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Beam polarization and CP asymmetry in neutralino production and decay

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Abstract

We study the impact of longitudinally polarized e^+ and e^- beams on a CP-odd asymmetry in neutralino production $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$ with subsequent leptonic three-body decay $\tilde{\chi}^0_2 \to \tilde{\chi}^0_1 l^+ l^-$ at a linear collider with $\sqrt{s} = 500$ GeV. Our framework is the Minimal Supersymmetric Standard Model with complex parameters M_1 and μ.

1 Introduction

Complex parameters in the Minimal Supersymmetric Standard Model (MSSM) introduce new CP-violating effects [1]. CP-odd observables defined with the help of triple products of momenta of the involved particles offer a possibility to study these CP-violating effects [2, 3]. In this note we focus on the effects of a complex $U(1)$ gaugino mass parameter M_1 and higgsino mass parameter μ in neutralino production and decay. We analyse the production process

$$e^+ + e^- \longrightarrow \tilde{\chi}^0_1 + \tilde{\chi}^0_2 \tag{1}$$

and subsequent leptonic three-body decay

$$\tilde{\chi}^0_2 \longrightarrow \tilde{\chi}^0_1 + l^- + l^+, \tag{2}$$

where $l = e, \mu$. The amplitude squared of the combined processes of production and decay can be written as

$$|T|^2 = PD + \Sigma^a_P \Sigma^a_D, \tag{3}$$

where P and D describe production and decay without spin correlation and Σ^a_P and Σ^a_D ($a = 1, 2, 3$) are the terms with spin correlation [4]. In Σ^a_P and Σ^a_D products like $i\epsilon_{\mu\nu\rho\sigma} p^\mu_i p^\nu_j p^\rho_k p^\sigma_l$ appear. This leads to CP-violating effects already at tree level. We introduce the triple product $\vec{p}_{l^+}(\vec{p}_{e^-} \times \vec{p}_{l^-})$, where $\vec{p}_{e^-}, \vec{p}_{l^-}$ and $\vec{p}_{l^+}$ are the momenta of initial e^- beam and the two final leptons l^- and l^+, respectively. We define a CP asymmetry as

$$A_T = \frac{\int sign\{(\vec{p}_{l^+}(\vec{p}_{e^-} \times \vec{p}_{l^-})\}|T|^2 dlips}{\int |T|^2 dlips}, \tag{4}$$

assuming that final state interactions and finite-widths effects can be neglected. A_T is proportional to the difference of the number of events with the final lepton l^+ above and below the plane spanned by $\vec{p}_{e^-}$ and $\vec{p}_{l^-}$. The analogous asymmetry for neutralino two-body decays has been studied in [5].

2 Numerical Results

We analyse the influence of longitudinal beam polarization on the CP asymmetry A_T in the scenarios defined in Tab.1. Scenario A is inspired by the SPS1a scenario [6], whereas in scenario B the mixing between gaugino and higgsino components is larger. We fix the center of mass energy $\sqrt{s} = 500$ GeV and take the phases of the complex parameters $M_1 = |M_1|e^{i\phi_{M_1}}$ and $\mu = |\mu|e^{i\phi_\mu}$ as $\phi_{M_1} = \frac{\pi}{2}$ and $\phi_\mu = 0$.

	$\lvert M_1\rvert$	M_2	$\lvert\mu\rvert$	$\tan\beta$	$m_{\tilde{e}_L}$	$m_{\tilde{e}_R}$	$m_{\tilde{\chi}^0_1}$	$m_{\tilde{\chi}^0_2}$
A	99.1	192.7	352.4	10	267.6	224.4	97.4	176.3
B	100.1	210	250	5	277.4	227.7	96	166.7

Table 1: Parameters $|M_1|$, M_2, $|\mu|$, $\tan\beta$, $m_{\tilde{e}_L}$ and $m_{\tilde{e}_R}$ in the scenarios A and B and the corresponding masses of $m_{\tilde{\chi}^0_{1,2}}$. All masses are given in [GeV].

In Fig.1a and b we show the CP asymmetry A_T, eq.(4), as a function of the e^- beam polarization P_{e^-} for different e^+ beam polarizations P_{e^+}, in the ranges $-0.9 \leq P_{e^-} \leq +0.9$ and $-0.6 \leq P_{e^+} \leq +0.6$, for the scenarios A and B . In both scenarios the highest CP asymmetry is reached for $P_{e^-} = -0.9$ and $P_{e^+} = +0.6$. For these polarizations the $\tilde{e}_L$ contributions to the spin density matrix dominate. With opposite signs of the beam polarizations the $\tilde{e}_R$ contributions are dominating. For scenario A (Fig.1a) one gets a CP asymmetry of about $14\%(-2\%)$ for the polarizations $P_{e^-} = -0.9(+0.9)$ and $P_{e^+} = +0.6(-0.6)$. In scenario B (Fig.1b) the CP asymmetry is about 3% in the unpolarized case whereas it is $5\%(-3\%)$ with polarizations $P_{e^-} = -0.9(+0.9)$ and $P_{e^+} = +0.6(-0.6)$. Fig.1c and d show the corresponding production cross sections σ as a function of the beam polarizations for the same parameters as in Fig.1a and b. In scenario A(B) the cross section and hence the expected rate necessary to measure A_T is enhanced by e^- beam polarization $P_{e^-} = -0.9$ by a factor $1.8(1.6)$ compared to the unpolarized case. In addition, a polarized e^+ beam with $P_{e^+} = +0.6$ would further enhance the cross section by a factor $1.5(1.6)$.

3 Summary and Conclusion

We have analysed the dependence on longitudinal beam polarizations of the CP asymmetry A_T, eq.(4), in neutralino production with subsequent leptonic three-body decay. Our framework has been the MSSM with complex parameters M_1 and μ. By changing the beam polarizations it is possible to increase the $\tilde{e}_L$ or $\tilde{e}_R$ contributions. We obtain the highest cross section and CP asymmetry with beam polarizations $P_{e^-} = -0.9$ and $P_{e^+} = +0.6$. Then in scenario A(B) the CP asymmetry is enhanced by a factor $1.1(1.5)$ and the cross section is enhanced by a factor $2.9(2.4)$ compared to the unpolarized case.

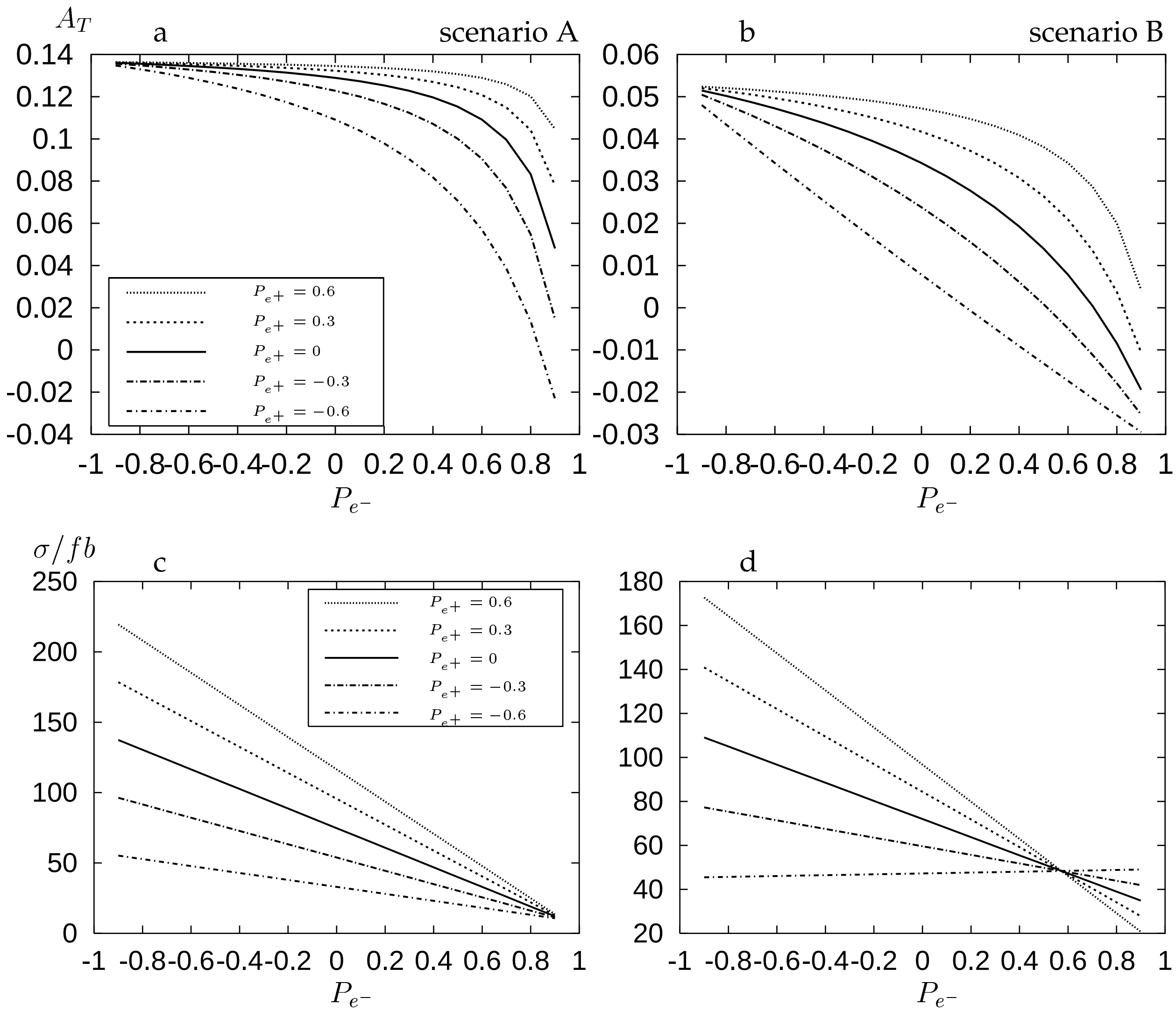

Figure 1: a,b CP asymmetry A_T, eq.(4), for $e^+e^- \longrightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0$ with subsequent leptonic three-body decay $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 l^+ l^-$, and c,d production cross section $\sigma(e^+e^- \longrightarrow \tilde{\chi}_1^0\tilde{\chi}_2^0)$, as a function of the e^- beam polarization P_{e^-} for different e^+ beam polarizations P_{e^+}, for $\sqrt{s} = 500$ GeV, $\phi_{M_1} = \frac{\pi}{2}$ and $\phi_\mu = 0$ for the scenarios A and B defined in Tab.1.

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