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Automatic procedure for mass and charge identification of light isotopes detected in CsI(Tl) of the GARFIELD apparatus

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ABSTRACT

Mass and charge identification of light charged particles detected with the 180 CsI(Tl) detectors of the GARFIELD apparatus is presented. A "tracking" method to automatically sample the Z and A ridges of "Fast–Slow" histograms is developed. An empirical analytic identification function is used to fit correlations between Fast and Slow, in order to determine, event by event, the atomic and mass numbers of the detected charged reaction products. A summary of the advantages of the proposed method with respect to "hand-based" procedures is reported.

1. Introduction

The availability of 4π multi-detectors [1–3] provides the opportunity for studying very complex nuclear phenomena and events associated to small cross-sections. The price to be paid, however, comes in form of a vast amount of multi-dimensional data, which need to be calibrated before obtaining physical correlations.

The calibration of the measured signals can be quite man-power and time consuming, for several reasons:

- the large number of detecting elements covering the laboratory solid angle,
- different detectors (ionization chambers, drift chambers, semiconductors, scintillators) can be used in experiments, each requiring an "ad hoc" procedure,
- the rich variety of nuclear species produced in the reaction in a wide energy rang.

New semi-automatic methods are therefore required to perform a comprehensive data calibration and analysis in a reasonable amount of time.

We recall hereafter the scheme of the usually employed procedures to identify (A,Z) isotopes, which do not rely on the "brute force", even more time-consuming, approach like graphical cuts.

Two steps are normally necessary for each detector used in the experiment (for instance when the (A, Z) identification is performed through Fast–Slow [4]) or via $\Delta E-E_{residual}$ [5]):

(1) In a bidimensional scatter plot several points are "by hand" sampled on the ridges of well defined isotopes. Some isotopes can be easily identified by simple inspection, either due to their abundance (^4He) or their separation from other masses ($^{1,2,3}H$). Charge, mass and coordinates of the sampled points are organized in a table.
(2) The parameters characterizing the detector response to the charge (Z) and mass (A) are determined by fitting the coordinates of the previously sampled points. If an analytical [5], even empirical [6] function, describing one of the two variables as a function of the other does not exist, the set of points for a given isotope (A, Z) are fitted one by one via polynomial functions [4,7]. The fit parameters are stored in a table.

Once the identification function is determined, by studying the ridges, therefore the most probable correlations, the event by event identification can be performed. For all the measured

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events, isotopes are identified in mass and charge, by minimizing the distance of the measured signals with respect to the values provided by the identification function, calculated with the parameters of the hit detector.

Clearly, in the case of a large number of detectors/telescopes, the most time consuming step of the identification procedure is the first one, because of the accurate sampling of a huge number of points on each isotope branch needed to obtain in the second step a reliable set of parameters. However, [6], even the efforts to analytically link the employed variables are of great importance, to make it possible to identify isotopes which cannot be sampled, because of their low statistics (e.g. in backward-angle detectors).

Our aim is to improve both the previous steps, in order to greatly reduce, for a large number of detectors, the time dedicated to offline calibration with respect to methods based on graphical cuts or "by hand" sampling procedures.

In this paper we present a new procedure, developed in the ROOT framework [11], aimed at extracting from Fast–Slow components coming from CsI(Tl) scintillators mass and charge of the detected Light Charged Particles (LCP, $Z \leq 2$) and Fragments. The ROOT powerful set of software tools uses object oriented programming and provides the user with several methods of displaying and analyzing data.

We will show that our procedure, compared with other methods, considerably saves time without loss of precision.

We present here the application of our identification procedure to data collected in experiments performed by the Nucl-ex collaboration [12] at the Tandem-Alpi complex of LNL (Laboratori Nazionali di Legnaro) with the GARFIELD apparatus [2]. These experiments have been performed after the completion of the upgrading to digital electronics; in this way, without the need of adding complicated and costly analog channels, we could obtain the Fast–Slow components from the CsI(Tl) by means of ADC-Digital Signal Processor (DSP) boards [8,9] which processed the electric signals directly fed by the charge preamplifiers.

2. The experiment

In this paper we show the results of the identification procedure firstly applied to the data coming from the reaction $^{32}S+^{58}Ni$ at 16.5 AMeV incident energy. At the end, we show the application of the same procedure to data of other measured reactions. For all the reactions the energy range of the measured particles and fragments extends from very low values up to 150 MeV.

The main detector of the GARFIELD apparatus consists on two gas chambers with microstrip readout, followed by CsI(Tl) scintillators [2], for a total of 180 telescopes made of ΔE gaseous detectors (filled by CF_4 gas at 50 mbar pressure) and CsI(Tl) stopping detectors. The GARFIELD chambers cover the angular range $30^\circ \leq \theta_{lab} \leq 150^\circ$.

The characteristics of the CsI(Tl) scintillators of the GARFIELD array used in these tests have been described in detail elsewhere [13,14]. We only recall here that the scintillators have been carefully tested in order to select those with light-output resolution of about 3% for $\alpha-$particles of about 5 MeV (standard three peaks radioactive source [13,14]). Moreover using around 8 AMeV *Li* and *C* elastically scattered beams on *Au* target the light-output resolution resulted in the range 2–3%.

Fragments ($Z \geq 3$) are identified in charge by analyzing $\Delta E-E$ matrices, where ΔE is the energy lost in the gas and E the residual energy, measured by the CsI(Tl) light output.

A new designed electronics [8,9] has been used for the signal coming from CsI(Tl) detectors for identifying the light isotopes by means of pulse-shape analysis. The Fast and Long components of the CsI luminescence have been obtained via ADC–DSP channel, one for each crystal as described hereafter.

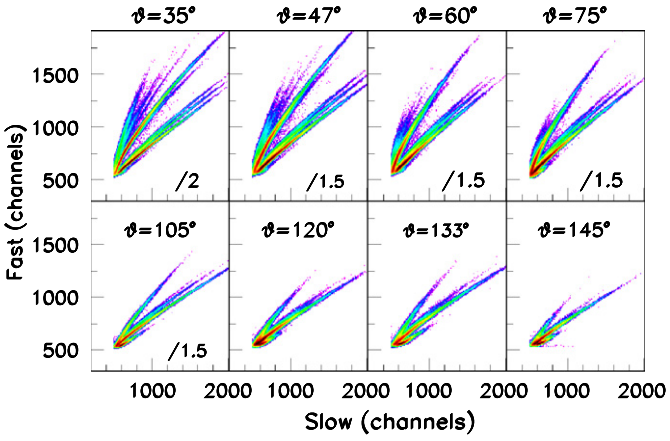

Fig. 1. (Color online) Fast–Slow bidimensional plots of a GARFIELD sector for the reaction $^{32}S+^{58}Ni$ 16.5 AMeV incident energy. For a better presentation in some of the panels Fast and Slow have been scaled by the reported factor.

The charge signal integrated in a preamplifier is sampled by an ADC (125 MS/s sampling frequency, nominal 12 bits precision) and the information is processed by a DSP which, among other variables, produces Short and Long components. These are obtained applying to the ADC sampled points two shaping filters with different time constants. In our case a semi-Gaussian filter (t_f=700 ns) produces the Short component, while a triangular shaping with a peaking time of about 6 μs [9] gives the Long contribution. The Long component is basically proportional to the total light output, for any particle species.

Of course, Short and Long contributions are largely linearly associated, since part of the signal produced by the long-time fluorescence components of the CsI(Tl) is integrated within the Short quantity. For a good isotope visualization and a better presentation of the data in the identification scatter-plots, one tries a partial decorrelation and fill the histos with new quantities obtained from a linear mixing of Short and Long. In our case we choose the quantities Fast=Short and Slow=Long$-4*$Short as done in Ref. [9], capable of separating the isotopic lines, leaving the Slow observable larger than 0 (see Fig. 1).

We show in Fig. 1 the Fast–Slow bidimensional plots for one of the 24 azimuthal sectors of GARFIELD, as shown on-line by the GARFIELD data monitor recently implemented [10]. An offset of 500 channels has been added to the signals, for a better presentation of all figures.

3. Identification procedure

The procedure we are proposing is based on an automatic tracking of the ridge of the LCP branches, with the aim of confining the action of the researcher only to check the final isotope mass spectra and to evaluate the quality of the isotopic designation, through a Figure-of-Merit [20] (FoM).

We show in Fig. 2 the two-dimensional Fast–Slow histogram, for the GARFIELD CsI(Tl) crystal placed at $\theta = 35^\circ$, which has been used for tuning the identification procedure, which will be shown to properly work for all the other crystals employed in the experiment (see Fig. 8 of Section 3.2).

Lines visible in the histogram correspond to particles with different A and Z values (isotope lines). The ridge sequence of γ, p, d, ^3H, ^3He and $\alpha-$particles can be easily distinguished, while other, more dispersed, ridges need to be more carefully studied.