arXiv:hep-ph/0105137v1 15 May 2001

Signals of R-parity Violating Supersymmetry at a Muon Storage Ring

Anindya Datta[1], Raj Gandhi[2], Biswarup Mukhopadhyaya[3]
Harish-Chandra Research Institute, Chhatnag Road, Jhusi, Allahabad - 211019.

* Poonam Mehta[4]
Department of Physics and Astrophysics, University of Delhi, Delhi - 110007.

Abstract

Neutrino oscillation signals at muon storage rings (MSR) can be mimicked by supersymmetric (SUSY) interactions in an R-parity violating scenario. We have investigated the τ-appearance signals for both long-baseline and near-site experiments, and concluded that the latter is of great use in distinguishing between oscillation and SUSY effects. On the other hand, SUSY can cause a manifold increase in the event rate for wrong-sign muons at a long-baseline setting, thereby providing us with signatures of new physics.

The increasingly strong empirical indications of neutrino oscillations from the observed solar and atmospheric neutrino deficits have emphasised the need for their independent confirmation in accelerator and reactor experiments. One of the actively discussed possibilities in this connection is the proposal of a neutrino factory based on a MSR [1] which can act as an intense source of collimated neutrinos impinging upon a fixed target. A μ^- (μ^+) beam can thus produce both ν_μ ($\bar{\nu}_\mu$) and $\bar{\nu}_e$ (ν_e), thereby providing an opportunity to test both ν_e-ν_μ and ν_μ-ν_τ oscillations which are the favoured solutions for the two anomalies mentioned above. At a MSR with a μ^- beam, one expects a certain fraction of the ν_μ's ($\bar{\nu}_e$'s) to oscillate into ν_τ ($\bar{\nu}_\mu$), depending on the energy and the baseline length. Interaction of these ν_τ's ($\bar{\nu}_\mu$'s) with an *isonucleon* target will produce $\tau^-(\mu^+)$-leptons, the detection of which may, in the simplest case, be interpreted as a signature of ν-oscillation at a MSR.

However, the predicted rates of τ-appearance or wrong-sign muons in a given experimental setting can be significantly affected by non-standard interactions, i.e. to say that some non-oscillation physics can intervene and mimic the oscillation phenomena. For example, it is possible for *unoscillated* ν_μ*'s* to scatter into τ's in an R-parity violating SUSY framework (*with* $R = (-1)^{(3B+L+2S)}$), by virtue of lepton-number violating trilinear couplings [2]. Also, such couplings can produce $\bar{\nu}_\mu$'s from μ^--decay and thus give rise to μ^+'s in the detector even in the absence of oscillation. It is important to know the effects of such interactions for two reasons : *(i)* to look for *enhancement* in τ and wrong-sign muon event rates and thus to *uncover* new physics effects, and *(ii)* to see *to what extent* the signals supposedly coming from oscillation are faked by such new physics. In this paper, we have shown that one can answer both questions by combining long-baseline experiments with those in which one places the neutrino detectors

[1]E-mail: anindya@mri.ernet.in
[2]E-mail: raj@mri.ernet.in
[3]E-mail: biswarup@mri.ernet.in
[4]E-mail: pmehta@physics.du.ac.in, delivered talk at XIV DAE Symposium on HEP, 18 - 22 December 2000.

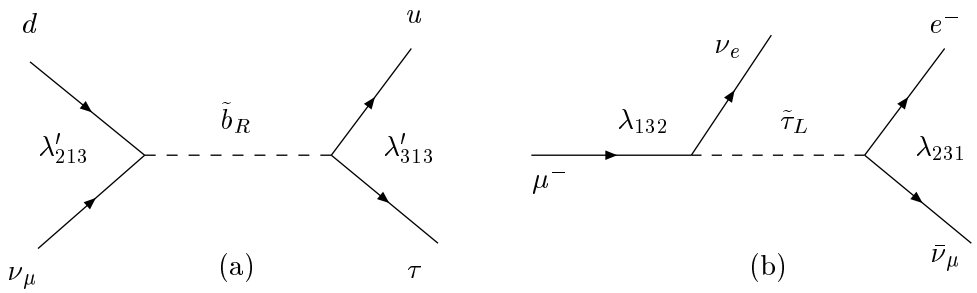

Figure 1: *Feynman diagrams for processes producing (a) a τ or (b) a wrong sign muon in R-parity violating supersymmetry.*

at a short distance from the storage ring, where the oscillation probability gets suppressed by the baseline length.

Let us first consider τ-appearance through oscillation. For a muon-neutrino with energy E_ν (in GeV) traversing a distance L (in km), the probability of oscillation into a tau-neutrino is given by

$$\mathcal{P}_{\nu_{\mu,e}\to\nu_\tau} = \sin^2 2\theta \ \sin^2\left[1.27\,\Delta m^2\,\frac{L}{E_\nu}\right] \tag{1}$$

where Δm^2 is the mass-squared difference between the corresponding physical states in eV^2, and θ, the mixing angle between flavours.

In an R-parity violating SUSY scenario [2] with broken lepton number, the trilinear terms in the superpotential (suppressing colour and $SU(2)$ indices) leads to interactions of the form

$$\begin{aligned}\mathcal{L} \;=\; & \lambda'_{ijk}\,[\,\tilde{d}^j_L\,\bar{d}^k_R\nu^i_L + (\tilde{d}^k_R)^*(\bar{\nu}^i_L)^c d^j_L + \tilde{\nu}^i_L\bar{d}^k_R d^j_L \\ & \quad - \tilde{e}^i_L\bar{d}^k_R u^j_L - \tilde{u}^j_L\,\bar{d}^k_R e^i_L - (\tilde{d}^k_R)^*(\bar{e}^i_L)^c u^j_L] + h.c. \\ & +\lambda_{ijk}\,[\,\tilde{e}^j_L\,\bar{e}^k_R\nu^i_L + (\tilde{e}^k_R)^*(\bar{\nu}^i_L)^c e^j_L + \tilde{\nu}^i_L\bar{e}^k_R e^j_L - (i\leftrightarrow j)] + h.c\end{aligned} \tag{2}$$

where, i,j and k are the generation indices . At a neutrino factory, these interactions can affect the τ or wrong sign μ event rates in the following ways :

1. $\nu_\mu N \longrightarrow \tau^- X$ via λ'-type interactions where ν_μ is produced by the standard muon decay.
2. $\bar{\nu}_\mu N \longrightarrow \mu^+ X$ via standard charged current process where $\bar{\nu}_\mu$ is produced via λ-type interactions in the muon decay.
3. $\nu_\tau N \longrightarrow \tau^- X$via standard charged current process where ν_τ is produced via λ-type interactions in the muon decay.
4. $\bar{\nu}_e N \longrightarrow \mu^+ X$via λ'-type interactions where $\bar{\nu}_e$ is produced by the standard muon decay.

Here we present results for cases 1 and 2 above (see figure 1). The results for cases 3 and 4 are also qualitatively similar.

The standard model charged current cross-section for $\nu_\tau N \longrightarrow \tau^- X$ is known [3]. Neglecting the left-right mixing in the squark sector , we get the following Fierz-transformed SUSY

amplitudes for the most favourable quark-level processes ($\nu_\mu d \longrightarrow \tau^- u$ and $\nu_\mu \bar{u} \longrightarrow \tau^- \bar{d}$):

$$\begin{aligned} \mathcal{M}_{SUSY}(\nu_\mu\ d \longrightarrow \tau^-\ u) &= \frac{\lambda'_{213}\lambda'_{313}}{2(\hat{s} - m^2_{\tilde{b}_R})}\,[\bar{u}_\tau \gamma_\mu P_L u_{\nu_\mu}]\,[\bar{u}_u \gamma^\mu P_L u_d] \\ \mathcal{M}_{SUSY}(\nu_\mu\ \bar{u} \longrightarrow \tau^-\ \bar{d}) &= \frac{\lambda'_{213}\lambda'_{313}}{2(\hat{t} - m^2_{\tilde{b}_R})}\,[\bar{u}_\tau \gamma_\mu P_L u_{\nu_\mu}]\,[\bar{v}_u \gamma^\mu P_L v_d] \end{aligned} \tag{3}$$

where $m_{\tilde{b}}$ is the b-squark mass and the product of two λ' couplings is taken to be real . This tells us that the R-parity violating contributions can be included, for $s << m^2_{\tilde{b}}$, on making the replacement $g^2/m^2_W \rightarrow (g^2/m^2_W + (\lambda'_{213}\lambda'_{313})/m^2_{\tilde{b}})$ in the standard expression for the charged current cross-section. Although there are phenomenological bounds [4] on the L-violating couplings, λ'_{213} and λ'_{313}, no conclusive limit exists for the product $(\lambda'_{213}\lambda'_{313})$, allowing it to be treated as a *free parameter when it comes to looking for experimental signals.*

From the plot of τ-event rates versus the baseline length for a 50 GeV muon beam, we found that for baselines of length $\geq$ 200 km, R-parity effects make a serious difference only when the couplings are close to their perturbative limits, while for shorter baselines ($\simeq$ 100 km), the R-parity violating effects are competitive even with values are on the order of the stand-alone bounds. In figure 2(a) we've shown some plots of τ-event rates (using CTEQ4LQ parton distributions) with a 1 kT, 2500 cm^2 detector placed at a distance of 40 m from the storage ring. The standard model contribution to the τ-production rates has been calculated assuming an oscillation probability corresponding to $\Delta m^2_{23} \simeq 5.0 \times 10^{-3}\ eV^2$ and $\sin^2\theta_{23} = 1$, which is approximately the central region of the solution space for the atmospheric ν_μ deficit. λ'-type couplings are found to *enhance* the number of τ-events to a level considerably higher than what the standard model predicts . The conclusion, therefore, is that *even when the couplings are well within the bounds for the stand-alone situation*, near-site effects arising from them lead to overwhelmingly large τ-production, while for long-baseline experiments, contamination of the oscillation signals through R-violating interactions is appreciable when one goes beyond the limits for the stand-alone situation .

Next, we consider wrong-sign muons produced due to R-parity violating effects in *muon decays*, see figure 1(b). The Mikhyev-Smirnov-Wolfenstein (MSW) solution to the solar neutrino problem with matter-enhanced ν_e-ν_μ oscillation requires a mass-splitting of $\simeq 10^{-5}\ eV^2$ between the mass eigenstates. It has been found earlier that with a muon beam energy of upto 50 GeV, and with standard charged current interactions, one can hardly expect to see any events given this kind of mass-splitting, for any realistic baseline length. The situation is even worse for the vacuum oscillation solution which requires $\Delta m^2 \simeq 10^{-10}\ eV^2$. Thus a *sizable* event rate for wrong-sign muons at a long-baseline experiment should be interpreted as a signal of some new effect, unless ν_e-ν_μ is *not* the solution of the solar neutrino puzzle.

In figure 2 (b) we've plotted the event rates for a typical ICANOE-type detector as functions of the muon beam energy, for a baseline of length 250kms using different values of the product $\lambda_{231}\lambda_{132}$, including those considerably smaller than the most stringent phenomenological limits. Even with conservative choices of the interaction strengths, a clear prediction of ten to several hundred events can be observed for $E_\mu \simeq 50\ GeV$ in the SUSY case, while no events are expected so long as masses and mixing in the ν_μ-ν_e sector offer a solution to the solar deficit.

In conclusion, we have investigated the effects of the R-parity violating trilinear couplings on signals of ν-oscillations at a MSR. We have found that, while new couplings have to be on the higher side to show a detectable enhancement in the τ-appearance rate with long baselines, even tiny R-violating couplings can lead to very large no. of τ's at a near-site detector setting, much

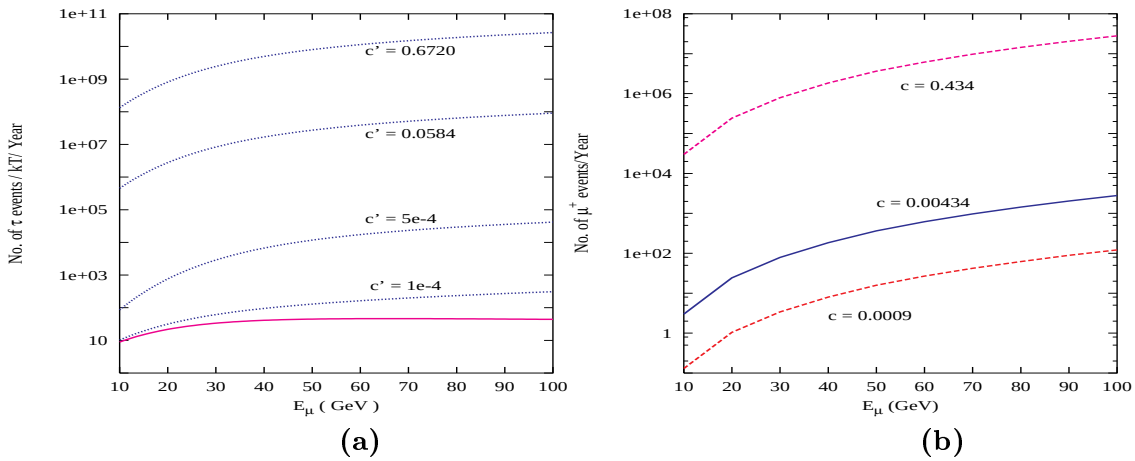

Figure 2: (a) *The τ-event rate as function of the muon beam energy for a near-site detector taking $N_\mu = 10^{20}$ per year and average τ detection efficiency = 30%. The solid line shows the contribution from $\nu_\mu - \nu_\tau$ oscillation, using SK parameters (see text) , while the SUSY contributions are included to the dashed lines, using different values of c' ($\equiv \lambda'_{213}\lambda'_{313}$) and $m_{\tilde{b}} = 300$ GeV.* (b) *The event rate for wrong-sign muons as a function of muon energy, for a baseline length of 250 km (K2K proposal) and a 10 kT detector of area 100 mt^2. Different values of c ($\equiv \lambda_{231}\lambda_{132}$) have been used, with $m_{\tilde{\tau}} = 100$ GeV.*

in excess to that expected via oscillation. Near-site experiments can thus be recommended for isolating the new physics effects that *mimic* the signals of ν-oscillation . On the other hand, a class of R-violating interactions, with strengths well below their current experimental limits, can be responsible for an enhanced rate of μ^+ even at a long-baseline experiment. Since the solution space for the solar ν-puzzle does not permit such event rates, such muons, if observed at a MSR, can therefore be greeted as harbingers of some new physics.

Acknowledgement:P.M. acknowledges financial support from the Council for Scientific and Industrial Research, India.

References

[1] S. Geer, (hep–ph/0008155); C. Quigg, (hep–ph/9803326); C. Albright et al. (hep–ph/0008064).

[2] V. Barger, G.F. Giudice, and T. Han, Phys. Rev. **D40,** 2987 (1989)

[3] S. Dutta, R. Gandhi, B. Mukhopadhyaya (hep–ph/9905475), Euro. Phys. J**C18,** 405 (2000).

[4] C. Allanach, A. Dedes and H. Dreiner, Phys. Rev. **D60,** 075014 (1999).