Monte Carlo Simulation of Neutrino Induced Extended Air Showers

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Abstract

The capability of generating reliable simulations of air showers induced by neutrinos is mandatory for doing high-energy neutrino astronomy. In this paper we describe preliminary results towards the development of a new version of the Monte Carlo CORSIKA, with neutrinos too as primary particles, which employs a call to the HERWIG event generator for simulating the first interaction of the primary neutrino.

1. Introduction

The new generation of cosmic ray surface detectors, like the Pierre Auger Observatory and the neutrino telescopes, like Amanda, Icecube, Antares, and EUSO [1] will be able to detect neutrinos of astrophysical origin in a wide range of energies. This will improve our understanding of the astrophysical acceleration mechanisms for bottom-up scenarios or, if top-down models were confirmed, will give new insights on fundamental interactions.

In the same way as the more usual components of cosmic radiation, also UHE ν's can initiate Extensive Air Showers (EAS) which could be detectable both by large surface and fluorescence detectors. Leaving apart vertical air showers, where the probability of a ν interaction within the ~ 1000 g/cm^2 of atmospheric depth is negligibly small, the best choice to look for a clear signature of neutrino induced events, studying EAS in array like AUGER, is the case of almost horizontal, skimming, or up-going air showers. In any case, a reliable simulation of these events is mandatory for the interpretation of the experimental data. In this respect, one has to take into account that none of the Monte Carlo's typically used for shower simulation in atmosphere treats neutrinos as primary particles.

This paper reports on the work [2] made towards the inclusion of neutrinos in the (already long) list of primary particles which the Monte Carlo CORSIKA

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can handle. This is realized including in the code a call to the generator HERWIG. The main advantage of our approach consists in the fact that HERWIG is continuously updated by particle physics community, which makes it an extremely reliable tool for the description of the first interaction (FI) of the neutrinos.

2. Methods

CORSIKA and HERWIG [3] are two Monte Carlo programs: the first simulates the EAS in the atmosphere initiated by photons, protons, nuclei and many other particles, the second is an event generator for high-energy processes particularly suited for detailed simulation of QCD parton showers. For the present analysis we adopted the CORSIKA version 6.014 and HERWIG 6.4.

The first step in the implementation of the neutrino modified version of CORSIKA consisted in the inclusion in the code of the neutrino cross-section quoted in [4]. The second one was the insertion in the program of a conditional call to a link subroutine, executed only for a primary neutrino and in the FI case, where the quantities necessary to HERWIG are generated from the inputs given to CORSIKA, that is the neutrino type (ν_e, $\bar{\nu}_e$, ν_μ, $\bar{\nu}_\mu$), its energy and zenith angle. The target nucleon is chosen randomly between a proton or a neutron, and the process, Charged Current (CC) or Neutral Current (NC) deep inelastic scattering, is selected by using the comparison of the respective cross-sections [4].

From the output of HERWIG the FI particles are selected and passed to CORSIKA, for the usual development of the shower. At this stage, since some of the particles produced by HERWIG cannot yet be treated by CORSIKA (mainly the charmed particles), they are directly substituted with their decay products, supplied by HERWIG. This solution is a very satisfying one at a low primary energy ($E_\nu \sim 10^{15}$ eV), but only an approximation at higher energies.

3. Results and Discussion

With the new neutrino version of CORSIKA we generated a series of inclined ($\geq 70°$) showers for the different neutrino species. A first set of showers were produced at a primary energy of $E_\nu = 10^{15}$ eV, using HDPM and QGSJET as hadronic models in CORSIKA. A correspondent set of proton showers with the same inclinations and primary energy was also simulated. In order to make the comparison between the two class of showers, the neutrino FI was realized at the same point of the corresponding proton shower. We show in the left plot in Fig. 1 the comparison of the average longitudinal profiles of charged particles versus the slant atmospheric depth for proton, electron and muon neutrinos and antineutrinos at $\theta = 70°$. No significant difference between neutrinos and antineutrinos of the same type is appreciable. For muon neutrinos the particle number at the maximum is lower than for protons, while for electron neutrinos is larger. This

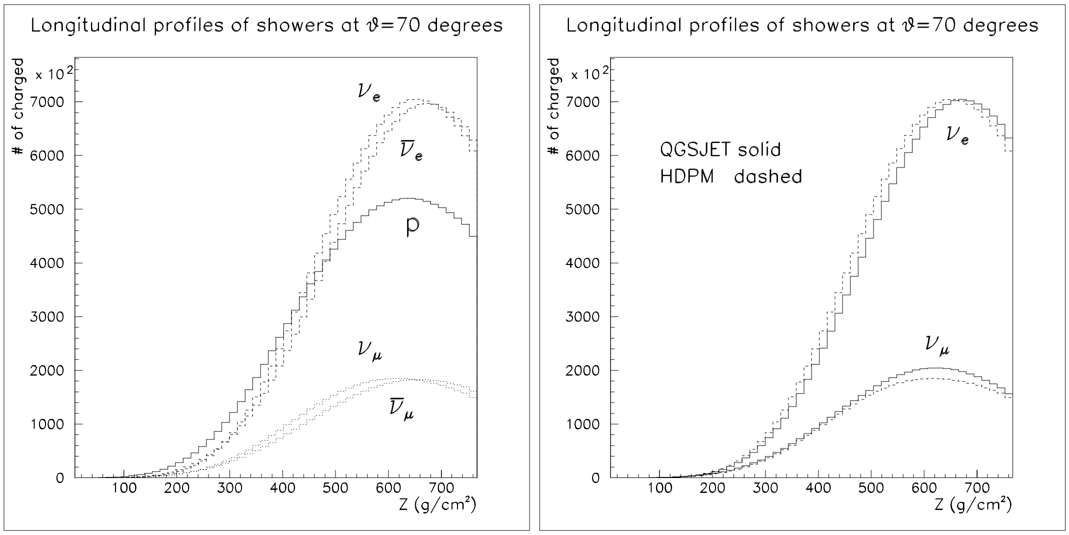

Fig. 1. Average longitudinal profiles of showers induced by a) different primary particles and b) different hadronic models at $\theta = 70°$ and $E_\nu = 10^{15}$ eV.

is explained by the fact that, for $E_\nu = 10^{15}$ eV, the outgoing lepton produced in the FI carries away more than 90% of the neutrino energy in 37% of the cases. This energy does not contribute to the development of the shower, and is then undetectable, either for a neutrino NC interaction or for a muon neutrino CC one which produces a very energetic muon hitting the ground at the core shower. On the other side, a CC interaction of a ν_e in most of the cases produces an electron with a large fraction of primary energy, and less energetic hadronic products. From these first interaction particles a mixed shower is generated, partly electromagnetic and partly hadronic. By increasing the energy fraction delivered to the electron, the electromagnetic features of this shower become dominant with respect to the hadronic ones, explaining the larger number of charged particles in the maximum. Right plot in Fig. 1, for $E_\nu = 10^{15}$ eV, shows a nice agreement between the results obtained with the two hadronic models used in our analysis.

An extension of the modified neutrino version of CORSIKA to energies $\geq 10^{15}$ eV is under development. In Fig. 2 we plot, at an energy of 10^{19} eV, the average profiles of e^- and p showers, compared to ν_e and ν_μ ones (for ν_e the CC component alone, ν_{eCC}, is also plotted). All this showers were obtained using the hadronic model QGSJET and the option of 10^{-6} optimal thinning of CORSIKA for reducing the computing time. From this preliminary results one sees that the ν_{eCC} profile is very similar to the e^- one, while the ν_e one is lower, showing that the electromagnetic features of a ν_e shower are diluted by the effect of the NC component of the FI events. In fact, though the ratio between NC and CC neutrino cross-sections is decreasing with the primary energy, the fraction

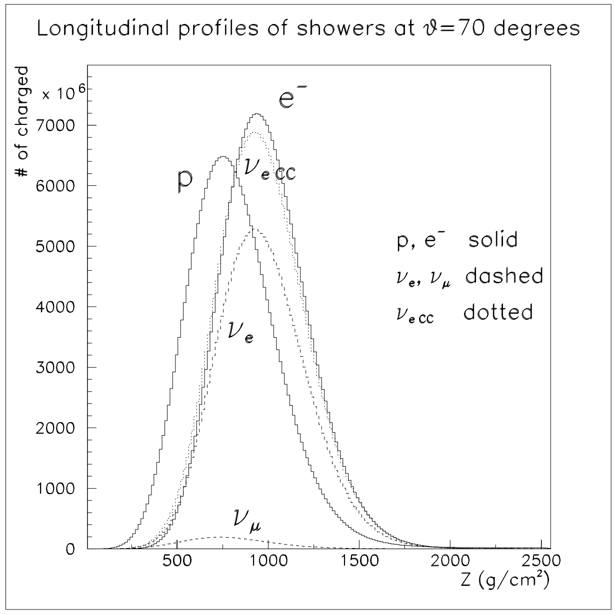

Fig. 2. Average longitudinal profiles of showers induced by different primary particles at $\theta = 70°$ and $E_\nu = 10^{19}$ eV.

of energy of the primary to the secondary ν produced in its NC interaction is growing.

4. Conclusions

In this paper we have described preliminary results obtained by a modified version of CORSIKA, with neutrinos as primary particles. The analysis suggests that the longitudinal profile of EAS induced by ν_e's is sensibly enhanced with respect to the corresponding p and ν_μ showers at a primary energy of 10^{15} eV, while at 10^{19} eV the previous feature is attenuated by the effect of the NC component of the neutrino FI. Future work aims to study in more details the neutrino FI in order to improve its implementation in CORSIKA. Care has also to be taken of the treatment of the τ lepton and charmed particles, which can be produced in the FI of the neutrinos, and of the interaction of high energy muons in CORSIKA.

1. see Ref.s [4-8] of Ambrosio M., Aramo C., Della Selva A., Miele G., Pastor S., Pisanti O., Rosa L. 2003
2. Ambrosio M., Aramo C., Della Selva A., Miele G., Pastor S., Pisanti O., Rosa L. 2003, Auger technical note GAP-2003-013, astro-ph/0302602
3. see Ref.s [12] and [14] of Ambrosio M., Aramo C., Della Selva A., Miele G., Pastor S., Pisanti O., Rosa L. 2003
4. Gandhi R., Quigg C., Reno M.H., Sarcevic I. 1998, Phys. Rev. D58, 093009