Status of a development of the large scale coordinate-tracking setup based on the drift chambers

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Abstract. The large-scale coordinate detector for registration of near-horizontal muon flux of ultrahigh energy cosmic rays is being developed in MEPhI. Detector is based on the drift chambers from the neutrino experiment at the IHEP accelerator U-70, their key advantages are the large effective area (1.85 m²), good coordinate and angular resolution with small number of measuring channels. Detector will be operated as a part of the experimental complex NEVOD, in particular, jointly with Cherenkov water detector with volume of 2000 m³. The current status of the project and results of studies of drift chamber characteristics are discussed.

1. Introduction

The large-scale coordinate detector for registration of near-horizontal muon flux of ultrahigh energy cosmic rays is being developed in MEPhI [1]. The detector is based on the drift chambers from the neutrino experiment at the IHEP accelerator U-70 [2], their key advantages are the large effective area (1.85 m²), good coordinate and angular resolution with small number of measuring channels.

The project aims at solving the problem of the excess of muon bundles that increases with the energy of the primary cosmic rays [3, 4], what can be caused by both astro- or nuclear-physical reasons [5]. The only characteristic that responds differently to changes in the composition of cosmic rays and the inclusion of new physical processes, but has not been investigated to the present time, is the energy of the muon component of extensive air showers [6]. Such studies are performed at the experimental complex NEVOD-DECOR [7, 8]; however, the coordinate detector DECOR does not cover the entire aperture of the water Cherenkov detector and does not exclude the possibility of passing of part of muons between the individual supermodules of the detector; besides the size of its cells limits the possibility of separating two or more particles at small distances (less than 3 cm). The new detector TREK will completely cover the side aperture of the Cherenkov water detector NEVOD and significantly improve the resolution of close tracks.

The detector is based on the multiwire drift chambers. The chamber represents an aluminum box (figure 1) with ends limited by plexiglas plugs, to which wires, gas inlets and high voltage connectors are mounted. A uniform electric field is formed by field-forming wires with a pitch of 5 mm, the potential on them varies linearly from 0 to 12 kV. The drift chamber is filled with gas mixture of 94% Ar and 6% CO₂; at field strength of 480 V/cm electron drift velocity is constant (~ 41 mm/µs for the...
gas mixture) and allows to use linear time/coordinate relation. The drift chamber has four signal wires alternately shifted by ± 0.75 mm in the drift direction relative to the center of the chamber. Gas amplification is generated by potential difference of 2.2 kV between the signal and ten cathode wires arranged symmetrically at a distance of 3 mm from the center of the chamber. Two guard wires eliminate the edge effects.

With the passage of a charged particle through the working volume of the chamber drift times of electrons to the signal wires are registered; taking into account the drift velocity of electrons, these times allow to reconstruct the projection of the track on the plane perpendicular to the wires. Thus, for the reconstruction of tracks in space at least two non-parallel drift chambers are required. Spatial resolution of the chamber is 1 mm, the angular resolution is about 0.05 rad, two close tracks can be separated at a distance of 3 mm. Active area is 3.7x0.5 m$^2$ it constitutes 91% of the total surface.

The signals from the wires are processed by on-board amplifier-shaper that forms 50 to 100 ns signals (depending on the pulse amplitude) in the ECL levels.

Figure 1. Schematic view of drift chamber cross section: (a) in plane perpendicular to sense wires, 1 - guard wires; 2 - cathode wires; 3 sense wires; 4 - field shaping wires; (b) in the plane parallel to sense wires.

The detector TREK consists of a two coordinate planes of 132 drift chambers installed on the external wall of the building of the EC NEVOD in a special protective box. Planes differ by the orientation of the chambers: in one plane they are placed vertically, in the other horizontally. The area of the coordinate planes is about 260 m$^2$, the effective area is about 94% what is provided by the installation of chambers with overlapping of the insensitive areas at the ends. The passages with hanged floors are provided between the planes, allowing installation and maintenance of the chambers. The protective box will be equipped with its own entrance and a climate control system. High- and low-voltage power supply systems and readout electronics will be located inside the NEVOD building.

Currently the project of the protective box and the drift chambers deployment is under development. Figure 2 shows the appearance of the protective box.

2. Study of drift chamber characteristics

Drift chambers are made in the mid 80-ies, for more than a decade they were used in the neutrino experiment at IHEP and for the same time they were stored. So tests for their performance are crucial. For the chambers testing and certification before installation to the TREK, a universal stand was developed, it allows to study temporal, spatial and noise characteristics of the drift chambers.

The base of the stand is an adjustable frame construction with three horizontal levels. Two of them have the compensation of the horizontal deflection of the beams under the weight of the chambers that is extremely necessary to improve the measurement accuracy. At each level, 7+7 drift chambers can
be placed. On the levels with the compensation chambers are placed in two layers, differing in the orientation and forming a full XY coordinate plane.

![Figure 2. Appearance of the TREK protective box on the outer wall of the NEVOD building.](image)

The timestamp for drift chambers is provided by a pair of scintillation counters, one of which is installed at the upper frame level, and the second at its base. The area of each counter is 1 m$^2$, it is sufficient to work simultaneously with 8 drift chambers mounted on two adjustable levels (their width equals to 508 mm). The thickness of the scintillator is 1 cm, the light collection to PMT is performed using fibers. The signals from the counters are transferred to the coincidence circuit made on the basis of two shapers and logical "AND" in the VECTOR system.

The stand has its own system of gas supply, based on digital Bronkhorst flowmeters, managed from the computer. Chambers are connected to the gas flow pipes in 7 line rows, purging is performed about once a month, the pressure excess inside the chambers is kept to prevent ingress of oxygen (efficiency significantly decreases when the oxygen content is more than 0.5%).

Processing of the signals from the drift chambers is carried out by the 128 channel time-to-digital converter CAEN VME V1190A, which can be simultaneously connected to 32 drift chambers. Management of the TDC is performed from a computer connected via fiber to the crate controller CAEN VME V2718. A software was developed to work with the TDC, it allows to implement both manual and automatic measurements of the drift chamber characteristics, as well as performing the online visualization of the results.

Since the trigger signal from the coincidence circuit is produced earlier than the TDC receives signals from drift chambers it is delayed by a dual digital timer.

A four-channel oscilloscope Tektronix, triggered by the signal from the coincidence circuit, is used as a debug mode for reception of signals from separate chambers. Waveforms are transmitted via USB to the computer, where they are further processed. The computer control of the high voltage source was implemented to study drift chambers noise characteristics. The source has the control analog input to which a voltage is applied from the DAC controller. The controller operates via I2C bus emulated in the stand software. The first batch of 36 drift chambers has been checked for their performance on the stand to the date.
Among the temporal characteristics of the drift chamber, the main are the dependence of the number of registered signals on the drift time and the distributions of combinatorial parameters \( K_1 \) and \( K_2 \), the description of them is given below.

Figure 4 shows the distribution of events over drift time obtained during one experimental run. The maximum drift time lies in the range from 6 to 6.5 \( \mu \)s; dividing 250 mm wide drift gap on this value we can obtain the drift velocity of \( \sim 40 \) mm/\( \mu \)s. A large number of events near zero is caused by the noise, the fall after 5.5 \( \mu \)s corresponds to the decrease of the detection efficiency for such events. If the maximum drift time does not reach 5.5 \( \mu \)s or distribution falls from the outset, in most cases, this indicates a violation of the composition of the gas mixture, and the chamber requires additional sealing or a new gas mixture flush.

For any direct track, crossing the drift gap of the chambers, at 100% efficiency, we have 4 measures of the drift time: 
\[
t_i = x_i \cdot v^{-1}, \quad i = 1, 2, 3, 4 - \text{wire order numbers},
\]
where \( v \) – drift velocity of electrons. Using these periods of time for tracks that do not cross the signal wire zone in the center of the chamber, it is possible to construct linear combinations:
\[
K_1 = t_1 - t_2 - t_3 + t_4 = 0, \quad \text{(1)}
\]
\[
K_2 = t_1 - 3 \cdot t_2 + 3 \cdot t_3 - t_4 = \pm 8 \cdot \delta \cdot v^{-1}, \quad \text{(2)}
\]
where \( \delta = 0.75 \) mm is the offset of the wires relative to the center of the chamber. The distribution of these parameters is built for all measurements made by means of drift chambers, it clearly shows their performance.
In an ideal case the parameter $K_1$ is equal to zero, but due to Coulomb scattering of the electrons, the electronics jitter, etc., its actual value is different from zero. A typical distribution for the parameter $K_1$ is shown in figure 5 on the left. Assuming that the signal wires equivalent, temporal resolution (and taking into account the drift velocity of electrons and spatial resolution) of the signal wires can be obtained through the variance of $K_1$:

$$\sigma(t) = \sigma(K_1) \cdot 0.5.$$ (3)

The distribution in figure 5 corresponds to the temporal resolution of 28 ns, or the spatial resolution of 1.2 mm. Mean value and width of the distribution are controlled during drift chamber tests, it allows to reject a chambers with poor resolution.

The parameter $K_2$ corresponds to the drift time of electrons at a distance of 6 mm, but the most important is the sign of this parameter, it shows at which side from the center of a chamber was a particle track is. Figure 5 (right) shows a typical distribution for this parameter. The distributions at left and right sides from the zero are not equal in area; it means that the different number of particles has passed at different sides. This is not a defect of the chamber, usually it is connected with uneven installation of scintillation counters relative to the chamber, which is inevitable for simultaneous tests of 8 chambers.
2.2. Noise characteristics

The noise characteristics of the drift chamber are the main criteria of chamber performance in addition to requirements for necessary spatial and angular resolution. The noise characteristics are the dependence of the counting rate on the voltage on signal wires. The gas amplification is not sufficient at low voltage, so efficiency significantly decreases with increasing distance from the point of ionization to the signal wires; on the other side, too high voltage causes electron emission from the cathode wires that are orders of magnitude larger than the number of signals from real events.

Figure 6 shows typical noise characteristics, the presence of a plateau in the area of 2200-2250 V is the sign of a good chamber performance. The given chamber has a nice wide plateau from 2050 to 2250 V. The gas mixture degrades over time so the width of the plateau decreases.

![Noise characteristics of the drift chamber.](image)

This characteristics should be measured not only when checking drift chambers on the stand, but it should be included in the procedure of monitoring of the TREK operation, allowing to adjust the voltage of the signal wires and to increase the gas mixture flow with increasing noise or performance drop.

3. CTUDC setup

For the improvement of the capabilities of joint operation of the NEVOD-DECOR experimental complex and the drift chamber setup, a new CTUDC setup is developed as a prototype. The CTUDC setup absolutely replicates the drift chamber deployment, data acquisition electronics and the method of data connection with NEVOD-DECOR events from the TREK. All the occurred deficiencies will be considered in the TREK detector project.

The coordinate planes of the setup are placed around the CWD (figure 7), such location allows the registration of near horizontal tracks as by own CTUDC data so by joint data with DECOR, that will significantly increase the range of muon track zenith angles (from 6° to 12° from horizon).
At present, the first coordinate plane is installed, its appearance is shown in a figure 8. The plane consists of 8 drift chambers installed in two rows, overlapped by 30 cm to exclude dead zone in the chamber ends. The effective area of the plane is 14.8 m$^2$. A special frame which allows a fine alignment of drift chamber mount in all coordinates is developed. It is also possible to vary a chamber overlap and an angle between chambers by regulating a distance to the floor and the walls.

Figure 7. Location of the CTUDC coordinate planes relative to CWD and DECOR.

Figure 8. The coordinate plane of the CTUDC in a NEVOD building gallery.

Figure 9 shows a connection of the setup to the NEVOD-DECOR trigger system that sends a trigger signal to CTUDC time-to-digital converter. After signal comes, the CTUDC software puts an event to RAM and waits for a net package from the NEVOD server. The package keeps information on the event number, event time and some CWD and DECOR event characteristics.
The setup uses the 128-channel time-to-digital converter EM-4 developed in IHEP for E-MISS bus. The converter has 8 ns LSD and memory for 1000 32-bit words that is sufficient for the assigned task.

![Diagram](image)

**Figure 9.** A scheme of a joint operation of drift chamber setup and NEVOD-DECOR.

4. Conclusion
The large-scale coordinate-tracking detector based on the drift chambers from the neutrino experiment at the IHEP accelerator U-70 is being developed in NRNU MEPhI. Detector is aimed for registration of near-horizontal muon flux as a part of experimental complex NEVOD-DECOR.

Currently, a study of the characteristics of the first batch of drift chambers obtained from IHEP after a long-term storage is being performed. For this purpose, the test stand has been developed, it will allow flow testing of the chambers before their installation into the detector.

To study the detector TREK performance, its prototype CTUDC is developed, it has the same chambers alignment and method of connection to experimental complex NEVOD-DECOR.

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