Sea quark contents of octet baryons

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Abstract

The flavor asymmetry of the nucleon sea, i.e., the excess of $d\bar{d}$ quark-antiquark pairs over $u\bar{u}$ ones in the proton, can be explained by several different models; therefore, it is a challenge to discriminate these models from each other. We examine in this Letter three models: the balance model, the meson cloud model, and the chiral quark model, and we show that these models give quite different predictions on the sea quark contents of other octet baryons. New experiments aimed at measuring the flavor contents of other octet baryons are needed for a more profound understanding of the non-perturbative properties of quantum chromodynamics (QCD).

Key words: balance model, meson cloud model, chiral quark model, flavor asymmetry
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1 Introduction

The composition of hadrons is one of the central issues of hadronic physics and can be handled in two languages, i.e., in terms of quark-gluon degrees of freedom and/or meson-baryon degrees of freedom. Practically, hadron structures are found to be nontrivial and more complicated than naive expectations from constitute quark models. The complications are mainly due to the important contributions from the non-perturbative behaviors of quantum chromodynamics (QCD). For instance, as quark-antiquark pairs are created perturbatively, the sea quarks generated by leading twist evolution, i.e., from gluon splitting, are necessarily flavor-symmetric and CP-invariant. Nevertheless, various experiments discovered a notable flavor asymmetry between $u\bar{u}$ and $d\bar{d}$ quark-antiquark pairs of the proton [1,2,3,4,5,6,7]. This flavor asymmetry of the nucleon sea is attributed to the non-perturbative properties of QCD, and currently, it is still a big challenge to perform calculations from the first principle of QCD.

From experimental aspects, the $u\bar{u}$ and $d\bar{d}$ asymmetry was observed from the violation of the Gottfried sum rule, i.e., $S_G = \int_0^1 [(F_2^p - F_2^n)/x] \mathrm{d}x = 1/3$ [8], where F_2^p and F_2^n are the structure functions of the proton and neutron, respectively, and x is the Bjorken variable, which measures the fraction of momentum carried by the parton compared to that of the hadron in the infinite momentum frame (or on the light-cone). In 1991, the New Muon Collaboration (NMC) utilized muon-induced deep-inelastic scattering (DIS), and found that $S_G = 0.240 \pm 0.016$ [1] (re-evaluated as 0.235 ± 0.026 [2]). The result is significantly below the prediction of 1/3 from naive constitute quark considerations. This was attributed to the flavor asymmetry between $\bar{d}$ and $\bar{u}$ sea quarks [9]. While the DIS process detects the difference between $\bar{d}$ and $\bar{u}$ quarks, the Drell-Yan process can measure their ratios [10,11]. Later, the deviation was confirmed by the NA51 Collaboration ($\bar{u}/\bar{d} = 0.51 \pm 0.04 \pm 0.05$ at $x = 0.18$ [3]) from muon pair production through the Drell-Yan process in $p+p$ and $p + d$ reactions. More accurate ratios of x-dependent $\bar{u}/\bar{d}$ were obtained by the Fermilab E866/NuSea Collaboration [4,5,6], using the 800 GeV protons interacting with liquid hydrogen and deuterium targets. The HERMES Collaboration at DESY used an independent method, through semi-inclusive DIS [7], and obtained results consistent with that of the NMC, NA51, and E866/NuSea experiments. Thus, the flavor asymmetry of light quarks is well established (for reviews, see Refs. [12,13]).

From theoretical aspects, the violation of the Gottfried sum rule could be alternatively accounted for, at least partially, by isospin symmetry breaking between the proton and the neutron at the parton level [14,15]. To disentangle

two possible scenarios, W$^\pm$ creation, which is free of the p-n isospin symmetry breaking effect, is suggested [16,17,18]. Moreover, it has the opportunity to extract $\bar{d}/\bar{u}$ ratios at large x and very high Q^2, through the measurements of ratios of W^+, W^- production cross-sections in $p + p$ collisions at RHIC and LHC [19]. In this Letter, we assume that the isospin symmetry between the proton and the neutron holds.

To describe partons inside hadrons, the light-cone presentation is a natural language [20]. In the light-cone Fock-state language of bound states [21,22,23], the hadronic eigenstate of QCD Hamiltonian is expanded on the complete set of color-singlet quark-gluon eigenstates,

$$|h\rangle = \sum_{i,j,k,l} c_{i,j,k,l} |\{q\}, \{i,j,k\}, \{l\}\rangle \,, \tag{1}$$

where $\{q\}$ represents the valence quarks of the hadron $|h\rangle$; i is the number of quark-antiquark $u\bar{u}$ pairs; j is the number of $d\bar{d}$ pairs; k is the number of gluons; and $\{l\}$ denotes other heavier flavors (s, c, b, and t).

It is worthy to mention that the quarks and gluons in the Fock states are the "intrinsic" partons of hadrons, since they are non-perturbatively multi-connected to valence quarks [24,25]. They are different from the "extrinsic" partons generated from QCD hard bremsstrahlung or gluon splitting as part of the lepton scattering interaction. The "extrinsic" sea quarks and gluons only exist for a short time, $\sim 1/Q$; in contrast, the "intrinsic" sea quarks and gluons exist over a relatively long lifetime within hadronic bound states. Partons measured at certain Q^2 include both "intrinsic" and "extrinsic" contents. Since "extrinsic" partons are generated without association with flavor structure, the light flavor sea quark asymmetry mainly originates from "intrinsic" partons and is practically Q^2-independent or slightly Q^2-dependent [12,13].

The initial distributions of nucleon sea flavors are not required to be symmetric because the nucleon state itself is not CP-invariant. It is crucial to understand the role of the "intrinsic" parton distributions of hadrons, since they set the boundary conditions for QCD evolution. Theoretically, there are many phenomenological models that can account for the flavor asymmetry of the nucleon sea, e.g., meson cloud models [26,27,28,29,30,31,32,33,34,35,36], chiral quark models [37,38,39,40,41,42,43,44], and statistical models [45,46,47,48,49]. Besides the u and d flavors, the strange flavor of the nucleon sea has been also extensively studied [25,42,43,44,50,51,52,53,54].

While different models give fairly good descriptions of the current data, measurable differences exist among their predictions, especially when other members of octet baryons other than nucleons are considered [55]. The quark flavor

and spin distributions, as well as the probabilities to probe them experimentally, are discussed for Λ^0 [56,57] and $\Sigma^{\pm}$ [58,59,60,61]. Since Λ^0 is charge-neutral and its lifetime is short, it is hard to accelerate it as an incident beam or use it as a target. Fortunately, various Λ^0 fragmentation processes can be used to uncover quark distributions [55,56,57]. As for Σ, Drell-Yan experiments with Σ beam on protons and deuterium can be carried out to detect quark distributions [55,58,59,61].

To examine model-dependent predictions explicitly, in this Letter, we calculate the sea contents of octet baryons in each of the different frameworks of the balance model, meson cloud model, and chiral quark model. We present the different predictions of these models numerically, for convenience, when comparing the experiments. We expect new experiments to discriminate the models from each other and to provide a deeper and more profound understanding of the flavor structure of hadrons as well as the non-perturbative behaviors of QCD.

2 The balance model

The detailed balance model [45,46,48] and the balance model [47], which are free from any parameters, were proposed to look into the statistical effects of the nucleon and to search for the origin of $d\bar{d}$ and $u\bar{u}$ asymmetry. It was found that the detailed balance model generates $\bar{d} - \bar{u} \simeq 0.124$, while the balance model gives $\bar{d} - \bar{u} \simeq 0.133$. It is a big surprise that both models provide a remarkable agreement of their predictions of $d\bar{d}$ over $u\bar{u}$ with the E866/NuSea result of 0.118 ± 0.012 [4,5,6], without any parameters. Assuming equal probability for every energy configuration of each n-parton Fock state, one can get x-dependent parton distribution functions as well [46]. The method was also extended to pions [62] and the nucleon spin structure [63].

The main idea of the balance model is rather simple and intuitive. It takes the proton as a bag of quark-gluon gas in dynamical balance, where partons keep combining and splitting through processes such as $q(\bar{q}) \Leftrightarrow q(\bar{q})g$, $g \Leftrightarrow q\bar{q}$, and $g \Leftrightarrow gg$. The model starts from the valance quark structure of the proton without any parameters, even the QCD color coupling constant of α_s. In this picture, while $d\bar{d}$ and $u\bar{u}$ sea quark-antiquark pairs are produced by gluon splitting with equal probability, the reverse process, i.e., the annihilation of antiquarks with their quark partners into gluons, is not flavor symmetric due to the net excess of u quarks over d quarks in the proton. As a consequence, $\bar{u}$ quarks have a larger probability to annihilate than $\bar{d}$ quarks, hence bringing an excess of $\bar{d}$ over $\bar{u}$.

Table 1
Sea contents of octet baryons in the balance model.

Valance quark	Hadron	$\bar{u}$	$\bar{d}$	$\bar{d} - \bar{u}$	g
uud	p	0.337	0.470	0.133	1.099
uds	Λ^0	0.469	0.469	0.000	1.095
uds	Σ^0	0.469	0.469	0.000	1.095
uus	Σ^+	0.334	0.744	0.410	1.090
uss	Ξ^0	0.466	0.742	0.276	1.087

From Eq. (1), it is easy to see that the probability of finding a hadron in the Fock state $|\{q\}, \{i, j, k\}, \{l\}\rangle$ equals to $\rho_{i,j,k,l} = |c_{i,j,k,l}|^2$, which satisfies the normalization condition

$$\sum_{i,j,k,l} \rho_{i,j,k,l} = 1 \,. \tag{2}$$

In principle, we reasonably assume that the basic property of the ensemble of the proton does not change with time. As for the detailed balance model, it is presumed that any two nearby quark-gluon Fock states should be balanced with each other [45,48]. We ignore heavier quarks at first. The channels from $|\{uud\}, \{i, j, k\}\rangle$ to $|\{uud\}, \{i, j, k-1\}\rangle$ are $ug \xrightarrow{(2+i)\times k} u$, $\bar{u}g \xrightarrow{i\times k} \bar{u}$, $dg \xrightarrow{(1+j)\times k} d$, $\bar{d}g \xrightarrow{j\times k} \bar{d}$, and $gg \xrightarrow{C_k^2} g$; thus,

$$|\{uud\}, \{i, j, k\}\rangle \xrightarrow{(3+2i+2j)\times k + C_k^2} |\{uud\}, \{i, j, k - 1\}\rangle \,, \tag{3}$$

where $C_k^2 = k(k-1)/2$ and the number above the arrow is the possible number of the channel. Inversely, we have

$$|\{uud\}, \{i, j, k\}\rangle \xleftarrow{3+2i+2j+k-1} |\{uud\}, \{i, j, k - 1\}\rangle \,. \tag{4}$$

The detailed balance condition requires

$$\rho_{i,j,k} \times [(3 + 2i + 2j) \times k + C_k^2] = \rho_{i,j,k-1} \times (3 + 2i + 2j + k - 1) \,. \tag{5}$$

Similarly,

$$\rho_{i,j,0} \times [i \times (i + 2)] = \rho_{i-1,j,1}, \quad \rho_{i,j,0} \times [j \times (j + 1)] = \rho_{i,j-1,1} \,. \tag{6}$$

Eqs. (2, 5, 6) provide a complete set to solve the "intrinsic" structure of the proton [45].

However, there exist some inconsistent points, which are attacked when a more general principle, named the balance principle, is adopted [47]. The balance

principle demands that each Fock state should be balanced with all of its nearby Fock states, not only one Fock state. It induces a set of linear equations. After including Eq. (2), we can determine the parton contents of the proton uniquely as well. For more details, see Ref. [47], which also introduced a method to include heavier quarks.

The procedure used for the proton is also workable for other hadrons, and the results for all members of octet baryons, derived from the balance principle, are listed in Table 1. The u-d isospin symmetry among octet baryons is preserved in our balance model. Thus, for the neutron n and hyperons Σ^- and Ξ^- (not listed in the table), we can immediately obtain their parton contents through u-d isospin symmetry, e.g., $\bar{u}^n = \bar{d}^p$, $u^{\Sigma^-} = d^{\Sigma^+}$.

3 The meson cloud model

Sullivan [26] displayed that virtual meson-baryon states directly contribute to the nucleon structure. Later, Thomas [27] demonstrated the relevance of the pion cloud for sea quark distributions, treating SU(3) symmetry as breaking in the nucleon sea. Further, several authors included ω meson [35], σ meson [36], as well as pions and kaons [26,27,28,29,30,31,32,33,34]. We now refer to these models as meson cloud models. However, in our calculation, only pions, which contribute to structure functions most significantly due to their lightest mass, are considered. For the same reason, only baryons in the octet and decuplet states are taken into account in this Letter.

The proton has virtual states such as πN and $\pi\Delta$. Here we write its wavefunction as follows [13],

$$
|p\rangle \rightarrow \sqrt{1-a-b}\,|p_0\rangle + \sqrt{a}\,\left(-\sqrt{\frac{1}{3}}|p_0\pi^0\rangle + \sqrt{\frac{2}{3}}|n_0\pi^+\rangle\right)
$$
$$
+ \sqrt{b}\,\left(\sqrt{\frac{1}{2}}|\Delta_0^{++}\pi^-\rangle - \sqrt{\frac{1}{3}}|\Delta_0^+\pi^0\rangle + \sqrt{\frac{1}{6}}|\Delta_0^0\pi^+\rangle\right),
$$

where the subscript "0" denotes the bare part, or equivalently speaking, where only valence quarks are involved; the coefficients inside the brackets are from isospin couplings [64]; a and b are weight factors for states from the baryon octet and decuplet states, respectively, satisfying

$$
a > 0, \quad b > 0, \quad a + b < 1. \tag{7}
$$

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Table 2
Expressions of sea contents of octet baryons in the meson cloud model. The numbers inside the brackets are typical values when a commonly used relation, $a = 2b$ [13], is adopted.

Hadron	$\bar{u}$		$\bar{d}$		$\bar{d} - \bar{u}$	
p	$1/6a + 2/3b$	(0.130)	$5/6a + 1/3b$	(0.260)	$2/3a - 1/3b$	(0.130)
Λ^0	$1/2a + 1/2b$	(0.195)	$1/2a + 1/2b$	(0.195)	0	(0.000)
Σ^0	$a + 1/2b$	(0.325)	$a + 1/2b$	(0.325)	0	(0.000)
Σ^+	$1/4a + 1/4b$	(0.098)	$7/4a + 3/4b$	(0.553)	$3/2a + 1/2b$	(0.455)
Ξ^0	$1/6a + 1/6b$	(0.065)	$5/6a + 5/6b$	(0.325)	$2/3a + 2/3b$	(0.260)

We impose another constraint,

$$a > b\,, \tag{8}$$

considering the fact that baryons in the decuplet state are heavier than those in the octet state; thus, they are suppressed.

From the wavefunction of the proton, we get the $\bar{d}$ and $\bar{u}$ contents directly,

$$\bar{d} = \frac{5}{6}a + \frac{1}{3}b\,, \tag{9}$$

$$\bar{u} = \frac{1}{6}a + \frac{2}{3}b\,. \tag{10}$$

As for $\bar{d}$-$\bar{u}$ asymmetry, the NMC experiment gave $\bar{d} - \bar{u} = 0.148 \pm 0.039$ [1,2], while the E866/NuSea Collaboration reported $\bar{d} - \bar{u} = 0.118 \pm 0.012$ [4,5,6] and the HERMES Collaboration obtained $\bar{d} - \bar{u} = 0.16 \pm 0.03$ [7]. They are illustrated in Fig. 1 in the shaded area, light colored area, and dark colored area, respectively. For convenience, we adopt $\bar{d} - \bar{u} = 0.130$ in our following calculations,; thus, the three experimental results are all satisfied with errors considered. Thereafter, by substituting Eq. (9) and Eq. (10), we reach a relation of a and b, as

$$\bar{d} - \bar{u} = \frac{1}{3}(2a - b) = 0.130\,, \tag{11}$$

which will later be used extensively as an experimental constraint.

After combining the constraints, i.e., Eqs. (7, 8, 11), we can set down the relation between a and b, as well as the boundary, as

$$b = 2a - 0.39, \quad a \in (0.195, 0.390)\,, \tag{12}$$

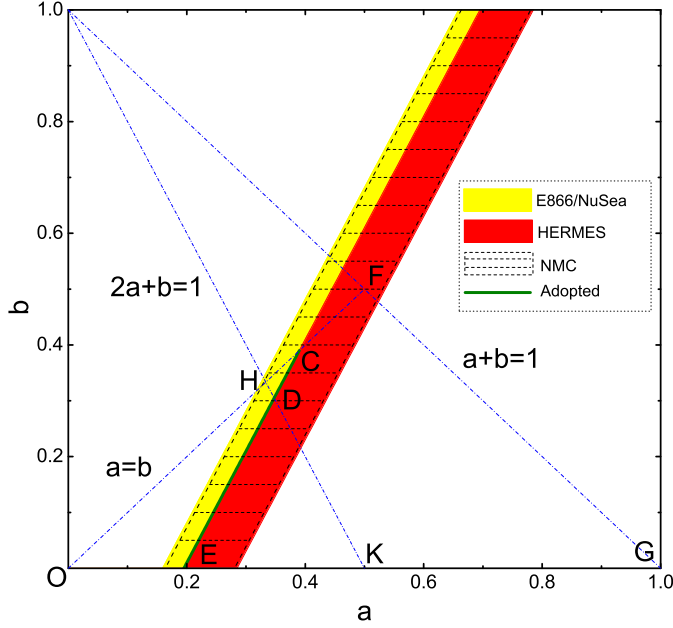which is shown in Fig. 1 as the segment $\overline{\text{CE}}$.

Fig. 1. Determinations of parameters a and b in the meson cloud model. The dash–dotted lines limit a and b to the bottom triangle according to Eqs. (7,8,13): $\triangle$OFG for nucleons, Λ, Ξ, and $\triangle$OHK for Σ. The shaded area, light colored area, and dark colored area are results from NMC [1,2], E866/NuSea [4,5,6], and HERMES [7], respectively. The heavy line represents the scope of parameters we ultimately adopt in our calculations: the segment $\overline{\text{CE}}$ for nucleons, Λ, Ξ, and the segment $\overline{\text{DE}}$ for Σ.

Further, within the same framework, we also explicitly write down the wave-functions for Λ^0, Σ^0, Σ^+, and Ξ^0 ,

$$|\Lambda^0\rangle \rightarrow \sqrt{1-a-b}\,|\Lambda_0^0\rangle + \sqrt{a}\,\left(\sqrt{\frac{1}{3}}|\Sigma_0^+\pi^-\rangle - \sqrt{\frac{1}{3}}|\Sigma_0^0\pi^0\rangle + \sqrt{\frac{1}{3}}|\Sigma_0^-\pi^+\rangle\right)$$
$$+ \sqrt{b}\,\left(\sqrt{\frac{1}{3}}|\Sigma_0^{*+}\pi^-\rangle - \sqrt{\frac{1}{3}}|\Sigma_0^{*0}\pi^0\rangle + \sqrt{\frac{1}{3}}|\Sigma_0^{*-}\pi^+\rangle\right) ,$$

$$|\Sigma^0\rangle \rightarrow \sqrt{1-2a-b}\,|\Sigma_0^0\rangle + \sqrt{a}\,\left(\sqrt{\frac{1}{2}}|\Sigma_0^+\pi^-\rangle - \sqrt{\frac{1}{2}}|\Sigma_0^-\pi^+\rangle\right) + \sqrt{a}\,|\Lambda_0^0\pi^0\rangle$$
$$+ \sqrt{b}\,\left(\sqrt{\frac{1}{2}}|\Sigma_0^{*+}\pi^-\rangle - \sqrt{\frac{1}{2}}|\Sigma_0^{*-}\pi^+\rangle\right) ,$$

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Table 3

Numerical results of sea contents of octet baryons in the meson cloud model.

Hadron	$\bar{u}$	$\bar{d}$	$\bar{d} - \bar{u}$
p	$(0.033, 0.325)$	$(0.163, 0.455)$	0.130
Λ^0	$(0.098, 0.390)$	$(0.098, 0.390)$	0.000
Σ^0	$(0.195, 0.501)$	$(0.195, 0.501)$	0.000
Σ^+	$(0.049, 0.164)$	$(0.341, 0.839)$	$(0.293, 0.675)$
Ξ^0	$(0.033, 0.130)$	$(0.163, 0.650)$	$(0.130, 0.520)$

$$|\Sigma^+\rangle \rightarrow \sqrt{1 - 2a - b}\,|\Sigma_0^+\rangle + \sqrt{a}\,\left(\sqrt{\frac{1}{2}}|\Sigma_0^+\pi^0\rangle - \sqrt{\frac{1}{2}}|\Sigma_0^0\pi^+\rangle\right) + \sqrt{a}\,|\Lambda_0^0\pi^+\rangle$$

$$+ \sqrt{b}\,\left(\sqrt{\frac{1}{2}}|\Sigma_0^{*+}\pi^0\rangle - \sqrt{\frac{1}{2}}|\Sigma_0^{*0}\pi^+\rangle\right),$$

$$|\Xi^0\rangle \rightarrow \sqrt{1 - a - b}\,|\Xi_0^0\rangle + \sqrt{a}\,\left(-\sqrt{\frac{1}{3}}|\Xi_0^0\pi^0\rangle + \sqrt{\frac{2}{3}}|\Xi_0^-\pi^+\rangle\right)$$

$$+ \sqrt{b}\,\left(-\sqrt{\frac{1}{3}}|\Xi_0^{*0}\pi^0\rangle + \sqrt{\frac{2}{3}}|\Xi_0^{*-}\pi^+\rangle\right).$$

Through the same procedure, we derive the $\bar{d}$ and $\bar{u}$ contents inside the above baryons. The expressions of these results in terms of a and b are listed in Table 2.

One should caution that a new constraint,

$$a > 0, \quad b > 0, \quad 2a + b < 1 \tag{13}$$

should replace Eq. (7) for Σ. Thereafter, the former constraint, the segment $\overline{CE}$ in Fig. 1, is replaced by the segment $\overline{DE}$ for Σ. Equivalently, Eq. (12) changes into

$$b = 2a - 0.39, \quad a \in (0.195, 0.348). \tag{14}$$

From Table 2 and the corresponding constraints, Eq. (12) for nucleons, Λ, Ξ, and Eq. (14) for Σ, we finally arrive at numerical results for the $\bar{d}$ and $\bar{u}$ sea quarks, as shown in Table 3.

Table 4
Sea contents of octet baryons in the chiral quark model.

Hadron	$\bar{u}$	$\bar{d}$	$\bar{d} - \bar{u}$
p	$7/6w = 0.228$	$11/6w = 0.358$	$2/3w = 0.130$
Λ^0	$w = 0.195$	$w = 0.195$	0.000
Σ^0	$w = 0.195$	$w = 0.195$	0.000
Σ^+	$1/3w = 0.065$	$5/3w = 0.325$	$4/3w = 0.260$
Ξ^0	$1/6w = 0.033$	$5/6w = 0.163$	$2/3w = 0.130$

4 The chiral quark model

In the chiral quark model, the mesons are emitted by valence quarks [37,38,39,40,41,42,43,44] instead of baryons in the meson cloud model. The u and d flavors of hadrons can be read as

$$|u\rangle \rightarrow \sqrt{1-w}\,|u_0\rangle + \sqrt{w}\,\left(-\sqrt{\frac{1}{3}}|u_0\pi^0\rangle + \sqrt{\frac{2}{3}}|d_0\pi^+\rangle\right),$$

$$|d\rangle \rightarrow \sqrt{1-w}\,|d_0\rangle + \sqrt{w}\,\left(-\sqrt{\frac{2}{3}}|u_0\pi^-\rangle + \sqrt{\frac{1}{3}}|d_0\pi^0\rangle\right),$$

where w is a weight factor indicating the probability of emitting pions. At a first approximation, the strange quarks are assumed to be highly suppressed (i.e., no emissions) because of their heavier mass. The above expressions are equivalent to

$$u \rightarrow \left(1 + \frac{w}{6}\right)u + \frac{5w}{6}d + \frac{w}{6}\bar{u} + \frac{5w}{6}\bar{d}, \tag{15}$$

$$d \rightarrow \left(1 + \frac{w}{6}\right)d + \frac{5w}{6}u + \frac{w}{6}\bar{d} + \frac{5w}{6}\bar{u}. \tag{16}$$

For the proton $|uud\rangle$, we have

$$\bar{d} - \bar{u} = \frac{11}{6}w - \frac{7}{6}w = \frac{2}{3}w. \tag{17}$$

Again, we adopt the experimental constraint of $\bar{d} - \bar{u} = 0.130$, as discussed previously, thereby making $w = 0.195$. The analytical results together with the numerical results for octet baryons are listed in Table 4.

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5   Discussion

In order to get a physical understanding of hadron structure, and to explain experimental data, people have suggested many phenomenological models for hadrons in terms of quark-gluon degrees of freedom and meson-baryon degrees of freedom. Here we considered three candidate models in their simple versions, and accomplished an extensive study of the sea contents for octet baryons. The results are listed in Tables 1, 2, 3, and 4.

The meson cloud model of simple version only presents wide ranges for its parameters, due to our simple consideration of obvious constraints. However, to compare between models more conveniently, we introduce another commonly used relation between parameters a and b [13],

$$a = 2b\,. \tag{18}$$

Using this relation, together with Eq. (11), we can determine a and b straightly, as

$$a = 0.26\,, \quad b = 0.13\,. \tag{19}$$

The results for this special case are listed in Table 2 within the brackets. Therefore, the fluctuations of octet baryons into meson-baryon states contribute $a + b \sim 39\%$ for nucleons, Λ, Ξ, and $2a + b \sim 65\%$ for Σ, which are rather significant.

The predicted results of the three models, together with the above typical case, are illustrated in Fig. 2. The horizontal axis is the integrated number of $\bar{d}$ and $\bar{u}$ contents. The dark marks and lines stand for the $\bar{d}$ quarks, while the light marks and lines represent the $\bar{u}$ quarks. The horizontal lines stand for the ranges predicted by the meson cloud model. The squares, crosses, and circles are predictions of the balance model, a typical case of meson cloud model with $a = 2b$, and the chiral quark model, respectively.

In Fig. 2, we see many differences among the models. The balance model, for most of the time, gives the maximum sea contents for the $\bar{d}$ and $\bar{u}$ quarks, especially for $\bar{d}$ inside the proton, Λ^0, Ξ^0, and $\bar{u}$ inside the proton, Λ^0, Σ^0, Ξ^0. As for Σ^+ and Ξ^0, the balance model presents a remarkably large $\bar{u}$ sea, compared to other models. Also worthy of mentioning, the balance model can predict gluons as well, as shown in Table 1. If we just consider the $a = 2b$ case to stand for the meson cloud model, it is found that with the number of strange quarks increasing, the sea contents predicted from the meson cloud model become larger related to the chiral quark model, albeit always smaller than the balance model. For Λ^0 and Σ^0, three models all give a symmetric sea, and no $\bar{d}$ and $\bar{u}$ asymmetry is predicted; this can be used to experimentally
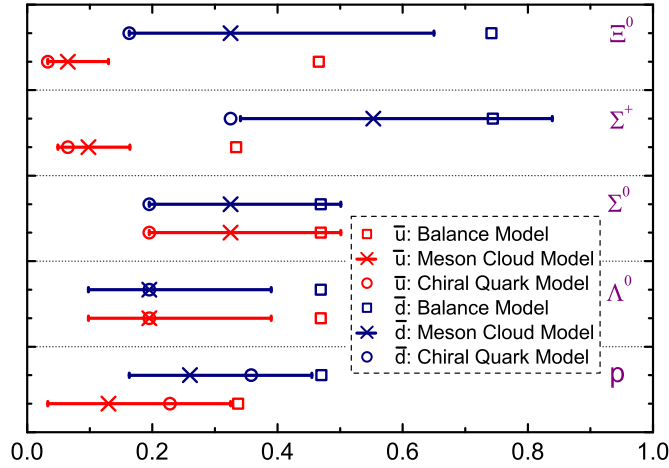
Fig. 2. Sea contents predicted by three models for five baryons. The horizontal axis is the integrated number of the $\bar{d}$ and $\bar{u}$ contents. The dark marks and lines stand for the $\bar{d}$ quarks, while the light marks and lines represent the $\bar{u}$ quarks. The horizontal lines stand for the ranges predicted by the meson cloud model. The squares, crosses, and circles are predictions for the balance model, a typical case of meson cloud model with $a = 2b$, and the chiral quark model, respectively.

test the robustness of all three models. Very tiny $\bar{u}$ sea quarks are predicted for Σ^+ and Ξ^0, except by the balance model; thus, this also provides a window to discriminate models from each other.

6 Summary

Flavor structure, in terms of quark-gluon degrees of freedom or meson-baryon degrees of freedom, is of great interest among the hadronic society, mainly due to the nontrivial and complicated contents of sea quarks, e.g., $d\bar{d}$ and $u\bar{u}$ asymmetry, originating from multi-connected, non-perturbative quantum chromodynamics (QCD). Because there calculations still remain difficult when the perturbative assumption falls down, many phenomenological models are raised to account for the experimental results. However, their predictive powers appear successful at some places while not so satisfactory at other places; hence, it is hard to decide which one is better at describing the flavor content of hadrons.

As suggested, new domains of Λ physics and Σ physics could provide plentiful opportunities to discriminate models from each other and to search for the

more profound nature of hadronic physics. While nucleons have been studied extensively both experimentally and theoretically, other hadrons still need more investigation.

In this Letter, we present an extensive study on the sea contents of octet baryons based on the balance model, meson cloud model, and chiral quark model. Numerical results are given explicitly, and these results can be used to distinguish models from each other once relevant experiments become available. The difference between models is significant; hence, new experiments aimed at determining the sea content of other members of octet baryons can open windows to test different scenarios of the sea content of baryons.

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