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Detection Efficiency of New Solar Neutron Detector

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Abstract

Scintillator based solar neutron detectors were constructed at various high mountains in the world. They are located at(1)Gornergrat, Switzerland, (2)Mt. Aragatz, Armenia,(3)Yangbajing, Tibet, China,(4)Mt. Norikura, Japan,(5)Mauna Kea, Hawaii, USA, and (6)Chacaltaya, Bolivia. All those detectors are capable of measuring the energy of solar neutrons and some of them [(1),(3),(4) and (5)] identify the arrival direction of solar neutrons. They work as neutron telescopes. The detection efficiencies of those neutron detectors have been investigated by the accelerator neutron beam at RCNP, Osaka University at the energies 100MeV, 200MeV and 300MeV. In this paper, the results are reported, together with a Monte Carlo simulation of the attenuation of neutrons in the atmosphere based on the Shibata model. In the Monte Carlo calculation, the minimum path length effect has been taken into account for solar neutrons.

1 New International Solar Neutron Network (ISNN)

The detection of solar neutrons has been classified in the rare events of cosmic rays, even though it has been recognized that solar neutrons bring us very important information on the ion acceleration mechanism at the solar surface.

Nowadays, it is essential to collect more events for establishing correct features on the particle acceleration at the Sun. For this sake, a new type of detector must be prepared which has high S/N ratio in comparison with traditional neutron monitors (Hatton,1971;Simpson,1983). The new detectors must be capable of charged particle rejection. Furthermore the detector can measure the arrival direction of solar neutrons. Then, the enormous amount of background can be discriminated by the directionality information and high sensitivity of the detector is realized. The background is produced by galactic cosmic rays. New detectors have also the capability to measure the energy of neutrons. Since neutrons have a mass, low energy neutrons arrive at the Earth later than high energy neutrons, even if they were emitted at same time at the Sun. To satisfy these requirements, plastic scintillators were selected as the main detector target. Neutrons are converted into protons inside the plastic scintillators and those secondary protons are detected.

In this paper, we present the results of experimental determination of detection efficiencies that have been obtained by the accelerator beam at RCNP.

2 Experiment at Osaka University

The neutron beam was prepared by the bombarding accelerated proton beam onto the lithium target. The charged particles were swept away by the magnet and neutrons which were emitted in the forward direction by charge exchange processes were extracted. The mini neutron detectors were located at a distance of R=63m away from the Li target. The flight time of neutrons were measured and neutrons which had nearly the same energy of incident protons were selected. Neutrons made nuclear interactions in the plastic scintillator either with protons or carbons. The track length of secondary protons was measured by the pulse height method. When protons deposited energies higher than > 40MeV, > 80MeV, > 120MeV, or > 160MeV in scintillator, the events were selected by the discriminator and recorded on tapes. The neutron flux N_0 has been obtained from a previous measurement (Muraki et al.,1998) by the following equation : $N_0 = \mathrm{const} \times N_i \times S/R^2 \times \sigma_{c.m.}$. Here $\sigma_{c.m.}$(mb/sr) is the differential cross-section at $\theta = 0$ in CMS and the value is nearly constant as 27mb/sr in the energy range between 100 and 400MeV (Taddeucci et al.,1990). S represents the area of each detector and N_i corresponds to the incident proton beam intensity. The counting rate of each solar neutron detector was divided by the above intensity (N_0), and the detection efficiency was obtained.

3 Experimental Results

Fig. 1 presents the detection efficiency of the Bolivian type solar neutron detector. The size of the plastic scintillator was 30cm×30cm and the thickness of the scintillator was 40cm. The detection efficiency was about 10 $\sim$ 20 % in the neutron energy range between 100MeV and 300MeV. Fig. 2 represents the detection efficiency of the Hawaiian type neutron detector.

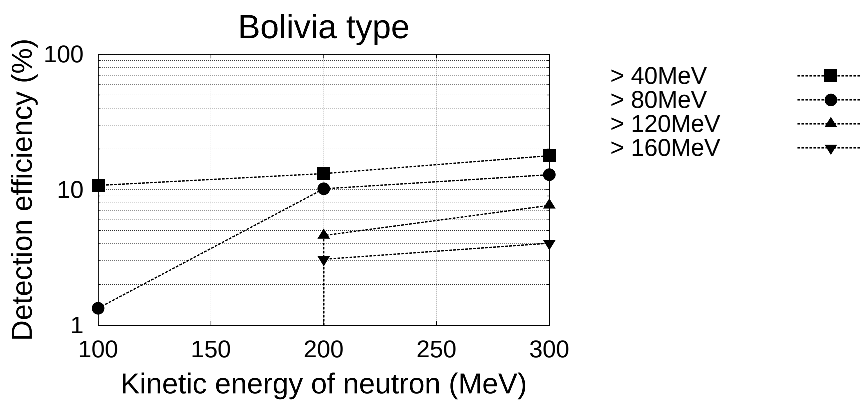

Figure 1: Detection efficiency of the Bolivia type solar neutron detector.

The Hawaiian type detector consists of 4 layers of 10cm wood. However, in the accelerator experiment, it was difficult to prepare a thick wood target. Therefore we used 4 layers of polyethylene target with thickness of 10cm. The polyethylene target includes hydrogen and heavy wood also includes hydrogen. That is the reason why we used this target. The open circle in Fig. 2 shows a Monte Carlo result. The detection efficiency turns out to be 4 % to 7 %. The detection efficiency of the Norikura type detector is presented in Fig. 3. The Norikura type detector is a combination of a 20cm thick plastic scintillator and 40cm polyethylene target. The value of the detection efficiency comes to around 10 %.

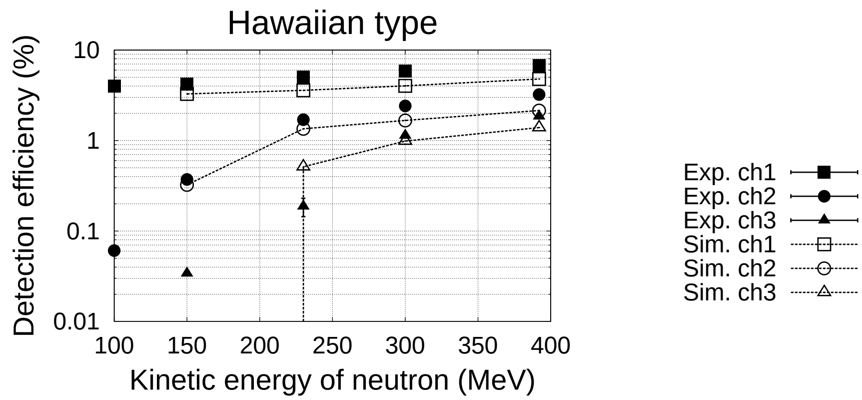

Figure 2: Detection efficiency of the Hawaiian type neutron telescope.

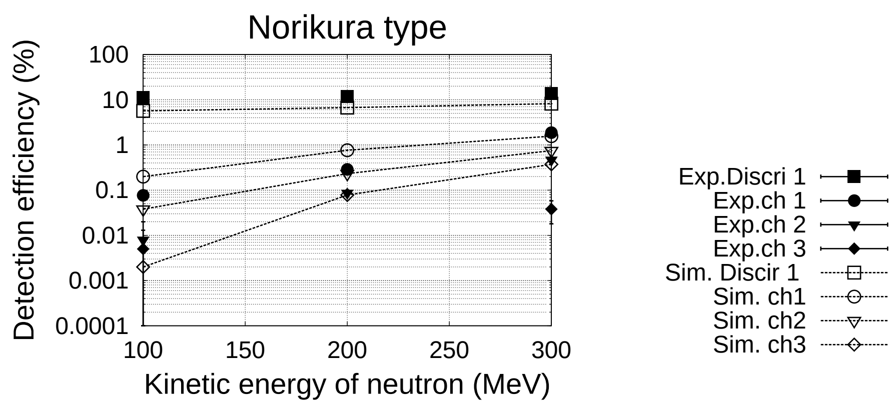

Figure 3: Detection efficiency of the Norikura type neutron telescope.

4 Attenuation of Neutrons in the Atmosphere

In actual experiments, energy spectra of solar neutrons are obtained. In order to get the energy spectrum for each event, the counting rate must be divided by both the attenuation factor of neutrons in the atmosphere and by the detection efficiency of neutron detector. Therefore, it is important to make a reliable Monte Carlo calculation of the neutron attenuation in the atmosphere. In this paper, we present the attenuation curve for different energy of neutrons based on the Shibata model (Shibata,1994). In the Monte Carlo calculation, the minimum path length effect was taking account of (Debrunner, Lockwood,

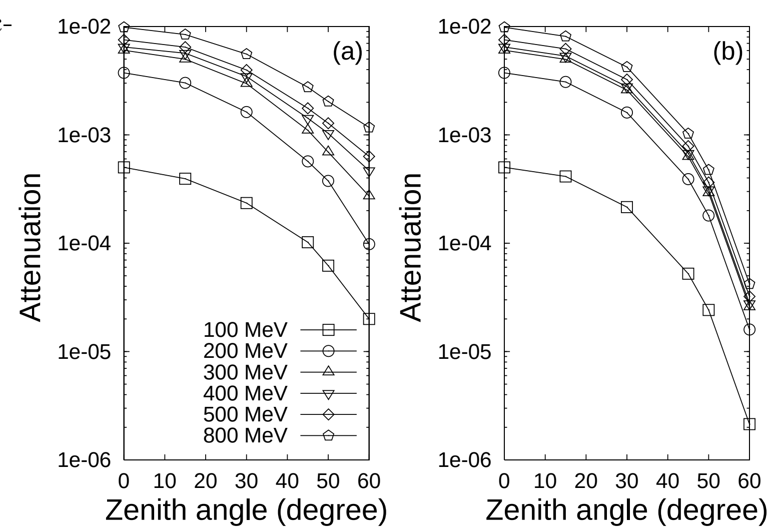

Figure 4: The result of Monte Carlo calculation for the attenuation of neutrons in the atmosphere, (a) with the minimum path length effect and (b) without the minimum path length effect at 4300m altitude.

& Ryan,1993;Smart, Shea & O'Brein,1995). The results are presented in Figs. 4 and 5. Fig. 4 shows the attenuation of neutrons in the atmosphere for various incident angles with the minimum path length effect(a) and without the effect(b). The values are expected for the observation point at 4300m altitude. For neutrons with energies 100MeV, the effect of increasing the cross-section between neutron and atmospheric nucleus can be clearly seen.

Fig. 5a gives the daily attenuation curve for neutrons with 500MeV expected at 4300m observatory in Tibet. The graph gives the values for the summer solstice, the equinox and the winter solstice. In Fig. 5b represents the same curve, but for Mt. Norikura (2800m altitude).

In this paper, we have presented the results of the detection efficiencies of each solar neutron detector and the results of the simulation of the attenuation of solar neutrons in the atmosphere.

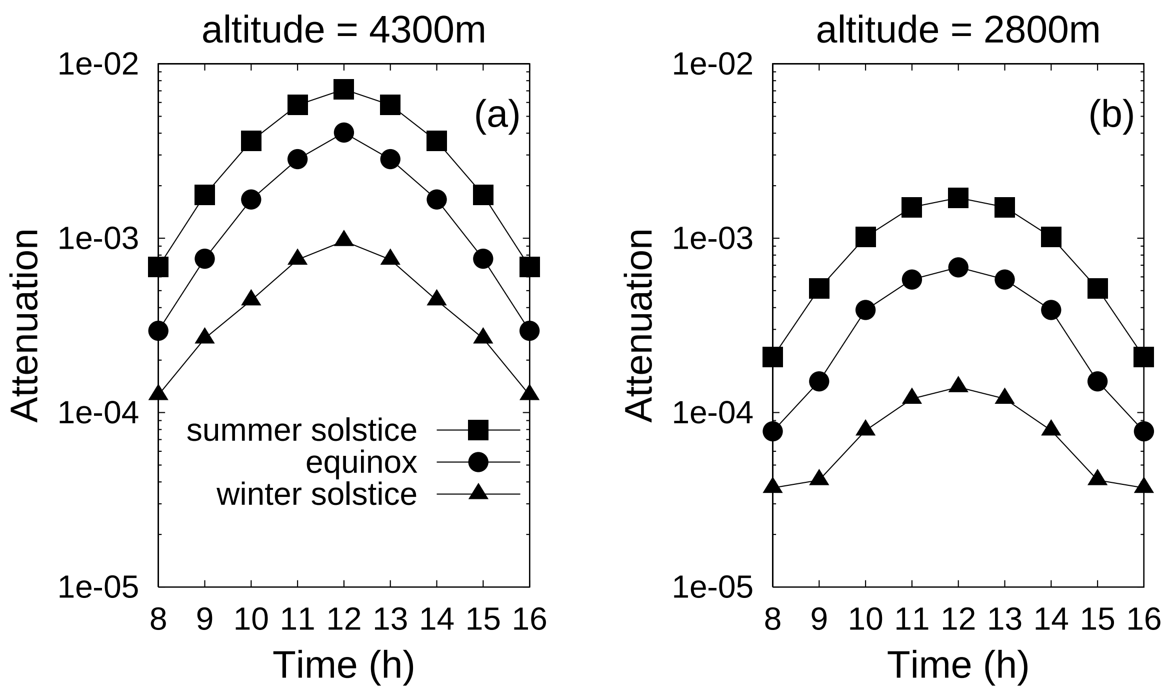

Figure 5: Daily attenuation curve for neutrons with 500MeV at two observation points.

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