4.3. Flavor SU(3) CQSM and Strange Nucleon Sea

model lagrangian

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

with

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

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

basic dynamical assumptions

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

embedding of SU(2) hedgehog solution

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

(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

"Light flavor sea quark distributions in the nucleon in the SU(3) chiral quark soliton model", Phys. Rev. D67 (2003) 034005, 034006

Comparison with High Energy Data

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

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

$$\Downarrow$$

no other free parameter

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

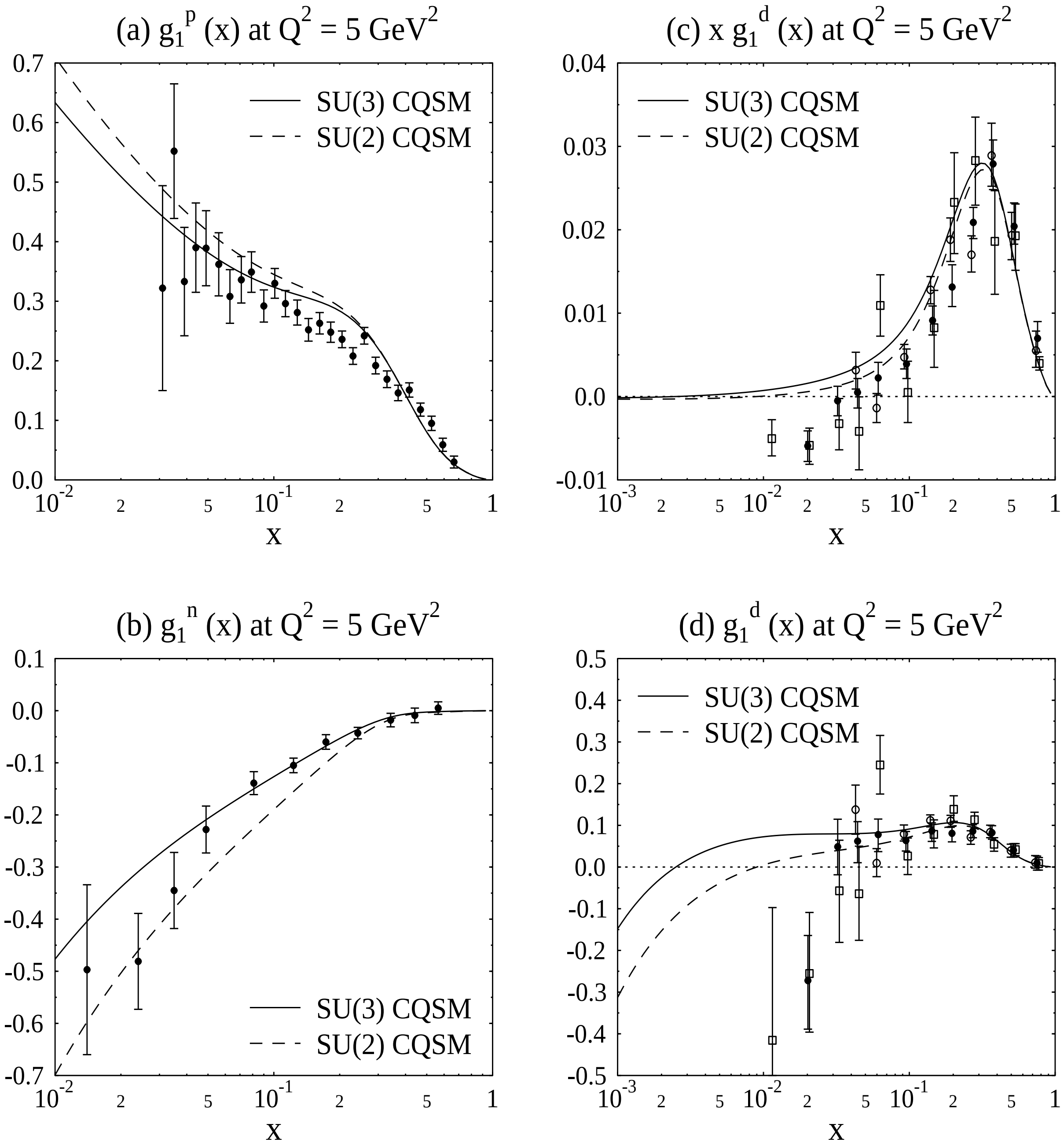
$$Q^2_{ini} \;=\; 0.30\,\mathrm{GeV}^2 \quad \simeq \quad (550\,\mathrm{MeV})^2$$

$$\boldsymbol{u(x),\; d(x),\; s(x),} \qquad \boldsymbol{\Delta u(x),\; \Delta d(x),\; \Delta s(x)}$$

$$\boldsymbol{\bar{u}(x),\; \bar{d}(x),\; \bar{s}(x),} \qquad \boldsymbol{\Delta \bar{u}(x),\; \Delta \bar{d}(x),\; \Delta \bar{s}(x)}$$

$$\boldsymbol{g(x) \;=\; 0}, \qquad \boldsymbol{\Delta g(x) \;=\; 0}$$

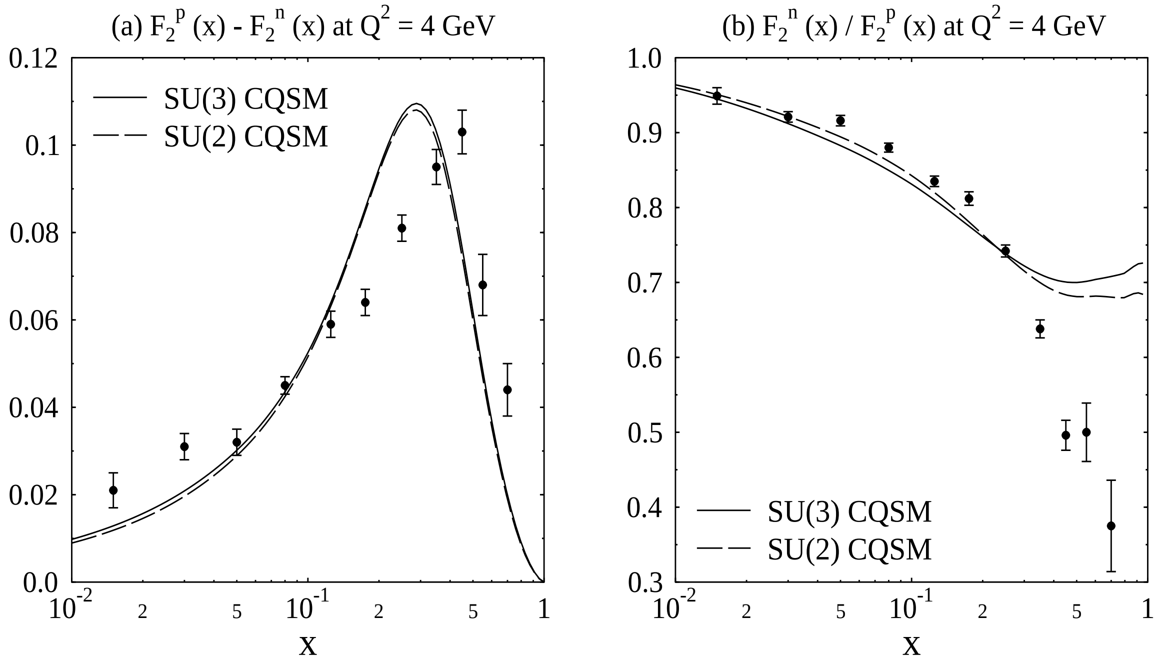
SU(3) vursus SU(2) model predictions

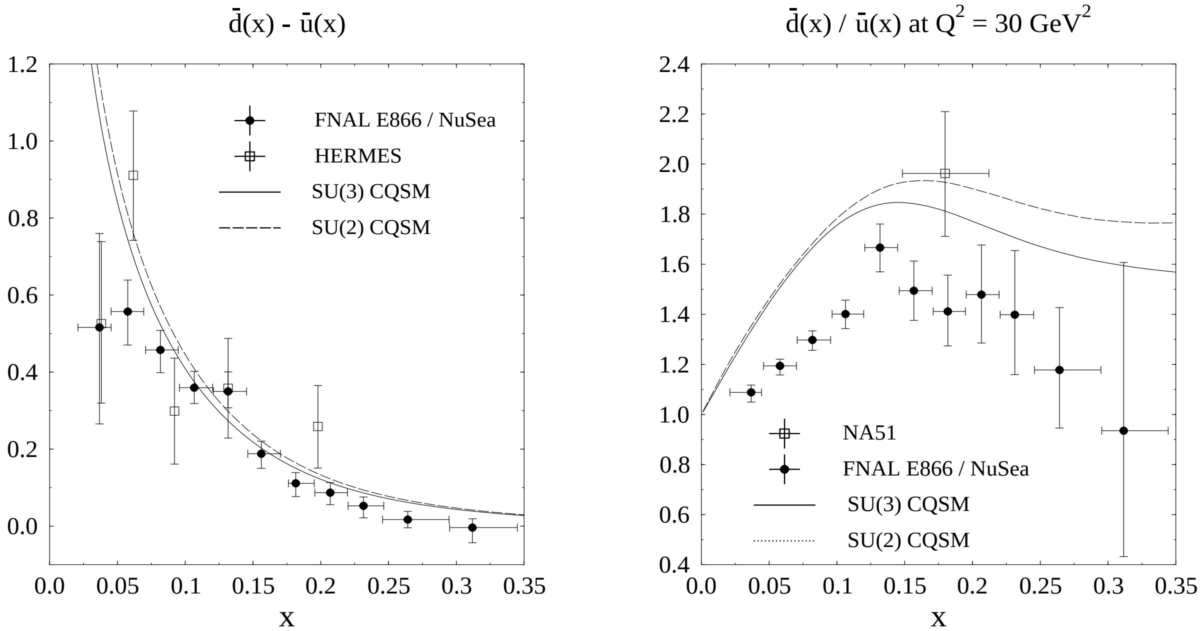


relevant 1st moments

	SU(2) CQSM	**SU(3) CQSM**	**Experiment**
$g_A^{(3)}$	1.41	1.20	1.257 ± 0.016
$g_A^{(8)}$	—	0.59	0.579 ± 0.031
$g_A^{(0)}$	**0.35**	**0.36**	**0.31 ± 0.07**
Δu	0.88	0.82	0.82 ± 0.03
Δd	-0.53	-0.38	-0.44 ± 0.03
$\boldsymbol{\Delta s}$	**0**	**-0.08**	**-0.11 ± 0.03**
F	—	0.45	0.459 ± 0.008
D	—	0.76	0.798 ± 0.008
F/D	—	0.59	0.575 ± 0.016

SU(2) asymmetry of sea quark distributions



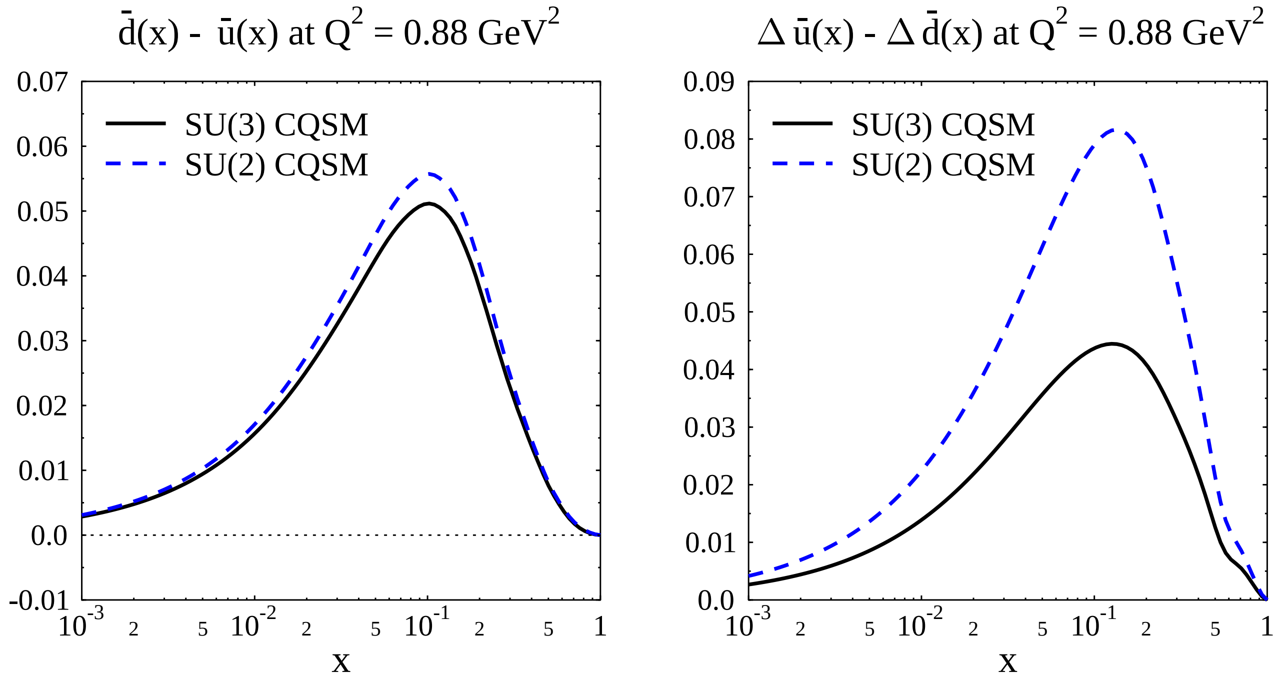


problem of **isospin asymmetry** of **sea quark distributions**

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

$$\Downarrow$$

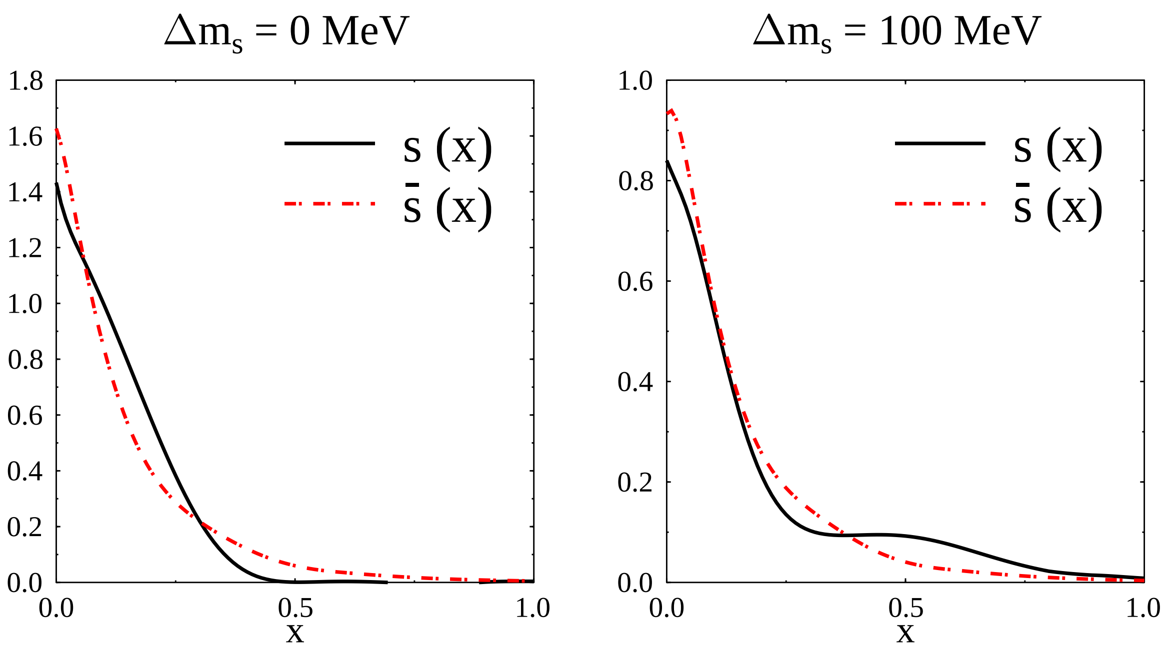
SU(3) CQSM ?



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

theoretical strange distributions at model energy scale

(A) **unpolarized strange distribution**



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

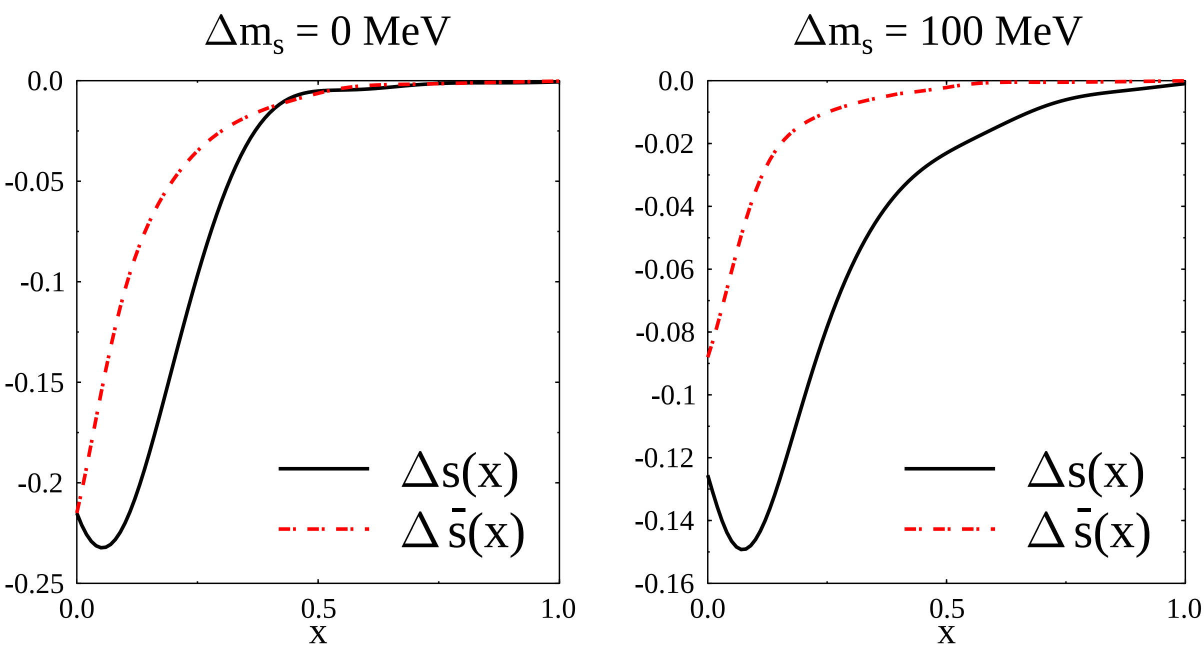
- difference $\boldsymbol{s(x) - \bar{s}(x)}$ has **oscilatory** $\boldsymbol{x}$ **dependence** with **several zeros**, due to the **restrictions** :

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

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

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

(B) **longitudinally polarized strange distributions**



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

$$\Downarrow$$

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

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

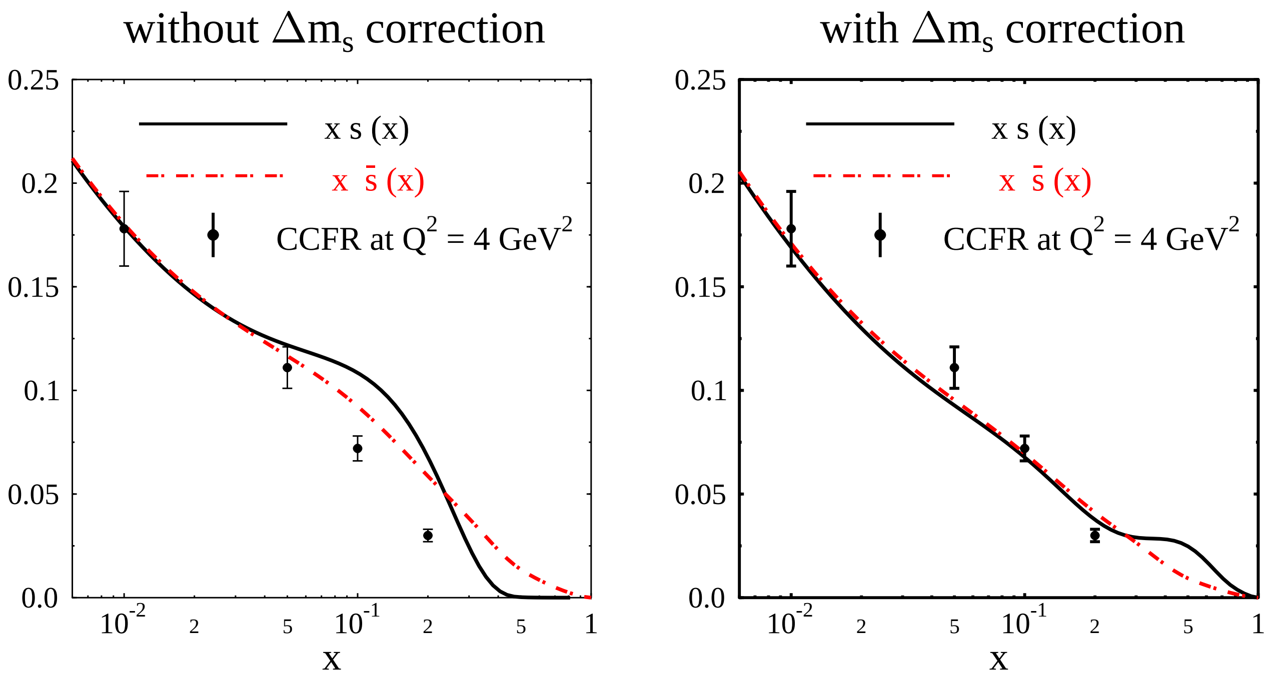
— **no conservation law** —

comparison with existing high-energy data

CCFR analysis of **neutrino-induced charm productions**

with the **constraint** $\bar{s}(x) = s(x)$

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

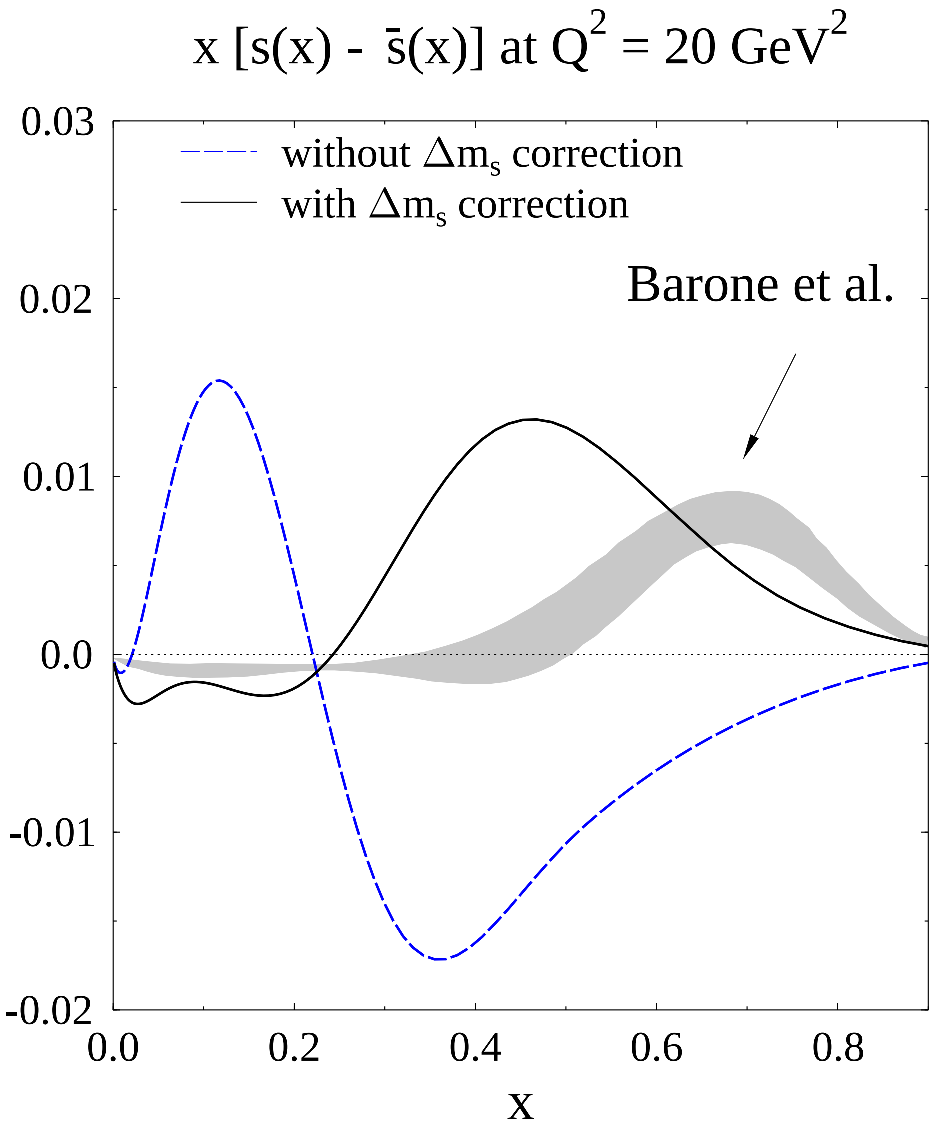


- after inclusion of the **SU(3) breaking corrections**, the theory reproduces **qualitative tendency** of the CCFR fit

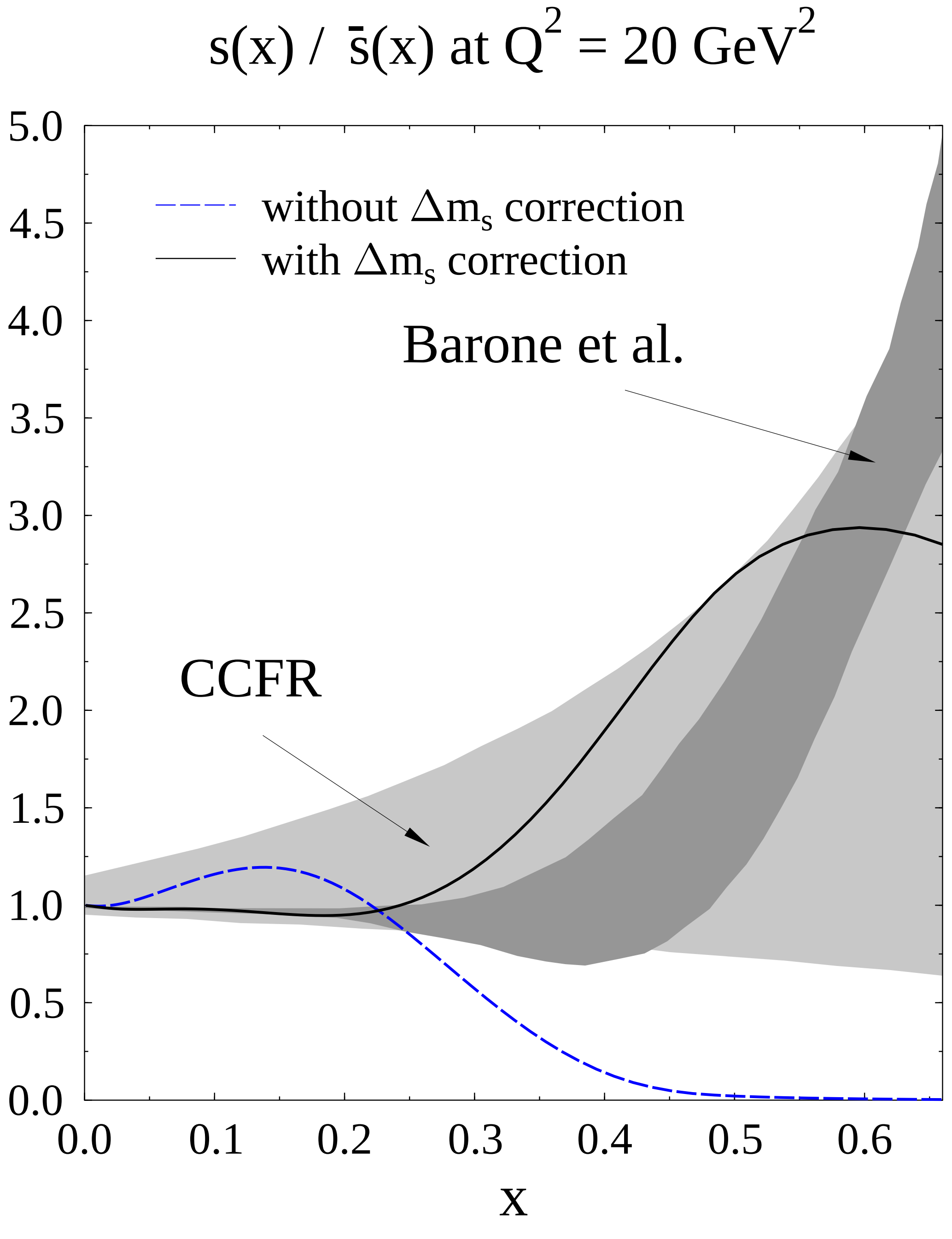
global analysis including **all the neutrino data**

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

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



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

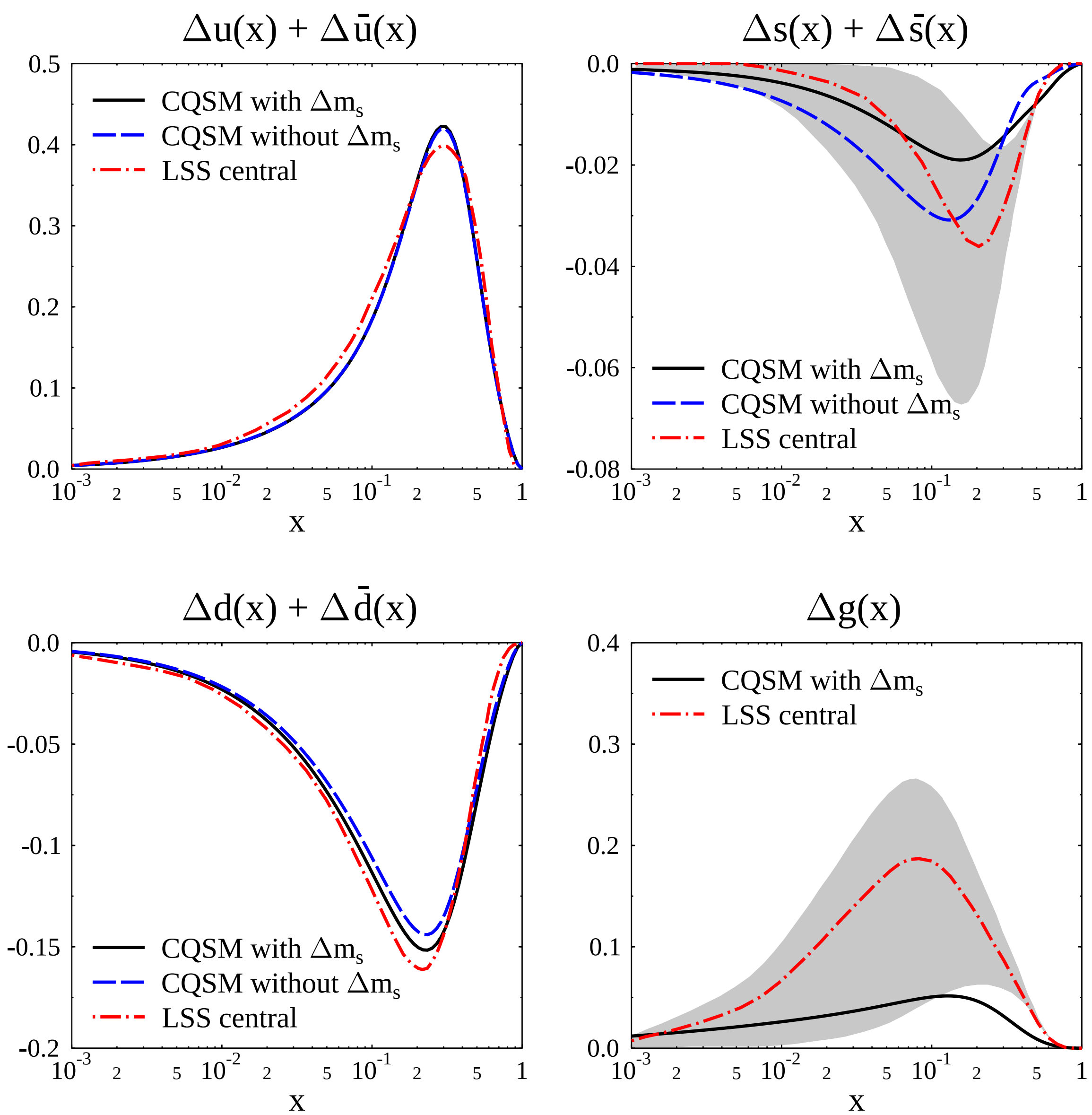


LSS fits of polarized DIS data at $Q^2 = 1\,\mathrm{GeV}^2$

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

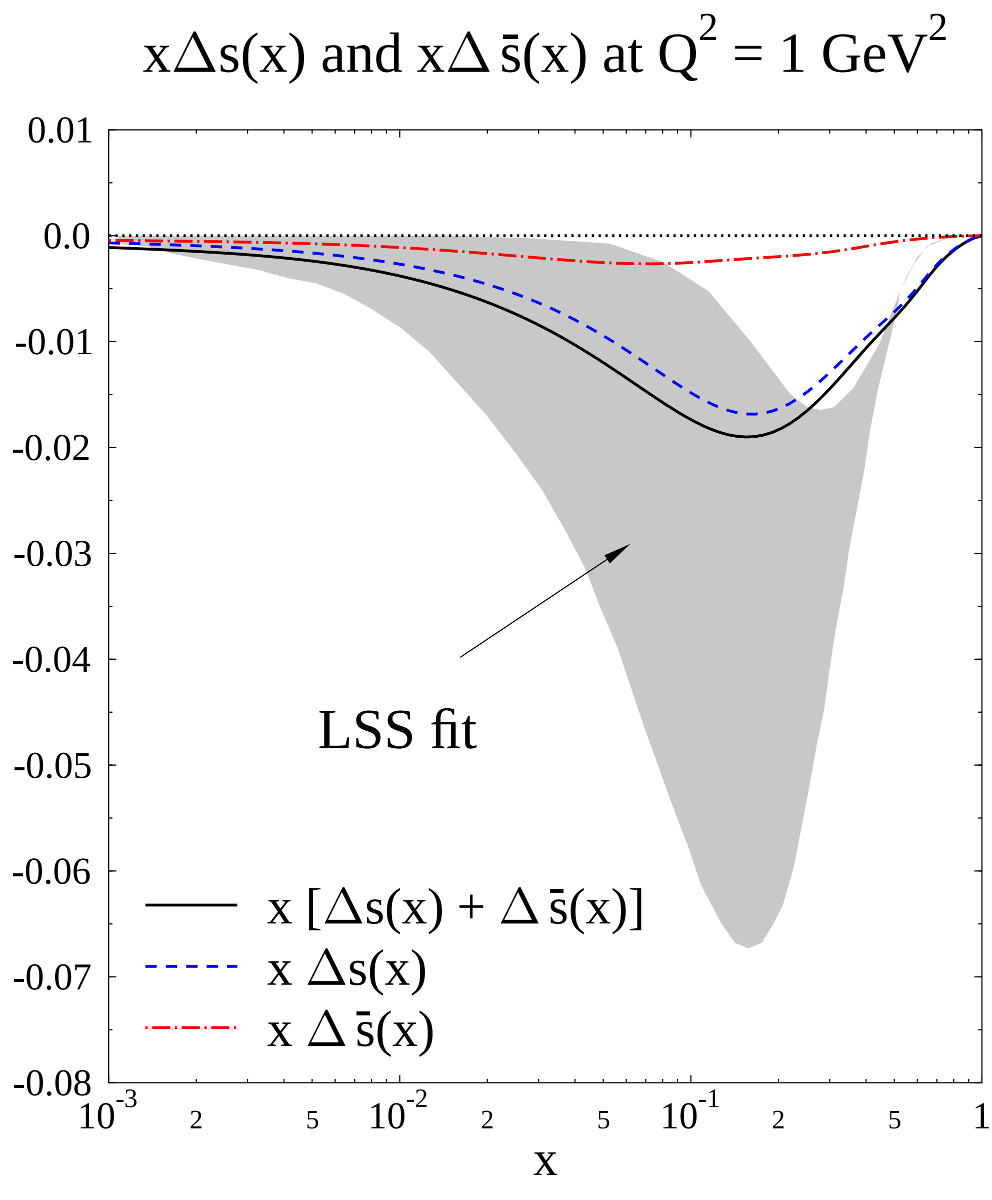
relaxing groundless assumptions of past analyses like

— **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

NuTeV anomaly

neutrino & antineutrino $\begin{cases} \text{neutral-current cross section} \\ \text{charged-current cross section} \end{cases}$

Paschos-Wolfenstein ratio (naive expression)

$$R^- \equiv \frac{\sigma_{NC}^{\nu} - \sigma_{NC}^{\bar{\nu}}}{\sigma_{CC}^{\nu} - \sigma_{CC}^{\bar{\nu}}} = \frac{1}{2} - \sin^2\theta_W$$

NuTeV determination of **Weinberg angle** θ_W

$$\sin^2\theta_W = 0.2277 \pm 0.0013 \pm 0.0009$$

$\Updownarrow$ $3\,\sigma$ deviation

world average : 0.2227 ± 0.0004

Paschos-Wolfenstein ratio with various correction

$$R^- = \frac{1}{2} - \sin^2\theta_W + \delta R_A^- + \delta R_{EW}^- + \delta R_{QCD}^-$$

δR_A^- : 標的原子核の **non-isoscalarity correction**
δR_{EW}^- : **高次の electroweak correction**
δR_{QCD}^- : **QCD correction**

QCD correction

$$\delta R^-_{QCD} \;=\; \delta R^-_s \;+\; \delta R^-_I \;+\; \delta R^-_{NLO}$$

δR^-_s : 核子中の s-$\bar{s}$ asymmetry correction

δR^-_I : isospin violation $(u_{p,n} \neq d_{n,p})$

δR^-_{QCD} : NLQ QCD correction

核子中の s-$\bar{s}$ asymmetry による補正

$$\delta R^-_s \;\simeq\; -\left(\frac{1}{2} - \frac{7}{6}\sin^2\theta_W\right)\frac{[S^-]}{[Q^-]}$$

ただし

$$[S^-] \;\equiv\; \int_0^1 x\,[s(x) - \bar{s}(x)]\,dx$$
$$[Q^-] \;\equiv\; \int_0^1 x\,[u(x) - \bar{u}(x) + d(x) - \bar{d}(x)]\,dx$$

CTEQ group の global PDF fit (including **NuTeV data**)

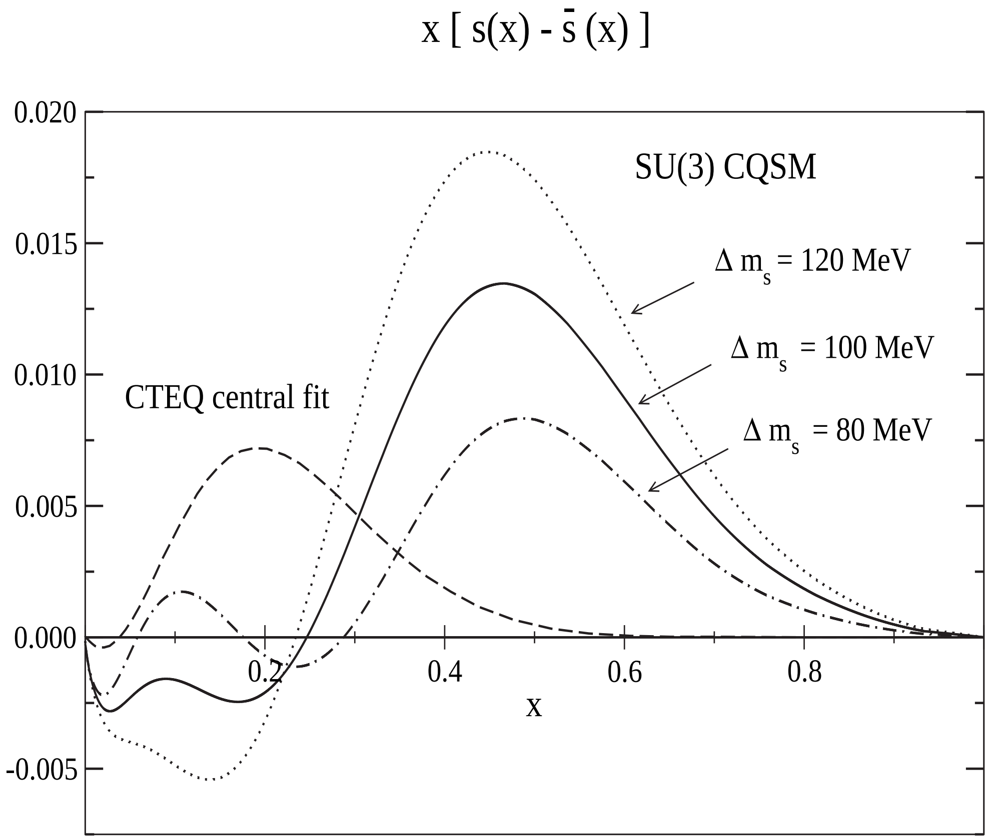
$$\Downarrow$$

$[S^-] \;\simeq\; +0.002$: central value

$-0.001 < [S^-] < 0.004$: conservative bound

- $[S^-] > 0 \Rightarrow$ NuTeV anomaly を減らす方向
- $[S^-] > 0$ は s-クォークの運動量分布が $\bar{s}$-クォークの運動量分布よりも大きな x 成分（ハード成分）を持つことを意味する

prediction of SU(3) CQSM



Δm_s (MeV)	80	100	120
S^-	0.0025	0.0040	0.0055
Q^-	0.226	0.227	0.228
δR_s^-	- 0.0034	- 0.0055	- 0.0075

$$\Updownarrow$$

$$-0.001 \; < \; [S^-]_{CTEQ} \; < \; +0.004$$

$$\delta(\sin^2\theta_W)_{exp} \; \simeq \; -0.0050$$