# Flavor separation of polarized parton distributions: Challenges for 6 and 12 GeV

Ch. Weiss (JLab), JLab Hall C Summer Workshop, Aug. 18–19, 2005

- Flavor in inclusive DIS

  Singlet vs. non-singlet PDF's,   NLO scheme dependence, . . .

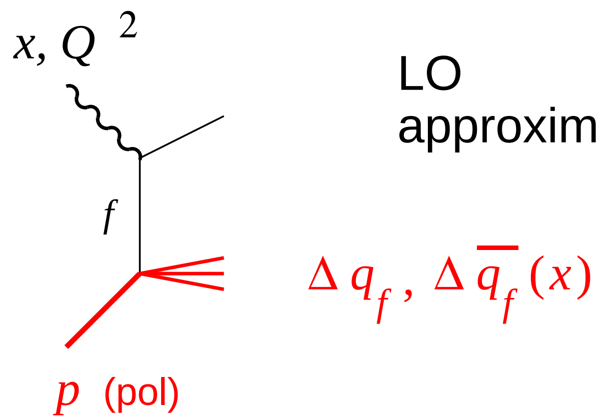
- Theoretical ideas on $\Delta\bar{u} - \Delta\bar{d}$

- Flavor separation in semi-inclusive DIS

  Test of LO $x$–$z$ dependence
  Status of fragmentation functions
  Purity method
  FF–independent analysis, . . .

- Flavor in inclusive DIS

$$g_1(x, Q^2) = \sum_{f=u,d,s} e_f^2 \, [\Delta q_f + \Delta \bar{q}_f] \, (x, Q^2)$$




LO
approximation

  - Probes only sum of quark and antiquark distributions (cf. unpolarized DIS: Charged current, Drell–Yan)

  - Three light flavors, but only two targets $(p, n)$ Information on all three flavors only for first moments

$$\int_0^1 dx \, [\Delta q_f + \Delta \bar{q}_f] \quad \longleftrightarrow \quad \langle p | \underbrace{\bar{\psi}_f \gamma_\mu \gamma_5 \psi_f}_{\text{axial current}} | p \rangle \quad \longleftarrow$$

Hyperon weak decays
$SU(3)$ flavor symmetry

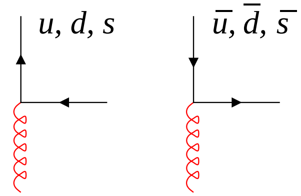
  - Gluon only via $Q^2$ evolution

- QCD evolution: Singlet vs. non-singlet

"Organize" PDFs according to

$$
\begin{aligned}
q^{(0)} &= u + d + s \\
q^{(3)} &= u - d \\
q^{(8)} &= u + d - 2s
\end{aligned}
\qquad\qquad
\begin{aligned}
q_{\mathrm{val}} &= q - \bar{q} \\
q_{\mathrm{tot}} &= q + \bar{q}
\end{aligned}
$$

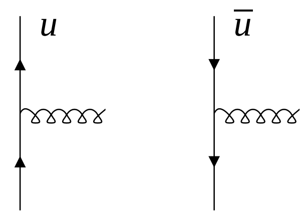
$\Delta q^{(0)}_{\mathrm{tot}} \longleftrightarrow \Delta G$




singlet

$\Delta q^{(3)}_{\mathrm{tot}}, \; \Delta q^{(8)}_{\mathrm{tot}}$

all $\Delta q_{\mathrm{val}}$



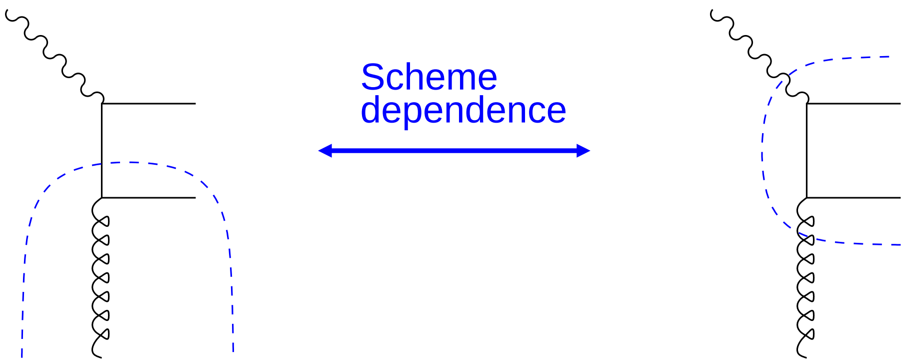

flavor/charge non-singlet

| |
|---|
| Flavor–nonsinglet $(3, 8)$ and valence quark distributions do not "mix with" gluon distribution . . . Individual flavors $\Delta u, \Delta\bar{u}, \Delta d \ldots$ do! |

- NLO: Scheme dependence of PDFs

$$g_1 = \sum_{f=u,d,s} e_f^2\, C_q \otimes (\Delta q_f + \Delta\bar{q}_f) \; + \; (\sum_f e_f^2)\, \alpha_s C_g \otimes \Delta G$$

involves gluons explicitly!




$O(\alpha_s)$ term can be attributed either to singlet quark or to gluon distribution

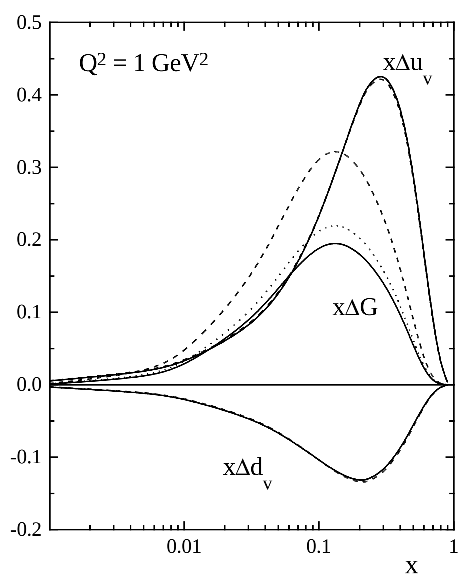



Fig. 2

- Scheme dependence crucial for $\Delta G$ and singlet quark distribution $q_{\rm tot}^{(0)}$

- Does practically not affect valence quark or flavor non-singlet distributions

[Leader, Stamenov, Sidorov 98: JET, AB, $\overline{MS}$ schemes]

- Antiquark flavor asymmetries

  - $\bar{u} - \bar{d} < 0$ known from $pp/pd$ Drell–Yan [Fermilab E866] and unpolarized DIS [NMC]

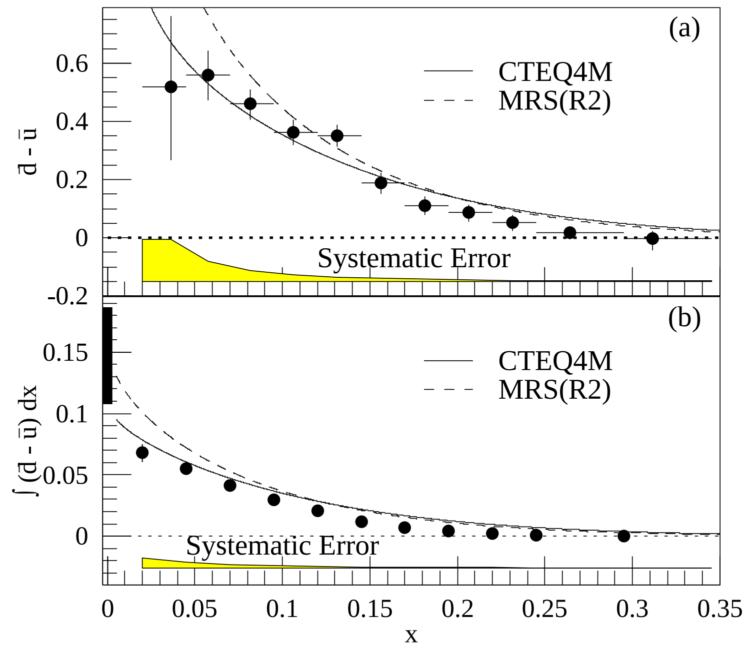
  - Weak scale dependence

    $\int_0^1 dx \ \left[\bar{u} - \bar{d}\right](x) = \text{const in LO}$

    $\longrightarrow$ Non-perturbative origin!

    "Creation, not evolution"

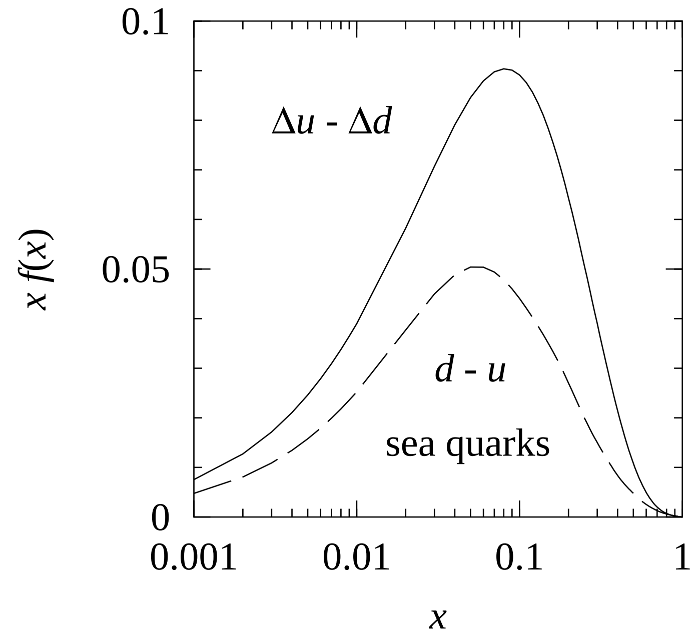
  - What about polarized asymmetry $\Delta\bar{u} - \Delta\bar{d}$?



- Theoretical ideas about polarized antiquark flavor asymmetry

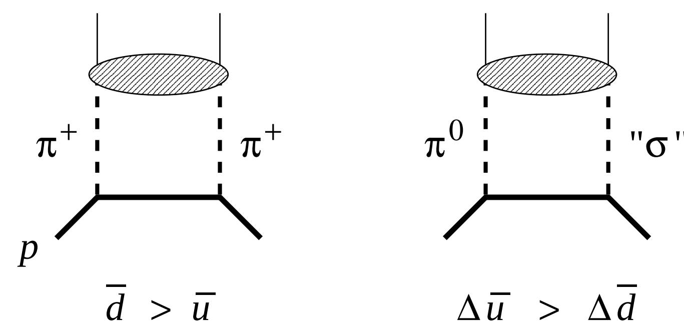
  - Large–$N_c$ limit of QCD suggests
    $|\Delta\bar{u} - \Delta\bar{d}| \;\gg\; |\bar{u} - \bar{d}|$

    Chiral quark–soliton model
    [Diakonov et al. 96]




  - Statistical quark models: Pauli blocking
    [Bourrely et al. 02, Bhalerao 01]

  - Meson cloud models: Large $\Delta\bar{u} - \Delta\bar{d}$
    obtained from "$\pi$–$\sigma$ interference"
    [Fries, Schäfer, CW 02]

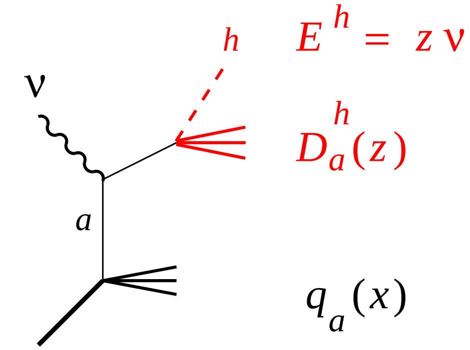



**Different models suggest large $\Delta\bar{u} - \Delta\bar{d} > 0$**

- Semi–inclusive DIS: QCD factorization

  – Specified hadron in current jet (CM rapidity $> 0$)

$$\Delta\sigma^h = \sum_{a=u,\bar{u},\ldots} e_a^2 \, \Delta q_a(x) \, D_a^h(z)$$




LO approximation

  – QCD factorization (leading twist): Quark fragmentation independent of quark spin and spectator configuration

    $\rightarrow$ Fragmentation functions universal (process–independent)!

  – NLO approximation: Gluon fragmentation, $x$– and $z$–dependence no longer separated!

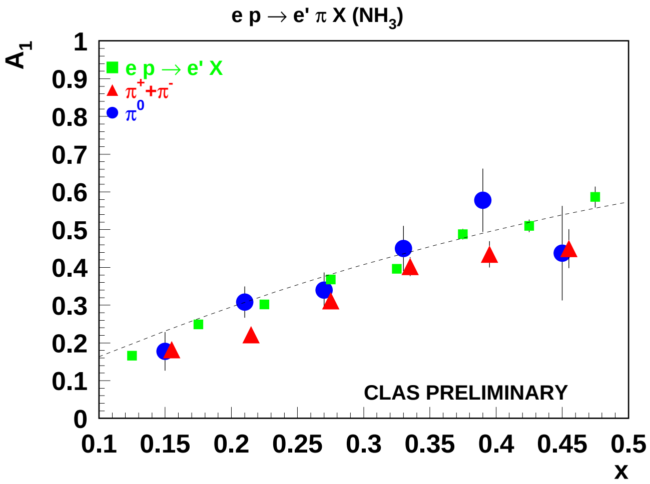
| Fragmentation "tags" flavor and charge of struck quark |
|---|

- Test of LO approximation [Frankfurt et al. 89]

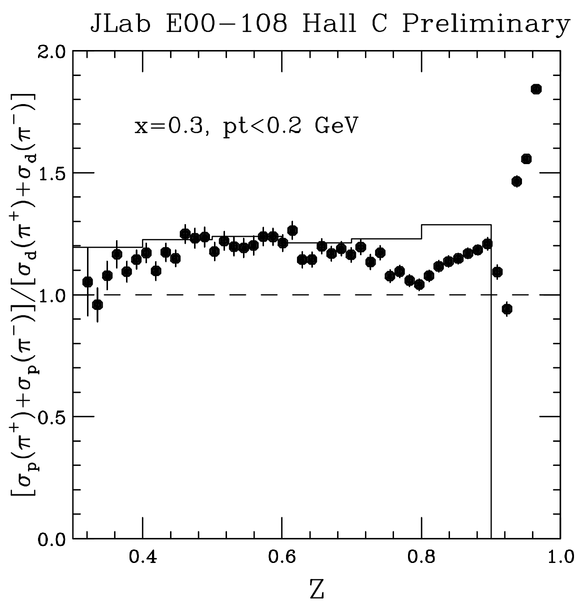
$$\frac{\sigma^{\pi^+ + \pi^-}}{\sigma_{\text{incl}}} = \frac{e_u^2\, u(x)\, (D_u^{\pi+} + D_u^{\pi-})(z) + \ldots}{e_u^2\, u(x) + \ldots}$$

$$= \underbrace{(D_u^{\pi+} + D_u^{\pi-})(z)}_{x\text{–independent!}} + \text{small terms } \frac{e_s^2\, s(x)\, D_s^{\pi}(z)}{F_1(x)}$$

... Similarly: $p + \bar{p}$




[H. Avakian]

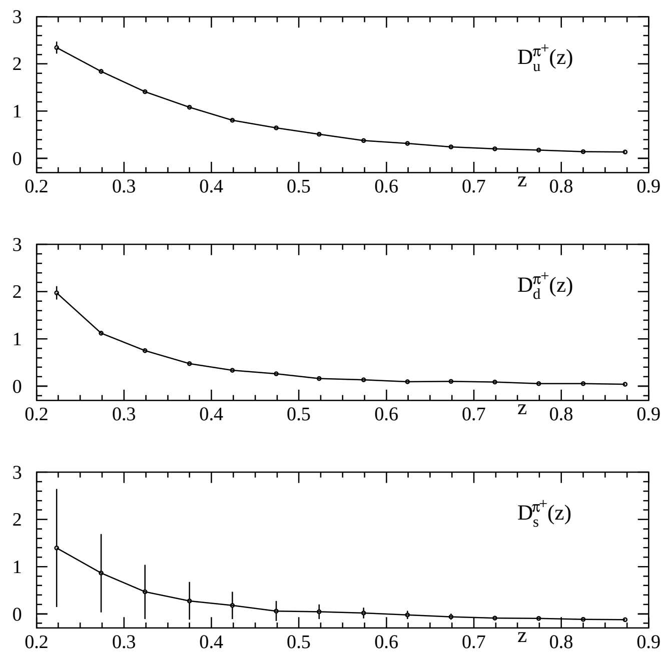



[P. Bosted, R. Ent, et al.]

- Determination of fragmentation functions

  - Flavor–singlet combination $D_u^{\pi+} + D_d^{\pi+} + D_s^{\pi+}$ determined by $e^+e^- \to \pi^+ + X$ at $Q^2 = M_Z^2$ [Binnewies et al. 95, Kretzer 00]

  - Flavor dependence from unpolarized semi-inclusive $\pi^\pm$ production [HERMES]




$\rightarrow$ $D_u^{\pi+}$, $D_d^{\pi+}$ well determined
$D_s^{\pi+}$ poorly known
[Kretzer, Leader, Christova 00]

  - Theory: Standard non-perturbative methods (lattice, QCD sum rules, instantons) fail for timelike quark momenta . . . no “Euclidean” representation!

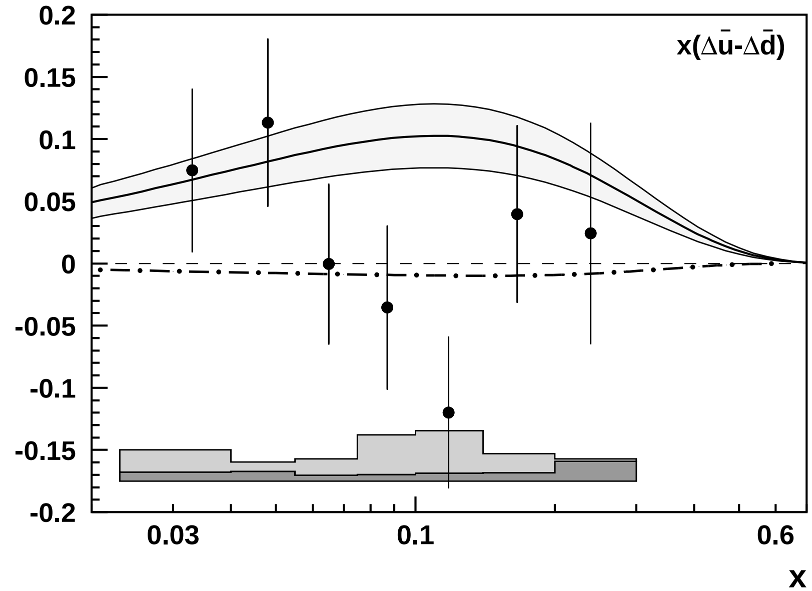
- Purity method [HERMES Airapetian et al. 99/04]

$$A_1^h \equiv \frac{\Delta\sigma^h}{\sigma^h} = \sum_a \underbrace{\frac{e_a^2\, q_a(x)\, D_a^h(z)}{\sum_b e_b^2\, q_b(x)\, D_b^h(z)}}_{P_a^h(x,z)} \frac{\Delta q_a(x)}{q_a(x)}$$

Distribution of cross section for hadron $h$ over quark flavors $a$

$\sum_a P_a^h = 1$

- Requires only spin asymmetry $A_1^h$, not absolute cross section
- HERMES $z$–integrated purities generated using MC
- Kotzinian 05: MC purities inconsistent with leading–twist fragmentation (→ spin and $x$–dependence of FF's)



- FF–independent analysis [Frankfurt et al. 89; Christova, Leader 01]

$$A_1^{\pi^+ - \pi^-} = \frac{\Delta\sigma^{\pi^+} - \Delta\sigma^{\pi^-}}{\sigma^{\pi^+} - \sigma^{\pi^-}} = \frac{4\Delta u_{\text{val}} - \Delta d_{\text{val}}}{4u_{\text{val}} - d_{\text{val}}} \quad \text{proton}$$

$$= \frac{\Delta u_{\text{val}} + \Delta d_{\text{val}}}{u_{\text{val}} + d_{\text{val}}} \quad \text{deuteron}$$

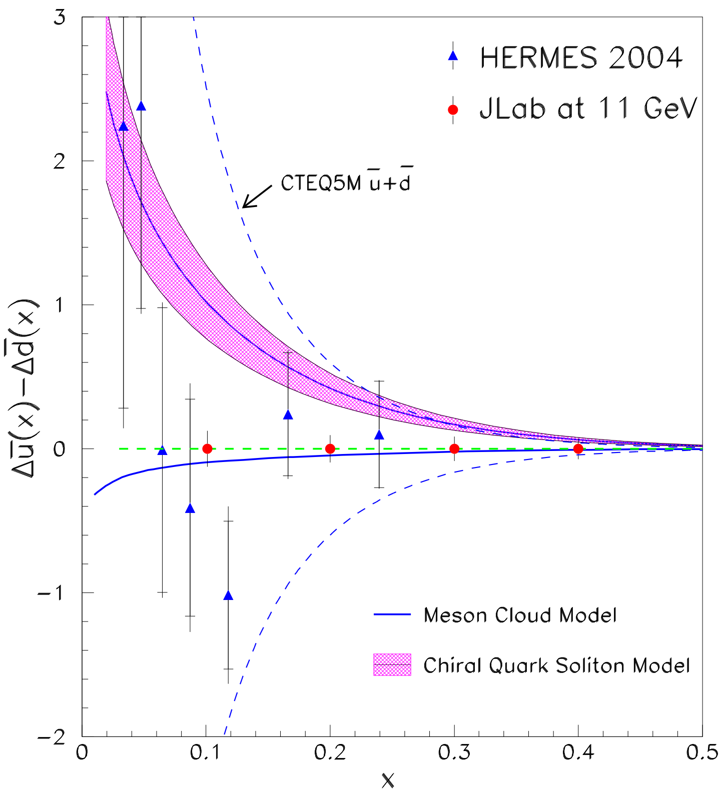
Helicity asymmetry of cross section difference

  - Requires measurement of cross section differences
  - Dependence on fragmentation functions cancels . . . clean!
  - Reconstruct $\Delta\bar{u} - \Delta\bar{d}$ using

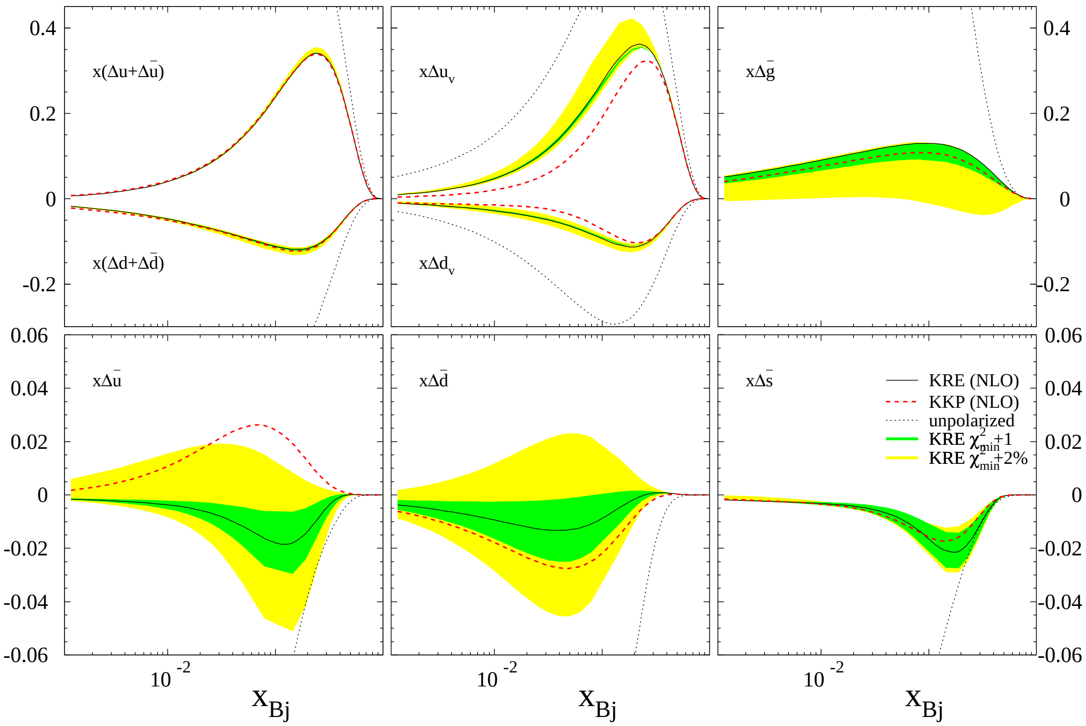
$$\left.\begin{array}{l} \Delta u_{\text{val}} - \Delta d_{\text{val}} \ \ \text{from semi-inclusive } \pi^{\pm} \\ \Delta u + \Delta\bar{u} - (\Delta d + \Delta\bar{d}) \ \ \text{from } \ g_1^p - g_1^n \end{array}\right\} \ \text{Non-singlet only!}$$

– Becomes feasible with high–statistics measurements at JLab 12 GeV

[X. Jiang]



- Global NLO analysis (inclusive and semi–inclusive) [de Florian, Navarro, Sassot 00/05]




– Low sensitivity to $\Delta\bar{u}$ and $\Delta\bar{d}$

- Non-perturbative effects ("higher twist") in semi-inclusive DIS

  - Exclusive channels at large $z$ [Diehl, Kugler, Schäfer, CW 05]

  - "Vacuum structure": Chiral symmetry breaking

    massless QCD quarks $\longleftrightarrow$ constituent quarks
    $M \approx 300 - 400$ MeV

- Not covered here: Measurement of $\Delta\bar{u} - \Delta\bar{d}$
  through $W^{\pm}$ production in polarized $pp$ at RHIC

Summary

- Non-singlet quark spin distributions much more "physical" than singlet and gluon (scale, scheme dependence)

- Flavor asymmetry $\Delta\bar{u} - \Delta\bar{d}$ of non-perturbative origin, provides interesting information on structure of nucleon

- FF-dependent extraction of $\Delta\bar{u} - \Delta\bar{d}$ difficult because of low sensitivity

- FF–independent methods seem to be feasible at JLab
  - high statistics
  - equal acceptance for $\pi^+/\pi^-$, etc.

- Need to understand non-perturbative aspects of semi-inclusive reactions

. . . Very interesting problem!