Strange quark polarization & Quark Fragmentation Functions

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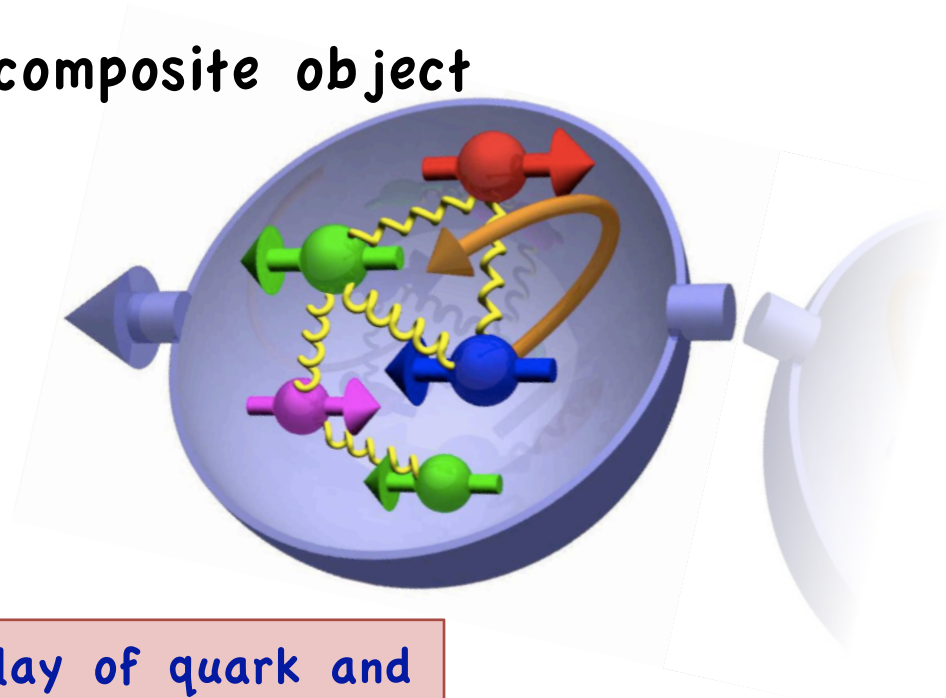
Nucleon Spin Structure

Quark Model/QCD: proton is a composite object

How ½ spin is build ?



Spin ½ must be a result of an interplay of quark and gluon spins and their angular momenta

Spin Sum Rule : $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q,g}$

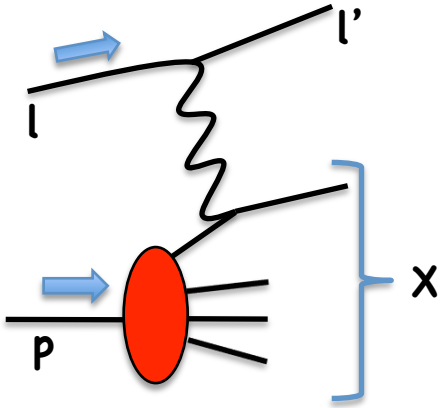
Quark Gluon Orbital momentum

$(\Sigma_q \Delta q)$

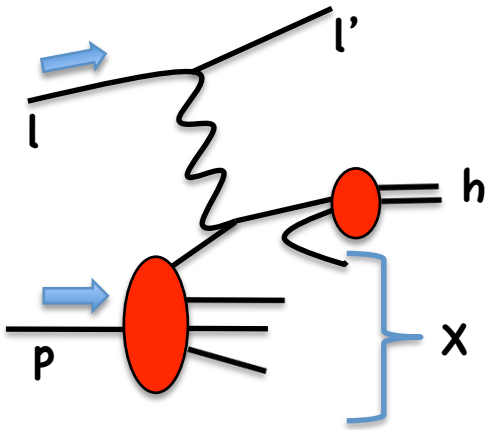
How to look inside the nucleon ?

Probes of Nucleon (Spin) structure

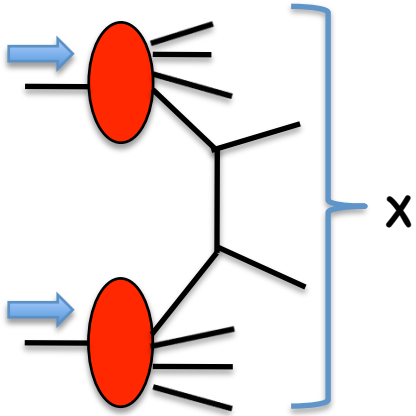
- Information on nucleon (spin) structure can be extracted from different processes :



Deep Inelastic Scattering(DIS) :
l + p -> l' + X



Semi Inclusive DIS (SIDIS) :
l + p -> l' + h + X



hadron-hadron
h + h -> X

- All processes contain information on nucleon spin.
- Each process provides different kind of information.
  DIS: $\Delta q+\Delta\bar{q}$ SIDIS: $\Delta q,\Delta\bar{q}$ hadron-hadron: $\Delta q,\Delta\bar{q},\Delta g$

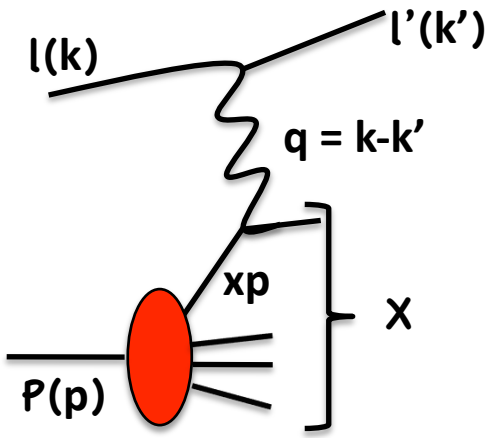
Best knowledge of polarized PDFs emerges from a global QCD analysis fitting all existing data.

How to describe Deep Inelastic Scattering process ?

Basics of the DIS process

- **Inclusive DIS**

  only scattered lepton is detected



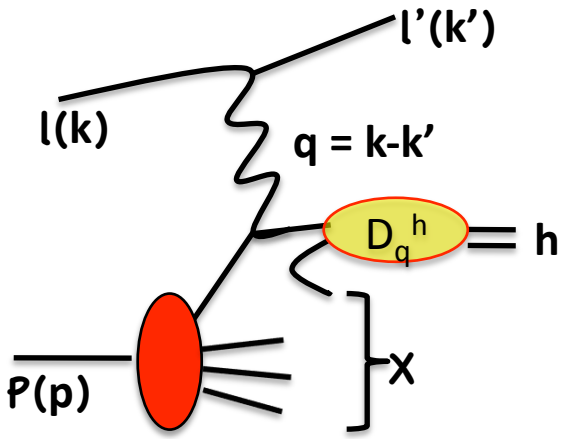
Kinematic variables :

$$Q^2 = -q^2 \quad x = \frac{Q^2}{2p.q} \quad y = \frac{p.q}{p.k}$$

- Q^2 : Photon virtuality => resolution at which proton is probed
- x : momentum fraction of struck parton in the proton
- y : momentum fraction lost by lepton (carried by virtual photon)

Deep inelastic : $Q^2 > 1$ GeV^2

- **Semi-inclusive DIS (SIDIS):**

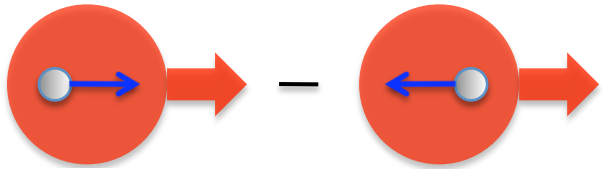


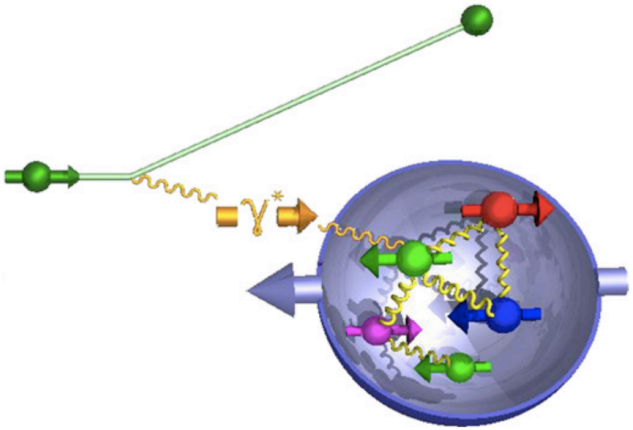
At least one hadron is detected in addition to scattered lepton.

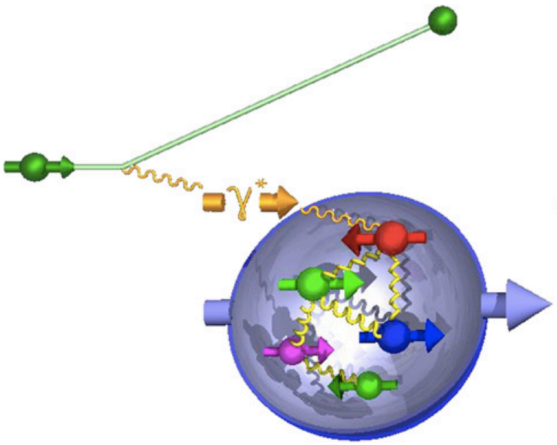
D_q^h probability that a quark of type q fragments into hadron of type h

Spin Asymmetries and Δq

Scattering of longitudinal polarized leptons off polarized nucleons provides information on

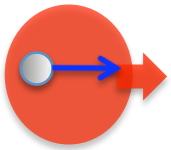
$\Delta q \equiv$ 



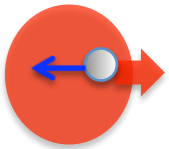


helicity conservation

$S_\gamma + S_N = 1/2 \rightarrow \sigma_{1/2}$

γ^* probes 

$S_\gamma + S_N = 3/2 \rightarrow \sigma_{3/2}$

γ^* probes 

Longitudinal Spin Asymmetries

$$A = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

- Inclusive case
- Semi Inclusive case

Spin Asymmetries and Δq

Longitudinal Spin Asymmetries

- **Inclusive case**

$$A = \frac{\sum_q e_q^2 \Delta q(x, Q^2)}{\sum_q e_q^2 q(x, Q^2)}$$

-> 1 equation

- **Semi Inclusive case**

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

-> 1 equation for each type of hadron

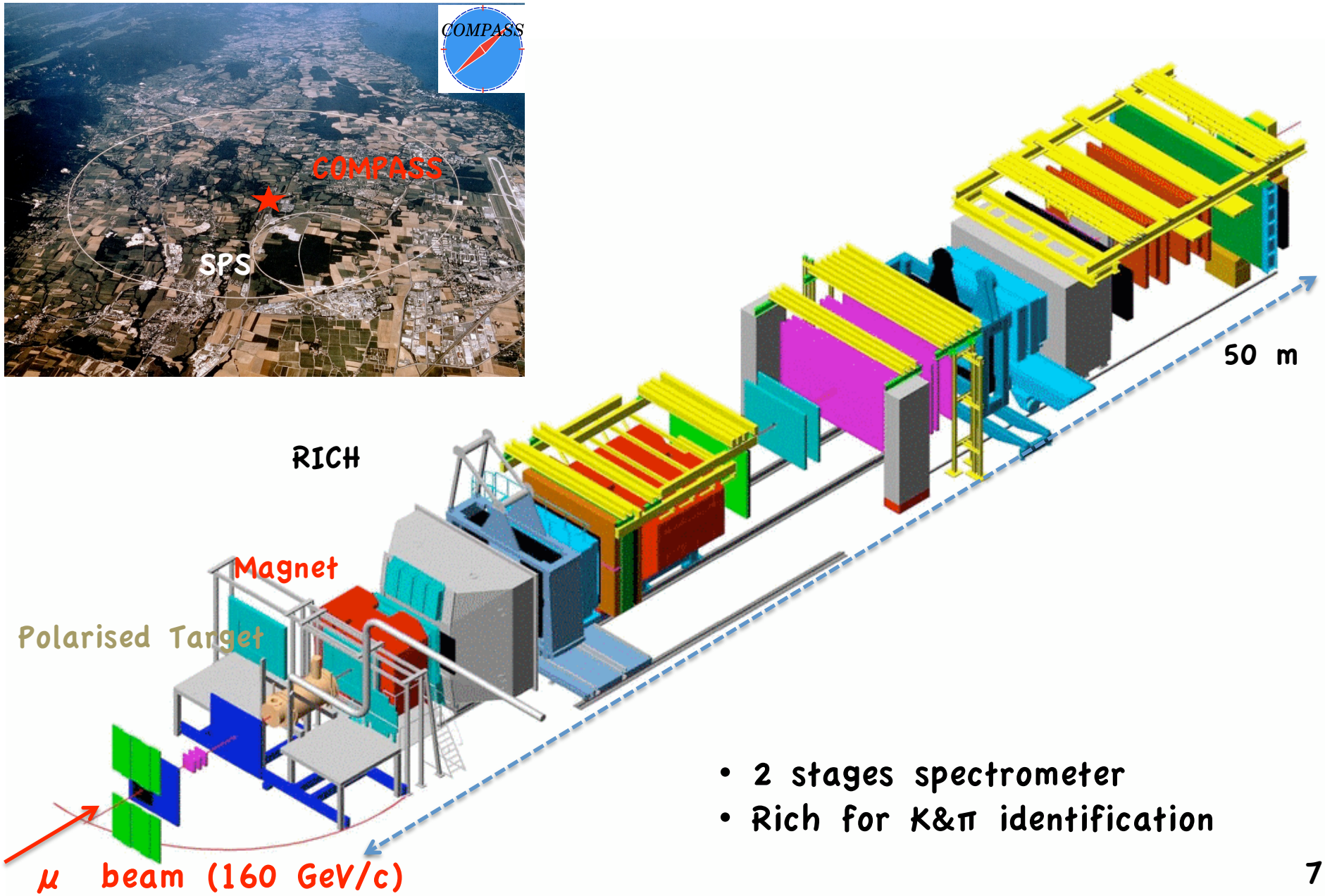
$$A_i = \Sigma_j M_{ij} (q, D_q^h) \cdot \Delta q_j$$

experimentally measured — unknowns

Taking unpolarized quark distributions $q(x,Q^2)$ and fragmentation functions from parametrizations, extraction of Δq is possible.

=> Extraction of Δq

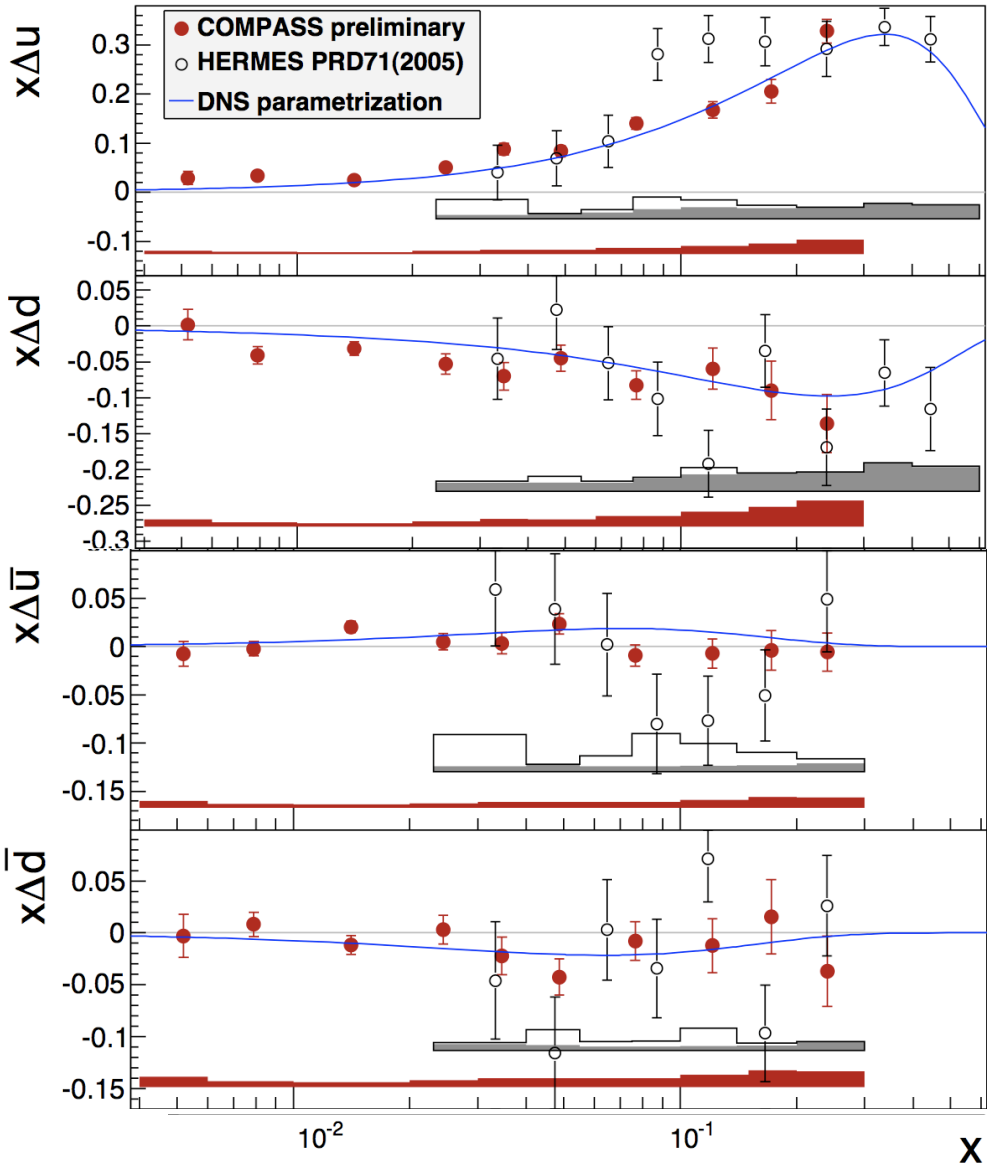
COMPASS Experiment At CERN



- 2 stages spectrometer
- Rich for K&π identification

Polarized Quark Distributions

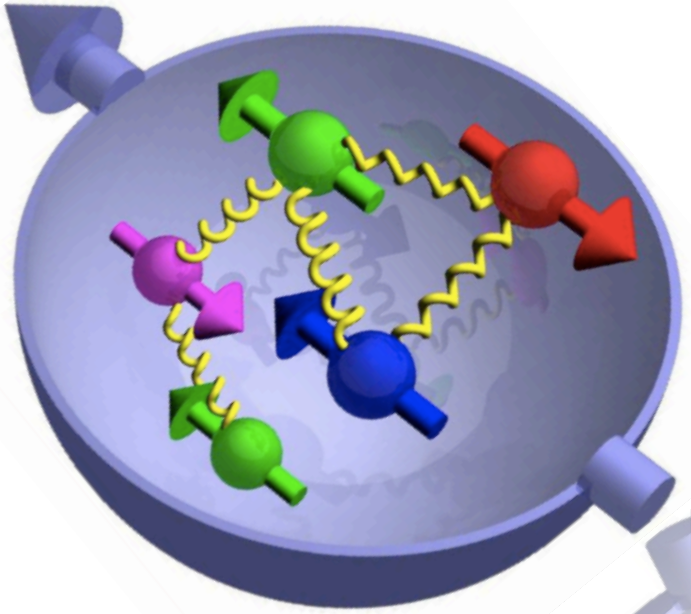
— DNS : global fit of DIS data



COMPASS Collaboration Phys. Lett. B693 (2010) 227

- Polarized sea quark distribtions ~0
- Good agreement with global fits of (DIS) data and Combined (DIS & SIDIS) data.

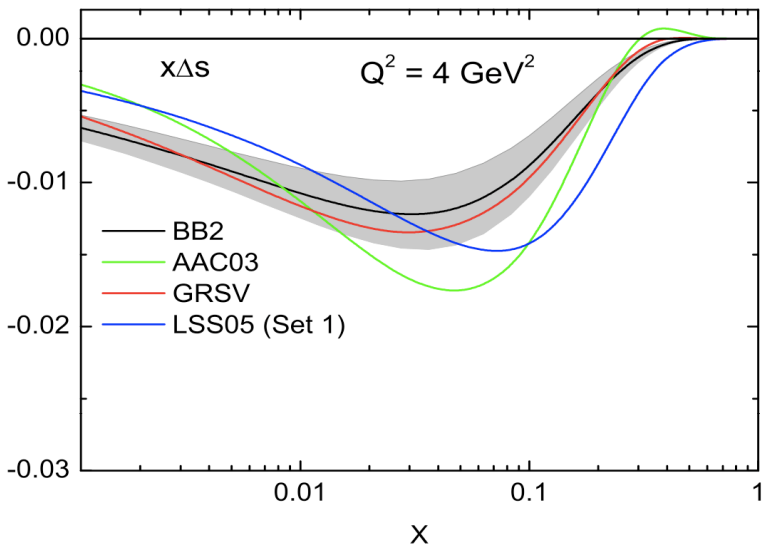
No problem with Polarized up and down quarks & antiquarks.



What about polarization of strange quark ?

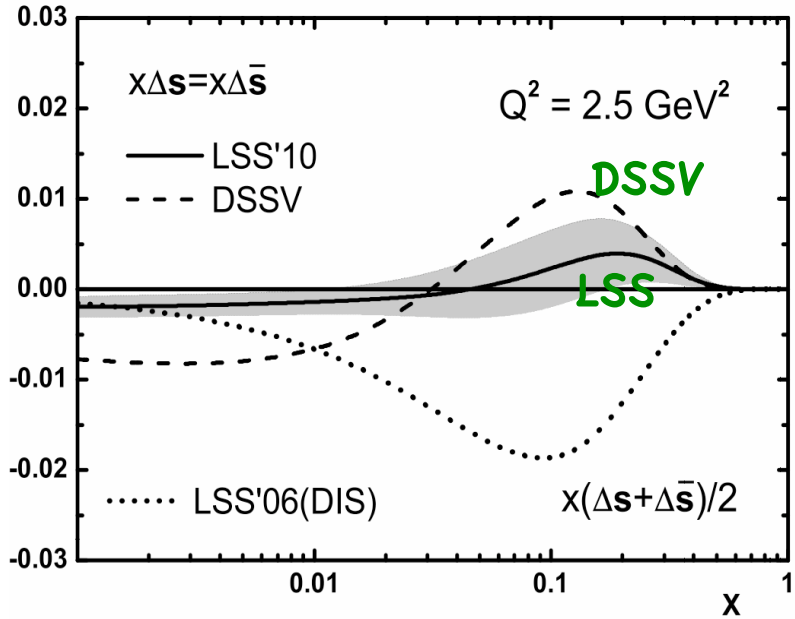
Polarized Strange Quark Distribution

- All QCD global fits of inclusive DIS data give negative value for Δs.



- 2 NLO QCD global fits of combined DIS & SIDIS data exist and give :
  - positive Δs at large x.
  - negative Δs at small x.

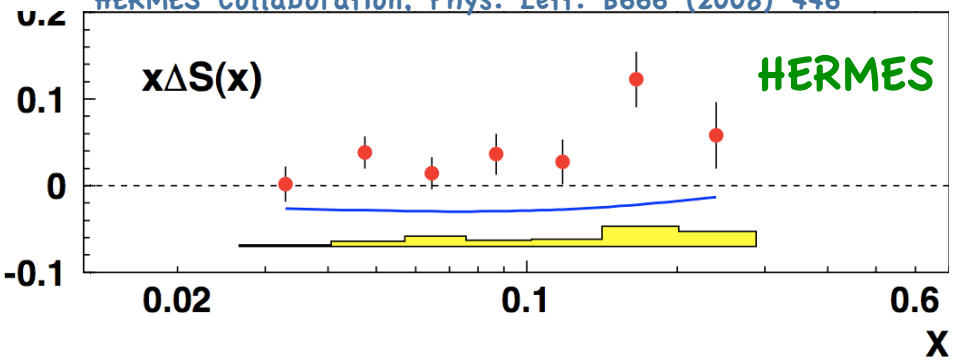
Leader, Sidorov, Stamenov, arXiv 1010.0547



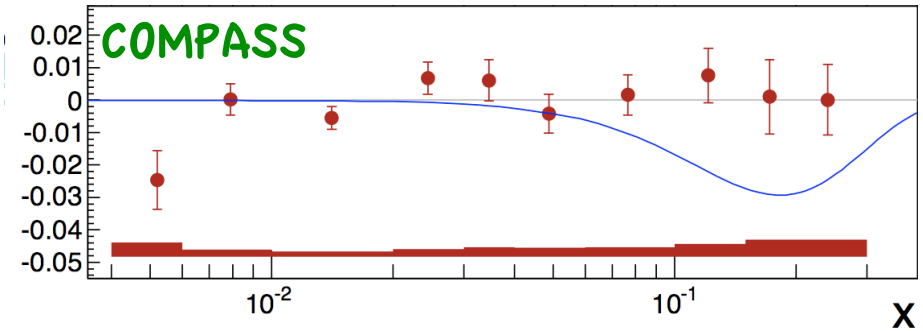
Polarized Strange Quark Distribution

Experimental extraction of Δs :

HERMES Collaboration, Phys. Lett. B666 (2008) 446



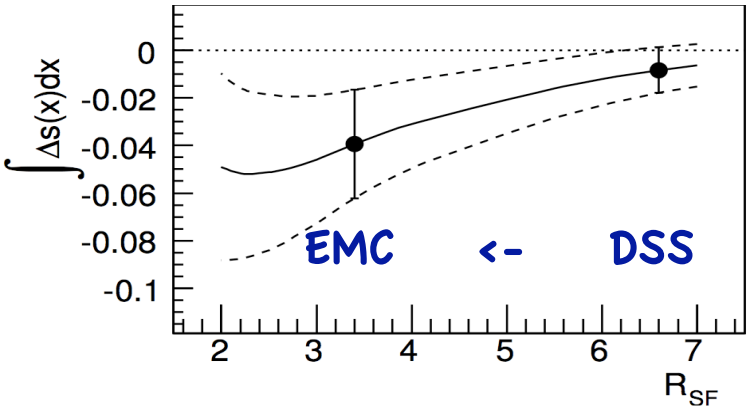
COMPASS Collaboration Phys. Lett. B693 (2010) 227



LO extraction, using DSS, by HERMES & COMPASS disagree with QCD fits of DIS data

BUT Result relies on :

- Kaon Fragmentation functions



- Unpolarized PDFs :

HERMES s(x) result found to be in disagreement with CTEQ.

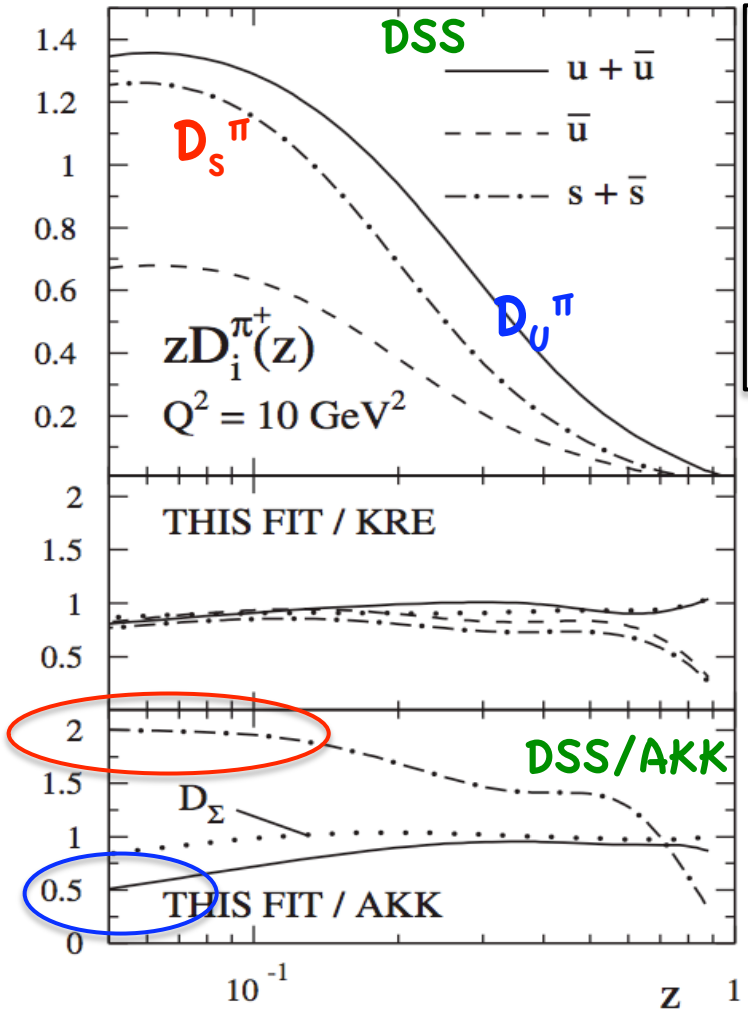
What do we know about Fragmentation functions ?

Status of Fragmentation functions

Several parametrization of FFs exist.

- different assumptions used (and data sets)
- disagreement among themselves.

De Florian, Sassot, Stratmann Phys. Rev. D 75, 094009 (2007)



Assumptions in DSS, KRE & AKK (example)

DSS,KRE : fav and unfav FFs are proportional => 4 FFs

AKK : all fav. FF are equal & 2 unfav. FF => 3 FFs

Different assumptions give different fragmentation functions.

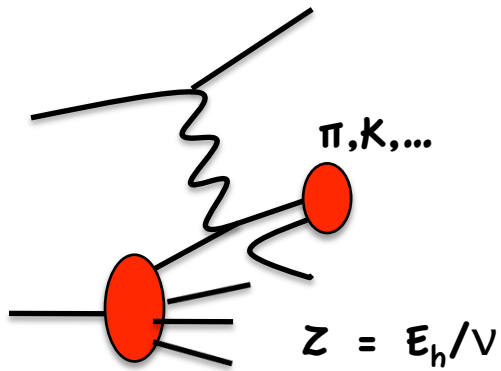
An extraction of FFs directly from data is needed.

Fragmentation functions from Hadron Multiplicities

Hadron Multiplicities are defined as the avereged number of hadrons per DIS event

PDFs FFs

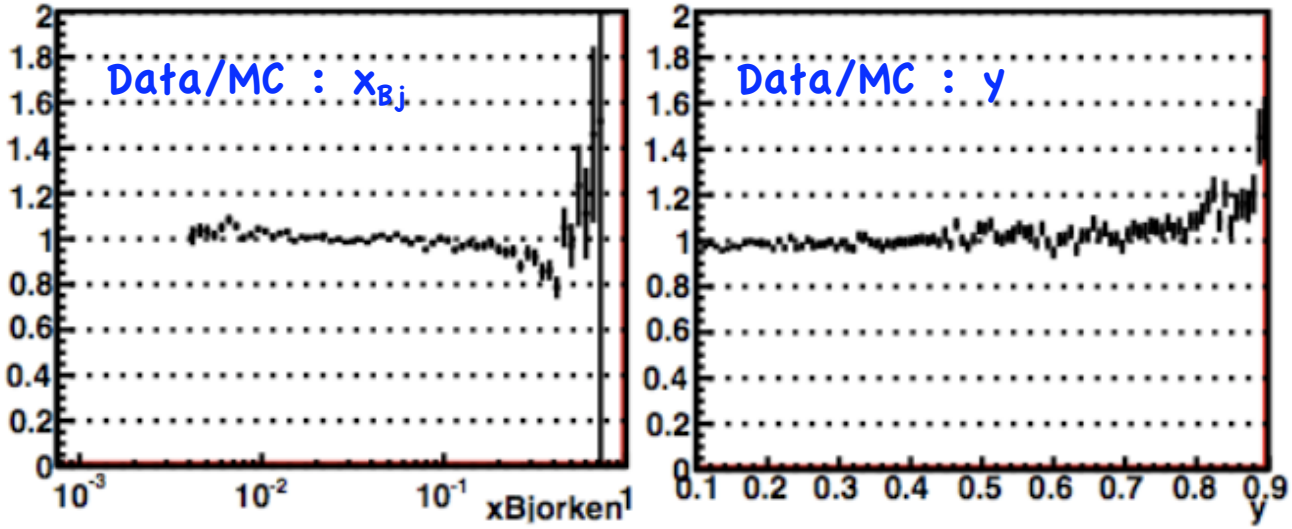
$$\frac{1}{N^{DIS}} \frac{dN^h}{dx\, dz\, dQ^2} = \frac{\sum_q e_q^2\, q(x,Q^2)\, D_q^h(z,Q^2)}{\sum_q e_q^2\, q(x,Q^2)}$$



Extraction of FFs

- Raw hadron multiplicities from Data
- Correction for acceptance & smearing
  - MC sample of events (deuteron target).

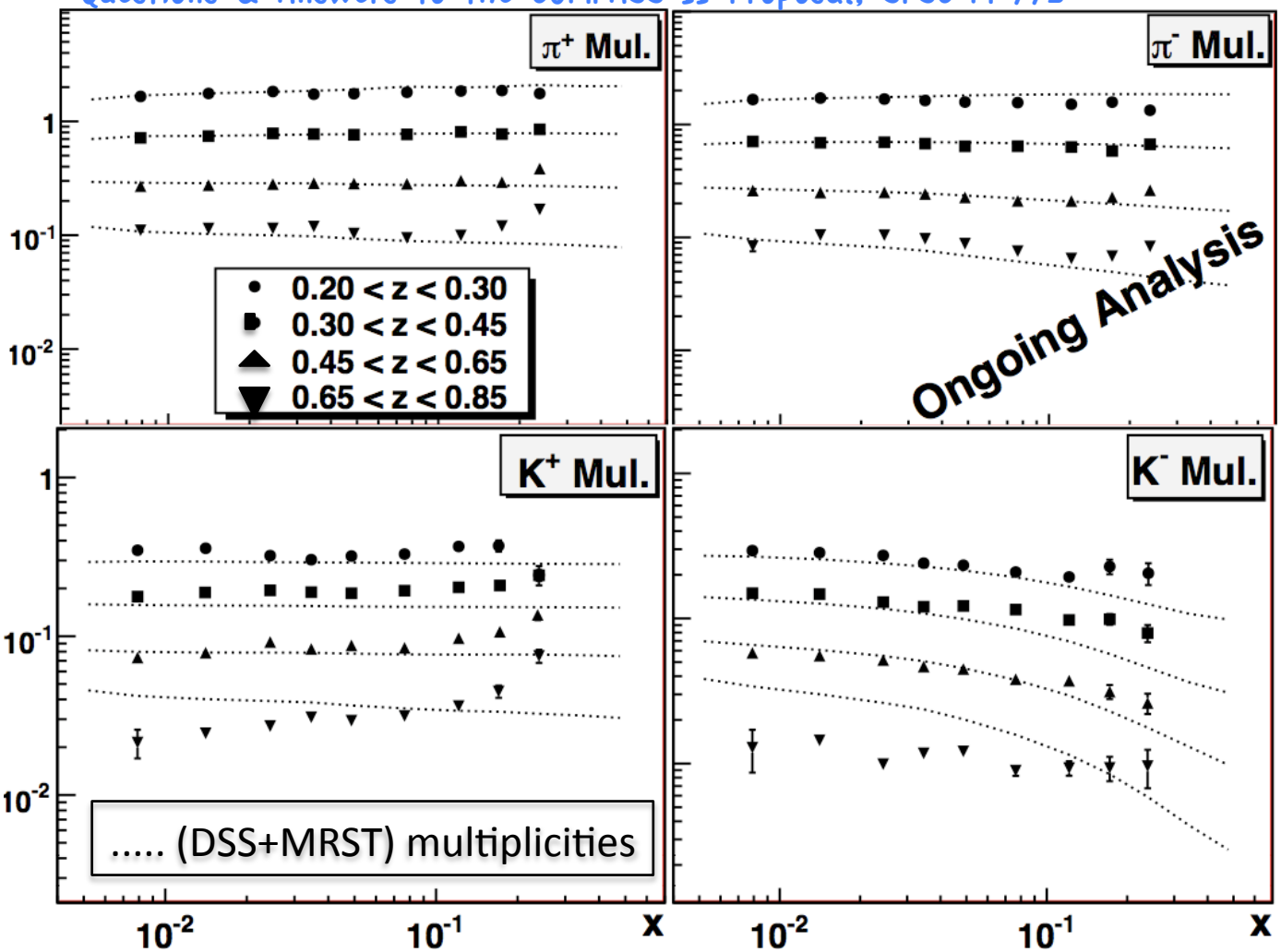
Good description of data by MC



Corrected Hadron Multiplicities ($\pi^{\pm}$,$K^{\pm}$)

2D Corrected Hadron multiplicities as a function of x & z.

Questions & Answers to the COMPASS-II Proposal, SPSC-M-772



Kinematical domain

- Q2 > 1
- 0.1 < y < 0.9
- 0.2 < z < 0.85

- only Statistical errors shown
- Systematics errors dominate (RICH, MC)
- Q^2 evolution not included.

Conclusion

- Negative Δs from inclusive DIS data.
- $\Delta s(x)$ compatible with zero in measured range

  Uncertainty on quark fragmentation functions (D_s^K : strange FF to K)

  -> Need the extraction of FFs from data.

- Ongoing extraction of COMPASS Pion & kaon Multiplicities on deuteron target.
  - Extraction of FFs (quark FFs to π & K).
  - Extraction of unpolarized s(x).
  - Include Pion and kaon multiplicities in global QCD fits.

How to extract Fragmentation functions

Multiplicity for an hadron of type h, for deuteron target :

$$\frac{1}{N^{DIS}}\frac{dN^h}{dx} = \frac{(u+d)(4D_u^h + D_d^h) + (\bar{u}+\bar{d})(4D_{\bar{u}}^h + D_{\bar{d}}^h) + 2(sD_s^h + \bar{s}D_{\bar{s}}^h)}{5(u + \bar{u} + d + \bar{d}) + 2(s + \bar{s})}$$

$h = \pi^+, \pi^- \rightarrow D_{q,\bar{q}}^{\pi+,\ \pi-} \rightarrow$ 12 FF

- charge conjugation ($D_q^{h+} = D_{\bar{q}}^{h-}$) $\rightarrow$ 6 FF
- assumption : favored FF are equal
  unfavored FF are equal } 3 FF

$D_1 = D_{fav}^{\pi}, \quad D_2 = D_{unf}^{\pi}, \quad D_3 = D_s^{\pi}$

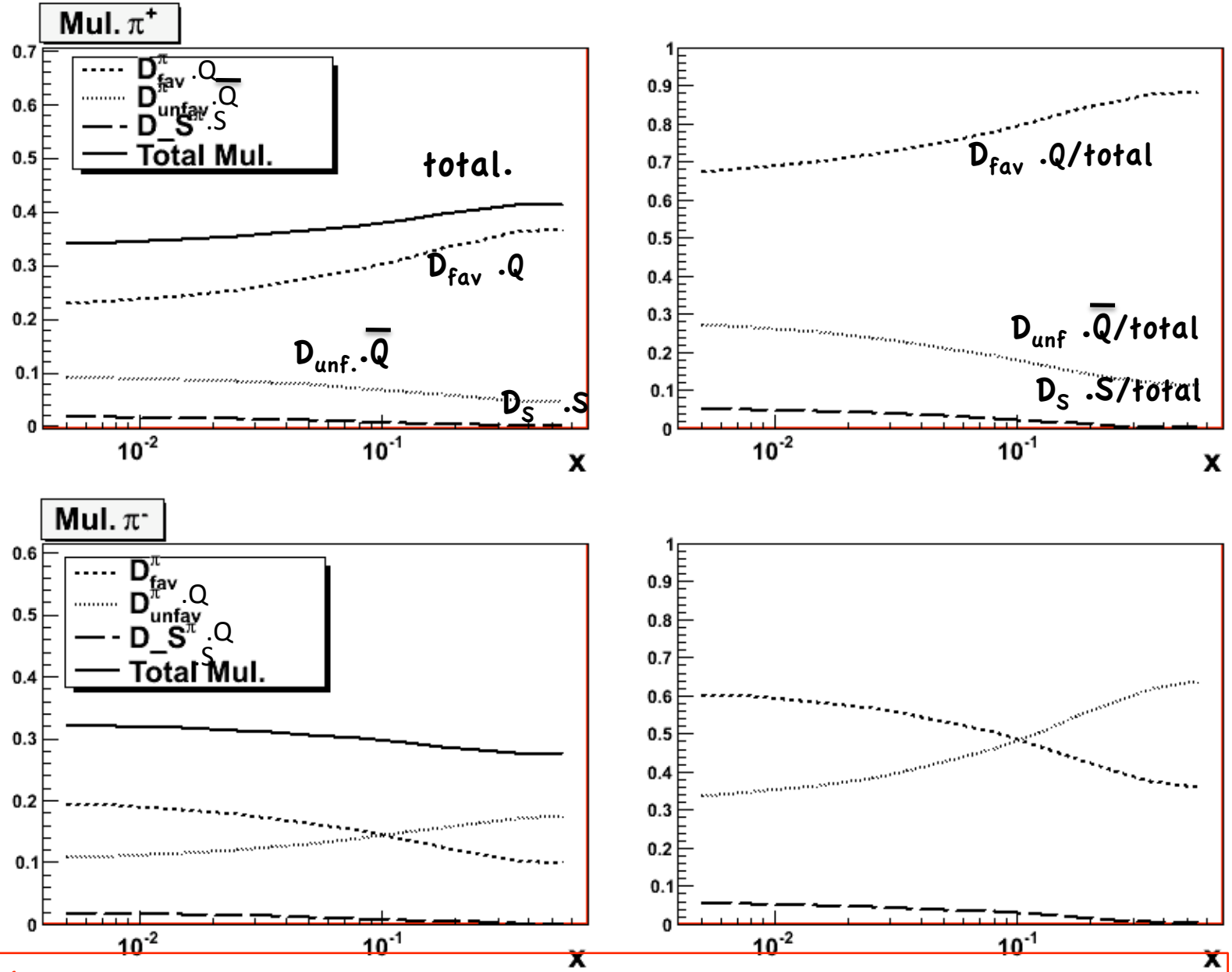
$$\frac{dN^{\pi+}}{dN^{DIS}} = \frac{[4(u+d)+\bar{u}+\bar{d}]D_1 + [u+d+4(\bar{u}+\bar{d})]D_2 + 4s)D_3}{5Q + 2S}$$

$$\frac{dN^{\pi-}}{dN^{DIS}} = \frac{[4(\bar{u}+\bar{d})+u+d]D_1 + [\bar{u}+\bar{d}+4(u+d)]D_2 + 4s)D_3}{5Q + 2S}$$

16 equations
&
3 unkowns

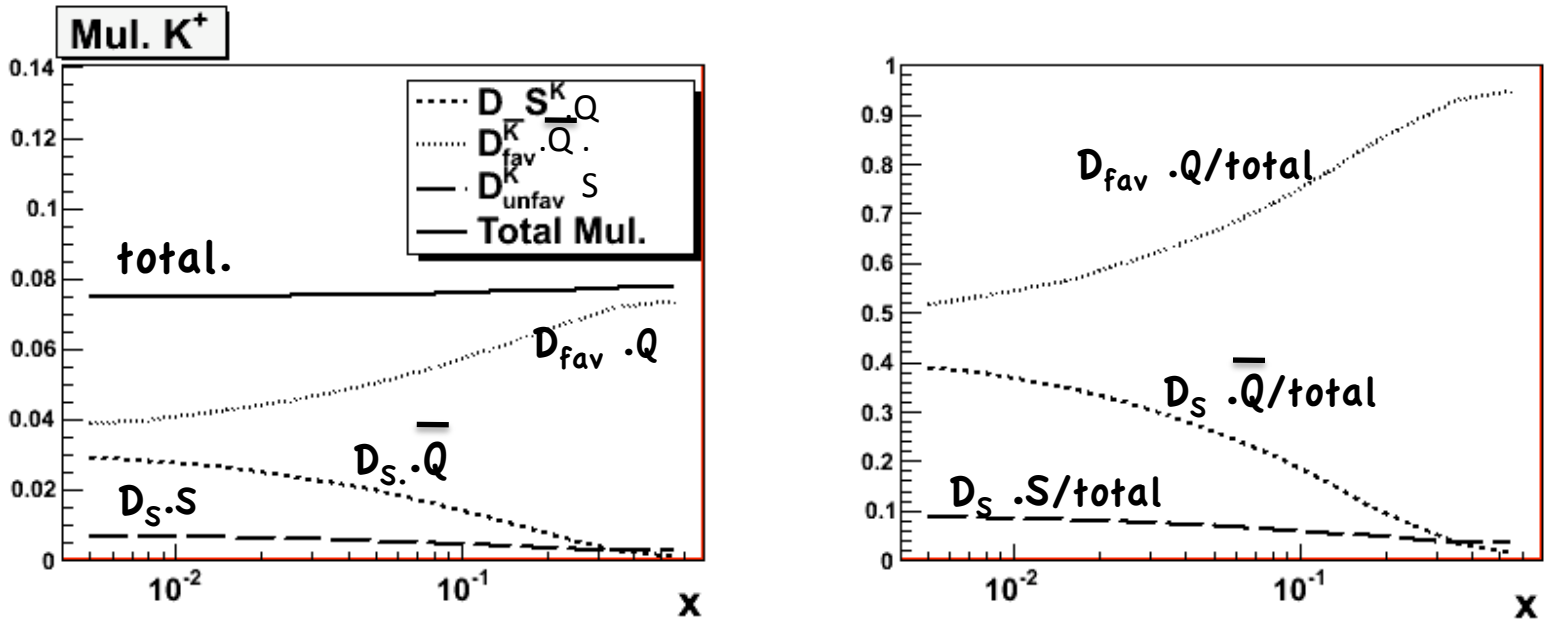
... System of equations to solve ....

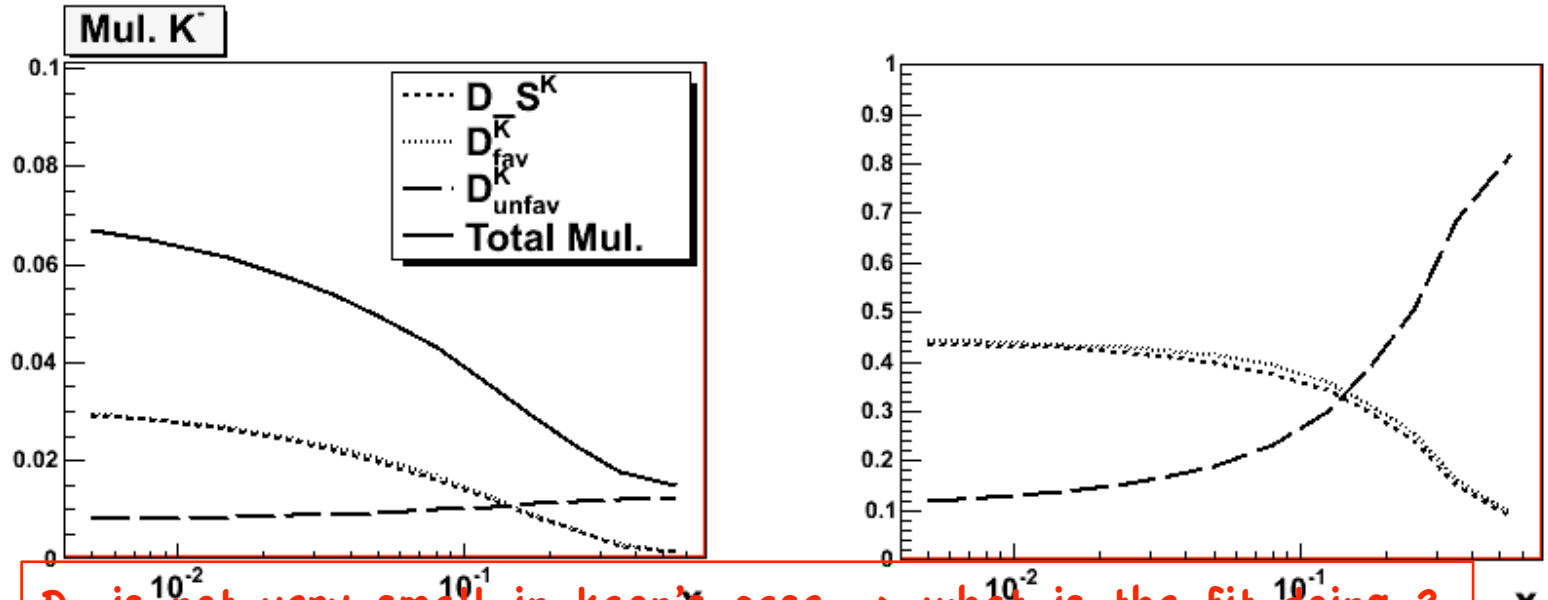
Pion multiplicities calculated using DSS+MRST



D_S is the smallest contribution to total multiplicities => Hard to extract it.

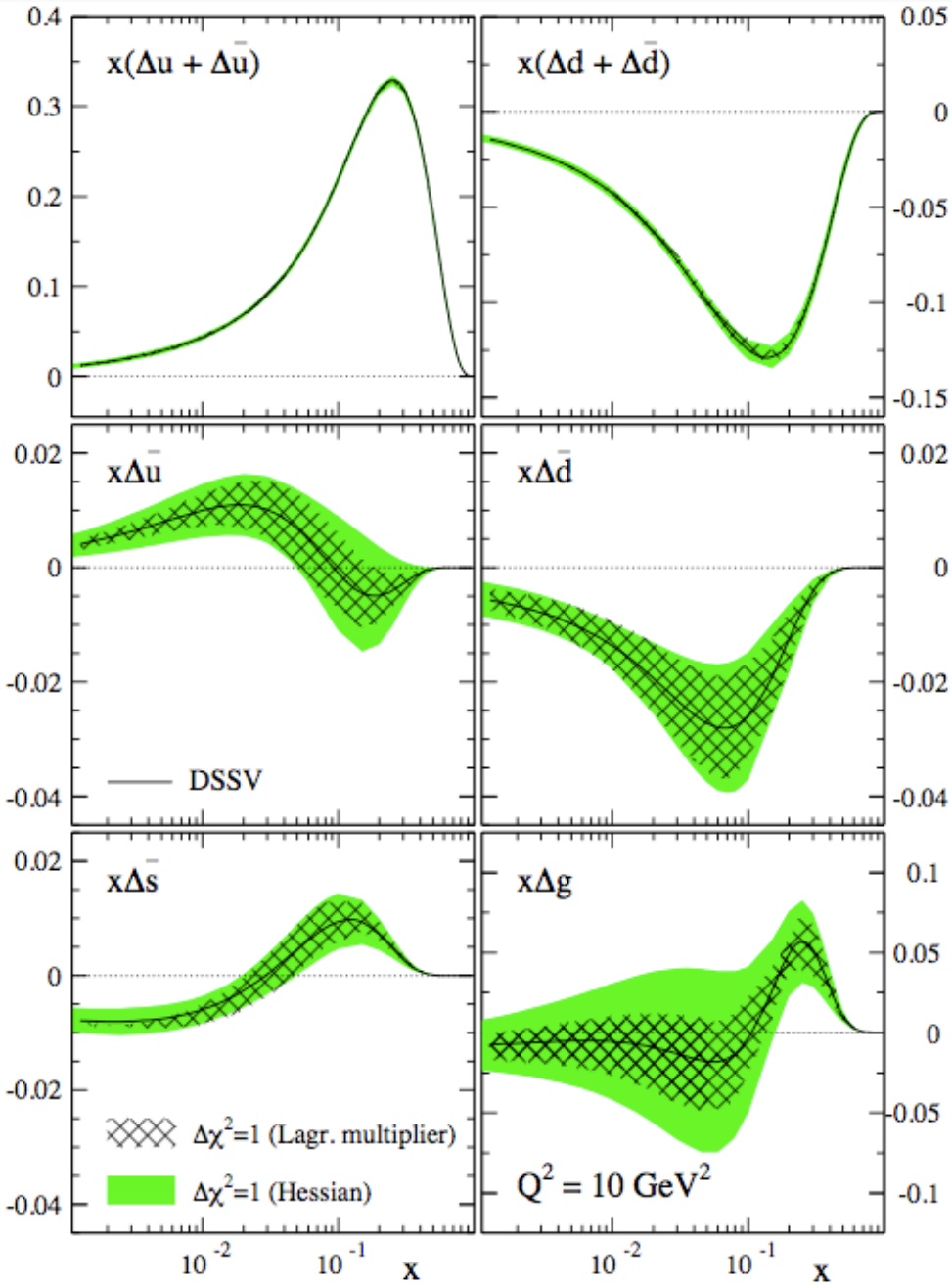
Kaon multiplicities calculated using DSS+MRST



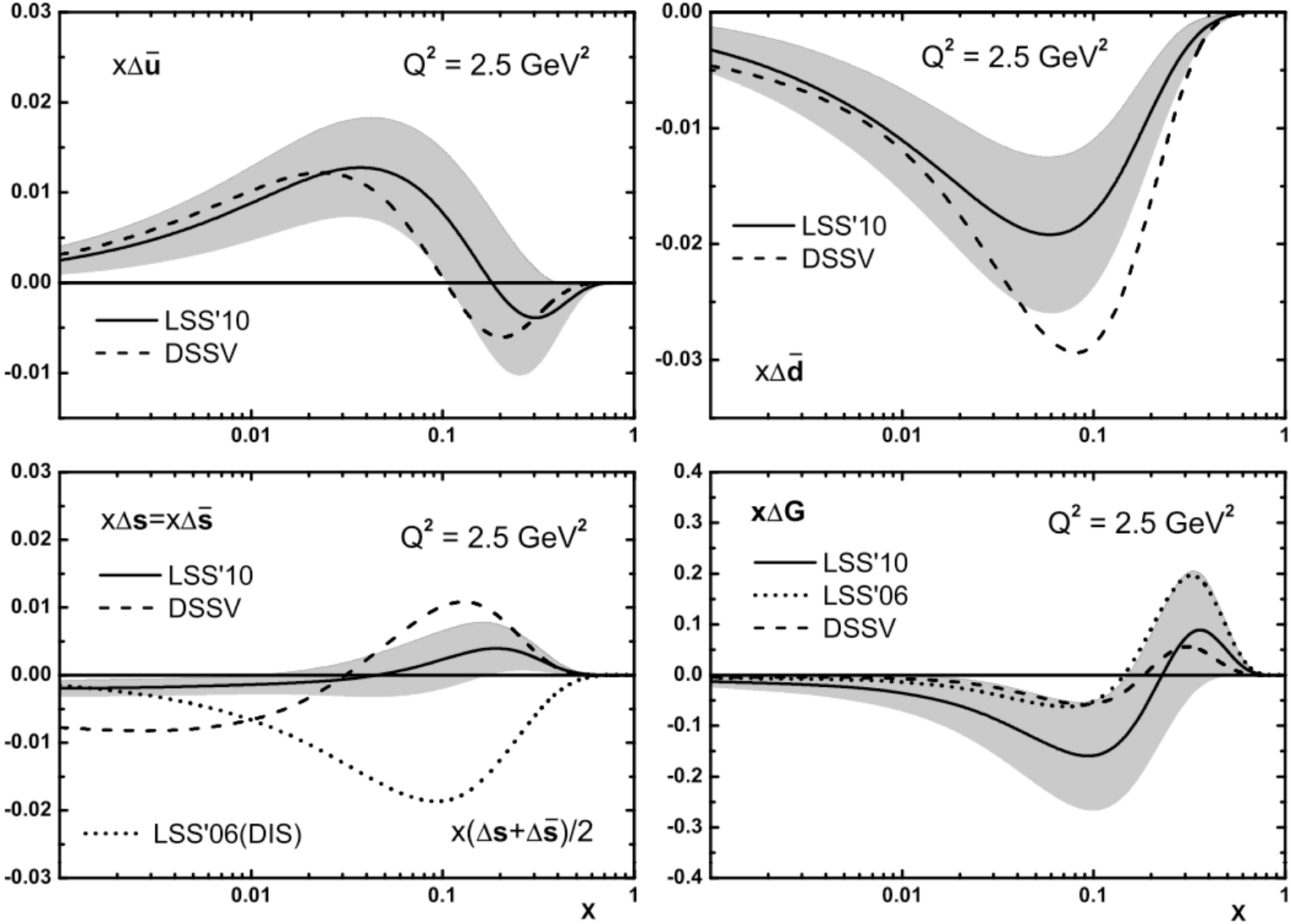


D_S is not very small in kaon's case => what is the fit doing ?

DSSV fit


x(Δu + Δū)
x(Δd + Δd̄)
xΔū
xΔd̄
xΔs̄
xΔg
DSSV
Δχ²=1 (Lagr. multiplier)
Δχ²=1 (Hessian)
Q² = 10 GeV²
x

LSS fit


xΔū
Q² = 2.5 GeV²
LSS'10
DSSV
xΔd̄
xΔs=xΔs̄
LSS'06(DIS)
x(Δs+Δs̄)/2
xΔG
LSS'06
x