The Strange Quark Polarization from COMPASS data

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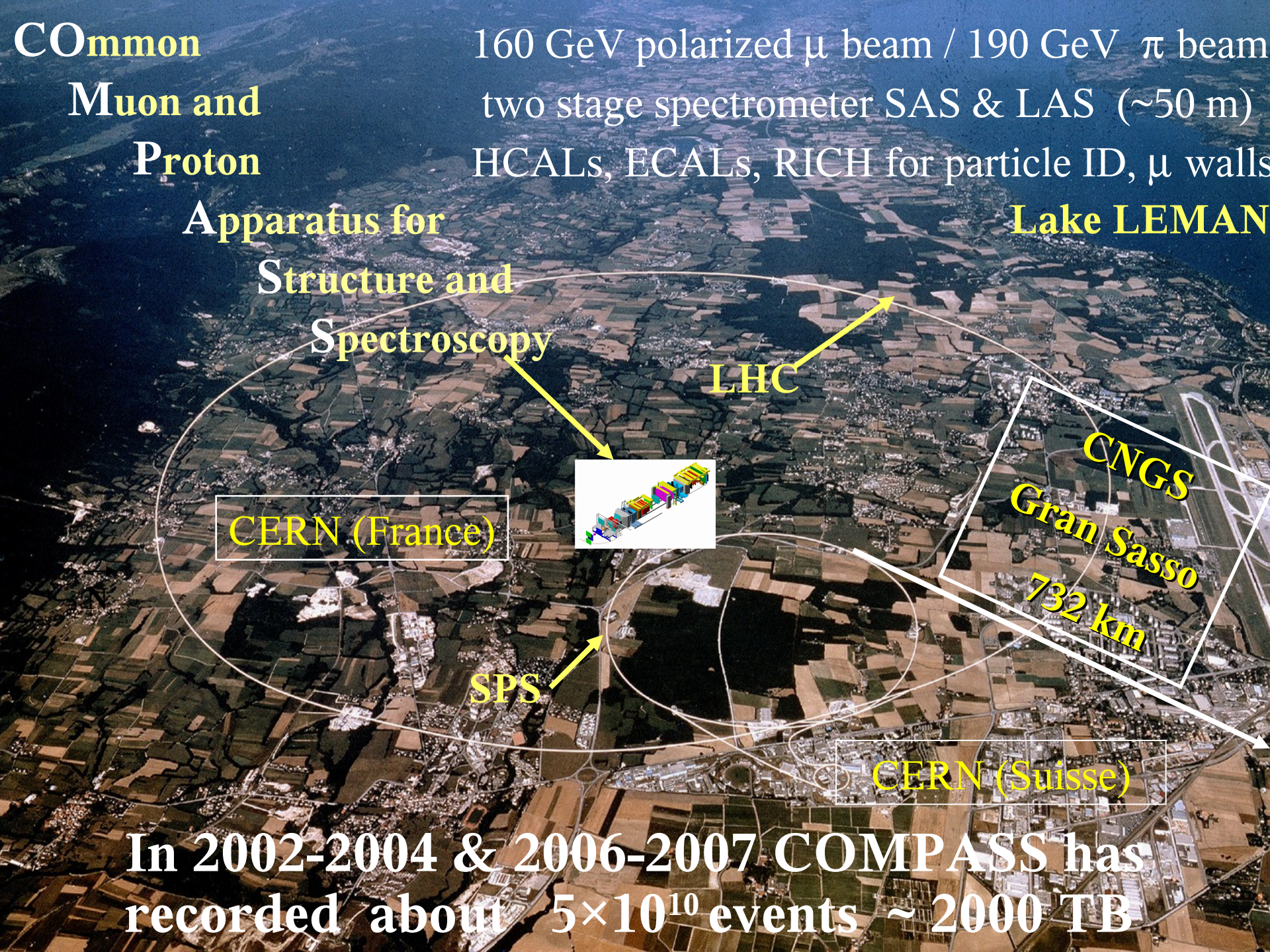
CIPANP 2009: San Diego, California—26 May to 31 May

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

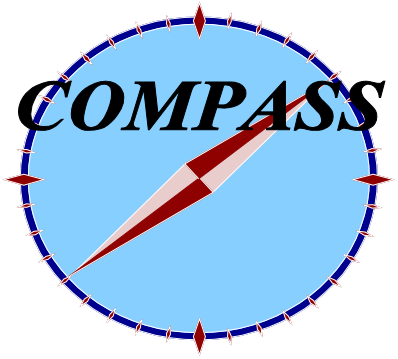
160 GeV polarized μ beam / 190 GeV π beam

two stage spectrometer SAS & LAS (~50 m)

HCALs, ECALs, RICH for particle ID, μ walls



In 2002-2004 & 2006-2007 COMPASS has recorded about 5×10^{10} events ~ 2000 TB



NA58 experiment at CERN

~230 physicists from 11 countries

Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal and Russia

COMPASS is located at M2 SPS beam line with a variety of high intensity μ & h beams

- **Muon program** (2002-2007)

  Deep Inelastic Scattering (DIS) of polarized 160 GeV/c muons on polarized deuterons and protons

- **Hadron program** (2008-2009)

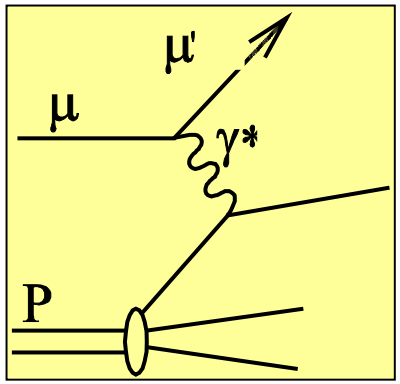
  190 GeV/c π, K , p beams search for exotics in diffractive excitation and central production, polarizability of π, K

Polarized beam and target

TWO STAGE SPECTROMETER

COMPASS in μ run

NIM A 577(2007) 455



Ring Imaging Cherenkov Detector

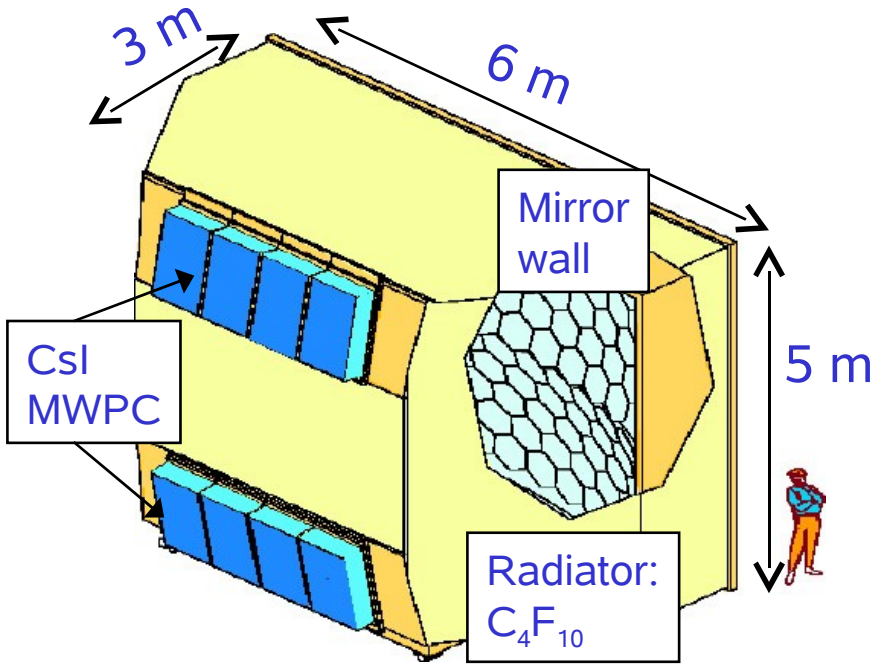
Identification of π, K and protons

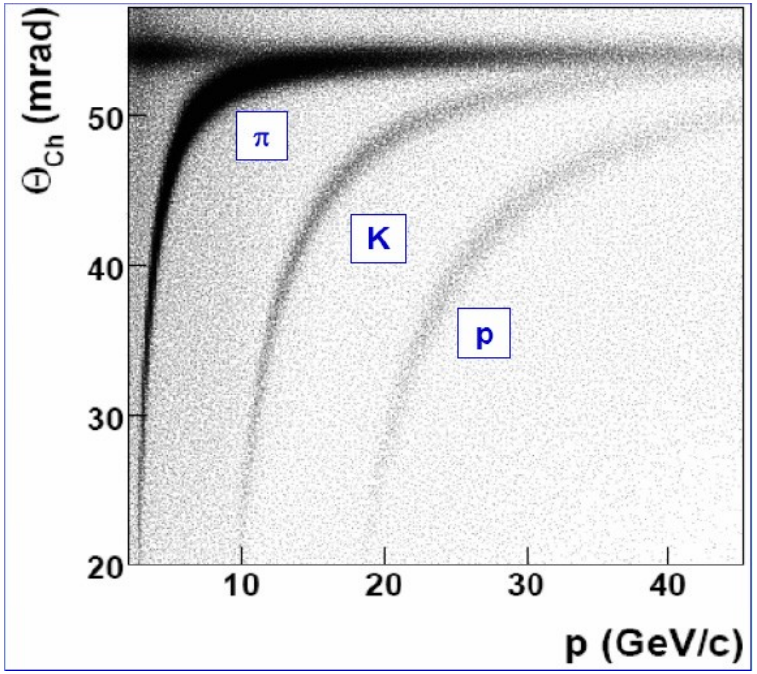
Cherenkov thresholds: π ≈ 3 GeV/c

K ≈ 9 GeV/c

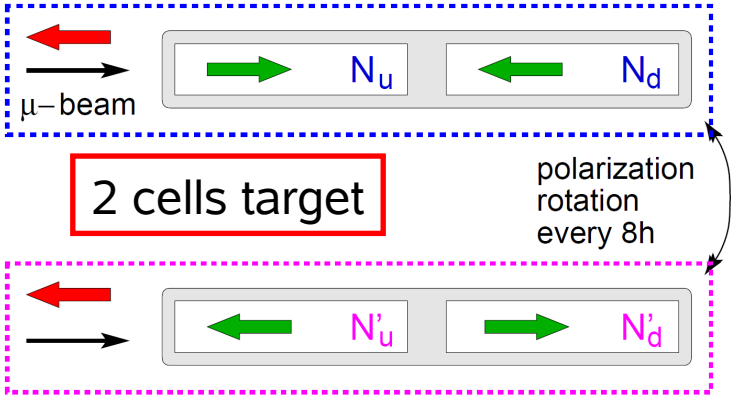
p ≈ 17 GeV/c

2σ π/K separation at 50 GeV/c



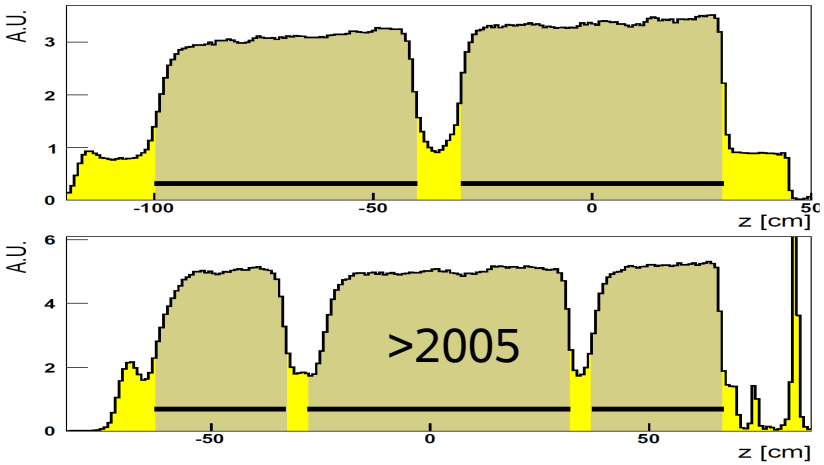


Asymmetry measurement



- **flux normalisation:** $\frac{\Phi_u}{\Phi_d} = 1$
- **acceptance:** $\frac{a_u \cdot a'_d}{a_d \cdot a'_u} = 1$
  (Polarisation rotation)

$$A_{\parallel} = \frac{\sigma^{\Uparrow\downarrow} - \sigma^{\Uparrow\uparrow}}{\sigma^{\Uparrow\downarrow} + \sigma^{\Uparrow\uparrow}} \Rightarrow \frac{A_{\parallel}}{D} = \frac{1}{P_T P_B f D} \frac{1}{2}\left(\frac{N_u^{\uparrow\downarrow} - N_d^{\uparrow\uparrow}}{N_u^{\uparrow\downarrow} + N_d^{\uparrow\uparrow}} + \frac{N_d^{\uparrow\downarrow} - N_u^{\uparrow\uparrow}}{N_d^{\uparrow\downarrow} + N_u^{\uparrow\uparrow}}\right)$$



target polarisation $P_T \approx 0.50$

dilution factor $f \approx 0.40$

beam polarisation $P_B \approx 0.76$

depolarisation factor $D \approx 0.60$

Strange quarks contribution to the nucleon spin…. is still ?

DIS ➔ evaluaion of the first moment $\Delta s + \Delta \bar{s}$ only

- EMC (1988) the first moment of the strange quark helicity distribution $\Delta s + \Delta \bar{s}$ is negative
- HERMES (2007)

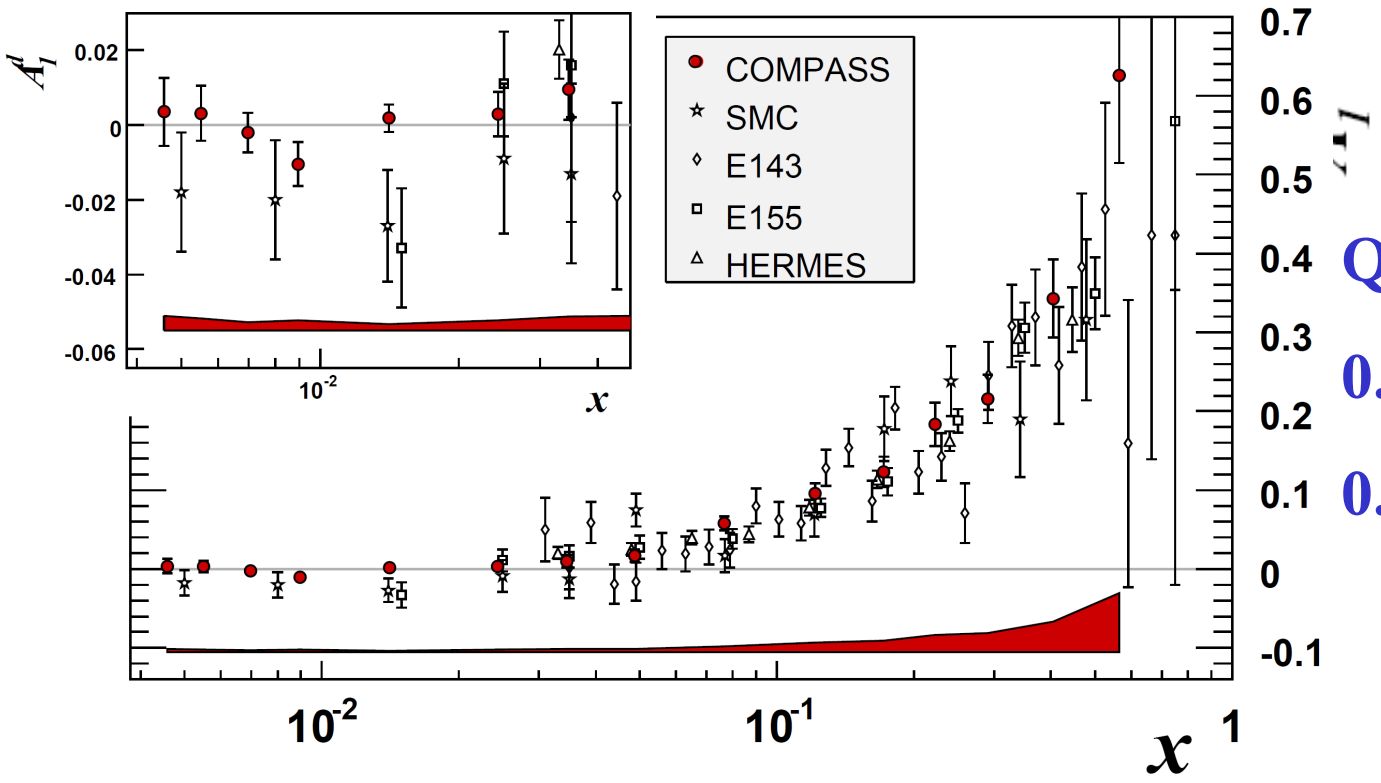
$$\Delta s + \Delta \bar{s} = -0.103 \pm 0.007(\text{exp.}) \pm 0.013(\text{theor.}) \pm 0.008(\text{evol.})$$

- COMPASS (2008) $\Delta s + \Delta \bar{s} = -0.09 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})$

SIDIS ➔ direct information on the distribution Δs(x)

- HERMES (2005) $\Delta s = 0.028 \pm 0.033(\text{stat.}) \pm 0.009(\text{syst.})$
- HERMES (2008) $\Delta s + \Delta \bar{s} = 0.037 \pm 0.019(\text{stat.}) \pm 0.027(\text{syst.})$
- COMPASS(2009) this talk (hep-ex/0905.2828 sub. *Phys.Lett.B)*

Inclusive DIS Asymmetry (2002-2004)



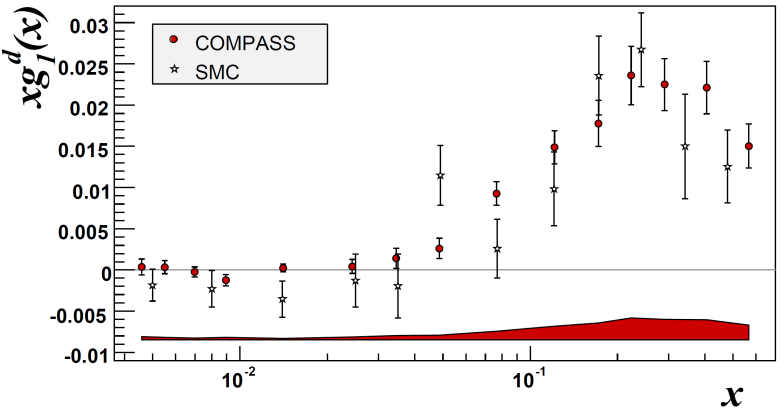
$Q^2 > 1\ GeV^2$

$0.1 < y < 0.9$

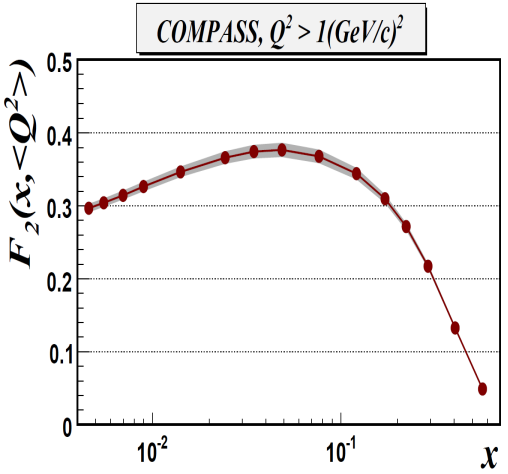
$0.004 < x < 0.7$

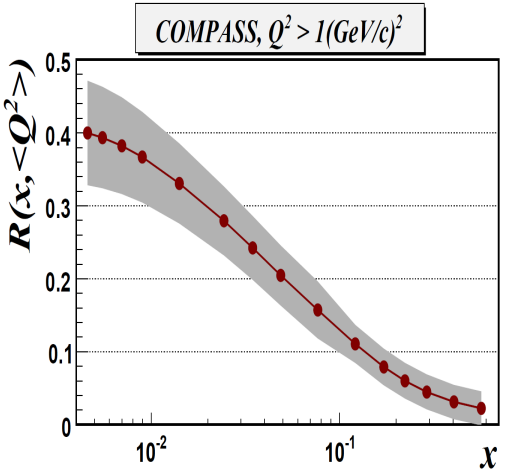
- A_1 compatible with 0 for $x < 0.05$; Large asymmetry at large x
  - systematic errors: p_μ (5%), p_T (5%, f (2–3%), D (6%) $\Longrightarrow \delta A_1 \approx 0.1 A_1$
  - additional contributions from false asymmetries, radiative corrections

$g_1(x)$ and first moment of the strange quark helicity distribution $\Delta s + \Delta \bar{s}$



$$g_1 = A_1 \cdot \frac{F_2}{2x(1+R)}$$





$$\Gamma_1^N \ (Q^2 = 3(\mathrm{GeV/c})^2) = \int_0^1 g_1^N(x)\,dx$$

$$= 0.0502 \pm 0.0028(\mathrm{stat}) \pm 0.0020(\mathrm{evol.}) \pm 0.0051(\mathrm{syst.})$$

$$\Delta s + \Delta \bar{s} = -0.09 \pm 0.01(\mathrm{stat.}) \pm 0.02(\mathrm{syst.}) \quad \text{(LO)}$$

Semi-inclusive DIS Asymmetry 2002-2006

CERN-PH-EP/2009-008 & hep-ex/0905.2828 sub. *Phys.Lett.B*

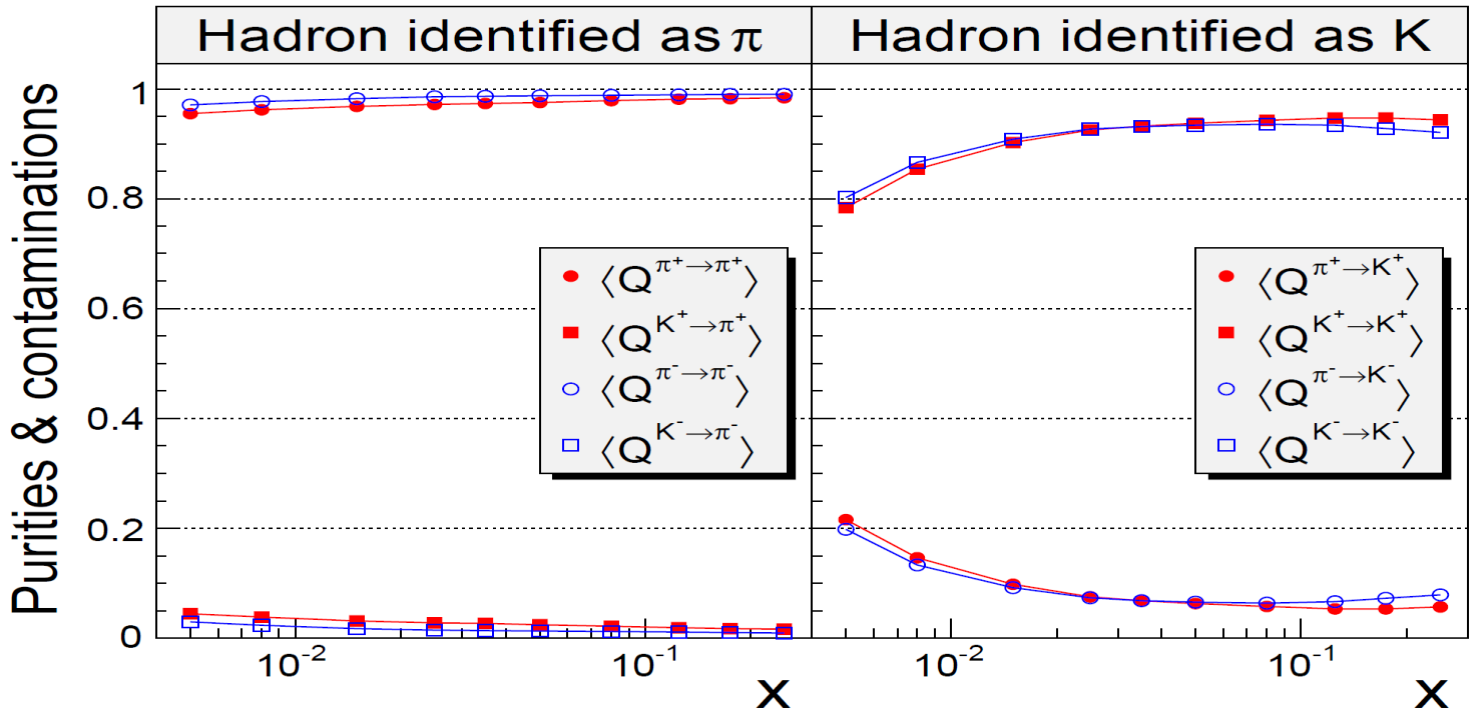
- Full COMPASS deuteron data
- SIDIS asymm $A^{\pi+}(x)$, $A^{\pi-}(x)$, $A^{K+}(x)$, $A^{K-}(x)$
  (hadron identification by RICH)
- Polarized parton densities $\Delta u_v(x) + \Delta d_v(x)$,
  $\Delta\overline{u}(x) + \Delta\overline{d}(x)$, $\Delta s(x) \equiv \Delta\overline{s}$
- $\Delta s(x)$ from $A^{K^+ + K^-}$ asymmetry

- 2006 data: polarized target & spectrometer updated

– g_1^d analysis *Phys.Lett. B647 (2007) 8*

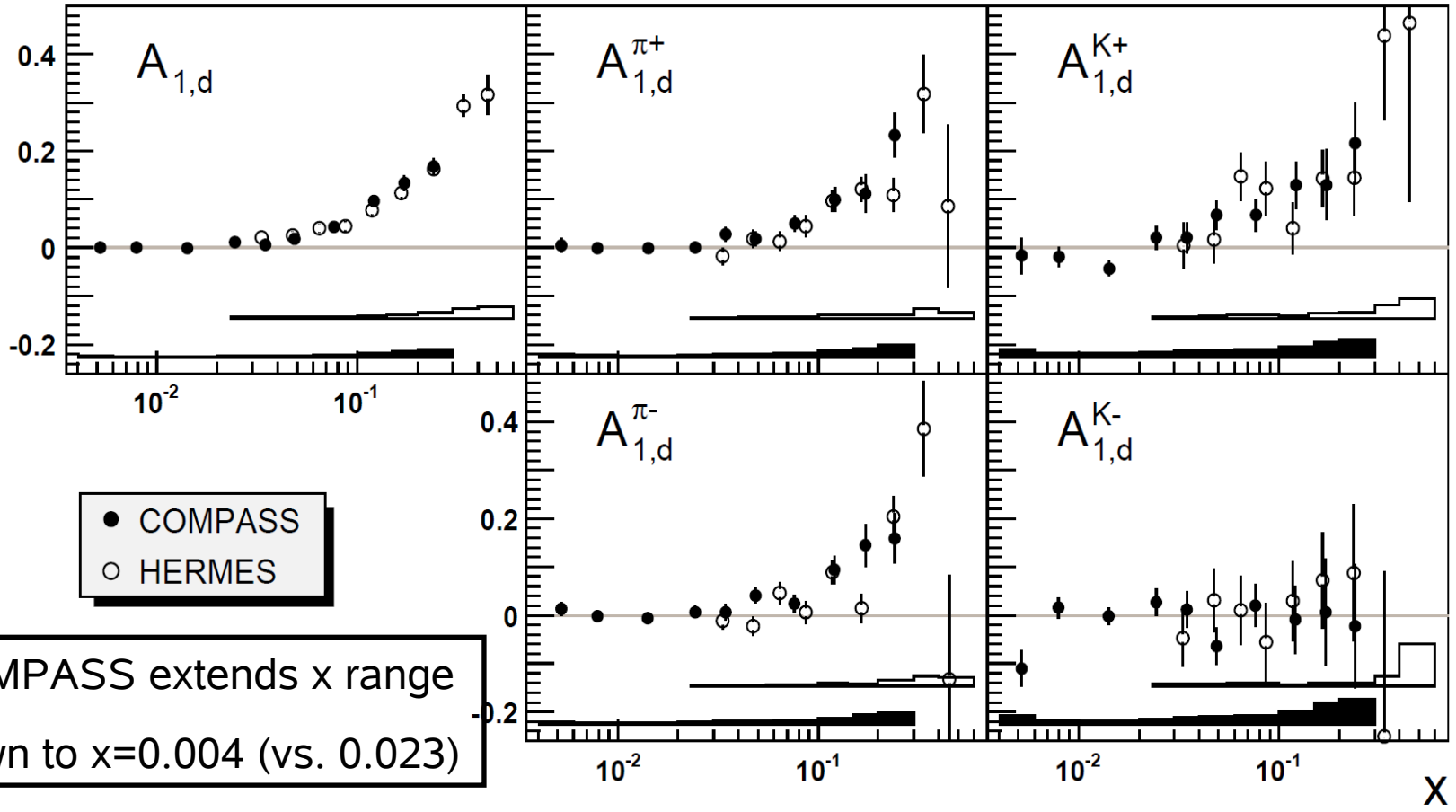
– $\Delta u_v + \Delta d_v$ analysis *Phys.Lett. B660 (2008) 458*

RICH: purities $Q^{\pi\to\pi}$, $Q^{K\to K}$ and contaminations $Q^{\pi\to K}$, $Q^{K\to\pi}$



- Unfolding procedure (UP) was applied year by year, in bins of (p, θ)
- Identification efficiency: $\pi^{\pm}$ from K^0 decay & $K^{\pm}$ from ϕ decay
- Effect of UP on asymmetries was found to be small

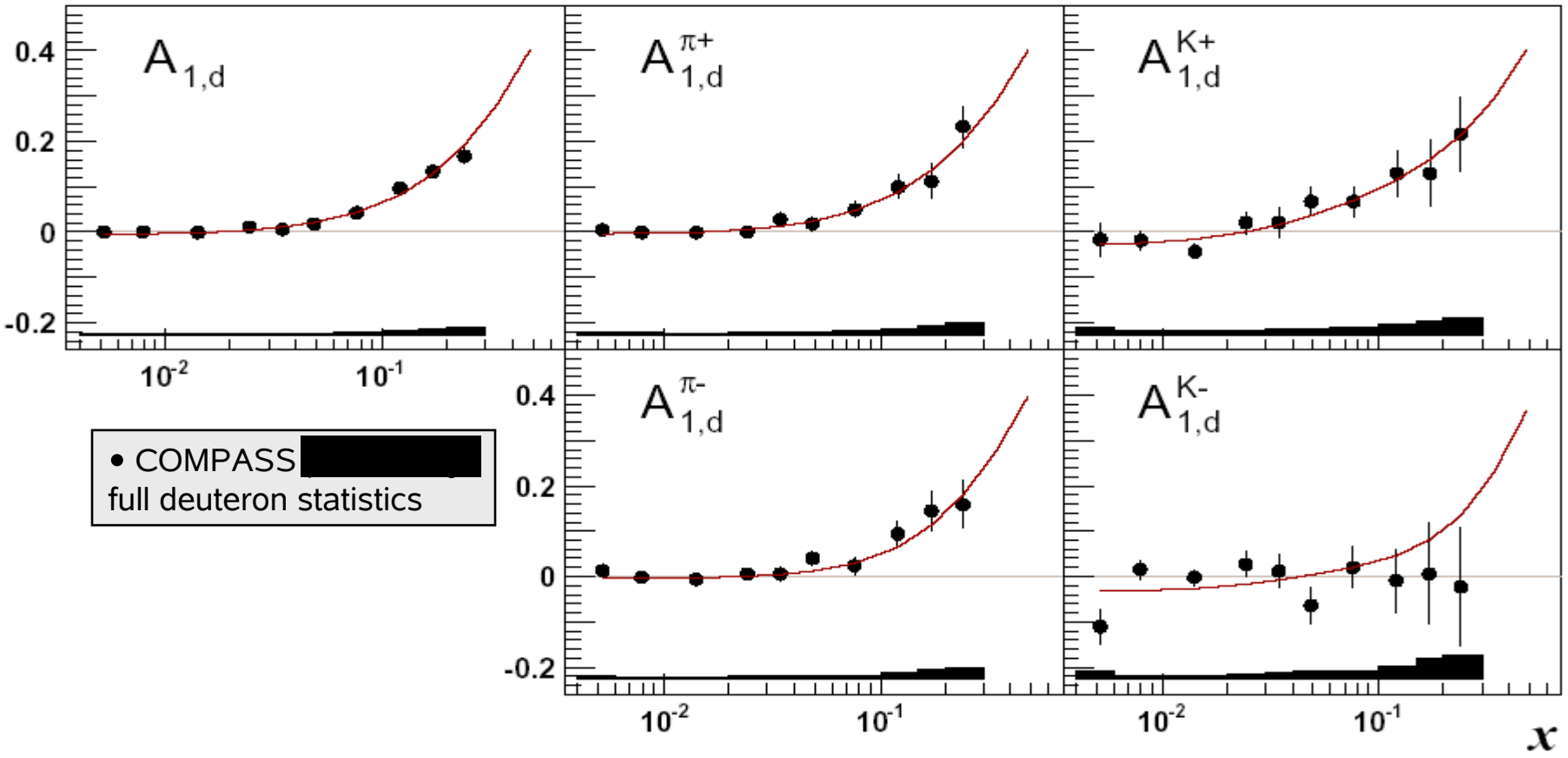
Asymmetries and comparison with HERMES



COMPASS extends x range down to x=0.004 (vs. 0.023)

- Phase space: $Q^2 > 1(\text{GeV/c})^2$, $0.004 < x < 0.3$, $10 < p < 50$ GeV/c, $0.2 < z < 0.85$
- Statistics: $N(\pi^+) = 23\text{x}10^6$, $N(\pi^-) = 21\text{x}10^6$, $N(K^+) = 4.8\text{x}10^6$, $N(K^-) = 3.3\text{x}10^6$
- Systematics errors: $\delta \cong 0.08A$ (δP_B, δP_T, δf and δD); $\sigma_{false\ asym} < 0.4\sigma_{stat}$

COMPASS data and predictions for SIDIS asymmetries



Curves are predictions from DSSV Phys. Rev. Lett. 101 (2008) 072001 & Phys. Rev. D 75 (2007) 114010

Polarized PDFs from a fit to the asymmetries

$$\left(A_1, A_1^{\pi+}, A_1^{\pi-}, A_1^{K+}, A_1^{K-}\right) \rightarrow \left(\Delta u_v + \Delta d_v, \Delta\overline{u} + \Delta\overline{d}, \Delta s\right)$$

Two important assumptions:

Symmetrically polarised strange sea $\Delta s \equiv \Delta\overline{s}$

All asymmetries are considered as independent on Q^2

Two sets of fragmentation functions (FF):

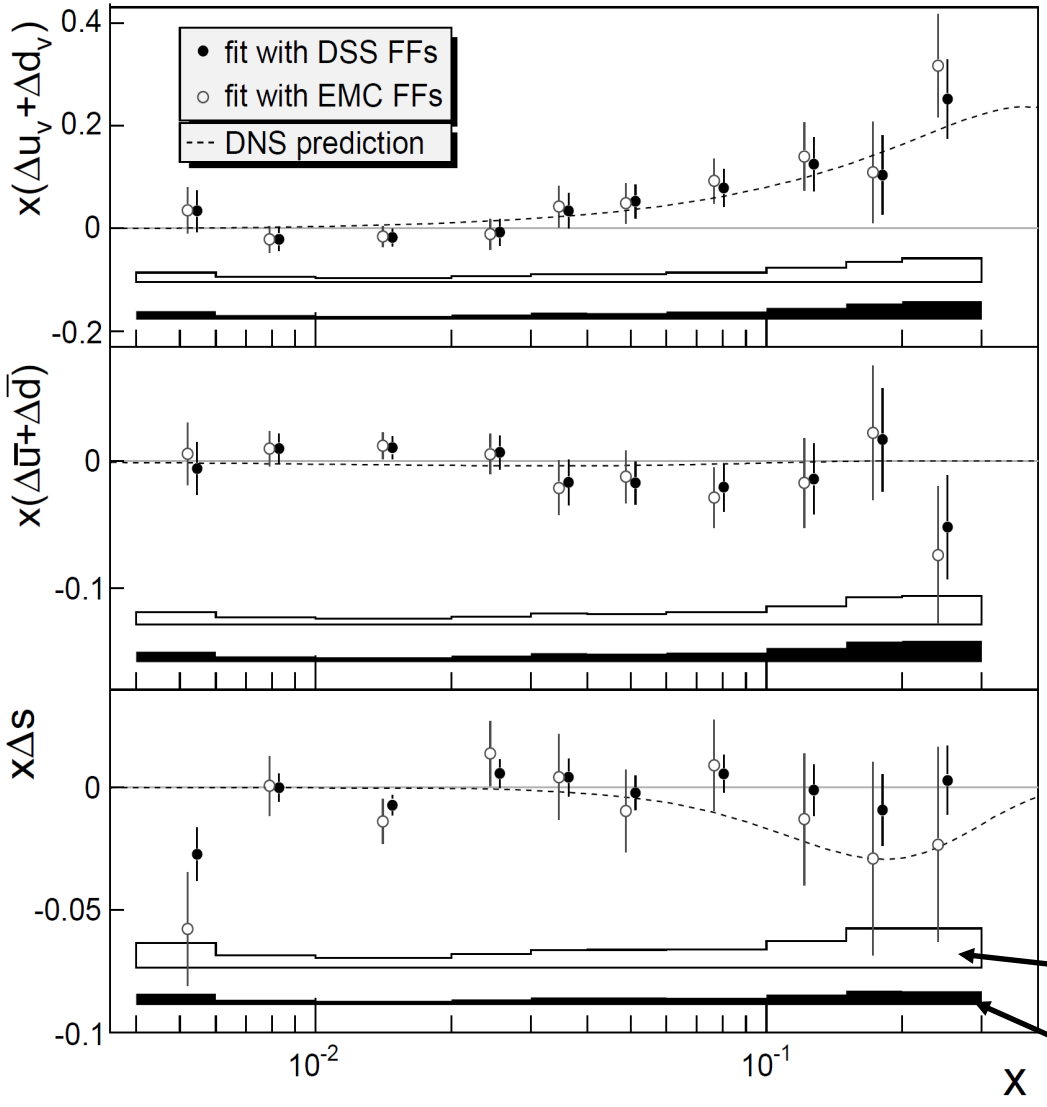
***DSS(LO) parametrisation**: combined analysis of e–e+, SIDIS and p+p data ..... more recent analysis of world data (2007)*

***EMC parametrisation** ($D_u^{\pi+,\pi-}$, $D_u^{K+,K-}$ measured; assumed $D_{\bar{s}}^{K+} = D_{\bar{u}}^{\pi+} = \text{Favored FF}$ .....for comparison only (1989)*

Unpolarised PDFs: MRST04 (LO)

Least square fit in each x bin

Polarized PDFs, FF from DSS and EMC



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

$\Delta u_v + \Delta d_v$:
small sensitivity to different FFs; good agreement with DNS curve

$\Delta u + \Delta d$:
compatible with 0; little effect from different FFs

Δs: statistical errors 2–3 times larger with EMC FFs

Systematics EMC FFs

Systematics DSS FFs

First moments $\Delta u_v + \Delta d_v$, $\Delta \bar{u} + \Delta \bar{d}$ and Δs

FF		DSS	EMC
$\Delta u_v + \Delta d_v$	measur.	$0.26 \pm 0.06 \pm 0.02$	$0.30 \pm 0.08 \pm 0.02$
	DNS	0.225	
$\Delta \bar{u} + \Delta \bar{d}$	measur.	$-0.04 \pm 0.03 \pm 0.01$	$-0.05 \pm 0.04 \pm 0.01$
	DNS	-0.009	
$\Delta s (= \Delta \bar{s})$	measur.	$-0.01 \pm 0.01 \pm 0.02$	$-0.05 \pm 0.03 \pm 0.03$
	DNS	-0.035	

truncated to measured range ($0.004 < x < 0.3$) at $Q^2 = 3$ (GeV/c)^2

From COMPASS 2002-2004 results:

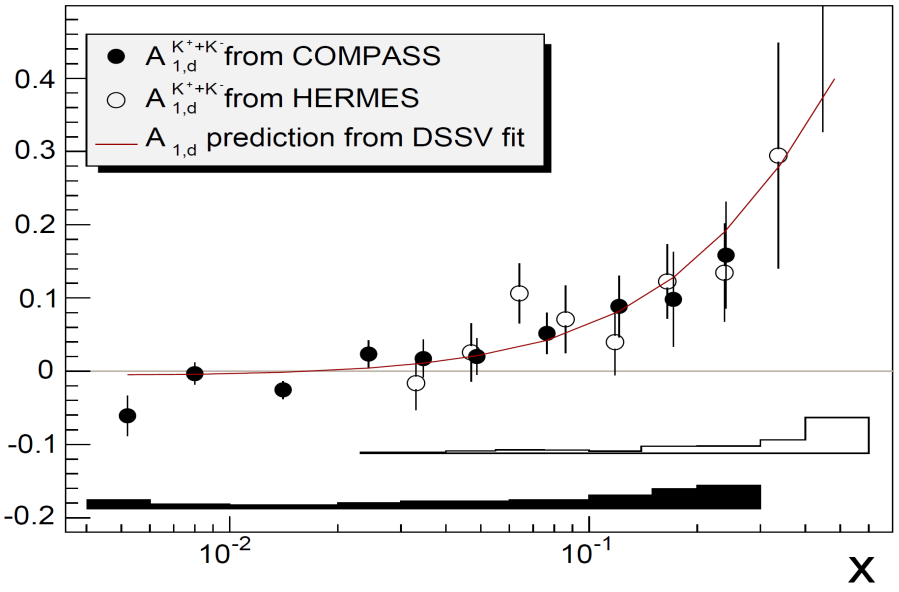
$\Delta u_v + \Delta d_v = 0.40 \pm 0.07 \pm 0.06$, from $A_1^{h^+ - h^-}$ approach ($0.006 < x < 0.7$) at Q^2 = 10 (GeV/c)^2) with contribution $\Delta u_v + \Delta d_v = 0.26 \pm 0.07 \pm 0.04$ for $x<0.3$

Phys. Lett. B 660 (2008) 458

$\Delta s + \Delta \bar{s} = -0.09 \pm 0.01 \pm 0.02$, from Γ_1 ($0 < x < 1$) – LO evaluation

Phys. Lett. B 647 (2007) 8

Δs from charged kaon asymmetry



$$A_{1,d}^{K^+ + K^-} = \frac{\sigma^{K^+} A_{1,d}^{K^+} + \sigma^{K^-} A_{1,d}^{K^-}}{\sigma^{K^+} + \sigma^{K^-}}$$

Kaon asym very stable vs. $\sigma^{K^-}/\sigma^{K^+}$

At LO $\sigma^{K^-}/\sigma^{K^+}$ ratio depends on the unpolarized PDFs and on the ratios

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

$$\frac{\Delta s}{s} = \frac{1}{\xi}\left[A_{1,d} + (A_{1,d}^{K^+ + K^-} - A_{1,d})\frac{Q/s + \alpha}{\alpha - 0.8}\right] \qquad Q = u + \bar{u} + d + \bar{d}$$

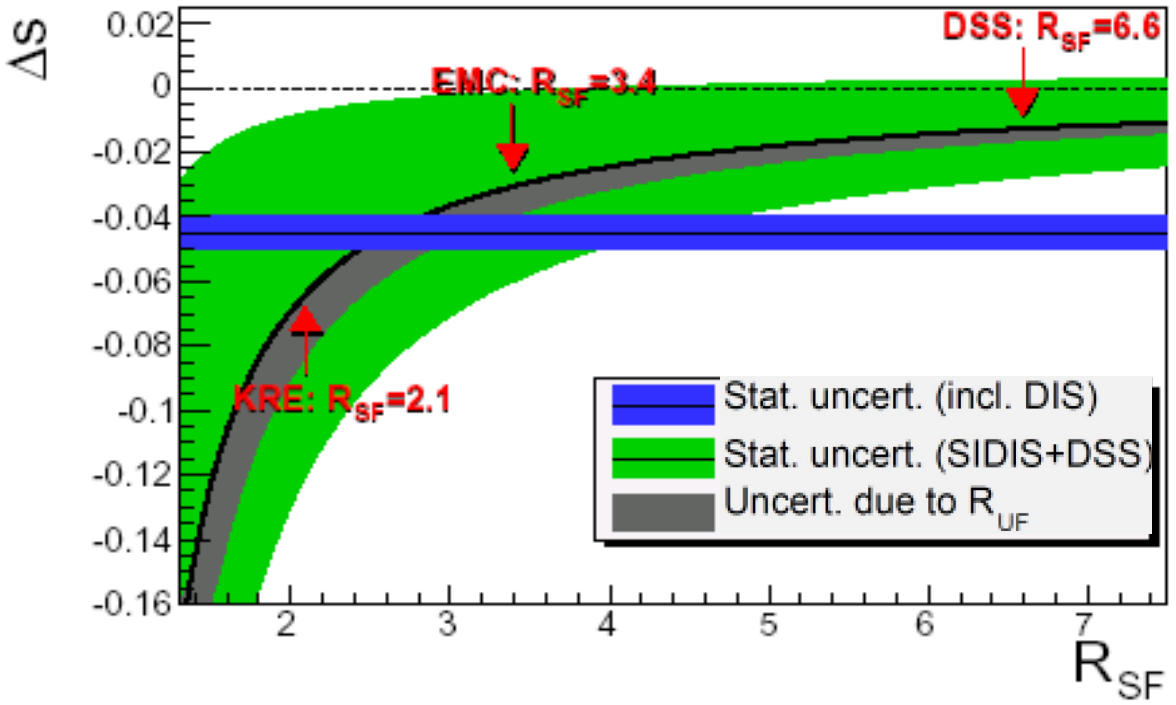
$$\alpha = (2R_{UF} + 2R_{SF})/(2 + 3R_{UF})$$

$A_{1,d}^{K^+ + K^-} = A_{1,d}$ ➔ **Δs ≥ 0 insensitive to FFs**

$A_{1,d}^{K^+ + K^-}$ **< 0** where $A_{1,d}$ **~ 0** ➔ **Δs <0**

ξ is correction factor for quark helicity distributions

Δs as a function of R_{SF}



$$R_{SF} = \frac{\int D_{\bar{s}}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

$$R_{UF} = \frac{\int D_{d}^{K^+}(z)dz}{\int D_{u}^{K^+}(z)dz}$$

R_{UF} fixed at 0.13 from the DSS FFs

Large statistical uncertainty due to R_{SF}; slight dependence on R_{UF}

If $R_{SF} \geq 5$: $\Delta s(\text{SIDIS}) > \Delta s(\text{DIS})$ ➔ $\Delta s(x) < 0$ for $x < 0.004$ (unmeasured), but 2σ difference only

If $R_{SF} \leq 4$: $A_{1,d}^{K^+ + K^-}$ becomes insensitive to Δs (small $D_{\bar{s}}^{K^+}$)

Summary

SIDIS analysis of full 2002-2006 deuteron COMPASS data

-- Δs (SIDIS) = –0.01 ± 0.01(stat.) ± 0.01(syst.)

{ DIS $\Delta s + \Delta\overline{s} = -0.09 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})$ }

-- Strange quark polarisation strongly dependent on R_{SF}

-- New evaluation of valence quark polarisations

-- The results for valence quarks and non-strangesea quarks are in good agreement with the DNS parametrisation

Next steps

-- 2007 proton data analysis with Δu , Δd separation (short term)

-- Extruction of R_{SF} from COMPASS data (long term)

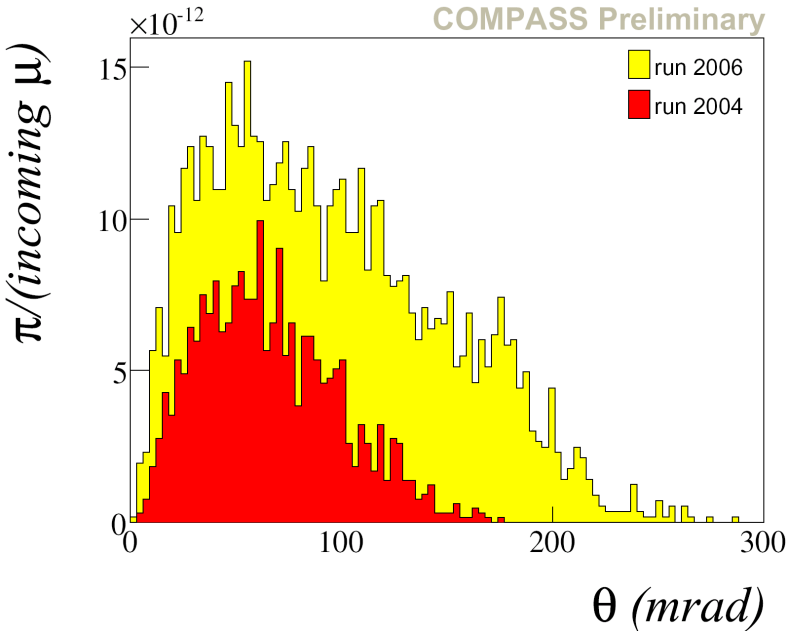
Spares

Spectrometer Upgrade

Performed during SPS shutdown in 2005

POLARISED TARGET

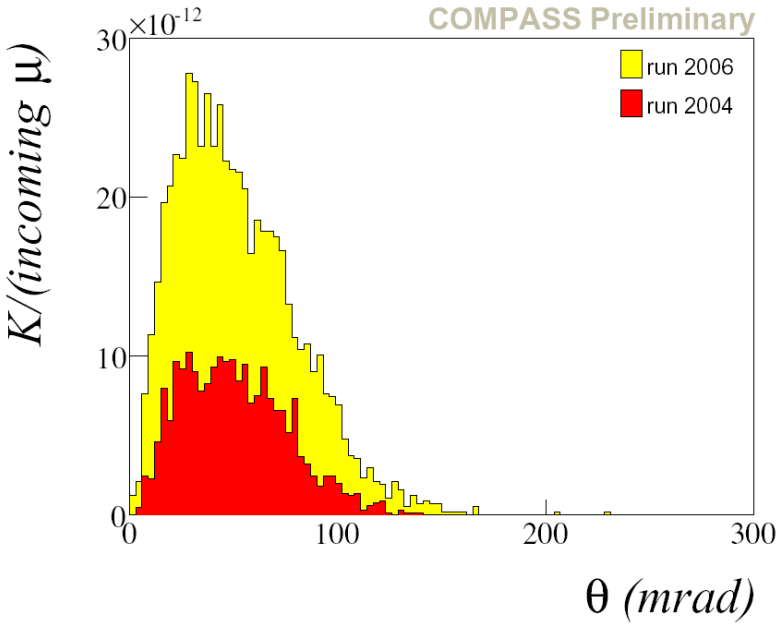
- Larger acceptance: 70 → 180 mrad
- 2 → 3 target cells for false asymmetries reduction



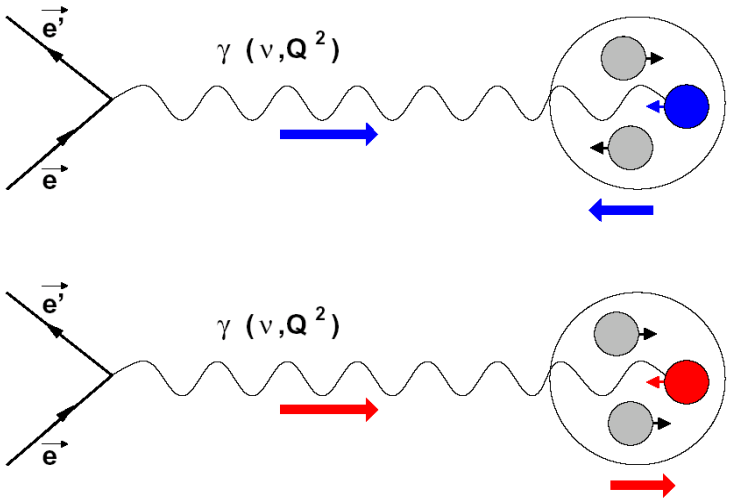
RICH DETECTOR

- Central part replaced by MAPMTs
  → Increase number of detected photons
- New readout system in the peripheral region

Improved resolution → π /K separation at 2.5σ up to 50 GeV/c



Polarised Deep Inelastic Scattering



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

$$q(x) = q(x)^+ + q(x)^-$$

\+ quark ⇈ nucleon

– quark ⇅ nucleon

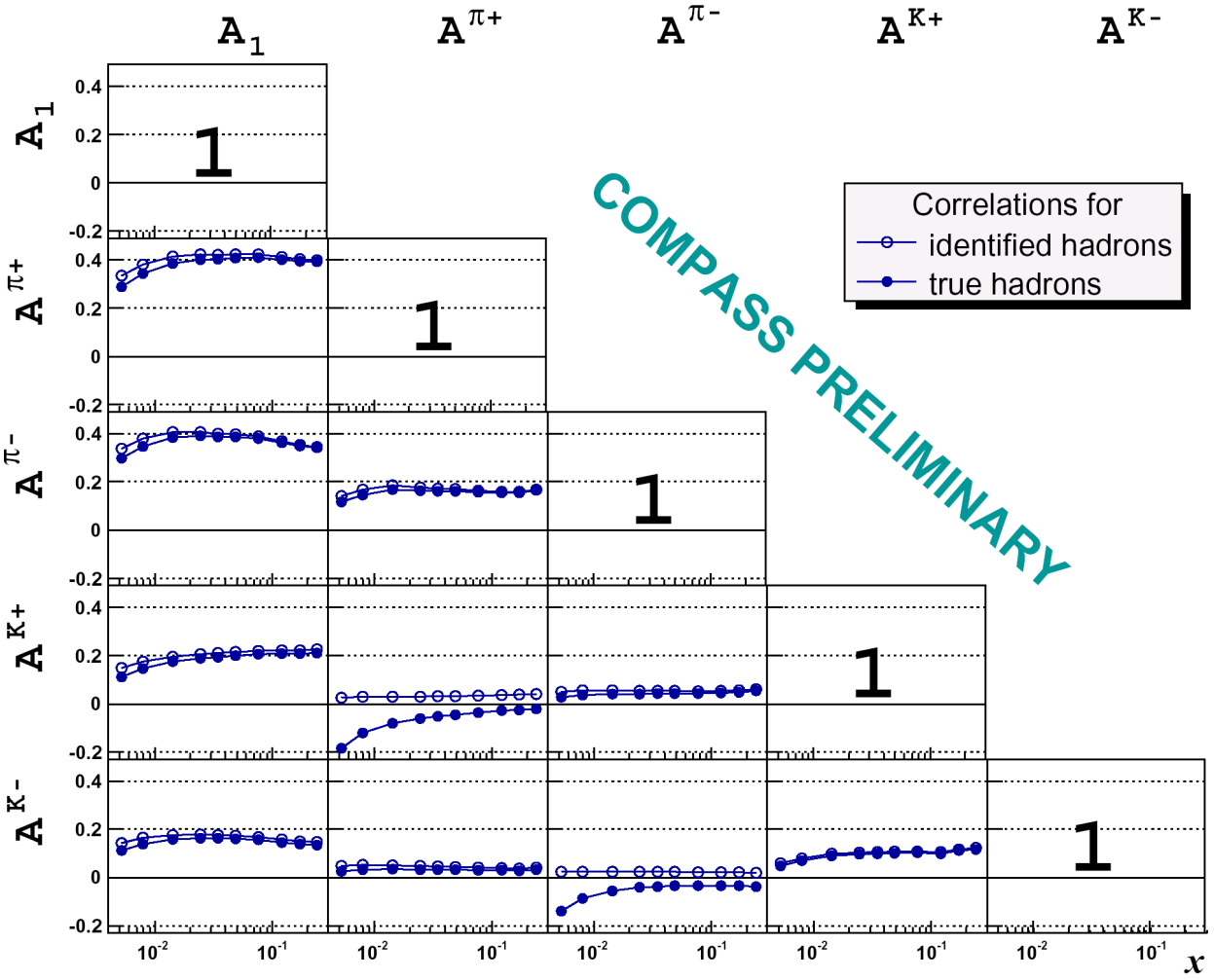
Inclusive asymmetry

$$A_1(x,Q^2) = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \, \Delta q(x,Q^2)}{\sum_q e_q^2 \, q(x,Q^2)} = \frac{g_1(x,Q^2)}{F_1(x,Q^2)}$$

Semi-inclusive asymmetry

$$A_1^h(x,z,Q^2) = \frac{\sigma^h_{\uparrow\downarrow} - \sigma^h_{\uparrow\uparrow}}{\sigma^h_{\uparrow\downarrow} + \sigma^h_{\uparrow\uparrow}} \approx \frac{\sum_q e_q^2 \, \Delta q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 \, q(x,Q^2) D_q^h(z,Q^2)}$$

Correlations



Asymmetry correlation matrices, before and after unfolding

PDFs before and after unfolding