Search for supersymmetric baryons near production threshold in terms of the superflavor symmetry

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Abstract

The supersymmetry (SUSY) may be one of the most favorable extensions of the standard model (SM), however, so far at LHC no evidence of the SUSY particles were observed. An obvious question is whether they have already emerged, but escaped from our detection or do not exist at all. We propose that at future ILC which may provide sufficient energy to produce SUSY particles if they are not too heavy as suggested by many authors and low background environment. The superflavor symmetry associates baryons with mesons as long as both of them contain a heavy constituent and a light one. Thus in this work, we are able to calculate the production rate of SUSY baryons near their production threshold in terms of the $B\bar{B}$ production data. Our analysis unambiguously indicates that the future ILC data would determine if the SUSY particles with a mass below $\sqrt{s}/2$ ($\sqrt{s}$ is the ILC energy) indeed exist.
I. INTRODUCTION

As is well known, the most important goal of high energy research is to look for new physics beyond standard model (BSM), and SUSY may be the most favorable one because it can reasonably explain the naturalness problem of Higgs and provide a dark matter candidate. Moreover, its existence makes the three strong, electromagnetic and weak interactions to merge into one point at the grand unification scale \[1\]. However, so far, at Tevatron and LHC, no SUSY particles have ever been observed. One may wonder if the SUSY model is wrong or should be radically modified. Of course, there is one more possibility that the SUSY particles have indeed been produced, but are not identified, namely buried in the messy background at hadron colliders. Several authors \[2\] notice this possibility and have tried to reanalyze the LHC data and indicate the probability of misidentifying the SUSY particles.

It is also widely recognized that the hadron collider is a machine for discovery, while the electron-positron collider is for precise measurement and unambiguous confirmation of the discoveries.

In the minimal supersymmetric standard model (MSSM) and the modified SUSY models, the superpartner of top quark has two mass eigenstates, \(\tilde{t}_1\) and \(\tilde{t}_2\), and the lighter one (\(\tilde{t}_1\)) is assumed to be the lightest squark. Generally, it is believed that the lightest supersymmetric particle (LSP) is the colorless neutral neutralino, whereas squark \(\tilde{t}_1\) is in a color anti-triplet and can form a hadron with a color triplet SM quark \[3–7\]. As in most works of literature, the squark \(\tilde{t}_1\) is supposed to be the next-to-lightest supersymmetric particle (NLSP) whose mass is not far away from that of LSP, so that its lifetime of the light stop \(\tilde{t}_1\) would be longer than \(1/\Lambda_{QCD}\) \[8–12\] and can attract a light quark(anti-quark) to make a color singlet SUSY baryon \(\tilde{X}(\tilde{t}_1\bar{q})\), which is also named as mesino in literature. For SUSY baryons consisting of \(\tilde{t}_1\) and a heavy anti-quark \(Q\) (\(Q=c,b\)), the fragmentation functions were calculable through perturbative QCD and studied by Chang et al. \[13\]. In their scheme, to reliably determine the initial condition for the evolution differential equation, the SM quark must be heavy so that perturbative QCD can apply, and therefore this production rate is much suppressed. Whereas, if the SM constituent quark is light (u,d,s), the non-perturbative QCD effects would be dominant and make the computation not reliable \[14\].

In this work, we are going to calculate the production rate of SUSY baryon which consists of a heavy scalar quark and a light SM antiquark at future ILC. Indeed, the production rate
of a pair of SUSY squark-anti-squark is easy to be calculated no matter at the tree-level or loop-level according to the corresponding Feynman rules. The key point is how to calculate the hadronic matrix elements which are fully governed by the non-perturbative QCD. Obviously, it is hard to directly evaluate the relevant hadronic matrix elements. An alternative scheme can be adopted, namely we could associate the data of B-meson production near its threshold obtained by CLEO [15], Belle [16], and BaBar [17] collaborations, with the production of SUSY baryons which may be obtained at ILC near their threshold by means of the superflavor symmetry. The superflavor symmetry [18] establishes a definite relation between the processes where heavy baryons and mesons are respectively involved. Both of the baryon and meson contain a heavy constituent and a light quark(anti-quark). For the meson case the heavy constituent is a heavy quark(anti-quark) of color-triplet (anti-triplet) $b(\bar{b})$ or $c(\bar{c})$, whereas for the SUSY baryon case the heavy constituent is a color-triplet(anti-triplet) scalar (or vector). In our previous study [14], we suppose the heavy constituent to be a heavy diquark ($bb$, $bc$ or $cc$) whose inner structure may manifest as a complicated form factor. Of course, it is more natural to consider the SUSY case where the heavy constituent in the baryon is a color-triplet (anti-triplet) squark (anti-squark). Once we have the relation, by the measured production rates of the B-meson at the B-factories, we can obtain the production rate of the SUSY baryons at ILC.

In our scenario, we use the data which naturally involve any non-perturbative QCD effects, to determine the production rate of SUSY baryon via the superflavor symmetry, in that way we do not need to directly calculate the troublesome non-perturbative QCD effects.

The application of superflavor symmetry is related to the kinematics of the concerned processes. In the heavy quark effective theory (HQET) [19–21], for the transition of $b \to c$, a gluon (or photon) is exchanged at t-channel and the hadronic transition matrix element can be described by a unique Isgur-Wise function $\xi(\omega)$ where $\omega = v \cdot v'$ is the recoil variable and $v, v'$ are the four-velocities of initial and final heavy mesons. For the production process, the exchange of gluon, photon or $Z_0$ (see in the following) exists at the s-channel and the kinematic region is different as $v \to -v$ [14]. We just need to generalize the Isgur-Wise function to this kinematic region and the situation was thoroughly discussed in our earlier work [14]. Moreover, as the collision energy is much above the production threshold of the SUSY baryons, for example at the LHC, one should consider an evolution of a squark into a SUSY baryon [13]. In that case, the sub-processes could be $q\bar{q}' \to \tilde{q} \tilde{q}'$ or gluon fusion $gg \to \tilde{q} \tilde{q}$. Then only the inclusive process
\[ pp \rightarrow \tilde{X} + \tilde{q} + X \] where \( \tilde{X} \) is a SUSY baryon, can be used to search for SUSY baryons \[13\], but the background is extremely messy. Thus one cannot apply the superflavor symmetry there and we lose the advantage of using the data of B-meson production which are obtained by the B-factories. Unless, we can evaluate the evolution which is described by the Altereli-Parrasi equation \[13\], we are unable to make any definite prediction on the production rate of \( \tilde{X} \). By contrast, ILC is an electron-positron collider and one can expect to observe \( e^+e^- \rightarrow \tilde{X}\tilde{X} \) in a low background. Moreover, for avoiding the uncertainties brought up by evaluating the evolution from squark to SUSY baryon where the non-perturbative QCD effects play a crucial role, we turn to calculate the production rate of \( e^+e^- \rightarrow \tilde{X}\tilde{X} \) near its threshold.

To predict the production rate of the SUSY baryons at threshold, one could use the data of B-factories where B mesons are produced near threshold. Namely, we are going to use the ratio

\[
\frac{\sigma^{\text{theor}}(e^+e^- \rightarrow \tilde{X}\tilde{X})}{\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})} = \frac{\sigma^{\text{theor}}(e^+e^- \rightarrow \bar{B}B)}{\sigma^{\text{exp}}(e^+e^- \rightarrow \bar{B}B)},
\]

(1)

where the superscript "theor" means the theoretically predicted value and \( \sigma^{\text{exp}}(e^+e^- \rightarrow \bar{B}B) \) is the measured value at B-factories and \( \sigma(e^+e^- \rightarrow \tilde{X}\tilde{X}) \) is what we expect. The ratio of

\[
\frac{\sigma^{\text{theor}}(e^+e^- \rightarrow \tilde{X}\tilde{X})}{\sigma^{\text{theor}}(e^+e^- \rightarrow \bar{B}B)}
\]

can be obtained in terms of the superflavor symmetry, so that we can eventually obtain \( \sigma(e^+e^- \rightarrow \tilde{X}\tilde{X}) \). In fact, by the superflavor symmetry we can relate the matrix element \( < \tilde{X}\tilde{X}|J^\mu|0 > \) to the matrix element \( < \bar{B}B|J'^\mu|0 > \), where \( J^\mu \) and \( J'^\mu \) are vector currents corresponding to squark-anti-squark and quark-anti-quark productions respectively. Indeed the non-perturbative QCD effects are involved in those matrix elements which so far cannot be accurately evaluated based on a fundamental field theory, thus once we relate them, the unknown factor is canceled in the ratio, thus one can use the data of \( \bar{B}B \) production data which are well measured at the B-factories to predict the SUSY baryon production rate.

However, there is a problem that all the available data about the B-meson productions are not exactly what we need, because the available data are from \( e^+e^- \rightarrow \Upsilon(4S)/\Upsilon(5S)/\Upsilon(6S) \rightarrow \bar{B}B \), namely via the \( \Upsilon \) resonances. We need the data on the direct production of \( e^+e^- \rightarrow \bar{B}B \), i.e the contribution of the continuum spectrum near the threshold. The total spectrum on \( R_B \) was presented by experimentalists \[17\], and we are going to use it as our input.

In the ILC technical design report (volume II) \[22\], the top squark \( \tilde{t}_1 \) is expected to be found as long as \( m_{\tilde{t}_1} \leq \sqrt{s}/2 \). At early stage, ILC will be running at the \( \sqrt{s} = 500 \) GeV with luminosity
In this stage, the $t_1$ mass will be determined to 1 GeV and even to 0.5 GeV accuracy. Then the center of mass energy will be upgraded to 1 TeV with luminosity 1000 fb$^{-1}$. At that energy scale, a SUSY particle with mass less than 0.5 TeV could be found, and if considering possible R-violation, even heavier SUSY particles might be observed.

The work is organized as follows: after this introduction where we explicitly introduce our strategy, we formulate the cross sections for SUSY baryon $\tilde{X}$ and heavy SM meson $B$ in Sec. II. In Sec. III, we present our numerical results along with all input parameters, and we especially show how to get the continuum spectrum from the $R_b$ data of B-factories, i.e. to subtract the peak contributions from measured data. The last section is devoted to our conclusion and some discussions.

II. THE SUPERFLAVOR SYMMETRY AND THE CROSS SECTION

Let us first have a quick review of the superflavor symmetry, and then focus on its application. Georgi introduced the superflavor symmetry [18] which relates the processes involving a heavy meson made of a heavy quark $h_v^+$ and a light anti-quark to a heavy baryon made of a color triplet scalar $\chi_v$ and a light color anti-triplet quark. In HQET, one has $\not{h}_v^+ = h_v^+$. Putting $h_v^+$ and $\chi_v$ altogether into a 5-column vector with a given velocity [18], one has

$$\Psi_v = \begin{pmatrix} h_v^+ \\ \chi_v \end{pmatrix}. \quad (2)$$

Here one can write the wavefunctions of the meson and baryon consisting of $h_v$ and $\chi_v$ as

$$\Psi_H(v) = \begin{pmatrix} \sqrt{m_h}\gamma_5 \frac{1}{2}(1 - \not{v}) \\ 0 \end{pmatrix} \quad (3)$$

and

$$\Psi_X(v) = \begin{pmatrix} 0 \\ u C \frac{1}{\sqrt{2m_\chi}} \end{pmatrix}, \quad (4)$$

where $C$ is the charge conjugation operator and $u$ is the spinor wave function of the $\chi$ bound state.
The matrix elements for meson and baryon were given by Georgi and Wise \[\text{[18]}\] as
\[
\langle H(v')\bar{H}(v)|J^\mu|0 \rangle = \langle H(v')\bar{H}(v)|\bar{h}\gamma^\mu h|0 \rangle = \xi(-v\cdot v')m_h(v' - v)^\mu, \tag{5}
\]
\[
\langle X(v')\bar{X}(v)|J^\mu|0 \rangle = \langle X(v')\bar{X}(v)|i\gamma^\mu\partial^\mu|0 \rangle = \xi(-v\cdot v')\frac{1}{2}(v' - v)^\mu\bar{u}v, \tag{6}
\]
where \(\xi(-v\cdot v')\) is the Isgur-Wise function normalized as \(\xi(1) = 1\).

Below we will derive the transition amplitudes and cross sections for the processes \(e^+e^-\to B\bar{B}\) and \(\bar{X}X\), where \(B\) and \(X\) denote the meson and baryon respectively. For the process \(e^+e^-\to B\bar{B}\) in B factories, the collision energy \(\sqrt{s}\) is much less than the mass of \(Z_0\), thus the \(Z_0\) contribution can be safely ignored. By contrast, since in the process \(e^+e^-\to \bar{X}X\), \(\sqrt{s}\) is larger than the mass of \(Z_0\), the \(Z_0\) contribution must also be included. The differential cross sections for meson is
\[
d\sigma(B\bar{B}) = \frac{1}{8\pi s_1} \sum_{s_1,s_f} \left| i\frac{-1}{3}e\langle B\bar{B}|\bar{b}\gamma^\mu b|0 \rangle \frac{1}{s_1} \langle 0|\bar{e}(-ie)\gamma_\mu e|e^+e^- \rangle \right|^2 d\bar{v}, \tag{7}
\]
where only photon contribution is taken into account, and for baryon is
\[
d\sigma(\bar{X}X) = \frac{1}{8\pi s_2} \sum_{s_i,s_f} \left| i\frac{2}{3}e\langle \bar{X}X|\bar{t}^+\gamma^\mu t|0 \rangle \frac{1}{s_2} \langle 0|\bar{e}(-ie)\gamma_\mu e|e^+e^- \rangle - g_{tz}\langle \bar{X}X|\bar{t}^+\gamma^\mu t|0 \rangle \frac{1}{s_2-m_Z^2} \langle 0|\bar{e}\gamma_\mu g_{ez}e|e^+e^- \rangle \right|^2 d\bar{v}, \tag{8}
\]
where \(g_{tz} = \frac{ie}{\sin\theta_w\cos\theta_w}(\frac{1}{2}\cos^2\theta_t - \frac{3}{2}\sin^2\theta_w)\) is the coupling constant between stop and \(Z_0\) boson, \(\theta_t\) in \(g_{tz}\) is the mixing angle \[\text{[8]}\], \(\theta_w\) is Weinberg angle, \(g_{ez} = \frac{-ie}{\sin\theta_w\cos\theta_w}(1 - \frac{\gamma_5}{2}) - \sin^2\theta_w\) is the coupling constant between electron and \(Z_0\) boson, \(\sqrt{s_1}\) is the center of mass energy of B factory and \(\sqrt{s_2}\) is the center of mass energy of ILC. It is noted that \(s_i\) (i=1,2) is the spin projections of the electron and position in the initial state and \(s_f\) is the spin projections of the produced SUSY baryons in the final state and \(d\bar{v}\) is the corresponding final state phase space.

Fig\[\text{[1]}\] and Fig\[\text{[2]}\] show the leading order Feynman diagrams for the processes \(e^+e^-\to B\bar{B}\) and \(e^+e^-\to \bar{X}X\) respectively. The complete transition amplitudes are
\[
i\mathcal{M}_B = \xi(-\omega)(\frac{-1}{3}e(p_2 - p_1)_\mu)\frac{\bar{v}(k_2)(-ie\gamma^\mu)}{s_1}, \tag{9}
\]
for mesons, and
\[
i\mathcal{M}_\bar{X} = \xi(-\omega)[\bar{u}(p_2)i\frac{-2e}{m_i}(\frac{p_2 - p_1}{2m_i})_\mu v(p_1)\frac{-i}{s_2}\bar{v}(k_2)(-ie\gamma^\mu)u(k_1) + \bar{u}(p_2)g_{tz}\frac{(p_2 - p_1)_\mu}{2m_i}v(p_1)\frac{-i}{s_2-m^2_Z}\bar{v}(k_2)\gamma_\mu g_{ez}u(k_1)], \tag{10}
\]
FIG. 1: The process of $e^+e^- \rightarrow B\bar{B}$.

FIG. 2: The process of $e^+e^- \rightarrow \tilde{X}\bar{\tilde{X}}$.

for superbaryons. Here $\omega = v \cdot v' = \frac{s}{2m^2} - 1$, $k_1$ and $k_2$ are the momenta of the incoming electron and positron, $p_1$ and $p_2$ are the momenta of the outgoing anti-hadron and hadron. It is noted that here the hadronic matrix elements are determined according to the superflavor symmetry as shown in Eqs.(5) and (6). Thus we obtain the cross section for pair productions as

$$\sigma = \frac{1}{22} \int \frac{d^3p_1}{(2\pi)^3} \frac{d^3p_2}{(2\pi)^3} \frac{\delta^4(p_1 + p_2 - k_1 - k_2)}{2E_1 2E_2} (2\pi)^4 \delta^4(p_1 + p_2 - k_1 - k_2) \frac{1}{4} \sum_{\text{spin}} |M|^2. \quad (11)$$

The final expression includes the Isgur-Wise function $|\xi(-\omega)|^2$ which determines the hadronic matrix elements and manifests the non-perturbative QCD effects in the hadronization. Generally it can be obtained by employing some phenomenological models, instead, here by comparing the two production processes near their production thresholds which have the same $|\xi(-\omega)|^2$ one can evaluate the production rate of the SUSY baryons using the well measured $B\bar{B}$ production rates.

In this scenario, we eliminate the model dependence of the computations. In next section, we will deal with the cross section along with all the inputs which are used for the numerical
computations.

III. NUMERICAL RESULTS

So far, the collider experiments including Tevatron and LHC have not set stringent constraints on $m_{\tilde{t}}$ yet, and we would like to assume $m_{\tilde{t}}$ varying from 150 GeV to 500 GeV.

In our numerical calculation, $m_B = 5.3$ GeV, $m_{\tilde{t}} = 210 \sim 250$ GeV is taken for $\sqrt{s} = 500$ GeV and $m_{\tilde{t}} = 420 \sim 500$ GeV for $\sqrt{s} = 1$ TeV respectively, the running Weinberg angle $\sin^2 \theta_w$ is $2.398$ for $\sqrt{s} = 500$ GeV and $2.444$ for 1 TeV, $\alpha_e$ is approximately equal to $\alpha_e(m_Z) = 1/128.78$, the range of mixing angle $\theta_t$ is uncertain and generally can span in a rather wide range of $0 \sim \pi$. Following Ref. [8], in our computation we take a few special values of $\cos^2 \theta_t$ as 0, 1/2 and 1. The advantage of our scheme is that one does not need to use the concrete value of $|\xi(-\omega)|^2$. By comparing $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})$ with $\sigma(e^+e^- \rightarrow BB)$ at the same value of $\omega = s/(2m^2) - 1$ which is close to unity near the production thresholds of SM mesons $BB$ at the B-factories or SUSY baryons $\tilde{X}\tilde{X}$ at future ILC, we can eliminate the bothersome uncertainty, namely let the data take care of it.

In Ref. [17] the experimental data on the $R_b$ versus the $\sqrt{s}$ for $BB$ between $\sqrt{s} = 10.54$ and 11.2 GeV are presented and Fig. 1 of Ref. [17] where $R_b$ is defined as $R_b(s) = \sigma_b(s)/\sigma_{\mu\mu}(s)$. In our computations, we consider the direct production of $BB$ from $e^+e^-$ annihilation into a photon which later turns into the meson pair, we need only the contribution from the continuum spectrum. Instead of using the data given in literature, which mostly include the contribution of resonances $\Upsilon(4s)$, $\Upsilon(5s)$ and $\Upsilon(6s)$, we read out the $R_b$ values which correspond to the energies slightly below the peak region, directly from the figure of Ref. [17] and list them in table I.

| $\sqrt{s}$ (GeV) | 10.628 | 10.632 | 10.638 | 10.666 | 10.678 | 10.688 | 10.698 |
|-----------------|--------|--------|--------|--------|--------|--------|--------|
| $R_b$           | 3.32   | 3.19   | 3.25   | 3.20   | 3.31   | 3.12   | 3.36   |
| $\sqrt{s}$ (GeV)| 10.703 | 10.718 | 10.736 | 11.158 | 11.168 | 11.180 | 11.192 |

TABLE I: The $R_b$ for the process $\sigma(e^+e^- \rightarrow BB)$ [17].
The experimental errors of $R_b$ shown in Fig.1 of Ref. [17] is about $0.015$, thus in this paper we take the uncertainty of $R_b$ as 5%. Ref [17] determines the relation $R_b(s) = \sigma_b(s)/\sigma^{0}_{\mu\mu}(s)$ with $\sigma^{0}_{\mu\mu}(s) = 4\pi\alpha^2/3s$. For the uncertainty from $R_b$ is large, it is reasonable to omit the uncertainties from other sources while numerically computing the $\sigma_b(s)$ value.

| $\omega$ | 1.00 | 1.17 | 1.36 | 1.58 | 1.83 |
|----------|------|------|------|------|------|
| $m_{\tilde{t}}$(GeV) | 250  | 240  | 230  | 220  | 210  |
| $\sigma(e^+e^- \to \tilde{X}\tilde{X})/|\xi(-\omega)|^2$(pb) | 0.00051 | 0.00302 | 0.00864 | 0.01845 |

TABLE II: The cross section for the process $\sigma(e^+e^- \to \tilde{X}\tilde{X})$ with the center of mass energy $\sqrt{s}=500$ GeV, $\cos^2 \theta_t$ is set to 1/2.

| $\omega$ | 1.00 | 1.17 | 1.36 | 1.58 | 1.83 |
|----------|------|------|------|------|------|
| $m_{\tilde{t}}$(GeV) | 500  | 480  | 460  | 440  | 420  |
| $\sigma(e^+e^- \to \tilde{X}\tilde{X})/|\xi(-\omega)|^2$(pb) | 0.00013 | 0.00075 | 0.00214 | 0.00457 |

TABLE III: The cross section for the process $\sigma(e^+e^- \to \tilde{X}\tilde{X})$ with the center of mass energy $\sqrt{s}=1$ TeV, $\cos^2 \theta_t$ is set to 1/2.

| $\omega$ | 1.00 | 1.17 | 1.36 | 1.58 | 1.83 |
|----------|------|------|------|------|------|
| $\sqrt{s}$(GeV) | 10.60 | 11.04 | 11.52 | 12.04 | 12.62 |
| $\sigma(e^+e^- \to B\bar{B})/|\xi(-\omega)|^2$(pb) | 1.461 | 3.68 | 5.99 | 8.14 |

TABLE IV: The cross section for the process $\sigma(e^+e^- \to B\bar{B})$ for the CM energy of the B-factories.

In Tab.II and III we show the numerical values of the cross sections in the range of $m_{\tilde{t}} = 250 \sim 210$ GeV and $m_{\tilde{t}} = 500 \sim 420$ GeV corresponding to $\omega$ varying from 1 to 1.83 at the
center of mass energy $\sqrt{s} = 500$ GeV and $\sqrt{s} = 1$ TeV respectively, and $\cos^2 \theta_t$ is set to be 1/2. Tab.IV gives the results of $\sigma(e^+e^- \rightarrow BB)$ with the same $\omega$ values as that in Tabs. II, III.

Comparing with the experimental data given in Ref. [17] we can obtain the cross section of $\tilde{X}\tilde{X}$ production. Those results are listed in table V and VI. In those table s it is noticed that when $\cos^2 \theta_t$ varying from 0 to 1/2, the cross section changes only slightly. But when $\cos^2 \theta_t$ varying from 1/2 to 1, the cross section is almost doubled. We also demonstrate the dependence of $\tilde{X}\tilde{X}$ cross section on $m_{\tilde{t}}$ with $\cos^2 \theta_t = 1/2$ in Fig. 3, Fig. 4 respectively.

| $\omega$ | 1.00 | 1.17 | 1.36 | 1.58 | 1.83 |
|----------|------|------|------|------|------|
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 0)$ | 0 | 0.0965 | 0.2058 | 0.3305 | 0.4734 |
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 1/2)$ | 0 | 0.0933 | 0.1991 | 0.3196 | 0.4578 |
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 1)$ | 0 | 0.1404 | 0.2996 | 0.4809 | 0.6889 |

TABLE V: The cross section for the process $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})$ with the center of mass energy $\sqrt{s}=500$ GeV.

| $\omega$ | 1.00 | 1.17 | 1.36 | 1.58 | 1.83 |
|----------|------|------|------|------|------|
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 0)$ | 0 | 0.0243 | 0.0519 | 0.0834 | 0.1195 |
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 1/2)$ | 0 | 0.0231 | 0.0493 | 0.0791 | 0.1133 |
| $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})(pb)(\cos^2 \theta_t = 1)$ | 0 | 0.0335 | 0.0714 | 0.1114 | 0.1643 |

TABLE VI: The cross section for the process $\sigma(e^+e^- \rightarrow \tilde{X}\tilde{X})$ with the center of mass energy $\sqrt{s}=1$ TeV.

From Fig. 3 and Fig. 4 we can see that the solid line corresponds to experimental $\sigma_{b\bar{b}}$ data with center of mass energy $\sqrt{s} = 11.2 \sim 10.6$ GeV and the error bar originates from experimental uncertainty in $R_b$ measurement [17], while the dotted line is a presumable extension of the solid line which is the experimentally measured region.
FIG. 3: The dependence of cross section on the stop mass in the center of mass energy $\sqrt{s} = 500$ GeV. The solid line corresponds to the experimental data from the BaBar experiment, the error bar corresponds to the experimental uncertainty of $R_b$, the dotted line is the result extending from the BaBar experimental data.

IV. CONCLUSION AND DISCUSSION

With the help of superflavor symmetry, we associate the production of the stop-baryon pairs with $B\bar{B}$ production at the B-factories. Thus the production rate of the SUSY baryon pair near its production threshold at the future ILC is obtained in terms of the experimental measured B-meson pair production rate at the B-factories.

According to the proposals for ILC, we choose two typical cases, i.e., the CM energy of the machine is at 500 GeV and 1 TeV respectively. Since we consider the SUSY baryon production near the threshold, here we set the mass of the stop at the vicinities of 240 GeV and 480 GeV respectively. Even though, with the special choice, our strategy does not lose generality, by contrary, as the LHC may provide hints about the SUSY particles, our results would offer a theoretical guide for designing the new machine and selecting the CM energies.

The advantage of our scheme is that the results are almost model-independent, and directly
FIG. 4: The dependence of cross section on the stop mass in the center of mass energy $\sqrt{s} = 1$ TeV. The solid line corresponds to the experimental data from the BaBar experiment [17], the error bar corresponds to the experimental uncertainty of $R_b$, the dotted line is the result extending form the BaBar experimental data.

determined by the well measured data of the B-factories. The HQET and the superflavor symmetry is based on the general principles of quantum field theory, so the values are relatively trustworthy. In this way, we avoid to evaluate the non-perturbative QCD effects which causes a large uncertainty in the theoretical estimate of the processes where hadronization is involved. Moreover, as considering the stop baryon production near its threshold, we do not need to worry about the evolution from a quark or squark into a hadron.

At the center of mass energy $\sqrt{s} = 500$ GeV, the cross section of the baryon pair containing a $\tilde{t}$ is estimated as $0.46 \sim 0.1$ pb when $m_{\tilde{t}}$ spans a range from 210 GeV to 240 GeV. For the center of mass energy increasing to $\sqrt{s} = 1$ TeV, the cross section of the baryon pair production ranges from 0.113 pb to 0.024 pb as $m_{\tilde{t}}$ increasing from 420 GeV to 480 GeV.

The ILC is proposed to be built up in 10 years [22]. Its early stage is designed to be running at the center of mass energy of $\sqrt{s} = 500$ GeV with luminosity 500 fb$^{-1}$, then the energy will be updated to 1 TeV with luminosity 1000 fb$^{-1}$ [22]. This means that the ILC should generate $10^5$
SUSY stop baryon pairs (for $m_{\tilde{t}} = 230$ GeV and $\sqrt{s} = 500$ GeV) and $5 \times 10^4$ pairs (for $m_{\tilde{t}} = 460$ GeV and $\sqrt{s} = 1$ TeV) per year. Taking into account of detection efficiency there would be a great amount of event to be observed.

Another problem is how to observe and identify the SUSY events. As is commonly considered, the mass of the scalar top quark $\tilde{t}_1$ is next-to-lightest SUSY particle and the lightest one is the neutralino. With R-parity conservation, the main decay mode of stop is $\tilde{t}_1 \rightarrow \tilde{\chi} + a$ SM quark. If the mass splitting between stop and neutralino is very small, the decay channel $\tilde{t}_1 \rightarrow \tilde{\chi} + b + W^{(*)}$ is allowed, and generally this channel would be suppressed by the final state phase space. If this channel is more suppressed, the next one would be $\tilde{t}_1 \rightarrow \tilde{\chi} + c (u)$, those channels would be loop suppressed. Therefore we can expect a stop baryon with a relatively longer lifetime. For the baryon $\tilde{\bar{b}}_1d$ which has the same production rate as $\tilde{\bar{t}}_1u$, is charged, it is easy to record its trace in a sensitive detector. Moreover, for the small mass splitting case, a large missing energy will appear at the center of mass energy of the collider, and it is also a way to search neutralino type dark matter.

Thus we really lay hope on the next run of LHC which may provide information about the SUSY particles, then we can definitely take the hint to look for the SUSY hadrons at the future ILC where, as we suggested, it is easy to firmly identify the SUSY particles. Of course it also offers a possibility to negate the beautiful theory, if the SUSY particles are not found at 500 GeV or 1 TeV ILC or alternatively they might be even heavier than generally expected.

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