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The cosmic ray veto system of the Mario Schenberg gravitational wave detector

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ABSTRACT

Q3 The Mario Schenberg gravitational wave antenna is a spherical cryogenic resonant mass detector located at IFUSP, São Paulo. It is well known that cosmic rays interact with cryogenic resonant mass detectors generating acoustic signals. Depending on the shower energy, they could provide a substantial background noise which should be vetoed to reduce the false alarm rate. For this purpose, in December 2011, we have installed a cosmic ray veto system which is, since then, acquiring data. The cosmic ray veto system is composed of three particle detectors containing each one a scintillator, a photomultiplier and a tension divider.

As the shower number of particles is used to define a threshold for the veto, it is important that the cosmic ray veto provides a linear response to high-energy cosmic ray events. The veto setup response was optimized and allows measurements up to 23,000 equivalent muon charge particles per square meter.

We present here the experimental setup, its calibration and performance. Finally, to confirm the linearity of the data acquisition we show the measured particle multiplicity.

1. Introduction

The experimental study of matter oscillation due to particle interaction was first studied by Beron in 1969 [1]. It is now well known that energetic cosmic-ray events can excite mechanical vibration modes in a metallic resonant mass at its resonant frequencies. This phenomenon is described by the Thermo-Acoustic Model (TAM), which was first established by Grassi in 1979 [2] for metallic bars and then refined by other authors [3–6]. When particles interact with the resonant mass of gravitational wave (GW) detectors operating at low temperature (~ 1 K), they deposit energy, locally warming up the matter which provokes a thermal expansion. These expansions excite the solid modes of the detector. At a high number of interacting particles, the thermal expansions overpass the thermal random oscillations, making them measurable by the GW detector transducers. Therefore cosmic rays become a noise source which need to be vetoed. The measure of the cosmic ray showers is usually given in terms of multiplicity rate, which is the rate of events as a function of their particle superficial density (particles/m^2).

In 1994, the gravitational wave detector NAUTILUS, located at Frascati, Italy, installed a cosmic ray veto system around the gravitational antenna. This cosmic ray detector is composed of seven layers of limited streamer tubes, three layers, each of 36 m^2, above the gravitational antenna and four, of 16.5 m^2 each, below it [7]. In 2002, the GW detector EXPLORER, CERN, Switzerland, also installed a cosmic ray veto system [8]. This one was composed of three layers of plastic scintillators. One layer of 9.9 m^2 was located above the cryostat and two others, each one with 6.3 m^2, were located below it. Both experiments have measured coincidences of triggers between their gravitational antennas and their cosmic ray detectors [9,10]. They also showed that the TAM agrees with measurements and, finally, that high energetic Extensive Air Showers (EAS) are a significant source of noise for sensitive gravitational wave bar experiments.

Presently there are two resonant spherical mass detectors under commissioning, MiniGRAIL (Netherlands) and Mario Schenberg (Brazil). The MiniGRAIL experiment uses two cosmic ray detectors installed on the roof above the GW antenna as a veto for cosmic rays [11]. This cosmic ray system is part of the HiSPARC array, a network of cosmic ray detectors all over the Netherlands [12]. However measurements in coincidence have not been performed yet.

The resonant sphere of the Mario Schenberg antenna is made of a high mechanical Q alloy CuAl (6%). The sphere has 65 cm of

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diameter and weighs 1150 kg. Gravitational waves couple with the five quadrupolar modes of the sphere [13]. Six parametric transducers are installed on the sphere surface to convert mode oscillations into electro-magnetic signals. In order to reduce thermal noise [14], the Mario Schenberg antenna aims to operate at a temperature lower than 1 K.

A first estimation of the false alarm rate due to cosmic ray was established using the local flux and the TAM developed for the sphere [15,16]. A rate of ~ 5 triggers per day (due to muons, proton and EAS) is expected at a thermal noise of 10 μK. In order to veto these triggers a cosmic ray veto system was added to the Mario Schenberg experiment in December 2011. Since then it is continuously measuring the local particle multiplicity.

Currently, a low latency data analysis pipeline for the GW detector is under development. It will be able to determine, in few seconds, the direction of high SNR bursts with an average angular resolution (in angular distance) from $\delta s \sim 8^\circ$ at SNR ~ 12 to $\delta s \sim 1^\circ$ at SNR ~ 80 [17]. Triggers due to cosmic rays should be vetoed without slowing down the pipeline. The particle multiplicity will be used as a threshold to veto these triggers, therefore the veto setup is designed to provide a linear response to events with a high energy density.

In Section 2, we describe the cosmic ray veto setup and Section 3 shows its stability during the data acquisition. The charge to number of particles conversion is explained in Section 4. Finally, in Section 5, we summarize the theoretical performance of measurable multiplicity and present the measured particle multiplicity during the data acquisition period.

2. The cosmic ray veto setup

The cosmic ray veto system uses three identical particle detectors. Each one is composed of a polished cylindrical polyvinyltoluene scintillator ($h = 10$ cm, $R = 10$ cm) and a photomultiplier tube (PMT) “Philips® XP2040” collecting the scintillator photons. PMT operational voltage (1400 V) is provided by a high voltage power supply “Bertan® series 225”, which is highly accurate. Each photomultiplier is shielded by a mu-metal cylinder surrounding it. In order to decrease photon losses, the scintillator cylinder is wrapped with a reflective Tyvek® foil. Fig. 1 shows a schema and an open view of the cosmic ray detector.

The XP2014 PMT has 14 dynodes. We are expecting a large range of particle numbers, thus to increase the measured range, we use three different output channels. The PMT voltage divider has two outputs, one for the anode signal and another for the 12th dynode signal. Then the anode signal is split and one of the two subsequent signals is attenuated by a factor of 10. Each signal is converted by an analog to digital converter (ADC, LeCroy® mod. 2249W in a Camac crate). The anode and the dynode have different gains, therefore the ADC saturation is reached with different charges. We will use the following nomenclature:

- anode charge, named Q_{a1}, range a1;
- anode charge attenuated by 10, named Q_{a10}, range a10;
- 12th dynode charge, named Q_{d12}, range d12.

The cosmic ray detector 1 serves as a trigger for all detectors. When the pulse amplitude passes a voltage threshold, the three charges, Q_{a1}, Q_{a10} and Q_{d12}, of the three detectors, are recorded by a data acquisition (DAQ) system which is independent of GW DAQ. Presently, data are saved with a time reference given by a Network Time Protocol program [18,19] with a few milliseconds precision. But in a near future, the output of the cosmic ray DAQ will be directly transferred to the GW DAQ and therefore the veto will be included in the low latency pipeline. In this case the precision will be 64 μs.[1]

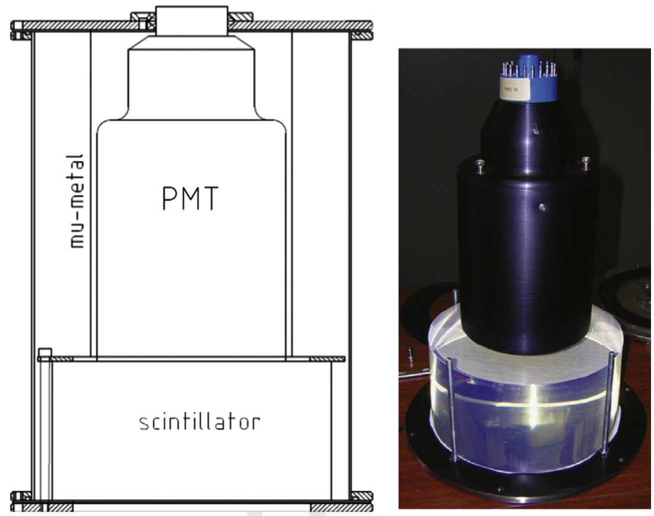

Fig. 1. Left: schema showing a vertical section of the cosmic ray detector, with plastic scintillator, photomultiplier, mu-metal and the stainless steel housing. Right: view of the open detector. The black cylinder is the PMT and below we can see the scintillator before being wrapped with the Tyvek foil.

3. Experimental setup stability

The three cosmic ray detectors are acquiring data since the 16th of December 2011. The last data used in this paper were recorded on the 26th of April 2013. The data acquisition was almost continuous. The duty cycle was 89%. No interruption was due to the setup itself but only due to short sporadic electrical power cuts. During this period all parameters were kept constant during the acquisition except the voltage threshold that we changed once to include single muon interactions. A total of $\sim 57 \times 10^6$ triggers were registered: $\sim 494 \times 10^3$ events with a threshold = 250 mV and $\sim 56 \times 10^6$ with a threshold of 25 mV.

In order to monitor the experiment stability we used three indicators, as seen in Table 1. Both the voltage and the electric current serve to check system failure. The voltage variation implies a photomultiplier gain variation. Assuming that the applied voltage is equally divided among the 14 dynodes, we can apply the following equation from Leo [20]:

$$\frac{dG}{G} = n\frac{dV}{V} \tag{1}$$

where G is the gain, V is the voltage applied on the photomultiplier and dV is its variation, and n is the number of dynodes. Therefore, the measured variation of 0.4 V corresponds to a gain variation of 0.4%. The gain is estimated using a Geant4 [21] simulation: $G \sim 6000$.

Measurements of ADC channel pedestal are performed by reading 1000 times the residual electrical charge before every new data file. There are nine pedestals, three per detector: the anode, anode attenuated by 10 and the dynode. The pedestal is subtracted from the measured charge. Their small variations warrant that the registered values have no unexpected influence due to pedestals.

No abnormal behavior was observed during this acquisition period.

[1] Minimum resolution limited by the sampling rate 15,625 Hz.

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