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Automatic intrinsic calibration of double-sided silicon strip detectors

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ABSTRACT

A reliable and simple-to-use algorithm was developed for the energy-calibration of double-sided silicon strip detectors (DSSSDs). It works by enforcing mutual consistency of p-side and n-side information for every detected event. The procedure does not rely on a dedicated data set for calibration and is robust enough to work fully automated without human supervision. The method was developed and applied to data from a DSSSD of the Lund-York-Cologne CAlorimeter (LYCCA) for the HISPEC experiment at FAIR. It has been tested on ions in the $A\approx 90$ mass range at energies of $E_{\mathrm{kin}}\approx 300$ MeV/u.

1. Introduction

Double-sided silicon strip detectors (DSSSDs) are widely used for charged particle detection in nuclear and particle physics experiments to obtain position, energy or energy-loss information and particle identification [1]. They are constructed as large area silicon detectors with segmented p-side and n-side contacts. The intersecting areas of both side's segments form pixels. All signals on both sides are read out through individual channels. For each event, the channel numbers on both sides indicate the pixel that was hit by the charged particle. Typical applications for DSSSDs make use of square [1] or circular shapes [2] (see Fig. 1). In applications where energy information is required, it is essential to calibrate the individual segments of the DSSSD. We distinguish between "absolute" and "intrinsic" calibration of such detectors in the following way: by "absolute energy calibration", we refer to a set of calibration coefficients that map measured amplitudes to units of energy. A set of coefficients can be obtained by recording spectra for all segments using particle sources of known energy, such as α-sources, or a particle beam from an accelerator. By analyzing these spectra, single segment gains can be obtained in units of energy per ADC-channel. In addition, pulsers can be used to inject charge with calibrated value into the front end electronics (FEE)[1] of all strips [2], to correct for non-linearities in the FEE. For highly segmented DSSSDs, this procedure is difficult for two reasons: first, the analysis has to be performed for each channel, i.e. the effort increases with the number of channels. Second, and more important, the active area per segment decreases with higher segmentation. Consequently, a long measurement time for calibration is required to accumulate a sufficient number of events in the calibration spectra. This can be exceedingly expensive if an accelerator is used as a calibration source.

An absolute calibration implies that all segments deliver comparable information about the energy-loss of a particle, i.e. the information does not depend on which strip was hit. If this is the case, but the absolute energy scale is not determined, we call this "intrinsic calibration". Intrinsic calibration of the individual strips of the detector is sufficient, for example in particle tracking and identification applications [1,3].

A detector with pre-existing intrinsic calibration of the individual strips is easier to calibrate absolutely with known sources. The problem of increasing measurement time for highly segmented detectors does not occur, because the segmentation does not matter anymore, as far as the calibration spectrum is concerned.

In this work we will show that it is possible to obtain an intrinsic calibration for DSSSDs by using the correlations of p-side and n-side data. We demonstrate this by presenting one possible algorithm that exploits these correlations to obtain a set of intrinsic calibration coefficients from any data set from the detector. Further, we show results of its application to data from a DSSSD, that was used as part of the Lund-York-Cologne-CAlorimeter (LYCCA), a detector system for relativistic heavy-ion identification and tracking. Finally, limitations and possible improvements of the method will be discussed.

2. Method

For a single event of energy deposition inside a DSSSD, the created charge carriers induce signals in all electrical segments as

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[1] Only the FEE, not the detector itself is calibrated by this method.

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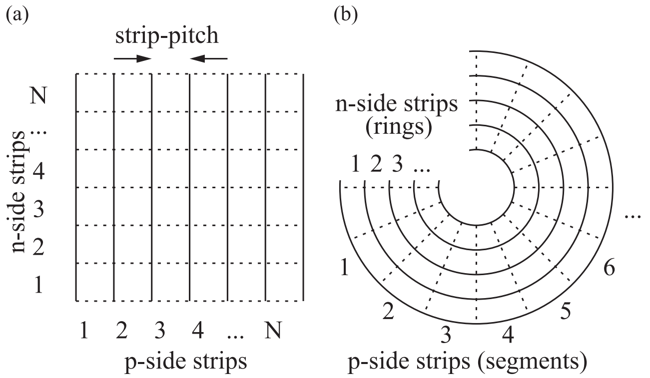

Fig. 1. Schematic view of two common configurations for DSSSDs: (a) shows a rectangular shaped, (b) a circular shaped segmentation layout. Solid and dashed lines indicate the borders of front-side and back-side segments, respectively.

they move within the detector volume. The measured signal amplitudes depend on the geometry of the detector and its segmentation, in particular, of the distance between the segment and the location of charge carriers. Cross-talk between different channels in the FEE can modify the signal amplitudes of all channels. The presented algorithm neglects cross-talk in the FEE and assumes that there is at least a fraction of events, where the deposited energy

$$E = s_i A_i \tag{1}$$

in the detector is proportional to a signal in channel i of amplitude A_i, and that all other channel amplitudes are negligible:

$$A_i \gg A_j \quad \text{for } i \neq j. \tag{2}$$

The slope factor s_i is the only calibration coefficient for a given channel i. In Section 4 we will generalize (1), allowing for an additional offset in the energy dependence. Note that the principle of correlating p-side and n-side information does not demand the exclusion of cross-talk and multi-segment hits. However, this simplified treatment turned out to be sufficient for achieving good results as will be shown in Section 5.

The basic idea of the procedure is the following: given a DSSSD with N_p and N_n strips on the p-side and n-side, respectively, 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 $(n, p = 1 \ldots N_{n,p})$. Assuming that both strips measure the same deposited energy E in the active area of the detector, one can write

$$E_p = s_p A_p, \quad E_n = s_n A_n \quad \text{and} \quad E_p = E_n = E \tag{3}$$

with s_p and s_n being the calibration coefficients (slopes) for the pth p-side strip and the nth n-side strip, respectively. For each pixel that was hit, the corresponding segments on both sides will deliver signal amplitudes, A_p and A_n, that are unambiguously related. Since we assume in this section that Eq. (1) is valid, this relation between the two measured amplitudes is also linear without offset

$$A_p = S_{pn} A_n. \tag{4}$$

The slope $S_{pn} = A_p / A_n$ of this line can be experimentally determined for each pixel, based on a given set of measured events. A schematic representation of the relations can be seen in Fig. 2. For each pixel, this slope can be visualized by plotting for each event the amplitudes (A_p and A_n). Fig. 3 shows such a plot for measured data of a single DSSSD pixel, which allows us to determine S_{pn} and its uncertainty ΔS_{pn} for this pixel. The set of $N_p N_n$ measured S_{pn}-values can be used to get a set of $N_p + N_n$ calibration coefficients $\{s_p, s_n\}$ that best reproduces the set of measured $\{S_{pn}\}$. Both

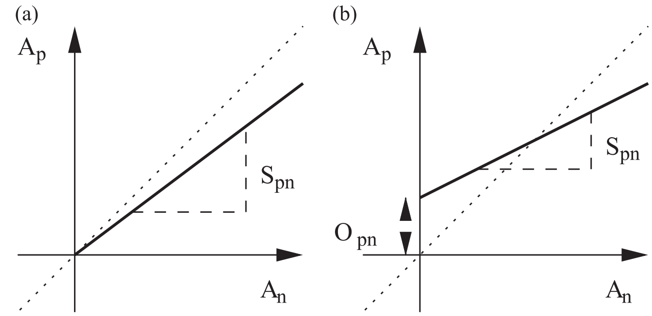

Fig. 2. The relation between A_p and A_n for one single pixel of the detector (thick, solid line) with slope S_{pn}. In general, this line does not coincide with the diagonal (dotted line). In (a) no offset is present, while in (b) an offset O_{pn} is allowed (see Section 4).

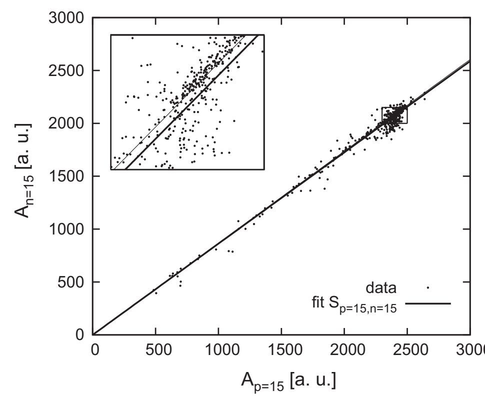

Fig. 3. This plot shows a typical distribution p/n-side amplitude pairs (dots) for a single pixel (p=15, n=15), after selecting single-strip events on both sides as described in Section 2. Even though there is not much background, a simple χ^2-fit (thick, solid line) of the slope S_{pn} misses the correct value. The inset shows a zoom-in to the most densely populated part of the graph where the mismatch of data and χ^2-fit is obvious to the human eye. For comparison, the thin solid line shows the result determined by our algorithm.

sets are related by

$$S_{pn} = \frac{s_n}{s_p} \tag{5}$$

which follows from Eqs. (3) and (4). One way of finding a set of $2N$ calibration parameters $\{s_p, s_n\}$ is to minimize the following expression:

$$\chi^2 = \sum_{p,n} \left(\frac{S_{pn} - \frac{s_n}{s_p}}{\Delta S_{pn}} \right)^2 \tag{6}$$

where ΔS_{pn} is the experimental uncertainty for the pixel slopes S_{pn}. The calibration parameters that minimize (6), also fulfill the condition (3) and therefore represent the best set of calibration coefficients for a given input data set on an arbitrary scale, if the simplifying assumptions are valid.

The proposed method, as described above, requires the following conditions to be fulfilled: it is essential, that p-side and n-side strips have intersection points and that both side's strips are readout. In addition, a sufficient amount of single-strip events has to be present, i.e. events where Eq. (2) is valid. Events with inter-strip hits on one or both sides will contribute to the background and should be excluded from the calibration procedure. Note, that this procedure could also be applied to detectors with segmentation on one side only, as long as signals from all segments and the unsegmented side are recorded.