Status of the NEVOD-DECOR experiment

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Abstract: Present status of the experimental complex NEVOD-DECOR including the big Cherenkov water detector NEVOD (2000 m^3) and the large area coordinate-tracking detector DECOR is described. The main goal of the experiments conducted in 2002 – 2007 with the setup was investigation of inclined EAS by means of a new method of local muon density spectra (LMDS). This method allows explore a wide interval of EAS energies from 10^{15} to about 10^{19} eV. Now the second phase of NEVOD-DECOR setup is being constructed, and the experiments in which not only the number of muons but also their energy deposit in Cherenkov water calorimeter will be measured, are started.

Keywords: Cosmic rays, muons, muon bundles, extensive air showers, coordinate detector, streamer tube chambers, Cherenkov water detector.

1 Introduction

The idea to construct on the Earth's surface the detector with the ability to provide effective detection of all cosmic ray components is very attractive. Experimental complex NEVOD-DECOR (Fig. 1) is the first in the world multi-purpose facility specially created to solve this complex task [1, 2].

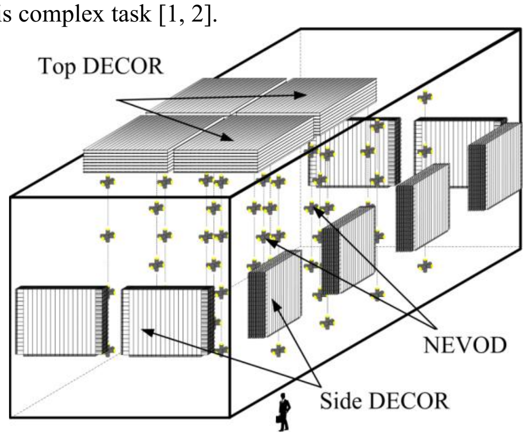

Figure 1. Experimental complex NEVOD-DECOD.

The setup is located in the campus of the National Research Nuclear University MEPhI in a special four-story building and equipped with necessary technical and technological systems to provide the detector operation. The basis of the complex is the Cherenkov water detector (ChWD) NEVOD with a reservoir volume 9×9×26 m^3 inside the building. The detecting system (Fig. 2) is formed by a spatial lattice of quasispherical modules (QSM, Fig. 3) including six PMTs with flat cathodes directed along the coordinate axes which allow to detect Cherenkov radiation from any direction with practically the same efficiency [3], estimate the energy deposit in the ChWD volume and reconstruct the direction of particle motion.

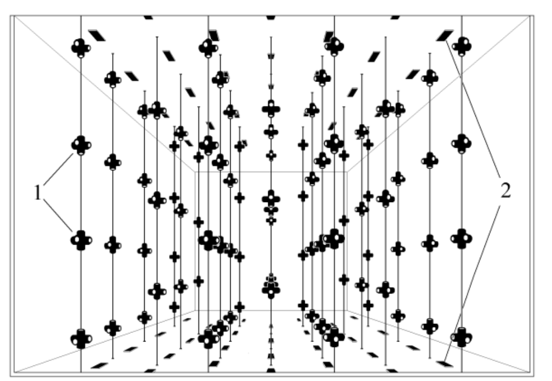

Figure 2. Detecting system: 1 - quasispherical modules, 2 - scintillation counters.

Reconstruction approach is based on the analysis of response amplitudes of every PMT, which allows to estimate arrival direction of Cherenkov light with angular accuracy about 10° and locate points of their radiation with spatial accuracy about 0.5 m. The distances between the modules are 2.5 m along the detector, and 2.0 m across it and over the depth. The modules in the adjacent planes are shifted by a half-distance to provide better detection conditions for particles traversing different parts of the detector.

Figure 3. Quasispherical module.

Constructively, the lattice is formed by a set of vertical strings containing 3 or 4 modules each. Now detecting system consisting of 91 QSM (NEVOD-91, 546 PMT in total) is under operation. The structure of NEVOD-91 setup is shown in Fig. 2. It includes 7 planes of the modules (along each of the coordinate axes of the detector), four of them contain 16 QSM and three - 9 QSM. A nearly cubic shape and structure of the detector provides similar conditions for the detection of Cherenkov light produced by particles and cascade showers arriving from any direction, and creates a detecting system with properties of a 4π-detector.

For calibration of PMTs during long experimental runs, the calibration telescope system (CTS) is used (Fig. 2). For the NEVOD-91, CTS consists of 40 upper scintillation counters (located on the top of the water tank) and of 40 lower ones (on the tank bottom). Each counter consists of a water-proof box containing a plastic scintillator sheet with a size $40\times20\times1$ cm^3. The vertical pairs of these counters provide possibility to calibrate the PMTs of four surrounding strings. Other combinations of counters allow to get the calibration curves for different distances from muon tracks and different angles.

Functionally, NEVOD data acquisition system consists of several sub-systems: measuring, triggering, control, monitoring and readout ones. In NEVOD, there are two main separated electronics levels: innermodule electronics, which is located directly inside the QSM, and outer systems arranged "on shore" (outside the water volume).

To improve the event reconstruction accuracy, the coordinate detector DECOR [4] was constructed in frame of Russian–Italian cooperation around the Cherenkov water calorimeter NEVOD (see Fig. 1). DECOR represents a modular multi-layer system of plastic streamer tube chambers with resistive cathode coating. The side part of DECOR includes eight vertically suspended eight-layer assemblies (supermodules, SMs) of chambers with the total sensitive area 70 m^2. Chamber planes are equipped with two-coordinate external strip readout system that allows to localize charged particle tracks with about 1 cm accuracy in both coordinates (X, Y). Angular accuracy of reconstruction of muon tracks crossing the SM is better than 0.7° and 0.8° for projected zenith and azimuth angles, respectively. Selection of events by the triggering system is based on coincidences between signals from SMs of different groups, and signals formed by the system of Cherenkov detector. A more detailed description of the triggering system is given in [4].

During 2002 – 2007, several long-term series of measurements with experimental complex NEVOD-DECOR have been conducted. The main task of these studies was elaboration of a new and promising approach to the investigation of the EAS characteristics at ground level by means of detection of muon bundles in a wide range of zenith angles (up to the horizon).

2 The new approach to EAS characteristics study

The new approach to studies of inclined EAS is based on the phenomenology of local muon density spectra obtained on the basis of detection of muon bundles by DECOR setup in wide ranges of multiplicity and zenith angles. At large angles, the transverse area of showers (mainly muons at ground level) exceeds square kilometers. Hence, muon detector may be considered as a point-like probe, and capability of UHE primary particles detection is determined not by the size of the setup but by effective EAS dimensions in a plane orthogonal to the axis. In this case the observed muon bundle multiplicity m is related to the local muon density D as $D \approx m / S_{\text{det}}$. Events with fixed muon density, arriving from different zenith angles correspond to substantially different energies of primary particles, since the distance from the generation point increases with increasing of zenith angles. Contribution to the flux of events with a fixed local density is given by showers with different primary energies detected at different (random) distances from the axis; however, due to a fast decrease of cosmic ray flux with the increase of energy, the effective interval of primary particle energies appears relatively narrow [5, 6]. The analysis of detected distributions of muon bundles in terms of a new EAS observable – local muon density spectra – has shown that by means of not so large detector as DECOR it is possible to investigate primary CR spectrum characteristics in a very wide energy range (from the knee to the ankle). The analysis of obtained LMDS [7] has demonstrated the growth of muon density in comparison with the expected one in the energy range 10^{16} – 10^{18} eV, the difference being increased with primary energy increase (in more details, this question is discussed in the talk #322 presented at this conference [8]).

New approach has an additional very important advantage - measurements of energy characteristics of muons bundles can provide independent information on possible changes in interaction models at ultrahigh energies. Experimental complex NEVOD-DECOR has a necessary ability to conduct such investigations, since ChWD NEVOD can be used as a calorimeter. But the older detection system had insufficient dynamic range of spectrometric channels of QSM (~10^3 photoelectrons). It was one of the reasons to carry out a deep modernization of measuring system of ChWD NEVOD.

3 Modernization of Cherenkov water detector NEVOD

The objectives of modernization were the following: extending of dynamic range of detected signals to provide correct measurements of the spectrum of cascades generated inside the water detector with energies from 10 to 10^4 GeV, and also energy deposits of muon bundles and EAS cores; the increasing the efficiency of single muon detection (to ensure the hodoscope operation mode) for the measurements of angular distribution of muons in the whole range of zenith angles from 0° to 180° and investigation of muon flux variations at different angles and energy thresholds; improving the calibration systems in order to increase the reliability of experimental data.

During modernization, all photomultipliers of the detector were replaced by new type Russian PMT FEU-200. This type PMT was designed specially for detection of a weak flux of Cherenkov radiation. PMT FEU-200 with a bialkali flat 15 cm diameter cathode provides significantly better integral cathode sensitivity compared to earlier Russian PMTs, and has low dark noise rate. The use of low noise photomultipliers allows to refuse of demand of double coincidences of triggered PMT in the former innermodule electronics, and increases efficiency of Cherenkov flashes detection by the module that improves the precision of single muon track reconstruction. Some functions of the former innermodule electronics (ADC digitization, pulse-forming and discrimination, elaboration of the first level trigger signals) were moved to a new Block of Electronics of the Cluster (BEC) proceeding signals from PMTs of QSMs of one string. Electronics of every BEC is housed in a water protected stainless steel box located between the surface of water and light shielding water tank cover.

For selection of different type events, in particular of rare events (upward muons, etc.) against the background of atmospheric muons, the multi-level triggering system was designed. Signals from triggered PMTs are transmitted to the corresponding BEC where their digitization is carried out, and three types of trigger signal are elaborated depending on the combination of triggered PMTs (see Fig. 4): “A” (any) – logical “OR” of signals from 12th dynodes of six PMTs of one QSM; “B” (bottom) – hits of downward-looking PMT, and “C” (coincidence) – the coincidence of any two PMT, besides of oppositely directed, within a certain time window. Triggering signals are transmitted to the receiver block where their selection to the three groups (“A”, ”B”, ”C”) is performed for transmitting to outer triggering system implemented on the basis of four programmable logic blocks VME CAEN V1495 (see Fig. 4), three of which are intended for system trigger formation, and the fourth is used for the joint operation with other detectors of the experimental complex.

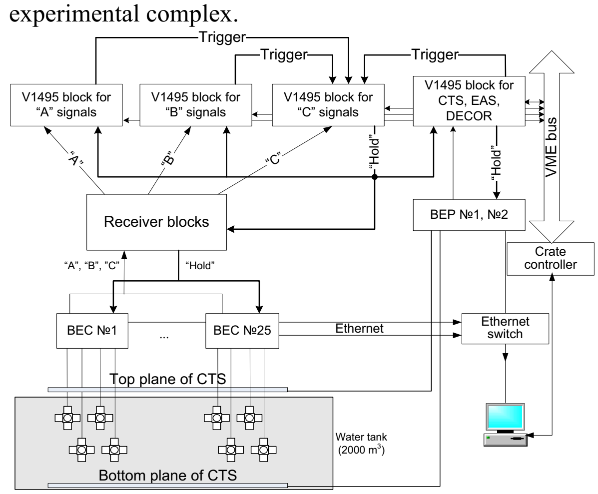

Figure 4. Measuring system of NEVOD-91 setup.

For extending of the dynamic range of detected signals, the new electronics providing the readout of signals from 12th and 9th PMT dynodes was designed. It allows to reach dynamic range from 1 up to 10^5 photoelectrons for every PMT.

To get correct information about characteristics of detected events it is necessary to provide the proper calibration of all measuring channels. Calibration procedures can be divided in two stages:

1. Periodical monitoring of all PMTs during long experimental runs by means of innermodule monitoring sys-

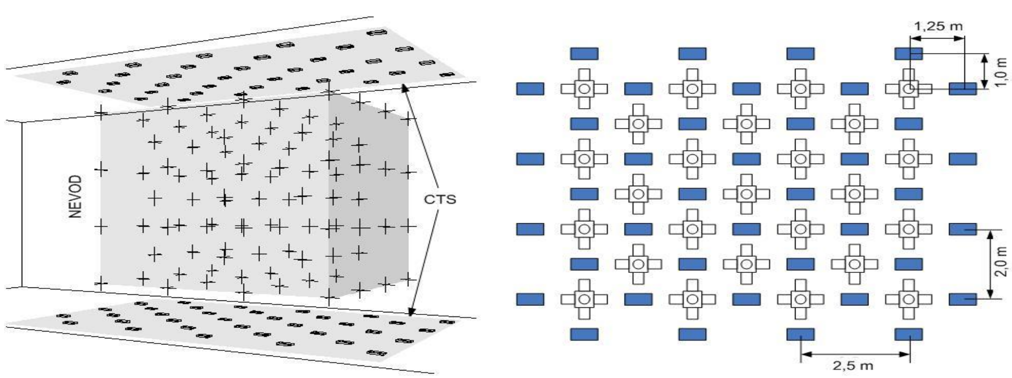

Figure 5. Calibration telescope system

tem on the basis of fast blue LEDs (470 nm) to provide illumination of every photomultiplier by short flashes in a wide dynamic range of intensity. It gives possibility to control the PMT gain on the basis of response spectrum shape analysis.

2. Calibration by means of Cherenkov light from muons with known track positions, selected by calibration telescope system (CTS). Counters are located in the regular order with 2 m step across and 2.5 m along the water tank, in such a way that the axis of every vertical telescope is situated in the middle between four QSM strings (Fig. 5). The new detection system of scintillation detectors provides the amplitude analysis of responses of triggered scintillation counters. It allows to use the arrays of CTS counters as an additional EAS detector.

Signals from CTS counters enter the Block of Electronics of Planes (BEP) of top and bottom counter layers (Fig. 4 and 5). BEP provides processing of the signals and transmitting of the information about triggered counters to the outer triggering system which forms system signal "Hold". When signal "Hold" comes back to the BEP, all ADCs complete digitizing the data and transmit them to the central computer trough the Ethernet link.

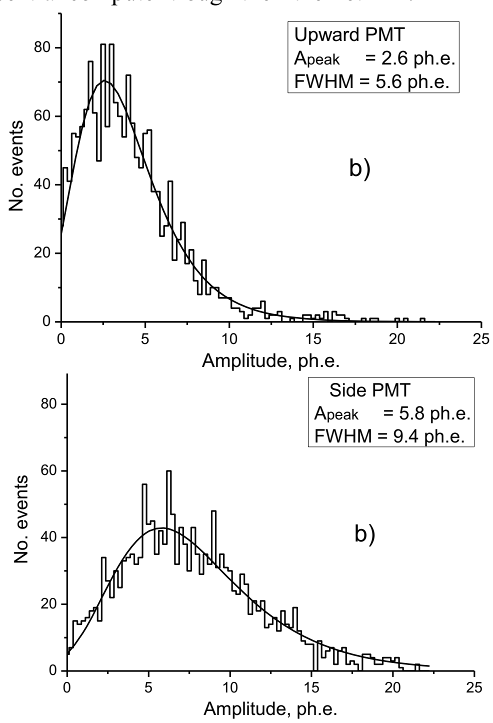

Figure 6. Calibration amplitude spectra of PMT responses at vertical muon detection: a – response of upward PMT; b – response of side PMT. Distance between the axes of the telescope and of the QSM strings equals to 1 m.

Examples of calibration spectra measured in one of the top and one of the side PMTs of QSM at detection of vertical down-going muons selected by the CTS telescope of are presented in Fig. 6. The axis of the telescope was positioned at the distance of 1 m from the QSM string. Angular accuracy of the track location is about ~ 2°, threshold muon energy E_{th} ~ 2 GeV. Shapes of the spectra have a good resolution and can be used for the purpose of calibration. Difference of spectra-averaged amplitudes of PM responses is related with different integral efficiency of photomultipliers (all PMTs have an equal gain ~ 10^6), different light incidence angles and distances from the cathode to the track (1.0 m for the top PMT and 0.725 m for the side one).

4 Conclusion

Currently, the deployment of measuring system of ChWD NEVOD and counters of the calibration telescope system is being completed. The modes of triggering system operation and selection of different type events, procedures of detection system monitoring and calibration by Cherenkov light from muons with known track positions are being elaborated during methodical experimental runs.

The start of systematic measurements with the modernized ChWD NEVOD with coordinate-tracking detector DECOR is planned for the autumn of 2011.

5 Acknowledgments

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6 References

[1] V.M. Aynutdinov et al. Proc. 24 Int. Cosmic Ray Conf., 1995, V.1 pp. 1076-1079.
[2] V.M. Aynutdinov et al., Astrophysics and Space Science, 1998, 258 pp. 105-115.
[3] V.V. Borog et al. Proc. 16th Int. Cosmic Ray Conf., 1979, V.10, pp. 380-383.
[4] M.B. Amelchakov et al. Proc. 27th ICRC, 2001, v. 3, pp. 1267-1271.
[5] M.B. Amelchakov et al. Physics of Atomic Nuclei, 2007, v. 70, no. 1, pp. 175-183.
[6] I.I. Yashin et al. Int. J. Mod. Phys., 2005, A 20, pp. 6937-6941.
[7] A.G. Bogdanov et al. Physics of Atomic Nuclei, 2010, v. 73, no. 11, pp. 1904 - 1920.
[8] I.I. Yashin et al. Proc. 32th ICRC, 2011, paper ID322.