IL NUOVO CIMENTO **42 C** (2019) 65
DOI 10.1393/ncc/i2019-19065-2

COLLOQUIA: EuNPC 2018

Particle identification using current maximum obtained from charge

First results of the DIGIGARF experiment

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received 5 February 2019

Summary. — Particle identification plays a crucial role in the study of isospin dynamics, and several identification techniques have been developed in the last decades. Amongst them, the pulse shape analysis methods allow to identify those fragments that are fully stopped in a single detector layer by studying the shape of the signal induced by the impinging fragment. The correlation of the maximum of the induced current signal with the energy of the fragment is known to give a good isotopic identification, but requires to acquire the current signal. However, when the current signal isn't available, it can be reconstructed from the digitized charge signal. The algorithms used for the reconstruction are presented briefly along with the first results obtained during the DIGIGARF experiment at LNL.

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1. – The Garfield+RCo apparatus

The GARFIELD+RCo apparatus ([1] and references therein) is a 4π apparatus for charged particle detection and identification hosted in the third experimental hall at Legnaro National Laboratories of INFN. The apparatus is managed by the NUCL_EX collaboration, which is also involved in the FAZIA project ([2] and references therein). The RingCounter (RCo from now on) is a three stage telescope placed at forward angles ($5^\circ < \theta < 17^\circ$). The first stage is a Ionization Chamber (IC), it is followed by a layer of $300\mu m$ silicon (Si) strip detectors and by CsI(Tl) scintillators ($45mm$ thick). The silicon layer is made up of 8 pie-shaped Si pads (sectors), each divided in 8 annular strips. Fragments that are stopped inside the Si layer can be identified in charge using the standard $\Delta E - E$ technique applied to the IC and the Si layerBruno. To achieve mass identification, the pulse shape analysis methods (PSA from now on) are used. During the R&D phase, the FAZIA collaboration has tested two PSA methods, based on the two correlations "Energy *vs* Charge rise time" (Q_{rise} from now on) and "Energy *vs* Current maximum" (I_{max}), showing that the latter has better performances in terms of isotopic identification [3]. However, up to now the RCo apparatus was capable of exploiting only the Q_{rise} method, since the I_{max} requires to acquire the current signal which is not directly measured by the apparatus.

The readout electronic of RCo is fully digital, and each detector is read by a dedicated front-end channel. The front-end electronics is currently being upgraded, and the old channels, which have a 12-bit ADC and a DSP for signal processing [4], will be replaced. The new front-end channels have a 14-bit ADC (hence a higher precision of the digital electronics) and are equipped with a FPGA [5] for advanced signal processing.

2. – Current maximum extraction

We have developed an algorithm for the extraction of the current maximum from the charge signal. The first step of the extraction algorithm is the interpolation of the charge signal using the "Smoothing Spline" method [6-9]([1]) to obtain an interpolated (continuous) charge signal. The second step is the differentiation and sampling of the interpolated charge signal that produces a sampled reconstruction of the current signal, from which the maximum is extracted. Both steps can be implemented with good approximation in terms of finite impulse response linear filters. They have been implemented on the FPGA of the new RCo digitizers, so that only the I_{max} value is transmitted to the acquisition system and not the full digitized signal, thus greatly reducing the needed data throughput.

3. – First Results of the DIGIGARF experiment

To test the new electronic board and the algorithms for the extraction of the current maximum we studied the reaction ^{16}O + $^{12,13}C$ at 107 MeV/nucleon with the RCo detector at LNL (DIGIGARF experiment - april/may 2018). The signals coming from the silicon layer of RCo have been acquired with both the old and new front-end electronics

([1]) Smoothing spline interpolation is similar to cubic spline interpolation. The only difference is the introduction of a smoothing effect that reduces interpolation artefacts and filters out high frequencies. At variance with proper interpolation, the resulting signal is not constrained to pass through the original samples.

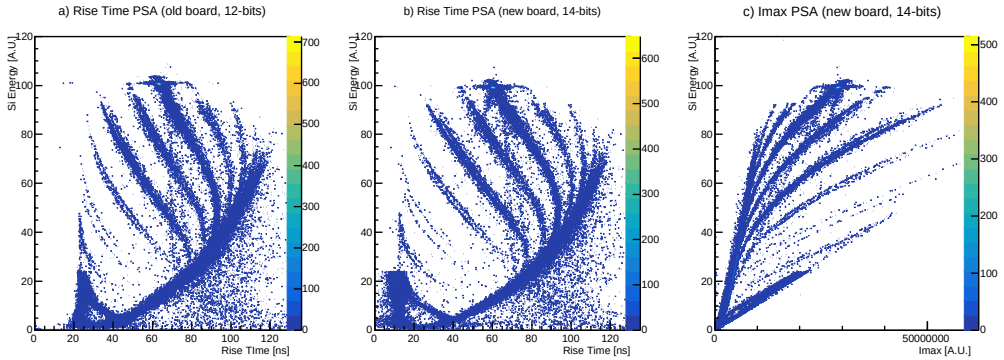

Fig. 1. – The three PSA plots used for the comparison. In (a) the rise-time vs energy correlation obtained with the old FEE board, in (b) the same correlation with the data from the new FEE and in (c) the new I_{max}-Energy correlation. In all the plots the ^{16}O elastic scattering is evident and the regions associated with $Z = 5$, 6, 7 can be easily identified.

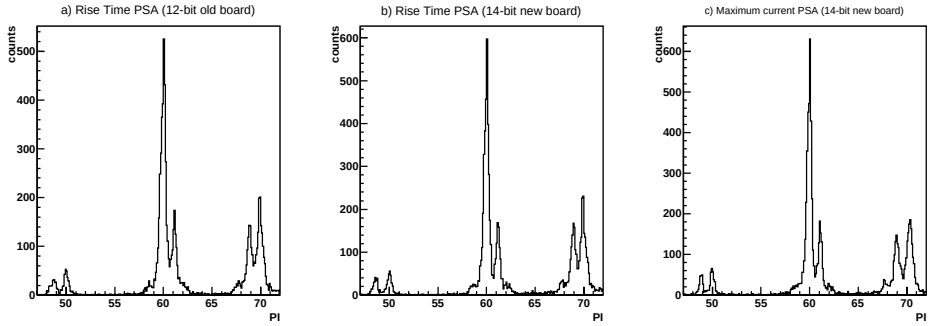

Fig. 2. – PI distributions obtained by linearization of the three plots in fig. 1. The isotopes of Boron (leftmost peaks in each plot), Carbon (middle peaks) and Nitrogen (rightmost peaks) are separated in all the three plots. Since there is no qualitative difference between them a more quantitative approach is needed to compare the performances of the three methods.

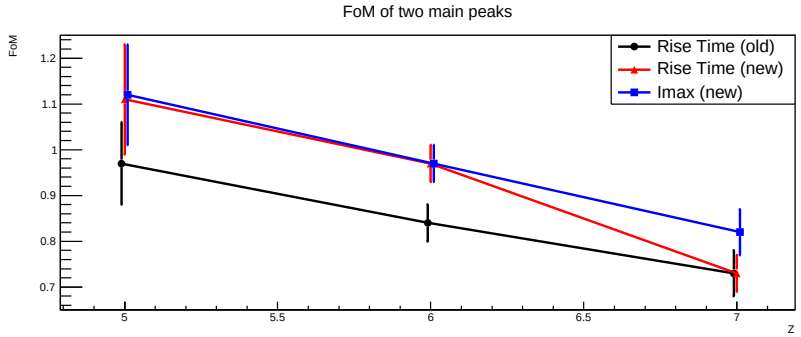

Fig. 3. – FoM values obtained from the PI distributions in fig. 2. For each element the two most populated isotopes are considered. The FoM values are presented in table I. The points are shifted along the x-axis to make error bars more readable.

TABLE I. – *The FoM values for the two most intense isotopic peaks of Boron, Carbon and Nitrogen, obtained by fitting the PI distributions in fig. 2 with a bi-gaussian fit. The errors on the fit parameters are assumed to be independent and are propagated to the FoM.*

	Rise Time PSA (old)	Rise Time PSA (new)	Imax PSA (new)
$^{10,11}B$	0.97 ± 0.09	1.11 ± 0.12	1.12 ± 0.11
$^{12,13}C$	0.84 ± 0.04	0.97 ± 0.04	0.97 ± 0.04
$^{13,14}N$	0.73 ± 0.05	0.74 ± 0.04	0.82 ± 0.05

in order to allow a full comparison of the different identification methods. To take into account also the effect of the increased digital precision, the Q_{rise} PSA plot obtained with the old electronic board is taken as a reference. For the comparison of the three PSA methods the data coming from the best performing Si detector (Strip 4, sector 1) are used in order to reduce the contribution of the detector to the isotopic resolution, and the three plots of fig. 1 are obtained.

The linearization procedure described in [10] is used to assign to each detected fragment a Particle Identification (PI) number, so that all the fragments that are placed near the same ridge of the plot are assigned similar PI values. The outcome of the linearization of the three plots of fig. 1 is presented in fig. 2, where the peaks corresponding to the isotopes of B, C, and N are evident. The separation between adjacent peaks is estimated using the FoM parameter [11], which for two gaussian peaks is defined as:

$$FoM = \frac{|C_1 - C_2|}{2.35(\sigma_1 - \sigma_2)} \tag{1}$$

where C_1 and C_2 represent the centroids and σ_1 and σ_2 the standard deviations of the two peaks. The higher the FoM, the better is the peak separation The FoM values obtained for the two most intense peak for B, C, N are presented in table I and fig.3. Considering Boron and Carbon isotopes, the FoM increases when using data collected with the new electronic board, suggesting that this increment is due to the higher precision of the ADC. On the other hand, for Nitrogen the FoM increases when using the I_{max} method, in agreement with published results [3]. The obtained results are very preliminary, and further measurements exploiting better performing silicon detectors (such as the FAZIA ones) will be a stricter test of the performances of our algorithm for current maximum extraction.

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