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PHENOMENOLOGY OF $SU(3) \otimes SU(2) \otimes U(1)$ SUPERSYMMETRIC MODEL WITH DIRAC NEUTRINO MASSES

N.V.Krasnikov[1)]

Institute for Nuclear Research RAS
117312 Moscow, Russia

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We consider minimal supersymmetric extension of standard electroweak model with Dirac neutrino masses. In such model for significant region of the parameters right-handed tau sneutrino is the lightest superparticle and right-handed charged tau slepton is the next to lightest superparticle. Due to the smallness of the neutrino masses the right-handed tau slepton is long-lived particle that changes the standard signatures used in the search for supersymmetry at supercolliders. The most striking signatures of such scenario is the existence of highly ionizing tracks and excess of multilepton events that is similar to the phenomenology of gauge-mediated supersymmetry breaking models.

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Supersymmetric electroweak models offer the simplest solution of the gauge hierarchy problem [1 – 4]. In real life supersymmetry has to be broken and the masses of superparticles have to be lighter than $O(1)$ TeV provided the supersymmetry solves the gauge hierarchy problem [4]. Supergravity gives a natural explanation for the supersymmetry breaking, namely, taking the supergravity breaking into account in the hidden sector leads to soft supersymmetry breaking in the observable sector [4]. For the supersymmetric extension of the Weinberg – Salam model, soft supersymmetry breaking terms usually consist of the gaugino mass terms, squark and slepton mass terms with the same mass at the Planck scale and trilinear soft scalar terms proportional to the superpotential. Another standard assumption is that the "Minimal Supersymmetric Standard Model" (MSSM) conserves R-parity. As a consequence of R-parity conservation supersymmetric particles can only be produced in pairs and supersymmetric particles can't decay into ordinary particles, so the lightest superparticle (LSP) is stable. The typical SUSY signature for supercolliders involves missing E_T transverse energy as a signal for SUSY particles production [5].

In this paper we consider supersymmetric extension of the Weinberg – Salam model with nonzero Dirac neutrino masses (the MSSM model with Dirac neutrino masses). We show that in such model for the significant range of the parameters the right-handed sneutrino is the LSP and the charged right-handed tau slepton is the next to lightest superparticle. Due to the smallness of the neutrino masses the right-handed tau slepton is long-lived particle and it decays outside of the detector that drastically changes the standard signatures used in the search for supersymmetry at supercolliders. Namely, the most striking signatures for the SUSY search in considered model include highly ionizing tracks from long-lived right-handed tau sleptons and excess of multi-muon signals[2)].

[1)] e-mail: krasniko@ms2.inr.ac.ru

[2)] The phenomenology of the considered model is similar to the phenomenology of some gauge-mediated supersymmetry breaking models [6] and a model [7] with superweak R-parity violation.

Consider supersymmetric $SU(3) \otimes SU(2) \otimes U(1)$ model with Dirac neutrino masses. The superpotential of the model has the form

$$W = h_{u_i} Q_i H_1 \bar{u}_i + h_{d_i} Q_i H_2 \bar{d}_i + h_{\nu_i} L_i H_1 \bar{\nu}_i + h_{e_i} L_i H_2 \bar{e}_i + \mu H_1 H_2. \tag{1}$$

Here $Q_i = (u_i, d_i)_L$, $L_i = (\nu_i, e_i)_L$, $H_1 = (H_{11}, H_{12})$, $H_2 = (H_{21}, H_{22})$, $\bar{u}_i = u^c_{R,i}$, $\bar{d}_i = d^c_{R,i}$, $\bar{\nu}_i = \nu^c_{R,i}$, $\bar{e}_i = e^c_{R,i}$, $H_1 H_2 = \epsilon^{ij} H_{1i} H_{2j}$. The considered model is a minimal generalization of the MSSM, the single difference is that neutrinos are massive and Dirac particles. The standard assumption of the MSSM is that at GUT scale $M_{GUT} \approx 2\times \times 10^{16}$ GeV soft supersymmetry breaking parameters are universal. For the gaugino masses, an account of the evolution from the GUT scale to the observable electroweak scale leads to the formula [8]

$$M_i = \frac{\bar{\alpha}_i(M_Z)}{\alpha_{GUT}} m_{1/2}. \tag{2}$$

The gaugino associated with the $U(1)$ gauge group is the lightest among the gauginos, and numerically its mass is given by the formula

$$M_1 \approx 0.43 m_{1/2}. \tag{3}$$

Here $m_{1/2}$ is common gaugino mass at GUT scale. In the MSSM the right-handed sleptons usually are the next to the lightest superparticles and in the neglection of the Yukawa interactions their masses are determined by the formula [8]

$$m^2_{\tilde{E}_R} \approx m_0^2 + 0.14 m^2_{1/2} - 0.22 \cos 2\beta M_Z^2. \tag{4}$$

Here m_0 is common squark and slepton mass at GUT scale and $\tan(\beta) = \langle H_1 \rangle / \langle H_2 \rangle$. In neglection of the Yukawa interactions the right-handed sneutrino masses coincide with m_0. As it follows from the formulae (2,3) for $m_{1/2} \geq 2.3 m_0$ the right-handed sneutrino are the lightest superparticles. Especially interesting is the particular case when $m_0 \leq 0.17 m_{1/2}$. In this case the charged right-handed sleptons are the next to lightest superparticles. The case $m_0 \ll m_{1/2}$ is theoretically very attractive since it allows to solve SUSY flavour changing problem. For the scenario when the lightest superparticle is the right-handed sneutrino[3] and the right-handed sleptons are the next to lightest superparticles (to be precise an account of nonzero Yukawa interactions makes tau right-handed slepton the lightest among right-handed sleptons) the right-handed tau slepton is long-lived particle due to the smallness of the neutrino masses. After the integration over the superfields H_1, H_2 one can find the effective superpotential describing the decay of right-handed sleptons into right-handed sneutrino

$$W_{eff} = h_{\nu_i} h_{e_j} L^k_i L^l_j \epsilon_{kl} \bar{\nu}_i \bar{e}_j \frac{1}{\mu}. \tag{5}$$

For $m_{\nu_\mu} \gg m_{\nu_e}$ and $m_{\tilde{\tau}_R} \gg m_{\tilde{\nu}_i}$ the tau slepton decay width into $\tilde{\tau}_R \to \to \tilde{\nu}_{\mu,R} \nu_\tau \mu, \tilde{\nu}_{\mu,R} \nu_\mu \tau$ is determined by the formula

$$\Gamma(\tilde{\tau}_R) \approx \frac{1}{192\pi^3} \frac{m^3_{\tilde{\tau}_R}}{\mu^2} \frac{m_\tau^2 m^2_{\nu_\mu}}{v^2 (\sin(2\beta))^2}, \tag{6}$$

[3] As it has been shown in ref.[9] the right-handed sneutrino with a mass $\sim$ 2 GeV is a natural candidate for dark matter.

where $v = 174\text{GeV}$ and $m_{\tilde{\tau}_R}$ is the tau right-handed slepton mass. As it follows from the formula (5) due to the smallness of the muon neutrino mass the right-handed tau slepton is long-lived particle. For instance, for $m_{\tilde{\tau}_R} = 100\,\text{GeV}$, $\mu = 500\,\text{Gev}$, $\sin(2\beta) = 0.1$ and $m_{\nu_\mu} = 100\,\text{eV}$ the stau lifetime is $\tau(\tilde{\tau}_R) \sim 0.3$ sek. For $m_{\nu_\mu} = 10\,\text{eV}$ the stau lifetime is $\tau(\tilde{\tau}_R) \sim 30$ sec. Such charged particle is long-lived (it decays outside of the detector) that changes comletely the signatures for the search for supersymmetry at supercolliders. Remember that standard signatures used for the search for supersymmetric particles at supercolliders in the assumption that LSP is neutral and escapes from being registrated at the detector are events with hadronic jets + missing E_T + ($n \geq 0$) isolated leptons. Missing E_T arises from nonobservation of electrically neutral LSP. In our case we shall not have missing transverse energy E_T but instead as a result of the right-handed sleptons decays we shall have two opposite sign long-lived charged sleptons in the SUSY event. If such sleptons are nonrelativistic we can distinguish them from muons by highly ionized tracks. For relativistic sleptons it is difficult to distinguish them from muons so we shall have the excess of multi-muon events in the final states with 5 or more isolated muons and very little hadronic activity. The standard background with 5 or more isolated muons is extremely small and the predicted signature is very clean. It should be noted that in gauge-mediated supersymmetry breaking models charged sleptons could be the next to lightest superparticles and decay outside of the detector for large region of parameter space [6]. Similar situation takes place in a model with superweak explicit R-parity violation [7]. The phenomenology of these models is very similar to the phenomenology of the considered model and it has been discussed in refs. [6, 10].

In conclusion let us formulate our main results. We considered the simplest generalization of the MSSM model – the MSSM with nonzero Dirac neutrino masses. We have shown that for large regions of parameter space which are theoretically very attractive the lightest superparticle is the right-handed sneutrino and the next to lightest superparticle is right-handed tau slepton. Due to the smallness of the tau neutrino mass the right-handed tau slepton is long-lived particle and it decays outside of the detector that changes comletely the MSSM signatures used for the search for supersymmetry at supercolliders.

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