ASTRI Astrofisica con Specchi a Tecnologia Replicante Italiana

cta cherenkov telescope array

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Pre-selecting muons in ASTRI.

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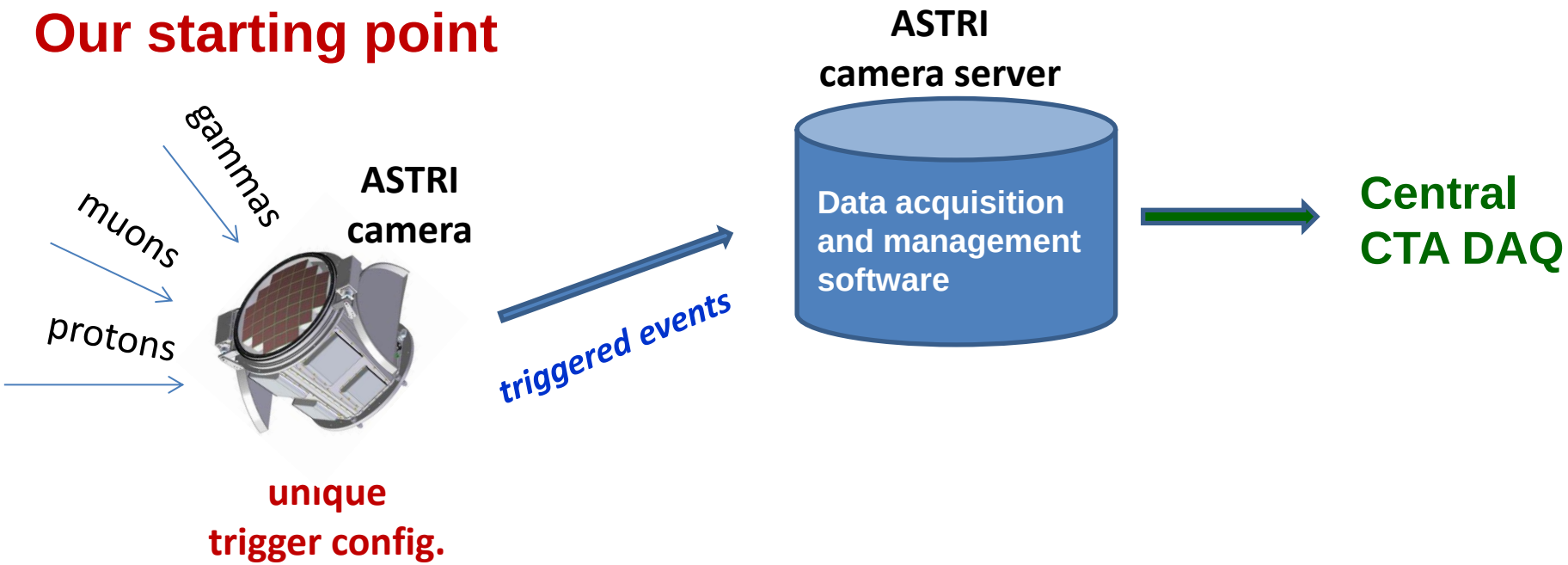
Pre-selecting muon images in the camera (server)

Preface

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



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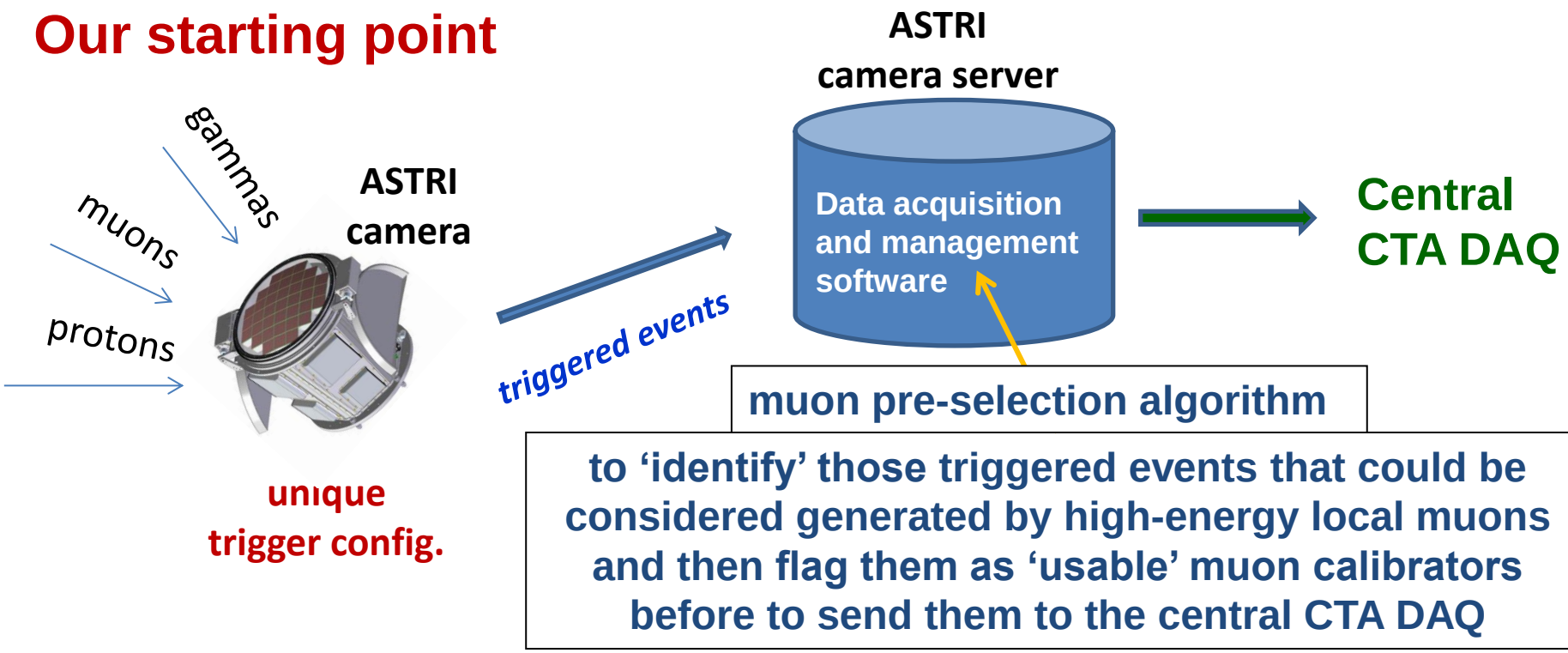


Pre-selecting muon images in the camera server

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 data management)
- It does not have to require additional information:
  - is must be applied on uncalibrated raw data

Two methods, based on image statistics and image morphology, have been developed (first results, CCF meeting Barcelona, October 2015). Both of them are applied on uncalibrated (but cleaned) raw data.

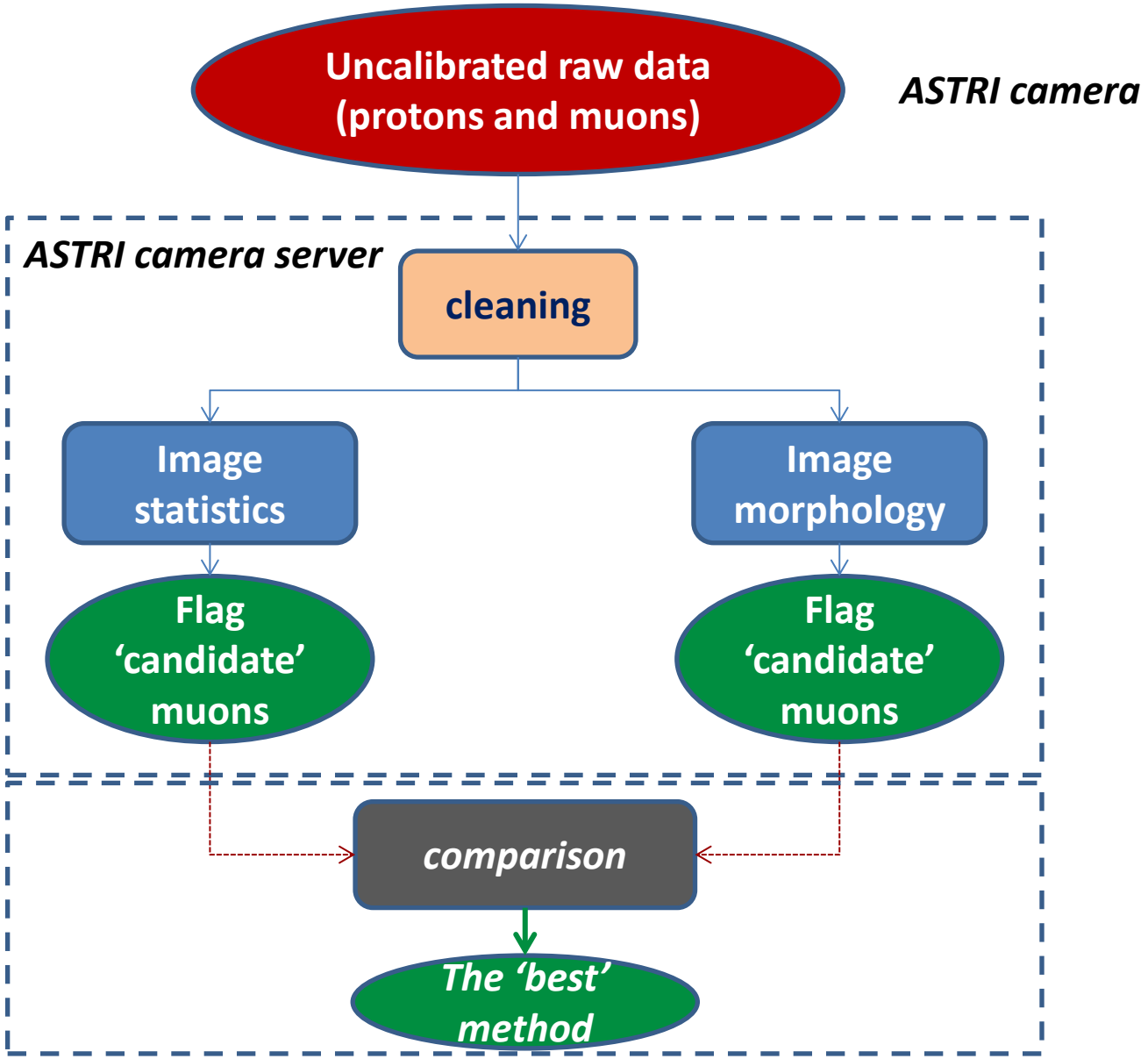
Pre-selecting muon images in the camera server

The procedure

(described here on simulated data)

Key points:

simply consider the event raw data as a digital image and analyze 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



Our simulation data set (enriched w.r.t. October 2015)

- **CORSIKA - Site Paranal, Obslev 2150 m asl, Atmosphere 26**
  (1M muons+, 1M muons-, 1M protons)

	PRMPAR	ERANGE	ESLOPE	VIEWCONE	CSCAT	FIXCHI g/cm^2
Muons+	5	6 GeV – 1 TeV	-2	0 – 4 deg	2.153 m	753.59
Muons-	6	6 GeV – 1 TeV	-2	0 – 4 deg	2.153 m	753.59
Protons	14	2 – 100 TeV	-2.72	0 – 4 deg	400 m	---

500 m above Obslev

- **ASTRI telescope: pointing to zenith**
- **Telescope Simulation: by means of the Palermo ASTRI simulator**
- **Night Sky Background: extra-galactic dark sky without bright stars in the FoV of the telescope, → ~ 1 pe/pixel every 50 ns, ~ 20 MHz per pixel**
- **Trigger – standard: (no dedicated trigger is required for muons in ASTRI) at least 5 adjacent pixels in a PDM (8x8 pixels), each pixel with at least 4 pe. This configuration enables the camera to trigger on almost all (>99%) of our muon events.**

The cleaning

- A two-level cut (in a 3x3 window) maintains the basic shape of the signal avoiding the presence of isolated pixels:

$$\chi_1 = \overline{NSB} + k_1 \cdot RMS(NSB)$$

$$\chi_2 = \overline{NSB} + k_2 \cdot RMS(NSB)$$

- The NSB values (mean and root mean square, RMS) can be evaluated from the image by looking at a region where the main significant signal is not present; work is in progress to define a fast and efficient method of achieving this.
- As a first step, in the fast procedures described here the NSB is evaluated considering each image as formed only by NSB signal characterized by a Poisson distribution; the contribution of NSB per pixel will then be equal to the mean value $<NSB>$ of the distribution whose standard deviation is

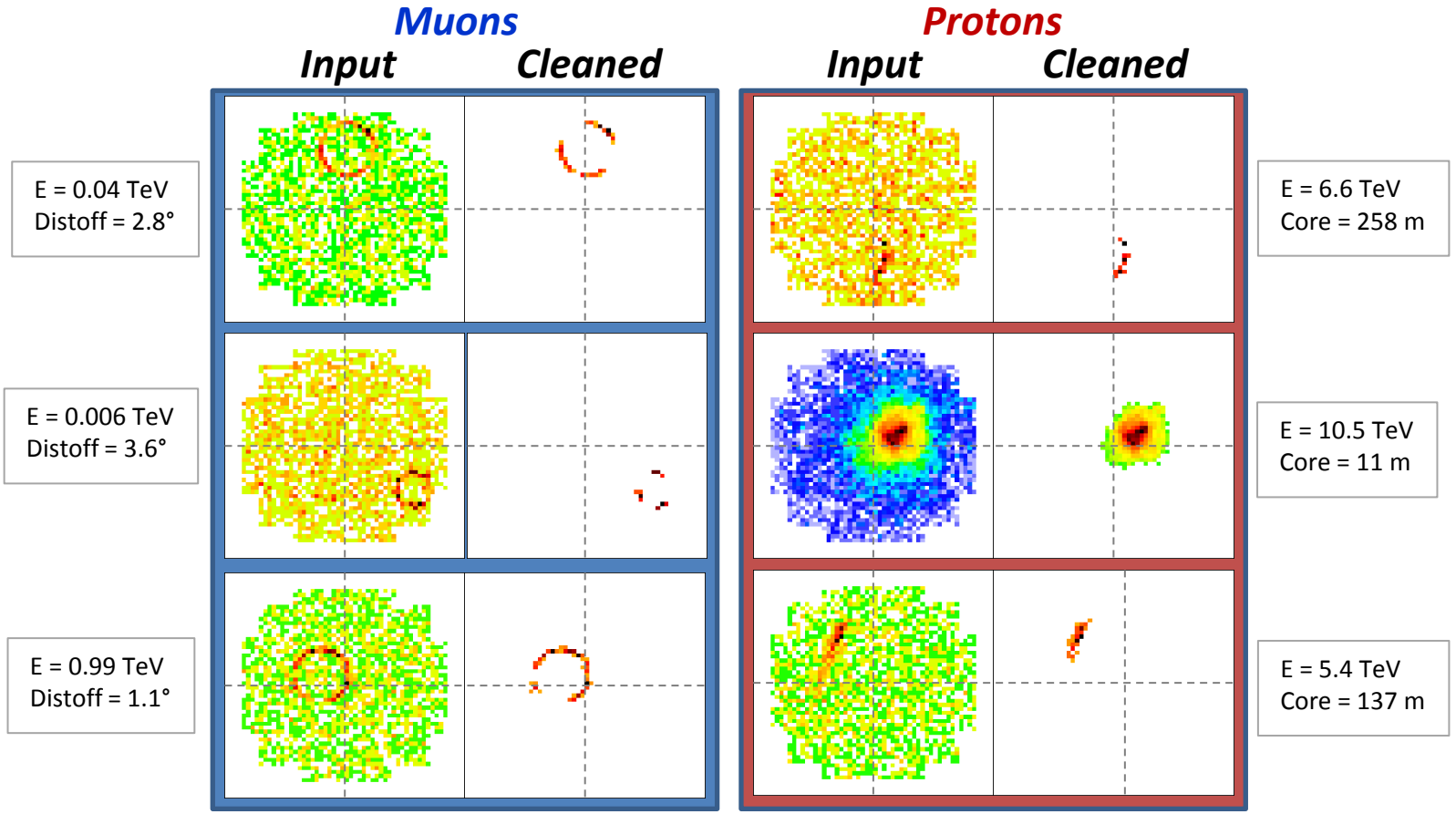
$$RMS(NSB) = \text{sqrt}(<NSB>)$$

The two-level cut cleaning

examples with k_1=2, k_2=5

$$\chi_1 = \overline{NSB} + k_1 \cdot RMS(NSB)$$

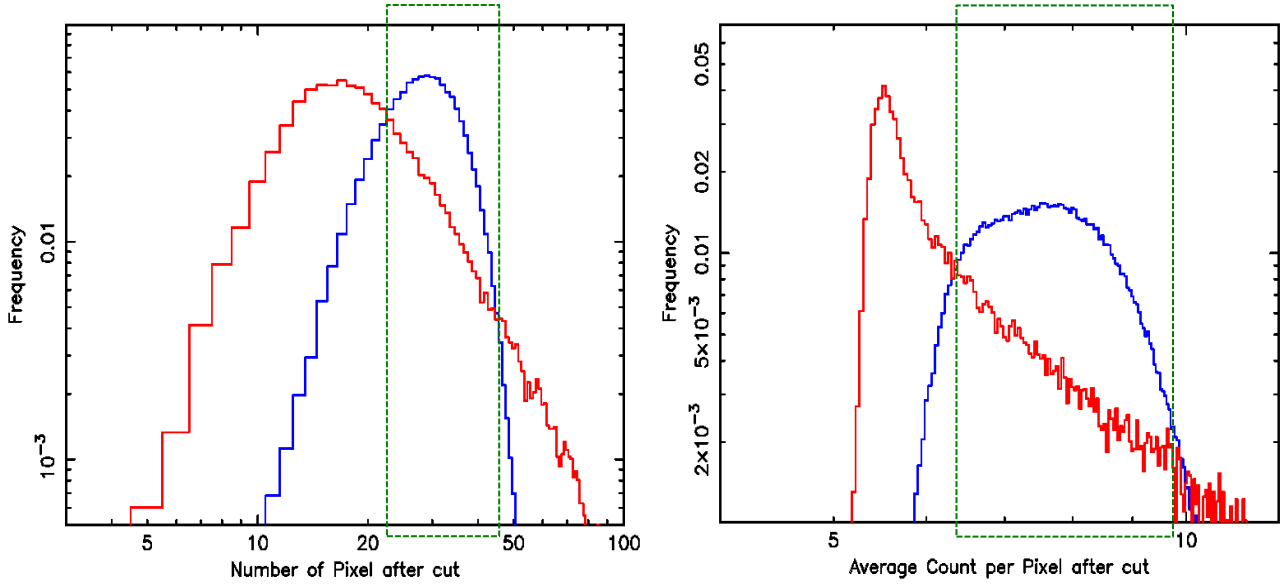
$$\chi_2 = \overline{NSB} + k_2 \cdot RMS(NSB)$$



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 criteria: 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.

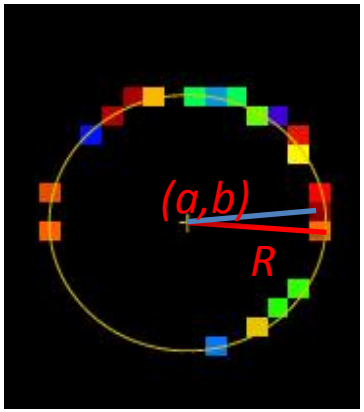
Pre-selecting muon images in the camera server

The image morphology approach

Taubin method: The coordinate of the center (X_c, Y_c) and the radius (R) are computed minimizing the function ξ given by :

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

where X and Y are the image coordinates of the N_{pix} pixels survived to the cleaning. 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.



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

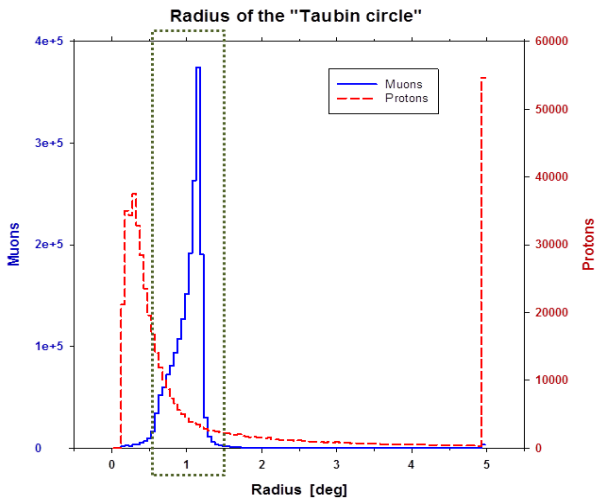
Selection criteria	Selection parameters
Taubin circles fitted in very few iterations,	N_{iter}
fully contained in the camera,	*R, CenterDistance **
avoiding rings too small, and	*R*
discarding filled images produced by non-muon events	*Fullness = RMS(R)/R*

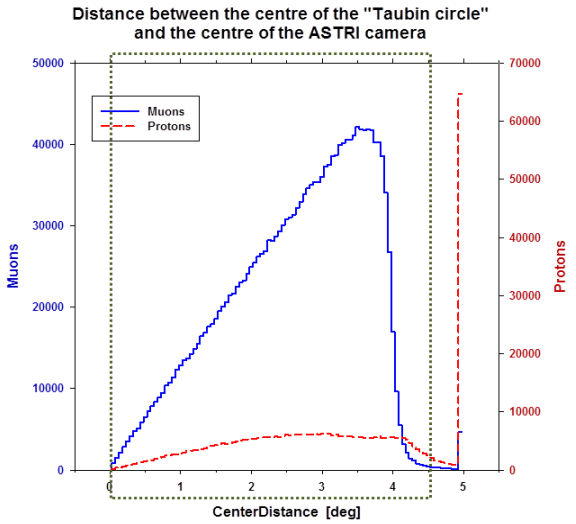
Note: no selection on RingWidth alone because it could be useful in the analysis phase to study PSF enlargement.
*** CenterDistance denotes the distance between the centers of the Taubin circle and of the ASTRI camera.**

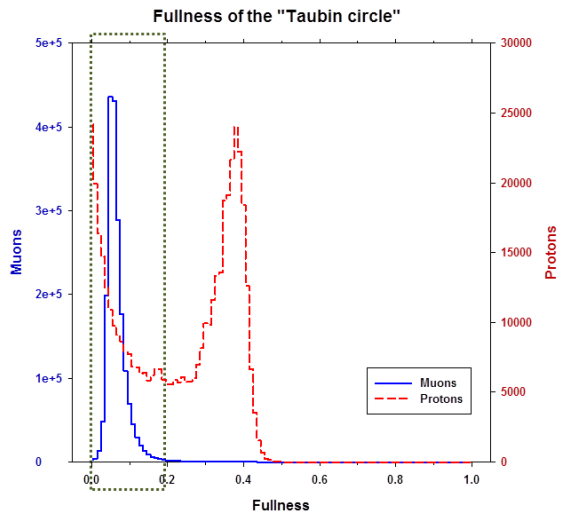
The image morphology (Taubin) approach: acceptance ranges used (conservative)

1) $N_{pix} \geq 5$ .and. $N_{iter} < 10$ .and.
2) $0.5° \leq R \leq 1.5°$ .and. CenterDistance<4.5° .and.
3) Fullness<0.2°

Percentage of events left w.r.t. triggered	
Protons	Muons
56 %	99 %
16 %	97 %
8 %	96 %







Distribution of the reconstructed ring parameters *R* (left), *CenterDistance* (center) and *Fullness* (right) of the images surviving to the first basic selections (N_{pix}≥5 and N_{iter}<10). The dotted green boxes indicate the limits chosen to be applied for the next selection. The 'exaggerated' number of protons at *R*=5° and *CenterDistance*=5° is simply an artifact after dumping the overflow into these bins.

Conclusions

(Ref.Paper SPIE-2016 n.9913-70)

- **Both methods** are fast, computationally efficient, can operate on-line at the level of the ASTRI camera server without using additional 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.

	Percentage of events selected as possible muon candidate		
	Statistical approach		Morphological approach (Taubin)
	No.pixels	<Counts/pixel>	
Protons	30 %	40 %	8 %
Muons	90 %	95 %	96 %

The resulting percentages could improve if more stringent limits on the selection criteria are adopted; this will be considered when the entire procedure will be tested on real data.

Pre-selecting muons with ASTRI SST-2M

Both algorithms will be tested on real data acquired with the ASTRI SST-2M prototype and then optimized for their implementation in the camera server of the ASTRI telescopes that will form the mini-array proposed for the CTA Southern site. The choice will also depend on the data volume and rate (TBD).

ToDoList :

- Optimize evaluation of NSB from the raw image (taking a 'wide' region as in the past)
- Inclusion of higher levels of the Night Sky Background (and bright stars)
- Investigation of the effect on the zenith angle other than vertical (20°, 40°)
- Inclusion of camera degradation effects (dead pixels, …)
- More stringent selection limits, if feasible …

… work is in progress …