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Analysis of Muon Production Heights using KASCADE parameters

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The Muon Tracking Detector (MTD; E_μ^{th}=0.8 GeV, $128m^2$) [1] of the KASCADE-Grande experiment [2] enables the analysis of the longitudinal shower development by means of the Muon Production Height (MPH). The analysis employs radial and tangential angles of the muon track with respect to the shower direction and in addition the distance of the muon hit to the shower core. Dividing the air shower data into heavy and light primary enriched samples, by means of lg(N_μ^0)/lg(N_e^0) ratio, a clear sensitivity of the MTD parameters to the mass of the primary particle has been observed.

1. Efficiency and Data Selection

To describe the orientation of muon tracks with respect to the shower axis, radial and tangential angles are used [3]. Both angles are studied with respect to lg(N_μ^{tr}) which corresponds to the total number of muons that are within 40-200m of the KASCADE array and which represents [4] an approximate energy estimator of the primary cosmic ray particles. In the present analysis a consistency check between the array data and the MTD data is performed.

The simulated detection efficiencies for the KASCADE array for proton and iron primaries is shown in the left part of Fig.1 as solid symbols. Also included in Fig.1 is the efficiency of having at least one muon track in the MTD ($>$ 40m from shower core, open symbols). Iron showers which are richer in muons are having a larger probability already at the threshold of the KASCADE array but proton showers are not fully measured even above lg(N_e)>4.8 (arrow) where usually the KASCADE array analysis starts.

The right side of Fig.1 shows the mean lg(N_μ^0)/lg(N_e^0) ratio which turned out [4] to be a good mass discrim-

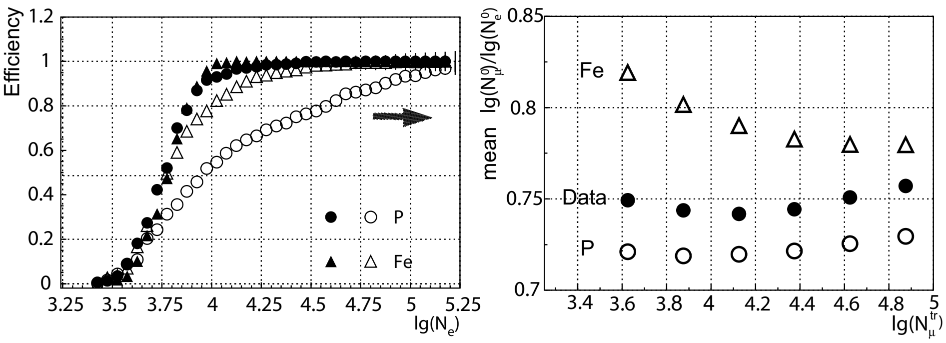

Figure 1. Simulated efficiencies of the KASCADE array (full symbols) and the MTD (open symbols) (left panel). Simulated lg(N_μ^0)/lg(N_e^0) ratios compared to data (right panel).

ination parameter. The lg(N_μ^0), lg(N_e^0) numbers are the shower angle (Θ_s) and attenuation lengths (λ_e, λ_μ) corrected [5] original lg(N_μ^{tr}), lg(N_e) numbers. Such presentation was employed in the past [4] to deduce the relative weights of light and heavy cosmic ray primaries. In Fig.1 (right panel) iron (Fe) exhibits strongest dependence on shower energy, because of strong dependence of electron longitudinal shower development. The simulations involved in Fig.1 are based on the CORSIKA [6] program version 6.156 with QGSJet01. Selecting the shower data ($\Theta_s < 30^o$) according to the lg(N_μ^0)/lg(N_e^0) ratio being larger (electron poor) or smaller (electron rich) than 0.74, heavy or light cosmic ray primaries are chosen, respectively. Choosing e.g. a ratio of 0.75 would provide a larger fraction of light primaries.

2. Mean Radial Angles and Muon Production Heights

Mean radial angles have been calculated between $0^o - 6^o$ and derived as function of lg(N_μ^{tr}) in different distance bins with respect to the shower core. In Fig.2 we concentrate on distance values between the muon hit and the shower core from 80-120m. The mean radial angles exhibit a clear dependence on the shower energy and on light and heavy enriched shower samples. This observation provides an interesting aspect with respect to even larger shower energies and core distances in the upcoming KASCADE-Grande data analysis. Extending the distance range helps in getting more abundantly larger radial angles and, therefore, testing lower muon pseudorapidities [7]. The band around the light or heavy data points corresponds to a variation of the ratio cut from 0.73 (large $< \rho >$) to 0.75 (small $< \rho >$). Selecting in future analysis different muon multiplicities in the MTD may help to improve the discrimination between light and heavy primaries.

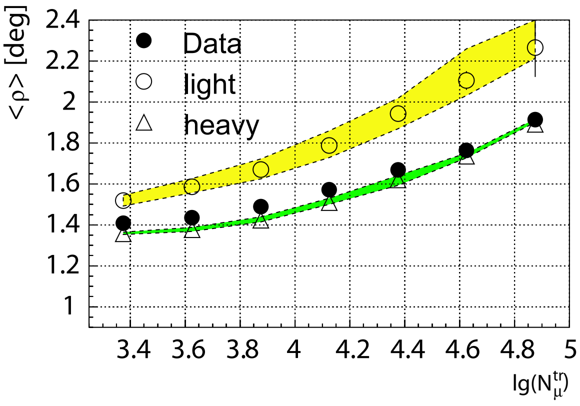

Figure 2. Mean radial angles $< \rho >$ and their dependence on $lg(N_\mu^{tr})$ for 80-120m core distance. Note bias of full 'Data' towards heavy primaries.

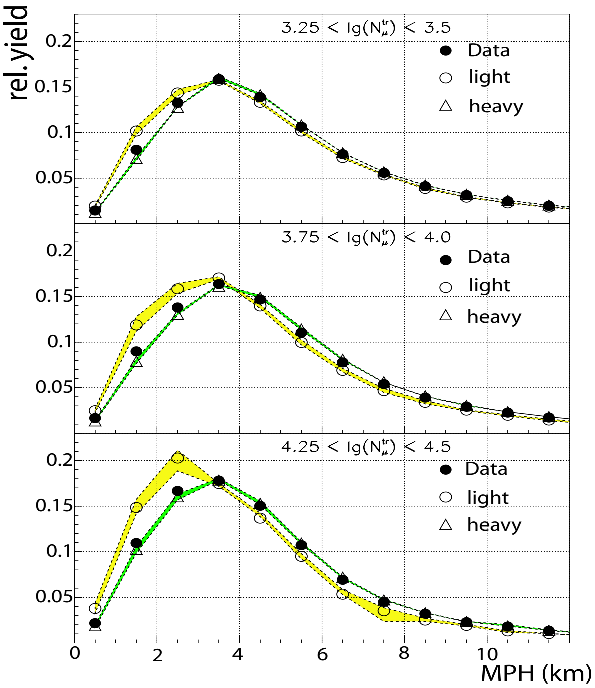

Figure 3. Muon production height distributions for full data together with light and heavy data subsamples.

We observe from Fig.1 (left) for $lg(N_e) > 4.8$ due to the comparatively reduced efficiency for proton showers, that the full data lie closer to the heavy enriched part of the data. Therefore, our data exhibit an over-representation of heavy showers. Application of an efficiency correction may move the data for small $lg(N_\mu^{tr})$ towards the light enriched data and hence providing a more pronounced trend towards heavy primaries with increasing shower energy. This correction will be investigated in an ongoing analysis.

The MPH is calculated by triangulation employing the radial angles and the distance of the muon hit to the shower core. Applying a tangential angle cut by excluding the tails above 0.7^o one enriches data sample with higher energy muons. Again, light and heavy data subsamples were created, in a similar way as for $< \rho >$, based on a lg(N_μ^0)/lg(N_e^0) ratio boundary value 0.74.

In Fig.3 MPH distributions along the shower axis are shown for 80-120m muon distance range to the shower core. With increasing primary energy $lg(N_\mu^{tr})$ comparatively more muons stem from lower production heights.

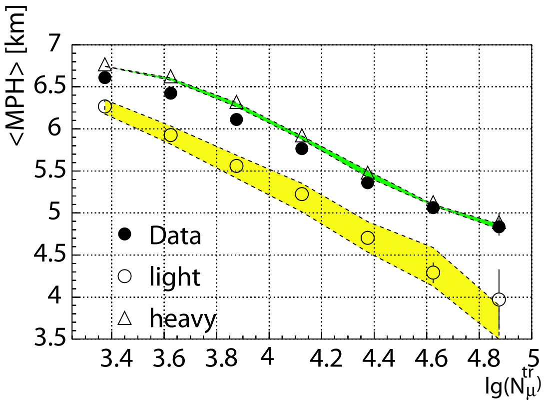

Figure 4. Mean muon production heights $< MPH >$ and their dependence on $lg(N_\mu^{tr})$ for 80-120m core distance. Note bias of full 'Data' towards heavy primaries.

Selecting in future analysis different muon multiplicities in the MTD may provide more detailed information on longitudinal shower development. In Fig.4 the mean MPH values (calculated between 0-15km) a clear distinction between light and heavy enriched data samples is observed which is of similar size as known from simulations. The bias towards heavier composition at lower primary energies, resulting from the efficiency discussed above, is also present here. Having this in mind one can notice the clear trend towards heavier composition with increasing primary energy also in this analysis. Moving to larger distances in KASCADE-Grande, as shown in [7], will improve the accuracy of MPH analysis.

3. Conclusion

The mean radial angle and mean MPH analysed with the experimental data alone show the trend towards heavier primary composition with the increase of the energy in the “knee” region of the primary spectrum. Extending the analysis to KASCADE-Grande showers and to even larger shower energies enables the continuation of this type of analysis with respect to an expected change above a conjectured iron knee.

4. Acknowledgements

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