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The upgraded solar neutron detector at Gornergrat

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Abstract. Since 1998 a solar neutron detector at Gornergrat, Switzerland, has been in operation as the European cornerstone of a worldwide network for the study of high-energy neutrons produced during energetic processes at the Sun. In autumn 1999 additional proportional counters and logic electronics were added to determine the direction of incoming neutrons. The paper discusses the principles of the additional components and the characteristics of the upgraded detector.

1 Introduction

In contrast to charged particles emitted in association with solar flares and coronal mass ejections neutrons are not affected by the magnetic field of the Sun, nor by the interplanetary magnetic field, nor by the geomagnetic field. Observations of solar neutrons therefore offer a direct insight into the mechanisms of high energy processes at the Sun. The additional possibility to measure the energy spectrum of the neutrons gives information about the timing and the duration of the high energy solar processes. This allows to get a better understanding of the acceleration mechanism of charged particles at the Sun. This information, along with measurements of solar gamma ray emission and charged particles, is the basis for building solar flare models.

The first identification of a solar neutron event by ground-based detectors on 3 June 1982 (Debrunner et al. 1983; Chupp et al., 1987) initiated extensive theoretical and experimental work on the production of solar neutrons during high-energy processes at the Sun, their propagation to 1 AU, and their detection near and at the Earth. One part of the activities was setting up standardized neutron monitors at favorable observational locations, such as Haleakala, Hawaii (Pyle and Simpson, 1991). Another part was the development of new ground-based detectors with enhanced sensitivity for solar neutrons (e.g. Shibata et al., 1991; Muraki et al., 1993).

Initiated by the Solar-Terrestrial Environment Laboratory of the Nagoya University a new global network was built to make possible the observation of solar neutrons during 24 hours. Today the following neutron detectors are in operation: Gornergrat, Switzerland (7.78° E, 45.98° N, 3135 m asl (Flückiger et al., 1998)), Mt. Aragats, Armenia (45° E, 40° N, 3500 m asl (Tsuchiya, 1998)), Yangbajing, Tibet (90.53° E, 30.11° N, 4300 m asl (Katayose et al., 1999)), Mt. Norikura, Japan (138° E, 36° N, 2770 m asl (Muraki et al., 1997)), Mauna Kea, Hawaii (155° W, 20° N, 4200 m asl (Matsubara et al., 1997)) and Mt. Chacaltaya, Bolivia (68° W, 16° S, 5250 m asl (Matsubara et al., 1993)).

In this paper the Gornergrat detector with the upgradings made in autumn 1999 and the possibilities of the direction determination of neutrons are presented.

2 Detector and data storage before the upgrading

The solar neutron detector at Gornergrat (Flückiger et al., 1998), in operation since 1998, can discriminate neutrons from charged particles. It is capable providing information about the energy of incoming neutrons by measuring the energy deposition along the total track length of recoil protons produced inside the plastic scintillators by elastic n-p and inelastic n-C reactions.

The detector has an effective area of 4 m^2. It consists of a horizontal matrix of four 1 m $\times$ 1 m $\times$ 0.4 m plastic scintillators. Scintillation flashes in each scintillator are collected by a photomultiplier (Hamamatsu R1512). The pulse height obtained from each photomultiplier is discriminated at four levels, which correspond to the deposited energy of a recoil proton of 40 MeV, 80 MeV, 120 MeV, and 160 MeV. The scintillators are surrounded at the top by 20 and at the two sides (east and west) by 32 proportional counters which veto charged particles. Neutrons are identified by the scintillators in anti-coincidence with the veto counters.

After proper amplification and discrimination the signals

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of the photomultipliers and of the proportional counters are counted in two 16-channel 100 MHz CAMAC scalers (N-TS 112). Every 10 s the scalers are read out by a PC and the data are saved on a hard-disk and on a Exabyte tape. Accurate time is taken from GPS, whereas the barometric pressure is measured by a barometer near the detector.

3 Upgrading of the detector

In autumn 1999 additional proportional counters were added to the detector. Four counter units with a total of 32 counter tubes were mounted on the two open sides of the detector (south and north) to complete the veto system. For the determination of the direction of incoming neutrons, two layers of 20 proportional counters each were added at the bottom under the plastic scintillators. The active length of these proportional counter tubes is 185 cm. The proportional counters are aligned in the east-west direction and the vertical displacement of the two layers of counters is 23 cm.

The configuration of the upgraded detector is illustrated in Figure 1.

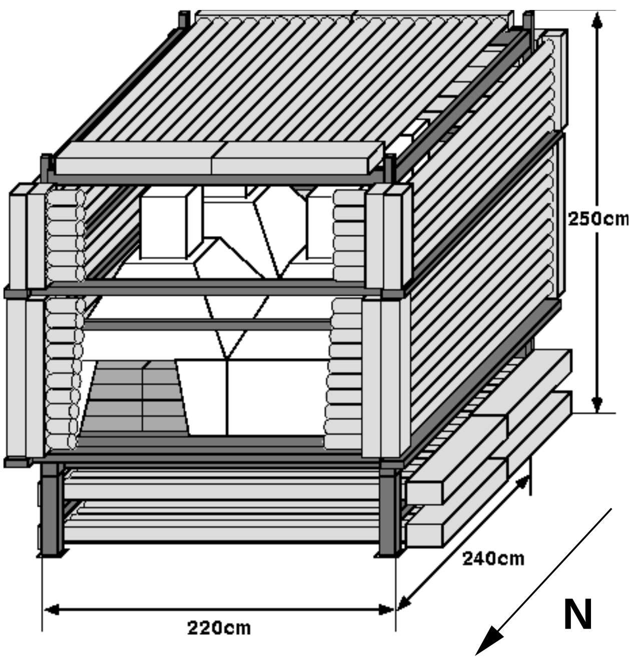

Fig. 1. Configuration of the upgraded Gornergrat solar neutron detector.

The direction of recoil protons is determined by measuring coincidences between two counters of the two bottom layers of proportional counters. The arrival directions of neutrons are classified into 5 bins. Coincidences between two counter tubes, one in the upper and one in the lower layer with -2, -1, 0, $+1$, $+2$ horizontal counter tube displacements are measured. With this configuration a rough distinction between the following zenith angle regions is possible: around 40° N, 25° N, 0°, 25° S and 40° S. The principle is illustrated schematically in Figure 2. To assure that only the direction of recoil protons produced by a neutron will be counted, the input to the direction counters is in coincidence with the channel $E > 40$ MeV of the scintillator counters with veto. Therefore, pulses are only counted if there is simultaneously also a count signal from a photomultiplier, but not from a veto proportional counter.

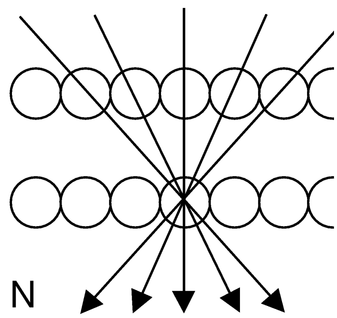

Fig. 2. Cross-section in the north-south direction of the bottom proportional counters illustrating the principle for determing directional information. For details see the text.

The comparison of the count rates from the solar direction (south) with the count rates from northerly direction makes it possible to reduce the galactic cosmic ray background. Furthermore the determination of the direction of neutrons allows to verify if an excess in the counting rate was produced by neutrons coming from the Sun's direction, i.e. solar neutrons.

4 Measurements

The average quiet-time count rates of the scintillators, of the veto counters, and of the direction counters are listed in Table 1.

	without veto [cts/s]	with veto [cts/s]
Scintillators		
Channel 1: > 40 MeV	2200	1400
Channel 2: > 80 MeV	1400	840
Channel 3: > 120 MeV	490	290
Channel 4: > 160 MeV	100	55
Proportional counters	5000	
Directions (zenith angle)		
0°	260	
25° S	220	
25° N	220	
40° S	140	
40° N	140	

Table 1. Average quiet-time count rates of the scintillators, of the veto counters, and of the direction counters (time period: 1 December 2000 - 26 March 2001).

Estimations of the directional response of the detector were made for a solar neutron event such as the one on 3 June 1982 observed by the IGY neutron monitor at Jungfraujoch (Debrunner et al., 1983). The results show a clear identification of incoming neutrons from the south direction. The direction of incoming neutrons can, however, only be determined if the neutrons have enough energy to produce recoil protons that penetrate the plastic scintillator, deposit at least 40 MeV in the scintillator, and make afterwards also a count signal in both proportional counter layers under the scintillator blocks. Therefore, it is concluded that during a solar neutron event an increase in the count rate of the south direction counters due to solar neutrons will be observed only for a limited time during the event.

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