INTRODUCTION

Digital pulse processing has replaced nowadays the traditional shaping and timing circuitry with mathematical routines operating on digitized waveform signals. Pulse Shape Analysis techniques allow the implementation of sophisticated algorithms with substantially more information to be extracted from a measured pulse than is possible with a traditional analog system. These techniques have been recently also applied for the identification of pileup events in Nuclear Spectroscopy with silicon detectors [1]. The main goal of the present study is to explore the possibilities of applying Pulse Shape Analysis techniques not only for the identification but also for the energy and time reconstruction of pileup events. A method is developed for the extraction of the energy information of time overlapping signals in a three stage Si-telescope used in nuclear reactions with unstable radioactive beams.

EXPERIMENTAL SETUP AND DATA ACQUISITION SYSTEM

In a recently performed measurement of the $^{8}$B+$^{28}$Si total reaction cross section at energies near the Coulomb barrier ($E_{l}$=25-40 MeV) [2], an incident $^{8}$B beam was produced at the EXOTIC facility [3], at LNL (Laboratori Nazionali di Legnaro) INFN/Padova, Italy. The $^{8}$B beam needed for this experiment was delivered as a secondary beam product by means of the reaction $^{3}$He($^{6}$Li,$^{8}$B)$n$ of a primary $^{6}$Li$^{3+}$ beam on a $^{3}$He gas target. Although the secondary $^{8}$B beam was purity optimized, $^{7}$Be, $^{6}$Li and $^{3}$He contaminants were present in the extracted beam as non-filtered by-products of transfer and elastic processes of the primary beam. The extracted beam was directed through two Parallel Plate Avalanche Counters (PPAC_A and PPAC_B) before hitting a three stage Si-telescope placed at zero degrees inside the scattering chamber (Figure-1). This telescope comprises of three Si layers (S1, S2, S3) with $\Delta E_{1}$=45$\mu$m, $\Delta E_{2}$=45$\mu$m and $E_{3}$=2000$\mu$m and acts simultaneously as active target and detector. Position information inside the PPACs, as well as Time of Flight (TOF) signals between both PPACs and target, were recorded. These signals are primarily used to discriminate the different species of the incident beam and to calculate the spot size at target distances. The energy information is separately read out for each stage of the Si telescope using home-made preamplifiers. The event trigger of the main Data Acquisition system required a coincidence of the type PPAC_A$\cap$PPAC_B$\cap$(S1$\lor$S2$\lor$S3).

Fig. 1. The DAQ-system developed for the $^{8}$B+$^{28}$Si experiment. It was integrated on a separate VME crate using the CAEN A2818 / V2718 PCI$\rightarrow$VME controller kit with the CONET optical link.

In this experiment, the nature of the unstable $^{8}$B beam nucleus, which beta-decays ($T_{1/2}$=750ms) into $^{8}$Be and consequently in two alphas, necessitates the usage of appropriate pileup rejection techniques. Various conventional pileup rejection techniques based also on home-made electronics were proposed [2] and they have...
been successfully applied during this experiment. In an alternative approach, a decision has been made to record the Si-detector signals via a waveform digitizer. This option potentially gives a promising solution not only to the identification of possible pileup events, but also to the successful reconstruction of the underlying energy information. For this purpose, the CAEN flash ADC module V1729A [4] was used and the recorded waveforms were offline analyzed to resolve time overlapping signals. In this context, an additional DAQ-subsystem based on VME electronics, which run parallel to the main system and synchronized with the master DAQ-trigger signal has been developed (Figure-1). This DAQ-subsystem has been integrated and tested on a separate VME crate using the CAEN V2718 master module which is controlled by a standard PC equipped with the PCI controller card A2818 via an optical fiber link. The CONET (Chainable Optical NETwork) link guarantees a transfer data rate of at least 70 MByte/s.

**PULSE SHAPE ANALYSIS**

The developed algorithm is mainly based on the time differentiation of the obtained waveforms. A simple time differentiation applied to the recorded waveform yields to a peak structure. For a normal non-pileup event, as shown in the upper part of Figure 2, this peak structure reveals certain characteristics, having the form of a Gaussian shaped line with an unchanging width for a given type of a silicon detector.

\[ E = \Delta V = S_2 - S_1 \]

Equivalently, for the time differentiated waveform (derivative), the energy information can be calculated by summing up all accumulated signal changes:

\[ E = \int (dS/dt)dt \]

In the case of a pileup occurrence, the signal time differentiation leads to a double-peak structure, as shown in the typical example of the Figure 3. According to the previous equations, in case the double-peak structure is well separated, the energy information can be again extracted by integrating each of the peak structures. Alternatively, a two-gauss line fit can be performed to the differentiated signal and the resulting area and peak location can be used to calculate the energy and time information [5].

![Fig. 2. Energy calculation from a single, non-PileUp event (upper part) and a typical PileUp event (lower part) based on the time differentiation of the obtained waveform.](image)

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![Fig. 3. Typical example of an identified PileUp event with a resolvable energy trace in both S1 and S2 detector stages.](image)

The performance of the developed algorithm with respect to its ability to successfully extract the pileup energy information for each particle is measured to be ~80% for all analyzed events in the current experiment. Basic limiting factors are the time difference between the two particles in a pileup occurrence and their relative amplitudes. A 4ns time limit in the particle separation for the first stages of the Si telescope used here is estimated.