OBSERVATION OF AN EXCESS OF COSMIC RAY MUONS OF ENERGIES > 2 TeV FROM THE DIRECTION OF CYGNUS X-3

G. Battistoni[1], E. Bellotti[2], C. Bloise[1], G. Bologna[3], P. Campana[1], C. Castagnoli[3], A. Castellina[3], V. Chiarella[1], A. Ciocio[1], D. Cundy[4], B. D'Ettorre Piazzoli[3], E. Fiorini[2], P. Galeotti[3], E. Iarocci[1], C. Liguori[2], G. Mannocchi[3], G. Murtas[1], P. Negri[2], G. Nicoletti[1], P. Picchi[3], M. Price[4], A. Pullia[2], S. Ragazzi[2], M. Rollier[2], O. Saavedra[3], L. Satta[1]. P. Serri[2], S. Vernetto[3] and L. Zanotti[2].

[1] Laboratori Nazionali dell'INFN, Frascati, Italy.
[2] Dipartimento di Fisica dell'Università and INFN, Milano, Italy.
[3] Istituto di Cosmogeofisica del CNR, Torino, Italy.
[4] CERN, European Organization for Nuclear Research; Geneva, Switzerland.

INTRODUCTION

A high flux of muons from the Cygnus X-3 direction has been observed in NUSEX experiment at depths greater than 4600 hg/cm^2 s.r. [1]. The excess muons show the 4.8 hour modulation in arrival time typical of this source.

A study of this modulation has been done in order to find the best value of the period and of the period derivative.

The muon flux underground from NUSEX and SOUDAN (1800 hg/cm^2) experiments are used to determine the energy spectrum at sea level. The shape and the absolute intensities are found similar to those attributed to "γ-rays" responsible for production of air showers detected in direction of Cygnus X-3 in the energy range 10^{12} - 10^{15} eV.

ANALYSIS OF THE PERIOD

The phase plot of the 151 events recorded in a window 10° x 10° around the direction of Cygnus X-3 is shown in Fig. 1. The more recent ephemeris of van der Klis and Bonnet-Bidaud [2] has been used :

T_0 = JD 2440949.8986

p = .1996830 d

p = $1.18 \cdot 10^{-9}$

32 events are found in the phase range .7 - .8 giving an excess of 19 ± 5 over the expected background of 13 events.
The histogram using 40 bins shows that the excess is concentrated in a phase width of about 29'.

In analyzing our data the χ^2 test for uniformity, the probability of fluctuation and the confidence level as obtained from the relative likelihood method have been considered to set an estimate of the statistical significance of the excess. To determine the best value of the period p and its derivative $\dot{p}$ we varied p and $\dot{p}$ in steps of $4 \cdot 10^{-7}$ d and $2 \cdot 10^{-10}$ respectively searching for the maximum concentration of events in any of the 10 phase bins, as defined by the above criteria. A change in period of $4 \cdot 10^{-7}$ d gives a phase shift, for our data recorded between June 82 and January 85, of .042 to 0.052. A change in the period derivative of $2 \cdot 10^{-10}$ gives a phase shift in the range 0.050 to 0.066.

In the scanning over the period, the derivative has been set to the ephemeris value. The result is shown in Fig. 2 where the fluctuation probability is plotted. The minimum is found for the ephemeris value of the period. The other statistical tests give the same result. An inspection of the phase plot in 40 bins confirms that the minimum width of the signal corresponds to this period . The scanning in period derivative gives an analogous result, indicating the best derivative as that of the ephemeris, Fig. 2.

MUON SPECTRUM

The depth distribution of the 119 "off-phase" events follows the one expected for atmospheric muons. Thus from 32 "in phase" events we subtract 13 events background according to the depth distribution expected for atmospheric muons so obtaining the distribution for the 19 excess events (dashed line in Fig. 3). Only 1 event is found in the depth region around 7000 hg/cm^2 corresponding to the maximum of our exposure (Fig. 4). This result rules out the hypothesis of muons generated by neutrinos in the surrounding rock. The intensity at four depths is shown in Fig. 5 together with the intensity point at 1800 hg/cm^2 from the SOUDAN experiment [3]. The measured intensity is more than four orders of magnitude greater than the muon flux expected from the quoted gamma spectrum from Cygnus X-3 ($\sim 1.5 \cdot 10^{-15}$ cm^{-2}s^{-1} at a depth 5000 hg/cm^2).

Using the survival probability functions we fit a power law differential spectrum to these data. The muon integral spectrum is found to be $(7.4 \pm 1.7) \cdot 10^{-7} \cdot E^{-(1.4 \pm .2)}\ cm^{-2}s^{-1}$ much flatter than the ordinary atmospheric muon one ($\gamma \sim 2.75$). In Fig. 6 this spectrum is compared to the estimated flux of "γ rays" from Cygnus in the range 10^{12}–10^{15} eV [4] . Spectral index and absolute intensities are roughly in agreement within the errors.

CONCLUSION

The analysis of the events coming from the direction of Cygnus X-3 shows that the best period and derivative coincide with the van der Klis and Bonnet-Bidaud ephemeris. The width of the muon excess in the interval phase 0.7 - 0.8 is about 29'. The depth dependence of the muon excess rules out the hypothesis of conventional neutrino-induced events. The muon spectrum derived by the analysis of NUSEX and SOUDAN data has a spectral index and an absolute intensity roughly in agreement with the primary flux attributed to photons from Cygnus X-3 at energies > 1 TeV.

From this fact we argue that these events could be due to the interaction of a new neutral particle with a large cross section for muon production.

References

[1] G. Battistoni et al. Observation of a time modulated muon flux in the direction of Cygnus X-3, to be published in Phys. Letters B.
[2] M. Van der Klis and J. M. Bonnet-Bidaud, Astr. and Ap. 95, (1981) L5 .
[3] M.L. Marshak et al. Phys. Rev. Lett. 54, (1985) 2079 .
[4] J.Lloyd-Evans et al. Nature, 305, (1983) 784 .

Figure captions

Fig. 1 - Phase distribution for muons coming from an observation window of 10°x10° centred on Cygnus X-3.
Fig. 2 - Probability of fluctuation as a function of a trial period p (a) or period derivative p(b). The zero of the scale indicates the values found by van der Klis and Bonnet-Bidaud from X-ray data.
Fig. 3 - Depth distribution for the 32 "in phase" events.
Fig. 4 - Exposure integrated over the running time and averaged over the total phase.
Fig. 5 - Underground intensity of muons from the direction of Cygnus X-3 (NUSEX and SOUDAN results).
Fig. 6 - Integral energy spectrum of muons from the direction of Cygnus X-3 compared to the estimated flux of "γ-rays".

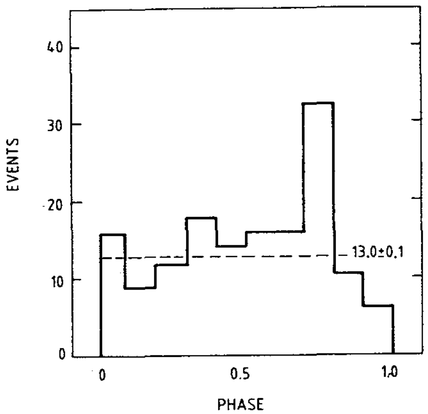

FIG. 1

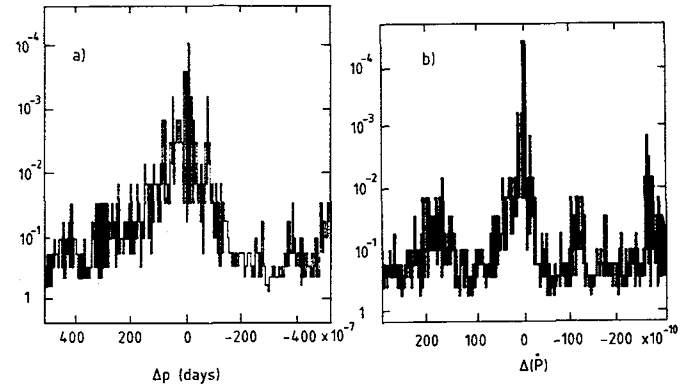

FIG. 2

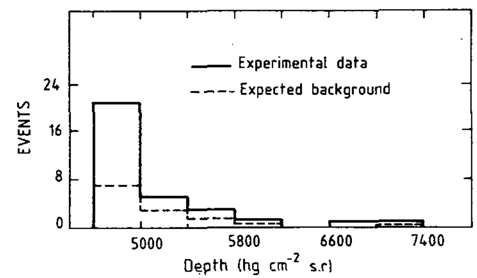

FIG. 3

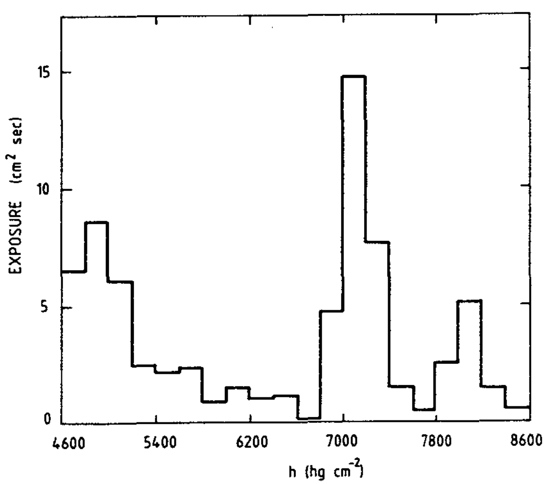

FIG. 4

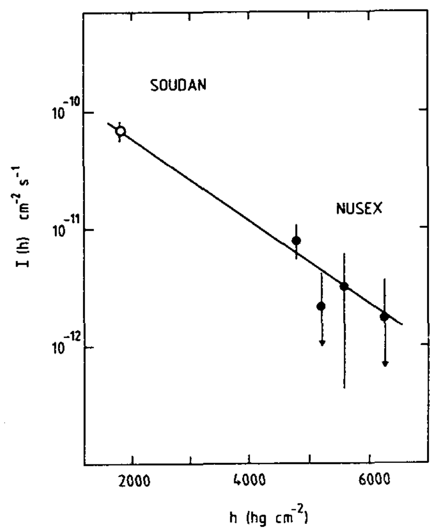

FIG. 5

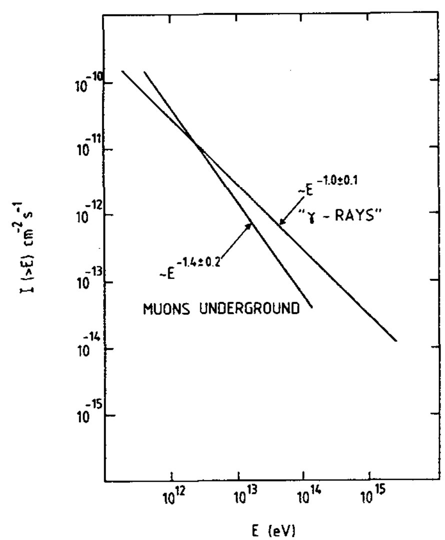

FIG. 6