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U_3(W)-gauge theory IV. The Kolar events

L K PANDIT and S N PANDIT
Tata Institute of Fundamental Research, Bombay 400 005

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Abstract. Pursuing the starting motivation of the recently proposed U_3 (W)-gauge theory of weak and electromagnetic interactions, we attempt a rough quantitative description of the origin of the unusual Kolar events reported in deep underground cosmic ray neutrino experiments by Krishnaswami *et al.* These events are interpreted as due to production, in ν_μ-nucleon collision, of a charged heavy muonic lepton M^- in association with hadrons carrying new heavy quark flavours named grace and taste (g, t), followed by the decay $M \to E + e + \mu$, where E is another heavy lepton of the electronic type. The production cross-sections are estimated by using the standard quark parton model. The long life of the Kolar particle is explained by taking the mass difference of the M and the E to be sufficiently small. With suitable illustrative choices of the masses of the proposed new particles involved, it is shown that the threshold for production could be rather high so that neutrinos with energy of several hundreds of GeV upwards, available in cosmic rays, may be responsible for the processes suggested here for explaining the Kolar events. Comments are made relating to the currently available accelerator neutrinos in this context. Attention is also drawn to the possible role of the above heavy leptons in interpreting the events recently observed in cosmic ray experiments at Tbilisi.

Keywords. U_3(W)-gauge theory; Kolar events; heavy leptons; new flavours; grace; taste; neutrinos.

1. Introduction

Stimulated by the report of certain unusual events, suggestive of a new long-lived heavy particle, observed in the deep underground experiments at Kolar (Krishnaswami *et al* 1975), a unified U_3 (W)-gauge theory of weak and electromagnetic interactions was proposed recently (Pandit 1976, referred to as I). It was assumed in this theory that sufficiently energetic cosmic ray neutrinos can produce a new heavy charged lepton to be identified with the Kolar particle. Along with new leptons, two new quark flavours (called taste and grace) beyond the older four (including charm) had to be introduced. According to the model, the new (Kolar?) lepton can only be produced in association with new (still to be discovered) hadrons carrying taste and/or grace. Thus the threshold for the production will be accordingly high, depending on the masses of the new particles involved. And, since, the presumed Kolar-lepton has to decay only into a set of particles that must include a new heavy particle, its life-time depends on the mass-differences involved, which may be suitably chosen to adjust to the desired large value for the life-time.

After formulating the general framework of the model in paper I, wherein only qualitative remarks were made on the experimental consequences, some approximate quantitative implications for the weak neutral current phenomena were studied and reported (Pandit 1977a; to be referred to as II). It was found that the observed neutral current phenomena involving neutrinos can be reasonably well described by the model. In a subsequent work (Pandit 1977b; to be referred to as III) it was also shown how a slight natural generalisation of the mechanism adopted for the spontaneous breaking of the gauge symmetry is capable of producing a rather small parity-violation in atomic Bi (studied experimentally by Lewis *et al* 1977; Baird *et al* 1977).

In the meantime, the recent discovery of Υ's in the 10 GeV region (Herb *et al* 1977), suggesting the existence of a new flavour beyond charm, makes our introduction of taste- and grace-carrying quarks into a possibly reasonable proposition also from the experimental point of view.

Having satisfied ourselves, thus, that the $U_3(W)$-gauge theory framework is in reasonable accord with the conventional old charged-current as well as the more recently discovered neutral-current weak interaction phenomena, we now address ourselves to the starting motivation for proposing the model. That is, we wish to establish by approximate quantitative calculations, assuming for orientation some suitable values for masses of the relevant (yet to be established) heavy leptons and taste- and grace-carrying hadrons, that the Kolar events might well be as envisaged in the model. At this stage, this is all we can reasonably hope to do.

The main question we have to address ourselves to is: can we account for the rather long life of the Kolar particle concomitantly with its rather large production by cosmic ray neutrinos? With certain assumptions that donot contradict well established experimental results, our answer to this crucial question will, to a reasonable extent, be in the affirmative.

Further, although accelerator neutrino experiments have not so far been set up to look for Kolar type events, arising from the production and decay of a charged heavy lepton as suggested by us, we shall assume that the presently available accelerator neutrino energies do not suffice to produce these in a sizable number.

On the other hand, in cosmic rays we can have extremely energetic neutrinos capablve of producing such events. At the highest energies, neutrinos may arise through decays of many new particles (yet to be discovered) as expected in the $U_3(W)$ gauge theory scheme, besides from the conventional mechanism involving decays of pions, kaons and muons. In fact, the recent ' Beam Dump Experiments ' might be taken as suggesting the existence of such new additional sources of approximately equal numbers of electronic and muonic neutrinos (Alibran *et al* 1978; Hansl *et al* 1978; Bosetti *et al* 1978).

We also point out (end of § 5) that the heavy lepton, identified here with the Kolar particle, could very well be responsible for the events recently seen in cosmic ray experiments at Tbilisi (Barnaveli *et al* 1977).

In § 2 we write down the relevant interaction Lagrangian and discuss the suggested scenario for the Kolar events. In § 3 we discuss the decays of the heavy leptons in question. Section 4 is devoted to describing the parton model calculation of the neutrino production of these heavy leptons. Finally the interpretation of the Kolar events is taken up in § 5.

2. The interaction and the scenario

Referring to § 5 of paper I, we pick out the terms in the interaction Lagrangian density relevant to our present discussions:

$$L_{int} = -f/\sqrt{2}\,[R_\mu{}^+ J_\mu(R^+) + H_\mu J_\mu(H) + \text{h.c.}] + \ldots, \tag{1}$$

$$-iJ_\lambda(R^+) \equiv \bar{\nu}_e\,\Gamma_\lambda\, E + \bar{\nu}_\mu \Gamma_\lambda M - \bar{t}'\Gamma_\lambda d' - \bar{g}'\Gamma_\lambda s' + \ldots, \tag{2}$$

$$-iJ_\lambda(H) \equiv \bar{e}\Gamma_\lambda E + \bar{\mu}\Gamma_\lambda M - \bar{t}'\Gamma_\lambda u - \bar{g}'\Gamma_\lambda c + \ldots,$$

$$\Gamma_\lambda \equiv \tfrac{1}{2}\,\gamma_\lambda\,(1+\gamma_5), \tag{3}$$

where d' and s' denote the standard Cabibbo rotated (angle θ_c) combinations of the d and s quarks; t' and g' similarly denote rotated combinations of the t and g quarks, rotated by an angle θ'. It is important to note, however, that the (higher order one loop) hadronic $|\triangle S| = 2$ effective interaction responsible, e.g., for the $K_L - K_S$ mass-difference implies a stringent constraint on $(\theta' - \theta_c)$. The consideration follows Gaillard and Lee (1974) and Vainshtein and Khriplovich (1973) determining the mass of the c-quark. The currently accepted value of the mass of the c-quark already accounts for the $K_L - K_S$ mass-difference and hardly any room is left for the contribution of the g and t quarks. To ensure a vanishing contribution from the g and t quarks, which is proportional to $\sin^2 2(\theta' - \theta_c)$, it is thus necessary for us to postulate that $\theta' = \theta_c$.

Ignoring the generalisation of the gauge symmetry-breaking mechanism considered in III in connection with the question of parity-violation in atomic physics, as it can imply only minor corrections to our calculations here, we have for the masses of the intermediate vector bosons of interest here:

$$m^2(R) = m^2(H) = m^2(W) \gtrsim (43\ \text{GeV})^2. \tag{4}$$

Here W stands for the intermediate vector boson coupled to the conventional charged current. We note the relation of the coupling constant f with the standard effective four-fermion Fermi coupling constant G:

$$G = f^2/[4\sqrt{2}\,m^2(W)] \simeq 1{\cdot}026 \times 10^{-5}\, m_p^{-2}. \tag{5}$$

On account of (4), the effective four-fermion interactions of interest to us here, arising from the mediation of the R and H vector bosons, will also be characterized by the Fermi constant G. Thus the neutrino-induced productions of the E and the M could, once the thresholds have been overcome, be rather sizable.

We have now to decide on a scenario for the Kolar events. For this we need to assume a suitable ordering and values of the masses of the particles involved. Denoting by H_g and H_t the least massive hadrons carrying grace and taste, respectively, we shall assume for the ordering of the masses:

$$m(H_t) > m(H_g) > m(M) > m(E). \tag{6}$$

Then (see § 3) the heavy lepton E will be a stable particle and the lepton M will have just the following two decay channels available.

$$M^- \to E^- + \mu^- + e^+, \tag{7a}$$

$$M^- \to E^- + \nu_\mu + \bar{\nu}_e, \tag{7b}$$

mediated, respectively, by the H and the R vector bosons, according to the interaction (1) to (3). The decay (7a), wherein all the three final particles are charged, will be observationally spectacular. We assume this to correspond to the observed Kolar events.

We shall assume that the recently discovered Υ states at around 10 GeV (Herb *et al* 1977) suggest the existence of a new heavy-quark with mass around 5 GeV. We shall be led to identify this with our g-quark. Thus $m\ (H_g)$ may be taken to be $\approx$ 5-6 GeV. We shall also be led to adopt tentatively a suitably high value ($\gtrsim 10$ GeV) for the t-quark mass (see § 4).

The long life of the Kolar particle will be incorporated here by taking (see § 3) a sufficiently small value for $m\ (M) - m\ (E)$, of the order of 2-3 times $m\ (\mu)$. Thus the E and the M are very close in mass.

Any charged stable or long-lived heavy leptons that be (like the E and the M) are not produced in e^+e^- annihilations at the highest energies available so far. Also, we note in passing, that the measured value ($\simeq$ 5·5) of $R \equiv \sigma(e^+e^- \to X)/\sigma(e^+e^- \to \mu^+\mu^-)$, where X stands for anything other than $e\bar{e}$ and $\mu\bar{\mu}$, at the present highest available energy of around 7·8 GeV still leaves room for only one short-lived new heavy lepton. The triply coloured quarks u, d, s and c provide $3\frac{1}{3}$ units, and the newly discovered heavy lepton τ (designated the l_1 in paper I) provides an additional unit, leaving room for only one more unit, which we take is provided by another heavier lepton, say the l_2 of the U_3 (W)–gauge theory (I). For the E and the M we thus adopt higher masses $\approx$ 4–5 GeV.

Of course, we should still keep open the possibility that $m(E) > m(M)$. In that case it is the E that will be identified with the Kolar particle produced in ν_e reactions. Our considerations below will then apply with obvious changes of particle symbols. For definiteness, we shall now on keep to the ordering specified in (6). This appears more favourable a choice, since the flux of the ν_μ is expected to be larger than that of the ν_e in cosmic rays and the rather large rate of the Kolar events would need the kind of neutrinos with the larger flux.

3. Decays and life-times of the *M* and the *E*

The only decay modes available to the M are those of (7):

$$M^- \to \begin{cases} E^- + \nu_\mu + \bar{\nu}_e \\ E^- + \mu^- + e^+ \end{cases}$$

Of these the latter involves three charged particles in the final state and is supposed to correspond to the spectacular Kolar events. The E has clearly no such decay channels available, on account of the assumed ordering of the masses given in (6).

Before we discuss the rates for these decays, it is important to note that

$$M \not\to \mu + \gamma,$$

$$E \not\to e + \gamma,$$

even though higher order weak interactions involving loops of intermediate vector bosons. This is because, e.g., whereas the vector boson W couples to $(\bar{\nu}_\mu \mu)$, it is the vector boson R that couples to $(\nu_\mu M)$, etc. Such mismatches of the intermediate vector bosons involved do not permit the closing of vector boson loops needed for a decay like $M \to \mu + \gamma$ in higher orders. The E, being a stable charged heavy lepton in our picture, will appear as a very penetrating particle that could be confused with the muon in detection systems.

For the decay rates we use the following formula (Bjorken and Llewellyn Smith 1973):

$$\frac{\Gamma(M \to E\,\nu_\mu\,\nu_e)}{\Gamma(\mu \to e\,\nu_\mu\,\bar{\nu}_e)} = \left[\frac{m\,(M)}{m\,(\mu)}\right]^5 f_1\,(z), \tag{8}$$

where

$$f_1\,(z) \equiv (1-z^4)\,(z^4-8\,z^2+1) + 24\,z^4\,(\ln\,(1/z);\; z \equiv m\,(E)/m(M), \tag{9}$$

and $m\,(M)$ stands for the mass of the M, etc. We are interested in the case where

$$[m\,(M) - m\,(E)]\,/m\,(M) \ll 1, \tag{10}$$

to account for the long life of the M (the assumed Kolar particle). In this case we have

$$\Gamma\,(M \to E\,\nu_\mu\,\bar{\nu}_e)/\,\Gamma\,(\mu) \simeq \frac{64}{5}\left[\frac{m(M)-m(E)}{m(\mu)}\right]^5\left[1-\frac{3}{2}\,\frac{m(M)-m(E)}{m(M)}\right]. \tag{11}$$

Also, taking the phase space ratios and ignoring the e mass for an approximate estimate, we have

$$\begin{aligned} r &\equiv \Gamma\,(M^- \to E^-\,\mu^-\,e^+)/\Gamma(M^- \to E^-\,\nu_\mu\,\bar{\nu}_e) \\ &\simeq (1-\delta^2)^{1/2}\left(1-\frac{9}{2}\,\delta^2 - 4\,\delta^4\right) + \frac{15}{2}\,\delta^4 \ln\,\frac{1+(1-\delta^2)^{1/2}}{\delta}\,; \\ \delta &\equiv m\,(\mu)/[m\,(M) - m\,(E)]\,. \end{aligned} \tag{12}$$

Some typical values for r and the life-time are given below for $m\,(M) \simeq 40\; m\,(\mu)$:

$$\begin{aligned} \delta &= \tfrac{1}{3} : r \simeq 0{\cdot}6, \quad \tau\,(M) \simeq 5 \times 10^{-10}\,\text{s}, \\ \delta &= \tfrac{1}{2} : r \simeq 0{\cdot}3, \quad \tau\,(M) \simeq 5 \times 10^{-9}\,\text{s}. \end{aligned} \tag{13}$$

Thus the desired long-life-time can be accounted for by a suitable choice of $m\,(M) - m\,(E)$; the actual value of $m\,(M)$ hardly affects the results as long as the inequality (10) holds.

4. Neutrino production of the *M* and the *E*

We shall now make elementary, and by now quite standard, quark parton picture calculations for estimating the cross-sections for the production of the M and the E

by collisions of the ν_μ and the ν_e with an average nucleon. The crucial point of importance, in the U_3 (W)-gauge theory, is that these heavy leptons must necessarily be produced in association with the new heavy quarks carrying taste or grace. This will raise the thresholds accordingly.

For outlining the steps let us consider the production of the M in ν_μ collisions. The elementary processes of interest in terms of quarks, corresponding to the R-mediated interactions of (1) to (3) are:

$$\nu_\mu + d' \to M^- + t', \tag{14a}$$

$$\nu_\mu + s' \to M^- + g', \tag{14b}$$

$$\bar{\nu}_\mu + \bar{d}' \to M^+ + \bar{t}', \tag{15a}$$

$$\bar{\nu}_\mu + \bar{s}' \to M^+ + \bar{g}'. \tag{15b}$$

The average nucleon target has only the d available in its valence quarks. The 'sea' quarks and anti-quarks in the nucleon provide also s, $\bar{s}$, $\bar{d}$ and d. We assume the new heavy quark components in the 'sea' to be entirely negligible. Thus M^+ production in $\bar{\nu}_\mu$ collisions will be greatly suppressed with respect to the M^- production in ν_μ collisions on account of the former having to rely on the presence of the 'sea' in the target nucleon. This is an important characteristic of our model.

If, as an approximation, we ignore the small Cabibbo angle (i.e., take $\sin\theta_c = \sin\theta' \simeq 0$) the dominant reactions initiated by ν_μ are:

$$\nu_\mu + d \to M^- + t, \tag{16a}$$

$$\nu_\mu + s \to M^- + g. \tag{16b}$$

Since the t quark is assumed much more massive than the g quark, the threshold for the process (16a) will be much higher than that for the process (16b). On the other hand, the process (16b) will go via the s quark available only in the sea component of the nucleon. Thus the particular ordering and values of the t and g quark masses is used to suppress Kolar type of events with the presently available accelerator neutrinos.

The elementary processes (14) and (15) are to be used in arriving at the cross-sections for the following physical processes in the laboratory:

$$\nu_\mu + N \to M^- + X, \tag{17a}$$

$$\bar{\nu}_\mu + N \to M^+ + X, \tag{17b}$$

where N stands for the average nucleon and X for 'anything' (hadronic) carrying grace or taste as the case may be. Using p with subscripts for the various four-momenta, and denoting by E and E' the laboratory energies of the incident and final leptons, we introduce the standard kinematic variables:

$$Q^2 \equiv (p_\nu - p_M)^2 = (p_X - p_N)^2;$$

$$\nu \equiv E - E'; \; y \equiv \nu/E;$$

$$\xi \equiv [Q^2 + m^2(t, g)]/2\nu m(N). \tag{18}$$

Here $m(N)$ stands for the nucleon mass and $m(t)$ and $m(g)$ for the masses of the t and the g quarks, to be used appropriately depending on the elementary process in question. The light quark masses are neglected as usual.

The elementary differential cross-sections are:

$$\frac{d^2\sigma}{d\xi dy} = \frac{G^2 m(N) E}{\pi} 2\xi \left[1 - \frac{m^2(t, g) + m^2(M)}{2m(N) E \xi}\right], \tag{19}$$

using $m(t)$ for the processes (16a) and $m(g)$ for the processes (16b). To obtain the cross-sections for the average nucleon target we have only to multiply (19) with the appropriate ξ-dependent light quark or anti-quark distribution functions and integrate in the kinematically allowed regions. The integration region in (Q^2, ν)–plane is bounded by the curves:

$$2m(N)\nu - Q^2 + m^2(N) = m^2(H_g, H_t),$$

$$\nu = \frac{Q^2 E}{Q^2 + m^2(M)} - \frac{Q^2 + m^2(M)}{4E}, \tag{20}$$

where H_g and H_t, let us recall, stand for the lightest hadrons carrying grace and taste, respectively, and are to be used in (20) depending on the elementary differential cross-section being integrated. The threshold energy is given by:

$$E_{\text{th}} = \frac{[m(M) + m(H_g, H_t)]^2 - m^2(N)}{2m(N)}. \tag{21}$$

To obtain our desired cross-sections we need the quark-parton ξ-distribution functions. These we may take from standard fits to the data on the conventional deep inelastic neutrino scattering. For our present rough estimate any fit would do. We have chosen the fits obtained by Barger and Phillips (1976). The ‘ sea ’ contribution to the momentum fraction carried by $u, d, \bar{u}, \bar{d}$ is around 6% and that by $s, \bar{s}$ around 3%. Rather arbitrarily we also take, for orientation purposes, $m(H_g, H_t) \simeq m(g, t) + 1$ GeV.

Results of illustrative calculations as outlined above are displayed in figures 1 and 2. In figure 1 we plot against E the ratio:

$$\frac{\sigma(M, g)}{\sigma(\mu)} \equiv \frac{\sigma(\nu_\mu + N \to M^- + X(g))}{\sigma(\nu_\mu + N \to \mu^- + X)}, \tag{22}$$

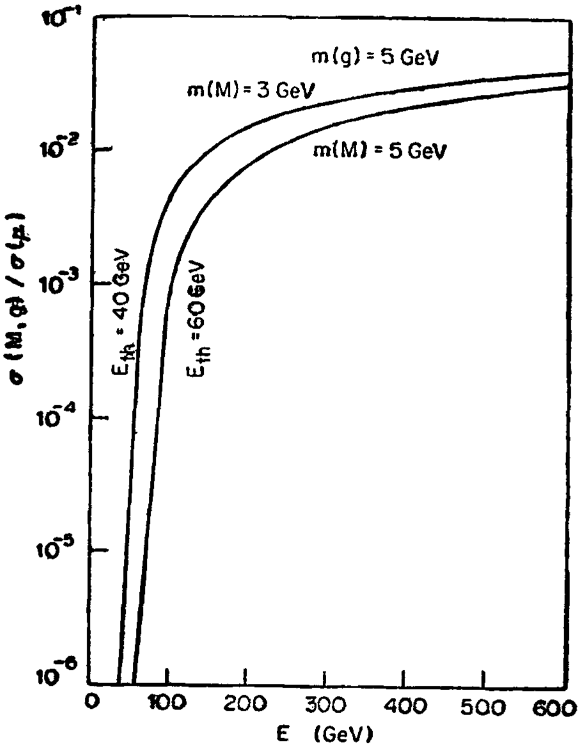

Figure 1. Plot of $\sigma(M,g)/\sigma(\mu) \equiv \sigma(\nu_\mu + N \to M^- + X(g))/\sigma(\nu_\mu + N \to \mu^- + X)$ against the incident neutrino energy E. The symbol X stands for 'anything', and $X(g)$ for 'anything containing grace'.

and in figure 2 the ratio:

$$\frac{\sigma(M,t)}{\sigma(\mu)} \equiv \frac{\sigma(\nu_\mu + N \to M^- + X(t))}{\sigma(\nu_\mu + N \to \mu^- + X)}, \tag{23}$$

where X stands for 'anything' (hadronic) and $X(g)$ and $X(t)$ mean that a g- and t-carrying hadron must be present in the 'anything'. The threshold energies for the M-production processes, depending on the assumed values of the relevant masses, are also indicated along the different curves.

We see from figure 1 that with $m(M) \simeq 4$ GeV, $m(g) \simeq 5$ GeV, the threshold is $E_{th} \simeq 50$ GeV. This is well within the range of energies available to accelerator neutrinos. However, the cross-section ratio $\sigma(M,g)/\sigma(\mu)$ rises to only $\simeq 10^{-3}$ at around 100 GeV and to $\simeq 10^{-2}$ at around 200 GeV. This suppression, as already pointed out, is due to $\sin \theta_c$ coming with production off the valence quarks and $\cos \theta_c$ off the 'sea' quarks. Such a suppression is not operative in figure 2; but the threshold is much higher. Thus, with $m(M) \simeq 4$ GeV and $m(t) \simeq 10$ GeV, we have $E_{th} \simeq 110$ GeV, and a major part of the spectrum of machine neutrinos will be inoperative for the production of M^- in association with t. The value of $\sigma(M,t)/\sigma(\mu) \simeq 10^{-3}$—$10^{-2}$ in the range $E \simeq 150$–200 GeV.

We thus see, that with the above choice of masses, the presently available accelerator neutrinos will not be very efficient in producing the M^-. Higher energies are

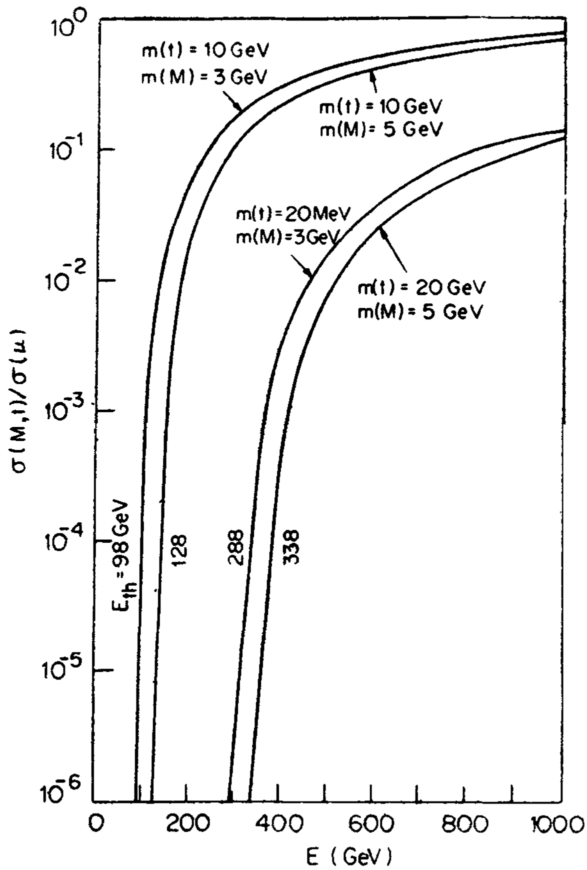

Figure 2. Plot of $\sigma(M, t)/\sigma(\mu) \equiv \sigma(\nu_\mu+N \to M^-+X(t))/\sigma(\nu_\mu+N \to \mu^- X)$ against the incident neutrino energy E. The symbol X stands for 'anything', and $X(t)$ for 'anything containing taste'.

needed. On the other hand, cosmic ray neutrinos with energies ranging from a few hundred GeV upwards will have no such difficulty in producing the M^- in competition with the μ^-. Decay of the so produced M^- into $E^-\mu^-e^+$ mode could account for the Kolar events. We discuss this in the next section.

It is important to note that the E being stable, according to the scheme envisaged here, it would be an extremely penetrating charged particle and would thus be liable to confusion in detectors with the muon.

5. Kolar events

We assume that cosmic rays provide us with ν_μ's of several hundreds of GeV and higher. In our view, there may be energetic neutrinos (both electronic and muonic) also arising from the decays of hitherto undiscovered new particles, besides from the conventional sources, viz., from the decays of pions, kaons and muons. The U_3(W) gauge theory makes many such particles available. Such a possibility cannot be ruled out at present—rather it is possibly even suggested by the latest 'Beam Dump Experiments' (Alibran *et al* 1978; Hansl *et al* 1978; Bosetti *et al* 1978).

If so, figures 1 and 2 tell us that, with $m(M) \simeq 4$ GeV, $m(g) \simeq 5$ GeV and $m(t) \simeq 10$ GeV (for example), the ratio $\sigma(M)/\sigma(\mu)$ could easily range from $\simeq 0{\cdot}3$ to $\simeq 0{\cdot}8$ and rise slowly to a slightly higher value beyond 1000 GeV. Let us take, for illustration, an average value $\simeq 0{\cdot}6$. Using, as example, $m(M)-m(E) \simeq 3m(\mu)$, we see from (13) that $\tau(M) \simeq 5\times10^{-10}$ s and the branching ratio for the decay mode $M^- \rightarrow E^-\mu^-e^+$ is $\simeq 0{\cdot}4$. Thus, effectively the cross-section for the Kolar events, interpreted as due to M production followed by decay into three charged leptons as above, will be $\simeq 0{\cdot}6\times0{\cdot}4=0{\cdot}24$ times that for the conventional μ production. Assuming, then, a sufficiently long and sizable tail of very high energy ν_μ's in cosmic rays, the rate for such events could be quite a sizable fraction of that for the single μ events.

It must be emphasised again that the various mass values, etc., chosen here are only for illustration. Detailed fitting can hardly be attempted at this stage.

Since the M^-, in our picture, is produced by very energetic ν_μ's of several hundreds of GeV upwards, it will be produced with a very large Lorentz factor. Taking the average inelasticity $\langle y \rangle \approx 0{\cdot}5$, according to the parton model calculations, the Lorentz factor of M can be as large as $\simeq 50$ for $E=400$ GeV and $\simeq 100$ for $E=800$ GeV, etc. Thus the effective dilated life time of M could well be $\gtrsim 2$–5×10^{-8} s., Such a fast M can thus travel several metres in the rock at Kolar before decaying.

The crucial question then arises: can, in the decay of such a highly relativistic M^-, the final charged particles $(E^-\mu^-e^+)$ emerge with rather large opening angles as seen in the Kolar events? The answer is in the affirmative. This is because the decay, matrix element $\mathcal{M}$, with our interaction Lagrangian, gives approximately the angular correlation in laboratory:

$$\sum_{\text{spins}} |\mathcal{M}^2| \propto (1-\cos\theta_{Me})(1-\cos\theta_{E\mu}), \tag{24}$$

where we neglect the masses compared to the high energies involved. Here θ_{Me} is the angle between the momenta of the M and the e, and $\theta_{E\mu}$ that between the momenta of the E and the μ. Thus with the E going forward around the direction of the M, the e and the μ tend to go backwards. Phase space alone would (because of the high Lorentz factors) tend to make them all go forward. Computer simulation of the events, taking account of both these two factors, shows that a compromise is reached so that the three final particles go forward with rather large opening angles.

In a rare case it may also happen, e.g., that a g-carrying hadron (produced by the ν_μ in association with the M) decays near the detector into a set containing charged particles that include the M, which proceeds some way in the detector before itself decaying into $E\mu\bar{e}$. One of the Kolar events displays this kind of cascade character.

The M^- and M^+ can also be pair produced by real or virtual energetic photons in the cosmic rays. They may also be produced in the decays of grace and taste carrying hadrons produced through strong interactions in cosmic rays. Decays of such M's into three charged particles, as discussed above, could provide the explanation of the events reported recently from Tbilisi (Barnaveli *et al* 1977).

In view of the encouraging results obtained so far, we feel that the U_3(W)-gauge theory deserves further examination.

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