The Polarized Structure Function g_1^p at Low Bjorken-x and Low Q^2 and Polarized Parton Distributions at HERMES

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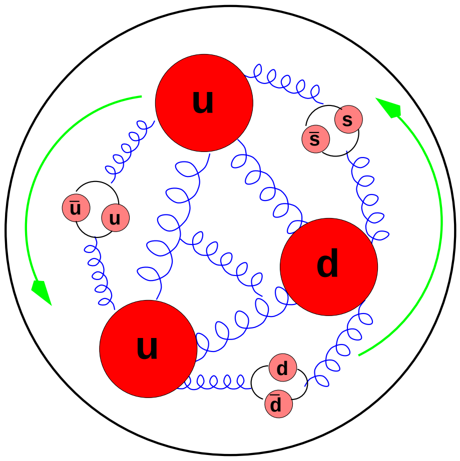
Outline:

- Introduction
- The Hermes Experiment
- Measurement of g_1^p at low x_{Bj} and low Q^2
- Extraction of Polarized Parton Distributions
- Summary

La Thuile, March 3rd 2000

The Spin of the Proton

CONTRIBUTIONS TO THE SPIN OF THE PROTON:



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

$$\begin{aligned} \Delta\Sigma &= (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s}) \\ &= (\Delta u_v + 2\Delta\bar{u}) + (\Delta d_v + 2\Delta\bar{d}) + (2\Delta\bar{s}) \end{aligned}$$

$\Longrightarrow$ POLARIZED DEEP INELASTIC LEPTON NUCLEON SCATTERING

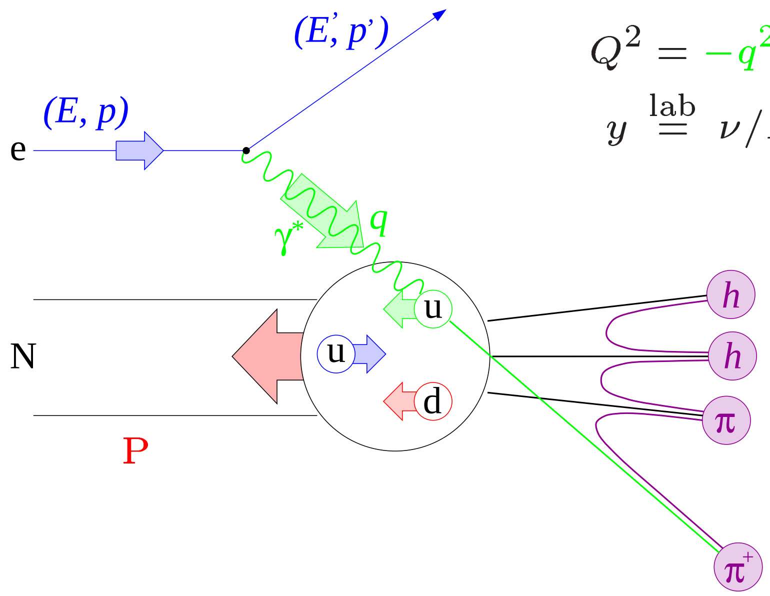
$\Delta\Sigma$ IS FOUND TO BE SMALL IN INCLUSIVE DIS EXPERIMENTS (EMC, SMC, SLAC, HERMES)

$$\Delta\Sigma \approx 0.2 \ldots 0.4$$

POSSIBLE CONTRIBUTIONS TO S_z:

- STRANGE SEA POLARIZATION Δs IS NEGATIVE?
- GLUON POLARIZATION ΔG IS POSITIVE?
- ORBITAL ANGULAR MOMENTUM L_z IS POSITIVE?

Deep Inelastic Scattering



$$Q^2 = -q^2 \overset{\text{lab}}{\approx} 4EE' \sin^2\theta/2$$
$$y \overset{\text{lab}}{=} \nu/E \overset{\text{lab}}{=} (E-E')/E$$
$$x \overset{\text{lab}}{=} Q^2/(2M\nu)$$
$$\gamma^2 = Q^2/\nu^2$$

target fragments

$$\mathrm{W}^2 = (\mathrm{q} + \mathrm{P})^2$$

current fragments

- Inclusive: detect only the scattered lepton
- Semi-Inclusive: detect a hadron h in coincidence with the scattered lepton

$\Longrightarrow$ Flavor Decomposition $\Longleftarrow$

- Longitudinal Cross Section Asymmetry:

$$A_{||} = \frac{\sigma^{\uparrow\Downarrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\uparrow\Downarrow} + \sigma^{\uparrow\Uparrow}} = D(A_1 + \eta A_2)$$

$$A_{||}^{(h)} = \frac{1}{< P_T P_B >} \frac{\left(N^{(h)}/L\right)^{\uparrow\Downarrow} - \left(N^{(h)}/L\right)^{\uparrow\Uparrow}}{\left(N^{(h)}/L\right)^{\uparrow\Downarrow} + \left(N^{(h)}/L\right)^{\uparrow\Uparrow}}$$

P_T, P_B :	target and beam polarisation
$N^{(h)}$:	number of (semi-)incl. DIS events
L :	deadtime corrected luminosity

$$A_1^{(h)} = \left(\frac{g_1}{F_1}\right) = \frac{A_{||}^{(h)}}{D(1+\eta\gamma)} \qquad (g_2 = 0))$$

Why g_1^p at Low x_{Bj} and Low Q^2

Why low x_{Bj}?

- Low x region is crucial for pinning down the spin content of the nucleon (extrapolation into unmeasured region).

Why low Q^2?

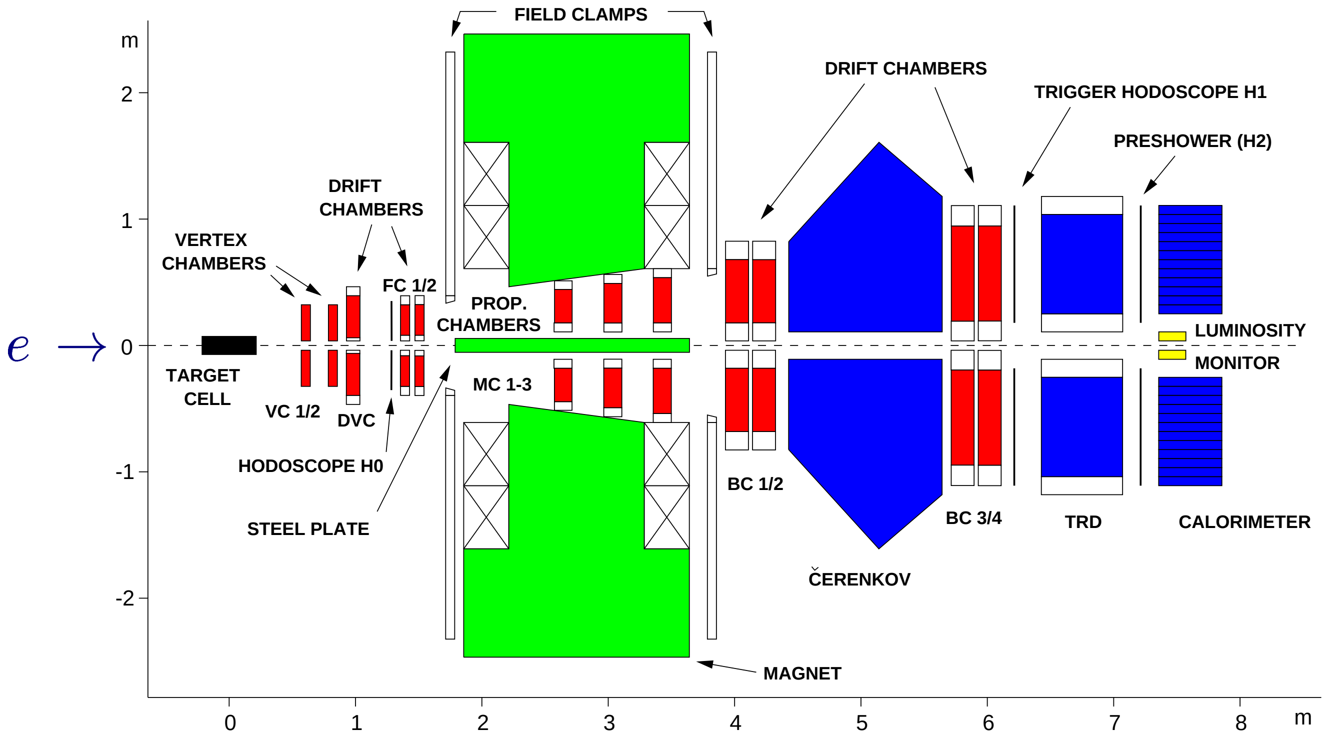
- Provide new data for studying the scaling violations.
- Allow further tests of the pQCD concept: down to which Q^2 is the concept valid?

$$
\begin{aligned}
x g_1(x, Q^2) &= x g_1^{tw-2}(x, Q^2) \\
&+ \frac{1}{Q^2} h^{tw-4}(x, Q^2) \\
&+ \frac{1}{Q^2}\left(h_{TMC}^{tw-2}(x, Q^2) + h_{TMC}^{tw-3}(x, Q^2) \right) \\
&+ \mathcal{O}\left(\frac{1}{Q^4}\right)
\end{aligned}
$$

$\Longrightarrow$ field in progress

- LO tw-4 calculation for deuteron at $Q^2 = 4$ GeV^2 [DIS '99: E.Stein, NP B (proc. Suppl.)79 (1999) 567]
- LO target mass contribution to $g_1^p(x, Q^2)$ at tw-2 level [DIS '99: J.Blümlein, A.Tkabladze, NP B (proc. Suppl.) 79 (1999) 541]

The HERMES Experiment at DESY



- Beam: transversally self-polarizing 27.6 GeV e-beam of HERA, rotated to longitudinally spin orientation at the HERMES IP; $P_{\text{beam}} \approx 0.55 \pm 0.02$
- Target: cooled open-ended storage cell inside the beam pipe, longitudinally polarized pure (^{1}H, D, ^{3}He) gas atoms of $(7-33) \times 10^{13}$ nucleons/cm^2; $P_{\text{H}} = 0.88 \pm 0.04$, $P_{\text{D}} \approx P_{\text{H}}$, $P_{\text{He}} = 0.46 \pm 0.02$
- Tracking: forward dipole magnet spectrometer with 57 chamber planes ($40\,\text{mrad} < \theta < 220\,\text{mrad}$); resolution: $\delta\theta < 0.6$ mrad, $\delta p/p < 1.5\%$
- Particle ID: threshold Cerenkov detector, TRD, preshower, lead-glass calorimeter; e/h misidentification $< 0.4\%$
- Fast Trigger: scintillator hodoscopes H0, H1, H2; calorimeter; energy threshold 1.4(3.5) GeV
- Luminosity Monitor

Inclusive DIS Data at Low x ...

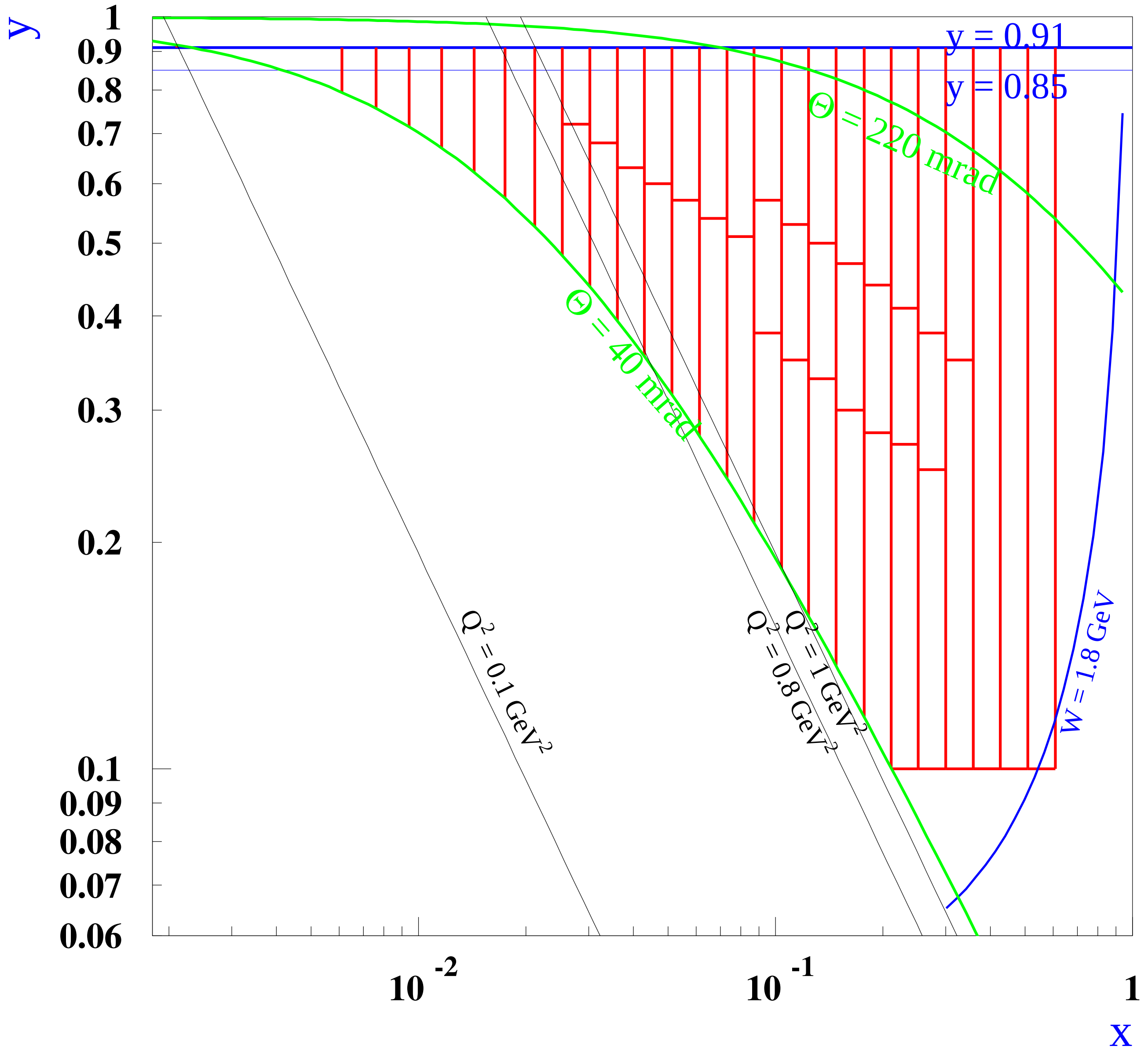
- Extension of the Kinematic Range:

$$0.85 > x > 0.0021\ (0.0212)$$

$$0.1 < y < 0.91\ (0.85)$$

$$Q^2 > 0.1\ (0.8)\ \mathrm{GeV}^2$$

- The kinematic plane:



Inclusive DIS Data at Low x ...

- STATISTICS (1997 HERMES DATA ON H) :

$\rightarrow$ EVENTS AFTER DATA QUALITY CUTS: $2.5 * 10^6$

- EXPERIMENTAL SYSTEMATIC UNCERTAINTIES:

$\rightarrow$ BEAM POLAR.: $\Delta_{P_B} = 3.4\ \%$

$\rightarrow$ TARGET POLAR.: $\Delta_{P_T} = 4.7\ \%$

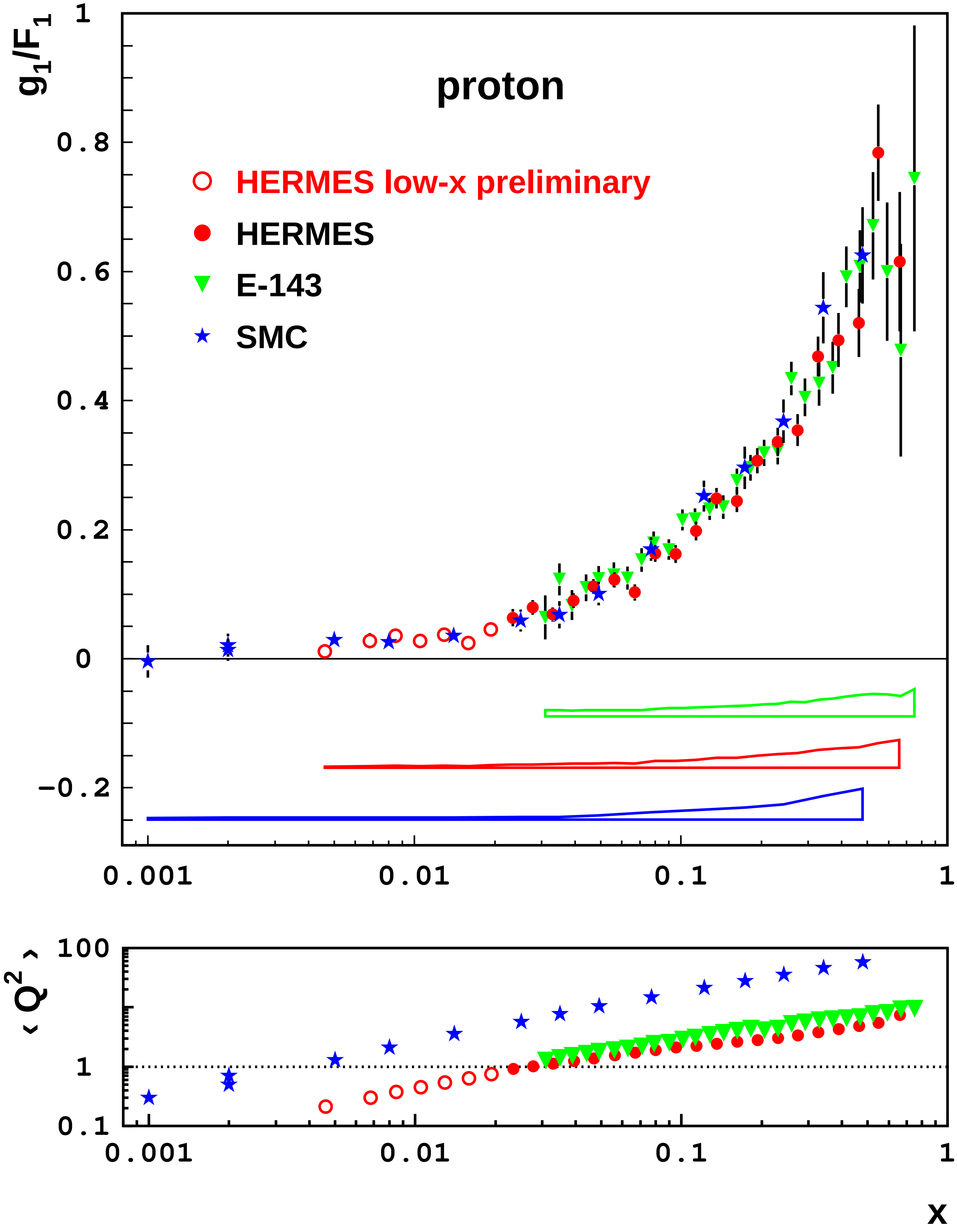
$\rightarrow$ OTHER SOURCES: $\Delta_{\mathrm{misc}} = 5.5\ \%$
(NORMALIZATION, CUT STABILITY, ALIGNMENT)

- SYSTEMATIC UNCERTAINTIES FOR THE EXTRACTION OF THE BORN ASYMMETRY:

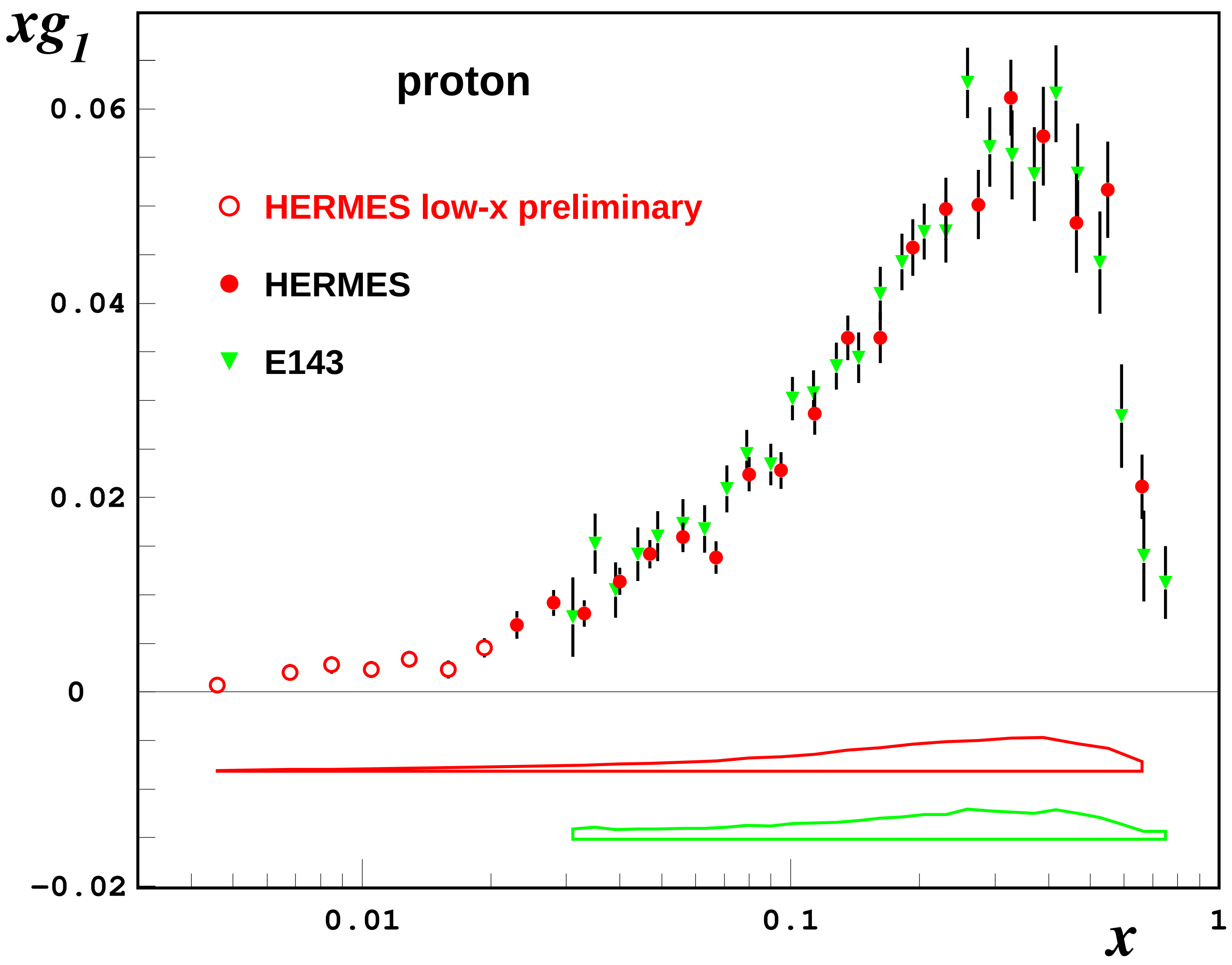
$\rightarrow$ F2: ALLM WITH BODEK-MODIFICATION
(BODEK FOR W $< 2.2\ GeV$ AND $Q^2 < 0.5\ GeV^2$)
AND R1990: FIXED
+ RADIATIVE CORR. (RADCOR)
+ SMEARING CORR.: $\Delta \approx 5.0\ \%$ (11 % LOWEST x)

$\Rightarrow$ TOTAL LOW x-RANGE: 9.4 % (13.6 % LOWEST x BIN)

Resulting g_1/F_1 at Low x and Q^2



Resulting xg_1 at Low x and Q^2



Semi-Inclusive DIS Data

$\Longrightarrow$ DETECT A HADRON h IN COINCIDENCE WITH THE SCATTERED LEPTON

- DETERMINE KINEMATICS BY SCATTERED LEPTON:
  $0.02 < x < 0.8,\ Q^2 > 1\,GeV^2,\ W^2 > 4\,GeV^2$
  $y < 0.85$

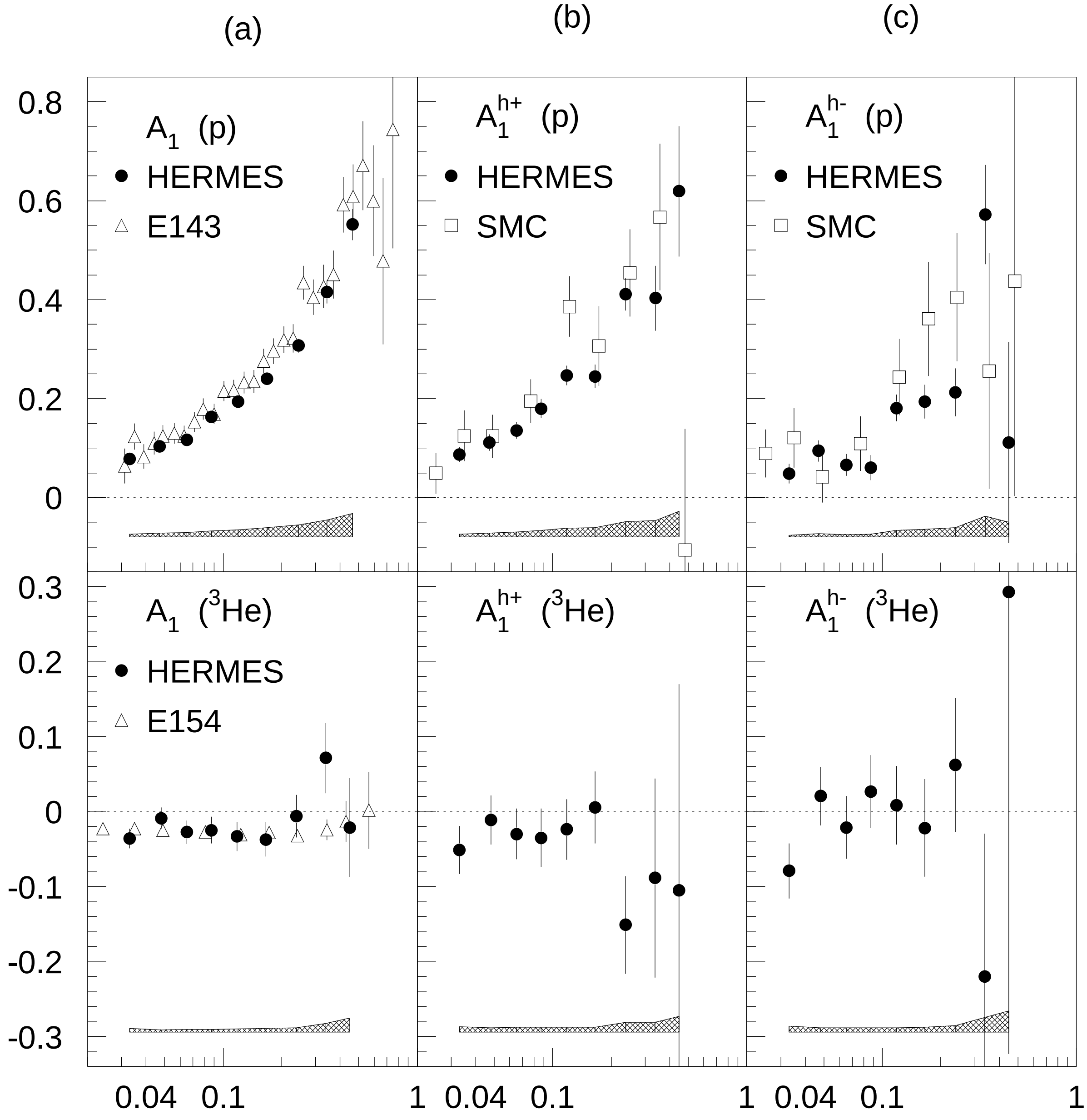
- SELECT HADRONS FRAGMENTED IN CURRENT REGION:
  $z \stackrel{\text{lab}}{=} E_h/\nu \approx E_\pi/\nu > 0.2, \quad x_F \approx 2p_L/W > 0.1$

- NUMBER OF HADRONS:
  h^+: $284 * 10^3\ {}^3He$ AND $306 * 10^3\ H$
  h^-: $178 * 10^3\ {}^3He$ AND $175 * 10^3\ H$

$\longrightarrow$ HADRONS CONTAIN INFORMATION ON THE STRUCK QUARK (FLAVOR TAGGING)

$\longrightarrow$ FORM SPIN ASYMMETRIES FOR THE PRODUCTION OF POSITIVE OR NEGATIVE CHARGED HADRONS USING THE SAME FORMALISM AS FOR LEPTONS

Semi-Inclusive Asymmetries



[PUBLISHED IN Phys. Lett. B464(99)123)]

(a) INCLUSIVE ASYMMETRIES IN COMPARISON TO SLAC

(b) SEMI-INCLUSIVE ASYMMETRIES FOR POSITIVELY CHARGED HADRONS IN COMPARISON TO SMC

(c) SEMI-INCLUSIVE ASYMMETRIES FOR NEGATIVELY CHARGED HADRONS IN COMPARISON TO SMC

DATA ARE AVERAGED OVER Q^2 (AND z) IN EACH x BIN:

$\rightarrow$ AGREEMENT WITHIN 1 σ

$\rightarrow$ NO STATISTICALLY SIGNIFICANT Q^2 DEPENDENCE

Flavor Separation and Purities

REWRITE PHOTON-NUCLEON ASYMMETRY ASSUMING FACTORIZATION, SPIN-INDEPENDENCE AND SCALING OF FRAGMENTATION FUNCTIONS $D_q^h(z)$

$$A_1^h(x) = \sum_q P_q^h(x) \cdot \frac{(1+R(x))}{(1+\gamma^2)} \cdot \frac{\Delta q(x)}{q(x)}$$

WITH

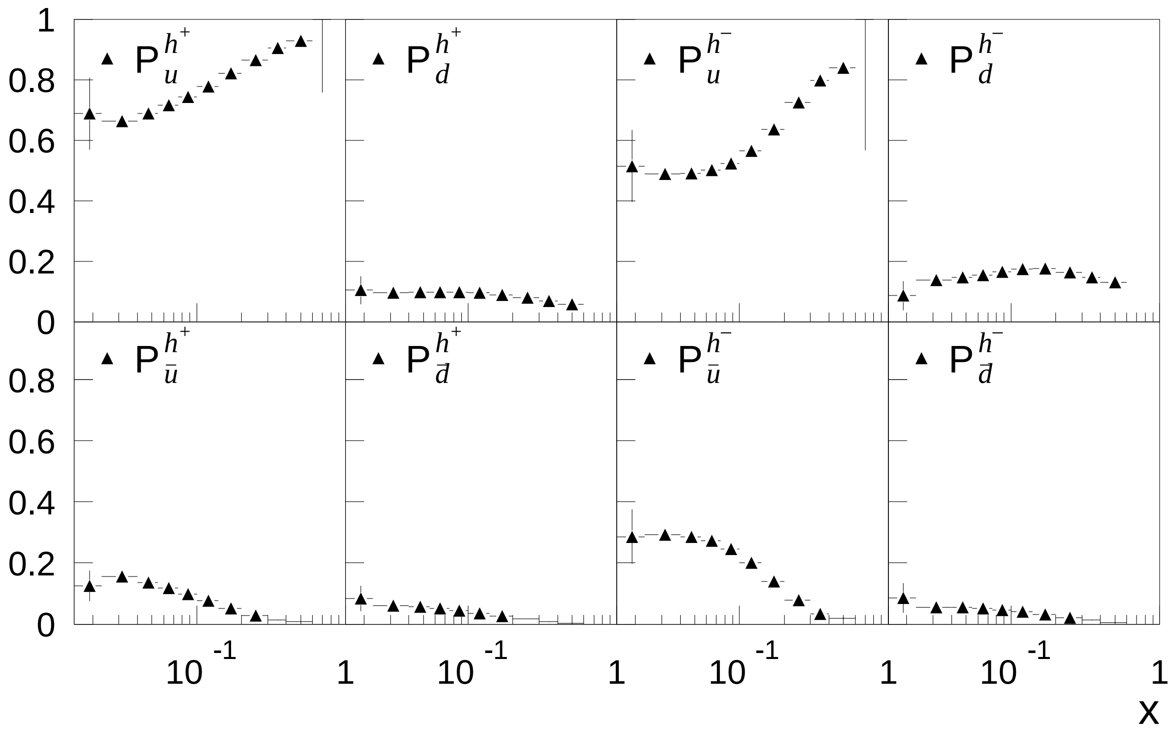
$$P_q^h(x) = \frac{e_q^2 q(x) \int_{0.2}^1 dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int_{0.2}^1 dz' D_{q'}^h(z')}$$

MATRIX FORM:

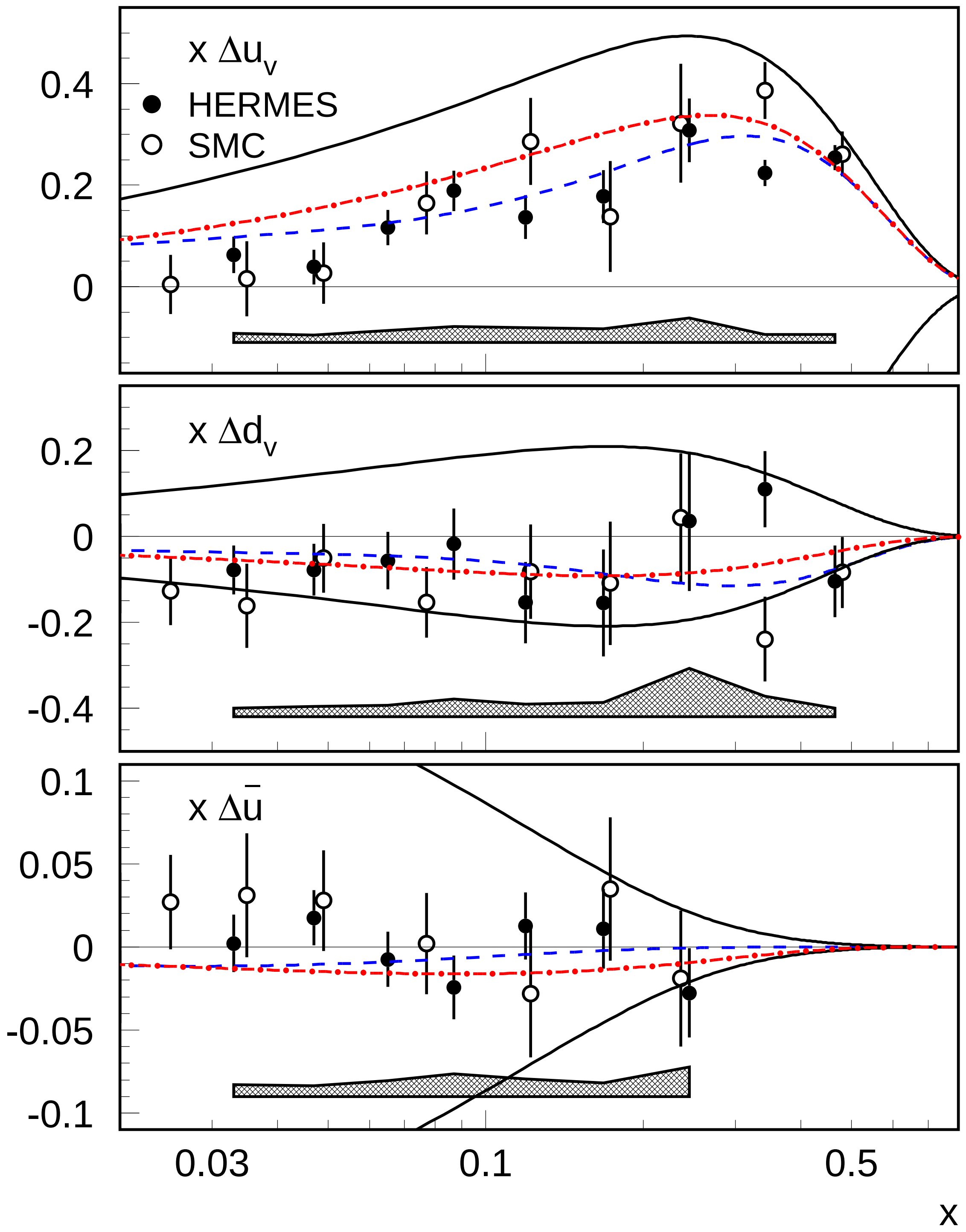
$$\vec{A}_1(x) = \mathcal{P}(x) \cdot \vec{\mathcal{Q}}(x)$$

PURITY $P_q^h(x)$ GIVES THE PROBABILITY THAT A QUARK q WAS STRUCK WHEN A HADRON h IS DETECTED

- CALCULATED BY MONTE CARLO (LO QCD)
- UNPOLARIZED QUANTITY
- EXAMPLE: z INTEGRATED PURITIES FOR A PROTON TARGET



Valence- And Sea Quark Distributions At $Q^2 = 2.5$ GeV^2



DASHED LINE: GS (LO); DASHED-DOTTED LINE: GRSV (LO)

HERMES: $\frac{\Delta u_s}{u_s} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta \bar{s}}{\bar{s}}$

SMC: $\Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}$

RESULTS ARE INSENSITIVE TO SEA ASSUMPTIONS

Spin Contributions And $SU(3)_f$

COMPARISON OF THE HERMES INTEGRALS WITH SMC RESULTS AT $Q^2 = 2.5$ GeV^2 AND IN THE HERMES x-RANGE OF $0.023 < x < 0.6$.

	HERMES	SMC
Δu_v	$0.52 \pm 0.05 \pm 0.08$	$0.59 \pm 0.08 \pm 0.07$
Δd_v	$-0.19 \pm 0.11 \pm 0.13$	$-0.33 \pm 0.11 \pm 0.09$
$\Delta \bar{u}$	$-0.01 \pm 0.02 \pm 0.03$	$0.02 \pm 0.03 \pm 0.02$
$\Delta \bar{d}$	$-0.02 \pm 0.03 \pm 0.04$	$0.02 \pm 0.03 \pm 0.02$

$\longrightarrow$ AGREEMENT WITHIN $1\ \sigma$

TEST OF $SU(3)_f$ PREDICTIONS ($Q^2 = 2.5\ GeV^2$)

	TOTAL INTEGRAL	$SU(3)_f$
$\Delta u + \Delta \bar{u}$	0.57 ± 0.04	0.66 ± 0.03
$\Delta d + \Delta \bar{d}$	-0.25 ± 0.07	-0.35 ± 0.03
$\Delta s + \Delta \bar{s}$	-0.01 ± 0.05	-0.08 ± 0.02

(UNCERTAINTY FOR THE LOW x EXTRAPOLATION NOT INCLUDED)

$\longrightarrow$ A DEFINITE STATEMENT AS TO WHETHER THE INTEGRATED POLARIZED QUARK DISTRIBUTIONS VIOLATE $SU(3)_f$ OR NOT IS NOT POSSIBLE YET

$\longrightarrow$ A DIRECT MEASUREMENT OF THE STRANGE SEA IS REQUIRED (NOTE SEA ASSUMPTIONS!)

Summary

- ADDITIONAL KINEMATIC RANGE EXPLORED FOR g_1^p AT HERMES:

  $$0.0021 < x < 0.0212,\ 0.1 < Q^2 < 0.8\ \mathrm{GeV}^2$$

  $\Rightarrow$ 7 NEW LOW-x DATA POINTS WITH SYST. UNCERTAINTIES $\approx$ 9.0% (EXCEPT THE LOWEST X BIN)

- NEW TESTING GROUND FOR THE VALIDITY RANGE OF THE pQCD CONCEPT

- QUARK POLARIZATION:
  - UP QUARKS: **positive**
  - DOWN QUARKS: **negative**
  - SEA QUARKS: COMPATIBLE WITH **zero**

- FUTURE: HERMES IS PREPARED TO MEASURE STRANGE SEA POLARIZATION
  - RICH DETECTOR (KAON ID)