Estimation of the SONTRAC Detector Efficiency for Solar Flare Neutrons by Geant4 Monte Carlo Simulations

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Abstract

The SONTRAC (SOlar Neutron TRACking) instrument is designed to measure the direction and energy of neutrons in the energy range 20–250 MeV. The detection principle is based on single and double elastic scattering of neutrons off ambient protons within a block of densely packed scintillating plastic fibers. This paper presents Geant4 computed estimates of the SONTRAC detector efficiency at different distances from the Sun, for a realistic solar neutron emission spectrum, and for different detector sizes. The calculations show that an instrument 20 cm on a side positioned at 1 AU can be as efficient as the COMPTEL instrument on the CGRO.

1. Introduction

The precise determination of the energy of solar flare neutrons should allow a better estimate of the spectrum of protons and ions accelerated in solar flares and therefore should improve our understanding of the acceleration mechanism taking place during such eruptive events. The SONTRAC (SOlar Neutron TRACking) detector is designed to measure the direction and energy of neutrons in the energy range 20–250 MeV [3]. The detection principle is based on single and double elastic scattering of neutrons off ambient protons within a block of densely packed scintillating plastic fibers. The imaging system in SONTRAC allows to reconstruct 3D recoil proton tracks in the scintillating block. The Lorentz momenta of the recoil protons are computed from these tracks. The energy and direction (only for double scatters) of incident neutrons are deduced from these Lorentz momenta.

A detailed Monte Carlo simulation of the SONTRAC instrument is necessary to optimize the instrument's design and to obtain a quantitative estimate of the detector's capabilities. For this purpose we have developed a Monte Carlo code based on the use of Geant4. In this paper we describe the code and present results.

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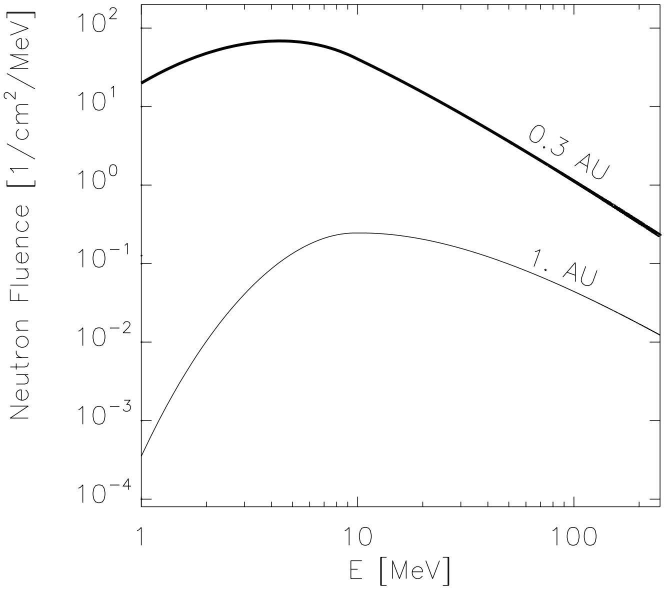

Fig. 1. Neutron fluence spectra at 0.3 and 1 AU used in the simulations, assuming solar neutron emissivity according to Debrunner et al. [1]

2. Geant4 Monte Carlo Model of the SONTRAC Detector

We have developed a SONTRAC Monte Carlo code based on the Geant4 toolkit. In this code the scintillating fiber block is modeled by a polystyrene block with the same density and composition as in the SONTRAC scientific model [3,5]. The principal physical processes considered in the code are the elastic scattering of neutrons on hydrogen nuclei (np scatters), the elastic and inelastic scattering of neutrons on carbon nuclei (nC scatters), the ionizing energy loss and the multiple scattering of charged particles. For np and nC elastic scattering we have implemented our own model. Total and differential cross sections of these mechanisms have been taken from the Evaluated Nuclear Data File library. For modeling the nC inelastic scattering we have selected two models available in Geant4: the low energy neutron model for energies lower than 20 MeV, and a precompound model at higher energies.

In the neutron detection mode of the SONTRAC Monte Carlo model, for each neutron interacting within the polystyrene block, we register the range and direction of single and double recoil proton tracks, and the number of np elastic and nC inelastic scatters occurring during this event. In earlier publications we presented reconstructed neutron energies and directions deduced from recoil proton ranges and directions [2,5]. Here, we use the number of single and double np scatters to quantify the neutron detection capability of a flight version of SONTRAC.

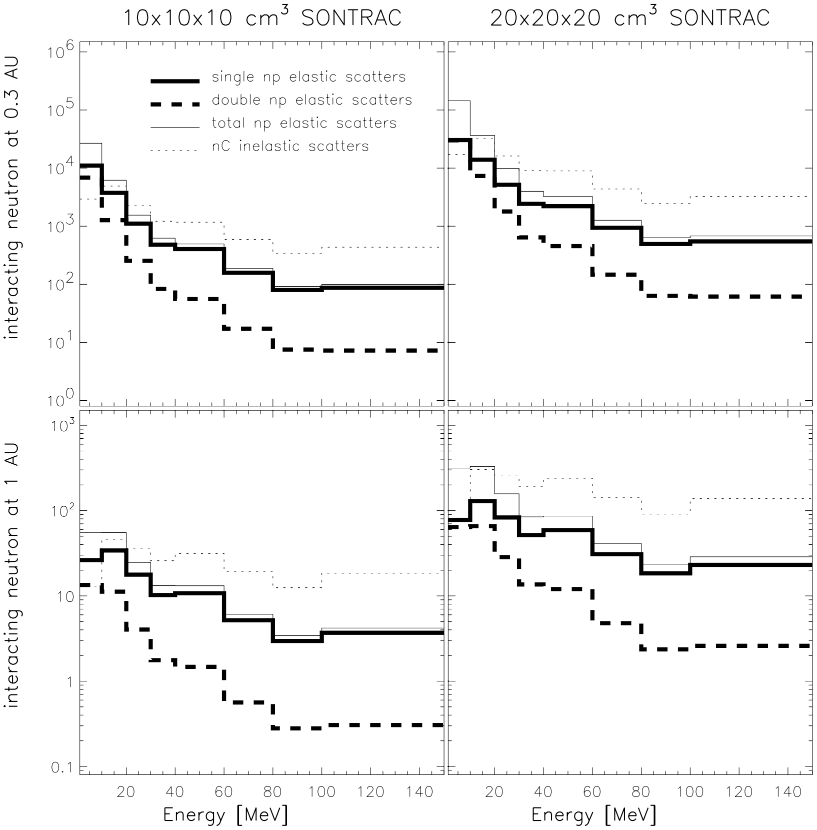

Fig. 2. Computed number of solar flare neutrons (assuming the spectra in Fig. 1) that should be detected at 0.3 AU (top) and 1 AU (bottom), by $10 \times 10 \times 10$ cm^3 (left) and $20 \times 20 \times 20$ cm^3 SONTRACs (right) in different detection modes and in different energy bins.

3. Detector Efficiency for a Realistic Solar Neutron Spectrum

We computed the SONTRAC response to a solar flare at a distance of 0.3 AU and 1 AU from the Sun. For the neutron emission we choose that of the 15 June 1991 solar flare deduced by Debrunner et al. [1], i.e. 8.8×10^{27} sr^{-1} over 30 minutes in the energy range of 10–100 MeV. Above 20 MeV the neutron spectrum is described by a power law, but at lower energy it rolls over into an exponential spectrum ($E_0 = 5\,\mathrm{MeV}$) that would be representative of a nuclear evaporation spectrum. The resulting neutron fluence spectra at 0.3 AU and 1 AU are plotted in Fig. 1. At 1 AU the flux below 10 MeV is greatly reduced due to neutron decay.

Fig. 2 presents the resulting number of neutrons detected at 0.3 AU (top) and 1 AU (bottom), in different energy bins, by $10 \times 10 \times 10$ cm^3 (left) and $20 \times 20 \times 20$ cm^3 SONTRAC detectors (right). Four different interaction modes were considered: single np elastic scatters without inelastic scatters, double np elastic scatters without inelastic scatters, more than two np elastic scatters without inelastic scatters and at least one nC inelastic scatter. For this simulation only neutrons incident normally at the center of the detector surface were considered.

4. Discussion

From Fig. 2 we see that, for a neutron fluence spectrum as defined in Fig. 1, a $10 \times 10 \times 10$ cm^3 SONTRAC instrument would detect at 0.3 AU about 425 and 9 double elastic np scatters in the energy ranges 20–150 MeV and 100–150 MeV, respectively. It would also detect about 6100 elastic np single scatter events in the energy range 10–150 MeV. Double scatters will be used for imaging the Sun and for spectroscopy. The np single scatters mode could be used as well for spectroscopy providing that the S/N ratio is high enough for a background substraction. At 1 AU this instrument would detect only 9 double np scatters above 20 MeV and 84 single np scatters above 10 MeV. This is certainly not enough and at this distance a larger SONTRAC should be used.

A $20 \times 20 \times 20$ cm^3 SONTRAC instrument would detect at 0.3 AU about 3160 and 65 double elastic np scatters in the energy range 20–150 MeV and 100–150 MeV, respectively. This larger instrument would, however, be more appropriate in Earth orbit rather than deep space. There it would register about 63 solar neutrons in the double np scatter mode in the energy range 20–150 MeV, and about 267 solar neutrons in the single np elastic scatter mode in the same energy range. This compares to the number of neutrons that COMPTEL registered as double scatter events in the 15 June 1991 solar flare [4]. This performance is in a package on the order of 1% of the mass and 0.1% of the volume of COMPTEL.

Other events may be useful in detecting solar neutrons. One such event type includes an elastic scatter followed by a nC scatter. Since the nC scattering cross section remains high beyond 80 MeV, such a data channel may greatly increase the number of usable SONTRAC events. We will study this mode in future work.

5. Acknowledgments

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6. References

1. Debrunner H. et al. 1993, Proc. 23rd ICRC, 3, 115
2. Desorgher L. et al. 2001, Proc. 27th ICRC, 8, 3065
3. Miller R. S. et al. 2003, Nucl. Instr. Meth. A, accepted for publication
4. Nieminen P. 1997, Inauguraldissertation, University of Bern
5. Ryan J. et al. 2002, SPIE Conf. Proc., 4853, 399