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**Showrec – A Program for
Reconstruction of
EAS Observables from
KASCADE-Grande Observations**

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Abstract

The report describes the basis and main features of a flexible computer code for reconstructing lateral distributions of charged particles and various other observables from KASCADE-Grande EAS observations by taking into account the detector response of the Grande stations. The concept and applications are illustrated by some examples. The structure of the input and output files is described in detail.

Zusammenfassung

SHOWREC – ein Rechenprogramm für die Rekonstruktion von Luftschauer Observablen aus KASCADE-Grande Beobachtungen

Der Bericht beschreibt die Grundlagen und die wesentlichen Eigenschaften eines flexiblen Rechenprogramms für die Rekonstruktion der lateralen Verteilungen der geladenen Teilchen und anderer Beobachtungsgrößen aus Luftschauermessungen mit dem KASCADE-Grande Detektor Array unter Berücksichtigung des Detektor-Response der Grande Stationen. Das Konzept und Anwendungen werden mit Beispielen illustriert. Ein- und Ausgabe des Rechenprogramms werden ausführlich beschrieben.

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1 Introduction

A generic method to investigate experimentally extensive air showers (EAS) is the measurement of the number of secondary charged particles generated by the interaction of the primary particle in the atmosphere, the lateral density and energy distributions of various EAS components, observed at different energy thresholds and of the arrival time distributions of the shower particles [1]. The measurements are usually performed by large extended arrays of detectors of different kinds which sample the particle distributions arriving on ground. Estimating the capabilities of the experimental layout of such arrangements and studies of observables which carry relevant physical information on the EAS require an understanding of the response of the detectors and a reconstruction of the observables from the detector signals in terms of the particle distributions. This task is in addition to a consideration of the efficiency of the sampling, which is mainly determined by the effective detector area of the particular detector set-up.

The present study is related to the KASCADE-Grande experiment [2] which extends the former KASCADE experiment to higher primary energies (up to 10^{18} eV) and has been recently put in operation. The report describes the procedures how from the detector response i.e. the measured energy deposition in the KASCADE-Grande scintillators the number of hitting charged particles is reconstructed and lateral distributions $\rho_{ch}(r)$ (r = distance from the shower axis) are deduced. The reconstruction procedures have been developed with the help of particle distributions ρ_{ch} (electrons, γ -quanta, muons and hadrons) provided by advanced Monte Carlo EAS simulations by use of the program CORSIKA [3] (vers.6.014) with the hadronic interaction model QGSJET [4]. The response of the detectors is calculated with the detector simulation tool GEANT [5] and the reconstruction leads generally in some experimental distortions of $\rho_{ch}(\rho_{\mu}) \rightarrow S(S_{\mu})$. The problems in reconstructing the lateral distributions (ρ_{ch}, S) for inclined showers in a plane normal to the shower axis are outlined.

For studies of the muon arrival time distributions (see Ref. [6]) the point of view is adopted that they will be measured by the timing facilities of the KASCADE Central Detector [7] for muons identified with the Multiwire Proportional Chambers (MWPC) [8] at a muon energy threshold of 2.4 GeV. Here the number of detected muons is determined by the geometrical and inherent efficiency of the MWPC, while the timing is affected by time fluctuations and by the time resolution of the scintillators in the so-called "Trigger Plane" of the Central Detector (see Ref. [9]).

The report summarizes the basis and the main features of the reconstruction program SHOWREC whose technical details are given in the appendices. Some examples, addressing the reconstruction of lateral density distributions and of observables characterizing the time structure of the EAS muon component illustrate its application. In this context the use of truncated charged particle numbers $N_{ch}^{l-r_u}$ i.e. the charged particle density integrated within the radial range $r_l - r_u$ is introduced.

The program code of SHOWREC is constructed to run in a stand alone version, but it is possible and aspired to include the main features in the standard reconstruction program package KRETA of the KASCADE-Grande experiment.

Presently, the full program is available by contact with osima@pcnet.pcnet.ro . The authors encourage colleagues to use the program in the current version, but kindly ask to report about discovered bugs or possibilities of improvements.

2 Layout and observables of the KASCADE-Grande experiment

The basic layout of the KASCADE-Grande detector installation is embedding the former KASCADE set-up [10]. It combines KASCADE with the Grande array of 37 stations of 10m^2 each of scintillator counters (basically the electromagnetic detectors from EAS-TOP experiment [11]) at mutual distances of about 130m (Fig.1), installed on site of Forschungszentrum Karlsruhe, and covering globally 0.5km^2 . Technical details of the

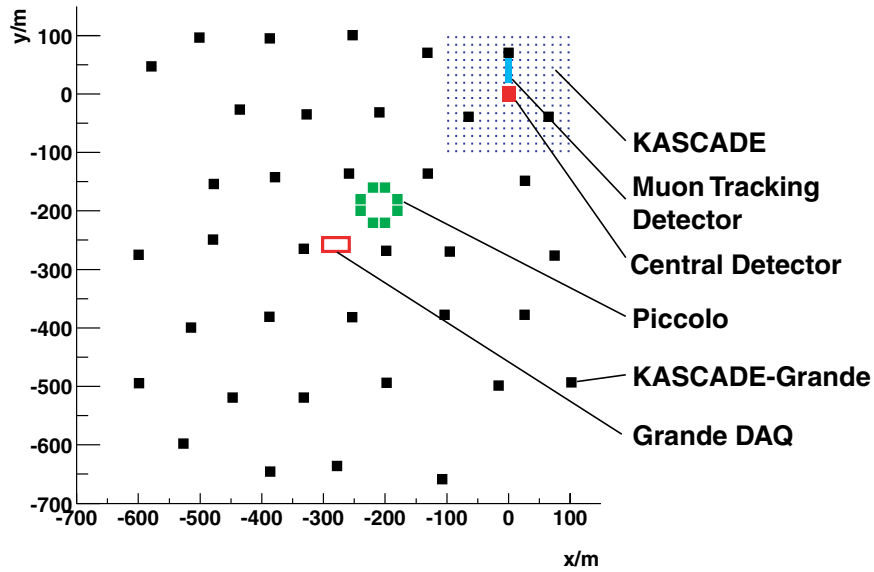


Figure 1: *Layout of the KASCADE-Grande detector.*

experiment are given in Ref. [2]. The Grande stations are distributed coarsely in a hexagonal grid over an area of about $700\text{m} \times 700\text{m}$. There is a further more densely structured scintillator array placed near the center of KASCADE-Grande: Piccolo with the main aim to provide an external trigger for recording events coincidentally seen in the KASCADE and Grande arrays. The reconstruction of the observations with Piccolo has not been considered in the present report. The KASCADE experiment [10] includes three major components: a (field) array of e/γ and muon detectors, a Central Detector which is a complex setup with an iron sampling calorimeter [7] for hadron detection and substantial muon detection areas, and an underground tunnel with Limited Streamer Tube telescopes for measuring the angles of incidence of EAS muons for muon energies $E_\mu \leq 0.9\text{GeV}$.

The e/γ and muon detectors of the field array cover an area of $200\text{m} \times 200\text{m}$ and are arranged in 252 detector stations placed in square grids of 13m separation, with a total area of about 490m^2 for e/γ detection ($E_e > 5\text{MeV}$) and 622m^2 for the muon detectors ($E_\mu > 240\text{MeV}$), respectively.

The Central Detector is composed of different detector components. In the basement there is an installation of large area position sensitive multiwire proportional chambers, arranged in double layers with a telescope effect identifying muons of energies larger than 2.4GeV and giving information about the mean arrival direction. They allow to investigate the average lateral distributions of EAS muons of the energy $E_\mu > 2.4\text{MeV}$. Below the third iron layer of the hadron calorimeter, at a depth of $30X_0$ and with a mean muon energy

threshold of 490MeV, plastic scintillators provide a fast trigger signal and are used for timing measurements. This timing "eye" is composed of 456 detector elements, covering 64% of the total Central Detector area of $16\text{ m} \times 20\text{ m}$. The averaged time resolution of these detector elements has been determined to $1.5 - 1.7\text{ ns}$. For details see Ref. [12].

The main observables measured with the Grande detectors is the particle density ρ_{ch} of charged particles. By these densities the total number N_{ch} of charged particles of the shower and the lateral density distribution are reconstructed. Presently there is no experimental possibility to separate the different types of charged particles with these detectors. This is in contrast to the included KASCADE field array which allows to determine the muon contribution and to present a partial muon number N_{μ}^{part} , comprising the EAS muons hitting the KASCADE part of the total installation. The correlation of N_{ch} with N_{μ}^{part} is expected to be mass discriminative, in addition to the shape of the lateral distribution ρ_{ch} [13] and to the correlation of N_{ch} with a quantity, which represents the primary energy independent from the mass of the EAS primary. Therefore special attention is paid to the charged particle density in the distance $r = 500 - 600\text{ m}$ from the shower axis which has been successfully used [14] to signal the energy of the primary particle.

The reconstruction of the EAS quantities observed with the KASCADE set-up are not object of this report. Only for the case of muon arrival time distributions measured with the Central Detector a simplified procedure for realistic estimates is introduced.

3 The reconstruction of the particle densities in the plane normal to the shower axis and the origin of azimuthal asymmetries

Irrespectively of the inclination of the EAS axis (zenith angle Θ , azimuth angle Φ), the measured particle densities or the simulated particle densities computed by a Monte Carlo program like CORSIKA are given in a horizontal plane at the observation level. However, lateral distributions of shower particles are more conveniently studied and compared in a plane normal to the shower axis (Fig. 2). Therefore an adequate procedure to map

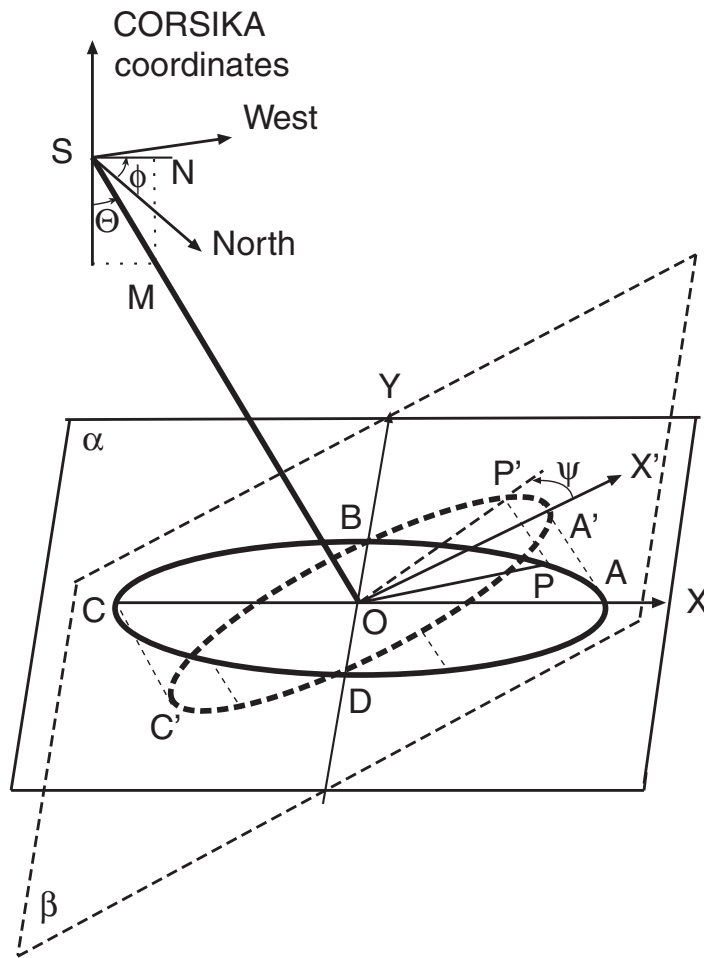


Figure 2: Schematic display of the geometry of shower analysis. The shower axis SO is characterized by the angles Θ and ϕ in the CORSIKA coordinate system. The intersection of the vertical plane SMN containing the shower axis with the horizontal plane α (the observation level) defines the OX axis in the observation level. Positive values of x correspond to the late region of the shower development, negative values - to the early region. The intersection of the plane SMN with the plane β which is perpendicular on the shower axis defines the OX' axis in the plane normal to the shower axis. The point P' from the normal plane corresponding to the point P in the observation level has the angular coordinate ψ .

the particle densities from the observation level to the plane normal to the shower axis is required.

Three procedures have been analyzed:

a. The densities in the normal plane are obtained by projecting the particle impact point from the observation level onto the normal plane. This is the common procedure. It introduces an artificial dependence of the lateral distributions from the azimuth measured in the normal plane with respect to the shower axis (Θ, Φ): $\rho = \rho(r, \psi)$.

b. The densities in the normal plane are obtained by the intersection of the unperturbed particle trajectory detected in the observation level with the normal plane. This is a more rigorous procedure, but it requires the knowledge of the momentum vector of the particle.

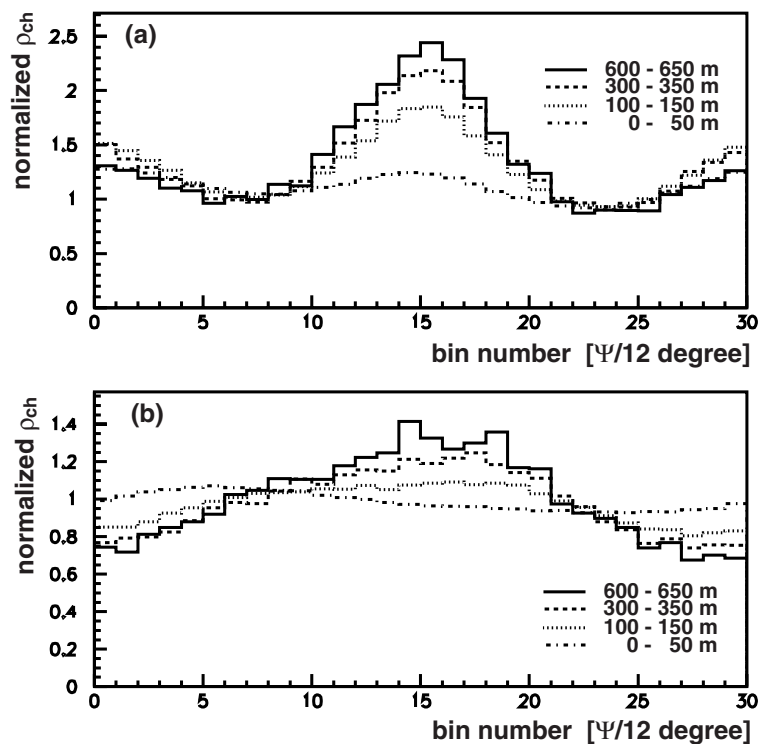


Figure 3: Charged particle density $\rho_{ch}(r, \psi)$ in several radial bins as a function of the angle ψ . The data are evaluated in angular bins of 12° and are normalized to the density in the bin along the Y-axis (Fig.2) both in the observation level (a) and in the plane normal to the shower axis (b). The case relates to an EAS induced by a iron primary with the following parameters: $E = 7.6 \cdot 10^{17} \text{ eV}$, $\Theta = 36.6^\circ$, $\phi = 255^\circ$.

c. The densities in the normal plane are deduced by a two-steps procedure. The first step assumes that the global arrival time (relative to the shower center) is known. Additionally assuming that the particle has been produced on the shower axis and does not experience substantial scattering on its way to the observation level, the particle production locus can be computed by triangulation. Under these conditions the intersection of the trajectory starting from the production point and ending in the observation level with the normal plane is obtained. This procedure is useful for higher-energy muons like detected in the Central Detector of the KASCADE array where the timing facilities may provide the necessary information.

Considering these procedures the lateral distributions of EAS muons, electrons, photons, protons and neutrons generated by EAS Monte Carlo simulations have been studied. In particular, the features of the azimuthal distribution in the normal plane have been studied. Actually, in general anisotropies of the azimuthal distribution in the normal plane are expected resulting from the influence of the magnetic field of the Earth. Additionally, for inclined showers, if the distribution in the normal plane is deduced from the distribution registered at the observation level, anisotropies may result from the differences in the attenuation due to the fact that the particles arriving below the shower axis (the "fast component") do cross a smaller atmospheric grammage than the particles arriving above the shower axis (the "late component" of the shower). This anisotropy could be corrected using an attenuation correction specific for each type of shower particles.

If the first procedure for constructing the distributions in the normal plane is adopted, a different kind of anisotropy is introduced. The origin of this artificial anisotropy is the following. The particles which hit the observation level at the same distance to the shower axis would be mapped onto the normal plane also at equal distances from the shower axis, while in fact the particles below the shower axis (the "early component") arrive at a larger angle with respect to the shower axis and should therefore have been observed at a larger distance from the axis than the particles which hit the observation level at the same distance but in the region located above the shower axis (the "late component").

If the lateral distribution is integrated over the angle in the normal plane, the effects of the anisotropy are greatly canceled. However, if it is integrated over an incomplete azimuthal sector (which is the usual case in real shower observations and analyses), the effect of the anisotropy remains. In case that most of the data would come from the "early component" of the shower particles, the lateral distributions would get overestimated, while in the case that most of the data originate from the "late component", the particle density would be underestimated. In this sense, this kind of dependence on azimuth ψ (see Fig. 3) is an unwanted feature, which should be removed.

On the other hand, observations of a true azimuthal dependence in the normal plane may also carry useful information. This can be qualitatively understood by comparing the behavior of Fe induced showers with the case of proton induced showers. Indeed, in the case of Fe induced showers, the particle production is typically distributed at locations of higher atmospheric altitude than in the case of proton induced showers. Consequently, the anisotropy resulting from the differences in the angle with respect to the shower core for the particles placed at the same distance from the core in the normal plane (procedure a.) should be reduced for Fe as compared to p induced showers. Simultaneously, for the same primary energy the fraction of electrons with respect to muons of Fe induced showers is lower than in the showers induced by protons; thus differences in the attenuation of the fast component and of the late component of the shower should be smaller in the case of Fe induced showers (because the attenuation is more pronounced for electrons than for muons). Both effects act in the same direction. In conclusion, the anisotropy should be higher in the case of proton induced showers than in the case of Fe induced showers. The effects should be more pronounced at large distances from the shower axis. It remains to be studied whether these qualitative considerations would lead to observable effects and result in useful quantitative information.

With respect to practical handling of the procedures mapping the observations of the detector level to the plane normal to the shower axis, the reconstruction program SHOWREC adopts following view and provides following options.

As long as the additional information needed for the application of the procedures b. and c. is missing. SHOWREC applies the procedure a., but with considering all four different azimuthal sectors and averaging over the four results, thus relieving, in general, the artificially introduced anisotropy. In case of the high energy muons detected with the MWPC of the Central Detector at least theoretically the arrival times of the muons are provided by the simulations. Hence in this case the procedure c. is feasible.

4 The lateral energy correction function

The reconstruction of the charged particle density $S(r)$ at a certain distance r from the shower center from the measurements with KASCADE-Grande starts on the level of detector signals calibrated in terms of the energy deposit. Hence it implies the knowledge of the energy deposit in the scintillator detectors in terms of a single particle. In order to develop fast procedures for the calculation of the energy deposited in the scintillators, the response of these detectors to muons, electrons, photons, protons and neutrons has been studied at various particle energies.

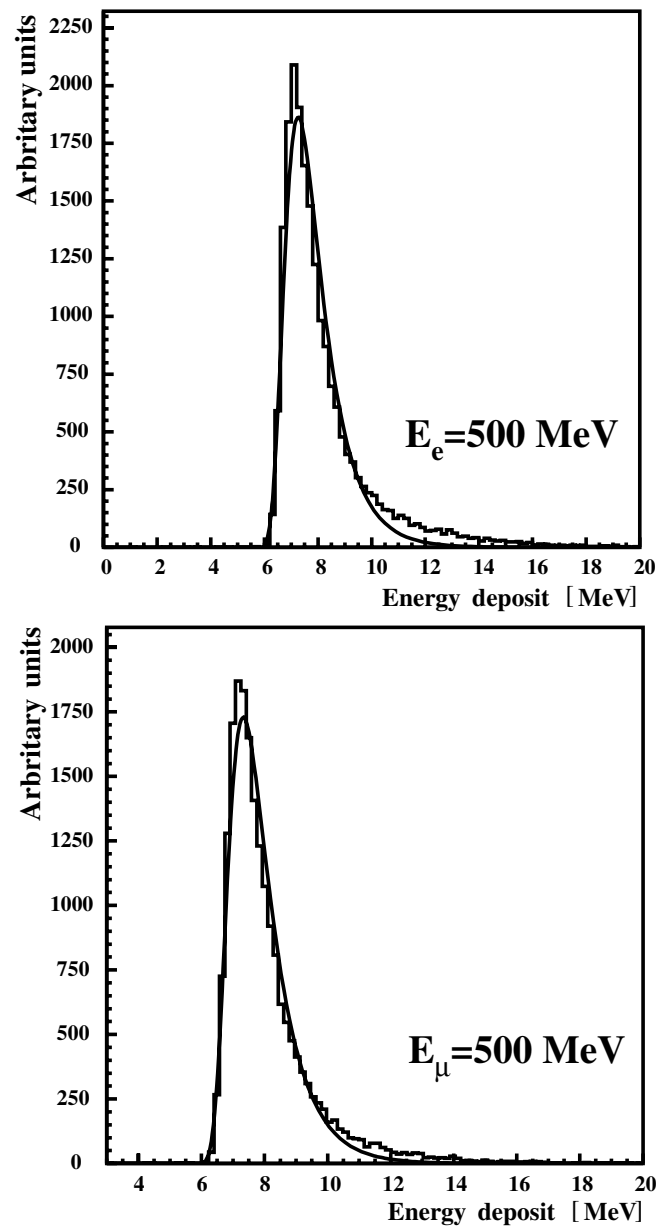


Figure 4: The energy deposition of single muons and electrons.

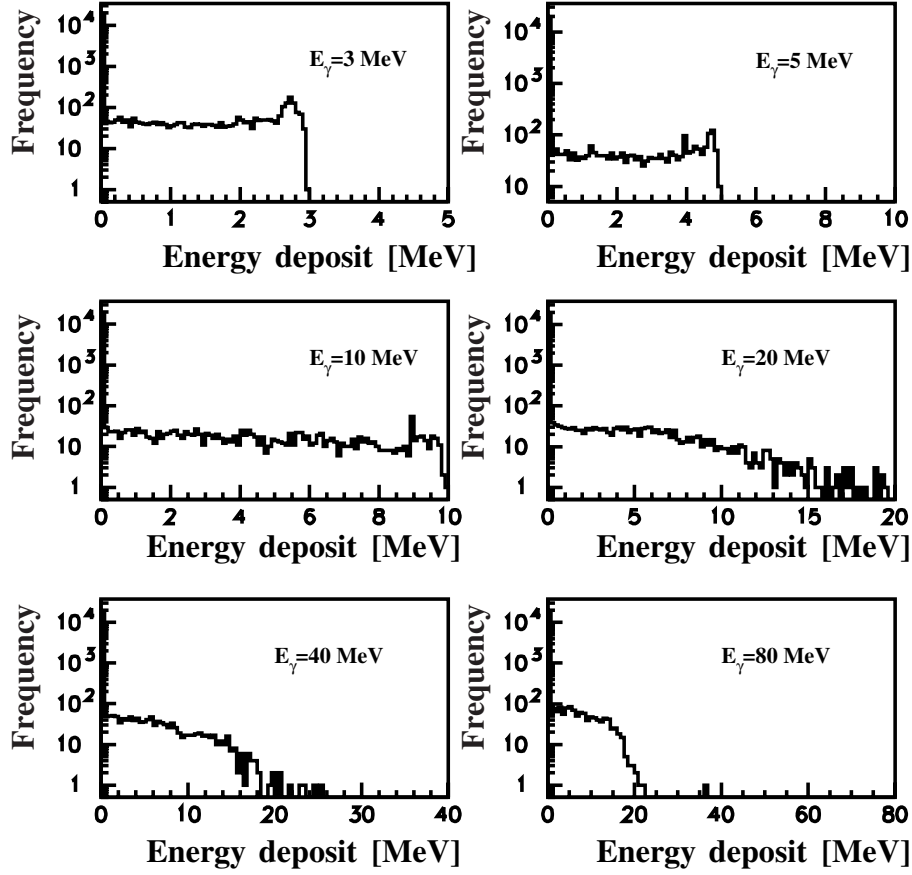


Figure 5: *The energy deposition of single photons at various energies.*

Realistic energy deposition values were computed by use of the GEANT program [5] invoking the Bethe-Bloch formula for charged particles. Subsequently the distributions computed by GEANT have been fitted by Landau-Vavilov distributions [15] for muons and electrons (Fig. 4), while the situation for photons is more complex (Fig. 5). Here combinations of Gaussian, linear and exponential forms (photons, protons and neutrons), with the parameters adjusted as a function of the incident energy were applied.

Specific subroutines (EDEPMU, EDEPEL, EDEPG, EDEPP, EDEPN) were developed for the fast computation of the energy deposition.

In this way by use of the output of the CORSIKA program, the energy deposited per minimum ionizing charged particle (muons and electrons) in the KASCADE-Grande detectors has been evaluated as a function of the distance from the shower axis for core distances up to 1000m. This "lateral energy correction function" (LECF) proves to be practically the same for iron and proton induced showers. In Fig. 6 the calculated LECF is represented with the assumption that the particles enter vertically the detectors. The energy deposit for particles which enter oblique on the scintillator is of course higher. Due to this fact the mean energy deposit per charged particle is increased; the difference is bigger at large distances from the shower core than at small distances. The LECF was computed and recorded in a file called LATCORF.LCF, included in the SHOWREC package.

It should be noted that the presented LECF is slightly dependent on the used hadronic interaction model (here QGSJET) at the simulations.

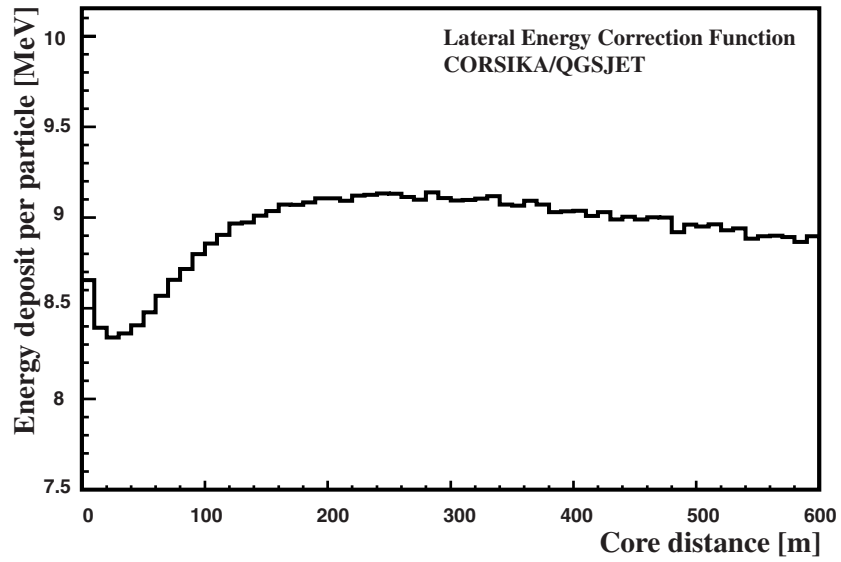


Figure 6: *The average energy deposit per charged particle in a KASCADE-Grande station as function of the core distance.*

5 The shower reconstruction program SHOWREC

On basis of the described studies a computer program SHOWREC for the shower reconstruction with observations of the KASCADE-Grande set-up has been developed. The initial purpose of the program was rather specialized, namely to investigate how detector efficiency and experimental resolution affect the conclusions of theoretical studies made with ideal (i.e. CORSIKA provided) information about the muon arrival times. The structure of the initial version was inherited by the present version of the program; on this skeleton further developments are planned.

Details about the procedures applied in the program and about various quantities of interest are given in the appendix with numerous explaining comments. Here the most important items are summarized.

5.1 FORMAT

The input file is adapted to the output file of the Monte Carlo program CORSIKA. The program SHOWREC can be run in an interactive or in a non-attended mode.

In the interactive mode, SHOWREC prints a dialogue prompting the user to input specific data: the name of the CORSIKA file, the index of the event of interest from that file, the radius of the region close to the core excluded from the time analysis, the region over which the shower core will be randomly distributed, the time resolution (separately for core arrival time and for each muon providing time information), the maximum radius for constructing the lateral distributions (Appendix A).

In the non-attended mode, all the above input data are read from an input file prepared in advance.

5.2 CORE LOCATION

The shower core is randomly distributed over the surface delimited by the extreme Grande detectors or optionally over a smaller area defined by the user. In the latter case, either a rectangular or a ring shaped surface can be chosen.

The geometry defining the random positioning of the shower core is presented in Fig.7. If a rectangular area is selected, this is delimited by the coordinates (x_l, x_u) , (y_l, y_u) ; if a ring around the central detector (CD) is selected, it is defined by the radial coordinates (r_l, r_u) and the angular coordinates (α_l, α_u) . In the case of the ring, the figure displays the region selected for a vertical shower; for an inclined shower the ring is defined in the plane normal to the shower axis (Fig.2), that is, the distance between the shower core and the projection of the Central Detector onto the plane normal to the shower core is inside the ring.

5.3 LATERAL DISTRIBUTION

For each muon and electron read from the CORSIKA output file the corresponding radial and angular co-ordinates in the plane normal to the shower axis (Fig. 2) are deduced according to procedure a. of section 3. Using these data, the lateral distribution of charged particles (muons and electrons) in the normal plane up to a distance r selected by the user (typically 1000m) is computed in 4 angular intervals: 1 $(-\pi/4, \pi/4)$, 2 $(\pi/4, 3\pi/4)$, 3 $(3\pi/4, 5\pi/4)$, 4 $(5\pi/4, 7\pi/4)$. In the reference system defined in Fig. 2 the first interval represents the late region, interval 3 the early region and the other two intervals are in between. In the end of the program the charged particle distributions ($\rho_{ch}(r)$ or $S(r)$) are fitted with a chosen lateral distribution function (LDF), and the total number of charged particles N_{ch} , the number of charged particles in definite radial bins $N_{ch}^{r_l-r_u}$ and the shape parameters of the LDF are evaluated, both for the distribution in each of the 4 angular intervals and

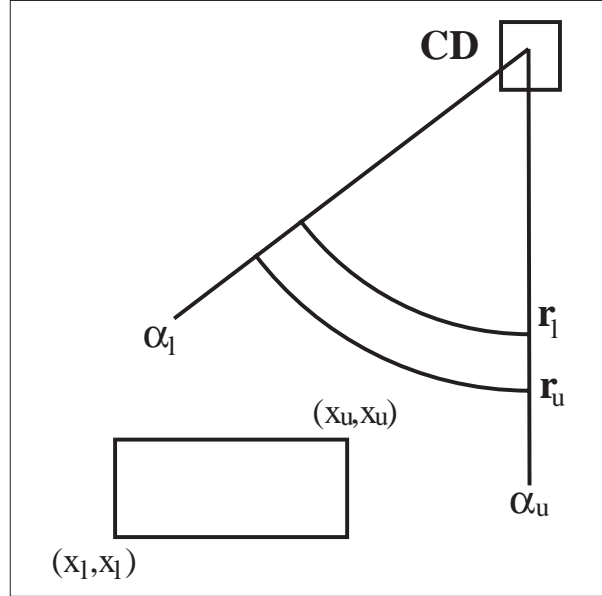


Figure 7: Coordinate system for locating the shower core position in SHOWREC. The outer rectangle represents the Grande area, the inner rectangle and the ring the type of specific regions which can be selected. CD represents the Central Detector.

for the averaged distribution. The entire range from 0 to r is used in the fit, but also specific intervals (e.g. the radial interval spanned by the Grande detectors) are automatically considered.

As standard for the LDF the phenomenological parameterization proposed by Linsley [16] has been introduced:

$$\rho_{ch}(r) \text{ or } S(r) = (N_{ch}/R_0^2) \cdot C(\alpha, \eta) \cdot (r/R_0)^{-\alpha} \cdot (1 + r/R_0)^{-(\eta-\alpha)}$$

where

$$C = \Gamma(\eta - \alpha) [2\pi\Gamma(2 - \alpha)\Gamma(\eta - 2)]^{-1}.$$

In addition to the scaling radius R_0 ("Molière radius", taken as $R_0 = 92\text{m}$) there are two shape parameters α and η .

Alternatively the NKG approximation [17] can be chosen, where also a Molière radius R_0 and a (lateral) age parameter s characterize the LDF.

The extended output file produced by SHOWREC contains the lateral distributions evaluated on the basis of the CORSIKA file. These data can be later analyzed using alternative lateral distribution functions without the need to process the output of CORSIKA again.

5.4 RECONSTRUCTION FROM DETECTOR RESPONSE

For each muon, electron, photon, proton and neutron that hits one of the Grande detectors, the energy deposit in that detector is evaluated using the appropriate energy distributions. After processing all the CORSIKA particles, the total energy deposited in each Grande detector is evaluated. This energy is subsequently divided by the mean energy deposited per charged particle at the corresponding distance from the shower core, as read from the LATCORF.LCF file. In this way the reconstructed number and density $S(r)$ of charged particles is obtained. The original CORSIKA number of charged particles hitting each detector is also recorded. From the reconstructed number of charged particles the charged

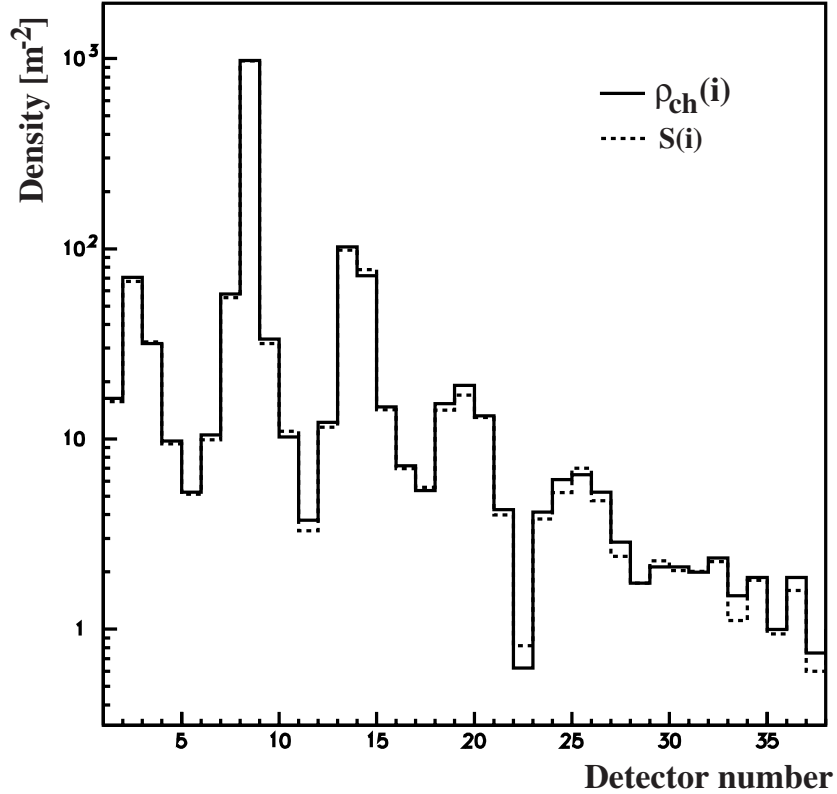


Figure 8: The comparison of the charged particle density $\rho_{ch}(i)$ based on the number of CORSIKA particles which hit the Grande detectors ($i=1,\dots,37$) with the reconstructed $S(i)$ obtained from the energy deposit in detectors for an iron induced shower with parameters: $E = 7.6 \cdot 10^{17} eV$, $\Theta = 36.6^\circ$, $\Phi = 255^\circ$.

particles density in the normal plane is computed (Fig. 8).

The energy deposited in each Grande detector is subsequently used for obtaining the reconstructed position of the shower core. The position of each detector in the normal plane associated with the reconstructed position of the core is determined.

The reconstructed charged particles density in the normal plane is fitted to a chosen LDF in function of the radial coordinate of the detectors with respect to the reconstructed core position, by adjusting its parameters. All the detectors are included in the fit but also the fit is performed separately over the detectors from the angular intervals 1, 3 and 2+4 (when the number of detectors in that angular interval permits a reasonable fit). Additionally the fitted parameters are used for the computation (interpolation) of the charged particle density at specific prefixed distances from the shower axis and of the number of charged particles registered in the radial bins 0 - 100, 100 - 200, ... 500 - 600 m in the plane normal to the shower axis.

5.5 MUONS

From the number of muons with the energy above 0.24 GeV and above 2.4 GeV, respectively which hit the Central Detector, the muon densities with the specified thresholds are evaluated. Actually the lateral distribution $\rho_\mu(r)$ for muons can be also reconstructed and

analyzed in context with the various LDF options like for the charged particles.

5.6 MUON ARRIVAL TIMES

The muons which are detected in the area of the Central Detector are carefully analyzed in order to determine whether they interact with the sensitive volume of the trigger detector and with the multiwire proportional chambers set. The detailed geometry of the detectors is included and the global detection efficiency is taken into account. For the muons which fulfill the required conditions the global and the local arrival times [18] are evaluated from the time information provided by CORSIKA. Another set of times (more realistic) is obtained by superimposing random fluctuations to the above times, simulating the experimental distortion of the time information by the detectors. The natural time fluctuations of the muon arrival times arising from the stochastic character of the shower development (and depending on the number of registered muons (multiplicity [9]) spanning the distributions of the single events (and given by the CORSIKA simulations) are overlaid with the instrumental fluctuations along Gaussian shaped distributions with the time resolution σ of the timing detectors and the uncertainty of the determination of the arrival of the shower core ("time resolution of the core") in the case of global times.

For all the muons which provide time information the mean and the quartiles of the arrival time distributions are computed. Two sets of results are evaluated. In the first set the ideal times, undisturbed by experimental resolution (i.e. the time values provided by the CORSIKA program) are used; in the second set, the realistic values of times, including the experimental resolution, are processed. In the case of inclined showers the corrections for obtaining the time values in the plane normal to the shower axis are evaluated using the procedure a. from section 3.

Then each muon arrival time is analyzed in order to check whether the procedure c. (Section 3) can be also applied. The muons for which the assumptions underlying the procedure are clearly violated (e.g. the difference between the muon arrival time and the core arrival time multiplied by the speed of light is bigger than the distance between the impact point in the observation plane and its projection onto the normal plane) are discarded from this analysis. For the muons passing the tests, the method c. is applied, providing by triangulation the production height, the atmospheric depth traversed through the atmosphere up to the production point and the angle with respect to the shower axis for each muon. The mean values and the quartiles of the above quantities are computed, both for the ideal time values and for time values distorted by experimental resolution as above.

The centered moments of the logarithms of the arrival times (both ideal and realistic) up to the fourth order are also evaluated [19].

As an extension the program can be compiled with the RING option. In this case the arrival time of each muon hitting the plane normal to the shower axis in the same ring in which the Central Detector is placed is registered. The mean and the quartiles of the time distributions and the centered moments of the logarithms of the arrival times of these muons are evaluated as above.

5.7 STEERING PARAMETERS AND OUTPUT

The program SHOWREC needs an input file with the values of some parameters defining the chosen options. In Appendix A the structure of the input file is presented. The program produces output files of ASCII type and also HBOOK files. In Appendix B a detailed presentation of the ASCII output files is given. Also, a detailed information about the procedures applied in the program is included by extended comments. In Appendix C the structure of the HBOOK file is discussed.

6 Examples of application

In the following some typical cases of applications of SHOWREC are compiled demonstrating the output of the program.

6.1 Comparison of the original and the reconstructed lateral distributions of charged particles

In this case the values of $S(r)$ reconstructed at the positions of the KASCADE-Grande detectors for ten simulated proton induced EAS have been added up and are fitted by the Linsley distribution to provide an average LDF for comparison with the distribution $\rho_{ch}(r)$ of the original CORSIKA data (Fig. 9). For comparison the charge particle number N_{ch} of the CORSIKA simulation is given.

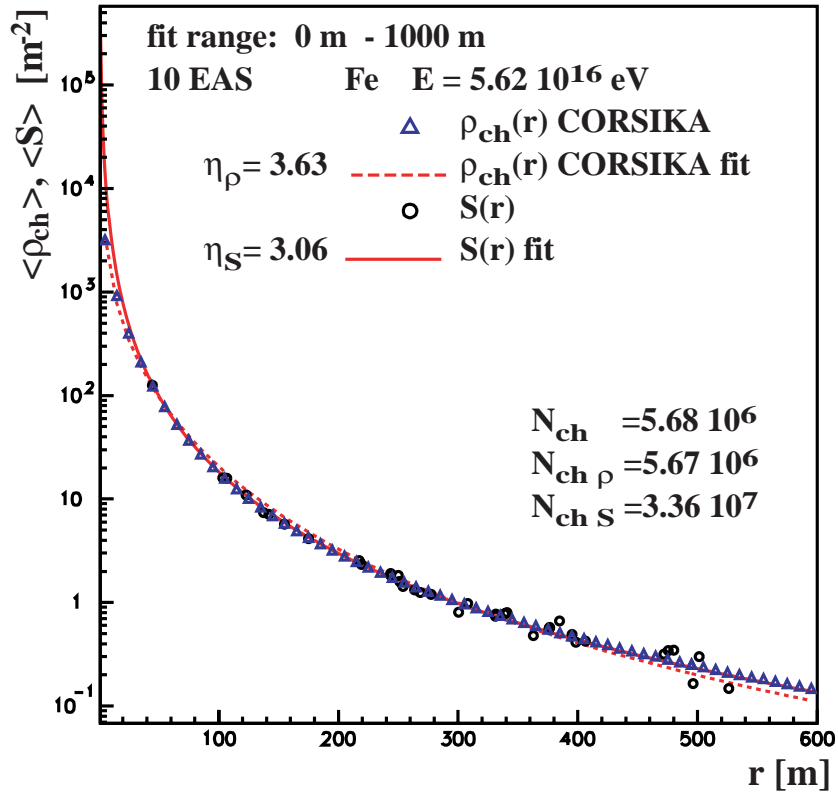


Figure 9: Comparison of the lateral distributions averaged over 10 proton induced EAS of the primary energy $E = 5.62 \cdot 10^{16} eV$, fitted by a Linsley type LDF.

6.2 Comparison of $S(r)$ and $\rho_{ch}(r)$ of proton and iron induced EAS of the energy $E = 1 \cdot 10^{17}$ eV at prefixed values of r

In this case the values of $S(r)$ haven been interpolated for each EAS by invoking the fit with the Linsley parameterization so that the values of $S(r)$ at the prefixed positions are basically not free from the bias of the adopted LDF (Fig. 10).

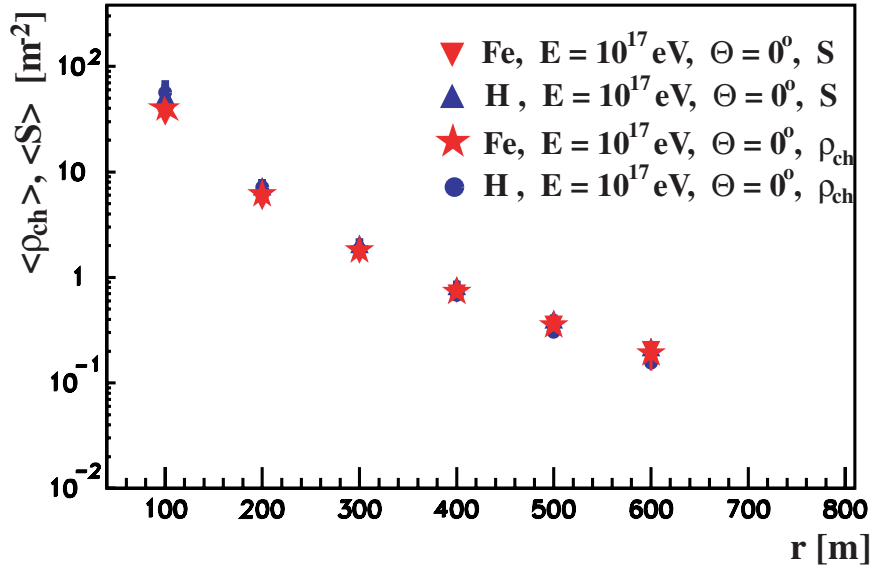


Figure 10: Comparison of the lateral distributions of averaged values of $S(r)$ and $\rho_{ch}(r)$ of charged particle densities deduced from 20 simulated proton and iron induced showers of the energy $E = 1 \cdot 10^{17}$ eV at prechosen values of r .

6.3 The use of different r -ranges for fitting the LDF and truncated charged particle numbers $N_{ch}^{r_l-r_u}$

When fitting the lateral distributions $\rho_{ch}(r)$ and $S(r)$, respectively, by a certain LDF, in general the result of the fit depends on the radial range ($r_l - r_u$) taken into account. That implies that the total number of charged particles N_{ch} and other LDF parameters, resulting from the fit, differ. In particular, the results gets dominated by the extrapolation of LDF to the small r region, where no "experimental" information is available, when results for $\rho_{ch}(r)$ and $S(r)$ are compared. Such effects reveal that the description of the lateral distribution by the considered type of the LDF is only partially sufficient. In order to illustrate the features in Figs. 11 different fitting ranges are compared for the case of a Linsley type LDF. In addition to $N_{ch}(\text{total})$ truncated charge particle numbers $N_{ch}^{r_l-r_u}$ are given, which represent the contributions of different radial ranges: $N_{ch}^{350-650}(\text{p}) = 2.55 \cdot 10^5$, $N_{ch}^{350-650}(\text{Fe}) = 2.49 \cdot 10^5$ (Fig. 11) and $N_{ch}^{40-200}(\text{p}) = 2.96 \cdot 10^6$, $N_{ch}^{40-200}(\text{Fe}) = 1.92 \cdot 10^6$ (Fig. 11). The different sensitivities of different radial ranges to energy and mass of the primary particle [20, 21] enable some use for energy identifying and mass discrimination.

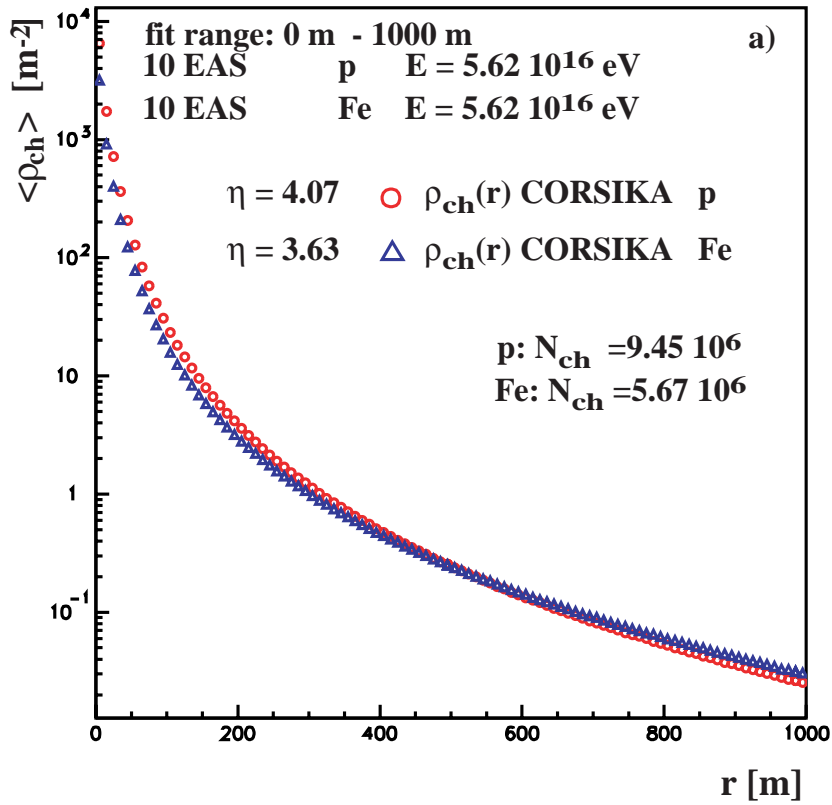
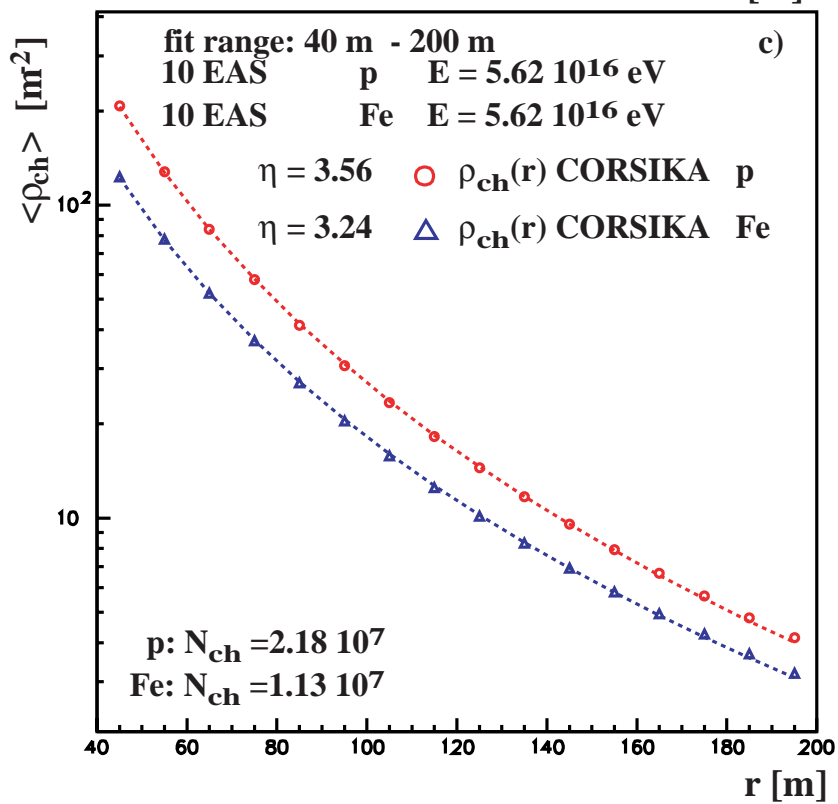
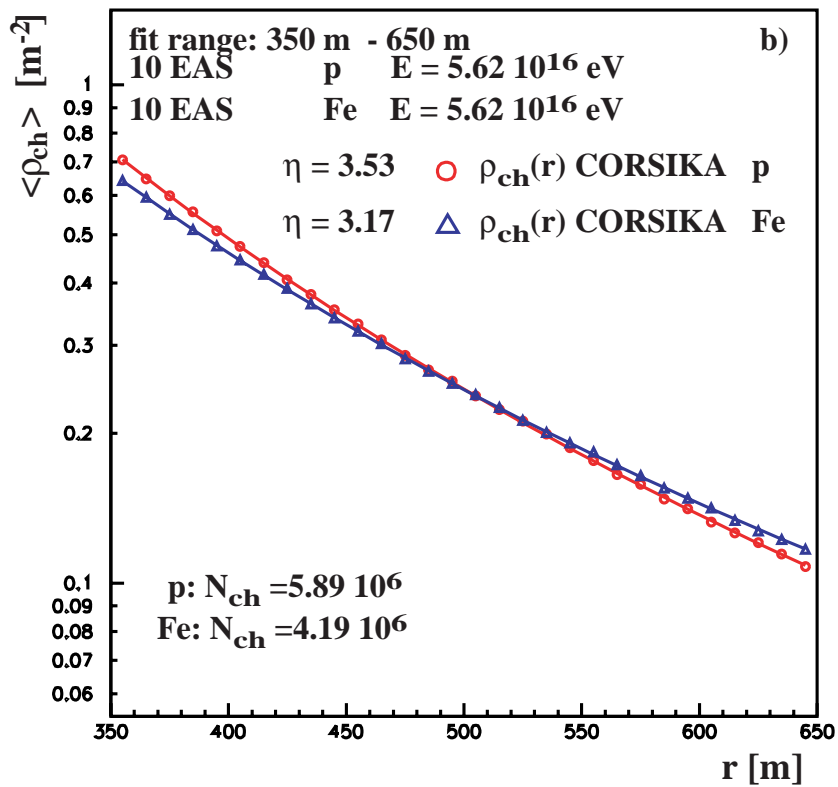


Figure 11: Result of adjusting a Linsley type LDF to the lateral density distributions in different radial ranges for 10 simulated proton and iron induced showers. a) In the range of 0-1000 m; b) and c) (next page) in the range 350-650 m and 40-200 m, respectively. The slope parameter η for each fit is given as well as the total number of charged particles obtained by integration of the Linsley function in the range from zero to infinity.



6.4 Muon arrival time distributions

Fig. 12 displays the distribution of the median values of the local muon arrival time distributions for simulated proton and iron induced EAS of vertical incidence and the primary energy $E = 1 \cdot 10^{17}$ eV observed at the distance of $95 \text{ m} \leq r < 105 \text{ m}$. It compares the true distribution directly from the CORSIKA simulations with the more realistic distributions distorted by the experimental conditions. The CORSIKA distribution is collected taking a virtual ring detector around the shower center, thus with statistically more accurately defined medium values.

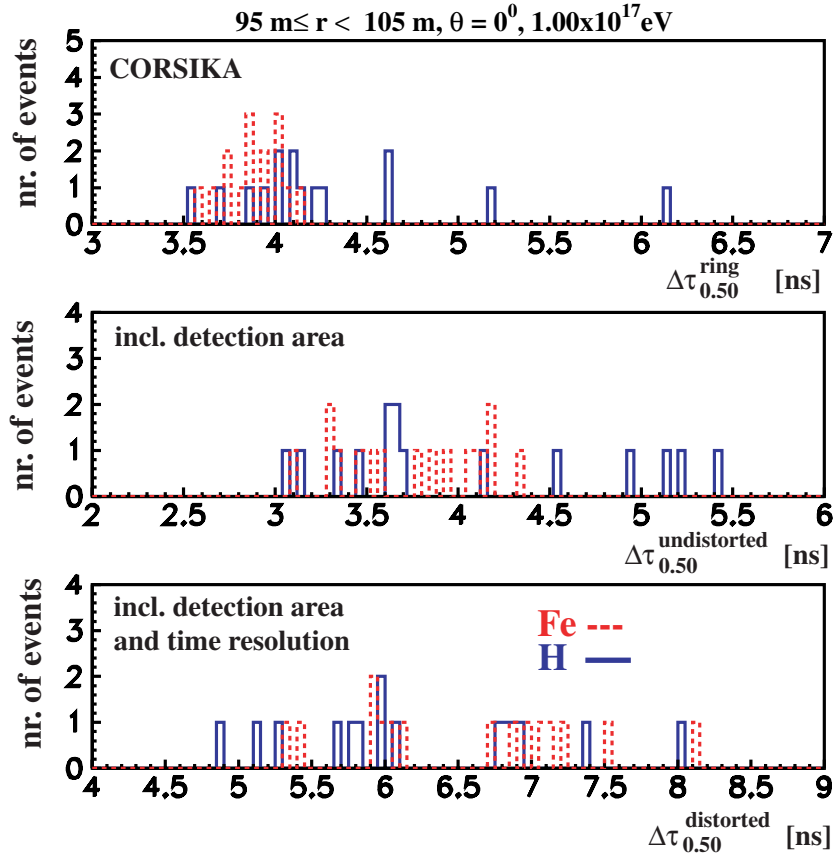


Figure 12: Comparison of the distributions of the median values $\Delta\tau_{0.50}$ of the undistorted and distorted muon arrival time distributions.

7 Concluding remarks

The main goal of the KASCADE-Grande experiment is the determination of the primary energy spectrum and mass composition of cosmic rays up to energies of 10^{18} eV with a detailed investigation of the energy range, where the so-called knee induced by the iron component of Cosmic Rays should appear. Therefore adequate EAS observables are considered to signal the primary energy and mass of the observed EAS. The described reconstruction program SHOWREC is mainly focused to enable to reveal the role of the EAS lateral charged particle and muon distributions, of the number of charged particles measured with the KASCADE-Grande array, and of the muon arrival time distributions, measured with the facilities of the Central Detector, taking realistically into account the layout and response of the detector installations. SHOWREC is flexibly structured to allow easily extensions for other EAS observables or to specify the measuring situation in more detail.

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A Structure of the input file for the SHOWREC program

The SHOWREC program can be run in interactive or silent (non-attended) mode.

In the **interactive mode** the program prints a dialogue guiding the user to input appropriate data.

a. The first data required are the name (including full path) of the input file (which is the output file produced by CORSIKA) and the index of the shower of interest from the CORSIKA file.

b. The next data refer to shower core position. The program prints:

```
SPREAD CORE OVER GRANDE (0) OR SPECIFIC AREA (1)?
```

If the answer is 0, the shower core will be placed in a random point chosen from a uniform distribution in an area delimited by the positions of the extreme Grande detectors. The next item printed will be at point c.

If the answer is 1, the shower core will be randomly placed in a specific area inside the Grande array. The program prints:

```
RECTANGLE (1) OR CIRCLE AROUND CENTRAL DETECTOR (0)?
```

If the answer is 1, then the user is asked to enter the limiting x and y coordinates of the rectangle (see Fig.7); if the answer is 0 the core will be positioned inside of a ring and the user should input the inner and outer radius of the ring and the limiting angles.

c. The region for analysis is defined. The program prints:

```
MAXIMUM DISTANCE (M) FOR LATERAL DISTRIBUTIONS:
```

The program constructs theoretical ("ideal") lateral density functions by counting (then properly normalizing) the number of particles from the output file of CORSIKA in various radial intervals, up to this maximum distance.

```
MINIMUM DISTANCE (M) TO CORE FOR TIME ANALYSIS:
```

Due to experimental reasons it is not possible to get the arrival time for muons coming very close to the shower core; the limiting radius of the excluded region should be given (at least 10 m).

d. Values of the experimental time resolution:

```
TIME RESOLUTION (NS) FOR CORE AND MUONS:
```

The user should input the uncertainty with which the shower core arrival time can be evaluated and the time resolution of the facilities of the Central Detector which provide information about muon arrival time.

d. Initialization of the random generator:

```
AUTOMATICALLY SELECTED RANDOM SEED (0) OR NOT (1)?
```

In case that the answer is 0, the program uses for the initialization of the random generator a seed resulting from the last call of the random generator from a previous run of SHOWREC (or a default value, if there were no other runs of SHOWREC). If the user intends to give a specific seed, the answer should be 1 and then the seed is asked by the program.

In the **silent mode** the program reads the input data from an input file. The data which should be included in the input file correspond exactly with the data which should be entered in the interactive mode.

For example the input file can have the following structure:

```

'/lxdata/d1lx54/joe/fee17m562_05'
1
1
0
175. 185.
0. 0.
1000.
10.
2. 1.5
0

```

In this example the first line indicates the CORSIKA file with the complete path. The first event from the file should be analyzed. The core is distributed in a ring with radii 175 and 185 m, with the default angular limits. The range for constructing the lateral distributions is 1000 m and the exclusion region for muon arrival time analysis has a radius of 10 m. The resolution for reconstructing the core arrival time is 2 ns, for individual muons 1.5 ns. The random generator is initialized automatically.

NOTES =====

- The meaning of the index of the shower in the input file is the following: SHOWREC analyzes individual showers ("events") and produces output results for each shower. In the case when the CORSIKA file contains several showers (this is typical for low energy simulations) it is necessary to indicate which shower from the file should be currently analyzed.
- If the shower core is spread over the entire Grande area, this means the area defined by the left edge of the leftmost Grande detector and the right edge of the rightmost detector on the X axis and by the bottom edge of the bottommost Grande detector and the top edge of the topmost Grande detector on the Y axis. In the KASCADE reference coordinate system, the area is defined by (-609.84, 102.80) X (-656.44, 103.31). The X axis points approximately towards east, the y axis towards north.

If a specific rectangular area is selected, the area of core location is defined by (minx, maxx) on X axis and by (miny, maxy) on Y axis, in the same reference coordinate system as above.

If the selected region is circular around the Central Detector, then the shower core is randomly selected in a ring delimited by (minr, maxr) and the angular interval. If the default angular interval is selected, this is defined by the lines starting from the central detector towards the extreme north-western Grande detector and towards the extreme south-eastern Grande detector. The corresponding angles are 1.411 and 3.296 radians; here 0 radians represents the positive Y axis (approximately North). If the user gives the angular interval, this should be inside the default interval, i.e. between 1.411 and 3.296 radians. **NOTE:** In the case of vertical showers, the observation plane and the plane normal to the shower core coincide. The ring in which the core is located is the same in both planes. However, in the case of inclined showers, the ring is defined in the normal plane and not in the observation level; that is, the shower core impact point in the observation level is generated in such a way as to ensure that the distance between the shower core and the projection of the center of the Central Detector onto the normal plane lies inside the specified ring.

- The radial distance for CORSIKA lateral distributions has the following meaning. The muons and electrons given by CORSIKA are analyzed by the program and if the distance (in the normal plane) between the particle impact point and the shower axis is smaller than the above radial distance, that particle is counted for the evaluation of the lateral density in the corresponding radial bin in the normal plane. The width of

the radial bin is equal to $1/100$ from the maximum radial distance. In the end of the shower analysis, the lateral distributions constructed in this way and extending up to the radial distance given in the input are fitted with the Linsley and with the NKG formula.

- The minimum distance from core for time analysis is introduced because very close to the shower core impact point it is not possible to obtain information about muon arrival time due to the massive presence of many other particles. If the distance from the shower core to the central detector (see above) is bigger than this minimum distance the value of the minimum distance is in fact redundant.
- When the same CORSIKA file is used repeatedly, of course the initialization of the random number should be different in each run, otherwise identical results will be obtained for each run. Additionally it should be noted that the first use of the random number is for the selection of the shower core impact point in the observation level. Therefore, if the same random number initialization is used for the analysis of different CORSIKA output files the shower core impact point will be the same for all these CORSIKA files, even if other results (reconstructed charge density, arrival times) will be different. Consequently, it is recommended to use another value for the random number initialization for each input file of SHOWREC. This can be done without user intervention if the option automatically selected random number is used: the program initializes the seed for random number generator on the basis of the last call of the generator in the most recent previous run of SHOWREC. On the other hand, for tests and debugging purposes the user can select a specific random seed overriding the automatically selected random seed.
- In the current version of SHOWREC, only standard CORSIKA output files can be analyzed. In the future the output files produced with the THINNING option will be also included.

B Structure of the output files produced by the SHOWREC Program - Output for each run

Each run of SHOWREC produces 3 types of output. The name of the output files is the same for all these 3, but the extension differs. The name is automatically assigned by the program in the following way: the name of the CORSIKA input file (without the path; if not already in lower case letters, the name is converted to lower case) plus an underscore ("_") plus the index of the event currently analyzed from the input file plus an underscore plus an identifier number. This number is equal to the number of files with the same name (except the identifier) augmented by 1. So in the first run for a given event from a given CORSIKA file the identifier is 1, then if the same event is analyzed again the identifier becomes 2 and so on. This procedure helps in identifying the files and events and prevents overwriting files.

The extension differentiates the 3 types of files produced in the same SHOWREC run. The first type (extension `.shwrc`) is the detailed output file. The second one (extension `.smmry`) contains only most important results provided by SHOWREC. Both the above types are ASCII files. The last type (extension `.hbook`) is the hbook file containing many output data in a form appropriate for a direct analysis. In this Appendix the structure of the first two files will be presented, while the structure of the hbook file will be presented in Appendix C.

For an easier explanation of the output of the program, relevant items from an output file will be listed in verbatim format. Comments will be inserted in between for explaining the meaning of the various quantities and for a short description of the procedures applied for getting the results.

B.1 The detailed output file `.shwrc`

The structure of the file is as follows:

- presentation of the input data;
- observables evaluated directly from the CORSIKA file;
- fits of these observables;
- observables computed on the basis of the fits;
- shower core impact point;
- ideal (CORSIKA) and reconstructed quantities for each detector (densities and energy deposits);
- time quantities and quantities related with time quantities;
- fits of the reconstructed charged particle density and related quantities;
- quartiles of the time variables and associated quantities;
- hbook data.

The output file begins with the presentation of the input data:

```

PROGRAM SHOWREC
=====
INPUT FILE:      /lxddata/d1lx54/joe/fee17m562_05

INDEX OF THE EVENT IN INPUT FILE:      1

```

```

SPREAD CORE OVER GRANDE (0) OR SPECIFIC AREA (1)?
  1
RECTANGLE (1) OR CIRCLE AROUND CENTRAL DETECTOR (0)?
  0
MINIMUM AND MAXIMUM RADIUS (M) :
  175.0000      185.0000
ANGLE LIMITS (MIN,MAX RAD) OR DEFAULT (0. 0.)?
  0.0000000E+00  0.0000000E+00
MAXIMUM DISTANCE (M) FOR LATERAL DISTRIBUTIONS:
  1000.000
MINIMUM DISTANCE (M) TO CORE FOR TIME ANALYSIS:
  10.00000
TIME RESOLUTION (NS) FOR CORE AND MUONS:
  2.000000      1.500000
AUTOMATICALLY SELECTED RANDOM SEED (0) OR NOT (1)?
  0
SEED FOR RANDOM NUMBER INITIALISATION:
  491136416

SHOWREC VERSION: MUON ARRIVAL TIME ON A RING

PRIMARY = 5626.      ENERGY = 8.9322E+17 eV
THETA = 32.867 DEGREES  PHI = 272.365 DEGREES
HEIGHT OF THE FIRST INTERACTION (M) : 34160.34

```

The above quantities are self-explanatory.

The next items listed are:

```

NO. MUONS, ELECTRONS, GAMMA, PROTONS, NEUTRONS (CORSIKA)
  6311610.00000000      47886947.0000000      270959975.0000000
  96268.0000000000      297545.000000000
NO OF MUONS PLUS ELECTRONS (CORSIKA) :
  54198557.0000000

```

The quantities represent the total number of muons, electrons, photons, protons and neutrons as well as of charged particles (muons+electrons), as given by CORSIKA in the observation level. Neglecting the attenuation (or considering that the attenuation effects are completely canceled out) the same number of particles should be found in the normal plane. In SHOWREC no specific condition (i.e. threshold energy) is imposed for counting these particles; consequently, the values reported above depend only on the CORSIKA cut-offs.'

The next lines list the densities of muons and electrons in the plane normal to the shower core. Each line contains data for a radial bin, from bin 1 to bin 100. In the listing below only part of the data has been included.

```

LATERAL DISTRIBUTIONS IN RADIAL BINS OF 10.00000 M:

CORSIKA DENSITY OF MUONS IN THE NORMAL PLANE (1/m^2) :
FIRST SECOND THIRD FOURTH ANGULAR BIN AND MEAN:
  1  204.0748      207.0287      208.7731      205.0552
  206.2330
  2  119.1073      120.6055      121.2167      119.7949
  120.1811
.
.

```

```

.
.
      100  0.2083890      0.2294390      0.2606622      0.2343017
0.2331980

CORSIKA DENSITY OF ELECTRONS IN THE NORMAL PLANE (1/m^2):
FIRST SECOND THIRD FOURTH ANGULAR BIN AND MEAN:
      1  28036.13      28627.81      29320.30      28838.67
28705.73
      2  7916.809      8298.454      8742.063      8379.028
8334.089
.
.
.
.
      100  7.8633733E-02  0.1132479      0.1652012      0.1220774
0.1197901

```

For the reconstruction of the density of muons (electrons) in the normal plane, the correspondence between the impact point of a trajectory in the observation level and in the plane normal to the shower axis was obtained by the projection of the impact point in the observation level onto the normal plane (procedure a. in Section 3). In the normal plane the density is evaluated in 4 angular intervals for the angle ψ (Fig.2): 1 (-45, 45), 2 (45, 135), 3 (135, 225), 4 (225, 315). The the first interval represents the late region of the shower development, the third the fast region and the other two are in between. In the case of vertical showers, the angle ψ is irrelevant; it is randomly chosen between 0 and 360°. The data reported for each bin represent: the number of the radial bin, the density in that radial bin in the first angular interval, in the second, third and fourth angular interval and finally the density in that radial bin averaged over the whole angular interval.

Next the results of the fits performed on the charged particles density in the normal plane are presented. The charged particles density is obtained by summing the densities of the muon and electron component. The fits are separately done on each angular bin and also on the angle averaged density. In the example below, the fits for the first angular interval (-45°, 45°) are presented. The fits are carried out using the HFITV function, calling the MINUIT minimization package. In the present version of SHOWREC the Linsley formula is considered for the theoretical density.

```

FIT OF CORSIKA CHARGE DENSITY IN ANGULAR BIN      1
  CHI SQUARED:      2051.279
  N CHARGE:      4.9459056E+07
  LG10 (NCHARGE)  7.694246      ERR  8.9215217E-05
  ALPHA:      1.174184      ERR  5.2957510E-04
  ETA:      3.580896      ERR  1.1447184E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.6530256E+07  6382533.      2443907.      1225295.      712842.1
456159.8
UPPER ERROR OF INTEGRATION
365302.6      63825.33      24439.07      12252.95      7128.420
4561.597
FIT OF CORSIKA DENSITY <600 M IN ANGULAR BIN      1
  CHI SQUARED:      2806.027
  N CHARGE:      4.8642324E+07
  LG10 (NCHARGE)  7.687015      ERR  1.3836806E-04
  ALPHA:      1.128974      ERR  6.0076197E-04

```



```

ETA:          3.721755      ERR  1.4114386E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.6676272E+07  6232762.      2285149.      1107886.      627277.1
392372.3
UPPER ERROR OF INTEGRATION
366762.7      62327.61      22851.49      11078.86      6272.771
3923.723
FIT OF CORSIKA DENSITY <RDMAX IN ANGULAR BIN      1
CHI SQUARED:    2914.619
N CHARGE:      4.8455552E+07
LG10 (NCHARGE)  7.685344      ERR  1.5704808E-04
ALPHA:         1.119076      ERR  6.0923904E-04
ETA:          3.754257      ERR  1.9722390E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.6703664E+07  6192290.      2247425.      1081136.      608291.1
378495.9
UPPER ERROR OF INTEGRATION
367036.6      61922.90      22474.25      10811.36      6082.911
3784.959
FIT OF CORSIKA DENSITY (RING) IN ANGULAR BIN      1
RING LIMITS:      0      550
DETECTOR LIMITS:  7.420668      549.1765
CHI SQUARED:    2914.619
N CHARGE:      4.8455552E+07
LG10 (NCHARGE)  7.685344      ERR  1.5704808E-04
ALPHA:         1.119076      ERR  6.0923904E-04
ETA:          3.754257      ERR  1.9722390E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.6703664E+07  6192290.      2247425.      1081136.      608291.1
378495.9
UPPER ERROR OF INTEGRATION
367036.6      61922.90      22474.25      10811.36      6082.911
3784.959

```

As seen above, for this angular interval several ranges of the lateral densities are considered for fitting: the default interval from 0 to 1000 m, the interval from 0 to 600 m, the radial interval from 0 to the position RDMAX of the farthest Grande detector and finally, under the denomination RING, the radial interval defined by the radial bins containing the closest and the farthest Grande detector from the shower core impact point. Above the radial coordinates of the two detectors are about 7.42 and 549.18 m, so the bins included in the fit start with bin 1 and end with bin 54 (radial interval 0 - 550 m).

After displaying the parameters of the fits, the integrated number of charged particles in the rings 0 to 100 m, 100 to 200 m, ... 500 to 600 m are presented. The integration is done using the adaptive Gauss quadrature, using the fitted parameters. The integration starts with a target error of 1%; if that accuracy can not be obtained, automatically the limiting accuracy is increased until a result with a proper characterized error is obtained.

The same type of data is presented for each angular interval and also for the angle averaged densities:

```

FIT OF CORSIKA CHARGE DENSITY AVERAGED OVER ANGLE:
CHI SQUARED:    576.0161
N CHARGE:      5.3975196E+07
LG10 (NCHARGE)  7.732194      ERR  1.7656124E-04
ALPHA:         1.156686      ERR  9.7280554E-04

```

```

ETA:          3.515035      ERR  2.0018588E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.8825116E+07  7259357.      2857668.      1460221.      862004.1
558205.3
UPPER ERROR OF INTEGRATION
388251.2      72593.56      28576.68      14602.21      8620.040
5582.053
FIT OF CORSIKA DENSITY <600 M ANGLE AVERAGED:
CHI SQUARED:   782.0289
N CHARGE:     5.2996988E+07
LG10 (NCHARGE)  7.724251      ERR  1.8951358E-04
ALPHA:        1.108954      ERR  1.1461405E-03
ETA:          3.660587      ERR  2.6199659E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.9025396E+07  7094265.      2670828.      1318381.      756794.3
478702.7
UPPER ERROR OF INTEGRATION
390253.9      70942.64      26708.27      13183.81      7567.942
4787.027
FIT OF CORSIKA DENSITY <RDMAX ANGLE AVERAGED:
CHI SQUARED:   810.2889
N CHARGE:     5.2772352E+07
LG10 (NCHARGE)  7.722406      ERR  3.3262029E-04
ALPHA:        1.098546      ERR  1.2929001E-03
ETA:          3.694145      ERR  3.2154878E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.9062568E+07  7048471.      2626105.      1285941.      733401.1
461391.4
UPPER ERROR OF INTEGRATION
390625.7      70484.70      26261.04      12859.41      7334.011
4613.914
FIT OF CORSIKA DENSITY (RING) ANGLE AVERAGED:
RING LIMITS:      0      550
DETECTOR LIMITS:  7.420668      549.1765
CHI SQUARED:   810.2889
N CHARGE:     5.2772352E+07
LG10 (NCHARGE)  7.722406      ERR  3.3262029E-04
ALPHA:        1.098546      ERR  1.2929001E-03
ETA:          3.694145      ERR  3.2154878E-03
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
3.9062568E+07  7048471.      2626105.      1285941.      733401.1
461391.4
UPPER ERROR OF INTEGRATION
390625.7      70484.70      26261.04      12859.41      7334.011
4613.914

```

The angle averaged densities are also fitted with the NKG formula:

```

NKG FIT OF CORSIKA AVERAGE CHARGE DENSITY:
CHI SQUARED:   1309.582
N CHARGE:     5.0780980E+07
LG10 (NCHARGE)  7.705701      ERR  1.7576059E-04
AGE:          1.212749      ERR  4.0946607E-04

```

Next the program collects the results of the total number of charged particles resulting from the default fit (0 - 1000 m) with the Linsley formula in each angular interval:

```
FITTED CORSIKA NO. OF CHARGED PARTICLES (4 BINS AND MEAN) :
4.9459056E+07  5.3787948E+07  5.8500972E+07  5.4151320E+07  5.3975196E+07
```

If the SHOWREC program was compiled with the DETAILED option (which is default) then the fitted charge particle densities (m^{-2}) in the normal plane are listed; if the DETAILED option was inhibited, the next data are not printed.

```
FITTED CORSIKA CHARGE DENSITY IN 4 ANGULAR BINS AND MEAN:
5.000000      30812.13      31614.81      32552.46      31833.31
31708.24
15.00000     6697.900      7029.287      7402.065      7112.970
7059.897
.
.
.
995.0000     0.1835279     0.2332184     0.2871663     0.2285754
0.2328802
```

In each line the radial coordinate and the density in that point computed using the fitted parameters (fitting range 0 to 1000 m) for each angular interval and for the entire angular interval are included. The data span the interval from 5 to 995 m. If the fits are good, the data presented above should be close to the sum of the densities computed directly by counting the muons and the electrons reported by CORSIKA in the appropriate radial bin, as presented above under the headings "CORSIKA DENSITY OF MUONS IN THE NORMAL PLANE ($1/\text{m}^2$)" and "CORSIKA DENSITY OF ELECTRONS IN THE NORMAL PLANE ($1/\text{m}^2$)" respectively. In the future a better fitting function will be tried.

Up to this point the ideal data, provided by CORSIKA, independent of the positions of the detectors with respect to the shower core and independent of the detector responses were reported in the file. The next section displays quantities depending on the position of the shower core and on the experimental conditions.

```
SHOWER CORE IMPACT POINT IN KASCADE COORDINATES:
X, Y, DISTANCE TO THE CENTRAL DETECTOR (M) :
-110.4625     -164.8715     202.7878
R PHI COORDINATES IN THE NORMAL PLANE, DISTANCE:
181.8512      139.7962      89.73876
```

Above the coordinates of the shower core are given. First the Cartesian coordinates with respect to the KASCADE reference system of coordinates are indicated (-110.46, -164.87). The distance from the shower core impact point to the center of the Central Detector (202.78 m) in the horizontal plane is also reported. Then the radial coordinate (181.85 m) and the angular coordinate (139.79°) of the projection of the center of the Central Detector in the coordinate system defined in the plane β normal to the shower axis (Fig.2) are presented. Also the distance (89.73 m) from the center of the Central detector to its projection onto the normal plane is included; by conventions this distance is positive when the projected point lies below the center of the Central Detector. In this context it should be stressed that in the case of the ring geometry the shower core is positioned in such a way as to ensure the correct distance between the shower core and the projection of the center of Central Detector onto the plane β and not in the horizontal plane.

The next data give the reconstructed shower core position, evaluated as the center of gravity of the energy deposited in all Grande detectors.

```

RECONSTRUCTED SHOWER CORE IN KASCADE COORDINATES:
DELTAX, DELTAY TO THE CORSIKA SHOWER CORE (M) :
-29.77406      12.26363
X, Y, DISTANCE TO THE CENTRAL DETECTOR (M) :
-140.2366     -152.6079      211.1077
R PHI COORDINATES IN THE NORMAL PLANE, DISTANCE:
 194.3529      131.0229      82.42223

```

DELTAX and DELTAY represent the distance between the true shower core impact point and the reconstructed point. The other quantities are similar with the quantities discussed above, but evaluated with respect to the reconstructed shower core impact point; the plane normal to the shower axis is redefined also with respect to the reconstructed core position.

```

MUON DENSITY ABOVE 240 MEV IN THE CENTRAL DETECTOR
 8.261990
MUON DENSITY ABOVE 2.40 GEV IN THE CENTRAL DETECTOR
 6.192216

```

The listed densities of muons [m^{-2}] above the threshold of 240 MeV respectively 2.4 GeV in the region of the Central Detector are obtained simply by counting, then normalizing, the number of muons above the given thresholds which hit the surface of the Central Detector. The values correspond to densities in the plane normal to the shower axis.

The muons which hit the Central Detector are further analyzed for getting time information.

```

NO. OF MU IN THE TRIGGER, IN CD ABOVE 0.24 AND 2.4 GEV
      382   1932.000      1448.000
IDEAL GLOBAL TIME, INCLINATION CORRECTED:
 15.75000      2.812500      5.750000      15.57813      13.84375
.
.
.
 16.40625      32.79688

```

In the example presented above from the number of muons hitting the Central detector (1932 above 0.24 GeV from which 1448 above 2.4 GeV), 382 provided time information. In the case of the default SHOWREC program (that is, the program compiled without the FAST option) the conditions which should be fulfilled in order to count a muon in this category are: 1. to have the energy above the threshold of 2.4 GeV; 2. to hit a sensitive region of the trigger detector; 3. to hit a sensitive region of the upper MWPC layer; 4. to hit a sensitive region of the lower MWPC layer; 5. to be selected (with 90% probability) as generating the signal (that is, a detection efficiency of 90% is considered for the muons which fulfill the conditions 1-4). The detailed geometry of the detectors is taken into account, including the level with respect to the KASCADE reference level, the presence of inactive shifter bars, the positions and dimensions of the MWPCs etc. (In the case of the SHOWREC program compiled with the FAST option, the conditions which should be fulfilled are: 1. to have the energy above the threshold of 2.4 GeV; 2. to pass through the rectangular surface delimited by the extreme points of the trigger detector on X and Y axes; 3. to pass through the rectangular surface delimited by the extreme points of the upper MWPC array on X and Y axes; 4. to pass through the rectangular surface delimited by the extreme points of the lower MWPC array on X and Y axes; to be selected (with 90% probability) as generating the signal. Clearly the results obtained with the default version are more realistic. The number of muons which fulfill the conditions is evidently bigger in the case of the FAST version. Ideally the quartiles of the time quantities should be the

same in both versions, but the statistical spread of the results should be bigger in the case with lower number of particles, that is, in the case of the default version of the program.)

Then for each muon satisfying the conditions, the global arrival time (ns) is printed. The global arrival time is computed by subtracting from the time reported by CORSIKA for that muon the estimated time required for the core to arrive from the first interaction point to the observation level. The values are corrected for the difference between the normal plane and the observation level. In the example given above, the arrival times were 15.75, 2.81, 5.75, 15.57, 13.84, ... 16.40, 32.79 ns.

```

REALISTIC GLOBAL TIME, INCLINATION CORRECTED:
 15.98438      6.500000      7.125000      17.18750      14.37500
.
.
.
 15.31250      32.39063

```

The realistic global times are obtained by superposing random fluctuations (different for each muon but a common single fluctuation for shower core) to the values of the ideal global time reported above. Note that the realistic global times reported above do not take into account the difference between the level of the detectors which give the time information for muons and the level of the detectors which give the signals from which the shower core arrival time is inferred (in a previous version of SHOWREC this difference was taken into account). Specifically, all the values of the arrival times are reported to the KASCADE reference level.

```

IDEAL GLOBAL TIME, TRIANGULATION BASED:
 16.14120      2.835154      5.798228      15.96108      14.16080
.
.
.
 16.84535      34.48734

```

Another set of arrival time values in the normal plane can be obtained using the procedure c. presented in Section 3. These values are denominated in the output file as "triangulation based" and are presented above. Muons (especially high energy ones) are not much scattered between the production point and the detection point. Furthermore, these muons have practically the speed of light. If these assumptions are valid and also, if the muons are produced on the shower axis, then using the global arrival time the muon production point can be computed using triangulation. In the computation the distortion of the trajectory due to the local magnetic field is neglected. In most cases the above assumptions are not strongly violated by the muons and the procedure can be applied. If the assumptions are evidently not fulfilled for a particular muon (e.g. the time difference between muon arrival and core arrival times is bigger than the time required for a particle with the speed of light to travel in the observation level from the shower axis to the detection point - which can only happen if either the muon has been produced far off-axis or has been substantially scattered), then that muon is not considered further for triangulation based analysis. In the case of quantities based on triangulation, the correspondence between the coordinates in the observation level and in the plane normal to the shower axis is established using the reconstructed trajectory, starting from the production point and ending in the observation point. For example, the reconstructed point of intersection with the normal plane is given by the intersection of the reconstructed trajectory with the normal plane (and not by the projection of the detection point onto the normal plane). The radial distance associated with that muon in the normal plane is the distance from the reconstructed point of intersection with the plane to the shower axis. The arrival time computed in the normal plane is obtained from the time in the observation level corrected by the time difference required to

travel on the reconstructed trajectory between the normal plane and the observation level (and not to travel along the distance between the detection point and its projection onto the normal plane).

NOTE: it should be emphasized that the time quantities reported until this section include all the muons which fulfill the trigger conditions as presented above, while the quantities reported in the section on quantities based on triangulation include only those muons which besides the trigger condition fulfill also the condition of not evidently violating the assumptions presented in the beginning of this comment. The quantities reconstructed in the normal plane by triangulation are more realistic than quantities reconstructed by the simple projection onto the normal plane, but the triangulation procedure can be applied only for muons which fulfill certain conditions, while the projection method can be applied for any particle.

Using the above set of triangulation based global times for each muon several quantities are evaluated and printed under the headings:

IDEAL PRODUCTION HEIGHT:

.
.
.

IDEAL ATMOSPHERIC DEPTH:

.
.
.

IDEAL ANGLE WITH RESPECT TO SHOWER AXIS:

.
.
.

IDEAL RADIAL DISTANCE:

.
.
.

These quantities represent in turn:

- The distance along the shower axis (cm) from the reconstructed point of production of each muon to the observation level. For vertical showers this quantity is indeed equal to the production height, but for inclined showers the altitude of the production point is in fact $\cos(\theta)$ multiplied by the quantity reported above;
- The atmospheric depth ($\text{cm}^2 \text{g}^{-1}$) penetrated by the primary particle and then by the shower core from the entrance into the atmosphere until the production point of each muon for which the triangulation method is applied. The standard US atmosphere parameters are used;
- The angle (radians) between the muon trajectory reconstructed by triangulation and the shower axis;
- The radial coordinate of the intersection of the muon trajectory reconstructed by triangulation with the normal plane, i.e. the distance (cm) from that intersection point to the shower axis in the normal plane.

In the next section of the output program the same quantities are reported but for realistic arrival times, i.e. times distorted by experimental resolution and by the uncertainty in the reconstruction of the core arrival time. The data are presented under the following headings:

REALISTIC GLOBAL TIME, TRIANGULATION BASED:

REALISTIC PRODUCTION HEIGHT:

REALISTIC ATMOSPHERIC DEPTH:

REALISTIC ANGLE WITH RESPECT TO SHOWER AXIS:

REALISTIC RADIAL DISTANCE:

In the next section of the output file the angle between the muon trajectory and the shower axis is also computed using the information about the muon momentum provided in the CORSIKA file:

ANGLE BASED ON MOMENTUM:

3.0305877E-02 8.8219438E-03 1.5682772E-02 3.2573134E-02 4.0981017E-02
 .
 .
 .
 5.4612819E-02 8.9960448E-02

The values are given in radians. If the assumptions applied in the triangulation method are valid then the results reported in this section should be close to the results obtained using procedure c. (Section 3) for reconstructing the trajectory.

In the next section of the output file the parameters characterizing the time distributions are displayed, both for the case of global times and for the case of local times. In each case the ideal (CORSIKA provided) and the realistic (experimentally distorted) values are separately analyzed. The local arrival times are defined by subtracting from the global arrival time of each muon the arrival time of the earliest detected muon. Besides the mean values the 25%, 50% and 75% quartiles (ns) are printed.

MEAN VALUE OF THE IDEAL AND REALISTIC GLOBAL TIME:

11.60868 12.29193

MEAN VALUE OF THE IDEAL AND REALISTIC LOCAL TIME:

9.358680 11.85443

QUANTILES. FIRST LINE IDEAL, SECOND REALISTIC

QUANTILES OF THE GLOBAL ARRIVAL TIMES:

6.312500 9.312500 15.23438

7.015625 10.42188 15.64063

QUANTILES OF THE LOCAL ARRIVAL TIMES:

4.062500 7.062500 12.98438

6.578125 9.984375 15.20313

The quartiles of the quantities reported above under the denomination "Triangulation Based" are further reported (triangulation corrected arrival time, production height, atmospheric depth of the production point, angle with respect to the shower axis and radial coordinate in the normal plane). For each quartile (25%, 50% and 75%) in the first line the values based on the ideal time distributions are presented, in the second the values relying on resolution distorted distributions.

Finally the moments of the distribution of the logarithm (base 10) of the global arrival time up to the fourth order are listed.

```

QUARTILES OF QUANTITIES BASED ON GLOBAL ARRIVAL TIMES:
25% -----
TIME, HEIGHT, ATMDEPTH, THETA, RADIUS
  6.382304      341869.7      482.3736      2.0881398E-02  18078.84
  7.106437      353159.7      532.2574      2.3383310E-02  18075.64
50% -----
TIME, HEIGHT, ATMDEPTH, THETA, RADIUS
  9.453278      614079.6      657.9072      3.0772816E-02  18431.91
 10.59757      569757.7      708.0092      3.4506958E-02  18465.88
75% -----
TIME, HEIGHT, ATMDEPTH, THETA, RADIUS
 15.62902      877367.8      1229.016      5.0240848E-02  18751.27
 16.04761      766149.1      1229.092      5.1271327E-02  18770.66
QUARTILES OF THE THEORETICAL THETA
1.6641205E-02  2.3559254E-02  3.3035815E-02
MOMENTS OF THE LOG(TIME):
0.9845008      6.7716002E-02  2.3819208E-03  1.3443470E-02
1.013414      6.7910314E-02 -6.0772896E-03  2.2777796E-02

```

The following section is printed only if the program SHOWREC was compiled using the TIMERING option. With this option all the muons which hit the normal plane in the ring defined in the input are analyzed for time information. Both ideal and resolution distorted time values are processed. The resolution parameters are identical with the values applied for muons detected in the Central Detector. For the definition of the local times the arrival time of the earliest muon coming on the ring is used as time reference (in fact this is not quite a good reference for the local time, especially for a ring far from the core and covering a large area). All the values are of course evaluated for quantities corresponding to the plane normal to the shower axis. The corresponding section of the output file is the following:

```

OBSERVABLES FOR THE RING FROM 175.0000 TO 185.0000
NUMBER OF MUONS ABOVE 2.4 GeV ANALYZED: 73415
TOTAL NUMBER OF MUONS ABOVE 2.4 GeV IN RING: 73415.00
MEAN VALUE OF THE IDEAL AND REALISTIC GLOBAL TIME:
 11.92037      12.74171
MEAN VALUE OF THE IDEAL AND REALISTIC LOCAL TIME:
 10.65474      14.33546
QUARTILES. FIRST LINE IDEAL, SECOND REALISTIC
QUARTILES OF THE GLOBAL ARRIVAL TIMES:
 6.390625      9.640625      15.01563
 7.187500      10.57813      15.95313
QUARTILES OF THE LOCAL ARRIVAL TIMES:
 5.125000      8.375000      13.75000
 8.781250      12.17188      17.54688
MOMENTS OF THE LOG(TIME):
0.9933974      6.7988098E-02  4.4291019E-03  1.4528036E-02
1.025924      6.9122434E-02 -4.0824413E-03  2.3976564E-02

```

The distinction between the number of muons above 2.4 GeV analyzed and the total number of muons above 2.4 GeV in the ring is relevant only if the number of muons detected in the ring is bigger than 900000; then only 900000 from them is analyzed, but the user is warned that a part of the muon population of interest was not analyzed.

The next sections of the output file give informations about the interactions in the Grande detectors. First for each detector a summary is presented:


```

IDEAL AND RECONSTRUCTED DENSITY IN DETECTORS:
RADIUS, IDEAL DENSITY, RECONSTRUCTED:
      1  232.1441      24.08428      24.48313
      2  188.1166      33.50338      33.56981
.
.
.
      37  549.1765      1.192291      1.519138

```

The first value on each line indicates the index of the Grande detector, the second the radial coordinate of the center of the detector in the plane normal to the reconstructed shower axis. The third value is the local charged particles density (m^{-2}) obtained by counting the number of muons and of electrons which hit that detector and normalizing it such as to obtain the density in the plane normal to the shower axis. The last value is the reconstructed charged particle density in the normal plane. It is obtained as follows: for each muon, electron, photon, proton or neutron which hits the detector, the energy deposited in the detector is randomly sampled using specific distribution functions of the energy deposition. Then the total energy deposited in that detector is divided by the mean energy deposited per charged particle and thus the reconstructed number of charged particles is obtained. The mean energy deposited per charged particle is taken from the LATCORF.LCF file. This file is prepared in advance and contains the mean energy deposited per charged particle as a function of the distance between the detector and the shower axis in the normal plane. This function is practically independent of the type of primary particle. Finally the number of reconstructed charged particles is normalized such as to give the density in the normal plane. The densities will be considered as corresponding to the radial coordinate of the center of the detector when the lateral densities will be fitted with Linsley or NKG formulas.

NOTE. The ideal density depends on the energy cut-off imposed in CORSIKA. The case of the reconstructed density is somehow more complex. If the same cut-off is applied in the CORSIKA output files which have been used for evaluating the lateral energy correction function (i.e. for preparing the LATCORF.LCF file) as in the CORSIKA output files which are evaluated by SHOWREC the reconstructed density depends on the cut-off in the same way as the ideal density; the reconstructed and the ideal density should be close to each other. On the other hand, if the LATCORF.LCF file was prepared using very low values of the energy cut-off in CORSIKA in such a way that particles with even lower energy are stopped before entering into the sensitive volume of the detectors, then the reconstructed density is independent of the energy cut-off imposed in CORSIKA if the cut-off is low enough; but the ideal density still depends on the value of the energy cut-off applied in CORSIKA.

Then for each detector (specified detector index) a more detailed description is given including the angular interval in which the projection of the center of the detector in the normal plane is situated, the numbers of muons, electrons, photons, protons and neutrons which have hit that detector and the energy deposited (MeV) by each type of particles.

```

NO. OF MU, E, GAMMA, P AND N HITS IN DETECTORS
AND THE ENERGY DEPOSITED (MEV) BY EACH TYPE:
DETECTOR      1  ANGULAR INTERVAL:      3
      49      153      1880      0      2
      402.1714      904.7657      641.2880      0.0000000E+00      0.0000000E+00
DETECTOR      2  ANGULAR INTERVAL:      3
      64      217      2660      4      3
      520.7700      1291.605      740.1513      106.6168      0.0000000E+00
.
.
.

```

```

DETECTOR          37  ANGULAR INTERVAL:          4
          9          1          62          0          0
72.75211         14.85576         30.58931         0.0000000E+00  0.0000000E+00

```

The charged particles density reconstructed from the energy deposition in the detectors is fitted with the Linsley formula. After a first set of fit parameters is obtained, with these parameters the expected density in each detector is computed and used for improving the estimated error of the charged particles density in the detectors. With the improved error estimate the fit is repeated. The procedure is especially important in the case when the reconstructed charged particle density is zero; in this case the first estimate of the error is unreliable and corrupts the fit. Using the fit parameters the number of charged particles in radial intervals 0 - 100 m, 100 - 200 m, ... 500 - 600 m is obtained similarly with the case of CORSIKA provided densities:

```

FIT OF ALL DETECTED CHARGED PARTICLES
  CHI SQUARED:      241.9950
  N CHARGE:        2.6069504E+07
  LG10 (NCHARGE)   7.416132      ERR  9.5177989E-04
  ALPHA:           0.5000000      ERR  1.4681167E-04
  ETA:             3.012419      ERR  3.0463913E-03
ALL DETECTORS FIT, ITERATED:
  CHI SQUARED:      35.83936
  N CHARGE:        2.9752042E+07
  LG10 (NCHARGE)   7.473516      ERR  7.1989074E-03
  ALPHA:           0.5000001      ERR  6.9979846E-04
  ETA:             2.911551      ERR  1.4701626E-02
CHARGE INTEGRAL IN 100 M BINS UP TO 600 M
1.0293377E+07  5485164.      3043858.      1929105.      1333319.
978002.9
UPPER ERROR OF INTEGRATION
102933.8      54851.63      30438.58      19291.05      13333.19
9780.029

```

Also the NKG formula is used for the fit in the similar way:

```

NKG FIT OF RECONSTRUCTED AVERAGE CHARGE DENSITY:
.
.
REPEATED NKG FIT, ITERATED
.
.

```

The results of the Linsley fit are used for computing the fitted density in the detectors, which is compared with the density computed on the basis of the CORSIKA muons and electrons which hit the detectors:

```

CORSIKA AND FITTED DENSITY IN DETECTORS:
RADIUS, CORSIKA DENSITY, FITTED DENSITY:
  1  232.1441      24.08428      22.52209
  2  188.1166      33.50338      35.57663
.
.
.
  37  549.1765      1.192291      2.826409

```

The analysis of the reconstructed charged particles density is repeated selecting for the fit only the detectors which lie in the same angular interval in the normal plane. First the radial coordinate of each detector is listed, together with the reconstructed charge density and its error, then the fit is performed with the Linsley formula if there are sufficient detectors in that angular interval:

```

NUMBER OF DETECTORS IN ANGULAR BIN           1           12
112.2224      166.3445      1.475235
115.6161      85.82651      1.059663
.
.
.
FIT OF DETECTED CHARGED PARTICLES IN BIN           1

REPEATED FIT, ITERATED

CHARGE INTEGRAL IN 100 M BINS UP TO 600 M

UPPER ERROR OF INTEGRATION

```

The appropriate data are displayed under each heading, as in the case of the fit of all detector data.

The same results are evaluated for the other angular intervals. However, the intervals 2 and 4 (45° , 135°) and (225° , 315°) for which the results are less affected by shower incidence angle, are considered together in order to increase the statistics.

The analysis of the charged particles density is finished by printing the reconstructed number of charged particles based on the fit of all detector data:

```

RECONSTRUCTED NUMBER OF CHARGED PARTICLES, 1,2+4,3,MEAN
2.4496072E+08  2.7962574E+07  3.6922992E+07  2.9752042E+07

```

The last section of the output file contains the listing of the values included in the hbook file (see Appendix C).

B.2 The summary output file .smmry

In this file a selected set from the data included in the detailed output file is reported. The quantities have the same meaning as in the detailed output file.

C The Hbook output file for each run

In this Appendix the HBOOK output of SHOWREC is presented. The ASCII output files have been presented in Appendix B.

The HBOOK output of a given SHOWREC run contains the same quantities as in the main output, but stored in the HBOOK form. Two ntuples, 100 and 101 are used. The definition of the quantities stored in these ntuples will be given below, followed by a short discussion. For a more detailed discussion concerning a specific quantity recorded in the HBOOK file see the comments related to that quantity in Appendix B.

NTUPLE 100 - shower ntuple:

SHOW.NO 'index of the shower (shower number) as read from CORSIKA output'
 PRIMARY 'code of the primary particle as given by CORSIKA'
 PRIMENER 'primary energy (GeV)'
 PRIMTHE 'theta (degrees) of the trajectory of the primary particle'
 PRIMPHI 'phi (degrees) of the trajectory of the primary particle'
 HFIRSTIN 'the height (m) of the first interaction given by CORSIKA'
 XCORE 'the X coordinate (m) of the shower core in the KASCADE coordinates'
 YCORE 'the Y coordinate (m) of the shower core in the KASCADE coordinates'

NTUPLE 101 - observables ntuple:

IDPRI 'CORSIKA code of the primary particle'
 ENPRI 'energy (GeV) of the primary particle'
 THPRI 'theta angle (degrees) of the primary particle trajectory'
 PHPRI 'phi angle (degrees) of the primary particle trajectory'
 HEPRI 'height (m) of the first interaction of the primary particle'
 SHCOX 'X coordinate (m) of the shower core in the KASCADE reference system'
 SHCOY 'Y coordinate (m) of the shower core in the KASCADE reference system'
 SHCHR 'distance (m) from the center of the Central Detector to the shower axis in the observation level'
 SHCNR 'distance (m) from the projection of the center of the Central Detector to the shower axis in the plane normal to this axis'
 SHCNP 'psi angle (degrees) coordinate of the projection of the Center of the Central Detector in the reference system defined in the plane perpendicular to the shower axis. In this system 0 represents the intersection of the vertical plane containing the shower axis with the normal plane, namely the intersection located in the late region of the shower.'
 SHCNZ 'distance from the center of the Central Detector to its projection onto the normal plane; positive when the detector is above its projection.'
 NOCHT 'number of charged particles (muons+electrons) given by CORSIKA'
 NOMUT 'number of muons given by CORSIKA'
 NOELT 'number of electrons given by CORSIKA'
 NOGAT 'number of photons given by CORSIKA'
 NOPRT 'number of protons given by CORSIKA'
 NONET 'number of neutrons given by CORSIKA'
 L1NOCHT 'logarithm (base 10) of NOCHT'
 ROMUL 'muon density in the normal plane for a threshold equal to 240 MeV, based on the number of muons above threshold which hit the central detector'
 ROMUH 'muon density in the normal plane for a threshold equal to 2.40 GeV, based on the number of muons above threshold which hit the central detector'

THCHA 'fitted number of charged particles obtained by fitting the charged particles density (given by CORSIKA) in the normal plane with the Linsley formula. All angular intervals in the normal plane are included in the fit.'
 THCH1 'fitted number of charged particles obtained by fitting the charged particles density (given by CORSIKA) in the normal plane with the Linsley formula. Only data from the first angular interval in the normal plane are included in the fit.'
 THCH2 'fitted number of charged particles obtained by fitting the charged particles density (given by CORSIKA) in the normal plane with the Linsley formula. Only data from the second angular interval in the normal plane are included in the fit.'
 THCH3 'fitted number of charged particles obtained by fitting the charged particles density (given by CORSIKA) in the normal plane with the Linsley formula. Only data from the third angular interval in the normal plane are included in the fit.'
 THCH4 'fitted number of charged particles obtained by fitting the charged particles density (given by CORSIKA) in the normal plane with the Linsley formula. Only data from the fourth angular interval in the normal plane are included in the fit.'
 L10THCHA 'logarithm (base 10) of THCHA'
 THALA 'alpha parameter from Linsley formula. Data from all angular intervals in the normal plane included in the fit.'
 THAL1 'alpha parameter from Linsley formula. Only data from the first angular interval in the normal plane included in the fit.'
 THAL2 'alpha parameter from Linsley formula. Only data from the second angular interval in the normal plane included in the fit.'
 THAL3 'alpha parameter from Linsley formula. Only data from the third angular interval in the normal plane included in the fit.'
 THAL4 'alpha parameter from Linsley formula. Only data from the fourth angular interval in the normal plane included in the fit.'
 THETA 'eta parameter from Linsley formula. Data from all angular intervals in the normal plane included in the fit.'
 THET1 'eta parameter from Linsley formula. Only data from the first angular interval in the normal plane included in the fit.'
 THET2 'eta parameter from Linsley formula. Only data from the second angular interval in the normal plane included in the fit.'
 THET3 'eta parameter from Linsley formula. Only data from the third angular interval in the normal plane included in the fit.'
 THET4 'eta parameter from Linsley formula. Only data from the fourth angular interval in the normal plane included in the fit.'
 TCDA1 'charge density [m⁻²] in the normal plane obtained from the Linsley formula using the parameters from the fit including all the angular intervals. The value given is the density at 100 m from the shower axis.'
 TCDA2 'as TCDA1, but at 200 m.'
 TCDA3 'as TCDA1, but at 300 m.'
 TCDA4 'as TCDA1, but at 400 m.'
 TCDA5 'as TCDA1, but at 500 m.'
 TCDA6 'as TCDA1, but at 600 m.'
 TCD11 'as TCDA1, but using the parameters resulting from the fit of the data from the first angular interval.'
 TCD12 'as TCD11, but at 200 m.'
 TCD13 'as TCD11, but at 300 m.'

TCD14 'as TCD11, but at 400 m.'
TCD15 'as TCD11, but at 500 m.'
TCD16 'as TCD11, but at 600 m.'
TCD21 'as TCDA1, but using the parameters resulting from the fit of the
data from the second angular interval.'
TCD22 'as TCD21, but at 200 m.'
TCD23 'as TCD21, but at 300 m.'
TCD24 'as TCD21, but at 400 m.'
TCD25 'as TCD21, but at 500 m.'
TCD26 'as TCD21, but at 600 m.'
TCD31 'as TCDA1, but using the parameters resulting from the fit of the
data from the third angular interval.'
TCD32 'as TCD31, but at 200 m.'
TCD33 'as TCD31, but at 300 m.'
TCD34 'as TCD31, but at 400 m.'
TCD35 'as TCD31, but at 500 m.'
TCD36 'as TCD31, but at 600 m.'
TCD41 'as TCDA1, but using the parameters resulting from the fit of the
data from the fourth angular interval.'
TCD42 'as TCD41, but at 200 m.'
TCD43 'as TCD41, but at 300 m.'
TCD44 'as TCD41, but at 400 m.'
TCD45 'as TCD41, but at 500 m.'
TCD46 'as TCD41, but at 600 m.'
AGETH 'NKG age of the shower obtained by fitting the charged particles
density (based on CORSIKA) in the normal plane with NKG formula.
All angular intervals included in the fit.'
EXCHA 'fitted number of charged particles obtained by applying the Linsley
formula to the reconstructed charged particles densities from
the response of all Grande detectors'
EXCH1 'as EXCHA, but including only the response of the detectors from the
angular interval 1 in the normal plane'
EXCH2 'as EXCH1, for intervals 2+4'
EXCH3 'as EXCH1, for interval 3'
L10EXCHA 'logarithm (base 10) of EXCHA'
EXALA 'alpha parameter of Linsley formula obtained from the same fit as
EXCHA'
EXAL1 'alpha parameter of Linsley formula obtained from the same fit as
EXCH1'
EXAL2 'alpha parameter of Linsley formula obtained from the same fit as
EXCH2'
EXAL3 'alpha parameter of Linsley formula obtained from the same fit as
EXCH3'
EXETA 'eta parameter of Linsley formula obtained from the same fit as
EXCHA'
EXET1 'eta parameter of Linsley formula obtained from the same fit as
EXCH1'
EXET2 'eta parameter of Linsley formula obtained from the same fit as
EXCH2'
EXET3 'eta parameter of Linsley formula obtained from the same fit as
EXCH3'
ECDA1 'reconstructed charged particles density [m^{-2}] in the normal
plane obtained from the Linsley formula using the parameters
from the fit including the response of the Grande detectors

from all the angular intervals. The value given is the density at 100 m from the shower axis.'

ECDA2 'as ECDA1, but at 200 m'

ECDA3 'as ECDA1, but at 300 m'

ECDA4 'as ECDA1, but at 400 m'

ECDA5 'as ECDA1, but at 500 m'

ECDA6 'as ECDA1, but at 600 m'

ECD11 'reconstructed charged particles density [m^{-2}] in the normal plane obtained from the Linsley formula using the parameters from the fit including the response of the Grande detectors from the first angular interval. The value given is the density at 100 m from the shower axis.'

ECD12 'as ECD11, but at 200 m'

ECD13 'as ECD11, but at 300 m'

ECD14 'as ECD11, but at 400 m'

ECD15 'as ECD11, but at 500 m'

ECD16 'as ECD11, but at 600 m'

ECD21 'reconstructed charged particles density [m^{-2}] in the normal plane obtained from the Linsley formula using the parameters from the fit including the response of the Grande detectors from the angular intervals 2+4. The value given is the density at 100 m from the shower axis.'

ECD22 'as ECD21, but at 200 m'

ECD23 'as ECD21, but at 300 m'

ECD24 'as ECD21, but at 400 m'

ECD25 'as ECD21, but at 500 m'

ECD26 'as ECD21, but at 600 m'

ECD31 'reconstructed charged particles density [m^{-2}] in the normal plane obtained from the Linsley formula using the parameters from the fit including the response of the Grande detectors from the third angular interval. The value given is the density at 100 m from the shower axis.'

ECD32 'as ECD31, but at 200 m'

ECD33 'as ECD31, but at 300 m'

ECD34 'as ECD31, but at 400 m'

ECD35 'as ECD31, but at 500 m'

ECD36 'as ECD31, but at 600 m'

AGEEX 'NKG age of the shower obtained by fitting the reconstructed charged particles density in the normal plane with NKG formula. The data provided by the Grande detectors from all angular intervals were included in the fit.'

CHNTHT1 'the number of charged particles in the radial interval 0 - 100 m from the fit of angle averaged CORSIKA density extended up to the position of the farthest Grande detector'

CHNTHT2 'as CHNTHT1, but for the interval 100 to 200 m'

CHNTHT3 'as CHNTHT1, but for the interval 200 to 300 m'

CHNTHT4 'as CHNTHT1, but for the interval 300 to 400 m'

CHNTHT5 'as CHNTHT1, but for the interval 400 to 500 m'

CHNTHT6 'as CHNTHT1, but for the interval 500 to 600 m'

CHNTHL1 'the number of charged particles in the radial interval 0 - 100 m from the fit of angle averaged CORSIKA density extended from the position of the closest Grande detector to the position of the farthest Grande detector'

CHNTHL2 'as CHNTHL1, but for the interval 100 to 200 m'

CHNTHL3 'as CHNTHL1, but for the interval 200 to 300 m'
 CHNTHL4 'as CHNTHL1, but for the interval 300 to 400 m'
 CHNTHL5 'as CHNTHL1, but for the interval 400 to 500 m'
 CHNTHL6 'as CHNTHL1, but for the interval 500 to 600 m'
 CHNEXT1 'the number of charged particles in the radial interval 0 - 100 m
 from the fit of all detectors data'
 CHNEXT2 'as CHNEXT1, but for the interval 100 to 200 m'
 CHNEXT3 'as CHNEXT1, but for the interval 200 to 300 m'
 CHNEXT4 'as CHNEXT1, but for the interval 300 to 400 m'
 CHNEXT5 'as CHNEXT1, but for the interval 400 to 500 m'
 CHNEXT6 'as CHNEXT1, but for the interval 500 to 600 m'
 NMUTRIG 'the number of muons which provide time information in the Central
 Detector'
 TGTHM 'mean value of the global arrival time (ns) undistorted by
 experimental resolution. Correction for shower inclination
 based on the distance between the impact point in the
 observation level and its projection onto the plane normal
 to the shower axis. The values do not take into account the
 difference in the level of the detectors which provide
 information regarding muon arrival time and the detectors which
 provide information regarding the shower core arrival time.'
 TGEXM 'mean value of the global arrival time (ns) distorted by
 experimental resolution. Correction for shower inclination
 based on the distance between the impact point in the
 observation level and its projection onto the plane normal
 to the shower axis. The values do not take into account the
 difference in the level of the detectors which provide
 information regarding muon arrival time and the detectors which
 provide information regarding the shower core arrival time.'
 TLTHM 'mean value of the local arrival time (ns) undistorted by
 experimental resolution.'
 TLEXM 'mean value of the local arrival time (ns) distorted by
 experimental resolution.'
 TGTQ1 '25% quartile of the global arrival time undistorted by experimental
 resolution. See TGTHM.'
 TGTQ2 'as TGTQ1, but 50% quartile'
 TGTQ3 'as TGTQ1, but 75% quartile'
 TGEQ1 '25% quartile of the global arrival time distorted by experimental
 resolution. See TGEXM.'
 TGEQ2 'as TGEQ1, but 50% quartile'
 TGEQ3 'as TGEQ1, but 75% quartile'
 TLTQ1 '25% quartile of the local arrival time undistorted by experimental
 resolution.'
 TLTQ2 'as TLTQ1, but 50% quartile'
 TLTQ3 'as TLTQ1, but 75% quartile'
 TLEQ1 '25% quartile of the local arrival time distorted by experimental
 resolution.'
 TLEQ2 'as TLEQ1, but 50% quartile'
 TLEQ3 'as TLEQ1, but 75% quartile'
 L10MOTG1 'logarithm (base 10) of the first moment of the global arrival time
 undistorted by experimental resolution.'
 L10MOTG2 'logarithm (base 10) of the second centered moment of the global
 arrival time undistorted by experimental resolution.'
 L10MOTG3 'as L10MOTG2, for the third centered moment'

L10MOTG4 'as L10MOTG2, for the fourth centered moment'
 L10MOEG1 'logarithm (base 10) of the first moment of the global arrival time
 distorted by experimental resolution.'
 L10MOEG2 'logarithm (base 10) of the second centered moment of the global
 arrival time distorted by experimental resolution.'
 L10MOEG3 'as L10MOEG2, for the third centered moment'
 L10MOEG4 'as L10MOEG2, for the fourth centered moment'

The HBOOK described above corresponds to the case when SHOWREC was compiled
 without the TIMERING option. If this option is selected then in addition to the above data
 NTUPLE 101 contains the following quantities:

NMURING 'the number of muons from the ring for which time information was
 analyzed'
 RITGTHM 'as TGTHM but for the ring muons'
 RITGEXM 'as TGEXM but for the ring muons'
 RITLTHM 'as TLTHM but for the ring muons'
 RITLEXM 'as TLEXM but for the ring muons'
 RITGTQ1 'as TGTQ1 but for the ring muons'
 RITGTQ2 'as TGTQ2 but for the ring muons'
 RITGTQ3 'as TGTQ3 but for the ring muons'
 RITGEQ1 'as TGEQ1 but for the ring muons'
 RITGEQ2 'as TGEQ2 but for the ring muons'
 RITGEQ3 'as TGEQ3 but for the ring muons'
 RITLTQ1 'as TLTQ1 but for the ring muons'
 RITLTQ2 'as TLTQ2 but for the ring muons'
 RITLTQ3 'as TLTQ3 but for the ring muons'
 RITLEQ1 'as TLEQ1 but for the ring muons'
 RITLEQ2 'as TLEQ2 but for the ring muons'
 RITLEQ3 'as TLEQ3 but for the ring muons'
 RILMOTG1 'as L10MOTG1 but for the ring muons'
 RILMOTG2 'as L10MOTG2 but for the ring muons'
 RILMOTG3 'as L10MOTG3 but for the ring muons'
 RILMOTG4 'as L10MOTG4 but for the ring muons'
 RILMOEG1 'as L10MOEG1 but for the ring muons'
 RILMOEG2 'as L10MOEG2 but for the ring muons'
 RILMOEG3 'as L10MOEG3 but for the ring muons'
 RILMOEG4 'as L10MOEG4 but for the ring muons'