# Performance of Cosmic Ray Tracking (CRT) Detectors

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**Abstract**

The Cosmic Ray Tracking (CRT) detectors as a new type of air shower detectors have undergone extensive performance tests at the site of the HEGRA array on La Palma. Ten detectors are in operation there for two years now. The CRT detectors are made of two large-volume drift chambers and a 10 cm thick iron plate in between. Muons can be distinguished from other types of particles. With an array of CRT detectors air showers can be reconstructed from the arrival directions of secondary particles in the shower. The detectors, performance parameters of single detectors like track reconstruction efficiencies, muon identification, and angular resolution are presented as well as the resolution of the mini-array currently in operation on La Palma.

## 1 The CRT detectors, electronics, and readout

The CRT detector system was designed to measure the direction of air showers by the tracking method, i.e. by the directions of secondaries in the showers [1]. With ideal detectors an angular resolution of the order of $2.5°/\sqrt{n}$ could be achieved where $n$ is the number of registered tracks in a shower ($3.5°/\sqrt{n}$ under realistic assumptions). In small showers, an array of tracking detectors can use the directional information provided by the particles near the shower core. Therefore, an array of tracking detectors can achieve a lower threshold in terms of shower size or primary energy than a scintillator array of comparable size. If such an array provides a good hadron discrimination by selecting muon-poor showers it can be used to search for $\gamma$-ray sources.

A CRT detector consists of two circular drift chambers of 1.8 m diameter and a 10 cm thick iron plate in between as a muon filter. Drift chambers and iron plate are mounted in a gas-tight container filled with an argon-methane mixture. The gas needs to be exchanged only once per year. Each drift chamber has 'D'-shaped field cages on both sides of the wire frame with six proportional wires between aluminium profiles. To determine through which field cage an ionizing particle passed, the wires are offset (staggered) by $\pm 2$ mm with respect to the middle plane of the wire frame.

In each drift chamber a fully three-dimensional track reconstruction is achieved. For that purpose two wires per chamber are read out on both sides (charge-division) and four wires are equipped with segmented cathode boards (pads). All wire and pad signals are digitized with a 40 MHz Flash-ADC system and read out by a local computer. One coordinate ($x$) is obtained from the drift time of reconstructed hits, one ($y$) from the charge-division and the pad signals, and the third ($z$) is the height of the wires. To save readout channels every fourth of the 88 pads of a cathode board is connected to the same preamplifier. The less precise charge-division is therefore required to resolve a 22-fold ambiguity of the pad coordinates. For an easy calibration of the drift velocity with cosmic-ray muons penetrating the iron plate, the drift directions in upper and lower drift chambers are perpendicular. For details see [2].

A central station is used to coordinate triggers and event numbers and to record event times. A UNIX workstation is used to collect the data from the CRT modules and the central station. Each CRT detector module is taking data independent of the other modules, except for the common trigger plus event number from the central station. FADC readout, hit and track reconstruction, and transmission to the UNIX workstation via Ethernet are done by the local computer, using multiple queues for raw and processed data to minimize dead-times. The detector calibration is also done online, mainly with the cosmic-ray data. With a 25 MHz Motorola 68040 CPU about 50 events can be processed per second.

A prototype CRT array of 10 detectors is in operation at the site of the HEGRA array [3] on La Palma island for about two years. For part of the time the CRT array has been operated independent of HEGRA and for the other part it has been taking data with a trigger provided by the HEGRA array. HEGRA data are recorded separately and combined offline with CRT.

## 2 Track reconstruction and muon identification

Tracks are identified if hits on at least four of the six wires are close enough to a straight line in drift direction ($x$–$z$ plane). Then, the reconstruction in the second projection is done, using the measured charges of the charge-division wires and the pads.

Muons are identified if a pair of a track in the upper chamber and one in the lower chamber is found with an angle between them of less than $2.5^\circ$ in each projection. The track intersection in the iron plate must match to better than 30 mm in a linear combination independent of the trigger delay and to better than 50 mm in the orthogonal combination when triggered by the HEGRA array. Random muons arriving before or after the shower are identified as such.

To reduce the background of punch-through electrons it is required that there are no other tracks in the lower chamber with an intersection in the iron plate less than 60 mm from the muon track. In HEGRA-triggered showers only $0.07\%$ of the electrons are misidentified as muons. A large CRT array searching for $\gamma$-ray point sources could reject hadronic showers by a single identified muon. The overall muon identification efficiency was found to be about 87%, and above 2 GeV/c muon momentum the efficiency is about 92%.

Near the cores of large showers the track reconstruction and even more the muon identification are hampered when a CRT detector is hit by many particles. The preamplifiers are saturated after about 20 hits. Usually, no more than 10–15 tracks are found in a chamber. A noticeable deterioration of the muon identification already sets in when a CRT detector is hit by more than about 5 particles. This would be of no concern for a possible low-threshold CRT array with hundreds of detectors where in a typical shower about 40 tracks would be recorded, distributed over 30 detectors.

## 3 Track resolution

The angular resolution of a CRT detector for particle tracks in general and for muons in particular has been measured in several ways with consistent results.

The spatial resolution for single hits can be deduced from the residuals of the track fits, independently for drift and wire direction. Due to the diffusion of electrons during their drift to the wires this resolution depends on the drift distance. Due to the fluctuation of the ionization along the paths of the particles the resolution also depends on the angle of incidence. Both effects are illustrated in fig. 1. On average, spatial resolutions of 0.9 mm in drift and 1.1 mm in wire direction are achieved, corresponding to angular resolutions of $0.31^\circ$ and $0.43^\circ$, respectively.

For a muon the angle between the track in the upper chamber and the one in the lower chamber is measured. For shower muons of a typical momentum of about 10 GeV the multiple scattering in the iron plate is small compared to the angular resolution. The resolution can, thus, be obtained from the angles between upper and lower tracks as shown in fig. 2. The measured RMS angle of $0.57^\circ$ accounts for the resolution in both chambers and the multiple scattering. It corresponds to a resolution per drift chamber of $0.40^\circ$. This is consistent with the angles of muons with respect to the

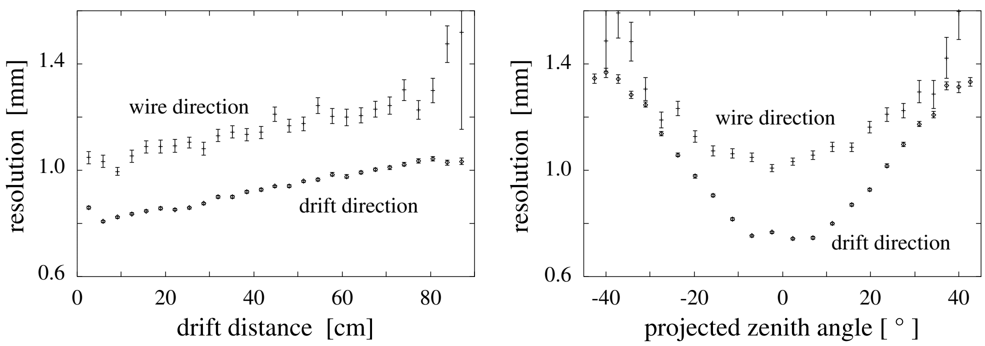


Figure 1: Hit resolution of the CRT drift chambers as functions of drift distances to the wires (left) and zenith angles in the corresponding projection (right).

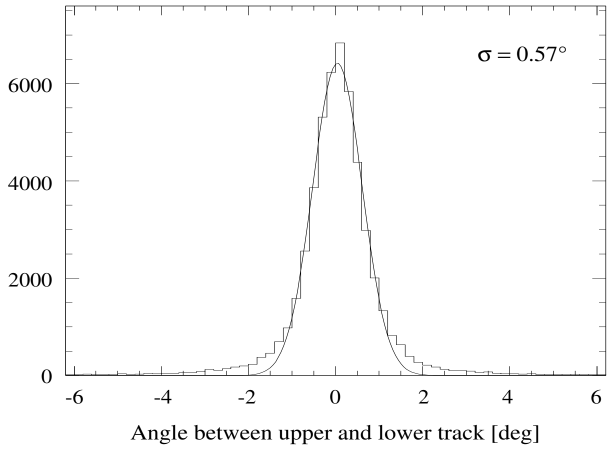


Figure 2: Histogram of angles between muon tracks in the upper chamber and the corresponding tracks in the lower chamber. Muons from air showers were selected with a trigger from the HEGRA scintillator array.

shower axis measured by the HEGRA scintillator array [4] and the angles between multiple muons in one shower.

## 4 Performance of the small CRT array

The angular shower resolution achieved with eight CRT detectors has been evaluated by comparison with the HEGRA scintillator array, using HEGRA-triggered data. Tracks in the CRTs were transformed to a common reference frame and a maximum-likelihood fit was applied to derive the CRT shower direction. The CRT shower resolution has shown to improve like $A/\sqrt{n}$ with increasing number of recorded tracks. For showers with cores inside the CRT test-array $A \approx 4.0-4.5°$. This is essentially consistent with the anticipated resolution of about $3.5°/\sqrt{n}$ for a large CRT array, considering the incomplete covering of showers by only eight detectors and the saturation effects: a typical HEGRA shower inside the test-array has several tracks per detector while in a large CRT array a typical shower would have of the order of 0.1 tracks per detector.

It can be concluded that the CRT detectors are successfully operating at La Palma for two years now – usually remotely controlled, without permanent on-site staff – and that the expected performance goals with the test-array have been met. The developed detectors, including the drift chambers and all custom-designed electronics are robust enough for long-term operation at mountain-altitude conditions.

## References

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[4] K. Bernlöhr et al., this conference, session OG 6.