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PORTABLE MUON TELESCOPE FOR COSMIC RAY MONITORING

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Abstract. A portable muon telescope for monitoring of cosmic rays has been developed, based on GM counters shielded with lead adsorbers. The triple coincidence mode of operation results in a relatively good spatial resolution allowing to measure the cosmic ray flux, its east-west anomaly and also to detect the consequences of the special theory of relativity. The apparatus is suitable for long term observations of the cosmic ray flux and due to its simple and robust construction can also be used also for educational purposes.

Key words: muon telescope, cosmic rays, monitoring.

INTRODUCTION

Cosmic rays have a strong influence on interplanetary space and Earth's atmosphere. New research shows that global climate change, such as the end of the last Ice Age, has been linked to a sharp increase in cosmic ray intensity. The cosmic rays stimulate cloud formation and are responsible for the generation of radioisotopes in the upper atmosphere (^{3}H, ^{7}Be, ^{10}Be, ^{11}C, ^{14}C) and in the Earth's crust (^{26}Al, ^{36}Cl, ^{39}Ar, ^{41}Ca, ^{81}Kr), which have been widely applied in dating methods and in environmental studies. Cosmic rays are responsible for part of the natural exposure of the population, especially for the inhabitants of mountain areas. A number of questions concerning the nature, generation and interaction of cosmic rays with the environment are still poorly understood. In this regard, there is increasing interest in creating affordable devices for individual observation of cosmic rays, which, in addition to the use as monitors of cosmic "whether", can be used for educational purposes in physics, electronics and theory of relativity.

Cosmic rays were discovered by Victor Hess (1911-1913) in a balloon high-altitude experiments. Solar eclipse measurements have shown that the radiation originates from other space [1]. Cosmic rays consist of high-energy particles and are composed mostly of nuclei, protons (90%), alpha particles (9%), nuclei of heavier elements (1%) and electrons [2]. When bombarding the upper atmosphere, protons react with the nuclei of nitrogen (78%) and oxygen (21%) and produce secondary radiation, which consists mainly of muons moving at a speed close to the speed of light (0.995c). Travelling through the atmosphere, some of the muons decay ($T_{1/2}$ = 1.56 μs) and the rest reach the Earth's surface. Due to the relativistic speed of the muons, its lifetime is delayed and a higher number can be detected on Earth.

Considerable progress in cosmic ray observations was made by Bruno Rossi, who developed a cosmic ray telescope, introducing the first electronic coincidence circuit of parallel type [3]. This circuit not only revolutionized the electronic instruments in nuclear spectroscopy, but also presents the first electronic AND circuit, a fundamental element of the digital logic in modern electronics. In Rossi's telescope, two, or more detectors are connected in coincidence to study the directional correlation of the cosmic radiation [4]. For recent studies more sophisticated telescopes for cosmic ray muon tomography have been developed using advanced scintillator detectors [5], which are out of the scope of our research aimed at simple and easy to operate device.

MATERIAL AND METHODS

Experimental setup. In the proposed paper the construction of a simple portable muon telescope for cosmic ray monitoring is described. It is based on Geiger-Müller (GM) -counters, connected in coincidence and shielded with thick lead adsorbers against low energy background radiation.

The mechanical construction of the telescope consists of a holder box, made from 4 mm plexiglass (polymethyl methacrylate). Three GM-counters are mounted horizontally on an adjustable and inclinable support. The detectors are aligned, one above the other, and spaced 60 mm apart. The spaces allow to mount lead shields with different thickness up to 30 mm to study the relative energy distribution of the muons. The detectors work in coincidence setup, i.e. only particles that pass through all three detectors give rise to an impulse on the detectors at the same time and are registered. The telescope can be adjusted on different angles from 0 to 180 degree using an inclination button and an inclination scale. A rotating table is used for azimuthal adjustment (Fig.1).

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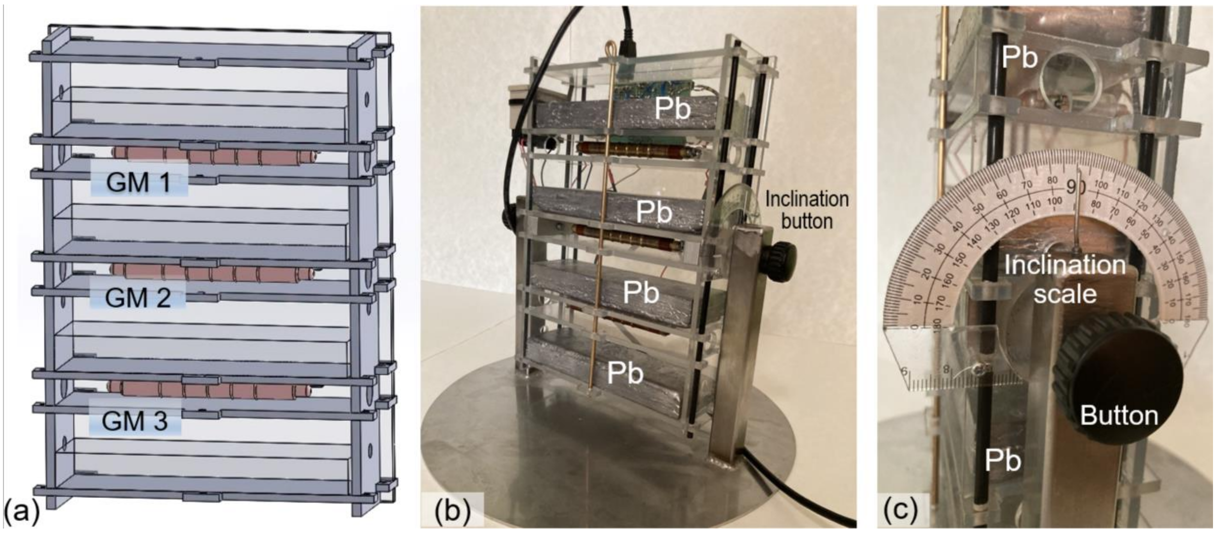

Fig. 1 (a) Sketch of the mechanical holder box. The three GM-counters (GM-1, 3) are placed between lead (Pb) adsorbers; (b) The completed telescope. The holder box is mounted on inclinable support fixed on a rotating table used for azimuthal adjustment; (c) The inclinable support allows to adjust different inclination angles from 0 to 180 degree.

The block scheme of the telescope is shown on Fig. 2. The transformerless power supply delivers 290 V anode voltage for the GM-counters. This voltage is chosen near the center of the working plateau. The detector block consists of three selected GM counters of type SBM 20 with equal parameters. The adapting block has three identical transistor amplifiers with high input impedance and low output impedance. By means of the coincidence mode selector the detectors can be connected in single, double and triple coincidence modes. The pulse shaper extends the 200 µS input pulses to 100 mS output pulses to be in compliance with the counter.

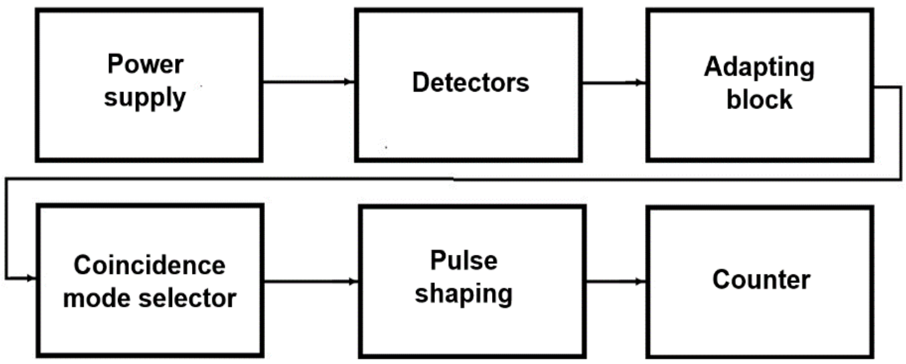

Fig. 2 Block scheme of the cosmic ray telescope

Electronics. The electronics setup is shown on Fig.3. The power supply of 5 V is delivered externally by power bank or by phone power supply. It is driven by a blocking generator, based on the integrated circuit NE555P. The amplifiers (adapting block) with BC547 transistors, the three diodes, the jumpers and the transistor invertor BC547 build up the coincidence logic circuit, analogue to the Rossi's triode scheme [3] – the first electronic coincidence circuit of parallel type. The signal shaper, based on the integrated circuit NE555P, optimizes the coupling with the low frequency OMRON counter.

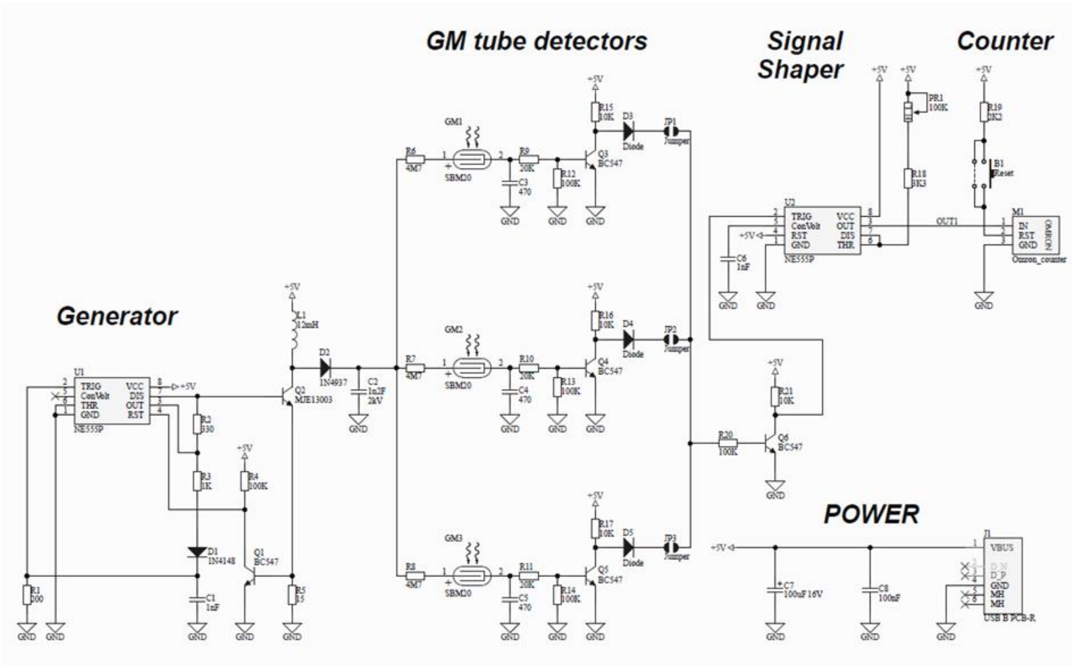

Fig. 3. Electronic setup of the muon telescope

RESULTS AND DISCUSSION

The telescope was tested in triple coincidence mode, with 3 lead absorbers of 20 mm thickness, during night time in 12 single measurements, lasting 12 hours each. The first measurement was made at zenith position (90^{o}), where the thickness of the atmosphere is minimal. Here, the number of counts of 5 successive measurements gave a mean value of 238±15 counts. Pointing the telescope at different inclinations resulted in gradually decreasing counting rate in both sides of the zenith. The length of the path in the atmosphere varies proportional to cos^2 of the inclination angle, as the measurements show. In Fig. 4 the results of our observations of the cosmic ray flux versus inclination are shown.

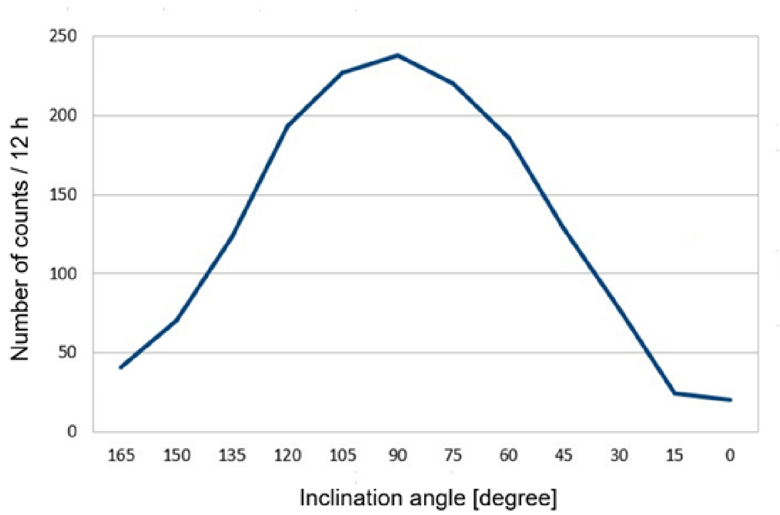

Fig.4. Number of counts versus different angles of inclination, measured during night in 5 sessions of 12 hours duration each

East-West asymmetry. The movement of the primary cosmic rays is influenced by the Earth magnetic field and driven by the Lorentz force. The trajectories of the muons, produced at high altitude, are also deflected in different directions depending on their charge. Positive muons are deflected eastwards and negative muons are deflected westwards. Since most cosmic rays are positively charged, there should be slightly more positive muons than negative muons detected at the Earth surface (east-west asymmetry).

During the measurements in eastward and westward directions at 45^o we observed about 5-6% asymmetry. Because of the daily fluctuations of the muon flux it was not possible to achieve better accuracy. For more precise measurement of the effect, the 45^o values should be corrected by means of independent 90^o monitor.

Relativistic survivor. The telescope can be used for educational purposes in physics to demonstrate the implications of the special theory of relativity (STR). The cosmic ray muons are produced in the upper atmosphere at about 10-20 km altitude. They have a mean life time of about 2.2 μs. Since muons travel with a speed of 0.995c, they need 02.2 μs to reach the Earth surface. Thus, on average, the percentage of muons predicted to be detected at ground level would be 9.7×10^{-8} %, i.e. in the classical physics approach no muons will be measured. Taking into account special relativity, the percentage on average of muons predicted to be detected at ground level is 0.06%, a significantly larger value, as shown in the above measurements.

CONCLUSIONS

A portable muon telescope for monitoring of the cosmic ray flux (cosmic weather) has been developed, based on GM counter and modern electronics. The triple coincidence mode, combined with thick lead adsorber, allow to measure the $\cos^2$ dependence of the cosmic ray flux versus inclination angles, and also the observe the east-west anomaly. The telescope can be used for educational purposes in particle physics and for demonstration of the validity of the Theory of Special Relativity.

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