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Lateral distributions of EAS muons (E_μ >800 MeV) measured with the KASCADE-Grande Muon Tracking Detector in the primary energy range 10^{16}–10^{17} eV

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ABSTRACT

The KASCADE-Grande large area (128 m^2) Muon Tracking Detector has been built with the aim to identify muons (E_μ^{thr} = 800 MeV) in Extensive Air Showers by track measurements under 18 r.l. shielding. This detector provides high-accuracy angular information (approx. 0.3°) for muons up to 700 m distance from the shower core. In this work we present the lateral density distributions of muons in EAS measured with the Muon Tracking Detector of the KASCADE-Grande experiment. The density is calculated by counting muon tracks in a muon-to-shower-axis distance range from 100 m to 610 m from showers with reconstructed energy of 10^{16}–10^{17} eV and zenith angle $\theta < 18°$. In the distance range covered by the experiment, these distributions are well described by functions phenomenologically determined already in the fifties (of the last century) by Greisen. They are compared also with the distributions obtained with the KASCADE scintillator array (E_μ^{thr} = 230 MeV) and with distributions obtained using simulated showers.

1. Introduction

Investigations of the muonic component in extensive air showers (EAS) is of primary importance for understanding air shower physics. Muons carry nearly undistorted information about their parent particles, pions and kaons. These parent particles are the most numerous products of hadronic interactions responsible for the development of the shower cascade in the atmosphere. This

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longitudinal development contains the information on the nature (mass) of the primary cosmic ray particle, which is related to astrophysical questions. It also carries information relevant to particle physics on the underlying properties of hadronic interactions in the energy range and the kinematical region only recently being accessed by the forward detectors of the LHC [1]. Therefore, study of the mass composition of cosmic rays and the tests of various hadronic interaction models are in many cases related to the investigation of this longitudinal development of showers.

The most common way used by all EAS experiments with sufficient number of muon detectors is the investigation of lateral distributions of muons, being a projection of the development of the muonic component onto the shower plane [2,3]. This is usually measured with arrays of scintillation detectors, where the number of muons in each detector is derived from the energy deposited in the scintillators, using non-trivial procedures based on simulations [4,5].

Muon Tracking Detectors, actually counting muons in EAS, have rather not been used for this purpose due to the difficulty of building sufficiently large detectors of this type. Earlier attempts were based on neon flash tubes, either in tracking [6] or hodoscopic [7] configurations. Muon densities were measured close to the shower core (< 30 m in Ref. [7] and 5–70 m in Ref. [6]), and for shower sizes corresponding to the 'knee' region of the primary energy spectrum, around 10^{15} eV. A possibility of the investigation of muon tracks from more energetic showers at larger distances has been created in the KASCADE-Grande EAS experiment [8], being an extension of the KASCADE experimental setup [9]. It is a multi-detector system (Fig. 1) located on the site of the Karlsruhe Institute of Technology (KIT) – Campus North, Germany at 110 m a.s.l. It was designed to detect the three EAS particle components: hadrons, electrons and muons (at 4 energy thresholds) in a wide range of distances from the shower core (up to 700 m), and for primary particle energies from 5×10^{14} eV to 10^{18} eV. High precision measurements of particle densities and tracks – the latter by means of a dedicated Muon Tracking Detector (MTD) [10] – at different energy thresholds allow investigation of many features of EAS and are the basis for multi-parameter analyzes (e.g.: [4,11]).

In particular, the MTD gives a possibility to study the longitudinal development of EAS. For the first time it was possible to investigate the lateral distribution of muons using the muon tracks in a distance up to several hundred meters from the core from a large number of showers with energies above 10^{16} eV. The results of this investigation are reported in this work.

2. Muon tracking in KASCADE-Grande

The KASCADE-Grande experiment (Fig. 1) contains several detector systems. First, it consists of the KASCADE experimental setup located in the North-East corner, where the MTD is also situated. A detailed description of this part of the experiment and its performance can be found elsewhere [9]. In view of the research presented here, apart from the MTD, an array of 252 detector stations (called the *KASCADE Array*), covering an area of 200 m × 200 m, is an important part of the setup. The stations are placed on a square grid with 13 m spacing and are organized in 16 clusters. Each station is equipped with scintillation counters registering the electromagnetic shower component (E^{thr}=5 MeV), and in the outer 12 clusters, also the muonic part of EAS (E_{μ}^{thr} = 230 MeV).

A second major part of KASCADE-Grande is the *Grande Array*, being an extension of the KASCADE Array. It consists of 37 detector stations organized in a grid of 18 clusters of overlapping hexagons, covering an area of 0.5 km^2 [8]. In the centre there is a small trigger array of plastic scintillation stations, called *Piccolo*, built to provide additional fast triggers for some of the KASCADE detector components.

2.1. Design of the MTD

The MTD is located in the northern part of the KASCADE Array (as shown in Fig. 1) and houses 16 muon telescopes made of *strea-*

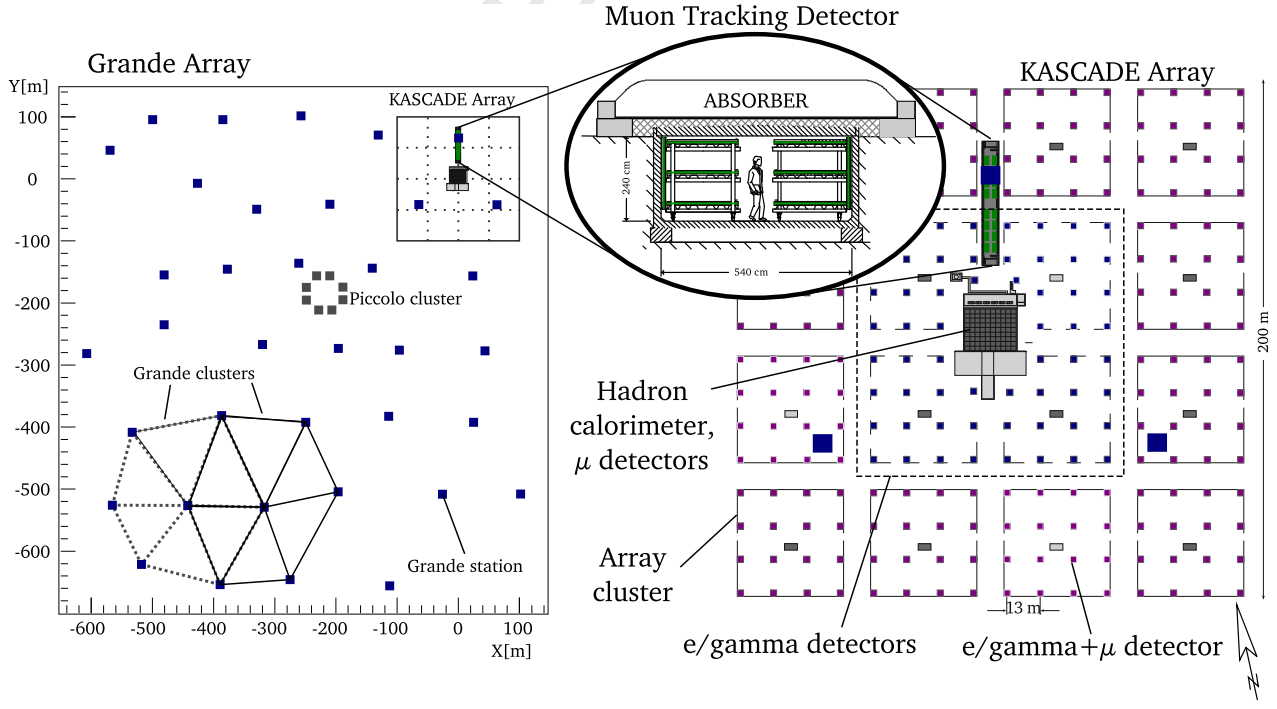

Fig. 1. Layout of the KASCADE-Grande experiment. Note the location of the Muon Tracking Detector (MTD) within the KASCADE Array.

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