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Large area scintillation muon hodoscope for monitoring of atmospheric and heliospheric processes

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Abstract. A new muon hodoscope for investigations of the processes in heliosphere and terrestrial atmosphere by means of cosmic ray muons is described. The setup design is based on multi-layer assemblies of narrow long scintillation strips with WLS fiber readout. Features of the hodoscope design are described and results of tests of a full-scale prototype of the basic unit of the hodoscope detection system – the module – are discussed.

1 Introduction

Muon diagnostics is a new and promising direction in the development of the world environmental observation system, based on penetrative ability of cosmic ray muons. Muon flux is formed in the lower stratosphere and is sensitive to the changes of main thermodynamic atmospheric parameters as well as to the processes in the heliosphere and the magnetosphere of the Earth related with the activity of the Sun (Barbashina et al., 2007; Timashkov et al., 2007). Variations of the muon flux at the Earth's surface caused by these reasons are the object of the study of muon diagnostics. Muon diagnostics technique is based on the simultaneous detection of muon flux from all directions of the celestial hemisphere in the hodoscopic mode. Such measurements give possibility to study the processes in the heliosphere and the Earth's atmosphere and magnetosphere and to follow their dynamics.

2 Hodoscope setup

For practical application of the methods of muon diagnostics, large area precise coordinate-tracking detectors – muon hodoscopes – are required. They must ensure continuous detection of cosmic ray muons from the celestial hemisphere in real-time mode. Possibilities of muon diagnostics were demonstrated by means of the first generation of the hodoscopes: scintillation muon hodoscope TEMP (MEPhI, Russia; Borog et al., 1995) and the eight-layer muon hodoscope URAGAN (MEPhI, Russia; Barbashina et al., 2008). The TEMP detection system consists of two two-coordinate planes mounted at 1 m distance from each other on a rotatable frame. The setup includes 512 narrow long scintillation strips (1 cm ×3 cm ×300 cm) with signal readout by separate photomultiplier tubes (PMT), and has 9 m^2 sensitive area and an angular resolution of about 2°. The hodoscope URAGAN is assembled on the basis of streamer tubes (1 cm^2 cross-section, 3.5 m length) with external two-coordinate data readout (about 20 000 channels) and has 46 m^2 total area and an angular resolution of better than 1°.

However, gas-discharge detectors (similar to URAGAN installation) are not optimal for muon diagnostics purposes since the efficiency of their operation depends on external meteorological parameters (temperature, pressure, humidity) which are the subjects of the study. Furthermore, for streamer tube operation a high-voltage power supply (4.5 kV), sophisticated gas preparation system and high-skilled personnel for the setup maintenance are required. The experience of operation of the first generation of such detectors allows us now to formulate main requirements to muon hodoscopes: sensitive area more than 40 m^2; angular resolution better than 2°; efficiency of muon track detection about 98%; modular approach for an easier construction; easy handling, maintenance and transportation. The optimal choice of the detecting system for such muon hodoscope is a multi-channel scintillation detector with wavelength shifting (WLS) optical fiber light collection. This experimental technique is widely used for the construction of new generation of large area coordinate-tracking detectors in particle physics (e.g. Michael, 2002; Adam et al., 2007).

A new scintillation muon hodoscope (ScMH), being con-

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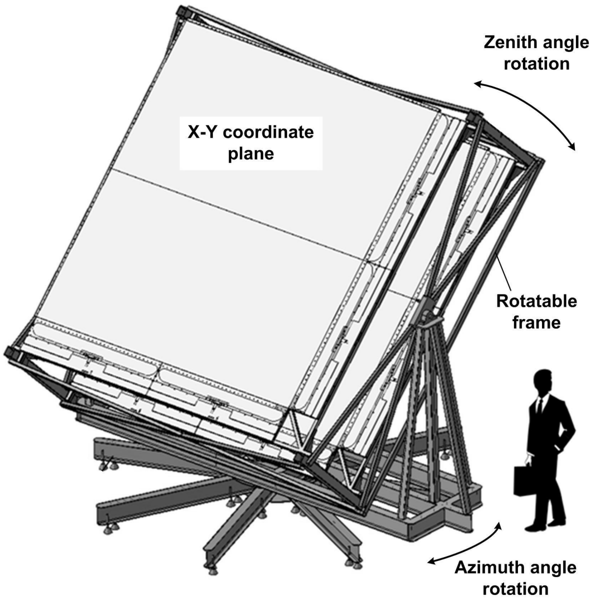

Fig. 1. Model of a wide-aperture rotatable scintillation hodoscope.

structed now in MEPhI, has a modular structure and is composed of identical units – basic modules (BM). The module is composed of 64 strips read out by means of WLS fibers coupled to one 64-pixel multi-anode photodetector (H7546 PMT). The choice of the detection element of the hodoscope (scintillation strip – WLS fiber – 64-pixel PMT) provides possibility to use a single PMT for simultaneous detection and processing of signals from 64 readout channels of the BM. Moreover, the use of WLS fibers allows us to reduce requirements to the transparency of scintillation strips. All elements of the module are contained in a single housing which has a simple construction and ensures reliable light insulation. Two such modules constitute the detection layer with $3.5 \times 3.5\,\mathrm{m}^2$ sensitive area. Two layers of modules with orthogonally oriented strips form the coordinate plane that provides XY coordinate information. Two planes mounted on a common frame form the multi-channel muon hodoscope (see Fig. 1) which contains eight 64-strip basic modules (512 detection channels). The distance of 1 m between the planes provides angular accuracy of track reconstruction of about 1.5° (for muon incidence orthogonal to the plane of the module).

Each detection channel of the hodoscope represents a narrow long scintillation strip (10.6 mm ×26.3 mm ×3460 mm size; polystyrene with 2% p-terphenyl and 0.02% POPOP; Amcrys-H[1]). To improve the light collection, a diffuse reflective compound of polystyrene and TiO_2 coextruded with the scintillator surface is used. At the middle of each strip a groove (2 mm deep, 1.6 mm wide) is made for WLS fiber (Y11-175 1 mm, Kuraray Co., Ltd.[2]) pasted with high-transparency glue BC-600 (Saint-Gobain Crystals[3]). The end of the fiber of every strip is positioned in front of the corresponding pixel of a 64-anode H7546 PMT (Hamamatsu Photonics K.K.[4]) by means of an optical connector. At passage of a charged relativistic particle through the strip a scintillation flash is formed, where a part of the primary flash photons enter into the WLS fiber, are re-emitted in the green part of the spectrum and reach the PMT. On the surface of each strip above the groove a silvered polyamide scotch (3M[5]) is glued in order to decrease the loss of photons. The PMT H7546 has a very compact geometry ($3 \times 3 \times 7\,\mathrm{cm}^3$ including the resistor divider and connectors) with a matrix of 8×8 pixels. The average gain of the PMT at 800 V voltage is about 10^6. This provides the efficient detection of single photoelectron signals. The channel-to-channel gain difference is compensated by readout electronics which allows us to adjust the amplification for each channel. As a whole, the basic module represents a "sandwich-type" structure with elements fixed by means of a double face adhesive film between two aluminum sheets (3460 mm ×1689 mm ×0.8 mm) and unites 64 strips with one photodetector. PMT and front-end electronics box are located near the optical coupling area.

3 Readout electronics

The block-diagram of the electronic system of the hodoscope is shown in Fig. 2. The 64-channel ASIC (CNRS-IN2P3, Omega design centre[6]) is the basis of the readout electronics of BM; it receives signals from all anodes of the PMT. Each channel includes an adjustable gain preamplifier to compensate the spread of PMT gains (which may differ about a factor of three), a charge-sensitive amplifier and an adjustable threshold comparator. This ASIC also has a multiplexed analog output. Shaped signals are sent to the programmable logical chip (FPGA) which provides formation of the first-level trigger. When at least one of the ASIC channels produces a signal, the FPGA sends a trigger signal – OR(64) – to the central trigger block and data acquisition system (DAQ and Trig. Controller FPGA). When OR signals from two coordinate layers are received within a certain time gate, the external trigger system generates the storage signal (Hold) and returns it to all FPGAs of basic modules. In this case, data from all hit channels are read by the DAQ system. All detected events are reconstructed, analyzed and, if necessary, recorded in a real-time mode. The adjustment of 64-channel amplifier-shaper-comparator chip settings is performed by

[1] Amcrys-H, Scientific and Technical Concern "Institute for Single Crystals": http://www.amcrys-h.com/

[2] http://www.kuraray.co.jp/en/

[3] Saint-Gobain Ceramics & Plastics, Inc.: http://www.detectors.saint-gobain.com/

[4] http://jp.hamamatsu.com/en/

[5] http://www.3m.com/

[6] CNRS-IN2P3 microelectronics design centre – Omega: http://omega.in2p3.fr/

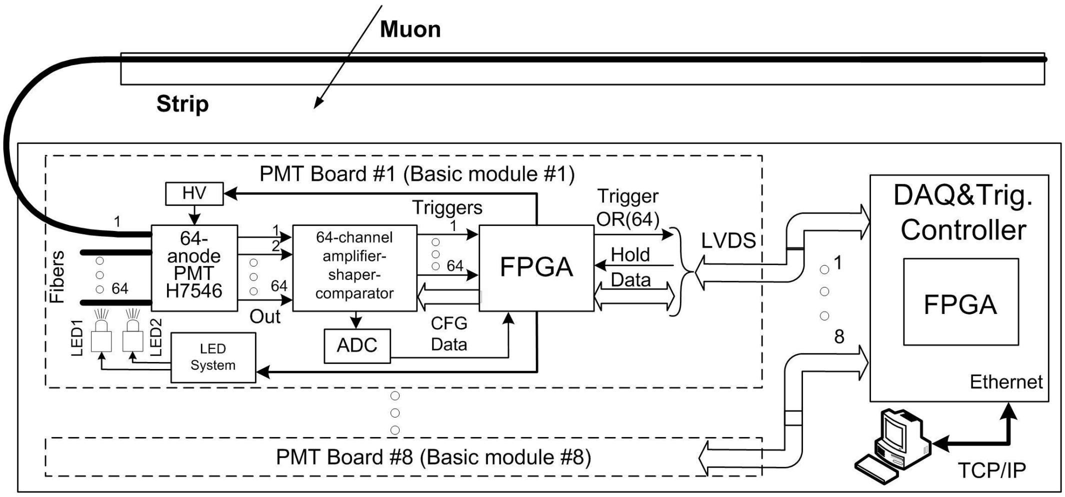

Fig. 2. General block-diagram of the hodoscope electronics.

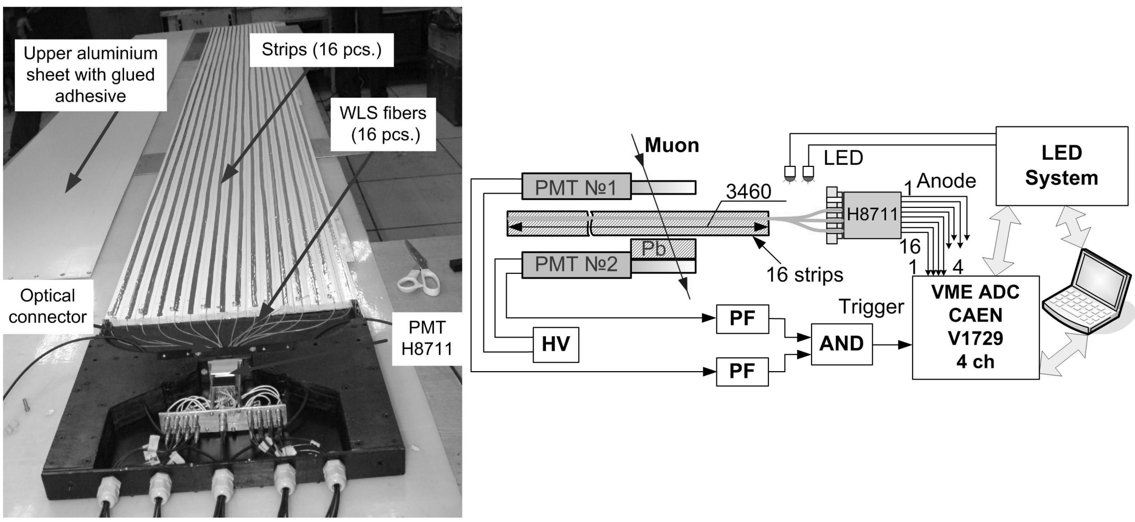

Fig. 3. Assembled basic module prototype (without the upper sheet, left) and general block-diagram of prototype test system and electronics (right).

means of the FPGA. In order to check the linearity range of the spectrometric channels and for PMT calibration, a LED system is used. The two-channel LED system (Aynutdinov et al., 2003) consists of a controller and two LED drivers which provide necessary duration and adjustable intensity of light flashes. The LED drivers are located in the fiber coupling area. The adjustment of the LED controller operation parameters is also provided by the FPGA.

4 Basic module prototype

For design optimization, development of data acquisition procedures, and full-scale strip yield study, a prototype of the basic module was constructed. It includes 16 strips and one 16-anode Hamamatsu PMT H8711 for readout. The end-cap of the basic module prototype represents a thin box which is divided into two parts: a fiber coupling area and a front-end electronics area. The registering electronics is located outside this prototype. The assembled prototype (without the upper aluminum sheet) is shown in Fig. 3 (left).

The prototype was tested by means of a special facility equipped with a LED system and a calibration telescope system which consisted of two scintillation counters (200 mm $\times$100 mm $\times$ 20 mm) with FEU-85 PMT readout (see Fig. 3, right). Signals of the H8711 PMT were analyzed with a 4-channel digital oscilloscope CAEN VME V1729. The gain of each channel of the PMT was estimated from the output pulse charge spectra, obtained in a single photoelectron (p.e.) mode by means of LED flashers with the requirement of about 10% detection efficiency at

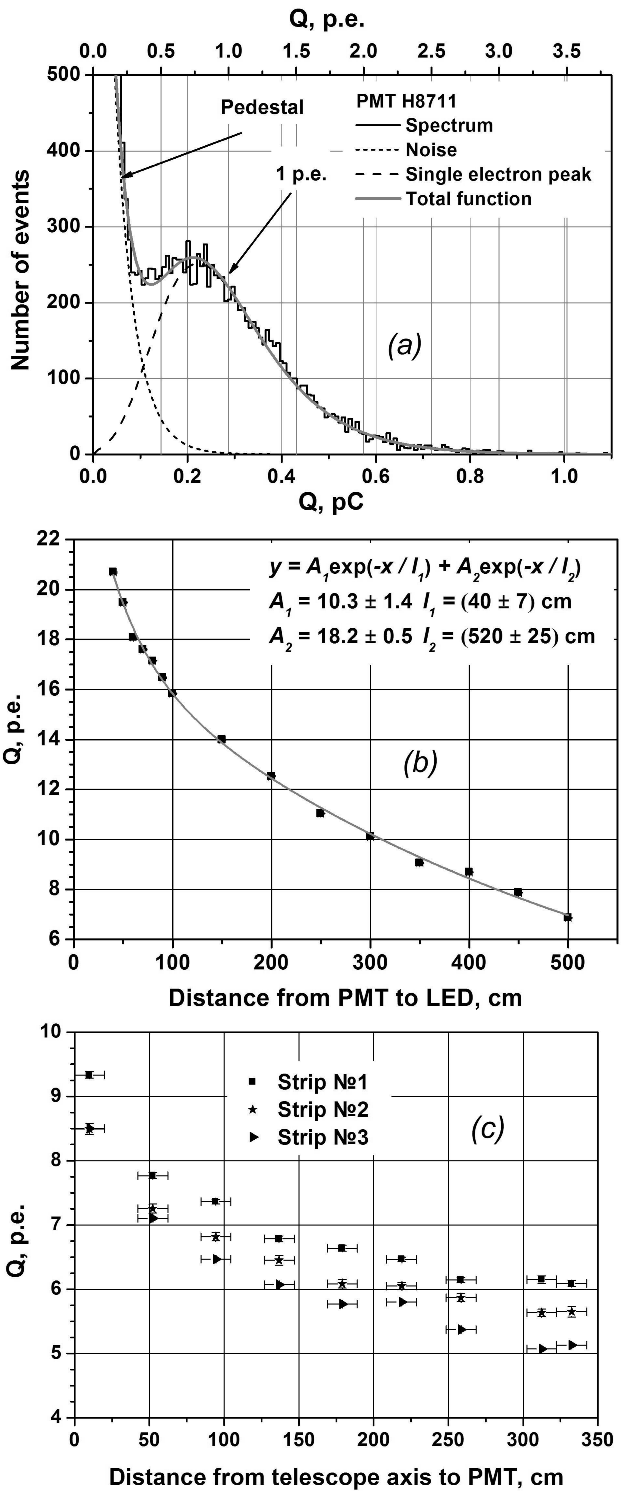

Fig. 4. Results of basic module prototype tests: **(a)** single photoelectron spectra for one of the channels of the H8711 PMT; **(b)** dependence of the light yield on the LED position for WLS fiber; **(c)** dependences of the light yield on the distance between muon calibration telescope axis and PMT for three strip samples.

1/3 p.e. threshold (Fig. 4**(a)**). The average gain of 16 channels is $< M > = 1.9 \times 10^6$, and the end of the linearity range is about 60 p.e. The attenuation length in the optical fiber was estimated from the dependence of the PMT response on the distance to the position of the blue LED illuminating the WLS fiber (Fig. 4**(b)**). The measured attenuation length is 520 ± 25 cm. For investigation of the strip yield at muon detection, the calibration telescope was used. The light yield is always above 4 p.e., even for hits at the far end of the strip (Fig. 4**(c)**). It corresponds to the single muon detection efficiency of more than 98% at 1/3 p.e. threshold.

5 Conclusions

For the development of experimental methods of muon diagnostics of heliospheric and atmospheric processes, the new muon hodoscope with fiber optic light collection has been designed. The prototype of the basic module of the hodoscope has been constructed and tested. The results of the study of the prototype characteristics demonstrate that the used technique and the designed apparatus provide necessary efficiency of single muon detection in the hodoscopic mode.

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References

Adam, T., Baussan, E., Borer, K. et al.: The OPERA experiment Target Tracker, Nucl. Instr. Meth. A, 577, 523–539, 2007.

Aynutdinov, V. M., Bonifazi, C. B., Creusot, A. et al.: The Pierre Auger surface detector LED flashers and their use for monitoring and calibration, in: Proc. 28th ICRC, Tsukuba, Japan, 31 July – 7 August 2003, 2, 825–828, 2003.

Barbashina, N. S., Borog, V. V., Dmitrieva, A. N. et al.: Muon diagnostics of the Earth's atmosphere and magnetosphere, Bull. Rus. Acad. Sci., Phys., 71, 1041–1043, 2007.

Barbashina, N. S., Kokoulin, R. P., Kompaniets, K. G. et al.: The URAGAN wide-aperture large-area muon hodoscope, Instrum. Exp. Tech., 51, 180–186, 2008.

Borog, V. V., Burinskij, A. Y., Gvozdev, A. V. et al.: Large aperture muon hodoscope for studies in solar-terrestrial physics, in: Proc. 24th ICRC, Roma, Italy, 28 August – 8 September 1995, 4, 1291–1294, 1995.

Michael, D.: The MINOS experiment, Prog. Part. Nucl. Phys., 48, 99–109, 2002.

Timashkov, D. A., Barbashina, N. S., Borog, V. V. et al.: Muon diagnostics of the Earth's atmosphere, near-terrestrial space and heliosphere: first results and perspectives, in: Proc. 30th ICRC, Merida, Mexico, 3–11 July 2007, 1, 685–688, 2007.