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CP observables with spin–spin correlations in chargino production

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Abstract

We study the CP-violating terms of the spin–spin correlations in chargino production $e^+e^- \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\mp}$, and their subsequent two-body decays into sneutrinos plus leptons. We propose novel CP-sensitive observables with the help of T-odd products of the spin–spin terms. These terms depend on the polarizations of both charginos, with one polarization perpendicular to the production plane. We identify two classes of CP-sensitive observables; one requires the reconstruction of the production plane, the other not. Our framework is the Minimal Supersymmetric Standard Model with complex parameters.

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1. Introduction

Supersymmetric (SUSY) extensions of the Standard Model (SM), like the Minimal Supersymmetric Standard Model (MSSM) [1], give rise to new sources of CP violation [2]. From a

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mathematical point of view, this means that in the SUSY Lagrangian complex parameters enter whose phases cannot be removed by redefining the fields. The presence of CP phases can drastically alter the phenomenology of the underlying model (for a recent review, see [3]). For instance, contributions of SUSY CP phases to the electric dipole moments (EDM) of electron, neutron, and that of the atoms ^{199}Hg and ^{205}Tl can be close or beyond the present experimental upper bounds [4,5], and thus in turn constrain the size of these CP phases [4,5]. These constraints, however, are strongly model dependent, see e.g. [5]. Thus measurements of CP observables outside the EDM sector are necessary to independently determine or constrain the CP phases. Furthermore, non-vanishing phases can significantly change masses, cross sections and decay branching ratios of SUSY particles, compared to the real case, see e.g. [6,7]. Hence, in determining the underlying model parameters, the effect of their CP phases has to be taken into account. The phases could be measured once supersymmetric particles are accessible at future colliders. A genuine signal for CP violation would be the measurement of non-vanishing CP-sensitive observables.

In this paper, we propose CP-sensitive observables in chargino production

$$e^+e^- \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\mp}, \tag{1}$$

within the MSSM. For the processes $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_2^+\tilde{\chi}_2^-$ the CP-sensitive terms in the amplitude squared vanish at tree level since all coupling factors are real [8,9]. The chargino mass matrix, in the weak basis, is given by

$$\mathcal{M}_C = \begin{pmatrix} M_2 & \sqrt{2}m_W \sin\beta \\ \sqrt{2}m_W \cos\beta & \mu \end{pmatrix}, \tag{2}$$

with M_2 the SU(2) gaugino mass parameter, and $\tan\beta$ the ratio of the vacuum expectation values of the two Higgs fields. M_2 and $\tan\beta$ can be chosen real and positive, while the higgsino mass parameter can be complex $\mu = |\mu|e^{i\phi_\mu}$. At tree level, ϕ_μ is the only CP-violating phase that gives rise to CP-sensitive observables in chargino production, while phases from other sectors can contribute at loop level [10,11]. For example, phases of the gaugino mass parameter M_1, and the trilinear coupling parameters A_t in the stop-sector, lead to rate differences in $\tilde{\chi}_1^+\tilde{\chi}_2^-$ production and that of the charge conjugated pair $\tilde{\chi}_1^-\tilde{\chi}_2^+$ at the percent level [10]. For chargino decays, rate asymmetries of the partial chargino decay widths can exceed 10%, mainly due to the phases of M_1 and $A_{t,b}$ [12] (see also [13]).

Another class of promising CP-sensitive observables are based on so-called *T-odd correlations* (or *T-odd products*), see e.g. [14]. They can give rise to CP-violating effects already at tree-level, and therefore suffer not from loop suppression as rate asymmetries. Previous studies of CP-sensitive observables, based on T-odd products in chargino production and decay, have been focussing on the spin correlations between production and decay of only one chargino [8,9]. The corresponding terms in the amplitude squared involve the polarization vector perpendicular to the production plane of one of the produced charginos. Such a transverse polarization component is a genuine signal of CP violation. The transverse polarization is then retrieved from asymmetries in the azimuthal distribution of the decay products, which can be as large as 30%, even for small ϕ_μ of order $\pi/10$ [9]. In such an analysis of the spin-correlations, the polarization, i.e. the decay, of only one chargino needs to be considered. However, if the decays of both charginos are taken into account, one can probe their spin–spin correlations [15]. These are terms in the amplitude squared that include the polarization vectors of both charginos. The angular distributions of the decay products of the two charginos are correlated to one another due to total angular momentum conservation. Spin–spin correlations in chargino production and decay have been utilized for the determination of CP-even coupling factors [15,16]. Moreover, spin–spin correlations have been