Prompt Neutrino Production by the Lunar Surface

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Abstract

We report on the preliminary results of our current Monte Carlo investigation into prompt neutrino production by cosmic-ray (CR) impacts on the lunar surface using the latest available enhancements in FLUKA. In contrast to previous work, the effects of charm are now included. The model of the lunar surface is taken to be the chemical composition of soils found at various landing sites during the Apollo and Luna programs, and then averaging over all such sites to define a generic regolith for this analysis. We present examples of fluences and fluxes predicted for charged particles, neutrons, photons, and neutrinos produced by FLUKA for energetic CR impacts.

1. Introduction

Groups have analyzed the production rates of various particles and elemental species by planetary surfaces when bombarded with Galactic CR fluxes, both theoretically [1, 2] and by means of various transport codes [3]. In particular, the question of whether a physics laboratory placed on the Moon might have certain advantages over a similar laboratory on Earth was addressed [2, 4]. Such an analysis of planetary regoliths for their backscatter albedos produced by cosmic rays is important for space exploration and its potential contributions to science investigations in astrophysics as well as the study of fundamental physics in space. All such albedos produced in the secondary backscatter affect science experiments and the personnel that operate them. The *in situ* background neutrino flux, for example, limits the available neutrino sky for investigations in neutrino astronomy from either the Earth or the Moon. Because the prompt neutrino background due to charmed meson decay is recent new physics, its contribution to the question is particularly interesting and its investigation concerns us here.

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Table 1. Lunar Surface Model.

Element	Atomic Weight	Z	Percent Weight	Element	Atomic Weight	Z	Percent Weight
Si	28.09	14	20.86	Mg	24.31	12	5.54
O	16.00	8	43.47	Ca	40.08	20	8.93
Ti	47.88	22	1.46	Na	22.99	11	0.32
Al	26.98	13	9.63	K	39.10	19	0.15
Cr	52.00	24	0.22	P	30.97	15	0.09
Fe	55.85	26	9.08	S	32.07	16	0.09
Mn	54.94	25	0.16				

2. The Monte Carlo

Monte Carlos utilize transport codes for the propagation of particle scattering and nuclear fragmentation events. The radiation transport code chosen for the study is FLUKA modified with an advanced 3-D graphics geometry package [5]. This is used in conjunction with an object-oriented (OO) physics analysis infra-structure that is currently evolving at CERN known as ROOT. The FLUKA-Executing-Under-ROOT or FLEUR simulation packages [6] are launched on a multi-processor Linux-based architecture.

A related investigation into Earth atmospheric neutrino fluxes using FLUKA has already been reported [7].

3. Model of the Lunar Surface

The model of the lunar surface is taken to be an average chemical composition of soils found at various landing sites during the Apollo and Luna programs [8]. This is the same model as used in [3] where charm was not considered. The resulting weight percentages by element have been calculated and are given in Table 1. Neglecting biogenic elements (H, C, and N), these are the 13 elemental abundances measured to be present on the Moon with more than a trace, having atomic mass A and charge Z. The lunar surface model is assumed to have a negligible magnetic field and a mean density of 2.85 g cm^{-3} [8].

The collisional tracking volume is defined to be a cylindrical tube comprised of a thin wafer of vacuum (tracking medium 1) followed by a homogeneous mixture of the lunar surface material in Table 1 (tracking medium 2). The differential CR flux is taken to be protons (H, hydrogen) obeying a Galactic CR (GCR) power-law spectrum $dN = E^{-\gamma} dE$ for energy E with $\gamma = 2.7$. Other GCR nuclei will be considered later.

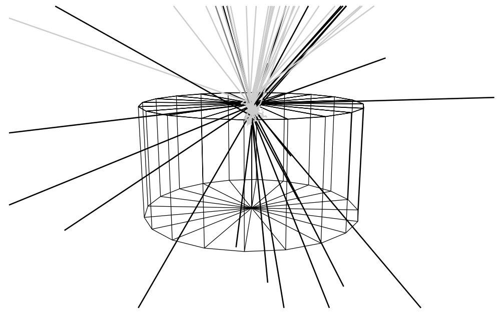

Fig. 1. Shower cascade and albedo backscatter in lunar regolith.

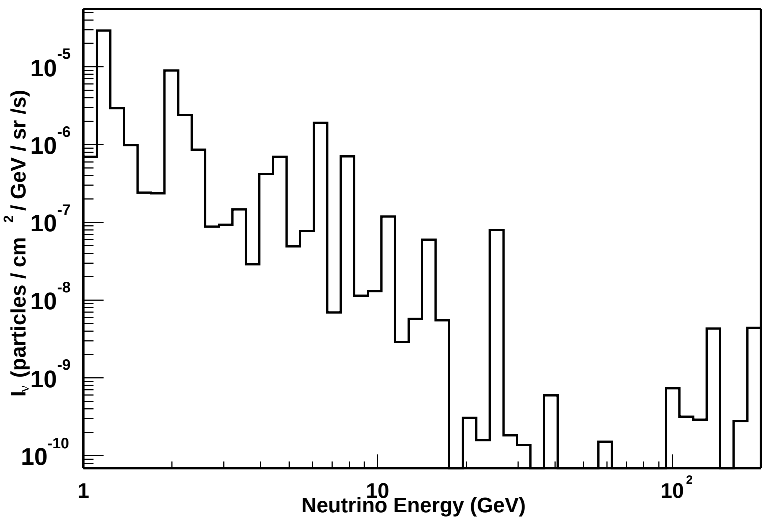

Fig. 2. Neutrino flux I_ν in the region of the onset of charmed meson decay.

4. Results

A GCR-induced particle cascade (lines going down) and albedo backscatter (lines going up) are given in Fig. 1, viewing a cylindrical volume (radius and height = 1700 cm) from its side. The pie-sector format is a root-rendering feature only, as FLUKA makes no such approximation. A primary H nucleus (proton) incident at zenith angle $\theta = 0$ with energy E = 100 GeV is shown producing prompt neutrinos (black), protons (dark gray), and other particles (light gray).

Similarly, Fig. 2 and Fig. 3 illustrate the prompt neutrino flux production I_ν by the lunar surface commencing in the neighborhood of 1-100 GeV, as a result of 10 GeV - 10 TeV incident protons. At lower energies, the neutrino flux is primarily due to pions (π-mesons) and kaons (K-mesons). At higher energies, the prompt decay of charmed D-mesons into neutrinos begins to appear. Fig. 3

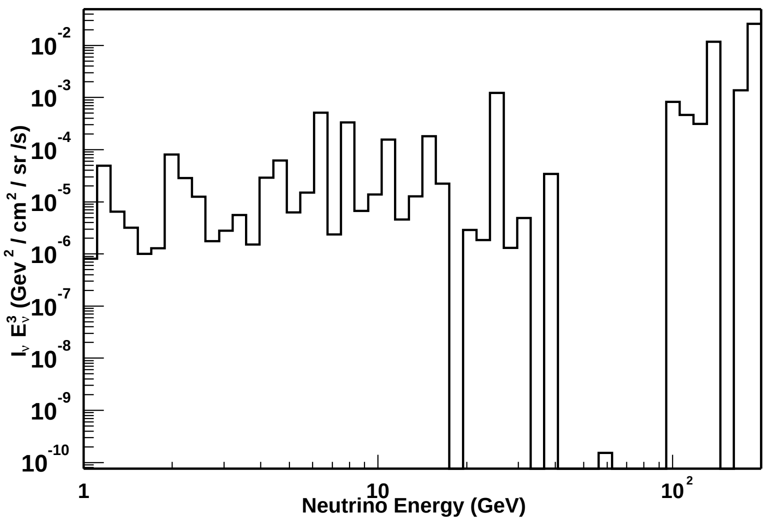

Fig. 3. Neutrino production $E^3 I_\nu$ in the region of the onset of charmed meson decay.

is re-scaled in units of $E^3 I_\nu$ for direct comparison with the results of Volkova [2].

5. Conclusions

Earlier Monte Carlo investigations [3] were unable to give rigorous results because the prompt neutrino production from charmed meson decay on the Moon was not simulated. Using the latest available enhancements in FLUKA, the simulation now produces expected results and additional study is in progress to define windows of opportunity more favorable in Moon-based physics experiments as compared to Earth-based ones.

6. References

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