Operation and Performance of CRT Detectors at the HEGRA Array

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ABSTRACT

In the beginning of 1993, two CRT (Cosmic Ray Tracking) detectors were put into operation at the HEGRA air shower array. At least ten are planned to be installed there during 1993. The HEGRA array is used for the performance evaluation of single CRT detectors as well as for testing a small CRT array. The experimental setup at La Palma is described. Data from the HEGRA scintillator array and the two CRT detectors have been combined and a preliminary analysis of the data shows that the CRT detector performance is as good as expected. After installation of more CRT detectors, triggering with a small CRT array and shower reconstruction will be examined in detail.

1. INTRODUCTION

The Cosmic Ray Tracking detectors were proposed [1] in 1988 as a new method for the reconstruction of primary particle directions from extensive air showers (see also [2][3][4]). Conventional EAS arrays with scintillation counters derive the shower directions from timing measurements. Due to the scatter of arrival times of individual particles in the shower front, the scintillator EAS arrays need hits in many spatially separated detectors for a successful shower fit. Tracking detectors on the other hand take advantage of the correlation of arrival directions of individual secondary particles with the direction of the primary. The correlations predicted by Monte Carlo air shower simulations were verified by Gamp et al. [5] using a small-scale CRT detector prototype.

In the meantime, 20 full-scale detectors are being built, mainly for performance tests together with the HEGRA air shower array on La Palma, Canary Islands, at 2200 m a.s.l. The first two were delivered to La Palma in January and February 1993 and put into operation within two days after installation on the mountain. This paper is based on the experience with these two detectors and on a preliminary analysis of data obtained during the first weeks of operation.

2. DETECTOR OPERATION AT LA PALMA

Each CRT detector is equipped with a custom-designed VME-based FADC system and a local Motorola 68040 CPU. FADC readout, hit finding, track-finding, and detector self-calibration are done by the local computer running OS-9. The diskless local systems are connected to an OS-9 file server and a DECstation via Ethernet. Data (raw data, hits, tracks, monitor data, calibration data, as desired) are sent to the CRT DECstation for further processing and tape backup.

The CRT detectors can be operated stand-alone, except for data transfer, with an internal trigger or can be synchronized with a common trigger. In the current configuration at La Palma, the common trigger is obtained from the HEGRA EAS array. The programmable trigger systems of the CRT detectors allow changing quickly from one mode to the other.

Because HEGRA data and CRT data are recorded and processed separately, a cross reference list of run and event numbers is maintained on the OS-9 file server which has control of the common trigger. HEGRA event numbers are obtained there by a CAMAC-to-VME input register and CRT event numbers are sent to each detector before the next common trigger is enabled. The CRT modules process non-empty events and transmit the data to the DECstation at a rate of up to 35 Hz. Empty events with no tracks in a detector (about two third of all HEGRA triggers) require only a few milliseconds.

3. DETECTOR RESOLUTION

Each of the two drift chambers of a CRT detector is equipped with 6 sense wires. The drift time of each pulse (hit) is obtained by the difference-of-samples (DOS) method from the rising part of the FADC raw data. The internal error of this method is below 0.1 FADC bins, corresponding to less than 0.2 mm for typical isolated hits. In the case of overlapping pulses better results are obtained with an inverse z transformation, resulting in a 90% reconstruction efficency of hits separated by just 6 FADC bins (10 mm). The resolution in drift direction is mainly limited by diffusion (depending on drift distance) and ionization fluctuations along the track (depending on the inclination). The average resolution per hit is 1.0 mm, resulting in a $0.35°$ resolution for the reconstructed tracks.

The position along the wire direction in each chamber is obtained on two wires by charge division and the signals induced on cathode strips (pads). The resolution of the charge division (10 mm at a wire length of 1800 mm) is sufficient to resolve the ambiguity of the pads where every fourth pad of 20.5 mm length is connected to the same readout channel and, therefore, the coordinate is known only modulo 82 mm. Two additional wires (one wire in the first five modules) are equipped with pads to improve the track resolution and for a safer track reconstruction in the case of multi-hits or overflows on the charge-division wires. The pad coordinate resolution is mainly limited by noise due to the pad capacitance. The pad as well as the charge-division resolution can be improved by raising the gas gain. In practice, the gas gain is limited to avoid saturation of the charge-integrating preamplifiers, except very close to the shower core. With a saturation limit of some 30 hits per wire, the pad resolution is about 1.2 mm, resulting in a $0.5°$ track resolution in wire direction. The fit residuals in drift and wire direction were also used to look for systematic misalignments. For wires as well as pads the relative misalignments were found to be below 0.1 mm.

A first internal check of the resolution is achieved by comparing the slopes of muon tracks in both chambers. Muons are identified as matching pairs of tracks above and below the 10 cm thick iron plate. Isolated muons obtained with the internal trigger have typical energies of the order of 2 GeV, corresponding to multiple scattering angles in the iron plate of the order of $1°$. Muons in air showers triggering the HEGRA array have typical energies an order of magnitude higher, according to Monte Carlo simulations, giving only some 0.1–$0.2°$ scattering in the iron plate. The $0.87°$ resolution of the matching angle (see fig. 1) of muons selected from HEGRA-triggered events shows that the expected $0.6°$ resolution is not much deteriorated by electric field irregularities and mechanical distortions of the drift caches. The average misalignment of upper and lower drift chamber is of the order of $0.05°$.

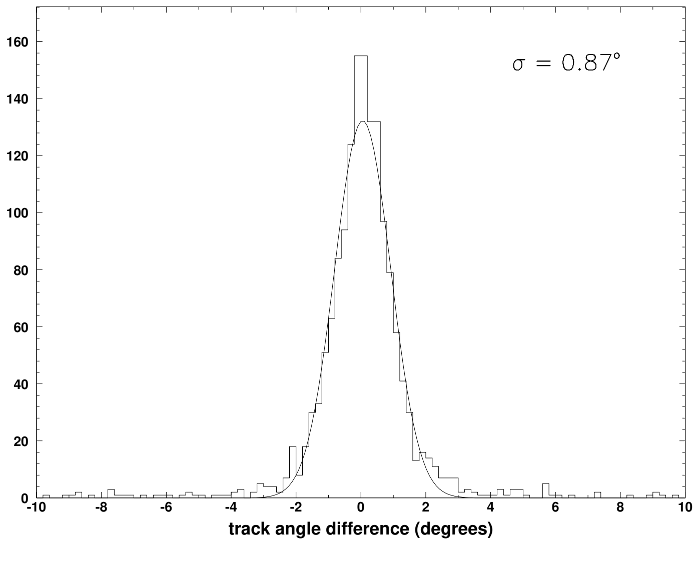

Fig. 1: Histogram of projected angles between tracks in upper and lower drift chambers for muons selected from HEGRA-triggered events.

4. MEASUREMENTS OF PARTICLE ANGLES IN SHOWERS

After calibration of the positions and rotation angles of the CRT detectors in the reference frame of the HEGRA array, the muons in HEGRA-triggered events were also used for tests of the external angular resolution. In this test the angular resolution of the HEGRA array and the intrinsic angular distribution of particles have both to be taken into account. The CRT detector resolution can be improved for muons by combining the track slopes in the upper and the lower chamber. The resolution of the HEGRA scintillator array, as obtained by observation of the sun and moon 'shadows' is $0.7 \pm 0.1°$ in solid angle [6], corresponding to $0.5°$ in projected angles.

Concerning the intrinsic distribution, two projections have to be distinguished in the reference frame of the shower. Apart from multiple scattering in the atmosphere, the radial angle component between track and shower (see fig. 2) reflects the production angles and distribution along the shower axis, where the muons (or more precisely their parent pions and kaons) were created. The distribution of tangential angles, on the other hand, is expected to be quite narrow, due to the narrow hadronic part of the shower.

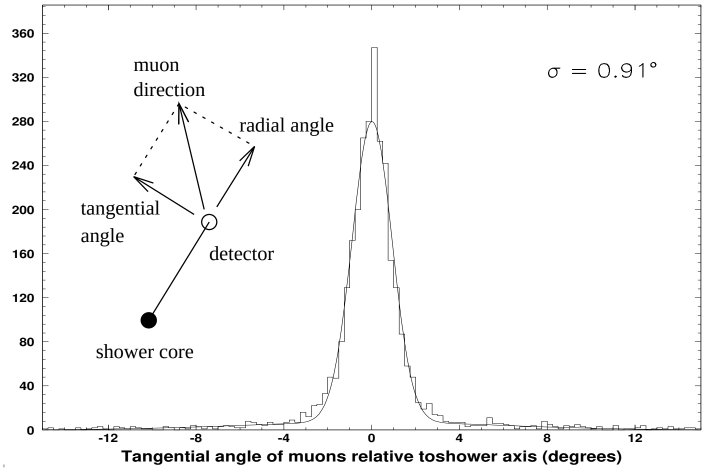

Fig. 2: Distribution of tangential angle differences between single muon tracks observed by CRT detectors and the shower direction obtained from the HEGRA scintillator array.

After a preliminary correction for a systematic deviation between CRT and HEGRA zenith angles which becomes significant only for zenith angles exceeding some $25°$, the combined resolution of CRT muon track reconstruction, HEGRA shower fit, and intrinsic muon width is $0.9°$ (see fig. 2). Without any correction, a $1.1°$ resolution was achieved. This resolution is essentially independent of the distance of the CRT detectors from the shower core.

The electron distributions in radial as well as tangential projection (fig. 3) with a full-width-half-maximum of $5°$ are significantly broader than the muon distributions. The tails of the distributions include badly reconstructed tracks from very crowded events due to the

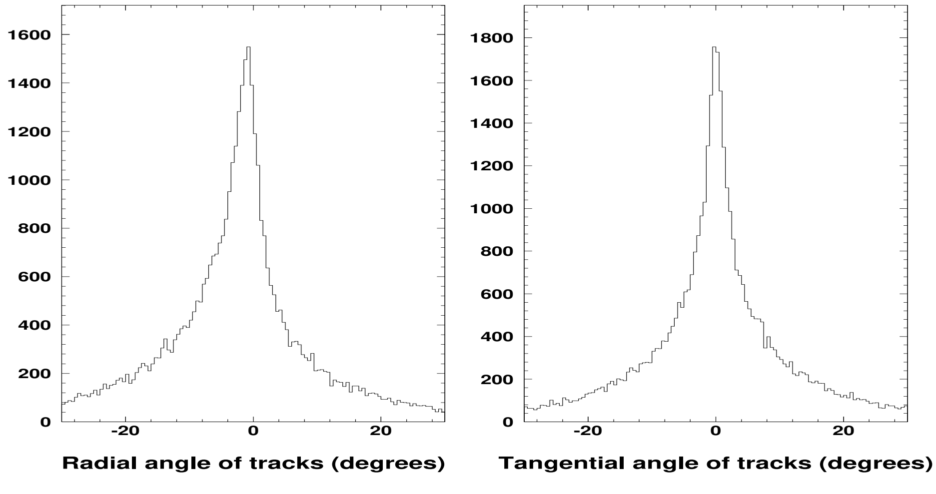

Fig. 3: Distributions of radial and tangential angle differences between charged particles (mainly $e^{\pm}$) observed by CRT detectors and the shower direction obtained from the HEGRA scintillator array.

deterioration of charge-division and pad coordinates of multi-hits. This should not affect much the resolution of an array of CRT detectors if the detectors are installed at alternating angles. It will also be significantly improved with detectors having 4 instead of 3 wires per chamber with cathode-strips readout.

It is quite interesting to see the dependence of the mean (or more precisely: the most probable) radial angles of electrons and muons as a function of core distance (fig. 4). Electrons in the inner part of the shower have an average inclination to the shower axis increasing by $0.1°$ per meter distance, corresponding to an apparent origin on the shower axis at a height of 570 m (1.5 radiation lengths) above the detectors. The curve flattens to $0.035°/\mathrm{m}$, corresponding to an apparent origin at 1600 m relative height, i.e. much closer to the shower maximum. The apparent origin of muons is much higher, between 2800 m in the inner part and 4400 m in the outer part, i.e. around the shower maximum.

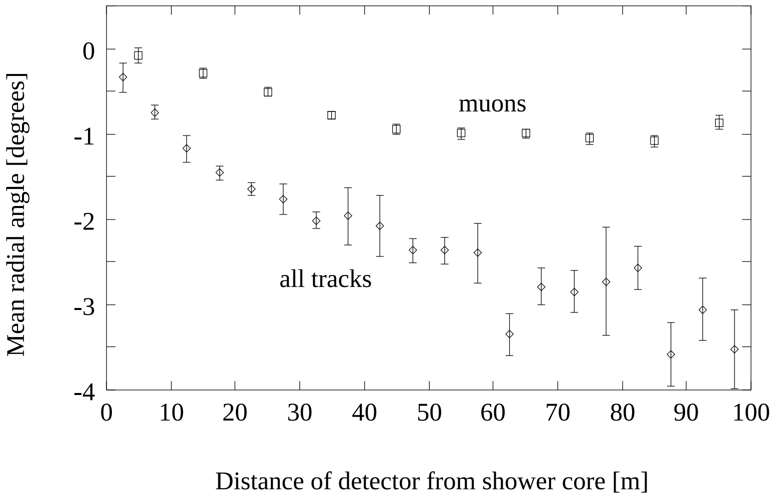

Fig. 4: Dependence of the mean (most probable) radial angle of muons and all charged particles (electrons) on horizontal distance of the CRT detector from the HEGRA shower core.

5. CONCLUSIONS

The transport of the first CRT detectors to La Palma, the installation there, and the detector operation, stand-alone as well as together with the HEGRA array, worked without problems. The detectors were even operated unattended over several weeks, with automatic detector self-calibration. No gas degradation was observed so far.

The internal resolution of the CRT detectors and also the resolution obtained by comparison with HEGRA data are well within the initial specifications. The single-detector resolution is good enough for a detailed study of the angular distributions of shower particles. A 10-detectors CRT test array at La Palma, although being too small for a search for cosmic γ-ray sources, will enable us to test shower reconstruction algorithms under realistic online conditions and to evaluate the performance that can be expected from the planned full-sized CRT array consisting of almost 400 modules.

References

[1] J. Heintze et al., 1988, Cosmic Ray Tracking – ein neuer Weg für die γ-Astronomie bei hohen Energien, Proposal an das BMFT;
M. Feuerstack et al., 1990, Addendum to the proposal "Cosmic Ray Tracking – A New Approach to High-Energy γ-Astronomy"

[2] J. Heintze et al., 1989, Nucl. Instr. and Meth. A277, 29

[3] J. Heintze et al., 1989, Exp. Astron. 1, 21

[4] D. Brecht et al., 1992, Nucl. Instr. and Meth. A323, 60

[5] S. Gamp et al., 1992, Phys. Rev. D46, 2831

[6] M. Merck et al., 1992, 26th Intern. Conf. on High-Energy Physics, Dallas, USA