Summary of ILD performance at SPS1a’

Mikael Berggren, Nicola d’Ascenzo, Peter Schade, and Olga Stempel

DESY-FLC
Notekstr. 85, 22607 Hamburg-Germany

The performance of the ILD detector at the ILC for the analysis of μ and τ channels at the SUSY benchmark-point SPS1a’ has been studied with full detector simulation. It is concluded that if 500 fb$^{-1}$ is delivered to the experiment, $\Delta(M_{\tilde{\chi}^0_1}) = 920$ MeV/$c^2$, $\Delta(M_{\tilde{\mu}_L}) = 100$ MeV/$c^2$, $\Delta(M_{\tilde{\chi}^0_2}) = 1.38$ GeV/$c^2$, and $\Delta(\sigma(e^+e^-\rightarrow\tilde{\mu}_L\tilde{\mu}_L)) = 1.35$ fb can be achieved from the μ channels alone. The preliminary results from the τ channels, indicates that $\Delta(P_{\tau}) = 13\%$ is also achievable.

1 Introduction

The SUSY benchmark point SPS1a’ [2] offers a rich phenomenology at the ILC. It is point with quite low mass-spectrum in the slepton sector, and heavy squarks. Bosinos up to $\tilde{\chi}^0_3$ (in $e^+e^-\rightarrow\tilde{\chi}^0_1\tilde{\chi}^0_3$) would be produced at $E_{CMS} = 500$ GeV. It is a pure mSUGRA model, hence R-parity and CP is conserved. The unification scale parameters are: $M_1/2 = 250$ GeV, $M_0 = 70$ GeV, $A_0 = -300$ GeV, $\tan\beta = 10$, and $\text{sign}(\mu) = +1$. The point is not in contradiction with any experimental limits [3]. The τ is the NLSP, and $M_{\tilde{\tau}_1} = 107.9$ GeV/$c^2$ and $M_{\tilde{\chi}^0_1} = 97.7$ GeV/$c^2$, so $\Delta(M) = 10.2$ GeV/$c^2$. At $E_{CMS} = 500$ GeV, this yields $P_{\tilde{\tau},\text{min}} = 2.2$ GeV/$c$ hence $\gamma\gamma$ events will pose a problem. As SPS1a’ is a point with an important co-annihilation contribution to the dark-matter relic density, the $M_{\tilde{\chi}^0_1}$ is a most important quantity to determine. An other consequence of the $\tilde{\tau}$ being the NLSP, is that τ:s are present in large fraction of the SUSY decays, so that SUSY itself will be a mayor background source for τ channels. On the other hand, the $M_{\tilde{\mu}_L}(M_{\tilde{\mu}_R})$ is 189.9(125.3) GeV/$c^2$, so that the minimum μ energy is 32.1(6.6) GeV. As, in addition, the branching ratios to μ in bosino decays are quite low, the μ final states offer cleaner conditions, and are well suited for doing the most precise measurements.

The present note reports on the status of the analysis of of the μ and τ channels of the SPS1a’ scenario in the LDC’ detector. SPheNo [4] was used to run the unification-scale model to the EW scale, and Whizard [5] was used to generate events. The LCWS/ILC 2008 detector model was fully simulated using MOKKA [6], and the events were reconstructed with MarlinReco [7]. The same chain was used to produce background events.

2 Analysis of μ channels

Two channels containing only μ:s in the final state was chosen as a first study [8]: $\tilde{\mu}_L\tilde{\mu}_L \rightarrow \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$ and $\tilde{\chi}^0_1\tilde{\chi}^0_2 \rightarrow \mu\mu\tilde{\chi}^0_1\tilde{\chi}^0_1$. As mentioned in the introduction, the SUSY background problem is not too severe in the μ channels, and it is advantageous to run the ILC at the polarisation giving the largest signal. Hence, these channels were studied assuming 80 % left $e^-$ polarisation and 60 % right $e^+$ polarisation. Under these conditions, the $\tilde{\mu}_L\tilde{\mu}_L$ process has a large cross-section, and is well suited to determine $M_{\tilde{\mu}_L}$ and $M_{\tilde{\chi}^0_1}$. $\tilde{\chi}^0_1\tilde{\chi}^0_2$ has a small cross-section × BR, but can be used to determine $M_{\tilde{\chi}^0_2}$, without the need

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The uncertainty on the observed cross-section was determined using the extended likelihood formed by these numbers. The production of SUSY background was mainly from WW and ZZ. Finally, each of the two processes is background to the other one.

The following kinematic variables were used to disentangle signal and background, and to separate the two signal channels: The momentum of \( \mu \), the acolinearity angle between the \( \mu \)s (\( \theta_{acol} \)), the acolinearity angle between them, defined as the acolinearity in the projection perpendicular to the beam-axis (\( \theta_{acol} \)), the polar angle of the missing momentum (\( \theta_{miss} \)), the invariant mass of the two \( \mu \)s (\( \mu \)), and the velocity \( \beta \) of the \( \mu \) system. The distributions of \( P_\mu \) and \( M_{\mu\mu} \) are shown in Fig. 1 and that of \( \beta \) in Fig. 2.

The \( \mu_L \mu_L \) channel was selected by demanding that \( E_{miss} \in [200, 430] \) GeV, \( M_{\mu\mu} \notin [80, 100] \) GeV and < 30 GeV/c², and \( \theta_{missing} p \in [0.1\pi, 0.9\pi] \). Assuming an integrated luminosity of 500 fb⁻¹, this leaves 13000 events of SM background and 11000 events of SUSY background, while 16300 signal events were selected, corresponding to an efficiency of 60 %. The \( \mu_L \) and \( \tilde{\chi}_1^0 \) masses were then extracted by fitting the edges of the \( P_\mu \) distribution, see Fig. 3. The errors on the fitted masses are \( \Delta(M_{\mu_L}) = 100 \) MeV/c² and \( \Delta(M_{\tilde{\chi}_1^0}) = 920 \) MeV/c², respectively. The beam-energy spread dominates these numbers. The production cross-section was determined using the extended likelihood formed by \( L(p_T\mu, \theta_{acol}) \), as these two variables were not used in selecting the signal. The uncertainty on the observed value is \( \Delta(\sigma(e^+e^+ \to \mu_L\mu_L)) = 1.35 \) fb.

The \( \tilde{\chi}_1^0 \tilde{\chi}_1^0 \) channel was selected by demanding that \( \theta_{missing} p \in [0.2\pi, 0.8\pi], \beta > 0.6, E_{miss} \in [355, 395] \) GeV, \( p_{Tmiss} > 40 \) GeV/c, \( M_{\mu\mu} \in [40, 85] \) GeV/c² and \( E_{miss} > 40 \) GeV/c².
Further reduce the γγ LCWS/ILC 2008 due to the large γγ E P of the spectrum spectrum is at φ significant activity in the BeamCal, and that the axis, in the projection perpendicular to the beam) was also done: ρ > 3 sin θ acop + 1.7. To further reduce the γγ background to acceptable levels, it was demanded that there be no significant activity in the BeamCal, and that the φ angle of the missing momentum was not in the direction of the incoming beam-pipe.

Figure 3: The fit to the lower (left) and upper (right) edges of the Pμ distribution

At the assumed integrated luminosity, 500 events of SM background and 2400 events of SUSY background is expected, while 720 signal events were selected, corresponding to an efficiency of 34 %. Assuming that the χ1 0 mass is known from the previous channel, the mass of χ2 0 can be extracted by a fit to the edge in the invariant mass spectrum, Fig. 4 and an uncertainty of ∆(Mχ2 0) = 1.38 GeV/c2 was found.

3 τ channels

As mentioned in the introduction, SUSY itself poses a background problem in the τ analysis, and it is therefore needed to run the ILC at the polarisation that minimises the background. For 100 % left e− polarisation and 100 % right e+ polarisation, the cross-sections for χ2 0χ2 0 and χ1 1χ1 1 are several hundred fb, and the branching ratios to τ is above 50 %. With the opposite polarisation, however, these cross-sections will almost vanish. Hence, these channels were studied assuming 80 % right e− polarisation and 60 % left e+ polarisation.

As the γγ background poses another challenge for the τ channels, quite strong criteria must be applied: A correlated cut in ρ (the transverse momentum of the jets wrt. the thrust axis, in the projection perpendicular to the beam) was also done: ρ > 3 sin θ acop + 1.7. To further reduce the γγ background to acceptable levels, it was demanded that there be no significant activity in the BeamCal, and that the φ angle of the missing momentum was not in the direction of the incoming beam-pipe.

The τ mass can be extracted from the end-point of the spectrum of Eν , which is equal to Eτ max , and the χ1 0 mass, known e.g. from the μτ analysis above. In principle, the maximum of the spectrum spectrum is at Pτ min , so that the τ can be used to find Mχ1 0 as well, but due to the large γγ background, the maximum is quite hard to observe.

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To extract the signal in order to determine the end-point the following cuts were applied: $E_{\text{miss}} \in [430, 490]$ GeV, $M_{\text{jet}} < 2$ GeV/c$^2$, $\theta_{\text{jet}}$ above 20 degrees, $\theta_{\text{acop}} < 160$ degrees, $\theta_{\text{acol}} \in [80, 170]$ degrees, $|\cos \theta_{\text{missingp}}| < 0.9$, and charge of each jet = ±1. In addition, the anti-$\gamma\gamma$ cut described above was applied. After these cuts, the SM background was 222 events, the SUSY background was 2747, while 8262 signal events remained (10.2 % efficiency).

Fig. 5 shows that the end-point is almost background free, and also that the turn-over point (expected to be at $P_{\tilde{\tau}, \text{min}} = 2.2$ GeV/c) is too distorted by the cuts to be useful.

The $\tilde{\tau}$ mass-eigenstates are expected to be different from the chiral ones, and the off-diagonal term of mass-matrix is $-M_{\tilde{\tau}} (A_{\tilde{\tau}} - \mu \tan \beta)$. The diagonal terms in the mass matrix are known from $M_{\tilde{\mu}}$ and $M_{\tilde{\mu}}$, so a measurement of $\theta_{\text{mix}}$ gives $A_{\tilde{\tau}} - \mu \tan \beta$. If $\tilde{\chi}_1^0$ is purely bino - it is in SPS1a’ - the $\tau$ polarisation ($P_{\tau}$) depends only on $\theta_{\text{mix}}$. $P_{\tau}$ can be extracted from spectrum for exclusive decay-mode(s). In this analysis, the $\tau \rightarrow \pi^+ - \nu_{\tau}$ mode has been studied. The spectrum of $\pi$:s in the decay-chain $\tilde{\tau} \rightarrow \tau \rightarrow \pi^+ - \nu_{\tau}$ is shown in Fig. 6, with and without ISR and beam-spread. The highest sensitivity to the polarisation is in the region with $P_{\pi} < P_{\tilde{\tau}, \text{min}}$.

The $\tilde{\tau} \rightarrow \tau \rightarrow \pi^+ - \nu_{\tau}$ signal is selected with a set of cuts that intend to distort the spectrum as little as possible. The following pre-selections were first applied: The events should pass the anti-$\gamma\gamma$ cut, $E_{\text{vis}}$ should be $< 120$ GeV, the number of reconstructed particles $< 20$, and at least one of the two jets should contain a single particle. This single particle should be identified as a $\pi$, and have $E < 43$ GeV. Finally, the total charge should be 0. Events passing this preslection should then also fulfil the following criteria: The mass of the rest of the event (ie. after removing the signal pion) should be below 2.5 GeV/c$^2$ $|\cos \theta|$ of both jets should be $< 0.9$, and $\theta_{\text{acop}}$ should be above 85 degrees. Finally, the sum over the two jets of the $p_T$ of one jet wrt. the direction of the other should be below 30 GeV/c.

With these cuts, 134 SM jets remain, and 373 SUSY jets, while 2311 signal-jets are retained (13 %). The initial and final $\pi$ spectra are shown in Fig. 7. The procedure to extract the polarisation in the presence of background is to first fit the simulated background alone to a heuristic function. The signal selections cuts are then applied to the

*When real data is available, the simulation of the background can be verified by reversing cuts to select
signal+background sample, and the function is subtracted from the observed distribution. An efficiency correction function, determined from signal-only simulation, is applied. The resulting distribution is then fitted with the theoretical spectrum, corrected for ISR and beam-spread, and the polarisation is obtained, see Fig. 7 right. Assuming an integrated luminosity of 500 fb$^{-1}$, the value found is $P_\tau = (93 \pm 13)$ %, where the error also includes the uncertainty of the background parametrisation.

4 Conclusions

A study of some channels in SPS1a’ SUSY scenario fully simulated in the LDC’ detector at the ILC was presented. By analysing the channel $e^+e^- \rightarrow \mu_L \mu_L$, it was concluded that $\Delta(M_{\tilde{\chi}_1^0}) = 920$ MeV/c$^2$, $\Delta(M_{\tilde{\mu}_L}) = 100$ MeV/c$^2$ and $\Delta(\sigma(e^+e^- \rightarrow \mu_L \mu_L)) = 1.35$ fb, could be attained with an integrated luminosity of 500 fb$^{-1}$ with 80 % left $e^-$ polarisation and 60 % right $e^+$ polarisation. In the channel $\chi_1^0 \chi_1^0 \rightarrow \mu_R \chi_1^0 \rightarrow \mu \chi_1^0 \chi_1^0$, $\Delta(M_{\chi_2^0}) = 1.38$ GeV/c$^2$, was found, under the same conditions. It should be noted that this value is comparable to what a dedicated scan of the $\chi_1^0 \chi_1^0$ threshold would give.

In addition, a progress report on $\tau$ production was given. The preliminary result on the measurement of the $\tau$ polarisation gives $\Delta(P_\tau) = 13$ %. Note, however, that this requires that the beam-polarisations are opposite to what the was used in the $\mu$ channel.

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a signal-free, but SUSY-dominated region in the parameter-space.

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