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Auger front-end ASIC simulations

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Abstract. The Auger Observatory is intended to observe the highest energy cosmic rays. It is designed to trigger with approximately 100% efficiency on air showers induced by primary particles with energies exceeding 10^{19} eV. The surface array of the Observatory contains approximately 1600 stations arranged on a hexagonal grid. Stations store data locally and communicate with the central data facility in order to determine whether a large air shower has struck the array. Data stored at each station undergo some filtering before an overall global trigger is decided upon. Parameters of the trigger determined from simulation studies are presented.

1 Introduction

The surface detectors of the Pierre Auger Observatory are water tanks viewed by three photomultiplier tubes. Single muons, small showers and PMT noise will produce a rate of approximately 5 kHz from a 10m^2 detector. This is known as the Level 0 trigger, based on registering pulses above a modest threshold. A next-level trigger (Level 1) provides discrimination against uncorrelated single muons and small showers, reducing the rate to 100 Hz or less at each station. The logic of the Level 1 trigger is implemented using an application-specific integrated circuit (ASIC). The ASIC analyzes digitized photomultiplier waveforms from a 40 MHz Flash Analogue to Digital Converter (FADC).

There are three main functions of the Level 1 trigger ASIC. The first is to produce a trigger unbiased by primary composition. The second is to differentiate large distant showers from smaller 'local' showers without discarding potentially interesting near-horizontal showers. Lastly the trigger is to be $\sim 100\%$ efficient for 10^{19}eV showers.

The ASIC Level 1 trigger occurs for any of five circumstances. One is used for muon calibration, two others are random triggers. We will discuss the two triggering schemes used to indicate large extensive air showers (Trg2 and Trg3).

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The logic of Trg2 is designed to flag detectors far from the shower core, while Trg3 aims to register those at close distances. To do so, Trg3 seeks larger pulse heights over a smaller time span than Trg2. The two triggers separately examine the re-binned FADC waveform. Trg2 analyzes a 6.3μs span (64 bins, each 100 ns) while Trg3 sees 1.575μs (64 bins, each 25 ns).

Both triggers are time-over-threshold triggers. The trigger parameters to be studied here are:

- The width of a time window in which the total pulse height should exceed some level,
- The number of occupied bins in that window,
- The FADC-sum threshold within a single time bin such that the bin should be considered occupied.

2 Simulations

The array is intended to be nearly 100% efficient for air showers exceeding 10^{19}eV in energy, and have a very low efficiency at lower energies (say 10^{18}eV). Even though Iron showers are, on average, have less total ground particles than do Proton showers of the same total energy, their muon content is higher. The Auger detectors are very sensitive to muons. We will assume that if a 10^{19}eV Proton air shower triggers well, then a Iron air shower with the same energy will do so also. Conversely if a 10^{18}eV Iron air shower does not trigger well, then neither will an Proton air shower of the same energy.

One hundred 10^{18}eV Iron showers and 10^{19}eV Proton air showers were used in this simulation. The air showers were generated at 20 degrees zenith & thinned at 10^{-7}, using the AIRES siumulation package (version 2.2.0) and the Sibyll hadronic interaction option. In order to get individual detector responses these showers were passed thru a modified version of the AGAsim package (0.95) which realistically constructs FADC waveforms for each of the three PMT's in each detector. The simulation included a detailed description of all the electronics.

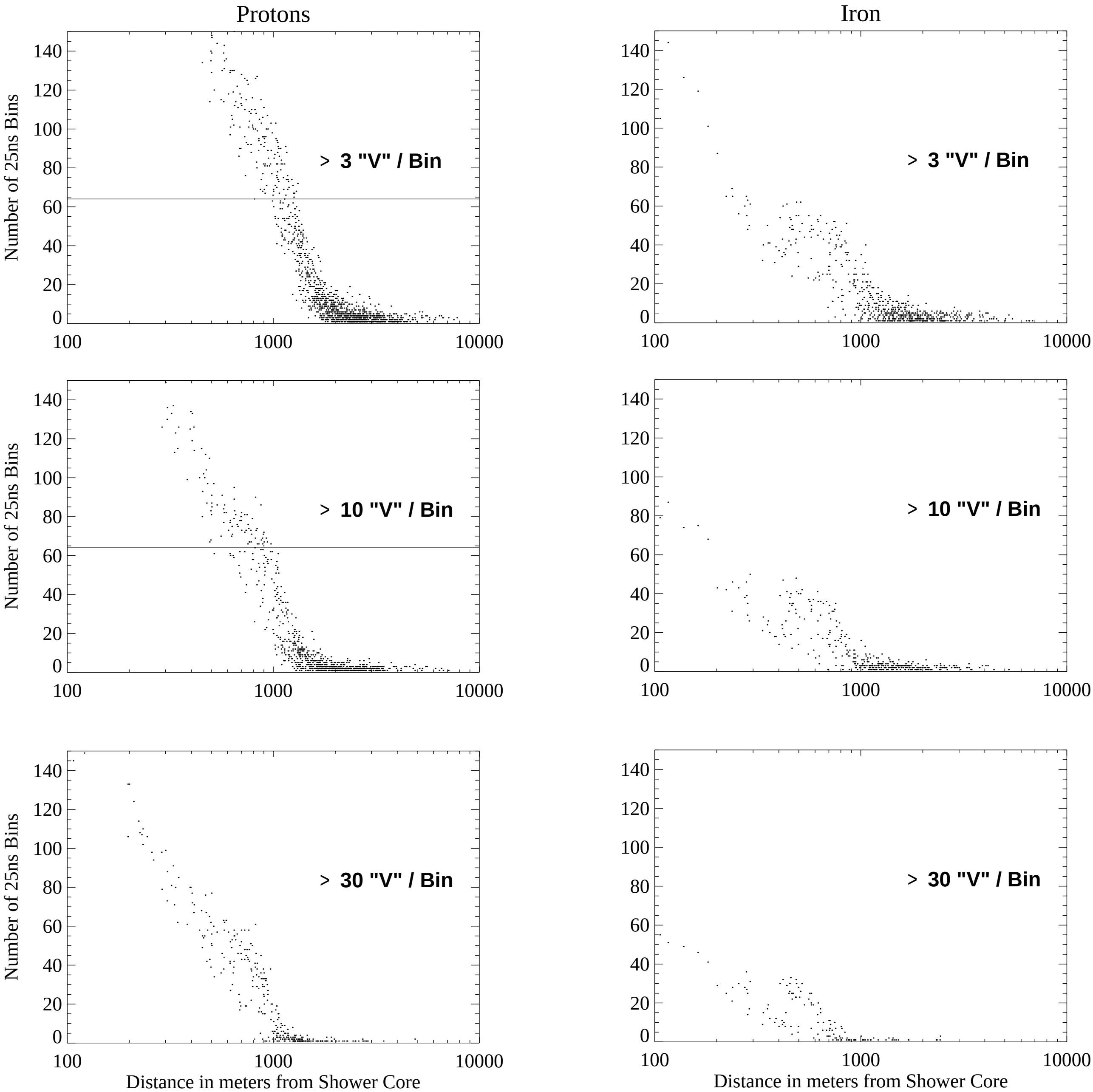

Fig. 1. Plots of the number of occupied 25ns bins as a function of distance from the shower core above a particular threshold/bin, indicated in the top right of each figure (in 'V'). Note the greater number of points in the Proton 10^{19}eV showers indicate the larger number of detectors with FADC outputs compared to the Iron 10^{18}eV showers. The horizontal line indicates the maximum number of bins (64) that are available for the trigger.

3 Results

We use the simulation to establish operating parameters which maximize the triggering efficiency of 10^{19}eV showers with minimum contamination from random single particle noise and lower energy (10^{18} eV) showers. We will require at least 5 triggered detectors for an 'Event Trigger'. The triggers will be studied using two sets of simulated events - low energy ("Iron") and high energy ("Proton").

The number of occupied 25ns FADC bins as a function of distance from the shower core for all detectors in all the Proton and Iron showers is shown in Figure 1. The plots show what happens when the 25ns bins are required to contain at least a certain pulse height. (The pulse height is quoted in units of 'V's, where 1.0 'V' corresponds to the peak pulse for a 1 photoelectron signal). The higher energy Proton showers contain more 25ns bins, the peaks are typically a factor of two greater. The density of dots in Figure 1 are an indication of the number of detectors hit, the higher energy Proton showers typically having a larger number of hits. Figure 2a shows the number of hit detectors for each set.

The peak pulse height distribution and the charge as a function of peak pulse height is shown in Figures 2b and c. The typical peak pulse height of a single muon is approximately 20 'V's. The peak pulse height distribution falls off with number of 'V's as expected, but there is an enhancement corresponding to single throughgoing muons around 20 'V'. This single muon peak is also seen as an increase in density of dots in plot 2c.

It is evident that a good way to discriminate against lower energy showers ($\leq 10^{18}$eV) is to require a larger number of 'hit' detectors and more occupied bins within a detector pulse train. If we require 5 or more detectors for an 'Event', Figure 2a suggests that a modest threshold level will retain the Proton showers and remove most of the Iron set.

The plots shown so far are for all detectors in the entire sample of simulated showers. To evaluate tirgger efficiencies. we must know the number of detectors in a shower that have detector triggers. A contour plot of the number of detectors in a given shower as a function of threshold level and number of occupied bins is shown in Figure 3, for Trg2 and Trg3. The contours for Protons correspond to **at least** 95% of showers having those properties. Conversely the Iron contours are for none of the showers having those properties.

It is possible to find various points on the Proton contours in Figure 3 that will not produce any triggers for Iron showers. We would like to operate at the lowest possible combination of threshold and number of occupied bins, however that is going to be dictated by the background random triggers (noise) and maximum communications rate. Further studies are underway to characterize random triggers and to optimize the mix of Trg2 and Trg3.

Another aspect that we wish to include is the "hybrid" trigger. We do not wish the surface array to trigger efficiently for 10^{18}eV showers, but is desirable to have at least one detector register for such events. This will help in the reconstruction analysis of Auger fluorescence detector triggers, which will

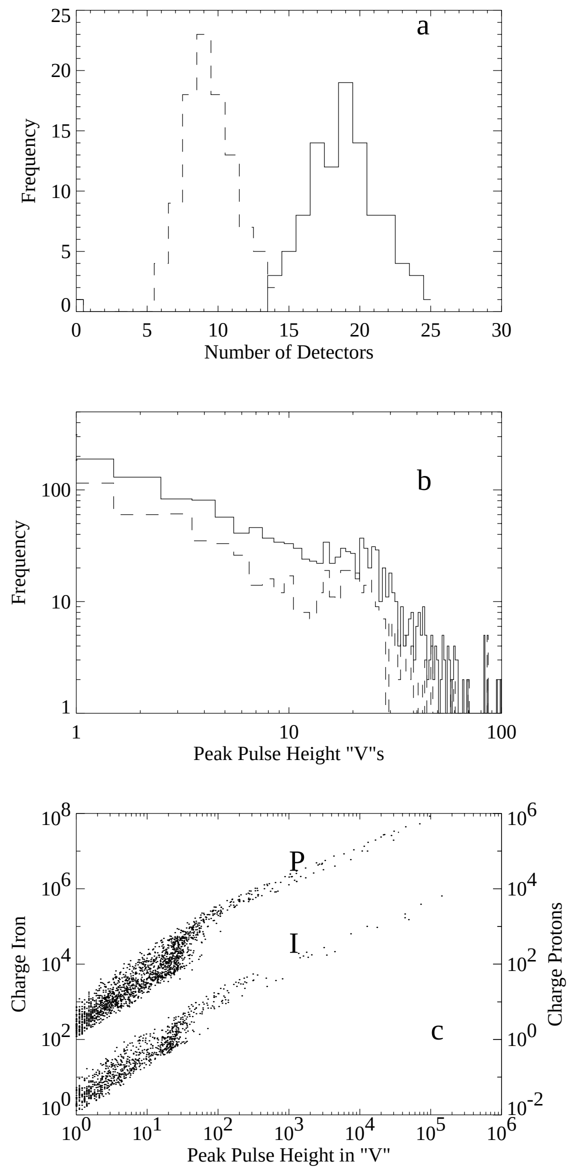

Fig. 2. (a) The distribution of 'hit' detectors before the trigger in a shower, the dashed line is for 10^{18} eV (Iron) events, the solid line for 10^{19} eV (Protons), (b) the peak pulse height distribution, the single muon peak is evident at approximately 20 "V"s, (c) the total charge in a detector FADC pulse vs the peak pulse height, the Protons are multiplied by 100 to separate them.

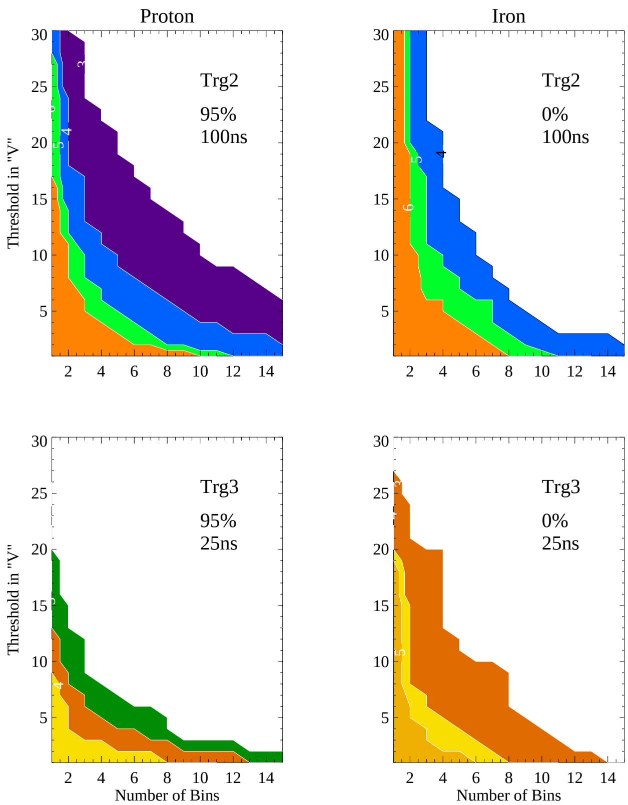

Fig. 3. Contour plots showing the number of triggered detectors per shower as a function of threshold (in 'V') and bin number for Proton and Iron showers. The Trg2 contours have 100ns wide bins, and the Trg3 contours have 25ns wide bins. The Proton 10^{19}eV contours are for a triggering efficiency of at least 95% and the Iron 10^{18}eV contours correspond to a triggering efficiency of 0%. Triggered detectors are represented in Trg2 by Purple (3), Blue (4), Green (5), and Orange (6); Trg3 by Green (2), Orange(3), Yellow (4).

be common at these energies.

Figure 4 shows the trigger efficiency for a particular threshold of Trg2 and Trg3 together with five or more detectors, so that 10^{19}eV showers are nearly 100% efficient at triggering the array.

In summary, it is possible to find an operating parameter for the ASIC trigger that gives high efficiency for 10^{19}eV showers, with almost no triggers at energies $\leq 10^{18}$ eV. However, the detector triggers can still provide one or a few stations registering at low energies for use in combined fluorescence and ground array analysis.

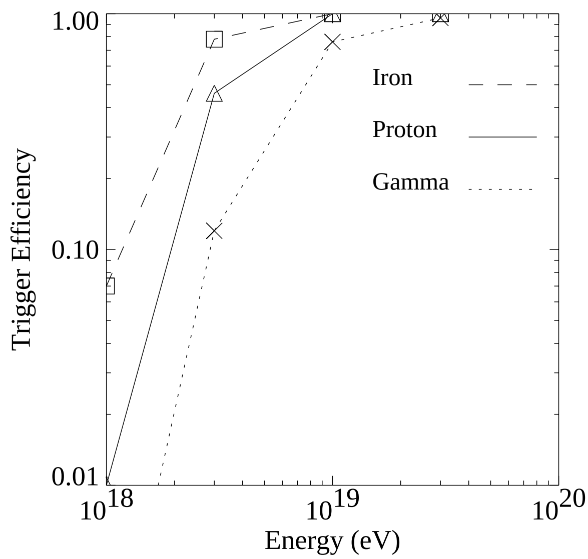

Fig. 4. Trigger Efficiency curves requiring a particular threshold of Trg2 and Trg3 and five or more detectors. Iron, Proton, and γ-induced shower sets are shown separately.

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