Search for the next-to-lightest neutralino

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Abstract

We study the inclusive production of the next-to-lightest neutralino \( \tilde{\chi}_2^0 \), decaying directly, or via slepton, into two leptons and the lightest neutralino. The dilepton invariant mass spectrum in these decays has a characteristic sharp edge near the kinematical upper limit. We propose to exploit this feature as a search strategy for the \( \tilde{\chi}_2^0 \), and thereby for SUSY. The possibilities to determine neutralinos and slepton masses are also discussed.


1 Introduction

The Standard Model (SM), despite its phenomenological successes, is most likely a low energy effective theory of matter fermions interacting via gauge bosons. A good candidate for the new physics is the Supersymmetry (SUSY), which in its minimal version introduces a scalar (fermion) partner to each ordinary fermion (boson) with the same couplings. If \( R \)-parity is conserved, SUSY particles are produced in pairs and a stable Lightest Supersymmetric Particle (LSP) appears at the end of each sparticle decay chain. Weakly interacting LSP escapes detection and masses of sparticles cannot be reconstructed explicitly. Usually, one characterises the SUSY signal significance by an excess of events over the SM background expectation.

SUSY partners of gauge and Higgs bosons mix to form physical states, charginos \( \tilde{\chi}^\pm_{1,2} \), and neutralinos, \( \tilde{\chi}^0_{1,2,3,4} \). Depending on a particular SUSY scenario the decays \( \tilde{\chi}_2^0 \rightarrow l^+l^-\tilde{\chi}_1^0 \) and/or \( \tilde{\chi}_2^0 \rightarrow l^+\tilde{\ell}^- \rightarrow l^+l^-\tilde{\chi}_1^0 \) can take sizable branching ratios. The dilepton invariant mass spectrum in these decays has a specific shape with the sharp edge near the kinematical upper limit. In case of three-body (direct) decays \( \tilde{\chi}_2^0 \rightarrow l^+l^-\tilde{\chi}_1^0 \) the position of edge is

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

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and in case of two-body (cascade) decays it is

\[ M_{l^+l^-}^\text{max} = \frac{\sqrt{(M_{\tilde{\chi}_0}^2 - M_{\tilde{l}}^2)(M_{\tilde{l}}^2 - M_{\tilde{\chi}_0}^2)}}{M_{\tilde{l}}} \]  

(2)

As discussed in Ref. [1] for \( \tilde{\chi}_1^\pm \chi_2^0 \) Electro-Weak (EW) production, the three-body leptonic decays of \( \tilde{\chi}_2^0 \) can be used to measure the mass difference between \( \tilde{\chi}_2^0 \) and \( \tilde{\chi}_1^0 \). At LHC, however, much higher production cross-sections are expected for strongly interacting gluinos and squarks. If \( \tilde{q} \) (\( \tilde{g} \)) is lighter than \( \tilde{g} \) (\( \tilde{q} \)), it can decay to quark plus neutralino or chargino: \( \tilde{q} \rightarrow q\tilde{\chi}_0^i/q\tilde{\chi}_1^\pm \) (\( \tilde{g} \rightarrow qq'\tilde{\chi}_0^i/qq'\tilde{\chi}_1^\pm \)). Eventually, this source of \( \tilde{\chi}_2^0 \) is much more prolific than direct EW production. Therefore, we propose to perform inclusive search for \( \tilde{\chi}_2^0 \) and to use the specific shape of the dilepton mass spectrum as evidence for SUSY [2]. For the SM background suppression, besides two same-flavour opposite-sign leptons, one can ask an additional signature characterising SUSY. This can be: missing energy taken away by escaping LSPs, or additional jets coming from gluinos and squarks cascade decays, or an extra high-\( p_T \) lepton from charginos, neutralinos, sleptons, IVBs, or b-quarks copiously produced in SUSY. Depending on sparticle masses and predominant decay modes one of these extra requirements can turn out to be more advantageous than the others, or to be complementary.

In this paper we discuss the possibility to observe the \( \tilde{\chi}_2^0 \) in the inclusive 3 leptons and 3 leptons + \( E_T^{\text{miss}} \) final states with the CMS detector at LHC. 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 an event excess over the SM expectations. Such an observation would reveal SUSY through \( \tilde{\chi}_2^0 \) production, and at the same time would allow to constrain sparticle masses and some of the SUSY model parameters. We also propose a way to resolve the \( \tilde{\chi}_2^0 \) decay type ambiguity (three-body versus two-body), and a method of slepton mass determination in the \( \tilde{\chi}_2^0 \) two-body decay chain.

The present analysis is performed within the framework of the minimal Supersymmetry Model motivated by Supergravity (mSUGRA), where only five extra parameters are introduced [3]: \( m_0 \), the universal scalar mass, \( m_{1/2} \), the universal gaugino mass and \( A_0 \), the universal trilinear term at GUT scale; \( \tan\beta \), the ratio of vacuum expectation values of two Higgs fields; \( \text{sign}(\mu) \), the sign of the Higgsino mass parameter. Once these parameters are specified all sparticle masses and couplings at EW scale are evolved via the renormalization group equations. In the following we limit ourselves to the set: \( \tan\beta = 2, \ A_0 = 0, \ \mu < 0 \) and investigate what is the region of \( (m_0,m_{1/2}) \) parameter space, where the dilepton invariant mass edge is visible [2].
Within mSUGRA the following relations are valid:

\[ M_{\tilde{\chi}_2^0} \approx M_{\tilde{\chi}_1^\pm} \approx 2M_{\tilde{\chi}_1^0} \approx (0.25 \div 0.35)M_\tilde{g} \approx 0.9m_{1/2} \quad (3) \]

\[ M_{l_L}^2 = m_0^2 + 0.52 m_{1/2}^2 - 0.5(1 - 2\sin^2 \theta_W) \ m_Z^2 \cos 2\beta \quad (4) \]

\[ M_{l_R}^2 = m_0^2 + 0.15 m_{1/2}^2 - \sin^2 \theta_W \ m_Z^2 \cos 2\beta \quad (5) \]

The three-body leptonic decays of \( \tilde{\chi}_2^0 \) dominate below \( m_{1/2} \sim 200 \) GeV nearly for all values of \( m_0 \), and there is also a small region at higher \( m_{1/2} \) where these decays are open. In these regions the measurement of \( M_{l_{1L}}^{max} \) within mSUGRA allows to get estimate of \( M_{\tilde{\chi}_1^0} (\tilde{\chi}_1^0 = \text{LSP}) \), \( M_{\tilde{\chi}_2^0} \), \( M_{\tilde{\chi}_1^\pm} \), \( M_\tilde{g} \) and \( m_{1/2} \) (c.f. eqs. (1), (3)). At \( m_{1/2} \sim 200 \) GeV, the modes, \( \tilde{\chi}_2^0 \rightarrow h \tilde{\chi}_1^0 / Z \tilde{\chi}_1^0 \), become kinematically allowed thus suppressing direct leptonic decays of \( \tilde{\chi}_2^0 \). The two-body decays of the \( \tilde{\chi}_2^0 \) via \( \tilde{l}_{L/R} \) occur mostly at a low values of \( m_0 \). In these regions the measurement of only the edge position does not provide information on masses unambiguously (c.f. eq. (2)). However, as shown later, by analysing some kinematical distributions, the masses of \( \tilde{\chi}_1^0, \tilde{\chi}_2^0 \) and of the intermediate 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, e.g., from the Higgs sector of the model. In some regions of parameter space the two-body and three-body leptonic decays coexist or both modes \( \tilde{\chi}_2^0 \rightarrow l^{\pm} \tilde{l}_{R}^{\mp} \) and \( \tilde{\chi}_2^0 \rightarrow l^{\pm} \tilde{l}_{L}^{\mp} \) are open, leading to a possible observation of a ”double edge”.

At LHC the \( \tilde{\chi}_2^0 \) is abundantly produced either from gluinos or from squarks over almost the whole \( (m_0, m_{1/2}) \) plane, as illustrated in Figs.1a, b. Figure 1c shows the \( \tilde{\chi}_2^0 \) decay branching ratio into leptons \( (l = \mu \text{ or } e) \). Finally, the \( \tilde{\chi}_2^0 \) inclusive production cross-section times branching ratio into leptons is shown in Fig.1d. Clearly, one expects quite large rates of opposite-sign same-flavour dileptons from inclusive \( \tilde{\chi}_2^0 \) production over a large portion of \( (m_0, m_{1/2}) \). Similarly to the \( \tilde{\chi}_2^0 \), the lightest chargino is also copiously produced from strongly interacting sparticles. Moreover, the leptonic decay branching of the \( \tilde{\chi}_1^\pm \) always exceeds 0.1 per lepton flavour. For low values of \( m_0 \), in the regions where decays to sleptons are kinematically allowed, the \( \tilde{\chi}_1^\pm \) gives a lepton with a probability close to 1. 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 for an additional high-\( p_T \) lepton. Thus the \( \tilde{\chi}_2^0 \) inclusive production can be studied in 3 lepton and 3 lepton + \( E_T^{miss} \) final states.
mSUGRA parameters: $\tan\beta = 2, \: A_0 = 0, \: \mu < 0$

Fig. 1. $\tilde{\chi}_2^0$ 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) $B(\tilde{\chi}_2^0 \rightarrow l^+l^- + invisible)$ and d) $\tilde{\chi}_2^0$ inclusive production cross-section times branching ratio into $l^+l^- \ (l = \mu \ or \ e)$.

3 Event simulation and selection

For signal simulation we have generated all mSUGRA processes, using ISAJET 7.14 [4]. The considered SM sources of background, $WZ, \ t\bar{t}, \ ZZ$ and $Z\bar{b}b$ productions, have been simulated by PYTHIA 5.7 [5]. The following production cross-sections have been assumed at LHC energy of $\sqrt{s} = 14$ TeV: $\sigma_{WZ} = 26$ pb, $\sigma_{t\bar{t}} = 670$ pb for a top mass of 170 GeV, $\sigma_{ZZ} = 15$ pb and $\sigma_{Z\bar{b}b} = 580$ pb.

We have used a parameterised detector simulation program [6]. It takes into
account: i) particle bending in a 4 T magnetic field; ii) smearing of lepton momentum according to parameterisation obtained from detailed simulations; iii) 90% triggering plus reconstruction efficiency per lepton within geometrical acceptance $|\eta| < 2.4$; iv) 90% reconstruction efficiency per charged track with $p_T > 1$ GeV within $|\eta| < 2.4$; 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 parameterisation of the lateral and longitudinal profiles. For the high luminosity study, $L = 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, on top of each signal and background events we have superimposed on average 15 "hard" pile-up events (PYTHIA QCD jet production with $\hat{p}_T > 5$ GeV) fluctuated by Poissonian distribution.

In the inclusive 3 lepton channel we require: 1) two opposite-sign, same-flavour leptons ($\mu$ or e) with $p_T > 10$ GeV; 2) a third "tagging" lepton with $p_T > 15$ GeV; 3) lepton 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. The leptons $p_T$ thresholds are variable depending on the region of $(m_0, m_{1/2})$ studied. In some cases leptons are not required to be isolated. In the inclusive 3 lepton + $E_T^{\text{miss}}$ channel, beside the above three requirements we also ask: 4) $E_T^{\text{miss}} > 200$ (300) GeV.

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

4 Dilepton invariant mass spectrum

The dilepton invariant mass spectrum for a representative mSUGRA parameter space point $(m_0 = 200$ GeV, $m_{1/2} = 100$ GeV) superimposed on the expected SM background is shown in Fig.2a. The number of events corresponds to an integrated luminosity of $L_{\text{int}} = 20$ pb$^{-1}$, i.e. a few hours of LHC running at a luminosity of $L = 10^{33}$ cm$^{-2}$s$^{-1}$. The $p_T$ thresholds on all three leptons are 15 GeV and two of them entering mass distribution are isolated. The SM background is negligible, with the dominant contribution from WZ production around the Z mass peak and $t\bar{t}$ production at lower invariant masses. The specific shape of the distribution with its sharp edge reveals SUSY through $\tilde{\chi}^0_2$ production. At this mSUGRA point the $\tilde{\chi}^0_2$ has three-body decay modes, and the relevant masses are $M_{\tilde{\chi}^0_2} = 97$ GeV, $M_{\tilde{\chi}_0^0} = 45$ GeV. The edge is situated at the expected value of $M_{l^+l^-}^{\text{max}} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0} = 52$ GeV and its position can be measured with an accuracy better than 0.5 GeV. Within the model this allows to determine $M_{\tilde{\chi}_1^0}$, $M_{\tilde{\chi}_2^0}$, $M_{\tilde{\chi}_1^\pm}$, $M_{\tilde{\gamma}}$ and $m_{1/2}$ (c.f. (3)). Note, that the Z peak seen in Fig.2 serves as an overall calibration signal; it allows to control
Fig. 2. Expected $l^+l^-$ mass spectrum for mSUGRA points: a) $m_0 = 200$ GeV, $m_{1/2} = 100$ GeV in the inclusive 3 lepton final states; b) $m_0 = 150$ GeV, $m_{1/2} = 700$ GeV in the 3 lepton + $E_T^{miss}$ final states. The other mSUGRA parameters are $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. The hatched histogram corresponds to the SM background.

the mass scale as well as the production cross-section.

With increasing $m_{1/2}$ the observation of the "edge" becomes more difficult due to a rapid fall of gluino/squark production cross-sections. Here, on the other hand, heavier $\tilde{g}$ and $\tilde{q}$ provide higher missing transverse energy. Asking $E_T^{miss} > 200$ (300) GeV rejects most of the SM background whilst retaining a large fraction of signal events. Figure 2b shows the dilepton spectrum for the mSUGRA point (150 GeV, 700 GeV) in the 3 lepton + $E_T^{miss}$ final states. In this region of high $m_{1/2}$ dileptons are mainly produced through cascade decays of $\tilde{\chi}_2^0$ through intermediate state sleptons. The third, "tagging" lepton, predominantly comes from a $\tilde{\chi}_1^\pm$ produced in association, again from $\tilde{g}, \tilde{q}$ cascades.

In order to delineate the region of parameter space where the $l^+l^-$ edge is visible, the $(m_0, m_{1/2})$ plane has been systematically scanned for fixed $\tan\beta = 2$, $A_0 = 0$ and $\mu < 0$. At least 40 signal events in a mass interval $> 10$ GeV just below the edge position and a statistical significance $S = N_S/\sqrt{N_S + N_B} > 7$ are required ($N_S$ and $N_B$ are the number of signal and background events in this mass interval). Figure 3 shows the domain explorable under these conditions with an integrated luminosities of $L_{int} = 10^4$ pb$^{-1}$ and $L_{int} = 10^5$ pb$^{-1}$ for 3 lepton and 3 lepton + $E_T^{miss}$ channels, respectively. Of particular importance is the fact, that already at $L_{int} = 10^4$ pb$^{-1}$ the cosmologically preferred region $0.15 \lesssim \Omega h^2 \lesssim 0.4$ [7], where the $\tilde{\chi}_1^0$ would be a good candidate for dark matter, is entirely covered; here $\Omega$ is the ratio of the $\tilde{\chi}_1^0$ relic density to the
mSUGRA parameters: \( \tan \beta = 2, \: A_0 = 0, \: \mu < 0 \)

![Graph showing the explorable region of mSUGRA parameters](image)

Fig. 3. Explorable region of mSUGRA in inclusive 3 lepton and 3 lepton + \( E_T^{\text{miss}} \) final states with \( L_{\text{int}} = 10^4 \) pb\(^{-1} \) and \( L_{\text{int}} = 10^5 \) pb\(^{-1} \), respectively. Shaded regions are excluded by theory and/or experiment. The simulated mSUGRA points are shown by circles. The cosmologically preferred region \( 0.15 < \Omega h^2 < 0.4 \) is also given.

Critical density of the Universe and \( h \) is the Hubble constant scaling factor. In the 3 lepton + \( E_T^{\text{miss}} \) final states with \( L_{\text{int}} = 10^5 \) pb\(^{-1} \) the reach extends up to \( m_{1/2} \sim 900 \). A detectable edge is seen as long as \( \sigma \cdot B \gtrsim 10^{-2} \) pb (see Fig.1d).

### 5 \( \tilde{\chi}_2^0 \) decay type and slepton mass determination

The \( \tilde{\chi}_2^0 \) decay type (three-body versus two-body) determination is essential for the interpretation of the observed edge. The \( p_T \) spectra of leptons from \( \tilde{\chi}_2^0 \) (cascade) two-body decays are more asymmetric compared to the three-body ones. To characterise this 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 given for the mSUGRA point (100 GeV, 150 GeV). Here the \( \tilde{\chi}_2^0 \) decays via \( \tilde{\chi}_2^0 \rightarrow l^+ \tilde{l}_R \rightarrow l^+ l^- \tilde{\chi}_1^\pm \) with 0.54 branching ratio and the sparticle masses are \( M_{\tilde{\chi}_2^0} = 135 \) GeV, \( M_{\tilde{\chi}_1^0} = 65 \) GeV, \( M_{l_R} = 120 \) GeV. Figure 4 shows the dilepton spectrum for
this point with \( L_{\text{int}} = 5 \cdot 10^3 \text{ pb}^{-1} \), superimposed on the SM background, in the inclusive 3 lepton final states. An edge is situated at \( \sim 52 \text{ GeV} \), as expected. To look at the lepton \( p_T \) asymmetry distribution, we pick up the lepton pairs with \( M_{l^+l^-} < 52 \text{ GeV} \). Figure 5 (full line) shows the corresponding \( A \) spectrum for the selected events. The pronounced asymmetry in \( p_T \) indicates the cascade nature of \( \tilde{\chi}_0^2 \) decays. The dotted histograms are obtained with the assumption that the ”observed” edge is due to direct three-body decays with various \( M_{\tilde{\chi}_0^2}, M_{\tilde{\chi}_1^0} \) combinations providing \( M_{\tilde{\chi}_0^2} - M_{\tilde{\chi}_1^0} = 52 \text{ GeV} \). In these cases the asymmetry \( A \) distributions peak at zero.

After the decay type is determined a further analysis step is carried out to extract the masses of involved particles: i) assume \( M_{\tilde{\chi}_2^0} = 2M_{\tilde{\chi}_1^0} \), ii) generate samples of \( \tilde{\chi}_2^0 \) 2-body cascade decays for various \( M_{\tilde{\chi}_1^0} (M_{\tilde{t}}) \); note, that the slepton mass is constrained to provide the ”observed” position of an edge given by eq. (2), iii) the best combination of \( M_{\tilde{\chi}_1^0}, M_{\tilde{\chi}_2^0} \) and \( M_{\tilde{t}} \) is then chosen by means of a \( \chi^2 \)-test of the shape of the lepton \( p_T \)-asymmetry distributions. This procedure provides the following precisions on masses: \( \delta M_{\tilde{\chi}_0^2} \lesssim 5 \text{ GeV}, \delta M_{\tilde{t}} \lesssim 10 \text{ GeV} \). The use of the total number of observed events, as well as the dilepton invariant mass spectrum itself in a combined \( \chi^2 \)-test would further improve these results.
Fig. 6. Predicted $l^+l^-$ mass spectra for two values of slepton mass: $M_{l} = 120$ GeV (full line) and $M_{l} = 77$ GeV (dashed line); mSUGRA parameters are as in Fig.4.

Fig. 7. Expected $l^+l^-$ mass spectrum for mSUGRA Point $m_0 = 50$ GeV, $m_{1/2} = 125$ GeV, $\tan\beta=2$, $A_0 = 0$ and $\mu < 0$. The hatched histogram corresponds to the SM background.

6 Double edge

As discussed in section 2, in some regions of the $(m_0, m_{1/2})$ plane the different leptonic decay modes of $\tilde{\chi}^0_2$ can be simultaneously open and observation of "double edges" is possible if the branching ratios are not too dissimilar. This is the case, for instance, for the mSUGRA point (100 GeV, 150 GeV) discussed in the previous section. Here, beside the $\tilde{\chi}^0_2 \rightarrow l^+l^-\tilde{\chi}^0_1$ decays, the direct three-body decay mode is also open, though, with a much smaller branching ratio, $B(\tilde{\chi}^0_2 \rightarrow l^+l^-\tilde{\chi}^0_1) = 0.05$. The second edge at $M_{l^+l^-}^{\text{max}} = 69$ GeV seen in Fig.4 is thus less spectacular than the one at 52 GeV. The $p_T$-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 edge positions and assuming $M_{\tilde{\chi}^0_2} = 2M_{\tilde{\chi}^0_1}$, we obtain two solutions for the slepton mass from equations (1) and (2): $M_{l} = 120$ GeV and 77 GeV. Corresponding dilepton invariant mass spectra for these two solutions are shown in Fig.6. The clear difference in the predicted spectra (Fig.6 vs. Fig.4) allows to eliminate the $M_{l} = 77$ GeV solution. At this particular mSUGRA point the use of both edges provides a precision of $\delta M_{\tilde{\chi}^0_2, l} \lesssim 1$ GeV.

Another example of a "double edge" is given in Fig.7 for the mSUGRA point (50 GeV, 125 GeV). Here the sparticle masses are $M_{\tilde{\chi}^0_2} = 116$ GeV, $M_{\tilde{\chi}^0_1} = 55$ GeV, $M_{l_L} = 110$ GeV, $M_{l_R} = 78$ GeV and now two two-body decays coexist, with a comparable branching ratios $B(\tilde{\chi}^0_2 \rightarrow l^+l^+_R \rightarrow l^+l^-\tilde{\chi}^0_1) = 0.037$ and $B(\tilde{\chi}^0_2 \rightarrow l^+l^-_R \rightarrow l^+l^-\tilde{\chi}^0_1) = 0.013$ and their analysis could proceed as indicated above providing a strong constraint on the underlying model.
7 Conclusions

• Observation of an edge in the dilepton invariant mass spectrum reflects production of \(\tilde{\chi}^0_2\) and hence establishes existence of SUSY; this observation in some cases is possible with very small statistics and could be the first evidence for SUSY at 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 and with \(L_{int} = 10^5\) pb\(^{-1}\) most of the region where the \(\tilde{\chi}^0_2\) inclusive production cross-section times branching ratio into leptons \(\gtrsim 10^{-2}\) pb can be covered.

• From the observation of characteristic edge(s) and with mSUGRA motivated assumptions, it is possible to determine masses of \(\tilde{\chi}^0_1\) and \(\tilde{\chi}^0_2\) in case of direct decays and masses of \(\tilde{\chi}^0_1, \tilde{\chi}^0_2\) and sleptons in case of cascade decays.

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References