**Leptonic Rare Decay and Mini-Split SUSY**

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**Abstract :**

The lack of sign for new physics at LHC reveals the overall absence of sparticles from the weak scale. But Supersymmetry gauge coupling unification would not have been possible without the presence of sparticles at low energy. In order to solve this argument a theory called Split Susy motivated by the multiverse came into light with scalars below 105 TeV. Gauge coupling unification favors Higgsinos below 100 TeV. Charged Lepton Flavor Violation (cLFV) processes like μ→ e γ are rare decay processes, that are another signature of physics beyond Standard Model (BSM). We also comment on our recent results in mSUGRA and NUHM models, in which we have studied the possibility of detection of SUSY particles at next run of LHC as allowed by the cLFV (Charged Lepton Flavor Violation) constraints.

**I. Introduction**

The LHC has discovered the last missing ingredient of the Standard Model, the 126 GeV Higgs boson [1,2] and it has laid striking constraints on the supersymmetry (SUSY) model building. The absence of significant hints for physics beyond the standard model in electroweak precision tests, studies of lepton and quark flavor physics, measurements of CP violation, and exploration for new states at the LHC and other colliders proposes that electroweak sector may well be fine-tuned to some extent. The extremely small value of the cosmological constant is a threat to our concept of naturalness. Many dynamical solutions for stabilizing the EW scale have been proposed. Among these, supersymmetry (SUSY) plays a major role because it quantitatively predicts the unification of the gauge couplings [3]. The unique motivation for the minimal supersymmetric standard model (MSSM) was to explain the Higgs naturalness problem with superpartners at the weak scale. In fact, the Higgs mass mh around 125 GeV requires stop masses above a few TeV implying some tuning in the MSSM. Such large radiative corrections can be evaded if there are extra contributions to the Higgs quartic self-coupling. However, direct bounds on colored superpartners from the LHC are already so strong that even after raising the value of the Higgs mass in a natural way, the fine tuning does not improve. Thus, the only chance for finding a natural implementations of SUSY is to look for models that can lessen the most rigorous bounds set by the LHC searches. Recently, three classes of models [4] have fascinated major attention – mini-split SUSY, baryonic R-parity violating SUSY (bRPV), and models with Dirac gauginos. The Higgs mass in mini-split models influences the third generation squarks to be between 1 and 105 TeV, depending on tanβ [3].

 One can also have limits on the masses of sparticles,from some other studies, like charged lepton flavor violation (cLFV). It is known that lepton flavor is violated in neutrino sector from the experiments observed in oscillation phenomena. In this work we also comment on our recent studies [5], carried out in cLFV (μ → eγ) decays, using type I see saw mechanism in μ-𝞽 symmetric SUSY SO(10) theories [6]. We have presented sensitivity to test the observation of sparticles at next run of LHC [7], in mSUGRA (minimal supergravity models), NUHM (non-universal Higgs mass model) models, in these studies. The analysis have been done for tan β = 10, and MGUT = 2×1016 GeV. The form of Dirac neutrino Yukawa couplings is used from [5]. The value of Higgs mass as measured at LHC [7] and global fit values of reactor mixing angle θ13 as measured at Daya Bay, Reno [8] have been used in this work. Also, after the improved constraints on BR(μ → eγ) at MEG experiment [9], this is the first study in type I See Saw scenario. Such studies in type II See Saw have been carried out in [10], but they were done before improved BR(μ → eγ) MEG limits [11], using CKM or PMNS like Dirac neutrino Yukawa couplings. In [12], such studies were done using type I see saw formula, using older value of BR(μ → eγ) [9].

**2. LHC and SUSY**

The most noticeable feature of SUSY (Supersymmetry) is the solution of the hierarchy problem. In a supersymmetric version of the SM, where SUSY is unbroken, the radiative quadratic divergence to the Higgs mass are exactly cancelled by diagrams with SUSY partners of the SM particle fields in the loops. Successful unification of the three gauge couplings in SM takes place at around 1016 GeV in the MSSM. In conserved R parity SUSY models, the lightest SUSY particle (LSP) is stable on cosmological time scales, this particle is a viable candidate for dark matter. These essential features motivates us to study SUSY. SUSY is a space time symmetry of nature, that relates every fermionic state to a bosonic state, or vice versa, via

 , = or = …………….(2.1)

where *Q* are the fermionic operators or Weyl spinors, generators of the SUSY algebra. So, if SUSY were to exist, we would have found the sparticles, experimentally

 It is well known that SUSY can be broken by soft terms of type − A0, m0, M1/2, where A0 is the universal trilinear coupling, m0 is the universal scalar mass, and M1/2 is the universal gaugino mass. Strict universality between Higgs and matter fields of mSUGRA models can be relaxed in NUHM (non universal higgs mass) Models. We find from our calculations shown in the cLFV studies, in Sec.4 in mSUGRA, that the spectrum of M1/2 and m0 lies towards heavy side, as allowed by MEG constraints on BR(μ → eγ), though in NUHM lighter spectra is possible (due to partial cancellations in flavor violating term). From above it is seen that signatures of cLFV could be tested at next run of LHC, if SUSY sparticles are observed within few TeV range. It is worth mentioning here that, during last run of LHC, no SUSY partner of SM has been observed. The LHC has stringent limits on sparticles, which could imply a tuning of EW symmetry at a few percent level [13-18]. And hence some alternatives to low scale SUSY theories have been proposed. Some of them are − minisplit SUSY [3] and maximally natural SUSY [19]. In the former the scalar sparticles are heavier than the fermions (gauginos and higgsinos), so that sfermions could be observed at LHC.

**3. Mini- Split SUSY**

Multiverse motivates a weak scale supersymmetry with the spectrum often called spread or mini-split supersymmetry. In this set up gauginos are at the TeV scale, while scalar sparticles can be anywhere between the GUT scale and the weak scale ( ~ 100 GeV). The measured Higgs mass limits the scalar sparticles to be below 105 TeV, whereas gauge coupling unification supports Higgsinos below 100 TeV. In many models gaugino masses are suppressed and remain within reach of the LHC. Fine tuning of the weak scale and the renormalization group evolution of the squark and the up-higgs, which often run tachyonic due to the smallness of gaugino masses, result in successful EWSB (Electroweak Symmetry Breaking), only when higgsinos are heavy near the scalar mass scales.

Effective tuning of EWSB in split susy requires that the Higgs sector parameters at the scalar mass scale follow the following relations [3] :

(μ2 + m2Hu)(μ2 + m2Hd) + BμBμ\* = 0……………………………………………(3.1)

tanβ = ………………………………………………………(3.2)

where Hu and Hd are the complex Higgs doublet. is the Higgsino parameter which is the analogue of Higgs mass in Standard Model. Bμ represents gaugino masses.

**4. LHC and cLFV studies.**

In this section we comment on our recent studies in the charged LFV constraints in μ-𝞽 SO(10) SUSY type I Seesaw mechanisms with mSUGRA, NUHM boundary conditions, through detailed numerical analysis done by using the software SuSeFLAV [20]. For mSUGRA we scan the soft parameter space in the following ranges.

 MSUSY = 1TeV

 mh ∈ [122.5, 129.5] GeV

 m0 ∈ [0, 7] TeV

 M1/2 ∈ [0.3, 3.5] TeV

 A0 ∈ [−3m0,+3m0] ……………………. (4.1)



 Figure 1: Mini-Split spectrum

Here m0 is the universal SSB mass parameter for sfermions. A0 is the trilinear scalar interaction coupling, tanβ is the ratio of the MSSM Higgs vacuum expectation values (VEVs). We carry out the numerical analysis using the publicly available package SuSeFLAV . We also study cLFV for the non universal Higgs model without completely universal soft masses at high scale. Range of scan of various susy parameters in NUHM are:

 mh ∈ [122.5, 129.5] GeV

 30 GeV ≤ m0 ≤ 6 TeV

 30 GeV ≤ M1/2 ≤ 2.5 TeV

 −8.5 TeV ≤ mHu ≤ +8.5 TeV

 −8.5 TeV ≤ mHd ≤ +8.5 TeV

 −18 TeV ≤ A0 ≤ +18 TeV……………………….(4.2)

Due to partial cancellations in the entries of left handed slepton mass matrices in NUHM case large region of parameter space can be explored by MEG compared to mSUGRA.

 The present and future MEG bound on BR(μ → e γ) are 5.7 \* 10 -13 and 6 \* 10 -14 respectively. We find that, the updated MEG limit [11] together with a large θ13 puts significant constraints on SUSY parameter space in mSUGRA.

 In Fig 2 we find that parameter space M1/2 ≥ 1 TeV is allowed by present MEG bounds on BR(μ → eγ), while future MEG limit excludes small M1/2 space ≤ 3.5 TeV. Strict universality between matter and Higgs fields can be relaxed [12]. These models are Non-Universal Higgs Mass models (NUHM).



Figure 2 - The results of our calculations are presented for mSUGRA case. Here different horizontal lines represents the present (MEG 2013) and future MEG bounds for BR(μ →e +γ).

Cancellations in the flavor violating entry can absolutely relax the LFV constraints on the SUSY parameter space. In figure 3 we have shown our results in SUSY parameter space M1/2 [GeV] Vs Log[BR(μ → e+γ)], in NUHM.

 

Fig 3 - The results of our calculations are presented for NUHM case. Different

horizontal lines represent the present (MEG 2013) and future MEG bounds for BR(μ → e +γ ).

**5. Conclusion**.

To conclude, in this work we have studied the rare cLFV decay μ → e γ in SUSY SO(10) theories, using type I see saw mechanism, in mSUGRA, NUHM. We found that in mSUGRA very heavy M1/2 region is allowed by future MEG bound of BR(μ → e), though in NUHM case a low M1/2 is also allowed. As compared to mSUGRA, in NUHM, a wider parameter range is allowed. For present and future MEG bound, NUHM allows soft scalar masses around 100-2500 TeV, which would be easily accessible at next run of LHC satisfying cLFV constraints. So far LHC has not seen any SUSY particles. Therefore, much efforts are going into the study of less constrained models of low energy SUSY with a large variety of spectra. In this light, Mini-Split SUSY is an attractive scenario with scalars below 105 TeV. Flavor contributes an additional motivation for a split spectrum with gauginos lighter than scalars. If we consider that there are indeed large flavor violations in the soft masses then the most obvious worry are huge FCNCs, but these can be decoupled by making the scalars arbitrarily heavy. But in a theory with no splitting between scalars, Higgsinos and gauginos, there is a difficulty with flavor that cannot be decoupled by pushing up the scale of SUSY breaking. FCNCs pushes the scalars to be above a few thousand TeV. Therefore in any Split model either the flavor problem or the tachyon problem must be solved. Nonetheless, nature leaves open the possibility that all sparticles are in the multi-TeV range, which could be tested at the next run of LHC, while still in tune with the higgs mass and unification.

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