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Time and orientation long-distance correlations between extensive air showers detected by the MRPC telescopes of the EEE Project

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Summary. — A search for long-distance correlations between Extensive Air Showers (EAS) detected by pairs of MRPC telescopes of the Extreme Energy Events (EEE) network was carried out. A dataset obtained by all possible pairings between ten EEE cluster sites (hosting at least two telescopes) with an overall exposure of 3968 days was analyzed. A few candidate events with unusually small time difference and angular distance were observed.

1. – Introduction

The possibility to observe time correlations between cosmic ray detectors separated by distances much larger than the extent of the highest energy Extensive Air Showers (EAS), *i.e.* a few km, has been discussed for many years. A possible physical mechanism which could justify the existence of such events was originally proposed in [1] and later discussed by many authors.

In this picture, a heavy primary nucleus A could be photodisintegrated (for instance into a proton and a nucleus $A-1$) by interaction with the solar photons, since the relative energy between a high energy proton and the photons from the solar field could correspond to an enhancement in the photodisintegration cross section. The two particles could then propagate in the interplanetary magnetic field and arrive on the Earth atmosphere producing two individual yet correlated showers.

A few experimental searches for such events have been reported without any definite conclusion [2-6]. Current rate expectations are very low and range from 10^{-3} to 1 event per km^2 per year. The Extreme Energy Events (EEE) network [7], based on Multigap Resistive Plate Chamber (MRPC) telescopes, located in Italian high schools over a large territory, reconstructs cosmic muons with high efficiency and good angular resolution. The wide coverage, number of sites, and large time exposure due to continuous data taking are unique characteristics of the EEE network which allow for the current investigation. We report preliminary results of a search for long-distance time and orientation correlations between independent extensive air showers detected by telescope pairs.

2. – The EEE Project

The EEE Project is a joint educational and scientific initiative by Centro Fermi (Enrico Fermi Historical Museum of Physics and Research and Study Centre) [7], in Collaboration with INFN (Italian National Institute for Nuclear Physics), CERN and MIUR (the Italian Ministry of Education, University and Research). The Project has built and installed an array of cosmic ray detectors.

The detection technique employed by the EEE telescopes is based on three MRPCs, each $0.82 \times 1.58\,\mathrm{m}^2$, which reconstruct the incoming muon tracks with high efficiency and good angular resolution. The absolute time of each event is recorded with a GPS unit, to a precision of a few tens of nanoseconds, for later combination with data from other telescopes. Presently, 53 telescopes have been taking data for several years, collecting more than 5×10^{10} muon tracks. A complete description of the experimental setup and recent physics results from the EEE Project are reported in [8-11].

The research goals of the Project are focused on the study of the properties of the local muon flux and its dependence on the Earth and solar environment, the detection of high-energy extensive air showers created in the Earth's atmosphere and the search for possible long-distance correlations between telescopes. Other physics items of interest include the study of the upward muon flux and the search for small anisotropies in the equatorial coordinate sky map. A powerful impact on education is also envisaged by the EEE Project, which has already introduced a large number of school teachers and students to particle and astroparticle physics.

3. – Experimental results and discussion

To enhance the probability of observation of rare events and minimize the amount of spurious coincidences, different strategies were considered. The correlation between independent telescopes —due to their individual single rates— is not selective enough; even with a cut imposed on the relative orientation between the detected muons, the number of random coincidences per day is still of the order of 10^3–10^4 in a time window of 1 ms. Since in the EEE network there are a few (cluster) sites which are equipped with at least two telescopes in the same town, we may consider however the correlation between telescope pairs, each detecting a local shower. With this strategy, the accidental coincidence rate in a time window of 1 ms goes down to the level of about 1 event per year. A dataset originating from 10 EEE cluster sites, each equipped with two MRPC detectors was considered in the present analysis. The distances between these sites range from 86 km to 1200 km, and the overall time exposure (summing all 45 pairings) was about 11 years.

All candidate events which stay within the time window dictated by the distance between the sites were considered, and for each of them we evaluated the p-value (according to a Poisson distribution) to obtain such an event by chance, considering the number of expected events in a time window corresponding to the measured Δt and with a relative angle between the two showers not exceeding the actual observed value of ϑ_{rel}.

The uncertainty in the relative angle between the two showers depends on several factors. The angular resolution in the reconstruction of individual muon tracks in each telescope is of the order of $1°$, resulting from the spatial and time resolution of the MRPC detectors, which was experimentally measured and also compared to simulations. The geographical orientation of the telescopes also plays some role in the overall angular uncertainty. However, a larger contribution (a few degrees) originates from the intrinsic uncertainty associated with the shower axis, when estimated by the average direction of the two detected muons, which is only roughly correlated to the direction of the primary. The angular spread of an extensive air shower may indeed amount to a few degrees, depending on the energies of the primary particle and of the secondary muons, and has been evaluated by EAS shower simulation codes in a previous paper [8].

TABLE I. – *List of candidate events observed within a time window compatible with the distance between the sites. The columns report the site pair observing the event, the relative distance between the sites, the measured time difference, the relative angle between the showers, the expected number of accidental coincidences in that time window, and the corresponding p-value. The labels identifying the various sites refer to the geographical locations of Bologna (BOLO), Cagliari (CAGL), Catania (CATA), CERN, Grosseto (GROS), L'Aquila (LAQU), Torino (TORI).*

Event	EEE pairs	Distance (km)	Δt (μs)	ϑ_{rel} (deg)	Expected events	p-value
(A)	BOLO-CAGL	614	86	27.1	0.0069±0.0002	0.007
(B)	BOLO-LAQU	290	740	9.1	0.014±0.001	0.014
(C)	CATA-TORI	1040	88	9.2	0.0265±0.0005	0.026
(D)	GROS-TORI	377	297	14.4	0.032±0.001	0.031
(E)	CERN-CATA	1200	248	9.3	0.049±0.001	0.048

From this analysis we selected five candidate events for which the p-value is relatively low (smaller than 0.05), given the time difference between the two sites, the relative angle, and the number of expected accidental events in that time window. Such events are reported in table I, with their main properties. For some events (A, C), the time difference is smaller than 100 μs, and three events have a relative angular distance smaller than 10°.

For the events reported in table I, the trend of the number of accidental events as a function of the coincidence time window, with a relative angle not greater than that actually observed, may be analyzed. Figure 1 shows an example of the analysis performed for a pair of telescopes (Event A in table I). The event of interest has the smallest time difference, which may be compared in the plot with the observed trend of the accidental rate as a function of the time window.

Table I only reports the most 5 significant events observed (*i.e.* those events which have a p-value smaller than 0.05). However, the total number of events observed within the correct time window, dictated by the mutual distance between the telescope pairs and by the maximum detectable angle for the two showers, is 96, arising from all 45 pairings.

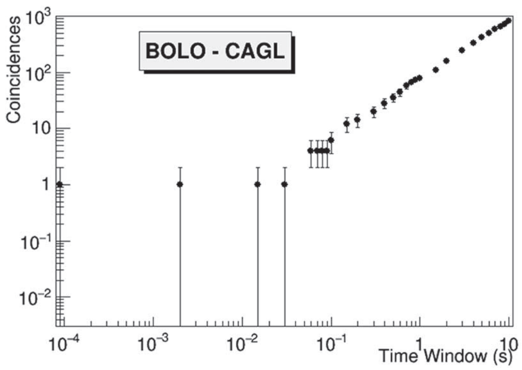

Fig. 1. – Number of coincident events as a function of the time window, with an angular cut corresponding to the value observed for the event A reported in table I.

To estimate an overall significance, we considered all the observed events, comparing the result with the corresponding number of background events, which turns out to be equal to 77.8, roughly corresponding to a 2σ effect. A more detailed discussion of this procedure is reported in a recently published paper [11].

4. – Conclusion and future prospects

A first analysis of a representative dataset of cosmic ray events detected by EEE telescope clusters located at large distances has been carried out. A few candidate events which are characterized by small values of the time difference —and in some cases also by a small angular difference— were extracted from the analysis. The observation of this kind of anomalous events is one of the goals of our experiment. To investigate in more detail a possible evidence for long-distance correlations will require higher statistics. An increase in the available statistics in the EEE Project could come within a few years from longer data taking periods, larger duty cycles, greater telescope detection efficiency, and the inclusion of additional clusters in the EEE network.

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