

# Calibration and Stability of the High Resolution Fly's Eye Detector

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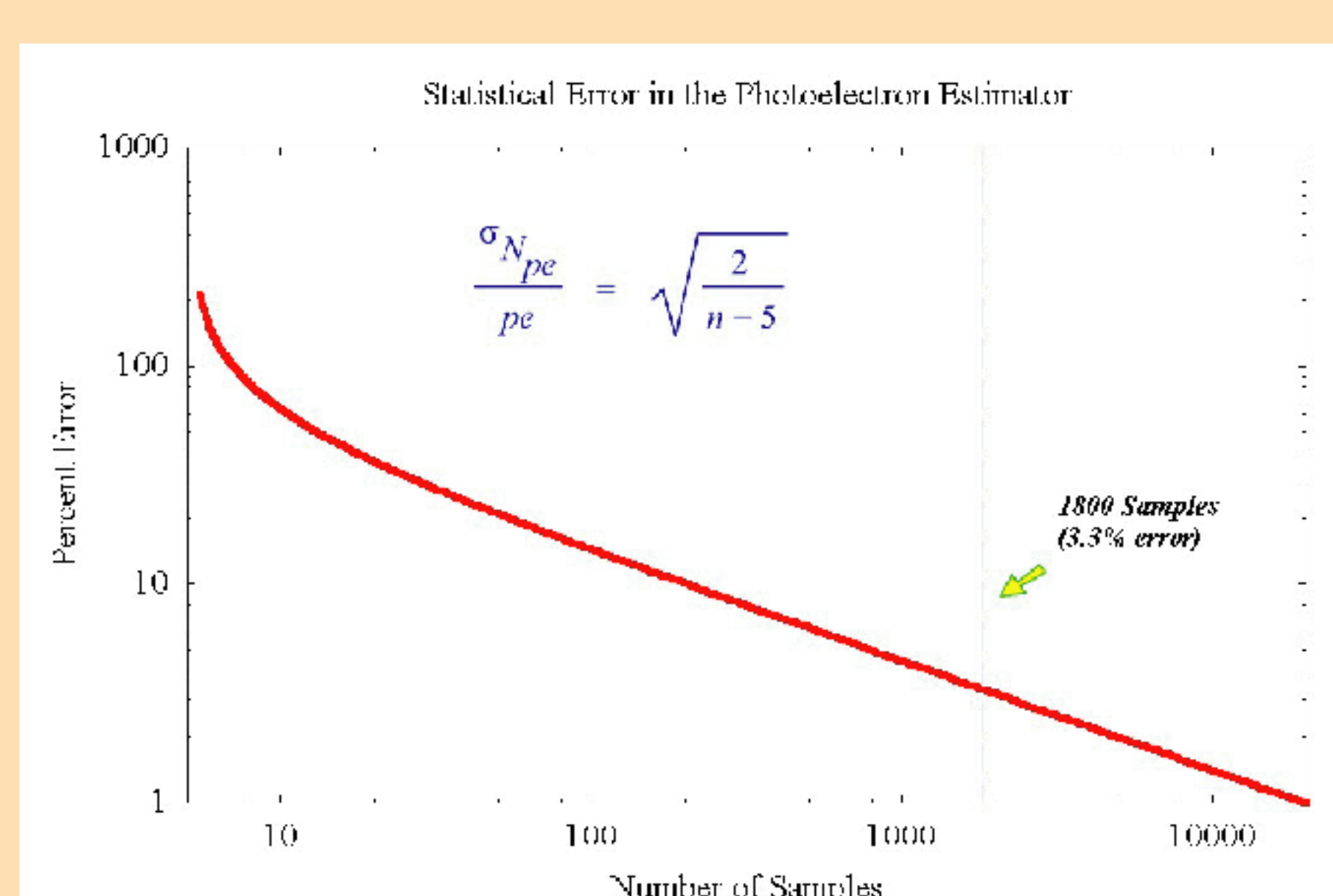


The High Resolution Fly's Eye (HiRes) Observatory consists of two sites separated by 12.6 km. The first site, HiRes-I, is composed of 22 cameras, while the second site, HiRes-II views a larger slice of elevation and is composed of 42 cameras. The light from an Extensive Air Shower is collected by large mirrors and focused onto cameras, each consisting of 256 PMT's.

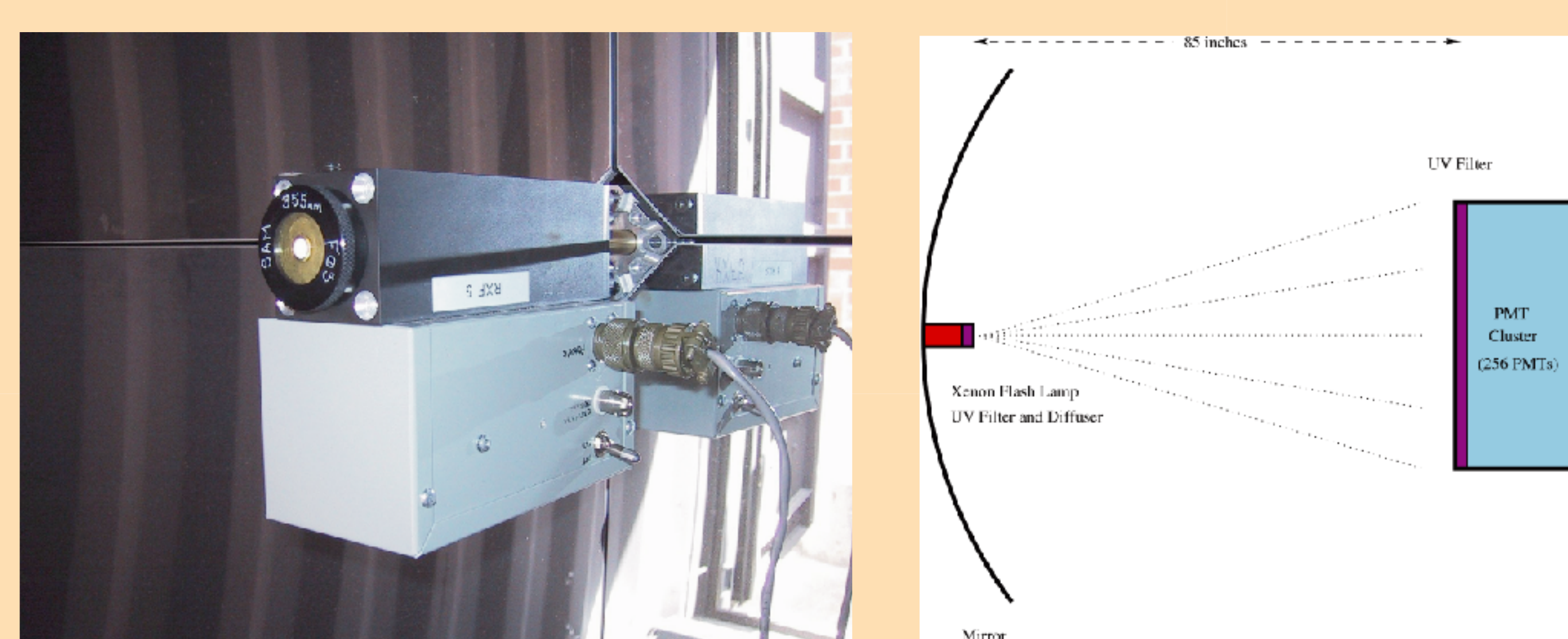
The fundamental detector elements in HiRes are the 16,384 photomultiplier tubes (PMT's) contained in the 64 cameras. Routine monitoring and calibration of the PMT's and associated electronics is crucial to the proper interpretation of the data.

## Calibration

The main calibration device at HiRes is a portable high stability xenon flash lamp. The Roving Xenon Flasher (RXF) provides a standard candle that can be moved from camera to camera, site to site, and from controlled laboratory conditions to the harsh environment in the field. The RXF offers several advantages. The pulse-to-pulse variation in intensity is very small (0.3%) and the stability over a night is better than 2%. The emission spectrum of the RXF is sufficiently broad to allow calibration at various wavelengths. However, most calibration work is done at 355 nm. via narrow band filters so that the results can be easily compared with YAG laser measurements.



A large number of samples are required to obtain an accurate measurement of the gain. A typical measurement consists of more than 1800 samples. This reduces the statistical error to about 3%.



The first step in the calibration of a PMT is the measurement of the average number of photoelectrons. The mean number of photoelectrons is estimated from the shape of the measured charge distribution.

$$\mu = G \cdot pe$$

$$\sigma = G \sqrt{\alpha} \cdot \sqrt{pe}$$

The number of photoelectrons is computed using the following formula:

$$N_{pe} = \frac{(n-3)}{(n-1)} \cdot \alpha \frac{Q^2}{S^2} - \frac{\alpha}{n}, \quad n > 3$$

If the number of photoelectrons and the number of measurements are large enough this formula approaches the more familiar expression:

$$N_{pe} \approx \alpha \frac{Q^2}{S^2}, \quad n \gg 3$$

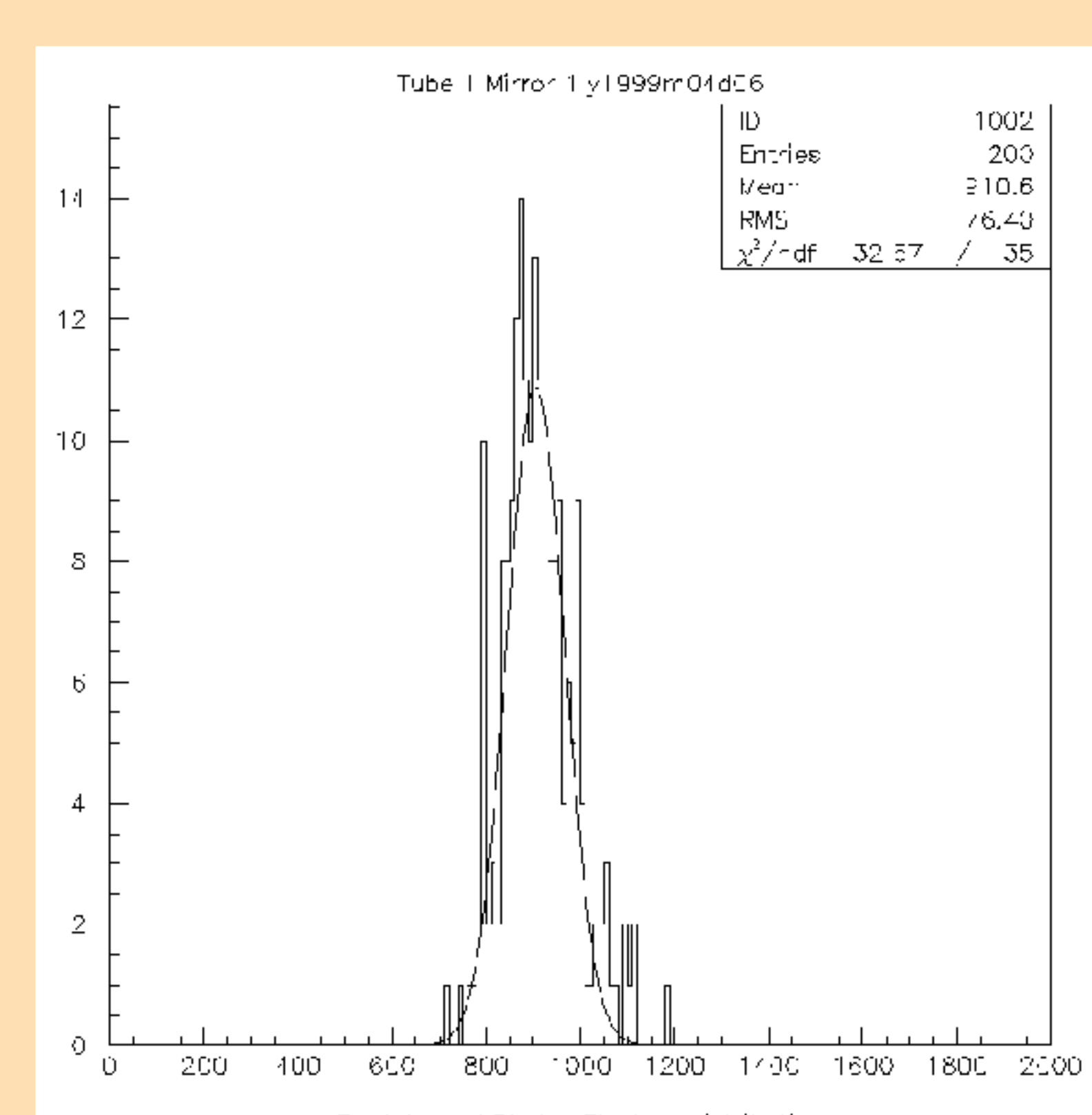
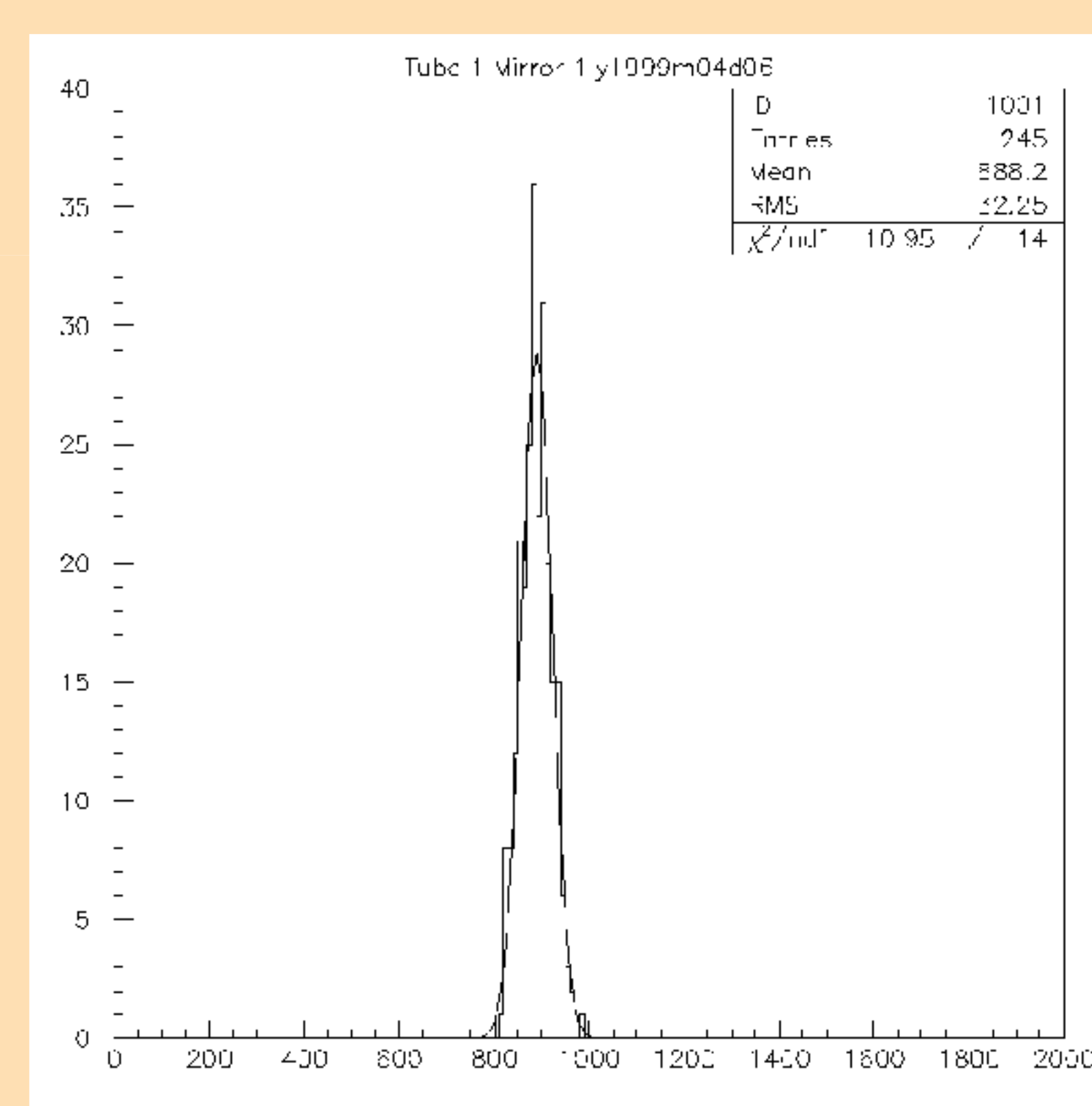
The statistical error for the estimate is given by:

$$\sigma_{N_{pe}}^2 = \frac{2}{(n-5)} pe^2 \left[ 1 + 2(n-2) \left( \frac{\alpha}{n \cdot pe} \right) + (n-2) \left( \frac{\alpha}{n \cdot pe} \right)^2 \right], \quad n > 5$$

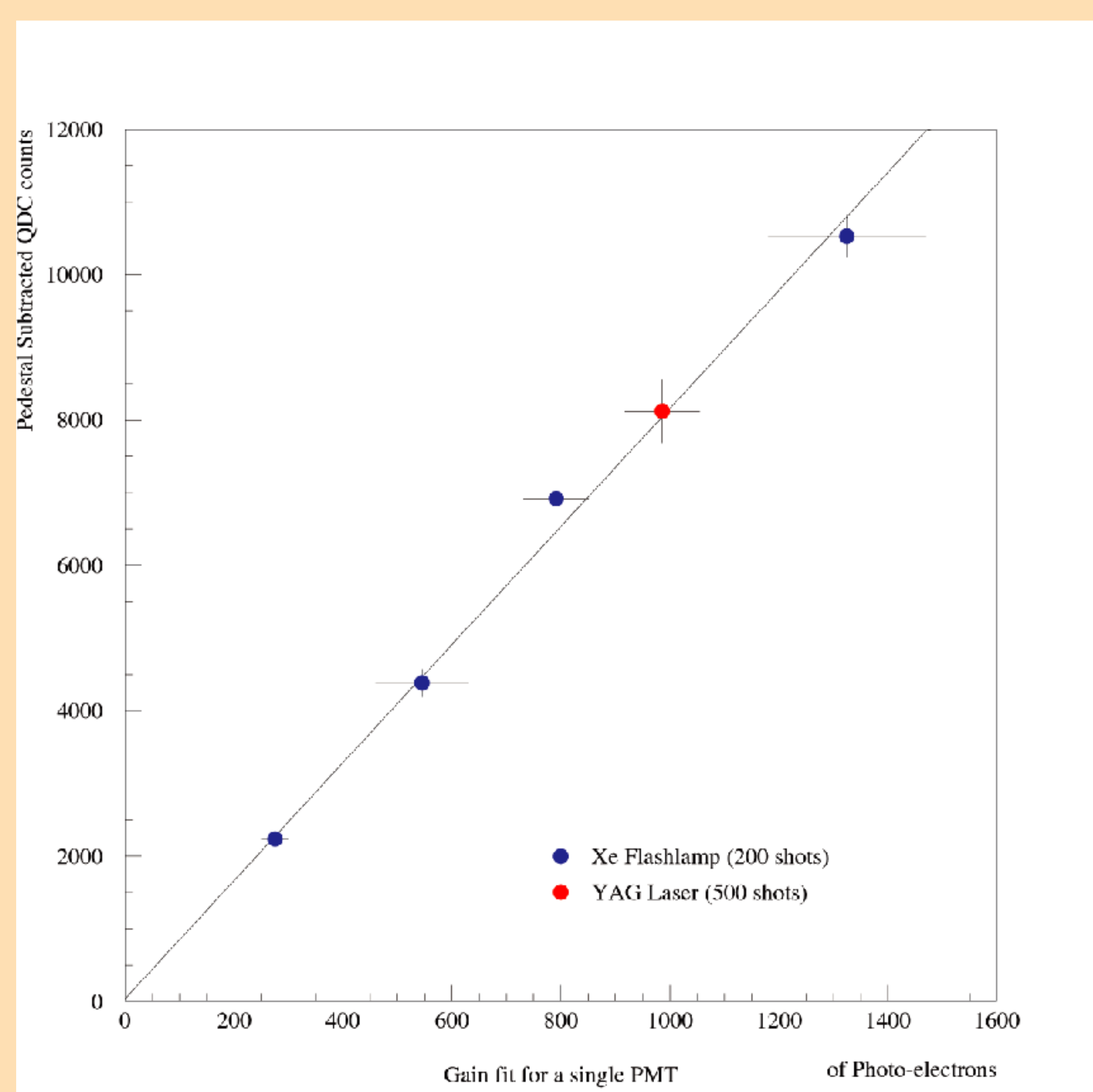
This expression simplifies when the number of measurements and number of photoelectrons are sufficiently large:

$$\sigma_{N_{pe}}^2 \approx \frac{2}{(n-5)} pe^2, \quad n \gg 5$$

The ratio of the output charge to the number of photoelectrons (i.e. electronic gain) is independent of the choice of light source. Measurements employing various sources of light, such as Xenon flashers, lasers, blue or UV LED's, etc. can, therefore, be directly compared.

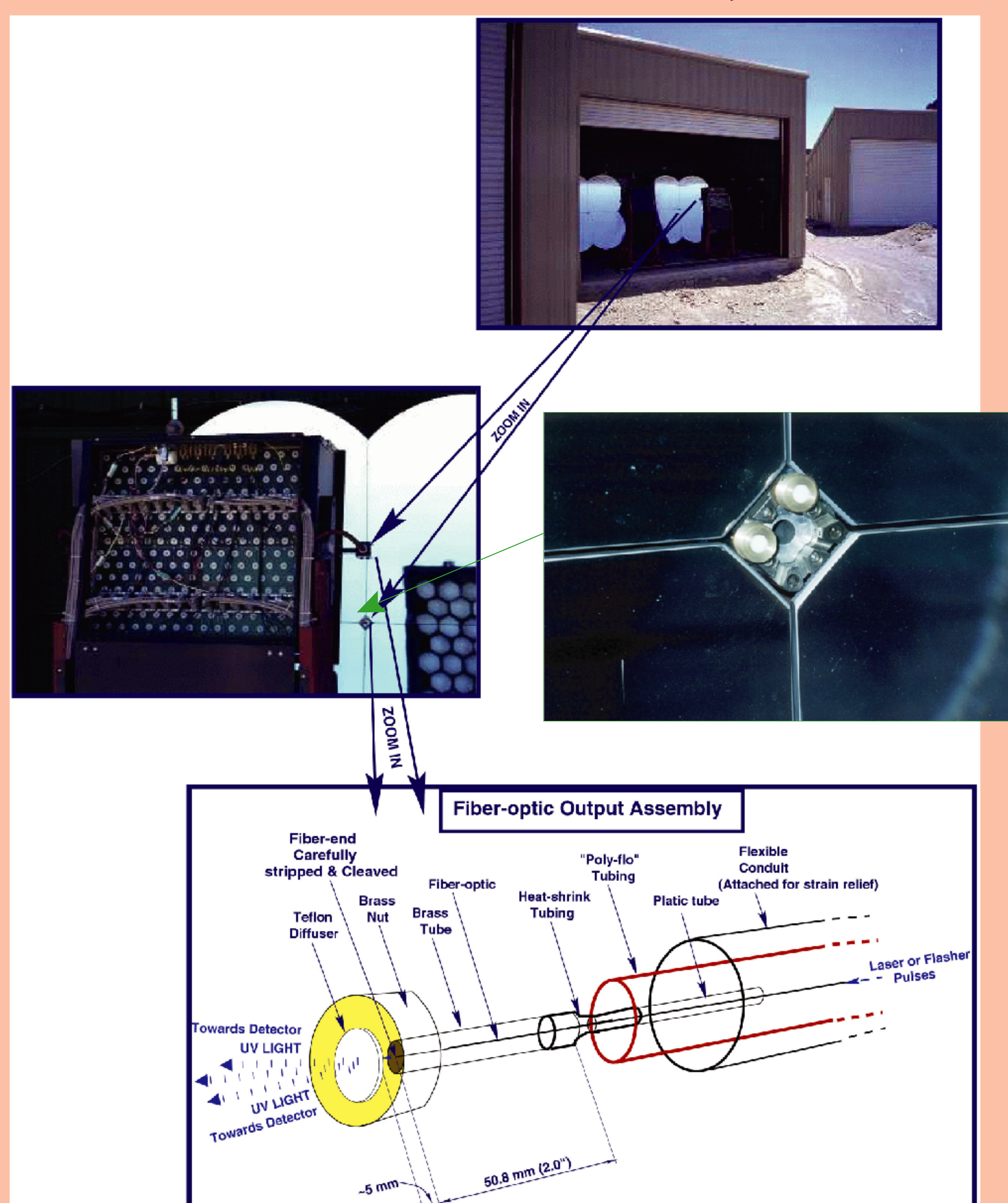


In practice a bootstrap process is used to compute a photoelectron distribution for each measured charge distribution. This gives us the mean number of photoelectrons as well as a robust error estimate based on the actual data.



Several light intensities are measured at each mirror using neutral density filters. The overall gain for one phototube is measured by fitting a line to the charge vs. photoelectron data.

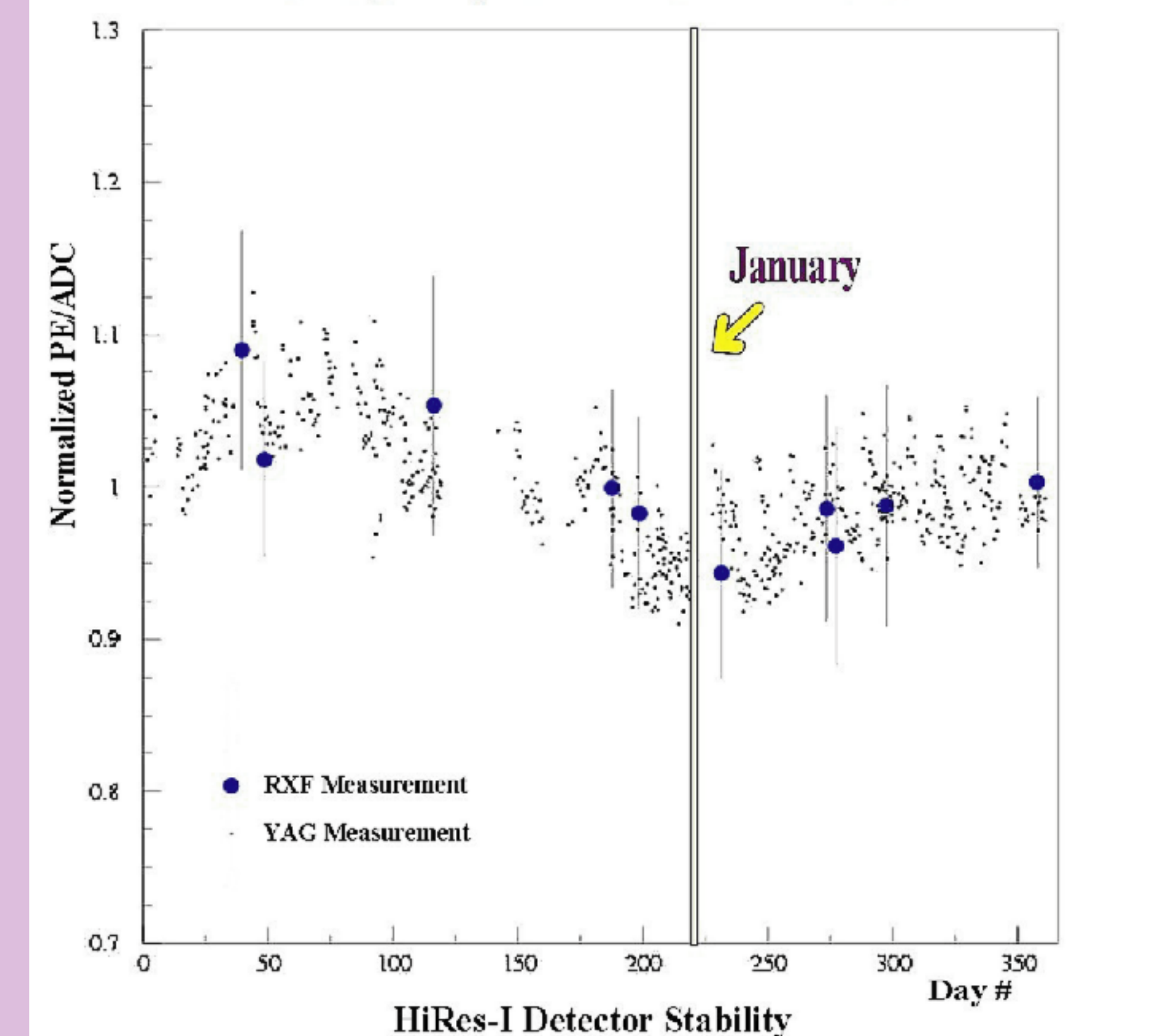
## YAG/Fiber Calibration System



Each building houses two mirror/PMT cluster assemblies. One fiber is routed to the center of each mirror, and one is routed to each side of each PMT cluster. From the mounts in the center of the mirrors, the PMT cluster can be illuminated directly. From the mounts on the sides of the PMT clusters, the PMT cluster can be illuminated with light reflected off the mirrors, allowing monitoring of mirror reflectivity.

## HiRes-I Detector Stability

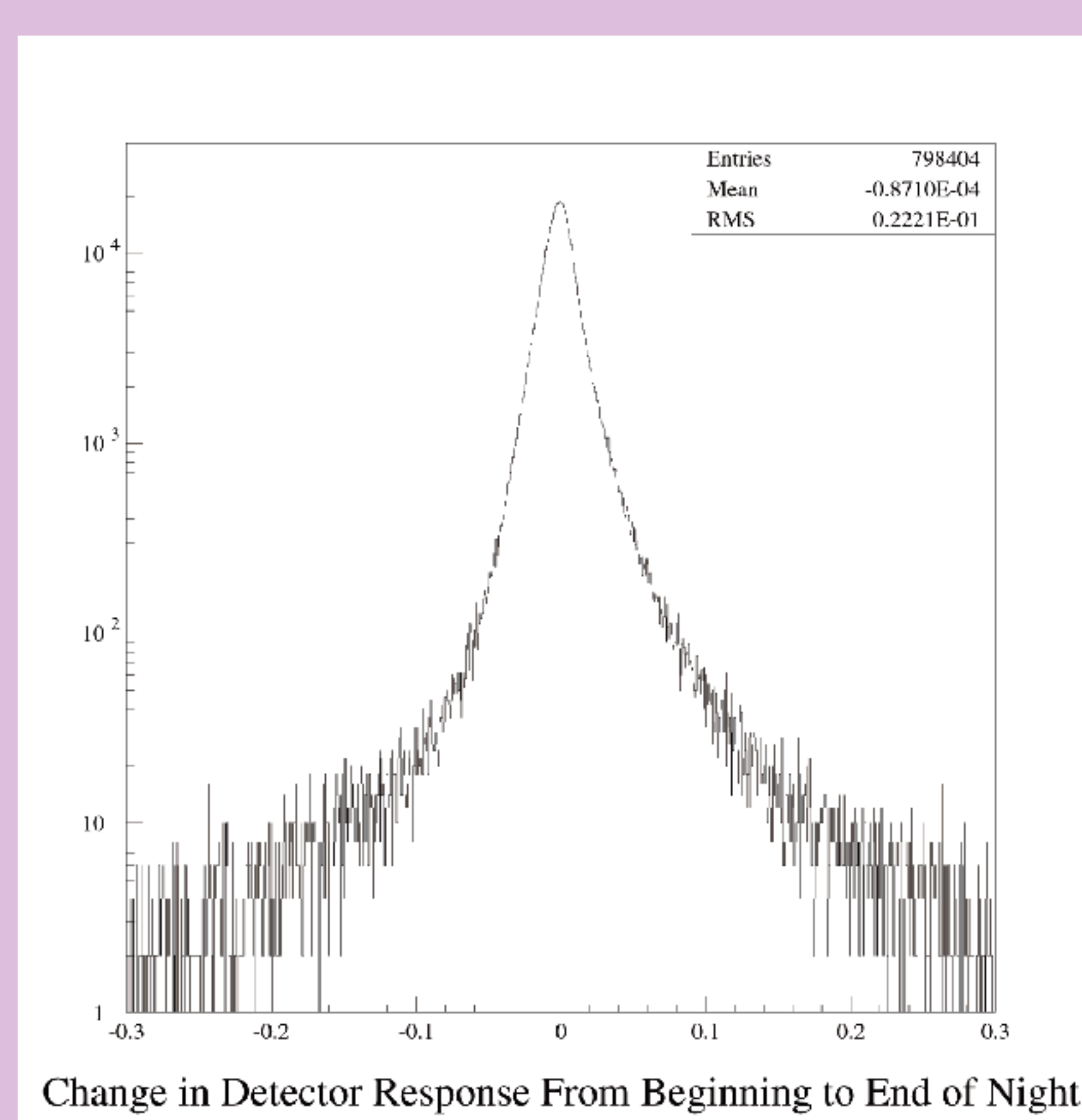
### \$10,000,000 Thermometer



The technique described here has been used to track the gains of the detectors in the HiRes experiment over a period of three years. The plot shows the system wide variation in gain over this period plotted as a function of day of the year. Each PMT's gain is normalized to its average gain over the entire period to show system wide behavior.

The change consists primarily of a ~5% seasonal variation. The gain variation is related to the seasonal variation in temperature.

In the plot the RXF measurements are superimposed on the measurements made using the YAG/fiber system. The error bars represent the spread of the individual PMT's in the detector. The plot clearly demonstrates the excellent agreement between the YAG and RXF measurements.

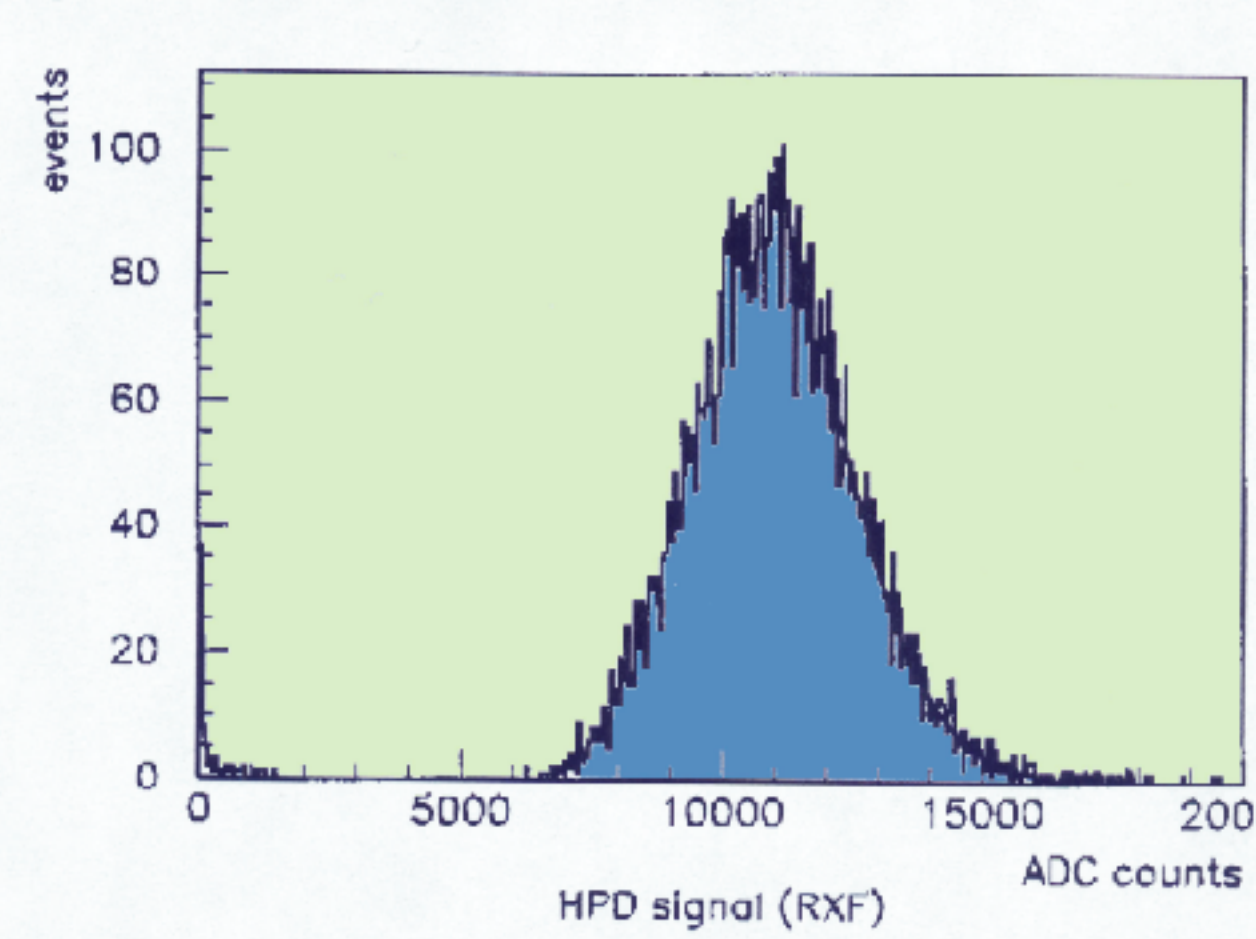
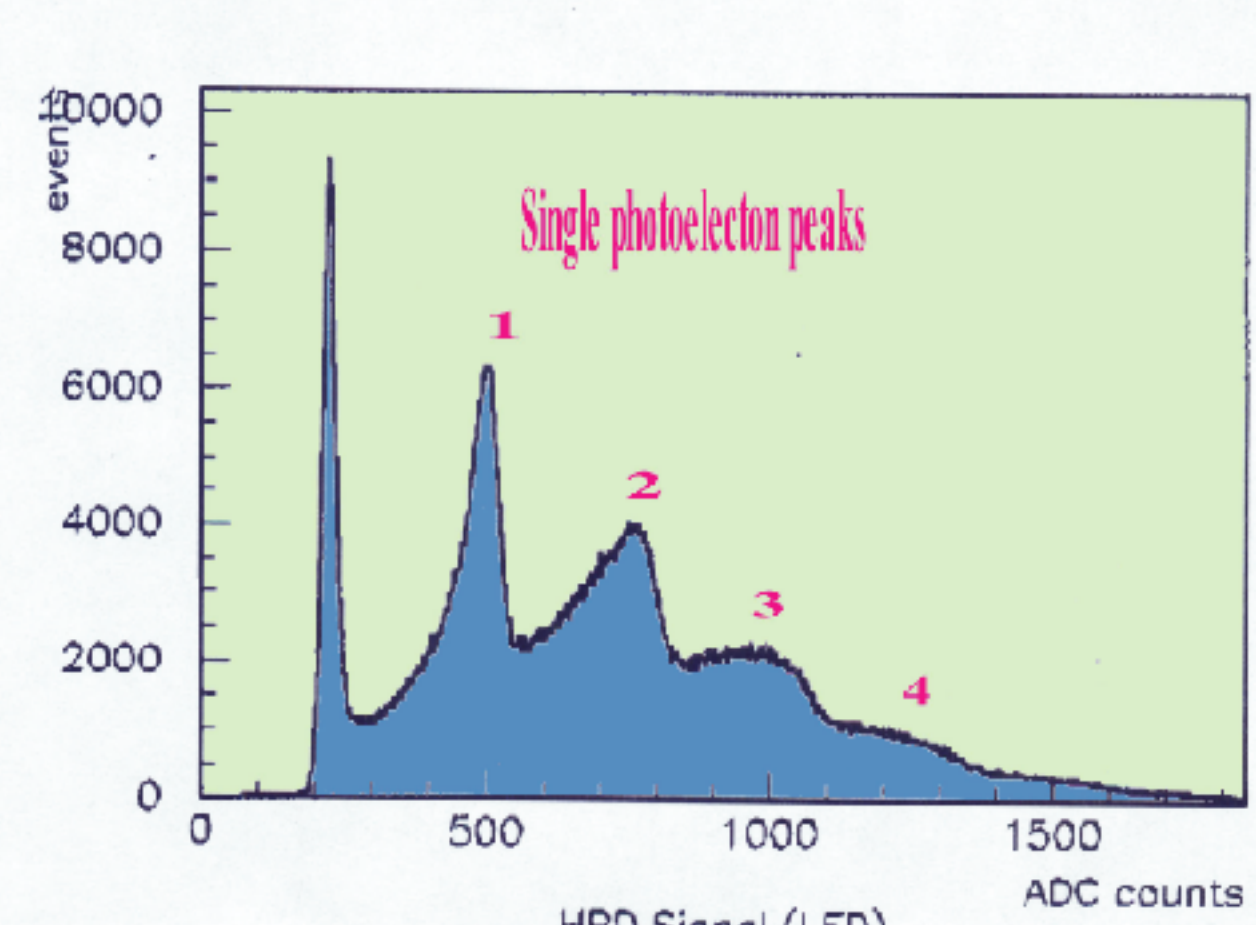


The plot at left shows the relative gain change over a single night, for all PMT's in the detector over a three year period. Although the gains of the PMT's exhibit noticeable variation over time, these changes are routinely monitored at the level of a few percent.

## Future Work

In the near future we will be adding new types of detectors for absolute calibration. Currently the average PMT quantum efficiency is assumed to be 26.5% based on the manufacturer's measurements. We have recently acquired several new detector standards including hybrid photodiodes (HPD) for calibrating the light output of our RXF devices precisely. The HPD can measure single photoelectron peaks as well as the light output of the RXF as shown.

If the light output of RXF devices is known before calibration data is taken, we can measure the PMT quantum efficiencies independent of the manufacturer.



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