Sea quark polarization and nucleon structure

Ch. Weiss (JLab), PVAS Workshop, BNL, Apr. 26–27, 2007

Q: "How" do polarized sea quarks appear in nucleon?

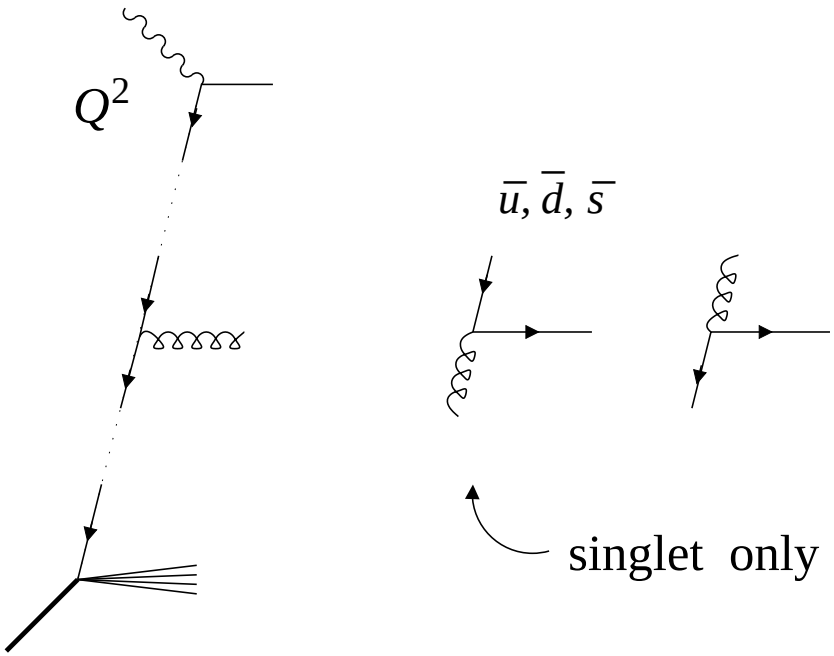
- Dynamical models of nucleon structure

  "Pion cloud," Pauli blocking

- General properties of QCD

  Chiral dynamics, large–N_c limit, . . .

PDFs in QCD: Non-singlets vs. singlet



- Non-singlet sea quark distributions do not mix with gluon
  cf. valence $q - \bar{q}$

- Total numbers conserved in LO

$$\int dx \left[\bar{u} - \bar{d}\right](x, Q^2) \quad = \quad \text{const}$$

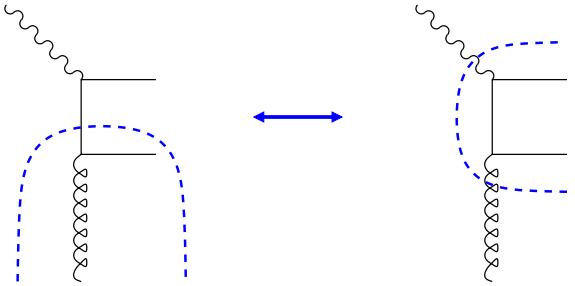
$$\Delta\bar{u} - \Delta\bar{d} \quad \text{etc.}$$

NLO: Weak Q^2–dependence

$\bar{u} + \bar{d} + \bar{s}$	singlet
$\bar{u} - \bar{d}$	non-singlet
$\bar{u} + \bar{d} - 2\bar{s}$	non-singlet

Non-perturbative origin!
"Creation, not evolution"

PDFs in QCD: Scheme dependence at NLO



$C_q \times \Delta q(x)$ $\quad$ $C_g \times \Delta G(x)$

- NLO: PDFs generally depend on factorization scheme

- Non-singlets much less affected than singlets

  cf. Leader, Stamenov, Sidorov 98:
  $\Delta q_v(x)$ vs. $\Delta G(x)$ in
  JET, AB, $\overline{\text{MS}}$ schemes

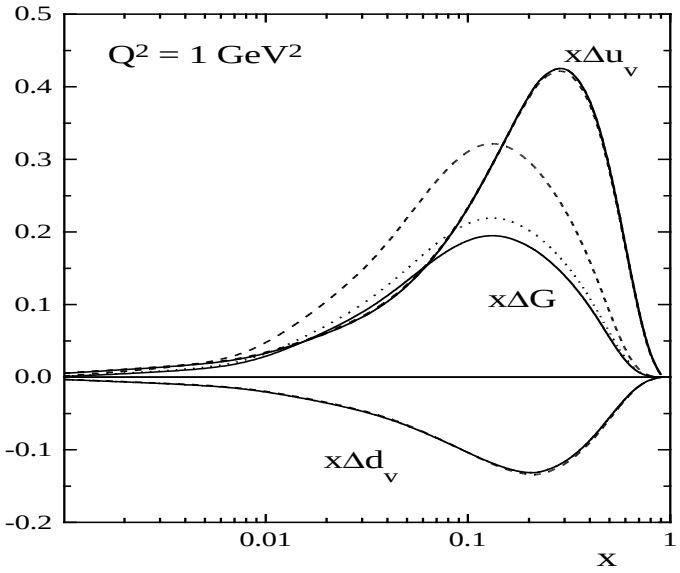
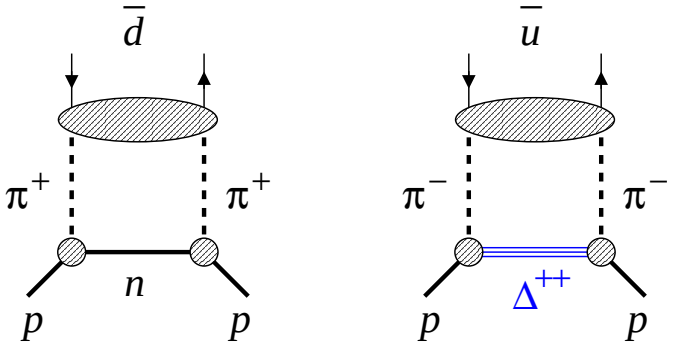
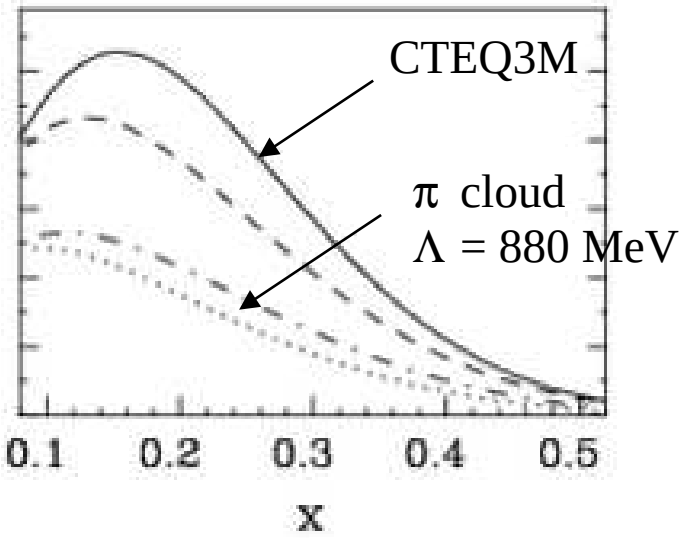


Fig. 2

Easy matching pQCD $\leftrightarrow$ non-perturbative models in non-singlet sector

Pion cloud: Flavor asymmetry $\bar{d} - \bar{u}$



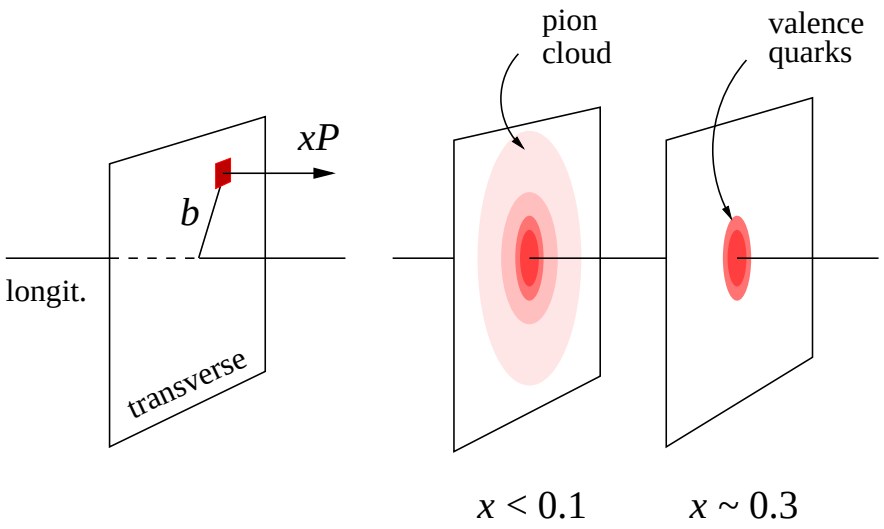


Koepf et al., PRD 53, 2586 (1996)

- Qualitatively explains why $\bar{d} > \bar{u}$ in proton [Sullivan 72, Thomas 83]
- Quantitative fit of data requires unrealistic hard πN formfactors $\Lambda > 1\,\text{GeV}$ (cf. Bonn potential) [Jülich group 90's, . . .]
- More realistic soft formfactors give at most 50% of exp. value [Koepf, Frankfurt, Strikman 95]

Consistent with chiral dynamics?

Pion cloud: Impact parameter representation

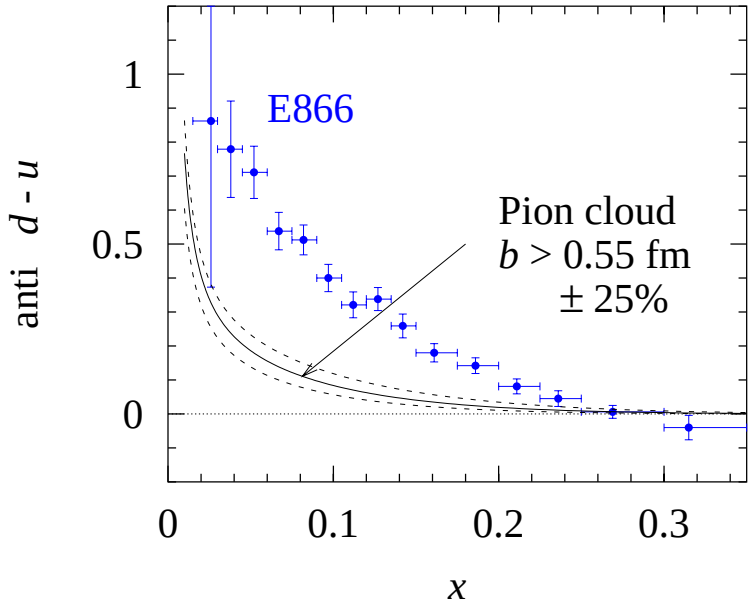


- Impact parameter–depend. PDF

$$q(x) = \int d^2b\, q(x,b)$$

- Pion cloud unique contribution at

$$b \sim 1/M_\pi \qquad \text{“Yukawa tail”}$$
$$x < M_\pi/M_N$$

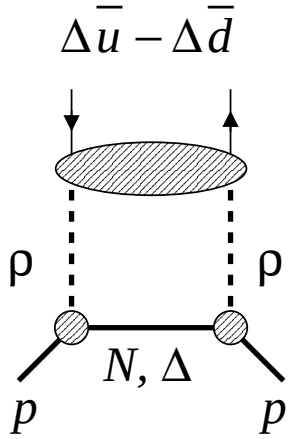


- Large–b region accounts for only small part of exp. asymmetry!

Model–independent formulation, consistent with chiral dynamics

Strikman, CW 03/07

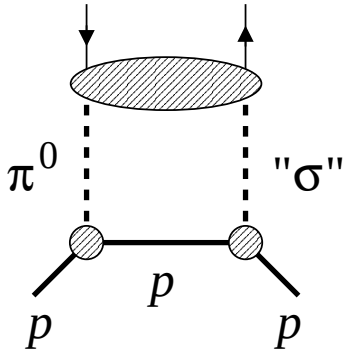
Pion cloud: Polarization



- $\pi\pi$ gives zero polarized asymmetry

- Various models with vector meson exchange give very small polarized asymmetry
  . . . not distinctive . . . arbitrary!

  [Fries et al. 98; Boreskov et al. 98, Cao et al. 01, . . .]

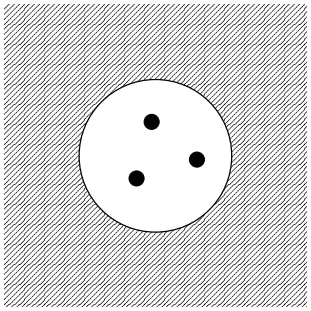


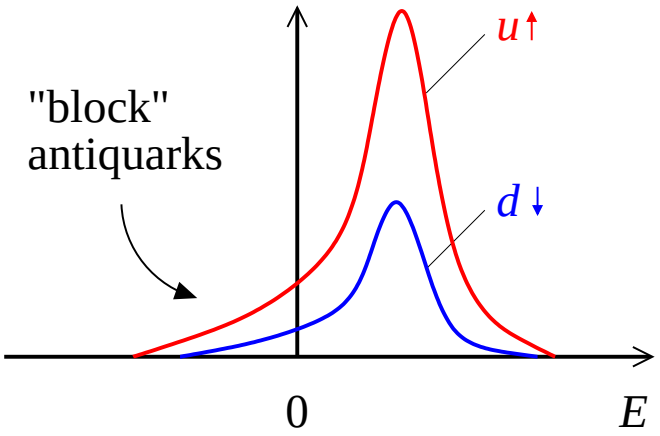
- π–"σ" interference with hard formfactors gives large positive $\Delta\bar{u} - \Delta\bar{d}$
  $\rightarrow$ qualitative agreement with quark models!

  [Dressler et al. 99; Fries, Schäfer, CW 02]

$\pi\sigma$ closest analog to $\pi\pi$ in polarized case
. . . qualitative picture!

Quark models: Pauli blocking





- Dirac wave function of confined quark has negative energy components
- Cavity creates non-perturbative sea of $\bar{q}q$ pairs (cf. "Temperature" $T \neq 0$)
- Pauli blocking:
  $u\uparrow, d\downarrow$ reduce $\bar{u}\downarrow, \bar{d}\uparrow$
  $\rightarrow \quad \bar{d} - \bar{u} > 0, \qquad \Delta\bar{u} - \Delta\bar{d} > 0.$

Qualitative picture,
predicts $\Delta\bar{u} - \Delta\bar{d} > 0$

[Signal, Thomas 88; Cao, Signal 01; see also: Bourrely, Soffer 95; Bhalerao et al. 99]

Large–N_c limit: Scaling of PDFs

- General N_c scaling of PDFs ($x \sim 1/N_c$) [Diakonov et al. 96]

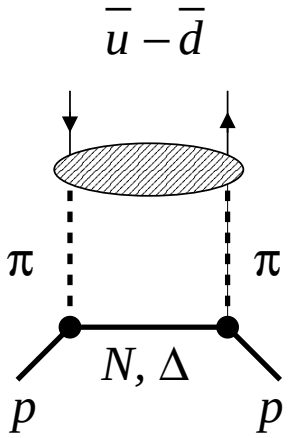
$$\bar{u}+\bar{d},\ \ \Delta\bar{u}-\Delta\bar{d} \ \sim\ N_c^2 \times \text{function}(N_c x) \quad \text{leading} \quad \leftarrow$$
$$\bar{u}-\bar{d},\ \ \Delta\bar{u}+\Delta\bar{d} \ \sim\ N_c \times \text{function}(N_c x) \quad \text{subleading}$$

- Generally works well quantitatively

  cf. $g_A^{(3)} \sim N_c$ [num: 1.26], $g_A^{(0)} \sim N_c^0$ [num: ~ 0.3]

Large–N_c limit suggests $|\Delta\bar{u}-\Delta\bar{d}| \gg |\bar{u}-\bar{d}|$
. . . no dynamics yet!

Large–N_c limit: Pion cloud in $\bar{d} - \bar{u}$



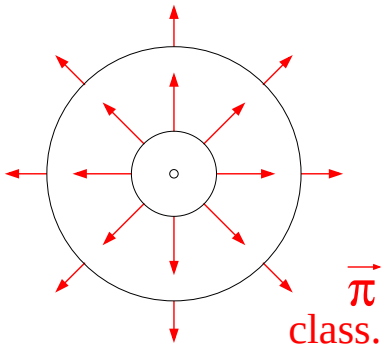
$$g_{\pi NN} \sim N_c^{3/2}$$
$$x_\pi \sim N_c^{-1}$$

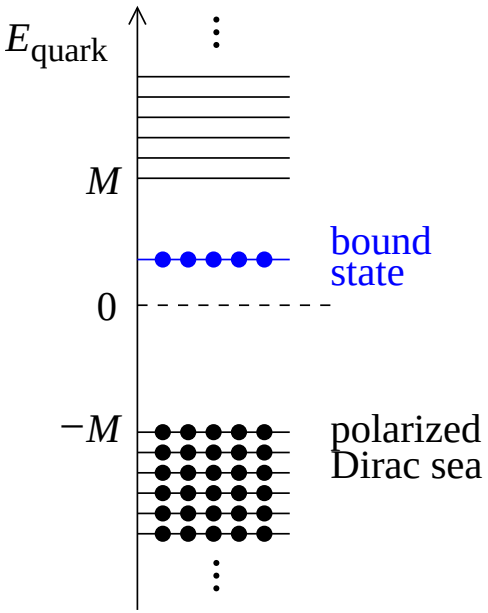
- Nucleon intermediate state alone gives
  $\bar{u} - \bar{d} \sim N_c^2 \times$ function$(N_c x)$ ↯ subleading!
- N and Δ degenerate at large N_c:
  $M_N - M_\Delta \sim N_c^{-1}, \quad g_{\pi N\Delta} = \frac{3}{2} g_{\pi NN}$
- Cancellation between N and Δ restores proper subleading behavior

Pion cloud contribution to $\bar{u} - \bar{d}$ absent in large–N_c limit!

Strikman, CW 03

Chiral quark–soliton model: Concept

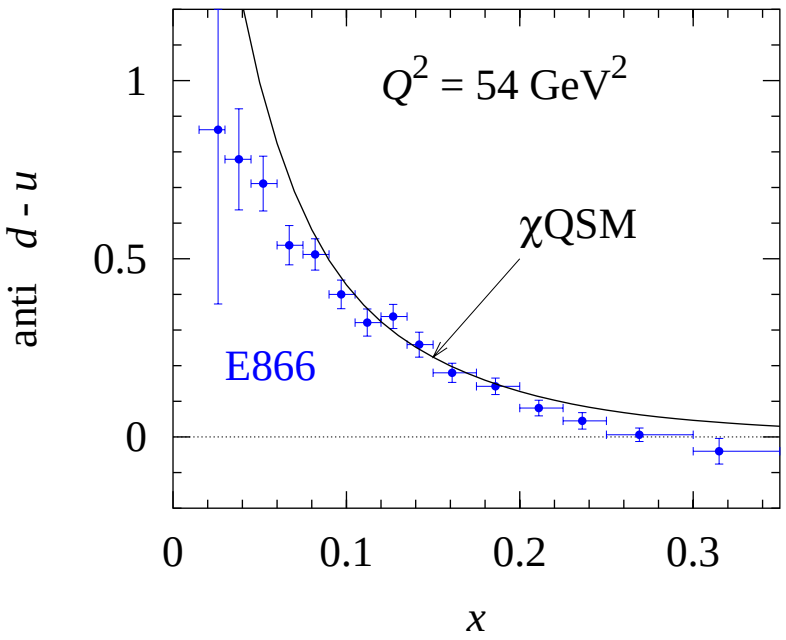


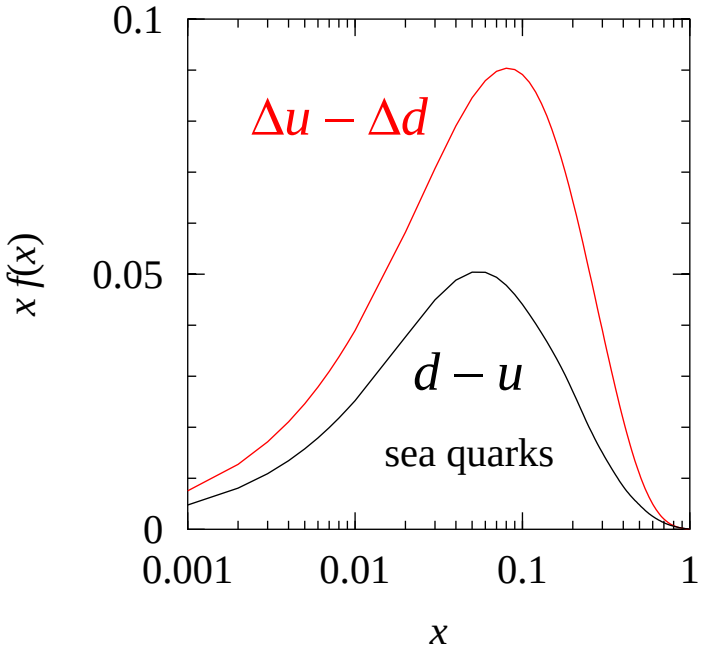


- Generic model of nucleon based on
  - Large–N_c limit
  - Effective chiral dynamics
- Quarks move independently in self–consistent classical pion field ("soliton")
- Fully relativistic, field–theoretical description: Completeness of states
  - Partonic sum rules
  - Positivity $q(x), \bar{q}(x) > 0$
- Describes PDFs at scale $\mu \sim 600\,\text{MeV}$ ("cutoff" of chiral symmetry breaking)

[Basics: Diakonov, Petrov, Pobylitsa 88;
PDFs: Diakonov et al. 96+]

Chiral quark–soliton model: Polarized sea quarks

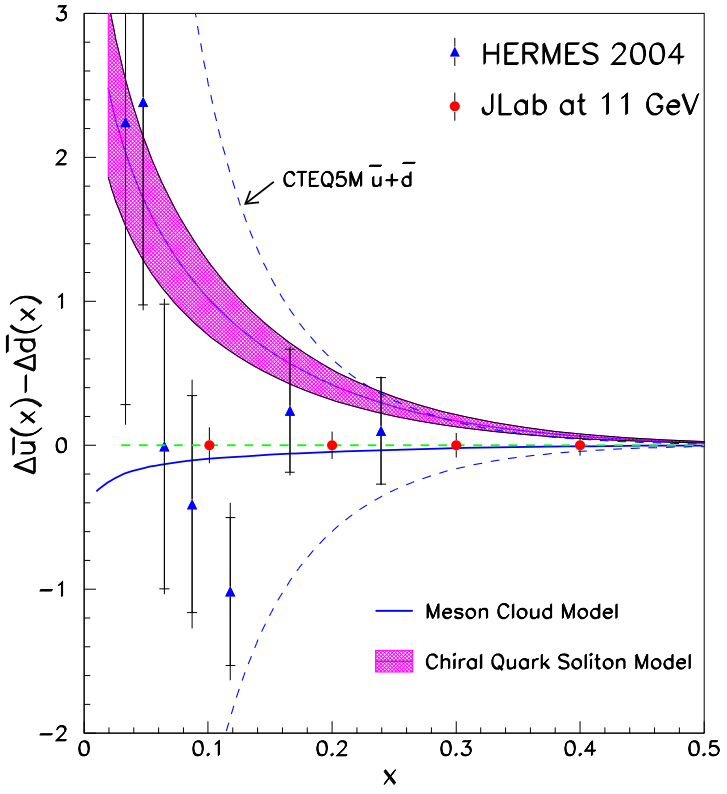


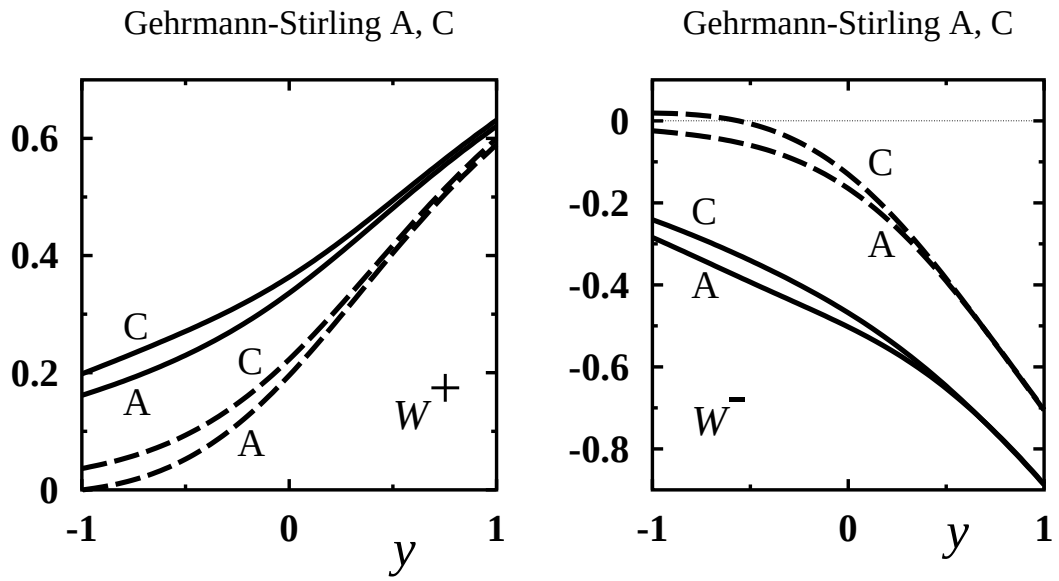


- Describes $\bar{d} - \bar{u}$ data parameter–free!
- Predicts large $\Delta\bar{u} - \Delta\bar{d} > 0$
- SU(3) symmetry: $\Delta\bar{u} + \Delta\bar{d} - 2\Delta\bar{s} = \dfrac{3F - D}{F + D}(\Delta\bar{u} - \Delta\bar{d})$ [num: 5/9]

[Diakonov et al. 96, Pobylitsa et al. 98]

Chiral quark–soliton model: Polarized experiments





dashed: no polarized asymmetry

solid: $\Delta\bar{u} - \Delta\bar{d}$ from χQSM

$\Delta\bar{u}-\Delta\bar{d}$ extracted from $A_1^{\pi,K}$ in SIDIS [HERMES, JLab 12 GeV]

Dressler et al., EPJC 14, 147 (2000)

LO predictions for SSA A_L in $W^\pm$ [RHIC]

Dressler et al. EPJC 18, 719 (2001)

Summary

- Sea quark flavor asymmetries ("non-singlets") clean probe of nucleon structure, cf. valence quark distributions
- Simple qualitative pictures seem to agree on $\Delta\bar{u} - \Delta\bar{d} > 0$
- Chiral quark–soliton model predicts $\Delta\bar{u} - \Delta\bar{d} > |\bar{u} - \bar{d}|$

Further studies

- Polarized quark distributions concentrated at smaller transverse distances than unpolarized ones (cf. GPDs) [Strikman, CW, in progress]
  $\rightarrow$ more central pp collisions
  $\rightarrow$ different event characteristics (multiplicity)
  $\rightarrow$ new "handle" on transverse structure!