Using Cherenkov pulse shapes to estimate mass composition

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Abstract

Composition measurements at TeV energies are traditionally made with satellite or balloon borne detectors which benefit from good discrimination but are severely limited by their collecting area and so yield poor statistics, particularly at higher energies. We have made ground based measurements with the atmospheric Cherenkov telescope BIGRAT, discriminating between different species of cosmic ray primary through characteristics of the Cherenkov pulse shape. By collecting data at low elevations, an increasing energy threshold for the detector allows us to probe a large energy range while maintaining reasonable statistics. A comparison of our data with Monte Carlo simulation is presented here.

1 Introduction:

The mass composition of the galactic cosmic ray background is well studied at low energies. However, above 1 TeV these measurements become difficult due to the steeply falling energy spectrum and the limited collecting area of the satellite experiments (Asakimori et al., 1999).

It is also possible for measurements to be made employing the atmospheric Cherenkov technique of ground based *Gamma ray astronomy*. While we suffer a loss in the ability to identify cosmic ray species on an individual basis, this is more than made up for by a drastic increase in collecting area (typically from about 0.1 km^2 at zenith, to about 1 km^2 at a zenith angle of 70^o and beyond).

By looking down through more and more atmosphere at larger zenith angles, the increase in energy threshold allows us to probe from TeV energies up to potentially PeV energies (particle array energies) in a far more effectual way than by a simple increase in triggering threshold of the detector. We then do not require the detector to have a particularly large dynamic range, and the increased collecting area at these low elevations provide us with a reasonable data collection rate even at energies of 100 TeV.

2 The atmospheric Cherenkov detector:

It is common in Gamma ray astronomy to distinguish the faint gamma ray signal from the cosmic ray background by selecting data on the basis of the Cherenkov angular image observed in the telescope's field of view.

Another technique, which is less powerful as a Gamma ray selector, is to classify these Cherenkov events from extensive air showers by their relative arrival time distributions or *pulse shapes* which are sensitive to the longitudinal development of the extensive air shower. There has been renewed interest in the pulse shape method recently (Chitnis & Bhat, 1999; Roberts, 1999), especially as a means to probing the mass composition, because of the simplicity and relative low cost of such an experiment.

2.1 Data collection: Data were collected using the University of Adelaide Gamma ray telescope BIGRAT situated at Woomera, South Australia. Fast response photomultipler tubes (PMTs) with a field of view of about 1.5^o were set on-axis at the focus of the two (four metre diameter) outer mirrors of the telescope. Cherenkov signals from each PMT were sampled in time steps of 0.4 ns, and only coincident events triggering both PMTs were considered for analysis. Pulses with heights off-scale were removed and the remaining data were then parameterised.

Cherenkov signals from local muons are used to directly measure the system response and are used for modelling the telescope performance in simulation. Also background light (sky noise) is directly sampled with the telescope by randomly triggering on the night sky. This is collected for each Cherenkov data file so that we can create the same operating conditions when matching real and simulated data.

2.2 System calibration:

The system is calibrated by a number of methods:

1) Triggering the system with Cherenkov pulses produced in the glass faceplate of the PMTs by local muons.
2) Measuring the tube gain of each PMT in the lab.
3) Matching trigger rates of the data with that of simulated cosmic ray events.

3 The Cherenkov pulse shape:

The pulse shape is parameterised typically into three quantities: rise-time, RT (10 - 90% of pulse maximum); full-width-at-half-maximum, FWHM (50 - 50% of pulse maximum); and fall-time, FT (90 - 10% of pulse maximum).

Even though it has been claimed elsewhere (Chitnis & Bhat, 1999) as the most sensitive parameter to primary species, FT has been ignored here due to the difficulties in optimising the electronics of the PMT base to obtain a clean consistent trailing edge on the output pulse,

The FWHM of the pulse is largely a measure of the bulk Cherenkov signal from the electromagnetic component of the extensive air shower, and is highly dependent on core distance.

It has been shown elsewhere (Roberts, 1993) that, inside the shoulder of the Cherenkov lateral distribution, the leading edge of the pulse contains the signal from the penetrating muon component of the shower which precedes the rest of the pulse. At larger zenith angles, the increased distance from observer to shower maximum allows this muon signal to separate more from the electromagnetic component and the leading edge should broaden appreciably. This will be true mainly for lower energy showers, close to the energy threshold of the detector, which develop high up in the atmosphere and so reach shower maximum earlier than the more penetrating high energy showers.

The dynamic range of the current system is only about 25 - 170 photoelectrons of pulse height, but (as indicated above) this will not be a hindrance since we will use the increased atmospheric thickness at low elevations to probe higher energies.

4 Comparison of simulations with real data:

From July 1997 to September 1998, Cherenkov events were collected across a range of zenith angles. The complete data set consists of 2.5 hours at zenith, 3.5 hours at 60^o, 5 hours at 70^o, 7 hours at 75^o, and 25 hours at 80^o. Table 1 shows the dependence of event rate on zenith angle. Even at 80^o (looking through about 5 atmospheres) the the event rate is still reasonable.

Only data at zenith will be presented here. The simulation package CORSIKA (Knapp & Heck, 1999) was used in conjunction with the HEGRA IACT routines (Bernlohr, 1999) to produce some data files of proton and iron primaries. The proton file was generated with a spectral index of -2.8 consistent with satellite measurements (Asakimori et al., 1999) and the iron file was generated with a flatter spectrum of -2.5 (Nilsen & Zager, 1999). The respective energy thresholds are approximately 2 TeV for protons and 11 TeV for iron nuclei. Figure 1 shows the comparison of the FWHM and RT distributions for these cosmic ray primaries with that of some real Cherenkov data recorded at zenith. At this elevation, it appears that FWHM would be the better discriminating tool as suggested elsewhere (Roberts, 1993). However even from the RT distributions, it can be seen that the real data cannot be fully matched using purely proton data. Previously, we had analysed our

Zenith Angle (deg)	0	60	70	75	80
No. Atmospheres (approx)	1	2	3	4	5
Event Rate (Hz) $\geq$ 25pe	0.4	0.15	0.05	0.015	0.003

Table 1: Experimentally measured event rates compared with the zenith angle of observation (and the corresponding atmospheric thickness).

real data using the simulation package MOCCA92 (Sinnott et al., 1997), and found that even for a composition of pure Iron the simulated FWHM distribution was narrower than that obtained from the real data.

5 Conclusion:

There appears to be useful information in the relatively simple pulse shape parameters for making estimates of the mass composition of primary cosmic rays. Running simulations at larger zenith angles for a comparison with the available data will hopefully shed some light on the efficacy of this technique for future work.

6 Acknowledgements:

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References

Asakimori, K. et al. 1999, ApJ (in press)
Bernlohr, K. 1999, CORSIKA and SIMTELARRAY User Guide (private communication)
Chitnis, V.R. & Bhat, P.N. 1999, Astrop. Phys. (in press)
Knapp, J. & Heck, D. 1999, CORSIKA User Guide 5.86 (private communication)
Nilsen, B.S. & Zager, E. 1999, Antarctic Journal of the United States (in press)
Roberts, M.D. 1993, Phd thesis, Adelaide
Roberts, M.D. 1999, 'Cosmic Ray Composition estimation below the knee of the spectrum' (in press)
Sinnott, M.D. et al. 1997,Proc. 25th ICRC (Durban),4,61

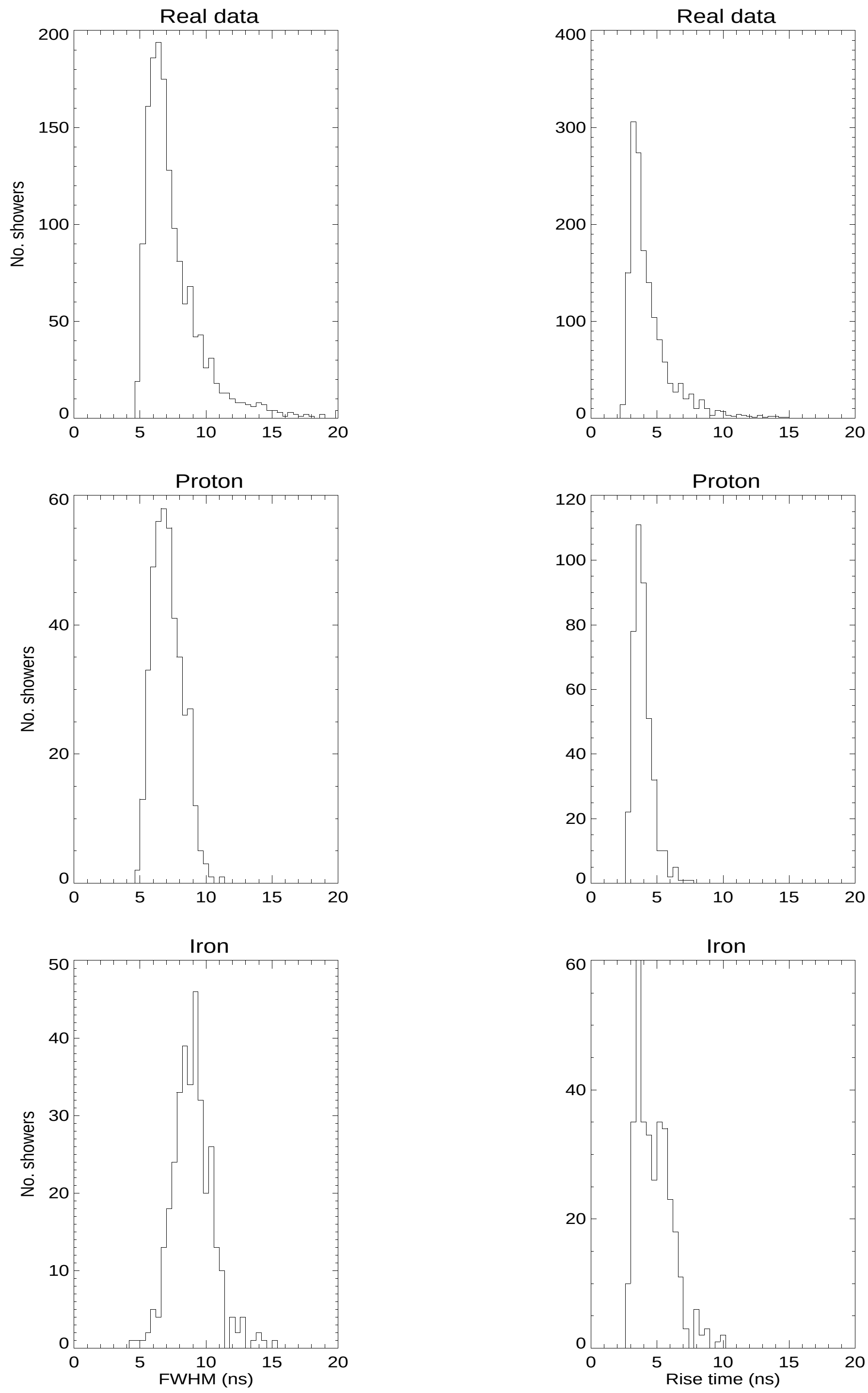

Figure 1: FWHM and RT distributions of real data, proton primaries and iron primaries.