Update on muon pre-selection in ASTRI

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- Motivation and purpose in brief
- Résumé about our early results (2016)
- Updates (2017)
- To Do List

The ASTRI starting point

B-M/SST-1300 *The camera must be able to trigger on, and flag from pre-calibration data, fully contained muon rings impacting the mirror with an energy >20 GeV with an efficiency greater than 90%, even if visible in only one telescope camera.*

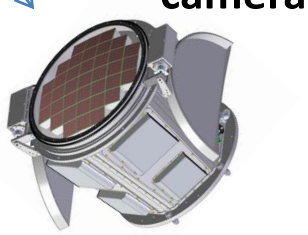
Our starting point

gammas

muons

protons

ASTRI camera



unique trigger config.

triggered events

ASTRI camera server

CTA Central Trigger (stereo trigger)

raw data acquisition, event building, pre-processing

Central CTA DAQ

for events not passing the stereo trigger

muon pre-selection algorithm

to ‘identify’ those triggered events that could be considered generated by high-energy local muons, ‘flag’ them as ‘usable’ muon calibrators and, as such, ‘send’ them to the Central CTA DAQ.

Pre-selection and camera server

The best algorithm… a trade-off among different points of view

The pre-selection

- High efficiency in 'identifying' candidate muon images while rejecting, as much as possible, images produced by proton induced triggers
  - to avoid saturating the readout budget towards the central CTA DAQ.

The camera-server

- The algorithm must be fast and low consuming:
  - It must not jeopardize all several important functions of the camera server (acquisition and event building)
- It does not have to require additional information from external sources:
  - it must be applied on uncalibrated raw data

Few slides about our early results (2016)

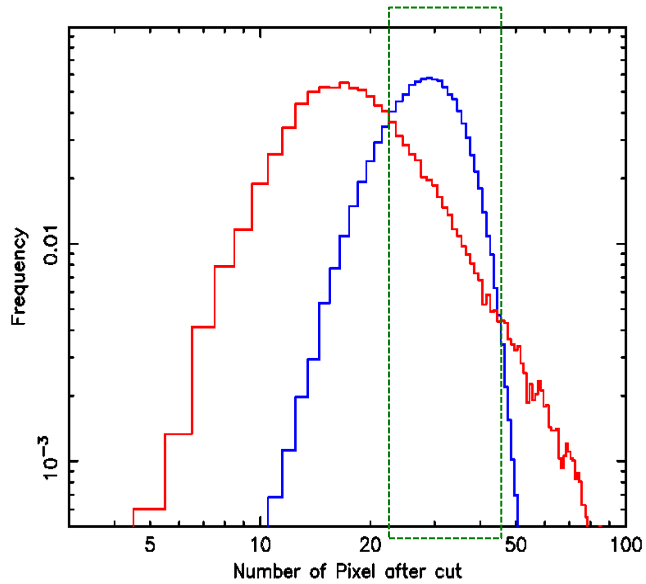
Two different approaches, based on image statistics and image morphology, have been investigated. Both of them applied on simulated uncalibrated (but cleaned) raw data.

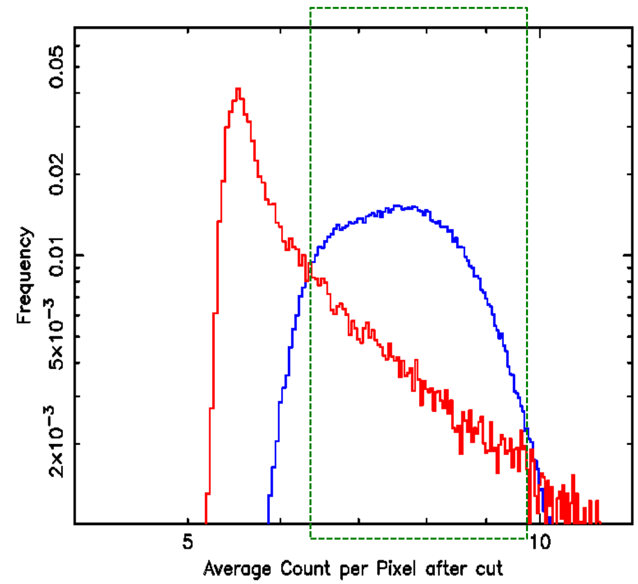
Pre-selecting muons from image statistics

The image statistics approach

based on the expected distributions (**a training set from simulated data**) of

- the number of pixels surviving the cleaning procedure, and/or
- their average counts per pixel.





Distribution, after cleaning, of the remaining pixel (left) and of the average counts per pixel (right). The dotted green boxes denote the range of values used for the selection.

Selection criterium: the acceptance range is the region of the average counts per pixel where the distribution is higher for **muons** than for **protons**; similarly for the number of pixels surviving the cleaning.

Pre-selecting muons from image morphology

The image morphology approach

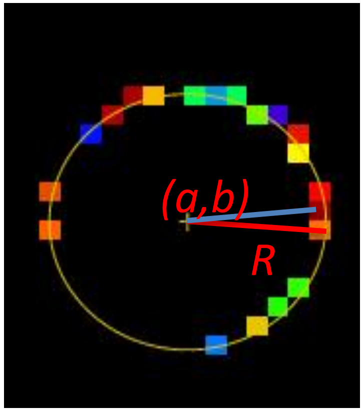
What we search is a 'circle'. Let us indicate with ***X*** and ***Y*** the image coordinates of the N_{pix} pixels survived to the cleaning. The coordinate of center (X_c, Y_c) and radius (***R***) of the 'circle' are computed minimizing the function ξ given by :

Taubin method:
(G. Taubin, IEEE Trans PAMI, 1991)

$$\xi = \frac{\sum[(X-X_c)^2+(Y-Y_c)^2-R^2]^2}{\sum[(X-X_c)^2+(Y-Y_c)^2]}$$

Pros: Very accurate. Few N_{pix} are required to successfully fit a Taubin circle. Few N_{iter} iterations are needed to minimize the function in the case of a circle.

Cons: iterative method, although $N_{iter} < 10$ is ok.



Kasa method:
(I. Kasa, IEEE Trans IM, 1976)

$$\xi = \sum[(X-X_c)^2+(Y-Y_c)^2-R^2]^2$$

Pros: Very simple and fast, it does not require iterations.

Cons: Few N_{pix} could result in Kasa circles with radius less than expected.

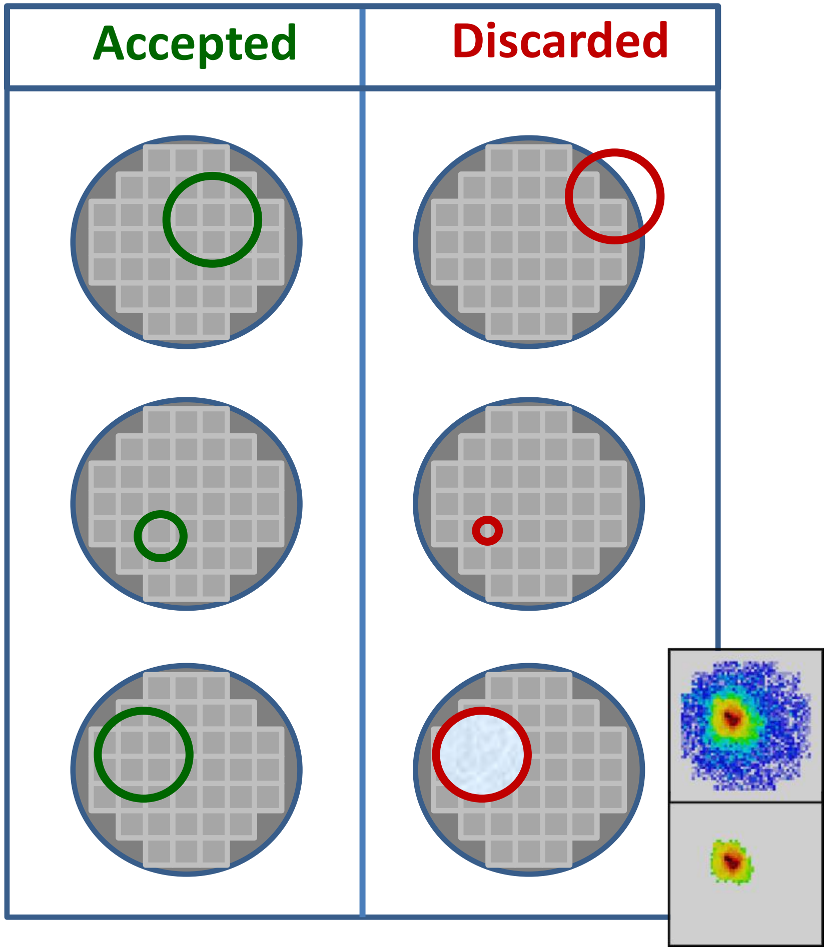
center (X_c, Y_c), radius ***R*** and ***RMS(R)***

Pre-selecting muons from image morphology

Selection criteria in the image morphology approach

The method must be able to identify 'candidate' circles that are:

- **fully contained in the camera,** ***(R, BorderDistance)***
- **avoiding rings too large wrt the Cherenkov angle, or too small** ***(R)***
- **discarding filled images produced by non-muon events** ***(Fullness = RMS(R)/R)***



N.B.: ***BorderDistance = FoV/2 – CenterDistance – R*****, where** ***CenterDistance*** **denotes the distance between the center of the reconstructed circle and of the ASTRI camera. No pre-selection on** ***RMS(R)*** **alone because it could be useful in the analysis phase to study PSF enlargement.**

Updated comparison between statistical and morphological methods

- **Both statistical and morphological methods** are fast, computationally efficient, can operate on-line at the level of ASTRI camera server without using external information.
- **The statistical approach** is the simplest one, but the large number of proton-induced triggers retained could saturate readout in the CTA acquisition system.
- **The morphological approach** is more efficient, keeping the number of proton-induced triggers low. The **Kasa method** seems to be more than sufficient for the pre-selection purposes, differently from the **Taubin method** that will be primarily used for detailed analysis of the pre-selected ring images.

… applying the selection ranges described before	Percentage of events selected as possible muon candidates (approx. values)			
	Statistical approach		Morphological approach	
	<Counts/pixel>	No.pixels	Taubin	Kasa
Protons	40 %	30 %	5 %	3 %
Muons	95 %	90 %	96 %	96 %

A further point in favor of the 'morphological approach':

It simply considers the event raw data as a digital image and:

- **analyzes it taking into account the topology and content of its pixels only,**
- **without using any additional information coming from the camera or from external auxiliary sources.**

Updates (2017)

- **Improved NSB evaluation**
- **Implemented all algorithms in the camera server of the ASTRI SST-2M prototype located in Sicily. Main attention to the Kasa method.**

Improved NSB evaluation: the algorithm

- evaluates the average level (and RMS) of NSB per pixel from image regions that do not contain the ‘useful' signal (muon, adron, gamma, whatever it is),
- does not use the geometry-topology of the region where the signal itself is present, but rather applies the sorting on the pixel content, and considers, as a set of pixels useful for NSB evaluation, the first $\mathbf{N_PB}$ of lower content.
- Given $\mathbf{N_{pixon}}$ in the image, the first $\mathbf{N_PB}$ useful for the NSB evaluation are given by:

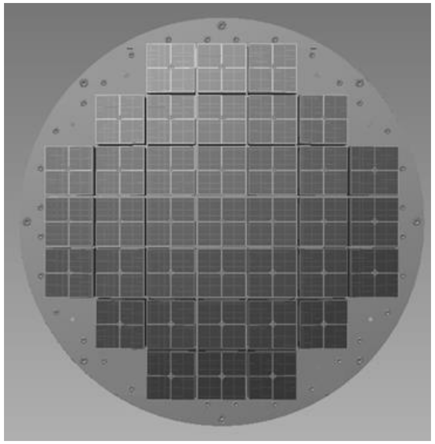
$$\mathbf{N_PB = N_{pixon} - N_PS_{Max}}$$

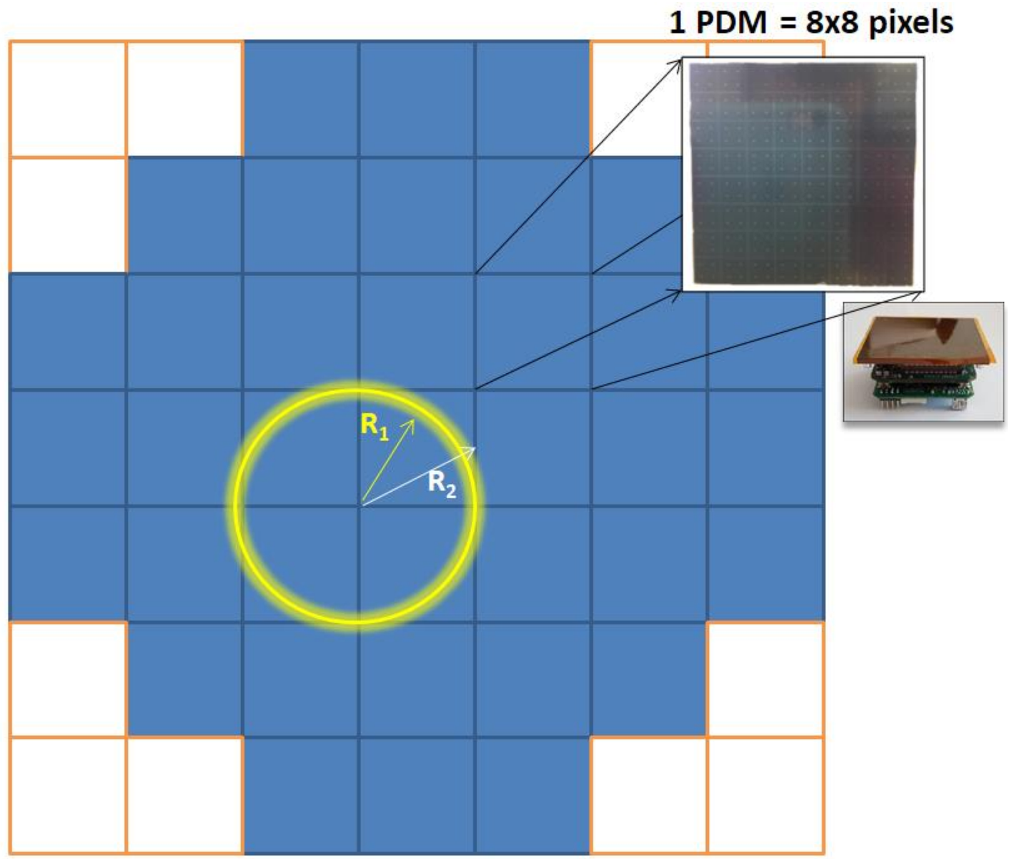
- The expected region of the signal is defined by the first $\mathbf{N_PS_{Max}}$ pixel of higher content.

The expected region of the signal we are looking for corresponds, more or less, to the maximum closed muon ring.

What is the maximum closed muon ring we expect in the ASTRI camera?

ASTRI μ-preselection and camera server





ASTRI camera:
37 PDM
1 PDM = 8x8 pixels
2368 pixels in toto (**N_{pixon}**)

Approx. Values:
1pixel = 0.19°x0.19°
1 PDM = 1.52°x1.52°

R_{max} = 1.5° = 8 pixels
N_{pix} (R_{max}) = 50 pixels

R_1 = 1.3° = 7 pixels
R_2 = 1.7° = 9 pixels
N_{pix}(R_2-R_1) = 100 pixels

N_PS_{Max} = 100, Npixon = 2368

$N_PB = N_{pixon} - N_PS_{Max}$ = 2268

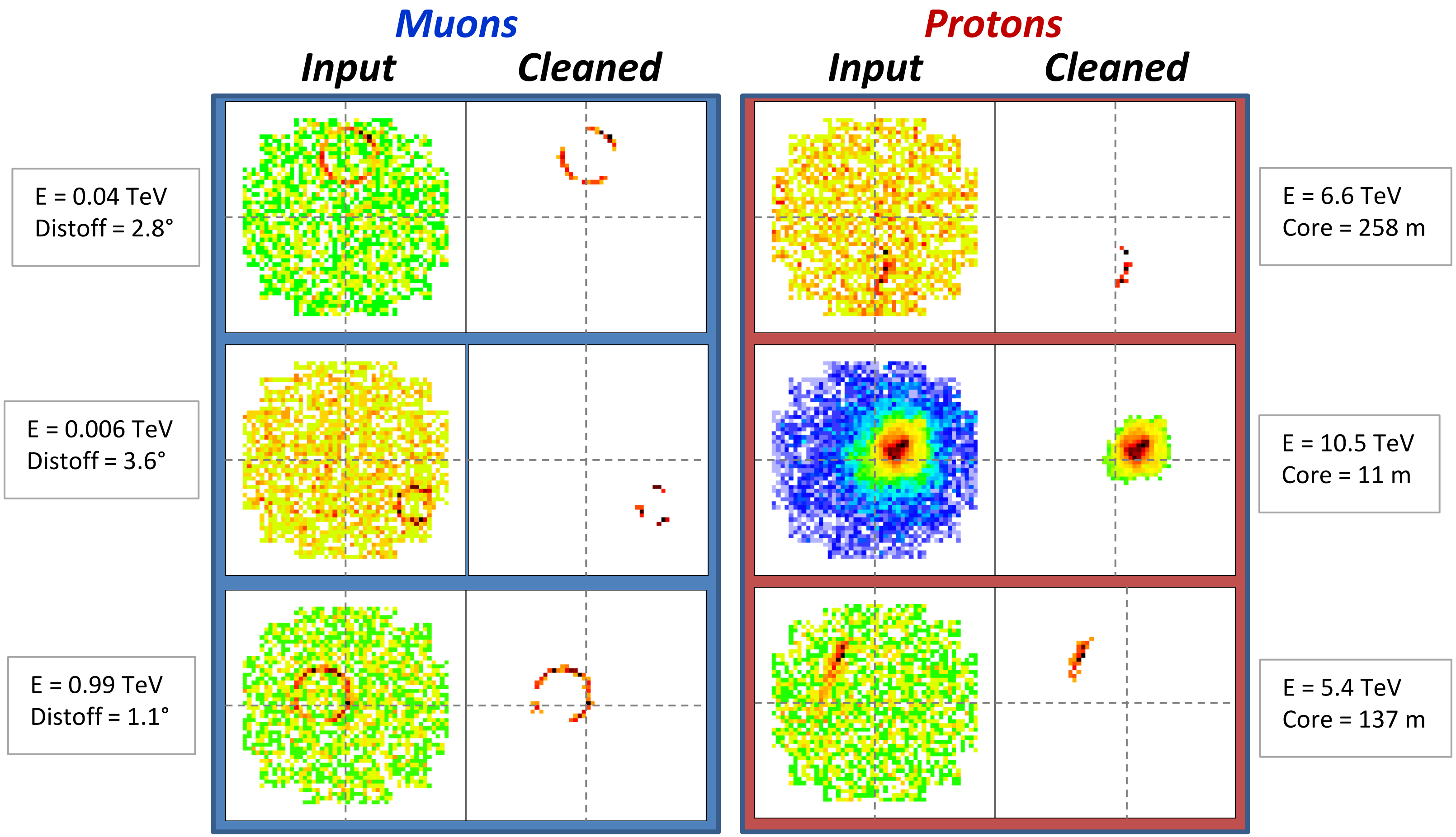
<NSB>, RMS<NSB>

The two-level cut cleaning

examples with k_1=2, k_2=5

$$\chi_1 = \langle NSB \rangle + k_1 \times RMS(\langle NSB \rangle)$$

$$\chi_2 = \langle NSB \rangle + k_2 \times RMS(\langle NSB \rangle)$$

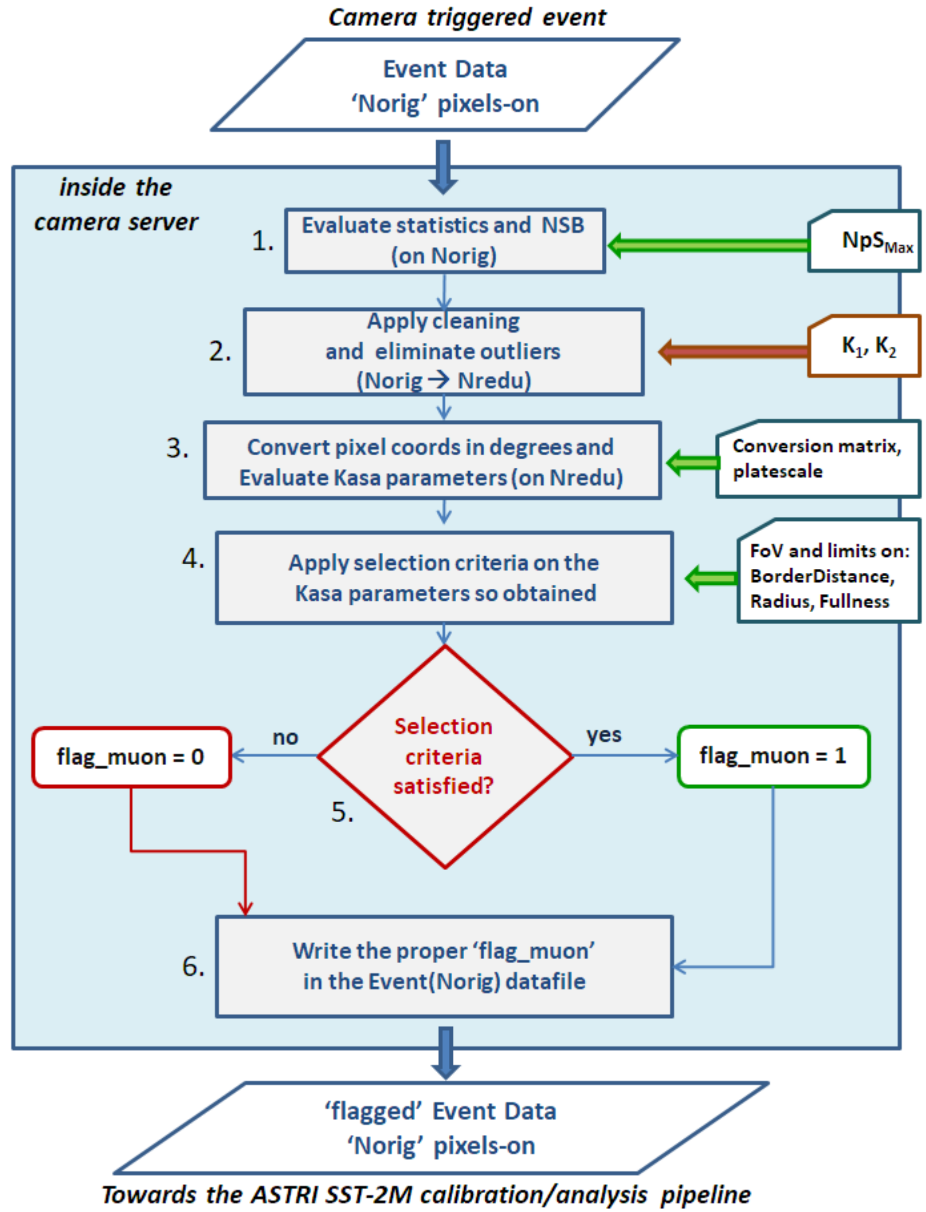


Inside the ASTRI prototype camera server

- **Implementation in the camera server of the ASTRI SST-2M telescope prototype in Sicily (muon preselection through the Kasa method)**

In the ASTRI prototype:
All camera events (flag_muon=0 or 1) are maintained for check purposes.

Under CTA array configuration:
Events not-satisfying the preselection will be discarded while the preselected ones will be sent to the Central CTA DAQ.

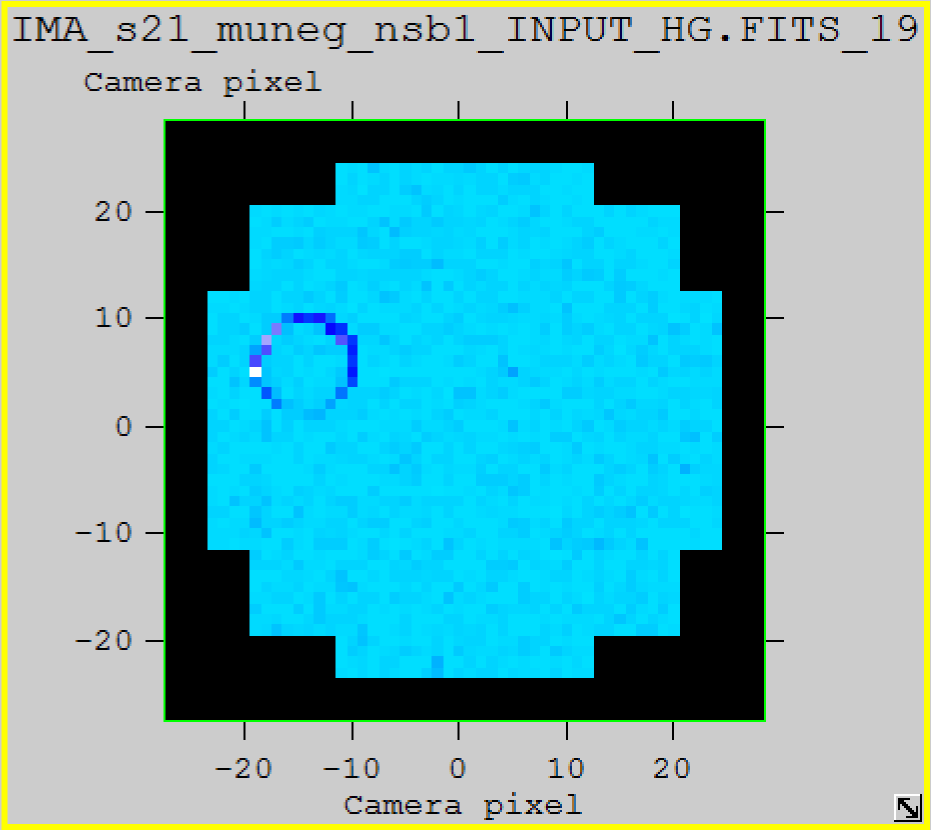


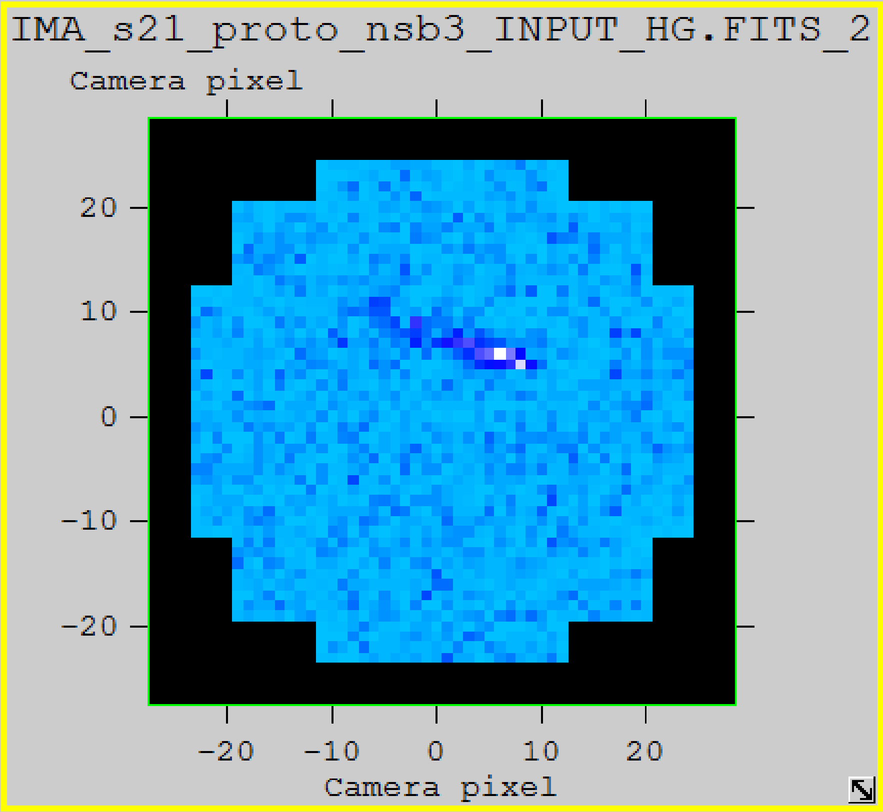
Muons and ASTRI FFE

Muon events in ASTRI will be 'studied' analyzing the FEE HighGain channel.

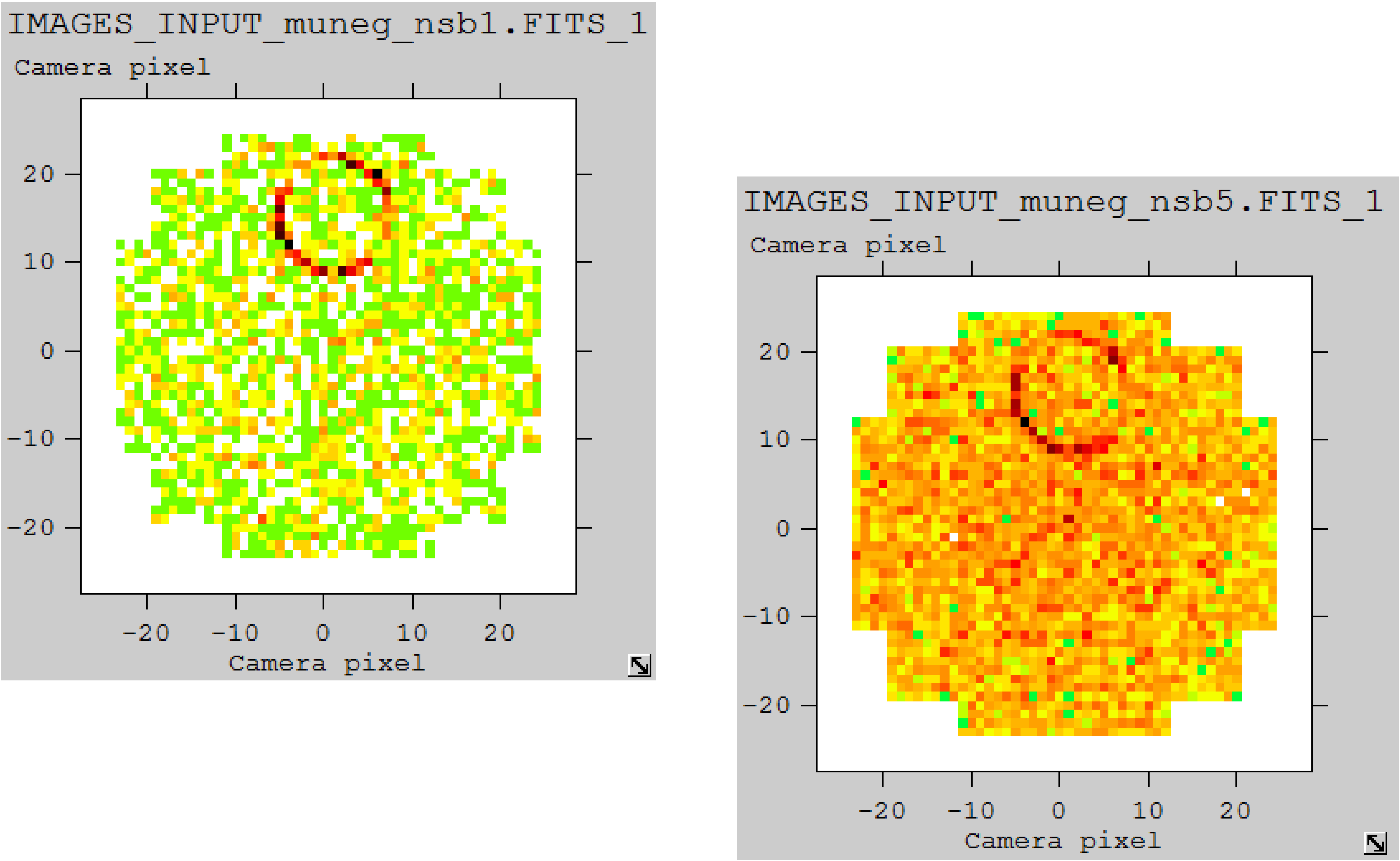
- **The ASTRI FEE is characterized (among other things) by a double gain chain, High and Low, that allows extension of the dynamical range.**
- **The Low Gain channel is devoted to events with high number of photoelectrons per pixel while the High Gain channel is devoted to events with low number of photoelectrons per pixel or to events with energy near to the inferior limit achievable (it saturates in case of high number of photoelectrons).**
- **The High Gain channel is the primary one to detect muon events.**

Few examples (simulated data)





Few examples (simulated data)



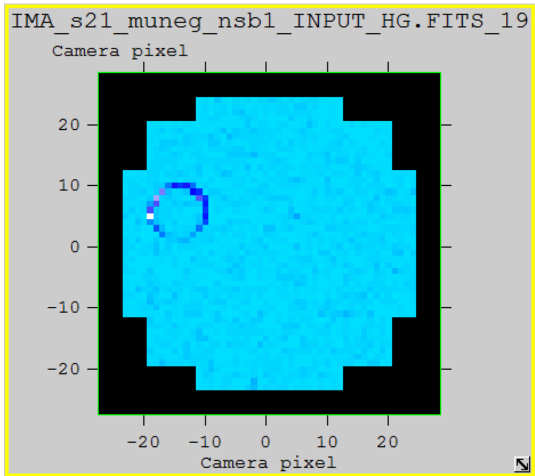
Cleaning and cuts (to be optimized)

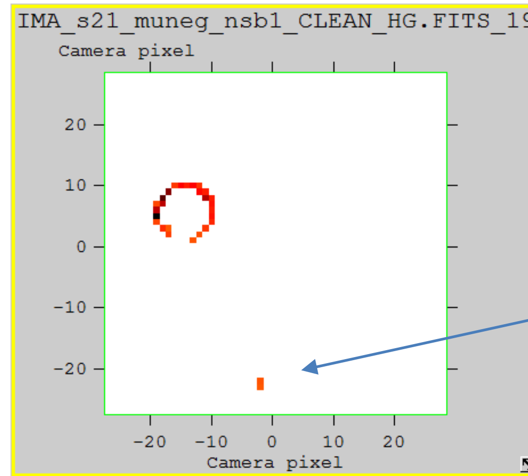
$\chi_1 = \langle NSB \rangle + k_1 \times RMS(\langle NSB \rangle)$

$\chi_2 = \langle NSB \rangle + k_2 \times RMS(\langle NSB \rangle)$

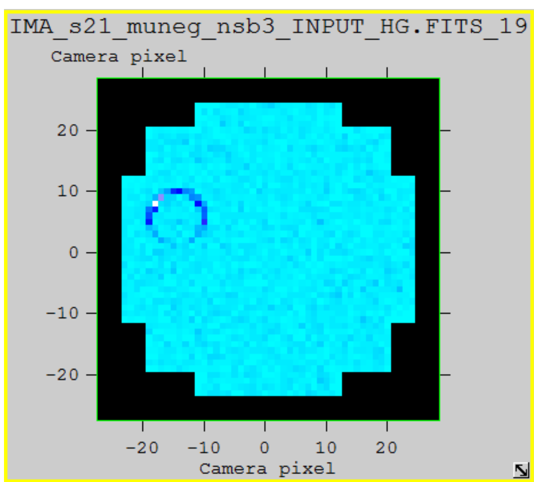
$k_1=2$, $k_2=5$

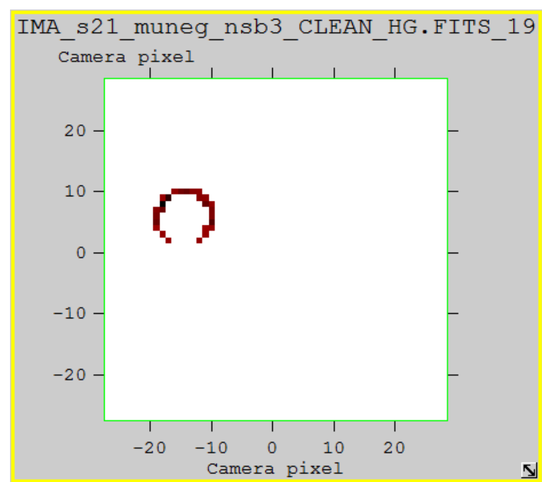
NSB lev.1
ADC_HG_Max = 3153





NSB lev.3
ADC_HG_Max = 3329





Next steps

Completed:

- ✓ Optimized evaluation of NSB level from the raw image
- ✓ Implemented all algorithms in the camera server of the ASTRI SST-2M prototype located at Serra La Nave, Italy

In progress (simulated data):

- Inclusion of higher levels of NSB (and bright stars)
- Investigation of the effect of the 20° zenith angle
- Optimization of cleaning method and cuts

ToDo (simulated data):

- Investigation of the effect of the 40° zenith angle

ToDo (real data):

- Final verification (all aspects)
- Optimization in view of the CTA configuration

… when on ‘real’ data?

↓

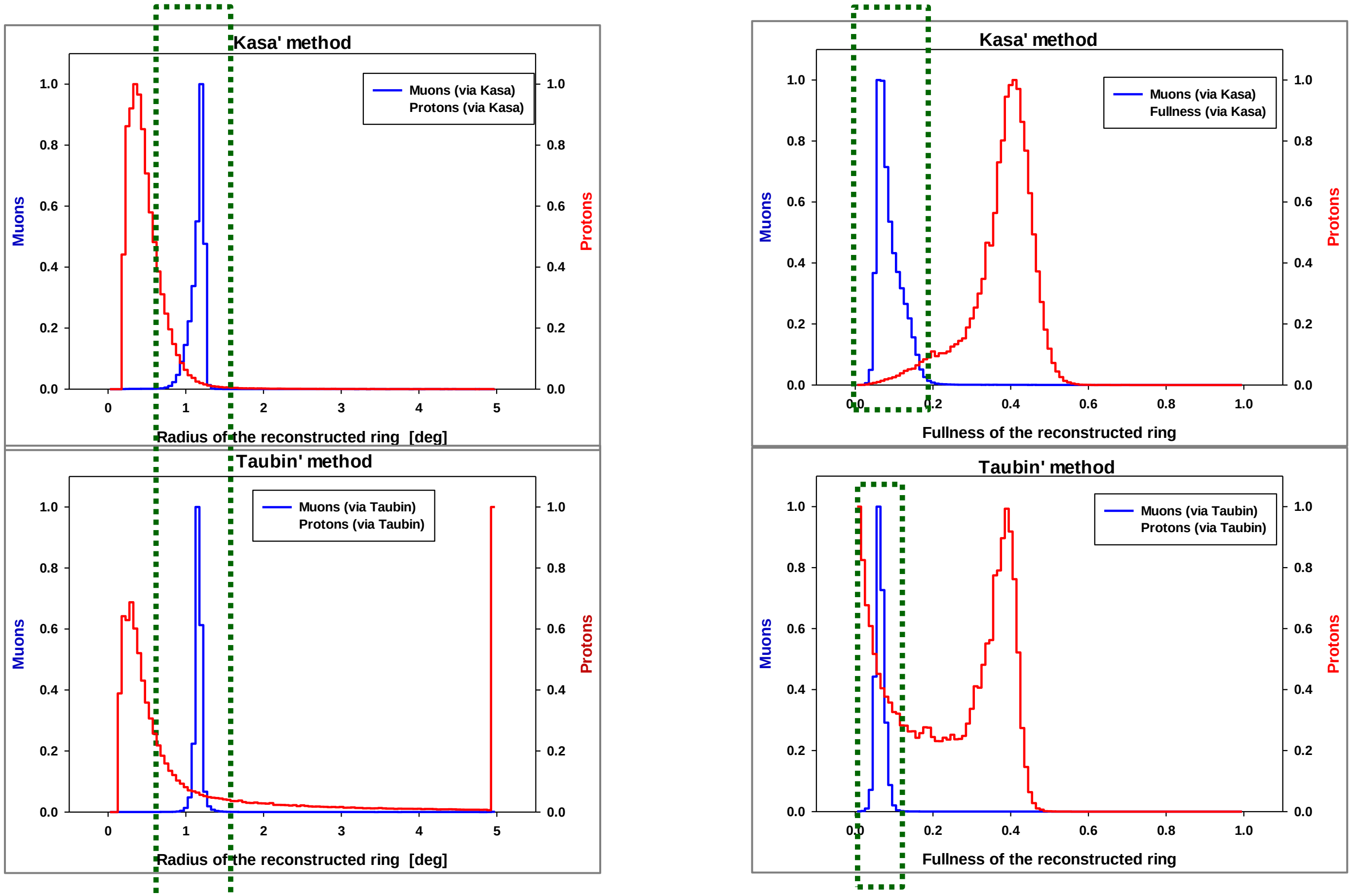
next week the ASTRI camera will be installed on the prototype

Thank you for your attention

… backup slides

Acceptance ranges differ for Taubin and Kasa methods

Few ***N_{pix}*** surviving in the **cleaned** image could result in Kasa circles with radius less than expected, and this influences the choice of the ***Fullness*** acceptance range.



Distribution of the reconstructed ring parameters *R* (left) and *Fullness* (right) for Kasa (top) and Taubin (bottom) methods. The dotted green boxes indicate the limits chosen to be applied for the next selection. The 'exaggerated' number of protons at *R*=5° in Taubin plot (bottom left) is simply an artifact after dumping the overflow into these bins.

Pre-selecting muons from image morphology

Acceptance ranges in the image morphology: a conservative example

Taubin		Requirements to be satisfied		Kasa
Npix ≥ 5 .and. Niter < 10		The morphological reconstruction was successfull, selecting rings		Npix ≥ 5 (adjacent)
0.5° ≤ R ≤ 1.5° .and. BorderDistance > 0.19°		fully contained in the camera, avoiding rings too large or too small		0.5° ≤ R ≤ 1.5° .and. BorderDistance > 0.19°
Fullness < 0.12°		discarding filled images produced by non-muon events		Fullness < 0.20°