GEANT applications for the interpretation of ground-based solar neutron observations

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Abstract

For the interpretation of data from ground-based solar neutron detectors we developed GEANT Monte Carlo applications to simulate the propagation of neutrons through the Earth's atmosphere and to determine detector responses.

1. Introduction

Initiated by the Solar-Terrestrial Environment Laboratory of the Nagoya University in Japan, a global network of Solar Neutron Telescopes was set up during the 1990's, allowing ground-based solar neutron observation 24 hours a day. Solar neutron detectors are in operation at Mt. Norikura, Japan [9], Mt. Chacaltaya, Bolivia [6], Mauna Kea, Hawaii [7], Mt. Aragats, Armenia [10], Yangbajing, Tibet [5] and Gornergrat, Switzerland [1].

In order to interpret the ground-based recordings, it is necessary to know the relationship between the counting rates of the detectors and the primary particle flux penetrating the Earth's atmosphere. Since this relationship can hardly be determined experimentally or analytically, we developed a Monte Carlo software based on the GEANT3 and GEANT4 codes to simulate the neutron propagation through the Earth's atmosphere [8, 3] and to determine the detector properties [8]. In a case study the response of the detector at Gornergrat (SONTEL) was simulated for historic solar particle events and compared with measurements.

The developed Monte Carlo applications are a convenient tool to simulate possible improvements of the detectors within the Solar Neutron Telescope network. Furthermore, they can be used for the development of new ground-based solar neutron detectors.

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2. Simulation results

2.1. Detector efficiencies

For the various detection channels of SONTEL we determined the detection efficiencies as a function of energy and direction of incidence. Fig. 1 shows the vertical efficiencies of the energy channels $>$ 40 MeV for different types of radiation.

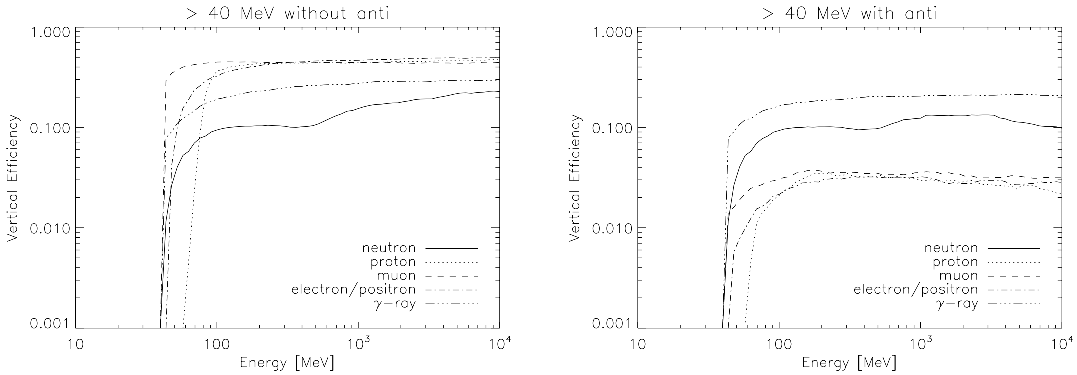

Fig. 1. Simulated vertical efficiencies of the $>$ 40 MeV energy channel without anti (left) and with anti coincidence (right).

Fig. 2 represents the vertical efficiencies for neutrons of the four energy channels with anti and of the directional channels. The results for the directional channels also contain the contributions by multiple signals of m different directional channels to the total efficiency.

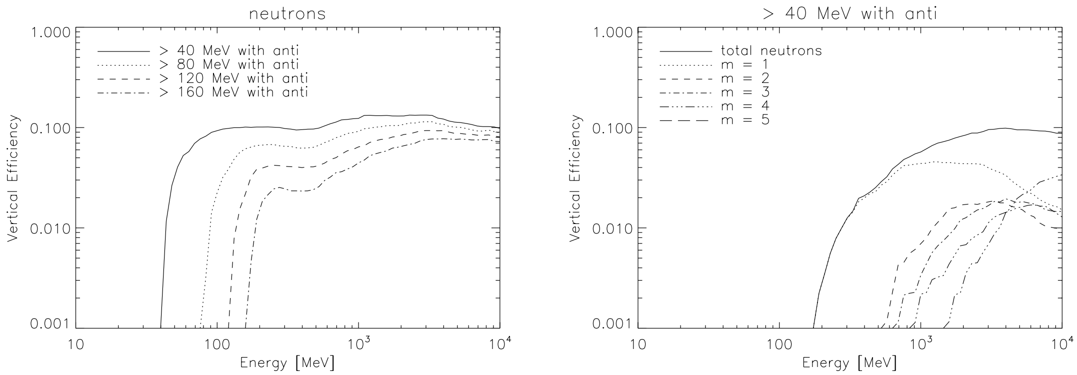

Fig. 2. Simulated vertical efficiencies for neutrons of the energy channels with anti (left) and of the directional channels (right).

2.2. Response to galactic cosmic rays

The average counting rates of the various SONTEL detection channels due to secondary galactic cosmic rays have been simulated for mean solar activity.

These results are in satisfactory agreement with experimental data. Table 1 lists the theoretically derived relative contributions of the various secondary cosmic ray components to total SONTEL counting rates. The results show significant differences to standard neutron monitors [4] with respect to the neutron, muon, and γ-ray components.

Radiation type	SONTEL > 40 MeV with anti	SONTEL > 40 MeV without anti	SONTEL A = B	IGY	NM64
neutron	40%	8%	29%	84%	85%
proton	2%	4%	2%	7%	6%
muon	30%	76%	40%	7%	6%
electron	2%	6%	1%		
γ-ray	26%	6%	27%		

Table 1. Relative contributions of the various radiation types to the total SONTEL counting rates > 40 MeV, A = B (zenith direction), and to the counting rates of an IGY and NM64 at high latitude sea-level locations [4], at mean solar activity.

2.3. Propagation of neutrons through the Earth's atmosphere

We simulated the propagation of neutrons through the Earth's atmosphere considering monoenergetic neutron beams entering a U.S. Standard Atmosphere 76 at an altitude of 20 km. As an example Fig. 3 shows the simulated secondary particle spectra at Gornergrat altitude for a primary neutron energy of 1068 MeV and zenith angle 25.5° for the solar neutron event on June 3, 1982. Assuming that in this event the neutrons were emitted at the Sun as a δ-function in time, the selected energy corresponds to the neutron energy at the onset of the counting rate increase as recorded by the Jungfraujoch neutron monitor [2].

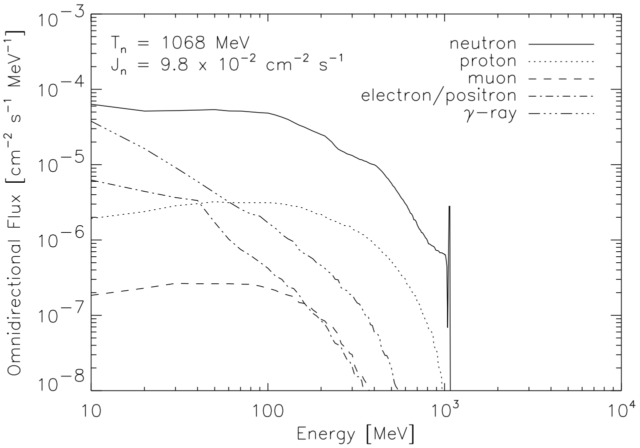

Fig. 3. Omnidirectional spectra of secondary particles at an altitude of 3135 m a.s.l. for a primary neutron energy of 1068 MeV as calculated for the June 3, 1982, event.

2.4. Response to solar neutrons

For the June 3, 1982, solar neutron event we simulated the evolution of the response of the SONTEL detector. Fig. 4 shows that SONTEL could have identified solar neutrons above $\sim 400\,\mathrm{MeV}$ with a significance of up to $\sim 10\sigma$ in the 1-minute values. The differential energy spectra, however, would not have provided significant information on the primary neutron spectrum.

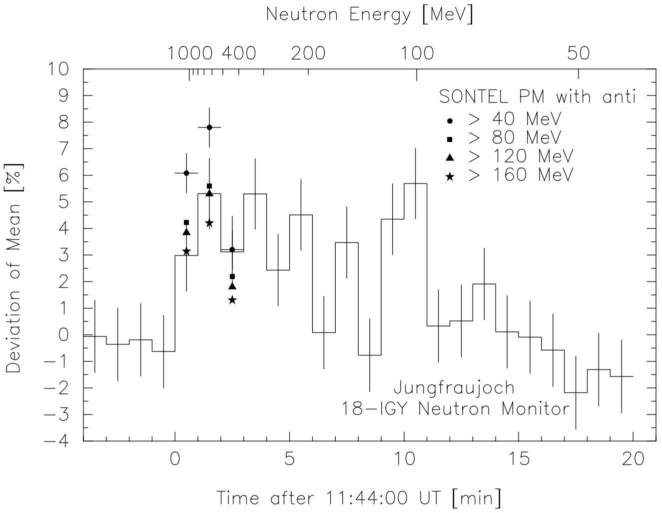

Fig. 4. Increase in the 18-IGY neutron monitor counting rate at Jungfraujoch during the solar neutron event on June 3, 1982 [2]. The simulated increases in the SONTEL neutron channels are indicated for neutron energies 1068, 648, and 454 MeV.

3. Acknowledgments

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4. References

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