29th International Cosmic Ray Conference Pune (2005) **7**, 365–368

Calibrating the High Resolution Fly's Eye (HiRes) Detector

J.N. Matthews and S.B.Thomas for the HiRes Collaboration

University of Utah, Department of Physics and High Energy Astrophysics Institute
115 S. 1400 E., Salt Lake City, Utah, USA 84112
Presenter: J.N. Matthews (jnm@cosmic.utah.edu), usa-matthews-John-abs3-he14-poster

We calibrate the HiRes detector via a variety of means. These include roving xenon flashers, lasers fired through optical fibers, and lasers fired in the atmosphere. Each of these techniques has advantages and disadvantages. For example, the roving xenon flasher is very stable; it can be measured and transported from detector to detector as a "Standard Candle". The optical fiber system has the advantage that each detector can be illuminated and compared simultaneously while the vertical laser system at 4km provides an end-to-end test all of the optical components (including mirrors and filters) at once. We discuss and compare the various techniques and their results.

1. Introduction

The High Resolution Fly's Eye (HiRes) detector [1] is calibrated and maintains its calibration via a variety of means. The calibration is measured and tested both piecewise and "end-to-end". The piecewise calibration uses such tools as Roving Xenon Flashers (RXF), YAG laser and optical fiber systems, reflectometers, NIST calibrated photodiodes, and spectrophotometers. The end-to-end calibration uses nitrogen and YAG lasers, filters and pyroelectric probes. In the end, all techniques are compared both to determine consistency in the calibration as well as to assess its uncertainty.

2. Piecewise Calibration

The Roving Xenon Flasher is a portable stable standard candle which can be taken from camera to camera and site to site over the course of an evening and used to illuminate each detector in turn. The final optical element in the RXF is a 355 nm narrow band pass filter (10 nm FWHM) so that this calibration can be directly compared to that of the YAG system which is also 355 nm. This wavelength is approximately at the center of the HiRes UV band pass filter acceptance. The RXF has been shown to be stable at the level of 0.5% over an evening and to a few percent over months. [2] One night per month is typically devoted to RXF calibration and the standard candle is taken to each detector.

Most frequently the RXF calibration data is analyzed using pulse height analysis and a comparison of width to mean. [3] However, periodically, the RXF itself is calibrated at the beginning and end of the evening. Its output is measured via a hybrid-photodiode and an NIST calibrated photo-diode. [4] The RXF is placed at the same separation from the photodiodes as it is in the field from the PMT cameras. The output of the RXF is then measured in terms of photons/mm^2. The two techniques have been found to be in excellent agreement.

The RXF calibration, especially when the RXF itself is absolutely calibrated against an NIST traceable standard, is a man-power intensive endeavor. Thus, a much quicker calibration check is performed at the beginning and end of each night's data collection. This is done with a YAG laser and a system of quartz optical fibers. [5] The light from the YAG is filtered to remove the primary and secondary harmonic wavelengths and then passes through a computer controlled filter wheel (for intensity variation) before being measured via a pyroelectric probe and being injected into a system of optical fibers. Different bundles of optical fibers allow either direct illumination of the PMT clusters or illumination of the mirror which gathers and reflects the light back onto the cluster.

The YAG calibration data is all analyzed via pulse height (width/mean) comparison and the RXF calibrations are used to anchor the YAG calibration. YAG calibration data is always collected on nights when an RXF calibration is performed. The nightly YAG calibration allows us to monitor night to night variation in the gain caused by such effects as inter-run night sky light exposure and seasonal temperature changes. The nightly gains are calculated and stored in a data base for later use in Monte Carlo generation and in data analysis.

The RXF calibration is usually done with the HiRes UV band pass filter (normally in front of the PMTs) removed. However, occasionally, the measurements are made both with and without filter so that the filter transmission can be measured. These same measurements have also been performed with the YAG laser/optical fiber system. One filter was cut into many 4x4 inch squares and many of these pieces had their transmission measured as a function of wavelength. The pieces were all very consistent and the transmission at 355 nm was in excellent agreement with the transmission measured via the PMT cluster using the RXF or the YAG laser and optical fiber system.

Mirror reflectivity is an additional important parameter in the reconstruction of an air shower. Since air fluorescence is not monochromatic, it is very important to measure the reflectivity over the range of relevant wavelengths. We have made a reflectometer from a small portable spectrometer and a dual (deuterium + tungsten-halogen) light source. The light source injects light into a fused silica optical fiber with a collimating lens at its end. A second collimating lens captures the reflected light and focuses it into a second optical fiber which transports the light to the spectrometer. The reflectometer measures the reflectivity from 200 to 850 nm with 1.5 nm resolution and an integration time which can be set. Data is read out to a laptop via USB. The approximate reflectivity verses wavelength can be viewed in near real time. The calculation of absolute reflectivity uses reflectometer measurements both of a flat black flock for background subtraction and an NIST traceable high specular reflectance standard. Post-processing of the data yields the absolute reflectivity as a function of wavelength of a sample.

The two lens+fiber ends of the reflectometer are held at a precise angle via machined threaded openings in a small dark box. Thus, the reflectivity can be measured at a series of precise angles from 3 to 30 degrees. The small dark box has a three point (ball bearing) base which assures alignment of the optics to the mirror surface. The box is held in place by hand during measurement. Since the measurement is a local one, only covering the spot illuminated by the optical fiber, each HiRes mirror segment is measured in a semi-random series of points and the average reflectivity is calculated for all points.

The average reflectivity of all 42 mirrors at HiRes-2 as measured by the reflectometer is shown in figure 1. Since the mirrors are housed in buildings which have open doors during data collection, it is important to monitor the reflectivity over time as dust builds up. Also, we wash the mirrors periodically. After 1.5 years of dust accumulation, the mirrors had their reflectivity measured, then were washed, and finally were measured again. The reflectivity increased about 3% across all wavelengths due to this washing.

In addition to the full wavelength band local measurement of the reflectivity, an attempt has been made to measure the global reflectivity of the mirrors. To do this, the RXF was placed in the detector's focal plane both above and below the PMT cluster box. After correcting for geometrical acceptance, the detector's response is compared with the response from direct illumination. The global reflectivity measurement was in very good agreement with local reflectivity measurements, typically within a few per cent.

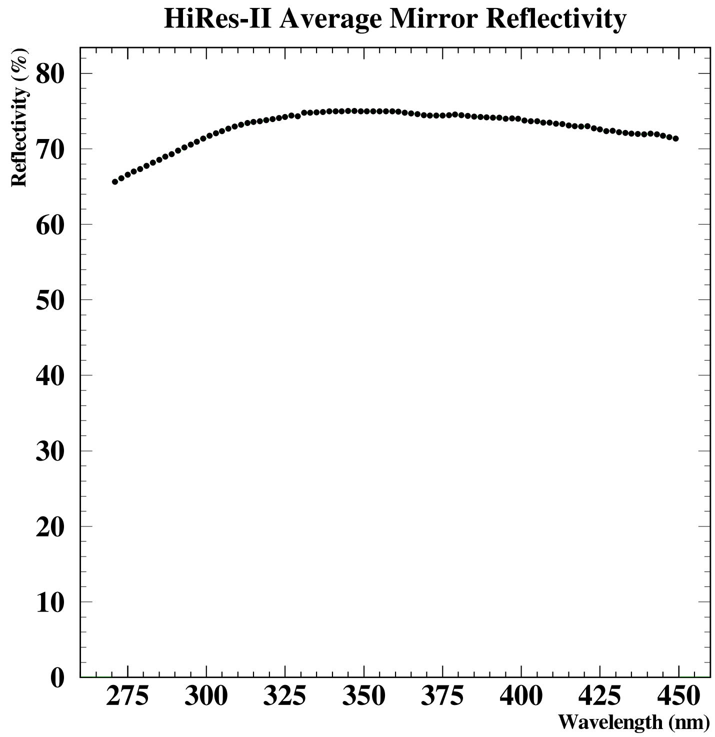

Figure 1. The average reflectivity of all 42 mirrors at HiRes-2 as measured by the reflectometer. Each mirror is composed of four segments and each segment was measured at seven points.

3. End-to-End Calibration

The mirrors, UV band pass filters, PMTs and electronics make up the individual pieces of the system for the piece by piece calibration of the detectors. Each has been calibrated by more than one method. Next we perform an "end-to-end" calibration. We do this by using the detector to look at nearby laser shots. The laser shots provide well understood linear sources of scattered light similar to actual air showers. [6]

For these measurements, we have used nitrogen (337nm) and YAG (355nm) lasers fired vertically at a distance of 3-4 km from the detectors. At this distance, the light flux at the detector is easily calculated and is insensitive to variations in the concentration of atmospheric aerosols. This is because increasing aerosol concentrations increase the amount of light scattered out of the beam making the beam appear brighter. However, the attenuation of the light as it propagates through the atmosphere also increases. At 3-4 km the two effects approximately cancel each other leaving the flux at the detector unchanged. The laser's energy is measured at the laser with a pyroelectric probe which has 5% uncertainty. The laser energy is reconstructed using the standard HiRes analysis and is compared to the energy measured at the laser. This way, we not only verify our end-to-end calibration, but also event reconstruction and analysis in as much as a laser track simulates an actual air shower. The calibration as measured by such end-to-end laser shots agrees with the piecewise calibration within about 10%.

4. Conclusions

The main components of the HiRes detector are the mirror, UV band-pass filter, PMT camera (including electronics). They have each been calibrated by multiple techniques which are in good agreement with each other. Further, the entire system has been calibrated by an end-to-end calibration using lasers which also resemble air showers. This calibration is also in good agreement with the piecewise calibration. This gives us confidence that we understand each piece of the detector and the performance as a whole. This means both the calibration as well as its uncertainty.

5. Acknowledgments

This work is supported by US NSF grants PHY-9321949, PHY-9322298, PHY-9904048, PHY-9974537, PHY-0098826, PHY-0140688, PHY-0245428, PHY-0305516, PHY-0307098, and by the DOE grant FG03-92ER407 32. We gratefully acknowledge the contributions from the technical staffs of our home institutions. The cooperation of Colonels E. Fischer and G. Harter, the US Army, and the Dugway Proving Ground staff is greatly appreciated.

References

[1] J.N. Matthews, *et al.*, Proceedings of ICRC 2001, Hamburg, Germany, 350-353, (2001).
[2] B.F Jones, *et al.*, Proceedings of ICRC 1999, Salt Lake City, UT USA,5-429 (1999).
[3] B.F Jones, *et al.*, Proceedings of ICRC 2001, Hamburg, Germany, 641-644, (2001).
[4] J.N. Matthews, *et al.*, Proceedings of ICRC 2003, Tsukuba, Japan, 911-914, (2001).
[5] G. Archbold, *et al.*, Proceedings of ICRC 2001, Hamburg, Germany, 623-626, (2001).
[6] E.J. Mannel, *et al.*, Proceedings of ICRC 2003, Tsukuba, Japan, 489-491, (2003).