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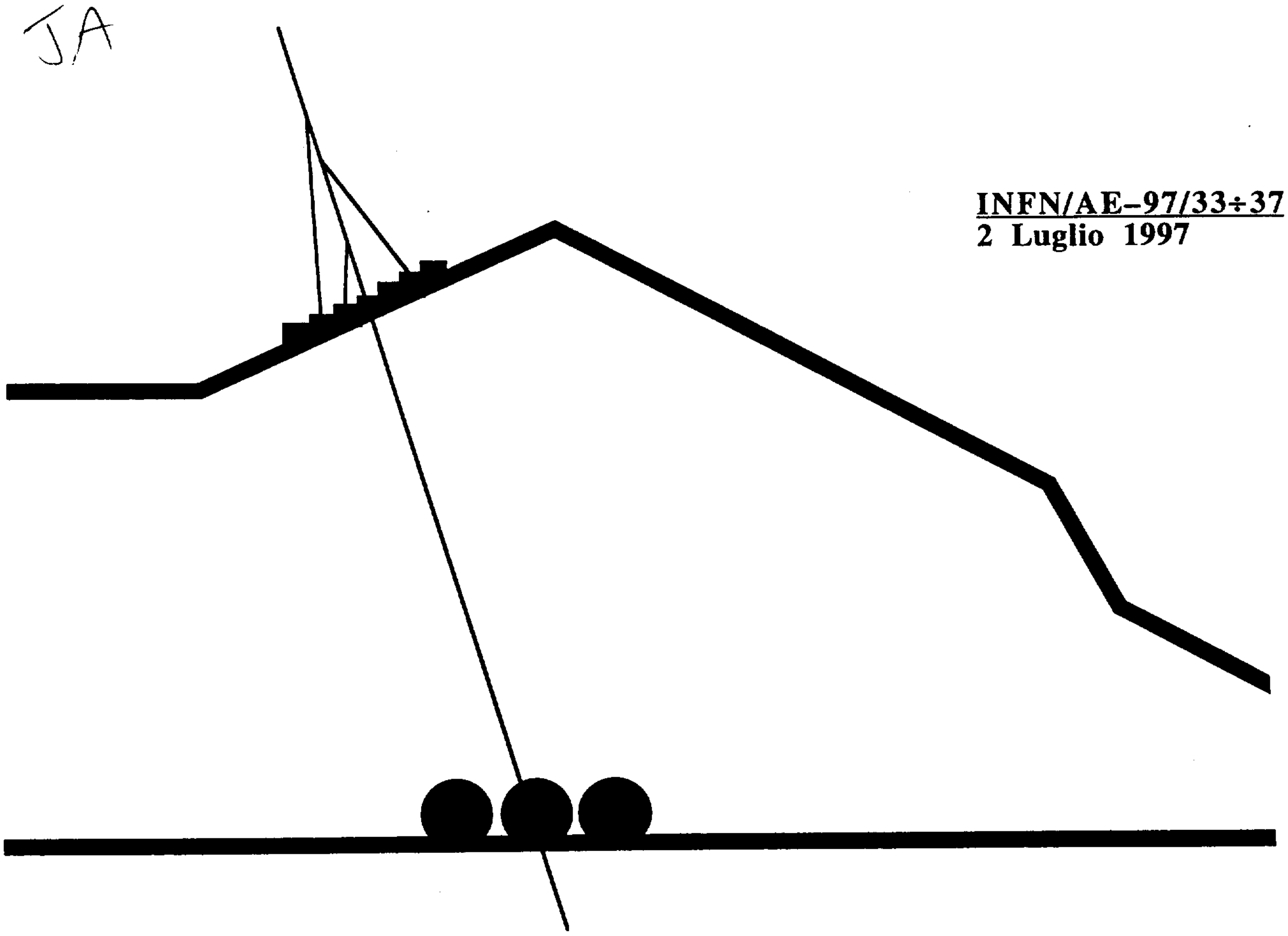

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SEARCH FOR POINT SOURCES WITH MUONS OBSERVED BY LVD

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ABSTRACT

Single muons collected by the first tower of LVD during 14431 hours of live time were used in a search for point sources of ultra high energy photons. We have made an all–sky survey of point sources of cosmic muons. We searched for any significant excess in the muon flux above simulated background in the right ascension – declination coordinates. We found no evidence for point sources. We also report a search for an excess of undeground muons from the directions of several known sources. Analysis of the data contained in the narrow cones around the source positions shows no signals from the sources.

INTRODUCTION

The experiments to search for point sources of underground muons started more than 10 years ago when Samorski and Stamm (Samorski and Stamm, 1983) observed high energy gammas from the Cyg X-3 direction in their EAS experiment. In 1985 NUSEX (Battistoni et al., 1985) and SOUDAN (Marshak et al., 1985) collaborations reported a muon excess from the same direction in the sky. The source of high-energy muons could be neutral stable particles (gammas or neutrinos). However, the signal was too high to be explained by known processes of muon production in the atmosphere. The production of high-energy muons in the gamma-induced showers in the atmosphere and possible detection of these muons underground were discussed by Kudryavtsev and Ryazhskaya (1985), Stanev et al. (1985), Stanev (1986) and Berezinsky et al. (1988).

Since 1985 many underground detectors have continued to look for excesses of downward-going muons in their data. Single muons measured by LVD underground have been used to search for anisotropies in the flux of underground cosmic–ray muons. The results of such analysis are presented here.

DATA ANALYSIS

The LVD (Large Volume Detector) (Aglietta et al., 1994, 1995), located in the underground Gran Sasso Laboratory at a latitude of $42^{o}27'$ N and longitude $13^{o}34'$ E, detects atmospheric muons passing through 3000 hg/cm^2 to more than 12000 hg/cm^2 (which correspond to the muon energies at the sea level from 1.5 TeV to 40 TeV) at the zenith angles from 0^{o} to 90^{o}. For the present analysis we used the single muons observed by the first tower of LVD. It has a dimensions 13m × 6.3m × 12m and geometric acceptance of about 1700 m^2 sr. The staggered double layers of limited streamer tubes and their orthogonal readout strips providing bidimensional information about the muon impact point allow LVD to reach high detection efficiency and accuracy of muon track reconstruction better than 1^{o}. A muon track is defined by alignment of at least 3 impact points in the tracking planes and the presence of at least 2 firing scintillation counters along the muon track. For this analysis we have chosen runs with duration more than 1 hour. The muons coming from nearly horizontal zenith angles (greater than 88^{o}) were excluded from the analysis due to the ambiguity of the track direction. After these cuts we selected 1185866 muons for further analysis.

The sky was surveyed from 0^{o} to 360^{o} in right ascension and from -10^{o} to 90^{o} in declination using the sample of single muons. The right ascension (R.A.) and declination, δ, for each muon were calculated and a two – dimensional map was stored using a cell size of 0.01×1^{o} from -1 to 1 in $\sin\delta$ and from 0^{o} to 360^{o} in R.A. (and $1^{o} \times 1^{o}$ in R.A. – δ coordinates). To search for a muon excess from any angular cell we compared the measured distribution in R.A. – $\sin\delta$ coordinates with a simulated background of atmospheric muons produced in hadronic showers initiated in the interactions of the primary nuclei with air. To calculate the background the following procedure was used. The direction of incoming muon was simulated from the experimental zenith and azimuthal distribution of muons observed by LVD in the same set of runs. The time of muon arrival was simulated as a Poisson process following the procedure described in (Ahlen et al., 1994). The mean time between two consecutive muons was calculated for each run and used in the simulation. Then, zenith and azimuthal angles and time of muon arrival were converted to right ascension–declination coordinates. The total number of simulated muons is 30 times more than the number of detected muons. Figure 1a shows a distribution of the data versus declination (after summing over R.A.). The shape of this distribution reflects the mountain structure at the LVD site. Figure 1b shows a distribution of the muon flux versus R.A. (summed over declination). For both these distributions the data and the Monte Carlo simulation of the atmospheric muon background are found to be in good agreement.

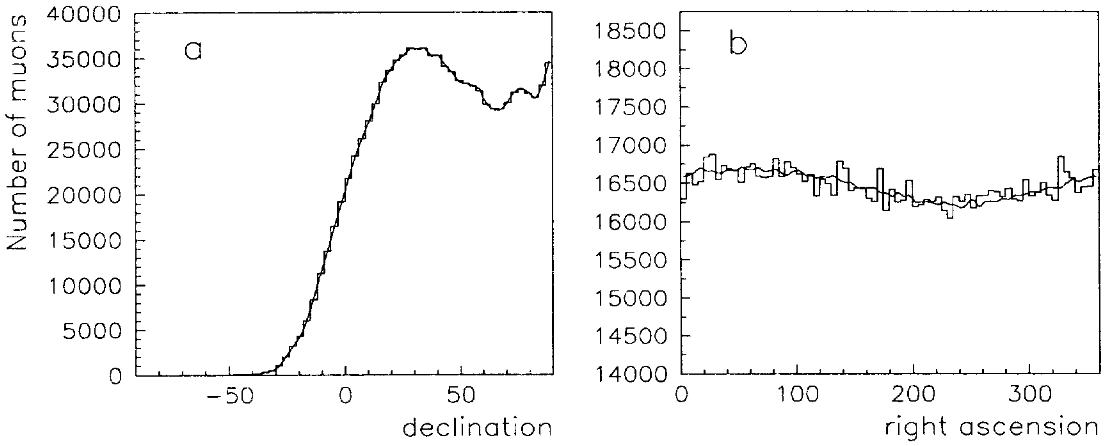

Fig. 1: Distribution of muon events versus declination (a) and right ascension (b). The histograms are experimental data, solid curves show Monte Carlo simulated background from atmospheric muons initiated in hadronic showers

Equal solid angle bins (3^o in right ascension and 0.04 in $\sin\delta$) were chosen to search for steady emission from point sources. The number of muons accumulated in each bin, n_{exp}, was compared to the Monte Carlo simulated background in the same bin, n_{mc}. We plot in Figure 2 the distribution of deviations from the mean $\Delta = \frac{n_{exp}-n_{mc}}{\sqrt{n_{exp}}}$ and a Gaussian fit to this distribution. We have no positive deviations greater than 3.5 σ. We have used the data for the bin with 3.5 σ muon excess to calculate the upper limit on the flux from any angular cell. The upper limit (95% C.L.) on the time independent flux from any point source of underground muons is $8.2 \cdot 10^{-12}$ cm^{-2}s^{-1}.

We also made a search in narrow cones (1.5^o half angle) around the positions of several possible sources of UHE photons and obtained the upper limits on steady fluxes of muons coming from those directions at the 95% C.L. using the formula:

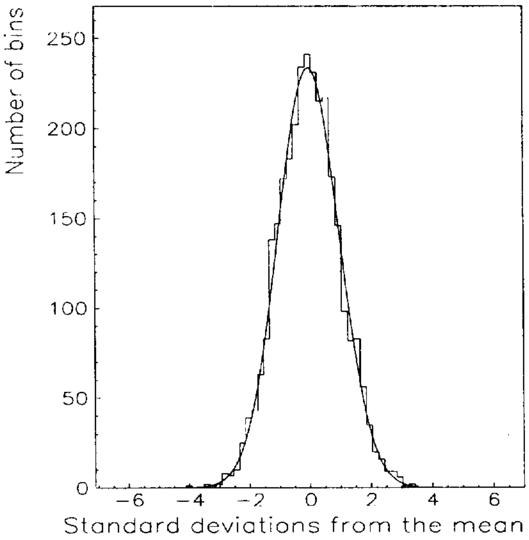

Fig. 2: Distribution of deviations from mean value of muon flux and Gaussian fit

$$F = \frac{1.65 \cdot \sqrt{n_{mc}}}{\langle \epsilon \cdot A \rangle \cdot T} \tag{1}$$

where $\langle \epsilon \cdot A \rangle$ is the weighted average of the product of efficiency of muon detection and reconstruction by the area of the cross–section of detector perpendicular to the muon track, and T is the exposure time.

Table 1: The steady flux limits (95% C.L.) from selected sources.

Source	⟨Depth⟩, m.w.e.	n_{exp}	n_{mc}	Flux limit, cm^{-2}s^{-1}
Cyg X–3	4037	320	314	$6.74 \cdot 10^{-13}$
Her X–1	4018	349	341	$1.16 \cdot 10^{-12}$
Crab Nebula	3429	394	399	$7.40 \cdot 10^{-13}$
SS433	3493	310	294	$7.13 \cdot 10^{-13}$
3C273	3551	290	261	$6.89 \cdot 10^{-13}$
Geminga	3410	384	401	$7.58 \cdot 10^{-13}$
Mrk 421	4009	324	321	$6.99 \cdot 10^{-13}$

CONCLUSIONS

We looked for an excess of muons both in an all-sky search with no a priori sources and in a search around positions of possible sources of UHE gammas. We did not see statistically significant muon excess (more than 3.5 σ), above the simulated background from any angular cell on the sky. The upper limit (95% C.L.) on the time independent flux from any point source of underground muons is $8.2 \cdot 10^{-12}$ cm^{-2}s^{-1}. This limit corresponds to the angular bin $3^o \times 0.04$ in R.A.–$\sin\delta$ coordinates. We obtained also the steady flux limits from selected astrophysical objects.

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