On the flavour structure of the constituent quark

Antoni Szczurek\textsuperscript{1}, Alfons J. Buchmann\textsuperscript{2}, and Amand Faessler\textsuperscript{2}

\textsuperscript{1} Institute of Nuclear Physics, ul. Radzikowskiego 152, PL-31-342 Cracow, Poland
\textsuperscript{2} Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

March 31, 2022

Abstract

We discuss the dressing of constituent quarks with a pseudoscalar meson cloud within the effective chiral quark model. \(SU(3)_f\) symmetry breaking effects are included explicitly. Our results are compared with those of the traditional meson cloud approach in which pions are coupled to the nucleon. The pionic dressing of the constituent quarks explains the experimentally observed violation of the Gottfried Sum Rule and leads to an enhanced nonperturbative sea of \(q\bar{q}\) pairs in the constituent quark and consequently in the nucleon. We find 2.5 times more pions and 10-15 times more kaons in the nucleon than in the traditional picture. The \(\bar{d} - \bar{u}\) asymmetry obtained here is concentrated at somewhat smaller \(x\) and the \(\bar{u}/\bar{d}\) ratio is somewhat different than in the traditional meson cloud model of the nucleon.

PACS numbers: 11.30.Hv,11.30.Rd,11.55.Hx,12.39.Ki,14.20.Dh

The deviation of the Gottfried Sum Rule (GSR) from its classical value \[\text{observed by the New Muon Collaboration (NMC) at CERN [2, 3]} (S_G = 0.235 \pm 0.026)\] has created a lot of interest in the possible sources of its violation. It is commonly believed that this violation is a consequence of an internal asymmetry of the \(\bar{d}(x)\) and \(\bar{u}(x)\) quark distributions in the nucleon. Since at large \(Q^2\) the perturbative QCD evolution is flavour independent and, to leading order in \(\log Q^2\), generates an equal number of \(\bar{u}u\) and \(\bar{d}d\) sea quarks [3, 5] nonperturbative effects must play an important role here. An asymmetry has been predicted by meson cloud models in which the physical nucleon contains an admixture of the \(\pi\pi N\) and \(\pi\Delta\), etc. components in the Fock expansion [7]. It has only recently been shown that such a model is consistent with both the violation of the Gottfried Sum Rule and with the result of the NA51 CERN experiment on Drell-Yan processes [8].

Parallel to the traditional approach Eichten-Hinchliffe-Quigg [9] have pointed out that the effective chiral quark theory formulated by Manohar and Georgi [10] may provide an alternative explanation. In chiral quark theory, the relevant degrees of freedom are constituent quarks, gluons, and Goldstone bosons. The chiral quark model employing both gluon and pion exchange between constituent quarks together with corresponding exchange currents, has been fairly successful in simultaneously explaining the positive parity mass spectrum and the low-energy electromagnetic properties of the nucleon [12]. It has also been successfully applied to the two-baryon sector [14]. Recently, it has been argued [14] that Goldstone
boson exchange alone can explain the baryon spectrum without introducing gluon degrees of freedom. The latter are the main ingredients of the Isgur-Karl model. The important question of the relevant degrees of freedom and the related question whether the pions couple effectively to the nucleon or to the constituent quarks is presently actively discussed. At present, it seems premature to decide which picture of the nucleon is closer to reality and which are the correct degrees of freedom. Instead it is necessary to study the consequences of these different scenarios in a broad range of physical processes.

In this paper, we study the flavour structure of the constituent quark and the nucleon. While the problem of the flavour structure of the nucleon, and the $d - u$ asymmetry has been recently discussed in some detail within the conventional mesonic cloud picture, no detailed analysis exists in the chiral quark model ($\chi$QM). In Ref. the $\chi$QM was used as a motivation to introduce $SU(2)$ asymmetric parametrizations for the $x$ dependence of the $d$ and $u$ distributions. In this work we calculate the $d - u$ asymmetry directly from the $\chi$QM. In particular, we discuss the effect of $SU(3)_f$ symmetry breaking which was not considered in Ref. This may be especially important in understanding the strangeness content of the nucleon and the closely related nucleon spin problem. We also study the implications of the GSR violation on the $\Delta - N$ mass splitting.

The interaction Lagrangian of the effective chiral quark theory is in leading order of an expansion in $\Pi/f$

$$L_{\text{int}} = -\frac{g f}{\Pi} \bar{\Psi} \gamma^\mu \gamma_5 \gamma^\mu \gamma^5 \Psi$$

(2)

where $\Pi$ is the Goldstone boson field, $f \approx 93$ MeV the pion decay constant, and $\Psi$ the constituent quark field. The effective chiral Lagrangian of Eq. describes the coupling of Goldstone bosons to massive $(m_Q \approx m_N/3)$ constituent quarks. Both the mass of the constituent quark and its coupling to Goldstone bosons are consequences of the spontaneously broken chiral symmetry of QCD. The light-front Fock decomposition of the constituent quark wave functions (see also Fig.1) reads

$$|U\rangle = Z^{1/2} |u\rangle + \sqrt{\frac{1}{3}} \alpha_{\pi/U} |u\pi^0\rangle + \sqrt{\frac{2}{3}} \alpha_{\pi/U} |d\pi^+\rangle + \alpha_{K/U} |sK^+\rangle + ... ,$$

$$|D\rangle = Z^{1/2} |d\rangle + \sqrt{\frac{1}{3}} \alpha_{\pi/D} |d\pi^0\rangle + \sqrt{\frac{2}{3}} \alpha_{\pi/D} |u\pi^-\rangle + \alpha_{K/D} |sK^0\rangle + ... ,$$

(3)

where capital (small) letters denote constituent quarks dressed (undressed) by Goldstone bosons and $Z$ is a wave function renormalization.

For simplicity, we list all formulae for pions although kaons are included in the actual calculation. In analogy to the nucleonic Sullivan process in deep-inelastic scattering (DIS), we consider the pion-quark splitting function $f_{q\rightarrow p\pi}(x_\pi, k_\perp^2)$ (flux factor summed over quark spin polarizations). The splitting function determines the probability for finding a Goldstone boson of mass $m_\pi$ carrying the light-cone momentum fraction $x_\pi$ of the parent constituent quark $Q$

$$f_{q\rightarrow p\pi}(x_\pi, k_\perp^2) = \frac{g^2_{Q\pi}}{16\pi^2} \frac{1}{x_\pi(1-x_\pi)} |G_{QQ\pi}(x_\pi, k_\perp^2)|^2 \left( \frac{(1-x_\pi)m_Q - m_Q}{(1-x_\pi)(m_Q^2 - M_{Q\pi}^2)} \right)^2,$$

(4)

where $k_\perp$ is the perpendicular momentum of the recoiling quark $q'$.

The constituent quark-pion coupling constant can be obtained from the quark version of the Goldberger-Treiman relation

$$g^2_{QQ\pi} = \frac{g^2_A (m_Q + m_Q')^2}{4},$$

(5)

\[ \text{... continued on the next page...} \]
with $g_A$ being the axial-vector constant of the constituent quark. In practical calculations we investigate two cases: $g_A = 1$ as suggested by an $1/N_c$ expansion [7] (model A); and $g_A = 0.75$ as suggested by the nonrelativistic quark model [10] (model B). We also take $m_l = m_Q = m_Q' = m_N/3 = 313$ MeV for the light up and down quarks and $m_s = m_Q' = m_S - m_N + m_l = 567$ MeV for the strange quarks. As in ref. [4] we do not explicitly calculate the contribution of the meson cloud to the mass and coupling constant of the constituent quark but consider all masses and coupling constants as renormalized quantities.

The $G_{QQ'}(\pi, k_\perp^2)$ is a vertex function, which accounts for the extended structure of both the pion (and other Goldstone bosons) and the constituent quark

$$G_{QQ'}(\pi, k_\perp^2) = \exp \left( \frac{m_Q^2 - M_{QQ'}^2(\pi, k_\perp^2)}{2\Lambda^2} \right), \quad (6)$$

with $M_{QQ'}^2(\pi, k_\perp^2) = (m_\pi^2 + k_\perp^2)/\pi + (m_Q^2 + k_\perp^2)/(1 - \pi)$, being the invariant mass squared of the $\pi + Q'$ system. A form factor of this type fulfills the number and momentum sum rules by construction [3].

Isospin symmetry leads to the following simple relations for the integrated (over $k_\perp^2$) pion and kaon splitting functions

$$f_{u\rightarrow \pi^+ - d}(x_\pi) = f_{d\rightarrow \pi^- - u}(x_\pi) = 2 f_{u\rightarrow \pi^0 - u}(x_\pi) = 2 f_{d\rightarrow \pi^0 - d}(x_\pi),$$

$$f_{u\rightarrow K^+ - s}(x_K) = f_{d\rightarrow K^0 - s}(x_K). \quad (7)$$

The integral of the splitting function

$$P_{M/Q} = |\alpha_{M/Q}|^2 = \sum_{q'} \int_0^1 f_{q\rightarrow MQ'}(x_M) dx_M, \quad (8)$$

is the probability of finding a Goldstone boson $M$ in the constituent quark $Q$ and $\alpha_{M/Q}$ is the corresponding amplitude appearing in Eq. (3).

The regularization parameter $\Lambda$ in (3) is not known a priori. Assuming that the GSR violation

$$S_G = \frac{1}{3} + \frac{2}{3} \int_0^1 \left( \bar{u}(x) - \bar{d}(x) \right) dx = \frac{1}{3} - \frac{4}{9} P_{\pi/Q} \quad (9)$$

is entirely due to the dressing of the constituent quark by pions one obtains $\Lambda$ by fitting $P_{\pi/Q}$ to the NMC value for $S_G$ [3]. In Fig.2a we present the total splitting function of the constituent quark $f_{M/Q}(x_M) \equiv \sum_{q'} f_{q\rightarrow MQ'}(x_M)$ into the pion $M = \pi$ and kaon $M = K$ for model A (solid line) and model B (dashed line). The average momentum fraction carried by the meson in the $|MQ'$) Fock state is $\langle x_\pi \rangle = 0.597$ (A), 0.594 (B) and $\langle x_K \rangle = 0.606$ (A), 0.589 (B) for the pion and kaon, respectively.

By construction the number of pions, $P_{\pi/Q} = 0.22$ (0.22), remains the same, but the number of kaons $P_{K/Q} = 0.051$ (0.084) is different for models A(B). Thus, the number of pions and kaons in the nucleon is respectively $P_{\pi/N} = 0.66$ and $P_{K/N} = 0.15-0.25$. These numbers are considerably larger than those found in traditional nucleonic meson cloud models [7]. We get considerable damping of the kaon splitting function with respect to the pion splitting function. The strong suppression of the kaonic loops with respect to pionic loops is caused by the large mass difference between kaons and pions and between strange and non-strange constituent quarks. Due to the inclusion of these $SU(3)_{f}$ symmetry breaking effects we find a considerably smaller number of strange quarks in the nucleon than EHQ [3] (0.15-0.25 here vs. 0.63 in EHQ). However, our result for the number of strange quarks is still a factor of 10-15(!) larger in comparison to the traditional meson cloud model [3].

These results have direct consequences for the spin problem. Assuming a naive $SU(6)$ spin-flavour constituent quark wave function of the nucleon we get an upper limit for the strange quark contribution to the nucleon polarization

$$|\Delta s_N| = |\Delta s_Q| < P_{s/Q} = P_{K/Q} = 0.051(A), 0.084(B) \quad (10)$$
and a lower limit for the spin polarization carried by quarks

\[ 1 > \Sigma > 1 - 2(P_{\pi/Q} + P_{K/Q}) = 0.46(A), 0.39(B). \] (11)

As a direct consequence of the pion cloud dressing, the constituent \( U \) and \( D \) quarks in the proton (\( UUD \)) and neutron (\( DDU \)) contain not only \( u \) and \( d \) quarks, respectively, but also some admixture of (anti)quarks of different flavours. Formally, the DIS-quark distributions in the constituent \( U \) or \( D \) quarks at the initial scale of the QCD evolution can be written as

\[
\begin{align*}
  u_U(x) &= u_U^{(0)}(x) + u_U^{(i)}(x) + u_U^{(\pi)}(x), & d_D(x) &= d_D^{(0)}(x) + d_D^{(i)}(x) + d_D^{(\pi)}(x), \\
  d_U(x) &= d_U^{(i)}(x) + d_U^{(\pi)}(x), & u_D(x) &= u_D^{(i)}(x) + u_D^{(\pi)}(x),
\end{align*}
\] (12)

where the contributions denoted with \((0)\) correspond to the bare (undressed of pions) constituent quarks, those denoted with \((i)\) to the intermediate quarks associated with pions and finally those denoted with \((\pi)\) originate from the pion. The distribution of the bare (undressed of pions) quarks in the constituent quarks is

\[ u_U^{(0)}(x) = d_D^{(0)}(x) = (1 - \sum_M P_{M/Q}) \delta(x - 1). \] (14)

The contribution of the \( Q' \) (intermediate) quarks is fully determined by the pion splitting function

\[ u_U^{(i)}(x) = d_D^{(i)}(x) = \frac{1}{3} f_{\pi/Q}(1 - x), \quad u_D^{(i)}(x) = d_U^{(i)}(x) = \frac{2}{3} f_{\pi/Q}(1 - x). \] (15)

We assume hereafter that at the confinement scale, antiquarks originate exclusively from the virtual Goldstone bosons. In analogy to the classical Sullivan process [16], the antiquark distributions can be calculated as

\[
\begin{align*}
  \bar{u}_U(x) &= \bar{u}_U^{(\pi)}(x) = \bar{d}_D(x) = \bar{d}_D^{(\pi)}(x) = \frac{1}{6} I_\pi(x), \\
  \bar{u}_D(x) &= \bar{u}_D^{(\pi)}(x) = \bar{d}_U(x) = \bar{d}_U^{(\pi)}(x) = \frac{5}{6} I_\pi(x),
\end{align*}
\] (16)

where \( I_\pi(x) = \int_x^1 dy y^{-1} f_{\pi/Q}(y) q_\pi(x/y) \).

As an example, we show in Fig.2b the \( x\bar{u}(x) \) (solid), \( x\bar{d}(x) \) (dashed) and \( x(s(x) + \bar{s}(x))/2 \) (dotted) DIS-quark distributions in the constituent \( U \) quark at the initial QCD scale. By an appropriate isospin rotation corresponding distributions are obtained inside the constituent \( D \) quark. We find a large asymmetry between \( \bar{d} \) and \( \bar{u} \) quark distributions and a rather large (anti)strange quark component. This will have important consequences for the nucleon sea. In this calculation we have taken the quark distributions in the pion as parametrized for different values of \( Q^2 \) in Ref. [19], where they have been adjusted to describe the pion-nucleus Drell-Yan data.

The quark distributions in the nucleon \( q_{f,N}(x) \) can be obtained from those of the constituent quarks as

\[ q_{f,N}(x) = \int_x^1 \left[ U_N(y)q_{f,U}(x/y) + D_N(y)q_{f,D}(x/y) \right] \frac{dy}{y}. \] (17)

The consistency of our approach requires that the distributions of the constituent quarks \( U_N(y) \) and \( D_N(y) \) inside the nucleon are \( Q^2 \) independent in contrast to \( u_U(x, Q^2), u_D(x, Q^2), \)
d_U(x, Q^2), d_D(x, Q^2), etc. which are subjected to the QCD evolution. In practical calculations we parametrize the distributions of constituent quarks in the nucleon as \( Q_N(y) = C_{\alpha\beta} y^\alpha (1-y)^\beta \). The parameters \( \alpha \) and \( \beta \) can be obtained from the requirements \( \int_0^1 Q_N(y) dy = 1 \) (number sum rule) and \( 3 \int_0^1 y Q_N(y) dy = 3/4 \) (momentum sum rule) and by imposing the counting rules at \( y \to 1 \). This yields \( \alpha = 1/3 \) and \( \beta = 3 \). The number and momentum sum rules put stringent constraints on the quark distributions in any model. Following Ref. [18] we assume a valence-like gluon distribution which for simplicity is taken to be identical to the valence quark distribution in the nucleon \( g(x, Q_N^0) = Q_N(x) \). Fairly similar gluon distributions can be obtained by dressing quarks with gluons in the nonperturbative regime with massive \( (m_g^{eff}) \) effective gluons and frozen running \( \alpha_s \). Rather heavy effective gluons \( m_g^{eff} > 0.4 \) GeV and small \( \alpha_s < 0.5 \) are required in order to limit the momentum carried by quarks to approximately 1/4 as required by the phenomenology [18].

In Fig.3a we compare the \( \chi QM \) prediction for the antiquark distributions \( x\bar{u}(x) \) and \( xd\bar{d}(x) \) in the proton to the phenomenological GRV antiquark distributions at low momentum transfers [18]. The \( \chi QM \) antiquark distributions peak approximately at the same Bjorken-x but are considerably smaller.

In comparison to the traditional formulation of the meson cloud model [8] the strange sea quark distributions predicted by the \( \chi QM \) (shown in Fig.3b) are enhanced. Similar to the traditional nucleonic meson cloud approach [8] we get \( s(x) \equiv \bar{s}(x) \). In contrast to the nucleonic meson cloud picture, the quark meson cloud approach leads to some difference between \( s(x) \) and \( \bar{s}(x) \) distributions which could be detected in the (anti)neutrino DIS experiments. The momentum carried by the sea quarks \( \sum_f \int_0^1 x (q_f^{sea}(x) + \bar{q}_f^{sea}(x)) dx = 2 \sum_f \int_0^1 x q_f(x) dx = 0.08-0.09 \) This large number remains, however, nearly unchanged by the QCD evolution and is somewhat smaller than the result of the CCFR collaboration [20] at \( Q^2 = 16.85 \) GeV^2.

In Fig.4a we compare the antiquark distributions at \( Q^2 = 4 \) GeV^2, obtained from the ones of Fig.3 by QCD evolution [7], to the recent Martin-Roberts-Stirling (MRS A) parametrization of the world data on DIS and Drell-Yan processes [21]. The leading order (LO) antiquark distributions obtained in the \( \chi QM \) are significantly smaller than the quark distributions obtained from the next-to-leading order (NLO) analysis of Martin, Roberts and Stirling [21]. Considerable part of this effect is due to the known difference between LO and NLO antiquark distributions (for an illustration see [22]). A big fraction of the missing strength is presumably due to the neglect of the quark meson exchange currents [14]. This deserves further study in the future. The effect of the meson exchange currents cancels in the difference \( x(d - \bar{u}) \) which is shown in panel (b). In comparison to the MRS(A) parametrization and the traditional meson cloud approach [3], the \( \chi QM \) result for this difference is concentrated at smaller Bjorken-x. In panel (c) we present (anti)strange quark distributions obtained from our model at \( Q^2 = 4 \) GeV^2.

While at present the extraction of the \( x \)-dependence of various sea quark components is a matter of some controversy, the total sea quark distribution \( x\bar{q}(x) = x(\bar{u}(x) + d(x) + s(x)) \) can be obtained from the (anti)neutrino DIS [23]. In Fig.4d we confront the \( x \)-dependence obtained from the chiral quark model with the experimental data of the CCFR collaboration at \( Q^2 = 3 \) and 5 GeV^2. The antiquark distribution \( x\bar{q}(x) \) obtained in the \( \chi QM \) underestimates the experimental data by about 20-30\%, leaving room for some other unknown contributions. We expect the meson exchange current contribution to be the dominant missing contribution.

It is instructive to study different ratios of the quark distributions rather than the quark distributions themselves. In Fig.4e we present the ratio \( R(x) \equiv \bar{u}(x)/d(x) \) and in Fig.4f the ratio \( R_s(x) \equiv \frac{s(x) + \bar{s}(x)}{u(x) + d(x)} \). The latter is usually assumed to be a constant in all available parametrizations of the data (including MRS(A)). The simple model discussed here predicts an interesting Bjorken-\( x \) dependence of \( R_s(x) \) which could be the subject of a dedicated experimental study. In Figs. 4(e-f) we show also the corresponding ratios at the initial confinement scale \( Q_0^2 \). The ratio \( R(x, Q_0^2) = \bar{u}(x, Q_0^2)/d(x, Q_0^2) \) (dashed line) is independent

\[ \int_0^1 Q_N(y) dy = 1 \]
of Bjorken-x and equals to \( \frac{2}{11} \). Since the QCD evolution (solid line) even enhances this ratio, our result for \( R(x, Q^2) \approx 0.74 \) is too large compared to the recent NA51 CERN experiment \[ R = \bar{u}/\bar{d} = 0.51 \pm 0.04 \text{(stat)} \pm 0.05 \text{(syst)} \) at \( x = 0.18 \). Note that our prediction for the \( x \)-dependence of this ratio is quite different from the MRS(A) parametrization. A measurement of \( R(x) \) would shed further light on the problem, which picture (traditional meson cloud vs. chiral quark model) is more appropriate.

Finally, we study the consequences of the \( \chi QM \) for the \( N - \Delta \) mass splitting \( \delta^{N\Delta} \equiv m_{\Delta} - m_N \). Both, the spin-dependent gluon and pion exchange potentials between constituent quarks contribute to \( \delta^{N\Delta} = \delta^g_{\pi\Delta} + \delta^{\pi\Delta}_{\pi} \). The size of the pion contribution \( \delta^{\pi\Delta}_{\pi} \) is mainly determined by the (unknown) structure of the \( QQ'\pi \) vertex and is therefore model-dependent \[ \text{[12] [14]}. \] Fixing the cut-off parameter \( \Lambda \) of the \( QQ'\pi \) vertex by the experimental value for the Gottfried sum rule, \( S_G \), also fixes \( \delta^{\pi\Delta}_{\pi} \). We calculate \( \delta^{\pi\Delta}_{\pi} \) for both models A and B using \( G_{QQ'\pi}(t) = \left( \frac{\Lambda^2}{\Lambda^2 - t} \right)^{1/2} \text{[12]} \) and determine \( \Lambda \) from the experimental value of \( S_G \). We obtain for model A: \( \Lambda = 1.26 \text{ GeV} \) which corresponds to \( \delta_{\pi\Delta}^{\pi\Delta} = 222 \text{ MeV} \). Likewise we obtain for model B: \( \Lambda = 3.31 \text{ GeV} \) and \( \delta_{\pi\Delta}^{\pi\Delta} = 140 \text{ MeV} \). Evidently, \( \delta_{\pi\Delta}^{\pi\Delta} \) depends strongly on the pion-quark coupling constant \( g_{\pi QQ'} \) for which quite different values have been used in the recent literature \[ \text{[1] [2] [25]}. \] However, even in the extreme case of a very strong \( g_{\pi QQ'} \) (model A) we obtain only about 3/4 of the experimental \( \delta_{\pi\Delta}^{\pi\Delta} \). We have checked that this conclusion does not depend on the functional form of the \( QQ'\pi \) vertex.

Summarizing, we have studied the flavour structure of the nucleon in the effective chiral quark model \[ \text{[10]} \] in which the Goldstone bosons couple directly to the constituent quarks. With a Goldstone boson – constituent quark light-cone wave function adjusted to reproduce the experimental Gottfried Sum Rule \[ \text{[4]}. \] we have calculated the resulting antiquark distributions inside the constituent quark and inside the nucleon. We find 2–3 times more pions and 10–15 times more kaons in the nucleon than in the traditional meson cloud model in which the Goldstone bosons couple effectively to the nucleon \[ \text{[8]}. \] In general, the corresponding sea is concentrated at rather small Bjorken-x. The predicted \( \bar{u}(x)/\bar{d}(x) \) ratio is larger than the one obtained by the NA51 experiment at CERN \[ \text{[4]}. \] It may be expected that the gluon-exchange interaction between constituent quarks, which leads to the different \( x \)-dependence of up and down valence quarks, may to some extent modify the \( \bar{u}(x)/\bar{d}(x) \) ratio obtained here. Additional measurements of the \( x \)-dependence of this ratio are required to distinguish between different models. In comparison to the nucleonic meson cloud model, the \( x(\bar{d} - \bar{u}) \) difference is concentrated at smaller Bjorken-x, rather inconsistent with the recent MRS phenomenological analysis \[ \text{[21]} \] (see also a discussion in Ref.\[26\]). The discrepancy with the Drell-Yan data and the phenomenological MRS analysis may, in our opinion, be due to the many-body effects neglected in independent dressing of (interacting) constituent quarks. These effects are rather difficult to include on the microscopic level. In the traditional (nucleonic) formulation of the meson cloud they are treated in the strong binding limit (see a discussion in Ref.\[27\]). The \( \chi QM \) leads to enhanced strange sea distributions and a measurable difference between \( s(x) \) and \( \bar{s}(x) \) distributions. Finally, the experimental Gottfried Sum Rule violation provides stringent limits on the pionic contribution to the nucleon-delta mass splitting.

References

[1] K. Gottfried, \textit{Phys. Rev. Lett.} \textbf{18} (1967) 1174.
[2] P. Amaudruz \textit{et al.}, \textit{Phys. Rev. Lett.} \textbf{66} (1991) 2712.
[3] M. Arneodo \textit{et al.}, \textit{Phys. Rev.} \textbf{D50} (1994) R1.
[4] A. Baldit \textit{et al.}, \textit{Phys. Lett.} \textbf{B332} (1994) 244.
[5] G. Altarelli and G. Parisi, \textit{Nucl. Phys.} \textbf{B126} (1977) 298.
[6] D.A. Ross and C.T. Sachrajda, *Nucl. Phys.* B149 (1979) 497.

[7] E.M. Henley and G.A. Miller, *Phys. Lett.* B251 (1990) 453; A. Signal, A.W. Schreiber and A.W. Thomas, *Mod. Phys. Lett.* A6 (1991) 271; S. Kumano, *Phys. Rev.* D43 (1991) 59; W-Y.P. Hwang, J. Speth and G.E. Brown, *Z. Phys.* A339 (1991) 383; V.R. Zoller, *Z. Phys.* C53 (1992) 443; A. Szczurek and J. Speth, *Nucl. Phys.* A555 (1993) 249; A. Szczurek, J. Speth and G.T. Garvey, *Nucl. Phys.* A570 (1994) 765.

[8] H. Holtmann, A. Szczurek and J. Speth, *Nucl. Phys.* A596 (1996) 631; H. Holtmann, N.N. Nikolaev, J. Speth and A. Szczurek, *Z. Phys.* A353 (1996) 411; A. Szczurek, M. Ericson, H. Holtmann and J. Speth, *Nucl. Phys.* A596 (1996) 397.

[9] E.J. Eichten, I. Hinchliffe and C. Quigg, *Phys. Rev.* D45 (1992) 2269.

[10] A. Manohar and H. Georgi, *Nucl. Phys.* B234 (1984) 189.

[11] J. Ashman et al., *Nucl. Phys.* B328 (1989) 1.

[12] A. Buchmann, E. Hernández, and K. Yazaki, *Phys. Lett.* B269 (1991) 35; *Nucl. Phys.* A569 (1994) 661; Georg Wagner, A. J. Buchmann, and Amand Faessler, *Phys. Lett.* B359 (1995) 288.

[13] Amand Faessler, A. Buchmann, and Y. Yamauchi, *Int. J. Mod. Phys.* E2 (1993) 39.

[14] L.Ya. Glozman and D.O. Riska, *Phys. Rep.* 268 (1996) 263.

[15] N. Isgur and G. Karl, *Phys. Rev.* D18 (1978) 4187; *Phys. Rev.* D19 (1979) 2653.

[16] J.D. Sullivan, *Phys. Rev.* D5 (1972) 1732.

[17] S. Weinberg, *Phys. Rev. Lett.* 65 (1990) 1181.

[18] M. Glück, E. Reya and A. Vogt, *Z. Phys.* C67 (1995) 433.

[19] M. Glück, E. Reya and A. Vogt, *Z. Phys.* C92 (1992) 651.

[20] C. Foudas et al., *Phys. Rev. Lett.* 64 (1990) 1207.

[21] A.D. Martin, W.J. Stirling and R.G. Roberts, *Phys. Rev.* D50 (1994) 6734.

[22] A.O. Bazarko et al., *Z. Phys.* C65 (1995) 189.

[23] S.R. Mishra, *Phys. Rev. Lett.* 68 (1992) 3499.

[24] G.T. Garvey et al., *FNAL proposal, P866* (1992) .

[25] S. Baumgärtner, H.J. Pirner, K. Königsmann and B. Povh, *Z. Phys.* A353 (1996) 397.

[26] S. Kretzer, *Phys. Rev.* D52 (1995) 2701.

[27] E. Jenkins and A.V. Manohar, *Phys. Lett.* B255 (1991) 558.
Figure 1: The dressing of the constituent quarks with pions.
Figure 2: (a) Total splitting function (flux factor) of the constituent quark into the pion and kaon as a function of the light-cone momentum fraction $x_M$ carried by the Goldstone boson in the constituent quark; model A (solid lines) and model B (dashed lines). The corresponding vertex function parameters of the light-cone wave function $|MQ\rangle$, $\Lambda=2.287$ GeV (A) and 5.5 GeV (B) have been obtained by fitting to the experimental value of $S_G$. (b) The $x\bar{u}(x)$ (solid), $x\bar{d}(x)$ (dashed) and $x(s(x)+\bar{s}(x))/2$ (dotted) DIS-quark distributions in the constituent $U$ quark at the initial low-momentum scale.
Figure 3: Antiquark momentum distributions in the nucleon for the $\chi$QM model A. (a) $x\bar{u}(x)$ and $x\bar{d}(x)$ antiquark distributions in the proton (solid lines). For comparison we show the phenomenological antiquark distribution used in Ref. [18] (dashed lines, GRV95). Note that the $\bar{d}$ distributions are always above the $\bar{u}$ distributions. (b) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed).
Figure 4: Antiquark momentum distributions in the nucleon at $Q^2 = 4 \text{ GeV}^2$ (solid lines) as calculated from the ones of Fig.3 by QCD evolution. The results at the initial scale $Q_0^2 = 0.25 \text{ GeV}^2$, are shown by the dashed lines. Here, $\Lambda_{QCD} = 200 \text{ MeV}$ and the number of active quark flavours is $n_f = 3$. For comparison we show the recent MRS(A) parametrization [21] (dashed-dotted line) (a) $x\bar{u}(x)$ and $x\bar{d}(x)$, (b) $x(\bar{d}(x) - \bar{u}(x))$, (c) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed), (d) $x(u(x)+d(x)+s(x))$ compared with the experimental data of the CCFR collaboration [23], (e) $R(x) = \frac{\bar{u}(x)}{\bar{d}(x)}$, (f) $R_s(x) = s(x) + \bar{s}(x)$. 

Here, $\Lambda_{QCD} = 200 \text{ MeV}$ and the number of active quark flavours is $n_f = 3$. For comparison we show the recent MRS(A) parametrization [21] (dashed-dotted line) (a) $x\bar{u}(x)$ and $x\bar{d}(x)$, (b) $x(\bar{d}(x) - \bar{u}(x))$, (c) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed), (d) $x(u(x)+d(x)+s(x))$ compared with the experimental data of the CCFR collaboration [23], (e) $R(x) = \frac{\bar{u}(x)}{\bar{d}(x)}$, (f) $R_s(x) = s(x) + \bar{s}(x)$. 

Here, $\Lambda_{QCD} = 200 \text{ MeV}$ and the number of active quark flavours is $n_f = 3$. For comparison we show the recent MRS(A) parametrization [21] (dashed-dotted line) (a) $x\bar{u}(x)$ and $x\bar{d}(x)$, (b) $x(\bar{d}(x) - \bar{u}(x))$, (c) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed), (d) $x(u(x)+d(x)+s(x))$ compared with the experimental data of the CCFR collaboration [23], (e) $R(x) = \frac{\bar{u}(x)}{\bar{d}(x)}$, (f) $R_s(x) = s(x) + \bar{s}(x)$. 

Here, $\Lambda_{QCD} = 200 \text{ MeV}$ and the number of active quark flavours is $n_f = 3$. For comparison we show the recent MRS(A) parametrization [21] (dashed-dotted line) (a) $x\bar{u}(x)$ and $x\bar{d}(x)$, (b) $x(\bar{d}(x) - \bar{u}(x))$, (c) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed), (d) $x(u(x)+d(x)+s(x))$ compared with the experimental data of the CCFR collaboration [23], (e) $R(x) = \frac{\bar{u}(x)}{\bar{d}(x)}$, (f) $R_s(x) = s(x) + \bar{s}(x)$. 

Here, $\Lambda_{QCD} = 200 \text{ MeV}$ and the number of active quark flavours is $n_f = 3$. For comparison we show the recent MRS(A) parametrization [21] (dashed-dotted line) (a) $x\bar{u}(x)$ and $x\bar{d}(x)$, (b) $x(\bar{d}(x) - \bar{u}(x))$, (c) $xs(x)$ (solid) and $x\bar{s}(x)$ (dashed), (d) $x(u(x)+d(x)+s(x))$ compared with the experimental data of the CCFR collaboration [23], (e) $R(x) = \frac{\bar{u}(x)}{\bar{d}(x)}$, (f) $R_s(x) = s(x) + \bar{s}(x)$.