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Tau Flavour Violation in Sparticle Decays at the LHC

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ABSTRACT

We consider sparticle decays that violate τ lepton number, motivated by neutrino oscillation data. We work in the context of the constrained minimal supersymmetric extension of the Standard Model (CMSSM), in which the different sleptons have identical masses at the GUT scale, and neutrino Dirac Yukawa couplings mix them. We find that the branching ratio for decay of the heavier neutralino $\chi_2 \to \chi + \tau^\pm \mu^\mp$ is enhanced when the LSP mass $m_\chi \sim m_{\tilde{\tau}_1}$, including the region of CMSSM parameter space where coannihilation keeps the relic χ density within the range preferred by cosmology. Thus $\chi_2 \to \chi + \tau^\pm \mu^\mp$ decay may provide a physics opportunity for observing the violation of τ lepton number at the LHC that is complementary to $\tau \to \mu + \gamma$ decay. Likewise, $\chi_2 \to \chi + e^\pm \mu^\mp$ decay is also enhanced in the coannihilation region, providing a complement to $\mu \to e + \gamma$ decay.

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1 Introduction

Mixing between different neutrino flavours has now been amply confirmed by experiments on both atmospheric [1] and solar [2, 3] neutrinos. The distorted zenith-angle distributions observed by Super-Kamiokande provided a 'smoking gun' for atmospheric-neutrino oscillations, establishing that they are most likely due to near-maximal $\nu_\mu - \nu_\tau$ mixing. More recently, SNO has provided two 'smoking guns' for solar-neutrino oscillations, providing direct evidence for near-maximal $\nu_e \to \nu_{\mu,\tau}$ oscillations [4] through its measurements of the charged- and neutral-current scattering rates.

These observations lead one to expect the corresponding charged-lepton numbers to be violated at some level. However, the rates for such processes would be unobservably small if neutrino masses were generated by the seesaw mechanism [5] and there was no lower-energy physics beyond the Standard Model. However, the naturalness of the gauge hierarchy, grand unification of the gauge couplings and the relic density of supersymmetric dark matter all suggest that supersymmetry should appear at an energy scale $\lesssim 1$ TeV. This suggests that processes violating the different charged lepton numbers might be observable in low-energy experiments. Indeed, charged-lepton-number violating processes could occur at embarrassingly large rates if the soft supersymmetry-breaking masses of the squarks and sleptons were not universal. For this reason, it is often assumed that these masses are equal at the grand-unification scale, as in the constrained minimal supersymmetric extension of the Standard Model (CMSSM).

Even in this case, renormalization of the soft supersymmetry-breaking slepton masses would occur in the minimal supersymmetric version of the seesaw model for neutrino masses, thanks to the Dirac Yukawa couplings of the neutrinos [6]. These are active in the renormalization-group equations at scales between the GUT scale and the heavy singlet-neutrino mass scale, and are not expected to be diagonal in the same basis where the light leptons are flavour-diagonal. This scenario provides the minimal credible amount of charged-lepton-flavour violation: it could be enhanced by GUT interactions and/or non-universal slepton masses at the GUT scale.

Many signatures for charged-lepton-flavour violation have been considered in this scenario [7, 8, 9, 10, 11, 12], including $\mu \to e\gamma$ and related decays, $\tau \to \mu\gamma$ and $\tau \to e\gamma$ decays. Any or all of these may be favoured by the (near-)maximal mixing observed amongst the corresponding neutrino species. Other things being equal, one expects these decays to be relatively large when the soft supersymmetry-breaking masses $m_{1/2}$ and/or m_0 are relatively small, as has been borne out in specific model-dependent studies. Another possibility that has been considered is the decay $\chi_2 \to \chi + e^\pm \mu^\mp$ [13, 14], where χ is the lightest neutralino, assumed here to be the lightest supersymmetric particle (LSP), and χ_2 is the second-lightest neutralino. It has been argued that this decay might have a rate observable at the LHC for certain choices of the CMSSM parameters.

In this paper, we consider the alternative decay $\chi_2 \to \chi + \tau^\pm \mu^\mp$ [15]. This has certain theoretical advantages over the decay $\chi_2 \to \chi + e^\pm \mu^\mp$ considered previously, since the feedthrough into the charged-lepton sector may be enhanced by larger Dirac Yukawa couplings and/or lighter singlet-neutrino masses, as compared to the $\nu_\mu - \nu_e$ sector, if neutrino masses exhibit the expected hierarchical pattern, and $\nu_\tau - \nu_\mu$ mixing is also known to be essentially maximal. On the other hand, the decay $\chi_2 \to \chi + \tau^\pm \mu^\mp$ has a less distinctive experimental signature than $\chi_2 \to \chi + e^\pm \mu^\mp$. Both decays should be explored at the LHC and a possible linear e^+e^- collider, and which mode offers better prospects may depend on the neutrino-mass model and the experiment.

We find that the branching ratio for $\chi_2 \to \chi + \tau^\pm \mu^\mp$ decay is enhanced when $m_{\chi_2} > m_{\tilde{\tau}_1} > m_\chi$, where $\tilde{\tau}_1$ is the lighter stau slepton. This occurs in a wedge of the $(m_{1/2}, m_0)$ parameter plane in the CMSSM that is complementary to that explored by $\tau \to \mu\gamma$. The region of CMSSM parameter space where this enhancement occurs includes the region where $\chi - \tilde{\ell}$ coannihilation suppresses the relic density Ω_χ, keeping it within the range $0.1 < \Omega_\chi h^2 < 0.3$ preferred by astrophysics and cosmology, even if $m_{1/2}$ is comparatively large. The interest of this coannihilation region has been accentuated by the latest experimental constraints on the CMSSM, such as m_h and $b \to s\gamma$ decay, which disfavour low values of $m_{1/2}$. We show that the branching ratio for $\chi_2 \to \chi + \tau^\pm \mu^\mp$ decay may be a large fraction of that for the flavour-conserving decay $\chi_2 \to \chi + \mu^\pm \mu^\mp$. An analogous enhancement is expected for the flavour-violating decay $\chi_2 \to \chi + e^\pm \mu^\mp$ considered by other authors [13, 14], although the absolute branching ratio is expected to be smaller. Nevertheless, this decay may provide another way of probing lepton flavour violation in the coannihilation region.

2 Calculational Framework

We assume the minimal supersymmetric extension of the seesaw mechanism for generating neutrino masses, in which there are three heavy singlet-neutrino states N_i, and the leptonic sector of the superpotential is:

$$W = N_i^c (Y_\nu)_{ij} L_j H_2 - E_i^c (Y_e)_{ij} L_j H_1 + \frac{1}{2} N^c{}_i \mathcal{M}_{ij} N_j^c + \mu H_2 H_1 \,, \tag{1}$$

where Y_ν is the neutrino Dirac Yukawa coupling matrix, $\mathcal{M}_{ij}$ is the Majorana mass matrix for the N_i, the L_j and H_I are lepton and Higgs doublets, and the E_i^c are singlet charged-lepton supermultiplets. The superpotential of the effective low-energy theory, obtained after the decoupling of heavy neutrinos is [16]

$$W_{eff} = L_i H_2 \left(Y_\nu^T \left(\mathcal{M}^D \right)^{-1} Y_\nu \right)_{ij} L_j H_2 - E_i^c (Y_e)_{ij} L_j H_1. \tag{2}$$

In the basis where the charged leptons and the heavy neutrino mass matrices are diagonal,

$$\mathcal{M}_\nu = Y_\nu^T \left(\mathcal{M}^D \right)^{-1} Y_\nu v^2 \sin^2 \beta \tag{3}$$

where the $v = 174$ GeV and $\tan\beta = v_2/v_1$.

As mentioned above, we work in the context of the CMSSM, where the soft supersymmetry-breaking masses of the charged and neutral sleptons are assumed to be universal at the GUT scale, with a common value m_0. In the leading-logarithmic approximation, the non-universal renormalization of the soft supersymmetry-breaking scalar masses is by an amount

$$\left(\delta m_{\tilde{L}}^2\right)_{ij} \approx -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger Y_\nu)_{ij} \log \frac{M_{GUT}}{M_{N_i}}. \quad (4)$$

We note that, in this approach, non-universality in the soft supersymmetry-breaking left-slepton masses is much larger than that in right-slepton masses when the trilinear soft supersymmetry-breaking parameter $A_0 = 0$, as we assume here [1]. The pattern of charged-lepton-flavour violation induced by renormalization depends on the details of $(Y_\nu)_{ij}$.

In plausible mixing textures, the renormalization of the soft supersymmetry-breaking parameters at low energies can be understood approximately in terms of the dominant non-universality in the third-generation left-slepton mass:

$$m_{0_{LL}}^2 = \mathrm{diag}(m_0^2, m_0^2, x \times m_0^2), \quad (5)$$

where a typical value of the non-universality factor is $x \sim 0.9$. Correspondingly, we assume there is an off-diagonal $\tilde{\tau}_L - \tilde{\mu}_L$ mixing term in the soft mass-squared matrix:

$$\Delta m_{0_{LL}}^2 = (1-x) m_0^2 \frac{\sin(2\phi)}{2}, \quad (6)$$

where ϕ is the mixing angle between the second and third generation in the charged-lepton Yukawa matrix. For the type of non-universalities introduced in (5), this angle can be quite large without entering in conflict with the current bounds for $\tau \to \mu\gamma$, though in this case large mixing in the 2-3 sector must be combined with a small mixing angle between the first and second generation, due to the very restrictive bound in the $\mu \to e\gamma$ decay [17]. This mixing leads to lepton-flavour violation $\sim \sin^2(2\phi)$, as long as $\sin(2\phi)$ is not too large [2].

We give below numerical results for sample choices of the parameters (x, ϕ) that may be representative of the possibilities in specific models. We also show how the results vary as (x, ϕ) are varied.

In the following, we consider mixing between the left-handed τ- and μ-flavoured sleptons, but $\tilde{\tau} - \tilde{e}$ mixing might also be present, or even favoured in some models. In such cases, the results would be rather similar to those we present, simply with μ replaced by e in the L_τ-violating decay modes studied.

We consider the following flavour-violating and -conserving χ_2 decays:

$$\chi_2 \to \tilde{\ell}_i \ell_j \to \chi \ell_i^+ \ell_j^- \;,\; \chi_2 \to \tilde{\nu}_i \nu_j \to \chi \nu_i \bar{\nu}_j \quad (7)$$

$$\chi_2 \to \chi Z \to \chi \ell_i^+ \ell_i^- \;,\; \chi_2 \to \chi Z \to \chi \nu_i \bar{\nu}_i \quad (8)$$

$$\chi_2 \to \chi h \to \chi \ell_i^+ \ell_i^- \quad (9)$$

[1] In the case $A_0 \neq 0$, this parameter would also be renormalized analogously to $m_{\tilde{L}}^2$ (4).

[2] We have checked that this parametrization is generally a very good approximation for $\tau \to \mu\gamma$ decay, as well as for $\chi_2 \to \chi \tau^\pm \mu^\mp$.

The first two decays are the only ones in which flavour violation may be expected, and it would of course be unobservable in $\chi_2 \to \chi\nu\bar{\nu}$ decay. The intermediate sleptons are produced on-shell if they are lighter than the χ_2, while the Z and the h are always on-shell for the range of parameters that are of interest to us. Slepton exchanges and h decays may give significantly different rates for the various flavor-conserving decays $\chi_2 \to \chi\ell_i^+\ell_i^-$, suppressing the cases $\ell = \mu, e$ relative to the case $\ell = \tau$, an effect we see in subsequent plots.

Our calculations are similar to [14], except that we also include the Yukawa interactions, which are relevant for decays into τ leptons at large $\tan\beta$. Furthermore, we include finite-width effects in our calculations of Z^0 and slepton exchanges. The neutralino and slepton widths, which arise mainly from two-body decays, were calculated using the `ISAJET` package [18], and a check with `calcHEP` [19] found good agreement. For the decays $\chi_2 \to \chi + \mu^\pm\mu^\mp$, we found good agreement between our code and `calcHEP`, once we incorporated the `VEGAS` adaptive Monte Carlo programme for the momentum integrals in three-body decays. The results from `VEGAS` differ by several orders of magnitude from those obtained using `ISAJET` for $\chi_2 \to \chi + \mu^\pm\mu^\mp$ decay close to the $\tilde{\tau}$ resonances.

For the decay $\chi_2 \to \chi + \tau^\pm\tau^\mp$ the channels mediated by Higgses are important in the areas where $m_{\tilde{\chi}_2} - m_{\tilde{\chi}} < m_{\tilde{\tau}_1}$. The widths have been obtained using `calcHEP`, after adding to the package the one-loop QCD corrected Higgs widths from `HDECAY` [20]. For flavour-violating decays, our calculation agrees with `calcHEP`, once we modify the MSSM Lagrangian included in this package to allow flavour-mixing among $\tilde{\tau}_1$, $\tilde{\tau}_2$ and $\tilde{\mu}_L$.

3 Numerical Results

The solid (black) lines in Fig. 1 denote the total χ_2 decay width, as well as the partial widths for the flavour-violating and flavour-conserving decays, for the particular cases (a) $\tan\beta = 10, \mu > 0, m_{1/2} = 600$ GeV and (b) $\tan\beta = 40, \mu > 0, m_{1/2} = 600$ GeV. In both plots, we make the representative choices $x = 0.9$ and $\phi = \pi/6$. In Fig. 1(a), we see a first edge in the flavour-violating width $\Gamma(\chi_2 \to \chi + \tau^\pm\mu^\mp)$ at $m_0 \sim 280$ GeV, which is less pronounced in $\Gamma(\chi_2 \to \chi + \mu^\pm\mu^\mp)$ and almost absent in $\Gamma(\chi_2 \to \chi + \tau^\pm\tau^\mp)$. This reflects the dominant role of $\tilde{\tau}_2 \sim \tilde{\tau}_L$ exchange in the flavour-violating case. We also note a second edge when $m_{\tilde{\tau}_1} = m_{\chi_2}$ at $m_0 \sim 430$ GeV, which is visible in all the flavour-violating and flavour-conserving decays to χ and leptons. The differences between $\Gamma(\chi_2 \to \chi + \tau^\pm\tau^\mp)$ and $\Gamma(\chi_2 \to \chi + \mu^\pm\mu^\mp)$ are due, at smaller m_0, to the different masses and couplings of the $\tilde{\tau}_{1,2}$ and $\tilde{\mu}_{L,R}$ being exchanged, whilst the differences at larger m_0 are due to $\chi_2 \to \chi + h$ decay.

We see in panel (b) of Fig. 1 features at $m_0 = 300$ GeV, 420 GeV and 580 GeV, corresponding to $m_{\chi_2} = m_{\tilde{\tau}_1}, m_{\tilde{\mu}_R}$ and $m_{\tilde{\tau}_2}$, respectively. The lowest and highest features show up in $\Gamma(\chi_2 \to \chi + \tau^\pm\mu^\mp)$ and $\Gamma(\chi_2 \to \chi + \tau^\pm\tau^\mp)$ and the middle feature in $\Gamma(\chi_2 \to \chi + \mu^\pm\mu^\mp)$, as one would expect. We note that $\Gamma(\chi_2 \to \chi + \tau^\pm\tau^\mp)$ may become relatively large for 300 GeV $< m_0 <$ 580 GeV, becoming the dominant χ_2 decay mode.

The analogous plot for $\tan\beta = 10, \mu < 0, m_0 = 600$ GeV is quite similar to panel (a) of Fig. 1,

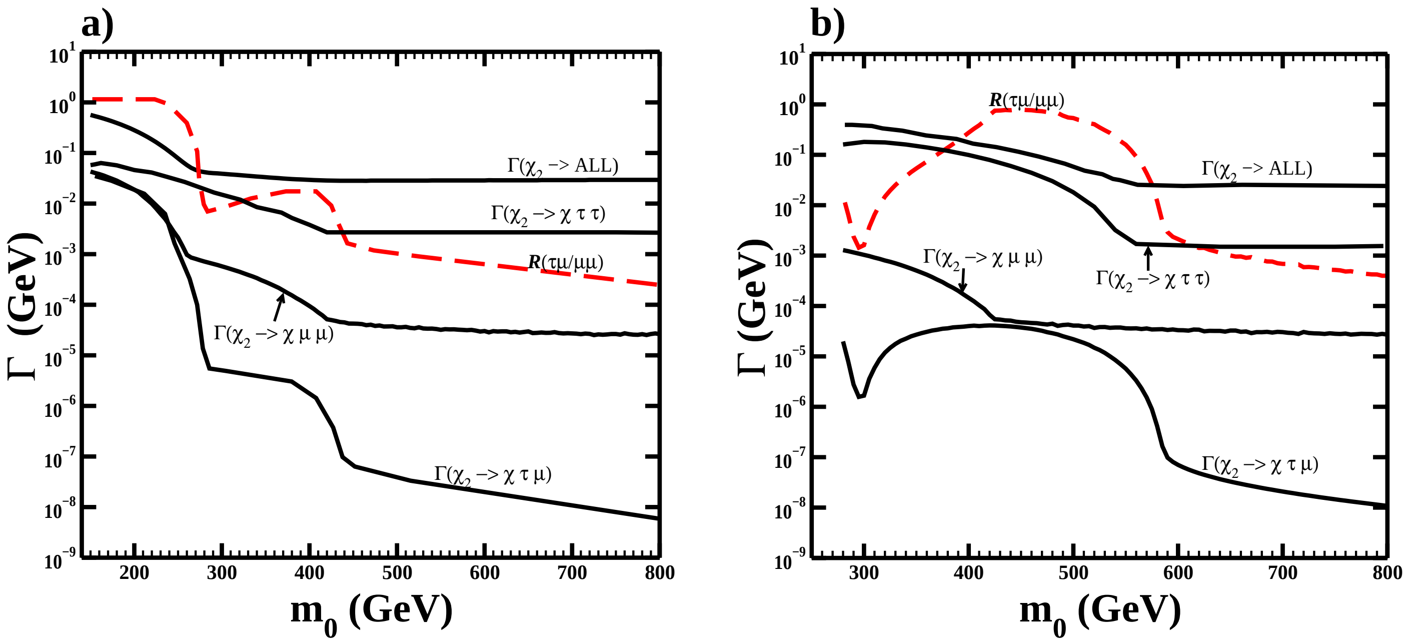

Figure 1: *Comparison of flavour-changing and -conserving χ_2 decay modes as functions of m_0 for (a) $\tan\beta = 10, \mu > 0, m_{1/2} = 600$ GeV and (b) $\tan\beta = 40, \mu > 0, m_{1/2} = 600$ GeV. We assume for illustration a non-universality factor $x = 0.9$ and a mixing angle $\phi = \frac{\pi}{6}$.*

whilst that for $\tan\beta = 30, \mu > 0, m_0 = 600$ GeV is intermediate between panels (a) and (b). Hence these are representative of the possibilities for flavour-violating χ_2 decays.

The ratio of branching ratios $R(\tau\mu/\mu\mu) \equiv \Gamma(\chi_2 \to \chi + \tau^\pm\mu^\mp)/\Gamma(\chi_2 \to \chi + \mu^\pm\mu^\mp)$ is shown as (red) dashed lines in Fig. 1(a,b). In panel (a), the quantity $R(\tau\mu/\mu\mu)$ also exhibits clearly the first edge at $m_0 \sim 280$ GeV. The second edge at $m_0 \sim 430$ GeV also appears strongly, reflecting the facts that flavour violation appears mainly in the left-slepton sector, and that the $\tilde{\tau}_2$ is mainly $\tilde{\tau}_L$. We see that, for our choices of x and ϕ, $R(\tau\mu/\mu\mu)$ may be of order unity for $m_0 < 270$ GeV, and $\sim 10^{-2}$ for $m_0 < 430$ GeV. Only at larger m_0, where the $\chi_2 \to \chi + \tilde{\tau}$ decay becomes kinematically inaccessible, does $R(\chi_2 \to \chi + \tau^\pm\mu^\mp)$ drop below 10^{-3}. In panel (b) of Fig. 1, we see that $R(\tau\mu/\mu\mu) \sim 0.1$ to unity for 350 GeV $< m_0 <$ 580 GeV, dropping below 10^{-3} only for $m_0 > 600$ GeV.

In Fig. 2 we display contours of the ratio $R(\tau\mu/\mu\mu)$ of the branching ratios for the flavour-violating decay $\chi_2 \to \chi + \tau^\pm\mu^\mp$ and the flavour-conserving decay $\chi_2 \to \chi + \mu^\pm\mu^\mp$ in the x, ϕ plane, for the particular choices $\tan\beta = 30$, $m_{1/2} = 400$ GeV and $m_0 = 200$ GeV of the CMSSM parameters. We see that the previous choice $x = 0.9, \phi = \pi/6$ is not particularly exceptional. To quite a good approximation, $R(\tau\mu/\mu\mu)$ scales by the square of the factor $(1 - x)\sin(2\phi)$ shown in (6). This makes it relatively easy to reinterpret our illustrative results in the context of any specific flavour texture model that makes definite predictions for x and ϕ.

We display in Fig. 3 contours of the branching ratio for the flavour-violating decay $\tau \to \mu\gamma$ (thin blue lines) and the flavour-violating ratio $R(\tau\mu/\mu\mu)$ (thick black lines) in the $(m_{1/2}, m_0)$

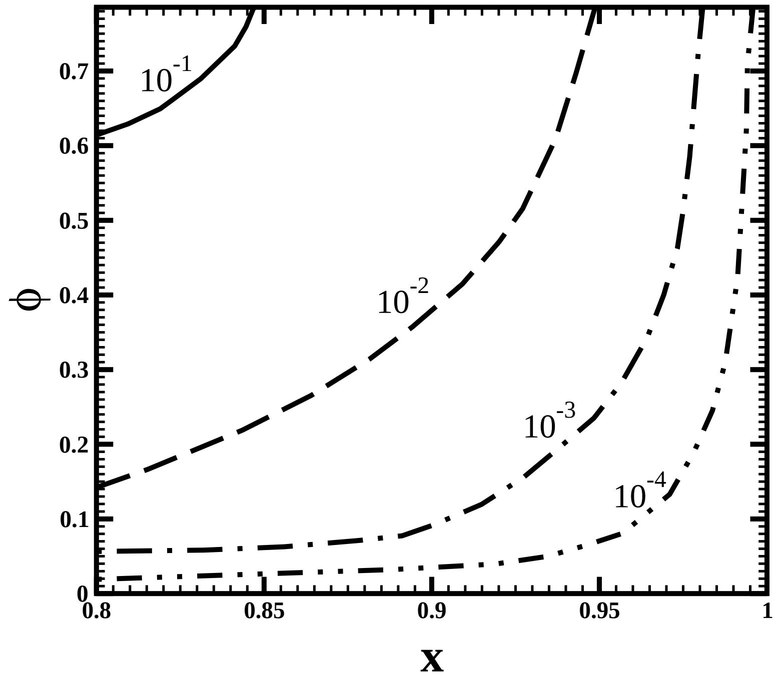

Figure 2: *Contours of the ratio* $R(\tau\mu/\mu\mu)$ *of the branching ratios for the flavour-violating and flavour-conserving decays in the* x*,* ϕ *plane, for* $\tan\beta = 30$*,* $\mu > 0$*,* $m_{1/2} = 400$ *GeV and* $m_0 = 200$ *GeV.*

planes for different choices of $\tan\beta$ and the sign of μ. In each case, we have again made the representative choices $x = 0.9$ and $\phi = \pi/6$.

The contours where $R(\tau\mu/\mu\mu) = 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}$ and 10^{-5} are shown as thick black solid, dashed, dot-dashed, dot-dot-dashed and dot-dashed-dashed lines. We also display contours of $BR(\tau \to \mu\gamma) = 10^{-6}, 10^{-7}, 10^{-8}, 10^{-9}$ as thin blue solid, dashed, dot-dashed and dot-dot-dashed lines. We see that large $\tilde{\mu} - \tilde{\tau}$ (or $\tilde{e} - \tilde{\tau}$) mixing is not excluded by the present upper limits on $BR(\tau \to \mu(e)\gamma)$, which are both just above 10^{-6}. We also recall that the χ_2 is observable at the LHC in cascade decays of heavier sparticles [21] for many choices of CMSSM parameters [22]. We see immediately from Fig. 3 that the regions where $\chi_2 \to \chi + \tau^{\pm}\mu^{\mp}$ may be observable at the LHC (or a future linear e^+e^- collider?), perhaps where $R(\tau\mu/\mu\mu) \gtrsim 10^{-2}$, are largely complementary to those where $\tau \to \mu\gamma$ may be observable at the LHC or a B factory, perhaps where $BR(\tau \to \mu\gamma) \gtrsim 10^{-8}$.

The darker (green) shaded regions in the bottom right corners of the panels in Fig. 3 are excluded because there the LSP is the lighter stau: $\tilde{\tau}_1$. Such a charged LSP would be in conflict with basic astrophysics. The lighter (grey) shaded regions are those in which the cosmological relic density of the neutralino LSP χ is in the range preferred by cosmology: $0.1 < \Omega_\chi h^2 < 0.3$ as calculated using `MICROMEGAS` [23], and in agreement with our previous calculations [24, 25, 26], where $h \sim 0.7$ is the current Hubble expansion rate in units of 100 km/s/Mpc. In each panel,

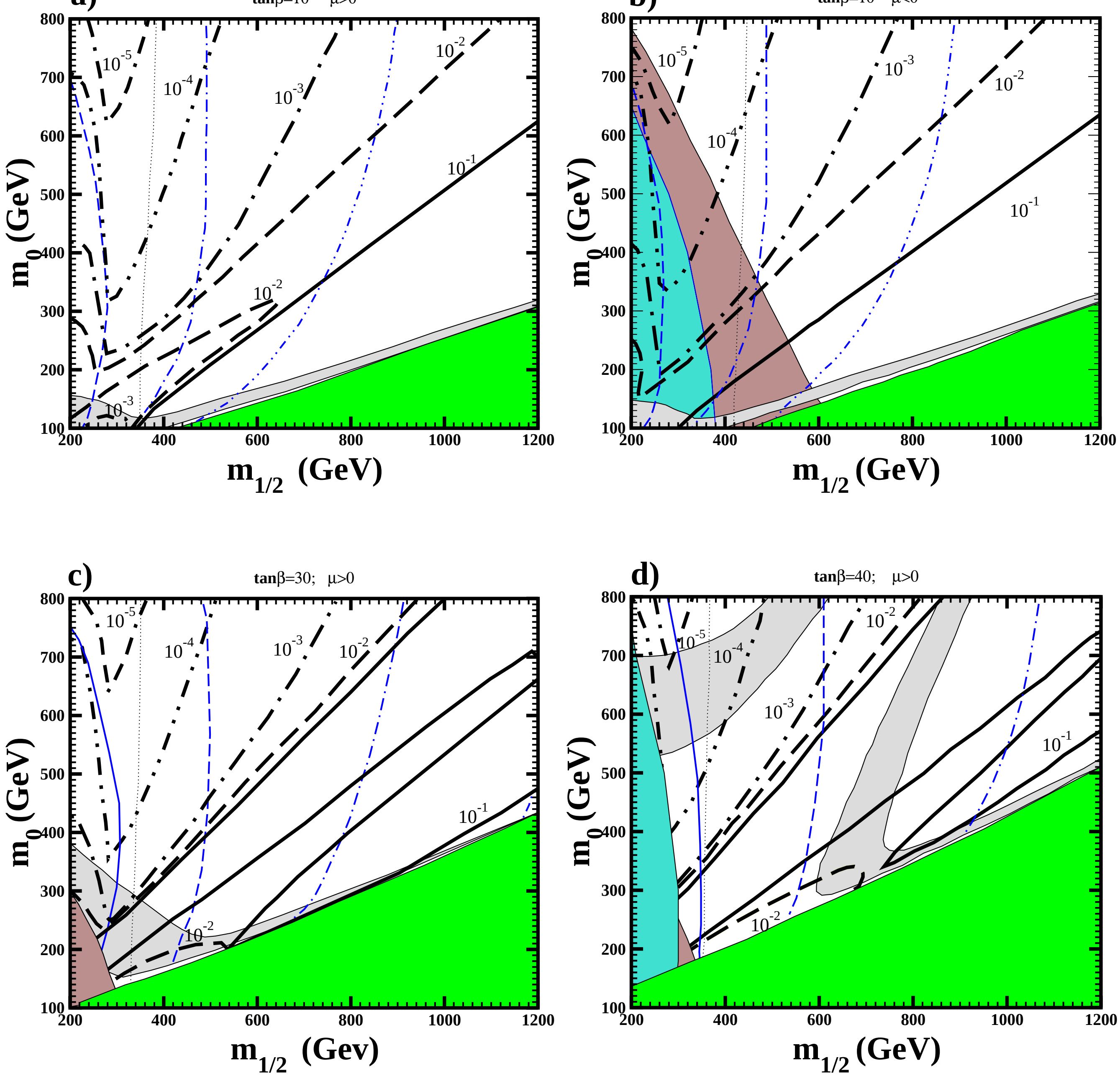

Figure 3: *Contours of* $R(\tau\mu/\mu\mu)$ *(thick black lines) and* $BR(\tau\to\mu\gamma)$ *(thin blue lines) in the* $(m_{1/2}, m_0)$ *planes for (a)* $\tan\beta = 10, \mu > 0$*, b)* $\tan\beta = 10, \mu < 0$*, (c)* $\tan\beta = 30, \mu > 0$*, (d)* $\tan\beta = 40, \mu > 0$*, for* $x = 0.9$ *and* $\phi = \pi/6$*. The regions disallowed at low* $m_{1/2}$ *and* m_0 *by the E821 measurement of* a_μ *at the 2-*σ *level [28] are dark (brown) shaded, the dark (green) shaded regions at large* $m_{1/2}$ *and low* m_0 *are excluded because the LSP is the charged* $\tilde{\tau}_1$*, the light grey shaded regions are those with* $0.1 < \Omega_\chi h^2 < 0.3$ *that are preferred by cosmology (calculated using* `MICROMEGAS` *[23]), and the medium (blue) shaded regions are excluded by* $b\to s\gamma$ *[25] and the dotted line is* $m_h = 114.1$ *GeV (calculated using* `FeynHiggs` *[27]).*

there is a region at small $m_{1/2}$ that is disfavoured by laboratory experiments. The regions at small $m_{1/2}$ excluded by the $b \to s\gamma$ decay rate are medium (blue) shaded, the regions disfavoured by $g_\mu - 2$ at small $m_{1/2}$ and m_0 are darker (brown) shaded, and the (dotted) line is where $m_h = 114.1$ GeV as calculated using `FeynHiggs` [27]. Together, these constraints favour the coannihilation strip where $m_{\tilde{\tau}_1} \sim m_\chi$ in all the panels, and the channels at large $m_{1/2}$ and m_0 in panel (d) where direct-channel $\chi\chi \to A, H$ annihilation is relatively rapid.

In panel (a), for $\tan\beta = 10, \mu > 0$, the LEP search for the Higgs boson disfavours $m_{1/2} \lesssim 360$ GeV. In panel (b), for $\tan\beta = 10, \mu < 0$, the observed rate for $b \to s\gamma$ decay excludes $m_{1/2} \lesssim 300$ GeV, the LEP search for the Higgs boson disfavours $m_{1/2} \lesssim 430$ GeV, and $g_\mu - 2$ excludes a triangle extending up to $m_{1/2} \sim 600$ GeV. In panel (c) for $\tan\beta = 30, \mu > 0$, the LEP Higgs limit disfavours $m_{1/2} \lesssim 340$ GeV, and the other constraints are weaker. A similar pattern is repeated in panel (d), for $\tan\beta = 40, \mu > 0$.

In cases (a, b, c), the only region of the $(m_{1/2}, m_0)$ plane that survives these constraints is the strip parallel to the boundary of the disallowed region, where $m_\chi/m_{\tilde{\tau}_1} \sim 1.1 - 1.2$, and coannihilation keeps $\Omega_\chi h^2$ within the range allowed by astrophysics and cosmology. This is precisely the region where $R(\tau\mu/\mu\mu)$ is maximized, and hence the chances of observing the decay may be maximized. We do note, however, that $R(\tau\mu/\mu\mu)$ has a tendency to fall as $m_{1/2}$ increases along this strip, which is apparent in panels (c) and (d). We further note in panel (d) that $R(\tau\mu/\mu\mu) \gtrsim 10^{-2}$ also on the right side of the rapid $\chi\chi \to A, H$ annihilation channel, but may be significantly lower on the left side of this channel.

4 Conclusions

We have demonstrated in this paper that the decay $\chi_2 \to \chi\tau^\pm\mu^\mp$ provides an opportunity to look for τ flavour violation at the LHC that is largely complementary to the search for $\tau \to \mu\gamma$. Essentially all the above analysis would apply also if the slepton mixing texture favours $\chi_2 \to \chi\tau^\pm e^\mp$ and $\tau \to e\gamma$ over $\chi_2 \to \chi\tau^\pm\mu^\mp$ and $\tau \to \mu\gamma$: it is even possible that both $\chi_2 \to \chi\tau^\pm\mu^\mp/e^\mp$ decays may be observable at the LHC.

We have phrased this analysis as model-independently as possible. Specific models will predict values for the mixing parameters x and ϕ, and the scaling of our results with these parameters is quite simple. We would expect the relevant mixing parameters to be much smaller in the case of $\chi_2 \to \chi\mu^\pm e^\mp$ decay, but the corresponding $R(\mu e/\mu\mu)$ would be enhanced in a similar region of the CMSSM parameter space.

We note that the $\mu^\mp$ produced in $\chi_2 \to \chi\tau^\pm\mu^\mp$ decay are likely to have significant transverse momentum, and any event in which the χ_2 is produced is likely to have considerable missing transverse energy and jet activity associated with the decays of other sparticles. Therefore, we do not expect such events to be suppressed badly at the trigger level at the LHC, though it might be more difficult to see $\chi_2 \to \chi\tau^\pm e^\mp$ decays. However, a detailed simulation goes beyond the scope of this paper. There should be even less problem seeing $\chi_2 \to \chi + \tau^\pm\mu/e^\mp$ decays at a linear e^+e^- collider. We therefore urge more detailed simulations of this decay mode for this machine, as well as for the LHC.

References

[1] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **81** (1998) 1562.

[2] Y. Fukuda *et al.* [Super-Kamiokande Collaboration], Phys. Rev. Lett. **82** (1999) 1810; Phys. Rev. Lett. **82** (1999) 2430.

[3] Q. R. Ahmad *et al.* [SNO Collaboration], Phys. Rev. Lett. **87** (2001) 071301.

[4] V. Barger, D. Marfatia and K. Whisnant, hep-ph/0106207; G. L. Fogli, E. Lisi, D. Montanino and A. Palazzo, hep-ph/0106247; J. N. Bahcall, M. C. Conzalez-Garcia and C. Pena-Garay, hep-ph/0106258; A. Bandyopadhyay, S. Choubey, S. Goswami and K. Kar, hep-ph/0106264.

[5] M. Gell-Mann, P. Ramond and R. Slansky, Proceedings of the Supergravity Stony Brook Workshop, New York, 1979, eds. P. Van Nieuwenhuizen and D. Freedman (North-Holland, Amsterdam); T. Yanagida, Proceedings of the Workshop on Unified Theories and Baryon Number in the Universe, Tsukuba, Japan 1979 (edited by A. Sawada and A. Sugamoto, KEK Report No. 79-18, Tsukuba); R. Mohapatra and G. Senjanovic, Phys. Rev. Lett. **44** (1980) 912.

[6] F. Borzumati and A. Masiero, Phys. Rev. Lett. **57** (1986) 961.

[7] Y. Kuno and Y. Okada, Rev. Mod. Phys. **73** (2001) 151.

[8] J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Rev. D **53** (1996) 2442.

[9] J. A. Casas and A. Ibarra, hep-ph/0103065.

[10] J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Rev. D **53** (1996) 2442; J. Hisano, D. Nomura and T. Yanagida, Phys. Lett. B **437** (1998) 351; J. Hisano and D. Nomura, Phys. Rev. D **59** (1999) 116005; W. Buchmüller, D. Delepine and F. Vissani, Phys. Lett. B **459** (1999) 171; M. E. Gómez, G. K. Leontaris, S. Lola and J. D. Vergados, Phys. Rev. D **59** (1999) 116009; J. R. Ellis, M. E. Gómez, G. K. Leontaris, S. Lola and D. V. Nanopoulos, Eur. Phys. J. C **14** (2000) 319; W. Buchmüller, D. Delepine and L. T. Handoko, Nucl. Phys. B **576** (2000) 445; J. L. Feng, Y. Nir and Y. Shadmi, Phys. Rev. D **61** (2000) 113005; J. Sato and K. Tobe, Phys. Rev. D **63** (2001) 116010; J. Hisano and K. Tobe, Phys. Lett. B **510** (2001) 197; S. Baek, T. Goto, Y. Okada and K. Okumura, hep-ph/0104146; S. Lavignac, I. Masina and C.A. Savoy, hep-ph/0106245.

[11] D. Carvalho, J. Ellis, M. Gómez and S. Lola, Phys. Lett. B **515** (2001) 323;

[12] See, for example, J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, in [8], and J. Ellis, M. Gómez, G. Leontaris, S. Lola and D. Nanopoulos, in [10]; T. Blazek and S. F. King, hep-ph/0105005.

[13] N. Arkani-Hamed, H. Cheng, J. L. Feng and L. J. Hall, Phys. Rev. Lett. **77** (1996) 1937; Nucl. Phys. B **505** (1997) 3.

[14] J. Hisano, M. M. Nojiri, Y. Shimizu and M. Tanaka, Phys. Rev. D **60** (1999) 055008.

[15] I. Hinchliffe and F. E. Paige, Phys. Rev. D **63** (2001) 115006.

[16] For the early works see, e.g., J. Schechter and J. W. Valle, Phys. Rev. D **22** (1980) 2227 and Phys. Rev. D **23** (1981) 1666.

[17] D.F. Carvalho, M.E. Gómez and S. Khalil, JHEP **0107** (2001) 001; J.Ellis, J.Hisano, M.Raidal and Y.Shimizu, hep-ph/0206110.

[18] H. Baer, F. Paige, S. Protopopescu and X. Tata, proceedings of the workshop on *Physics and Current Accelerators and Supercolliders*, ed. J. Hewett, A. White and D. Zeppenfeld (Argonne National Laboratory, 1993).

[19] Complete information about the package can be found at `http://www.ifh.de/~pukhov/calchep.html`.

[20] A. Djouadi, J. Kalinowski and M. Spira, Comput. Phys. Commun., **108** (1998) 56.

[21] I. Hinchliffe, F. E. Paige, M. D. Shapiro, J. Soderqvist and W. Yao, Phys. Rev. D **55** (1997) 5520 [arXiv:hep-ph/9610544].

[22] M. Battaglia *et al.*, Eur. Phys. J. C **22** (2001) 535 [arXiv:hep-ph/0106204].

[23] G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, arXiv:hep-ph/0112278.

[24] J. R. Ellis, T. Falk, K. A. Olive and M. Srednicki, Astropart. Phys. **13** (2000) 181 and **15** (2001) 413.

[25] J. R. Ellis, T. Falk, G. Ganis, K. A. Olive and M. Srednicki, Phys. Lett. B **510** (2001) 236; J. R. Ellis, K. A. Olive and Y. Santoso, arXiv:hep-ph/0202110.

[26] M. E. Gómez, G. Lazarides and C. Pallis, Phys. Lett. B **487** (2000) 313, Phys. Rev. D **61** (2000) 123512 and hep-ph/0203131.

[27] S. Heinemeyer, W. Hollik and G. Weiglein, Eur. Phys. J. C **9** (1999) 343, Comput. Phys. Commun. **124** (2000) 76 and hep-ph/0002213.

[28] H. N. Brown *et al.*, BNL E821 Collaboration, Phys. Rev. Lett. **86** (2001) 2227.