Performance of the SciCR as a component muon detector of the Global Muon Detector Network (GMDN)


1Physics Department, Faculty of Science, Shinshu University, Asahi, Matsumoto 390-8621, Japan
2Solar-Terrestrial Environment Laboratory, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan
3College of Engineering, Chubu University, Kasugai 487-8501, Japan
4Faculty of Engineering, Aichi Institute of Technology, Toyota 470-0392, Japan
5High-energy Astrophysics Laboratory, Riken, Hirosawa, Wako 351-0198, Japan
6Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Yoshinodai, Chuo-ku, Sagamihara 252-5210, Japan
7SLAC National Accelerator Laboratory, Menlo Park, CA94025-7015, USA
8Instituto de Geofísica, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacan DF 04510, México
9Instituto Nacional de Astrofísica, Óptica y Electrónica, Tonantzintla, Puebla C. P. 72840, Puebla, México
kmuna00@shinshu-u.ac.jp

DOI: 10.7529/ICRC2011/V11/0373

Abstract: We plan to use the SciCR 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 interference to the solar neutron detection, we trigger the muon measurement by the four-fold coincidence between pulses from the top and bottom pairs of the x- and y-layers. We analyze the data recorded by a prototype detector “mini-SciCR” at the observation site for the SciCR and evaluate the observed count rate, zenith- and azimuth-angle distributions and the atmospheric pressure effect by comparing with the numerical expectations from the response of the atmospheric muons to the primary galactic cosmic rays.

Keywords: Global Muon Detector Network, SciCR detector, Multi-directional measurement of the muon intensity

1 Introduction

The Global Muon Detector Network (GMDN) which currently consists of four multi-directional muon detectors in Nagoya (Japan), Hobart (Australia), São Martinho (Brazil) and Kuwait University (Kuwait) started operation in March 2006 for the real-time monitoring of the cosmic-ray anisotropy in three dimensions. The real-time monitoring of the cosmic ray anisotropy enables us to deduce the cosmic-ray distribution in three dimensions at the Earth’s orbit in space and give us the important information on the magnetic structure and its temporal variation which is responsible to the cosmic-ray distribution [1, 2]. The cosmic ray anisotropy also often shows the precursory signatures which are observed within a small pitch angle around the sunward IMF in advance to the arrival of the solar disturbances at the Earth [3, 4, 5].

The total number of the conventional viewing directions available in the network was 60 at March 2006, but it is now increased to 212 by installing a new recording system using the field-programmable gate arrays (FPGAs). The median rigidity ($P_m$) of primary cosmic rays observed by the GMDN ranges from about 55 to about 150 GV according to the calculation utilizing the response function of the atmospheric muons to the primary particles [6]. Each open symbol in Figure 1 shows the asymptotic viewing direction at rigidity $P_m$ of each conventional directional channel, after the correction for geomagnetic bending as determined using a particle trajectory code [7]. Although open symbols display only the conventional viewing directions, it is seen that there is a gap remaining in the GMDN’s directional coverage over the north and middle America. The solid symbols in this figure display possible viewing directions to be added by installing a pair of new detectors in Mexico and South Africa. It is evident that the gap can be filled with a new single detector in Mexico which we now plan to put in operation by using the SciCR. The SciCR is a particle track detector used for the accelerator beam experiments and now going to be installed in Mexico [8]. Since the primary objective of the SciCR is the detection of solar neutrons, we need to minimize the interference to the
solar neutron detection expected from the muon measurement using the same detector. In this paper, we evaluate the performance of the SciCR as a muon detector under this condition by analyzing the data recorded with the prototype detector (mini-SciCR) at the observation site. About the SciCR and mini-SciCR, readers can refer to our separate papers in this conference [8, 9].

2 Data analysis and results

We analyze the data recorded by the mini-SciCR at the observation site on the top of Mt. Sierra Negra (97°W, 19°N, 4580 m a.s.l.) during a period between October, 2010 and January, 2011. The prototype detector (mini-SciCR) uses 128 (8×8×2) plastic scintillator bars (PSBs), each of which is 2.5 cm wide, 1.3 cm thick and 20 cm long equipped with a wavelength shifter fiber for reading out by the photomultiplier-tube (PMT). Eight PSBs aligned horizontally in x- or y-direction compose a x- or y-plane. The mini-SciCR consists of sixteen horizontal layers in which the x- and y-planes are alternatively piled up. A 64 ch multi-anode PMT (MAPMT) connected to 64 fibers monitors outputs from 64 PSBs in eight x-planes, while another 64 ch MAPMT monitors y-planes. We trigger the muon recording by the four-fold coincidence between the top and bottom pairs of the x- and y-planes which are separated vertically by 18.2 cm. The incident direction of each muon is identified from x-y positions of the hit signals on the top and bottom pairs and the muon count rate is recorded in each of 15×15 directional channels covering 360° of azimuth angle and 0°-54° of zenith. We thus use for our muon measurement only signals from the top and bottom pairs of the x- and y-planes without looking at signals from the remaining planes. This is for minimizing the interference to the solar neutron detection and the same detection method will be adopted also in the measurement with the full-scale detector of the SciCR.

| four-fold coincidence | $16477.63 \pm 32.09$ |
| single-hit            | $5433.38 \pm 18.43$ |
| double-hit            | $8371.44 \pm 22.87$ |

Table 1: Hourly count rates of the mini-SciCR. Error is statistical.

Table 1 shows the hourly count rates of the mini-SciCR at the observation site. In this measurement, a 5 cm layer of lead was placed above the detector to absorb the soft component radiation in the air. In the column “single-hit” in this table represents the count rate of the events in which only one hit is recorded in each plane, while the “double-hit” de-
notes the events in which two hit signals are yielded from a pair of neighboring PSBs. It is seen that the “double-hit” events corresponding to muons passing through the boundary between a pair of neighboring PSBs have a major contribution to the total muon rate together with the “single-hit” events. It is essential for our muon measurement with a sufficient count rate, therefore, to identify the muon incident direction of the “double-hit” event properly. While the incident direction of the “single-hit” event can be uniquely identified from the x-y positions of the hit signals, there are several possible directions for each “double-hit” event. Among them, we temporally assign in this report the direction closest-to and furthest-from the vertical incident alternatively from one event to the next. We identify the incident direction of each event in this way and record the muon rate in each of 15×15 directional channels. By comparing the observed muon rate with the numerical expectation calculated by utilizing the response function of muons in the atmosphere to primary cosmic rays [6], we find the observed rate being consistent with the calculation within ∼±10%. For instance, the observed count rate in the vertical channel (for which the calculated geomagnetic cut-off rigidity and the median primary rigidity are 7.9 GV and 34 GV, respectively) is 473 ± 5.27 count/hour, while the calculated rate is 434 count/hour. However, we also note a systematic dependence of the difference on the viewing direction which is not fully understood yet. In order to remove this difference from the data, we need to continue the measurement further and identify the origin of the directional non-uniformity of the detector response. Figure 2 shows the observed and calculated zenith angle distributions of the flux. By fitting a $\cos^n(\theta)$ function of the zenith angle $\theta$ to each distribution, we obtain $n = 2.12 ± 0.01$ and $n = 1.87 ± 0.01$ from the data and calculation, respectively. This implies that the observed distribution is consistent with zenith angle distribution of the muon flux. We also measured the temporal variation of the count rate recorded over 28 days between October 20, 2010 and January 31, 2011. The lead layer over the detector was removed during this period for the measurement of the background radiation together with muons and neutrons. The day-to-day variation of the count rate was relatively small at the observation site when compared with the daily variation. The observed daily variation of the count rate is averaged and displayed in Figure 3 by solid symbols together with the average variation of the atmospheric pressure at the observation site by open symbols. The anti-correlation of the count rate with the atmospheric pressure is evident with the derived regression coefficient of $-0.36 ± 0.06%$/hPa, while the coefficient expected for muons from the numerical calculation is $-0.18%$/hPa. This large (negative) coefficient observed is probably due to the contribution from the air shower. The regression coefficient for the air shower intensity is about seven times larger than that for the muon intensity [10]. According to our preliminary analysis, the observed regression in Figure 3 suggests ∼30% contribution of air showers to the rate recorded by the mini-SciCR running without the overhead lead layer.

![Figure 2: Zenith angle distributions of the muon flux. The observed and calculated muon fluxes are plotted by solid and open symbols, respectively, each as a function of the zenith angle cosine of the incident direction. Two straight lines indicate the best-fit curves to the data points (see text).](image)

3 Summary

We evaluated the performance of the SciCR as a muon detector by analyzing data collected with a prototype detector (mini-SciCR) at the observation site for the SciCR. In order to minimize the interference to the solar neutron measurement, we trigger the muon measurement by the four-fold coincidence between pulses from the top and bottom pairs of the x- and y-planes. By comparing the observed vertical count rate, the zenith angle distribution of muon intensity and the atmospheric pressure effect with the numerical calculations, we conclude that the muon observation with the mini-sciCR has been successfully carried out. The observed directional intensity in the field of view, on the other hand, shows a ∼±10% difference from the numerical calculation, which varies with the viewing direction in an un-

![Figure 3: Average daily variations of the hourly count rate and the atmospheric pressure. The solid and open symbols display the count rate and pressure, respectively, each as a function of the universal time. Note that the scale of the right vertical axis for the pressure is reversed.](image)
known systematic manner. In order to remove this difference from the data, we need to continue the measurement and analyze the directional non-uniformity of the detector response further.

4 Acknowledgement

The authors thank INAOE to tentatively provide them with the place where they work for the SciCR experiment, and allow them to start the new cosmic ray experiment at the top of Sierra Negra. This work was carried out by the joint research program of the Solar-Terrestrial Environment Laboratory, Nagoya University. The SciCR project is supported by Grants-in-Aid for Scientific Research(B) 22340054 in Japan.

References