Particle-Antiparticle Asymmetry of the Nucleon Strange Sea

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1. Introduction

key observation

- In their semi-phenomenological fit, Glück, Reya and Vogt prepared the **initial PDF** at pretty **low energy scale** of $Q^2 \simeq (600\,\mathrm{MeV})^2$ in contrast to the common sense of perturbative QCD, and concluded that
- sea-quark (or antiquark) components are **absolutely necessary even at this low energy scale** !

- Even the **isospin asymmetry** of the **sea-quark distributions** are established by the **NMC measurement**
- The origin of this **sea-quark asymmetry** is definitely **nonperturbative**, and it **cannot be radiatively generated** through the perturbative QCD evolution processes

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need low energy (nonperturbative) mechanism

generating sea-quark distributions

best candidate of study

- **Chiral Quark Soliton Model** (CQSM) is the **simplest** and **most powerful** effective model of QCD which fulfills the above requirement
- Most important would be its **field theoretical nature**, i.e., proper account of **polarization** of **Dirac sea quarks**, which enables

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$\boxed{\textbf{reasonable estimation} \text{ of antiquark distributions}}$

- **without introducing any adjustable parameter**, it reproduces **almost all** qualitatively noticeable features of the recent DIS observations including **NMC and EMC experiments**

What was lacking for the flavor **SU(2) CQSM** is the neglect of

hidden strange components in the nucleon

Here, we attack this problem by using

$\boxed{\textbf{flavor SU(3) generalization of CQSM}}$

which is constructed on the basis of SU(2) CQSM with some

additional dynamical assumptions

2. Flavor SU(3) CQSM

model lagrangian

$$\boxed{\mathcal{L} = \bar{\psi}(x)\,(\,i\,\not\partial - M\,U^{\gamma_5}(x) - \Delta m_s\,P_s\,)\,\psi(x)}$$

with

$$U^{\gamma_5}(x) = e^{i\,\gamma_5\,\pi(x)/f_\pi}, \qquad \pi(x) = \pi_a(x)\,\lambda_a \quad (a = 1, \cdots, 8)$$

$$\Delta m_s\,P_s = \begin{pmatrix} 0 & & \\ & 0 & \\ & & \Delta m_s \end{pmatrix} \quad : \quad \text{SU(3) breaking term}$$

basic dynamical assumptions

(1) **lowest energy classical solution** is obtained by

embedding of SU(2) hedgehog solution

$$U_0^{\gamma_5}(\boldsymbol{x}) = \begin{pmatrix} e^{i\,\gamma_5\,\boldsymbol{\tau}\cdot\hat{\boldsymbol{r}}\,F(r)} & 0 \\ 0 & 1 \end{pmatrix} \quad \in \quad \mathbf{SU(3)}$$

(2) **quantization** of **symmetry restoring rotational motion** in **SU(3) collective coordinate space**

$$U^{\gamma_5}(\boldsymbol{x}, t) \;=\; A(t)\, U_0^{\gamma_5}(\boldsymbol{x})\, A^{\dagger}(t)$$

with

$$A(t) \;=\; e^{-i\Omega t}, \quad \Omega \;=\; \frac{1}{2}\Omega_a \lambda_a \;\in\; \mathrm{SU}(3)$$

(3) **perturbative treatment** of **SU(3) breaking term**

$$\Delta \tilde{H} \;=\; \Delta m_s \cdot \gamma^0 A^{\dagger}(t) \left(\frac{1}{3} - \frac{1}{\sqrt{3}} \lambda_8 \right) A(t)$$

$$\Delta m_s \;=\; (60 \;\sim 180)\,\mathrm{MeV}$$

we have taken account of **3 types** of $\boldsymbol{O(\Delta m_s)}$ **corrections**

- "dynamical Δm_s correction"
- "kinematical Δm_s correction"
- " representation mixing Δm_s correction"

For more detail $\Downarrow$ See

"A chiral theory of light-flavor sea-quark distributions in the nucleon", hep-ph/0209011

3. Comparison with High Energy Data

- **only 1 parameter** of the **SU(3) CQSM**, is fixed to be

$$\Delta m_s = 100\,\mathrm{MeV}$$

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no other free parameter

- use predictions of CQSM as **initial-scale distributions**

$$\begin{array}{ll} u(x),\ d(x),\ s(x), & \Delta u(x),\ \Delta d(x),\ \Delta s(x) \\ \bar{u}(x),\ \bar{d}(x),\ \bar{s}(x), & \Delta \bar{u}(x),\ \Delta \bar{d}(x),\ \Delta \bar{s}(x) \\ g(x) = \mathbf{0}, & \Delta g(x) = \mathbf{0} \end{array}$$

- **scale dependence of PDF**

$\boxed{\text{Fortran code of } \textbf{DGLAP} \text{ eqs. at } \textbf{NLO}}$

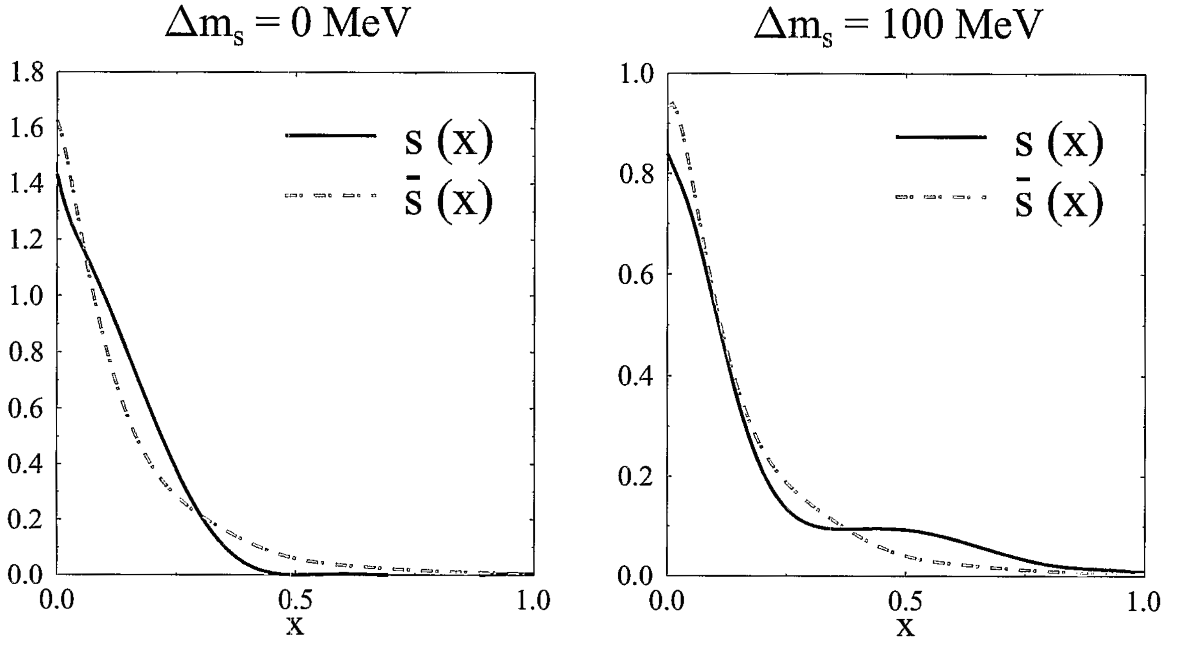
provided by Saga group

initial energy scale is fixed to be

$$Q^2_{ini} = 0.30\,\mathrm{GeV}^2 \simeq (550\,\mathrm{MeV})^2$$

theoretical distributions at model energy scale

(A) **unpolarized strange distribution**



- $\boldsymbol{s - \bar{s}}$ **asymmetry** of the **unpolarized** distribution functions certainly **exists**

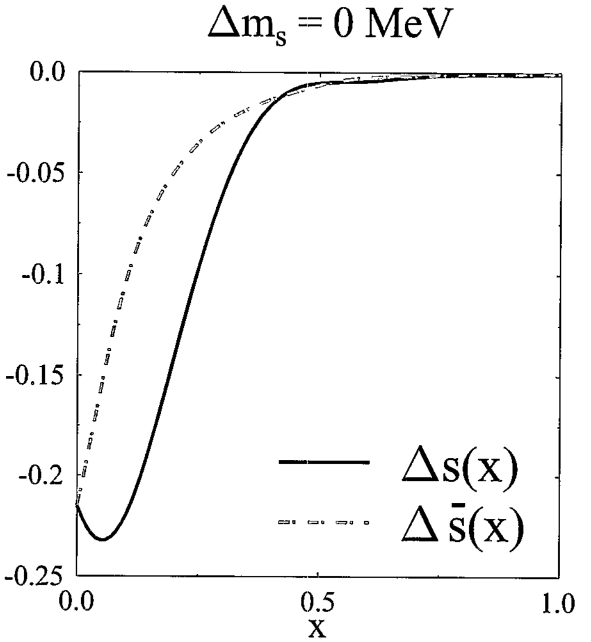
- difference $\boldsymbol{s(x) - \bar{s}(x)}$ has **oscilatory $\boldsymbol{x}$ dependence** with several zeros, due to the **restrictions** :

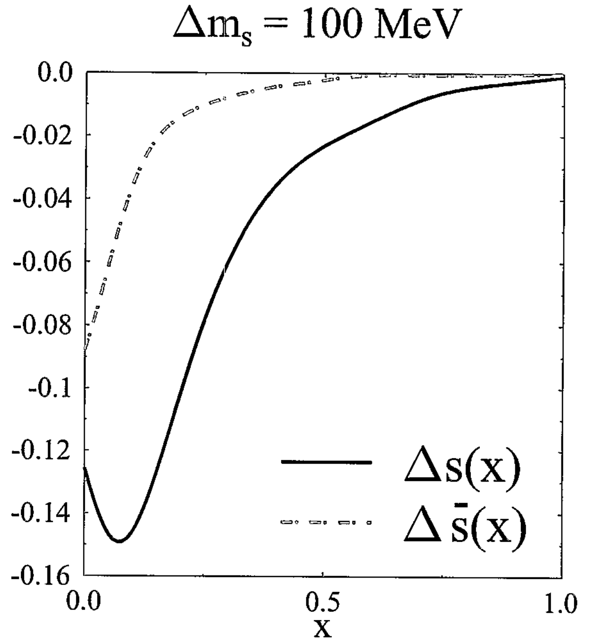
$$s(x) > 0, \quad \bar{s}(x) > 0 \quad : \quad \text{positivity constraint}$$

$$\int [\, s(x) - \bar{s}(x) \,] \, dx = 0 \quad : \quad \text{strangeness conservation}$$

- $\boldsymbol{s(x) - \bar{s}(x)}$ is very sensitive to SU(3) breaking

(B) **longitudinally polarized strange distributions**





- In chiral limit, s and $\bar{s}$ are both **negatively polarized**
- after introducing **SU(3) symmetry breaking effects**

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$$\begin{cases} \boldsymbol{\Delta s(x)} \text{ still remains } \textbf{large and negative} \\ \boldsymbol{\Delta \bar{s}(x)} \text{ becomes } \textbf{very small} \end{cases}$$

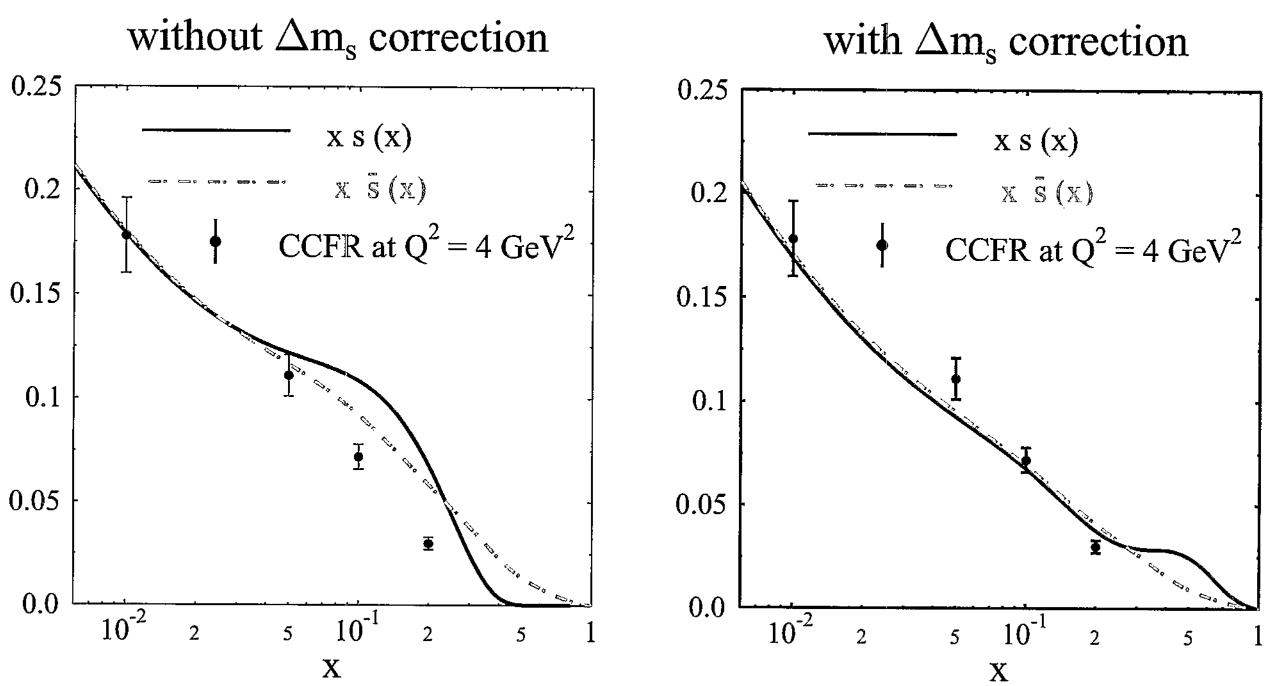
- $\boldsymbol{s - \bar{s}}$ **asymmetry** of the **longitudinally polarized** distribution is **more profound** than the **unpolarized one**

— **no conservation law** —

comparison with existing high-energy data

CCFR analysis of **neutrino-induced charm productions** with the **constraint** $\bar{s}(x) = \boldsymbol{s(x)}$

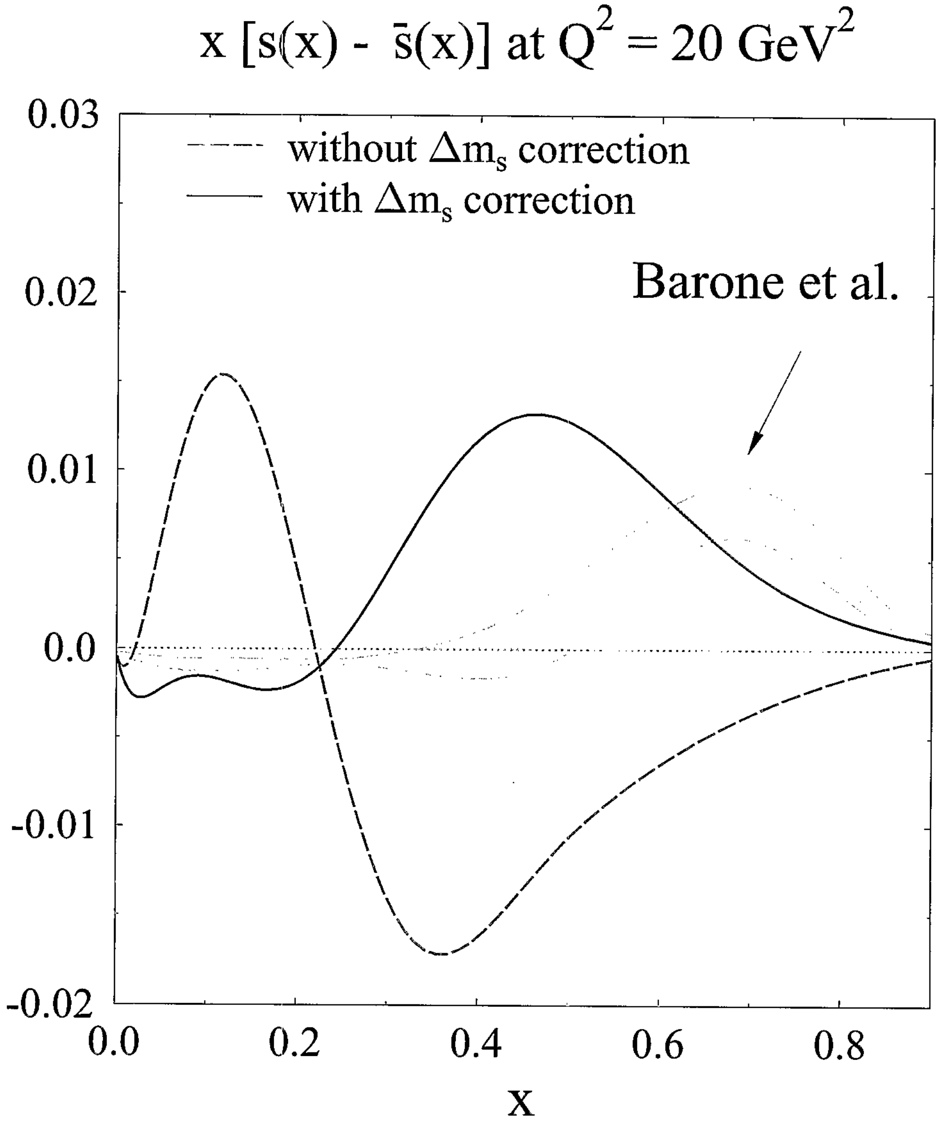
A.O. Bazarko et al., CCFR Collab., Z. Phys. C65 (1995) 189



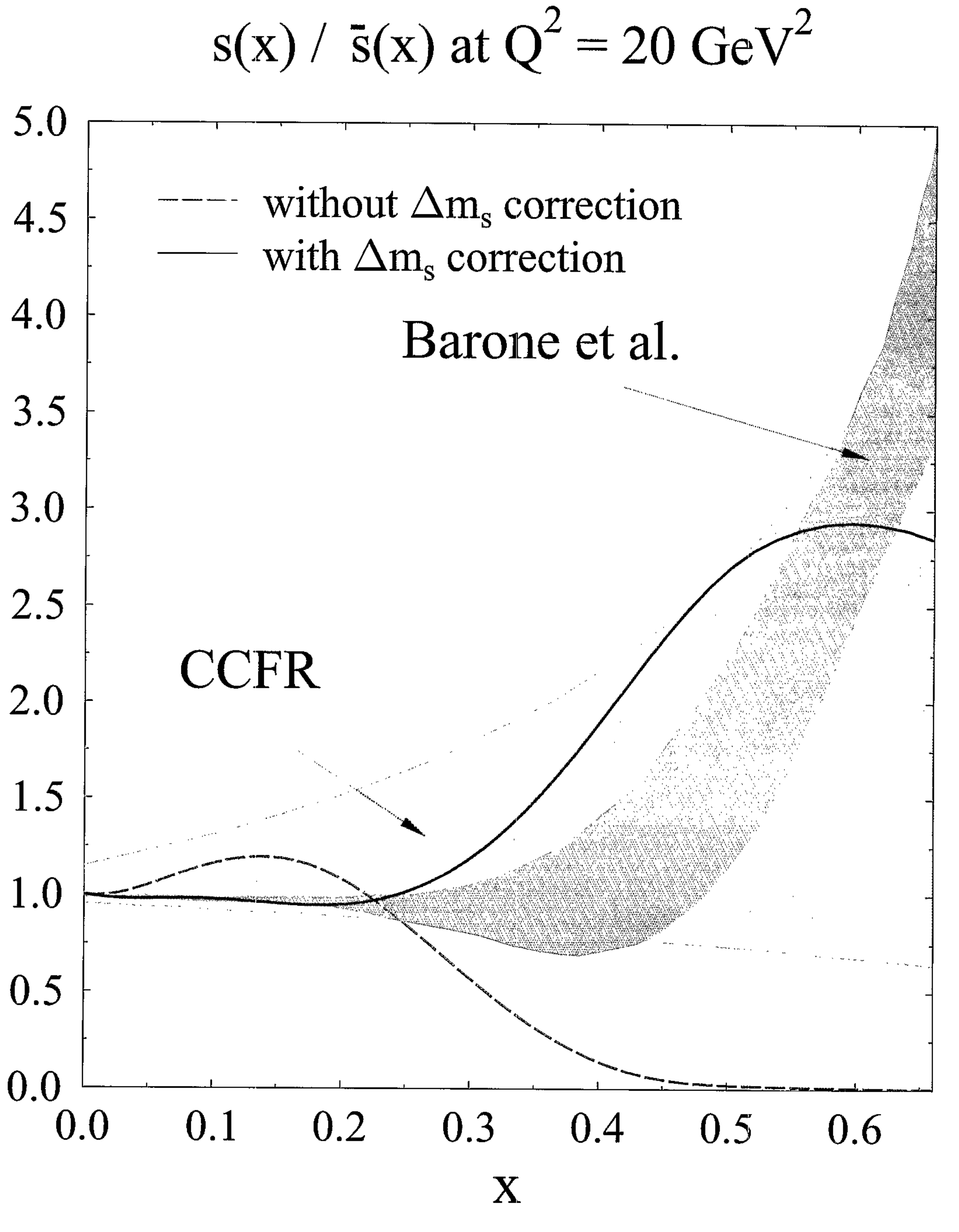
- After inclusion of the **SU(3) breaking corrections**, the theory reproduces **qualitative tendency** of the CCFR fit global analysis including all the neutrino data

- V. Barone et al., Eur. Phys. J. C12 (2000) 243

difference of $s(x)$ and $\bar{s}(x)$ at $Q^2 = 20\,\mathbf{GeV}^2$



ratio of $s(x)$ and $\bar{s}(x)$ at $Q^2 = 20\,\mathbf{GeV}^2$

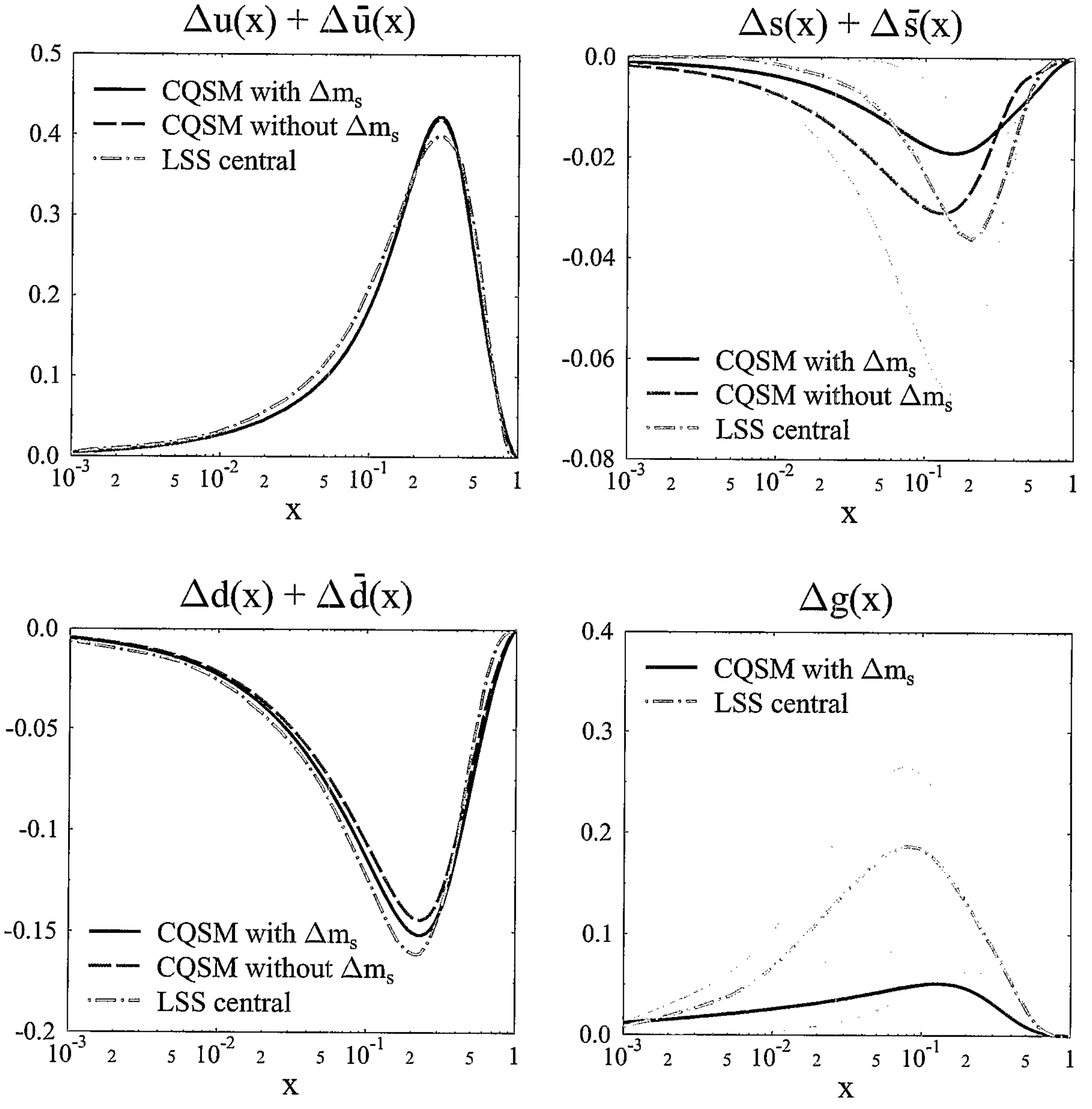


LSS fits of polarized DIS data at $Q^2 = 1\,\mathrm{GeV}^2$

E. Leader, A.V. Sidorov, D.B. Stamenov, P.L. B488 (2000) 283

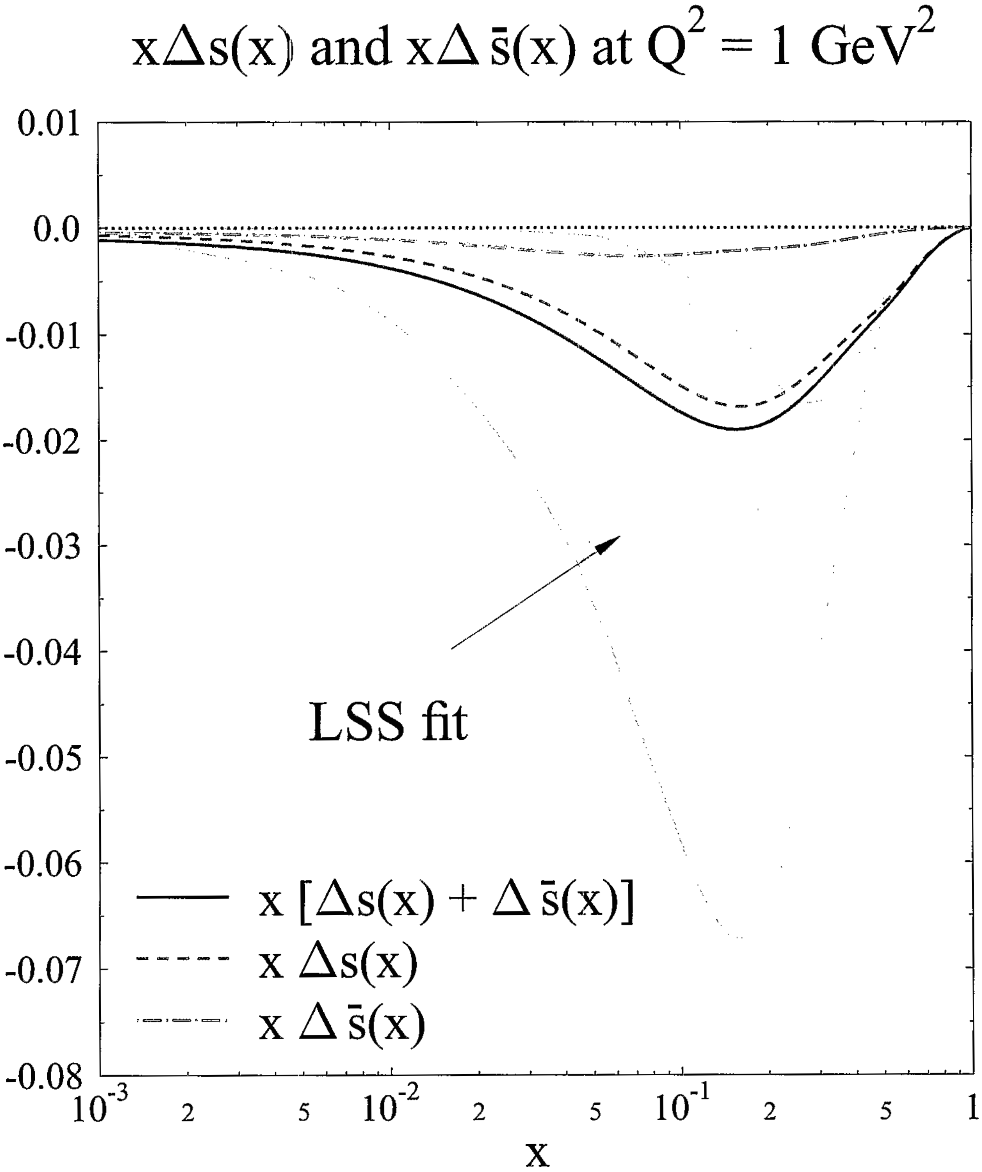
relaxing groundless assumptions of past analyses like

— flavor symmetric sea —



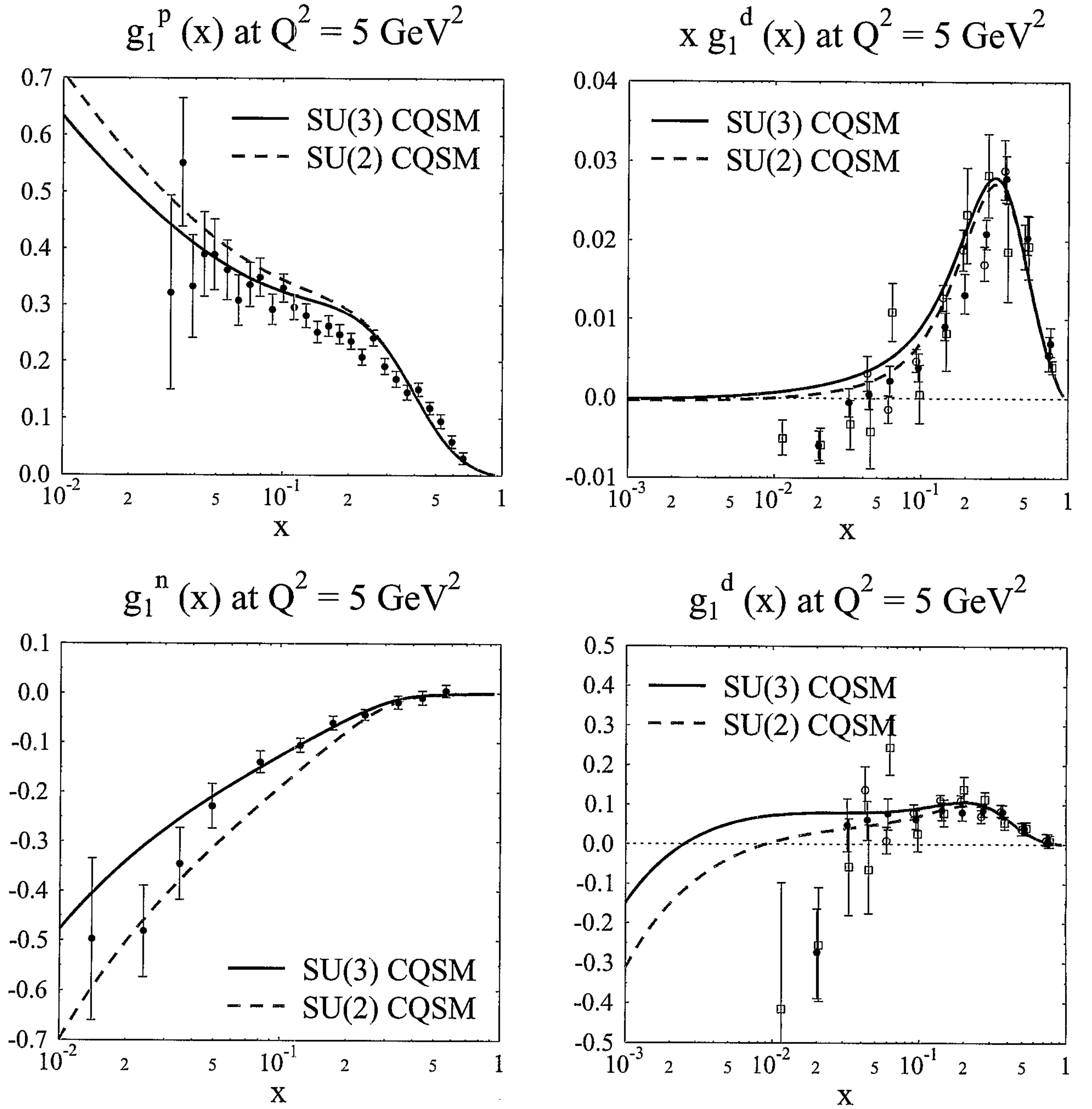
separate contribution of $\Delta s(x)$ and $\Delta \bar{s}(x)$

to polarized strange sea



- polarization of strange sea almost solely comes from s-quark, and the contribution of $\bar{s}$-quark is very small

comparison with EMC and SMC data



problem of isospin asymmetry of **sea quark distributions**

SU(2) CQSM predicts $\begin{cases} \bar{u}(x) - \bar{d}(x) < 0 \\ \Delta\bar{u}(x) - \Delta\bar{d}(x) > 0 \end{cases}$

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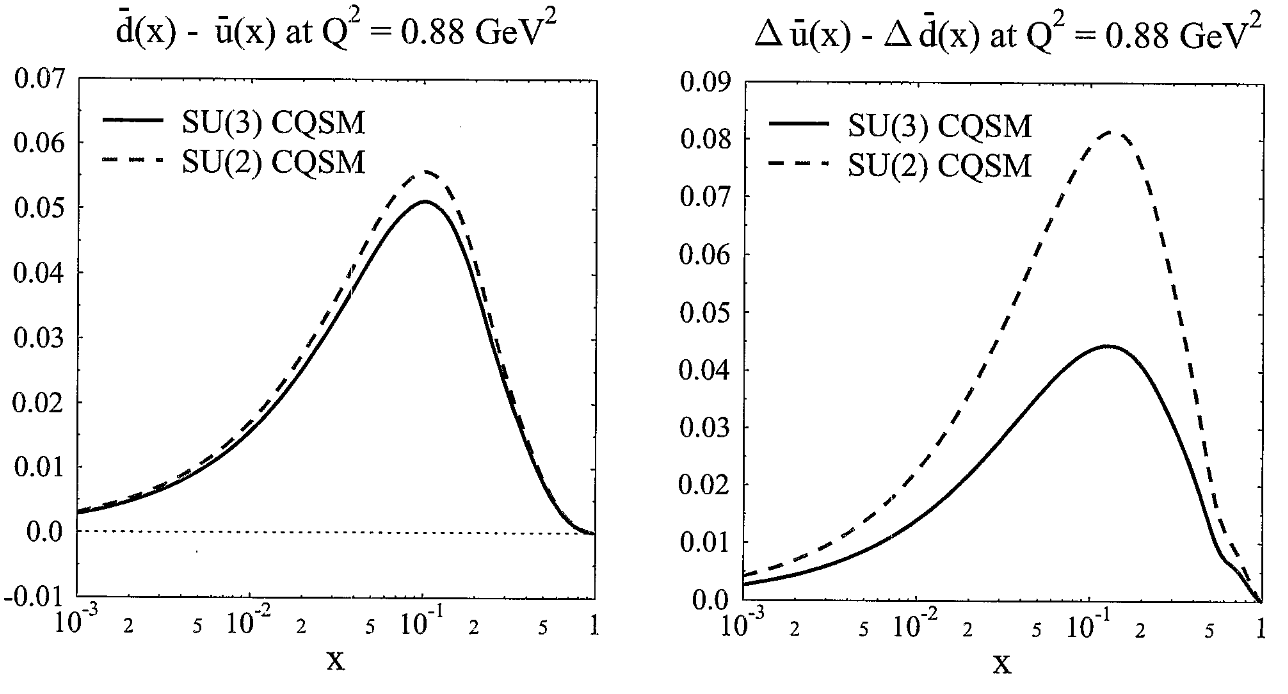
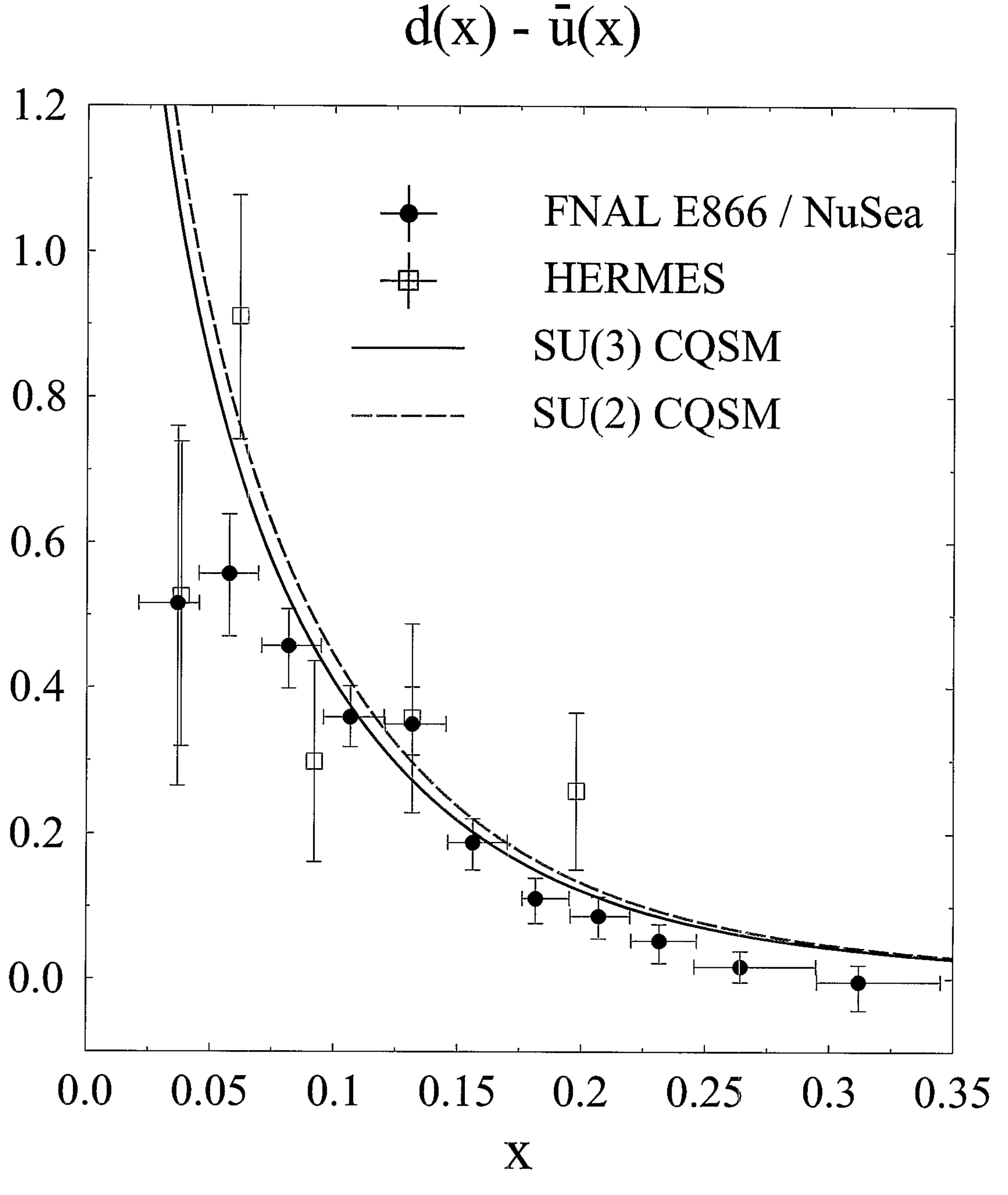
SU(3) CQSM ?

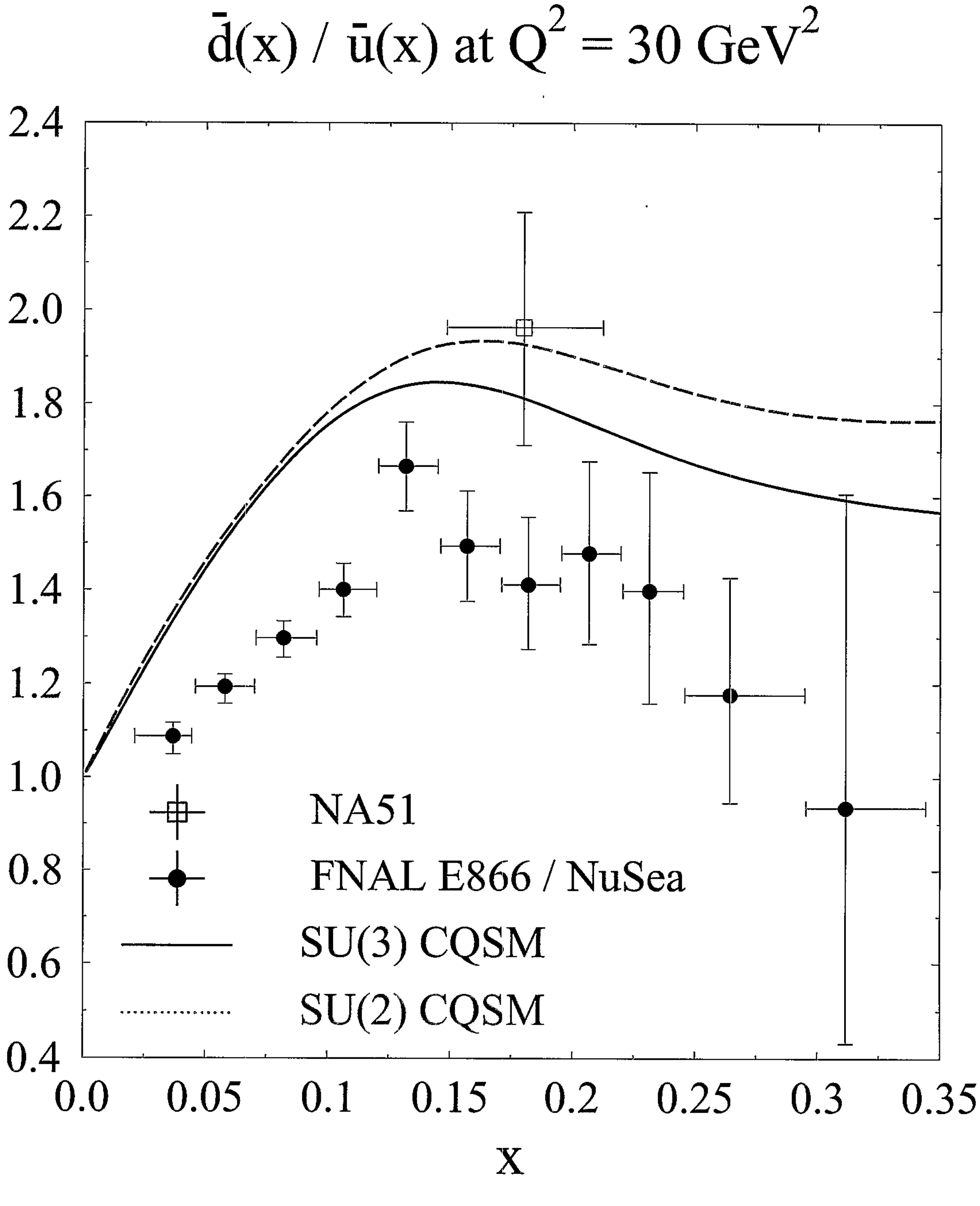


- $[\bar{d}(x) - \bar{u}(x)]^{SU(3)} \simeq [\bar{d}(x) - \bar{u}(x)]^{SU(2)}$
- $[\Delta\bar{d}(x) - \Delta\bar{u}(x)]^{SU(3)} < [\Delta\bar{d}(x) - \Delta\bar{u}(x)]^{SU(2)}$

difference of $\bar{d}(x)$ and $\bar{u}(x)$: E866



<u>ratio of $\bar{d}(x)$ to $\bar{u}(x)$</u> : E866



5. Conclusion

♣ An **incomparable** feature of the **CQSM** as compared with many other effective models like the **MIT bag model** is that it can give reasonable predictions also for the

antiquark distribution functions

♣ This feature is essential also for giving any reliable predictions for **hidden strange distributions** in the nucleon, which totally have

non-valence character

<u>**with** **a single parameter**, **SU(3) CQSM predicts**</u>

- $s(x) - \bar{s}(x)$ has some **oscilatory x dependence** due to

  * **positivity constraint** for $s(x)$ and $\bar{s}(x)$

  * **strangeness quantum number conservation**

- after inclusion of the **SU(3) symmetry breakings**, **x dependence** of $s(x) - \bar{s}(x)$ and $s(x)/\bar{s}(x)$ are qualitatively consistent with global analysis of **Barone et al.**

- s-$\bar{s}$ **asymmetry** of **longitudinally polarized sea** is more profound than that of **unpolarized sea**

$$\begin{cases} \Delta s(x) & : \quad \text{large and negative !} \\ \Delta \bar{s}(x) & : \quad \text{close to zero !} \end{cases}$$

- model also predicts **large isospin asymmetric sea**

$$\left. \begin{array}{l} \bar{u}(x) \; - \; \bar{d}(x) \; < \; 0 \\ \\ \Delta\bar{u}(x) \; - \; \Delta\bar{d}(x) \; > \; 0 \quad \left(\Delta\bar{u}(x) > 0 > \Delta\bar{d}(x) \right) \end{array} \right\} \quad \text{in p}$$

Important lesson

nonperturbative QCD dynamics due to **spontaneous** χ**SB** manifests most clearly in the spin & flavor dependence

of

antiquark distributions

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What is **absolutely** required in future experiments is

$$\left\{ \begin{array}{c} \text{flavor} \\ \\ \text{valence} \;\; \oplus \;\; \text{sea} \end{array} \right\} \text{ decomposition of } \textbf{PDF}$$