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CHIRAL SYMMETRY AND THE CHARGE ASYMMETRY OF THE $S\bar{S}$ DISTRIBUTION IN A PROTON[*]

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ABSTRACT

Based on a simple K-cloud model, as well as the Gross-Neveu and the Nambu–Jona-Lasinio model, it is predicted that the $s\bar{s}$ sea in a proton is not charge symmetric at large Bjorken-x. The s quarks are shifted to larger values of x_{bj} than the $\bar{s}$ quarks. Furthermore these large x_{bj} s quarks carry a negative polarization.

Most virtual $s\bar{s}$ pairs in a proton have a very short lifetime[†][‡]. They are concentrated at small x_{bj} and arise primarily from logarithmic QCD evolution.1) The underlying microscopic process is incoherent fragmentation of a gluon into an $s\bar{s}$ pair where interactions with other partons (spectators) are neglected. The resulting distributions of s and $\bar{s}$ quarks are the same, since the $s\bar{s}$ pair is too short-lived to interact with the rest of the proton (and thus cannot find out whether it has been created in a proton or antiproton). The spin and momentum carried by the pair are proportional to the gluon spin and momentum and thus the $s\bar{s}$ pairs are typically concentrated at low x_{bj}.

Besides these perturbative or extrinsic $s\bar{s}$ pairs the proton is expected to contain also a more long-lived[§] component of virtual pairs.3) Of course the initial process for creation of $s\bar{s}$ pairs is always the same: fragmentation of a gluon. However, a few of these sea quarks—the "intrinsic" component—do not immediately recombine and they interact for some time with other quarks and gluons in the hadron. One major difference to extrinsic $s\bar{s}$ pairs is that intrinsic ones can be found at larger values of x_{bj}. This is because they have time to reach an energetically more favorable (i.e. less off-shell) state, where the light-cone kinetic energy, $P^-_{\text{kin}} = \sum_i \frac{m_i^2 + k_{i\perp}^2}{x_i}$, is close to the minimum value3) , i.e. small values of x_{bj} — in particular for heavy quarks — are excluded. In order to reach large values of x_{bj} (i.e. $x_{bj} \gtrsim 0.2$) a sea quark has to undergo several interactions while accumulating more and more momentum fraction. This indicates already that perturbative QCD is inadequate to describe this soft component of the proton wavefunction

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[†] $\tau \sim \frac{1}{\sqrt{-q^2}}$, where q is the momentum transfer in the deep inelastic scattering process.

[‡] Most of the conclusions in this work remain qualitatively correct if we replace $s\bar{s}$ by $c\bar{c}$ though there will be a quantitative difference.

[§] Long-lived means here a lifetime of $O(M_{s\bar{s}}^{-1})$2)

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and effective theories — like the Gross-Neveu (GN)[4] or Nambu–Jona-Lasinio (NJL)[5] model — are more appropriate.

Both models exhibit dynamical breakdown of chiral symmetry, which makes them interesting for studying the low and medium energy components of hadronic wavefunctions. In particular one can investigate the impact of chiral symmetry and chiral symmetry breaking on structure functions[6] . Since we will describe these models in terms of quark degrees of freedom only, the Goldstone bosons will be automatically composite. Thus a consistent and physically simple interpretation of the parton distribution arising from the meson cloud becomes possible. Note that these models do not confine the constituent quarks. This allows us to simplify the discussion by considering the meson cloud around a single constituent quark instead of the meson cloud around a nucleon.[7] Typical numerical results are shown in Fig.1 and 2.[#1]

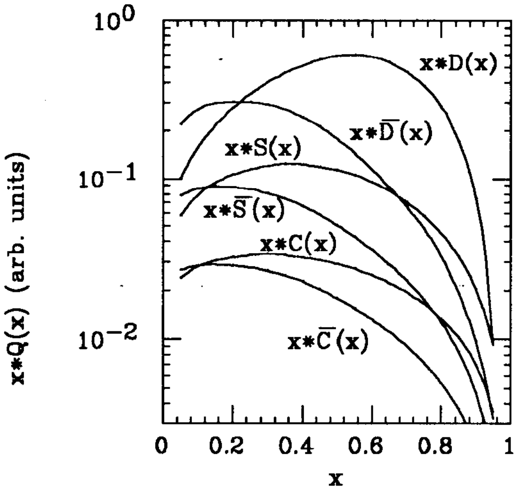

Figure 1. $O(\frac{1}{N_c})$ results for the structure functions of the $d\bar{d}$, $s\bar{s}$ and $c\bar{c}$ cloud around a u quark in the GN model.

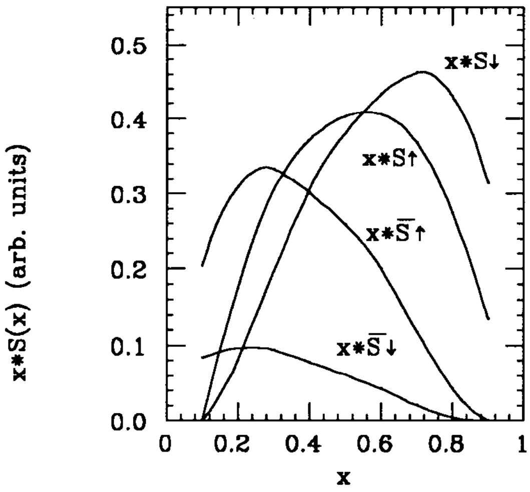

Figure 2. Spin dependent structure functions resulting from the $s\bar{s}$ sea around a u quark in the NJL model to $O(\frac{1}{N_c})$.

Both the GN as well as the NJL model predict that s quarks are shifted to larger values of x_{bj} than $\bar{s}$ quarks.[#2] Intuitively this can be understood as follows. The small mass of the kaon (relative to other mesons with strangeness) make the virtual process $u \longrightarrow sK^+$ dominant for the strange meson cloud around a u quark. Neglecting the residual interaction and minimizing the light-cone kinetic energy between the remaining s and the K^+ yields[#3]

[#1] Details of the calculation can be found in Ref.8

[#2] A qualitatively similar result has been found in Ref. 9 .

[#3] Replacing the u and s quark by a p and a Λ yields similar results[8] .

$$< x_s > \;\approx\; \frac{M_s}{M_s + M_K}, \qquad < x_K > \;\approx\; \frac{M_K}{M_s + M_K}. \tag{1}$$

Similarily for the momentum fractions carried by the constituents of the kaon

$$\langle x_{\bar{s}} \rangle \;\approx\; \frac{M_s}{M_s + M_u} \langle x_K \rangle \;\approx\; \frac{M_K}{M_s + M_u} \langle x_s \rangle \;<\; \langle x_s \rangle\,, \tag{2}$$

where the last inequality arises because the kaon is bound! The interpretation of the spin dependent structure function of the s quark in the kaon-cloud picture is also straightforward. Since the K is a pseudoscalar, parity and angular momentum conservation demand that the virtual K is emitted in a p-wave. Using elementary Clebsch-Gordan algebra one finds that the s[#4] is polarized mostly antiparallel to the initial u-spin.

Since the K is spinless its constituents are unpolarized. Therefore, this simple K-cloud picture is too crude to understand the (positive) polarization of the $\bar{s}$ quarks. Here chiral symmetry plays an important role, since it requires a coupling of the quarks to a scalar field — in addition to the pseudoscalar Goldstone field. Due to interference between scalar and pseudoscalar degrees of freedon(8) the $\bar{s}$ emerges with a small polarization parallel to the initial u-spin.

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[#4] which has spin $\frac{1}{2}$ and is coupled with $l = 1$ to $j = \frac{1}{2}$.