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A cluster approach to the analysis of experimental data of the NEVOD-EAS shower array

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Abstract. The NEVOD-EAS array for the detection of extensive air showers in the energy range 10^{15} – 10^{17} eV is being created in MEPhI on the basis of the Experimental complex NEVOD. The array will allow independent estimations of the size, axis position and arrival direction of EAS registered by the detectors of the experimental complex. The NEVOD-EAS registering system is organized in a cluster principle, and data analysis is performed using a newly developed cluster approach. The features of this approach to the NEVOD-EAS experimental data analysis are discussed.

1. Introduction

At present, a new installation NEVOD-EAS [1] for the registration of electron-photon component of extensive air showers (EAS) in the energy range of 10^{15} – 10^{17} eV which corresponds to the “knee” region of the primary cosmic ray energy spectrum is under construction on the basis of the Experimental complex NEVOD (MEPhI, Moscow). It will be operated in conjunction with the detectors NEVOD [2] and DECOR [3], as well as with setups URAN [4] and CTUDC [5] which are now being constructed. The array will allow independent estimations of the size, axis position and arrival direction of EAS registered by aforementioned installations.

Since the array is being created at densely built territory of the MEPhI campus and detecting elements cannot be deployed in the same plane like in usual shower installations, its registering system is organized in a cluster principle. Present configuration of the first part of the NEVOD-EAS includes 6 clusters deployed at the roofs of MEPhI buildings and on the ground surface around the Experimental complex NEVOD over the area of about 10^4 m².

Each cluster of the array is a system including 16 scintillation counters of EAS electron-photon component particles combined in 4 detector stations (DS) and a local post (LP) of preliminary data processing. Detailed descriptions of scintillation counters, detector station and cluster electronics are presented in [6, 7, 8]. Typical cluster dimensions are 15×15 m². Characteristic distance between the centers of clusters is about 30 m. LP electronics digitizes signals, selects local events according to intra-cluster triggering conditions and timestamps local events with an accuracy of 10 ns. Information



on local events is transferred to the central DAQ post (CP) [8] which performs its storage and analysis, as well as controls clusters and synchronizes their internal clocks with an accuracy of 10 ns.

Thus, the cluster of the NEVOD-EAS array represents an independent installation capable to determine in each event the number of particles registered by each DS and the EAS arrival direction. Consequently, the NEVOD-EAS array is a set of individual installations synchronized with a common source. To analyze the experimental data of the array a newly developed cluster approach is used.

According to the cluster approach the analysis of the NEVOD-EAS data includes 3 main stages: separate analysis of data on local events of each cluster; combination of cluster events into EAS events at the array according to the timestamps; reconstruction of the array responses to the detected EAS.

2. Analysis of data on cluster local events

2.1. Cluster data

Experimental series at the NEVOD-EAS array is a sequence of runs with a duration of 24 hours. One run consists of 6 equal 4-hour intervals. During each interval the array operates in 2 modes: “exposition” and “monitoring” lasting 3 hours 50 minutes and 10 minutes, respectively.

During “exposition”, clusters detect EAS independently from each other. The intra-cluster triggering condition is at least 2-fold coincidence of DS signals within the time gate with a duration determined by the maximal distance between the stations. Registration threshold for each DS is about 0.75 MIP. In “monitoring”, the charge spectra of the DS responses are measured in a self-triggering mode (minimal multiplicity of triggered DS is 1, registration threshold is about 0.5 MIP).

Information package from clusters contains 8 waveforms of signals from 4 DS (2 waveforms per stations for standard and additional channels) and a local event timestamp according to the cluster internal clock. Each waveform of signal digitized with a sampling rate of 0.2 GHz has a duration of about 5 μ s and contains 1024 5-ns points. Using this waveform, for each local event the following parameters of signals are obtained: ADC baseline position, signal amplitude, charge and length, time of signal leading and trailing edges. Parameters of these signals are then used for calculation of cluster calibration parameters and reconstruction of EAS arrival direction in each local event.

2.2. Cluster calibration parameters

At the end of each run of experimental series, the following parameters are obtained for every cluster of the array: counting rates of cluster and its DS during the run; ADC baseline position and standard deviation during the run for each spectrometric channel; relative triggering delays of DS at EAS registration; responses of DS to the passage of single muons, calibration coefficients for the responses of additional PMTs. The techniques for determining these parameters are described in [9].

Relative triggering delays and responses to the passage of single muons of cluster detector stations, as well as the calibration coefficients for additional PMTs are then accounted for the reconstruction of EAS events at the array. Also, all aforementioned parameters are used to estimate the stability of the array during the run and to control the quality of obtained experimental data.

2.3. Reconstruction of EAS arrival direction

Due to the different altitudes of the DS location, the reconstruction of EAS arrival direction by the classical method in which all triggered stations are considered as a single array is greatly complicated because of the necessity to introduce additional corrections to the DS response times depending on the unknown EAS arrival direction. Therefore, in the NEVOD-EAS the “cluster” method is used. According to this method, a set of “cluster” (local) EAS arrival directions are reconstructed by the relative response times of the stations of each cluster. The resulting EAS arrival direction in an event is determined as a superposition of several local directions.

The EAS direction in local events is determined in the assumption of the flat shower front. Direction is reconstructed only for local events with at least 3-fold coincidence of DS. Figure 1 shows the distributions of local events detected by a cluster during one run in cosine of zenith angles θ (left) and in azimuthal angles φ (right) of arrival direction of EAS. The line shows the result of approximation of the distribution in the cosine of the EAS arrival direction zenith angle by the

function $N(\theta) = N_0 \cdot \cos^\alpha \theta$. The exponent α obtained by the distribution approximation is ≈ 8.6 and agrees with the expected value for EAS generated by hadrons. The excess of the number of events in comparison with the expected distribution at zenith angles more than 63° may be due to the showers produced by high-energy muons. Distribution in azimuthal angles is close to uniform.

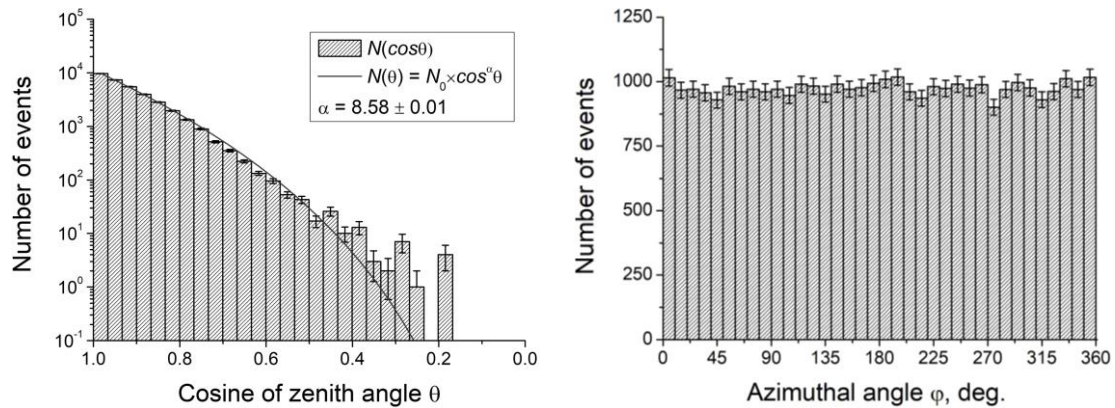


Figure 1. Distributions of EAS detected by the array cluster during one run in the cosine of zenith angles (left) and azimuthal angles (right) of arrival direction.

3. Combining of cluster events into EAS events at the array

Combining of events in separate clusters into EAS events at the array includes several stages: forming of a timeset of local events in clusters; timeset analysis and search for coincidences of local events in different clusters within the specified time gate; forming of a database of EAS events at the array.

To determine the optimal time gate for searching coincidences between local events and combining them into EAS events at the array, the dependence of the ratio $\beta(T_{\text{gate}})$ of the number of selected events N_m with cluster triggering multiplicity m to the number of events selected with the $T_{\text{gate}} = 400$ ns on the time gate duration (figure 2) was considered. Optimal time gate duration corresponds to the value at which the dependence for the maximal cluster triggering multiplicity becomes flat and is about 350 ns.

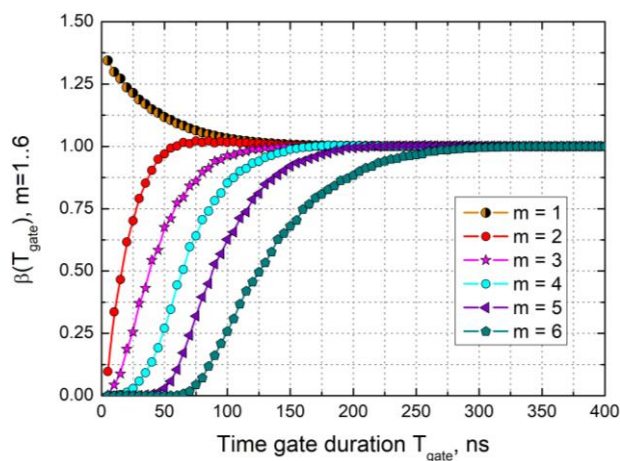


Figure 2. Dependence of the ratio $\beta(T_{\text{gate}})$ of the number of selected events N_m with cluster triggering multiplicity m to the number of events selected with the $T_{\text{gate}} = 400$ ns on the time gate duration.

4. Reconstruction of the array response

During the event reconstruction, the resulting EAS direction is determined as a superposition of “cluster” directions and the number of particles registered by each detector station is determined as the ratio between the DS response charge and its response to single particle. At high particle densities (> 100 particles/m²) the data of the DS additional PMTs are accounted. Figure 3 (a) shows the visualization of the array response. Detector stations are presented as circles. Their coordinates are plotted along the figure axes. Circle tone corresponds to the number of registered particles. The cross shows the EAS core position. The resulting EAS direction, as well as the local EAS directions in

clusters are noted. It is seen that local directions are close to each other and deviate from the resulting direction at less than 2.7° . To estimate the deviation of local directions from the resulting direction in EAS events, the distribution of the number of events per unit of solid angle in intervals of average angular deviation of local direction from the resulting direction shown in figure 3 (b) was analyzed. According to this distribution, in 90 % of events local direction deviates from the resulting EAS arrival direction by less than 4.5° .

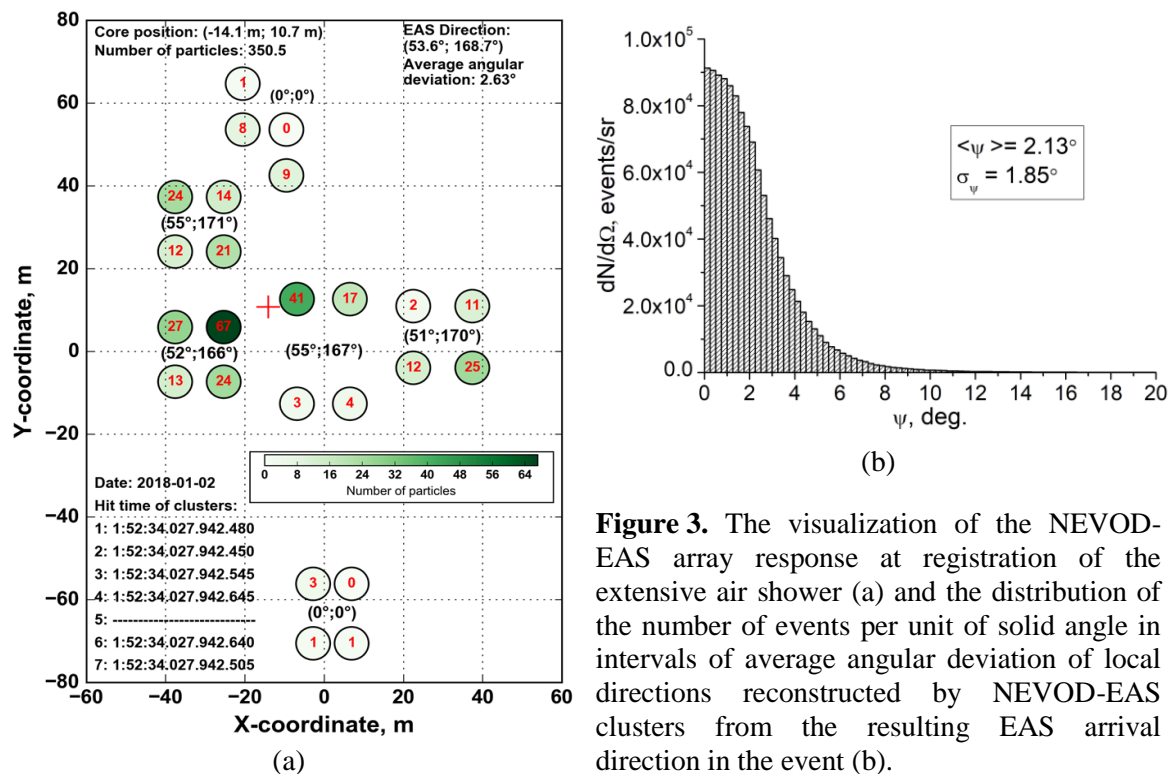


Figure 3. The visualization of the NEVOD-EAS array response at registration of the extensive air shower (a) and the distribution of the number of events per unit of solid angle in intervals of average angular deviation of local directions reconstructed by NEVOD-EAS clusters from the resulting EAS arrival direction in the event (b).

5. Conclusion

First experimental series at the first part of the NEVOD-EAS array including 6 independent clusters of scintillation detector stations deployed at the area of about 10^4 m^2 has allowed to check the main procedures of cluster response calibration, as well as has proved the possibility of using of the cluster approach to the analysis of the NEVOD-EAS data and reconstruction of EAS parameters.

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