Displacement damage dose effects of protons in the X-ray detector (pnCCD) of the SVOM mission

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CONTEXT

SVOM (Space based Variable Object Monitor) is a Sino-French mission, dedicated to the study of the most luminous explosions in the Universe: gamma-ray bursts. It is due for launch early 2024, and among the four space borne instruments is the Micro-channel X-ray Telescope (MXT). This focussing X-ray telescope has for main goal to improve the localization of the celestial sources, as well as the timing and spectral characterization of the X-ray afterglows. Over the nominal mission, lasting 3 years, due to SAA crossing in a low-Earth orbit, MXT will suffer from irradiation, in particular proton irradiation. We predict the MXT performances over the mission lifetime by the full characterization of a partly irradiated detector flight model.

INTRODUCTION

Camera (M-CAM)

The MXT Camera implements the MXT focal plane, ensures the correct operation of the detector and pre-processes data in order to save only established X-ray events. The imaging area, based on a pn-CCD of 256 x 256 pixels, integrates events during 100 ms. The generated charges are then transferred to the frame-store area thanks to a parallel read-out, column by column.

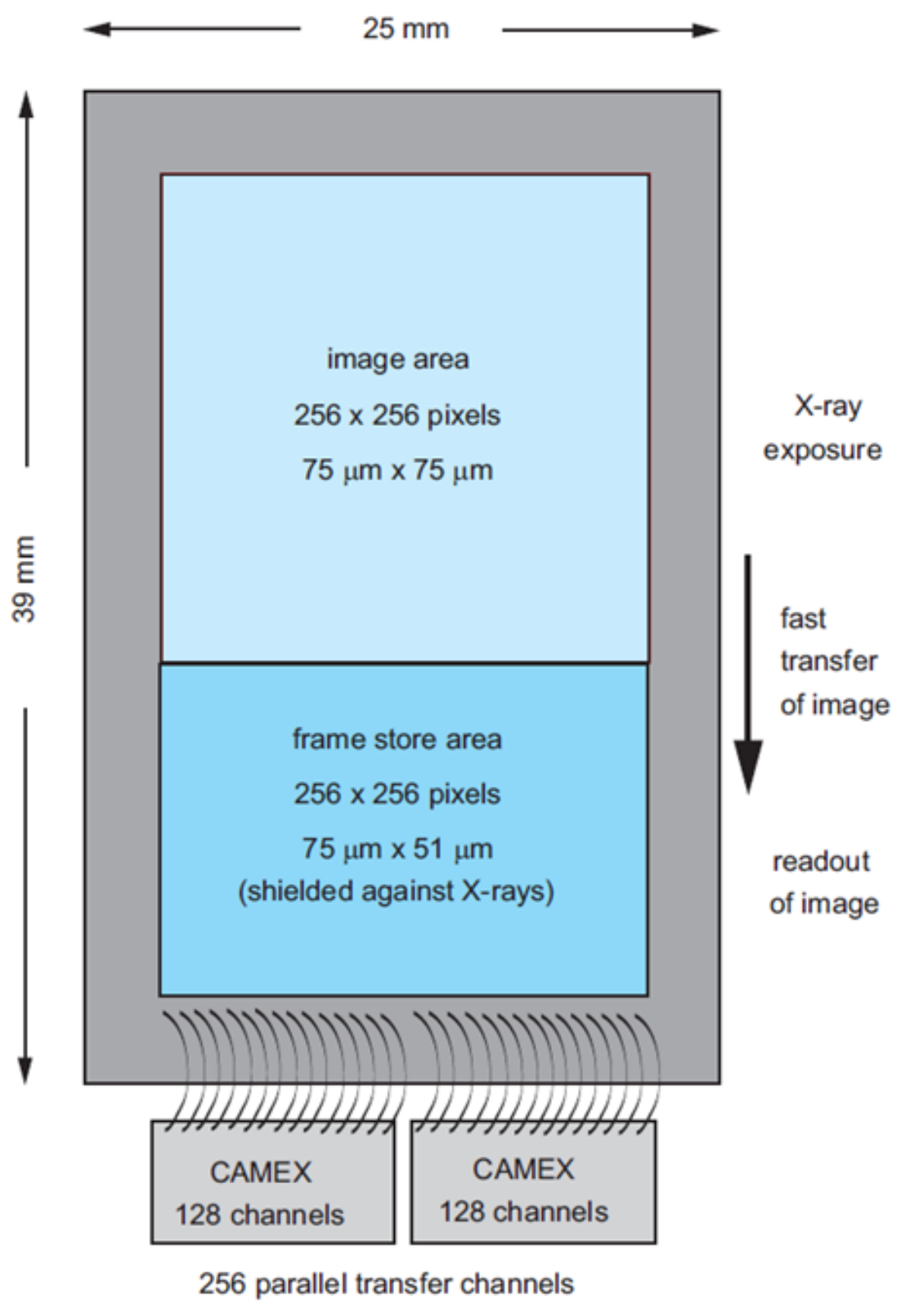

Fig 1: Front side schematic of the MXT detector assembly

Irradiation campaign

A flight spare model has been irradiated on half of its area at the Arronax facility. The detector and CAMEX were turned off and at room temperature. The proton dose was equivalent to the one expected over 3 years, that is a fluence of 50 MeV-equivalent 6.10^{9} protons/cm^{2} [F. Ceraudo PhD thesis](with a 2.10^{5} protons.s^{-1}.cm^{2} flux).

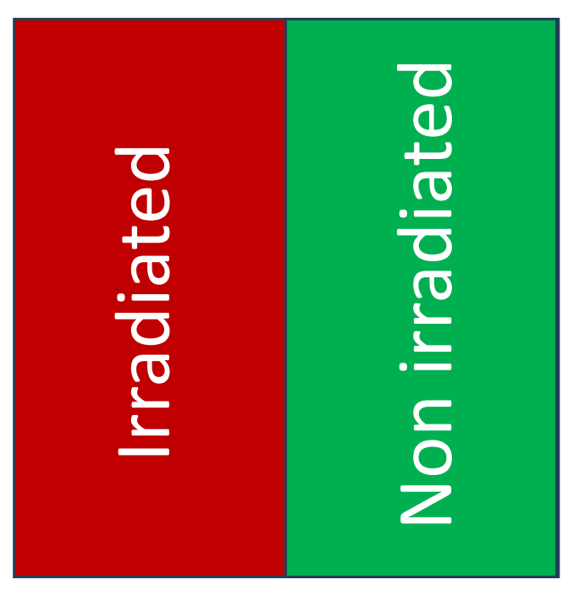

Fig 2: Representation of the detector image area after proton irradiation

Aim: full characterization of the irradiated detector to predict MXT performances over the lifetime of the mission

METHOD

Spectral characterization

Energetic protons hitting the detector matrix damage the silicon lattice, creating traps for the electrons. The global deterioration can be quantified thanks to the following detector intrinsic parameters:

- **Gain-offset:** the transfer function allows to recover the photon energy in eV from the Pulse Height Amplitude in ADU transmitted by the electrons. The linear assumption is valid and the energy calibration is column-wise.
- **CTI:** the Charge Transfer Inefficiency (CTI) quantifies the amount of charge lost during the transfer from one row to the next due to charge trapping. The total energy shift depends on the number of transfers *n*, i.e. the photon row position in the image.

$$\frac{\Delta E}{E} = CTE^{n}$$

with CTE the Charge Transfer Efficiency:

$$CTE = 1 - CTI$$

The CTI is derived by plotting the energy position of a given spectral line as a function of the number of transfers n.

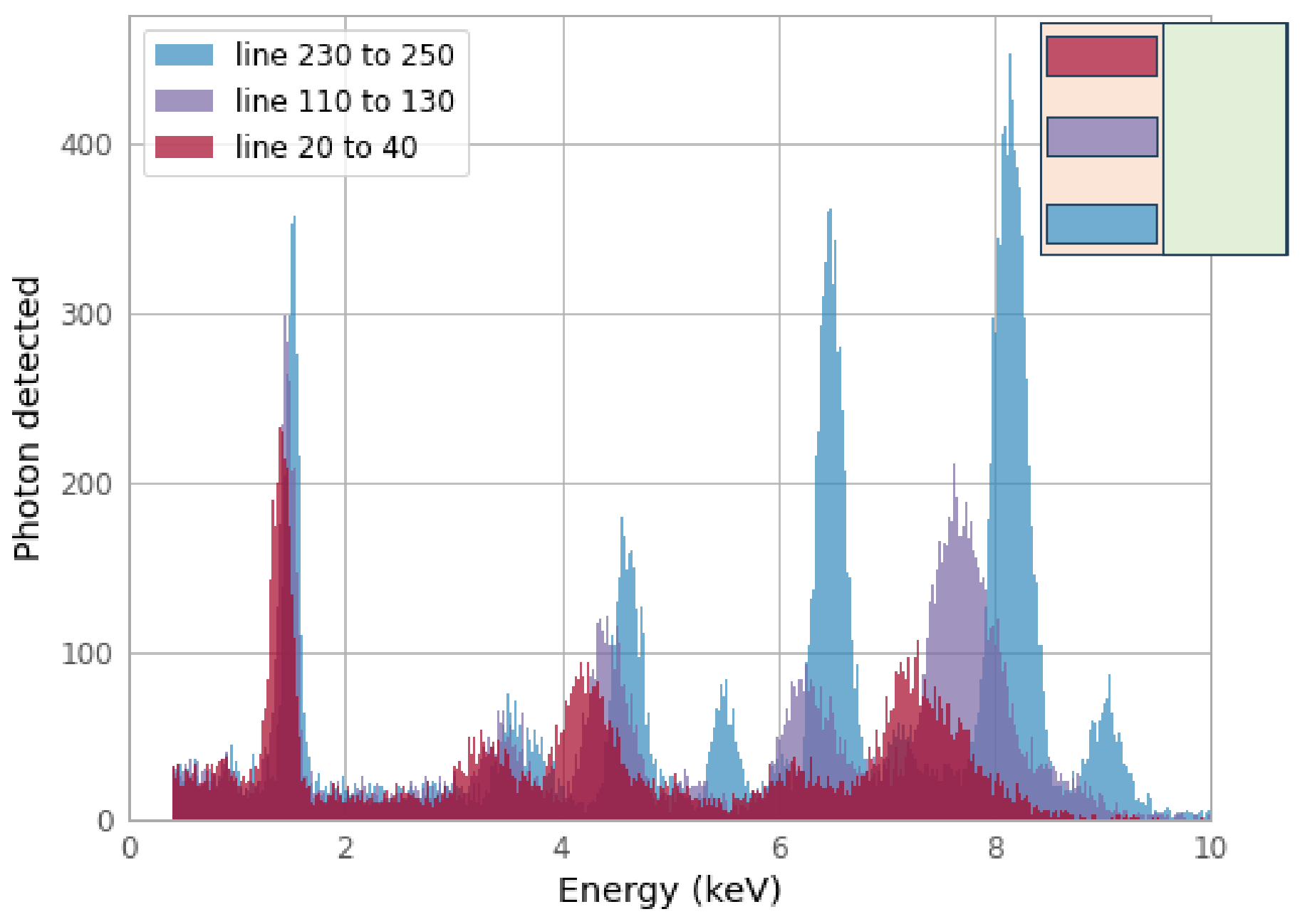

Fig 3: Spectra superposition for 3 detector areas to show the CTI effect

- **FWHM:** the Full Width at Half Maximum (FWHM) of the spectral lines defines the energy resolution of the detector.

These parameters have been extensively studied for the flight model detector (Götz et al. Exp. Astron. 2023). A 1.5 keV, the FWHM was measured to be 78 eV and CTI is 3.5 10^{-5}. For the performances after proton irradiation, preliminary studies reveal a CTI one order of magnitude larger, and a FWHM twice as important. To further infer on scientific capabilities, the CTI behaviour as a function of energy needs to be assessed in the new detector operating conditions, in order to adequately correct the energy.

Approach: complete spectral characterisation to obtain precise calibration, enabling FWHM measurements and thus a conjecture on scientific objectives.

Charge Transfer Inefficiency MODELING

We measured the CTI at 4 energies with the detector operating at -70°C. The results do not depend much on the temperature [-80°C, -60°C] and the voltage operating conditions. The centroids of the spectral lines are obtained with a gaussian fit on spectra grouped by 10 rows along the whole length of the image area.

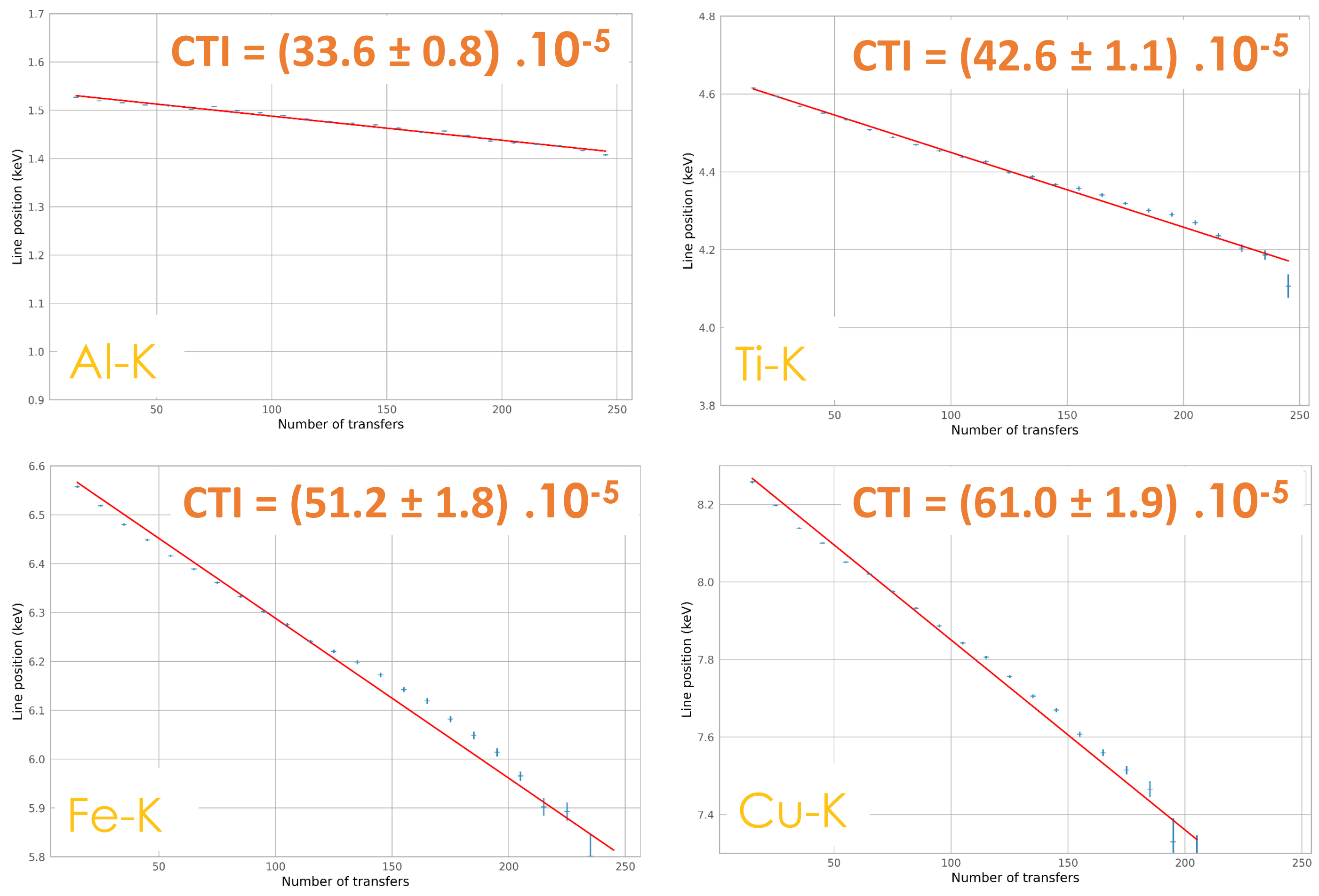

Fig 4: Line centroid position as a function of the number of transfer *n* for 3 energies to extract the CTI at each energy.

From these measurements, we derive the following model for CTI correction :

$$CTI(E) = 2.10^{-4} + 3.10^{-5} * E(keV)$$

RESULTS

CTI correction

After an initial energy calibration, the energy is corrected for each photon event impinging row *n* according in to the formula:

$$E' = \frac{E}{(1 - CTI(E))^{n}}$$

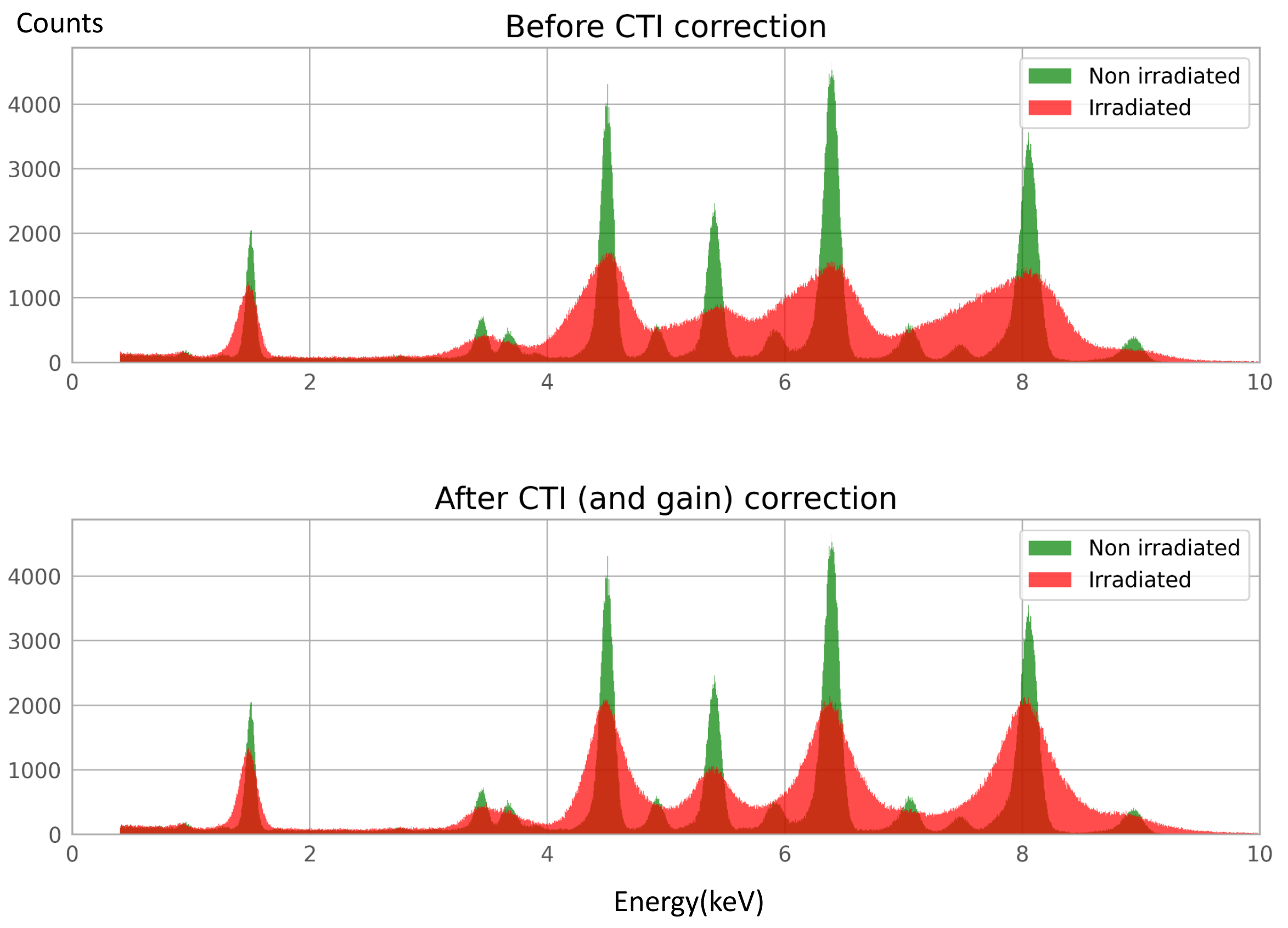

Fig 5: Highlight of the CTI correction on the irradiated detector

The initial gain computed before the CTI correction shall be slightly corrected in a final step.

Measured energy resolution

Table 1: FWHM results for both the irradiated and non irradiated parts of detector

Line	FWHM Irradiated (eV)	FWHM non irradiated (eV)
Al-K (1.486 keV)	166 ± 2	86 ± 1
Ti-K (4.509 kev)	249 ± 9	124 ± 1
Fe-K (6.395 keV)	296 ± 8	153 ± 1
Cu-K (8.040 keV)	352 ± 15	168 ± 2

CONCLUSIONS AND PERSPECTIVES

The degradation of the energy resolution is compliant with the mission requirement (80 eV beginning of life and 200 eV end of life at 1.5 keV).

Measurements in the X-ray metrology beamline of SOLEIL synchrotron should help consolidating the model of CTI versus energy in the main energy range of MXT (0.2- 2 keV).

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