New analysis of SUSY dark matter scenarios at ILC

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Applying realistic veto efficiencies for the low angle electromagnetic calorimeter located in the very forward direction of the future international linear collider, we revisited the Standard Model background contributions studied previously in stau analyses with supersymmetrical dark matter scenarios.

In supersymmetry (SUSY) models with R-parity conservation, the lightest SUSY particle neutralino, $\tilde{\chi}_1^0$, is often considered as the best candidate to satisfy the cosmological constraints on cold Dark Matter (DM) of the universe.

In two previous studies [1, 2], one of the most challenging scenarios analyzed concerns the benchmark point D' [3] in the so-called co-annihilation region. In the mSUGRA model, the mass spectrum depends on two parameters m_0 and $M_{1/2}$, the common masses of scalars and gauginos superpartners at the unification scale. The parameter μ, defining the higgsino mass, is derived, in absolute value, by imposing the electroweak symmetry breaking condition in terms of these two parameters and of $\tan\beta$, the ratio of the vacuum expectations which appear in the two Higgs doublets of SUSY. In scenario D', these parameters take the value $m_0 = 101\,\text{GeV}$, $M_{1/2} = 525\,\text{GeV}$, $\tan\beta = 10$ and $\text{sign}(\mu) < 0$. The resulting $\tilde{\chi}_1^0$ has a mass value of 212 GeV and the next lightest SUSY particle stau, $\tilde{\tau}$, has a mass value of 217 GeV. The mass difference is only 5 GeV. When the mass difference is small, the co-annihilation process $\tilde{\chi}_1^0\tilde{\tau} \to \tau\gamma$ becomes the dominant process for regulating the relic DM density of the universe. It is therefore crucial to measure precisely the mass values of $\tilde{\chi}_1^0$ and $\tilde{\tau}$.

The $\tilde{\chi}_1^0$ mass can be measured [2] using the end-point method with a precision down to 170 MeV (80 MeV) relying on $e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\tilde{\chi}_1^0\mu^-\tilde{\chi}_1^0$ ($\tilde{e}^+\tilde{e}^- \to e^+\tilde{\chi}_1^0 e^-\tilde{\chi}_1^0$) for the modified SPS $1a$ scenario with a mass value of $\tilde{\mu}$ or $\tilde{e}$ of 143 GeV and $\tilde{\chi}_1^0$ of 135 GeV under the following experimental conditions: a center-of-mass energy (Ecm) of 400 GeV, an integrated luminosity ($\mathcal{L}$) of 200 fb^{-1} and a polarized electron (positron) beam at 0.8 (0.6).

The stau analyses are more challenging not only because the final state particle of the tau decay is very soft with missing energy due to undetected neutrino(s) in addition to $\tilde{\chi}_1^0$ but also because the Standard Model (SM) background processes have rates which are many orders of magnitude larger than that of the signal. The cross section values of the signal and the dominant SM background processes are given in Table 1. The signal row with Ecm= 442 GeV corresponds to the optimal center-of-mass energy method (referred to hereafter as *method one* using the cross section measurement or event counting near threshold) proposed in [1] whereas the other signal rows correspond to cases studied in another method (*method two* relying on the measured energy spectra of the tau decay final state, the first and other rows are respectively studied in [2] and [4]).

The suppression of the dominant SM background processes $e^+e^- \to \tau^+\tau^- e^+e^-$, $c\bar{c}e^+e^-$ depends critically on whether the spectator e^+ and/or e^- can be found in the low angle calorimeter (BeamCal) located at 370 cm from the interaction point in the very forward

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Ecm (GeV)	Beam polarization (P_{e^-}/P_{e^+})	σ (fb)
Signal		
600	0.8/0.6	50
600	unpolarized	20
500	0.8/0.6	25
500	unpolarized	10
442	unpolarized	0.456
Dominant SM backgrounds		
500	unpolarized	$4.3 \cdot 10^5 (e^+e^- \to \tau^+\tau^- e^+e^-)$ $8.2 \cdot 10^5 (e^+e^- \to c\bar{c}e^+e^-)$

Table 1: Cross section values of the signal ($e^+e^- \to \tilde{\tau}^+\tilde{\tau}^-$) and the dominant SM background processes for different Ecm and beam polarizations.

direction around the beam pipe. In the previous studies [1, 2], either an ideal veto or an old realistic veto [5] was assumed.

In this analysis, we revisit the SM background suppression using realistic veto efficiencies obtained in a recent study [6]. In this study, the BeamCal design is different for the small (0 or 2 mrad) or large (20 mrad) crossing angle beam configuration. In the small crossing angle case, the BeamCal has an inner (outer) radius of 1.5 cm (16.5 cm). In order to identify an energetic spectator e^+ or e^- out of several TeV energy deposit from huge number of low energy e^+e^- pairs stemming from beamstrahlung photon conversions, the BeamCal is designed to have fine granularity and large longitudinal segmentation. The resulting veto efficiency is about 100% for high energy electrons close to the beam energy (250 GeV), decreases down to 20% for a 75 GeV electron near the inner side of the calorimeter and is assumed to be fully inefficient for electrons below 75 GeV.

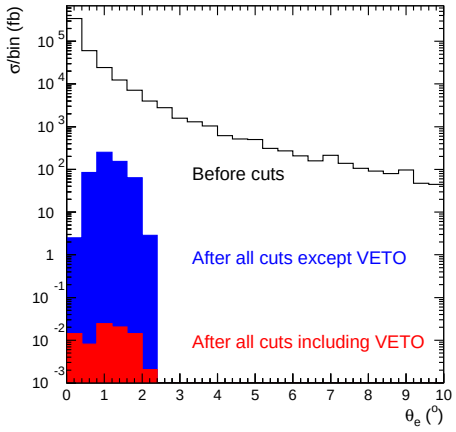

Figure 1: Angular distribution of the spectator electrons from $e^+e^- \to \tau^+\tau^- e^+e^-$ expressed in fb/bin. The blue shaded distribution corresponds to the distribution obtained after all the selections described in [1] with the exception of the forward veto and the red shaded distribution corresponds to the distribution when the veto is further included.

Taking the background process $e^+e^- \to \tau^+\tau^- e^+e^-$ as an example, after applying all analysis cuts of *method one* defined in [1], the remaining background amounts to 0.08 fb (561 fb) when the forward veto is included (excluded). This is illustrated in Fig. 1. This should be compared with the final signal cross section of $0.456 \times 5.7\% = 0.026$ fb taking into account of the efficiency of the analysis. The corresponding numbers for *method two* are 0.26 fb(168 fb without the veto) for the two-photon $\tau^+\tau^-$ background and $10 \times 6.4\% = 0.64$ fb for the signal at Ecm= 500 GeV and also with unpolarized

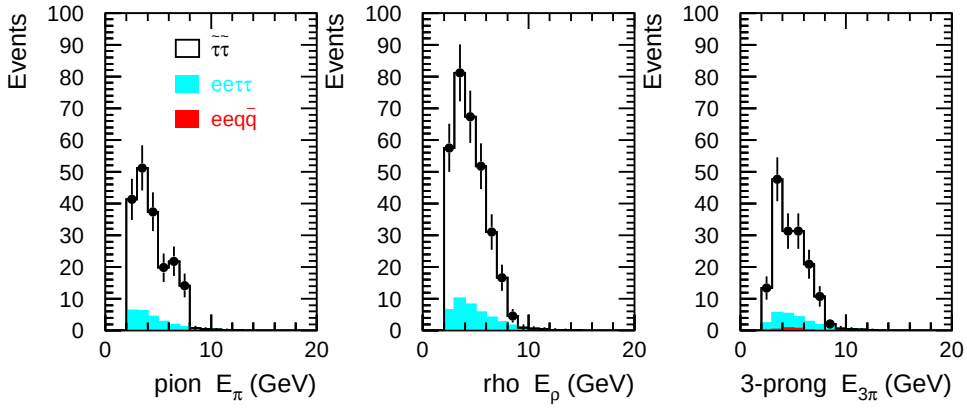

Figure 2: The energy spectra of the hadronic final state in $\tau \to \pi\nu_\tau$, $\tau \to \rho\nu_\tau$ and $\tau \to 3\pi\nu_\tau$ decays from the signal reaction $e^+e^- \to \tilde{\tau}^+\tilde{\tau}^- \to \tau^+\tilde{\chi}_1^0\tau^-\tilde{\chi}_1^0$ and two-photon production assuming head-on collision and Ecm= 500 GeV, $\mathcal{L} = 300\,\text{fb}^{-1}$ and $P_{e^-} = 0.8$ and $P_{e^+} = 0.6$.

Ecm (GeV)	P_{e^-}/P_{e^+}	$\mathcal{L}$ (fb^{-1})	σ (fb)	Efficiency (%)	$\delta m_{\tilde{\tau}}$ (GeV)	$\delta\Omega h^2$ (%)
600	0.8/0.6	300	50	7.6	$0.11 - 0.13$	$1.4 - 1.7$
600	unpolarized	300	20	7.7	$0.14 - 0.17$	$1.8 - 2.2$
500	0.8/0.6	300	25	6.4	$0.13 - 0.20$	$1.7 - 2.6$
500	unpolarized	500	10	6.5	0.15	1.9
442	unpolarized	500	0.456	5.7	0.54	6.9

Table 2: Experimental conditions (Ecm, the beam polarizations and the integrated luminosity) and the corresponding results (the analysis efficiency, the stau mass uncertainty and the relative uncertainty on the DM density determination).

beams. The signal over background ratios for *method one* and *method two* are respectively 0.3 and 2.5. Therefore for *method one* where one is aiming for a background free selection, the current veto and analysis selections are not good enough and need further improvement.

For *method two*, although the absolute remaining background is larger than that from *method one*, the background level is already acceptable, given the much bigger signal production cross section for an Ecm well beyond the mass threshold. In particular the signal over background ratio can substantially improve when the beams are polarized. This is shown in Fig. 2.

Experimentally, the maximum τ energy ($E_{\max}$) can be determined from the upper endpoint of the spectra, after having subtracted the small SM background contribution, from a fit using for instance a polynomial function. Since the maximum τ energy depends on Ecm, the mass values of $\tilde{\tau}$, $\tilde{\chi}_1^0$ and τ, knowing $E_{\max}$, Ecm, $m_{\tilde{\chi}_1^0}$ and m_τ will thus allow one to derive the mass value of $\tilde{\tau}$. Assuming conservatively a precision of 100 MeV for the $\tilde{\chi}_1^0$ mass measurement, the $\tilde{\tau}$ mass is expected to be measured in the range of $0.13 - 0.2$ GeV. This in turn will result in an uncertainty of the DM density of $1.7 - 2.6\%$ based on the microMegas program [7].

The results for the benchmark scenario D' are summarized in Table 2. For the result of *method one*, we have assumed that the background-free selection could be eventually achieved. The methods can also be applied to other co-annihilation scenarios. In general, the larger the mass difference between $\tilde{\tau}$ and $\tilde{\chi}_1^0$ is, the better the precision on the DM density will be [1, 2].

In summary, we have revisited the SM background contributions to the challenging stau scenarios using the realistic veto efficiencies obtained recently. If these scenarios are close to the one realized in nature, the uncertainty on the relic DM density obtained in linear collider can well match the precision to be expected from the Planck mission.

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References

[1] P. Bambade, M. Berggren, F. Richard and Z. Zhang, hep-ph/0406010; Z. Zhang, hep-ph/0411035.

[2] H.-U. Martyn, hep-ph/0408226.

[3] M. Battaglia *it al.*, Eur. Phys. J. **C33** (2004) 273, hep-ph/0306219.

[4] Z. Zhang, contribution to ILC-ECFA and GDE Joint Meeting, Valencia, 6-10 Nov., 2006.

[5] A. Stahl, private communication.

[6] P. Bambade, V. Drugakov and W. Lohmann, physics/0610145.

[7] G. Bélanger *et al.*, Comput. Phys. Commun. **149** (2002) 103-120, hep-ph/0112278.