NRC "Kurchatov Institute" – IHEP(Protvino)

Development of 10 m² hodoscope made of drift tubes for cosmic ray muon registration

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Introduction

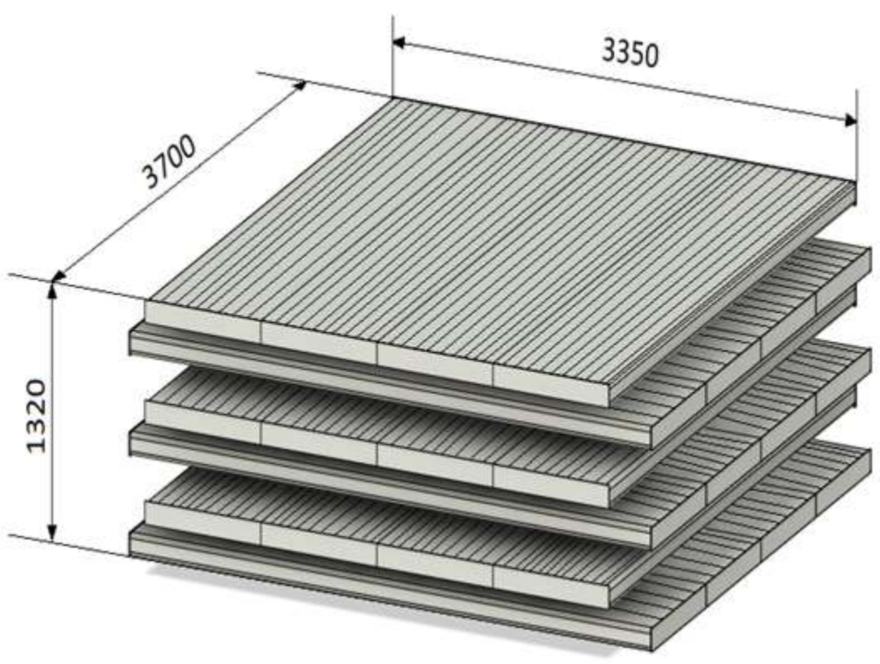


Fig. 1. Sketch and dimensions of the hodoscope

Muon hodoscopes consisting of large-area track detectors are used for muonography of large-scale industrial, geological, historical objects, such as nuclear reactors, blast furnaces, volcanoes, Egyptian pyramids etc. [1]. A widely used type of large track detectors for operation in relatively low-intensity beams are drift chambers composed of separate drift tubes (DTs) of long length. For example, the ATLAS detector at the Large Hadron Collider at CERN contains drift chambers with a sensitive area of up to 10 square meters consisting of DTs with a diameter of 30 mm and a length of up to 6.3 m [2]. Given that the cosmic ray flux is not so intensive, it is quite reasonable, for its registration, to increase significantly the diameter of the tube in order to minimize the number of registration channels per unit area and, accordingly, the cost of the detector.

As a working gas for the DT operation, a cheap 93% Ar + 7% CO_2 gas mixture at small (few tenths of bar) overpressure can be used. As shown in [3], in case the tubes are tight enough and their drift velocity is properly controlled, they can operate without continuous flashing of gas mixture; once filled they can work one year or even more, without efficiency and spatial resolution degradation.

The development and construction of a muon hodoscope with a sensitive area of 10 sq.m, made of DTs of 52 mm diameter and a length of 3.7 m arranged into 12 DT planes (6 + 6 planes with orthogonal orientation of tubes), able to work in a triggerless mode [4] for a long time without working gas refreshing, equipped with specialized on-chamber electronics, is a purpose of this work. The sketch and dimensions of the hodoscope are shown in Fig. 1.

Drift tubes

To create the hodoscope, it was decided to use, having previously upgraded, DTs (Fig.2) dismantled from the muon spectrometer [5] of the "Tagged Neutrino Facility" operated in NRC "Kurchatov Institute" – IHEP about 35 years ago. The body of the DT is aluminum cylinder of 52 mm outer diameter with wall thickness 0.8 mm; its inner surface serves as a cathode. An anode is a tungsten gold plated 50 mkm wire stretched with ~250 grams tension between two endplugs and fixed by soldering in their central brass pins with precision of ~ 1 mm with respect to the endplug centers. The endplug consists of two plexiglass parts – a body and a cap. DT tightness is ensured by 2 mm rubber o-ring clamped between these two endplug parts with screws. Pumping of working gas is carried out through 3 mm inner diameter brass tube pressed and sealed with sealant to the endplug body.

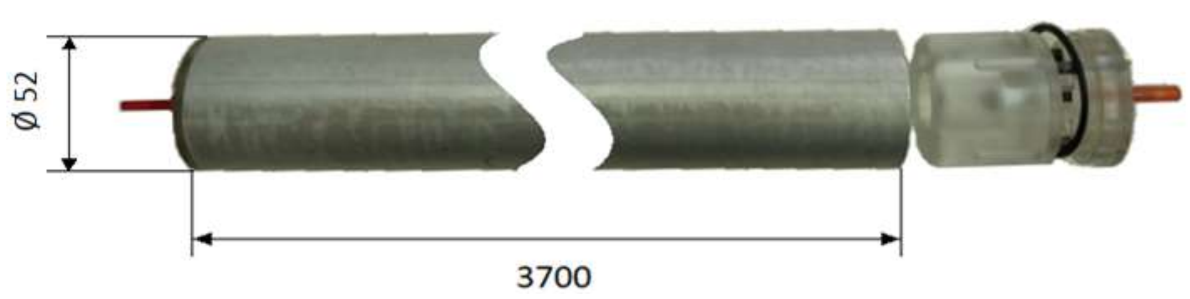
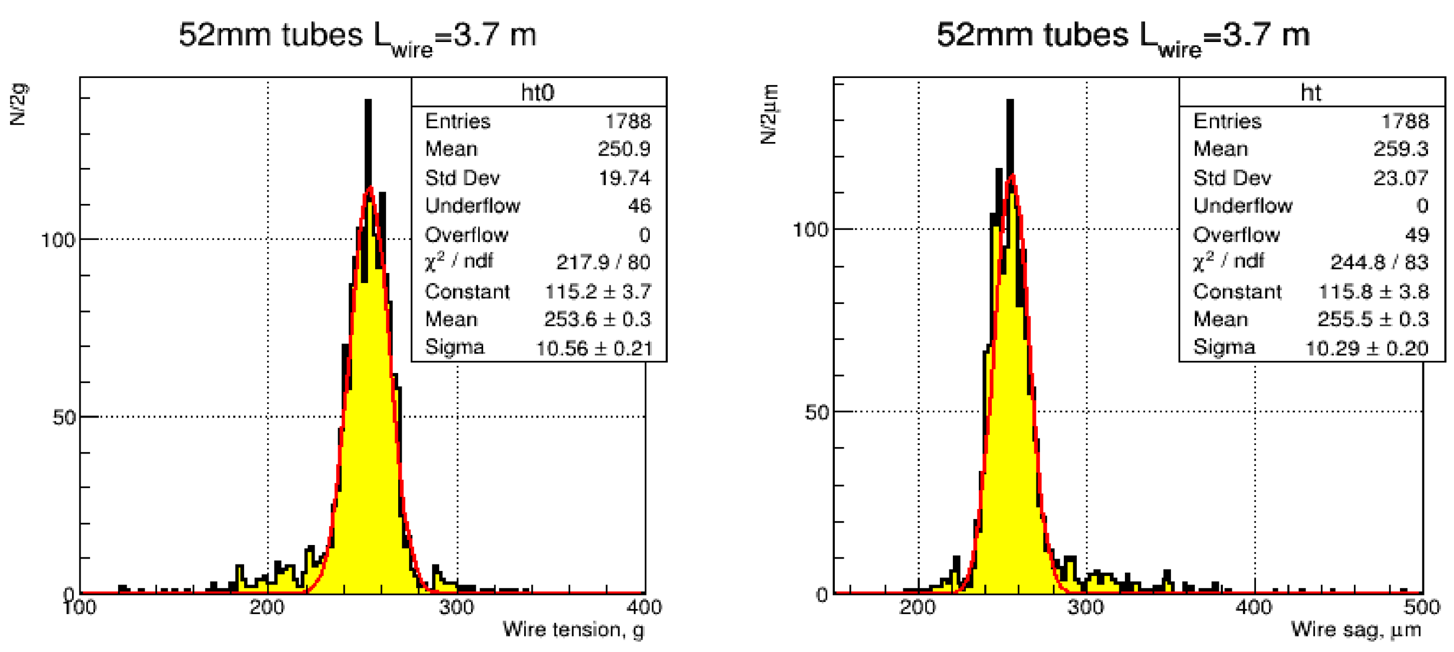


Fig. 2. Drift tube

As a result of old age, most of the DTs lost their tightness, therefore we have replaced o-rings in all DTs to be used for hodoscope construction. Then actual tightness was evaluated by measuring of pressure drop rate of the group of tubes or, if necessary, of the individual tube pumped with ~0.5 bar overpressure. We have established the allowed gas leak rate to be less than 2 mbar/day, in order to ensure a possibility of at least one year working without gas refreshing [3]. Of course, the traditional system of continuous gas mixture blowing can also be used.

Some DTs had a weakening of the wire tension and even wire breaks. We have measured actual tensions of wires with indirect method - by measuring the frequency of their resonant vibrations [6]. The wire tension and calculated wire sag distributions for 1788 DTs are shown in Fig. 3. The broken and weakened (up to less than 90 grams) wires were replaced with new ones.



(a) (b)

Fig. 3. Wire tension (a) and sag (b) distributions

Mechanical design of the hodoscope

The hodoscope is made up of modules, each consisting of 32 DTs (Fig. 4). The DTs of the module are glued together being arranged in two layers, 16 DTs in each, according to the "dense packing method", so the DTs of the second layer are shifted with respect to the DTs of the first layer for the tube radius. The layer's mechanical rigidity is provided by six aluminum plates (three in the module top and three in the bottom) glued to the DTs. These plates serve also for precise mechanical coupling of four adjacent modules forming the hodoscope X- or Y- multilayer depending on tube orientation. The described design provides ~1 mm precision of DT location in the multilayer.

Fig. 4. Module of 32 DTs, view from two ends

There are three X- and three У- multilayers alternating with each other; this means that hodoscope has totally 12 DT planes. For filling or continuous blowing with Ar-CO2 (93-7) gas mixture all the DTs of the multilayer are connected in series by means of flexible pipes. On the one end of each module, there is an auxiliary fiberglass plate (Fig. 4, b) designed for the installation on it the high and low voltage connectors and distributing conductors, on-chamber electronics and their Faraday cages, passive electronic components, gas supply connectors etc. Both ends of the module are protected from mechanical damage by protective shields made of aluminum.

The hodoscope will be placed in a rigid frame, equipped with adjusting screws providing the possibility of mutual alignment of multilayers in all directions with 1 mm accuracy. It results, together with mentioned above precision of wire location and sag, and 0.5 mm precision due to diffusion in gas and r-t relation [5], that the spatial resolution of the hodoscope is expected to be as good as 2.5 – 3.0 mm, angle resolution ~ 3 mrad.

On-chamber and DAQ electronics

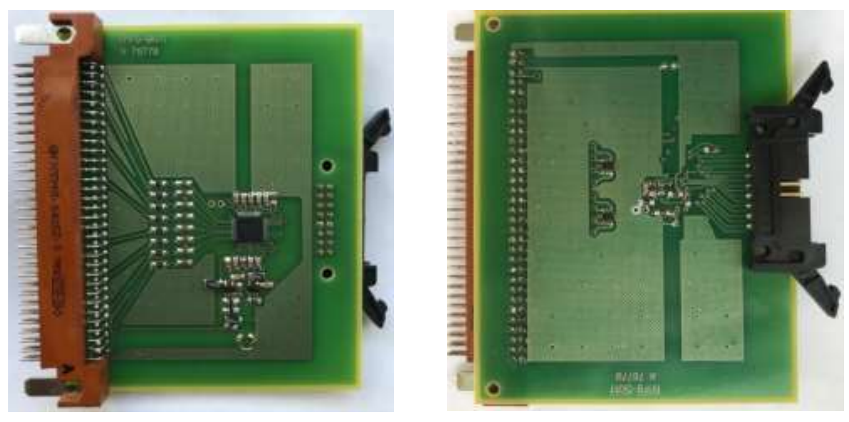


Fig. 5. Photo of the 8-channel amplifier, view from two sides

The signals read out of the DTs are amplified by an 8-channel amplifier (Fig. 5) based on an OKA-2 integrated circuit designed using the superhigh-frequency low-noise Bi-jFET technology, which allows production of n-p-n transistors with a threshold frequency of >3 GHz and current gain of > 150. The chips are produced in QFP48 plastic package.

The OKA-2 integrated circuit includes 8 channels of charge-sensitive amplifiers-shapers-discriminators. The processing of a signal consists in converting a short current pulse into a voltage and recording the signal exceeding the predetermined threshold. The output signals correspond to the LVDS standard.

The threshold sensitivity of the channels (all 8 channels at once) to the input signal is adjustable in the voltage range 100 – 500 mV. The sensitivity of the amplifier is varied from 0.2 to 1.3 mkA. At a threshold voltage of 150 – 160 mV, the amplifier sensitivity is set at ~ 1 mkA.

NAK-96 boards [7] (Fig.6) are to be used as time-to-digital conversion devices, as well as an interfaces to a computer. Up to 96 signals from the DT amplifiers in the LVDS levels are fed to 12 connectors of the NAK-96 board (each connector receives signals from 8 amplifiers). Signals from some channels can be masked if necessary. Processing of received signals is performed in a hardware processor implemented in FPGA ALTERA type EP3C16Q240C8 (ALTERA manufacturer, Cyclone III). Intermediate data accumulation is carried out in the internal memory of 16 kB. The conversion and reading processes, as well as the configuration of the system from several boards, are controlled via a USB channel.

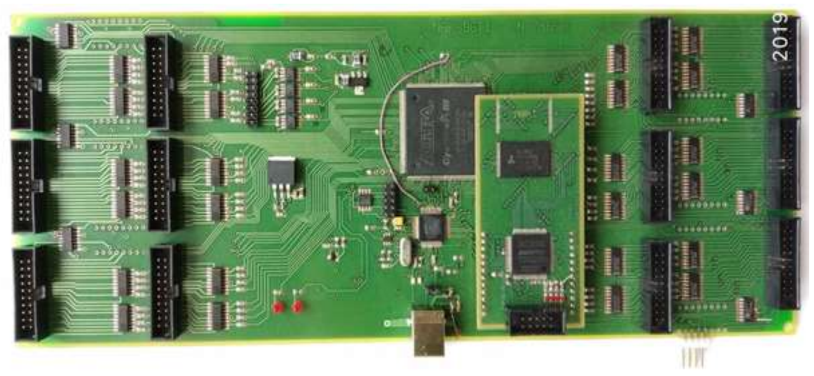


Fig. 6. Photo of the NAK-96 board

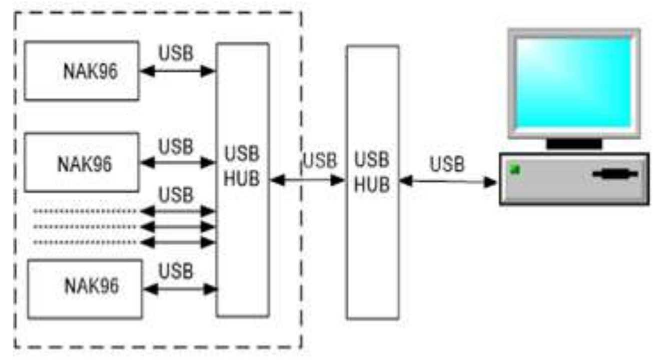


Fig. 7. Data flow diagram

Recording of signal arrival times from amplifiers occurs continuously during the recording interval (up to 27 ms set during initialization) with a resolution time of 1.66 ns (2.5 ns or 5 ns is set when configuring the FPGA). The dead time of registration in the registration channel should depend on the maximal drift time (2.2 µs for described DTs). It is set when configuring the FPGA. The measurement of times is performed by 24-bit counters with time verniers.

To perform operations on setting the necessary parameters of the board, control the correctness of the entered parameters, and also read data from the FPGA's internal memory, an FPGA-USB bridge built on the FT2232 IC (Future Devices) and some FPGA resources are used. The bridge provides USB 2.0 mode and 480 Mbps speed.

One of the boards in the system is MASTER, others are SLAVES (determined at initialization).

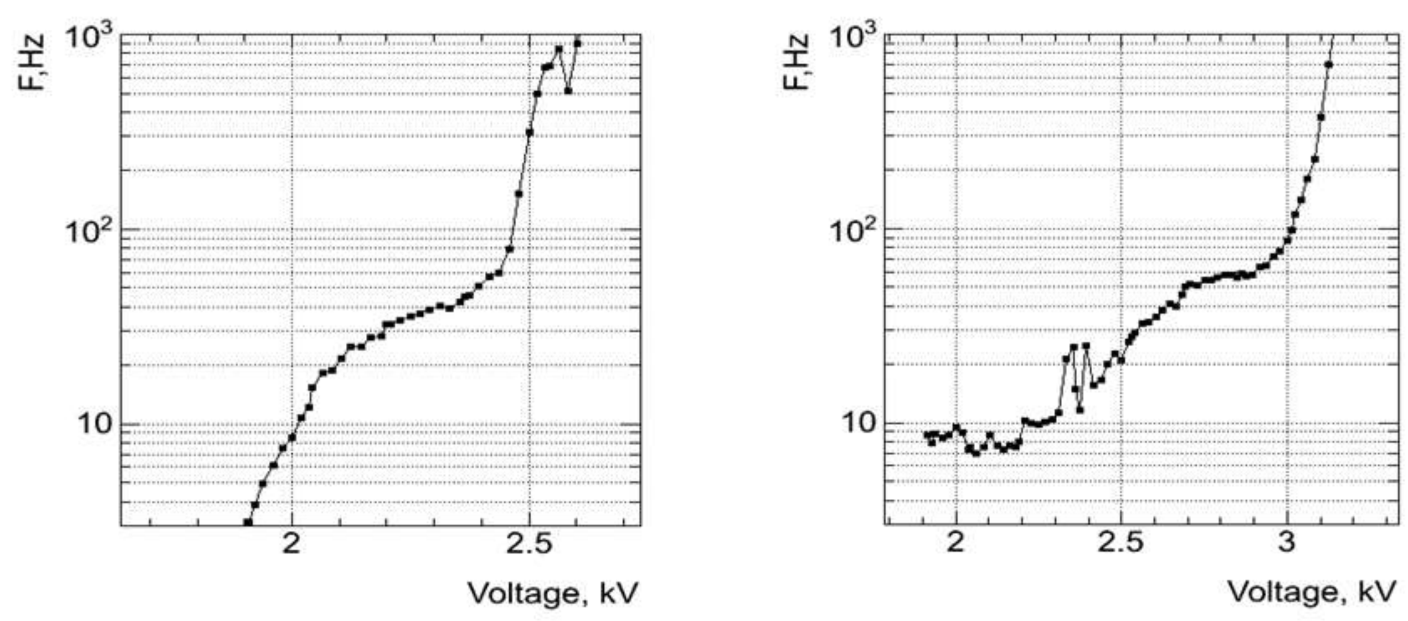
The board is powered with +5 V with consumption below 1 A.

As there are 4 DT modules in each multilayer, we find optimal that one NAK-96 board serves 2 modules. It means that totally 12 NAK-96 boards will be used in the hodoscope.

Data flow diagram with use of NAK-96 boards is shown on Fig. 7.

Drift tube tests

Working ability of the 52 mm DTs with 93% Ar + 7% CO_2 gas mixture at normal and increased (1.8 bar) pressure was proved using electronics described in [4]. Tubes 1 m long were used for the tests. Dependences of the counting rate on high voltage applied to the anode wire are shown on Fig. 8. The working range is 2.2 – 2.4 kV at normal gas pressure, 2.7 – 2.9 kV at 1.8 bar. Typical TDC spectrum is shown on Fig. 9. Maximal drift time is about of 2.2 mks.



(a) (b)

Fig. 8. Counting rate vs high voltage at normal (a) and 1.8 bar gas pressure (b)

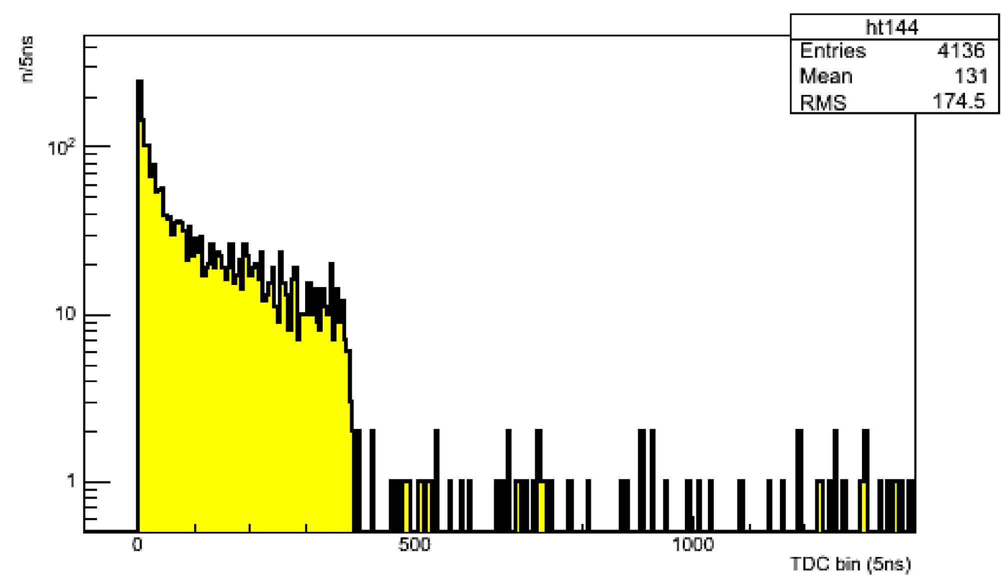


Fig. 9. TDC spectrum at 1.8 bar gas pressure

Conclusions

1. A10 sq.m muon hodoscope made of 52 mm diameter DTs arranged into 12 DT planes has been developed and now is under construction.
2. All 768 DTs composing the hodoscope have passed quality control tests. Allowed gas leak is below 2 mbar/day.
3. On-chamber and DAQ electronics prototypes have been manufactured.
4. Tests of 1 m DTs have been performed with 93% Ar + 7% CO_2 gas mixture. The working range is 2.2 – 2.4 kV at normal gas pressure, 2.7 – 2.9 kV at 1.8 bar.
5. Spatial resolution of the hodoscope is expected to be as good as 2.5 – 3.0 mm, angle resolution ~ 3 mrad.

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