

Status of muon hodoscope URAGAN

K.G. Kompaniets*, N.S. Barbashina*, D.V. Chernov*, A.N. Dmitrieva*, R.P. Kokoulin*,
G. Mannocchi[†], A.S. Mikhailenko*, A.A. Petrukhin*, O. Saavedra[‡], V.V. Shutenko*,
D.A. Timashkov*, G. Trincherio[†] and I.I. Yashin*

*Moscow Engineering Physics Institute, 115409, Moscow, Russia

[†]Istituto di Fisica dello Spazio Interplanetario, INAF, 10133, Torino, Italy

[‡]Dipartimento di Fisica Generale dell' Università di Torino, 10125, Torino, Italy

Abstract. The wide-aperture large-area multilayer muon hodoscope URAGAN is constructed in Scientific and Educational Centre NEVOD of the Moscow Engineering Physics Institute. The hodoscope is used for the study of heliospheric processes responsible for variations of muon flux at the Earth's surface. The structure of the detector and its system of data acquisition and processing are described. The data obtained during continuous experimental series in 2005-2008 by means of the first three supermodules of the setup are analyzed, and preliminary results of this analysis are discussed.

Keywords: cosmic ray variations, muon hodoscope

I. INTRODUCTION

The muon flux at the Earth's surface is formed by interactions of primary cosmic rays in the upper atmosphere. It carries information, on the one hand, about active processes in the interplanetary magnetic field, which modulate the flux of galactic and solar cosmic rays that reach the Earth and, on the other hand, about different atmospheric processes. Separation of the effects due to atmospheric processes and the processes in the near-Earth space is a rather complicated experimental task. It can be solved by simultaneously detecting muons from all directions of upper sky hemisphere in order to obtain the spatial and time characteristics of the muon flux. This information provides possibilities of separating the effects of the heliospheric and magnetospheric factors, which change the cosmic ray flux in wide spatial regions, and the effects of the atmospheric factors, which have a local character. For these purposes, a wide-aperture precision muon hodoscope URAGAN was constructed in MEPhI (Moscow). Since 2006, URAGAN is used for conduction of continuous measurements of muon flux variations, and in this paper the present status of experimental investigations by means of this muon hodoscope is described.

II. DESCRIPTION OF THE DETECTOR

The hodoscope consists of separate horizontal assemblies—supermodules—with the area of 11.5 m² each, located above the NEVOD Cherenkov detector [1]. Three supermodules of hodoscope are now under

operation in the exposure mode. Each supermodule consists of eight layers of streamer tube chambers equipped with a two-coordinate system of external readout strips. In every layer, there are 320 X channels and 288 Y channels with pitches of 1.0 and 1.2 cm, respectively. The layers are interleaved with 5 cm thick foam-plastic sheets. A limited streamer mode is maintained in the chambers by means of the three-component gas mixture (argon+CO₂+n-pentane) and proper selection of the operating voltage. The supermodule detects muons with a high spatial and angular accuracies (1 cm and 1°, respectively) over a wide range of zenith angles (0° – 80°).

The triggering and data acquisition systems of the hodoscope have a distributed multilevel architecture. The modular organization makes it possible to easily change the configuration and develop the system with the use of additional supermodules. The basic element of the data acquisition system of the hodoscope is a specially developed fast readout card, which provides amplification, discrimination, formation, storage of signals and serial data transfer from 16 strips. The trigger signal in a plane is formed by data acquisition cards at triggering of any X channel in this plane. The condition for triggering of the supermodule measurement system is the coincidence of no less than four trigger signals from different triggered planes during 300 ns (in this case, a muon crossing eight planes of streamer chambers is identified with 99% efficiency). The average counting rate of one supermodule is about 1700 events per second. The readout time from a supermodule is determined by the number of triggered cards and does not exceed 38 μs for 99% events. This readout speed, taking into account the triggering probability, makes it possible to detect each muon with a 90% probability. The instrumental tools of the measurement and trigger systems support the following operation modes:

- (1) Measurement of the counting rates of OR signals simultaneously from eight planes.
- (2) Testing of the circuits of shift registers and D-triggers of readout cards.
- (3) Operation in the cyclic exposure mode according to the following algorithm:
 - (i) expectation of an event with simultaneous mea-

- surement of the “live” time;
- (ii) triggering of an event and interruption in the computer;
- (iii) data acquisition from readout cards and their transfer through the direct memory access channel to the circular buffer of the computer at a rate of 5 MB/s.

The supermodule response contains information about triggered strips in each of the X and Y projections. The track parameters (two projection angles) are reconstructed in real time in each projection plane, and are accumulated in a two-dimensional array (θ_X, θ_Y) during a 1-min interval. The results of the data processing (1-min matrices containing about 8×10^4 events) are then recorded on the hard disc for further analysis and also transferred to the local net along with the monitoring data. A more detailed description of muon hodoscope URAGAN can be found in [2].

III. EXPERIMENTAL MEASUREMENTS IN 2005–2008

A few sets of adjustment measurements were performed with a pilot supermodule assembly in 2005 [3]. The main objectives of these experiments were to adjust and test the data acquisition and trigger systems and the software. Since April 7, 2006, two and since Feb 6, 2007, three supermodules of the setup were commissioned and used in a continuous exposure mode. Experimental data from the detectors constitute spatial-angular matrices covering the whole celestial hemisphere (at zenith angles from 0° to 80°). Although muon hodoscope detects and reconstructs muon tracks from any directions of the upper hemisphere forming a continuous zenith-azimuthal distribution, to provide a high statistics the muon matrix with dimensions 90×90 cells is used. These matrices are used to form time series of long duration, which help investigate dynamics of the muon flux. These are essentially 8100 time series characterizing the variations in the muon flux from the selected directions. Analyses of these time series were based on the wavelet transform [4] and the anisotropy vector of the muon flux [5].

The intensity of reconstructed events in two supermodules of the hodoscope and behavior of the atmospheric pressure are presented in Fig. 1. The well-known anticorrelation of these quantities is clearly seen. Using the pressure values and the counting rates in the periods of calm geomagnetic situation, one can determine the barometric coefficient. For the URAGAN supermodule, this value is 0.18 %/mbar. The upper curve in Fig. 1 presents the ratio of intensities of reconstructed events in the two supermodules. The deviation of this dependence from the constant value is <0.3 %, which confirms that the stability of the setup is sufficient for carrying out investigations of variations in the muon flux at the Earth’s surface.

Uninterrupted operation of muon hodoscope URAGAN continues already more than two years. In Fig. 2 (upper plot) variations of the average intensity of reconstructed

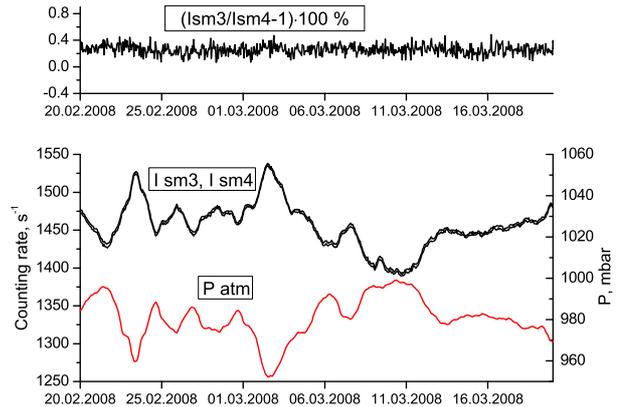


Fig. 1: The intensity of reconstructed events in the supermodules No3 and No4 of the hodoscope in Feb–Mar 2008 and the behavior of the atmospheric pressure. The ratio of the intensities of reconstructed events in the two supermodules is shown at the top.

tracks in three supermodules with one hour step corrected for changes in the atmospheric pressure I_{av} is presented. On the graph it is well visible a seasonal variation, caused by temperature effect in cosmic-ray muon flux. The value of intensities of reconstructed events averaged over URAGAN supermodules is about 1430 count/s, which corresponds to statistical error 0.03% for one-hour intervals.

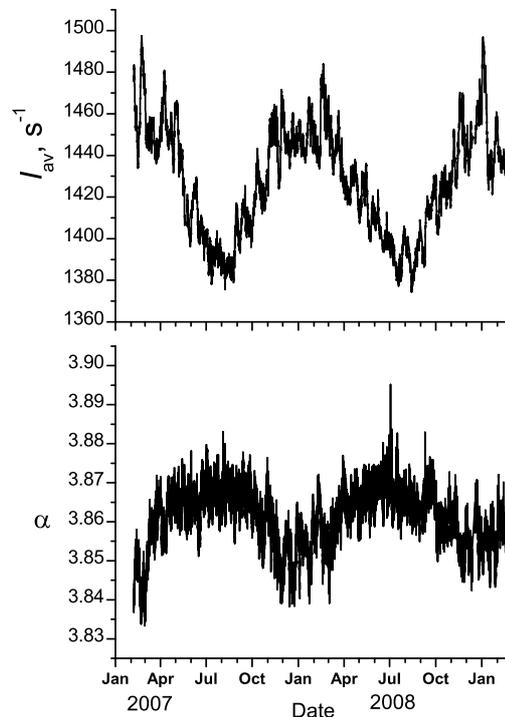


Fig. 2: The intensity of reconstructed events (upper plot) and the behavior of the parameter α (lower one) from Feb 2007 to Feb 2009.

The possibilities of muon hodoscope make it possible to measure the angular dependence of the muon flux every minute. The angular distribution of muons recorded by hodoscope may be approximated by the following

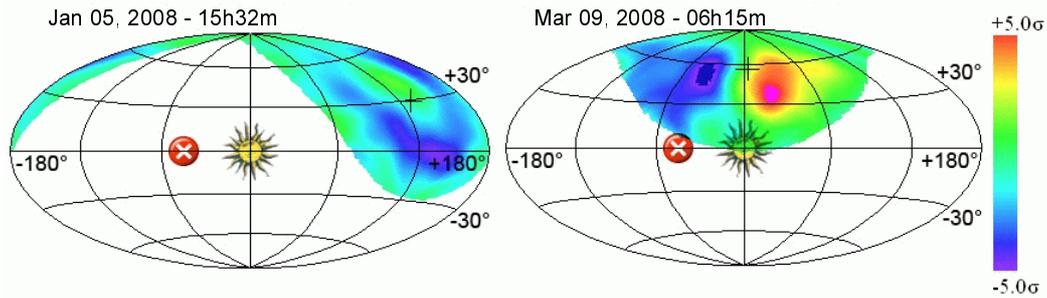


Fig. 3: Examples of GSE-images obtained during passing of corotated interaction regions near the Earth on January 5 (on the left) and on March 9 (on the right) in 2008.

formula: $I = \cos^\alpha \theta$, where θ is zenith angle, the value of α is approximately equal to 3.86 (this value includes the angular dependence of the muon flux on the Earth's surface, the decrease of the acceptance of installation with an increase in the zenith angle, the dependence of threshold energy on the angle). Fig. 2 (lower plot) depicts the behavior of the parameter α , whose changes testify about seasonal variations of the hardness of the angular and, therefore, energy dependence of the muon rate at the Earth's surface.

Significant statistical material for the analysis of different disturbances in heliosphere and Earth's atmosphere was accumulated during URAGAN operation. The registration of the muon flux in the hodoscopic regime opens the wide possibilities of conducting the muon survey of celestial hemisphere, and taking into account the asymptotic directions of the arrival of primary cosmic rays also of neighbor heliosphere in GSE system of coordinates (Fig. 3). During December 13, 2006 GLE event, for the first time the 2D-dynamics of muon flux formed in the atmosphere by energetic solar protons was measured in real-time mode by means of two URAGAN supermodules [6]. Analysis of URAGAN data during Forbush-effects allows to explore the dependence of muon flux decrease on various threshold energies and measure in "muon light" two-dimensional pictures of cosmic-ray deflection by interplanetary CMEs and shocks [7]. More than 15000 hourly muonographs are now accumulated, which make it possible to directly observe variations in the anisotropy of the flow of cosmic rays caused by various solar and heliospheric phenomena [8]-[14].

IV. CONCLUSIONS

Operation of a wide-aperture coordinate detector—a muon hodoscope URAGAN—with high spatial (~ 1 cm) and angular ($\sim 1^\circ$) resolutions and an area of 35 m² continues for more than two years. This setup allows the muon flux from the upper hemisphere to be continuously monitored simultaneously from thousands of directions at zenith angles of $< 80^\circ$. This hodoscope is a new type of ground-based cosmic-ray detector designed to study the relations between the space-time variations of the cosmic ray muon flux and different dynamic processes in the heliosphere, magnetosphere, and atmosphere of the Earth. Analysis of experimental data accumulated during the continuous measurements in 2006-2008 has demon-

strated significant correlations between the GLE events, the Forbush decreases, the magnetic storms, and the active atmospheric processes, on the one hand, and the variations in the muon fluxes measured by the URAGAN detector, on the other. Development of the URAGAN hodoscope offers a chance to attain a new qualitative level in investigating and monitoring processes in the Earth's atmosphere and near-Earth space, in particular those of a dangerous character.

The on-line information and history about intensities of reconstructed events in each of three URAGAN supermodules and one-hour matrix of muon arrival directions are presented at the web-site (<http://nevod.mephi.ru/English/graph.htm>).

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