29th International Cosmic Ray Conference Pune (2005) **4**, 399–402

Observation of a Flare Signal from a Fixed Position in the Northern Hemisphere through Muons with L3+C

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The observation with the L3+C spectrometer of a three days lasting enhancement of cosmic ray muons originating from a fixed position in the northern sky is discussed. The ”flare” was detected in a $2°$ by $2°$ sized sky cell with a chance probability of $2.6 \cdot 10^{-3}$. The signal exhibits a clear time evolution, persists up to muon energies above 50 GeV, suggests a neutral primary and was recorded within opening angles of $2.5°$ down to less than $1°$. It happened between 51773.489 and 51776.333 MJD (17-20 Aug. 2000). The origin is located at a galactic longitude of $(265.02 \pm 0.42)°$ and a latitude of $(55.58 \pm 0.24)°$.

1. Introduction

To-day some 20 point sources are known emitting TeV gamma-ray signals. The measured high-energy gamma spectra are unfortunately incomplete in the sense that there is 1.) a lack of data in the energy range between $\sim$ 10 and 300 GeV, and 2.) a cut-off at energies above typically 5 to 10 TeV for distant sources, due to the absorption of the gamma rays by interactions with the infrared and background radiation, or due to absorption in the neighbourhood of the acceleration region. Another characteristic of these sources is that the signal can be of steady, and/or periodic, and/or sporadic nature. These facts indicate the problems to be met while trying to determine the mechanism(s) at work producing and accelerating particles to high energies.
To test models one has first to try to find new sources in order to increase the statistics of particular data for the different kind of sources, and secondly to build more sensitive detectors, capable to measure the spectra also in the energy range between 10 and 300 GeV. Such efforts have been undertaken in the last few years (TACTIC, CANGAROO, HESS, MAGIC, VERITAS) and a lot of new results are expected soon. While imaging Cherenkov detectors can detect only one source at a time with relatively good angular and energy resolution, sky survey air shower experiments have the opportunity to continuously search large sky regions for new signals, although with slightly less good angular and energy resolution, as well as with higher energy thresholds.

In this paper the search for point sources is presented based on the detection of secondary muons above 20 GeV with the L3+C set-up [1]. High energy muons originating from the decay of photoproduced pions or K-mesons have practically the same direction as the incoming gamma ray and point also back to the source (effective pointing: $< 0.1°$ [2]). Of course the detection probability is reduced, due to the much smaller cross-section for photo-production compared to the electron-pair production cross-section. Nevertheless, if the flux and the energy of the signal is large enough, a source could be found. The original idea of the L3+C collaboration was not to detect sources emitting steady signals, since the energy flow of all known sources is below the detection threshold of the L3+C detector, but to record possible intense, very high energy flare-signals, or even gamma ray burst signals.
Deep underground detectors, like e.g. MACRO and NUSEX [3] have also been used for this purpose. But probably due to the high muon energy threshold, MACRO has not recorded any signal in even a rather long lasting sky survey. The SOUDAN collaboration [4], on the contrary, has observed a flare signal from Cyg X-3 in 1985 and a second signal in 1991. This type of signals could never be observed again by another experiment. Few GeV muons have been recorded with air shower scintillator arrays to separate gamma initiated showers from nuclei initiated showers. Only values for upper gamma ray fluxes have been published. The MILAGRO air shower experiment [5] offers a continuous sky survey capability for relatively low primary gamma energies.

The L3+C spectrometer is located at a shallow depth of 30 m, with a muon energy-threshold around 15 GeV, and therefore sensitive to primary gamma energies below 200 GeV. Other experimental advantages are a continuous sky survey (zenith angle 0° to 60°), selection of the muon momentum threshold off-line, continuous monitoring of the background, following of candidate sources across the sky, good angular resolution ($< 0.22^\circ$ for $E_\mu > 100$ GeV), excellent pointing precision ($< 0.1^\circ$), a geometrical acceptance of 200 m^2sr.
The L3+C spectrometer [1] was installed at the Large Electron-Positron collider, LEP, CERN, Geneva. Three layers of cylindrically arranged drift chambers are mounted inside a 0.5 T solenoidal magnet of 1000 m^3 volume. To record the arrival time of cosmic muons 202 m^2 of scintillators are installed on the top of the iron yoke. The detector was located 450 m above sea level, at a latitude of 46.25° N and 6.02° E, and 30 m below ground. It provided a precision measurement of the atmospheric muon momentum spectrum between 20 and 3000 GeV [6].

2. Search procedure for short bursts or flares

The whole data taking period (July to November 1999 and May to November 2000, effective live-time = 252.4 days) has been divided into twelve sets of different time window lengths, lasting 2^m minutes, with m ranging from 1 to 12. The sky has been subdivided into 6 sets of different sized rectangular cells (α_i, δ_j): - $\Delta\delta = 1.0^\circ$, 1.5°, 2.0°, $2.5^\circ, 3.0^\circ$, 3.6° and $\Delta\alpha = \Delta\delta/cos\delta$, but rounded to integer number of divisions).
The number of background events for a given cell at a given time and for a particular time window is determined in the following way: Background regions BG(α_i, δ_j) of hollow rectangular shape around the cell of interest were defined with half widths $w_a = 0.75 \times \Delta\delta$ to $w_b = \Delta\delta + 1^\circ$ in δ, $w_a \times (\Delta\alpha/\Delta\delta)$ to $w_b \times (\Delta\alpha/\Delta\delta)$ in α. The ratio of the event numbers measured in the particular cell and the corresponding background region has been precisely determined beforehand during the whole data taking period and stored in a table. These ratios are then used to determine the actual background event number in the particular cell of interest for the particular time after having determined the number of background events in the surrounding background region at the same time. This procedure takes care of the time and geometrical dependent detection efficiency of the detector. The significance of a signal is determined with the widely used Li-Ma prescription [7].
The trial numbers have been calculated for each particular time bin- and cell- size, removing statistically unsignificant contributing combinations. In addition a MC calculation has been performed to get the importance of the cell size on the significance of a possible signal. The result showed that for different assumed gamma spectra the cell size has not a very strong effect on the significance of a possible signal. Therefore only three "optimized" cell sizes have been kept for the effective search, corresponding to the particular time binning: $(2.0 - 3.0)^\circ$ for $2^1 - 2^4$ min time binning, $(1.5 - 2.5)^\circ$ for $2^5 - 2^8$ min time binning, and $(1.0 - 2.0)^\circ$ for $2^9 - 2^{12}$ min time binning.
In total 12×3 skymaps have been retained, corresponding to the 12 choices of time windows and the 3 sizes of cells. Accordingly the chance probability was precisely determined for each cell.

3. Results

One and only one candidate has been found from the sky survey described above. It appeared in the sky survey with the 2^{12} minutes time window and a cell size of $(2.0^\circ)^2$. The number of events inside the "signal" cell was 726 and the number of background events 562.3. The excess of events above the background is therefore 163.7 and the significance is equal to 6.356 σ, according to the Li-Ma prescription. But the chance probability to observe a background fluctuation as an excess is $2.6 \cdot 10^{-3}$ for this particular analysis. The exact position of the excess has been determined fitting the event distribution by minimizing the negative log-likelihood function: Right ascension $\alpha = (172.53 \pm 0.17)^\circ$ and declination $\delta = (-1.19 \pm 0.24)^\circ$, or in galactic coordinates:

longitude = $(265.02 \pm 0.42)°$, latitude = $(55.58 \pm 0.24)°$.The fitted angular resolution amounts to $0.70 \pm 0.13°$ (see Figure 1). The "excess" occurred between the Modified Julian Dates = 51773.489 and 51776.333 MJD, corresponding to the calendar date and UT time of 11:44 $17/08/2000$ – 08:00 $20/08/2000$. A careful study about the detector performances has not revealed any malfunctioning at the flare time.
Four remarkable facts enhance the confidence that the observed "excess" may not simply be a background fluctuation: 1.) The signal shows a clear time evolution as can be seen in Figure 4. The signal is clearly observed in time windows ranging from 10^8 up to 10^{14} minutes. 2.) An integral energy spectrum of the flare could be extracted thanks to the presence of the signal for several applied energy thresholds (Figure 2. For comparison the result of a CORSIKA simulation [8] for integral μ-spectra with different power indices of the differential primary gamma spectrum are displayed, as well as the simulated muon background spectrum (solid line). All data points and curves are normalized to 1.0 at a momentum threshold of 20 GeV). 3.) The muon charge ratio, as a function of the opening angle containing the excess, suggests a neutral primary (Figure 3). 4.) The signal was observed for 3 different cell sizes: $(3.0°)^2$, $(2.0°)^2$ and $(1.0°)^2$ (not shown here).

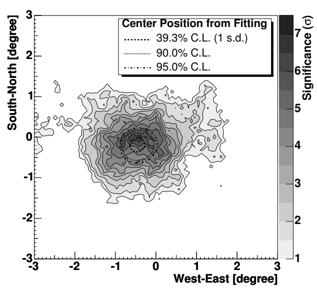

Figure 1. Source map and significance.

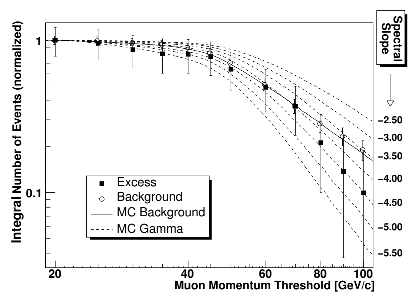

Figure 2. Integral number of excess events vs. energy threshold.

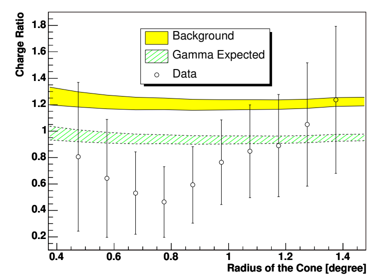

Figure 3. Muon charge-ratio vs. size of opening angle.

4. Conclusions

An excess of events with a chance probability to be a background fluctuation of $2.6 \cdot 10^{-3}$ is a relatively weak signature (but note the conservative approach of this analysis). Nevertheless the characteristics of the signal, the duration, the evolution in time, the energy spectrum, the muon charge ratio and the angular distribution, are quite suggestive for a Blazar like flare. It was not possible to attribute the flare to a known source: Within a radius of 2° one finds a gamma source (3EGJ 1133+0033), as well as several QSOs and unidentified objects. A big difficulty occurs when estimating the necessary gamma flux to produce such a large muon signal in L3+C. According to the observed muon spectrum and Monte Carlo calculations (CORSIKA) the gamma spectrum must be very steep and the low energy part of the flux extremely large. E.g. for a spectral index of -4.5 the gamma differential fluxes would be of the order of $3.5 \cdot 10^2$, $4.6 \cdot 10^0$ and $5.9 \cdot 10^{-1}$ Crab flux units at energies 1, 10 and 30 TeV respectively. No such signal has ever been observed. Unfortunately at the time of the flare no satellite was pointing in this direction, nor any ground based detector active - at least to our knowledge. The MAGIC collaboration has performed a 5 hours search for a remnant signal in February this year, but found no signal.

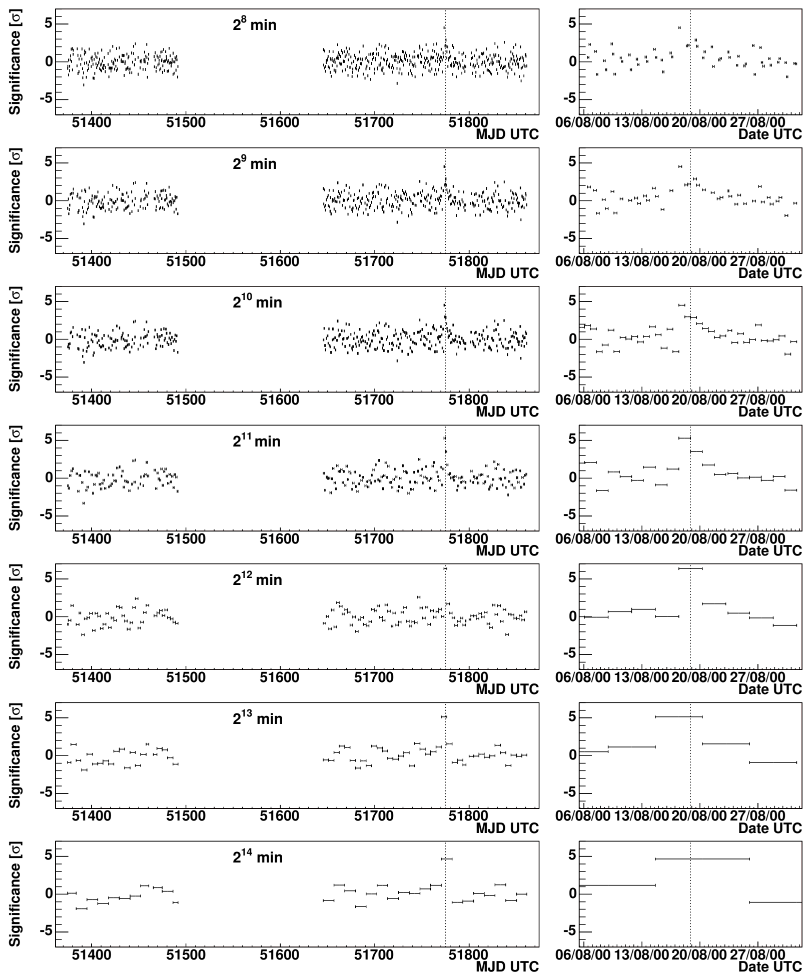

Figure 4. The significances of the signal found in the "flare" cell are are shown for different time windows, ranging from 2^8 min to 2^{14} min, between MJD 51650 and 51850. On the right hand side a zoomed image is shown around the signal time (vertical, dashed line).

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