Astrofisica con Specchi a Tecnologia Replicante Italiana

Pre-selecting muons with ASTRI telescopes: image morphology analysis.

M.C. Maccarone, T. Mineo – INAF/IASF-Palermo, Italy

for the ASTRI Collaboration & the CTA Consortium

Pre-selecting muon images in the camera (server)

Preface

Extracted from "Muons for CTA", COM-CCF/150310, Vers.4.7

During a dedicated interface meeting between ACTL and the telescope cameras in May 2015 in Heidelberg, the cameras committed to accept a common clock distribution and trigger timestamping (UCTS) board, and to provide an input trigger signal to that board for time-stamping of stereo triggers. The timestamp is then provided to **the SoftWare Array Trigger (SWAT)** which **takes the ultimate trigger decision.**

The camera server has however the option to force readout and storage of an individual event. This is the case for local muon images which need to be recognized as such in the camera server (from un-calibrated events) at high efficiency while keeping the number of mis-identified events as low as not to saturate the readout.

This task may be challenging for the SSTs, given the relatively small size of their muon images. That's why the ASTRI telescope has started to develop an efficient and fast algorithm to recognize muons in the camera server.

Pre-selection based on:

~~image statistics~~ → image morphology

Important Notes

The pre-selection

- **aims to 'identify' those events (triggered in the camera) that could be considered generated by muons and then 'usable' as calibrators**
- **it does not require deep analysis of the muon ring**
- **It must be fast and efficient**
- **the algorithm must satisfy the new suggested level B-requirement:**

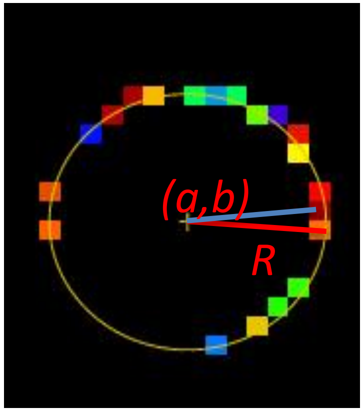
> **B-M/SST-1300** *The camera must be able to trigger on, and flag from pre-calibration data, fully contained muon rings impacting the mirror with an energy >20 GeV with an efficiency greater than 90%, even if visible in only one telescope camera.*

ASTRI SST-2M – Muon pre-selection method

Muon morphological pre-selection based on Taubin method

0) … on the cleaned image:

1) **Selection on the ring geometrical parameters (ring radius, ring center distance, ring width)**



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

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 pixels survived to the cleaning.
The width of the reconstructed ring is here defined as ***RingWidth = RMS(Radius).***

Main selection criteria:

0.5°≤Radius ≤1.5° .and. CenterDistance<4.5° .and. RingWidth<0.2°

as agreed in "Muons for CTA", COM-CCF/150310 *plus* " "

ASTRI SST-2M – Simulation/Analysis parameters

Yesterday

- **CORSIKA - Site Aar, Obslev 1640 m asl, Atmosphere 24**

	PRMPAR	ERANGE	ESLOPE	VIEWCONE	CSCAT	FIXCHI g/cm^2
Muons+	5	6 GeV – 1 TeV	-2	0 – 4 deg	2.153 m	802.45
Muons-	6	6 GeV – 1 TeV	-2	0 – 4 deg	2.153 m	802.45
Protons	14	2 – 100 TeV	-2.72	0 – 4 deg	400 m	---
Gamma Crab-like	1	1.5 – 100 TeV	-2.49	0°	400 m	---

500 m above Obslev

- **Telescope Simulation – by means of the Palermo ASTRI simulator**
- **Trigger – standard: (no dedicated trigger is required for muons in ASTRI) at least 5 adjacent pixels in a PDM, each pixel with at least 4 pe**
- **Night Sky Background – not present (the image is considered well-cleaned)**
- **Analysis – at least 20 pixels fired-on**
- **Taubin selection cuts – 0.5°≤Radius ≤1.5°, RingWidth<0.2°, CenterDistance<4.5°**
- **Results - > 99% muons selected (no difference between mu+ and mu-, as expected) while > 98% protons rejected**

Today

- **CORSIKA - Site Paranal, Obslev 2150 m asl, Atmosphere 26**
  (1000000 Muons+, 98815 Protons)

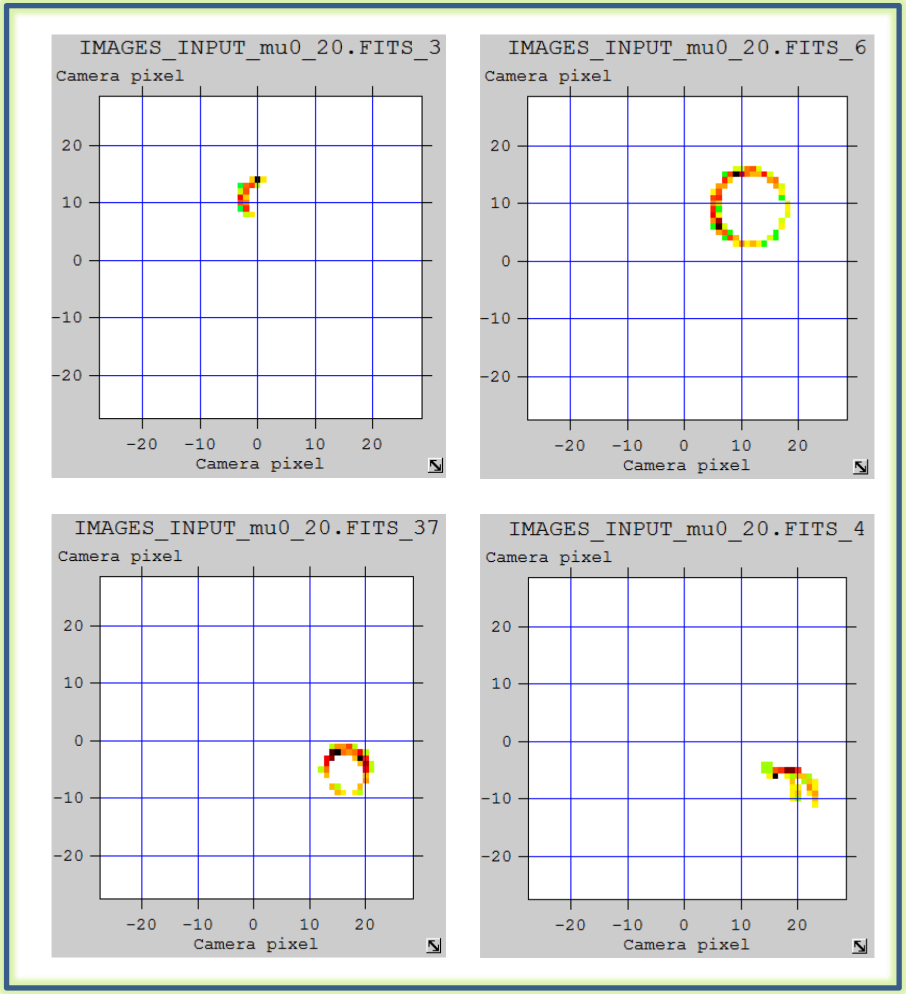
	PRMPAR	ERANGE	ESLOPE	VIEWCONE	CSCAT	FIXCHI g/cm^2
Muons+	5	6 GeV – 1 TeV	-2	0 – 4 deg	2.153 m	753.59
Protons	14	2 – 100 TeV	-2.72	0 – 4 deg	400 m	---

500 m above Obslev

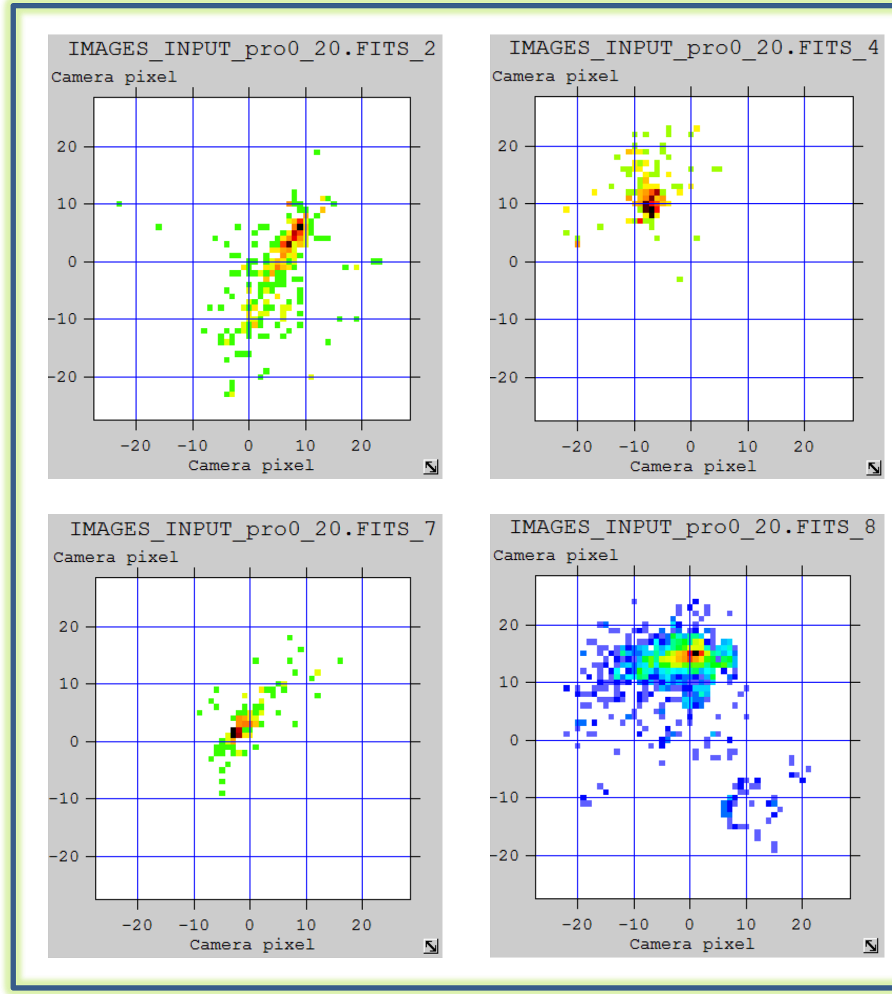
- **Telescope Simulation – by means of the Palermo ASTRI simulator**
- **Night Sky Background:**
  - **nsb_0 (no inclusion, images used as reference ← 'well-cleaned')**
  - **nsb_1 (~ 1 pe/pixel every 50 ns, ~ 20 MHz per pixel) → cleaning is required)**
- **Trigger – standard: (no dedicated trigger is required for muons in ASTRI) at least 5 adjacent pixels in a PDM, each pixel with at least 4 pe**
- **Analysis – at least *'Npixon'* pixels remaining fired-on after cleaning**
- **Selection cuts – as before plus a further selection parameter**

- **Case nsb_0 (no NSB inclusion) – few examples of simulated input images**

Muons

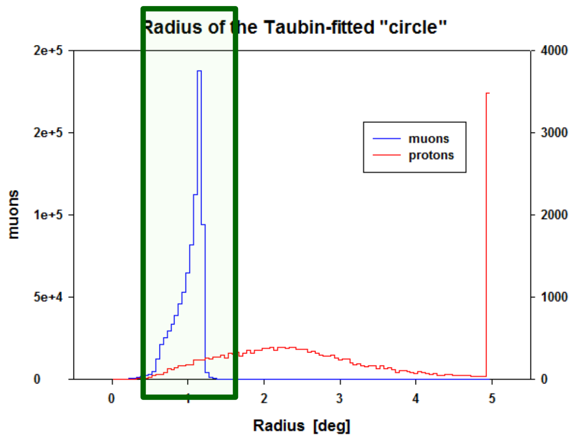


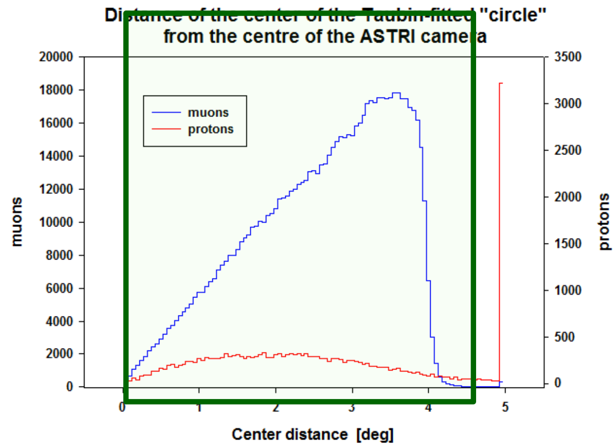
Protons

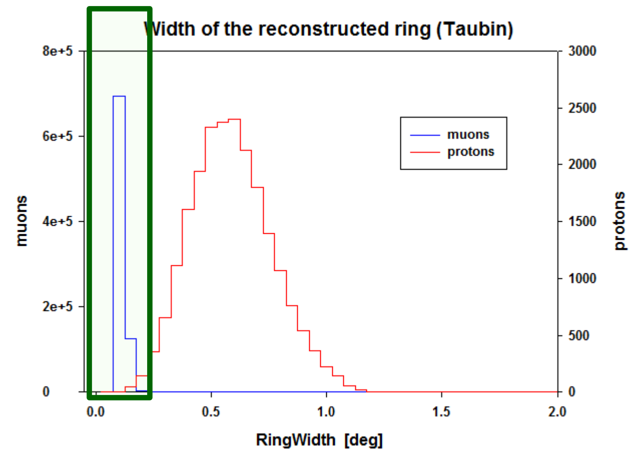


ASTRI SST-2M – Pre-selecting parameters

- **Case nsb_0 (no NSB inclusion, no cleaning, Npixon=4, images 'well-cleaned' as ref.**
- **Selection_0: iok_circle=1 (Taubin method found the circle parameters)**







- **Selection_1: iok_circle=1 .and. 0.5°≤Radius ≤1.5° .and. CenterDistance<4.5° .and. RingWidth<0.2°**

	Events triggered	Events remaining after Selection_1	Percentage remaining after Selection_1
Muons+	826650	814450	**98.5%**
Protons	21502	93	**0.4 %**

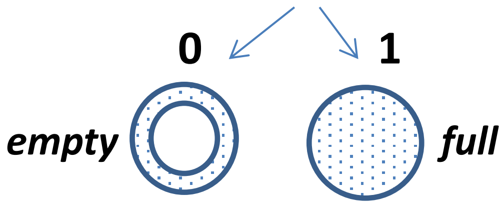
B-M/SST-1300:

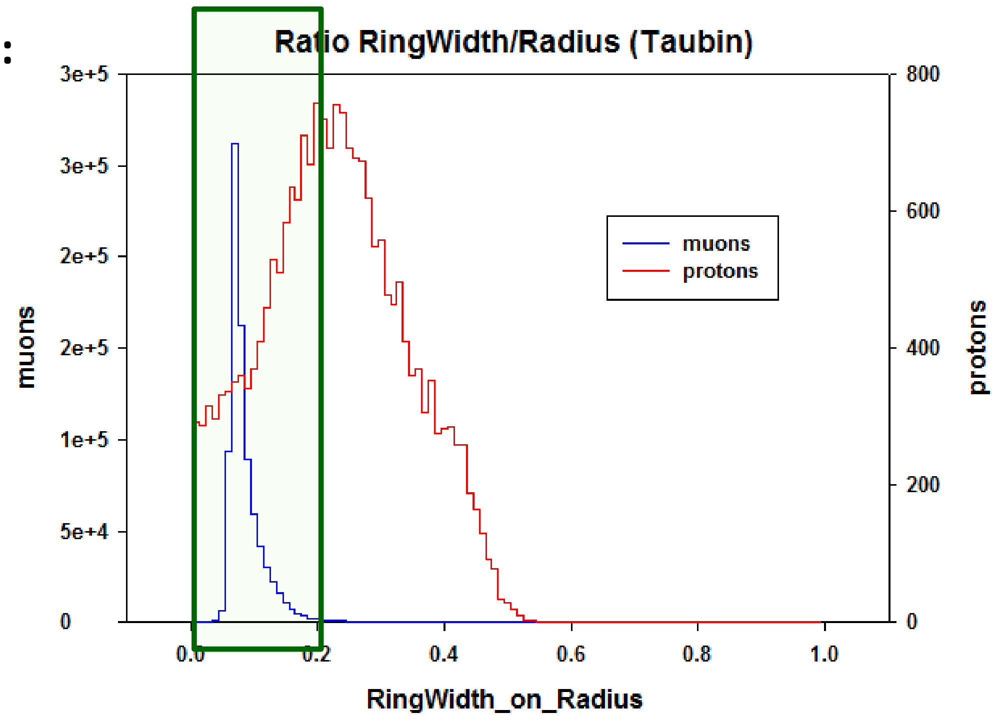
OK

OK

… a further parameter from Taubin:

RingWidth/Radius





- **Selection_2: iok_circle=1 .and. 0.5°≤Radius ≤1.5° .and. CenterDistance<4.5° .and. RingWidth<0.2° . and. RingWidth/Radius<0.2°**

	Events triggered	Percentage remaining after Selection_1	Percentage remaining after Selection_2
Muons+	826650	98.5%	98.2%
Protons	21502	0.4%	0.2 %

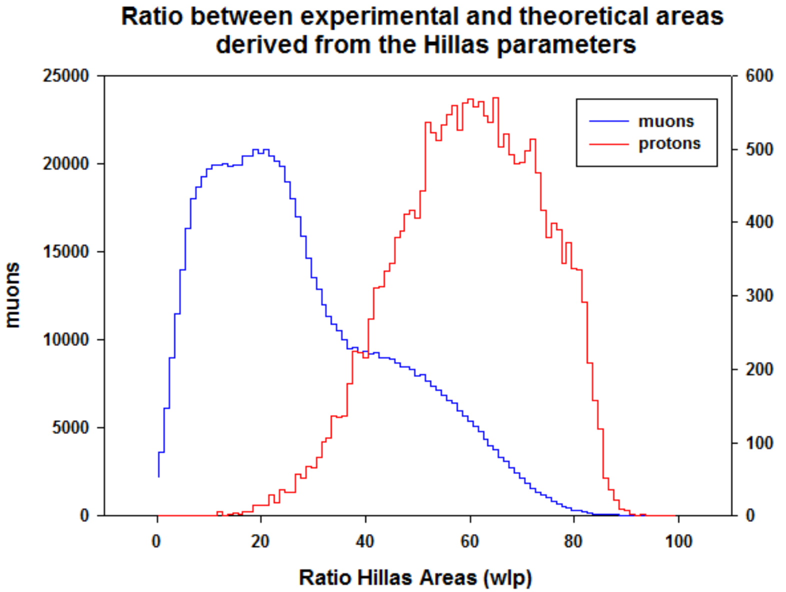
B-M/SST-1300:

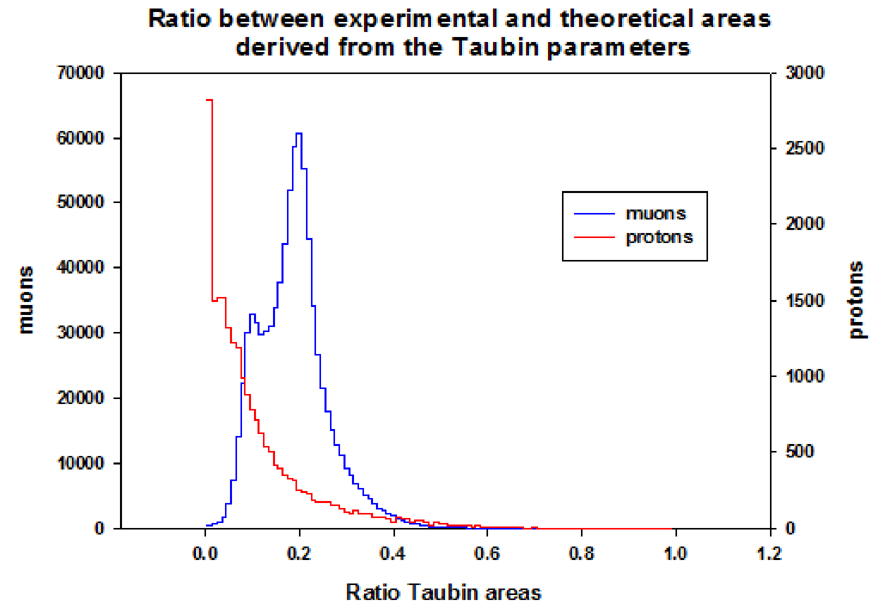
OK

OK

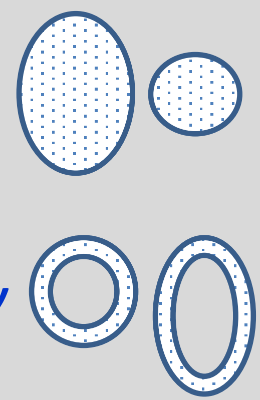
Further useful selection parameters from Taubin and Hillas?

… maybe …





$$\mathrm{Area}_{exp}/\mathrm{Area}_{theor} = \begin{cases} \rightarrow 1 & \textit{full} \\ \rightarrow 0 & \textit{empty} \end{cases}$$



… under study …

… not discussed today …

But … what happens in the 'natural' case of signal embedded in the Night Sky Background?

To successfully apply the pre-selection procedure, as for all analysis procedures in general, the image must be cleaned and the pre-selection results depend on its 'correct cleanness'

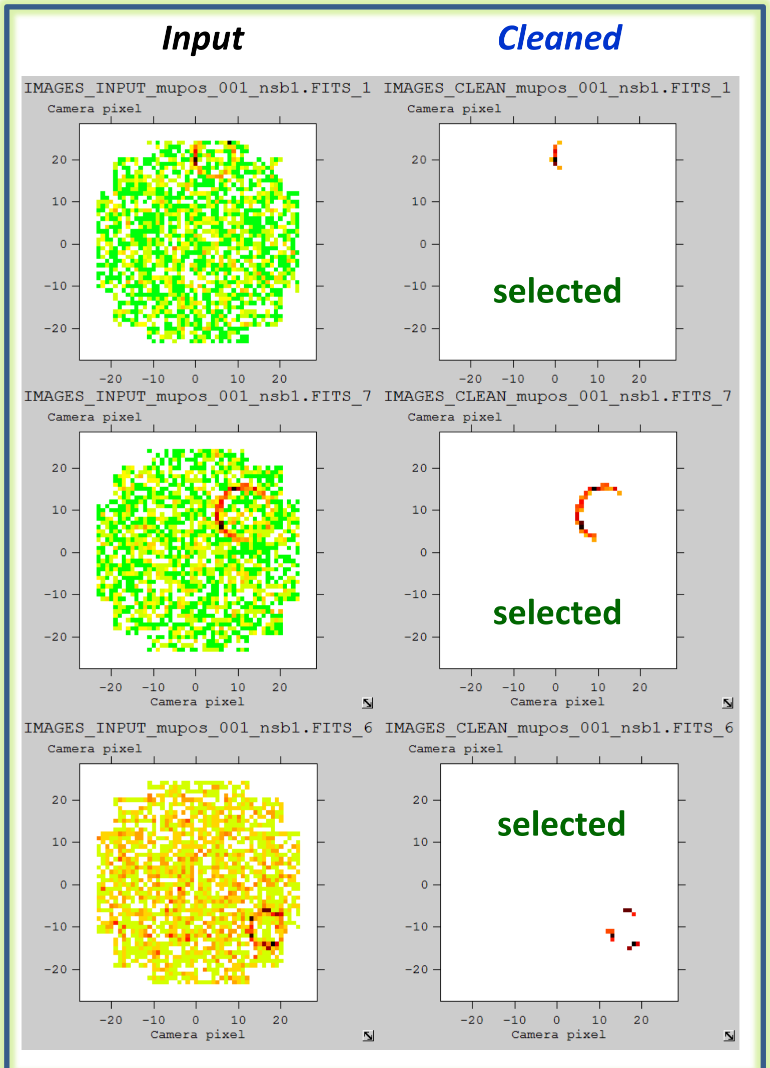
Just an example with a simple and fast image cleaning method:

- **Night Sky Background:**
  - **nsb_1 (~ 1 pe/pixel every 50 ns, ~ 20 MHz per pixel)**
- **Cleaning mode: bi-level threshold on each pixel w.r.t. its neighbors within a 3x3 window; thresholds w.r.t. the RMS(NSB), evaluated from the image.**

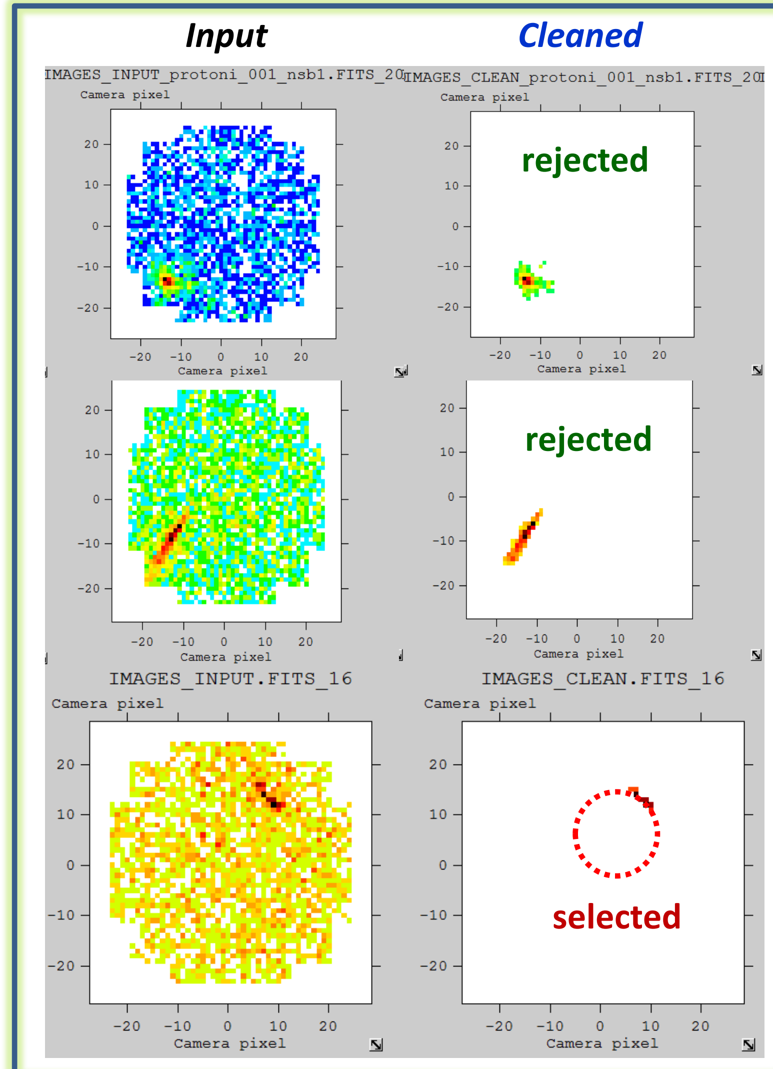
ASTRI SST-2M – Pre-selecting muons in NSB

- **Case nsb_1:** **~ 1 pe/pixel every 50 ns, standard CTA bi-level cleaning, 4/8 RMS(NSB)**

Muons

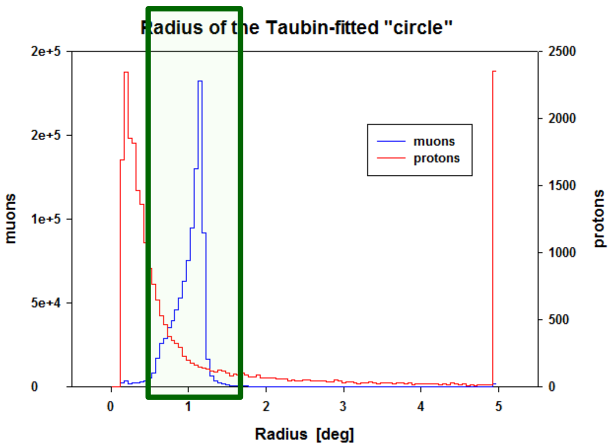


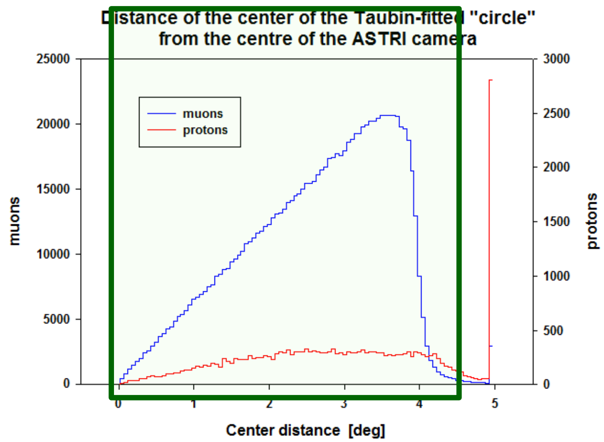
Protons

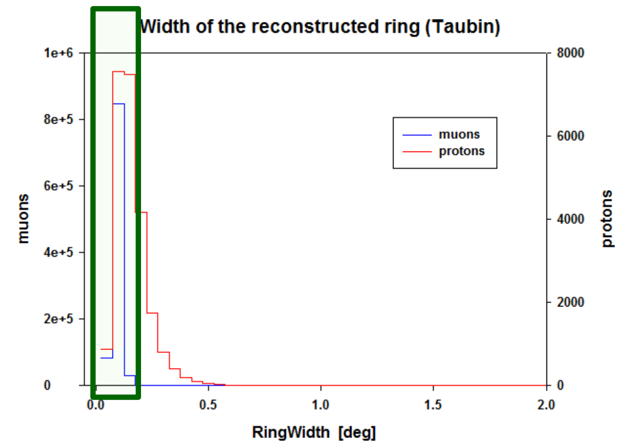


ASTRI SST-2M – Pre-selecting muons in NSB

- **Case nsb_1: ~ 1 pe/pixel every 50 ns, standard CTA bi-level cleaning, 4/8 RMS(NSB)**
- **Selection_0: iok_circle=1 (Taubin method found the circle parameters)**







- **Selection_1: iok_circle=1 .and. 0.5°≤Radius ≤1.5° .and. CenterDistance<4.5° .and. RingWidth<0.2°**

	Events triggered	Events remaining after Selection_1	Percentage remaining after Selection_1
Muons+	972670	928011	**95.4%**
Protons	41186	4021	**9.7 %**

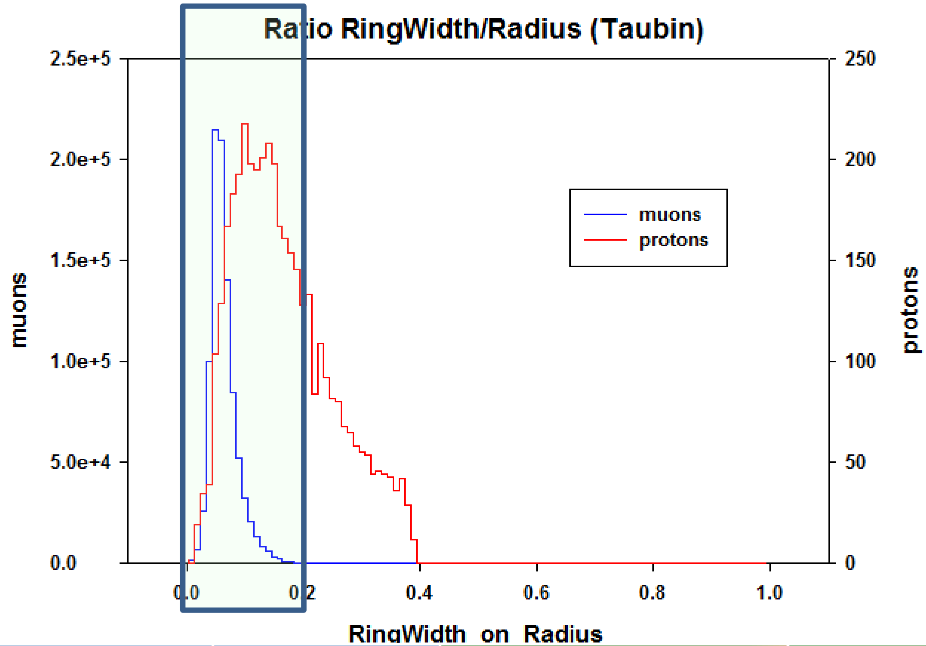
B-M/SST-1300:

OK

Not so good !!!

ASTRI SST-2M – Pre-selecting muons in NSB

- How to improve the muons pre-selection without acting on the cleaning?
- What further parameters could be investigated?
- What about RingWidth/Radius?



- Selection_2: iok_circle=1 .and. 0.5°≤Radius ≤1.5° .and. CenterDistance<4.5° .and. RingWidth<0.2° .and. RingWidth/Radius<0.2°

	Events triggered	Remaining percentage after Selection_1	Remaining percentage after Selection_2
Muons+	972670	95.4%	95.3%
Protons	41186	9.7 %	6.5 %

B-M/SST-1300:

OK

Not sufficient !!!

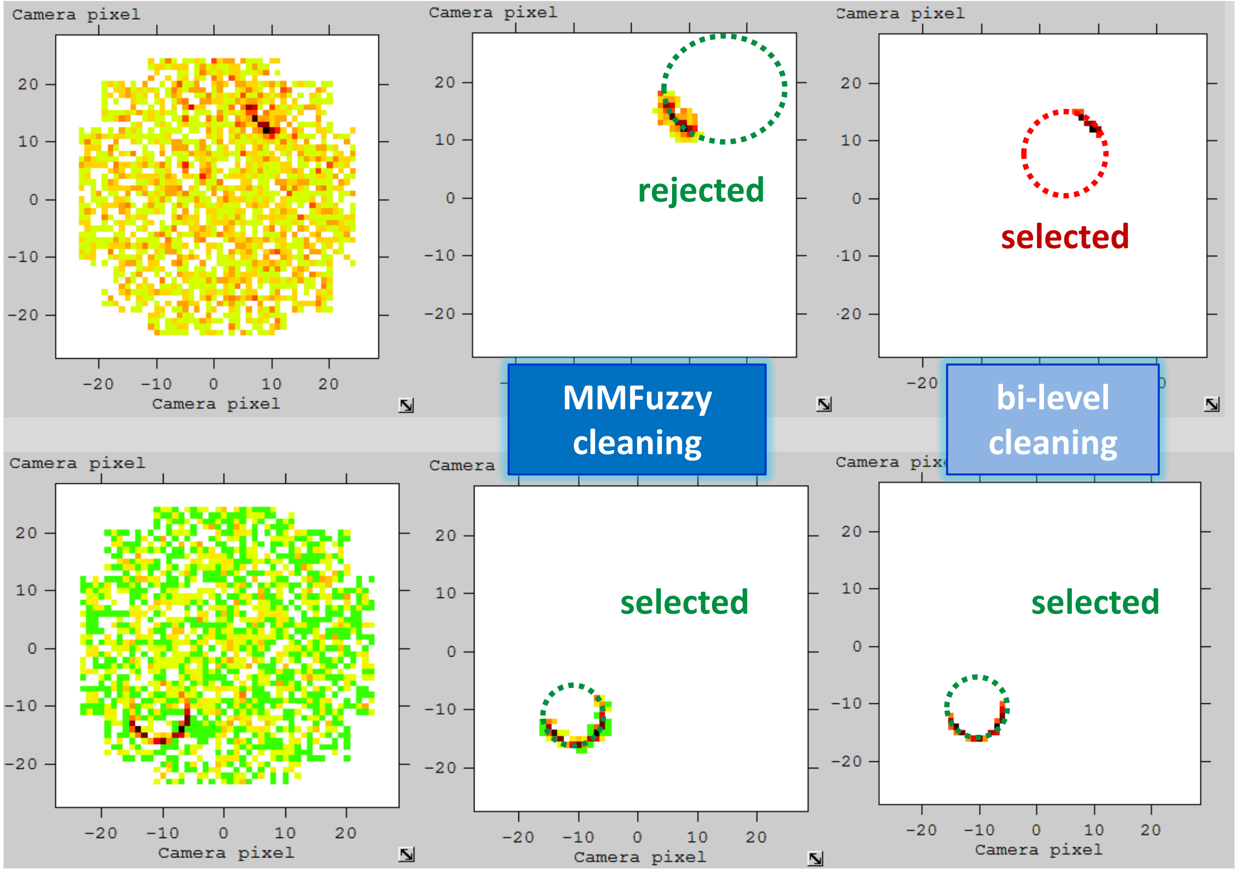
The problem seems to be the cleaning !

The cleaning method does not have to be too much strong; it must maintain memory of the morphology of the signal. Any suggestion?

The fuzzy mathematical morphology, MMFuzzy, [1] could be a solution. The method is based on the combination of morphological operators (erosion, dilation). Its feasibility for Cherenkov images is under investigation together with the proper optimization.

proton

muon



[1] M.C. Maccarone, Vistas in Astronomy, 40,4, 1996.

Conclusions

Image Statistics: cuts based on the number of pixels in the cleaned image, or the average count per pixel are not good (see T.Mineo presentation).

Morphological Analysis: Taubin Method: OK, simple, fast, 'potentially' highly efficient (see cleaning). **Selection parameters:** Radius, CenterDistance, RingWidth, RingWidth/Radius seems to be more than sufficient (further parameters under study, if Hillas method is required).

Morphological Analysis: Hillas Method: fast, not deeply considered here, but it could be not-necessary in the pre-selection procedure.

Cleaning Method: the bi-level algorithm is OK for muons but not for protons: need to optimize for both of them or to define a different method that does not have to be too much strong; it must maintain memory of the signal' morphology.

ToDoList :

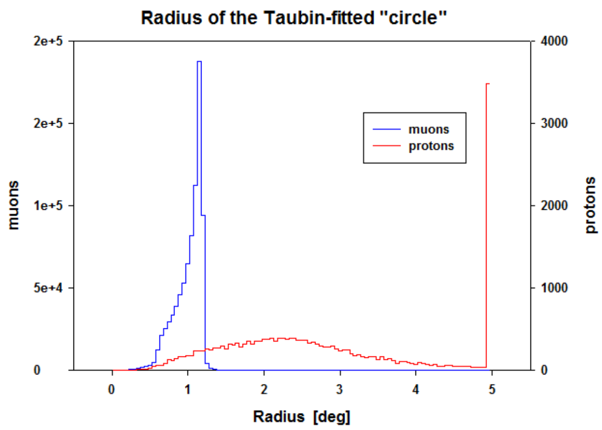
- Optimize image cleaning (different cuts, other methods, MMFuzzy, …?)
- Inclusion of higher levels of the Night Sky Background
- Statistically significant simulation dataset (protons)
- Investigation of the effect on the zenith angle other than vertical
- Study of further parameters, if needed (Hillas, $Area_{exp}/Area_{theor}$, …)

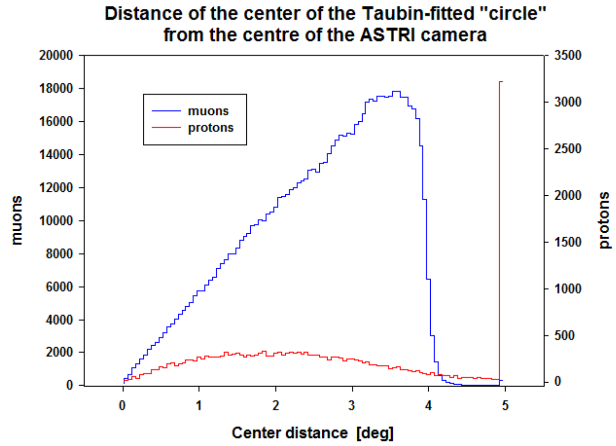
Pre-selecting muons in Camera Server

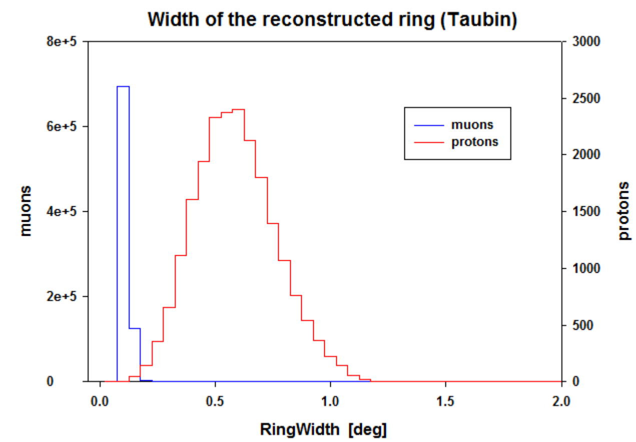
… work is in progress …

Back-up slides

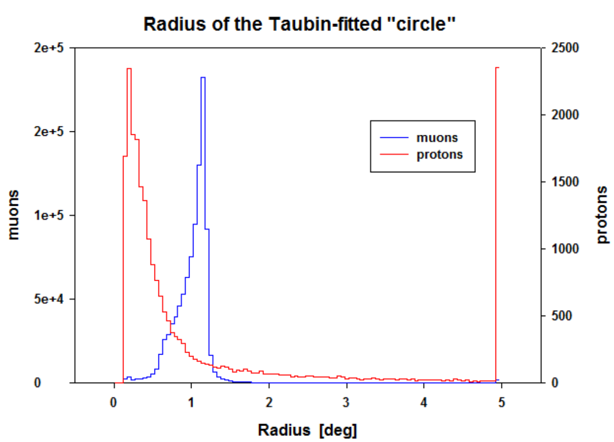
- **Case nsb_0 (no NSB inclusion, no cleaning, Npixon=4, images ‘well-cleaned’ as ref**

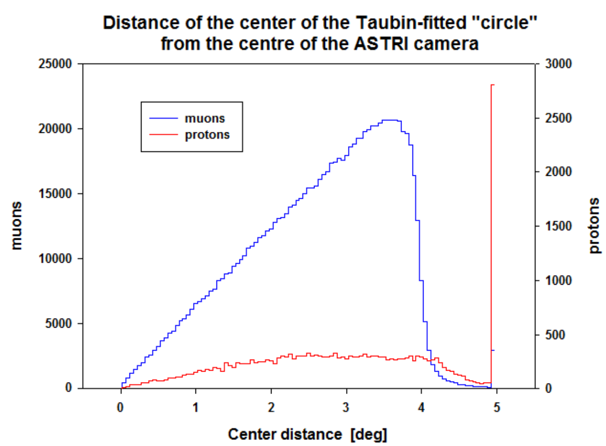


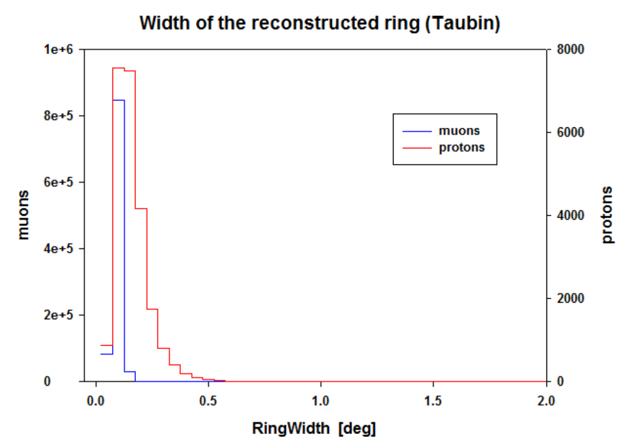




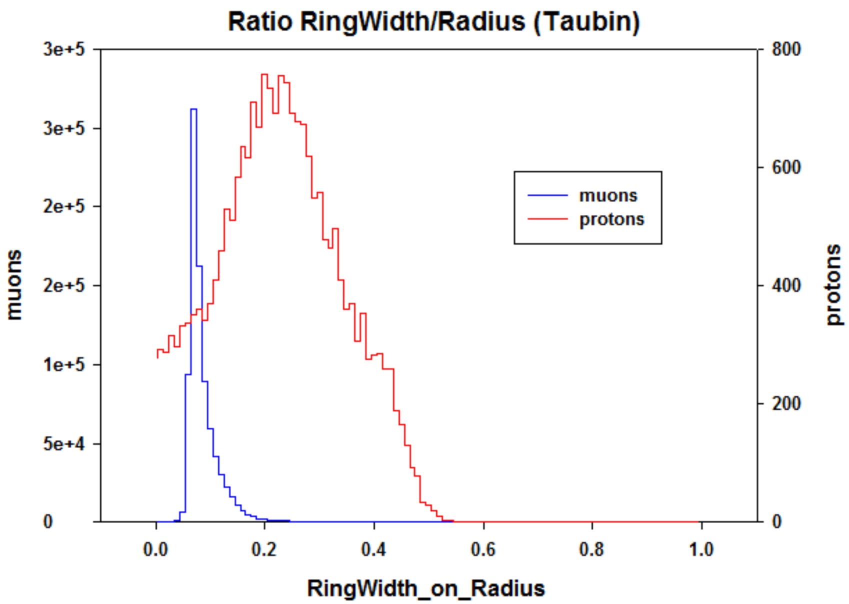
- **Case nsb_1: ~ 1 pe/pixel every 50 ns, standard CTA bi-level cleaning, 4/8 RMS(NSB)**

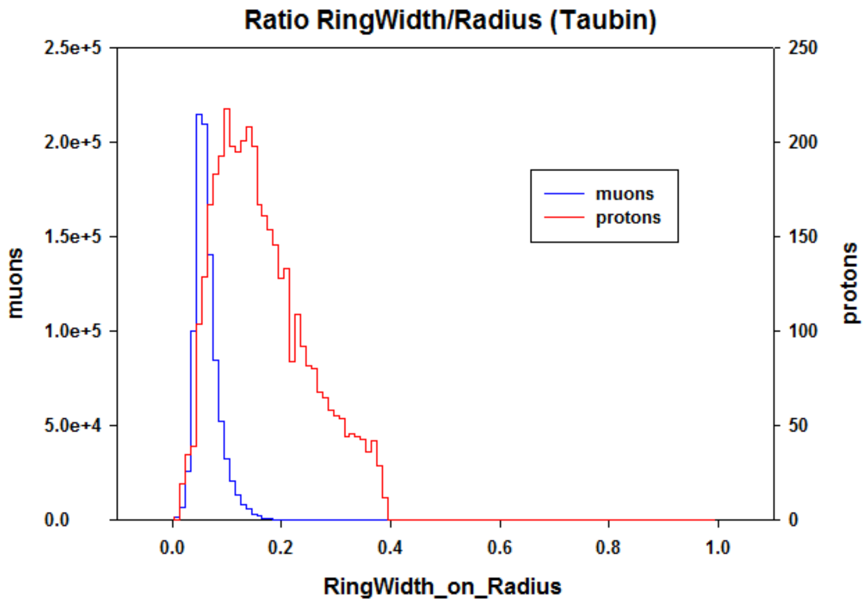






ASTRI SST-2M – Pre-selecting parameters



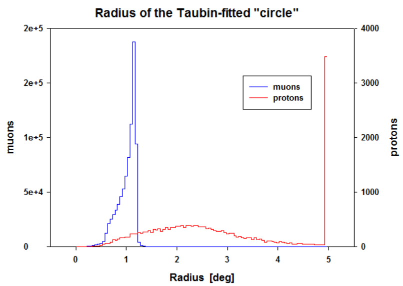


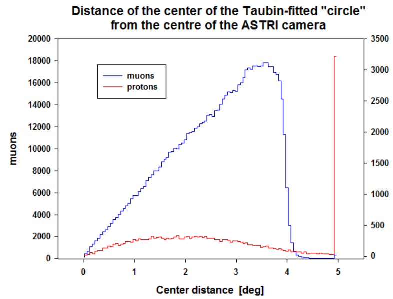
- **Case nsb_0 (no NSB inclusion, no cleaning, Npixon=4, images 'well-cleaned' as ref**

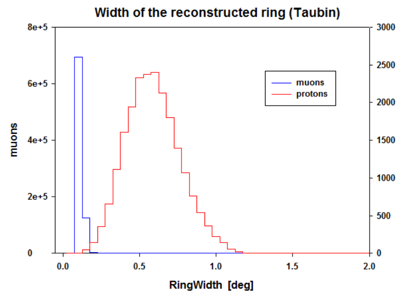
- **Case nsb_1: ~ 1 pe/pixel every 50 ns, standard CTA bi-level cleaning, 4/8 RMS(NSB)**

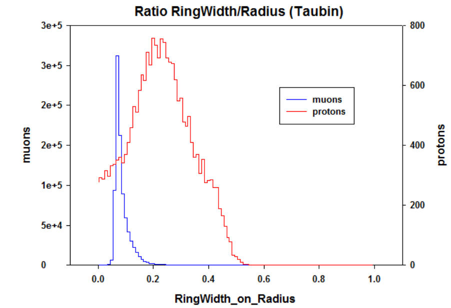
ASTRI SST-2M – Pre-selecting parameters

Case nsb_0 (no NSB inclusion, no cleaning, Npixon=4, images ‘well-cleaned’ as ref









Case nsb_1: ~ 1 pe/pixel every 50 ns, standard CTA bi-level cleaning, 4/8 RMS(NSB)