A New Solar Neutron Telescope in Mexico

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Abstract

A new solar neutron telescope has been constructed on Mount Sierra Negra (4580m) in Mexico at 19.0°N, 97.3°W. In this paper we describe the scientific purpose of the experiment and details of the detector.

1. Introduction

In order to understand the acceleration of ions in solar flares near the solar surface, it is necessary to determine just when they are accelerated. The traditional neutron monitor is highly sensitive as a detector of neutrons but is unable to measure their energies. The reason is that in a neutron monitor, incoming energetic neutrons are degraded into many low energy neutrons. These are thermalized and captured by BF_3 gas, resulting in the production of α-particles which can be detected by a proportional counter (Hatton, 1971). However the neutron monitor also has advantages: Firstly, it has low sensitivity (~1%) to the high energy muon background (E > 1 GeV) (Clem et al., 2000). Secondly, the neutron monitor is very stable and has a high sensitivity to neutrons with energies down to 10 MeV. [This has been confirmed by accelerator experiments in the energy range 100–396 MeV (Shibata et al., 2001).]

In contrast to photons, neutrons have mass, therefore high energy particles produced in a solar flare arrive before low energy particles. Accordingly, in order to understand whether ions are accelerated abruptly or in a continuous fashion near the solar surface, we have designed and installed a new type of neutron detector. A 1 m^2 prototype telescope installed on Mount Norikura in 1990 succeeded in detecting neutrons from a large solar flare that occurred on 4th June

pp. 3433–3436

1991 (Muraki et al., 1992). The basis of the detector design is plastic scintillator in which the energy of incoming neutrons is measured in terms of the range of protons produced by interactions with carbon and hydrogen nuclei in the scintillator material. Thus we can measure the threshold energies of neutrons with E $>$ 40 MeV, 80 MeV, 120 MeV, etc.

This new neutron detector can function as a telescope and determine the direction of incoming neutrons against the background with improved sensitivity. Thus if we can divide the sky into smaller regions (5×5 or 9×9), the background can be reduced by a factor N=25 (81) for neutrons that are more-or-less unidirectional. In the case of Mount Norikura, the 12 m^2 neutron monitor has less sensitivity to background than 64 m^2 telescope. However, the 64 m^2 telescope has 5.3 times the sensitive area and using the directional possibility, the signal-to-noise ratio of the 64m^2 telescope is improved by a factor 12 ($\sigma = \mathrm{S}/\sqrt{\mathrm{N}}$). [The trigger rate of the neutron monitor at Mount Norikura (2700m) is 3000 (counts/min) /m^2 with the scintillation counter of the neutron telescope showing 20,000 (counts/min)/m^2 for E $>$ 20 MeV (S1 channel). With anti-coincidence (S1-anti channel), this is reduced to 6000 (counts/min)/m^2, which is still twice that of the neutron monitor and involves photons as well as neutrons.] We have good evidence that solar neutrons are scattered by about 15° on passing through the atmosphere, so the directional capability should improve the sensitivity of our detector substantially (Smart et al.1995; Shibata 1994; Dorman 1999, Tsuchiya et al. 1999; Valdes-Galicia et al. 2000). In fact the Tibet solar neutron telescope has observed the expected enhancement using this technique, apparently against expectations which might suggest that solar neutrons can only be observed in summer when the Sun is at its zenith (Tsuchiya et al., 2001).

Our aim is, besides collecting data during solar neutron events, to determine (a) if the ions and electrons are accelerated together in a flare, (b) if they are accelerated instantaneously and (c) if the shock acceleration process works at the solar surface. To obtain good quality data the detector should be located at as high an altitude as possible near the equator to minimize the atmospheric path length. We have chosen Mount Sierra Negra as one of the best possible places and the project will accordingly be conducted jointly between Japan and Mexico.

2. The Solar Neutron Detector at Sierra Negra

The new solar neutron telescope consists of a 4 m^2 array of 30 cm thick plastic scintillator. The detector is surrounded by a gondola of anti-coincidence proportional (PR) counters. Beneath the array, two layers of PR counters are employed to determine the E-W arrival direction, and two more to determine the N-S arrival direction. [The directions are determined from the protons produced by neutrons interacting within the scintillator material. This provides enough accuracy to determine the incoming neutron direction to within 15°]. A schematic

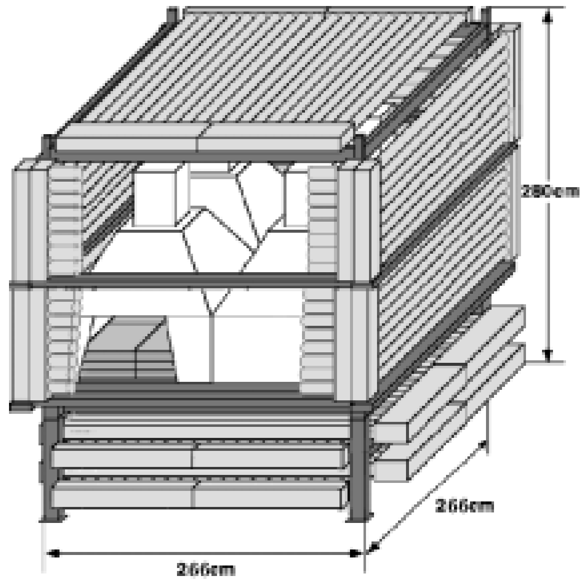

Fig. 1. The solar neutron telescope at Mt. Sierra Negra (4600m). Four $1m^2$ scintillators are shielded by the anti-coincidence system. On the top of the telescope, a 5mm thick lead plate is installed to convert background photons into electron and positron pairs. Below of the scintillator, four layers of proportional counter array are used to identify the arrival direction of neutrons.

diagram of the detector is shown in Fig. 1 and intermediate views are shown in Figs. 2 and 3. Above the anti-coincidence gondola there is a 5 mm lead plate in which 67% of incoming photons are converted into electron-positron pairs. To reduce background coming from the sides, the PR counters are shielded from any low energy photon background by 10 mm thick iron plates. The detector was completed and tested in March 2003 with a local electricity supply. A commercial supply of electricity is expected to be provided in June 2003 and the first data will be made available on the internet.

3. Preliminary Results

The counting rate at Mount Sierra Negra for charged particles (electrons, positrons, muons) is 47,000(counts/min)/m^2. With the anti-coincidence gondola active, the counting rate in the plastic scintillator is reduced to 20,000(counts/min) /m^2. Both rates appear to be reasonable on the basis of Monte Carlo calculations. We expect that the new telescope will provide a great deal of new information during the remainder of solar cycle 23 and in solar cycle 24, especially in conjunction with the solar neutron detector situated on Mount Chacaltaya (5250m) in Bolivia.

Fig. 2. The first scintillator was in place.

Fig. 3. All scintillators and side anti-counters installed.

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