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SQUARK DECAYS INTO CHARGINOS AND NEUTRALINOS IN THE MSSM WITH COMPLEX PARAMETER

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Abstract. *In this paper, we consider squark decays into charginos and neutralinos with complex parameters. The one loop vertex correction to the decay width has been calculated. The numerical results are also perfomed.*

I. INTRODUCTION

The minimal supersymmetric standard model (MSSM) is one of the most promising extensions of the Standard Model. The MSSM predicts the existence of scalar partners to all known quarks and leptons. Each fermion has two spin zero partners called sfermions $\tilde{f}_L$ and $\tilde{f}_R$, one for each chirality eigenstate: the mixing between $\tilde{f}_L$ and $\tilde{f}_R$ is proportional to the corresponding fermion mass, and so negligible except for the third generation. In particular, this model allows for the possibility that one of the scalar partners of the top quark ($\tilde{t}_1$) is higher than other scalar quarks and also than the top quark [1].

As well known, CP violation arises naturally in the third generation Standard Model and can appear only through the phase in the CKM-matrix. In the MSSM with complex parameters additional complex couplings are possible leading to CP violation within one generation at one-loop level [2, 3]. Very recently, Higgs boson in the MSSM with explicit CP violation is studied [4] and CP violation as a probe of flavor origins in supersymmetry is discussed [5].

In this paper we study the decays of squarks into charginos and neutralinos in the MSSM with complex parameters.

II. DIAGONALIZATION OF MASS MATRICES

We neglect generation missing as pointed out in Refs. [6, 7] only three terms in the supersymmetric Lagrangian can give rise to CP violating phases which cannot be rotated away: The superpotential contains a complex coefficient μ in the term bilinear in the Higgs superfields. The soft supersymmetry breaking operators introduce two further complex terms, the gaugino mass $\tilde{M}$, and the left- and right-handed squark mixing term A_q. In the MSSM one has two types of scalar quarks (squarks), $\tilde{q}_L$ and $\tilde{q}_R$, corresponding to the left and right helicity states of a quark.

The mass matrix in the basis ($\tilde{q}_L$, $\tilde{q}_R$) is given by[1]

$$M_q^2 = \begin{pmatrix} m_{\tilde{q}_L}^2 & a_q m_q \\ a_q m_q & m_{\tilde{q}_R}^2 \end{pmatrix} = (R^{\tilde{q}})^+ \begin{pmatrix} m_{\tilde{q}_1}^2 & 0 \\ 0 & m_{\tilde{q}_2}^2 \end{pmatrix} (R^{\tilde{q}}) \tag{1}$$

with

$$m_{\tilde{q}_L}^2 = M_{\tilde{q}}^2 + m_Z^2 \cos 2\beta (I_{3L}^q - e_q s_w^2) + m_q^2, \quad (2)$$
$$m_{\tilde{q}_R}^2 = M_{\{\tilde{u},\tilde{D}\}}^2 + e_q m_Z^2 \cos 2\beta s_w^2 + m_q^2, \quad (3)$$
$$a_q = A_q - \mu\{\cos\beta, \tan\beta\} \quad (4)$$

for { up, down} type squarks, respectively. e_q and I_{3L}^q are the electric charge and the third component of the weak isospin of the squark $\tilde{q}$, and m_q is the mass of the partner quark. $M_{\tilde{q}}$, $M_{\tilde{u}}$ and $M_{\tilde{D}}$ are soft SUSY breaking masses, and A_q are trilinear couplings.

According to eq. (1) $M_{\tilde{q}}^2$ is diagonalized by a unitary matrix $R^{\tilde{q}}$. The weak eigenstates $\tilde{q}_1$ and $\tilde{q}_2$ are thus related to their mass eigenstates $\tilde{q}_L$ and $\tilde{q}_R$ by

$$\begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} = R^{\tilde{q}} \begin{pmatrix} \tilde{q}_L \\ \tilde{q}_R \end{pmatrix}, \quad (5)$$

$$R^{\tilde{q}} = \begin{pmatrix} e^{\frac{i}{2}\phi_{\tilde{q}}} \cos\theta_{\tilde{q}} & e^{-\frac{i}{2}\phi_{\tilde{q}}} \sin\theta_{\tilde{q}} \\ -e^{\frac{i}{2}\phi_{\tilde{q}}} \sin\theta_{\tilde{q}} & e^{-\frac{i}{2}\phi_{\tilde{q}}} \cos\theta_{\tilde{q}} \end{pmatrix} \quad (6)$$

with $\theta_{\tilde{q}}$ is the squark mixing angle and $\phi_{\tilde{q}} = \arg(A_q)$. The mass eigenvalues are given by

$$m_{\tilde{q}_{1,2}}^2 = \frac{1}{2}\left(m_{\tilde{q}_L}^2 + m_{\tilde{q}_R}^2 \mp \sqrt{\left(m_{\tilde{q}_L}^2 - m_{\tilde{q}_R}^2\right)^2 + 4\left|a_q\right|^2 m_q^2} \right) \quad (7)$$

By convention, we choose $\tilde{q}_1$ to be the lighter mass eigenstate. For the mixing angle $\theta_{\tilde{q}}$ we require $0 \le \theta_{\tilde{q}} \le \pi$. We thus have

$$\cos\theta_{\tilde{q}} = \frac{-\left|a_q\right| m_q}{\sqrt{\left(m_{\tilde{q}_L}^2 - m_{\tilde{q}_1}^2\right)^2 + a_q^2 m_q^2}}, \quad \sin\theta_{\tilde{q}} = \frac{m_{\tilde{q}_L}^2 - m_{\tilde{q}_1}^2}{\sqrt{\left(m_{\tilde{q}_L}^2 - m_{\tilde{q}_1}^2\right)^2 + a_q^2 m_q^2}} \quad (8)$$

III. TREE LEVEL RESULT AND VERTEX CORRECTIONS

Our terminology and notation are as in Ref. [8].

The tree-level amplitude for decay $\tilde{q}_i \to q' \tilde{\chi}_j^{\pm}$ is (see Fig. 1)

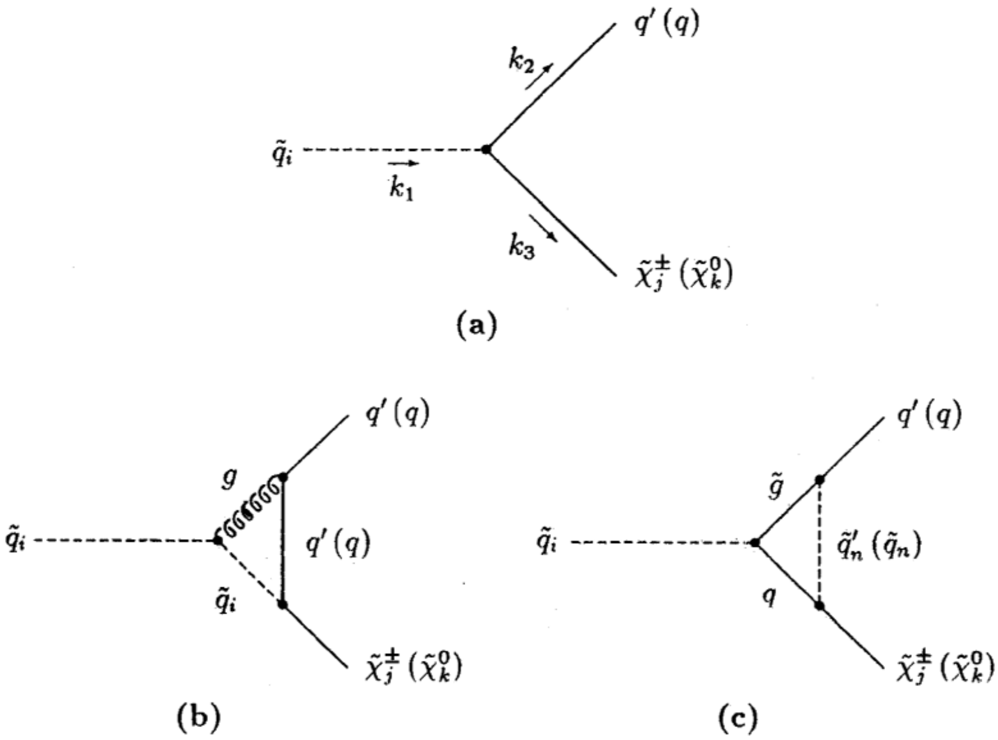

Fig. 1. Feynman diagrams for the O(α_s) SUSY-QCD correction to squark decay into charginos and neutralinos: (a) tree level; (b), (c) vertex corrections.

$$M^0\left(\tilde{q}_i \to q'\tilde{\chi}_j^\pm\right) = ig\bar{u}(k_2)\left[k_{ij}^{\tilde{q}}P_L + l_{ij}^{\tilde{q}}P_R\right]v(k_3) \tag{9}$$

The decay width at tree-level is thus given by

$$\begin{aligned}\Gamma^0\left(\tilde{q}_i \to q'\tilde{\chi}_j^\pm\right) =& \frac{g^2 k\left(m_{\tilde{q}_i}^2, m_{q'}^2, m_{\tilde{\chi}_j^\pm}^2\right)}{16\pi m_{\tilde{q}_i}^3}\times \\ & \left\{\left[\left|k_{ij}^{\tilde{q}}\right|^2 + \left|l_{ij}^{\tilde{q}}\right|^2\right]X - 2\left[k_{ij}^{\tilde{q}+}l_{ij}^{\tilde{q}} + k_{ij}^{\tilde{q}}l_{ij}^{\tilde{q}+}\right]m_{q'}m_{\tilde{\chi}_j^\pm}\right\}\end{aligned} \tag{10}$$

with $X = m_{\tilde{q}_i}^2 - m_{q'}^2 - m_{\tilde{\chi}_j^\pm}^2$

Analogously, we get for squark decays into neutralinos

$$M^0\left(\tilde{q}_i \to q\tilde{\chi}_j^0\right) = ig\bar{u}(k_2)\left[b_{ij}^{\tilde{q}}P_L + a_{ij}^{\tilde{q}}P_R\right]v(k_3) \tag{11}$$

$$\Gamma^0\left(\tilde{q}_i \to q\tilde{\chi}_j^0\right) = \frac{g^2 k\left(m_{\tilde{q}_i}^2, m_q^2, m_{\tilde{\chi}_j^0}^2\right)}{16\pi m_{\tilde{q}_i}^3} \times \left\{\left[\left|b_{ij}^{\tilde{q}}\right|^2 + \left|a_{ij}^{\tilde{q}}\right|^2\right]\hat{X} - 2\left[b_{ij}^{\tilde{q}+} a_{ij}^{\tilde{q}} + b_{ij}^{\tilde{q}} a_{ij}^{\tilde{q}+}\right] m_q m_{\tilde{\chi}_j^0}\right\} \tag{12}$$

with $\hat{X} = m_{\tilde{q}_i}^2 - m_q^2 - m_{\tilde{\chi}_j^0}^2$

The vertex correction terms from the four diagrams are shown in Figs. 1b-e. The gluon vertex correction (Fig. 1. b) yields

$$\begin{aligned}
\delta\Gamma_1 = {} & \frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}_i}^3}\frac{1}{2}\left\{\frac{1}{2}X\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right] - m_{q'} m_{\tilde{\chi}^\pm}\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right] m_{q'} m_{\tilde{\chi}_j^0}\right\}(B_0 + B_0^+) \\
& + \left[\left(-2m_{q'}^2 m_{\tilde{\chi}^\pm}^2 + 3m_{q'}^2 \frac{X}{2}\right)\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right]\right. \\
& \qquad \left. - m_{q'} m_{\tilde{\chi}^\pm}(3m_{q'}^2 + X)\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right]\right](C_{11} + C_{11}^+) \\
& + \left[\left(\frac{X^2}{2} + m^2\tilde{q}' m_{\tilde{\chi}^\pm}^2\right)\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right]\right. \\
& \qquad \left. - m_{\tilde{q}'} m_{\tilde{\chi}^\pm}\left(2m_{\tilde{\chi}^\pm}^2 + \frac{3}{2}X\right)\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right]\right](C_{12} + C_{12}^+) \\
& + \left[\left(X^2 - 2m_{q'}^2 m_{\tilde{\chi}^\pm}^2 + X m_{q'}^2\right)\right]\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right] \\
& \qquad \left. - m_{q'} m_{\tilde{\chi}^\pm}(2m_{q'}^2 + X)\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^\pm} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^\pm}\right]\right]\left(C_0 + C_0^+\right)\Big\} \\
& + \frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}_i}^3}\frac{1}{2}\left\{\frac{X}{2}m_{q'}^2\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right] - m_{q'}^3 m_{\tilde{\chi}^\pm}\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right]\left(iC_{11} - iC_{11}^+\right)\right. \\
& + \left[m_{q'}^2 m_{\tilde{\chi}^\pm}^2\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right] - m_{q'} m_{\tilde{\chi}^\pm}\frac{X}{2}\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right]\right](iC_{12} - iC_{12}^+) \\
& + \left[m_{q'}^2\left(X + 2m_{\tilde{\chi}^\pm}^2\right)\left[|l_{ij}^{\tilde{q}}|^2 + |k_{ij}^{\tilde{q}}|^2\right]\right. \\
& \qquad \left.\left. - m_{q'} m_{\tilde{\chi}^\pm}(2m_{q'}^2 + X)\left[l_{ij}^{\tilde{q}} k_{ij}^{\tilde{q}^+} + k_{ij}^{\tilde{q}} l_{ij}^{\tilde{q}^+}\right]\right](iC_{12} - iC_{12}^+)\right\}
\end{aligned} \tag{13}$$

where $\varepsilon = -\dfrac{\alpha_s}{3\pi}$

The contribution due to the graph of Fig. 1c with a gluino and a squark $\tilde{q}_n'$ (n=1, 2) in the loop is:

$$\delta\Gamma_2 = \frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}}^3}\left\{\left[\frac{iX}{2}C_\mu^\mu + \left(\frac{X}{2}m_{q'}^2 + m_{q'}^2 m_{\tilde{\chi}^\pm}^2\right).iC_{11} + \left(\frac{X^2}{2} + \frac{X^2}{2}m_{\tilde{\chi}^\pm}^2 - m_{q'}^2 m_{\tilde{\chi}^\pm}^2\right)\right]\right.$$
$$\times\, \alpha_{LR}k_{nj}^{\tilde{q}'}l_{nj}^{\tilde{q}+} + \alpha_{LR}l_{nj}^{\tilde{q}'}k_{nj}^{\tilde{q}+}]$$
$$+\left[-\frac{iX}{2}C_\mu^\mu - \left(\frac{X}{2}m_{q'}^2 + m_{q'}^2 m_{\tilde{\chi}^\pm}^2\right).iC_{11}^+ - \left(\frac{X^2}{2} + \frac{X}{2}m_{\tilde{\chi}^\pm}^2 - m_{q'}^2 m_{\tilde{\chi}^\pm}^2\right).iC_{12}^+\right]$$
$$\times\,[\alpha_{LR}^+ k_{nj}^{\tilde{q}'+}l_{nj}^{\tilde{q}} + \alpha_{LR}^+ l_{nj}^{\tilde{q}'+}k_{nj}^{\tilde{q}}]$$
$$- m_{q'}m_{\tilde{\chi}^\pm}\left[iC_\mu^\mu + \left(m_{q'}^2 + \frac{X}{2}\right).iC_{11} + \left(\frac{X}{2} + m_{\tilde{\chi}^\pm}^2\right).iC_{12}\right]\left[\alpha_{LR}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+} + \alpha_{RL}l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}\right]$$
$$\left.-m_{q'}m_{\tilde{\chi}^\pm}\left[-iC_\mu^{\mu+} - \left(m_{q'}^2 + \frac{X}{2}\right).iC_{11}^+ - \left(\frac{X}{2} + m_{\tilde{\chi}^\pm}^2\right).iC_{12}^+\right]\left[\alpha_{LR}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}} + \alpha_{RL}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}\right]\right\}$$
$$+\frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}_i}^3}\left\{-m_{q'}m_q\frac{X}{2}\left[\alpha_{RL}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{LR}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{RL}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{11} + \alpha_{LR}l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{11}\right]\right.$$
$$- m_{q'}m_q m_{\tilde{\chi}^\pm}\left[\alpha_{RL}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{LR}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{RL}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{12} + \alpha_{LR}l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{12}\right]$$
$$+ m_{q'}^2 m_q m_{\tilde{\chi}^\pm}\left[\alpha_{RL}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{LR}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{RL}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{11} + \alpha_{LR}^+ l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{11}\right]$$
$$\left.+\frac{X}{2}m_q m_{\tilde{\chi}^\pm}\left[\alpha_{RL}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{LR}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{RL}k_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{12} + \alpha_{LR}l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{12}\right]\right\}$$
$$+\frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}_i}^3}\left\{m_{q'}m_q\frac{X}{2}\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{11} + \alpha_{LL}l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{11}\right]\right.$$
$$+ m_{q'}m_{\tilde{g}}m_{\tilde{\chi}^\pm}\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{12} + \alpha_{LL}^+ l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{12}\right]$$
$$+ m_{q'}^2 m_{\tilde{g}}\left(\frac{X}{2} + m_{\tilde{\chi}^\pm}^2\right)\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_0^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_0^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_0 + \alpha_{LL}^+ l_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_0\right]$$
$$- m_{\tilde{q}'}^2 m_{\tilde{g}}m_{\tilde{\chi}^\pm}\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{11}^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{11} + \alpha_{LL}^+ l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{11}\right]$$
$$- \frac{X}{2}m_{\tilde{g}}m_{\tilde{\chi}^\pm}\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_{12}^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_{12} + \alpha_{LL}^+ l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_{12}\right]$$
$$\left.- \left(m_{q'}^2 + \frac{X}{2}\right)m_{\tilde{g}}m_{\tilde{x}^\pm}\left[\alpha_{RR}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}C_0^+ + \alpha_{LL}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}C_0^+ + \alpha_{RR}k_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}C_0 + \alpha_{LL}l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}C_0\right]\right\}$$
$$+\frac{g^2 k\varepsilon}{16\pi m_{\tilde{q}_i}^3}\left\{m_{q'}m_{\tilde{g}}\frac{X}{2}\left[-\alpha_{LL}^+ k_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}iC_0^+ - \alpha_{RR}^+ l_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}'}iC_0 + \alpha_{LL}k_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}'+}iC_0 + \alpha_{RR}l_{nj}^{\tilde{q}'}k_{nj}^{\tilde{q}'+}iC_0\right]\right.$$
$$- m_{q'}m_{\tilde{g}}m_q m_{\tilde{\chi}^\pm}\left[-\alpha_{LL}^+ k_{nj}^{\tilde{q}'+}k_{ij}^{\tilde{q}}iC_0^+ - \alpha_{RR}^+ l_{nj}^{\tilde{q}'+}l_{ij}^{\tilde{q}}iC_0^+ + \alpha_{LL}k_{nj}^{\tilde{q}'}k_{ij}^{\tilde{q}+}iC_0 + \alpha_{RR}^+ l_{nj}^{\tilde{q}'}l_{ij}^{\tilde{q}+}iC_0\right] \tag{14}$$

The total vertex correction is given by

$$\delta\Gamma^{(v)} = \delta\Gamma_1 + \delta\Gamma_2 \tag{15}$$

III. NUMERICAL RESULTS AND DISCUSSION

Let us now turn to the numerial analysis. Masses and couplings of charginos and neutralinos depend on the parameters M, μ and $\tan\beta$ ($M' = \frac{5}{3}M\tan^2\theta_w$) For the stop sector we use $m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$, $\cos\theta_{\tilde{t}}$, μ and $\tan\beta$ as input values. The sbottom masses and mixing angle are fixed by the assumptions $M_{\tilde{D}} = 1.12 M_{\tilde{q}}(\tilde{t})$ and $\mathrm{A}_b = \mathrm{A}_t$.

We first discuss the decay $\tilde{t}_1 \to b\tilde{\chi}_1^+$. In order to study the dependence of the ratio of the two decay widths Γ_R and Γ_C on $\cos\phi_{\tilde{q}}$ (for simplicity of notation we abbreviate $\phi_{\tilde{q}}$ by $\phi_{\tilde{q}}$, Γ_R and Γ_C are corresponding to real and complex parameters, respectively), we have chosen three sets of M and μ values:

$M \ll |\mu|$ (M = 163 Gev, μ = 500 Gev) ; $M \approx |\mu|$ ($M = \mu = 219$ Gev) ; $M \gg |\mu|$ ($M = 500$ Gev, $\mu = 163$ Gev)

For this purpose, we have computed:

$$\frac{\Gamma_R}{\Gamma_C} = \frac{15430}{16603 - 1173\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{6964}{7494 - 530\cos\phi - 1149\sin\phi} \tag{16}$$

for $M = 163$ Gev, $\mu = 500$ Gev

$$\frac{\Gamma_R}{\Gamma_C} = \frac{294}{2301 - 2007\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{1328}{10386 - 9058\cos\phi - 295430\sin\phi} \tag{17}$$

for $M = \mu = 219$ Gev

$$\frac{\Gamma_R}{\Gamma_C} = \frac{6481}{10474 - 3993\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{29254}{47278 - 18024\cos\phi - 152320\sin\phi} \tag{18}$$

for M = 500 Gev, μ = 163 Gev

Fig. 2 shows the cosϕ dependence of the ratio Γ_R/Γ_C. It is interesting to note that the ratio increases quickly with increasing cosϕ for $M \gg \mu$ while the ratio varies only little for $M \ll \mu$.

The ratio $\delta\Gamma_R/\delta\Gamma_C$ of this decay are shown in Fig. 3 as a function of ϕ. As can be seen, the ratio decreases quickly with increasing ϕ near the threshold for $M \gg \mu$ or $M = \mu$ while it varies only little for $M \ll \mu$.

From these results, we conclude that CP violation in the case of $M \gg \mu$ is expected to be large according to the MSSM. This is again in sharp constrary with the case of $M \gg \mu$ in which CP violation is vanishingly small.

For the decay $\tilde{b}_1 \to t\tilde{\chi}_1^-$, we obtain

$$\frac{\Gamma_R}{\Gamma_C} = \frac{2593}{2651 - 58\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{-221}{-226 + 5\cos\phi - 89\sin\phi} \tag{19}$$

for M = 163 Gev, μ = 500 Gev

$$\frac{\Gamma_R}{\Gamma_C} = \frac{3555}{3608 - 53\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{-304}{-309 + 5\cos\phi + 67\sin\phi} \tag{20}$$

for $M = \mu = 219$ Gev

$$\frac{\Gamma_R}{\Gamma_C} = \frac{7282}{7374 - 92\cos\phi} \quad ; \quad \frac{\delta\Gamma_R}{\delta\Gamma_C} = \frac{-622}{-630 + 8\cos\phi + 164\sin\phi} \tag{21}$$

for $M = 500$ Gev, $\mu = 163$ Gev

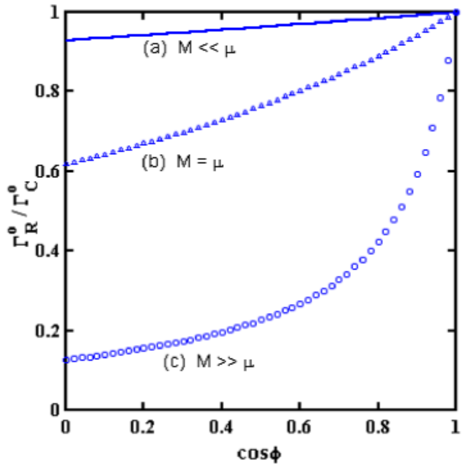

Fig. 2

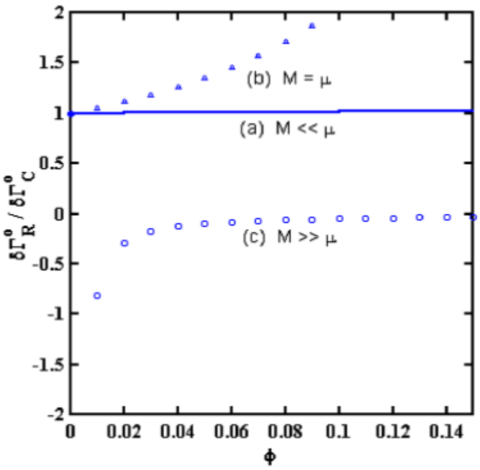

Fig. 3

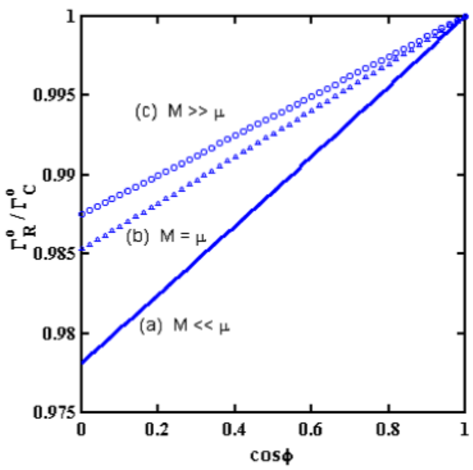

Fig. 4

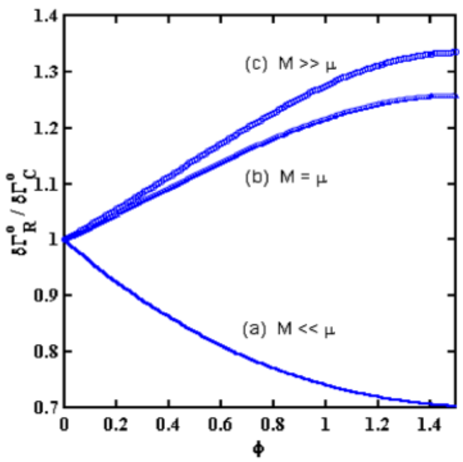

Fig. 5

The dependences of Γ_R/Γ_C on $\cos\phi$ and $\delta\Gamma_R/\delta\Gamma_C$ on ϕ are shown in Fig. 4 and Fig. 5. The dependences are similar to those of $\tilde{t}_1 \to b\tilde{\chi}_1^+$.

For the decay $\tilde{b}_2 \to t\tilde{\chi}_1^-$ and $\tilde{t}_2 \to b\tilde{\chi}_1^+$, the dependences of Γ_R/Γ_C on $\cos\phi$ are shown in Fig. 6 and Fig. 7. However, these dependences in the case of sbottom decay are weaker than those in the case of stop decay. Therefore, CP violation in the sbottom decay is to be weak[9].

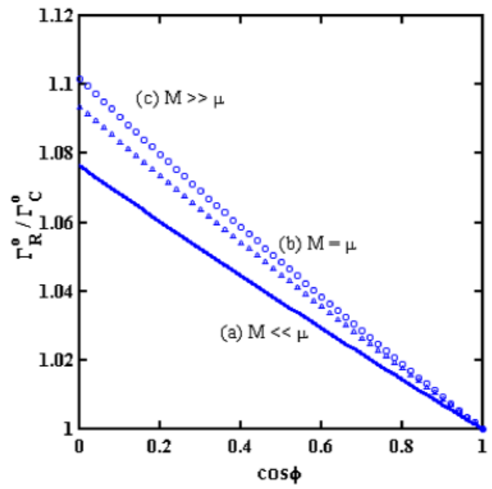

Fig. 6

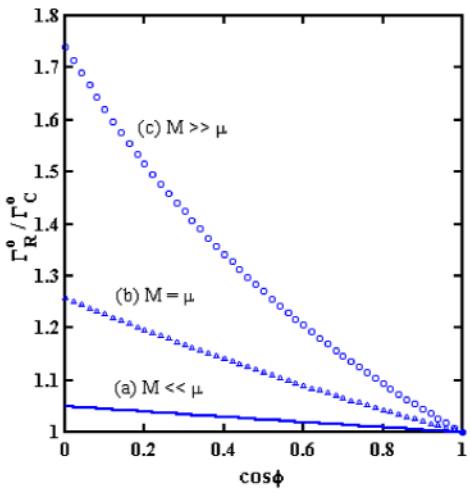

Fig. 7

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