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A Search for Time-Coincident Air Showers Observed with Two Shower Arrays at CERN

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Abstract: We report here the results of an experiment carried out at CERN, to search for strangelets whose breakup in space may result in arrival of a large number of time and angle-coincident air showers spread over a large area. The search was carried out with two shower detector arrays, located on the surface at points P2 and P4 at the LHC at CERN, which are separated horizontally by about 8 kms. The arrival time of showers was recorded at each array with 100 ns accuracy and the spatial arrival angle of showers was determined to an accuracy of ~ 3°. Data were collected over an effective overlapping time of $4.59 \times 10^7 s \sim 531$ days spread over the period, Jun 2004 - Dec 2006. A total of 5.18×10^7 showers were collected at P2 and 3.95×10^7 at P4.

We searched for pairs of showers arriving, within $30\mu s$ in time and within 5^{o} in spatial angle, at the two stations. None were detected. This permits us to put a 90% C.L. upper limit of $5.1 \times 10^{-20} cm^{-2} sr^{-1} s^{-1}$ on the flux of strangelets which could have broken up somewhere in nearby space giving a spray of high energy baryons over the sensitive area bounded by the two arrays on the Earth.

Keywords:

1 Introduction

An interesting possibility of generating a burst of time and angle-coincident air showers arose from the idea of Witten [1] who proposed the possible production of strange quark matter with nearly equal numbers of up, down and strange quarks in the early Universe. Initially, only strange quark matter with very large baryon number (A) was thought to be stable, however, later works, see review by Madsen [2], have shown it to be stable for almost all possible values of A. In addition to the strangelets of cosmological origin, as remnants of the cosmic QCD phase transition [3], the strangelets could also have been added to the cosmic ray flux through collisions of strange stars [4, 5]. In fact, Madsen [6] has pointed out that the search for cosmic ray strangelets may be the most direct way of testing the stable strange matter hypothesis and has estimated the flux of strangelets in cosmic rays making plausible assumptions about acceleration and propagation in interstellar space and their breakup through spallation in collisions with interstellar matter. Interestingly, strangelets are likely to be accelerated in supernova shocks, just like the nuclei. A highly energetic strangelet headed towards the Earth but breaking

up within the Solar system would spray the Earth with energetic baryons spread over a very large area, depending on the distance of its breakup. These energetic baryons, if in the 100-1000 TeV energy range, would produce air showers detectable with small shower arrays. These showers would appear to come from the same direction in space and temporally almost simultaneously, except for the relative delay determined by the zenith angle of the showers and the projected distance between the arrays.

Time and angle correlations are not expected among charged cosmic rays travelling over large astrophysical distances due to scattering by the irregular and often chaotic magnetic fields pervading the interstellar medium. Some of the early searches for time and angle correlated showers [7, 8, 9, 10, 11, 12, 13] with well-separated shower arrays have reported observing unusual phenomena though these could not be uniquely interpreted due to lack of sufficient information.

We report here the details of an experiment carried out at CERN, using two shower arrays, located at points P2 and P4 at LEP/LHC, during 2004-6.



Figure 1: Schematic layout of the detectors for the arrays at P2.



Figure 2: Schematic layout of the detectors for the arrays at P4.

2 Experimental Details

The schematic layout of the 40-detector shower array placed on the roof of the hall above the main shaft at point P2 on the LEP/LHC is shown in the left panel of Figure 1. The scintillation detectors, each 0.5 m² in area, are arranged in six rows with average separation of $\sim 7m$ between the detectors, except for a few larger gaps, covering an area of 30 m \times 54 m.

The schematic layout of the 20-detector shower array placed on the ground near the hall above the main shaft at point P4 on the LEP/LHC is shown in the right panel of Figure 2. The detectors are arranged in three rows with average separation of $\sim 7m$ between the detectors, covering an area of $10m \times 60m$. Each detector consists of four blocks of plastic scintillators, each 1 m² in area.

The signals from the anodes of the photomultipliers are taken directly to the electronics control room for amplitude and timing measurement as well as for the generation of the shower trigger. Logic pulses from the detectors for each of the rows are OR'd together to form the 'row' signal. A 3-fold coincidence between the 'row signals' from any three adjacent rows constitutes the 'shower trigger', which generates the gates to the ADC's and the TDC's. The trigger latches the time of the Real Time Clock running on a 10 MHz temperature-stabilised crystal. The clock is kept aligned to the GPS time through the signal received each minute from a Meinberg GPS Receiver, permitting the recording of the absolute arrival time of the shower to an accuracy of 100 ns. After a suitable delay for the ADC/TDC conversion time, the shower trigger initiates the data transfer from ADC's, TDC's, Clock and Counters



Figure 3: Variation of the shower rate per minute over the 24 hour period observed on 2006 Apr 10 at P2.



Figure 4: Distribution of the inter-shower time difference observed at P2 over the 24 hour period on 2006 Apr 10.

to the PC through a temporary memory data buffer. The data acquisition is essentially free of dead time, except for the $\sim 450 \mu s$ required for conversion and readout following each shower trigger.

A simple 'muon telescope' using two 15 cm x 15 cm scintillation detectors, has been used to measure the response I_{min} of the shower detectors to minimum ionizing particles using cosmic ray muons. The ADC signal S_n from each detector (n) for a shower is converted to equivalent number N^n_{μ} of 'muons' using the calibration signal I_{min} after subtracting the ADC 'pedestal'. The pedestal for all the ADC channels was continually monitored by reading out 'pedestal' events generated by the 'Minute' signal of the GPS clock.

In view of the small size of the arrays, no attempt has been made to determine the position of the shower core, which is outside the array for most of the showers, and the shower size. The total number of detected particles $N_{sum} = \Sigma N_{\mu}^{n}$, summed over the all the detectors of the arrays, is used as an estimator for the shower size and the primary energy of the shower. The average rate of the 3-fold coincidence of the 'row' signals was 0.99 Hz at P2 and 0.83 at P4.



Figure 5: Particle number spectrum for detector # 1 at P2 on 2006 Apr 10.



Figure 6: Distribution of the time difference, $\delta T_{(P2-P4)}$, between the showers of pairs arriving within 100 microseconds for the full data set.

3 Data Collection and Analysis

Data were collected round the clock from Jun 2004 to Dec 2006 except for a few breaks in between due to logistics. Data were collected independently at the two stations and time collation was done only during analysis. The actual run times at P2 and P4 were 5.20×10^7 s and 4.79×10^7 s respectively but the time overlap between data at the two stations was only 4.59×10^7 s due to brief interruptions at one or the other station.

Data collected at both the stations were checked initially for various expected features. Initially, the variation of the shower rate for each 24 hour period on each day was examined for stable operating conditions since the expected time-coincidences between showers recorded at the two stations are crucially dependent on the stability of shower rates. For example, the variation of the shower rate per minute over the 24 hour (1440 minutes) period on 2006 Apr 10 at P2 is shown in Figure 3.

A related distribution is the distribution of inter-event time between successive showers as it may also show the presence of non-Poissonian fluctuations, if any, in the shower



Figure 7: Distribution of the time difference, $\delta T_{(P2-P4)}$, between the showers of pairs arriving within 100 milliseconds for the full data set.

rate. This distribution is shown in Figure 4 for data taken on 2006 Apr 10 at P2. A good fit of an exponential function may be seen in this figure as expected for random time distribution of showers. However, a perfect fit is not expected for data on some of the days due to small changes in rates caused by changes in the atmospheric pressure and temperature.

The particle number spectrum observed for each detector for each 24 hour period was also examined to ensure the stability of the gain of the photomultipliers. For example, the particle number spectrum for detector # 1 at P2 on 2006 Apr 10 is shown in figure 5. Another important quantity which needs to be monitored closely is the distribution of relative arrival time of particles over the detectors for showers. since its stability is essential for accurate determination of the arrival direction of showers.

4 Results on P2-P4 Time and Angle Correlations

Though the primary shower selection required only a 3fold coincidence between detectors of three adjacent rows, the arrival angles of showers could be determined only for showers which gave a signal of ≥ 1 particle in at least 5 detectors, reducing the number of showers for study of interarray time distribution by almost 50%. The inter-array time difference study has been done in two separate steps. First, for every shower at P2, the time separation between the shower at P2 and a shower immediately following it at P4 was computed. The distribution of this time difference, $\delta T_{(P2-P4)}$, was studied on two time scales, 100 μ s and 100 ms. Both these distributions were observed to give a good fit to exponential functions, showing very good agreement of data with the expected random distribution of the arrival time of showers at P2 and P4 for both the time scales. A similar study of the distribution of time separation between a shower at P4 and the shower immediately following at P2 has also been made. Again, the observed inter-array shower



Figure 8: Distribution of space angle between the showers of a pair with a shower detected at one station followed by a shower at the other station within a time difference of 30 μ s for the full data set.



Figure 9: Distribution of space angle between the showers of a pair with a shower detected at one station followed by a shower at the other station within a time difference between 30 μ s and 300ms for the full data set.

time distibutions show good agreement with the expected random distribution of arrival time of showers at P4 and P2.

The distribution of time separation between showers at P2 and P4 for the full data set is shown in Figure 6 for time window of 0-100 μ s and Figure 7 for time window of 0-100 ms, combining together both type of cases mentioned above. It is seen from these figures that both the distributions are fully consistent with the absence of time correlation between showers observed at P2 and P4. Also, there is no significant excess within the 0-30 μ s expected as a signal for the detection of showers due to the break-up of strangelets in space near the Earth.

The space angle distribution for the full data set is shown in Figure 8 for pairs of showers at the two stations which arrived with time separation less than 30 us. Figure 9 shows the distribution of the space angle between showers of the pairs with arrival time within the time window, 30 μ s - 300 ms for the full data set. Using the fraction of 1.18 % of shower pairs with space angle $\leq 5^{\circ}$ observed in the distribution shown in Figure 9, the expected number of shower pairs with time separation less than 30 μ s and space angle $\leq 5^{\circ}$ is 8.2 compared with the observed number of 4. This good agreement between the observation and the expectation leads to the conclusion that there is no significant excess of shower pairs above the background.

5 Discussion and Conclusions

Detailed analysis of data collected on showers with arrays at points P2 and P4 of LEP/LHC over an effective period of \sim 531 days spread over the observing period, Jun 2004 to Dec 2006, has shown good internal consistency for various observational parameters. A study of the time difference between showers observed with the two arrays has shown good agreement with expectations from the absence of any time correlation over two time scales, 100 μ s and 100 ms. A detailed study of the distribution of spatial angle between pair of showers arriving with time difference $< 30\mu$ s at the two arrays has also shown no evidence of any excess within $< 5^{\circ}$, expected due to correlated showers arising from the breakup of strangelets in space near Earth. Assuming a collection area with diameter of 8 kms covered by the two arrays, an overlapping observation time of 4.59×10^7 s, a 90% C.L. upper limit of $5.1 \times 10^{-20} cm^{-2} sr^{-1} s^{-1}$ has been put on flux of strangelets which could have broken up in space near the Earth causing a spray of high energy air showers detectable a the observational altitude of Geneva.

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