MEASUREMENT AND RECONSTRUCTION OF EXTENSIVE AIR SHOWERS WITH THE KASCADE FIELD ARRAY

G. MAIER[B]*, T. ANTONI[A], W.D. APEL[B], F. BADEA[A,1], K. BEKK[B], A. BERCUCI[B,1], H. BLÜMER[B,A], H. BOZDOG[B], I.M. BRANCUS[C], C. BÜTTNER[A], A. CHILINGARIAN[D], K. DAUMILLER[A], P. DOLL[B], J. ENGLER[B], F. FEßLER[A], H.J. GILS[B], R. GLASSTETTER[A], R. HAEUSLER[A], A. HAUNGS[B], D. HECK[B], J.R. HÖRANDEL[A], A. IWAN[A,2], K.-H. KAMPERT[A,B], H.O. KLAGES[B], H.J. MATHES[B], H.J. MAYER[B], J. MILKE[A], M. MÜLLER[B], R. OBENLAND[B], J. OEHLSCHLÄGER[B], S. OSTAPCHENKO[A,3], M. PETCU[C], H. REBEL[B], M. RISSE[B], M. ROTH[B], G. SCHATZ[B], H. SCHIELER[B], J. SCHOLZ[B], T. THOUW[B], H. ULRICH[A], J.H. WEBER[A], A. WEINDL[B], J. WENTZ[B], J. WOCHELE[B], J. ZABIEROWSKI[E]

[a] Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76021 Karlsruhe, Germany,
[b] Institut für Kernphysik, Forschungszentrum Karlsruhe, 76021 Karlsruhe, Germany
[c] National Institute of Physics and Nuclear Engineering, 7690 Bucharest, Romania
[d] Cosmic Ray Division, Yerevan Physics Institute, Yerevan 36, Armenia
[e] Soltan Institute for Nuclear Studies, 90950 Lodz, Poland

[1] on leave of absence from National Institute of Physics and Nuclear Engineering, 7690 Bucharest, Romania
[2] on leave of absence from University of Lodz, 90236 Lodz, Poland
[3] on leave of absence from Moscow State University 119899 Moscow, Russia

The main aim of the KASCADE experiment is the determination of the primary energy spectrum and chemical composition of cosmic rays through the measurement of extensive air showers at energies around $4 \cdot 10^{15}$eV, the so called knee region. An overview over the measurement and reconstruction procedures of the large field array is presented in this proceeding.

*corresponding author; gernot.maier@ik.fzk.de, phone +49 7247 824174

1. Introduction

The energy spectrum of cosmic rays (CR) extends over at least 12 decades in energy and 30 decades in intensity. It follows a power law with only few features, the most prominent is a change of the spectral index at about 4 PeV, the so called *knee*. Little is known about the origin of the knee.This is mainly due to the very low fluxes of CR at this energies of about 1 particle per square meter and year. Direct measurements, usually with balloons and satellites, are impossible at these low fluxes. CR are therefore studied at ground level with large detector systems via their secondary particles in extensive air showers (EAS).

An EAS induced by a primary particle with an energy of i.e. 1 PeV consists at sea level typically of about 10^6particles, mainly photons and electrons but also muons and hadrons. The secondary particles form a shower disk with a thickness of typically 1 m in the center with a lateral extension of up to few hundred meters. In a simplified picture, the number of muons of an EAS is an estimator of the energy of the primary particles, the number of electrons is more sensitive to its mass. Detailed measurements of many different components of individual EAS allow the reconstruction of the primary energy spectra and chemical composition of cosmic rays.

2. The KASCADE experiment

The KASCADE[a][1] (Karlsruhe Shower Core and Array Detector) experiment is located at the Forschungszentrum Karlsruhe, Germany (110 m a.s.l.). It consists of three major detector systems (see Fig. 1), the 200x200 m^2 field array with electron and muon counters, a central detector with a large hadronic calorimeter and muon detectors with different threshold energies and a muon tracking detector in an underground tunnel. Lateral distributions and time profiles for all particle types as well as incident angles of individual high energetic muons or hadrons and the energies of the hadrons are measured. This gives a very complete picture of air showers and in combination with detailed EAS simulations, answers to the main scientific questions of KASCADE, the energy spectra and chemical compositions of cosmic rays can be expected.

This paper will focus on the field array. More details about the other components of KASCADE can be found in Ref.[1].

[a] WWW pages of KASCADE: http://www-ik.fzk.de/KASCADE_home.html

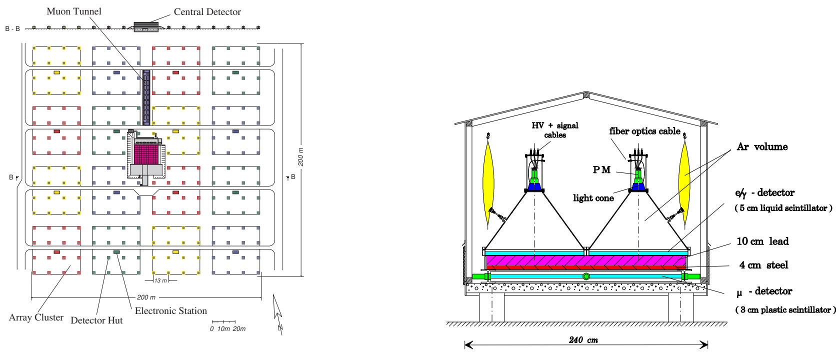

Figure 1. Schematic layout of the KASCADE experiment (left) and KASCADE field array detector station (right)

3. Field Array

The purpose of the field array is the reconstruction of the incident angle, shower core, and electron and muon numbers of individual air showers.

The 252 detector stations of the field array are arranged on a rectangular grid of 13 m spacing (Fig. 1, left). The stations are organized in 16 electronically independent clusters each with 16 stations in the 12 outer cluster and 15 stations in the four inner clusters.

The stations (Fig. 1, right) contain four detectors in the four inner resp. two in the 12 outer clusters filled with 5 cm thick custom made liquid scintillator (PMP) with an area of 0.8 m^2 each for the electromagnetic component. The energy resolution of the detectors at 12 MeV (energy deposit of m.i.p) is about 12%, the time resolution 0.8 nsec. Energy deposits equivalent to 1250 m.i.p. are detected linearly with a threshold of 0.25 m.i.p. (about 3 MeV). The 192 stations in the 12 outer clusters are additionally equipped with four sheets of plastic scintillator detectors, 90 x 90 x 3 cm^3 each. These detectors, mounted below an absorber of 10 cm lead and 4 cm iron which corresponds to more than 20 radiation lengths and to a muon threshold of 0.3 GeV, are used to measure the muonic component of an air shower. The total detector area is about 490 m^2 for the electromagnetic and 622 m^2 for muon detectors. The energy sum, the arrival time of the first shower particle in a station and the hit detectors are read out individually for the muon and e/γ detectors. In addition, 16 Flash ADCs are installed in one cluster to measure more detailed the time profile of electrons and muons in the shower disk.

The present trigger conditions are a detector multiplicity of 10/20 out of 32/60 e/γ detectors fired in at least one of the outer/inner clusters. This results in a 3 Hz trigger rate and a threshold in primary energy of about 0.6 PeV for proton and 0.8 PeV for iron showers.

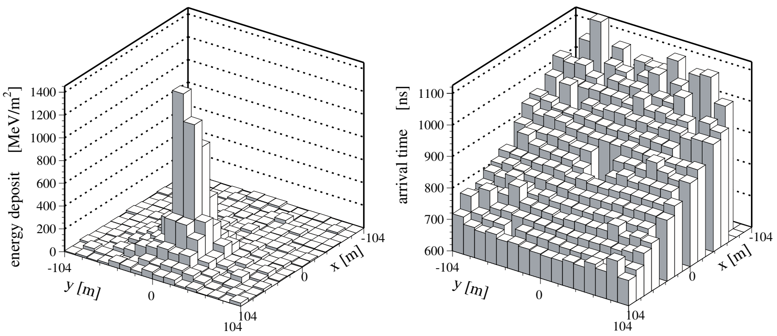

Figure 2. Energy deposits (left) and arrival times (right) of the particles in an air shower measured by the e/γ detectors. The reconstructed electron number is about 258000 electrons, the shower core is at x = 40 m, y = 0.6m and the zenith angle 32 degrees.

4. Reconstruction of extensive air showers

A typical shower event seen by the KASCADE electron detectors in the field array is shown in Fig. 2. The reconstruction of the shower parameters is done by an threefold iteration procedure.

In the reconstruction, detector signals are corrected for 'wrong' particle contributions, i.e. the electron detectors are corrected for contributions of particles others than electrons, the muon detectors for the punch-through of other particles than muons. The expected contamination of wrong particles is estimated from their fitted lateral distributions of previous reconstruction levels. These corrections are obtained from CORSIKA[2] air shower simulations followed by a detailed detector simulation based on GEANT[3].

In the first reconstruction level the shower core is obtained by a center of gravity of the signals in the electron detectors, the shower direction by applying a gradient method using the the arrival times in this detectors. Electron and muon shower sizes are obtained by weighted sums of the relevant detector signals. No minimizations are used in this level, its main purpose is giving good starting parameters for the following levels.

In level 2 and 3, the shower direction fit takes into account expectation values and spreads of the arrival time distributions dependent on the dis-

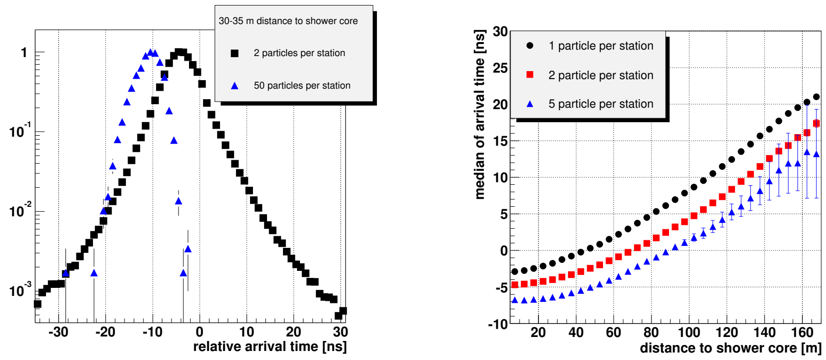

Figure 3. Two examples of arrival time distributions (left) for two and 50 particles per station and 30-35 m shower core distance. The right figure shows three examples of the median of these distributions vs. the shower core distance for 1, 2 and 5 particles per station. The arrival times are relative to a plane fitted to the shower front.

tance to the shower core and the particle numbers in one station[4]. Fig. 3 shows as an example the arrival time distributions for 2 and 50 particles per station for a distance of 30-35 m from the shower core. Stations with more particles have arrival time distributions with expectation values shifted to earlier times and a smaller spread compared to stations with less particles. The latter gives them a larger weight in the direction fit. The distance dependence of the median of the arrival time distributions can also be seen for some particle numbers in Fig. 3. A parameterization of the median and spread of these measured distributions is used in a robust absolute value minimization to determine the shower direction.

A fit of the Nishimura-Kamata-Greisen (NKG) function to the particle densities gives the core position and the electron and muon numbers. The NKG-function is an approximation of an analytical calculation of electromagnetic showers and describes the particle density at a distance r from the shower core for an vertical EAS with particle number N and form parameter (age) s:

$$\rho_{NKG}(r,s,N) = \frac{N}{r_M^2}\frac{\Gamma(4.5-s)}{2\pi\Gamma(s)\Gamma(4.5-2s)}\left(\frac{r}{r_M}\right)^{s-2}\left(1+\frac{r}{r_M}\right)^{s-4.5}$$

The Moliere radius r_M is fixed because of its strong correlation to the shower age (see Fig. 4 in Ref.[5]) to 89 m respectively 420 m for the fit to the electron resp. muon lateral distribution.

The accuracy of the direction and core reconstruction can be seen in Fig. 4, the accuracy of the electron and muon reconstruction in Fig. 5.

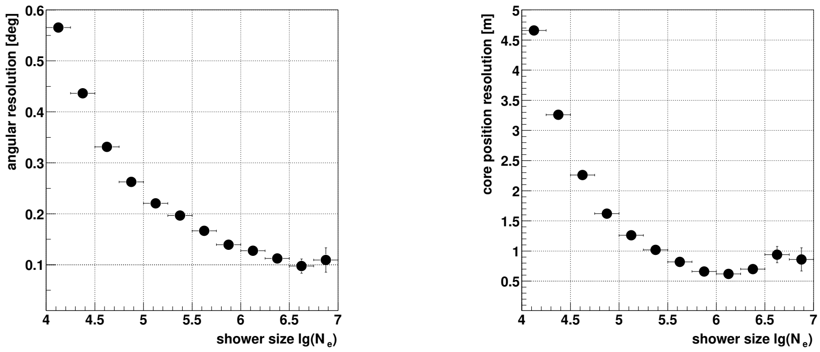

Figure 4. Angular and core position resolution obtained by the chessboard method for KASCADE array data. The stated values correspond to 68% confidence levels of the associated distributions. The core position resolution worsens due to detector overflows at very large shower sizes.

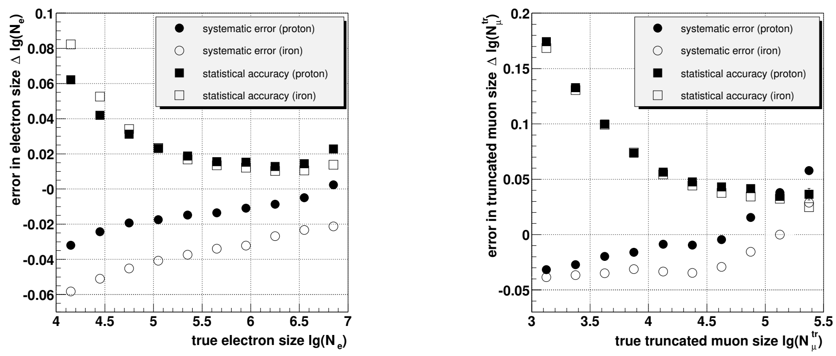

Figure 5. Systematic error and statistical accuracy of reconstructed electron (left) and muon (right) number obtained from Monte Carlo simulations. The truncated muon number is the number of muons observed between 40 and 200m.

5. Summary and Conclusion

The KASCADE array is in operation since December 1995, more than 650 millions events have been measured. The measured electron and muon number spectra (Fig. 6) of KASCADE at various zenith angles show all the changing of the power law index due to the knee. The more prominent knee in the electron size spectra attenuates as expected with zenith angle of the EAS due to the increasing thickness of the passed atmosphere[6].

Several analysis of the electron and muon size spectra have been carried out to obtain the primary energy spectra[7,8,9,10]. An overview over recent results of KASCADE is given in Ref.[11].

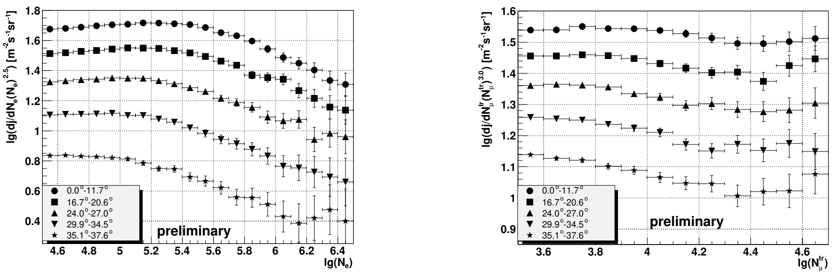

Figure 6. Electron (left) and muon (right) size spectra for different angular bins.

References

1. T.Antoni et al.,(KASCADE Collaboration), *Nucl.Instr.and Meth.in Phys.Res. A*, to be published, 2002.
2. D.Heck et al., Report FZKA 6019, Forschungszentrum Karlsruhe, 1998.
3. GEANT, CERN Program Library Long Writeup W5013, Geneva, 1993.
4. H.Krawczynski et al., *Nucl.Instr. and Meth. in Phys.Res. A* **383**, 431-440, 1996.
5. T.Antoni et al., (KASCADE Collaboration), *Astroparticle Physics* **14**, 245-260, 2001.
6. G.Maier et al., (KASCADE Collaboration), Proc. 27$^{\text{th}}$ ICRC, Hamburg, 161, 2001.
7. R.Glasstetter et al., (KASCADE Collaboration), Proc. 26$^{\text{th}}$ ICRC, Salt Lake City, **2**, 222, 1999.
8. J.Weber et al., (KASCADE Collaboration), Proc. 26$^{\text{th}}$ ICRC, Salt Lake City, **1**, 347, 1999.
9. T.Antoni et al., (KASCADE Collaboration), *Astroparticle Physics* **16**, 245-263, 2001.
10. H.Ulrich et al., (KASCADE Collaboration), Proc. 27$^{\text{th}}$ ICRC, Hamburg, 97, 2001.
11. K.-H.Kampert et al., (KASCADE Collaboration), Highlight talk, 27$^{\text{th}}$ ICRC, Hamburg, 2001.