2.3.1 The CRT project

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The Cosmic Ray Tracking (CRT) detectors use two drift chambers of 2.5 m^2 area and a 10 cm thick iron plate between them to measure particle tracks in extensive air showers and to distinguish muons from other particles. The installation of ten of these detectors at the HEGRA experiment on La Palma was operated until May 1996. Analysis of data taken together with the HEGRA array was continued and the average mass composition of cosmic rays at energies near 10^{15} eV was studied.

Introduction

The original aim of the CRT project [1] was to install an observatory for γ-rays with energies from a few 10^{12} eV (TeV) to 10^{15} eV (PeV). Such γ-rays cause particle cascades in the air, the extensive air showers, and could be observed by measuring the shower particles with a large number of tracking detectors. The much more abundant showers induced by charged cosmic rays (protons and nuclei) could be discriminated due to the larger number of muons in such showers. Suitable detectors [2] were developed in recent years and ten detectors were tested under mountain-altitude conditions at the site of the HEGRA (High-Energy Gamma-Ray Astronomy) experiment on La Palma (Canary Islands).

Despite the fact that these detectors performed very well [3] and a CRT array would achieve a lower energy threshold and better sensitivity than any existing array [4], the plans for an observatory with 400 detectors have been given up. Instead, the institute is focusing on the imaging atmospheric Cherenkov technique which achieves still lower energy thresholds and better discrimination of hadronic showers than possible with a CRT observatory. In contrast to a CRT array, however, Cherenkov telescopes are not suitable for all-sky monitoring.

The CRT test installation on La Palma, on the other hand, turned out to be of high value in a slightly different area than originally planned. In conjunction with the HEGRA array it was used to investigate changes of the average mass of cosmic rays at the so-called knee in the cosmic-ray flux spectrum at energies near 10^{15} eV.

Measurements on La Palma

The ten CRT detectors on La Palma were taking data together with the HEGRA array until May 1996. Then the two detectors located on helicopter ports outside of the HEGRA array had to be relocated and the helicopter ports to be cleared for a visit of the Spanish king. The measurements for the cosmic-ray mass composition could not be continued without detectors measuring muons far from the shower core. Because of delays in the delivery of the 120 MHz FADC systems for the Cherenkov telescopes it was decided to use 40 MHz FADCs from the CRTs in the meantime. Therefore, no data was taken after May.

Until then, the CRT detectors worked – like in previous years – without problems. Data taking was controlled via network from Heidelberg. All data reconstruction was done on-line and no maintenance or operator work on La Palma – other than changing of the data tapes by the HEGRA shift crew – was necessary. The argon-methane counting gas in the steel containers was still of good quality after more than two years since the last refilling. No decision has been made yet if the CRTs should be operated again when the FADCs are available or if the detectors should be removed from La Palma.

Investigation of the cosmic-ray composition

The cosmic-ray flux spectrum follows a power-law over more than nine decades in energy, except for the *knee* near 10^{15} eV. Whether this kink in the spectrum is due to changes in the acceleration mechanism or in the propagation in our Galaxy, or due to a turnover from one class of sources to another is yet unclear. Possible hints to solve this puzzle are expected from studies of the mass composition at energies around the knee.

The data from the CRT detectors and the HEGRA array are combined to measure angles of particles with respect to the shower axis. For muons this can be done very well over a large range of shower sizes N_e (the number of electrons and positrons arriving at detector level), with very small systematic uncertainties. Although the mass of individual cosmic-ray primaries cannot be determined with only 25 m^2 of muon detection area, the radial angle method [5] allows an accurate determination of $\langle \ln A \rangle$, the mean logarithm of mass numbers A of many showers.

For this purpose, the median of muon radial angles (angles projected on a plane through shower core

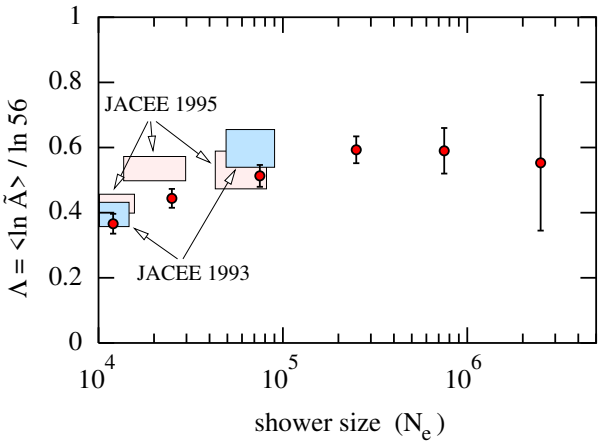

Fig. 2.1: Results of the cosmic-ray composition analysis based on muon radial angles in terms of the parameter Λ. Only statistical errors are shown. The range of shower sizes displayed corresponds to energies from about 10^{14} to more than 10^{16} eV. For comparison the direct composition measurements of the JACEE collaboration [6] are indicated with corresponding statistical errors (boxes).

and CRT detector) is determined as a function of shower core distance and compared with expected values from simulations. Showers of protons and light nuclei penetrate deeper into the atmosphere and therefore give larger median radial angles than showers of heavy nuclei. Results of this comparison can be expressed in terms of a parameter Λ which is zero if the data matches simulations for protons and which is one, if the data matches simulations for iron nuclei. For the muons there is a good compensation of the HEGRA selection bias (in favour of protons and light nuclei) by the larger number of muons in showers induced by heavy nuclei. It turns out that in fact $\Lambda \approx \langle \ln A \rangle \; / \; \ln 56$, quite independent of the actual composition. Results (see figure 2.1) indicate that $\langle \ln A \rangle$ indeed increases near the knee but no change to a completely different class of sources is seen.

[1] J. Heintze et al., Nucl. Instr. and Meth. A277, 29 (1989).
[2] K. Bernlöhr et al., Nucl. Instr. and Meth. A369, 284 (1996).
[3] K. Bernlöhr et al., Nucl. Instr. and Meth. A369, 293 (1996).
[4] K. Bernlöhr, Space Science Reviews 75, 185 (1996).
[5] K. Bernlöhr, Astroparticle Physics 5, 139 (1996).
[6] K. Asakimori et al., Proc. 23rd ICRC, Calgary, Vol. 2, p. 21 and 25 (1993).
T. Tominaga et al., Proc. 24th ICRC, Rome, Vol. 2, p. 707 (1995).