



Energy calibration via correlation



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ABSTRACT

The main task of an energy calibration is to find a relation between pulse-height values and the corresponding energies. Doing this for each pulse-height channel individually requires an elaborated input spectrum with an excellent counting statistics and a sophisticated data analysis. This work presents an easy to handle energy calibration process which can operate reliably on calibration measurements with low counting statistics. The method uses a parameter based model for the energy calibration and concludes on the optimal parameters of the model by finding the best correlation between the measured pulse-height spectrum and multiple synthetic pulse-height spectra which are constructed with different sets of calibration parameters. A CdTe-based semiconductor detector and the line emissions of an ^{241}Am source were used to test the performance of the correlation method in terms of systematic calibration errors for different counting statistics. Up to energies of 60 keV systematic errors were measured to be less than ~ 0.1 keV. Energy calibration via correlation can be applied to any kind of calibration spectra and shows a robust behavior at low counting statistics. It enables a fast and accurate calibration that can be used to monitor the spectroscopic properties of a detector system in near realtime.

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1. Introduction

After digitizing detector signals, the pulse-height analysis (PHA) of signals is expressed in the abstract analogue-to-digital unit (ADU) which is the binary output of the analogue-to-digital converter (ADC). In principle, knowing the exact response of the detector and of the preprocessing electronics (amplifier, pulse shaper, ADC) allows deriving the average energy of the absorbed radiation for each pulse-height value. Instead of this theoretical approach, a calibration which is based on a spectral measurement of a known calibration source can be applied for the transformation from PHA values to energies without knowing the detailed response of the detector system.

Using an ADC with an N -bit resolution, a *full energy calibration* assigns for each of the 2^N pulse-height values a corresponding energy. Furthermore, a full calibration aims at measuring the quantum efficiency¹ of the detector system precisely. See [1] for an overview of the extensive calibration test for the pn-CCD onboard the X-ray satellite XMM-Newton.

The high requirements concerning the calibration source and the large effort for the analysis of the calibration itself make a full energy calibration often not the first choice for detector systems

which are in a development phase and which require a frequent recalibration due to changes of their system parameters like operating temperatures or voltage settings.

1.1. The line fitting approach

Instead of a full energy calibration, discrete energy-pulse-height reference points (EPRPs) can be obtained by measuring the line emission of radio-isotopes or X-ray fluorescence lines. Fitting a parametric model according to the expected response of the detector system to these EPRPs allows deriving the optimal parameters for the energy calibration; see [2] for such an emission line fitting with a linear model and [3] for a fit using a surrogate function. Because of uncertainties in the measurements of the EPRPs, a model with p free parameters requires the determination of q EPRPs with $q \geq p$. The reference points can be obtained by fitting q Gaussian line profiles² to a calibration spectrum which is observed using q monoenergetic emission lines.

In addition to these requirements, the calibration source must have a sufficiently high flux. Detector systems consisting of m independent channels, each with a slightly different response caused by inhomogeneities during their fabrication, require a channel specific energy calibration [2–4]. Instead of one

¹ Obtaining the quantum efficiency is not the goal of this work, but see the discussion in Section 5 on this topic.

² In the following, a Gaussian shaped detector response is assumed.

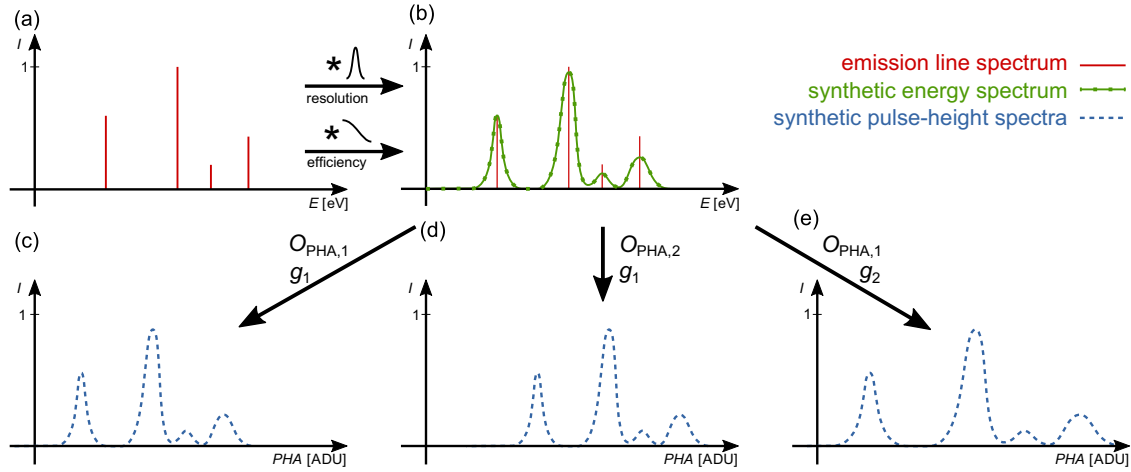


Fig. 1. Creation of synthetic pulse-height spectra. Top: the emission line spectrum [(a), red], normalized to the intensity of the most dominant line, is convolved with the expected energy resolution and quantum efficiency of the detector in order to create the synthetic energy spectrum [(b), green]. Both, the energy resolution and the quantum efficiency are a function of the energy. Bottom: using different parametrizations for the energy-to-pulse-height relation results in different synthetic pulse-height spectra. For a linear model, like it is shown, different offsets O_{PHA} shift the spectra to lower or higher pulse heights; see the shift between the spectra (c) and (d) which are constructed with the same gain but different offset values. Different gain values g stretch or squeeze the spectra which is shown for the spectra (c) and (e) which use the same offset but different gain values. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

calibration spectrum, m spectra with sufficient statistics (more than 500 counts per channel are reported in [2]) must be obtained during the calibration measurement. To conclude, a precise energy calibration which is based on *emission line fitting* puts high requirements on the calibration source and on the analysis of the channel specific calibration.

The theoretical basis of an energy calibration which is based on correlation (ECC)³ is described in the following section. The core of the ECC method is similar to a fitting approach but uses all PHA values—and not just the peak positions—which results in an enhanced statistics of the ECC technique compared to a line fitting approach.

Section 3 presents the application of an ECC on the example of a linear and a non-linear calibration of a CdTe-based semiconductor detector system using the radio-isotope ²⁴¹Am. The spectroscopic implications are finally presented in Section 4.1. Section 4.2 compares the calibration errors resulting from an ECC with the errors resulting from a line fitting approach for different counting statistics. The following discussion in Section 5 is directed to other kinds of calibration sources and to the limitations of the ECC technique.

2. Description of the method

Starting point of the ECC method is the known energy spectrum of the calibration source which is in the following called the *synthetic energy spectrum* $I_{syn}(E)$. The transformation between pulse-height values PHA and energies E is defined via the parametric description $E(PHA | P)$ or its inverse function $PHA(E | P)$. Here and in the following, $f(A | B)$ describes a function f with variable set A and parameter set B . Different parameter sets P result in different *synthetic pulse-height spectra* $I_{syn}(PHA | P)$

$$I_{syn}(PHA | P) = I_{syn}(E(PHA | P)). \quad (1)$$

The degree of correlation between a synthetic and the *observed pulse-height spectrum* I_{obs} is obtained via a correlation factor C

$$C(P) = \sum_{PHA=0}^{2^N-1} I_{syn}(PHA | P) \cdot I_{obs}(PHA). \quad (2)$$

The spectral intensities I_{syn} and I_{obs} are normalized relative to the strongest line emission. The parameter set P^* with a correlation factor $C(P^*)$ that approaches the autocorrelation

$$C_{max} = \sum_{PHA=0}^{2^N-1} I_{obs}(PHA) \cdot I_{obs}(PHA) \quad (3)$$

is taken as the optimal parameter set for the transition between pulse heights and energies and can be used to transform all measured data via $E(PHA | P^*)$.

3. Application

The ECC method was tested with a 8×8 pixel CdTe detector Caliste 64 [5] within the detector setup CANDELA [6,7]. The following linear and non-linear application is based on a calibration measurement using the radio-isotope ²⁴¹Am.

3.1. Linear calibration

The synthetic energy spectrum is constructed using tabulated data [8] for the gamma and X-ray emission of ²⁴¹Am in terms of energy and intensity, see Fig. 1(a). The line emissions are convolved with the expected spectral resolution and the quantum efficiency of the detector system which are both considered to be energy dependent, see Fig. 1(b). In the easiest case, a linear model is used to describe the pulse-height-to-energy transformation via

$$E(PHA | g, O_E) = g \cdot PHA + O_E \quad (4)$$

or

$$PHA(E | g, O_E) = g^{-1}(E - O_E) = g^{-1} \cdot E + O_{PHA} \quad (5)$$

respectively. Here, the energy offset O_E is the energy assigned to $PHA = 0$ ADU, the pulse-height offset $O_{PHA} = -O_E/g$ is the pulse height assigned to $E = 0$ keV, and the gain g describes the linear increase of energy per pulse-height channel. Different offset values shift the resulting synthetic pulse-height spectrum to lower or higher pulse-heights, while different gain values squeeze or stretch $I_{syn}(PHA)$, see Fig. 1(c)–(e). The correlation factor C is obtained for different combinations of offset and gain values, which are sampled in equally spaced steps between their upper and lower limits.

³ Energy Calibration via Correlation.

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