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High-resolution large area coordinate detector for investigations of high energy cosmic ray phenomena at the ground level

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Abstract. Coordinate detector DECOR is deployed around the Cherenkov water calorimeter NEVOD and is intended for detailed studies of angular, lateral and energy characteristics of multi-particle cosmic ray events (muon bundles, air showers, etc.) in a whole interval of zenith angles. Description of the coordinate detector and its data acquisition and triggering systems is given. In 2000, the first test runs with the side part of coordinate detector, both in autonomic mode of operation and in coincidence with Cherenkov calorimeter, were conducted. Preliminary results concerning coordinate detector performance are presented.

1 Introduction

In 1999, installation of the side coordinate detector DECOR containing 8 eight-layer supermodules with total working area about 70 м^2, located around water calorimeter NEVOD (Aynutdinov et al., 1995) and intended for horizontal cosmic ray flux investigations at the ground level, was completed. Experiments with pilot assembly of the detector confirmed the correspondence of the performance accuracy to expected values, allowed to test specially designed multi-functional controller of DECOR data acquisition system, and demonstrated possibility of detection and selection of muon groups generated in the atmosphere (Aglietta et al., 1997; Petrukhin et al., 1999).

In addition to the side coordinate detector, construction of the top detector (4 horizontal supermodules, 12 m^2 each, above the Cherenkov setup) for vertical cosmic ray flux investigations (0° - 60°) is now in progress. After finishing of this detector assembling, experimental complex NEVOD-DECOR will allow to register particles in a whole zenith angle range by means of the same technique. The purposes of these investigations will be the study of cosmic ray energy transformation processes including multiple muon generation, estimation of the contribution of different channels to muon group formation, and searches of new state of matter and/or new particles, decaying with high-energy muon production.

In the present paper, a brief description of the coordinate detector structure and of its data acquisition and triggering systems is given. Results of methodical experimental runs conducted both in autonomic regime of coordinate detector operation and in coincidence with Cherenkov water detector NEVOD in 2000 are discussed.

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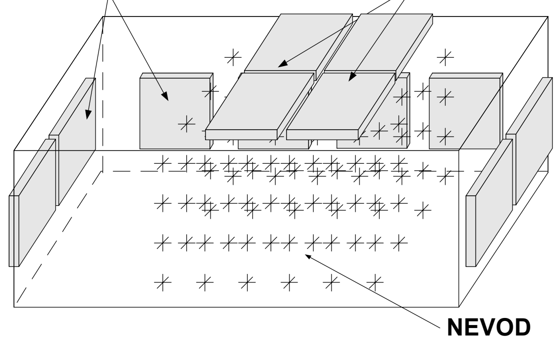

Fig. 1. Experimental complex NEVOD-DECOR.

2 Detector description

The general lay-out of the coordinate detectors around Cherenkov calorimeter NEVOD is shown in Fig.1. The whole configuration of the side detector (Aglietta et al.,

1995) includes 64 basic modules (planes) located in the galleries of the NEVOD building. Each basic module has an area 2.7×3.1 m^2 and consists of 16 chambers, arranged in a vertical plane one above another and equipped with two-coordinate external strip readout system (256X+256Y channels with 1.0 and 1.2 cm pitch, respectively). Eight such modules (arranged vertically side by side) form one supermodule (SM). Pairs of neighbouring supermodules are served by local stations which include low-voltage and high-voltage supply, gas distribution posts and peripheral computers of the data acquisition system (DAQ).

The basic element of the coordinate detector is a plastic streamer tube chamber with resistive cathode coating. Earlier these chambers were used in the NUSEX proton decay experiment (Battistoni et al., 1986). Each chamber contains 16 tubes with 9×9 mm^2 inner cross section and 3.5 m length, integrated in one PVC box. A special three-component gas mixture ($Ar+CO_2$+n-pentane) provides chamber operation in a limited streamer mode.

3 Data acquisition system

The data acquisition and triggering systems of the coordinate detector DECOR have distributed two-level architecture. The general structure of the data acquisition system is shown in Fig.2. Modular organization gives a possibility of easy changes of configuration and system extension with the arrangement of additional detector supermodules.

As a front-end electronics of data acquisition, the cards LeCroy STOS M4200 are used. Each card provides detection, discrimination, storage in shift registers and subsequent readout of signals from 32 registration channels (strips). One module includes eight X-coordinate and eight Y-coordinate cards. Fast data readout, transmission to local station and formation of the first-level trigger is implemented for each SM by means of two specially designed 4-channel controllers (Vonsovskii et al., 1999), operating in the ISA bus standard. The elaboration of the controller in this standard has allowed to use personal computers (IBM PC type) as a part of local stations without any additional specialized apparatus. Integration of several functions in one plate permitted to minimize the amount of slots required for DAQ system organization, and to optimize the traffic of data transmission. The controller includes four identical independent channels, each of them maintains one chamber module.

The controller structure contains the following subsystems:

– 16-bit interface for communication with ISA bus;
– circuit for serial transmission and reception of the data from M4200 cards;
– monitor of the rate of module counts;
– circuit generating the first-level trigger and LOAD signals.

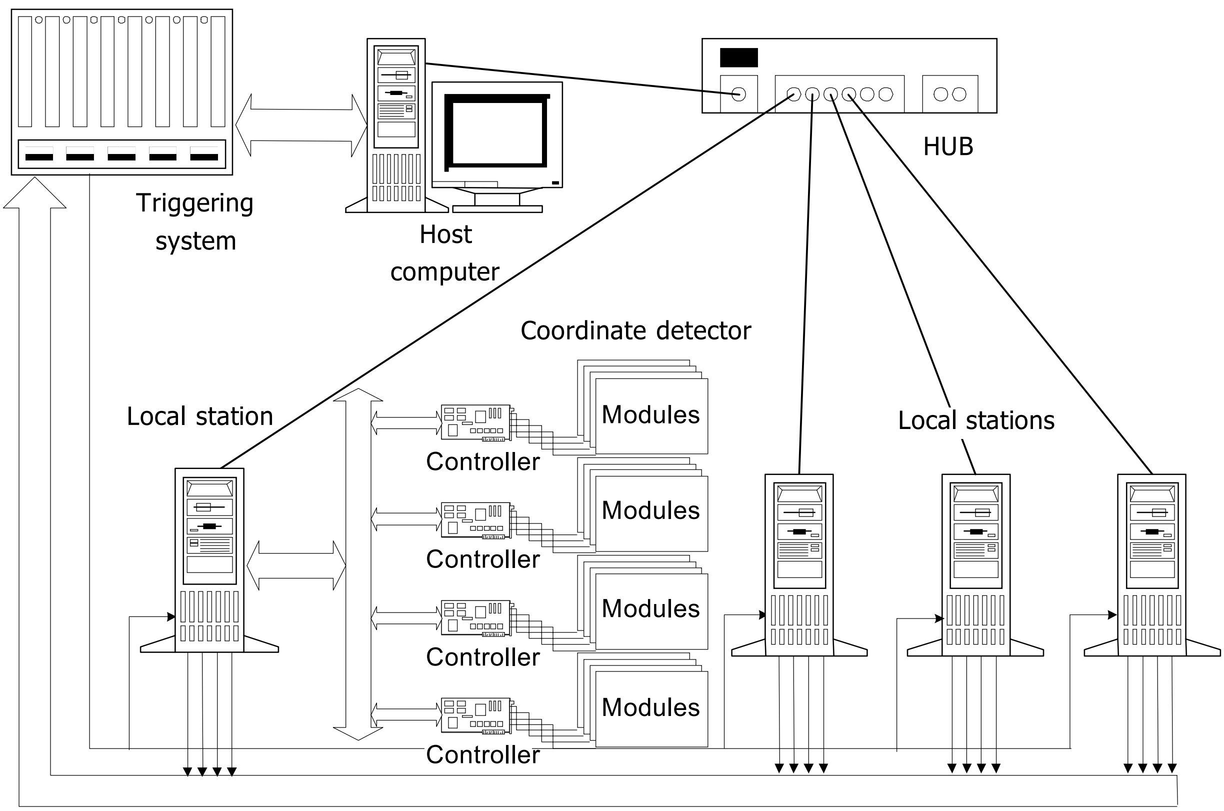

Fig. 2. Structure of DECOR data acquisition system.

The controller provides sequential data exchange with PC at a speed up to 1 Mbit/s in each channel. It comprises also 4-channel counter, 4-bit majority coincidence circuit for trigger decision, and 31-bit timer.

At the exposition mode, data acquisition is performed by the following algorithm. For events selected by trigger logic, data readout and transmission to a local computer for preliminary processing is provided by four controllers installed in it. Each local PC can work both as a part of a whole system and in autonomic regime. The further data transmission from the local station to the central computer is implemented by means of 10 Mbit/s "Ethernet" network. Periodically, by the command of the host computer, the local system is switched to self-test mode or to the mode of module pulse rate monitoring.

4 Triggering system

The triggering system of the coordinate detector has two levels, and is intended for effective registration both of multi-particle events and of single muons. The time resolution of the basic module is determined mainly by jitter conditioned by the drift of electrons inside the tubes to the anode wires (about 100 ns) and by the spread of propagation time of logical signals inside the modules (up to 30 ns). Correspondingly, typical pulse duration used for different coincidences in the trigger system is 0.2 - 0.3 μs.

The circuit of the first-level trigger formation is implemented inside the multi-functional peripheral controller. Condition of the generation of first-level trigger is the coincidence of at least two of four signals from odd or even planes of the supermodule within 300 ns, that with efficiency 97 % identifies a particle crossing SM. At vertical plane arrangement with area of 8.4 m^2, the first-level trigger rate is about 400 Hz.

General trigger signal is produced in the central trigger unit, which includes the following subsystems:

– receiver block which provides SM trigger formation (as a coincidence of first-level trigger signals from odd and even planes of a given supermodule);
– circuit ensuring SM trigger rate monitoring and "live" time counting;
– scanning RAM, in which SM trigger status is written with 40 MHz frequency;
– logical coincidence matrix which selects SM signal combinations corresponding to system trigger conditions set at the system initialisation;
– delay unit block, which provides the time adjustment of the signals that could be used for additional triggers (for example, outer signals from NEVOD).

All system trigger signals are combined (in logical OR) and are used for generation of the common GATE signal. The status of triggers is saved in a special register. The trigger system plate is designed in ISA bus standard and is installed in the DECOR host computer.

5 Experimental runs 2000

In 2000, methodical experimental runs on cosmic ray registration by the side coordinate detector both in an autonomic mode and together with Cherenkov water calorimeter NEVOD were conducted. The configuration of the Cherenkov detector included 27 quasispherical optical modules (Aynutdinov et al., 1995) hanged on 9 strings thus forming the rectangular spatial lattice with a step of 2 m in vertical direction and across the water tank, and 2.5 m along its axis.

The main tasks of these runs were: adjustment and tests of streamer chamber and readout electronics operation in conditions of real experiment; development and tests of the coordinate detector triggering system, check of its possibilities to select different classes of events (Figs.3-5).

Selection of events by coordinate detector triggering system is based on coincidences between signals from

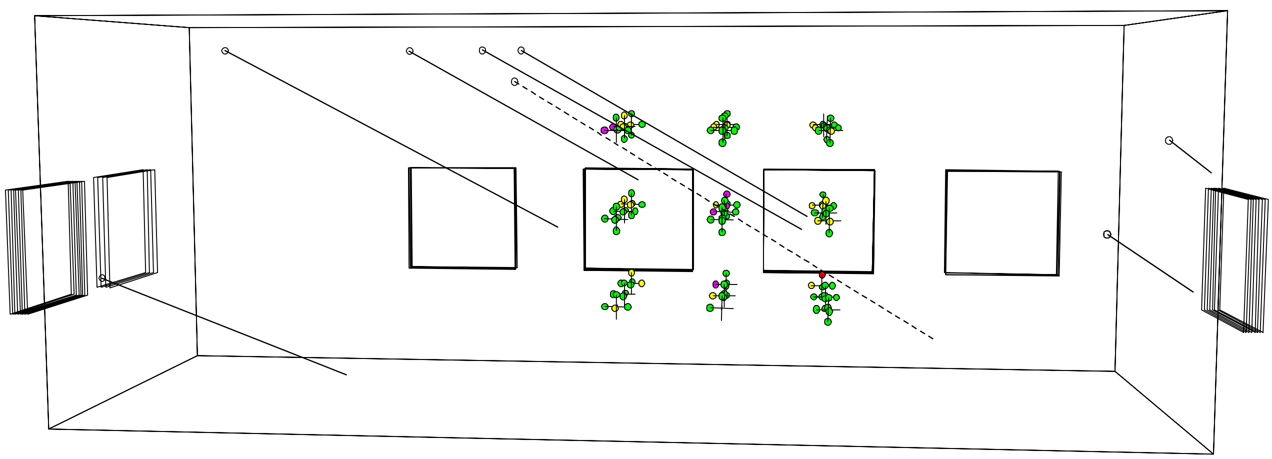

Fig. 3. Muon component of EAS ($\theta = 70°$). Here and in Figs. 4 and 5 solid lines and dashed ones represent tracks reconstructed by DECOR and NEVOD, correspondingly. The circles in the figures correspond to hit photomultipliers of the NEVOD modules.

separate supermodules, and also with signals formed in external electronics system of Cherenkov detector NEVOD. The side coordinate detector was partitioned into three groups: four supermodules located in a long gallery (group of supermodules LONG) and two pairs of supermodules located in two opposite short galleries (two groups SHORT). The following system triggers were used in the conducted experimental runs:
#1 - triggering of any SM of the coordinate detector;
#4 - coincidences between any SM installed in a long gallery with any SM of short galleries (LONG × SHORT). Muons, coming at large zenith angles within 16 different intervals of azimuth angle are selected with this trigger.
#5 and #6 - coincidences of supermodules located in opposite short galleries (SHORT × SHORT). Such events correspond to muons with maximum values of zenith angles ($\theta > 84°$), crossing all volume of the water detector.
#7 - coincidences of signals from any coordinate detector supermodule with NEVOD trigger (≥ 2 quasispherical modules of NEVOD detection system);
#8 - coincidences of any two or more SM (for multi-particle event selection).

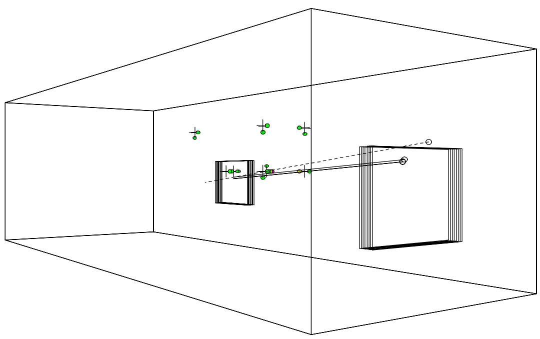

Fig. 4. Example of event selected by trigger #4 (LONG×SHORT), zenith angle $\theta = 88°$.

Results of muon track reconstruction on the basis of both coordinate detector and Cherenkov calorimeter data presented in Fig.3 - Fig.5. In multi-particle event presented in Fig.3, seven of eight supermodules of the side coordinate detector are hit.

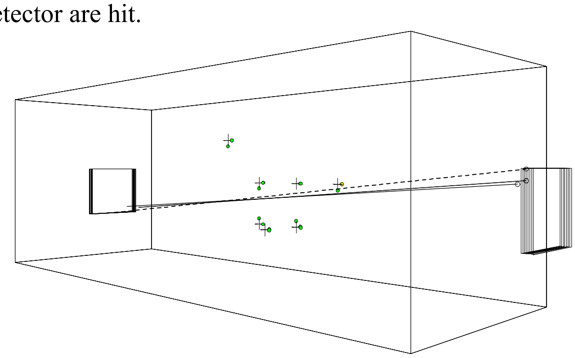

Fig. 5. Example of event selected by trigger #5 (SHORT×SHORT), zenith angle $\theta = 86°$.

The preliminary analysis of the data of methodical runs demonstrates that the side coordinate detectors works quite satisfactorily and sufficiently stable. The triggering system provides the detection of single muons at large zenith angles and of multi-particle events of different classes both in autonomic mode and in coincidence with water calorimeter. The experimental material is used for careful statistical analysis of the performance of both every module and all streamer chambers. These data will allow to check the operation of the trigger system with a purpose of further optimisation of trigger selection conditions for the experimental complex NEVOD-DECOR.

Conclusion

The side coordinate detector DECOR with high spatial (~ 1 cm) and angular (~ 1 degree) resolution intended for investigations of horizontal cosmic ray flux on the Earth's surface is deployed around the water Cherenkov detector NEVOD. Triggering system of the experimental complex for selection of events relevant to different classes of cosmic ray events is designed. The methodical experimental runs demonstrated reliability of operation of all systems of the side coordinate detector.

At present, the second part of the coordinate detector (TOP-DECOR, about 40 m^2), is assembled above the sensitive volume of the water calorimeter NEVOD. This detector is intended for carrying out the precision investigations of the spatial and angular distribution of vertical cosmic ray flux in the range 0° - 60°.

After that, the experimental complex NEVOD-DECOR will be used for conduction of investigations of basic components of cosmic rays at the ground level in the whole interval of zenith angles with the help of the described above technique.

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