Flux of Secondary Particles induced by Solar Neutrons and Protons

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Abstract—**At the 30th International Conference on Cosmic Rays we reported the fluxes of secondary particles produced by solar neutrons and protons. The fluxes were calculated using two Monte Carlo codes, GEANT4 and CORSIKA [1]. We found systematic differences between the fluxes of neutrons predicted by the two codes, but not between the fluxes of electrons or photons. We investigated the former difference, and found two feasible causes, as described in [1].**

In [1] we discussed neutron fluxes at an observational altitude of 600g/cm^2 only. However, observations were made at various altitudes, 5,250m (Chacaltaya), 4,200m (Tibet and Mauna Kea, Hawaii), 2,770m (Mt. Norikura) and ground level. Monte Carlo techniques are needed to deduce the intensity of solar particles incident at the top of the atmosphere from observations made at these altitudes. In this paper we provide basic data for this conversion.

1. PURPOSE OF THE MONTE CARLO CALCULATIONS

Large numbers of particles are accelerated to high energies in solar flares, sometimes beyond 10 GeV. These particles reach Earth and produce Ground Level Enhancements (GLEs). They used to be monitored by the GOES satellite. When we try to deduce the energy spectra of SEPs at the top of the atmosphere, it is necessary to combine data obtained by the GOES satellite with data obtained by neutron monitors at ground levels. A conversion factor of the neutron monitor data is then needed to deduce fluxes at the top of the atmosphere. Neutron monitors are sited at various altitudes and observations are often made at different altitudes. Atmospheric attenuation factors of SEPs at various altitudes are therefore required.

A good code of Monte Carlo calculations was not made available until recently. This is because the interaction processes of very low energy neutrons in nuclear cascades are complicated. However, the new GEANT 4 code (version 4.6.2.p02) together with the interaction model, QGSP_BERT, is now available with improved simulations of neutron cascade processes at low energies down to a few MeV [2]. It is now possible to deduce initial neutron and proton fluxes at the top of the atmosphere with use of these codes. In the previous paper, we have presented the results on atmospheric attenuation and compare these with results calculated by CORSIKA. The new results should be useful in future cosmic ray research, especially for understanding SEPs. However at that time, we have presented only the result at the atmospheric depth 600g/cm^2. In this paper we present the secondary fluxes at different altitudes.

2. CONDITIONS OF CALCULATIONS

We calculated integral spectra of electrons, photons, muons, protons and neutrons for primary incident protons and neutrons with energies 1-10GeV, 1-100GeV, and 1-1000 GeV. The power indices of proton and neutron primaries were both assumed to be -2.5 above 1 GeV. The calculations were made using CORSIKA with options QGSJET01 plus GHEISHA 200. The results are shown in Figs. 1 to 4. These results correspond to the flux of neutrons at the observation attitude for 500 g/cm^2, 600 g/cm^2, 700 g/cm^2 and 800 g/cm^2 respectively. The plots were obtained for vertically incident neutrons. For the proton, photon and muon component, the results are given by Figs. 5-8, Figs.9-12 and Figs. 13-15 respectively..

The upper lines of the panels (solid line) represent for the contribution of primary neutron components with E_n= 1-1000 GeV, the middle line (dashed) for E_n= 1-100 GeV and the lower line (dotted) for only the contribution of neutrons with E_n=1-10 GeV. A note must be made here that on the neutron components, the GEANT 4 prediction is doubles that of CORSIKA [1]. This stems from the fact that the contribution of anti-neutron production in the early stages of the nuclear cascade was not included in present calculation by CORSIKA.

It must be noted that in the treatment of CORSIKA results, anti-neutrons produced are not selected in the sampling of the "neutron component" ; the number of anti-neutrons produced in CORSIKA is practically symmetric of the neutron number and when we denominate "neutron component" the neutron and anti-neutron content the result turns to be double.

Another discrepancy may come from both QGSJET01 and GHEISHA. An excess of produced pions for QGSJET01

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model was ascertained during comparisons with p-C collisions in NA49 experiment at 158~GeV/c (3); one consequence is again an excess of muons and hadrons in the cascade simulated. This circumstance supports the preference of QGSJET II for further analysis. However, this discrepancy is present only in the upper part of the cascade above 80 GeV. Under this energy, GHEISHA is performing the simulation of the hadron component inside CORSIKA; the comparison with other options selected, for instance FLUKA to be more close of GEANT shows also an excess of pions produced in the case of GHEISHA (4). It could be interesting to repeat the simulation with other options implemented in CORSIKA such as QGSJET II-FLUKA or EPOS-FLUKA.

3. RESULTS AND CONCLUSION

We have calculated the energy spectra of secondary components of cosmic rays that are produced by the collisions of energetic solar particles in the atmosphere at various altitudes. The spectra will be used in future analyses of SEPs. To obtain fluxes of primary solar particles at the top of the atmosphere, the intensity of the secondary cosmic rays observed by neutron monitors or plastic scintillator needs to be divided by the value shown on the vertical axis, after correction of the detection efficiency of each detector. Thus we will be able to deduce the energy spectra of solar particles in a wide range of solar particles from 10 MeV to 1000 GeV. This will enable the shock, stochastic and DC acceleration processes at the solar surface to be differentiated.

ACKNOWLEDGMENT

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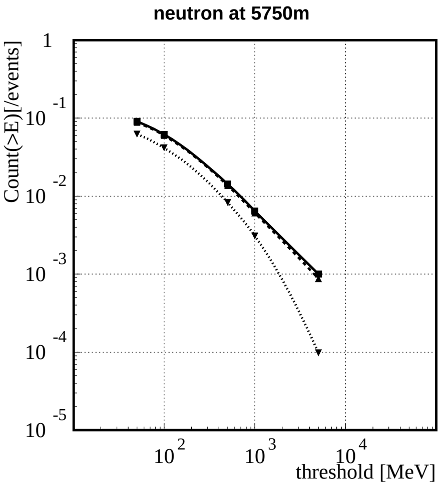

Fig. 1 Neutron flux at 500g/cm^2.

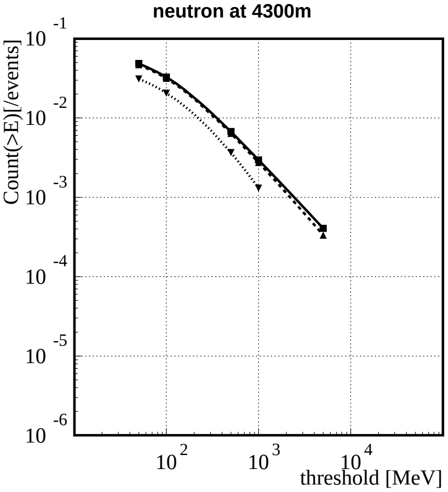

Fig. 2 Neutron flux at 600g/cm^2.

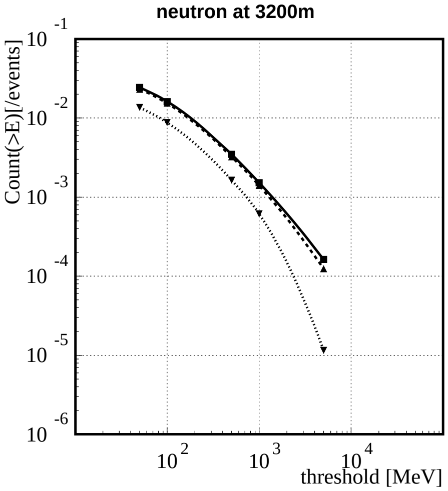

Fig. 3 Neutron flux at 700g/cm^2.

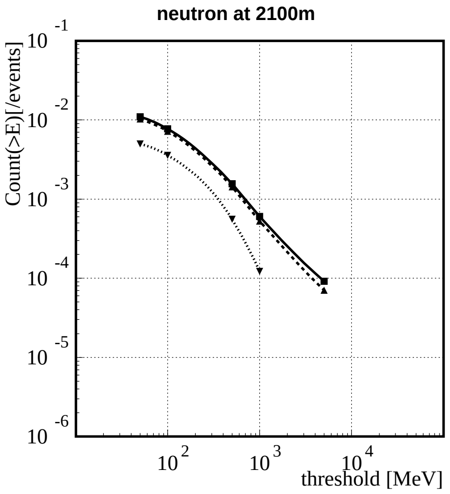

Fig. 4 Neutron flux at 800g/cm^2.

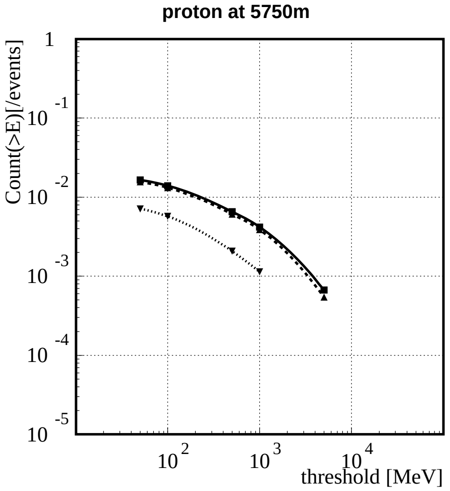

Fig. 5 Proton flux at 500g/cm^2

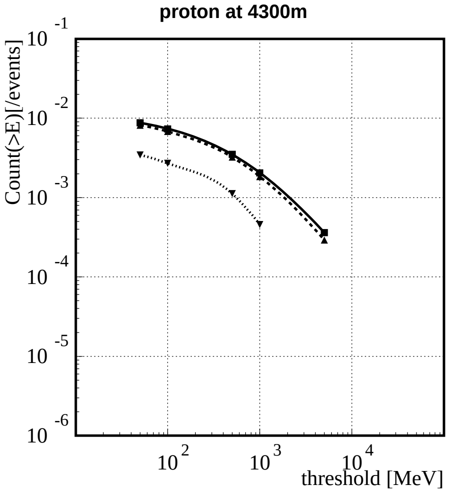

Fig. 6 Proton flux at 500g/cm^2

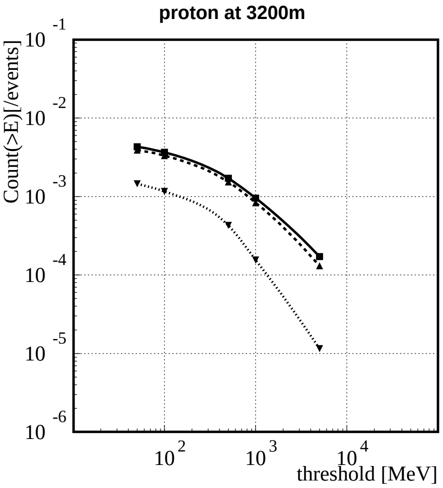

Fig. 7 Proton flux at 700g/cm^2

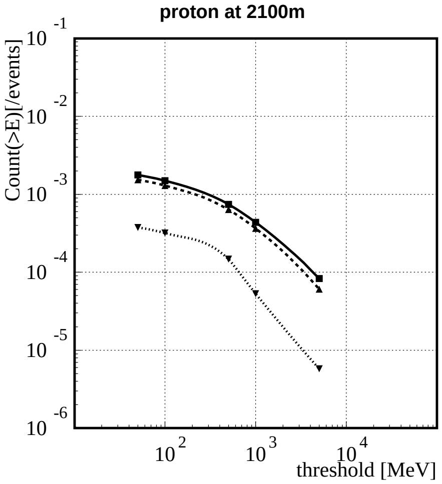

Fig. 8 Proton flux at 800g/cm^2

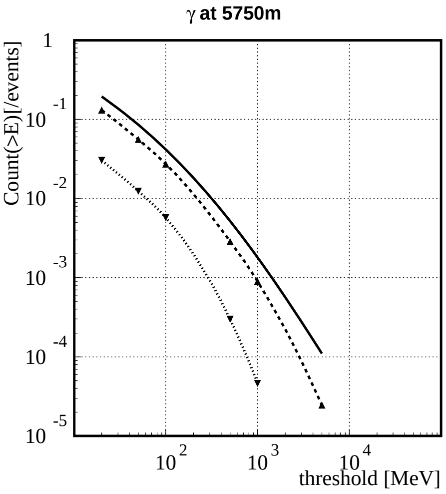

Fig. 9 Photon flux at 500g/cm^2

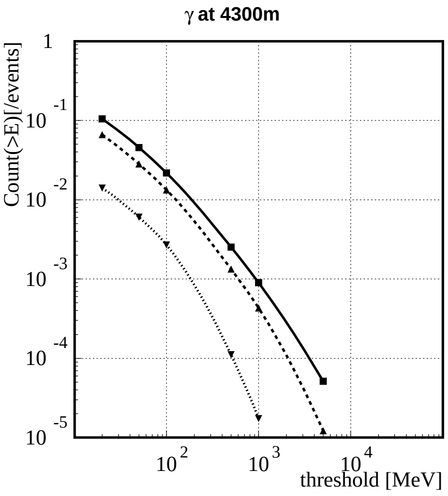

Fig. 10 Photon flux at 600g/cm^2

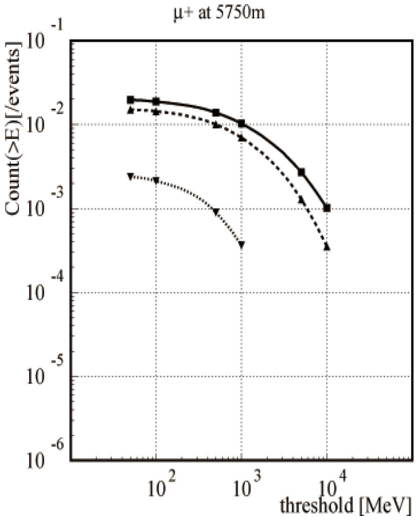

Fig. 13 Positive muon flux at 500g/cm^2

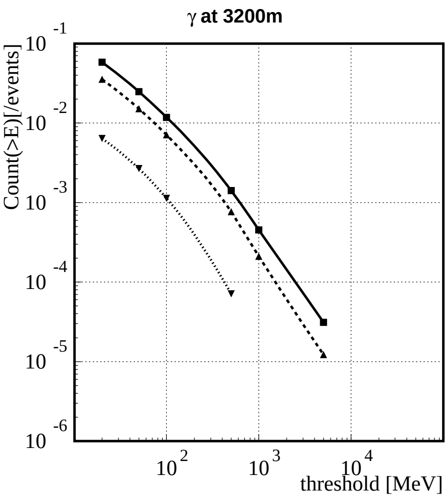

Fig. 11 Photon flux at 700g/cm^2

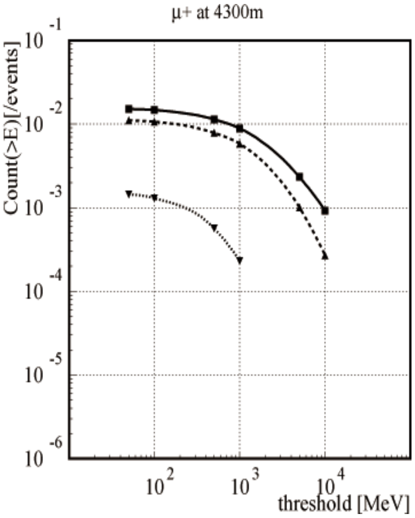

Fig. 14 Positive muon flux at 600g/cm^2

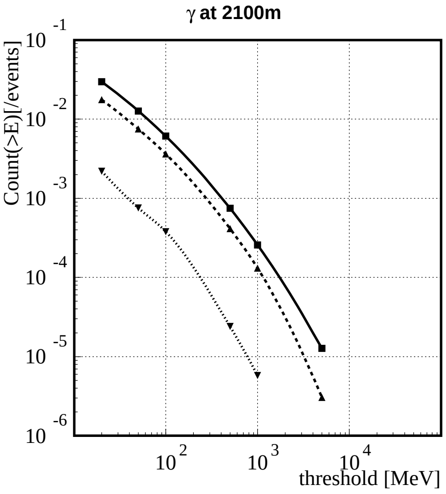

Fig. 12 Photon flux at 800g/cm^2

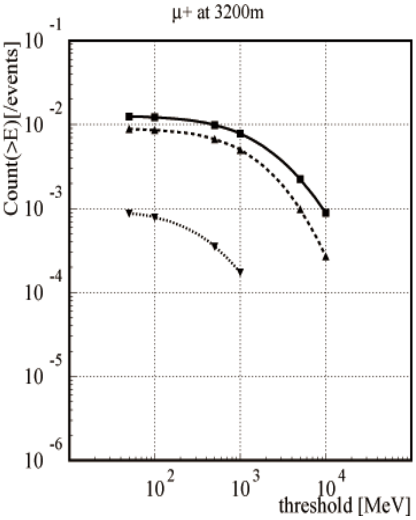

Fig. 15 Positive muon flux at 700g/cm^2