Reconstruction of characteristics of extensive air showers detected with the NEVOD-EAS array


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In 2018, the creation of the central part of the NEVOD-EAS cluster type array aimed at detection of the electron-photon component of extensive air showers in the energy range from 10^11 to 10^15 eV was completed. At present, a continuous data taking is being performed at the array. The results of the reconstruction of extensive air showers registered during the first period of data taking (from 2018-10-26 to 2019-12-15), as well as the reconstruction technique developed within the framework of the cluster approach to experimental data analysis are presented.

Central part of the NEVOD-EAS shower array

In 2014, the creation of the NEVOD-EAS shower array was started. Since the setup 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 arrays, its registering system is organized in a cluster principle, and a newly developed cluster approach is used not only for data collection but also for experimental data analysis. Each cluster of the array is an independent system including 16 scintillation counters of EAS electrons (DS). Typical cluster dimensions are 15±15 m². Characteristic distance between the clusters is ~ 50 m. Cluster electronics digitizes signals, selects local events according to intra-cluster triggering conditions, timestamps local events. Information on local events is transferred to the central DAQ post of the array. According to timestamps, local events and their characteristics from different clusters are then (offline) combined into EAS events at the array. In 2015-2018, the NEVOD-EAS central part including 9 clusters deployed around the Experimental Complex NEVOD at the area of about 10^4 m² was created and launched in operation. Clusters No. 1, 2, 3 and 9 are located on the roofs of MEPhI buildings and the others are on the ground surface. In 2019, experimental series at the NEVOD-EAS array was started.

Experimental series at the array

Experimental series is a sequence of RUNs with a duration of 24 hours. RUN includes 6 intervals consisting of “exposition” and “monitoring”.


Exposition (3 hours 50 minutes):
- EAS detection
- multiplicity of triggered DS – 2
- registration threshold ~ 0.75 MIP

Monitoring (10 minutes):
- measurement of DS responses to single muons
- multiplicity of triggered DS – 1
- registration threshold ~ 0.5 MIP

Using the data of the RUN:
- calibration and monitoring parameters of NEVOD-EAS clusters are determined;
- EAS arrival direction and number of particles registered by DS for every ‘‘cluster’’ event are calculated;
- ‘‘cluster’’ events are combined in EAS events at the NEVOD-EAS array;
- parameters (arrival direction, size, age, axis position) of all detected EAS are reconstructed.

EAS arrival direction reconstruction

According to the relative hit times of the cluster stations, the ‘‘cluster’’ directions are calculated. The resulting EAS direction is the superposition of ‘‘cluster’’ directions.

The directing vector of the EAS front plane is determined by minimization of the functional:

\[ F = \sum_{i} \left( r_{i} - B_{0} - C_{0} - D \right)^{2} \]

A, B, C – coordinates of the EAS front plane normal vector related by an expression \( A^2 + B^2 + C^2 = 1 \)
D – free parameter in the equation of EAS front plane
\( e \) – speed of light
\( \gamma \) – relative time of the cluster DS hit
\( \delta \) – r.m.s. error of DS hit time determination
\( x_{i}, y_{i}, z_{i} \) – coordinates of the i-th DS

To obtain the initial EAS size \( N_{0} \), the DS response charges are recalculated in number of registered photons \( N_{i} \) using the calibration information. The initial size is estimated as:

\[ N_{0} = \frac{q_{i}}{p} \]

\( N_{i} \) – number of particles registered by the i-th DS
\( p \) – density of charged particles determined using the modified Nishimura-Kamata-Greisen function:

\[ p(R) = \frac{1}{R} \exp \left( \frac{R}{\gamma} \right) \]

\( R \) – distance between detector station and the axis of extensive air shower
\( \gamma = 70.8 \text{ m} \) – the Molière radius
\( \Delta \) – region of detection (0.5 m – the smallest dimension of the DS counter)

Reconstruction of EAS axis position, size and age

The axis position, size and age of extensive air showers are reconstructed by minimizing of logarithmic functional:

\[ L = -\ln \left( \prod_{i=1}^{N} P(n_{i}, N_{i}) \right) \]

where \( P(n_{i}, N_{i}) \) is a probability of detection of \( n_{i} \) particles in i-th DS at the expected number of \( N_{i} \) particles, \( m \) is a number of operating detector stations in the array. For the current magnitudes of EAS parameters, the expected number of particles is calculated according to the formula:

\[ N_{i} = N_{0} P(R, S) \]

The minimization of the functional \( L \) is performed iteratively. At each iteration the consistent determination of EAS axis position (using gradient descent optimization method) and its size and age (using golden-section search method) is performed.

Conclusion

In 2018, the central part of the NEVOD/EAS air-shower array including 9 clusters of scintillation detector stations was launched into continuous operation. The results of reconstruction of the parameters of extensive air showers registered with the installation demonstrates that the obtained arrival directions, as well as the EAS age and spectrum of size are in good accordance with the expected distributions. That means that the developed methods for EAS parameters reconstruction work correctly, and the information about EAS electron-photon component obtained with the NEVOD/EAS array can be used for conduction of multi-component studies of extensive air showers according to the data of the detectors and facilities of the Experimental Complex NEVOD.

Acknowledgements

The work was performed at the Unique Scientific Facility “Experimental complex NEVOD” with the support of the Ministry of Science and Higher Education of the Russian Federation (State task and MEPhI Academic Excellence Project of August 27, 2013, no. 02.a03.21.0005) and the Russian Foundation for Basic Research (grant 18-32-00164-mol-a).