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A study of upward going particles with the Extreme Energy Events telescopes

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ABSTRACT

In this paper the first study of the upward going events detected by the telescopes of the Extreme Energy Event (EEE) project is reported. The EEE project consists of a detector array of Multigap Resistive Plate Chambers located at selected sites on the Italian territory. During autumn 2014 the first coordinated data taking period took place and around one billion candidate tracks were collected. Among them, of particular interest is the sample of particles which cross the telescopes from below. The results obtained demonstrate that the EEE telescopes can distinguish the electrons produced as decay products of cosmic muons stopped in the ground, or in the last chamber of the telescopes themselves, confirming the excellent performance of the system for the investigation of intriguing cosmic phenomena.

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1. Introduction

The Extreme Energy Events (EEE) project is an innovative experiment with the main goal of detecting the ground muon component of Extensive Atmospheric Showers (EAS)—particularly those generated by primaries with energy $>10^{19}$ eV [1,2].

The project started in 2004 and essentially consisted of building an array of about 50 telescopes scattered in the Italian territory and hosted in as many Italian high schools (plus two telescopes at INFN sections and two at CERN) [3]. Each station consists of three large area Multi-Gap Resistive Plate Chambers, very similar to the ones used for the time-of-flight system of the ALICE experiment at CERN, and therefore providing accurate particle tracking and timing information [4].

After its initial phase, the EEE collaboration has started a series of coordinated acquisition periods, during which data from all the active stations are collected, processed and analysed. The first period of coordinated data taking, hereafter *Pilot Run*, took place in October–November 2014. The data collected during the Pilot Run —$\sim$1 billion of candidate tracks in total—are now being analysed, with the purpose to continue, with a much improved statistics and monitored conditions, the analysis performed in the past years using limited time periods and sets of telescopes. In particular, events registered in coincidence at different sites are a direct measure of the EAS flux, and are thoroughly investigated [5-7]. Also, the variations of the cosmic muon rate at each telescope are interesting, since they can be correlated with astrophysical events such as, for instance, Forbush decreases [8].

Moreover, the study of events related to particles crossing the EEE telescope and directed from the ground upwards is intriguing. In principle, some of these events could be related to neutrinos crossing the Earth and interacting close to its surface just under the telescopes. In fact, these have been extensively investigated in the past [9]. Upward going events were also detected by the EEE telescopes, and their observation was reported elsewhere [10,11]. However, due to the rather limited statistics, it was not possible to draw definitive conclusions about their nature; however, from the beginning, it was clear that they were far too numerous to be interpreted just as events derived from neutrinos.

Here a more thorough analysis is reported, allowing the identification of the majority of the upward-going events as electrons produced by downward going muons crossing the telescope, but stopping in the material in the ground or in the telescope itself, where they decay. The fact that it was possible to discern these events among the billions collected in total is a clear indication of the excellent performance of the system during the whole Pilot Run.

2. The Extreme Energy Events project

The scientific multi-disciplinary value of the EEE project [3], its technical basis and its performance have been already described in [4,5,12,13]. Here, just a a synthetic description is presented.

2.1. Description of the telescopes

Each EEE telescope comprises three Multigap Resistive Plate Chambers (MRPCs), mounted horizontally on a metallic frame with vertical separation ranging between 0.4 and 1.0 m depending on the different stations.

An MRPCs consists of six gas gaps, as shown schematically in Fig. 1; the structure consists of two thicker glass plates (1.9 mm thick), coated with resistive paint, and five thinner glass plates (1.1 mm thick), spaced by 300 μm by means of commercial nylon fishing line; the glass volume resistivity is $\sim 10^{13}$ Ωcm. Each MRPC features 24, 2.5 cm-wide, copper readout strips, separated from each other by 0.7 cm (i.e., a strip pitch of 3.2 cm) and an overall active area of 0.82×1.58 m^2; these readout strips are mounted on external fiberglass panels. The MRPCs are flushed with 98% of $C_2H_2F_4$ and 2% of SF_6 gas mixture. The chambers are operated in avalanche mode with a typical operating voltage around 18 kV supplied by DC/DC converters.

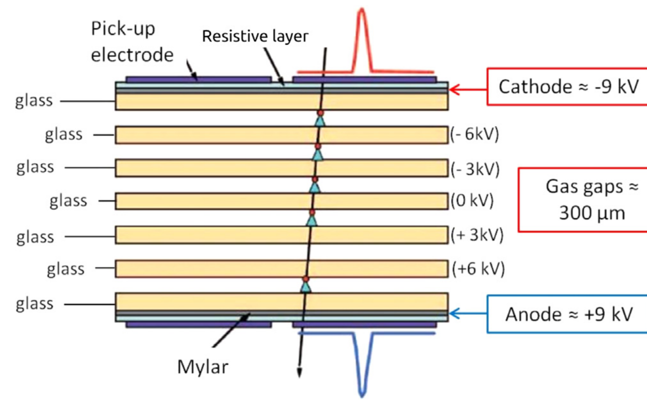

Fig. 1. Basic layout of a Multigap Resistive Plate Chamber used in the EEE telescopes.

When an ionizing particle passes through the gas, it creates a number of primary ion-electron pairs, which exponentially grows in the avalanche process. Since the MRPCs glass plates have high resistivity, they act as dielectrics for the fast signal produced by the drift of the electrons in the gas avalanches. The induced signal, picked up by the copper strips, corresponds to all gas avalanches in all the gas. These signals are transmitted to the front-end boards (FEA) mounted at the two ends of the chamber.

The signals coming from the FEAs on each telescope are processed by a trigger card in order to provide information to the VME-based data acquisition. A six-fold coincidence of both front-end cards of the three MRPCs generates the data acquisition trigger. The particle impact point is determined by the position of the hit strip in one direction; in the other direction the difference of signal arrival time at the strip ends, measured by two multi-hit TDCs (CAEN Mod. V1190A/B), localizes the position along the lenght of the strip. At the operating voltage, the measured MRPC efficiency is typically 95%. The TDCs are operated with a 100 ps bin width, so that strip dimension and time difference provide an overall spatial resolution of about 1 cm along the two coordinates.

The absolute time of each event is recorded and synchronized by means of Global Positioning System modules, in order to get the event time stamp and to correlate the information collected by different telescopes. The data acquisition is controlled by a LabView program running on a PC connected to the VME crate via an USB-VME bridge. A picture of one of the EEE stations selected for the analysis described in this work is shown in Fig. 2.

2.2. Data processing and data quality monitoring

The data-processing infrastructure for the EEE experiment is provided by CNAF (*Centro Nazionale Analisi Fotogrammi*), the central computer facility of the Italian National Institute for Nuclear Physics (INFN) and one of most prominent centers for distributed computing in Italy.

The data acquisition is organized in units (or *runs*) of 50,000 events each, corresponding to 15–30 min of data taking, depending on the acceptance of the telescope. During periods of coordinated data acquisition, the DAQ systems are running continuously under the direct supervision of the students and professors. Data