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Cross-Calibration between the Light Level Measured with SGARFACE and the Whipple 10 m Telescope

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The Short GAmma Ray Front Air Cherenkov Experiment (SGARFACE) uses the Whipple 10-meter telescope to search for gamma ray bursts of more than 200 MeV with durations from 60 ns to 35 μs. SGARFACE began operating in parallel with the Whipple 10m telescope in February 2003. The calibration of the photo-electron to digital-counts, relevant to establish the received light flux, is presented.

1. Introduction

The SGARFACE experiment is used to search for gamma-ray bursts of various astrophysical origin, e.g. primordial black hole evaporation, on time scales from 60 ns to 35 μs and with energies above 200 MeV [1].

The SGARFACE experiment [2] is part of the Whipple 10 m telescope [3], an imaging air Cherenkov telescope located in southern Arizona. SGARFACE began operating in February, 2003, and has collected about 1 million events during 1800 hours of observations. Analysis of this data set is ongoing. We present here the calibration of the number of photo-electron (pe) produced by the photomultiplier tubes (PMT) in terms of the digital-counts (dc) produced by the data acquisition system (DAQ). This calibration establishes the flux sensitivity of the experiment.

Given the larger angular extend of burst images compared to gamma-ray images, the signals from up to 7 nearest neighbor Whipple PMTs are summed into 55 SGARFACE channels, also reducing cost. The channels are sampled by a flash analog-to-digital (FADC) converter at an interval of 20 ns and with memory depth of 35 μs. The SGARFACE trigger operates on six time scales, ranging from 60 ns to 14.6 μs, with the discriminator thresholds set conservatively above the night-sky background level. During most of the observations, 7 nearest neighbor SGARFACE pixels were required to exceed this threshold, minimizing accidental triggers.

2. Data Preparation for Cross-Calibration

The analysis of SGARFACE events proceeds in the following way: (1) pedestal subtraction, (2) gain correction, (3) removal of samples that contain mostly noise (image cleaning), and (4) image and timing parameterization. Also, samples that saturate the FADC are flagged before analysis proceeds.

A constant DC offset, called pedestal level, is present on each FADC channel and must be subtracted before calculating the total charge. The mean, ped, and standard deviation, σ_{ped}, are measured from the first 700 samples of each event. Events are 1752 samples long with the event usually starting at sample 938. Any large positive outliers in excess of $ped + 4\sigma_{ped}$ are removed from the trace and then the pedestal level is recalculated. Fluctuations of the pedestal level have been tested for consistency with statistical fluctuations alone on time scales up to 30 minutes.

A relative gain correction of the pixels is necessary to achieve a uniform response over the field of view of the camera. Traditionally, for Whipple 10 m data, the gain correction is calculated from events taken with a bright Nitrogen flasher uniformly illuminating the camera. Unfortunately, these events are too bright for the SGARFACE FADCs and completely saturate all channels. Therefore, a set of special data runs were taken using a laser flasher with various neutral density filters. The laser light pulses are of about 4 ns duration. The SGARFACE FADCs are sampled every 20 ns, but are smoothed at the input with an RC time constant of 20 ns. The Whipple DAQ charge integration time is 20 ns, also completely containing the short laser pulses. Data were taken simultaneously with the SGARFACE and Whipple 10 m DAQ. For the analysis of data taken with the Whipple DAQ; the Whipple PMTs were summed in software into the appropriate SGARFACE channels.

In the gain analysis, the digital counts in each SGARFACE channel is corrected if less than the usual 7 Whipple PMTs are summed into one SGARFACE pixel. This is the case for some of the outer SGARFACE pixels were in some cases only 4 Whipple PMTs are summed. This geometrical correction is not applied during the image parameterization as this is a moment analysis, i.e. the distance-weighted pixel values are used.

Because only the Nitrogen flasher taken by Whipple is available on a nightly basis, the following steps establish that the Whipple data can be used to derive the gain correction for the SGARFACE analysis:

1. Using the laser flasher, establish that the gain coefficients derived using SGARFACE and Whipple data are similar. The very good correlation, with χ^2/ndf=13.4/54=0.25, is shown in Figure 1.

2. Using the Whipple DAQ, establish that the gain coefficients derived from laser and nitrogen flasher are similar. This is shown in Figure 1.

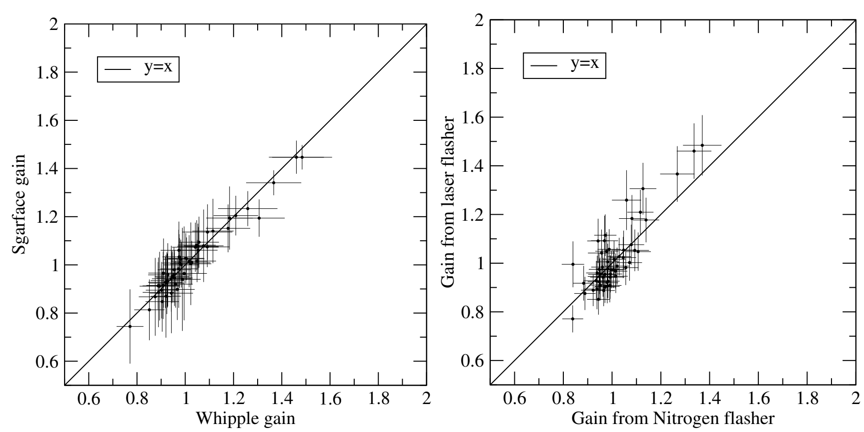

Figure 1. *Left*: Comparison of gain coefficients derived from SGARFACE and Whipple data taken with the laser flasher. *Right*: Comparison of gain coefficients between laser run and a traditional Nitrogen run taken earlier during the night. In both cases, the data were taken with the 10 m DAQ and pixels were summed in software to the SGARFACE system.

Before parameterization of the events, the FADC traces are cleaned by suppressing all samples below a certain signal-to-noise ratio. Valid samples are identified in two stages. First, those samples above a high threshold, called picture threshold, are identified. Then neighboring pixels/samples in space/time are identified that are still above a lower threshold, called boundary threshold. The picture threshold is chosen at 4.0 and the boundary threshold at 2.0 times σ_{ped}. At a later time, these threshold may be optimized for better signal to noise separation.

The images are parameterized by their zero, first and second order moments. The resulting parameters are the total amount of light collected, $size$, the centroid, the RMS length of the major and minor axis of an ellipse, and the image orientation.

Timing information includes the peak and Gaussian width of the summed FADC traces, and the dispersion between the peaks of the 55 FADC channels. Event times are corrected for an offset with respect to the FADC trigger time; the trigger occurs at sample 939. Events of short duration: cosmic rays and artificial laser flashes, are identified by the peak of the summed FADC trace and traces are summed with a window size that is chosen to envelope the pulse completely: beginning one sample before the peak until two sample past the peak. We are in the process of modeling the pulse-shaping produced by the analog electronics chain.

3. Light Calibration

To calibrate the SGARFACE dc values in terms of the number of photo-electrons, we use the known dc/pe calibration of the Whipple DAQ together with events that are recorded by both SGARFACE and Whipple. To cross-calibrate the two systems, a search was carried out for common events with a coincidence time window of $\pm 1\mu$s on both, laser runs and regular observations, i.e. cosmic-ray events. The laser completely illuminates the camera and hence the total amount of light, $size$, covers a larger dynamic range without FADC saturation than the more compact cosmic-ray images. Also, for laser runs the gain correction is unimportant because all pixels are illuminated and hence summed into the $size$ parameter.

The $size$-$size$ correlation for laser events common between SGARFACE and Whipple is shown in Figure 2. The linear fit to the $size$-$size$ correlation is given by $S = (-52 \pm 109) + (0.267 \pm 0.0023) \times W$, where S and W are the $size$ measured by SGARFACE and Whipple. Events for which more than 10 FADC samples were saturated were excluded from the linear fit. The dc/pe ratio of the Whipple DAQ is known from direct measurements of the electrical components and is corrected for aging of the PMTs using a muon calibration algorithm. The Whipple dc/pe ratio at the time of the laser runs was dc/pe$_W$ = 2.4 ± 0.1, resulting in a Sgarface dc/pe$_S$ = 0.64 ± 0.03. This neglects an 20% systematic error arising from the muon calibration and the initial dc/pe measurement.

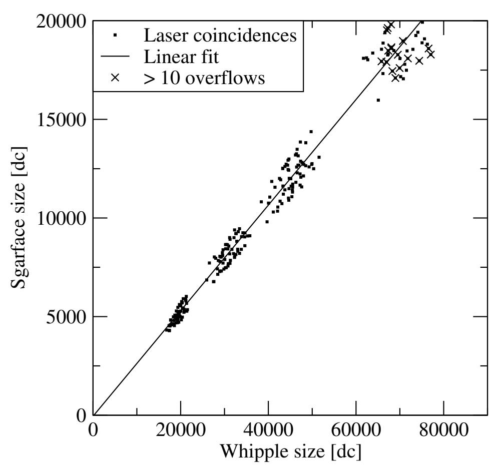

Figure 2. Image brightness recorded for simultaneous laser events by SGARFACE and Whipple. For the linear fit, only events were selected for which less than 10 FADC samples were saturated.

The calibration between the SGARFACE and Whipple DAQ systems will be extended over a longer time period through the use of coincident cosmic-ray events. The fraction of cosmic-ray events that SGARFACE detects and that are also detected by Whipple is about 70%, corresponding to a coincidence rate of 0.16 Hz. An example of a coincident CR event is shown in Figure 3. Bright events saturate the SGARFACE FADCs at much smaller $size$ than for laser events. This is expected because cosmic-ray images are more compact.

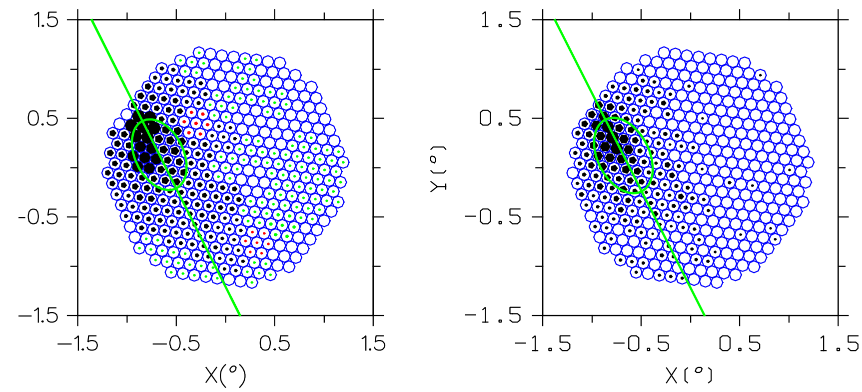

Figure 3. Example of a cosmic-ray event detected by both, SGARFACE (*Left*), and Whipple (*right*). The total charge is represented by the size of shaded area in each pixel. The image is parameterized by an ellipse in each case.

4. Conclusions

We have established the dc/pe calibration of SGARFACE through cross-calibration with events detected simultaneously by both, SGARFACE and Whipple. The data for this calibration was taken with a special laser flasher, operated only during one night on the telescope. The cross-calibration will be extended over a longer period of time by using cosmic-ray events that are a present as a steady background in both experiments.

5. Acknowledgments

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