Automatic Self-consistent Gain-Matching of DSSSD Detector Channels*

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Double-sided silicon strip detectors (DSSSD) are a widely used type of detector in nuclear and particle physics experiments for position and energy measurements. This report describes an automatic method that allows to gain-match all strips of DSSSD detectors without the need of dedicated in-beam calibration.

Introduction

DSSSD detectors are constructed as large area silicon diodes with electrically segmented p and n-side contacts. Signals are read out on both, p and n-side simultaneously. The segmentation is usually such that there are unique intersection points of opposite side's contacts, the measurement of one p and on n-side signal allows to reconstruct the two dimensional spatial position of an event inside the detector.

Method

In the following, it will be assumed that the deposited energy $E = s \cdot A$, in the detector is proportional to the amplitude, i.e. there are no offsets or nonlinearities in the electronics. A is the measured amplitude of the detected signal and s the slope factor for calibration.

Given a DSSSD detector with N strips on each side, each event that is registered in a given pixel will create a signal with amplitude A_p in the strip number p on the p-side and a signal with amplitude A_n in strip number n on the n-side $(n, p = 1 \ldots N)$. Assuming that both strips measure the same energy E deposited in the active area of the detector, one can write

$$E_p = s_p\, A_p\,, \quad E_n = s_n\, A_n \quad \text{and} \quad E_p = E_n = E\,, \tag{1}$$

with s_p and s_n being the calibration coefficients (slopes) for the p-th p-side strip and n-th n-side strip, respectively.

For each pixel of the detector, the values of A_p and A_n for various values of energy depositions ΔE are assumed to be linearly related. For each pixel, the relation between the amplitudes is

$$A_p = S_{pn}\, A_n\,, \tag{2}$$

with the slope parameter S_{pn} which can be determined from the data (see below). The set of N^2 slope parameters can be used to deduce a set of $2N$ calibration coefficients $\{s_p, s_n\}$ by minimizing the expression

$$\chi^2 = \sum_{p,n} \left(\frac{S_{pn} - \frac{s_n}{s_p}}{\Delta S_{pn}} \right)^2 , \tag{3}$$

that follows directly from Eqs. (1,2).

Implementation

There are two independent steps: First, the determination of the coefficients S_{pn}. Second, finding a set of calibration coefficients $\{s_p, s_n\}$ based on S_{pn}. The former is done using a Bayesian approach, updating the posterior probability distribution of the quantity of interest for each detected event. The latter is done by a nonlinear least squares fit algorithm.

Determination of S_{pn}*:* The posterior probability distribution of the quantity of interest is in this case $p\left(S_{pn} | \{d_{pn}\}\right)$, with $\{d_{pn}\}$ being the set of all measured data points, i.e. the ratio of amplitudes $d_{pn} = A_p/A_n$. Knowing this distribution allows to get the most likely value for each slope parameter S_{pn} and its variance ΔS_{pn}. Starting with an initial guess for this distribution, i.e. uniform within reasonable limits, one can refine it by iterating over the measured data points, each time applying Bayes' theorem [4, 5]

$$p\left(S_{pn} | d_{pn}\right) = \frac{p\left(S_{pn}\right)\, p\left(d_{pn} | S_{pn}\right)}{p\left(d_{pn}\right)}\,, \tag{4}$$

with the commonly used terminology [6]: $p\left(S_{pn} | d_{pn}\right)$ is called posterior distribution, $p\left(S_{pn}\right)$ is the prior distribution, $L\left(d_{pn} | S_{pn}\right)$ the likelihood function and $p\left(d_{pn}\right)$ the evidence of the measured data. After each treated data point the normalized posterior distribution becomes the prior for the next data point.

The likelihood function is chosen to be a Lorentzian-shaped distribution with width w

$$L\left(d_{pn} | S_{pn}\right) \propto \frac{1}{w^2 + \left(\log d_{pn} - \log S_{pn}\right)^2}\,. \tag{5}$$

Such a distribution makes the result less sensitive to abundant background events as it would be the case with a Gaussian-shaped likelihood function. It depends on the logarithm of the slope parameter, because the slope is a scale parameter with a possible range inside $[0, \infty[$.

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While iterating over the data, the posterior distribution is represented as a discrete number N_p of points between the limits $S_{\min}$ and $S_{\max}$. The density of points depends on the desired accuracy of the final result and can be in the order of a few thousands. After all data is processed, the best estimates for all slopes S_{pn} and their uncertainties ΔS_{pn} are determined from the mean and variance of the final posterior probability distribution. For the example data shown here, the set of values was: $N_p = 1000$, $S_{\min} = 0.3$, $S_{\max} = 3$ and $w = 0.1$

Computing a set of calibration coefficients: Minimizing (3) is done using the implementation of a nonlinear least squares fit provided by [2]. The set of fit parameters is $\{s_p, s_n\}$, and the data is the complete set of measured slope parameters $\{S_{pn}\}$. The algorithm performs the minimization of (3). After convergence is reached, the parameter set describes the best calibration coefficients for the data set on a common arbitrary scale.

Results

The described procedure was applied to data from the PreSPEC-AGATA setup [7]. The DSSSD detector was mounted close to the position of the secondary target and had 2×32 strips, read out with two 32-channel ADCs. It is part of the Lund-York-Cologne CAlorimeter (LYCCA) [1] that is tracking and identifying heavy ions.

The result of the procedure is best summarized in a two-dimensional sum histogram of all p-side vs. all n-side amplitudes, without and with calibration coefficients as determined by the described method. In a correctly calibrated detector, each event should have equal calibrated amplitudes for both sides of the detector. That is confirmed by the Fig. 1.

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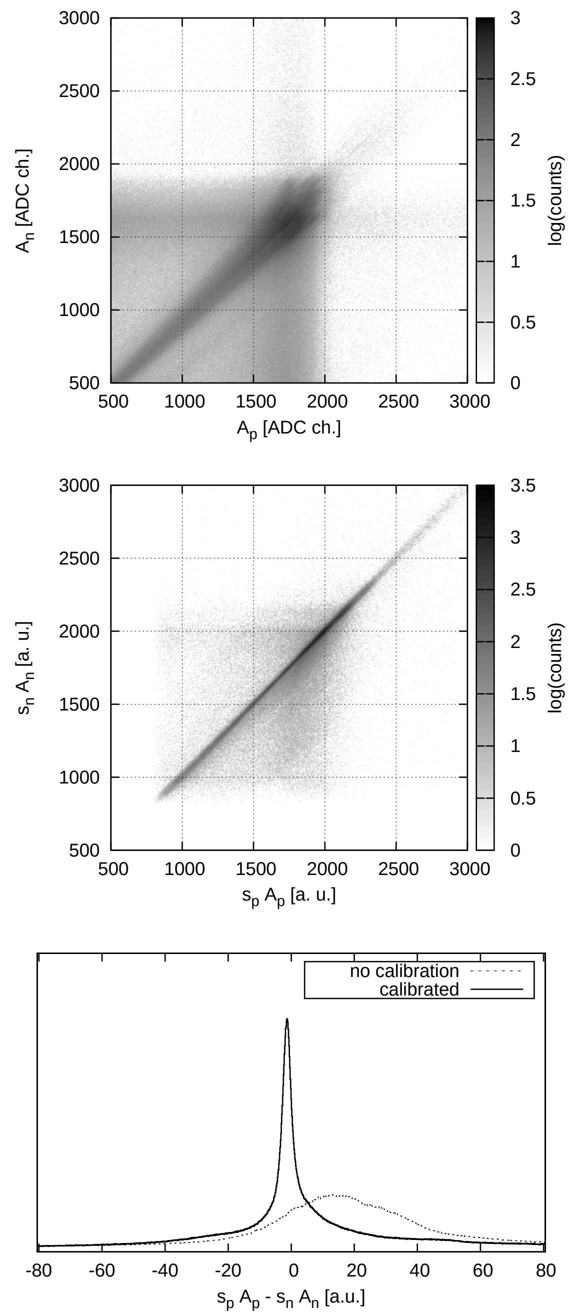

Figure 1: Sum histogram of the p and n-side amplitude distributions before (top) and after (middle) the calibration procedure. The picture on the bottom shows the difference of p and n-side amplitude before and after calibration.

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