Principle of balance and the sea content of the proton

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In this study, the proton is taken as an ensemble of quark-gluon Fock states. Using the principle of balance that every Fock state should be balanced with all of the nearby Fock states (denoted as the balance model), instead of the principle of detailed balance that any two nearby Fock states should be balanced with each other (denoted as the detailed balance model), the probabilities of finding every Fock state of the proton are obtained. The balance model can be taken as a revised version of the detailed balance model, which can give an excellent description of the light flavor sea asymmetry (i.e., $\bar{u} \neq \bar{d}$) without any parameter. In the case when $g \Leftrightarrow gg$ subprocesses are not considered, the balance model and the detailed balance model give the same results. In the case when $g \Leftrightarrow gg$ subprocesses are considered, there is about a 10 percent difference between the results of these models. We also calculate the strange content of the proton using the balance model under the equal probability assumption.

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I. INTRODUCTION

One of the goals of hadronic physics is to describe the hadrons in terms of their fundamental quark and gluon degrees of freedom from basic principles. The structure of hadrons has been found to be rather complicated due to the nonperturbative and relativistic nature of the quark and gluon motions inside the hadrons. The sea of hadrons plays a particular role as a source for the complication. There have been many surprising discoveries concerning the structure of the nucleon, and the sea content of the nucleon has been found to be rather more plentiful than naturally expected. For example, it was generally assumed that there should be a symmetry between the light flavor u and d sea quarks inside the proton. However, a surprisingly large asymmetry between the $\bar{u}$ and $\bar{d}$ quark distributions of the proton has been observed from experiments of both deep inelastic scattering and Drell-Yan processes [1–6]. The strange content of the proton sea is also found to be nontrivial in the spin contribution [7] as well as in the quark-antiquark content [8].

Many theoretical attempts have been made to understand the sea flavor asymmetry [1], and it is believed that the mesons inside the nucleon can account for such asymmetry. Recently, there has been a new attempt to understand the sea flavor asymmetry of the proton from a pure statistical consideration in a detailed balance model [9,10]. The idea is rather simple and perspicuous: while the sea quark-antiquark $u\bar{u}$ and $d\bar{d}$ pairs can be produced by gluon splitting with equal probabilities, the reverse processes of the annihilation of the antiquarks with their quark partners into gluons are not flavor symmetric due to the net excess of u quarks over d quarks. As a consequence, the $\bar{u}$ quarks have large probability to annihilate with the u quarks than that of the $\bar{d}$ quarks, and this brings an excess of $\bar{d}$ over $\bar{u}$ inside the proton. Taking the proton as an ensemble of a complete set of quark-gluon Fock states, and using the principle of detailed balance that any two nearby Fock states should be balanced with each other, one can obtain the probabilities of finding every Fock state of the proton. Thus one can calculate the quark and gluon content of the nucleon without any parameter from a pure statistical consideration. It is interesting that the model gives a sea flavor $\bar{u}$ and $\bar{d}$ asymmetry as $\bar{d}-\bar{u} \sim 0.124$, which agrees surprisingly with the experimental data $\bar{d}-\bar{u}=0.118\pm0.012$. A further numerical calculation [11] also reproduced the explicit x dependence of $\bar{d}(x) - \bar{u}(x)$, in good agreement with the experimental data.

The purpose of this paper is to reexamine the detailed balance model with more careful and general considerations. It will be shown that the requirement of detailed balance, that any two nearby Fock states should be balanced with each other, is an overstrong constraint. It leads to inconsistency in cases if more channels of subprocesses are introduced, as will be shown explicitly. We are thus forced to start from a more general consideration which only requires that every

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Fock state should be balanced with all of the nearby Fock states, and then we construct the balance model as a revised version of the detailed balance model. It will be shown that in the case of $g\Leftrightarrow gg$ subprocesses not considered, the balance model and the detailed balance model give the same results. In the case of $g\Leftrightarrow gg$ subprocesses considered, there is a difference of about 10% between the results of the two models. We also calculate the strange content of the proton using the balance model under the equal probability assumption.

II. GENERAL PRINCIPLE OF BALANCE INSTEAD OF DETAILED BALANCE

In the detailed balance model [9,10], the proton state is expended by a complete set of quark-gluon Fock states as

$$|p\rangle=\sum_{i,j,k} c_{i,j,k}|uud,i,j,k\rangle, \tag{1}$$

where i is the number of quark-antiquark $u\bar{u}$ pairs, j is the number of quark-antiquark $d\bar{d}$ pairs, and k is the number of gluons. Then the probability of finding the proton in the Fock state $|uud,i,j,k\rangle$ is

$$\rho_{i,j,k}=|c_{i,j,k}|^2, \tag{2}$$

where $\rho_{i,j,k}$ satisfies the normalization condition,

$$\sum_{i,j,k} \rho_{i,j,k}=1. \tag{3}$$

Then using the detailed balance principle, and with subprocesses $q\Leftrightarrow qg$ and $g\Leftrightarrow q\bar{q}$ considered, one can calculate all $\rho_{i,j,k}$ explicitly [9,10]. The detailed balance principle means that any two nearby quark-gluon Fock states should balance with each other. However, when the detailed balance principle is used in the case with the subprocesses $g\Leftrightarrow gg$ also considered, there is an inconsistency which is not easy to notice. For example, there are two ways to calculate $\rho_{uud\bar{u}ug}/\rho_{uudg}$. One way is

$$|uudg\rangle \underset{2\times 3+1}{\overset{3+1}{\rightleftharpoons}} |uudgg\rangle \underset{1\times 3}{\overset{2}{\rightleftharpoons}} |uud\bar{u}ug\rangle, \tag{4}$$

which leads to

$$\rho_{uudgg}=\frac{4}{7}\rho_{uudg}, \quad \rho_{uud\bar{u}ug}=\frac{2}{3}\rho_{uudgg}, \quad \frac{\rho_{uud\bar{u}ug}}{\rho_{uudg}}=\frac{8}{21}. \tag{5}$$

Another way is

$$|uudg\rangle \underset{1\times 3}{\overset{1}{\rightleftharpoons}} |uud\bar{u}u\rangle \underset{1\times 5}{\overset{5}{\rightleftharpoons}} |uud\bar{u}ug\rangle, \tag{6}$$

which leads to

$$\rho_{uud\bar{u}u}=\frac{1}{3}\rho_{uudg}, \quad \rho_{uud\bar{u}ug}=\rho_{uudgg}, \quad \frac{\rho_{uud\bar{u}ug}}{\rho_{uudg}}=\frac{1}{3}. \tag{7}$$

One way gives the result $\frac{8}{21}$, while another way gives the result $\frac{1}{3}$. This inconsistency forces us to adopt a more general principle, named the balance principle, instead of the detailed balance principle.

The basic property of the ensemble assumption of the proton is that the probability of finding the proton in any Fock state should not change during the time. Both the detailed balance principle and balance principle can give this property of ensemble assumption.

The detailed balance demands that any two nearby Fock states A and B balance with each other [10],

$$\rho_A R_{A\rightarrow B}=\rho_B R_{B\rightarrow A}, \tag{8}$$

where ρ_A is the probability of finding the proton in state of A, ρ_B is the probability of finding the proton in state B, $R_{A\rightarrow B}$ is the transition probability of A to B, and $R_{B\rightarrow A}$ is the transition probability of B to A.

The balance principle demands that the "go out" probability just balances the "come in" probability for any Fock state. For a Fock state A, the go out probability is

$$\sum_B \rho_A R_{A\rightarrow B}, \tag{9}$$

where B is a completed set of all nearby Fock states other than A, while the come in probability is

$$\sum_B \rho_B R_{B\rightarrow A}. \tag{10}$$

So the balance principle can be written as

$$\sum_B \rho_A R_{A\rightarrow B}=\sum_B \rho_B R_{B\rightarrow A}. \tag{11}$$

From formulas (8) and (11), it is easy to find that the detailed balance principle (8) gives a stronger constraint than the balance principle (11). That is why the detailed balance principle leads to the inconsistency discussed above while the balance principle does not. Similarly to the detailed balance principle, the balance principle can also determine all $\rho_{i,j,k}$, but the situation becomes a little more complicated and solving an equation set with a large number of equations is needed.

III. THE BALANCE MODEL WITH NO $g\Leftrightarrow gg$ SUBPROCESSES CONSIDERED

In this section we only consider the transition processes involving the subprocesses $q\Leftrightarrow qg$ and $g\Leftrightarrow q\bar{q}$, with the subprocesses $g\Leftrightarrow gg$ not considered at first. When applying the balance principle to Fock state $|uud\rangle$, we have the go out process as

$$|uud\rangle \overset{3}{\Rightarrow} |uudg\rangle, \tag{12}$$

and the "come in" process as

$$|uud\rangle \overset{3}{\Leftarrow} |uudg\rangle. \tag{13}$$

According to formula (11), we have the equation

$$3\rho_{uud} = 3\rho_{uudg}. \tag{14}$$

When using the balance principle to the Fock state $|uudg\rangle$, we have the go out processes as

$$|uudg\rangle \overset{3\times 1}{\Rightarrow} |uud\rangle, \tag{15}$$

$$|uudg\rangle \overset{3}{\Rightarrow} |uudgg\rangle, \tag{16}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uud\bar{u}u\rangle, \tag{17}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uud\bar{d}d\rangle, \tag{18}$$

and the come in processes as

$$|uudg\rangle \overset{3}{\Leftarrow} |uud\rangle, \tag{19}$$

$$|uudg\rangle \overset{3\times 2}{\Leftarrow} |uudgg\rangle, \tag{20}$$

$$|uudg\rangle \overset{1\times 3}{\Leftarrow} |uud\bar{u}u\rangle, \tag{21}$$

$$|uudg\rangle \overset{1\times 2}{\Leftarrow} |uud\bar{d}d\rangle. \tag{22}$$

From formula (11), we have the equation

$$(3\times 1+3+1+1)\rho_{uudg} = 3\rho_{uud} + (3\times 2)\rho_{uudgg} + (1\times 3) \times \rho_{uud\bar{u}u} + (1\times 2)\rho_{uud\bar{d}d}. \tag{23}$$

When using the balance principle to a general Fock state $|uud,i,j,k\rangle$, we have the go out processes as

$$|uud,i,j,k\rangle \overset{(3+2i+2j)k}{\Rightarrow} |uud,i,j,k-1\rangle, \tag{24}$$

$$|uud,i,j,k\rangle \overset{3+2i+2j}{\Rightarrow} |uud,i,j,k+1\rangle, \tag{25}$$

$$|uud,i,j,k\rangle \overset{k}{\Rightarrow} |uud,i+1,j,k-1\rangle, \tag{26}$$

$$|uud,i,j,k\rangle \overset{i(i+2)}{\Rightarrow} |uud,i-1,j,k+1\rangle, \tag{27}$$

$$|uud,i,j,k\rangle \overset{k}{\Rightarrow} |uud,i,j+1,k-1\rangle, \tag{28}$$

$$|uud,i,j,k\rangle \overset{j(j+1)}{\Rightarrow} |uud,i,j-1,k+1\rangle, \tag{29}$$

and the come in processes as

$$|uud,i,j,k\rangle \overset{3+2i+2j}{\Leftarrow} |uud,i,j,k-1\rangle, \tag{30}$$

$$|uud,i,j,k\rangle \overset{(3+2i+2j)(k+1)}{\Leftarrow} |uud,i,j,k+1\rangle, \tag{31}$$

$$|uud,i,j,k\rangle \overset{(i+1)(i+3)}{\Leftarrow} |uud,i+1,j,k-1\rangle, \tag{32}$$

$$|uud,i,j,k\rangle \overset{k+1}{\Leftarrow} |uud,i-1,j,k+1\rangle, \tag{33}$$

$$|uud,i,j,k\rangle \overset{(j+1)(j+2)}{\Leftarrow} |uud,i,j+1,k-1\rangle, \tag{34}$$

$$|uud,i,j,k\rangle \overset{k+1}{\Leftarrow} |uud,i,j-1,k+1\rangle. \tag{35}$$

Then from formula (11), we have the equation

$$\begin{aligned}[(3+2i+2j)k+(3+2i+2j)+k+i(i+2) \\ +k+j(j+1)]\rho_{i,j,k} \\ =(3+2i+2j)\rho_{i,j,k-1} \\ +(3+2i+2j)(k+1)\rho_{i,j,k+1} \\ +(i+1)(i+3)\rho_{i+1,j,k-1}+(k \\ +1)\rho_{i-1,j,k+1} \\ +(j+1)(j+2)\rho_{i,j+1,k-1}+(k \\ +1)\rho_{i,j-1,k+1}.\end{aligned} \tag{36}$$

When one applies Eq. (36) to a certain Fock state, he should make sure that the corresponding Fock states in processes (24)–(35) exist, otherwise he should delete the corresponding terms. For example, when one applies Eq. (36) to the Fock state $|uud\rangle$, only one corresponding Fock state in processes (24)–(35) exists, i.e., it is $|uudg\rangle$. So Eq. (36) leads to Eq. (14).

For every Fock state $|uud,i,j,k\rangle$, there is an equation according to formula (36). If we can construct an equation set using these equations, then $\rho_{i,j,k}$ can be solved. However, there is an infinite number of Fock states that lead to an infinite number of equations. We must choose the upper limits of i, j, and k to select a finite number of Fock states. Then by increasing the upper limits, we can approach the values for $\rho_{i,j,k}$ because $\rho_{i,j,k}$ decreases quickly in a manner somewhat like $1/i!j!k!$ as i, j, and k increasing. When choosing the upper limits of i to N_i, j to N_j, and k to N_k, we get

$$|p\rangle = \sum_{k=0}^{N_k}\sum_{j=0}^{N_j}\sum_{i=0}^{N_i} c_{i,j,k}|uud,i,j,k\rangle. \tag{37}$$

There are $N=(N_i+1)(N_j+1)(N_k+1)$ Fock states selected. So there are N numbers of $\rho_{i,j,k}$ to be solved. There are N equations when using formula (36) to these N Fock states. However, these N equations are not independent. In order to show this fact, we write the formula (11) in the new form by including these upper limits as

$$\sum_{m'=1}^{N} \rho_{A_m}R_{A_m\to A_{m'}} = \sum_{m'=1}^{N} \rho_{A_{m'}}R_{A_{m'}\to A_m}, \tag{38}$$

where A_m and $A_{m'}$ are any two Fock states of those N Fock states selected by formula (37) and we let $R_{A_m\to A_m}=0$ which does not give any physical effect but is convenient for mathematical calculations. There are N such equations as formula (38) for N selected Fock states. Summing over all these equations, we get

$$\sum_{m=1}^{N}\sum_{m'=1}^{N} \rho_{A_m}R_{A_m\to A_{m'}} = \sum_{m=1}^{N}\sum_{m'=1}^{N} \rho_{A_{m'}}R_{A_{m'}\to A_m}. \tag{39}$$

On the other side, from the pure mathematical point, we have the relation of

$$\begin{aligned}\sum_{m=1}^{N}\sum_{m'=1}^{N} \rho_{A_m}R_{A_m\to A_{m'}} &\overset{\text{exchange } m \text{ and } m'}{\equiv} \sum_{m'=1}^{N}\sum_{m=1}^{N} \rho_{A_{m'}}R_{A_{m'}\to A_m}\\ &= \sum_{m=1}^{N}\sum_{m'=1}^{N} \rho_{A_{m'}}R_{A_{m'}\to A_m},\end{aligned} \tag{40}$$

which is the same form as relation (39). So the relation (39) does not depend on the existence of Eq. (38) and it is always right in mathematics. It means that the relation (39) is a constraint of these N equations so that there are only $N-1$ independent equations left. With the normalization condition (3) included, there are just N equations to construct a complete equation set for N variables ($\rho_{i,j,k}$). Thus this equation set can be solved.

By solving this equation set numerically, we find that the balance model and detailed balance model give the same results in case of subprocesses $g\Leftrightarrow gg$ not considered. From a strict sense, by substituting the solution of the detailed balanced model, i.e., Eq. (26) of Ref. [9],

$$\rho_{i,j,k} = \frac{2}{i!(i+2)!j!(j+1)!k!}\rho_{0,0,0}, \tag{41}$$

for the corresponding terms in Eq. (36), we find that Eq. (36) is exactly satisfied. This proves that the balanced model has the exact solution as that of the detailed balance model.

IV. THE BALANCE MODEL WITH $g\Leftrightarrow gg$ SUBPROCESSES CONSIDERED

In this section the processes involving subprocesses $g\Leftrightarrow gg$ are also considered. When using the balance principle to Fock state $|uud\rangle$, we have the go out process as

$$|uud\rangle \overset{3}{\Rightarrow} |uudg\rangle, \tag{42}$$

and the come in process as

$$|uud\rangle \overset{3}{\Leftarrow} |uudg\rangle. \tag{43}$$

According to formula (11), we have the equation

$$3\rho_{uud} = 3\rho_{uudg}. \tag{44}$$

When using the balance principle to the Fock state $|uudg\rangle$, we have the go out processes as

$$|uudg\rangle \overset{3\times 1}{\Rightarrow} |uud\rangle, \tag{45}$$

$$|uudg\rangle \overset{3+1}{\Rightarrow} |uudgg\rangle, \tag{46}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uud u\bar{u}\rangle, \tag{47}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uud d\bar{d}\rangle, \tag{48}$$

and the come in processes as

$$|uudg\rangle \overset{3}{\Leftarrow} |uud\rangle, \tag{49}$$

$$|uudg\rangle \overset{3\times 2+1}{\Leftarrow} |uudgg\rangle, \tag{50}$$

$$|uudg\rangle \overset{1\times 3}{\Leftarrow} |uud u\bar{u}\rangle, \tag{51}$$

$$|uudg\rangle \overset{1\times 2}{\Leftarrow} |uud d\bar{d}\rangle. \tag{52}$$

From the Eq. (11), we have the equation

$$\begin{aligned}[3\times 1+(3+1)+1+1]\rho_{uudg} = 3\rho_{uud} &+ (3\times 2+1)\rho_{uudgg}\\ &+(1\times 3)\rho_{uudu\bar{u}}\\ &+(1\times 2)\rho_{uudd\bar{d}}.\end{aligned}$$

When using the balance principle to a general Fock state $|uud,i,j,k\rangle$, we have the go out processes as

TABLE I. The probabilities $\rho_{i,j,k}$ of finding the quark-gluon Fock states of the proton, calculated using the principle of balance without any parameter. $|uud,i,j,k\rangle$ is the Fock state of proton, i is the number of $u\bar{u}$ quark pairs, j is the number of $d\bar{d}$ pairs, and k is the number of gluons.

i	j	$\|uud,i,j,0\rangle$	$\rho_{i,j,0}$	$\rho_{i,j,1}$	$\rho_{i,j,2}$	$\rho_{i,j,3}$	$\rho_{i,j,4}$	$\cdots$
0	0	$\|uud\rangle$	0.148793	0.148793	0.081887	0.032056	0.009876	$\cdots$
1	0	$\|uud\bar{u}u\rangle$	0.052960	0.054978	0.030419	0.011787	0.003564	$\cdots$
0	1	$\|uud\bar{d}d\rangle$	0.080334	0.082708	0.045441	0.017500	0.005263	$\cdots$
1	1	$\|uud\bar{u}u\bar{d}d\rangle$	0.029306	0.030569	0.016763	0.006386	0.001889	$\cdots$
0	2	$\|uud\bar{d}d\bar{d}d\rangle$	0.014570	0.015242	0.008381	0.003201	0.000949	$\cdots$
2	0	$\|uud\bar{u}u\bar{u}u\rangle$	0.007231	0.007642	0.004240	0.001632	0.000488	$\cdots$
1	2	$\|uud\bar{u}u\bar{d}d\bar{d}d\rangle$	0.005355	0.005620	0.003073	0.001160	0.000339	$\cdots$
2	1	$\|uud\bar{u}u\bar{u}u\bar{d}d\rangle$	0.004011	0.004223	0.002315	0.000877	0.000257	$\cdots$
0	3	$\|uud\bar{d}d\bar{d}d\bar{d}d\rangle$	0.001327	0.001403	0.000773	0.000294	0.000086	$\cdots$
3	0	$\|uud\bar{u}u\bar{u}u\bar{u}u\rangle$	0.000531	0.000567	0.000315	0.000121	0.000036	$\cdots$
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\ddots$

$$|uud,i,j,k\rangle \overset{(3+2i+2j)k+C_k^2}{\Rightarrow} |uud,i,j,k-1\rangle, \tag{53}$$

$$|uud,i,j,k\rangle \overset{3+2i+2j+k}{\Rightarrow} |uud,i,j,k+1\rangle, \tag{54}$$

$$|uud,i,j,k\rangle \overset{k}{\Rightarrow} |uud,i+1,j,k-1\rangle, \tag{55}$$

$$|uud,i,j,k\rangle \overset{i(i+2)}{\Rightarrow} |uud,i-1,j,k+1\rangle, \tag{56}$$

$$|uud,i,j,k\rangle \overset{k}{\Rightarrow} |uud,i,j+1,k-1\rangle, \tag{57}$$

$$|uud,i,j,k\rangle \overset{j(j+1)}{\Rightarrow} |uud,i,j-1,k+1\rangle, \tag{58}$$

and the come in processes as

$$|uud,i,j,k\rangle \overset{3+2i+2j+k-1}{\Leftarrow} |uud,i,j,k-1\rangle, \tag{59}$$

$$|uud,i,j,k\rangle \overset{(3+2i+2j)(k+1)+C_{k+1}^2}{\Leftarrow} |uud,i,j,k+1\rangle, \tag{60}$$

$$|uud,i,j,k\rangle \overset{(i+1)(i+3)}{\Leftarrow} |uud,i+1,j,k-1\rangle, \tag{61}$$

$$|uud,i,j,k\rangle \overset{k+1}{\Leftarrow} |uud,i-1,j,k+1\rangle, \tag{62}$$

$$|uud,i,j,k\rangle \overset{(j+1)(j+2)}{\Leftarrow} |uud,i,j+1,k-1\rangle, \tag{63}$$

$$|uud,i,j,k\rangle \overset{k+1}{\Leftarrow} |uud,i,j-1,k+1\rangle. \tag{64}$$

From formula (11), we have the equation

$$\begin{aligned}
&\{[(3+2i+2j)k+C_k^2]+(3+2i+2j+k)\\
&\quad +k+i(i+2)+k+j(j+1)\}\rho_{i,j,k}\\
&=(3+2i+2j+k-1)\rho_{i,j,k-1}+[(3+2i+2j)(k+1)\\
&\quad +C_{k+1}^2]\rho_{i,j,k+1}+(i+1)(i+3)\rho_{i+1,j,k-1}\\
&\quad +(k+1)\rho_{i-1,j,k+1}+(j+1)(j+2)\rho_{i,j+1,k-1}\\
&\quad +(k+1)\rho_{i,j-1,k+1},
\end{aligned} \tag{65}$$

where $C_k=k(k-1)/2$. An equation set for $\rho_{i,j,k}$ can be constructed by using the above equation after choosing the upper limits on i, j, and k. We can solve the equation set by increasing the upper limits to a situation where the results are not sensitive to the upper limits further. Thus $\rho_{i,j,k}$ can be obtained and the results are shown in Table I. Data of Table I show that the balance model give different results compared with that of the detailed balance model. From the data of Table I we have

$$\bar{u}=\sum_{i,j,k} i\rho_{i,j,k}=0.337, \tag{66}$$

$$\bar{d}=\sum_{i,j,k} j\rho_{i,j,k}=0.470, \tag{67}$$

$$g=\sum_{i,j,k} k\rho_{i,j,k}=1.099, \tag{68}$$

$$\bar{d}-\bar{u}=0.133. \tag{69}$$

We notice that $\bar{d}-\bar{u}=0.133$ for the light-flavor sea asymmetry in comparison with the result of detailed balance model $\bar{d}-\bar{u}=0.123$ [9], while the FNAL/NuSea experiment is $\bar{d}-\bar{u}=0.118\pm0.012$ [6]. The balance model is different from the detailed balance model by about 10%, but both are compatible with the experimental result.

V. STRANGE QUARK CONTENT AND GLUON ENERGY DISTRIBUTION

It has been known that the strange sea is nontrivial inside the proton, and a phenomenological analysis suggests that the number of $s\bar{s}$ pairs inside a proton is about 0.05 [8]. Here we extend the balance model to include the strange quark-antiquark pairs, and write the proton state as

$$|p\rangle = \sum_{i,j,k,l} c_{i,j,k,l} |uud,i,j,k,l\rangle, \tag{70}$$

where l is the number of quark-antiquark $s\bar{s}$ pairs. Then the probability of finding the proton in the Fock state $|uud,i,j,k,l\rangle$ is

$$\rho_{i,j,k,l} = |c_{i,j,k,l}|^2, \tag{71}$$

where $\rho_{i,j,k,l}$ satisfies the normalization condition,

$$\sum_{i,j,k,l} \rho_{i,j,k,l} = 1. \tag{72}$$

The $s\bar{s}$ pairs are generated from gluons by the subprocesses $g \Rightarrow s\bar{s}$. However, the mass of the strange quark M_s is big and should not be neglected as for the light-flavor quarks. So only those gluons with energy larger than two times of the strange quark mass, $\varepsilon_g > 2M_s$, can take part in the process of splitting into strange quark-antiquark pairs by the constraint of energy conservation. So we should know the gluon energy distribution before the calculation of the strange content of the proton.

An equal probability assumption is presented in paper [11], assuming that for a n-parton Fock state $|uud,i,j,k\rangle$, any parton's energy configuration $(E_1, \ldots, E_n)$ has the same probability to appear,

$$d\rho_n(p_1, \ldots, p_n) = \delta^4\left(P - \sum_{i=1}^{n} p_i\right) \prod_{i=1}^{n} \frac{dE_i d\Omega_i}{2(2\pi)^3}, \tag{73}$$

with P the 4-momentum of the proton, and $p_1, \ldots, p_n$ the 4-momenta of n partons. The formula (73) is equivalent to a series of constraints,

$$f^n(E_1, E_2, \ldots, E_n) \propto 1, \tag{74}$$

$$E_1^2 - p_{1x}^2 - p_{1y}^2 - p_{1z}^2 = 0, \tag{75}$$

$$E_2^2 - p_{2x}^2 - p_{2y}^2 - p_{2z}^2 = 0, \tag{76}$$

$$\cdots,$$

$$E_n^2 - p_{nx}^2 - p_{ny}^2 - p_{nz}^2 = 0, \tag{77}$$

$$f_{E_1}(p_{1x}^2, p_{1y}^2, p_{1z}^2) \propto 1, \tag{78}$$

$$f_{E_2}(p_{2x}^2, p_{2y}^2, p_{2z}^2) \propto 1, \tag{79}$$

$$\cdots,$$

$$f_{E_n}(p_{nx}^2, p_{ny}^2, p_{nz}^2) \propto 1, \tag{80}$$

$$p_{1x} + p_{2x} + \cdots + p_{nx} = 0, \tag{81}$$

$$p_{1y} + p_{2y} + \cdots + p_{ny} = 0, \tag{82}$$

$$p_{1z} + p_{2z} + \cdots + p_{nz} = 0, \tag{83}$$

$$E_1 + E_2 + \cdots + E_n = M_{\text{proton}} = 938 \text{ MeV}, \tag{84}$$

where Eq. (74) gives the principle of equal probability, Eqs. (75)–(77) mean that the partons are massless and on shell, Eqs. (78)–(80) mean that the distribution does not depend on the 3-momentum, and Eqs. (81)–(84) mean that the energy-momentum conservation constraint is satisfied and our calculation is in the rest frame of the proton.

If we are only concerned about the energy distribution, then from constraint (74) and (84), we may get it as

$$f^n(E_1, E_2, \ldots, E_n) = (n-1)!\,\delta\left(1 - \frac{E_1}{M_{\text{proton}}} - \frac{E_2}{M_{\text{proton}}} - \cdots - \frac{E_n}{M_{\text{proton}}}\right), \tag{85}$$

which satisfies the normalization condition.

Before we extend the formula (85) to include the strange quark, a new concept named free energy needs to be introduced to deal with the strange quark mass M_s. For an n-parton Fock state $|uud,i,j,k,l\rangle$ where $n = 3 + 2i + 2j + k + 2l$, the parton's free energy is presented as $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_n$. Here the parton's free energy denotes the energy of a parton that can be used to produce other partons, and it is defined as the total energy of one parton minus the mass of that parton, $\varepsilon = E - M$. For the partons as u, d, and g, they are almost massless so that we have

$$\varepsilon = E. \tag{86}$$

For the strange quark s, we have

$$\varepsilon = E - M_s. \tag{87}$$

Then the total free energy of the Fock state $|uud,i,j,k,l\rangle$ is

$$\xi_f = \sum_m \varepsilon_m = \sum_m E_m - 2lM_s = M_{\text{proton}} - 2lM_s, \tag{88}$$

where M_{proton} is the mass of the proton.

We define the dimensionless free energy as

$$y_1 = \frac{\varepsilon_1}{\xi_f}, \tag{89}$$

$$y_2 = \frac{\varepsilon_2}{\xi_f}, \tag{90}$$

$$\cdots$$

$$y_n = \frac{\varepsilon_n}{\xi_f}, \tag{91}$$

which lead to

$$\sum_m y_m = 1. \tag{92}$$

Replacing the variable of energy E by the variable of free energy ε, we rewrite the energy distribution formula (85) to a form as

$$f^n(y_1, y_2, \ldots, y_n) = (n-1)!\,\delta(1 - y_1 - y_2 - \cdots - y_n), \tag{93}$$

which can be used to deal with s quarks as well as u quarks, d quarks, and gluons.

Then for one parton in a n-parton Fock state, the free energy distribution is

$$\begin{aligned} f^n(y) &= \int_0^1 dy_1 \cdots \int_0^1 dy_{n-1} f^n(y, y_1, \ldots, y_{n-1}) \\ &= \int_0^1 dy_1 \cdots \int_0^1 dy_{n-1} (n-1)! \\ &\quad \times \delta(1 - y - y_1 - \cdots - y_{n-1}) \\ &= (n-1)(1-y)^{n-2}, \end{aligned} \tag{94}$$

which can be proved using the following completed derivation.

It is easy to see

$$\int_0^1 dy_1 \delta(1 - y - y_1) = 1, \tag{95}$$

$$\int_0^1 dy_1 \int_0^1 dy_2 2\,\delta(1 - y - y_1 - y_2) = \int_0^{1-y} dy_1 2 = 2(1-y), \tag{96}$$

if

$$\begin{aligned} &\int_0^1 dy_1 \cdots \int_0^1 dy_{n-1} (n-1)!\,\delta(1 - y - y_1 - \cdots - y_{n-1}) \\ &= (n-1)(1-y)^{n-2}, \end{aligned} \tag{97}$$

then

$$\int_0^1 dy_1 \cdots \int_0^1 dy_n n!\,\delta(1 - y - y_1 - \cdots - y_{n-1} - y_n) \tag{98}$$

$$= \int_0^{1-y} dy_n n(n-1)(1 - y - y_n)^{n-2} \tag{99}$$

$$= n(1-y)^{n-1}, \tag{100}$$

so formula (94) is proved.

Applying formula (94) to a gluon in an n-parton Fock state $|uud,i,j,k,l\rangle$, we get the gluon's free energy distribution

$$f_g^n(y) = (n-1)(1-y)^{n-2}. \tag{101}$$

Then we introduce a parameter

$$c_l = \frac{2M_s}{\xi_f} = \frac{2M_s}{M_{\text{proton}} - 2lM_s}. \tag{102}$$

Only those gluons satisfying $y > c_l$ have the energy $E > 2M_s$, so that they can split into $s\bar{s}$ pairs. Then for a gluon in an n-parton Fock state $|uud,i,j,k,l\rangle$, the probability that it can split to an $s\bar{s}$ pair is

$$\int_{c_l}^1 dy (n-1)(1-y)^{n-2} = (1 - c_l)^{n-1}. \tag{103}$$

Taking $(1 - c_l)^{n-1}$ as a suppressing factor of generating $s\bar{s}$ from a gluon, the content of strange quark of proton can be calculated by using the balance model.

A. Strange content with no $g \Leftrightarrow gg$ subprocesses considered

We first consider the strange quark content of the proton with the processes involving the $g \Leftrightarrow gg$ subprocesses not considered. When using the balance principle to Fock state $|uud\rangle$, we have the "go out" process as

$$|uud\rangle \overset{3}{\Rightarrow} |uudg\rangle, \tag{104}$$

and the come in process as

$$|uud\rangle \overset{3}{\Leftarrow} |uudg\rangle. \tag{105}$$

According to formula (11), we have the equation

$$3\rho_{uud} = 3\rho_{uudg}. \tag{106}$$

When using the balance principle to Fock state $|uudg\rangle$, we have the go out processes as

$$|uudg\rangle \overset{3\times 1}{\Rightarrow} |uud\rangle, \tag{107}$$

$$|uudg\rangle \overset{3}{\Rightarrow} |uudgg\rangle, \tag{108}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uudu\bar{u}\rangle, \tag{109}$$

$$|uudg\rangle \overset{1}{\Rightarrow} |uudd\bar{d}\rangle, \tag{110}$$

$$|uudg\rangle \overset{1\times(1-c_0)^3}{\Rightarrow} |uuds\bar{s}\rangle, \tag{111}$$

and the come in processes as

$$|uudg\rangle \overset{3}{\Leftarrow} |uud\rangle, \tag{112}$$

$$|uudg\rangle \overset{3\times 2}{\Leftarrow} |uudgg\rangle, \tag{113}$$

$$|uudg\rangle \overset{1\times 3}{\Leftarrow} |uud\bar{u}u\rangle, \tag{114}$$

$$|uudg\rangle \overset{1\times 2}{\Leftarrow} |uud\bar{d}d\rangle, \tag{115}$$

$$|uudg\rangle \overset{1\times 1}{\Leftarrow} |uud\bar{s}s\rangle. \tag{116}$$

Then we have the equation

$$\begin{aligned}[3\times 1+3+1+1+1\times(1-c_0)^3]\rho_{uudg} \\ =3\rho_{uud}+(3\times 2)\rho_{uudgg}+(1\times 3)\rho_{uud\bar{u}u} \\ +(1\times 2)\rho_{uud\bar{d}d}+(1\times 1)\rho_{uud\bar{s}s}.\end{aligned} \tag{117}$$

Applying the balance principle to a general Fock state $|uud,i,j,k,l\rangle$, we have the go out processes as

$$|uud,i,j,k,l\rangle \overset{(3+2i+2j+2l)k}{\Rightarrow} |uud,i,j,k-1,l\rangle, \tag{118}$$

$$|uud,i,j,k,l\rangle \overset{3+2i+2j+2l}{\Rightarrow} |uud,i,j,k+1,l\rangle, \tag{119}$$

$$|uud,i,j,k,l\rangle \overset{k}{\Rightarrow} |uud,i+1,j,k-1,l\rangle, \tag{120}$$

$$|uud,i,j,k,l\rangle \overset{i(i+2)}{\Rightarrow} |uud,i-1,j,k+1,l\rangle, \tag{121}$$

$$|uud,i,j,k,l\rangle \overset{k}{\Rightarrow} |uud,i,j+1,k-1,l\rangle, \tag{122}$$

$$|uud,i,j,k,l\rangle \overset{j(j+1)}{\Rightarrow} |uud,i,j-1,k+1,l\rangle, \tag{123}$$

$$|uud,i,j,k,l\rangle \overset{k(1-c_l)^{n-1}}{\Rightarrow} |uud,i,j,k-1,l+1\rangle, \tag{124}$$

$$|uud,i,j,k,l\rangle \overset{l^2}{\Rightarrow} |uud,i,j,k+1,l-1\rangle, \tag{125}$$

and the come in processes as

$$|uud,i,j,k,l\rangle \overset{3+2i+2j+2l}{\Leftarrow} |uud,i,j,k-1,l\rangle, \tag{126}$$

$$|uud,i,j,k,l\rangle \overset{(3+2i+2j+2l)(k+1)}{\Leftarrow} |uud,i,j,k+1,l\rangle, \tag{127}$$

$$|uud,i,j,k,l\rangle \overset{(i+1)(i+3)}{\Leftarrow} |uud,i+1,j,k-1,l\rangle, \tag{128}$$

$$|uud,i,j,k,l\rangle \overset{k+1}{\Leftarrow} |uud,i-1,j,k+1,l\rangle, \tag{129}$$

$$|uud,i,j,k,l\rangle \overset{(j+1)(j+2)}{\Leftarrow} |uud,i,j+1,k-1,l\rangle, \tag{130}$$

$$|uud,i,j,k,l\rangle \overset{k+1}{\Leftarrow} |uud,i,j-1,k+1,l\rangle, \tag{131}$$

$$|uud,i,j,k,l\rangle \overset{(l+1)(l+1)}{\Leftarrow} |uud,i,j,k-1,l+1\rangle, \tag{132}$$

$$|uud,i,j,k,l\rangle \overset{(k+1)(1-c_{l-1})^{n-2}}{\Leftarrow} |uud,i,j,k+1,l-1\rangle. \tag{133}$$

From formula (11), we have the equation

$$\begin{aligned}\{[(3+2i+2j+2l)k]+(3+2i+2j+2l)+k+i(i+2) \\ +k+j(j+1)+k(1-c_l)^{n-1}+l^2\}\rho_{i,j,k,l} \\ =(3+2i+2j+2l)\rho_{i,j,k-1,l} \\ +[(3+2i+2j+2l)(k+1)]\rho_{i,j,k+1,l} \\ +(i+1)(i+3)\rho_{i+1,j,k-1,l}+(k+1)\rho_{i-1,j,k+1,l} \\ +(j+1)(j+2)\rho_{i,j+1,k-1,l}+(k+1)\rho_{i,j-1,k+1,l} \\ +(l+1)(l+1)\rho_{i,j,k-1,l+1}+(k+1) \\ \times(1-c_{l-1})^{n-2}\rho_{i,j,k+1,l-1},\end{aligned} \tag{134}$$

where $n=3+2i+2j+2l+k$.

Once the strange quark mass M_s is given, we can choose the upper limits on i,j,k,l to construct an equation set to determine $\rho_{i,j,k,l}$ and the strange content of proton. We will take the strange quark mass M_s as a parameter. By solving the equation set, we give the relation between the number of $\bar{s}s$ pairs and the strange quark mass M_s in Fig. 1 and give the relation between $\bar{d}-\bar{u}$ and M_s in Fig. 2. When $0<M_s<\infty$, The parton number's changing scope is

$$\bar{u}=\sum_{i,j,k,l} i\rho_{i,j,k,l}\subset[0.309,0.310], \tag{135}$$

$$\bar{d}=\sum_{i,j,k,l} j\rho_{i,j,k,l}\subset[0.433,0.434], \tag{136}$$

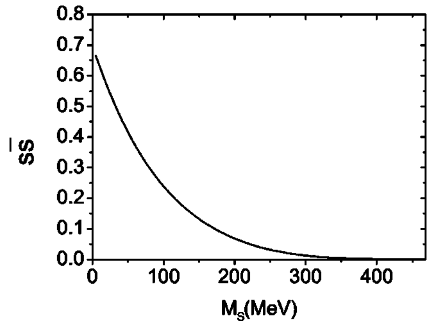

FIG. 1. The relation between the number of the $s\bar{s}$ pairs and the strange quark mass M_s in the case with the subprocesses $g\Leftrightarrow gg$ not considered. The number of the $s\bar{s}$ pairs is 0.05 at $M_s\approx 220$ MeV.

$$\bar{s}=\sum_{i,j,k,l} l\rho_{i,j,k,l}\subset[0,0.666], \tag{137}$$

$$g=\sum_{i,j,k,l} k\rho_{i,j,k,l}\subset[1.000,1.003], \tag{138}$$

$$\bar{d}-\bar{u}\subset[0.1243,0.1245]. \tag{139}$$

B. Strange content with $g\Leftrightarrow gg$ subprocesses considered

We now consider the strange quark content of the proton with processes involving the $g\Leftrightarrow gg$ subprocesses also considered. When using the balance principle to Fock state $|uud\rangle$, we have the go out process as

$$|uud\rangle\overset{3}{\Rightarrow}|uudg\rangle, \tag{140}$$

and the come in process as

$$|uud\rangle\overset{3}{\Leftarrow}|uudg\rangle. \tag{141}$$

According to formula (11), we have the equation

$$3\rho_{uud}=3\rho_{uudg}. \tag{142}$$

When using the balance principle to Fock state $|uudg\rangle$, we have the go out processes as

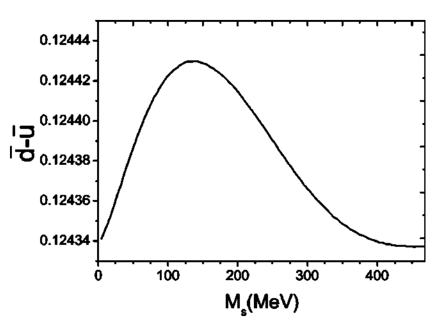

FIG. 2. The relation between flavor asymmetry $\bar{d}-\bar{u}$ and the strange quark mass M_s in the case with the subprocesses $g\Leftrightarrow gg$ not considered.

$$|uudg\rangle\overset{3\times 1}{\Rightarrow}|uud\rangle, \tag{143}$$

$$|uudg\rangle\overset{3+1}{\Rightarrow}|uudgg\rangle, \tag{144}$$

$$|uudg\rangle\overset{1}{\Rightarrow}|uud\bar{u}u\rangle, \tag{145}$$

$$|uudg\rangle\overset{1}{\Rightarrow}|uud\bar{d}d\rangle, \tag{146}$$

$$|uudg\rangle\overset{1\times(1-c_0)^3}{\Rightarrow}|uud\bar{s}s\rangle, \tag{147}$$

and the come in processes as

$$|uudg\rangle\overset{3}{\Leftarrow}|uud\rangle, \tag{148}$$

$$|uudg\rangle\overset{3\times 2+1}{\Leftarrow}|uudgg\rangle, \tag{149}$$

$$|uudg\rangle\overset{1\times 3}{\Leftarrow}|uud\bar{u}u\rangle, \tag{150}$$

$$|uudg\rangle\overset{1\times 2}{\Leftarrow}|uud\bar{d}d\rangle, \tag{151}$$

$$|uudg\rangle\overset{1\times 1}{\Leftarrow}|uud\bar{s}s\rangle. \tag{152}$$

Then from formula (11), we have the equation

$$\begin{aligned}[3\times 1+(3+1)+1+1+1\times(1-c_0)^3]\rho_{uudg}\\ =3\rho_{uud}+(3\times 2+1)\rho_{uudgg}+(1\times 3)\rho_{uud\bar{u}u}\\ +(1\times 2)\rho_{uud\bar{d}d}+(1\times 1)\rho_{uud\bar{s}s}.\end{aligned} \tag{153}$$

Applying the balance principle to a general Fock state $|uud,i,j,k,l\rangle$, we have the go out processes as

$$|uud,i,j,k,l\rangle\overset{(3+2i+2j+2l)k+C_k^2}{\Rightarrow}|uud,i,j,k-1,l\rangle, \tag{154}$$

$$|uud,i,j,k,l\rangle\overset{3+2i+2j+2l+k}{\Rightarrow}|uud,i,j,k+1,l\rangle, \tag{155}$$

$$|uud,i,j,k,l\rangle\overset{k}{\Rightarrow}|uud,i+1,j,k-1,l\rangle, \tag{156}$$

$$|uud,i,j,k,l\rangle\overset{i(i+2)}{\Rightarrow}|uud,i-1,j,k+1,l\rangle, \tag{157}$$

$$|uud,i,j,k,l\rangle\overset{k}{\Rightarrow}|uud,i,j+1,k-1,l\rangle, \tag{158}$$

$$|uud,i,j,k,l\rangle \overset{j(j+1)}{\Rightarrow} |uud,i,j-1,k+1,l\rangle, \tag{159}$$

$$|uud,i,j,k,l\rangle \overset{k(1-c_l)^{n-1}}{\Rightarrow} |uud,i,j,k-1,l+1\rangle, \tag{160}$$

$$|uud,i,j,k,l\rangle \overset{l^2}{\Rightarrow} |uud,i,j,k+1,l-1\rangle, \tag{161}$$

and the come in processes as

$$|uud,i,j,k,l\rangle \overset{3+2i+2j+2l+k-1}{\Leftarrow} |uud,i,j,k-1,l\rangle, \tag{162}$$

$$|uud,i,j,k,l\rangle \overset{(3+2i+2j+2l)(k+1)+C_{k+1}^2}{\Leftarrow} |uud,i,j,k+1,l\rangle, \tag{163}$$

$$|uud,i,j,k,l\rangle \overset{(i+1)(i+3)}{\Leftarrow} |uud,i+1,j,k-1,l\rangle, \tag{164}$$

$$|uud,i,j,k,l\rangle \overset{k+1}{\Leftarrow} |uud,i-1,j,k+1,l\rangle, \tag{165}$$

$$|uud,i,j,k,l\rangle \overset{(j+1)(j+2)}{\Leftarrow} |uud,i,j+1,k-1,l\rangle, \tag{166}$$

$$|uud,i,j,k,l\rangle \overset{k+1}{\Leftarrow} |uud,i,j-1,k+1,l\rangle, \tag{167}$$

$$|uud,i,j,k,l\rangle \overset{(l+1)(l+1)}{\Leftarrow} |uud,i,j,k-1,l+1\rangle, \tag{168}$$

$$|uud,i,j,k,l\rangle \overset{(k+1)(1-c_{l-1})^{n-2}}{\Leftarrow} |uud,i,j,k+1,l-1\rangle. \tag{169}$$

Thus we have the equation

$$\begin{aligned}
&\{[(3+2i+2j+2l)k+C_k^2]+(3+2i+2j+2l+k)+k\\
&\quad +i(i+2)+k+j(j+1)+k(1-c_l)^{n-1}+l^2\}\rho_{i,j,k,l}\\
&=(3+2i+2j+2l+k-1)\rho_{i,j,k-1,l}\\
&\quad +[(3+2i+2j+2l)(k+1)+C_{k+1}^2]\rho_{i,j,k+1,l}\\
&\quad +(i+1)(i+3)\rho_{i+1,j,k-1,l}\\
&\quad +(k+1)\rho_{i-1,j,k+1,l}+(j+1)(j+2)\rho_{i,j+1,k-1,l}\\
&\quad +(k+1)\rho_{i,j-1,k+1,l}+(l+1)(l+1)\rho_{i,j,k-1,l+1}\\
&\quad +(k+1)(1-c_{l-1})^{n-2}\rho_{i,j,k+1,l-1},
\end{aligned} \tag{170}$$

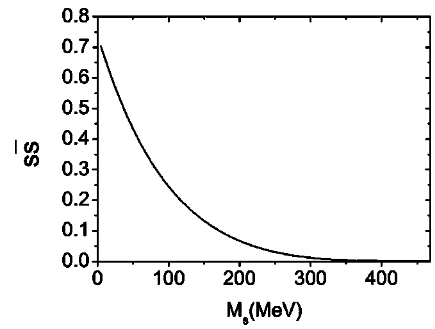

FIG. 3. The relation between the number of the $s\bar{s}$ pairs and the strange quark mass M_s in the case with the subprocesses $g \Leftrightarrow gg$ considered. The number of the $s\bar{s}$ pairs is 0.05 at $M_s \approx 220$ MeV.

where $n=3+2i+2j+2l+k$.

By solving the equation set constructed from Eq. (170) after choosing the upper limits on i,j,k,l, we give the relation between the number of $s\bar{s}$ pairs and the strange quark mass M_s in Fig. 3 and give the relation between $\bar{d}-\bar{u}$ and M_s in Fig. 4. When $0<M_s<\infty$, the parton number's changing scope is

$$\bar{u}=\sum_{i,j,k,l} i\rho_{i,j,k,l}\subset[0.331,0.337], \tag{171}$$

$$\bar{d}=\sum_{i,j,k,l} j\rho_{i,j,k,l}\subset[0.463,0.470], \tag{172}$$

$$\bar{s}=\sum_{i,j,k,l} l\rho_{i,j,k,l}\subset[0,0.703], \tag{173}$$

$$g=\sum_{i,j,k,l} k\rho_{i,j,k,l}\subset[1.079,1.099], \tag{174}$$

$$\bar{d}-\bar{u}\subset[0.131,0.134]. \tag{175}$$

We find that the number of $s\bar{s}$ pairs equals to 0.05 at $M_s \approx 220$ MeV, which is in the reasonable range of the strange mass. We also notice that the introduction of the strange sea content brings very small influence to the results for the light-flavor sea content.

VI. CONCLUSION

We improved the detailed balance model to a balance model because the detailed balance model leads to inconsistency some times. We find that there is about a 10% difference between the results of these two models in the case where subprocesses $g \Leftrightarrow gg$ are also considered. The detailed balance model is simple and perspicuous, and it is a good approximation of the balance model, while the balance model is from a more general consideration but is complicated, and needs to introduce the upper limits on i,j,k,l and to solve an equation set with a big number of equations. To consider the strange content inside the proton, we use the equal probability assumption to get the gluon energy distri-

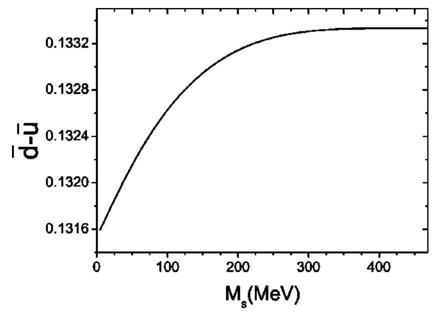

FIG. 4. The relation between flavor asymmetry $\bar{d}-\bar{u}$ and the strange quark mass M_s in the case with the subprocesses $g\Leftrightarrow gg$ considered.

bution and from which we get the relation between the suppressing factor of $g\rightarrow s\bar{s}$ and the strange quark mass. Then in the balance model, the number of $s\bar{s}$ pairs in the proton can be determined once the strange quark mass is given.

We make some comments about the limitations of our results such as those in Table I. The quarks and gluons in the Fock states are the ''intrinsic'' partons of the proton, since they are multiconnected nonperturbatively to the valence quarks [8]. Such partons are different from the ''extrinsic'' partons generated from the QCD hard bremsstrahlung and gluon splitting as part of the lepton scattering interaction. Thus the results in our paper are expected to work at a scale for the ''intrinsic'' partons, which is about $Q^2\sim 1$ GeV^2. The total number of intrinsic partons inside the proton is around 5.5, which is a small number of particles for the feasibility of the statistical method.

The detailed balance model and balance model can be taken as a new statistical model besides other successful statistical models such as [12] and [13]. We also noticed that the effect from the interaction of the quark-antiquark pairs with the quarks inside the nucleon has been also considered in a simple model that can account for the light-flavor sea asymmetry [14]. The advantage of the balance model is that a complete set of all quark-gluon Fock states can be obtained without any parameter in the case with only light-flavor quarks, but we still need to deal with the more complicated situation with parton polarizations taken into account for more general applications.

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