

NMSSM in disguise: discovering singlino dark matter with soft leptons at the LHC

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(Dated: November 3, 2008)

Abstract

We suggest an NMSSM scenario, motivated by dark matter constraints, that may disguise itself as a much simpler mSUGRA scenario at the LHC. We show how its non-minimal nature can be revealed, and the bino–singlino mass difference measured, by looking for soft leptons.

PACS numbers: 12.60.Jv, 14.80.Ly

I. INTRODUCTION

The Next-to-Minimal Supersymmetric Standard Model (NMSSM) provides an elegant solution to the μ problem of the MSSM by the addition of a gauge singlet superfield \hat{S} [1, 2, 3, 4]. The superpotential of the Higgs sector then has the form $\lambda\hat{S}(\hat{H}_d \cdot \hat{H}_u) + \frac{1}{3}\kappa\hat{S}^3$. When \hat{S} acquires a vacuum expectation value, this creates an effective μ term, $\mu \equiv \lambda\langle S \rangle$, which is automatically of the right size, *i.e.* of the order of the electroweak scale.

The addition of the singlet field leads to a larger particle spectrum than in the MSSM: in addition to the MSSM fields, the NMSSM contains two extra neutral (singlet) Higgs fields – one scalar and one pseudo-scalar – as well as an extra neutralino, the singlino. Owing to these extra states, the phenomenology of the NMSSM can be significantly different from the MSSM; see Chapter 4 of [5] for a recent review and references. In particular, the usual LEP limits do not apply to singlet and singlino states. Moreover, the singlino can be the lightest supersymmetric particle (LSP) and a cold dark matter candidate.

In this paper, we investigate the LHC signature of an SPS1a [6]-like scenario supplemented by a singlino LSP. In such a setup, gluinos and squarks have the ‘conventional’ SUSY cascade decays into the bino-like neutralino, $\tilde{\chi}_2^0 \sim \tilde{B}$, which then decays into the singlino LSP, $\tilde{\chi}_1^0 \sim \tilde{S}$, plus a pair of opposite sign same-flavour (OSSF) leptons. The $\tilde{\chi}_2^0$ decay proceeds dominantly through an off-shell slepton. A dark matter relic density of $\Omega h^2 \sim 0.1$, compatible with astrophysics measurements, is obtained if the $\tilde{\chi}_1^0$ and/or $\tilde{\chi}_2^0$ annihilate through pseudo-scalar exchange in the s-channel.

One peculiar feature of this scenario, taking into account experimental constraints in particular from LEP, is that the mass difference between $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ turns out to be small; it reaches at most ~ 12 GeV, and is often much smaller. The leptons originating from the bino decay to the singlino,

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-, \tag{1}$$

hence tend to be soft. With the recent interest in soft leptons at the Tevatron [7], searches for these should have appeal also beyond the model presented here.

In the standard SUSY analysis for LHC events, often requiring $p_T(l^\pm) > 20$ GeV, there is a risk of missing these leptons and wrongly concluding to have found the MSSM instead of the NMSSM, with $\tilde{\chi}_2^0$ as the erroneous LSP and dark matter candidate. Discovery of the

Parameter	M_1	M_2	M_3	μ_{eff}	$M_{\tilde{L}_{1,3}}$	$M_{\tilde{E}_1}$	$M_{\tilde{E}_3}$	$M_{\tilde{Q}_1}$	$M_{\tilde{U}_1}$	$M_{\tilde{D}_1}$	$M_{\tilde{Q}_3}$	$M_{\tilde{U}_3}$	$M_{\tilde{D}_3}$
Value [GeV]	120	240	720	360	195	136	133	544	526	524	496	420	521

TABLE I: Input parameters in for our SPS1a-like scenario. The NMSSM-specific parameters λ , κ , A_λ and A_κ are given in Table III.

additional Higgs states will also be very difficult at the LHC in this scenario.¹ The aim of this paper is to explore the possibility of detecting the $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$ decay, and measuring the bino–singlino mass difference, by looking for soft di-leptons at the LHC. Some preliminary work on this scenario was carried out in [9].

In Section II we begin by describing the particular NMSSM scenario under investigation, and define five benchmark points typifying the small bino–singlino mass difference. We go on to discuss the Monte Carlo simulation of these benchmark points in Section III, using the fast simulation of a generic LHC detector as a basis for studying the possibility of detecting the resulting soft leptons in LHC collisions. In Section IV we further discuss the extraction of mass constraints on the singlino from the di-lepton invariant mass distribution using shape fitting, before we conclude in Section V.

II. THE NMSSM SCENARIO

We use the NMHDECAY [10, 11] program to compute the NMSSM mass spectrum and Higgs branching ratios, and to evaluate the LEP bounds; SPHENO [12] is used to calculate the sparticle branching ratios, and MICROMEAS [13, 14] for the relic density. The SUSY-breaking parameters of our scenario are listed in Table I. The main difference from the familiar mSUGRA scenario SPS1a [6] is that we choose a larger $M_1 = 0.5M_2 = 120$ GeV, leading to bino and wino masses of 115 GeV and 222 GeV, respectively, in order to evade LEP bounds when adding the singlino and singlet Higgses. In the original SPS1a scenario, the bino and wino masses are 96 and 177 GeV. The resulting SUSY spectrum, with the exception of the NMSSM-specific masses, is shown in Table II.

¹ The lightest scalar S_1 and pseudo-scalar A_1 are mostly singlet states with masses of about 80–100 GeV and decaying dominantly into $b\bar{b}$; decays of heavier Higgs states into them occur only with branching ratios at the permille level. For a discussion of search strategies, see [8].

Particle	$\tilde{\chi}_2^0$	$\tilde{\tau}_1$	\tilde{e}_R	\tilde{e}_L	$\tilde{\tau}_2$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_5^0$	\tilde{t}_1	$\tilde{q}_{L,R}$	\tilde{g}
Mass [GeV]	115	132	143	201	205	222	365	390	397	550–570	721

TABLE II: Mass spectrum of our SPS1a-like scenario; $m_{\tilde{\mu}_{L,R}} = m_{\tilde{e}_{L,R}}$ and $m_{\tilde{\chi}_{1,2}^\pm} \simeq m_{\tilde{\chi}_{3,5}^0}$. The LSP and Higgs masses depend on the NMSSM-specific parameters and are given in Table III.

Point	$\lambda [10^{-2}]$	$\kappa [10^{-3}]$	A_λ	A_κ	$m_{\tilde{\chi}_1^0}$	m_{A_1}	m_{A_2}	m_{S_1}	Ωh^2	$\Gamma(\tilde{\chi}_2^0)$
A	1.49	2.19	-37.4	-49.0	105.4	88	239	89	0.101	7×10^{-11}
B	1.12	1.75	-42.4	-33.6	112.1	75	226	100	0.094	9×10^{-13}
C	1.20	1.90	-39.2	-53.1	113.8	95	256	97	0.094	1×10^{-13}
D	1.47	2.34	-39.2	-68.9	114.5	109	259	92	0.112	4×10^{-14}
E	1.22	1.95	-44.8	-59.1	114.8	101	219	96	0.096	8×10^{-15}

TABLE III: NMSSM benchmark points used in this study. Masses and other dimensionful quantities are in [GeV]. The other parameters/the rest of the spectrum are/is given in the previous tables.

To obtain a singlino LSP, we further choose $\lambda \sim 10^{-2}$ and $\kappa \sim 0.1\lambda$. This way $\tilde{\chi}_1^0 \sim 99\% \tilde{S}$, and $m_{\tilde{\chi}_2^0}$ hardly varies with λ and κ ($\Delta m_{\tilde{\chi}_2^0} \sim 0.1$ GeV). In addition, the trilinear Higgs couplings A_λ and A_κ are chosen such that $m_{\tilde{\chi}_i^0} + m_{\tilde{\chi}_j^0} \sim m_{A_2}$ for at least one combination of $i, j = 1, 2$, in order to achieve a dark matter density of $0.094 \leq \Omega h^2 \leq 0.135$ [15]. We thus obtain a set of NMSSM parameter points with varying $\Delta m \equiv m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$.

The five points used in this study are summarised in Table III. Points A–E have $\Delta m = 9.71, 3.05, 1.45, 0.87$ and 0.60 GeV, respectively. The SM-like second neutral scalar Higgs, S_2 , has a mass of 115 GeV for all these points, consistent with the LEP limit of 114.4 GeV [16]. By contrast, the lightest neutral scalar S_1 and the lighter pseudo-scalar A_1 are mostly singlet states, and can hence be lighter than 114.4 GeV. Concerning the efficient neutralino annihilation needed to achieve an acceptable dark matter density, for Point A the dominant channel is $\tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow b\bar{b}$, contributing 88% to the thermally averaged annihilation cross section times relative velocity, $\langle \sigma v \rangle \propto 1/(\Omega h^2)$. For Point B, $\tilde{\chi}_1^0 \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ and $\tilde{\chi}_2^0 \tilde{\chi}_2^0$ annihilation to $b\bar{b}$ contribute 10%, 15%, and 50%, respectively. Point C has again dominantly $\tilde{\chi}_2^0 \tilde{\chi}_2^0$, while Point D has about 50% $\tilde{\chi}_2^0 \tilde{\chi}_2^0$ and 35% $\tilde{\chi}_1^0 \tilde{\chi}_2^0$ annihilation. Finally, for Point E, $\tilde{\chi}_1^0 \tilde{\chi}_1^0$, $\tilde{\chi}_1^0 \tilde{\chi}_2^0$

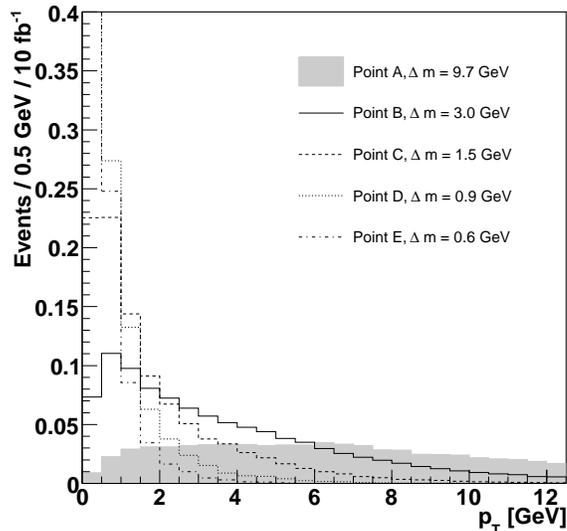


FIG. 1: p_T distributions for leptons from the decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$ in benchmark points A–E. All distributions are normalised to unity over the whole momentum range.

and $\tilde{\chi}_2^0 \tilde{\chi}_2^0$ annihilation to $b\bar{b}$ contribute 29%, 34%, and 13%, respectively.

Assuming that the non-MSSM nature of the Higgs sector will be very time and integrated luminosity consuming to determine at the LHC, or even be difficult to clarify at all, early signatures of this scenario will have to rely on the leptons produced by the two $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$ decays present in the vast majority of SUSY events. Figure 1 shows the p_T distributions of these leptons for all five benchmark points.² Clearly, cuts on lepton transverse momentum of even 10 GeV will remove the vast majority of events for points B–E, and hence remove the one remaining clue to the non-minimal nature of the scenario. However, one should also notice that the distributions have considerable tails beyond the simple mass difference Δm , due to the boost of the $\tilde{\chi}_2^0$. Thus, a reduction in the lepton p_T -cut holds the promise of giving considerable extra reach in this scenario.

² For details of the Monte Carlo simulation used, see Section III.

III. MONTE CARLO ANALYSIS

We perform a Monte Carlo simulation of the benchmark points described above by generating our SUSY signal with `PYTHIA 6.413` [17] and SM background events with `HERWIG 6.510` [18, 19], interfaced to `ALPGEN 2.13` [20] for production of high jet multiplicities and `JIMMY 4.31` [21] for multiple interactions. The generated events are then put through a fast simulation of a generic LHC detector, `AcerDET-1.0` [22].

Although `PYTHIA` does not contain a framework for generating NMSSM events *per se*, it has the capability to handle the NMSSM spectrum and its decays. Since our scenario predicts the same dominant cross section as in the MSSM, namely gluino and squark pair-production, with negligible interference from the non-minimal sector, we use the built-in MSSM machinery for the hard process, and take the conservative approach of generating only events with squark and gluino production. For the signal, `PYTHIA` gives a LO cross section of 24 pb, and 240 000 events are generated per benchmark point, corresponding to 10 fb^{-1} of data.

For the SM background we have generated a wide variety of samples that in addition to two, possibly soft, OSSF isolated leptons at low invariant mass, could potentially yield the hard jets and missing energy expected for SUSY events. These consist of n -jet QCD samples, generated with jet-parton matching using `ALPGEN`, and the production of W , Z , WW , WZ , ZZ , $b\bar{b}$, and $t\bar{t}$ with n additional jets ($n \leq 3$). In addition to this we have also looked at the Drell-Yan production of lepton pairs at low invariant masses ($3 \text{ GeV} < m_{ll} < 20 \text{ GeV}$) with n additional jets.

These samples were passed through the `AcerDET` detector simulation. For the scenario we consider `AcerDET` gives a reasonable description of the response of an LHC detector, with the exception of soft objects. Given the importance of soft leptons to our study, we therefore modified `AcerDET` as follows:

1. the p_T threshold for leptons was lowered to 2 GeV;
2. the lepton momentum resolutions used were parameterised from the results of a full simulation of the ATLAS detector, as presented in [23];³

³ For muons we use the results for combined muon system and inner detector tracks with $|\eta| < 1.1$. The electrons are smeared according to a pseudo-rapidity dependent parametrisation.

3. we applied parameterised lepton reconstruction efficiencies extracted from results given in [23].⁴

This simulation then incorporates the most relevant effects for the analysis, such as a sensible description of the rapidly deteriorating lepton momentum resolution for electrons at $p_T < 20$ GeV. Also, the applied reconstruction efficiencies fall off steeply for low p_T , and are different for electrons and muons, adding another degree of realism to the reconstruction of an invariant mass distribution using both lepton flavors.

However, there are some issues regarding detector performance at low p_T that are not modelled by these additions, chiefly the introduction of fake electrons through, e.g., the misidentification of charged pions. In particular, one might worry about the potential of pure QCD events to fake our signal because of the huge cross section in conjunction with detector effects. To improve on the parameterisations used here one would need a full simulation of the detector, or even efficiencies from data. We shall show below that all backgrounds with pairs of uncorrelated leptons may in principle be estimated from data, assuming lepton universality or some knowledge of the degree of non-universality. Therefore, the purity of the reconstructed electron sample is less important than the efficiency for reconstructing the sample in the first place.

We carry out our analysis along the lines of the ‘standard’ di-lepton edge analysis [24, 25], see also [26, 27]. To isolate the SUSY signal from SM background we apply the following cuts:

- Require at least three jets with $p_T > 150, 100, 50$ GeV.
- Require missing transverse energy $\cancel{E}_T > \max(100 \text{ GeV}, 0.2M_{\text{eff}})$, where the effective mass M_{eff} is the sum of the p_T of the three hardest jets plus missing energy.
- Require two OSSF leptons with $p_T > 20, 10$ GeV.

After these cuts the background is small compared to the number of SUSY events. For all five benchmark points the resulting di-lepton invariant mass distributions have the expected

⁴ Again we use results from combined muon system and inner detector tracks for the muons, where muons down to 1 GeV have been simulated. For electrons we use the efficiency of so-called “tight cuts”, defined in [23], in busy physics events.

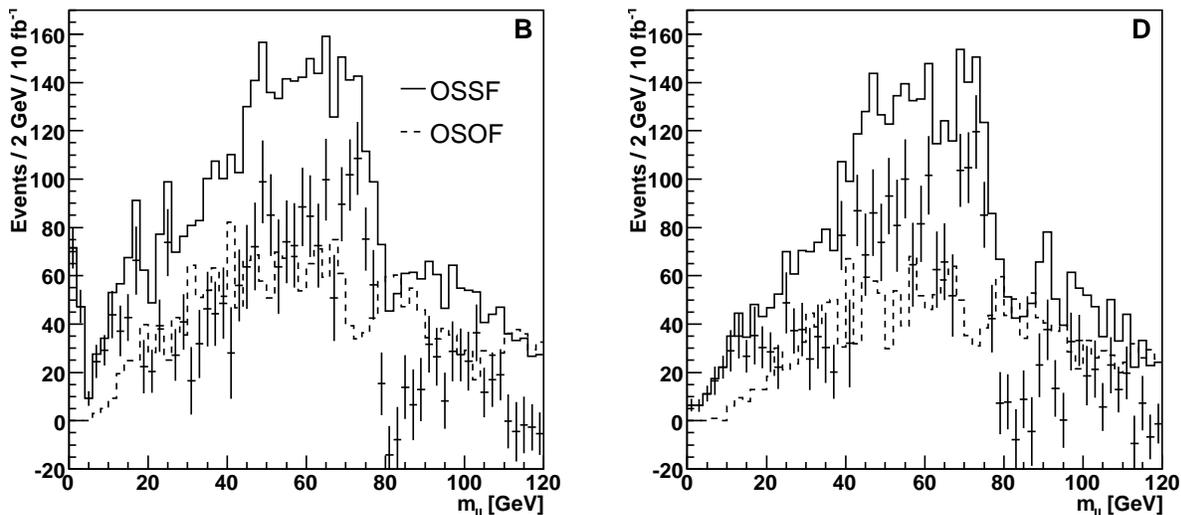


FIG. 2: Di-lepton invariant mass distributions for point B (left) and point D (right) with standard lepton p_T cuts. Shown are OSSF (solid), OSOF (dashed) and subtracted (with error bars) distributions.

edge structure at ~ 80 GeV from the decay chain

$$\tilde{\chi}_3^0 \rightarrow \tilde{l}_L^\pm l^\mp \rightarrow \tilde{\chi}_2^0 l^+ l^-, \quad (2)$$

and another, much less visible structure, at ~ 110 GeV, due to the same decay through a right handed slepton. These can be treated in the usual manner to extract two relationships between the four involved SUSY masses, based on the position of the endpoints.

For benchmark points A and B there is also an excess of events at low invariant mass coming from the decays of $\tilde{\chi}_2^0$ to singlinos, but for points C, D and E the OSSF lepton selection cut has removed all trace of the $\tilde{\chi}_2^0$ decay. This is demonstrated in Figure 2, showing the di-lepton invariant mass distribution for two of the benchmark points. In scenarios like C, D and E, one would therefore risk missing the singlino and taking the $\tilde{\chi}_2^0$ to be the LSP dark matter candidate.⁵ For a further breakdown of the content of the di-lepton invariant mass distribution in such scenarios, see [9].

It is clear that to increase sensitivity to the disguised NMSSM scenario, one needs to

⁵ In fact, our SPS1a-like scenario is an optimistic one for soft leptons under the standard cuts, in that there are extra leptons at hand from the longer decay chain (2) to fulfil the cut requirement.

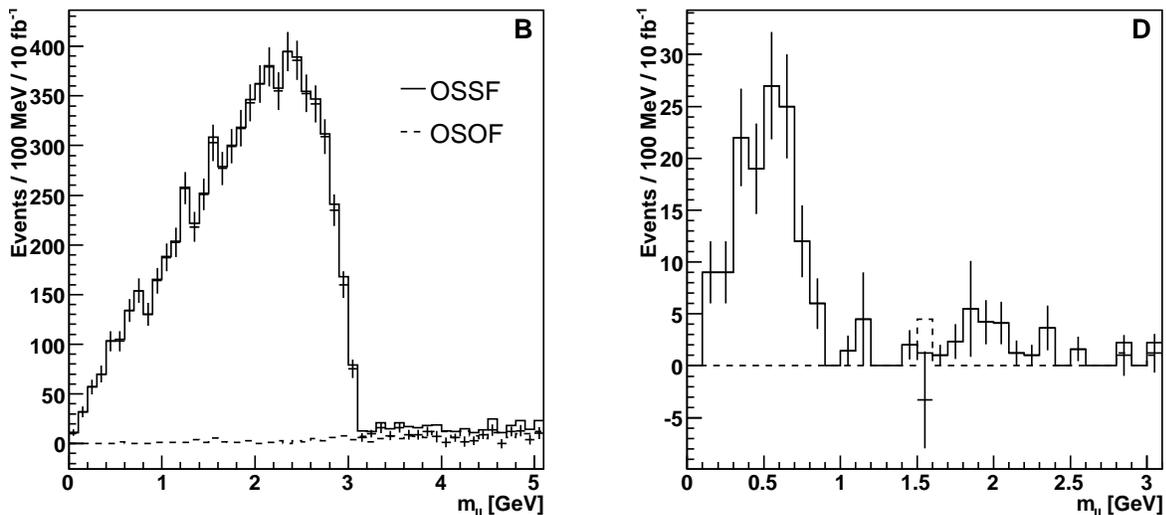


FIG. 3: Di-lepton invariant mass distributions for point B (left) and point D (right). Shown are OSSF (solid), OSOF (dashed) and subtracted (with error bars) distributions.

lower the lepton p_T cuts. Due to the hard requirements on jets and missing energy, the vast majority of these events should still pass detector trigger requirements. However, lower cuts come with the possibility of large increases in SM backgrounds. Most of this background, that from uncorrelated leptons, can in principle be removed by subtracting the corresponding opposite sign opposite-flavour (OSOF) distribution, assuming lepton universality. However, larger backgrounds will increase the statistical error. In addition, a soft lepton sample is more vulnerable to the introduction of non-universality from e.g. pion decays. The result of lowering the p_T requirement on leptons to 2 GeV, after application of the reconstruction efficiency, is shown in the left and right panels of Fig. 3, for benchmark points B and D respectively. While there is an increase in backgrounds, the effect on the signal is much more significant. For both benchmarks, the decay to the singlino is now visible as a large excess at low invariant masses.

To quantify the potential for discriminating between the disguised NMSSM and mSUGRA, we show in Fig. 4 the significance S/\sqrt{B} of any excess at low invariant masses as a function of Δm for all five benchmark points and for both the standard and 2 GeV lepton p_T cut. The expected number of events B , in the absence of any signal, is estimated by the OSOF distribution plus the expected number of mSUGRA low invariant mass leptons

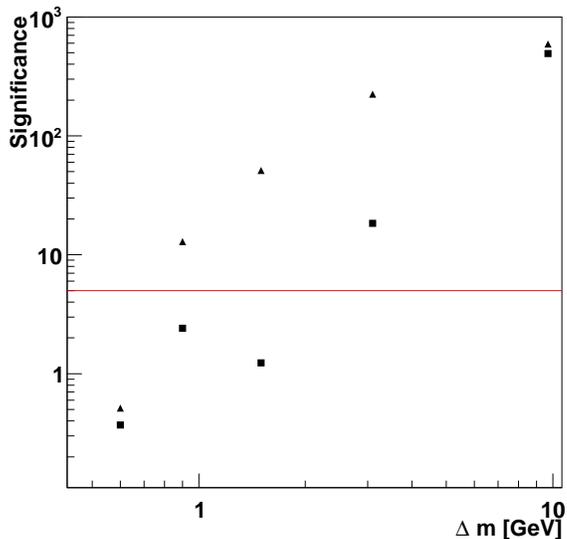


FIG. 4: Significance vs. bino–singlino mass difference Δm . We show the significance both with the standard lepton p_T cut (squares) and the 2 GeV lepton cut (triangles).

from a fit to the edge at ~ 80 GeV, continued down to low invariant masses. This means that the expected number of events can be determined entirely from data. The number of signal events S are the events in excess of this. S/\sqrt{B} is evaluated for low invariant masses, taking $m_{\tilde{u}} < 10$ GeV as an upper limit. The exact significance will naturally depend on the interval chosen, but 10 GeV should in any case be conservative. At low significance there is, as expected, some fluctuation in the significance due to the random nature of the signal generation and background generation. From Fig. 4 we find that we should be able to observe a significant excess down to $\Delta m \simeq 0.8$ GeV, under the assumptions on lepton efficiencies described above.⁶ However, it is worth noting that even with the standard lepton cuts one should be sensitive to mass differences down to 2 – 3 GeV.

IV. MASS CONSTRAINTS

In the standard di-lepton analysis the edges at ~ 80 GeV and ~ 100 GeV are used to determine the relationship between the neutralino and slepton squared-mass differences, in

⁶ For such small mass differences we may also begin to see neutral displaced vertexes, cf. [28].

our scenario $m_{\tilde{\chi}_3^0}^2 - m_{\tilde{l}_{L/R}}^2$ and $m_{\tilde{l}_{L/R}}^2 - m_{\tilde{\chi}_2^0}^2$, and the slepton squared-mass $m_{\tilde{l}_{L/R}}^2$. With the addition of further edges from longer decay chains, the individual masses $m_{\tilde{\chi}_3^0}$, $m_{\tilde{l}_{L/R}}$ and $m_{\tilde{\chi}_2^0}$ can be constrained, although mass differences are determined much more precisely. For the SPS1a benchmark point, with similar masses to our scenario, one finds that a precision of $\sim 4\%$ is achievable on the masses of the neutralinos and sleptons involved, when the measurement is systematics dominated [27].

In the same manner we could also attempt to extract information on the singlino by determining the position of the edge at low invariant masses, giving access to the mass difference $m_{ll}^{\max} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$, for the three-body decay. Since the shape of an invariant mass distribution *a priori* contains more information than an endpoint, it could be hoped that a fit to the whole distribution would further constrain the SUSY parameters involved, e.g. setting the scale of the masses as well as their difference [29, 30, 31]. In fact, the full matrix element for the $\tilde{\chi}_2^0$ three-body decay via a virtual slepton, as calculated in [32], is used in PYTHIA. From Eq. (11) of [32] we can see that the invariant mass distribution, in addition to the neutralino masses, also depends on the left and right handed slepton masses and their widths.

We perform fits to the di-lepton invariant mass distributions at low invariant masses with a Gaussian smearing of the shape given in [32], under the assumption that effectively only one slepton contributes.⁷ The Gaussian smearing is meant to emulate smearing by finite detector resolution. The results for benchmark points B and D are shown in Fig. 5. In subtracting the OSOF distribution before fitting, we have taken into account the effective lepton non-universality induced by the difference in electron and muon efficiencies. This is done by re-weighting pairs of leptons with the inverse of their combined efficiencies, according to the lepton momenta involved. This effectively unfolds the non-universality effects on the invariant mass distribution from the differing efficiencies, at the cost of increasing statistical errors due to large weights. It should be a simple extension to include geometry dependent efficiencies into this re-weighting. Naturally, the re-weighting can only be effective if the errors on the measured lepton efficiencies are small compared to the other errors involved in the fit. The resulting differences in shape can clearly be seen by comparing Figs. 3 and 5.

⁷ For our benchmark points the right handed slepton contributes $\sim 90\%$ to the decay amplitude. We have checked that the fits are completely insensitive to whether there are one or two sleptons participating.

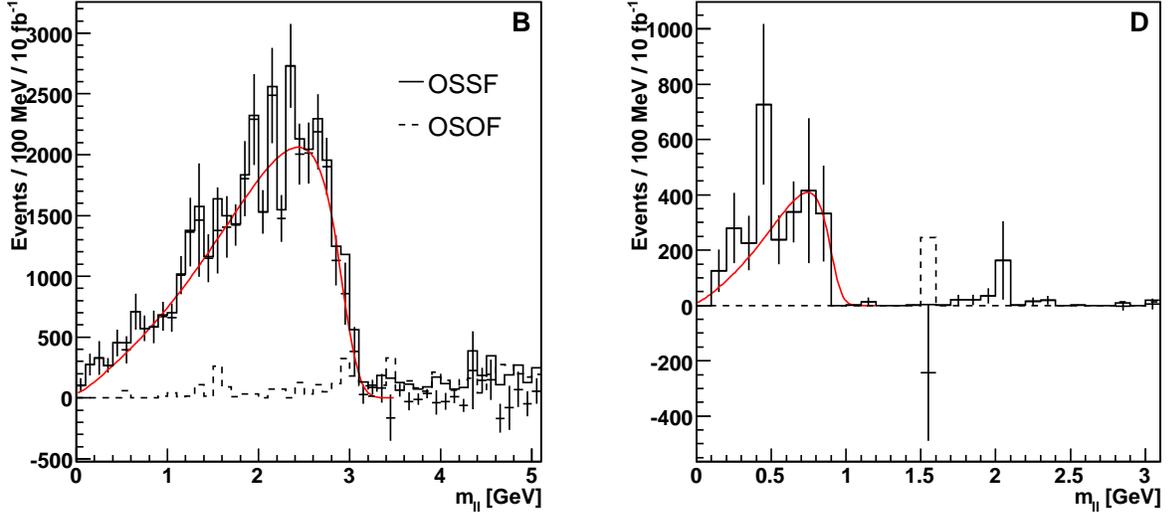


FIG. 5: Di-lepton invariant mass distributions for point B (left) and point D (right) after reweighting with lepton efficiencies. Fits (in red) are described in the text.

Benchmark point	A	B	C	D
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	9.77 ± 0.03	2.98 ± 0.02	1.39 ± 0.03	0.92 ± 0.02
$m_{\tilde{l}} - m_{\tilde{\chi}_1^0}$	46.5 ± 12.7	52.7 ± 21.9	69.0 ± 53.6	57.2 ± 95.8
χ^2/ndf	1.20	1.29	2.06	0.90

TABLE IV: Mass differences in [GeV] and fit quality χ^2/ndf from fits to the di-lepton invariant mass distributions.

Despite our hopes, we find that the shape fits do not constrain the slepton width at all, nor do they constrain the absolute mass scale significantly. For benchmark point A, with the largest statistics, it indicates a singlino mass of $m_{\tilde{\chi}_1^0} = 83.2 \pm 44.1$ GeV. However, when parametrised in terms of the bino–singlino and slepton–singlino mass differences, keeping also the scale as free parameter, the fits give quite good bounds, which can be found in Table IV.

For both benchmark points A and B, with the larger statistics, the fit gives a useful bound on the slepton–singlino mass difference. These can be compared to the nominal values of $m_{\tilde{l}_R} - m_{\tilde{\chi}_1^0} = 37.1$ GeV and 30.4 GeV, for points A and B respectively. This sensitivity can

be understood physically as the effect the proximity of the slepton pole has on the shape of the invariant mass distribution. For much larger slepton masses this sensitivity should go away. For all four points the fit gives an accurate determination of Δm . Comparing to the nominal values given in Section II, in particular the result for benchmark point B indicates that there are potential sources of significant systematic error, larger than the statistical errors with 10 fb^{-1} of data.

With the information obtainable from a long decay chain involving an on-shell slepton, see above, the absolute singlino mass can be found with the same precision as the other two neutralinos involved, i.e. around 4% for our scenario, meaning that we are dominated by the errors of the long decay chain. The results on the slepton–singlino mass difference in Table IV would indicate, for benchmarks A and B, that the decay (1) occurs dominantly through a different slepton than the decay (2), which one may speculate could in turn give some restriction on the neutralino mixing parameters.

V. CONCLUSIONS

We have demonstrated that lowering the requirements on lepton transverse momentum in the standard search for the SUSY di-lepton edge may reveal unexpected features, such as the NMSSM in disguise. While our numerical results are sensitive to the exact lepton efficiencies and momentum resolutions at low transverse momenta — to be measured by the LHC experiments — the OSOF subtraction procedure ensures that the background can be estimated from data and that the NMSSM scenario in question is both discoverable down to very small bino–singlino mass differences, $\Delta m = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} \simeq 0.8 \text{ GeV}$, and that this mass difference is measurable to good precision. We have also shown that the di-lepton invariant mass distribution has some sensitivity to the slepton–singlino mass difference.

We would also like to note that, since virtually all SUSY cascades in these scenarios will contain two decays of the type (1), this lower edge in the di-lepton distribution may appear much earlier than the ‘standard’ decay through a slepton, if at all present, provided that the soft leptons are searched for. This may in fact be an early discovery channel for SUSY.

ACKNOWLEDGEMENTS

We thank members of the ATLAS Collaboration for helpful discussions. ARR and MJW acknowledge funding from the UK Science and Technology Facilities Council (STFC). This work is also part of the French ANR project ToolsDMColl, BLAN07-2-194882.

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