Results from the HERMES experiment

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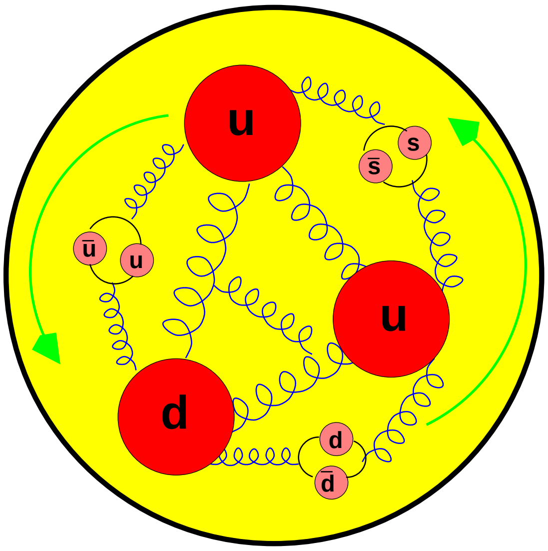
on behalf of the HERMES Collaboration

ECT* Conference on the Spin Structure of the Proton
Trento, July 23-28, 2001

- Introduction to polarised DIS
- The HERMES experiment
- Double-Spin Asymmetries
  - ▷ inclusive ⇒ Polarized SF g_1
  - ▷ semi-incl $h^{\pm}$ ⇒ Polarized PDF Δq
  - ▷ High p_t $h^{\pm}$ ⇒ Gluon polarization $\Delta G/G$
- Single-Spin Asymmetries
  - ▷ semi-incl $\pi^{\pm}$⇒ New polarised SF and FF
  - ▷ exclusive mesons and photons⇒ New SPD
- Unpolarised Physics
  - ▷ Sea Flavor Asymmetry
  - ▷ Multiplicity and FF
- Other Physics Results
- Summary

The Nucleon Spin



proton (neutron) = complex object with moving and interacting quarks (valence and sea) and gluons that contribute to the total spin

$$1/2 = 1/2\Sigma + \Delta G + \Delta L_{\mathrm{q/g}}$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$

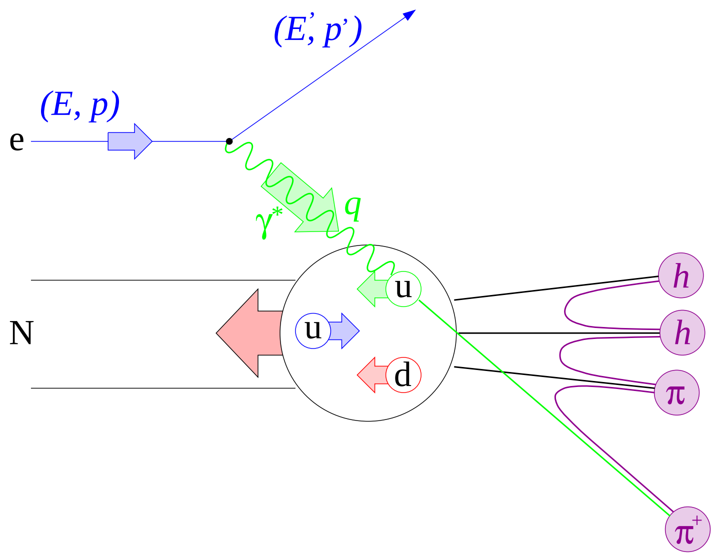
$$\Delta u + \Delta d = \Delta V \longrightarrow \text{inclusive}$$

$$\Delta s \longrightarrow \text{semi} - \text{inclusive}$$

$$\Delta G \longrightarrow \text{PGF}$$

$$\Delta L_{\mathrm{q/g}} = L_{\mathrm{q}} + L_{\mathrm{g}} \longrightarrow \text{GPD} \quad \text{(DVCS)?}$$

Polarised DIS



DIS Variables:

$$
\begin{array}{llllll}
Q^2 & \stackrel{lab}{=} & 4EE'\sin^2(\frac{\theta}{2}) & \nu & \stackrel{lab}{=} & E-E' \\
x & \stackrel{lab}{=} & \frac{Q^2}{2m\nu} & y & \stackrel{lab}{=} & \frac{\nu}{E}=\frac{p\cdot q}{p\cdot k} \\
W^2 & \stackrel{lab}{=} & -Q^2+M^2+2M\nu & z & \stackrel{lab}{=} & \frac{E_h}{\nu}
\end{array}
$$

- Inclusive: detect E'

  ▷ DIS limit : Q^2 (> 1 GeV^2) and ν ($\gg 1$ GeV) $\rightarrow$ elastic scattering on the parton

  ▷ x = DIS scaling variable = fraction of the proton momentum carried by the struck quark

- Semi-inclusive: detect E' and h

  ▷ z = SIDIS scaling variable = fraction of the energy of the quark carried by the hadron

How to measure g_1

Measurable Asymmetries:

$$A_{\parallel} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \qquad A_{\perp} = \frac{\sigma^{\uparrow\rightarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\uparrow\rightarrow} + \sigma^{\uparrow\leftarrow}}$$

$A_{\parallel} = D(A_1 + \eta A_2)$ where ηA_2 is small
$A_{\perp} = d(A_2 + \xi A_1)$
D, η, d, ξ are kinematic variables

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1}$$

$$A_2 = \frac{\sigma_{TL}}{\sigma_T} = \frac{\gamma(g_1 + g_2)}{F_1} \qquad \gamma = \frac{2Mx}{\sqrt{Q^2}}$$

Neglecting $g_2 \Longrightarrow g_1(x) \approx \frac{F_1(x)}{D} A_{\parallel}$

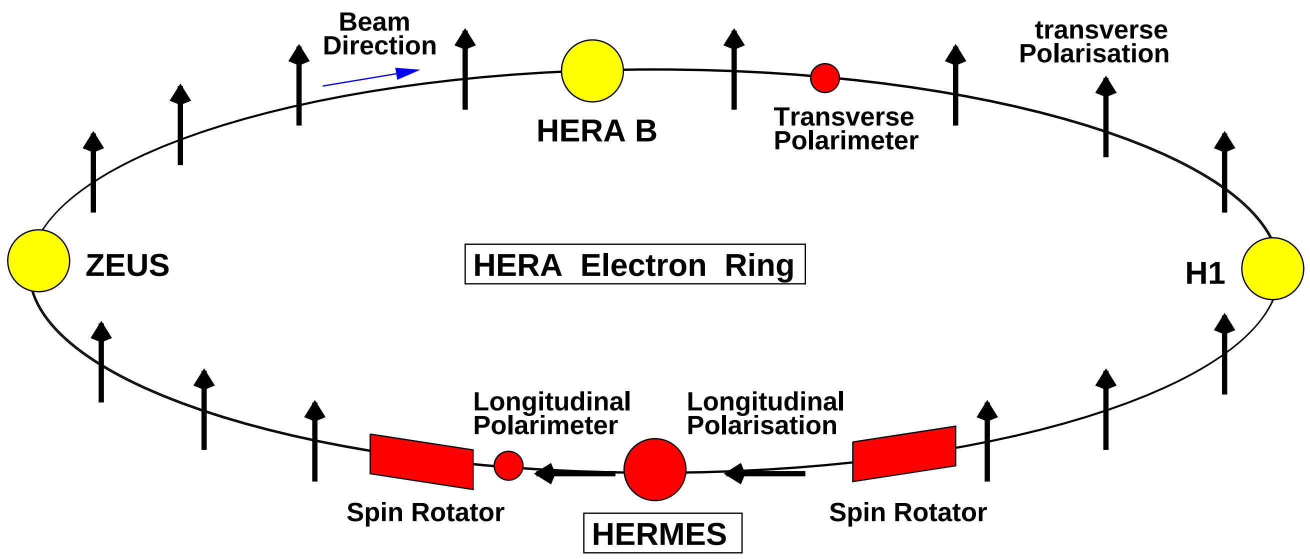
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \simeq \frac{g_1}{F_1} = \frac{\sum_f e_f^2 \, \Delta q_f(x, Q^2)}{\sum_f e_f^2 \, q_f(x, Q^2)}$$

D,d: virtual photon depolarization factor

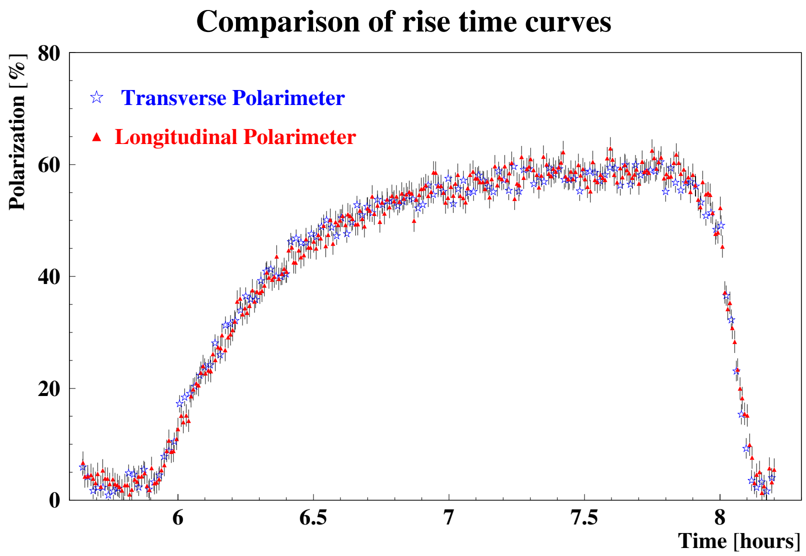
R: ratio of long. to trans. photo-absorption

ϵ: transverse pol. of the virtual photon

Polarised Beam

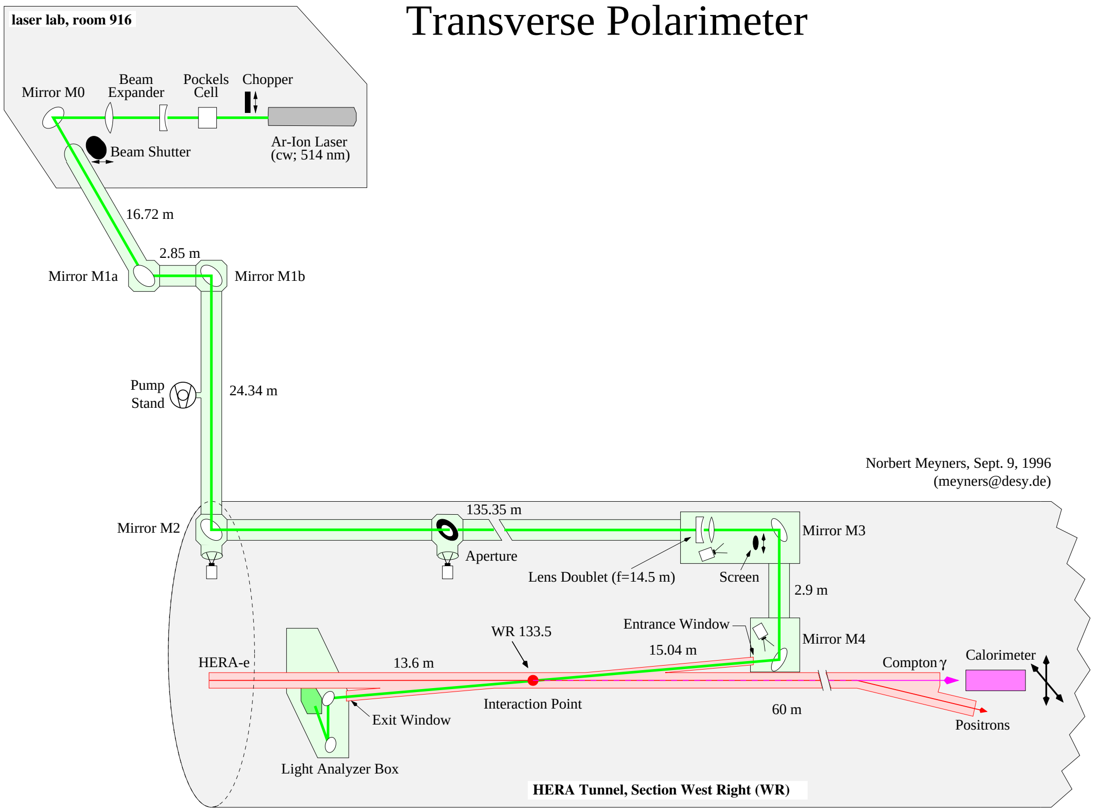


- 27.5 GeV e^+ (e^-), 10 mA$<I<$40 mA
- Emission of synchrotron radiation $\rightarrow$ self-polarization $P_b(t) = P_b^{\max}[1 - exp(t/\tau)]$
- Longitudinal polarization $\rightarrow$ spin rotators
- 2 Polarimeters (Compton laser backscattering)
- Average beam polarization $\langle P_b \rangle \approx 55\%$



Beam Polarimeters

Transverse Polarimeter



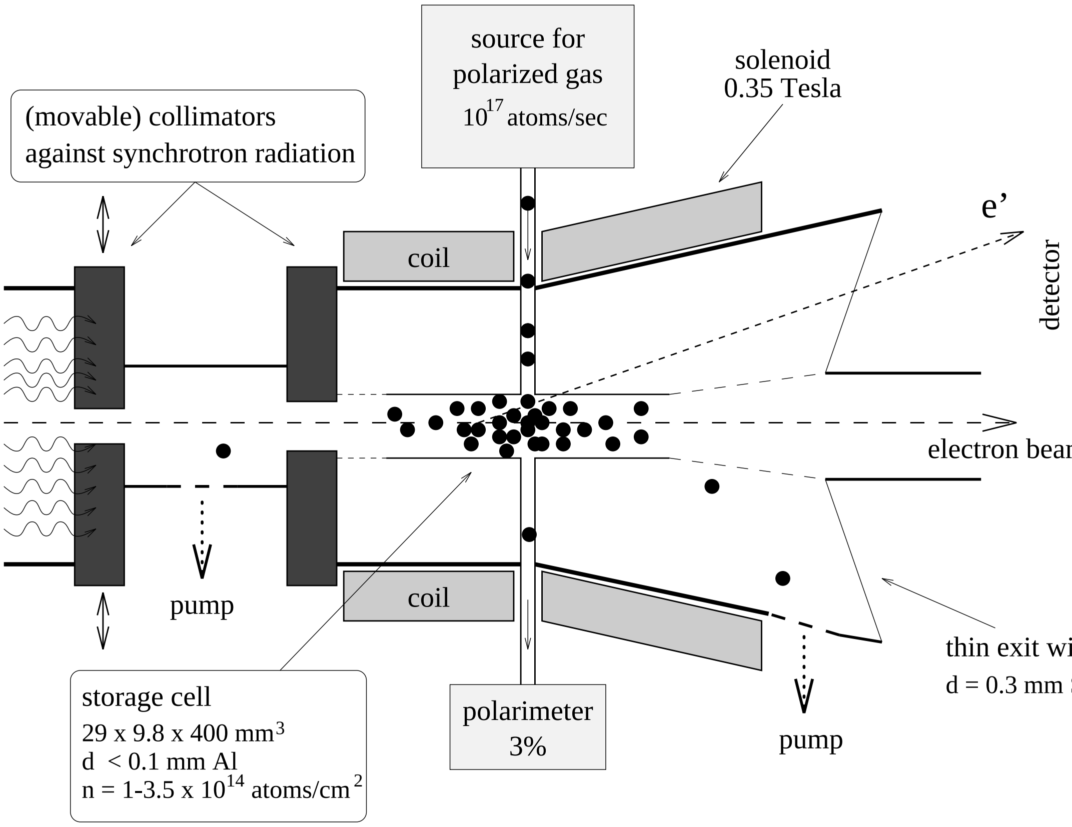
Transverse polarimeter : Compton scattering of circular polarised light with focus < 1 mm at 190 m. Up-down asymmetry in the calorimeter of $\sim 100\ \mu$m

NIM A329 (1993) 79, NIM A338 (1994) 166

Longitudinal polarimeter (high power pulsed Nd:YAG laser at 532 nm) : difference in the total energy deposited in the calorimeter by $10^3 - 10^4$ Compton photons per bunch

NIM A (2001), in press [DESY 00-106]

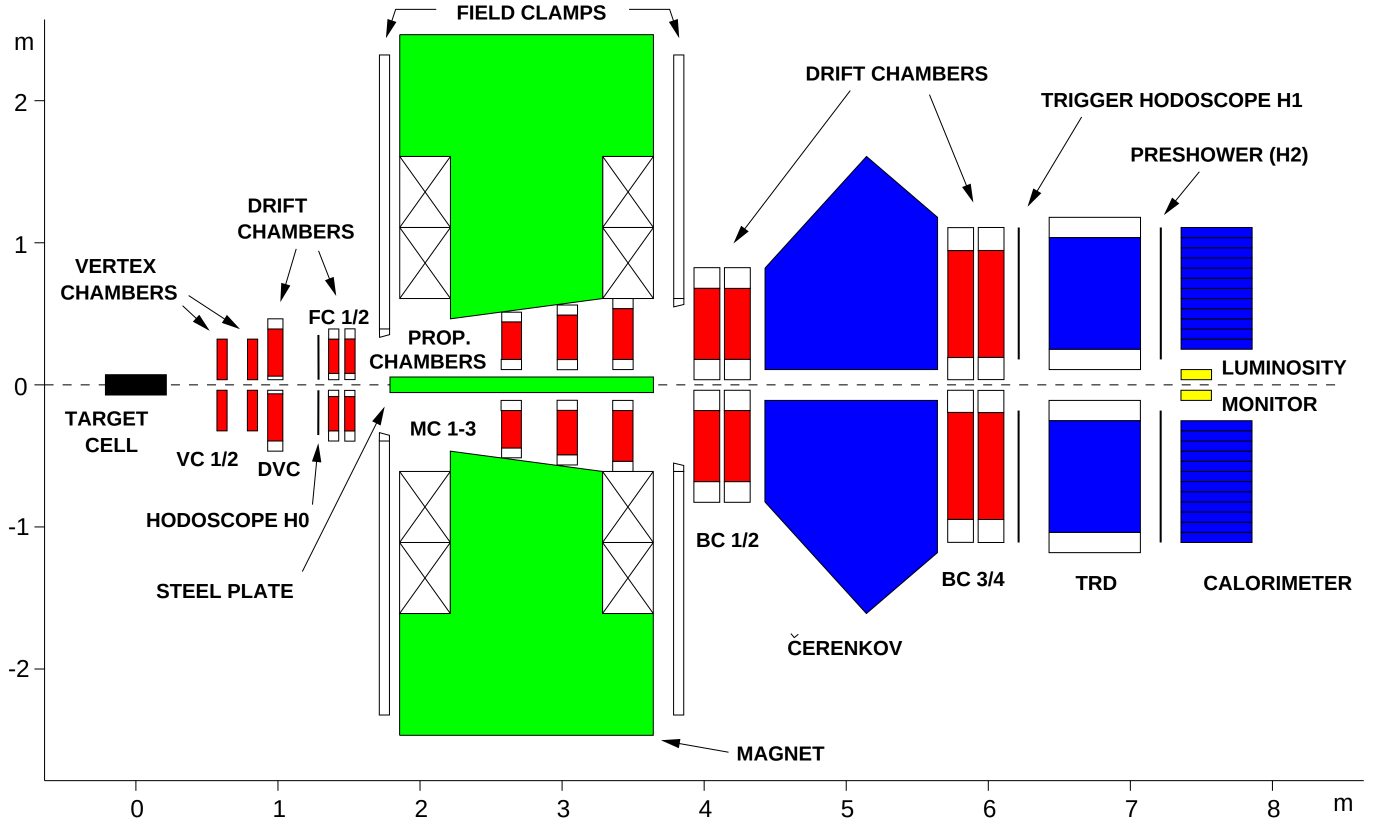
Polarised Internal Targets



- Pure (no dilution factor) gas target
- Laser driven polarised ^{3}He target ($p_T \sim 50\%$) in 95
- Atomic beam source for polarised H target ($p_T \sim 90\%$) in 96-97
- Atomic beam source for polarised D target ($p_T \sim 90\%$) in 98-00
- Transversely polarised H/D target in 01-..
- Unpolarised high density nuclear target (H, D, ^{3}He, ^{4}He, N, Ne, Kr) in 97-00

NIM A343 (1994) 334; Phys. Rev. Lett. 82(1999) 1164

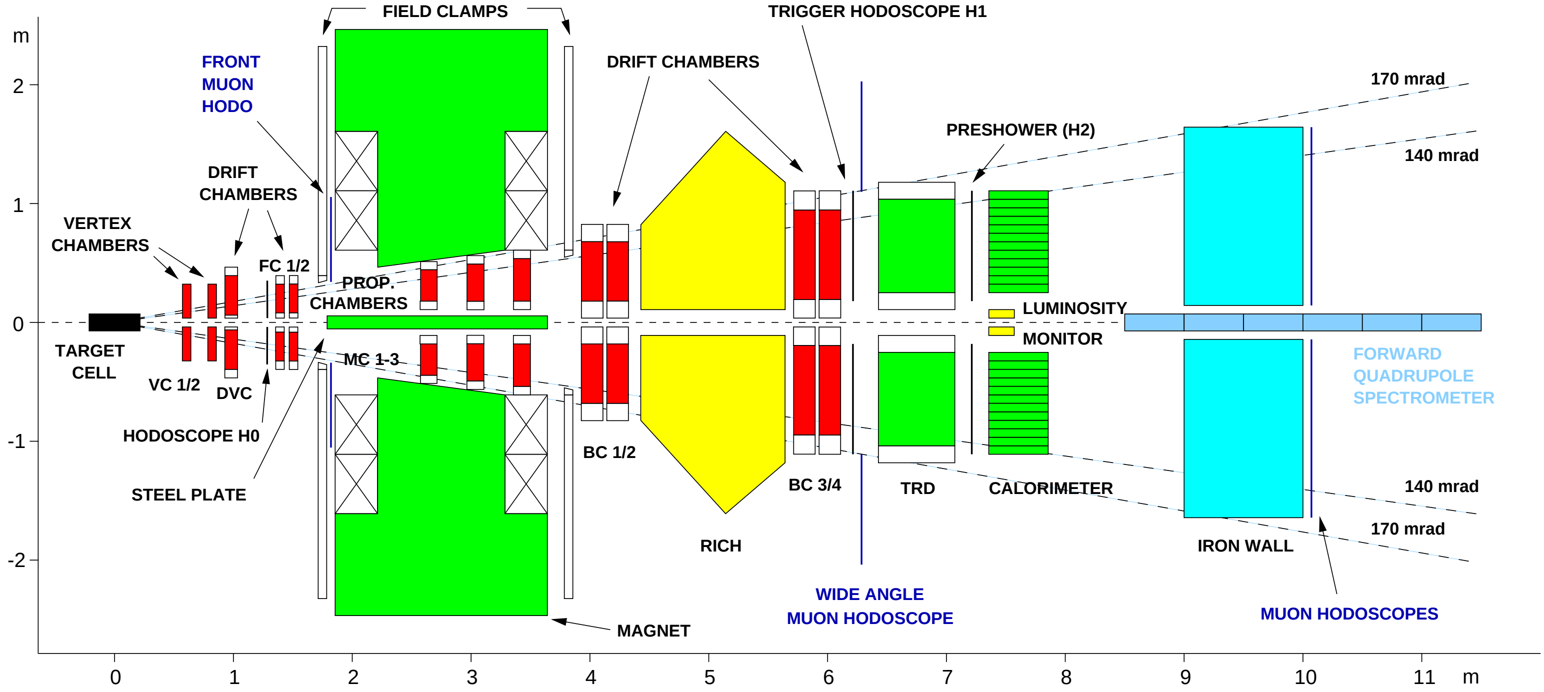
HERMES Spectrometer



- Forward dipole spectrometer:
  1.5 Tesla·m , $40 < \theta < 220$ mrad
- Charge particle tracking: 57 tracking planes,
  $\delta P/P = (0.7 - 1.3)\%$, $\delta\theta < 0.6$ mrad
- Calorimeter: 840 lead-glass blocks,
  $\delta E/E \sim 5\%/\sqrt{E}$, $\delta\theta \sim 1$ mrad
- Particle identification:
  Threshold Čerenkov, TRD, Preshower, Calorimeter

NIM A417 (1998) 230

HERMES Upgrade



- Double radiator [Aerogel (n=1.03) + C_4F_{10} gas (n=1.0014)] RICH detector for complete PID in 98
- Muon hodoscope for charm physics in 98
- Forward quadrupole spectrometer for low Q^2 physics in 99
- Large acceptance silicon detector Λ physics in 00
- Silicon recoil detector for exclusive physics in 01

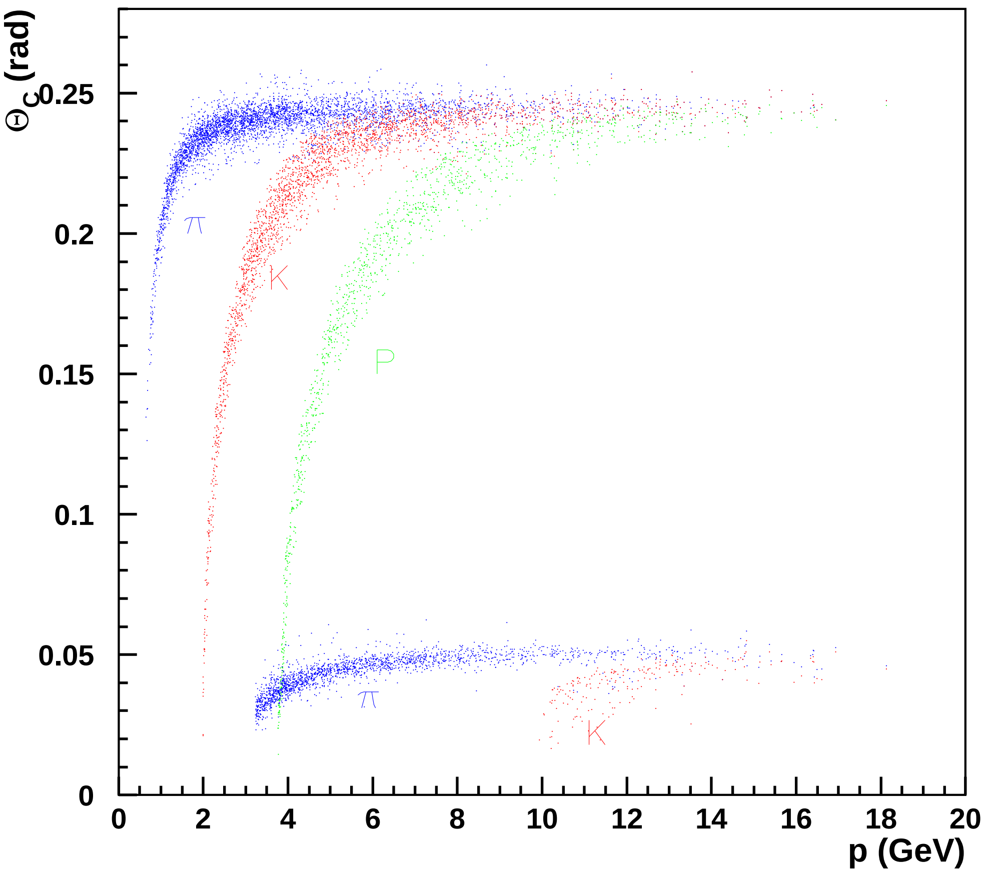
Particle Identification

- ('95-'97) Lepton-hadron separation $\rightarrow$
  Čerenkov + TRD + Preshower + Calo:
  - ▷ e^+ contamination $< 1\%$
  - ▷ $\pi^\pm$ identification $\rightarrow$ Čerenkov threshold:

$$4.5 \;\; GeV < P_{\pi^\pm} < 13.5 \;\; GeV$$

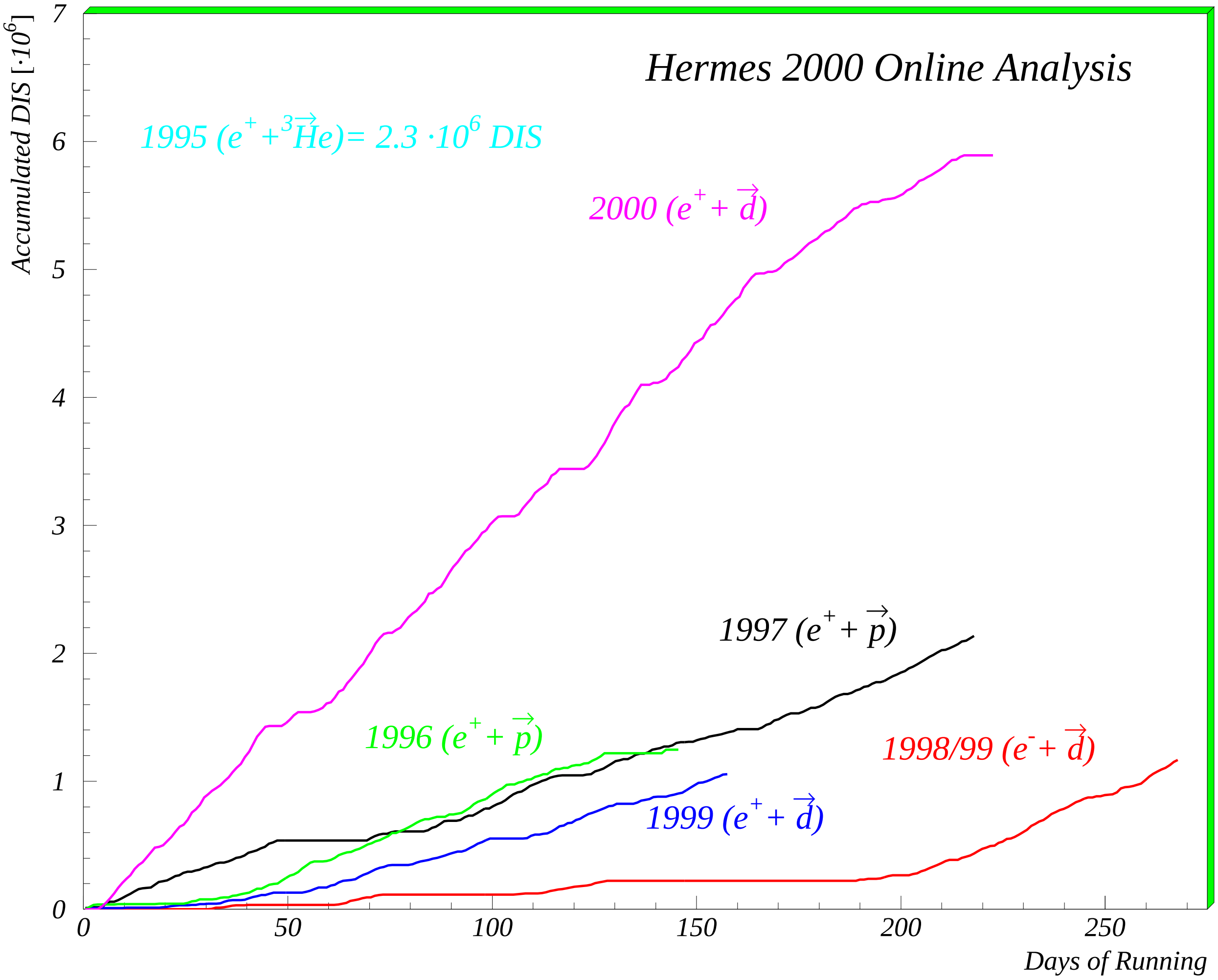
- (>'98) Hadron Identification $\rightarrow$ 2 RICH detectors:
  - ▷ Detection efficiencies:

$$93\% \; (\pi), \; 85\% \; (K), \; 85\% \; (p)$$



NIM A440 (2000) 338; NIM A (2001) to be publ.

HERMES data



Year	1995	1996	1997	1998	1999	2000
Target	$^3\overrightarrow{\mathrm{He}}$	$\overrightarrow{\mathrm{H}}$	$\overrightarrow{\mathrm{H}}$	$\overrightarrow{\mathrm{D}}$	$\overrightarrow{\mathrm{D}}$	$\overrightarrow{\mathrm{D}}$
DIS (x10^6)	2.2	0.7	1.5	1.0	1.1	5.5

2000

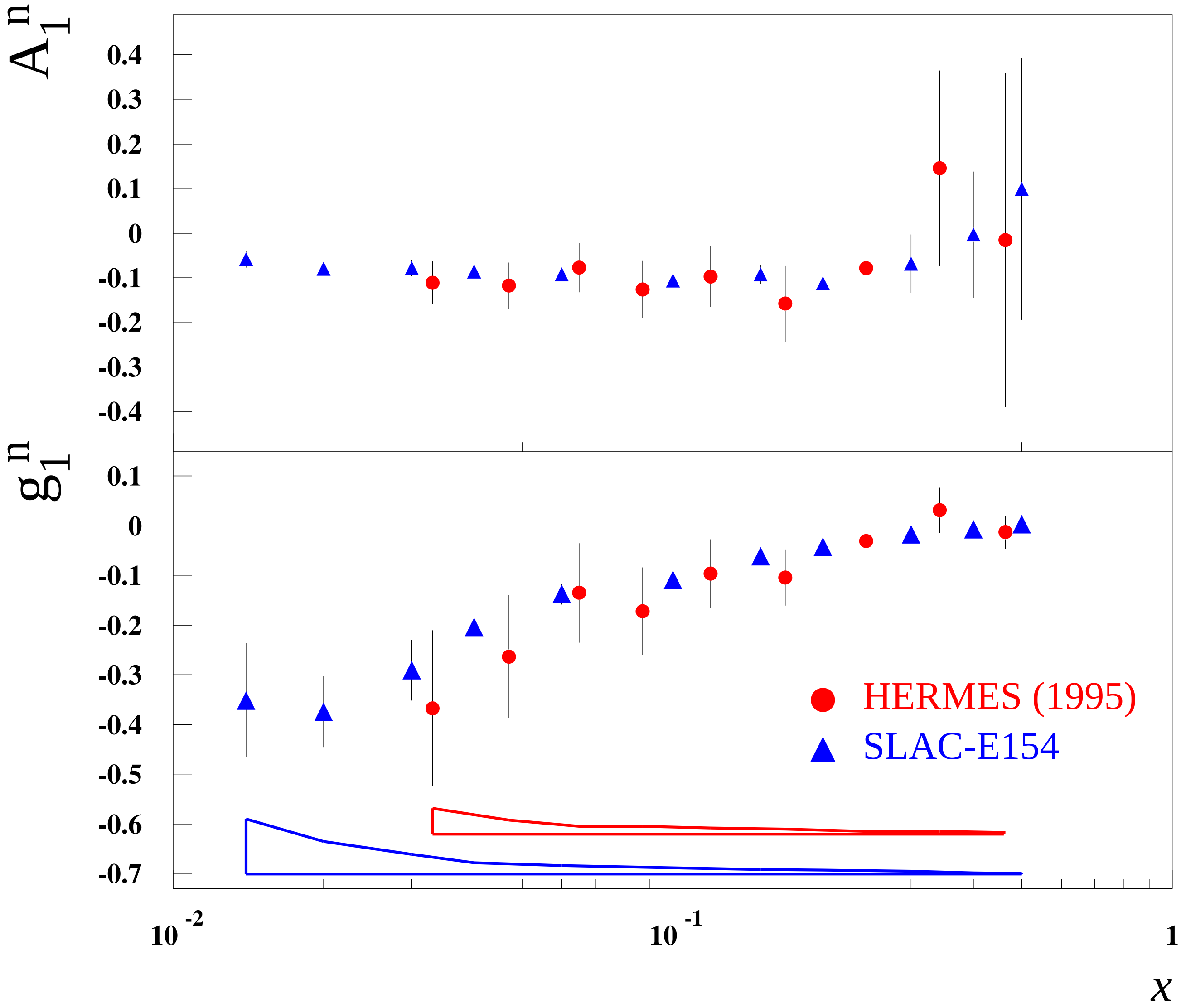
- 10x10^6 $\overrightarrow{\mathrm{D}}$ DIS events including low-x region
- 1x10^6 tensor-polarised D $\Longrightarrow$ first meas. of b_1^d
- 30x10^6 unpolar. gas (^{1}H, ^{2}D, ^{3}He, ^{14}N, ^{20}Ne, ^{84}Kr)

Spin SF $g_1^n(x)$

Target: $^3\overrightarrow{\mathrm{He}}$ (2 protons paired with spin 0)

$$A_1^{^3\mathrm{He}} \xrightarrow{\mathrm{Nucl.Corr.}} A_1^n$$

$$g_1^n \simeq A_1^n \cdot F_1^n = A_1^n \cdot \frac{F_2^n}{2x(1+R)}$$

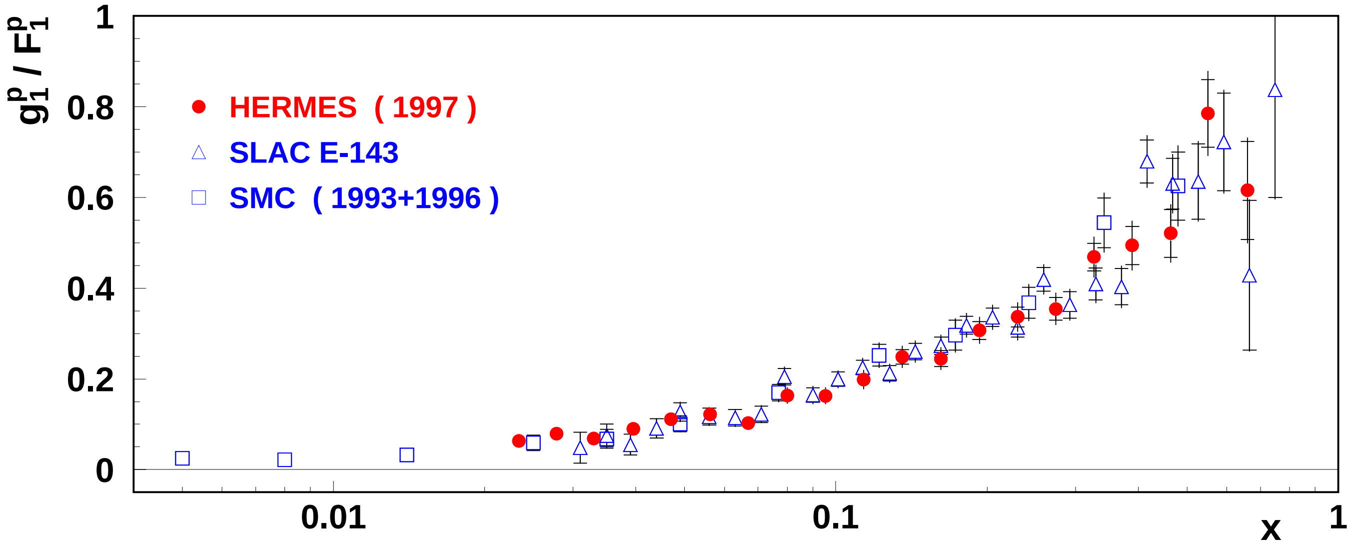


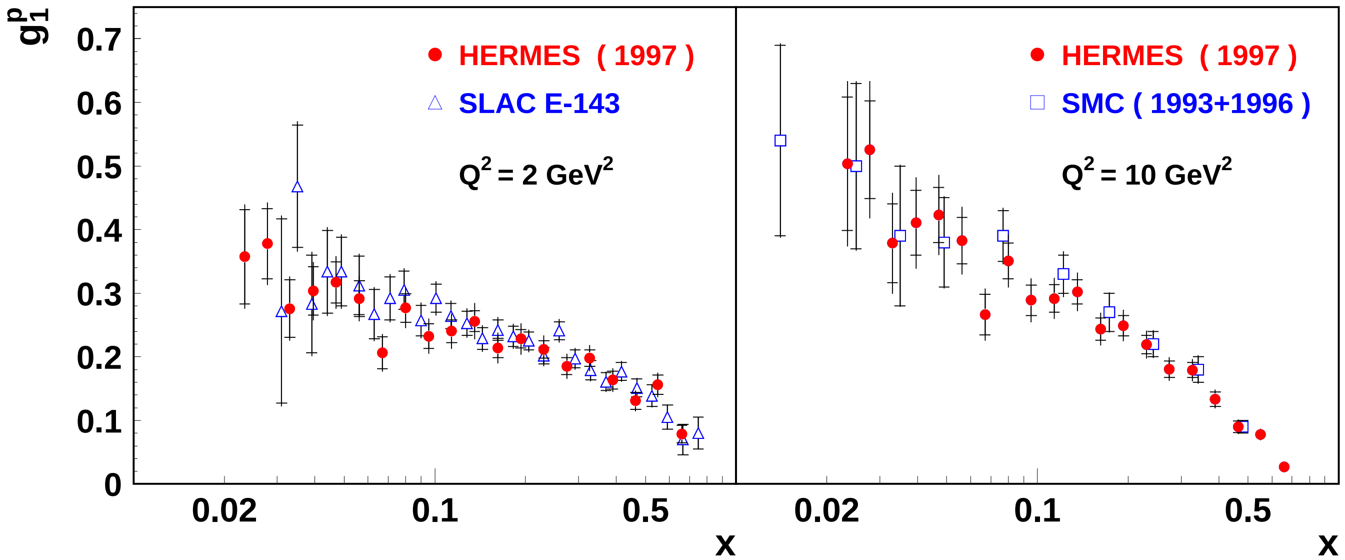
Phys. Lett. B404 (1997) 383

Spin SF $g_1^{\rm p}(x)$

Target: $\overrightarrow{\rm H}$

$$A_1^{\rm p} \simeq g_1^{\rm p}/F_1^{\rm p} \Rightarrow g_1^{\rm p} \simeq A_1^{\rm p} \cdot F_1^{\rm p} = A_1^{\rm p} \cdot \frac{F_2^{\rm p}}{2x(1+R)}$$



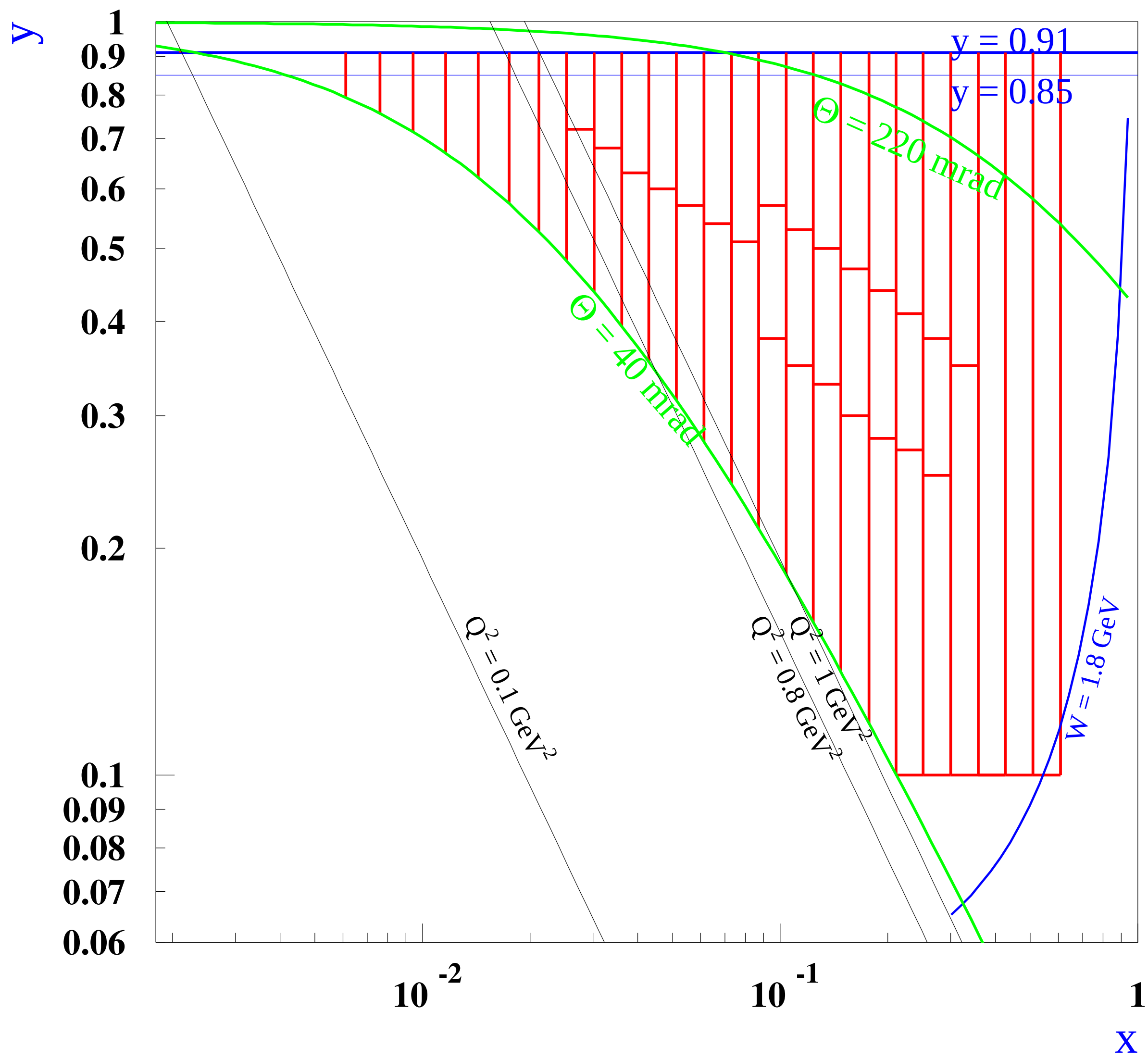


$0.02 < x < 0.85 \rightarrow 1$ (res); $y < 0.85$; $Q^2 > 0.8$ GeV^2

Phys. Lett. B442 (1998) 484

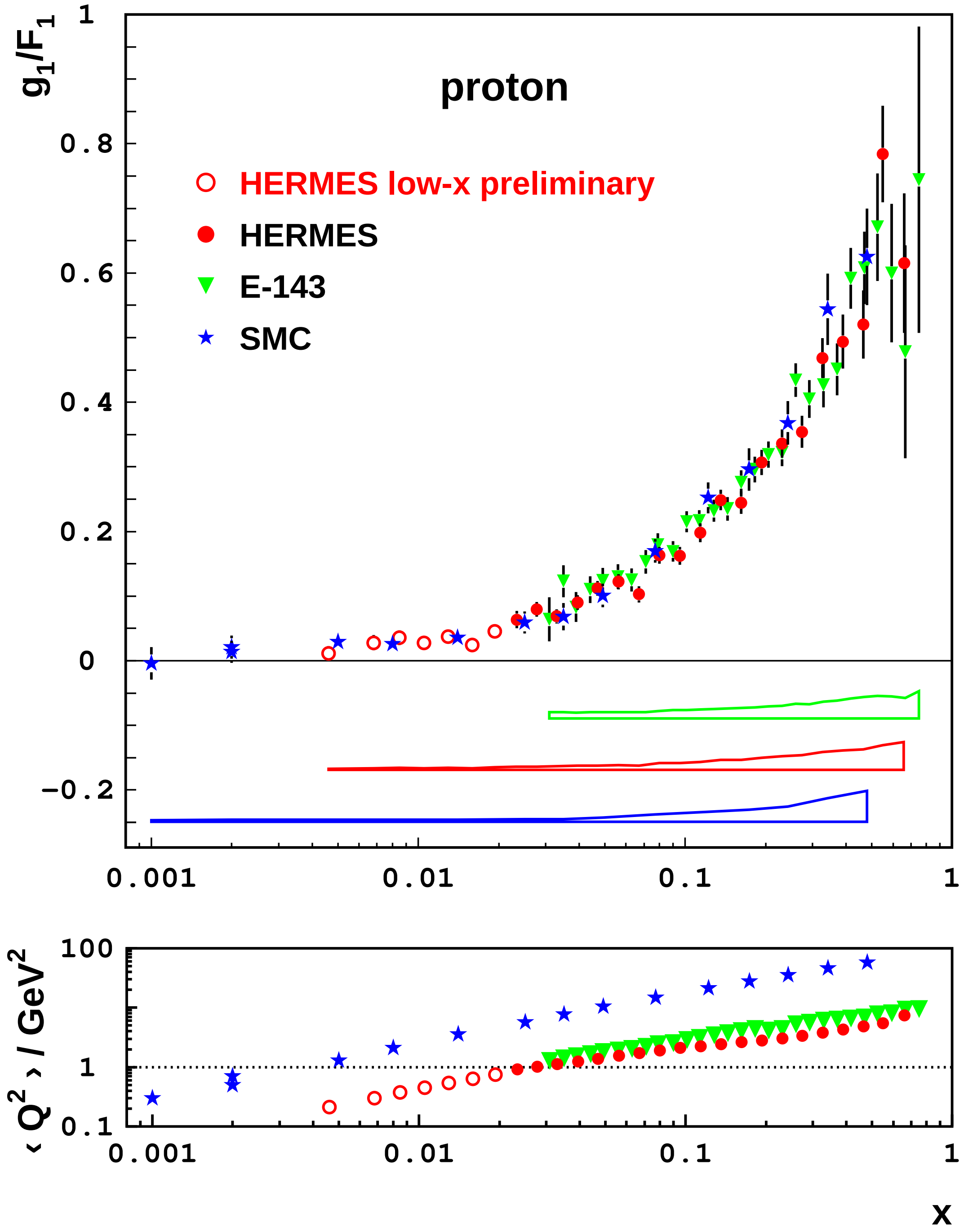
low-x data

- low x region is important for determining the quark contribution $\Delta\Sigma$ to the nucleon spin (extrapolation into the unmeasured region)
- low Q^2 provide new data for the study of scaling violations $\Longrightarrow$ indirect access of ΔG



$$0.002 \leftarrow 0.02 < x < 0.85;$$
$$0.1 < y < 0.85 \rightarrow 0.91;$$
$$0.1 \text{ GeV}^2 \leftarrow 0.8 < Q^2$$

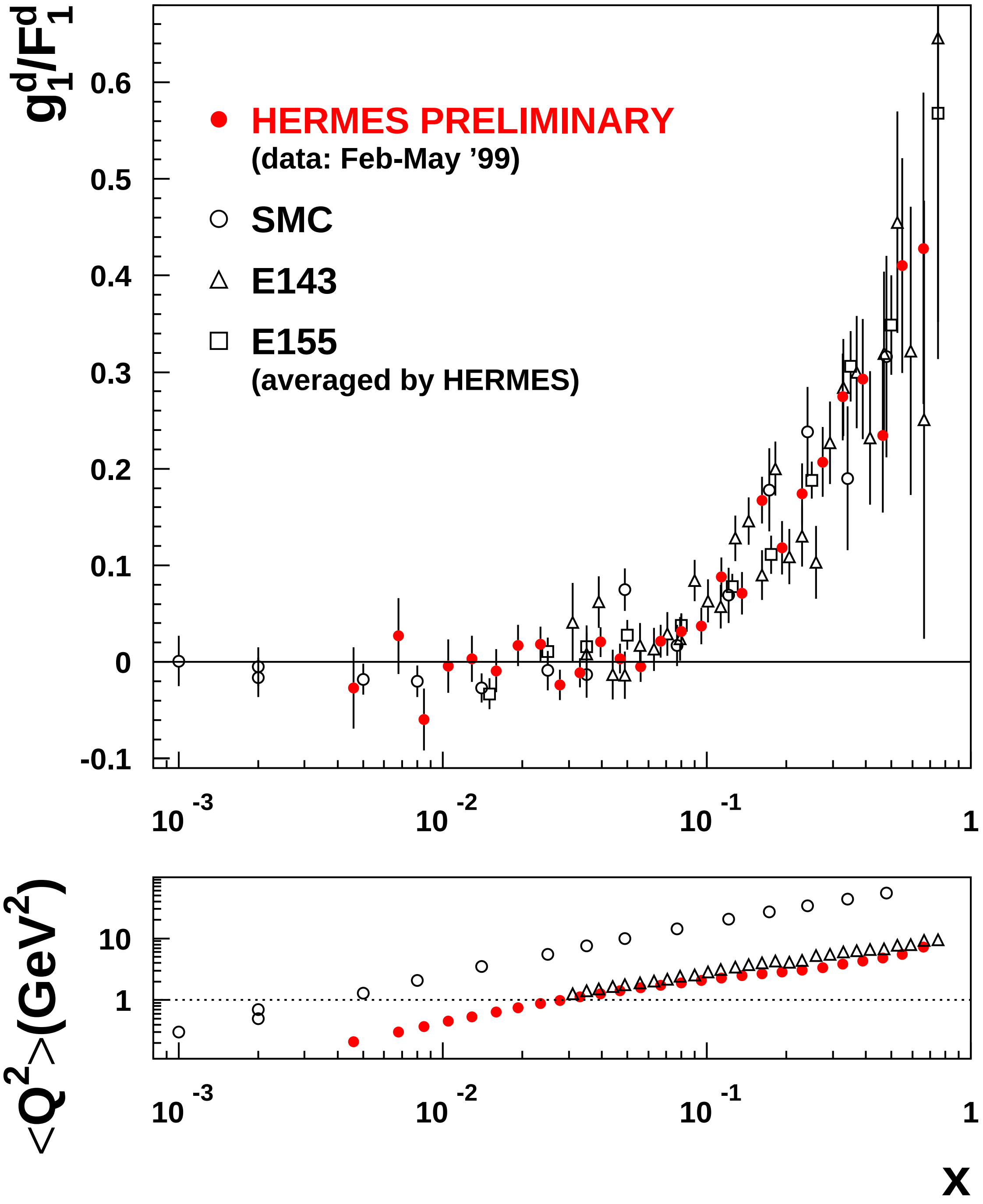
g_1^{p}/F_1 low-x data



$$0.002 < x < 0.85 \to 1 \text{ (res)}; \quad y < 0.91; \quad Q^2 > 0.1 \text{ GeV}^2$$

- very good agreement for g_1/F_1 with other data
- no statistically significant Q^2 dependence observed

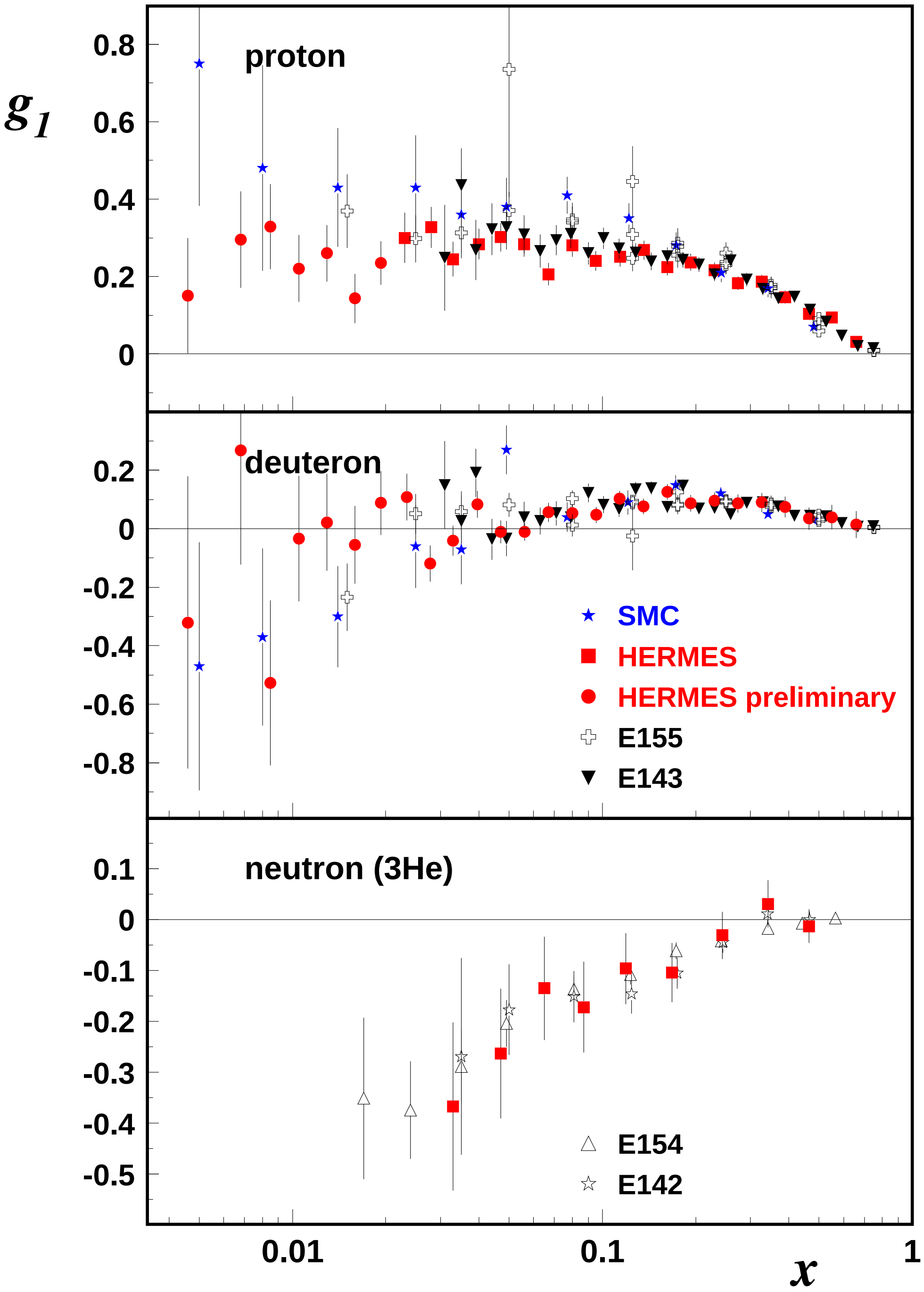
$g_1^{\rm d}(x)/F_1$



$0.02 < x < 0.85; \quad y < 0.85; \quad Q^2 > 0.8\ \mathrm{GeV}^2$

- good agreement for g_1/F_1 with other data
- no statistically significant Q^2 dependence observed
- more precise data needed (1/6 data available)

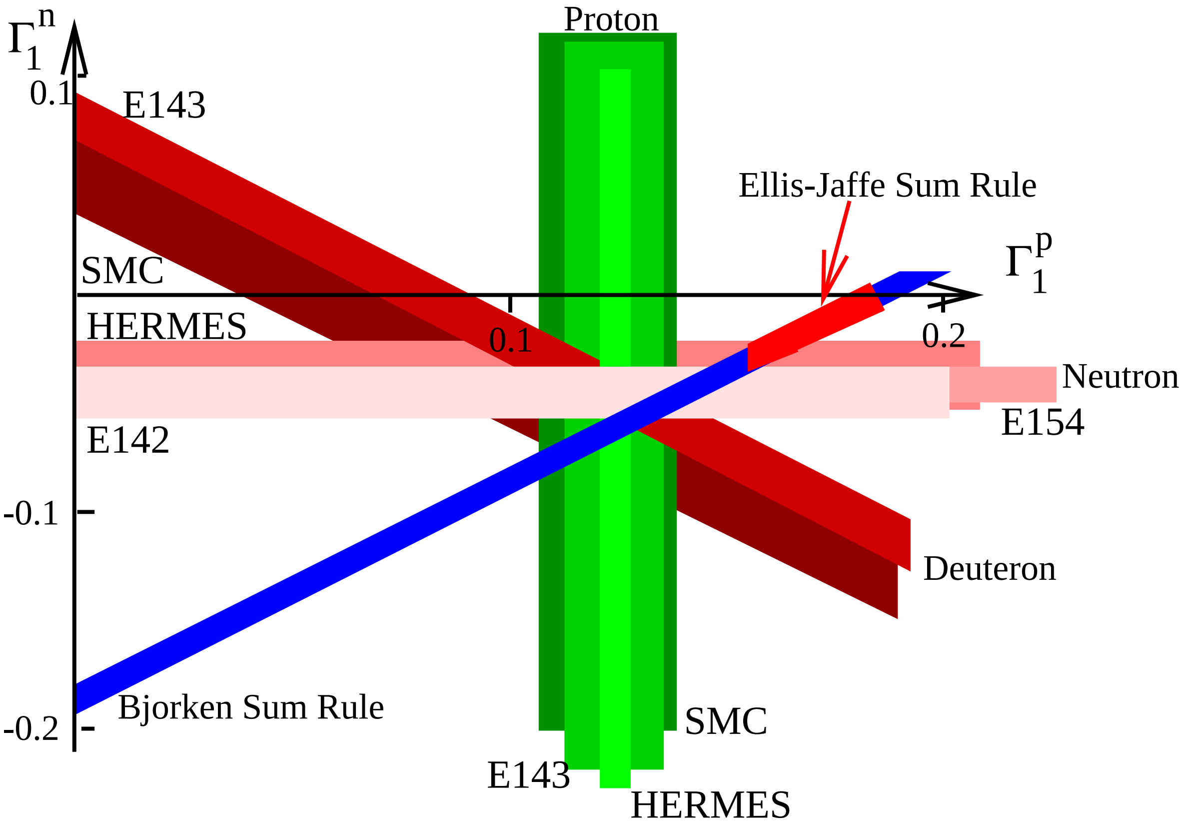
Nucleon Spin SF $g_1(x)$



Data points at measured Q^2 values
SMC data shown for Q^2 >1 GeV^2

Full statistics will allow the precise determination of the Bjorken, Ellis-Jaffe, Generalized GDH sum rules

Bjorken sum rule



$$\Gamma_1^p = \int_{x=0}^{x=1} g_1^p(x)dx \quad \Gamma_1^n = \int_{x=0}^{x=1} g_1^n(x)dx$$

- Bjorken Sum Rule OK @ 10% level
- $\Delta\Sigma \approx 0.3$ small fraction of the nucleon spin is carried by quarks
- New results expected for Deuteron (HERMES) and Proton (E155)

GDH Sum Rule

The GDH sum rule relates the anomalous contribution κ to the magnetic moment of the nucleon ($\kappa_{\rm p}$=1.79, $\kappa_{\rm n}$=−1.91) with the total absorption cross sections for circularly polarised real photons on polarised nucleons:

$$\int_0^\infty \left[\sigma_{1/2}(\nu) - \sigma_{3/2}(\nu)\right] \frac{d\nu}{\nu} = -\frac{2\pi^2\alpha}{M^2}\kappa^2$$

Never been tested directly

The integral can be generalised to the absorption of virtual photons with energy ν and squared four-momentum $-Q^2$:

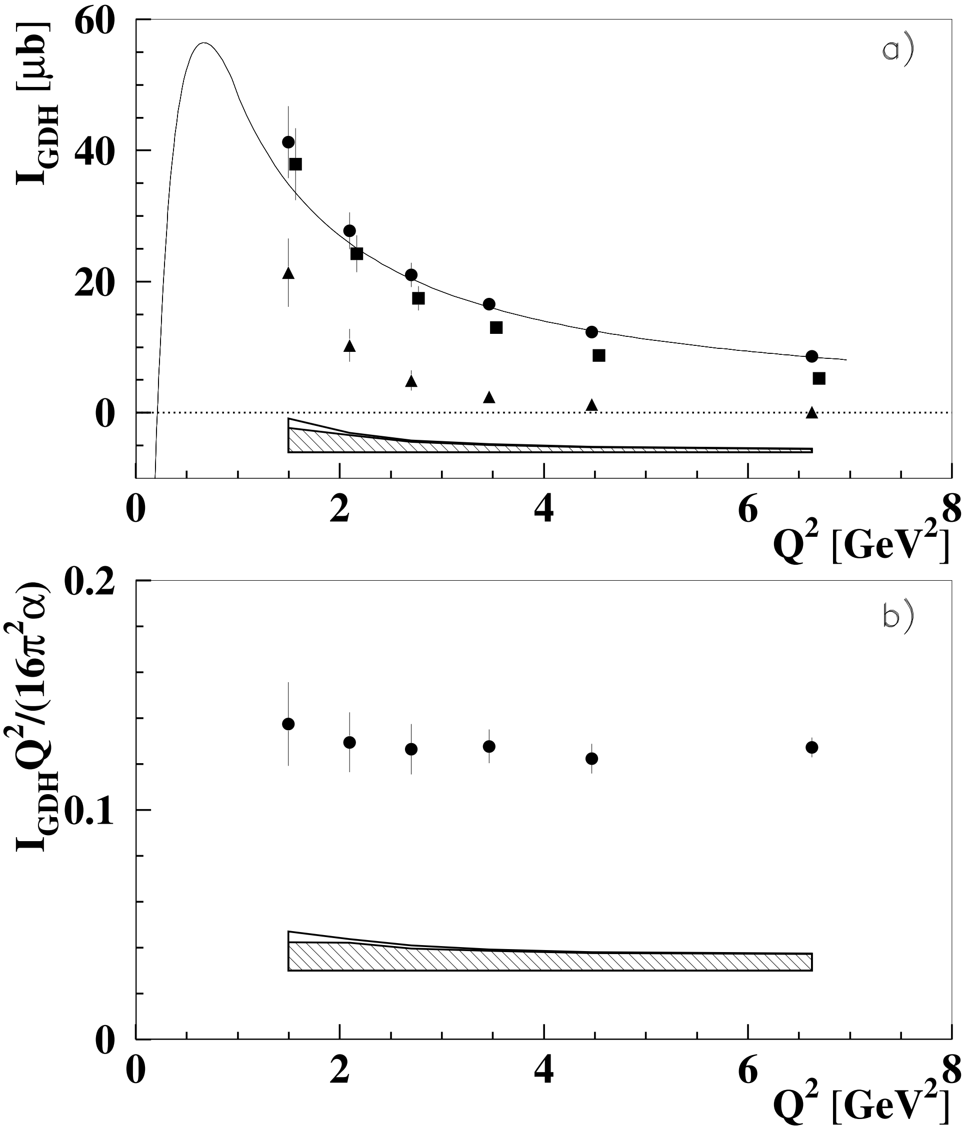
$$I(Q^2) \equiv \int_{Q^2/2M}^\infty \left[\sigma_{1/2}(\nu,Q^2) - \sigma_{3/2}(\nu,Q^2)\right] \frac{d\nu}{\nu}$$

$$= \frac{8\pi^2\alpha}{M} \int_0^1 \frac{g_1(x,Q^2) - \gamma^2 g_2(x,Q^2)}{K} \frac{dx}{x}$$

$I(Q^2)$ connects the GDH expectation for real photon with the Ellis-Jaffe (or Bjorken in the case of p-n) in the asymptotic region

The Q^2 dependence of $I(Q^2)$ connects the static ground state properties of the nucleon with its helicity structure as measured in inelastic scattering in the resonance and deep inelastic regions

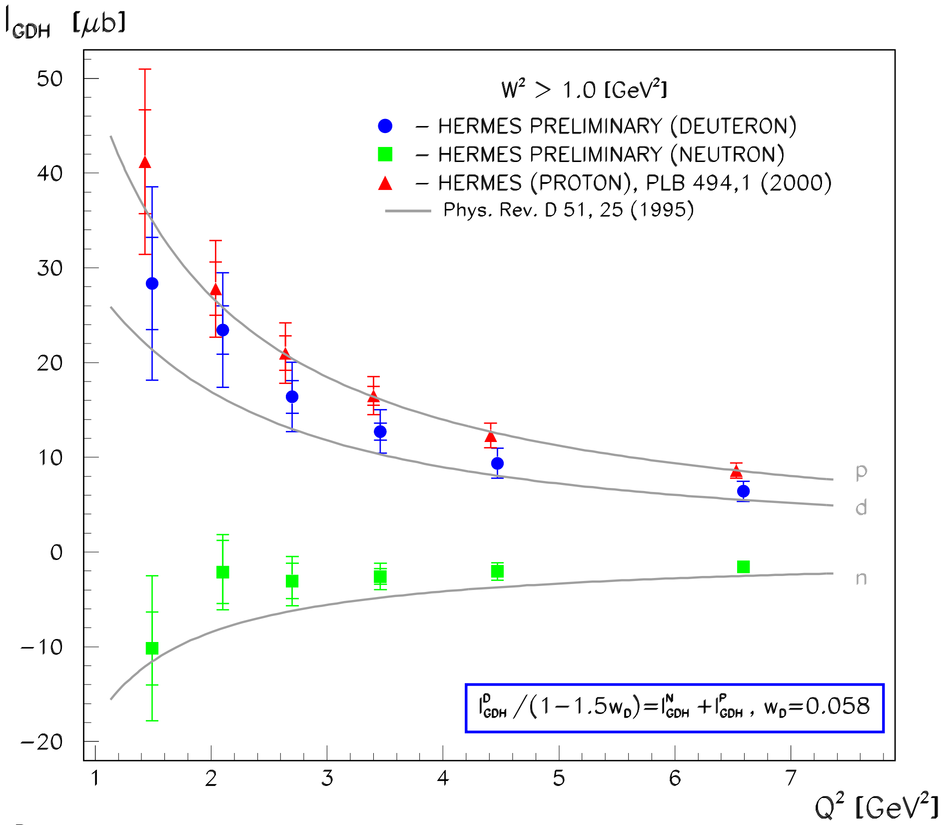
Proton GDH Sum Rule

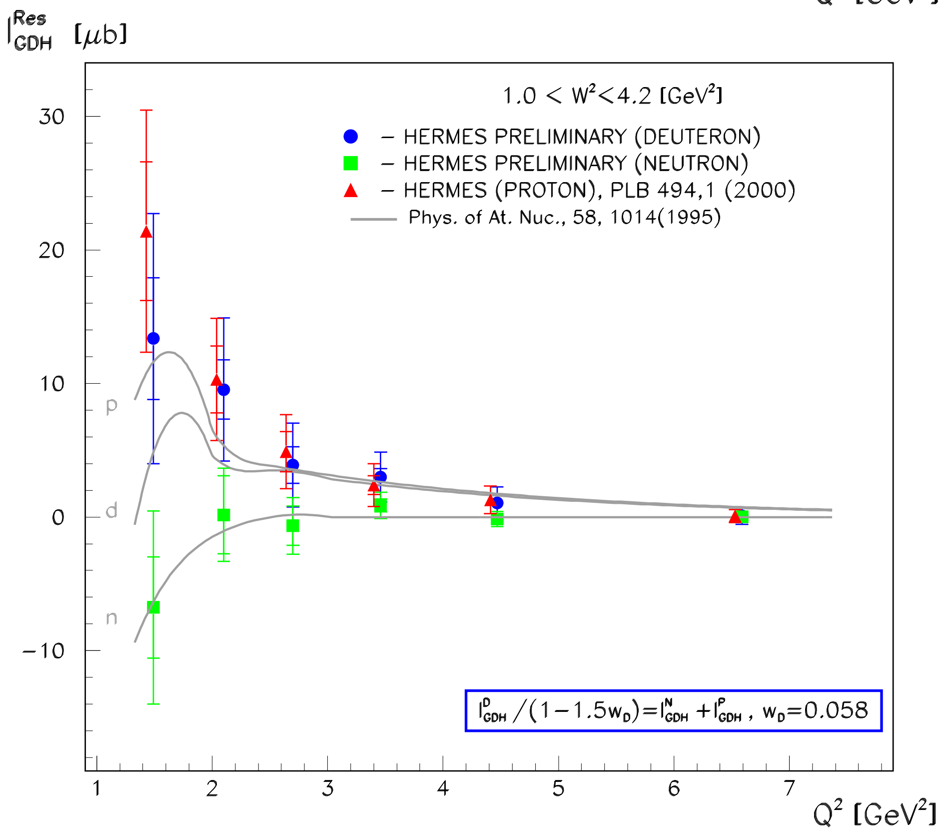


- $I_{\mathrm{GDH}}^{\mathrm{res}}$ small for Q^2 above 2 GeV^2
- Prediction in reasonable agreement with exp. data
- I_{GDH} consistent with $1/Q^2$ law
- No sign of resonance excitation or higher twist effects in the GDH sum rule for Q^2 > 1.5 GeV^2
- The strong turn down of $I(Q^2)$ towards the real photon prediction of -204 μb should occur at Q^2 lower than 1.2 GeV^2

Phys. Lett. B444 (1998) 484; Phys. Lett. B494 (2000) 1

Neutron, Deuteron GDH





No sign of resonance excitation or higher twist effects in the GDH sum rule for $Q^2 > 1.5$ GeV^2

Duality

Duality = Relation between the DIS region and the resonance region in lepton hadron scattering

The smooth scaling curve measured in DIS processes at high Q^2 is in average equal to the curve measured in the nucleon resonance region at lower Q^2 for a fixed range of the Bjorken variable scaling x.

This can be checked comparing the integrals of the structure function in the DIS and resonance region, in the same x interval

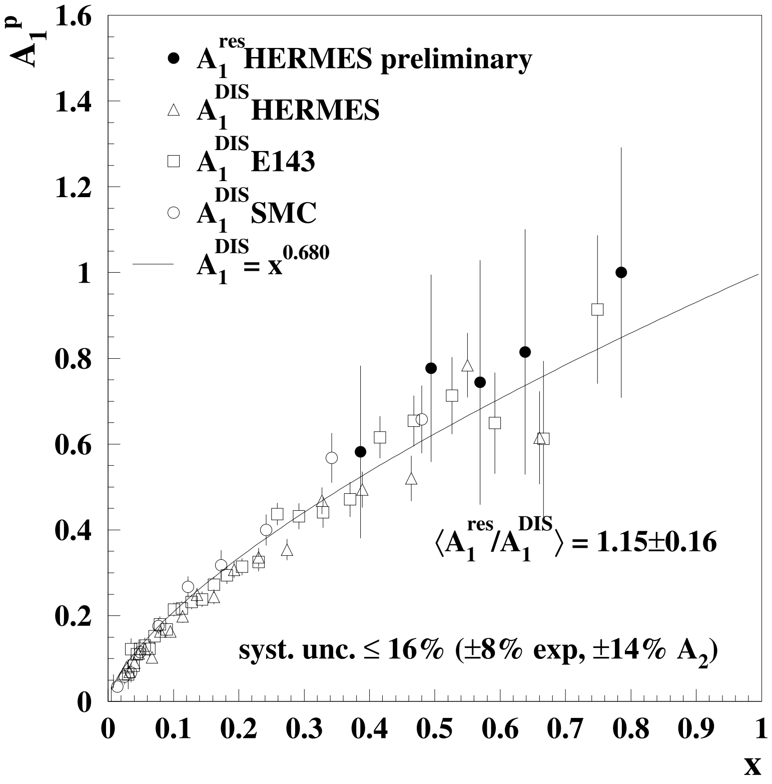
$\int_{x_m}^{x_M} F_2^{Res}(x)\, dx \,/ \int_{x_m}^{x_M} F_2^{Scaling}(x)\, dx$
independent of $Q^2 \Longrightarrow$ first test of duality

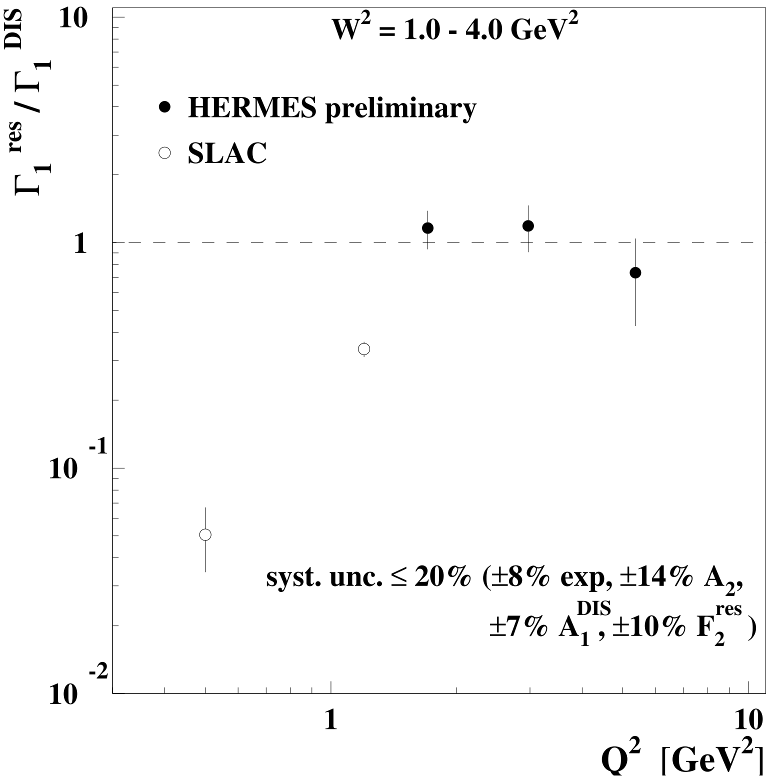
→ Resonances oscillate around an average scaling curve
→ The resonance strengths average to a global scaling curve if averaged over large kinematic region
→ Resonance region can be described in terms of quark degrees of freedom

Quark-hadron duality in spin structure function non trivial for the different helicities amplitude of the nucleon resonance
The Δ resonance is the dominant nucleon resonance in the photon case (Q^2=0) and has opposite helicity of the polarised DIS processes

- HERMES $\Longrightarrow$ first study of duality for polarised structure functions

Duality for Proton





$\Longrightarrow$ Onset of duality for $Q^2 \approx 1.7$ GeV^2

Semi-inclusive asymmetry

Correlation between struck q_f and detected h

$$A_1^{\mathrm{h}}(x,Q^2) \simeq \frac{g_1^{\mathrm{h}}(x,Q^2)}{F_1^{\mathrm{h}}(x,Q^2)} = \frac{\int dz \sum_f e_f^2 \Delta q_f(x,Q^2) D_f^{\mathrm{h}}(z,Q^2)}{\int dz \sum_f e_f^2 q_f(x,Q^2) D_f^{\mathrm{h}}(z,Q^2)}$$

- A_1^{h} = Measured semi-inclusive asymmetry
- Δq_f (q_f) = Polarized (unpolarized) quark distributions
- $D_f^{\mathrm{h}}(z)$ = Fragmentation Functions (FF) $\Longrightarrow$ probability of a given flavor f to produce a given type of leading hadron

<u>Unpolarized inputs:</u>

- $q_f(x,Q^2)$ parameterization
- $D_f^{\mathrm{h}}(z,Q^2)$ from LUND MC

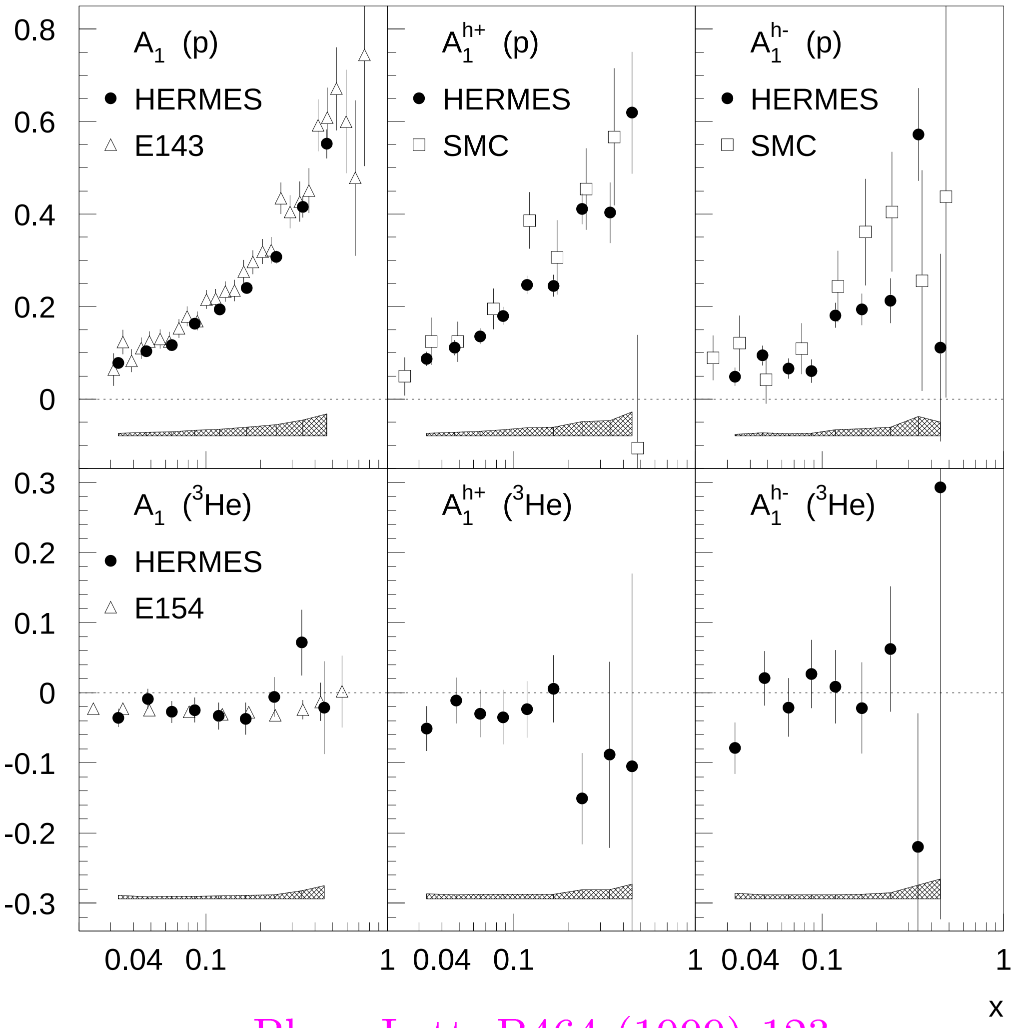
<u>Assumptions:</u>

- Factorization (DIS, hadronisation)
- Fragmentation functions spin-independent

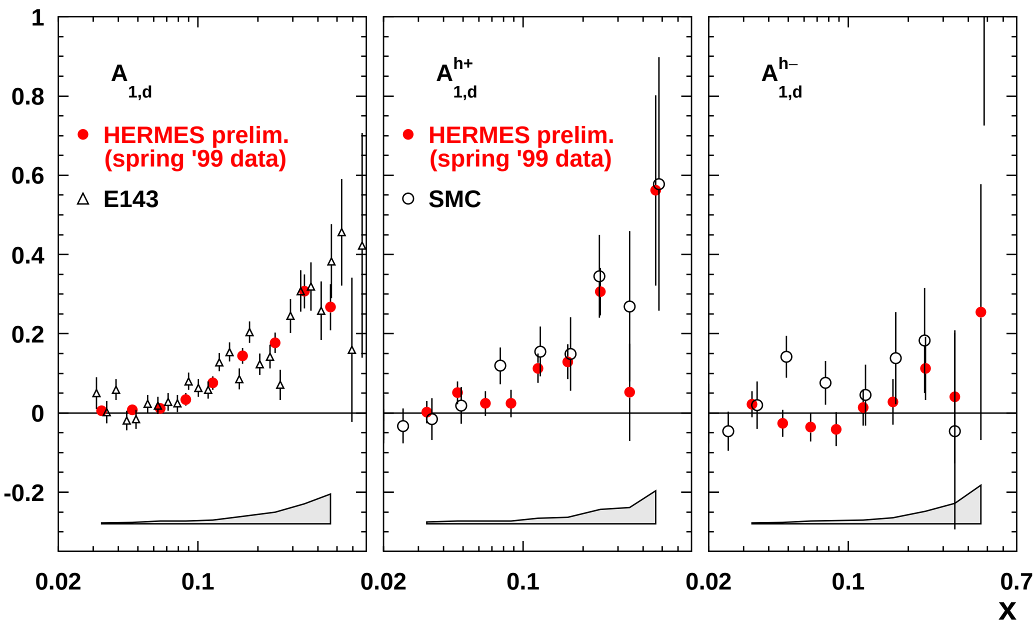
Hadron asymmetries

Data: $^3\overrightarrow{\mathrm{He}}$ (1995), $\overrightarrow{\mathrm{H}}$ (1996+1997), $\overrightarrow{\mathrm{D}}$ (spring 1999)

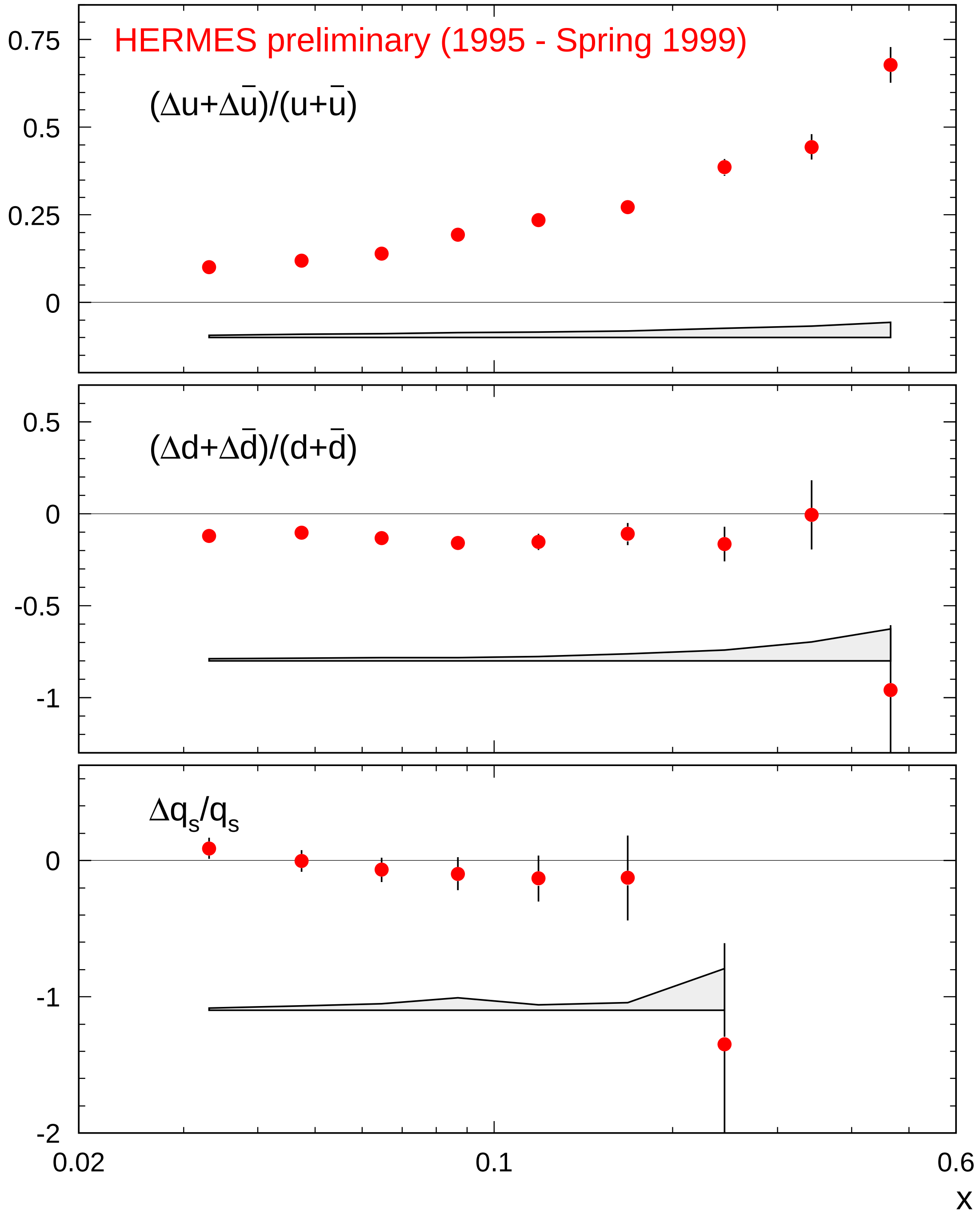
$z = E_h/\nu \geq 0.2$ $\quad x_F \geq 0.1$ $\quad W^2 \geq 10$ GeV^2



Phys. Lett. B464 (1999) 123



Flavor Decomposition

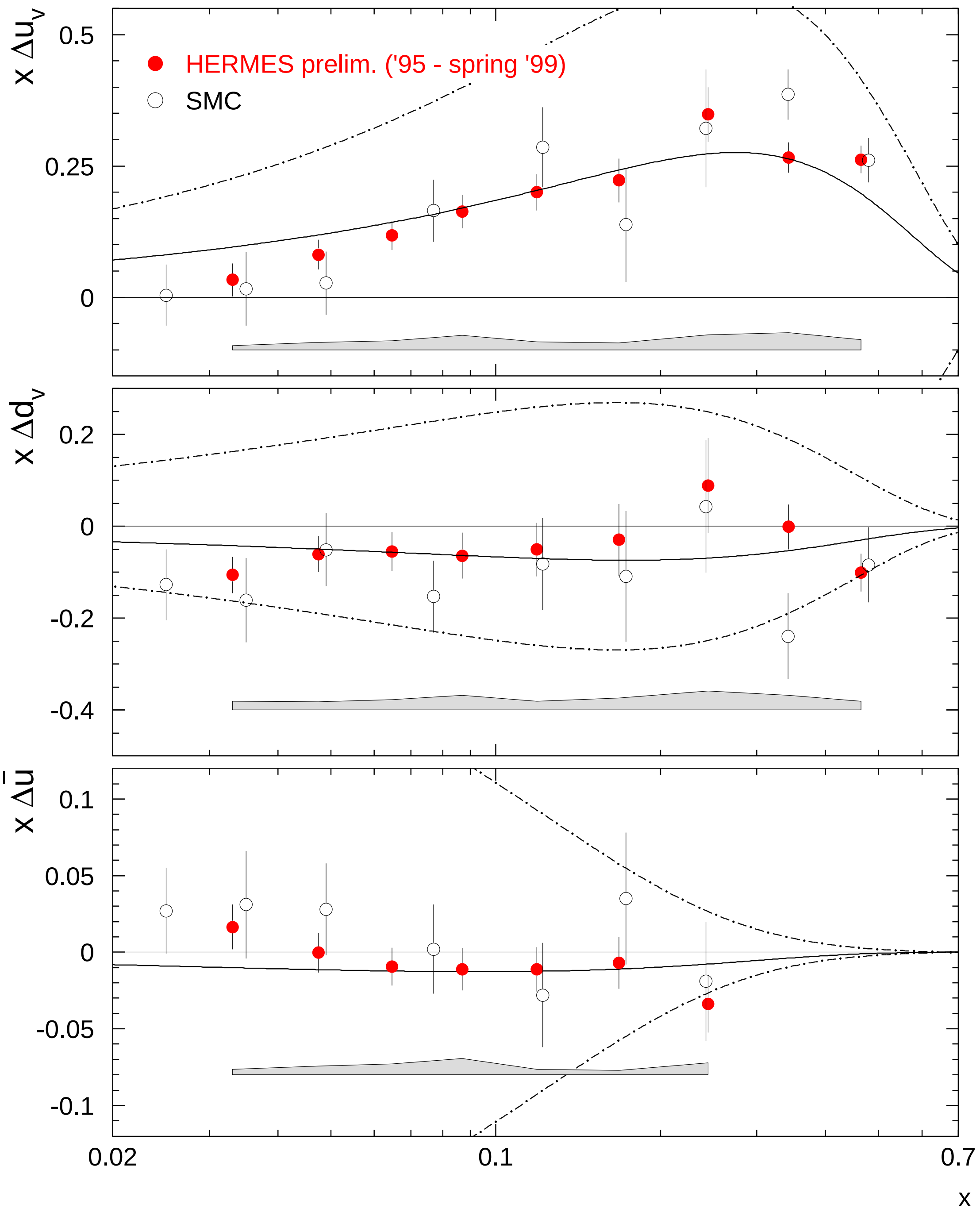


Insensitivity to the choice of sea model:

$$\frac{\Delta q_s(x)}{q_s(x)} = \frac{\Delta u_s(x)}{u_s(x)} = \frac{\Delta d_s(x)}{d_s(x)} = \frac{\Delta s(x)}{s(x)} = \frac{\Delta \overline{u}(x)}{\overline{u}(x)} = \frac{\Delta \overline{d}(x)}{\overline{d}(x)} = \frac{\Delta \overline{s}(x)}{\overline{s}(x)}$$

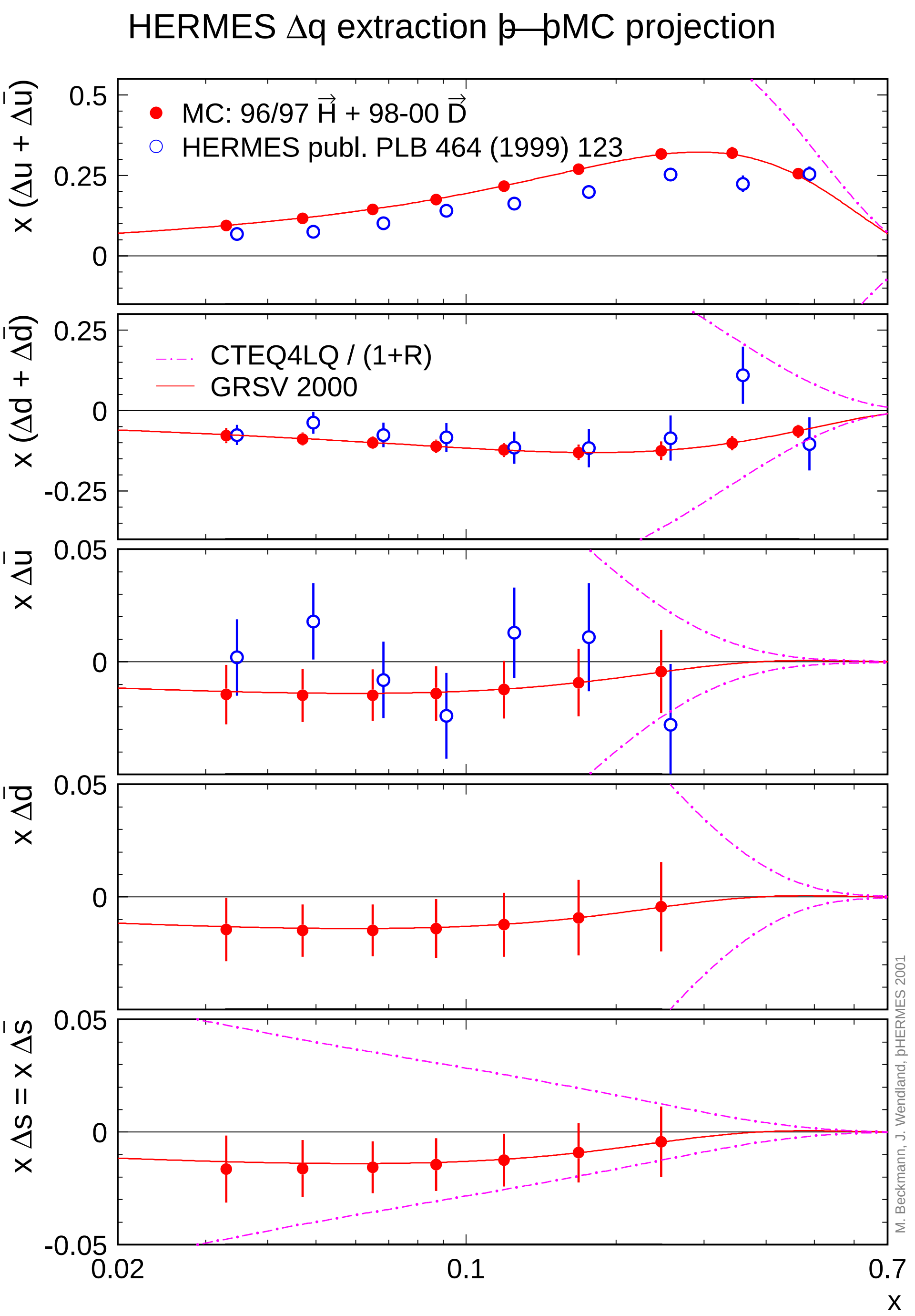
$$\Delta q_s(x) = \Delta u_s(x) = \Delta d_s(x) = \Delta s(x) = \Delta \overline{u}(x) = \Delta \overline{d}(x) = \Delta \overline{s}(x)$$

Polarised Valence and Sea Quark Distribution



- SMC data points evolved to $Q^2 = 2.5\ \mathrm{GeV}^2$
- Solid lines: Gehrmann- Stirling paramaterisation ('Gluon A', LO)
- Dashed lines: Positivity limits

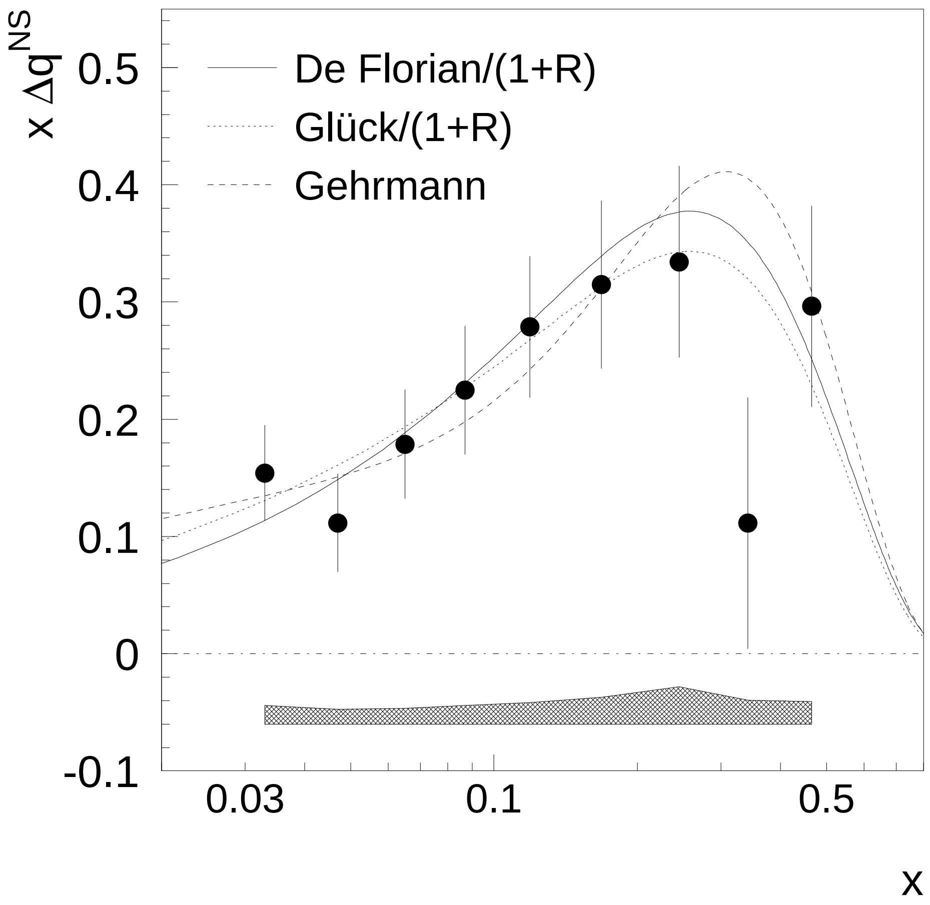
MC Prediction for future



Prediction based on $7.5 \cdot 10^6$ DIS events on $\bar{D}$ with :
semi-inclusive $h^{\pm}$, $\pi^{\pm}$, $K^{\pm}$ asymmetries,
$< P_T \cdot P_B >$ =0.45
The $\pi^{\pm}$, $K^{\pm}$ identification by RICH will allow to separate the light sea components from the strange sea

Non Singlet Contribution

$$x\Delta q^{NS} = x(\Delta u + \Delta\bar{u} - \Delta d - \Delta\bar{d}) \Longrightarrow \text{Bjorken SR}$$



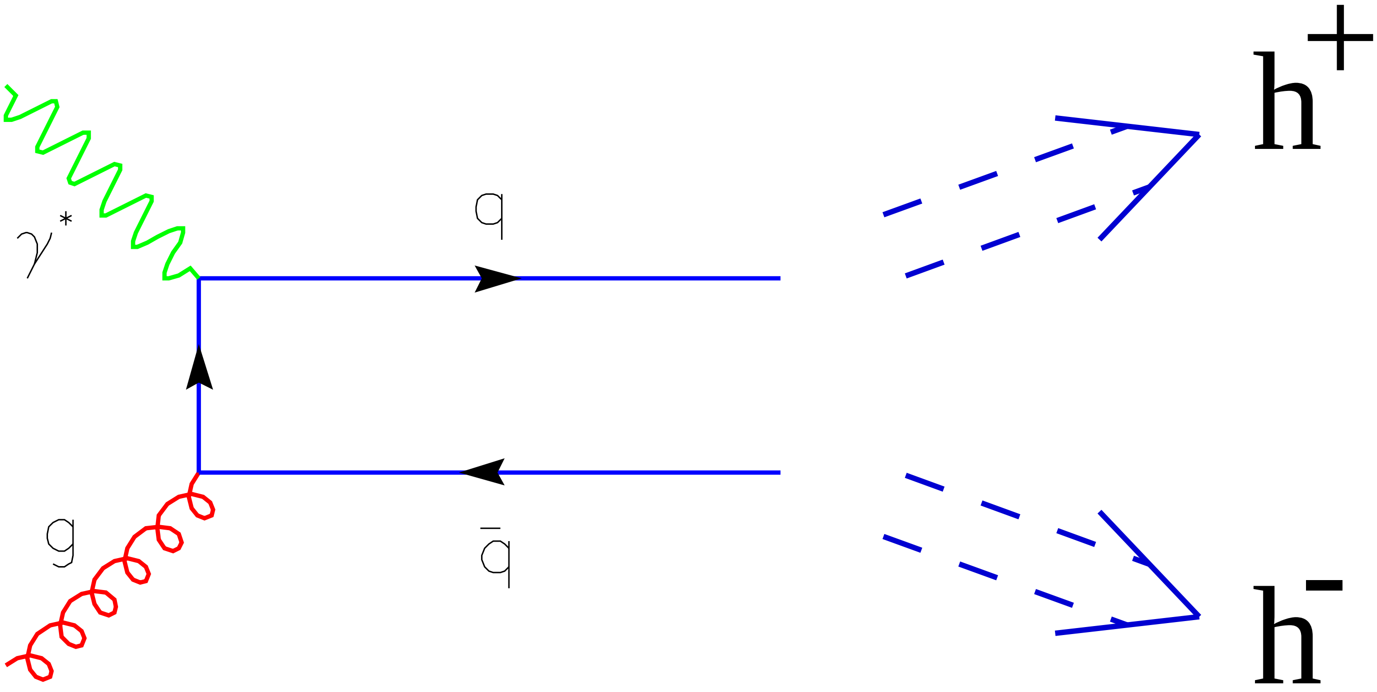
	Direct measurement total integral	prediction inclus. $SU(3)$
$\Delta u + \Delta\bar{u}$	$0.57 \pm 0.02 \pm 0.03$	0.66 ± 0.03
$\Delta d + \Delta\bar{d}$	$-0.25 \pm 0.06 \pm 0.05$	-0.35 ± 0.03
$\Delta s + \Delta\bar{s}$	$-0.01 \pm 0.03 \pm 0.04$	-0.08 ± 0.02
$\Delta\Sigma$	$0.30 \pm 0.04 \pm 0.07$	0.23 ± 0.04

Full kaon identification with RICH $\Longrightarrow$
direct measurement of the strange sea contribution

Gluon Contribution

Through Photon Gluon Fusion (PGF) in $(\gamma g \rightarrow q\bar{q})$

- PGF process $\Longrightarrow G(x_G)$
- Spin asymmetry in PGF $\Longrightarrow \Delta G/G$

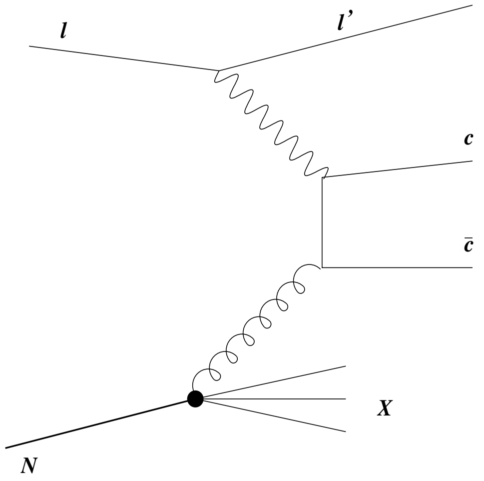


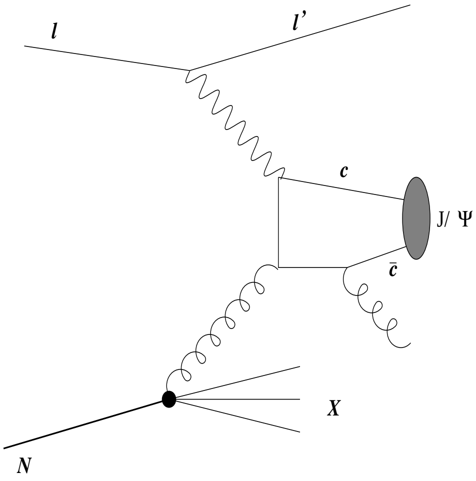
How to suppress the DIS process?

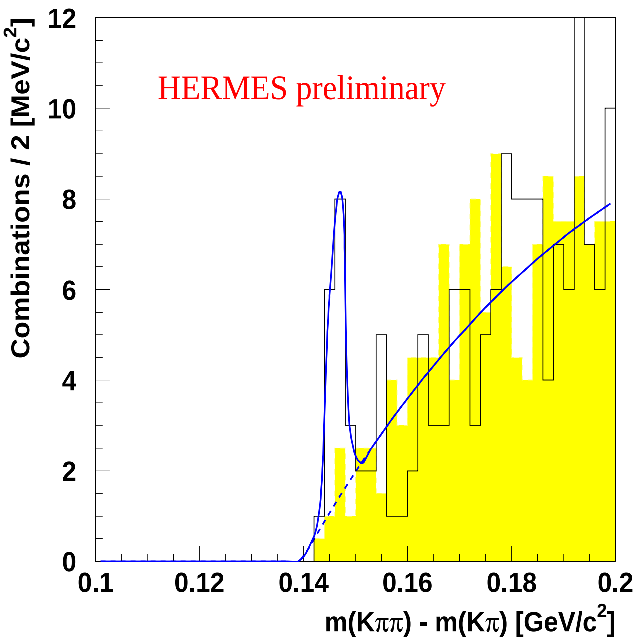
- Open and hidden charm: $\gamma^* G \rightarrow c\bar{c} \rightsquigarrow$ D, J/ψ
- Hadron pairs with large transverse momentum p_T

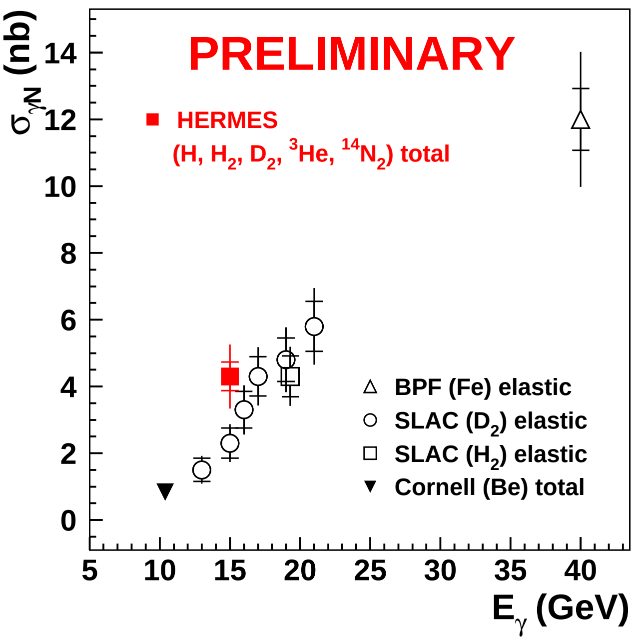
$$A_{||} = \frac{N_{h^\pm}^{\uparrow\downarrow} - N_{h^\pm}^{\uparrow\uparrow}}{N_{h^\pm}^{\uparrow\downarrow} + N_{h^\pm}^{\uparrow\uparrow}} \qquad A^{\gamma^* p \rightarrow h^\pm} \sim \Delta G/G$$

Charm Production





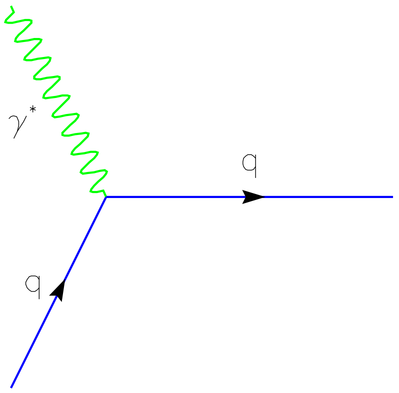




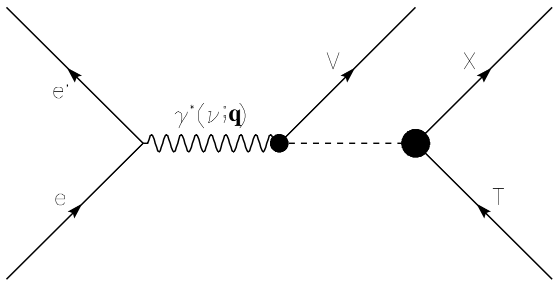
- Clear signature of open charm ($D^* \to D^0\pi^0$) and of hidden charm J/Ψ
- Charm production cross section is low in the HERMES energy range

$\Longrightarrow$ HERMES detector upgrade to improve charm detection

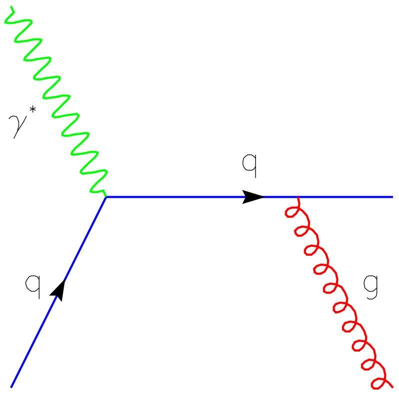
Different contributions



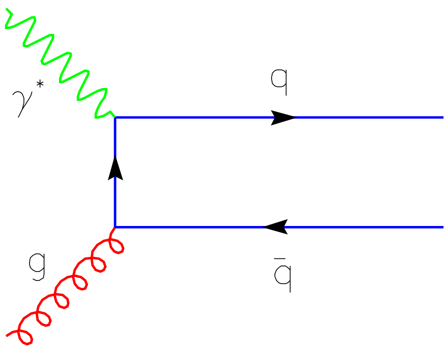
DIS
negligible contribution



VMD
assume $A_{VMD} = 0$



QCDC
$A_{QCDC} \sim \frac{\Delta q}{q}$



PGF
$A_{PGF} \sim \frac{\Delta G}{G}$

$$A_{||} = A_{\mathrm{QCDC}} f_{\mathrm{QCDC}} + A_{\mathrm{PGF}} f_{\mathrm{PGF}} + A_{\mathrm{DIS}} f_{\mathrm{DIS}} + A_{\mathrm{VMD}} f_{\mathrm{VMD}}$$

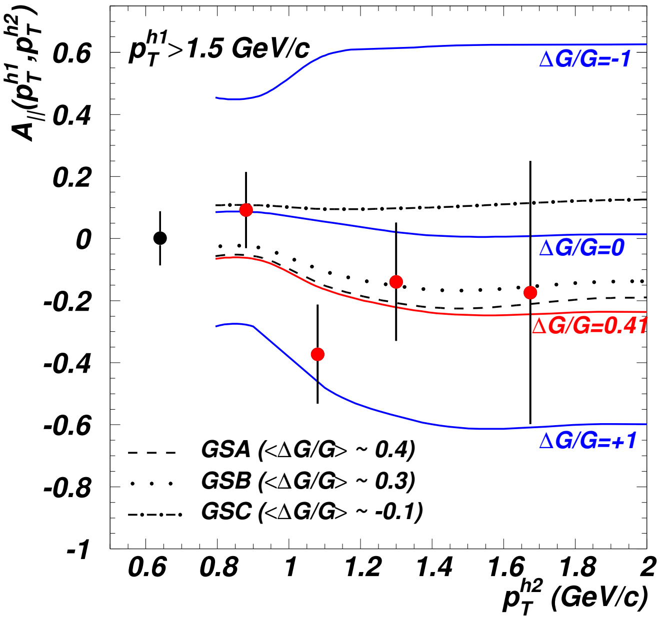
f_i... unpolarised fraction of events for process i

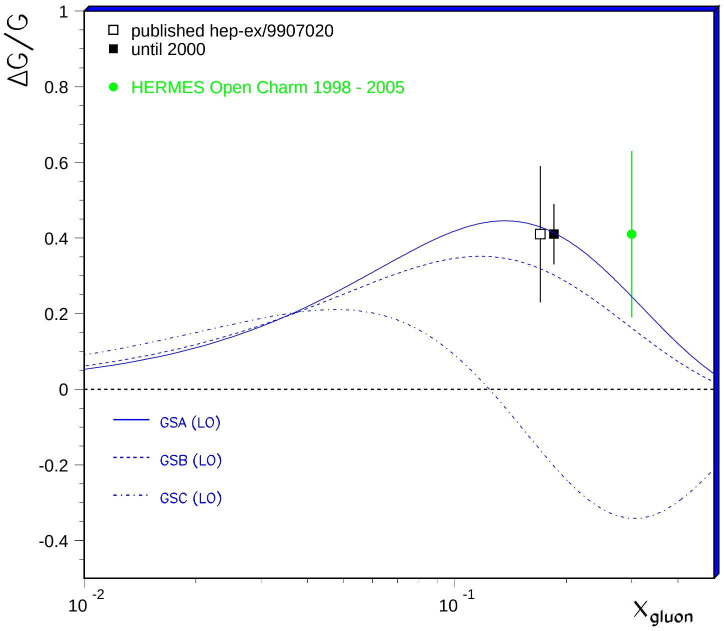
$f_{DIS} \sim 0$, $A_{VMD} \sim 0 \Longrightarrow$
$A_{||} \approx A_{\mathrm{QCDC}} f_{\mathrm{QCDC}} + A_{\mathrm{PGF}} f_{\mathrm{PGF}}$

$A_{QCDC} = a(\gamma q \to qg)\Delta q/q \sim +0.5\Delta q/q$
$A_{PGF} = a(\gamma g \to q\overline{q})\Delta G/G \sim \Delta G/G < 0$

First result for $\Delta G/G$

$\overrightarrow{\mathrm{H}}$ (1996+1997)





- Observed negative asymmetries in contrast to the positive DIS asymmetries
- Extraction strongly Model dependent
- 2x smaller errors with 1998 + 2000 data

$\Delta G/G$ is positive

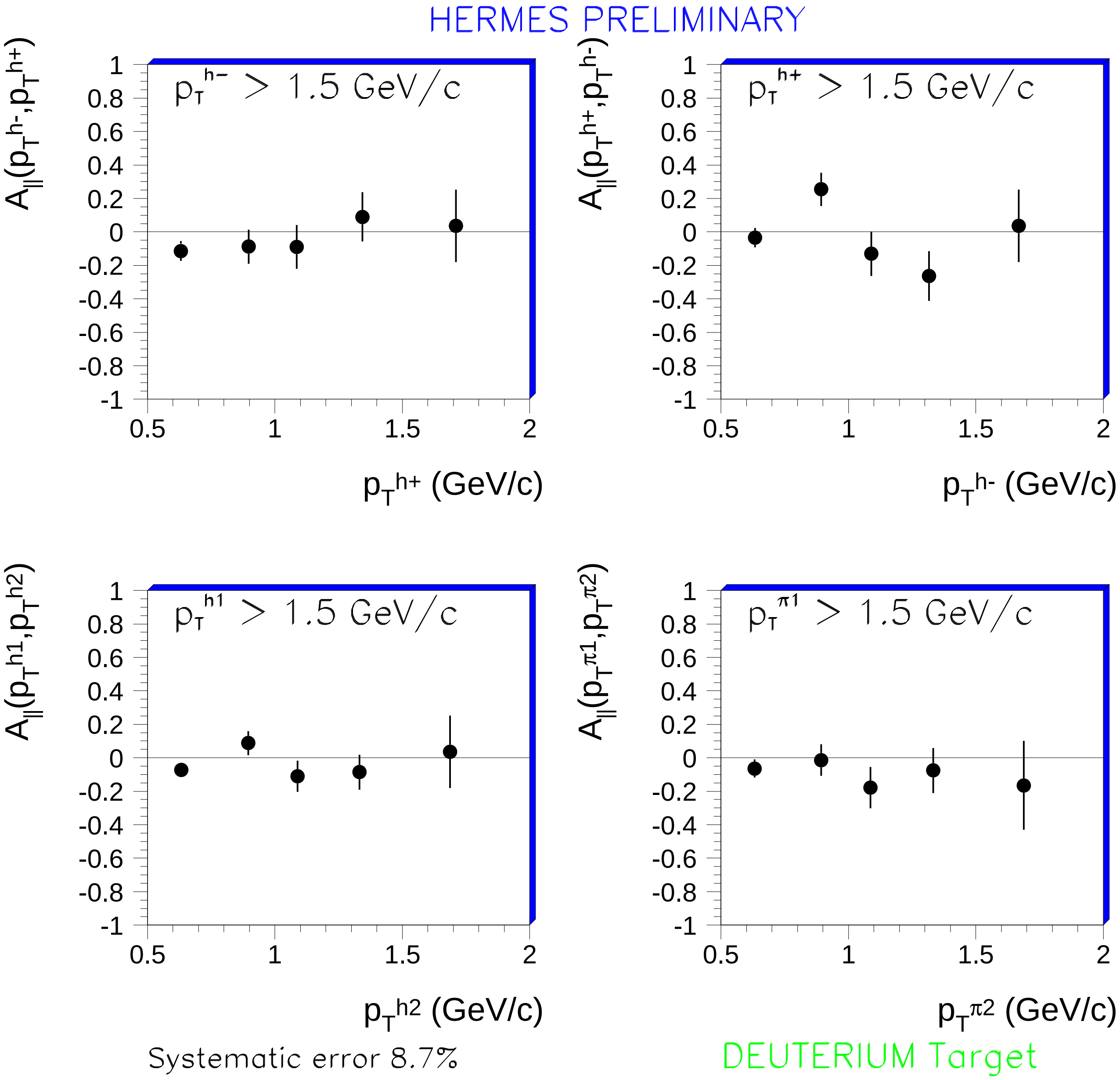
$$\Delta G/G = +0.41 \pm 0.18 \pm 0.03$$
at $\langle x_G \rangle = 0.17$ and $\langle \hat{p}_T^2 \rangle = 2.1\ \mathrm{GeV}^2$

Phys. Rev. Lett. 84 (2000) 2584

Confirmed by ongoing analysis on new data

High p_t h pair asymmetries

Include statistics correspond to 8.9x10^6 DIS (1998-2000)

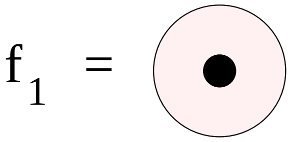


$\Delta G/G$ extraction still underway

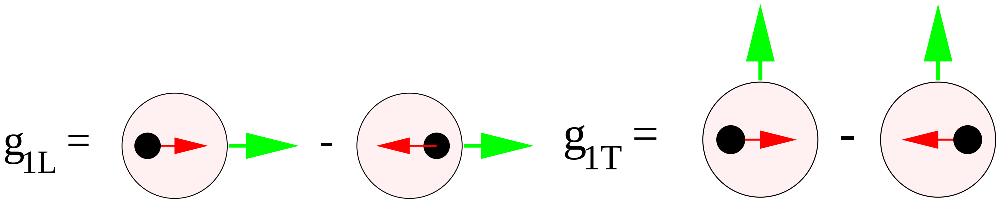
Distribution Functions

3 Parton Distribution Functions (PDF) at leading twist

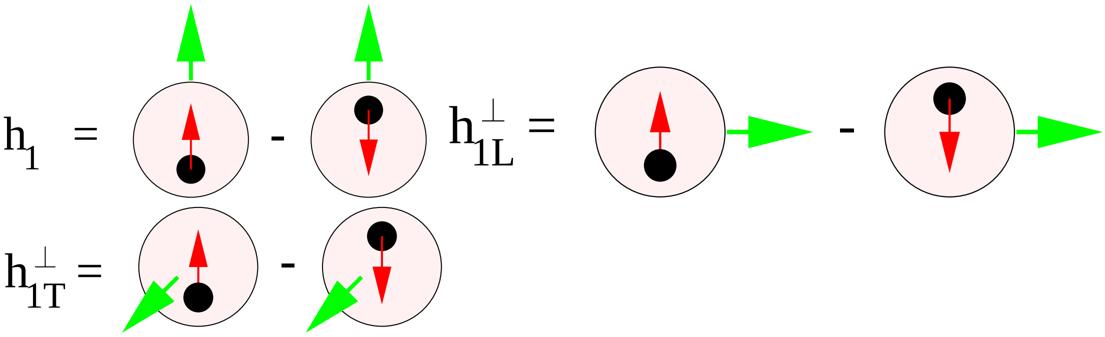
Unpolarized quark in unpolarized nucleon:



Longitudinal quark in longitudinal and transverse nucleon:

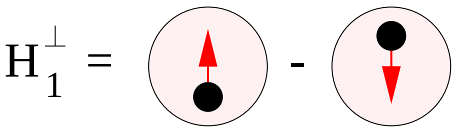


Transverse quark in longitudinal and transverse nucleon:



$\Longrightarrow$ Transverse quark polarization densities accessible via Single Spin Azimuthal asymmetries (SSA)

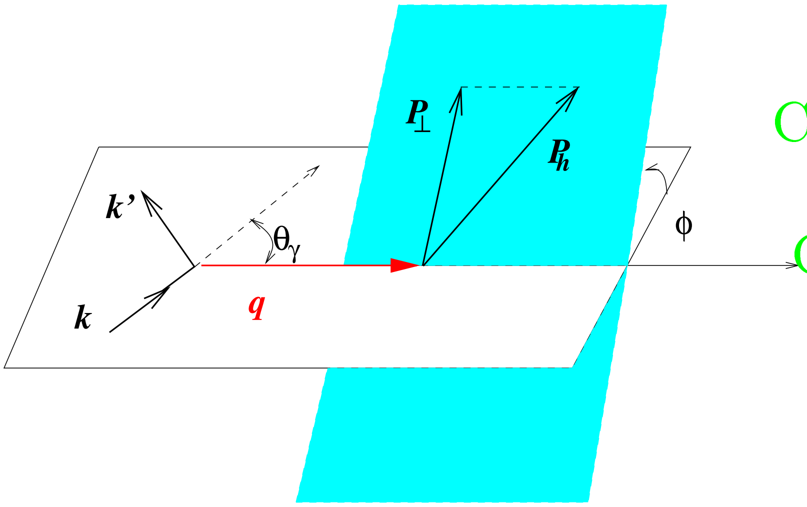
h_1 is chiral odd $\rightarrow$ observed only in combination with an other chiral odd structure $\rightarrow$ (Collins) FF in SIDIS



SSA asymmetries

$$\sigma^{ep\rightarrow ehX} = \sum_q f^{H\rightarrow q} \otimes \sigma^{eq\rightarrow eq} \otimes D^{q\rightarrow h}$$

$\downarrow$ chiral odd h_1 $\downarrow$ chiral odd $H_1^\perp$ Collins FF



Chiral odd, T-even DF

$\Downarrow$

Chiral-odd T-odd FF

$\Downarrow$

SSA

$P_\perp$ = pion transverse momentum
Φ = azimuthal angle of π around the virtual-photon direction

To access transversity and preserve chirality simultaneously $\Longrightarrow$ involve a *chiral-odd* DF + a *chiral-odd* FF

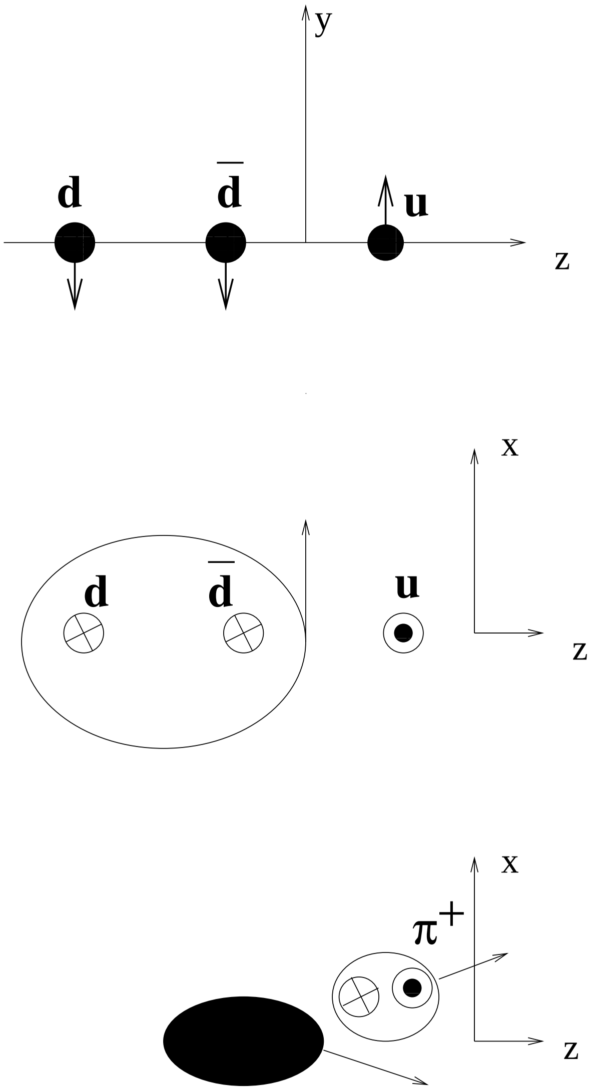
SSA = 0 in naive parton models: non interacting collinear parton and parity, angular momentum, helicity conservation

SSA originates from multi-parton correlation and intrinsic quark transverse momentum k_T

Collins FF

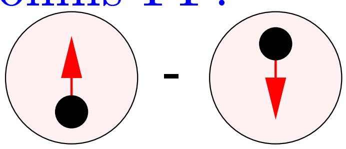
transverse quark polarization

Simple interpretation (Semi classical string model)



Correlation between the spin of the valence quark and the transverse momentum of the outgoing $\bar{q}$ (pion)

Collins FF:

$H_1^{\perp} =$ 

Contribution to $\sin\Phi$

It is possible to access to h_1 and to $H_1^{\perp}$ by $<\sin\phi>_{UL}$:

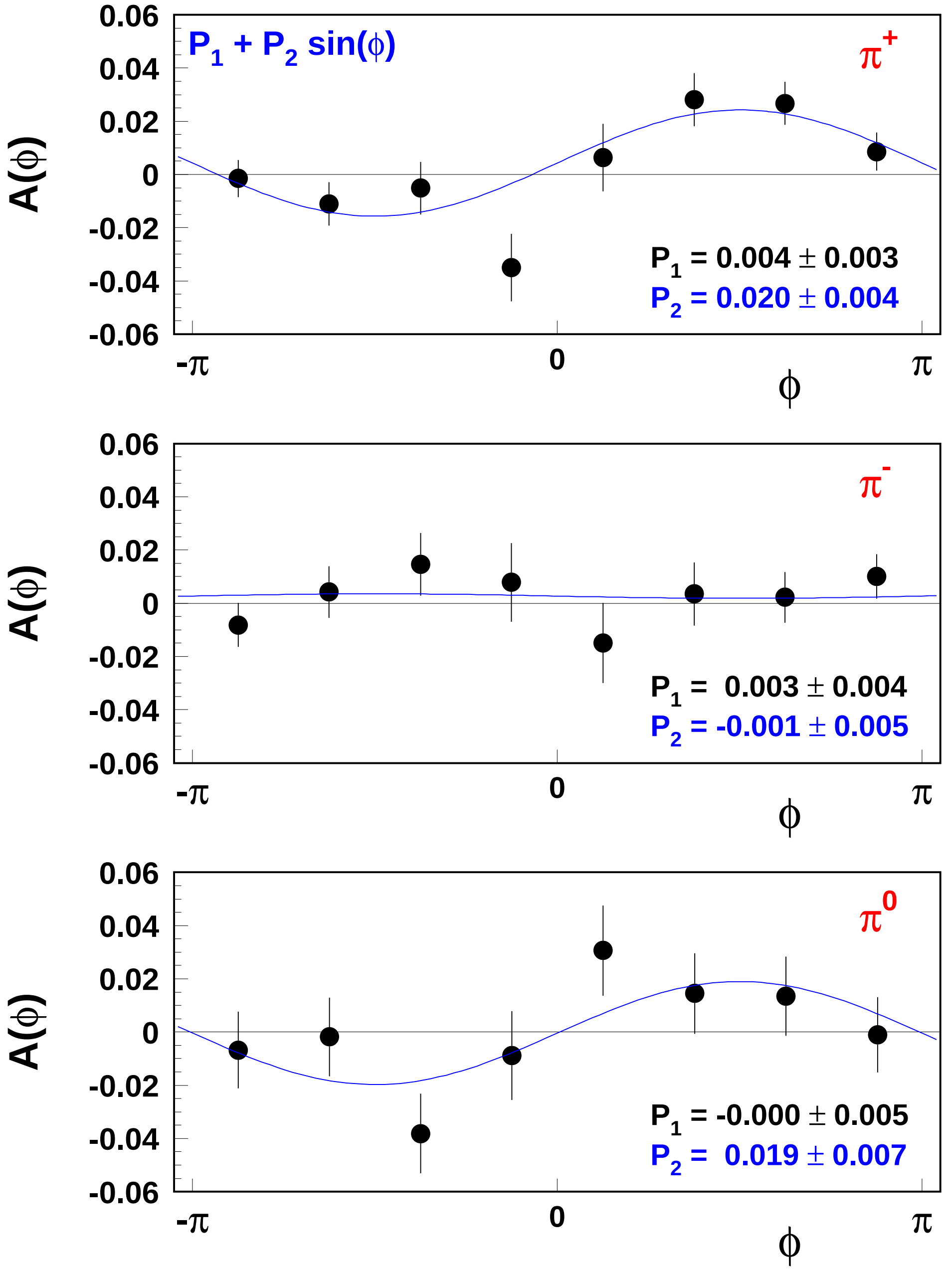
$$
\begin{aligned}
<\sin\phi>_{UL} \quad &\propto \quad S_L \frac{2(1-y)}{Q\sqrt{1-y}} \sum_{a,\bar{a}} e_a^2 x h_L^a(x) H_1^{\perp a}(z) \\
&+ \quad S_T (1-y) \sum_{a,\bar{a}} e_a^2 x h_1^a(x) H_1^{\perp a}(z)
\end{aligned}
$$

In HERMES $(e\vec{p}_{\parallel} \to e'hX)$ $S_T << S_L$

		T-even DF		T-odd FF	
		chirality even	chirality odd	chirality even	chirality odd
twist 2	U	$\mathbf{f}_1$			$H_1^{\perp}$
	L	$\mathbf{g}_{1L}$	$h_{1L}^{\perp}$		
	T	g_{1T}	$\mathbf{h}_1$ $h_{1T}^{\perp}$	$D_{1T}^{\perp}$	
twist 3	U	$f^{\perp}$	$\mathbf{e}$		$\mathbf{H}$
	L	$g_L^{\perp}$	$\mathbf{h}_L$	$D_L^{\perp}$	E_L
	T	$\mathbf{g}_T$ $g_T^{\perp}$	h_T $h_T^{\perp}$	$\mathbf{D_T}$	E_T

Cross section Asymmetry

$$A(\phi) = \frac{1}{<P_t>} \frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$



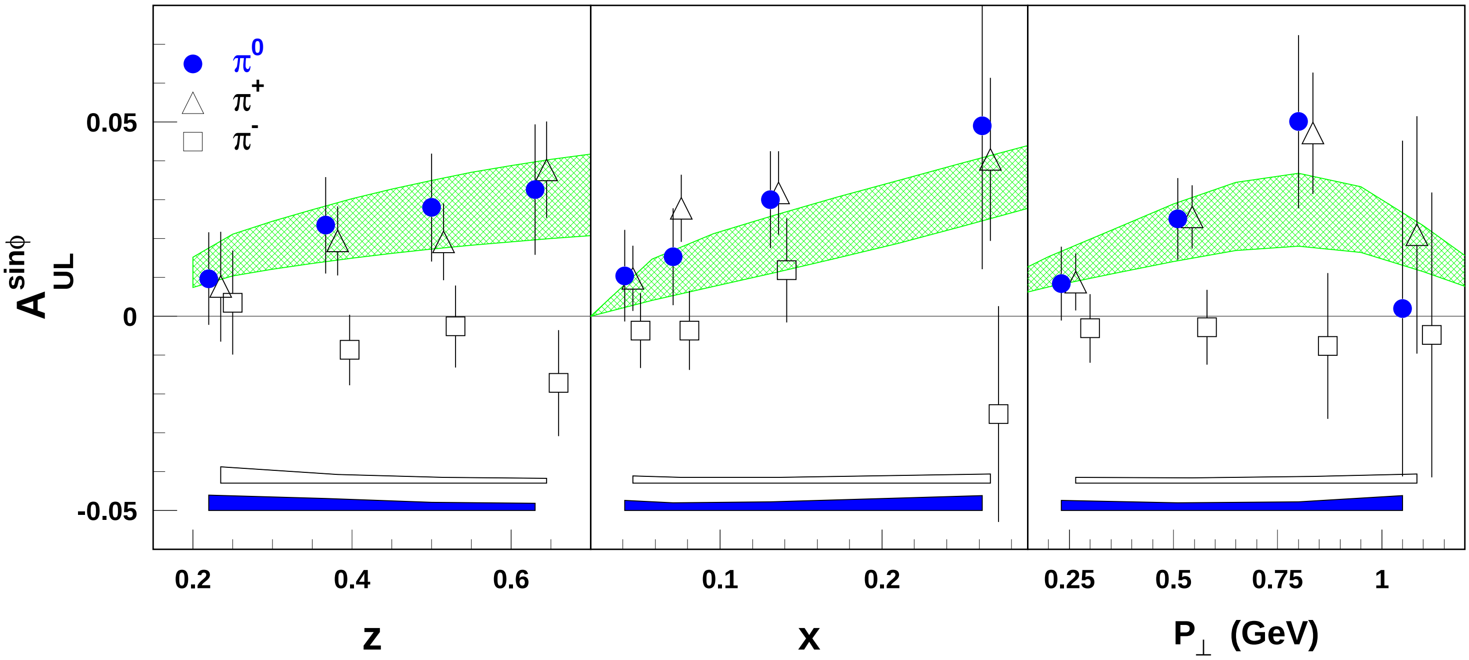
$$\pi^+ \quad \mathcal{A}_{UL}^{sin\phi} \propto \frac{4}{9} h_L^u \mathbf{H_1^{\perp u \to \pi^+}} + \frac{1}{9} h_L^d H_1^{\perp d \to \pi^+}$$

$$\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \propto \frac{4}{9} h_L^u H_1^{\perp u \to \pi^-} + \frac{1}{9} h_L^d \mathbf{H_1^{\perp d \to \pi^-}}$$

$$\pi^0 \quad \mathcal{A}_{UL}^{sin\phi} \propto \frac{1}{9} (4 h_L^u + h_L^d) H_1^{\perp u \to \pi^0}$$

Phys. Lett. 84 (2000) 4047

Azimuthal Asymmetry and Transversity



First evidence of transversity in a longitudinal target

- z dependence

  ▷ different behavior of SSA in semi-inclusive and (semi-)exclusive region for π^0 and π^+

- $P_\perp$ dependence

  ▷ related to dominant kinematic role of the intrinsic transverse momentum of the quark, if $P_\perp$ remains below te typical hadronic mass of $\sim$ 1 GeV

- x dependence

  ▷ similar behavior of π^0 and π^+

  ▷ behavior consistent with increase suggests that single spin asymmetries are associated with valence quark contributions

New data are expected from future HERMES measurements on a transversely polarised target, which will give direct access to the transversity $\Longrightarrow$ W. D. Nowak talk

Phys. Rev. D (2001) in print; hep-ex/0104005

Project for Transversity

HERMES $\Longrightarrow$ first result of transversity in longitudinal target

- significant x, $P_\perp$ and z dependence of $A_{\rm UL}^{\sin\phi}$ for π^+ and π^0
  $\mathcal{A}_{UL}^{sin\phi} = 0.022 \pm 0.005 \pm 0.003$
- π^0 asymmetry is similar to π^+ asymmetry
  $\mathcal{A}_{UL}^{sin\phi} = 0.019 \pm 0.007 \pm 0.003$
- π^- asymmetry consistent with zero
  $\mathcal{A}_{UL}^{sin\phi} = -0.005 \pm 0.008 \pm 0.004$

Other Measurements for Transverse Targets:

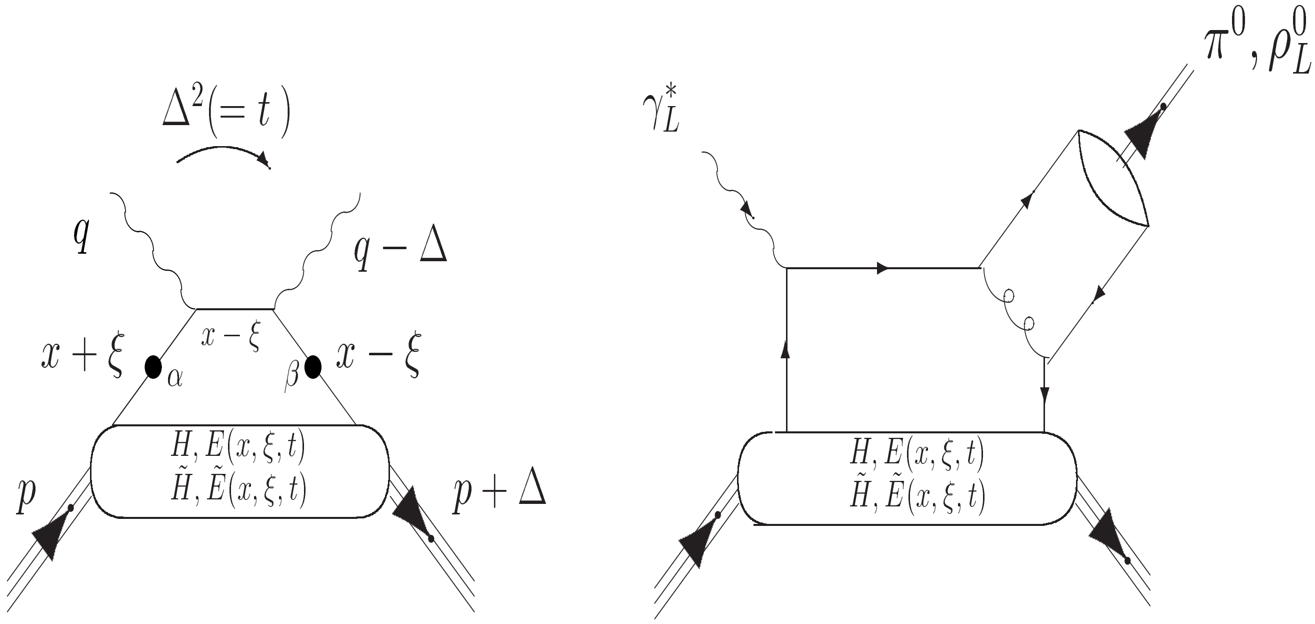
- E704 $p^\uparrow p \to \pi^\pm + X$
- DELPHI $e^+ + e^- \to Z^0 \to 2jets$
- SMC azimuthal asymmetries with transverse polarised target
- HERMES 2001+2002 $\Longrightarrow$ Transverse running

Transversity is one of the key goal of future experiment (COMPASS, RICH, EPIC, eRICH, Tesla-N)

Exclusive processes

HERMES $\Longrightarrow$ mainly designed for SIDIS to study ordinary polarized parton distributions

Recently $\Longrightarrow$ study Genaralised Parton Distribution GPD via exclusive processes



Quantum numbers of final states $\rightarrow$ select different GPD

- Vector mesons : $\rho_L^0 \rightarrow$ unpol. GPD E, H
- Pseudoscalar mesons : $\pi^0 \rightarrow$ pol. GPD $\tilde{E}, \tilde{H}$
- Pseudoscalar mesons : $\pi^+ \rightarrow$ pol. GPD + pion pole
- DVCS : $\gamma \rightarrow$ pol. and unpol. GPD $\tilde{E}, \tilde{H}, E, H \rightarrow$ information on the orbital angular momentum contribution to the nucleon spin

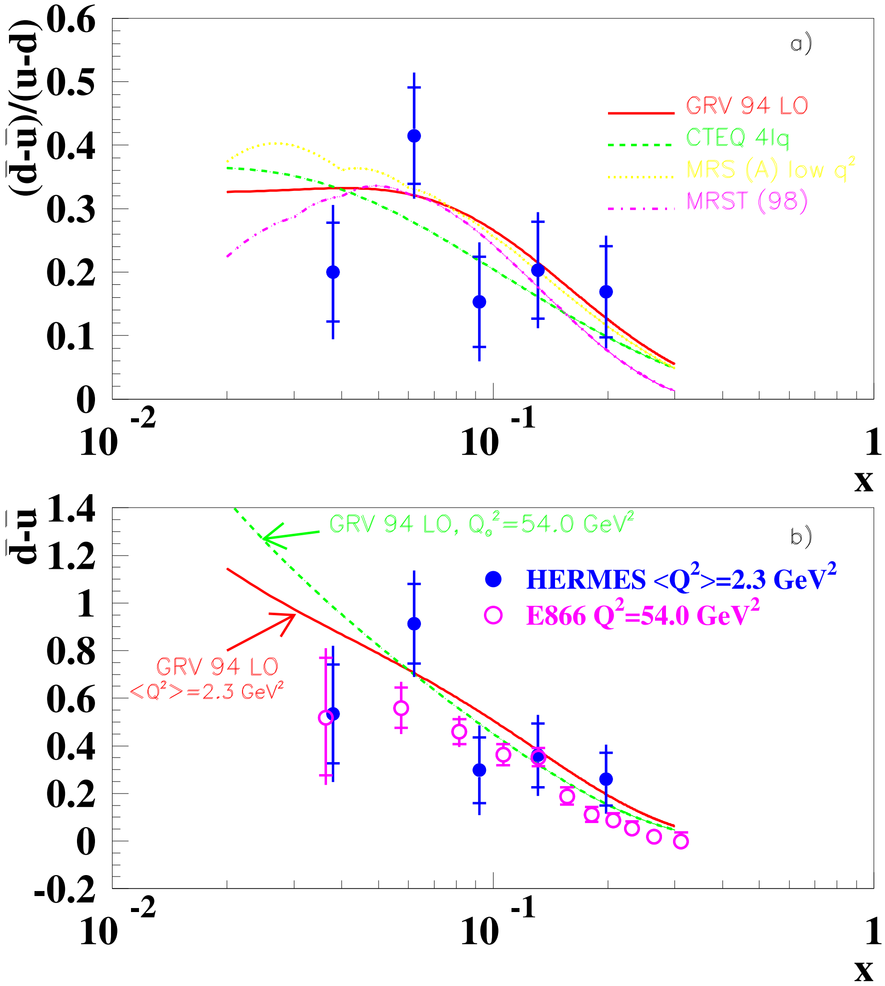
$$\frac{1}{2} = \frac{1}{2}\Sigma + \Delta G + Lq/g$$

$\Longrightarrow$ M. Amarian talk

Unpolarised: Flavor Decomposition

Flavor asymmetry of the light quark sea of the nucleon determined from semi-inclusive DIS in H and D

$0.02 < x < 0.3 \qquad 1 < Q^2 < 10\ \mathrm{GeV}^2$



- $(\bar{d}-\bar{u})/(u-d)$ found to be non-zero in x range measured $\Longrightarrow$ excess of $\bar{d}$ quarks over $\bar{u}$ quarks in the proton sea
- $\int_{0.02}^{0.3}(\bar{d}(x)-\bar{u}(x))/(u-d)$=0.107±0.021±0.017 at Q_0^2=2.3 GeV^2 (accounts 2/3 of the Gottfried Sum Rule deficit)

Phys. Rev. Lett. 81 (1998) 5519

Unpolarised: Multiplicity & FF

$$\frac{1}{N_{DIS}}\frac{N^{\pi^0}}{dz} =$$

$$= \frac{1}{\sum_f e_f^2 q_f}\left[\left(\frac{4}{9}u+\frac{1}{9}\bar{d}+\frac{4}{9}\bar{u}+\frac{1}{9}d\right)D_u^{\pi^0}+\frac{1}{9}(s+\bar{s})D_s^{\pi^0}\right]$$

Neglecting s and $\bar{s}$ contributions:

$$\frac{1}{N_{DIS}}\frac{N^{\pi^0}}{dz} \simeq D_u^{\pi^0}(z)$$

For isospin invariance:

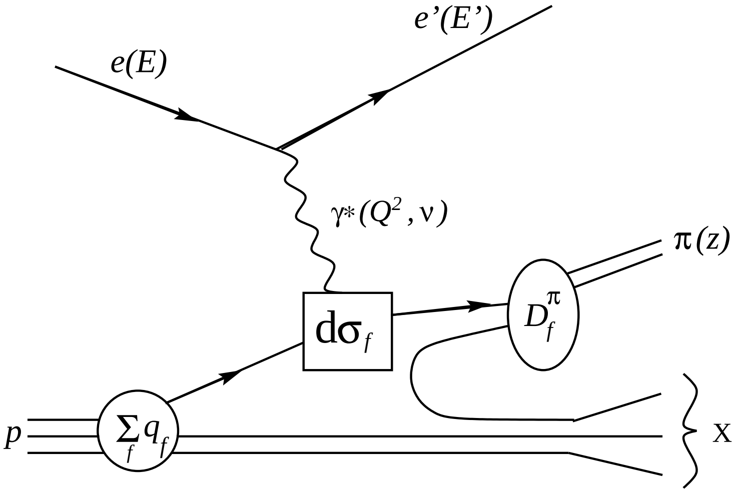
$$\sigma^{\pi^0} = \frac{\sigma^{\pi^+}+\sigma^{\pi^-}}{2}$$

$\Longrightarrow$ comparison:

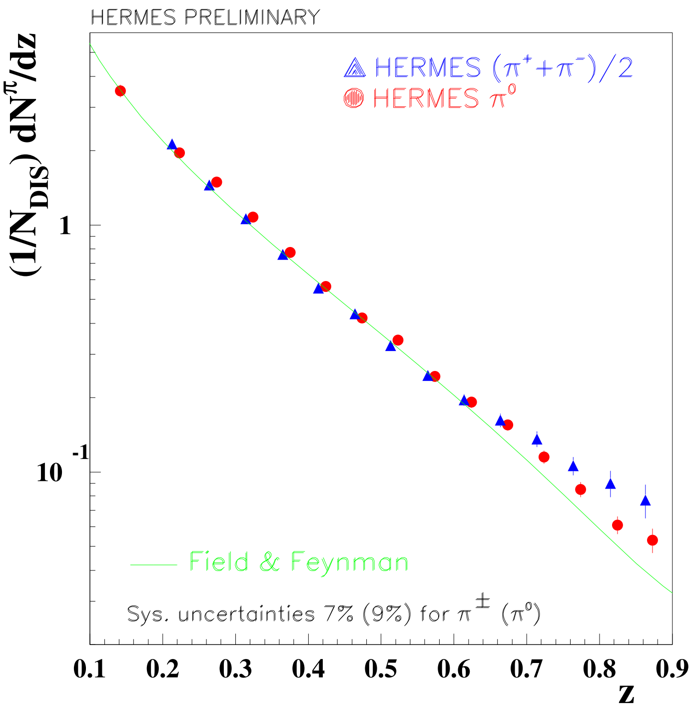
$$\sigma^{\pi^0} \leftrightarrow D^{\pi^0}; \quad \sigma^{\frac{\pi^+ + \pi^-}{2}} \leftrightarrow \sigma^{\pi^0}; \quad \sigma^{\pi^0} \leftrightarrow \frac{D_\pi^+ + D_\pi^-}{2}$$

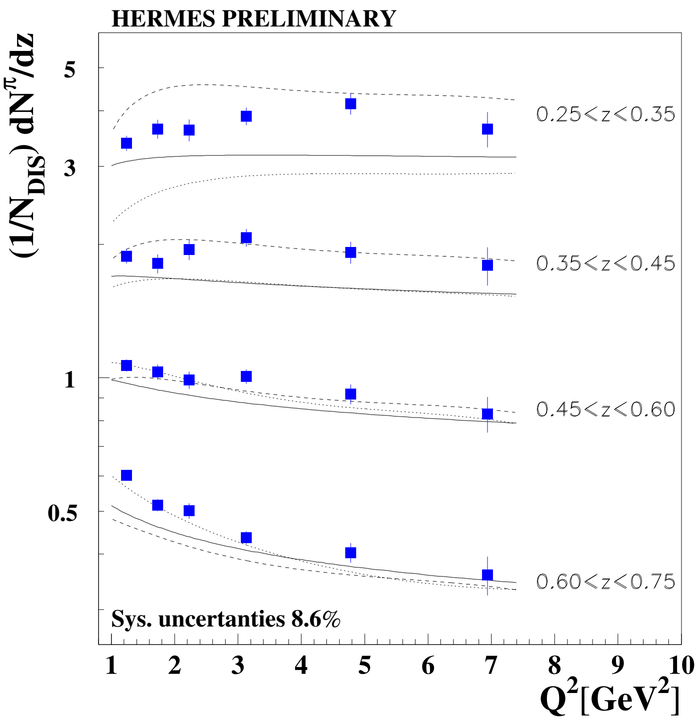
The π^0 or $\frac{\pi^+ + \pi^-}{2}$ multiplicity provides the u-quark fragmentation for π^0 (i.e. $D_u^{\pi^0}$)

Unpolarised: Multiplicity & FF



$$d\sigma^\pi(x,z,Q^2) \propto \sum_f q_f(x,Q^2)\cdot d\sigma_f \cdot D_f^\pi(z,Q^2)$$





Good isospin invariance up to $z = 0.7$. For higher z exclusive channels and higher twist contributions are suggested

Scaling violation of Fragmentation Functions Agreement with NLO-QCD models calculated at the LEP energies

EPJC (2001) in print, hep-ex/0104004

Alessandra Fantoni, Trento 2001

Other Physics Results

Polarised Physics Program:

- Longitudinal Spin Transfer to Λ

  Phys. Rev. D (2001) submitted; hep-ex/0104005

- Spin asymmetries in diffractive Vector Meson Production

  Phys. Lett. B (2001) in print; hep-ex/0102037

Unpolarised Physics Program:

- Vector Meson Production (VMP)
- Fragmentation Functions for light quarks $\longrightarrow \pi,\ K,\ P,\ \Lambda$
- Longitudinal and Transverse Polarization of Λ

Nuclear Physics Program:

- Diffractive VMP (coherence length effect)

  Phys. Rev. Lett. 82 (1999) 3025

- $\sigma^{N/He/Kr}/\sigma^{D} \longrightarrow$ HERMES effect on σ_L/σ_T

  Phys. Lett. B475 (2000) 386

- Measurement of the hadron formation times in the fragmentation process

  EPJC (2001) in print; hep-ex/0012049

  $\Longrightarrow$ talk V. Muccifora

Summary

Structure Functions g_1

- Good agreement with other experiments
- Extension of g_1 to low-x region
- Generalised GDH SR in Resonance and DIS regions
- First test of duality for polarised SF

Quark flavor decomposition of the spin

- Δu large and positive
- Δd negative
- $\Delta\Sigma$=0.30 $\Longrightarrow$ Rest ?
  Gluons (ΔG), orbital angular momentum ($L_z^{q,g}$)
- Δq_{sea} compatible with 0
- Results from longitudinal $\overrightarrow{\mathrm{D}}$ target $\rightarrow$ $\Delta d_v(x)$, $\Delta u_v(x)$
- RICH $\rightarrow$ direct meas. of sea polarisation
  Δs, $\Delta\bar{u}(x)$, $\Delta\bar{d}(x)$

Gluon contribution to the spin

- $\Delta G/G$ positive at $\langle x_G \rangle = 0.17$
- Results from longitudinal $\overrightarrow{\mathrm{D}}$
  $\Longrightarrow$ enhanced stat., diff. signal/background
- RICH + μ wall $\Longrightarrow$ J/Ψ, $\Delta G/G$ at $x_G \sim 0.3$

Single Spin Asymmetries

- First evidence of transversity in a longitudinal target
- SIDIS : $\pi^+, \pi^0 \quad \mathcal{A}_{UL}^{sin\phi} \simeq 2\%$; $\pi^- \quad \mathcal{A}_{UL}^{sin\phi} \simeq 0$
- Start with transverse polarised target