IC/95/214

INTERNATIONAL CENTRE FOR
THEORETICAL PHYSICS

SOME SIGNALS FOR A LIGHT NEUTRALINO

Rathin Adhikari

and

Biswarup Mukhopadhyaya

INTERNATIONAL ATOMIC ENERGY AGENCY

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

MIRAMARE-TRIESTE

IC/95/214

International Atomic Energy Agency
and
United Nations Educational Scientific and Cultural Organization
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

SOME SIGNALS FOR A LIGHT NEUTRALINO[1]

Rathin Adhikari[2]
International Centre for Theoretical Physics, Trieste, Italy

and

Biswarup Mukhopadhyaya[3]
Mehta Research Institute of Mathematics and Mathematical Physics,
Allahabad - 211 002, India.

ABSTRACT

If a light gaugino sector exists in the supersymmetric standard model then the mass of lightest neutralino may be of the order of 1 GeV or less. As a consequence of neutral flavor violation in supersymmetric theories B_s–meson may decay into a pair of lightest neutralinos in such a case. It is found that the parameter space for such light neutralinos can be appreciably constrained by looking for such decays. We also show how a rare B–decays ($B \to K(K^*) +$ *invisible* channels) can help us in probing a light neutralino in B–factories in a reasonably model–independent manner. Finally, we observe that the decay of a tau–lepton into a muon and a pair of light neutralinos can cause a violation of weak universality which is larger in magnitude than that from any source known so far.

MIRAMARE – TRIESTE

August 1995

[1]Presented at the International Symposium and Workshop on Particle Theory and Phenomenology, 17–26 May 1995, IITAP, Iowa State University, USA.

[2]Address after November 1995: Physical Research Laboratory Ahmedabad, India. E–mail: rathin@prl.ernet.in

[3]E–mail: biswarup@mri.ernet.in

Although the lower bound on the gluino mass in the minimal supersymmetric (SUSY) model, as obtained from hadronic collision experiments, is about 150 GeV [1], the stringency of the event selection criteria there allows a window [2, 3, 4] in the range of 2.5 - 5 GeV, which cannot be unambiguously closed even from low-energy phenomena. Such a light gluino also relaxes the squark mass limits [3]. There are some theoretical motivations also for a light gluino from the viewpoint of improved consistency in the running of the strong coupling constant α_s[5]. Naturally, such a situation also calls for a small value for the mass of the lightest SUSY particle (LSP) which is the lightest neutralino in most theories. Furthermore, in this light gluino scenario such a lightest neutralino is predominantly a photino in a SUSY model embedded in a Grand Unified Theory (GUT) [6]. In such a case the range in the parameter space that is allowed by LEP experiments and is simultaneously compatible with a light gluino corresponds to lightest neutralino mass ≈ 0.5 to 1.5 GeV, $\mu \approx -50$ to -100 GeV and $\tan\beta \approx 1.0 - 1.8$, μ and $\tan\beta$ being respectively the Higgsino mass parameter and the ratio of the scalar vacuum expectation values. Recently a lightest stable neutralino in this mass range has been claimed to be consistent with astrophysical constraints in a special type of SUSY model [7].

Here we suggest some methods for exploring the parameter space of a scenario containing a light neutralino. This discussion is model independent, except that, to keep the calculations simple and transparent, we have assumed the LSP to be a photino following the guidelines of a GUT-based theory.

First we consider the two body decay of B_s meson, namely, $B_s \longrightarrow \chi_1^0\chi_1^0$ where χ_1^0 is the LSP [8]. Such an invisible decay of the B_s has no backgrounds in the standard model. At the quark level, the the above decay process corresponds to $b \longrightarrow s\chi_1^0\chi_1^0$. Interestingly, such a flavor-changing neutral current (FCNC) process can be allowed at the tree-level [9] in SUSY, due to a mismatch between the quark and squark mass matrices in the left sector. The interaction involving $b \longrightarrow s$ in this fashion is controlled by a term Γ_{23}, Γ_{jk} being the (jk)-th element of the unitary matrix that diagonalises $M_{\tilde{d}}^2$ where

$$M_{L_{\tilde{d}}}^2 = \left(m_L^2\, \mathbf{1} + m_d^2 + c_0\, K\, m_u^2\, K^\dagger \right) \tag{1}$$

The last term in $M_{\tilde{d}}^2$ is crucial here; it arises from evolution of the squark mass parameter which receives corrections from couplings of the charged Higgsinos. The value of Γ_{23} depends on m_t and c_0. In view of the recent results from the Fermilab Tevatron, we have chosen $m_t = 170$ GeV here. The value of c_0 is model dependent; however, as recent estimates indicate, a value around 0.01 or slightly above is likely even from a rather conservative point of view [10]. Here we write $(\frac{\Delta m_{\tilde{q}}^2}{m_{\tilde{q}}^2})\Gamma_{23} = cK_{23}$, where c is treated as a phenomenological input, K is the Kobayashi-Maskawa matrix and $\Delta m_{\tilde{q}}^2$ is the squark mass square splitting. From rare decays such as $b \to s\,\gamma$ [11], a value of $|\, c_0 \,| \approx 0.05$ is allowed for $m_t \approx 175$ GeV and $m_{\tilde{q}} \approx 60$ GeV. For higher $m_{\tilde{q}}$ this constraint gets more relaxed. In such cases Γ_{23} is of the same order of magnitude as K_{23} . Thus for about 1% splitting in squark masses, $c \approx 0.01$ is easily possible.

The two-body decay-width shown in fig. (1) is given by

$$\Gamma \;=\; \frac{g^4\, \sin^4\theta_w\, |K_{23}|^2\, \left(c^2 f_{B_s}^2\right)}{216\,\pi\, m_{\tilde{q}}{}^4}\; m^2\, \left(m_B{}^2\; - 4\, m^2 \right)^{1/2} \tag{2}$$

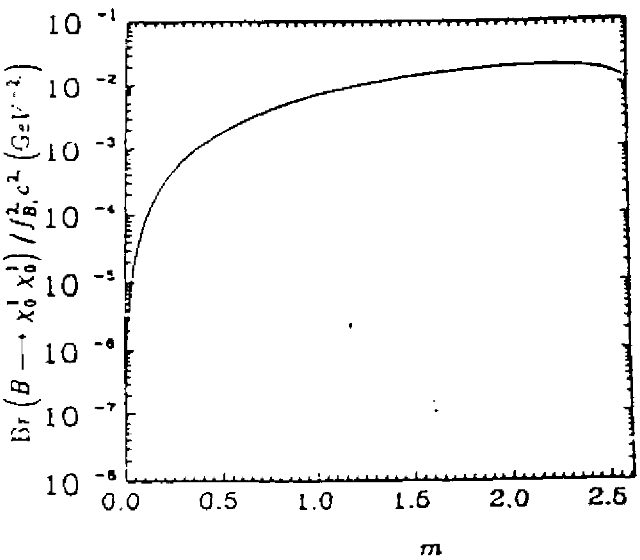

Fig. 1. The branching ratio for invisible B_s-decay (in units of $c^2\ f_{B_s}^2$) plotted against the LSP mass for $m_{\tilde{q}}\ =\ 80$ GeV

where f_{B_s} is the B_s-decay constant, and m and $m_{\tilde{q}}$ are respectively the mass of LSP and the average of the b-and s (left) squark masses. In the light gluino scenario, $m_{\tilde{q}}$ = 80 GeV is within the allowed region of the parameter space. The branching ratio corresponding to other values of $m_{\tilde{q}}$ can be obtained from the same graph using eqn. (2) and with appropriate scaling.

In the graph, mass of LSP in the range 0.5 to 1.5 GeV corresponds to a branching ratio of $(10^{-3} - 10^{-2})\ c^2\ f_{B_s}^2\ GeV^{-2}$. The value of the parameter f_{B_s}, although not completely known yet, can be expected to lie in the range of 0.3 GeV [12]. Depending on this, a branching ratio of $O(10^{-4} - 10^{-3})c^2$ can be expected for the invisible channel. If an accumulation of 10^8 $B\overline{B}$-pairs takes place in a B-factory, then the observation (or absence) of such decays could be employed to set limits in the $m - c$ parameter space from the viewpoint of light LSP's. This should be an independent laboratory constraint, in addition to those obtained from, say, decays of light charginos which often occur in the light LSP scenario. Moreover, if one wants to ignore gaugino mass relations from GUT's and restrict light LSP's from a purely phenomenological point of view, then it is possible to put limits in the range of 1-2 GeV as well, the branching ratio being even higher in that range.

Experimental observability of this invisible decay needs the efficiency of reconstruction of one B_s in the pair which is at present $O(10^{-3})$ [13]. However, this efficiency can be increased to $O(10^{-2})$ by extending the search techniques to decays like $B_s \longrightarrow D_s^{*\pm} X$ [14, 15], taking into account both $\pi^{\pm}$ and $\rho^{\pm}$ as products, and also using semileptonic tags.

We next consider the flavour-changing neutral current (FCNC) three-body decays $B \longrightarrow K(K^*)\chi_1^0\chi_1^0$ [16]. The energy spectrum of the $K(K^*)$ in this decay (which has the same final state as that with $K(K^*)$ and neutrinos) shows an interesting distortion depending on the LSP mass. At the quark level this decay has the same matrix element as the earlier two-body decay process. However, we need various form factors to express hadronic matrix elements for the quark current. Our results are based upon numerical values of the various form-factors (and pole fits for their momentum-transfer dependence) obtained from the relativistic quark model of reference [17]. These form-factors have been computed in the literature using other models, too [18]; We find that the uncertainties in the values of the form-factors do not destroy the general features of our results.

Also, the results to be shown below are susceptible to QCD corrections. Though such corrections moderately alter the decay rates [19], the key featurs are not expected to be lost. This is because at the lowest order electroweak level, the SUSY and standard model effective interactions have the same operator structure, and our results depend on their relative magnitudes.

To compute the energy distribution, one has to add the differential decay rates for the SUSY process with that for $\Sigma B \longrightarrow K(K^*)\nu_i\overline{\nu_i}$ which occurs via triangle as well as box diagrams [20]. The net observed variation of $d\Gamma/dE_{K(K^*)}$ with the K(K*)-energy is a result of superposition of the two types of final states, leading to a distribution with a kink. The position of the kink and the distortion to the spectrum relative to the purely SM case depends on the mass of the LSP.

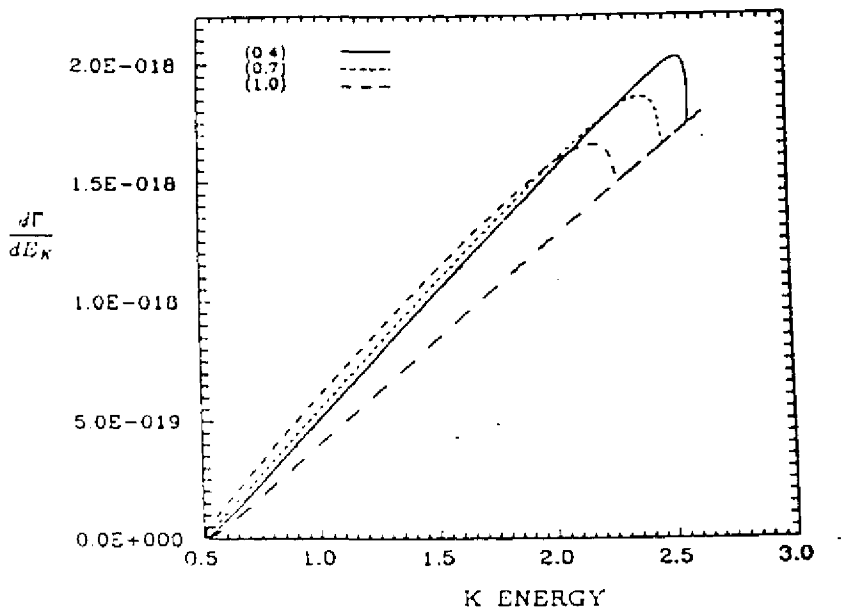

Fig.2. The differential decay rates for $B \longrightarrow K$ + *nothing* for $m_{\tilde{q}} = 100GeV$, $c = 0.1$. The solid, dotted and short-dashed curves correspond to three LSP masses expressed in GeV. The long-dashed curve below is for the purely standard model case with three massless neutrinos

The numerical results are shown in figures 2 for K final states only. We have drawn the graphs for $m_{\tilde{q}} = 100GeV$ which is easily allowed in this scenario and c, is treated here as a free input parameter. This enables us to extend this study, if necessary, even beyond the minimal SUSY model. Evidently, one can notice distortions to the spectrum over a considerable region of the parameter space. The effect becomes less and less obvious with increasing squark mass, and is barely perceptible for $B \longrightarrow K\chi_1^0\chi_1^0$ with $c \approx .5$, $m_{\tilde{q}} = 500GeV$ or $c \approx 0.05$, $m_{\tilde{q}} = 100GeV$. Also, the response to a variation in the mass of the LSP in the region $0.5 - 1.5GeV$ is manifest. A few hundred events in a B-factory should suffice to explore this kind of a distortion .

It is to be noted that while the differential decay rate for $\Sigma(B \longrightarrow K\nu_i\overline{\nu_i})$ increasess monotonically with E_K, it dips after an initial rise in the case of $\Sigma(B \longrightarrow K^*\nu_i\overline{\nu_i})$ and the kinky characteristics of the distribution pattern is not so prominent for the K^* final states. If 10^{7-8} $B\overline{B}$-pairs are produced in a B-factory per year, then the above types of decays in B-factory experiments are going to help one in constraining the light sparticle scenario to a large extent.

As a digression, it may be mentioned that the same spectral distortion as the one described above occurs in the minimal SUSY standard model in a general scenario also. The process in question is the decay $H \longrightarrow Z + invisible$ where one has to add the contributions from Z and pairs of lightest neutralinos as well as Z and neutrinos (three massless species) as final decay products. Here also we see the high sensitivity of the neutralino mass in the kinky characteristics of the differential decay width distributions against Z-energy [21] which would otherwise have had a uniform rise due to the neutrino contributions alone. This feature is visible for the LSP mass in the range 150 - 200 GeV, for the decay of a Higgs having mass 500 GeV or so.

Lastly we like to mention that for the lightest neutralino in the range of a few hundred MeV, the decay $\tau \longrightarrow \mu\chi_1^0\chi_1^0$ is also allowed and this leads to the violation of tau-universality [22]. Here, again the flavour violation is controlled by an effect of non-diagonal corrections to the slepton mass matrix, and is favored in models with massive (Majorana?) neutrinos. It is found that this violation can be greater than both non-universal electroweak radiative corrections and supersymmetric one-loop corrections over a considerable region of SUSY parameter space allowed by experiments so far. Thus in addition to B-factories, tau factories may also be quite helpful in either constraining the parameter space for lightest neutralino in the low mass region or in finding it.

Acknowledgements

R. A. likes to thank the High Energy Physics section, International Centre for Theoretical Physics, Trieste, Italy for its hospitality during writing this and IITAP, Iowa State University for invitation to present these works.

References

1. F. Abe *et al.*, *Phys. Rev. Lett.* **69** (1992) 3439.
2. Review of Particle Properties, *Phys. Rev.* **D50** (1994) S1, and references therein.
3. C. Albajar *et al.*, *Phys. Lett.* **B198** (1987) 261.
4. P. Tuts *et al.*, *Phys. Lett.* **B186** (1987) 233; J. Lopez *et al.*, *Phys. Lett.* **B313** (1993) 241; C. Carlson and M. Sher, *Phys. Rev. Lett.* **72** (1994) 2686.
5. L. Clavelli, *Phys. Rev.* **D46** (1992) 2112; J. Blümlein and J. Botts, *Phys. Lett.* **B325** (1994) 190; L. Clavelli, Talk presented at this conference.
6. L. Hall *et al.*, *Nucl. Phys.* **B221**, 285 (1983); G. Ross and R. Roberts, *Nucl. Phys.* **B377**, 571 (1992); L. Ibanez and G. Ross in *Perspectives on Higgs Physics,* G. Kane (ed), World Scientific (1993).
7. G. R. Farrar and E. W. Kolb, FERMILAB-Pub-95/068-A, RU-95-18, astro-ph/9504081, (1995).
8. R. Adhikari and B. Mukhopadhyaya, To appear in *Phys. Rev.*D.
9. J. Donoghue *et al.*, *Phys. Lett.* **B128** (1983) 55; M. Duncan, *Nucl. Phys.* **B221** (1993) 285; A. Bouquet *et al.*, *Phys. Lett.* **B148** (1984) 69.
10. J. Hagelin *et al.*, *Nucl. Phys.* **B415** (1994) 293.
11. G. Bhattacharyya and A. Raychaudhuri, CERN Report CERN-TH-7245/94 (1994).
12. See, for example, M. Neubert, *Phys. Rep.* **245** (1994) 259 and references therein.
13. D. Bortoletto *et al.*, *Phys. Rev. Lett.* **64** (1990) 2117; H. Albrecht *et al.*, *Z. Phys.* **C54** (1992) 1.
14. D. Bortoletto and S. Stone, *Phys. Rev. Lett.* **65** (1990) 2951.
15. S. Stone, Private Communication.
16. R. Adhikari and B. Mukhopadhyaya, *Phys. Lett.* **B353** (1995) 228.
17. M. Baur *et al.*, *Z. Phys.* **C29** (1985) 637, *ibid*, **C34** (1987) 103.
18. N. Isgur *et al.*, *Phys. Rev.* **D39** (1989) 799; N. Isgur and M. Wise, *Phys. Lett.* **B237** (1990) 527; W. Jaus and D. Wyler, *Phys. Rev.* **D41** (1989) 3405; G. Greub *et al.*, University of Zurich Report ZU-TH-25/94 (1994).
19. M. Grinstein *et al.*, *Nucl. Phys.* **B319** (1989) 271.
20. W. Hou *et al.*, *Phys. Rev. Lett.* **58** (1987) 1608.
21. R. Adhikari and B. Mukhopadhyaya, *Mod. Phys. Lett.* **9** (1994) 3741.
22. R. Adhikari and B. Mukhopadhyaya, hep-ph / 9507252