LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

UCRL-TR-229452

Monte Carlo Simulation of Proton-induced Cosimc Ray Cascades in the Atmosphere

C. A. Hagmann, D. J. Lange, D. M. Wright

March 28, 2007

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

DMC doc 0v1
UCRL-TR-

Monte Carlo Simulation of Proton-induced Cosmic Ray Cascades in the Atmosphere

Cosmic-ray Physics Team
Lawrence Livermore National Laboratory

February 15, 2007

Abstract

We have developed a Monte Carlo model of the Earth's atmosphere and implemented it in three different codes (GEANT4, MCNPX, and FLUKA). Primary protons in the energy range of 1 GeV - 100 TeV are injected at the top of the atmosphere. The codes follow the tracks of all relevant secondary particles (neutrons, muons, gammas, electrons, and pions) and tally their fluxes at selectable altitudes. Comparisons with cosmic ray data at sea level show good agreement.

1 Model of Atmosphere

The atmosphere was modeled as a series of 42 constant-density flat layers, each composed of 78 change between adjacent layers was set to 10%, and the densities were derived from the 1976 US Atmosphere Model. The top of the atmosphere in our model was located at an altitude of ~ 31 km, and the integrated column density was ~ 1000 g/cm^2. Void cells were placed at both top and bottom.

2 Cosmic Primaries

The flux of cosmic ray particles in the atmosphere and on the ground is mostly due to galactic protons, with minor contributions from alphas and heavier nuclei. At present, we restrict ourselves to the MC modeling of primary protons only. Figure 1 shows the spectrum of galactic protons at Earth. The low-E flux is anti-correlated with the solar wind. As more magnetized solar plasma fills the interplanetary system, the more low-E energy galactic protons are deflected away from Earth. The Earth's magnetic field acts as a further filter on the low-E spectrum, effectively imposing a low energy latitude-dependent cutoff (~ 15 GeV at the equator, 0 GeV at the poles).

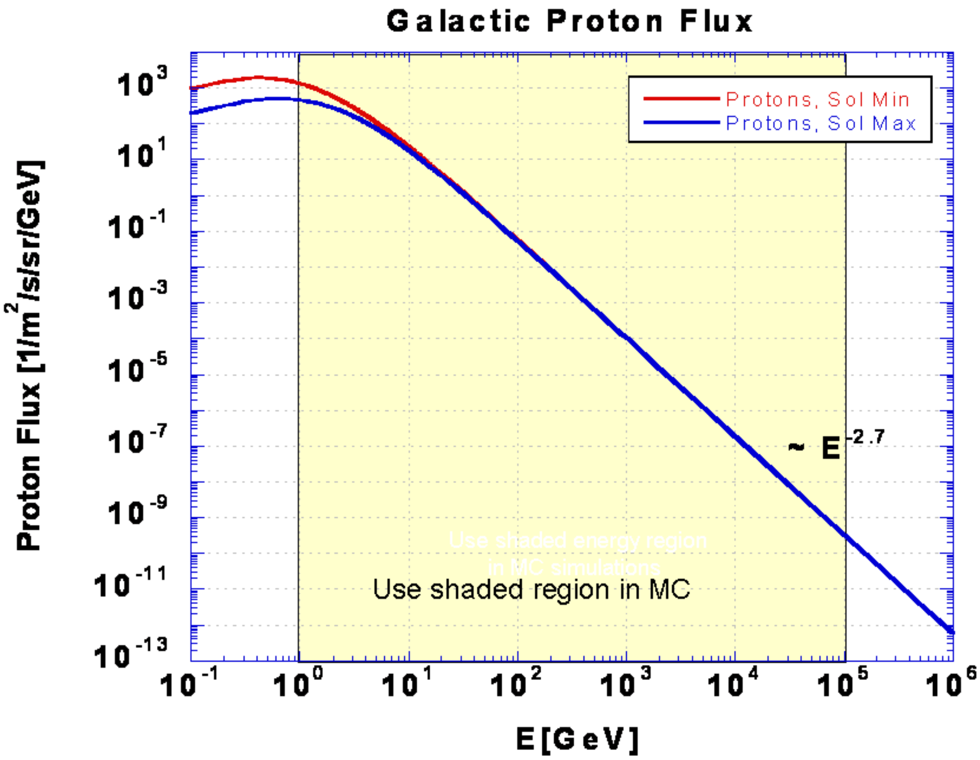

Figure 1: Spectrum of Galactic Protons incident on Earth [1].

3 Inter-Code Comparisons

Instead of relying on a single MC code and to guard against potential pitfalls, we ran a couple of problems with three independently developed multi-purpose codes, i.e. Fluka-2005, Geant4, and Mcnpx-v2.5.0. The same model of the atmosphere was implemented in each code and primary protons of fixed energy were injected at the top and the particles of interest (muons, neutrons, protons, gammas, electrons, and pions) were tallied at sea level.

Our general conclusion is that the codes give almost equivalent spectra for all particles except neutrons below 1 MeV, where Geant4 predicts too small of a flux. Neutron transport at these energies has only recently been implemented in Geant4. On the other hand, Fluka and especially Mcnpx have been heavily used and are considered verified and validated in this energy region.

Figures 2 and 3 show the tallied neutron and gamma spectra at sea level for incident proton energies of 1 TeV and 100 GeV respectively.

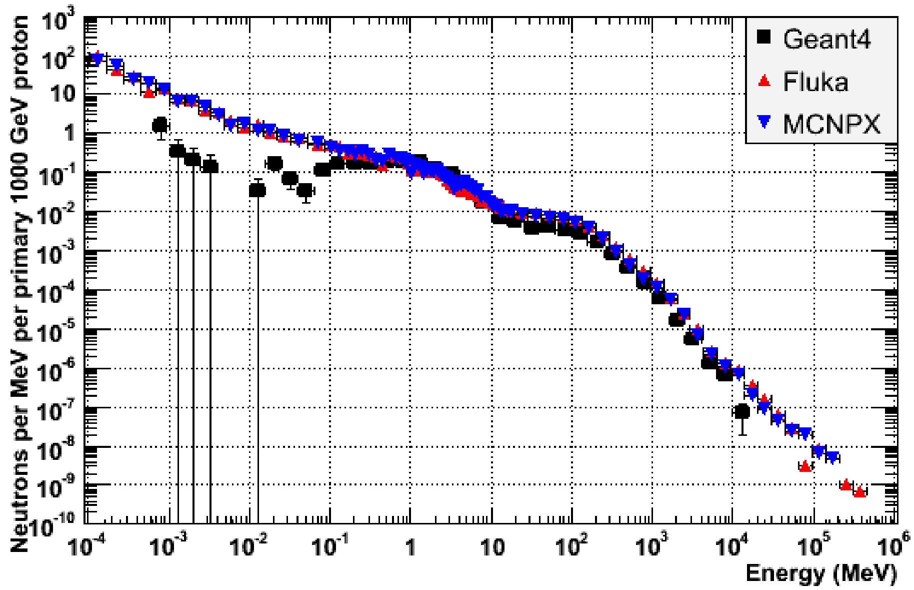

Figure 2: MC-generated neutron spectra at sea level. The incident proton energy is 1TeV.

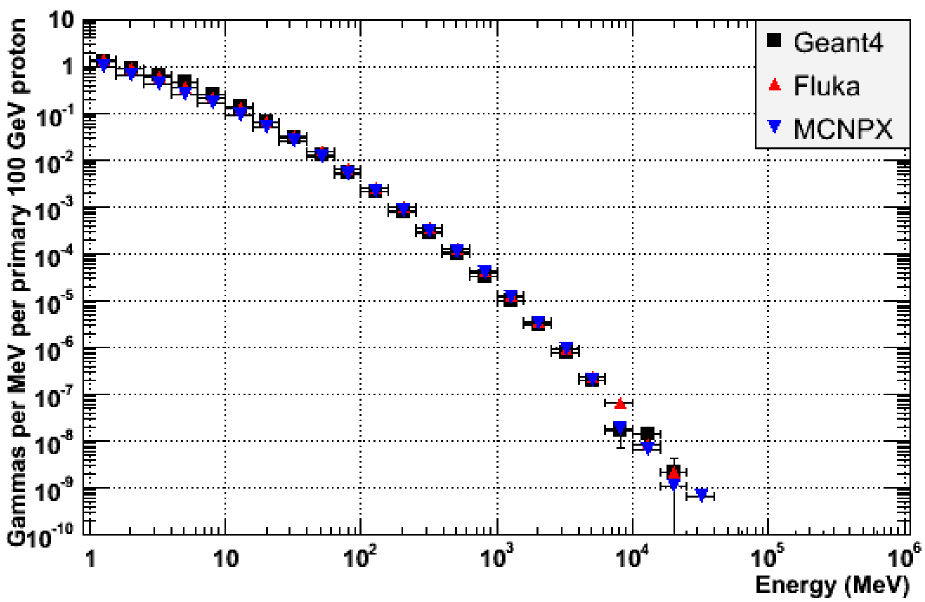

Figure 3: MC-generated gamma spectra at sea level . The incident proton energy is 100GeV.

4 Code-Data Comparisons

Most of our high statistics production runs were made with Mcnpx v.2.5.0 and comprise ¿ 10000 cpu-hrs. To this end, we divided the shaded region into 33 energy groups: 14 equally spaced flat bins from 1 GeV to 15 GeV, plus 19 logarithmically spaced bins up to 100 TeV. The latter ones had a power law distribution within each bin with a spectral index of 2.7. All protons were sourced with an isotropic angular distribution and the atmosphere response functions were accumulated for each incident energy bin. By suitable weighting and co-adding of sub spectra, total absolute spectra at any position in the solar cycle and any value of the geomagnetic cutoff can be calculated.

Shown in Figures 4-7 are the predicted muon, proton, pion , and neutron fluxes for no geomagnetic cutoff and average solar modulation, along with the data points from Rastin[2], Brooke and Wolfendale [3], Ashton and Saleh [4], and Kornmayer et al [5] .

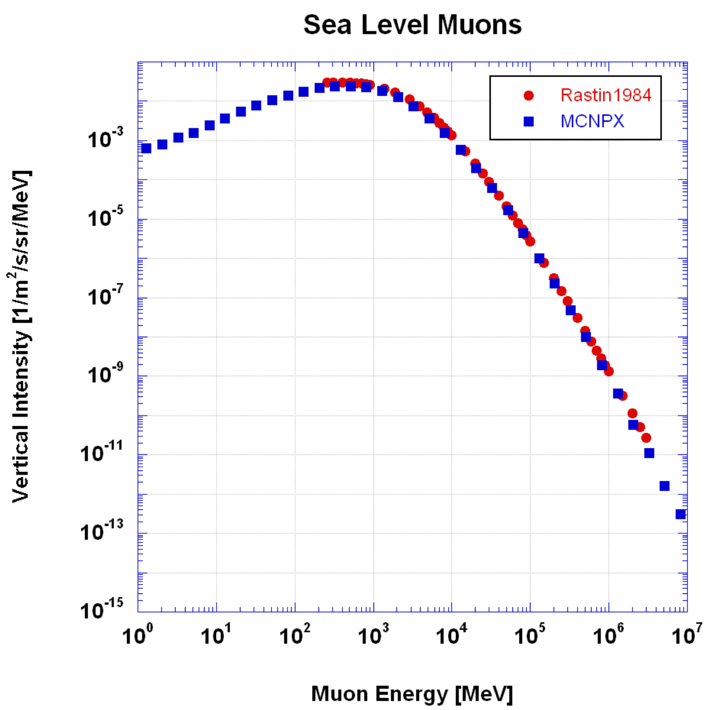

Figure 4: MC-generated muon spectrum and data measured at sea level.

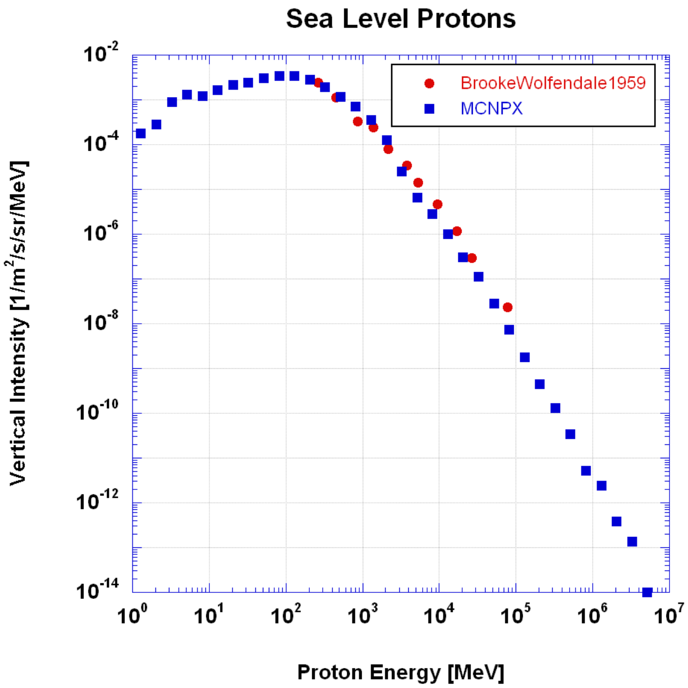

Figure 5: MC-generated proton spectrum and data measured at sea level.

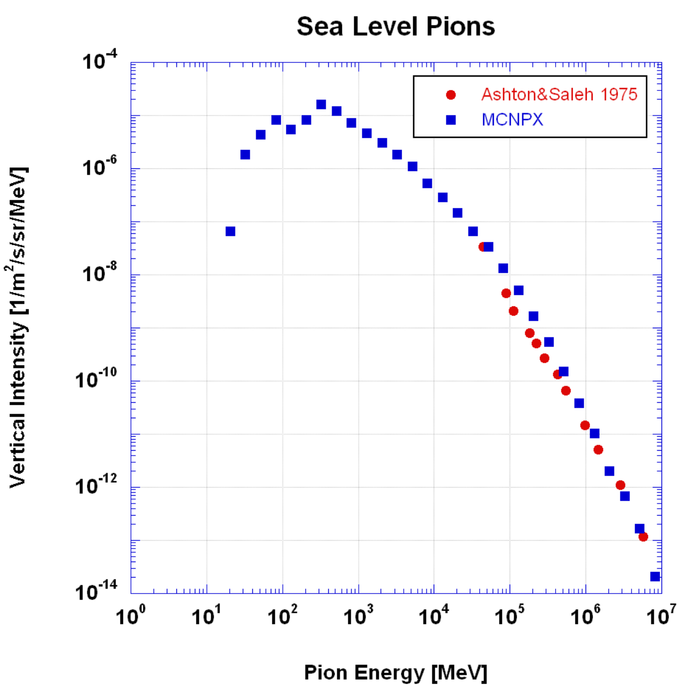

Figure 6: MC-generated pion spectrum and data measured at sea level.

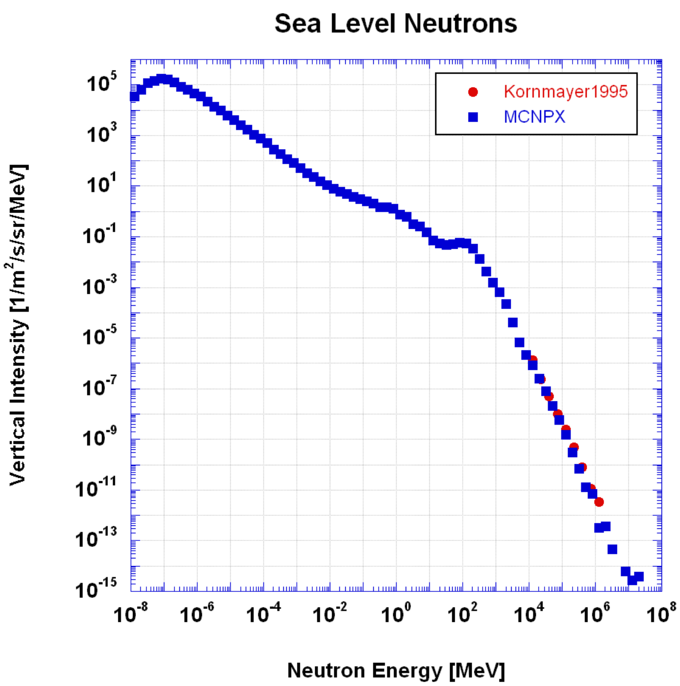

Figure 7: MC-generated neutron spectrum and data measured at sea level.

5 Conclusion

We have calculated cosmic ray fluxes at sea level employing three different Monte Carlo codes. Except for low energy neutrons, all codes give essentially similar distributions of cosmic ray secondaries. We have also compared our calculations to published data and found good agreement. Hence MC calculations should give quite reliable predictons of cosmic ray distributions in situations where data are not available.

References

[1] P. Papini, C. Grimani,and S.A. Stephens, Nuovo Cim C 19 , 367 (1996).

[2] B.C. Rastin, J. Phys. G: Nucl. Part. Phys. 10, 1609 (1984).

[3] G. Brooke and A. Wolfendale Proc. Phys. Soc. 83, 843 (1964).

[4] F.Ashton and A. Saleh PICRC 7, 2707 (1975).

[5] H. Kornmayer et al., J. Phys. G: Nucl. Part. Phys. 21, 439 (1995).