

Highest Energy Neutrons Detected by a Solar Neutron Telescope in Association with the November 28th 1998, Solar Flare

Y. Muraki^a, H. Tsuchiya^{a,b}, P. Evenson^{a,c}, K. Fujiki^a, Y. Matsubara^a, H. Menjyo^a, S. Masuda^a, T. Sako^a, K. Watanabe^a, S. Ohnishi^d, A. Shiomi^d, T. Yuda^d, Y. Katayose^e, N. Hotta^f, S. Ozawa^f, T. Sakurai^g, T. Sakai^h, Y.H. Tanⁱ

(a) Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya 464-8601, Japan

(b) Institute of Physical and Chemical Research, Wako 351-0198, Japan

(c) Bartol Research Institute, University of Delaware, Newark, DE19716, USA

(d) Inst. for Cosmic Ray Research, Univ. of Tokyo, Kashiwa 272-8582, Japan

(e) Faculty of Education, Yokohama National Univ., Yokohama 240-8501, Japan

(f) Dep. of physics, Utsunomiya Univ., Utsunomiya 321-8505, Japan

(g) Solar Physics div., National Astronomical Observatory, Mitaka 181-8588, Japan

(h) College of Industrial Technologies, Nihon University, Narashino 275-0005, Japan

(i) Institute of High Energy Physics, Academia Sinica, Beijing 100039, China

Presenter: T. Sako (sako@stelab.nagoya-u.ac.jp), jap-sako-T-abs3-sh11-poster

A large solar flare was observed at N17E32 of the solar surface at 5:31 UT and the intensity of the flare measured by the *GOES* satellite was X3.3. In association with this flare, the solar neutron telescope located at Tibet observed an enhancement from the direction of the Sun. In this paper we discuss a possibility that quite high energy neutrons are detected by the solar neutron telescope at Tibet (600 g/cm^2). If so, this is the first evidence that solar neutrons detected beyond 10 GeV and even in the winter time under some conditions, we can detect solar neutrons at the northern hemisphere, if we use the telescope function.

1. Neutron event on November 28th, 1998

In the conference proceeding of 26th ICRC, the authors reported arrival of solar neutrons in association with a large solar flare on November 28th 1998 [1, 2, 3]. In this paper we report the results of further analysis for the data.

On November 28th 1998, an X3.3/3N solar flare was observed at N17E32 in active region 8395. According to *GOES* spacecraft data, the flare onset time and the maximum time were 4:54 UT and 5:52 UT respectively. A complicated loop structure was observed by the soft X-ray telescope on board *Yohkoh*. The loop started growing at $\sim 5:30$ UT with thermal emission from the loop reaching a maximum intensity at $\sim 5:50$ UT. *Yohkoh* detected hard X-ray emission (93 – 252 keV) between 5:39 UT and 5:43 UT (the peak time was $\sim 5:41$ UT). *CGRO/BATSE* also detected hard X-ray emissions (30 – 58 keV) with the peak at 5:40:46 UT. Hard X-ray emission started at 5:31:26 UT with a rapid increase beginning at 5:37 UT. The Nobeyama Radio heliograph detected radio emissions at a frequency of 17 GHz and 34 GHz with the maximum emission observed at 5:39:51 UT.

We have investigated the time profile obtained by the Tibet solar neutron telescope near the time when the solar flare occurred. There is no noticeable enhancement of the counting rate obtained by the upper scintillators around 5:31–5:37 UT. In this respect, the data from the scintillation counters shows the same behavior as the data from the neutron monitor in Tibet [4].

Quite surprisingly, as shown in Figure 1, the higher energy counting rate from the south (the direction of the Sun) clearly shows an enhancement in comparison with the (off-source) data obtained from the north. The neutron telescope detects neutrons higher than 270 MeV and is also sensitive to photons with energy higher

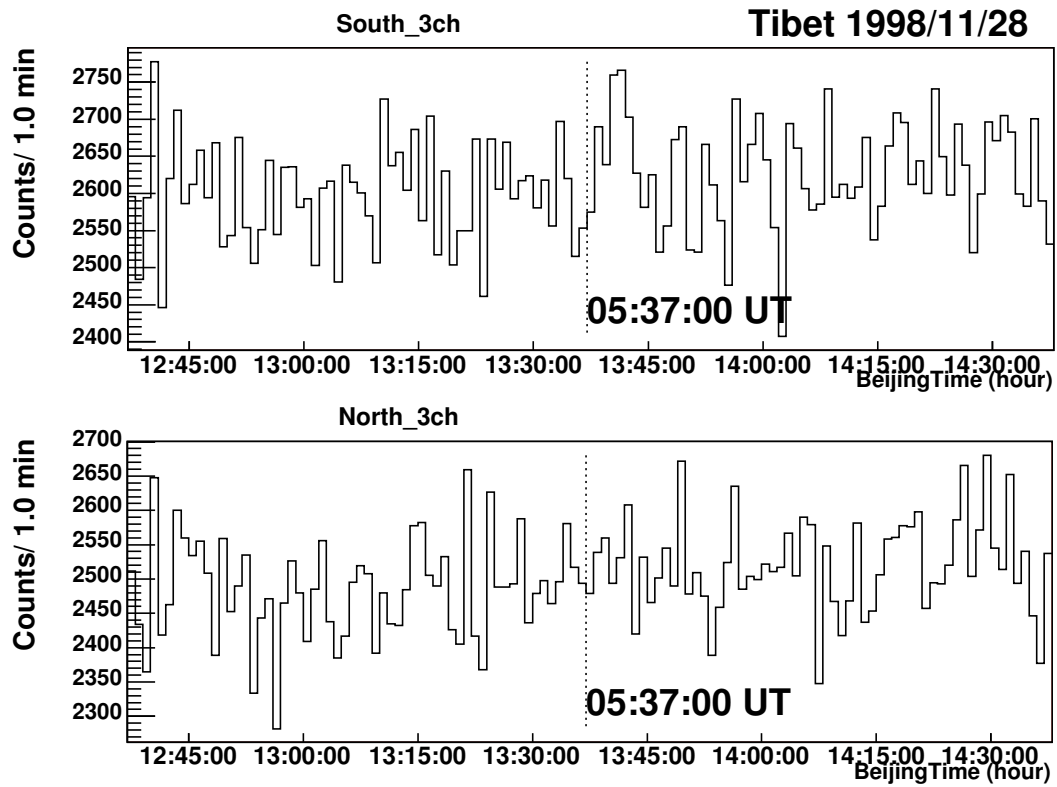


Figure 1. Comparison of the flux of neutrons from the north and the south directions. Three directional data for north and south were summed up independently.

than 80 MeV. The difference in the threshold energy comes from the difference in ionization loss between electrons and protons since low energy protons lose more energy in the scintillator and the wood than electrons. In the first stage of the data analysis, we did not consider a possible contamination of high energy photons in neutron events since photons are much more strongly absorbed in the atmosphere than are neutrons. (This is not true if the energy of the photon is over 10 GeV, at which point a few particles produced by the cascade shower arrive at high altitude.) In Figure 2, the counting rate of secondary particles produced by vertically incident neutrons is shown, based on a Monte Carlo calculation made using GEANT4. In the calculation a power law spectrum of incoming solar neutrons is assumed with $\gamma = -2.5$ in the energy range $E_n = 1$ to 100 GeV. From Figure 2, the number of neutrons over 270 MeV at Tibet is estimated as to be 0.05 event per high energy neutron (over an area equal to that of the detector) at the top of the atmosphere and 0.045 event for each photons with energy higher than 80 MeV. This implies that the attenuation of electrons and neutrons is the same order of magnitude and we could expect to see an effect due to photons when high energy neutrons interact at the top of the atmosphere.

For the attenuation 750 g/cm^2 , the actual case, the number of neutrons over 270 MeV at Tibet is estimated as to be > 0.008 event/neutron and > 0.012 events for each photon. We estimate the sensitivity by the multiplying the attenuation of each component by the detection efficiency. The result, obtained from the Monte Carlo

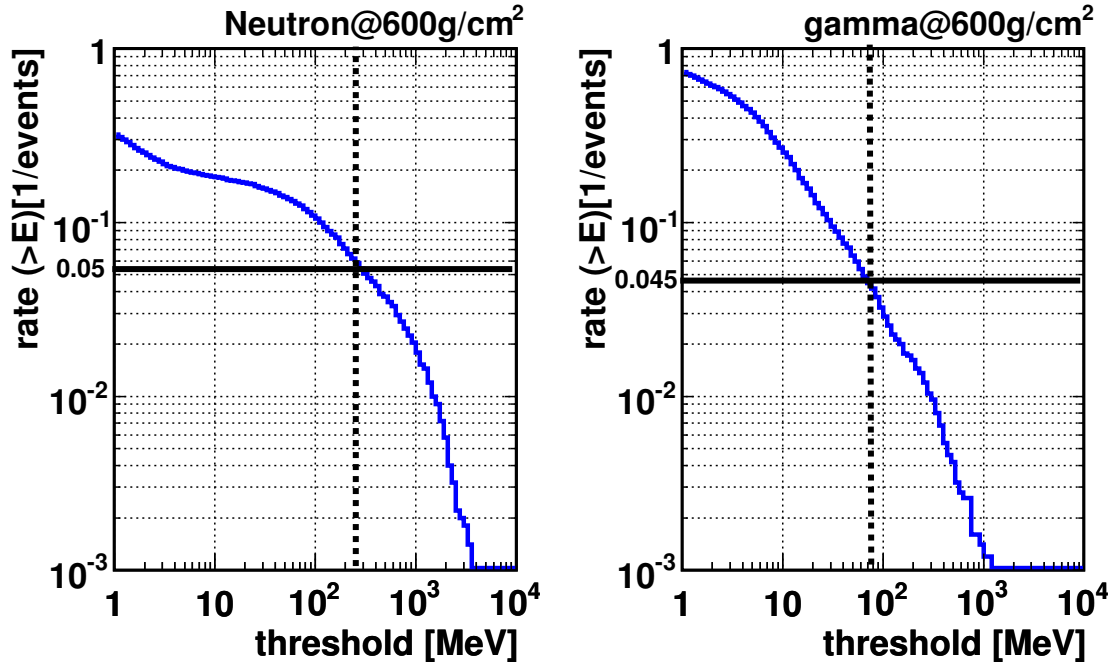


Figure 2. Counting rate of secondary particles produced by neutrons. The Monte Carlo calculation by GEANT4.

calculation and analytically based on the data is 0.25% and 0.2% for neutrons (> 270 MeV) and photons (> 72 MeV) respectively.

2. A new interpretation for the November 28th 1998, event

On February 22nd 1999, Japanese solar physicists who observe the Sun at different wave lengths met at the Solar-Terrestrial Environment Laboratory, Nagoya University to discuss this event.

One of the difficulties in understanding this event is that the number of events detected by the channel3 (E_p or $E_e > 120$ MeV) of the upper scintillators is the same as that in the down side proportional counters ($E_p > 270$ MeV). If the excess of the event were due to neutrons, according to Monte Carlo calculations, the number of events detected by upper scintillator should be greater than the number of penetrating events. Trigger pulses are produced by the coincidence between the upper channels (at least > 40 MeV deposited energy is necessary in the scintillator) and lower four layers of the proportional counters. Inside the four layers of the proportional counters are two layers of wood with a total thickness of 20 cm. According to the Monte Carlo calculation the ratio of the upper channel to coincidence signal is expected as to be a factor of four to ten, depending on the energy of the neutrons in the range 270 – 1000 MeV.

Recently we have concluded that high energy neutrons, beyond 5 GeV, were involved in this event. Therefore photons must be included in the calculation. Only the most recent version of GEANT4 can treat neutron cas-

cade in the atmosphere correctly down to a few MeV (Koi et al, private communication). We have determined the best model using a new version of GEANT4 and compared the results to those of Shibata [5]. In this process, we discovered that the intensity of photons is expected as to be the same order as that of neutrons.

Hence we have arrived at a new interpretation for this event, namely that the flare must have accelerated protons to beyond 100 GeV and thereby also produced high energy neutrons. In our simulation we have assumed a power law spectrum of neutrons with index $\gamma = -2.5$. Such high energy neutrons produce not only charged pions in the atmosphere but also neutral pions, which immediately decay into two photons and initiate an electromagnetic cascade. Those photons penetrate the solar neutron telescope through the anti-counter which cannot separate neutrons from photons. The radiation length of upper scintillator is just one radiation length, so most photons are converted into electron positron pairs in the scintillator. These are minimum ionizing particles which can penetrate both layers of wood and all four layers of the proportional counters.

We conclude that in this solar flare, particles were accelerated to at least 10 GeV, and probably to over 100 GeV over a time interval of a few minutes. Confirmation of such high energy solar particles will be one of the most important tasks of the next solar cycle.

References

- [1] Hoshida et al., Proceed. 26th ICRC, 6, 38 (1999).
- [2] Katayose et al., Proceed. 26th ICRC, 6, 58 (1999).
- [3] Tsuchiya et al., Proceed. 27th ICRC, 8, 3056 (2001).
- [4] Kohno et al., Proceed. 26th ICRC, 6, 65 (1999).
- [5] Shibata, JGR, 99, 6651 (1994).