Results from HERMES

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Collaboration

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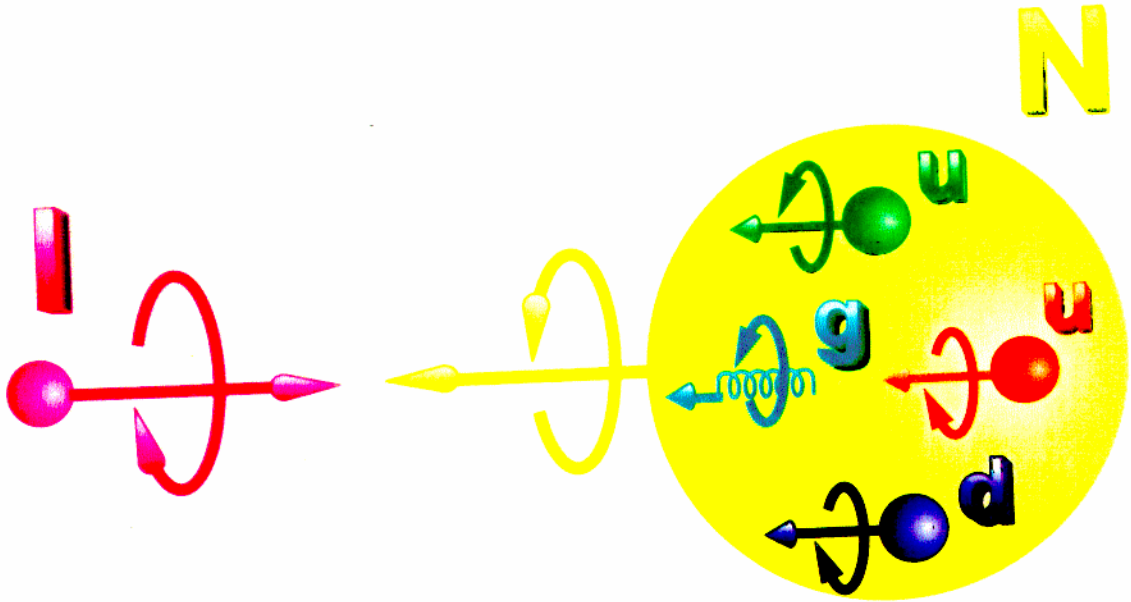
- Introduction
- HERMES Experiment
- Results
  - Inclusive Data
  - Semi-Inclusive Data
    - polarized
    - unpolarized
- Future and Summary

Components of the Nucleon Spin

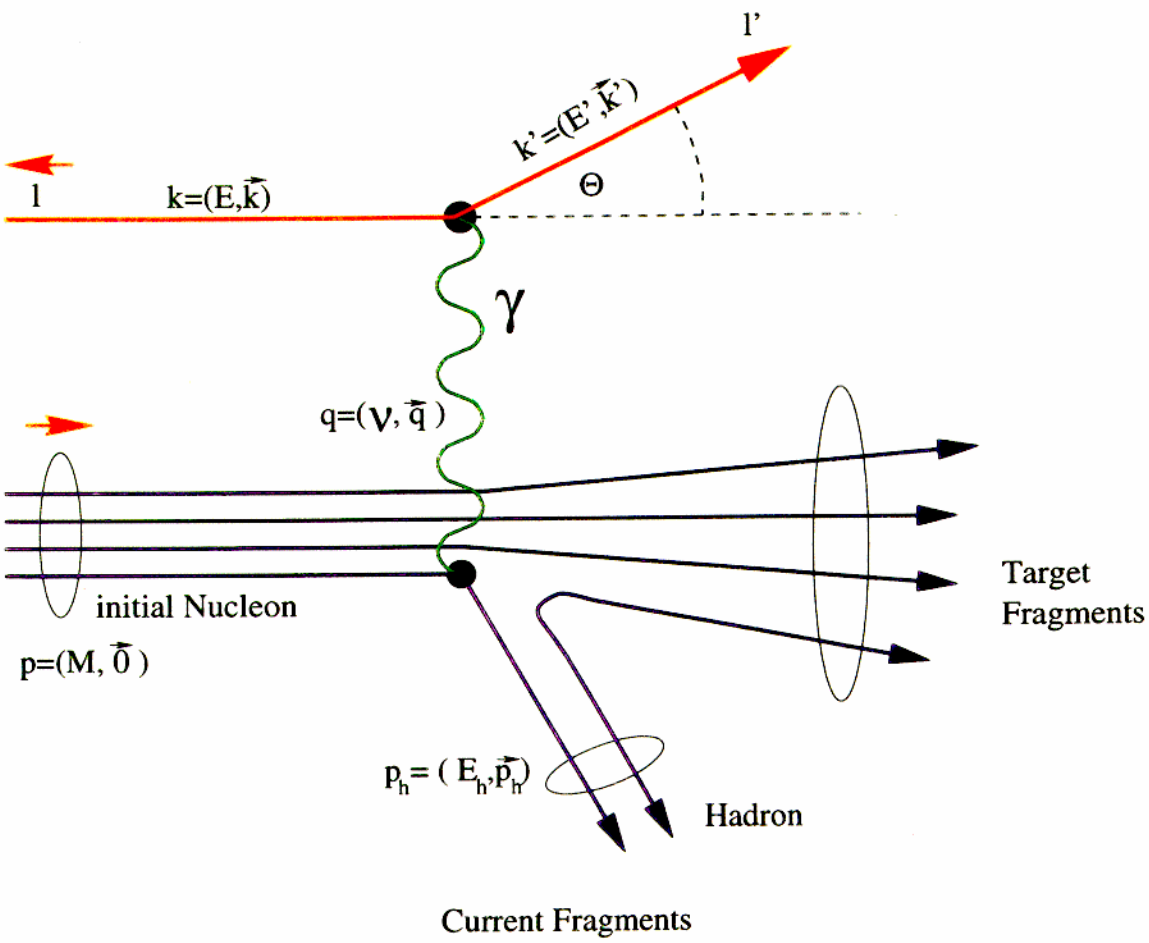


$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + \Delta G + L_q + L_G$$

From Deep Inelastic lepton scattering:

- quark spins — $\Delta\Sigma \sim 0.2$
- gluon spins — $\Delta G = ??$
- orbital angular momenta — $L_q = ??,\ L_G = ??$

Deep Inelastic Scattering



- Inclusive: detect e' only
- Semi-inclusive: detect e' and hadrons
- to probe spin require beam and nucleon to be polarized

HERMES Physics Program

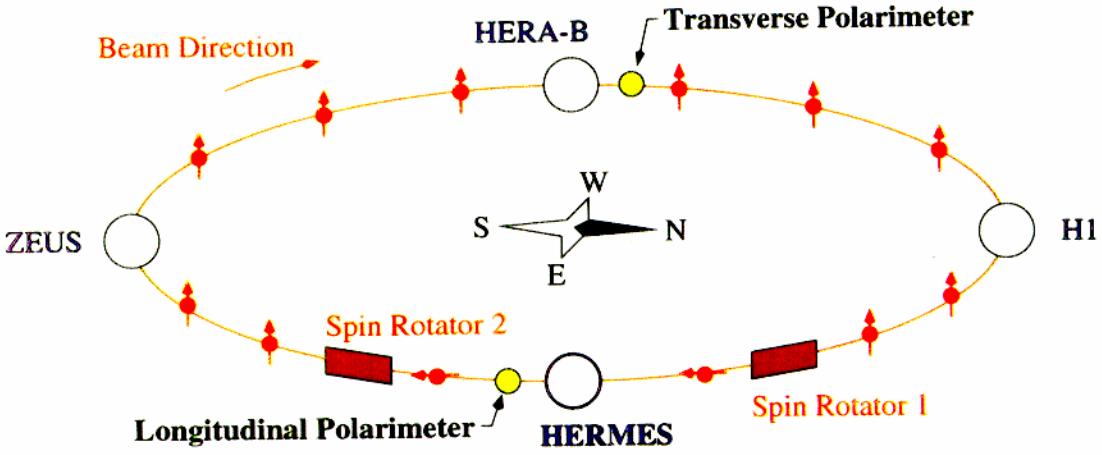
- Study of the Spin Structure of the Nucleon
  - Inclusive / Semi-Inclusive Scattering
  - Proton / Neutron Target

  $\Rightarrow$ g_1, g_2, Δu, Δd, Δs, ΔG, ...
- Unpolarized Structure Functions

  $\Rightarrow$ F_2^n / F_2^p, $F_2^{^3He}$ / F_2^D, $F_2^{^{14}N}$ / F_2^D
- Light Sea Flavor Asymmetry

  $\Rightarrow$ $\frac{(\bar{d}-\bar{u})}{u-d}$
- Fragmentation Functions & Hadronization in Nuclei
- Diffractive Vector Meson Production (ρ^o, ϕ, ω, J/Ψ)
  - Cross Sections
  - Decay Angular Distributions
  - Nuclear Transparency
- Polarized Λ^o Production
  - Transversity, Azimuthal Distributions
- + more

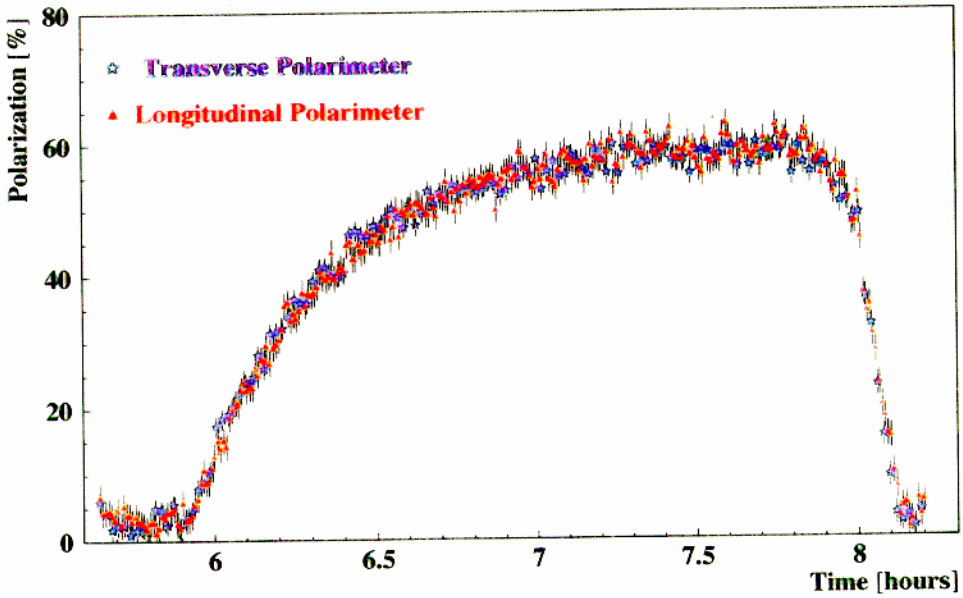
Electron Polarization at HERA



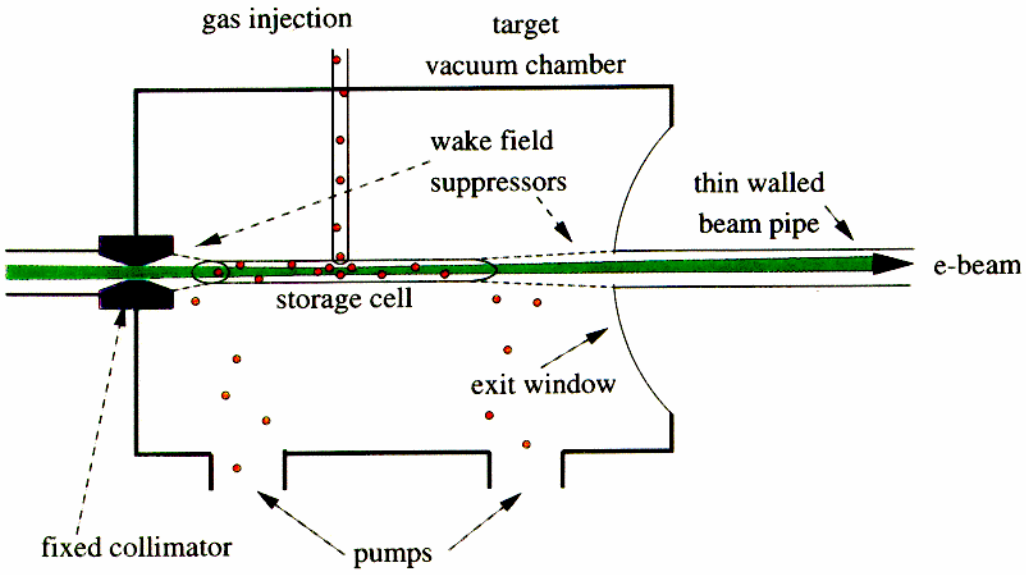
Self polarization of electrons by Synchrotron radiation in the curved sections ($\rightarrow$ "Sokolov–Ternov Effect").

Polarization rise time according to:

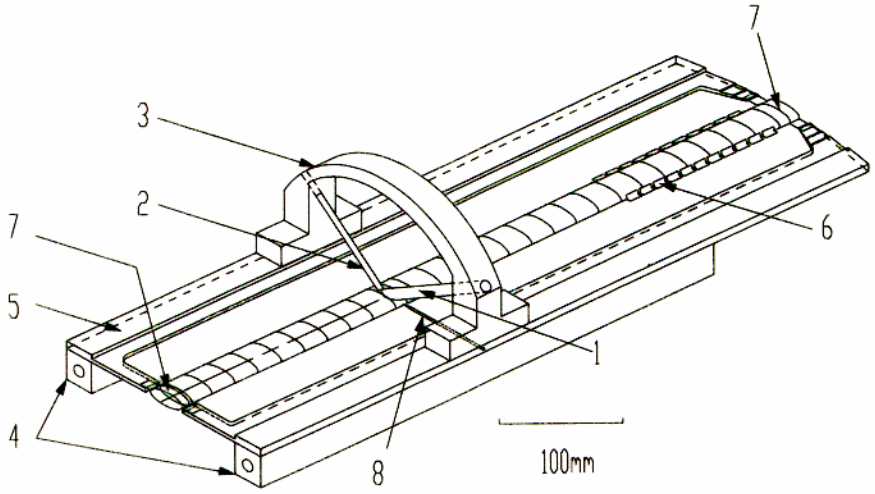
$$P(t) = P_{\max} \cdot (1 - e^{-t/\tau}).$$



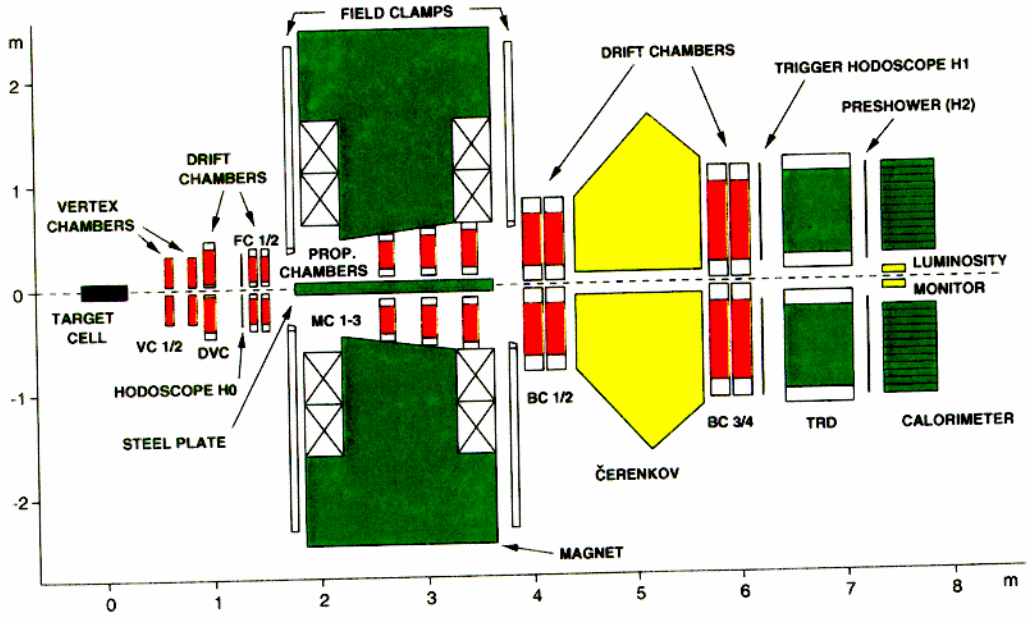
Storage Cell Target



- laser driven polarized ^{3}He target
  $p_T \sim 50\%$ (1995)
- Atomic beam source for polarized H/D target
  $p_T \sim 80 - 95\%$ (1996/97)
- unpolarized gas of any type (H/D/He/N)



HERMES Detector



Horizontally separated two arm standard forward spectrometer with components for

Tracking

Microstrip Gas, Drift, and Proportional Chambers

Particle Identification

TRD, Cerenkov, Preshower, Calorimeter

Momentum Measurement

Magnet (1.3 Tm)

Calorimetry

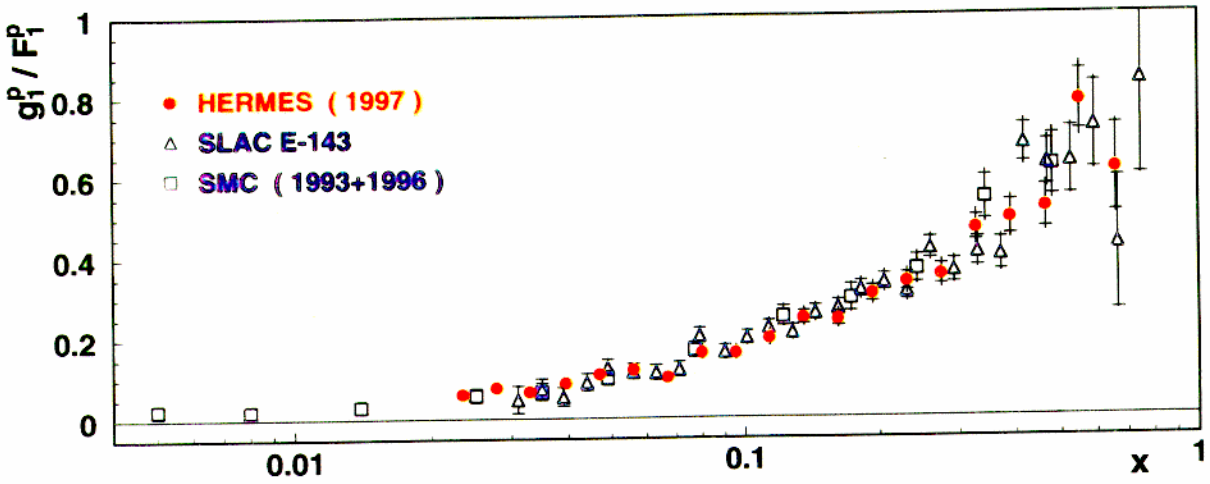
Lead Glass Wall

Trigger

Scintillator Hodoscopes

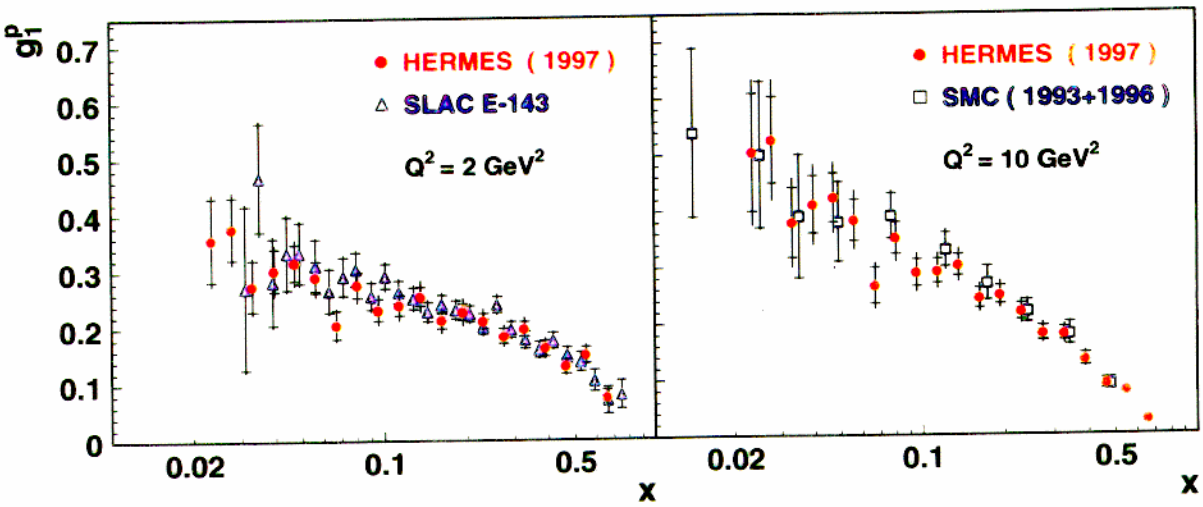
The Proton Spin Structure

- HERMES, SLAC and SMC data on ^{1}H:



$\Rightarrow$ no statistically significant Q^2 dependence of g_1^p/F_1^p ratio in Q^2 range of these experiments

- $g_1^p(x)$ data evolved to common Q^2:



$\Rightarrow$ Apparent Q^2 dependence entirely originates from Q^2 dependence of F_2^p and R

Summary of Experiments

Exp.	Year	Beam		Target	meas. quantities
SLAC					
E80	75	23 GeV	e^-	H–butanol	A_1^p
E130	80	23 GeV	e^-	H–butanol	A_1^p
E142	92	25 GeV	e^-	^{3}He	A_1^n
E143	93	29 GeV	e^-	NH_3/ND_3	$A_1^p, A_1^d, A_2^{p,d}$
E154	95	49 GeV	e^-	^{3}He	$A_1^n,\ A_2^n$
E155	97	49 GeV	e^-	NH_3/LiD	A_1^p, A_1^d
CERN					
EMC	85	100-200 GeV	μ^-	NH_3	A_1^p
SMC	92	100 GeV	μ^+	D–butanol	$A_1^d,\ A_{1,h}^d$
SMC	93	190 GeV	μ^+	H–butanol	$A_1^p, A_{1,h}^p$
SMC	94/95	190 GeV	μ^+	D–butanol	$A_1^d, A_{1,h}^d$
SMC	96	190 GeV	μ^+	NH_3	$A_1^p, A_{1,h}^p$
DESY					
HERMES	95	28 GeV	e^+	^{3}He	$A_1^n,\ A_{1,h}^n,\ A_{1,\pi}^n$
HERMES	96/97	28 GeV	e^+	H	$A_1^p,\ A_{1,h}^p,\ A_{1,\pi}^p$

Conclusions on Inclusive Experiments

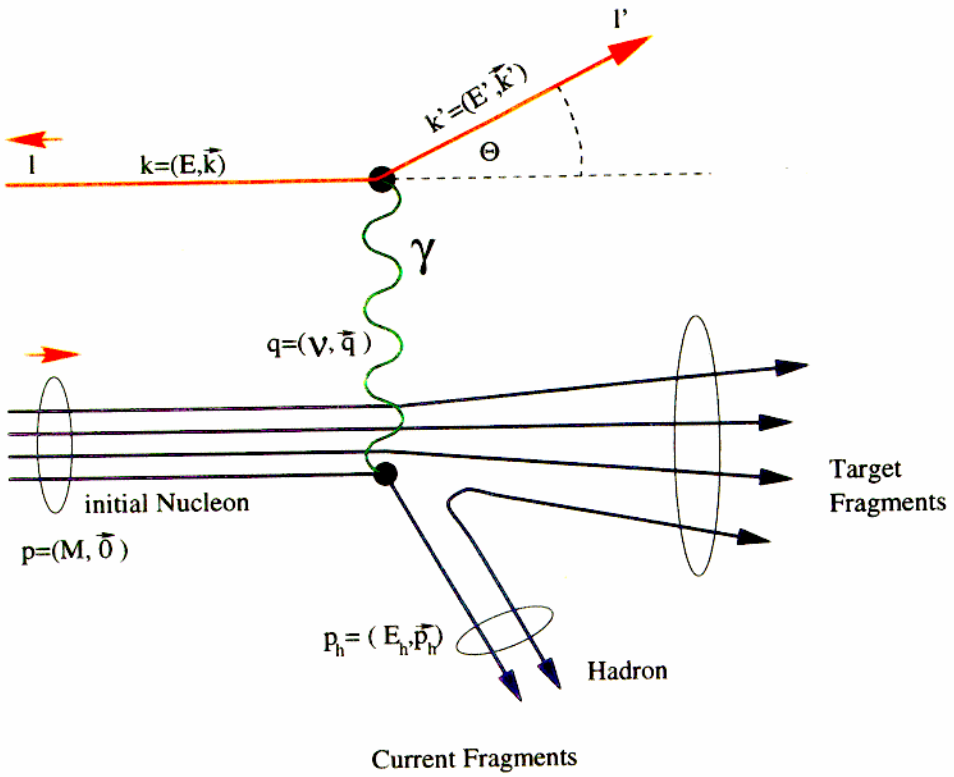
- Extensive program of complementary polarized DIS measurements performed over the past six years
- Focused on inclusive scattering using
  - sum rules
  - assumption of SU(3) flavor symmetry
    $\rightarrow$ extract information on spin structure
  - confirmation of EMC result
  - Bjorken sum rule satisfied at 1σ level
    $\rightarrow$ successful test of QCD on spin observables
  - experiments appear to be consistent if they are evolved to same $\mathbf{Q}^2$
  - only about 20% of the spin comes from the spin of the quarks
  - question of how the spin of the nucleon is related to its internal structure is NOT resolved.

$\Rightarrow$ NEW GENERATION OF EXPERIMENTS / DIFFERENT APPROACH NEEDED

- g_1 at small x < 0.001
- polarization of sea, in particular Δs flavor decomposition
- gluon helicity distribution ΔG

Semi-Inclusive Physics

- Detect hadron in coincidence with the scattered lepton



- Flavor of struck quark is reflected by the type of hadron in current jet
- Cuts on $(z > z_{min} = 0.2)$ and $(x_F > x_{F,min} = 0.1)$ to isolate the current fragmentation region
- Assuming factorization the hadron asymmetry can be expressed as:

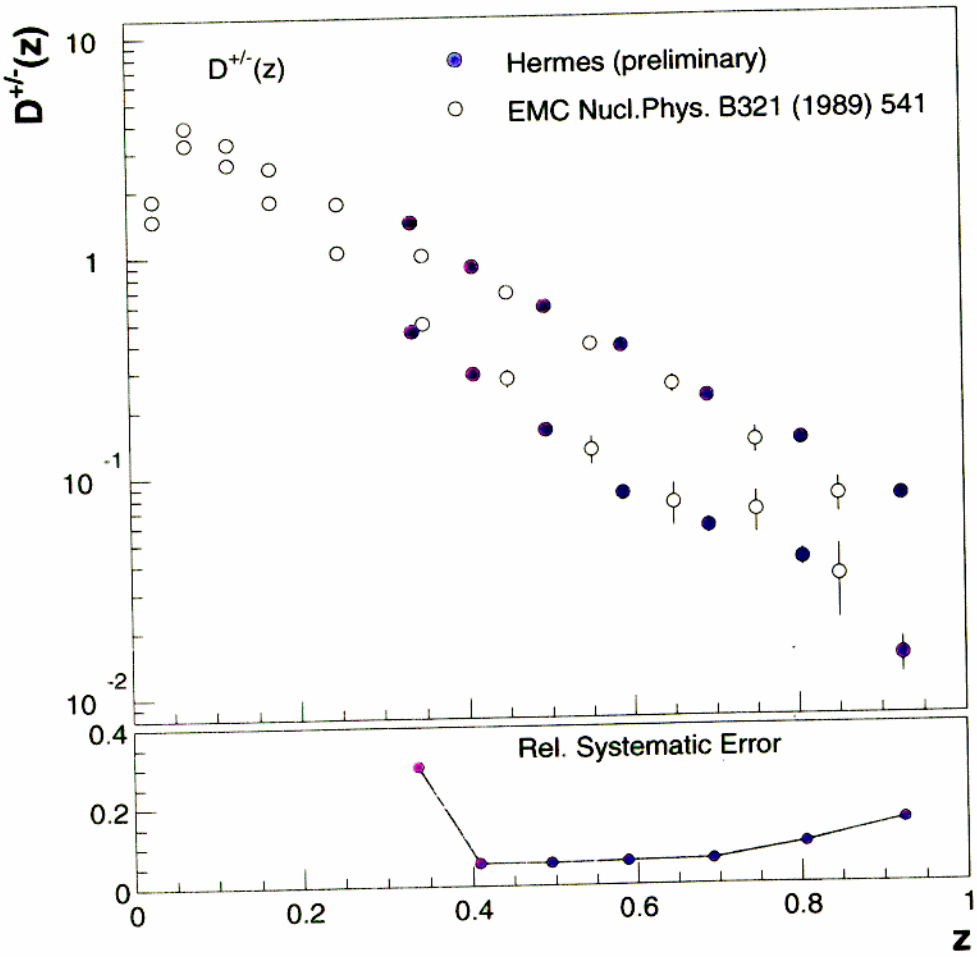
$$A_1^h(x,z) \simeq \frac{A_{\parallel}^h(x,z)}{D(x,Q^2)} \simeq \frac{\sum e_f^2 \Delta q_f(x) \cdot D_{q_f}^h(z)}{\sum e_f^2 q_f(x) \cdot D_{q_f}^h(z)}$$

Measurement $A_1^h \Rightarrow$ new linear combinations of Δq

π Fragmentation Functions

In QPM:

- fragmentation function $D^h_{q_f}(z)$ = probability for a quark of flavor f to fragment into a hadron of type h
- π fragmentation functions using EMC extraction method

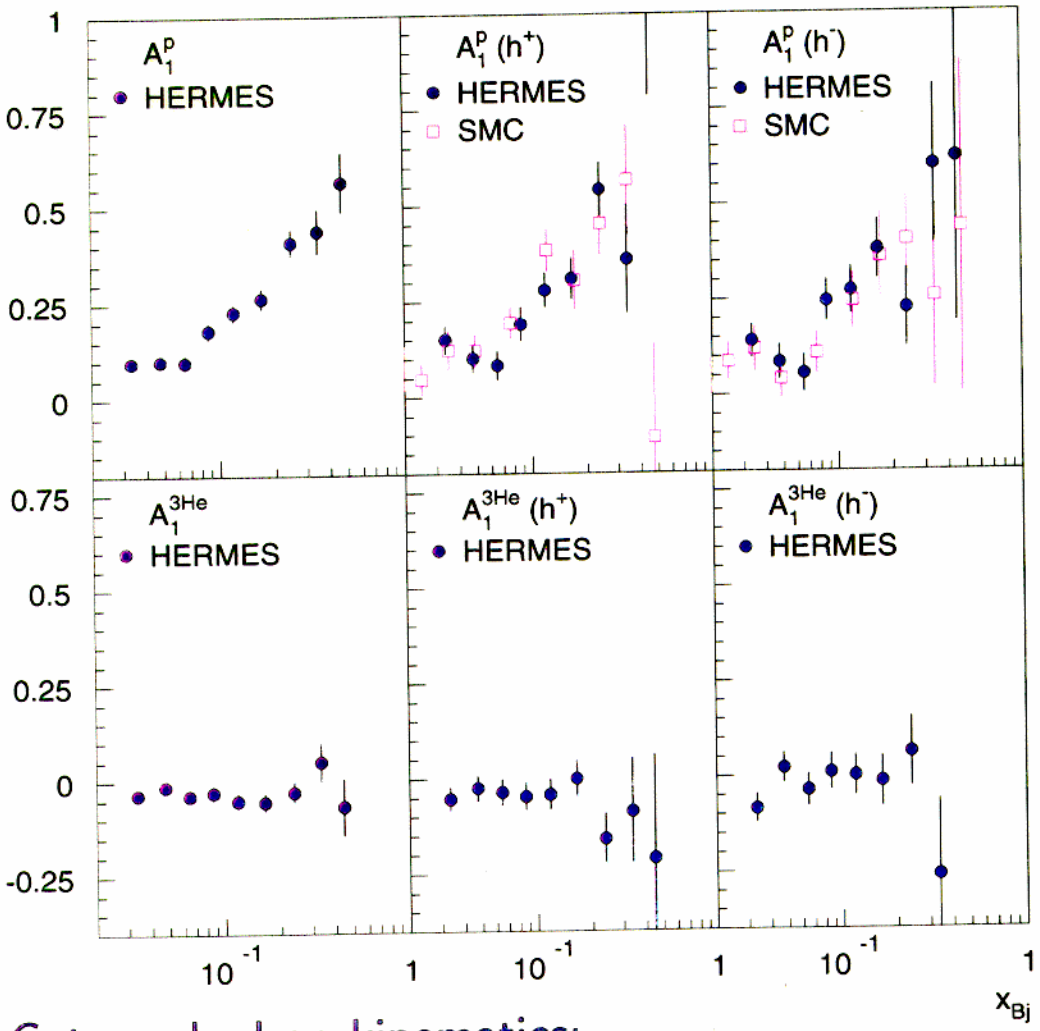


Fragmentation Functions

FAVORED D^+ hadron contains struck quark
UNFAVORED D^- hadron does not contain struck quark

Semi-Inclusive Measurements

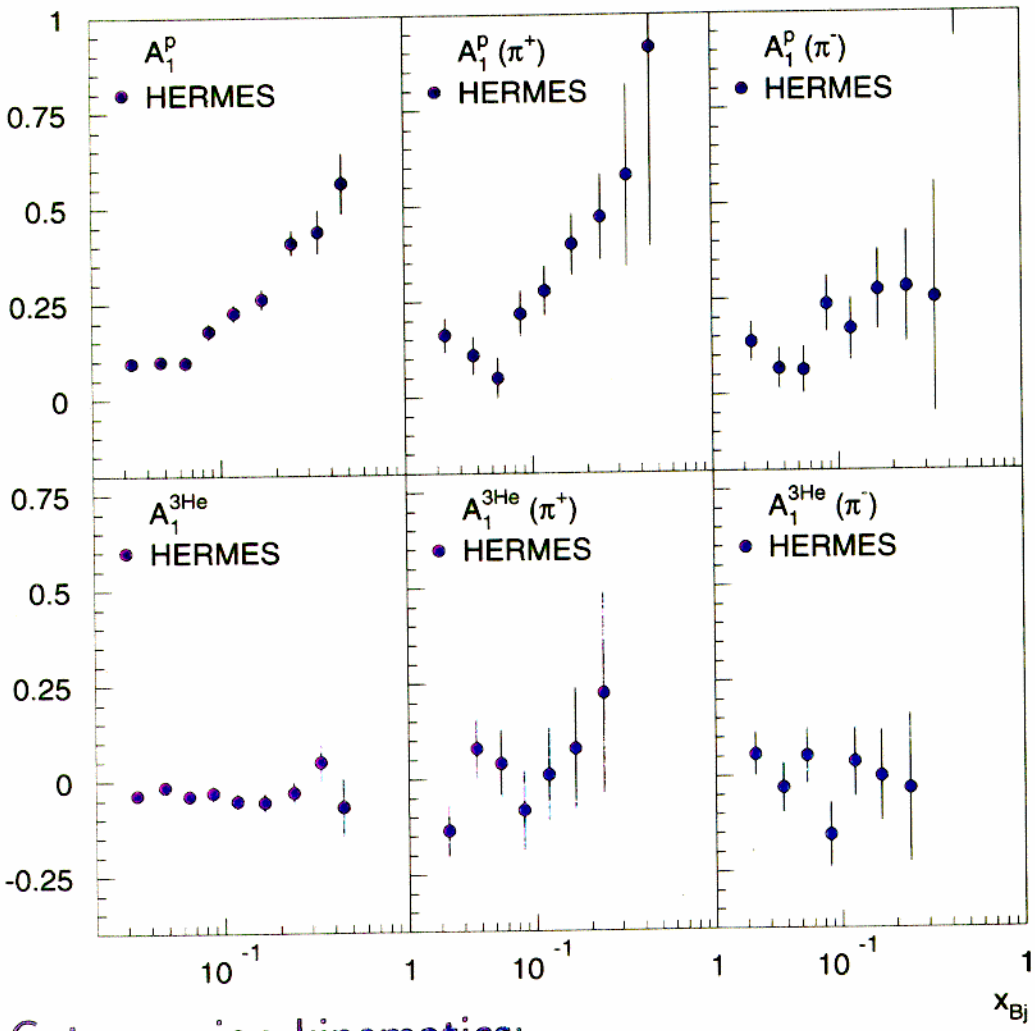
- Preliminary HERMES results (1995 and 1996):



- Cuts on hadron kinematics:
  $z > 0.2$; $x_F > 0.1$; $W^2 > 10\ GeV^2$
- Data points based on 0.7×10^6 (for p) and 2.7×10^6 (for ^{3}He) DIS events.

Pion Asymmetries

- Pion identification in HERMES PID allows extraction of pion asymmetries
- Preliminary HERMES results (1995 and 1996):



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  $z > 0.2$; $x_F > 0.1$; $W^2 > 10\ GeV^2$
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Polarized Quark Distributions

- Extraction of polarized quark distributions needs as input:
  - measured hadron asymmetries $A_1^h(x,z)$
  - unpolarized quark distributions $q(x)$
  - fragmentation functions $D_q^h(z)$
- Rewrite Photon-Nucleon Asymmetry:

$$A_1^h(x,z) = \sum_q \frac{e_q^2 q(x) D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) D_{q'}^h(z)} \cdot \frac{\Delta q(x)}{q(x)}$$

$$= \sum_q P_q^h(x,z) \cdot \frac{\Delta q(x)}{q(x)}$$

- The quark-purity P_q^h is the probability that a quark q was struck in an event $l + N \longrightarrow l' + h + X$
- Purities are spin-independent (unpolarized) quantities !
- Define

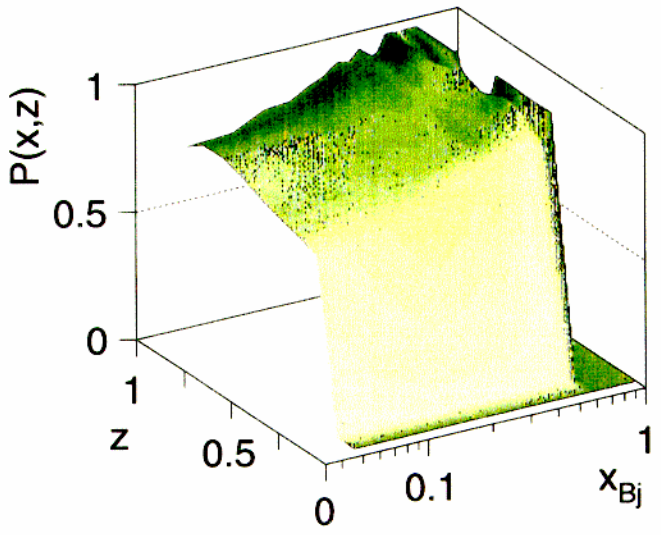
$$\vec{A} = \begin{pmatrix} A^{h_1}(x) \\ \cdots \\ A^{hm}(x) \end{pmatrix}, \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \cdots \\ \Delta q_n(x)/q_n(x) \end{pmatrix}, \mathcal{P} = \left[P_q^h(x) \right]$$

To measure quark polarizations invert:

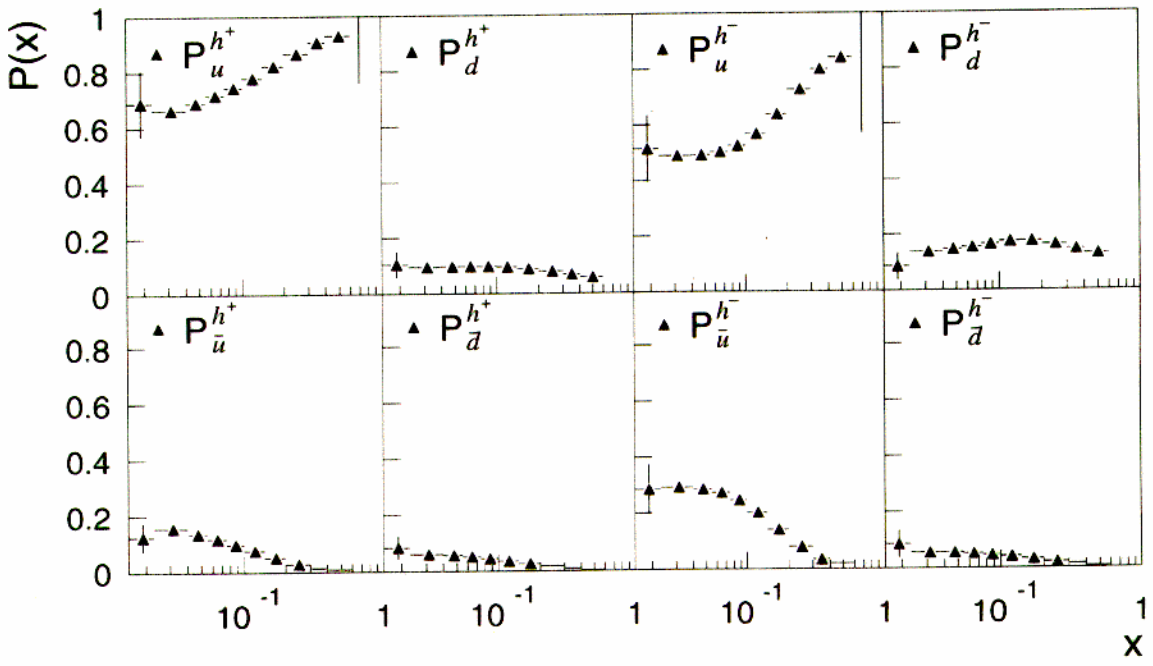
$$\vec{A} = \mathcal{P}\vec{Q}$$

Generated Purities

- Generated hadron-quark purities, e.g. $P_u^{h^+}(x,z)$ (proton target):



- Integrated over z:

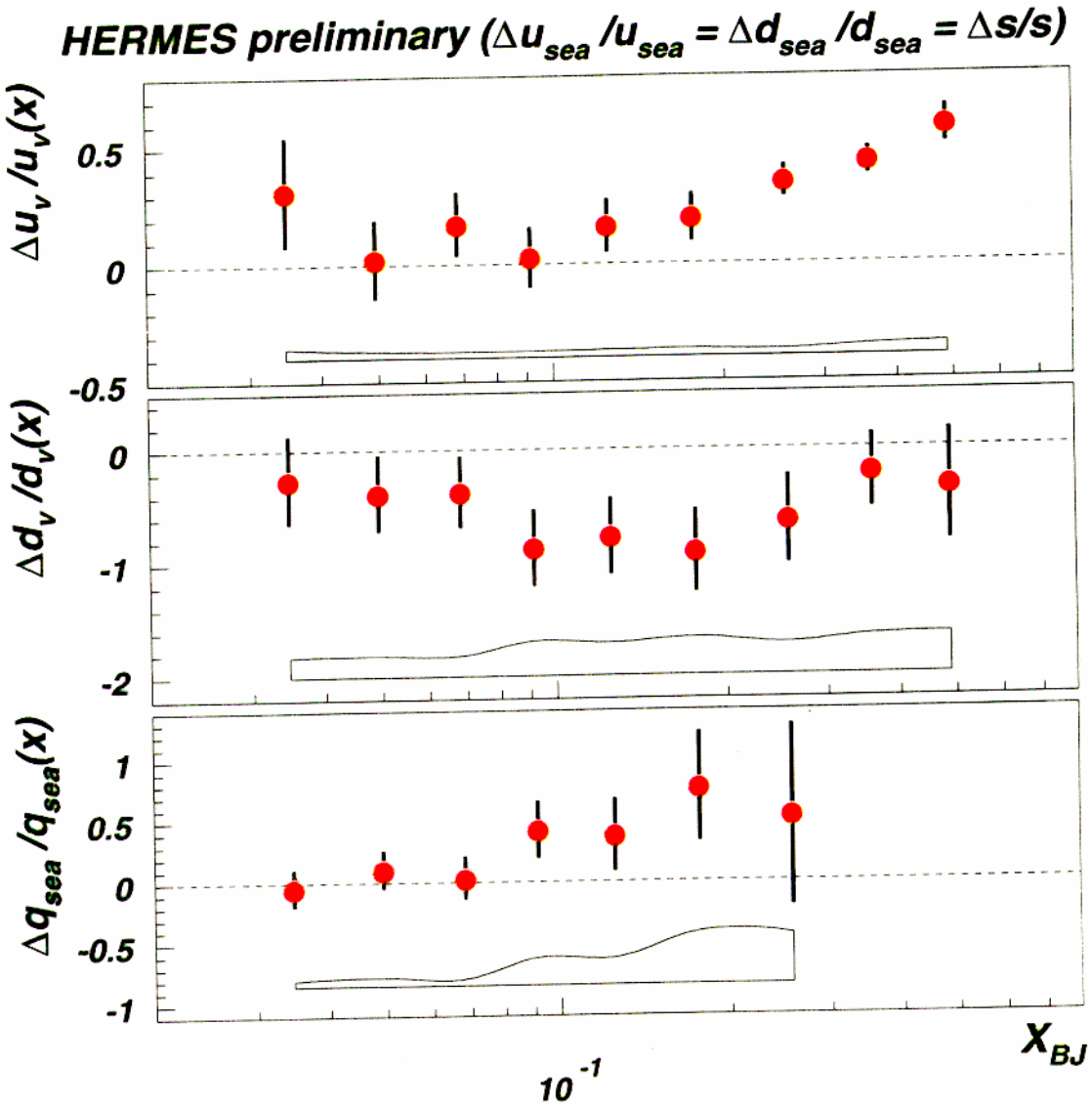


Polarized Quark Distributions

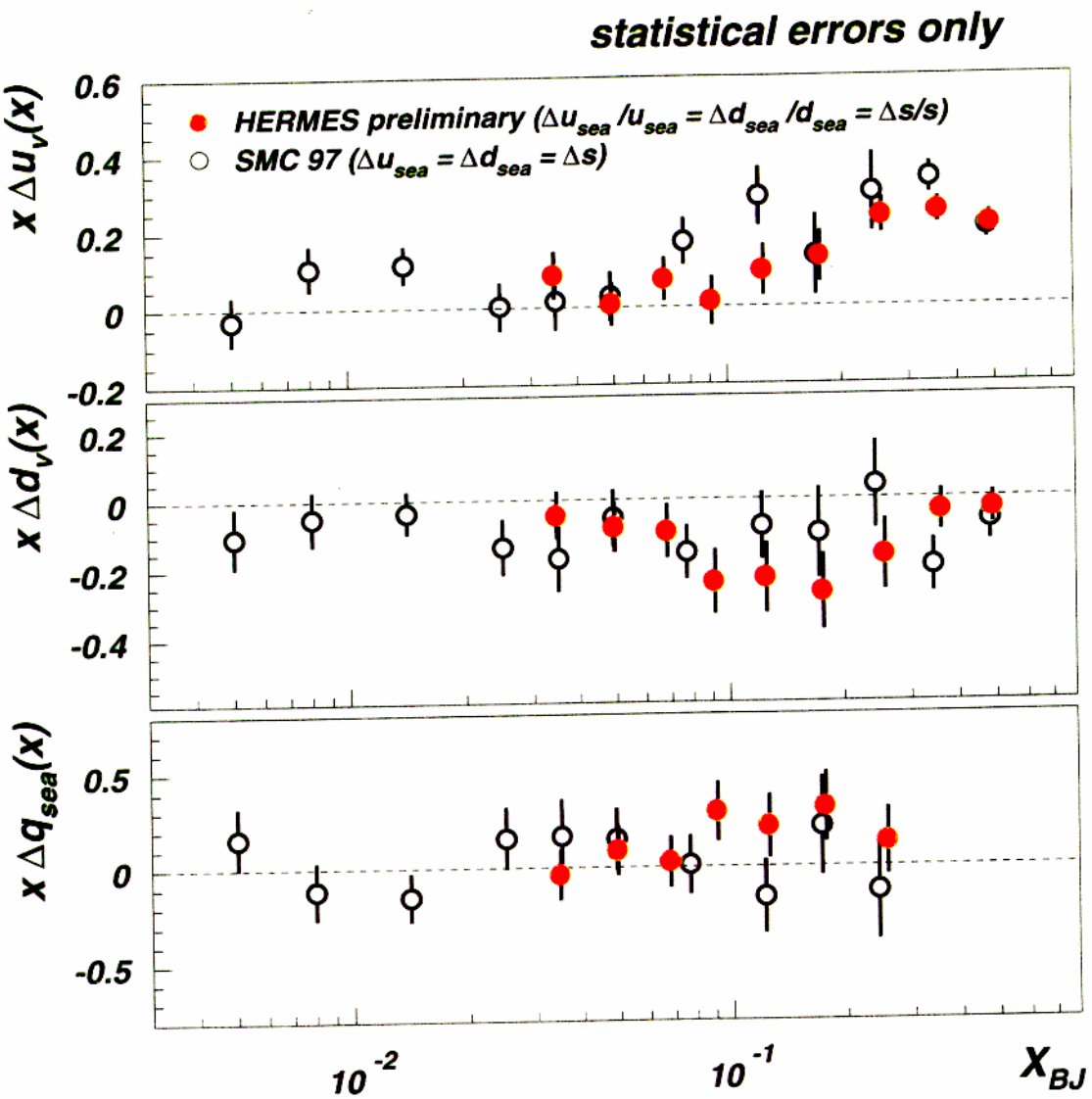
- Sea purities are too small for decomposition with available statistics
  → assume a polarization symmetric sea

$$\frac{\Delta u_{sea}}{u_{sea}} = \frac{\Delta d_{sea}}{d_{sea}} = \frac{\Delta s}{s}$$

to reduce number of quark polarizations



Comparison to SMC



- SMC results (at $Q_o^2 = 10GeV^2$) are in rough agreement with the extracted Δq functions at Hermes (at measured Q^2)
- Different sea quark assumptions change results by less than 10%

Light Sea Flavor Asymmetry

In QPM:

- assuming:
  - flavor symmetric light quark sea
  - isospin symmetry between p and n

  $\rightarrow$ results in Gottfried sum rule

$$S_G = \int_0^1 \frac{dx}{x}(F_2^p(x) - F_2^n(x)) = \frac{1}{3} - \frac{2}{3}\int_0^1 (\bar{d}(x) - \bar{u}(x))dx$$

- NMC: $S_G = 0.235 \pm 0.026$ (Phys. Rev. D50, 1 (1994))
- Hermes can measure the ratio $(\bar{d} - \bar{u})/(u - d)$ from ratio of charged pion yields in semi-inclusive DIS on ^1H and ^2D.

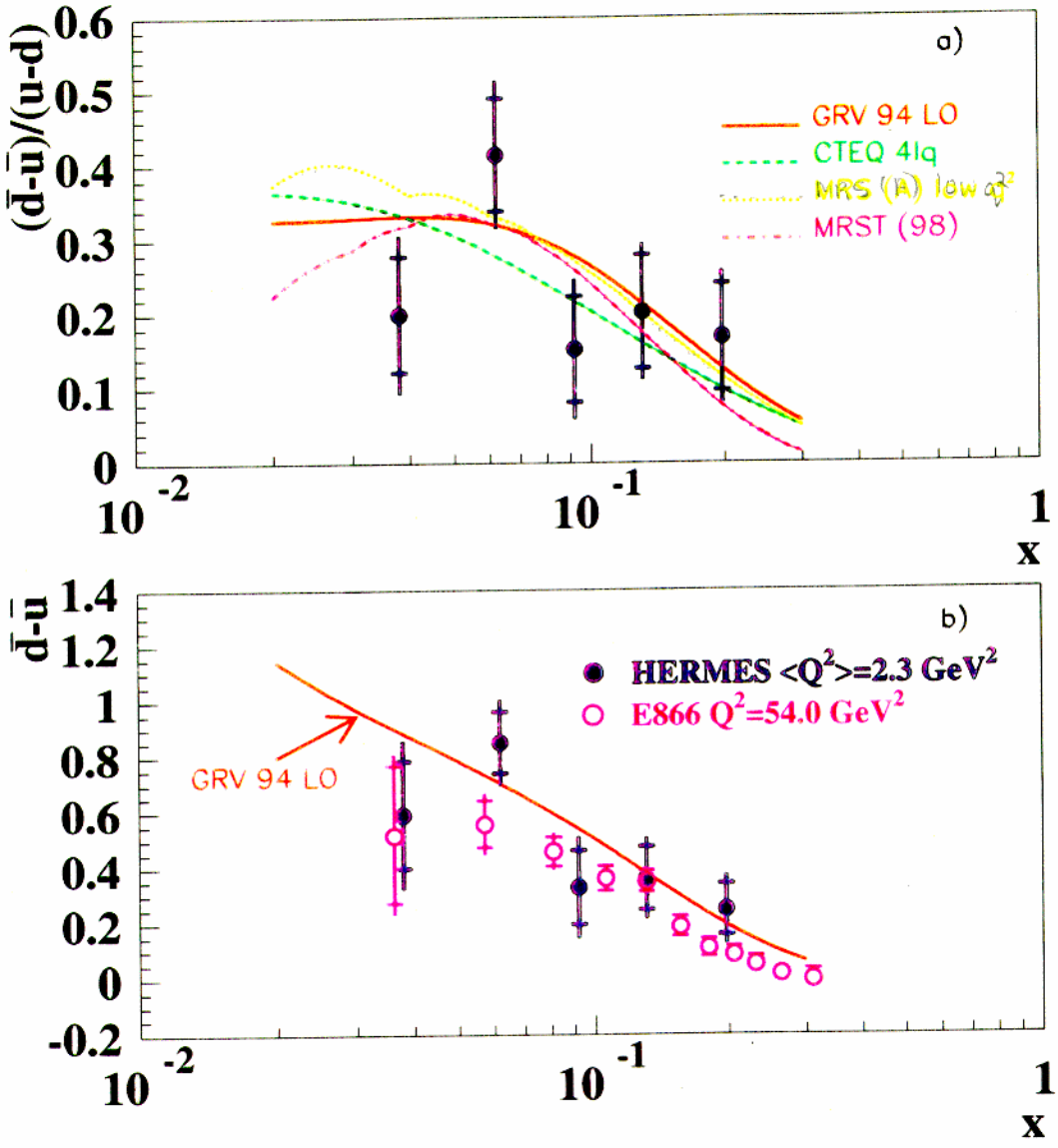
$$r(x,z) = \frac{N_p^{\pi^-}(x,z) - N_n^{\pi^-}(x,z)}{N_p^{\pi^+}(x,z) - N_n^{\pi^+}(x,z)}$$

With $J(z) = \frac{5}{3}\left(\frac{1 + D'(z)}{1 - D'(z)}\right)$ and $D'(z) = \frac{D_u^{\pi^-}(z)}{D_u^{\pi^+}(z)}$

one receives

$$\frac{\bar{d}(x) - \bar{u}(x)}{u(x) - d(x)} = \frac{J(z)\,[1 - r(x,z)] - [1 + r(x,z)]}{J(z)\,[1 - r(x,z)] + [1 + r(x,z)]}$$

Light Sea Flavor Asymmetry — Comparison to E866



- Sea asymmetry in semi-inclusive DIS (HERMES) and Drell–Yan (E866) experiments agree
- Q^2 of two experiments differ by factor ~ 20

Future → 2000

Upgrades to HERMES spectrometer completed:

Kaon identification with RICH → probe strange sea

Charm Identification → probe gluon spin

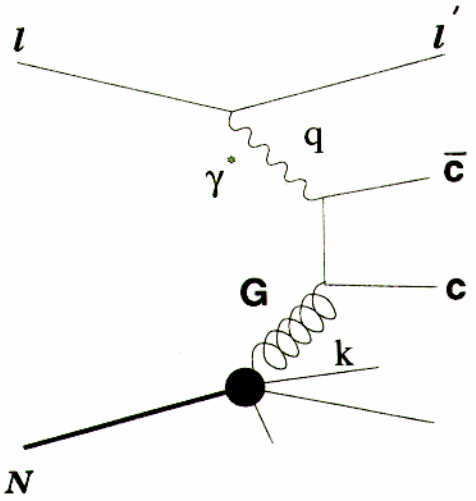
Exp.	Year	Beam		Target	meas. quantities
E155x	99	49 GeV	e^-	NH_3	A_2^p
HERMES	98/99	28 GeV	e^-	D	A_1^d $A_{1,h}^d$ $A_{1,\pi}^d$ $A_{1,K}^d$ charm production

end of 99:

- precise knowledge of g_1^p and g_1^n
- precision test of Bjorken Sum Rule
- precise knowledge of Δu_v, Δd_v, and $\Delta(\bar{u}+\bar{d})$
- first direct measurement of Δs
- first direct measurement of $\Delta G/G$?

Possibility to measure gluon spin directly

photon gluon fusion:



J/Ψ

open charm

- HERMES
- COMPASS
- E-156

Dijet production:

- polarized HERA

direct photon gluon production: $g + q \rightarrow \gamma + q$

- RHIC

Summary of experiments to probe gluon spin

Experiment	when ?	kin. range	$\delta\left(\frac{\Delta G}{G}\right)$
HERMES	running	$x_g \sim 0.3$	~ 0.5 /year after 98
RHIC	$\sim 2001/2$	$x_g \sim 0.05 - 0.3$	$\sim 0.01 - 0.3$
COMPASS	$\sim 2002/3$	$x_g \sim 0.15$	~ 0.1
SLAC E-156	deferred	$x_g \sim 0.1 - 0.5$	~ 0.02
pol. HERA	not approved	$x_g \sim 0.01 - 0.1$	~ 0.1

Summary

- HERMES successfully finished third year of running
- Competitive results on inclusive and semi-inclusive structure functions using a novel technique with different systematic errors than previous experiments
- 1997/98 upgrades
  - Kaon identification with RICH (probe strange sea)
  - Charm identification (probe gluon spin)
- HERMES will provide NEW information on the spin structure of the nucleon