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A plausible explanation for muon events due to radiation from Cygnus X-3

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Abstract. The muon events produced at Soudan-I and NUSEX proton decay detectors due to radiation from Cygnus X-3 are given a plausible explanation on the basis of E_6 GUT. The possibility of verifying the explanation by using the accelerator experiments is suggested.

Keywords. Muon events; Cygnus X-3.

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1. Introduction

The Soudan-I proton decay detector group (Marshak *et al* 1985) analysed the single muon events observed at Soudan-I proton decay detector during September 1981 to November 1983. The correlation of the events with the 4·8 hour period of the X-ray binary source Cygnus X-3 indicates that the radiation comes from Cygnus X-3. The observed secondary flux appears to be due to primary radiation of energy $\simeq$ 1 TeV. The NUSEX group (Battisoni *et al* 1985) analysed the phase and angular distribution of high energy muons recorded in the NUSEX nucleon decay detector located in Mont Blanc tunnel and found evidence for a signal correlated with the direction and time modulation of Cygnus X-3. The fact that Soudan-I and NUSEX results are independent, in spite of showing the same effect, enhances our confidence in the experimental result.

2. Possible explanations

The Soudan-I proton decay detector group (Marshak *et al* 1985) considered some of the possible explanations. Neutrons being too unstable to be a source of primary radiation, cannot reach the earth from Cygnus X-3. Photons as primary sources are also ruled out because they are not capable of producing such high energy muons with the observed cross-sections. In the case of neutrino primary we expect isotropic zenith angle dependence for muons which is not supported by the data. This result can be explained by a hitherto undiscovered particle with fairly large cross-section for either direct or indirect muon production. The particle has to be neutral to avoid deflection by the galactic magnetic field.

3. Ruddick's model-independent analysis

Ruddick (1986) carried out a model-independent analysis of the data. From the phase coherence of the signal he estimated that the particle coming from Cygnus X-3 must have a mass less than a few tens of MeV. These particles, called Cygnets, must be neutral to avoid deflection by the galactic magnetic field. The life-time of the particle must be greater than 3×10^7 seconds so as to reach the earth. An important aspect of the data considered by Ruddick and which has not been studied before is the finite angular spread up to 5° in the observed muon arrival direction relative to the actual direction of Cygnus X-3. The angular resolution in each detector is less than 1° while the multiple coulomb scattering is less than 0·5°. The spread is suggestive of the production of a massive particle in the interaction of the primary with the rock in earth with its subsequent decay to atleast one muon. Any model involving direct muon production by the Cygnets would produce too many muons at very small angles. From the data he estimated the mass of the secondary particle to be 10 to $40\,\mathrm{GeV}/c^2$ for producing the particle due to interaction of the Cygnets with nucleons.

4. Grand unified theories

Several explanations of the data on the basis of supersymmetric particles have been attempted without success (Mohapatra *et al* 1985; Auriemma *et al* 1985; Berezinsky *et al* 1986). We consider the grand unified theories for an explanation. Currently there are three models for grand unification which explain all the low energy data including the value of the Weinberg angle (Langacker 1981). These models are based on the gauge groups (i) SU (5) (ii) SO (10) (iii) E_6. The limited particle content of the GUTs based on SU (5) and SO (10) makes it impossible to explain the above data. In what follows it is shown that a satisfactory explanation can be provided on the basis of the E_6 GUT.

5. Explanation using E_6 GUT

According to the present standard E_6 GUT each family of lepton and quarks is placed in the $\underline{27}$ fundamental representation of the E_6 group (Barbieri and Nanopoulos 1980). Under the symmetry breaking in which E_6 branches into SO (10) × U (1) the $\underline{27}$ irrep of E_6 splits as $\underline{27} = \underline{16} + \underline{10} + \underline{1}$. Under further symmetry breaking in which SO(10) branches as SU (5) × U (1), the $\underline{16}$ irrep splits as $\underline{16} = (\underline{10} + \underline{\bar{5}} + \underline{1})$ and the $\underline{10}$ irrep splits as $\underline{10} = (\underline{5} + \underline{\bar{5}})$. The $\underline{10} + \underline{\bar{5}}$ of $\underline{16}$ corresponds to the particles of the standard model. The $(\underline{5} + \underline{\bar{5}})$ of $\underline{10}$ corresponds to new particles which are unique to the E_6 group. It contains a Dirac neutral heavy lepton N° and a charged heavy lepton E^- which form a doublet $\binom{N^0}{E^-}$ under SU (2) and a singlet under SU $(3)_c$. It also contains a $Q = -\frac{1}{3}$ colour triplet quark. Under suitable Higgs symmetry breaking N° can also be a Majorana particle. We identify the Cygnet and the secondary particle of Ruddick which the Cygnet produces on interaction with the nucleons in the rock as N_e° and E_e^- respectively of the electron family. Then from Ruddick's analysis, the mass of N_e° is less than a few tens of MeV and the mass of E_e^- is between 20 and 40 GeV. It is proposed here that the Cygnus X-3, due to some mechanism which is not relevant here, produces highly energetic E_e which decays to N_e° having energy $\simeq 1$ TeV. This constitutes the primary radiation.

Some of the N_e° reaches the earth and reacts with the nucleons of the rocks above the proton decay detectors as follows. $N_e^\circ \pm \text{nucleon} \rightarrow E_e^- + X$. E_e decays through the following two channels.

$$E_e^\mp \rightarrow \tau^\mp + \bar{\nu}_\tau(\nu_\tau) + N_e^\circ(\bar{N}_e^\circ) + \text{Debris}$$

$$\tau^\mp \rightarrow \mu^\mp + \bar{\nu}_\mu(\nu_\mu) + \nu_\tau(\bar{\nu}_\tau)$$

$$E_e^\mp \rightarrow \mu^\mp + \bar{\nu}_\mu(\nu_\mu) + N_e^\circ(N_e^\circ) + \text{Debris.}$$

The analysis by Marshak *et al* (1985) and Battisoni *et al* (1985) shows the absence of isotropic zenith angle dependence of muons. If the interaction of the primary with the nucleons is $(V - A)$ then one obtains an isotropic zenith angle dependence of muons and if the above interaction is purely vectorial or axial vectorial, then the cross-section will decrease with increase of the zenith angle. Then from the analysis we can infer that the interaction should be purely vectorial or axial vectorial. As the E_6 GUT (Langacker 1981) predicts the interaction for production of the secondary E_e^- by N_e° interacting with the nucleons, as vectorial, our interpretation that N_e° as the primary and E_e^- as the secondary is favoured.

6. Possible accelerator verification

Neither N_e° nor E_e^- has been observed in accelerator experiments. At present the highest beam dump experiment corresponds to $\sqrt{s} = 27\,\text{GeV}$. The non-observation of E_e^- sets a lower limit of 20 GeV for its mass (Ruddick 1986). The ideal way to search for the particles E_e^- and N_e° is through e^+e^- collider experiments with $\sqrt{s} = 100\,\text{GeV}$. In such experiments $E_e^- E_e^+$ will be created through electromagnetic interaction and whose purely vector nature of decay to N_e° will make it possible to identify them uniquely. If LEP of CERN achieves a c.m. energy $\simeq 100\,\text{GeV}$, it will also serve this purpose.

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