A Search for Astrophysical Point Sources and a Solar Anisotropy measurement

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Abstract

The L3 detector at LEP, CERN, has been employed for the search of point sources through the observation of muons with energies above 20, 30, 50, and 100 GeV. Excesses lasting for only one day, as well as steady emissions of single muon events pointing to a particular direction in the sky were searched for in the data obtained from mid July to October 1999 and from April to November 2000. Special attention was also given to a selection of known γ-sources. No statistically significant excess has been observed for any direction or particular source in the time periods considered. In addition a dedicated study of the angular distribution of muons above 20 GeV revealed evidence for a Solar anisotropy of the primary flux.

1. Introduction

Quite stringent upper flux limits for high energy steady gamma sources have been published during the past 15 years. Typically satellite experiments detect gammas up to tens of GeV and ground based Cherenkov detectors or shower arrays detect signals above several hundreds of GeV. The remaining energy domain can be studied by muon detectors located at a shallow depth. The muon production in gamma induced showers is much reduced compared to nuclei initiated ones. Nevertheless, if high enough gamma fluxes are emitted by a particular source, e.g. in burst like eruptions, there remain a probability for their detection. Located under only 30 m of overburden inside the LEP tunnel at CERN, Geneva, the L3+C spectrometer [1] has a muon energy threshold of 15 GeV and offers a new opportunity to search for such type of signals. The possibility to select the muon momentum threshold off-line makes it possible to optimize the signal to background ratio. L3+C consists of a huge magnet with a volume of 1000 m^3 and a field of 0.5 Tesla. High precision drift chambers measure the muon momentum accurately. The geometrical acceptance of the detector is $\leq$ 200 m^2sr. The angular resolution has been measured by analyzing di-muon events and is better than $0.2°$ above 100 GeV. A pointing precision of better than $0.1°$ has been obtained from the observation of the moon shadow. $1.2 \cdot 10^{10}$ cosmic ray muon triggers have been collected for an effective live-time of 312 days in the periods from July

pp. 2537–2540

to October 1999 and from April to November 2000.

2. Study of the anisotropy of the cosmic ray flux

Two methods have been applied to study the primary cosmic ray anisotropy [2]. Both are based on the idea that a fixed detector scans the sky in the right ascension direction (α) due to the Earth's rotation. No attempt is made to record also a declination dependent anisotropy. Method $\mathcal{A}$ looks for time variations of the muon detection rates with a period of one day, regardless of the arrival direction of the muons. Method $\mathcal{B}$ takes the directional information into account. A harmonic analysis of the result is performed and the first three harmonics of the anisotropy function $\delta^{dir}(\alpha) = (I(\alpha) - <I>)/<I>$, at the sideral frequency are extracted. $\delta^{dir}(\alpha)$ is defined here according to [3]. $I(\alpha)$ is the intensity as a function of the right ascension α; $<I>$ is the mean intensity.

Careful data selection permits to obtain sensitivities for $\delta^{dir}(\alpha)$ of a part in 10^{-4}. Corrections for the effective live-time, as well as for the Compton-Getting effect [4] are applied to all data. No significant deviation from isotropy is observed at the sideral diurnal frequency for any of the first three harmonics. The results obtained with a muon energy cut at 100 GeV are compatible with the experimental result of Cutler et al. [5]. The measurement for a 20 GeV energy cut of the first harmonic doesn't follow the prediction of the recent NFJ model [6] to observe a deficit of galactic origin at α = 12h, as shown in Figure 1.

A significant deviation from isotropy is found for the second harmonic of the Solar frequency at the lowest energy thresholds (20 and 30 GeV) (figure 2). The pseudo-right ascension $\tilde{\alpha}$ is used ($\tilde{\alpha} = \hat{\phi} - h$, in which $\hat{\phi}$ is the phase of the concerned frequency and h the hour angle). The structure of this anisotropy function is similar in shape to what has been reported by the GRAND experiment at a muon energy threshold of 100 MeV [7], but with an amplitude which is five times smaller.

Further analyses, including the tidal frequency and the anisotropy of multi-muon events showed no significant signal. It should be kept in mind when interpreting the results presented here, that the data-taking period did not span a full year.

3. Search for point sources

The technique used for the anisotropy study is applied for the study of point sources as well [2]. The background muon rate as a function of the right ascension is determined along thin declination bands. The total number of detected muons above a given energy for all sky cells in given periods of stable data taking has been measured and agrees with expectations, taking into account the time and direction dependent detection efficiency. To find rate excesses in par-

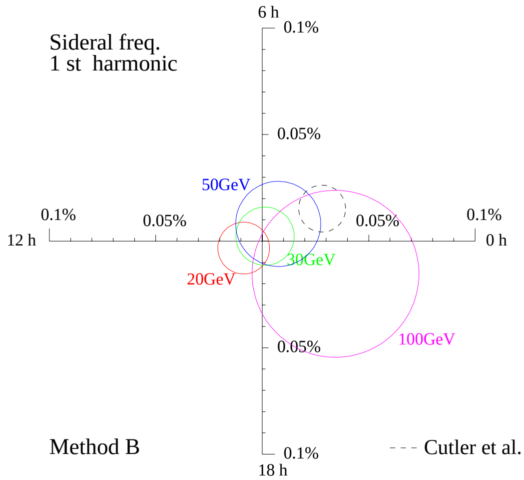

Fig. 1. Dial plot showing the results of the first harmonic of the anisotropy function of the sideral frequency for four different energy cuts (method $\mathcal{B}$). The circles represent the 68.5% confidence level region. The hatched circle is the result of Cutler et al. [5].

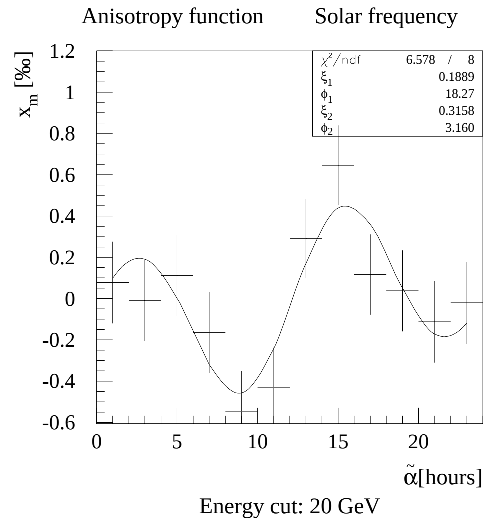

Fig. 2. Anisotropy distribution in “pseudo-right ascension” $\tilde{\alpha}$ for muons with energies larger than 20 GeV. The distribution is fitted with the sum of the first two harmonics. The vertical bars represent the statistical errors.

ticular sky cells (the cell size has been optimized for the particular momentum threshold), the Poisson probability $\mathcal{P}$ to observe a muon number equal or larger than the number of observed events has been calculated for each cell. In order to be sure that the systematic uncertainties on the background due to direction dependent efficiency variations are negligible, cumulative distributions of - log($\mathcal{P}$) for all trials have been produced. The upper limit of possible signal events has been determined with a 90 % CL. From this, the flux upper limits could be estimated assuming the source to be located at the zenith and that the signal to background ratio is independent of the direction.

The cumulative distribution for four different muon energy thresholds and for all one-day periods revealed no excess. Also no excess was found for all time periods analyzed (months), up to the full 312 day period. For the complete sky region ($0h < \alpha < 24h$ and $0° < \delta < 90°$) scanned during the integral time of 312 days by L3+C, steady muon flux upper limits ranging from $0.3 \cdot 10^{-10}$ and 10^{-8} cm^{-2}s^{-1} have been determined at the 90 % CL for four different muon energy thresholds (20, 30, 50 and 100 GeV) respectively. Typically $0.5 \cdot 10^6$ events are contained in the sky cells for an energy threshold of 20 GeV. The sensitivity for excesses is therefore at the per mil level.

A second independent method for an overall sky survey for steady sources has been made, with less stringent event selection criteria and for a fixed muon energy threshold of 20 GeV. The sky has been subdivided into 40 (δ) by 90 (α) by 40 ($\theta =$ zenith angle) cells. The background for a given zenith bin (which is fixed with respect to a particular direction of the detector - with its particular acceptance and efficicency) has been measured from the content of the corresponding declination band swept from $\alpha = 0$ to 24 hrs accross the particular bin. For each of the 90 bins in α (with given δ and θ) the event distributions have been found to be uniform. The significance of the number of excess events above background was calculated with the student's t - distribution. One cell at $\alpha = (118 \pm 2)^\circ$ and $\delta = (31 \pm 1)^\circ$) has been found with an excess. The significance for this excess to be a statistical fluctuation of the background is 3.6 σ. The significance depends on the cell binning and vanishes for muons above 50 GeV.

The muon flux for four muon energy thresholds has also been extracted for 10 well known γ-sources (Mrk 421, Mrk 501, 3-C 273, Crab, Cyg X-1, Cyg X-3, Her X-1, Geminga, 1ES1426+428, 1ES2344+514). The estimate based on the entire data set (1999 and 2000 data) yields upper limits two orders of magnitude above already existing limits [8]. Also the daily search revealed no excesses of events.

4. Conclusions

The angular distribution of muons above 20 GeV revealed a Solar anisotropy of the primary flux. No cosmic ray point source emitting neutral particles has been detected through the study of muons underground with muon energies above 20, 30 ,50 and 100 GeV for time periods between one day and two years. In particular the novel technique employed to optimize the signal-to-noise ratio by selecting the muon momentum threshold has not succeeded in identifying any source. For the 312 day period two independent analyses confirm these findings. The possibility of observing shorter, burst-like emissions is still under investigation.

5. References

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