CALIBRATION OF THE KASCADE-GRANDE HADRON DETECTOR AT AN ACCELERATOR

S. Plewnia[1], Th. Berghöfer[1], H. Blümer[1], P. Buchholz[2], J. Engler[1], J.R. Hörandel[1], R. Lixandru[2], J. Milke[1], W. Walkowiak[2], J. Wochele[1]
[1] *Forschungszentrum and University of Karlsruhe, 76021 Karlsruhe, Germany*
[2] *University of Siegen, Emmy-Noether-Campus, 57072 Siegen, Germany*
plewnia@ik.fzk.de

Abstract An iron sampling calorimeter with warm-liquid ionization chambers has been tested at the CERN SPS in order to study the signal development and to verify the energy calibration of the hadron calorimeter in the KASCADE-Grande air shower experiment. The signal calibration of the detectors is discussed. First results of the analysis of the longitudinal shower development in the calorimeter are presented and compared with results from simulations based on the GEANT/ FLUKA code.

Keywords: air shower, hadron calorimeter

Introduction

The astrophysical interpretation of air shower data requires a precise understanding of the interaction processes in the atmosphere. The shower development is driven both, by the high-energy hadronic interactions and their particle production in the extreme kinematical forward region as well as by the low energy interactions influencing mostly the lateral particle density distributions. Unfortunatelly, both processes are only poorly known, e.g. (Drescher et al. 2004). In order to improve the contemporary understanding of hadronic interaction processes the multi detector set-up of the KASCADE experiment (Antoni et al. 2003) is operated, providing detailed insight into air shower development. Emphasize is given to the hadronic backbone of air showers which is investigated with a large hadron calorimeter.

The detector (Engler et al. 1999) is an iron sampling calorimeter with the lateral dimensions 16×20 m^2. It consists of 9 layers of ionization chambers and a layer of plastic scintillation counters to provide fast trigger signals interspaced between 4000 t iron absorber. A lead filter above

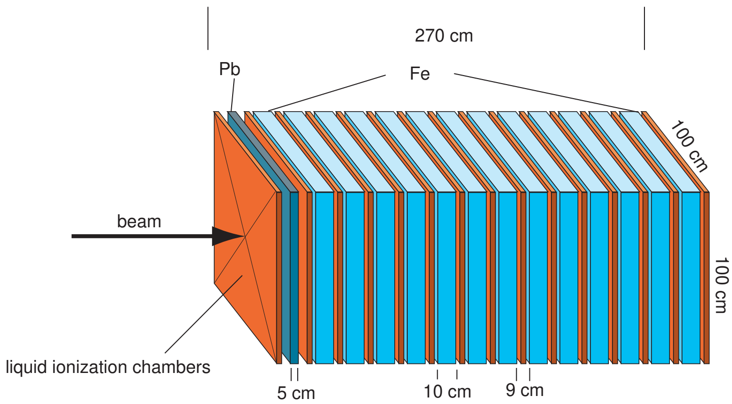

Figure 1. The calorimeter set-up at the CERN SPS secondary beam line.

the iron absorber serves to suppress the electromagnetic component of air showers.

The energy calibration of the ionization chambers, filled with a "warm liquid" (Engler 1996), is based on measurements with single muons (Engler et al. 1999). The conversion (Milke et al. 2000) from energy measured in the calorimeter to the energy of the incident hadron is based on simulations with the GEANT package (GEANT 1993) using the FLUKA92 code (Aarnio et al. 1990). The signal damping of strongly ionizing particles in liquid ionization chambers is taken into account in the code, based on measurements at the Karlsruhe cyclotron (Engler et al. 1992, 1993).

Goal of the present investigations is to study the signal development in the chambers for the highest accelerator energies available to complement earlier measurements at lower energies (Engler et al. 1992) and to check the Monte-Carlo based energy calibration applied so far. First results of the analysis are presented.

1. Experimental Set-Up

A set-up similar to the longitudinal structure of the KASCADE-Grande calorimeter has been chosen as sketched in Fig. 1. 60 ionization chambers are arranged in 15 layers (each divided in 16 segments), forming a detector with 1 m^2 active area. The absorber consists of a lead layer (5 cm thick) followed by 13 layers of iron slabs, each 10 cm thick, corresponding to 8.2 hadronic interaction lengths. The read-out electronics is identical to the one used in the KASCADE-Grande calorimeter (Engler et al. 1999). Two plastic scintillators where used in coincidence in

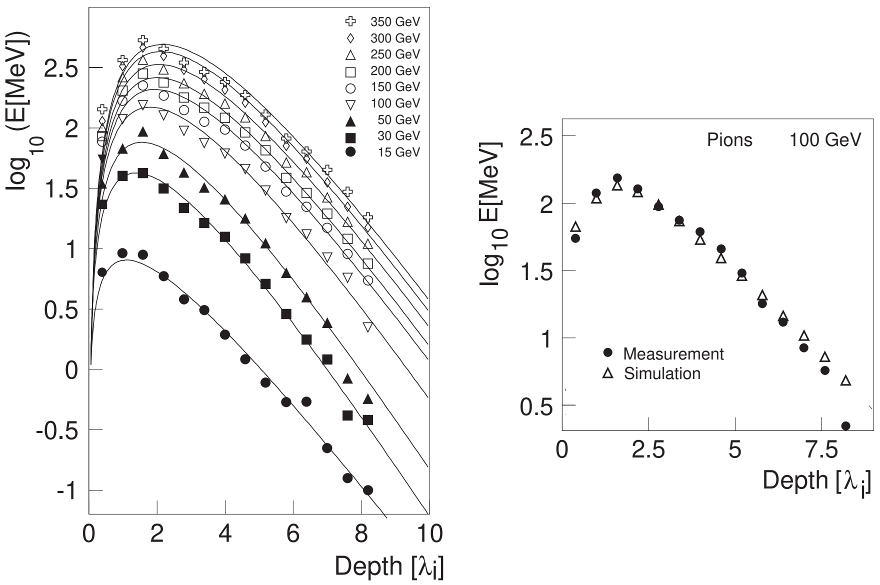

Figure 2. Energy deposition in the calorimeter as function of depth in hadronic interaction lengths as measured for pions/protons with energies from 15 to 350 GeV (left) and measurements for 100 GeV compared to simulations with GEANT/FLUKA (right).

front of the calorimeter as trigger, a third one was installed behind the detector to select muons.

The calorimeter was set up at the H4 beamline of the Super Proton Synchrotron (SPS) at CERN and was tested with beams of protons, pions, electrons, and muons with energies between 15 and 350 GeV (Plewnia et al 2004). Protons and pions could not be distinguished, they are treated as hadrons, as in the air shower experiment. To identify electrons, a lead plate (15 mm thick, corresponding to three radiation lengths) has been placed in front of the first layer of ionization chambers and the signal in this chambers was used to select primary electrons. Contaminations of muons and pions in the "electron" beam could be efficiently rejected.

2. Results

Firstly, the calibration of the individual chambers has been verified with muon runs. The charge yield obtained agrees well with the cosmic-ray muon calibrations performed several years ago. This is an indication for the long-term signal stability of these detectors.

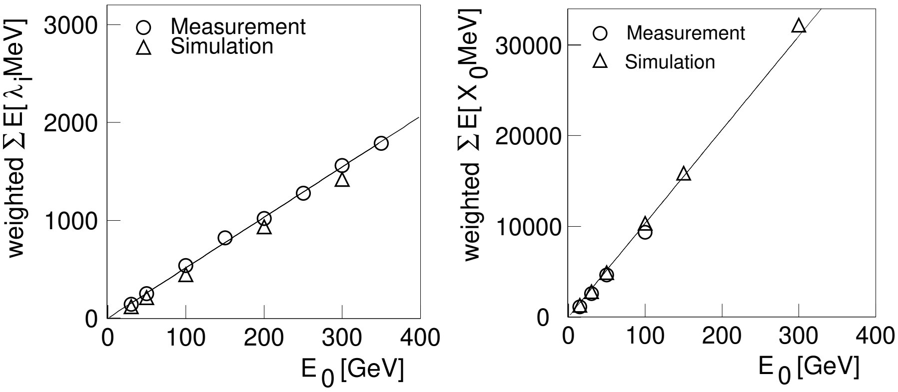

Figure 3. Weighted energy sum in the calorimeter as function of the incident particles energy for hadrons (left) and electrons (right). Measured values are compared with GEANT/FLUKA simulations.

The response of the detector for hadrons from 15 to 350 GeV is depicted in Fig. 2 (*left*), where the energy deposition in the ionization chambers is plotted as function of the depth in the calorimeter, measured in hadronic interaction lengths λ_i. To guide the eye, the measurements are parameterized according to

$$E_{dep}(x) = A\,x^B\,e^{-Cx} \tag{1}$$

giving the energy deposition as function of depth x in the detector. This function has been derived for electromagnetic showers, but apparently, describes hadronic cascades as well. The showers penetrate deeper into the calorimeter with increasing energy, and the maxima shift proportional to $\ln(E)$ as expected.

The measurements are compared to results from simulations in Fig. 2 (*right*) for pions of 100 GeV. The preliminary results indicate a good agreement between data and calculations. This verifies the description of signal generation for ionization chambers in the GEANT code.

The integral under the curves shown in Fig. 2 is expected to be proportional to the incident particle energy. This weighted energy sum (the energy measured in the chambers is weighted with the amount of absorber in front of each layer of ionization chambers) is shown in Fig. 3 as function of the incident particle energy for hadrons (*left*) and electrons (*right*). One recognizes a linear correlation as indicated by the straight lines in both diagrams. Also results of GEANT/FLUKA calculations are shown, which are found to agree with the measurements.

The RMS value of the frequency distribution of the weighted energy sum for a particular energy is taken as the energy resolution of the calorimeter. The present results can be approximated by

$$\frac{\sigma(E)}{E} = \frac{130\%}{\sqrt{E\ [\mathrm{GeV}]}} + 14\% \quad . \tag{2}$$

A good value for a large-area detector in a cosmic-ray experiment, which measures hadrons with energies up to beyond 10 TeV.

3. Conclusion

A hadron sampling calorimeter equipped with warm-liquid ionization chambers has been tested at a CERN SPS test beam in order to verify the energy calibration of the large hadron calorimeter in the KASCADE-Grande experiment. The longitudinal development of the energy deposition of hadrons and electrons in the calorimeter has been investigated. First results are in agreement with Monte Carlo calculations based on GEANT/FLUKA. More detailed analyses are in progress. They will increase the precision of the KASCADE data, and help to improve the understanding of high-energy interactions, necessary for an astrophysical interpretation of air shower data.

Acknowledgments

We would like to thank all colleagues at CERN who made this work possible, in particular I. Efthymiopoulos, M. Hauschild, and L. Linssen. We acknowledge the valuable technical contributions by N. Bechtold, H. Bolz, W. Paulus, and M. Riegel of Forschungszentrum Karlsruhe as well as the assistance of N.O. Hashim from Siegen University during data acquisition.

References

Antoni T. et al. (2003), *Nucl. Instr. and Meth.* A **513**, 490.

Aarnio P.A. et al. (1990), Fluka user's guide. Technical Report TIS-RP-190, CERN.

Drescher H.J. et al. (2004), *Astrop. Phys.* **21**, 87.

Engler J. et al. (1992), *Nucl. Instr. and Meth.* A **311**, 479.

Engler J. et al. (1992), *Nucl. Instr. and Meth.* A **320**, 460.

Engler J. et al. (1993), *Nucl. Instr. and Meth.* A **327**, 128.

Engler J. (1996), *J. Phys. G: Nucl. Part. Phys.* **22**, 1.

Engler J. et al. (1999), *Nucl. Instr. and Meth.* A **427**, 528.

GEANT 3.15 (1993), Detector Description and Simulation Tool, CERN Program Library Long Writeup W5013, CERN.

Milke J. et al. (2000), in Calorimetry in High Energy Physics, G. Barreira, B. Tome, Eds., World Scientific p. 803, ISBN 981-02-4304-9

Plewnia S. et al. (2004), in Calometry in High Energy Physics, World Scientific, in press.