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Search of the paired events in cosmic rays with energy above 5 EeV in Yakutsk EAS array data

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The highest energy extensive air showers that come one after the other in a narrow time interval and have similar galactic coordinates are analyzed. There is no significant excess in overall statistics of paired events over the random distribution. Next, the showers with the difference in arrival time up to five hours, and the difference of galactic coordinates less than 10 degrees were selected for analysis from Yakutsk EAS Array data. We found that such paired EAS events have an approximately the same characteristics: energy and the content of muons.

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1. Introduction

Recently it was reported [1] that the Yakutsk array detected two EAS events with energies of primary particles 3.6×10^{19} and 3.5×10^{19} eV that came one after another within 12 hours on January 22, 2009. The former arrived from the direction with right ascension $\alpha = 356.3°$ and declination $\delta = 65.8°$, while the coordinates of the latter are $\alpha = 333.3°$ and $\delta = 62.3°$. The angular distance between the arrival directions of these particles on the celestial sphere is 11°. At the Yakutsk array the frequency of particles with an energy $E \geq 3 \times 10^{19}$ eV on the total area is one event in 225 days. Events with such energy of primary cosmic rays are too rare and it is highly unlikely to be a coincidence in energy, in time and in arrival direction by chance.

Moreover, in the data of the Telescope Array [2] a shower with an energy 5.8×10^{19} eV and coordinates $\alpha = 311.2°$ and $\delta = 51.1°$ recorded on the same day. All three showers came from the same narrow region of the sky. It was suggested that this events have been produced by the short-lived beam of particles that resulted from the interaction of cosmic rays with a relativistic shock [1].

In the present work, a further analysis of the Yakutsk array database is performed in order to investigate the paired events of EAS arriving one after another on a time interval of less than 24 hours.

2. Experimental data

The Yakutsk EASA is a ground based experiment for the detection of cosmic rays with energies between 10^{15} and 10^{19} eV, see [3, 4] for details. It is located near Yakutsk, Russia (61.661°N, 129.367°E), 100 m above the sea level (1020 g cm^{-2}). It has been continuously operating for over 45 years. Additionally, in contrast to other experiments, at the Yakutsk EAS array measurements of various EAS components are carried out: electrons, muons, Cherenkov light and radio emission [5]. After the modernization of the array, carried out in the period 1994-2000, the measurements became better, because the number of stations, the Cherenkov and muon detectors increased, the uniform master for the selection of showers worked, the temporal measurements of the EAS front were improved. This allowed for a temporal analysis of the arrival of showers. The analysis of the showers was carried out not only by the time of registration, but also taking into account all the characteristics of EAS, including the galactic and equatorial coordinates of showers arrival directions.

Year	2001	2002	2003	2004	2005	2006	2007	2008
N	52	61	55	66	60	52	60	52
n	6	8	7	8	8	4	7	4

Year	2009	2010	2011	2012	2013	2014	Total
N	61	57	52	71	49	54	802
n	6	3	3	6	5	5	80

Table 1: The total number of showers with $E_0 \geq 5 \times 10^{18}$ eV (N) and the number of pairs of showers with the time between events less than 24 hours (n) year by year.

Table 1 shows the number of showers with the energy of primary particle $E_0 \geq 5 \times 10^{18}$ eV (N) and the number of pairs of this showers with the time between events less than 24 hours (n) by year of observation. One can see, that the paired events are distributed almost uniformly by year of observation. The total number of showers during the analyzed period is 802, which gives the average rate $\lambda = 0.212$ per 24 hours. Here the fact that the array usually stops operating for 3 summer months is taken into account. The number of pairs during the same period is 80 and amounts 10% of the total number of events. This is in rough agreement with the random Poisson distribution for independent events.

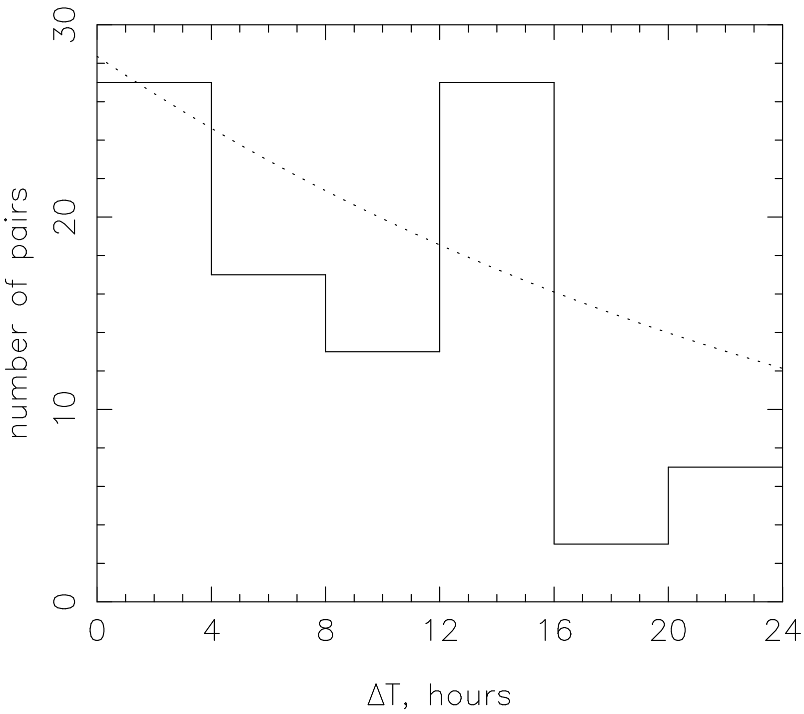

Figure 1: Distribution of the time difference between EAS events with $E_0 \geq 5 \times 10^{18}$ eV (solid lines) and the corresponding interarrival time distribution for the random events (dotted line).

On Figure 1 the histogram of the time difference between all EAS events with $E_0 \geq 5 \times 10^{18}$ eV observed during 14 years on Yakutsk EAS array is shown by solid lines. One can see that it also within statistics agree with the exponential distribution of the interarrival time for the Poisson-like random events (dotted line).

It should be noted that the peak at $\Delta T = 12\breve{~}16$ hours is statistically significant, and requires additional analysis. Preliminarily it can be stated that these showers have similar characteristics, including galactic coordinates. Typically in these events a small fraction of muons is observed at a distance of 600 m from the shower axis.

It is in interest to select and analyze pairs with the most similar properties. To do this we use the criteria: $\Delta T \leq 10$ hours, $\Delta(\lg E_0) \leq 0.08$, and $\Delta\theta \leq 5^\circ$. To this strong criteria fulfill only four pairs and they listed in the Table 2.

The last event in the Table 2 is the same pair as reported in [1]. Taking into account that the systematic error in determining the energy at the Yakutsk array is 25% [6] one could say that the

Date	ΔT, h	$\Delta(\lg E_0)$	b_1, $^\circ$	l_1, $^\circ$	b_2, $^\circ$	l_1, $^\circ$	$\rho_\mu/\rho_{\mu+e}$
18.04.03	12.13	0.03	32.5	124.2	37.0	108.4	0.16, 0.16
02.05.03	07.15	0.08	-0.5	101.4	6.3	107.0	0.20, 0.13
31.03.04	01.51	0.01	41.5	144.1	32.4	143.2	0.15, 0.17
22.01.09	11.11	0.01	6.2	110.7	9.5	100.6	0.14, 0.14

Table 2: Pairs of showers with the most similar properties. Here b and l are galactic latitude and longitude, respectively. Indexes 1 and 2 correspond to first and second shower. $\rho_\mu/\rho_{\mu+e}$ is the fraction of muons observed at a distance of 600 m from the shower axis, the values for first and second shower are separated by coma.

primary particles in pairs have almost the same energy. The low values of the fraction of muons $\rho_\mu/\rho_{\mu+e}$ measured at a distance of 600 m from the shower axis mean that the primary particle was the gamma photons or protons. All four pairs arrived from the direction of the Galactic Local Arm.

The probability that such pair happened by chance was estimated to be very low, 0.0052. Despite this fact we found three more pairs with the very similar properties. This could mean that there is a phenomenon, the nature of which has to be understood. This phenomenon can be a key element in understanding the origin of ultrahigh-energy cosmic rays.

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