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Impact of beam polarization on CP asymmetries in neutralino pair production

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Abstract

We analyze the dependence of CP-odd asymmetries on longitudinally polarized e^+ and e^- beams in neutralino production and subsequent leptonic two-body decays. We give numerical examples of the asymmetries and of the cross sections in the Minimal Supersymmetric Standard Model with complex parameters μ, M_1 and A_τ for a collider with $\sqrt{s} = 500$ GeV. We show that longitudinally polarized electron and positron beams can enhance considerably both the asymmetries and the cross sections.

1 Introduction

In the neutralino sector of the Minimal Supersymmetric Standard Model (MSSM) [1], the gaugino mass parameter M_1, the higgsino mass parameter μ, and the trilinear coupling parameter A_τ in the stau sector, can be complex. The physical phases φ_{M_1}, φ_μ and φ_{A_τ} of these parameters can cause large CP-violating effects already at tree level.

In neutralino production

$$e^- + e^+ \;\rightarrow\; \tilde{\chi}_i^0 + \tilde{\chi}_j^0 \tag{1}$$

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and the subsequent leptonic two-body decay of one of the neutralinos

$$\tilde{\chi}_i^0 \;\rightarrow\; \tilde{\ell} + \ell_1, \tag{2}$$

and of the decay slepton

$$\tilde{\ell} \;\rightarrow\; \tilde{\chi}_1^0 + \ell_2; \quad \ell_{1,2} = e, \mu, \tau, \tag{3}$$

the neutralino spin correlations lead to several CP-odd asymmetries. With the triple product $\mathcal{T} = (\vec{p}_{e^-} \times \vec{p}_{\ell_2}) \cdot \vec{p}_{\ell_1}$, we define the *T-odd* asymmetry of the cross section σ for the processes (1)-(3):

$$\mathcal{A}_\mathcal{T} = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)}. \tag{4}$$

If absorbtive phases are neglected, $\mathcal{A}_\mathcal{T}$ is CP-odd due to CPT invariance. The dependence of $\mathcal{A}_\mathcal{T}$ on φ_{M_1} and φ_μ was analyzed in [2, 3, 4].

In case the neutralino decays into a τ-lepton, $\tilde{\chi}_i^0 \to \tilde{\tau}_k^\pm \tau^\mp$, $k = 1, 2$, the T-odd transverse τ^- and τ^+ polarizations P_2 and $\bar{P}_2$, respectively, give rise to the *CP-odd* observable

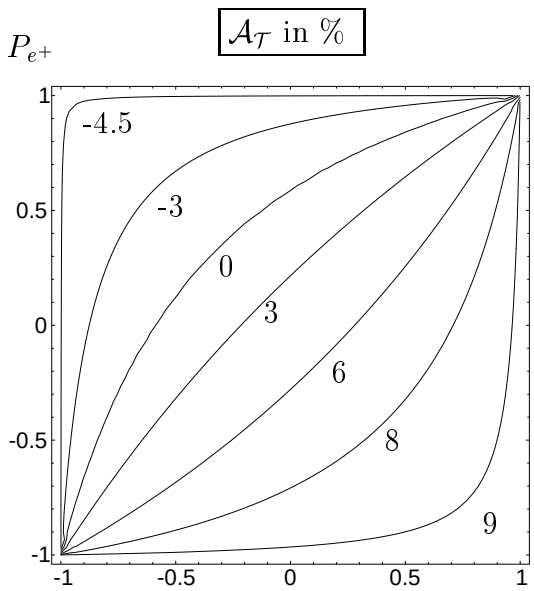
$$\mathcal{A}_{\rm CP} = \frac{1}{2}(P_2 - \bar{P}_2), \tag{5}$$

which is also sensitive to φ_{A_τ}. For various MSSM scenarios, $\mathcal{A}_{\rm CP}$ was discussed in [5]. For measuring the asymmetries, it is crucial to have both large asymmetries and large cross sections. In this note we study the impact of longitudinally polarized e^+ and e^- beams of a future linear collider in the 500 GeV range on the asymmetries $\mathcal{A}_\mathcal{T}$, $\mathcal{A}_{\rm CP}$ and on the cross sections σ.

2 Numerical results

We present numerical results for $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$ with the subsequent leptonic decay of $\tilde{\chi}_2^0$ for a linear collider with $\sqrt{s} = 500$ GeV. For $\mathcal{A}_\mathcal{T}$, Eq. (4), we study the neutralino decay into the right selectron and right smuon, $\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell_1$, $\ell = e, \mu$ and for $\mathcal{A}_{\rm CP}$, Eq. (5), that into the lightest scalar tau, $\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$. We study the dependence of the asymmetries and the cross sections on the beam polarizations P_{e^-} and P_{e^+} for fixed parameters $\mu = |\mu|\, e^{i\,\varphi_\mu}$, $M_1 = |M_1|\, e^{i\,\varphi_{M_1}}$, $A_\tau = |A_\tau|\, e^{i\,\varphi_{A_\tau}}$, M_2 and $\tan\beta$. We assume $|M_1| = 5/3 M_2 \tan^2\theta_W$ and use the renormalization group equations [6] for the selectron and smuon masses, $m^2_{\tilde{\ell}_R} = m_0^2 + 0.23 M_2^2 - m_Z^2 \cos 2\beta \sin^2\theta_W$ with $m_0 = 100$ GeV. The interaction Lagrangians and details on stau mixing can be found in [4].

In Fig. 1a we show the dependence of $\mathcal{A}_\mathcal{T}$ on the beam polarization for $\varphi_{M_1} = 0.2\ \pi$ and $\varphi_{A_\tau} = \varphi_\mu = 0$. A small value of φ_μ is suggested by constraints on electron and neutron electric dipole moments (EDMs) [7] for a typical SUSY scale of the order of a few 100 GeV (for a review see, e.g., [8]). It is remarkable that in our scenario the asymmetry can be close to 10% even for the small value of $\varphi_{M_1} = 0.2\ \pi$ and for $\varphi_\mu = 0$. The cross section $\sigma = \sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0) \times {\rm BR}(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell_1) \times {\rm BR}(\tilde{\ell}_R \to \tilde{\chi}_1^0 \ell_2)$ is shown in Fig. 1b.



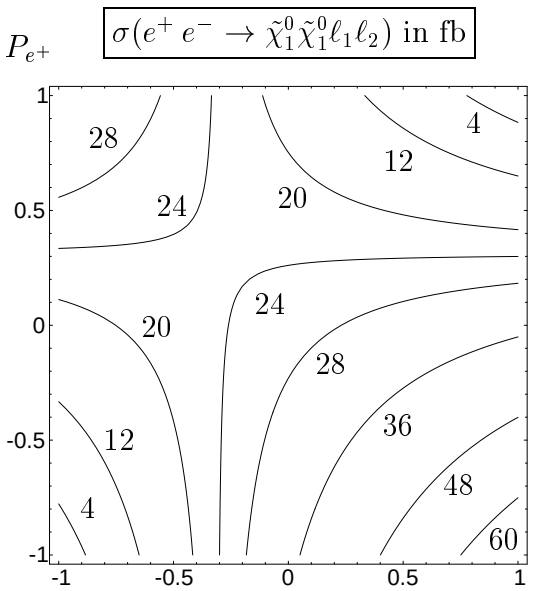


Figure 1: Contour lines of $\mathcal{A}_\mathcal{T}$ and σ for $\varphi_{M_1} = 0.2\pi$, $\varphi_\mu = 0$, $|\mu| = 240$ GeV, $M_2 = 400$ GeV, $\tan\beta = 10$ and $m_0 = 100$ GeV.

For our scenario with $|A_\tau| = 250$ GeV and $\varphi_{A_\tau} = 0$, the neutralino branching ratio is $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell_1) = 0.63$ (summed over both signs of charge) and $\mathrm{BR}(\tilde{\ell}_R \to \tilde{\chi}_1^0 \ell_2) = 1$. Note that the asymmetry $\mathcal{A}_\mathcal{T}$ and the cross section σ are both considerably enhanced for negative positron and positive electron beam polarization. This choice of polarization enhances the contributions of the right slepton exchange in the neutralino production, Eq. (1), and reduces that of left slepton exchange [9, 10]. While the contributions of right and left slepton exchange enter σ with the same sign, they enter $\mathcal{A}_\mathcal{T}$ with opposite sign, which accounts for the sign change of $\mathcal{A}_\mathcal{T}$.

In Fig. 2a we show the contour lines of the τ polarization asymmetry $\mathcal{A}_{\mathrm{CP}}$, Eq. (5), for $\varphi_{A_\tau} = 0.5\pi$ and $\varphi_{M_1} = \varphi_\mu = 0$ in the P_{e^-}-P_{e^+} plane. We have chosen a large value of $|A_\tau| = 1500$ GeV because $\mathcal{A}_{\mathrm{CP}}$ increases with increasing $|A_\tau| \gg |\mu| \tan\beta$ [5]. For unpolarized beams the asymmetry is 1%. However, it reaches values of more than $\pm 13\%$ if the e^+ and e^- beams are polarized with the opposite sign. If at least one of the beams is polarized (e.g. $P_{e^-} = 0.8$, $P_{e^+} = 0.6$), the asymmetries are somewhat smaller ($\sim 10\%$). The reason for this dependence is again the enhancement of either the right or the left selectron exchange contributions in the production process. The cross section $\sigma = \sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0) \times \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1^+ \tau^-)$ is shown in Fig. 2b with $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1^+ \tau^-) = 0.22$. Also σ is very sensitive to variations of the beam polarization and varies between 1 fb and 30 fb.

Since the asymmetry $\mathcal{A}_{\mathrm{CP}}$ is also very sensitive to the phases φ_{M_1} and φ_μ we show for $\varphi_{M_1} = 0.2\pi$ and $\varphi_\mu = \varphi_{A_\tau} = 0$, the dependence of $\mathcal{A}_{\mathrm{CP}}$ and $\sigma = \sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0) \times \mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1^+ \tau^-)$ on the beam polarization in Figs. 3a, b, respectively. The neutralino

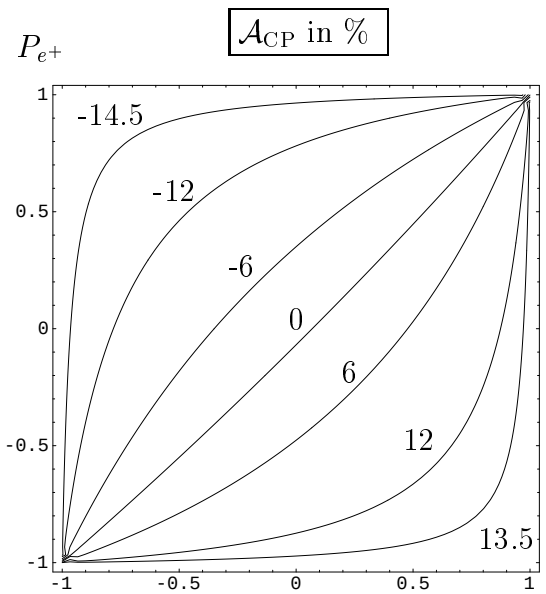


Fig. 2a P_{e^-}

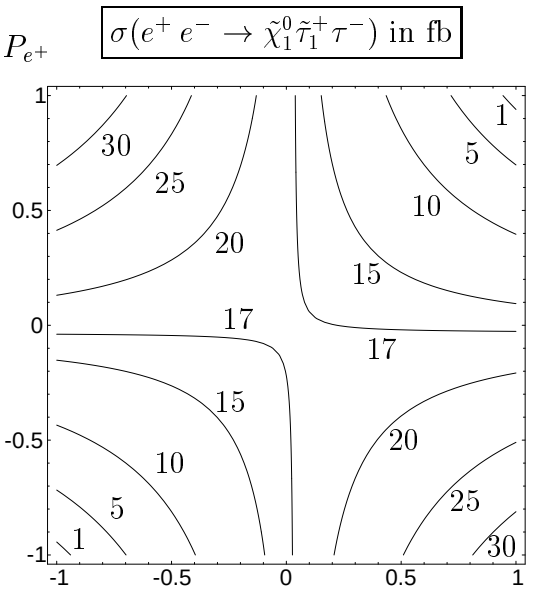


Fig. 2b P_{e^-}

Figure 2: Contour lines of $\mathcal{A}_{\rm CP}$ and σ for $\varphi_{A_\tau} = 0.5\pi$, $|A_\tau| = 1500$ GeV, $\varphi_{M_1} = \varphi_\mu = 0$, $|\mu| = 250$ GeV, $M_2 = 200$ GeV, $\tan\beta = 5$ and $m_0 = 100$ GeV.

branching ratio is $\mathrm{BR}(\tilde{\chi}_2^0 \to \tilde{\tau}_1^+ \tau^-) = 0.19$ for our scenario. Despite the small phases, $\mathcal{A}_{\rm CP}$ reaches values up to -12% for negative e^- and positive e^+ beam polarizations.

3 Summary and conclusion

Within the MSSM we have analyzed the dependence on the beam polarization of two CP-odd asymmetries in $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$ and the subsequent leptonic two-body decay of $\tilde{\chi}_2^0$. For the decay process $\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell_1$, $\tilde{\ell}_R \to \tilde{\chi}_1^0 \ell_2$ with $\ell_{1,2} = e, \mu$, we have found that the asymmetry $\mathcal{A}_\mathcal{T}$ of the triple product $(\vec{p}_{e^-} \times \vec{p}_{\ell_2}) \cdot \vec{p}_{\ell_1}$, which is sensitive to φ_{M_1} and φ_μ, can be twice as large if polarized beams are used, with e.g. $P_{e^-} = 0.8$ and $P_{e^+} = -0.6$. Also for these polarizations the cross section can be enhanced up to a factor up to 2. For the neutralino decay, $\tilde{\chi}_2^0 \to \tilde{\tau}_1^\mp \tau^\pm$, we have given numerical examples for the beam polarization dependence of the CP-odd τ polarization asymmetry $\mathcal{A}_{\rm CP}$, which is also sensitive to φ_{A_τ}. For the scenarios considered, both $\mathcal{A}_{\rm CP}$ and the cross section depend sensitively on the beam polarizations and can be enhanced by a factor between 2 and 3. The dependence on the beam polarizations of the asymmetries $\mathcal{A}_\mathcal{T}$, $\mathcal{A}_{\rm CP}$ and of the cross sections is due to the contributions from right and left selectron exchange in the neutralino production process. Generally, negative (positive) e^- and positive (negative) e^+ beam polarization enhances right (left) selectron exchange. Due to the fact that both asymmetries and cross sections can be enhanced significantly, we conclude that the option of having both beams polarized at an e^+e^--collider is advantageous for the determination of the CP-odd asymmetries.

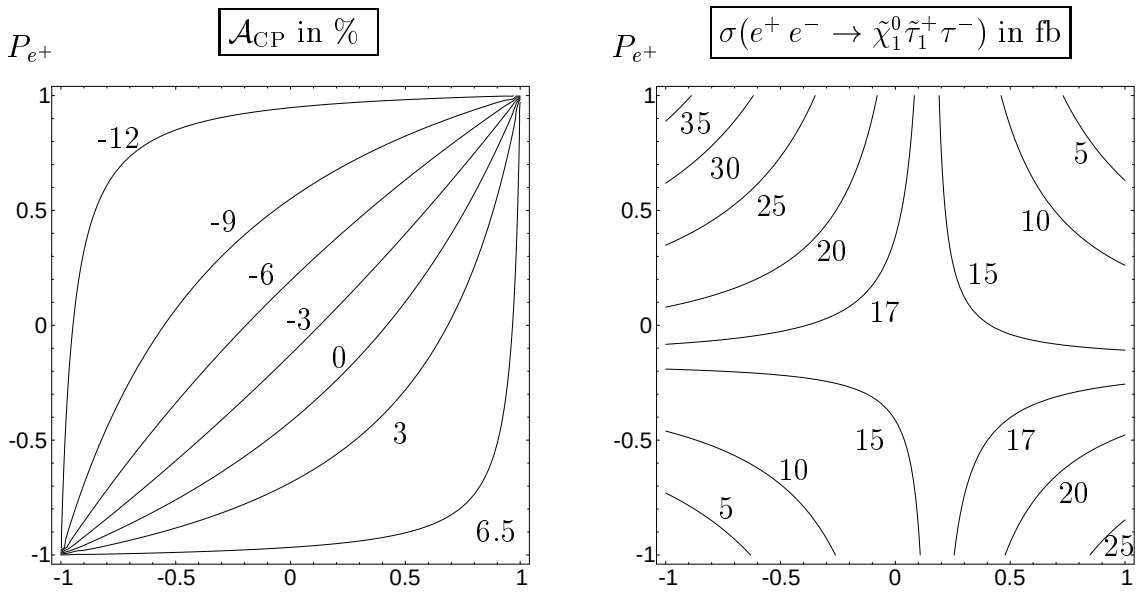


Figure 3: Contour lines of $\mathcal{A}_{\rm CP}$ and σ for $\varphi_{M_1} = 0.2\pi$, $\varphi_\mu = 0$, $|\mu| = 250$ GeV, $M_2 = 200$ GeV, $\varphi_{A_\tau} = 0$, $|A_\tau| = 250$ GeV, $\tan\beta = 5$ and $m_0 = 100$ GeV.

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References

[1] H. E. Haber an G. L. Kane, Phys. Rep. **117** (1985) 75.

[2] Y. Kizukuri and N. Oshimo, Phys. Lett. **B 249** (1990) 449.

[3] S. Y. Choi, H. S. Song and W. Y. Song, Phys. Rev. **D 61** (2000) 075004.

[4] A. Bartl, H. Fraas, O. Kittel and W. Majerotto, [arXiv:hep-ph/0308141]; A. Bartl, H. Fraas, O. Kittel and W. Majerotto, [arXiv:hep-ph/0308143].

[5] A. Bartl, T. Kernreiter, O. Kittel, in preparation.

[6] L. J. Hall and J. Polchinski, Phys. Lett. **B 152** (1989) 335.

[7] I. S. Altarev et al., Phys. Lett. **B 276** (1992) 242; I. S. Altarev et al., Phys. Atom. Nucl.**59** (1996) 1152 and Yad. Fiz. **59 N 7**; E. D. Commins, S. B. Ross, D. DeMille, B. C. Regan, Phys. Rev. **A 50** (1994) 2960.

[8] P. Nath, Talk at the 9th International Conference on Supersymmetry and Unification of Fundamental Interactions, 11-17 June 2001, Dubna (hep-ph/0107325) and references therein.

[9] G. Moortgat-Pick, H. Fraas, A. Bartl and W. Majerotto, Eur. Phys. J. **C 9** (1999) 521; Erratum-ibid. **C 9** (1999) 549.

[10] G. Moortgat-Pick, in *Proc. of the APS/DPF/DPB Summer Study on the Future of Particle Physics (Snowmass 2001)* ed. N. Graf, eConf **C010630**, E3008 (2001) [arXiv:hep-ph/0202082]; G. Moortgat-Pick, A. Bartl, H. Fraas and W. Majerotto, Eur. Phys. J. C **18** (2000) 379.