The strange and antistrange quark distributions of the nucleon

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1. Introduction
2. Mechanism for the sea quark production
3. Total strange sea distributions
4. Strange-antistrange symmetry
5. Summary

1. How well do we know the strange sea

- Strange sea distributions is less constrained that the light quark sea

For example, CTEQ6.5S [H. L. Lai et. al, JHEP 0704:089 (2007)]

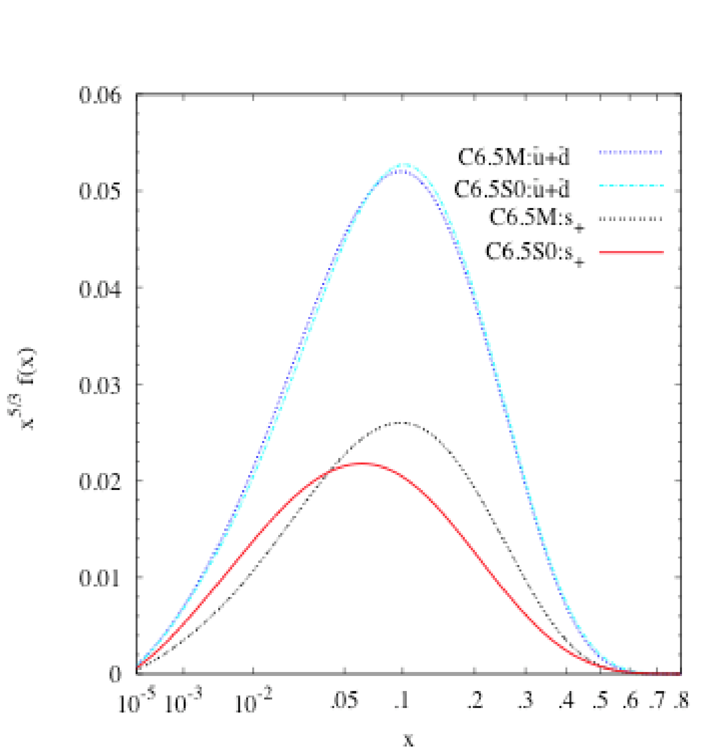
$$s_{\pm}(x,Q_0) = s(x,Q_0) \pm \bar{s}(x,Q_0)$$

$$s_{+}(x,Q_0) = A_0 x^{A_1}(1-x)^{A_2}$$

$A_1^{s_+} = A_1^{(\bar{u}+\bar{d})_+}$ is assumed

A_0 is related to suppression factor

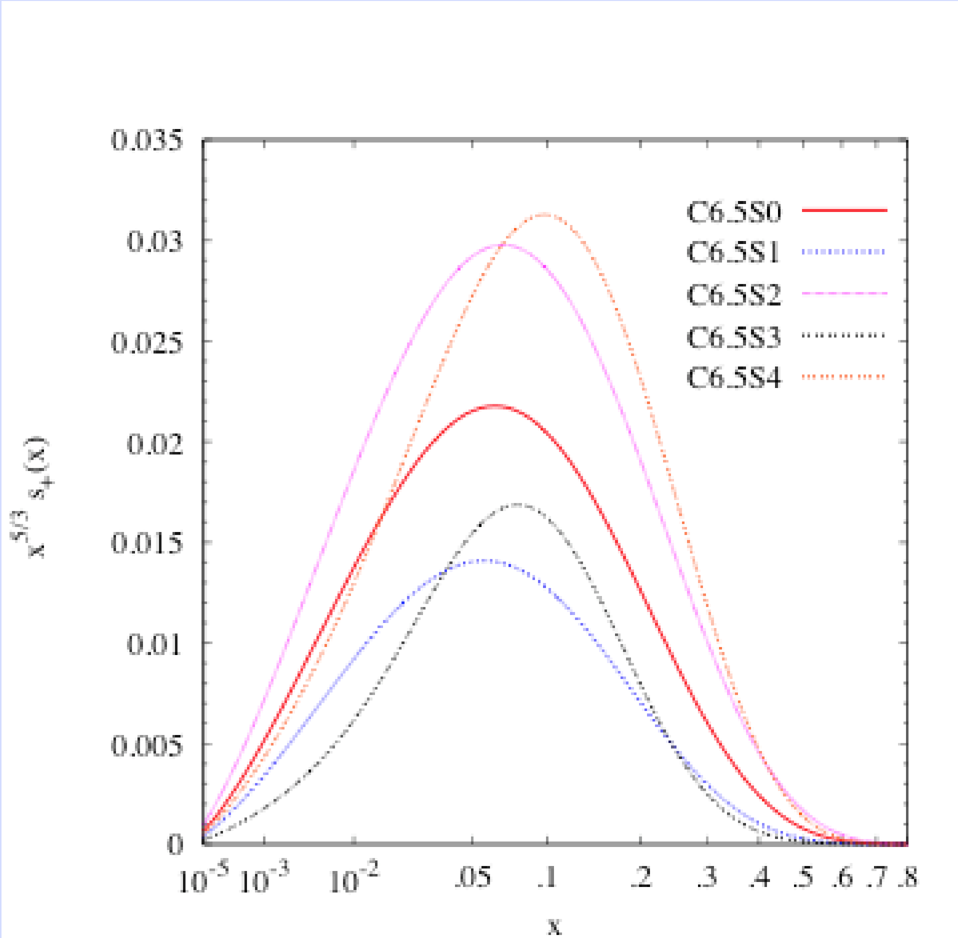
$$r = \frac{\langle x \rangle_{s+}}{\langle x \rangle_{\bar{u}(x)+\bar{d}(x)}}$$



Light sea is almost unchanged while $s_+(x)$ becomes smaller and softer compared to CTEQ6.5M.

$r = 0.44$ (CTEQ6.5S$_0$) vs. 0.50 (CTEQ6.5M)

- Allowed range for s_+(x)



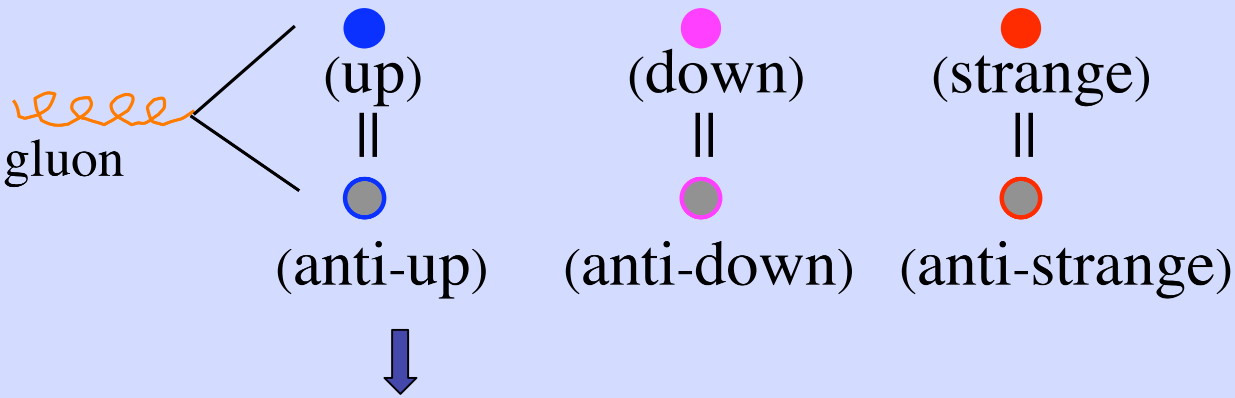
Monentum fraction

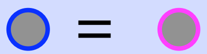
$0.018 < \langle x \rangle < 0.040;$

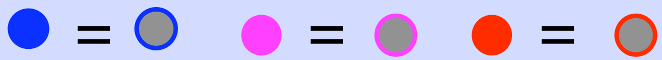
Different parameterizations

2. Mechanism for the strange sea

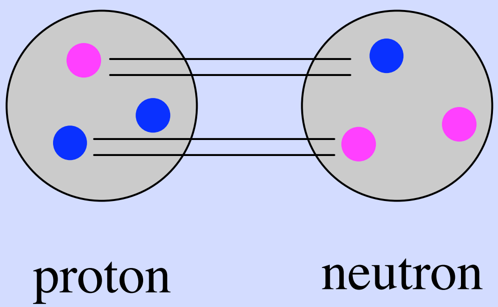
- Perturbative mechanism for the nucleon sea



Flavour symmetry  $(\bar{u} = \bar{d})$

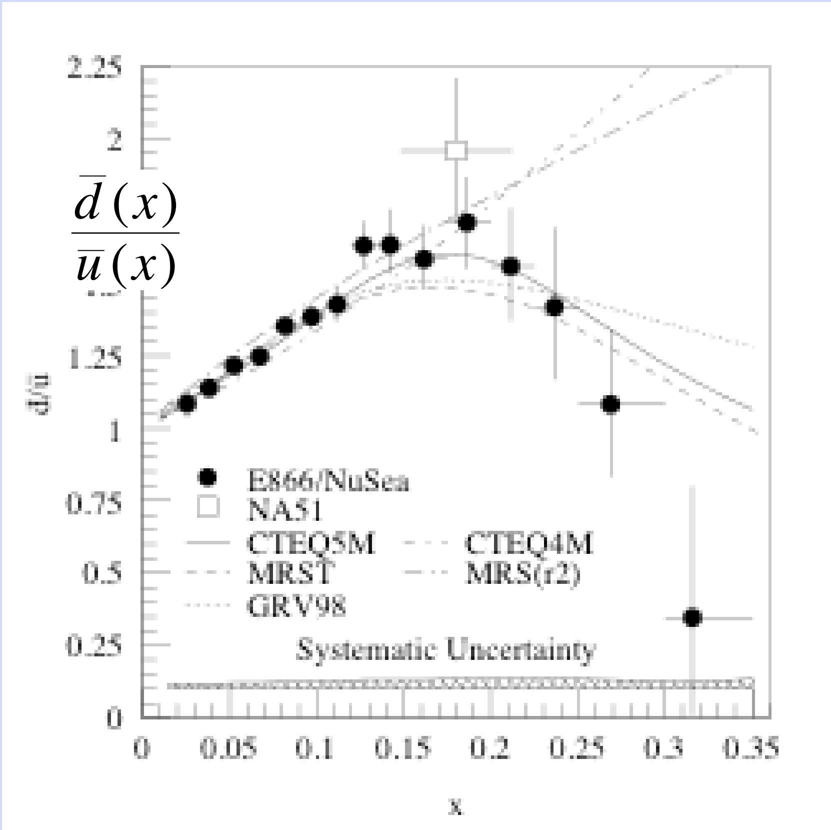
Quark-antiquark symmetry  $(q = \bar{q})$

Charge symmetry

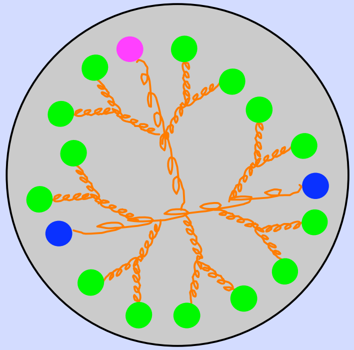


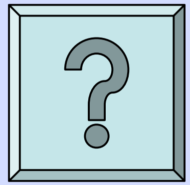
$$\begin{pmatrix} d^p = u^n \\ u^p = d^n \end{pmatrix}$$

Experiments found: SU(2) flavour asymmetry ○ ≠ ○



Garvey&Peng, Prog.Part.Nucl.Phys. 47 (2001) 203-243





- Non-perturbative mechanism for the nucleon sea

→ Meson cloud model $\left|\pi^{+}n\right\rangle > \left|\pi^{-}\Delta^{++}\right\rangle$

→ Pauli blocking

→ Chiral perturbation theory

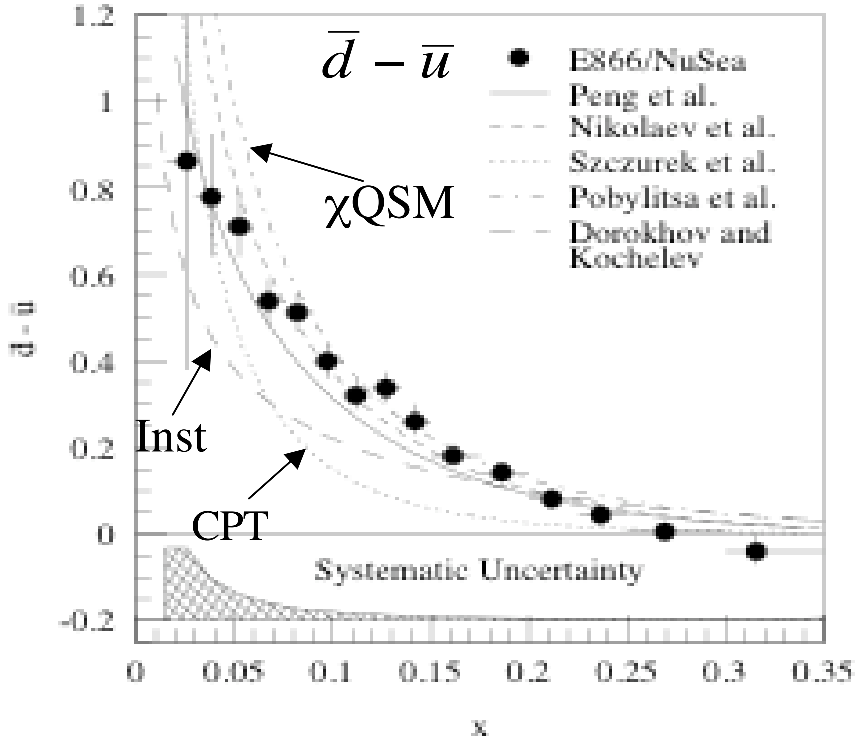
$$u \to d\,\pi^{+}, \quad d \to u\pi^{-}$$

→ Chiral quark-soliton model

$$\bar{d} - \bar{u} = N_c f(xN_c)$$

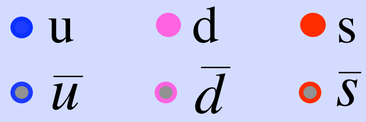
→ Instanton model

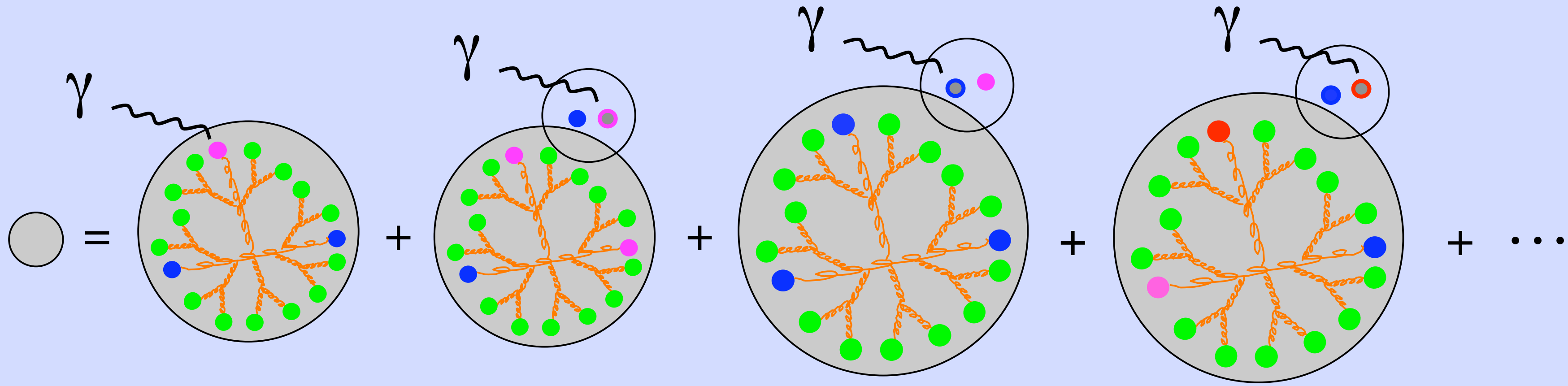
→ Isospin breaking



Phys. Rev. D64 (2001) 052002

2. Meson Cloud Model





$$|p\rangle_{phys} = |p\rangle_{bare} + |n\pi^+\rangle + |\Delta^{++}\pi^-\rangle + |\Lambda K^+\rangle + \cdots$$

-- Fock state expansion of proton's wave function

- The photons may 'see' the anti-quarks in the mesons.
- Observed PDFs: $q_{phys} = q_{bare} + \delta q$ with $\delta q = \int_x^1 \frac{dy}{y} f_{BM}(y)\, q^{B(M)}(\frac{x}{y})$
- Mechanism for symmetry breaking:

  probabilities are different; PDFs of meson and baryon are different

Meson Cloud Model (cont.)

- Each NBM vertex is described by an effective Lagrangian

$$e.g. \quad L = i\, g_{NN\pi} \bar{N} \gamma_5\, \pi\, N \quad \text{for the } NN\pi \text{ vertex}$$

- f is calculated by employing time-order perturbative theory (TOPT) in the infinite momentum frame

$$f_{BM}(y) = \sum_{\lambda\lambda'} \int_0^\infty dk_\perp^2 \left| \phi_{BM}^{\lambda\lambda'}(y, k_\perp^2) \right|^2, \qquad \phi_{BM}^{\lambda\lambda'}(y, k_\perp^2) \propto V_{IMF}(y, k_\perp^2)\, G(y, k_\perp^2)$$

G ↑ Phenomenological form factor

- Prescriptions for $q^{B(M)}$

→ Bag model calculations

→ Ansatz based on lattice calculations $\int_0^1 \Delta V_\rho(x) dx = 0.6 \int_0^1 V_\rho(x) dx$

$$\rightarrow \Delta V_\rho = 0.6\, V_\rho = 0.6\, V_\pi$$

→ SU(3) symmetry $\quad s^\Lambda = s^\Sigma = \frac{1}{2} u^N; \qquad u^N \Rightarrow MRST\,98$

Successes and predictions of the MCM

- SU(2) flavour asymmetry in the unpolarized nucleon sea is well established

- Possible SU(2) flavour asymmetry in the polarized nucleon sea?

- The extent of SU(3) flavour symmetry breaking.

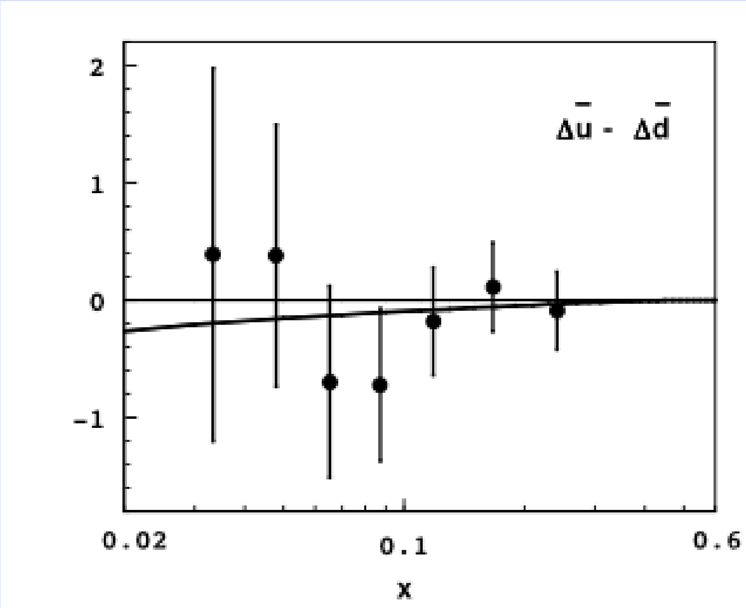
Common practice in most global QCD analyses of PDFs is

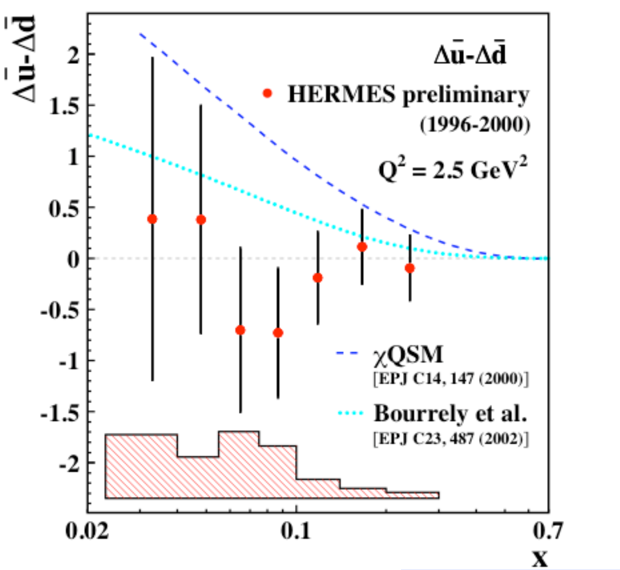
$s(x)+\bar{s}(x)=r\left[\bar{u}(x)+\bar{d}(x)\right]$ with $r=0.50$ (CTEQ6.5M)

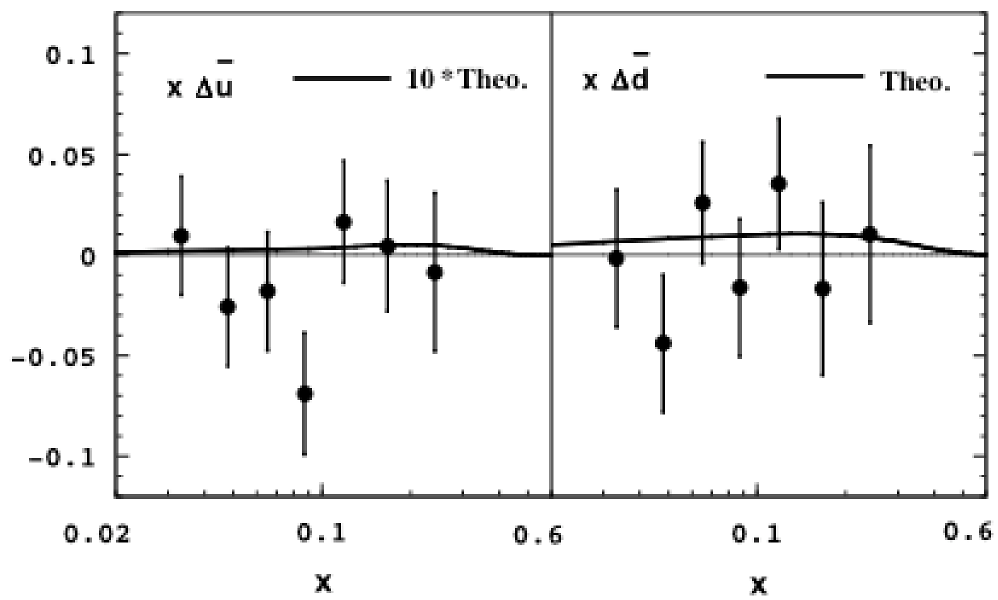
while $r=1.0$ under SU(3) symmetry and $q-\bar{q}$ symmetry.

Direct experimental evidence for the value of r is very weak.

SU(2) flavour asymmetry in the polarized nucleon sea

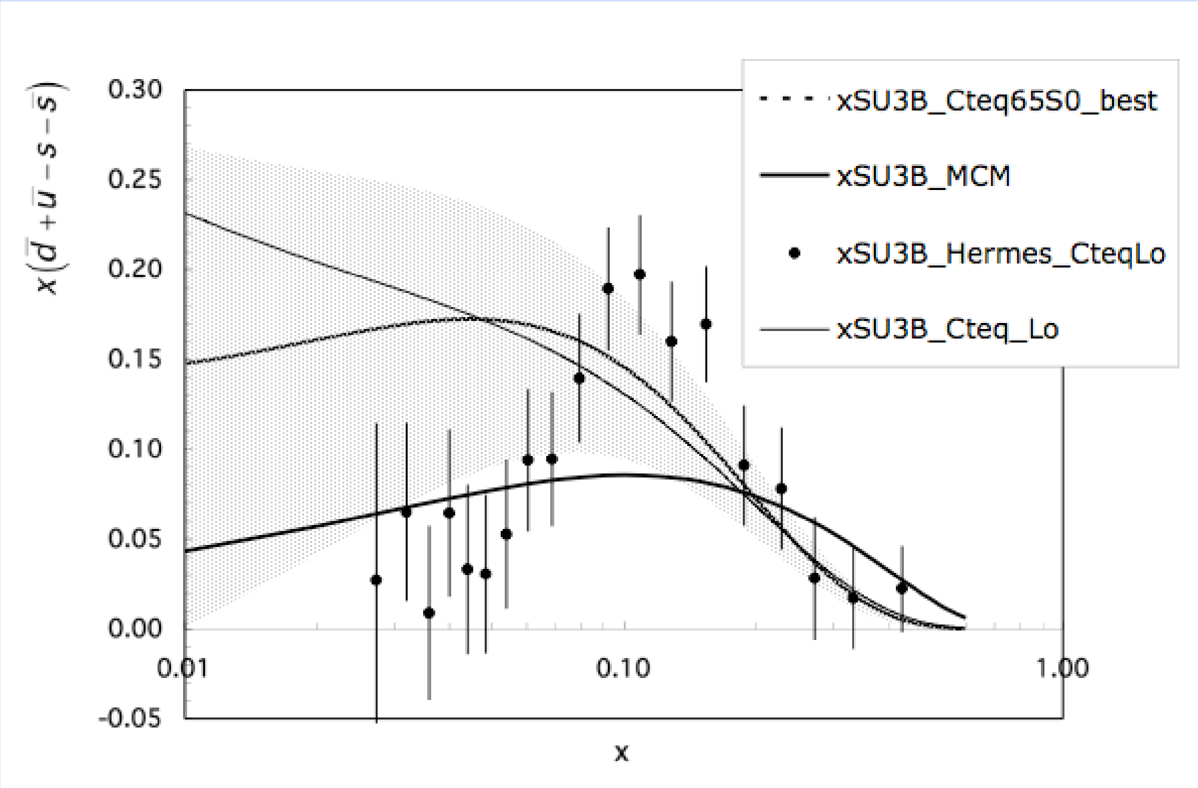






SU(3) flavour asymmetry in the unpolarized nucleon sea

$$x\Delta(x) = x\left[\bar{d}(x) + \bar{u}(x) - s(x) - \bar{s}(x)\right]$$



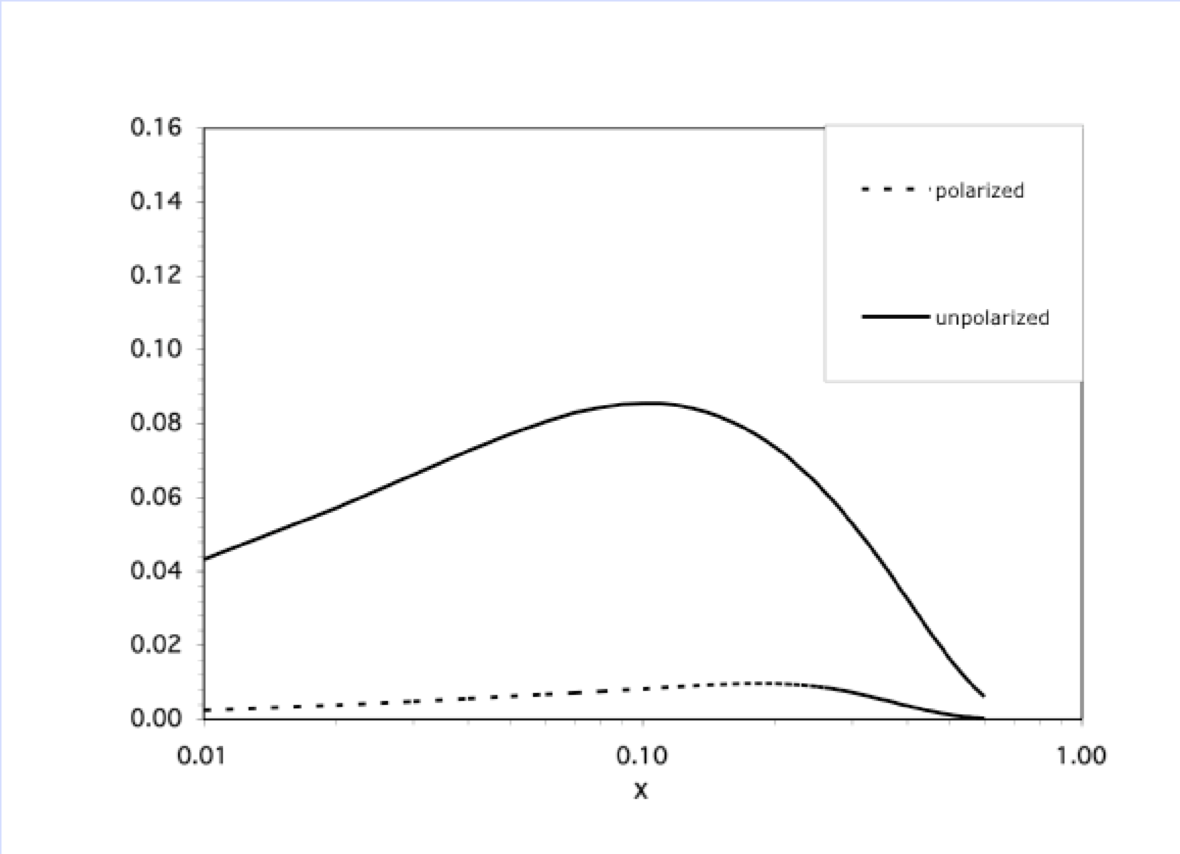
CTEQ65S [JHEP 0704 : 089,2007] :

$s(x) + \bar{s}(x)$ has different shape from $\bar{d}(x) + \bar{u}(x)$

HERMES[PLB666(2008)446 also arXiv : 0803.2993] :

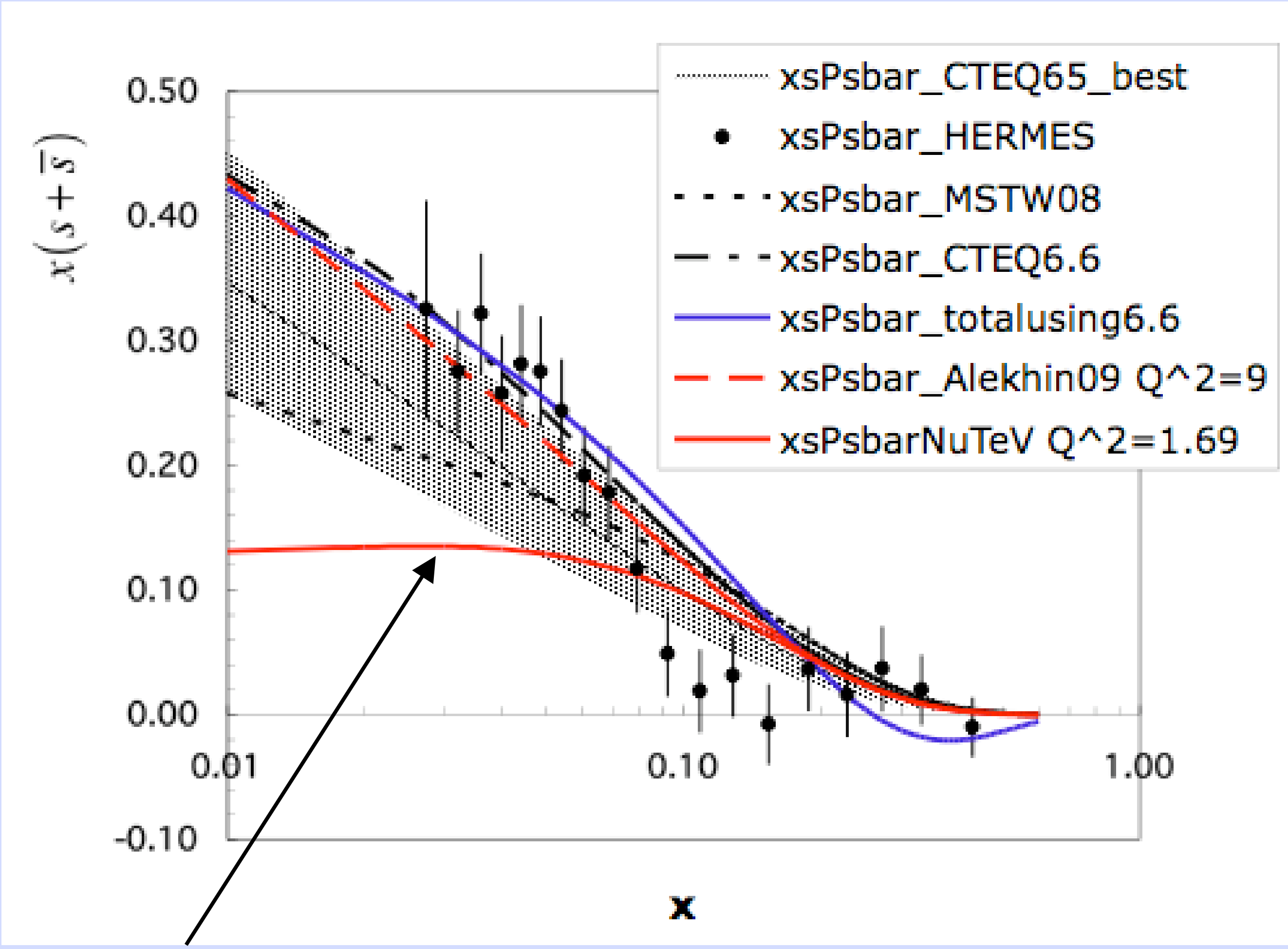
a measurement of $s(x) + \bar{s}(x)$ and $\Delta s(x) + \Delta\bar{s}(x)$

SU(3) flavour asymmetry in the polarized nucleon sea



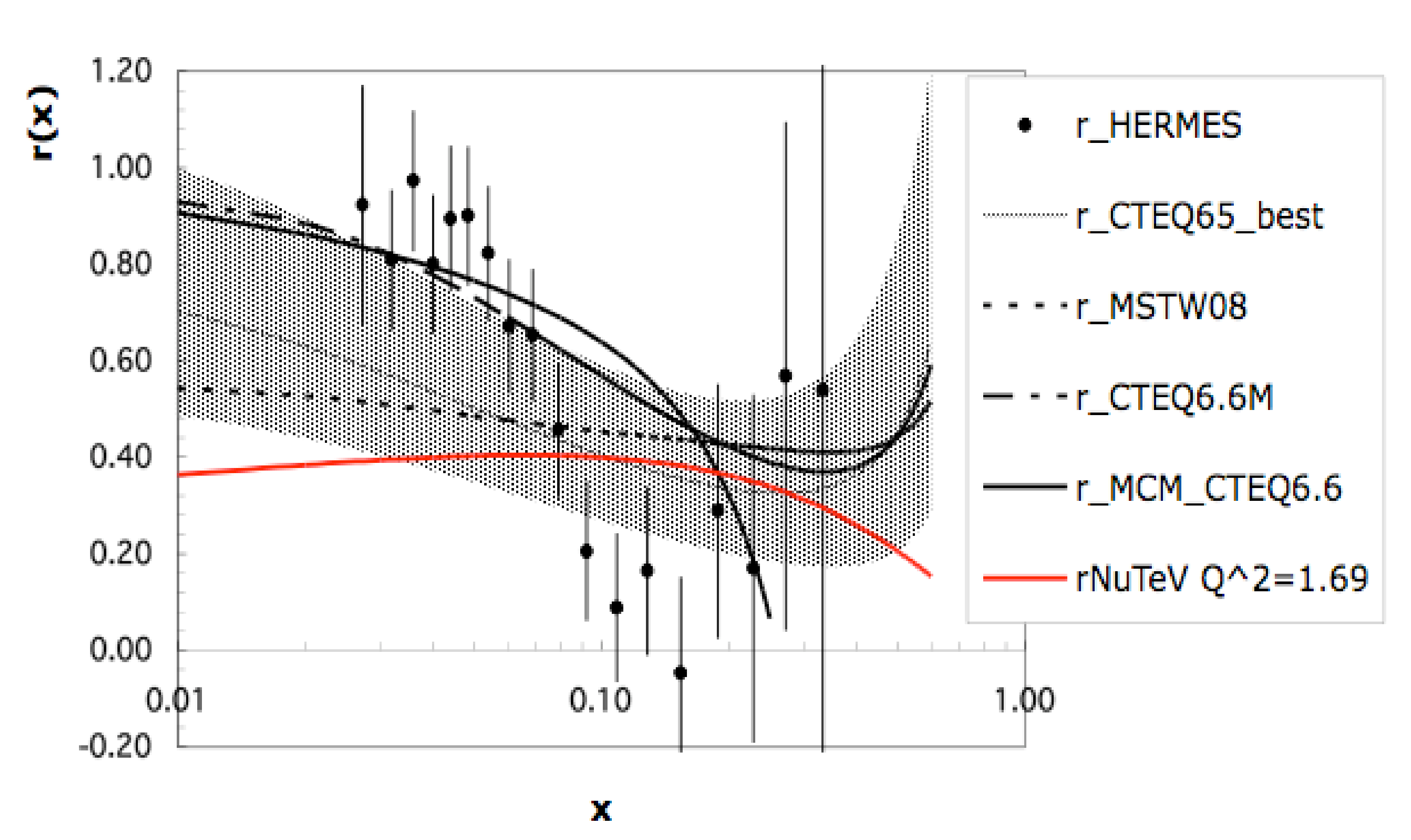
3. Total strange sea distributions

$$xs_+(x) = \left[\bar{d}(x) + \bar{u}(x)\right]_{\mathrm{Fit}} - x\Delta(x)$$



NLO analysis of NuTeV data
PRL99(2007)192001

The suppression factor $r(x) = \frac{s(x) + \bar{s}(x)}{\bar{d}(x) + \bar{u}(x)}$



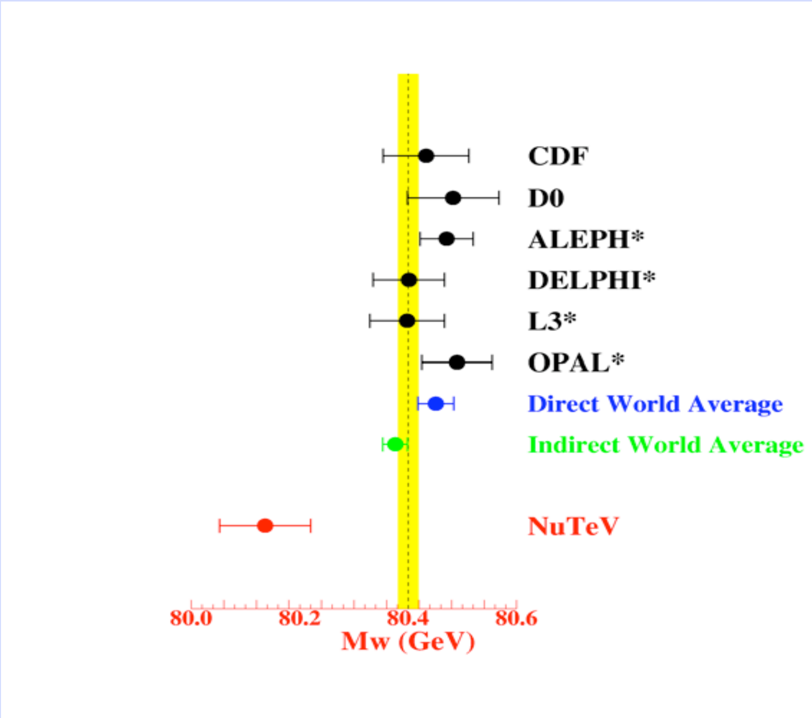
4. Quark-antiquark asymmetry

Strange-antistrange asymmetry and the measurement of $\sin^2\theta_W$

NuTeV (2002): 0.2277 ± 0.0013(stat) ± 0.0009(syst)
World Average: 0.2227 ± 0.0004

2% difference ➔ 3σ discrepancy →

The probability that it is consistent with the expected result is only about 1 in 400



$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$

$$M_Z = 91.1882 \pm 0.0022$$

← $M_W = 80.451 \pm 0.033$

← $M_W = 80.136 \pm 0.084$

- QCD corrections to the Paschos-Wolfenstein ratio

$$R^{-} = \frac{\sigma_{NC}^{\nu} - \sigma_{NC}^{\bar{\nu}}}{\sigma_{CC}^{\nu} - \sigma_{CC}^{\bar{\nu}}} = \frac{1}{2} - \sin^2\theta_W + 1.3\left[\frac{1}{2}\left(\langle\delta u\rangle - \langle\delta d\rangle\right) - \left(\langle s\rangle - \langle\bar{s}\rangle\right)\right]$$

$\delta u = u^p - d^n; \quad \delta d = d^p - u^n$ Charge symmetry breaking

$\langle s\rangle = \int_0^1 dx\, x\, s(x); \quad \langle\bar{s}\rangle = \int_0^1 dx\, x\, \bar{s}(x)$ s-sbar asymmetry

Parton distribution function (PDF): u(x), d(x), s(x) …

x is the fractional parton momentum

[…]=–0.0038 is needed to explain the NuTeV anomaly

- No well established experimental evidence for these symmetry breakings
- Models to break these symmetries are known, e.g. the Meson Cloud Model

Strange-antistrange asymmetry: unpolarized nucleon sea

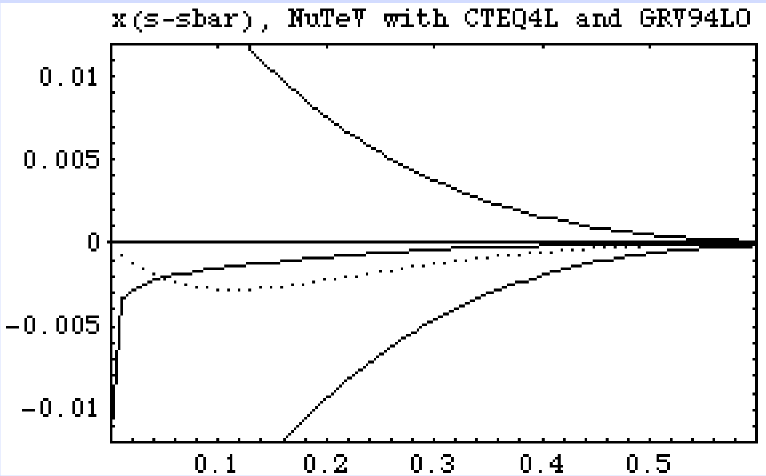
- No net strangeness: $\int_0^1 dx\, s(x) = \int_0^1 dx\, \bar{s}(x)$

- CCFR (Z. Phys. C65 (1995) 189)

$$x\, s = \kappa\, \frac{\bar{u}+\bar{d}}{2}(1-x)^{\alpha}, \quad x\, \bar{s} = \bar{\kappa}\, \frac{\bar{u}+\bar{d}}{2}(1-x)^{\bar{\alpha}}$$

$\Rightarrow$ No evidence for $s(x) \neq \bar{s}(x)$

- NuTeV (PRD 64 (2001) 112006)



o CTEQ4L: $\langle s \rangle - \langle \bar{s} \rangle = -0.0004$

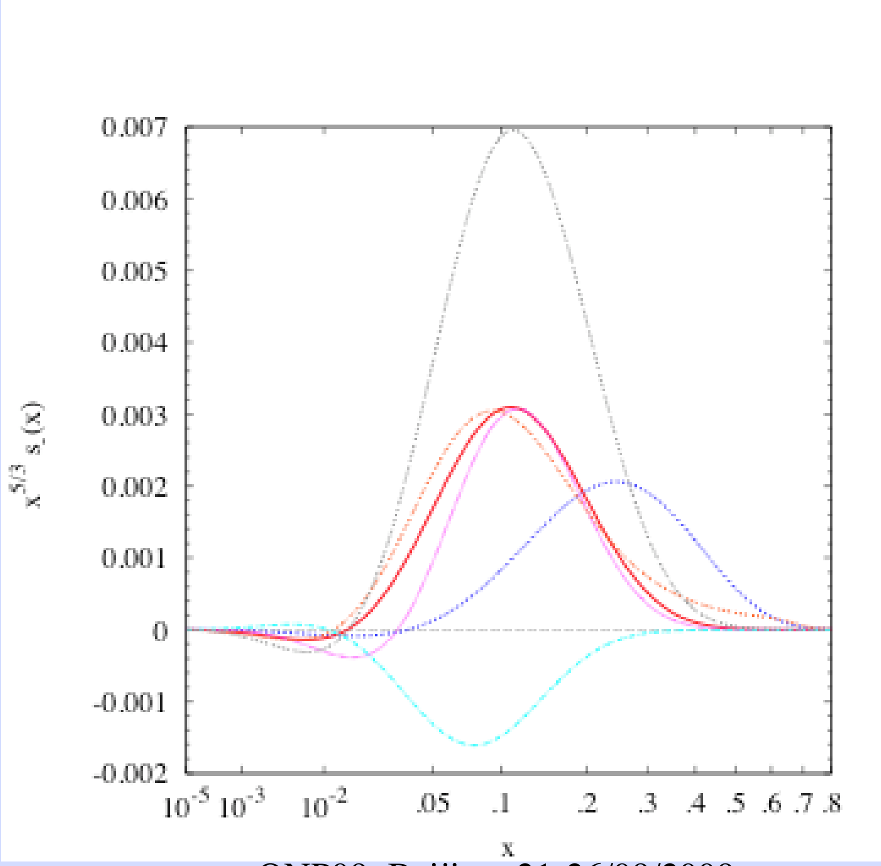
o GRV94LO: $\langle s \rangle - \langle \bar{s} \rangle = -0.0008$

o Large experimental uncertainties exist

• H. L. Lai et. al (CTEQ6.5S), JHEP 0704:089 (2007) (alos hep-ph/0702268)

$$s_-(x,Q_0) = s_+(x,Q_0)\frac{2}{\pi}\tan^{-1}\left[cx^a(1-\tfrac{x}{b})e^{dx+ex^2}\right]$$

$$-0.001 < \langle x \rangle_{s_-} < 0.005$$



Strange-antistrange asymmetry: unpolarized nucleon sea

- MCM calculation: $p \to \Lambda K; \Sigma K; \Lambda K^*; \Sigma K^*$

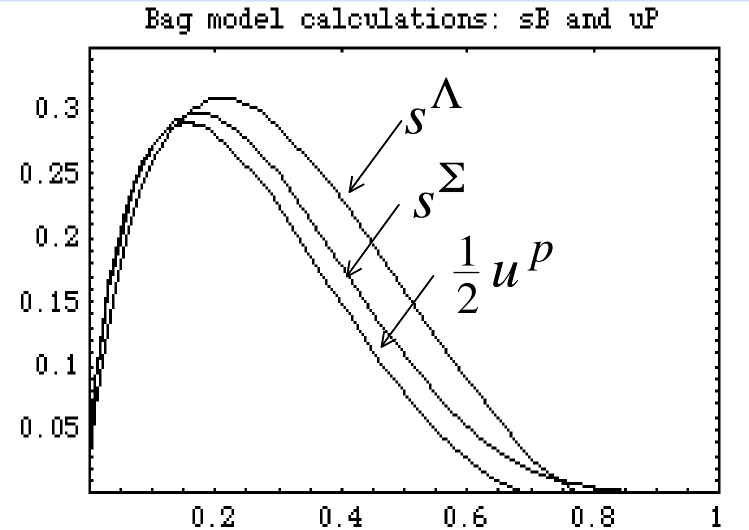
Prescriptions for PDFs: $s^\Lambda, s^\Sigma, \bar{s}^K$

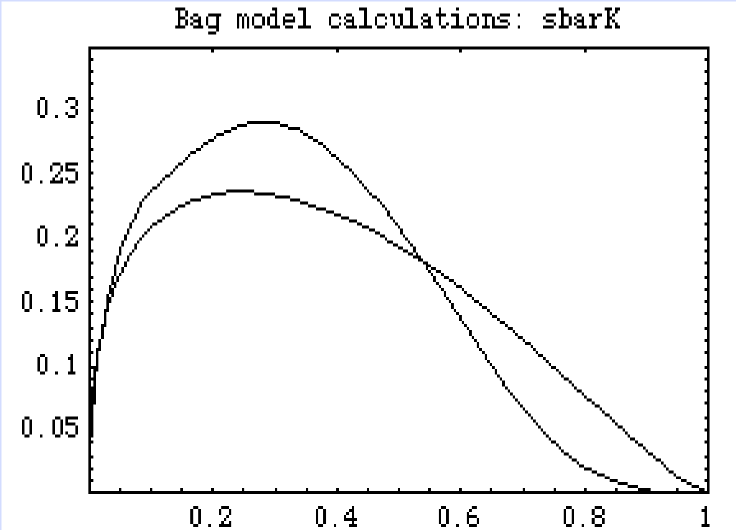
→ SU(3) symmetry for s distribution in the baryon

$$s^\Lambda = s^\Sigma = \tfrac{1}{2} u^N; \qquad u^N \Rightarrow MRST\,98$$

$$\bar{s}^K \Rightarrow GRV\,98$$

→ Bag model calculations suggest $s^\Lambda \neq s^\Sigma \neq \tfrac{1}{2} u^N$



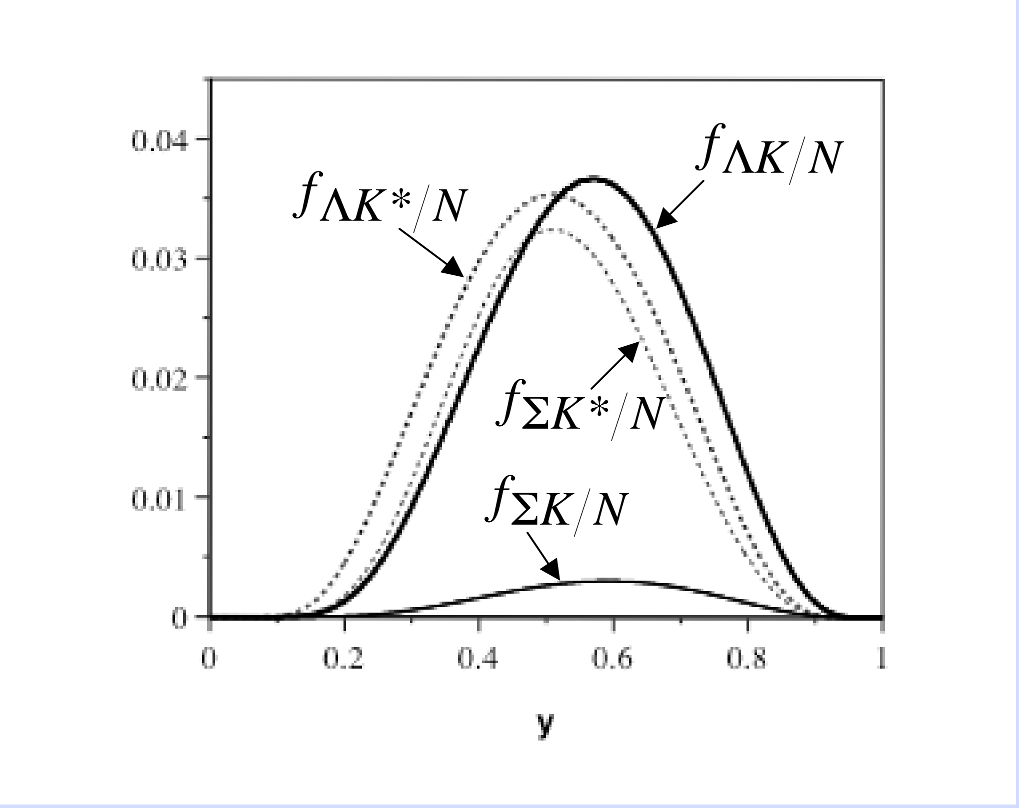


Strange-antistrange asymmetry: unpolarized nucleon sea

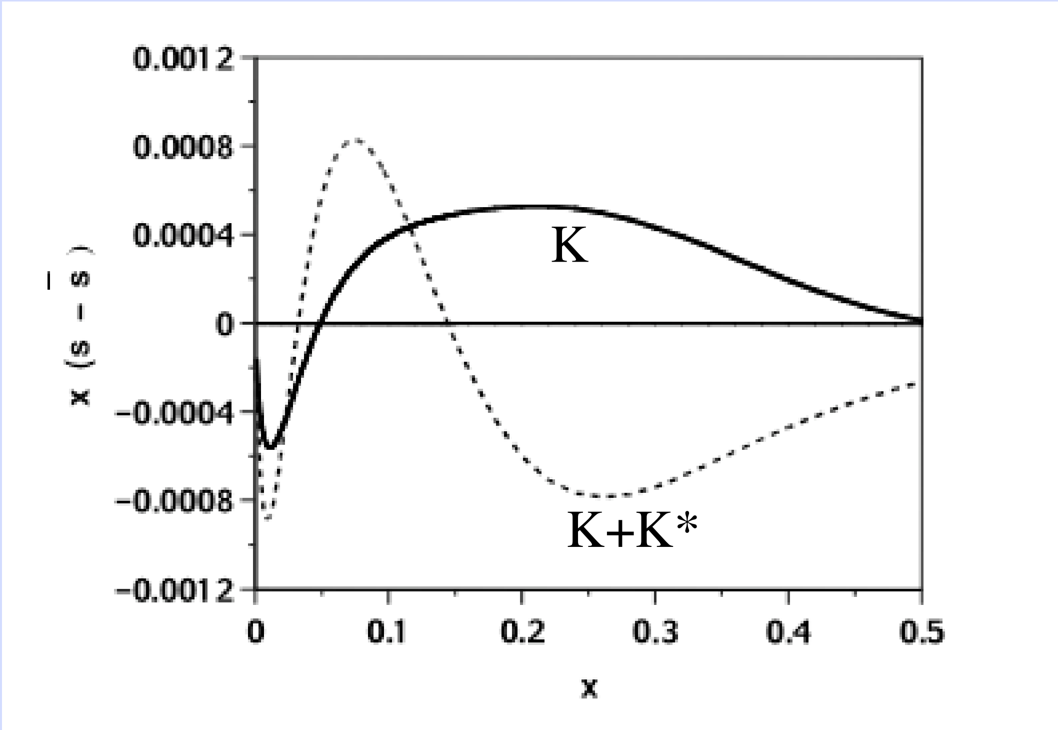
- Contributions from $p \to \Lambda K^*; \Sigma K^*$

  Expected to be suppressed due to higher mass of K*

- Fluctuation functions



Strange-antistrange asymmetry: unpolarized nucleon sea



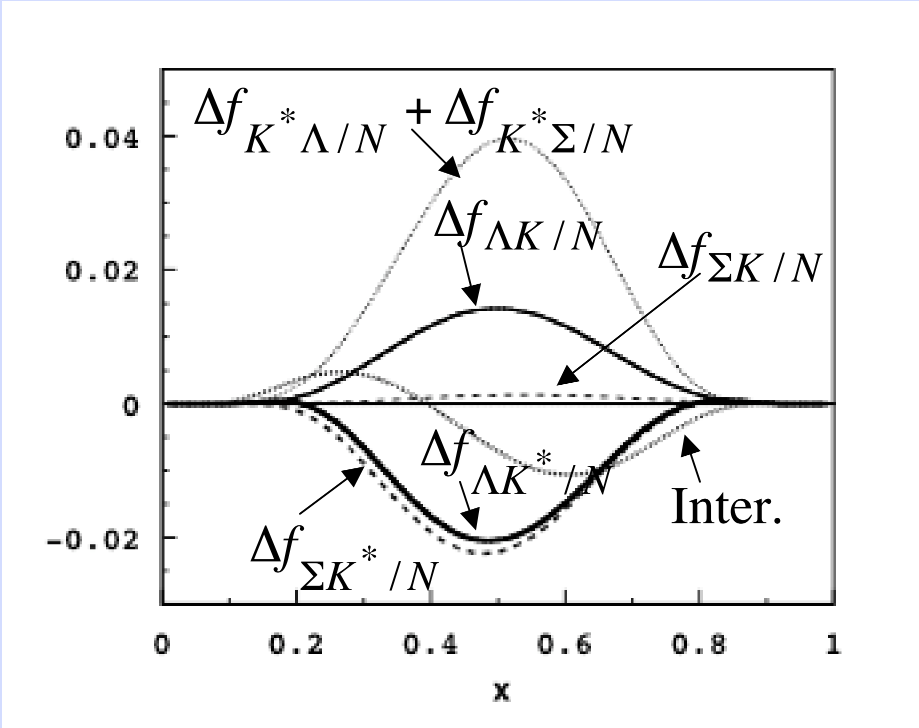
$\langle s \rangle - \langle \bar{s} \rangle = 0.00014$ including only K

$\langle s \rangle - \langle \bar{s} \rangle = -0.00014$ including K+K*

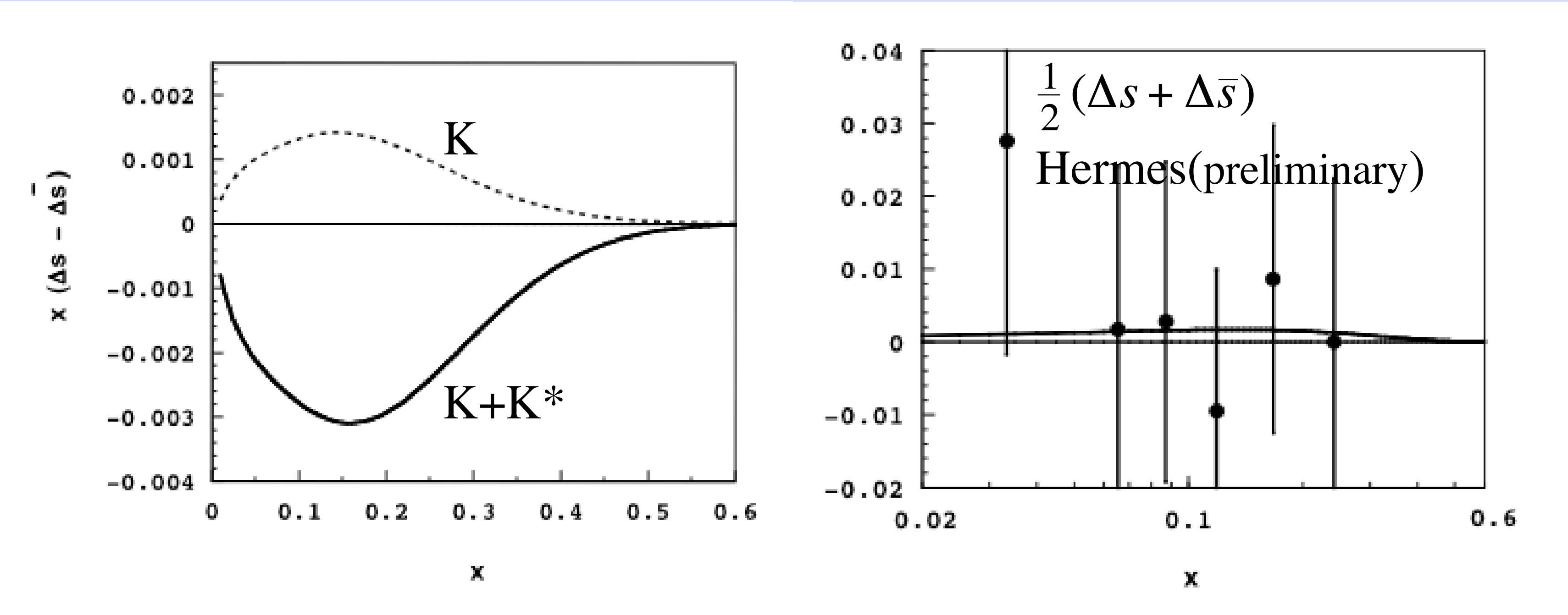
- Contributions from fluctuations involving K* are important

Strange-antistrange asymmetry: polarized nucleon sea

- Fluctuation functions

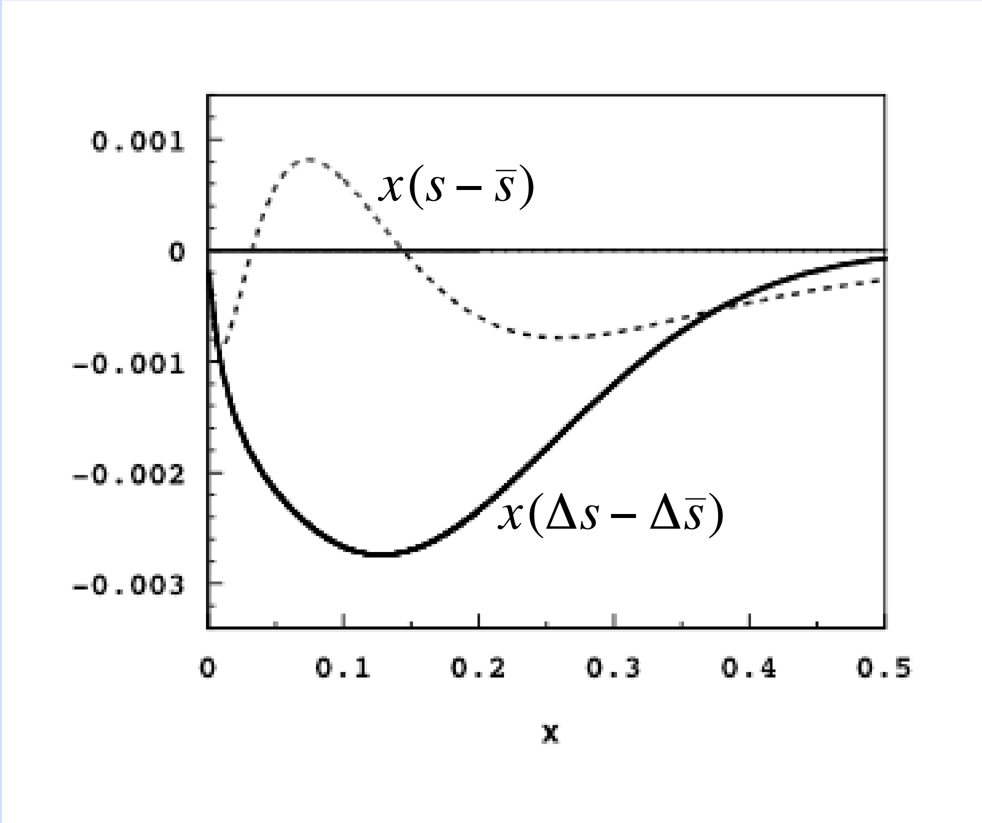


Strange-antistrange asymmetry: polarized nucleon sea



- Strange-antistrange symmetry is broken in the polarized nucleon sea.

Strange-antistrange asymmetry: polarized nucleon sea



- Strange-antistrange asymmetry is more significant in the polarized nucleon sea than that in the unpolarized nucleon sea.

5. Summary

1. Strange sea distributions are not well constrained.
2. Non-perturbative QCD models for the nucleon structure can make reliable predictions for the symmetry breaking effects.
3. Combining the MCM calculations for the SU(3) breaking effect with global analysis results for the light quark sea, we estimated the total strange sea distributions. The calculations agree with HERMES results, but not with the NLO analysis of NuTeV dimuon data.
4. Possible strange-antistrange asymmetry is of great interest.

Acknowledgement

- Tony Signal (Massey)
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