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Muon Tracking In KASCADE-Grande: CORSIKA Simulation Study

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The use of Muon Tracking Detector of KASCADE EAS experiment in the KASCADE-Grande setup is analyzed. By means of Monte Carlo simulations done with modified CORSIKA code benefits and new possibilities are shown when tracking muons arriving up to 700 m from the shower core comparing to 160 m maximum distance available in KASCADE.

1. Introduction

The Muon Tracking Detector (MTD; E_{μ}^{th}=0.8 GeV, area=128m^2) [1] in KASCADE-Grande EAS experiment [2] allows precise measurement of muon directions in air showers. This information has been used to investigate mean muon production heights (primary mass sensitive parameter) [3] as well as muon pseudorapidities and momenta [4]. The latter, being highly correlated with pseudorapidities and momenta of parent hadrons, are very good probe of high-energy hadronic interactions and thus serve as a tool to test and improve existing hadronic interaction models. In the KASCADE-Grande experimental setup muons arriving up to 700 m from the shower core can be tracked, comparing to 160 m maximum distance available in KASCADE. The experiment layout is shown in Fig. 1 where the distance relations can be seen. The CORSIKA [5] Monte Carlo simulations with the QGSJET and GHEISHA hadronic interaction models were used to show how the increase in this distance influences the measured distributions of various quantities characterizing muons. A special version of CORSIKA code has been used, which allowed to get not only information on muons at the detection level but also on their "mother" and "grandmother" hadrons. For the analysis large statistics of muons was simulated ($\approx 1.8 \times 10^7$) for proton and iron primaries with $10^{16} eV$ primary energy. With this Monte Carlo data muon pseudorapidity and muon production heights distributions were analysed. Only muons with energy above 1 GeV (MTD threshold) were considered.

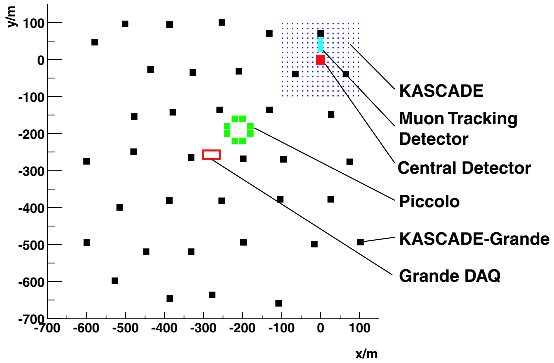

Figure 1. Layout of KASCADE-Grande experiment. Note the location of Muon Tracking Detector.

2. Muon pseudorapidity distributions in EAS - investigation of hadronic interactions

Using angular information about muon directions with respect to the direction of the shower it is possible to calculate the pseudorapidities of registered muons in the shower coordinates, where the vertical axis coincides with the axis of the shower [6]. Investigation of pseudorapidity distribution of EAS muons on ground is of interest because its shape nearly exactly follows the shape of pseudorapidity of their parent hadrons (Fig. 2 - left panel). One gets this way an inside look into VHE hadronic interaction in the forward kinematical region.

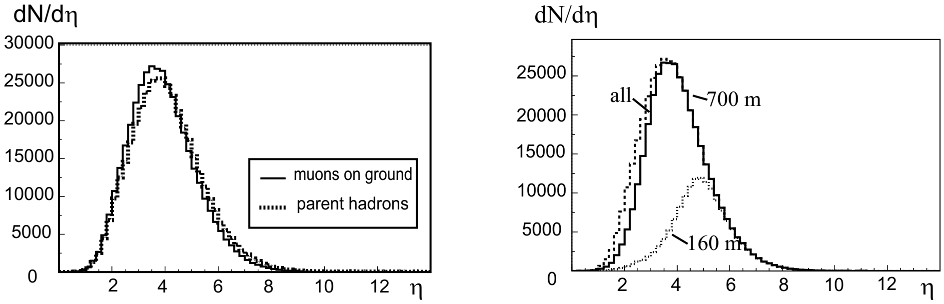

Figure 2. Pseudorapidity distributions for EAS muons. Comparison with the pseudorapidities of parent hadrons (left) and influence of the collecting distance to the core (right).

The right panel of Fig. 2 shows the influence of the experimental conditions, namely distance from the shower core at which one can track muons, on the shape of pseudorapidity distribution. It is seen that in KASCADE-Grande conditions (tracking up to 700 m) one obtains nearly true pseudorapidity distribution of all muons created in a shower which survived to the observation level. In KASCADE, where tracking is possible maximum to 160 m, the obtained distribution contains only a small fraction of all muons, where muons below $\eta = 4$ are nearly absent. As seen from Fig. 3 only in KASCADE-Grande one collects 90% of muons having parent hadrons of energy > 80 GeV and 75% of those with parent hadron energy < 80 GeV. So, high- and low-energy interaction model tests with muon pseudorapidity are possible rather only there.

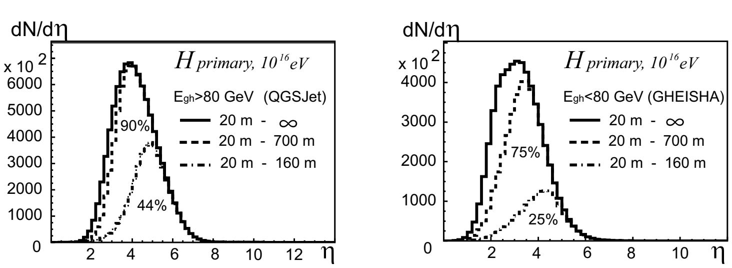

Figure 3. Distributions of muon pseudorapidities for different collecting distances for two ranges of grandmother hadron energies: $E_{gh} > 80$ GeV (left) and $E_{gh} < 80$ GeV (right)

3. Muon production heights

Muon production height distribution is showing sensitivity to the primary mass, as seen in Fig. 4. Muons from iron showers are generated higher than from proton ones. This feature allows to use a mean production height of muons as a mass sensitive parameter. Fig. 4 shows also, that the shape of the distribution for distance 20 -160 m (KASCADE case) has no pronounced peak. Comparing mean values is then prone to large systematic errors. Measuring muons up to larger distances, e.g. 20 - 700 m, one gets the distributions being close to the distribution for all muons in a shower. Dividing the full numbers of tracked muons into two groups, depending on their grandmother hadron energy, one finds also the possibility to disentangle between low- (GHEISHA) and high- (QGSJet) energy interaction models. As it is shown in Fig. 5, with the small collection distance muons created by hadrons of energy < 80 GeV (below this energy GHEISHA model is used in simulations) are nearly absent. Therefore, any discrepancy between data and simulations one can assign mostly to the high energy model. With the distance 20 - 700 m data contains large fraction of muons from both, low- and high-energy hadron regions. Therefore, low-energy interaction models can also be tested.

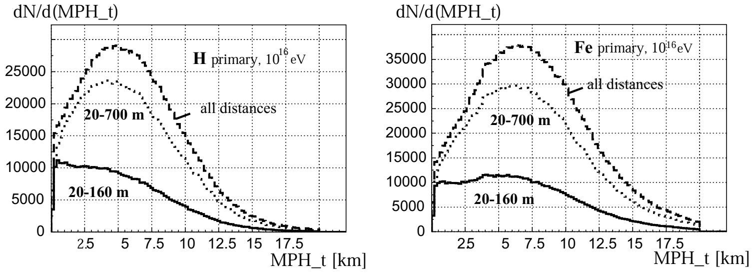

Figure 4. Distributions of true (MPH_t) muon production heights for different collecting distances for two primary particles: protons and iron nuclei.

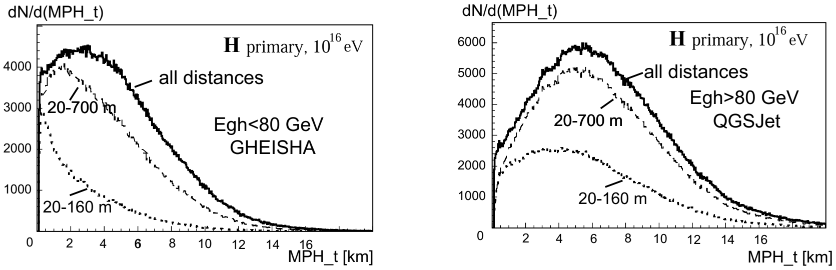

Figure 5. Distribution of true (MPH_t) muon production heights for two groups of grandmother hadron energies and three ranges of collecting distances.

Such separate tests of low- and high-energy hadronic interaction models are really of interest. In Fig. 6 the distribution of grandmother hadrons of muons which can be registered in the MTD as a function of their energy is shown for three collecting distances.

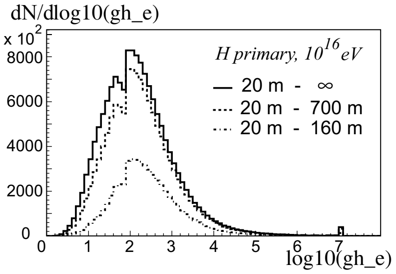

Figure 6. Distribution of "grandmother" hadron energies for muons reaching the MTD. Note the break at 80 GeV, where the interaction models change.

The break at 80 GeV, where the change of the interaction model takes place is clearly seen. It is more pronounced in KASCADE setup and indicates that number of muons produced according to both models do not match at the boundary energy.

4. Conclusions

It has been shown, that in KASCADE-Grande much larger part of longitudinal development of muon component in a shower is probed. Therefore, the composition study and model tests with the mean muon production heights and muon pseudorapidity distributions will give much more reliable results. In addition, tests of low-energy interaction models become now possible.

5. Acknowledgements

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