

CP VIOLATION IN CHARGINO PRODUCTION IN e^+e^- COLLISIONS*

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We present the analysis of CP-violating effects in non-diagonal chargino pair production in e^+e^- collisions. These effects appear only at the one-loop level. We show that CP-odd asymmetries in chargino production are sensitive to the phases of μ and A_t parameters and can be of the order of a few %.

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1. Introduction

Supersymmetry (SUSY) is one of the most promising extensions of the Standard Model (SM) [1] since, among other things, it solves the hierarchy problem, provides a natural candidate for dark matter *etc.* It also introduces many new sources of CP violation that may be needed to explain baryon asymmetry of the universe. These phases, if large $\mathcal{O}(1)$, can cause problems with satisfying experimental bounds on lepton, neutron and mercury EDMs [2]. This can be overcome by pushing sfermion spectra above a TeV scale or arranging internal cancellations [3].

Most unambiguous way to detect the presence of CP-violating phases would be to study CP-odd observables measurable at future accelerators — the LHC and the ILC. Such observables in the chargino sector are, for example, triple products of momenta of initial electrons, charginos and their decay products [4]. However, they require polarized initial electron/positron beams or measurement of chargino polarization.

In this talk we present another possibility of detecting CP-violating phases in the chargino sector. As it was recently pointed out [5, 6], in non-diagonal chargino pair production

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$$e^+e^- \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^\mp \quad (1)$$

a CP-odd observable can be constructed beyond tree-level from production cross section without polarized e^+e^- beams or measurement of chargino polarization. We show here the results of the full one-loop calculation of this effect. In the reaction (1) the CP violation can be induced by the complex higgsino mass parameter μ or complex trilinear coupling in top squark sector A_t . Since these asymmetries can reach a few percent, they can be detected in simple event-counting experiments at future colliders.

2. CP-odd asymmetry at one loop

In e^+e^- collisions charginos are produced at tree-level via the s -channel γ, Z exchange and t -channel $\tilde{\nu}_e$ exchange. As it was shown in [7] no CP violation effects can be observed at the tree-level for the production processes of diagonal $\tilde{\chi}_i^+ \tilde{\chi}_i^-$ and non-diagonal $\tilde{\chi}_i^+ \tilde{\chi}_j^-$ chargino pairs without the measurement of polarization of final chargino. However, the situation is different for non-diagonal production if we go beyond tree-level approximation.

Radiative corrections to the chargino pair production include the following generic one-loop Feynman diagrams: the virtual vertex corrections, the self-energy corrections to the $\tilde{\nu}$, Z and γ propagators, and the box diagrams contributions. We have also to include corrections on external chargino legs.

One-loop corrected matrix element squared is given by

$$|\mathcal{M}_{\text{loop}}|^2 = |\mathcal{M}_{\text{tree}}|^2 + 2\text{Re}(\mathcal{M}_{\text{tree}}^* \mathcal{M}_{\text{loop}}). \quad (2)$$

Accordingly, the one-loop CP asymmetry for the non-diagonal chargino pair is defined as

$$A_{12} = \frac{\sigma_{\text{loop}}^{12} - \sigma_{\text{loop}}^{21}}{\sigma_{\text{tree}}^{12} + \sigma_{\text{tree}}^{21}}, \quad (3)$$

where σ^{12} , σ^{21} denote cross sections for production of $\tilde{\chi}_1^+ \tilde{\chi}_2^-$ and $\tilde{\chi}_2^+ \tilde{\chi}_1^-$, respectively. Since the asymmetry vanishes at tree-level it has to be finite at one loop, hence no renormalization is needed.

The CP asymmetry Eq. (3) arises due to the interference between complex couplings, which in our case are due to complex mixing matrices of charginos or stops, and non-trivial imaginary part from Feynman diagrams — the absorptive part. Such contributions appear when some of the intermediate state particles in loop diagrams go on-shell. This is illustrated in Fig. 1 where the contribution to A_{12} from double selectron exchange appears at the threshold for selectron pair production at $\sqrt{s} = 806$ GeV.

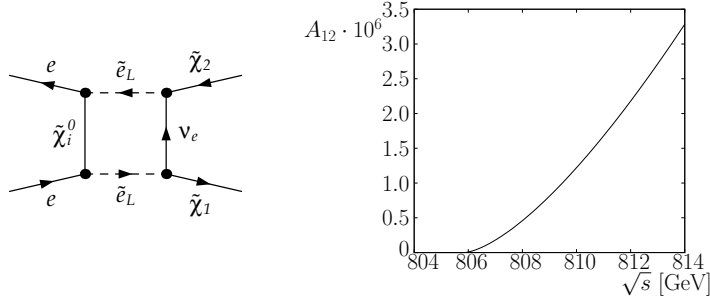


Fig. 1. Box diagram with selectron exchange and its contribution to the asymmetry A_{12} versus center of mass energy. The selectron mass is 403 GeV.

3. Numerical results

For the numerical results in this section we use two parameter sets (A) and (B) with gaugino/higgsino mass parameters defined as follows at the low scale:

$$\begin{aligned} \text{A:} \quad & |M_1| = 100 \text{ GeV}, \quad M_2 = 200 \text{ GeV}, \quad |\mu| = 400 \text{ GeV}, \\ \text{B:} \quad & |M_1| = 250 \text{ GeV}, \quad M_2 = 200 \text{ GeV}, \quad |\mu| = 300 \text{ GeV}, \end{aligned}$$

and with $\tan \beta = 10$. This gives the following chargino masses:

$$\begin{aligned} \text{A:} \quad & m_{\tilde{\chi}_1^-} = 186.7 \text{ GeV}, \quad m_{\tilde{\chi}_2^-} = 421.8 \text{ GeV}, \\ \text{B:} \quad & m_{\tilde{\chi}_1^-} = 175.6 \text{ GeV}, \quad m_{\tilde{\chi}_2^-} = 334.5 \text{ GeV}. \end{aligned}$$

For the sfermion mass parameters in scenario (A) we assume

$$\begin{aligned} m_{\tilde{q}} &\equiv M_{\tilde{Q}_{1,2}} = M_{\tilde{U}_{1,2}} = M_{\tilde{D}_{1,2}} = 450 \text{ GeV}, \\ M_{\tilde{Q}} &\equiv M_{\tilde{Q}_3} = M_{\tilde{U}_3} = M_{\tilde{D}_3} = 300 \text{ GeV}, \\ m_{\tilde{l}} &\equiv M_{\tilde{L}_{1,2,3}} = M_{\tilde{E}_{1,2,3}} = 150 \text{ GeV}, \end{aligned}$$

and for the sfermion trilinear coupling: $|A_t| = -A_b = -A_\tau = A = 400 \text{ GeV}$. Scenario (B) is for comparison with Ref. [5] for which we take

$$M_S = M_{\tilde{Q}} = M_{\tilde{U}} = M_{\tilde{D}} = M_{\tilde{L}} = M_{\tilde{E}} = 10 \text{ TeV}.$$

In our numerical analysis we consider the dependence of the asymmetry (3) on the phase of the higgsino mass parameter $\mu = |\mu|e^{i\Phi_\mu}$ and soft trilinear top squark coupling $A_t = |A_t|e^{i\Phi_t}$. In Fig. 2 we show the CP asymmetry in scenario (A) as a function of the phase of μ and A_t , left and middle panel, respectively. Contributions due to box corrections, vertex corrections and self energy corrections have been plotted in addition to the full result.

In this scenario the asymmetry can reach $\sim 1\%$ for the μ parameter and $\sim 6\%$ for A_t , respectively. We note that for the asymmetry due to the non-zero phase of the higgsino mass parameter there are significant cancellations among various contributions. In addition, we also show in the right panel of Fig. 2 the dependence of the asymmetry due to A_t as a function of $\tan\beta$.

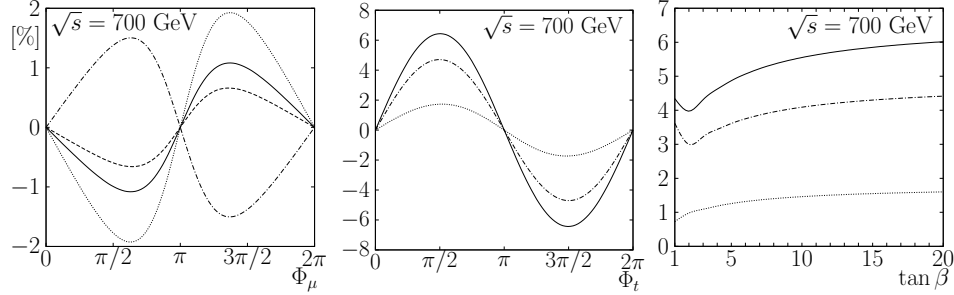


Fig. 2. Asymmetry A_{12} in scenario (A) as a function of the phase of μ parameter (left), the phase of A_t (middle), and as a function of $\tan\beta$ with $\Phi_t = \pi/3$ (right). Different lines denote full asymmetry (full line) and contributions from box (dashed), vertex (dotted) and self energy (dash-dotted) diagrams.

For the asymmetry generated by the μ parameter all possible one-loop diagrams containing absorptive part contribute. The situation is different for the phase of the trilinear coupling A_t — when chargino mixing matrices remain real. In this case only vertex and self-energy diagrams containing stop lines contribute to the asymmetry [6].

We present also the results for the heavy sfermion scenario (B). This is to compare with [5] where only box diagrams with γ , W , Z exchanges have been calculated neglecting all sfermion contributions. As can be seen in the

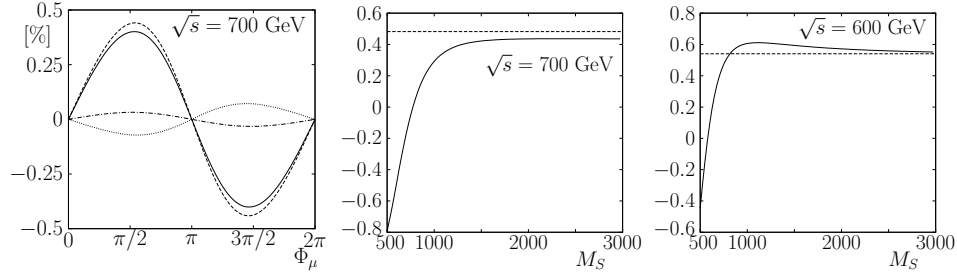


Fig. 3. Left: Asymmetry A_{12} in scenario (B) as a function of the phase Φ_μ . Different lines denote full asymmetry (full line) and contributions from box (dashed), vertex (dotted) and self energy (dash-dotted) diagrams. Middle and Right: Asymmetry A_{12} as a function of the universal scalar mass M_S with $\Phi_\mu = \pi/2$ at different cms. The full lines denote full result and dashed lines show only the box contributions after neglecting diagrams with slepton exchange.

left panel of Fig. 3 these gauge-box diagrams constitute the main part of the asymmetry A_{12} , however this is due to partial cancellation of vertex and self-energy contributions. For lower values of the universal scalar mass M_S the discrepancy between full and approximate result of [5] increases significantly. This is illustrated in the middle and right panel of Fig. 3 where we show two paths of approaching of the full result to the gauge-box approximation as the function of M_S . As can be seen these paths depend strongly on the center of mass energy.

4. Summary

It has been shown that CP-odd asymmetry can be generated in non-diagonal chargino pair production with unpolarized electron/positron beams. The asymmetry is a pure one-loop effect and is generated by interference between complex couplings and absorptive parts of one loop integrals. The effect is significant for the phases of the higgsino mass parameter μ and the trilinear coupling in stop sector A_t . At future linear collider, it may give information about CP violation in chargino and stop sectors.

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