Implementation of a digital data readout system for double-sided silicon strip detectors for ion and alpha particle spectroscopy

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Abstract. The experimental investigation of superheavy elements, one of the prominent research areas of the GSI Helmholtzzentrum für Schwerionenforschung (GSI), has reached a region of short-lived nuclei with expected lifetimes of the order of 1 µs. As signal processing times for conventional analogue front-end electronics are typically longer than 10 µs, new developments are mandatory. Continuously sampling ADCs with virtually no dead time are presently being implemented for various signal processing applications in particle and photon spectroscopy. In this paper, a new flash-ADC based data acquisition system (DAQ) is presented. It has been tested using an α source and heavy ion reaction measurements at GSI’s UNILAC accelerator facility. In addition, a novel analysis algorithm has been implemented thus increasing the sensitive area of the double-sided silicon strip detector (DSSD) in use.

1. Introduction

In the last three decades, the research of superheavy elements has led, in addition to a wealth of other spectroscopy data, to the discovery of six elements (Z = 107 – 112) in cold fusion experiments with lead and bismuth targets at the velocity filter SHIP (Separator for Heavy Ion reaction Products) of the GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Germany. In February 1996, an isotope of the heaviest of these Elements, 277Cn, was synthesized for the first time [1]. It has a half-life of 280 µs. The VME based data acquisition electronics in use until recently at SHIP has a dead time of ≈20 µs [2]. Due to the expected decay time of less than 1 µs for superheavy elements with proton numbers higher than Z = 118, new digital data acquisition (DAQ) electronics with shorter dead times have to be implemented.
2. GSI fast digital electronics

The VME-based DAQ system has an intrinsic dead time of about 20 µs which is due to (i) coincidence requirements in the trigger logic, (ii) the conversion time of the ADCs and (iii) the readout. The new FEBEX2/8 [3] DAQ system investigated in this work is based on a flash ADC with two data buffers implemented and an on-board FPGA. While one of the buffers is being read out, the other one is available for data storage thus resulting in continuous data acquisition with virtually no dead time at a sampling rate of 65 MHz. Similar techniques have been employed with great success in other laboratories, notably at Oak Ridge National Laboratory, for some time [4]. Most of the progress e. g. in the investigation of proton emission from heavy nuclei [5] is directly connected to the usage of such fast digital systems.

The FEBEX system is mounted on a standalone board and communicates via a fast optical data link with the GSI standard data acquisition system MBS [6]. The system is able to process signals from different sources, amplified as well as shaped. One implementation of the DAQ system will feature a so-called APFEL ASIC chip [7] which incorporates two output channels with different gain factors for each input signal. In this way, the signals caused by α irradiation (up to 12 Mev) and the signals from fission products (50-300 MeV) can be scanned and processed in two different energy ranges simultaneously. The output signals will also be shaped in Gaussian form with a pulse length of τ = 250 ns.

In a recent experiment at GSI the TASCA collaboration [8] tested the current implementation of the system with a charge-sensitive preamplifier [9] connected to the strips on the back of a double-sided silicon strip detector (DSSD). For the fusion evaporation reaction

\[ ^{48}\text{Ca} + ^{176}\text{Yb} \rightarrow ^{220}\text{Th} + 4n \]

signal traces were recorded [10] (see Figure 1 for details).

**Figure 1.** The plot shows an example of a trace with a length of 18.5 µs recorded on-line in the reaction \(^{48}\text{Ca} + ^{176}\text{Yb}\). After about 3 µs (200 samples; 1 sample = 15.4 ns) the evaporation residue (ER) is implanted. 7.7 µs later, the first α-decay (\(^{220}\text{Th}, T_{1/2} = 9.7 \mu s\)) appears, followed by a second one (\(^{216}\text{Ra}, T_{1/2} = 0.18 \mu s\)) only 308 ns (20 samples) later [2].

The signal was recorded with an amplification factor of three set at the preamplifier. The signal level corresponds to the charge collected due to implantation of the heavy ions or the subsequent α-decays. The higher the collected amount of charge, the more negative is the signal height visible in the
trace. The baseline was set to a value of approximately 2040. After an event had been detected, the preamplifier discharged with a time constant of $\tau = 13 \mu s$, as can be seen in Figure 1.

The flash ADC FEBEX2/8 has a resolution of 12 bits. As traces are recorded, a maximum time resolution of 125 ns (8 samples) is available. Each FEBEX2/8 board can handle 8 differential input signals. The data can be further processed with suitable filtering algorithms.

3. Digital filtering

The sample data were analyzed with three different digital filters in order to extract the energy deposited by either the heavy ion or the $\alpha$-particle. Figure 2 gives the relevant details.

![Figure 2. The event shows the energy of the ER ($E_\alpha \approx 20$ MeV). In the picture on the left hand side, the energy is calculated by simply subtracting the lowest value from the highest. In the middle, the lowest value is subtracted from a calculated base line. A more complex approach is shown on the right hand side. Here, an extrapolated lowest value is subtracted from a calculated base line.](image)

The simplest energy filter calculates the difference between the maximum and the minimum value of the signal $E_\alpha \approx S_{\text{high}} - S_{\text{low}}$. By using this filter, the calculated energy includes a potential signal noise.

A second version of an energy filter calculates a baseline. The first 10 samples values were averaged. In combination with the peak value of the pulse, the energy can be calculated ($E_\alpha \approx S_{\text{base}} - S_{\text{low}}$). Errors caused by noise are still possible when $S_{\text{low}}$ is captured.

A third method is to use an extrapolation of the exponential function to approximate the pulse. The result of the signal analysis with these three filters is summarized in Table 1. It can be seen that the three approaches result in slightly different energy values (s. Table 1).

Table 1. Here the different filter methods are compared. It is obvious, that the trapezoidal filter has the smallest range of all tested filters.

| filter       | method 1 | method 2 | method 3 | trapezoidal |
|--------------|----------|----------|----------|-------------|
| max. value ($\approx 0$ MeV ) | 2050     | 2040     | 2040     | 0 (calc.)   |
| min. value   | 1770     | 1770     | 1760     | 244 (calc.) |
| $\Delta$ value ($\approx 20$ MeV ) | 280      | 270      | 280      | 244         |
More reliable values for the energies were obtained by using a trapezoidal filter [11]. Here, two windows of equal length n were defined. In between these two windows, a gap of fixed size was set. The energy values were calculated by subtracting the averages of the trace in the two windows, namely $E_\alpha \approx \left( \frac{\sum \text{Window}_1 - \sum \text{Window}_2}{n} \right)$. Figure 3 shows the energy spectrum which was calculated with a trapezoidal filter from the data of Figure 1. The results of this procedure are also listed in Table 1.

\[\text{Figure 3.} \text{ By using the trapezoidal filter, three energy peaks were calculated from the trace depicted in Figure 1. The first one shows the energy deposited by the ER (20.67 MeV). The second shows the energy of the } \alpha \text{-decay of } ^{220}\text{Th} (E_\alpha = 8.79 \text{ MeV}) \] and the last one the energy of the $\alpha$-decay of $^{216}\text{Ra} (E_\alpha = 9.35 \text{ MeV}).$

4. Sensitive detector area
The strip structure on the DSSD [12] is realized as metalized electrode areas on the surface, featuring 32 strips with a pitch width of 1.6 mm each, and perpendicular orientation of the front relative to the back, resulting in a 1.6 mm$^2$ pixel identification by the combined information on the front and back strip number. There is a gap of 75 µm between the strips in order to separate them electrically from each other. Whenever an event, i.e. the deposition of energy by a particle, takes place, the electrical charge is collected by the strip that has been hit. By combining the signals from the front and back of the detector, an exact location of the position where the event occurred is feasible. In case the event occurs in a gap, the electric charge is divided and collected by the neighbouring strips. In order to gain positional and energy information for these events as well, a novel analysis routine was developed. The analysis checks continuously if an event occurred in two neighbouring detector strips. If that is the case, the detected energies are summed up and written to a gap spectrum. An example of such a spectrum is presented in the lower panel of Figure 4.

In $\alpha$ source test measurements we could show that summing the respective signals, yields the recovery of about 50% of the gap events at the correct energy level. The energy resolution is comparable to the single strip events. Applying this summing procedure, the sensitive area of the DSSD can be raised from 96 to 98%.
5. Summary and Outlook

With the new fast electronic setup it is possible to perform experiments with a time resolution of 123.2 ns. Currently, a new DSSD-based detector for this system is being planned. The flexibility of the system allows for the scanning of traces as shown in this paper as well as the deduction of exact energy information by producing shaped signals. A new version of the ASIC has just been finished.

Acknowledgements

The authors gratefully acknowledge the support of J. Adamczewski-Musch, L.-L. Anderson, M. Block, H.-G. Burghard, V. Comas, C. Droese, Ch. E. Düllmann, S. Heinz, J. Hoffmann, S. Hofmann, J. Khuyagbaatar, N. Kurz, M. Laatiaoui, J. Maurer, E. Minaya Ramirez, D. Rudolph and A. B. Yakushev.
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