The strange asymmetry of the proton sea

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Outline

- Introduction
- The structure of the proton
- The strange sea of the proton
- Conclusions

Introduction

- First speculations about an asymmetric strange sea of the nucleon dates from 1987 (PLB **191** (1987) 205).
- Since then on, several models of the nucleon structure allowing for an asymmetric strange sea have been proposed.
- There is no compelling experimental evidence of $s - \bar{s}$ asymmetries.
- There is some indication of such asymmetry coming from a global fit of Deep Inelastic Scattering data (EPJC **12** (2000) 243).

- Notice that

$$\int_0^1 dx\,[s(x) - \bar{s}(x)] = 0 \qquad\qquad s(x) \neq \bar{s}(x)$$

- A small $s - \bar{s}$ asymmetry arises as a perturbative effect at NNLO (PRL 93 (2004) 152003)

$$S = \int_0^1 x[s(x) - \bar{s}(x)]dx \simeq -5 \times 10^{-4}$$

- There exist firm experimental evidence of $\bar{u}$ - $\bar{d}$ asymmetries (Gotfried sum rule violation – New Muon Collaboration: PRL 66 (1991) 2712; E866: PRL 80 (1998) 3715).

$$\int_0^1 dx[\bar{d} - \bar{u}] = 0.100 \pm 0.018,$$

- A s - $\bar{s}$ asymmetry in the nucleon sea is conceivable

The structure of the proton

- Assume that at some low Q_0^2 scale the proton is made of valence quarks, $v_u(x)$ and $v_d(x)$
- Valence quarks interact by the exchange of gluons (needed, they have to form a bound state)
- You can describe the emission of gluons from valence quarks using

$$P_{gq}(z) = \frac{4}{3}\frac{1+(1-z)^2}{z}$$

Probability of gluon emission with momentum fraction z from a parent quark

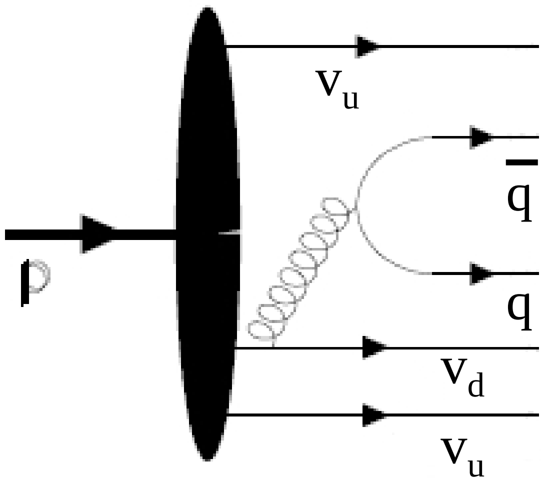
- Assume now that the gluon, before interacting with another valence quark, produces a q-$\bar{q}$ pair. This gluon splitting can be described by

$$P_{qg}(z) = \frac{1}{2}\left(z^2 + (1-z)^2\right)$$

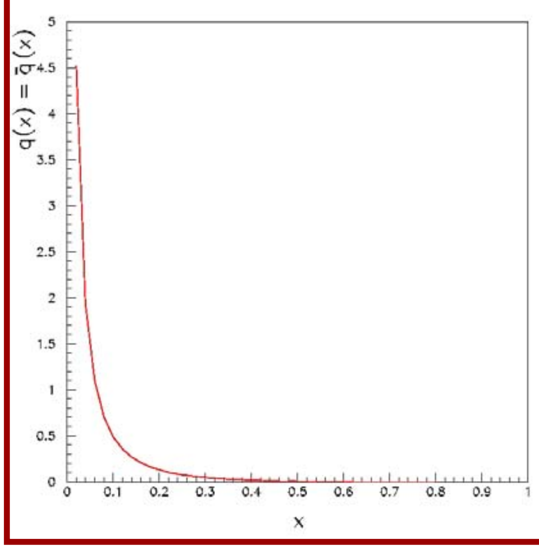
Probability of q-$\bar{q}$ creation with momentum fraction z from a parent gluon

- Then the joint probability density of having a q or a $\bar{q}$ coming from the subsequent decays v → v + g → v + q + $\bar{q}$, is

$$q(x, Q^2) = \bar{q}(x, Q^2) = N\frac{\alpha_{st}^2(Q^2)}{(2\pi)^2}\int_x^1 \frac{dy}{y} P_{qg}\left(\frac{x}{y}\right)\int_y^1 \frac{dz}{z} P_{gq}\left(\frac{y}{z}\right) v(z)$$



QCD scale: q-q̄ pair creation should occur at some value of the order of $Q_0 \leq 1$ GeV. We use $Q_0 = 0.7$ GeV (then $\alpha_{st}(Q_0^2)/2\pi \sim 0.3$)



N = normalization constant depending on the flavor being created

$$q(x,Q^2) = \bar{q}(x,Q^2) = N \frac{\alpha_{st}^2(Q^2)}{(2\pi)^2} \int_x^1 \frac{dy}{y} P_{qg}\left(\frac{x}{y}\right) \int_y^1 \frac{dz}{z} P_{gq}\left(\frac{y}{z}\right) v(z)$$

- The next step is to let the $q - \bar{q}$ pair to interact with the valence quarks.
- Using the ideas of recombination models we get

$$P_M(x) = \int_0^x \frac{dy}{y} \int_0^{x-y} \frac{dz}{z} F(y,z) R(x,y,z)$$

$$F(y,z) = \beta y v(y) z \bar{q}(z) \rho(y,z)$$

$$R(y,z) = \alpha \frac{yz}{x^2} \delta\left(1 - \frac{y+z}{x}\right)$$

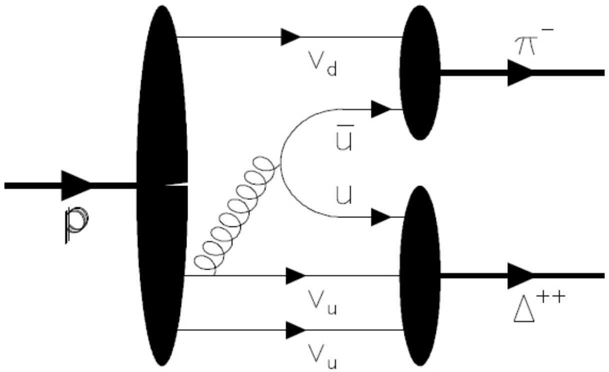
- And similar for the Baryon inside the proton with the constraints

$$\int_0^1 dx\,[P_B(x) - P_M(x)] \; = \; 0,$$

$$\int_0^1 dx\,[xP_B(x) + xP_M(x)] \; = \; 1,$$

Flavor sum rule

Momentum sum rule



The proton wave function at Q_0^2 can be thought as

$$|p\rangle = a_0\,|p_0\rangle + a_1\,|pg\rangle + \sum_{i=2}^{n} a_i\,|M_i B_i\rangle$$

The strange sea of the proton

- The strange sea of the proton at the Q_0^2 scale comes from the $|KH\rangle$ Fock state.
- The strange sea quark and anti-quark pdfs are

Hyperon probability density

$$s^{NP}(x) = \int_x^1 \frac{dy}{y} P_H(y)\, s_H(x/y)$$

s-quark inside the H

$$\bar{s}^{NP}(x) = \int_x^1 \frac{dy}{y} P_K(y)\, \bar{s}_K(x/y)$$

$\bar{s}$-quark inside the K

Kaon probability density

For the valence strange quarks inside the Kaon and the Hyperon we use the simple forms

$$
\begin{aligned}
\bar{s}_K(x) &= \frac{1}{\beta(a_{\rm K}+1, b_{\rm K}+1)} x^{a_{\rm K}} (1-x)^{b_{\rm K}} \\
s_H(x) &= \frac{1}{\beta(a_{\rm H}+1, b_{\rm H}+1)} x^{a_{\rm H}} (1-x)^{b_{\rm H}}
\end{aligned}
$$

Normalization constants to ensure one strange valence quark inside the Kaon and the Hyperon

Fit to experimental data

Instead of using the full form of the recombination model, we parameterize the P_H and P_K inside-hadron probability densities as

$$P_{\mathrm{K}}(x) = \frac{1}{\beta(a_{\mathrm{KN}}+1, b_{\mathrm{KN}+1})} x^{a_{\mathrm{KN}}}(1-x)^{b_{\mathrm{KN}}}$$

$$P_{\mathrm{H}}(x) = \frac{1}{\beta(a_{\mathrm{HN}}+1, b_{\mathrm{HN}}+1)} x^{a_{\mathrm{HN}}}(1-x)^{b_{\mathrm{HN}}}$$

Normalized to one Kaon and one Hyperon in the $|KH\rangle$ Fock state

- The use of the above expressions for P_K and P_H does not imply to loose generality.
- Remembering that

$$P_M(x) = \int_0^x \frac{dy}{y} \int_0^{x-y} \frac{dz}{z} F(y,z) R(x,y,z)$$

with

$$F(y,z) = \beta y v(y) z \bar{q}(z) \rho(y,z)$$

is possible to choose ρ(y,z) such that

$$P_M(x) = \mathbf{N}\, x^a (1-x)^b$$

The momentum sum rule

$$\int_0^1 dx\,[xP_B(x) + xP_M(x)] \;=\; 1$$

requires that

$$\frac{\Gamma(a_{\mathrm{KN}}+b_{\mathrm{KN}}+2)\Gamma(a_{\mathrm{KN}}+2)}{\Gamma(a_{\mathrm{KN}}+1)\Gamma(a_{\mathrm{KN}}+b_{\mathrm{KN}}+3)} + \frac{\Gamma(a_{\mathrm{HN}}+b_{\mathrm{HN}}+2)\Gamma(a_{\mathrm{HN}}+2)}{\Gamma(a_{\mathrm{HN}}+1)\Gamma(a_{\mathrm{HN}}+b_{\mathrm{HN}}+3)} = 1$$

fixing one parameter in the meson probability density

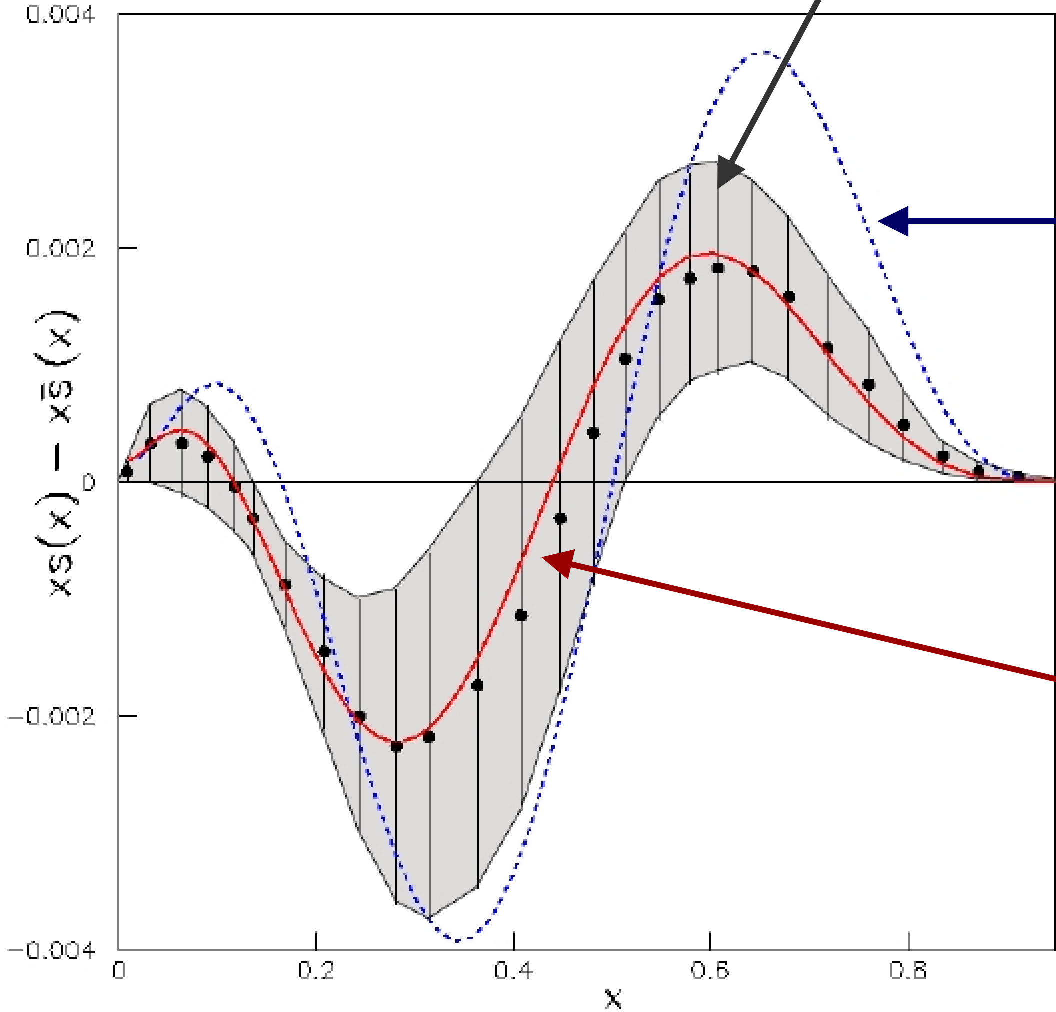
Then our fitting function

$$xs(x) - x\bar{s}(x) = N^2 \left[xs^{NP}(x) - x\bar{s}^{NP}(x) \right]$$

has 8 free parameters:

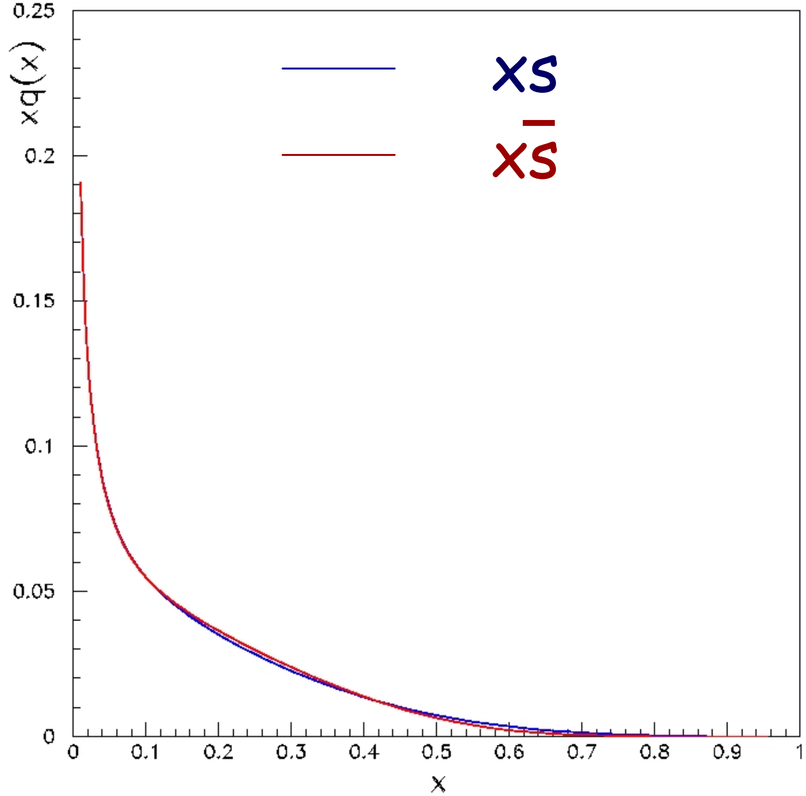
- global normalization N.
- 4 parameters from the s_K and s_H valence probability densities.
- 3 parameters from the Kaon and Hyperon probability densities.

Global fit to DIS data at $Q^2 = 20$ GeV^2 (JHEP, 0601:006 (2006))



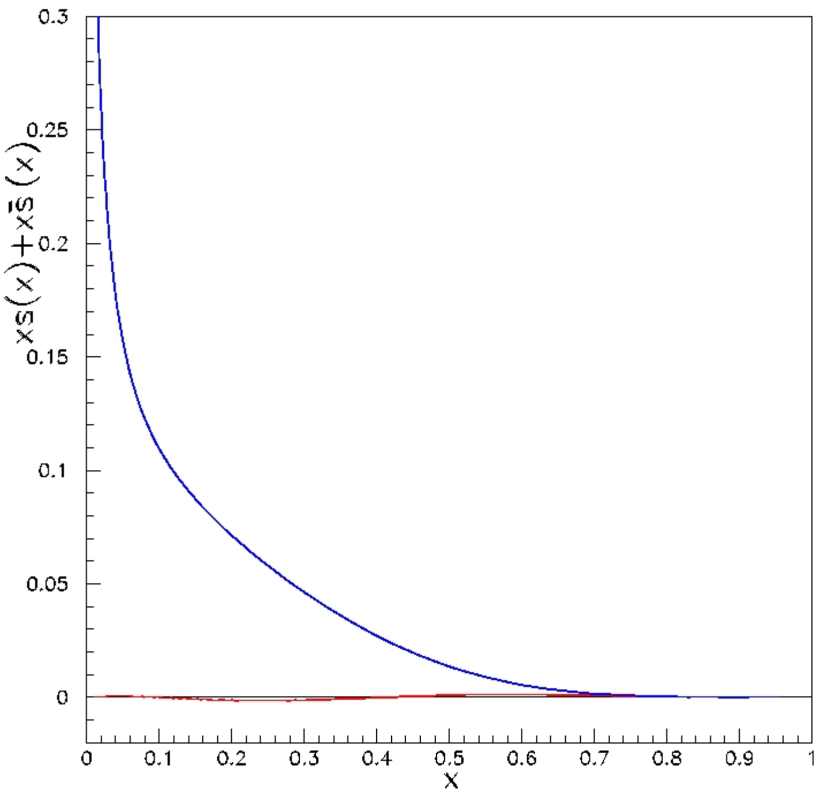
The model at $Q_0^2 = 0.49$ GeV^2

Result of the fit at $Q^2 = 20$ GeV^2



$xs(x)$ and $x\bar{s}(x)$ parton distributions at Q^2 = 20 GeV^2

$xs(x) + x\bar{s}(x)$ and $xs(x)-x\bar{s}(x)$ at Q^2 = 20 GeV^2



Results of the fit

Parameter	Value
a_{KN}	$2.06 \pm 2.62\times10^{-7}$
b_{KN}	2.14 ± 0.11
a_K	5.14 ± 1.93
b_K	0.90 ± 0.34
a_{HN}	1.17 ± 0.35
a_H	9.47 ± 0.61
b_H	2.51 ± 0.61
N^2	0.04 ± 0.02

$b_{HN} = 1.1$ is fixed by the momentum sum rule

Conclusions

- The model provides a prescription for the sea quark and gluon pdfs at the scale Q_0^2, where pQCD evolution starts.

- The model describes quite well the results on the $xs - x\bar{s}$ asymmetry from the global fit to DIS data.

- Independent measurement of xs and $x\bar{s}$ by the same experiment are needed to over-constraint the parameters of the model.

This work is being done in collaboration with C. Ávila and J.C. Sanabria, from Los Andes University, Bogotá, Colombia