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Core structure of extensive air showers

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Abstract

The experimental results obtained from the old Kiel device have been used in the investigation of the core structure of extensive air showers. The analysis has been made of the properties of a core of electromagnetic component as well as hadron and muon components as measured by the underground neon hodoscope. Muon densities at small distances from the core have been analysed for proton-like and iron-like showers.

1 Introduction:

We continued to investigate the properties of shower cores for showers detected by the old Kiel experiment [1]. Using the multifractal moment analysis for the structure of the density of charged particles near the extensive air shower (EAS) cores we selected samples of showers, significantly enriched in proton- and iron-initiated showers [2]. Then these two groups of selected showers have been used for the analysis of the core structure and muon density distribution near the core to find possible differences between the two groups. For the analysis described in this paper the 31 m^2 unshielded neon hodoscope has been used as the core detector of EAS charged particles and the 65 m^2 shielded neon hodoscope for hadrons and muons. Only EAS of $1.4 \cdot 10^5 \leq N_e \leq 5 \cdot 10^6$ and $0 \leq \Theta \leq 30^o$ recorded with a very good accuracy by the Kiel experiment have been used.

2 Experimental Setup:

Details of the Kiel EAS array have been published [1] previously. A total of 28 unshielded scintillation counters were available for the determination of shower sizes and core locations (further we call this core position as a scintillator core). 11 scintillation counters, connected to 22 fast-timing channels of about 1 ns time resolution, provide information on the arrival directions of the showers (the zenith angle error was about 1^o). The 31 m^2 neon hodoscope for the investigation of the electron core structure was located below a 2.5 gcm^{-2} wooden roof. It incorporated 176400 neon flash tubes of 1 cm diameter each and enabled us to localise the core position directly from the density distribution of the charged particles in the EAS core region as well as to investigate the fractal moments (we call that core position: a fractal core).

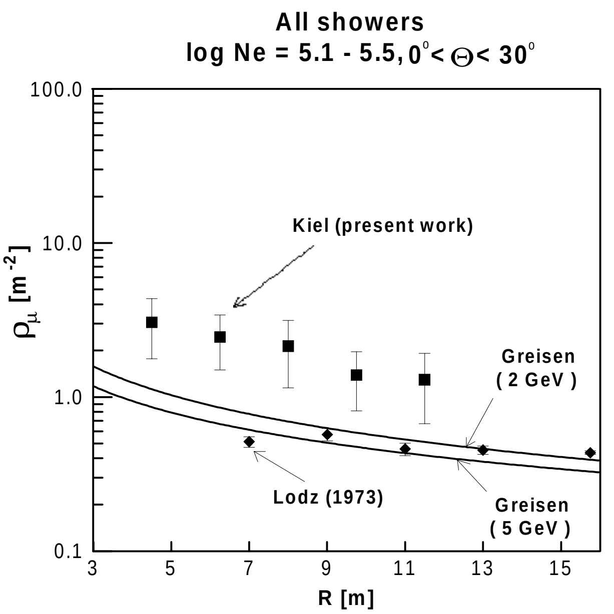

Figure 1. Lateral muon density distributions for showers below the ‘knee’. Uncorrected Kiel data are presented against the background of muon density distrbution as given by Greisen. The old Lodz data [5] are also shown.

The 65 m^2 underground neon hodoscope for the investigation of the hadron core structure and the lateral distribution of muons was located below 3.5 m of concrete and incorporated 367500 neon flash tubes.

Lateral muon density distributions at distances below 10 m from the shower axis are, in fact, unknown. The pictures taken by an underground neon hodoscope in old Kiel experiment allow for making attempts to measure muon densities near the shower core. Only those fragments of the photographs were used by us in which the groups of neon tubes, which could have been flashed by hadron initiated cascades, were not seen.

The results, which were obtained in such a way, are overestimated. We were able to check these values with Monte Carlo calculations, made with the use of GEANT programme and we found out that the experimental muon densities are overestimated by factor of two [4] due to the fact that neon tubes are flashed by δ - electrons and also by hadrons. In Figure 1 the muon density distributions are presented for all the showers for which log N_e= 5.1 ÷5.5.

The obtained results are shown against the background of muon density distributions as given by Greisen approximations for the two different thresholds of muon energy and Lodz data [5]. It can be observed that the muon densities obtained by us are clearly overestimated by the factor suggested above.

3 The analysis of experimental results:

We performed the analysis of each individual EAS in the following way [2]. For each EAS with the core falling into the unshielded neon hodoscope we estimated scintillator and fractal core positions. Then for such showers the position of the most energetic hadron, as detected by the shielded neon hodoscope, has been estimated.

The average distances between the position of the scintillator core and the most energetic hadrons are

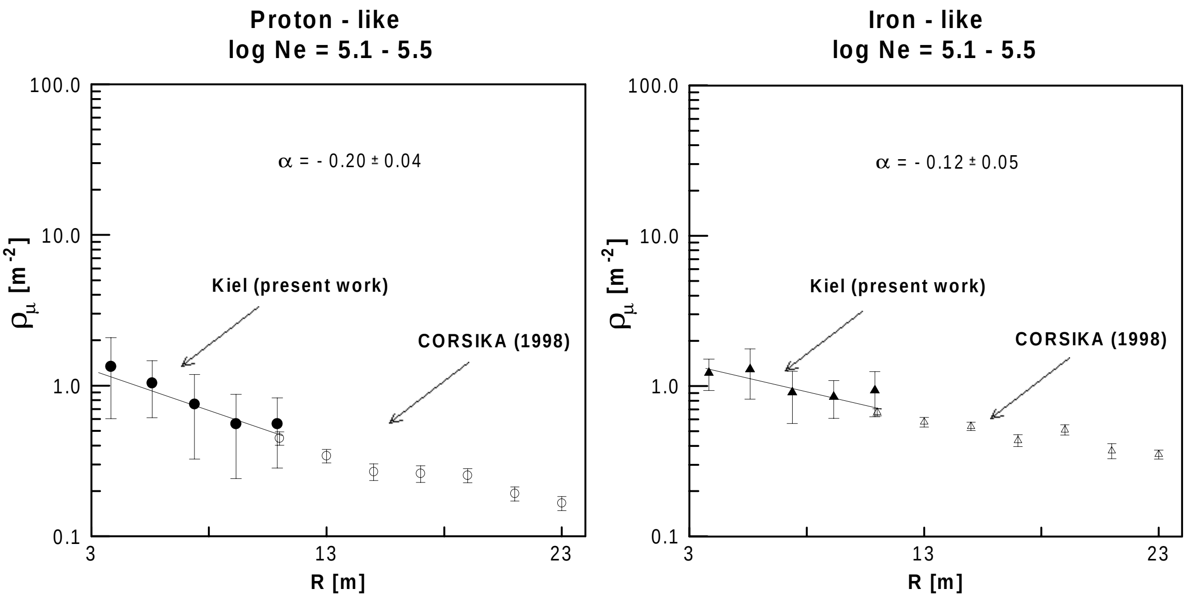

Figure 2. Muon lateral density distributions for proton-like showers (left) and iron-like showers (right) for showers below the 'knee'. The CORSIKA predictions are also shown.

135 ± 13 cm for the iron-like showers and 145 ± 13 cm for the proton-like showers.

The average distances between the scintillator and fractal core positions for the two groups of showers are: 56 ± 7 cm and 54 ± 8 cm, respectively. The numbers mentioned above put certain natural limits equal up to about 50 cm; such is our concept of the core and positions of the symmetry axis of an extensive air shower in case of the electromagnetic component.

The corrected muon density distributions of the showers below the 'knee' are presented in Figure 2 and above it in Figure 3, and are compared with the theoretical distributions of the CORSIKA [3]. The experimental results were divided into two groups, for proton-like and iron-like showers, by means of fractal analysis of particle densities, which were observed in a ground-level detector [2].

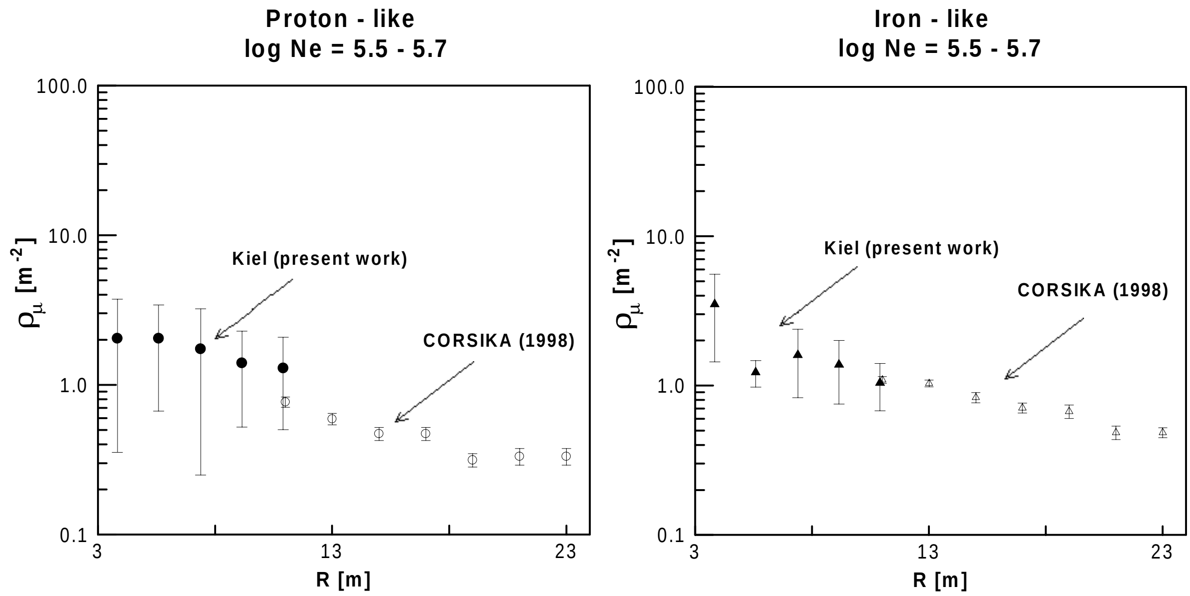

Figure 3. The same as in Figure 2, but for showers above the 'knee'.

The statistics made it possible to find out a slope α from the relation:

$$\rho_\mu \sim r^{-\alpha}$$

for the two groups: of proton-like showers and iron-like showers (for the showers with log N_e=5.1 ± 5.5). The proton-like showers seem to have a steeper muon lateral distribution than the iron-like showers. The experimentally obtained ratio: $\alpha_p / \alpha_{Fe} = 1.67 \pm 0.36$. The values expected from CORSIKA [3] equals to: $\alpha_p / \alpha_{Fe} = 1.92 \pm 0.01$.

No dependence on the primary mass has been found.

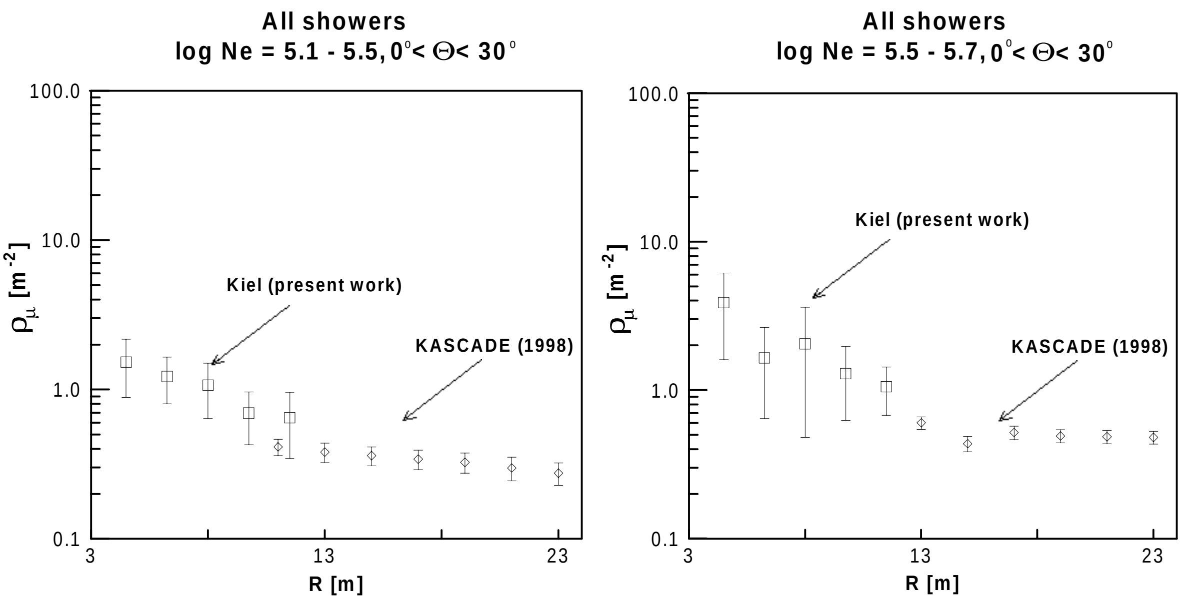

Figure 4. Measurred muon lateral distributions of the Kiel experiment compared with the KASCADE data [3].

4 Conclusions:

In the present paper the lateral muon density distributions have been obtained for the very short distances (3 m. to 11 m.) from the shower axis.

No significant discrepancy can be observed between these distributions and both the old (Figure 1) and the new measurements (Figure 4) from KASCADE.

The analysis of proton-like and iron-like showers shows that muon lateral distributions in proton initiated showers are steeper than those in the showers initiated by heavy primary nuclei.

References

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