Baryon-antibaryon flavor correlations in e^+e^- annihilation

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(Received 1 February 1990)

Under the assumption that in e^+e^- annihilations baryons and antibaryons are produced by the stochastic combination of quarks and antiquarks, the baryon-antibaryon flavor correlations come completely from the global compensation of the flavors of all of the quarks and antiquarks. This can at least provide us with a lower limit for the baryon-antibaryon flavor correlations in various models, and by comparing them with experiment, we can see if and to what extent one has the necessity or freedom to introduce any other mechanism to produce extra baryon-antibaryon flavor correlations. Starting from this assumption, we have made calculations on $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_\Lambda\rangle$, $\langle n_{\Xi^-\bar{\Lambda}}\rangle/\langle n_{\Xi^-}\rangle$, and $\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle/\langle n_{\Lambda(1520)}\rangle$, which have already been measured, and on similar quantities such as $\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle/\langle n_{\Sigma^\pm}\rangle$, $\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle/\langle n_{\Sigma^{*\pm}}\rangle$, $\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle/\langle n_{\Xi^{*-}}\rangle$, and $\langle n_{\Omega^-\bar{\Lambda}}\rangle/\langle n_{\Omega^-}\rangle$, which have not been measured yet. Comparing with the available data, it seems that there is little room left for other mechanisms which result in extra flavor correlations.

I. INTRODUCTION

With the thoroughness of the studies on multiparticle production at high energies, especially where baryon production in e^+e^- annihilation is concerned, many discrepancies or even contradictions have been revealed between the presently popular understandings and the experimental data.[1] While some of them are remediable by introducing some more sophisticated hypotheses, some of them seem difficult. This became more striking when recently the ARGUS Collaboration published their data on baryon production in e^+e^- annihilation at around 10 GeV.[2,3] The ARGUS data, which are consistent with others, show that the strangeness and spin suppression factors for hyperon production are independent of the flavor contents of the hyperons.[2] This is in strong contradiction with the diquark as well as cluster models. Just as pointed out by Drescher recently in Ref. 1, this flavor independence can be interpreted as evidence for baryon production via a stochastic quark arrangement and against a simple diquark mechanism. In the latter case one would expect a strong flavor dependence of these factors.

Moreover, to further study the stochastic versus diquark baryon production mechanisms, one should go into the baryon-antibaryon ($B\bar{B}$) flavor correlations. The ARGUS Collaboration has also published[3] their measurements on $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_\Lambda\rangle$, $\langle n_{\Xi^-\bar{\Lambda}}\rangle/\langle n_{\Xi^-}\rangle$, and $\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle/\langle n_{\Lambda(1520)}\rangle$. The value $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_\Lambda\rangle \approx 0.3$, which is much smaller than the predictions of the pure diquark models,[3,1] is already another sign of stochastic production, but contradicts the diquark models.

In fact, it can easily be seen that, if we assume baryons and antibaryons in e^+e^- annihilation are produced by the stochastic combination of the quarks and antiquarks with u, d, and s flavors being produced in the ratio of $1:1:\lambda$, the strange-suppression factor measured by the experiments can be explained naturally. And, in this case, the spin suppression may be independent of the flavor contents of the baryon,[4] which is at least not in contradiction with the available data. In Refs. 5 and 6, the authors start from just this assumption to calculate many of the properties of the final hadrons and obtain the results that are in agreement with the data. Apparently, under this assumption, the baryons (antibaryons) are combined by three quarks (antiquarks) choosing randomly from all of the N quarks (N antiquarks); the $B\bar{B}$ flavor correlations come completely from the global flavor compensation of all of the quarks and antiquarks. Such an origin of $B\bar{B}$ flavor correlations must exist in all kinds of models. Hence the obtained results under this assumption can at least provide us with a lower limit for different models. Comparing them with the data, we can see if there is any necessity or freedom and, if any, to what extent to introduce other elaborate mechanisms to produce extra $B\bar{B}$ flavor correlations. Starting from this assumption, we have made calculations on $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_\Lambda\rangle$, $\langle n_{\Xi^-\bar{\Lambda}}\rangle/\langle n_{\Xi^-}\rangle$, and $\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle/\langle n_{\Lambda(1520)}\rangle$ in e^+e^- annihilation which have been measured by experiments and also other similar quantities such as $\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle/\langle n_{\Sigma^\pm}\rangle$, $\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle/\langle n_{\Sigma^{*\pm}}\rangle$, $\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle/\langle n_{\Xi^{*-}}\rangle$, $\langle n_{\Omega^-\bar{\Lambda}}\rangle/\langle n_{\Omega^-}\rangle$. The results can show us how large $B\bar{B}$ flavor correlations we can obtain from the global flavor compensation and how they vary with the energy $\sqrt{s}$. The general formulas are given in Sec. II. In Sec. III, a numerical calculation is presented and is compared with the available data. Section IV gives our conclusions and some discussions.

II. GENERAL FORMALISM OF THE CALCULATIONS

The high-energy multiparticle production is a stochastic process with certain statistical rules. Every phenomenon has its statistical aspect and may also have a dynamical origin. Only if the statistical nature is investigated sufficiently will the dynamical aspect be understood correctly.[7] The calculation of the $B\bar{B}$ flavor correlations in the stochastic combination of quarks and antiquarks is also helpful for us to analyze the contributions from the statistical aspects and hence to study the production mechanisms of baryons and antibaryons in e^+e^- annihilation.

Suppose in the stochastic combination of N quarks and N antiquarks a baryon B is produced; then there must be also an antibaryon $\bar{B}$ accompanied somewhere. We do not consider those cases in which there is more than one baryon-antibaryon pair created.[8] Now let us calculate the probability to see a Λ hyperon or a $\Lambda\bar{\Lambda}$ pair in the final hadrons.

Taking the resonance decay into account, the probability for B to be Λ or to decay into Λ, i.e., that we can detect Λ in experiments, is given by

$$P_{B\Longrightarrow\Lambda}(N)=\sum_{(q_1q_2q_3)}\alpha^{\Lambda}_{q_1q_2q_3}P_{B=(q_1q_2q_3)}(N)\ , \tag{1}$$

where $P_{B=(q_1q_2q_3)}(N)$ is the probability for the flavor content of B to be $(q_1q_2q_3)$ and $\alpha^{\Lambda}_{q_1q_2q_3}$ is the probability for B to be Λ or to decay into Λ if its flavor content is $(q_1q_2q_3)$. The sum runs over all of the possible flavor content $(q_1q_2q_3)$ of B.

At a given total number of all of the quarks, the numbers of the quarks of different flavors obey a certain kind of distribution. Both theories[9] and experiments[10] show that the probability for a $q\bar{q}$ pair created in the vacuum excitation by strong interaction to take a certain flavor can be determined by the "tunneling effect." From that, one obtains that the probabilities for u, d, and s flavors production satisfy

$$p_u:p_d:p_s=1:1:\lambda\ , \tag{2}$$

and that the heavy flavors c, b, etc, can be neglected completely. It follows immediately that the numbers of the u, d, and s quarks, N_u, N_d, and N_s, satisfy the Bernoulli distribution

$$B(N;N_u,N_d,N_s)=\frac{N!}{N_u!N_d!N_s!}p_u^{N_u}p_d^{N_d}p_s^{N_s}\delta_{N,N_u+N_d+N_s}\ , \tag{3}$$

where p_u, p_d, and p_s are determined by Eq. (2) as

$$p_u=p_d=1/(2+\lambda),\quad p_s=\lambda/(2+\lambda)\ . \tag{4}$$

If the numbers N_u, N_d, and N_s of the u, d, and s quarks are given, the probability for B to take a certain flavor content $(q_1q_2q_3)$ can easily be calculated. It just equals the probability for one to get three quarks of the flavors $(q_1q_2q_3)$ if one chooses them randomly from these $N=N_u+N_d+N_s$ quarks. For example,

$$W_{B=(uds)}(N_u,N_d,N_s)=6\frac{N_uN_dN_s}{N(N-1)(N-2)}\ , \tag{5a}$$

where the factor 6 comes from the fact that one has six different equivalent manners to get three quarks of flavor (uds) from the N quarks. Similarly, one has

$$W_{B=(uus)}(N_u,N_d,N_s)=3\frac{N_u(N_u-1)N_s}{N(N-1)(N-2)}\ , \tag{5b}$$

$$W_{B=(uss)}(N_u,N_d,N_s)=3\frac{N_uN_s(N_s-1)}{N(N-1)(N-2)}\ , \tag{5c}$$

$$W_{B=(sss)}(N_u,N_d,N_s)=\frac{N_s(N_s-1)(N_s-2)}{N(N-1)(N-2)}\ , \tag{5d}$$

and so on. Correspondingly, the probability for B to be Λ or to decay into Λ at given N_u, N_d, and N_s is given by

$$W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)=\sum_{(q_1q_2q_3)}\alpha^{\Lambda}_{q_1q_2q_3}W_{B=(q_1q_2q_3)}(N_u,N_d,N_s)\ . \tag{6}$$

Averaging over the various values of N_u, N_d, and N_s at a given N, one has

$$P_{B=(q_1q_2q_3)}(N)=\sum_{N_u,N_d,N_s}B(N;N_u,N_d,N_s)W_{B=(q_1q_2q_3)}(N_u,N_d,N_s)\ . \tag{7}$$

After some simple algebra, one gets the simple expressions for $P_{B=(q_1q_2q_3)}(N)$. For example,

$$\begin{aligned}P_{B=(uds)}(N)&=6\sum_{N_u,N_d,N_s}\frac{N_uN_dN_s}{N(N-1)(N-2)}\frac{N!}{N_u!N_d!N_s!}\\&\quad\times p_u^{N_u}p_d^{N_d}p_s^{N_s}\delta_{N,N_u+N_d+N_s}\\&=6p_up_dp_s=6\lambda/(2+\lambda)^3\ .\end{aligned} \tag{8a}$$

And similarly,

$$P_{B=(uus)}(N)=3\lambda/(2+\lambda)^3\ , \tag{8b}$$

$$P_{B=(uss)}(N)=3\lambda^2/(2+\lambda)^3\ , \tag{8c}$$

$$P_{B=(sss)}(N)=\lambda^3/(2+\lambda)^3\ , \tag{8d}$$

which are independent of N. Putting them into Eq. (1), one has

$$\begin{aligned}P_{B\Longrightarrow\Lambda}(N)=[&6\lambda\alpha^{\Lambda}_{uds}+3\lambda(\alpha^{\Lambda}_{uus}+\alpha^{\Lambda}_{dds})\\&+3\lambda^2(\alpha^{\Lambda}_{uss}+\alpha^{\Lambda}_{dss})+\lambda^3\alpha^{\Lambda}_{sss}]/(2+\lambda)^3\ .\end{aligned} \tag{9}$$

We do not write out those terms corresponding to $(q_1q_2q_3)=(uuu)$, (uud), (udd), and (ddd) since obviously one has $\alpha^{\Lambda}_{q_1q_2q_3}=0$ in these cases. In general, $\alpha^{\Lambda}_{q_1q_2q_3}$ is determined by the decay properties of the baryons and the relative weights for the productions of the baryons with the same flavor content $(q_1q_2q_3)$ but different spin. It is independent of the number N of the quarks. So $P_{B\Longrightarrow\Lambda}(N)$ in Eq. (9) is also independent of N. We will denote it by $P_{B\Longrightarrow\Lambda}$ in the following.

Considering the symmetry between u and d, one has $\alpha^{\Lambda}_{uus}=\alpha^{\Lambda}_{dds}$ and $\alpha^{\Lambda}_{uss}=\alpha^{\Lambda}_{dss}$. Putting them into Eq. (9), one gets

$$P_{B\Longrightarrow\Lambda}=(6\lambda\alpha^{\Lambda}_{uds}+6\lambda\alpha^{\Lambda}_{uus}+6\lambda^2\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Lambda}_{sss})/(2+\lambda)^3\ . \tag{10}$$

Multiplying by the average number of baryons $\bar{n}_B(N)$ produced in the combination of N quarks and N antiquarks, one gets the average number of Λ hyperons in the final state as

$$\bar{n}_{\Lambda}(N)=P_{B\Longrightarrow\Lambda}\bar{n}_B(N)\ . \tag{11}$$

At a given energy $\sqrt{s}$, the average value of N, $\langle N\rangle$, is fixed, but N follows a certain distribution $P(\langle N\rangle;N)$. So the corresponding average number of Λ hyperons is

$$\begin{aligned}\langle n_{\Lambda}\rangle&=\sum_N P(\langle N\rangle;N)\bar{n}_{\Lambda}(N)\\&=\sum_N P(\langle N\rangle;N)\bar{n}_B(N)P_{B\Longrightarrow\Lambda}=\langle n_B\rangle P_{B\Longrightarrow\Lambda}\ ,\end{aligned} \tag{12}$$

where $\langle n_B\rangle=\langle\bar{n}_B(N)\rangle=\sum_N P(\langle N\rangle;N)\bar{n}_B(N)$ is the average number of baryons produced at a given $\langle N\rangle$ or $\sqrt{s}$. Both $\langle n_{\Lambda}\rangle$ and $\langle n_B\rangle$ are functions of $\langle N\rangle$ or $\sqrt{s}$.

In the same way, we can calculate the average number of the $\Lambda\bar{\Lambda}$ pairs in the final hadron state.

If the N_u, N_d, and N_s are given, the probability for the $B\bar{B}$ to be $\Lambda\bar{\Lambda}$ or to decay into $\Lambda\bar{\Lambda}$ in the final states is given by

$$\begin{aligned}W_{B\bar{B}\Longrightarrow\Lambda\bar{\Lambda}}(N_u,N_d,N_s)&=\left[\sum_{(q_1q_2q_3)}\alpha^{\Lambda}_{q_1q_2q_3}W_{B=(q_1q_2q_3)}(N_u,N_d,N_s)\right]\left[\sum_{(\bar{q}_4\bar{q}_5\bar{q}_6)}\alpha^{\bar{\Lambda}}_{\bar{q}_4\bar{q}_5\bar{q}_6}W_{\bar{B}=(\bar{q}_4\bar{q}_5\bar{q}_6)}(N_u,N_d,N_s)\right]\\&=[W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)]^2\ .\end{aligned} \tag{13}$$

Averaging over the distribution of N_u, N_d, and N_s, one has

$$\begin{aligned}P_{B\bar{B}\Longrightarrow\Lambda\bar{\Lambda}}(N)&=\sum_{N_u,N_d,N_s}B(N;N_u,N_d,N_s)[W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)]^2\\&=[6\lambda\alpha^{\Lambda}_{uds}G_1(N)+6\lambda\alpha^{\Lambda}_{uus}G_2(N)+6\lambda^2\alpha^{\Lambda}_{uss}G_3(N)+\lambda^3\alpha^{\Lambda}_{sss}G_4(N)]/(2+\lambda)^3\ .\end{aligned} \tag{14}$$

The definitions of the $G_i(N)$ are

$$G_1(N)=\sum_{N_u,N_d,N_s}B(N-3;N_u-1,N_d-1,N_s-1)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\ , \tag{15a}$$

$$\begin{aligned}G_2(N)&=\sum_{N_u,N_d,N_s}B(N-3;N_u-2,N_d,N_s-1)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\\&=\sum_{N_u,N_d,N_s}B(N-3;N_u,N_d-2,N_s-1)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\ ,\end{aligned} \tag{15b}$$

$$\begin{aligned}G_3(N)&=\sum_{N_u,N_d,N_s}B(N-3;N_u-1,N_d,N_s-2)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\\&=\sum_{N_u,N_d,N_s}B(N-3;N_u,N_d-1,N_s-2)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\ ,\end{aligned} \tag{15c}$$

$$G_4(N)=\sum_{N_u,N_d,N_s}B(N-3;N_u,N_d,N_s-3)W_{B\Longrightarrow\Lambda}(N_u,N_d,N_s)\ . \tag{15d}$$

In fact, these $G_i(N)$'s and their coefficients in Eq. (14) have clear physical meanings. The $G_1(N)$, $G_2(N)$, $G_3(N)$, and $G_4(N)$ are the conditional probabilities for $\bar{B}$ to be $\bar{\Lambda}$ or to decay into $\bar{\Lambda}$ at a given N under the condition that the flavor content of B is (uds), (uus) or (dds), (uss) or (dss), and (sss), respectively. Their coefficients are the joint probabilities for B not only to be Λ or to decay into Λ but also have the flavor content (uds), (uus) or (dds), (uss) or (dss), and (sss), respectively.

Similarly, the average number of $\Lambda\bar{\Lambda}$ pairs in the final hadrons at a given N is

$$\bar{n}_{\Lambda\bar{\Lambda}}(N)=P_{B\bar{B}\Longrightarrow\Lambda\bar{\Lambda}}(N)\bar{n}_B(N)\ . \tag{16}$$

Averaging over the distribution of N, we obtain the average number of $\Lambda\bar{\Lambda}$, $\langle n_{\Lambda\bar{\Lambda}}\rangle$, at a given $\sqrt{s}$ or $\langle N\rangle$ as

$$\begin{aligned}\langle n_{\Lambda\bar{\Lambda}}\rangle&=\sum_N P(\langle N\rangle;N)\bar{n}_{\Lambda\bar{\Lambda}}(N)\\&=\sum_N P(\langle N\rangle;N)P_{B\bar{B}\Longrightarrow\Lambda\bar{\Lambda}}(N)\bar{n}_B(N)\ .\end{aligned} \tag{17}$$

Put Eq. (14) into Eq. (17), and one has

$$\langle n_{\Lambda\bar{\Lambda}}\rangle=[6\lambda\alpha_{uds}^{\Lambda}g_1(\langle N\rangle)+6\lambda\alpha_{uus}^{\Lambda}g_2(\langle N\rangle)+6\lambda^2\alpha_{uss}^{\Lambda}g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Lambda}g_4(\langle N\rangle)]\langle n_B\rangle/(2+\lambda)^3 , \tag{18}$$

where $g_1(\langle N\rangle)$ are the conditional probabilities for $\bar{B}$ to be $\bar{\Lambda}$ or to decay into $\bar{\Lambda}$ at a given $\langle N\rangle$ if B takes different flavor contents, respectively. They are functions of $\langle N\rangle$ or $\sqrt{s}$ with the definitions

$$g_i(\langle N\rangle)=\left[\sum_N P(\langle N\rangle;N)G_i(N)\bar{n}_B(N)\right]\Big/\left[\sum_N P(\langle N\rangle;N)\bar{n}_B(N)\right]=\langle G_i(N)\bar{n}_B(N)\rangle/\langle n_B\rangle . \tag{19}$$

It follows from Eq. (18), Eq. (11) and Eq. (10) that

$$\frac{2\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda+n_{\bar{\Lambda}}\rangle}=\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda\rangle}=\frac{6\lambda\alpha_{uds}^{\Lambda}g_1(\langle N\rangle)+6\lambda\alpha_{uus}^{\Lambda}g_2(\langle N\rangle)+6\lambda^2\alpha_{uss}^{\Lambda}g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Lambda}g_4(\langle N\rangle)}{6\lambda\alpha_{uds}^{\Lambda}+6\lambda\alpha_{uus}^{\Lambda}+6\lambda^2\alpha_{uss}^{\Lambda}+\lambda^3\alpha_{sss}^{\Lambda}} . \tag{20}$$

The coefficients of $g_i(\langle N\rangle)$ in this equation are the conditional probabilities for B to take various flavor contents under the condition that B is Λ or is going to decay into Λ.

In the same way, one has

$$\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle}=\frac{3\lambda^2(\alpha_{uss}^{\Xi^-}+\alpha_{dss}^{\Xi^-})g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Xi^-}g_4(\langle N\rangle)}{3\lambda^2(\alpha_{uss}^{\Xi^-}+\alpha_{dss}^{\Xi^-})+\lambda^3\alpha_{sss}^{\Xi^-}} , \tag{21}$$

$$\frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}=\frac{6\lambda\alpha_{uds}^{\Lambda(1520)}g_1(\langle N\rangle)+6\lambda\alpha_{uus}^{\Lambda(1520)}g_2(\langle N\rangle)+6\lambda^2\alpha_{uss}^{\Lambda(1520)}g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Lambda(1520)}g_3(\langle N\rangle)}{6\lambda\alpha_{uds}^{\Lambda(1520)}+6\lambda\alpha_{uus}^{\Lambda(1520)}+6\lambda^2\alpha_{uss}^{\Lambda(1520)}+\lambda^3\alpha_{sss}^{\Lambda(1520)}} , \tag{22}$$

and, also,

$$\frac{\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle}{\langle n_{\Sigma^\pm}\rangle}=\frac{6\lambda\alpha_{uds}^{\Sigma^\pm}g_1(\langle N\rangle)+3\lambda(\alpha_{uus}^{\Sigma^\pm}+\alpha_{dds}^{\Sigma^\pm})g_2(\langle N\rangle)+3\lambda^2(\alpha_{uss}^{\Sigma^\pm}+\alpha_{dss}^{\Sigma^\pm})g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Sigma^\pm}g_4(\langle N\rangle)}{6\lambda\alpha_{uds}^{\Sigma^\pm}+3\lambda(\alpha_{uus}^{\Sigma^\pm}+\alpha_{dds}^{\Sigma^\pm})+3\lambda^2(\alpha_{uss}^{\Sigma^\pm}+\alpha_{dss}^{\Sigma^\pm})+\lambda^3\alpha_{sss}^{\Sigma^\pm}} , \tag{23}$$

$$\frac{\langle n_{\Sigma^{*\pm}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle}=\frac{6\lambda\alpha_{uds}^{\Sigma^{*\pm}}g_1(\langle N\rangle)+3\lambda(\alpha_{uus}^{\Sigma^{*\pm}}+\alpha_{dds}^{\Sigma^{*\pm}})g_2(\langle N\rangle)+3\lambda^2(\alpha_{uss}^{\Sigma^{*\pm}}+\alpha_{dss}^{\Sigma^{*\pm}})g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Sigma^{*\pm}}g_4(\langle N\rangle)}{6\lambda\alpha_{uds}^{\Sigma^{*\pm}}+3\lambda(\alpha_{uus}^{\Sigma^{*\pm}}+\alpha_{dds}^{\Sigma^{*\pm}})+3\lambda^2(\alpha_{uss}^{\Sigma^{*\pm}}+\alpha_{dss}^{\Sigma^{*\pm}})+\lambda^3\alpha_{sss}^{\Sigma^{*\pm}}} , \tag{24}$$

$$\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle}=\frac{3\lambda^2(\alpha_{uss}^{\Xi^{*-}}+\alpha_{dss}^{\Xi^{*-}})g_3(\langle N\rangle)+\lambda^3\alpha_{sss}^{\Xi^{*-}}g_4(\langle N\rangle)}{3\lambda^2(\alpha_{uss}^{\Xi^{*-}}+\alpha_{dss}^{\Xi^{*-}})+\lambda^3\alpha_{sss}^{\Xi^{*-}}} , \tag{25}$$

$$\frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}=\frac{\lambda^3\alpha_{sss}^{\Omega^-}g_4(\langle N\rangle)}{\lambda^3\alpha_{sss}^{\Omega^-}}=g_4(\langle N\rangle) . \tag{26}$$

The $\alpha_{q_1q_2q_3}^{B_i}$ can be calculated using the data on resonances decays[11] and that on the production weights of the baryons of the same flavor content but different spin and parity.[2] $g_i(\langle N\rangle)$ can be calculated from Eq. (19). Then we can calculate those yield ratios given above, which measure the $B\bar{B}$ flavor correlations. Although the exact calculations can be done only if we know $P(\langle N\rangle;N)$ and $\bar{n}_B(N)$, which depend on models, some approximate estimations can be achieved without knowing the exact forms of $P(\langle N\rangle;N)$ and $\bar{n}_B(N)$. This is given in the following section.

III. NUMERICAL CALCULATIONS AND COMPARISONS WITH THE AVAILABLE DATA

Experiments seem to tell us that in e^+e^- annihilation the production of the baryons with orbital excitation $L\neq0$ takes only a very small fraction of the total baryons.[12] And the decays of the $L\neq0$ baryons almost all are strong decays and hence the strangeness and isospin, etc., are conserved.[11] Conventionally, it is believed that the influence from the production and decay of the $L\neq0$ baryons on the values of $\alpha_{q_1q_2q_3}^{B_i}$ is very small if B_i is a $L=0$ baryon. As an approximation, we simply neglect it. Thus if the $\frac{3}{2}^+$ to $\frac{1}{2}^+$ baryon ratio β for the baryons of the same flavor content is given, we can calculate $\alpha_{q_1q_2q_3}^{B_i}$ for the various $L=0$ baryons using the data on the decay properties of the $L=0$ baryons given by the Particle Data Group.[11] As an example, we give the $\alpha_{q_1q_2q_3}^{\Lambda}$'s for different flavor contents $(q_1q_2q_3)$ in Table I.

But when we calculate $\langle n_{\Lambda(1520)}\rangle$, we have to take the production of the $L\neq0$ baryons into account since the $\Lambda(1520)$ itself is a $L\neq0$ baryon. From the data on the decays of the $L\neq0$ baryons now available,[11] we see that $\alpha_{q_1q_2q_3}^{\Lambda(1520)}$ is very small for any $(q_1q_2q_3)$ other than (uds). We suppose that they can be neglected. In this approximation, those yield ratios mentioned in Sec. II that measure the $B\bar{B}$ flavor correlations can be calculated without knowing how many $L\neq0$ baryons are produced exactly.

Substituting the $\alpha_{q_1q_2q_3}^{B_i}$'s obtained in this approximate way into Eqs. (20)–(26), we get

$$\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_{\Lambda}\rangle}=\frac{6[1-0.12\beta/(2+\beta)]g_1(\langle N\rangle)+5.64\beta/(1+\beta)g_2(\langle N\rangle)+6\lambda g_3(\langle N\rangle)+\lambda^2 g_4(\langle N\rangle)}{6[1-0.12\beta/(2+\beta)]+5.64\beta/(1+\beta)+6\lambda+\lambda^2}\,, \tag{27}$$

$$\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle}=[3g_3(\langle N\rangle)+0.086\lambda g_4(\langle N\rangle)]/(3+0.086\lambda)\,, \tag{28}$$

$$\frac{\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle}{\langle n_{\Sigma^\pm}\rangle}=\frac{0.72\beta/(2+\beta)g_1(\langle N\rangle)+6[1-0.88\beta/(1+\beta)]g_2(\langle N\rangle)}{0.72\beta/(2+\beta)+6[1-0.88\beta/(1+\beta)]}\,, \tag{29}$$

$$\frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}=g_1(\langle N\rangle)\,, \tag{30}$$

$$\frac{\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle}=g_2(\langle N\rangle)\,, \tag{31}$$

$$\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle}=g_3(\langle N\rangle)\,, \tag{32}$$

$$\frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}=g_4(\langle N\rangle)\,. \tag{33}$$

It is already quite sure from experiments that $\lambda\approx 0.3$ and is independent of energy $\sqrt{s}$ (or $\langle N\rangle$) and the flavor content of the baryons.[2,10] The measured $\frac{3}{2}^+$ to $\frac{1}{2}^+$ baryon ratios for the final hyperons are about 0.3.[2] Taking the $\frac{3}{2}^+$ baryon decay into account, one has $\beta\approx 0.5$ for the primary hadrons. And it seems that β is also independent of the flavor content of the hyperons and the energy $\sqrt{s}$.[2] But from Eq. (19) we see that $g_i(\langle N\rangle)$ depends on $\langle N\rangle$ or $\sqrt{s}$. So from Eqs. (27)–(33), in one respect, we can see that the $B\bar{B}$ flavor correlations result-

TABLE I. The probabilities $\alpha^{\Lambda}_{q_1q_2q_3}$ for B to be Λ or to decay into Λ if B takes various flavor contents ($q_1q_2q_3$).

$q_1q_2q_3$	The corresponding baryons and their production weights		The decay modes and their corresponding branching ratios through which experiments can see Λ		$\alpha^{\Lambda}_{q_1q_2q_3}$
uds	Λ	$1/(2+\beta)$		100%	
	Σ^0	$1/(2+\beta)$	$\Lambda\gamma$	100%	$1-0.12\beta/(2+\beta)$
	Σ^{*0}	$\beta/(2+\beta)$	$\Lambda\pi^0$	88%	
uus	Σ^+	$1/(1+\beta)$			
	Σ^{*+}	$\beta/(1+\beta)$	$\Lambda\pi^+$	88%	$0.94\beta/(1+\beta)$
			$\Sigma^0\pi^+$	6%	
dds	Σ^-	$1/(1+\beta)$			
	Σ^{*-}	$\beta/(1+\beta)$	$\Lambda\pi^-$	88%	$0.94\beta/(1+\beta)$
			$\Sigma^0\pi^-$	6%	
uss	Ξ^0	$1/(1+\beta)$	$\Lambda\pi^0$	100%	
	Ξ^{*0}	$\beta/(1+\beta)$	$\Xi^0\pi^0$	1/3	1
			$\Xi^-\pi^+$	2/3	
dss	Ξ^-	$1/(1+\beta)$	$\Lambda\pi^-$	100%	
	Ξ^{*-}	$\beta/(1+\beta)$	$\Xi^0\pi^-$	2/3	1
			$\Xi^-\pi^0$	1/3	
sss			ΛK^-	67.8%	
	Ω^-	1	$\Xi^0\pi^-$	23.6%	1
			$\Xi^-\pi^0$	8.6%	

$\alpha^{\Lambda}_{q_1q_2q_3}=0$ for other $q_1q_2q_3$'s.

ing from the global flavor compensation of the quarks and antiquarks for various baryons vary with energy. And, in another respect, we can also see that there are certain relations among the flavor correlations for different baryons at a given energy, and these relationships are independent of energy $\sqrt{s}$. The studies of both aspects, namely, the study of the relations among the $B\bar{B}$ flavor correlations for various baryons at a given energy and the study of the variations of the $B\bar{B}$ flavor correlation for a given baryon with energy $\sqrt{s}$, can provide us with some quantitative results and hence quantitative comparison with experiment.

Putting $\lambda=0.3$ and $\beta=0.5$ into the Eqs. (27)–(33), we obtain the relations among the

$$\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda\rangle},\quad \frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle},\quad \frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle},$$

$$\frac{\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle}{\langle n_{\Sigma^\pm}\rangle},\quad \frac{\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle},\quad \frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle},\quad \frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}$$

as follows:

$$\begin{aligned}\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda\rangle} &= 0.608g_1(\langle N\rangle)+0.195g_2(\langle N\rangle)\\ &\quad +0.187g_3(\langle N\rangle)+0.009g_4(\langle N\rangle)\\ &= 0.608\frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}+0.195\frac{\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle}\\ &\quad +0.187\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle}+0.009\frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}\,,\end{aligned} \tag{34a}$$

$$\begin{aligned}\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle} &= 0.991g_3(\langle N\rangle)+0.009g_4(\langle N\rangle)\\ &= 0.991\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle}+0.009\frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}\,,\end{aligned} \tag{34b}$$

$$\begin{aligned}\frac{\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle}{\langle n_{\Sigma^\pm}\rangle} &= 0.034g_1(\langle N\rangle)+0.966g_2(\langle N\rangle)\\ &= 0.034\frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}+0.966\frac{\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle}\,,\end{aligned} \tag{34c}$$

and so on. Notice that the coefficients in these equations are normalized. This can easily be understood by referring to the physical meanings of them given in Sec. II below Eq. (20).

Examining the experimental data on various $B\bar{B}$ flavor correlations, we can see whether or not they satisfy these relations. If they do satisfy these relations, this will tell us that the $B\bar{B}$ flavor correlations can be understood using only the global flavor compensation of the quarks and antiquarks. If they do not satisfy them, this will tell us if there is any necessity or freedom and to what extent we need another elaborate mechanism resulting in extra $B\bar{B}$ flavor correlations. Unfortunately, there are no data available on $\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle/\langle n_{\Sigma^{*\pm}}\rangle$, $\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle/\langle n_{\Xi^{*-}}\rangle$, and $\langle n_{\Omega^-\bar{\Lambda}}\rangle/\langle n_{\Omega^-}\rangle$ which are needed in Eqs. (34). The data we have now merely are on $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_\Lambda\rangle$, $\langle n_{\Xi^-\bar{\Lambda}}\rangle/\langle n_{\Xi^-}\rangle$, and $\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle/\langle n_{\Lambda(1520)}\rangle$.

But as we will be able to see from the discussions and the calculations given in the following, all $g_i(\langle N\rangle)$'s are always of the same order of magnitude for any $\langle N\rangle$, and especially for a slightly large $\langle N\rangle$ ($\langle N\rangle>7$), $g_1(\langle N\rangle)\approx g_2(\langle N\rangle)$. So, approximately, we can replace the $0.009g_4(\langle N\rangle)$ in Eq. (34b) by $0.009g_3(\langle N\rangle)$ and get

$$\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle}=g_3(\langle N\rangle)=\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle} \tag{35a}$$

and similarly replace the $0.009g_4(\langle N\rangle)$ in Eq. (34a) by $0.009g_3(\langle N\rangle)$ and $g_2(\langle N\rangle)$ by $g_1(\langle N\rangle)$ and get

$$\begin{aligned}\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda\rangle} &= 0.80g_1(\langle N\rangle)+0.20g_3(\langle N\rangle)\\ &= 0.80\frac{\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}+0.20\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle}\,.\end{aligned} \tag{35b}$$

Putting the ARGUS data in the Υ energy region for direct Υ decay or for the nearby continuum into Eq. (35b), one has for direct Υ decay that the left side is $0.328\pm0.025\pm0.023$ and the right side 0.39 ± 0.15, and for the continuum that the left $0.306\pm0.044\pm0.021$ and the right 0.44 ± 0.15. Both satisfy Eq. (35b) within the error bars. This tells us that the available data can be understood using only the global flavor compensation at the present stage.

To further study the energy dependence of these $B\bar{B}$ flavor correlations and further compare them with experimental data, we make the following remarks on the values of $g_i(\langle N\rangle)$'s.

(i) Limits at very large $\langle N\rangle$. When $\langle N\rangle$ is very large, only those terms with very large N contribute to the sum in Eq. (19) to calculate $g_i(\langle N\rangle)$. And if N is very large, the main contributions to the sums in Eqs. (15) to calculate $G_i(N)$'s will also come only from those terms with very large N_u, N_d, and N_s. If N, N_u, N_d, and N_s are all very large, we approximately have

$$\begin{aligned}B(N-3;N_u-1,N_d-1,N_s-1) &\approx B(N-3;N_u-2,N_d,N_s-1)\\ &\approx B(N-3;N_u-1,N_d,N_s-2)\\ &\approx B(N-3;N_u,N_d,N_s-3)\\ &\approx B(N;N_u,N_d,N_s)\,.\end{aligned} \tag{36}$$

Putting them into Eqs. (15), one gets

$$G_1(N)\approx G_2(N)\approx G_3(N)\approx G_4(N)\approx P_{B=\Lambda} \tag{37}$$

which is independent of N. Under this approximation

$$g_i(\langle N\rangle)=G_i(N)\approx P_{B=\Lambda}=\{6\lambda[1-0.12\beta/(2+\beta)]+5.64\lambda\beta/(1+\beta)+6\lambda^2+\lambda^3\}/(2+\lambda)^3\,. \tag{38}$$

In this case all $P_{B\bar{B}\Longrightarrow B_i\bar{B}_j}$ for any B_i and $\bar{B}_j$ can be written as $P_{B\bar{B}\Longrightarrow B_i\bar{B}_j}=P_{B\Longrightarrow B_i}P_{\bar{B}\Longrightarrow \bar{B}_j}$, which shows that only in this extreme case of $\langle N\rangle\to\infty$ can the influence of the global flavor compensation of the quarks and antiquarks on the production of one baryon-antibaryon pair be neglected; hence the baryon and antibaryon can be regarded as being produced completely independently. And the yield ratios in Eqs. (20)–(26) can all be written as

$$\frac{\langle n_{B_i\bar{\Lambda}}\rangle}{\langle n_{B_i}\rangle}=P_{B\Longrightarrow\Lambda}$$
$$=\{6\lambda[1-0.12\beta/(2+\beta)]+5.64\lambda\beta/(1+\beta)+6\lambda^2+\lambda^3\}/(2+\lambda)^3\ . \quad (39)$$

Putting the experimental data $\lambda=0.3$ and $\beta=0.5$ into it, one has $\langle n_{B_i\bar{\Lambda}}\rangle/\langle n_{B_i}\rangle=0.237$.

(ii) Limits at very small $\langle N\rangle$. Suppose $\langle N\rangle$ is so small that only the $N=3$ term contributes to $g_i(\langle N\rangle)$. In such an extreme case, the flavor content of the baryon must be completely the same as that of the antibaryon giving the maximum $B\bar{B}$ flavor correlations.

From the physical meanings of $G_i(N)$'s given below Eqs. (15), one gets immediately that, in this limiting case,

$$G_1(N=3)=\alpha^{\Lambda}_{uds},\quad G_2(N=3)=\alpha^{\Lambda}_{uus}=\alpha^{\Lambda}_{dds}\ ,$$
$$G_3(N=3)=\alpha^{\Lambda}_{uss}=\alpha^{\Lambda}_{dss},\quad G_4(N=3)=\alpha^{\Lambda}_{sss}\ . \quad (40)$$

Putting them into Eqs. (20)–(26), one has

$$\frac{\bar{n}_{\Lambda\bar{\Lambda}}(N=3)}{\bar{n}_{\Lambda}(N=3)}=\frac{6\lambda(\alpha^{\Lambda}_{uds})^2+6\lambda(\alpha^{\Lambda}_{uus})^2+6\lambda^2(\alpha^{\Lambda}_{uss})^2+\lambda^3(\alpha^{\Lambda}_{sss})^2}{6\lambda\alpha^{\Lambda}_{uds}+6\lambda\alpha^{\Lambda}_{uus}+6\lambda^2\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Lambda}_{sss}}\ , \quad (41)$$

$$\frac{\bar{n}_{\Xi^-\bar{\Lambda}}(N=3)}{\bar{n}_{\Xi^-}(N=3)}=\frac{3\lambda^2(\alpha^{\Xi^-}_{uss}+\alpha^{\Xi^-}_{dss})\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Xi^-}_{sss}\alpha^{\Lambda}_{sss}}{3\lambda^2(\alpha^{\Xi^-}_{uss}+\alpha^{\Xi^-}_{dss})+\lambda^3\alpha^{\Xi^-}_{sss}}\ , \quad (42)$$

$$\frac{\bar{n}_{\Lambda(1520)\bar{\Lambda}}(N=3)}{\bar{n}_{\Lambda(1520)}(N=3)}=\alpha^{\Lambda}_{uds}\ , \quad (43)$$

$$\frac{\bar{n}_{\Sigma^\pm\bar{\Lambda}}(N=3)}{\bar{n}_{\Sigma^\pm}(N=3)}=\frac{6\lambda\alpha^{\Sigma^\pm}_{uds}\alpha^{\Lambda}_{uds}+3\lambda(\alpha^{\Sigma^\pm}_{uus}+\alpha^{\Sigma^\pm}_{dds})\alpha^{\Lambda}_{uus}+3\lambda^2(\alpha^{\Sigma^\pm}_{uss}+\alpha^{\Sigma^\pm}_{dss})\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Sigma^\pm}_{sss}\alpha^{\Lambda}_{sss}}{6\lambda\alpha^{\Sigma^\pm}_{uds}+3\lambda(\alpha^{\Sigma^\pm}_{uus}+\alpha^{\Sigma^\pm}_{dds})+3\lambda^2(\alpha^{\Sigma^\pm}_{uss}+\alpha^{\Sigma^\pm}_{dss})+\lambda^3\alpha^{\Sigma^\pm}_{sss}}\ , \quad (44)$$

$$\frac{\bar{n}_{\Sigma^{*\pm}\bar{\Lambda}}(N=3)}{\bar{n}_{\Sigma^{*\pm}}(N=3)}=\frac{6\lambda\alpha^{\Sigma^{*\pm}}_{uds}\alpha^{\Lambda}_{uds}+3\lambda(\alpha^{\Sigma^{*\pm}}_{uus}+\alpha^{\Sigma^{*\pm}}_{dds})\alpha^{\Lambda}_{uus}+3\lambda^2(\alpha^{\Sigma^{*\pm}}_{uss}+\alpha^{\Sigma^{*\pm}}_{dss})\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Sigma^{*\pm}}_{sss}\alpha^{\Lambda}_{sss}}{6\lambda\alpha^{\Sigma^{*\pm}}_{uds}+3\lambda(\alpha^{\Sigma^{*\pm}}_{uus}+\alpha^{\Sigma^{*\pm}}_{dds})+3\lambda^2(\alpha^{\Sigma^{*\pm}}_{uss}+\alpha^{\Sigma^{*\pm}}_{dss})+\lambda^3\alpha^{\Sigma^{*\pm}}_{sss}}\ , \quad (45)$$

$$\frac{\bar{n}_{\Xi^{*-}\bar{\Lambda}}(N=3)}{\bar{n}_{\Xi^{*-}}(N=3)}=\frac{3\lambda^2(\alpha^{\Xi^{*-}}_{uss}+\alpha^{\Xi^{*-}}_{dss})\alpha^{\Lambda}_{uss}+\lambda^3\alpha^{\Xi^{*-}}_{sss}\alpha^{\Lambda}_{sss}}{3\lambda^2(\alpha^{\Xi^{*-}}_{uss}+\alpha^{\Xi^{*-}}_{dss})+\lambda^3\alpha^{\Xi^{*-}}_{sss}}\ , \quad (46)$$

$$\frac{\bar{n}_{\Omega^-\bar{\Lambda}}(N=3)}{\bar{n}_{\Omega^-}(N=3)}=\frac{\lambda^3\alpha^{\Omega^-}_{sss}\alpha^{\Lambda}_{sss}}{\lambda^3\alpha^{\Omega^-}_{sss}}=\alpha^{\Lambda}_{sss}\ , \quad (47)$$

and so on. Proceeding in the same manner as we did above to calculate these $\alpha^{B_i}_{q_1q_2q_3}$, we obtain these ratios as shown in Table II. We notice that $\langle n_{\Xi^-\bar{\Lambda}}\rangle/\langle n_{\Xi^-}\rangle$, $\langle n_{\Xi^*\bar{\Lambda}}\rangle/\langle n_{\Xi^{*-}}\rangle$, and $\langle n_{\Omega^-\bar{\Lambda}}\rangle/\langle n_{\Omega^-}\rangle$ are equal to 1 but $\langle n_{\Lambda\bar{\Lambda}}\rangle/\langle n_{\Lambda}\rangle$, $\langle n_{\Lambda(1520)\bar{\Lambda}}\rangle/\langle n_{\Lambda(1520)}\rangle$, $\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle/\langle n_{\Sigma^\pm}\rangle$, and $\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle/\langle n_{\Sigma^{*\pm}}\rangle$ are not. This is because that, when Ξ^-, Ξ^{*-}, or Ω^- are produced in this limit, two of the three antiquarks in the antibaryon must be strange antiquarks. According to the data given by the Particle Data Group,[11] this antibaryon must decay into $\bar{\Lambda}$. But when $\Sigma^\pm$, $\Sigma^{*\pm}$, Λ or $\Lambda(1520)$ is produced, there is only one strange antiquark in the antibaryon which may not be or decay into $\bar{\Lambda}$.

(iii) An approximate estimation of $g_i(\langle N\rangle)$ *at moderate* $\langle N\rangle$. After some numerical calculations, we obtain $G_i(N)$'s as functions of N shown in Fig. 1. It can easily be seen that when N becomes very large, $G_i(N)$ ($i=1$, 2, 3, and 4) have the common limit $P_{B\Longrightarrow\Lambda}$. If N is relatively small, $G_i(N)$ are relatively large, and the smaller the N is, the larger the $G_i(N)$'s are, with only one exception that $G_3(N=3)$ is smaller than $G_3(N=4)$. Approximately, we take

$$g_i(\langle N\rangle)=\langle G_i(N)\bar{n}_B(N)\rangle/\langle n_B\rangle$$
$$\approx\langle G_i(N)\rangle\langle\bar{n}_B(N)\rangle/\langle n_B\rangle$$
$$=\langle G_i(N)\rangle\approx G_i(\langle N\rangle) \quad (48)$$

and then we can estimate those yield ratios given in Eqs. (27)–(33) at different energies $\sqrt{s}$ or $\langle N\rangle$. From Fig. 1, we see that $G_i(N)$'s vary with N monotonically for $N>3$ and do not change very fast with N. So we can expect that the approximation shown in Eq. (48) is not bad. To see the accuracy of it, we take $P(\langle N\rangle;N)$ as a Poissonian,

$$P(\langle N\rangle;N)=\frac{\langle N\rangle^N}{N!}e^{-\langle N\rangle}\,, \tag{49}$$

and $\bar{n}_B(N)$ as $\bar{n}_B(N)\propto N$, and make calculations on $g_i(\langle N\rangle)$. The results are given in Table III. We see from the table that Eq. (48) is really a good approximation.

The average number of quarks $\langle N\rangle$ at a given energy $\sqrt{s}$ is about the same as the charged multiplicity $\langle n_{\mathrm{ch}}\rangle$ of the final hadrons at the same energy.[13,6] To compare with the data, we take several $\langle N\rangle$ around $\langle n_{\mathrm{ch}}\rangle$ to calculate these yield ratios. The calculated results and their comparison with the available data are given in Table II. In the event selection, the ARGUS Collaboration chose those Λ's coming from the main vertex consciously.[3] In this way, they could reduce although not completely eliminate the contributions from the decays of Ξ's or Ω's. For comparison we also calculate the yield ratios if the contributions to the Λ's from the decays of the Ξ's and Ω's are completely eliminated, i.e., taking α_{uss}^{Λ} and α_{sss}^{Λ} in Eqs. (20)–(26) and also when calculating $G_i(N)$ as zero. The results are given in parentheses in the table. From comparison with the data, we see that there is little room left for one to introduce any other mechanism to produce extra $B\bar{B}$ flavor correlations other than that coming from the global flavor compensation of the quarks and the antiquarks. In the table, the predictions in the CERN LEP energy region, $\sqrt{s}\approx 90$ GeV, $\langle N\rangle\approx\langle n_{\mathrm{ch}}\rangle\approx 21$ (Ref. 15) are also given.

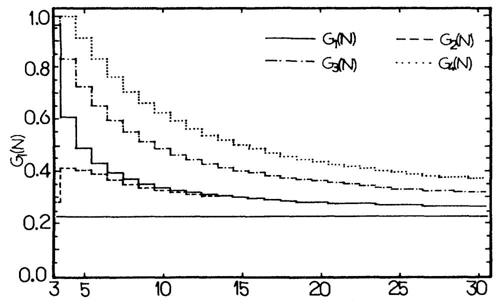

FIG. 1. The calculated $G_i(N)$'s as functions of N from Eqs. (15) in the text. The straight line represents the $p_{B\Rightarrow\Lambda}$. In the calculations we take $\lambda=0.3$ and $\beta=0.5$.

TABLE II. Comparison of the calculated $B\bar{B}$ flavor correlations in this paper with the ARGUS data. Those data followed by (Υ)'s are for direct Υ decay and those that are not are for the nearby continuum. The numbers in parentheses are the calculated results when the contributions from Ξ and Ω decays to Λ's are completely eliminated.

Baryon ratios	The ARGUS data (Ref. 3) Υ energy region $\sqrt{s}\approx 10$ GeV $\langle n_{\mathrm{ch}}\rangle\approx 8$ (Ref. 14)	Limits at $N=3$	Theoretical predictions: Approximate results using Eq. (48) at $\langle N\rangle$ being equal to 7	8	9	10	12	21	Limits at large $\langle N\rangle$
$\frac{\langle n_{\Lambda\bar{\Lambda}}\rangle}{\langle n_\Lambda\rangle}$	0.306±0.044±0.021	0.851	0.444	0.416	0.396	0.379	0.355	0.304	0.237
	0.328±0.025±0.023(Υ)	(0.815)	(0.319)	(0.298)	(0.282)	(0.271)	(0.254)	(0.224)	(0.191)
$\frac{\langle n_{\Xi^-\bar{\Lambda}}\rangle}{\langle n_{\Xi^-}\rangle}$	0.65±0.18±0.06	1	0.608	0.565	0.530	0.502	0.460	0.366	0.237
	0.46±0.17±0.05(Υ)	(0)	(0.342)	(0.334)	(0.326)	(0.317)	(0.302)	(0.261)	(0.191)
$\frac{\langle n_{\Lambda(1502)\bar{\Lambda}}\rangle}{\langle n_{\Lambda(1520)}\rangle}$	0.39±0.17	0.976	0.409	0.383	0.365	0.351	0.330	0.288	0.237
	0.37±0.17(Υ)	(0.976)	(0.326)	(0.302)	(0.285)	(0.273)	(0.256)	(0.224)	(0.191)
$\frac{\langle n_{\Sigma^\pm\bar{\Lambda}}\rangle}{\langle n_{\Sigma^\pm}\rangle}$		0.336	0.381	0.365	0.351	0.340	0.324	0.287	0.237
		(0.336)	(0.298)	(0.283)	(0.272)	(0.263)	(0.250)	(0.223)	(0.191)
$\frac{\langle n_{\Sigma^{*\pm}\bar{\Lambda}}\rangle}{\langle n_{\Sigma^{*\pm}}\rangle}$		0.313	0.380	0.364	0.351	0.340	0.323	0.287	0.237
		(0.313)	(0.297)	(0.283)	(0.271)	(0.263)	(0.249)	(0.223)	(0.191)
$\frac{\langle n_{\Xi^{*-}\bar{\Lambda}}\rangle}{\langle n_{\Xi^{*-}}\rangle}$		1	0.607	0.563	0.529	0.501	0.459	0.366	0.237
		(0)	(0.342)	(0.334)	(0.326)	(0.317)	(0.302)	(0.261)	(0.191)
$\frac{\langle n_{\Omega^-\bar{\Lambda}}\rangle}{\langle n_{\Omega^-}\rangle}$		1	0.775	0.720	0.674	0.637	0.577	0.439	0.237
		(0)	(0.272)	(0.295)	(0.307)	(0.312)	(0.312)	(0.285)	(0.191)

TABLE III. Comparison of the calculated $G_i(\langle N\rangle)$ with $g_i(\langle N\rangle)$ calculated using a Poissonian for $P(\langle N\rangle;N)$ and $\bar{n}_B(N)\propto N$. In the calculations, we take $\lambda=0.3$ and $\beta=0.5$.

$\langle N\rangle$	3	4	5	6	7	8	9	10	11	12	13	14	15
$G_1(\langle N\rangle)$	0.976	0.621	0.505	0.446	0.409	0.383	0.365	0.351	0.339	0.330	0.322	0.316	0.310
$g_1(\langle N\rangle)$	0.650	0.568	0.504	0.454	0.417	0.390	0.369	0.354	0.341	0.331	0.323	0.316	0.311
$G_2(\langle N\rangle)$	0.313	0.434	0.422	0.400	0.380	0.364	0.351	0.340	0.331	0.323	0.317	0.311	0.306
$g_2(\langle N\rangle)$	0.387	0.390	0.386	0.378	0.368	0.357	0.347	0.338	0.330	0.323	0.316	0.311	0.306
$G_3(\langle N\rangle)$	1	0.846	0.739	0.663	0.607	0.563	0.529	0.501	0.478	0.459	0.442	0.428	0.416
$g_3(\langle N\rangle)$	0.816	0.751	0.692	0.639	0.595	0.557	0.525	0.499	0.477	0.458	0.441	0.427	0.415
$G_4(\langle N\rangle)$	1	1	0.919	0.841	0.775	0.720	0.674	0.637	0.604	0.577	0.553	0.532	0.514
$g_4(\langle N\rangle)$	0.936	0.891	0.842	0.792	0.744	0.701	0.662	0.628	0.599	0.573	0.550	0.530	0.512

IV. CONCLUSIONS AND DISCUSSIONS

Starting from the assumption that baryons and antibaryons are produced by the stochastic combination of quarks and antiquarks, we have calculated the $B\bar{B}$ flavor correlations for various types of hyperons in e^+e^- annihilation. In this case the only origin of the $B\bar{B}$ flavor correlations is the global flavor compensation of all of the quarks and antiquarks. This can at least provide us with a lower limit in different models. Comparing with the data, we see that it seems that no other elaborate mechanisms which can produce extra $B\bar{B}$ flavor correlations are needed to fit the data.

In the calculations we did not make any detailed discussion of the values of λ and β. This is because $\lambda\approx0.3$ has been proved by many experiments[10,2] and it seems that this is accepted by almost everyone. The value of β is not that sure in experiments but our calculations are not sensitive to it.

In our calculations, the only assumption we used was that the baryons are produced in the stochastic combination of quarks and antiquarks. No assumption is made on how they combine into mesons and baryons. In this context, the results given by the ARGUS Collaboration on baryon production in the Υ energy region can easily be understood. They found that the average yields of various baryons in direct Υ decay are much higher than those in the nearby continuum, but the $B\bar{B}$ flavor correlations are almost the same in both cases.[2,3] This seems to tell us that in both cases the baryons and antibaryons are produced by the stochastic combination of quarks and antiquarks, but the detailed mechanisms are different.

ACKNOWLEDGMENTS

This work was supported in part by the National Natural Science Foundation of China.

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