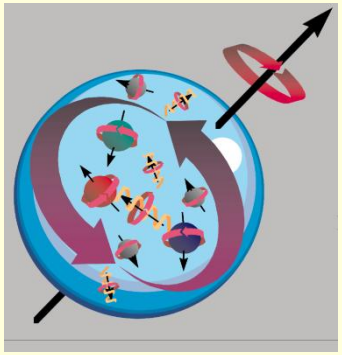
Probing strangeness in SIDIS at HERMES & COMPASS

F.Kunne - CEA Saclay, France

- Longitudinal spin: Strange quark helicity $\Delta s(x)$
- Unpolarized case: Strange quark distribution $s(x)$
- Outlook

International Workshop on Probing Strangeness in Hard Processes, Frascati, Italy, Oct.18-21, 2010

Nucleon spin



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

Quark Gluon Orbital Momentum

Quark spin contribution $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

$\Delta q = \vec{q} - \overleftarrow{q}$ Parton spin parallel or anti parallel to nucleon spin

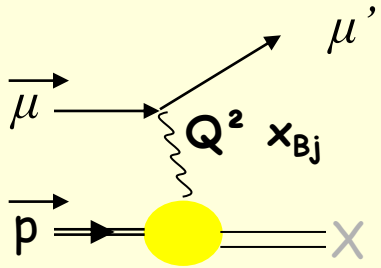
Acces to integral of $\Delta\Sigma$ and Δs through inclusive DIS
Access to x distributions through semi-inclusive DIS (SIDIS)

Quark spin contribution $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

from inclusive DIS…

μ N Deep Inelastic Scattering DIS

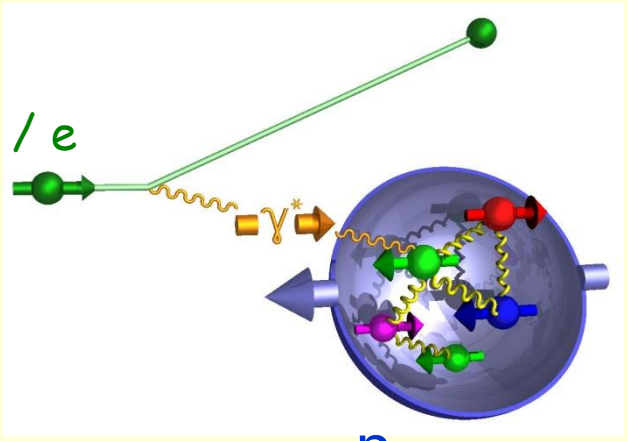
$$F_1(x) \rightarrow 1/2 \sum_{u,d,s} e^2 q(x)$$



$Q^2 > 1\ (GeV/c)^2$

x_{Bj} parton momentum fraction

$\vec{\mu}\,\vec{N}$ Polarized DIS



Virtual γ couples to opposite helicity quark

→measure one helicity distribution $\vec{q}(x)$

By reversing nucleon polarization

→ measure other helicity distribution $\overleftarrow{q}(x)$

$$\Delta q = \overleftarrow{q} - \vec{q}$$

$$g_1(x) \rightarrow 1/2 \sum_{u,d,s} e_q^2\, \Delta q(x)$$

Spin asymmetry $A = \dfrac{\vec{N} - \overleftarrow{N}}{\vec{N} + \overleftarrow{N}} = \dfrac{g_1}{F_1}$ $\xrightarrow{\text{QPM}}$ $\dfrac{\sum_{u,d,s} e_q^2\, \Delta q(x)}{\sum_{u,d,s} e_q^2\, q(x)}$

g_1 and quark spin contribution $\Delta\Sigma$

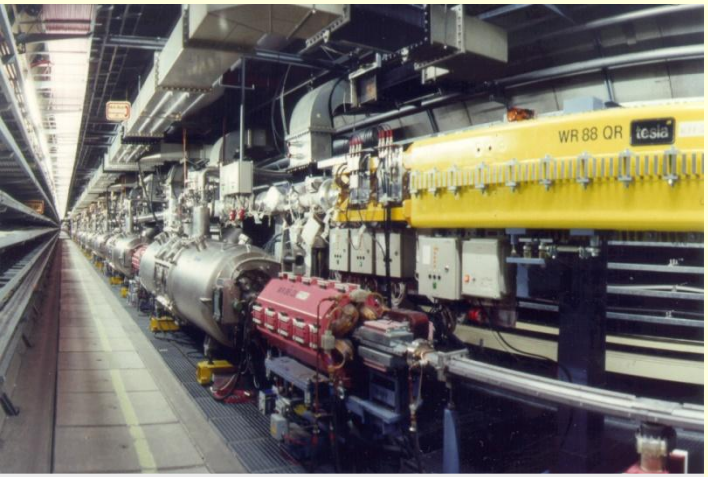
from inclusive DIS…

- measure $\int_0^1 g_1^p \, dx \longrightarrow 4\Delta u + \Delta d + \Delta s$
- neutron decay constant $a_3 = \Delta u - \Delta d = g_A = 1.257$
- hyperon β decay +SU(3) $a_8 = \Delta u + \Delta d - 2\Delta s = 0.585 \pm 0.025$

→ Extract Δu, Δd, Δs and the sum $\Delta\Sigma$

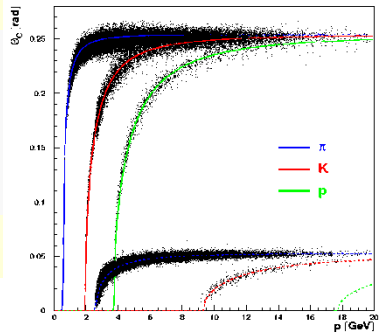
HERMES at DESY

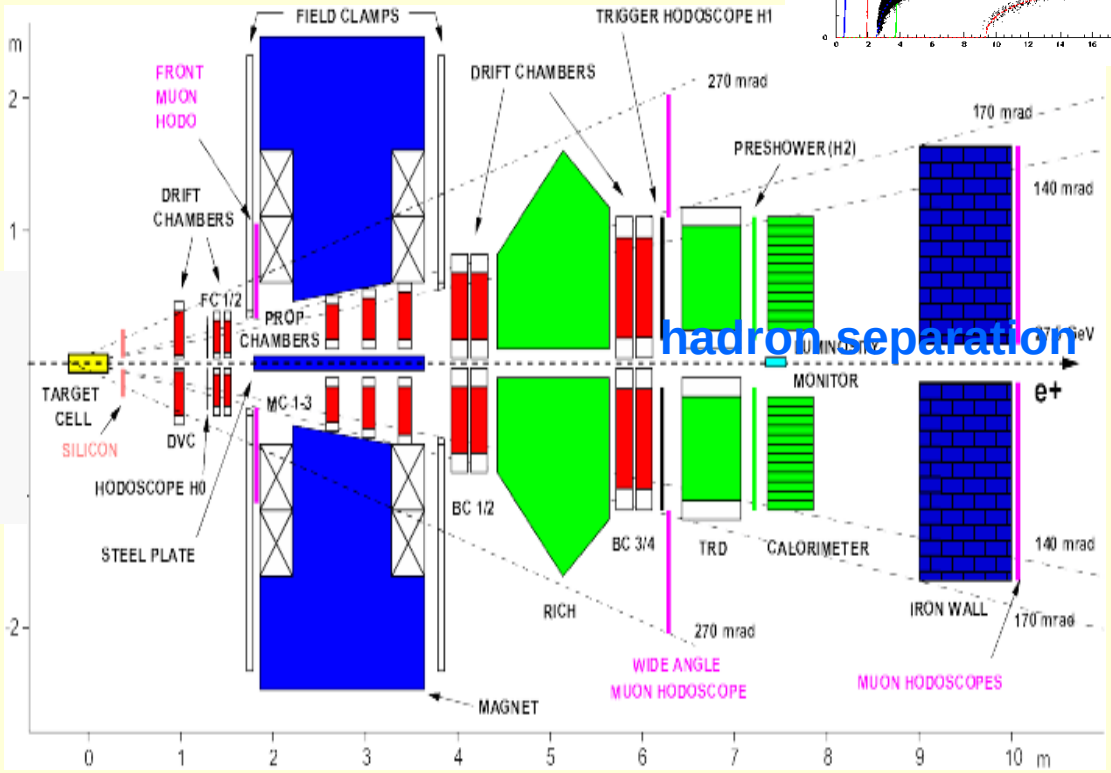
1995 to 2007



HERA e^+ & e^- 27 GeV
longitudinaly polarized ~ 54%

Spectrometer :
$\Delta p/p \sim 2\%$, $\Delta\Theta < 1$ mrad
Excellent separation of π, K, p





Gaseous internal target

Longit. Polar. 85% H, D, He
Transv. Polar H
Unpol H, D, Ne, Kr

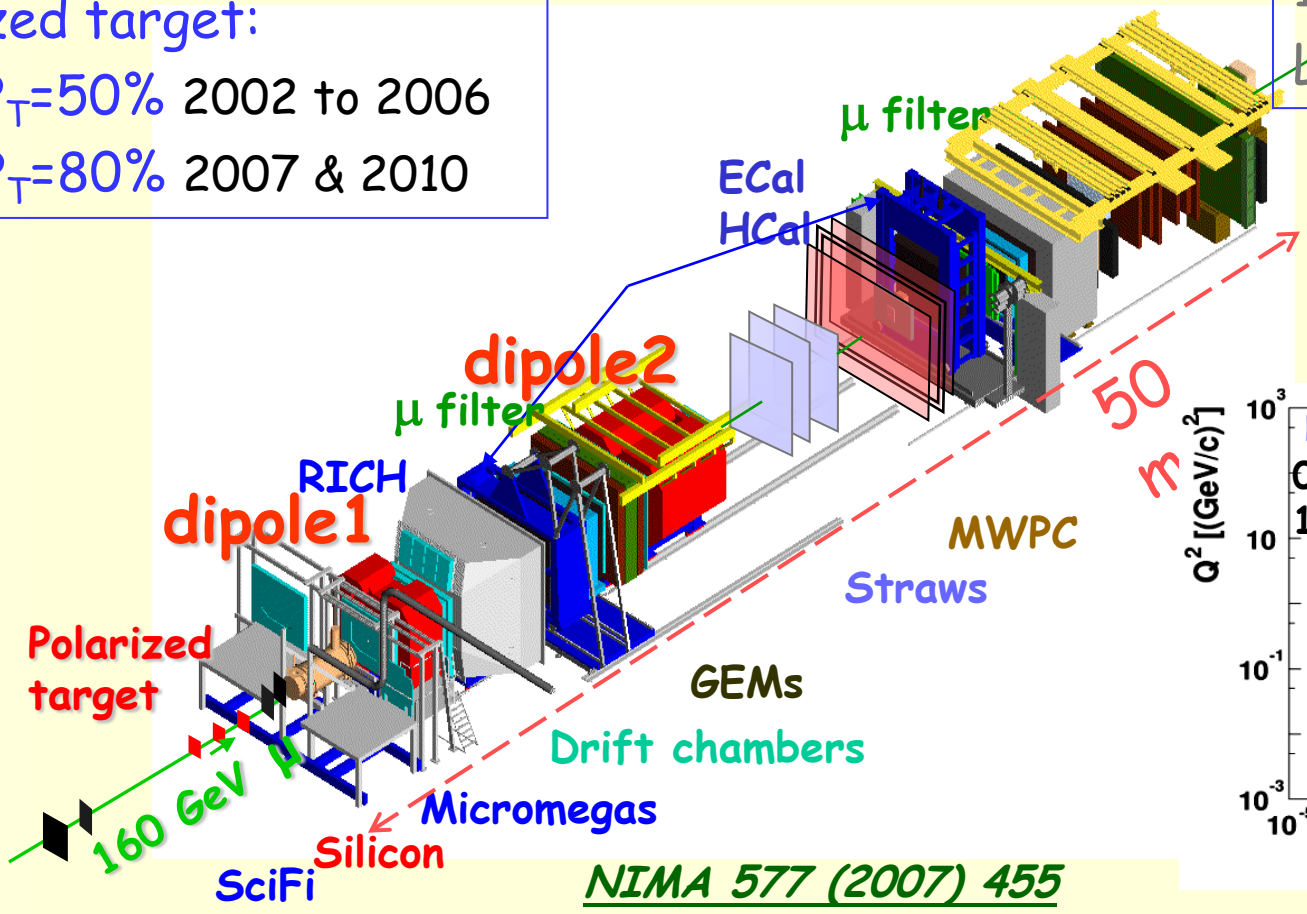
COMPASS at CERN

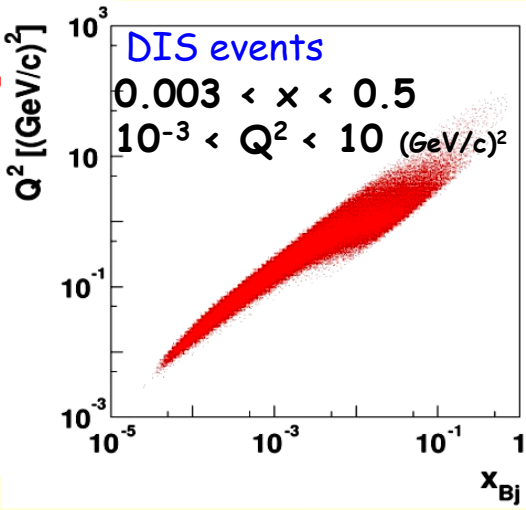
Nucleon spin structure

Polarized muon beam:
160 GeV μ, $\overrightarrow{P_B}$=80%
Polarized target:
^{6}LiD P_T=50% 2002 to 2006
NH_3 P_T=80% 2007 & 2010

Meson spectroscopy

Hadron beam :
190 GeV π / p
LH_2 2008-2009





NIMA 577 (2007) 455

$\Delta\Sigma$ from Spin structure function g_1

from inclusive DIS…

COMPASS

$\Delta\Sigma = 0.30 \pm 0.01$ (stat) $\pm$ 0.02 (evol)

COMPASS fit to $g_1^{p,n,d}$ world data, $\overline{\text{MS}}$ scheme, $Q^2=3$ (GeV/c)^2
PLB 647 (2007) 8

$\Delta s + \Delta\bar{s} = -0.08 \pm 0.01$ (stat) $\pm$ 0.02 (evol) COMPASS data only

HERMES

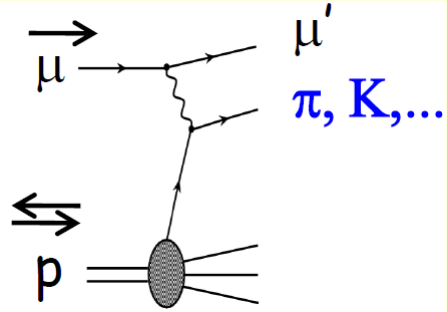
$\Delta\Sigma = 0.33 \pm 0.011$ (stat) $\pm$ 0.025 (theo) $\pm$ 0.028 (evol)

HERMES from g_1^d data, $\overline{\text{MS}}$ scheme, $Q^2=5$ (GeV/c)^2,
neglecting $x < 0.02$contrib., PRD75 (2007)012007

$\Delta s + \Delta\bar{s} = -0.085 \pm 0.013$ (th) $\pm$ 0.008 (exp) $\pm$ 0.009(evol)

Flavor dependent quark helicity distributions

from semi-inclusive DIS…



- Outgoing hadron tags quark flavour
- Need to know fragmentation functions

of quark q into hadron h: $D_q^h(z)$

$z=E_h/(E\mu-E\mu')$

at LO: $$A_1^{h(p/d)}(x) = \frac{\sum_q e_q^2 \, D_q^h \, \Delta q(x)}{\sum_q e_q^2 \, D_q^h \, q(x)}$$

$$D_q^h = \int_0^1 D_q^h(z)dz$$

all depend also on Q^2

With deuteron data alone, can extract
$\Delta u_v+\Delta d_v$, $\Delta\bar{u}+\Delta\bar{d}$, $\Delta s=\Delta\bar{s}$

With deuteron + proton data, 10 asymmetries, 5 or 6 unknowns:
Δu_v, Δd_v, $\Delta\bar{u}$, $\Delta\bar{d}$, Δs and $\Delta\bar{s}$ separately

Inputs needed: PDFs $q(x)$ & FFs D_q^h (from fits of e+e-, DIS and hh data)

Data selection and analysis

HERMES

Events:
$Q^2 > 1$ GeV/c^2
$\langle Q^2 \rangle = 2.5$ GeV/c^2
$y < 0.85$
$0.023 < x < 0.3$

Hadrons:
$0.2 < z < 0.8$
$x_F > 0.1$
$W^2 > 10$ GeV^2
$(2 < p < 15$ GeV/c)
$4 < p < 13.8$ GeV/c

100000 $K^+ + K^-$

Use CTEQ5L for pdf.

For fragm.fct., use 'purities' estimated from simulation with Lund fragm & JETSET, HERMES multiplicities

COMPASS

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

Q^2 dependence neglected
$\langle Q^2 \rangle = 3\ (\mathrm{GeV/c})^2$

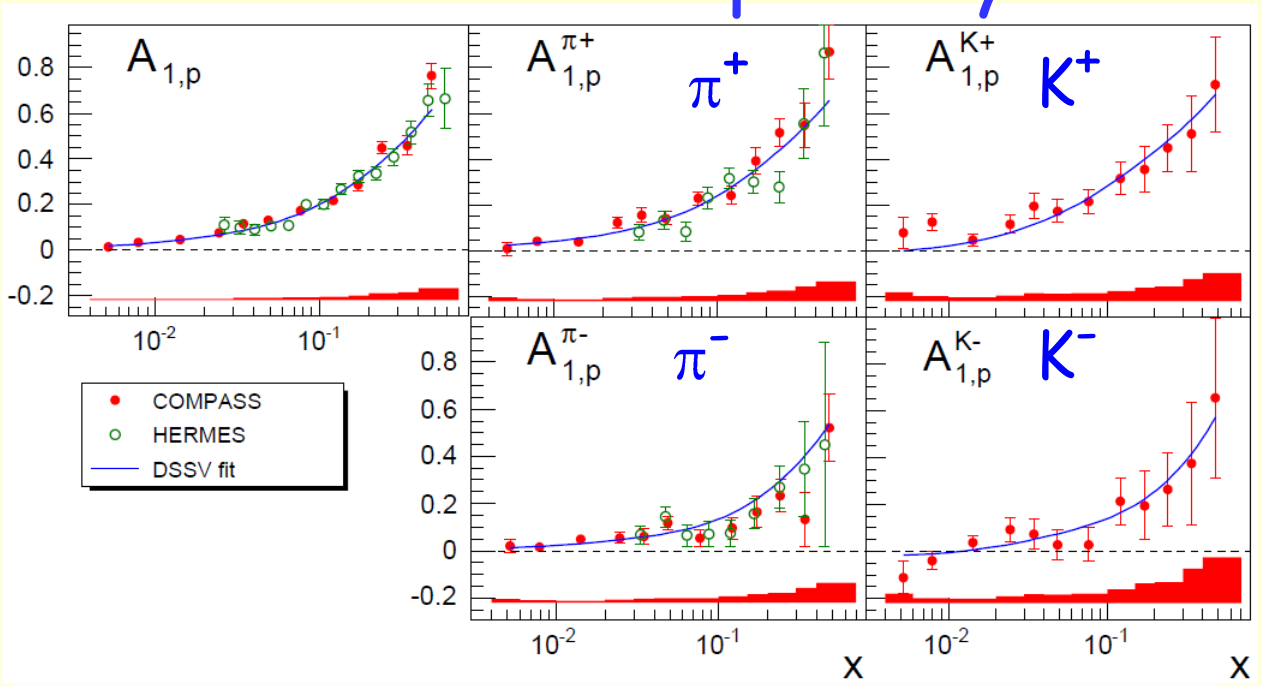
RICH efficiency and purity measured using pions from $K^0 \rightarrow \pi\pi$ and kaons from $\phi \rightarrow KK$

Use MRST pdf

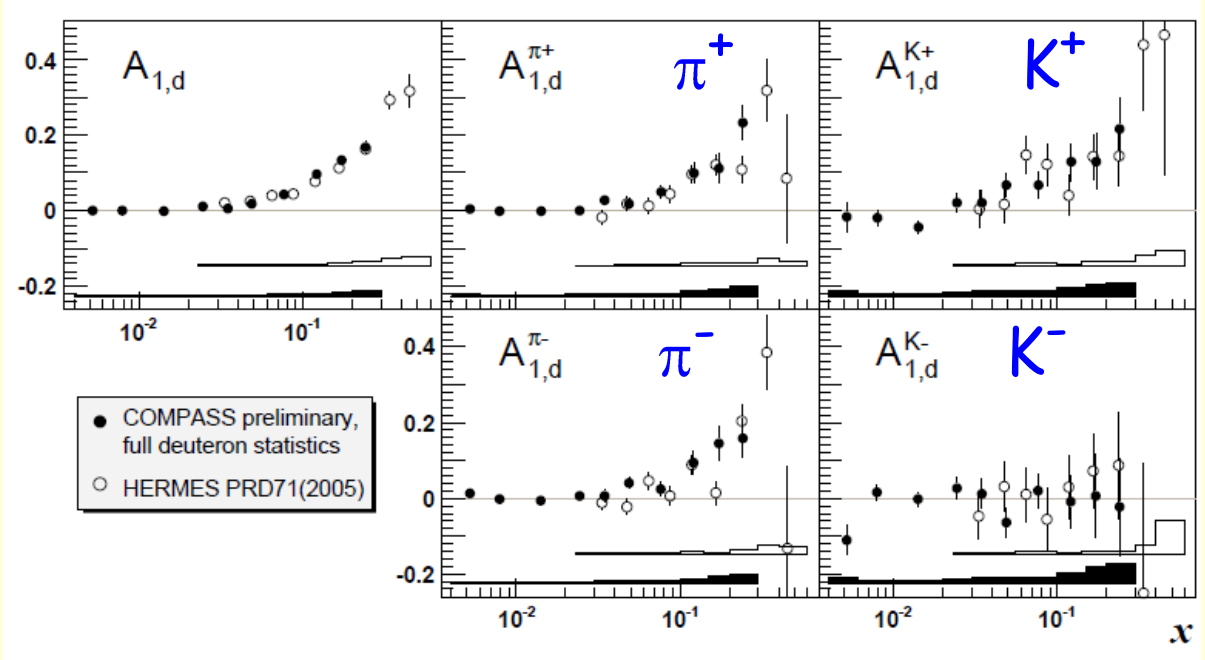
DSS fragm. fct.

Inclusive & Semi-inclusive Spin Asymmetries

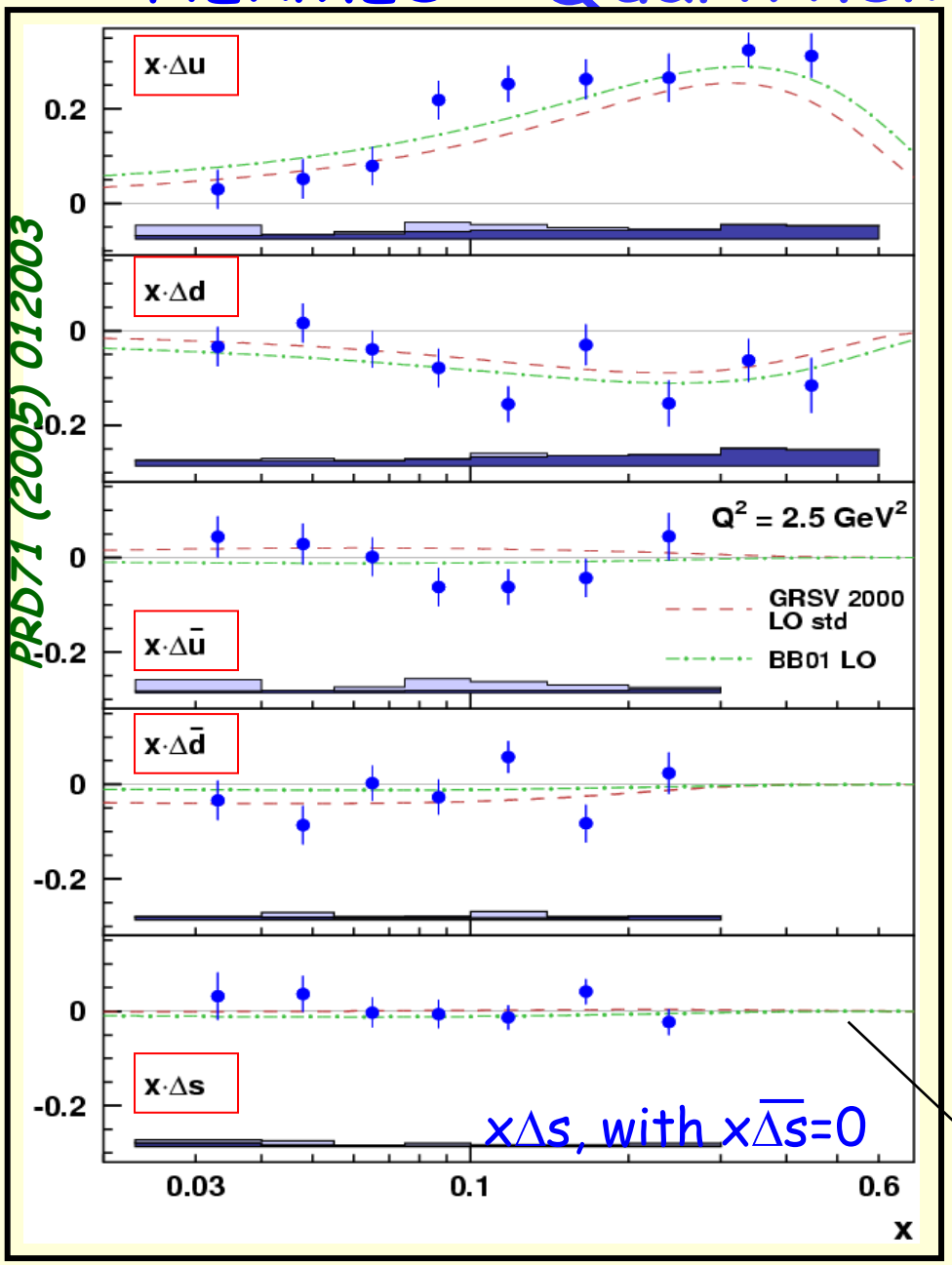
Proton



Deuteron

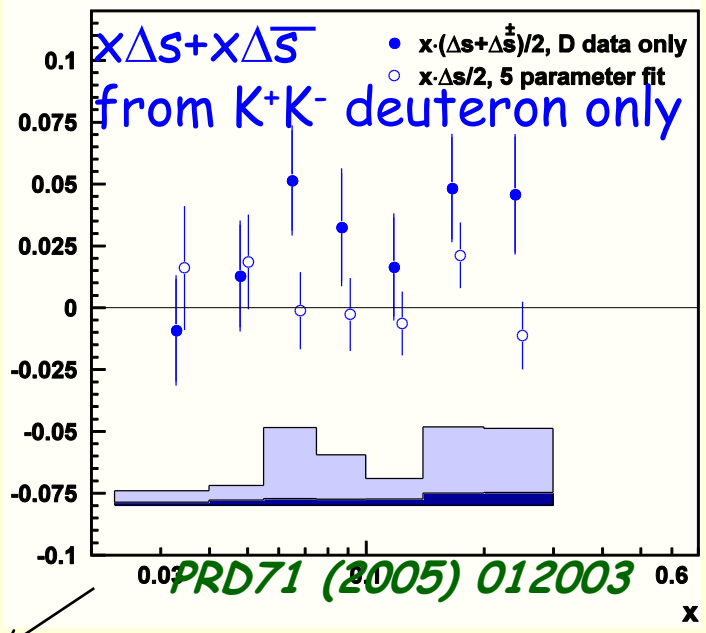


HERMES – Quark helicities from SIDIS



$\Delta u(x)$ and $\Delta d(x)$ agree with LO-QCD fit to inclusive data

$\Delta \bar{u}(x)$, $\Delta \bar{d}(x)$ and $\Delta s(x)$ ~ zero in measured region $0.02<x<0.3$

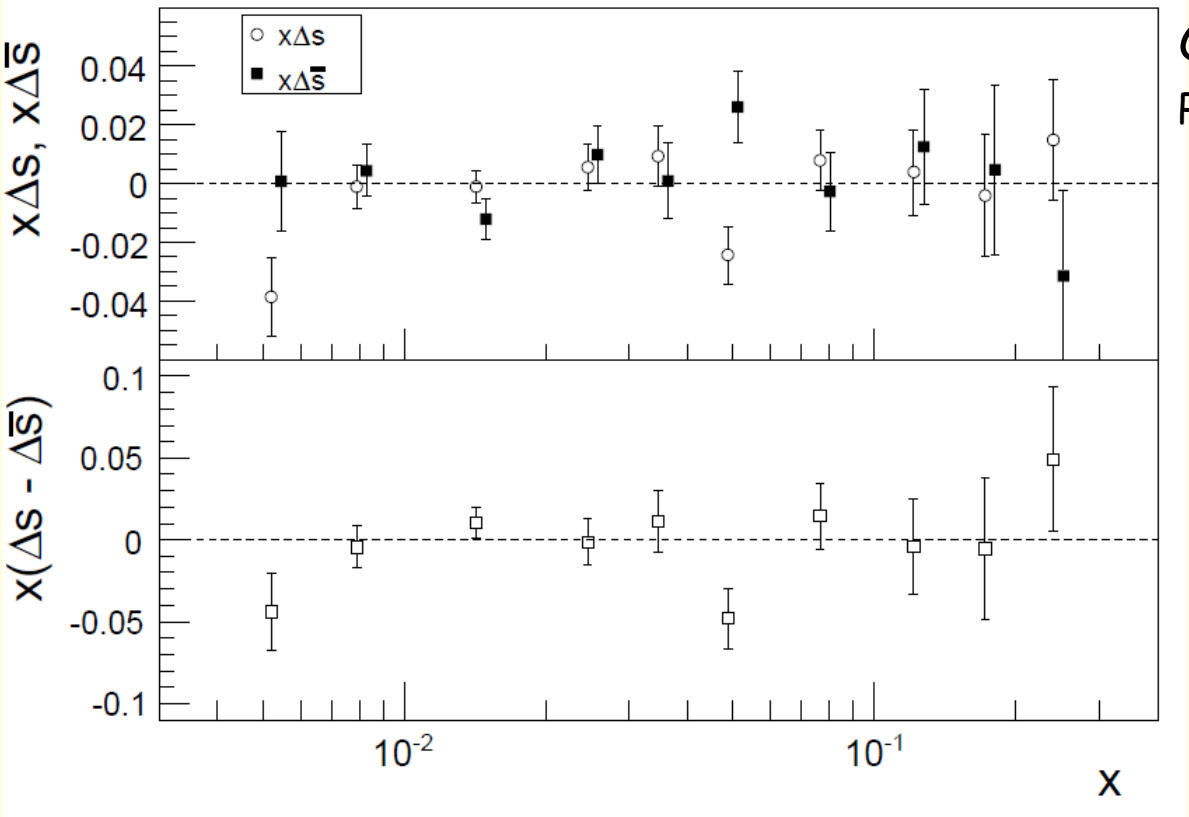


$\Delta s + \Delta \bar{s} = 0.13 \pm 0.04 \pm 0.13$

$\Delta s = 0.028 \pm 0.033 \pm 0.009$

See 2008 estimation later

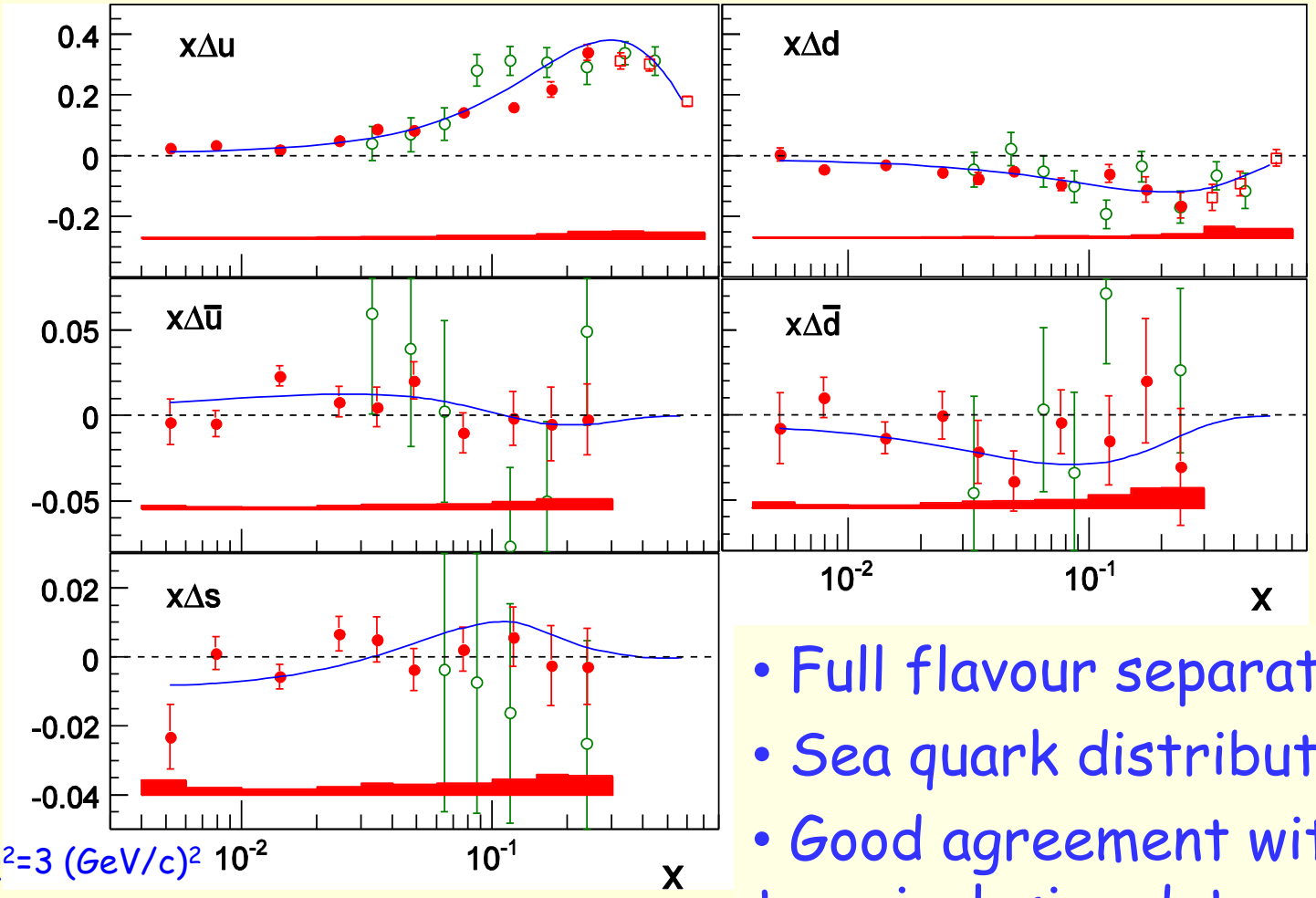
Δs and $\Delta\bar{s}$ separately



COMPASS
PLB693(2010)227

No significant difference; one point at 2.7 sigma
Assume $\Delta s=\Delta\bar{s}$ in subsequent analysis

Quark helicities from SIDIS



- COMPASS
  PLB693(2010)227
- HERMES
  PRD71(2005)012003
  Difference in error bar size mainly due to FF treatment
- DSSV

- Full flavour separation→x~0.004
- Sea quark distributions ~ zero
- Good agreement with global fits to g_1 inclusive data

COMPASS $\Delta s = -0.01 \pm 0.01 \pm 0.01$ for $0.003 < x < 0.3$

Knowledge of Quark Fragmentation Functions

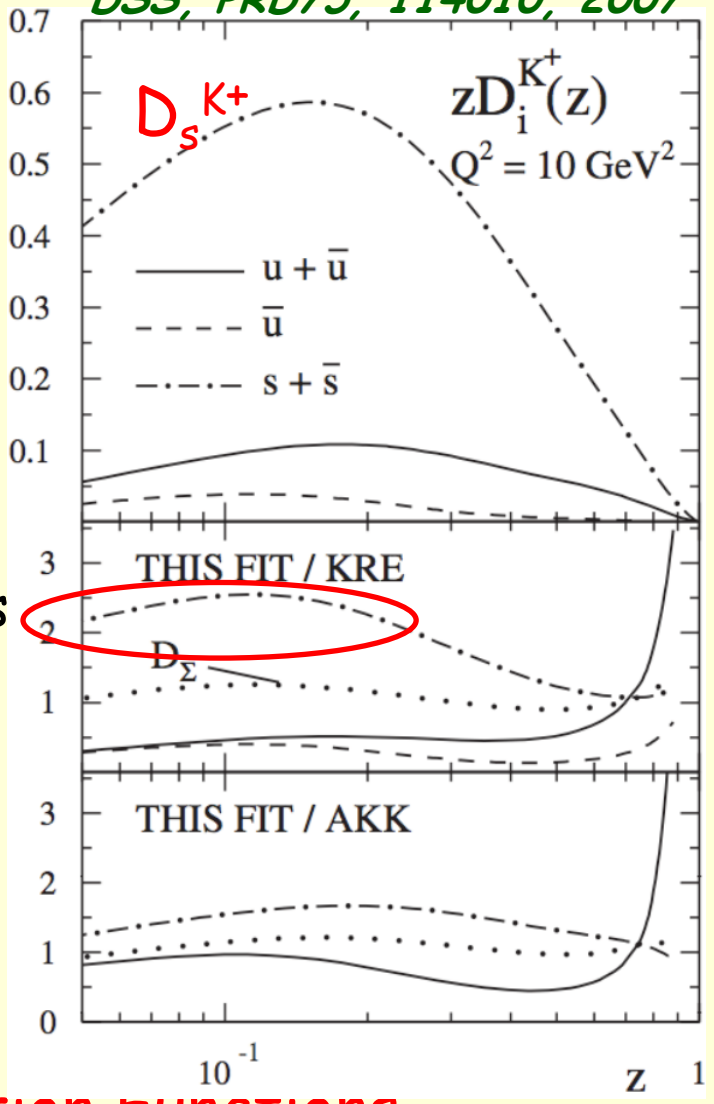
From NLO global analyses of single hadron production in e+ e- , pp collider, DIS lp, mostly high Q^2,
various assumptions

DSS analysis: SIDIS (HERMES), pp (RHIC)
→q qbar separation

Large discrepancies between various analyses

See talk of E. Christova

DSS, PRD75, 114010, 2007



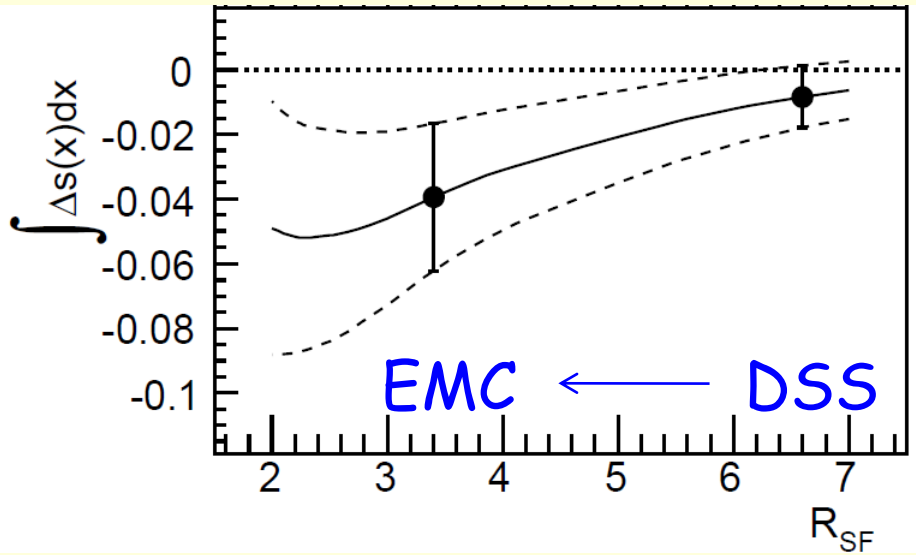
Lack of data,
→ huge uncertainties on Fragmentation Functions

Dependence on Quark Fragmentation Functions

Result depends on two ratios of FF:
'unfavoured/favoured' & 'strange/favoured'

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

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



Move simultaneously R_{UF} and R_{SF} from DSS to EMC value
→Change Δs from -0.01 to -0.04 and double error.

Isoscalar extraction of $\Delta s(x)$ (and $s(x)$)

- Use kaon multiplicities ($K^+ + K^-$) from deuteron data only

  high sensitivity to *s(x)* $\quad K^+ = u\bar{s} \qquad K^- = \bar{u}s$

- From spin asymmetries A_1^d and $A_1^{d\ (K+ + K-)}$
extract $\Delta Q = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d}$ and $\Delta S = \Delta s + \Delta\bar{s}$

Assume : isospin symmetry p & n
charge conjugation invariance in fragmentation

$$D_q^{K^+ + K^-}(z) = D_{\bar{q}}^{K^+ + K^-}(z)$$

This FF better measured at e+e-

Isoscalar extraction of $\Delta s(x)$

HERMES

Helicity distributions

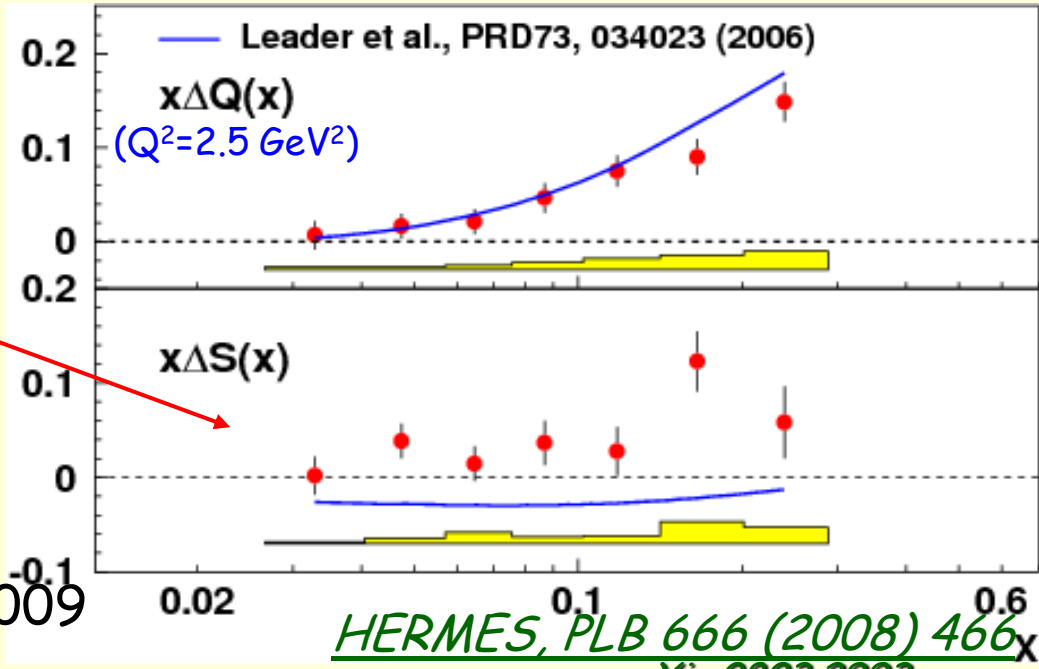
First moment in measured range $0.2<x<0.8$:

$\Delta s + \overline{\Delta s} = 0.037 \pm 0.019 \pm 0.027$

~zero or slightly >0

To be compared to result from inclusive data $0<x<1$

$\Delta s + \overline{\Delta s} = -0.085 \pm 0.013 \pm 0.008 \pm 0.009$



HERMES, PLB 666 (2008) 466
arXiv:0803.2993

Δs puzzle

Inclusive data (g_1^N & a_8 from hyperon decay +SU(3))

→ $\int \Delta s = -0.08$

While semi inclusive data → $\Delta s(x) \approx 0$

- Uncertainty on quark fragmentation functions (s-quark to K)
  - would need a factor of ~2 from DSS value of FF

- Global fits (DSSV, LSS) suggest negative Δs at low x
  - reconciles the two approaches
  - indeed COMPASS SIDIS : Δs=-0.01 with linear extrap.
    Δs=-0.05 with DSSV extrap.

- Assume SU(3) violation a_8 from0.58 to 0.42 → Δs=-0.02

Bass & Thomas, PLB684(2010) 216

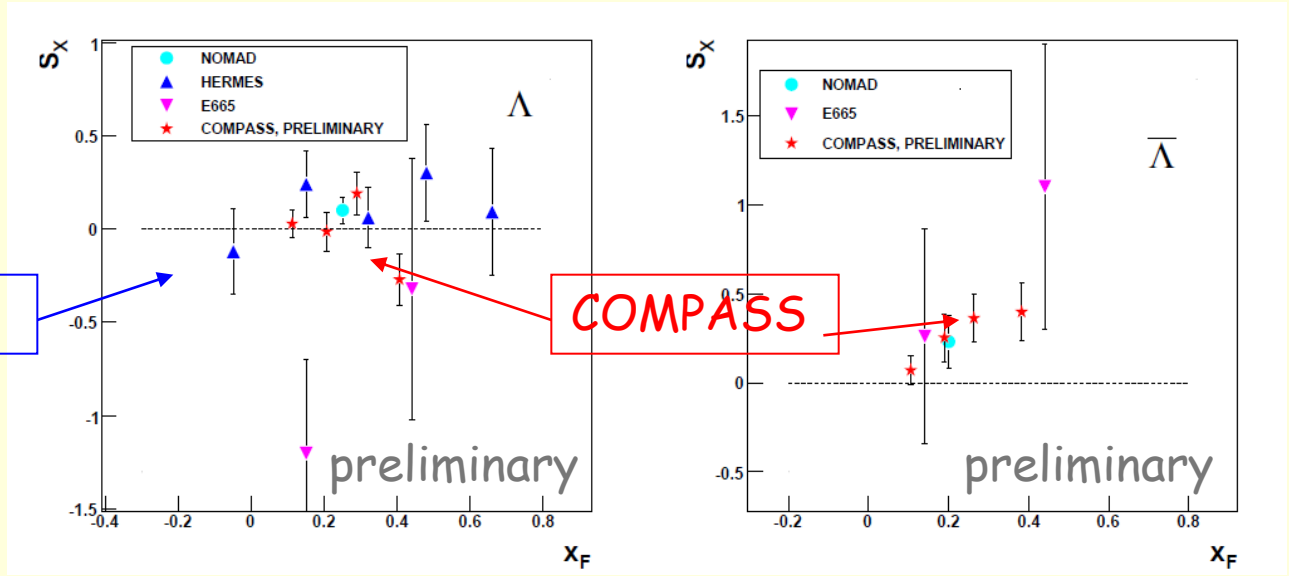
Longitudinal spin transfer to Λ & $\bar{\Lambda}$

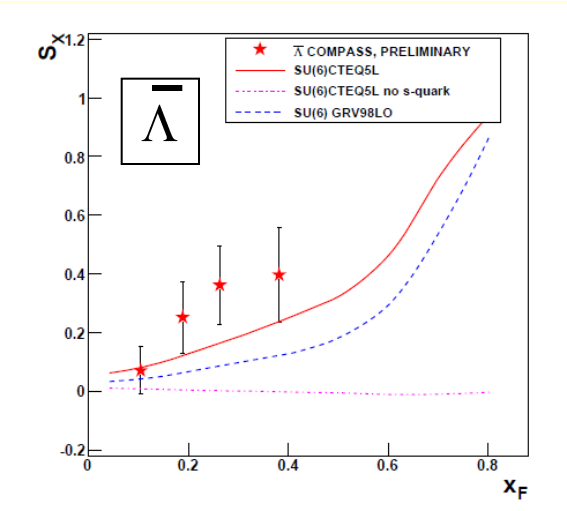
$\vec{\gamma^*}N \rightarrow \vec{\Lambda}X$

Polarized beam
Unpolarized target

HERMES

COMPASS



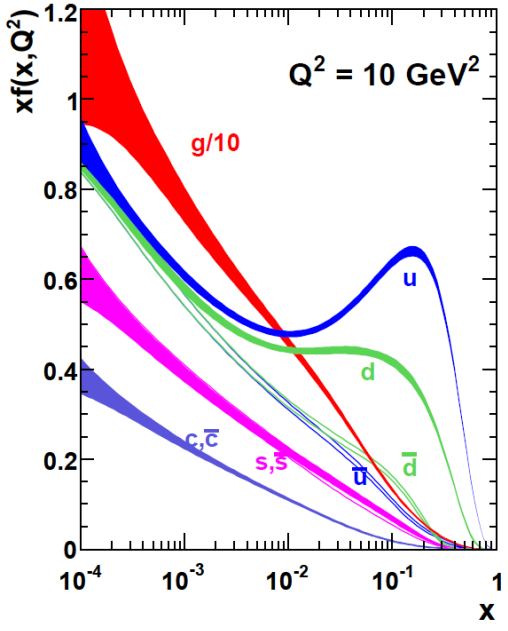


- Spin transfer for anti-Λ large and positive
- Alternate way to access s distribution and Δs if polarized target

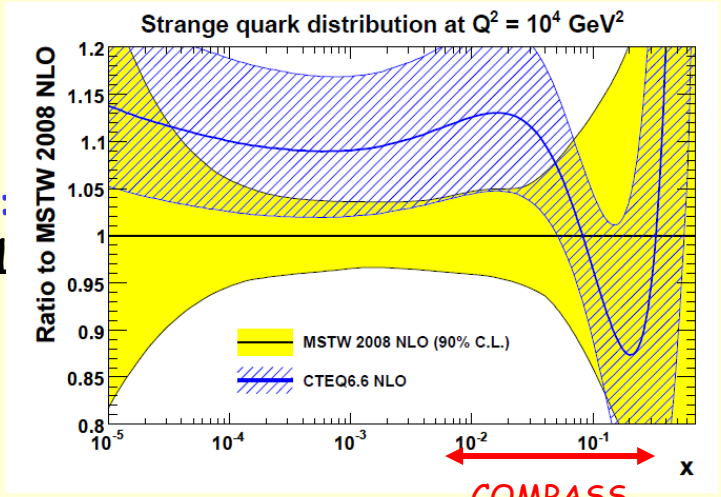
See talk of A. Kotzinian

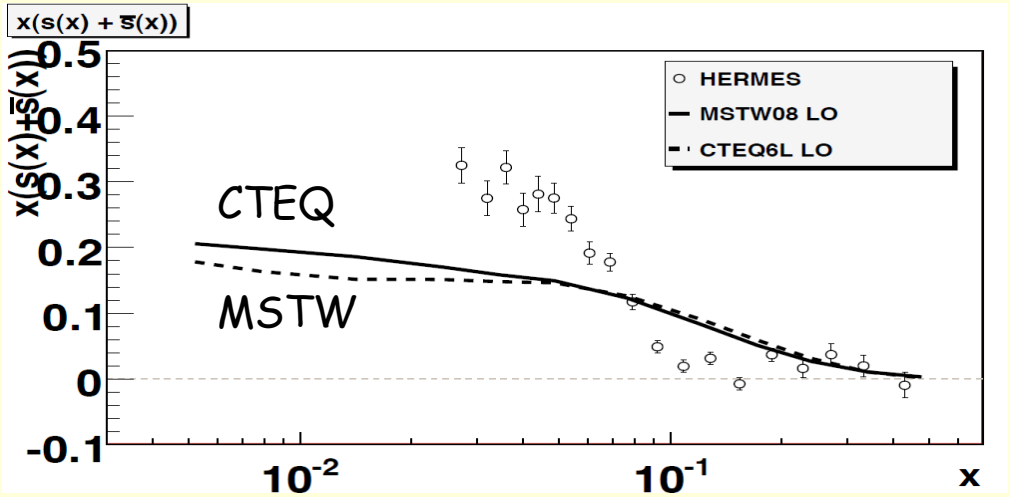
Knowledge of s(x)

MSTW
NNLO
PDF for LHC



CTEQ/MSTW08:
ratio ~ 1.1





Need more measurements

Unpolarized PDF s(x) and quark FFs

hadron multiplicities at LO

$$\frac{dN^h(x,z,Q^2)}{dN^{DIS}} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

depend on *x*

depend on *z*, fraction of energy of the outgoing hadron

→ Possibility to disentangle PDFs and FFs

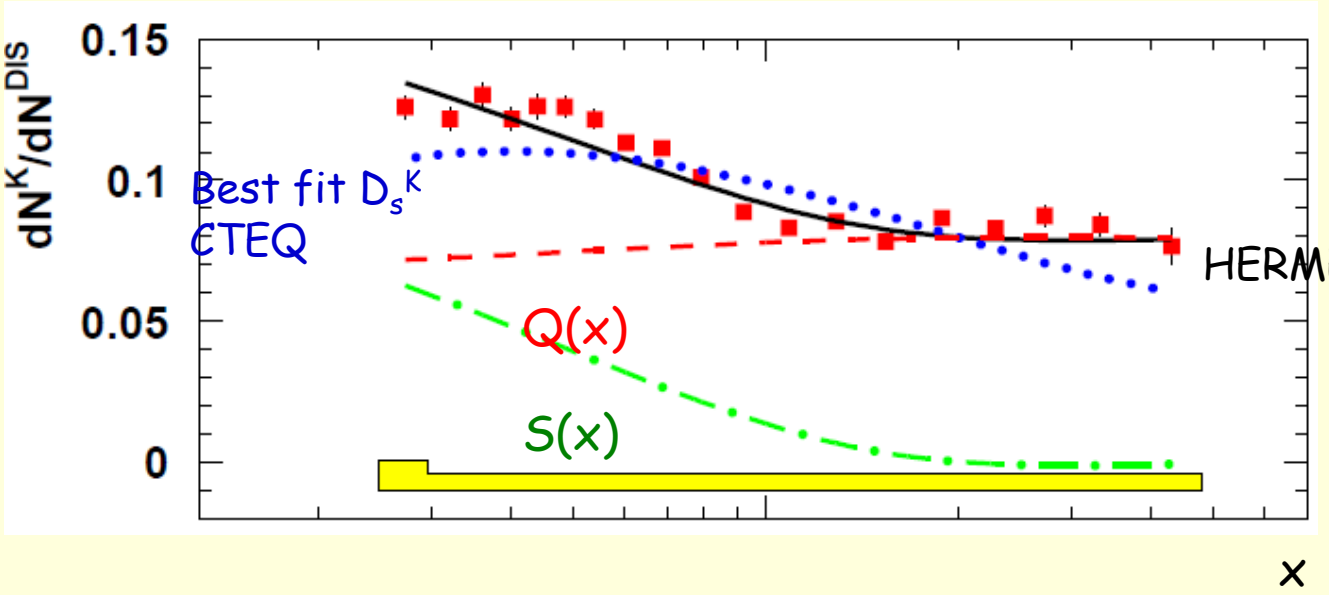
- extensive measurement (x, z,…) will provide input to NLO global analyses

- LO analysis ofdata integrated over z
  → s(x) & Fragmentation Functions (HERMES and COMAPSS)

First extraction of s(x) from SIDIS

HERMES

$K^+ + K^-$ multiplicity, d target

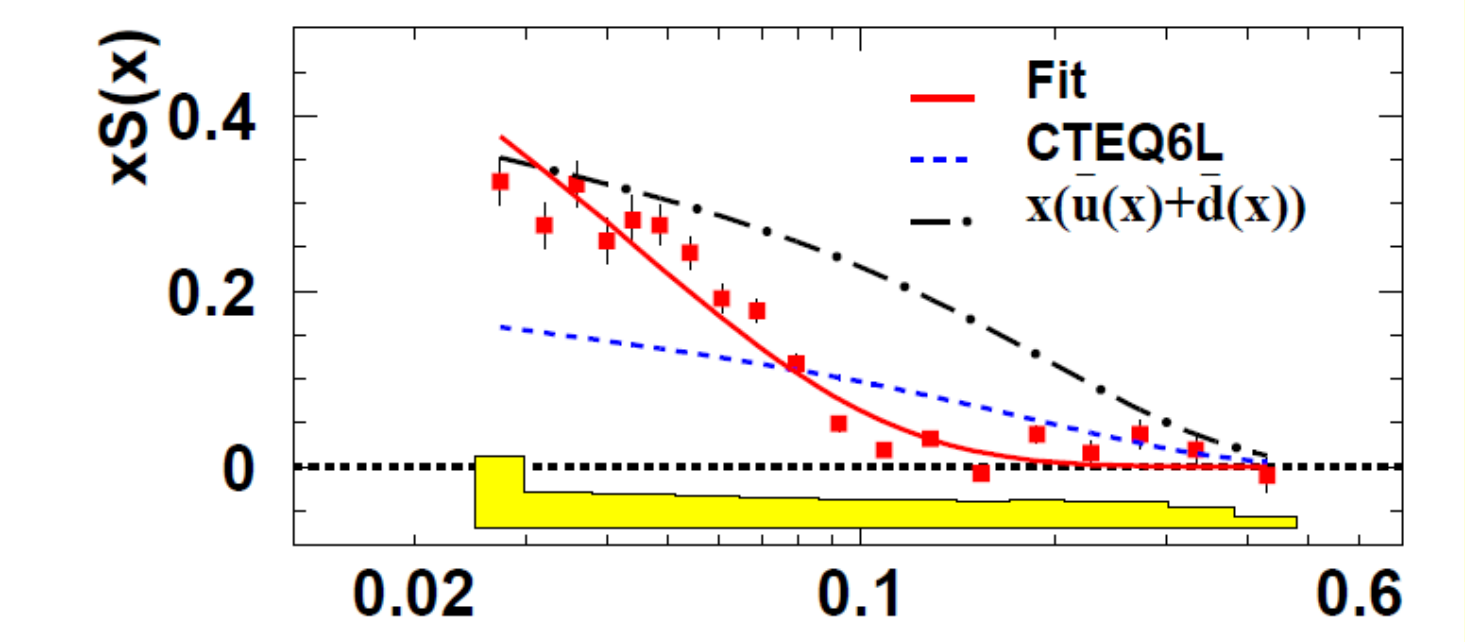


Assuming s(x) from CTEQ, best fit to D_s^K does not describe shape of multiplicity

Q(x) at large x → non strange FF
(found in agreement with DSS)
Determine $s(x).D_s^K$ at small x,

First extraction of s(x) from SIDIS

HERMES



$$S(x)\int \mathcal{D}_S^K(z)dz \simeq Q(x)\left[5\frac{\mathrm{d}^2N^K(x)}{\mathrm{d}^2N^{DIS}(x)} - \int \mathcal{D}_Q^K(z)dz\right]$$

=1.27 from DSS

Evaluated at large x, found close to DSS

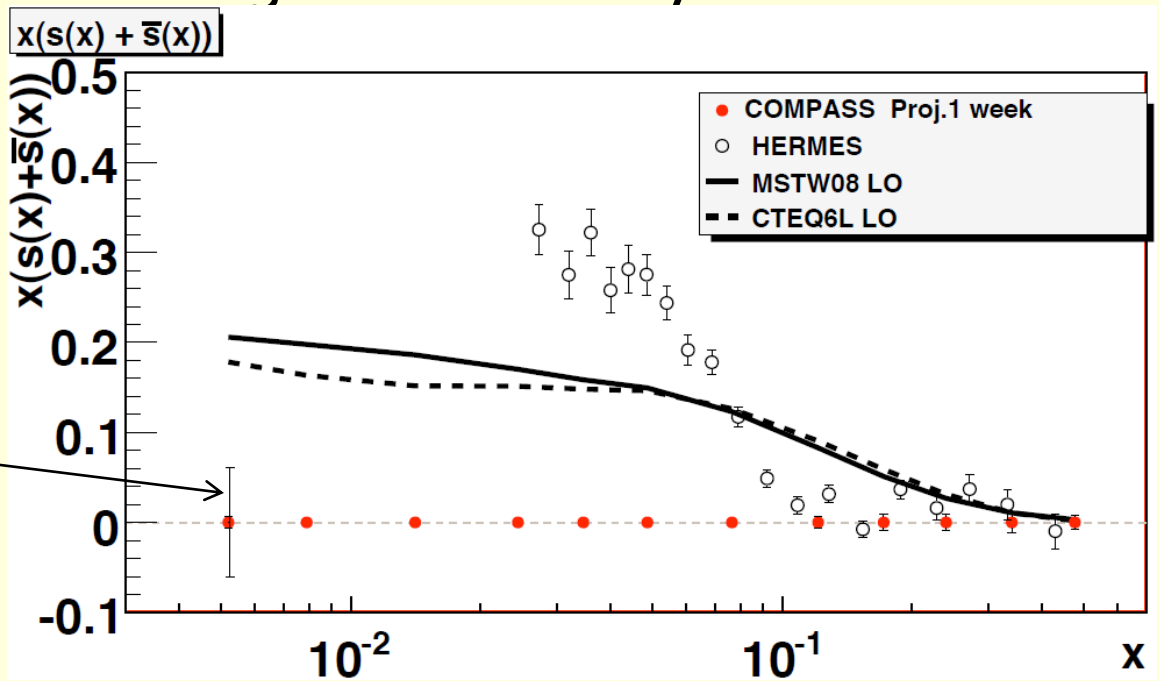
Measurement of unpolarized PDFs

New

COMPASS –II approved by CERN SPSC for initial period 2013-1015

During DVCS program, get (for free) SIDIS data on LH_2
→s(x) and quark FF from K multiplicities

Short term goal: LO analysis



Difficulties:
- determination of absolute acceptance
- separation of FF and PDFs

Longer term goal : π and K multiplicities as fct of x, z for global QCD analyses

Summary

- Strange quark polarization

$\Delta s(x) \sim 0$ from SIDIS in measured region,
while $\int \Delta s < 0$ from DIS
Still various possible explanations

- Strange quark distribution

Discrepancies between various parameterizations

More SIDIS measurements to come on:
- kaon multiplicities
- kaon spin asymmetries
→ Will improve knowledge on FF, $\Delta s(x)$ and $s(x)$

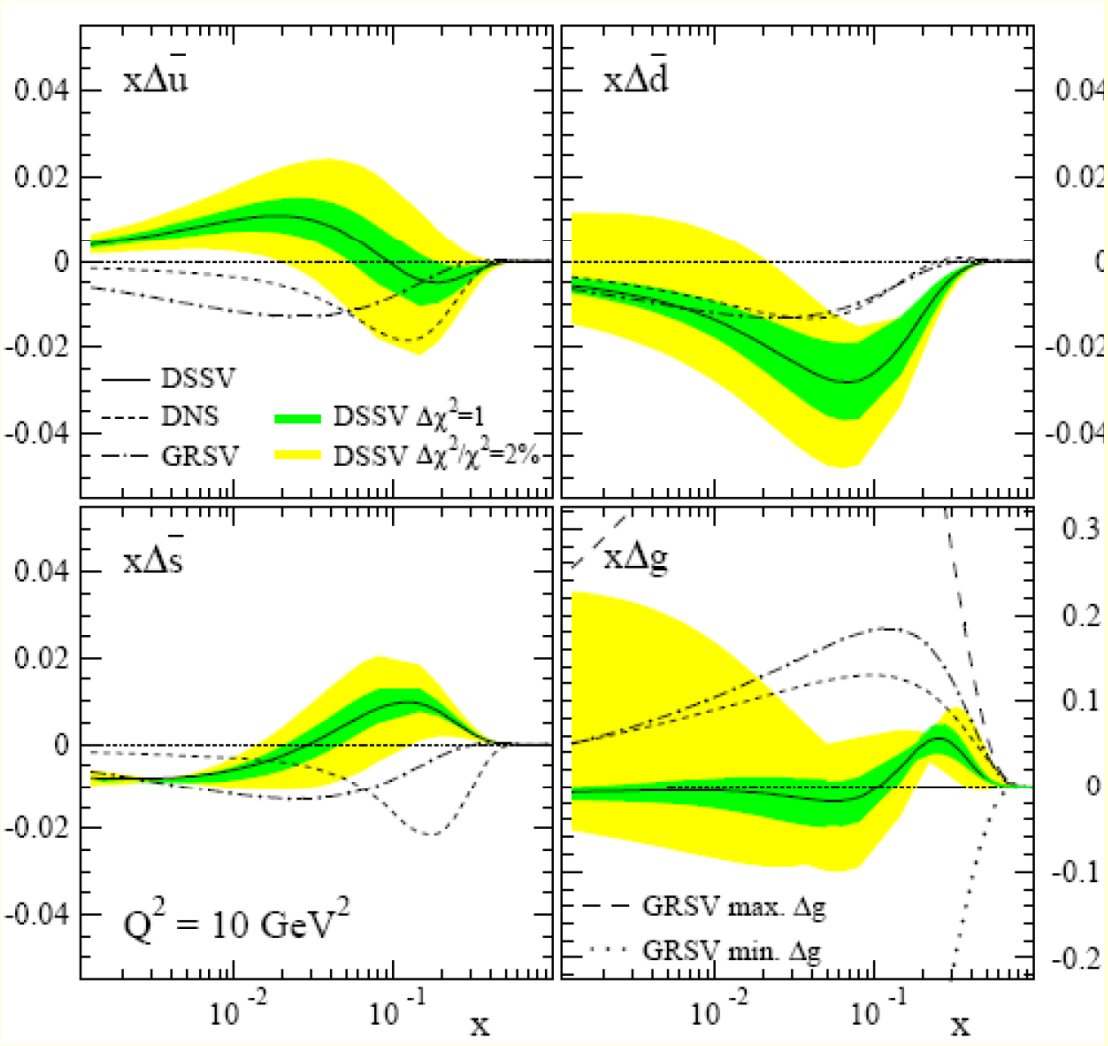
spares

HERMES quark helicity distributions

- $0.02<x_{Bj}<0.6$
- $\Delta q_8=\Delta Q-2\Delta S$
- $\Delta q_8=\int_0^1 \Delta q_8(x)dx$ =0.586+- 0.031 from hyperon decay and SU(3) symmetry

	Moments in measured range
ΔQ	$0.359 \pm 0.026(\text{stat.}) \pm 0.018(\text{sys.})$
ΔS	$0.037 \pm 0.019(\text{stat.}) \pm 0.027(\text{sys.})$
Δq_8	$0.285 \pm 0.046(\text{stat.}) \pm 0.057(\text{sys.})$

NLO QCD analyses of world data



DSSV
PRL101(2008)072001
$\Delta G = -0.1 \pm 0.1$
$\Delta s < 0$ at low x
> 0 at $x \sim 0.1$

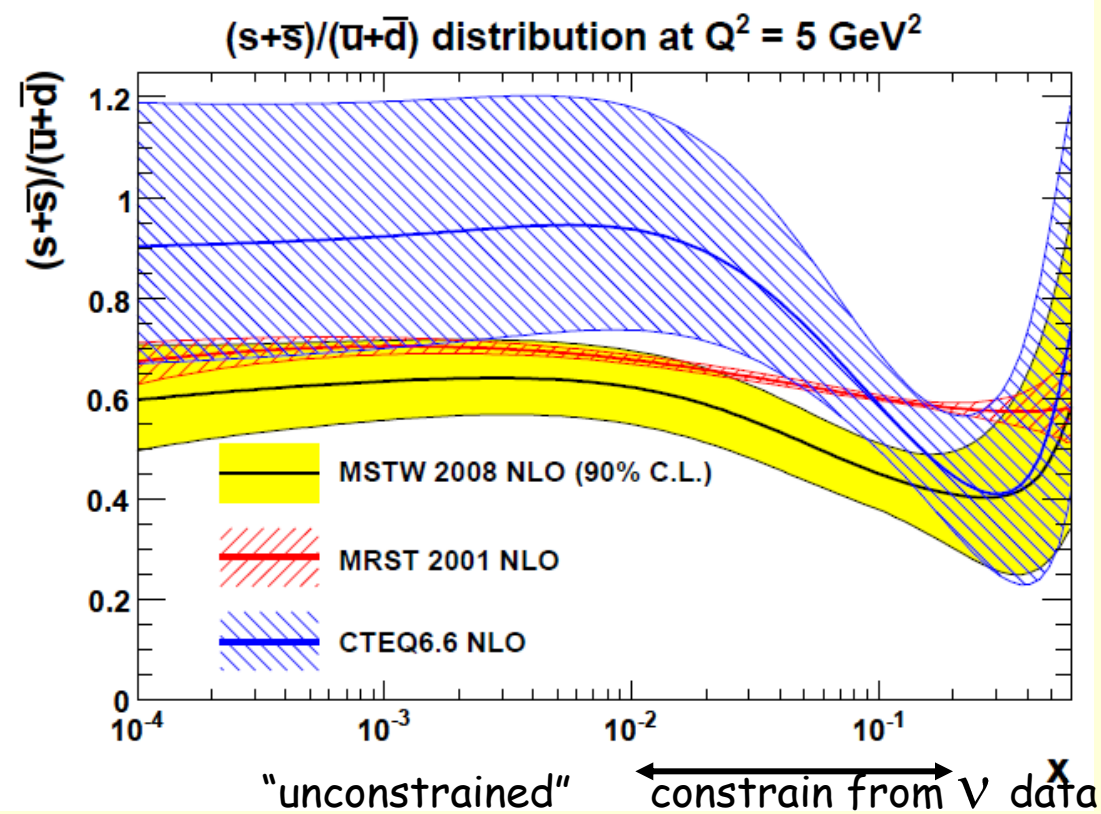
(s+sbar) /(ubar+dbar) CTEQ & MWST08

$$\int_0^1 \mathrm{d}x \ \left[s(x,Q^2) - \bar{s}(x,Q^2)\right] = 0$$

$s = \bar{s} = \frac{\kappa}{2}(\bar{u} + \bar{d})$ was assumption in previous fit with k=0.4-0.5

s+sbar and s-sbar now parameterized separately

Wider error band vs MRST01



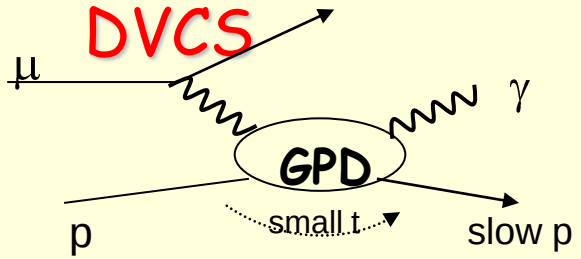
Future: COMPASS II

New

approved by CERN SPSC for initial period 2013-1015

- GPD (Generalized Parton Distributions) $\mu p \rightarrow \mu p \gamma$

by exclusive reactions DVCS (Deep Virtual ComptonScattering)
and DVMP (Meson production),
2 year 'beam charge and spin asymmetry' measurement



- Polarized Drell-Yan $\pi p^{\uparrow} \rightarrow \mu^+\mu^- X$

Sivers & Boer-Mulders
Transverse Momentum Dependent distributions
1 year with transversely polarised proton target
Test of factorization approach :
Comparison SIDIS/ Drell-Yan