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Observation of cosmic ray flux deficit in the direction of the sun using a charged particle traking telescope

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ABSTRACT

A cosmic ray tracking telescope has been made for the measurement of the secondary cosmic ray flux at ground level. The observations have been made both looking in the direction of the sun and away from the sun. Our observations by the telescope shows a deficiency in the detected number of cosmic rays entering the telescope when its axis was pointing to the sun compared to that entering the telescope with no sun in its field of view. The statistical significance of this deficit with the Li and Ma method stands near 1.3σ for all of our observations.

1. Introduction

Primary Cosmic Rays(CRs) which are high-energy charged particles entering the earth atmosphere from cosmos can collide with sun or be deflected by its magnetic field and thus attain an observable change in their direction which is interpreted as the sun's shadow. Cosmic rays below a certain energy ($E \le 1$ TeV) will not be able to hit the sun and deflected away it. On the other hand some other particles with the same energy will be deflected into the sun direction and this compensates the particles that were deflected away. In fact low energies ($\sim$ GeV) do not have sufficient momentum to retain information of their trajectory before entering the solar system, so these particles will not contribute to the shadow. An energy of above $\sim$ 1 TeV is necessary for a cosmic ray to be absorbed by the sun. The primary high energy cosmic rays produce an Etensive Air Shower(EAS) in the earth atmosphere. The sun's shadow has been observed in EAS experiments which have a high angular resolution for determination of the direction of the EAS axis from measurements on the secondary particles in the shower at the ground level [1,2]. However, as shown by our computer simulations in this work (Section 3.3), there is a rather strong correlation between the mean direction of the shower secondary particles at ground level and the direction of the shower axis. Thus it could be expected that sun's shadow can be also observed at ground level by comparing the number of secondary cosmic rays received from direction of sun with those from other directions.

The aim of this paper is to report the results of series of observations we have made on the sun's shadow using a home-made cosmic ray tracking telescope. In the next section a description of the telescope and cosmic ray detection method, and various observations on sun's shadow is described. In Section 3 the results and data analysis is presented, and Section 4 is devoted to discussion of results and some concluding remarks.

2. Description of telescope and observations

2.1. Cosmic-ray detector and tracking system

The detection of cosmic rays in this telescope is achieved by means of scintillators, Photo-Multiplier tubes(PMTs), and the associated electronics. Two plastic scintillators each of 1 m^2 area and thickness of 3cm are placed parallel to each other along a common axis (axis of the telescope) perpendicular to their surface. The scintillators are separated along this axis by 6 m and each is enclosed in a pyramidal light enclosure whose height had been optimized to yield highest efficiency (for details see ref. [3]). The calculated geometrical acceptance solid angle of the telescope is about 274 cm^2sr. Each scintillator is viewed by a single PMT (EMI9813B with diameter of 5 cm) placed at vertex of the pyramidal light enclosure (Fig. 1(a)). The detection of a CR is recorded when a CR passes through both scintillators and the time lag between two passes is within the window defined by the Time to Amplitude Converter(TAC, ORTEC 566) setting (200 ns). The entire system of the detectors with their light enclosure is placed on a rather light steel support structure which seats on an axle pointing to North Celestial Pole and driven by a stepper motor via gear box and a chain belt. The system of support structure and axle itself

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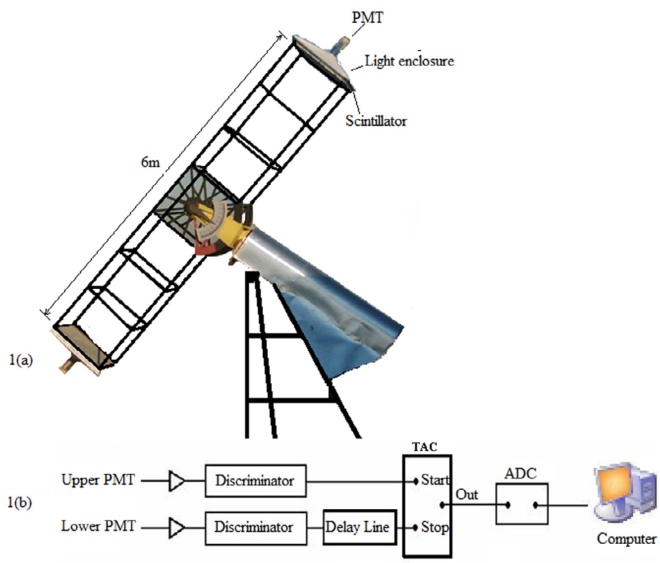

Fig. 1. Configuration of the telescope(1a) and its electronic circuit(1b).

is placed on a horizontal table which allows the whole system to rotate along the vertical axis manually in order to make reorientation and adjustment of the telescope axis possible. Fig. 1(a) shows a schematic diagram of the telescope and its detectors.

The telescope is placed on the roof of the 30 m high building of physics department of Sharif University of Technology. The pulses from PMTs are taken via cable(RG58) to the electronic circuit which is housed in the roof-top control room. The stepper motor, computer and electronics is also housed in this control room. Fig. 1(b) shows the electronics circuit of the detection system. When a secondary cosmic ray hits both scintillators, the signals generated in the two PMTs, with the single rates $R_t \simeq 230$ Hz and $R_b \simeq 200$ Hz for the top and bottom PMTs, are entered into two channels of an eight-channel fast discriminator (CAEN N413A). The discriminator thresholds are set to values of 50 and 23 mV for the signals of the top and the bottom scintillators respectively. Then the outputs of the discriminators are connected to the start and stop inputs of a time-to-amplitude converter (TAC, ORTEC 566) with a time range of 200 ns, which length difference of cables into the stop and start of TAC is about 14 m. The output of the TAC which was set at a full scale of 200 ns is fed into a multi-channel analyzer (MCA) via an analog to digital converter (ADC) unit.The stepper motor is operated in two different modes via its computer control. In the normal(tracking) mode the speed of rotation is set to compensate for the rotation of earth. In the fast mode the speed of rotation is much faster in order to allow a quick reorientation of the telescope axis to any desired direction.

2.2. Observation

The cosmic rays observation has been carried out since 2008 on roof of building of physics department at Sharif University of Technology. During each data acquisition day, two different sets of observations were carried out. In the first observation(the “on” observation) telescope axis was pointing to sun and the motor driver was operating in the tracking mode. While in the second observation(the “off” observation) there was no sun in the field of view of the telescope. For each observation the number of cosmic rays and time lags of the two PMTs for each CR, detected by the telescope as described above were recorded for a continuous 4-hour period each day. As is well-known [4] the number of secondary cosmic rays depends on the local direction (zenith and azimuthal angle) of the cosmic ray. In particular the zenith angle dependence

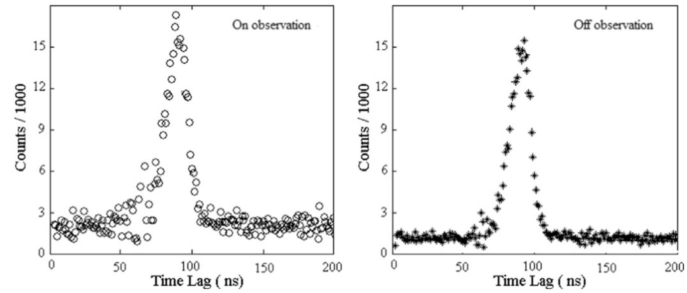

Fig. 2. Time lag spectra of CR events with and without sun.

which indicates the various depth of the overlying atmosphere is rather strong. In order to ensure that our two observations are under exactly similar conditions as far as these dependences are concerned, the following daily routine procedure was adapted: each day at 10:00am, using the motor drive in the fast mode, the telescope axis was manually oriented towards sun and the “on” observation was started with drive motor in tracking mode. This observation was carried steadily for four hours. Then, after one hour relaxation of system, at 3:00 p.m. the telescope was reoriented manually using the motor drive in its fast mode to exactly the start direction of “on” observation and with the drive motor again in the tracking mode, the “off” observation was started and carried out steadily for four hours until 7:00 p.m.. Even though the tacking mode described is effective in removing the affect of the zenith angle dependence to the rate it does not remove any changes in atmospheric conditions between the “on” and “off” periods. As these periods always occur during the same time of the day (“on” is always between 10:00 a.m. and 2:00 p.m., while “off” is between 3:00 p.m. and 7:00 p.m.), it is possible that there is a systematic effect on the rate due to diurnal variations in the cosmic ray rate. Hence it is necessary to remove any systematic effect due to pressure, temperature or inherent changes.

3. Presentation of results and data analysis

3.1. Comparison of “on” and “off” CR counts

Fig. 2 shows the time lag distributions of cosmic rays recorded by the telescope for the above-mentioned two observations. Each data set covers a total time of 3200 h. In these spectra each count is a start-stop event recorded by TAC and corresponds to the passage of a cosmic ray (predominantly muon, see the Appendix) through both scintillators in our experimental set up shown in Fig. 1. The main difference in these spectra is the true counts under the peak. In computing the true counts under the peak(true events) for each spectrum, the background counts(obtained from channels far from the peaks) have been subtracted. The background contamination from random coincidences is due to optical photons of the sunshine at time of data acquisition and electronic noise, which are suppressed with the following method. In fact, Optical photons can pass the covers of top and bottom detectors, so that when one optical photon passes through the cover of the top detector and other one optical photon from the bottom detector, which have not any time correlation with together, a uniform spectrum can be produced. Electronic noise produces a uniform spectrum as well. These spectra are added to the true spectrum. The background counts under the peak is suppressed as bellow:

a) The average number of background coincidences in each time interval (here 1 ns) is calculated from the time region of 10 ns–50 ns, and of 150 ns–190 ns,
b) The region of time under the peak is between 65 ns and 105 ns, that is 40 ns. The total number of background under the peak