Testing SUSY models for the muon g-2 anomaly via Chargino-Neutralino Pair Production at the LHC

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Abstract

Non-universal gaugino mass models can naturally account for the dark matter relic density via the bulk annihilation process with relatively light bino LSP and right sleptons in the mass range of \(\sim 100 \text{ GeV}\), while accommodating the observed Higgs boson mass of \(\sim 125 \text{ GeV}\) with TeV scale squark/gluino masses. A class of these models can also account for the observed muon g-2 anomaly via SUSY loops with wino and left sleptons in the mass range of \(400 – 700 \text{ GeV}\). These models can be tested at LHC via electroweak production of charged and neutral wino pair, leading to robust trilepton and same sign dilepton signals. We investigate these signals along with the standard model background for both 8 and 13 TeV LHC runs.
1 Introduction

A large part of the SUSY phenomenology over the past years has been based on the minimal supergravity or the so-called constrained minimal supersymmetric standard model (CMSSM), which assumes universal gaugino and scalar masses $m_{1/2}$ and $m_0$ at the GUT scale [1–3]. In this case the lightest superparticle (LSP), i.e., the dark matter, is dominantly a bino over most of the model parameter space. Since the bino does not carry any gauge charge, its main annihilation process is via sfermion exchange into a pair of fermions. And the cosmologically compatible dark matter relic density requires rather small bino and sfermion masses $\sim 100$ GeV. This is the so-called bulk annihilation region. Unfortunately, the LEP limit on the light Higgs boson mass, $m_h > 114$ GeV practically rules out the bulk annihilation region of the CMSSM as it requires TeV scale squark/gluino masses [4]. This is further reinforced now with the reported discovery of Higgs boson at LHC by the ATLAS and CMS experiments [5, 6]

\[ m_h \simeq 125 \text{ GeV} \]  

It was shown in [7] that the natural explanation of the cosmologically compatible dark matter relic density in the bulk annihilation region can be reconciled with the Higgs boson mass limit from LEP in a class of simple and well motivated MSSM with non-universal gaugino masses (NUGM) based on SU(5) GUT [8, 9]. In these models one can have relatively small bino and right slepton masses in the range of $\sim 100$ GeV to account for the former along with TeV scale squark/gluino masses to account for the latter. Moreover, these models can raise the Higgs boson mass to the observed range of $\sim 125$ GeV with the help of a TeV scale tri-linear coupling term $A_0$ [10]. More recently it was shown in [11] that some of these models have relatively modest wino and left slepton masses in the range of 400-700 GeV, so that they can also account for the reported muon $g-2$ anomaly [12, 13] via wino-left slepton loops [14–18].

In this work we investigate the prospect of probing the above mentioned mass range of 400-700 GeV for wino and left sleptons in these models at the 8 TeV and the forthcoming 13 TeV runs of the LHC. Section 2 gives a brief description of the non-universal gaugino mass models based on SU(5) GUT. Section 3 discusses the weak scale SUSY spectra and muon $g-2$ prediction for two such models, where the wino and left slepton lie in the mass range of 400-700 GeV. In particular we shall list them for a few benchmark points of these models for computing the LHC signal. Section 4 describes the electroweak production of charged and neutral wino pair, leading to distinctive trilepton and same sign di-lepton signals at the LHC. It also discusses the selection cuts used in this analysis to extract these signals from the main standard model background. Section 5 discusses the results of our analysis of these two channels for both the 8 TeV and the forthcoming 13 TeV runs of LHC. We conclude with a summary in section 6.

2 Non-universal Gaugino Mass model in SU(5) GUT

The gauge kinetic function responsible for the gaugino masses in the GUT scale Lagrangian originates from the vacuum expectation values of the F-term of a chiral superfield $\Omega$ responsible for SUSY breaking,

\[ \frac{\langle F_\Omega \rangle}{M_{\text{planck}}} \lambda_i \lambda_j \]  

(2)
where $\lambda_{1,2,3}$ are the U(1), SU(2) and SU(3) gaugino fields—bino, wino and gluino respectively. Since gauginos belong to the adjoint representation of the GUT group, $\Omega$ and $F_\Omega$ can belong to any of the irreducible representations occurring in their symmetric product, i.e.,

$$(24 \times 24)_{\text{sym}} = 1 + 24 + 75 + 200$$

for the simplest GUT group SU(5). Thus for a given representation of the SUSY breaking superfield, the GUT scale gaugino masses are given in terms of one mass parameter as $[8, 9]$

$$M^G_{1,2,3} = C^n_{1,2,3} m^n_{1/2}$$

where

$$C_{1,2,3} = (1,1,1), C_{1,2,3}^{24} = (-1, -3, 2), C_{1,2,3}^{75} = (-5, 3, 1), C_{1,2,3}^{200} = (10, 2, 1).$$

The CMSSM assumes $\Omega$ to be a singlet, leading to universal gaugino masses at the GUT scale. On the other hand, any of the non-singlet representations of $\Omega$ would imply non-universal gaugino masses at the GUT scale via eqs. 4 and 5. These non-universal gaugino masses are known to be consistent with the universality of gauge couplings at the GUT scale $[8, 9, 19]$ with $\alpha_G \approx \frac{1}{8}$. The phenomenology of non-universal gauginos arising from each of these non-singlet $\Omega$ have been widely studied $[20–22]$.

It was assumed in $[7]$ that SUSY is broken by a combination of a singlet and a non-singlet superfields belonging to the 1+24, 1+75 or 1+200 representations of SU(5). Then the GUT scale gaugino masses are given in terms of two mass parameters,

$$M^G_{1,2,3} = C^l_{1,2,3} m^l_{1/2} + C^\ell_{1,2,3} m^\ell_{1/2}, \quad \ell = 24, 75, 200.$$  

The corresponding weak scale superparticle and Higgs boson masses are fixed in terms of these two gaugino mass parameters and the universal scalar mass parameter $m_0$ along with the tri-linear coupling $A_0$ via the RGE. In these models one could access the bulk annihilation region of dark matter relic density, while keeping the Higgs boson mass above the LEP limit of 114 GeV $[7]$ and raise it further to the LHC value of $\sim 125$ GeV with the help of a TeV scale $A_0$ parameter $[10]$. To understand this result, one can equivalently consider the two independent gaugino mass parameter of eq.6 in any of these three models to be $M_1^G$ and $M_3^G$. The corresponding weak scale gaugino masses are given to a good approximation by the one loop RGE,

$$M_{1,2,3} = \frac{\alpha_{1,2,3}}{\alpha_G} M^G_{1,2,3} \simeq \frac{25}{60, 30, 9} M^G_{1,2,3}. $$

Thus one can choose a relatively small $M_1^G \sim 200$ GeV along with a small $m_0 \sim 100$ GeV to ensure a small weak scale bino mass $M_1 \sim 80$ GeV along with right slepton masses $\sim 100$ GeV. Then the annihilation of the bino LSP pair via right slepton exchange

$$\chi \chi \rightarrow \tilde{\ell}_R \tilde{\ell}_L$$

(8)
gives the desired dark matter relic density. The other mass parameter $M_3^G$ can then be raised to an appropriate level to give TeV scale squark/gluino masses as required by the Higgs boson mass of $\sim 125$ GeV and the negative squark/gluino search results from LHC.

Note that with given $M_1^G$ and $M_3^G$ inputs, each of the above three models makes a definitive prediction for $M_2^G$. It follows from eqs. 5 and 6 that the (1+200) model predicts the smallest $M_2^G$ and hence the smallest weak scale wino and left slepton masses among all the three models.
Hence it offers the best chance to account for a significant SUSY contribution to the muon g-2 anomaly, as discussed in [11]. As further discussed in [11], one can extend the analysis to a general non-universal gaugino mass model with three independent gaugino mass parameters, $M_G^1$, $M_G^2$ and $M_G^3$. This can be realized in a scenario of SUSY breaking by three superfields, belonging to different adjoint representations of the GUT group, e.g., a (1+75+200) model. In this case one can have very modest wino and left slepton masses $\sim 400$ GeV, so as to give a SUSY contribution to the muon g-2 anomaly very close to its experimental central value. In the next section we shall focus on some benchmark points from these two models, which can account for the muon g-2 anomaly within 2σ level.

### 3 The weak scale SUSY spectra and muon g-2 contributions in the (1+200) model and the general non-universal gaugino mass Model

We have used the two-loop RGE code in SusPect [23] to generate the weak scale SUSY and Higgs spectra. One should note that the $\overline{\text{MS}}$ renormalization scheme used in the SusPect RGE code is known to predict a lower Higgs boson mass than the on-shell renormalization scheme used in FeynHiggs [24] by 2-3 GeV [25–29]. Therefore a predicted Higgs boson mass $\gtrsim 122$ GeV in the following tables is compatible with the reported mass of $\sim 125$ GeV [5,6].

The resulting dark matter relic density and the muon anomalous magnetic moment (g-2) were computed using the microOMEGAs code [30–32]. In view of the high precision of the dark matter relic density data [33] we have considered solutions lying within 3σ of its central value as in [11], i.e.,

$$0.102 < \Omega h^2 < 0.123.$$  \hspace{1cm} (9)

On the other hand the measured value [12] of the muon anomalous magnetic moment excess has a relatively large uncertainty,

$$\Delta a_\mu = (28.7 \pm 8.0) \times 10^{-10}$$  \hspace{1cm} (10)

where

$$a_\mu = \frac{(g-2)_\mu}{2}.$$  \hspace{1cm} (11)

Therefore we have considered SUSY solutions to $a_\mu$ [11] lying within 2σ of the central value, i.e.,

$$\delta a_\mu = \Delta a_\mu - a_\mu^{\text{SUSY}} < 2\sigma$$  \hspace{1cm} (12)

so that $a_\mu^{\text{SUSY}}$ is at least of the same order as the central value of the experimental excess of eq. 10.

Explicit formulae for $a_\mu^{\text{SUSY}}$, arising from wino-left slepton and bino-right slepton loops, can be found e.g., in [14, 15]. It increases linearly with $\tan \beta$ at constant SUSY masses. However, one has to choose a higher $m_0$ at larger $\tan \beta$ to maintain the $\tilde{\tau}_1$ mass in the desired range for the dark matter relic density of eq. 9. The resulting increase in slepton masses compensate the linear rise of $a_\mu^{\text{SUSY}}$ with $\tan \beta$. This results in a broad peak of $a_\mu^{\text{SUSY}}$ at $\tan \beta \approx 15$, which remains nearly constant over the moderate $\tan \beta (=10-20)$ regions [11]. Therefore we have chosen the following benchmark points at $\tan \beta=15$.

Table 1 lists three benchmark points from [11], of which the BP1 and BP2 belong to the (1+200) model and BP3 to the general non-universal gaugino mass model. The corresponding weak scale
Table 1: Benchmark points of SUSY parameter space taken from Ref. [11] to simulate signal process (all masses are in GeV and A parameters are in TeV). The corresponding SUSY contributions to muon anomalous magnetic moment are shown along with their differences from the measured central value of eq. 10.

| Point | $\tilde{g}$ | $\tilde{q}_L$ | $\tilde{q}_R$ | $\tilde{t}_{1,2}$ | $\tilde{b}_1$ | $\tilde{t}_L$ | $\tilde{\tau}_1$ | $\chi_1^0$ | $\chi_2^0$ | $\chi_1^+$ | $\chi_2^+$ | $h$ |
|-------|-------------|---------------|---------------|----------------|-----------|----------|------------|---------|---------|---------|---------|----|
| BP1   | 1764        | 1600          | 1540          | 820,1531       | 1311      | 479      | 85         | 80      | 593     | 593     | 1494    | 124  |
| BP2   | 1967        | 1778          | 1711          | 1012,1524      | 1490      | 531      | 83         | 80      | 666     | 666     | 1584    | 124  |
| BP3   | 2578        | 2252          | 2235          | 1596,1994      | 1967      | 380      | 81         | 78      | 461     | 461     | 1871    | 123  |

Table 2: Masses of SUSY particles (in GeV) calculated using SuSpect v2.41 [23] for the three benchmark points given in Table 1.

SUSY and Higgs spectra are listed in Table 2. The $M_3^G$ inputs for the BP1 and BP2 were chosen rather high to ensure that the resulting squark/gluino masses are well above the 8 TeV LHC search limits [34]. This results in a fairly high values of $M_3^G$, so that the corresponding wino ($\chi_1^\pm$, $\chi_2^0$) masses are $\gtrsim 600$ GeV. The resulting $\delta a_\mu$ is in the range of 1.6-1.9 $\sigma$. For BP3, all the three gaugino mass inputs are independent. Thus we have chosen a large enough $M_3^G$ to correspond to squark/gluino masses even beyond the reach of 13 TeV LHC along with a modest $M_2^G$ to correspond to wino ($\chi_1^\pm$, $\chi_2^0$) mass $\approx 460$ GeV. The resulting $a_{\mu}^{SUSY}$ is within 0.26$\sigma$ of the experimental value. However, we shall see below that this benchmark point can be easily tested with the available 8 TeV data.

We note from Table 2 that the left slepton ($\tilde{l}_L$), representing left selectron and smuon is always $\approx 20\%$ lighter than the charged and neutral wino ($\chi_1^\pm$, $\chi_2^0$). It is a robust feature of these non-universal gaugino mass models, following from a small and universal $m_0$ – the smallness being required by the bulk annihilation region of dark matter relic density. It ensures that the produced $\chi_1^\pm$, $\chi_2^0$ pair dominantly decay via the left sleptons, resulting in viable trilepton and same sign dilepton signals with two hard leptons. The latter signal is unaffected even if the left sleptons mass becomes very close to the wino mass. These multilepton signals will become unviable only if the left slepton becomes heavier than the wino, which will require a large $m_0$. This means one has to sacrifice either the bulk annihilation region of dark matter relic density or the common scalar mass for the left and right sleptons. With these two resonable constraints, the muon $g-2$ satisfying SUSY models predict trilepton and even more robust same sign dilepton signals at LHC. LHC searches for other muon $g-2$ satisfying SUSY models have been discussed in [35–37].

### 4 Signal and Background

As discussed in the previous section the NUGM models provide a framework which can accommodate the bulk annihilation region of the right DM relic density as well as the required muon $g-2$. It implies that the wino masses are in the range of 400-700 GeV, which implies pair production of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ at the LHC with a sizable cross section. Once this pair is produced in proton-proton collision, their cascade decays lead to the final state containing hard leptons along with lightest...
neutralinos (\tilde{\chi}_1^0), which is assumed to be the lightest SUSY particle (LSP). The presence of LSPs in the final state results in an imbalance in the measured transverse momentum ($p_T$) due to its very weak interaction with the detector. Hence the decay channel,

$$\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to (\ell^\pm \nu \tilde{\chi}_1^0)(\ell^\mp \ell^- \tilde{\chi}_1^0)$$  \hspace{1cm} (13)

with $\ell = e, \mu$, leads to a trilepton signal having same flavor opposite sign (SFOS) leptons or a same sign dilepton (SSDL) signal, each with a reasonable amount of $p_T$. It is to be noticed that this signal is hadronically quiet which can be exploited to get rid of standard model (SM) backgrounds. The dominant SM background is due to the WZ production with the leptonic decays of W and Z boson providing identical final states like the signal events. In addition, the pair production of top quarks with the semi leptonic decays, $t \to bW \to b\ell\nu$, and semileptonic decay of one of the $b$-quark leads to three lepton final states. Besides these two dominant SM backgrounds, there are other sources of backgrounds, e.g. from WW, WZ and Wγ/Zγ production, where the decay hadronic jets from W/Z can fake as leptons. However, these backgrounds are expected to be very small. In the present analysis, we consider only the SM backgrounds due to the top pair and WZ production. It is to be noted that in comparison with the SM backgrounds the leptons and $p_T$ in the signal are expected to be harder, since they originate from comparatively more massive particles like $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$. We have exploited all these signal characteristics to isolate signal events from large background samples.

The signal and background events are simulated using PYTHIA6 [38]. In cross section calculation we use CTEQ6L1 [39] for parton distribution function setting both factorization and renormalization scales to $\hat{s}$ – the center of mass energy in the partonic frame. In our simulation we adopt the following strategy to select events:

• Lepton selection: As already mentioned, the signal events are expected to contain two hard leptons due to the large mass gap between the left slepton and the LSP. So we apply hard cuts on the first two leptons and a soft cut on the third lepton. Here leptons are arranged in decreasing order of $p_T$. For three lepton case with same flavor opposite sign (SFOS),

$$p_T^{\ell_1,2,3} \geq 80, 50, 10 \text{ GeV;} \quad |\eta^{\ell_1,2,3}| \leq 2.5$$  \hspace{1cm} (14)

and for same sign dilepton events (SSDL),

$$p_T^{\ell_1,2} \geq 50, 50 \text{ GeV;} \quad |\eta^{\ell_1,2}| \leq 2.5.$$  \hspace{1cm} (15)

The isolation of lepton is ensured by the total accompanying transverse energy cut $E_T^{ac} \leq 20\%$ of the $p_T$ of the corresponding lepton, where $E_T^{ac}$ is the scalar sum of transverse energies of jets within a cone of size $\Delta R(l, j) \leq 0.2$ between jet and lepton. These selection of cuts are very useful in suppressing the background events, which will be discussed later.

• Jet selection: Jets are reconstructed using FastJet [40] with jet size parameter $R=0.5$ and anti $k_T$ algorithm [41]. Jets are selected with following thresholds,

$$p_T^j \geq 30 \text{ GeV;} \quad |\eta^j| \leq 3.0.$$  \hspace{1cm} (16)

As mentioned before, signal events are hadronically quiet at the parton level where as $t\bar{t}$ background events has reasonable hadronic activities. Hence, vetoing out events having at least one jet drastically reduce the $t\bar{t}$ background by enormous amount, which can be observed from Tables 3-6 below.

• In case of SFOS, we require opposite sign and same flavor dilepton invariant mass should not lie
within the range 70 - 110 GeV, i.e if $70 < m_{ll} < 110$, events are rejected. This cut is applied with a goal to suppress background from WZ, where this dilepton invariant mass is expected to have a peak around $M_Z$.

- The transverse missing momentum ($p_T$) is calculated adding the momentum of visible particles vectorially and then reverse its sign. and it is required to be $p_T > 150$ GeV.

- Another important observable, the transverse mass is found to be very useful to eliminate SM backgrounds without costing signal events too much. The transverse mass is defined to be,

$$m_T(\ell, p_T') = \sqrt{2p_T^\ell p_T'(1 - \cos \phi(p_T^\ell, p_T'))}$$

(17)

where $\phi(p_T^\ell, p_T')$ is the azimuthal angle between lepton and missing transverse momentum. In SFOS case, after applying $m_{ll}$ cut, the remaining third lepton is used to construct $m_T(\ell_3, p_T')$. The $m_T$ distribution for leptons coming from W decay either in top pair production or from WZ channel is expected to show a jacobian peak around $M_W$; hence a cut on $m_T(\ell_3, p_T') > 150$ GeV effectively suppresses these backgrounds. The main suppression of the WZ background comes of course from the $m_{ll}$ cut.

- For SSDL case, transverse mass for each lepton, $m_T(\ell^{\pm}_1, p_T')$ and $m_T(\ell^{\pm}_2, p_T')$ are constructed and selection cuts are applied separately requiring these to be more than 100 GeV. These cuts are very useful in suppressing the $t\bar{t}$ and WZ backgrounds. In this case a transverse mass cut of the dilepton system with the $p_T', m_T(\ell_1 + \ell_2, p_T') > 125$ GeV, also helps to suppress these backgrounds further.

The signal and backgrounds are simulated for both LHC energies 8 TeV and as well as 13 TeV which is expected to be the Run 2 LHC energy in the next year. For illustration, the signal rates are estimated for the three representative choices of parameter space as shown in Table 1, and the corresponding mass spectra as presented in Table 2.

## 5 Results and Discussions

We present the summary of events in Table 3-6 for both 8 and 13 TeV energies simulating both signal and SM backgrounds $t\bar{t}$ and WZ, adopting the strategy as described in the previous section. Table 3 presents the number of trilepton events for 8 TeV energy after each set of cuts as shown on top of each columns. The 2nd and 3rd columns show the number of events(NoE) simulated and
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| Proc    | NoE | $\sigma$(fb) | $n_\ell = 2$ SSDL | $p_T \geq 150$ | $m_T(\ell_1, p_T) \geq 100$ | $m_T(\ell_2, p_T) \geq 100$ | $m_T(\ell_1 + \ell_2, p_T) \geq 125$ | $n_j = 0$ JetVeto(JV) | $\sigma \times \epsilon$(fb) |
|---------|-----|--------------|-----------------|--------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| BP1     | 50K | 1.8          | 9249            | 7180         | 6953            | 6082            | 5921            | 3338            | 0.21            |
| BP2     | 50K | 0.88         | 9692            | 7876         | 7642            | 6753            | 6790            | 3678            | 0.12            |
| BP3     | 50K | 11.3         | 6541            | 4260         | 4131            | 3548            | 3469            | 2031            | 0.78            |

Table 4: Same as Table 3, but for same sign dilepton case(SSDL).

| Proc    | NoE | $\sigma$(fb) | $3\ell \neq l$ | $p_T \geq 150$ | $m_T(\ell_1, p_T) \geq 100$ | $m_T(\ell_2, p_T) \geq 100$ | $n_j = 0$ JetVeto(JV) | $\sigma \times \epsilon$(fb) |
|---------|-----|--------------|----------------|--------------|-----------------|-----------------|-----------------|-----------------|
| BP1     | 50K | 7.4          | 8880           | 7123         | 6459            | 5519            | 2883            | 0.81            |
| BP2     | 50K | 4.2          | 9290           | 7753         | 7168            | 6228            | 3084            | 0.52            |
| BP3     | 50K | 3.8          | 6941           | 4882         | 4196            | 3470            | 1885            | 2.64            |

Table 5: Event summary for SFOS case, same as Table 3 but for 13 TeV energy.

leading order(LO) cross sections(in fb) respectively for each process, where as the fourth column presents the number of events having 3 leptons in the final states passing cut, eq. 14. Note that the $t\bar{t}$ events are simulated for three $p_T$ bins to consider statistics appropriately in different phase space regions. Here $p_T$ is the transverse momentum of top quark pair in partonic frame. Notice that selection cuts on $p_T$ and $m_T(\ell_3, p_T)$ are very effective to suppress background events, in particular $t\bar{t}$ events, where as dilepton invariant mass($m_{\ell\ell}$) cut suppresses mainly WZ background, with little effect on signal events. Eventually the jet veto(JV) criteria, i.e. reject events if there exist jets in the final states, reduces the $t\bar{t}$ backgrounds drastically with a mild effect on signal events. As noted earlier, in signal events presence of jets are mainly due to initial state radiation; and hence the signal events are not expected to have many hard jets unlike the $t\bar{t}$ background. The last two columns display the final cross sections multiplying by acceptance efficiency for both cases, with and without jet veto. Clearly, jet veto completely brings down the top backgrounds to a negligible level, but residual WZ background remains.

In Table 4 we show event summary for SSDL case at 8 TeV energy. In this case we apply same set of selection cuts as discussed before, but in addition two more selection cuts $m_T(\ell_1, p_T)$ and $m_T(\ell_2, p_T)$ are used with a purpose to suppress mainly WZ background. It is motivated by the fact that in WZ channel two leptons always come from W and Z decays, and the one coming from W decay will not kinematically pass the $m_T > 100$ GeV cut. In contrast the signal events, where leptons originate from heavier $\chi^\pm_1$ and $\chi'^\pm_2$ decays pass the $m_T > 100$ GeV cut for both the leptons. Finally, as indicated by the Table 4, the level of backgrounds cross sections turn out to be negligible. So the discovery limit in the SSDL channels is determined essentially by the signal size.

Similarly we simulate signal and background events for 13 TeV energy using same set of cuts for both SFOS and SSDL cases, which are presented in Tables 5 and 6 respectively. The pattern
of suppression of background events with respect to signal events are more or less the same as observed before. However, effect of jet veto kills signal events a little more than at 8 TeV due to the fact that hadronic activities from ISR/FSR are more at this higher energy.

Finally we summarize our results presenting signal and background cross sections along with the signal significance ($S/\sqrt{B}$) in Tables 7 and 8 for SFOS and SSDL cases respectively. The significance are estimated for integrated luminosity 20 $fb^{-1}$ and 100 $fb^{-1}$ for 8 and 13 TeV energies respectively. In calculating both signal and background cross sections, we have taken into account the next to leading order effect by multiplying the K-factors for each cases. For example, for $t\bar{t}$ and WZ processes, we multiply cross sections by 1.6 [42] and 1.7 [43], whereas for signal it is 1.5 [44]. Although these K-factors are derived for 14 TeV energy, they are not expected to be very different at 8 and 13 TeV.

Table 7 shows the summary of the tri-lepton(SFOS) channel results. We see from this Table that the BP3 corresponding to modest wino ($\chi^{\pm}$, $\chi^{0}_{2}$) mass of $\approx 460$ GeV can be probed at 5(6)$\sigma$ level with 24(15) trilepton signal events without(with) jet veto from the available 20 $fb^{-1}$ data at 8 TeV. Even without a dedicated search with the model, it may be reasonable to assume that trilepton signal of this size could not be missed in generic search of chargino-neutralino pair production events. On the other hand for BP1 and BP2, corresponding to wino mass $m_{\chi^{\pm}}$, $m_{\chi^{0}_{2}} > \sim 600$ GeV, one expects only a couple of trilepton signal events at a significance level < 2$\sigma$ with the
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| Process | 8 TeV | 13 TeV |
|---------|-------|--------|
|         | No JV | JV     |
|         | .002  | 0      |
|         | .005  | 0.28   |
| .007    | .005  | 0.01   |
| Total Bg | .007  | .005   |
|         | .31   | .09    |
| BP1     | 6     | 1.26   |
| S       | 3.6   | 76.6   |
| BP2     | 0.18  | .82    |
| S       | 3.6   | 82.3   |
| BP3     | 1.17  | 3.85   |
| S       | 23    | 13     |

Table 8: Same as Table 7, but for SSDL case. In this case we show the expected number of signal events for the integrated luminosities of 20 fb$^{-1}$ and 100 fb$^{-1}$ for 8 and 13 TeV respectively. The corresponding $S/\sqrt{B} \geq 10$ for all cases.

available 20 fb$^{-1}$ data at 8 TeV. But with the 100 fb$^{-1}$ data at 13 TeV one can probe BP1(BP2) at a significance level of $\sim 8\sigma$(5\sigma) with 60(40) trilepton signal events. This means that even with a 20 fb$^{-1}$ data at 13 TeV a negative search result can rule out wino ($\chi_1^\pm, \chi_2^0$) masses up to 600-700 GeV at $>2\sigma$ level. This will essentially cover the non-universal gaugino mass models satisfying muon g-2 anomaly up to $2\sigma$ level.

The summary of the corresponding results for the SSDL channel is shown in Table 8. In this case possibility of observing signal events is more promising due to the presence of tiny backgrounds. Indeed the $S/\sqrt{B}$ ratio is $\geq 10$ for all the cases studied here so that the discovery limit is essentially determined by the number of signal events. Therefore, we show this number here instead of the $S/\sqrt{B}$ ratio. We see from this table that the BP3, corresponding to modest wino mass of $\approx 460$ GeV, can be probed with 23(13) SSDL signal events without(with) jet veto from the available 20 fb$^{-1}$ data at 8 TeV. Again it is reasonable to assume that a signal of this size cannot be missed even in a generic search of chargino-neutralino pair production with this data. For BP1 and BP2, corresponding to wino mass $\gtrsim 600$ GeV, one expects only 4-6 and 2-3 SSDL signal events respectively. This falls short of a conservative discovery limit of at least 5-6 events. With the 100 fb$^{-1}$ data at 13 TeV one can probe BP1(BP2) at a significance level of $\approx 26-66\sigma(15-39\sigma)$ with 125-65(80-40) SSDL signal events. Thus even with a 20 fb$^{-1}$ data at 13 TeV a negative search results can rule out wino($\chi_1^\pm, \chi_2^0$) masses up to 600-700 GeV at $>5\sigma$ level. Thus one can unambiguously probe the muon g-2 anomaly satisfying non-universal gaugino mass models at the 13 TeV LHC using either the trilepton or SSDL channels. The SSDL channel has the advantage of a very small background. Besides the SSDL channel also has the advantage of being viable even when the left slepton mass comes very close the wino mass, as discussed earlier.

Recently the ATLAS collaboration have published the analysis of their 20 fb$^{-1}$ data at 8 TeV for chargino pair production signal in the unlike sign dilepton channel [45]. For a 80 GeV LSP ($\tilde{\chi}_1^0$), they show an expected exclusion region up to $m_{\chi_1^\pm}$=450 -550 GeV at the 95% C.L. ($\approx 2\sigma$), which is similar to our BP3. There is a preliminary CMS result of search for electroweak chargino-neutralino pair production in the tri-lepton channel using their 20 fb$^{-1}$ data at 8 TeV [46]. While most of their analysis focuses on a left slepton mass midway between the $\chi_1^0$ and $\chi_2^0(=\chi_1^\pm)$ masses, there is one figure (Fig.15b in Ref. [46]) showing the 95% C.L. exclusion regions in $\chi_1^0$ and $\chi_2^0$ masses for left slepton mass close to the latter. The edge of their expected 95% C.L. ($\approx 2\sigma$) exclusion region for $m_{\tilde{\chi}_1}^0$=80 GeV touches $m_{\tilde{\chi}_2}^0$=600 GeV which is close to our BP1. Thus their
expected $2\sigma$ exclusion limit is stronger than our estimated $1.5\sigma$ exclusion for BP1 in Table 7. The main reason for this seems to be their use of b-jet veto instead of a general jet veto, so that they can suppress the $t\bar{t}$ background without sacrificing the SUSY signal. Their b-jet veto criteria have been tuned to their $t\bar{t}$ data. Having no access to this data, we had to rely on the general jet veto to suppress the $t\bar{t}$ background. We hope the CMS collaboration will do a dedicated analysis of their 8 TeV data for chargino-neutralino pair production in tri-lepton and SSDL channels in these non-universal gaugino mass models, where the electroweak super particle masses are fairly well constrained by the dark matter relic density and the muon g-2 anomaly.

6 Summary

Non-universal gaugino mass models can naturally account for the dark matter relic density via the bulk annihilation process with relatively light bino LSP and right sleptons in the mass rage of $\sim 100$ GeV, while accommodating the observed Higgs boson mass of $\sim 125$ GeV with TeV scale squark/gluino masses. Some of these models can also account for the observed muon g-2 anomaly via SUSY loops with wino and left sleptons in the mass range of 400-700 GeV. We have investigated the prospect of testing these models via electroweak production of charged and neutral wino pairs at the LHC. The left slepton masses in these models are predicted to lie typically $\sim 20\%$ below the wino mass. Thus one expects robust trilepton and same sign dilepton signals of these models arising from the cascade decays of the charged and neutral wino pair via the left sleptons. In particular the SSDL signal holds even when the left slepton mass lies very close to the wino mass. It also has the advantage of a very small standard model background. Our simulation study shows that the available 8 TeV LHC data is adequate to probe the wino mass range of 400-500 GeV in both the trilepton and the SSDL channels. This mass range of wino covers the muon g-2 range within $0-1\sigma$ of its observed central value. Moreover the probe can be extended to the wino mass range of 600-700 GeV with the 13 TeV LHC data, which covers the muon g-2 range up to $2\sigma$ of its central value. Thus the non-universal gaugino mass models satisfying the observed dark matter relic density and the muon g-2 anomaly can be unambiguously tested via electroweak production of the charged and neutral wino pair at the forthcoming 13 TeV run of LHC.

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