Selection Strategies For Low Energy Events In Imaging Atmospheric Čherenkov Telescopes

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Abstract

Two alternative strategies for extraction of low energy gamma-ray events detected using the 490 pixel Whipple 10 m IACT high resolution camera are described. Method one (*MC-A*) is an optimisation based on observations of Mrk 421 in a flaring state. Method two (*MC-B*) is an optimisation which addresses inherent differences in sky brightness between ON source and OFF source observations of the Crab Nebula. In each case a set of parameter cuts was derived and optimised to give a maximum signal rate excess.

1. Introduction

Supercuts 2000 was developed to establish new sources of gamma radiation at a statistically significant level. The efficiency of *Supercuts 2000* was shown to be greatly enhanced by the application of a *length/size* cut to data obtained with the earlier Whipple 331 pixel camera. This cut was designed to reject background images caused primarily by local muons. The disadvantage of using this cut is that it rejects a majority of low energy events, including real gamma rays. It also generates a low energy threshold which is difficult to interpret. Using the earlier vintage 331 pixel camera, several strategies for selection of small gamma-ray showers were examined by Moriarty et al. [1], based on observations of Mrk 421 at the Whipple Observatory during 1995 and 1996. Despite inherent difficulties in attempting to extract a significant signal in an energy regime subject to systematic effects, a statistically significant detection of Mrk 421 was made in the energy range 170 GeV to 300 GeV.

2. Optimisation of small event cuts (*Minicuts - MC*)

Extraction of a genuine signal in the background-dominated energy regime at or below the nominal threshold of a Čerenkov imaging telescope, is a potentially rich source of small events. The *MC-A* optimisation of new cuts for small events is based on the selection of a sample of eight Mrk 421 scans taken during a period of high flare activity in March 2001, each file exhibiting a significance of

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10 standard deviations or more when *Supercuts 2000* was applied to the data and to an equivalent set of matching comparison files. Following traditional Gaussian padding [2] and moment parameterisation, events were binned into three size ranges (a) $<$ 275 dc (b) 275 $<$ size $<$ 450 dc and (c) $>$ 450 dc. The low size band events were rejected and new optimised parameter cuts were developed for the event cohort in the 275 dc to 450 dc size band. New optimum parameter range cut values are summarised in Table 1.

The optimised *MC-A* selection has been re-applied to the original eight Mrk 421 data set (on which they were optimised). The cuts have also been applied to an independent 16 pairs of data taken on the Crab Nebula during 2001 and to an independent sample of 20 pairs, also taken during the prolonged period of flaring activity of Mrk 421, in March 2001. As a check that the new cuts were not just finding small events which the standard *Supercuts 2000* analysis might have detected, the eight Mrk 421 pairs were also analyzed using *Supercuts 2000* and using *Supercuts 2000* with a lower size cut of $>$ 450 dc. The detection significances and rates per minute for these analyses were 37.02 σ [38.48 σ] and 11.27 $\pm$ 0.30 γ min^{-1} [10.5 $\pm$ 0.27 γ min^{-1}] respectively. Clearly detections of this source in the small event size range are in addition to those detected with *Supercuts 2000*.

The *MC-B* optimisation is a more intricate process involving 16 Crab pairs of data from 2001. Since the inner 379 pixels of the current 490 pixel camera are small, they are dominated by Poissonian rather than Gaussian noise fluctutations. Inherent sky brightness differences between Crab ON and OFF fields introduces a significant bias which traditionally is compensated for using Gaussian padding. This process is not sufficiently robust in the small event regime ($<$ 450 dc). In this *MC-B* optimisation, padding was applied using random variables drawn from a Poisson distribution and applied to the darker sky region. This departure from traditional image processing necessitated a contingent re-optimisation of the *Picture/Boundary* image cleaning values from 4.25/2.25 to 5.50/1.75. Subsequently the moment parameter values were optimised and the resulting cut values are tabulated as *MC-B* in Table 1.

The *MC-B* re-optimised cuts applied to Crab data in the size range 250 $<$ size $<$ 450 dc reflect a detection significance of 4.81 σ corresponding to a rate of 1.93 $\pm$ 0.40 γ min^{-1}. When these cuts were applied to the two independent Mrk 421 datasets the detection significances and rates per minute for these analyses were 7.71 σ [15.48 σ] and 4.60 $\pm$ 0.60 γ min^{-1} [5.96 $\pm$ 0.38 γ min^{-1}] respectively.

3. Conclusion

Two independent strategies have been presented, which extract low energy gamma-ray events from data. Although each strategy uses a different padding process and slightly different moment parameter cuts, the results obtained when

Table 1. Optimum cut values for low energy events. No *length/size* cut is employed in this selection. *MC-A* and *MC-B* represent the alternative strategies evaluated.

Parameter	Cuts	
	MC-A	MC-B
length	0.11 - 0.22	0.10 - 0.25
width	0.05 - 0.11	0.05 - 0.11
distance	0.5 - 1.0	0.4 - 1.0
size	275 - 450	250 - 450
alpha	0 - 17.5	0 - 15.0
max1, max2, max3	30, 26, 0	30, 30, 0
frac3	0.98	0.98

Table 2. Application of optimised cuts to different data sets (* data used for optimisation).

Source	Cuts	events (on)	events (off)	σ	Rate/min
Mrk 421	MC-A*	5126	4157	10.06	4.40 ± 0.43
(8 pairs)	MC-B	9120	8108	7.71	4.60 ± 0.60
Crab	MC-A	11207	10379	5.60	1.90 ± 0.34
(16 pairs)	MC-B*	16186	15333	4.81	1.93 ± 0.40
Mrk 421	MC-A	13768	11314	15.50	4.54 ± 0.29
(20 pairs)	MC-B	23181	19965	15.48	5.96 ± 0.38

applied to common data sets are very similar. As expected, both *MC-A* and *MC-B* give significant results when applied to the data that the cuts were optimised on, (Mrk 421, 8 pairs and Crab, 16 pairs, respectively). The rate of 4.40 ± 0.43 γ min^{-1} produced by the application of *MC-A* on the 8 Mrk421 pairs was tested by the application of *MC-B* to this data, this yielded a rate of 4.60 ± 0.60 γ min^{-1}, which is comparable to the *MC-A* result. Conversely, *MC-B* was then tested by applying *MC-A* to the 16 Crab pairs used in the optimisation of these cuts, this gave a rate of 1.90 ± 0.34 γ min^{-1}, which agrees with the rate of 1.93 ± 0.40 γ min^{-1} produced by *MC-B*. An independent dataset of 20 Mrk421 pairs taken during the flare of March 2001, was selected and both strategies applied, the results are shown in Table 2, as before they are in close agreement. Figure 1 shows the alpha plots produced by each strategy when applied to the 20 pairs, each plot clearly exhibits a statistically significant excess at low alpha values.

The results presented here show that it is possible to extract a significant number of events in an energy domain below the peak energy response of the

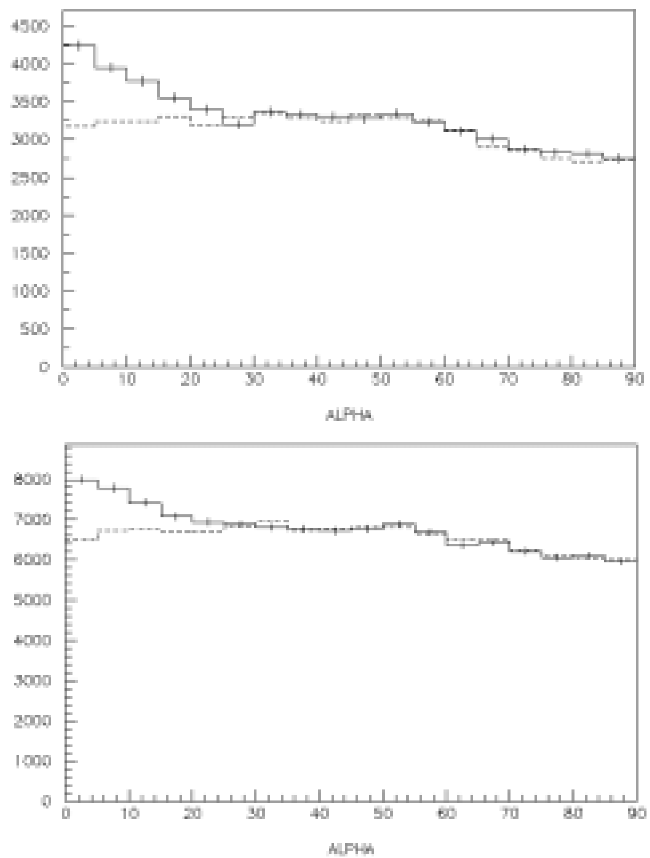

Fig. 1. Alpha distributions resulting from the application of small event cuts to Mrk 421 flare data consisting of 20 pairs (this data was not used for either optimisation). The top plot shows results produced by application of *MC-A* while the bottom plot shows the distribution produced by application of *MC-B* (note different scales on axes).

current Whipple configuration to a Crab-like spectrum which is estimated to be $\approx$ 400 Gev, and currently unexploited by *Supercuts 2000*. The small size events which are targeted make both strategies ideal for the detection of sources with steep spectra. Investigation of this low energy region through the application of *MC-A* and *MC-B* to other gamma-ray sources and candidates is in progress.

4. References

1. Moriarty P. et al. 1997, Astropart. Phys. 7, 315
2. Cawley M.F. 1993, Workshop Towards a Major Čerenkov Detector (Calgary), 176