Performance of the full-scale SciCRT as a component muon detector of the Global Muon Detector Network (GMDN)

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Abstract: We use the SciCRT as a new muon detector and fill a gap remaining in the viewing directions of the present GMDN over the north and middle America. In order to minimize the data acquisition time, we trigger the muon measurement by the four-fold coincidence of hit signals from the top and bottom pairs of the X- and Y-layers and identify the location of muon on each layer by choosing the scintillator bar yielding the maximum ADC count in each layer. By analyzing the cosmic ray data observed by a full-scale SciCRT detector assembled for the test operation in the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) in Mexico, we confirm that more than 95 % of muon trigger events are successfully recorded with their correct incident directions. The angular resolution of the muon incident direction is also evaluated to be $\sim 3°$.

Keywords: Multidirectional muon detector, Space Weather, Heliospheric modulation of galactic cosmic rays.

1 Introduction

A solar disturbance propagating away from the Sun affects the pre-existing population of galactic cosmic rays (GCRs) in a number of ways. By measuring the directional anisotropy (or streaming) of high energy GCR intensity, we can infer the spatial gradient of GCR density (or isotropic component of GCR intensity) which reflects the magnetic structure such as the interplanetary shocks and the magnetic flux ropes in the ICME (Interplanetary Coronal Mass Ejection). Only a global network of detectors can measure the dynamic variation of the anisotropy accurately and separately from the temporal variation of the GCR density. The GMDN (Global Muon Detector Network) started operation measuring the three dimensional anisotropy on hourly basis as two-hemisphere observations using a pair of muon detectors at Nagoya (Japan) and Hobart (Australia) in 1992. Since then, the current network consisting of four multidirectional muon detectors in Nagoya, Hobart, São Martinho (Brazil) and Kuwait University (Kuwait) was completed in 2006 [1, 2].
There is a gap remaining in the GMDN's directional coverage, however, over the North and central America and the gap can be filled with a new multidirectional detector in Mexico which is now in operation as the SciCRT [3]. The SciCRT is a particle track detector used for the accelerator beam experiments and has been installed at the top of Mt. Sierra Negra (4600 m a.s.l.) in Mexico. For the SciCRT, readers can refer to our separate paper in this conference [4]. Since the primary objective of the SciCRT is the detection of solar neutrons, we need to minimize the interference by the muon measurement to the solar neutron detection using the same detector. In this paper, we evaluate the performance of the SciCRT as a muon detector by analyzing the data recorded in the preliminary measurement using SciCRT carried out in November-December, 2012 at the Instituto Nacional de Astrofisica, Optica y Electronica (INAOE) at an altitude of 2,149 m a.s.l.. The analyses of data recorded in the full-scale operations of SciCRT at Mt. Sierra Negra will be presented elsewhere.

2 Data analysis and results

The SciCRT consists of plastic scintillator bars (each 2.5 cm wide, 1.3 cm thick and 300 cm long) arranged in horizontal layers. In each layer, 300 cm axes of scintillator bars are aligned in X- or Y-orientations forming the X- or Y-layer with 290×295 cm^2 detection area. The X- and Y-layers are piled up alternatively forming the total 128 layers. Output light signals from X- or Y-layer are viewed by 64 ch multi-anode photomultiplier tubes (MAPMTs) through the Wave Length Shifting fibers (WLS-fibers) and converted to ADC counts and recorded by the VME-based DAQ system. For more detail of SciCRT, readers can refer to our paper in this conference [4].
After the transportation from the Fermi National Accelerator Laboratory in US, the SciCRT was assembled once in the INAOE for checking performances. The measured dead time for recording outputs from entire scintillator bars is about 20 ms per event, while the expected muon rate at the observation site is about 700 Hz. For muon ob-

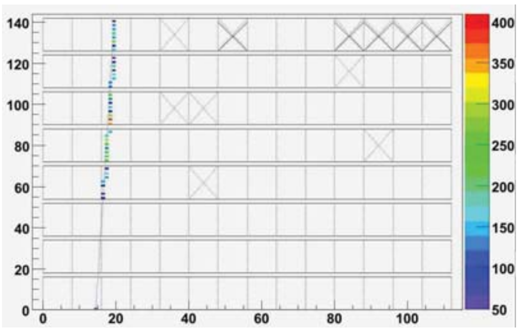

Figure 1: X-side view of a sample single track event. Small color pixels represent the scintillator bars yielding hit signals, each with the color coded ADC count. The color scale is shown on the right. The muon track best-fitting to the hit pattern is plotted by a thin dotted line.

servation at the observation site, therefore, we need to reduce the dead time by minimizing the total amount of data for the muon identification. We use only the top and bottom pairs of X- and Y-layers (hereafter “muon layers”) and trigger the muon observation by the four-fold coincidence of hit signals from muon layers. In each muon trigger event, we search for a scintillator bar recording the maximum ADC count in each muon layer and identify the location of muon passing by the location of scintillator bar yielding the maximum ADC count. This allows us unique identification of the muon track in the detector even for events with multiple hits in each muon layer.

In this paper, we analyze the data recorded in the muon trigger runs at INAOE in which ADC counts from all MAPMT in SciCRT are recorded with 20 ms dead time. For each muon trigger event, we first derive the muon track (hereafter “best-fit-track”) by best-fitting a straight line to the recorded hit pattern. Figure 1 shows a sample event in which the best-fit-track is plotted by a thin dotted line together with hit patterns in the entire SciCRT by small solid pixels with colors denoting the recorded ADC counts. It is clear that the best-fit-track in this event agrees with the actual hit pattern very well. We calculate the average deviation (S) of X- and Y-coordinates of the best-fit-track in all layers from those in the hit pattern. Figure 2 shows the distribution of S divided by the width (2.5 cm) of a scintillator bar on the horizontal axis. It is seen that the most of events are recorded with $S \leq 5$. The event displayed in figure 1 is a typical example of such single track event with $S \leq 5$. Out of 40,000 muon trigger events analyzed, 36,790 events (91.98 %) were recorded as single track events with $S \leq 5$.

Figure 3 shows an example of the remaining events with $S > 5$ in which many tracks in a shower are recorded. Events with $S > 5$, on the other hand, also contain multiple muon events. Figure 4 displays a typical example of such events. It is clear that the best-fit-track shown by a dotted line correctly follows one of two track patterns recorded. We confirmed the best-fit-track correctly following one of multiple track patterns in 1,567 (3.92 %) events out of 3,210 events with $S > 5$. If we include these multiple track events in the muon events in which one of track patterns is successfully best-fitted, muons are successfully identified in 95.89 % of muon trigger events.

We also derived the muon track (hereafter “reconstructed-track”) by using only outputs from muon layers

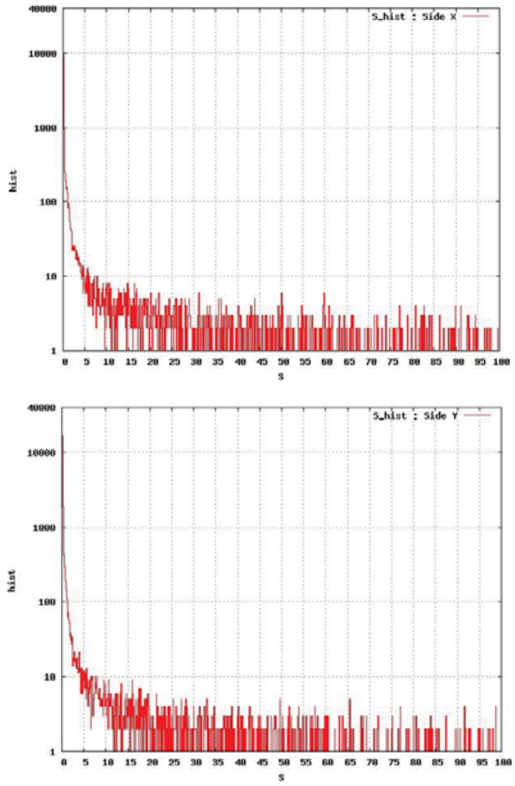

Figure 2: Histogram of the average deviation (S) of X- and Y-coordinates on the best-fit-track from those on the hit pattern. Event number is plotted as a function of S for X (upper panel) and Y (lower panel) coordinates. Note that S on the horizontal axis is divided by the width (2.5 cm) of a scintillator bar.

and examined the histogram of the deviation ($\Delta X = |X_{recon.} - X_{best-fit}|, \Delta Y = |Y_{recon.} - Y_{best-fit}|$) of X- and Y-coordinates on the reconstructed-track ($X_{recon.}, Y_{recon.}$) from those on the best-fit-track ($X_{best-fit}, Y_{best-fit}$). We confirmed 34,881 events (94.81 %) out of 36,790 single muon events recorded with $\Delta X, \Delta Y \leq 3.5$ scintillator bars. This implies that the angular resolution of the muon incident direction is about 3°.

3 Summary

We evaluated the performance of the SciCRT as a multi-directional muon detector by analyzing the muon trigger events generating the four-fold coincidence of signals from muon layers which consists the top and bottom pairs of X- and Y-layers of scintillator bars. In each muon trigger event, we search for a scintillator bar yielding the maximum ADC count in each muon layer and identify the location of muon by the location of scintillator bar yielding the maximum ADC count. This allows us unique identification of the muon track in the detector. We analyzed the data recorded in the muon trigger runs in which ADC counts from all scintillator bars of SciCRT are recorded with 20 ms dead time. By examining the histogram of the average deviation of the best-fit-track from the hit pattern, we confirmed that muons are successfully identified in 95.89 % of muon trigger events. The angular resolution of the muon incident direction is also found to be $\sim 3°$. The analyses of the absolute muon flux and the zenith-angle distribution

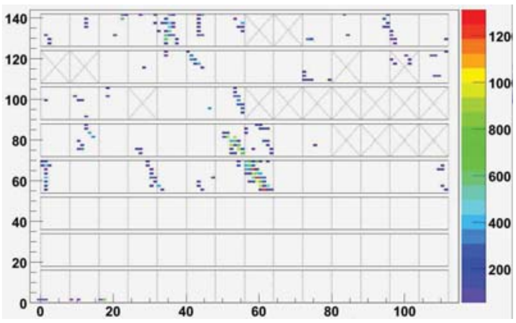

Figure 3: X-side view of a sample shower event with $S > 5$. Format is same as figure 1, but the best-fit-track is not plotted in this figure.

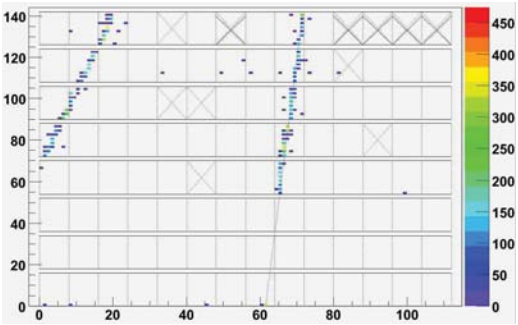

Figure 4: X-side view of a sample multiple track event with $S > 5$. Format is same as figure 1.

are currently on going. The SciCRT has been moved to the top of Mt. Sierra Negra, 4,600 m a.s.l., and started operation in April, 2013. The analyses of muon observation at the observation site will be given elsewhere.

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