The Cosmic Ray Experiment KASCADE:
A Survey

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ABSTRACT

The cosmic ray air shower experiment KASCADE (KArlsruhe Shower Core and Array DEtector) has been completed on the site of the Forschungszentrum Karlsruhe in the Rhine valley in the south of Germany. This article gives a short overview of the experimental setup and the physical goals of the experiment. In addition, some first results are presented.

1 Introduction

Up to now there are several open questions in cosmic ray physics. The composition is only measured up to energies of about 10^{14} eV, above this energy it is not known. The cosmic ray energy spectrum follows a power law with two different slopes. The point at about $3\cdot 10^{15} eV$ at which the slope changes is commonly called *the knee*. An important question is the unknown origin of this knee. A further point of interest concerns the sources of high–energy cosmic rays. The sources for the lower energies are known, most particles are emitted by star winds like the solar wind and by supernovae in our galaxy. Finally there exists no known mechanism to accelerate particles up to energies of about 10^{20} eV.

The main goal of the KASCADE experiment [1] is to make a contribution to solve these problems. To answer them it is necessary to determine the mass and the energy of the primary particles and to measure their energy spectrum in the energy range from

$3 \cdot 10^{14}$ up to 10^{17} eV. In addition to these astrophysical questions KASCADE intends to work on particle physics questions.

With high flying balloons and satellites numerous direct measurements of cosmic rays have been performed up to energies of 10^{14} eV. These measurements are restricted to these energies due to the steep decline of intensity with energy, because the instruments used are limited in detector area and time of exposion. The only way to measure higher energies are indirect measurements at ground level with large area detectors, using the development of extensive air showers when high energy particles are penetrating the atmosphere. The electromagnetic and muonic components have wide lateral distributions with radii of the order of a hundred and several hundred meters, respectively. The hadronic component has the narrowest lateral distribution of the order of some 10 m.

According to this form of an extensive air shower, KASCADE consists of a large detector array for the muonic and electromagnetic component and a compact central detector for the hadronic and high–energy muonic component in the shower core. A schematic sketch of the setup is given in figure 1.

2 Experimental Setup

2.1 The Array

The array consists of 252 detector stations in a rectangular grid of 13 m spacing. It's full size is 200×200 m. Each detector station contains four electron detectors. These detectors consist of stainless steel containers with a circular shape and a diameter of 1 m, filled with liquid scintillator 4 cm deep. The light is guided by an air light cone to the phototube on the top. In addition, under a shield of lead and iron muon detectors are installed, consisting of 3 cm plastic scintillator, read out via wavelength shifters with phototubes. The threshold for muon detection is about 300 MeV.

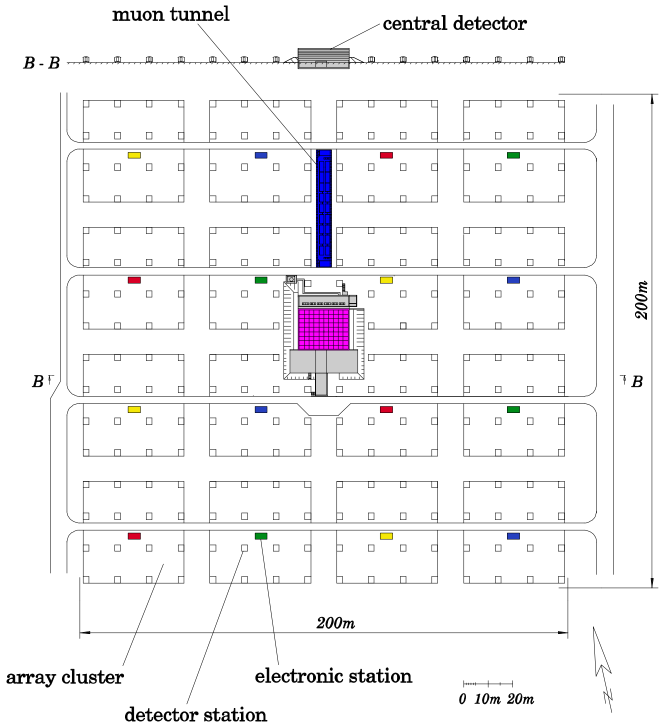

Figure 1: The setup of the experiment KASCADE.

The goal of the array is the measurement of particle densities and arrival times of the electromagnetic and muonic component.

2.2 The Muon Tunnel

In the north of the array an underground muon tunnel is located. Under a shield of iron, concrete and soil, we plan to install 3 horizontal and 2 vertical layers of streamer tubes with a sensitive area of about 150 m^2. With these detectors it is planned to measure particle coordinates in 3 layers to reconstruct the tracks of muons with an energy threshold of 1 GeV.

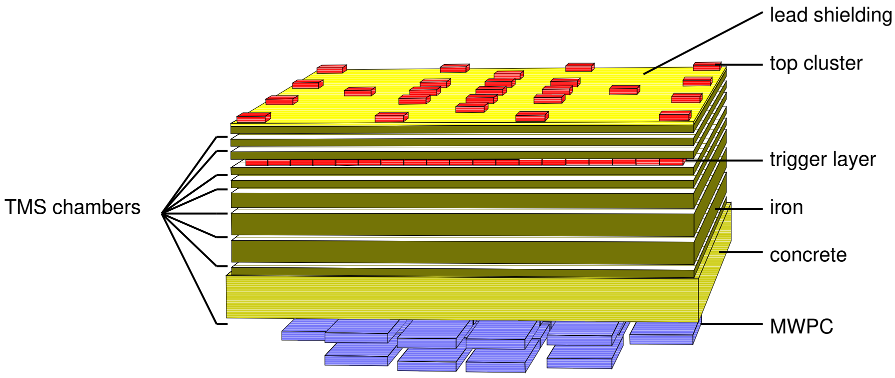

Figure 2: Schematic view of the central detector.

The central detector with a size of $16 \times 20\ m^2$ is located in the middle of the array. It consists of 4 different detector systems to measure the hadronic and muonic component of an extensive air shower as sketched in figure 2. The principal parts are the iron absorbers with increasing thicknesses of 12 to 36 cm, from top to bottom. On the top of the first absorber 5 cm of lead serves to shield the detector against electromagnetic punch–through.

The iron sampling calorimeter consists of 8 active layers with 10 000 liquid ionizing chambers in total filled with tetramethylsilane (TMS). The read–out comprises 40 000 electronic channels. The main physics goal of the calorimeter is the separation of individual hadrons in a shower core and to determine their direction and energy separately. The depth of the detector corresponds to approximately 11 hadronic interaction lengths, and hadrons up to an energy of 10 TeV are contained to 95% in the calorimeter.

In the basement of the detector under 70 cm of shielding concrete 32 multiwire proportional chambers detect muons. They have an active area of 150 m^2 and an energy threshold of about 2 GeV.

Above the lead on the top of the calorimeter an array of 32 scintillation counters serves to detect small fragments of showers from low energy primaries. The third gap in the iron absorber contains the trigger layer with 456 scintillation counters. Both detector systems generate a trigger for the calorimeter and the multi–wire proportional chambers.

Liquid Ionizing Chambers

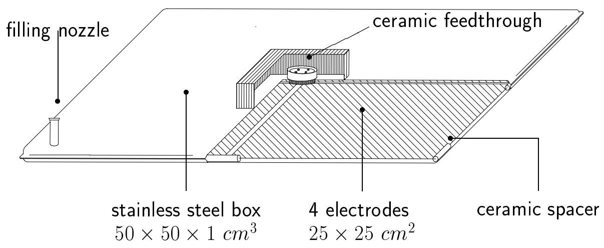

Figure 3: A liquid ionizing chamber.

The active elements of the calorimeter are a new type of liquid ionizing chambers at room temperature which have been developed at our institute. The chambers are flat stainless steel containers of lateral dimensions $50 \times 50\ cm^2$ and 1 cm thickness as sketched in figure 3. The inner electrode is segmented into 4 electronic channels, which are read out separately. A preamplifier housing is mounted directly on top of the chamber. They are filled with 1.75 l of tetramethylsilane, a nonpolar liquid exhibiting fast electron conduction. The signal generated by these chambers is proportional to the energy deposit and independent of the position of the penetrating particle. They have a large dynamical range of about $5 \cdot 10^4$, only limited by the amplifier electronics. With these chambers we can measure minimum ionizing particles depositing 0.8 MeV in the liquid up to hadrons which can deposit 10 GeV and more in one electronic channel. An important issue is the fact that the chambers can be absolutely calibrated with cosmic ray muons. The KASCADE calorimeter is the only large device operating successfully with a warm liquid.

3 Characteristic features of KASCADE

In the following, some characteristic features of KASCADE in relation to other cosmic ray experiments are summarized. It is a multidimensional experiment allowing simultaneous measurements of the electromagnetic, the muonic and the hadronic component. A large coverage with detectors of about 2% ensures that the precision of the measurements is only limited by intrinsic fluctuations of the individual shower development and not by a too small detector area. In the hadronic component individual hadrons, their energy, position and direction are measured separately. Finally, KASCADE has three different thresholds for muon energies and a timing system to measure arrival times of all particles.

4 First Results

KASCADE has started to operate with all components at the beginning of 1996. Below some results of the calorimeter are presented, first results from the detector array are discussed elsewhere in these proceedings.

A cosmic ray event in the hadron calorimeter is displayed as an example in figure 4. Each pixel represents a single electronic channel. The fine spatial resolution of the detector can be recognized. This enables the separation of single hadronic showers. A lot of hadronic energy penetrates deep into the calorimeter down to approximately 7 interaction lengths. The energy in the core of this particular shower corresponds to 10 TeV.

The same event is plotted in figure 5 showing the energy deposition in the trigger layer. The open squares are counters with energies above the muon threshold, the full circles are counters with energies above the hadron threshold which is approximately 50 times the signal of a minimum ionizing particle. In addition, the arrival times are plotted.

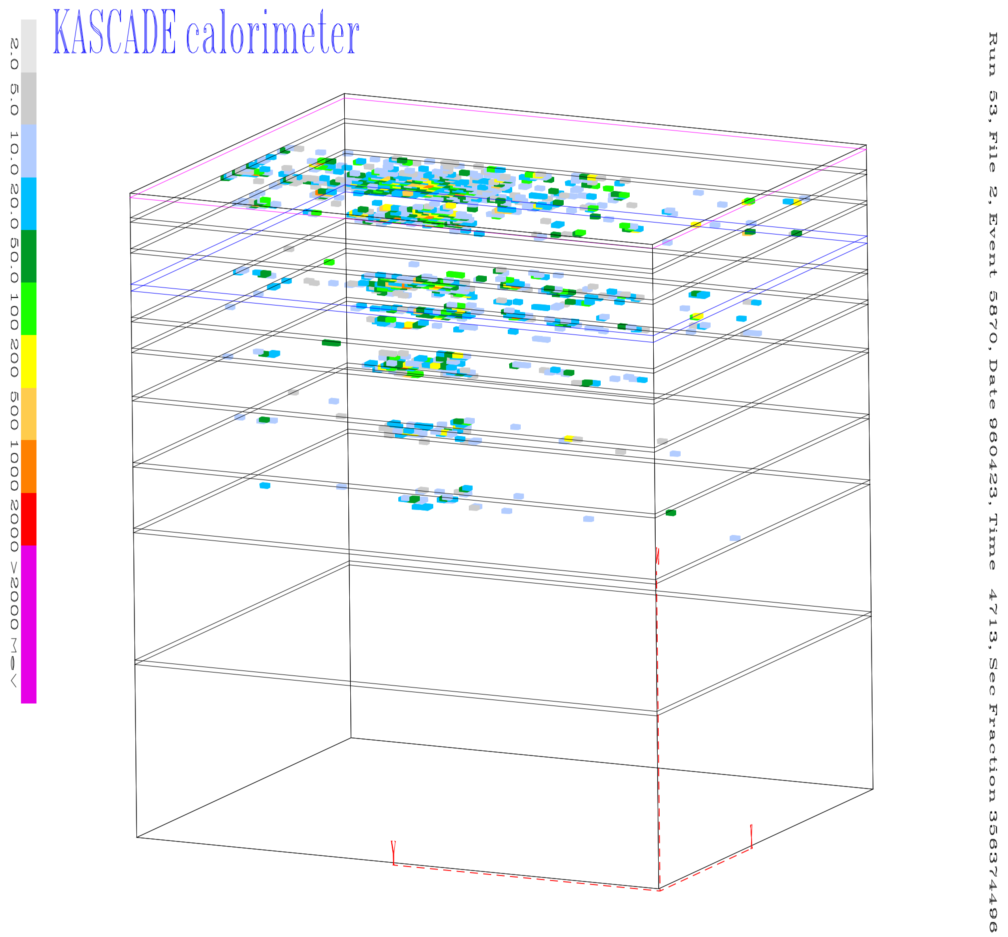

Figure 4: A cosmic ray event in the hadron calorimeter. Each pixel represents a single electronic channel.

4.1 Hadron Spectrum

Many different checks have been performed to compare measured data with Monte Carlo simulations, e.g. the lateral and longitudinal cascade development within the iron absorber. Also, the stability of the apparatus has been checked carefully [2]. One of the first results was the single–hadron flux spectrum as plotted in figure 6. The plot contains a preliminary result of the KASCADE

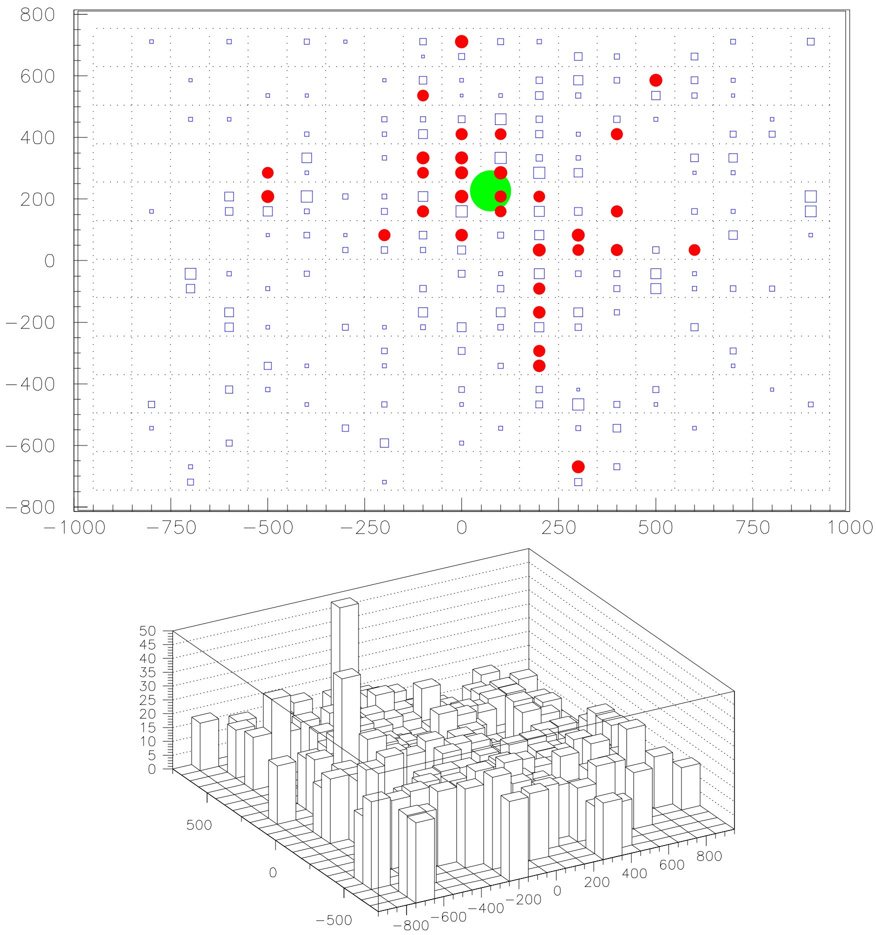

Figure 5: A cosmic ray event in the trigger layer with energy depositions (top) and arrival times $[ns]$ (bottom).

calorimeter and measurements of a prototype [3]. The calculated spectral index is 2.72 ± 0.1. The energy dependence of the inelastic cross–section of protons on air nuclei has been measured [3]. The values obtained show an increase from 275 mb to 312 mb in the energy range from 10 GeV up to 15 TeV.

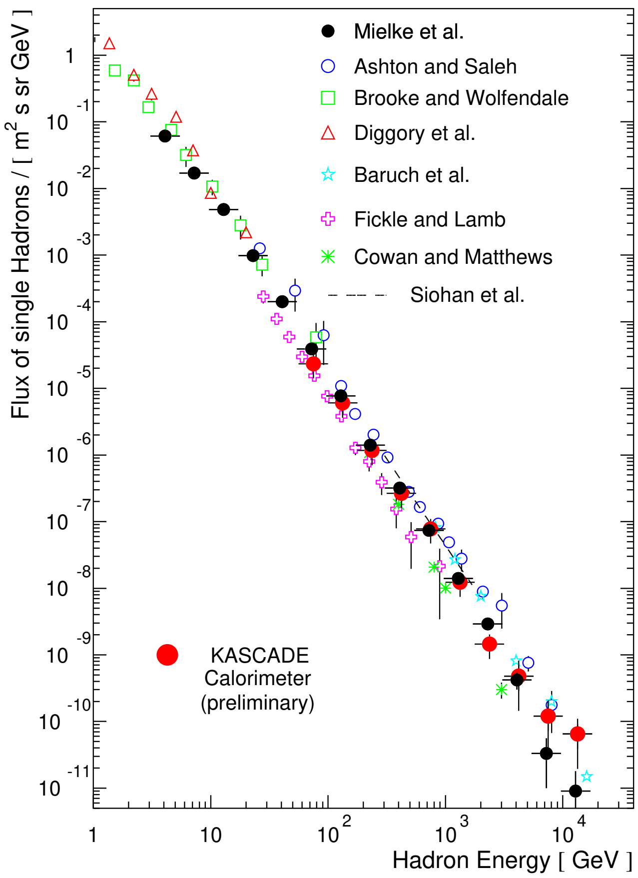

Figure 6: The flux of all single hadrons at sea level versus energy.

4.2 Ratio Neutral–to–Charged Hadrons

With a prototype of the hadron calorimeter the neutron spectrum and the neutral–to–charged ratio of unaccompanied hadrons has been measured [5]. The ratio decreases from about 0.55 to 0.25 in the energy range from 10 GeV to 1 TeV. Taking this fraction and the fraction of neutrons to protons of about 0.9, the pion flux has been calculated. The fraction of pions to nuclei increases from less than 0.1 up to about 0.8 in the energy range from 10 GeV up to 1 TeV.

4.3 Barometric Attenuation

A further result is the atmospheric attenuation of hadrons at sea level, measured with the prototype [4]. The hadron flux decreases with rising barometric pressure at ground level. The value of the barometric coefficient is about $-0.8\,\%/(g/cm^2)$ for hadron energies above 250 GeV. This value corresponds to an attenuation length of hadrons in the atmosphere of $\lambda_{att} = 121\ g/cm^2$.

5 Conclusion

All detector components of the KASCADE experiment are operating since the beginning of 1996. Our first measurements confirm prototype results and they are in good agreement with values found in the literature. We expect first physical results by the end of 1996.

Thanks to M. Főller, H.–H. Mielke and J. Unger for preparing some pictures.

6 References

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