Spin Physics: where will we be in 2006?

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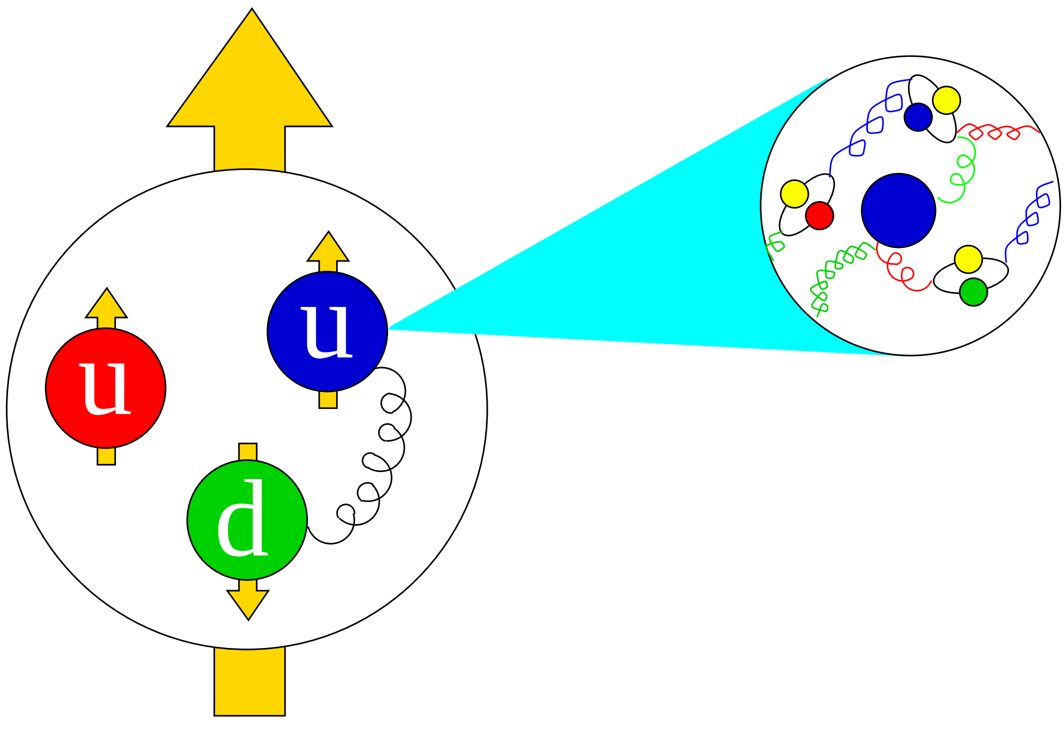
hermes

Durham (UK), 6 December 2001



IPPP Workshop on Future Physics at HERA

Introduction

- The origin of spin in the baryon octet:

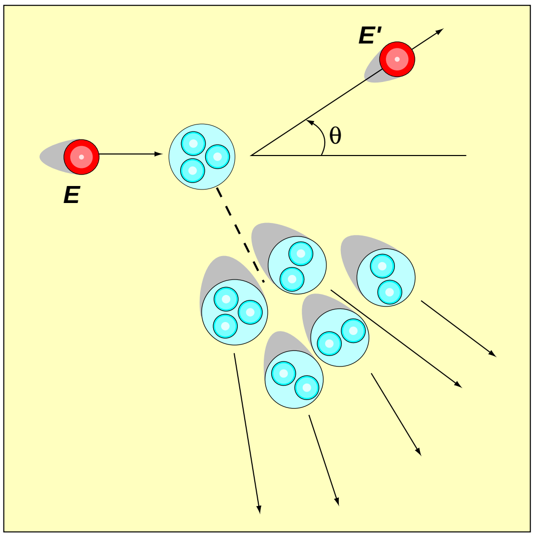
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma_q + \Delta G + L_z$$

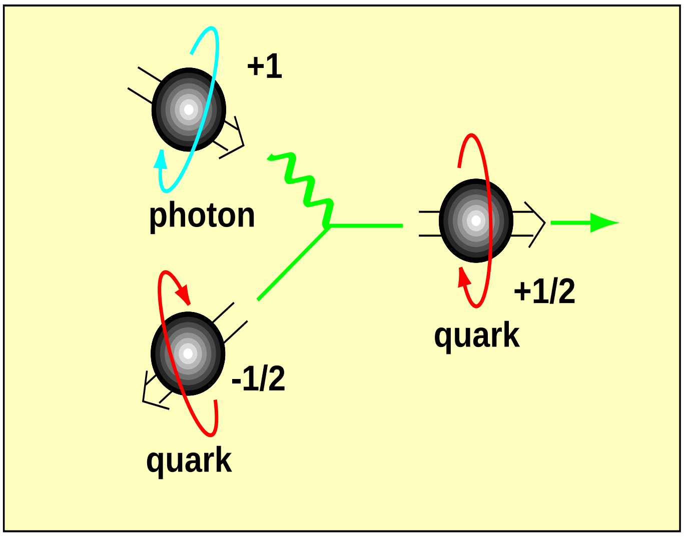
- Developing insight:
  - EMC (SLAC, SMC and HERMES): $\Delta\Sigma_q \approx 0.3 \pm 0.1$
  - The quark model: $\Delta\Sigma_q = (\uparrow\downarrow\uparrow) = 1.0$
  - Relativistic MIT bag model: $\Delta\Sigma_q \simeq 0.60 - 0.75$

- Experimental questions:
  - What about flavour dependence?
    $\Delta u(x)$, $\Delta d(x)$, $\Delta s(x)$
  - What about gluons?
    $\Delta G(x)$
  - What about orbital angular momentum?
    Deeply Virtual Compton Scattering: L_z?
  - What about other baryons?
    n,Λ^0,..
  - What about lattice QCD?
    longitudinal spin: $\Delta\Sigma_q \simeq 0.18 \pm 0.10$
    transverse spin: $\delta\Sigma_q \simeq 0.56 \pm 0.09$

Spin Physics

- Polarized Deep Inelastic Scattering @ 27 GeV:





- Asymmetry w.r.t. to target spin orientation:

$$A_1 = \frac{1}{DP_TP_B}\frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{N_{\uparrow\downarrow} + N_{\uparrow\uparrow}}$$

- The spin-dependent structure function $g_1(x)$:

$$A_1 \simeq \frac{g_1(x)}{F_1(x)} \simeq \frac{1}{F_1(x)}\sum_f e_f^2 \Delta q_f(x)$$

with the quark polarization:

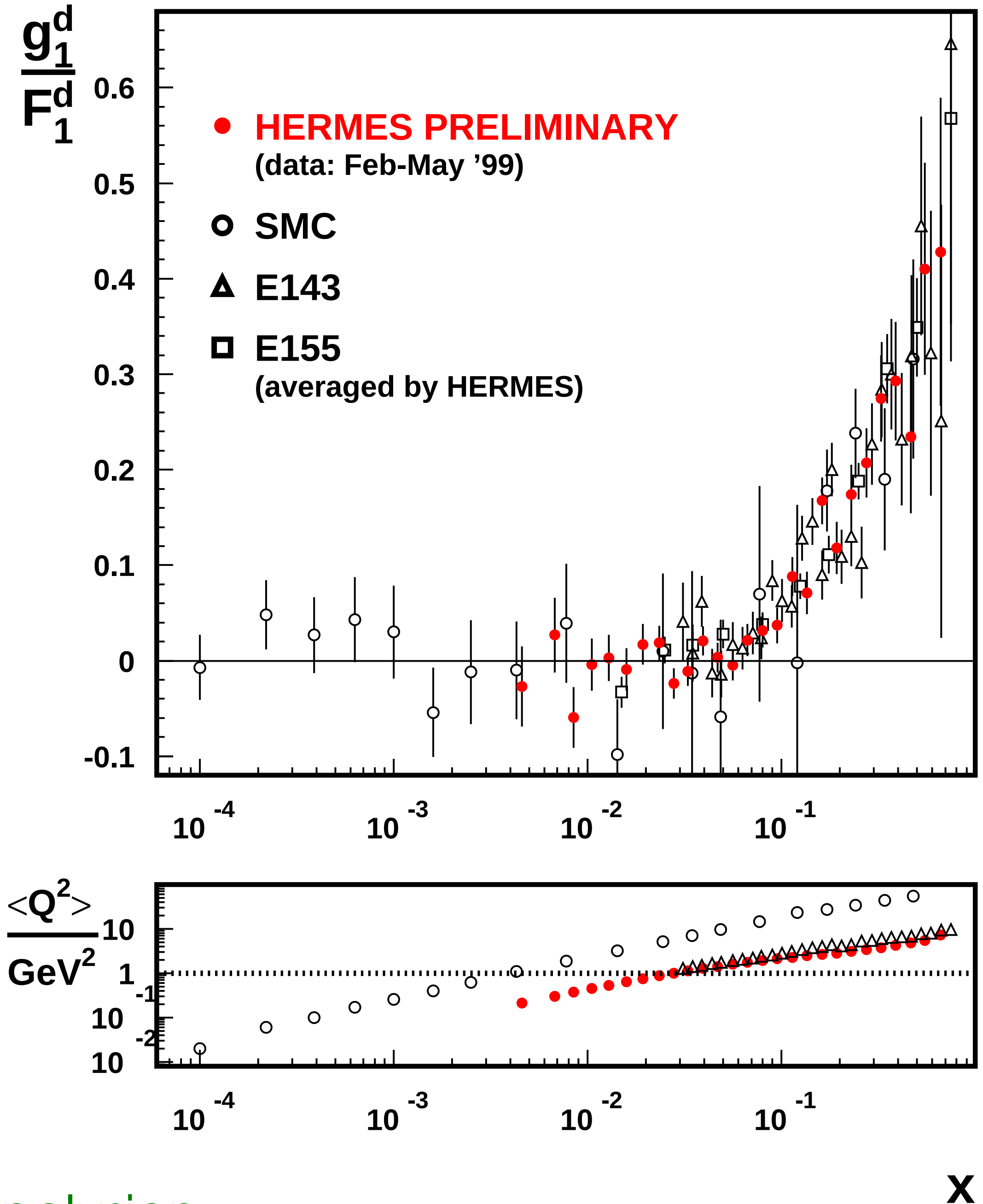
$$\Delta q_f(x) = q_f^+(x) - q_f^-(x)$$

- Use hadron final state as a tag:

$$\pi^+ \rightarrow \Delta u(x); \quad K^- \rightarrow \Delta s(x); \quad D^0 \rightarrow \Delta G(x)$$

New inclusive data on ^{2}H

- Compare to existing data:



- Conclusion:

$g_1^d(x)$: no strong Q^2 dependence

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Polarized Structure Functions

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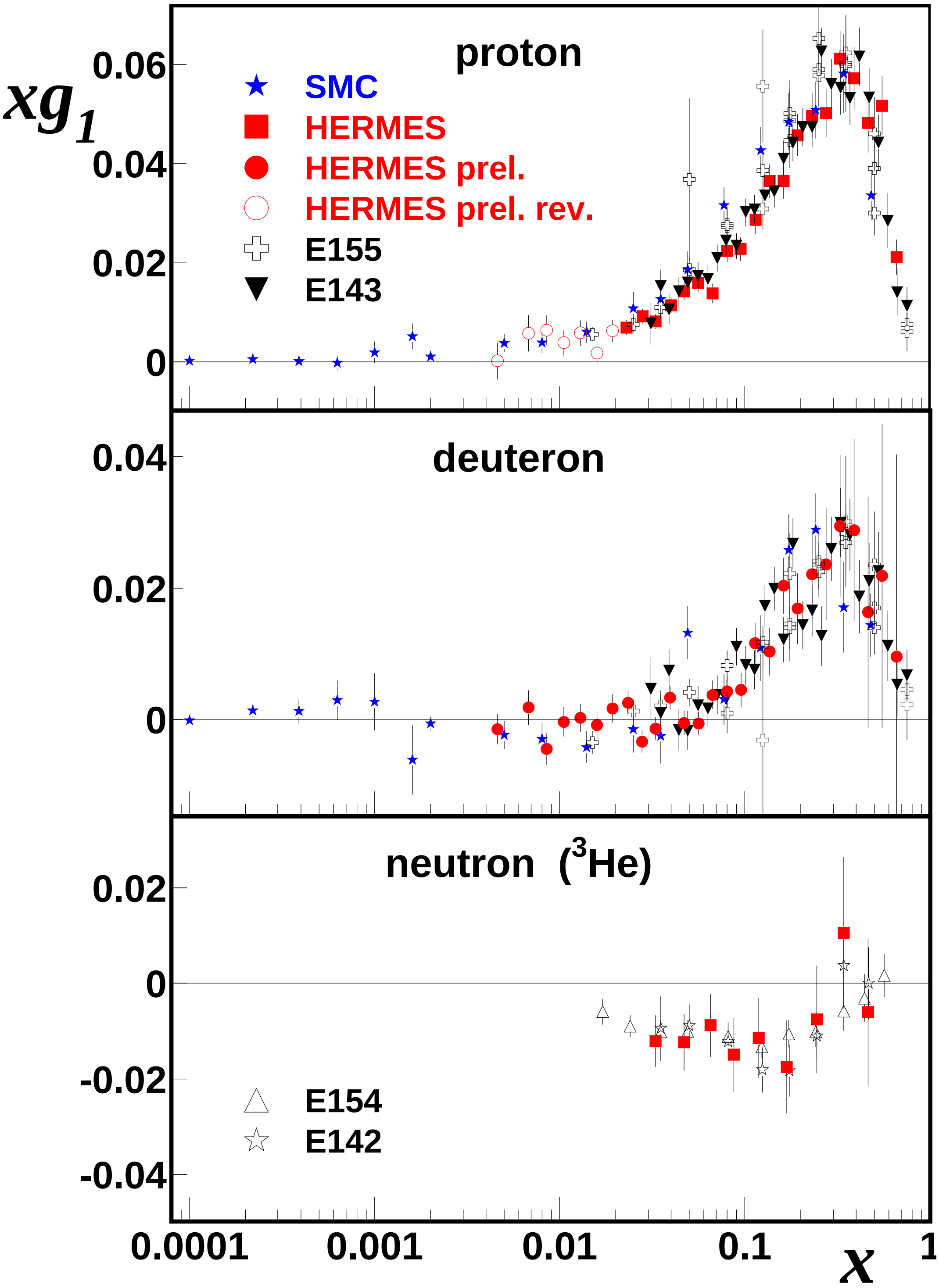
- Comparison to existing $g_1^p(x)/F_1^p(x)$ data:



Semi-Inclusive Asymmetries

- Asymmetry for semi-inclusive hadron (h) production:

$$A_1^h(x) = \frac{\int dz \sum_f e_f^2 \, \Delta q_f(x) \, D_f^h(z)}{\int dz \sum_f e_f^2 \, q_f(x) \, D_f^h(z)} \propto \frac{N_{\uparrow\downarrow}^h - N_{\uparrow\uparrow}^h}{N_{\uparrow\downarrow}^h + N_{\uparrow\uparrow}^h}$$

- Define purity $P_f^h(x)$:

$$P_f^h(x) = \frac{e_f^2 q_f(x) \int D_f^h(z) dz}{\sum_f e_f^2 q_f(x) \int D_f^h(z) dz}$$

(probability that hadron h is produced when quark f is hit)

- Measure asymmetries on various targets:

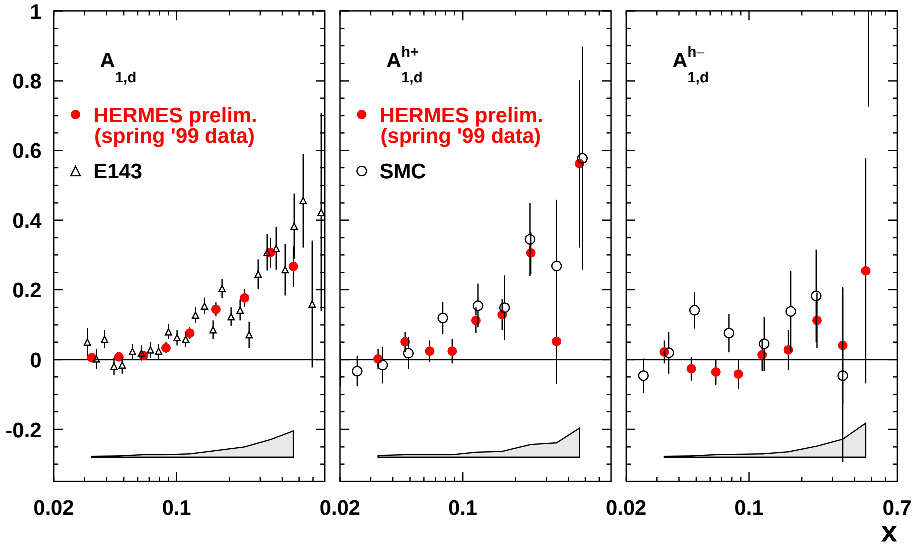
$$\boxed{\vec{A}(x) = \mathbf{P}(x) \, \vec{Q}(x)}$$

with $\vec{A}(x)$ = $(A_{1p}, A_{1p}^{h^+}, A_{1p}^{h^-}, A_{1d}, \ldots)$
and $\vec{Q}(x)$ = $(\Delta u(x), \Delta d(x), \Delta \bar{u}(x), \ldots)$

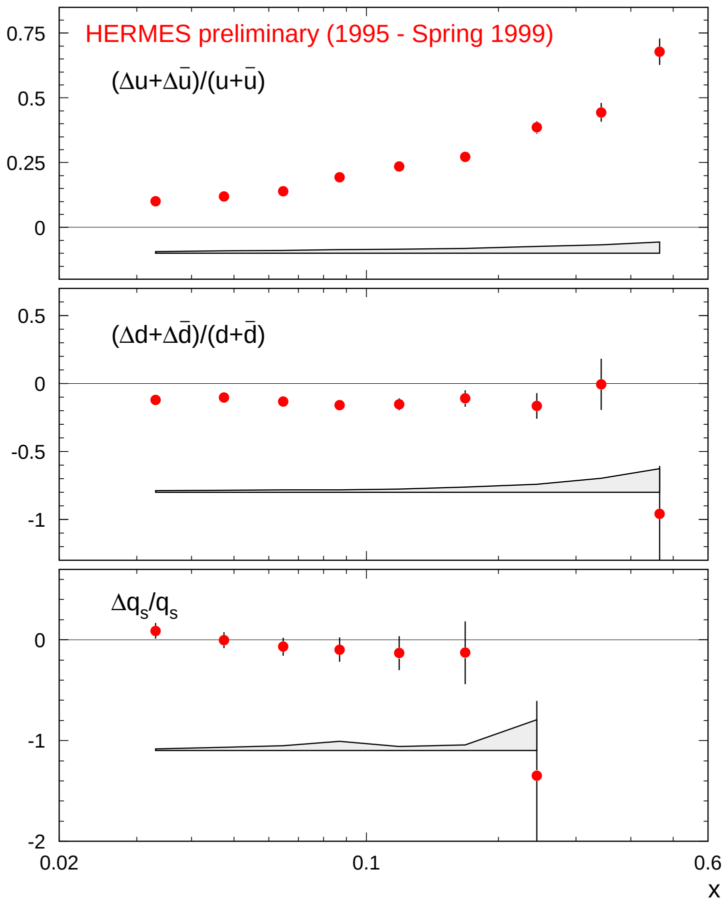
$\Rightarrow$ Polarized quark distributions: $\Delta u(x)$, $\Delta d(x)$, ...

Polarized quark distributions - 1

- Measured semi-inclusive asymmetries $A_1^h(x)$:



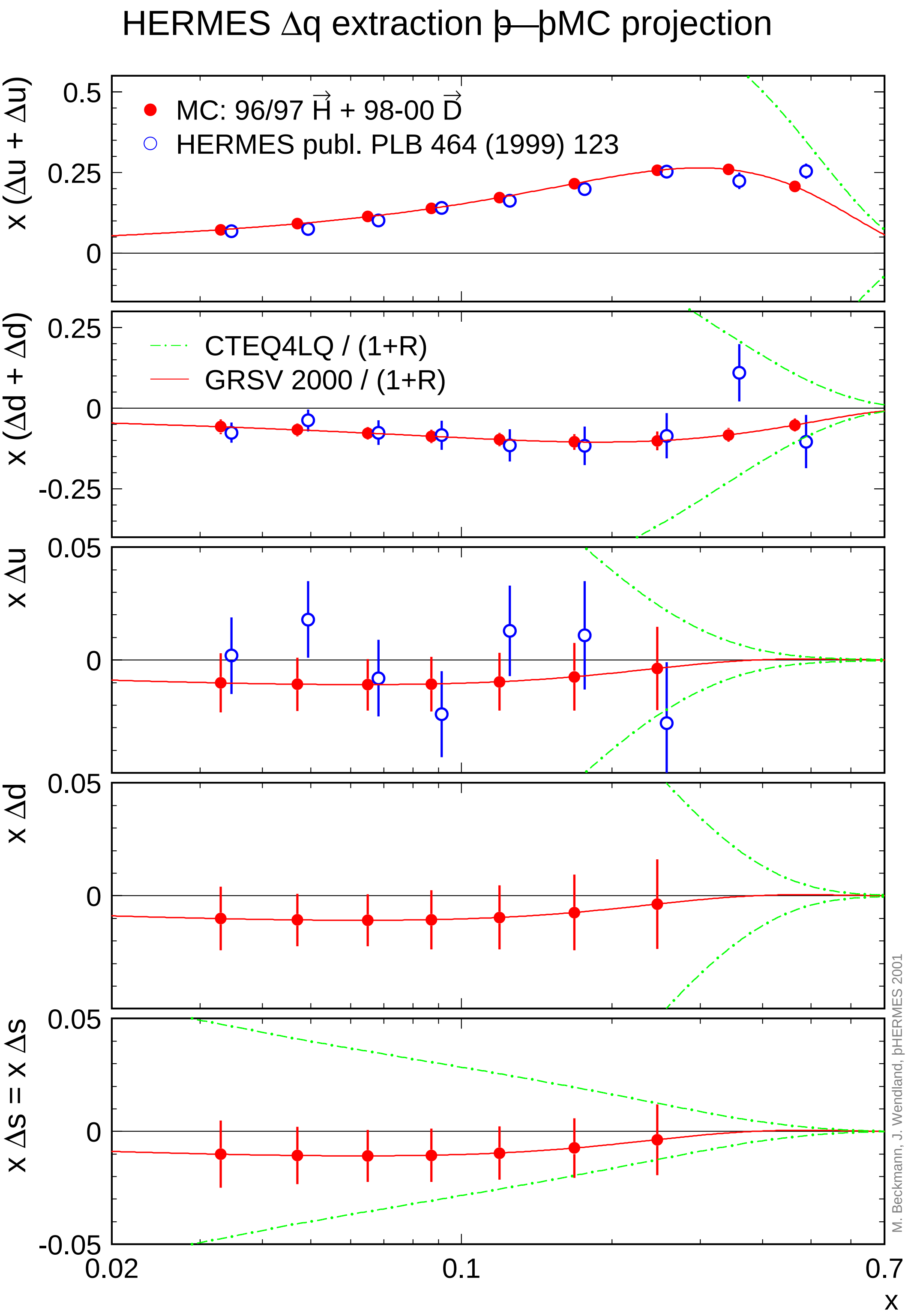
- Extracted quark spin distributions:



Spin - flavour separation.

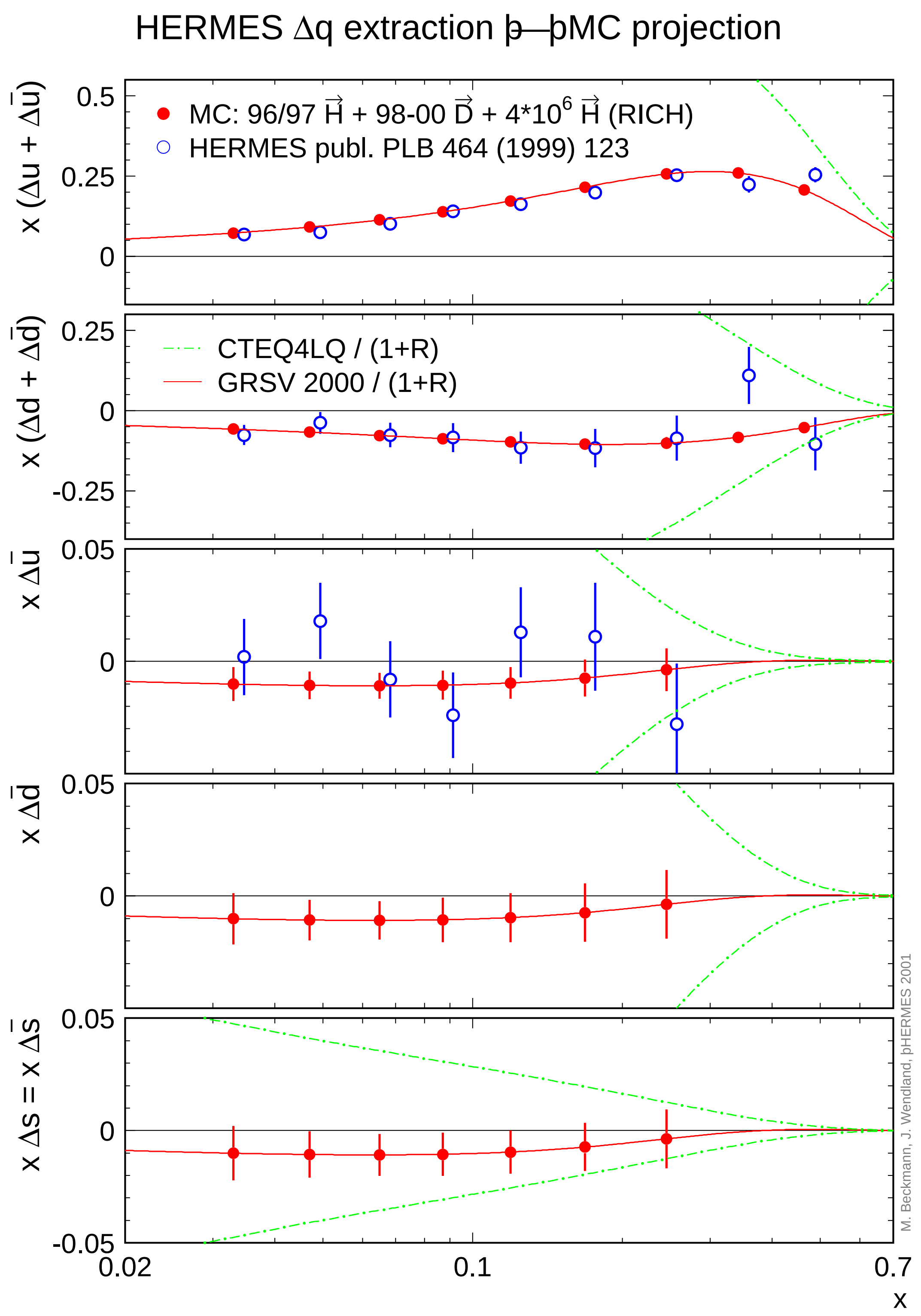
Polarized quark distributions - 2

- Expected data quality with all 2000 data analyzed:



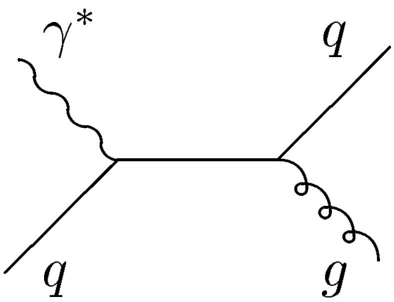
Where will we be in 2006?

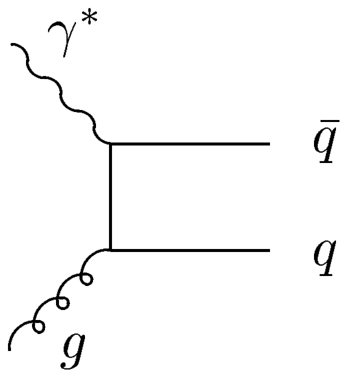
- Assume one more year of data on long. pol. ^{1}H



High-p_T hadron pairs from ^{1}H

- pQCD Compton graph and Photon-Gluon Fusion:

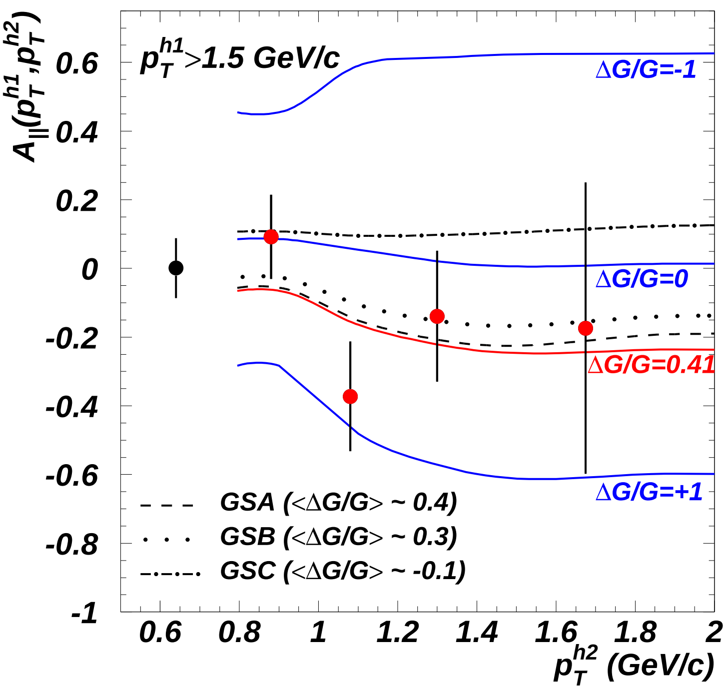




- Asymmetry for high-p_T pions $(R = \sigma_{PGF}/\sigma_{Com})$:

$$A_{LL}^{eN\rightarrow h_1 h_2} = \hat{a}_{QCDC}\frac{\Delta q}{q}\frac{1}{1+R} + \hat{a}_{PGF}\frac{\Delta G}{G}\frac{R}{1+R}$$

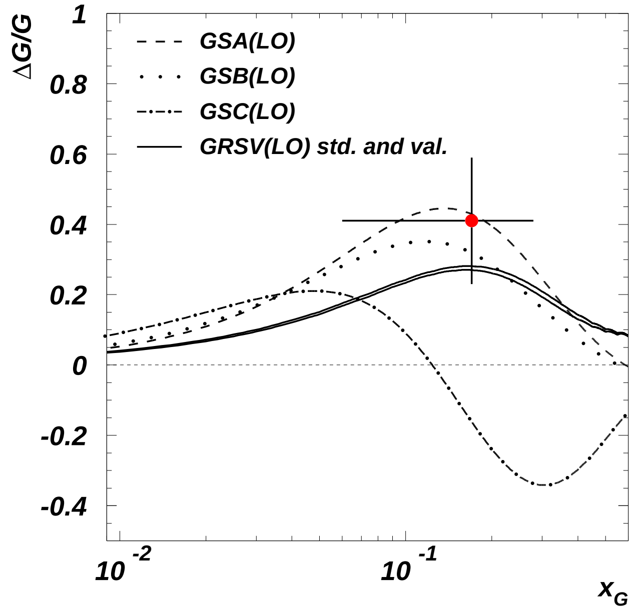
- Target spin-asymmetry on long. polarized ^{1}H:



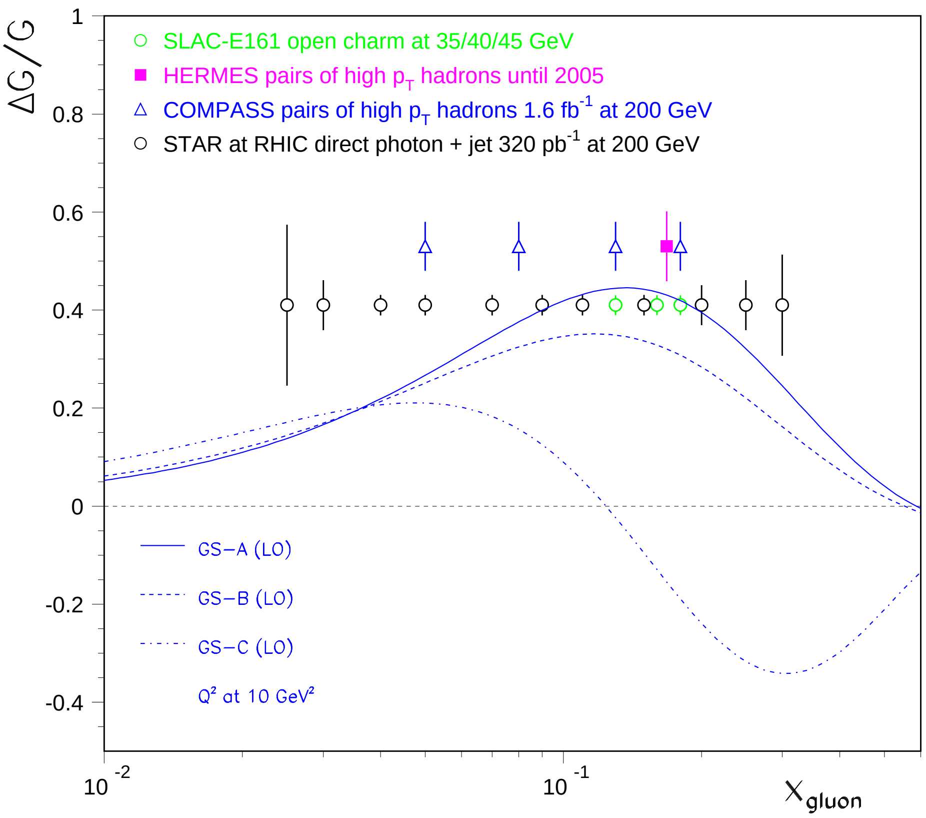
Gluon polarization in 2006

- First paper on $\Delta G/G$ (HERMES, PRL 84 (2000) 2584):

Note: remaining model dependence!

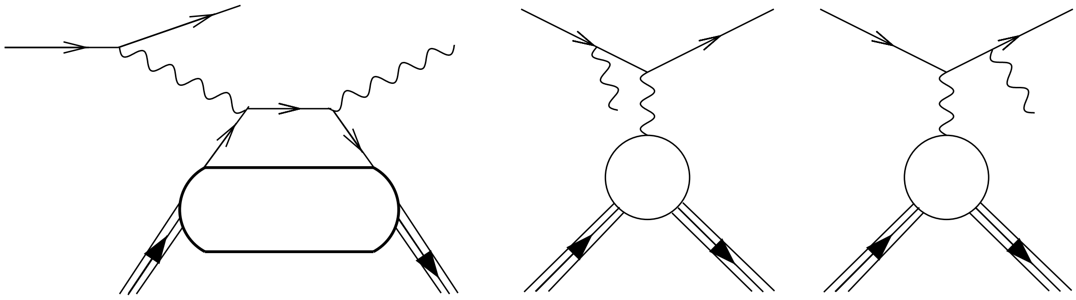


- Anticipated data quality in 2006:



Deep Virtual Compton Scattering

- Off-shell photon*-quark scattering:
  - Detect e' and γ, and require: E_{miss} = 0



- Ji's sumrule (Phys. Rev. Lett. 78 (1997) 610):

$$\int xdx[H(x,\Delta^2,\xi) + E(x,\Delta^2,\xi)] = A_q(\Delta^2) + B_q(\Delta^2)$$

with $\Delta^2 = -t$ and

$$\lim_{\Delta^2 \to 0} [A_q(\Delta^2) + B_q(\Delta^2)] = 2J_{quark} = \Sigma_q + 2L_q$$

$\Rightarrow$ DVCS: total quark angular momentum

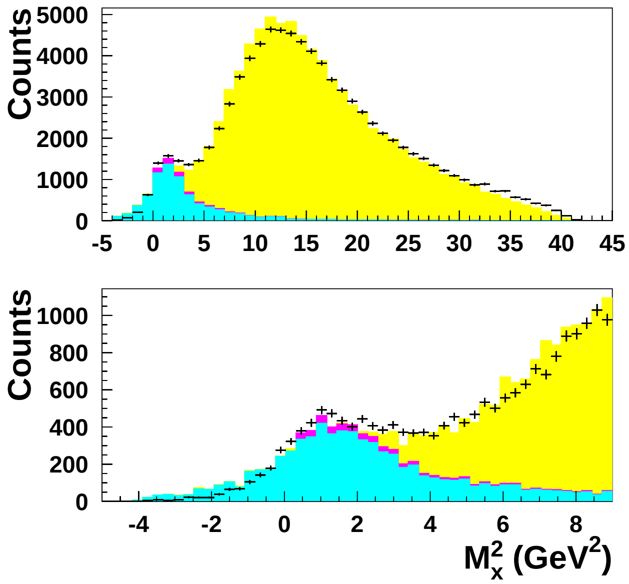
- Experimental considerations:
  - Interference with Bethe-Heitler process:

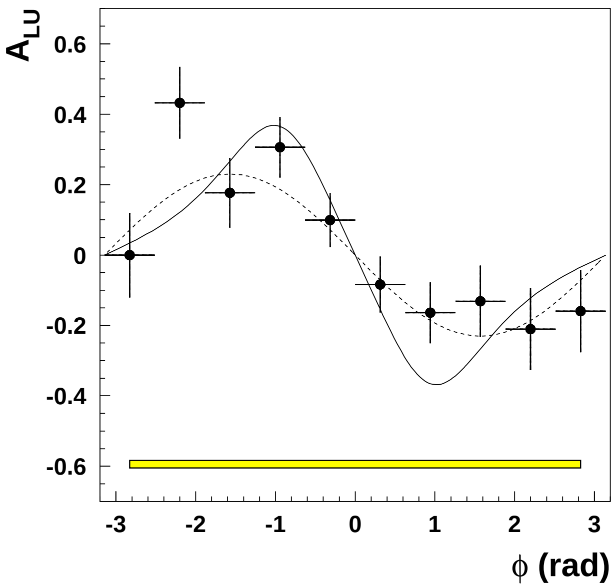
    DVCS $\otimes$ BH makes DVCS measurable

  - Detect scattered photon, but suppress π^0's
  - Observe azim. asymmetry: $A_{LU}^{BetheHeitler} = 0$

First observations of DVCS

- Missing mass spectrum and azimuthal distribution:



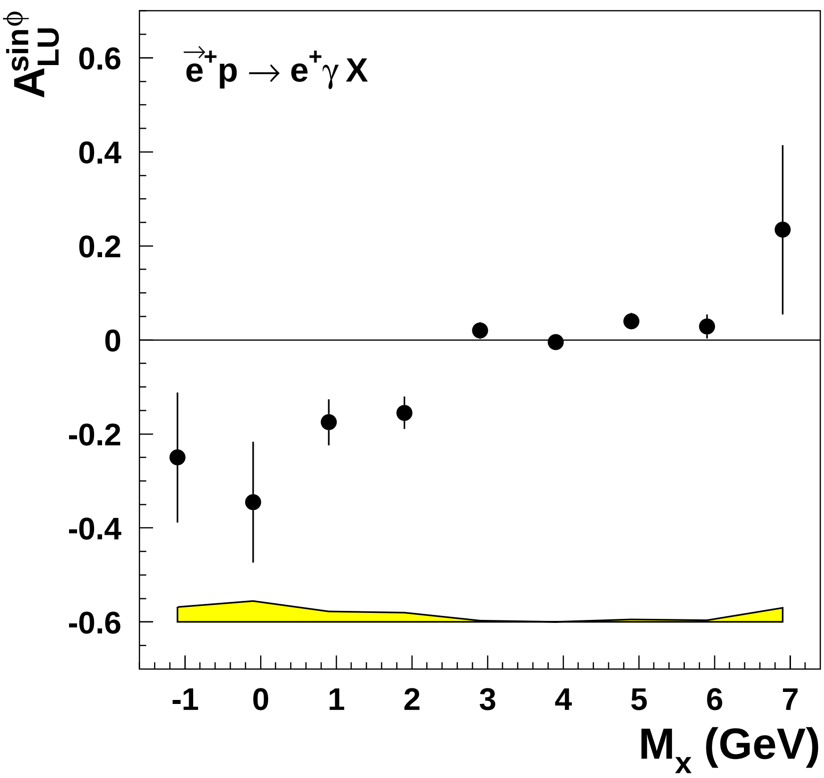


- Extract $\sin(\phi)$-moment, $A_{LU}^{\sin\phi} = \frac{2}{N}\sum_{i=1}^{N} \frac{\sin\phi_i}{(P_l)_i}$:

DVCS observed !

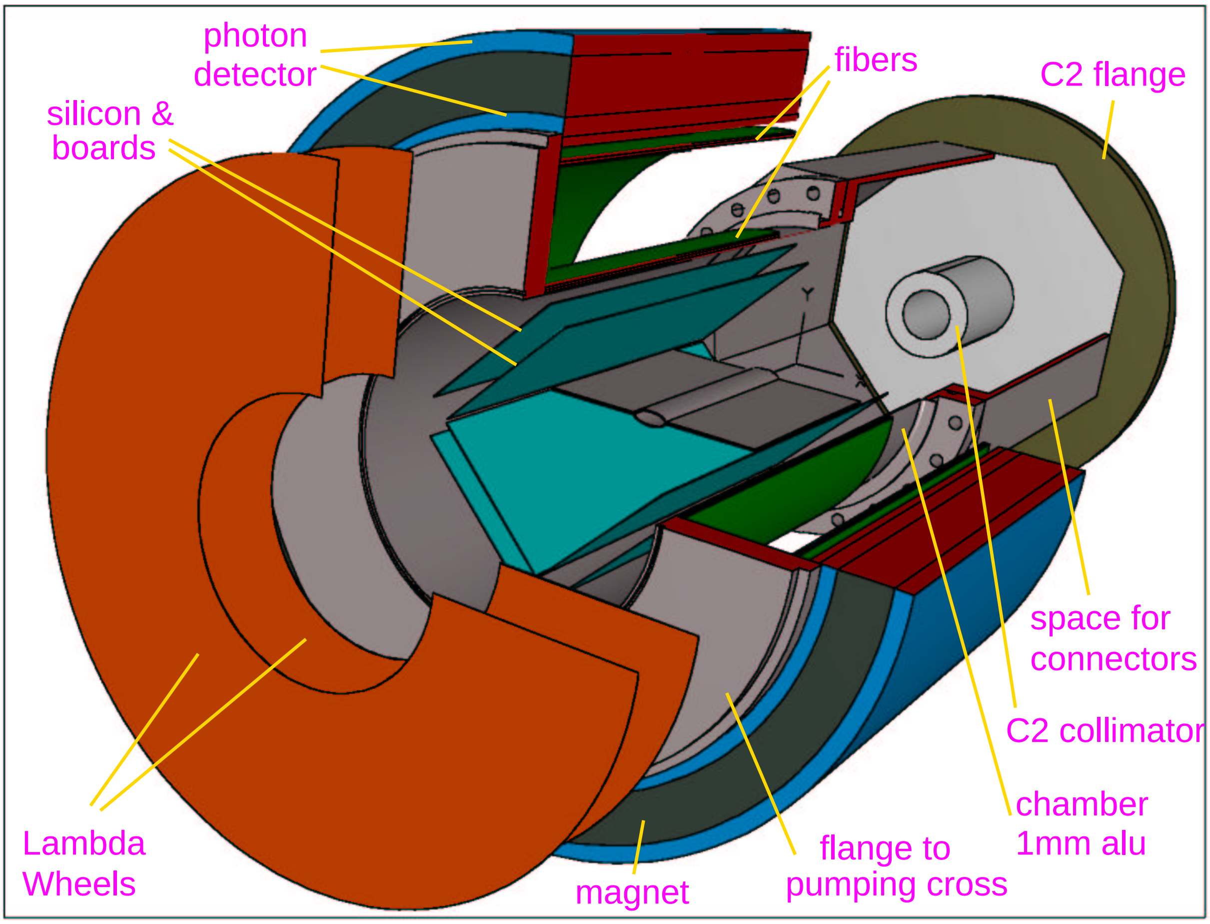
HERMES Collab., PRL 87, 182001

CLAS Collab., PRL 87, 182002



HERMES Recoil Detector

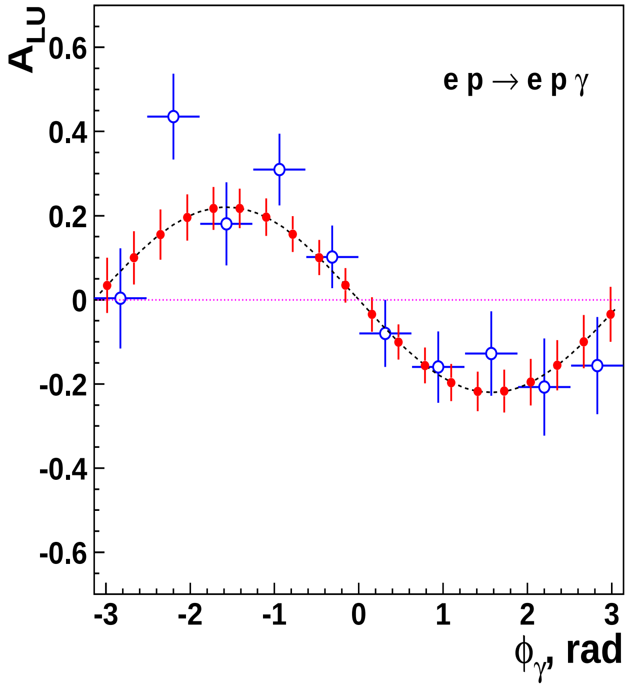
- Design large acceptance recoil detector:

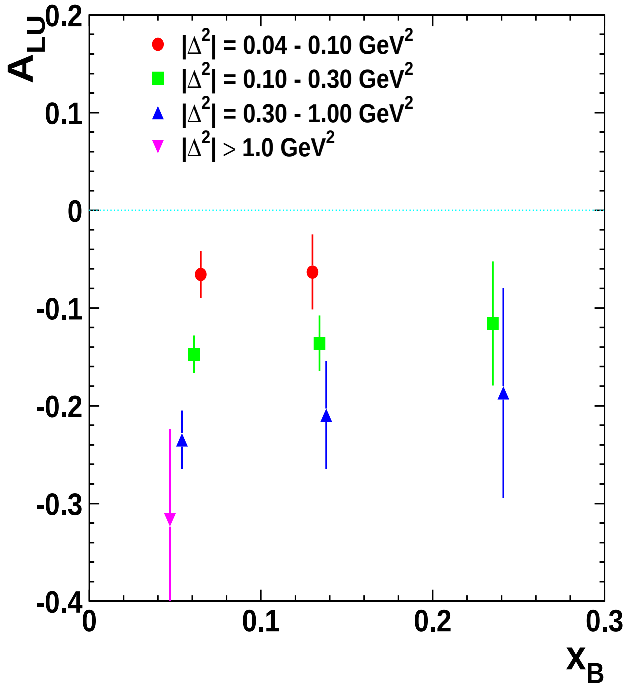


- Experimental objectives:
  - Identify recoil protons $(0.1 < p_{rec} < 1.2$ GeV/c)
  - $\pi - p$ separation: identify $\Delta(1232)$ final state
  - Hermeticity (together with Lambda Wheels):
    suppress non-exclusive events
  - Physics: Exclusive Reactions

DVCS in 2006

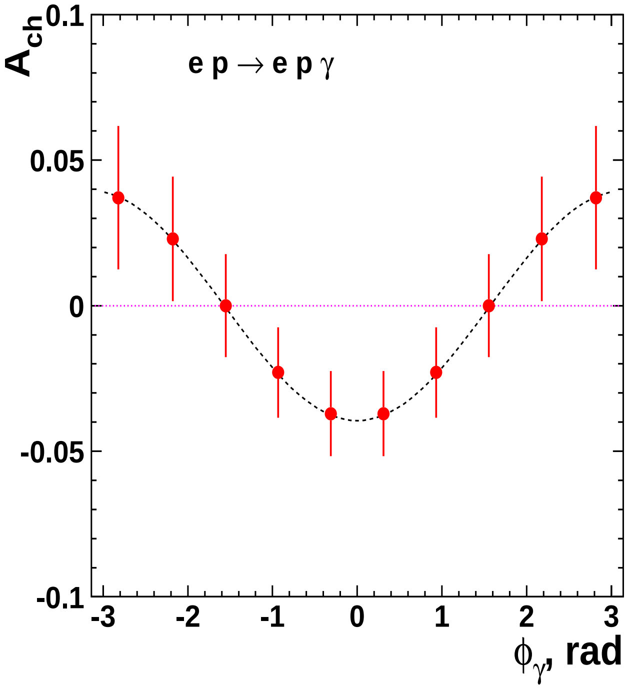
- Beam-spin asym. - anticipated data (2 fb^{-1}):

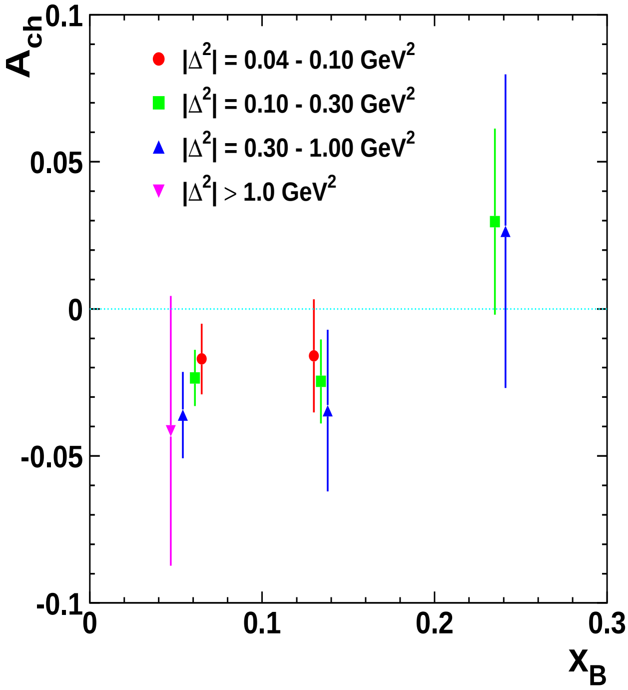




(HERMES Large Acceptance Recoil Detector proposal.)

- Beam-charge asym. - anticipated data (2 fb^{-1}):





The Λ spin structure - 1

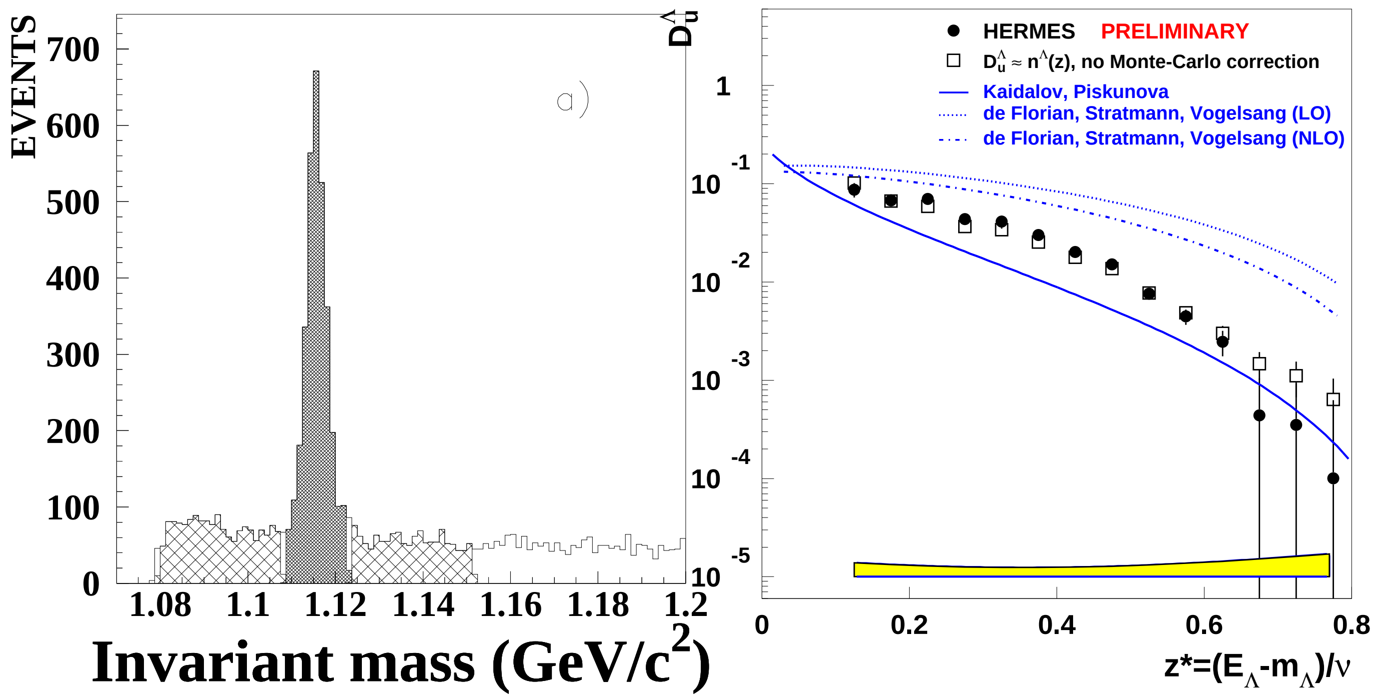
- Two schemes for the Λ spin content:
  - Quark parton model: Δs = 1.00
  - SU(3) flavour symm.: Δs = 0.6, Δu = Δd = -0.2
- Measure the Λ polarization from $\Lambda \to p\pi^-$:

$$\frac{1}{N}\frac{dN}{d\Omega} = \frac{1}{4\pi}\left(1 + 0.64\,\vec{P}_\Lambda \cdot \hat{p}\right)$$

- Determine $u \to \Lambda$ spin transfer $D^{\Lambda}_{LL'}$:

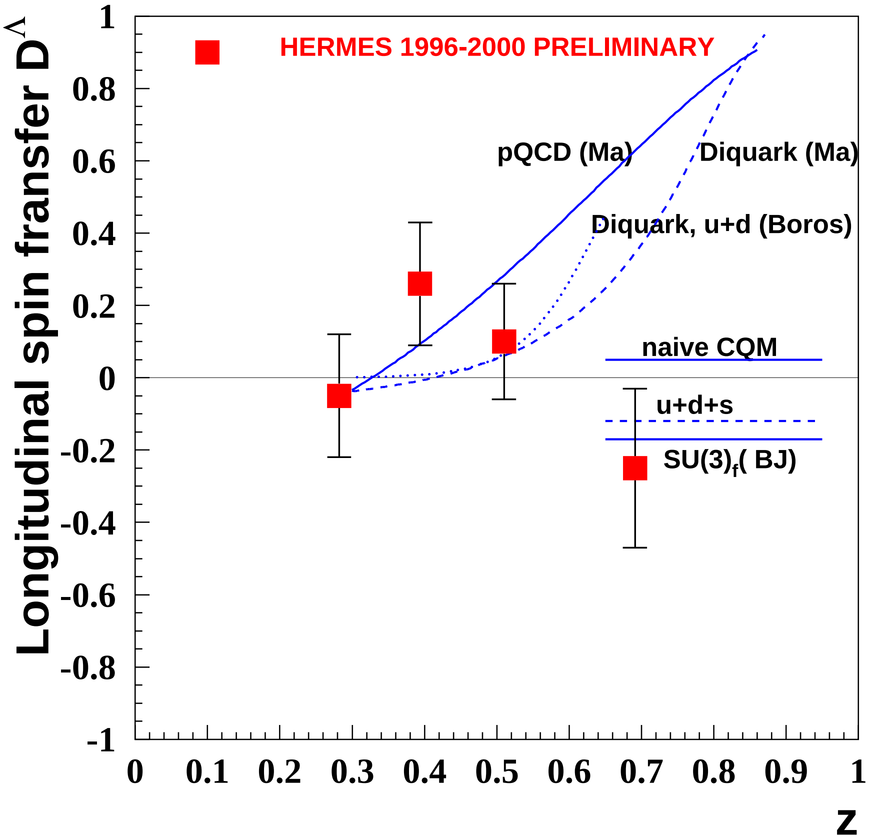
$$D^{\Lambda}_{LL'} = \frac{\vec{P}_\Lambda \cdot \hat{L}'}{P_B D(y)} = \frac{\sum_f e_f^2\, q_f^N(x)\, \Delta D_f^{\Lambda}(z)}{\sum_f e_f^2\, q_f^N(x)\, D_f^{\Lambda}(z)} \approx \frac{\Delta D_u^{\Lambda}(z)}{D_u^{\Lambda}(z)}$$

- Electroproduction of Λ hyperons at HERMES:



The Λ spin structure - 2

- Data for $u \rightarrow \Lambda$ spin transfer:



$< D^{\Lambda}_{LL'} >$ = 0.04(9) consistent with $\Delta u^{\Lambda} \approx 0$ (CQM prediction).

- Negative polarisation for x_F (= $\frac{2p_L}{W}$) < 0:

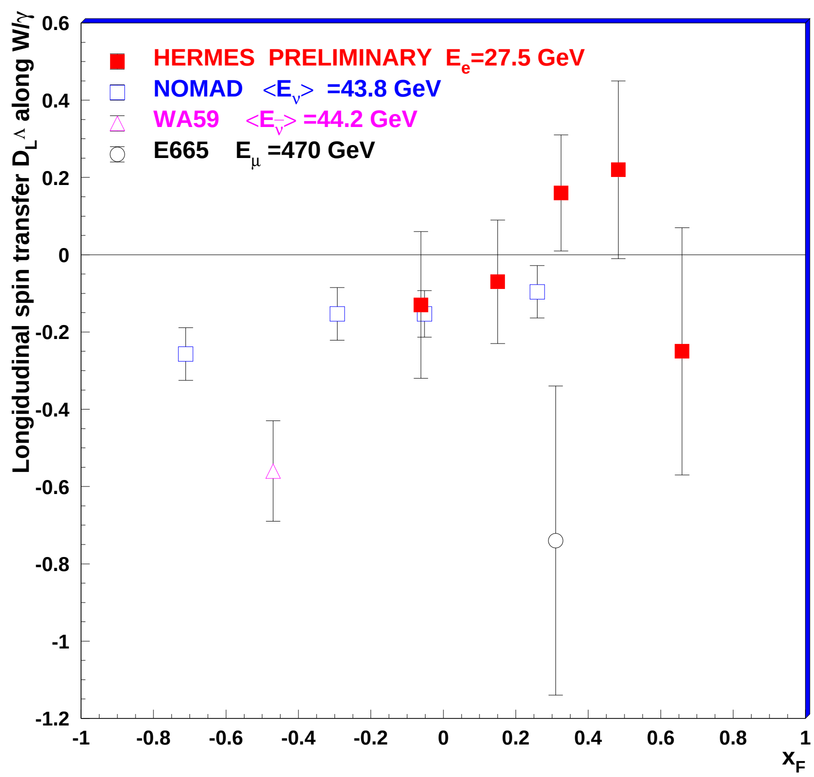
NOMAD Collab. NPB 588 (2000) 3

Contributions from:

$\Sigma^* \rightarrow \Lambda\pi$

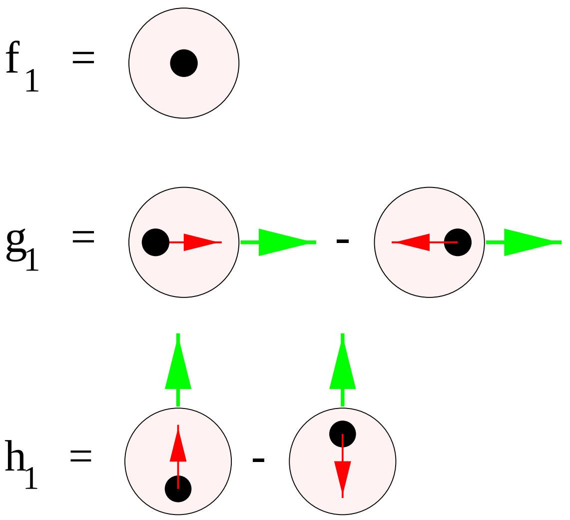
$\Sigma^0 \rightarrow \Lambda\gamma$

$\Xi^0 \rightarrow \Lambda\pi^0$



Transverse polarization

- Three leading order distribution functions:



momentum carried by quarks

longitudinal quark spin, $\Delta\Sigma$

transverse quark spin, $\delta\Sigma$

- Importance of $h_1(x)$ measurements:
  - HERMES data: $\Delta\Sigma$ = 0.30 $\pm$ 0.04 $\pm$ 0.09
  - $\Delta\Sigma$ is so small because of axial anomaly:
    * Redistribution of angular momentum in nucleon:

$$\frac{1}{2}\Delta\Sigma \approx +0.15, \quad \Delta G \approx +1.0, \quad L_z \approx -0.65$$

    * Redistribution is less in transverse case:

$\Delta\Sigma \ < \ \delta\Sigma \ < \ 1$ (Quark Parton Model)

    * Lattice QCD calculation (Phys. Rev. D 56 (1997) 433):

$\Delta\Sigma$ = 0.18(10) and $\delta\Sigma$ = 0.56(9)

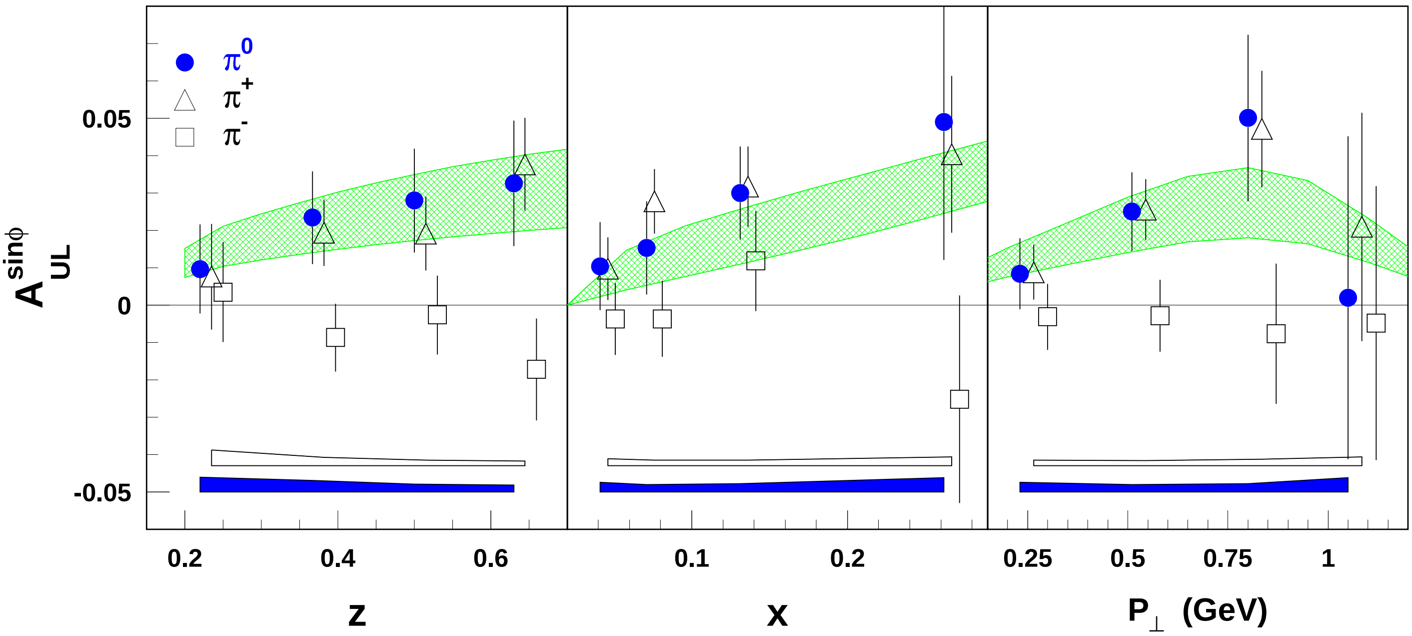
Measurements of $h_1(x)$

- The structure function $h_1(x)$ is chirally odd :
  - Not accessible in inclusive DIS
  - Use semi-inclusive DIS with chirally-odd $H_1^{\perp(1)u}(z)$
  - Assume u-quark dominance
  - Asymmetry for Collins process:

$$A_T^{\pi^+}(x,y,z) = P_T \cdot D_{nn} \cdot \frac{\delta u(x)}{u(x)} \cdot \frac{\mathrm{H}_1^{\perp(1)u}(z)}{\mathrm{D}_1^u(z)},$$

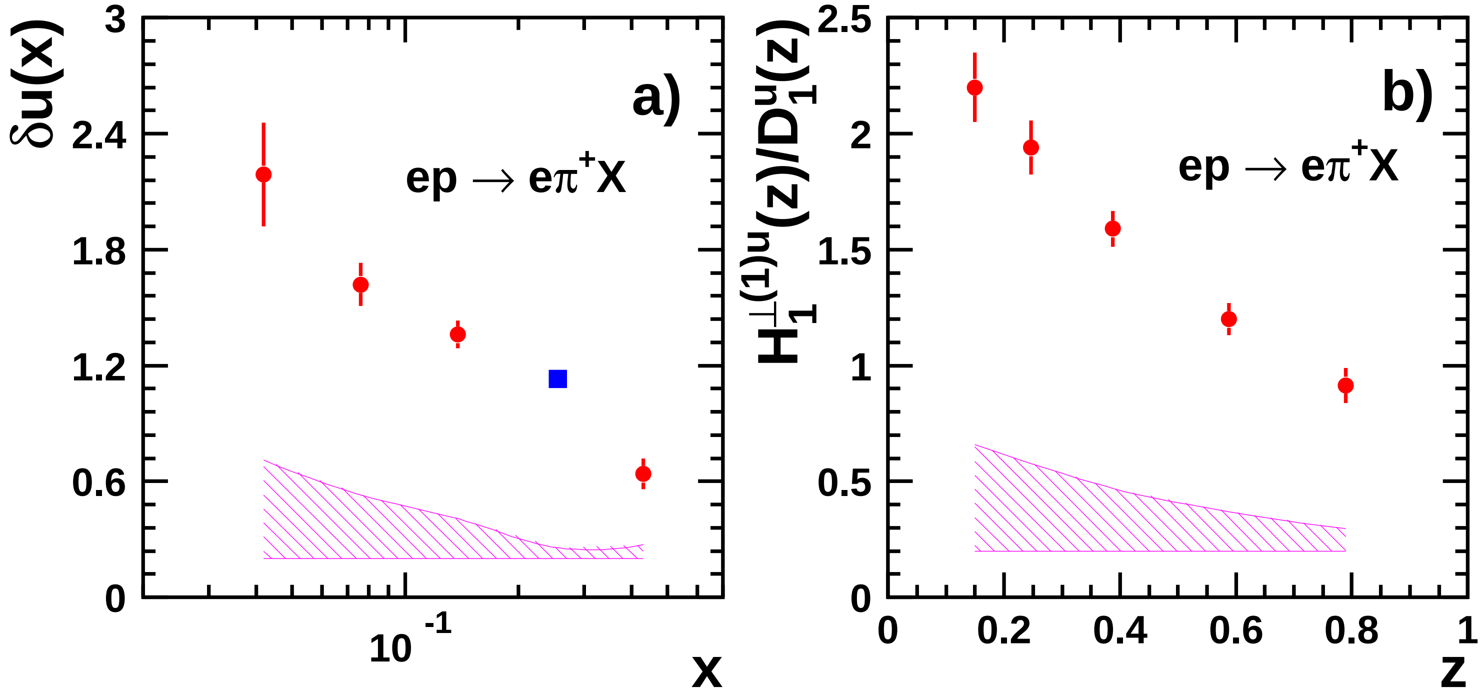
  - $\mathrm{H}_1^{\perp(1)u}$ depends on $\phi_c = \phi_h + \phi_s - \pi$

- Evidence for transversity from HERMES data:

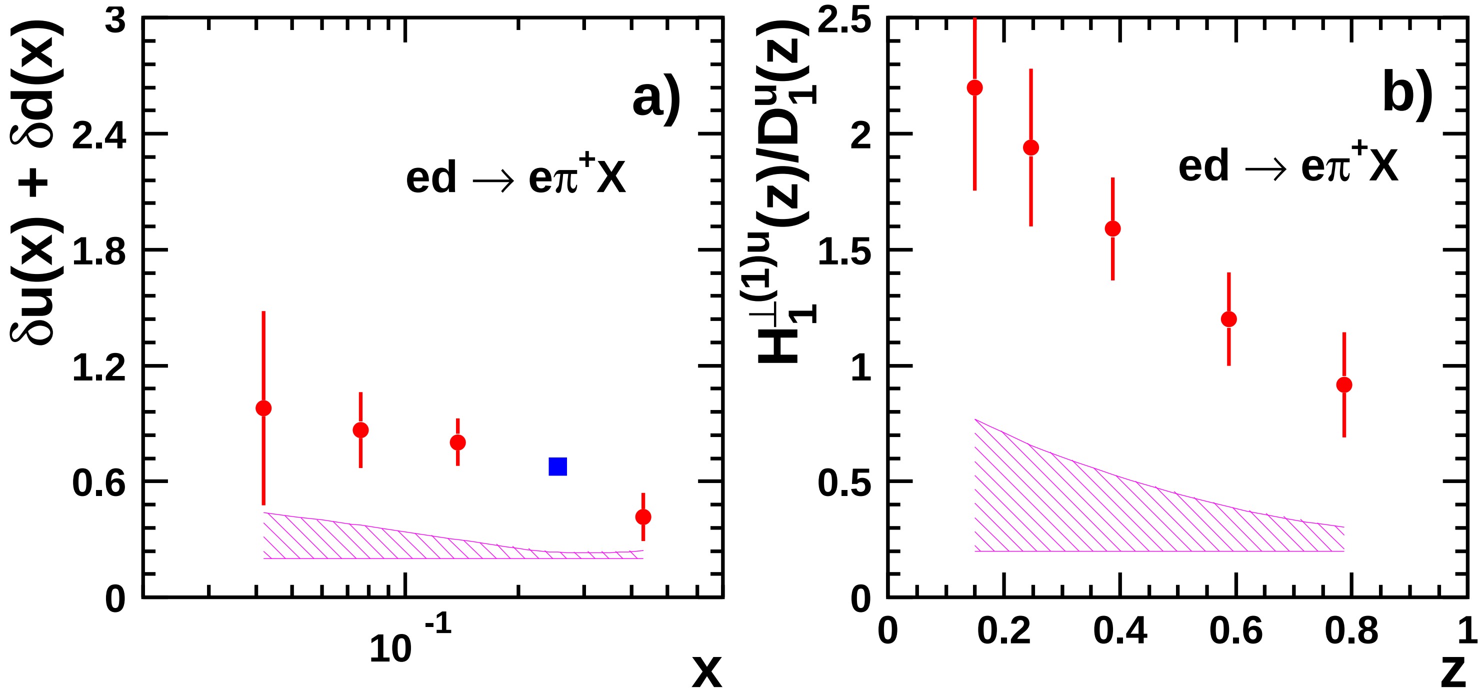


$h_1(x)$ in 2006

- Expected data on transv. pol. ^{1}H (7×10^6 DIS ev.):



- Expected data on transv. pol. ^{2}H (7×10^6 DIS ev.):



Outlook

- HERMES - Run II: 2001 – 2006
  - Transverse spin ≈ 2001 - 2003
  - Longitudinal spin ≈ 2003 - 2004
  - Unpolarized end-of-fill runs ≈ 2001 - 2004
  - Excl. react. w. Recoil Detector: ≈ 2004 - 2006
- COMPASS (CERN): 2001 - ??
  - Commissioning + first data taking: 2001
    - Optimized for $\Delta G/G$
    - 2^{nd} spectrometer partially equiped
      (no RICH2, no ECAL2, partial DAQ, old SMC target)
  - First transverse data taking: $>$ 2003
    - Requirement: 2^{nd} spectrometer fully equipped
      (including new COMPASS target solenoid)
- RHIC-SPIN: 2001 – ??
  - First $p - p$ collisions at $\sqrt{s}$ = 200 GeV: 2001
  - Test with transverse polarization: Oct. 2001
    - Measure A_N for π^0 at high x_F (1.5 pb^{-1})
  - Install spin rotators: 2002
    - Measure $\Delta G/G$ from $\vec{p} + \vec{p} \to \gamma + jet + X$
    - Measure Δq_f from $\vec{p} + p \to W^{\pm} + X$
  - Extensive transverse running: $\approx$ 2006

Spin Physics in 2006

- What have we learned, and what remains?
  - Flavour decomposition of spin:
    - Good data on $\Delta u(x)$, $\Delta d(x)$
    - Least precise: $\Delta s(x)$
  - Gluon polarization:
    - Good $\Delta G(x)$ data
    - No data at $x < 0.01$ (where the gluons are!)
  - Measurements of orbital angular momentum:
    - DVCS: $x, -t$ dependence
    - Uncertainties prevent evaluation of J_q
  - The spin structure of heavier baryons:
    - Fairly good data on Λ^0
  - Transverse spin:
    - First $h_1(x)$ data on the proton from HERMES
    - Not yet: test anomalous Q^2 evolution

- Major challenges for after 2006:
  - At intermediate energies (30 GeV):
    - DVCS: determination of J_q
    - Exclusive reactions: GPD's
  - At higher energies (> 200 GeV):
    - $h_1(x, Q^2)$ at low x
    - $\Delta G(x)$ at low x
    - DVCS, GPD's