Laboratori Nazionali di Frascati

To be submitted to Nuovo Cimento C

LNF-87/88(P)
21 Settembre 1987

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HIGH STATISTICS STUDY OF THE LOW ENERGY COSMIC MUON ANGULAR DISTRIBUTION: RESULTS FROM MICRO

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ABSTRACT

We present results from MICRO, a muon telescope with good angular resolution, which has collected more than $31 \cdot 10^6$ cosmic muons. Upper limits are given for the flux coming from point sources and for the periodic component from Cygnus X3.

INTRODUCTION

Wide angle anisotropies in the arrival directions of high energy cosmic muons have been reported by various experiments [1]. The existence of narrow angle anisotropies is however still an open question.

The aim of MICRO (Monitor for Intense Cosmic Ray Outbursts) is to give an high statistics survey of the low energy muon flux, with good angular resolution, to search for narrow peaks and time variations in the cosmic muon distribution.

The apparatus has been operated since March 1986 through May 1987 in Frascati - latitude=41°47', longitude=-12°40' at 300 m. above sea level - collecting more than $31 \cdot 10^6$ muons whose arrival directions cover the range (in celestial coordinates) -50°< Declination (δ) < 90°.

The μ arrival directions have been binned in 8x8 degrees (R.A. vs. δ) intervals. Minimum energy of detected μ's is $\approx$ 2 GeV, owing to absorption in the atmosphere. Selecting muons with zenith angle $\theta > 80^{\circ}$ corresponds to a cut $E_{\mu} > 10$ GeV at 95% confidence level.

The data have been scanned searching for narrow (i.e. angular width <1 bin) excesses, and an upper limit on the flux coming from the direction of known gamma ray sources has been derived. The same search has been performed for each month looking for possible sporadic signals.

Searching for large scale anisotropies requires a precise evaluation of the expected flux, taking into account the efficiency and acceptance of the apparatus in the observation period, and will be reported in a forthcoming paper.

Some underground experiments [2] have reported evidence for a periodic muon signal coming from the direction of Cygnus X3. In order to search for such an effect, a phase analysis has been performed using the known X rays 4.8 hours period, for the muons coming from a direction within 15 degrees in celestial coordinates around Cygnus X3. An upper limit on the flux is given.

EXPERIMENTAL SETUP

The apparatus consists (Fig. 1) of six 1 m^2 planes of 1 cm^2 streamer tubes of the same type as those used in the NUSEX experiment [3]. The tubes are arranged in two groups, 95 cm apart. Within each group the distance between the planes is 1 cm, with a 1 mm iron sheet in front to each group to allow recognition of electrons. The overall geometric angular resolution of the telescope is better than 1 degree.

The axis of the telescope is horizontal, in order to bring down the counting rate an accetable value for the acquisition system, and aimed to a direction maximizing the exposure to Cygnus X3. The absolute orientation of the apparatus is known to be better than 1 mrad. The measured terrestrial angular distribution is reported in Fig. 2 for part of the data set. We assume that no muons come from below the horizon, so that there is no front-back ambiguity. The data acquisition system consists of the standard streamer tube electronics [3] read out by a Camac processor and sent to a non dedicated VAX through an Apple II acting as interface. The trigger is made by the coincidence of at least 2 planes in each group, giving a trigger rate of 3 Hz. The acquisition system could register data at this rate with a dead time of 10%.

Typically a run consisted of 100000 events, after which the data file was automatically closed and a new run started. At the same time a job residing on the host VAX automatically started for track reconstruction and histogram filling. The output of this program is a file containing the distribution in local and sideral time and local and celestial coordinates. Moreover the data coming within a 15° window around Cyg X3 have been analized in phase, dividing the period in 20 intervals.

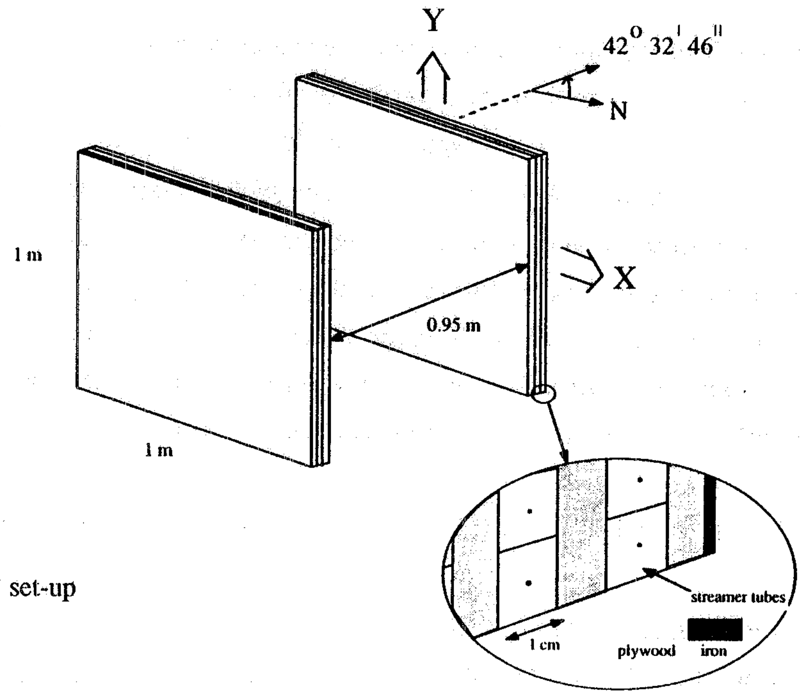

FIG. 1 - Experimental set-up

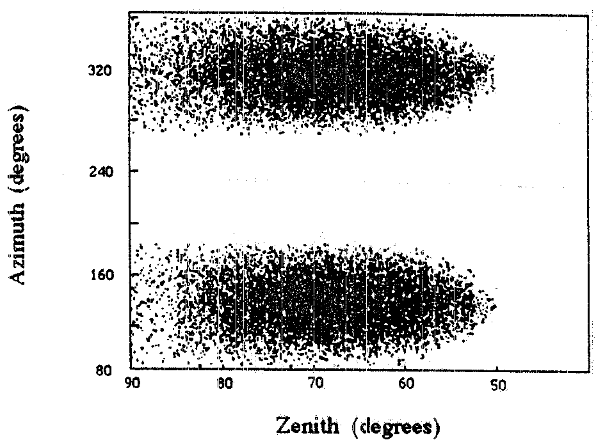

FIG. 2 - Angular distribution in the laboratory.

SEARCH FOR NARROW STRUCTURES

The energy threshold in MICRO is determined by the transparency of the atmosphere to muons of given energy. It has been determined by means of an analytic calculation [4] as well as a 3-dimensional Montecarlo, based on the Hillas algorithm [5] for hadronic interactions, which takes into account muon energy loss and decay, as well as the effect of the geomagnetic field. We derived in this way the relation between zenith angle and minimum muon energy; the selection of μ coming from $\theta > 80^o$ implies $E_\mu > 10$ GeV.

The angular distribution of the muons with respect to the direction of the primary has been computed; this calculation takes into account the lateral spread of the shower due to the non zero transverse momentum in hadronic interactions and the effect of the geomagnetic field.

On the basis of the above calculations the muons with $\theta > 10^\circ$ have been binned in 8x8 degree intervals (R.A. vs. δ). The R.A. distribution of all the muons, summed over declination, is shown in Fig. 3, that in δ in Fig. 4, while a typical data plot at a given bin of declination is in Fig. 5.

A detailed evaluation of the expected shape of the muon distribution, essential to reveal large scale structures, requires a very accurate knowledge of the acceptance of the apparatus and local non uniformities of the muon flux. In the case of the search for signals entirely contained in one angular bin this is not necessary and a simpler procedure has been used. For each angular bin we have computed the expected muon flux by linearly fitting the measured contents of the six nearby R.A. bins. The significance of possible excesses has been computed with the following estimator [6]:

$$T = (S - B)^2 / (B + \sigma^2)$$

(where S is the measured signal, B the expected value and σ its standard deviation), which is distributed as $\chi^2(1)$, if there are no signals.

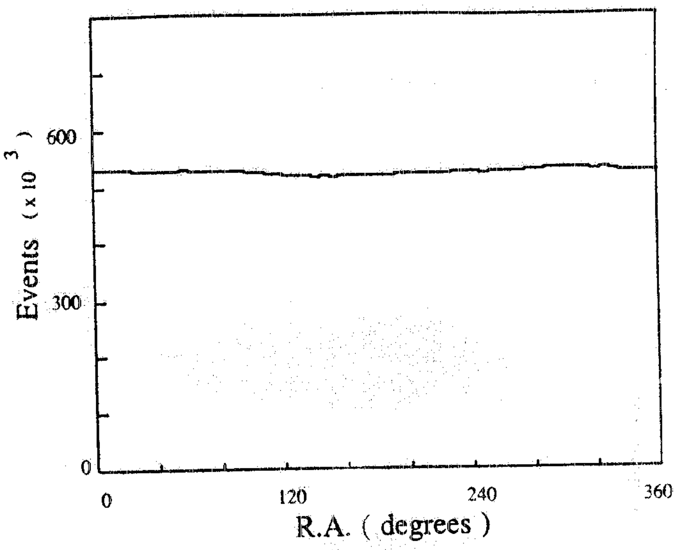

FIG. 3 - Right Ascension distribution of all the μ's (all θ).

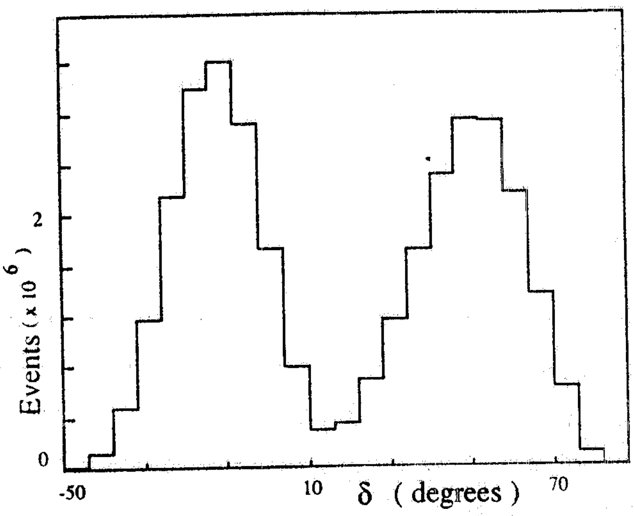

FIG. 4 - Declination distribution of all the μ' s.

From this analysis we conclude that the number and distribution of the excesses are compatible with the expected ones. The same conclusion has been achieved subdividing the data in one month samplings. From the above result we can derive an upper limit (at 95 % C.L.) for the μ flux as a function of declination, which is presented in Fig. 6.

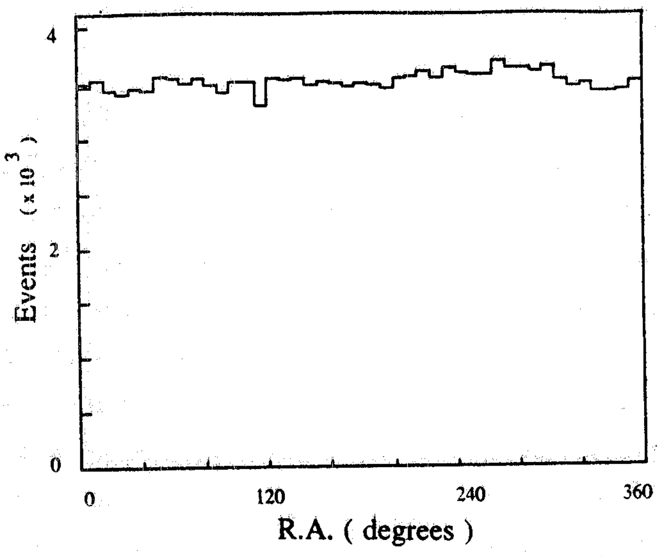

FIG. 5 - R.A. distribution for $-18^{o} < \delta < -10^{o}$ ($\theta > 80^{o}$).

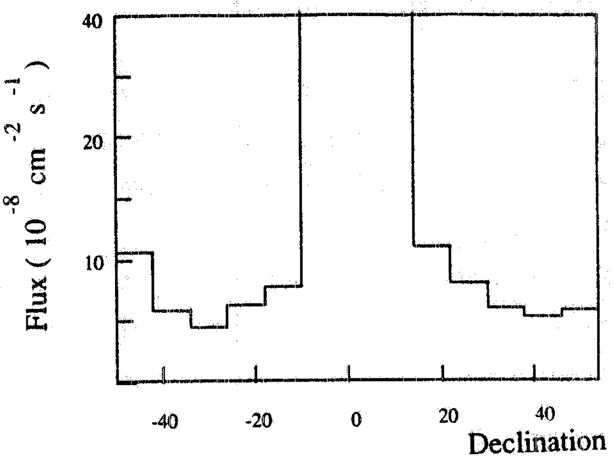

FIG. 6 - Upper Limit (95% C.L.) to the μ flux vs. δ.

At $\delta = 9^{o} \pm 6^{o}$ and A.R. $\approx 48^{o}$ where a 4 σ excess in higher energy muons was reported in Ref [1], our data present a small excess of 2 σ while the negative anisotropy at A.R.= 120° reported in the same Ref. does not appear.

In Table I we report the 95 % C.L. upper limit for flux coming from the directions of some known X and γ ray sources, and some other interesting objects. These results should be compared with those in Ref.[7], taking into account the different energy thresholds.

TABLE I - 95% C.L. upper limits for the flux coming from known X and γ ray sources.

	R.A.	δ	95% U.L. (10^{-8} cm^{-2} s^{-1})
Cyg X1	299.1	35.1	5.1
Cyg X2	325.6	38.1	3.3
Her X1	254.0	35.4	1.2
Sco X1	244.3	-15.5	3.7
Geminga	97.7	17.8	8.2
4U1758-25	269.5	-25.1	2.1
Crab	82.9	22.0	9.8
AM Her	273.3	50.0	5.0
Kepler	261.9	-24.4	3.5
IC443	93.5	22.6	5.4

CYGNUS X3

Cygnus X3 has been reported as a periodic source in X [8], High and U.H.E. γ rays [9] with a very well known period (in the X emission) P=4.792392 hours. The period is not constant but its derivative dP/dt = 1.18 10^{-9} is also known. An underground μ signal has also been reported [2]. Common feature of all high energy signals from Cyg X3 (and similar very high energy emitters) is that the source is "on" in a small part of the period, typically 1/10 to 1/20.

To search for such a signal, we have selected the μ ($\theta > 80^o$) coming from a region of 15^o x 15^o centered on the position of Cyg X3, which has been divided in 25 3 x 3 degree bins. Due to the effect of the geomagnetic field, muons pointing to the source are spread in more than one angular bin: this deflection has ben computed with our Montecarlo and collected data have been corrected accordingly. Although in priciple this correction depends on the assumed source spectral shape, we thave found this dependence to be marginal, at least for differential spectral indices in the range 2.1÷2.7 which are appropriate for point sources.

In Fig. 7 we report the phase plot at the Cyg X3 position ("on source"), corrected as described above, for spectral index 2.1. Fig. 8 is the weighted average of the bins which do not contain muons coming from the source direction ("off source"), while in Fig.9 we have the ratio "on source" / "off source". The fluxes in Figs. 7, 8 are averaged over a period.

It has to be noted that, by selecting muons with $\theta > 80°$, the direction of Cyg X3 is observed for 1.53 hours, i.e. only a fraction of its period. This implies that we do not expect to see a flat phase distribution in our data, even in the absence of signal.

The comparison of "on source" with "off source" data shows that there is no significant difference, giving a χ^2 of 20.35 (19 degrees of freedom) for the hypothesis that the plots are compatible. Taking the largest difference between on-source and off-source phase plots we have computed the 90% C.L. upper limit on the flux: $\phi<1.7\ 10^{-9}\ cm^{-2}\ s^{-1}$ which is also reported in Fig. 10, together with the results from other experiments [10]. If we instead consider the phases .2÷.4 and .6÷.8, where signals have been reported, the limits are 5.8 10^{-10} and 3.6 $10^{-10}\ cm^{-2}s^{-1}$ respectively.

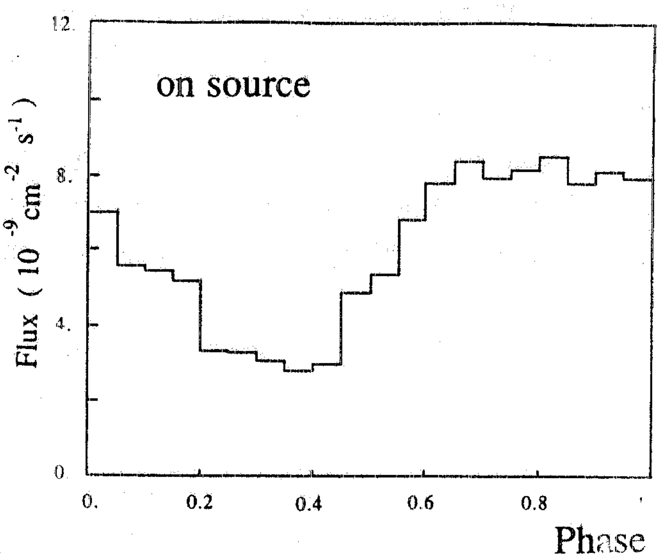

FIG. 7 - Phase plot for muons pointing to Cyg. X3, after correction for geomagnetic effect ("On source"). Fluxes are averaged over a period.

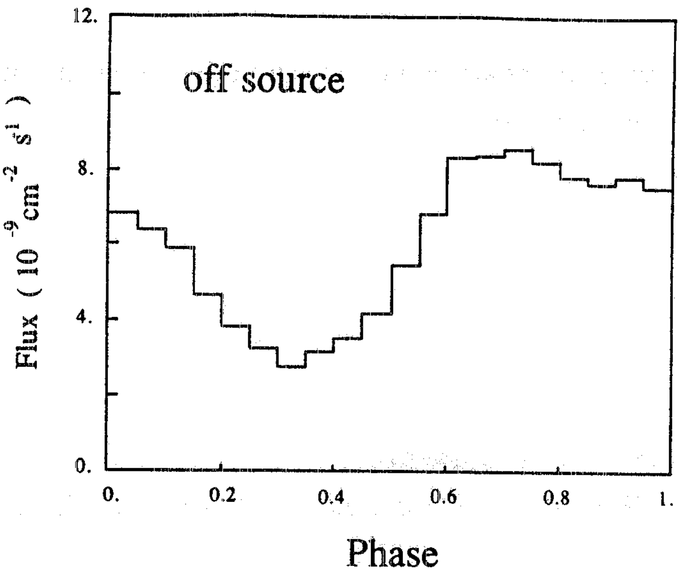

FIG. 8 - Evaluated background phase plot ("Off Source").

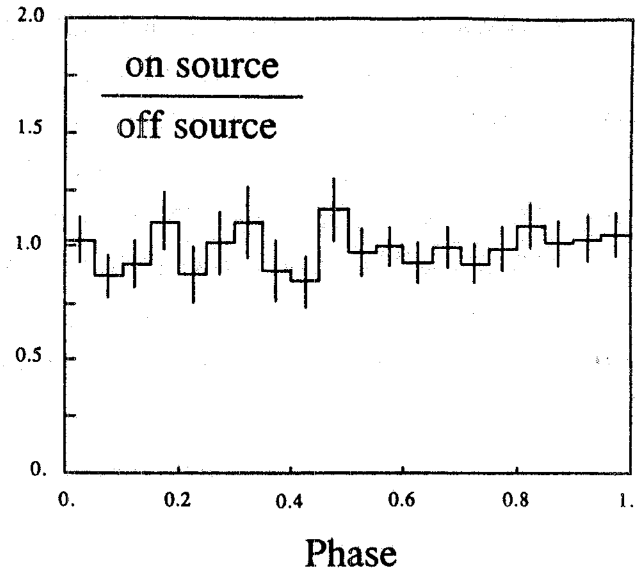

FIG. 9 - "On source" / "Off source" phase plot.

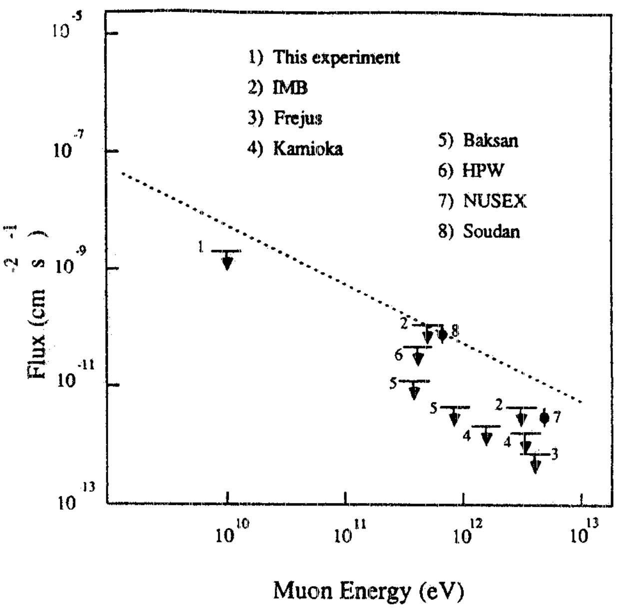

FIG.10 -Upper limits for the flux from Cyg. X3. The dotted line is the γ flux extrapolated from U.H.E experiments [10].

AKNOWLEDGEMENTS

We wish to thank Dr. S. Torres who helped us in setting up the data acquisition system, and G. Mazzenga who built the mechanical structure of the apparatus.

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