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MONTE CARLO CALCULATION OF THE ENERGY DEPOSITED IN THE KASCADE GRANDE DETECTORS

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Abstract: The energy deposited by protons, electrons and positrons in the KASCADE GRANDE detectors is calculated with a simple and quick Monte Carlo method. The standard method to calculate the energy deposit in the detectors is based on the Geant package from the CERN library. A new method that calculates the energy deposit by fitting the Geant based distributions with simpler functions is proposed in this work. In comparison with the method based on the Geant package this method is substantially faster. The time economy is important because the number of particles involved is large,e.g. 10^9 particles in one high energy air shower.

Keywords: Monte Carlo simulation, KASCADE GRANDE experiment

INTRODUCTION

The energy spectrum of primary cosmic rays extends from 1 Gev to 10^{20}eV (100 EeV), the highest energies of known individual particles in the universe. We have only a limited understanding of where these particles are coming from, how they are accelerated to such high energies, how they propagate through interstellar space and how they interact with matter.

The energy spectrum follows an overall power-law $I(E) = \alpha * E^\gamma$, indicating the non-thermal character of the cosmic rays, but with some characteristic changes of the slope, first from $\gamma = -2.7$ to $\gamma = -3.1$ around the energy region called the "knee" (10^{15} eV). The study of the "knee" region brings information about the acceleration

mechanism of the primary cosmic rays. It is believed that the particles are accelerated by shock waves of supernova explosions in a process called diffusive shock acceleration. Such mechanisms lead to a power law spectrum with a maximum energy of about $Z*10^{15}$ eV.

Another distinct change in the energy spectrum takes place around the "ankle" region (about 6 $*10^{19}$eV) where the spectrum seems to flatten, contrary to the predicted Greisen-Zatsepin-Kuz'min (GZK) cut-off, expected due to the interaction of the cosmic rays with the 2.7 ºK primordial background radiation.

Observations of extensive air shower provide indirect information about the energy spectrum of the primary cosmic rays above 10^{14} eV. Because of the small flux of particles it is impossible to measure directly the energy and mass of the cosmic rays, this kind of information is inferred from secondary effects, from the lateral and longitudinal development of the particle cascades initiated by the primary cosmic particles in the atmosphere. These techniques require a good knowledge of the shower development in the atmosphere and of the interaction mechanisms of high-energy particles with air molecules.

Extensive Monte Carlo simulation procedures are used as reference patterns. For the high-energy hadronic interactions theoretical low-energy models and parameterizations are extrapolated.

Most of the particles produced in hadronic collisions with air nuclei are pions and kaons, which decay into muons and neutrinos before interacting, thus producing the most penetrating component of the atmospheric showers: the muon component.

The most intense component, the electromagnetic component (electrons and photons) originates from the decay of neutral pions in photons, which initiate electromagnetic showers, thus distributing the originally high energy of one primary particle over milions of charged and neutral particles. Nucleons, pions and other particles form the hadronic component that feeds the electromagnetic component and muons component. The hadronic component is concentrated around the shower axis, nevertheless neutrons are also distributed far of the shower axis due to multiple scattering.

THE KASCADE GRANDE EXPERIMENT

The KASCADE GRANDE experiment (3) is an array of plastic scintillators of large collecting area that operate jointly with the KASCADE multi-detector experiment measuring the energy spectrum of the primary cosmic rays around and above the "knee" region. The array set up at Forschungszentrum Karlsruhe in Germany provides comprehensive observations of particles with energies from 0.1 PeV to 100 PeV.

The aim of the KASCADE GRANDE experiment is the observation of the "iron-knee" in the cosmic ray spectrum at around 100 PeV, which is expected following recent KASCADE observations (2) where the positions of the knees of individual mass groups suggest a rigidity dependence. The reconstruction of the energy spectra of various mass groups will provide a complete picture of the physics around the "knee" region. Additionally, the validity of hadronic models used in CORSIKA Monte Carlo simulations will be tested. Investigations of radio emission in high energy air shower will be performed with an array of broad band antennas. The existing KASCADE multi-detector experiment consists of three, nearly independent parts: the detector array, the central detector system and the muon tunnel.

The KASCADE experiment was extended to KASCADE-GRANDE by installing a large array of 37 stations consisting of 10 m^2 scintillation detectors, with an average spacing of 137 m. These detectors are sensitive to all charged particles. The joint measurements are ensured by an additional cluster (Piccolo) close to the center of the array for triggering purposes. Piccolo consists of 8 stations each 10 m2 equipped with plastic scintillators.

The main observables measured with the Grande detectors are the particle density of charged particles. These densities reconstruct the total number of charged particles of the shower and the lateral density distribution. Presently there is no experimental possibility to separate the different types of charged particles with these detectors. This in contrast to the KASCADE field array, which allows to determine the muon contribution and to present a partial muon number, comprises the EAS muons hitting the KASCADE part of the total installation.

The concept of KASCADE-Grande is the measurement of as many as possible observables of air showers to perform multi-parameter analyses determining the primary energy and mass. The Grande detectors will provide basic shower observables like the core position, angle of incidence or total number of charged particles. The estimation of energy and mass of charged particles will be based on a combined investigation of the charged particles, electron and muon components.

AIR SHOWER RECONSTRUCTION

The air shower reconstruction involves detailed simulation of the air shower development, evaluation of the detector response and reconstruction of the observables experimentally available.

The simulation of the development of the air shower is made using the CORSIKA () program. CORSIKA is a detailed Monte Carlo program to study the evolution and properties of extensive air showers initiated by high-energy cosmic particles. The CORSIKA program allows simulating interactions and decays of nuclei, hadrons, muons, electrons, and photons up to energies of some 10^{20} eV. It gives type, energy, location, and direction and arrival times of all secondary particles that are created in an air shower and pass a selected observation level.

The evaluation of the detector response is made with a program based on the Geant package from the Cern library. The Geant package allows simulating the trajectory of a particle in complex experimental installations taking into account the hadronic and leptonic interactions, the disintegration of particles and deflections by electromagnetic fields. The simulation of the detector response using the Geant package can be time consuming especially if the particles involved are high-energy hadrons.

In this work a new method that calculates the energy deposited in the detectors by simply fitting the Geant based distributions with simpler functions is proposed.

Extensive simulations where made using the Geant package taking into account the dimensions and chemical composition of the detectors for all particles present in an air shower with energies from 100 MeV to 10.000 GeV and angles of incidence from 0 to 90 degrees. The distributions where fitted with linear, exponential, Gauss, Landau and Vavilov functions using the PAW program from Cern library.

CORSIKA simulations have shown that most of the particles in an air shower have low energy and small angles of incidence and therefore it is important that the energy deposit for these particles is evaluated with good precision.

The energy deposit spectrum of the energy deposited by protons and neutrons in the detector has the same shape at large energies where hadronic interactions are predominant.

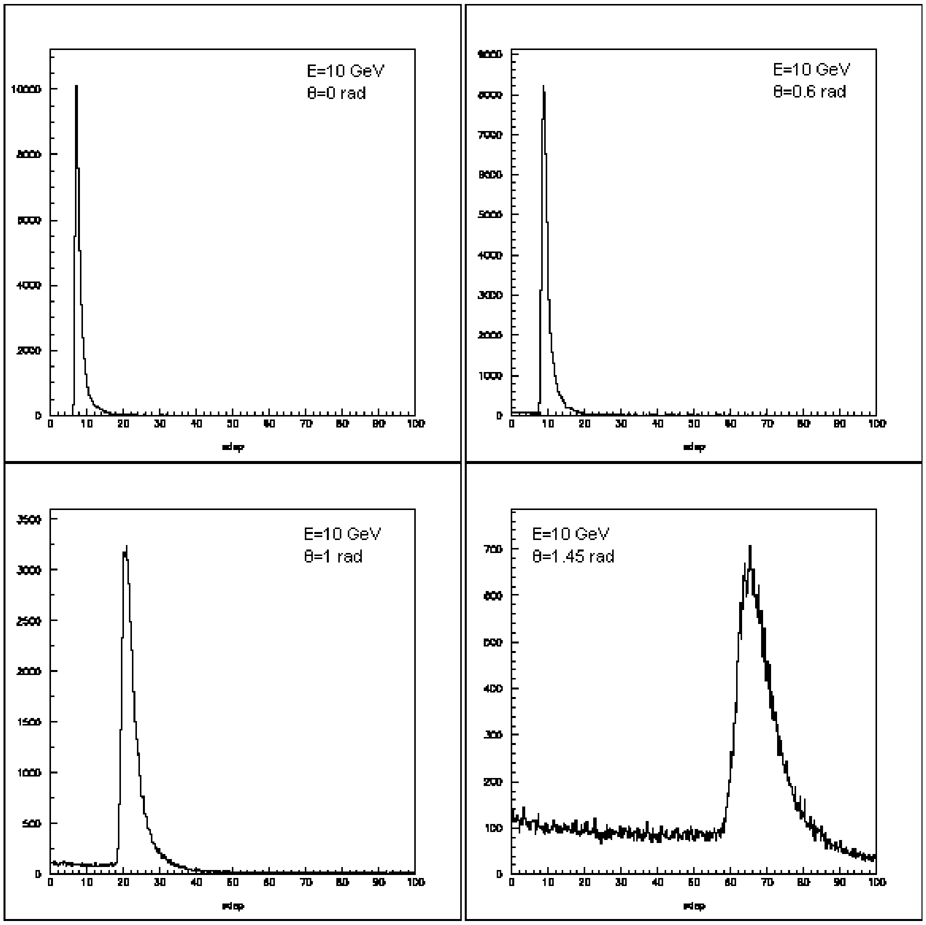

Figure 1 - The energy deposit of protons with energy of 10 GeV at various angles of incidence

Figure 1 shows the energy deposited by protons with energy of 10 Gev at angles of incidence θ=0, 0.6, 1, 1.45 rad calculated with the Geant program. The mean and the standard deviation of the distributions are correlated with the length of the particle trajectory in the detectors. They follow a linear law in respect to 1/cosθ.

At large angles of incidence the energy spectrum suffer large fluctuations due to large number of particles that escape from the detector after the first interaction.

Figure 2 shows the energy deposit of protons with the angle of incidence θ=0.6 rad
at energies of 1.5, 4, 10, 100 GeV calculated with the Geant program. The parameters of the distributions vary quite slowly with the energy of protons. Only the standard deviation has a linear dependence in respect to the incident energy.

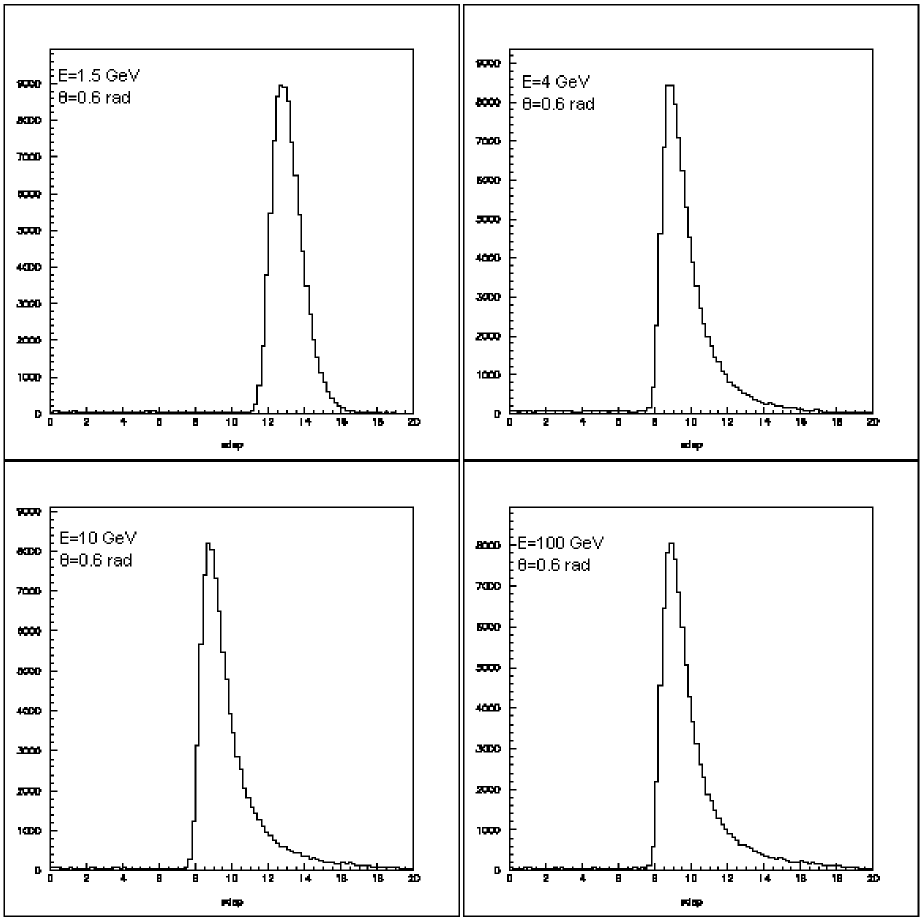

Figure 2 - The energy deposit of protons with angle of incidence of 0.6 rad at 1.5, 4, 10, 100 GeV

The energy deposit spectrum of electrons, positrons and muons is best fitted with Landau and Vavilov functions. The spectrum has the same shape and the parameters have the same variation in respect to the incident energy and angle of incidence only the numerical value of the parameters are different.

Figure 3 shows the energy deposit of positrons with energies of 0.5, 1, 10, 100 Gev at the angle of incidence θ=0.6 rad calculated with the Geant program.

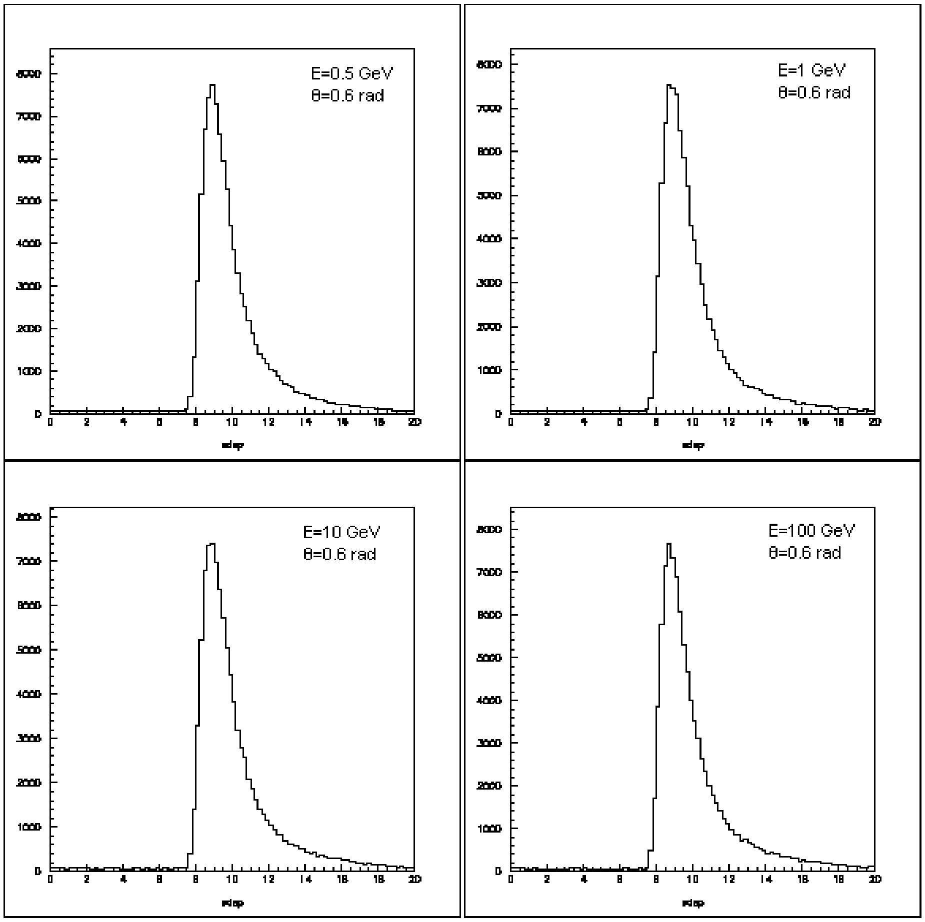

Figure 3 - The energy deposit of positrons with energies of 0.5, 1, 10, 100 GeV

Figure 4 shows a comparison between the energy spectrum obtained with the Geant program and the new method. For obtaining the energy spectrum a combination of exponential, linear and Gauss functions is used.

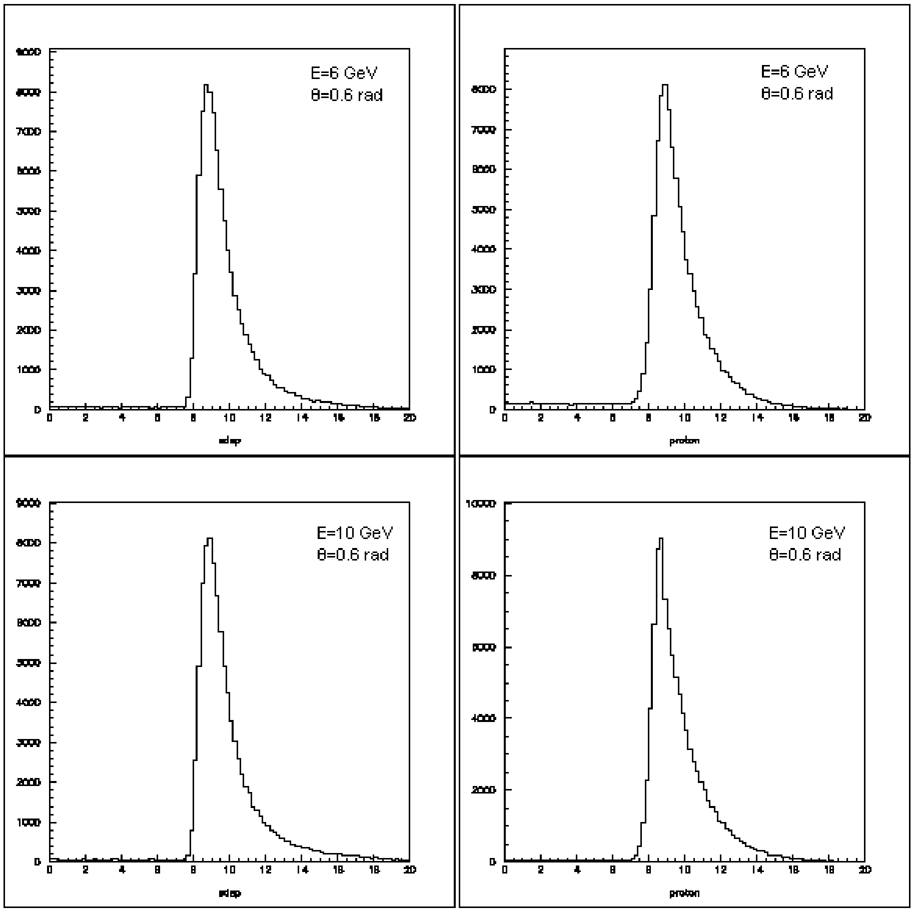

Figure 4 - Comparison between the distributions obtained with the Geant program (left) and the new method (right) for protons with energies of 6 Gev and 10 GeV

The results are in good agreement with the Geant simulation and the program works substantially faster.

CONCLUSIONS

Preliminary results for protons show that this method reproduces the Geant energy deposit spectrum with accuracy. But the most important is the time economy achieved with this method. As an example the time necessary for calculating the energy deposit with the Geant program for 10^5 particles varies between 1 minute and 4 hours and with the new method is about 1 seconde.

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