32nd International Cosmic Ray Conference, Beijing 2011

Performance of the SciCR as a solar neutron detector

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DOI: 10.7529/ICRC2011/V10/0026

Abstract: The SciCR, SciBar for the Cosmic Ray Observations, is a new multi-purpose cosmic ray experiment. The main aim of the SciCR is the detection of solar neutrons, and it will operate at Mt. Sierra Negra in Mexico, at 4,600m above sea level. The detector is made of 15,000 plastic scintillator bars. The dimension of each bar is 2.5cm x 1.3cm x 3m. We made a small prototype experiment called as mini-SciCR, using the same scintillator bars, with smaller length (20cm). One of the purposes of the mini-SciCR is to test the hardware of the experiment at Mt. Sierra Negra before the installation of the SciCR. The other purpose is to measure the cosmic ray background. We will present the result of the mini-SciCR experiment, and the detection efficiency of SciCR for solar neutrons obtained by a Monte Carlo simulation taking into account the mini-SciCR results.

Keywords: solar neutron, sensitive cosmic ray detector, SciCR

1 Introduction

The particle acceleration on the solar surface have been studied by radio and optical telescopes, X-ray and γ-ray satellites, and cosmic-ray detectors. Electrons and ions are accelerated on the solar surface, but understanding ion acceleration is difficult because ions are affected by the interplanetary magnetic field, and come along with the magnetic field line. To understand the particle acceleration from the observation of solar ions, it is necessary to take into account the interplanetary magnetic field. On the other hand, it is simpler to observe solar neutrons produced by accelerated ions at the solar atmosphere, because solar neutrons arrive to the Earth without being affected by or free from the effects by the interplanetary magnetic field. We have observed solar neutrons by Solar Neutron Telescopes (SNTs) [1]. SNTs are located on seven mountains near the equatorial line and observe the Sun 24 hours a day. SNTs have observed several solar neutron events, for example, see [2]. We plan to construct a new SNT to discuss about the efficiency of the acceleration and the production time of neutrons in detail. We will start the SciCR (SciBar for the Cosmic-Ray observations) using the SciBar detector [3]. The concept of the SciCR and the status of SciCR is presented in a separate paper [4]. In this paper, we concentrate on the preliminary experiment of the SciCR and the performance of the SciCR.

Before setting up the SciCR, we made a small prototype detector named mini-SciCR using the same scintillator bars and the recording hardware. We have tested the hardware of the SciCR and measured the cosmic ray background by the mini-SciCR. We calculated the detection efficiency of the SciCR for solar neutrons obtained by a Monte Carlo simulation (MC) taking account of the mini-SciCR result.

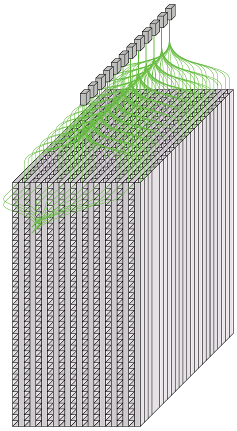

Figure 1: SciBar detector is made of plastic scintillator bars (vertical and horizontal) and WLS-fibers (top of bars). Sixty-four WLS-fibars are bundled and connected to a MAPMT.

2 Detector

2.1 SciCR

The SciCR consists of the detector part, the reading out hardware and the environment monitors. The detector part shown in Figure 1 of the SciCR is made of 14,848 plastic scintillator bars. The dimension of each bar is 2.5cm $\times$ 1.3cm $\times$ 3m. Each bar has a hole of 1.8mm in diameter and a Wave Length Sifting fiber(WLS-fiber) of 1.5mm in diameter is inserted. Sixty-four WLS-fibers are bundled and connected to a 64 channel multi-anode photomultiplier (MAPMT) H8804 (Hamamatsu). Signals from MAPMTs are read by an Analog to digital converter. When a charged particle is injected to this detector, we can identify a trajectory of the particle from the ADC data as shown in the left of Figure 2. On the other hand, a neutron is identified when a recoil proton is produced in the detector. Therefore the trajectory of a neutron starts in the middle of the detector as shown in the right of Figure 2. To select neutron events the outer bars are used as anti-counters.

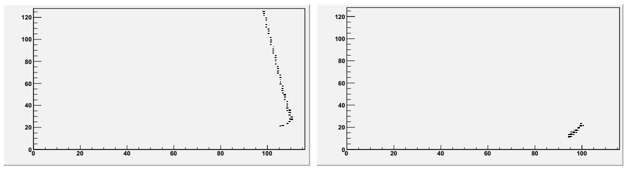

Figure 2: Left: An example of the one side view of the SciCR when a cosmic-ray muon was injected. Right: An example of a neutron. Vertical and horizontal axes are coordinate per unit bar size, respectively. The black boxes are signals, with the size of each box proportional to the ADC value. Both pictures are for the Monte Carlo events.

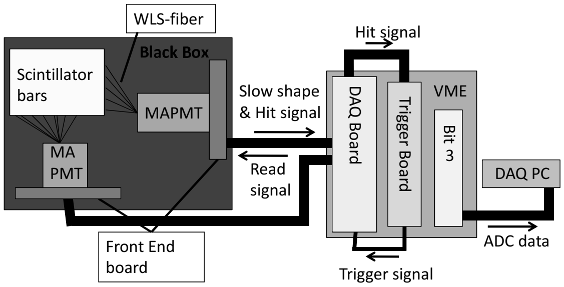

Figure 3: Read out system of the SciCR. FEBs make hit signals and slow shape analog signals. Hit signals pass through DAQ boards and make a trigger signal at the trigger board. The DAQ board makes a reading signal when there is a trigger signal, and analog signals are sent to the ADC of DAQ from FEBs.The DAQ PC records these information.

The reading hardware of the SciCR is shown in Figure 3. Each MAPMT is connected to a Frond End Board (FEB). One FEB has two TA/VA IC chips. TA has discriminators and makes a hit signal when any one of the MAPMT anode signal exceeds the threshold level, and VA makes slow shape of the MAPMT anode signals. Eight FEBs are connected to one DAQ board. The DAQ board has ADCs and reads voltage conducted from the VA chips. The role of the trigger board is to make trigger signal from hit signals collected by some DAQ boards.

The environment monitors record a temperature, the clock of PC and GPS, and applied voltage of MAPMTs.

2.2 mini-SciCR

The mini-SciCR uses the same hardware as the SciCR, although the length of scintillator bars and the number of reading hardware are different. The length of scintillator bars is 20cm, each side of the detector has 64 channels and

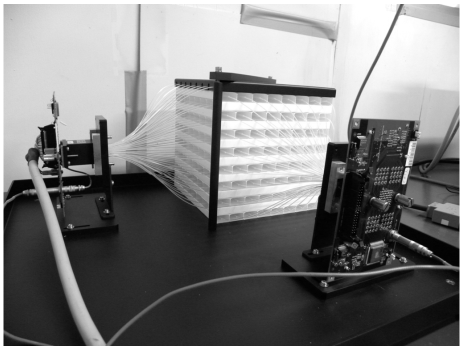

Figure 4: The detector part of mini-SciCR. It uses two MAPMTs and 128 scintillator bars.

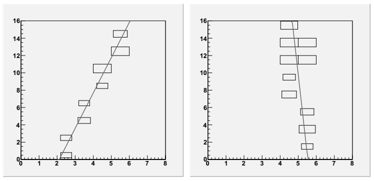

Figure 5: Cosmic-ray trajectory detected by the mini-SciCR at Nagoya. The track shown is fitted by least square method.

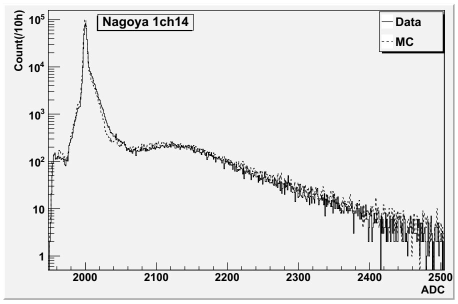

Figure 6: The ADC spectrum of background cosmic-rays obtained in Nagoya. The solid line is the experiment data and the dashed line is MC. The left steep peak of the ADC value 2000 is a pedestal which was obtained by the event without the trajectory of cosmic-rays. The right broad peak of the ADC value 2120 is made by the incident cosmic-rays.

is read by one MAPMT. Figure 4 is a picture of the detector part of the mini-SciCR. We tested the hardware of the mini-SciCR. The dead time of reading ADC was 1 ms. The cross-talk at the surface of a MAPMT was measured to be 2.72% for the adjacent channels and 0.45% to kitty-cornered channels. A hit signal is obtained when there is a signal from the upper 32 or the lower 32 of the MAPMT channels. Then the trigger was created by the coincidence of X-side upper and Y-side upper hit signals, or X-side lower and Y-side lower hit signals. Figure 5 is background cosmic-ray event sampled by the mini-SciCR.

We set up and started data taking of the mini-SciCR on Mt. Sierra Negra from October 19 to 28, 2010. All components operated correctly, and the result of cosmic-ray data is compared with MC simulation in Section 3.

3 Monte Carlo Simulation

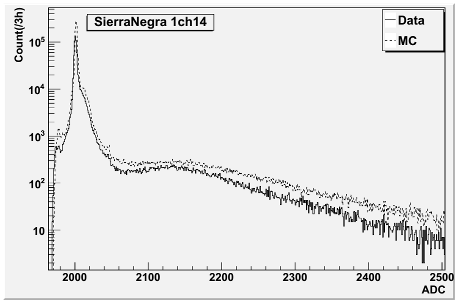

Figure 7: The ADC spectrum of background cosmic-ray on Mt. Sierra Negra.

We used PHITS [5] package to estimate the background cosmic-ray, to calculate injecting particles to the detector, and Geant4 was used to estimate particle behavior in the detector. We estimated the response of the mini-SciCR to background cosmic-ray considering the hardware performance, for example, the cross talk, the dead time, and the pedestal signals due to noise. The result of MC is compared with experiment data in Figure 6 and 7. The MC is similar to the experiment data at Nagoya , but the counting rate obtained by the MC on Mt. Sierra Negra is about 30% higher than the experiment data. We will measure more precise performance of the hardware to understand this difference. This difference is not so important for our study.

We tuned the MC to interpret the experimental data, and examined the performance of the SciCR. The trigger condition of the SciCR was studied by MC taking account of the results from the mini-SciCR, and we chose the trigger condition so that the highest efficiency is given for the solar neutron event on September 7, 2005 [2]. For this study, the energy spectrum of neutrons at the Sun is assumed by a power law $6.1 \times 10^{27}(E/100MeV)^{-3.8}MeV^{-1}sr^{-1}$, and the zenith angle of the Sun was fixed to 17.46 degrees. The propagation of solar neutrons through the atmosphere of the Earth is calculated by Shibata model [6].

We regard each scintillator bar as a hit channel when there is an energy loss exceeding 7 MeV. When there are hits for 5 sets of two adjacent planes, without any hit for the top, side and bottom planes, we recorded ADC data in the SciCR. The data taking of the SciCR uses two types of triggers, one is to take ADC data, which we call as track event. When some DAQ boards send ADC information to the PC, it produces the dead time. We cannot read ADC but read hit signals for some boards to reduce the dead time. We record only hit signals for the other trigger ,which we call as hit event. The performance of data taking is improved by two types of triggers.

4 Result

The upper panel of Figure 8 is the time profile of solar neutron event occurred on September 7, 2005 detected by SNT at Mt. Sierra Negra, and the lower panel is the time profile of hit event of the SciCR assuming the same flux of solar neutrons as upper panel. The fluctuation of cosmic-ray backgrounds are shown. The SNT significance is 16σ, and the SciCR got significance is 57σ for the same event. The SciCR has much higher efficiency than the SNT.

Because the SciCR has higher sensitivity, it is possible to analyze the same event with higher time resolution. In the top of Figure 9, the time profile of solar neutrons injected

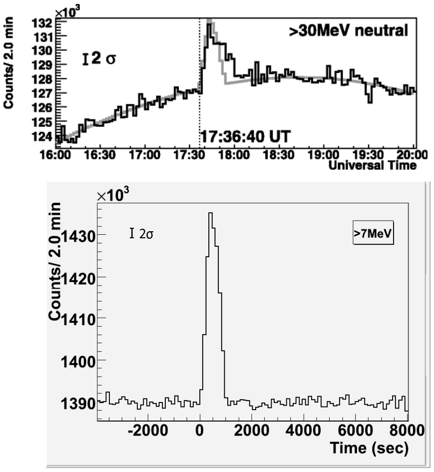

Figure 8: The time profile of the SNT (upper) and MC calculation of the SciCR (lower) for the solar neutron event on September 7, 2005. Zero sec at the lower panel corresponds to 17:36:40 UT (dashed line) at the upper panel which is the peak time of hard X-rays.

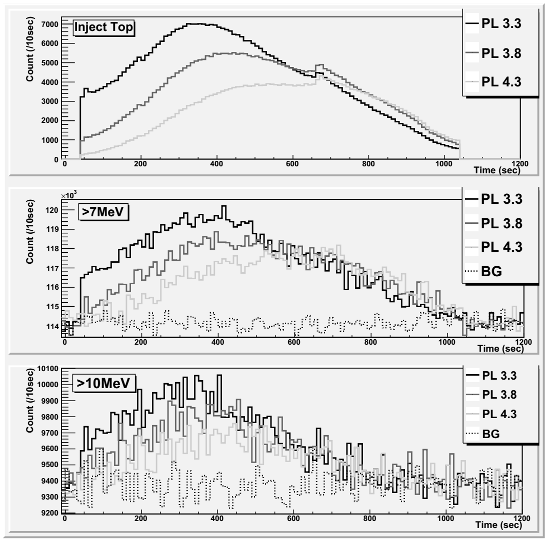

Figure 9: Top panel: The time profile of solar neutrons injected on the top of the detector for 3 power law indexes. Zero sec is flare time and all solar neutrons were assumed to be emitted this timing.The middle panel: The counting rate obtained by the hit trigger. The bottom panel: The count rate obtained by the tracking trigger.

of the detector are shown by assuming 3 power law index of the neutron spectrum for the solar neutron flux on September 7, 2005. The time resolution of 10 seconds in Figure 9 is much finer than 2 minutes in Figure 8. The middle and bottom of Figure 9 are time profiles obtained at the detector by the hit trigger and the track trigger respectively. We note that the SciCR has high sensitivity to energy spectrum.

5 Summary

The SciCR is the new solar neutron telescope which has higher sensitivity than current SNTs. We made a prototype detector named mini-SciCR using the same scintillator bars and the reading hardware. Following test in Nagoya, we operated the mini-SciCR at Mt. Sierra Negara and confirmed all components working normally. After confirming that the MC of the mini-SciCR is almost consistent with the experimental data, we evaluated the sensityvity of the SciCR to the solar neutron event by using the MC. The SciCR got significance of 57σ when flux of solar neutron is assumed as the event occurred on September 7, 2005 detected by SNT at Mt. Sierra Negra (16σ). The SciCR not only has high significance but also high sensitivity to energy spectrum as shown in Figure9.

6 Acknowledgment

The author are grateful for the group of the SciBar and the SciBooNE experiments to allow them to use the SciBar detector for the cosmic-ray experiment. They thank FNAL, especially Particle Physics Divsion, to allow and support them to dismantle the SciCR experiment, and allow them to start the new cosmic-ray experiment at the top of Sierra Negra. This work is supported by Grants-in-Aid for Scientific Research(B) 22340054 in Japan.

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