Estimation of the chemical composition in the "knee" region from the muon/electron ratio in EAS

J.H.Weber[1] for the KASCADE Collaboration

[1] *Forschungszentrum Karlsruhe, Postfach 3640, 76021 Karlsruhe, Germany*

Abstract
New data on the muon/electron ratio derived from the KASCADE extensive air shower experiment are presented. This ratio is known to be the most sensitive parameter in the determination of the mass of the primary particle when using ground array data. The particle numbers are measured from the KASCADE array comprising 500 m^2 of e/γ- and 620 m^2 of μ- detectors. The primary mass is inferred on an event-by-event basis by comparing the experimental data to corresponding EAS simulations. We observe a change towards a heavier composition with increasing energy above the knee. The sensitivity of this result to the specific hadronic interaction model employed (e.g. VENUS and QGSJET) is discussed.

Experimental setup and observables.
The KASCADE detector array measures the lateral electron and muon distributions in extensive air showers. One aim is to obtain the electron and muon numbers that give important clues to mass and energy of the primary particle. The array comprises about 500 m^2 of e/γ- and 620 m^2 of μ- detectors which are housed in 252 detector stations and are arranged in a grid of 200 x 200 m^2 size. They are described in more detail elsewhere (Klages,1997a,1997b). The muon detectors are positioned directly below the e/γ- detectors and are shielded by slabs of lead and iron corresponding to 20 radiation lenghts in total. This imposes an energy threshold of about 300 MeV to muons. Because of the geometrical arrangement many muons will deposit energy in the e/γ- detector before entering the muon detector. On the other hand, energetic photons or electrons may penetrate the shielding, thereby faking a muon signal. Hadrons will also deposit energy in both types of detectors. These effects were corrected for by an iterative method using the energy deposits in the detectors and applying results of simulations: The mutual deposits of electrons, photons and hadrons in the e/γ- and μ- detectors were obtained by extensive simulations with the CORSIKA event generator (Heck,1998) taking into account the response of the KASCADE experiment. The produced simulation data set includes different primary masses, zenith angles and covers a wide energy range. With these simulations lateral energy correction functions were calculated to convert energy deposits into particle numbers.

Determination of electron and muon numbers.
Data processing and shower analysis is performed in a three-step procedure. In a first step the shower core and shower direction are reconstructed to apply the lateral correction functions and to convert the energy deposits into particles. A rough

estimation for the electron and muon numbers is done by parametrisation of the total energy deposits. After iterative corrections for electromagnetic punch through in the μ detectors and the muonic energy deposit in the e/γ- detectors the electron and muon densities are both fitted by a NKG-function. The electrons are fitted with a radius parameter of 89 m, the muon fit function uses a fixed slope parameter, calculated from electron number and zenith angle, and a radius parameter of 420 m in a fit range of 40-200 m. The lower radius cut is due to uncertainties of hadronic and electromagnetic punch through, that can deposit even more energy than the muons at distances close to the shower core. The upper cut reflects the limits of geometrical acceptance. In a final level a subsequent NKG fit using the fitted muon distributions as a background function provides the final electron numbers. This fitted function is used to correct the energy deposits in the μ- detectors. The muon densities are then fitted with a NKG function again. By integrating this function from zero to infinity, we obtain the muon size N_μ. Alternatively, an integration within the range of the fits gives the truncated muon size N_μ^{tr}, which is approximately a factor of 3 smaller than the total muon size. This observable has the advantage to be free of systematical errors caused by extrapolations outside the experimental acceptance and, according to simulations, gives a good estimation of the primary energy. The systematic uncertainties of the reconstructed particle numbers are about 5% and its behaviour is well understood. The reconstruction accuracy is dominated by sampling fluctuations and is about 5% for the electron size and 10% for the muon size at the knee.

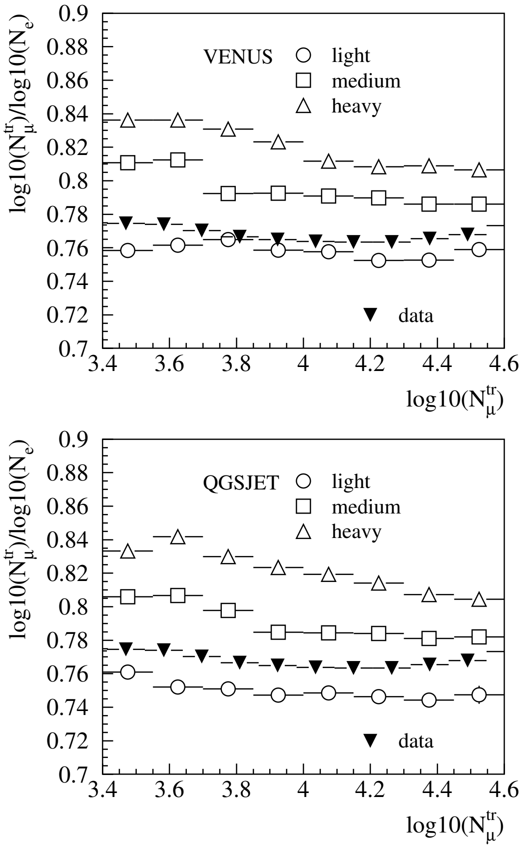

Fig. 1: the muon/electron ratio as a function of truncated muon size.

The muon/electron ratio.

The data presented here were taken out of $\sim 3 \cdot 10^7$ reconstructed showers. The following principal cuts were applied to the reconstructed events in order to ensure reliable reconstruction results:

The reconstructed shower core was within a radius of 91 m from the center of the array and the accepted shower age was restricted from $0.2 \leq \text{age} \leq 2$. An energy threshold of approximately 10^{15} eV guarantees 100% trigger and reconstruction efficiency for proton and iron showers. The data was subdivided into narrow zenith angle bins. The zenith angle of the data shown in Figure 1 was restricted to $18^o \leq \theta \leq 26^o$. About 411.000 showers survived these cut. Figure 1 shows the muon/electron ratio as a function of the truncated muon size for these showers. Simulated results for light masses (represented by protons and helium), medium masses (oxygen and silicium) and the heavy masses (iron) are shown for comparision at 22^o. This set consists of 5000 showers for each of these groups and the two models simulated with an energy slope of E^{-1}. These showers were finally analysed with the reconstruction code used for the raw data and given a weight of $E^{-1.7}$ to be comparable with data.

Figure 1 a) reveals the prediction of simulations for the VENUS model, Figure 1 b) shows the QGSJET prediction. The simulations show the very good ability to distinguish between the mass groups. Both models show a good compability to the data and both show in comparision to the data a mild change towards a heavier composition with increasing energy above $\log N_\mu^{tr} \sim 4.2$. This value corresponds to the knee position in electron size spectra analysed by (Glasstetter,1997). The difference between VENUS and QGSJET predictions comes mainly from the predictions for the light particles, so when looking only at the mean muon/electron ratio the VENUS model may predict more light particles than the QGSJET model. A more quantitative analysis was done with the distributions of the muon/electron ratio in $\log N_\mu^{tr}$ bins as explained below.

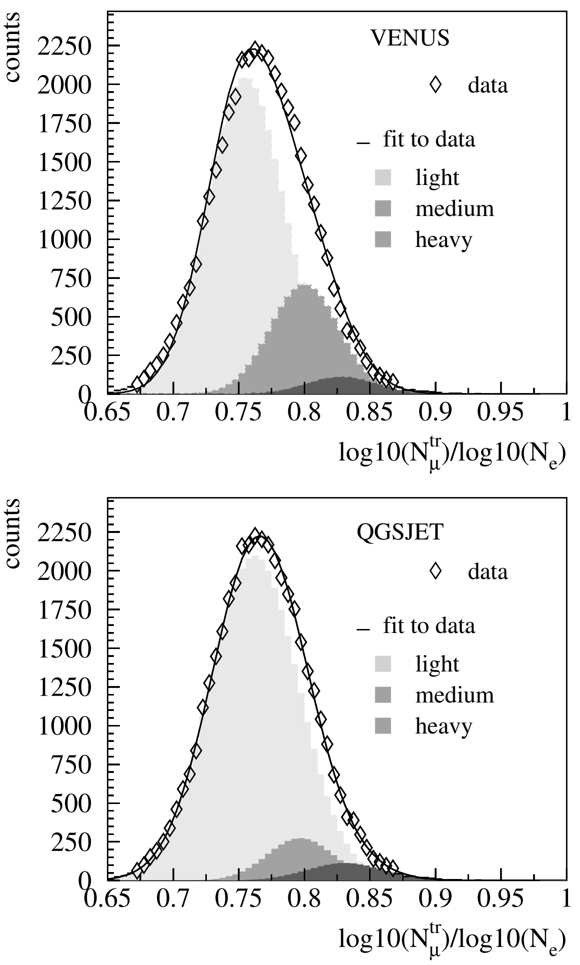

Fig. 2: the muon/electron ratio distributions for $3.85 \leq logN_m u^{tr} \leq 4$.

The estimation of composition from the muon/electron ratio.

The data was subdivided into 8 $\log N_\mu^{tr}$ bins in a range of $3.4 \leq \log N_\mu^{tr} \leq 4.6$ corresponding to an energy range of $\sim 8 \cdot 10^{14}$ eV$\leq E_0 \leq 10^{16}$eV. A five-parameter maximum likelihood fit was performed to the muon/electron ratio distributions within these bins. The fit function was given by the sum of the five simulated element distributions which where approximated by Gaussians. The fitted parameters are the weights of these distributions. The results for helium and proton were added to give the weight of the light group, the medium group was obtained with the results from oxygen and silicon. Figure 2 demonstrates the quality of the fit for one bin ($3.85 \leq \log N_\mu^{tr} \leq 4.$). The experimental data can be described reasonably well by both VENUS and QGSJET simulations. There is no severe shift to the left or the right side of the data distribution. The different results of the fits are due to larger shower fluctuations predicted by the QGSJET model for the light mass group (at this bin).

Figure 3 a) shows the fit results for all 8 bins for the VENUS prediction: A mild trend to a lighter composition up to the knee and then an increasing part of the medium and heavy masses can be observed. Using the QGSJET model (Figure 3 b) the composition is dominated by light masses before the knee but the behaviour after the knee looks qualitatively similar to the VENUS results. The lowest energy bin may be affected by efficiency effects.

Figure 4 shows the mean logarithmic mass as a function of the reconstructed primary energy.The energy scale is obtained with the detailed composition results (5 elements) and the model dependent correlations between primary energy and the truncated muon size. The errors bars include the fit errors and the uncertainties of the Gaussian parametrisations to the simulated distributions. A qualitatively similar result is observed with both models: The mean logarithmic mass shows no significant change up to an energy $E_0 \sim 3 \cdot 10^{15}$eV. A trend to a heavier composition is observed with increasing energy.

A fit to the simulated showers that have been used for the parametrisation of the Gaussian functions shows no systematical bias of the mean mass. The careful study of the appropriate parametrisation of the simulated distributions and resulting systematic errors will be continued.

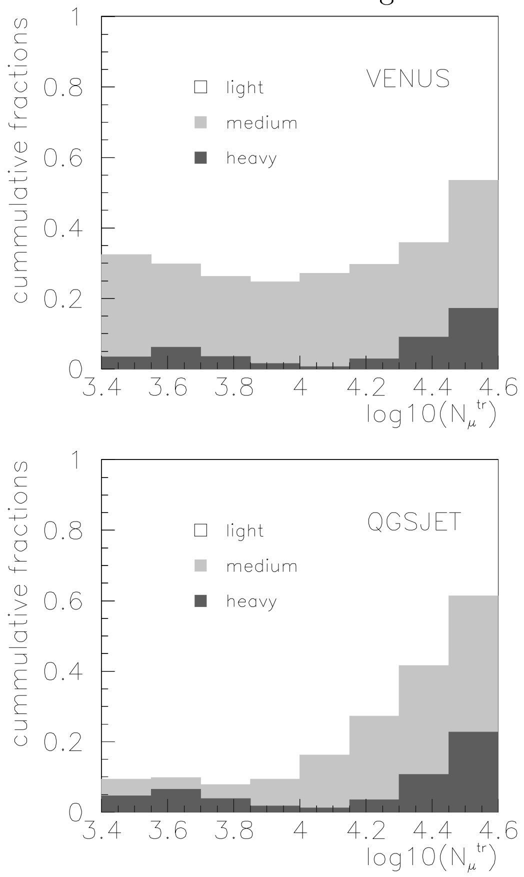

Fig. 3: the fractions of three mass-groups as function of truncated muon size for two interaction models.

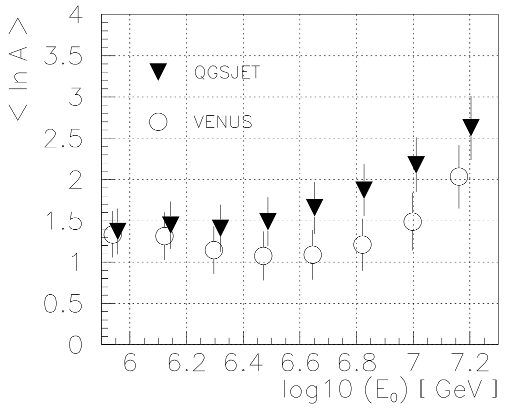

Fig. 4: the mean logarithmic mass as function of primary energy.

References

R. Glasstetter et al., *25th ICRC.* (1997) 157–160

D. Heck, J. Knapp et al., FZKA 6019 Forschungszentrum Karlsruhe (1998)

H.O. Klages et al., *Nucl. Phys. B (Proc. Suppl.)* 52B (1997) 92