Extraction of Polarized Quark Distributions from Semi-inclusive Data

Michael Ruh

University of Freiburg

for the hermes Collaboration

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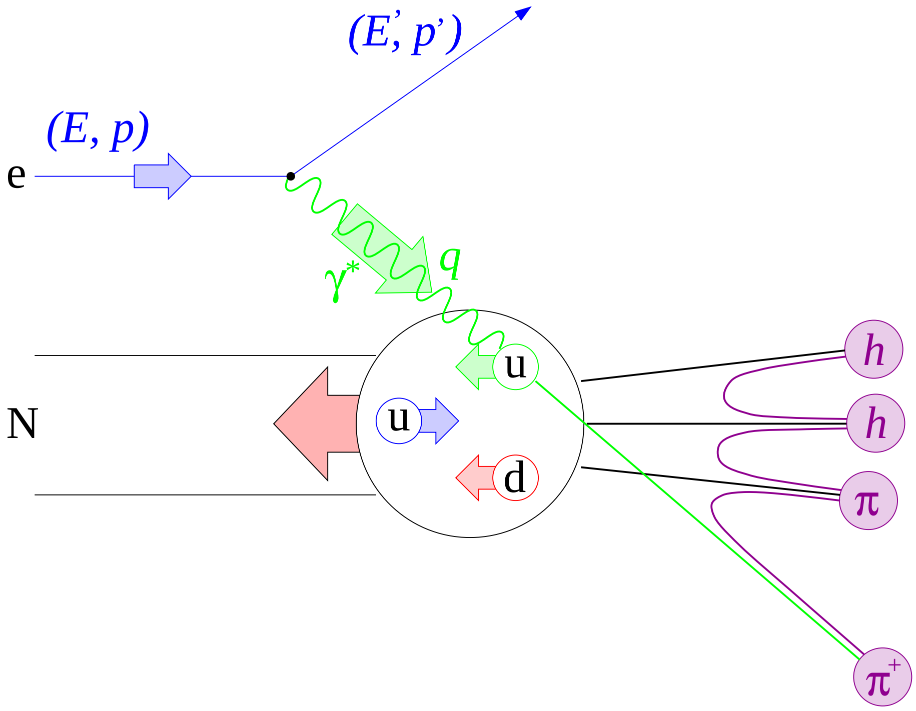
Semi-inclusive DIS

In semi-inclusive DIS a hadron h is detected in coincidence with the scattered lepton



- Select hadrons from the current fragmentation region by cuts on $z = E_h/\nu \geq 0.2$ and $x_F = 2p_L^*/W \geq 0.1$
- In LO QCD (Assuming spin-independence of fragmentation):

$$\frac{g_1^h}{F_1^h}(x, Q^2) = \frac{\int_{z_{\text{min}}}^1 dz \sum_q e_q^2 \, \Delta q(x, Q^2) \cdot D_q^h(z, Q^2)}{\int_{z_{\text{min}}}^1 dz \sum_q e_q^2 \, q(x, Q^2) \cdot D_q^h(z, Q^2)}$$

$(\Delta q)\ q$: (Polarized) quark distribution, D_q^h: Fragmentation function

Experimental determination of g_1/F_1

The ratio

$$\frac{{g_1}^{(h)}}{{F_1}^{(h)}} = \frac{\sum_q e_q^2 \, \Delta q \cdot D_q^h}{\sum_q e_q^2 \, q \cdot D_q^h}$$

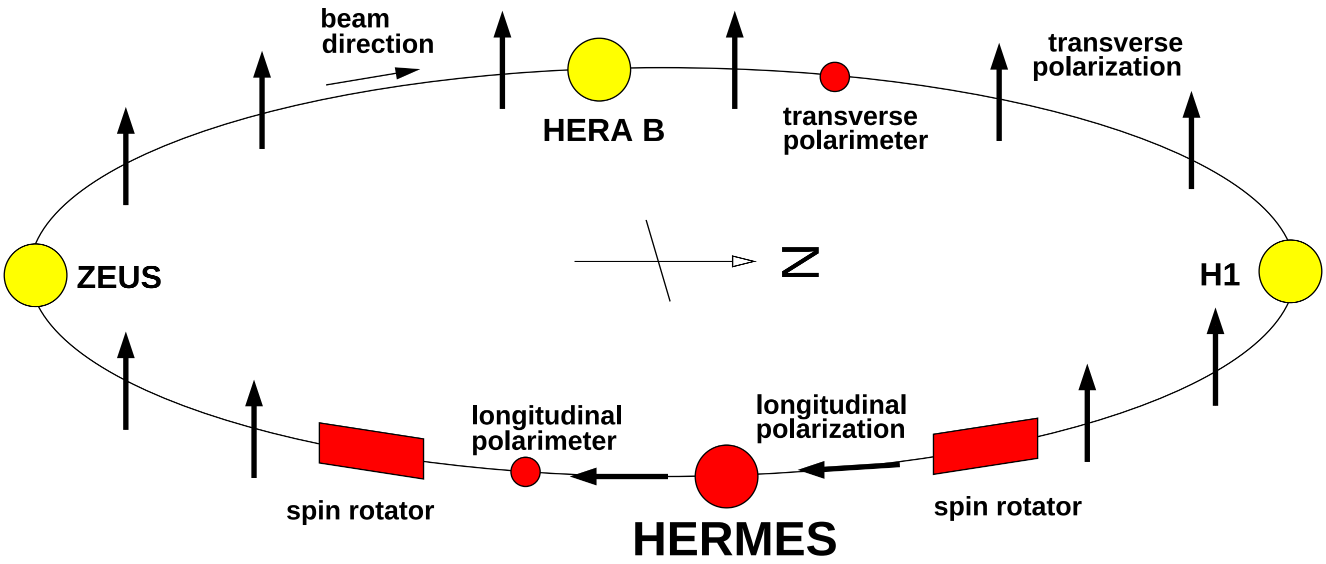
is related to the *measured lepton nucleon asymmetry* ${A_\parallel}^{(h)}$ by

$$\frac{{g_1}^{(h)}}{{F_1}^{(h)}} = \frac{1}{1+\eta\gamma}\left[\frac{{A_\parallel}^{(h)}}{D} + \gamma(\gamma-\eta)\cdot\frac{g_2^{(h)}}{F_1^{(h)}}\right]$$

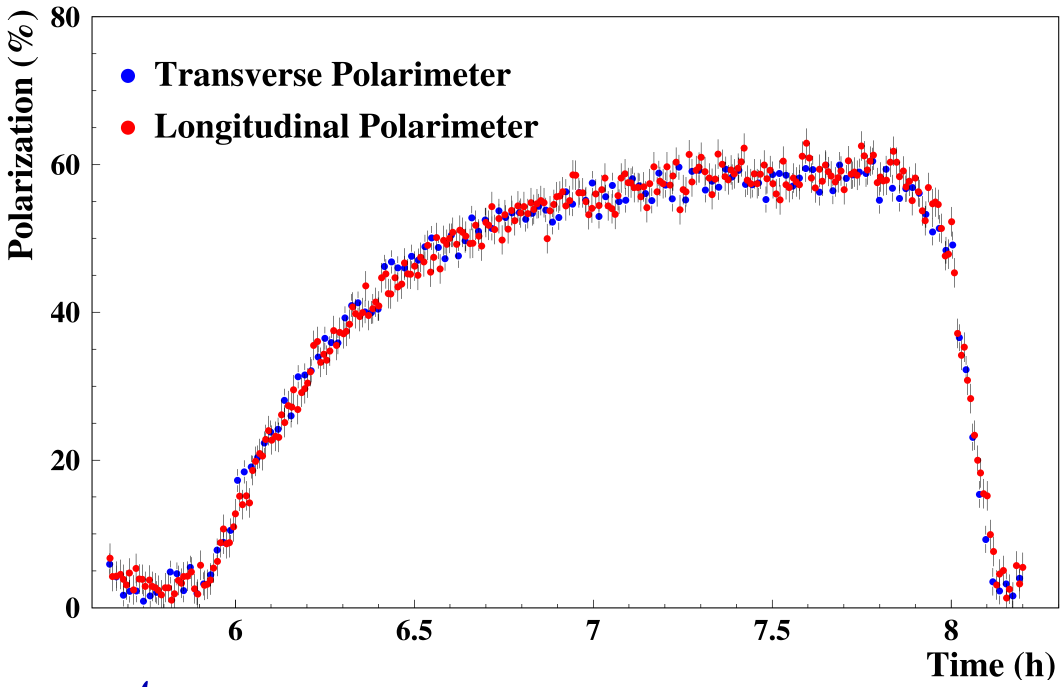
QPM: $g_2^{(h)} = 0$ in agreement with experiment. Assuming $g_2^{(h)} = 0$ it follows (remember $A_1 = (g_1 - \gamma^2 g_2)/F_1$)

$$\boxed{A_1^{(h)} = \frac{{g_1}^{(h)}}{{F_1}^{(h)}} = \frac{{A_\parallel}^{(h)}}{D(1+\eta\gamma)}}$$

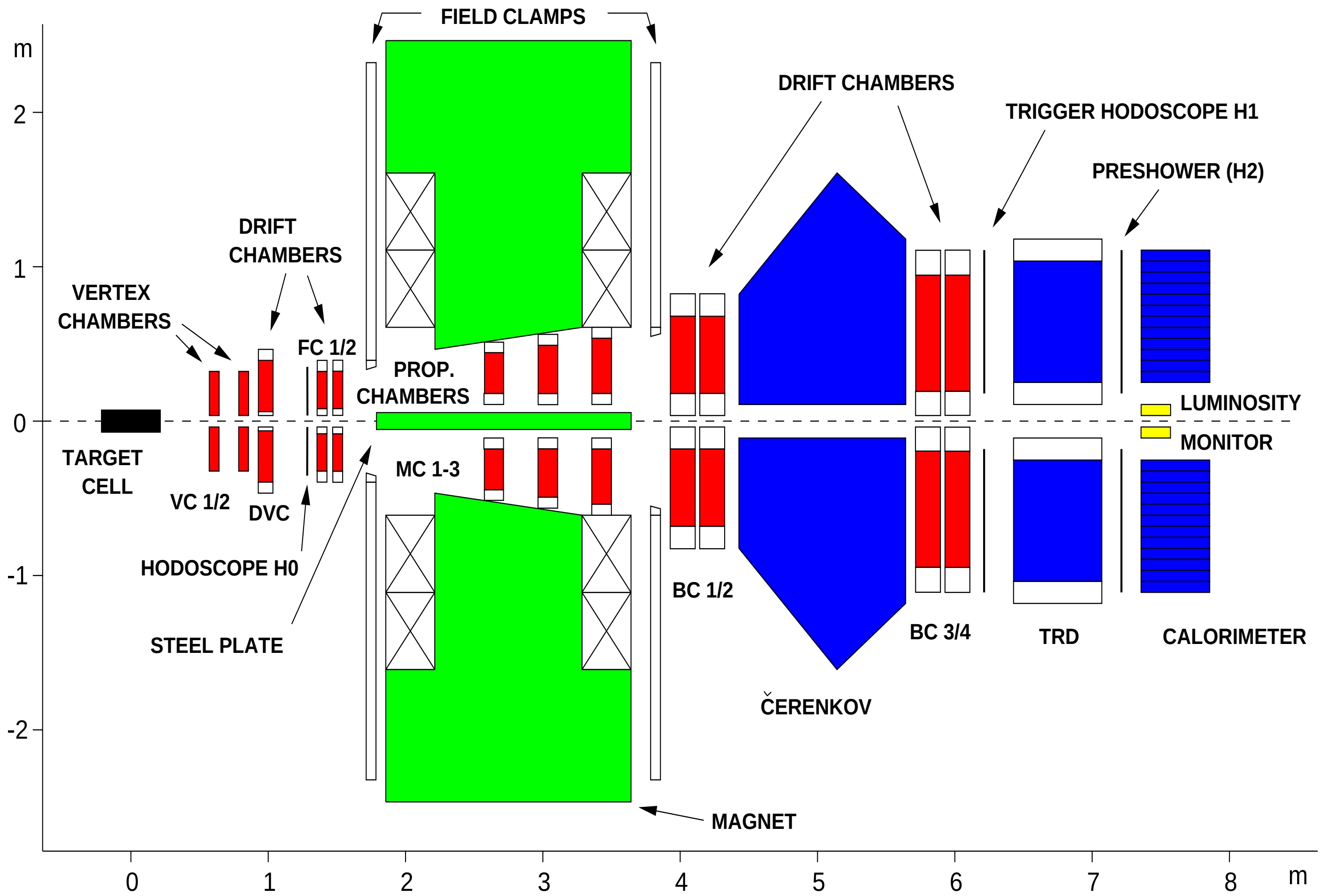
The Polarized Positron Beam at HERA



- Self-polarization by emission of synchrotron radiation, $p_b(t) = p_b^{\mathrm{max}}\,[1 - \exp(-t/\tau)]$
- Spin rotators $\rightarrow$ longitudinal polarization at HERMES IP
- 2 Compton Polarimeters
- Average beam polarization $\langle p_b \rangle \approx 55\%$



The HERMES Experiment

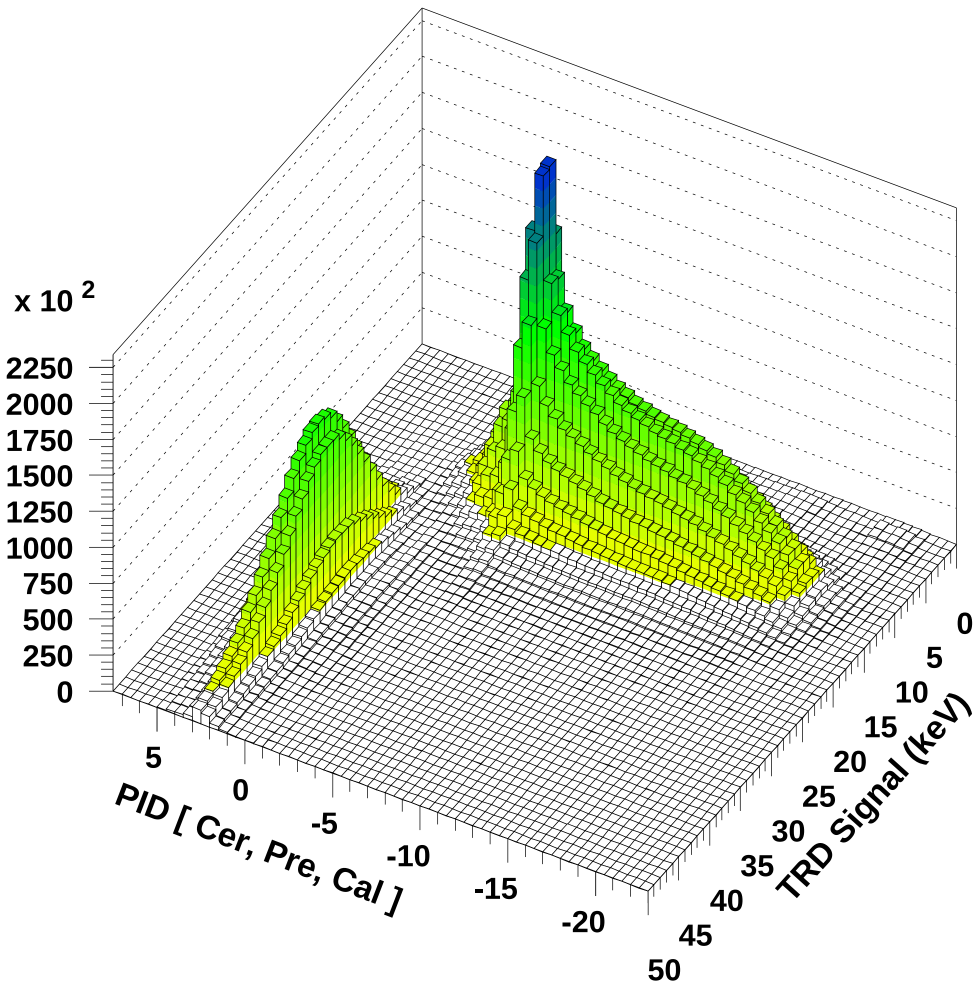


- **Target:** Internal storage cell target, polarized gas atoms (^{1}H, ^{2}H,^{3}He), density: $7 \times 10^{13} - 3 \times 10^{14}$ atoms/cm^2
- **Kinematic range:**
  $0.02 \le x \le 0.8$ for $Q^2 \ge 1$ GeV^2 and $W \ge 2$ GeV
- **Track reconstruction:** 57 tracking chamber planes, $\delta P/P = 0.7 - 1.3\%$, $\delta\theta \le 0.6$ mrad
- **Particle ID**: Threshold Čerenkov (RICH $\ge$ 1998), TRD, Preshower, Lead Glass Calorimeter

Particle Identification at hermes

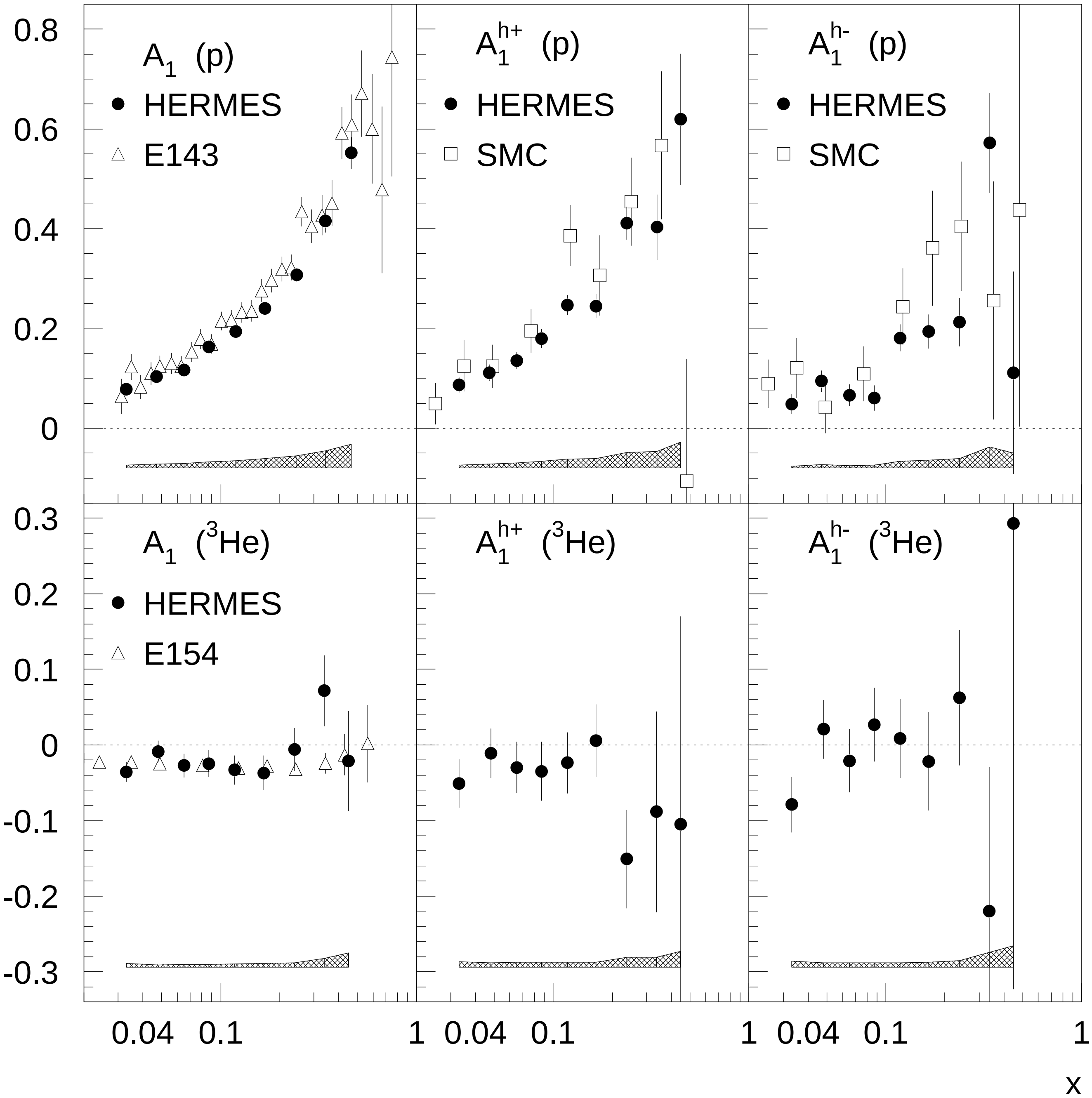
Combination of Čerenkov/Preshower/Calorimeter/TRD

- Clean separation of leptons and hadrons
- π identification for $p_\pi \geq 4$ GeV



$\Rightarrow$ Lepton identification with average efficiency of 98% and hadron contamination of $\leq$ 1%

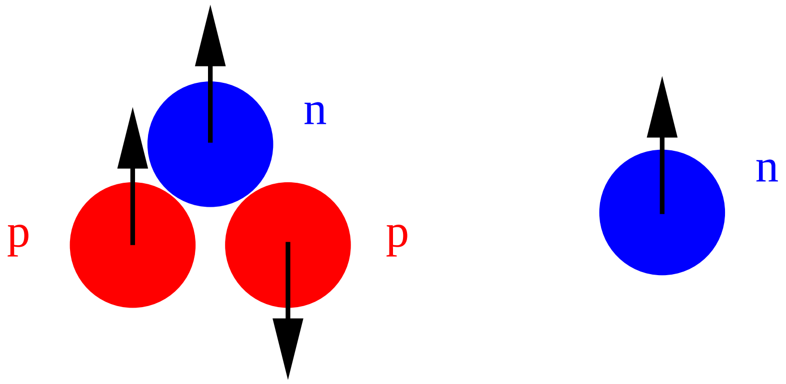
Semi-inclusive Asymmetries



Data given at mean Q^2 of each x. Error bars of HERMES (SLAC and SMC) are statistical (total) uncertainties. Bands are HERMES systematic error. Inclusive results compared to SLAC g_1/F_1

^{3}He as Neutron Target

- Dominant ^{3}He configuration



- Effective nucleon polarizations[1]

$$p_p = -0.028 \pm 0.004 \qquad p_n = 0.86 \pm 0.02$$

- Nuclear correction

$$A_{He}^{(h)} = f_p^{(h)}\, p_p\, A_p^{(h)} + f_n^{(h)}\, p_n\, A_n^{(h)}$$

- Dilution factors

$$f_p^{(h)} = \frac{2\sigma_p^{(h)}}{\sigma_{He}^{(h)}} = \frac{2F_{2p}^{(h)}}{2F_{2p}^{(h)} + F_{2n}^{(h)}}$$

$$f_n^{(h)} = 1 - f_p^{(h)}$$

[1] C. Ciofi degli Atti *et al.*, Phys. Rev. C **48** (1993) R968

where

$$F_2^h(x) = x \sum_q e_q^2 \, q(x) \cdot \int_{z_{\mathrm{min}}}^1 D_q^h(z) \, dz$$

Δq-Extraction

- Rewrite Photon-Nucleon asymmetry

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

- *Purity* $P_q^h(x,z)$ gives probability that a quark $q(x)$ was struck when a hadron $h(z)$ is detected

- Purities are *spin-independent* quantities

- Define

$$\vec{\mathcal{A}} = \begin{pmatrix} A_1^{h_1}(x) \\ \dots \\ A_1^{h_m}(x) \end{pmatrix} \quad \vec{Q} = \begin{pmatrix} \Delta q_1(x)/q_1(x) \\ \dots \\ \Delta q_n(x)/q_n(x) \end{pmatrix} \quad \mathcal{P} = \left[P_q^{h_j}(x) \right]_{mn}$$

where $P_q^h(x) = \int_{z_{\mathrm{min}}}^1 P_q^h(x,z)\, dz$

- To extract quark polarizations solve

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

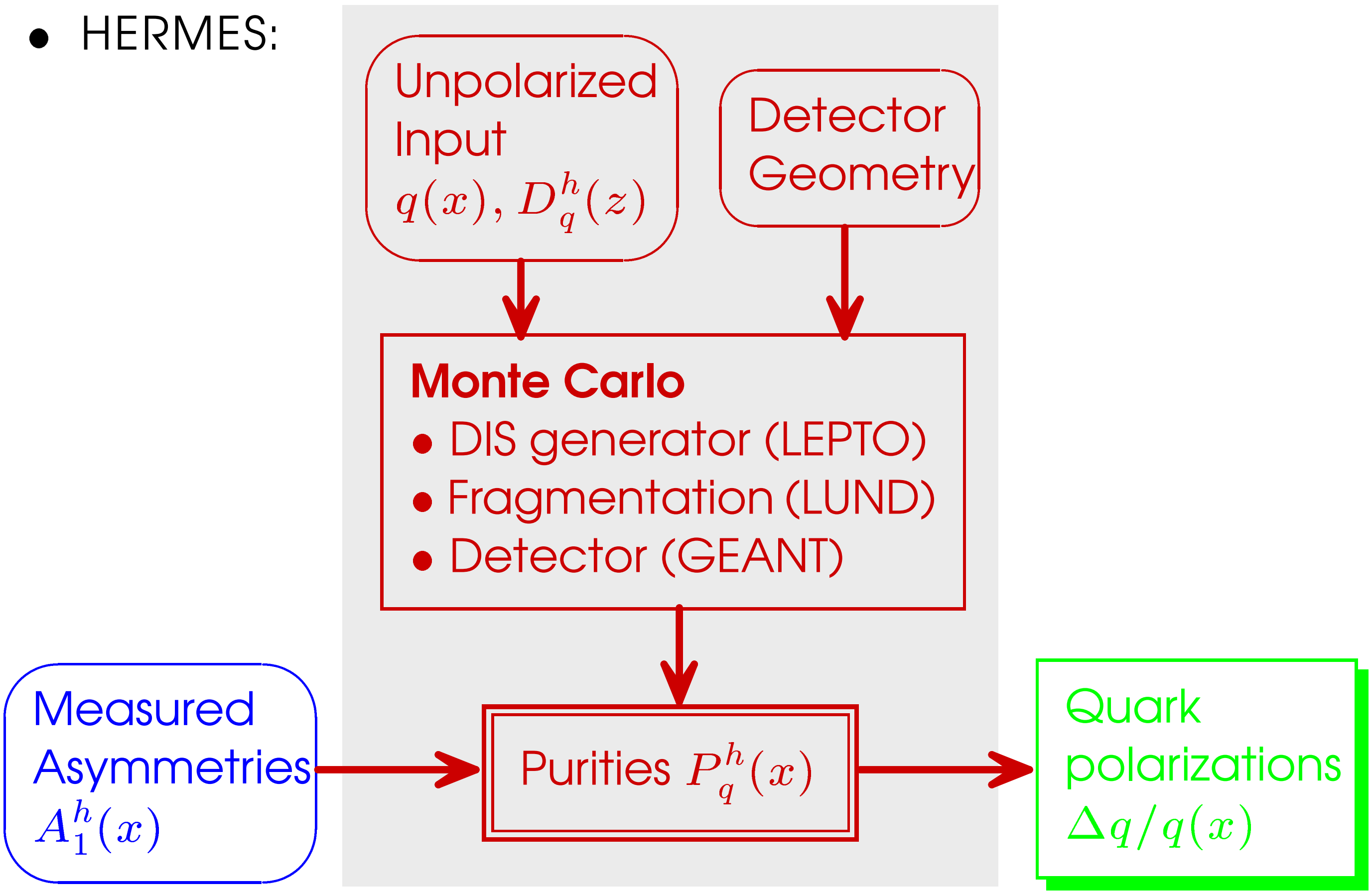
Where do the Purities come from ?

- SMC: Purities

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

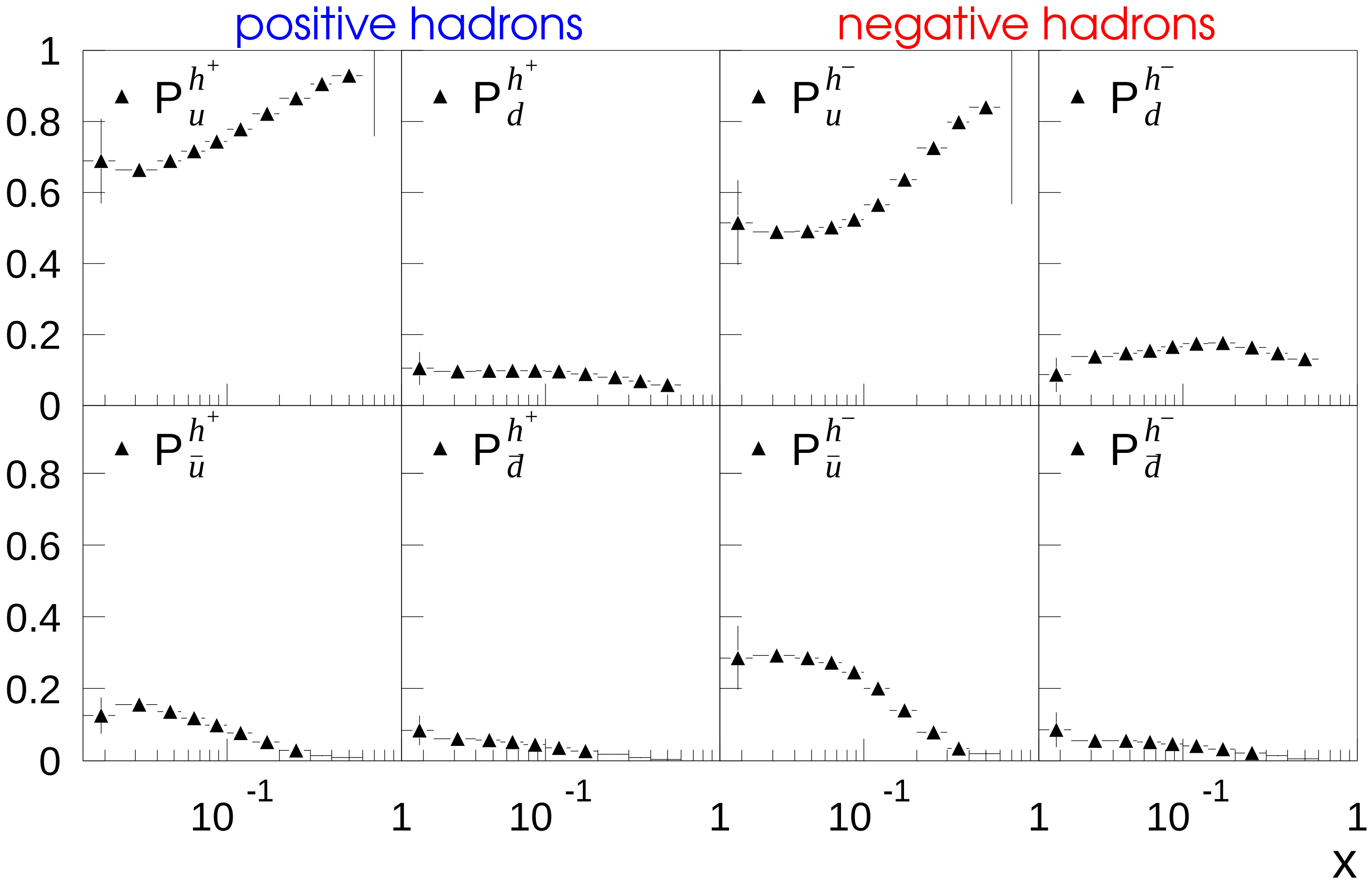
are derived from *measured* $D_q^h(z)$ and parametrizations of $q(x)$

- HERMES:



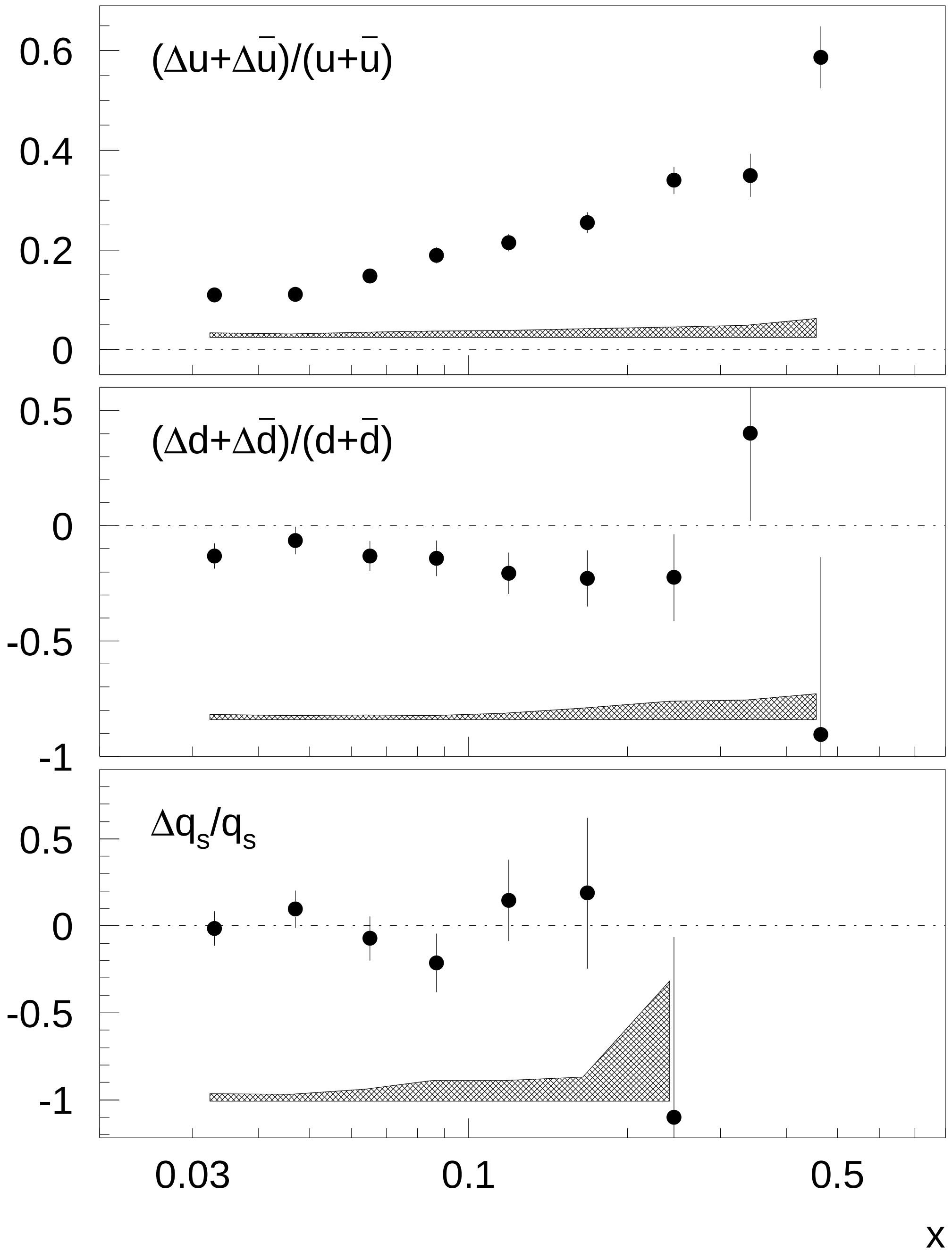
Purities

Purities $P^{h^\pm}_{u,\bar{u},d,\bar{d}}(x)$ for a *proton target* (z-integrated):



- h^+, h^- asymmetries on the proton dominated by $\Delta u(x)$
- Sensitivity to $\Delta d(x) \equiv \Delta u_n(x)$ via neutron (^{3}He – data)
- Sensitivity to $\Delta \bar{u}(x)$ & $\Delta \bar{d}(x) \approx 10\%$ for $x \leq 0.2$

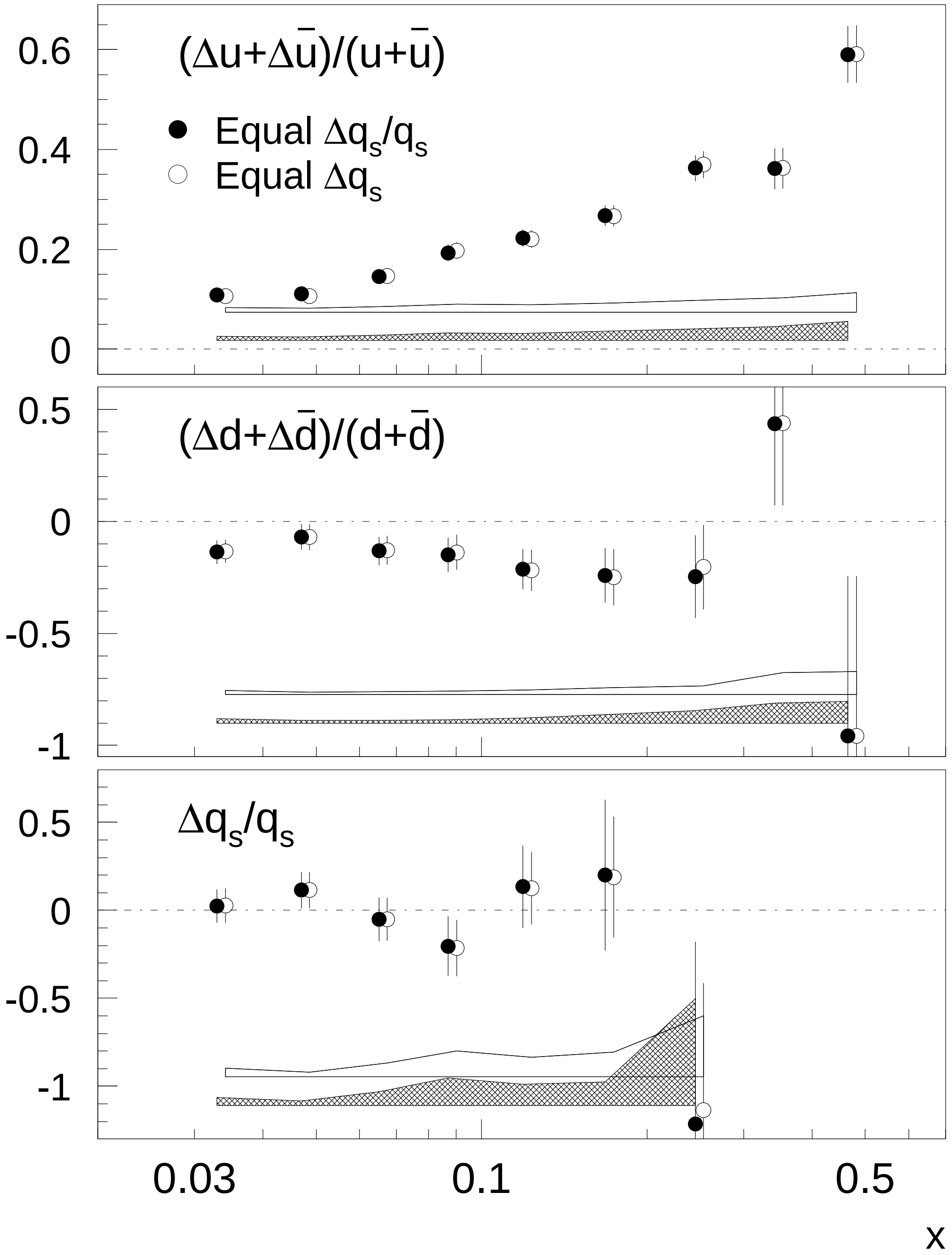
Flavor Decomposition



Flavor decomposition of quark polarizations as a function of x at measured Q^2.

Sea assumption: $\frac{\Delta q_s}{q_s} \equiv \frac{\Delta u_s}{u_s} = \frac{\Delta d_s}{d_s} = \frac{\Delta s}{s} = \frac{\Delta \bar{u}}{\bar{u}} = \frac{\Delta \bar{d}}{\bar{d}} = \frac{\Delta \bar{s}}{\bar{s}}$

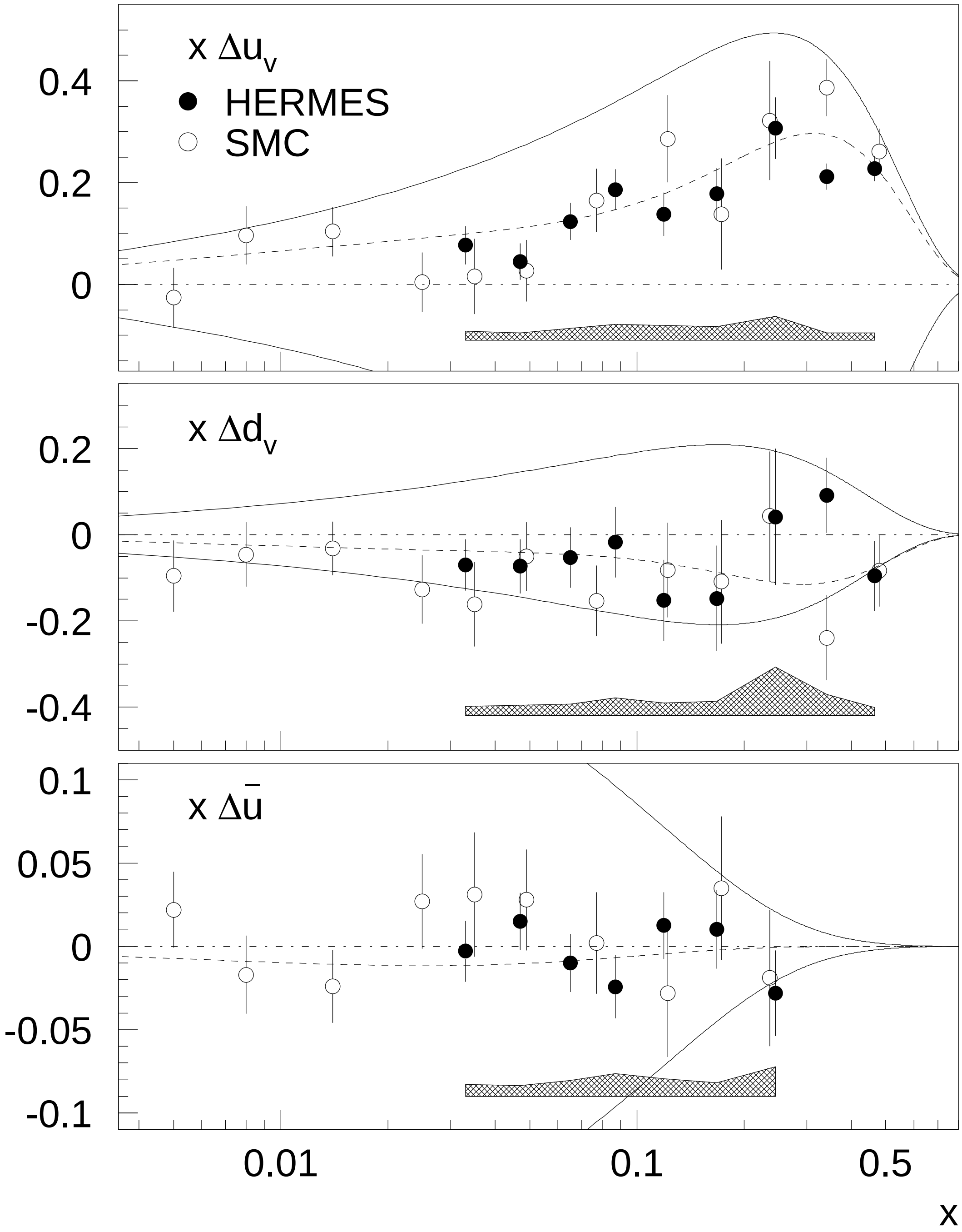
Comparison of Sea Assumptions



Flavor decomposition of quark polarizations at assuming a *flavor symmetric sea* (open circles) or *flavor independent polarization* (full circles)

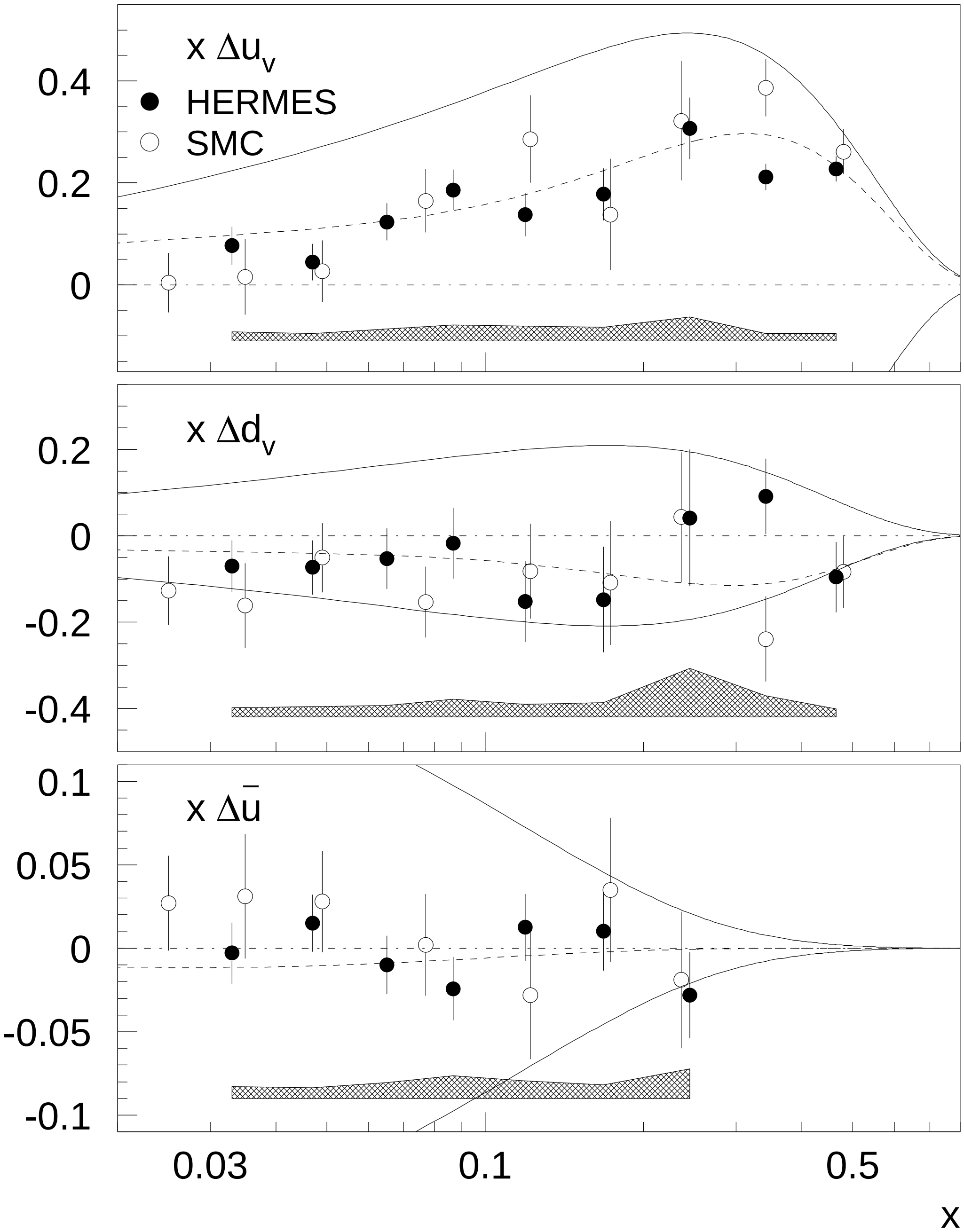
⇒ Result insensitive to sea assumption

Valence- and Sea Quark Distributions



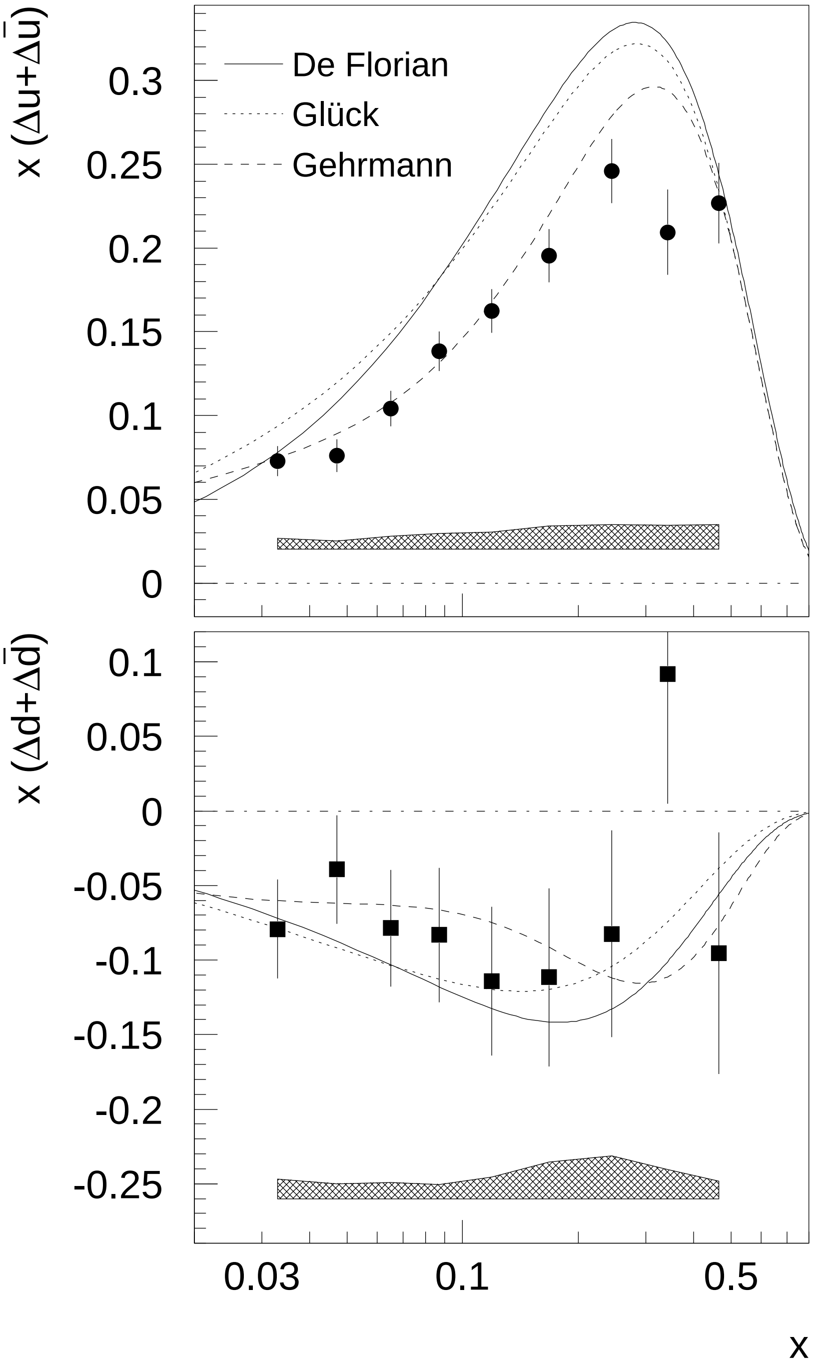
Polarized valence- and sea quark distributions at at $Q^2 = 2.5$ GeV^2 compared to SMC. Dotted line: *Gehrmann and Stirling* ('Gluon A', LO). (SMC sea assumption: $\Delta u_s = \Delta d_s = \Delta s = \Delta\bar{u} = \Delta\bar{d} = \Delta\bar{s}$)

Valence- and Sea Quark Distributions



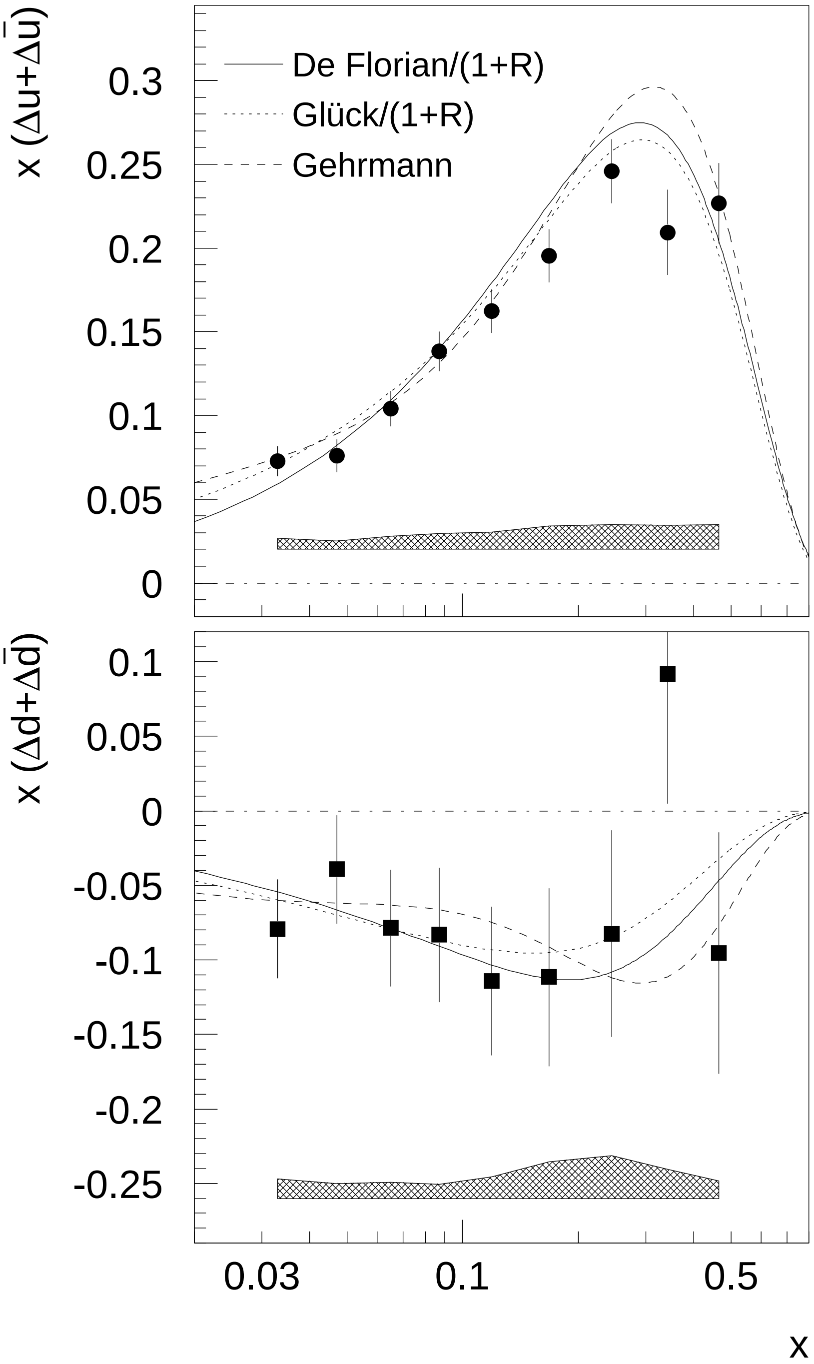
Polarized valence- and sea quark distributions at at $Q^2 = 2.5$ GeV^2 compared to SMC in the HERMES *range of* x. Dotted line: *Gehrmann and Stirling* ('Gluon A', LO).
(SMC sea assumption: $\Delta u_s = \Delta d_s = \Delta s = \Delta \bar{u} = \Delta \bar{d} = \Delta \bar{s}$)

Comparison to Parametrizations (1)



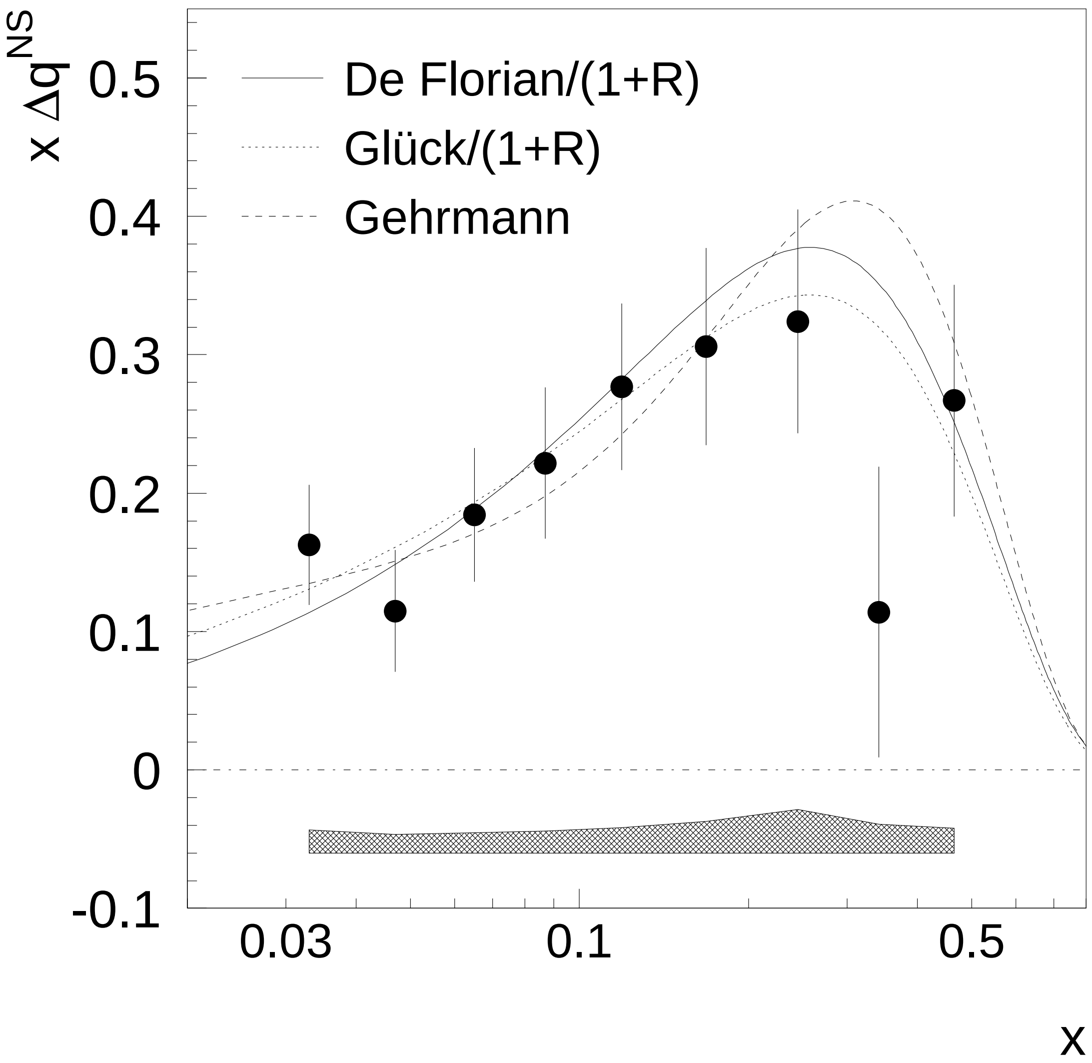
Polarized quark distributions at $Q^2 = 2.5$ GeV^2 compared to parametrizations. *De Florian et al.* ($0.1 < \Delta g < 0.8$, LO), *Gehrmann and Stirling* ('Gluon A', LO) and *Glück et al.* ('Standard Scenario', LO).

Comparison to Parametrizations (2)



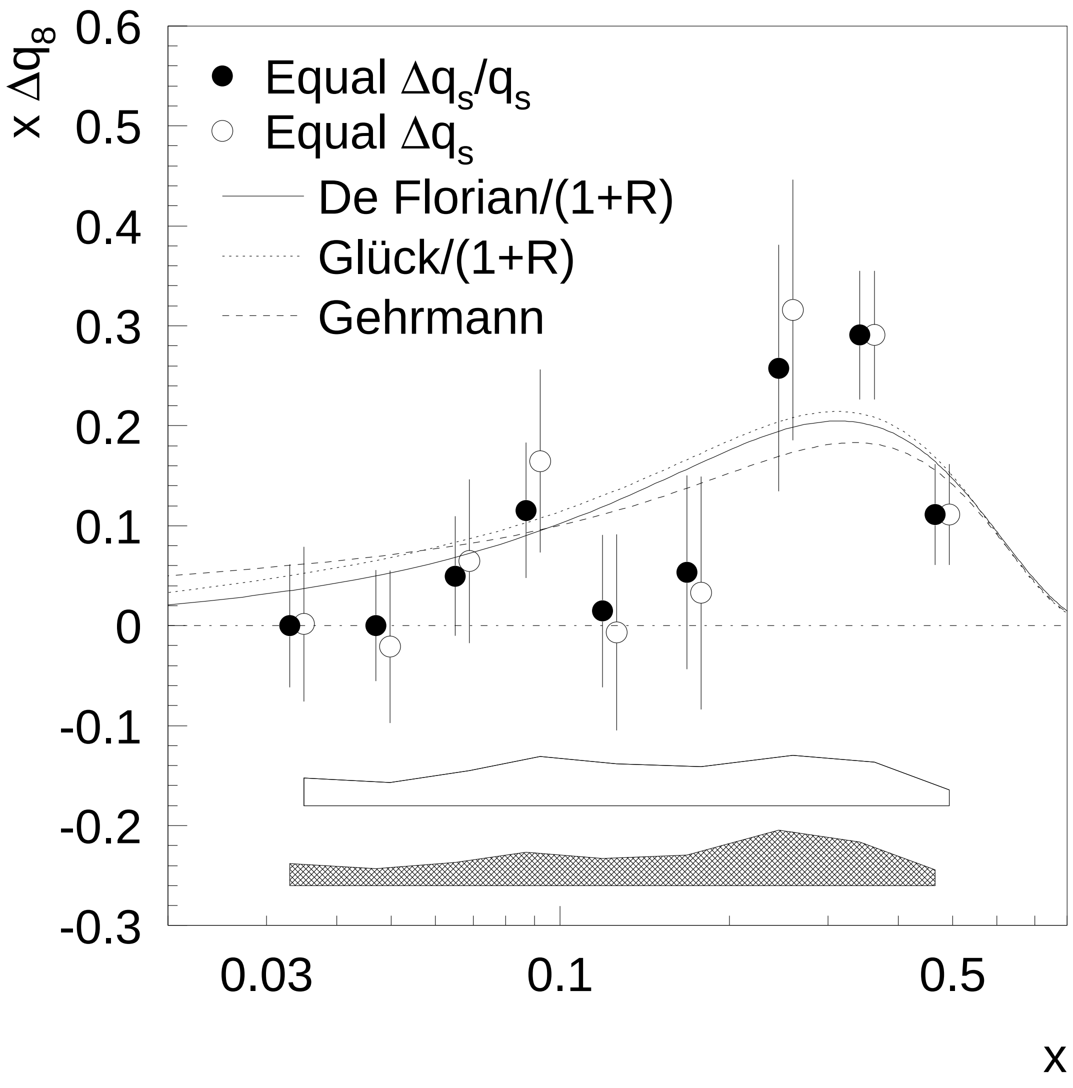
Polarized quark distributions at $Q^2 = 2.5$ GeV^2 compared to parametrizations. *De Florian and Glück parameterizations corrected by $(1+R)$ to allow for direct comparison*

$x\ \Delta q^{\mathrm{NS}}$



Non-singlet contribution $x\Delta q^{\mathrm{NS}} = x\ (\Delta u + \Delta\bar{u} - \Delta d - \Delta\bar{d})$ at $Q^2 = 2.5$ GeV^2 compared to parametrizations

$x\ \Delta q_8$



Octet combination $x\Delta q_8 = x\ (\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} - 2(\Delta s + \Delta\bar{s}))$ at $Q^2 = 2.5$ GeV^2 assuming a *flavor symmetric sea* (open circles) or a *flavor independent polarization* (full circles)

Integrals over measured range

Integral over measured range is obtained as

$$\Delta q = \sum_i \left(\frac{\Delta q}{q}\bigg|_i \int_{x_i}^{x_{i+1}} q(x)\, dx \right)$$

where $(\Delta q/q)|_i$ is constant within each bin $[x_i, x_{i+1}]$

	HERMES	SMC
Δu_v	$0.52 \pm 0.05 \pm 0.08$	$0.59 \pm 0.08 \pm 0.07$
Δd_v	$-0.18 \pm 0.10 \pm 0.13$	$-0.33 \pm 0.11 \pm 0.09$
$\Delta \bar{u}$	$-0.01 \pm 0.02 \pm 0.03$	$0.02 \pm 0.03 \pm 0.02$
$\Delta \bar{d}$	$-0.02 \pm 0.03 \pm 0.04$	$0.02 \pm 0.03 \pm 0.02$
$\Delta \bar{s}$	$-0.01 \pm 0.02 \pm 0.02$	$0.01 \pm 0.03 \pm 0.02$

Comparison of HERMES and SMC integrals in the HERMES x-range of $0.023 \leq x \leq 0.6$. *All values given at* $Q^2 = 2.5$ GeV^2

$\Rightarrow$ **Agreement of** SMC **and** HERMES **results**

First and Second Moments

Valence distributions

	total integral (extrap.) HERMES	SMC[1]	prediction	Q^2
Δu_v	$0.57(+5) \pm 0.09$	$0.77(+4) \pm 0.13$	0.84 ± 0.05[2]	5
Δd_v	$-0.21(-3) \pm 0.16$	$-0.52(-5) \pm 0.17$	-0.25 ± 0.02[2]	5
$x\Delta u_v$	0.124 ± 0.016	0.156 ± 0.020	0.198 ± 0.008[2]	4
$x\Delta d_v$	-0.022 ± 0.034	-0.056 ± 0.028	-0.048 ± 0.003[2]	4

HERMES (SMC) integrals of polarized valence distributions at $Q^2 = 2.5$ (10) GeV^2 compared to Lattice QCD. Low-x: HERMES: Regge, SMC: Parametrizations

HERMES **flavor decomposition** ($Q^2 = 2.5$ GeV^2)

	total integral(extrap.)	prediction		Q^2
$\Delta u + \Delta\bar{u}$	$0.56(+6) \pm 0.04$	0.82 ± 0.03	SU(3)[3]	3
$\Delta d + \Delta\bar{d}$	$-0.25(-3) \pm 0.08$	-0.44 ± 0.03	SU(3)[3]	3
$\Delta s + \Delta\bar{s}$	$-0.02(\ \ 0) \pm 0.05$	-0.11 ± 0.03	SU(3)[3]	3

HERMES **Singlet** (Δq_0), **Triplet** (Δq_3), **and Octet** (Δq_8) ($Q^2 = 2.5$ GeV^2)

	total integral(extrap.)	prediction		Q^2
Δq_0	$0.28(+2) \pm 0.10$	0.27 ± 0.04	SU(3)[3]	3
Δq_3	$0.83(+11) \pm 0.09$	0.95 ± 0.10	$\lvert g_A/g_V \rvert \times C_{\mathrm{QCD}}$	2.5
Δq_8	$0.32(+1) \pm 0.13$	0.44 ± 0.05	$(3F - D) \times C_{\mathrm{QCD}}$	2.5

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[1] SMC, Phys. Lett. B **420** (1998) 180

[2] M. Göckeler *et al.*, Phys. Lett. B **414** (1997) 81

[3] J. Ellis and M. Karliner, Phys. Lett. B **341** (1995) 397; hep-ph/9601280

Summary and Outlook

- $A_1^{(h)}$ measured on $^3\vec{\mathrm{He}}$ and $^1\vec{\mathrm{H}}$ targets
- Quark polarizations extracted for *up* and *down* quarks, and for *valence* and *sea* quarks
- Polarization of *up* quarks *positive*, of *down* quarks *negative*, and of *sea* quarks compatible with *zero*
- *Singlet combination* Δq_3 agrees with Bjørken Sum Rule
- Flavor-separated first moments differ from inclusive results based on SU(3)$_f$ symmetry
- *Octet combination* Δq_8 consistent with value of $3F - D$ predicted using SU(3)$_f$
- Quenched Lattice QCD overestimates first and second moments of $\Delta u_v(x)$
- *Forthcoming results:*
  - Improved precision for $\Delta d(x)$ with deuterium target
  - π, K, p asymmetries and fragmentation functions from RICH data
  - Separation of light and strange sea polarization

$(1 + R)$ – Correction

Δq extraction based on (HERMES & SMC):

$$A_1 = \frac{\sum_q e_q^2 \, \Delta q}{\sum_q e_q^2 \, q} \times (1 + R) \tag{1}$$

2 classes of Δq parametrizations (LO):

- *GRSV, De Florian*: Fit of Δq to measured A_1 according to

  $$A_1 = \frac{\sum_q \; e_q^2 \; \Delta q}{\sum_q \; e_q^2 \; q}$$

  Inconsistent with Eq. (**??**) $\Rightarrow$ Divide Δq by $(1 + R)$

- *Gehrmann & Stirling*: Fit of Δq to measured g_1 according to

  $$g_1 = \frac{1}{2} \sum_q \; e_q^2 \; \Delta q$$

  where

  $$g_1 = A_1 \frac{F_2}{2x(1 + R)} \Leftrightarrow A_1 = \frac{2 g_1}{\sum_q e_q^2 \, q}(1 + R)$$

  Consistent with Eq. (**??**). No correction