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Calibration of a 2D-CDB spectrometer using a reference ^{133}Ba source

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Abstract

A procedure for calibrating a FAST-ComTec 2D-CDB spectrometer using a ^{133}Ba source is presented. The energy calibration consisted of acquiring two-dimensional (2D) spectra by measuring simultaneously with two HPGe detectors the 356 and 511 keV peaks. As the ^{133}Ba source only emits one photon per decay, the Ba contribution to the 2D spectra was built up by taking two successive and uncorrelated events, i.e. one from each detector (pseudo-coincidence technique). The FWHM of the spectrometer was estimated from the $E_1 = E_2$ diagonal of the spectra.

1. Introduction

Recently, it has been proposed that the high momentum contribution of the e^+–e^- momentum can be used to identify the chemical surrounding of the positron annihilation trapping sites (Lynn et al., 1977; Alatalo et al., 1996; Szpala et al., 1996). For example, this method has been used to identify the sub-lattice of a vacancy as well as vacancy–impurity complexes in pure elements, semiconductors and alloys (Alatalo et al., 1996; Szpala et al., 1996; Kruseman et al., 1997; Brusa et al., 2001; Somoza et al., 2002; Brusa et al., 2005). The technique itself, coincidence Doppler broadening spectrometry (CDB), is based on the coincident detection of both 511 keV γ-quanta from a single annihilation event. As a consequence of the strong reduction of the otherwise disturbing background, this method allows the observation of the high-momentum e^+–e^- annihilation distribution. CDB gives a peak to background ratio of $\sim 10^5$ and an improvement of the effective resolution function by a factor of $\sqrt{2}$ (Kruseman et al., 1997). Nowadays, the set-up of the two detectors used for the measurements is quite simple. The availability of versatile computer-based multiparameter systems allows to process big two-dimensional (2D) data arrays and also to establish the time coincidence. For the present work, a FAST-ComTec system was used. Among the positron groups worldwide, it became a standard CDB measurement system (Gebauer et al., 1999). The motivation of the present work arises from the lack of methodological information reported about the energy calibration procedure using the set-up above mentioned. Specifically, a method to calibrate a CDB spectrometer using a ^{133}Ba source is presented. The most important advantage of the procedure followed is due to the simultaneous measurement of the calibration curve and the CDB response function. On the other hand, a way to evaluate the response function of the spectrometer is developed.

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This method is an extension of the procedure used for calibrating the 1D Doppler broadening spectroscopy (DBS) micro-spectra measurements (Brusa et al., 1992).

2. Experimental

Basically, a CDB set-up consisted of two HPGe detectors aligned in a collinear geometry plus the corresponding amplifiers and ADCs. These last devices were connected to a busbox containing the coincidence electronics. The busbox was fed to a PC running the multiparameter software that stores the coincidence events in a 2D array. Tuning the spectroscopy amplifier at 3 μs shaping time, the energy resolution of each detector was 1.75 keV (FWHM) and 1.81 keV, respectively, in the 1.33 MeV peak of the ^{60}Co source. The relative efficiency measured was 35% for detector #1 and 16% for detector #2. A positron source 40 μCi of ^{22}NaCl deposited on a thin Kapton foil was used. In both cases, the source–detectors distance was 20 cm. In the configuration described above, under the 511 keV peak, a counting rate of ~250–300 count/s was obtained.

3. Energy calibration

The energy calibration of the system was obtained by acquiring simultaneously the ^{133}Ba source characteristic photopeaks (302.9, 356 and 383.8 keV) and the annihilation peak in a 2D spectrum.The procedure used was:

(i) For each detector, a range of the total spectrum collected was selected in order to contain in 4096 channels the γ-peaks emitted by the ^{133}Ba source and the 511 keV peak corresponding to the annihilation process. In such a way, the amplification of the signal and the ADC offset were adequately chosen.

(ii) The coincidence mode of the multi-parameter software was set using a coincidence time window wide enough to allow the detection of two successive and uncorrelated events coming from the ^{133}Ba source. Specifically, a coincidence time window of 10 μs was used.

(iii) 4096 × 4096 2D spectra were acquired.

In Fig. 1, a capture of the PC's screen shows a typical complete 2D coincidence spectrum. In Fig. 2, a magnified detail of the pseudo-coincidence between two successive 356 keV γ-rays is shown. In the same figure, the pseudo-coincidences 384–384 keV and 356–384 keV are also shown.

To determine the energy calibration function, a cross-section to the 2D spectra along the $E_1 = E_2$ diagonal has been taken. In practice, the cross-section mentioned is usually taken considering a small slice of ten channels width. The choice is made with the purpose to increase the statistics. As a result, a 1D representation is obtained (see Fig. 3). In such a case, from the 1D-distribution the ratio energy/channel can be obtained. In our case, a ratio 36.85 eV per channel was derived.

4. CDB spectrometer resolution

While the resolution of a single detector and the calibration can be easily determined from a DB measurement, it is more hard to obtain these figures from a 2D spectra of a CDB system. To this aim, the

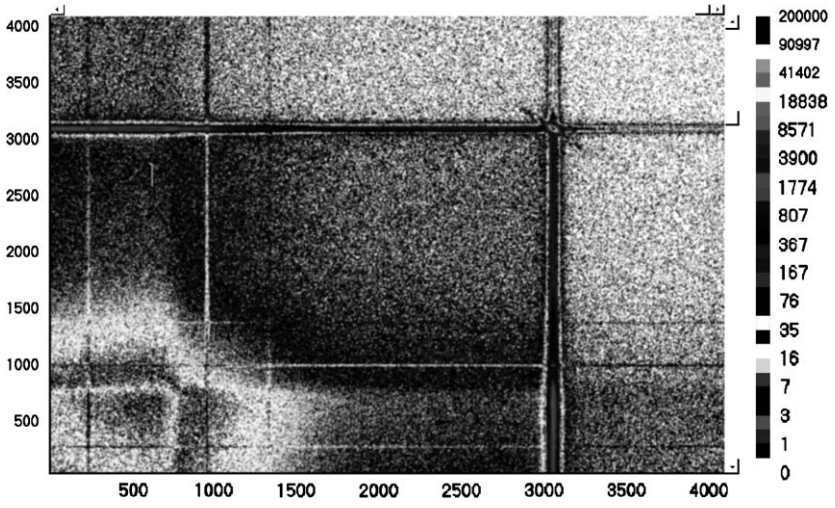

Fig. 1. Image obtained from the PC's screen showing a typical complete 2D coincidence spectrum.

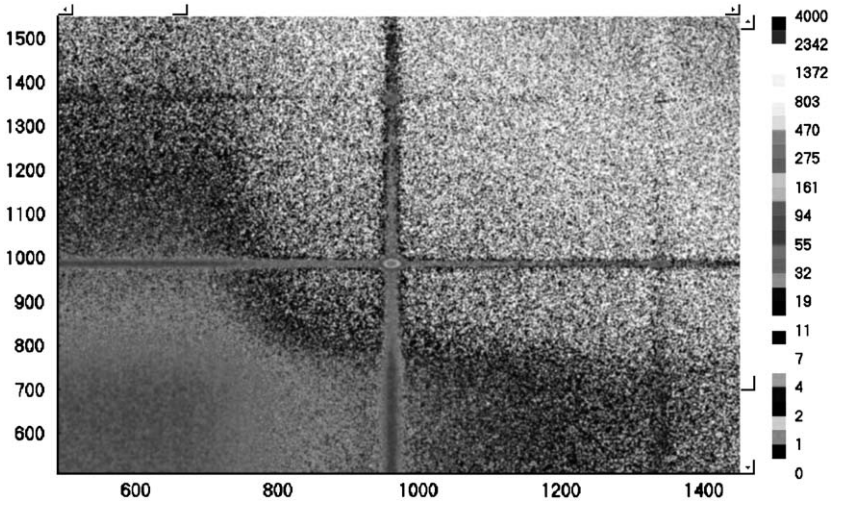

Fig. 2. Magnified detail of Fig. 1 of the pseudo-coincidence between two successive 356 keV γ-rays. The pseudo-coincidences 384–384 and 356–384 keV are also shown.

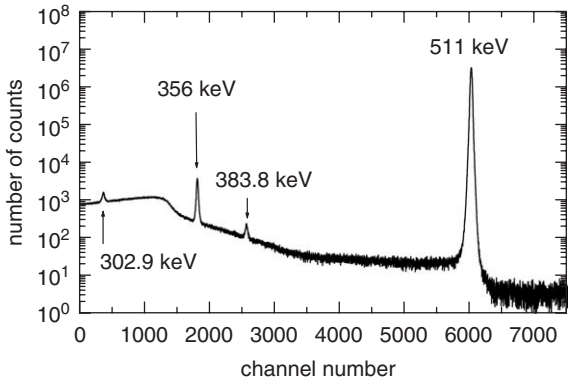

Fig. 3. One-dimensional representation of CDB spectra. To this aim, a cross section to the 2D spectra along the $E_1 = E_2$ diagonal was used (see text).

accidental coincidence of two γ-quanta emitted from the same radioactive source must be measured. From that, the cross-section of the spectra measured (i.e. the slice) along the diagonal, $E_1 = E_2$ represents a good approximation of the effective resolution R of the system (Kruseman et al., 1997) if the energy/channel is known. Previously, to estimate the response function the characteristic γ-rays obtained from the radioactive sources ^{85}Sr (514 keV) or ^{103}Ru (497 keV) were used (Lynn et al., 1977; Britton et al., 1992). The advantage in using these two γ-ray emitter sources is assigned to the close of the characteristic γ-ray energies to that corresponding to the e^+–e^- annihilation process. However, from the experimental point of view it must be considered as a disadvantage that both radioactive sources used have very short half-decay lives. Specifically, 39 days for ^{103}Ru and 64 days for ^{85}Sr.

Conversely, our method also allows to obtain the spectrometer resolution simultaneously with the evaluation of the calibration (energy/channel) using the most practical long living ^{133}Ba source. An analog procedure to that followed to obtain the resolution of a conventional 1D-DB spectrometer was applied to the spectrum of Fig. 3, just used for the above calibration. Summarizing, from the spectra shown in Fig. 3, the 356 keV peak, of that spectrum, was satisfactory fitted by using only one Gaussian function and the FWHM calculated. However, even using a wide time coincidence window the counting rate obtained under the 356 keV photopeak was still low (~ 0.2 cps). In such a case, this implies a large acquisition time, which obviously is affected by critical systematic instabilities (e.g., temperature or electronic drifts). In order to check the drift influence on the CDB spectrometer FWHM, the same 2D spectrum was acquired for different accumulating times starting from 16 h until reaching 168 h. In Fig. 4 three typical 356 keV photopeaks obtained at different accumulation times are shown. As a result, in each case it was found that the FWHM obtained varies from 0.81 keV for 16 h accumulation time (after the subtraction of baseline background ~6000 counts under the peak were obtained) up to 0.94 keV for a measurement time of 168 h (~140,000 counts under the peak). Finally, using a well-known relationship to estimate the FWHM at another energy position in the spectra (Knoll, 1979), the resulting FWHM at 511 keV varies from 0.97

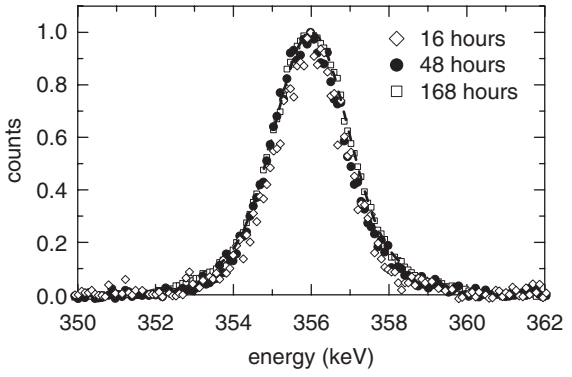

Fig. 4. Three typical 356 keV photopeaks (normalized to peak) obtained for different accumulation times.

to 1.12 keV for the different accumulation times mentioned above.

5. Summary

In the present work, a practical method to simultaneously calibrate and evaluate the resolution function in CDBS spectra acquired by a FAST-ComTec system is presented.

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