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Large Muon Tracking Detector in the KASCADE EAS Experiment

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Abstract.

Accurate measurements of the muon component in EAS are particularily important for determination of the primary CR spectrum and composition. Multiparameter analysis possibilities in KASCADE have been recently enhanced by starting the operation of a large area streamer tube muon tracking detector. With its acceptance of about 500 $m^2 \cdot sr$ it identifies EAS muons with energy exceeding 0.8 GeV. The reconstruction of the mean muon production height, a parameter related to the nature of primary UHE particle, is a main goal of this detector. In addition, this detector is capable of independent determination of the shower direction, therefore, it can be used in combination with the scintillator array to improve the overall angular resolution of KASCADE. For the above-mentioned applications a good and well understood accuracy in determination of the angles of the muon tracks is of primary importance. The construction of the whole detector, as well as streamer tubes and electronics specially developed for it, allowed to reach high efficiency of muon track detection, on the level of 0.72. Various approaches to the concept of the angular resolution in track determination are discussed. The influence of the design and operation factors on the resolution, which can approach the level of 0.2°, is shown. Example of the detector performance in muon density measurements is given.

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1 Introduction

Investigation of the UHE cosmic ray particles (with energy above 10^{15} eV), due to their very low flux (being much below $10^{-5} s^{-1} m^{-2}$), is possible only via indirect observations of extensive air showers (EAS), created as a result of interactions of those particles with nuclei of the atmosphere. Ground based experiments of large detection area have to measure precisely as many components of the cascade developing in the atmosphere as possible. Particularly important is the measurement of the muon component of the EAS, because some of the muons reaching the observation level carry information about the very first interactions at the top of the atmosphere. For large distances from the shower core individual muon tracks point to the muon production height (MPH) and help to identify the nature of the primary UHE particle. Monte Carlo calculations show, that by means of the mean MPH parameter, for a good statistics of showers, primary particles like iron nuclei (Fe) can be separated from light ones, like hydrogen (p).

As an extension to the KASCADE EAS experiment (Klages et al., 1997) a large area streamer tube (ST) Muon Tracking Detector (MTD) was put into operation. KASCADE at the *Forschungszentrum Karlsruhe* has been taking data since 1996, measuring various shower parameters with the 200 × 200 m^2 scintillator array and a central detector, consisting of a hadron calorimeter and muon detectors. The new MTD of about 500 $m^2 \cdot sr$ is intended to track the muons created in the EAS. In addition, it will enhance the capability of KASCADE in measurement of the muon multiplicities and their

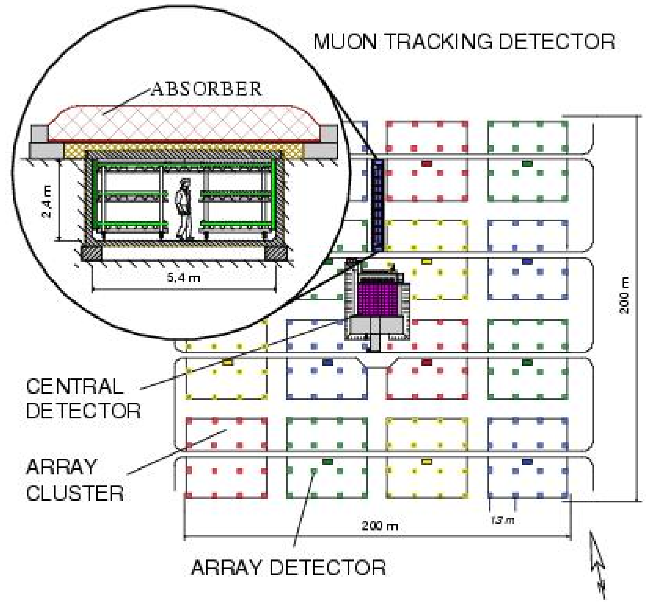

Fig. 1. Location of the MTD within the KASCADE experiment.

lateral distributions.

2 Detector and its components

The ST MTD is located within the KASCADE EAS experiment (fig.1) in the tunnel buried in the ground under a shielding of 18 r.l., made out of concrete, iron and soil. A multilayer of 6 iron plates of 3 cm thickness, separated each by 5 cm sand, provides a good absorber for a large fraction of low energy electromagnetic particles, thus enhancing the tracking capability and identification of the muons with an energy above 0.8 GeV. A cross section of the detector tunnel of $2.4 \times 5.4 \times 44$ m^3 and its location within the KASCADE experiment is shown in fig.1.

Table 1. Some ST design parameters.

PVC profile resistivity	100 kΩ/square
Bakelite cover resistivity	10^{11} $\Omega\times$cm
Anode wire diameter	100 μm
Anode wire tension	3 N at 20°C
Wire sagging between spacers	42 μm
ST chamber dimensions	$13 \times 166.6 \times 4000$ mm^3

The MTD consists of 16 muon telescopes, called detector *towers*, arranged in two rows. A *tower* is built up of four detector *modules*: three positioned on horizontal planes and one arranged vertically. A detector *module*, of the size 2×4 m^2, consists of 12 ST chambers.

2.1 Streamer Tube chambers

As a result of intensive studies (Doll et al., 1992, 1994, 1995), of various commercial (Pol.Hi.Tech.; Hungerford et al., 1990) and custom made STs (Alekseev et al., 1986), (DeWulf et al., 1986), as well as several technological improvements, ST chambers of the Iarocci type (Iarocci, 1983) were built for KASCADE by a company (WATECH) from Vienna.

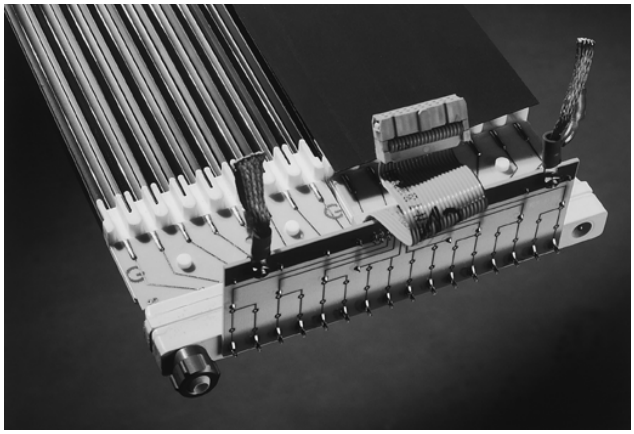

Fig. 2. Detailed view of opened ST chamber with adapter board. Anode wires connected in pairs and bakelite cover on one of the profiles are seen.

The chamber consist of two cathode comb profiles, being extruded out of conductive PVC for 8 parallel ST cells of 9×9 mm^2 cross section and 4000 mm length. High quality copper-beryllium wire, tempered and smoothed with 0.3 μm of silver has been used for anodes, being supported every 500 mm along the cells. A bakelite sheet closes the field around the anode wire very effectively (Pentchev et al., 1997) when applying negative HV to the cathode profiles. Profiles with wires and bakelite covers were slid into normal PVC envelopes and sealed off with endcaps, exhibiting connectors for anode wires, high voltage and gas. The details of the ST chamber construction can be viewed in fig. 2 and its basic design parameters are listed in Table 1.

2.2 Detector *modules* and electronics

Above the ST chambers in a detector *module* there is a layer of a rigid polyester foil of 75 μm thickness with evaporated aluminum strips of 20 mm pitch (18 mm width) and 2 m length, perpendicular to the wires. Another layer of such foil

Table 2. Operational parameters of MTD.

Detecting surface for vertical muons	128 m^2
Total detecting surface	512 m^2
Number of ST chambers	768
Number of readout channels	24 576
- wires	6 144
- strips	18 432
Number of readout boards	768
Gas mixture	70% isobutan + 30% argon
Gas flow rate	0.5 dm^3/h$\times$16 towers
Full MTD gas volume	$240\times16 = 3840$ dm^3

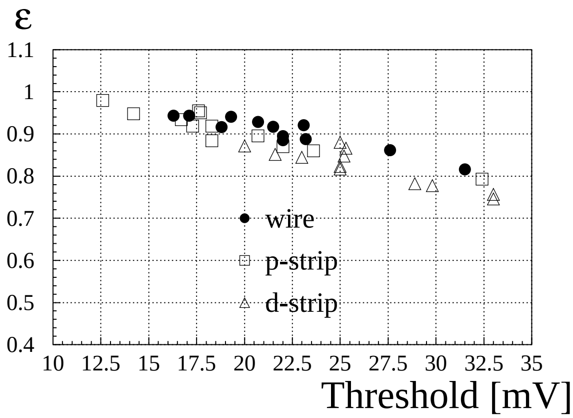

Fig. 3. Efficiency dependence on discriminator threshold for upper modules in all towers

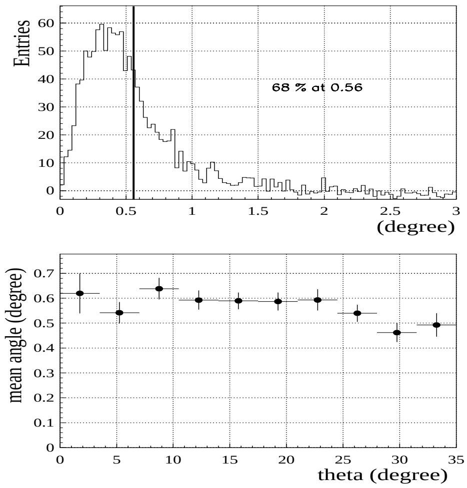

Fig. 4. Full intrinsic angular resolution of the MTD obtained with simulation (top) and its dependence on the zenith angle (bottom).

is mounted below the tubes but with strips oriented diagonally (60°). These *diagonal strips* are made out of the same strip material but 2 strips are combined at the readout side. Thus for the readout electronics every module is a source of 96 wire pairs signals, 192 perpendicular and 96 diagonal strip signals.

Our data readout system is of a chain type, commonly being used with the large scale ST detectors (e.g. Adams et al., 1999). Specially designed front-end boards (Zabierowski and Doll, 2001) are connected in series of 24 board long chains, which shift the data into CAMAC CAEN C267 STAS controllers. The MTD can be self triggered or receive triggers from other parts of KASCADE. Operational parameters of the MTD are listed in Table. 2.

3 The MTD efficiency

We define a *hit* in a *module* when a wire and corresponding perpendicular strip have data. The tracks are of two kinds. The *hits* found in three modules form *3-hit tracks* and, when data is found in two modules only, one has a *2-hit track*.

For the efficiency determination all tracks are used. Having a starting coordinate and the direction of each particle one checks for the wire and strip data in all modules along each track. The ratio of found to expected number of signals gives a measure of an efficiency in each wire or strip plane, which takes into account dead zones due to ST walls. This efficiency is also discriminator threshold dependent, as shown in fig. 3 for the upper module in all towers. As shown in the picture, for $\approx$ 17 mV threshold one has 95 $\%$ efficiency for wire and strips, what means $\approx$ 90$\%$ hit efficiency for a module and $\approx$ 72 $\%$ *3-hit track* efficiency for a MTD tower.

4 Angular resolution

The tracking detector has a *geometrical* angular resolution defined by its design and dimensions. With the 1640 mm separation of the top and bottom modules in towers, 20 mm strip widths and two 9 mm wide ST wire cells connected together the mean value of this parameter is $\approx$ 0.35° for vertical muons and improves with increasing zenith angle. However, this value can never be achieved, because of finite accuracy in the geometry determination and interactions of the particles in different materials that built up a detector, including tunnel shielding. We call *full intrinsic resolution* a parameter taking into account the above mentioned effects and showing how accurate a known muon direction above the tunnel can be reproduced with the MTD. In order to obtain this parameter a simulation study has been done, using the CRES (Cosmic Ray Event Simulation) Monte Carlo program, which is a GEANT3 based code developed for the KASCADE experiment. The sample of muons used as input particles reproduces the zenith and azimuth distributions of the showers reconstructed by the scintillator array with a realistic energy spectrum (Caso et al., 1998). In order to cover the uncertainty in the geometry of the detector two different *Geometry Data Bases* (DB) were used, one for the simulation of the reference track and another for the reconstruction of the track. The latter one was obtained starting from the former and smearing the positions of each module randomly with a sigma of 3 mm (assumed precision of our mechanical and optical measurements). The resulting distribution of true vs. reconstructed muon directions is plotted in top panel of fig. 4. The value, below which there is 68 $\%$ of all events, we call *full intrinsic angular resolution* of the MTD. In this case it is equal to 0.56°.

To lower this value one has to obtain better knowledge on detector geometry or/and improve *geometrical* resolution. The former is possible with various methods using cosmic muons, which allow to introduce corrections into DB. The latter requires some technical modifications such as single ST cell readout and utilizing drift time (Obenland et al., 2001).

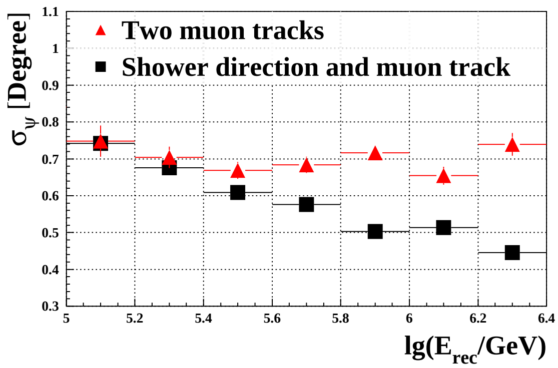

Fig. 5. Total angular resolution of the MTD as a function of reconstructed primary energy.

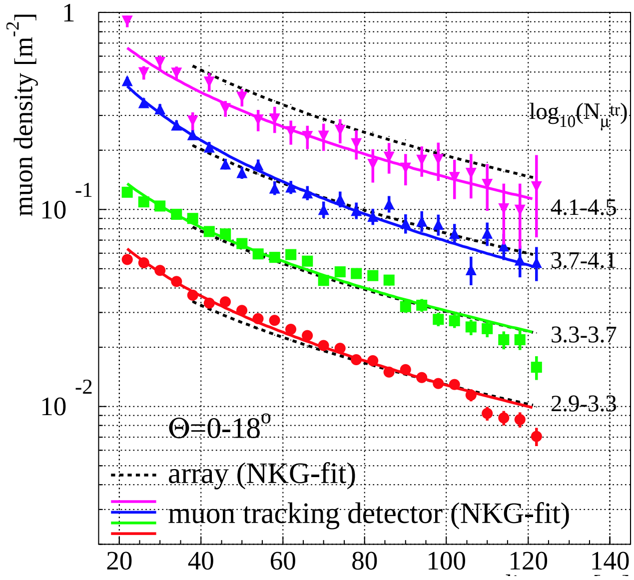

Fig. 6. Muon lateral density distributions for four different shower sizes $\lg(N_\mu^{tr})$ (Glasstetter et al., 1999) and zenith angles θ between 0° and 18°. Symbols represent data points from the MTD, and the solid lines fits to the data. The dashed lines are the fits to the data from the scintillation array (corrected for the threshold difference) for the same shower sample.

These techniques make it possible to obtain a *geometrical* resolution on the level of 0.2°.

In reality the true direction is not known and one is interested how accurate is the detector in pointing at the sky. This parameter, called *total angular resolution*, can be estimated by measuring the angle between two parallel muon tracks. High energy muons originating high in the atmosphere have to be used for this purpose. Tracks at large distance to the shower core are good candidates. They are not perfectly parallel, due to possible differences in production heights and due to multiple scattering in the atmosphere. But, since in real measurements we cannot avoid these two effects the value of resolution found this way includes these phenomena.

For the main application of the MTD, namely determination of the muon production height (Büttner et al., 2001), a resolution in determination of the angle between muon in MTD and the shower direction, determined from the array data, is an important parameter.

In fig. 5 the resulting *total angular resolution* as a function of reconstructed primary energy for the two cases mentionned above is given. We find that above 10^{14} eV one can measure the direction of a muon versus another muon with a precision of $\approx 0.7^\circ$. This number contains *full intrinsic resolution* of the MTD and the mean value of muon scattering angle in the atmosphere, which, based on the CORSIKA (Heck et al., 1998) simulations, one can estimate to be $\approx 0.6^\circ$. Measurements made with respect to the shower direction are more precise due to significantly better shower direction accuracy achieved by the scintillation array of KASCADE ($\leq 0.2^\circ$ above 10^{15} eV).

As an example of the MTD capabilities muon lateral distributions are presented in fig. 6. It has to be noted, that the good agreement with the KASCADE array results confirms the proper understanding of the MTD efficiency.

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