MONTE CARLO SIMULATIONS AND SEMIANALYTICAL PARAMETERISATIONS OF THE ATMOSPHERIC MUON FLUX

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Abstract
The atmospheric muon flux have been simulated using the CORSIKA code for two different geographical positions (Bucharest: 44°N, 26°E and Hiroshima: 34°N, 132°E). The simulations have been done for different angles of incidence between 0° and 70°. The comparison between the simulations and the experiment have been done using the measurements of the muon charge ratio with the WILLI detector in Bucharest. The results of the Monte Carlo simulations of the muon flux for the geographical positions of Hiroshima and Bucharest are compared with the semi-analytical formulae of Judge and Nash, and of Gaisser for different angles of incidence between 0° and 70° and with experimental results of the Bess experiment (vertical incidence). Various sensitivities of the approach of Judge and Nash, in particular to variations of the pion and kaon production spectra have been studied.

Keywords: Muon, flux, simulation

Introduction
The muon belongs to the family of elementary particles known as leptons. Like the electron it may be positively or negatively charged and has a spin \( \frac{1}{2} \). However its mass is about 100 MeV, more than two orders of magnitude larger than that of the electron, and about one order of magnitude less than of the proton. It is produced mainly by the decay of pions and kaons generated by high-energy collisions of cosmic rays with the atoms of the Earth atmosphere. Muons are unstable decaying to electrons and positrons and neutrinos (electron (\( \nu_e \)) and muon (\( \nu_\mu \)) neutrinos) with a half - life of \( \tau_\mu = 2.2 \mu s \).

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The air shower simulation program CORSIKA

The simulation tool CORSIKA has been originally designed for the four dimensional simulation of extensive air showers with primary energies around $10^{15}$ eV. The particle transport includes the particle ranges defined by the life time of the particle and its cross-section with air. The density profile of the atmosphere is handled as continuous function, thus not sampled in layers of constant density.

Ionization losses, multiple scattering, and the deflection in the local magnetic field are considered. The decay of particles is simulated in exact kinematics, and the muon polarization is taken into account.

In contrast to other air shower simulations tools, CORSIKA offers alternatively six different models for the description of the high energy hadronic interaction and three different models for the description of the low energy hadronic interaction. The threshold between the high and low energy models is set by default to $E_{Lab} = 80$ GeV/n.

Calculation of atmospheric muon flux

The calculation of muon flux proceeds by a full 3D-simulation (CORSIKA). The simulations have been done using for the primary particle’s spectrum the expression: $J_p(E) \sim E^{-2.78}$.

The differential particle flux $J_\mu$ was calculated by dividing the number of particles detected by the surface of the particle collection area (cm$^2$), solid angle, momentum bin size, and equivalent sampling time of the CR flux.

Semi-analytical approaches

There are several empirical approximations describing the fluxes in by analytical expressions like power-law distributions (see P.Grieder). Recent approaches by T.K. Gaisser display explicitely the dependence on primary energy, but with complicated mathematical procedures and valid only for muon energies above 10 GeV. This holds also for the simplication given in Gaisser’s Book:

$$
\phi_\mu = \frac{0.14}{cm^2 \cdot s \cdot sr \cdot GeV} \cdot (E/GeV)^{-2.7} \left[ \frac{1}{1 + \frac{E \cdot \cos \theta}{110 \text{GeV}}} + \frac{0.37}{1 + \frac{E \cdot \cos \theta}{760 \text{GeV}}} \right]
$$