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Possibility to Detect Upgoing Sleptons

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Some supersymmetric models predicted long lived charged sleptons. If they are exist, the $\widetilde{\tau}$, the supersymmetry partner of τ lepton, could be produced inside the earth by collisions of high energy neutrinos with nucleons. The investigation for the possible signals of upgoing $\widetilde{\tau}$ have been made by various way. Taken the atmospheric neutrino flux into account, the muons flux as the background are also estimated. By using the Waxman-Bahcall limit on the extraterrestrial neutrino flux, the resultant spectra shows that there are about 70 events per year could pass a km-scale underground experiments, such as ICECUBE.

1. Introduction

Substantial evidences show us that Dark Matter(DM) dominates the matter world, but composition of DM is still quite open. Weak scale supersymmetric theories of physics beyond the standard model, provide perhaps the most promising candidates for DM. Supersymmetric models typically have a symmetry, called R-parity, which exclusively ensures that the Lightest Supersymmetric Particle (LSP) is the most stable, and the Next to Lightest Supersymmetric Particle (NLSP) is at sub-stable state. Obviously, the LSP is the natural candidate for dark matter. Different Supersymmetric models predict different LSP, In the models where LSP is typically the quintessino [1]or the gravitino[2], NLSP tends to be a charged slepton, typically the right-handed $\widetilde{\tau}$, which has a long lifetime between microsecond and a year around, depending on the scale of supersymmetry breaking and the slepton's mass. Of course, these lifetimes are negligible comparing with the age of our universe, therefore, almost all these NLSP produced in the evolutive history of the universe decayed into LSP.

Based on a gravitino-LSP scenario, Albuquerque et al initiated that one can take neutrino telescopes as a direct probe of supersymmetry breaking[3]. Motivated by their work, our following calculations base on the quintessino-LSP scenario from Ref.[1] where it restricts the stau mass between $100GeV$ and $1TeV$ and the lifetime between $10^6 \sim 10^7$ seconds.

2. The upgoing flux calculations

High energy neutrinos interacting with nucleons will produce supersymmetric particles, and that will promptly decay into a pair of NLSPs, which have long lifetime. $\nu N \to \widetilde{l}\widetilde{q} \to 2\widetilde{\tau}$, the dominant process is analogous to the standard model charged current interactions. The cross section for supersymmetric production as a function of the neutrino energy is given in Ref.[4]. We take the earth as the target and consider the incoming of some diffuse fluxes of high energy neutrinos. A model of the earth density profile is considered as detailed in Ref.[5].

Dynamic analysis shows that the energy threshold for $\widetilde{\tau}$ production has to be over $\sim 100TeV$. We make use of atmospheric neutrino flux in Ref.[6, 7]. The diffuse fluxes of high energy extraterrestrial neutrinos have been wildely discussed in literatures. The Waxman-Bahcall (WB) upper bound [8] assumes that 100% of the energy of cosmic ray protons are lost to π^+ and π^- and that the π^+ all decay to muons that also produce neutrinos. Ref.[8] also discussed the maximum contribution due to possible extra-galactic component of lower-energy $< 10^{17}eV$, where protons have been first considered (max.extra-galactic p). Experimentally, AMANDA experiment gave a upper bound on diffuse neutrino flux [9]. By considering optically thick AGN

Table 1. Number of events per km^2 per year for taking WB, AMANDA+max.extra-galactic p and MPR as extraterrestrial fluxes, respectively. Atmospheric neutrino flux with the energy above $1GeV$ is taken into account as well. The first column refers to upgoing muons. The last two columns correspond to upgoing $\widetilde{\tau}$ for two different choices of squark masses: $150, 300GeV$.

	muon	$m_{\hat{q}} = 150GeV$	$m_{\hat{q}} = 300GeV$
Atmos.+ WB	4.83×10^5	69	26
Atmos.+ AMANDA+max.	4.90×10^5	470	139
Atmos.+ MPR	5.02×10^5	3164	1244

models or by involving very strong magnetic fields, Mannheim, Protheore, and Rachen (MPR) have argued that one might be able to avoid the WB limit and get a higher upper bound [10]. In this article, unless extra specification, the following results all make use of atmospheric neutrion flux with energy above $1GeV$ adding the conservative extraterrestrial WB Limit as the incoming neutrino flux.

The earth is opaque to ultra-high energy neutrinos, the attenuation of neutrinos must be considered: $\mathcal{I}_\nu(E_\nu, x) = \mathcal{I}_\nu^0(E_\nu)\exp(-x/l)$, where $\mathcal{I}_\nu^0(E_\nu)$ is the initial incoming neutrino flux, x is the depth a neutrino penetrating the earth, and l refers to the interaction length. Since the initial interactions produce slepton and these are nearly degenerated in flavor, the flavor of the initial neutrino does not affect the results.

The probability that a $\widetilde{\tau}$ produced in a νN interaction arrives in a detector with an energy above the $\widetilde{\tau}$ energy shreshold $E_{\widetilde{\tau}}^{min}$ depends on the range R of a $\widetilde{\tau}$ in rock, which follows from the energy-loss relation [11]

$$-\mathrm{d}E_{\widetilde{\tau}}/\mathrm{d}x = \alpha + E_{\widetilde{\tau}}/\xi, \tag{1}$$

here, the coefficients α and ξ characterize the ionization and radiation losses respectively. For numerical estimates of ionization loss here we use $\alpha = 2MeV/(gcm^{-2})$. For a given momentum impulse, the radiation energy loss is inversely proportional to the square of the mass of the radiation particle. Thus the radiation length for $\widetilde{\tau}$ is approximately $(m_{\widetilde{\tau}}/m_\mu)^2$ times large than that for muons. We take $\xi_\mu \approx 2.5 \times 10^5 g/cm^2$ in rock [11]. For those $\widetilde{\tau}$ ranging into the detector and fixing energy at $E_{\widetilde{\tau}}$, they can be contributed by any initial $\widetilde{\tau}$ with the energy above $E_{\widetilde{\tau}}$ and being produced at the distance $R(E_{\widetilde{\tau}}^{'}, E_{\widetilde{\tau}})$, therefore, the differential flux intensity can be expressed:

$$\frac{\mathrm{d}N_{\widetilde{\tau}}}{\mathrm{d}E_{\widetilde{\tau}}} = 2\pi \int_0^{\frac{\pi}{2}} \sin\theta \mathrm{d}\theta \int_0^R N_A \rho(r)\mathrm{d}x \int_{E_\nu^{th}} \mathcal{I}_\nu(E_\nu, x') \frac{\mathrm{d}\sigma_{\widetilde{\tau}}}{\mathrm{d}E_\nu \mathrm{d}E_{\widetilde{\tau}}^{'}} \mathrm{d}E_\nu, \tag{2}$$

here, we define the zenith angle θ as the angle between the incident direction of neutrinos and the direction of the line linking the center of both the earth and the detector. N_A is Avogadro's number, $\rho(r)$ corresponds to the earth density, and $r = \sqrt{(x^2 + R_\oplus^2 + 2xR_\oplus \cos\theta)}$ is the distance from the center of the earth, where $R_\oplus$ refers to the radius of the earth. We take $x' = 2R_\oplus \cos\theta - x$ instead of the distance a neutrino travelling in the earth.

In Table 1 we show the events rate for $\widetilde{\tau}$ pair production per km^2 per year on the atmospheric neutrino flux with the energy above $1GeV$ adding different extraterrestrial neutrino fluxes. For being comparable, we also show the rates of upgoing muons.

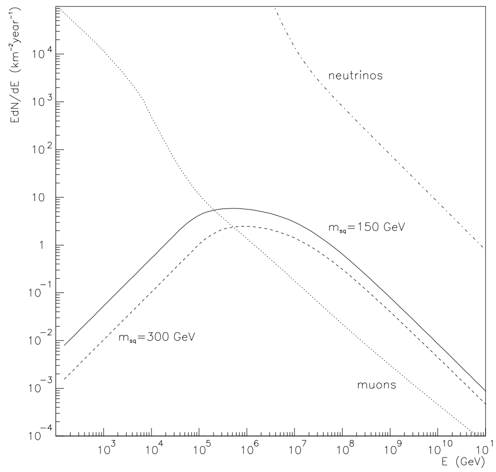

Figure 1. Energy spectrum of $\widetilde{\tau}$ pair events per km^2, per year, for $m_{\widetilde{q}} = 150, 300GeV$. Also shown are the upgoing neutrino and muon flux through the detector. We make use of atmospheric neutrion flux with energy above $1GeV$ adding the conservative extraterrestrial WB Limit as the incoming neutrino flux.

3. Possible signals analysis

High energy νN processes can produce $\widetilde{\tau}$ as well as muons. Obviously, the upgoing muons, as the background flux, will range into the detector accompanying with $\widetilde{\tau}$ by similar interacting process.

Figure 1 gives its differential energy spectrum. Some detectors have very well energy resolution, typically, L3+C detector[12], can reconstruct the exact tracks of charged particles in the magnetic field, which can determine the momentum, charges and direction of the incident particles at last. This can possibly provides the direct evidences for some exotic particles.

The NLSPs are produced in pairs and that will promptly decay into $\widetilde{\tau}$ with the average energy $(E^{'}_{\widetilde{\tau}})_{1,2} \approx 70\%(20\%)E_\nu$ [4]. As mentioned in Ref.[3], typical signal events include two tracks separated by certain distance $\delta L \approx D\vartheta$, where D refers to the distance to the production point, and ϑ is the angle between the pair particles. Figure 2 gives a Monte Carlo result for 1000 $\widetilde{\tau}$ pair events. An integral distribution for number of pair events$(< \delta L, 10m/bin)$ vs. the distance δL is gotten. From which one can conclude that typical pair events hold the δL about $120m(\sim 50\%)$ and most of them are within the confines of $320m(\sim 80\%)$. Owing to all muon signals are single tracks, seeking double tracks signals turns out to be an effective method to distinguish from background. if we take the two tracks which both enter into a detector within $\delta t = 4$ microsecond as a double-track event, then for per km^2 per $year$, the accidental coincidence rate of muons is as few as $2N_\mu N_\mu \delta t \approx 6 \times 10^{-2}$, where N_μ refers to the number of events for muons.

4. Conclusions

We discussed the exact production process of upgoing sleptons based on the long lifetime scenario with a quintessino LSP. The study shows that seeking double-track upgoing events is a feasible method to detect $\widetilde{\tau}$ signals. The event rates are also given, the quintessino-LSP scenario predicts more NLSPs than that of

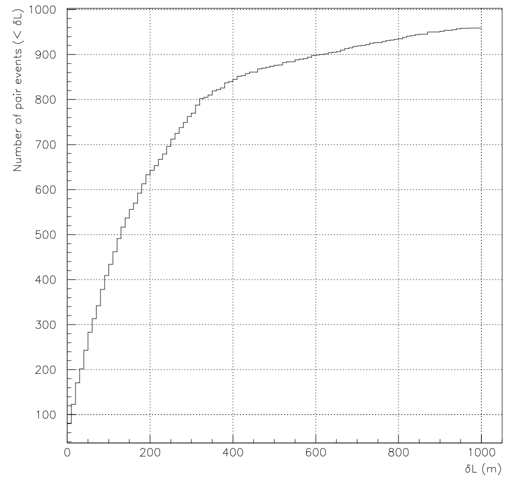

Figure 2. The Monte Carlo result for integral total 1000 pair events vs. their distance δL. We make use of atmospheric neutrion flux with energy above $1GeV$ adding the conservative extraterrestrial WB Limit as the incoming neutrino flux.

gravitino-LSP. The numeric results show that km-scale detectors are hopeful to get some positive results, such as ICECUBE[13].

The possible signals may provide a direct evidence for supersymmetry theory, furthermore, it can also offer a potential solution for dark matter problem.

References

[1] Xiao-Jun Bi, Mingzhe Li and Xinmin Zhang, *hep-ph/0308218*
[2] H.Pagels and J.R. Primack, Phys. Rev. Lett. **48**, 223(1982); S.Weinberg, Phys. Rev. Lett. **48**, 1303(1982).
[3] I. Albuquerque, G. Burdman and Z. Chacko, Phys. Rev. Lett. **92**, 221802(2004).
[4] Xiao-Jun Bi, Jian-Xiong Wang, Chao Zhang and Xinmin Zhang, *hep-ph/0404263*
[5] R. Gandhi, C. Quigg, M.H. Reno and I. Sarcevic, Astropart. Phys. **5**, 81-110(1996).
[6] Qingqi Zhu, Yuqian Ma, Linkai Ding and Chao Zhang, "Test of Monte-Carlo models with the L3+C muon spectrum measurement", 13 ISCRVHE at Pylos, 6-11 Sep. 2004, Greece
[7] R. Gandhi, C. Quigg, M.H. Reno and I. Sarcevic, Phys. Rev. **D58**, 093009(1998).
[8] E. Waxman and J. Bahcall, Phys. Rev. **D59**, 023002(1998); J. Bahcall and E. Waxman, Phys. Rev. **D64**,023002(2001).
[9] J. Ahrens *et al.*[AMNDA Collaboration], Phys. Rev. Lett. **90**, 251101(2003).
[10] K. Mannheim, R.J. Protheroe and J.P. Rache, Phys. Rev. **D63**,023003(2001).
[11] T.K. Gaisser (1990). *Cosmic Rays and Particle Physics*. Cambridge Universigy Press.
[12] O. Adriani, *et al.*, Nucl. Instrum. Methods A **488**, 209(2002).
[13] J. Ahrens *et al.*[The IceCube Collaboration], Nucl. Phys. Proc. Suppl. **118**, 388(2003).