A Fast Hybrid Approach to Air Shower Simulations and Applications

Hans-Joachim Drescher[1], Glennys Farrar[2], Marcus Bleicher[1], Manuel Reiter[1], Sven Soff[1], Horst Stöcker[1]
(1) Institut für Theoretische Physik, Johann Wolfgang Goethe Universität, Robert-Mayer Str. 8-10, Frankfurt am Main, Germany
(2) Center for Cosmologie and Particle Physics, New York University, 4 Washington Place, NY 10003, USA

Abstract

The SENECA model, a new hybrid approach to air shower simulations, is presented. It combines the use of efficient cascade equations in the energy range where a shower can be treated as one-dimensional, with a traditional Monte Carlo method which traces individual particles. This allows one to reproduce natural fluctuations of individual showers as well as the lateral spread of low energy particles. The model is quite efficient in computation time.

As an application of the new approach, the influence of the low energy hadronic models on shower properties for AUGER energies is studied. We conclude that these models have a significant impact on the tails of lateral distribution functions, and deserve therefore more attention.

1. Introduction

In the field of air shower simulations, large computation times limit the applicability of traditional Monte-Carlo approaches at very high energies. The thinning algorithm tries solve this problem, at the price of introducing artificial fluctuations. Here, we present a hybrid approach to air shower simulation, as introduced in [2]: A system of transport equations is employed in the energetic region where an air shower can be considered as one dimensional. The lateral spread of low energy particles is calculated with traditional Monte-Carlo methods, where one traces each particle individually.

2. Hadronic Cascade Equations

If one considers an air shower as a one-dimensional system, it can be described with the following set of cascade equations (CE) [1,2]:

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$$\frac{\partial h_n(E,X)}{\partial X} = -h_n(E,X)\left[\frac{1}{\lambda_n(E)} + \frac{B_n}{EX}\right] \tag{1}$$
$$+\sum_m \int_E^{E_{\max}^{\mathrm{had}}} h_m(E',X)\left[\frac{W_{mn}(E',E)}{\lambda_m(E')} + \frac{B_m D_{mn}(E',E)}{E'X}\right] dE' ,$$

where $h_n(E,X)dE$ is the number of particles of type n (basically nucleons, pions and kaons) with an energy $[E, E+dE]$ at an atmospheric depth X. The first line with the minus-sign accounts for particles falling out of the system by either inelastic collisions with air-nuclei or by decay. The second line accounts for producing particles by the same two mechanisms at higher energies, $W_{mn}(E,E') = \frac{dN}{dE'}$ is the differential energy spectrum for collisions of particle type m at energy E and D_{mn} are the corresponding decay functions. The technique to solve these equations is described in detail in references [1,2].

3. Electromagnetic Cascading

Electromagnetic cascades can in principle be described in a similar way. However, due to the fact that no decays are involved it is sufficient to compute the energy spectra of shower particles for a reference layer of air of a given thickness, e.g. 2.5 g/cm^2. We use discretized energies as $E_i = 10^{(i-1)/n_d}\ /rmGeV$, with n_d bins per decade. If V_{ji}^{mn} describes the energy of electrons/positrons and photons, for a particle of type m traversing this layer of air, then a simple iteration

$$g_i^n(X+\Delta X) = \sum_{m,j\geq i} g_j^m(X) V_{ji}^{mn}(\Delta X)\,. \tag{2}$$

describes the shower at any depth X.

4. Source Functions

The system of hadronic and electromagnetic cascade equations is solved down to energies of 1000 GeV and 10 GeV, respectively. Below these energies, the three-dimensional character of the air shower becomes important. Thus, instead of evolving further, we calculate directly the energy spectra of low energy particles in the following way:

$$\frac{\partial h_n^{\mathrm{source}}(E,X)}{\partial X} = \sum_m \int_{E_{\min}^{\mathrm{had}}}^{E_{\max}^{\mathrm{had}}} h_m(E',X)\left[\frac{W_{mn}(E',E)}{\lambda_m(E')} + \frac{B_m D_{mn}(E',E)}{E'X}\right] \mathrm{d}E'\,.$$

The source function is then used to generate low energy particles which are then followed in a standard Monte-Carlo approach.

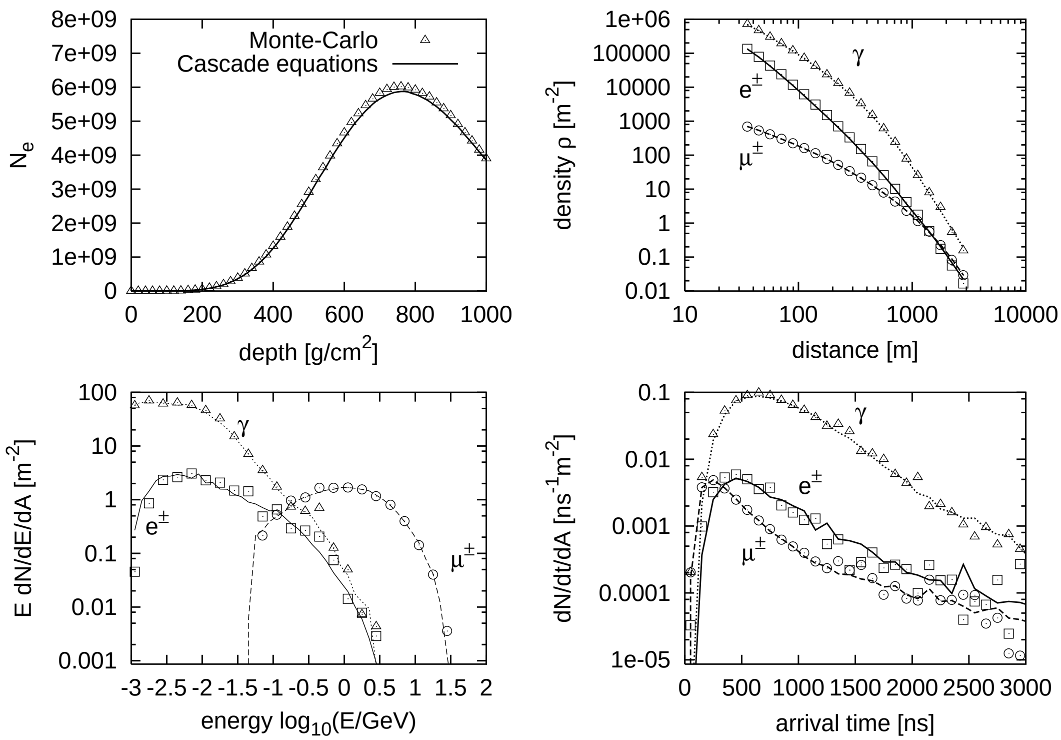

Fig. 1. Comparison of the hybrid method (lines) with the traditional Monte-Carlo (symbols).

5. Tests of Results

The use of cascade equations should be of technical nature only and not change the physics results. Therefore we compare results to the pure Monte Carlo approach with thinning. The average of 500 proton induced 10^{19} eV showers with thinning level 10^{-5} has been computed. Fig. 1 shows comparisons for longitudinal and lateral profiles as well as the energy and arrival time spectra at 1000 m distance from the shower axis. The agreement between the CE and the MC approach is satisfactory.

6. Low Energy Model Dependence on Lateral Distribution Functions

In Ref. [3] it was pointed out that the low-energy hadronic model is of crucial importance for muons in general, and for the tails the lateral distribution functions (LDF) of electrons and photons. The reason was that electromagnetic subshowers contributing to large distances are emitted by low energy particles at a large distance from the shower axis.

Here we want to analyse the influence of different low energy hadronic

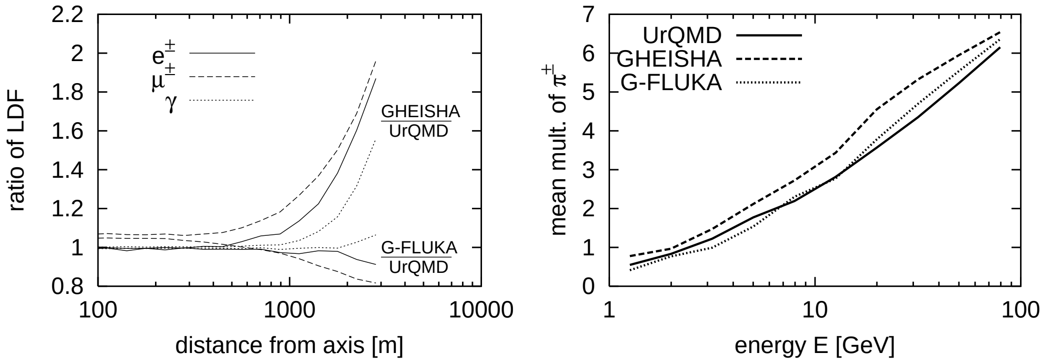

Fig. 2. Left:Ratio of LDF of G-FLUKA and GHEISHA to UrQMD as low energy hadronic model. Right: yield of π^{+-} production as a function of energy.

models on the LDF of electrons, muons and photons. We use the following models: GHEISHA [7] and G-FLUKA [8] as found in GEANT3.21, and the UrQMD [5,6] model developed at the University of Frankfurt. For high energies we employ the QGSJET01 [4] model. In Fig. 2 we show the ratio of LDFs of $e^\pm$, $\mu^\pm$ and γ for the different models. We see how the tails of the distributions change due to different choices of the low-energy hadronic model. GHEISHA produces more muons than UrQMD, since it gives a larger yield for charged pion production as seen in Fig. 2. The differences even influence the tails of the LDF of electrons and photons, though less pronounced. The results for UrQMD and G-FLUKA are more similar to each other.

7. Acknowledgments

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8. References

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