Asymmetry of strange sea in nucleons

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\begin{abstract}
Based on the finite-temperature field theory, we evaluate the medium effects in nucleon which can induce an asymmetry between quarks and antiquarks of the strange sea. The short-distance effects determined by the weak interaction can give rise to \( \delta m \equiv \Delta m_s - \Delta m_{\bar{s}} \) where \( \Delta m_s(\bar{s}) \) is the medium-induced mass of strange quark by a few KeV at most, but the long-distance effects by strong interaction are sizable. Our numerical results show that there exists an obvious mass difference between strange and anti-strange quarks, as large as \( 10 - 100 \) MeV.
\end{abstract}

PACS numbers: 11.10.Wx, 11.30.Na, 12.40.-y, 14.20.Dh

To be published in Phys. Rev. D.

\footnote{Mailing address.}
1 Introduction and Motivation

The existence of the Dirac sea is always an interesting topic which all theoretists and experimentalists of high energy physics are intensively pursuing, and the strange content of the nucleon sea is of particular interest for attention. Ji and Tang [1] suggested that if a small locality of strange sea in nucleon is confirmed, some phenomenological consequences can be resulted in. The CCFR data [2] indicate that \( s(x)/\bar{s}(x) \sim (1 - x)^{-0.46 \pm 0.87} \). Assuming an asymmetry between \( s \) and \( \bar{s} \), Ji and Tang analyzed the CCFR data and concluded that \( m_s = 260 \pm 70 \text{ MeV} \) and \( m_{\bar{s}} = 220 \pm 70 \text{ MeV} \) [1]. So if only considering the central values, \( \delta m \equiv m_s - m_{\bar{s}} \sim 40 \text{ MeV} \), which implies a quark-antiquark asymmetry. However, one may also alternatively conclude that the data are consistent with no asymmetry within err-bars [1, 2].

In the framework of the Standard Model \( SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \), we would like to look for some possible mechanisms which can induce the asymmetry between quarks and antiquarks.

The self-energy of strange quark and antiquark \( \Sigma_s(\bar{s}) = \Delta m_s(\bar{s}) \) occurs via loops where various interactions contribute to \( \Sigma_s(\bar{s}) \) through the effective vertices. Obviously, the QCD interaction cannot distinguish between \( s \) and \( \bar{s} \), neither the weak interaction alone in fact. Practical calculations of the self-energy also shows that \( \Delta m_s = \Delta m_{\bar{s}} \). In fact, because of the CPT theorem, \( s \) and \( \bar{s} \) must be of exactly the same mass. So we would ask ourselves what can make an asymmetry between \( s \) and \( \bar{s} \) which are supposed to be the sea quark-antiquark in nucleons. We can immediately find that in nucleons there are asymmetric quarks \( u \) and \( d \), namely the composition of \( u-\bar{u} \) and \( d-\bar{d} \) quark-antiquark is asymmetric. Here \( u-\bar{u}, d-\bar{d} \) include valence and sea portions of corresponding flavors. In proton, there are two valence \( u \)-quarks, but one valence \( d \)-quark, while in neutron, one \( u \), but two \( d \)’s. This asymmetry, as we show below, can stand as a medium effect which results in an asymmetry \( \Delta m_s \neq \Delta m_{\bar{s}} \) for strange sea quarks.

As discussed above, if we evaluate the self-energy \( \Delta m_s \) and \( \Delta m_{\bar{s}} \) in vacuum, the CPT theorem demands \( \Delta m_s \equiv \Delta m_{\bar{s}} \). However, when we evaluate them in an asymmetric environment of nucleons, an asymmetry \( \Delta^M m_s \neq \Delta^M m_{\bar{s}} \) where the superscript
\( M \) denotes the medium effects, can be expected. In other words, we suggest that the asymmetry of the \( u \) and \( d \) quark composition in nucleons leads to an asymmetry of the strange sea.

There exist both short-distance and long-distance medium effects. The short-distance effects occur at quark-gauge boson level, namely a self-energy loop including a quark-fermion line and a W-boson line or a tadpole loop (see below for details). The contributions of \( u \) and \( d \)-types of quark-antiquark to the asymmetry realize through the Kabayashi-Maskawa-Cabibbo mixing. Because of the small parton mass, the Higgs contributions can be neglected. By contrary, the long-distance effects are caused by loops which include a quark-fermion line and a meson (Kaon in our case) line.

In fact, Brodsky and one of us proposed a meson-baryon resonance mechanism and they suggested that the sea quark-antiquark asymmetries are generated by a light-cone model of energetically favored meson-baryon fluctuations \[3\]. It was first observed by Signal and Thomas \[4\] that the meson-cloud model of nucleon can introduce a mechanism for the strange-antistrange asymmetry in the nucleon sea, though their formalism is not consistent in treating the antiquark distributions in a strict sense \[5\]. An \( s-\bar{s} \) asymmetry was also predicted by Burkardt and Warr \[6\] from the chiral Gross-Neveu model at large \( N_c \) in the LC formalism. Our physics picture is similar and the method is parallel to theirs, while all the calculations are done based on the finite temperature field theory.

\section{The Formulation}

We are going to employ the familiar formulation of the Quantum Field Theory at finite temperature and density. As well-known, the thermal propagator of quarks can be written as \[7\]

\[
iS_q(k) = \frac{i(k + m_q)}{k^2 - m_q^2} - 2\pi(k + m_q)\delta(k^2 - m_q^2)f_F(k \cdot u),
\]

where \( u_\mu \) is the four-vector for the medium and \( f_F \) denotes the Fermi-Dirac distribution function

\[
f_F(x) = \frac{\theta(x)}{e^{\beta(x-\mu)} + 1} + \frac{\theta(-x)}{e^{-\beta(x-\mu)} + 1},
\]
and $\beta = 1/kT$, $\mu$ is the chemical potential. We notice that the first term of Eq. (1) is just the quark propagator in the vacuum. Its contribution to $\Sigma_1$ is of no importance to us because this is related to the wave-function renormalization of the quark in the vacuum. We need to focus on the medium effect, which comes from the second term of Eq. (1).

It is experimentally confirmed that the total light quark number in the nucleon is 3. If we omitted the small mass differences of the light quarks ($u$ and $d$ types, explicitly), the quark density in the nucleon is

$$n_q - n_\pi = \int \frac{d^3k}{(2\pi)^3} [f_F(\omega_k) - f_F(-\omega_k)] = \frac{3}{V_{\text{eff}}}, \quad (q = u, d).$$

In this expression $\omega_k = \sqrt{k^2 + m_q^2}$ is the energy of the light quark and $V_{\text{eff}}$ is the effective nucleon volume where $q(\bar{q})$ resides. Here we have ignored the possible sea quark asymmetry for light quarks of $u$ and $d$-flavors [8]. For up and down flavors, we have

$$n_u - n_\pi = \frac{2}{V_{\text{eff}}}, \quad n_d - n_\pi = \frac{1}{V_{\text{eff}}}, \quad (4)$$

in proton while

$$n_u - n_\pi = \frac{1}{V_{\text{eff}}}, \quad n_d - n_\pi = \frac{2}{V_{\text{eff}}}, \quad (5)$$

in neutron.

### 2.1 The short-distance contribution

The corresponding Feynman diagrams are shown in Fig.1 (a) and (b).

The two contributions to the self-energy of $s$-quark ($\bar{s}$) (a) and (b) are due to the charged current ($W^\pm$) and neutral current (including the $Z$ and $\gamma$) respectively, the later is usually called as the tadpole-diagram [9]. The total contribution is in analog to that given in [9], the mere difference is that for neutrino only weak neutral current plays a role while for quarks, the electromagnetic interaction also needs to be involved.

The contribution due to the charged current is

$$\Sigma_1^s = \sqrt{2}G_F\gamma^0 L \sin^2 \theta_C(n_u - n_\pi), \quad (6)$$
Figure 1 (a): The self-energy $\Sigma_1^s$ for strange quark where the exchanged bosons are either W-boson or kaon corresponding to short- and long-distance effects respectively.

Figure 1 (b): The tadpole diagram which contributes to the self-energy $\Sigma_2^s$ of strange quark.

where $G_F$ is the Fermi coupling constant, $\theta_C$ is the Cabibbo angle. The contribution due to the weak neutral current is

$$\Sigma_2^s = 3\sqrt{2}G_F(-1 + \frac{4}{3} Q^{(s)} \sin^2 \theta_W) \cdot \sum_f (T_3^{(f)} - 2Q^{(f)} \sin^2 \theta_W)(n_f - n\bar{f}), \quad (7)$$

where $Q^{(f)}$ refers to the charge of corresponding quark ($u$, $d$, $s$). Pal and Pham pointed that the axial part of the neutral current does not contribute [9].

For the electromagnetic current the situation is different. The exchanged photon connecting the $s$-quark line (or $\bar{s}$-quark) and the closed loop (tadpole) possesses zero
energy-momentum and its propagator

\[ \frac{1}{q^2 + i\epsilon} \]

results in an infrared divergence. In the regular field theory, it does not bring up any problem because the integration over the inner momentum of the loop is exactly zero. In the case of the gluon infrared divergence, because of the non-Abelian Yang-Mills properties, there can be a tachonic gluon mass [10] which can serve as an infrared cut-off. Unlike, photon as the gauge boson of the \( U_{em}(1) \) group cannot obtain an effective mass. It also means that there is no any connection between the closed fermion-loop and the \( s \)-quark line, thus the two parts are actually disconnected and such electromagnetic tadpole should not be included in the phenomenological calculations even though it has a superficial infrared divergence. Thus we drop out the electromagnetic tadpole in our later calculations.

As for the strange antiquark, one can obtain the corresponding self-energy by changing the direction of propagation. Obviously if ignore the small mass difference of \( u \) and \( d \)-quarks, we have

\[ \Sigma_1^{\bar{s}} = -\Sigma_1^s, \quad \text{and} \quad \Sigma_2^{\bar{s}} = -\Sigma_2^s, \]

and the mass difference between the strange and antistrange quarks is

\[ \delta m \equiv 2(\Sigma_1^s + \Sigma_2^s), \] (8)

due to the short-distance interactions.

\section*{2.2 The long-distance effects}

Up to now the dynamical picture of the sea quark interaction in QCD is not definitively understood. In our case of interest, the main contribution of the strong interaction will be attributed to the low-energy effective coupling between the internal Goldstone bosons and quarks. According to the common knowledge of low-energy effective strong interaction, the strange quark is generated from dissociation of nucleons into hyperons plus kaons. In this picture the \( s(\bar{s}) \)--quark in the sea interacts with
the light quark and the kaon meson essentially. This is in analog to that considered in Refs. [3, 4, 6] and by Kogan and Shifman who introduced such effects for weak radiative decay [11], but we estimate these effects with a quark-meson interaction instead of a baryon-meson interaction [12].

In the calculations, we need an effective vertex for $\bar{q}qM$ where $q$ can be either $u$ or $d$-quarks and $M$ is a pseudoscalar or vector meson. Here we only retain the lowest lying meson states such as $\pi, K, \rho$ etc. The effective chiral Lagrangian for the interaction between quarks and mesons has been derived by many authors [13, 14]. For completeness, we present the well-established form of the chiral Lagrangian as [14]

$$L_x = i\bar{q}(\not{\partial} + \not{\Gamma} + g_A\Delta\gamma_5 - i\not{\nabla})q - m\bar{q}q + \text{meson part.} \quad (9)$$

It is noted that in general, the chiral Lagrangian only applies to the interactions between constituent quarks and mesons, on other side the sea quark picture is valid for current quarks (or partons) [13]. Here we borrow the chiral Lagrangian picture just because the fundamental forms of interactions of either partons or constituent quarks with mesons are universal. The key point is the coupling constants, they may be different in the two pictures. However, we can assume that they do not deviate by orders from each other. Therefore we can use the coupling constants for constituent quarks in our estimation of the order of magnitude. Probably, the obtained results and new data would offer us an opportunity to determine the effective coupling between parton-quarks and mesons. Anyway, we would point out that the numerical results obtained in this work may have a relative large error of about 10 MeV, as we will see in the section of numerical calculations.

In this expression we omit the irrelevant part which only contains mesons. Here $\bar{q} = (\bar{q}_u, \bar{q}_d, \bar{q}_s)$ and

$$V_\mu(x) = \lambda \cdot V_\mu = \sqrt{2} \begin{pmatrix} \rho^0_\mu \over \sqrt{2} + \omega_\mu \over \sqrt{2} & \rho^\mu_- & K^{*+}_\mu \\ \rho^-_\mu & -\rho^0_\mu \over \sqrt{2} + \omega_\mu \over \sqrt{2} & K^{*0}_\mu \\ K^{*-}_\mu & K^{0*}_\mu & \phi_\mu \end{pmatrix}. \quad (10)$$

$\Delta_\mu$ and $\Gamma_\mu$ are defined as

$$\Delta_\mu = \frac{1}{2}((\xi^\dagger(\partial_\mu - ir_\mu)\xi - \xi(\partial_\mu - il_\mu)\xi^\dagger),$$

$$\Gamma_\mu = \frac{1}{2}((\xi^\dagger ir_\mu - i\xi)(\partial_\mu - il_\mu)\xi^\dagger).$$
\[ \Gamma_\mu = \frac{1}{2} (\xi^\dagger (\partial_\mu - i r_\mu) \xi + \xi (\partial_\mu - i l_\mu) \xi^\dagger), \] (11)

with

\[ \xi = \exp(i \lambda \Phi^a(x)/2f), \]

where the Goldstone bosons \( \Phi^a \) are the pseudoscalar mesons in the SU(3) octet and \( f \) is the decay constant.

From the chiral effective Lagrangian, the basic effective vertex is a pure-derivative axial vector (chiral-symmetric) coupling as \( f_{kqs} \bar{\psi} \gamma_5 \gamma_\mu \partial_\mu K \psi \). In the last part of this work, we will give more discussions on this issue. The quantum correction at one-loop level provides a self-energy \( \Sigma_s^3 \) for the strange quark shown in Fig. 1(a) (where we only need to replace the W-boson line by a kaon-line). Here we neglect the higher loop contribution which may be induced by the higher order graphs in the chiral Lagrangian. In general, for such an estimation, the effective coupling by itself may contain some higher loop contributions, thus their effects do not influence the qualitative conclusion although the quantitative result may change [14]. So we can write the amplitude due to the long-distance effective interaction as

\[ -i \Sigma_s^3 = i f_{kqs}^2 \int \frac{d^4 k}{(2\pi)^4} \gamma_5 \gamma_\mu i S_q(k) \gamma_5 \gamma_\mu \frac{(p - k)^2}{(p - k)^2 - M_K^2}, \] (12)

where \( M_K \) is the mass of kaons.

In the rest frame of the medium ( \( u_\mu = (1, 0) \) ) we use

\[ \delta (k^2 - m_q^2) = \frac{1}{2\omega_k} [\delta (k_0 - \omega_k) + \delta (k_0 + \omega_k)], \] (13)

where \( \omega_k = \sqrt{k^2 + m_q^2} \) is the energy of the light quark. So the long-distance medium correction to the mass of strange quark can be evaluated and we obtain

\[ \Sigma_s^3 = \gamma_0 \frac{f_{kqs}^2}{2} \int \frac{d^3 k}{(2\pi)^3} \left[ \frac{m_s^2 - 2m_s \omega_k}{m_s^2 - 2m_s \omega_k - M_K^2} f_F(\omega_k) - \frac{m_s^2 + 2m_s \omega_k}{m_s^2 + 2m_s \omega_k - M_K^2} f_F(-\omega_k) \right] \] (14)

After simple manipulations, it becomes

\[ \Sigma_s^3 = \gamma_0 \frac{f_{kqs}^2}{2} \left[ (n_q - n_\tau) + \int \frac{d^3 k}{(2\pi)^3} \frac{M_K^2}{m_s^2 - 2m_s \omega_k - M_K^2} f_F(\omega_k) \right. \\
- \left. \int \frac{d^3 k}{(2\pi)^3} \frac{M_K^2}{m_s^2 + 2m_s \omega_k - M_K^2} f_F(-\omega_k) \right]. \] (15)
In order to avoid the pole in the second term of Eq. (14), we use the familiar Breit-Wigner formulation. Then we give $\Delta m_s$ contributed by the long-distance effects as

$$
\Delta m_s = \frac{f_{kq_s}^2}{2} \int \frac{d^3k}{(2\pi)^3} \left[ \frac{(m_s^2 - 2m_s\omega_k - M_K^2)(m_s^2 - 2m_s\omega_k)}{(m_s^2 + 2m_s\omega_k - M_K^2)^2 + (M_K\Gamma_K)^2} f_F(\omega_k) \
- \frac{(m_s^2 + 2m_s\omega_k - M_K^2)(m_s^2 + 2m_s\omega_k)}{(m_s^2 + 2m_s\omega_k - M_K^2)^2 + (M_K\Gamma_K)^2} f_F(-\omega_k) \right]
\times \frac{k^2}{2\pi^2} \left[ \frac{(m_s^2 - 2m_s\omega_k - M_K^2)(m_s^2 - 2m_s\omega_k)}{(m_s^2 + 2m_s\omega_k - M_K^2)^2 + (M_K\Gamma_K)^2} f_F(\omega_k) \
- \frac{(m_s^2 + 2m_s\omega_k - M_K^2)(m_s^2 + 2m_s\omega_k)}{(m_s^2 + 2m_s\omega_k - M_K^2)^2 + (M_K\Gamma_K)^2} f_F(-\omega_k) \right],
$$

where in the Breit-Wigner expression, we take the usual approximation that $\Gamma_K$ is the measured value of the lifetime of $K^\pm$.

The statistical integral Eq. (16), as a function of temperature $T$ and chemical potential $\mu$, can be expressed in terms of the quark density and therefore the nucleon size (c.f. Eq. (3)) at a given temperature. In the practical calculation, we use the numerical integral method to relate the mass correction $\Delta m_s$ with the effective nucleon radius $R$.

## 3 The Numerical Results

### 3.1 For short-distance effects

Our numerical results show that

$$
\delta m = 92 \text{ eV} \sim 0.8 \text{ KeV}, \quad \text{for proton},
$$

$$
\delta m = 0.38 \text{ KeV} \sim 3.0 \text{ KeV}, \quad \text{for neutron},
$$

in the range of the effective nucleon radius $R \approx 0.5 - 1.0 \text{ fm}$. So we see that the short-distance interaction cannot result in a large asymmetry in the strange sea.
3.2 For the long-distance effects

According to the picture of chiral field theory [16, 17, 18, 19], the effective pseudovector coupling implies \( f_{kqs} = \frac{g_A}{\sqrt{2}} f \), where the axial-vector coupling \( g_A = 0.75 \). The pion decay constant \( f_\pi = 93 \text{ MeV} \), kaon decay constant \( f_K = 130 \text{ MeV} \), for our estimation, an approximate SU(3) symmetry might be valid, so that \( f \) can be taken as an average of \( f_\pi \) and \( f_K \). One can trust that the order of the effective coupling at the vertices does not deviate too much from this value.

In the chiral quark model from the framework of the standard chiral field theory [13], one usually takes the quarks as the constituent quarks [16, 20]. However, there is also a suggestion [21] to consider the quarks in the chiral dynamics as current quarks from the successful description of the proton spin data [17, 18], in consistent with our consideration to use the chiral Lagrangian picture for an effective description of current-quark and meson interaction. Therefore we present our calculated results of \( \Delta m_s \) for two cases:

(a) with the quark masses being the current quark masses \( m_s = 150 \text{ MeV} \) and \( m_u \approx m_d = 6 \text{ MeV} \);
(b) with the quark masses being the constituent quark masses \( m_s = 500 \text{ MeV} \) and \( m_u = m_d = 350 \text{ MeV} \).

We present the numerical results of \( \Delta m_s \) as a function of the effective nucleon radius in Fig. 2. We find that the result depends on the value of nucleon volume sensitively for small \( R \)-values, which correspond to the high density, but becomes mild as \( R \) turns larger.

In Fig. 2, one can notice that as \( R \) is about 0.5 fm, \( \Delta m_s \) can be as large as 50 MeV which results in \( \delta m \equiv 2 \Delta m_s \approx 100 \text{ MeV} \) for the current quark mass case, and even larger for the constituent quark mass case. But for the situation corresponding to a normal nucleon case, \( \delta m \) might be only of the order of around a few 10 MeV, which is within the uncertainties as estimated in Ref. [1].

We notice that at high temperature with ordinary density of nuclear matter, or at high density with ordinary temperature, the baryons and mesons may undergo
Figure 2: The medium correction $\Delta m_s$ for the strange quark mass vs the effective nucleon radius $R$, in two cases with different quark masses: (a) current quark masses $m_s = 150$ MeV and $m_u \approx m_d = 6$ MeV; (b) constituent quark masses $m_s = 500$ MeV and $m_u = m_d = 350$ MeV.

a phase transition to the quark-gluon-plasma with quarks and gluons as the basic degrees of freedom, and spontaneous chiral symmetry may be restored. Thus the effective $s$-kaon-$u$ coupling $f_{kqs}$ and the pion or kaon decay constant $f$ may decrease with increasing temperature and density, and the quark-antiquark asymmetry may also decrease with increasing temperature and density. However, here we consider the nucleon case, with $T$ refers to the temperature of normal nuclear matter in the chiral dynamics, in a range of about 100 MeV to a few hundreds MeV, which is lower than chiral symmetry restoration scale of about 1 GeV, and also with the density is not high for a nucleon as ordinary nuclear matter. Therefore we neglect the dependence of the coupling and decay constants on temperature and density in the present study. But it should be clear that the trend as shown in Fig. 2, where the strange quark-antiquark mass difference $\delta m_s$ increases with increasing temperature and density, will be changed if the chiral symmetry restoration is considered. Thus the quark-antiquark asymmetry caused by the long-distance effects should not be very larger than what we estimated above, if such asymmetry can be large.
4 Discussions and Summary

The strange asymmetry discussed above in fact may be caused by an asymmetry of the light quark contents in nucleons, but not the interaction itself. We show that $u(\bar{u}), d(\bar{d})$ quarks in nucleons can play a role as the medium which results in an asymmetry of the self-energy of $s$ and $\bar{s}$. The resultant values for $s$ and $\bar{s}$ have opposite signs which induce a net mass difference between $s$ and $\bar{s}$. The nucleon structure determines $\delta m = m_s - m_{\bar{s}} > 0$.

There exist both short-distance and long-distance effects which are mediated by W (Z) bosons and K-mesons respectively. Because the gauge bosons W and Z are very heavy, the net effects are much suppressed and their contribution to $\delta m$ can only be a few KeV. By contrast, kaon is much lighter and moreover, the effective interaction $\bar{q}qP$ where P denotes a meson with appropriate quantum number is due to non-perturbative QCD which is strong interaction, thus the effective coupling is much larger than that of weak interaction. This obvious enhancement gives a value of 10~100 MeV to $\delta m$, which is consistent with the estimate required to fit the experimental data within err-bars.

In our approach, we only keep the leading order in the effective chiral Lagrangian and leave the coupling constant as a parameter with an SU(3) symmetry. If we completely apply the chiral effective Lagrangian, the coupling constant is fully determined. In other side, the original formulation of the effective chiral Lagrangian is for the constituent quark whereas here we take the parton picture instead, thus the coupling constant might somewhat deviate from that in the effective chiral Lagrangian. In this work we take the value of the coupling constant according to the Lagrangian but with a factor $g_A$ as $f_{kqs} = \frac{g_A}{\sqrt{2}f}$. This factor $g_A$ partly includes the nucleon structure effects and compensates the errors as applying the chiral effective Lagrangian to the parton picture. We can expect that this choice does not much deviate from reality while using the Lagrangian for the parton picture. Certainly, such approximation may bring up errors, so that we cannot give precise predictions on the mass difference of $\bar{s}$ and $s$, but one can be convinced that the qualitative conclusion can be made and the order of magnitude is close to reality, because here we apply
all the established theories and models except the numerical value of the coupling constant to make this evaluation.

In summary, we investigate the influence of the environment on the asymmetry of the strange sea based on the well-established finite-temperature field theory. In our opinion, a natural explanation for this asymmetry is due to the light quark sea in nucleons which stands as a medium with certain asymmetries. There exist always three “net” light quarks which means an excess of $q$ over $\bar{q}$ in nucleons. The important feature is attributed to a non-zero chemical potential for the light quark (antiquark) in this theoretical framework. As a consequence, we obtain an obvious asymmetry of the strange sea ($\delta m \sim 10 – 100$ MeV), although the magnitude of the asymmetry should be also constrained by chiral symmetry restoration. Considering that the net strange quark number is zero, it leads to $\mu_s \neq \mu_{\bar{s}} \neq 0$. We expect that this point is helpful for understanding the non-negligible strangeness content of the nucleon.

On the other hand, we suggest that the low-energy effective interaction provides the main dynamical origin of the strange sea asymmetry. In fact, many authors have emphasized that the light-quark sea asymmetry can arise from effective interactions between the internal Goldstone bosons and quarks. So the essence of our approach is consistent with the treatments of [16, 17, 18, 19] in the dynamical sense.

Acknowledgment:

This work is partially supported by the National Natural Science Foundation of China.

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