Scientific performance evaluation of the PICsIT qualification model of the IBIS telescope

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ABSTRACT

IBIS is the imaging telescope onboard the ESA satellite INTEGRAL. IBIS will produce images of the gamma-ray sky in the region between 15 keV and 10 MeV by means of a position sensitive detection plane coupled with a coded aperture mask. The detection plane comprises two position sensitive layers: ISGRI and PICsIT. PICsIT is a 64x64 unit array of ~ 0.75 cm^2 crystals operating in the energy range between 150 keV and 10 MeV, arranged as 8 modules of 512 pixels. The PICsIT Qualification Model consists of one module and is therefore fully representative of the scientific performances of the flight model in terms of gain, linearity, lower energy threshold and energy resolution. The performances evaluated from the analysis of the module calibration data are presented.

Keyword: CsI(Tl) crystals, Scintillators Position sensitive detectors

1. INTRODUCTION

The International Gamma-Ray Astrophysics Laboratory (INTEGRAL)[1] is the gamma-ray observatory that the European Space Agency has scheduled for launch in October 2001. The Imager on Board the INTEGRAL Satellite (IBIS) instrument is the telescope devoted to creating images of the high-energy sky, and will achieve an angular resolution of 12 arcmin. Its design is based on the use of a tungsten coded mask situated 3.25 meters above a position sensitive detection plane. The image is obtained from the convolution of the shadowgram (consisting of many superimposed shadows of the mask cast by all sources in the field of view) recorded by the detector with the transmission function of the mask.

To achieve a broad energy range, 15 - 10.000 keV, the detector is built as two superimposed layers, each using a different detection technique: the upper, ISGRI[2] (Integral Soft Gamma-Ray Imager), consists of 16,384 CdTe micro-spectrometers of 4x4 mm in area and 2 mm thickness while the lower, PICsIT[3] (Pixelated Imaging CsI Telescope), is made from 4096 CsI(Tl) scintillating crystals with PIN photodiodes read out. Both planes are realised as a group of 8 identical modules so as to provide a high degree of modularity and a robust mechanical design. A modular veto system built from BGO slabs[4] actively shields both layers at the bottom and the four lateral sides. A thin passive lead collimator extends the ISGRI shielding from the diffuse background up to 300 keV, in the direction of the mask. Finally a tagged calibration ^{22}Na source is placed at ~1.9 m above the detectors. The IBIS detector Qualification Modules (QM) have been constructed and tested. Here the preliminary results from the PICsIT QM are reported.

2. PICsIT QM DESCRIPTION

The PICsIT detection plane consists of 8 identical and autonomous modules assembled on the IBIS mechanical frame. Each module receives its independent power supply and Tele-Commands and delivers scientific data and House-Keeping to a circuit common to the whole PICsIT layer that sorts the data from all the modules and interface PICsIT to the IBIS Data Handling System.

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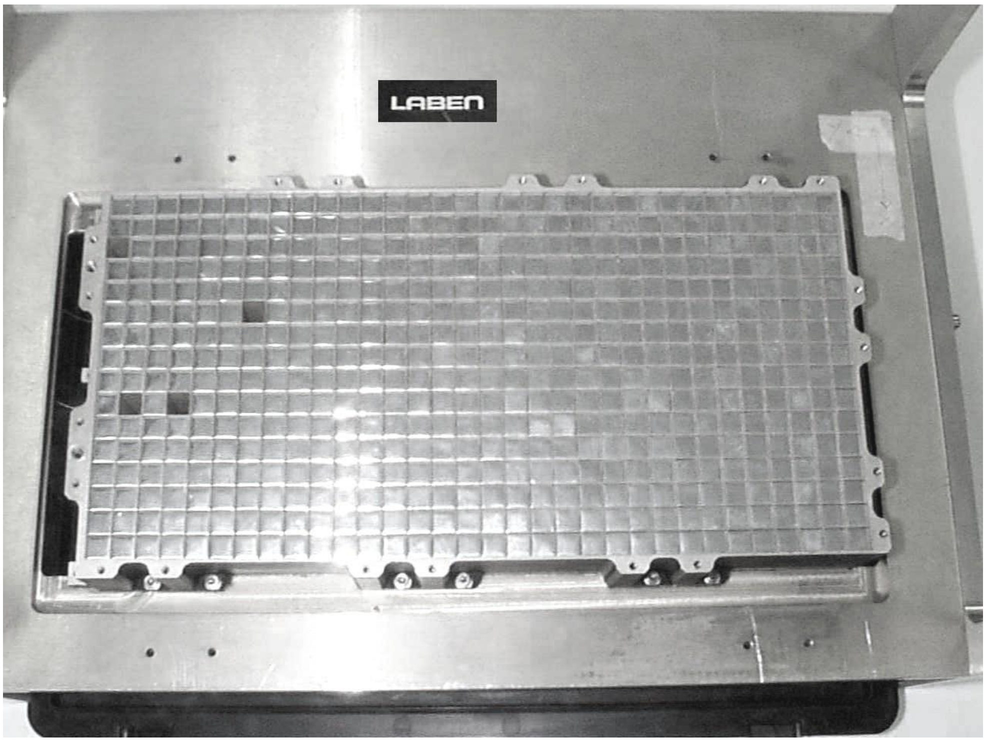

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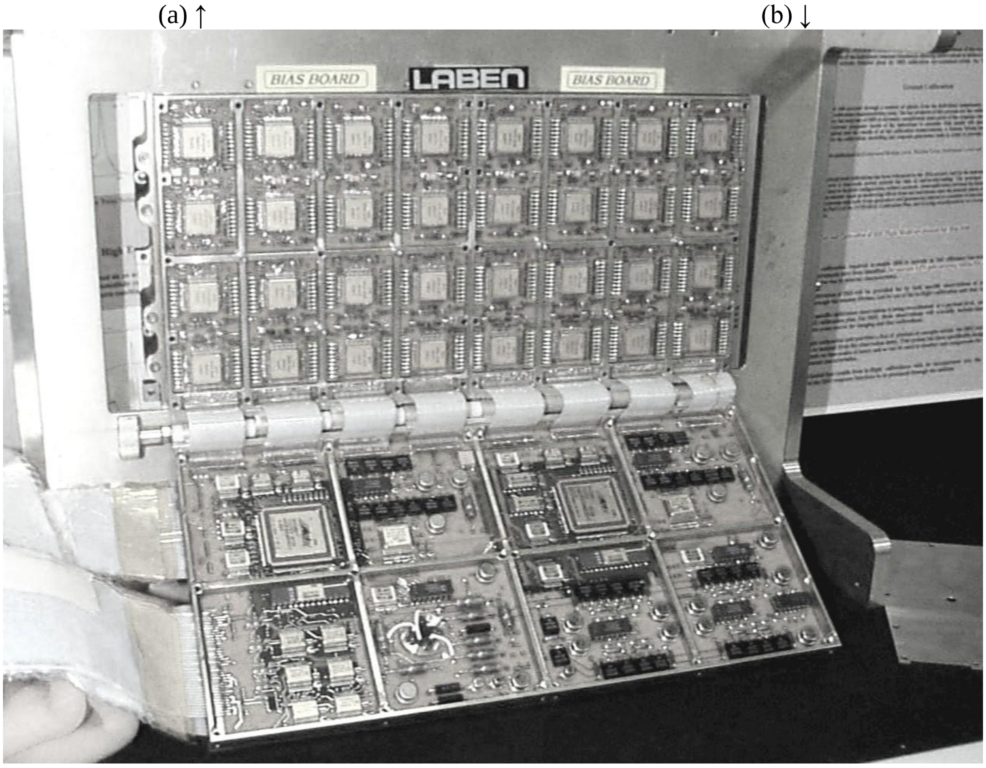

Fig 1. The PICsIT QM module.

a) Top view: crystal side before top plate assembly , 4 of the positions have been left intentionally empty.

b) Bottom view: front end electronics side. The AFEE with its 32 ASICs is on the vertical side. In the final assembly, module and boards are stacked together to form a very compact structure

Each module (Fig. 1), consists of:

- a mechanical frame that allows the precise positioning of the pixels,
- 512 scintillator crystals with PhotoDiode (PD) read out, the dimensions of each crystal being 8.6 x 8.6 x 30 mm
- an Analog Front End Electronics (AFEE) board; the AFEE mounts 32 Application Specific Integrated Circuits (ASIC) each one connected to 16 PD and are in charge of signal processing i.e. identification of the pixels triggered by a gamma ray detection, followed by signal amplification, filtering and holding of signal amplitude.
- a Digital Front End Electronics (DFEE) board that converts the data to digital form. A module contains two Analog to Digital Converters each one serving 256 pixels. The scientific data stream contains the pixel address, the signal amplitude and the time of occurrence referred to an internal clock of each event. Events that occur within a 2 μsec time window are considered coincident. When the coincident events are <= 3 all the events are converted assigning to them the same time. If the coincident events are > 3 just three of these events are converted, and marked for successive discard. The module House-Keeping data are also produced by the DFEE.

The PICsIT qualification module is fully representative of a flight module as described above, but with 4 of the 512 pixels lacking the CsI crystal (i.e. with just the PhotoDiode). This is in order to evaluate parameters which are difficult to measure with the crystal present, such as electronic noise.

3. PICsIT QM ASSEMBLY PROCEDURE

The PICsIT QM module activity was also the occasion to test and practice the procedures to be used during the assembly and test of the Flight Modules. The overall PICsIT plane has to fulfil constraints imposed by the requirements of the whole IBIS instrument which can be summarised as:

- scientific performances, such as energy range and energy resolution,
- pixel uniformity over the whole plane.

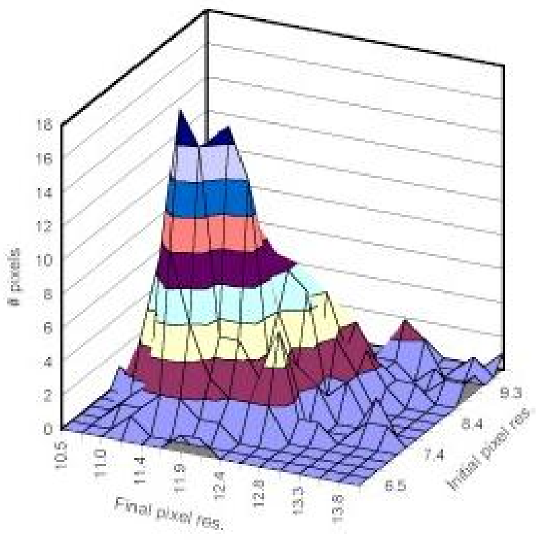

Fig 2 Comparison between the Pixels (Crystal plus PD) energy resolution FWHM @ 661keV evaluated before integration in the module with a low noise test equipment and after integration in the module with the final Front End Electronics. The relation between the two evaluations is evident showing that little or no degradation of the pixels is introduced by the assembly procedure.

All the main parameters of the detector[5] can be depend on the quality of the signal produced from each individual pixel, the pixel (i.e. both crystal and PD) , and the noise level of each ASIC channel chain, therefore the assembly procedure foresees a characterisation of each single pixel detector and of each single ASIC electronic channel before integration in the module.

The main parameters measured of all the channel of all the ASIC are gain, noise, time jitter of the self trigger; the data being evaluated with the ASIC connected to devices electrically representative of the PD.

The behaviour of each pixel was evaluated by measuring the signal, in charge, generated by gamma rays of known energy (the 661 keV of ^{137}Cs) and the width of the peak of the same source. These tests were done with dedicated test equipment whose front end electronics exhibits a noise figure lower than that of the ASIC, and were repeated at various times during the module assembly process:

- A first time after the process of crystal cutting, PD gluing and wrapping with diffusive material. Only the pixels exhibiting a signal level greater than 31 e^-/keV being used for integration.
- After pixel insertion into the mechanical frame of the module and before AFEE connection; the pixel that showed any performance degradation were removed and substituted.

Using the module electronic chain at the end of the assembly process the pixel performances were again evaluated in the final configuration. In Fig. 2 is shown a comparison on one of the data of main interest: the relation between the energy resolution (% FWHM at 661 keV) before pixel insertion in the frame and the final resolution achieved at the end of the assembly process.

4. PICsIT QM PERFORMANCES.

The aim of PICsIT qualification campaign is the characterisation of the QM in terms of functionality and performance. This characterisation was performed at the beginning of the campaign as well as during and after a series of environmental tests that include a thermo-vacuum and a vibration cycle. Only the initial characterisation of the module is reported here as the environmental tests are still on-going at the moment of writing. The PICsIT QM was exposed to a series of radioactive sources and background. The non-collimated sources were placed, one at a time, at a distance of about 40 cm from the top of the module. Table 1 reports some of the source characteristics as well as the total exposure times for the first module characterisation step.

Nuclide and half live	Energy (keV) of main Photon emitted	Intensity (μCu)	Total exposure time (sec) and (number of exposures)
^{203}Hg 46.6 days	279.2	10	7.250 (3)
^{137}Cs 30.0 years	661.7	10	23.400 (13)
^{88}Y 106.7 days	898.0 1836.1	10	41.600 (23)
Bkg			15.800 (6)

Table 1 Measurements performed during the calibration of PICsIT QM

The data from each exposure, recorded on the test equipment, contains all kinds of events:

- Single events i.e. when an energy deposit was recorded in just in one pixel
- Double and triple events i.e. when respectively two and three energy deposit are recorded with the same time (coincidence window of 2 μsec) in one semi-module corresponding to the 256 pixels with the same logic and ADC.
- Greater than three events recorded when more than three events occurs in the coincidence window in one semi-module.

Events that leave an energy deposit in more than one pixel but in the two different semi-modules are not recognised as multiple events but discarded. A simple image of the modules spectral behaviour is shown in Fig. 3 where are reported all

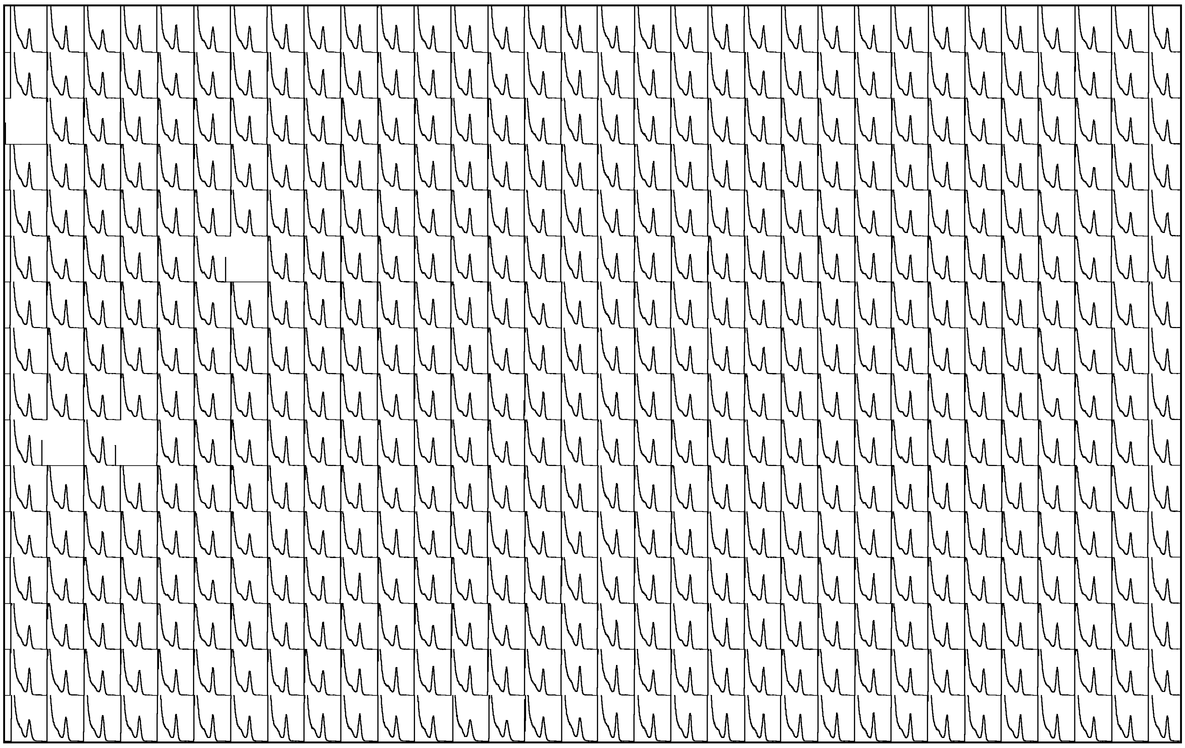

Fig. 3 Spectra of an uncollimated ^{137}Cs source recorded from each pixel. In each spectra the abscissa is keV while the ordinate is number of counts. The four pixels showing no spectra are those where the CsI(Tl) crystal not assembled.

the single event spectra recorded by every pixel constructed by summing all the exposures with the ^{137}Cs source. All the spectra have already been equalised.

The analysis software of the collected data has many task differentiated by the kind of event detected. The conversion from the raw data to physical quantities is performed with a linear equation; the two parameters, gain and offset, of each individual pixel are evaluated from the peak position in the single events spectra obtained with the various calibration sources. Pixel performances such as resolution and threshold are then evaluated.

Fig 4 shows the spread in the ^{137}Cs spectra (no background subtracted) of all 508 pixel in the QM and the sum of all pixel spectra with single event before and after equalisation of the pixel has been applied. The feature in the region around the 200 keV is due to source photons Compton backscattered by the passive material around the module.

After pixel equalisation, the spread of the gain and offset and of the energy resolution % FWHM at 661 keV is depicted in Fig. 5. The mean resolution is 11.8 % with a sigma of 1.65.

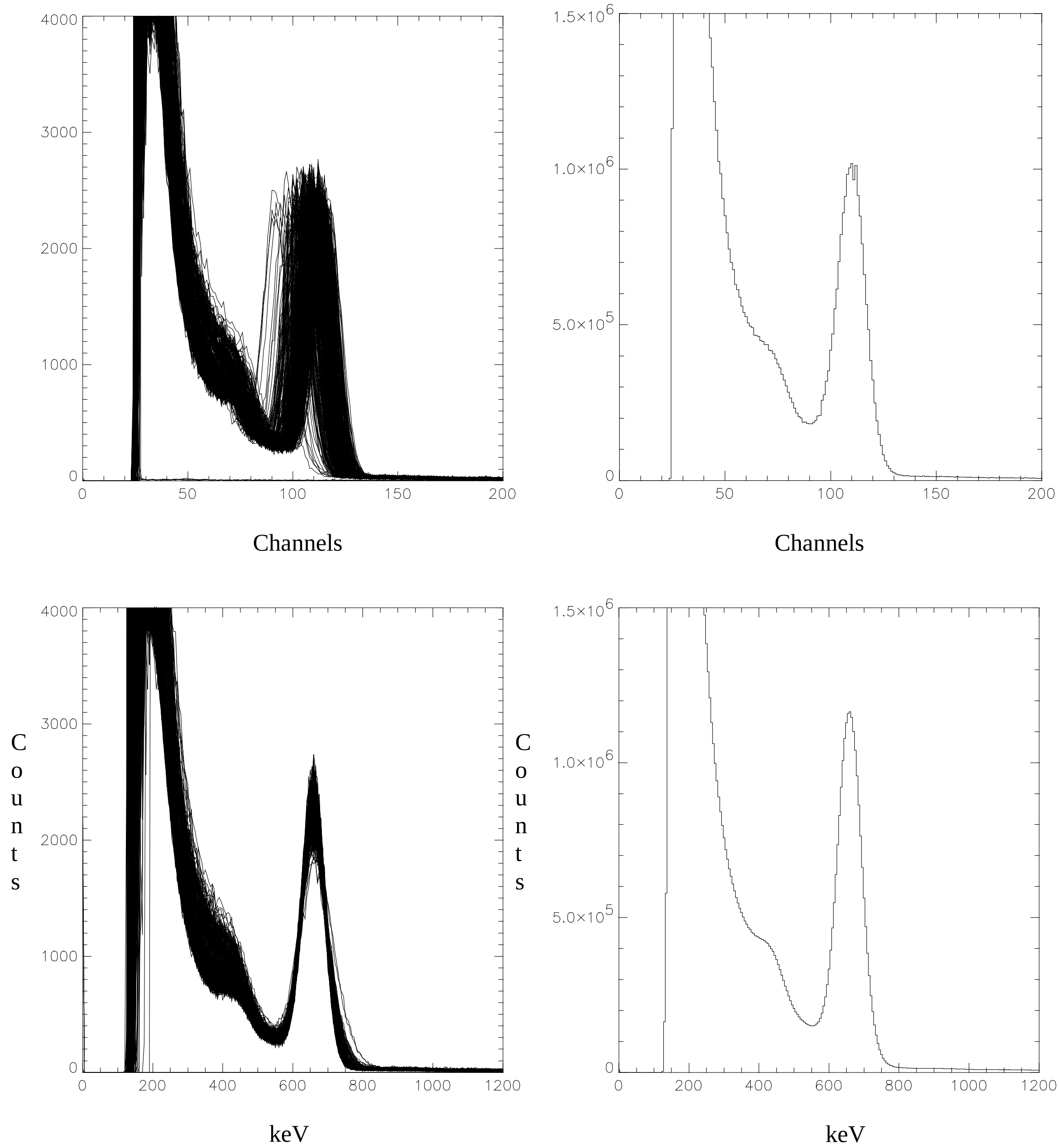

Fig. 4 Spectra of the ^{137}Cs source. On the left column the data of all the pixel are superimposed while on the right column the data of all the pixels are summed.
The top spectra are before gain equalisation of the pixels. The sum spectra exhibits an energy resolution for the 661 peak of 13.9 % FWHM. The bottom spectra are after the gain equalisation, where the energy resolution for the same peak is 11.8% FWHM.

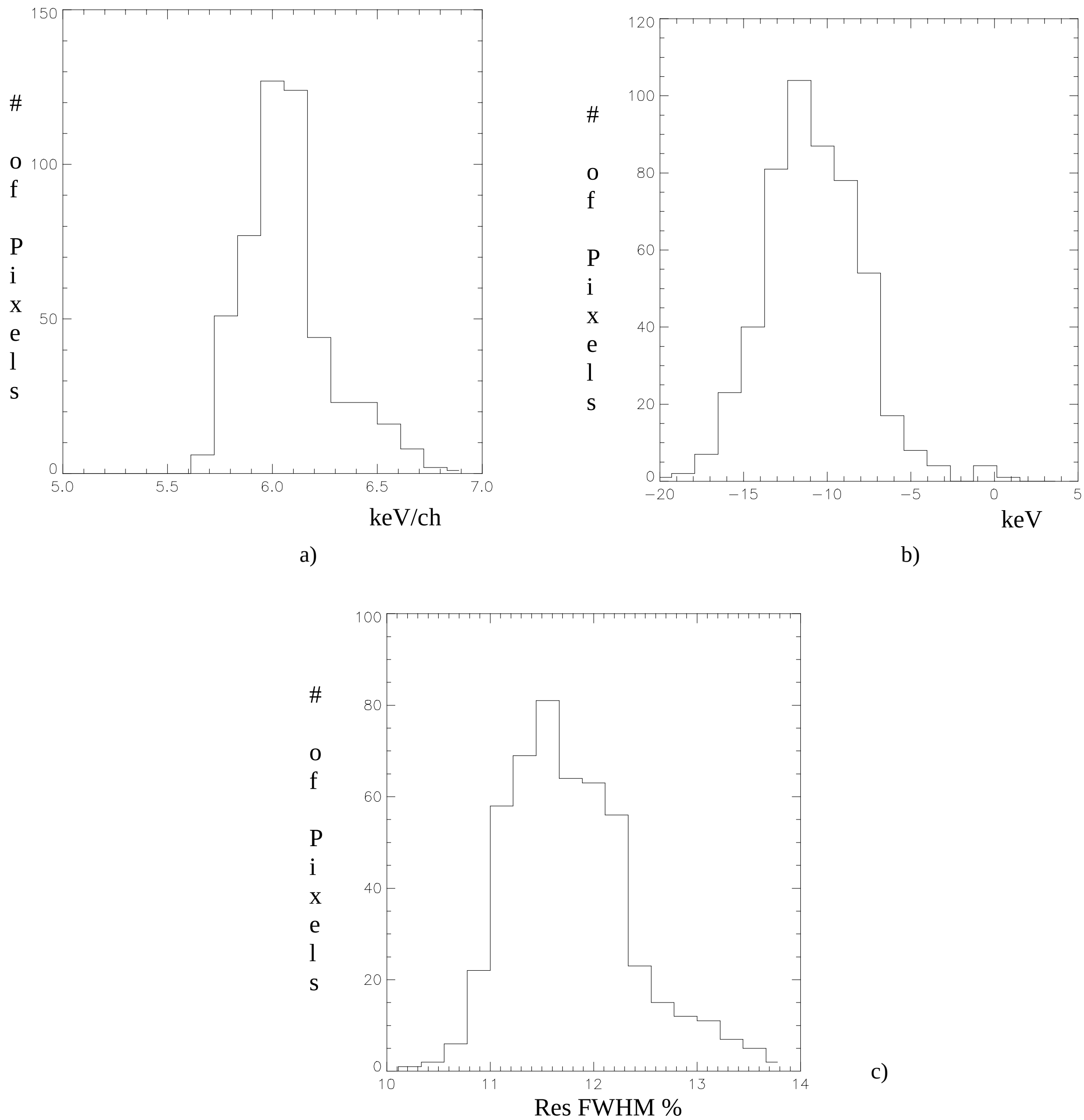

Fig. 5 Frequency distribution of some pixel parameters.

a) Gain , the mean value is 6.1 keV/channel with a sigma of 0.35
b) Offset, the mean value is –10.1 keV with a sigma of 8.6
c) Resolution FWHM @ 661 keV, the mean value is 11.8% with a sigma of 1.65.

For what concerns multiple events, double and triple, the energy is evaluated by just summing the energies of all primary events while the identification of the pixel where the primary photon has interacted is performed in the following manner, which has been shown to be statistically accurate at the $$ % level. For double events where Ei and Ek is the energy released in the pixels Pi and Pk the energy the events is considered having energy E occuring in the pixel P.

$E = E_i + E_k$

$P = P_i \quad \text{IF } E_i < E_k \text{ AND } E < 1\text{ MeV} \qquad P = P_i \quad \text{IF } E_i > E_k \text{ AND } E > 1\text{ MeV}$

For triple events where Ei , Eh, Ek is the energy released in the pixels Pi, Ph, Pk the energy the events is considered having energy E occuring in the pixel P

E = Ei + Eh + Ek
P = Pi IF Ei < E_k, Eh AND E < 1 MeV P = Pi IF Ei > Ek, Eh AND E > 1 MeV

Fig.6 shows the energy spectra of events produced by the ^{137}Cs source and marked as double before and after energy reconstruction summed on all the pixel after equalisation.

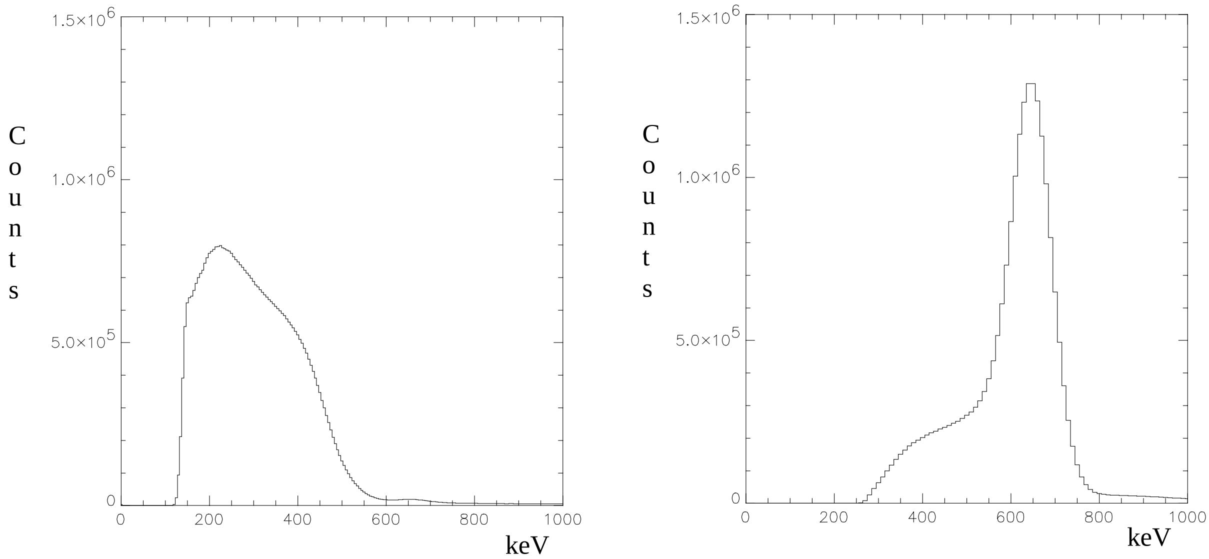

Fig. 6 Spectra of the double events produced by a ^{137}Cs source and summed for all the pixels. On the left is depicted the spectra produced by every energy deposit marked as double and that correspond to the Compton event. On the left is depicted the reconstructed spectra of the same events obtained summing, after equalisation, the energies released on the two involved pixels. The energy FWHM resolution achieved in this case for the 661 peak is 16.4 %.

5. PICsIT QM EVENT DISTRIBUTION.

The distribution of the position of events in PICsIT QM is both dependent from the kind of data observed and also on the logic criteria of the DFEE to mark single or multiple events. Fig. 7 shows the distribution of single and double events recorded with the ^{137}Cs source. The intensity of a pixel correspond to the number of counts recorded integrated on the overall spectra.

Single events show a minimum in the centre of the two semimodules; while the opposite behaviour is for double events. Such distributions are accounted for by the higher probability of Compton events, that produce multiple pixel energy deposit in the same semi-module, to be detected at centre module. The two semimodules have independent logical circuits to detect multiple events and that is clearly seen in the event distributions.

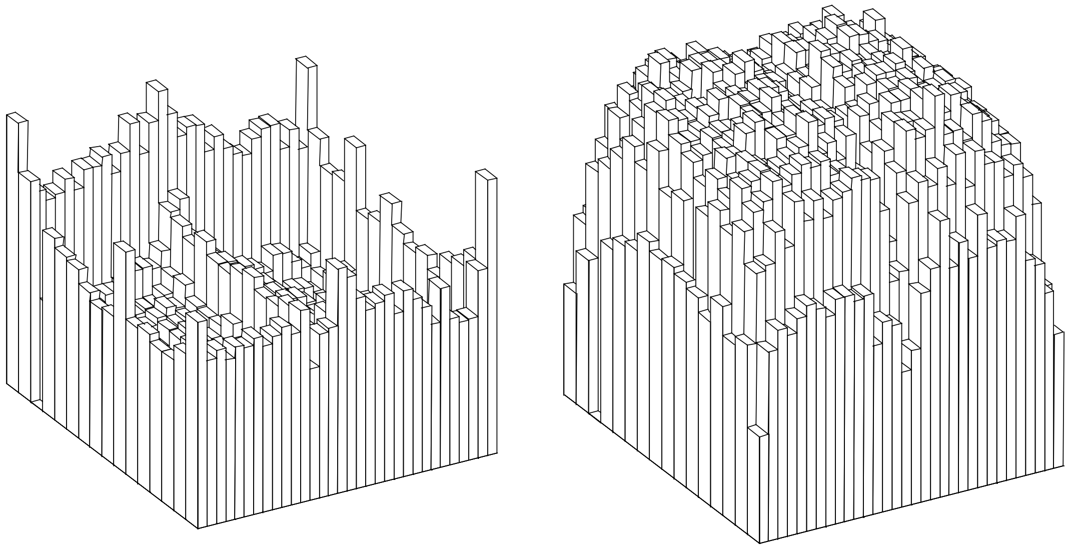

Fig. 7. The counts distribution over the two semi-modules of events produced by a ^{137}Cs source. On the left is the singles distribution and on the right the doubles distribution.

Finally to illustrate in a qualitative manner the imaging capabilities of the Module alone a Pb mask was built consisting of a 4 mm sheet with a pattern of thinner metal in the shape of the word PICsIT. The mask was put in front of the QM and illuminated with the ^{203}Hg source. The map of pixel events integrated under the photopeak is shown in Fig. 8

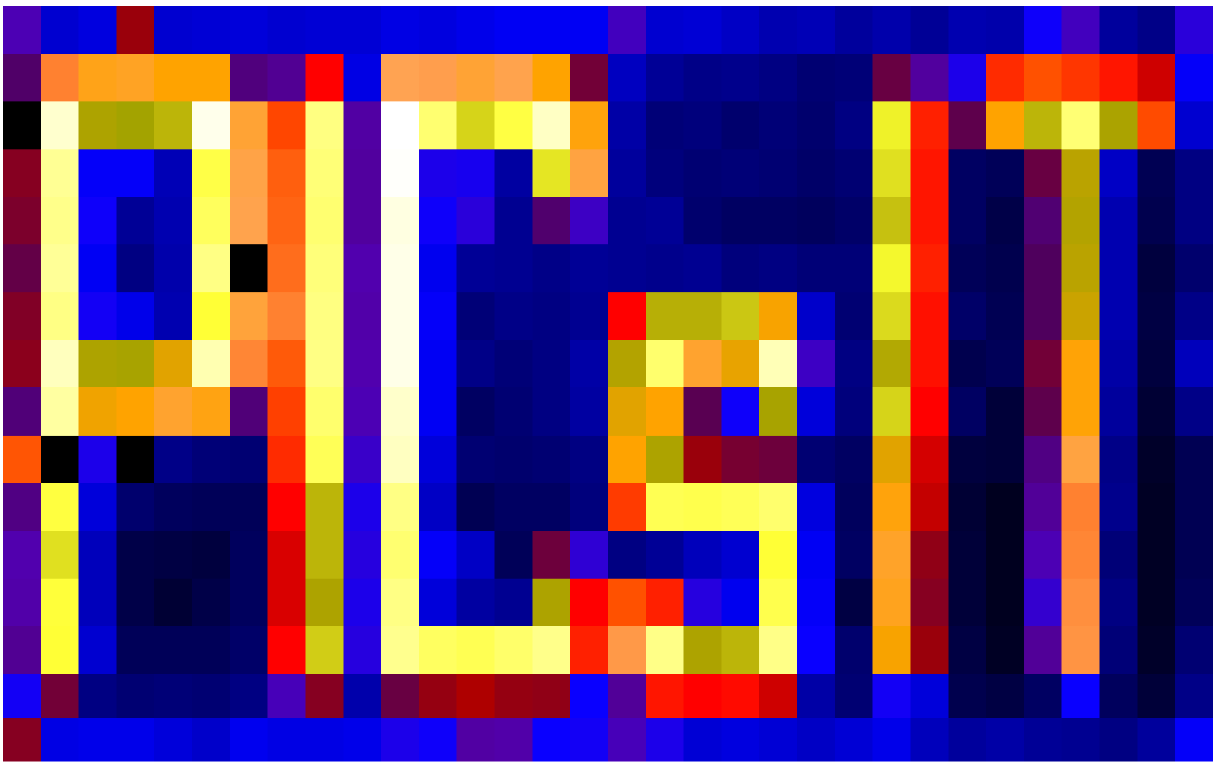

Fig. 8 Map of counts distribution, on a gray scale, on the module pixels of events produced by X-rays from a ^{203}Hg source seen throgh a Pb mask shaped with empty spaces to form the word PICsIT.

6. CONCLUSIONS

A complete PICsIT module has been tested with no major problems on its functional behaviour. The first results achieved show an average energy resolution FWHM @ 661 keV of 11.8 % and a threshold around 150 keV.

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