SEARCH FOR A PERIODIC SIGNAL FROM CYGNUS X-3 USING MUONS OBSERVED UNDERGROUND IN THE "FREJUS" DETECTOR (4800 mwe)

P. BAREYRE (4), R. BARLOUTAUD (4), K.H. BECKER (5), L. BEHR (3), C. BERGER (1), R.W. BLAND (3), G. CHARDIN (4), H.J. DAUM (5), B. DEGRANGE (3), S. DEMSKI (5), G. DEUZET (2), L. DI CIACCIO (4), B. DUDELZAK (2), P. ESCHTRUTH (2), D. EDMUNDS (4), J. ERNWEIN (4), G. GERBIER (4), R. HINNERS (5), A. HOFFMANN (1), M.A. JABIOL (4), S. JULLIAN (2), W. KOHRS (5), W. KOLTON (4), B. KUZNICK (5), D. LALANNE (2), F. LAPLANCHE (2), C. LONGUEMARE (2), R. MAYER (5), H. MEYER (5), L. MOSCA (4), L. MOSCOSO (4), U. NGUYEN-KHAC (3), D. ORTMANN (5), C. PAULOT (2), J. PETERS (5), F. RAUPACH (1), Ph. ROY (2), G. SCHMITZ (1), M. SCHUBNELL (5), P. SERRI (3), G. SZKLARZ (2), J. THIERJUNG (5), S. TISSERANT (3), J. TUTAS (1) and B. VOIGTLANDER (1).

(1) I. Phys. Institut der Techn. Hochschule, Aachen, Germany.
(2) Laboratoire de l'Accélérateur Linéaire, Orsay, France.
(3) Laboratoire PNHE, Ecole Polytechnique, Palaiseau, France.
(4) Département de Physique des Particules Elémentaires, Centre d'Etudes Nucléaires de Saclay, France.
(5) Universität - Gesamthochschule, Wuppertal, Germany.

1. Introduction.

Periodic signals from Cygnus X-3 in the ultra-high energy range have been recently reported by air-shower arrays [1] ; they are naturally attributed to γ-rays. Although γ-rays are expected to produce muon-poor showers [2] , the preceding observations have stimulated similar studies based on underground muons. Two groups [3,4] have claimed a significant underground signal coming from Cygnus X-3. Their results are however extremely difficult to explain in the present framework of Particle Physics, and clearly need confirmation.

We present here the preliminary results obtained from the "Fréjus" underground detector during its first 16 months of operation (March 1984-June 1985).

2. Site.

The "Fréjus" proton-decay detector is located in the "Modane underground laboratory" in the middle of the Fréjus tunnel linking France and Italy in the western Alps, about 80 km south of the Mont-Blanc. Figure 1 shows a sketch of the underground laboratory, whose main characteristics are summarized in Table 1.

TABLE 1

Longitude :	6.69° E
Latitude :	45.14° N
Average slant depth : (all muons)	4800 mwe
Average slant depth : (Cyg. X-3 direction)	5010 mwe
Average threshold for muons :	3 TeV
Muon angular deviation in the rock (average) :	1°
Muon rate :	4.2 m^{-2} day^{-1}
Primary cosmic ray energy range:	10 - 10^5 TeV
Dimensions of the main hall :	30m x 10m x 11m (L ℓ h)

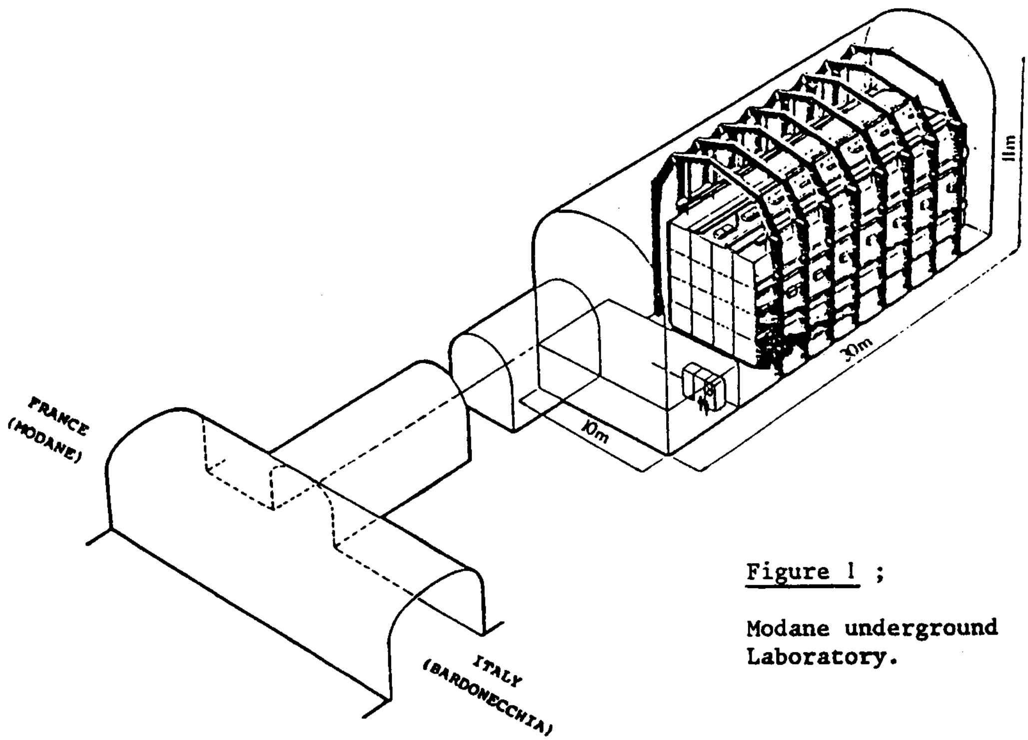


Figure 1 ;

Modane underground Laboratory.

3. The detector

The "Fréjus" proton -decay detector (12.3m x 6m x 6m) consists of a fine grain flash-tube calorimeter (0.93 10^6 flash-tubes) triggered by a set of 113 vertical Geiger planes. The trigger planes (each including 352 wires) are interspersed between flash-tube sections every 10.8cm, thus ensuring a good trigger efficiency for muons. Flash-chamber planes as well as Geiger planes are alternatively made of horizontal tubes (providing the side view of an event) and of vertical tubes (providing the top view), as is sketched in figure 2. The flash-tube section (5mm x 5mm) and the close spacing between flash-chamber planes (3mm of iron) lead to a high spatial resolution (2mm on a muon track). The projected area, averaged over all muon directions is 96 m^2. The total weight is 912 metric tons. The detector orientation is known with an accuracy of 0.2°.

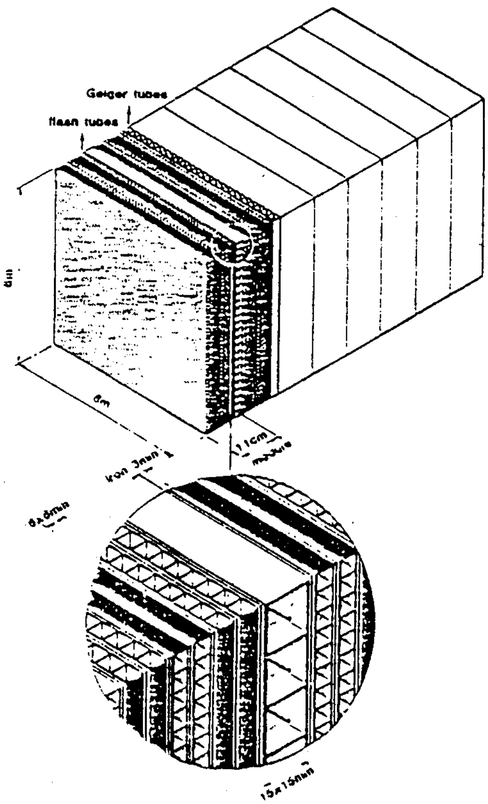


Figure 2 :

General structure of the detector.

The experiment started in March 1984 with only a part of the detector. The experimental set-up was completed at the end of June 1985. The data presented here have thus been taken in a detector with an increasing size. They mainly consist of 106 000 single muons, 3100 muon bundles (figure 3) and of 22 vertex-contained events, all of them being compatible with neutrino interactions (figure 4).

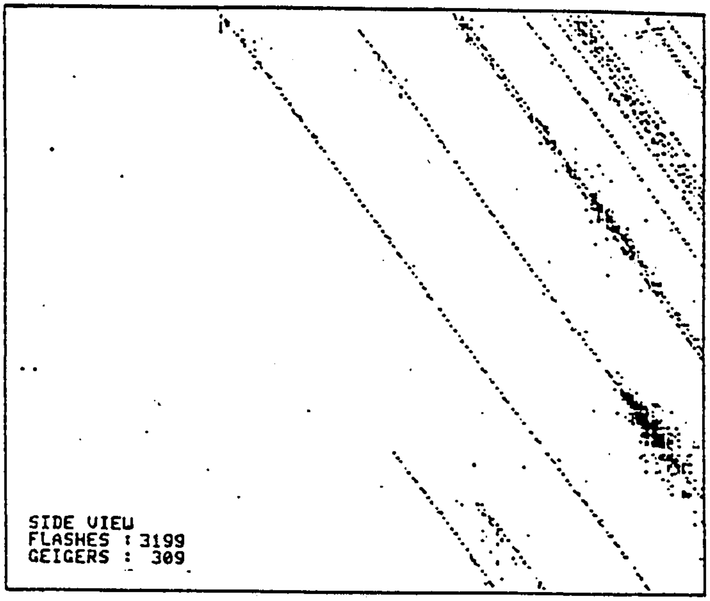


Figure 3 : A muon bundle

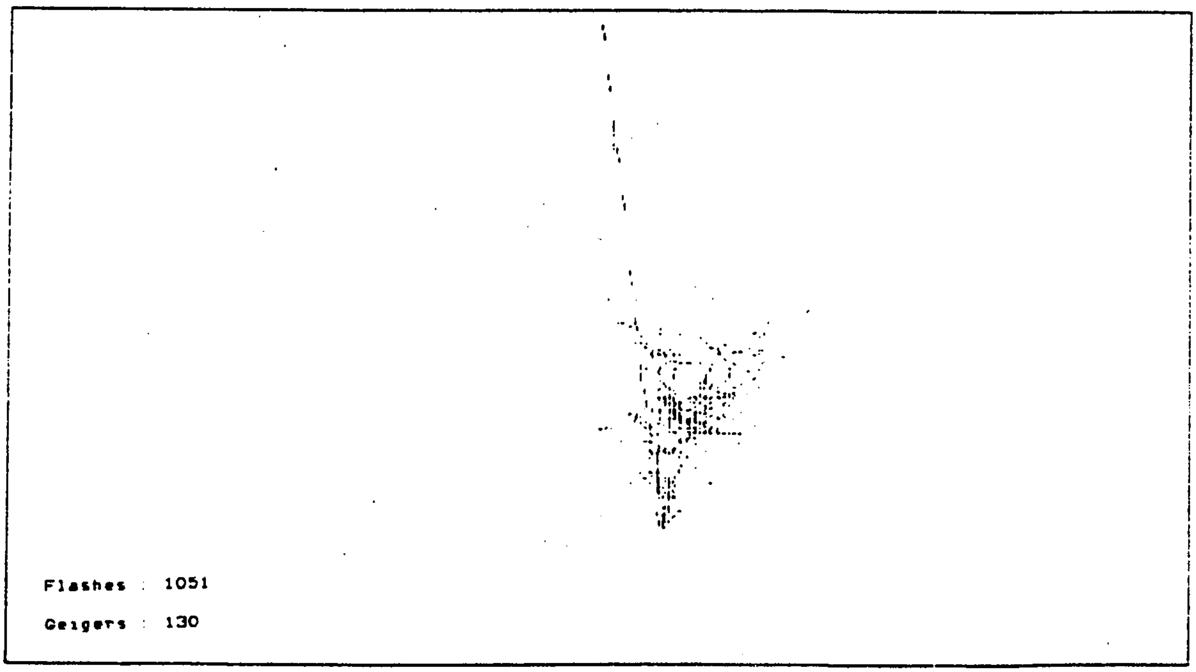


Figure 4 : A neutrino event

4. Search for a periodic signal from Cygnus X-3

In order to ensure a good direction measurement (a few milliradians), muons stopping in the detector as well as muons crossing less than 8 detection planes per view were removed from the sample of single muons. One is thus left with about 90 000 muons for which the average trigger efficiency is 96%. For such muons, the angular error on the source direction is dominated by the average angle of multiple scattering in the rock. Taking into account the small error on the arrival time of the muon (no precise clock being available to date), a conservative estimate of the angular resolution is 1.5°.

The present data are quite comparable to those of the NUSEX experiment [4] in the Mont-Blanc tunnel. Sites have nearby geographical positions and similar average slant depths; both experiments have the same angular resolution. For these reasons, we first follow the NUSEX analysis and select those muons pointing back to Cygnus X-3 within ±5° in right ascension and ± 5° in declination. This leaves us with 177 events, a statistics also comparable with that of NUSEX. No particular accumulation in the vicinity of the source is observed in figure 5. A possible signal can only be extracted by using the time structure expected from the X-ray light curve, following the ephemeris of Van der Klis and Bonnet-Bidaud [5] . The phase relative to the X-ray period was calculated taking into account its time derivative [5] and corrected for the effect of the earth orbital motion.

In order to check that no distortion of the phase histogram was induced by our apparatus or by the shape of the mountain, 6840 events within the same band in declination as the 177 selected events (Cygnus X-3 ± 5°) but with no restriction in right ascension were considered. Their phase distribution shown in figure 6 is found almost uniform, and yields an off-source background in the 10° x 10° window around Cygnus X-3 of 190 events, which is compatible with the number (177) of selected events. The phase distribution of these events is shown in figure 7. The most populated bin is the phase interval [0.6-0.7] containing 30 events, 19 being expected from a flat distribution. In the hypothesis of a uniform background, this represents a fluctuation of 2.5 σ only.

Moreover, structures of similar statistical significance can emerge if one selects an off-source window, keeping the same mean declination but shifting the mean right ascension. This is shown in figure 8 in which a shift of 30° in right ascension with respect to Cygnus X-3 has been chosen. For this reason, it is not possible to consider the structure in figure 7 as a definite signal.

Since our angular error is much smaller than the preceding window size, more restrictive conical windows have been chosen, with respective half opening angles 5° and 4°. The corresponding phase histograms are shown in figure 9. The phase interval [0.6-0.7] is still the most populated one, but the statistical significance of the excess of events with respect to background is not increased.

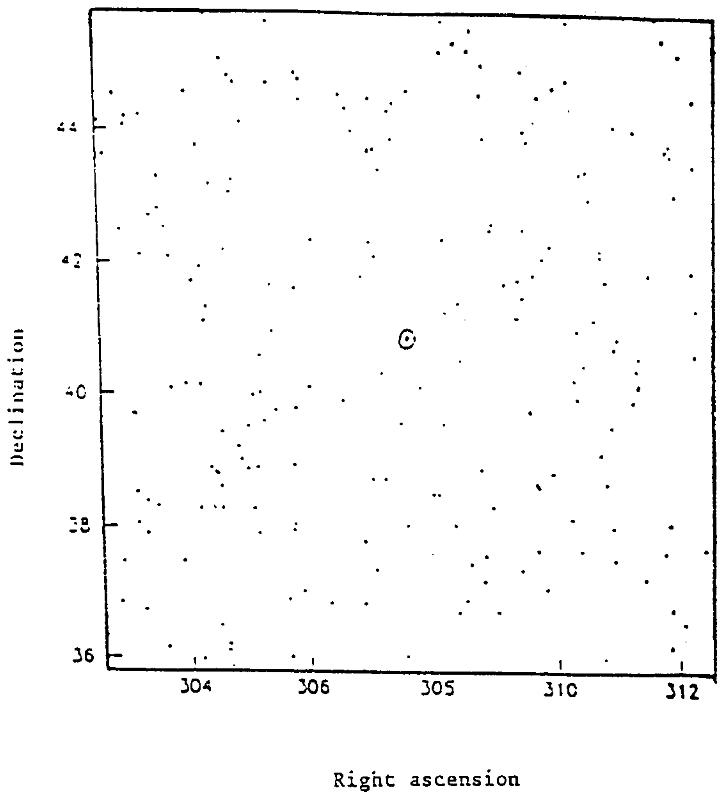
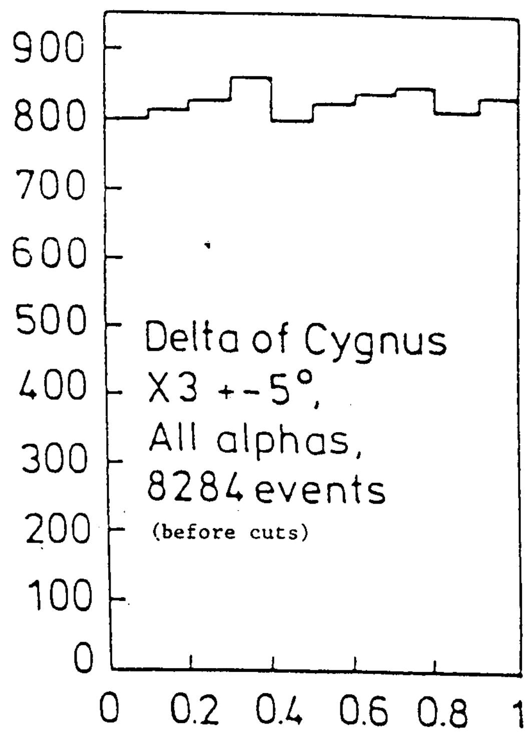

Declination
44
42
40
38
36
304
306
305
310
312
Right ascension

Figure 5


900
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
Delta of Cygnus
X3 +-5°,
All alphas,
8284 events
(before cuts)

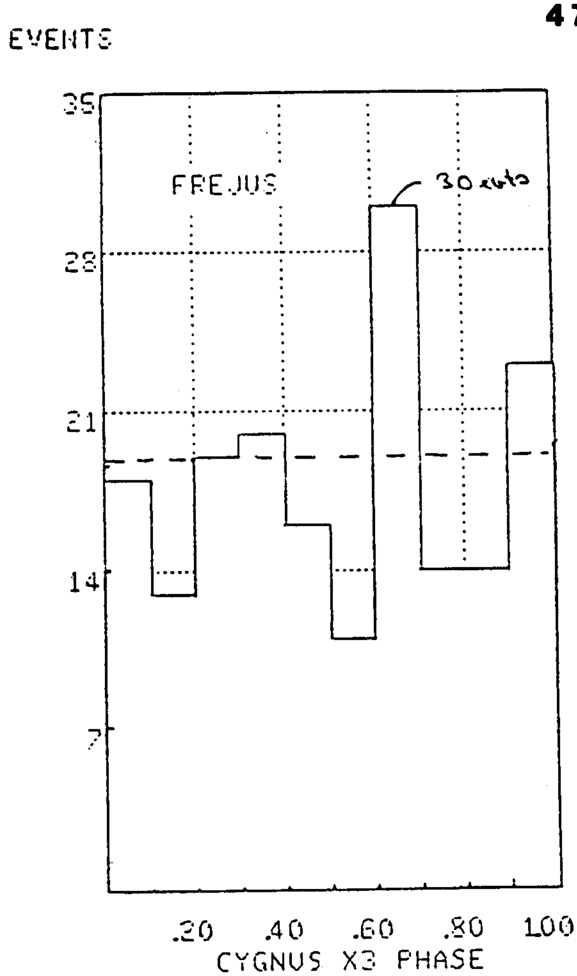
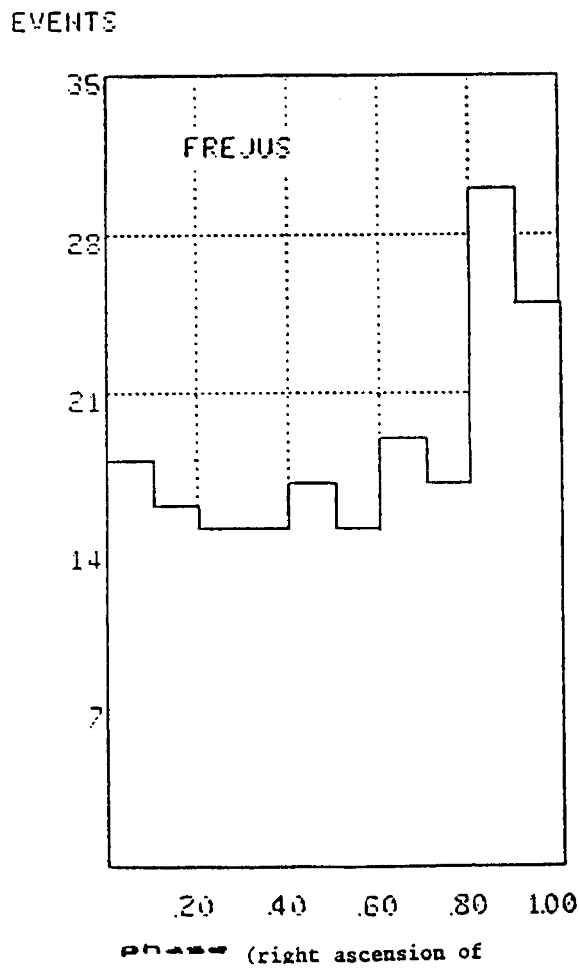

EVENTS
35
28
21
14
7
FREJUS
30 evts
.20
.40
.60
.80
1.00
CYGNUS X3 PHASE

Figure 7


EVENTS
35
28
21
14
7
FREJUS
.20
.40
.60
.80
1.00
phase (right ascension of

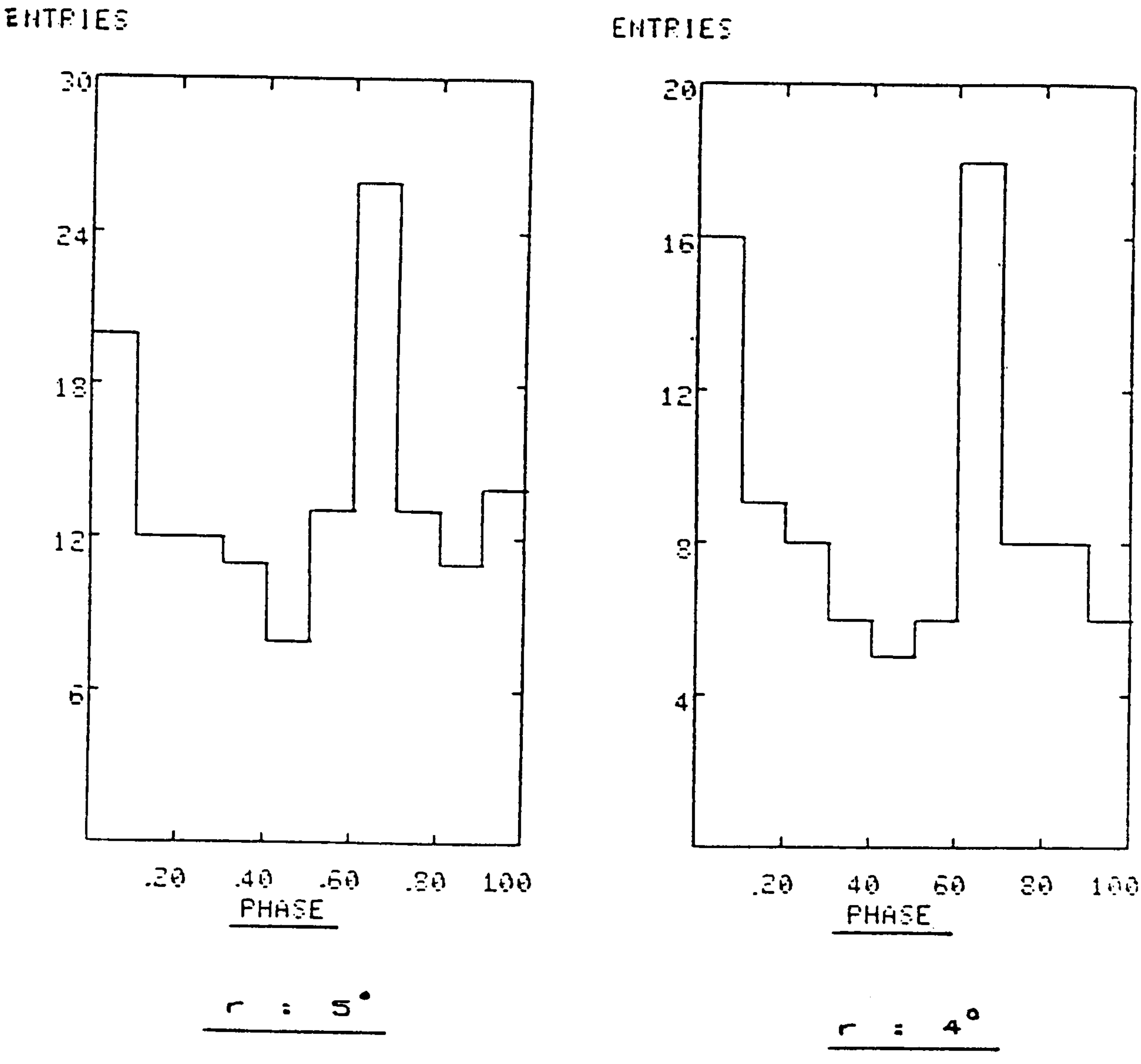


Figure 9 : Phase histograms with conical windows.

5. Conclusion

With the same window in right ascension and declination as the one chosen by the NUSEX group and a similar statistics, we find a phase histogram which is still compatible with a flat distribution, the most populated interval [0.6-0.7] being thus interpreted as a 2.5 σ fluctuation. Of course, a signal is not excluded but it should be noted that the NUSEX peak was found in the nearby phase bin [0.7-0.8] . Our statistics should be increased by a factor of 4 within 2 years. However, the source is suspected to vary with time [6] and it should be kept in mind for the comparison of the NUSEX and Fréjus data that the respective observation epochs are different.

References

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