Search for a Muon Flux Enhancement During the Solar Flare of 14 July 2000 with the L3+C Data

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Abstract

The solar slare of the 14 July 2000 offers a unique opportunity for the L3+C experiment at CERN to search for a correlated enhancement in the flux of muons using the precision spectrometer. The search for a directional excess in the flux of muons between 15 and 25 GeV, corresponding to primary proton energies above 40 GeV, is presented. We report an excess with a chance probability of $2.7 \cdot 10^{-3}$ at a time coincident with the peak increase of solar protons observed with neutron monitors and satellites. At higher energies no significant signal has been observed up to 1.5 hours after the Solar flare time.

1. Introduction

Since the first observation in 1946 [1], more than sixty Ground Level Enhancement (GLE) events have been detected [2,3], mainly using the worldwide network of neutron monitors (NMs). Many studies showed that solar protons in GLEs often follow a steep spectrum and the beam is often anisotropic. The solar flare of the 14 July 2000 (SF0714) is a well investigated GLE event which has been observed by more than 20 NMs. It also offers a unique opportunity for the L3+C experiment at CERN to study the correlated phenomena in the muon flux.

It is known that SF0714 was an X5.7/3B solar flare produced in the 9077 sunspot region. The X-ray flare reached its peak at 10:24 UT. The onset of a type II radio burst was at 10:20 UT. Then, GOES-8 observed a rapid increase in proton fluxes with energies up to above 100 MeV at 10:30 UT [4]. During this period a full halo, earth-directed Coronal Mass Ejection (CME) was developed and observed by SOHO/LASCO [5]. At ground level, more than 20 NMs observed increased cosmic ray intensities ranging from 2% to 60% [6-8]. The earliest increase occurred at 10:30 UT. It is also known from the study of 20 NMs data [8-11], the solar protons with an energy threshold up to 6.7 GeV presented anisotropic arrival direction and a soft spectrum with a power law index of -6 during the rising phase.

The L3 spectrometer is located near Geneva (6.02°E, 46.25°N) at an altitude of 450 m above sea level. The vertical geomagnetic rigidity cutoff of the

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experimental site is about 5 GV. Combining high precision muon drift chambers of L3 and 202 m^2 of plastic scintillators, which were installed on top of the magnet, the cosmic ray muons could be observed and recorded by an independent trigger and DAQ system. A drawing of the L3+C setup [12] is shown in figure 1. The muon drift chamber system, with an octant shape in the plane perpendicular to the beam (11 m $\times$ 11 m) and a square shape in the plane along the beam (11 m in length), installed in a 1000 m^3 magnetic field of 0.5 T were used to record cosmic ray muons and to measure their momenta. The maximum geometrical acceptance is $\sim$ 200 m^2sr, covering a zenith angle ranging from 0° to $\sim$60°. It is underneath 30 m of molasse which provides a 15 GeV cutoff for the muon energy. This corresponds to primary proton energies above 40 GeV.

The L3+C experiment started data taking in 1999 and finished in November 2000 with a total effective live-time of 312 days. The observed data from 14 July 2000 was used to study the correlation between the muon flux and SF0714 at energies above the maximum rigidity of NMs. The anisotropy of the arrival direction of the solar protons had been taken into account. A search was performed for both prompt and delayed excess with respect to NMs time.

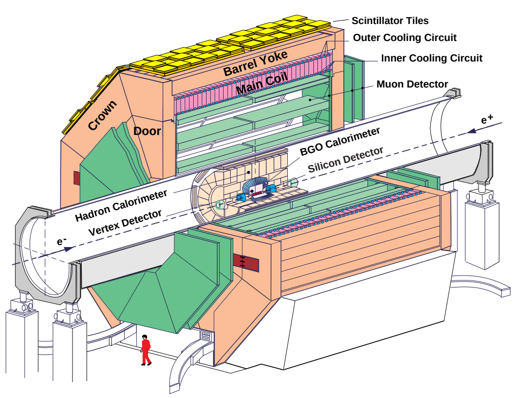

Fig. 1. The L3 spectrometer. Only the muon detectors, the magnet and the scintillator tiles were used in this experiment.

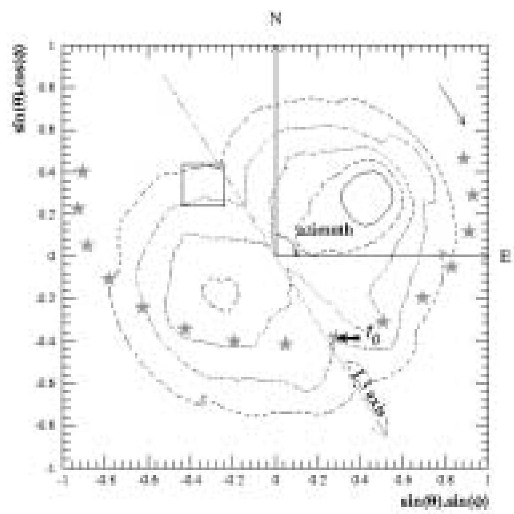

Fig. 2. The directional acceptance of L3+C. The contour lines indicate directions having an equal event rate. The star marks show directions of the Sun for each hour with t_0 denoting the flare time. The square indicates the sky cell No.37 (see the text).

2. Methods

The muons with surface energies between 15 GeV and 25 GeV within the full acceptance of the L3+C detector were used. The whole sky was divided into 10×10 equal sky cells. For each sky cell within the detector acceptance, muon events were accumulated in 83.9 s live-time bins, corresponding to 100 live-time units of the experiment. Ignoring those cells with poor statistics, 46 sky cells remain for the investigation. The contour lines for directions having an equal event rate are shown in figure 2, where θ and ϕ are zenith and azimuth angles of the muon direction at the surface. The data in 12 hours before 10:00 UT for each sky cell was used as background. For each sky cell the event rate was compared with the background in order to find a prompt or a delayed excess.

3. Results and discussions

The search for prompt signals yielded a 4.2σ excess above the background for sky cell No.37 (marked by a square in figure 2) in the period from 10:24 to 10:42 UT with 16.78 minutes of live-time bins. The result is shown in figure 3. Taken the sky cells and the number of the trials for the search into account, the probability for this excess being a background fluctuation is $2.7 \cdot 10^{-3}$.

By applying the same procedure to muons with energies larger than 25 GeV, no excess was seen either in the sky cell No.37, or at the peak time of increases observed with NMs. This is consistent with a known soft solar proton spectrum deduced from NM data.

From a Monte Carlo study using CORSIKA [13] to simulate a primary proton spectrum with a power law index of -6 starting at 20 GeV, it is found that about 85% of the recorded muons between 15 and 25 GeV are produced by primary protons of 40 to 100 GeV. The upper limit was estimated for the excess by comparing the simulation and the search result, assuming a solar proton beam incident from the direction around sky cell No.37 through the L3+C detector using the same program as used for the data. The normalization has been made by comparing the background counts and simulation result for primary cosmic ray protons following an energy spectrum $E^{-2.7}$. An upper limit with 90% of confidence level was obtained:

$$I(E_p \geq 40 \text{ GeV}) \leq 2.8 \times 10^{-3} \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}.$$

This number together with other results for integral solar proton fluxes is shown in figure 4 [14].

No evidence for any excess is obtained up to 1.5 hours after the peak time.

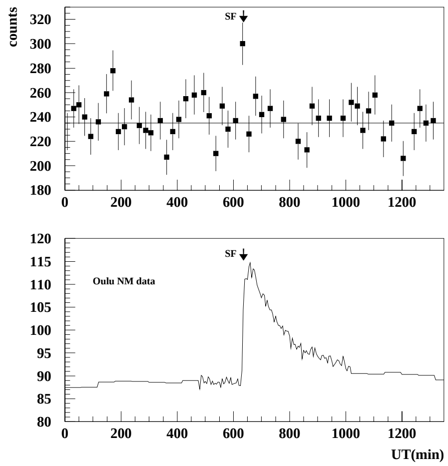

Fig. 3. Upper: number of events versus time in minutes for the whole day (14th July 2000) in sky cell No.37. The solar flare time (10:30 UT) is marked by 'SF'. The live-time bin width is 16.78 minutes. The solid line shows the mean value of background. Lower: shown is the increase measured by the NM of the Oulu station.

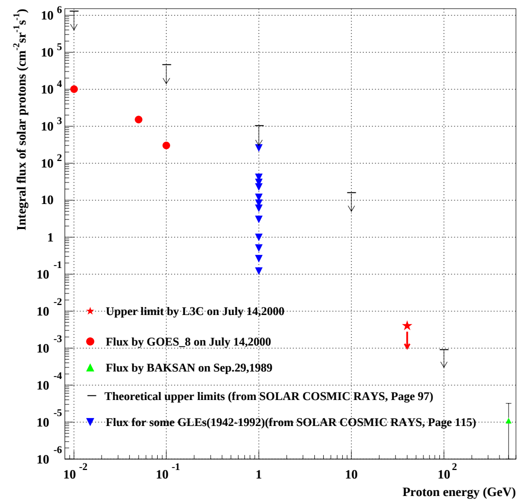

Fig. 4. The upper limit of solar proton flux obtained by this work compared with other results.

4. References

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