Application of a fast digital sampling system to ΔE–E identification and sub–nanosecond timing

L.Bardelli[1], M.Bini[1], G.Casini[1], S.Piantelli[1], G.Poggi[1], N.Taccetti[1] *and* the GARFIELD collaboration

1 I.N.F.N. and University of Florence

INTRODUCTION

In a recent paper [1] the applicability of digital sampling techniques to particle identification in scintillator detectors has been demonstrated. The same basic apparatus described in the previous paper (a custom design digitizer with 100 MSamples/s, 12 bit) has been used for different applications, namely the acquisition of signals coming from a standard Silicon–CsI(Tl) telescope and sub–nanosecond timing measurement, with main reference to particle identification via ΔE–E and Pulse Shape Analysis (PSA) and to Time of Flight (ToF).

The tests have been performed in the GARFIELD scattering chamber of Laboratori Nazionali di Legnaro, using the ^{16}O+^{116}Sn reaction at a beam energy of 250 MeV.

ENERGY RESOLUTION TESTS: ΔE–E IDENTIFICATION

The upgrade of the GARFIELD apparatus [2] will require to acquire a large number of signals coming from the ΔE–E Silicon–CsI(Tl) telescopes. As discussed in [1], our sampling system (4 acquisition channels with on-line processing not yet implemented) is now being integrated and provided with Digital Signal Processors (DSPs), to allow for application to a large number of channels: we performed a test run in order to verify whether our digitizer could be used for the acquisition of the new GARFIELD detectors, thus replacing the standard analog electronic chain. The main needed requirements are a good energy resolution, in particular for the Silicon signals, in order to obtain a good particle identification from the ΔE–E correlations from protons up to $Z \gtrsim 10$, as well as a wide dynamic range to allow for the measurement of their energy up to ~ 300 MeV.

The implemented electronic setup is straightforward: the two signals coming from a Silicon and a CsI(Tl) detectors of GARFIELD have been fed into two different channels of the sampling system. A Constant Fraction Discriminator (CFD) connected to the Silicon detector is used to trigger the acquisition. To cover the dynamic range needed, only one sampling channel is used for each detector, fully exploiting the 12 bits of the ADC. For each collected event the digitized signals have been shaped with a simple running average filter: the maximum of the filtered signal has been taken as the signal "amplitude". In Figure 1 the obtained results are shown.

It has to be noted that the intrinsic good resolution of the used detector telescope is not jeopardized at all by the digital sampling system, which -on the contrary- is indeed able to handle both the low-energy and the high-energy regions without using two separate channels (as done in the standard analog approach). Moreover, the correlation of Figure 1 has been obtained using a very simple algorithm for signal processing: the use of more sophisticated methods (FIR filters or "optimal" filters [3]) can possibly lead to an even better energy resolution, still preserving the required processing speed for on–line data acquisition.

TIMING TEST

While the good performances of a digital sampling system, provided with an adequate number of bits, in terms of energy resolution are quite obvious, the possibility of using the same system to perform accurate timing (e.g. for Time of Flight measurements) is less obvious and demanded for further investigation.

It is possible to better understand the main points in digital timing measurements studing the simple determination of the zerocrossing time between two sampled points, (t_1, A_1) and (t_2, A_2) (where A_i is the sampled amplitudes at time t_i, $A_1 \cdot A_2 < 0$ and $t_2 - t_1$ = sampling period). The error on the quantities t_2 and t_1 is expected to negligible (if the sampling system is controlled by a quartz); thus, in the semplifying hypothesis that the time dependence of the signal is linear, the final error on the (interpolated) zerocrossing time is mainly due to the uncertainty on A_1 and A_2. Thus, if the signal develops on a time span significantly longer than the sampling period, the overall timing resolution is mainly limited not by the sampling period but by the bit-resolution of the converter (assuming a sufficiently small electronic noise).

To verify these assumptions, a further test measurement has been performed, aimed at identifying fully stopped particles with the Time of Flight (ToF) technique. The Silicon detector used was mounted in the *reverse* field configuration, because the test was also meant to address the problem of pulse shape analysis in Silicon (results on this test will be reported elsewhere). The way which we devised for obtaining the time of flight information from a single digital sampling electronic chain, which to our knowledge is original, is as

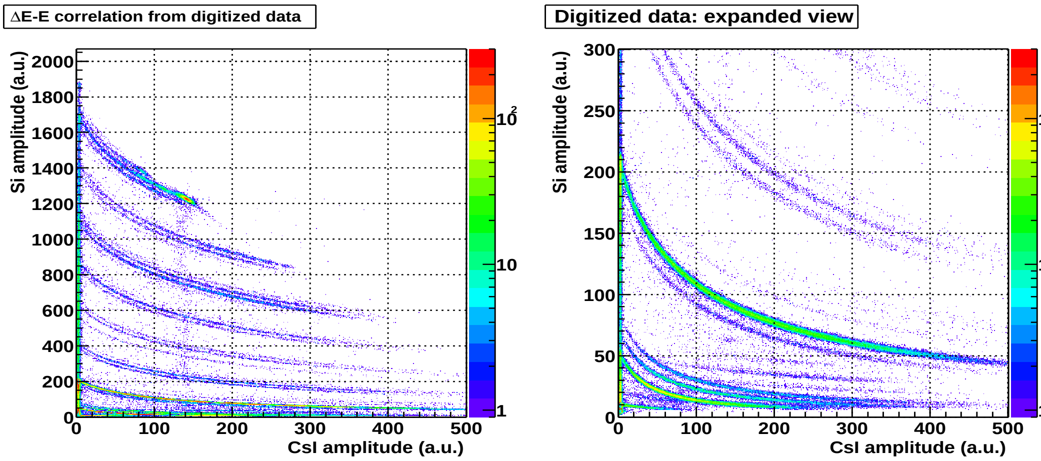

FIG. 1: ***Left Panel:*** *ΔE–E correlations obtained with the digital sampling method.* ***Right Panel:*** *expanded view.*

follows (see Figure 2). The preamplifier output is connected both to the sampling system and to a CFD, whose output is used for two purposes: *1)* it triggers the acquisition, *2)* a delayed copy (about 7 μs) of the CFD output selects a train of pulses from the radio-frequency signal of the accelerator and it is injected in the test input of the preamplifier, thus overlapping on top of the tail of the signal (see Figure 2). Using signals treated in this way, the ToF of the particle can be easily obtained from the digitized signal (thus *no need for external electronics*) as the difference between the start time of the signal (that can be computed using a digital CFD-like algorithm) and the position of train of pulses (computed for example as an average of many zerocrossing points).

Results obtained with this method are shown in Figure 2 (where a global offset has to be subtracted from the ToF value): the timing resolution is dominated by the beam resolution ($\simeq$ 1 ns FWHM), whereas the contribution coming from the digital sampling system is much smaller (better than 100 ps FHWM for the RF signal only, for details see [4]).

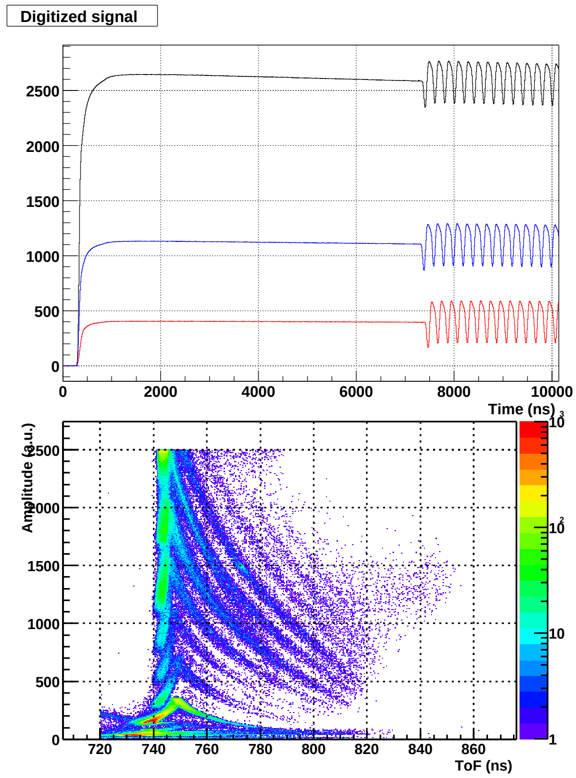

FIG. 2: ***Upper panel:*** *Three digitized signals: note the superposition of a train of pulses related to the timing signal from the accelerator (see text).* ***Lower Panel:*** *The Amplitude vs Time of Flight correlation obtained in a self consistent method with the digital sampling system.*

CONCLUSIONS

The digitizer [1] has proven to satisfy all the needed requirements for a replacement of the standard analog electronic chain for the energy measurement with a standard ΔE–E GARFIELD telescope. Moreover, the overall energy and particle identification procedure can be improved with on–line analyses as Pulse Shape Identification or Pileup algorithms that can be easily implemented in this system.

A timing test has been performed using an original solution for mixing the radio frequency information on the tail of the signal: the overall timing resolution is satisfactory (better than 200 ps FWHM), and allows for particle identification with a single sampling electronic chain.

[1] L.Bardelli et al., Nucl. Instr. and Meth. **A491** (2002) 244.
[2] F. Gramegna et al. - Nucl. Instr. and Meth. **A389** (1997) 474.
[3] Steven W. Smith, *The Scientist and Engineer's Guide to Digital Signal Processing*, available on `www.dspguide.com`.
[4] L.Bardelli et al., *to be published*.