

# BATATA: a buried muon hodoscope

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**Abstract.** Muon hodoscopes have several applications, ranging from astrophysics to fundamental particle physics. In this work, we present a detector dedicated to the study, at ground level, of the main signals of cosmic-ray induced showers above 6 PeV. The whole detector is composed by a set of three parallel dual-layer scintillator planes buried at fix depths ranging from 120 g/cm<sup>2</sup> to 600 g/cm<sup>2</sup> and by a triangular array of water cherenkov detectors located nearby on ground.

**Keywords:** Muon detectors, Cosmic rays, Radiation detectors

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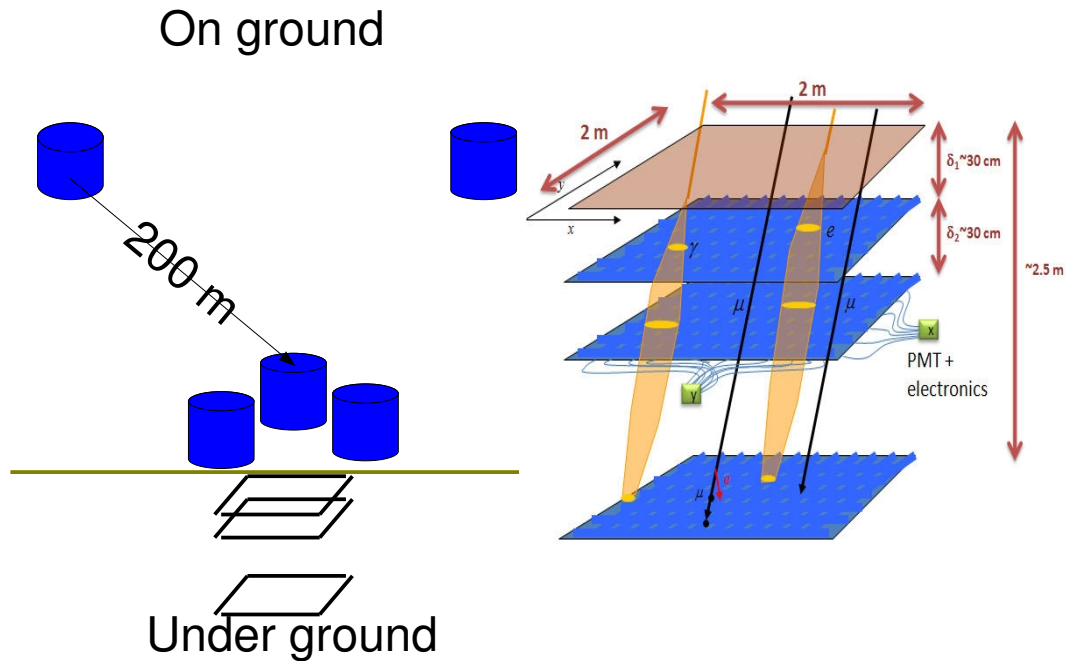
## INTRODUCTION

The Earth atmosphere is constantly hit by the cosmic radiation. This cosmic particles interacts with air molecules at high altitudes and give rise to showers of secondary particles which, eventually, may reach the ground. The fraction of these secondaries at the surface level depends on the atmospheric mass overburden but, in any case, the most important components are the muonic and the electromagnetic ones. Muons are the most numerous charged particles and are mainly produced from the decay of charged mesons at heights of around 15 km. The electromagnetic component at ground consists of electrons, positrons and photons primarily from electromagnetic cascades initiated by the decay of neutral and charged mesons and followed by pair production and Bremsstrahlung. The ratio of the electromagnetic to muon component at ground carries crucial information about the primary cosmic radiation. Indeed, the number of muons can be used to infer the fundamental physics involved in the first interactions points as well as the mass composition of the primary particle.

The main goal of the experimental setup presented in this work is to discriminate the muonic and electromagnetic component coming from cosmic ray induced showers above 6 PeV and measure their ratio as a function of the underground depth. As an additional goal, possible background muon excesses or modulations can be monitored.

## THE EXPERIMENTAL SETUP

BATATA is an cosmic radiation experiment which combines two techniques: water cherenkov surface detectors and a buried hodoscope. The cherenkov detectors lie on ground in a triangular array of  $\sim 200$  m side while the hodoscope is buried near one



**FIGURE 1.** Schematic view of the whole detector layout and the buried hodoscope.

of the triangle vertex (figure 1). The coincidence signal of the surface detectors selects cosmic ray induced showers above 6 PeV. While underground, the buried hodoscope is capable of distinguish muonic from electromagnetic signals. It has three horizontal x-y scintillator planes buried at different depths ranging from  $120 \text{ g/cm}^2$  to  $600 \text{ g/cm}^2$  (see figure 1, right). Each hodoscope's plane has 98 acquisition channels corresponding to the  $49 \times 2$  scintillator strips which lie perpendicularly to form the x-y plane.

We use 2 m long, 4 cm wide and 1 cm thick strips made of polystyrene doped with 1% PPO and 0.03% POPOP and co-extruded with a thin layer of  $\text{TiO}_2$  to improve light reflectivity [1]. The scintillation light is transported to a photomultiplier tube (PMT) by means of a 1.5 mm diameter wavelength shifting (WLS) optical fiber (we use Bicon-92) mounted on one central machined groove. The typical attenuation curve of this kind of fiber is shown in figure 2 together with a muon pulse example.

The rationale behind each acquisition channel is the following: charged particles propagating underground and depositing energy in a scintillator strip produce fluorescence light, a fraction of which, after multiple reflections inside the strip, gets into the wavelength shifter optical fiber, where part of it is absorbed and re-emitted in the appropriate solid angle for propagation. The optical fiber transports the light to its corresponding pixel of the PMT. The front-end (FE) electronic board applies the first level trigger (which is a pulse height threshold) and digitizes the signal coming from the PMT. Finally, the FE transmits the signal in differential mode to surface where the second

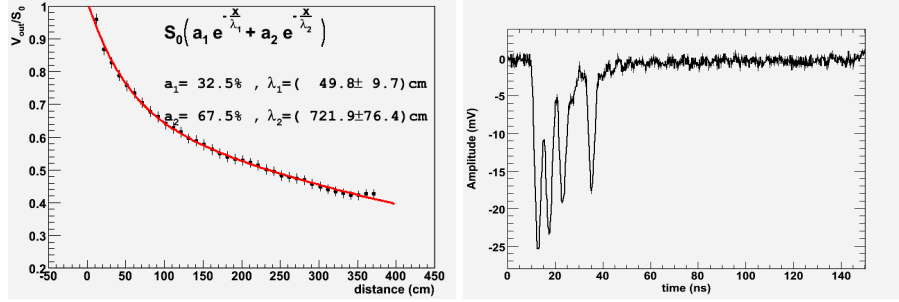


FIGURE 2. Light attenuation curve of Bicron-92 WLS optical fiber and a typical muon's pulse.

level trigger (SLT) is implemented on a FPGA. Because muons are the most penetrating charged particles that propagate underground and since their propagation is almost linear, they are expected to cross the whole detector volume leaving a well defined single-pixel signal in the three planes. On the other hand, photons, electrons and positrons, develop small showers underground that may leave a two-dimensional footprint on the shallower planes of the detector. BATATA takes advantage of this propagation difference to discriminate muonic from electromagnetic particles.

We use Hamamatsu H7546B PMTs [2] which are  $8 \times 8$  multianode with  $2 \text{ mm} \times 2 \text{ mm}$  anode size. These devices has a high speed response, high cathode sensitivity and low cross-talk (2% typical). A typical single photoelectron spectrum and the gain curve obtained in the laboratory are shown in figure 3. The gaussian peak around zero is the charge distribution of the baseline, while the shoulders after it is the single photoelectron distribution (as can be seen, we got  $\sim 1.2 \text{ pC}$  as mean charge value). As expected, the PMT gain grows exponentially with input voltage. As part of the detector characterization, we have also measured that the anode response variations ranges from 5% to 30% approximately, being the pixels on the edge the most sensitive.

We have also measured the interference between neighbouring PMT pixels injecting scintillator light in a single PMT pixel and recording the output from that pixel and two of its neighbours (we selected those pixels which are supposed to have the greater cross talk, i.e., the adjacent ones and not the diagonal ones). We found that if the FLT threshold is set to 15 mV (which is approximately 10% below the mean single photoelectron pulse

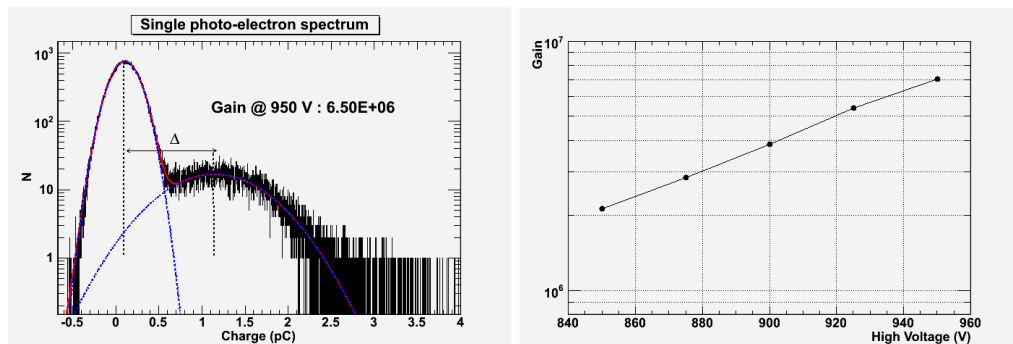


FIGURE 3. Single photoelectron spectrum at 950 V (left) and PMT gain curve (right).

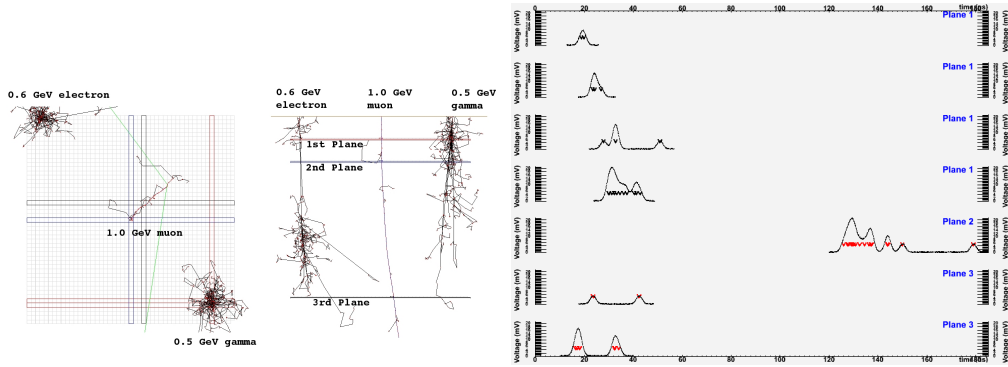


FIGURE 4.

height), then 6% of the muonic signals will be lost (i.e., the efficiency will be reduced to 94%) and 95% of the fake signals in one adjacent pixel will be avoided.

## DETECTOR SIMULATIONS

We develop a thorough end-to-end simulation toolkit for the BATATA detector: from the first interaction of the primary cosmic ray in the top of the atmosphere to the hodoscope electronic response simulation. We combined the Aires package [3] (which is used for the shower development in the atmosphere) with the Geant4 package [4] (which propagates the particles underground and simulates the detector). We have tuned the all the simulation parameters of the detector with laboratory characterization measurements in order to have realistic results. On the left of figure 4 some typical paths of particles propagating underground and hitting the hodoscope planes are shown while, on the right, simulated electronic pulses produced during a proton induced shower are plotted. It can be seen that the shower front width is highly reduced when it goes underground. Typical lasting times are rarely longer than  $\sim 200$  ns.

## CONCLUSIONS

We presented a cosmic radiation experiment that is under construction at present and that will be used to independently characterize the muon and electromagnetic components at ground level and to assess the magnitude of the tails of the electromagnetic distribution functions in extensive air shower. It is planned to begin stable operation in the summer 2009.

## REFERENCES

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