Search for the Next-To-Lightest Neutralino

I. Iashvili and A. Kharchilava

Institute of Physics, Georgian Academy of Sciences, Tbilisi, Georgia
Centre de Recherches Nucléaires, Strasbourg, France

Abstract

We study the inclusive production of the next-to-lightest neutralino decaying directly, or via slepton, into two leptons and the lightest neutralino. Events are selected in the inclusive 3 lepton or 3 lepton+ \( E_T^{miss} \) final states. The study is carried out in the framework of the minimal SUGRA model with one set of parameters: \( \tan \beta = 2, A_0 = 0, \mu < 0 \). The region of \( (m_0, m_{1/2}) \) parameter space, where the \( \tilde{\chi}_2^0 \) is observable by the characteristic shape of the dilepton invariant mass spectrum, is delineated. The possibilities to determine the model parameters through the measurement of neutralinos and slepton masses are discussed.
1 Introduction

Among many supersymmetric extensions of the Standard Model (SM) the minimal Supersymmetry Model motivated by Supergravity (mSUGRA) is the most "economic" in the sense that only five extra parameters are introduced \([1]\). These parameters are: \(m_0\), the universal scalar mass; \(m_{1/2}\), the universal gaugino mass; \(A_0\), the universal trilinear term; \(\tan\beta\), the ratio of vacuum expectation values of two Higgs fields; \(\text{sign}(\mu)\), the sign of the Higgsino mass parameter.

In the following we limit ourselves to the set: \(\tan\beta = 2\), \(A_0 = 0\), \(\mu < 0\). We also consider five representative points in mSUGRA parameter space suggested by theorists and listed in Table 1.

<table>
<thead>
<tr>
<th>Point</th>
<th>(m_0) (GeV)</th>
<th>(m_{1/2}) (GeV)</th>
<th>(A_0) (GeV)</th>
<th>(\tan\beta)</th>
<th>(\mu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>300</td>
<td>300</td>
<td>2.1</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>2</td>
<td>400</td>
<td>400</td>
<td>0</td>
<td>2</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>400</td>
<td>0</td>
<td>10</td>
<td>&gt; 0</td>
</tr>
<tr>
<td>4</td>
<td>200</td>
<td>100</td>
<td>0</td>
<td>2</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>5</td>
<td>800</td>
<td>200</td>
<td>0</td>
<td>10</td>
<td>&gt; 0</td>
</tr>
</tbody>
</table>

Table 1: mSUGRA representative points suggested by theorists

In \(R\)-parity conserving SUSY models sparticles are produced in pairs and a stable Lightest Supersymmetric Particle (LSP, which is the \(\tilde{\chi}^0\) in mSUGRA) appears at the end of each sparticle decay chain. Since it is weakly interacting and escapes detection, the complete reconstruction of SUSY masses is very difficult. Therefore the search strategy for Supersymmetry is to look for an excess of events over the SM expectation in specific final states. However, some particular final states resulting from the multitude of SUSY particle decays offer a good handle to get information on sparticle masses.

As discussed in ref. \([2]\) for \(\tilde{\chi}^\pm\rightarrow L^-\tilde{\chi}^0\) direct production, the three-body leptonic decays \(\tilde{\chi}^0_{2/1}\rightarrow L^+l^-\tilde{\chi}^0\), can be used to measure the mass difference between \(\tilde{\chi}^0_{2/1}\) and \(\tilde{\chi}^0_{1}\), since the \(L^+l^-\) mass distribution has its endpoint at \(M_{\chi^0_{2}} - M_{\chi^0_{1}}\). Here we propose to use the specific shape of the dilepton mass spectrum as evidence for discovery of SUSY. We emphasize that the \(\tilde{\chi}^0_{2}\) is abundantly produced through decays of strongly interacting particles over the entire \((m_0, m_{1/2})\) parameter space of the mSUGRA model. Due to this abundant production, it is possible to observe the sharp dilepton edge from the \(\tilde{\chi}^0_{2}\) decay in the most of the regions where leptonic modes are open. For the Standard Model background suppression, besides two same-flavor and opposite-sign leptons, one can ask additional signature characterizing SUSY. This can be: missing energy taken away by escaping LSPs, or additional jets due to the gluinos and squarks cascade decays, or an extra high \(p_T\) lepton from charginos, neutralinos, sleptons, IVBs, or b-quarks copiously produced in SUSY. Sparticle masses and predominant decay modes make one of these extra requirements more advantageous than others in particular regions of parameter space, or complementary. In this note we study the possibility to observe the \(\tilde{\chi}^0_{2}\) in the inclusive \(3\) lepton channel with no great demand on detector performance and in the \(3\) lepton + \(E_T^{miss}\) final states. The search strategy for SUSY is to look for a characteristic shape in the dilepton invariant mass spectrum with a sharp edge, rather than just for event excess over the SM expectation. Observation of such a spectacular shape will directly reveal SUSY through \(\tilde{\chi}^0_{2}\), and at the same time will allow to measure sparticle masses and some of the model parameters. We also study two-body leptonic decays \(\tilde{\chi}^0_{2}\rightarrow L^+l^-\tilde{\chi}^0_{1}\), which allow us to get information on the mass of sleptons involved in the decay chain.

First, we discuss \(\tilde{\chi}^0_{2}\) production, decay and some relations within the mSUGRA model in section 2. Simulation aspects and selection criteria are discussed in section 3. In sections 4 and 5 we delineate the region of parameter space, where SUSY is observable through \(\tilde{\chi}^0_{2}\) in the inclusive \(3\) lepton and \(3\) lepton + \(E_T^{miss}\) final states, respectively. Section 6 describes a way of slepton mass determination in two-body decays of \(\tilde{\chi}^0_{2}\). Some specific examples of double edges in dilepton mass distribution are given in section 7. Conclusions are drawn in section 8.

2 \(\tilde{\chi}^0_{2}\) Production and Decay

Within mSUGRA the following relations are valid:

\[
M_{\tilde{\chi}^0_{2}} \approx 0.45 m_{1/2} \quad (1)
\]
\[
M_{\tilde{\chi}^0_{2}} \approx M_{\tilde{\chi}^+_{1}} \approx 2M_{\tilde{\chi}^0_{1}} \quad (2)
\]
\[
M_{\tilde{\chi}^0_{2}} \approx (0.25 \div 0.35) M_{\tilde{\chi}^0_{1}} \quad (3)
\]
\[ M_{l+\ell^-}^{\text{max}} = \frac{\sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\chi}_2^0}^2)(M_{\tilde{\chi}_1^0}^2 - M_{\tilde{\chi}_1^0}^2)}}{M_{\tilde{\chi}_1^0}} \]

The useful kinematical feature of \( \tilde{\chi}_2^0 \) leptonic decays is the \( l^+l^- \) invariant mass spectrum with its characteristic edge near the endpoint, which is given by

\[ M_{l+\ell^-}^{\text{max}} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} \]

for direct decays, and by

\[ M_{l+\ell^-}^{\text{max}} = \frac{\sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\chi}_2^0}^2)(M_{\tilde{\chi}_1^0}^2 - M_{\tilde{\chi}_1^0}^2)}}{M_{\tilde{\chi}_1^0}} \]

for cascade decays through \( \tilde{\ell} \) intermediate states.

Clearly, for a correct interpretation of the observed dilepton invariant mass edge, it is necessary to distinguish the decay type, i.e. is it three-body or two-body. In the following we discuss ways to distinguish experimentally between these two possibilities.

In the mSUGRA model direct leptonic decays of \( \tilde{\chi}_2^0 \) dominate below \( m_{1/2} \lesssim 200 \text{ GeV} \) nearly for all values of \( m_0 \), and there is also a small region at higher \( m_{1/2} \) where direct decays are open (Fig.2a). In these regions of direct decay the measurement of \( M_{l+\ell^-}^{\text{max}} \) within mSUGRA allows to get estimate of \( M_{\tilde{\chi}_1^0}, M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0}, M_{\tilde{\chi}_2^0}, M_{\tilde{\chi}_1^0} \) and \( m_{1/2} \). At \( m_{1/2} \approx 200 \text{ GeV} \), the so called ”spoiler” modes, \( \tilde{\chi}_2^0 \rightarrow h \tilde{\chi}_1^0 \) and \( \tilde{\chi}_2^0 \rightarrow Z \tilde{\chi}_1^0 \), become kinematically accessible suppressing direct leptonic decays of \( \tilde{\chi}_2^0 \).

Cascade decays of the \( \tilde{\chi}_2^0 \) via \( \tilde{\ell}_L \) (Fig.2b) or \( \tilde{\ell}_R \) (Fig.2c) occur mostly at a low values of \( m_0 \), where the \( \tilde{\chi}_2^0 \) is heavier than sleptons. In these regions the measurement of only the edge position does not provide information on masses unambiguously. However, as shown later on, by analyzing some kinematical distributions, the masses of \( \tilde{\chi}_0^0, \tilde{\chi}_1^0 \) and of involved slepton can be determined with a reasonable precision. Therefore, with two-body decays one can constrain \( m_{1/2} \) and \( m_0 \) if the information on \( \tan \beta \) is available\(^1\) and hence all sparticle masses.

The expected position of the \( l^+l^- \) kinematical edge as a function of \( m_{1/2} \) is given in Fig.3 for two different values of the common scalar mass: \( m_0 = 400 \text{ GeV} \) and 100 GeV. The box size in the figure is proportional to the branching ratio \( B(\tilde{\chi}_2^0 \rightarrow l^+l^- + \nu \bar{\nu}) \). At \( m_0 = 400 \text{ GeV} \) the \( \tilde{\chi}_2^0 \) has only direct decay modes for all values of \( m_{1/2} \) up to \( m_{1/2} \approx 180 \text{ GeV} \). Thus the measurement of \( M_{l+\ell^-}^{\text{max}} \) yields the common gaugino mass parameter of the model unambiguously in this region. For the \( m_0 = 100 \text{ GeV} \) the situation is more complicated. Here at different values of \( m_{1/2} \), different leptonic decay modes of the \( \tilde{\chi}_2^0 \) are dominant: the direct decays occur up to \( m_{1/2} \lesssim 130 \text{ GeV} \); the cascade decays via \( \tilde{\ell}_R \) at \( 130 \text{ GeV} \lesssim m_{1/2} \lesssim 250 \text{ GeV} \) and, finally, cascade decays via \( \tilde{\ell}_L \) at \( m_{1/2} \gtrsim 250 \text{ GeV} \). In some regions of parameter space two different \( \tilde{\chi}_2^0 \) decay channels coexist leading to possibilities of having two distinct \( l^+l^- \) ”edges”.

The \( \tilde{\chi}_2^0 \) direct production cross-section is typically low, of the order of Drell-Yan process. However, there is an abundant production of \( \tilde{\chi}_2^0 \) either from gluinos or from squarks over almost the entire \((m_0, m_{1/2})\) plane, as illustrated in Figs.4a, b. Fig.4d shows the quantity \( \sigma \cdot B \), the \( \tilde{\chi}_2^0 \) inclusive production cross-section times branching

\(^1\) e.g., from the Higgs sector of the model.
ratio into leptons ($l = \mu$ or $e$). Clearly, there is a big portion of $(m_0, m_{1/2})$, where one expects quite large rates of opposite-sign same-flavor dileptons from inclusive $\tilde{\chi}_2^0$ production.

Similarly to the $\tilde{\chi}_2^0$, the lightest chargino $\tilde{\chi}_1^\pm$ is also copiously produced from strongly interacting sparticles, as illustrated in Figs.5a, b. Moreover, the leptonic decay branching of the $\tilde{\chi}_1^\pm (\tilde{\chi}_1^\pm \to l^\pm \nu \tilde{\chi}_2^0, \tilde{\chi}_1^\pm \to \nu l_L^\pm \to l^\pm \nu \tilde{\chi}_1^0, \tilde{\chi}_1^\pm \to l^\pm \bar{\nu} \to l^\pm \nu \tilde{\chi}_1^0, \tilde{\chi}_1^\pm \to W^\pm \tilde{\chi}_1^0 \to l^\pm \nu \tilde{\chi}_1^0)$ always exceeds 10% per lepton flavor (Fig.5c). For low values of $m_0$, in the region where decay to sleptons is kinematically allowed, the $\tilde{\chi}_1^\pm$ gives a lepton with a probability close to 100%. Making use of this prolific production of leptons from $\tilde{\chi}_1^\pm$, as well as from other SUSY sources, the SM background can be suppressed by asking additional high $p_T$ lepton. Thus the $\tilde{\chi}_2^0$ inclusive production can be studied in $3\text{lepton}$ and $3\text{lepton} + E_T^{\text{miss}}$ final states.

3 Event Simulation and Selection

For signal simulation we have generated all mSUGRA processes, $pp \to \text{all}$, using ISAJET 7.14 [3] with the CTEQ2L structure functions. As the SM sources of inclusive three leptons final state we have considered WZ, $t\bar{t}$, ZZ, and $Zb\bar{b}$ productions. Simulation of background is performed using PYTHIA 5.7 [4] with the CTEQ2L structure functions. The following production cross-sections at LHC energy of $\sqrt{s} = 14$ TeV are assumed: $\sigma_{WZ} = 26$ pb, $\sigma_{t\bar{t}} = 670$ pb for a top mass of 170 GeV, $\sigma_{ZZ} = 15$ pb and $\sigma_{Zb\bar{b}} = 580$ pb.

For simulation of the CMS detector response a fast, non-GEANT, program CMSJET [5] has been used. It takes into account: i) magnetic field effect on charged particles; ii) smearing of lepton momentum according to parameterization obtained from full GEANT simulations; iii) 90% triggering plus reconstruction efficiency per lepton within geometrical acceptance of CMS detector; $|y| < 2.4$; iv) 90% reconstruction efficiency per charged track with $p_T > 1$ GeV within $|y| < 2.4$; v) coverage, granularity, main cracks, energy resolution and electronic noise of the calorimetry system; vi) fluctuation of starting point and the spatial development of electromagnetic and hadronic showers by parameterization of the lateral and longitudinal profiles. For the high luminosity study, at $L = 10^{34}$ cm$^{-2}$ s$^{-1}$, we have superimposed on average 15 “hard” pile-up events, fluctuated by Poissonian distribution, on top of each signal and background events. These are PYTHIA QCD jet production with $p_T > 5$ GeV.

In the inclusive $3\text{lepton}$ channel we require:

1. Two opposite-sign, same-flavor leptons ($\mu$ or $e$) with $p_T > 10$ GeV.
2. Third “tagging” lepton with $p_T > 15$ GeV.
3. Isolation. If there is no track with $p_T > 2$ (1.5) GeV within $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$ around the lepton direction, it is considered as isolated. In some cases, explicitly mentioned, leptons are not required to be isolated.

In the inclusive $3\text{lepton} + E_T^{\text{miss}}$ channel, beside the above three requirements we ask:

4. $E_T^{\text{miss}} > 200$ (300) GeV

In the selected $3\text{lepton}$ events we reconstruct the invariant mass $M_{l+\ell^+}$ of lepton pair with the same flavor and opposite sign. When several $l^+l^-$ combinations per event are possible (in case of, e.g., three leptons of the same flavor) the one with minimal $\Delta R^{l+\ell^-}$ is chosen.

In this approach, a good knowledge of the SM dilepton mass spectrum is mandatory. The expected SM background in $3\text{lepton}$ final states at an integrated luminosity of $L_{\text{int}} = 10^4$ pb$^{-1}$ is shown in Fig.6. The main contribution around the Z mass peak comes from WZ production, while $t\bar{t}$ production dominates at lower invariant masses.

4 Inclusive $3\text{lepton}$ Channel

The dilepton invariant mass spectrum at parameter space Point 4 (see table 1) superimposed on the SM background is shown in Fig.7. The number of events corresponds to an integrated luminosity of $L_{\text{int}} = 20$ pb$^{-1}$, i.e. a few hours of initial LHC running. The $p_T$ thresholds on all three leptons are 15 GeV within $|y| < 2.4$. The contribution from the SM background is negligible. In Fig.7a the isolation of leptons is not required, whereas in Fig.7b two leptons out of 3 are isolated. The specific shape of the distribution with its sharp edge reveals SUSY through $\tilde{\chi}_2^0$ production. At this mSUGRA point the $\tilde{\chi}_2^0$ has three-body decay modes, with a branching ratio $B(\tilde{\chi}_2^0 \to l^+l^- + \chi_1^0) = 0.32$. The relevant masses are $M_{\tilde{\chi}_2^0} = 97$ GeV, $M_{\tilde{\chi}_1^0} = 45$ GeV. The sharp dilepton edge
situated at the expected value of $M^m_{\tilde{t}^+_1} = 52$ GeV allows determination of $M_{\chi^0_2} - M_{\chi^0_1}$ and within the model $M_{\tilde{\chi}^0_1}$, $M_{\tilde{\chi}^0_2}$, $M_{\tilde{\chi}^\pm}$, $M_{\tilde{g}}$ and $m_{1/2}$.

Fig.8 shows the expected $M_{\tilde{t}^+_1}$ distribution for the mSUGRA Point 1 with an integrated luminosity of $L_{int} = 10^4$ pb$^{-1}$. The $p_T$ thresholds for leptons are 15, 15, 30 GeV and all three leptons are isolated. At this mSUGRA point the $\tilde{\chi}^0_2$ possesses two-body decay mode with a branching ratio $\text{B}(\tilde{\chi}^0_2 \to l^+l^- + \chi^0_1) = 0.24$. The sparticle masses are $M_{\tilde{\chi}^0_2} = 231$ GeV, $M_{\chi^0_1} = 122$ GeV, $M_{\tilde{g}} = 157$ GeV. The edge of the distribution is situated near 108 GeV, as expected. We define a signal significance as $S = N_S/\sqrt{N_S + N_B}$, where $N_S$ and $N_B$ are the numbers of signal and background events, respectively, in a mass window below the edge. In this particular case the signal and background events are calculated in a mass window of 100 GeV < $M_{\tilde{t}^+_1} < 110$ GeV: $N_S = 140$ and $N_B = 39$, resulting in a signal significance of $S = 10.5$. $N_B$ consists of 113, 139, 65 and 85 events coming from WZ, $t\bar{t}$, ZZ and $Z\tilde{b}\tilde{b}$ production, respectively.

An example for the mSUGRA Point 5 is shown in Fig.9. The cuts are the same as in the previous case. At this Point the $\tilde{\chi}^0_2$ has three-body decay modes with $\text{B}(\tilde{\chi}^0_2 \to l^+l^- + \chi^0_1) = 0.06$ and the masses are $M_{\tilde{\chi}^0_2} = 124$ GeV, $M_{\chi^0_1} = 73$ GeV. The observed value of $M^m_{\tilde{t}^+_1}$ is close to the expected 51 GeV. In a mass window of 20 GeV < $M_{\tilde{t}^+_1} < 52$ GeV the numbers of signal and background events are $N_S = 588$ and $N_B = 402$ giving a signal significance of $S = 19$. $N_B$ consists of 113, 139, 65 and 85 events coming from WZ, $t\bar{t}$, ZZ and $Z\tilde{b}\tilde{b}$ production, respectively.

At mSUGRA Points 2 and 3 the $\tilde{\chi}^0_2$ leptonic decays are suppressed due to the dominating "spoiler" modes.

Following the same procedure, the mSUGRA parameters space ($m_0, m_{1/2}$) was systematically scanned for fixed $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. Figs.10-15 show the expected $M_{\tilde{t}^+_1}$ distributions for the different mSUGRA points, with optimal thresholds on leptons $p_T$ and isolation requirement needed for the SM background suppression. Generally, with increasing $m_{1/2}$ the observation of the edge becomes more difficult due to rapidly decreasing gluino and squark production cross-sections. At least 40 signal events in a mass interval > 10 GeV just below the edge and a statistical significance $S > 7$ are required. The domain explorable under these conditions with an integrated luminosity of $L_{int} = 10^4$ pb$^{-1}$ is shown in Fig.16. It entirely covers the cosmologically preferred region $0.15 < \Omega h^2 < 0.4$ [6]; here $\Omega$ is the ratio of the $\chi^0_1$ relic density to the critical density of the Universe, $h$ is the Hubble constant scaling factor and bounds are obtained assuming that the lightest neutralinos provide the cold dark matter in the Universe.

For some regions of mSUGRA parameter space $M^m_{\tilde{t}^+_1}$ is close to, or even hidden by the Z signal. At this points the accuracy of an edge measurement is ~10 GeV. Applying a cut on missing transverse energy and/or additional jets suppresses the contribution from the SM Z production, thus improving signal visibility.

Note, that the Z peak can be used as an overall calibration signal; it allows to control the mass scale as well as the production cross-section.

5 Inclusive 3 lepton + $E_T^{miss}$ Channel

With increasing $m_{1/2}$, gluino and squark masses increase and the missing transverse energy becomes larger. Asking $E_T^{miss} > 200$ (300) GeV rejects most of the SM background leaving a big fraction of signal events. Figs.17-30 show the dilepton spectra for various mSUGRA points in the 3 lepton + $E_T^{miss}$ final states. In the region of high $m_{1/2}$ dileptons are mainly produced through cascade decays of $\tilde{\chi}^0_2$. The third, "tagging" lepton, predominantly comes from a $\tilde{\chi}_1^{\pm}$ produced in association, again from $\tilde{g}, \tilde{q}$ cascades. Thus in this region of parameter space a big fraction of 3 lepton + $E_T^{miss}$ events are in fact inclusively produced $\tilde{\chi}_1^{\pm} \tilde{\chi}_1^0$ pairs. Therefore all three leptons are required to be isolated. The $p_T$ thresholds are chosen quite asymmetric, 50, 25, 10 GeV since leptons are produced in the cascades. The region of mSUGRA parameter space, where the $\tilde{\chi}^0_2$ is observable from the dilepton mass distribution shape in the 3 lepton + $E_T^{miss}$ events at $L_{int} = 10^6$ pb$^{-1}$ luminosity is shown in Fig.31. The reach extends up to $m_{1/2} \sim 900$ GeV and almost entirely covers the region where the $\tilde{\chi}^0_2$ has leptonic decay modes.$^2$

A detectable edge is seen as long as $\sigma \cdot B \gtrsim 10^{-5}$ pb (see Fig.4d).

$^2$ The maximal reach in mSUGRA parameter space via $\tilde{\chi}^0_2$ is expected in the dilepton + multijet + $E_T^{miss}$ final states [7].
Two-body Versus Three-body Decay Ambiguity and Slepton Mass Determination

An essential point in the analysis of the observed edge is the knowledge of the $\tilde{\chi}^0_2$ decay chain: is it due to a three-body or two-body decay. In general, the $p_T$ spectra of leptons from $\tilde{\chi}^0_2$ two-body decays are more asymmetric compared to the three-body decays. To characterize the asymmetry we introduce the variable:

$$A = \frac{p_T^{\text{max}} - p_T^{\text{min}}}{p_T^{\text{max}} + p_T^{\text{min}}} ,$$

where $p_T^{\text{max}}$ ($p_T^{\text{min}}$) corresponds to the lepton of maximal (minimal) transverse momentum.

An example of decay-type determination is discussed for the mSUGRA point $(m_0 = 100$ GeV, $m_{1/2} = 150$ GeV). The sparticle masses are $M_{\tilde{\chi}^0_2} = 135$ GeV, $M_{\tilde{\chi}^0_1} = 65$ GeV, $M_{\tilde{\tau}_2} = 120$ GeV and the $\tilde{\chi}^0_2$ decays via $\tilde{\chi}^0_2 \rightarrow t^\pm \tilde{t}_R^\mp \rightarrow t^\pm l^- \tilde{\chi}^0_1$ with 0.54 branching ratio. Fig.32 shows the dilepton spectrum for this point with an integrated luminosity of $L_{\text{int}} = 5 \times 10^3$ pb$^{-1}$, superimposed on the SM background, in the inclusive 3 lepton final states. Out of the three leptons with $p_T > 15$ GeV only two, which enter invariant mass distribution, are isolated. An edge is situated at $\sim 52$ GeV as expected. To look at the lepton $p_T$-asymmetry distribution, we pick up the lepton pairs with $M_{l^+l^-} < 52$ GeV. Fig.33 (full line) shows the corresponding $A$ spectrum for the selected events. The pronounced asymmetry in $p_T$ indicates the cascade nature of decays. On the same figure distributions for the other mSUGRA points with $\tilde{\chi}^0_2$ direct decays are also shown. In these latter cases distributions peak near zero, i.e. the leptonic $p_T$-asymmetry is much reduced.

After the decay type is determined a further analysis step is carried out to extract the masses of involved particles: $\tilde{\chi}^0_2, \tilde{\chi}^0_1$ and $\tilde{\tau}$. In case of sequential two-body decays the $l^+l^-$ kinematical upper limit is

$$M_{l^+l^-}^{\text{max}} = \frac{\sqrt{(M_{\tilde{\chi}^0_2}^2 - M_{\tilde{\tau}}^2)(M_{\tilde{\tau}}^2 - M_{\tilde{\chi}^0_1}^2)}}{M_{\tilde{\tau}}} = 52 \text{ GeV} .$$

This equation can be satisfied by an infinite number of $M_{\tilde{\chi}^0_2}, M_{\tilde{\chi}^0_1}$ and $M_{\tilde{\tau}}$ mass combinations. To find a solution, we assume $M_{\tilde{\chi}^0_2} = 2M_{\tilde{\chi}^0_1}$ and generate the $\tilde{\chi}^0_2$ two-body sequential decays for various assumptions on $M_{\tilde{\tau}} (M_{\tilde{\chi}^0_2})$, e.g. from 70 GeV to 150 GeV by 10 GeV steps; note, that the $\tilde{\chi}^0_1$ mass is constrained to provide the "observed" position of an edge.

For each value of $M_{\tilde{\tau}}$, one obtains two series of solutions for the quadratic equation (9). Some of them are shown in Figs.34a, c for "low mass" and Figs.34b, d for "high mass" solutions, respectively. The solid lines in the figures correspond to the "observed" spectra and the dotted histograms are the results obtained from eq. (9). Clearly, the "observed" $l^+l^-$ invariant mass spectrum itself and the asymmetry distributions allow us to eliminate the "high mass" solutions of eq. (9). To find the best combinations of $M_{\tilde{\chi}^0_2}, M_{\tilde{\chi}^0_1}$ and $M_{\tilde{\tau}}$ among the "low mass" solutions, we perform a $\chi^2$-test of the asymmetry distributions, taking into account only the difference in the shapes, but not the numbers of entries into histograms. The result is shown in Fig.35. The horizontal line in the figure corresponds to the expected uncertainty of simulations due to the detector resolution effects, background estimations, initial/final state radiations, etc. We obtain the following bounds for masses:

$$115 \text{ GeV} \lesssim M_{\tilde{\chi}^0_2} \lesssim 135 \text{ GeV}$$

$$64 \text{ GeV} \lesssim M_{\tilde{\chi}^0_1} \lesssim 74 \text{ GeV}$$

Double Edges

As discussed in section 2, in some regions of the $(m_0, m_{1/2})$ plane different leptonic decay modes of $\tilde{\chi}^0_2$ can be simultaneously open. In these regions the observation of "double edges" in the $M_{l^+l^-}$ spectra can be expected. This is the case, for example, for point (100 GeV, 150 GeV) discussed in the previous section. Here, beside the $\tilde{\chi}^0_2 \rightarrow H_R \rightarrow l^+l^- \tilde{\chi}^0_1$ decay, the direct decay mode is also open, however, with a much suppressed branching ratio, and the use of the total number of observed events, as well as the $l^+l^-$ invariant mass spectrum or some other distributions in a combined $\chi^2$-test would further improve the results presented here.
B(χ₂⁰ → ℓ⁺ℓ⁻ + χ₁⁰) = 0.05. The second edge at M_{m_{τ}} = 69 GeV due to the direct decay is thus less spectacular than the one at 52 GeV. The asymmetry distribution of dileptons with 55 GeV < M_{l⁺ℓ⁻} < 69 GeV indicates the three-body decay type of these events. Using now two measured values of edges positions and assuming eq. (2) to hold, we obtain directly two solutions for slepton mass from equations (6) and (7):

1) M_{l} = 120 GeV and 2) M_{l} = 77 GeV.

A detailed analysis of dilepton invariant mass spectra allows to resolve the ambiguity. Fig.36 shows the M_{l⁺ℓ⁻} spectra for the two above values of slepton masses. A clear difference between predicted spectra allows to eliminate the “ghost” solution M_{l} = 77 GeV. We conclude that, in case of observable direct and cascade decays, i.e. of an observed double edge, and with only minimal assumption about χ₂⁰ and χ₁⁰ masses, e.g. M₂⁰ = 2 M₁⁰, one can determine the slepton mass along with the M₂⁰. At this particular mSUGRA point (100 GeV, 150 GeV) the use of both edges provides the precision of 0.01 GeV.

Another example of a double edges is given in Fig.37 for the mSUGRA point (50 GeV, 125 GeV). Here the sparticle masses are M₂⁰ = 116 GeV, M₁⁰ = 55 GeV, M₁⁺ = 110 GeV, M₁⁻ = 78 GeV and now two two-body decays via left and right sleptons coexist, with the branching ratios B(χ₂⁰ → ℓ⁺L ++ ℓ⁻χ₁⁰) = 0.037 and B(χ₂⁰ → ℓ⁺R ++ ℓ⁻χ₁⁰) = 0.013.

8 Conclusions

It was shown, that

• Observation of an edge in the l⁺l⁻ invariant mass spectrum reflects production of χ₁⁰ and hence can be used to establish existence of SUSY; this observation in some cases is possible with very small statistics and could be the first evidence for SUSY at the LHC.

• In the inclusive 3 lepton final states, with no great demand on detector performance, a large portion of parameter space, including the cosmologically preferred mSUGRA domain, can be investigated at an integrated luminosity of L_{int} = 10^4 pb⁻¹.

• In the inclusive 3 lepton + E_T^{miss} final states most of the region where χ₂⁰ decays leptonically can be covered at L_{int} = 10^5 pb⁻¹.

• From the observation of one (or more) characteristic edge(s), with mSUGRA motivated assumptions, it is possible to determine masses of χ₁⁰ and χ₂⁰ in case of direct decays and masses of χ₁⁺, χ₁⁻ and sleptons in case of cascade decays.

Acknowledgments

We would like to thank Daniel Denegri for his suggestions and encouragement, Walter Geist, Tejinder Virdee and John Womersley for useful remarks.

References

mSUGRA parameters: $\tan\beta = 2$, $A_0 = 0$, $\mu < 0$

Figure 1: Isomass contours for $\tilde{\chi}_1^0$, $\tilde{\ell}_L$ and $\tilde{\ell}_R$. Mass values are given in GeV.
mSUGRA parameters: $\tan\beta = 2$, $A_0 = 0$, $\mu < 0$

Figure 2: $\tilde{\chi}_2^0$ decay branching ratios into two-leptons plus $\tilde{\chi}_1^0$: a) direct decay, b) cascade decay via $\tilde{t}_L$, c) cascade decay via $\tilde{t}_R$ and d) total.
Figure 3: Correlation between $M_{ll}^{max}$ and $m_{1/2}$ for fixed $m_0 = 400$ GeV and $m_0 = 100$ GeV; the other mSUGRA parameters are: $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. 

$m_0 = 400$ GeV  
$m_0 = 100$ GeV 

Box size $\propto B(\tilde{\chi}^0_2 \rightarrow l^+ l^- + \text{inv.})^2$ 

$m_0 = 400$ GeV  
$m_0 = 100$ GeV
mSUGRA parameters: $\tan\beta = 2, \ A_0 = 0, \ \mu < 0$

Figure 4: $\tilde{\chi}_2^0$ inclusive production and decay: a) branching ratio $B(\tilde{g} \rightarrow \tilde{\chi}_2^0 + x)$, b) $B(\tilde{u}_L \rightarrow \tilde{\chi}_2^0 + x)$, c) $B(\tilde{\chi}_2^0 \rightarrow l^+l^- + inv.)$ and d) $\tilde{\chi}_2^0$ inclusive production cross-section times branching ratio into $l^+l^-$. 

10
mSUGRA parameters: $\tan \beta = 2$, $A_0 = 0$, $\mu < 0$

Figure 5: $\tilde{\chi}_1^\pm$ inclusive production and decay: a) branching ratio $B(\tilde{g} \to \tilde{\chi}_1^\pm + x)$, b) $B(\tilde{u}_L \to \tilde{\chi}_1^\pm + x)$, c) $B(\tilde{\chi}_1^\pm \to l^\pm + inv.)$ and d) $\tilde{\chi}_1^\pm$ inclusive production cross-section times branching ratio into $l^\pm$. 

11
Three isolated lepton events from SM

Figure 6: Expected Standard Model background in the inclusive 3 lepton final state.
**mSUGRA Point 4**

\[ m_0 = 200 \text{ GeV}, \quad m_{1/2} = 100 \text{ GeV}, \quad \tan \beta = 2, \quad A_0 = 0, \quad \mu < 0 \]

\[ M(\chi^0_1) = 45 \text{ GeV} \]

\[ M(\chi^0_2) = 97 \text{ GeV} \]

Expected \( M_{ll}^{\text{max}} = 53 \text{ GeV} \)

**L_{int} = 20 \text{ pb}^{-1}**

\[ p_{T,1,2,3} > 15 \text{ GeV} \]

**SUSY + SM**

---

**Figure 7:**

Expected \( l^+l^- \) mass spectrum for mSUGRA Point 4: \( m_0 = 200 \text{ GeV}, \quad m_{1/2} = 100 \text{ GeV}, \quad \tan \beta = 2, \quad A_0 = 0 \) and \( \mu < 0 \). a) Leptons with \( p_T > 15 \text{ GeV} \) in \(|\eta| < 2.4\) are considered; b) as in previous case, but two leptons which enter invariant mass spectrum are required to be isolated. The dotted histogram corresponds to the SM background.
**mSUGRA Point 1**

\[ m_0 = 100 \text{ GeV}, \ m_{1/2} = 300 \text{ GeV}, \ \tan\beta = 2.1, \ A_0 = 300, \ \mu > 0 \]

- \( M(\tilde{\chi}^0_1) = 122 \text{ GeV} \)
- \( M(\tilde{\chi}^0_2) = 231 \text{ GeV} \)
- \( M(l_R) = 157 \text{ GeV} \)
- Expected \( M_{ll}^{\max} = 107 \text{ GeV} \)

\[ L_{int} = 10^4 \text{ pb}^{-1} \]

- \( p_T^{l_1, l_2} > 15 \text{ GeV} \)
- \( p_T^l > 30 \text{ GeV} \)

*No tracks with \( p_T > 2 \text{ GeV in } \Delta R < 0.3 \)*

Figure 8: Expected \( l^+l^- \) mass spectrum for mSUGRA Point 1: \( m_0 = 100 \text{ GeV}, \ m_{1/2} = 300 \text{ GeV}, \ \tan\beta = 2.1, \ A_0 = 300 \text{ GeV and } \mu > 0 \). The dotted histogram corresponds to the SM background.
**mSUGRA Point 5**

\( m_0 = 800 \text{ GeV}, \ m_{1/2} = 200 \text{ GeV}, \ \tan \beta = 10, \ A_0 = 0, \ \mu > 0 \)

\[
\begin{align*}
M(\tilde{\chi}_1^0) &= 72 \text{ GeV} \\
M(\tilde{\chi}_2^0) &= 124 \text{ GeV} \\
\text{Expected } M_{ll}^\text{max} &= 52 \text{ GeV}
\end{align*}
\]

- \( p_T^1,2 > 15 \text{ GeV} \)
- \( p_T^3 > 30 \text{ GeV} \)
- No tracks with \( p_T > 2 \text{ GeV in } \Delta R < 0.3 \)

**Figure 9:** Expected \( l^+l^- \) mass spectrum for mSUGRA Point 5: \( m_0 = 800 \text{ GeV}, m_{1/2} = 200 \text{ GeV}, \tan \beta = 10, \ A_0 = 0 \) and \( \mu > 0 \). The dotted histogram corresponds to the SM background.
**mSUGRA parameters**

$m_0=400 \text{ GeV}, \ m_{1/2}=150 \text{ GeV}, \ \tan\beta=2, \ A_0=0, \ \mu<0$

$m(\tilde{\chi}^0_1) = 65 \text{ GeV} \quad \text{M}(\tilde{\chi}^0_2) = 135 \text{ GeV} \quad \text{Expected } M_{jj\text{max}} = 70 \text{ GeV}$

$L_{\text{int}}=10^3 \text{ pb}^{-1}$

$p_{T}^{j,\ell,\ell}>15 \text{ GeV}$

No tracks with $p_T>2 \text{ GeV}$ in $\Delta R<0.3$

Figure 10: $l^+l^-$ mass distribution for $m_0 = 400$ GeV and $m_{1/2} = 150$ GeV; the other mSUGRA parameters are: $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

**mSUGRA parameters**

$m_0=400 \text{ GeV}, \ m_{1/2}=170 \text{ GeV}, \ \tan\beta=2, \ A_0=0, \ \mu<0$

$m(\tilde{\chi}^0_1) = 74 \text{ GeV} \quad \text{M}(\tilde{\chi}^0_2) = 151 \text{ GeV} \quad \text{Expected } M_{jj\text{max}} = 77 \text{ GeV}$

$L_{\text{int}}=10^3 \text{ pb}^{-1}$

$p_{T}^{j,\ell,\ell}>15 \text{ GeV}$

No tracks with $p_T>2 \text{ GeV}$ in $\Delta R<0.3$

Figure 11: $l^+l^-$ mass distribution for $m_0 = 400$ GeV and $m_{1/2} = 170$ GeV; the other mSUGRA parameters are: $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.
mSUGRA parameters

\(m_0 = 1800 \text{ GeV}, \ m_{1/2} = 100 \text{ GeV}, \ \tan \beta = 2, \ A_0 = 0, \ \mu < 0\)

\(M(\chi^0) = 43 \text{ GeV}\)

\(M(\chi^0) = 90 \text{ GeV}\)

Expected \(M_{ll}^{\text{max}} = 47 \text{ GeV}\)

\(L_{\text{int}} = 10^3 \text{ pb}^{-1}\)

\(p_T > 15 \text{ GeV}\)

No tracks with \(p_T > 2 \text{ GeV}\) in \(\Delta R < 0.3\)

Figure 12: \(l^+l^-\) mass distribution for \(m_0 = 1800 \text{ GeV}\) and \(m_{1/2} = 100 \text{ GeV}\); the other mSUGRA parameters are: \(\tan \beta = 2, \ A_0 = 0\) and \(\mu < 0\). The dotted histogram corresponds to the SM background.

mSUGRA parameters

\(m_0 = 100 \text{ GeV}, \ m_{1/2} = 400 \text{ GeV}, \ \tan \beta = 2, \ A_0 = 0, \ \mu < 0\)

\(M(\chi^0) = 173 \text{ GeV}\)

\(M(\chi^0) = 341 \text{ GeV}\)

\(M(l_l) = 302 \text{ GeV}\)

Expected \(M_{ll}^{\text{max}} = 138 \text{ GeV}\)

\(L_{\text{int}} = 10^3 \text{ pb}^{-1}\)

\(p_T > 15 \text{ GeV}\)

\(p_T > 30 \text{ GeV}\)

No tracks with \(p_T > 2 \text{ GeV}\) in \(\Delta R < 0.3\)

Figure 13: \(l^+l^-\) mass distribution for \(m_0 = 100 \text{ GeV}\) and \(m_{1/2} = 400 \text{ GeV}\); the other mSUGRA parameters are: \(\tan \beta = 2, \ A_0 = 0\) and \(\mu < 0\). The dotted histogram corresponds to the SM background.
mSUGRA parameters

\( m_0 = 100 \text{ GeV}, \ m_{1/2} = 450 \text{ GeV}, \ \tan \beta = 2, \ A_0 = 0, \ \mu < 0 \)

\[ \begin{align*}
M(\chi^0_1) & = 194 \text{ GeV} \\
M(\chi^0_2) & = 383 \text{ GeV} \\
M(l^\pm) & = 334 \text{ GeV} \\
\text{Expected} \ M_{\gamma}^\max & = 153 \text{ GeV}
\end{align*} \]

\( L_{\text{int}} = 10^4 \text{ pb}^{-1} \)

\( p_{T}^{1,2,3} > 50, 25, 15 \text{ GeV} \)

No tracks with \( p_T > 1.5 \text{ GeV} \) in \( \Delta R < 0.3 \)

Figure 14: \( l^+l^- \) mass distribution for \( m_0 = 100 \text{ GeV} \) and \( m_{1/2} = 450 \text{ GeV} \); the other mSUGRA parameters are: \( \tan \beta = 2, \ A_0 = 0 \) and \( \mu < 0 \). The dotted histogram corresponds to the SM background.

mSUGRA parameters

\( m_0 = 1800 \text{ GeV}, \ m_{1/2} = 150 \text{ GeV}, \ \tan \beta = 2, \ A_0 = 0, \ \mu < 0 \)

\[ \begin{align*}
M(\chi^0_1) & = 65 \text{ GeV} \\
M(\chi^0_2) & = 133 \text{ GeV} \\
\text{Expected} \ M_{\gamma}^\max & = 68 \text{ GeV}
\end{align*} \]

\( L_{\text{int}} = 10^4 \text{ pb}^{-1} \)

\( p_{T}^{1,2,3} > 30, 15, 15 \text{ GeV} \)

No tracks with \( p_T > 1.5 \text{ GeV} \) in \( \Delta R < 0.3 \)

Figure 15: \( l^+l^- \) mass distribution for \( m_0 = 1800 \text{ GeV} \) and \( m_{1/2} = 150 \text{ GeV} \); the other mSUGRA parameters are: \( \tan \beta = 2, \ A_0 = 0 \) and \( \mu < 0 \). The dotted histogram corresponds to the SM background.
Figure 16: Explorable region of mSUGRA in inclusive 3 lepton final states at $L_{\text{int}} = 10^4 \text{ pb}^{-1}$. Shaded regions are excluded by theory and experiment. Circles show the simulated mSUGRA points. The cosmologically preferable region $0.15 < \Omega h^2 < 0.4$ is also given.
Figure 17: $l^+l^-$ mass distribution for $m_0 = 100$ GeV and $m_{1/2} = 450$ GeV; the other mSUGRA parameters are: $\tan\beta=2, A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

Figure 18: $l^+l^-$ mass distribution for $m_0 = 190$ GeV and $m_{1/2} = 450$ GeV; the other mSUGRA parameters are: $\tan\beta=2, A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.
Figure 19: $l^+l^-$ mass distribution for $m_0 = 220$ GeV and $m_{1/2} = 450$ GeV; the other mSUGRA parameters are: $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

Figure 20: $l^+l^-$ mass distribution for $m_0 = 100$ GeV and $m_{1/2} = 500$ GeV; the other mSUGRA parameters are: $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.
**Figure 21:** $l^+l^-$ mass distribution for $m_0 = 200\ \text{GeV}$ and $m_{1/2} = 500\ \text{GeV}$; the other mSUGRA parameters are: $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

**Figure 22:** $l^+l^-$ mass distribution for $m_0 = 100\ \text{GeV}$ and $m_{1/2} = 600\ \text{GeV}$; the other mSUGRA parameters are: $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.
Figure 23: $l^+l^-$ mass distribution for $m_0 = 250$ GeV and $m_{1/2} = 600$ GeV; the other mSUGRA parameters are: $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

Figure 24: $l^+l^-$ mass distribution for $m_0 = 300$ GeV and $m_{1/2} = 600$ GeV; the other mSUGRA parameters are: $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.
Figure 25: $l^+l^-$ mass distribution for $m_0 = 150$ GeV and $m_{1/2} = 700$ GeV; the other mSUGRA parameters are: 
$tan\beta=2, A_0=0$ and $\mu<0$. The dotted histogram corresponds to the SM background.

Figure 26: $l^+l^-$ mass distribution for $m_0 = 300$ GeV and $m_{1/2} = 700$ GeV; the other mSUGRA parameters are: 
$tan\beta=2, A_0=0$ and $\mu<0$. The dotted histogram corresponds to the SM background.
**mSUGRA parameters**

\( m_0 = 350 \) GeV, \( m_{1/2} = 700 \) GeV, \( \tan \beta = 2 \), \( A_0 = 0 \), \( \mu < 0 \)

\[
\begin{align*}
M(\chi^0_1) &= 307 \text{ GeV} \\
M(\chi^0_2) &= 596 \text{ GeV} \\
\text{Expected } M_{\text{max}} &= 289 \text{ GeV}
\end{align*}
\]

\[ L_{\text{int}} = 10^5 \text{ pb}^{-1} \]

\( p_{T,1,2,3} > 50, 25, 10 \) GeV

No tracks with \( p_T > 2 \) GeV in \( \Delta R < 0.3 \)

\( E_T^{\text{miss}} > 300 \) GeV

Figure 27: \( l^+l^- \) mass distribution for \( m_0 = 350 \) GeV and \( m_{1/2} = 700 \) GeV; the other mSUGRA parameters are: \( \tan \beta = 2 \), \( A_0 = 0 \) and \( \mu < 0 \). The dotted histogram corresponds to the SM background.

**mSUGRA parameters**

\( m_0 = 200 \) GeV, \( m_{1/2} = 800 \) GeV, \( \tan \beta = 2 \), \( A_0 = 0 \), \( \mu < 0 \)

\[
\begin{align*}
M(\chi^0_1) &= 352 \text{ GeV} \\
M(\chi^0_2) &= 681 \text{ GeV} \\
M(l_1) &= 591 \text{ GeV} \\
\text{Expected } M_{\text{max}} &= 153 \text{ GeV}
\end{align*}
\]

\[ L_{\text{int}} = 10^5 \text{ pb}^{-1} \]

\( p_{T,1,2,3} > 50, 25, 10 \) GeV

No tracks with \( p_T > 2 \) GeV in \( \Delta R < 0.3 \)

\( E_T^{\text{miss}} > 300 \) GeV

Figure 28: \( l^+l^- \) mass distribution for \( m_0 = 200 \) GeV and \( m_{1/2} = 800 \) GeV; the other mSUGRA parameters are: \( \tan \beta = 2 \), \( A_0 = 0 \) and \( \mu < 0 \). The dotted histogram corresponds to the SM background.
Figure 29: $l^+l^-$ mass distribution for $m_0 = 350$ GeV and $m_{1/2} = 800$ GeV; the other mSUGRA parameters are: $\tan\beta = 2, A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

$mSUGRA$ parameters

$m_0 = 350$ GeV, $m_{1/2} = 800$ GeV, $\tan\beta=2, A_0=0, \mu<0$

$L_{int} = 10^5$ pb$^{-1}$

$M(\chi^0) = 352$ GeV

$M(\chi^0) = 681$ GeV

$M(l_\mu) = 656$ GeV

Expected $M_{ll max} = 154$ GeV

$p_{T1,2,3} > 50, 25, 10$ GeV

No tracks with

$p_T > 2$ GeV in $\Delta R < 0.3$

$E_T^{miss} > 300$ GeV

Figure 30: $l^+l^-$ mass distribution for $m_0 = 200$ GeV and $m_{1/2} = 900$ GeV; the other mSUGRA parameters are: $\tan\beta = 2, A_0 = 0$ and $\mu < 0$. The dotted histogram corresponds to the SM background.

$mSUGRA$ parameters

$m_0 = 200$ GeV, $m_{1/2} = 900$ GeV, $\tan\beta=2, A_0=0, \mu<0$

$L_{int} = 10^5$ pb$^{-1}$

$M(\chi^0) = 397$ GeV

$M(\chi^0) = 767$ GeV

$M(l_\mu) = 655$ GeV

Expected $M_{ll max} = 317$ GeV

$p_{T1,2,3} > 50, 25, 10$ GeV

No tracks with

$p_T > 2$ GeV in $\Delta R < 0.3$

$E_T^{miss} > 300$ GeV
mSUGRA parameters: \( \tan\beta = 2, \ A_0 = 0, \ \mu < 0 \)

Figure 31: Explorable region of mSUGRA in inclusive \( 3 \) lepton + \( E_T^{\text{miss}} \) final states at \( L_{\text{int}} = 10^5 \) pb\(^{-1}\). Shaded regions are excluded by theory and experiment. Circles show the simulated mSUGRA points. The cosmologically preferable region \( 0.15 < \Omega h^2 < 0.4 \) is also given.
**mSUGRA parameters**

\[ m_0 = 100 \text{ GeV}, \quad m_{1/2} = 150 \text{ GeV}, \quad \tan \beta = 2, \quad A_0 = 0, \quad \mu < 0 \quad \text{(GeV)} \]

- \( M(\tilde{\chi}_2^0) = 135 \text{ GeV} \)
- \( M(\tilde{t}_R) = 120 \text{ GeV} \)
- \( M(\tilde{\chi}_1^0) = 65 \text{ GeV} \)

**Figure 32:** \( l^+l^- \) mass distribution for \( m_0 = 100 \text{ GeV} \) and \( m_{1/2} = 150 \text{ GeV} \); the other mSUGRA parameters are: \( \tan \beta = 2, A_0 = 0 \) and \( \mu < 0 \). The dotted histogram corresponds to the SM background.
Figure 33: Lepton transverse momentum asymmetry distributions in $\tilde{\chi}^0_2$ decays. mSUGRA parameters ($m_0, m_{1/2}$) are the following: 100 GeV, 150 GeV (full and dashed-dotted lines); 100 GeV, 400 GeV (dashed line) and 400 GeV, 150 GeV (dotted line).
Figure 34: The dotted lines correspond to the invariant mass spectra and transverse momentum asymmetry distributions in $\chi^0$ two-body decays for several "low mass" and "high mass" solutions of eq. (10). The full line corresponds to the initial (or observed) spectra.
Figure 35: Results of the $\chi^2$-test of the shape of $p_T$-asymmetry distributions as a function of slepton mass. The corresponding values of $M_{\tilde{\chi}_1^0}$ are also indicated.
Figure 36: Predicted $l^+ l^-$ invariant mass spectra for two values of slepton masses: $M_{l^+} = 120$ GeV (full line) and $M_{l^+} = 77$ GeV (dashed line); mSUGRA parameters as in Fig.34.
Figure 37: Expected $l^+l^-$ mass spectrum for mSUGRA Point: $m_0 = 50 \text{ GeV}$, $m_{1/2} = 125 \text{ GeV}$, $\tan\beta = 2$, $A_0 = 0$, $\mu < 0$.

a) Leptons with $p_T > 15 \text{ GeV}$ in $|\eta| < 2.4$ are considered. Two leptons which enter invariant mass spectrum are required to be isolated; b) as in previous case, but all three leptons are isolated. The dotted histogram corresponds to the SM background.