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CYGNUS X-3 MUON SIGNAL IN THE NUSEX EXPERIMENT

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CYGNUS X-3 MUON SIGNAL IN THE NUSEX EXPERIMENT (*)

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1. - INTRODUCTION

Underground muons from the direction of Cygnus X-3 have been observed in the NUSEX experiment. Results concerning a period of about 2.4 years of effective working time from June '82 until December '84 have been presented at the First Symposium on Underground Physics (St.Vincent, 1985)(1) at the 19th ICRC (La Jolla, 1985)(2,3) and published(4).

An updating of these results concerning the year 1985 is presented here.

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2. - THE APPARATUS

NUSEX detector is installed in the garage 17 in the road tunnel linking France and Italy at 45.8° N latitude. The rock thickness is known with high accuracy ($\Delta h/h \sim 1\%$) in every direction at zenith angles $\theta<75°$. The minimum depth, near vertical direction, is about 4800 hg/cm^2 of standard rock. At this depth the muon energy corresponding to a survival probability of 20% is about 2.5 TeV.

The detector is a digital tracking calorimeter consisting of 134 horizontal iron plates 3.5x3.5 m^2, 1 cm thick, interleaved with planes of tubes having 1 cm x 1 cm cross section operated in the limited streamer mode.

Typical errors in reconstructing tracks are $\sigma_\theta \sim 1$ mr and $\sigma_\phi \sim 2$ mr for zenith and azimuthal angles respectively. Knowledge of the mountain pattern, high efficiency in the reconstruction of incoming muons (~100 %) and continuous operation (the effective working time is ~80 %) make NUSEX detector well suitable to perform underground muon physics in the depth range 5000-10000 hg/cm^2. More details on the site and on the detector performances are given in Ref. (5).

3. - ANALYSIS AND RESULTS

Muons are identified as penetrating particles crossing at least 10 planes. The updated sample consists of 27780 single muon events with zenith angle up to 75° recorded between June '82 and December '85. With this angular cut, Cygnus X-3 is observed for 64% of the total time.

In a cone of 4.5° half angle aperture centered around the source 171 events are found. The time of each event is reduced to the barycenter of the solar system and then folded modulo 4.8 hr using the Vanderklis and Bonnet-Bidaud quadratic ephemeris.

Data collected since 1982 until January 1985 provided a reasonable support for a 4.8 hr modulated signal as shown in Fig. 1. An excess of 19 events against an average off-source background of 11.39 events is found in the phase interval 0.7-0.8. The associated fluctuation probability that this effect occurs by chance is less than 10^{-4}. Moreover, an absolute excess from the Cygnus X-3 direction is found also when comparing the single muon events coming from the 30 contiguous cones of half-angle aperture 4.5° selected in the appropriate declination band, Fig. 2. The exposure for these cones (and for each phase bin) has been calculated and found to be uniform as expected for long time measurements. Details of calculations are given in Ref. (3).

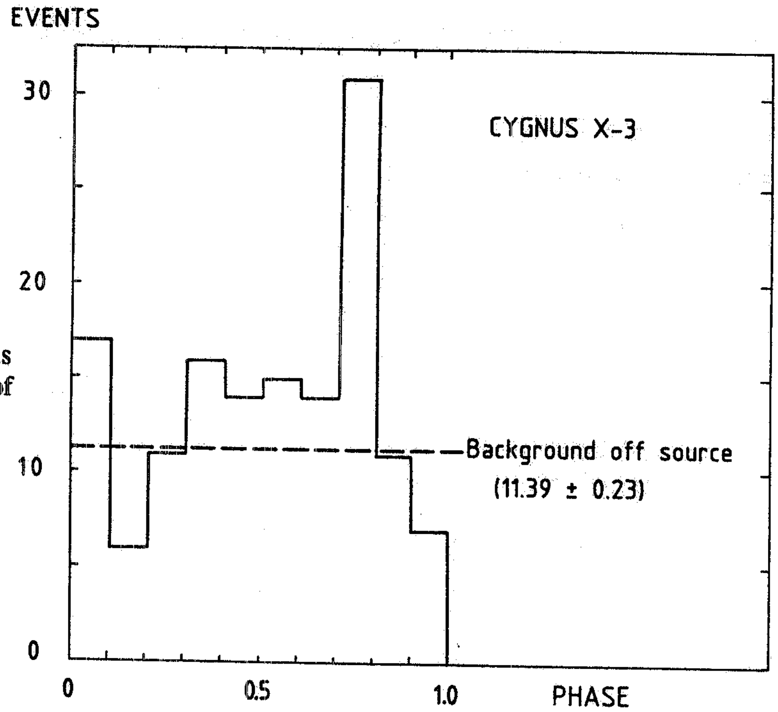

FIG. 1 - Phase distribution for muons arriving within 4.5° off the direction of Cygnus X-3 (June '82-January '85).

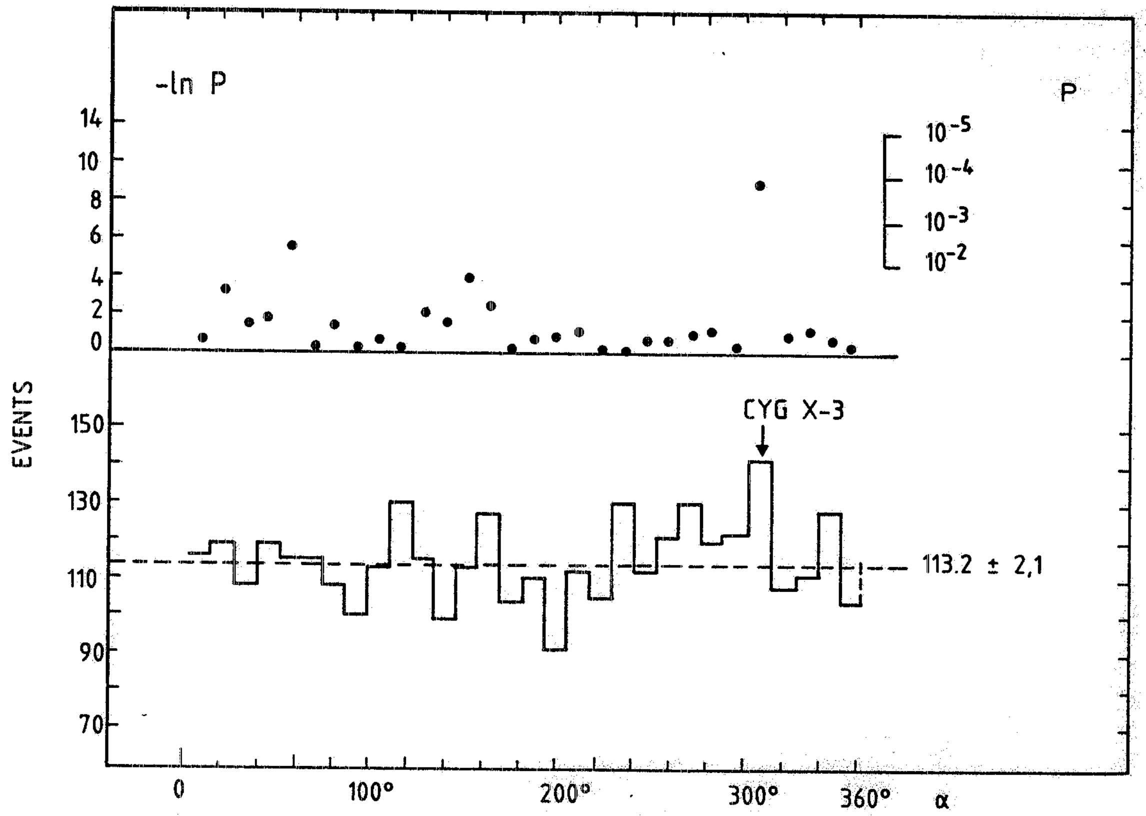

FIG. 2 - Muon distribution in the same declination band as Cygnus X-3. The events have been recorded in 29 contiguous cones of half angle aperture 4.5° selected in the ±4.5° off-Cygnus declination band. The phase analysis shows that no fluctuation is observed with probability P less than 10^{-3} in the background cones.

The muon distribution in the same declination band as Cygnus X-3 follows the expected one. No non-random dependences on phase or on direction have been found in the background data, implying that there are not priviliged phases or directions. That is evidenced in Fig. 3 showing the cumulative chi-square distribution for the 30 selected cones. Only in the cone centered around Cygnus X-3 is a deviation from the expectation found due to an enhanced flux in the phase interval 0.7÷0.8, Fig. 4.

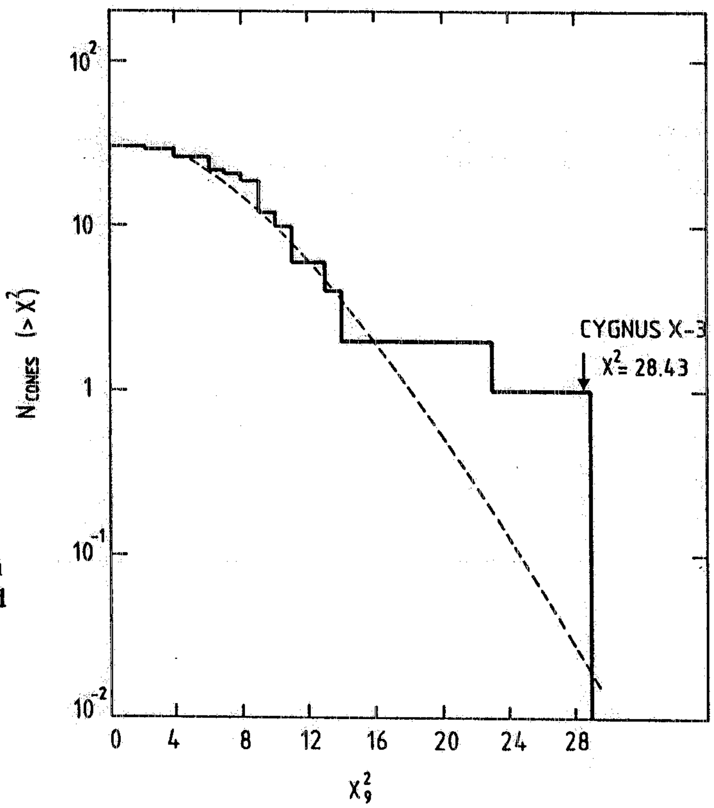

FIG. 3 - Cumulative chi-square distribution for the 30 selected cones in the declination band containing Cygnus X-3.

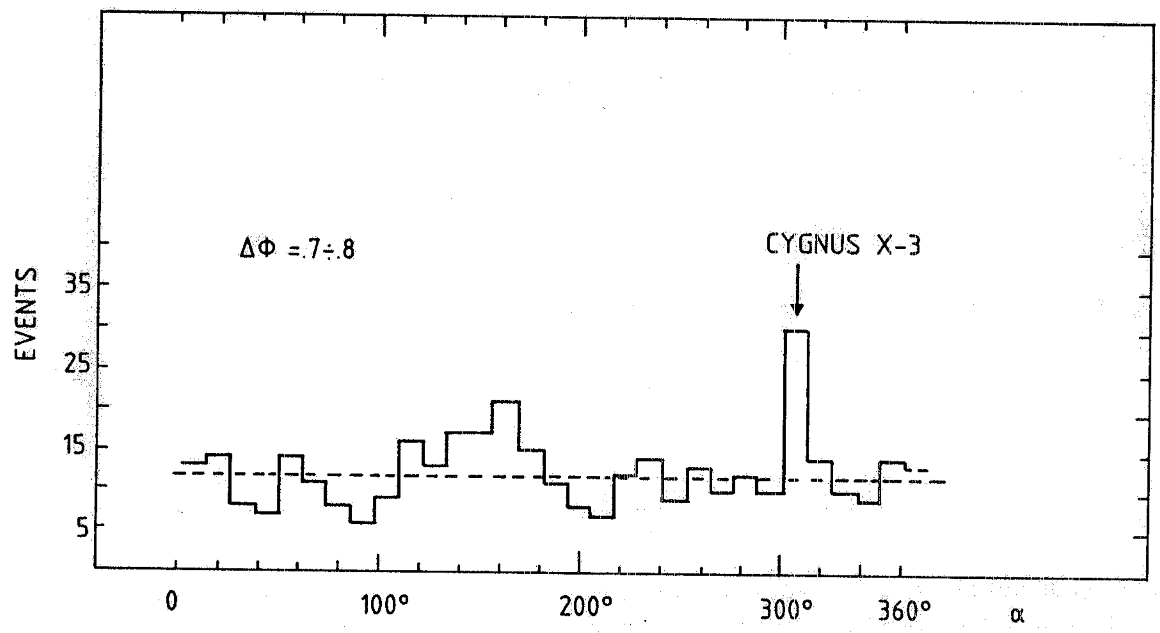

FIG. 4 - Muon distribution as in Fig. 2 for events in the phase interval 0.7÷0.8.

During the year 1985, observation has been continued except for a 2.5 months shut-down for normal maintenance and gas system upgrading. No evidence for enhanced flux in the phase interval 0.7-0.8 is found in the 33 events collected around the source direction. Phaseograms for data collected in each operation year are compared in Fig. 5 showing that the muon excess in the phase bin 0.7-0.8 has been recorded in the year 1983-1984 (a 4 σ signal). The time distribution of these events during the whole operation period suggests a concentration between July 1983 and July 1984 (20 events against an expected background of about 5), Fig. 6.

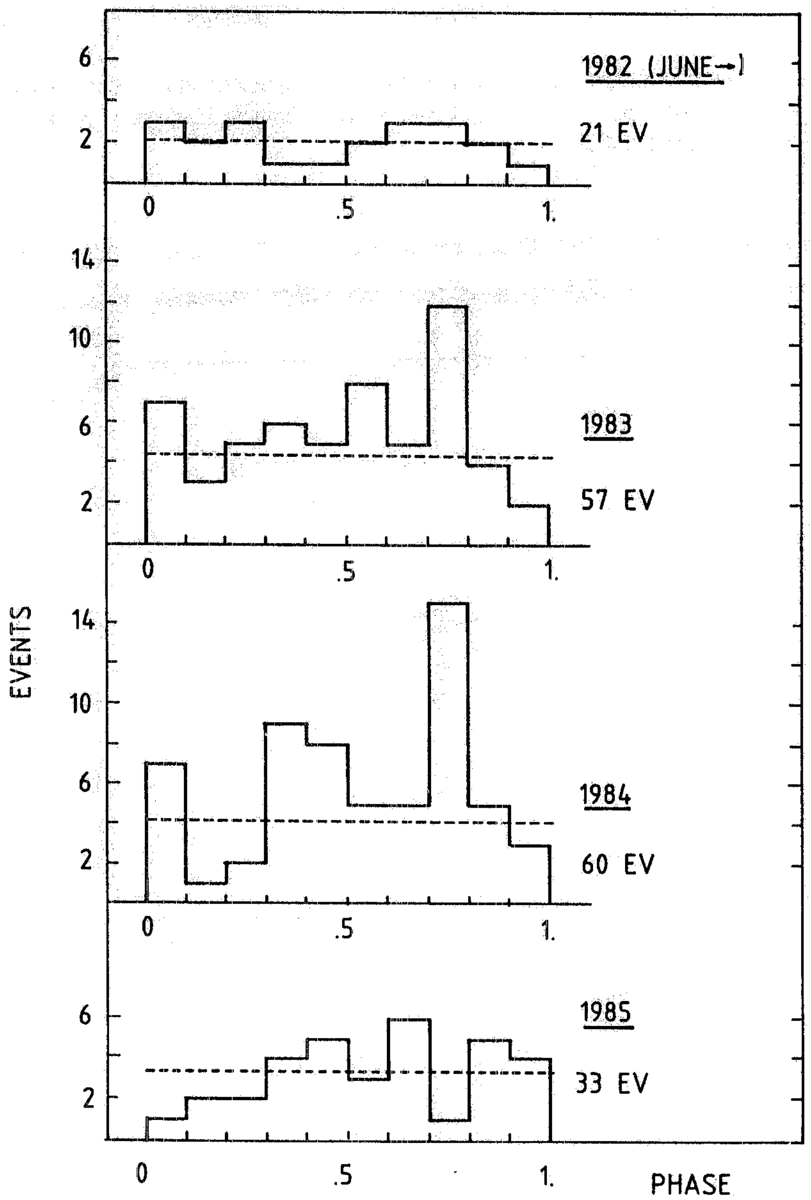

FIG. 5 - Phase histograms of the muons from the direction of Cygnus X-3 splitted into 1 year intervals.

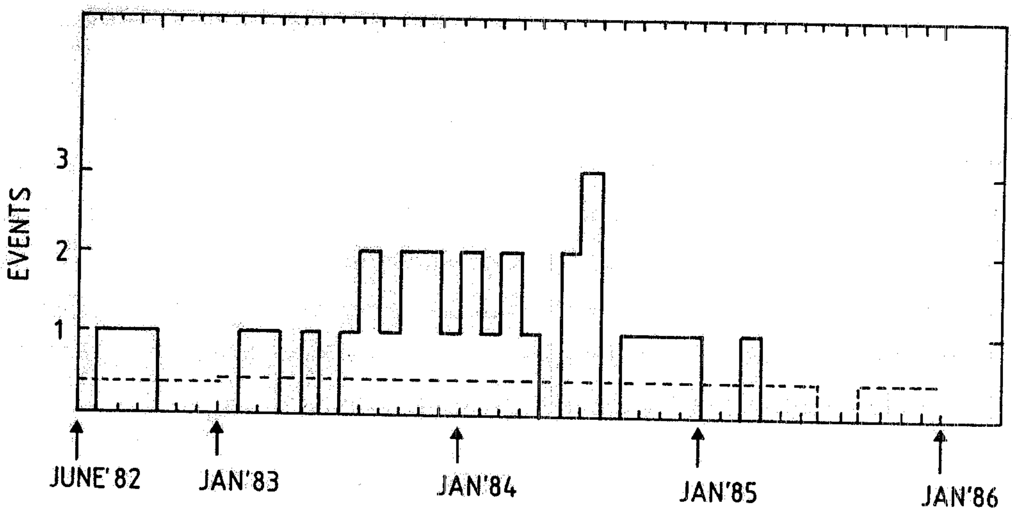

FIG. 6 - Time distribution of the muons recorded in the phase interval 0.7÷0.8 from the direction of Cygnus X-3. The dashed line shows the expected background.

On the other hand the 1982-1985 data produce the phaseogram shown in Fig. 7 with a muon excess at a 3 σ significance level and an associated intensity lower by a factor 1.6 with respect to that quoted in Ref. (3).

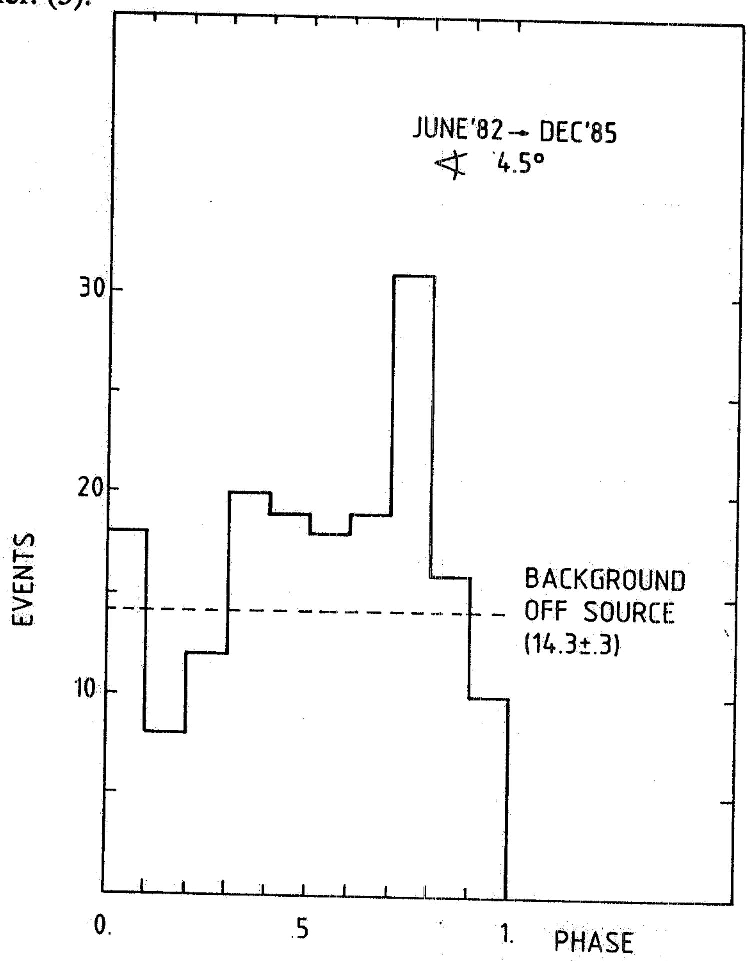

FIG. 7 - Phase distribution for June '82-December '85 data.

A possible correlation between muon events and the October '85 radio-burst, the largest since Cygnus X-3 discovery, has been investigated. The phase histogram of muons recorded in the period 2÷17 October contains 4 events, 3 of which are in the same phase bin 0.8÷0.9. The measured background off Cygnus X-3 is .24 events/bin in agreement with the expectations.

This bin is not coincident with the bin 0.7÷0.8 in which the excess has been observed in '83÷'84 data. On the other hand there are no firm theoretical predictions about the exact nature of any correlation between radio-bursts and processes producing high energy particles.

No other similar configurations have been found in the background cones in the same declination band. The probability to find 3 or more events in any one of the ten bins is about $4 \cdot 10^{-3}$, rather large to draw any conclusion.

4. - DISCUSSION AND CONCLUSIONS

These results have been received with scepticism essentially due to the following reasons

a) the muon flux looks surprisingly high not far from the flux of surface showers from Cygnus X-3 in the range 10^{12}-10^{15} eV. The signal carrier (the socalled "cygnet") has to be relatively light, neutral and long lived(6), but experimental data seems to exclude the natural candidates, photons and neutrinos(1,3,7).
b) The signal shows on angular dispersion at variance with the expectation. Using a gaussian distribution for point source resolution, a mean angle of about 2.5° is required to get a fair agreement with data. On the contrary, the experimental angular resolution is better than 1° and the multiple Coulomb scattering is expected to contribute with a mean dispersion angle of ~.6° as obtained by means of a Montecarlo calculation for underground muon transport(8). This result agrees with the experimental distribution of the angle between muon pairs in NUSEX (Fig. 9 in Ref. (3)). Thus, this angular spread has to be explained with large transverse momentum acquired at production.
c) other experiments, except for Soudan detector(9), have failed to confirm the effect.

Though the puzzling features a),b) cannot be explained in terms of conventional particle physics, they can be used as general constraints on the cygnet nature and on the models of muon production. Indeed, a few phenomenological models have been developed to accomodate experimental data (flux and angular spread) without requiring unlikely luminosities of the source. Common feature of these models is to hypothesize a local muon production near the detector by cygnets with a typical cross section $\sigma_{cyg\text{-}nucleon}$ between 1 and 20 μb(10).

Point c) does not necessarly mean a contradiction because of the difference in depth, resolution, exposure time, angular window etc. One problem with comparing different experiments is that

Cygnus X-3 (as well as the other VHE γ sources) is known to be an episodic and highly variable source.

Frejus[11] and Homestake[12] experiments, situated at comparable depths, have produced upper limits below the flux found by NUSEX. However the reported data cover an observing time period (mainly in '85) which is not overlapping with that of maximum muon excess at Mt.Blanc, so that there is no inconsistency between these results.

Other experiments at lower depths analyze muons at threshold energies comparable to the NUSEX ones by looking at large zenith angles. In this case the muon intensity is greater - approximately by a factor sec θ (θ = zenith angle) - than the vertical intensity at the same depth (this effect results for conventional muons from pion or kaon decay). Thus, if the production mechanism of muons by cygnets were of "prompt" nature (as for muons from charm decay or produced by neutrinos) and the cygnet emission episodic, a decrease in the ratio signal:background could arise for long time measurements.

More and better observations are urgently needed. An important lesson we have learnt is that experiments performed in different locations and depths or at different times are difficult to compare. NUSEX data taking is scheduled at least until 1989, thus providing a continuous and uniform monitoring of the source over a very long time.

Note added in proof.

Data collected in '86 until November 20 have been analyzed. 40 events have been found coming from the Cygnus X-3 direction. Their phase distribution is practically flat and compatible with uniformity.

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