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Can solar neutrino oscillation parameters be probed at accelerators ?

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If supersymmetry is realized with spontaneous breaking of R-parity, there will be many phenomenological consequences. Here we show that the masses and mixing angles of the neutrinos lie in the correct range for the MSW explanation of the solar neutrino problem. At the same time the rates for the processes $Z^0 \to \tau +$ chargino, $\tau \to \mu +$ Majoron and $\mu \to e +$ Majoron can be close to the present bounds.

1. Introduction

Most studies of supersymmetric phenomenology have been made in the framework of the *Minimal Supersymmetric Standard Model (MSSM)* which assumes the conservation of a discrete symmetry called R-parity (R_p)[1]. Under this symmetry all the standard model particles are R-even while their superpartners are R-odd. R_p is related to the spin (S), total lepton (L), and baryon (B) number according to $R_p = (-1)^{(3B+L+2S)}$. Therefore the requirement of baryon and lepton number conservation implies the conservation of R_p. Under this assumption the supersymmetric (SUSY) particles must be pair-produced, every SUSY particle decays into another SUSY particle and the lightest of them is absolutely stable. These three features underlie all the experimental searches for new supersymmetric states.

However, neither gauge invariance nor SUSY require R_p conservation. The most general supersymmetric extension of the standard model contains explicit R_p violating interactions that are consistent with both gauge invariance and supersymmetry. Detailed analysis of the constraints on these models and their possible signals have been made[2]. In general, there are too many independent couplings and some of these couplings have to be set to zero to avoid the proton to decay too fast.

For these reasons we restrict our attention to the possibility that R_p can be an exact symmetry of the Lagrangean, broken spontaneously through the Higgs mechanism[3–5]. This may occur via nonzero vacuum expectation values for scalar neutrinos, such as

$$v_R = \langle \tilde{\nu}_{R\tau} \rangle \qquad ; \qquad v_L = \langle \tilde{\nu}_{L\tau} \rangle \ . \tag{1}$$

If spontaneous R_p violation occurs in absence of any additional gauge symmetry, it leads to the existence of a physical massless Nambu-Goldstone boson, called Majoron (J)[3]. In these models there is a new decay mode for the Z^0 boson, $Z^0 \to \rho + J$, where ρ is a light scalar. This decay mode would increase the invisible Z^0 width by an amount equivalent to 1/2 of a light neutrino family. The LEP measurement on the number of such neutrinos is enough to exclude any model where the Majoron is not mainly an isosinglet[6]. The simplest way to avoid this limit is to extend the *MSSM*, so that the R_p breaking is driven by isosinglet VEVs, so that the Majoron is mainly a singlet[4].

2. A model for spontaneous R_p breaking

2.1. The model of Masiero and Valle

In order to set up our notation we recall the basic ingredients of the model for spontaneous violation of R parity and lepton number proposed in[4] The superpotential is given by

$$\begin{aligned} W &= h_u Q H_u u^c + h_d H_d Q d^c + h_e \ell H_d e^c \\ &+ (h_0 H_u H_d - \varepsilon^2)\Phi + \hat{\mu} H_u H_d + h_\nu \ell H_u \nu^c \\ &+ h \Phi S \nu^c + M \nu^c S + M_\Phi \Phi\Phi \end{aligned} \tag{2}$$

This superpotential conserves *total* lepton number and R_p. The superfields $(\Phi, {\nu^c}_i, S_i)$ are singlets under $SU_2 \otimes U(1)$ and carry a conserved lepton number assigned as $(0, -1, 1)$ respectively. All couplings $h_u, h_d, h_e, h_\nu, h, M$ are described by arbitrary matrices in generation space which explicitly break flavor conservation.

It has been shown[4, 7] that these singlets may

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drive the spontaneous violation of R parity leading to the existence of a Majoron given by the imaginary part of

$$\frac{v_L^2}{Vv^2}(v_u H_u - v_d H_d) + \frac{v_L}{V}\tilde{\nu_\tau} - \frac{v_R}{V}\tilde{\nu^c}_\tau + \frac{v_S}{V}\tilde{S_\tau} \quad (3)$$

where the isosinglet VEVs

$$v_R = \langle \tilde{\nu}_{R\tau} \rangle \quad , \quad v_S = \left\langle \tilde{S_\tau} \right\rangle \quad (4)$$

with $V = \sqrt{v_R^2 + v_S^2}$ characterize R_p or lepton number breaking and the isodoublet VEVS

$$v_u = \langle H_u \rangle \quad , \quad v_d = \langle H_d \rangle \quad , \quad v_L = \langle \tilde{\nu}_{L\tau} \rangle \quad (5)$$

drive electroweak breaking and the fermion masses.

2.2. Experimental constraints

All supersymmetric extensions of the standard model, are constrained by data that follow from several collider experiments, such as the recent LEP data on Z^0 decays and by $\bar{p}p$ collider data *e.g.*, on $W^\pm, Z^0$ and gluino production. This certainly applies to the spontaneously broken R_p models. In addition to these constraints, there are important restrictions, characteristic of broken R_p models, related to weak interactions and neutrino mass considerations. The most relevant constraints[5] include neutrinoless double beta decay and neutrino oscillation limits, direct searches for anomalous peaks at meson decays, limits on the neutrino masses, cosmological limits on neutrino lifetime, limits on μ and τ lifetimes, universality constraints, and limits on lepton flavour violating decays.

In order to take systematically these constraints into account, we have assumed the following values for the model parameters:

$$\begin{array}{lclclc} v_L & = & 100 \text{ MeV} & v_R & = & v_S = 1 \text{ TeV} \\ M_\Phi & = & 10 \text{ TeV} & M_{33} & = & 1 \text{ TeV} \end{array} \quad (6)$$

and for several values of $\tan\beta = \frac{v_u}{v_d}$ we have varied randomly the SUSY parameters μ, M_2, and the parameters $h_{\nu i3}$ in the range given by

$$\begin{array}{rclcl} -250 & \leq & \mu/\text{GeV} & \leq & 250 \\ 20 & \leq & M_2/\text{GeV} & \leq & 250 \\ 10^{-10} & \leq & h_{\nu 13}, h_{\nu 23} & \leq & 10^{-1} \\ 10^{-5} & \leq & h_{\nu 33} & \leq & 10^{-1} \end{array} \quad (7)$$

2.3. Main features of the model

Several phenomenological aspects of this model were previously[5, 8–10] studied and details can be found there. Here we just give the main features of the model:

- The neutral fermions are Majorana fermions. The mass matrix is 14×14 and mixes neutrinos and neutralinos.
- The charged fermion mass matrix is 5×5 and mixes the usual leptons with the charginos.
- The ν_τ has mass in the range 10 KeV to 35 MeV. It avoids the cosmological bounds by decaying via

$$\nu_\tau \to \nu_\mu + J \quad (8)$$

for which lepton flavour violation is needed.

- The lepton flavour violating decays

$$\tau \to \mu(e) + J \qquad \mu \to e + J \quad (9)$$

can be close to the present experimental limits.

- The most interesting signal at LEP would be single chargino production,

$$Z^0 \to \chi^\mp + \tau^\pm \quad (10)$$

with branching ratios as high as 5×10^{-5}.

3. Neutrino masses and mixings

To a good aproximation we can write

$$\begin{aligned} \nu_1 &= \cos\theta\nu_e - \sin\theta\nu_\mu \\ \nu_2 &= \sin\theta\nu_e + \sin\theta\nu_\mu \\ \nu_3 &= \nu_\tau \end{aligned} \quad (11)$$

where ν_i, $i = 1, 2, 3$ and ν_e, ν_μ and ν_τ are, respectively, the mass and weak interaction eigenstates. The mixing angle θ is given in terms of the model parameters by $\tan\theta = h_{\nu_{13}}/h_{\nu_{23}}$ The constraints on $h_{\nu_{13}}$ and $h_{\nu_{23}}$ do not restrict much their ratio. Therefore a large range of mixing angles is allowed. For the masses we get

$$\begin{aligned} m_1 &= 0 \quad \text{exact} \\ m_2 &\simeq \frac{(h_{\nu_{13}}^2 + h_{\nu_{23}}^2) v_u^2 v_L^2 [h(\hat{\mu} + h_0 v_F) + h_0 M]^2}{M_\Phi [h v_F + M]^2 h_{\nu_{33}}^2 v_d^2} \\ m_3 &\simeq \frac{\sum_i h_{\nu_{i3}}^2 M_0 v_d^2 v_R^2}{\mu(2 v_u v_d M_0 - \mu M_1 M_2)} \end{aligned} \quad (12)$$

where $M_0 = 1/2(g'^2 M_2 + g^2 M_1)$. For typical values we get

$$10^{-4}\ eV \leq m_2 \leq 10^{-2}\ eV \tag{13}$$

just in the right range for the MSW mechanism.

4. Spontaneously broken R_p and the MSW effect

As we have shown the mass difference and mixing angles for the two lightest neutrinos are naturally in the right range for the *MSW* explanation of the observed defficit in the solar neutrino flux.

We can therefore ask the question if it is possible to have, *at the same time*, the correct parameters for the *MSW* effect, and observe signals at LEP *and/or* in τ and μ decays. After all the experimental constraints have been taken in account we found out that this is indeed possible. In Fig.1 are shown the branching ratios contours for $Z^0 \to \chi^\pm \tau^\mp$ and $\tau \to \mu + J$ superimposed in the presently allowed region[11] for the *MSW* effect. The solid line corresponds to *both* $BR > 10^{-6}$ while the dashed line corresponds to *both* $BR > 10^{-5}$.

Similar plots for μ and τ decays have been given[9]. In all the cases there is a large region in parameter space where it is possible to have observable effects in LEP physics *and/or* muon and tau decays, and at the same time to have neutrino oscillation parameters in the range allowed by present solar neutrino data.

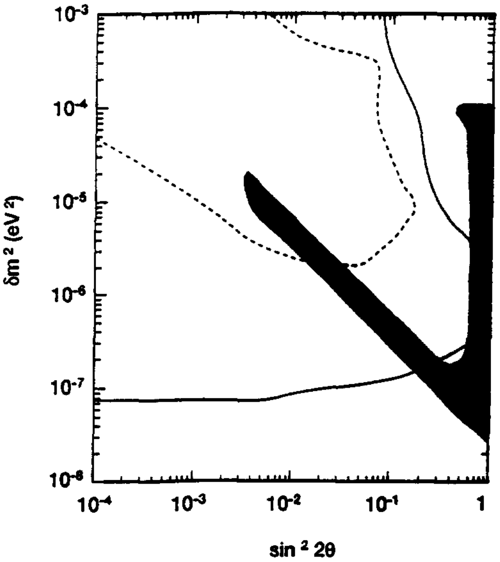

Figure 1. Contour plots for $BR(Z^0 \to \tilde{\chi} + \tau)$ and $BR(\tau \to \mu + J)$. Also shwon is the region allowed by present solar neutrino data.

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