Spin Asymmetries at

hermes

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on behalf of the HERMES collaboration

Hadron Structure 2000

October 6, 2000

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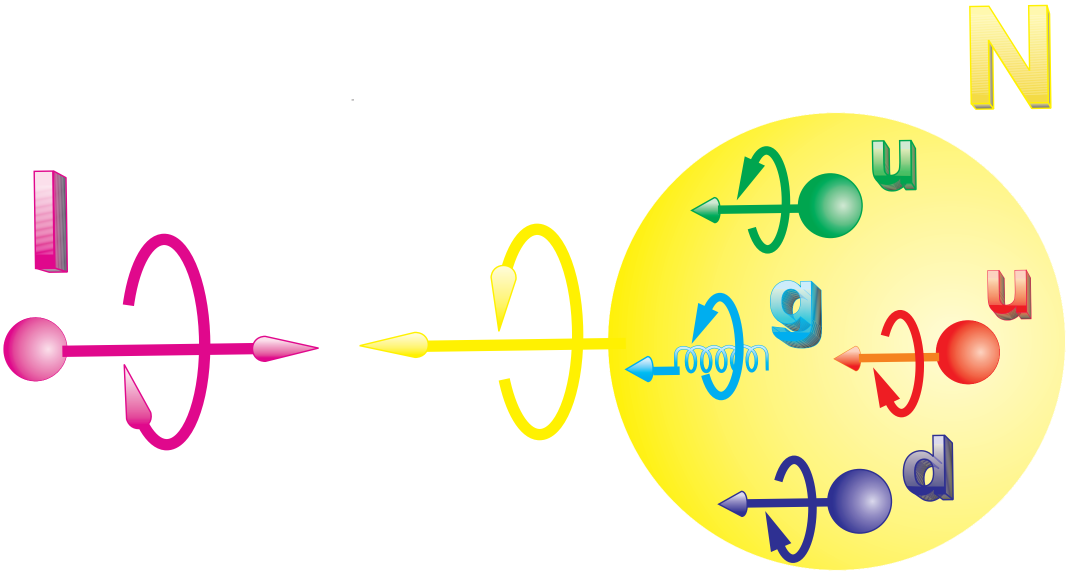
TRIUMF

Outline

- Introduction
- The HERMES Experiment at HERA
- Polarised Deep Inelastic Scattering (DIS)
  - Inclusive DIS
  - Semi-Inclusive DIS
- High p_t hadron pairs
- The HERMES RICH detector
- Conclusion and Outlook

The Spin of the Nucleon



$$\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + \Delta G + (L_q + L_g)$$

- Inclusive DIS:

  $\Delta\Sigma = (\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s})$

- Semi-inclusive DIS:

  $\Delta u,\ \Delta\bar{u},\ \Delta d,\ \Delta\bar{d},\ \Delta s,\ \Delta\bar{s}$

- High p_T hadron pairs:

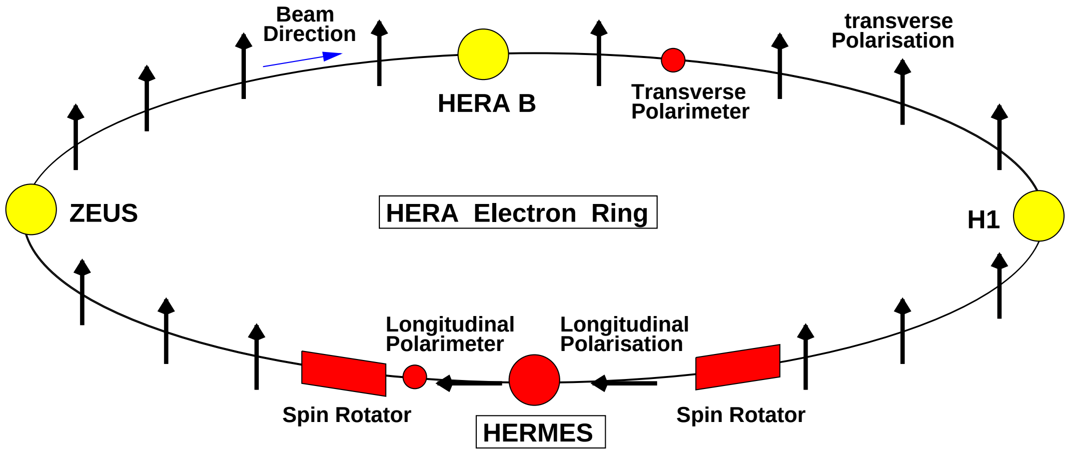
  ΔG

- Skewed Parton Distributions $\overset{?}{\rightsquigarrow}$ $L_q + L_g$
  (Deeply Virtual Compton Scattering)

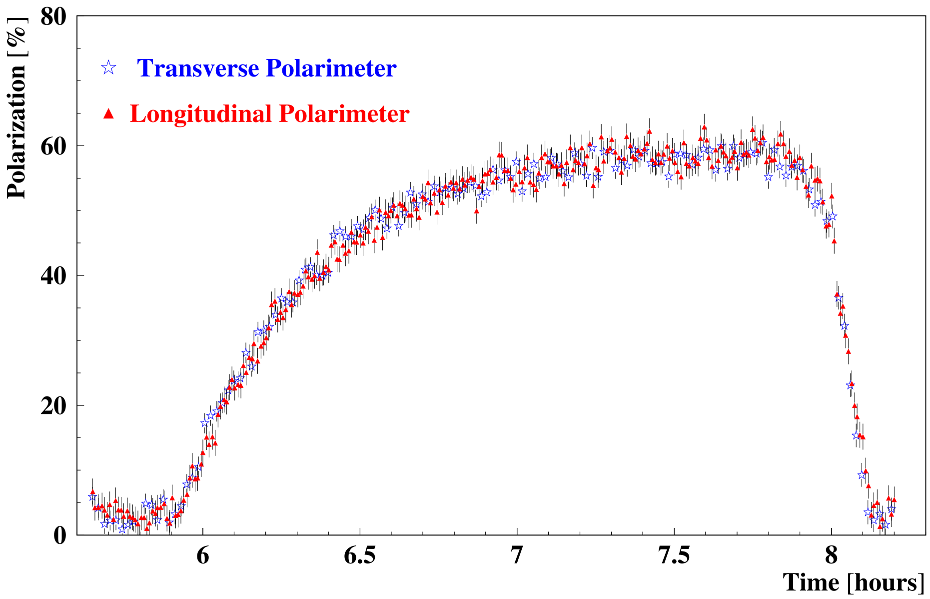
- Proton spin is made of the spin of the constituents
- Quarks carry only little spin
- Other contributions by the quark sea
- , the gluons
- and the angular momentum of the quarks and the gluons

- Inclusive DIS allows for the determination of the sum of the quark spins. (With QCD fits to world data on different inclusive asymmetries the quarks may be separated. Separation from sea not possible.)
  I will show measurements of the proton spin structure function and first measurements of the deuterium spin structure function.
- In semi-inclusive DIS the flavour of the outgoing hadron is tagged. =¿ Identification of the struck quark and unfolding of g1 into quark polarisations.
- Gluon polarisation accessible through events with hadron pairs of large transverse momentum.
  I will show the first ever direct measurement of the gluon polarisation.
- Finally the angular momentum may be accessible through the DVCS

HERA at DESY (Hamburg)

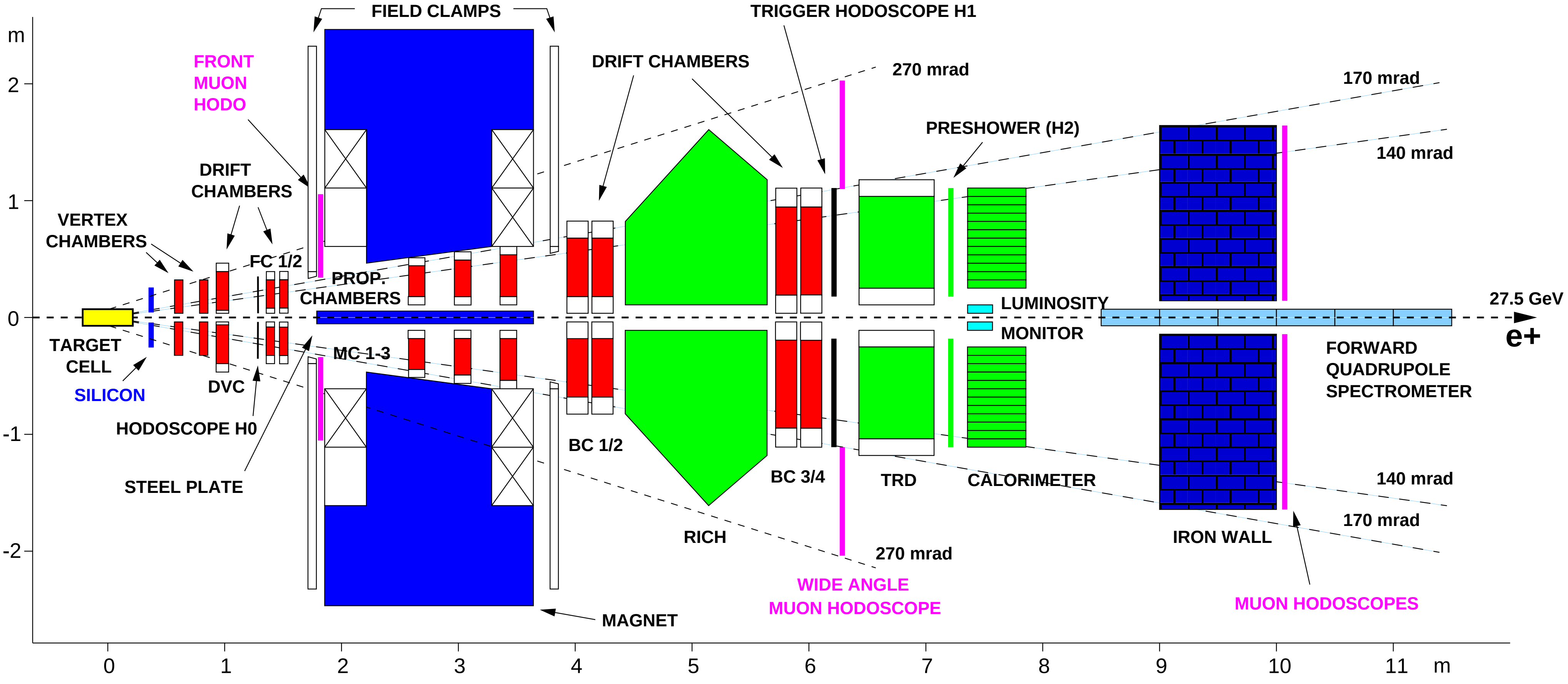


- Self-polarising electron beam
  through the Sokolov Ternov effect
- Longitudinal polarisation at HERMES
- Polarimetry based on Compton back scattering
- Average beam polarisation of 55%



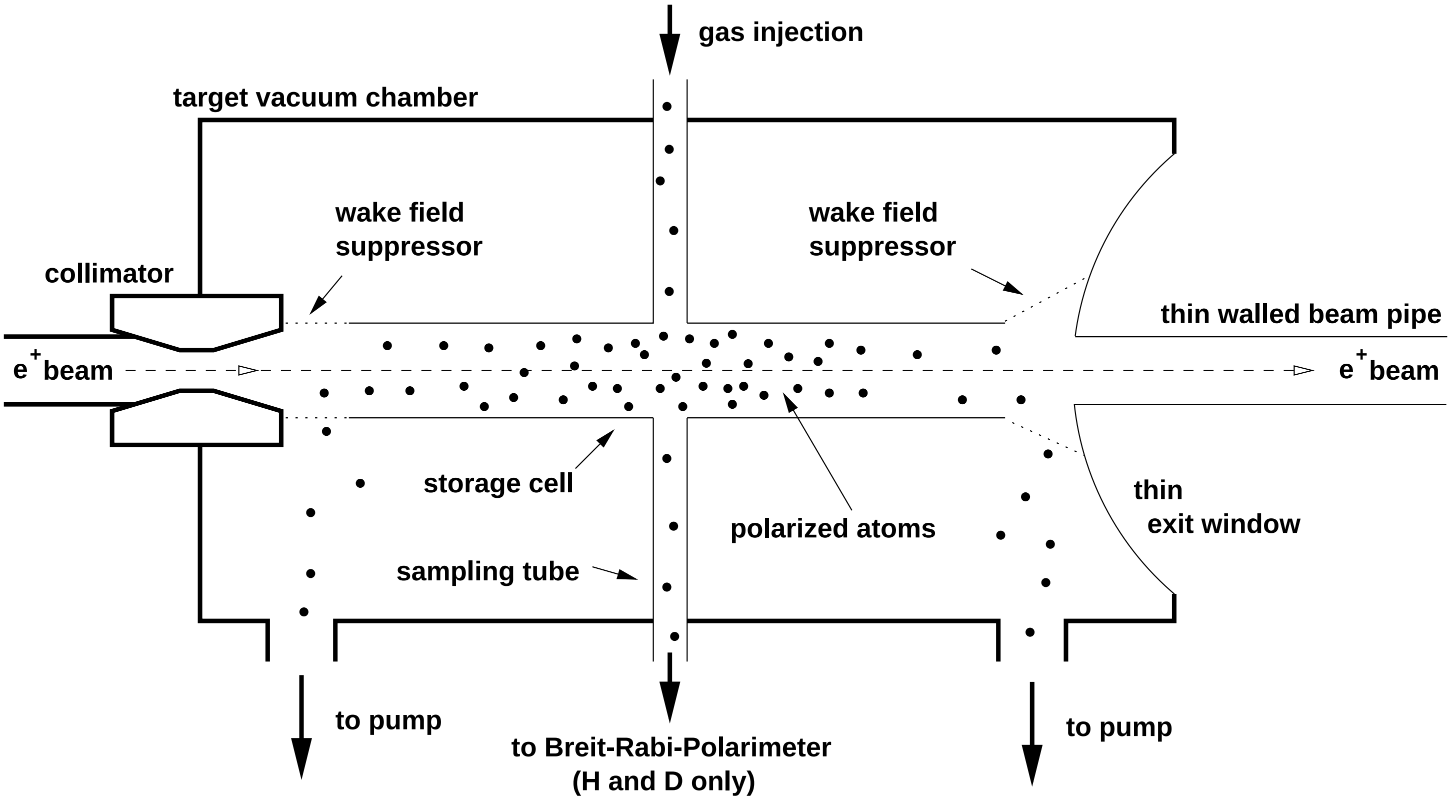
- HERMES is carried at HERA in Hamburg, Germany
- HERA is an ep collider with a proton energy of 920GeV and electron energy of 27.5 GeV
- HERMES is one of the four experiments carried out.
- East Hall
- HERMES only utilises the electron and as a spin dependent experiment relies on high polarisation of the beam
- The electron beam is self polarising through the Sokolov Ternov effect. The polarisation builds up in the transverse direction.
- Upstream of HERMES the polarisation is rotated into the longitudinal direction and downstream back into the transverse direction
- Beam polarisation is measured using two polarimeters
- Pol. measurement through Compton Back Scattering.
- The average polarisation after rise-time is 55%
- Figure shows a short fill, and nicely illustrates the rise to high polarisations in about an hour.
- An average fill at HERA is about 12h.

The HERMES Spectrometer



- where's the target
- Size of the thing.
- Forward spectrometer with large acceptance
- RED: Tracking System
- BLUE: Magnet
- GREEN: PID
- Tracking: 57 tracking planes
  $\delta p/p:\ 0.7 - 1.3\%,\qquad \delta\Theta \leq 0.6$ mrad
- Particle Identification:
  TRD, Preshower, Calorimeter
  Čerenkov (1995-1997) RICH (since 1998)
  Lepton ID efficiency: $\sim 98\%$
  Hadron contamination: $\leq 1\%$
- Large acceptance
- More upgrades: lambda wheels, WAM

The HERMES Target

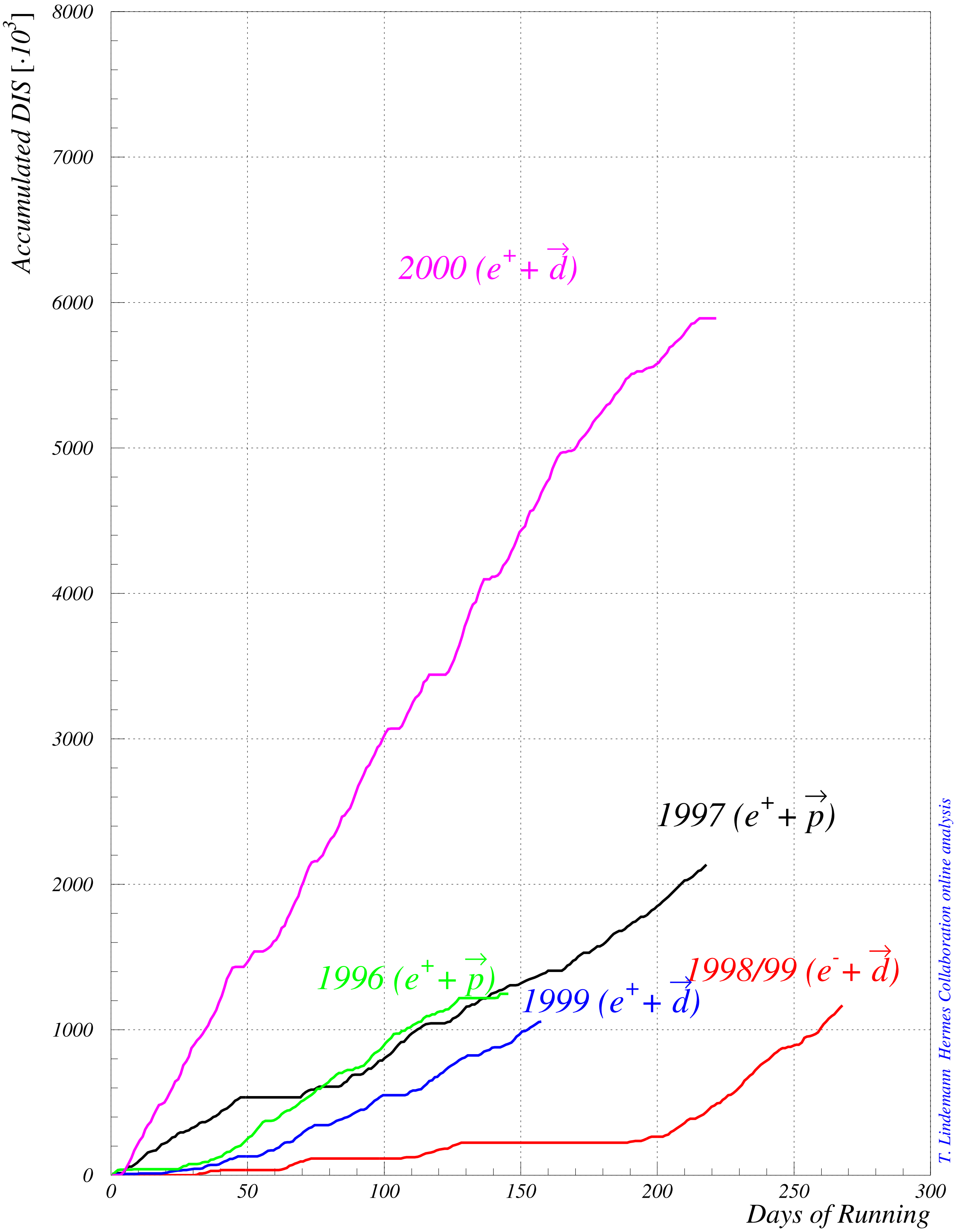


- Gas target internal to the electron pipe
- Target cell for high densities
- Virtually no dilution
- $\langle P \rangle \sim 90\%$, fast polarisation flips
- High atomic fraction
- Targets: $\overrightarrow{{}^3\mathrm{He}}$, $\overrightarrow{{}^1\mathrm{H}}$, $\overrightarrow{{}^2\mathrm{D}}$

  (unpol: H_2, D_2, He, N_2, Ne, Kr)

- Targets at other experiments: Butanol, Ammonia, Pol Lithium

Accumulated Statistics 1996 - 2000



- 1995 He - Target: $2.7 * 10^6$ DIS

Number of polarised DIS events

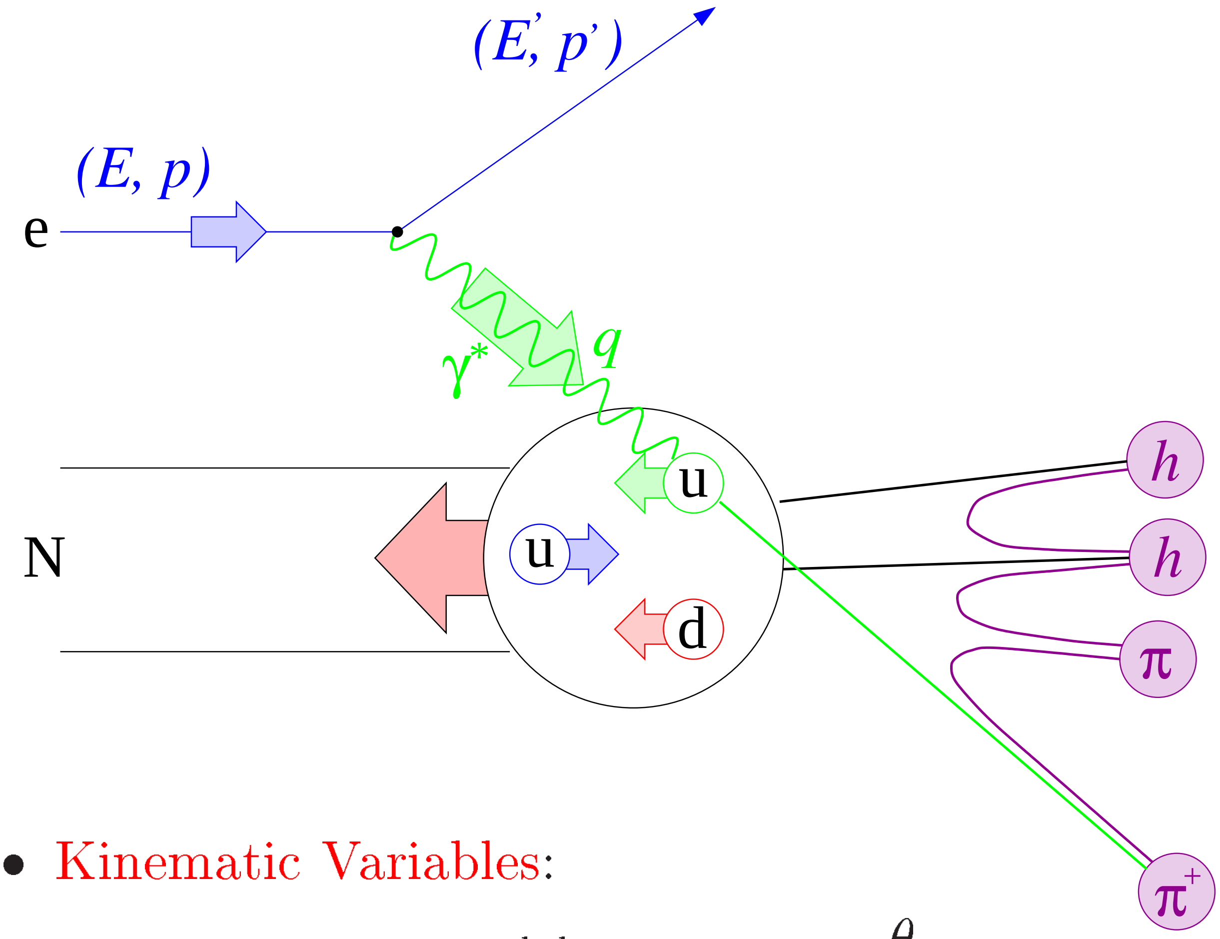
what are the numbers:

Results presented are only based on 95 -> 98/99 data

the decrease in slope caused by data taken with tensor polarisation to measure b_1, this data is not included in these statistics.

but also 14M unpolarised DIS

Polarised Deep Inelastic Scattering



- Kinematic Variables:

$$Q^2 \stackrel{lab}{=} 4EE' \sin^2(\frac{\theta}{2})$$

$$\nu \stackrel{lab}{=} E - E'$$

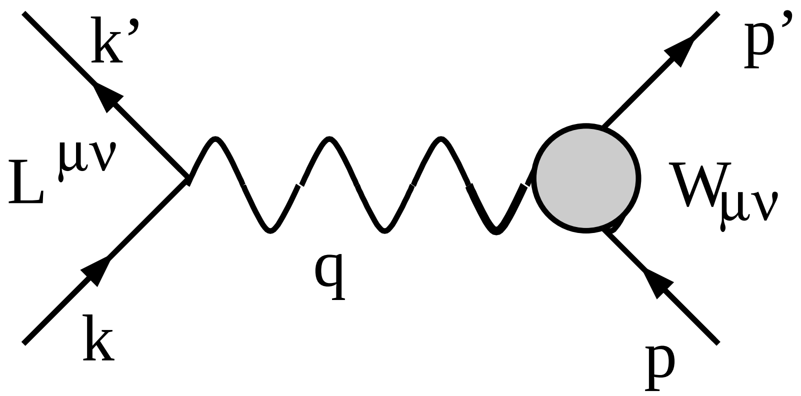
$$x \stackrel{lab}{=} Q^2/(2\,m\,\nu)$$

$$y \stackrel{lab}{=} \nu/E$$

$$z \stackrel{lab}{=} E_h/\nu$$

- Inclusive: $e + N \rightarrow e' + X$
- Semi-Inclusive: $e + N \rightarrow e' + h + X$

The DIS Cross Section



$$\frac{d^2\sigma}{d\Omega\, dE'} = \frac{\alpha^2}{M\, Q^4}\, \frac{E'}{E}\, L_{\mu\nu} W^{\mu\nu}$$

$$L_{\mu\nu} = 2\left[k_\mu k'_\nu + k_\nu k'_\mu - \left(k \cdot k' - m_e^2\right) g_{\mu\nu} + i\, m_e\, \epsilon_{\mu\nu\alpha\beta}\, s^\alpha \left(k - k'\right)^\beta\right]$$

$$W^{\mu\nu} = -\, g^{\mu\nu}\, F_1(x, Q^2) + \frac{p^\mu p^\nu}{\nu}\, F_2(x, Q^2) + \frac{i}{\nu}\, \epsilon^{\mu\nu\lambda\sigma}\, q_\lambda S_\sigma\, g_1(x, Q^2) + \frac{i}{\nu^2}\, \epsilon^{\mu\nu\lambda\sigma}\, q_\lambda \left(p \cdot q\, S_\sigma - S \cdot q\, p_\sigma\right)\, g_2(x, Q^2)$$

F_1, F_2 ... Unpolarised Structure Functions

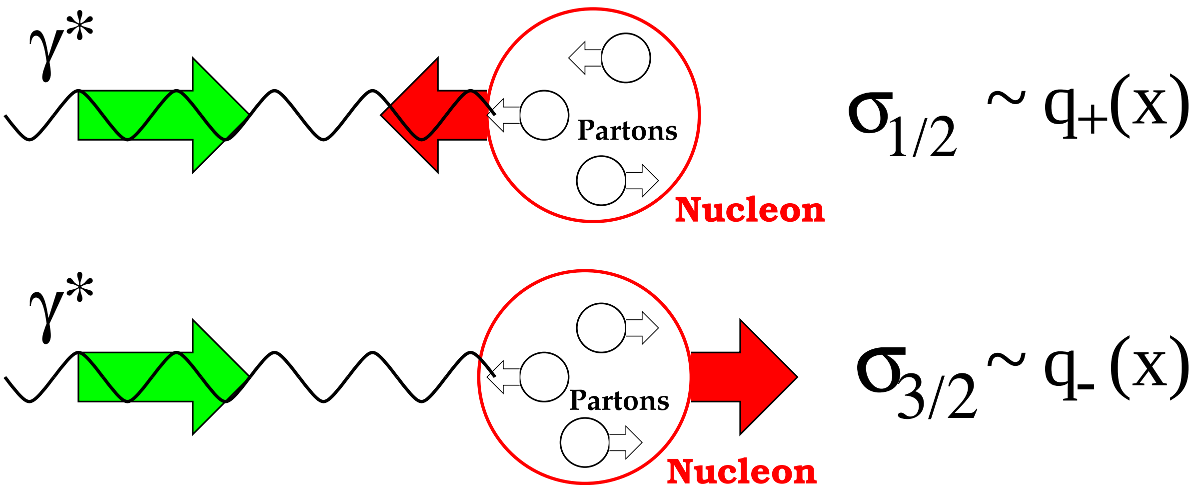
g_1, g_2 ... Polarised Structure Functions

Spin Asymmetries

eN-Asymmetry $A_{||}$ is measured:

$$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}$$

But need γN-Asymmetry A_1:



Turns out:

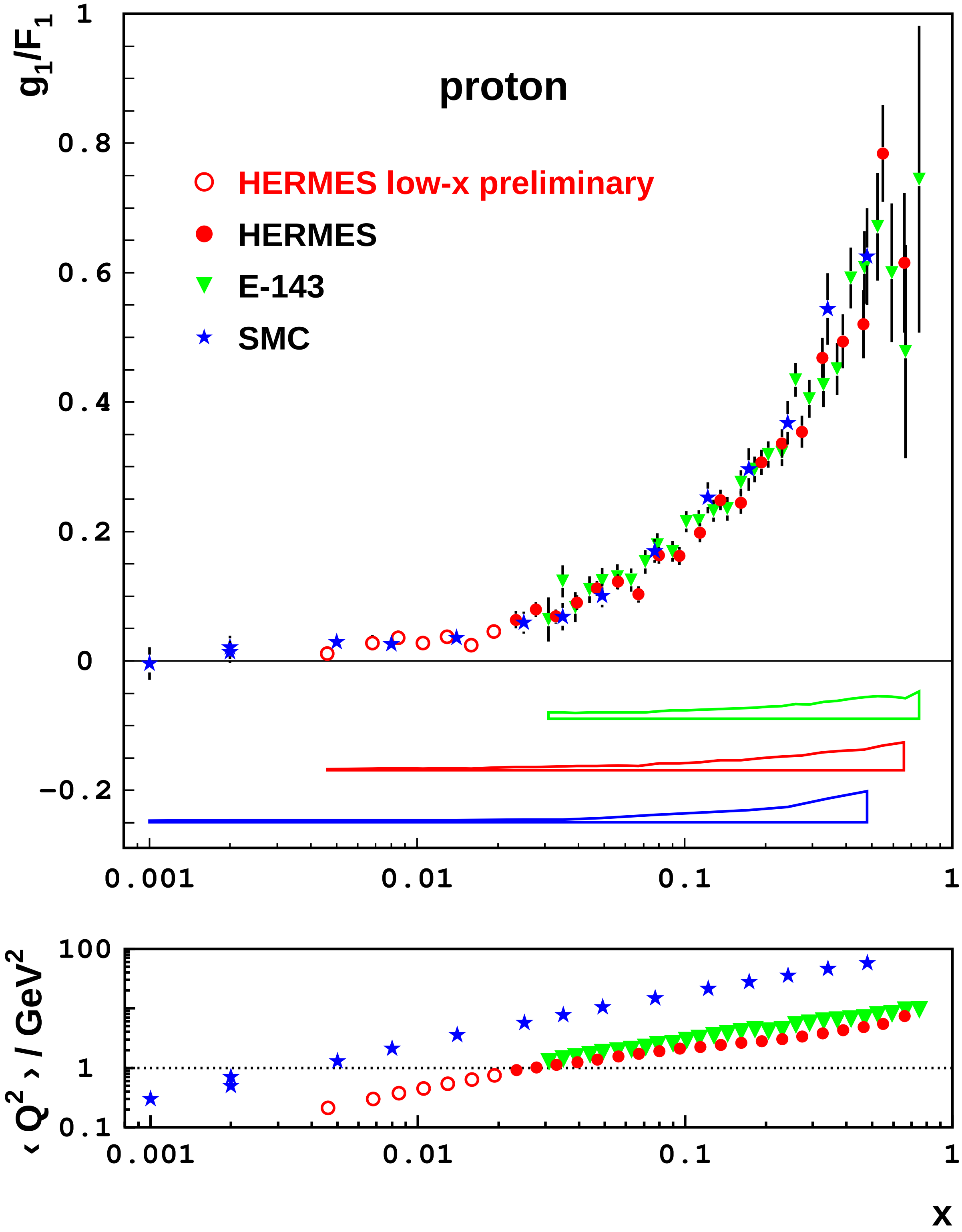
$$A_1 = \frac{1}{D(1+\eta\gamma)} A_{||}$$

D, η, γ are known kinematical factors.

A_1 relates to the nucleon structure functions:

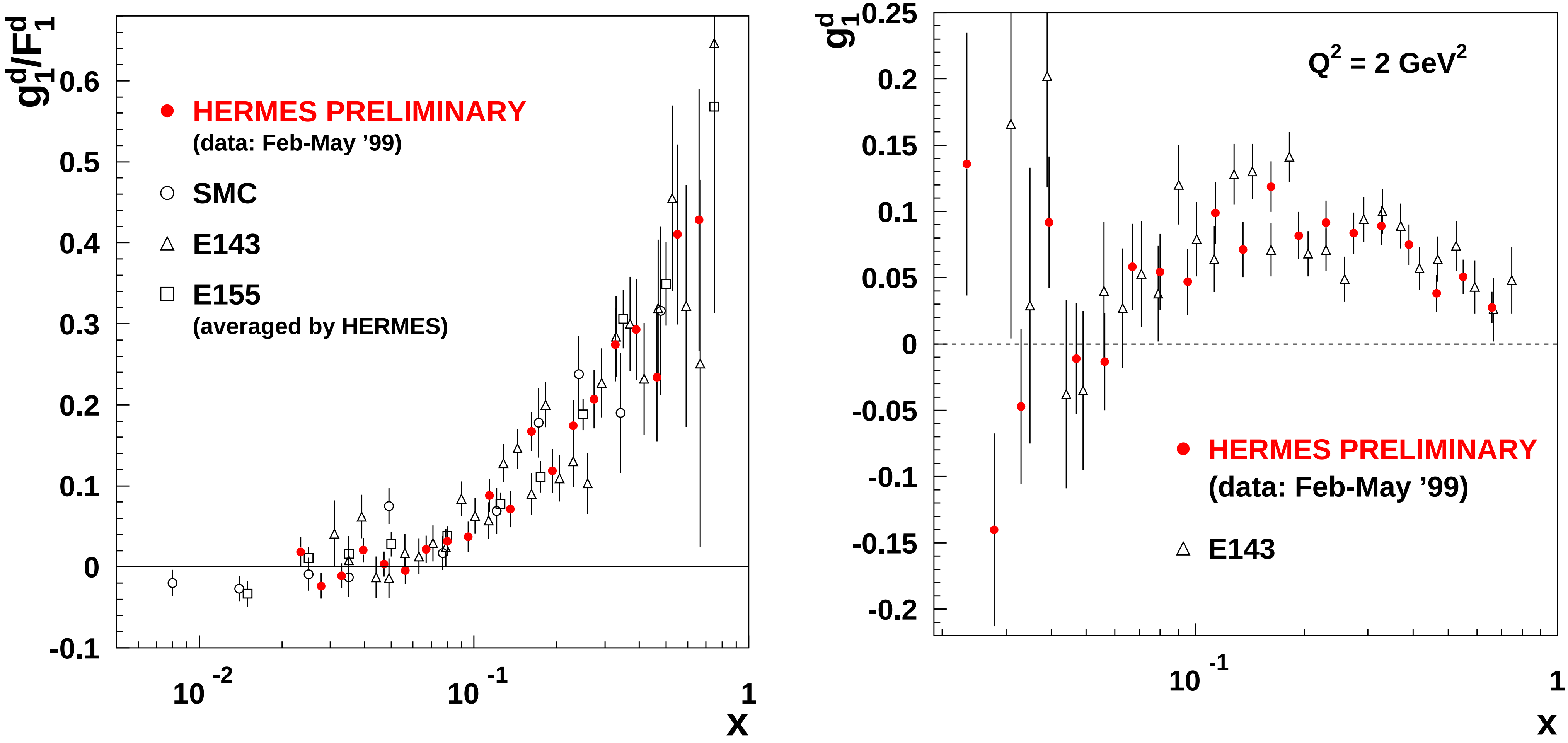
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1}$$

The Proton Spin Structure function g_1^p



- all experiments agree nicely
- Open circle show the new HERMES data at low x
- HERMES and SMC agree in the low x region
- Although the data were taken at different Q^2
- the new HERMES data is an interesting contribution for QCD studies due to the low Q^2

The Deuteron Spin Structure Function g_1^d



The shown data in good agreement with world data. Error bars are of comparable size, but the HERMES data used for this analysis are only about 20% of the total data on deuterium collected by HERMES

The Spin Structure Function g_1 II

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

In leading order:

$$F_1(x) = \frac{1}{2} \sum_f e_f^2 \, q_f(x), \quad q_f(x) \equiv q_f^+(x) + q_f^-(x)$$

$$g_1(x) = \frac{1}{2} \sum_f e_f^2 \, \Delta q_f(x), \quad \Delta q_f(x) \equiv q_f^+(x) - q_f^-(x)$$

$$A_1 = \frac{\sum_f e_f^2 \, \Delta q_f(x)}{\sum_f e_f^2 \, q_f(x)}$$

Would like to unfold $g_1(x)$ to find the $\Delta q_f(x)$'s.

$\rightsquigarrow$ Semi-inclusive deep inelastic scattering

- quark densities
- Global fits of inclusive data give an idea of the quark polarisations

Semi-Inclusive DIS: $e + N \to e' + h + X$

$$A_1^h(x) = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h}$$

$$= \frac{\sum_f \; e_f^2 \; \Delta q_f(x) \; \int \mathrm{d}z \; D_f^h(z)}{\sum_{f'} \; e_{f'}^2 \; q_{f'}(x) \; \int \mathrm{d}z \; D_{f'}^h(z)}$$

$$= \sum_f \underbrace{\frac{e_f^2 \; q_f(x) \int \mathrm{d}z \; D_f^h(z)}{\sum_{f'} e_{f'}^2 \; q_{f'}(x) \; \int \mathrm{d}z \; D_{q_{f'}}^h(z)}} \; \frac{\Delta q_f(x)}{q_f(x)}$$

$$\equiv \mathcal{P}_f^h(x)$$

$\mathcal{P}_f^h(x)$... Purity, the prob. that a hadron h originates from an event with struck quark f

$$\vec{A} = \begin{pmatrix} A^{h_1}(x) \\ \ldots \\ A^{h_m}(x) \end{pmatrix}, \; \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \ldots \\ \Delta q_n(x)/q_n(x) \end{pmatrix}, \; \mathcal{P} = [P_q^h(x)]$$

Solve:

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

- $\vec{A}$: various incl, and hadron A on various targets.
- targets: 3He, H2, and D2
- Fragmentation functions: the probability that a quark of flavour fragments into a hadron h
- Purities: The prob that a detected hadron originates from an event where a quark of flavour f was struck
- How's this done in practice => next slide

In Particular ...

- Use inclusive and $h^{\pm}$ asymmetries only
- Assume: Symmetric sea polarisation

$$\frac{\Delta q_s(x)}{q_s(x)} \equiv \frac{\Delta u_s(x)}{u_s(x)} = \cdots = \frac{\Delta \bar{s}(x)}{\bar{s}(x)}$$

Two different schemes for the decomposition:

- Flavour Decomposition (FDC)

$$\vec{Q}_{\mathrm{FDC}} = \left(\frac{\Delta u(x) + \Delta \bar{u}(x)}{u(x) + \bar{u}(x)}, \frac{\Delta d(x) + \Delta \bar{d}(x)}{d(x) + \bar{d}(x)}, \frac{\Delta s(x)}{s(x)} \right)$$

- Valence Decomposition (VDC)

$$\vec{Q}_{\mathrm{VDC}} = \left(\frac{\Delta u(x) - \Delta \bar{u}(x)}{u(x) - \bar{u}(x)}, \frac{\Delta d(x) - \Delta \bar{d}(x)}{d(x) - \bar{d}(x)}, \frac{\Delta q_s(x)}{q_s(x)} \right)$$

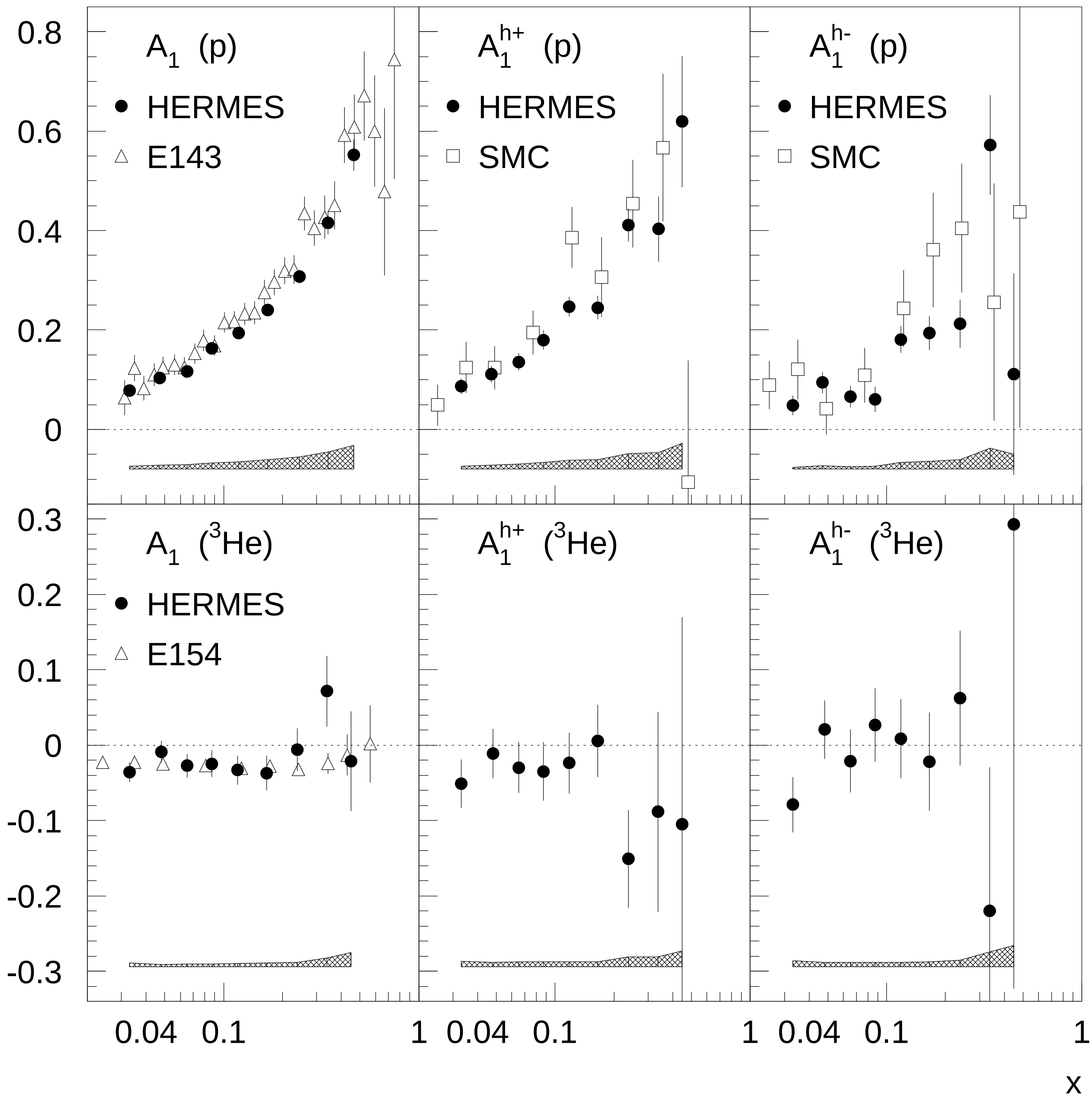
χ^2-minim. of the overconstrained SoE:

$$\vec{A}_{\mathrm{meas}} = \mathcal{P}_{\mathrm{FDC}} \cdot \vec{Q}_{\mathrm{FDC}}$$

- $\mathcal{P}_{\mathrm{FDC}}$ is an effective purity matrix
- Analogous for VDC

- quark densities
- Purities extracted from MC data using LEPTO, and the LUND string fragmentation model.
- MC has more than leading order
- it's not just a multiplication of q and D
- Fit only three parameters for overconstraint
- FDC: polarisations of the three quark flavours
- VDC: polarisations of the valence quarks and the sea

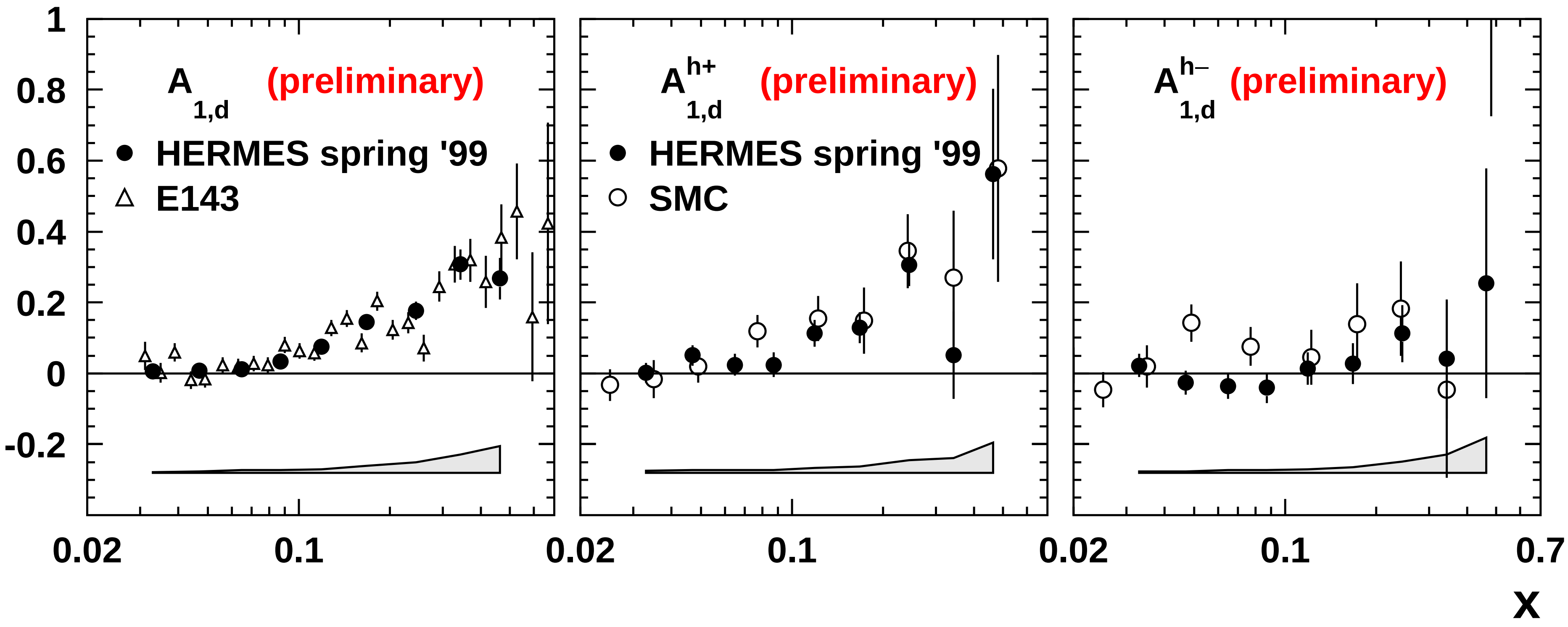
Hadron Asymmetries



- $^3\overrightarrow{\mathrm{He}}$ (1995) 2.2×10^6 DIS events and
- $\overrightarrow{\mathrm{H}}$ (1996+1997) 2.3×10^6 DIS events
- *Phys. Lett. B464 (1999) 123-134*, hep-ex/9906035

- Agreement with SMC data
- errorband, statistical error.

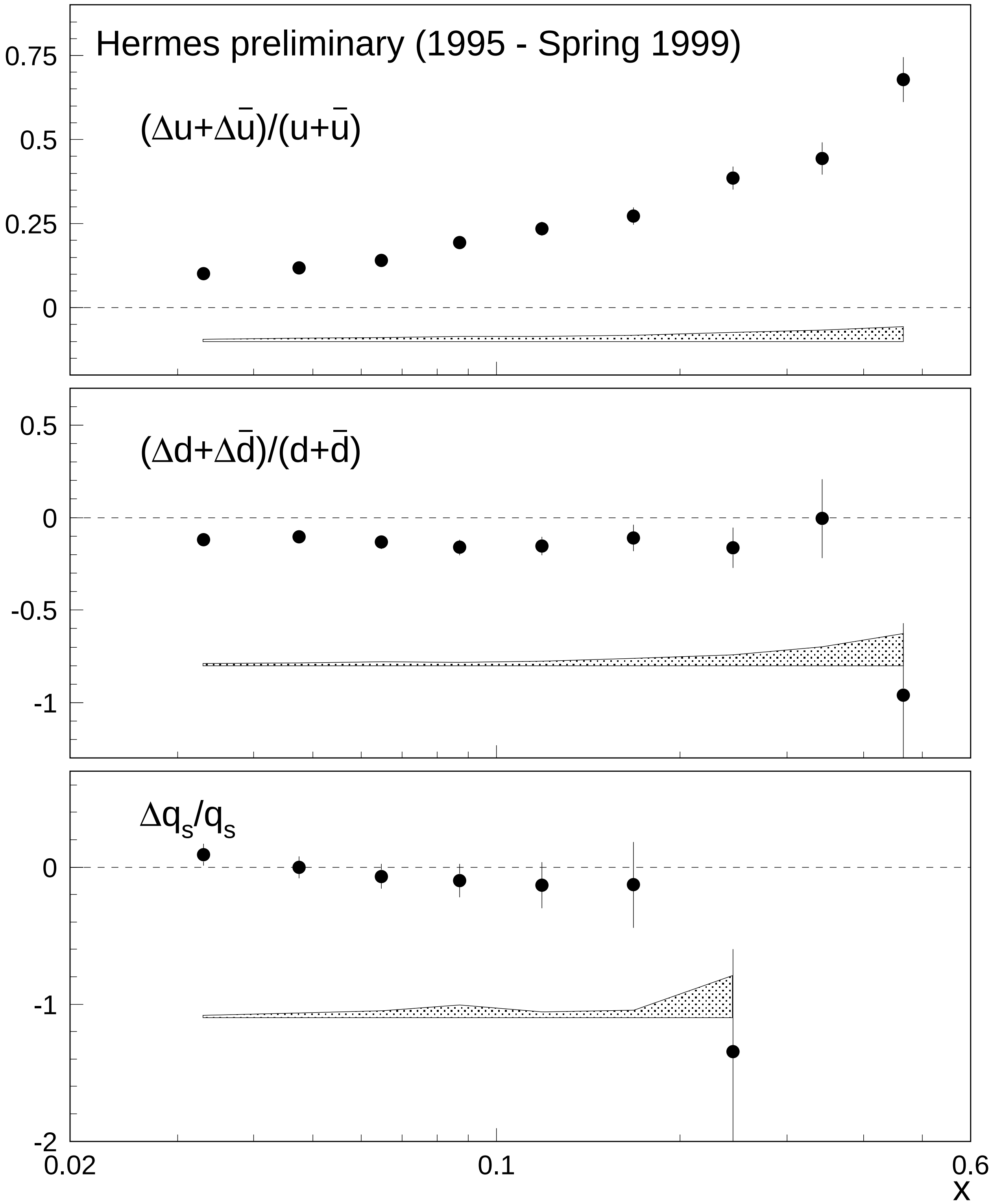
Asymmetries on Deuterium



- 0.9 M DIS events on ^{2}D (1999 spring data)
- Much more data expected from 1999 and 2000

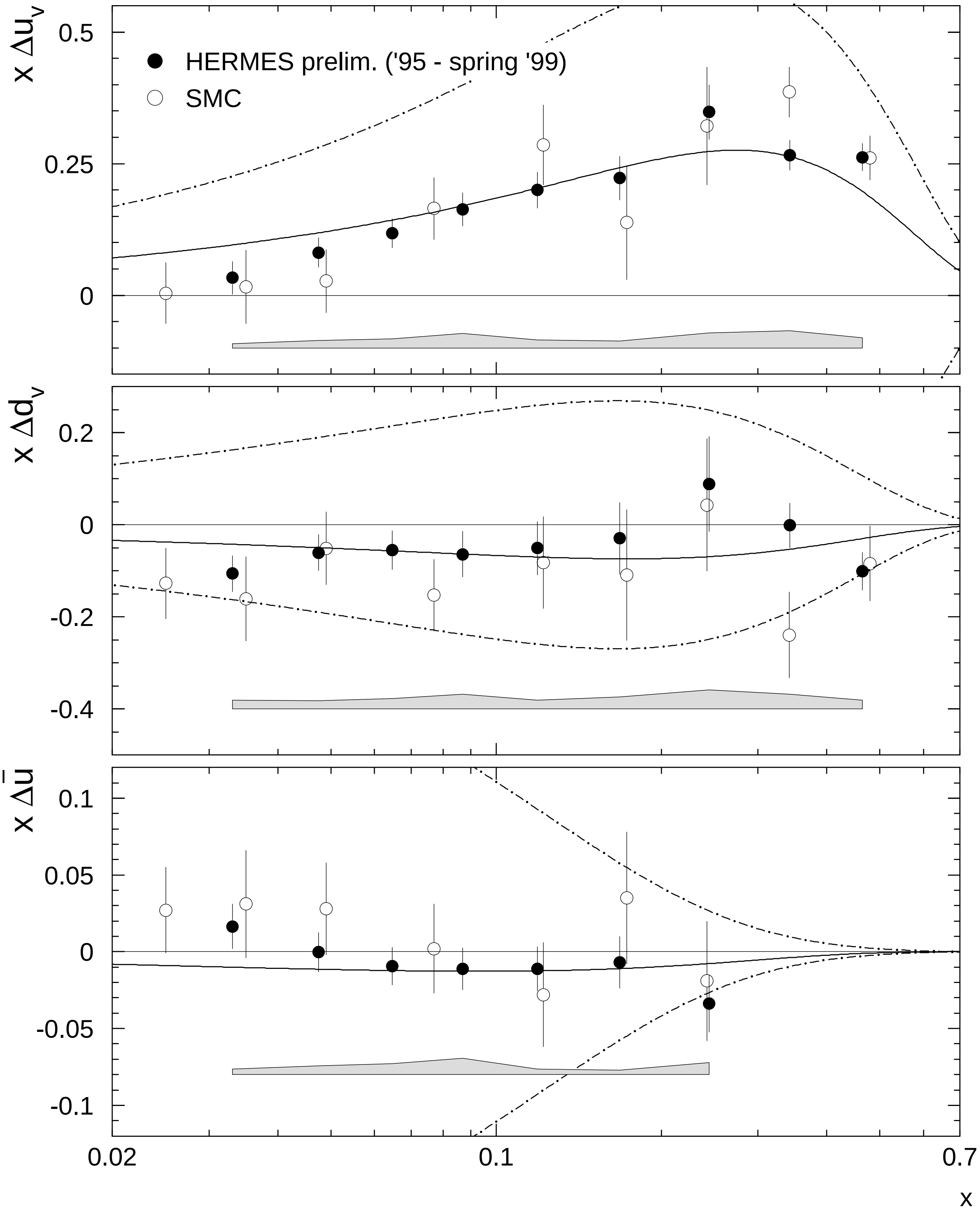
- first result from HERMES on ^2D

Quark Polarisations



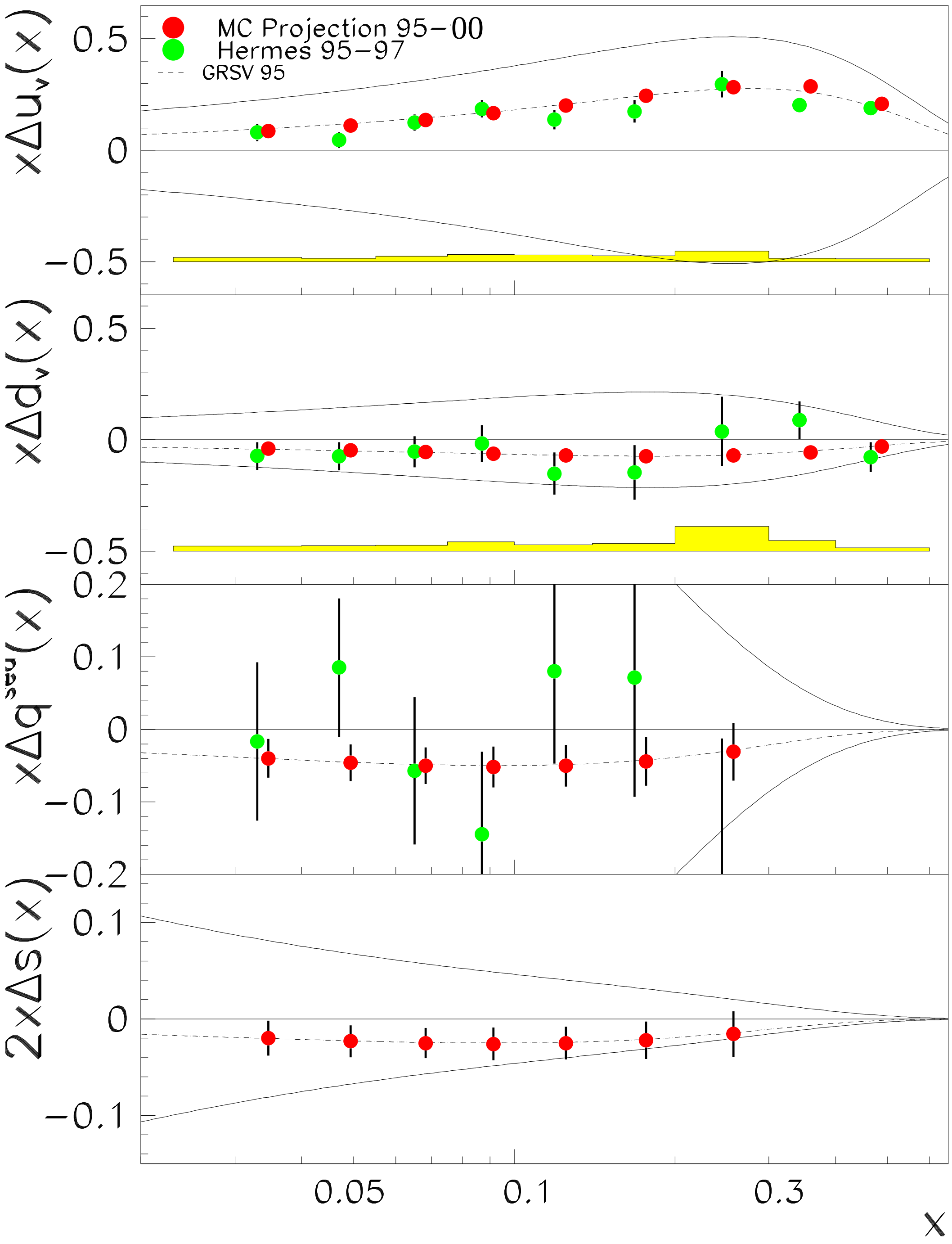
- result consistent with publication (included 95 to 97 data on 3He and hydrogen)
- u and d determined with good precision
- positive polarisation of the u
- negative pol of the d
- sea pol consistent with zero

Valence Quark Polarisations



Dashed: Positivity limit; Solid: GRSV

Projected Accuracy Δq



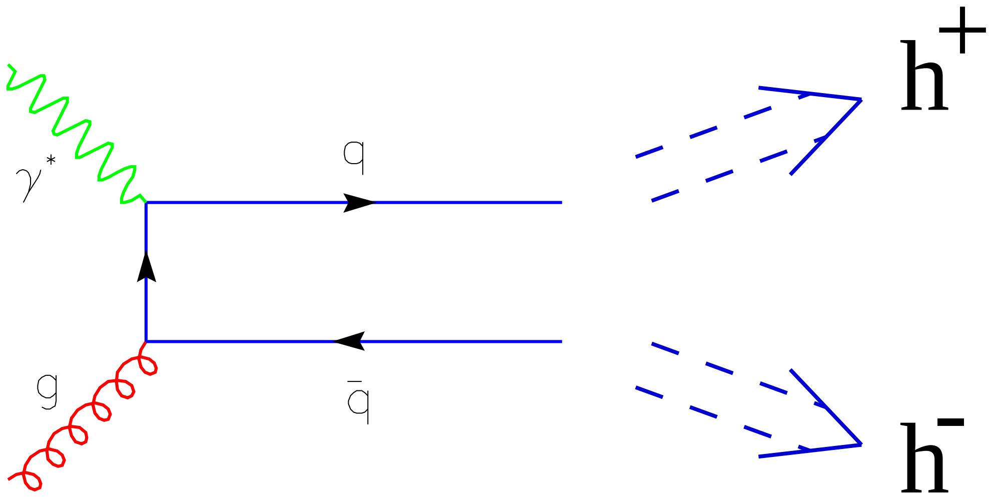
Projection based on

- 8×10^6 DIS events on ^{2}D
- Δs: semi inclusive $K^{\pm}$-asymmetries
- $\langle P_{target} \rangle = 0.88$ and $\langle P_{beam} \rangle = 0.5$

- The presented prelim/published results are not the end of the story
-
- plot shows the projected accuracy for 8M DIS
- This data has already been taken and is on tape
- Extraction and inclusion of kaon asymmetries later on.
- next slide: gluon polarisation

The Gluon Polarisation ΔG

Through Photon Gluon Fusion in $(\gamma g \to q\bar{q})$:



How to suppress the DIS process?

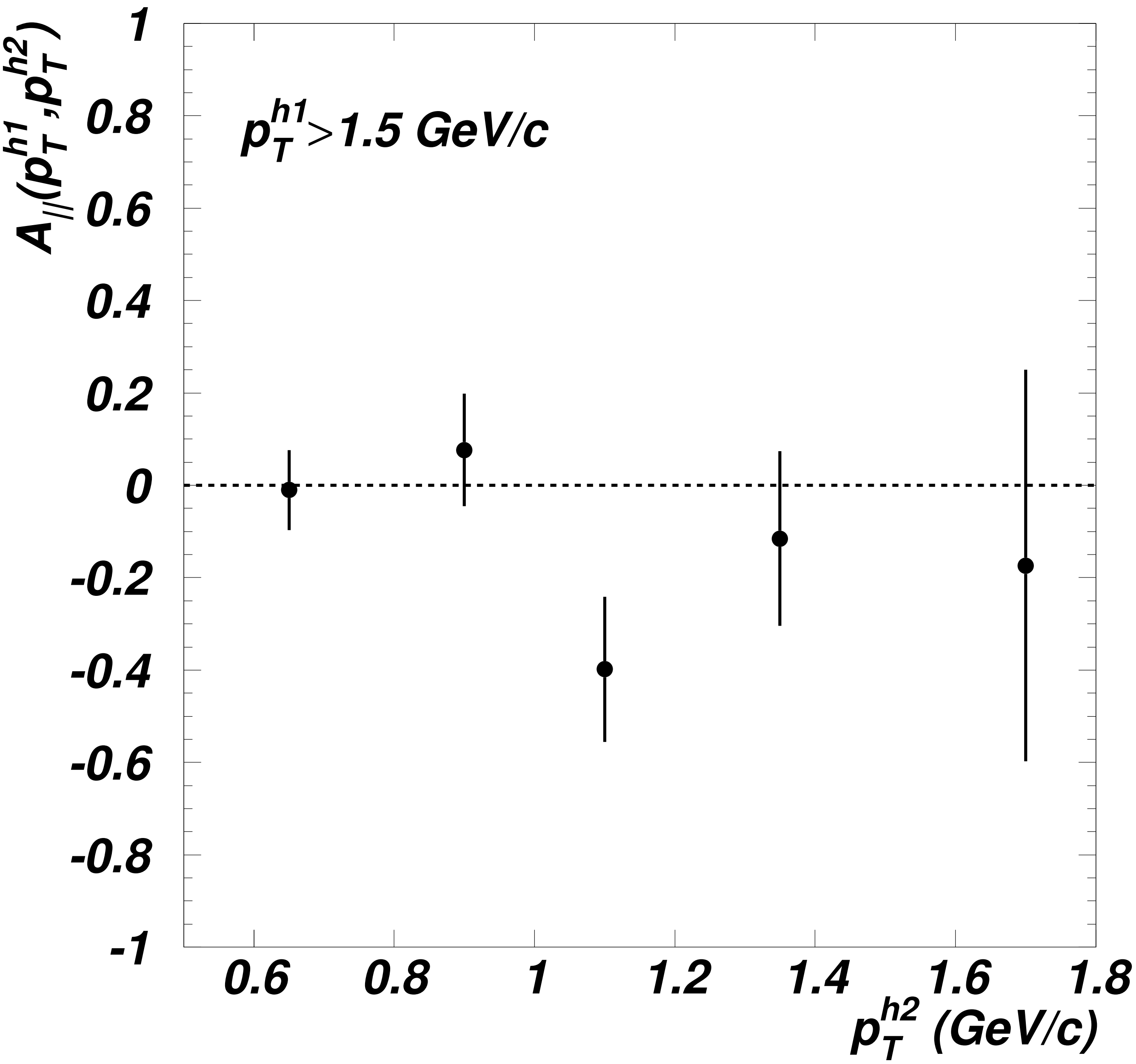
- Open and hidden charm: $\gamma^* G \to c\bar{c} \rightsquigarrow$ D, J/ψ
- Hadron pairs with large transverse momentum p_T

Measure a spin asymmetry $A_{||}$:

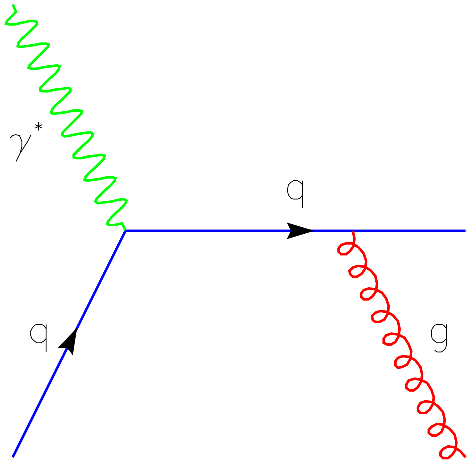
$$A_{||} = \frac{N_{h^\pm}^{\uparrow\downarrow} - N_{h^\pm}^{\uparrow\uparrow}}{N_{h^\pm}^{\uparrow\downarrow} + N_{h^\pm}^{\uparrow\uparrow}}; \qquad A^{\gamma^* p \to h^\pm} \sim \Delta G / G$$

- Until now only indirect access through scaling violation in g_1
- HERMES carried out the first direct measurement of delta G
- Must suppress the DIS process to measure PGF
- Two channels for current fixed target experiments:
  - charm prod: $D^+ = c\bar{d}$, $D^0 = c\bar{u}$, $D^- = \bar{c}d$ $\mathrm{J}/\psi = c\bar{c}$
  - high p_T hadron pairs. The transverse momentum of the gluons in the nucleon is a lot higher than that of the quarks.

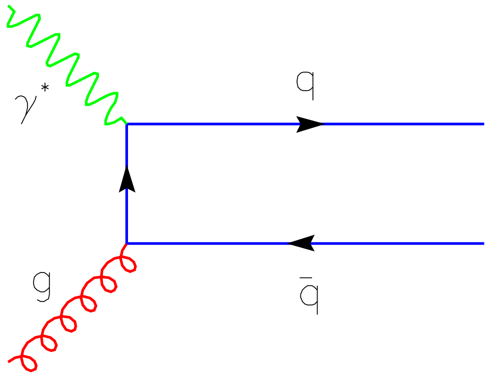
The High p_T asymmetry $A_{\|}$



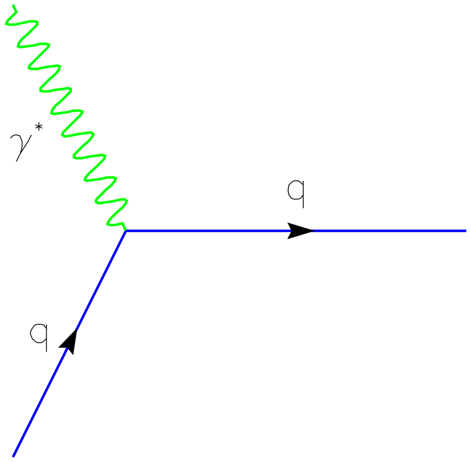
Four Competing Processes in LO QCD



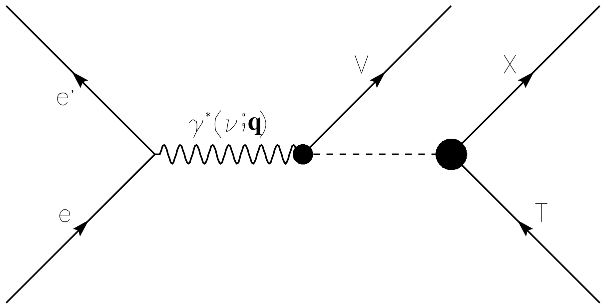
QCDC



PGF



DIS (negligible in high p_T)



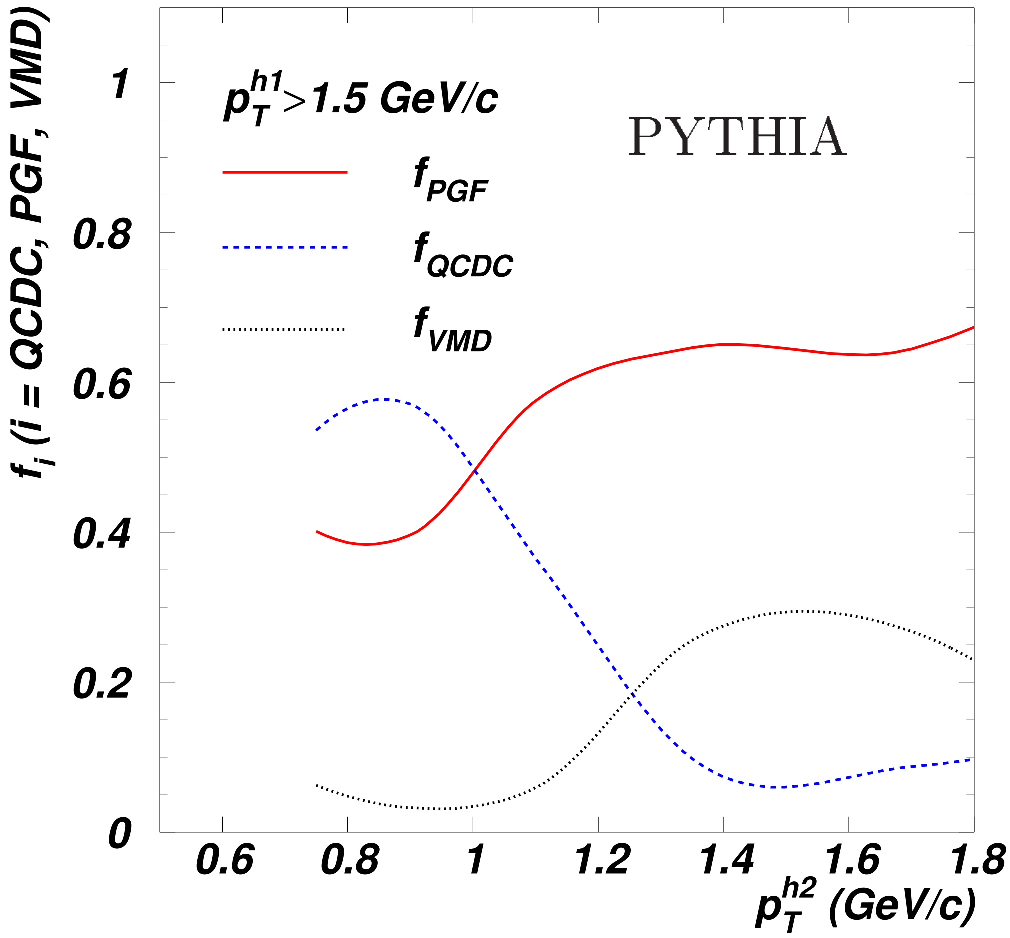
VMD (assume $A_{\mathrm{VMD}} = 0$)

$$\begin{aligned} A_{\|} &= A_{\mathrm{QCDC}}\, f_{\mathrm{QCDC}} + A_{\mathrm{PGF}}\, f_{\mathrm{PGF}} \\ &\quad + A_{\mathrm{DIS}}\, f_{\mathrm{DIS}} + A_{\mathrm{VMD}}\, f_{\mathrm{VMD}} \\ &\approx A_{\mathrm{QCDC}}\, f_{\mathrm{QCDC}} + A_{\mathrm{PGF}}\, f_{\mathrm{PGF}} \end{aligned}$$

f_i ... unpolarised fraction of events for process i

- PGF <u>a</u>nd QCDC plus
- DIS is negligible in high p_T photoproduction
- VMD has non-zero contribution, but the process is assumed to be spin-independent.
- So $A_{\|}$ is really only PGF and QCDC
- next slide: relative fractions of the subprocesses

Contributions to the Asymmetry



$$A_{\mathrm{PGF}} \approx \langle \hat{a}(\gamma g \to q\bar{q})\rangle \langle \frac{\Delta G}{G} \rangle \equiv \langle \hat{a}_{\mathrm{PGF}} \rangle \frac{\Delta G}{G}$$

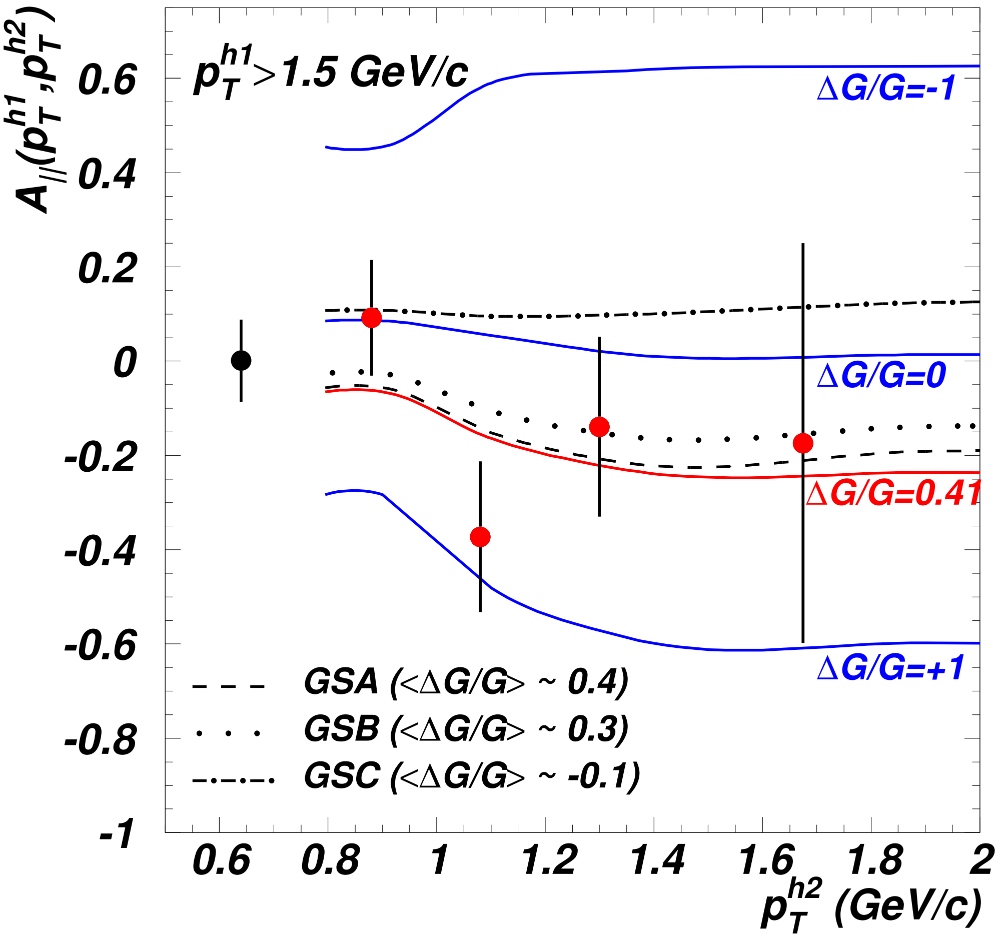
$$A_{\mathrm{QCDC}} \approx \langle \hat{a}(\gamma q \to qG)\rangle \langle \frac{\Delta q}{q} \rangle \equiv \langle \hat{a}_{\mathrm{QCDC}} \rangle \frac{\Delta q}{q}$$

LO QCD: $\langle \hat{a}_{\mathrm{PGF}} \rangle = -1, \quad \langle \hat{a}_{\mathrm{QCDC}} \rangle \approx 0.5$

$$\therefore \quad \frac{\Delta G}{G} \approx \frac{A_{\mathrm{meas}} - \langle \hat{a}_{\mathrm{PGF}} \rangle \frac{\Delta q}{q} f_{\mathrm{QCDC}} \langle D(y) \rangle}{\langle \hat{a}_{\mathrm{PGF}} \rangle f_{\mathrm{PGF}} \langle D(y) \rangle}$$

- Which deltaqs were used (I guess no HERMES data available)

ΔG Using The PYTHIA Monte Carlo



$$\Delta G/G = 0.41 \pm 0.18 \text{ (stat.)} \pm 0.03 \text{ (exp.syst.)}$$

$$\text{at } \langle x_G \rangle = 0.17 \text{ and } \langle \hat{p}_T^2 \rangle = 2.1 \text{ GeV}^2$$

$\boxed{\Delta G/G \text{ is positive}}$

2× smaller errors expected with 1998-2000 data

A. Airapetian et al, PRL 84 (2000) 2584, hep-ex/9907020

- LOOK UP contribution from non-resonant anomalous photon structure.

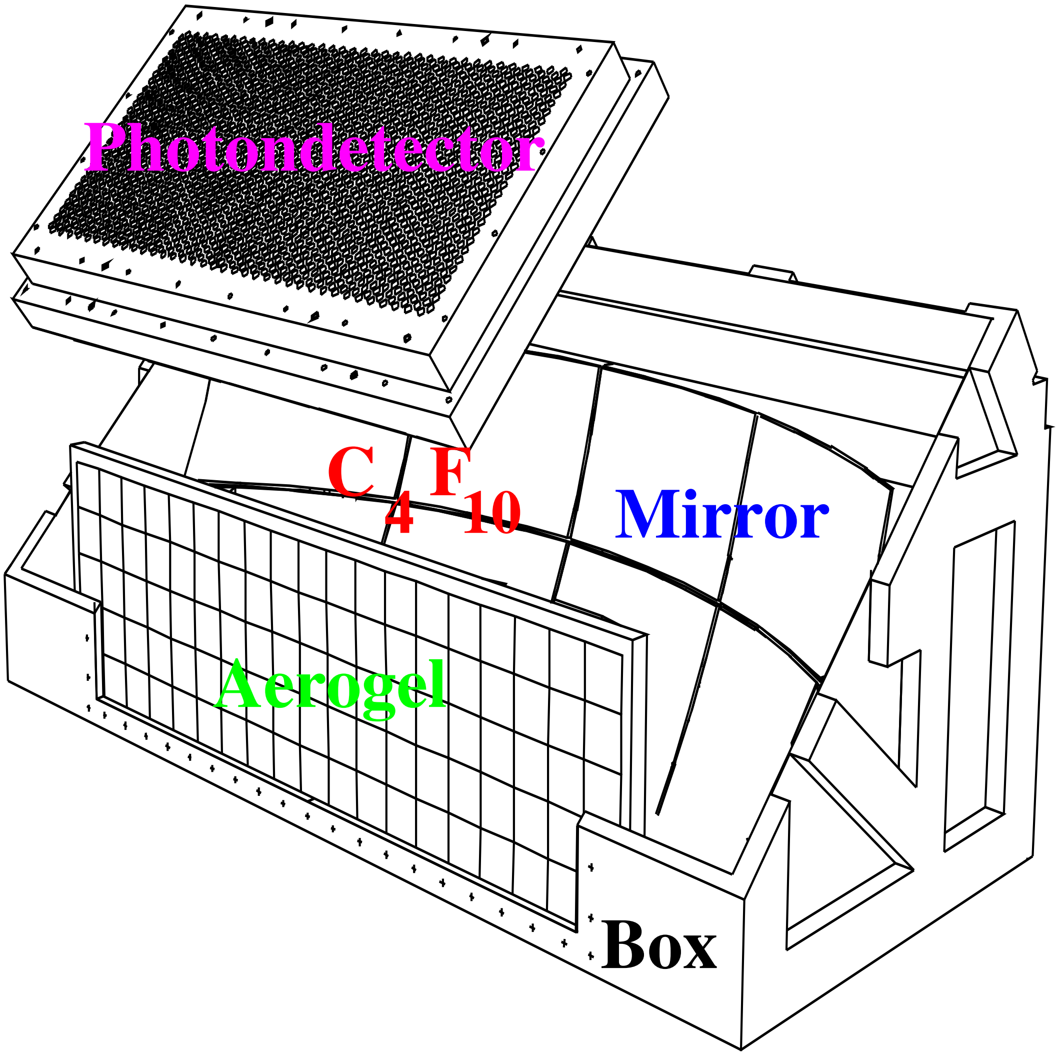
- $A_{||}$ of hight p_t pairs is negative in contrast to pos A

- HERMES measures a negative asymmetry

- In the used model it is interpreted as a positive gluon polarisation

- Even if processes such as VMD and DIS would contribute to the asymmetry, their asymmetries would be positive, increasing the absolute asymmetry of the high pt pairs.

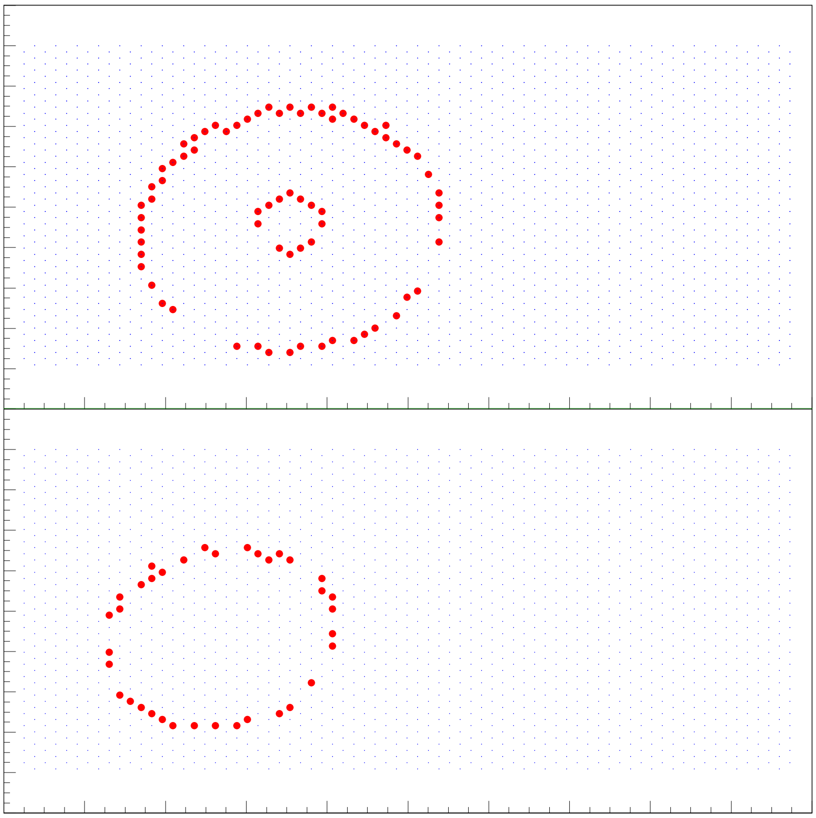
The HERMES RICH Detector

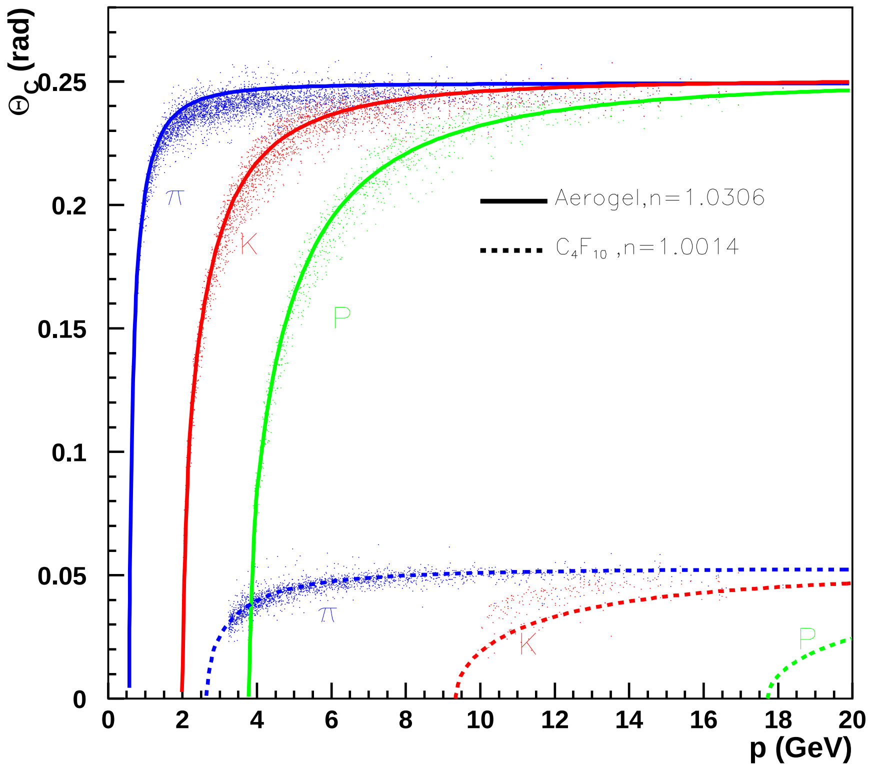


Photon Detector:	2000 Philips XP1911/UV	
	Read-out: PCOS4	
Radiators:	Aerogel	C_4F_{10}
Mirror:	spherical mirror (r=2.2m)	
	aluminised carbon fibres	

- aerogel and gas
- two detector halves
- some more from the proposal

Particle Identification with the RICH





- two rings in the upper panel
- theta c vs. momentum. Illustrates the aerogel being sensitive at low momenta and the gas at high momenta

Outlook: Polarisation of the Sea

- So far extraction only includes A_1, $A_1^{h^+}$, and $A_1^{h^-}$
- RICH allows for $\pi^\pm$, $K^\pm$ identification

  $\rightsquigarrow$ Whole new set of asymmetries

  $\rightsquigarrow$ Further constraints on the extraction

  $\rightsquigarrow$ Include asymmetries in the analysis
- $A_1^{K^-}$: Asymmetry of an all sea object ($K^- = \bar{u}s$)

  $\rightsquigarrow$ Sensitivity to the quark sea
- Using the purity formalism extract

$$\frac{\Delta u_v(x)}{u_v(x)}, \quad \frac{\Delta d_v(x)}{d_v(x)}, \quad \frac{\Delta \bar{q}_{\text{light}}(x)}{\bar{q}_{\text{light}}(x)}, \quad \frac{\Delta s(x)}{s(x)}$$

- Alternatively extract

$$\frac{\Delta u_v(x)}{u_v(x)}, \quad \frac{\Delta d_v(x)}{d_v(x)}, \quad \frac{\Delta \bar{u}(x)}{\bar{u}(x)}, \quad \frac{\Delta \bar{u}(x) - \Delta \bar{d}(x)}{\bar{u}(x) - \bar{d}(x)}$$

  Large asymmetry $\Delta\bar{u} - \Delta\bar{d} > 0$ predicted in the CQSM (B. Dressler et al.; hep-ph 9909541)

- Extend the purity formalism to include pion, kaon, and proton asymmetries
- These asymmetries result in more equations for the fit, will further constrain the fit
- Further degrees of freedom are possible
- $\mathrm{K}^- = (\bar{u}s)$ is sensitive to the sea.
- The fragmentation from a u-quark is actually suppressed by a factor of about 3 (SMC), so that A_{K^-} is actually sensitive to Δs.
- There are indications that the value of 3 is even higher at HERMES energies.
- AK- is an all sea object and sensitive to the sea
- AK+ in turn is sensitive to the u-quark, beacuse fragmentation from the $\bar{s}$ is strongly suppressed.
- (Pion asymmetries could be determined before, but the RICH covers a larger kinematical range than the threshold Č. In addition the RICH identifies kaons and protons as well)

Conclusion

- First HERMES data on g_1^d in agreement with previous experiments
- Polarisations of up and down quarks determined with good precision: $\Delta u > 0$, $\Delta d < 0$, $\Delta \bar{q} \approx 0$
- First evidence of gluon polarisation:
  HERMES measures negative high p_T asymmetry
  (indication of positive gluon polarisation)
- Additional information on the hadronic final state using the RICH
- Very successfull data taking in 1999 and 2000.
  More than 7,000,000 DIS still to be analysed

Outlook

- Spin program will continue:
  - Transverse structure functions
  - Longitudinal strange quark polarisation
  - Longitudinal gluon polarisation
- Detector upgrades:
  - RICH
  - Forward quadrupole chambers (FQS)
  - Wide Angle Muon Hodoscope (WAM)
  - Silicon counters downstream of the target (lambda wheels)
  - Recoil detection
- Additional subjects:
  - Spin structure of the Λ^0 hyperon
  - Nuclear effects: Shadowing,
    coherence length effects,
    hadron formation times,
    nuclear dependence of $R = \sigma_L/\sigma_T$

- Lumi higher due (i) smaller storage cell, (ii) initial electron current of 58mA (now: $\approx 40 mA$)