The KASCADE-Grande experiment

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Abstract

The KASCADE-Grande experiment will study the primary cosmic ray spectrum in the energy range from 10^{16} eV to 10^{18} eV. The array is located at the Forschungszentrum Karlsruhe and is made by all the detectors of the KASCADE experiment and by two new arrays: Grande (37 plastic scintillators stations, 10 m^2 each, covering an area of 700x700 m^2) and Piccolo (8 plastic scintillators stations for triggering purposes). We will describe the set up of the array, discuss its capabilities and present its current status. We present also the LOPES project, a prototype detector for the measurement of the radio emission from extensive air showers.

1 Introduction

One of the main results of the experiments that have studied the knee of the primary cosmic rays spectrum, in the last ten years (among the others KASCADE[1] and EAS-TOP[2]), is that the change of slope is due to the light component of primary cosmic rays. Moreover these experiments give a clear indication that also the spectra of heavier components show the change of slope and that this feature is observed at constant rigidity. This result is in agreement with the models that explain the knee with astrophysical processes (i.e. escape from magnetic fields or limit of the acceleration processes in supernova remnants); for a complete review see [3] and references therein. A conclusive argument to complete the picture would be the observation of the knee of the heavier component of cosmic rays (i.e. iron), that is expected at primary energy $E_0 \sim 10^{17}$ eV.

This energy is outside the range covered by all former experiments. An array tuned to study this energy range must fullfill the following characteristics: large acceptance and the possibility of detecting different components of extensive air showers with high resolution and large dynamic range.

Furthermore an experiment operating at these energies will study the primary composition of cosmic rays and will test different hadronic interaction models.

The KASCADE-Grande experiment [4] is located at the Forschungszentrum Karlsruhe and is an extension of existing KASCADE experiment, beside which two new arrays have been set up: Grande and Piccolo.

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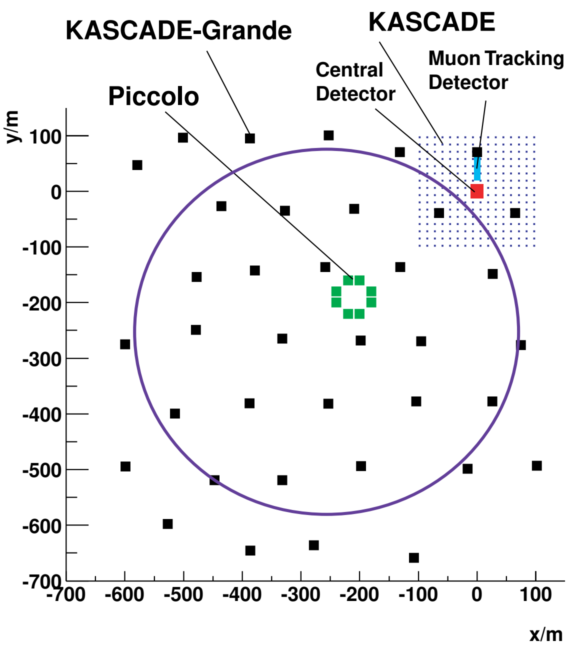

Figure 1: Sketch of the KASCADE-Grande experiment.

Grande[5] is an array made by 37 stations of plastic scintillators distributed over an area of 700x700 m^2 (distance between stations $\sim$ 130 m), sampling the energy deposit and arrival time of the charged particles of the EAS. Scintillators and photomultipliers used in this array are coming from the EAS-TOP experiment[6].

Piccolo is an array of 8 stations of plastic scintillators distributed over an area of 360 m^2 (the distance in between stations is 25 m), the main scope of this array is to provide a fast trigger both to Grande and to the KASCADE detectors.

2 The KASCADE-Grande experiment

A sketch of the KASCADE-Grande experiment is shown in figure 1 and all detetcors of the array are summarized in table 1. In the following we will describe the main charactristics of each of these detectors.

Detector	Particles	Area (m^2)	Threshold (MeV)
Grande	Charged	370	5
Piccolo	Charged	80	5
KASCADE array	e/γ	490	5
KASCADE array	μ	622	230
MTD	μ	128×4	800
Trigger Layer	μ	208	490
MWPC	μ	129×2	2400
LST	μ	250	2400
Calorimeter	hadrons	304×9	50000

Table 1: Compilation of the KASCADE-Grande detectors

2.1 The Grande array

The Grande array is made of 37 stations, each detector has a total surface of 10 m^2 segmented into 16 plastic scintillators 80×80 cm^2 and 4 cm thick. All scintillators are seen by an high gain photomultiplier whose signals are summed and used for timing and low particle density measurements. The four central scintillators are also read-out by photomultipliers working at a lower gain used for high particle density measurements.

For triggering the stations are divided in 18 clusters of hexagonal shape, each made of 7 detectors. The minimum trigger requirement is the coincidence of four stations, the trigger rate is $\sim 5\ Hz$. Moreover Grande is trigger by the KASCADE and by Piccolo. All Grande triggers in which at least one full cluster is fired (i.e. coincidence of 7 stations) are sent to the KASCADE array, their rate is $\sim 0.5\ Hz$.

For each event the informations available are: 3 adc channels for all stations and all firing times from all stations inside a window of $\pm$ 5 μs around the trigger signal. The dynamic range covered using the three adc signals is extended up to $3 \times 10^3 m.i.p.\ m^{-2}$.

In three years of data taking the expected number of events, above different energies, is: $\sim 2.5 \times 10^4$ for $E_0 > 10^{17}$ eV and ~ 250 for $E_0 > 10^{18}$ eV.

2.2 The Piccolo array

In order to provide a fast trigger to the KASCADE detectors a compact array, named Piccolo, has been built. Each Piccolo station contains 12 plastic scintillators organized in 6 modules, a trigger is generated and sent to KASCADE and Grande when at least 7 out of the 48 modules are fired. The corresponding trigger rate is 0.3 Hz. The trigger condition had been defined in order to achieve a 100% efficiency for energies greater than 2×10^{16} eV and events with core inside the region surrounded by the circle shown in figure 1.

2.3 The KASCADE experiment

KASCADE is an experiment operating in the energy range around the knee of the primary cosmic ray spectrum and is taking data since 1986, it provides measurements of different components of extensive air showers: electrons, muons (at 4 different energy thersholds) and hadrons. For a complete description of the array see[7], here we will briefly recall the main characteristics of the field array, of the muon tracking and of the central detector.

The field array is made of 252 detectors (divided in 16 clusters) sampling the electromagnetic (5 MeV energy threshold and 490 m^2 active area) and muonic component (230 MeV energy threshold and 622 m^2 active area) of extensive air showers.

The muon tracking detector measures the angles of incidence of muons over an area of 150 m^2, with an angular resolution (for single track) $\sim 0.5°$. The muon detection threshold is 800 MeV.

The central detector is an hadron sampling calorimeter (8 layers of ionisation chambers interleaved by iron absorber), the energy threshold for hadron detection is 50 GeV. Moreover there are two other muon detectors: the trigger plane (208 m^2 of plastic scintillators, $E_\mu > 490MeV$) and a system of multiwire proportional chambers and limited streamer tubes sampling muon with energy greater than 2.4 GeV.

3 First measurements at KASCADE-Grande

The KASCADE-Grande experiment is taking data in a continuous and stable way since the beginning of 2004. In figure 2 is shown the lateral distribution of electron and muons measured for a single event. This event shows the potential of the KASCADE-Grande experiment giving a clear indication of the possibility of measuring for single events the muon to electron ratio. Infact the array will provide, for each event, the sampling of the electrons (KASCADE e/γ array detectors), of the charged particles (Grande stations) and of the muons (KASCADE μ detectors). The electrons and charged component of EAS is sampled up to $\sim 600m$ from the core, the muon component

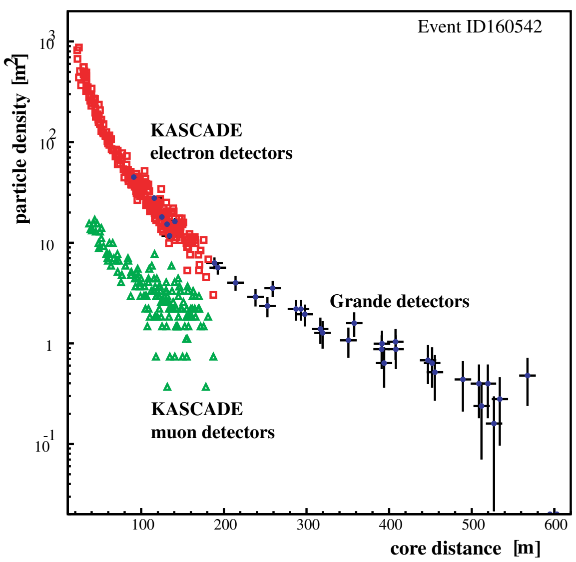

Figure 2: Particle densities measured for a single event by different detectors of the KASCADE-Grande experiment

of showers is sampled in a limited range of distances (due to the KASCADE experiment dimensions) but the sampling is good enough to reconstruct the muon number; the uncertainty being 20%-30% depending on the primary energy and on the core distance from the KASCADE array.

The reconstruction accuracy of the shower core position and direction has been estimated to be 4 m (13 m) and 0.18° (0.32°) with 68% and 90% confidence level for simulated proton and iron showers at $100PeV$ primary energy and 22° zenith angle.

A future development of the Grande stations will be the introduction of a Flash Analog-to-Digital Converter (FADC) system[8], that will provide a continuouos 4 ns sampling of the photomultiplier signals. The scintillator pulses of a Grande detector are digitized by cascaded FADCs with an effective sampling rate of 250 MHz. The digitizer board consist of two times four 12-bits FADCs (one for high gain and one for low gain photomultipliers). Once an adjustable thershold is crossed the signal waveform is transmitted to the Grande DAQ station, where a master PC scans the time stamp information from all detectors and looks for coincidences.

This system will provide the full shape information allowing the possibility of different analysis based on the pulse shape (i.e. possible muon/electron

Figure 3: One of the LOPES antennas at the KASCADE-Grande site. A Grande station and some detectors of the KASCADE array can also be seen.

separation or studies on delayed particles). A prototype digitizer board has been operated succesfully on the experimental site and during summer 2004 is foreseen the installation of the first 20 boards.

4 The LOPES project

A "**LO**far **P**rototype**E** **S**tation" (LOPES) [9] is under construction at the site of KASCADE-Grande in order to test the LOFAR technology and demonstrate its capability of measuring the radio emission of Extensive Air Showers. Combining the LOPES data with those of the KASCADE-Grande array will allow to calibrate the radio data with other air showers characteristics and will also provide a starting point for the air shower reconstruction simplifying the development process. This will enable us to clearify the nature and properties of radio emission from EAS and provide an energy calibration for future radio air shower experiments.

At present, LOPES operates 10 dipole radio antennas in coincidence with KASCADE. The antennas are disposed in 5 out of the 16 clusers of KASCADE. The radio data are collected when a trigger is received from KASCADE array, the logical condition being the coincidende of at least 10 out of the 16 clusters. The event rate is 2 per minute and the energy threshold is above 10^{16} eV. The antennas operate in the range 40-80 MHz. One of them, operating in the KASCADE-Grande field, is shown in fig. 3, it can be noticed its characteristic "inverted vee" shape.

In the near future 30 antennas will be installed at KASCADE-Grande.

With the amount of about 1000 measured events above 10^{17} eV, LOPES at KASCADE-Grande will be a very powerful instrument to study and eventually calibrate the detectors for radio emission in EAS.

5 Conclusions

The KASCADE-Grande experiment has began a continuos and stable data taking since January 2004 and will study the primary cosmic spectrum in the energy range $10^{16} - 10^{18}$ eV. The main goal of the experiment is the detection of the knee in the spectrum of the heavy component (iron) of cosmic rays that is expected at a primary energy E$\sim 10^{17}$ eV.

Future developments of the array and the possibility of testing a new technique for the detection of the radio component of EAS has been discussed.

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