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CZELTA: An overview of the CZECH large-area time coincidence array

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Abstract. Main goal of the project CZELTA (CZEch Large-area Time coincidence Array) is to study global properties of high-energetic cosmic rays. To present date, project consists of 5 stations covering large area in the Czech republic capable of detection of extensive air showers with energy exceeding 10^{14} eV. Such a network of distant stations can be an ideal tool for probing global structure of cosmic rays. We present the design of the detection system and obtained results.

1 Introduction

Nowadays, most of the ground based experiments studying the extensive air showers (EAS's) are realized as a relatively dense arrays of detectors (see e.g. Aug). Typically, in such experiments every EAS is observed by several detectors and hence the size of the shower, energy and type of the primary particle can be in principle inferred.

A complementary approach to this can be realized by shifting focus away from an isolated shower. For example, temporal and angular distribution of high-energetic cosmic rays is believed to be purely random. However, one can imagine various phenomena which can produce a small non-random fraction hidden in the total flux.

Such effects were indeed proposed. The effect of Gerasimova-Zatsepin (Gerasimova, 1960) is an example of a process that can produce pair of EAS's correlated (both in time and angle) on large distance. The Solar radiation field can break apart a high energy cosmic ray nuclei. The remnants of the nuclei will be deflected in the interplanetary magnetic field and, after hitting the Earth's atmosphere, two correlated EAS are produced. The distance of both EAS depends on the primary particle energy and composition and can exceed thousands of kilometers (Lafèbre et al., 2008). For study of such large scale phenomena, a very large sparse network of individual detectors is needed.

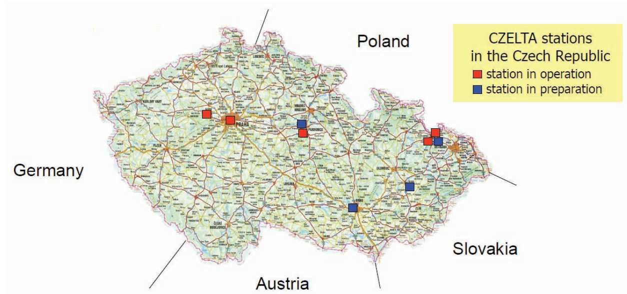

Fig. 1. Map of currently operating stations of the project CZELTA in the Czech Republic.

2 CZELTA

The Institute of Experimental and Applied Physics of the Czech Technical University in Prague and the Faculty of Philosophy and Science of the Silesian University in Opava realize a project for the detection of high energy cosmic rays, called CZELTA (CZEch Large-area Time coincidence Array) (CZE). In the experiment, a relatively sparse network of detection stations is being built in the Czech Republic (Fig. 1). The project CZELTA is related to the older project ALTA (Alberta Large-area Time coincidence Array) (ALT) of the University of Alberta in Canada. Both experiments use the same design and hardware of the detection stations.

The detection stations are placed mainly on the roofs of high school buildings in Canada and the Czech Republic. Students from those schools who are interested in research

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Fig. 2. Three boxes containing detection part of the station.

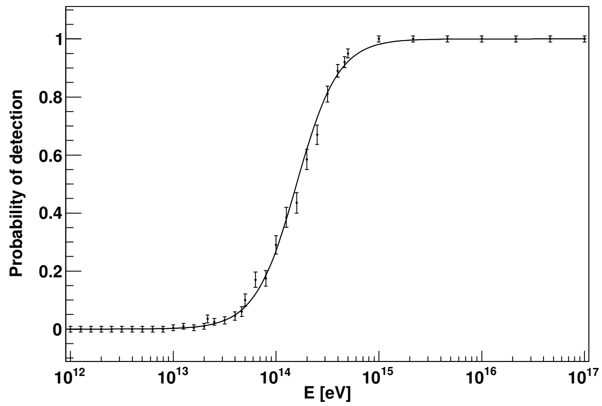

Fig. 3. The probability of detection of a shower produced by a primary proton with energy E. The direction of the primary particle is perpendicular to the surface and is oriented to the center of the detector triangle.

participate in the project. Therefore, the experiment has not only scientific, but pedagogical impact, too.

The same hardware, which is used in the CZELTA and ALTA detection stations in the Czech Republic and Canada, is used also in the parallel starting projects in Great Britain, Slovakia, and Romania. For the purpose of easier manipulation with measured data from the mentioned experiments, we developed a special web-based interface. Regularly every day, the system downloads new measured data from all connected stations to our server and provides them in a simple way for further analysis. The web-interface provides on-line check of running stations and information about meteorological conditions in the place of the detection site, too. The system is broadly used by the students of collaborating high schools and researchers involved in the project.

Similar projects, however with different design and hardware, are in operation in other countries, too. The network NALTA (North American Large-area Time coincidence Array) (NAL) was established within a Canada–USA cooperation. It covers local detection networks in Canada and the USA (ALTA, SALTA (SAL), WALTA (WAL), CHICOS (CHI), CROP (CRO), etc.). A similar project is running in Japan (LAAS (Ochi et al., 2003)) and detection stations are being built on the roofs of European high schools, too — in Sweden (SEASA (SEA)), Germany (SkyView (Sky)), the Netherlands (HiSPARC (HiS)), Great Britain (Cosmic School (Cos)) among other countries.

3 Design of the project

The hardware of the CZELTA station is identical with the hardware of the ALTA network (see Brouweret al., 2002; Brouwer et al., 2005, for more details). Each station is composed of three scintillation detectors, which are placed into an equilateral triangle configuration with 10 m long sides (Fig. 2) and use GPS signals for time-labeling of events. One scintillation detector has dimensions of $60\,\mathrm{cm} \times 60\,\mathrm{cm} \times 1\,\mathrm{cm}$ and is connected to a photomultiplier, which detects photons originating from the passage of an extensive air shower through the scintillator. The detectors work in a coincidence. A shower of secondary particles must hit all three scintillation detectors in order to be recorded. In these cases, the energy of the primary particle is at least $\sim 10^{14}$ eV.

For our purposes, extensive Monte-Carlo simulations have been provided using the CORSIKA package (Heck, 2001). Figure 3 shows the dependence of the probability of detection of an extended air shower produced by a primary proton with an energy E. The showers were simulated with the perpendicular direction aimed to the center of the detection triangle. Primary particle with energy higher than $\sim 2\times 10^{14}$ eV can produce a shower whose probability of detection is higher than 50%.

Probability of a shower detection depends on the length and density of a penetrated atmospheric column. Therefore, the minimal energy of a primary particle which can produce a detectable shower strongly increases with the zenith angle (see Fig. 4). Measured flux of showers strongly depends on the atmospheric pressure.

Based on this fact the decision to add local meteorological stations was accepted. Stored data are used for a correction of observed flux of cosmic rays on the influence of atmospheric pressure variations.

From the time differences among the measured signals, the direction of the extensive air shower as well as primary particle flight can be determined. For the estimation of the error of the direction measurement, data from two stations (rotated by 60°) located at the same place were analysed. The mean of the error of the reconstructed direction of the primary particle (for the showers with the altitude angle $>50°$) can be estimated as 5°, which conforms with our CORSIKA simulations.

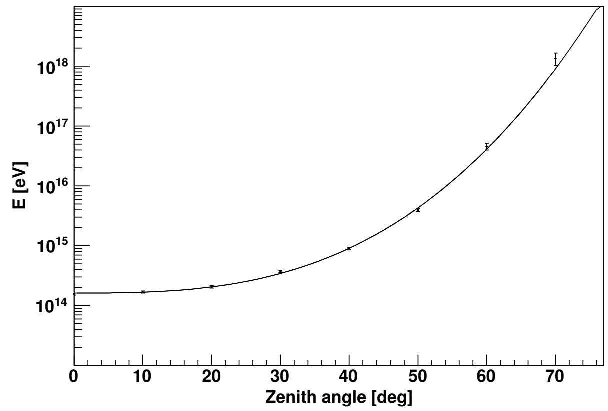

Fig. 4. Minimal energy of a primary proton which can produce a detectable shower in an ALTA/CZELTA station as a function of a zenith angle.

Recognition of a shower arrival time is done by GPS and an additional internal electronic board (with accuracy $\sim$10 ns). This method enables the study of time correlations of data measured with distant stations.

Table 1. Detection stations of CZELTA and ALTA projects.

ID	Name	TDM [day]	λ [s]
1	IEAP CTU	387	39.91
2	SU	1178	42.26
3	Pardubice	731	45.50
4	Opava Mendel	660	35.95
5	Kladno	426	39.53
6	Alta BC	98	83.87
7	O'Leary	699	25.07
8	O'Brien	998	28.34
9	Trinity	1006	25.79
10	MacDonald	1144	22.64
11	Maddock	719	19.82
12	Thorhild	716	26.78
13	G. Prairie	1133	30.66
14	Norbuck	913	6.19
15	Vegreville	977	27.29
16	Med. Hat	494	26.34
17	Phys. Roof	284	24.21
18	Laurent	585	24.46
19	Page	345	25.91
20	McNally	455	24.17
21	Beaumont	713	23.99

4 Very large area coincidences

There are several studies addressing the question whether the phenomena of the coincidencies of extended air showers on very large area exist. In 1994 Swiss group (Carrel and Martin, 1994) reported an interesting temporal increase of distant time-correlated showers. LAAS group (Ochi et al., 2003) reported few interesting candidates of correlated showers on large distance. However, interpretation that these events were only accidentally correlated, is also plausible. More recently, report of CHICOS group (Carlson et al., 2005) confirmed, that any correlation of EAS in their data, is consistent with a statistical fluctuation.

The data analysis provided in this article is focused on search for correlated EAS, i.e. pair or more of air showers with almost the same arrival time and direction which are detected by different stations, hence separated by large distances. We divide our work into two parts. First, we analyse the data taking into account only times of registration of showers. After that, we include directions of showers. In the first part we use combined data of ALTA and CZELTA projects, while the later part will consider data collected by CZELTA stations only.

Let us suppose that the detection of events by a single station is a Poisson process. If the total length of overlapping measurement by two stations with mean detected frequencies $1/\lambda_1$ and $1/\lambda_2$ (λ_1, λ_2 are mean time intervals between two consecutive events) is τ, the probability of observing k pairs of randomly correlated events by both the stations with the maximal absolute time difference t_{12} is

$$P_2(k) = \sum_{l=0}^{k-1} \frac{x_2^l}{l!} \mathrm{e}^{-x_2} \equiv S_k(x_2), \quad x_2 = \frac{2t_{12}\tau}{\lambda_1\lambda_2}, \tag{1}$$

where an expected number of observed pairs is x_2. For triple-coincidences, we can derive a similar formula:

$$P_3(k) = \sum_{l=0}^{k-1} \frac{x_3^l}{l!} \mathrm{e}^{-x_3}, \quad x_3 = \frac{4\tau(t_{12}t_{13}+t_{12}t_{23}+t_{13}t_{23})}{3\lambda_1\lambda_2\lambda_3}. \tag{2}$$

For two selected stations i, j, we use a time window t_{ij} computed as their distance divided by the speed of light. In the Table 1, total duration of measurement (TDM) and mean time intervals (λ) between two consecutive events are depicted for all ALTA/CZELTA stations.

In the data, we found many double-coincidences. With considered a combinatorial factor of selection pairs of stations, our results show no statistically significant doublets and a deeper analysis using shorter selection windows is necessary.

Let us suppose the mean time interval between two consecutive physical (caused by some phenomena in the Universe) double-coincidence events measured with a pair of stations is $\lambda^{(s)}$. If we measure k events, we can use Bayes' theorem and estimate a probability density of $\lambda^{(s)}$ as

$$f(\lambda^{(s)}|k) = \frac{\tau}{S_{k+1}(x_2)} \frac{1}{k!} \left(\frac{\tau}{\lambda^{(s)}} + x_2\right)^k \mathrm{e}^{-x_2-\tau/\lambda^{(s)}}. \tag{3}$$

Table 2. Triple-coincidences.

ID	Dist_{ij} [km]	t_{ij}^{obs} [ms]	p-value
1 & 9 & 15	7110 / 7050 / 90	15.7 / 15.5 / 0.2	0.16
11 & 14 & 16	90 / 450 / 420	0.1 / 0.4 / 0.3	0.0028

We can suppose the data from all pairs are almost statistically independent. If we serialize the time series from all pairs of stations, we can use Eq. 3 and estimate the lower limit of a mean time interval between two consecutive physical (non-statistical) double-coincidence events:

$$\lambda^{(s)} > 0.38\ \text{yr}, \quad 95\%\ \text{C.L.} \tag{4}$$

In other words, we can expect less than 2.6 physical coincidences detected with all 21 ALTA/CZELTA stations per year.

Whilst we can expect many double-coincidences in the data, triple-coincidences are expected to occur with much smaller probability. Indeed, we found only two triple-coincidences. We present them in Table 2. In the second column, there are distances between pairs of stations. In the third column, the observed time differences between detected events are presented. The last column shows the probability of a detection of at least one such coincidence. From both found triplets, the second one is most promising. However, after considering a combinatorial factor of selection of triplets of stations, we do not observe a statistically significant excess of triple-coincidences.

5 Correlated showers

Including the information about direction of the showers we can check whether the observed time-correlated pairs came from the same place on the sky or not. We considered cuts on the angular separation between events ranging from 5° to 10°. The only interesting correlation we've found is between stations UTEF and SU. Figure 5 depicts positions of showers on the Northern hemisphere. It clearly shows that from the 14 events numbered from 0 to 13 (event 12 is below the horizon), only two pairs separated by less than 10° were found. p-value was estimated to be close to 0.08. The UTC date of both events are presented.

6 Conclusions

At present, the global detection network suitable to study large-scale phenomena in the cosmic rays is being built. The analysis of data from the ALTA/CZELTA stations gives us two candidates for the correlated showers. However, further analysis with more data is necessary to decide, whether the phenomenon of the correlated showers really exists.

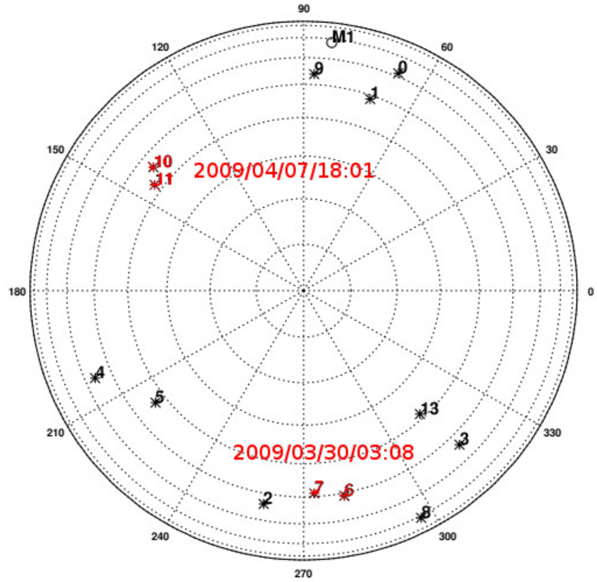

Fig. 5. Directions of all 7 pairs of events detected by UTEF and SU stations depicted on the Northen hemisphere.

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