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A layer of streamer tube detectors for the measurement of muons in the KASCADE central detector

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Abstract. For an improved detection of cosmic ray muons with a threshold of $2.4\ \mathrm{GeV}$, the KASCADE Central Detector has been upgraded with a new detector component built of limited streamer tubes. Combined with the operation of two layers of multiwire proportional chambers they enable studies of the muonic component of extensive air showers at higher particle densities. Due to the pad readout system of the streamer tubes, ambiguities in the muon track reconstruction, resulting from limitations of the readout system of the multiwire proportional chambers, can be resolved. Additionally the sensitive area for muon detection is increased from 40% to 82% of the area of the Central Detector by the new layer of streamer tubes, with a good spatial resolution in the parts not covered by the multiwire proportional chambers. The setup of the new detector system and the reconstruction procedures are described and demonstrated by first measurements.

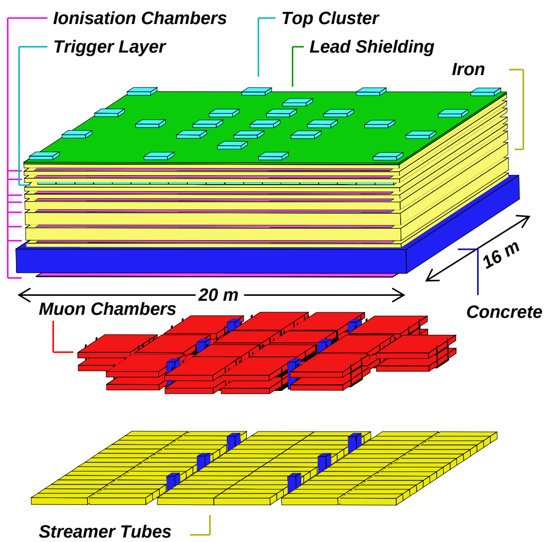

Fig. 1. Schematic view of the KASCADE Central Detector.

1 Introduction

The KASCADE experiment (Klages et al., 1997) at the site of the Forschungszentrum Karlsruhe aims at measuring extensive air showers (EAS) produced by the primary cosmic ray particles interacting with air nuclei in the earth's atmosphere. It consists of a $200 \times 200\ \mathrm{m}^2$ detector array built of scintillation counters for the measurement of the electromagnetic and muonic shower component. It also contains an underground muon tracking detector (Atanasov et al., 2000) that uses streamer tube detectors. In the middle of the detector array the Central Detector is placed which includes several components aiming at different observables of an EAS (Fig. 1). Its main component is an iron sampling calorimeter (Engler et al., 1999), which consists of eight layers of liquid ionisation chambers for the detection of the hadronic component of EAS. A ninth layer of the calorimeter detectors has been added on top of the iron shielding to investigate the electromagnetic shower component with a nearly full cover-

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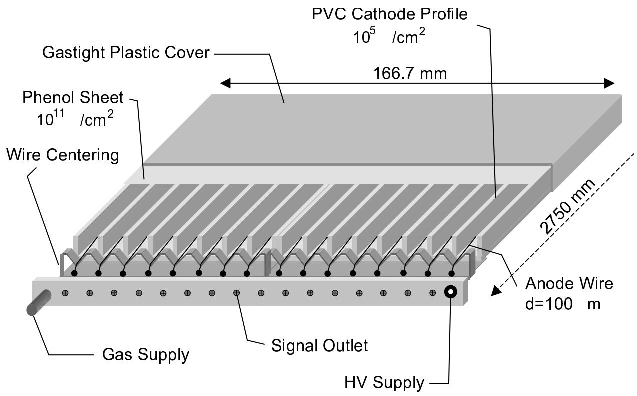

Fig. 2. Schematic view of one streamer tube.

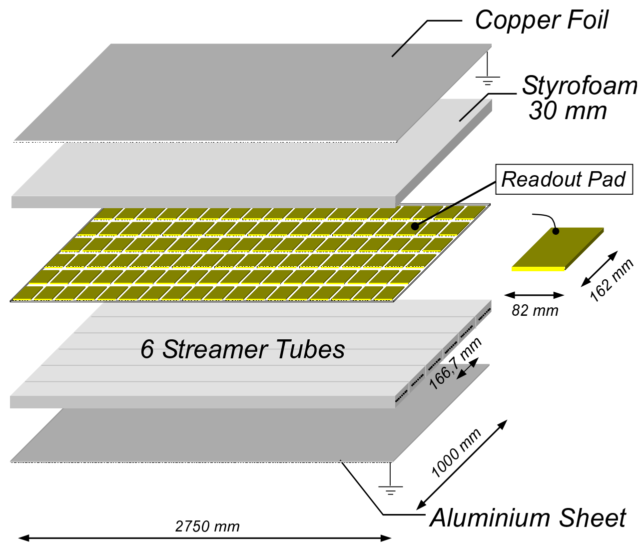

Fig. 3. Schematic view of a LST module with pad readout system.

age of the Central Detector area. On top of the calorimeter an array of 50 plastic scintillation detectors is installed. The purpose of this Top Cluster is the measurement of the electromagnetic component of EAS and to trigger the Central Detector for small shower sizes. In the third gap of the calorimeter a layer built of the same kind of scintillation counters is installed. This Trigger Plane consists of 456 detectors covering 64% of the area of the Central Detector. They are used to investigate the muonic shower component above a threshold of $490\ \mathrm{MeV}$ and to generate an additional trigger signal for the Central Detector. In the basement of the Central Detector two layers of multiwire proportional chambers (MWPC) are installed (Bozdog et al., 2000). They are used for investigating the muonic component of air showers above a threshold of $2.4\ \mathrm{GeV}$ for the muons, which is given by the iron shielding of the calorimeter. With these detectors the lateral distribution of muons (Haungs et al., 1996; Antoni et al., 2001) as well as muon density distributions (Haungs et al., 1999; Antoni et al., in press) have been studied. The investigations have been limited by the size of the detector system, as it covers only about 40% of the area of the Central Detector, and also by the ability to resolve multiple particle hits. Due to the layout of the MWPC detectors which consist of two layers of cathode stripes diagonal to each other and the anode wires, ambiguities occur above a particle density of $2\ \mathrm{m}^{-2}$. As a result of these ambiguities only particle densities in a range of up to $4\ \mathrm{m}^{-2}$ can be measured. To improve this situation a third layer of detectors has been installed below the MWPC, increasing the detector area and the resolution of ambiguities of the hit reconstruction.

2 The streamer tubes

The new detector component for measuring muons in the basement of the Central Detector is built of Limited Streamer Tubes (LST). These are gas detectors making use of the self-quenching streamer mode (Doll et al., 1994) that is reached when, due to the very high voltage between the anode and cathode, the charge multiplication becomes so large that the electric field in the space charge equals the outer field. This causes the electrons to recombine with the ions. To prevent secondary charge avalanches, induced by photons produced in these processes, from sreading along the anode wire a quenching gas is used, thus keeping the signals localized.

2.1 Detector layout

In the streamer tubes employed here, CO_2 has been used as counting gas since it has good characteristics for producing signals and quenching and additionally can be used without safety regulations. All LST used in the KASCADE experiment are manufactured by WATECH, Vienna, Austria. The dimensions of one streamer tube are $2750 \times 167 \times 13\ \mathrm{mm}^3$. The layout of one LST can be seen in Fig. 2. It consists of 16 anode wires of $100\ \mu\mathrm{m}$ that are positioned in a comb-like cathode profile with a cell size of $9 \times 9\ \mathrm{mm}^2$ made of conducting PVC. On the upper side this profile is closed with a sheet of conducting phenol paper. These components are located inside a gas tight plastic cover with a gas feed through on both ends and a signal outlet for each wire as well a high voltage supply on the front face. The cathode materials have a high resistivity which allows an electrostatic induction signal to be registered outside the streamer tube. This is done with a pad readout system to get a spatial resolution of the hits along the wires. The streamer tubes are installed in the basement of the Central Detector in modules containing six LST which are mechanically fastened together and are covered by a joint pad layer. The layout of these installation modules can be seen in Fig. 3. The pad layer consists of a styrofoam sheet of $30\ \mathrm{mm}$ thickness with copper foil glued to both sides. On the side facing the LST gaps are cut into the foil to produce the readout pads of a size of $162 \times 82\ \mathrm{mm}^2$. This amounts to 32 pads along one streamer tube and 192 on the whole module. The wires are grouped in pairs to reduce the number of electronic channels while still having a good spatial resolution.

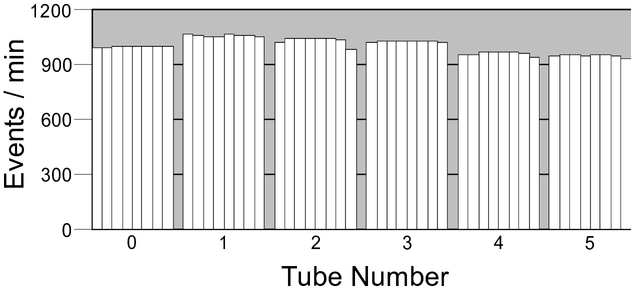

Fig. 4. Investigation of the homogeneity of the signals. The counting rate in the wire pairs of the six streamer tubes of the test module is shown here. The rate is homogeneous in each tube and there is a good agreement between the LST.

2.2 Readout electronics

The readout electronics for the LST detectors was developed at the Institut für Kernphysik of the Forschungszentrum Karlsruhe in co-operation with the Institute of Physics and Nuclear Engineering in Bucharest. It is a modified version of the electronics of the KASCADE Muon Tracking Detector (Zabierowski and Doll, 2001). The following basic conditions had to be fulfilled. The whole detector system consists of more than 22000 electronic channels which demands for a low price per channel. The signals of the LST are in the range of a few mV with a duration of several tens of ns, therefore special care has been taken in order to avoid noise and crosstalk between channels. A complete spatial separation between the analog and the digital parts of the electronics has been applied. The VME Streamer Tube Acquisition System (VME-STAS), that has been built, is a modular, VME controlled system. This VME-STAS consists of several modules. Two VME Streamer Tube Acquisition Modules (VME-STAM) each of which provides eight independent fast acquisition channels, which are fully controllable via VME bus. Each channel is receiving serial data (up to $2\ \mathrm{Mbit/s}$ sampling rate) coming from the acquisition boards of seven or eight streamer tube modules and saves them in a 512×8 bit FIFO memory. An external START signal commences the data acquisition with the internally chosen clock frequency. A splitter board controls the communication between the VME-STAM and the Acquisition Boards and collects the data from the acquisition chains. These readout chains consist of the Acquisition Boards that contain mainly the digital readout electronics to control the Amplifier/Discriminator Boards connected. The signals from either eight wires or eight pads are handled by one Amplifier/Discriminator Board. The delays and thresholds are adjustable via software controlled digital_to_analog converters.

3 Test measurements

As a first step in the study of the streamer tubes a test facility was built in the basement of the Central Detector. It consisted of one streamer tube module like they are in use in

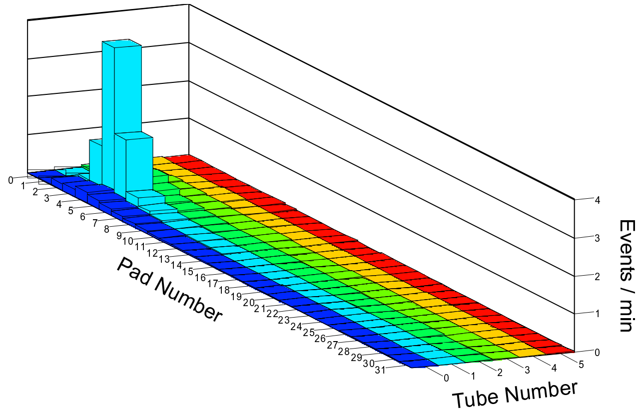

Fig. 5. Investigation of the crosstalk between the pads. The pad selected by the scintillator telescope shows the highest counting rate, but also the neighboring pads along the same tube show an increased rate. This is due to cross talk, geometry effects and the size of the charge cloud in the LST. Across the borders of the tubes there is almost no cross talk.

the final installation. This setup was equipped with a telescope of scintillation detectors to trigger on particles penetrating the module through one selected pad. The electronics used in this test facility was the prototype version of the electronics used later in the KASCADE system. Checks of its functioning showed the importance of a careful handling of the electric ground to minimize the noise disturbing the measurements. Two important results obtained with the test facility are shown in this paragraph. The homogeneity of the signals from the streamer tubes can can be seen in Fig. 4. The picture shows the free counting rate for each channel (wire pair). The rates of the channels belonging to the same tube are very homogeneous. The values for the different LST also show a good agreement, which is achieved by adjusting the thresholds. This result is also valid for the readout pads. Fig. 5 shows the result of a measurement triggered by the scintillator telescope that has been done to quantify the cross talk between the pads. It can be seen that there is almost no cross talk across the borders between different LST. In the direction of the wires the neighboring pads show an increased counting rate. This cross talk could be of electronic origin but also could be due to the extended space charge that can induce signals in more than one pad, since its size is roughly two thirds of the size of the pads, as a measurement with a finer segmentation showed. These effects are not distinguishable in this measurement. Summarizing, it can be said that the streamer tubes and the readout electronics seem to be working very well.

4 The streamer tubes in the KASCADE system

The LST have been installed in the basement of the KASCADE Central Detector $24\ \mathrm{cm}$ below the lower layer of the MWPC. The distance between the two layers of the MWPC is $38\ \mathrm{cm}$. The streamer tubes cover approx. 80% of the area

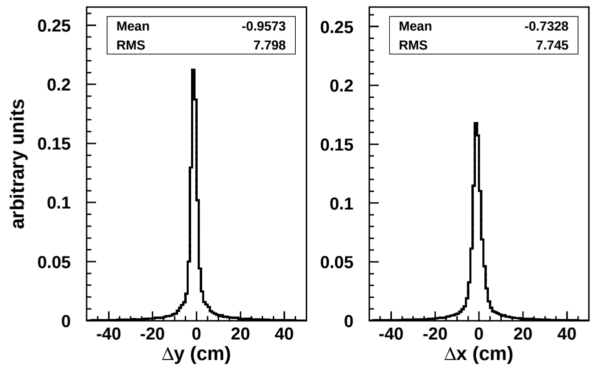

Fig. 6. Investigation of the agreement between the reconstruction of tracks in the multiwire proportional chambers and the hits in the streamer tubes. The pictures show the deviation in the x and y directions between the intersection of the MWCP tracks with the LST layer and the hits reconstructed in the LST.

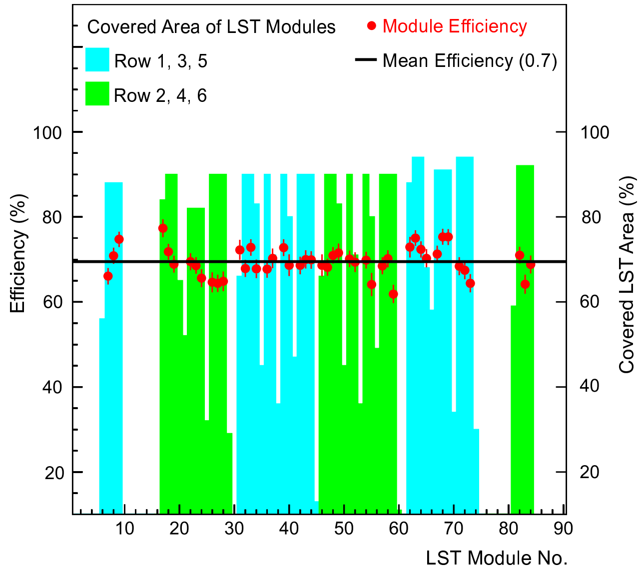

Fig. 7. Efficiency determination for the streamer tubes. The red dots show the efficiency for the modules that are covered by muon chambers to a large extend. The black line is the average over all these modules. The blue and green areas denote the percentage to which each LST module is covered with MWPC detection area.

of the Central Detector, which amounts to $16.5 \times 15\ \mathrm{m}^2$. The active area of the MWPC is only about 40%. As can be seen in Fig. 1 the LST layer is composed of six rows of 15 installation modules each. These 90 modules amount to 17280 pad channels and 4320 wire channels. After a period of stand alone measurements to test the functioning of the LST detectors and electronics, joint measurements and analyses of the MWPC and LST data have been started. As a first step the data of MWPC have been used to test the reconstruction algorithms for the LST data. The MWPC reconstruction offers two kinds of low level results. The hits in each of the two layers that have been reconstructed from the signals in corresponding anode wires and cathode stripes and the tracks calculated by correlating the hits in both MWPC layers. These MWPC tracks are intersected with the LST layer in order to check for matching hits in the streamer tube layer. Fig. 6 shows the distribution of the deviations between the expected and the measured hit positions in the LST. As expected the RMS of the distributions is about the size of the pads as can be seen in the two graphs that show the x and y directions. It can also be shown that there are no preferred directions in the deviations. With the same routines the efficiency of the LST can be investigated by checking the number of MWPC tracks that are intersected with the active area of the LST against the number of these tracks that have a matching LST hit. This procedure of course only is useful for LST modules that are for a large fraction covered by MWPC detectors. In Fig. 7 the blue and green areas denote the percentage to which each LST module is positioned below MWPC detectors. The efficiency of the LST for which this number is larger than $2/3$ is displayed by the red dots. The black line gives the mean of these values which is approx. 70%. From these tests we deduce that our reconstruction algorithms work properly and we can start with more sophisticated analyses to reach into the particle densities the MWPC alone can not resolve.

5 Outlook

Based on the present tests it seems possible in the future to analyze muon distributions closer to the shower core on an event by event basis. The joint analysis of the MWPC and LST data has to be improved, in addition to the efficiency of the LST. To achieve this, pure CO_2 will be replaced by a mixture of CO_2-*Argon-Isobutane* or *Argon-Isobutane* only.

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