Studies of the relative arrival time distributions of the electromagnetic and the muon EAS component in the KASCADE Experiment

R. Haeusler[1], **T. Antoni**[1], **W.D. Apel**[1], **A.F. Badea**[2], **K. Bekk**[1], **K. Bernlöhr**[1], **E. Bollmann**[1], **H. Bozdog**[2], **I.M. Brancus**[2], **A. Chilingarian**[3], **K. Daumiller**[4], **P. Doll**[1], **J. Engler**[1], **F. Feßler**[1], **M. Föller**[1] **H.J. Gils**[1], **R. Glasstetter**[4], **W. Hafemann**[1*], **A. Haungs**[1], **D. Heck**[1], **T. Holst**[1], **J.R. Hörandel**[1] **K.-H. Kampert**[1,4], **H. Keim**[1], **J. Kempa**[5], **H.O. Klages**[1], **J. Knapp**[4] **H.J. Mathes**[1], **H.J. Mayer**[1], **J. Milke**[1], **D. Mühlenberg**[1], **J. Oehlschläger**[1], **M. Petcu**[2], **U. Raidt**[1] **H. Rebel**[1], **M. Risse**[1], **M. Roth**[1], **G. Schatz**[1] **F.K. Schmidt**[4], **T. Thouw**[1], **H. Ulrich**[1], **A. Vardanyan**[3], **B. Vulpescu**[2], **J. Weber**[4], **J. Wentz**[1], **T. Wibig**[5], **T. Wiegert**[1], **D. Wochele**[1], **J. Wochele**[1], **J. Zabierowski**[6], **S. Zagromski**[1],

[1]*Forschungszentrum Karlsruhe, Institut für Kernphysik, D-76021 Karlsruhe, Germany*
[2]*Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[3]*Cosmic Ray Division, Yerevan Physics Institute, Yerevan, Armenia*
[4] *Institut für Experimentelle Kernphysik, University of Karlsruhe, Germany*
[5]*University of Lodz, Institute of Physics, Lodz, Poland*
[6] *Soltan Institute for Nuclear Studies, Lodz, Poland*

Abstract

Arrival time distributions of EAS muons and their differences from the arrival times of the electronmagnetic component, has been measured with the timing facilities of the central detector of the KASCADE experiment. The results have been analysed in terms of CORSIKA Monte-Carlo simulations of the EAS development, based on the QGSJET model.

1 Introductions:

Arrival time distributions of EAS particles reflect the longitudinal EAS development and provide information about the interactions driving the shower cascade. In particular, the muon component has been studied under these aspects. EAS Monte-Carlo simulations by use of the CORSIKA program (Heck et al., 1998) predict differences of the arrival time distributions of the electromagnetic and muon components, specifically showing, that the muon component arrives earlier with respect to the arrival time τ_{cor} of the shower core. Fig. 1 displays the time profile: the mean of the arrival times vs. the distance from the shower axis of the electromagnetic and muon component :

$$\langle \tau_{e,\mu} \rangle = \frac{1}{N} \cdot \sum_{i=1}^{N} \tau_{e,\mu}^{i} - \tau_{cor}^{i} \qquad (1)$$

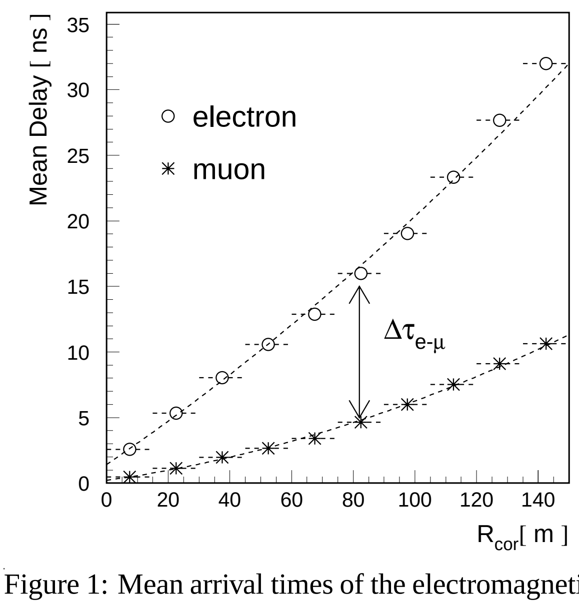

Figure 1: Mean arrival times of the electromagnetic and muon component for simulated EAS

The figure reproduces also the known feature (Ambrosio et al.; 1997, Brancus et al., 1998) that the time profile of the electromagnetic component varies by a steeper increase with the core distance, since the electrons

[*]corresponding author; e-mail: hafemann@ik3.fzk.de

arriving at the observation level are generally produced in deeper layers of the atmosphere than the observed muons. This fact leads also to the larger delay in the arrival of the electromagnetic component. Though there are practical difficulties to determine the arrival time of the shower core with sufficient accuracy, the difference $\Delta\tau_{e-\mu} = \langle\tau_e\rangle - \langle\tau_\mu\rangle$ is an experimentally accessible quantity. In the present contribution we report about measurements of the relative time profile $\Delta\tau_{e-\mu}(R_{cor})$ for two different energy thresholds of the detected muons. The results are compared with predictions of Monte-Carlo simulations.

2 Experimental setup and general procedures:

For the measurements the timing and particle detection facilities of the KASCADE central detector (Klages et al., 1997) are used: the so called topcluster, which is an array of 50 scintillation detectors placed on top of the central KASCADE detector (active area: 22.8 m^2 which correspond to an active area of 7.5%), the trigger plane, which is the third active layer of the calorimeter, an eye of 456 scintillation detectors (active area: 208 m^2 which correspond to an active area of 65%) and finally a setup of position sensitive multiwire proportional chambers (MWPC) installed below the calorimeter. The energy detection threshold for muons observed with the trigger plane is 0.4 GeV, while with the MWPC muons with $E_\mu > 2.0$ GeV can be filtered out.

The arrival times measured with the topcluster and the triggerlayer have to be corrected due to two experimental effects of the timing detectors:

(i) the timing signals are affected by the actual energy deposit due to the light production and the discriminator threshold (energy deposit effect),

(ii) the timing signal depends from the number of particles simultaneously hitting the scintillator detectors (multiplicity effect).

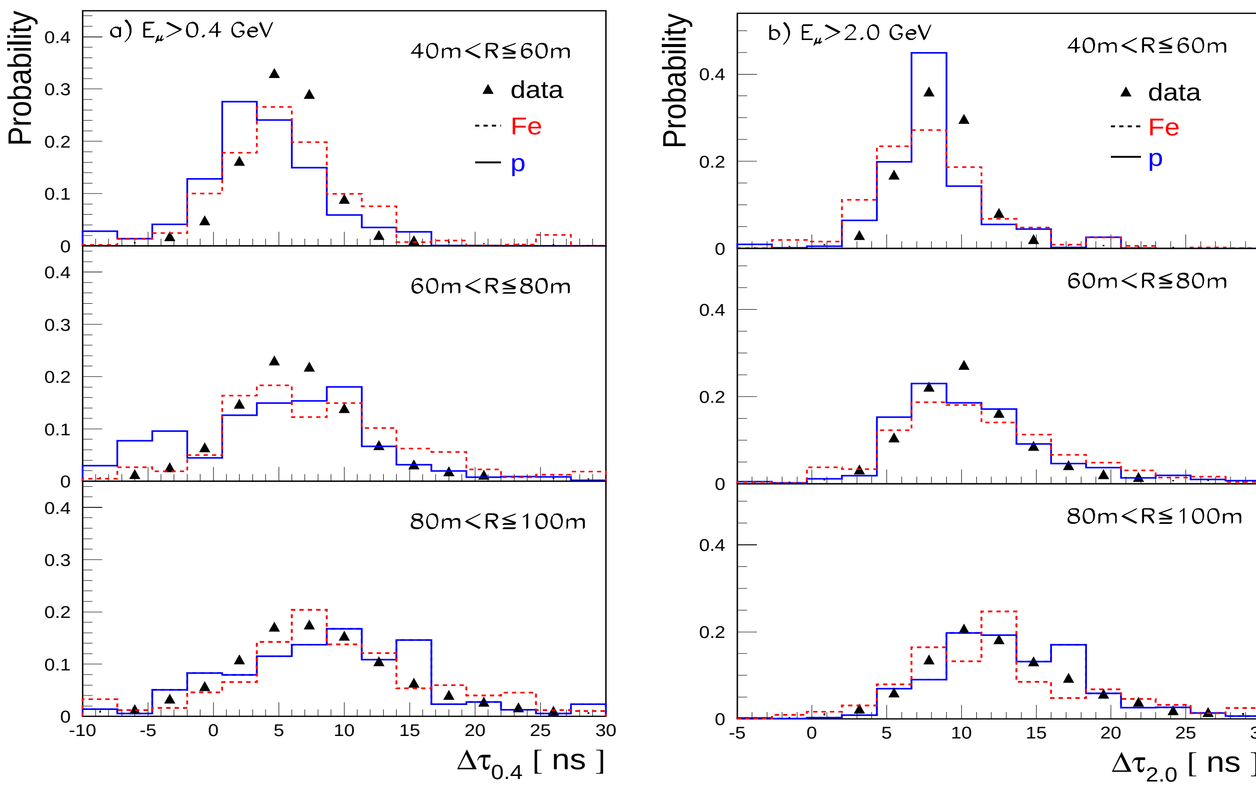

Figure 2: Distributions of relative arrival times of the electromagnetic and muon components (of two different muon detection thresholds) as compared with EAS simulation predictions

Therefore these effects have to be corrected by procedures based on realistic detector simulations. This is particularly nescessary for the topcluster detectors. For defining the electron component, as detected with the topcluster, the absence of a coincidence with events in the triggerlayer or MWPC is required. Detector simulations show that with this condition 70% of muon events in the topcluster are removed. This rate corresponds to the limit given by the active area of the trigger plane.

3 Comparison with predictions of Monte-Carlo EAS simulations:

The experimental data, accumulated in a period of 10 months comprise c. 200.000 EAS events with the requirement that at least 3 timing detectors must have fired and with the reconstructed zenith angle of EAS incidence of $15^\circ < \theta \leq 20^\circ$. Results of the measurements are shown in Figs. 2 and 3 and compared to simulation results in different ranges of the energy indicative muon number N_μ^{tr}. It has been shown that for the KASCADE case the number of muons N_μ^{tr} summed up between 40 and 200 m from the shower center is an energy identifier, nearly independent from the mass of the primary. The actual simulation calculations (based on QGSJET model) cover an energy range of $5 \cdot 10^{14} - 1 \cdot 10^{16}$ eV (divided in 5 overlapping energy bins for three mass groups: H = protons, O = CNO group, Fe = heavy group) for an energy distribution of a spectral index of -2.7. They comprise a set of 2000 showers for each case. The response of the KASCADE detector system and the timing qualities have been simulated using the CRES programm, dedicately developed by the KASCADE group on basis of the GEANT code.

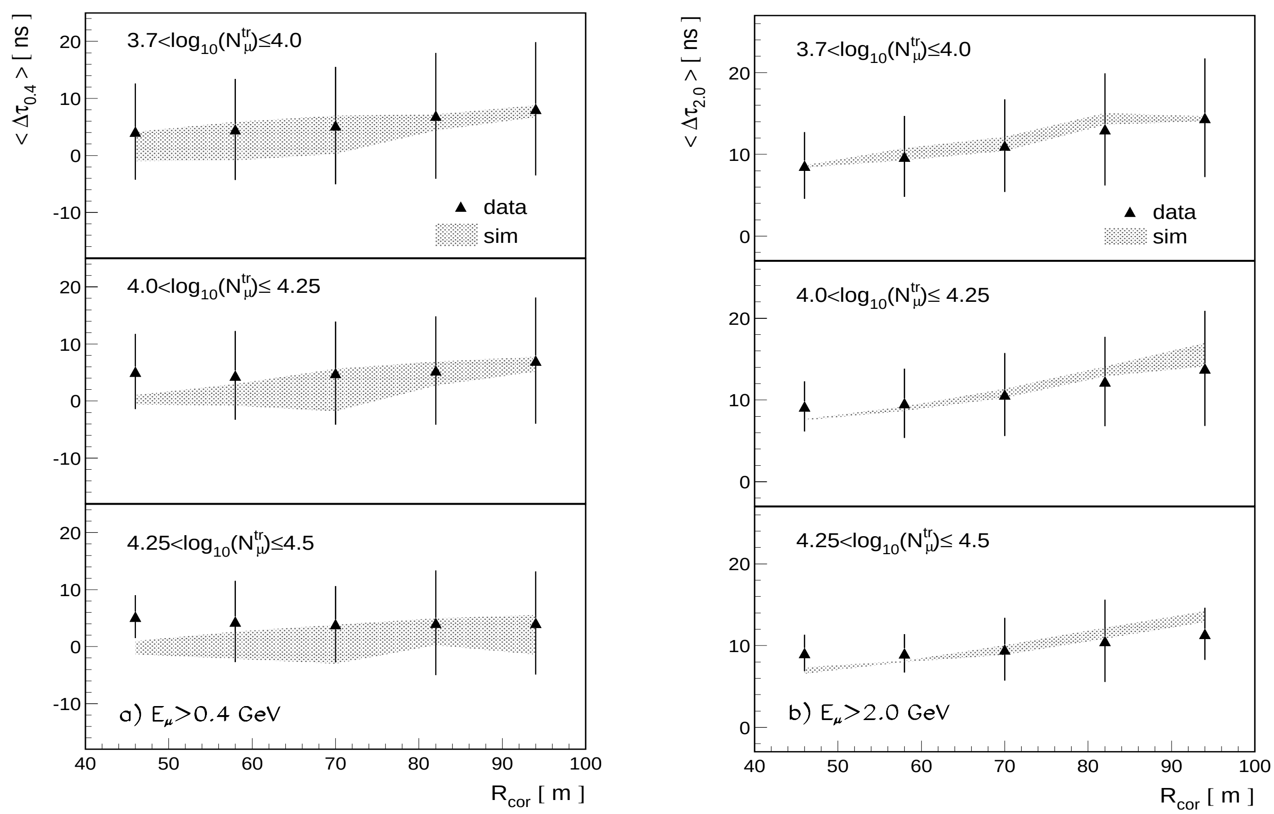

Figure 3: Comparison of the profiles of relativ arrival times of the electromagnetic and muon component with the predictions for simulated showers.

Fig. 2 displays such distributions of $\Delta\tau_{0.4}$ and of $\Delta\tau_{2.0}$, for $\log_{10} N_\mu^{tr} > 3.7$ (corresponding to a primary energy of about $E_{prim} > 2 \cdot 10^{15}$ eV) and for different distances from the EAS core. We notice the good agreement of the experimental data with the simulations, but significant differences between the different primaries in the relative arrival time distributions are not observed.

Fig. 3 presents the relative time profiles of $\Delta\tau_{0.4}$ and of $\Delta\tau_{2.0}$ for different $\log_{10} N_{\mu}^{tr}$ ranges. The data are compared with simulation results (which cover the range of proton and iron induced showers). For the low energy muon case there appears some slight disagreement. This might be an indication that at small distances, where the particle density is large, some problems with the corrections do remain.

4 Concluding remarks:

The present experimental studies of the relative arrival times of the EAS muon and electromagnetic component, give evidence for the different time profiles of the two EAS components and confirm former theoretical conjectures. The exploratory comparisons of the data with Monte-Carlo simulations exhibit a remarkably good agreement, but with insignificant discrimination power for the mass of the cosmic ray primary.

5 Acknowledgements:

The work has been partly supported by a grant of the Romanian National Agency for Science, Research and Technology as well as by a research grant (No.94964) of the Armenian Government and by the ISTC project A116. The collaborating group of the Cosmic Ray Division of the Soltan Institute of Nuclear Studies in Lodz and of the University of Lodz is supported by the Polish State Committee for Scientific Research (Grant No. 2 P03B 160 12). The KASCADE collaboration work is embedded in the frame of scientific-technical cooperation (WTZ) projects between Germany and Romania (No.RUM-014-97), Armenia (No. 002-98) and Poland (No.92-94).

References

Ambrosio, M. et al., 1997, Astropart. Phys., 7, 329
Brancus, I.M. et al., 1998, FZKA-Report 6151, (Forschungszentrum Karlsruhe)
Heck, D. et al., 1998, FZKA-Report 6019, (Forschungszentrum Karlsruhe)
Klages, H.O. et al., 1997, Nucl. Phys. B (Proc.Suppl.), 52B, 92