A method for background reduction of solid state detectors during low-flux periods

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Abstract
The pulse height analysis of the signals in traditional energetic particle telescopes provides a tool to separate a background arising from various factors from "genuine" particles. Commonly used methods, however, prove unsatisfactory at low intensity levels. A method based on the distribution of pulse heights of coincident signals in two detectors, approximating them by a 5-parameter function, is suggested. The method can effectively reduce the background at low-flux times as demonstrated for energetic particle intensity measurements by ERNE and EPHIN aboard SOHO during the recent solar activity minimum.

1 Introduction:

Energetic particle measurements in space generally use telescopes of stacked silicon detectors operated in coincidence, completed with an anticoincidence shield. The pulse heights of the signals from the stacked detectors are analyzed, and particle identification is based on the dE/dx versus residual energy method. There are always background events which fulfill the trigger conditions, although the analyzed combination of signals does not correspond to a real particle. Typical sources of background include accidental coincidences of two or more particles, leaks in the anticoincidence shield, as well as products of high-energy particles interacting with the surrounding structure.

The recorded background can be effectively eliminated for telescopes consisting of 3 or more elements. At energies below about 10 MeV, two-element telescopes allow less efficient methods to be applied. They usually select certain areas of the dE/dx-E plane representing various identified charge numbers, and all events falling on these areas are accepted as real particles. Although unable to discriminate between background and real particles falling on these areas, their results are accurate enough for high flux conditions. For low-flux periods or/and high instrumental background such methods prove unsatisfactory. The statistical method presented here estimates the contribution of background within these areas and is therefore more reliable for obtaining real particle fluxes as demonstrated for quiet-time data from the ERNE and EPHIN instruments, both aboard the SOHO spacecraft.

2 Instruments:

The low energy detector LED of the ERNE instrument is a simple telescope providing two pulse heights for each accepted particle (see Torsti et al., 1995). Initially, acceptable events are selected by the electronics by requiring a two-fold coincidence signal not vetoed by the anticoincidence detector underneath the energy loss (D1) and residual energy (D2) detectors. The energy loss detector is composed of seven, 20 and 80 μm thick individual parts, optimizing the performance in the range of 1.5-12 MeV for protons. Due to the simple mode of operation and because the sides of the sensor are not shielded by the anticoincidence detector, background rejection is not very efficient. For low fluxes during quiet times this causes a significant source of error. A background reduction method, not removing the background from the area covered by the tracks of real particles, would result in highly distorted intensities, particularly for protons.

The Electron Proton Helium Instrument (EPHIN) of the COSTEP experiment consists of a stack of 5 silicon detectors, surrounded by a plastic scintillator representing the anticoincidence shield (see Müller-Mellin et al., 1995). The two top sensors A and B are divided into 6 segments for position sensing. The background can be diminished by reducing the aperture cone, e.g. by exploiting the so-called “parallel” geometry, that is, taking only coincidences of the corresponding segments of A and B into account. Such a coincidence condition results in narrower tracks in the dE/dx-E plane thanks to lower pathlength variation, while on the other hand it reduces the geometry factor from about 5 cm^2sr to 1 cm^2sr.

3 Method of background reduction:

The methods discussed here are based on transforming the dE/dx-E pulse heights into particle identification numbers (PIN), which in principle correspond to scaled mass numbers, and presenting them as a function of the total energy. In such a presentation the tracks of protons and helium should ideally appear as straight vertical lines. Therefore, the projections of the tracks on the PIN axis would give distributions with their widths depending only on the energy dependent mass resolution of the instrument.

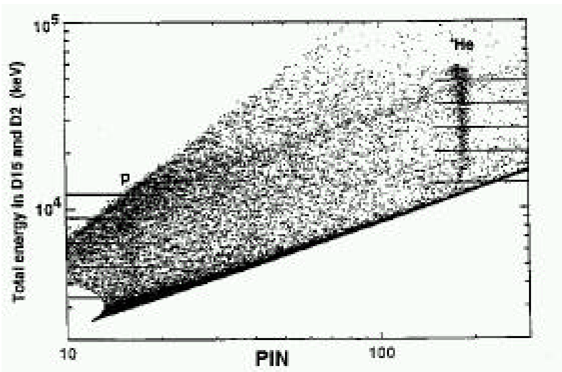

Figure 1: PIN plot of LED PHA data showing proton and ^{4}He tracks.

3.1 ERNE-LED: The particle identification numbers were calculated by the same simple relation as is applied in the ERNE on-board analysis of protons and helium nuclei: $PIN = C(E_{tot}^{\alpha} - E_{res}^{\alpha})/t$ (Valtonen et al. 1997). Here E_{tot} and E_{res} are the measured total and residual energies of the particle, t is the thickness of the energy loss detector, C is a scaling constant, and α is an empirical constant. The formula is based on the power-law approximation of the range-energy relationship and on the assumption that the ions are fully stripped. Fig. 1 shows the data collected by LED during 295 low-flux days in 1996 and 1997 transformed into the PIN representation with $\alpha = 1.75$. A rather vague proton track is seen at PIN values of about 15, and a more clear ^{4}He track around 170. The background is more or less uniform, excluding the heavy concentration at the lower edge of the plot, corresponding to the background at low residual energies. This background sets the operational lower energy limit of the instrument during low-flux periods, and restricts particularly the proton data. The background at the highest proton energies is also rather high, increasing the uncertainties of the results.

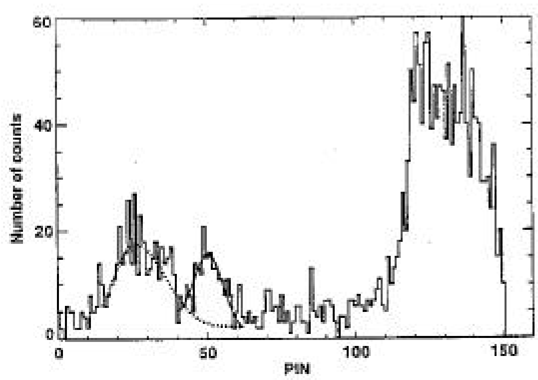

Figure 2: PIN projections of LED 3.4-5.0 MeV protons. Solid curve: fit to real particles + background, dotted curve: assumed background.

The operational energy range was divided into bins (indicated in Fig. 1 by horizontal lines), then the number of counts in each bin was projected on the PIN axis, giving distributions as a function of PIN of the superimposed real particles and the background. This was done separately for each D1-D2 pair. The peaks corresponding to various nuclei can be calculated. The number of real particles belonging to each peak were then estimated by first fitting to the peak region a sum of a Gaussian and a polynomial of second degree. The assumed background underlying the real particle peak, approximated by a polynomial, was then subtracted from the total counts, thereby obtaining the estimated number of real particles. An example of such a distribution is presented in Fig. 2 for protons. The background was calculated for each time period and was found to have the same constant value for all detectors of the same type.

3.2 EPHIN: The transformation described above has also been carried out for the pulse height data of the EPHIN detector for a 3-day period following the 6 November 1997 solar event, and for a 61 day quiet period in 1996. To calculate PIN the value α=1.75 was used, which gave the minimum variation of the maximum density line with particle energy for the parallel geometry. The E-PIN plane was then divided into 11 energy intervals in the range of 4.3 MeV to 22 MeV, over which the variation of the maximum density along the proton track is negligible as compared to the width of the peak, then the PIN histograms were constructed.

Within these narrow energy limits one can reasonably assume that the variation of the density of background counts with energy at a fixed PIN value is negligible.

High-flux data, dominated by solar low-energy particles over galactic ones, were used to determine the shape of the PIN distribution of “true” events as they are much “cleaner” in terms of the signal-to-noise ratio for several MeV particles: spurious events due to galactic particles penetrating the anticoincidence shield play a relatively minor role. The following assumptions are made: (1) the measured distribution is a sum of two distributions, one of the genuine particles $c_g(E,PIN)$ confined to a narrow PIN region at a fixed E, and another one of the background $c_b(E,PIN)$ which varies slowly with E and PIN; (2) at a fixed E_0 energy, the shape of the distribution $c_g(E_0,PIN)$ is independent of the particle flux. The distributions (denoting PIN with n) are written in the form of $c(E_0,n)=c_b(E_0,n)+c_g(E_0,n)$, where $c_b(E_0,n) = a+b(n-n_0)$ and $c_g(E_0,n) = g \exp(-h(n-n_0)^2)$.

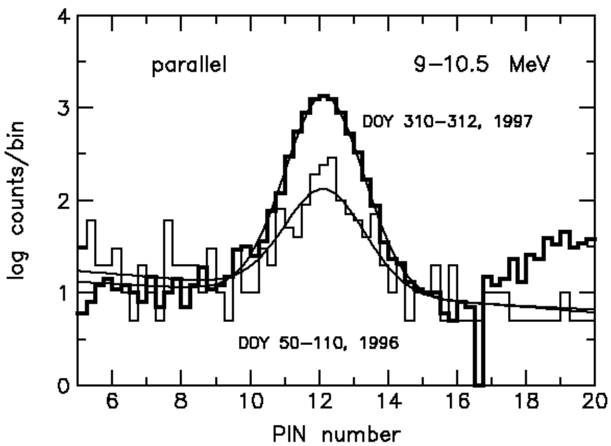

Figure 3: PIN histograms of logarithmic counts of EPHIN, near the proton track: high-flux (thick line), low-flux (thin line) period.

Assumption (2) means that the values of parameters h and n_0 must be the same for low and high-flux periods, while a, b, and g are allowed to be different. To find the most probable values of parameters a, b, n_0, g, and h, a procedure consisting of the following steps was executed for each energy interval.

(1) Appropriate bins of PIN were chosen which have sufficient statistics while resolving the peak of the distribution (for protons, at average PIN ~12, the width of the bins were taken as 0.25, while the width of proton track was about 4);

(2) The 5-parameter least squares fit was first performed for the high intensity period $c_1(E_0,n)=a_1+b_1(n-n_0)+g_1\exp(-h(n-n_0)^2)$ (see Fig. 3), and using the same values of h and n_0 the parameters of the linear trend of the quiet period a_2, b_2, and g_2 were determined.

(3) Linear trends were subtracted from both empirical distributions: $c_{g1}(E_0,n) = c_1(E_0,n) - (a_1+b_1(n-n_0))$, $c_{g2}(E_0,n) = c_2(E_0,n) - (a_2+b_2(n- n_0))$, then a factor R was determined by requiring that $Rc_{g1}(E_0,n)$ reach a best match with $c_{g2}(E_0,n)$ (this corresponds to a shift on the logarithmic scale, + marks in Fig. 4). Here only the points near the true particle track were taken into account.

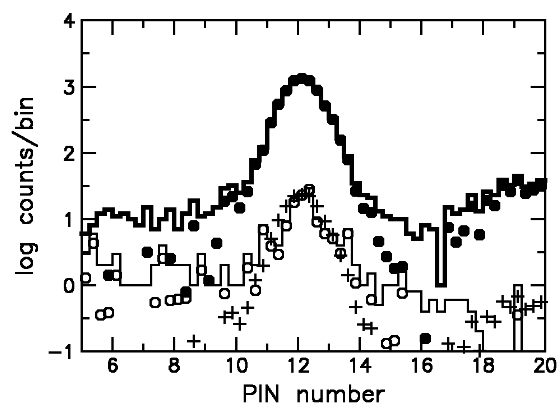

Figure 4: thin and thick lines as in Fig. 3, filled and empty circles: linear trend subtracted, + full circles shifted logarithmically.

(4) The logarithmically shifted high-flux distribution is subtracted from the low-flux one: $c_{b2}(E_0,n)=c_{g2}(E_0,n)-Rc_{g1}(E_0,n)$. The difference represents the background distribution of the low intensity period. A linear (or a higher polynomial if necessary) function can then be fitted to the remaining distribution on the linear scale (see the straight line in Fig. 5).

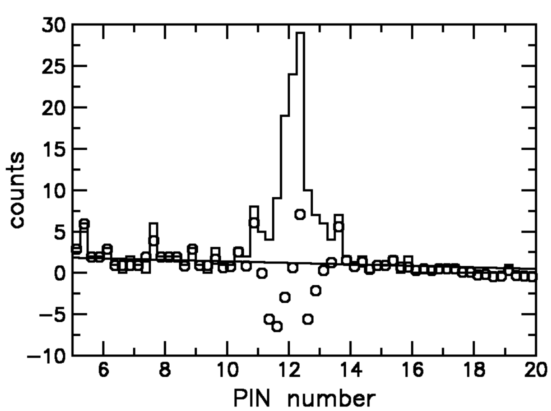

Figure 5: full line histogram: measured low-intensity data, circles: estimated background, straight line: linear approximation.

(5) The number of background particles can be determined by integrating over PIN values where the fitted Gaussian distribution yields numbers above a certain limit (say 0.5); beyond these limits the probability of finding a genuine particle can be expected to be small.

4 Results:

4.1 ERNE-LED As an example of the first simple method, the distribution in Fig. 2 was obtained by histogramming the logarithmic PIN data of 150 low-flux days in 1996 in the energy interval 3.4-5.0 MeV. The proton peak can be identified to lie around the PIN value 50, surrounded by and lying on a relatively high background. The number of real protons was estimated and described in Section 3.1 The same method was applied for LED in 6 energy intervals between 1.5-12 MeV for protons. in some cases the shape and position of the proton peak was even less obvious than in Fig. 2. In such cases high-flux period data were used to identify the peak. Even at very high background conditions (when the background exceeds the expected genuine counts) relatively reliable estimates of the flux could be obtained. The systematic errors in the determination of fluxes are estimated to be typically below 30%. Therefore, significant improvement in the quality of low-flux, high-background proton data of LED was achieved by applying this method.

4.2 EPHIN A procedure similar to that described in the previous section was carried out for a 61 days long contiguous very quiet period for >4 MeV protons between DOY 50 and 110 in 1996. First, the histograms were calculated in the 11 energy windows mentioned, the parameters adjusted for both high and low-flux periods. The high-flux PIN distribution turned out to be very well approximated by a Gaussian profile between PIN values of about 8 to 15 (Fig. 3). The smaller peak at the right is attributed to deuterons. The importance of determining the parameters of the Gaussian is clearly seen from the comparison with the low flux period, where the fit is much poorer due to the insufficient statistics. The position of the maxima and their width are compatible. The background can be relatively well approximated by a linear trend in each case. Proton and helium fluxes deduced from EPHIN pulse-height analysis are presented in the accompanying paper by Kecskeméty et al. (1999).

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