Simulation of Cherenkov Contamination for Cosmic-Ray Showers Observed with the Auger Fluorescence Telescopes

L. Perrone[1], C.K. Guerard[2], F. Nerling[3] and M. Risse[3]
(1) Universität Wuppertal, Fachbereich Physik, D-42097 Wuppertal, Germany
(2) Universität Karlsruhe, IEKP D-76021 Karlsruhe, Germany
(3) Forschungszentrum Karlsruhe, Institut für Kernphysik, 76021 Karlsruhe, Germany

Abstract

Any measurement of cosmic ray shower features relying on the fluorescence light technique requires a good knowledge of Cherenkov light contribution along shower development. The results of a simulation study concerning properties of Cherenkov light emission are shown using GEANT and CORSIKA. An evaluation of the Cherenkov contribution to the photon profile detected by fluorescence telescopes has been carried out by performing shower simulations with CORSIKA. For a given primary energy and geometry, an analytical function is then built, providing the number of Cherenkov photons at any depth and for any angle to shower axis. This method has been applied to a few hybrid events collected during the engineering prototype phase of the Auger Fluoresence Detector (12/2001-3/2002).

1. Introduction

For the primary energy determination by means of fluorescence telescopes, a reliable estimate of the Cherenkov contamination is required. The basic Cherenkov emission properties are studied using the GEANT [1] simulation tool and compared to the predictions given by the CORSIKA [2] code. Then, a simulation study of the (direct) Cherenkov contribution to the signal expected at the diaphragm of the Auger Fluorescence Telescopes [3] has been carried out using CORSIKA shower simulations.

2. Comparison of Basic Emission Properties

The GEANT and the CORSIKA predictions concerning Cherenkov light emission properties, i.e. number and angle of emitted photons, are compared for different air densities. Single electrons are simulated and the Cherenkov wavelength range has been chosen between 300−400 nm. Since in GEANT the Poissonian fluctuations are taken into account, an average of 1000 events is calculated

pp. 615–618

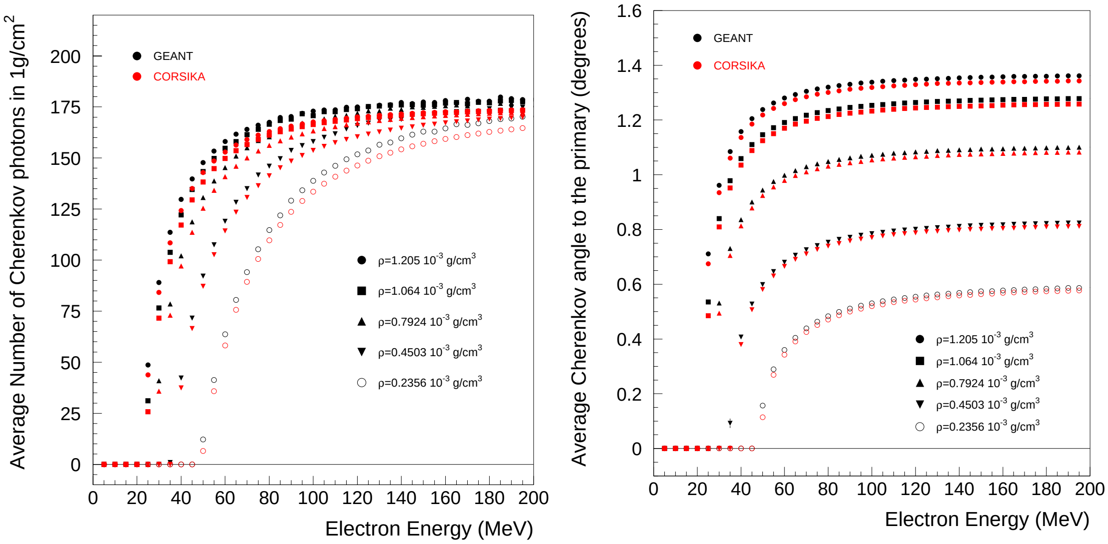

Fig. 1. Average number of Cherenkov photons produced by individual electrons in the next 1 g/cm^2 (left) and corresponding average emission angle (right) vs. electron energy. GEANT and CORSIKA values are compared for different air densities.

for each combination of electron energy and air density. In Fig. 1 (left), the average number of Cherenkov photons produced in the next 1 g/cm^2 is shown as a function of electron energy. The energy threshold for the production of Cherenkov photons ($v > c/n$ with v the velocity of the emitting particle and n the refractive index), as well as the "saturation region" for large electron energies can be clearly seen in figure. The agreement is fairly good, failing at most at the level of a few percent. The main reason of the slight difference is given by the different treatment of the refractive index. Indeed, CORSIKA is currently neglecting the wavelength dependence of this quantity. The calculation of the average number of Cherenkov photons has been repeated taking in GEANT the same index of refraction as used in CORSIKA. In this case, the relative disagreement is reduced at the level of 1.5% or better. A GEANT based study shows that the fluctuations of the average number of Cherenkov photons produced in the next 1 g/cm^2, stay, far from the energy threshold, at the level of 8%. In Fig. 1 (right), the average Cherenkov emission angles are shown as a function of electron energy and compared for different air densities. In this case the agreement between the two calculations is at the level of 1.5% and the fluctuations are always well below 1%.

3. Simulation of the Cherenkov Contribution

CORSIKA shower simulations have been performed in order to evaluate the Cherenkov light contribution along the shower development. Ten inclined

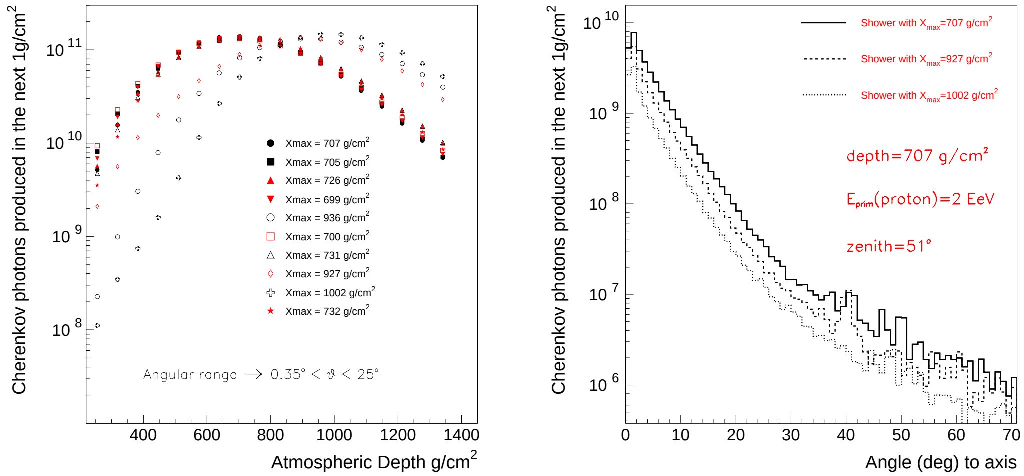

Fig. 2. *Left*: Number of Cherenkov photons produced in the next $1\mathrm{g/cm}^2$ and up to 25° to shower axis as a function of atmospheric depth, for ten proton-initiated showers. (E_{prim}= 2 EeV, zenith=51°). Corresponding depths at shower maximum are also given. *Right*: Angular distribution of Cherenkov photons at slant depth of 707 $\mathrm{g/cm}^2$ for three of the ten showers shown on the left.

proton-initiated showers with primary energy of 2 EeV and with zenith angle of 51° have been simulated for this study. The angular distribution of Cherenkov photons is extracted in bins of 0.250° and in vertical layers of 40 $\mathrm{g/cm}^2$. In Fig. 2 (left), the number of Cherenkov photons produced in the next 1 $\mathrm{g/cm}^2$ and up to 25° to shower axis is shown as a function of atmospheric depth. The shift in the profiles are due to different points of first interaction. The corresponding shower maxima (X_{max}) are also given with different keys. In Fig. 2 (right), the Cherenkov photon angular distribution at slant depth of 707 $\mathrm{g/cm}^2$ is shown for three of the ten showers shown on the left. Geometry and primary energy have been chosen following the method described in [4], based on a preliminary reconstruction of a hybrid event collected during the engineering prototype phase of the Auger Fluorescence Detector. Using these simulations and a Spline algorithm for interpolation, a two dimensional function giving the number of Cherenkov photons produced at any depth and any angle to shower axis is then calculated. The photons falling in the field of view of any particular photomultiplier are transmitted through the atmosphere down to the detector. Since the shower track is pointing roughly towards the observer we expect a large direct Cherenkov contribution. (More details on the photon profile simulation adopted here are given in [4]). In Fig. 3, the number of photons received at the detector diaphragm is shown as a function of time (left) and mirror pixel elevation (right). The shower with $X_{max} = 707\ \mathrm{g/cm}^2$ has been used for this plot. The contribution of direct

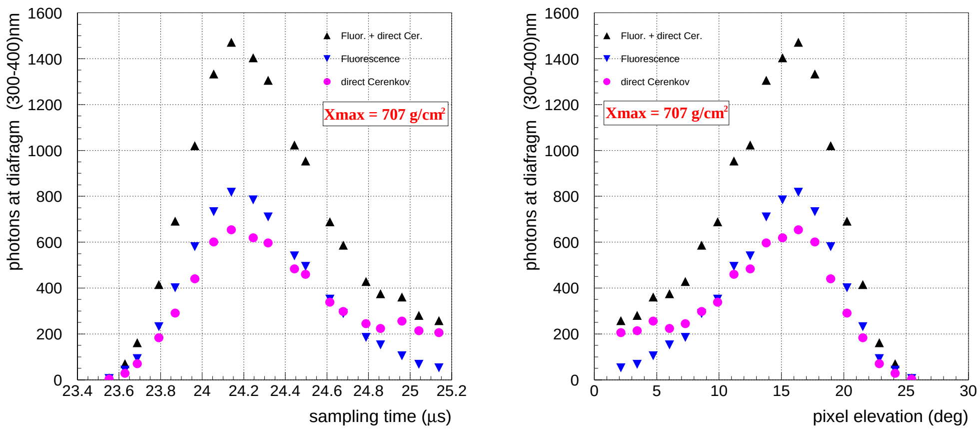

Fig. 3. Simulated photon profiles at the detector diaphragm as a function of time (left) and mirror pixel elevation (right). A proton-initiated shower with primary energy of 2 EeV and with zenith angle of 51° has been used for this study. The contribution of direct Cherenkov and fluorescence photons, as well as the total light signal, are shown with different keys.

Cherenkov and fluorescence photons, as well as the total light signal, are shown in Fig. 3 with different keys.

4. Conclusion

The agreement between GEANT and CORSIKA predictions for the basic Cherenkov emission features (number of emitted photons and emission angle) is at the level 2−3%. A simulation study concerning the direct Cherenkov photon contamination in the light signal received at the fluorescence detectors has been presented. This is mainly intended as a tool for contributing to the current and upcoming analyses of Auger Fluorescence Detector data.
Acknowledgments. The support by D. Heck is gratefully acknowledged.

5. References

1. GEANT 3.21, 1994 CERN Program Library Long Writeups W5013
2. Heck D. et al. 1998 Report **FZKA 6019**, Forschungszentrum Karlsruhe
3. Argiro S. for the Auger Collaboration, these Proceedings
4. Guerard C.K. et al., these Proceedings