Pramāṇa - J. Phys., Vol. 33, No. 6, December 1989, pp. 639–649. © Printed in India.

Interpretation of the recent Kolar events

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MS received 25 May 1989

Abstract. We give plausible interpretations of the unusual events seen in the proton decay detector at Kolar Gold Fields indicating the existence of a massive ($\gtrsim 2$ GeV) long lived ($10^{-8} - 10^{-9}$ s) particle. We show that it is possible to accommodate the particle in the standard model as a fourth generation neutrino, or in E_6 grand unified theory as a neutral fermion occurring in $\underline{27}$ representation or in supersymmetric theory as a scalar neutrino. However, there is a difficulty in explaining the large production rate for the particle.

Keywords. Kolar particle; heavy neutrino; fourth generation; standard model; E_6 grand unified model; heavy leptons; supersymmetric model; scalar neutrino.

PACS Nos 13·35; 14·60; 14·80; 96·40

1. Introduction

The proton decay detector at Kolar Gold Fields (KGF) recently found three events indicative of a long lived ($\sim 10^{-8}$ s) massive ($\gtrsim 2$ GeV) particle (Krishnaswamy *et al* 1986). These events are similar to earlier events found (Krishnaswamy *et al* 1975) at KGF. However, the recent events are obtained in a more refined detector which allows a clear distinction between e and μ and reliable estimates of the visible energy. Each of the three events consist of tracks corresponding to μ and an electromagnetic shower induced by an electron or a photon. Out of these, one event has a vertex in the air gap between the rock wall and detector about 6 m away from the rock wall. The vertex of the second event could be in air or in rock while the third event has a vertex inside the detector. On the basis of the high energy of the tracks, large opening angles and (in one case) a vertex about 6 m away from the rock, these events have been interpreted (Krishnaswamy *et al* 1986) as due to a slow moving particle with a lifetime of $10^{-8} - 10^{-9}$ and mass $\gtrsim 2\,\mathrm{GeV/C^2}$. Other details of the events are given in table 1 which is reproduced from Krishnaswamy *et al* (1986).

The aim of this paper is to give plausible interpretations for this particle on the basis of current theoretical framework. The limited statistics of the data does not allow us to draw any definite conclusions regarding the origin of the events. However, we are able to suggest possible scenarios which could account for most of the features found in the events. Our interpretations of the decay are consistent with the available experimental information, but we also point out how they could be ruled out by improved accelerator experiments in the future.

If we interpret the shower as being due to e, the presence of both e and μ and the

Table 1. The characteristics of the Kolar events (Krishnaswamy *et al* 1986).

Event No.	Energy in GeV Penetrating track	 Shower	Opening angle (deg.)	Vertex
1	$>1{\cdot}3$	$>2{\cdot}6$	32	in air
2	$>0{\cdot}4$	$>2{\cdot}5$	69	air or rock
3	>1	$\gtrsim 5$	41	inside detector

absence of any other charged particle in the final state is suggestive of the parent particle being neutral and we shall assume this to be the case. So, the scenerio here is different* from that of the earlier Kolar events (Krishnaswamy *et al* 1975) which were interpreted as being due to a charged particle (Rajasekaran and Sarma 1975; Sarma and Wolfenstein 1976). We shall consider three possible scenarios. The first one is in the context of the standard model and involves only a conservative and theoretically expected extension of known physics. The others are based on a E_6 grand unified model which may arise from the compactified heterotic string theories and on a supersymmetric version of the standard model.

2. The standard-model scenario

Whatever be the interpretation, it is clear that the Kolar particle which we denote by L^o should be weakly interacting. If it were a hadron, it would be difficult to understand its long life $\tau \sim 10^{-8}$ s and its penetration of rock before it emerged out. (At least in the case of the first event, the particle was apparently produced inside the rock and then it travelled a certain length of the rock before it emerged and decayed in air.) Within the standard SU(2) × U(1) model, two appropriate candidates for L^o are a neutral Higgs or a massive neutrino. In the minimal version of SU(2) × U(1), the neutral Higgs has only flavour conserving couplings to fermions and would not decay into $e^+\mu^-$ at tree level. The flavour changing couplings could appear at the tree level if more than one Higgs doublet is introduced. But in a generic model such couplings also contribute to other flavour changing effects such as $K_L - K_S$ mass difference. This contribution can be adequately suppressed only if the mass of the Higgs, causing flavour changing transitions is of the order of TeV (Sikivie 1976). In view of this, we prefer to identify L^o with a massive neutrino.

This massive neutrino L^o has to be assigned to the fourth generation since the neutrinos of the first three generations are known to be much lighter. There exists the limit $m(\nu_\tau) < 35$ MeV (Albrecht *et al* 1988) and for ν_e and ν_μ the mass limits are much lower. Because of its non-zero mass, L^o will mix with other neutrinos and thereby couple to electrons, muons and τ leptons.

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* For a simultaneous interpretation of the earlier charged particle events and the recent neutral particle events, see end of section 2.

In terms of the 4 × 4 mixing matrix U, the charged-current weak interaction in the standard model is

$$L = \frac{g}{2\sqrt{2}} \bar{\ell}_i \gamma_\mu (1 - \gamma_5) U_{ij} \nu_j W^\mu + \text{h.c.} \tag{1}$$

where $i, j = 1, 2, 3, 4$ go over the 4 generations, $\nu_4 \equiv L^o$ and ℓ_4 is its associated charged lepton. We assume that ℓ_4 is heavier than ν_4.

If ν_4 has a mass of about 2 GeV, its dominant decay modes through the interaction in (1) will be the following

$$\begin{aligned} \nu_4 &\to \mu \bar{e} \nu_e && \text{(a)} \\ &\to e \bar{\mu} \nu_\mu && \text{(b)} \\ &\to \mu \bar{\mu} \nu_\mu && \text{(c)} \\ &\to e \bar{e} \nu_e && \text{(d)} \\ &\to \mu u \bar{d} \to \mu \pi^+ \text{ etc.} && \text{(e)} \\ &\to e u \bar{d} \to e \pi^+ \text{ etc.} && \text{(f)} \end{aligned}$$

The decay rates for these processes can be estimated to be

$$\Gamma = \Gamma_\mu \left(\frac{M_4}{m_\mu} \right)^5 |U_{\mu 4}|^2 \tag{2}$$

for (a), (c) and (e), and

$$\Gamma = \Gamma_\mu \left(\frac{M_4}{m_\mu} \right)^5 |U_{e 4}|^2 \tag{3}$$

for (b), (d) and (f), where Γ_μ and m_μ denote the decay rate and the mass of the muon and M_4 is the mass of ν_4. We have taken the diagonal elements of the mixing matrix U to be unity approximately. If the lifetime and the mass of ν_4 are 10^{-8} s and 2 GeV respectively then, we get

$$|U_{e4}| \text{ or } |U_{\mu 4}| \sim 0{\cdot}5 \times 10^{-2}. \tag{4}$$

For a longer lifetime or higher mass, the required mixing would have to be still smaller.

Independent constraints already exist on the mixing of the fourth neutrino, from laboratory experiments. Let us briefly summarize these experimental constraints and show that the mixing required for our interpretation of the Kolar particle (i.e. eq. (4)) is consistent with them. These experiments have been discussed by Gilman (1986) to whom we refer for the original references.

Three types of experiments constrain the mixing of the heavy neutrino in the mass range > 1 GeV. (A) A ν_4 beam could be produced in beam dump experiments through the decays of charmed mesons. The decay products of ν_4 are then subsequently detected. Depending upon the distance between the detector and the beam dump one could constrain the lifetime and hence the mixing of ν_4 with ν_e and ν_μ. These experiments are sensitive for M_4 (mass of ν_4) $\lesssim 1{\cdot}5$ GeV and give the limits:

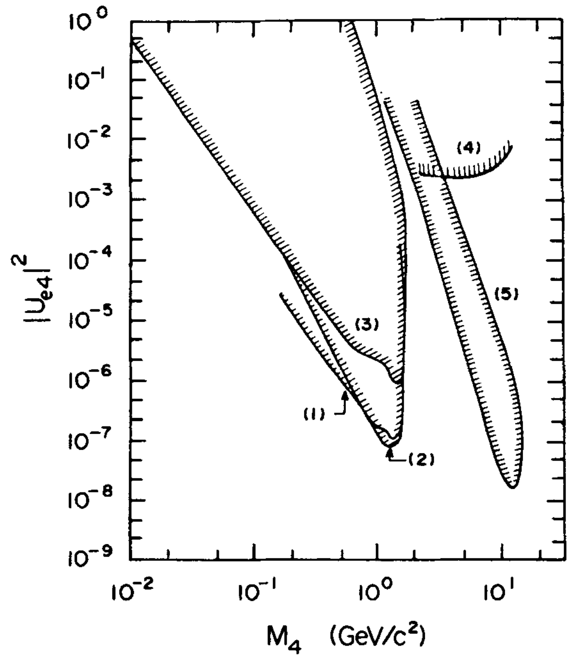

Figure 1. Limits on $|U_{e4}|^2$ as a function of the mass of the fourth neutral lepton adapted from Gilman (1986). Curves 1–3, 4 and 5 respectively denote limits obtained in type A, B, C experiments discussed in the text. Limits on $|U_{\mu 4}|^2$ are similar.

$|U_{e,\mu}|^2 < 10^{-6}$ (see figure 1). (B) In the second type of experiments, ν_4 is produced through the charged current process $e^+e^- \rightarrow \nu_4\bar{\nu}_e$. These events resemble monojet events whose search at PEP and PETRA gives the limit displayed in figure 1. (C) $\nu_4\bar{\nu}_4$ pairs could be produced also through Z^o exchange in e^+e^- annihilation and subsequent decays of ν_4 could be searched for. Such a search carried out at PEP at a distance between 0·2 and 10 cm from the interaction points exclude a region of $|U_{e4}|^2$ shown in the figure 1. The latter two types of experiments could explore a larger mass range (limited only by the center of mass energy of e^+e^-) of ν_4 compared to the first type.

It is clear from figure 1 that so far there does not exist any significant constraint on the mixing of ν_4 if its mass lies in the range $1 - 3$ GeV which is the region of interest for us. In fact there is a "hole" in the diagram just in this region. Hence, the mixing ($U^2 \sim 10^{-4} - 10^{-5}$) required to account for the lifetime of $10^{-9} - 10^{-8}$ s is allowed in this mass range. To check this interpretation one should search for ν_4 in this mass range. However, the existing limit on U^2_{e4} or $U^2_{\mu 4}$ can be improved by increasing the distance between the detector and the interaction point in the third type of experiments. Similarly, just as in the case of the charmed mesons, one could use the ν_4 produced from B-mesons in beam dump experiments to extend the limit to masses around 2·5 GeV. It has been suggested (Rosner 1985) that such an experiment could explore the region upto $U^2 \sim 10^{-6}$ for masses $\lesssim 2{\cdot}5$ GeV. Thus, it should be possible to confirm or rule out our interpretation by improved laboratory experiments.

By comparing the number of events containing L^o with the number of all the confined and partially confined events, Krishnaswamy et al (1986) conclude that if the former are assumed to be produced by neutrinos, the L^o event rate should be $\lesssim 5\%$ of the known ν-interactions. With the present interpretation, a production rate as high as 5% seems hard to understand. This is because the mixing which makes L^o long lived, suppresses production also in most of the reactions. If the L^o particles are produced in ν-interactions then one might expect a production rate suppressed by a factor $U^2 \sim 10^{-4}$, compared to the other ν-interactions. There exist however situations in which L^o production does not involve the mixing factor U^2. If the neutrino interacting with rock produces a hadron which could decay via neutral current to a $\nu_4\bar{\nu}_4$ pair, then U^2 would not enter the production cross section, since coupling of neutrinos of Z is flavour diagonal. One such example is the production of the upsilon ($b\bar{b}$) which has a mode of decay into $\nu_4\bar{\nu}_4$, but the branching ratio is expected to be quite small ($\sim 10^{-6}$).

The U^2 suppression would be absent if the ν_4 is produced in association with the fourth generation charged lepton ℓ_4 in the rocks. The upper limit on the charged lepton mass is 22·7 GeV on the basis of experiments at PETRA (Komamiya 1985) and 45 GeV set by the UA1 experiments (Honma 1986). However, Perl (1986) has argued that a low mass ℓ_4 cannot be ruled out if ℓ_4 and ν_4 are close in mass because of the kinematical cuts imposed in deriving the limit on m_{ℓ_4}. The analysis by Stoker and Perl (1987) shows that m_{ℓ_4} in the range 2–3 GeV is not ruled out experimentally if $m_{\nu_4} \sim 2$ GeV. If such a low mass ℓ_4 exists then sizeable production of $\ell_4\bar{\nu}_4$ would be possible by cosmic ray neutrinos interacting inside the rock. They can, for example, be produced by ν_e interacting with electrons or by secondary pions interacting with rocks.

If the masses of ℓ_4 and ν_4 are nearly equal then the earlier Kolar events (Krishnaswamy *et al* 1975) could also find an explanation within the present scheme. They were interpreted as due to a charged lepton (Rajasekaran and Sarma 1975; Sarma and Wolfenstein 1976) which in the present scheme could be identified with ℓ_4. The ℓ_4 could decay into $\nu_4 e\bar{\nu}_e$, $\nu_4\mu\bar{\nu}_\mu$ etc. through the charged current interaction. Due to the proximity of the masses of ℓ_4 and ν_4, the decay of ℓ_4 will however, be greatly suppressed accounting for the relatively long lifetime observed (Krishnaswamy *et al* 1975). However it is difficult to explain the decay into three charged leptons seen in the earlier events.

3. E$_6$-model scenario

In this scenario, we consider an extension of the standard model. The relevant group for our purpose is $G = \mathrm{SU(2)}_L \times \mathrm{U(1)}_Y \times \mathrm{SU(2)}' \times \mathrm{U(1)}_{Y'}$. We were led to this group by a study of the E_6 group, which naturally arises in compactified string theory (Candelas *et al* (1985)). Many different embeddings of G in E_6 have been considered in literature (see for instance, Deshpande (1986)). We consider a specific embedding which is such that a neutral fermion which occurs in the 27-plet of E_6 can decay only through the additional $\mathrm{SU(2)}' \times \mathrm{U(1)}_{Y'}$ interactions. The corresponding gauge bosons are expected to be heavier than W and Z, making $\mathrm{SU(2)}' \times \mathrm{U(1)}_{Y'}$ interactions weaker than $\mathrm{SU(2)}_L \times \mathrm{U(1)}$. Thus, the relatively long lifetime for the neutral fermion can be explained.

The $\underline{27}$ representation of E_6 to which the fermions of one generation belong contains new charged (E^+, E^-) as well as neutral (L, N, N^c) leptons and d-like quarks (D, D^c)

in addition to the usual 16 fermionic states of the same helicity. The lepton L is a singlet under SO(10) but couples to normal matter through SU(2)′ interactions which are chosen to lie outside the SO(10). The quantum numbers of the fermions with respect to G are shown in table 2. Since there are many neutral leptons in the E_6 model, there are many possibilities for interpreting the Kolar particle. But we restrict ourselves to one possibility.

From table 2, it is clear that L does not couple through normal weak interactions. Moreover, it couples only to $\mathrm{SU}(2)_L$ singlet states u^c, D^c and e^+. Since the charged 1/3 quark D^c is expected to be much heavier than 2 GeV, L cannot decay to quarks at all. This makes it an ideal candidate for L^0. We shall, therefore, identify L^0 with the L_μ contained in the 27-plet corresponding to the second (i.e. muonic) generation. If the masses of the other neutral fermions N, N^c are higher* than m_{L_μ} and if $m_{L_\mu} > m_{L_e}$ then the only allowed decay for L_μ is

$$L_\mu \to \bar{L}_e \mu e.$$

This occurs as shown in figure 2. We are neglecting here mixing among various charged and neutral leptons. When mixing is allowed, other channels are available,

Table 2. Transformation properties of the first generation fermions belonging to the representation $\underline{27}$ of E_6 under the subgroup $\mathrm{SU}(3)_C \times \mathrm{SU}(2)_L \times \mathrm{SU}(2)' \times \mathrm{U}(1)_Y \times \mathrm{U}(1)_{Y'}$. All the fermions shown in the first column are taken to be left-handed. $\mathrm{SU}(2)_L$ ($\mathrm{SU}(2)'$) acts vertically (horizontally) on the doublets.

	$\mathrm{SU}(2)_L$	$\mathrm{SU}(2)'$	Y	Y'	$\mathrm{SU}(3)_C$
$q{:}\begin{pmatrix} u \\ d \end{pmatrix}$	2	1	1/6	0	3
D	1	1	−1/3	0	3
d^c	1	1	0	1/3	3
(D^c, u^c)	1	2	0	−1/6	3
$\begin{pmatrix} E^+ & \nu \\ N^c & e^- \end{pmatrix}$	2	2	−1/6	1/6	1
$\begin{pmatrix} N \\ E^- \end{pmatrix}$	2	1	−1/6	−1/3	1
(e^+, L)	1	2	1/3	1/6	1
ν^c	1	1	1/3	−1/3	1

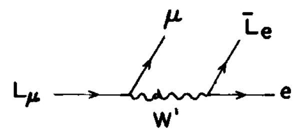

Figure 2. Decay of L_μ into $(e\mu \bar{L}_e)$ in E_6 model. W' is a new charged boson corresponding to the new SU(2)′ interaction.

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* In the converse case one could assign L^0 to N or N^c. We do not consider this possibility.

but they will be suppressed if the mixing is small. The value of the effective Fermi coupling G'_F for the SU(2)′ interations can be estimated from the lifetime of $L^o \sim 10^{-8} - 10^{-9}$ s. If $m_{L_\mu} \gg m_{\bar{L}_e}$ then we should have

$$\frac{\tau_L}{\tau_\mu} \sim \left(\frac{G_F}{G'_F}\right)^2 \left(\frac{m_\mu}{m_{L_\mu}}\right)^5, \tag{5}$$

where G_F is the usual Fermi coupling associated with $\mathrm{SU}(2)_L$. Let us write $G' \sim g'^2/m_{W'}^2$, where g' and $m_{W'}$ are the coupling constant and mass of the gauge bosons which mediate the SU(2)′ interactions. Then for $g' \sim g$, eq. (5) implies $m_{W'} \sim 10 m_W$ if $\tau_L \sim 10^{-8}$ s, and $m_{L_\mu} \sim 2$ GeV. Thus with $m_{W'}$ in the theoretically expected mass range of TeV, one could explain the relatively long lifetime for L_μ. The corresponding particle L_e for the first generation remains stable at this level.

Just as in the previous case, the underlying physics (namely, small effective coupling) which makes L_μ long lived, also suppresses its production. Additional mechanisms for the production of L_μ inside the rocks are possible if L_μ mixes with ν_e, ν_μ. Such mixing would occur in any generic model. In this case, L_μ would couple to e, μ through conventional charged current and could be produced as in the previous scenario. This mixing cannot however be large, otherwise L_μ would decay fast. As a result, one may not be able to account for the large production rate.

4. Supersymmetric scenario

In this scenario, we identify the Kolar particle with a scalar boson $\tilde{\nu}_\mu$ which is the supersymmetric (SUSY) partner of ν_μ. This interpretation naturally explains the decay pattern observed experimentally if some reasonable assumptions are made about the masses of the supersymmetric particles involved. We assume that $\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$ obey a mass hierarchy so that $\tilde{\nu}_e$ is the lightest neutrino. We shall also assume the photino ($\tilde{\gamma}$) mass to be sufficiently large so that the decay $\tilde{\nu}_\mu \rightarrow \nu_\mu \tilde{\gamma}$ is kinematically forbidden. The existing lower limits (Yost *et al* 1988) on the masses of the SUSY particles are ($m(\tilde{q}) > 60 - 70$ GeV, $m(\tilde{e}^\pm) \gtrsim 20$ GeV if $m(\tilde{\gamma}) < 15$ GeV). It is clear that a light $\tilde{\nu}_\mu$ with mass $M \sim 2 - 4$ GeV would have a very small number of decay channels available to it, namely

$$\tilde{\nu}_\mu \rightarrow \mu^- e^+ \tilde{\nu}_e \tag{A}$$

$$\rightarrow \nu_\mu \bar{\nu}_e \tilde{\nu}_e \tag{B}$$

$$\rightarrow \nu_\mu \nu_e \bar{\tilde{\nu}}_e. \tag{C}$$

Out of these, the only observable decay mode (A) of $\tilde{\nu}_\mu$ will have the unique signature found in the Kolar events.

To make this interpretation quantitative, we use the interactions given by the SUSY standard model (see eg. Dawson *et al* 1985 and other references therein). The decay of $\tilde{\nu}_\mu$ in this model proceeds through the diagrams given in figure 3. In these diagrams, $\tilde{W}$ and $\tilde{Z}$ are the SUSY partners of the usual W and Z bosons. Assuming the supersymmetric lepton mixing matrix to be unity, we get for the partial width for

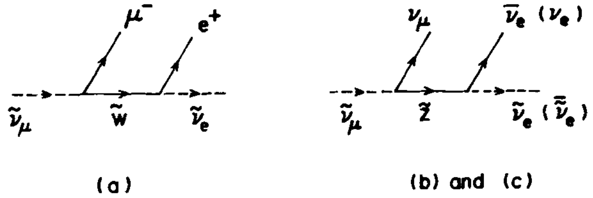

Figure 3. Decay of the scalar neutrino $\tilde{\nu}_\mu$.

the charged decay mode (A):

$$\Gamma_A = \frac{G_F^2 M^5}{192\pi^3}\left(\frac{m_W}{m_{\tilde{W}}}\right)^4 f(r) \tag{6}$$

where M is the mass of $\tilde{\nu}_\mu$ and

$$f(r) \equiv (1-r^4)(1-8r^2+r^4) - 24r^4 \ell n r; \quad r = \frac{m(\tilde{\nu}_e)}{M}. \tag{7}$$

The maximum value of the kinematic factor $f(r)$ occurs in the limit of massless $\tilde{\nu}_e, f(0)=1$, and decreases steadily to zero as $r \to 1$.

Given the lifetime τ for the Kolar particle, (6) and (7) can be used to find the wino mass $m_{\tilde{W}}$ as a function of the ratio r. We get

$$\begin{aligned} m_{\tilde{W}} &= m_W\left(\frac{M}{m_\mu}\right)^{5/4}\left(\frac{\tau}{\tau_\mu}\right)^{1/4}(f(r))^{1/4} \\ &\approx 471\cdot7\,\text{GeV}\,[f(r)]^{1/4}. \end{aligned} \tag{8}$$

In the last line we have used $M \sim 2\,\text{GeV}, \tau \sim 10^{-9}$ s and $m_W = 81\cdot8$ GeV. For a massless $\tilde{\nu}_e$, (8) requires a very heavy gaugino. A large class of SUSY models (Haber and Kane 1985) predict that the wino has a smaller mass than the W-boson. For this to be valid we must have $r \geqslant 0\cdot85$. Thus, this class of SUSY models would require $0\cdot85\, m(\tilde{\nu}_\mu) < m(\tilde{\nu}_e) < m(\tilde{\nu}_\mu)$.

To be more precise, τ in (8) should be replaced by the unknown partial lifetime τ_A since the $\tilde{\nu}_\mu$ has two neutral decay channels (B) and (C). The rates for these channels through the exchange of the zino, $\tilde{Z}^o$, are given by

$$\Gamma_B = \Gamma_C = \frac{G_F^2 M^5}{768\pi^3}\left(\frac{m_Z}{m_{\tilde{Z}}}\right)^4 f(r), \tag{9}$$

so that the total decay rate is $\Gamma_A + 2\Gamma_B$. Comparing, (6) and (9), it is clear that the estimate of (8) will not be substantially modified as long as $m_{\tilde{Z}}$ is comparable or larger than $m_{\tilde{W}}$.

We now come to production mechanisms. One may envisage two types of production processes for $\tilde{\nu}_\mu$, namely deep inelastic lepton-hadron scattering

$$\ell + q \xrightarrow[W,Z,\tilde{\gamma}]{} \tilde{\ell} + \tilde{q}$$

and the Drell-Yan process

$$\bar{q} + q \xrightarrow[W,Z,\gamma]{} \bar{\tilde{\ell}} + \tilde{\ell}$$

where ℓ is a generic symbol and denotes the leptons μ, ν_μ etc. and similarly $q, \tilde{\ell}$ and $\tilde{q}$ denote quarks, scalar leptons and scalar quarks respectively.

In the first type of process, the leptons $\overset{(-)}{\nu}_\mu$ or $\overset{(-)}{\mu}$ can scatter off from a quark of the nucleus either in the atmosphere or in the rock surrounding the mine. However, the limits on the masses of the SUSY particles, given earlier imply that the threshold energies of the lepton for these reactions are above 2 TeV. Since the lepton fluxes in the TeV region are negligibly small in the cosmic rays and since the cross sections also are small due to the exchange of massive $\tilde{W}$ and $\tilde{Z}$, these reactions appear to be unlikely candidates, for producing $\tilde{\nu}_\mu$.

In the second type of process, which is the Drell-Yan fusion of $\bar{q}q$, we have the advantage that it involves hadron-hadron collisions. To be more specific, let us write them in detail in the form

$$\bar{q} + q \xrightarrow[Z]{} \bar{\tilde{\nu}}_\mu + \tilde{\nu}_\mu \tag{10a}$$

$$\bar{q} + q \xrightarrow[\gamma]{} \bar{\tilde{\mu}} + \tilde{\mu}; \quad \tilde{\mu} \rightarrow \tilde{\nu}_\mu + \bar{\nu}_e + e^- \tag{10b}$$

$$\bar{q} + q' \xrightarrow[W]{} \bar{\tilde{\mu}} + \tilde{\nu}_\mu. \tag{10c}$$

The thresholds of these processes are 20 GeV, 1 TeV and 350 GeV respectively. Process (10a) has low enough threshold, but the cross section is small because it is a weak process. Process (10b) is electromagnetic, but the threshold is too high. Cosmic-ray produced hadrons in the atmosphere are relatively rare in the TeV region. Process (10c) is not only weak but in addition has a high threshold. Hence, again none of these processes seem to be capable of producing $\tilde{\nu}_\mu$ to the extent required in the Kolar experiments.

5. Concluding remarks

We have considered in this paper some possible scenarios to account for the surprisingly long lifetime of the particle found at KGF. The first of our scenarios is completely conventional and is shown to accommodate the KGF particle if a fourth generation exists. Improved accelerator experiments can test the hypothesis. Our second and third scenarios invoke new physics present in a grand unified E_6 model and a supersymmetric model respectively.

We do not have a clear understanding of the production mechanism in the scenarios considered here but some qualitative possibilities have been discussed. In particular, we have pointed out the interesting possibility of both the charged and neutral leptons of the fourth generation being in the mass region of 2 GeV. In this case production of the Kolar particles (identified as neutral leptons for the recent events and charged leptons for the older events) is not suppressed. More statistics at KGF and independent checks at accelerator experiments and at other non-accelerator experiments such as

Frejus would be needed before confirming or ruling out the interpretations given here.

We may ask whether there is any evidence in the accelerator experiments so far for the type of events seen by the KGF group. In this connection we note that the Aachen spark chamber group reported the tantalizing observation of a dozen anomalous events containing (μe) pairs produced with the CERN PS wideband neutrino beam, with an average energy of 2·2 GeV (Faissner *et al* 1981). For possible interpretations of these events, see Rein *et al* (1978). However a recent neutrino experiment at BNL does not confirm the CERN observations (Ahrens *et al* 1987).

One may also draw attention to the excess electron production apparently observed in some neutrino experiments. In an experiment by Bernardi *et al* (1986) with a neutrino beam extracted from the CERN proton synchrotron, the neutrino beam consisted predominantly of ν_μ and the ν_e contamination was estimated to be less than 1%. However more neutrino interactions producing electrons were seen than expected, as though ν_e made up 2–3% of the beam. Although such an excess of electrons was not seen in the experiment of Blumenfeld *et al* (1989) at the Brookhaven neutrino beam, a repetition of the experiment at Brookhaven by the other group who had earlier seen the electron excess at CERN continues to see the excess (Astier *et al* 1989). Clearly the experimental situation needs clarification. Here we only wish to point out that if such an electron excess is established it may be attributed, at least in part, to be due to ν_e in the beam arising from the decay of ν_4 (the decay modes (a) and (d) in §2).

Acknowledgements

We thank M R Krishnaswamy, V S Narasimham, S D Rindani and L M Sehgal for many helpful discussions. GR acknowledges the hospitality of the Tata Institute of Fundamental Research where this work was completed.

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