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Twin-Shaping Filter Technique Applied to CZT Detectors

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***Abstract*– CdTe/CdZnTe is an attractive and consolidated material with which to realize detectors with good efficiency and energy resolution, operating at room temperature for a large variety of applications such as astrophysics, medical imaging and security.**

However, this type of material suffers from the low mobility of the charge carriers (particularly the holes), which are trapped and so degrade the detector response in terms of charge collection efficiency, energy resolution and photopeak efficiency. The response of a planar CdTe/CdZnTe detector, which depends on the distance between the charge formation position and the collecting electrodes, can be improved by using two kinds of techniques, based on the optimization of the electrode geometry and/or signal compensation methods.

We are studying the feasibility and the reliability of a bi-parametric method that uses a twin pulse shaping active filter to analyze each signal from the detector twice: one "Slow", which is proportional to the energy of the incident photon, and one "Fast", which depends on the position of the interaction with respect to the collecting electrode.

In this paper we describe the bi-parametric technique applied to planar CdZnTe detectors grown by CNR/IMEM and to Spectrometer Grade detectors. We report the experimental results in terms of energy resolution, peak-to valley ratio and photopeak efficiency, as well as the compensated spectra obtained as a function of the bias voltage, photon energy and shaping time pairs. We also report the results obtained by using a CdZnTe drift strip detector.

Furthermore, this technique could be implemented in an array of detectors, whose front-end electronics is composed of ASICs, where the shaping time can be selected for each channel, like the RENA-3 IC (NOVA R&D).

I. INTRODUCTION

CdZnTe is a semiconductor material with a high atomic number and high density well suited for realizing efficient and compact room temperature hard-*X* and γ-ray detectors covering the energy range from a few keV to the MeV region. The fields of application of these detectors are various, such as astrophysics, nuclear medicine and material safeguards.

The spectroscopic performance in terms of energy resolution depends strongly on the detector geometry and on the quality of the semiconductor material: the detector capacitance and the leakage current produced at room temperature by the sensor contribute to the total noise of the system. In addition to these factors, the trapping centers in the semiconductor produce a loss in charge collection efficiency because of the low mobility of the charge carriers (particularly the holes) degrading the CdZnTe detector response as it depends on the distance between the charge formation position and the collecting electrodes.

The degradation of the spectroscopic performances can be reduced by both using hardware (HW) and software (SW) techniques. The described bi-parametric method is based on a hybrid HW and SW technique by utilizing a double pulse shaping active filter in order to analyze the detector signals. Using this method we can have an indirect measurement of the interaction position of an incident photon in the detector active volume.

We present the bi-parametric distributions obtained with the application of this technique both on CdZnTe detectors grown by the vertical Bridgman method at CNR/IMEM and on CdZnTe Spectrometer Grade detectors from eV-Products as a function of the shaping time pair values, for different primary photon energies and bias voltages.

The detector performances have been evaluated at several energies with calibration radioactive sources and the charge transport properties have been studied by mobility-lifetime product measurements.

We also report the corrected maps and compensated spectra of both detectors and a preliminary analysis obtained by applying the dual shaping time technique to a CdZnTe drift strip detector provided by CNR/IMEM.

II. PRINCIPLE OF THE TWIN-SHAPING TIME METHOD

The twin-shaping time method here described can be considered as a particular case of the rise time technique based on the correlation between the rise time of a signal from the detector and the loss in its pulse due to incomplete charge collection.

The rise time technique is usually applied to improve the performance of planar semiconductor detectors.

The signal from the CSP (Charge Sensitive Preamplifier) coupled with the detector is shaped by two parallel shaper amplifiers with different shaping time constants: one "Fast" and one "Slow". The "Slow" component of the signal represents the integrated charge collected at the detector anode which is proportional to the total energy of the

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incoming photon, while the "Fast" value mainly depends on the position of the interaction with respect to the collecting electrode. The ratio between the two signals ($R = V_{Fast}/V_{Slow}$) is an indirect measurement of the interaction position between the collecting electrodes [1, 2]. The off-line analysis of both signal components permits us to recover the loss of the charge inside the crystal and, as a consequence, to reconstruct the energy of the primary photon.

III. EXPERIMENTAL SET-UP

In Fig. 1 the experimental set-up used for the bi-parametric data acquisition is illustrated.

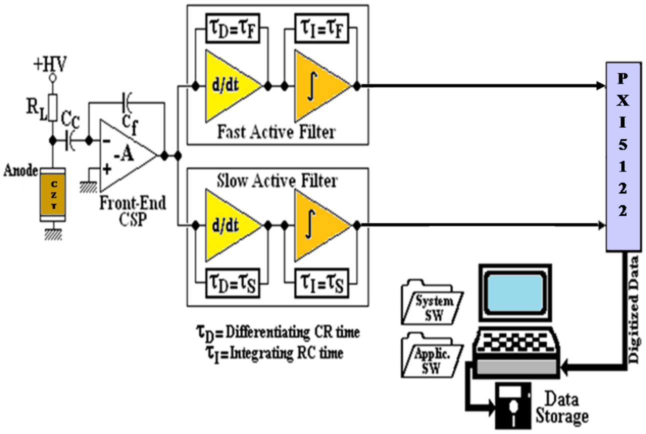
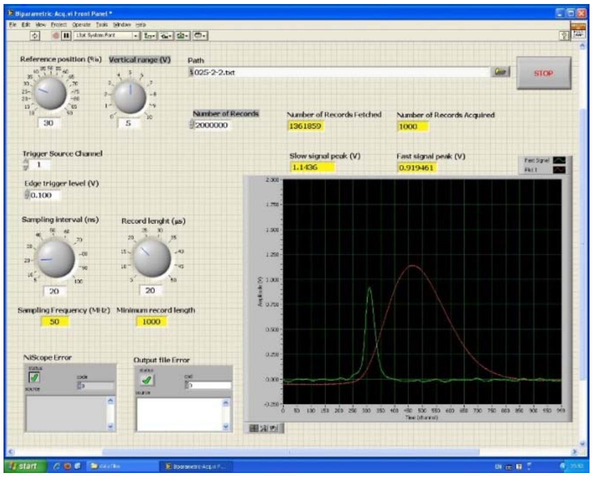


Fig. 1. Experimental set-up utilized for the bi-parametric data acquisition.

Through a decoupling capacitor, the anode pulses are coupled to a charge sensitive preamplifier (eV-5093) and then to the amplifiers, while the cathode is connected to ground.

The analogue post-processing is performed with standard NIM instrumentation. A National Instruments PXI-5122 Digitizer is used to perform the 14 bit A-to-D conversion of each amplitude pair and a dedicated LABVIEW procedure is used both to manage the acquisition and to handle the data collection by means of a Graphical User Interface (GUI), as we can see in Fig. 2.



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Vertical range (V): 5
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Number of Records: 2000000
Number of Records Fetched: 1361859
Number of Records Acquired: 1000
Trigger Source Channel: 1
Edge trigger level (V): 0.100
Slow signal peak (V): 1.1436
Fast signal peak (V): 0.919461
Sampling interval (ns): 20
Record lenght (µs): 20
Sampling Frequency (MHz): 50
Minimum record length: 1000
NiScope Error
Output file Error

Fig. 2. Graphical User Interface used to control the acquisition and to handle the data collection.

We have implemented a custom IDL programme to apply the signals compensation and to correct them.

Finally, we have tested different CdZnTe detectors realized by CNR/IMEM and eV-Products of which the main characteristics are reported in Table I.

TABLE I. Detectors parameters.

	CZT single crystal (IMEM/CNR)	CZT single crystal, Spectrometer Grade (eV-Products)
Size (mm^3)	5 x 5 x 2.75	10 x 10 x 5
Electrodes	Planar contacts	Planar contacts
$(\mu\tau)_e$ (10^{-3} cm^2/V)	(2.6±0.1)	(2.0±0.1)
Bias Voltages (V)	300, 500, 600	500, 900, 1100
Electric Field (V/mm)	110, 180 and 220	100, 180 and 220
Growth Method	VBM	HPB

The detectors supplied by CNR/IMEM were glued with silver paste on a Lexan support and bonded with Au wire of 25 µm to the electrodes [3, 4].

IV. DETECTOR CHARACTERIZATION

We have studied the electrical and transport properties of these detectors by acquiring the leakage currents, measuring the µτ product as well as by determining their response to irradiation with different calibration sources (^{241}Am, ^{57}Co, ^{109}Cd, ^{133}Ba and ^{137}Cs) using different shaping times. We have carried out this spectroscopic characterization for both detectors and we report the results obtained when using the detector provided by CNR/IMEM.

The I-V measurements have been performed by means of a current generator-voltage gauge unit (Keithley 236). Data acquisition was automatic and performed connecting a Macintosh computer with the Keithley unit. In Fig. 3 the leakage current is displayed as a function of the bias voltage.

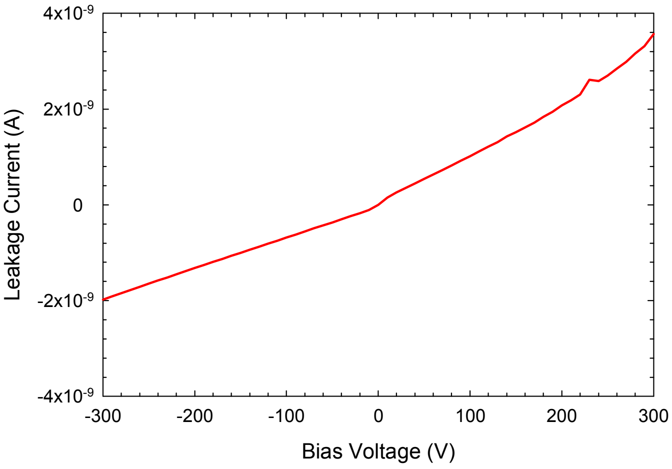

Fig. 3. Leakage current vs. bias voltage.

In Figures 4, 5 and 6 the spectra acquired by irradiating the detector through the cathode are illustrated, while the electron mobility-lifetime product measurements are reported in Fig. 7.

The $(\mu\tau)_e$ is (2.6 ± 0.2) 10^{-3} cm^2/V.

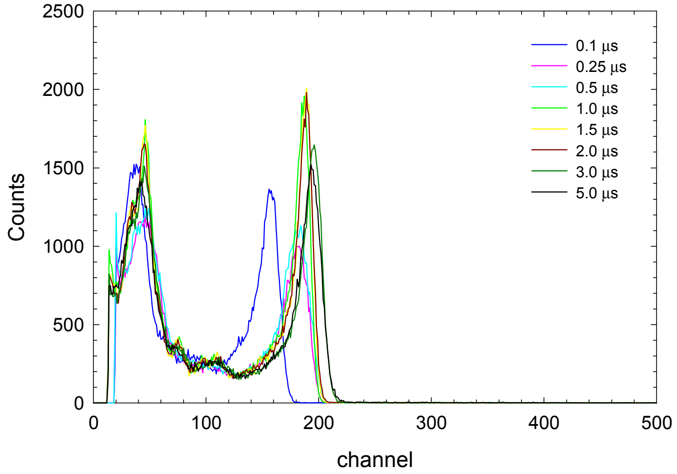

Fig. 4. ^{241}Am energy spectra recorded at different shaping times, by irradiating the first sample supplied by CNR/IMEM.

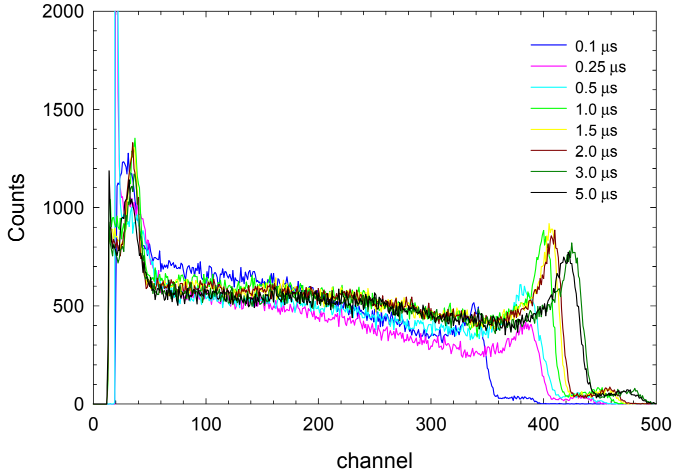

Fig. 5. ^{57}Co energy spectra recorded at different shaping times, by irradiating the same sample.

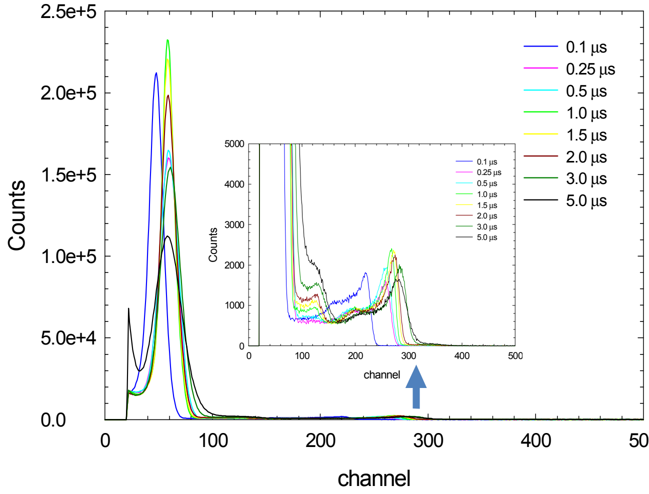

Fig. 6. ^{109}Cd energy spectra recorded at different shaping times, by irradiating the same sample. The inset shows the photopeaks at 88 keV.

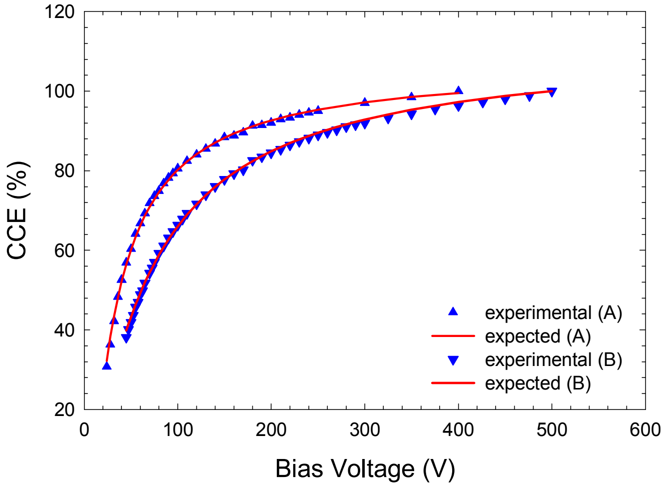

Fig. 7. Charge Collection Efficiency as a function of the bias voltage applied to two detectors grown by CNR/IMEM. The $(\mu\tau)_e$ of the first detector (A), of which we present the results by using the twin-shaping time method, is (2.6 ± 0.2) 10^{-3} cm^2/V.

The values of the energy resolution (FWHM) calculated at ~ 22.1, 59.54, 88 and 122 are reported in Table II.

TABLE II. FWHM AT DIFFERENT ENERGIES.

Energy (keV)	FWHM (keV)
22.10	4.3
59.54	3.9
88.04	4.7
122.06	5.4

V. BI-PARAMETRIC DATA

The data collected with the experimental set-up displayed in Fig. 1 are used to fill a two-dimensional map in which the horizontal axis reports the "Slow" signals while the vertical one represents the "Fast/Slow" ratios ($R = V_{Fast}/V_{Slow}$).

R becomes ~ 1 for interactions close to the cathode and it decreases more or less gradually as a function of the electrode distance.

The comparison of the bi-parametric distributions obtained with ^{57}Co and ^{137}Cs at 300 V is shown in Fig. 8. In the map acquired with ^{57}Co (top) it is possible to distinguish on the left at low "Slow" values a long vertical structure, which is the peak at 14 keV, and on the right the peaks at 122 keV and 136 keV, that are the two edge structures, while in the ^{137}Cs map (in the middle) the photopeak structure at 662 keV and the Compton edge are well distinguished.

We have also increased the bias voltage up to 600 V to improve the charge collection, as we can see in Fig. 8 (bottom). We have acquired this map by illuminating the same detector with ^{137}Cs and using the same shaping time pair. We can note that the interaction depth is enhanced.

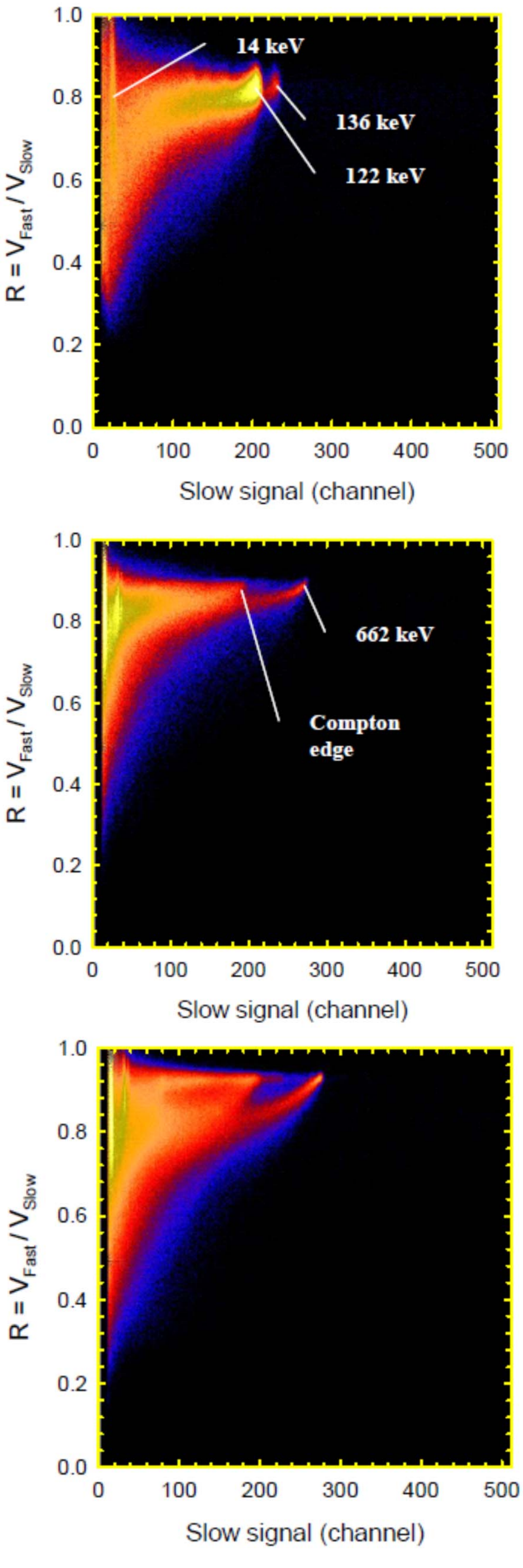

Fig. 8. Maps of the ratio V_{Fast} / V_{Slow} versus Slow signal obtained with a ^{57}Co source (top) and ^{137}Cs (middle), shaping time pair of 0.25–3.0 µs and by biasing the detector grown by IMEM/CNR at 300 V. Acquired map with the same shaping time pair by irradiating the detector with ^{137}Cs at 600 V (bottom).

To compensate the maps we have applied a compensation algorithm to each pair (Fast, Slow), calculated by using (1):

$$E_{comp} = \left[\frac{E_{\max}}{E_{slow}}\right] \times G(ratio) \qquad (1)$$

where $E_{\max}$ corresponds to the centroid in the best spectroscopy region and G(ratio) is a function which represents the best fit of E_{slow} as a function of the ratio values.

In Fig. 9 we report the corrected map obtained by applying a polynomial fit to compensate the photopeak structure.

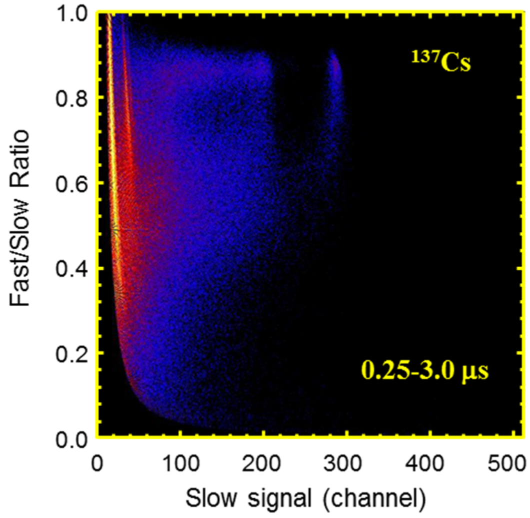

Fig. 9. Corrected map obtained with a ^{137}Cs source. The data were acquired by using the 0.25–3.0 µs shaping time pair and biasing the detector at 600 V.

The photopeak efficiency increases by a factor ~4 at 662 keV with respect to the original data and the peak-to-valley ratio improves by a factor ~2 at the same energy.

The comparison between the uncompensated and corrected data (see Figures 10, 11 and 12) acquired with the detector Spectrometer Grade by illuminating it with a ^{137}Cs radioactive source illustrates that the photopeak becomes more symmetric.

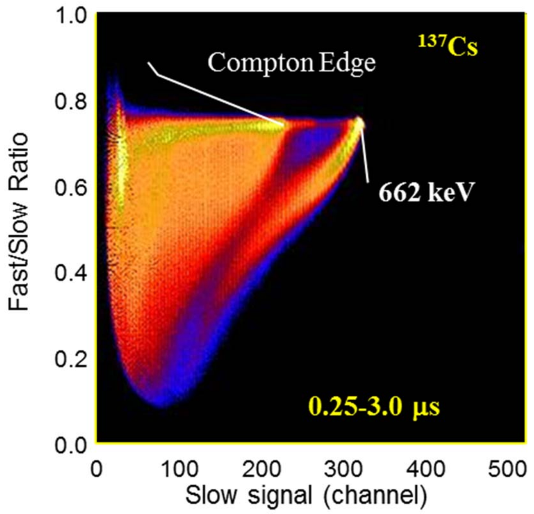

Fig. 10. Uncompensated map acquired at 900 V by illuminating the Spectrometer Grade detector with ^{137}Cs and with a 0.25–3.0 µs shaping time pair.

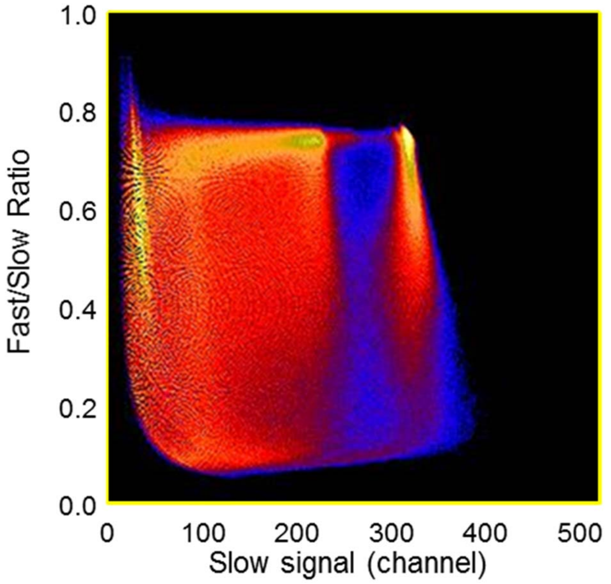

Fig. 11. Corrected map acquired at 900 V by illuminating the Spectrometer Grade detector with ^{137}Cs and with a 0.25–3.0 μs shaping time pair.

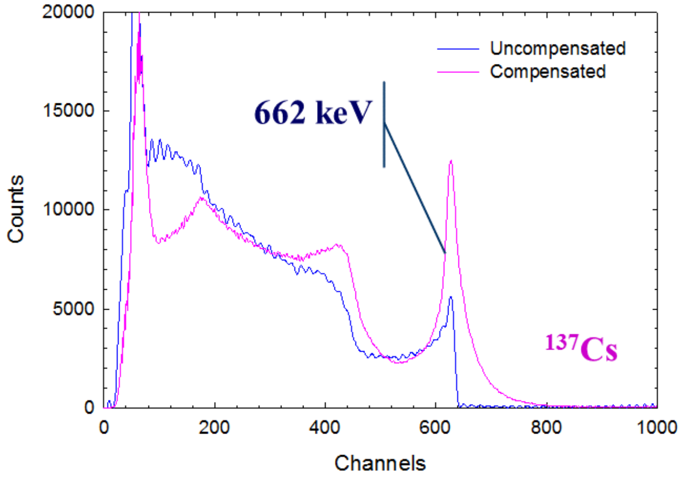

Fig. 12. ^{137}Cs spectra acquired with a 0.25–3.0 μs shaping time pair. The blue plot represents the original spectrum, while the pink one is the spectrum after the compensation.

As a consequence, the energy resolution of the compensated spectra is easier to measure than the original ones. In addition, the photopeak efficiency increases by a factor ~2÷3 at 662 keV compared to the uncompensated data and the peak-to-valley ratio improves by a factor ~2 at the same energy.

VI. FINAL RESULTS

The results of the data analysis are summarized in Fig. 13, where the Photopeak Efficiency ratio at 662 keV as a function of the fast shaping time, while the slow shaping time is set at 3 μs, is reported. This parameter increases from a factor by ~2 (Spectrometer Grade detector) to a factor greater than 5 (CNR/IMEM detector) compared to the original data.

The peak-to-valley ratio, shown in Fig. 14 when the slow shaping time is fixed at 3 μs, improves by a factor ~2 at 662 keV for both detectors.

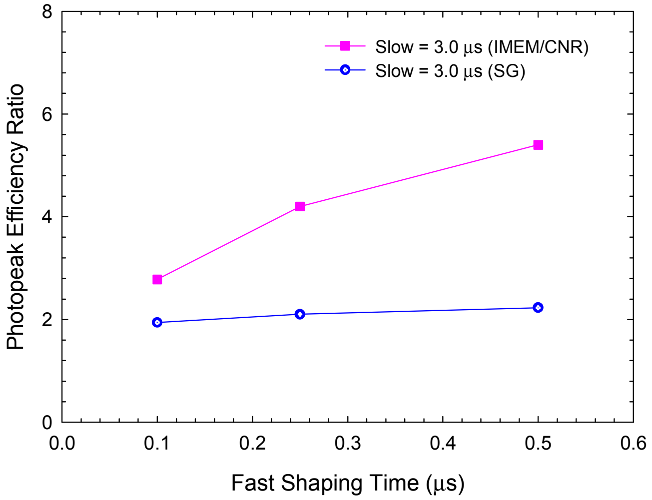

Fig. 13. Photopeak Efficiency ratio as a function of the fast shaping time at 662 keV.

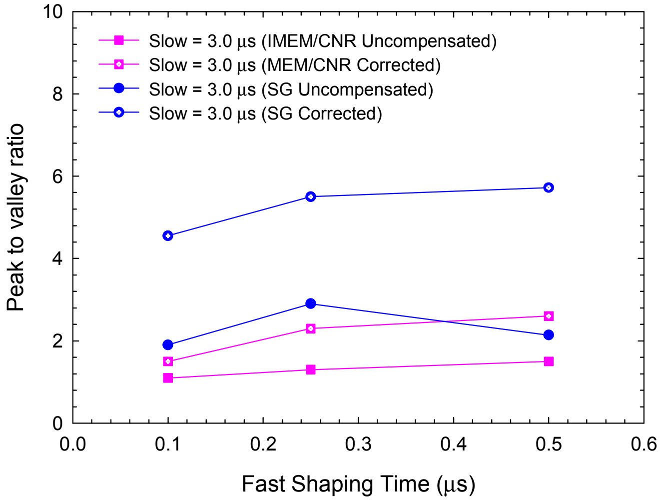

Fig. 14. Peak-to-valley ratio before and after compensation as a function of the fast shaping time at 662 keV.

We have also applied the dual shaping time technique to a drift strip detector which consists of a contiguous single cathode on one side and strips on the other side of the crystal. The drift cell consists of 8 drift strip electrodes, biased by a voltage divider, to focalize the charge on the anode readout strip, surrounded on each side by 4 drift strips. The dimensions of this detector are 20 mm x 5 mm x 5 mm; the pitch is 400 μm, while the strip width is 150 μm.

We have illuminated it in an irradiation configuration in which the direction of the incoming photons is perpendicular to the electrical field. In this configuration the photon absorption thickness can be increased up to a few centimeters without increasing the charge collection distance, avoiding severe spectroscopic performance degradation.

The peculiarity of the drift strip method is that the anode strip signal is quite independent of the photon interaction position, as we can see in the original map (Fig. 15, top). We have corrected the map (Fig 15, bottom) and in the spectra in Fig. 16 a slight improvement of the peak-to-valley ratio, the photopeak efficiency ratio and the energy resolution are evident. This detector has been provided by CNR/IMEM.

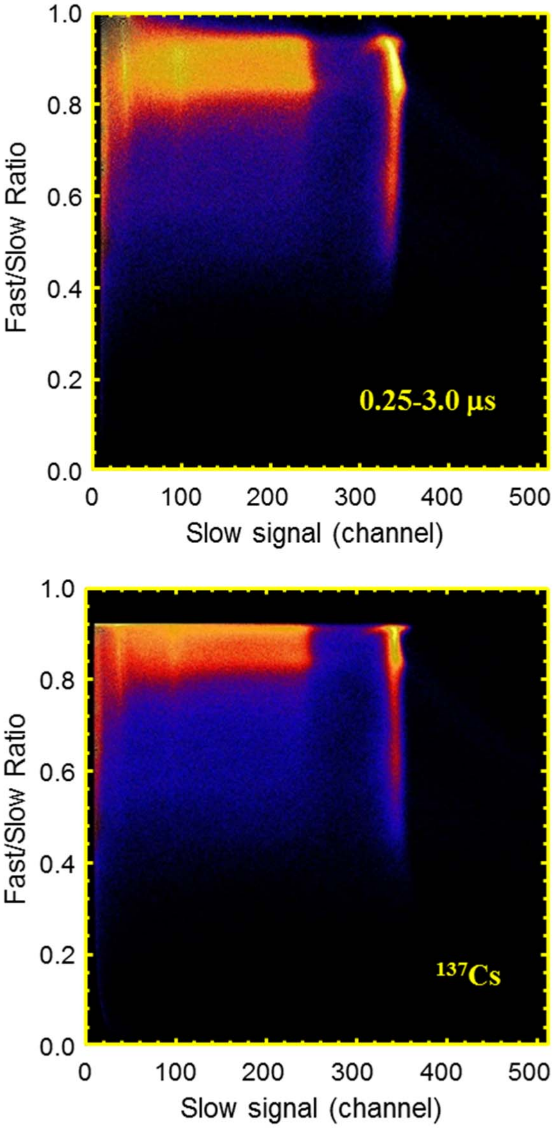

Fig. 15. Comparison of the uncompensated (top) and corrected (bottom) maps acquired with the drift strip detector provided by CNR/IMEM and a 0.25–3.0 μs shaping time pair.

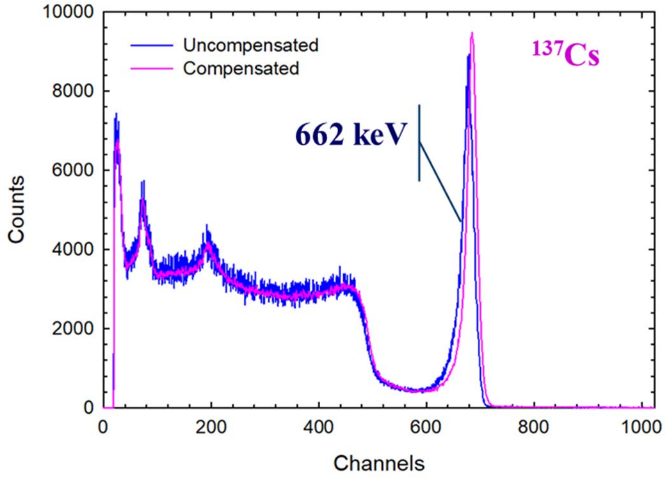

Fig. 16. ^{137}Cs spectra acquired with a 0.25–3.0 μs shaping time pair. The blue plot represents the original spectrum, while the pink one is the spectrum after compensation.

VII. CONCLUSIONS

The bi-parametric technique demonstrates the effectiveness of the double shaping filter based technique in improving the performances of CdZnTe spectrometers in terms of photopeak efficiency and Peak to valley ratio.

This method is easy to implement in a laboratory with standard instrumentation.

We have implemented different compensation algorithms by applying different laws to determine the most suitable fit.

The depth information can be used to discriminate between gamma rays and charged particles as their distributions are different. This peculiarity could have a great impact in space applications to reduce the background.

Finally, we want to point out that this technique could be implemented in an array of detectors, with front-end electronics composed of ASICs where the shaping time can be selected for each channel, like the RENA-3 IC (NOVA R&D).

VIII. WORK IN PROGRESS

We are studying this method as a tool to evaluate the quality of the detectors as a function of the interaction depth in association with other measurements of the charge transport properties like μτ measurements.

We are comparing the twin-shaping time method with the technique which uses the ratio between the planar electrode collected charge and the anode strip signal, in a drift strip detector, to correct the maps.

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