Super Solar Neutron Telescope for the Next Solar Maximum

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Abstract

We propose a new type of solar neutron detector, the Super Solar Neutron Telescope, for the next solar cycle 24. The new detector should retain the function of the present solar neutron telescopes, i.e., the capability for energy measurement and determination of the arrival direction of solar neutrons with high detection efficiency. For this purpose the detector should be composed of scintillator blocks with dimensions of 5cm×10cm×300cm. Those scintillator blocks will be aligned to compose a tracker and the proposed dimensions of the Super Solar Neutron Telescope are 300cm×300cm×150cm. The energy and direction of 70% of incoming neutrons with kinetic energies >150MeV can be measured by this telescope. The performance of the Super Solar Neutron Telescope has been investigated by Monte Carlo calculation.

1. Introduction

Solar neutrons, high energy neutrons emitted during solar flares, have been extensively monitored by the Solar Neutron Telescopes and Neutron Monitors (NMs). Although the NMs form a world wide network and have a high efficiency, the lack of information about energy, direction, and charge of the incoming particle is a disadvantage for the observation of solar neutrons. The Solar Neutron Telescopes [1] are designed to overcome these disadvantages and to solve the particle acceleration problem during solar flares. In the solar cycle 23, two interesting events have been observed using the function of the direction measurement [2][3]. These measurements confirmed the power of the Solar Neutron Telescopes. However, the number of events is small and any discussion using the energy spectrum information is still difficult.

To obtain much more information and statistics on solar neutrons, we propose a new type of Solar Neutron Telescope. First we discuss the problems of the current observation method. Next the concept for the new telescope is presented and finally its performance is estimated using a Monte Carlo calculation.

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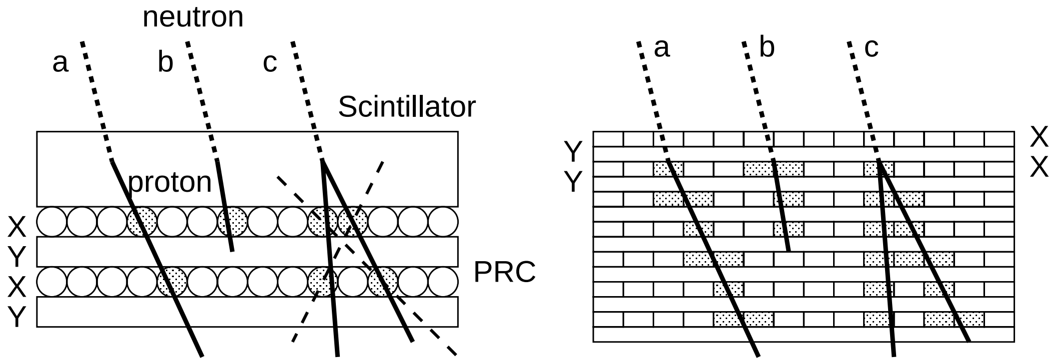

Fig. 1. Method of the direction measurement for determining direction of arrival.(See text for detail)

2. Current Observation

The concept of the current observation is illustrated schematically in the left of Fig.1. Incoming neutrons (dotted lines) are converted into charged particles (solid lines) in a plastic scintillator and the track of the recoiled particle is measured in the underlying Proportional Counters (PRCs). In a case like *a* in the Figure, we can regard the direction of the recoiled particle as that of the neutron. However, in the case of *b*, because of the shortage of the track, we can not infer the direction. This also happens when the recoil occurs near the top of the scintillator even if the recoiled particle has enough kinetic energy. Thicker scintillator makes the conversion efficiency higher, but then not all the recoiled particles can arrive at the bottom PRCs. Thus the efficiency of the direction measurement is limited. Moreover the case *c* is complex. We measure the counting rate of each direction as determined from the hit pattern of the PRCs. Because this process is done at the electronics level, inevitable misidentification of the direction occurs when multiple recoil particles are generated (dashed lines).

3. Concept of the New Telescope

To avoid the problems discussed above, we propose a new method shown in the right of Fig.1. Here rods of plastic scintillator with dimensions 5cm×10cm×300cm are used. A plane, with such rods horizontally aligned, a 1 dimensional position-sensitive detector and orthogonally-aligned such planes compose a 3 dimensional tracker. Because all components are composed of plastic scintillator, the whole tracker also acts as an active target. Consequently, the track of all recoiled particles can be measured wherever the interaction occurs. Even in case *b* in the Fig.1., the direction can be determined. (Of course, the track becomes shorter than in the PRC because of the difference of density.) With

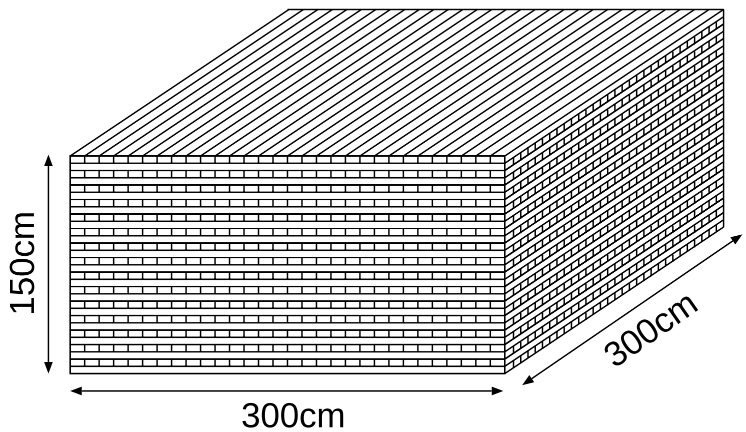

Fig. 2. Proposed design of the Super Solar Neutron Telescope

this new method, the conversion efficiency becomes higher with thicker detectors. The efficiency of the direction measurement also increases in proportion to the conversion efficiency. This is not the case for the current method. To measure the direction, the recoiled particle must penetrate at least 4 layers. The energy threshold of such a proton is 150MeV.

We propose to record the tracks of all triggered events. By means of track analysis, we can avoid misidentification of the direction as indicated in c in the left of Fig.1. Because recording the entire track results in a large data size, some kind of intelligent trigger logic at the electronics stage is needed. A study of a suitable Programmable Logic Device (PLD) is reported in [4].

Scintillator rods with dimensions of 4cm$\times$1cm$\times$300cm are now available. Each rod has a wavelength shifter fiber with a diameter of 1mm inside. A successful measurement of the signal from minimum ionizing particles has been reported from this unit. Because the solar neutrons are scattered in the atmosphere and the recoiled particle also has an opening angle of $\sim$10°, we do not need a very fine pixel size. We will combine several rods into one unit and the fibers from each rod are lead to a Multi-anode Photomultiplier.

4. Performance of the Super Solar Neutron Telescope

To demonstrate the power of this method, we assumed a realistic detector as illustrated in Fig.2. The dimensions are 300cm$\times$300cm horizontal and the thickness 150cm. When neutrons with kinetic energies of 500MeV enter the detector vertically, the direction of 70% of recoiled particles can be measured. Detector simulation is carried out using GEANT 3.21.

The background counting rate is also calculated follows: Primary cosmic rays of energies 10GeV–100TeV with zenith angles $<$60° are injected into the atmosphere and interactions are simulated using COSMOS 6.33. Secondary particles with kinetic energies >1MeV at an atmospheric depth of $600 g/cm^2$ are recorded with their energy and zenith angle. (No azimuthal effect is considered.)

When the outermost layers are used as veto counters for charged particles, a background counting rate of 700Hz is obtained. Using this background estimation, a response for a solar neutron event can be calculated. We assume the neutron emissivity observed on June 4, 1991 [5], $F(E) = 2.94 \times 10^{28} \times (E/100MeV)^{-4.8} \quad [/MeV/sterad]$. Such an event results in 2,000 excess counts from the direction of the sun during 150 seconds. From the same direction and time interval, the estimated background count is about 40,000, so that the excess corresponds to a 10σ statistical significance.

5. Summary

We propose a new type of Solar Neutron Telescope. Because it is composed only of plastic scintillators, the entire volume of the detector can act both as a target and a tracker. This makes the detector powerful in terms of detection efficiency and directional measurements. A study of a realistic sized detector, the Super Solar Neutron Telescope, shows that this detector has a high sensitivity for a reasonable solar neutron event intensity.

Although we have concentrated our arguments on the direction measurement (*i.e.*, the measurement of particles with kinetic energies >150MeV), low energy particles can also be detected. Because the dimensions of the detector are the order of the nuclear interaction length, an increase of the single counting rate of each scintillator unit will be concentrated on the side of the sun. Single counting rate will also provide additional information on the directionality of low energy particles.

We propose to install the Super Solar Neutron Telescope for the observation of the coming solar cycle 24 on mountains at high altitude. Basic studies of the scintillator, multianode photomultiplier and read-out system have been started and also more detailed study using Monte Carlo calculations will be made.

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