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# New measuring system of multipurpose Cherenkov water detector NEVOD

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**Abstract.** The purposes, tasks and design features of the new measuring system of the Cherenkov water detector NEVOD are discussed.

## 1 Introduction

The Cherenkov water detector (CWD) NEVOD is a multi-functional experimental facility with volume about 2000 m$^3$ (Fig. 1). CWD was created for investigations of all main cosmic ray components on the Earth's surface (Aynutdinov et al., 1994). To provide the detection of rare events at a very high background of atmospheric muon flux the quasispherical optical module (QSM) was designed. QSM is the detector of Cherenkov radiation in water and originally consisted of 6 PMT FEU-49B with flat photocathodes (15 cm diameter) and inner-module electronics, placed in the waterproof housing (Borog et al., 1979; Aynutdinov et al., 1995). Photomultipliers are oriented along the axes of the orthogonal coordinate system (Fig. 2). Such module has a quasispherical response, since square root of the sum of the squares of amplitudes of triggered PMTs does not depend on the angles of incidence of Cherenkov radiation on the QSM. On the other hand, these angles can be estimated by the amplitudes of the triggered PMTs and the value of QSM response.

The detecting system developed for the effective registration of the events from any direction is formed by a spatial lattice of QSM. Modules are combined into the vertical strings of 3 or 4 QSM in each. The distances between the modules are 2.5 m along the detector and 2.0 m across it and

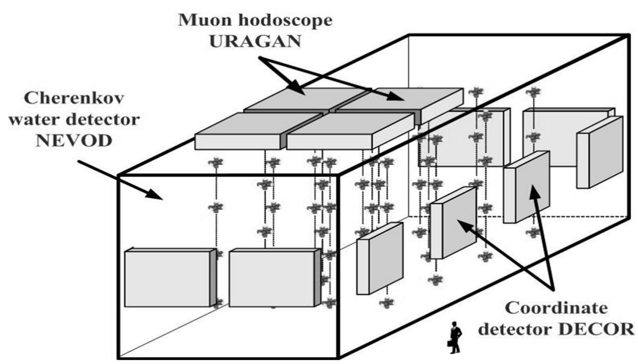


**Fig. 1.** Experimental complex NEVOD.

in the depth. This system makes it possible to reconstruct particle track parameters in $4\pi$ – geometry.

The former measuring system (MS) was designed for the upward-going neutrino detection on the Earth's surface under conditions of very high background of atmospheric muons (Aynutdinov et al., 1998). The MS consisted of inner-module electronics, cable communications and the interface block for data exchange with the external systems. Measurement, digitizing of signals from PMTs and formation of the first level triggers were implemented inside the module. As a fact of the QSM trigger, the requirement of double coincidence of the signals of any two adjacent PMTs was used. This choice of the trigger condition was forced by a large dark noise of used FEU-49B PMT, and as a result it decreased the effective registration area of QSM. The dynamic range of the analyzed signals did not exceed $10^3$ photoelectrons (ph. e.). This circumstance did not allow measuring the large energy deposits in events inside the detector. At the same time, the study of muons bundles in a wide range of zenith angles by means of

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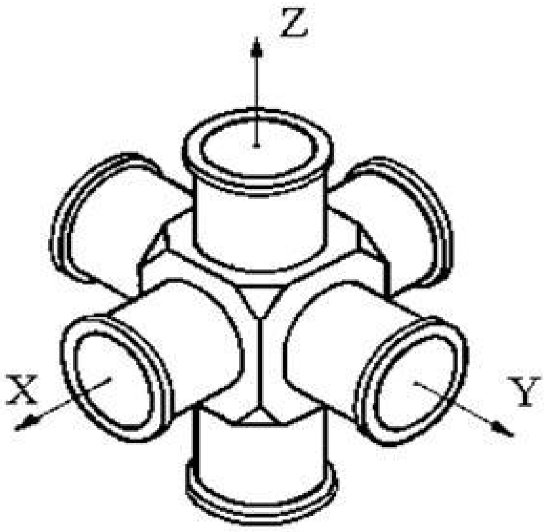


**Fig. 2.** Quasispherical module (QSM).

the coordinate detector DECOR (area about 70 $\mathrm{m}^2$, deployed around CWD) (Amelchakov et al., 2001) showed that for the formation of these bundles at large zenith angles the primary particles with energies up to $10^{18}-10^{19}$ eV were responsible (Bogdanov et al., 2010). For the analysis of energy characteristics of muon bundles, the new measuring system of CWD NEVOD is needed. The system should provide the effective detection of events from any direction in PMT signal range from 1 to $10^5$ ph. e.

## 2 Objectives of CWD modernization

The new measuring system was developed for replacement of an obsolete electronics with the new apparatus and for extension of the detection capabilities of CWD NEVOD. The new MS operates both in hodoscopic and calorimetric modes. The hodoscopic mode provides detection of single muons from any zenith angles ($0° \div 180°$) and investigation of muon flux variations in a wide range of energy thresholds ($1.5 \div 7$ GeV). The calorimetric mode provides measurements of cascade showers with energy from 10 to $10^4$ GeV and also energy deposits of EAS cores and muon bundles. Both autonomous and combined with other detectors of experimental complex DECOR and URAGAN (Barbashina et al., 2008) operation modes are foreseen.

## 3 The new measuring system

When the new MS was designed, the structure of the spatial lattice which provides the sensitivity of the detector in a whole solid angle was kept the same. As a new photomultiplier for QSM, FEU-200 (Russia) whose characteristics are specially optimized for detection of faint photon fluxes was selected. This PMT has about twice higher integral sensitivity compared to the PMT FEU-49B, and low noise (typically about $3 \cdot 10^3\ \mathrm{s}^{-1}$ for FEU-200 compared to about $10^5\ \mathrm{s}^{-1}$ for FEU-49B at the threshold of 0.25 ph. e.). This fact made it possible to refuse from the condition of double coincidences of signals from the photomultipliers of QSM.

The new MS has a multilevel structure of data collection and processing. MS includes inner-module electronics, blocks of electronics of the cluster (BEC) and external system of trigger formation. The inner-module electronics provides detection, formation and transmission of PMT signals. To provide the wide dynamic range of spectrometric measurements ($\sim 10^5$ ph. e.), the output signals from $9^{th}$ and $12^{th}$ dynodes are used. The time stability check of PMTs parameters is provided by the monitoring system on the basis of light-emitting diodes (LED). Signals from all QSM of a single string are transmitted to the BEC, where they are digitized and the generation of first level trigger signals is performed. BEC logics generates three types of trigger signals for each QSM: “a” (any) logical “OR” of six signals from $12^{th}$ dynodes of PMTs (is intended for selection of single muons); “b” (bottom) signal from the downward directed PMT (for selection of muons from the bottom hemisphere); “c” (coincidence) the coincidence of signals from any two PMT (except those oppositely directed) within 150 ns time gate (for detecting the events with large energy deposit in the detector volume).

Trigger signals from all BECs are transmitted to the external system of trigger formation, where analysis of a fired QSM configuration is performed. The system is implemented on the basis of four programmable units CAEN V1495 on the VME bus platform. The system provides generation of “Storage” signal using majority coincidence circuit, calculation of exposition live time and monitoring of BEC trigger signals. The “Storage” signal also can be generated by receiving trigger signals from other setups of the experimental complex. All BEC complete digitization of QSM PMT signals in the case of receiving of the “Storage” signal, and ensure data transfer to the central computer of CWD via Ethernet.

To check the operating principles of the new MS, the response of CWD on muons passing through its volume was simulated by means of the Geant4 code (Allison et al., 2006). As of preliminary, trigger conditions for selection of different kinds of the events have been chosen from simulation results. Thus, the condition “$\geq 7a$” provides effective suppression of random coincidences and a high efficiency for detection of muons from any direction. On the other hand, selection

"$\geq 9b$" ensures sufficiently high efficiency for registration of up-going muons (not less than 90%) crossing the detector and simultaneous rejection of most of the muons from the upper hemisphere. For selection of events with large energy deposits inside the detector volume, the condition "$\geq 12c$" may be used. The optimal width of the coincidence circuit gate of the trigger formation system was estimated as 150 ns. Further optimization of trigger conditions will be made on the basis of natural tests.

## 4 Conclusions

Currently, all elements and units of the new measuring system of Cherenkov water detector NEVOD have been tested by means of specialized test facilities. The assembly, certification and deployment of quasispherical modules and blocks of electronics of the clusters into the water tank are being carried out. Different modes of data readout from triggering system and clusters by the central computer of CWD are being debugged; adjustment of both monitoring mode of spectrometric channels and Cherenkov light detection mode is performed, including the technique of QSM calibration by means of muon scintillation telescopes. Operation of the full configuration of CWD NEVOD is expected to be started in the beginning of 2011.

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