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Muon cherenkov telescope

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Abstract: The Muon Cerenkov Telescope is a system of water cerenkov detectors, using the coincidence technique to register cosmic ray muons. It is constructed in order to study the variations of cosmic rays and their correlation with solar activity and processes in the Earth magnetosphere.

1 Basic design of the Muon Cerenkov Telescope

The telescope has 18 water cerenkov detectors / 0.25 m^2 each /, situated in two parallel planes. / Fig. 1/

Each detector /fig. 2/ consists of a container with dimensions 50x50x12.5 cm made of 3mm thick glass with mirror cover of the outer side. The container is filled with distilled water to 10cm level. A photomultiplier is attached to a transparent circle at the floor of the container and the discriminator is placed in its housing. When a charged particle with energy greater than the threshold energy for cerenkov radiation generation passes the radiator, cerenkov photons are initiated and a part of them reach the PMT cathode after multiple reflections from the mirror sides of the container.

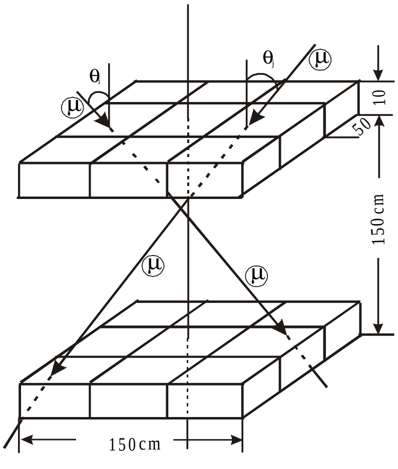

Fig. 1 Position of the detectors of the Muon Telescope

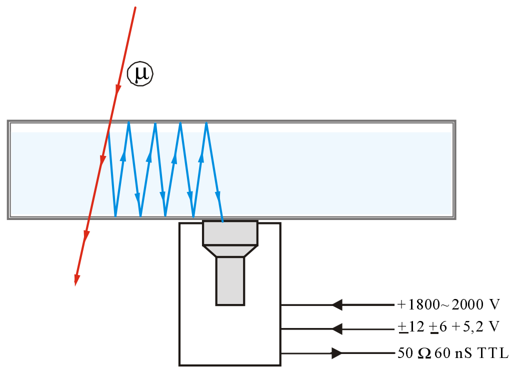

Fig .2 Water cerenkov detector

2 Energy threshold

The telescope is situated at the ground floor of the University building so that there is a *430 g/cm^2* layer of concrete above it. The ionization losses for muons slightly depend of energy and are about *0.22 GeV/g.cm^{-2}* . The lost energy is :

$$E_{lost} \approx 430\ g/cm^2\ .\ 0.22\ GeV/g.cm^{-2} = 0.95\ GeV$$

The integral spectrum of the muon component changes as shown on fig. 3. If we add the minimal energy for generation of cerenkov photons by muons in water, estimated as $E_{min} \geq 160\ GeV$, the energy threshold of the telescope becomes:

$$E_{thrt} \approx 0.95\ GeV + 0.16\ GeV \approx 1\ GeV$$

3 Methodical experiments and measurements

At first a module consisting of two detectors was constructed in order to optimize the characteristics of the water cerenkov detectors. /fig .4/ The tanks with distilled water were made in way allowing changing the radiator

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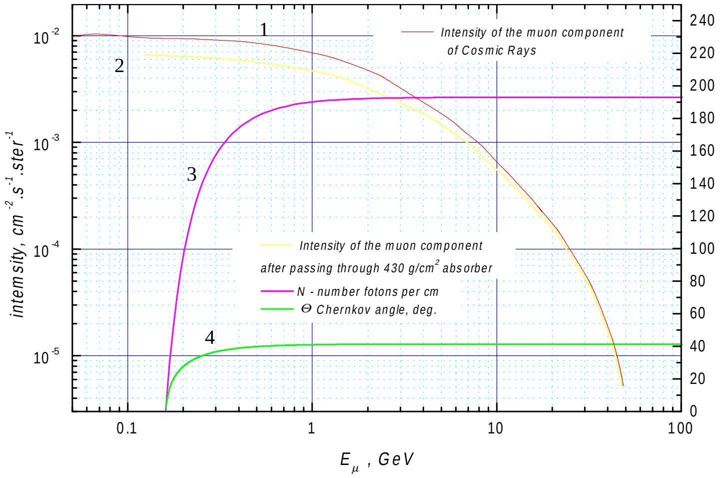

Fig 3 . – 1 . Integral spectrum of the muon component.

-- 2 . Spectrum of the muon component in the laboratory, after passing the absorber.

-- 3 . Number of cerenkov photons, generated per 1 cm water , into the range 400-600 nm.

(Frank and Tam's formula is used for this calculation.)

-- 4. Cerenkov angle. (degrees)

thickness in the range 5-50 cm. Because of the large quantity of water at high levels, the walls of the containers were made of double pieces of glass, 4mm each.

The dimensions of the detectors were 50x50 cm and the distance between them 75 cm. The gain of the preamplifier x5.

The expected count-rate of the module was 300 min^{-1}.

The dependencies of the count-rate on the high voltage power supply of the PMT and the threshold of the discriminator were studied, using two pairs of photomultipliers A horizontal efficiency range, corresponding to registration of all muons passing through the radiator was expected in these dependencies. It was not observed in the characteristics of the first pair of PMT and was slightly sloping for the other pair of PMT.

The main reasons for the lack of the efficiency range were :

- PMT noise pulses and the increasing number of accident coincidences at power supply voltages above 1.9kV;
- the angular uncertainty conditioned by the thickness of the radiators ;
- the double walls of the container, leading to poor light collection, since there were two planes glass between the radiator and the PMT.

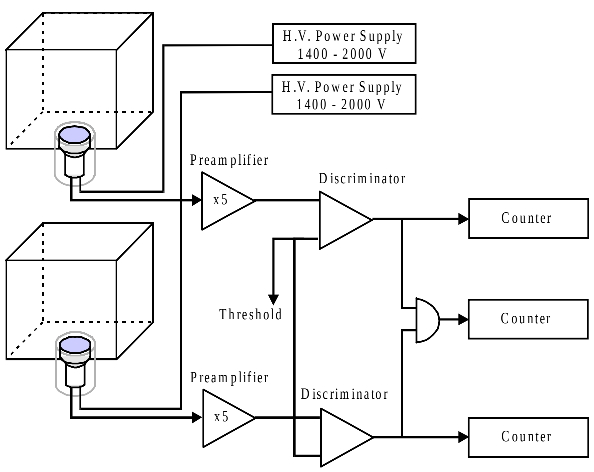

Fig. 4 The module, used for preliminary measurements for optimization of the characteristics of the detectors

Since the main aim of the detector application was to measure the variations of the cosmic ray muon flux (but not the absolute intensity) in given angular intervals, the thickness of the radiator was chosen to be 10 cm for the rest of detectors. Also was decided some measurements with preamplifiers with gain x50 and faster discriminators and coincidence circuits to be done.

4 Detector optimization

When the first two detectors of the telescope were constructed the dependence of the number of coincidence on high voltage power supplies of PMT and the threshold of the discriminators were studied. The dimensions of the detectors were 49x49x12.5 cm, 10 cm level of the distilled water and they were made of 3mm glass. Preamplifiers with gain x 50 and faster discriminators were used. Also the anode RC group of the PMT was changed in order to obtain pulses with higher amplitude, although with longer rise and fall times.

The results are shown on Fig.10 and Fig.11. A horizontal range corresponding to the registration of all muons passed through the radiator can be observed in both figures.

Since the obtained count-rate was high enough to obtain a statistical error ~0.4% for an hour intervals of measuring the intensity of cosmic ray muon flux, it was decided to increase the distance between the detectors to 1.5 m at the cost of expected count-rate of ~120 min^{-1} and ~0.8% statistical error, but with far better angular accuracy. The counting characteristics of a detector pair with distance between them 1.5m are shown on Fig.5, Fig.6.

The expected count-rate was 120min^{-1}, and the efficiency of the detectors was ≈95% although the area of the photomultipliers is about 5% of the area of the detector. It can be explained with the high reflective coefficient of the walls of the container and the comparatively high

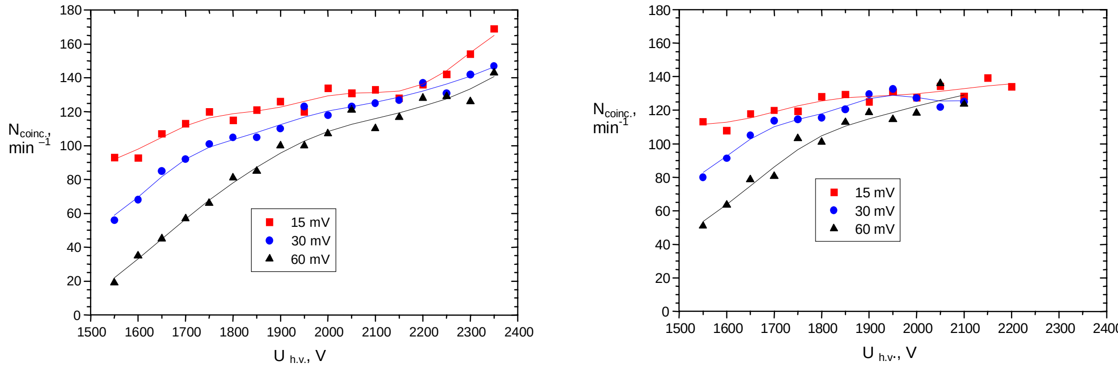

Fig 5 Dependences of the count rate on the high voltage power supply of the PMT at different thresholds of the discriminator. / For two pairs of photomultipliers. /

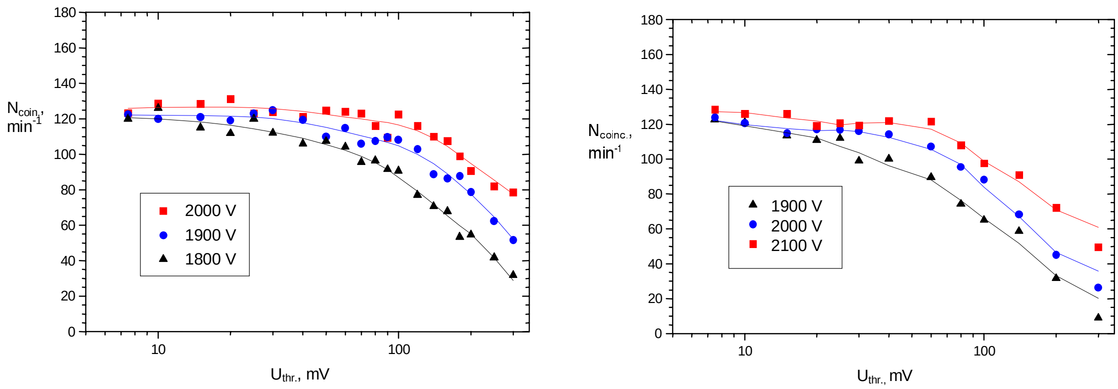

Fig 6. Dependences of the count-rate of the detector on the threshold of the discriminator at different high voltages. / For two pairs of photomultipliers /

number of Cerenkov photons generated by muons in the 10 cm radiator (Fig.3).

When the telescope was constructed, all the detectors were tuned for operation in the horizontal range of their counting characteristics.

5 Muon Cerenkov Telescope - Data acquisition.

The output signals of the detectors are connected to 33 coincidence circuits according to figure 7 and to table 1 .

In this way the intensity of the cosmic ray muon flux is measured in vertical direction in angular interval ±17,3 degrees, and in four inclined directions with zenith angle 17,3 degrees in angular intervals -17,3 +14,7 degrees with azimuth angles 0, 90, 180, 270 degrees.

The output signals from the coincidence circuits are connected to 33 counters, constructed as an ISA controller for a personal computer. The number of coincidence pulses for 1-minute time intervals is recorded on the hard disc drive of the used PC.

The controller is working in 20-minute cycles according to diagram 1. The record for every of the cycles contains 18 measurements of the muon flux – the number of coincidences from C1 – C33. The atmospheric pressure and temperature are measured once per cycle and data are recorded as they are necessary for the correction of the barometric and temperature effect for the cosmic ray muons. A test file with the individual count-rates of all the detectors is written.

A typical measurement of the variation of the vertical component of cosmic ray muon flux and the atmospheric pressure in October 2000 is shown on fig 8.

Software for data processing is in stage of development in this moment.

Conclusion

A muon telescope based on water cerenkov detectors was constructed and putted in operation. The main characteristics of the telescope are:

- energy threshold - 1 GeV;
- directions of measuring the intensity:
- vertical – 9 pairs of detectors. Observation angle ≈±18^{o}. Counting rate ~ 110 min-^{1};
- inclined – 6 pairs of detectors for every azimuth N-S, W-E, S-N, E-W. Zenith angle ≈ 18÷33 ^{o}. Counting rate ~ 75÷80 for a pair.

- statistical error σ =0.71% and σ =0.41% for 20 min. and an hour intervals of measurement the intensity of the muon component. (Vertical direction, 9 pairs of detectors.)

Table 1. Connections of the detectors to the coincidence circuits

Direction	Number of detector pairs	Detectors, connected to the coincidence circuits, for measurements in the given direction (u – up plane detector, d – down plane detector, c – number of the coincidence circuit) 33 coincidence circuits total								
Vertical	9	1u – 1d –c1	2u – 2d –c2	3u – 3d – c3	4u – 4d - c4	5u – 5d – c5	6u – 6d – c6	7u – 7d – c7	8u – 8d – c8	9u – 9d – c9
North - South	6	1u – 4d – c10	2u – 5d – c11	3u – 6d – c12	4u – 7d – c13	5u – 8d – c14	6u – 9d – c15	-	-	-
East – West	6	9u – 8d – c16	6u – 5d – c17	3u – 2d – c18	8u – 7d – c19	5u – 4d – c20	2u – 1d – c21	-	-	-
South - North	6	7u – 4d – c22	8u – 5d – c23	9u – 6d – c24	4u – 1d – c25	5u – 2d – c26	6u – 3d – c27	-	-	-
West – East	6	1u – 2d – c28	4u – 5d – c29	7u – 8d – c30	2u – 3d – c31	5u – 6d – c32	8u – 9d – c33	-	-	-

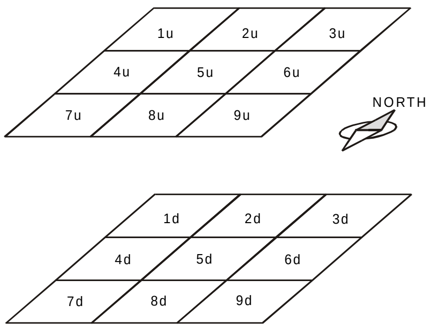

Fig. 7 Accepted designations of the detectors

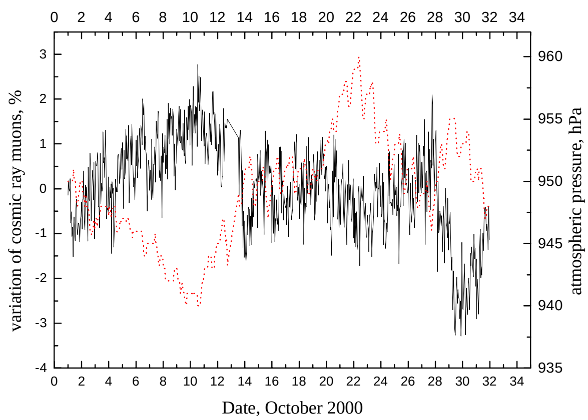

Fig 8 Variation of the cosmic ray muon flux, measured for the vertical component. /Coincidence circuits c1-c9/ Dot line – atmospheric pressure.

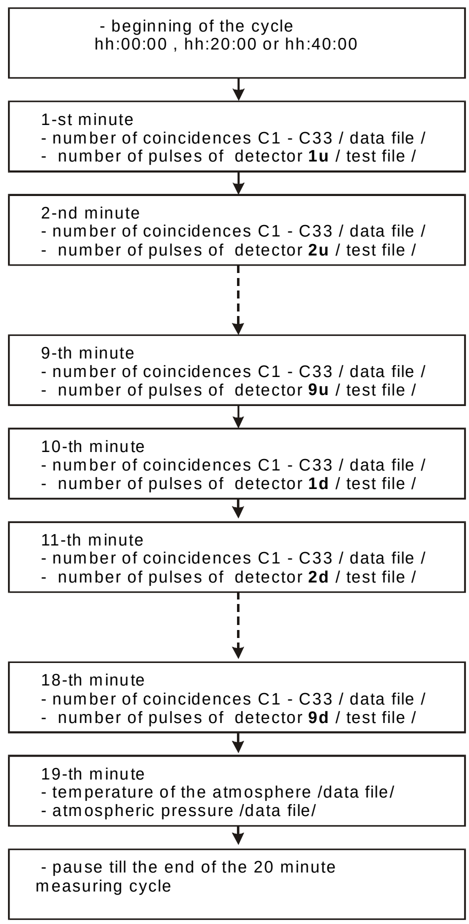

Diagram 1. Cycle of measurement and data recording .

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