# One-dimensional Hybrid Simulation of EAS Using Cascade Equations

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## Abstract

A hybrid simulation code is developed that is suited for fast one-dimensional simulations of shower profiles, including fluctuations. It combines Monte Carlo simulation of high energy interactions with a fast numerical solution of cascade equations for the resulting distributions of secondary particles. First results obtained with this new code, called CONEX, are presented and compared to CORSIKA predictions, focusing on the treatment of the electromagnetic shower component.

## 1. Introduction

At high energy, the number of air showers that can be simulated within conventional Monte Carlo approaches is mainly limited by the currently available computing power. The hybrid simulation technique allows a drastic reduction of the simulation time by combining explicit Monte Carlo simulation of high-energy interactions with fast numerical methods to describe sub-showers initiated by low-energy particles. Since shower fluctuations mainly arise from the fluctuations of the first few interactions of the primary particle and its energetic secondaries, the hybrid method allows good description of both mean shower properties as well as their distribution (see, for example, [2]).

In this work we employ a previously developed code for the treatment of the cascade equations for the hadronic shower core [1] and supplement it with a Monte Carlo simulation of high-energy hadronic interactions and a fast numerical solution of the electromagnetic cascade equations. Our approach is characterised by large flexibility. No libraries of previously simulated showers are needed and all shower parameters, including the atmospheric profile can vary from shower to

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shower.

## 2. The shower simulation code CONEX

In CONEX explicit Monte Carlo simulation of propagation, decay and interaction is performed for all particles above a given threshold, typically $E_0/100$. Hadronic high-energy interactions are calculated using either neXus 3 [3] or QGSJET 01 [7]. The extension to other models such as SIBYLL [4] and DPMJET [9] is planned. The Monte Carlo simulation of electromagnetic interactions is handled by the EGS4 code [8]. Particles falling below the energy threshold are binned according to their type in energy-depth tables. These tables are used as initial distribution for the cascade equations. The system of coupled differential equations are solved for each shower using the techniques described in [1].

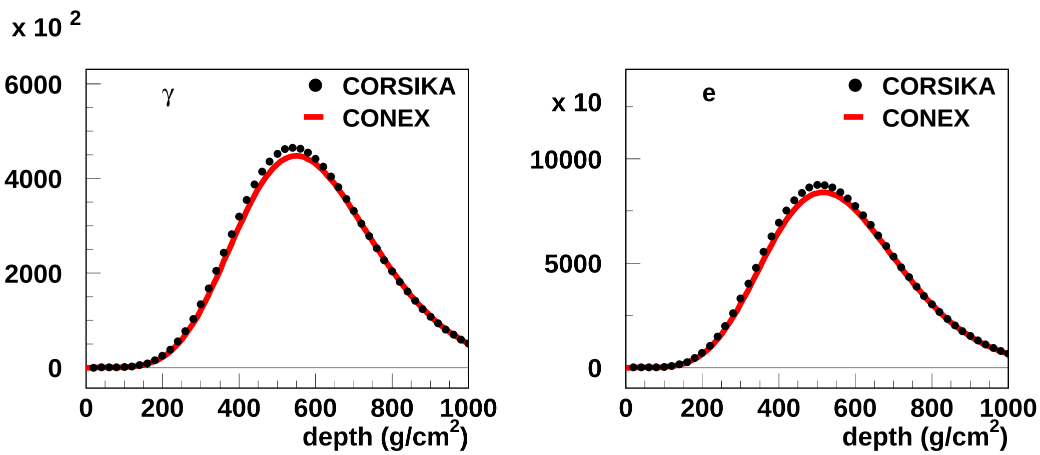


**Fig. 1.** Number of photons (left) and electrons/positrons (right) as function of slant depth for photon-induced showers of $10^{14}$ eV. Only particles with kinetic energy greater than 1 MeV are considered.

## 3. Comparison to CORSIKA results

To test the numerical treatment of the electromagnetic cascade equations we compare our results with CORSIKA simulations. Fig. 1 shows the average longitudinal shower profile of electrons and photons in $10^{14}$ eV photon-induced showers as predicted by CORSIKA [5] together with our calculation. Examples of electron and photon energy distributions at fixed atmospheric depths are given in Fig. 2. In all cases a good agreement is found, but some differences can be seen at very low energy.

Finally, in Fig. 3 we compare the longitudinal shower profiles of electrons and photons for $10^{18}$ eV proton-induced showers as obtained with CONEX and

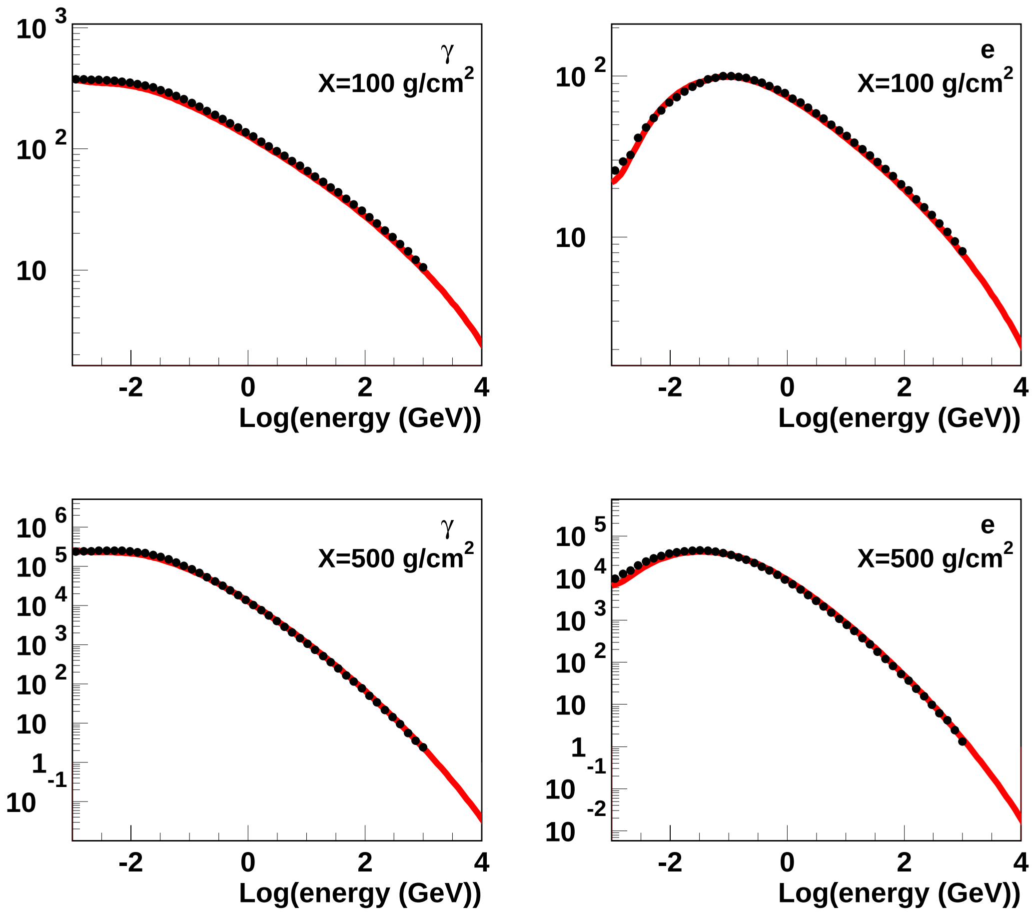


**Fig. 2.** Energy distributions of photons (left) and electrons (right). The symbols are CORSIKA predictions and the curves represents the results of the numerical solution of the cascade equations.

CORSIKA (100 events each). Again, only particles with $E_{\rm kin} \geq 1\,{\rm MeV}$ are shown. The CONEX predictions are lower than that of CORSIKA by about 5%. This agreement is reasonable, given the fact that CONEX uses a completely different, independently developed formalism of the hadronic and electromagnetic shower parts.

We plan to investigate the reasons for the differences between the CONEX and CORSIKA predictions in detail.

## 4. Conclusions and outlook

CONEX is a newly developed code for fast hybrid simulation of air showers. Its predictions are in good agreement with the results of the well-tested CORSIKA Monte Carlo program. CONEX is ideally suited for realistic shower

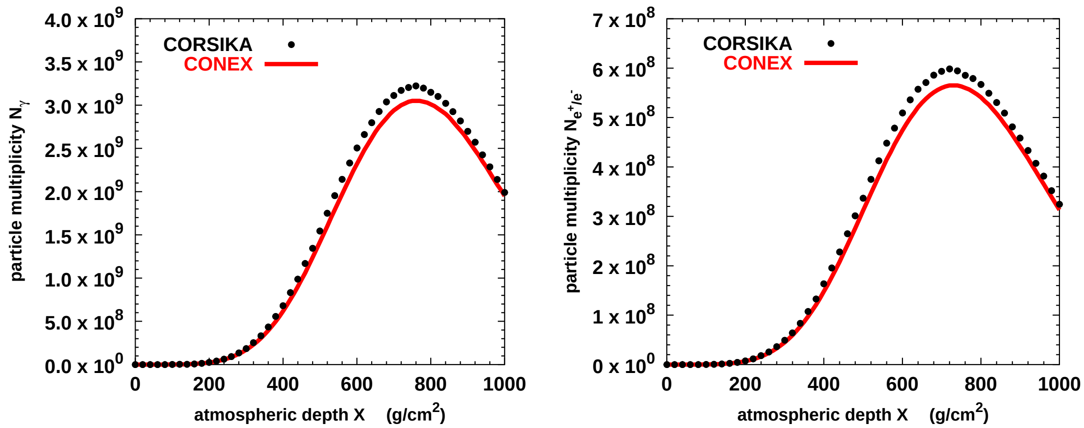


**Fig. 3.** Mean longitudinal shower profiles of photons (left) and electrons and positrons (right) for vertical proton-induced showers of energy $10^{18}$ eV. The curves represent CONEX hybrid simulations and the symbols are CORSIKA results.

profile simulations as needed for EAS experiments measuring fluorescence light, e.g. Auger, EUSO, or OWL. The current version of CONEX is restricted to the one-dimensional treatment of showers. It is planned to extend the code to allow a full three-dimensional description of extensive air showers [6].

**Acknowledgements:** S.O. acknowledges the support by the German Ministry of Education and Research (BMBF, grant 05 CU1VK1/9).

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