_1

- Recent data:

E155 $0.015 < x < 0.75$ $Q^2 > 1$ GeV^2

g_1^{p} publ. 2000

g_1^{d} publ.

Hermes $0.02 < x < 0.8$ $Q^2 > 1$ GeV^2

g_1^{d} preliminary release Feb'02

2000 data, high luminosity

g_1^{p} 1997 data published

$g_1^{\mathrm{p}/d}$ $0.004 < x$ $Q^2 > 0.2$ GeV^2

SMC $0.003 < x$ $Q^2 > 1$ GeV^2

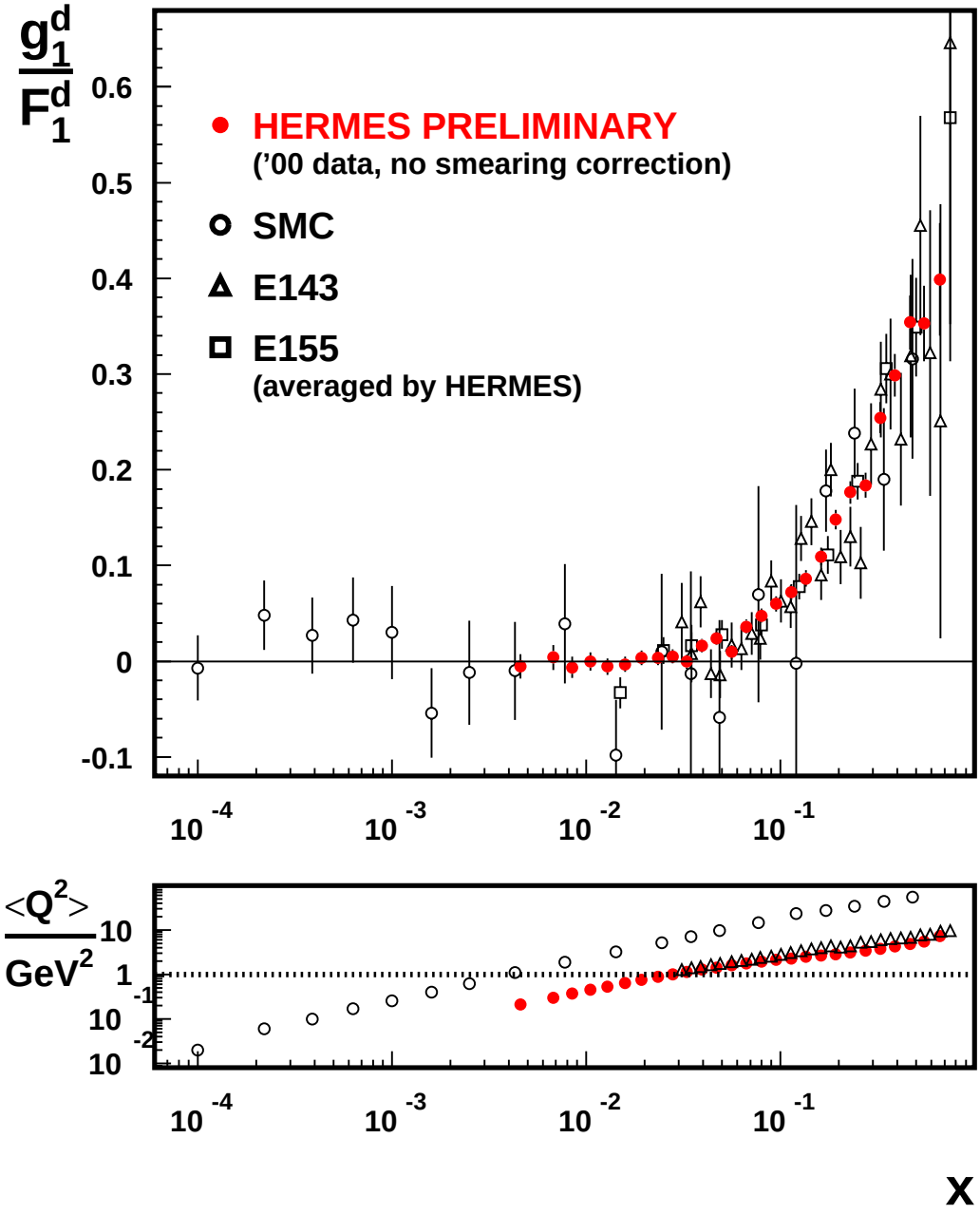
$6 \cdot 10^{-5} < x < 8 \cdot 10^{-4}$ $Q^2 > 0.02$ GeV^2

g_1^{p} publ.

g_1^{d} publ.

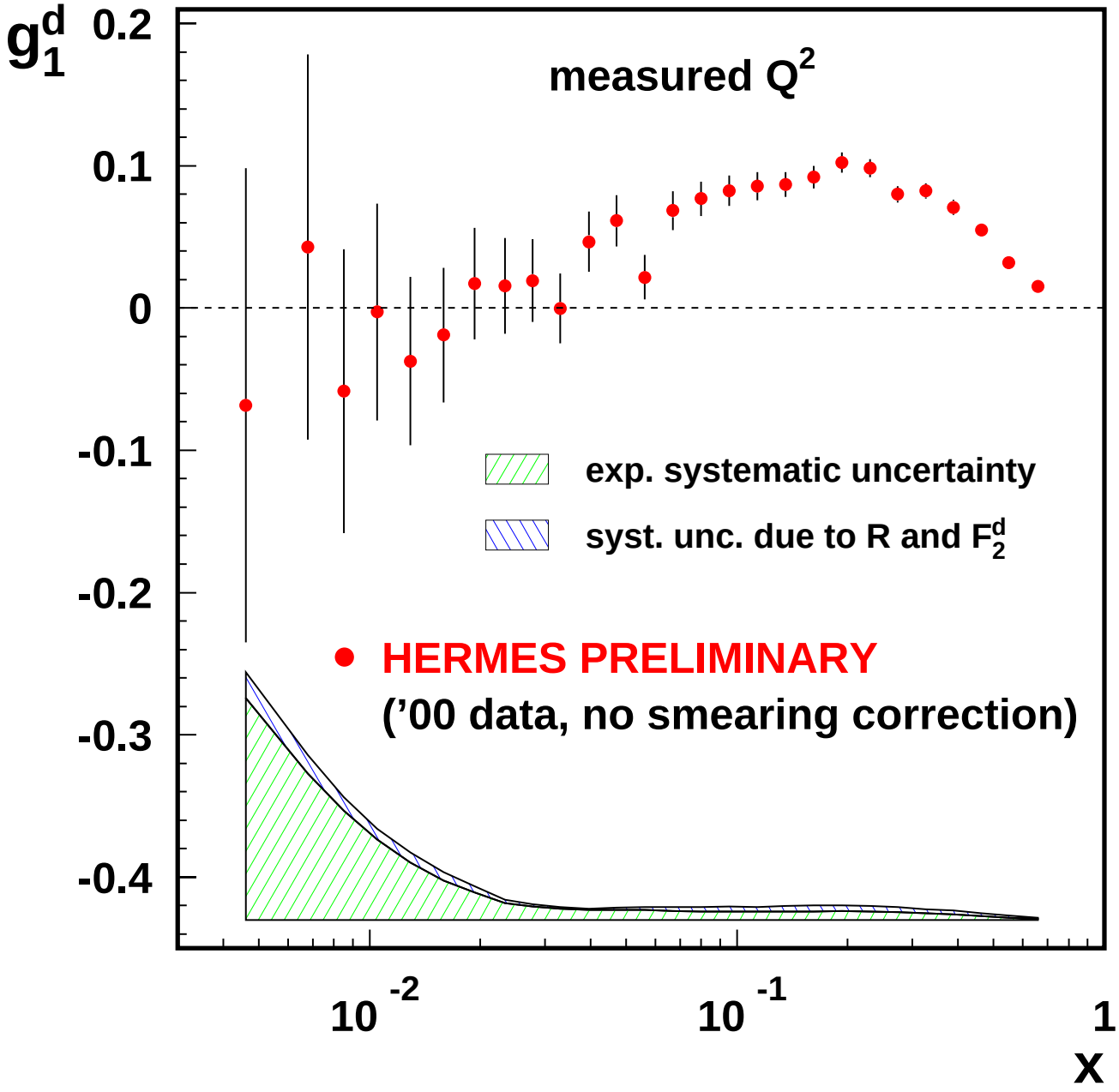
g_1^d/F_1^d WORLD DATA

- no Q^2 dependence visible
- execellent statistical precision

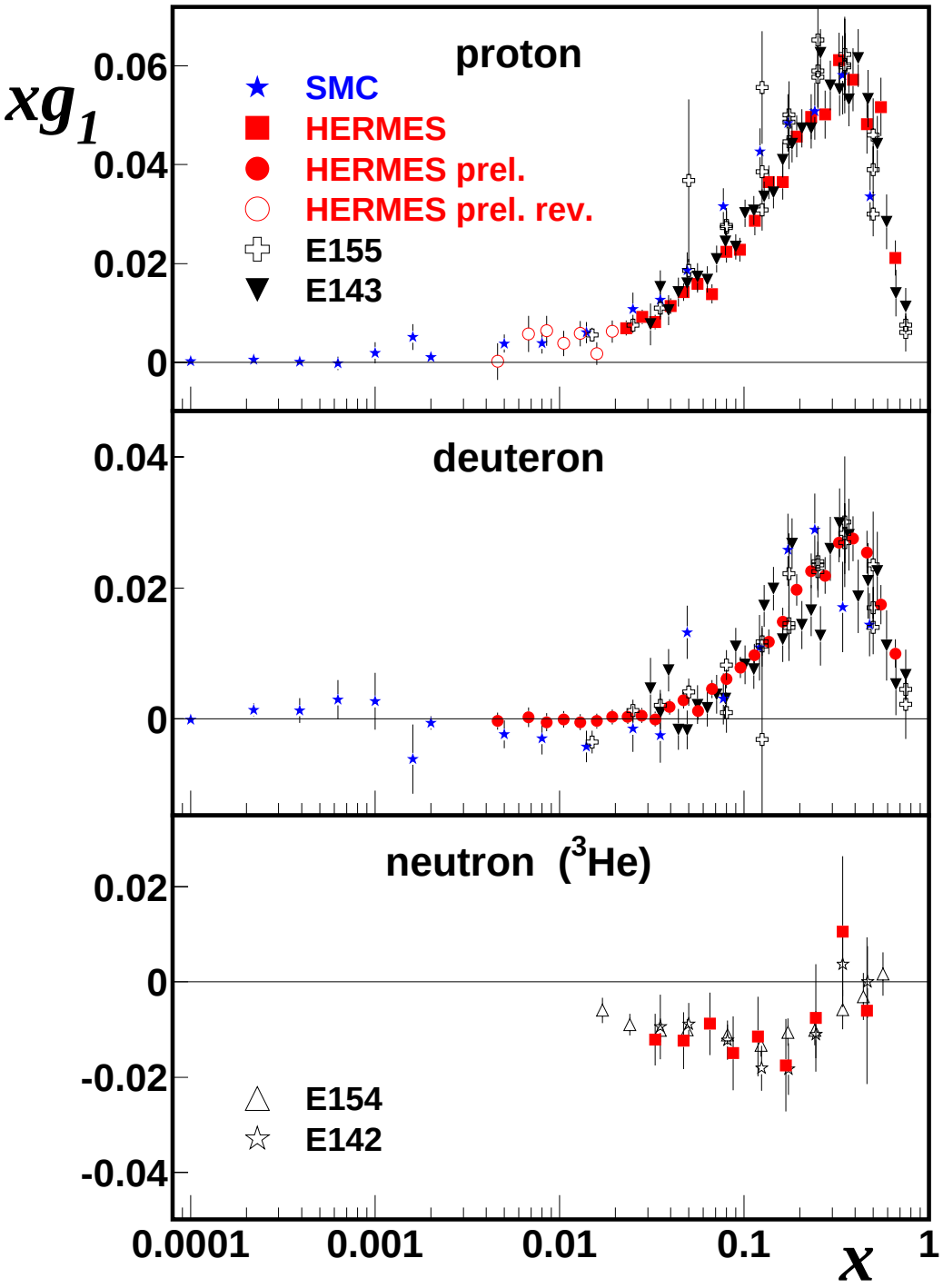


New g_1^d data

- Hermes year 2000 data



xg_1 WORLD DATA



QCD ANALYSIS, E.G. LSS

- Δu and Δd well determined

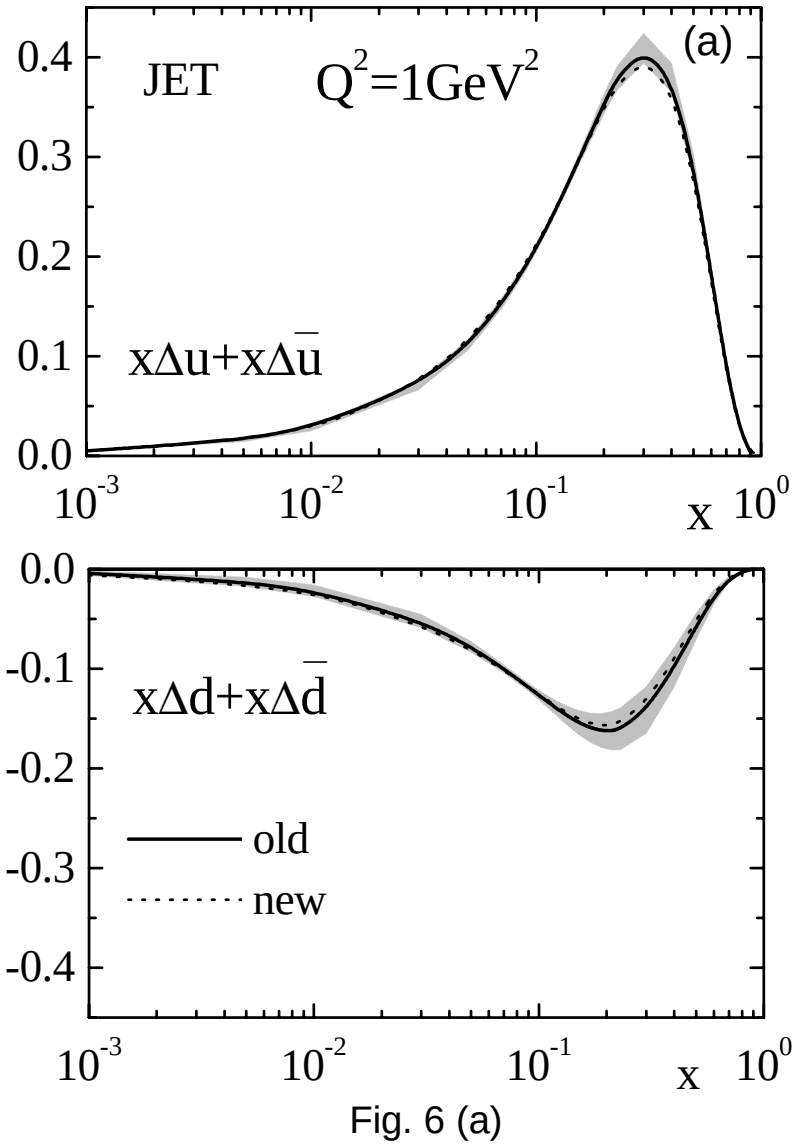


Fig. 6 (a)

Leader, Sidorov, Stamenov hep-ph/0111267

QCD ANALYSES

- Δg and Δs not well determined

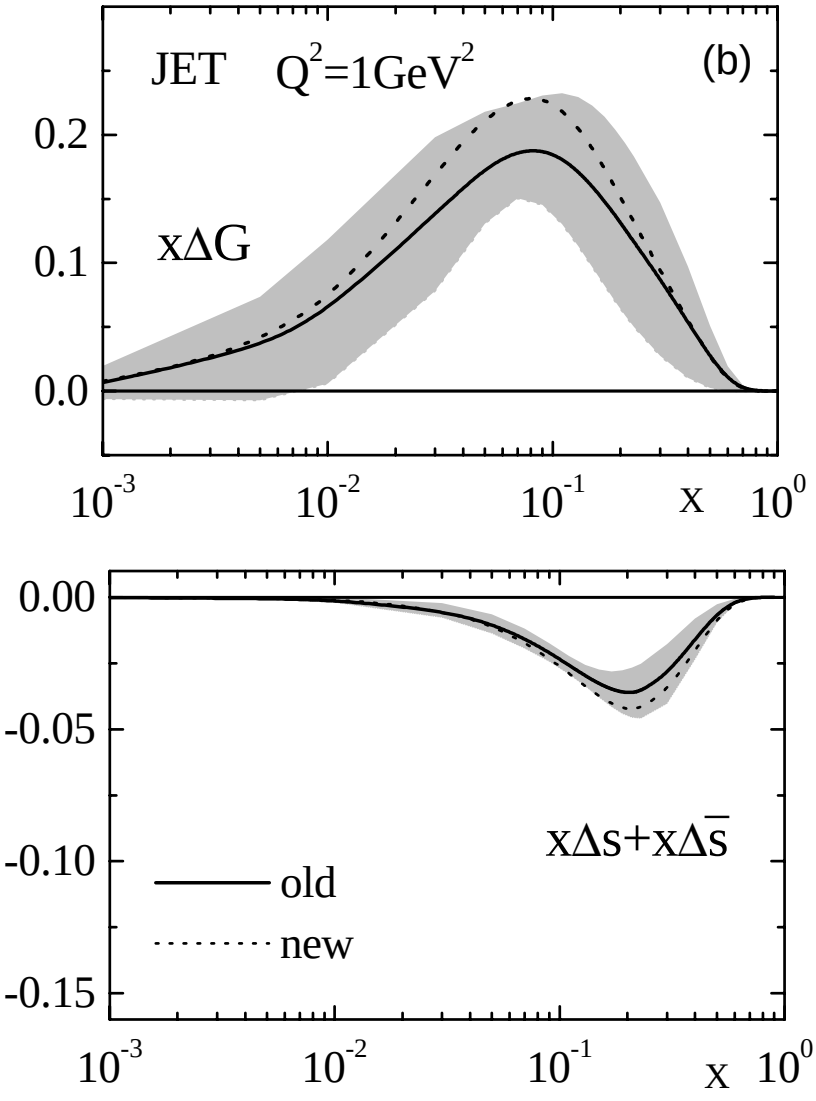


Fig. 6 (b)

Leader, Sidorov, Stamenov hep-ph/0111267

QCD ANALYSIS, E.G. LSS

- Δg and Δs in different analyses differ strongly

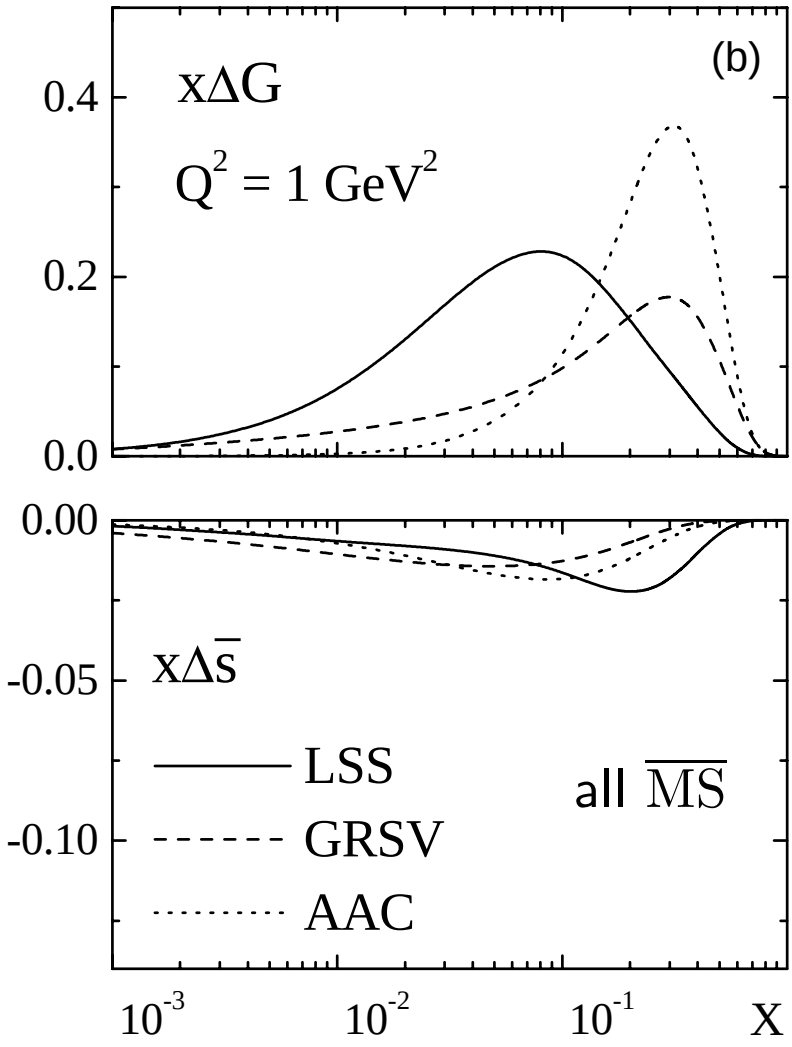
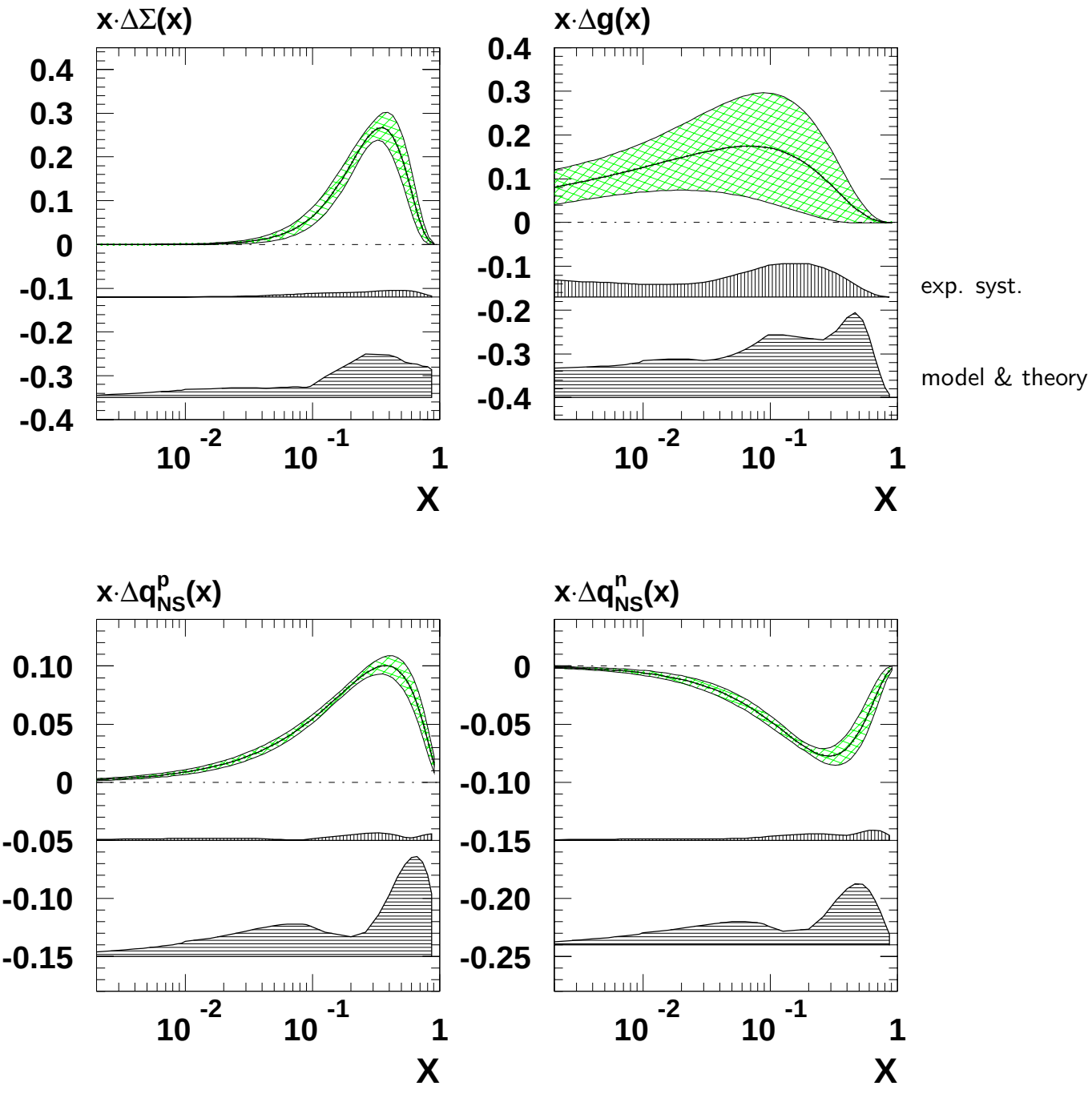


Fig. 8(b)

Leader, Sidorov, Stamenov hep-ph/0111267

SMC NLO FIT

- distribution functions, 'AB' scheme
- detailed error calculation



QCD Analyses

- good fits to data in NLO
- Δu, Δd well determined
- Δg, Δs, $\Delta \bar{s}$ hardly contrained
- first moments

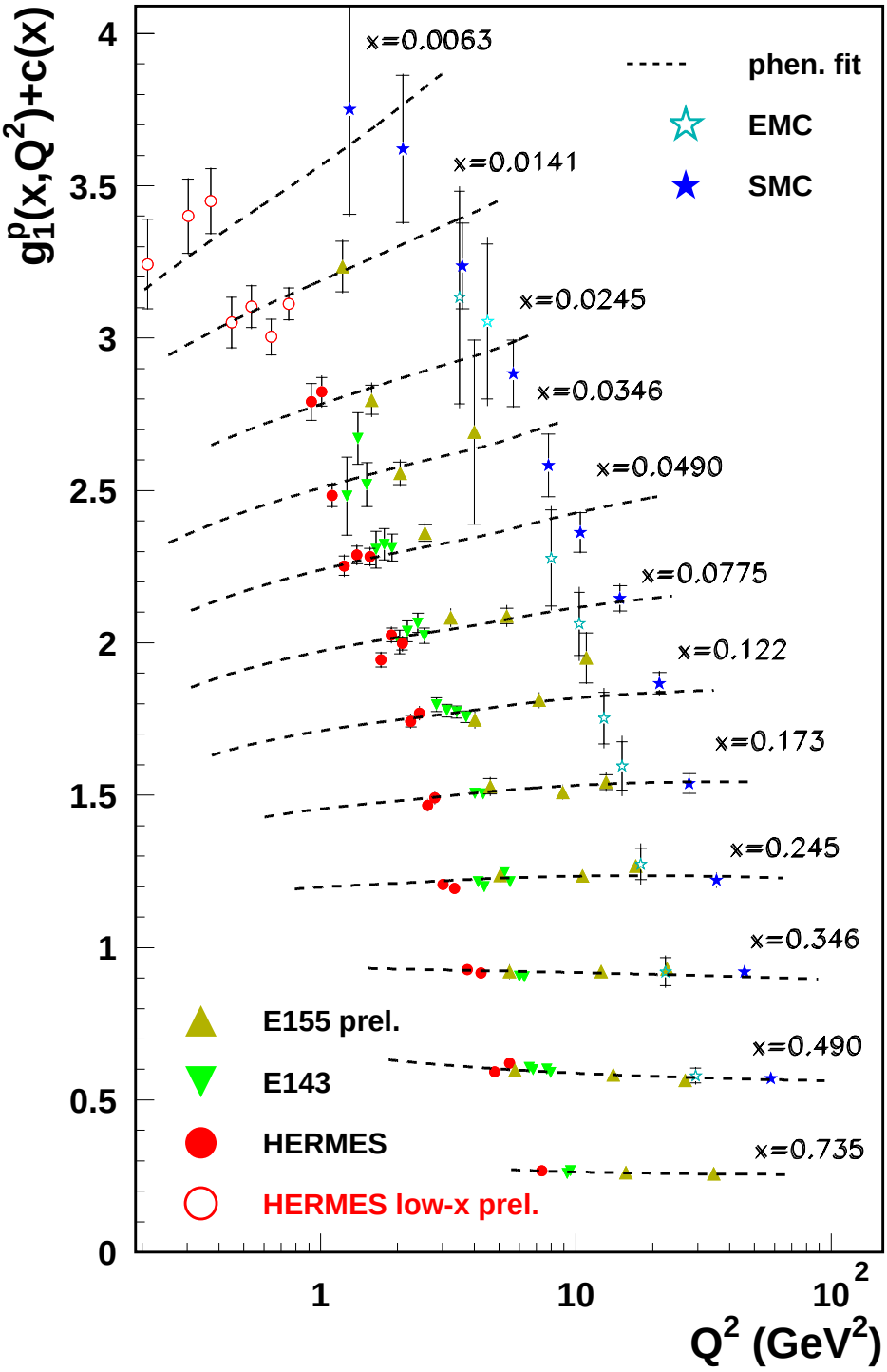
  $\Delta g > 0$ preferred, ≈ 0.7 @ $Q^2 = 1$ GeV^2
  $\Delta\Sigma \approx 0.3-0.4$ jet, 'AB'; AAC: $\Delta\bar{q}$ uncertain at low x
  $a_0 \approx 0.1$–0.2

- Impact of recent data limited although of excellent quality

$\Rightarrow$ more data in SLAC/Hermes kinematics will not improve Δg, $\Delta\bar{q}$ much

$\Rightarrow$ needed:
data at large Q^2 and small x
direct measurements of Δg and Δs

$g_1^{\mathrm{p}}(x)$ vs Q^2



C. Weiskopf, DIS2001

Status of A_2 and g_2

- $|A_2| \leq \sqrt{R}$

$$
\begin{aligned}
g_2(x,Q^2) &= g_2^{\mathrm{WW}} + \bar{g}_2(x,Q^2) \\
g_2^{\mathrm{WW}}(x,Q^2) &= -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y}\,\mathrm{d}y
\end{aligned}
$$

- twist-3 term $\bar{g}_2$, matrix element d_2

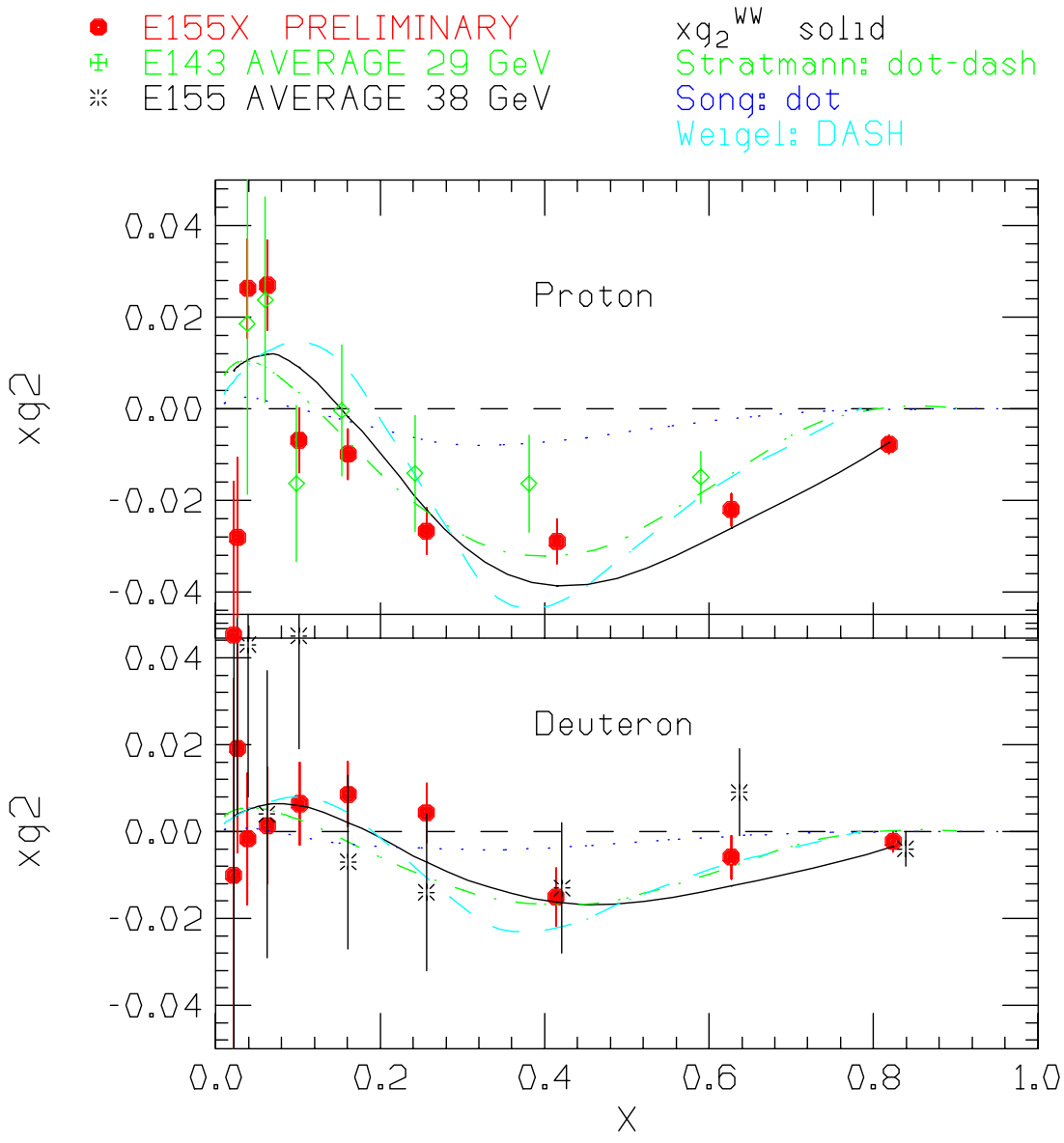
$$
d_2 = 3\int_0^1 x^2\,\bar{g}_2(x,Q^2)\,\mathrm{d}x
$$

- data:

SMC	exploratory $\lvert A_2\rvert << \sqrt{R}$
E142–E155	$A_2^p > 0$, A_2^n compatible with 0
E155x prelim.	precise data!

Structure function xg_2

- —— twist-2 term: g_2^{WW}
- -- -- bag model calculations



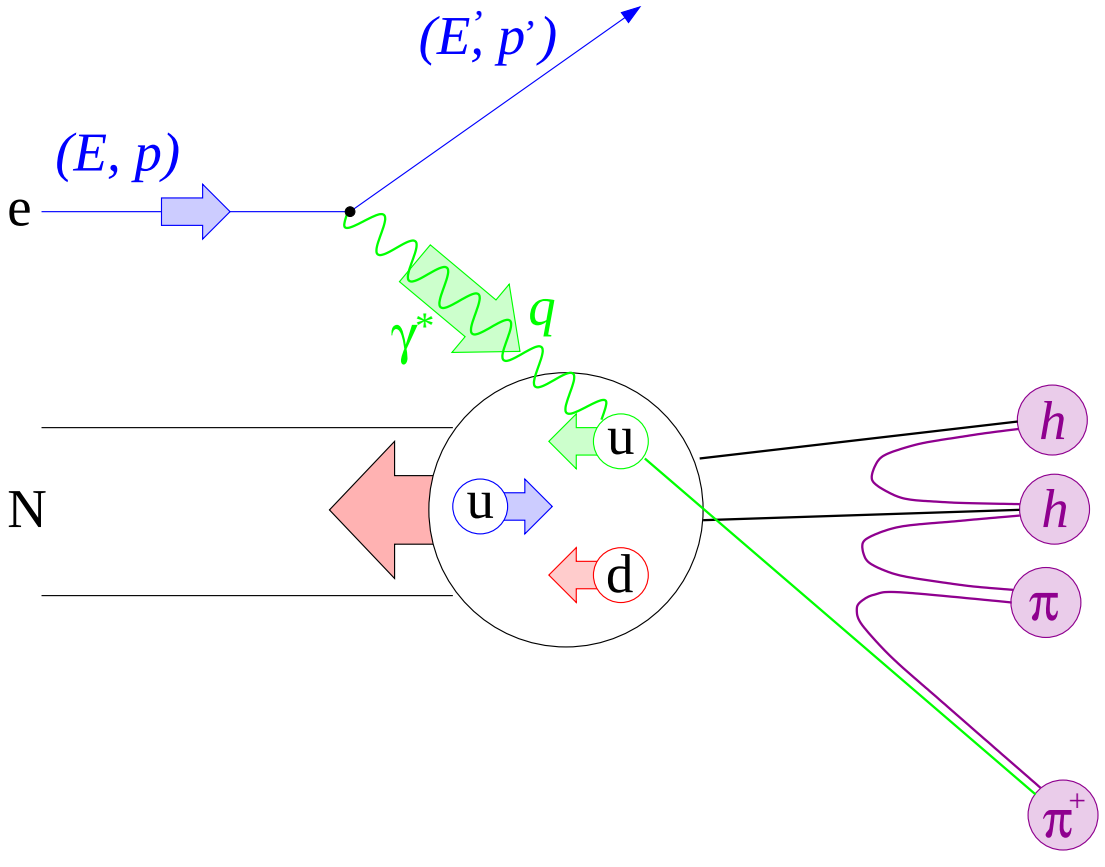
Semi-inclusive asymmetries

- Fragmentation function D

  D_q^h from quark q into hadron h

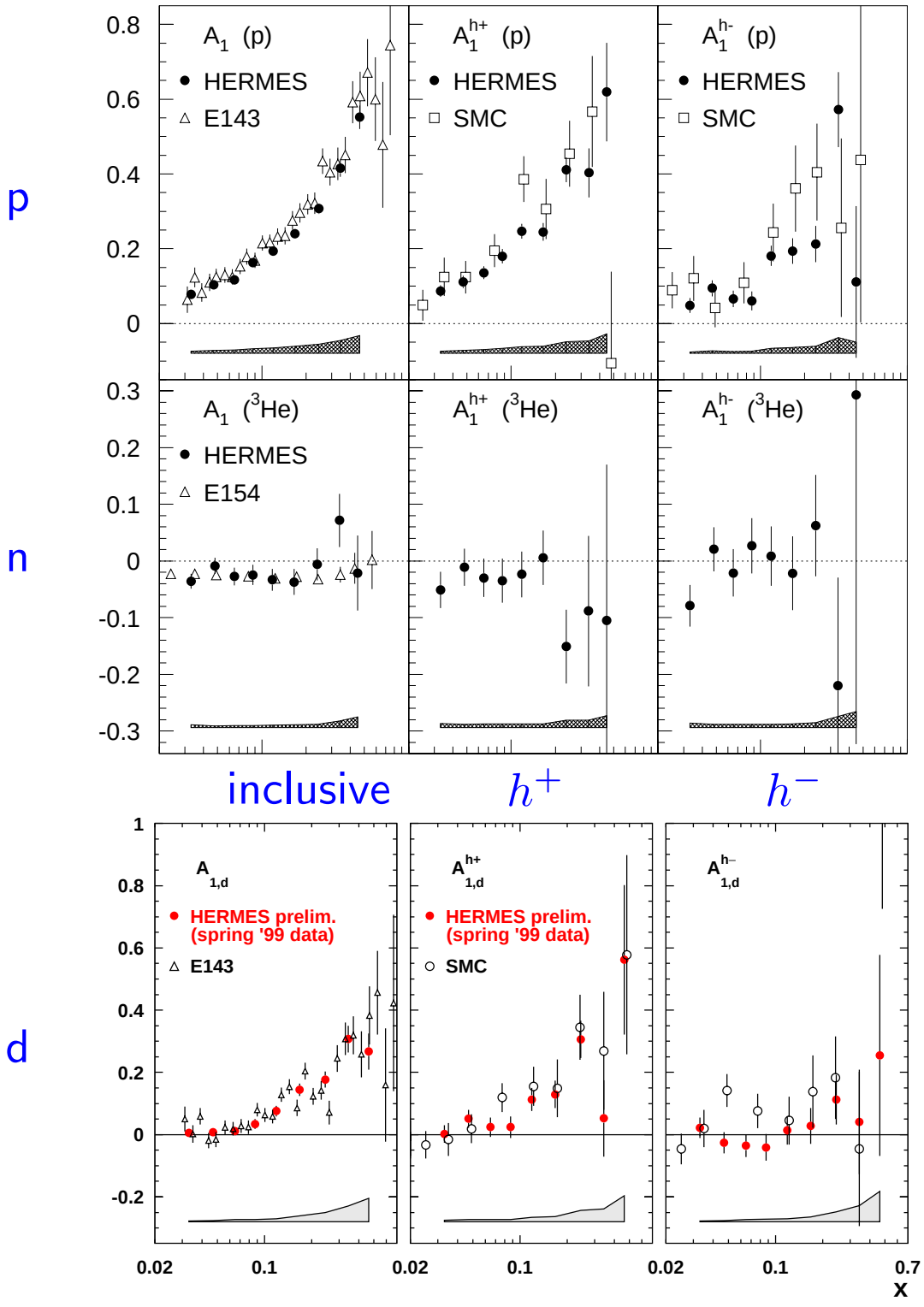
  $z = \frac{E_h}{\nu}$ energy fraction carried by h

$$A_1^h(x, Q^2) = \frac{\int \mathrm{d}z \sum_f e_f^2 \Delta q_f(x, Q^2) \cdot D_f^h(z, Q^2)}{\int \mathrm{d}z \sum_f e_f^2 \; q_f(x, Q^2) \cdot D_f^h(z, Q^2)}$$



Ruh

Semi-inclusive asymmetries

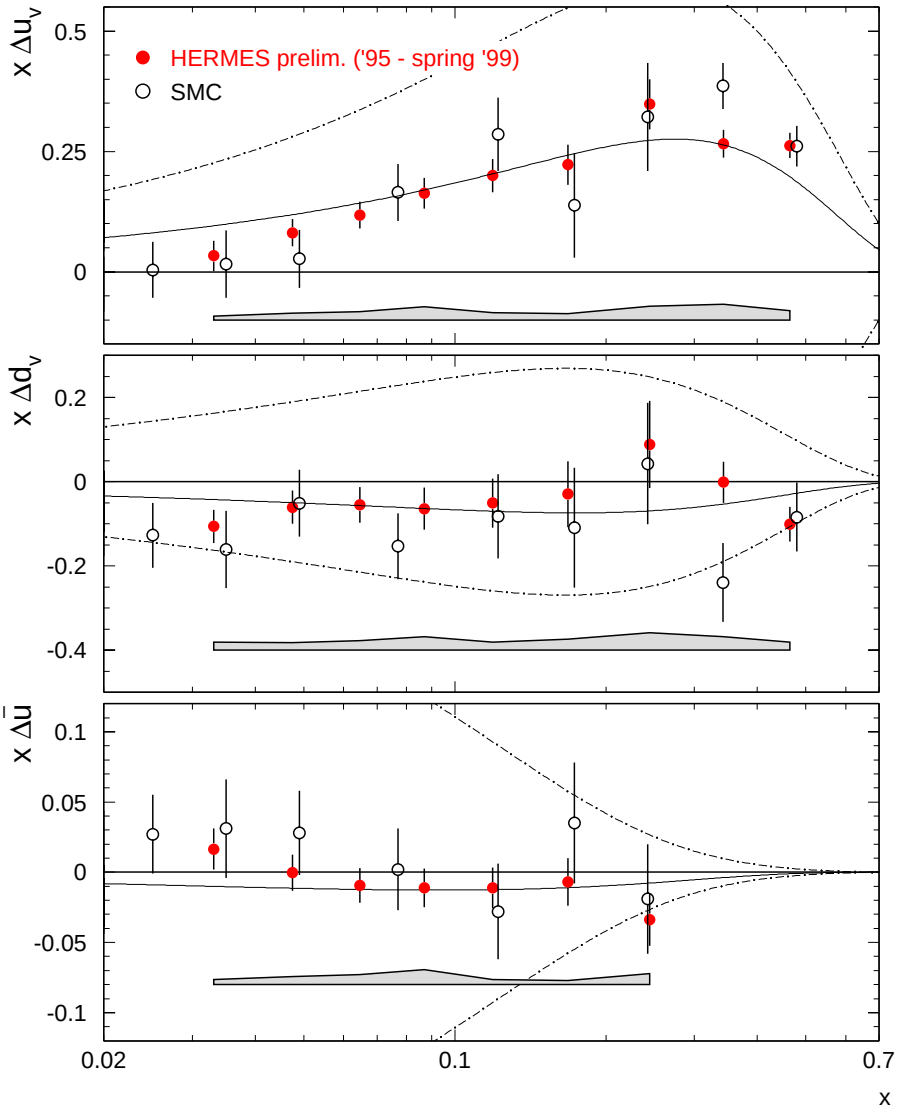


- low-x SMC data not shown

Valence and sea $\Delta q(x)$

- Hermes and SMC ($x > 0.02$) at $Q^2 = 2.5$ GeV^2
  errors: Hermes stat + syst. band, SMC total
  Hermes 2000 to come

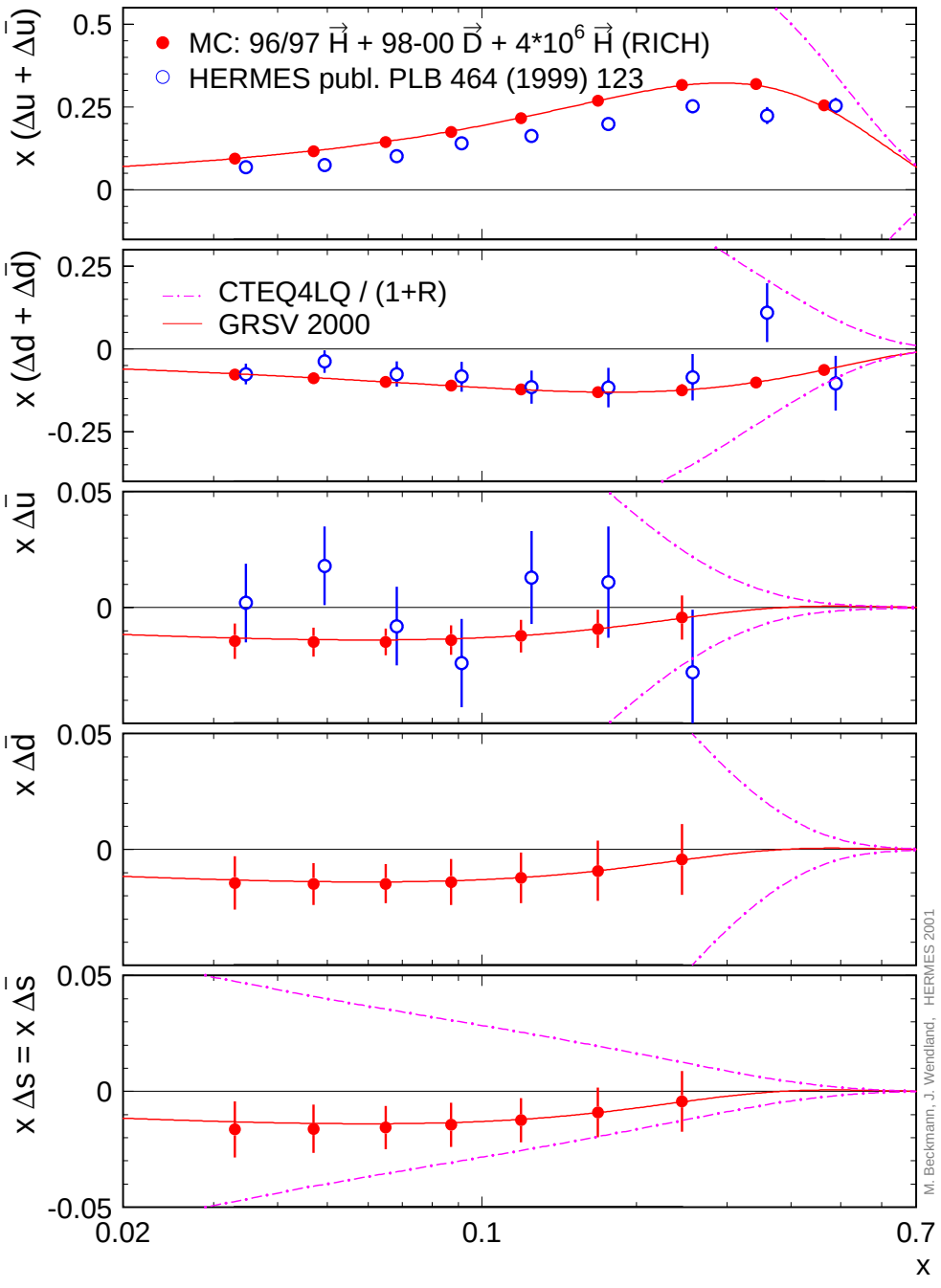
—— GS A (LO) ------- positivity limit



$x\Delta q(x)$ AND PROJECTION

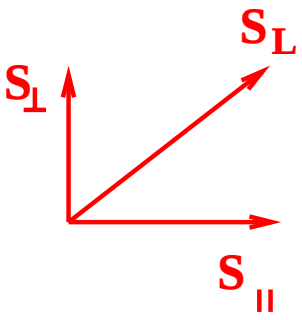
- Hermes data and projection

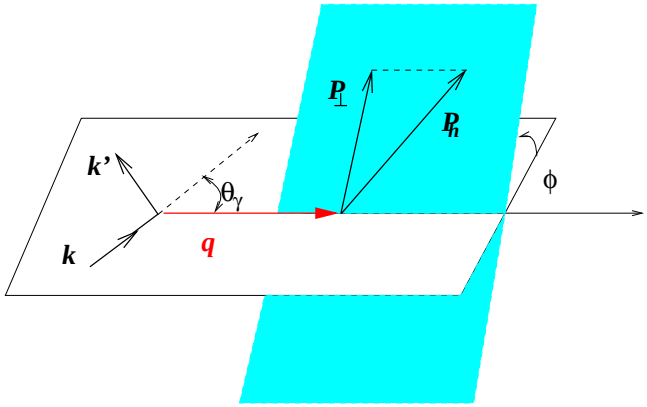
  incl. 2000 data + 1 year additional p with RICH



hep-ex/0108021

Hints for transversity





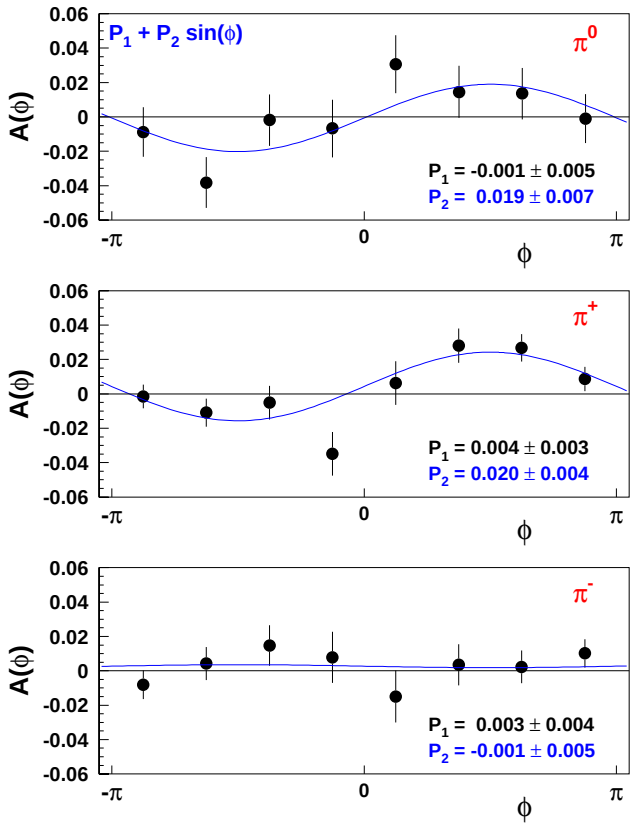
- Hermes: azimuthal asymmetry with longitudinal $P_{\rm target}$ due to transverse component in γ^* frame, $A_{UL}(\phi)$

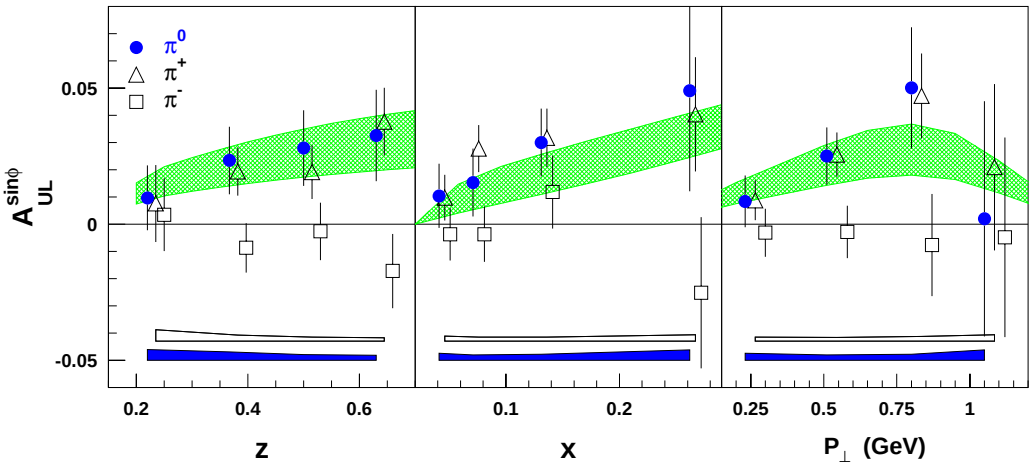
  $S_\perp/S \approx 0.17$ in 1997 data

- SMC: short run with transverse $P_{\rm target}$, $A_N(\phi)$

- $A_{UL}(\phi)$ and $A_N(\phi)$ related to h_1 and to Collins fragmentation function $H_1^\perp(z)$

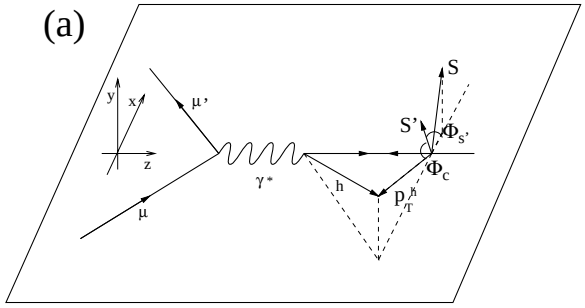
Hints for transversity





SMC Collins asymmetry

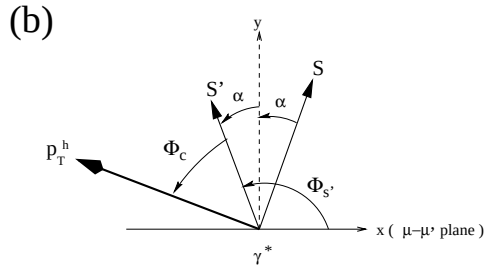
A. Bravar, DIS'99

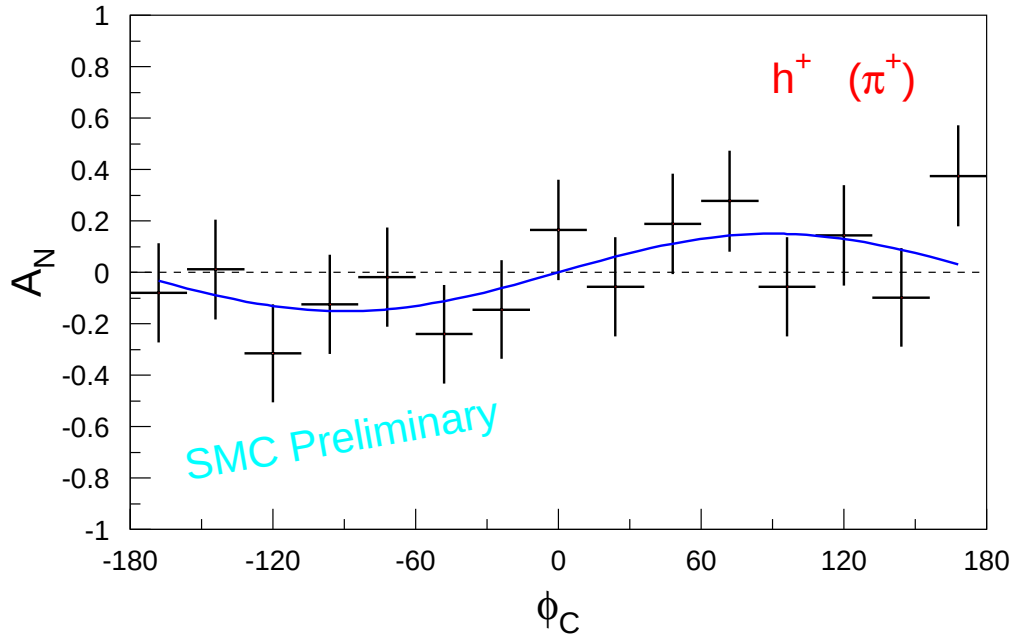


Transversely polarised target

$A_N = 0.11 \pm 0.06$ for π^+,

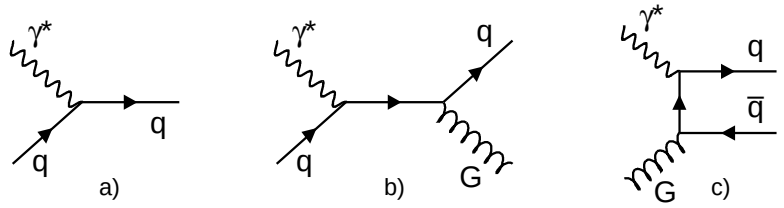
$A_N = -0.02 \pm 0.06$ for π^-





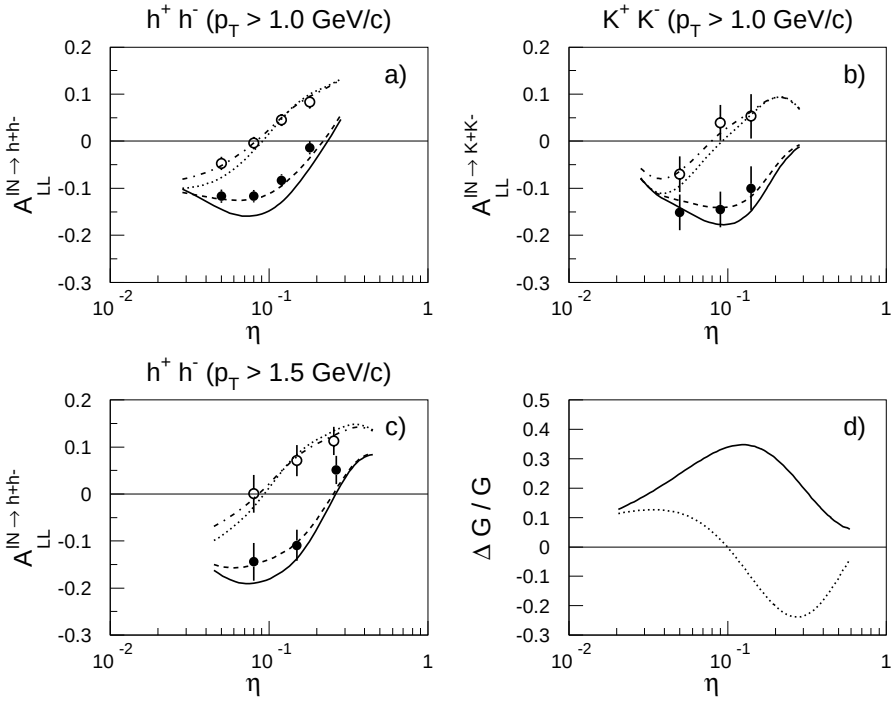
High-p_T hadron pairs

- Contributions: a) LO b) QCD Compton c) PGF



$$A_{\rm LL}^{\ell N} \simeq \langle \hat{a}_{\rm LL}^{\gamma g \to qg} \rangle \frac{\Delta q}{q} + \langle \hat{a}_{\rm LL}^{\gamma g \to q\bar{q}} \rangle \frac{\Delta g}{g}$$

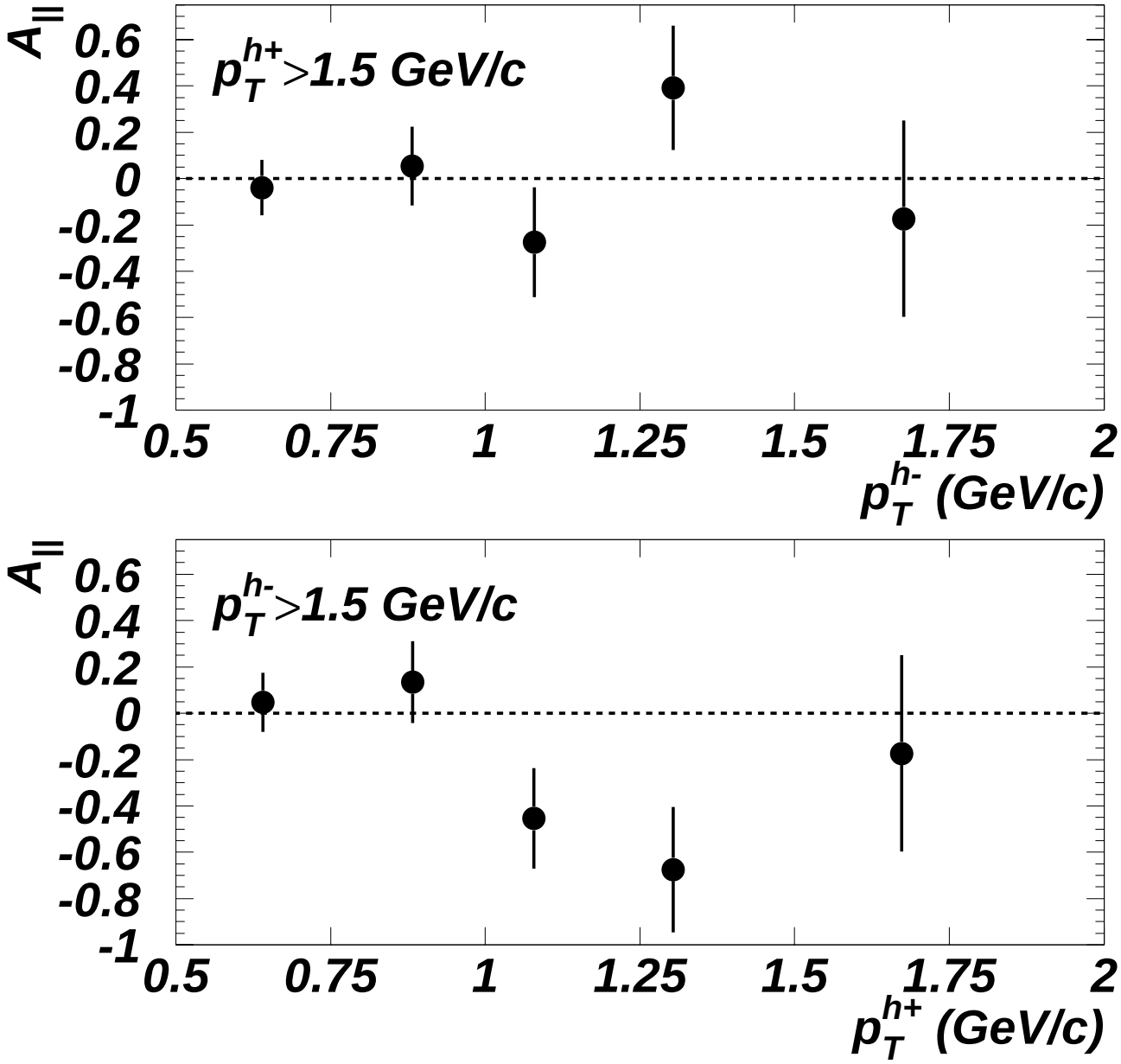
- projection for COMPASS hep-ph/9710266



—— GS A ---- GS C (1996)

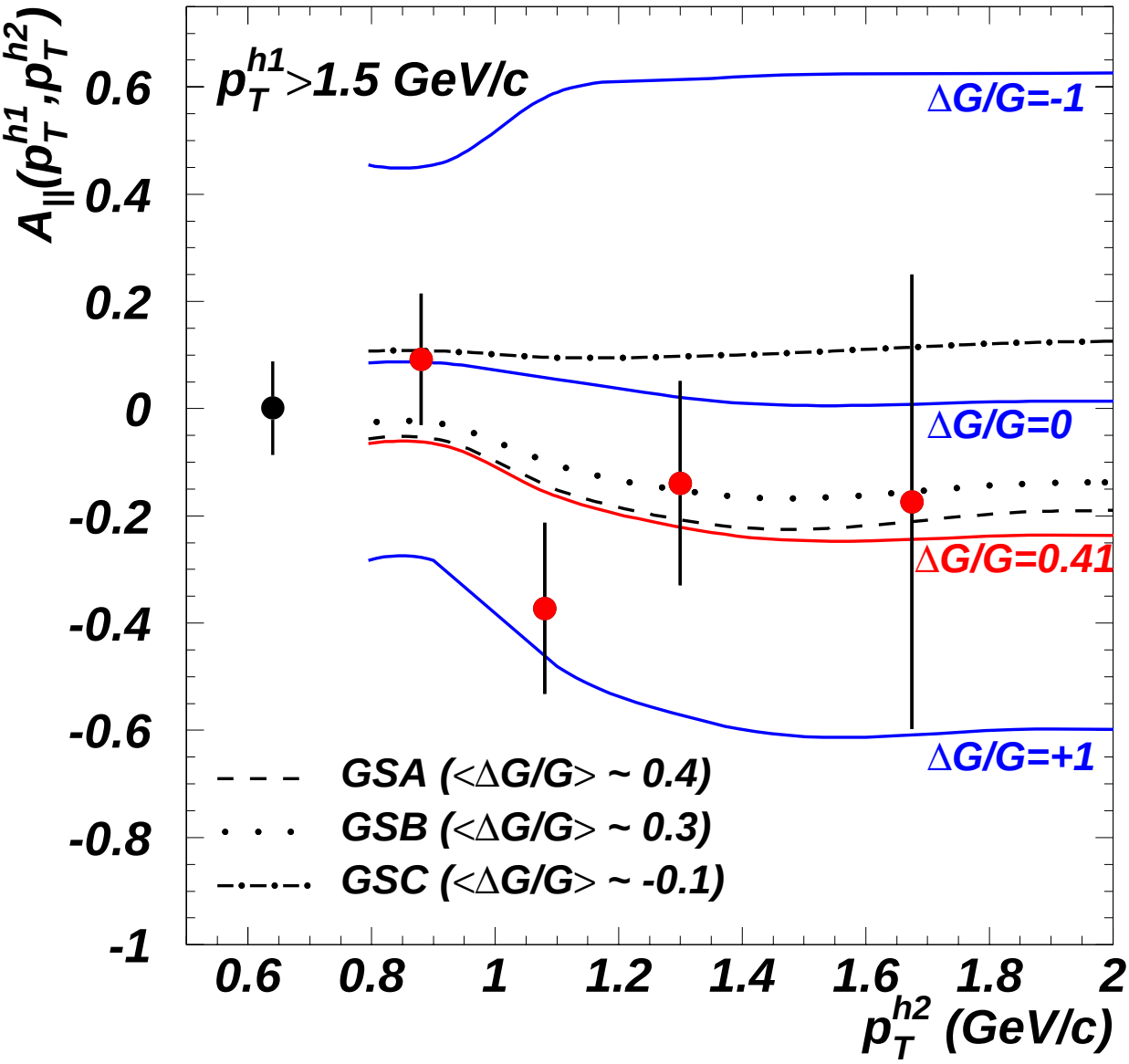
HERMES HIGH p_T HADRON PAIRS

- no effect for positive hadrons
- two points below zero at moderate p_T^2



High p_T hadron pairs

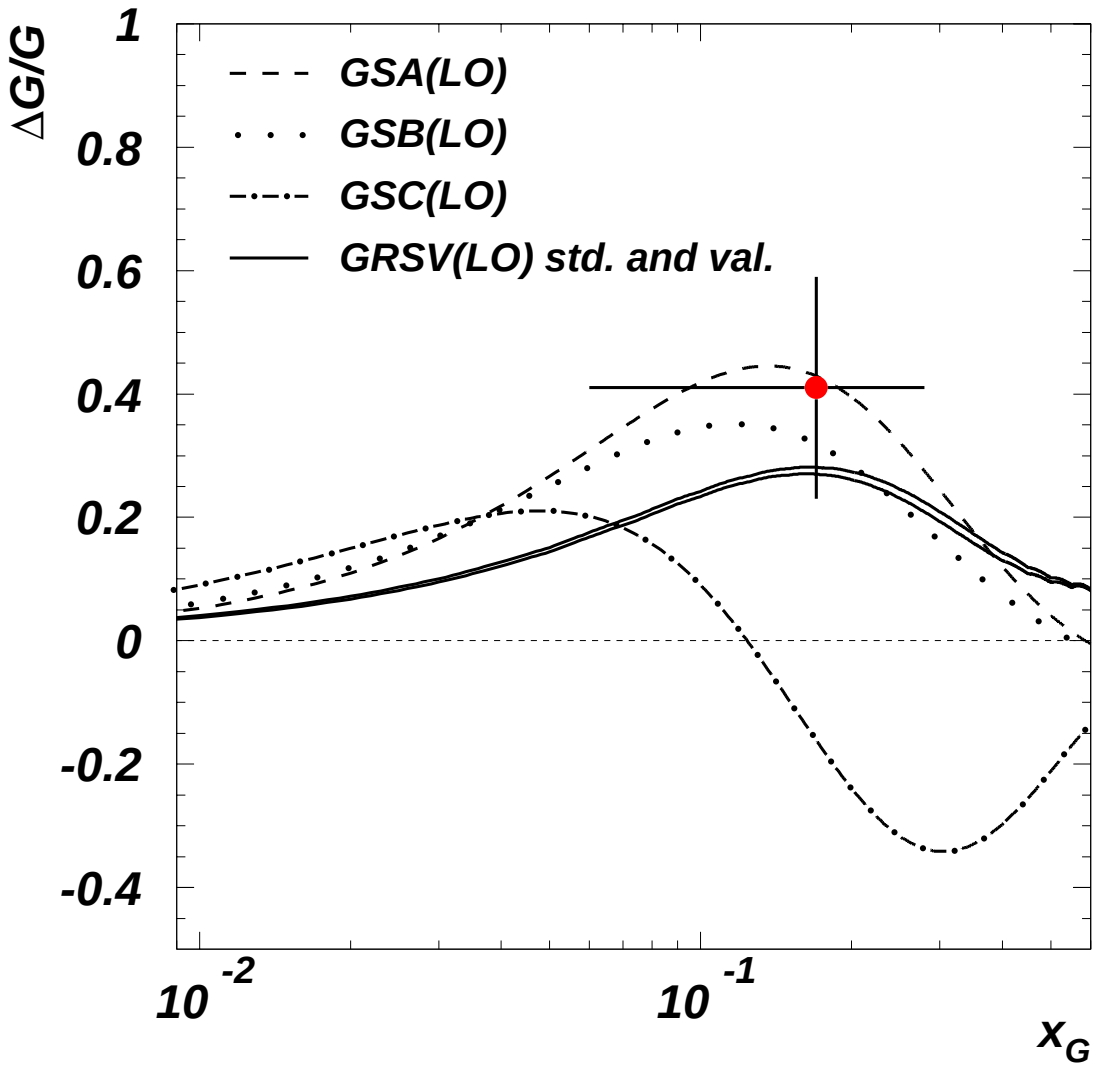
- Comparison for several gluon polarisations
- $\Delta g \neq 0$??????



High p_T hadron pairs

- Hermes conclusion:
  $\Delta g/g = 0.41 \pm 0.18(\text{stat}) \pm 0.03(\text{syst exp})$
  $\langle x_g \rangle = 0.17$; $\langle p_T^2 \rangle = 2.1$ GeV^2

$\int_{0.06}^{0.028} \frac{\Delta g}{g} g(x) \mathrm{d}x \approx 0.6$

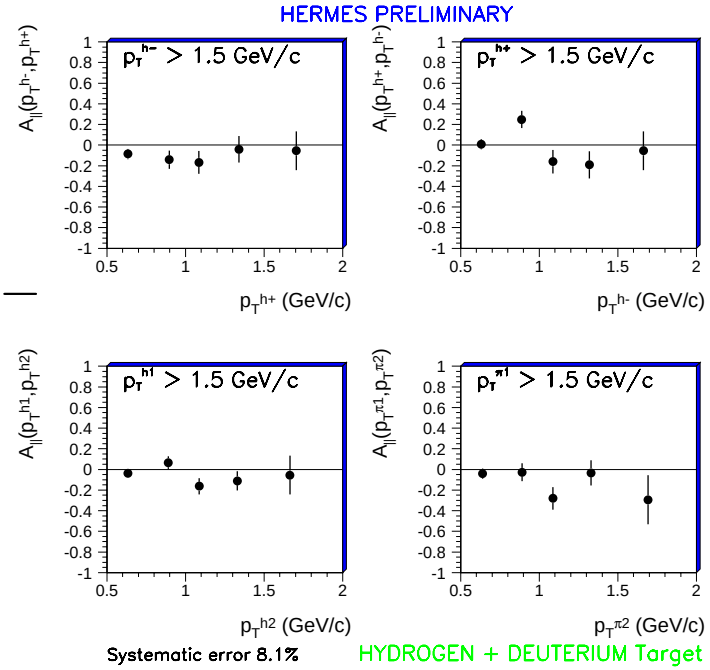


PRL84(2000)2584

High p_T h^+h^- & K^+K^- pairs

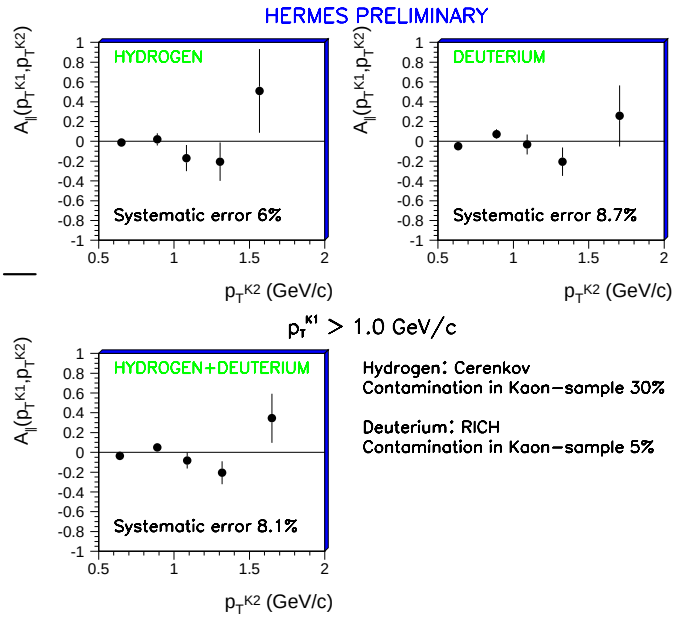
- Hermes preliminary 1996 – 2000

h^+h^-



$\pi^+\pi^-$

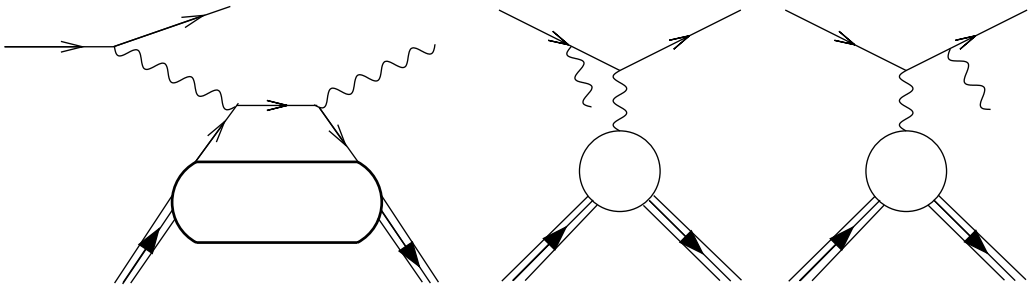
K^+K^-



DVCS and GPDs

- Deeply Virtual Compton Scattering
  exclusive electroproduction of high energy γ
  leaving nucleon intact $\ell N \to \ell' N \gamma$

- Interference with Bethe-Heitler process enhances its small amplitude



(a) (b)

- GPD's, $H, E, \tilde{H}, \tilde{E}$ describe DVCS and exclusive vector and pseudo-scalar meson production

- Ji's sumrule related to orbital angular momentum

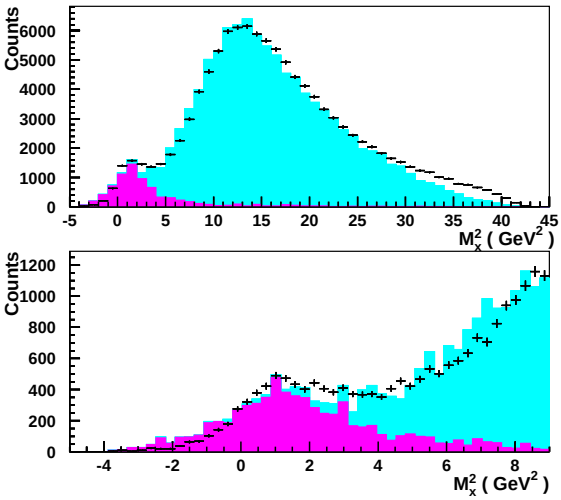
PRL78(1997)610

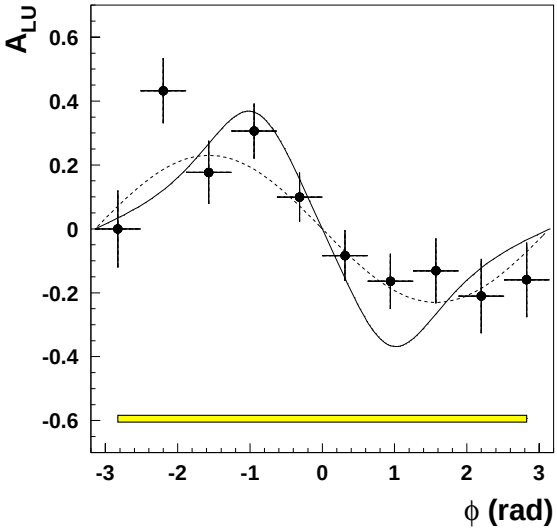
$$\int x \mathrm{d}x [H(x, \Delta^2, \xi) + E(x, \Delta^2, \xi)] = 2J_q$$

for $\Delta^2 = -t \to 0$

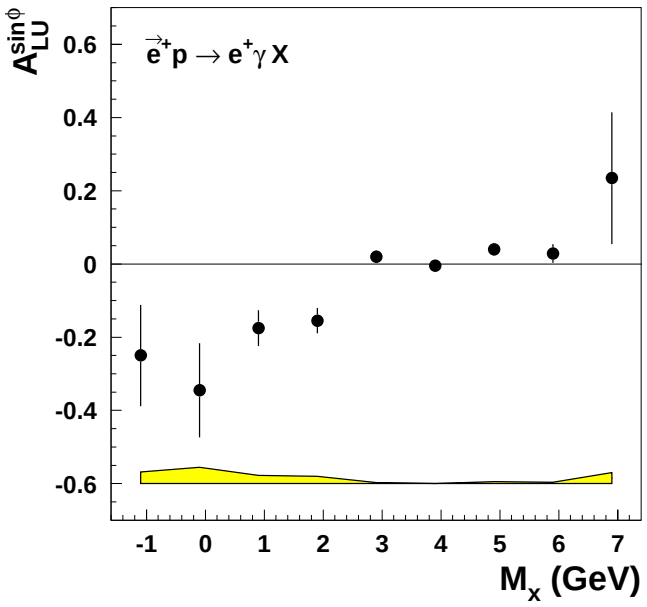
Observation of DVCS

- Hermes beam spin asymmetry in M_p region
  Missing mass spectrum and azimuthal distribution





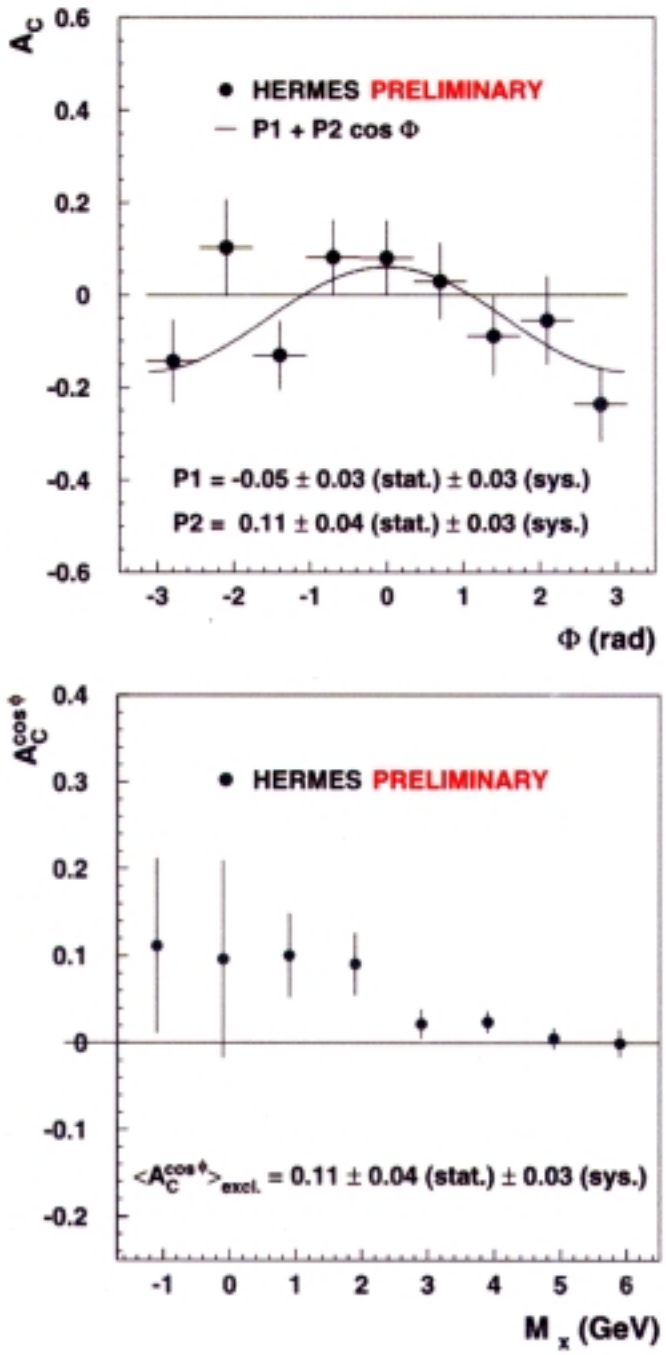
- Extract $\sin(\phi)$-moment, $A_{LU}^{\sin\phi} = \frac{2}{N}\sum_{i=1}^{N}\frac{\sin\phi_i}{P_l)_i}$



Hermes PRL87,182001

CLAS PRL87,182002

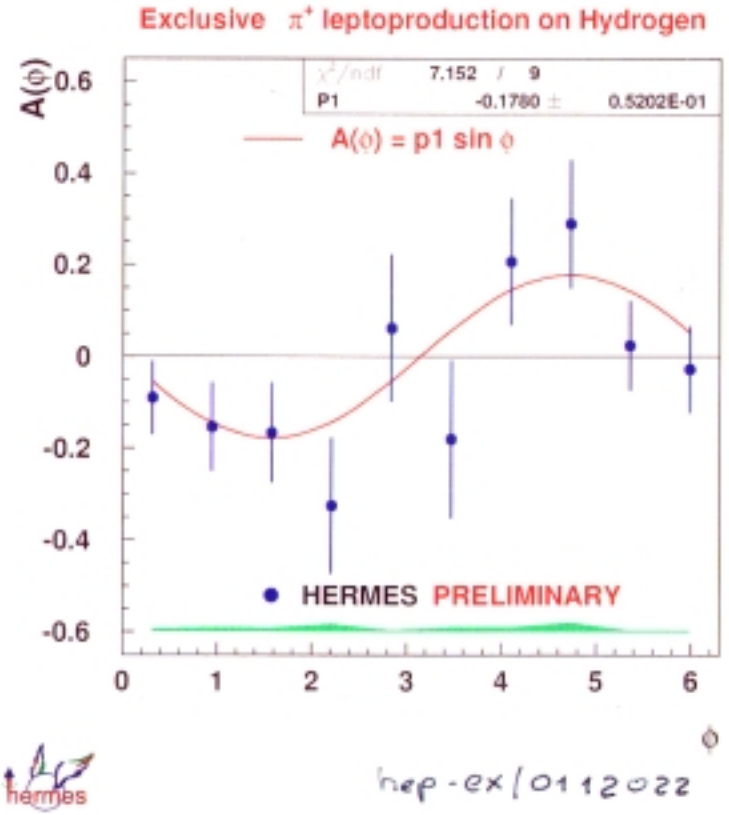
DVCS – charge asymmetry



K. Rith, Feb. 2002

Exclusive $e\vec{p} \rightarrow e' n \pi^+$

cross section asymmetry



$$A(\phi) = A_{\mathrm{UL}}^{\sin\phi} \cdot \sin\phi$$

$\sin 2\phi$, $\cos\phi$, $\cos 2\phi$ moments compatible with zero

$$A(\phi) = a \sin\phi + b \sin 2\phi + c \cos\phi + d \cos 2\phi$$

systematics:
- 5% on target polarisation
- 2% background correction

K. Rith, Feb. 2002

COMPASS AT CERN

Physics goals:

- with muon beam 100–190 GeV/c
  - ◇ $\Delta g/g$, gluon polarisation
    open charm production: $\mathrm{D}^0 \rightarrow \mathrm{K} + \pi$
    high p_T hadron pairs: h^+, h^-
  - ◇ Δq, flavour separation: Δq
  - ◇ h_1, transversity
  - ◇ ΔD_q^Λ spin dependent fragmentation
  - ◇ g_1, g_2, structure functions at small

- with hadron beams π,K, p, 80–300 GeV/c
  - ◇ polarisibility of π and K, Primakoff
  - ◇ glue balls
  - ◇ charm decay

Status of the Compass experiment (tracking)

1998 Start of construction at CERN

2000 First stage of commissioning, few detectors

2001 Complete commissioning, first data taking

Status tracking detectors:

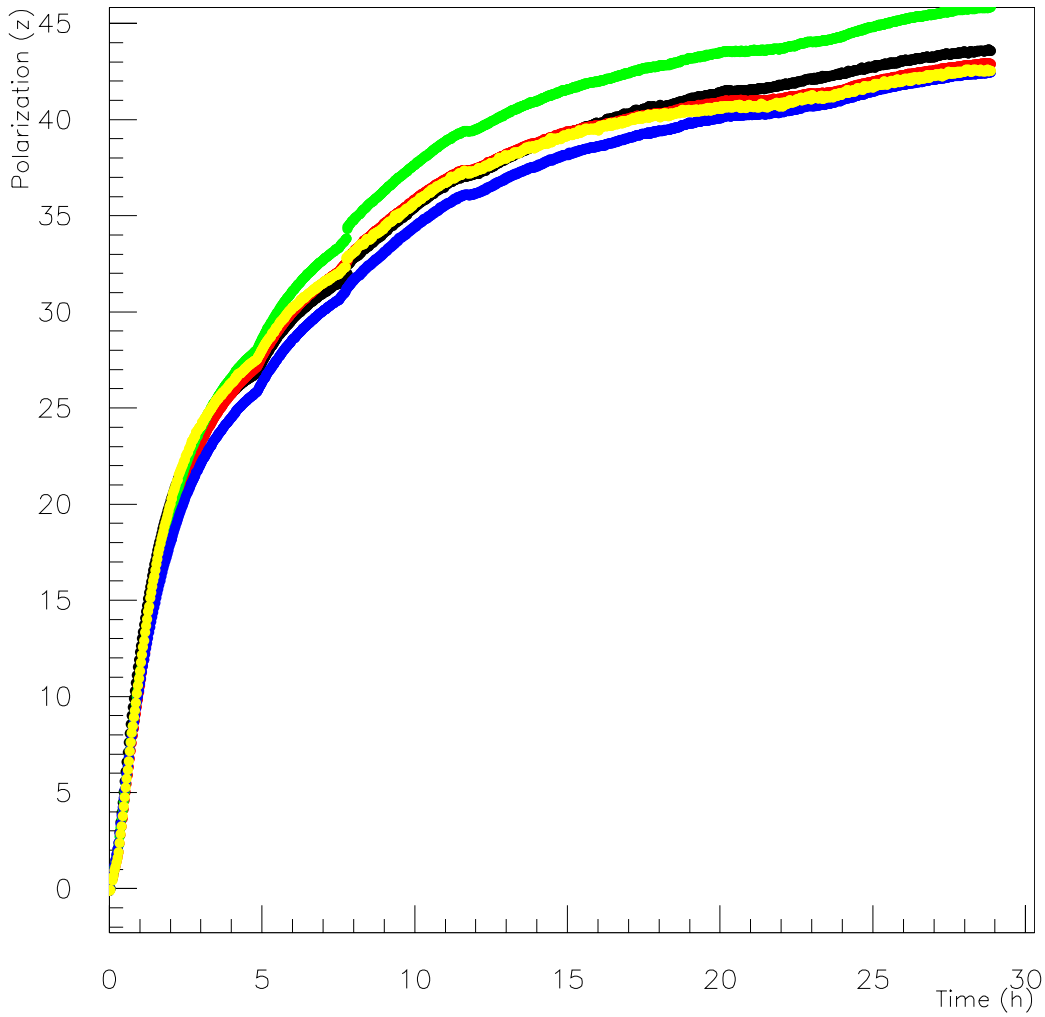
detector	# planes	fraction
SciFi	18	100 %
silicon	16	50 %
GEM	40	70 %
Micromegas	12	50 %
Drift	16	50 %
straws DL	15	27 %
MWPC	31	100 %
muon wall 1 DL†	8	10 %
muon wall 2 DL†	9	10 %

† prototype readout, inner muon identification by MWPC

Average: about 70 % operated in 2001!

Polarisation built-up

- target material ^{6}LiD ($^6\mathrm{Li} = \alpha + \mathrm{d}$)
- WR polarisations reached: +57 %, -49 %
  @ 2.5 Tesla field



COMPASS DATA TAKING 2001

- commissioning till Oct. 10
- smooth data taking for about two weeks
  with $2 \cdot 10^8$ muons/spill, 160 GeV
- complete 2001-detector
- 14 TByte of data with 30 kByte/event
- about 500 Mevents collected
- reconstruction started
- computing farm with 200 CPUs set up
- well on track for 2002 data taking: May 27 – Sep 10

Summary

- Excellent data on DIS from p, d, n targets
- Good description by NLO QCD
  however x, Q^2 range of data too small
- Δg, Δs hardly constrained
- first glimpse on transversity h_1
- semi-inclusive DIS:

  Δu, Δd well determined
  $\Delta\bar{q}$: $\Delta\bar{u} - \Delta\bar{d}$, $\Delta\bar{s}$, Δs hardly constrained
- GPDs: we saw tip of iceberg!

  GPDs cannot be mapped in full kinematic space
  combinations and special values measureable
  $\Rightarrow$ go exclusive
- new player COMPASS on track for 2002