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Polarized Parton Distributions in the Nucleon

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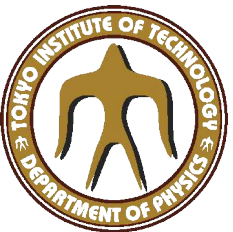
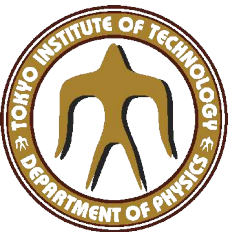
for "**Strange spin in neutrino scattering**" working group
http://www.nucl.phys.titech.ac.jp/~sspin/



Introduction

- Parton distribution function and nucleon spin
- Double polarized deep inelastic scattering experiments
  - Inclusive measurement
  - Semi-inclusive measurement
    - Quark flavor decomposition of nucleon spin
- Summary

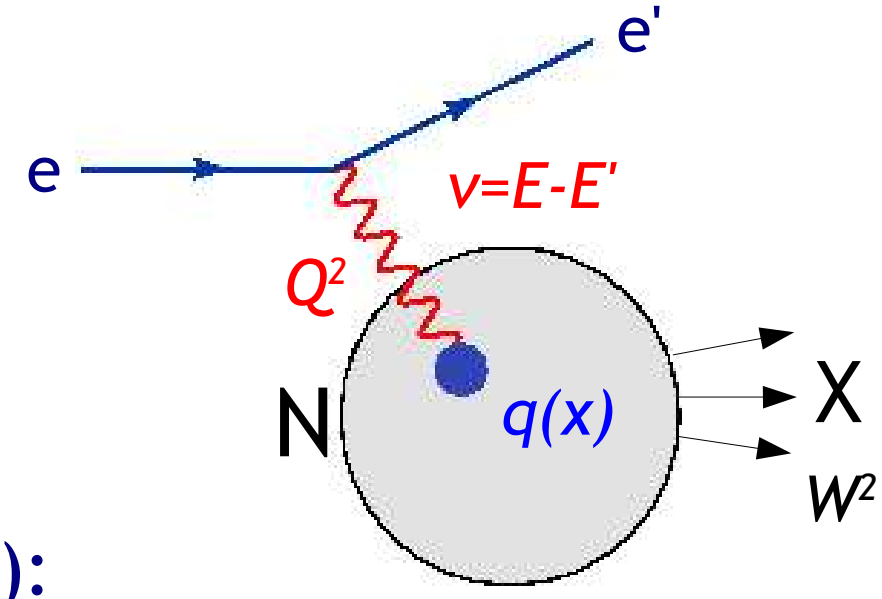


DIS and PDF

Deep Inelastic Scattering (DIS):

$$e + N \rightarrow e' + X$$

Q^2>1GeV^2, W^2>10GeV^2



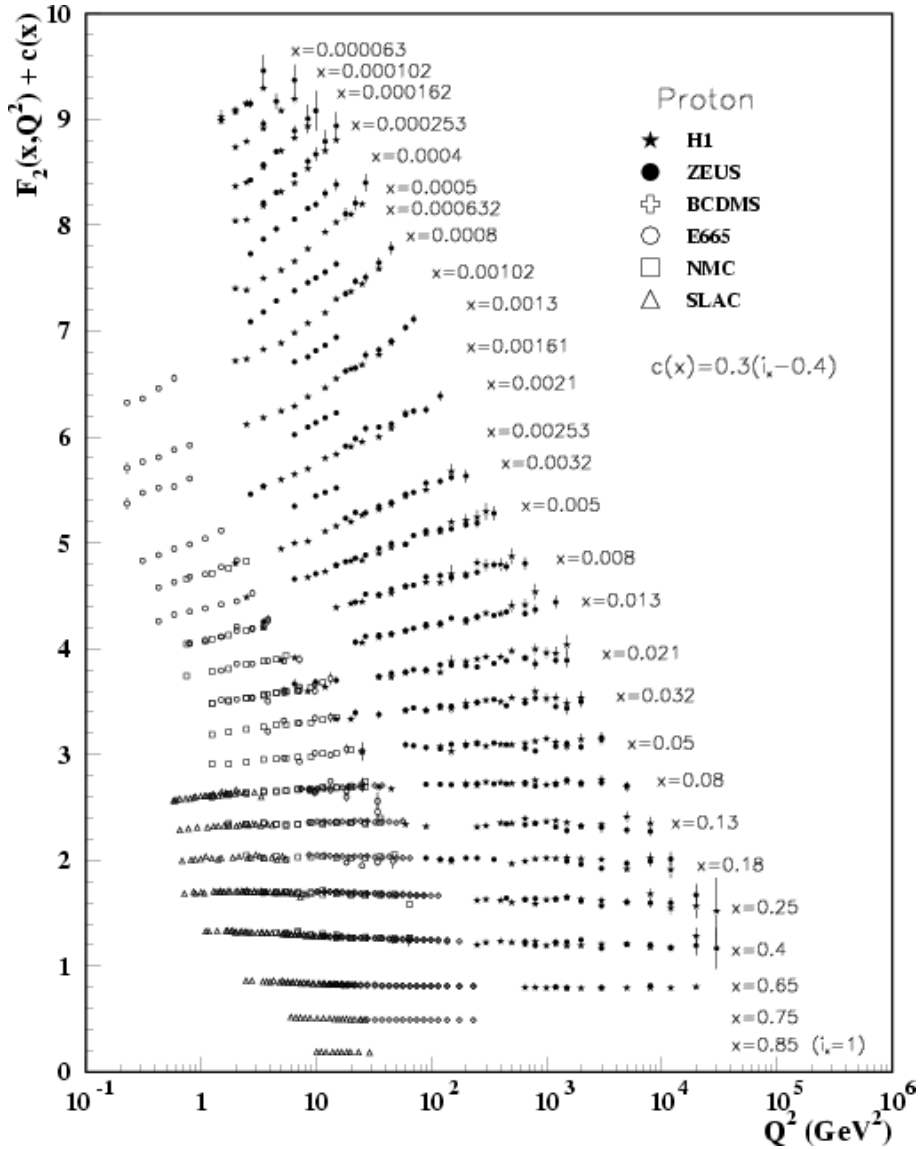
Parton Distribution Function (PDF):

Probability Distribution of finding quark inside nucleon which carries momentum fraction $x=Q^2/2M\nu$. $q(x)$

$$\frac{d^2\sigma}{dx\,dy} = \frac{2\pi\alpha^2 s}{Q^4}\left(x\,y^2 F_1(x) + (1-y)F_2(x)\right)$$

$$F_1(x) = \frac{1}{2}\sum_q e_q^2 q(x) \qquad F_2(x) = 2x F_1(x)$$

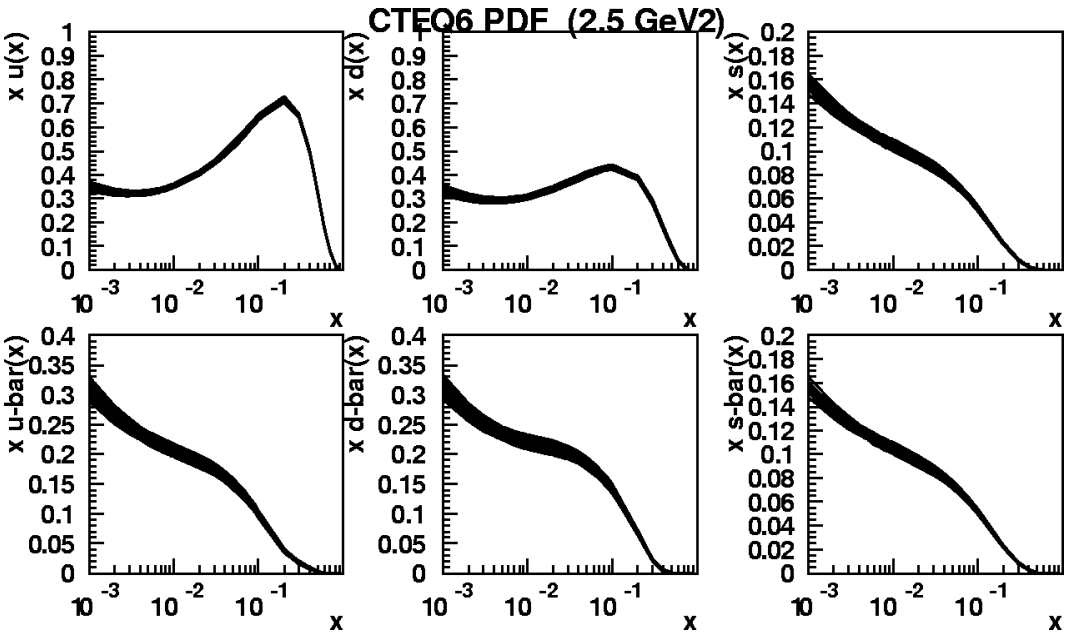
Structure Function and PDF



K. Hagiwara et al. (PDG),
Phys. Rev. D 66, 010001 (2002)

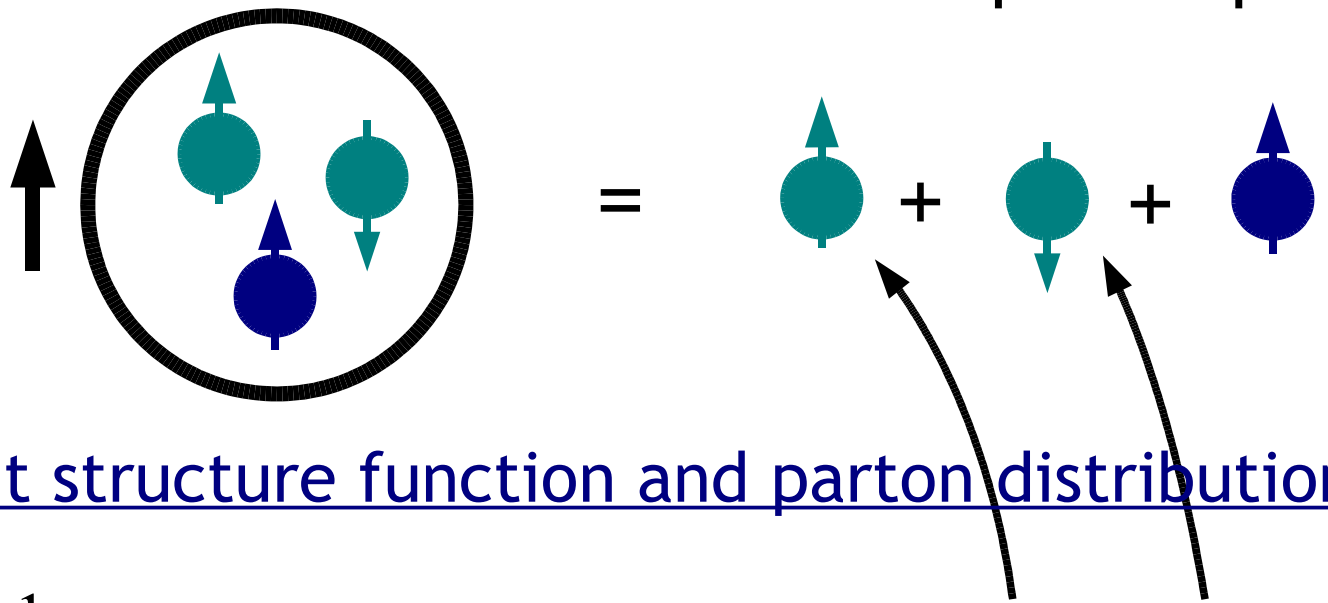
CTEQ, GRV, MRS, ALEKHIN, ...
PDF parameterizations are available.

ex.) CTEQ6



Spin structure of nucleon

Nucleon spin: ½ = sum of quarks spin



Spin dependent structure function and parton distribution:

$$g_1(x)=\frac{1}{2}\sum_q e_q^2 \Delta q(x) \qquad \Delta q(x)=q^{\uparrow}(x)-q^{\downarrow}(x)$$

Quark contribution to nucleon spin: 1st moment: $\int_0^1 dx\,\Delta q(x)=\Delta q$

$$\frac{1}{2}=\frac{1}{2}\Delta\Sigma=\frac{1}{2}\left(\Delta u+\Delta d+\Delta s+\Delta \bar{u}+\Delta \bar{d}+\Delta \bar{s}\right)$$

Quark Spin Contribution

Most simple case: $\Delta\Sigma=1$

Naïve Parton model: Assuming SU(3) flavor symmetry, taking axial current matrix

$$\Delta\Sigma=\Delta u+\Delta d+\Delta s=a_0$$
$$\Delta u-\Delta d=a_3$$
$$\Delta u+\Delta d-2\Delta s=a_8$$

From weak decay:
$a_3=1.26,\ \ a_8=0.58$

if $\Delta s=0$, $\Delta\Sigma=a_8=0.58$

EMC finding: "Spin Puzzle" (Nucl. Phys. B328 (1989) 1)

Double polarized DIS inclusive measurement:

$$\int_0^1 dx\, g_1^p(x)=\frac{1}{9}a_0+\frac{1}{12}a_3+\frac{1}{36}a_8=0.126\pm0.01\pm0.015$$

$a_0\sim0.1$ →

$$\Delta\Sigma=0.1,\ \ \Delta s+\Delta\bar{s}\sim-0.19$$

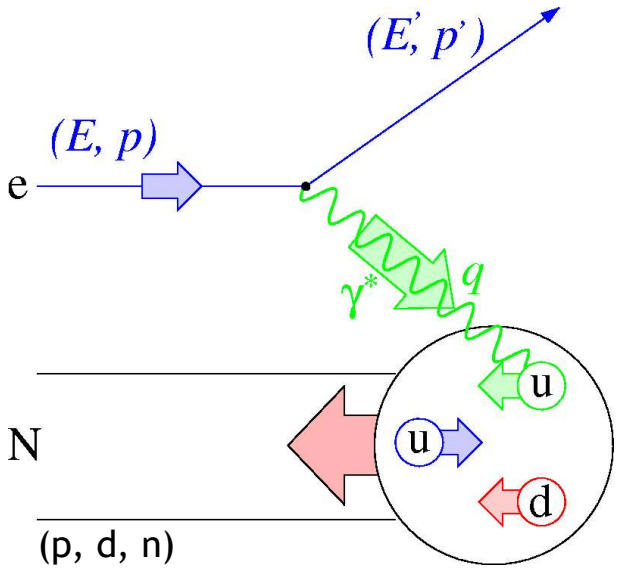
→ axial anomaly: $a_0=\Delta\Sigma-3\frac{\alpha_s}{2\pi}\Delta G \quad \Delta G>0$

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

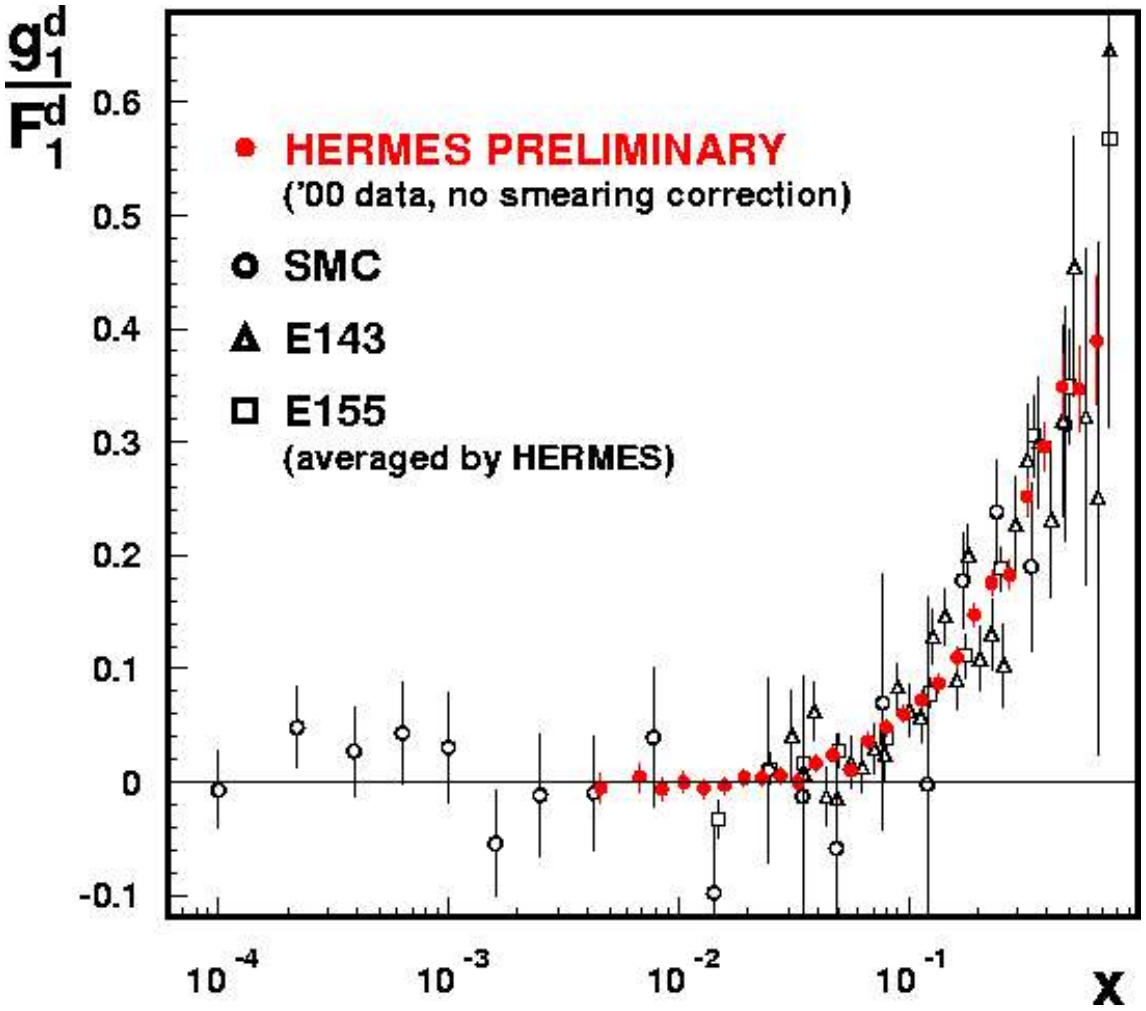
Inclusive DIS measurement

$$\vec{l} + \vec{N} \rightarrow l' + X$$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1}{F_1} = \frac{\sum_q e_q^2 \Delta q(x)}{\sum_q e_q^2 q(x)}$$



EMC, SMC, COMPASS,
E142, E143, E155, E154,
HERMES, Jlab
(http://durpdg.dur.ac.uk/HEPDATA/index.html)



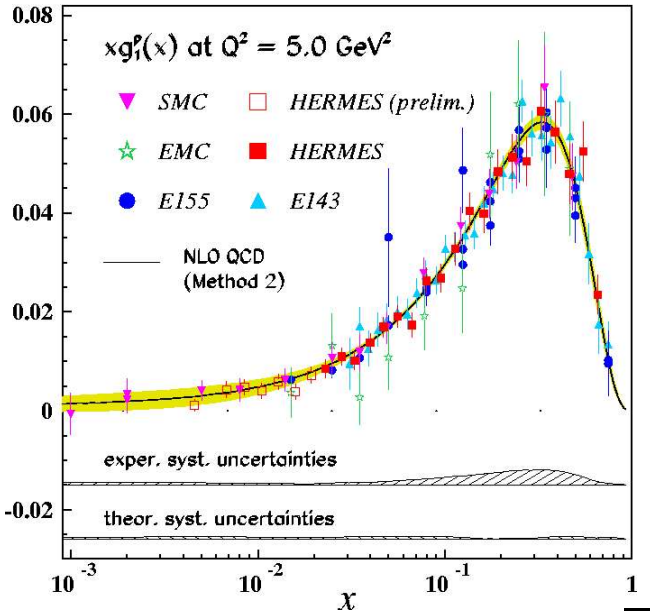
Spin dependent structure function $g_1(x)$

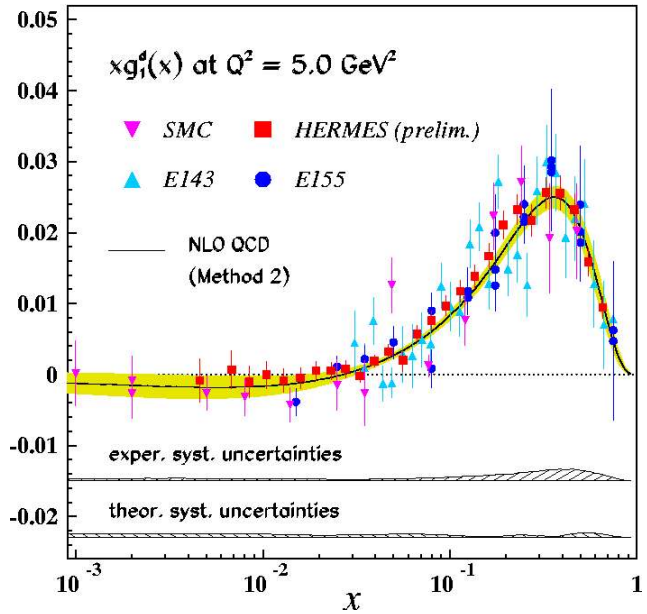
QCD improved parton model:

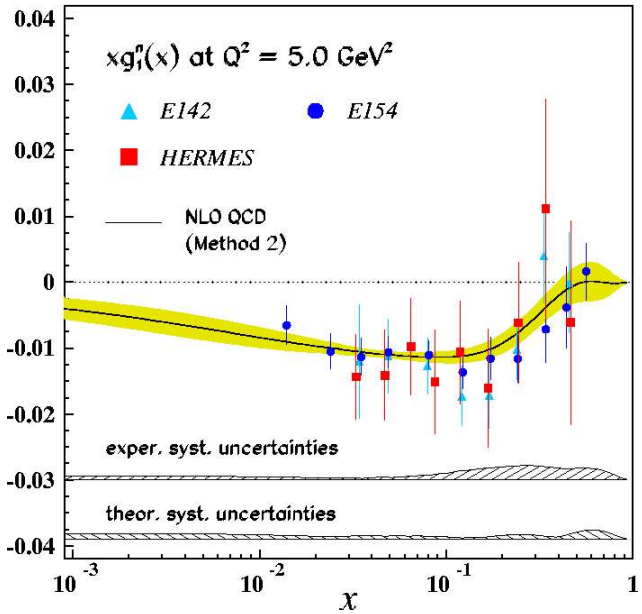
AB scheme

$$\Delta\Sigma(x,Q^2) - n_f \frac{\alpha_s}{2\pi} \Delta g(x,Q^2)$$

$$g_1(x,Q^2) = \frac{\langle e^2 \rangle}{2} \left[C^S(Q^2) \otimes \Delta q^S(x,Q^2) + C^{NS}(Q^2) \otimes \Delta q^{NS}(x,Q^2) \right]$$







$\overline{\mathrm{MS}}$ scheme

Assuming:
- flavor SU(3)
- fixed a_3 and a_8

$\Delta\Sigma = 0.2 \pm 0.1$

$\Delta G = 0.41 \pm 0.23$

Δq^{NS} : fixed

ΔG measurements:
SMC, HERMES
COMPASS, RHIC-Spin

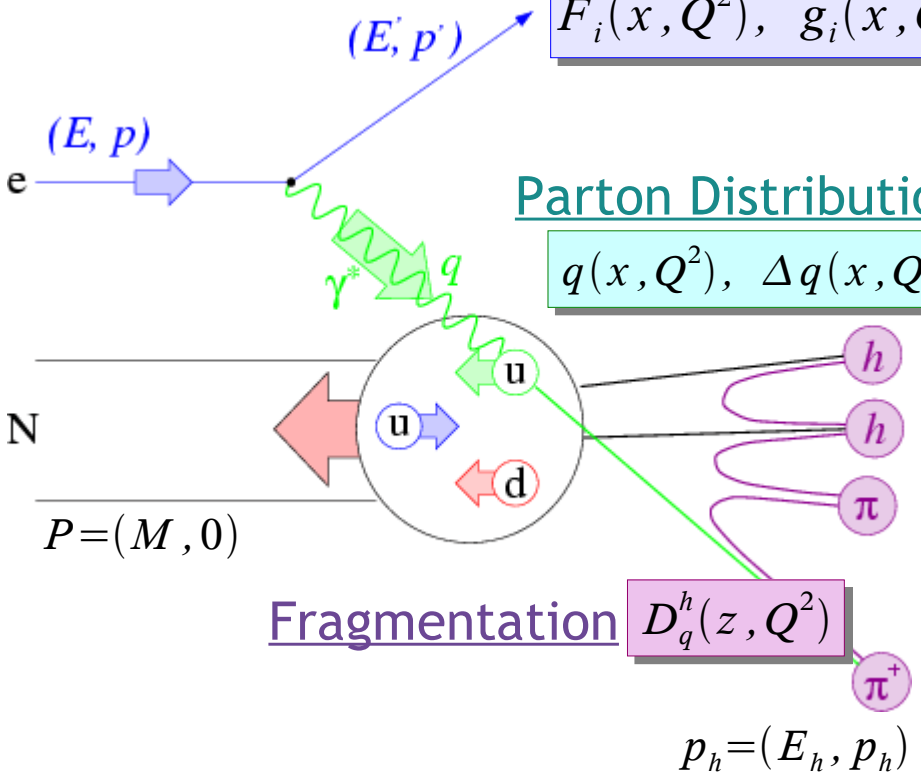
Flavor tagging: HERMES

Hadron coincidence measurement
Semi-inclusive DIS measurement

$$\vec{l} + \vec{N} \rightarrow l' + h + X$$

Structure Function

$$F_i(x, Q^2), \quad g_i(x, Q^2)$$



Parton Distribution

$$q(x, Q^2), \quad \Delta q(x, Q^2)$$

Measure hadron(s) in coincidence with the scattered lepton

Hadron carries information on quark flavor through fragmentation function

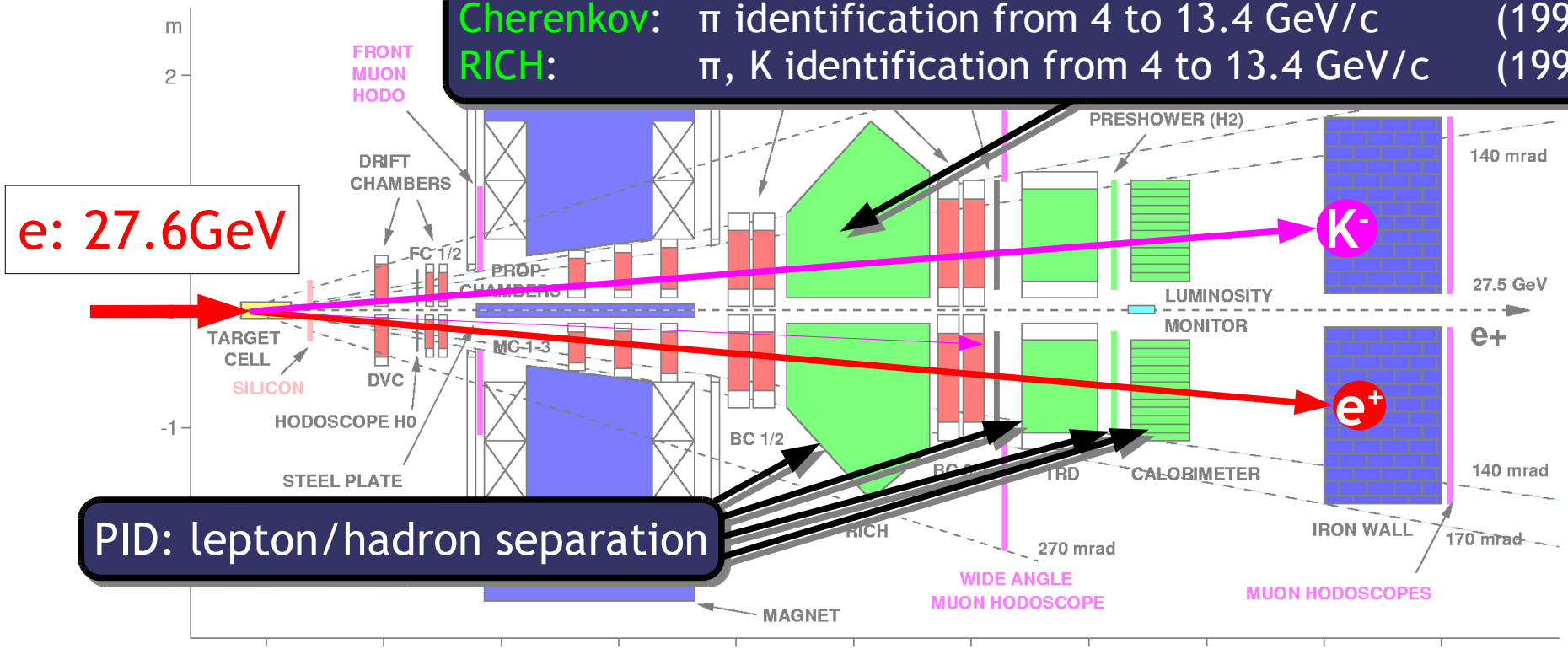
Flavor Tagging: $z = \frac{P \cdot p_h}{P \cdot q} = \frac{E_h}{\nu}$

$$\frac{d^3 \Delta \sigma^h}{dx\, dz\, dQ^2} \propto \sum_i e_q^2 \Delta q(x, Q^2) D_q^h(z, Q^2)$$

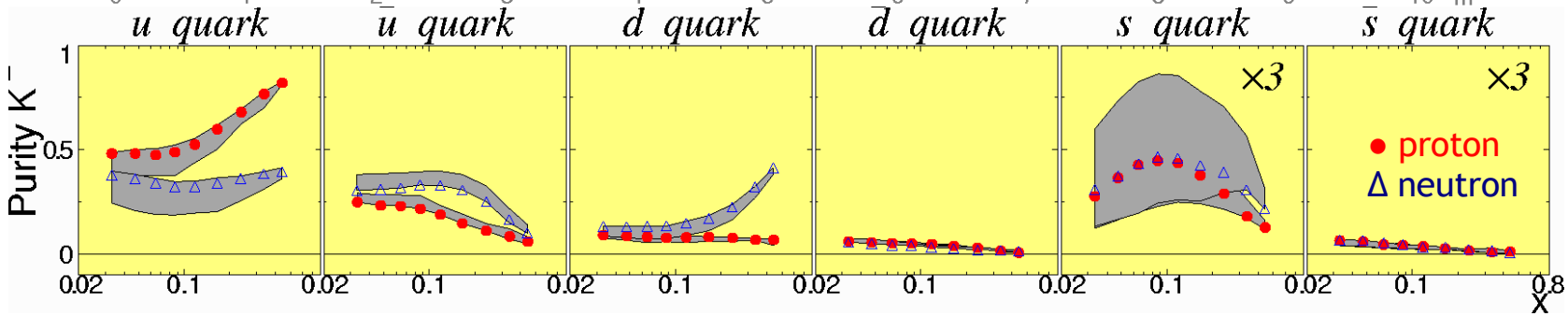
Flavor tagging (HERMES)

Cherenkov: π identification from 4 to 13.4 GeV/c (1995~1997)
RICH: π, K identification from 4 to 13.4 GeV/c (1998~)

e: 27.6GeV



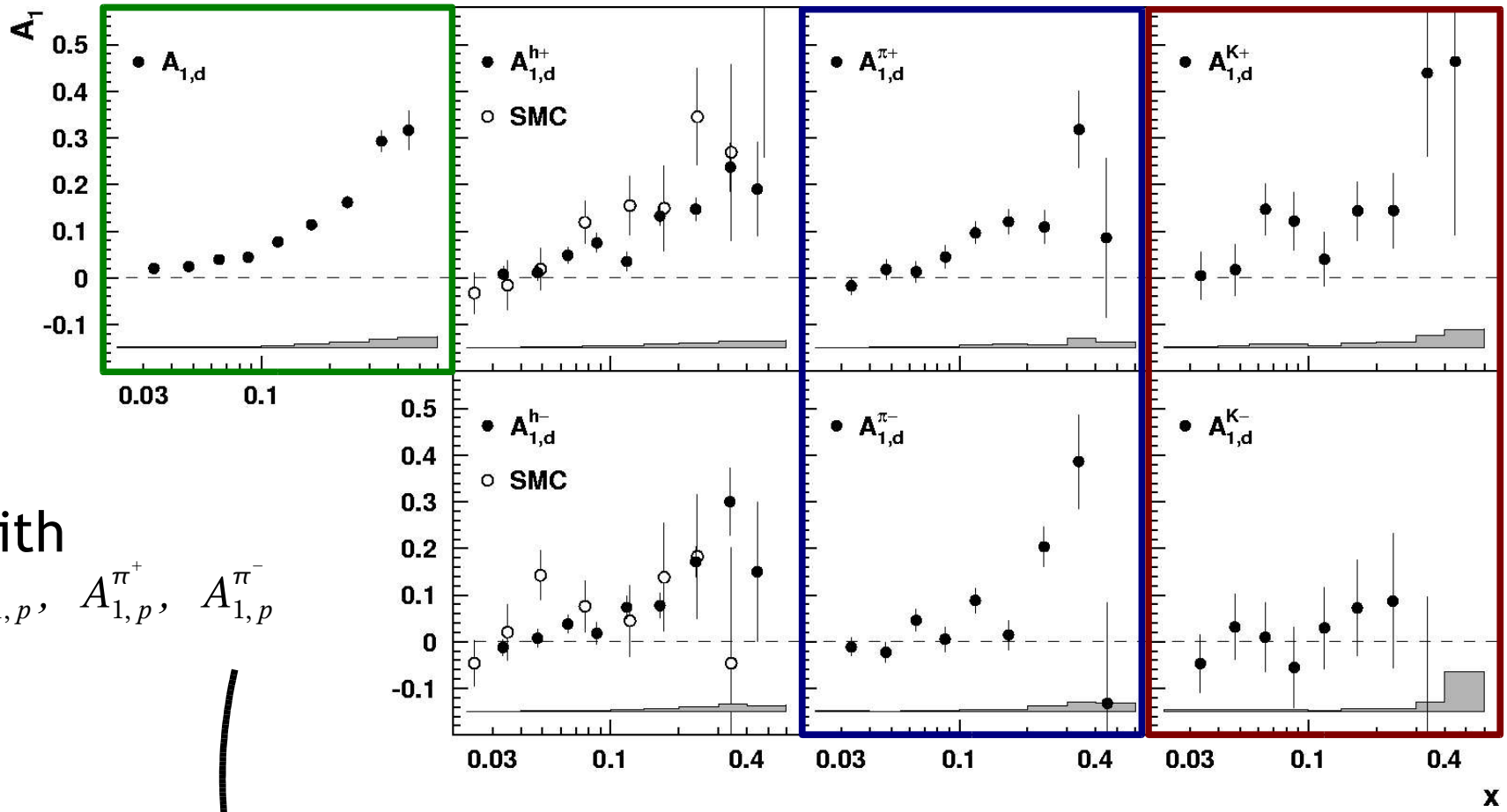
PID: lepton/hadron separation



Purity:
probability that quark "f" was struck when hadron "h" was observed

Double Spin Asymmetry (deuteron)

HERMES, Phys. Rev. Lett. 92 (2004) 012005



with

$A_{1,p}$, $A_{1,p}^{\pi^+}$, $A_{1,p}^{\pi^-}$

allowed to perform quark flavor decomposition

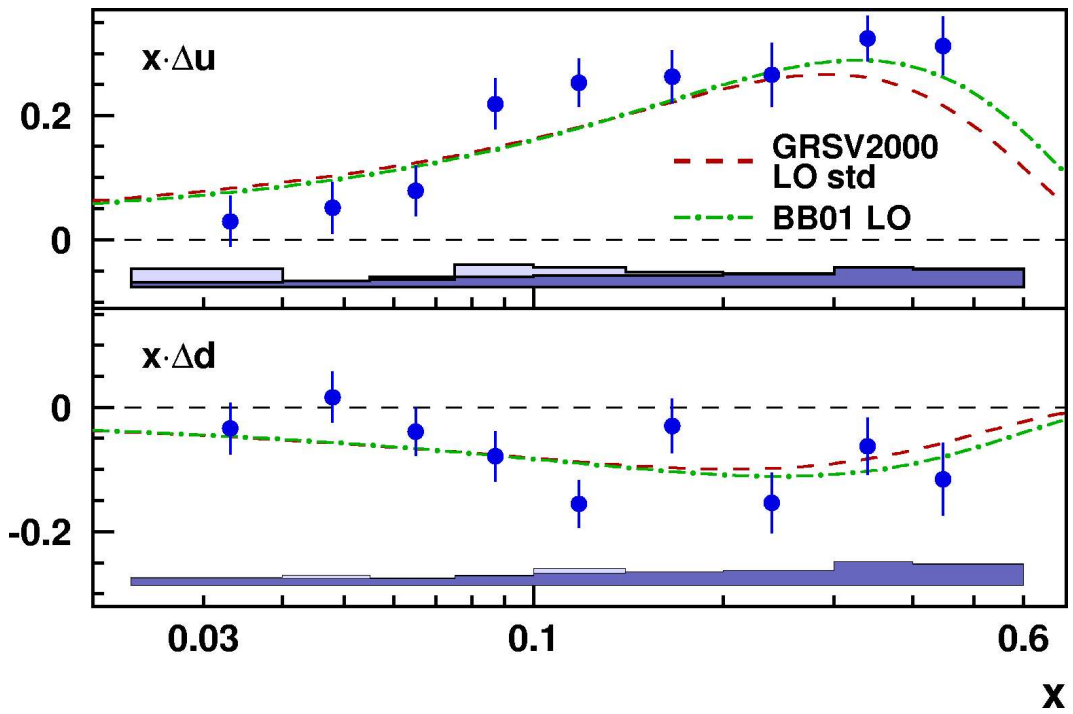
without assuming SU(3) flavor symmetry

with unpolarized anti-strange distribution

$$\Delta u(x),\ \Delta d(x),\ \Delta \bar{u}(x),\ \Delta \bar{d}(x),\ \Delta s(x),\quad \Delta \bar{s}(x)=0$$

Quark Helicity Distributions

$Q^2 = 2.5\,\mathrm{GeV}^2$



$$\Delta q = \int_{0.023}^{0.6} dx\, \Delta q(x) \qquad Q^2 = 2.5\,\mathrm{GeV}^2$$

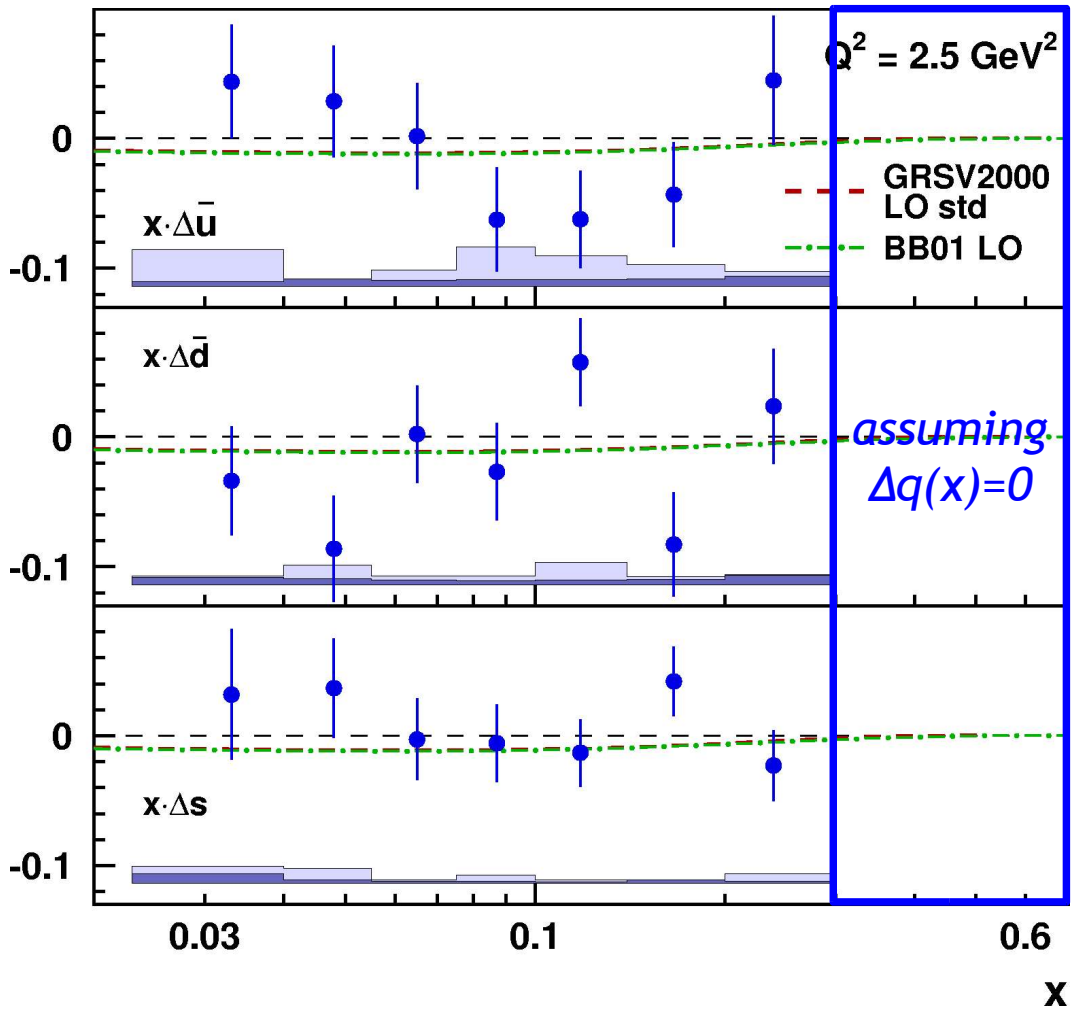
$$\Delta u = 0.601 \pm 0.039 \pm 0.049$$

$$\Delta d = -.226 \pm 0.039 \pm 0.050$$

HERMES, Phys. Rev. Lett. 92 (2004) 012005, hep-ex/0407032

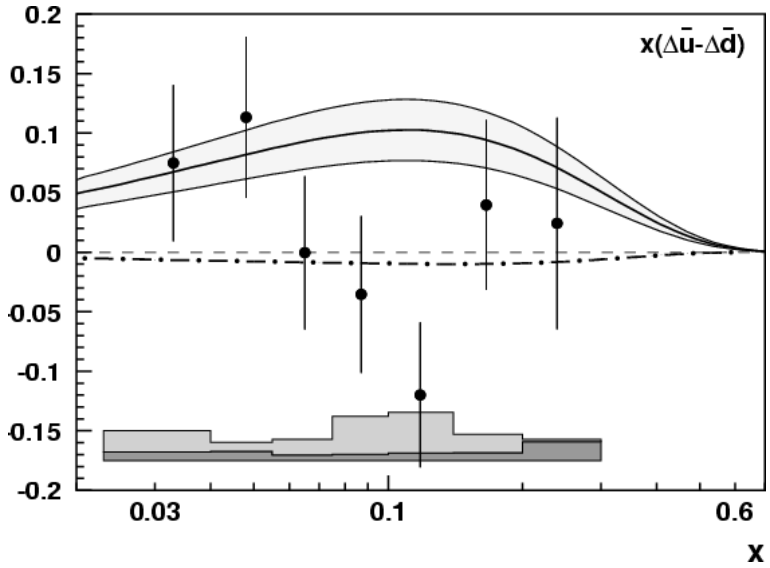
Sea Quark Distributions

$Q^2 = 2.5\,\mathrm{GeV}^2$



assuming $\Delta\bar{s} = 0$

$Q^2 = 2.5\,\mathrm{GeV}^2$



$$\Delta q = \int_{0.023}^{0.3} dx\, \Delta q(x) \quad Q^2 = 2.5\,\mathrm{GeV}^2$$

$\Delta\bar{u} = -.002 \pm 0.036 \pm 0.023$

$\Delta\bar{d} = -.054 \pm 0.033 \pm 0.011$

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

$\Delta\bar{u} - \Delta\bar{d} = 0.048 \pm 0.057 \pm 0.028$

HERMES, Phys. Rev. Lett. 92 (2004) 012005, hep-ex/0407032

1st moment of pol. PDF

HERMES, hep-ex/0407032

$Q^2 = 2.5\,\mathrm{GeV}^2$

Moments in the measured range

$$\Delta q = \int_{0.023}^{0.6} dx\, \Delta q(x)$$

$\Delta u = 0.601 \pm 0.039 \pm 0.049$

$\Delta d = -.226 \pm 0.039 \pm 0.050$

$\Delta \bar{u} = -.002 \pm 0.036 \pm 0.023$

$\Delta \bar{d} = -.0.054 \pm 0.033 \pm 0.011$

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

$\Delta \Sigma = 0.347 \pm 0.024 \pm 0.066$

$a_3 = 0.880 \pm 0.045 \pm 0.107$

$a_8 = 0.262 \pm 0.078 \pm 0.045$

without SU(3) symmetry
with unpolarized anti-strange

Δs

Inclusive measurement	-0.1
vN scattering	-0.25~0
Baryon magnetic moment	-0.2
Lattice QCD	-0.1

Partial moment of q_3 from QCD fit:

$a_3 = 1.27, \quad a_8 = 0.58$

$$\int_0^{0.023} dx\, q_3(x) = 0.41$$

$$\int_{0.023}^{0.6} dx\, q_3(x) = 0.82$$

$$\int_{0.6}^{1} dx\, q_3(x) = 0.04$$

HERMES, Phys. Rev. Lett. 92 (2004) 012005, hep-ex/0407032

Summary (1)

- Double polarized charged lepton nucleon DIS
  - by experiments at CERN, SLAC, DESY, Jlab
- Inclusive measurements
  - assuming flavor SU(3) symmetry
  - small $\Delta\Sigma \sim 0.2$ which implies $\Delta s \sim -0.1$, $\Delta G > 0$
- Flavor tagging (semi-inclusive measurement)
  - HERMES: π and K from 4 to 13.4 GeV/c with RICH
  - Δq for 5 quark flavors in $0.023 < x < 0.6$
    - positive $\Delta u(x)$, negative $\Delta d(x)$ and zero $\Delta q_{sea}(x)$
    - consistent with a_3 from β-decay in the measured x region
    - $\Delta s = 0$ in the measured x region within its error

Summary (2)

- For understanding spin structure of nucleon
  - flavor dependence is essential issue
    - key for understanding QCD
  - kinematic coverage of x was limited (HERMES)
  - constraint to the first moment of pol. PDF
    - non-singlet axial current matrix elements
    - strange axial form factor