Calibrating the High Resolution Fly's Eye Detector

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Abstract

We have studied various methods for the absolute and relative calibration of the High Resolution Fly's Eye detector elements. In this paper we discuss these methods and their merits with respect to the calibration of the HiRes photo-multiplier tubes. We also discuss the application of these studies to the installation and operation of the HiRes detector system.

1 Introduction

The High Resolution Fly's Eye (HiRes) is an experiment designed to search for cosmic rays of the highest energies. It does this by measuring the fluorescence light resulting from the Extensive Air Shower (EAS) of the primary cosmic ray particle. The calibration of the photo-multiplier tubes is crucial in the proper interpretation of the data, because the amount of fluorescence light collected is proportional to the number of secondaries in the air shower, which is in turn proportional to the energy of the primary particle.

An absolute calibration, as described in reference [1], is of course the preferred method. This procedure consumes far too much effort and time to be performed regularly. Therefore, other methods are needed to monitor the night-to-night and month-to-month variations in the gain of the PMT-electronics system. Two such systems are currently used by HiRes. The first is a system which illuminates all of the PMT clusters simultaneously with light from a YAG laser, transported by quartz optical fibers. The illumination is rendered uniform between PMT's within a cluster by the use teflon diffuser-attenuators. The teflon tuning also allows the approximate balancing of light between all clusters. The YAG calibration procedure is performed twice nightly, since all PMT's can be calibrated simultaneously. The disadvantages of the laser system are (a) the intrinsic $\approx$10% pulse-to-pulse variation in the intensity of the laser, (b) the lack of direct cluster-to-cluster relative calibration, since each PMT cluster is illuminated by a different quartz fiber, and, (c) the limitation of a monochromatic (355 nm) light source in simulating the broadband air fluorescence emission spectrum.

A second system involves the use of a xenon flash lamp, illuminating one PMT cluster at a time through diffusers and filters. The flash lamps offer two main advantages: (a) the flash-to-flash variation in intensity has been measured to be approximately 1/3%. Over the course of a night, the stability is better than 2% including detector changes in response (temperature etc.). This stability allows for direct relative cluster-to-cluster and site-to-site calibration. (b) The emission spectrum is sufficiently broad and the intensity sufficiently high to allow the placement of narrow band filters to allow calibration over the full range of fluorescence emission. The main drawback of this method, in comparison to the YAG system, is that each calibration pass requires one to several nights involving several people, and can only be performed about 6-8 times each year.

To minimize the number of absolute calibration passes needed for the experiment, it is important to extract a maximum amount of information from the flash lamp and laser data. We discuss in this report our current program to more fully exploit these techniques.

2 Photo-electron Estimation

Because of the variability of the laser system and the long-term variability of the xenon flash lamps, the most important aspect of these calibration methods is to extract the number of photo-electrons produced in the photo-cathode. In this report we describe our our procedure for estimating photo-electron numbers using the photo-statistics independently of a primary calibration of the light sources. The method we describe here is designed to be adaptable to any similar light source with a known emission spectrum. This flexibility will allow us to incorporate other sources, such as blue and UV LED's and narrow wavelength band sources, into the calibration of the HiRes detector.

A method for estimating the number of photo-electrons is to take advantage of the Poisson statistics associated with the photo-electron production at the cathode. In principle, if the gain of the first stage is sufficient, then the dynode chain itself does not introduce significant additional variations. The fluctuations in the integrated signal from each channel should be proportional to the fluctuation in the number of photo-electrons. For the dynode chain used by HiRes PMT's, both simulations and single-photo-electron measurements predict a broadening from the pure photo-cathode Poisson width by an additional factor of approximately 1.12. [2]

Assuming the integrated signals are proportional to the number of photo-electrons produced we have:

$$\bar{Q} = C\bar{p}, \tag{1}$$

where $\bar{Q}$ is the mean of the integrated output, Q, over a large number of pulses, $\bar{p}$ is the mean number of photo-electrons per pulse, and C is the gain constant for the tube. It follows then that the standard deviation of the output distribution will be given by:

$$\Delta Q = 1.12C\Delta p = 1.12C\sqrt{\bar{p}}. \tag{2}$$

Here we have included the broadening factor of 1.12 in the output fluctuations along with the Poisson fluctuations in the number of photo-electrons. [2] From these, the mean number of photo-electrons can be calculated by the formula:

$$\bar{p} = \left(1.12\frac{\bar{Q}}{\Delta Q}\right)^2 \tag{3}$$

During the course of a xenon flash lamp calibration pass, several pulse intensities are achieved through the use of neutral-density filters. Figure 1 shows the response of a typical PMT to four different filter settings. The mean (pedestal-subtracted) response of the system to a sequence of shots is plotted in the vertical direction, where the horizontal axis represents the mean photo-electron numbers for the same sequence estimated using the formula of equation 3. These points clearly fit well to a straight line through the origin as expected. The gain of the system is then extracted from the fitted slope. Shown also in figure 1 is a point corresponding to the YAG laser calibration taken during the same night. To remove the $\approx$10% variation in the laser output, we estimate the strength of each laser shot by averaging the response of all 256 PMT's in a cluster. We then normalize the tube response of each shot with ratio of the cluster mean for that shot to that of the average of the cluster means over the whole sequence of shots. The $\bar{p}$ value is then extracted from the normalized distribution. The laser data is clearly in excellent agreement with both the flash lamp results and the fitted line.

3 Discussion

We have finished preliminary studies calibrating the HiRes-I detector using the photo-electron estimation method described above. The results are consistent with expectations, and a full scale effort to incorporate this calibration into the analysis of HiRes-I data is nearly complete. The technique described in this report will allow the incorporation of a number of new calibration sources. The use of narrow band sources, or of narrow band filters in conjunction with the xenon flasher, will, in particular, allow us to test some of our basic assumptions regarding our system. For instance, the wavelength independence of tube gain, and the PMT quantum efficiency spectrums can now both be verified *in situ*.

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References

[1] T. Abu-Zayyad *et al.*, 25th ICRC (Durban, South Africa) **5**, (1997) pg. 333 (OG 10.6.4)

[2] T. Abu-Zayyad *et al.*, 25th ICRC (Durban, South Africa) **7**, (1997) pg. 213 (HE 6.1.5)

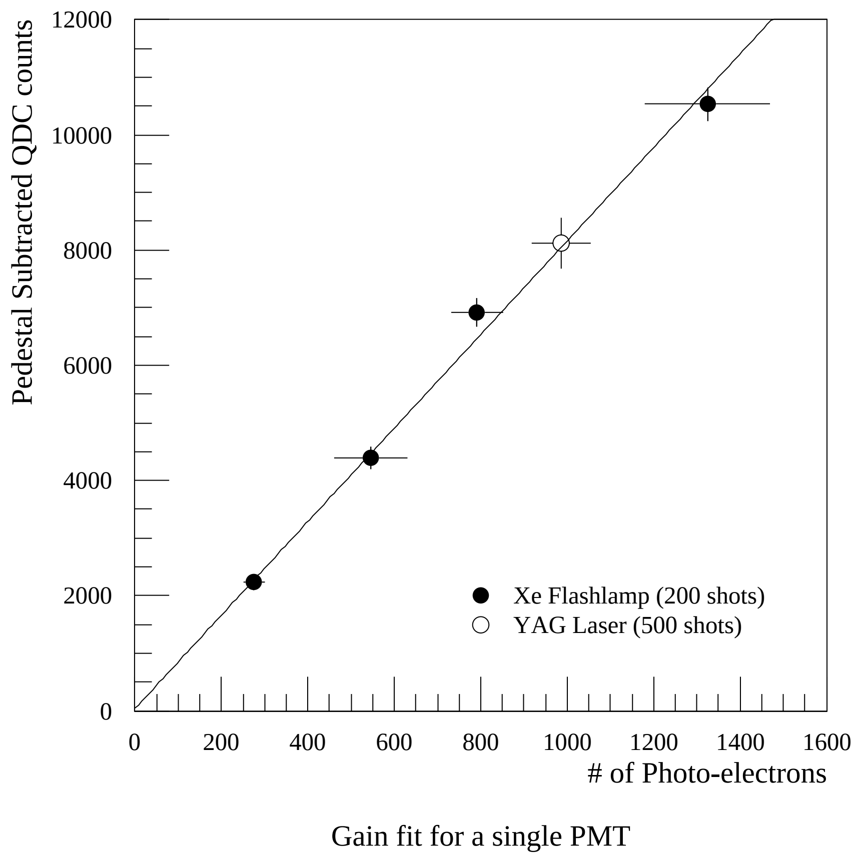

Figure 1: *Calibration data, including both xenon flash lamp and YAG laser results, for a typical tube at HiRes-I.*