Use of pixel time parameters in ASTRI Mini-Array event reconstruction: application in gamma/hadron separation.

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ABSTRACT

In preparation for the deployment of the ASTRI Mini-Array [1], the ASTRI team is developing a comprehensive Data Processing system that addresses all aspects of data management, reduction, and analysis. A key focus within this framework is enhancing the efficacy of the standard procedures in the Cherenkov data pipeline (A-SciSoft [2]) for event reconstruction. **To improve the sensitivity of the array, particularly in discriminating between gamma-ray induced showers and hadron-induced showers, we are investigating the temporal evolution of the shower images t**hat can provide additional discriminatory power beyond the traditional morphological parameters. We have developed and tested a set of parameters derived from the pixel time tags, which record when the photoelectron content of each pixel exceeds the trigger threshold. **Through extensive testing, we have identified a subset of these time parameters that exhibit good discriminatory efficacy.** Combining these time parameters with the standard morphological parameters has demonstrated a significant improvement in hadron rejection, especially at the lower end of the energy detection range. These preliminary results are encouraging, and we plan further tests and investigation to optimize their use.

The ASTRI Mini-Array is an international project led by the Italian National Institute for Astrophysics (INAF) aimed at operating an array of nine small-sized (4-m diameter) IACTs tol conduct extensive galactic and extragalactic gamma-ray sky observations in the 1–200 TeV energy band. It will be located at the Observatorio del Teide in Tenerife, Spain, where the first three telescopes are expected to be operational within the next year.

PIXEL TIME TAG ASSIGNMENT

At raw data level, **each camera pixel is assigned a value between 0 and 255 that represents the time (in ns) when the cumulative charge readout in the pixel exceeds the charge threshold T set for the trigger to occur**, referred to a zero time defined according to the camera trigger. The value 255 is assigned to pixels reading a signal below threshold T at the time of the topological trigger and for the entire duration of the readout process. The pixel time information is stored with the same array structure as the intensity image, and can be processed and used as an image as well.

SELECTED TIME PARAMETERS DESCRIPTION

We have explored several parameters based on the pixel time tags (La Parola et al. in preparation). Here we report those who have demonstrated a significant discriminating power.

T_RMS (Root Mean Square). It provides information on the dispersion of the arrival times of Cherenkov photons, to distinguish between the more regular photon-induced showers and the more irregular hadron-induced showers.

T_GRAD (Gradient). This measures the time gradient across the camera, helping to identify the shower orientation.

T_COHER (Coherence): It assesses the temporal coherence of the Cherenkov photons.

T_RMS_W (Weighted RMS). This is T_RMS weighted for the intensity of the signal in each pixel

T_LAC (Time Lacunarity). This parameter captures the largest deviations in the arrival times, highlighting the extremities of the temporal distribution, which can be indicative of hadron showers.

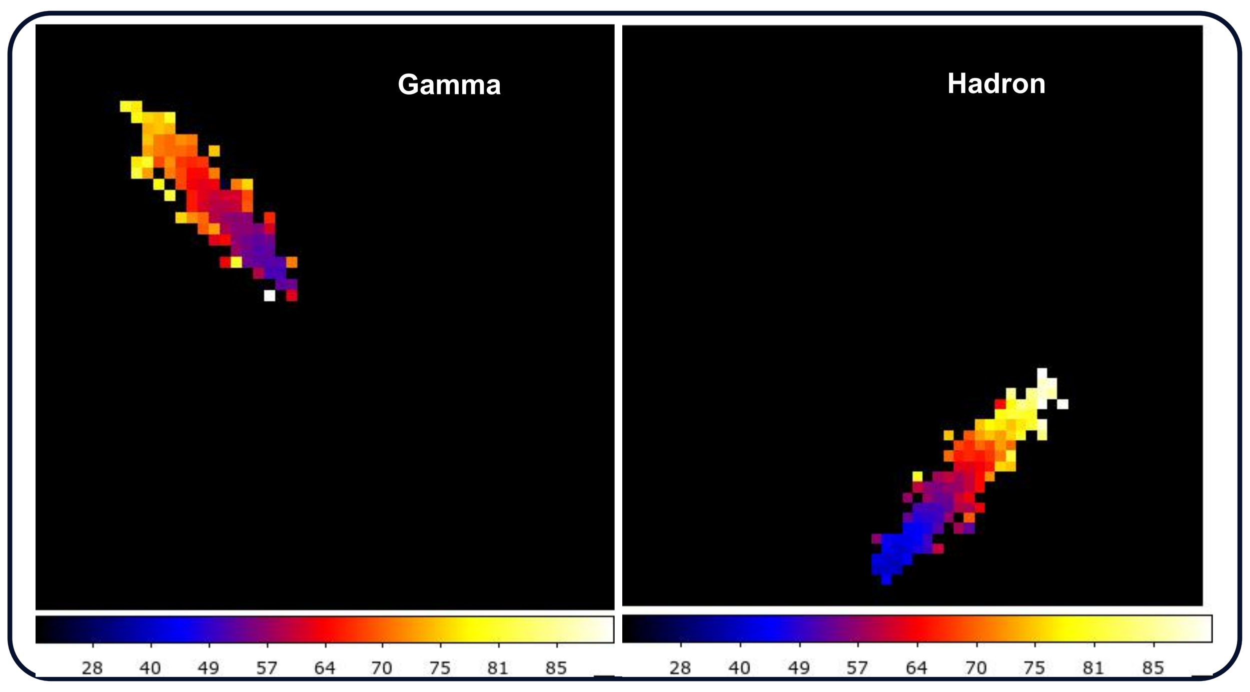
LEN_ST (Length in the size/time space). This parameter describes, if any, the correlation between pixel intensity and time.

LEN_DT (Length in the distance/time space). It represents the difference in time length across different parts of the shower, providing insights into the temporal asymmetry of the event.

LEN_ST_NORM (Normalized Length in the size/time space). This is the same as LEN_ST but normalized by image size.

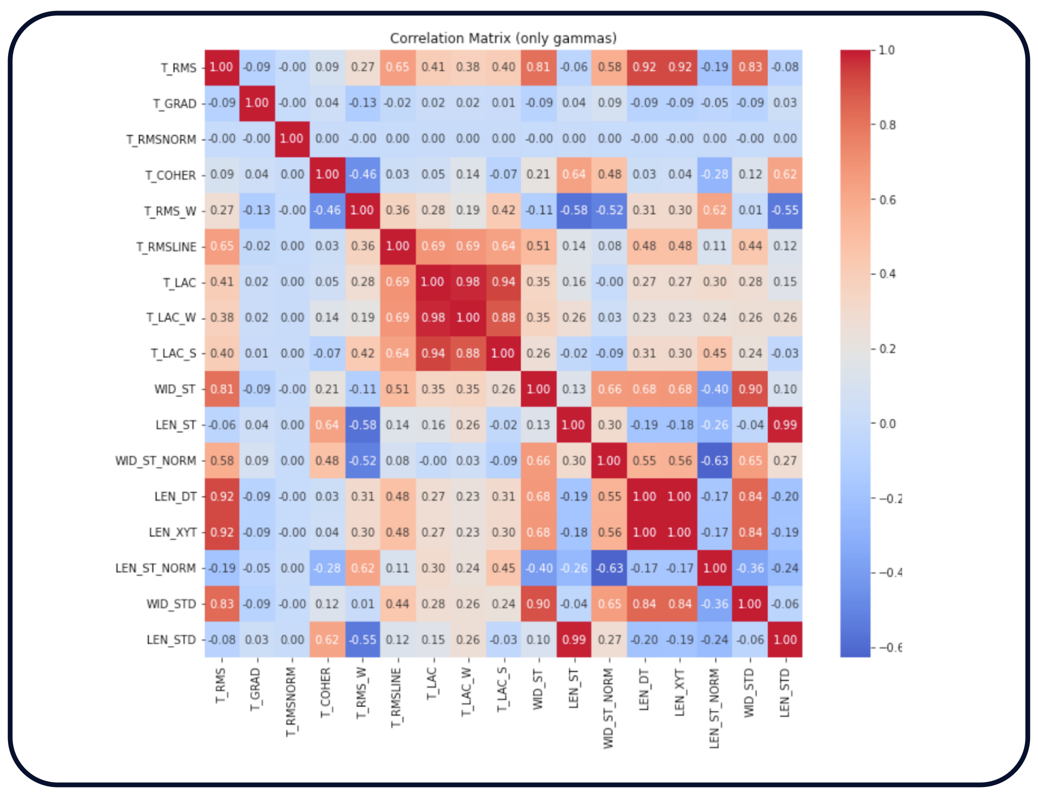
PARAMETER TESTING

The selected time parameters were included in the standard ASTRI analysis software [2] and used in the discrimination algorithm (based on Random Forest routines) along with the standard discrimination parameters (e.g. Hillas parameters etc). This brings the set of parameters from 12 to 20. This new set was tested on the so called ASTRI-Prod2 TEIDE MonteCarlo simulation production of Gamma and Hadrons and the results were compared with those achieved with the standard parameter set. Further tests are ongoing.



Pixel Timetag Images

The image time development can be visualized using a color code for the pixel recorded time on the cleaned image. Here we show two images with comparable size and morphology, but with different time development (that in this case can be measured by the time gradient along the major axis)

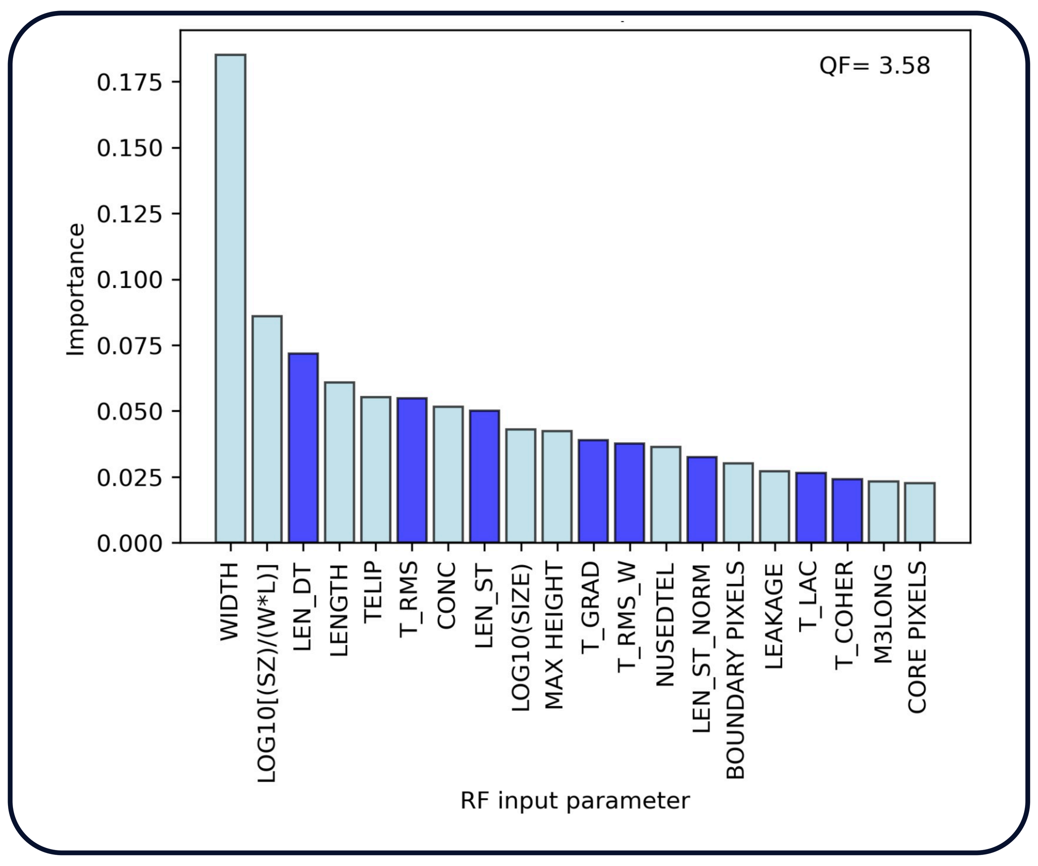


Parameter spaces explored in this work

We have explored several possible parameters, that can be grouped as follows:

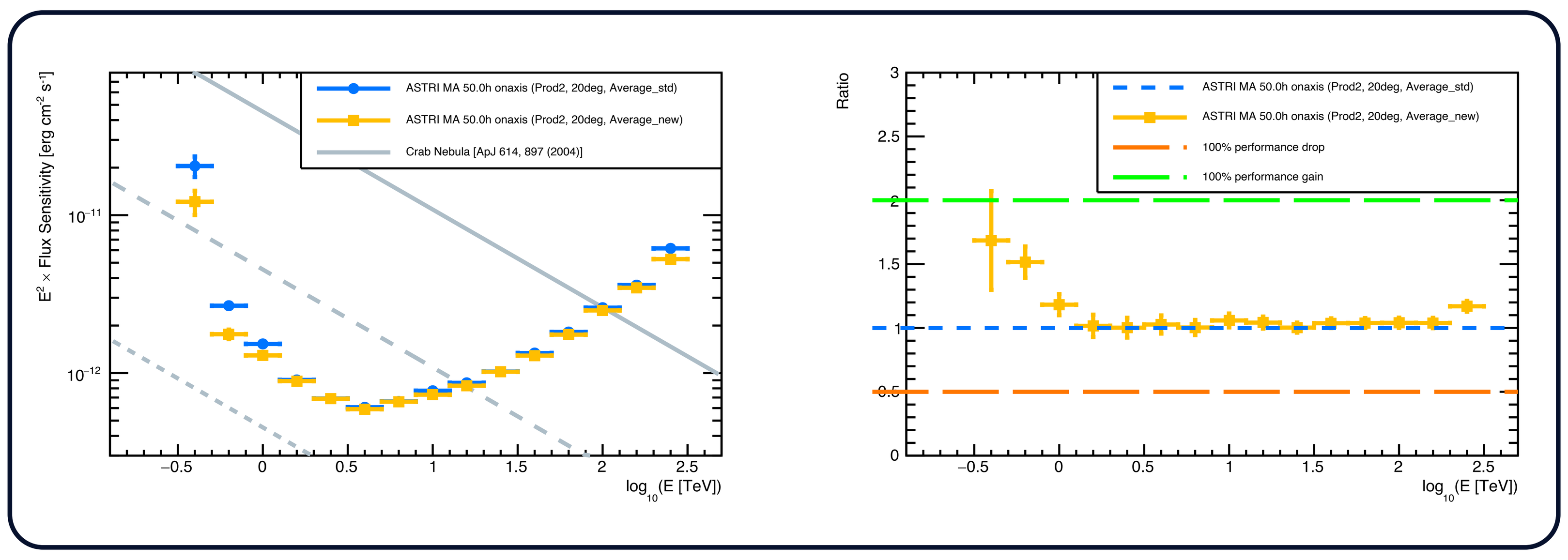
- Standard parameters (Gradient, RMS) [3];
- Parameters based on the RMS (weighted, normalized, linearized);
- Lacunarity
- Temporal coherence
- Parameters based on the size/time space (named as _ST)
- Parameter based on the distance/time space (_DT)
- Parameters based on the position/time space (_XYT)
- Parameters based on the size/time/distance space (_SDT)

We have then verified any correlation among them, so to optimize their use in the discrimination algorithm. In the diagram, the blue to red color progression goes from low to high correlation. After this analysis we selected the 8 parameters listed on the right



Feature Importance

The selected temporal parameters were used in the A-SciSoft procedure for the Gamma/Hadron separation, based on Random Forest algorithms, adding them to the standard set of morphological parameters. The histogram shows the contribution of each parameters in the new set (light blue are morphological, dark blue are temporal).



Performance

Including the selected time parameters in the G/H discrimination (orange points) allows for a significant improvement in the sensitivity at low energy, while maintaining optimal angular and energy resolution.

References. [1]Vercellone et al. Journal of High Energy Astrophysics, 2022, 35, 1
[2]Lombardi et al., Procs 10707 Software and Cyberinfrastructure for Astronomy
[3]Aliu et al., Astroparticle Physics, 2009, 293-305;

ACKNOWLEDGEMENTS

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