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DIFFICULTIES WITH INTERPRETATIONS OF UNDERGROUND
MUONS FROM CYGNUS X-3

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ABSTRACT

We develop and investigate the consequences of experimental constraints on interpretations of extended air showers (EAS) and underground muons from Cygnus X-3 involving new particles which we call cygnets. The large angular spread of the muons observed in the NUSEX experiment and the large ratio of muon and EAS fluxes suggest that the muons have low energies and are produced in the Earth close to the detector. We estimate that

$$4 \times 10^{-30} \text{ cm}^2 > \sigma_{\text{cygnet-nucleon}} > 2 \times 10^{-30} \text{ cm}^2$$

and the muons have energies 0 (100) GeV. It is difficult to reconcile the existence of such a cygnet with beam dump experiments, unless one speculates on another parent particle decaying into the cygnet. All theoretical models for the cygnet known to us have severe difficulties.

Signals emanating from Cygnus X-3 have been reported in extended air showers (EAS)¹⁾⁻⁹⁾ and in muons observed deep underground¹⁰⁾⁻¹²⁾. These observations have several puzzling features: 1) EAS produced by gamma-rays should be muon-poor, because they are purely electromagnetic showers. However, the Kiel experiment¹⁾ found the muon content of EAS from Cygnus X-3 to be almost the same as in nuclear EAS, and this result was confirmed by the Nottingham muon detector at Haverah Park⁹⁾. An attempt was made at Akeno⁸⁾ to look for muon-poor showers ($N_\mu/N_e = 0.001$ as opposed to nuclear showers with $N_\mu/N_e = 0.03$). Eighteen such showers were detected coming from the direction of Cygnus X-3, of which 15 were in the broad phase interval $\phi = 0.55$ to 0.85 . If one is brave enough to consider this as a real effect, and not just an upper limit, the deduced flux is $\phi_{\text{EAS}}^{\text{poor}}(>1 \times 10^6 \text{ GeV}) = (1.1 \pm 0.4) \times 10^{-14} \text{ cm}^{-2} \text{ sec}^{-1}$ during 1981 to 1984, while the Haverah Park observations for 1984⁹⁾ gave $\phi_{\text{EAS}}(>1 \times 10^6 \text{ GeV}) \approx 7 \times 10^{-14} \text{ cm}^{-2} \text{ sec}^{-1}$. Therefore the flux of muon-poor showers is $\lesssim 1/6$ of the total. 2) There must be absorption of gamma-rays due to e^+e^- production off the microwave background¹³⁾. This absorption should have the form of a relatively narrow dip at $E \sim 2 \times 10^6 \text{ GeV}$ with a suppression factor of about $4\frac{1}{2}$ if one assumes Cygnus X-3 is 13kpc away. No such absorption is observed. 3) Muons from the direction of Cygnus X-3 have been detected by the NUSEX¹⁰⁾ and Soudan I¹¹⁾ proton stability experiments. This flux is seen in the direction of minimum depth and not at large zenith angles. It is normally believed that the muons are produced in the atmosphere, and their energies are then estimated from the depth of earth apparently traversed: $\bar{E}_\mu \approx 5 \text{ TeV}$ for NUSEX and $\approx 0.85 \text{ TeV}$ for Soudan I. Then the fluxes of EAS and of muons with $E \sim 1 \text{ TeV}$ seem to be the same, as shown in the compilation in Fig. 1. This would mean that the muon fluxes at these inferred energies would be far too high for γ -ray primaries, and even too high for hadron (proton) primaries, as also seen in Fig. 1. 4) The angular spread of the muons in the NUSEX experiment is $(\pm 5)^\circ \times (\pm 5)^\circ$, which is surprisingly large. In what follows we mainly restrict ourselves to considering data from the NUSEX detector, which we regard as the most informative.

What known particle could be the cosmic ray primary - called here the cygnet and denoted by C - responsible for these observations? As discussed in more detail later, charged particles would be deflected by the galactic magnetic field, and hence would lose their memory of the Cygnus X-3 direction and phase. As for neutral particles, photons are disfavoured by the muon observations (1) and (2) above, while neutrons are too short-lived. Neutrinos have cross-sections which are too small to explain both the EAS and the underground muons¹⁴⁾⁻¹⁸⁾. Also, neutrinos would not give the zenithal angle dependence observed for the

underground muons¹⁰⁾. Moreover, all estimates based on acceptable ν luminosities give a muon flux from $\nu_{\mu} N \rightarrow \mu X$ underground which is at least two orders of magnitude less than the observed one¹⁴⁾⁻¹⁸⁾. Less conventionally, a quasistable dilambda hyperon $\Lambda\Lambda$ has been suggested¹⁹⁾ as the cygnet. However, it also cannot provide a large enough muon flux^{*}), and is at best marginally consistent²¹⁾ with general constraints on the cygnet mass and lifetime^{22),23)}.

The photino has been suggested²⁴⁾ as a candidate for the cygnet. However, detailed calculations²⁵⁾ showed that this hypothesis needed a source with luminosity $L_p > 2 \times 10^{44} (\Omega/0.01) \text{ erg/s}$ where Ω is the solid angle in steradians which contains the original proton beam, which is impossible for a galactic source. A glueballino $\tilde{G}$ ($\tilde{g}\tilde{g}$ bound state) has also been considered^{26),27)}. It can explain the EAS and their muon content, but gives a flux of TeV muons which is 1/30 of that observed, albeit larger than from proton primaries as seen in Fig. 1. Free massless coloured gluons produced through a breakdown of confinement in pp collisions at very high energies have also been proposed²⁸⁾ as cygnets. This was the only model known to us which tried to explain the $(\pm 5)^0 \times (\pm 5)^0$ angular spread of the NUSEX muons¹⁰⁾. It was proposed to originate from the scattering of the high energy gluon beam on relic gluons in interstellar space. However, as will be shown later, this also results in an unacceptable increase in the pulse duration. Thus we know of no successful attempt to explain the underground muon data.

In this paper we discuss general constraints on any new particle proposed as the cygnet. We are not foolish enough to claim a no-go theorem, but almost. We start by reviewing the well-known (a) lifetime and (b) mass^{22),26),27)} constraints on the cygnet. Then we show (c) that the upper limit imposed by the pulse duration on the difference in path length caused by multiple scattering means that the electric charge of the cygnet $Z_c < 2.3 \times 10^{-7} e$. Next we show (d) that the angular spread of the underground muons observed by NUSEX¹⁰⁾ cannot be due to multiple scattering in interstellar space, again because of the pulse duration. Our next observation (e) is that for $E_{\mu} \approx 5 \text{ TeV}$ there is an absolute upper limit on the angle θ between the primary cygnet and the produced muon of 1.1^0 , which is much less than the angular spread seen in the NUSEX data¹⁰⁾.

We conclude on the basis of the previous two points that the NUSEX muons could not be produced in the atmosphere, since then they would have had to traverse $5 \times 10^5 \text{ gm/cm}^2$ of matter, and hence have $\bar{E}_{\mu} \approx 5 \text{ TeV}$ and $\theta \lesssim 1.1^0$. To

*) The same is true for the particles considered in Ref. 20).

satisfy $\theta \sim 5^\circ$ as reported by NUSEX, the muon energies must be $E_\mu \lesssim 260$ GeV. Thus the muons are produced in the Earth near the detector. Probably the energies are actually even smaller ($\bar{E}_\mu \sim 100$ GeV), because our upper bound on the scattering angle is very conservative. From this remark, the known ranges R_μ of muons at this energy²⁹⁾, and the absence of muons with large zenith angles, we deduce that the range of the cygnet R_C must lie between

$$4 \times 10^5 \text{ g/cm}^2 < R_C < (6 \text{ or } 7) \times 10^5 \text{ g/cm}^2 \quad (1)$$

corresponding to a cygnet nucleon cross-section σ_{CN} between

$$4 \times 10^{-30} \text{ cm}^2 > \sigma_{CN} > 2 \times 10^{-30} \text{ cm}^2 \quad (2)$$

At this point we point out a remarkable similarity between the underground muon experiments and beam-dump experiments at CERN³⁰⁾, illustrated in Fig. 2. The primary beam energies are not very different, and the distance of matter between beam-dump and detector ($\sim 2 \times 10^5 \text{ gm/cm}^2$) is not much different from that above the NUSEX detector, or from the deduced range (1) of the cygnet. We then calculate that there should be a large flux of muons from cygnets produced in the beam-dump experiment:

$$\frac{\phi(c \rightarrow \mu)}{\phi(\nu \rightarrow \mu)} = O(10^6) \quad (3)$$

which was not observed³⁰⁾. The only way we see to avoid this apparent contradiction is believe that the cygnets are not produced directly ($pp \rightarrow C+X$) but indirectly via the production $pp \rightarrow \Gamma+X$ and $\Gamma \rightarrow c+X$ of some parent particle Γ . This additional particle should be strongly interacting, with mass less than 10 GeV - so as to have a large enough cross-section to provide the required cygnet flux - and a long lifetime - certainly above 10^{-10} s if its lifetime is to be longer than its mean free time between interactions in the beam dump experiment, and above 10^{-5} s if we want to reduce the ratio (3) of beam dump muons below unity. The postulated parent Γ should also have a mass above ~ 4 GeV to have avoided detection in other fixed-target search experiments³¹⁾. We do not find such a parent physically plausible^{*}), but we cannot exclude it logically, and so claim no no-go theorem.

^{*}) Its decay would need to be weaker than the conventional weak interactions, and we know of no well-motivated theoretical candidate.

The arguments of the previous paragraph were based on the angular spread of the NUSEX muons¹⁰⁾. If we discard these data, we can draw some less restrictive conclusions based on the fact that if the muons were produced in the atmosphere, the underground muon flux is roughly equal to the EAS flux at similar energies. This is difficult to reconcile with the falling EAS spectrum and the fact that produced muons probably have energies $\lesssim 1/10$ of the primary energy. We conclude that $\sigma_{\text{CN}} < 1\text{mb}$ (so that most cygnets do not interact in the atmosphere), and that we can accommodate the data if $\sigma_{\text{CN}} \lesssim (0.01 \text{ to } 0.1)\text{nb}$ and the probability of producing a muon in a CN collision is $\lesssim 0.1$ to 1.

We now review the preliminary remarks (a) to (e) in more detail, and then develop our arguments comparing muon production in the Earth and beam dump experiments³⁰⁾. (a) The lifetime τ of the cygnet must obey $\tau \gtrsim r/c\gamma$, where the distance r to Cygnus X-3 is at least 11.6 and probably 13 kpc $\approx 4 \times 10^{22}$ cm, and γ is the Lorentz time dilation factor. Thus

$$\tau \gtrsim 1.3 \times 10^6 \times \left(\frac{10^6}{8}\right) \text{ s} \quad (4)$$

(b) A pulse of cygnets of duration less than the observed spread $\lesssim \tau_0 \sim 1/10$ of the Cygnet X-3 period of ~ 4.8 hrs, i.e., $\tau_0 \sim 1.7 \times 10^3 \text{ s}$, must travel for $\gtrsim 40,000$ yrs without dispersing by a delay larger than τ_0 . Hence

$$m_c \lesssim E \left(\frac{2c\tau_0}{r}\right)^{1/2} \lesssim 5.7 \times \left(\frac{E}{100 \text{ TeV}}\right) \text{ GeV} \quad (5)$$

If there are 12.6 ms pulsations at $E_{\text{EAS}} \sim 1 \text{ TeV}$ ³²⁾, then the primary must have a mass $\lesssim 160$ keV. However, it may well be that the radiation at $E \sim 1 \text{ TeV}$ is not due to cygnets, but is mainly γ -rays produced by electrons, since this is known to be the case for other pulsars. (c) Multiple scattering of a charged particle in magnetic fields between the source and the observer produces a path difference Δr relative to the straight line. The difference produced between each pair of scatterings is $\Delta r_i = l_0(1 - \cos\theta_i) \approx l_0\theta_i^2/2$, where l_0 is the typical magnetic cloud dimension and θ_i the scattering angle. Thus

$$\Delta r = \sum_{i=1}^n \Delta r_i \approx \frac{1}{2} l_0 \sum_{i=1}^n \theta_i^2 \quad (6)$$

and assuming random orientations of the different magnetic fields:

$$\langle \Delta r \rangle = \frac{1}{2} l_0 \sum_{i=1}^n \theta_i^2 \approx \frac{1}{4} l_0 \theta_0^2 n^2 = \frac{1}{4} \frac{r^2}{l_0} \theta_0^2 \quad (7)$$

where $\theta_0 \sim l_0/R_H$ is the mean bending angle, with $R_H = E_C/(300Z_C \times H)$ the gyro-magnetic radius in a magnetic field H for a particle of energy E_C and charge Z_C . Imposing the constraint

$$\frac{\Delta r}{r} = \frac{1}{4} \frac{r l_0}{R_H^2} < \frac{c \tau_0}{r} \quad (8)$$

to maintain the short pulse duration, we infer

$$Z_C < \frac{1}{150} \frac{E_C(\text{eV})}{H(\text{Gauss})} \left(\frac{c \tau_0}{r} \times \frac{1}{l_0(\text{cm}) r(\text{cm})} \right)^{1/2} \quad (9)$$

Taking typical values $E_C = 1 \times 10^{15}$ eV, $H = 3 \times 10^{-6}$ Gauss, $l_0 \sim 1$ pc, $r \sim 4 \times 10^{22}$ cm and $\tau_0 \sim 1.7 \times 10^3$ s we find

$$Z_C < 2.3 \times 10^{-7} e \quad (10)$$

Thus integer-charged cygnets are totally excluded, as is well known. While some theories predict fractionally charged particles³³⁾, we know of none with a charge as low as (10) that could be produced in Cygnus X-3, and so recover the natural conclusion that the cygnet must be neutral. (d) It has been suggested²⁸⁾ that the large angular spread $(\pm 5)^\circ \times (\pm 5)^\circ$ of the NUSEX muons could be due to scattering in interstellar space. However, there is a simple connection between the overall angle of dispersion due to multiple scattering and a dispersion in the path length which would increase the pulse duration. Using Eq. (7) which also holds for scattering off objects in interstellar space with a mean free path l_0 , and setting $\theta^2 \approx n \theta_0^2$, we obtain

$$\frac{\langle \Delta r \rangle}{r} \approx \frac{1}{4} \langle \theta^2 \rangle \quad (11)$$

Taking $\langle \theta^2 \rangle \approx 3 \times 10^{-3}$ (radians)² for NUSEX, we get $\langle \Delta r \rangle/r \approx 1.5 \times 10^{-3}$, where the upper limit from the pulse duration is $\langle \Delta r \rangle/r < 1.3 \times 10^{-9}$. Alternatively, this upper limit on $\langle \Delta r \rangle/r$ yields $\langle \theta^2 \rangle < 5 \times 10^{-9}$, corresponding to an r.m.s. dispersion angle $\langle \theta^2 \rangle^{1/2} < 4 \times 10^{-3}$ radians. Thus the angular spread of the NUSEX muons, if a real effect, could not be due to scattering in interstellar space. (e) There is a simple kinematical limit on the scattering angle θ in the inclusive reaction $C+N \rightarrow \mu+X$, which holds even if the muon is produced by secondary decays, namely:

$$\theta^2 < \frac{2m_N}{E_\mu} \frac{E_x}{E_c} + \frac{(m_c^2 + m_N^2 - m_N^2 - m_x^2)}{2E_0 E_\mu} \quad (12)$$

The second term in Eq. (12) is probably very small, and in any case negative if we accept the pulse duration constraint (5) on m_c , so we are safe and conservative in neglecting it. Then we find

$$\theta < \sqrt{\frac{2m_N}{E_\mu} \frac{E_x}{E_c}} \leq \sqrt{\frac{2m_N}{E_\mu}} \quad (13)$$

corresponding to $\theta < 1.1^\circ$ if $\bar{E}_\mu = 5$ TeV as conventionally believed for NUSEX. This conservative upper bound is much smaller than the upper bound of 5° observed by NUSEX.

The last two arguments above indicate that the NUSEX muons cannot be produced in the atmosphere, if we take seriously their angular spread. To have an angular spread at production as large as 5° , the NUSEX muons must have $E_\mu < 260$ GeV. This is probably an overestimate, since we do not expect the bound to be saturated, and we believe a more realistic estimate is $E_\mu < 100$ GeV. The range R_μ of a 260 GeV muon is²⁹⁾ 9×10^4 g/cm², so the muons must be produced in the rock just above the detector, and the range R_c of the cygnet must be at least

$$R_c > h - R_\mu \approx (5-1) \times 10^5 \text{ g/cm}^2 \approx 4 \times 10^5 \text{ g/cm}^2 \quad (14)$$

where $h \approx 5 \times 10^5$ g/cm² is the depth of earth above the detector. On the other hand, no effect is seen by NUSEX at zenith angles corresponding to $h \sim 7 \times 10^5$ g/cm². Therefore, we conclude

$$4 \times 10^5 \text{ g/cm}^2 < R_c < 7 \times 10^5 \text{ g/cm}^2 \quad (15)$$

If we assume that a large fraction of the cygnet energy E_c is lost in each collision, which is usually true for strongly interacting particles, then the bounds (15) imply

$$4 \times 10^{-30} \text{ cm}^2 > \sigma_{cN} > 2 \times 10^{-30} \text{ cm}^2 \quad (16)$$

The cygnet-nucleon cross-section must lie in a relatively narrow band of semi-strong values.

Now it is instructive to compare Cygnus X-3 and the NUSEX experiment with the CERN beam dump experiments³⁰⁾, as in Fig. 2. Our arguments about the muon angular spread have forced us to $E_\mu < 260$ GeV or probably < 100 GeV, which is close to the beam dump energy range. Our cygnets are forced to interact in the Earth just above the detector. Any such cygnets produced in the beam dump experiments could penetrate the 2×10^5 g/cm² of earth between the target and produce a large flux of muons in the neutrino detectors downstream, which has not been seen. Quantitatively, for Cygnus X-3

$$\left. \frac{\phi(c \rightarrow \mu)}{\phi(\nu \rightarrow \mu)} \right|_{X3} = \frac{\sigma(pp \rightarrow C+X)}{\sigma(pp \rightarrow \pi+X)} \frac{\sigma(CN \rightarrow \mu+X)}{\sigma(\nu N \rightarrow \mu+X)} \gg 10^2 \quad (17)$$

since the observed μ flux is at 10^2 to 10^3 times that expected from neutrinos taking into account^{19),18)} the possible luminosity of the source^{*}). In the beam dump, neutrinos and hence downstream muons are mainly produced by charm D:

$$\left. \frac{\phi(c \rightarrow \mu)}{\phi(D \rightarrow \nu \rightarrow \mu)} \right|_{BD} = \begin{cases} \frac{\sigma(pp \rightarrow C+X) \sigma(CN \rightarrow \mu+X)}{B(D \rightarrow \nu+X) \sigma(pp \rightarrow D+X) \sigma(\nu N \rightarrow \mu+X)} \\ \text{or} \\ \frac{\sigma(pp \rightarrow C+X) \sigma(CN \rightarrow \mu+X)}{R(\nu/\pi) \sigma(pp \rightarrow \pi+X) \sigma(\nu N \rightarrow \mu+X)} \end{cases} \quad (18)$$

Using the lower bound (17) and either the observed (ν/π) ratio $R(\nu/\pi) \sim 10^{-4}$ or the known cross-sections for D and π production and branching ratios $B(D \rightarrow \nu+X) \sim 0.1$, which of course give similar results, we find

$$\left. \frac{\phi(c \rightarrow \mu)}{\phi(D \rightarrow \nu \rightarrow \mu)} \right|_{BD} \gg \frac{10^2}{R(\nu/\pi)} \approx 10^6 \quad (19)$$

This comparison is not completely fair, since the cygnet muon energies are presumably somewhat higher than those in the beam dump. Nevertheless, we think that

^{*}) Experimentally, the zenithal angle dependence of the underground muons only tells us that this ratio is more than 3 to 5. Taking this more empirical bound would soften but not remove our contradiction (19).

the apparent conflict with the beam dump results is serious^{*)}, and that life is difficult for the relatively low energy cygnet with range (15) and cross-section (16) into which we were forced by our attempt (a) to (e) to be consistent with all the underground muon information.

One possible way out is to postulate that the cygnet is produced by the decays of some more massive parent Γ . This should be strongly interacting in order to have an acceptably large production cross-section. Recalling Eq. (17) and interpreting $\sigma(pp \rightarrow C+X) = \sigma(pp \rightarrow \Gamma+X)$, we have

$$\left. \frac{\sigma(pp \rightarrow \Gamma+X)}{\sigma(pp \rightarrow \pi+X)} \right|_{X3} \geq 10^2 \frac{\sigma(\nu N \rightarrow \mu+X)}{\sigma(\nu N \rightarrow \mu+X)} \geq 3 \times 10^{-4} \quad (20)$$

and hence $\sigma(pp \rightarrow \Gamma+X) > 10^{-29} \text{ cm}^2$. Even for such a strongly interacting particle, such a large cross-section could only be obtained at the energies characteristic of Cygnus X-3 if $m_\Gamma \lesssim 10 \text{ GeV}$. If the parent Γ were produced in the CERN beam dump experiments³⁰⁾ as copiously as by Cygnus X-3, we would be back to the contradiction (19), unless Γ had a long lifetime τ_Γ and interacted in the beam dump before decaying. Then the result (19) would be decreased by a factor $(\lambda_{\text{int}}/c\gamma\tau_\Gamma)$, which would be acceptably small if $\tau_\Gamma \gtrsim 10^{-5} \text{ s}$ for a representative choice of parameters: $\lambda_{\text{int}} = 50 \text{ g/cm}^2$, $\gamma = 100$. This lifetime constraint could be relaxed if $\sigma(pp \rightarrow \Gamma+X)_{\text{BD}} < \sigma(pp \rightarrow \Gamma+X)|_{X3}$, as would happen if threshold effects were significant. It should be noted that other fixed target experiments³¹⁾ have looked for long-lived strongly interacting particles with $\tau > 10^{-10} \text{ s}$, and excluded any such particles with masses $\lesssim 4 \text{ GeV}$. This still leaves a small window for the cygnet C and its parent Γ , even if one accepts all the experimental data at face value.

The prime candidate for an experimental constraint to be jettisoned is the angular spread in the NUSEX experiment. As mentioned earlier, even in this case one can deduce that σ_{CN} must be less than lmb . If it were larger, the probability for EAS production in the atmosphere would be unity and the NUSEX muons would have $\bar{E}_\mu \sim 5 \text{ TeV}$. But it is difficult to imagine a mechanism which gives

^{*)}We have in fact neglected an effect which would go in the direction of increasing $\phi(C \rightarrow \mu)/\phi(D \rightarrow \nu + \mu)|_{\text{BD}}$ still further. This is that the beam dump matter depth is less than that between NUSEX and Cygnus X-3 ($2 \times 10^5 \text{ g/cm}^2$ vs at least $5 \times 10^5 \text{ gm/cm}^2$), so that the beam dump C flux could be significantly less attenuated.

more than 1/10 of the primary energy to the muon, so such a large σ_{CN} would require

$$\phi_{EAS}(E_{EAS} \geq 10E_{\mu}) = \frac{1}{P} \phi_{\mu}(E_{\mu}) \left(\frac{R_C}{R_{\mu}} \right) \exp\left(\frac{h}{R_C}\right) \quad (21)$$

where P is the probability that $CN \rightarrow \mu + X$. The prefactors in (21) are certainly >1 , and may well be $O(10)$, so there is a conflict with the measured flux $\phi_{\mu}(E_{\mu}) \sim \phi_{EAS}(E_{EAS} = E_{\mu})$ and the fact that the EAS spectrum falls as $1/E$. This contradiction is removed if $\sigma_{CN} \lesssim 0.1$ to 0.01 mb and the muon production rate per CN collision is $\lesssim 1$ to 0.1 . It is difficult to believe in a production probability larger than 0.1 , in which case we deduce

$$10 \times 10^{-30} \text{ cm}^2 \gtrsim \sigma_{CN} \gtrsim 2 \times 10^{-30} \text{ cm}^2 \quad (22)$$

since the previously deduced lower bound on σ_{CN} from the zenithal angle distribution still applies. Thus even in this case our argument that Cygnus X-3 muons must be produced in the Earth and not in the atmosphere can still be made, and our subsequent beam dump analysis is still applicable, albeit with less certainty. The difficulties with new particle interpretations of underground muons from Cygnus X-3 are substantial.

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FIGURE CAPTIONS

- Fig. 1 : Measurements of the fluxes of extended air showers (EAS) and of underground muons assuming the latter are produced in the atmosphere. The data are from NUSEX¹⁰⁾, Soudan¹¹⁾ and MUTRON¹²⁾. Also shown are upper limits from Baksan for muons in angular ranges of $10^0 \times 10^0$ or $5^0 \times 5^0$ centred on the direction of Cygnus X-3. Also shown are estimates of the possible flux of underground muons from γ , p or glueballino $\tilde{G}$ primaries^{26),27)}.
- Fig. 2 : Comparison of the configurations of Cygnus X-3, the Earth and NUSEX, with that of the SPS accelerator, the beam dump, its shielding, and the CERN neutrino experiments.

Fig. 1

Surface
of each

Fig. 2