The Campinas-Niterói twin muon telescopes for solar activity and climate change studies


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Abstract: Two muon telescopes to study solar events and climate changes are currently under construction in Campinas and Niterói, Brazil. These telescopes are located in the South Atlantic Magnetic Anomaly and will measure muon flux. The single apparatus consists of four detectors arranged to detect vertical muons and 45 degrees inclined muons from East or West. Each detector uses a plastic scintillator slab, 150x75x5cm³, and 130 mm photomultiplier assembled into a trapezoidal container. In this paper, we illustrate the main features of the telescopes, electronics and data acquisition.

Keywords: muon telescope, solar activity, cosmic rays, climate change.

1 Introduction

We are building two identical muon telescopes, one in Campinas, SP (22° 54' S, 47° 03' W, 854 meters above sea level) and another in Niterói, RJ (22° 53' S, 43° 06' W, 3 meters above sea level). Both instruments are inside the South Atlantic Anomaly (SAA) where the geomagnetic field is the weakest, causing the proton Van Allen radiation belt comes closest to the planet’s surface.

Measurements of the trapped proton, with E > 140 MeV, near the Earth’s surface are shown in figure 1. These are results of the Polar Orbiting Environmental Satellites (POES) and from the figure is clear that the SAA region has the highest flux of protons with high energy.

Abrupt solar wind variations such as pressure pulses associated with coronal mass ejections (CMEs) can induce significant particle precipitation into this region. The Tupi muon telescope, located in Niterói too, has measured variations on the muon flux associated with solar events proving that variations in the flux of muons are sensitive to large solar events.

2 The SAA effect on the muon flux

The South Atlantic Anomaly is the region where the magnetic field is decreasing at an unprecedented rate and constitute a dip in the magnetosphere. Thus the goal of this experiment is to study the response and time changes of the muon intensity at ground, due to magnetic anomaly over south Atlantic. Based on the data of two directional muon telescopes located inside of the SAA region.

This characteristic offers to the muon telescopes a low rigidity of response to cosmic protons and ions (1.0 GV). The magnetosphere’s dip is responsible for several processes, such as the high conductivity of the atmospheric layers due to the precipitation of energetic particles in this region from Van Allen inner belt, and an zonal electric field known as the pre-reversal electric field with an enhancement at evening hours, the so called sunset enhancement.

In addition, the open magnetosphere propitiate the magnetic reconstructions of the interplanetary magnetic field (IMF) lines that will take place in this site in the day side. This behavior is the origin of the day/night asymmetry. These factors are responsible for an unusually large particle flux present in the SAA region, including particles with energies above the pion production threshold. The main effect is an increase of the muon intensity (E ~ 1 GeV) at ground, in the day side, in up to ten times. We show that it is correlated with the pre-reversal electric field, and propitiate the observation of muon enhancements due to small solar transient events, such as corotating interaction region (CIR) and micro-flares. Details of these results are shown in figure 2.

On the other hands, in the SAA region the cosmic ray daily variation is amplified. We have used the fast Fourier transformation (FFT) for studying periodicities and scaling properties that might be present in our time series constructed using the hourly muon intensities. The power spectra of the hourly muon intensities for two months is shown in figure 3. In this case, there is a series of peaks, such as at 0.99 days (daily anisotropy), and a small peak can be also observed at 0.58 days known as the semi-diurnal anisotropy. There is also a strong signal of the harmonic
27=\pi/n$, with $n = 4$ giving a peak at 7 days, which corresponds to the quasi-periodic corotating streams that occurs due to solar rotation period of 27 days. We would pointed out that the harmonics like $27=\pi/n$ has been observed in the power spectra of solar wind speed measurements reported by Burlaga and Lazarus [7]. These results strongly suggest that the solar wind and the protons (ions), producing the muon intensity, are modulated by the Sun.

3 The muon telescopes

The telescope in each city consists of four modular detectors arranged in mode to register the flux of vertical and 45 degrees inclined muons from East or West. In both cities they are into laboratories sited below about 60 centimeters of concrete, that represents a threshold of 290 MeV in the kinetic energy of the detected muons. Figure 4 shows the geometrical positions of the four detectors forming with the center of each module a vertical square of 283 centimeters.

3.1 The modular detector

The modular detector has a classical trapezoidal truncated geometry used in several Extensive Air Showers experiments, but with some improvements to optimize the light collection by the photomultiplier. It uses a slab of 150 x 75 x 5 cm$^3$ El-208 plastic scintillator produced by EJlen, a NE-110 equivalent, with maximum spectrum emission at 435 nm and 9,200 photons/(MeV electron). For vertical muons the number of photons produced into the scintillator slab is about $10^5$.

All the internal part of the trapezoidal box is lined with DuPont Tyvek$^\text{T M}$ that is the best diffuse reflective material for the plastic scintillator photons. Figure 5 shows measurements of relative diffuse reflection on dry materials, using a Perkin-Elmer, Lambda 9 -series 1645 -UV/VIS/NIR Spectrometer, part of the “Gleb Wataghin” Institute of Physics facilities. In this figure the reflectivity of the Tyvek$^\text{T M}$ is above unity because it is better than the barium sulfate used as reference by the spectrometer.

All scintillator’s faces are polished, its refractive index is 1.58 and it is surrounded by air, so 75% of the scintillation light is piped to the edges [4]. There are 5 centimeters between the scintillator’s edges and the trapezoidal truncated box to allow some photons reflect diffusively toward the photomultiplier (PMT) and increase the muon signal.

Each modular detector uses a photomultiplier Hamamatsu, model R877, with 10 stages, 127 millimeters of diameter and Bialkali photocathode placed at the truncated part, see figure 4. The PMT high voltage divider, amplifier and high...
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Fig. 4: The geometrical positions of the modular detectors (left), the modular detector, without the cover, showing the scintillator slab (center), logical diagram of the trigger (right).

The voltage power supplier are in the ORTEC ScintiPack™ Photomultiplier Base 296.

3.2 The data acquisition system

The hardware of the data acquisition system (DAQ) is composed by a Advantech PCI card with 4 analogical channels, 30 MS/s, 12-bit, simultaneous and a desktop computer running Windows 7 64bit. All other instruments necessary for the DAQ are made by NI Lab View virtual instruments. With this technology we build discriminators, logical units and counters. Figure 4 shows the logical diagram of the trigger used to register two vertical and the East and West muon rates.

The computer clock will be synchronized with the GPS UTC time using a GPS receiver connected to a usb port. The time precision expected for each computer is about 5 microseconds, enough for muon flux variation due a solar events. A weather station, TFA Nexus Weather Station, will be integrated into the DAQ system, proving data of temperature, pressure, humidity, wind speed and direction and rainfall.

4 Conclusions

In this work the status of the twin muon telescopes from Campinas and Niteroi is presented. These new muon telescopes will increase the ability to detect transient solar events into the SAA that are being carried out by the Tupi experiment. We will have the possibility of detection the same transient event by two telescopes 500 km away. These muon excess at ground level associated with solar activity will permit study the SAA and solar events at higher energies than space experiments.

We are now preparing the two first detectors to start acquisition at August 2013. We also plan to install all detectors by the end 2013.

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References