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R Parity Can Break

J. C. Romão[1]

Centro de Física da Matéria Condensada, INIC

Av. Prof. Gama Pinto, 2 - 1699 Lisboa Codex, PORTUGAL

C. A. Santos

Faculdade de Engenharia, Dept. de Engenharia Civil

Secção de Matemática e Física, Rua dos Bragas, 4099 Porto Codex, PORTUGAL

and

J. W. F. Valle[2]

Instituto de Física Corpuscular - C.S.I.C.

Departament de Física Teòrica, Universitat de València

46100 Burjassot, València, SPAIN

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This paper is a comment on the paper *How can R Parity be Broken?* by Chaichian and Smilga. It explains why this paper is unsound and why no conclusions can be drawn from it. Moreover it summarizes the results we have recently obtained and which demonstrate explicitly how R Parity breaks spontaneously in a simple extension of the minimal supersymmetric standard model (MSSM) proposed previously. For suitable values of the parameters of the low energy theory, consistent with observation, the energy is minimum when both R parity and electroweak symmetries are spontaneously broken. The breaking of R parity has a characteristic scale that typically lies in the phenomenologically interesting range $\sim 10 GeV - 1 TeV$.

[1] *Bitnet ROMAO@PTIFM*

[2] *Bitnet VALLE@EVALUN11 - Decnet 16444::VALLE*

In a recent paper [1] Chaichian and Smilga criticized the recently proposed supersymmetric extension of the Standard Model with spontaneous R parity violation suggested in ref [2] and defined by the superpotential

$$h_u u^c Q H_u + h_d d^c Q H_d + h_e e^c \ell H_d + \hat{\mu} H_u H_d + (h_0 H_u H_d - \epsilon^2)\Phi + h_\nu \nu^c \ell H_u + h\Phi\nu^c S \tag{1}$$

For our purposes it suffices to assume that the coupling matrices $h_{\nu ij}$ and h_{ij} are nonzero only for the third generation *, so that we have effectively a one generation model. Note that we keep the bilinear $H_u H_d$ term in order to allow more flexibility in obeying all experimental LEP constraints (not taken into account in ref. [1]) but we neglect those terms, allowed by our symmetries, that do not play any important role for our present considerations. We take the scalar potential along neutral directions as

$$\begin{aligned} V_{total} = & \left|h\Phi\tilde{S} + h_\nu \tilde{\nu} H_u\right|^2 + |h_0 \Phi H_u + \hat{\mu} H_u|^2 + \\ & \left|h\Phi\tilde{\nu^c}\right|^2 + \left|-h_0\Phi H_d - \hat{\mu} H_d + h_\nu \tilde{\nu}\tilde{\nu^c}\right|^2 + \left|-h_0 H_u H_d + h\tilde{\nu^c}\tilde{S} - \epsilon^2\right|^2 + \left|h_\nu \tilde{\nu^c} H_u\right|^2 \\ & + \tilde{m}_0 \left[-A(-h\Phi\tilde{\nu^c}\tilde{S} + h_0\Phi H_u H_d - h_\nu \tilde{\nu} H_u \tilde{\nu^c}) + (1-A)\hat{\mu} H_u H_d + (2-A)\epsilon^2\Phi + h.c.\right] \\ & + \sum_i \tilde{m}_i^2 |z_i|^2 + \alpha(|H_u|^2 - |H_d|^2 - |\tilde{\nu}|^2)^2 \end{aligned} \tag{2}$$

where z_i denotes any neutral scalar field in the theory and $\tilde{m}_i$ are the corresponding soft-breaking masses, $\alpha = \frac{g^2+g'^2}{8}$, and A is the cubic soft breaking parameter in units of the gravitino mass $\tilde{m}_0$.

In ref [1] it is claimed that *the extremum of the potential found in this model is, in fact, a saddle point, while in the true minimum R-parity is not broken.* Without doing any further calculations they also claim that *no other existing model can describe succesfully the existing data.* They conclude therefore that *the problem to construct a viable model involving spontaneous R-parity breaking remains open.*

The goal of this comment is to clarify the situation. Indeed in ref [1] a no-go "theorem" on the nonexistence of minima was found. In order to understand why it is meaningless let us list their basic assumptions: (i) all soft-breaking scalar masses are equal to a common gravitino mass, and (ii) h_ν and v_L can be neglected in the minimization of the scalar potential. The first assumption may at most be taken as illustration, since it is expected to hold only at some ultrahigh unification scale, not at the scale characterising electroweak physics, relevant for us. For small h_ν (i) would lead to the near equality of the

*Of course a phenomenologically consistent model also has couplings which explicitly break flavour conservation, needed in order to ensure that the ν_τ decays fast enough via Majoron emission so as to obey cosmological limits [3].

vacuum expectation values (VEVS) v_u and v_d that break the electroweak symmetry (the notation here is the same used previously *i.e.*, $v_u = \langle H_u \rangle$, $v_d = \langle H_d \rangle$, $v_R = \langle \tilde{\nu^c}_\tau \rangle$, $v_L = \langle \tilde{\nu}_\tau \rangle$, $v_S = \left\langle \tilde{S}_\tau \right\rangle$ and $v_F = \langle \Phi \rangle$). This would require $\tan\beta = \frac{v_u}{v_d} \simeq 1$ while already in the minimal supersymmetric standard model (MSSM) one has many solutions with $\tan\beta > 1$, as required by LEP [4]. However, the most crucial flaw in the reasoning of ref [1] is the uncritical use of assumption (ii). This fundamental conceptual error is the basis of their no-go "theorem". Indeed, if $h_\nu = 0$ and $v_L = 0$ the theory conserves R parity exactly *irrespective of whether or not a nonzero VEV is induced for* v_R *and* v_S. It easy to realize from eq. (1) that we can assign in this case a positive R parity for the scalars in the chiral superfields ν^c and S so that R parity can *never* be broken spontaneously, irrespective of the potential! (there can be no violation of R parity in the gauge sector either, since $v_L = 0$). Thus their implicit assumption that R parity can be broken in this model in the absence of h_ν is absurd, and the problem they pose can have only academic interest, if any.

The minimization of the scalar potential eq. (3) has been performed explicitly in ref [5]. Here we only illustrate the main points. In order to find the minima we have assumed that colour and electric charge are not broken, in analogy with what has been verified to hold for a suitable range of parameters in the corresponding R parity conserving model [6]. Instead of directly solving the extremization equations that follow from eq. (3) with respect to the VEVS, we directly evaluate the squared-mass matrices of the neutral scalars by taking two derivatives of the potential. Next we study their positivity in parameter space. This way we bypass the need to find solutions of the nonlinear extremization equations. This also allows us to map out systematically the space of low energy parameters allowed by present experimental data and to discriminate against trivial solutions which are either unphysical (no electroweak breaking) or uninteresting for our purposes (no R parity breaking). The method and the criteria that have been applied have been explained in detail in ref [5]. Just for illustration purposes we choose among a large variety of possible minima where both $SU(2) \otimes U(1)$ and R parity break the point defined by the following parameters: $h_\nu = 8.59 \times 10^{-3}$, $h = -0.351$, $h_0 = 0.140$, $A = 1.196$, $\epsilon^2 = -3.715 \times 10^5\, GeV^2$, $\tilde{m}_0 = 355.6\, GeV$, $\hat{\mu} = -23.8\, GeV$, $\mu_{eff} = \hat{\mu} + h_0 v_F = 94.1\, GeV$, $\tilde{m}_d = 426.9\, GeV$, $\tilde{m}_u = 205.0\, GeV$, $\tilde{m}_L = 386.8\, GeV$, $\tilde{m}_F = 355.7\, GeV$, $\tilde{m}_R = 409.7\, GeV$, $\tilde{m}_S = 409.7\, GeV$, and the corresponding VEVS $v_d = 81.65\, GeV$, $v_u = 153.77\, GeV$, $v_L = -35.9\, MeV$, $v_R = v_S = 50.00\, GeV$ and $v_F = 840.89\, GeV$. We

have also checked that this minimum is not in conflict with present LEP limits [4] and that it lies indeed lower than the trivial minima discussed above. We display in Fig. 1 (reproduced from ref [5]) the shape of the potential around this minimum, as a function of the VEVS v_L and v_R, keeping all the others fixed at the minimum. More precisely, we plot $[V(v_L, v_R) - V_{min}]/V_{min}$. The figure shows how the potential behaves as v_L, v_R vary, illustrating the need a small amount of R parity breaking in the isodoublet sector.

We conclude that R parity can break spontaneously. For suitable values of the low energy parameters, consistent with observational constraints, the potential has true minima and not saddle points, as claimed in [1]. Moreover, for a wide choice of these parameters it is energetically favourable to have both R parity and electroweak symmetries broken. The characteristic R parity breaking scale is in the range $\sim 10\,GeV - 1\,TeV$. The minimization also implies a hierarchy between v_L and v_R, as required in order to avoid excessive stellar cooling rates and in order to explain the solar neutrino deficit by resonant ν_e to ν_μ convertions [7]. Additional phenomenological implications of these models were considered in ref [8, 9, 10]. Finally, barring a more detailed dynamical study of the alternative spontaneous R parity violation scenario considered in ref. [11], we can, again in this case, easily refute the claims of ref [1].

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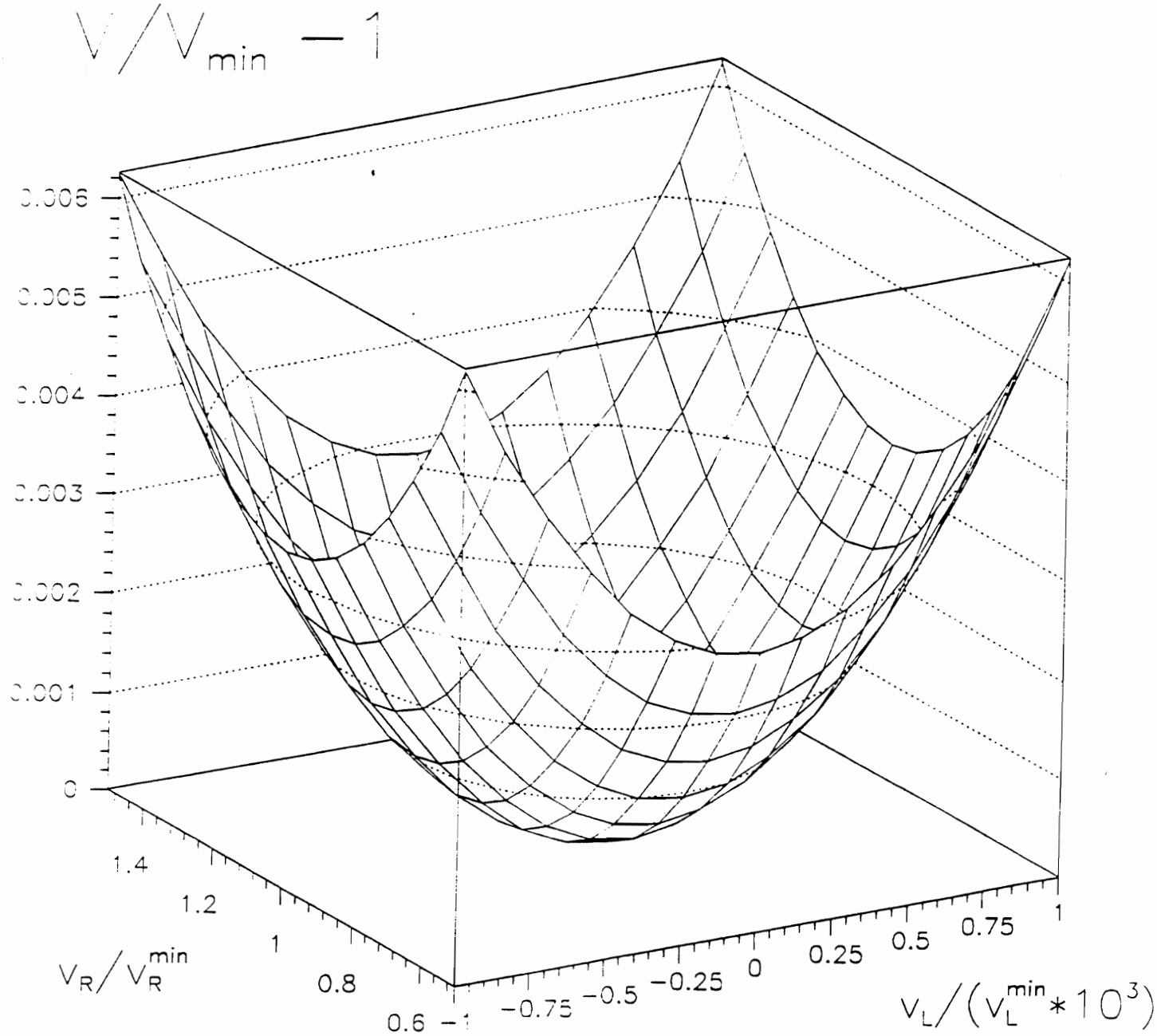
Fig. 1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