Quark Helicity Distributions from Longitudinal Spin Asymmetries in Muon-Proton and Muon-Deuteron Scattering measured by COMPASS at CERN

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On behalf of the COMPASS Collaboration

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A short review of COMPASS
DIS and SIDIS results

2007	$g_1^d(x), \int g_1^d(x)dx$	$\Delta\Sigma = \sum(\Delta q + \Delta\overline{q})$
2008	$A_{1,d}^{h^+-h^-}$	$\Delta u_v + \Delta d_v$
2009	$A_{1,d}, A_{1,d}^{\pi^{+,-}}, A_{1,d}^{K+,-}$	$\Delta u_v + \Delta d_v, \Delta\overline{u} + \Delta\overline{d}, \Delta s(= \Delta\overline{s})$
2010	$g_1^p(x), \int g_1^{NS}(x)dx$	$\lvert g_A/g_V \rvert$
2010	$A_{1,d}, A_{1,d}^{\pi^{+,-}}, A_{1,d}^{K+,-},$ $A_{1,p}, A_{1,p}^{\pi^{+,-}}, A_{1,p}^{K+,-}$	$\Delta u, \Delta d, \Delta\overline{u}, \Delta\overline{d},$ $\Delta s, \Delta\overline{s}$

COMPASS longitudinal SIDIS data

	$2002-2006$ ^{6}LiD target	2007 NH_3 target
E_μ	160 GeV	160 GeV
P_μ	≈ -0.80	≈ -0.80
$\lvert P_T \rvert$	≈ 0.50	≈ 0.90
Dilution factor f	≈ 0.37	≈ 0.14
$f \lvert P_T \rvert$	$\approx$ **0.20**	$\approx$ **0.13**

Selection criteria

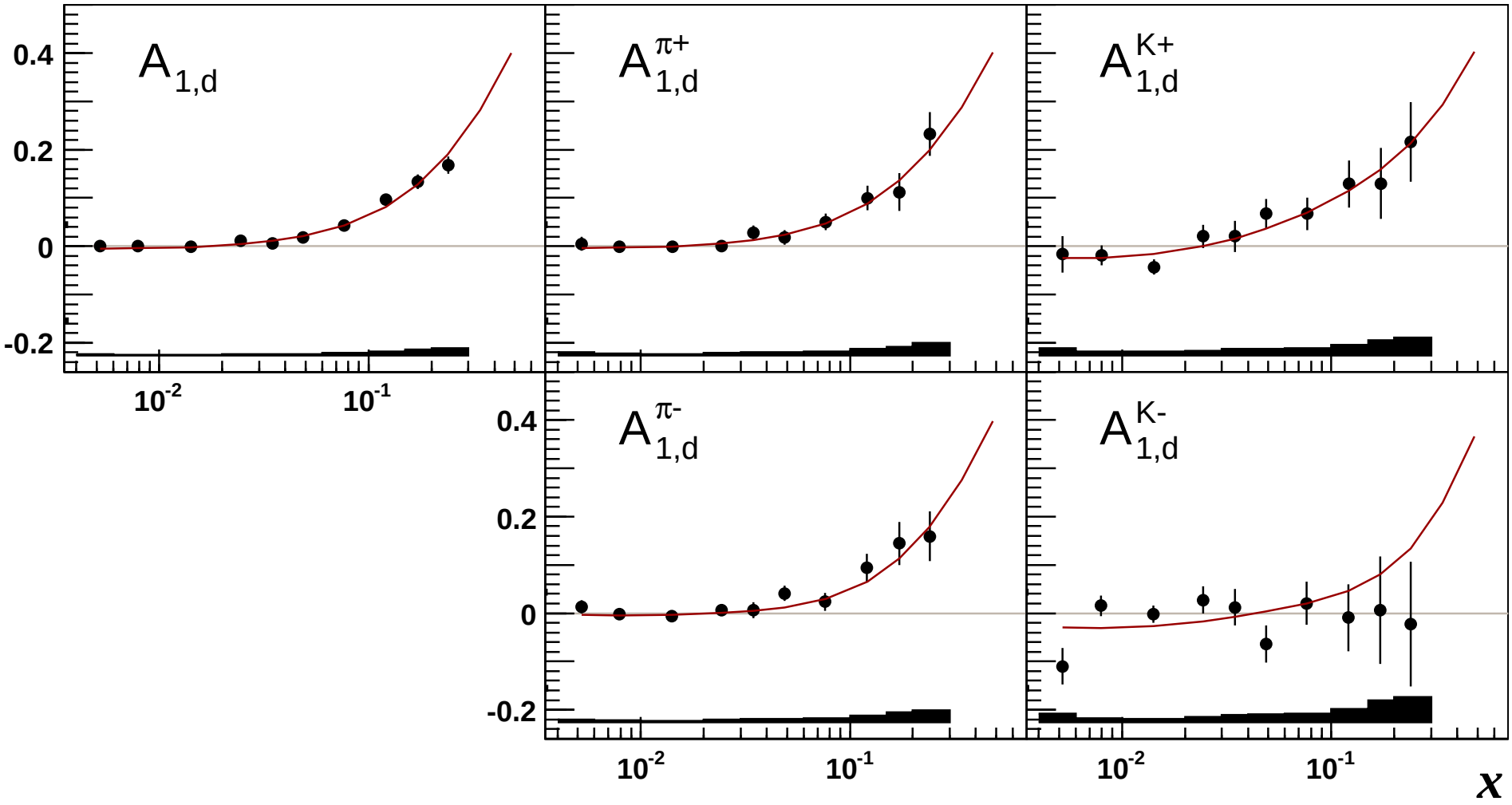
Events	Hadrons
$Q^2 > 1$ (GeV/c)^2	$0.2 < z < 0.85$
$0.1 < y < 0.9$	$10 < P < 50$ GeV/c
$0.004 < x < 0.7$	(RICH IDENT)

COMPASS longitudinal SIDIS data

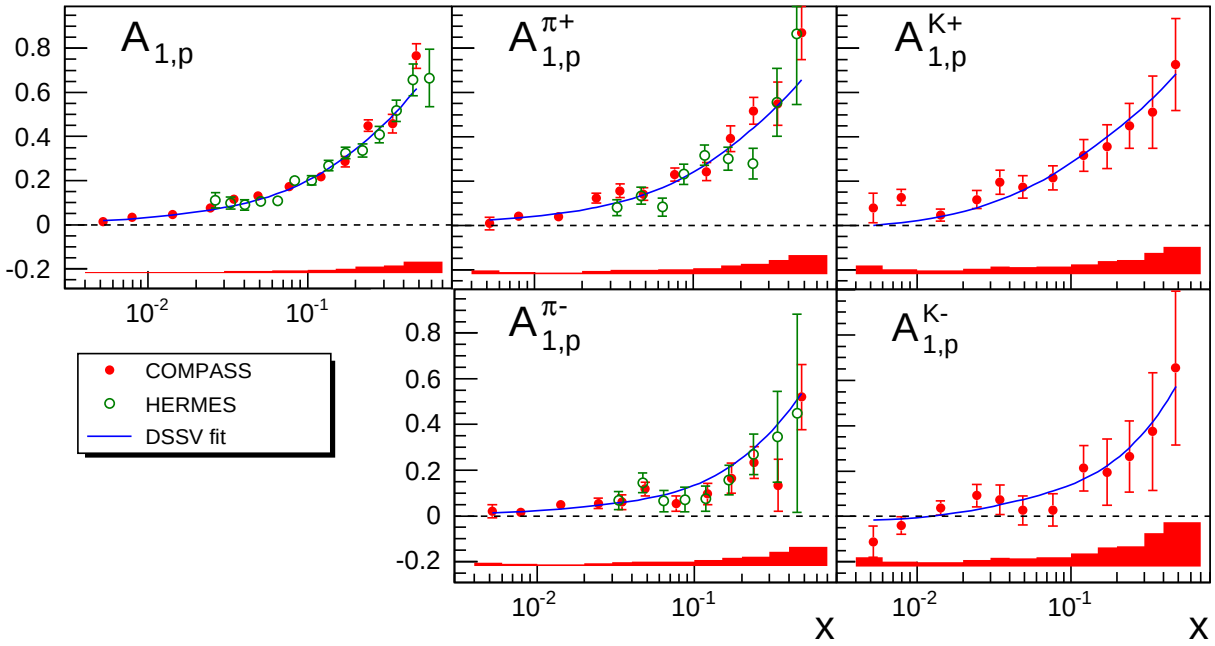
Purity of hadron samples

	^{6}LiD target	NH_3 target
π^+	≥ 0.98	≥ 0.98
π^-	≥ 0.98	≥ 0.98
K^+	$0.80 \Rightarrow 0.93$	$0.73 \Rightarrow 0.93$
K^-	$0.80 \Rightarrow 0.91$	$0.73 \Rightarrow 0.91$

COMPASS asymmetries on deuteron (2009)
Curves = DSSV fit



COMPASS asymmetries on proton
Comparison with HERMES and DSSV fit



- **Correlated statistical errors** in a given x interval:
  $\Rightarrow \quad \rho(A^{\pi+}_{1,p}, A_{1,p}) \approx (0.30 - 0.45)$.
- **Unfolding** of A^K, A^π
  $\Rightarrow \rho < 0$ if same sign (≈ -0.16 at small x).

Systematic errors on COMPASS asymmetries

	^{6}LiD target	NH_3 target
P_B	5%	5%
P_T	5%	2%
f	2%	1%
$R = \sigma_L/\sigma_T$	$2-3\%$	$\leq 3\%$
"False asym."	$\leq 0.4\,\sigma_{\text{stat.}}$	$\leq 0.56\,\sigma_{\text{stat.}}$

Corrections to asymmetries

- **QED** radiative corrections applied to all asymmetries (≤ 0.019).
- **Proton** asymmetries corrected for ^{14}N polarisation (≤ 0.015).
- **Deuteron** asymmetries corrected for ^{7}Li and ^{1}H admixture in target material (≤ 0.020). **NOT applied in the 2008 analysis.**

LO extraction of polarised PDFs

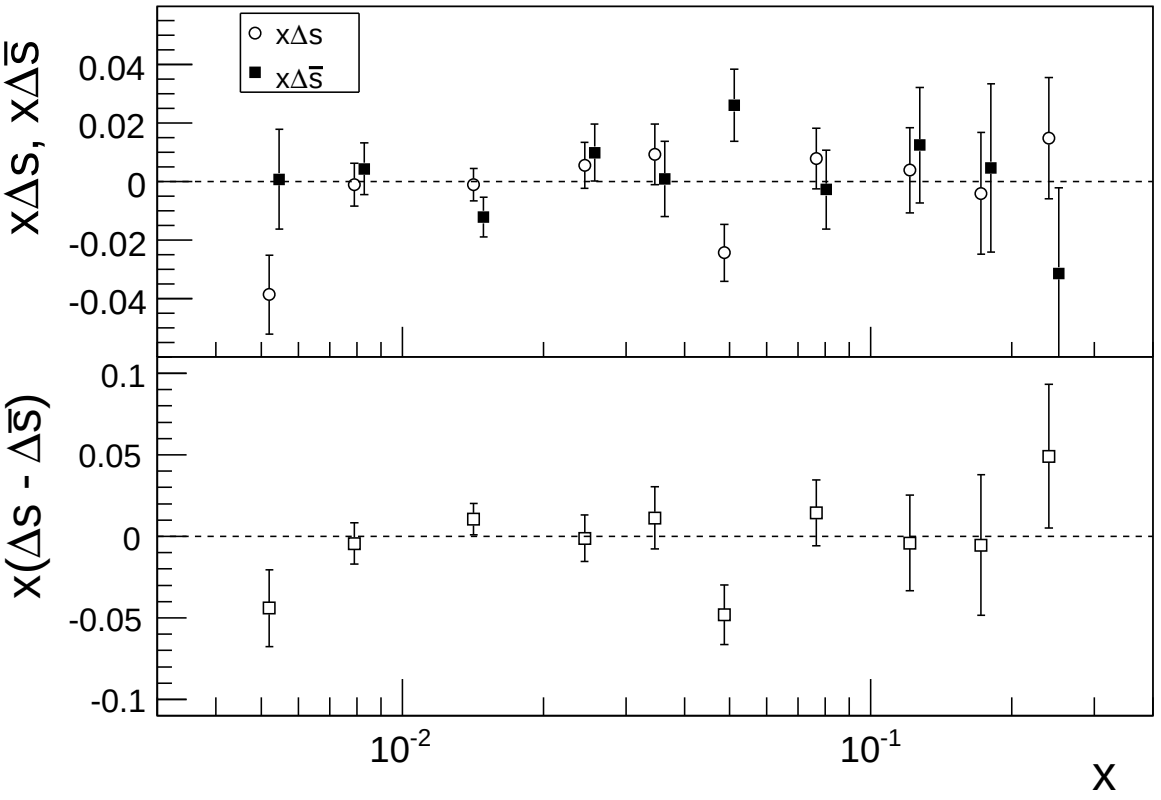
$$A^h(x,z) \quad = \quad \frac{\sum_q e_q^2 \Big[\Delta q(x) D_q^h(z) + \Delta\overline{q}(x) D_{\overline{q}}^h(z)\Big]}{\sum_q e_q^2 \Big[q(x) D_q^h(z) + \overline{q}(x) D_{\overline{q}}^h(z)\Big]}$$

- Inputs: 10 asymmetries for each interval of x

$$\begin{array}{ccccc} A_{1,p} & A_{1,p}^{\pi+} & A_{1,p}^{\pi-} & A_{1,p}^{K+} & A_{1,p}^{K-} \\ A_{1,d} & A_{1,d}^{\pi+} & A_{1,d}^{\pi-} & A_{1,d}^{K+} & A_{1,d}^{K-} \end{array}$$

- Unknowns: 6 polarised PDFs Δu, Δd, $\Delta\overline{u}$, $\Delta\overline{d}$, Δs, $\Delta\overline{s}$ ========> (reduced to 5 if $\Delta s = \Delta\overline{s}$ is assumed)
- Q^2 dependence of asymmetries neglected $\Rightarrow Q^2 = 3$ (GeV/c)^2
- $q(x), \overline{q}(x)$ from MRST2004LO, corrected by $(1 + R(x, Q^2))$
- $D_q^h, D_{\overline{q}}^h$ fragmentation functions (FF) from DSS fit at LO

Δs and $\Delta\bar{s}$ from COMPASS asymmetries and the Difference $\Delta s - \Delta\bar{s}$



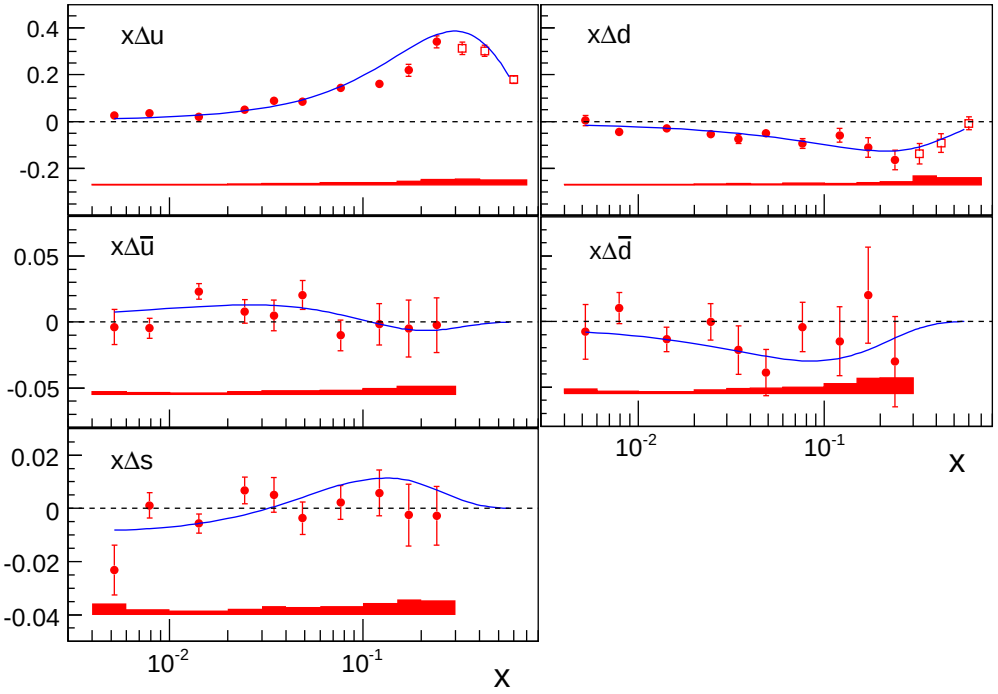
- Fixed $Q^2 = 3$ (GeV/c)^2
- FF from DSS
- No significant difference: one point at 2.7 σ
- Stable for changes in $s(x)$, $\bar{s}(x)$ or FFs
- $\Delta s = \Delta\bar{s}$ assumed for subsequent analysis

Extraction of PDFs assuming $\Delta s = \Delta \overline{s}$

- Least square fit in each interval of x ($0.004 < x < 0.3$):
  10 asymmetries, 5 unknowns
- Data compatible with LO formula:
  $1.8/5 < (\chi^2/ND) < 8.5/5$
- Errors reduced at least by factor 1.5

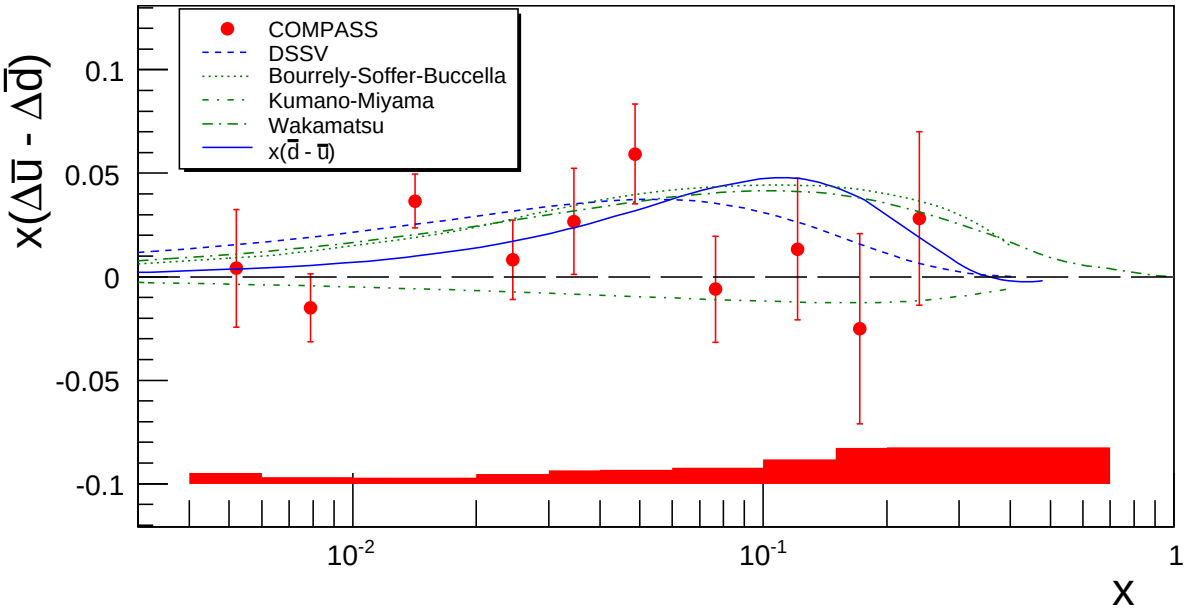
LO PDFs at $Q^2 = 3$ (GeV/c)^2 from COMPASS asymmetries

Curves = DSSV fit (NLO)



- Valence quarks
  - $\Delta u > 0$, $\Delta d < 0 \Rightarrow$ dominant
  - 3 points at $x > 0.3$ derived assuming $\Delta\overline{q} = 0$
  - shapes $\approx$ DSSV curves
  - Syst.error mainly from P_μ (5%)
- Sea quarks
  - All compatible with zero
  - Slight indication for $\Delta\overline{d} < 0$
  - No indication for $\Delta s < 0$ or changing sign
  - Syst.error mainly from "false asymmetries"

The flavour asymmetry of the sea $\Delta\overline{u}$ - $\Delta\overline{d}$



- $\Delta\overline{u} - \Delta\overline{d} \geq 0$ and $\Delta\overline{u} - \Delta\overline{d} \leq \overline{d} - \overline{u}$
- First moment: $\Gamma^{0.7}_{0.004} = 0.06 \pm 0.04 \pm 0.02$
- Consistent with *statistical model (BSB)* and *CQSM (Wakamatsu)* (≥ 0)
- Within errors also consistent with *meson cloud model (KM)* (< 0)
- Need reduction of error by factor $\geq$ 2 to discriminate between models

First moments of polarised PDFs at $Q^2 = 3$ (GeV/c)^2

- $0.004 < x < 0.3$ COMPASS, LO fit of asymmetries
- $0.3 < x < 0.7$ COMPASS, $g_1^d(x)$, $g_1^p(x)$, $\Delta\overline{q} = 0$ assumed
- $0.7 < x < 1$ Data extrapolation (negligible)
- $0 < x < 0.004$ 2 options:
  - Linear extrapolation $\Delta\overline{q} \approx 0$
  - DSSV fit $\Delta\overline{d} < 0,\ \Delta\overline{s} < 0$

First moments (continued)

$Q^2 = 3$ (GeV/c)^2

	$0.004 < x < 0.7$	$0 < x < 1$ (Extrap.)	$0 < x < 1$ (DSSV)
Δu	$0.69 \pm 0.02 \pm 0.03$	$0.71 \pm 0.02 \pm 0.03$	$0.71 \pm 0.02 \pm 0.03$
Δd	$-0.33 \pm 0.04 \pm 0.03$	$-0.34 \pm 0.04 \pm 0.03$	$-0.35 \pm 0.04 \pm 0.03$
$\Delta\overline{u}$	$0.02 \pm 0.02 \pm 0.01$	$0.02 \pm 0.02 \pm 0.01$	$0.03 \pm 0.02 \pm 0.01$
$\Delta\overline{d}$	$-0.05 \pm 0.03 \pm 0.02$	$-0.05 \pm 0.03 \pm 0.02$	$-0.07 \pm 0.03 \pm 0.02$
$\Delta s(\Delta\overline{s})$	$-0.01 \pm 0.01 \pm 0.01$	$-0.01 \pm 0.01 \pm 0.01$	$-0.05 \pm 0.01 \pm 0.01$
Δu_v	$0.67 \pm 0.03 \pm 0.03$	$0.68 \pm 0.03 \pm 0.03$	$0.68 \pm 0.03 \pm 0.03$
Δd_v	$-0.28 \pm 0.06 \pm 0.03$	$-0.29 \pm 0.06 \pm 0.03$	$-0.28 \pm 0.06 \pm 0.03$
$\Delta\Sigma$	$0.31 \pm 0.03 \pm 0.03$	$0.32 \pm 0.03 \pm 0.03$	$0.22 \pm 0.03 \pm 0.03$

First Moments (continued)

$Q^2 = 3$ (GeV/c)^2

Consistency with previous COMPASS results

- $\Delta\Sigma = 0.32 \pm 0.03 \pm 0.03$

  $a_0 = 0.33 \pm 0.03 \pm 0.05$ (NLO)

  from $\int g_1^d(x)dx$, with a_8 from hyperon decays ($= 0.585 \pm 0.025$)

  COMPASS, Phys. Lett.B647 (2007) 8

- $\Delta u_v + \Delta d_v = 0.39 \pm 0.03 \pm 0.04$

  $\Delta u_v + \Delta d_v = 0.41 \pm 0.07 \pm 0.06$

  from $A^{h^+ - h^-}$ (at $Q^2 = 10$ (GeV/c)^2)

  COMPASS, Phys. Lett.B660 (2008) 458

Dependence of moments of PDFs on fragmentation functions

- $D^{\pi}_{q,\overline{q}}$ better constrained by data than $D^{K}_{q,\overline{q}}$
- Relation asymmetries $\Leftrightarrow$ PDFs depends on two ratios of FFs into kaons: *"unfavoured to favoured"* R_{UF} and *"strange to favoured"* R_{SF}

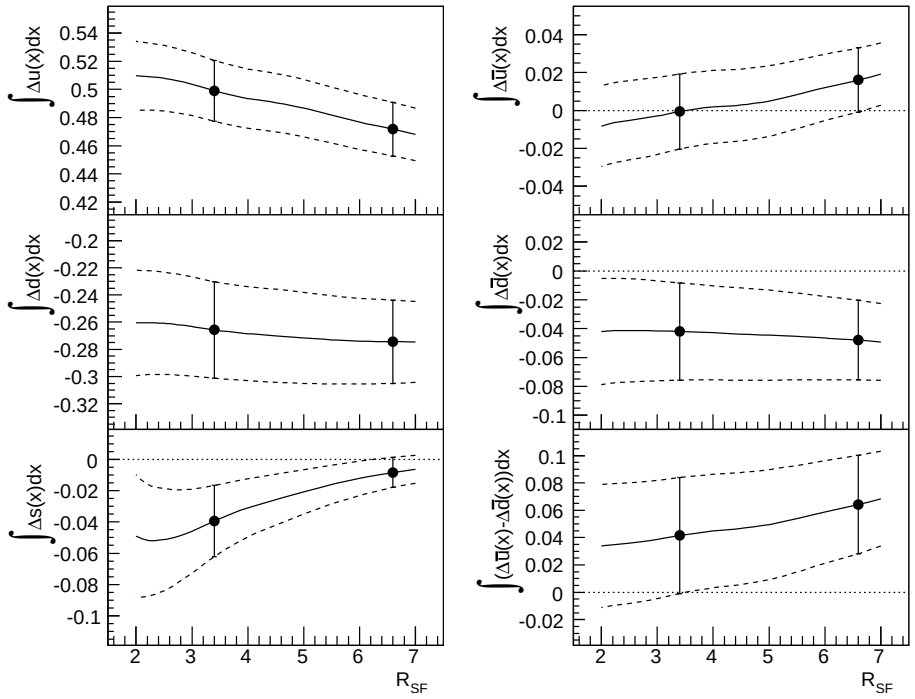
$$R_{UF} = \frac{\int D_d^{K^+}(z)dz}{\int D_u^{K^+}(z)dz} \quad \Leftrightarrow \quad R_{SF} = \frac{\int D_{\overline{s}}^{K^+}(z)dz}{\int D_u^{K^+}(z)dz}$$

- At $Q^2 = 3$ (GeV/c)^2:

	DSS	*EMC*
R_{UF}	0.14	*0.35*
R_{SF}	6.6	*3.4*

- Move simultaneously R_{SF} and R_{UF} from DSS to EMC values and check variation of moments Δq, $\Delta\overline{q}$

Moments of PDFs vs. fragmentation functions (decrease of R_{SF} and increase of R_{UF} from DSS to EMC values)



- Increase of Δu by $\approx 1.0\,\sigma_{\text{stat.}}$
- Decrease of $\Delta \overline{u}$ by $\approx 1.0\,\sigma_{\text{stat.}}$
- Negligible effect on Δd and $\Delta \overline{d}$
- Decrease of $\Delta \overline{u} - \Delta \overline{d}$ by $0.5\,\sigma_{\text{stat.}}$
- Decrease of Δs to -0.04 with two times larger statistical error
- *Limited effect on* K^+ *and* K^- *rates*

The Δs puzzle (DIS vs. SIDIS)

- Δs from DIS: $\Gamma_1^N = \frac{1}{2}\int (g_1^p(x) + g_1^n(x))dx$
  - LO relations

$$\begin{aligned} \Gamma_1^N &= \tfrac{1}{9}(a_0 + \tfrac{1}{4}a_8) \\ \Delta s + \Delta\overline{s} &= \tfrac{1}{3}(a_0 - a_8) \\ \Delta s + \Delta\overline{s} &= 3\Gamma_1^N - \tfrac{5}{12}a_8 \end{aligned}$$

  - $\Gamma_1^N \approx 0.05$ (COMPASS, $Q^2 = 3$ (GeV/c)^2)
    $a_8 = 0.585 \pm 0.025$ (Hyperon decays, assuming SU(3)$_f$ symmetry)
  - Hence $\Delta s + \Delta\overline{s} < 0$ (≈ -0.09)
- Δs from SIDIS: $\Delta s(x)$ measured in limited range of x
  - HERMES ($x > 0.02$): No indication for $\Delta s(x) < 0$
  - COMPASS ($x > 0.004$): No indication for $\Delta s(x) < 0$
- νp elastic data and PV $\vec{e}p$ asymmetries $\Rightarrow \Delta s < 0$ (*S. Pate, this conference*)

The Δs puzzle (DIS vs. SIDIS)
Possible ways out

- (1) Uncertainty on FFs $\Rightarrow$ SIDIS results questionable (?)
  Would need strong reduction of R_{SF} (to ≈ 3 vs. 6.6 in DSS fit)
- (2) SIDIS data cover a limited range in x
  Large negative contribution to Δs in unmeasured region at low x $\Rightarrow$
  $\int_{\rm SIDIS} \Delta s(x)dx = \int_{\rm DIS} \Delta s(x)dx$
  - DSSV fit (2008)
  - LSS10 fit, including COMPASS data (*cf. A. Sidorov, this conference*)
- (3) Assume $a_8 < 0.585$ due to SU(3)$_f$ violation
  $a_8 \rightarrow (a_8 - \epsilon)$ implies $a_0 \rightarrow (a_0 + \epsilon/4)$ to keep Γ_1^N constant and
  $\Delta s + \Delta\overline{s} \rightarrow \Delta s + \Delta\overline{s} + (5/12)\epsilon$
  Cloudy bag model calculations $\Rightarrow a_8 \approx 0.42$ and $\Delta s + \Delta\overline{s} \approx -0.02$
  cf. S.D.Bass and A.W.Thomas, Phys.Lett. B684(2010)216

Present fixed target data may improve on (1) but cannot discriminate (2) vs.(3).

Conclusions and prospects

- **New evaluation of polarised PDFs at LO**
  - Δq, $\Delta\overline{q}$ from COMPASS DIS and SIDIS $K^{+,-}$ and $\pi^{+,-}$ asymmetries on ^{6}LiD and NH_3 targets
  - $\Delta\overline{q}$ distributions are small over measured range of x ($0.004 < x < 0.3$)
  - No significant difference between $\Delta s(x)$ and $\Delta\overline{s}(x)$
  - $(\Delta\overline{u} - \Delta\overline{d}) > 0$ (at 1.5 $\sigma_{\rm stat}$ but not larger than $\overline{d} - \overline{u}$)
  - Moments of Δu, $\Delta\overline{u}$ and Δs found to vary with choice of kaon FFs. Variation is critical for Δs (becomes negative with large error for $R_{SF} \leq 4$)
- **Future**
  - 2011 COMPASS data on NH_3 target will improve precision on $(\Delta\overline{u} - \Delta\overline{d})$ and help discriminate between models
  - Ongoing investigations on FFs from COMPASS K^+ and K^- rates will at least clarify (if not solve) the Δs puzzle