The AGILE Silicon Tracker: pre-launch and in-flight configuration

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1 Introduction

AGILE (Astrorivelatore Gamma ad Immagini LEggero - Light Imager for Gamma-ray Astrophysics) is a scientific mission of the Italian Space Agency (ASI). The AGILE payload [1] is composed of three detectors: (1) a Tungsten-Silicon Tracker (ST) ([2]-[3]) with a large field of view (about 60°), a good time sensitivity and angular resolution; (2) a Silicon based X-ray detector, Super-AGILE (SA) [4], for imaging in the 18-60 keV energy range, and (3) a CsI(Tl)

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Mini-Calorimeter (MCAL) [5] that detects gamma-rays or particle energy deposits between 300 keV and 100 MeV. The instrument is surrounded by an anti-coincidence (AC) system [6] of plastic scintillators for the rejection of charged particles. ST, MCAL and AC form the so called Gamma-Ray Imaging Detector (GRID) for observations in the 30 MeV-50 GeV gamma energy range. The introduction of the most recent detector technologies in the construction of AGILE brings to the realization of a very light payload (100 kg) with an effective area adequate to produce new important scientific results. AGILE was successfully launched by the Indian PSLV C8 rocket from the Sriharikota base on April 23rd 2007, in a quasi-equatorial orbit with an inclination of 2.5°. The satellite in-orbit commissioning phase was carried out in the period May-June 2007. The scientific verification phase and scientific calibration (based on the Vela and Crab pulsars) were carried out during the period July-November 2007. The nominal scientific observation phase (AGILE Cycle-1, AO-1) started on December 1st, 2007.

In this paper we present the main results concerning the noise characterization and the front-end configuration of the Silicon Tracker. In particular, this work covers the configuration activities performed during the AIV (Assembly, Integration and Verification) phase of the Silicon Tracker, and during the in-flight commissioning phase. The main purpose of these activities was to reach an optimal ST efficiency.
The activities performed during the assembly phase of the modules of the AGILE Silicon Tracker are reported in [7].

The paper is organized as follows. The Silicon Tracker is described in Section 2 while Section 3 is devoted to the description of the on-board logic of the front-end for the determination of a GRID event cluster. Section 4 is dedicated to the identification procedure of the **anomalous** strips used during the assembly phase of the Silicon Tracker and Section 5 describes the parameters characterizing the noise. Section 6 reports some considerations about the concept of floating strip and the definition of the ST efficiency. The GRID clusters, the determination of the noisy strips and the characterization of the noise are the main tools used to **optimize** the ST efficiency, that is the final goal of this work, as described in Section 7. Sections 8-9 report the results obtained during the pre-launch AIV and in-flight commissioning phases.

2 The Silicon Tracker

The main purpose of the Silicon Tracker (Figure 1) is to provide a compact imager for gamma-ray photons of energy above 30 MeV. The Tracker plays two roles at the same time: it converts the gamma-rays in heavy-Z material layers (245 μm of Tungsten, 0.07 X_0), where the photon interacts producing an electron/positron pair (that are MIPs, Minimum Ionizing **Particles** corresponding to a most probable value of 110 keV) **deposited energy per layer** in the detector, and records the electron/positron tracks by a sophisticated combination of Silicon microstrip detectors and associated readout.

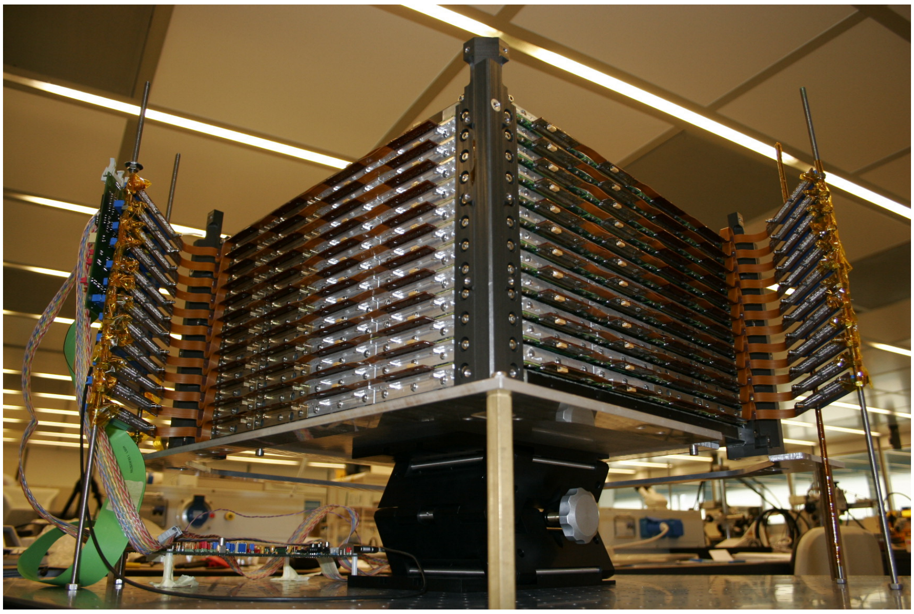

Fig. 1. *Photo of the tracker before the assembly of the 2 front-end boards (June 2005).*

A GRID event is a collection of all the electron/positron interactions into the microstrips of the silicon detector (each interaction generates a *cluster* that is a group of neighbouring strips collecting the charge deposited by the particle, see Section 3.3) together with the energy deposit in the MCAL bars and the information from the AC plastic scintillators (used as veto logic). A complete representation of the event topology allows the reconstruction of the incoming direction and energy of the γ-ray. A representation of a typical grid event is reported in Figure 2.

The Silicon Tracker [3] consists of 12 *planes*, each of them made of two layers of 16 single-sided, AC-coupled, 410 μm thick, 9.5×9.5 cm^2 silicon detectors. The 16 detectors of each plane side (*view*) are grouped in 4 *ladders* each one consisting of 4 detectors wire bonded one after the other along the direction of the strips. The two views of the plane are organized in a X-Z configuration. Figure 3 presents the reference system and the numbering and naming conventions of the Silicon Tracker used in this paper.

The physical strip pitch is 121 μm while the readout one is 242 μm: this "floating strip" scheme allows to read one strip every two thus decreasing the number of readout channels (and thus decreasing the power consumption of the instrument) while maintaining an excellent spatial resolution. Each ladder has 384 readout channels. The name "strip" throughout the paper refers to a

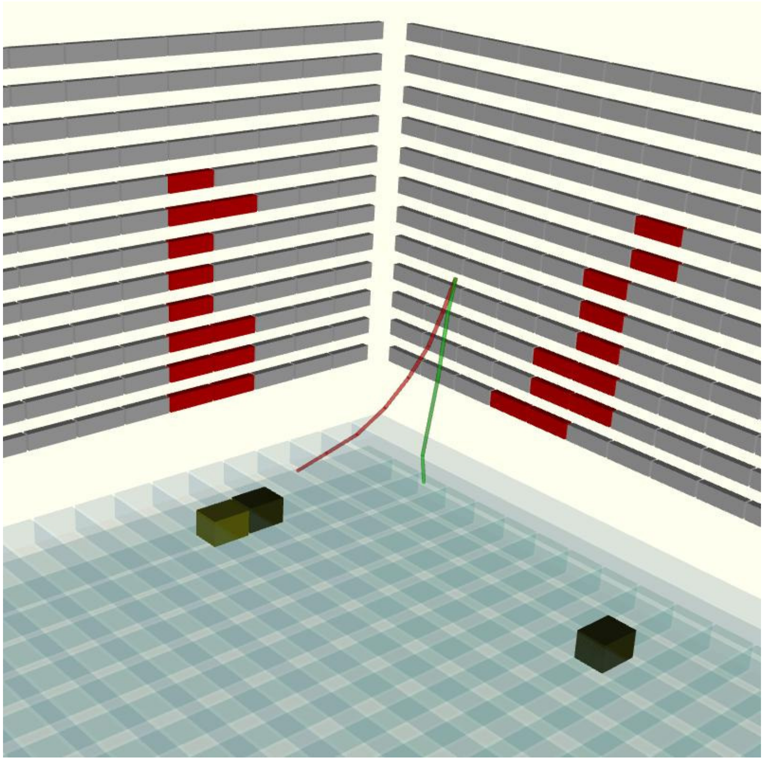

Fig. 2. *A γ-ray event acquired in space* **with a** *reconstructed energy of* ~ 100 *MeV. Gray boxes represent the ASICs and they are coloured in red if they have fired,* **dark-yellow boxes mark** *the hits of the event into the MCAL (the MCAL bars are cyan). The red and green lines are the reconstructed tracks (and thus the topology of the event) of the electron and the positron with a Kalman filtering technique.*

readout strip unless otherwise indicated; "strip" and "channel" are equivalent. The readout ASIC is the TAA1 (Gamma Medica - IDEAS), a mixed analog-digital, low noise, self-triggering ASIC used in a very low power configuration (< 400 μW/channel) with full analog readout. More details are reported in [2]. Each ASIC has 128 identical channels, containing a folded cascode pre-amplifier, a CR-RC shaper, a discriminator (with a threshold chosen by the user and a 3 bit trim DAC per channel for the fine setting) and a sample&hold circuit. The readout is a multiplexed one, with a clock maximum frequency of 10 MHz; the value chosen for the tracker is 3.5 MHz, meaning that the time needed to read one single ladder (that is 384 channels) is 109.7 μs. The total number of ASICs of the ST is 288, 24 **ASICs** for each plane.

Latch-up events and single event effects have been considered in the design of the electronics. Tests have been performed at the INFN Laboratories of Legnaro with ions to understand the behaviour of the ASIC. In the final design, care has been taken to prevent the single event effects with a constant check of the trigger mask and the latch-up problem with control and recovery circuits.

The 12 planes of the Silicon Tracker are organized in 13 trays (as indicated on the right of Figure 3) with a pitch of 1.9 cm. Each tray consists of a 12 mm

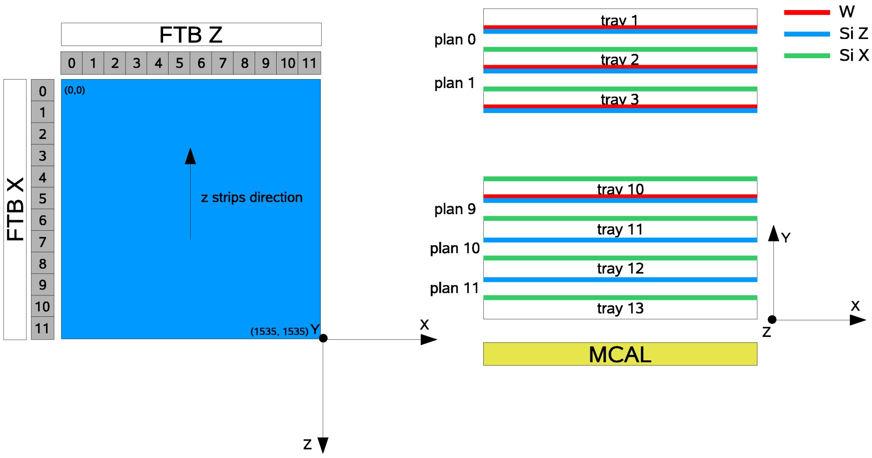

Fig. 3. *The reference system of the Silicon Tracker used in this paper. On the left a logical view of a single plane is shown: the gray boxes are the readout ASICs, the numbers into the blue plan represent the numbering convention used for the strips. A plan is composed of a Z view (blue, shown in the scheme) and a X view. The Y direction is oriented to the top of the ST. On the right side the trays and the planes are shown. The red box is the W layer, the blue box* **represents** *the Silicon views with the strips along the Z direction and the green box shows the Silicon views with the strips along the X direction. The elements are not in scale.*

core of aluminum honeycomb covered on both sides by a 0.5 mm carbon fiber layer. The first 10 trays are equipped with a tungsten layer 245 μm thick glued on the bottom side of the tray itself and with the same area of the silicon detectors. The overall on-axis ST radiation length is **0.8 $\mathbf{X_0}$** [1]; the silicon detector features allow to reach a spatial resolution of 40 μm over a wide range of incidence angles and an energy resolution (when working in the GRID configuration mode) at 400 MeV of $\frac{\Delta E}{E} \sim 1$. The Silicon Tracker has 36 864 readout channels, and is logically and physically divided in 2 *sides* (a side is a collection of all the views with the same strip **direction), called X and Z**, each one controlled by a dedicated front-end board (*FTB*, Frontend and Trigger Board, [8]). Each FTB is composed of 6 *FEBs* (FrontEnd Board) and each FEB controls 2 views of the same type. The FTB has to generate the voltages needed to operate the ASICs (± 2 V) and the bias voltage for the silicon detectors, to set the threshold value, to manage the trigger signals and the readout phase. The analog signals managed by the FEBs are Analog to Digital converted and hardware processed by 3 PDHU (Payload Data Handling Unit, see [9]) boards [2]. The silicon detectors have been manufactured on **six wafers with resistivity above 4 $k\Omega$-cm**; the corresponding full depletion

[1] There are 10 layers of W, each one of 0.07 X_0 radiation length, and 24 layers of Si, each one of 0.0410 cm. With the Si layers we obtain 0.1 X_0 radiation length.
[2] FTBs and PDHU have been designed by Thales Alenia Space (formerly Laben).

voltage ranges between 25 and 45 V and the bias voltage used on the satellite is 50 V.

The total height including the active elements is $\sim 21\,cm$ and therefore the tracker is the lightest and most compact γ−ray imager sent in orbit.

3 ST front-end characterization

3.1 Electronic Noise

The overall noise of each ladder has two components (see [2]):

- the intrinsic random noise, **characterizing** each floating or readout strip, whose single components are the ones listed below:
  · the leakage current;
  · the polarization resistors;
  · the resistance of the metal strip;
  · the TAA1 readout ASIC.
  The estimated *Equivalent Noise Charge* (ENC) is of the order of 800 electrons with the main contributions coming from the ASIC and the polarization resistor of the detector.
- the common mode (CM), that characterizes each ASIC, which is given by the fluctuation of all the channels at the same time mainly because of the pickup on the bias voltage.

The expected noise for each ladder is the sum in quadrature of the two components.

As far as the grounding of the detector is concerned, all the power supplies have a common return defined at the level of the PDHU. This common return is the general ground of the system . This solution has been verified in terms of noise to check it did not deteriorate the performances.

A too high CM could prevent the possibility of setting the trigger threshold at 1/4 of a MIP, that is the optimal value as specified in Section 6, **thus reducing** the detector trigger efficiency. In particular, with a too high threshold the floating strip could be lost. The CM has to be computed for each event to be subtracted together with the pedestal from the raw data, an operation performed by the FTB. For each ASIC j the CM component is calculated as

$$CM_j = \frac{\sum_{i=1}^{N}(raw_{ji} - ped_{ji})}{N_j} \tag{1}$$

where raw_{ji} is the raw content of the readout channel of the strip i in ADC counts, ped_{ji} is the channel pedestal (see Section 3.2) and N_j is the number of the ASIC good strips (noisy or dead strips are excluded).

3.2 Pedestal calculation

The pedestal of a channel is its baseline level when no signal is present. An on board procedure, activated by means of a dedicated telecommand, has been implemented for the pedestal calculation: the ASICs are divided in columns (corresponding to the first, second and so on ladders of each view); when the procedure starts each column is readout for 64 times generating random triggers and the values are stored on-board. The following quantities are then calculated, where j is the ASIC index and i is the strip index related to that ASIC:

- the mean value of each strip (36 864 values), ped_{ji};
- the rms value of each strip (36 864 values), rms_{ji};
- the common mode of each ASIC (288 values, one for each ASIC), CM_j, as reported in Equation 1.

In Figure 4 the histograms of the mean and rms (before the common mode subtraction) values and the common mode rms for each ASIC are presented. Given the overall noise rms is of the order of 30 ADC counts, and the common mode value is of the order of 6, the common mode contribution to the noise **is practically negligible**. Figure 5 shows the pedestal mean and rms for each strip of a single ASIC.

3.3 Determination of a cluster in an event

A cluster is a set of contiguous strips registering the passage of a particle. The following on-board algorithm is used to identify the clusters:

- the TAA1 ASIC contains a threshold discriminator per read-out channel. If the value of the charge of a strip is above this threshold (called *FTB threshold*) a *trigger signal* is generated (which is the OR of all the 128 channels of a TAA1). This signal starts a level 1 trigger algorithm (see [3]), that requires a signal in at least three out of four contiguous tracker planes, and a proper combination of fired AC panels;
- if the previous level 1 trigger is passed, a *hold signal* is generated and an intermediate level 1.5 trigger (see [3] for details) evaluates the event topology defined by the distribution of the fired ASICs with respect to the fired AC panels;

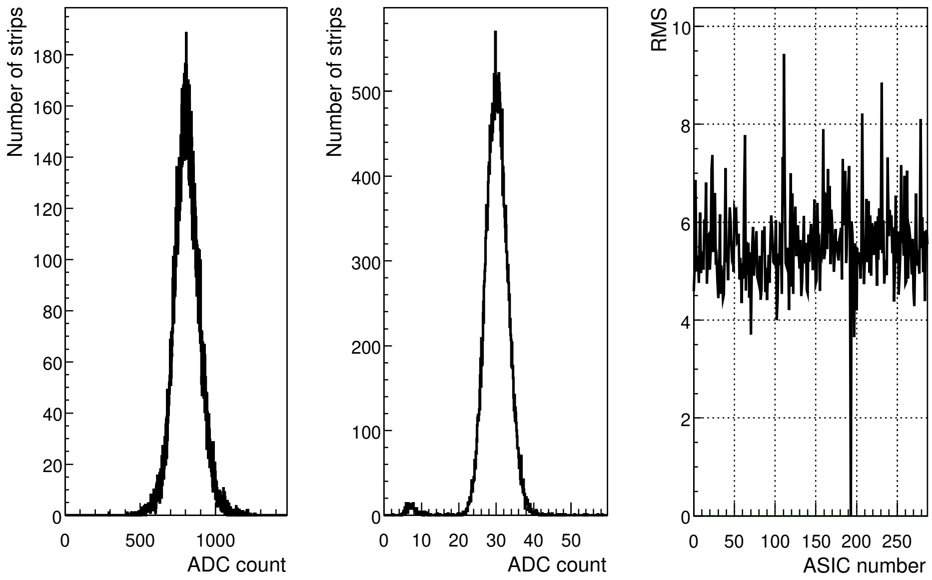

Fig. 4. *Histogram of the pedestal mean* (ped_{ji}) *and rms* (rms_{ji}) *and plot of the common mode rms of each ASIC (the x axis reports the index of the ASIC). The small peak below 10 ADC counts* **in the rms distribution** *is related to dead channels where only CM noise is present. The common mode rms near 0 ADC counts is due to a dead ASIC.*

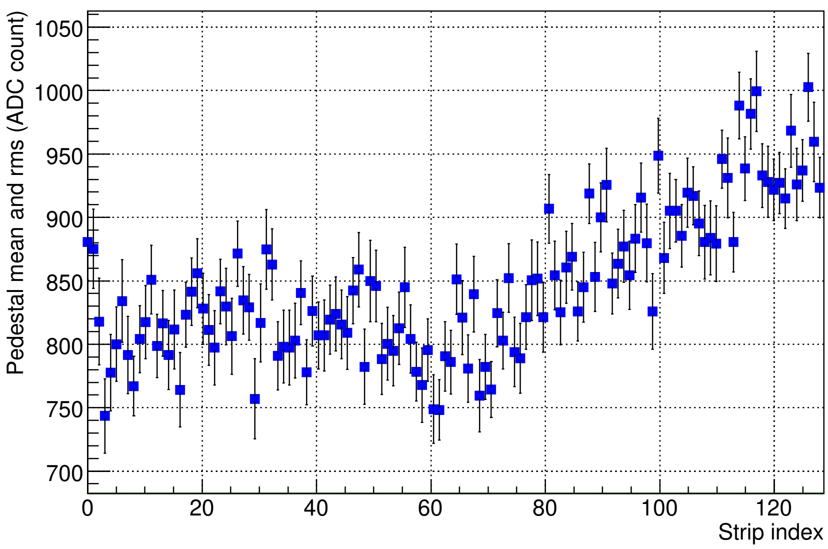

Fig. 5. *Pedestal mean* (ped_{ji}) *and rms* (rms_{ji}) *of each strip of an ASIC.*

- if the level 1.5 trigger is passed all the strips **with signal above the threshold for the fired ASICs** are acquired and their collected charge is converted **into** 12 bit digital values. To do this, the *front-end freeing* procedure implements a sparse readout of the triggered strips by means of a 5 MHz clock and the analog to digital converted values are saved in a dedicated RAM;

- at this point, a *preprocessing procedure* starts:
  - *raw data pre-analysis*: the pedestal and common mode values are subtracted; the pulse height of every strip i of ASIC j is thus defined as

$$C_{ji} = raw_{ji} - ped_{ji} - CM_j \tag{2}$$

  - *zero suppression*: **each** strip with a value C_{ji} smaller than N_1 times its rms is discarded. This reduces the data transfer to the PDHU. At the time of writing, $N_1 = 3$ [2];
- *cluster identification*; this procedure starts after the preprocessing procedure and **contains** the following steps:
  - in a group of contiguous strips at least one strip m should have a value $C_m > H_m$, where H_m is N_2 times the rms_m calculated with the pedestal procedure. At the time of writing, $N_2 = 5$ [2];
  - the **not suppressed** strips adjacent to the strip m are considered. This group of strips is called a cluster. If in this group there are two strips with a signal C larger than N_2 times their rms noise and they are not adjacent to **one another**, two clusters are generated with a shared strip.

For each cluster the payload telemetry contains:

- the total charge (the sum of the charges of all the cluster strips);
- the total width (the number of strips) of the cluster;
- the charge of the 5 central strips of the cluster, reduced to 8 bits (the least significant bits are removed). In this paper the central strip is called C_3, the left side strips are called C_1 and C_2, and the right side strips are called C_4 and C_5.

In addition, the following data are acquired for a full representation of the GRID event:

- the time of the event;
- the energy deposited in each Mini-Calorimeter bar;
- the configuration of the fired AC panels;
- the extra fired ASICs index: for each view of the Silicon Tracker the maximum number of triggered ASICs that can be acquired is 8. If more than 8 ASICs trigger, only the indexes of the additional triggered ASICs are sent to ground with the telemetry. The ASICs are ordered according to their physical position: from the first tray on the top of ST to last tray at the bottom, and for each tray according with the index reported in Figure 3.

3.4 The GRID Operation mode

The PDHU provides three main working modes for the GRID subsystem:

1 *observation mode*: with this configuration the GRID subsystem is **ready** to acquire photons in the 30 MeV-50 GeV energy band. A set of different on-board triggers (level 1 and level 1.5 hardware trigger, already described in Section 3.3, and a level 2 software trigger, see [9]) enables the discrimination of background events (mainly muons on ground or particles in the AGILE Low Earth Orbit) from gamma-ray events. This is the acquisition mode used during the calibration activities and in-flight. The corresponding telemetry flow is indicated as 3901;

2 *physical calibration mode*: in this configuration mode only the first step of level 1 trigger that requires a signal in at least three out of four contiguous tracker planes has been enabled. This data acquisition mode has been used extensively during the various AIV activities. The corresponding telemetry flow is indicated as 3902.

3 *electrical calibration mode*: this mode is used to check the behaviour (in terms of gain and stability) of each single strip in test mode; all the strips except one are disabled and a pulse with a variable amplitude is injected into the preamplifier input 64 times, after having set a proper threshold. The output is the number of times the strip has triggered. The procedure is repeated for every strip. The corresponding telemetry flow is indicated as 3904.

4 Procedure for the identification of anomalous strips

The procedure for the identification of anomalous strips has been defined during the assembly of the Silicon Tracker performed at Mipot S.p.A. [3] by the INFN Trieste team.
A channel is considered *anomalous* or *bad* from the point of view of the noise if the noise level is too low (low or dead channel) or too high (noisy channel). It can be observed that, excluding the anomalous channels, the plot of the noise versus the channel number is a function that has a continuous component. This is probably due to the fact that the physical properties that have influence on the noise level vary continuously (e.g. across the strips of the silicon detectors). An example of this behaviour can be seen in Figure 6, where the noise of the 384 channels of a unit of electronic readout (a PCB with three ASICs, not connected to the silicon detectors) is shown: **being the traces of the PCB not connected to the corresponding strips on the silicon**, the noise level is mainly determined by the different length of the strips on the board, that vary slightly from a channel to the next **one**.
For this reason, the procedure starts with a fit of the noise level versus the channel number with a curve of the second order; a different curve is obtained for each ASIC. Then, a sort of level of anomaly for each channel ($ANOM_n$)

[3] Mipot S.p.A., Via Corona 5, Cormons (GO, Italy); http://www.mipot.com

is defined dividing the level of the noise of the single channel (rms_n) by the corresponding theoretical level calculated from the fit. In this way, a quite flat function of the channel number is obtained, whose median is 1; a channel is being defined bad considering how far its anomaly level is with respect to 1. The noise level (rms_n), which is the rms value of a set of measurements of the pedestal acquired at different instants, has in turn a variance, that propagates to the anomaly level. Hence, for each ASIC, the median, the lower quartile q_1 and the upper quartile q_3 of the set of the 128 anomaly levels in the ASIC are calculated. Then, every single ($ANOM_n$) is compared to q_1 and to q_3: the cut level is defined with the help of an arbitrary constant L, so that a channel n is defined "low" or "dead" if $ANOM_n < {q_1}^L$, while it is "noisy" if $ANOM_n > {q_3}^L$. In the analysis, it has been chosen $L = 15$. An example concerning one of the 24 views is presented in Figure 7; the data shown in this picture refer to measurements acquired from a tray alone, not assembled on the payload, shielded against EM interference, and connected to a testbench electronic interface.

It has to be remarked that before every fit, the channels in the ASIC that are clearly anomalous must be excluded from the fit algorithm, otherwise a bad curve is obtained. The channels that are to be excluded from **the** fit are determined by applying an algorithm similar to the one just described above, except that the "fitting curve" is a flat line whose level is the median of the (rms_n) in the ASIC.

During the analysis, it has been noted that the noisy channels are better highlighted after the common mode subtraction. Therefore, noise after the common mode subtraction has been preferably used, instead of the raw rms, to find the noisy channels, applying the same procedure described above.

5 Other quantities to characterize the GRID noise

This section describes the other quantities, in addition to those defined in the pedestal calculation procedure (described in Section 3.2), that characterize and optimize the overall GRID **noise and** efficiency.

5.1 Pull and SNR of a cluster

The pull [2] is defined as the ratio between the signal of the strip with the maximum (C_3) and its rms.

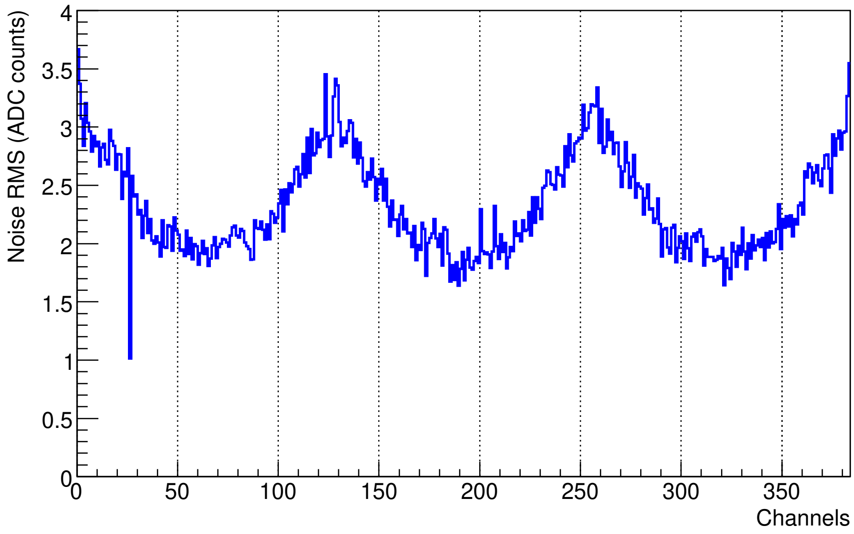

Fig. 6. *Noise profile of the 384 channels of a PCB not connected to the silicon detectors. The typical shape of the profile is determined by the different length of the strips on the PCB that are connected to each channel of the ASIC. A dead channel can also be seen.*

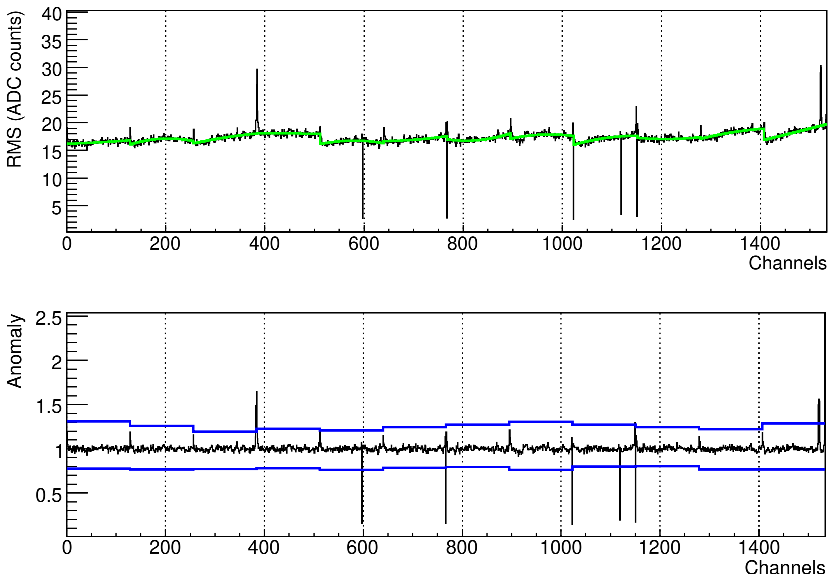

Fig. 7. *Rms and anomaly level of the 1536 channels of an entire view (12 ASICs). In the upper plot, the parabolic fits of the ASICs can be seen; in the anomaly graph, the two cut levels for the evaluation of the low and of the noisy channels are also shown. Dead channels are 598, 768, 1024, 1120, 1152; noisy channels are 383-384, 1150, 1521 to 1523.*

The signal/noise ratio (SNR) of a cluster is defined as

$$SNR = \frac{\sum_i C_i}{\sqrt{\frac{\sum_i rms_i^2}{N}}} \quad (3)$$

where the sum is performed over all the strips N in the cluster itself. Both these quantities have been used for the characterization of the Silicon Tracker. In particular, the peak of the pull (calculated as the most probable value of the fit with a Landau [2]) and the on-axis pull (the pull of particles or converted γ-ray events **with incidence angle** $< 5°$) have been used for a check on the threshold setting values N_1 and N_2 once the Silicon Tracker was integrated into the spacecraft. In addition, the on-axis pull has been used for the evaluation of the presence of events with particle crossing near the floating strip during the various phases of the configuration (see Section 6).

5.2 Zero cluster events

During the AIV activities, it has been found that the generation of GRID events with no clusters depends on the noise level of the Silicon Tracker itself. When the level 1.5 trigger is passed, all the ASICs over threshold are acquired and the preprocessing procedure is performed; during this procedure it is possible that all the ASICs are zero-suppressed but the on-board logic sends these events to ground within telemetry all the same.
This generation of zero cluster events is due to the fact that if the system is noisy the pedestal rms values are large and the two trigger levels can be passed all the same; on the other hand, the procedure of the pedestal/common mode subtraction and zero suppression eliminates all these clusters. For this reason the number of zero cluster events has been used as a noise indicator during the AIV and in-flight configuration of the Silicon Tracker front-end.

5.3 Extra-fired ASICs

As already stated, for each view of the Silicon Tracker the maximum number of triggered ASICs that can be acquired is 8. If more than 8 ASICs trigger (because of physics or because of the noise level of the detectors), only the index of the additional triggered ASICs is sent to ground within the telemetry. These ASICs are called *extra fired* and their number has been used as an additional indicator of noise.

5.4 Silicon Tracker rate-meters

The PDHU implements several rate-meters that can be used as indicators of the noise level of the system. In particular, the *ST rate-meters* are the OR of the trigger signals of all the TAA1 ASICs of a view (see Section 3.3). One rate-meter for each plane is generated, but only one view is sampled: the selection of the odd or even views is performed by means of a telecommand. Each rate-meter has an integration window of 16 s.

5.5 Central strip charge

The distribution of the charge of the cluster central strip C_3 can be used as indicator of the noise level of the Silicon Tracker. As reported in Section 8, the most probable value of the MIP charge is 630 ADC counts **for central strip** C_3, with a tipical distribution that can be fitted with a Landau function. For this reason the percentage of clusters with the central strip charge $C_3 < 100$ ADC counts has been evaluated, since this value is an indicator of a cluster triggered by noise.

6 Floating strip and efficiency measurement

The total charge collected by the readout strip depends on

- the diffusion during the charge collection;
- the capacitive charge coupling between the strips;
- the incidence angle of the incoming and secondary ionization particles.

As already stated, the AGILE Silicon Tracker is characterized by one floating strip between each readout strip. If a particle crosses the detector at the position of the floating strip, the charge is collected on this strip and induced on the nearby ones; capacitive charge division will then result in signals on more than one strip. Given the parameters of the detector strip (**such as width and pitch of implant strips and Al read-out electrodes**), when a particle crosses a floating strip, on each of the adjacent readout ones 38% of the produced charge is collected, as deteminated experimentally [3]. Such values are compatible with a 100% efficient detector if the trigger threshold is set at 1/4 of the charge released by a MIP crossing the silicon detector. A too high FTB threshold could reduce the detector efficiency preventing the readout strips to generate a trigger in case of an event on a floating strip.

If all the parameters are set correctly, the on-axis pull for the strip with the maximum signal in the event shows clearly the presence of the floating strip as presented in Figure 8, obtained with the Silicon Tracker in the final configuration, already integrated in the spacecraft before the launch. The peak on the left (whose most probable value is 10.6) corresponds to the case of the particle crossing nearby a floating strip, while the peak on the right (with a most probable value at 23.4) is the one of the readout strip collecting the whole charge.

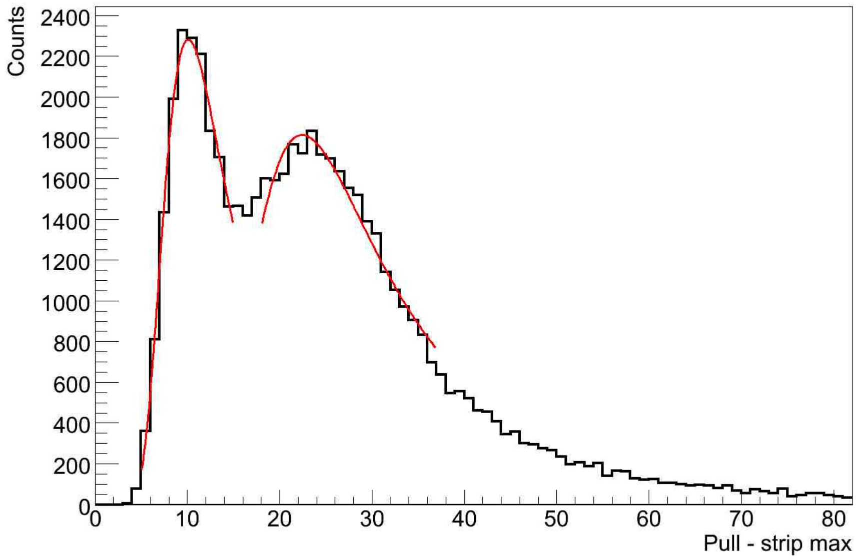

Fig. 8. *On-ground configuration: on-axis pull for the strip with the maximum with a FTB threshold set to 7 in physical calibration mode (data acquired on RUNID 11119). The peak on the left is due to the floating strip, while the peak on the right to the readout strip. The two peaks are fitted with a simplified Landau. The plot includes the data from all the ST planes.*

The easiest way to measure the plane efficiency is the following

$$eff(N) = N_s/N_t \tag{4}$$

where N_s is the number of GRID events with a signal (at least one cluster for each plane) in the planes N-2, N-1, N, N+1, N+2 and N_t is the number of GRID events with a signal (at least one cluster for each plane) in the planes N-2, N-1, N+1, N+2. The ST efficiency is the mean value of the plane efficiencies. The formula cannot be applied for planes 1, 2, 11 and 12, but due to the fact that there is a difference between the efficiencies of the different planes of the order of $1-2\%$, this formula has been used for the determination of the ST efficiency.

The optimization of the ST efficiency was the main goal of the ST configuration performed during the AIV and in-flight commissioning phases.

7 FTB threshold scan and strip mask definition

During the AIV activities several levels of the FTB threshold have been tested. All the tests have been performed with the same environmental conditions. For each threshold different strip masks have been chosen; in fact, the number and identity of noisy strips change as a function of the threshold and different masks of disabled strips have to be defined. This iterative procedure for the FTB threshold scan and noisy strip disabling has allowed the final configuration of the Tracker front-end; for each threshold the following steps are required:

- *First step*:
  - a set of consecutive (typically 8-10) pedestal runs (telemetry type 3903) is performed allowing to create a first list of noisy strips resulting from the statistical analysis of the pedestals themselves (i.e. tagging individual strips displaying fluctuations **not compatible with those expected according to poisson statistics from average strip signal**);
  - a second list is produced with the analysis of an electrical calibration (telemetry type 3904); the strips above a threshold (5 times the mean value of the number of triggers of all the strips of an ASIC) are selected. The digital value of the parameters used for electrical calibration are 1 for amplitude and 5 for threshold (see Section 3.4);
  - These two lists are merged with a list of 242 noisy strips (about $\sim 0.6\%$ of total strips) identified during the Silicon Tracker assembly with the procedure described in Section 4.
- *Second step*: this first list is uploaded in the PDHU and an acquisition of GRID events in physical calibration mode (telemetry type 3902) is performed. Noisy strips are searched for in this data set: for each ASIC the mean μ of the number of times δ_i that a strip i is a center of a cluster is calculated. A strip i is noisy if $\delta_i > \mu N$. A typical value of N used during this analysis is 3; with this value a good equalization of the counts of each strip has been obtained. At the end of this procedure a new list is produced.
- *Third step*: the list is tested with a new physical calibration and the procedure is repeated if there are still noisy strips. The ST rate-meters are used as a quick look of the data quality of the configuration and the already described noise indicators (see Section 5) and the ST efficiency are evaluated. The procedure stops when good noise indicators have been obtained and a run of GRID observation (telemetry type 3901) is performed as the last check of the current configuration. This run allows to evaluate the efficiency and noise level of the system with the same parameters used in physical

calibration together with the topology of the acquired events.

Once this procedure is completed, the FTB threshold is changed and the process restarts.
The lower the FTB threshold, the higher the ST efficiency. The FTB threshold scan procedure stops when the ST noise becomes too high and too many strips (more than $6-7\%$) should be disabled.

The values of FTB thresholds reported in this paper are digital values without a direct correspondence with the MIP.

For each strip mask the following quantities have been used to decide if the current configuration is correct and the noise is under control:

- maximum peak of the pull and presence of the floating strip peak in the on-axis pull;
- SNR ratio;
- percentage of zero cluster events;
- percentage of extra-fired ASICs;
- ST rate-meters;
- counts of clusters with $C_3 < 100$ ADC counts.

A configuration is good when the first 2 parameters of the list (in addition with the ST efficiency) have been maximized and the remaining **ones** minimized. In addition, the value of ST rate-meters should be uniform for each view.

In Table 1 the number of disabled strips for each configuration is reported. The configuration named 5 has been used during the GRID calibration performed in November 2005 at the INFN Laboratories of Frascati (Rome), while configuration 6 was the on-board configuration selected before the launch campaign. Configurations 7 and 8 have been defined during the in-flight commissioning phase performed in May-June 2007.

Table 1
Number of disabled strips for each configuration.

Configuration Name (Mask ID)	**Nr of disabled strips**	**% of total strips**
5	1956	5.3
6	529	1.4
7	407	1.1
8	665	1.8

8 ST characterization at the end of the AIV activities

The ST final configuration is a trade-off between the noise level and the efficiency of the Silicon Tracker and is the result of 597 runs in observation mode (telemetry type 3901) and 996 runs in physical calibration mode (telemetry type 3902) during the AIV activities. Each run is identified by its own RUNID number in the AGILE test environment (see [11]-[14]). In the following, one of the final runs is presented as an example (RUNID 11119). The main parameters of this final pre-flight configuration are the following:

- side X pull: 16.7 ± 0.2
- side Z pull: 16.2 ± 0.2
- events with less than 3 clusters: 1%
- clusters with less than 100 ADC counts for the central strip: 0%
- side X efficiency: $95 \pm 2\%$
- side Z efficiency: $97 \pm 2\%$

The strip mask used for this configuration is named 6 with 529 disabled strips.

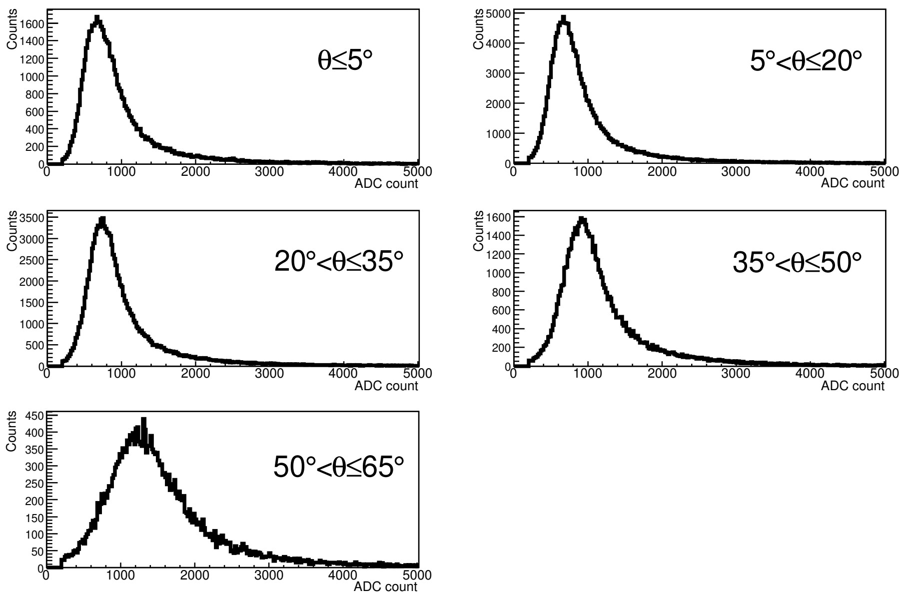

Fig. 9. *On-ground configuration: cluster total charge in ADC counts with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.*

Figure 9 shows the total charge deposit in ADC counts of each cluster with the FTB threshold set to 7 with data acquired in physical calibration mode. Figure 10 presents the charge (in ADC counts) of the cluster central strip: for near on-axis events it is possible to clearly distinguish the two peaks (first plot at the upper left of the Figure) corresponding to the floating strip (peak on the

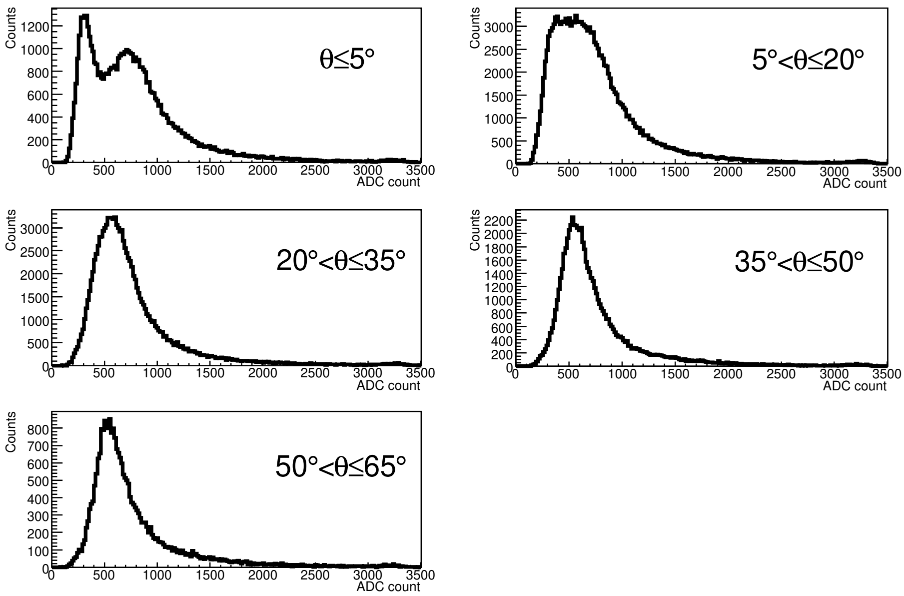

Fig. 10. *On-ground configuration: charge in ADC counts of the central strip C_3 with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ. In the first plot the peak on the left is due to the floating strip, the peak on the right to the readout one. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.*

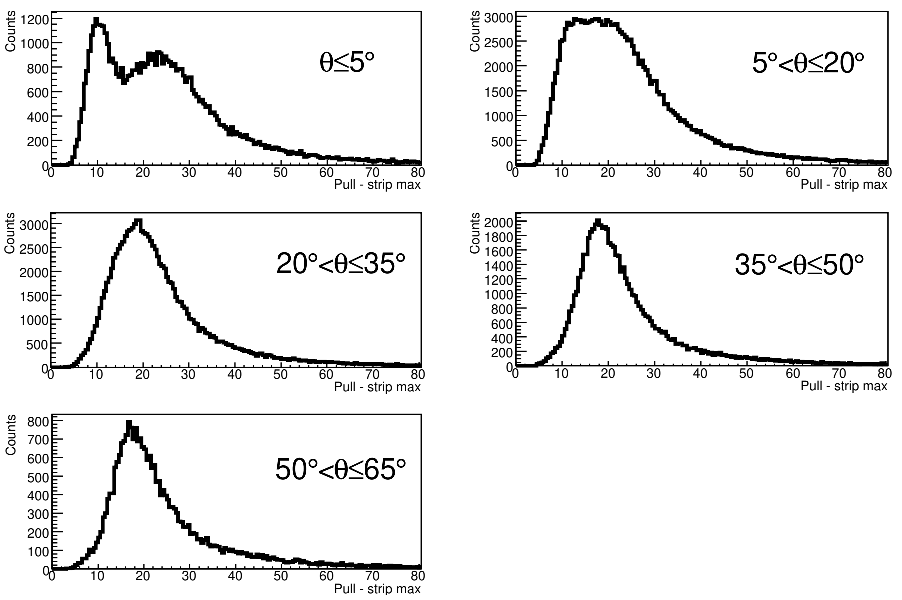

Fig. 11. *On-ground configuration: pull for the strip with the maximum signal in the event with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.*

left) and to the readout one (peak on the right). The two peaks merge into one for increasing incidence angles as a consequence of the charge signal spreading

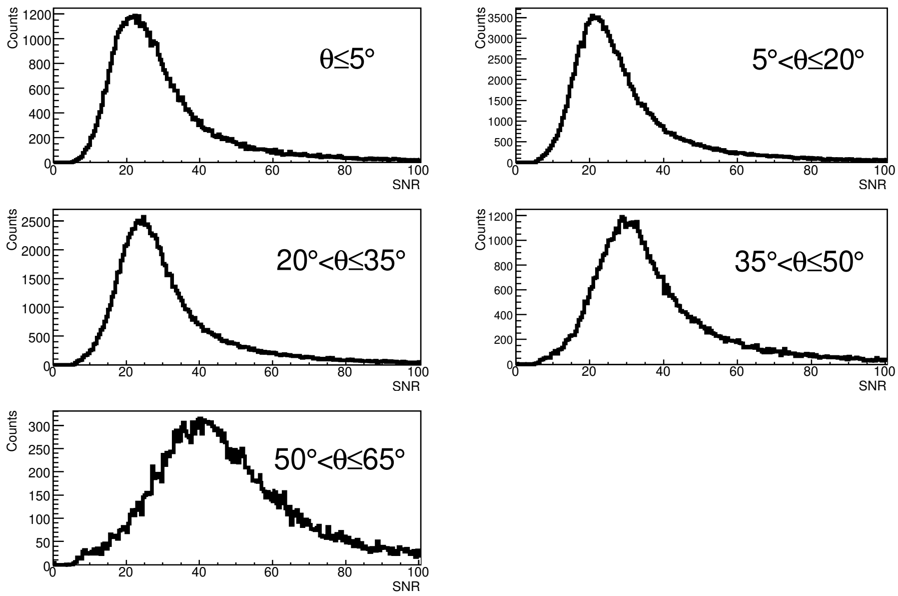

Fig. 12. *On-ground configuration: SNR with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.*

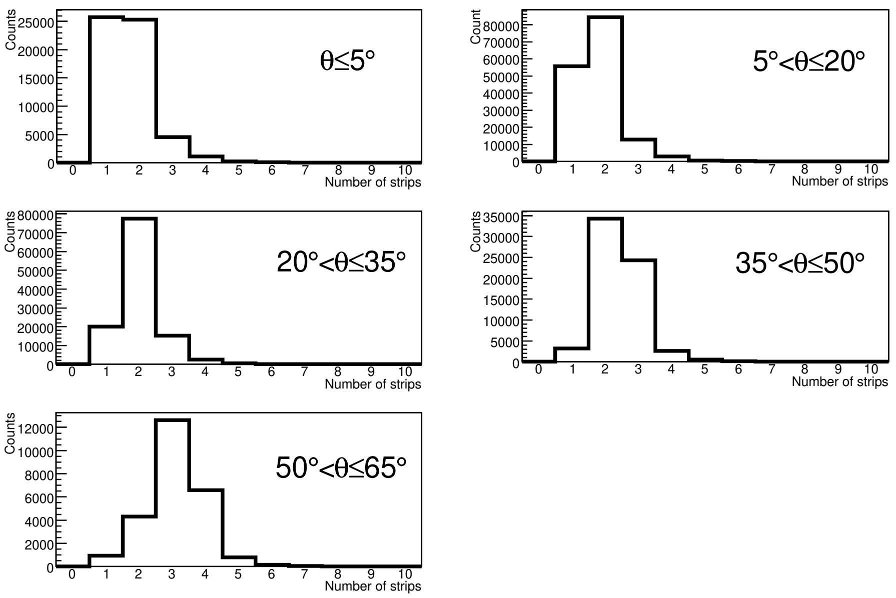

Fig. 13. *On-ground configuration: total width of the clusters with the FTB threshold set to 7 and strip mask ID 6 in physical calibration mode for GRID events with different incidence angles θ. Data acquired on RUNID 11119; the plots contain the data from all the ST planes.*

over more strips for large inclinations. **Considering all inclinations** the most probable value is about 630 ADC counts; this means that the conversion factor between C_3 **(ADC counts)** and MIP signal is about 0.174 keV / ADC

count.
Figure 11 shows the pull for different incidence angles **of** GRID events.
Figure 12 shows the SNR for different incidence angles and Figure 13 the total width of the clusters. This Figure demonstrates clearly why only 5 strips have been sent to telemetry.

9 The threshold scan during the in-flight configuration

During the in-flight configuration performed in the commissioning phase in May-June 2007 a scan of the FTB thresholds with the definition of new strip masks has been performed. The Silicon Tracker has been switched on the first time after the launch with a FTB threshold set to 20; the tests reported in Table 2 and Table 3 have been carried out after a verification that everything was working correctly.

Figures 14-17 report the on-axis pull for 3 values of the threshold (20, 6 and 5) and for the chosen final configuration (FTB threshold set to 6 and strip mask definition identified as configuration 8).

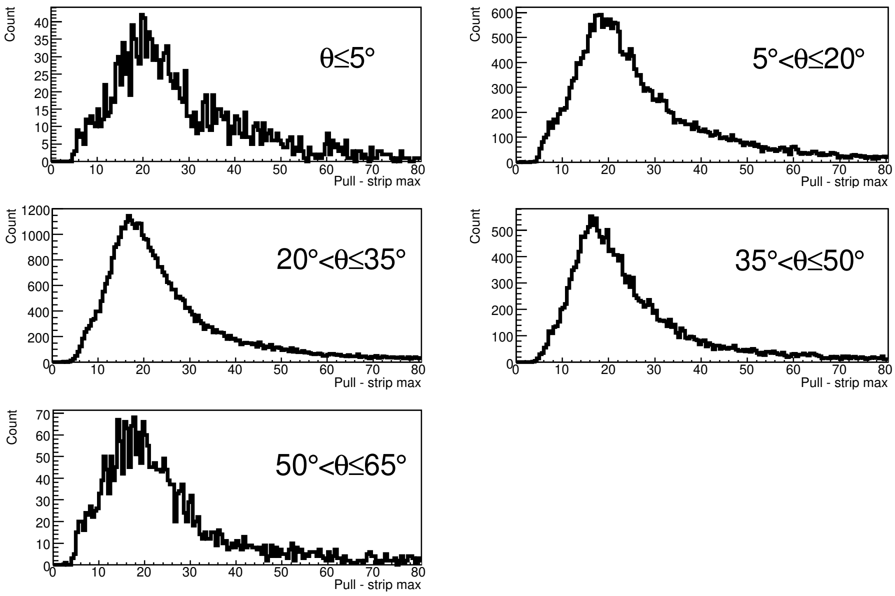

Fig. 14. *In-flight configuration: pull with the threshold set to 20 and strip mask ID 6 in physical calibration mode (data acquired with orbit 253) for GRID events with different incidence angles θ. The plots contain the data from all the ST planes.*

Table 2 reports the noise and efficiency indicators in physical calibration mode and Table 3 in observation mode.

Figure 14 shows the pull of the first in-flight switch-on of the Silicon Tracker after the launch with the FTB threshold set to 20; as expected, the peak of

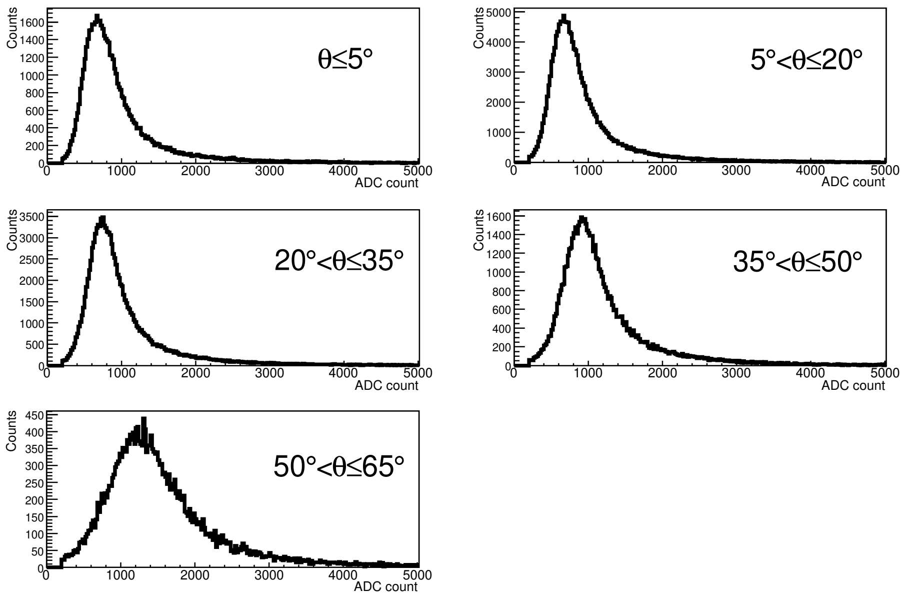

Fig. 15. *In-flight configuration: pull with threshold set to 6 and strip mask ID 6 in physical calibration mode (data acquired with orbit 510) for GRID events with different incidence angles θ. The plots contain the data from all the ST planes.*

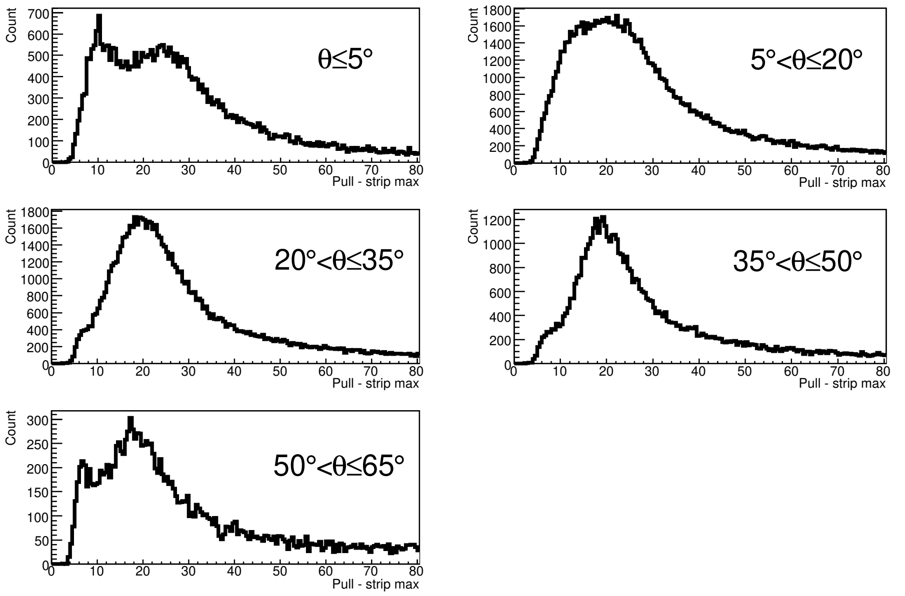

Fig. 16. *In-flight configuration: pull with threshold set to 5 and strip mask ID 7 in physical calibration mode (data acquired with orbit 522) for GRID events with different incidence angles θ. The plots contain the data from all the ST planes.*

the floating strip is not present, but this Figure, together with the additional parameters of the orbit 253 reported in Table 2 has proven that everything worked well after the launch.
Figure 15 reports a test in physical calibration mode with the FTB thresholds set to 6 and the same strip mask defined with the on-ground configuration.

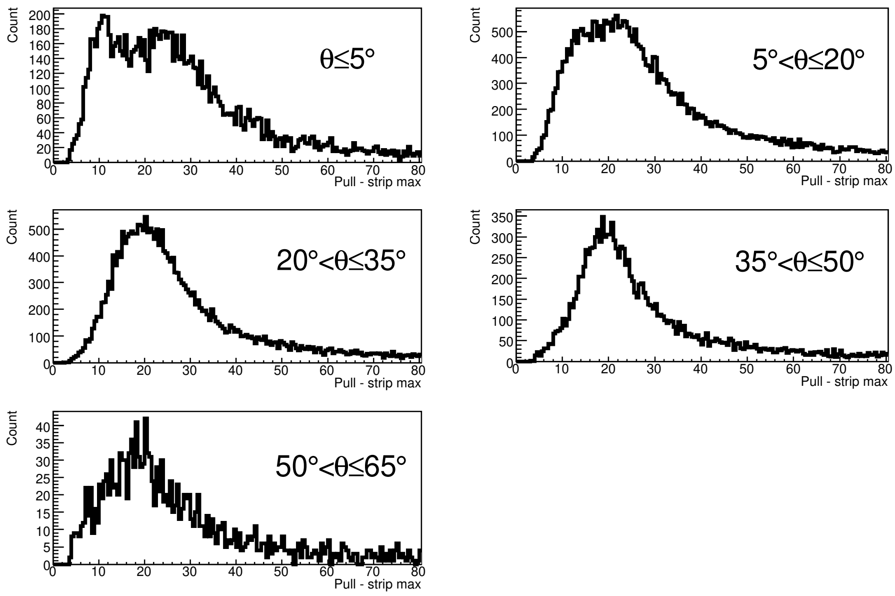

Fig. 17. *In-flight configuration: pull with threshold set to 6 and strip mask ID 8 in physical calibration mode and final strip mask configuration (data acquired with orbit 535) for GRID events with different incidence angles θ. The plots contain the data from all the ST planes.*

Table 2

On-ground (first row) test performed at the end of AIV activities and in-flight test performed during the commissioning phase in May-June 2007 (see Table 1 for a definition of the strip mask identifier): comparative table for GRID physical calibration mode. The orbit 535 has the same configuration of orbit 536.

Orbit	**FTB Thr**	**Mask ID**	**Pull X/Z**	**% event < 3 cl**	**% C_3 < 100 ADC**	**Eff. X**	**Eff. Z**
RUN 11119	7	6	16.7/16.2 ± 0.2	1.0%	0.0%	95 ± 2%	97 ± 2%
253	20	6	16.7/16.7 ± 0.3	1.5%	0.2%	80 ± 3%	83 ± 2%
510	6	6	18.1/17.4 ± 0.1	5.0%	2.5%	96 ± 1%	97 ± 1%
522	5	7	17.0/17.4 ± 0.2	7.5%	2.5%	96 ± 2%	97 ± 1%
536	6	8	17.2/17.2 ± 0.2	7.0%	2.0%	96 ± 2%	98 ± 2%

It is possible to see that with respect to the data acquired on-ground (see Figure 11) an additional noise peak was present (last plot) in events with an **incidence angle** greater than 50°: this means that for the higher **incidence angle** events **a larger fraction of** clusters due to noise are recorded,

Table 3

In-flight test performed in GRID observation mode during the commissioning phase in May-June 2007 (see Table 1 for a definition of the strip mask identifier): comparative table.

Orbit	**FTB Thr**	**Mask ID**	**Pull X/Z**	% **extra fired**	% $C_3 <$ **100 ADC**	**Eff. X**	**Eff. Z**
494	20	6	17.9/17.4 $\pm$ 0.2	1.0%	1.0%	84 $\pm$ 3%	88 $\pm$ 3%
495	10	6	17.8/17.0 $\pm$ 0.3	2.0%	1.0%	92 $\pm$ 2%	93 $\pm$ 2%
507	7	6	17.8/17.0 $\pm$ 0.1	6.5%	1.0%	94 $\pm$ 2%	95 $\pm$ 2%
509	6	6	17.8/17.0 $\pm$ 0.2	10.0%	2.0%	95 $\pm$ 3%	95 $\pm$ 3%
520	6	7	17.7/17.0 $\pm$ 0.2	6.6%	2.0%	94 $\pm$ 2%	95 $\pm$ 1%
523	5	8	18.2/17.0 $\pm$ 0.3	11.0%	1.5%	96 $\pm$ 2%	95 $\pm$ 1%
538	6	8	17.5/17.0 $\pm$ 0.2	8.0%	1.0%	96 $\pm$ 2%	95 $\pm$ 1%

a characteristic present only after the launch with this strip mask configuration; for highly **incidence angle** events the noise peak becomes relatively more important with respect to the bulk of particle clusters (because they are less) and thus it can be easily identified. To reduce this problem a new strip mask (called 7) has been defined and new tests with the orbit 522 have been performed (see Figure 16 and Table 2). Due to the time constraint of the commissioning phase, also a test with the FTB threshold set to 5 has been performed in the same orbit.
The final configuration has been reached with orbits 535-536 (see Figure 17 and Table 2). For a better stability of the system during the nominal phase a threshold of 6 has been chosen with the strip mask indicated with 8 with 665 disabled strips corresponding to 1.8% of the overall Silicon Tracker channels. A test in the GRID observation mode has been performed with the same configuration used in the physical calibration mode. The main results are reported in Table 3.

It is important to note the progressive trend towards improving of the in-flight ST configuration. In particular, the quite high values of the overall ST detection and trigger efficiency (95-96 %) have to be underlined. Considering the peculiar AGILE ST working and readout system based on analog signals, these **high efficiencies** are very important for an optimal scientific performance of the instrument.

10 Conclusions

This paper presents the main results of the extensive testing campaigns of the AGILE Silicon Tracker electronic configuration. The ST has been configured in different steps, and **it** reached an optimal performance during the pre-launch and post-launch tests. After almost 2 years of in-orbit operations the ST configuration that was consolidated during the commissioning phase is quite stable. Additional noisy strips (about 20) have been identified during the day-by-day data observations **in** the first 2 years with a negligible effect on the overall performance. The AGILE Silicon Tracker, that is the heart of the instrument, is then optimally configured and its digital readout system is remarkably stable for scientific observations in space.

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