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Flavor violating processes with sgoldstino pair production

S. V. Demidov* and D. S. Gorbunov†

Institute for Nuclear Research of the Russian Academy of Sciences, 60th October Anniversary prospect 7a, Moscow 117312, Russia

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In supersymmetric extensions of the standard model of particle physics (SM), goldstino superpartners—scalar and pseudoscalar sgoldstinos—can be light enough for emerging in decays of SM particles. Sgoldstino interaction with SM fields is suppressed by the scale of supersymmetry breaking in the whole theory. Hence, searches for sgoldstinos give an opportunity to probe the underlying mechanism of supersymmetry breaking. Sgoldstino couplings to SM fields are proportional to the supersymmetry breaking parameters—MSSM soft terms—and therefore can lead to flavor violating processes in quark and lepton sectors. We consider flavor violating processes involving sgoldstino pair production which are driven by sgoldstino couplings proportional to squark and slepton soft mass terms, $\tilde{m}^2_{LL}$ and $\tilde{m}^2_{RR}$. We find that present limits on off-diagonal entries in squark and slepton squared mass matrices allow t-, b-, c-quark and τ-lepton decays at levels available for study with existing data (BaBar, Belle, CLEOc) and in ongoing experiments (LHCb, CMS, ATLAS). In particular, we obtain the following branching ratios $\mathrm{Br}(t \to cSP) \lesssim 10^{-7}$, $\mathrm{Br}(\tau \to \mu SP) \lesssim 10^{-7}$, $\mathrm{Br}(B_s \to SP) \lesssim 10^{-4}$, $\mathrm{Br}(B \to K^{(*)}SP) \lesssim 10^{-4}$, $\mathrm{Br}(D \to SP) \lesssim 10^{-7}$ with sgoldstino subsequent decays into kinematically allowed pairs of SM particles $\gamma\gamma$, e^+e^-, $\mu^+\mu^-$, etc. Remarkably, the prominent signature of sgoldstino pair production is two muon pairs with pair momenta peaked at sgoldstino masses.

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I. INTRODUCTION

Low energy supersymmetry provides a technically natural solution to the gauge hierarchy problem and is still very attractive in spite of absence of a clear experimental evidence for superpartners. Supersymmetry if it exists, must be spontaneously broken and hence there is a special Goldstone supermultiplet, which includes scalar S and pseudoscalar P sgoldstinos, goldstino and auxiliary bosonic field whose vacuum expectation value F breaks supersymmetry in the whole theory. Sgoldstinos being massless at tree-level, get masses from higher order corrections. They can be light if supersymmetry breaking happens at relatively low energy, as in models with gauge mediation [1] and in no-scale supergravity [2].

Sgoldstino phenomenology was extensively studied in literature (for a brief review see [3]) and has got special attention after HyperCP anomaly: observation of three muon pairs with invariant mass 214.3 ± 0.5 MeV in hyperon decay $\Sigma \to p\mu^+\mu^-$ [4]. The anomaly may be explained as pseudoscalar sgoldstino production in $\Sigma \to pP$ with subsequent decay $P \to \mu^+\mu^-$ [4,5] (scalar sgoldstino should be somewhat heavier in this case, $m_S \gtrsim 300$ MeV, to avoid limits from $K \to \pi\mu^+\mu^-$). Sgoldstino mass scale lower than the SM superpartner mass scale implies that self-interaction in goldstino sector is somewhat weaker as compared to coupling responsible for mediation of supersymmetry breaking to the SM sector. Sgoldstino explanation can be tested in kaon [5] and D- and B-meson decays [6] and recent searches with negative results [7,8] close some part of the model parameter space.

In this *Letter* we proceed further with light sgoldstino phenomenology concentrating on flavor violating processes with sgoldstino pair production.

Indeed, there are two types of low energy interactions between sgoldstino and matter (quark and lepton) fields. The type-I involves single sgoldstino field, the type-II utilizes both scalar and pseudoscalar sgoldstinos. The type-I couplings are proportional to so-called left-right soft terms in squark (slepton) squared mass matrices, which are determined by trilinear soft supersymmetry breaking terms. The type-II couplings are proportional to left-left and right-right terms of the same matrices. The left-right terms are naturally suppressed by fermion (quark and lepton) masses with respect to other terms. However, the type-II couplings are suppressed by additional factor $1/F$ with respect to type-I couplings. For general low energy supersymmetry breaking models type-II couplings might dominate over type-I provided that soft trilinear parameters are additionally suppressed. Note also, that flavor violating patterns in the two types of sgoldstino couplings are generally different.

Type-I couplings are responsible for sgoldstino decays into light SM particles and give rise to single sgoldstino production. Possible variants of type-I flavor-violating couplings and corresponding phenomenology have been studied in detail [6,9–11]. Type-II flavor-violating terms in sgoldstino lagrangian were addressed only in Ref. [9], where annihilation of neutral mesons π^0, $K_{L(S)}$, D^0, B^0 into sgoldstino pair have been studies. In this *Letter* we extend the study of type-II terms to the three-body decays of heavy mesons, t-quark and τ-lepton.

*demidov@ms2.inr.ac.ru
†gorby@ms2.inr.ac.ru

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II. LAGRANGIAN

The relevant for present study interaction terms of sgoldstino with SM fields (up- and down-type quarks f_{U_i}, f_{D_i} and charged leptons f_{L_i}, $i = 1, 2, 3$) read [9]

$$\begin{aligned}\mathcal{L} = &\frac{1}{4F^2}(S\partial_\mu P - P\partial_\mu S)((\tilde{m}_{L_{ij}}^{LL^2} + \tilde{m}_{L_{ij}}^{RR^2})\bar{f}_{L_i}\gamma^\mu\gamma^5 f_{L_j} \\ &+ (\tilde{m}_{L_{ij}}^{LL^2} - \tilde{m}_{L_{ij}}^{RR^2})\bar{f}_{L_i}\gamma^\mu f_{L_j} + (\tilde{m}_{D_{ij}}^{LL^2} + \tilde{m}_{D_{ij}}^{RR^2})\bar{f}_{D_i}\gamma^\mu\gamma^5 f_{D_j} \\ &+ (\tilde{m}_{D_{ij}}^{LL^2} - \tilde{m}_{D_{ij}}^{RR^2})\bar{f}_{D_i}\gamma^\mu f_{D_j} + (\tilde{m}_{U_{ij}}^{LL^2} + \tilde{m}_{U_{ij}}^{RR^2})\bar{f}_{U_i}\gamma^\mu\gamma^5 f_{U_j} \\ &+ (\tilde{m}_{U_{ij}}^{LL^2} - \tilde{m}_{U_{ij}}^{RR^2})\bar{f}_{U_i}\gamma^\mu f_{U_j}),\end{aligned} \tag{1}$$

where sum goes over $i, j = 1, 2, 3$. Supersymmetry violating vacuum expectation value F of auxiliary component of goldstino supermultiplet has the dimension of squared mass and the scale of supersymmetry breaking in the whole theory is of order $\sqrt{F}$. Parameters $\tilde{m}_{(D,U,L)_{ij}}^{XX^2}$, $X = L, R$, are MSSM soft supersymmetry breaking terms entering squark and slepton squared mass matrices (e.g., $\tilde{m}_{D_{11}}^{LL^2}$ is the squared soft mass term for superpartner of left d-quark, etc).

There are bounds on off-diagonal elements of matrices $\tilde{m}_{(D,U,L)}^{LL^2}$ and $\tilde{m}_{(D,U,L)}^{RR^2}$ coming from absence of FCNC processes and non-SM contributions to neutral pseudoscalar meson mixings. For numerical estimates of the decay rates we use values of soft supersymmetry breaking terms which are in agreement with present constraints found in literature [12–15]. It is convenient to define the dimensionless variables which parametrize the relative strength of flavor violation as

$$\delta_{XX_{ij}}^{(D,U,L)} = \frac{\tilde{m}_{(D,U,L)_{ij}}^{XX^2}}{\tilde{m}^2}, \tag{2}$$

where $X = L, R$ and $\tilde{m}$ refers to a common mass scale of superpartners.

For numerical estimates we have to choose certain values of supersymmetric parameters. Without any confirmed evidence for the presence of supersymmetry in Nature we are free to choose them at will provided no contradictions with experiment. Let us fix general scale of SUSY particle masses at $\tilde{m} = 1000$ GeV, and put all RR-components of flavor violating terms to zero, $\tilde{m}_{(D,U,L)_{ij}}^{RR^2} = 0$. All others are taken as follows

$$\delta_{LL_{13}}^{D} = 0.14, \qquad \delta_{LL_{23}}^{D} = 0.2, \tag{3}$$

$$\delta_{LL_{12}}^{U} = 0.06, \qquad \delta_{LL_{23}}^{U} = 0.3, \qquad \delta_{LL_{13}}^{U} = 0.3, \tag{4}$$

$$\delta_{LL_{13}}^{L} = 0.1, \qquad \delta_{LL_{23}}^{L} = 0.1 \tag{5}$$

They are at upper bounds of phenomenologically allowed ranges; we have not found in literature relevant limits on $\delta_{LL_{23}}^{U}$ and $\delta_{LL_{13}}^{U}$. Hereafter we treat all the values (3)–(5) as reference numbers only. To simplify the presentation further, below we plot decay branching ratios for the special choice of supersymmetry parameters

$$\tilde{m}^2 = F, \tag{6}$$

which we call the unitarity limit [16]. We comment on the behavior of decay rates with change of model parameters in Sec. VI.

Sgoldstinos are even with respect to R-parity and hence unstable. Apart of (1), there are other interaction terms (see e.g. [3,9]) responsible for the instability. Sgoldstinos decay into SM particles and two-body decay mode dominates, see [9] for details. Generally, sgoldstino decays into $\gamma\gamma$, e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$ and other hadronic modes, if kinematically allowed. Which mode dominates depends strongly on the model parameters, but heavy leptons in final state are more natural, than light ones (for discussion see [5,9]). Thus, for sgoldstino pair production processes one can expect two muon pairs as a very promising signature to look for. Other interesting signatures include photon pair(s) and light mesons.

III. DECAY $\mathcal{P} \to SP$

Here we consider two body decays of heavy neutral mesons into sgoldstino pair, $B^0 \to SP$, $B_s \to SP$ and $D^0 \to SP$. Decay rate of heavy pseudoscalar meson $\mathcal{P}$ with quark content $\bar{q}_i q_j$ (i, j run over quark flavors) into sgoldstino pair due to interaction (1) is given by the formula (c.f. Eq (20) in [9])

$$\begin{aligned}\Gamma(\mathcal{P} \to SP) = &\frac{f_{\mathcal{P}}^2}{M_{\mathcal{P}}} \frac{|\tilde{m}_{(D,U)_{ij}}^{LL^2} + \tilde{m}_{(D,U)_{ij}}^{RR^2}|^2}{256\pi F^2} \frac{(m_S^2 - m_P^2)^2}{F^2} \\ &\times \sqrt{\left(1 + \frac{m_P^2 - m_S^2}{M_{\mathcal{P}}^2}\right)^2 - 4\frac{m_P^2}{M_{\mathcal{P}}^2}},\end{aligned} \tag{7}$$

where $M_{\mathcal{P}}$ and $f_{\mathcal{P}}$ are mass and decay constant of pseudoscalar meson $\mathcal{P}$ (see Appendix A for the numerical values adopted). For decay of antimeson $\bar{\mathcal{P}}$ (heavy meson with quark content $\bar{q}_j q_i$) the same formula is valid with substitution $i \leftrightarrow j$. For numerical estimates we adopt the set of parameter values given in Sec. II. The dependence of branching ratios of these decays on scalar sgoldstino mass m_S is depicted in Fig. 1, where we put pseudoscalar sgoldstino mass to $m_P = 214$ MeV, as suggested by the sgoldstino explanation of HyperCP anomaly [4,5].

Remarkably, the signal grows with sgoldstino mass, as the corresponding matrix element exhibits the same behavior, cf. (1) and (7). At large mass the branching ratio decreases because of limited phase space.

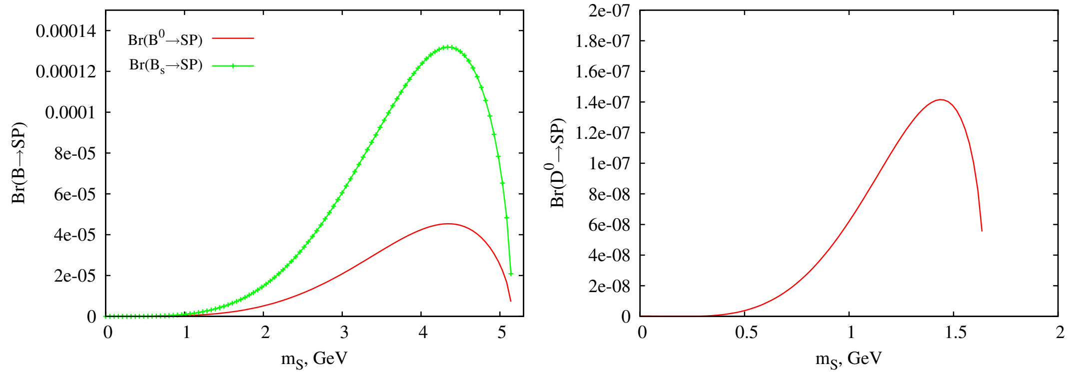

FIG. 1 (color online). Branching ratios of decays $B^0 \to SP$ and $B_s \to SP$ (left) and $D^0 \to SP$ (right) as functions of scalar sgoldstino mass m_S for pseudoscalar sgoldstino mass fixed at $m_P = 214$ MeV and other parameters fixed as explained in Sec. II.

IV. DECAYS $\mathcal{P} \to \tilde{\mathcal{P}} SP$ AND $\mathcal{P} \to \mathcal{V} SP$

The same off-diagonal entries of squark squared mass matrix which determine the heavy meson two-body decays into sgoldstino pairs described in Sec. III lead to three-body decays of the same meson $\mathcal{P}$ to light pseudoscalar meson $\tilde{\mathcal{P}}$ and sgoldstino pair and to light vector meson $\tilde{\mathcal{V}}$ and sgoldstino pair.

As an example of pseudoscalar meson in the final state, we consider decay $B^0 \to K^0 SP$ which is driven by the same flavor violating squark soft terms which trigger $B_s \to SP$. We use the following notations: P, p_1, p_2, p_3 are four-momentums of B^0, K^0, S and P; $m_{ij}^2 = (p_i + p_j)^2$ are the Dalitz variables. The relevant hadronic matrix element is parametrized by two form factors (see Appendix A) as [17]

$$\langle K^0 | \bar{s}\gamma^\mu b | B^0 \rangle = (P + p_1)^\mu f_+(m_{23}^2) + (P - p_1)^\mu f_-(m_{23}^2).$$

Then the squared matrix element of meson decay reads

$$|\mathcal{M}|^2 = \frac{|\tilde{m}_{D_{23}}^{LL^2} - \tilde{m}_{D_{23}}^{RR^2}|^2}{16F^4}[(m_{12}^2 - m_{13}^2)f_+(m_{23}^2) + (m_2^2 - m_3^2)f_-(m_{23}^2)]^2. \quad (8)$$

The decay rate is obtained by integrating $|\mathcal{M}|^2$ over the phase space as explained in Appendix B. For numerical estimates we use the set of parameter values chosen in Sec. II; the decay branching ratio for $m_P = 214$ MeV as a function of m_S is presented on left panel in Fig. 2.

Similarly to the two-body decays studied in Sec. III the obtained branching ratio grows (but rather slowly) with m_S in intermediate range of masses, because the matrix element contains a term with similar behavior, see Eq. (8).

Let us proceed with an example of heavy meson three-body decay into sgoldstino pair and vector meson, $\mathcal{P} \to \mathcal{V} SP$. We consider decay $B^0 \to K^{*0} SP$ which goes due to the same sgoldstino flavor violating couplings as $B_s \to SP$. We adopt the following notations: P, p_1, p_2, p_3 are four-momentums of B^0, K^{*0}, S and P; ϵ is polarization 4-vector of outgoing meson, $m_{ij}^2 = (p_i + p_j)^2$ are the Dalitz variables. We use the following hadronic matrix elements [17]

$$\langle K^* | \bar{s}\gamma^\mu b | B \rangle = \epsilon^\mu_{\nu\alpha\beta}\epsilon^{*\nu}(P + p_1)^\alpha (p_2 + p_3)^\beta g(m_{23}^2),$$
$$\begin{aligned}\langle K^* | \bar{s}\gamma^\mu \gamma^5 b | B \rangle = -i\{&\epsilon^{*\mu} f(m_{23}^2) \\ &+ (P + p_1)\epsilon^*[(P + p_1)_\mu a_+(q_{23}^2) \\ &+ (p_2 + p_3)_\mu a_-(q_{23}^2)]\},\end{aligned}$$

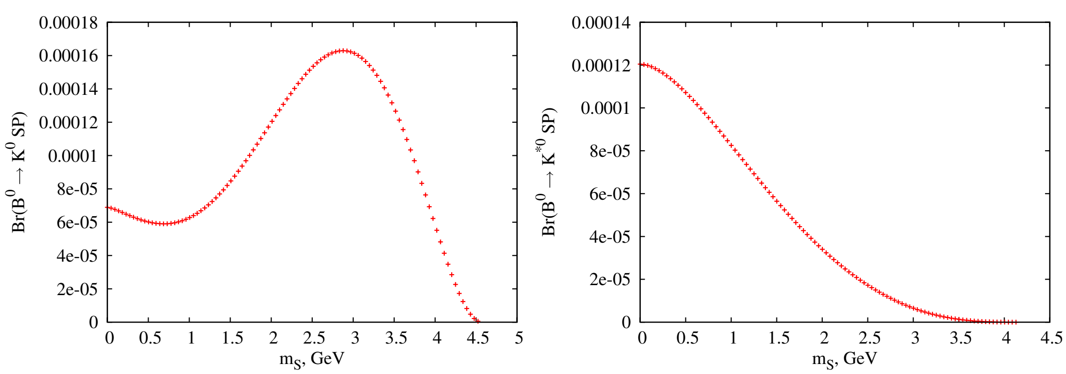

FIG. 2 (color online). Branching ratios of $B^0 \to K^0 SP$ (left) and $B^0 \to K^{*0} SP$ (right) as functions of scalar sgoldstino mass m_S. Other parameters are as in Fig. 1.

with form factors described in Appendix A. The decay amplitude can be written as follows

$$\mathcal{M}(B \to K^* SP) = -i\beta_1 (p_2 - p_3)^\mu \langle K^* | \bar{s}\gamma^\mu \gamma^5 b | B\rangle + \beta_2 (p_2 - p_3)^\mu \langle K^* | \bar{s}\gamma_\mu b | B\rangle,$$

where $\beta_1 = \frac{\tilde{m}^{LL^2}_{D_{23}} + \tilde{m}^{RR^2}_{D_{23}}}{4F^2}$ and $\beta_2 = \frac{\tilde{m}^{LL^2}_{D_{23}} - \tilde{m}^{RR^2}_{D_{23}}}{4F^2}$. We present the formulas below for the case of real α and β, which corresponds to P-conservation in squark soft terms. For the squared matrix element of three-body decay one obtains

$$|\mathcal{M}|^2 = |\beta_1|^2 \Big\{ \Big[m_{23}^2 - 2m_2^2 - 2m_3^2 + \frac{1}{4m_1^2}(m_{12}^2 - m_{13}^2 - m_2^2 + m_3^2)^2 \Big] f^2(m_{23}^2) + 2f(m_{23}^2) \Big[m_3^2 - m_2^2 + \frac{1}{4m_1^2}(M^2 - m_1^2 - m_{23}^2) \times (m_{12}^2 - m_{13}^2 - m_2^2 + m_3^2) \Big] [(m_{12}^2 - m_{13}^2) a_+(m_{23}^2) + (m_2^2 - m_3^2) a_-(m_{23}^2)] + \Big[\frac{1}{4m_1^2}(M^2 - m_1^2 - m_{23}^2)^2 - M^2 \Big] \times [(m_{12}^2 - m_{13}^2) a_+(m_{23}^2) + (m_2^2 - m_3^2) a_-(m_{23}^2)]^2 \Big\} + 4|\beta_2|^2 \{ 4m_1^2 m_2^2 m_3^2 - m_3^2(m_{12}^2 - m_1^2 - m_2^2)^2 - m_1^2(m_{23}^2 - m_2^2 - m_3^2)^2 - m_2^2(m_{13}^2 - m_1^2 - m_3^2)^2 + (m_{12}^2 - m_1^2 - m_2^2)(m_{23}^2 - m_2^2 - m_3^2)(m_{13}^2 - m_1^2 - m_3^2) \} g^2(m_{23}^2),$$

where M stands for the mass of decaying meson. The decay rate is obtained by integrating of $|\mathcal{M}|^2$ over the phase space as explained in Appendix B For numerical estimates we use the set of parameter values introduced in Sec. II; the decay branching ratio for $m_P = 214$ MeV is depicted on right panel of Fig. 2 for kinematically allowed values of scalar sgoldstino mass m_S.

Several comments are in order. The decay rates for charged mesons, e.g. $B^+ \to K^+ SP$, are given by the same formulas as presented above. The decay rates for $\bar{B}^0$ (and B^-) meson are given by the same formulas with replacement $\tilde{m}^{XX^2}_{D_{23}} \to \tilde{m}^{XX^2}_{D_{32}}$. Likewise it is straightforward to write down formulas for vector meson decays into sgoldstino and for various three-body decays of pseudoscalar and vector D-mesons and B_c mesons.

V. $t \to c(u)SP$ AND $\tau \to \mu(e)SP$

Flavor-violating couplings of sgoldstino to top-quark in Eq. (1) result in decays $t \to cSP$ and $t \to uSP$. To describe it below we use the following notations: P, p_1, p_2, p_3 are four-momentums of t-quark, lighter up-type quark (c or u), S and P; M denotes mass of top-quark, $m_{ij}^2 = (p_i + p_j)^2$ are the Dalitz variables. The squared matrix element of the three-body decay can be written as

$$|\mathcal{M}|^2 = 3 \cdot [(|\gamma_1|^2 + |\gamma_2|^2)\tau_1 + (|\gamma_2|^2 - |\gamma_1|^2)\tau_2], \quad (9)$$

where overall numerical factor 3 refers to the number of colors,

$$\tau_1 = (m_{12}^2 - m_{13}^2)^2 - (m_2^2 - m_3^2)^2 - (2m_2^2 + 2m_3^2 - m_{23}^2)(M^2 + m_1^2 - m_{23}^2),$$
$$\tau_2 = 2Mm_1(2m_2^2 + 2m_3^2 - m_{23}^2),$$

and $\gamma_1 = \frac{\tilde{m}^{LL^2}_{U_{23}} + \tilde{m}^{RR^2}_{U_{23}}}{4F^2}$, $\gamma_2 = \frac{\tilde{m}^{LL^2}_{U_{23}} - \tilde{m}^{RR^2}_{U_{23}}}{4F^2}$ for $t \to cSP$ and $\gamma_1 = \frac{\tilde{m}^{LL^2}_{U_{13}} + \tilde{m}^{RR^2}_{U_{13}}}{4F^2}$, $\gamma_2 = \frac{\tilde{m}^{LL^2}_{U_{13}} - \tilde{m}^{RR^2}_{U_{13}}}{4F^2}$ for $t \to uSP$.

For numerical estimates we use the set of values chosen in Sec. II. For the mass and width of top-quark we take 172.0 GeV and 1.3 GeV, respectively. Integrating $|\mathcal{M}|^2$ over the phase space as explained in Appendix B one obtains the decay branching ratios which are presented in Fig. 3 (left) as functions of m_S for $m_P = 214$ MeV.

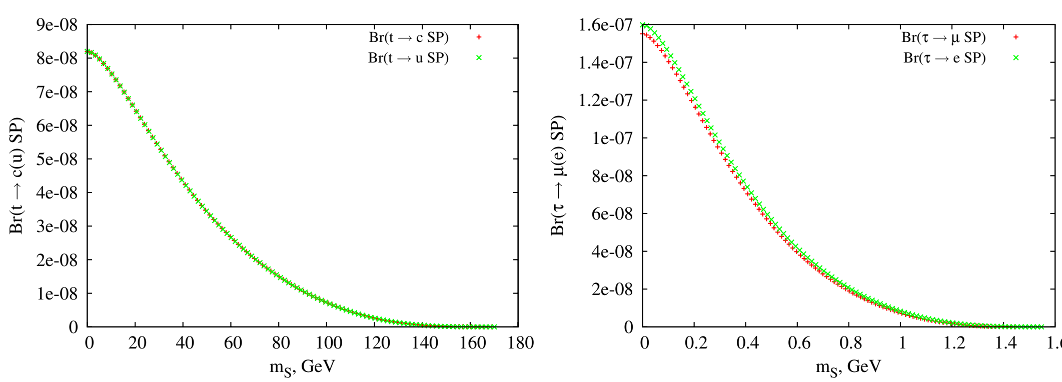

FIG. 3 (color online). Branching ratios for $t \to c(u)SP$ (left) and $\tau \to \mu(e)SP$ (right) as functions of m_S. Other parameters are as in Fig. 1.

Decays $\tau \to \mu SP$ and $\tau \to eSP$ can be treated in the similar way. Now the notations are as follows: P, p_1, p_2, p_3 are four-momentums of τ-lepton, light lepton l (muon μ or electron e), S and P; M stands for τ-lepton mass, $m_{ij}^2 = (p_i + p_j)^2$ are the Dalitz variables. The squared matrix element of the three-body decay is presented by Eq. (9) without color factor 3 and with $\gamma_1 = \frac{\tilde{m}_{L_{23}}^{LL^2} + \tilde{m}_{L_{23}}^{RR^2}}{4F^2}$, $\gamma_2 = \frac{\tilde{m}_{L_{23}}^{LL^2} - \tilde{m}_{L_{23}}^{RR^2}}{4F^2}$ for decay $\tau \to \mu SP$ and $\gamma_1 = \frac{\tilde{m}_{L_{13}}^{LL^2} + \tilde{m}_{L_{13}}^{RR^2}}{4F^2}$, $\gamma_2 = \frac{\tilde{m}_{L_{13}}^{LL^2} - \tilde{m}_{L_{13}}^{RR^2}}{4F^2}$ for decay $\tau \to eSP$. The decay rates are obtained by integrating $|\mathcal{M}|^2$ over the phase space as explained in Appendix B. For numerical estimates we adopt the parameter values given in Sec. II; the decay branching ratios for $m_P = 214$ MeV are presented in Fig. 3 (right) as functions of m_S.

VI. SUMMARY

To conclude we have studied sgoldstino pair production by heavy quark and τ-lepton decays. The obtained estimates of corresponding branching ratios for B- and D-mesons, t-quark and τ-lepton decays show that the processes are available for study already with collected statistics in Belle, *BABAR*, LHCb, CLEOc. The numerical results are presented for a particular set of supersymmetry parameters, see Sec. II. These are mixing angles in squark (slepton) squared mass matrices δ, superpartner mass scale $\tilde{m}$ and supersymmetry breaking parameter F. All the branching ratios discussed above scale as $\propto \delta^2 \cdot \tilde{m}^4/F^4$, which allows to give predictions for other phenomenologically viable values of the model parameters.

Note that generally, soft supersymmetry breaking terms violates CP-symmetry, that, in particular, splits rates of sgoldstino pair production in particle (meson) and antiparticle (antimeson) decays, e.g.

$$\mathrm{Br}\,(B_s \to SP) \neq \mathrm{Br}(\bar{B}_s \to SP).$$

Similar statement holds for the three-body decays. In case of two-body decays the splitting (so-called asymmetries) can be estimated with the help of decay *rate* formulas presented in Sec. III. Three-body decay rates with CP-violation can be calculated with help of formulas for *amplitudes* given in Sec. IV.

ACKNOWLEDGMENTS

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APPENDIX A: MESON FORM FACTORS USED IN NUMERICAL ESTIMATES

For meson leptonic decay constants we use $f_D = 207$ MeV [18], $f_B = 190$ MeV [19], $f_{B_s} = 231$ MeV [19]. For other meson form factors we adopt the universal form of dependence on momentum transfer q^2 [17]

$$F(q^2) = \frac{F(0)}{1 - a(q^2/M^2) + b(q^2/M^2)^2}$$

with values of dimensionless parameters listed in the Table I. These formfactors are related to those entering formulas in the main text, as follows [17]

$$\begin{aligned}
F_1(q_{23}^2) &= f_+(q_{23}^2), \\
F_0(q_{23}^2) &= \frac{q_{23}^2}{M^2 - m_1^2} f_-(q_{23}^2), \\
V(q_{23}^2) &= -(M + m_1) g(q_{23}^2), \\
A_1(q_{23}^2) &= -\frac{f(q_{23}^2)}{M + m_1}, \\
A_2(q_{23}^2) &= (M + m_1) a_+(q_{23}^2), \\
A_3(q_{23}^2) - A_0(q_{23}^2) &= \frac{q_{23}^2}{2m_1} a_-(q_{23}^2),
\end{aligned}$$

where

$$A_3(q_{23}^2) = \frac{M + m_1}{2m_1} A_1(q_{23}^2) - \frac{M - m_1}{2m_1} A_2(q_{23}^2).$$

APPENDIX B: THREE-BODY PHASE SPACE INTEGRATION

To calculate the rates Γ of the three-body decays described in the main text one has to integrate presented there squared matrix elements $|\mathcal{M}|^2$ over the three-body phase

TABLE I. Numerical coefficients in meson formfactors [17].

F	F_1^{BK}	F_0^{BK}	V^{BK}	$A_0^{BK^*}$	$A_1^{BK^*}$	$A_2^{BK^*}$
$F(0)$	0.35	0.35	0.31	0.31	0.26	0.24
a	1.58	0.71	1.79	1.68	0.93	1.63
b	0.68	0.04	1.18	1.08	0.19	0.98

space of corresponding final state. For the decay of particle of mass M into three particles of masses m_i with 4-momenta p_i, $i = 1, 2, 3$, one has the general formula (see e.g. Sec 39 in Ref. [20]) in terms of the Dalitz variables $m_{ij}^2 = (p_i + p_j)^2$,

$$\Gamma = \frac{1}{(2\pi)^3} \frac{1}{32M^3} \int_{(m_{12}^2)_{\min}}^{(m_{12}^2)_{\max}} dm_{12}^2 \int_{(m_{23}^2)_{\min}}^{(m_{23}^2)_{\max}} dm_{23}^2 |\mathcal{M}|^2,$$

where $(m_{12}^2)_{\min} = (m_1 + m_2)^2$, $(m_{12}^2)_{\max} = (M - m_3)^2$,

$$(m_{23}^2)_{\min} = (E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} + \sqrt{E_3^{*2} - m_3^2}\right)^2,$$

$$(m_{23}^2)_{\max} = (E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} - \sqrt{E_3^{*2} - m_3^2}\right)^2,$$

and $E_2^* = \frac{m_{12}^2 - m_1^2 + m_2^2}{2m_{12}}$, $E_3^* = \frac{M^2 - m_{12}^2 - m_3^2}{2m_{12}}$.

[1] G. F. Giudice and R. Rattazzi, Phys. Rep. **322**, 419 (1999); S. L. Dubovsky, D. S. Gorbunov, and S. V. Troitsky, Usp. Fiz. Nauk **169**, 705 (1999) [Phys. Usp. **42**, 623 (1999)].

[2] J. R. Ellis, K. Enqvist, and D. V. Nanopoulos, Phys. Lett. B **147**, 99 (1984); **151**, 357 (1985).

[3] D. S. Gorbunov and A. V. Semenov, arXiv:hep-ph/0111291.

[4] H. Park *et al.* (HyperCP Collaboration), Phys. Rev. Lett. **94**, 021801 (2005).

[5] D. S. Gorbunov and V. A. Rubakov, Phys. Rev. D **73**, 035002 (2006).

[6] S. V. Demidov and D. S. Gorbunov, JETP Lett. **84**, 479 (2007).

[7] H. J. Hyun *et al.* (Belle Collaboration), Phys. Rev. Lett. **105**, 091801 (2010).

[8] E. Abouzaid *et al.* (KTeV Collaboration), Phys. Rev. Lett. **107**, 201803 (2011).

[9] D. S. Gorbunov, Nucl. Phys. **B602**, 213 (2001).

[10] D. Gorbunov, V. Ilyin, and B. Mele, Phys. Lett. B **502**, 181 (2001).

[11] D. S. Gorbunov and V. A. Rubakov, Phys. Rev. D **64**, 054008 (2001).

[12] S. Jager, Eur. Phys. J. C **59**, 497 (2009).

[13] M. Antonelli, D. M. Asner, D. A. Bauer, T. G. Becher, M. Beneke, A. J. Bevan, M. Blanke, and C. Bloise *et al.*, Phys. Rep. **494**, 197 (2010).

[14] M. Artuso, D. M. Asner, P. Ball, E. Baracchini, G. Bell, M. Beneke, J. Berryhill, and A. Bevan *et al.*, Eur. Phys. J. C **57**, 309 (2008).

[15] J. Girrbach, S. Mertens, U. Nierste, and S. Wiesenfeldt, J. High Energy Phys. 05 (2010) 026.

[16] Indeed, by definition, all soft supersymmetry breaking terms are proportional to F, since they appear via transfer of supersymmetry breaking from the hidden sector to SM and hence should not exceed F.

[17] H.-Y. Cheng, C.-K. Chua, and C.-W. Hwang, Phys. Rev. D **69**, 074025 (2004).

[18] C. Bernard *et al.*, Proc. Sci., LATTICE2008 (2008) 278.

[19] E. Gamiz, C. T. H. Davies, G. P. Lepage, J. Shigemitsu, and M. Wingate, Phys. Rev. D **80**, 014503 (2009).

[20] K. Nakamura *et al.* (Particle Data Group Collaboration), J. Phys. G **37**, 075021 (2010).