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A MUON DETECTOR FOR A LARGE AIR SHOWER ARRAY

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A scintillation detector has been developed to select the muon component of extensive air showers. It consists of an array of counters buried 3 m below ground. The design and performance of the elements of this array are described.

The possibility of detecting point sources of cosmic rays with energies above 10^{14} eV has stimulated the construction of air shower arrays which distinguish between electrons and muons. Showers started by gamma rays should contain fewer muons than those initiated by hadrons. Thus by measuring separately the electron and muon content of showers, it should be possible to reject many originating from hadrons while retaining most of those started by gamma rays. An array of detectors with this ability is now being operated by the University of Michigan in collaboration with the University of Utah and a much larger array is being constructed by the University of Chicago, also in collaboration with the University of Michigan. These arrays have two types of components. On the surface of the ground there are scintillators which sample all the ionizing particles in the shower, mainly electrons, and from which the size and direction of the shower are measured. Beneath the ground, and thus shielded from the electrons, there is an array of counters which sample the muon content of the shower. In this paper we describe the design and performance of the elements of the muon array.

A muon counter is shown in fig. 1. It consists of a sheet of doped acrylic [1], 190 cm × 130 cm × 0.64 cm, viewed by a hemispherical photomultiplier tube (PMT), whose bulb nestles in a tapered hole at the center of the sheet. As illustrated in fig. 2, the PMT is pushed against the scintillator by a plastic disc which acts both as a spring and as a shield, keeping corona light from reaching the photocathode. A layer of silicone grease makes optical contact between the glass and acrylic. The PMT is housed in a cylinder of polyvinyl chloride (PVC) whose two parts are bolted together, clamping the scintillator and its cover between them. O-ring gaskets provide the watertight seals between the housing and the outer covers of black polyethylene which, in turn, are sealed to the perimeter of the scintillator with Wonder Tape [2].

Some of the light produced in the scintillator makes its way to the PMT by a series of internal reflections. However, when the detector is buried beneath 3 m of dirt, the pressure of the overburden is thought to produce patches of optical contact between the acrylic and its cover, thereby reducing the efficiency of light transmission along the sheet. To find an acceptable cover for the acrylic sheet, three different kinds were tested above

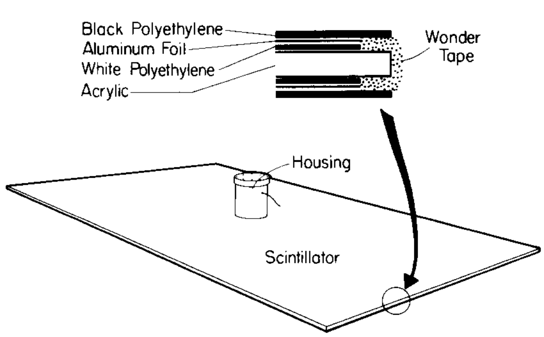

Fig. 1. An element of the muon array. It is 2.5 m^2 in area and operates 3 m below the surface of the ground.

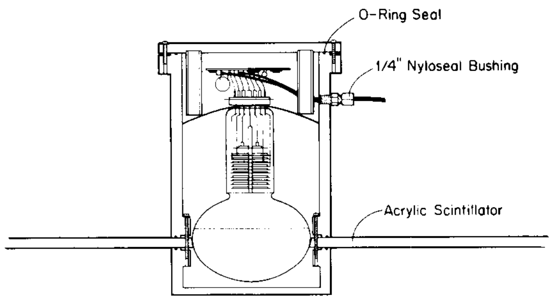

Fig. 2. A cross section through the housing of the muon counter. The PMT is type 9870B, made by EMI-Gencom. It is pushed against the acrylic scintillator by a plastic disc which acts both as a spring and as a light shield, keeping corona light from reaching the photocathode.

Table 1
Efficiencies (in percent) for detecting muons with different types of covers on the acrylic scintillator

	(1)	(2)	(3)
Above ground	83	89	97
3 m below ground	–	69	93

ground and the best two of these were retested under 3 m of dirt. The covers tested were the following:
(1) Black polyethelene sheet, 30 mil. in thickness.
(2) Aluminum foil placed between the black polyethelene and the acrylic.
(3) White (natural) polyethelene (20 mil.) placed next to the acrylic, followed by the aluminium foil and the outermost cover of black polyethelene.

Three small overlapping scintillation detectors placed above and below the sheet being tested were used to select muons which passed through a square area of 0.1 m^2 adjacent to a corner. The results of the tests are summarized in table 1. The values given have statistical errors of $\pm 1\%$. It is not known why the performance of (3) was so much better than that of (2). At any rate, it was judged to be good enough for our purpose and because of the expense involved with burying and retrieving detectors, no more tests of this type were made.

The array is expected to have a useful life of a decade or more. Since the buried components cannot be repaired, it is essential that they have at most a small chance of failing. To this end we have drawn on our experience with the Irvine–Michigan–Brookhaven detector [3] which, in its original configuration, used the same PMTs as those being installed in this array. There were two principal modes of PMT failure in that detector. Together they accounted for more than 90% of all losses.

(1) A small crack would develop where a pin entered the glass envelope thereby allowing air into the PMT. Initially the rate of failure from this process was acceptable, being about 1% per year. However, the rate increased steadily and by the third year had reached the unacceptable level of 10% per year. The cracking was caused by stress applied to the pins by the socket. In making the bases, the sockets were soldered directly to printed circuit boards thereby removing an important degree of freedom. The problem was solved by connecting the socket to the PC board with wires 2.5 cm long, thus allowing the pins to align themselves without stressing the glass.

(2) The resistors (value 1.2 M) used in the voltage divider circuit on the base of the PMT would fail at the rate of 0.6% per year. Since there are 13 resistors in each divider chain, the failure rate of this unit was 8% per year. It was noticed that these failures always occurred in bases with carbon film resistors, never with carbon composition resistors though both types were present. When all the carbon film resistors were replaced with carbon composition resistors, failures of this type became insignificant.

Experience with 256 elements of the muon array which have been in operation for more than a year is that the failure rate of components in the ground is about 1% per year, specifically 4 units in 1.4 years.

An important feature of this design is that the detectors are fairly rugged and therefore easy to handle in the field. The units are buried to a depth of 3 m in patches of 64, each detector lying adjacent to its neigbors in an 8×8 array. They are first imbedded in a layer of sand and then protected by an additional layer of sand before being covered with the original dirt and rocks.

The rate of random pulses in these detectors is dominated by the natural radio-activity of the surrounding dirt. This accounts for ~ 4 kHz while PMT dark noise adds an average of 2 kHz, though it can be as high as 10 kHz. Time jitter comes mainly from the PMT and corresponds to a full width at half maximum of 10 ns.

Acknowledgement

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References

[1] Acrylic Plastic Scintillators for Large Area Applications, Polycast Technology Corp., Stanford, Conn. (1985).
[2] "Wonder Tape" is an extruded rubber tape with excellent adhesion to both polyethylene and acrylic.
[3] R.M. Bionta et al., Phys. Rev. Lett. 51 (1983) 27.