29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

Active Atmospheric Calibration for H.E.S.S. Applied to PKS 2155-304

Brown, A.M.[a], Chadwick, P.M.[a], Dickinson, H.J.[a], Hadjichristidis, C.[a],
Latham, I.J.[a], Le Gallou, R.[a], Masterson, C.[b], McComb, T.J.L.[a], Nolan, S.J.[a],
Noutsos, A.[a], Orford, K.J.[a], Rayner, S.M.[a], Spangler, D[a]. for the H.E.S.S. Collaboration
(a) Physics Department, Durham University, South Road, Durham, County Durham, DH1 3LE, United Kingdom
(b) Max-Planck-Institut für Kernphysik, P.O. Box 103980, D 69029 Heidelberg, Germany
Presenter: S.J. Nolan (s.j.nolan@dur.ac.uk), uki-nolan-S-abs2-og23-poster

Using data derived from the H.E.S.S. telescope system and the LIDAR facility on site, a method of correcting for changing atmospheric quality based on cosmic-ray trigger-rate is presented and applied to data taken on the active galactic nuclei PKS 2155-304. These data were taken during August and September 2004, when the quality of the atmosphere at the site was highly variable. Corrected and uncorrected fluxes are shown, and the method is presented as a first step towards a more complete atmospheric calibration.

1. Introduction

Imaging Atmospheric Cherenkov Telescopes (IACTs) rely heavily on the atmosphere as their detecting medium. Although the atmosphere gives the telescope systems huge effective areas, daily variations in atmospheric quality can affect the system performance and lead, in the worst cases, to systematic bias in the estimated energy of a given event. Significant effort has been made in the past to take account of this problem by using the cosmic-ray background seen by the telescope on a given night to normalise the data [1]. However, given a better understanding of the location of atmospheric aerosol populations from LIDAR measurements and via modelling of these populations, it is possible to determine an active atmospheric correction to the data. Herein, such a technique is discussed as applied to observations with the H.E.S.S. telescope array of the active galactic nucleus (AGN) PKS 2155-304.

2. Technique

The LIDAR system at the H.E.S.S. site works at a wavelength of 905 nm, and has an active range of 7.5 km. It is mounted on an alt-azimuth drive allowing on-source pointing during observations. During August and September 2004, a large population of low-level aerosols was seen by the LIDAR, concurrent with a significant drop in the H.E.S.S. array trigger-rate for cosmic-rays. This population was seen to vary on a night to night basis, but not within a given night. In order to simulate its effects, the atmospheric simulation code MODTRAN was used to generate optical depth tables for wavelengths in the range 200 to 750 nm and for successive heights above the site (which is 1.8 km above sea level). The aerosol desert model within MODTRAN introduces a layer of aerosols into the first 2 km above ground level, whose density is then increased as the wind speed parameter is increased. Thus optical depth tables were produced for the range of wind speeds from 0 m/s to 30 m/s. The wind speed therefore acts as a tuning parameter to match simultaneously cosmic-ray trigger-rate and image parameter distributions, and is not a reflection of the measured wind speed at the site. These tables were then applied to a set of CORSIKA cosmic-ray simulations at 20 degrees from zenith and with a southern pointing, to best match the data taken on PKS 2155-304, and a cosmic-ray trigger-rate for each atmosphere was derived for the H.E.S.S. array based upon the spectra given in [2]. The simulated array trigger-rate versus wind speed is shown in figure 1.

By matching the trigger-rate from simulations and real data, taking into account zenith angle dependence

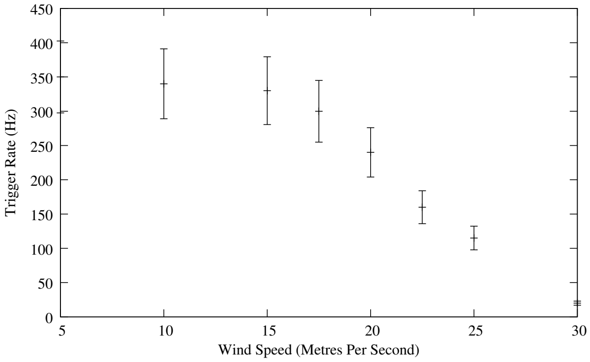

Figure 1. Simulated array trigger-rate for a spectrum of cosmic-rays [2], versus the wind speed used in the different atmospheric models applied.

effects and gain changes over the experiment lifetime, an atmospheric model can be selected. This is then applied to a full set of CORSIKA gamma-ray simulations within a telescope simulation code. The simulations cover the zenith angle range of the observations, and produce lookup tables for image parameter cuts, energy and effective area, and these in turn are applied to the data using the standard H.E.S.S. analysis procedure [3]. For August and September 2004, one of 3 possible atmospheric models matched for each night, with wind speeds of 17.5, 20.0 and 22.5 m/s, respectively. This can be seen in figure 2.

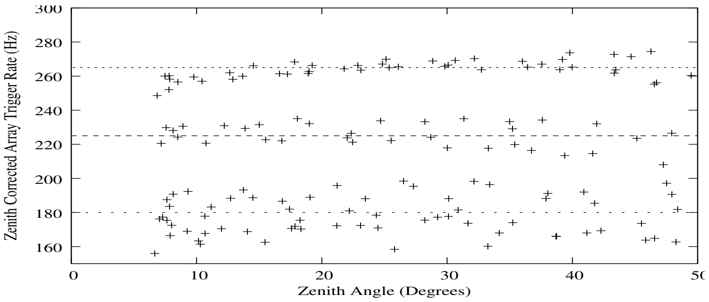

Figure 2. Shown is the H.E.S.S. zenith angle corrected cosmic-ray array trigger-rate versus zenith angle for nights in August and September 2004, for runs on PKS 2155-304. The dotted lines represent the cosmic-ray trigger-rate used for each of the three atmospheric models. In a given night, the atmospheric quality varied little, therefore a single model may be applied to a single night. The top population, clustered around ≈260 Hz, are also those runs passing the standard H.E.S.S. run selection. The three lines indicate the atmospheric models with wind speeds of 17.5, 20.0 and 22.5 m/s.

This three mode behaviour may also be seen if we consider the LIDAR output for a run on each of the three given classes of night, as shown in figure 3.

3. Application to the Crab Nebula

In order to test the method further, we selected several runs on the standard candle of very high energy (VHE) astronomy, the Crab nebula, under conditions where the LIDAR identified low-level dust. By creating simu-

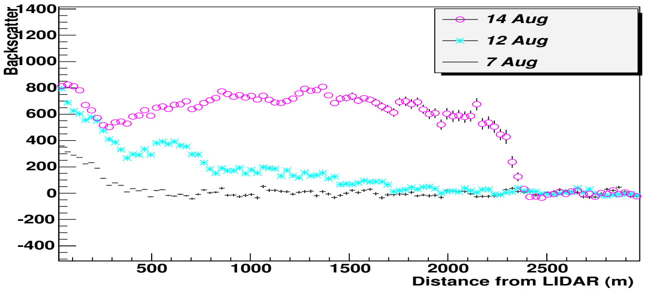

Figure 3. Shown is the H.E.S.S. LIDAR backscatter for runs taken in the direction of PKS 2155-304, for three separate nights. As discussed, the nights show the three different levels of atmospheric quality, and serve to verify that the aerosol population affecting the system is constrained to the first 2-3 km above the site.

lations with a North pointing (to take account of differences in the geomagnetic field), and matching the wind speed applied to the cosmic-ray trigger-rate seen on source, we studied a set of runs which would otherwise have been unusable, and were marked as such by our run selection criteria. Figure 4 shows the uncorrected and corrected integral flux above 1 TeV versus modified Julian date. The flux level reached by using an atmospheric model suggested by the cosmic-ray trigger-rate is consistent with the average integral flux seen from the Crab nebula under good atmospheric conditions. The spectral slope derived from these data remains within errors the same, although the flux normalisation is of course increased.

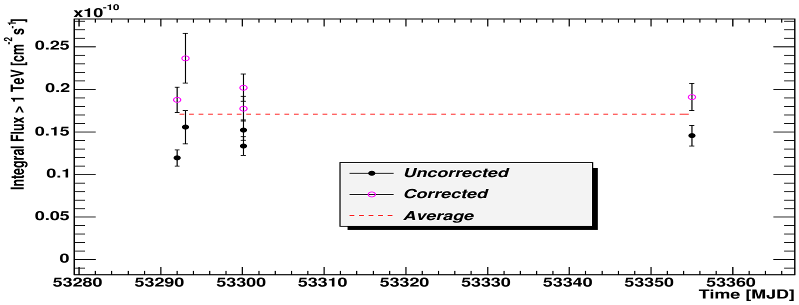

Figure 4. The run by run integral flux for the Crab nebula above 1 TeV derived from a total of 2.4 hours of observations taken in October 2004, when high aerosol levels were present. These data have a significance of detection of 38σ. The atmospheric model suggested by simulated cosmic-ray trigger-rate appears to be the best match the average flux reported in [4], which is marked on this figure as average.

4. PKS 2155-304

PKS 2155-304 is an AGN of the blazar class at a redshift of $z = 0.116$. It was first detected in TeV gamma-rays by the Durham Mark 6 telescope [5], and has been observed from the earliest days of H.E.S.S. experiment [3]. This data set is formed from 86 hours of four telescope observations. By combining flux data appropriately, figure 5 shows the results for corrected and non-corrected data in the form of a plot of the flux distribution derived on a run by run basis. Again, the derived spectral slope remains within errors the same.

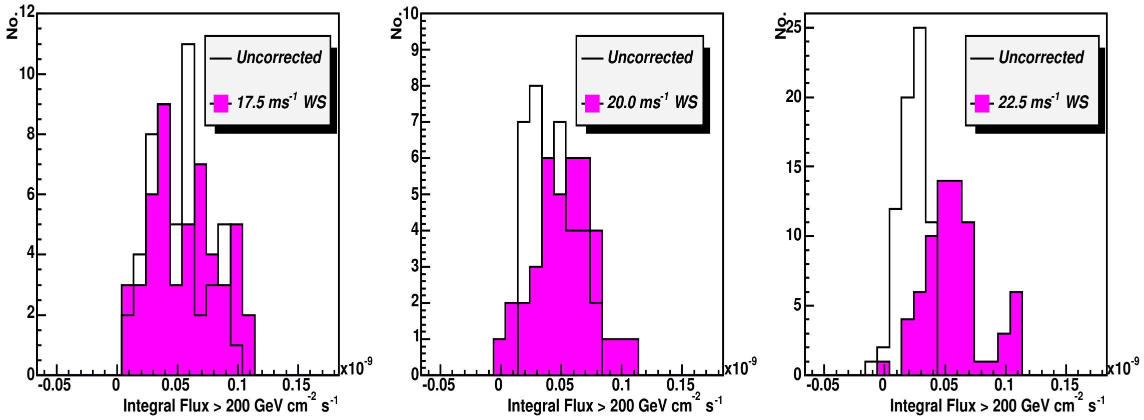

Figure 5. The distribution of the integral flux for PKS 2155-304 above 200 GeV derived from 28 minute runs is plotted before and after the application of corrections for low-level dust. As noted each panel shows a subset of the data for which the cosmic-ray trigger-rate and LIDAR suggest a differing atmospheric effect.

It is interesting to note, that if one considers the shift between corrected and uncorrected flux, the data recquiring the 17.5 m/s atmospheric model, which contains in fact only runs passing the standard selection criteria applied to all H.E.S.S. data, has a typical correction ratio which is within errors compatible with unity. All other runs would have been thrown out, and therefore the technique allow the resurrection of otherwise unusable data, and confirms the validity of current quality checks.

5. Conclusion

A new method for correcting for changes in low-level atmospheric quality is applied to the Crab nebula, a constant source, and to the variable source PKS 2155-304. The method, based on cosmic-ray trigger-rate, and LIDAR input, has allowed a corrected set of fluxes for PKS 2155-304 to be produced from data that would otherwise be unusable. To the lowest order, the effect on integral gamma-ray flux is seen to be proportional to the zenith and time corrected cosmic-ray trigger-rate. Further studies of this method are underway in application to a larger set of Crab nebula data and the reconstruction of cosmic-ray events as a testing ground for the procedure. In addition, with the implementation of a transmissometer for studying low-level atmospheric transmission [6], we hope to combine atmospheric modelling and measurements to further constrain our systematic errors.

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