Muon and electron-photon components detected in the NEVOD experimental complex

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The Experimental complex NEVOD (MEPhI, Russia) includes a number of detectors and installations designed to register various components of extensive air showers: electron-photon (CTS, NEVOD-EAS), muon (CWD NEVOD, CTS) and hadron (PRISMA-32, URAN) components, energy deposit of EAS cores (CWD NEVOD) and muon bundles (DECOR). All the detectors and installations of the complex are combined by the global time synchronization system which ensures a 10−10 level of accuracy of registering events to a single time source. This, in its turn, opens wide opportunities for conducting unique multi-component studies of extensive air showers.

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 3.2432.2017/4.6 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).

NEVOD-DECOR complex

- Cherenkov water detector (CWD) NEVOD with a volume of 2000 m³. CWD detecting system represents a regular spatial lattice of 91 quasi-spherical optical modules (QSM). The wide dynamic range (10−18−10−2 eV) and density spectrum measured by CWD allows to operate in the calorimetric mode, measuring the energy deposit of muon bundles, EAS cores, and cascades generated by single muons in the water volume.

- Calibration telescope system (CTS) containing 40 upper scintillation counters (on the CWD water tank top) and 40 bottom counters (on the tank bottom) with the dimensions of 40×20×2 cm³. Different pairs of counters from top and bottom planes allow to calibrate QSMs for various distances from muon tracks and Cherenkov light directions. Dense location of counters and the water volume between planes allow to separate EAS electron-photon and muon components, as well as to measure their local density spectra in energy ranges 10−18−10−6 eV and 10−15−10−3 eV, correspondingly.

- Coordinate-tracking detector DECOR consisting of 6 vertically arranged supermodules with a total area of 8 m². Good spatial and angular characteristics of the detector (accuracies of 1º and ~ 0.7º) allow to reconstruct the arrival direction of muon bundles of inclined (up to horizontal directions) EAS and to determine the multiplicity and density of muons in bundles.

Conclusion

The analysis of the experimental data collected during the first period of conjunctive data taking at the central part of the NEVOD-EAS air shower array and at the NEVOD-CTS-DECOR complex carried out in a period from 2018-10-26 to 2019-02-15 has allowed to determine the optimal conditions for searching joint EAS events in these installations, as well as to estimate the angular resolution of the NEVOD-EAS array central part. The obtained results has demonstrated a good accordance between:

- EAS arrival direction reconstructed by electron-photon component according to the data of NEVOD-EAS array and by muon bundles registered with the DECOR coordinate-tracking detector;
- densities of electron-photon component measured simultaneously by the 3rd NEVOD-EAS array cluster and the top plane of the CTS setup.

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Detectors of the Experimental complex NEVOD

The NEVOD-EAS array is dedicated to detection of electron-photon component and reconstruction of size, axis position and arrival direction of extensive air showers with energies in the range from 109 to 1013 eV registered in conjunction with the existing detectors NEVOD and DECOR, as well as with URAN air-shower array and coordinate-tracking detector TIREK which are now being constructed.

The present configuration of the NEVOD-EAS array (central part) includes 9 clusters of detector stations (DS) deployed over the area of 103 m² around the Experimental complex NEVOD. Each NEVOD-EAS cluster has typical dimensions of 15×15 m², includes 4 DS's and operates as an independent air-shower detector. DS has an area of 2.56 m² and a dynamic range from 0.3 to 1013 particles/str.

Clusters Nos. 1-3 and 9 are located at the roofs of the laboratory buildings of the Experimental complex NEVOD. Clusters Nos. 4-8 are on the ground surface.

Selection of joint events

Clusters of the NEVOD-EAS array, as well as NEVOD, CTS and DECOR detectors are connected to a single System of Global Time Synchronization (SGTS). SGTS ensures precise timestamping of NEVOD-EAS cluster events with accuracy of 10 ns and events in NEVOD-CTS-DECOR complex with accuracy of 25 ns. Timestamps are used for offline combining of cluster events into EAS event at the array and for searching of joint events in detectors of the experimental complex.

To determine the conditions for searching joint events in NEVOD-EAS array and NEVOD-CTS-DECOR, the following events were considered:

- for NEVOD-EAS - the events with at least 7-fold coincidence of clusters;
- for NEVOD-CTS - all events falling into the time gate from 0 to 850 ns from the trigger of the 3rd NEVOD-cluster.

On average cluster No. 3 is triggered 575 ns earlier than the NEVOD-CTS-DECOR complex.

The roof of the NEVOD-CTS-DECOR complex building acts like an absorber of electron-photon component of extensive air showers. At the same time with the growth of density (energy) of particles, the probability of secondary particle cascade generation inside the roof increases. The superposition of these two effects explains the behavior of the particle density spectrum measured by the CTS top plane in relation with the one obtained by the 3rd NEVOD-EAS cluster deployed on the building roof.

For μ of up to 70 m² the absorption is dominant. For μ in range from 70 to 200 m² absorption is compensated by cascade generation and two spectra coincide and have close slopes. At higher densities cascade generation is prevalent over the absorption inside the roof.

Distribution of the number of events per unit of solid angle in the NEVOD-CTS-DECOR and in the 3rd NEVOD-EAS cluster

The probability of incorrect joint event selection ≤ 5×10−5

The average time between events:

- in NEVOD-EAS: 21 ± 3 ms
- in NEVOD-CTS-DECOR: 12 ± 2 ms

The optimal time gate duration: 250 ns

Conclusion

The analysis of the experimental data collected during the first period of conjunctive data taking at the central part of the NEVOD-EAS air shower array and at the NEVOD-CTS-DECOR complex carried out in a period from 2018-10-26 to 2019-02-15 has allowed to determine the optimal conditions for searching joint EAS events in these installations, as well as to estimate the angular resolution of the NEVOD-EAS array central part. The obtained results has demonstrated a good accordance between:

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