PROCEEDINGS OF SCIENCE

Algorithm for Background Rejection using Image Residuals

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Identification of Cherenkov light generated by muons has been suggested as a promising way to dramatically improve the background rejection power of Imaging Atmospheric Cherenkov Telescopes (IACT) arrays at high energies. However, muon identification remains a challenging task, for which efficient algorithms are still being developed. We present an algorithm in which, rather than identifying Cherenkov light from muons, we simply consider the presence of Cherenkov light other than the main shower image in IACT with large mirror area. We show that in the case of the H.E.S.S. array of five telescopes this approach results in background rejection improvements at all energies above 1 TeV, while keeping high gamma-ray efficiency.

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1. Introduction

In gamma-ray astronomy, the separation between hadronic and electromagnetic cascades is a critical task due to the huge amount of background cosmic-rays. The rejection power of Imaging Atmospheric Cherenkov Telescopes (IACTs) worsens at energies higher than around tens of TeV, and a recent study [1] showed that an efficient identification of muon light can be a very useful tool to improve the background rejection power at this high energies, by using the image of a large-dish telescope. This method can potentially lead to background rejection levels up to 10^{-5} at energies above 10 TeV. A follow up paper has been recently published [2], which presents an *Algorithm for Background Rejection using Image Residuals* (ABRIR) and describes its performance and results. In this proceeding, we will summarize the presented algorithm, describe its application when analysing the data taken by the High Energy Stereoscopic System (H.E.S.S.) experiment [3] and give further improvements with respect to the version in [2].

The algorithm in development will be part of the software used in the H.E.S.S. experiment, called H.E.S.S. Analysis Package (HAP). The H.E.S.S. experiment is comprised of a total of five telescopes: four with a dish of 12 m diameter referred to as CT1-4 and a central one, CT5, with a dish of 28 m diameter. In this proceeding we present an approach in which only the data of CT1-4 is used for the event reconstruction (*stereo* reconstruction), and the data of CT5 is used exclusively for background rejection.

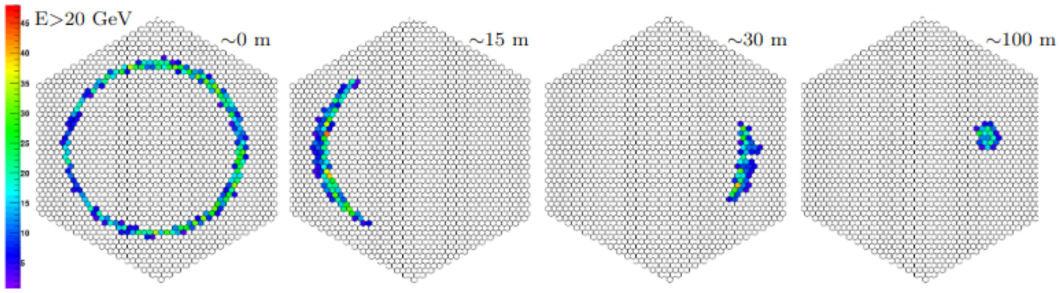

Figure 1: Example simulated muon images in a 28 m telescope at different impact distances. Simulated muons are produced at 11 km above sea level and are observed at 1835 m with a zenith angle of 20°. Figure extracted from [1].

2. The Algorithm

ABRIR extracts additional information from the detected event image taken by the large CT5 telescope in the H.E.S.S. array. This algorithm is applied after the usual event reconstruction, which includes an initial step of background rejection based on Boosted Decision Trees (BDTs) [4]. In particular, two sets of initial cuts are used: the H.E.S.S. *standard* selection cuts (see Section 4.2 of [4]) and the so-called *hard* cuts. The *standard* cuts only require images to have a total intensity larger than 60 photoelectrons (p.e.), while the *hard* cuts require a minimum of 200 p.e.. ABRIR is applied only to the events that survives this initial cut, and only at this step the data from CT5 is considered.

The algorithm used for event reconstruction is the Image Pixel-wise fit for Atmospheric Cherenkov Telescopes (ImPACT) [5], which is based on the likelihood fitting of camera pixel amplitudes to an expected image template and is routinely used by the H.E.S.S. experiment. ImPACT gives a expected image of the CT5 camera, with a certain goodness of fit, which helps us to identify the main shower in the data image (see panel b of fig. 2). The published ABRIR algorithm [2] uses the prediction to mask the main component of CT5 image, and analyzes the residual features.

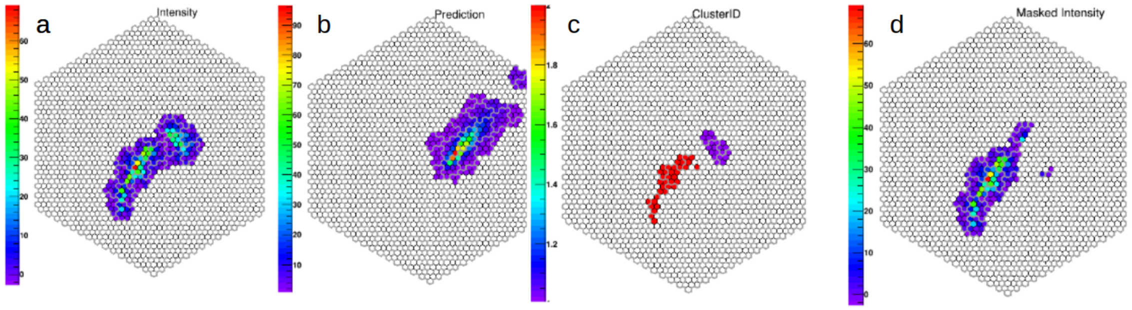

Figure 2: Large telescope (CT5) image of an example background event. The panels are a) the event image intensity, b) the template image given by ImPACT, c) the cluster information given by time-based cleaning algorithm and d) the masked image intensity. One can clearly see that this is unlikely a gamma-ray event.

After the main shower is masked, ABRIR loops over the remaining residual clusters to compute their distance to the main shower in the predicted image d_{N} and the total intensity $I_{\mathrm{tot,N}}$. A cluster is only considered if it is comprised of more than three pixels. The charge-distance is then computed as $I_{\mathrm{tot,N}} \cdot d_{\mathrm{N}}^2$. The event would be rejected by the algorithm if any of the residual clusters has a charge-distance larger than a threshold value 9×10^{-3} p.e. $\cdot$ degree^2 (equivalent to 2 p.e. $\cdot$ pixel^2, units used in [2]). This value is selected to maintain a gamma-ray efficiency of around 90%, which in turn results in the background rejection performance described in Section 3. This cut value is specific to the current state of the central telescope in the H.E.S.S. array.

2.1 Ongoing improvements

Here we present the improvements in development of the algorithm with respect to the already published version. First, a time-based cleaning algorithm is used before applying ABRIR to identify the light clusters in the image using the arriving time information per pixel (see panel c of fig. 2). Secondly, the ImPACT goodness of fit, which is defined by the equation 6 in [5], is also exploited to enhance the rejection power of this technique and identify those events with a poor reconstruction quality. We normalize the goodness of fit by the amplitude of the image since the value of the goodness increases with it. The distribution of the scaled goodness of fit for gamma-rays and background events is shown in Fig. 3, for two different zenith angles. The difference between simulations and background events is clear at both zenith angles. We are currently investigating the addition of these parameters to further improve the algorithm performance. A reasonable value for the goodness of fit cut is 1, which also keeps the gamma-ray efficiency above 90%.

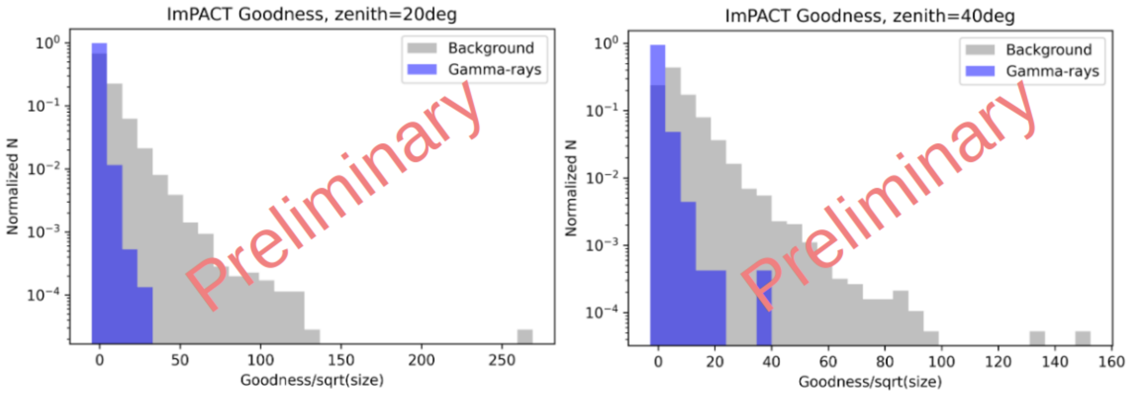

Figure 3: As an example of reconstruction quality parameters, we show here the distribution of the ImPACT goodness of fit for background and simulated gamma-ray events, for two different observation zenith angles.

3. Performance

In this section we show the performance of the algorithm presented in [2], since the improvements are still in development. Improved rejection power at the higher energies above 10 TeV is expected for the algorithm which includes reconstruction quality criteria.

The performance of the algorithm is tested on different types of events: simulated gamma-rays (using the CORSIKA [6] and the *sim-telarray* [7] packages), background events and data from the Crab Nebula. Fig. 4 shows the ABRIR cut efficiency for different sample datasets as a function of the reconstructed energy for several observation zenith angles. The upper panels shows the efficiency for those events surviving the H.E.S.S. *standard* cuts, whereas *hard* cuts are applied in the bottom panels. The efficiency is defined as the ratio of the number of events before and after applying ABRIR. We can see that the cut rejects a significant fraction of background events in both cases and at all energies. Background rate reductions of up to a factor 2.5 are obtained for the *standard* cuts case, while for the *hard* cut, this improvement goes up to factors of 3 and even 4. Moreover, it is also important to keep a high amount of true gamma-rays, and as can be seen in Fig. 4, the gamma-ray efficiency is mostly flat as a function of reconstructed energy, and at around 90%.

4. Summary and outlook

We have shown a promising way to improve the background rejection in IACT arrays using images of a large-dish telescope as a veto step. The performance of this algorithm presents improved rejection power at high energies above 1 TeV, by a factor ranging between 2 and 4, depending on the energy and the specifics of the initial H.E.S.S. *standard* or *hard* cut. The reduction of background rate leads to reduced uncertainty associated with it, and thus, improves the precision at high energies.

We aim to standardise the use of this algorithm in HAP which is one of the standard software packages used to analyze the data taken by the H.E.S.S. experiment. Additional reconstruction quality parameters, such as the ImPACT goodness of fit, are also being investigated in order to further improve the background rejection power for this instrument.

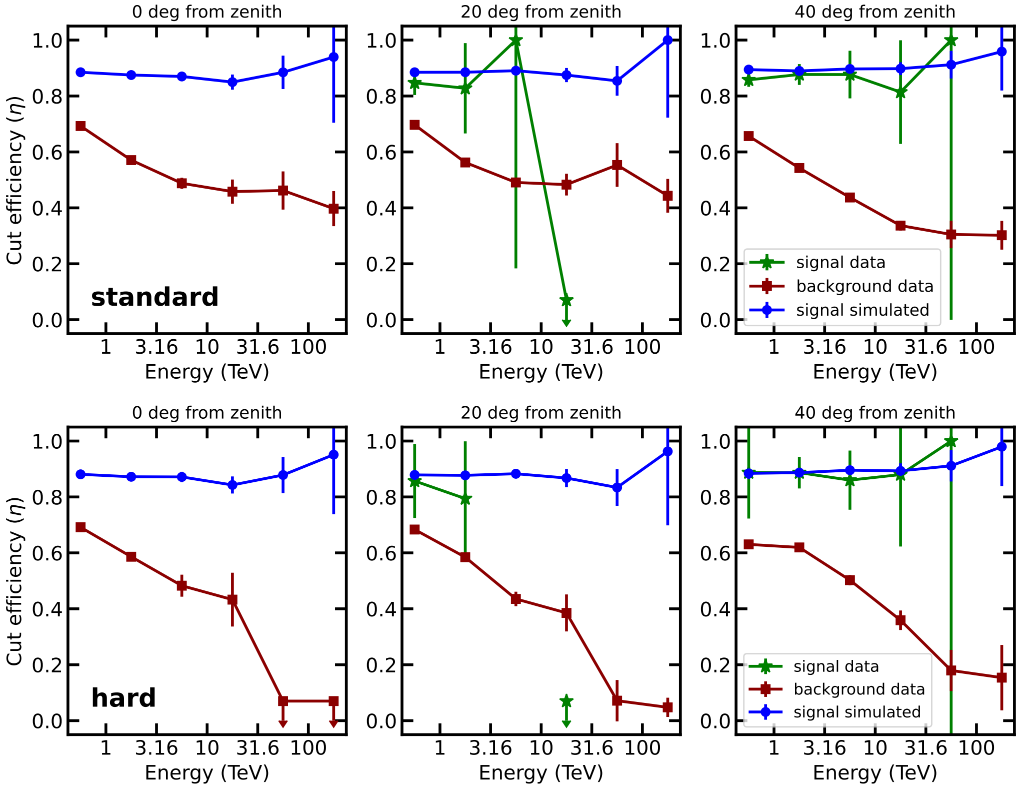

Figure 4: Fraction of events kept by ABRIR cut applied after the H.E.S.S. *standard* cut (upper panels) and *hard* cut (bottom panels) for simulated gamma-rays (blue), background data from off-runs (red) and events taken from a radius of 0.2°from bright gamma-ray sources (green). Figure extracted from [2].

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