Proceedings of ICRC 2001: 2271 © Copernicus Gesellschaft 2001

ICRC 2001

A new multi-detector telescope calibration method

C. Martin[1], **E. Bronchalo**[1], **J. Medina**[1], **E. Campo**[2], **D. Meziat**[2], **C. Olalla**[1], **M. Prieto**[2], **MD. R-Moreno**[2], **and S. Sánchez**[2]

[1]Departamento de Fsica. Universidad de Alcal. Ctra. Madrid-Barcelona km 33,600. 28871 Alcal de Henares (Madrid). Spain.
[2]Departamento de Automtica. Universidad de Alcal. Ctra. Madrid-Barcelona km 33,600. 28871 Alcal de Henares (Madrid). Spain.

Abstract. A new calibration method, applicable to multi-detector telescopes, is presented. This method is based on the comparison between experimental data and the ones obtained from Monte-Carlo simulation. The method just needs a accurate knowledgment of the detector spectrum. To test the method, data obtained in GANIL accelerator, are used. Obtained results are presented and the method accuracy is concluded.

1 Introduction

The calibration of a particle detector requires to find two calibration parameters (CP) relating the energy signal ΔE released by a particle with the ADC channel number N obtained at the output,

$$\Delta E = \alpha N + \beta \quad (1)$$

where α is the slope and β is the zero shift of the detector-amplifier-ADC chain. Here is supposed that the detector system is linear, that is, non-linearity in the electronics and pulse-height defect are neglected. For calibration procedures that considers non-linearities see Mulgin et al. (1997) and Tabacura et al (1999).

The complete calibration of a telescope composed of n detectors requires finding $2n$ parameter α_i and β_i. For this purpose several calibration methods are widely used. For telescopes intended to detect light ions, individual calibration of every single detector using radiactive alpha sources can provide enough precision, if the maximum energy to be released in every detector is not much higher than ~ 5-8 MeV (we return to this point on next section).

For higher energy ranges or heavier ions, calibration at accelerator is usually performed. In this case, there are two possibilities to know the energies of the ions detected. One is to align the telescope with a low intensity beam that contains ions of different charges but a well-defined rigidity, selected magnetically. The beam intensity must be kept low enough to avoid unacceptable damage in the detector materials. The other one is to detect beam ions scattered elastically from a target, whose energy can be easily known from the collision kinematics. In this second case, the elastic events from a beam-target pair provide only one energy peak for every detector, that can be inssuficient. Thus, several targets or a beam with several charges must be used. Besides, if the collision chamber is small, the solid angle covered by the telescope can be large, and the elastic peak detected in each detector can become wide because of kinematical effects.

Even if the energy of the events detected is not known, a calibration can be made through the comparison between the results of the calibration experiment and a Monte Carlo simulation of the same experiment (Matsinu et al., 1996; Fang et al., 1999). Indeed, this method requires a very good knowledge of the stopping powers of the different ions detected on the detector material, that is not always known with enough precision. In any case, a beam with very well defined energy is required.

In this work we propose a new calibration method that does not require a precise knowledge of stopping powers for the ions detected, neither a high precision in the beam energy or in the dispersion angle in the reaction chamber.

2 Calibration method

The main idea of the calibration method is to superpose on a ΔE_i - ΔE_{i+1} map two different data sets: experimental data from accelerator and data from a simulation of the same calibration experiment. In order to allow the representation of both data sets in the same map, the experimental data are converted from channels to MeV leaving the CP's as free parameters. Then a grid is built on this map and every event (experimental or simulated) is associated with the corresponding cell in the grid. The similarity between both bidimensional data distributions is greater as the CP's approach their correct values, and this is reflected in the

Correspondence to: C. Martín (martin@grc86.fis.alcala.es)

number of filled cells (NFC from now on) in the map. For CP values close to the correct ones, both distributions are nearly overlapping, and the NFC exhibit a minimum.

We must emphasise that the number of events associated to a cell is not taken into account to consider filled that cell, while being greater than zero. Although this procedure could seem strange from a statistical point of view, it has two advantages: a) is insensitive to small differences in shape and intensity between the energy spectra of simulated and experimental data; b) is much faster than a similar procedure counting the population of every cell in the grid. Nevertheless, if the experimental data set has a high noise level, the condition to consider filled a cell can be changed from *greater than zero* to *greater than a threshold* defined by the noise level.

Although based on a conceptually clear idea, the implementation of this calibration method meets several difficulties of numerical nature that we pass to expose.

1) Several local minima are observed on a NFC versus CP plot. This happens for CP values leading to the superposition of experimental and simulated ΔE-E lines corresponding to different elements. However, as the geometrical features of these lines (curvature, distance between neighbour lines, thickness) are different for different elements (and, on a lesser degree, for different isotopes), the similarity is greater and the NFC smaller when the overlapping lines correspond to the same elements. Therefore, the lower local minimum gives without ambiguity the correct CP values.

2) How to choose the cell size? To answer this question, two criteria that point to opposite directions have to be taken into account. On one side, the smaller cell size, the longer computation time. On the other side, the smaller cell size, the best can be compared experimental and simulated data, and so the best resolution can be reached on the CP's. The smaller scales on a ΔE-E map are the thicknesses of isotopic lines, if isotopes are resolved, or elemental lines, if they are not. This suggests choosing the cell thickness of the same order as these features.

3) For the simultaneous application of this method to a couple of successive uncalibrated detectors (let say detectors 1 and 2), the minimisation of the NFC must be performed in the four-dimensional space of the parameters α_1, β_1, α_2 and β_2. This is a very time consuming task, not forgetting the fact that the discrimination between local minima becomes more difficult as the dimension of parametric space increases. To overcome this problem, a numerical technique based on the theoretical expression for the stopping power has been developed which stablishes a linear relation between the CP's of two successive detectors. With this relation, the minimisation of the NFC can be performed on two (let say α_1 and β_1), instead of four (α_1, β_1, α_2 and β_2) parameters. Although integrated as a part of the calibration method, this technique is essentially independent, and could be used by a different calibration method or for different purposes. Let then explain it with some detail before showing results of the calibration method applied to a solid-state detector telescope.

2.1 Technique to reduce the number of free CP's.

For the sake of simplicity, consider a particle telescope whose detectors are made from the same material (the extension of the technique to heterogeneous detectors is quite easy). Then the energy losses of an energetic ion passing through the telescope depend only on its charge, mass and energy. In the energy region from some MeV/amu to some hundreds of MeV/amu, the stopping power can be expressed approximately as:

$$-\frac{dE}{dx} = C\frac{AZ^2}{E} f\left(\frac{E}{A}\right) \tag{2}$$

where Z, A, and E are the ion nuclear charge, mass and kinetic energy, respectively, and C is a constant for a given detector material. Below the GeV region, the relativistic corrections to this expression can be included approximately on $f(E/A)$. It is convenient to point out that the function $f(E/A)$ varies very slowly compared with the factor $1/E$.

The energy ΔE_i released on detector i can be obtained integrating the stopping power along the detector thickness X_i. Let suppose a particle whose energy is high enough to traverse detectors i and i+1 with small losses compared with that energy. In this case the energy losses can be well approximated by

$$\Delta E_i \cong X_i \cdot C\frac{AZ^2}{E_i} f_i \tag{3}$$

where E_i is the energy at the entrance of the detector and $f_i \approx f(E_i/A)$. Then we can stablish the following relation between the energy losses on detectors i and i+1:

$$\frac{\Delta E_{i+1}}{\Delta E_i} \cong \frac{X_{i+1}}{X_i}\frac{E_i}{E_{i+1}}\frac{f_{i+1}}{f_i} \tag{3}$$

In the limit of high incident energies, the energy losses are small enough to consider E_i and E_{i+1} essentially equal, and the same can be said about f_i and f_{i+1}. Then, for high enough incident energies the energy losses on two successive detectors are proportional (on the opposite to the case when the particle crosses detector i and stops on detector i+1, when both energy losses are anticorrelated):

$$\Delta E_i \cong \frac{X_i}{X_{i+1}}\Delta E_{i+1} \tag{4}$$

These energy signals are recorded at the output of the electronics as channel numbers N_i, N_{i+1}. Then, plotting on a N_i - N_{i+1} map the events corresponding to particles that traverse both detectors (and consequently that release on detector i+2 a signal higher than a threshold), a region of

points that tend to align along a straight asymptote is obtained. Let the equation of this asymptote be

$$N_i = A_{i,i+1} \cdot N_{i+1} + B_{i,i+1} \tag{5}$$

Indeed this equation, expressed in channels, must be the same as (4), whose units are energy units (MeV, usually). That way, from experimental data selected by a threshold on detector i+2 as the only condition, we can find a version in channels of relation (4). The numerical method to find the coefficients $A_{i,i+1}$ and $B_{i,i+1}$ of the asymptote from the selected (N_i,N_{i+1}) points is explained with some detail in the appendix at the end of this paper.

Then we can use CP's (yet as unknowns) to express linear equations (4) and (5) in the same units and equate coefficients. That leads to the following relations:

$$\left.\begin{aligned} \alpha_i &= \frac{X_i}{X_{i+1}} A_{i,i+1} \cdot \alpha_{i+1} \\ \beta_i &= \frac{X_i}{X_{i+1}} \left(\beta_{i+1} + B_{i,i+1} \cdot \alpha_{i+1}\right) \end{aligned}\right\} \tag{6}$$

For each detector pair (i,i+1), these relations reduce by two the number of free CP's. In fact, this reduction technique could be used to reduce the number of free CP's of a *n* detectors telescope from 2*n* to just 2, provided an enough number of experimental events of enough energy. A so big reduction is not always possible, however, because the straight asymptotes on all the (N_i,N_{i+1}) maps are not always clearly defined, depending on the spectra of experimental data. But for nearly any reasonably designed calibration experiment on accelerator, this technique can be applied without problems to, at very least, the first two detectors. This can serve as a seed to apply the calibration method described above repeatedly, but performing the minimisation of the NFC on two CP's.

As an additional use of this technique, a telescope that includes one pre-calibrated detector can be completely calibrated using (6) repeatedly with the CP's of the pre-calibrated detector as seed.

3 Application to experimental data

In this section we apply the method described in the previous section to the calibration of a heavy-ion telescope with calibration data. This telescope is the sensitive part of the PESCA instrument (Peral et al., 1997), intended to measure cosmic ions in the payload of the Russian spacecraft PHOTON. The calibration experiment was performed in GANIL in April 1997. At that time, the telescope had four silicon surface barrier detectors whose thickness was chosen to detect Fe ions with energies between 3.5 and 50 MeV/uma, with the fourth detector acting as veto detector. The events registered correspond to interaction fragments of the reaction between 52 MeV/uma ^{58}Ni ions with 30 μm thick ^{197}Au target, with the telescope placed at 45 cm from the target and a laboratory dispersion angle of 7º.

In figure 1 we show the lost energy spectra in channels. It has been chosen because the raw data show a good isotopical separation.

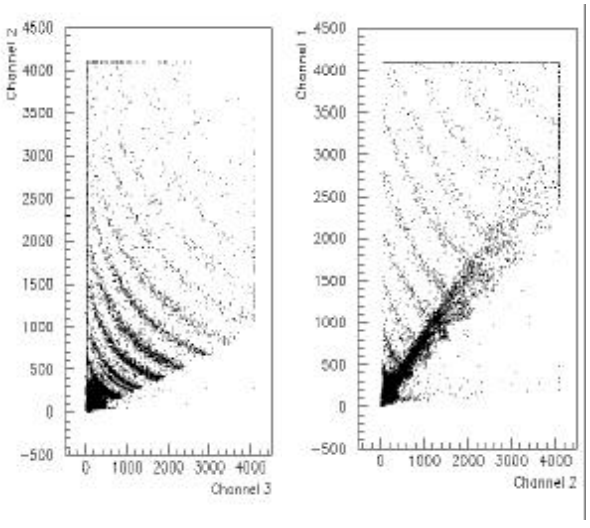

Fig. 1. Lost energy spectra ΔE-E in channels.

We have simulated the response of the telescope by means of the GEANT program. This program allows to simulate the response of any experimental device in the presence of a flux of charged energetic particles. We have simulated a cualitatively similar response to our device generating stable isotopes from hydrogen to iron with energies between 1 and 50 MeV/uma. The ΔE-E spectra corresponding to the GEANT simulation is shown on figure 2.

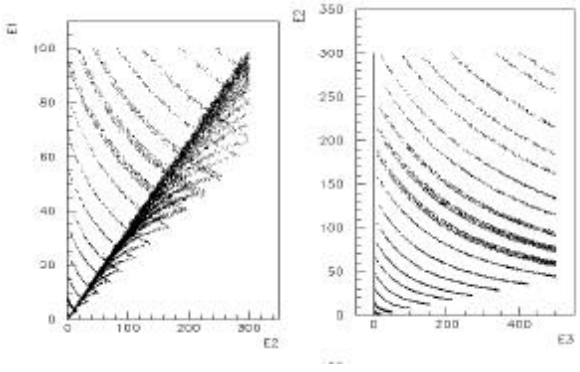

Fig. 2. Lost energy spectra ΔE-E simulated in MeV.

Once we have the two sets of spectra, we are be able to apply our calibration method. We have used a 200×200 cell grid for both (DE_1,DE_2) and (DE_2,DE_3) mapps. First, the (DE_1,DE_2) simulation values are projected onto the grid and then the (N_i,N_{i+1}) experimental data are projected too giving an initial value to the β_1 parameter (β_1=0 MeV) and successively changing the α_1 parameter in the [0, 0.02]

range with step $\Delta\alpha_1=10^{-4}$ MeV/channel. The number of "filled cells" vs α_1 is shown in figure 3.

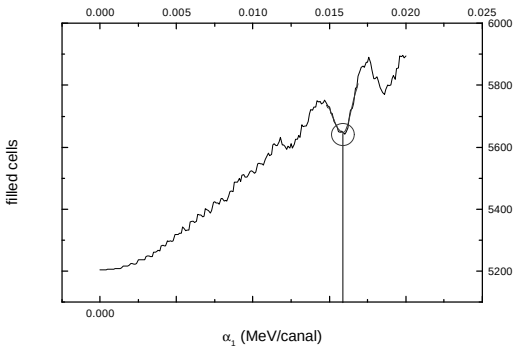

Fig. 3. Number of "filled cells" vs α_1

The graphic shows a inceasing tendence in the number of filled cells followed by a fluctuating behaviour, whose first minimum gives the correct value for the parameter α_1. Now, this parameter α_1 is used as initial value to determinate the offset parameter β_1 using the same process as before, making a succesive change of parameter β_1 in the [-2, 2] range with step $\Delta\beta_1=0.01$ MeV. The number of "filled cells" vs β_1 is shown in figure 4.

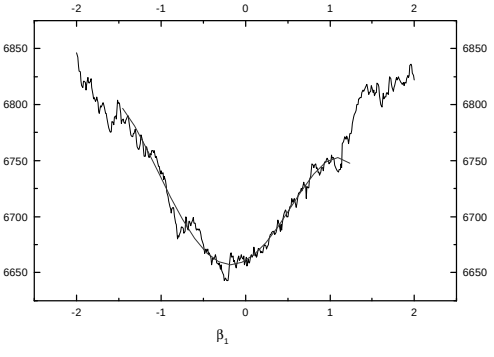

Fig. 4. Number of "filled cells" vs β_1.

With these calculated parameters α_1 and β_1, we use a recurrent process till the convergence of values is found.

As we said, we only need to know two parameters, the thickness of the detectors (X_i,X_{i+1}) and the coefficients $A_{i,i+1}$ and $B_{i,i+1}$ of the straight asymptote from the (N_i,N_{i+1}) points for the calibration of all detectors. If we make use of the equations in formulae (6), that leads to the following relations:

$$\begin{aligned} \alpha_2 &= \frac{X_2}{X_1} A_{1,2}\alpha_1 = \frac{151}{53}0{,}8863\,\alpha_1 \\ \beta_2 &= \frac{X_2}{X_1}\left(\beta_1 + B_{1,2}\,\alpha_1\right) = \frac{151}{53}\left(\beta_1 + 32{,}6\,\alpha_1\right) \end{aligned} \qquad (7)$$

Then we substitute the CP's of the first detector (α_1 and β_1) and obtain α_2 and β_2. The calibration of the third chain can be obtained using the previous method calculating the ecuation of the straight asymptote from the (N_2,N_3) points or we can apply the method of successive CP's variation since now we know the energy-channel relation for the second chain. In fig. 5 accelerator data converted to energies with the previous calculated relations together with simulation data are shown.

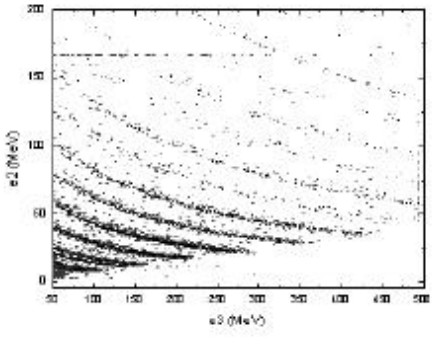

Fig. 5. Comparison between accelerator data converted and simulated data.

5 Conclusions

A new calibration in energies method has been developed that allow a effective conversion from ADC channels into energy values based on the comparation of experiment data with Monte Carlo simulation data of the same experiment. One of the acquisition registered in the GANIL accelerator with the PESCA instrument has been selected to apply this calibration method. This method is easily applied to any multimodular telescope and will give information about the gains we have to fix in the amplification chains. One of the main advantages of this method is that we obtain similar results to other methods using no references points.

Acknowledgements. This work have been souported by spanish CICYT (grant ESP99-1066-C02) and by the European Community-Access to Research Infrastructure action of the Improving Human Potential Programme, contract Nº HPRI-CT 1999-00019.

References

Fang D. et al., Chin. Phys. Lett., 16, 15-22, 1999.
Mastinu P.F. et al., Nucl. Instr. Meth., A371, 510-513, 1996.
Mulgin S.I. et al., Nucl. Instr. Meth., A388, 254-259, 1997.
Peral L. et al., IEEE Trans. Nucl. Sci., 44, 1442-1447, 1997.
Tabacaru G. et al., Nucl. Instr. Meth., A428, 379-390, 1999.