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A New Image Cleaning Method for the MAGIC Telescope

M. Shayduk, Th. Hengstebeck, O. Kalekin, N. A. Pavel and Th. Schweizer
on behalf of the MAGIC collaboration
Humpoldt-Universitaet zu Berlin, Newtonstrasse 15, D-12489 Berlin
Presenter: M. Shayduk (shayduk@physik.hu-berlin.de), ger-Shayduk-M-abs1-og27-oral

The MAGIC Telescope allows the cosmic gamma flux be explored in the new energy range below 100GeV, partially closing the gap between the EGRET data and former IACTs. The size of such events, however is so low, that more sophisticated methods are required to separate the true shower signal from the NSB and to rescue the signal of as many pixels as possible. The MAGIC telescope reflector has a parabolic shape, which conserves the time structure of the cosmic showers. Here a new Image Cleaning procedure is described, which uses this time information and exploits time coincidences of neighboured camera pixels. The time range over which the signal has to be integrated for the signal extraction, is optimized, thereby decreasing the NSB contribution and improving the SNR. This becomes extremely important for events near the telescope threshold, where an image may consist only of 4-10 pixels.

1. Introduction

The MAGIC telescope [1] has an isochronous reflector with an intrinsic time spread of *400ps*. Considering the DAQ system the overall time resolution is ∼*600ps*. Such a precision is sufficient to resolve the time structure of the cosmic showers and to exploit this to optimize the signal to noise ratio by reducing the integration ranges to the relevant limits around the shower signal, even for each individual event. The primary goal of the Image Cleaning method is the improvement of the separation between the NSB noise and the shower signal.

The FADCs of the MAGIC telescope sample the shower signal with 300 MHz over 50 ns, whereas the typical shower signal in a given pixel is much shorter (3-5 ns). In order to reduce the NSB contribution, the integration window for the signal extraction has to be reduced to a narrow region around a peak in the 50 ns window, which is declared as signal. In low signal pixels, high NSB fluctuations may be chosen instead of the true signal. The probability for such an erroneous decision can be determined by applying the signal extractor to pedestal data and obtaining from the NSB charge spectra the cumulative probability for NSB above a certain charge threshold. From the results shown in Fig.1 (left plot) for signal extraction by spline interpolation and with various widths of the signal peak search window, one can see that smaller search windows yield in better NSB suppression. It has to be pointed out that signal extraction and image cleaning algorithms are strongly related to each other.

2. Image Cleaning Method

Since in the experimental data the position of the shower signal is not fixed and no information about the pixels, which caused the event trigger, is available, the extraction of the image core demands artificially high thresholds in the Standard Image Cleaning procedure. In order to reduce such thresholds and the peak search range, compact next neighbour groups (*NN*-groups) within a given time coincidence window are searched for.

Figure 1 (right plot) shows the probabilities to find a *2NN*, *3NN* and *4NN* group within the time coincidence window indicated as a function of the threshold in pulse charge. The black line corresponds to the so-called Standard Image Cleaning procedure [2], where no timing information is used. These probability curves strongly depend on the star field in the telescope camera.

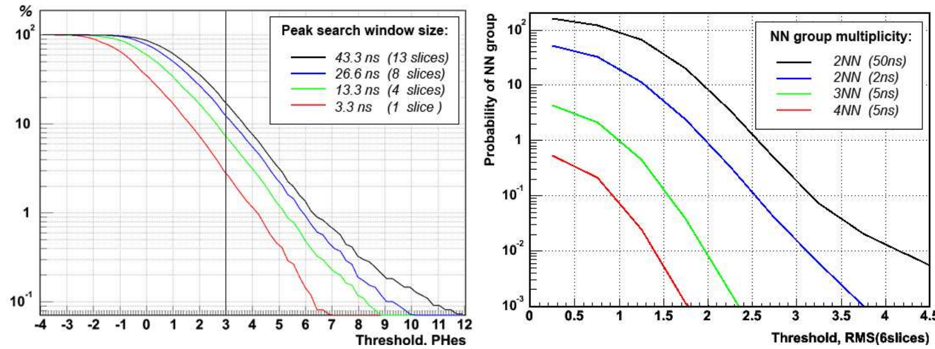

Figure 1. ***Left:*** Cumulative probability curves for different peak search windows, obtained from the integration of the NSB charge spectra. ***Right:*** Probability curves to find the *2NN*, *3NN*, and the *4NN* compact group in the pedestal event. The threshold expressed in units of standard deviation of pedestal charge, integrated over *6* FADC slices. For the CRAB Nebula NSB level: $RMS(6slices) \approx 2.72$ phes.

2.1 The concept of the next neighbour (NN) software trigger

In the standard analysis used so far [2], a *2NN* group with rather high signals without any timing information was used as trigger to accept the image. In low gamma energy events it is quite probable, that a NSB fluctuation is picked up instead of the true signal and the image is gathered around NSB core pixels, thus causing a strong bias in image parameter reconstruction. In order to avoid this but operating at low thresholds, a software trigger is defined by a *4NN* group with a low threshold of *3.5-4.5* phes. Preliminary studies show that for the hardware trigger with *4NN* groups within a 6ns time coincidence window, the probability for a trigger from NSB is about *1%*.

Since true signals in a pixel can be lost in the course of the signal extraction procedure (due to limited charge and time resolution) additional trigger possibilities are defined: *3NN* group with a threshold of *5.4* phes and also *2NN* groups with a threshold of *8* phes. The probability levels to get an NSB event with this trigger are kept equal to avoid an unnecessary complexity of the procedure. For a chosen probability level either the amplitude thresholds or coincidence time windows can be minimized.

The standard Image Cleaning and the one described here are compared in Fig. 2, where in the left plot the number of NSB events left over by the cleaning is shown as a function of the size of this "event" in units of photoelectrons. Much less NSB triggered events are found with the new method. In the right hand plot the *ALPHA* distributions [4] of MC-simulated gamma-events found by the standard and the new method are shown, demonstrating, that in the range of low gamma-energy ($<$ ca. 100 GeV) significantly more events are rescued (ca. *21%*).

2.2 Composing the image

The next step in forming the image is the search of the so-called *core pixels* - pixels with a signals at high confidence level. In the standard Image Cleaning procedure high confidence was provided only by the image topology and, accordingly, quite high threshold to accept the signal. Here, the core of the image is composed from compact time-correlated groups. The image will be formed step by step requiring a small difference in the photon arrival time for neighboured pixels. The total time spread in the whole image, however, may be

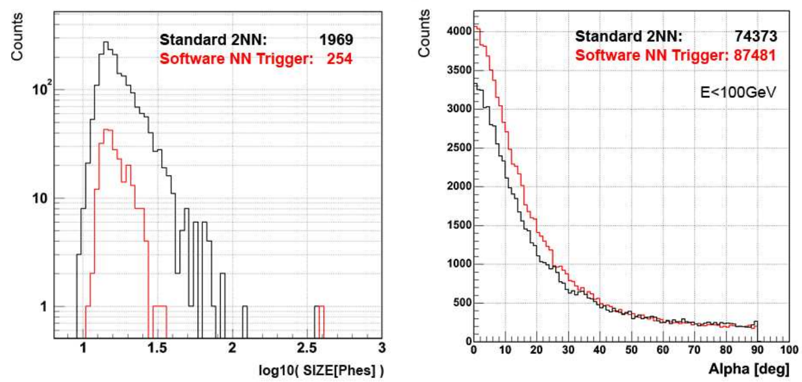

Figure 2. ***Left:*** *SIZE* distribution for pedestal events. *Standard trigger* and the new *NN software trigger* procedures applied to the same pedestal data with 25000 events. One can clearly see that new procedure gives ~ 8 times less triggers. ***Right:*** *ALPHA* distribution for MC gamma after cut in energy $E < 100GeV$. Gain of 21% in number of events is clearly seen.

large. Using such a procedure pixels with 4.5 phes charge can be already accepted as core pixels. Compared to the Standard Image Cleaning procedure this threshold is nearly twice lower.

Then, boundary pixels of an image have to be associated to the core, in order to reconstruct the image parameters with lowest possible bias. In case of low charge signals, the true signal may have been lost because a high fluctuation of NSB has been selected instead in another time slice. Since the arrival time of the event is known after the image core has been formed, the signal arrival time in a pixel with low pulse height, can be approximated as the average arrival time of the neighboured core pixels. In a narrow time window around this time a peak search in the FADC raw data is redone keeping the threshold for a signal still low.

In this manner misidentified low signals can be rescued and replace the false NSB values. This improves the reliability of the reconstruction of image parameters for low γ-energy events significantly as can be seen in the Fig. 3 (right plot), where the relationship between γ-energy and size of the event keeps linearity even at the low energy end.

The key point in the procedure presented here is, that the strategy of signal extraction and image reconstruction is connected and exploiting the time information in both cases reduces signal threshold significantly and allows low signal and, thus a larger part of the true image to be rescued.

3. Results

The method described above was compared with the standard analysis, using MC data, simulated with the CORSIKA air shower simulation program [3]. All MC data was simulated with the NSB noise of 0.4 phes/ns.

Besides the gain of low γ-energy events (se right plot on Fig. 2), the other significant effect of the of the new method is the strong reduction of the so-called ”pixelized” events (see left plot on Fig. 3), i.e. events in which the number of pixels in the image is so small that the discrete structure of the camera is visible. With more signal being rescued by the new method, a more complete image can be recovered.

The other quite remarkable effect of the new method is that the relation between the *SIZE* of the event and the energy of the gamma is linear down to lower values of energy (right plot on Fig. 3), because a larger fraction

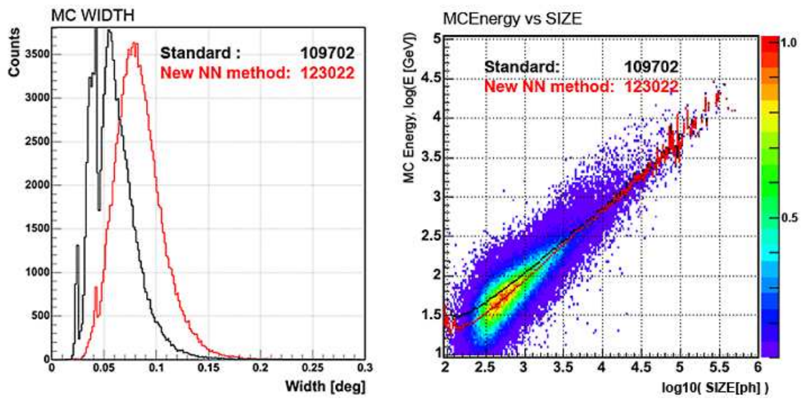

Figure 3. ***Left:***Comparison results for the standard Image Cleaning procedure and the new method. The pixelization effect in *WIDTH* distribution is dramatically reduced.***Right:*** Energy versus *SIZE* plot for the new method has a better linearity (black and red curves indicate the mean energy for each *SIZE* bin for standard and new image cleaning method respectively).

of the true shower signals can be extracted from the image. This is important for a more precise γ-energy determination.

4. Conclusions

There are several advantages of the New Image Cleaning Method: Less NSB triggers, higher purity of data, the gain of 21% in the number of events in the energy region below 100GeV, good sensitivity to islands and more informative Image Parameters. All these advantages give a possibility to lower the analysis threshold. Further overall improvements in the g/h-separation and the energy estimation, will be studied using the *Random Forest* procedure [5].

5. Acknowledgments

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