Measurement of Δs at COMPASS

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Motivation

Why this talk at this workshop?

- Parity violating electron scattering (PVES) experiments measure

$$G^{s}_{E,M}(Q^2) \;\Rightarrow\; \langle N,p' \,|\, \bar{s}\gamma_\mu s \,| N,p\rangle$$

- Strangeness can contribute also to the axial form factor $G_A(Q^2)$

$$G^{s}_{A}(Q^2) \;\Rightarrow\; \langle N,p' \,|\, \bar{s}\gamma_\mu\gamma_5 s \,| N,p\rangle$$

- Providing a connection with the strange quark helicity density $\Delta s(x)$ from deep inelastic scattering (DIS)

$$G^{s}_{A}(Q^2=0) = \int_0^1 dx\, \Delta s(x, Q^2=\infty) \equiv \Delta s$$

Comparison between PVES and DIS

1) Check of the sum rule

2) Mutual constraint

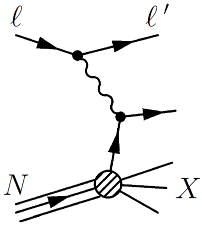
Outline

- Δs from DIS and Semi-inclusive DIS
- The COMPASS experiment
- Review of Δs results from COMPASS
- Ongoing work

Δs from inclusive DIS

Deep inelastic scattering (**DIS**): $\boxed{\ell\, N \rightarrow \ell'\ (X)}$

- $Q^2 > 1$ GeV^2 (hard scale)
  $\Rightarrow$ Scattering on quasi free partons (Parton model + pQCD)



unpol. σ $\Rightarrow F_1(x), F_2(x) \Rightarrow$ unpol. p.d.f. $\boxed{q(x)}$

pol. σ $\Rightarrow g_1(x), g_2(x) \Rightarrow$ pol. p.d.f. $\boxed{\Delta q(x)}$

From longitudinal double-polarisation asymmetry:

$$A = \frac{\sigma^{\uparrow\uparrow} - \sigma^{\uparrow\downarrow}}{\sigma^{\uparrow\uparrow} + \sigma^{\uparrow\downarrow}} \propto g_1(x, Q^2)$$

Δs from inclusive DIS

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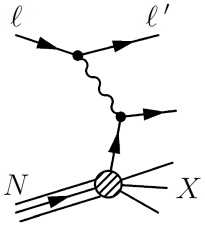

$$\Gamma_1 = \int_0^1 dx\, g_1(x) = \frac{1}{2}\sum_q e_q^2 \underbrace{\int_0^1 dx\, (\Delta q(x) + \Delta\bar{q}(x))}_{\equiv \Delta q}$$

e.g.

$$\Gamma_1^N \equiv \frac{1}{2}\left(\Gamma_1^{\mathrm{p}} + \Gamma_1^{\mathrm{n}}\right) = \frac{1}{36}\left[5\Delta\mathrm{u} + 5\Delta\mathrm{d} + 2\Delta\mathrm{s}\right]$$

Isospin symmetry:

$$\Delta\mathrm{u} \equiv \Delta\mathrm{u}^{\mathrm{p}} = \Delta\mathrm{d}^{\mathrm{n}}$$
$$\Delta\mathrm{d} \equiv \Delta\mathrm{d}^{\mathrm{p}} = \Delta\mathrm{u}^{\mathrm{n}}$$
$$\Delta\mathrm{s} \equiv \Delta\mathrm{s}^{\mathrm{p}} = \Delta\mathrm{s}^{\mathrm{n}}$$

Δs from inclusive DIS

Deep inelastic scattering (**DIS**): $\boxed{\ell\, N \rightarrow \ell'\ (X)}$

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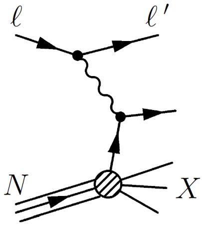


With Γ_1^N and SU(3):

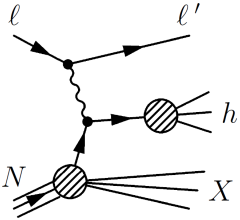
Use axial couplings from baryon β decays:

$$\begin{aligned}\Delta q_8 &= \Delta\mathrm{u} + \Delta\mathrm{d} - 2\Delta\mathrm{s} \\ &= 3F - D = 0.585 \pm 0.025\end{aligned}$$

$$\boxed{\Delta\mathrm{s} = 3\Gamma_1^N - \frac{5}{12}\Delta q_8}$$

Δs from SIDIS

Semi-inclusive DIS (**SIDIS**): $\boxed{\ell\, N \to \ell'\ h\ (X)}$



At LO in QCD:

$$A^h(x,z) = \frac{\sigma_h^{\uparrow\uparrow} - \sigma_h^{\uparrow\downarrow}}{\sigma_h^{\uparrow\uparrow} + \sigma_h^{\uparrow\downarrow}} \qquad (z = E_h/E_\gamma)$$

$$= \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h(z) + \Delta \bar{q}(x) D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}$$

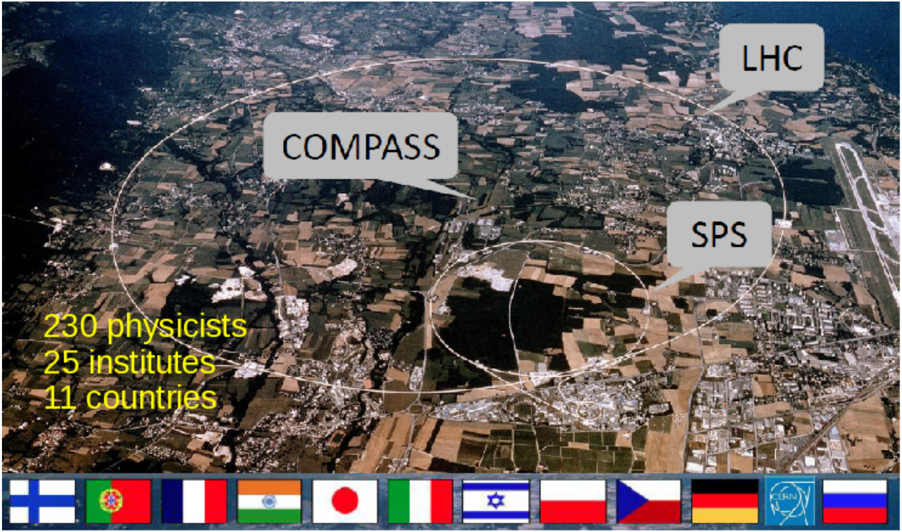
$h = \pi^+, \pi^-, \mathrm{K}^+, \mathrm{K}^-$...

$z > 0.2$ to suppress target fragmentation

$z < 0.85$ to suppress diffractive production

$$\Rightarrow \boxed{\Delta s(x)}$$

The COMPASS experiment at CERN



The COMPASS experiment

Broad experimental programme

<u>Muon beam</u>

- Deep inelastic scattering (DIS)
- Semi-inclusive DIS (SIDIS)
- Transversity
- DVCS/GPDs
- Λ polarisation

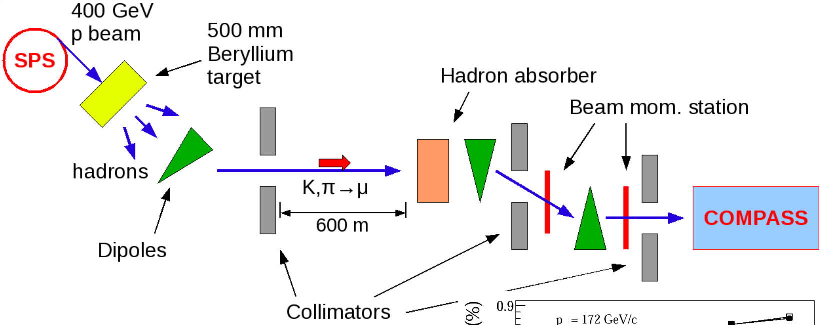
<u>Hadron ($\pi^{\pm}$, $K^{\pm}$) beams</u>

- Hadron spectroscopy
- Meson structure
- χPT tests
- Search for exotics
- Drell-Yan

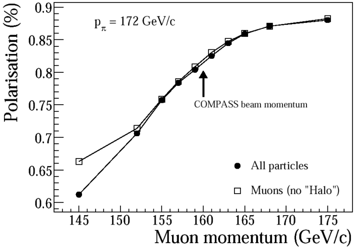
COMPASS setup for (SI)DIS

- Polarised muon beam
- Longitudinally polarised ^{6}LiD or NH_3 targets
- Spectrometer and PID
- Event selection and asymmetry measurement

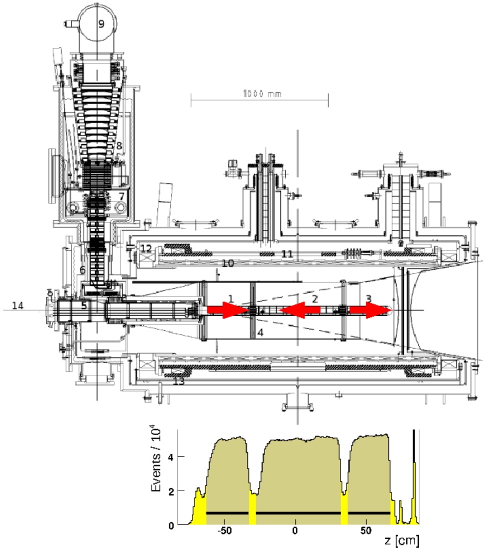
Polarised muon beam



- Energy: 160 GeV
- Polarisation: $\approx$ 80%
- Intensity: 2×10^{8} μ/spill

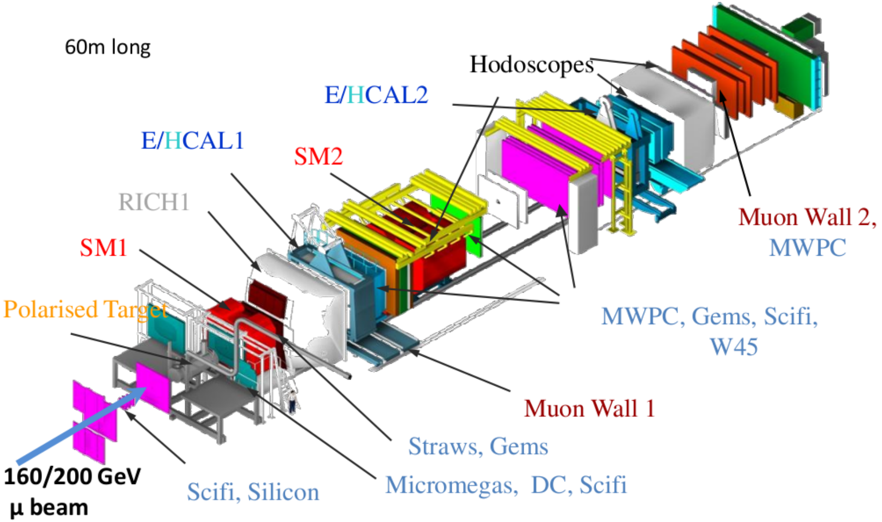


Polarised target



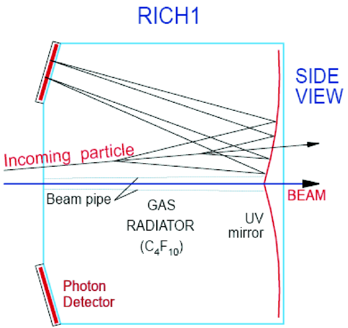
- ^{6}LiD or NH_3
- length: 1.20 m
- Pol.: 50% for ^{6}LiD, up to 90% for NH_3 measured via NMR
- Dilution factor f: 0.5 for ^{6}LiD, 0.2 for NH_3
- Polarisation reversed every 8 or 24 hours
- Repolarisation twice per year

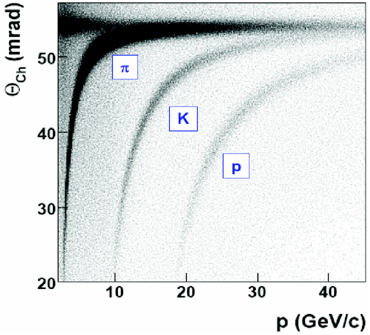
COMPASS spectrometer



Particle Identification

RICH detector ⇒ hadron identification in SIDIS

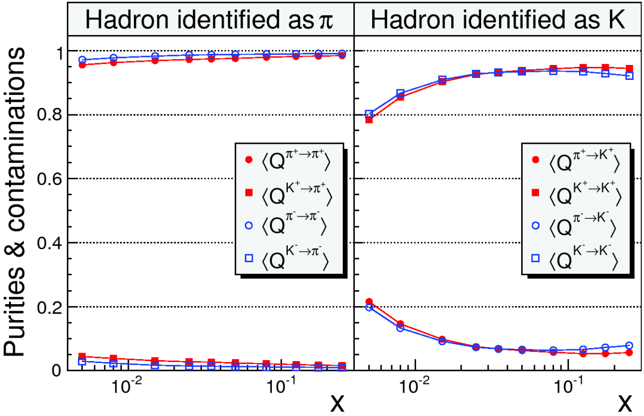




Particle Identification

RICH detector ⇒ hadron identification in SIDIS

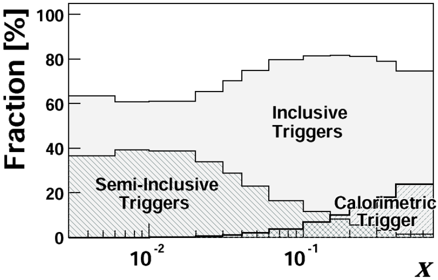
RICH characterisation from data



Event selection

Online event triggering

- **Inclusive trigger**: Hodoscopes coincidence with target pointing
- **Semi-inclusive trigger**: Muon energy loss + calorimeter signal ($> 3 \times E^{\mu}_{\mathrm{dep}}$)
- **Pure calorimetric trigger**: Only calorimeter signal ($> 9 \times E^{\mu}_{\mathrm{dep}}$)
- **Veto trigger** by hodoscopes upstream of the target $\Rightarrow$ halo suppression



Event selection

Offline event selection

Geometrical cuts

- Beam μ track extrapolation crosses all cells
- μ' crosses a material thickness > 30 rad. len. (μ identification)
- μ' track crosses triggering hodoscope
- Reconstructed primary vertex in target

Kinematical cuts (inclusive)

- 140 GeV $< p_\mu < 180$ GeV
- $Q^2 > 1$ (GeV$/c)^2$
- $0.1 < y < 0.9$
  ($y = \nu/E_\mu$, $\nu = E_\mu - E_{\mu'}$)

On hadrons (for SIDIS)

- $0.2 < z < 0.85$
  ($z = E_h/\nu$)

Asymmetry measurement

– Two types of target cells: u d
– Two field orientations: $+$ $-$

$\Rightarrow$ 4 measurements

$$N_i = \phi_i \, n_i \, a_i \, \sigma_{\mathrm{unpol}} \, (1 + P_{\mathrm{B}} \, P_{\mathrm{T}} \, f \, D \, A_1)$$

- ϕ: flux
- n: no. of target nucleons
- a: acceptance
- f: dilution factor
- D: depolarisation factor (depends on kinematics and $R = \sigma_L / \sigma_T$)

$$\phi_{\mathrm{u}} = \phi_{\mathrm{d}}$$

$$n_+ = n_-$$

$$\left(\frac{a_{\mathrm{u}}}{a_{\mathrm{d}}}\right)_+ = \left(\frac{a_{\mathrm{u}}}{a_{\mathrm{d}}}\right)_-$$

$$\frac{N_{+\mathrm{u}} \, N_{-\mathrm{d}}}{N_{+\mathrm{d}} \, N_{-\mathrm{u}}} = \frac{(1 + P_{\mathrm{B}} \, P_{\mathrm{T}} \, f \, D \, A_1)^2}{(1 - P_{\mathrm{B}} \, P_{\mathrm{T}} \, f \, D \, A_1)^2}$$

$$\Rightarrow A_1$$

$w = P_{\mathrm{B}} \, D$ known for each event $\Rightarrow$ used for weighting

Asymmetry measurement

Systematic errors

	^{6}LiD	NH_3
Multiplicative:		
Beam polarisation P_B	5%	5%
Target polarisation P_T	5%	2%
Dilution factor f	2%	2%
$R = \sigma_L/\sigma_T$	2–3%	2–3%
Total	8%	6%
False asymmetries		
Apparatus	$\sim$0	$\sim$0
DNP Microwave settings	$\sim$0	$\sim$0
Time stability	$< 0.40\ \sigma_\mathrm{stat}$	$< 0.56\ \sigma_\mathrm{stat}$

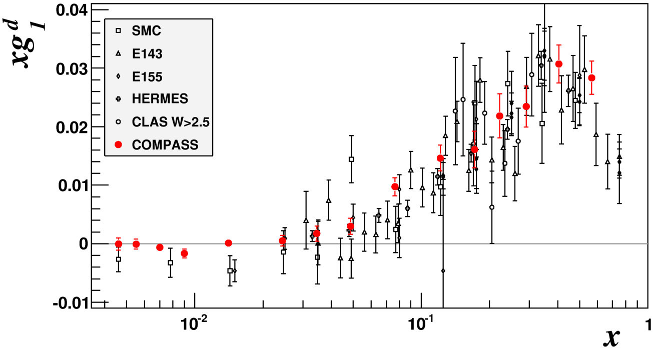
Review of COMPASS results

- Inclusive measurement of g_1^{d}
  (2002 – 2004, 2006 data)

- Semi-inclusive asymmetries for π and K
  - deuteron A_h^{d} (2002 – 2004, 2006)
  - proton A_h^{p} (2007)

Inclusive measurement: g_1^d

PLB 647 (2007) 8-17



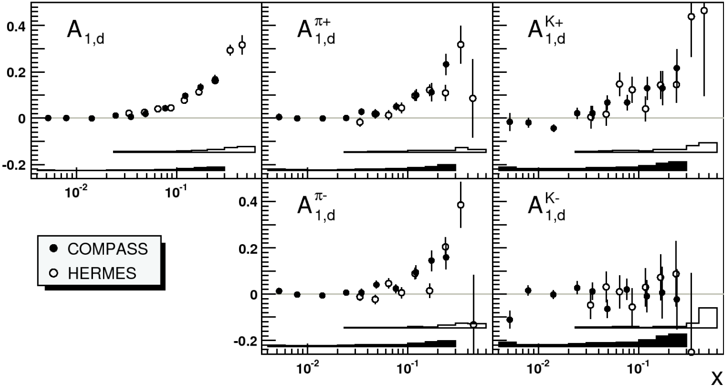
From NLO QCD Fit:

$$\Gamma_1^N(Q^2 = 3\ \mathrm{GeV}^2) = 0.050 \pm 0.003(\mathrm{stat.}) \pm 0.003(\mathrm{evol.}) \pm 0.005(\mathrm{syst.})$$

$$\boxed{\Delta s = -0.08 \pm 0.01(\mathrm{stat.}) \pm 0.02(\mathrm{syst.})}$$

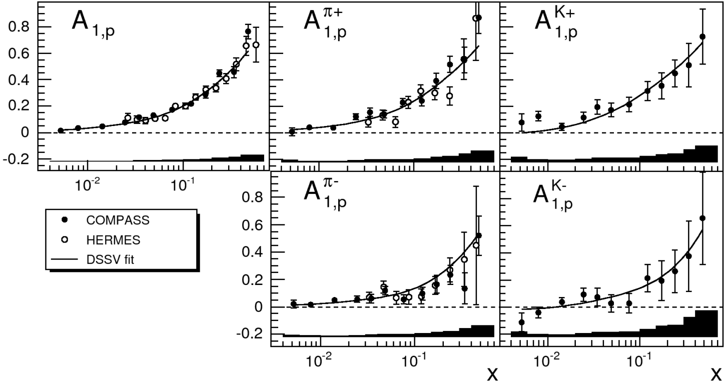
Deuteron SIDIS asymmetries

PLB 680 (2009) 217-224



Proton SIDIS asymmetries

PLB 693 (2010) 227-235



Flavour separation

$$A^h(x,z) = \frac{\sum_q e_q^2 \left(\Delta q(x) D_q^h(z) + \Delta \bar{q}(x) D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}$$

Using:

- MRST unpolarised p.d.f.
- DSS fragmentation functions
- $\Delta \mathrm{s} = \Delta \bar{\mathrm{s}}$

For each x value:

4 SIDIS measurements on d +
4 SIDIS measurements on p +
2 inclusive measurements

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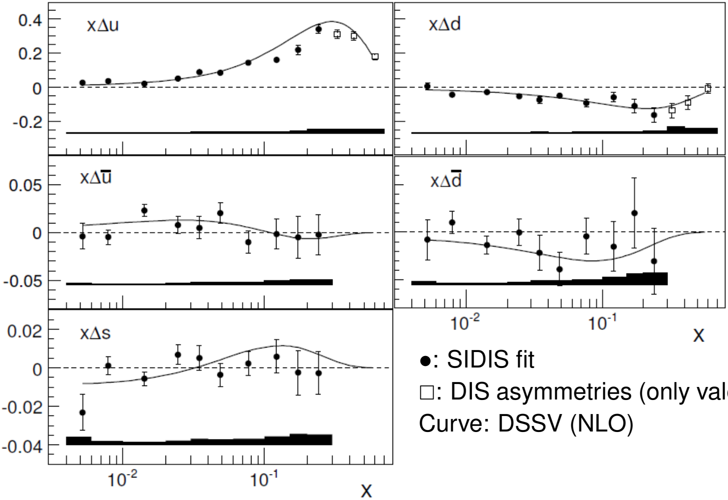
10 data points

$\Delta \mathrm{u}$, $\Delta \bar{\mathrm{u}}$, $\Delta \mathrm{d}$, $\Delta \bar{\mathrm{d}}$, $\Delta \mathrm{s}$ (=$\Delta \bar{\mathrm{s}}$)
$\Rightarrow$ 5 unknowns

Flavour separation



●: SIDIS fit

□: DIS asymmetries (only valence)

Curve: DSSV (NLO)

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

Δs puzzle persists

from DIS + SU(3):

$$\Delta s = -0.08 \pm 0.01(\text{stat.}) \pm 0.02(\text{syst.})$$

from SIDIS:

$$\Delta s = -0.02 \pm 0.02(\text{stat.}) \pm 0.02(\text{syst.})$$

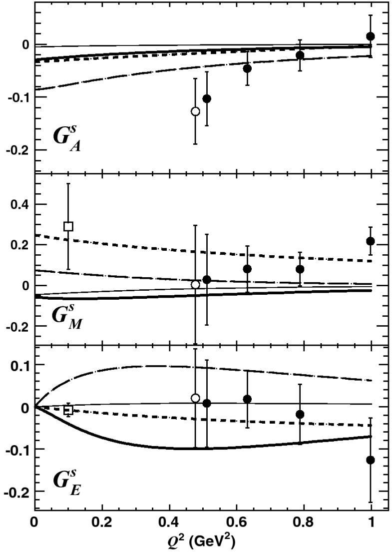
From PVS: e^- and ν

COMPASS

Negative Δs seems favoured

S. F. Pate *et al.*,

Phys. Rev. C 78 (2008), 015207



What's wrong?

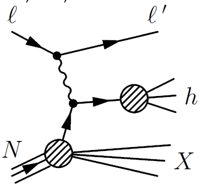
- on DIS + SU(3): SU(3) breaking?

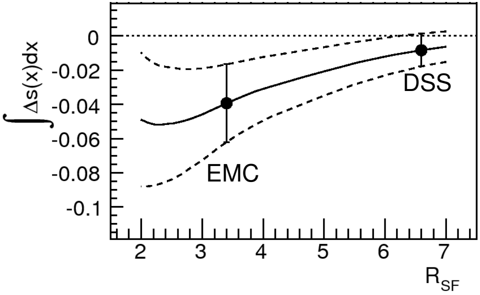
  (see e.g. S. D. Bass and A. W. Thomas, Phys. Lett. B684 (2010) 216)

- on SIDIS: Fragmentation functions D_q^h?

  Strong dependence on the ratio:

$$R_{\mathrm{SF}} = \frac{D_{\bar{\mathrm{s}}}^{\mathrm{K}^+}}{D_{\mathrm{u}}^{\mathrm{K}^+}}$$

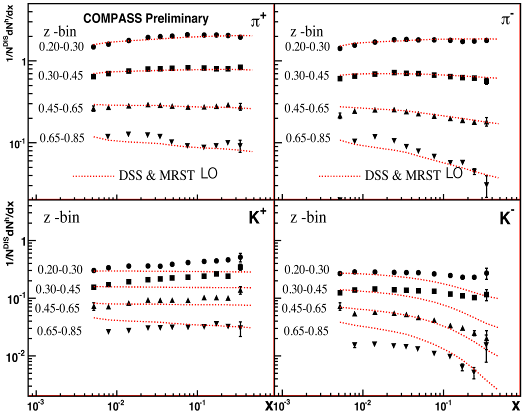




Measurement of FFs

From hadron multiplicities:

$$M^h(x,z) \equiv \frac{d\sigma^h_{\mathrm{SIDIS}}/dz}{\sigma_{\mathrm{DIS}}} = \frac{\sum_q e_q^2 \left(q(x) D_q^h(z) + \bar{q}(x) D_{\bar{q}}^h(z)\right)}{\sum_q e_q^2 \left(q(x) + \bar{q}(x)\right)}$$



Summary

- Constraints on Δs from COMPASS data
- DIS and SIDIS measurements do not agree
- Low x region not responsible for the discrepancy
- SU(3) breaking effects could play a role
- Strong dependence on FFs on SIDIS side

Ongoing work

- Extraction of FFs from hadron multiplicities with COMPASS data
- New 2011 proton data (@200 GeV) $\Rightarrow$ improve statistics + lower x

Backup

Q^2 dependence