Digitisation of the GABRIELA Time-of-Flight

Karl Hauschild

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1 Summary

The resolution of a time-of-flight measurement of alpha particles using two Micro-Channel Plates (MCP) in a completely digital electronics chain compares favourablly to the classic analogue approach[1]: $\sigma_{DIGITAL}$ = 0.48(4) ns cf $\sigma_{ANALOGUE}$ = 0.88(1) ns. However, a dependence on alpha particle energy on the resolution needs further investigation. Additional measurements using one foil and the DSSD (Double-sided Silicon Strip Detector) will be performed when a shorter cable between the detector and preamplifier (implying less stray capacitance and thus faster DSSD signal rise-time) is made. However, we can already state that the preliminary (not optimised) results using a long signal cable are promising with $\sigma_{MCP-DSSD} < 1.4(1)$ ns.

2 Background

A key element in correctly identifying and isolating the decay from excited nuclear states under investigation is the use of a Time-of-Flight (ToF) measurement to distinguish the recoils of interest from scattered beam and transfer reaction products. Typically the time-of-flight of the heavy ions is measured between two metalized foils. Electrons are ejected from these foils when the ions pass through them and electric and magnetic fields are used to accelerate and bend the electrons into the MCP detectors, shown schematically in Figure 1. The signals from the MCPs are passed through a fast (large bandwidth) preamplifier before being processed by an Ortec 935 CFD[2]. The CFD (Constant Fraction Discriminator) can provide a low jitter logic signal whose occurrence is independent of the amplitude and the rise-time of the analogue input signal. These logic signals are then used to start and stop a TAC (Time to Amplitude Converter) which provides an analogue pulse that is then recorded via conventional ADCs.

3 Special case of very heavy and very slow moving ions

For these nuclei the angular and energy straggling after the passage through two foils seriously impacts our transmission efficiency: not many of them reach the DSSD. The goal of these tests is to investigate the feasibility of obtaining a time of flight measurement between 1 foil (either MCP2 or MCP4) and the DSSD using only digital electronics. To understand the contribution to the timing resolution from the MCP to the MCP–DSSD measurement data

[1] since these tests were performed the TAC module has been replaced and the MCP preamplifiers upgraded
[2] Ortec 935: http://www.ortec-online.com/products/electronics/fast-timing-discriminators/935

were also acquired to obtain timing between two foils using both MCP2 and MCP4. As a benchmark measurements were also taken using a full analogue chain.

4 Set-up

A mixed sample of ^{233}U, ^{238}Pu and ^{239}Pu provided a source of multiple alpha particles (given in Table 1). This source was placed in upstream of the first foil (see Fig. 1) and after passing through both foils the alpha particles were detected in the DSSD. The distance between foils was 360 mm and the corresponding time of flight is given in Table 1.

source	energy [keV]	I [%]	time-of-flight [ns]
^{233}U	4824	84.3	23.6
	4784	13.2	23.7
^{239}Pu	5157	70.8	22.8
	5144	17.1	22.9
	5106	11.9	22.9
^{238}Pu	5499	70.9	22.1
	5456	29.0	22.2

Table 1: Energy and intensity of the main alpha lines for each isotope and expected flight time

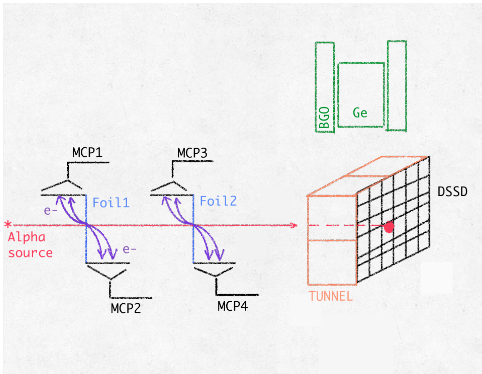

Figure 1: Schematic of the time-of-flight detection system

5 Measurements

5.1 Time-of-flight between 2 MCPs

5.1.1 Benchmark: standard analogue and full digital comparison

The digital electronics tests were limited to one 8 channel 5170R 250 MHz 14-bit digitiser with only two configurable triggers because of my current level of labVIEW expertise. Two front face strips of the DSSD were used to trigger the read-out of the signals from the preamps of two MCPs, these same signals after a CFD, the output from the analogue TAC and the triggering signals. Due to the fast rise-time ($\sim$ 4 ns) of signals from the preamps of the MCPs and of the NIM logic signals from the CFDs various low pass filtering[3] schemes were tested. A schematic of the electronics is shown in Figure 2.

For the digital processing a CFD signal was constructed from the digitised signal of both MCPs using the following expression

$$CFD[n] = f * S_{MCP}[n] - S_{MCP}[n - dN] \tag{1}$$

where f is typically 0.1-0.45 and dN $\sim$ (1-f)$\times$ signal rise-time and dN $<$ 0.5$\times$the signal rise-time. A zero-crossing was obtained from a linear interpolation between the last point above

[3]Consider the response of a simple first order RC low-pass filter: the band-width BW = $f_c = 1/(2\pi\tau_c)$, where f_c is the -3 dB cut-off frequency of the filter, and rise-time RT $\sim 2.2\tau$. One can therefore approximate the step function response of a low-pass filter to be RT [ns] = 350 / BW [MHz].

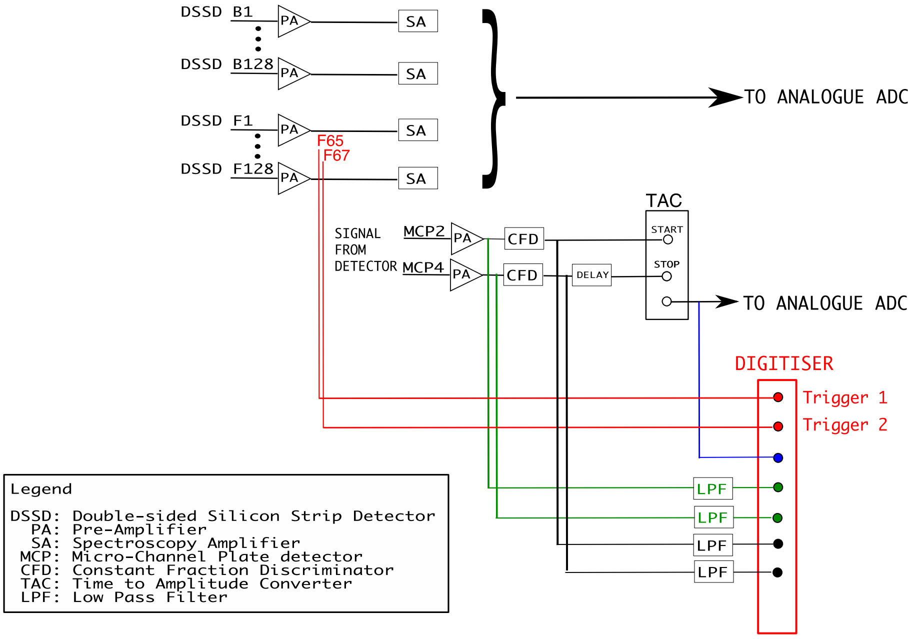

Figure 2: Schematic of the analogue and digital electronics schemes.

and the first point below zero: t_{zc} = t + CFD[t]/(CFD[t-1] - CFD[t]) (for a signal with negative slope)[4]. The digital time-of-flight is then calculated from the difference of the zero-crossing times for the CFDs constructed for MCP2 and MCP4. Some typical signals are shown in Figure 3: the digitised low-pass filtered signals from MCP2 and MCP4 and the CFD for MCP2 constructed using the expression above. Data were also acquired using a classic analogue electronics chain in order to have a benchmark. In the analogue set-up a known delay is introduced to the stop signal to be able to calibrate the response of the TAC. In Figure 4 are presented a direct comparison between the digital and analogue set-ups. The two-dimensional plot represents the measured Time-of-flight vs the alpha particle energy detected in strips 65 and 67 of the DSSD for the triple alpha source. A projection showing the time resolution[5] for the ^{233}U alpha particles is also shown: σ = 0.44(2) and 0.88(1) ns for the digital and analogue acquisition, respectively. The resolutions for the three alpha groups are given in table 2. It should be noted that the average timing resolution for the three lines was minimised as a function of f and dN (f=0.4 and dN=2). A better timing resolution of σ = 0.38(1) ns can be obtained for the ^{233}U using f=0.15 and dN=3, but, the resolution for the other lines is worse.

5.1.2 Mixed: digitizing the logic signal from the analogue CFD

For these measurements a low-pass filter was also used to "slow" the rise-time of the logic signal produced by the Ortec 935 CFD. The timing with respect to crossing points on the leading- and trailing edge of the logic pulse were investigated and the results are given in Table 2. Again a dependence of resolution on energy is apparent and requires further investigation.

[4] A spline fit to three points was also investigated using the TSpline3 function in ROOT which gave little or no improvement in the timing resolution

[5] The timing resolution for the individual MCPs is resolution of the ToF / $\sqrt{(2)}$.

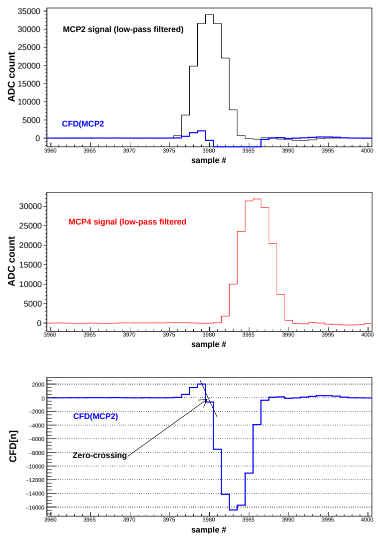

Figure 3: Typical signals for MCP2 and MCP4, and, a digitally constructed CFD from the MCP2 signal.

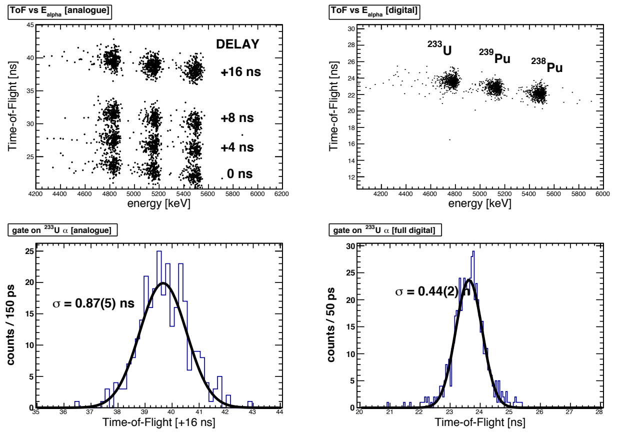

Figure 4: Schematic of the time-of-flight detection system

source	energy [keV]	time-of-flight [ns]	analogue	resolution [ns] full digital	digitised CFD
^{233}U	4819	23.6	0.88(1)	0.44(2)	0.77(2)
^{239}Pu	5149	22.8	0.87(1)	0.46(2)	0.84(2)
^{238}Pu	5487	22.1	0.88(1)	0.54(2)	0.93(2)

Table 2: Average energy, expected time-of-flight and the timing resolution obtained for three methods for each group of alpha particles from the mixed source

5.2 Discussion: timing between 2 MCPs

The first impression is that the digital acquisition is superior to that of the analogue chain (as it was tuned for these tests). Indeed, the digital acquisition has both better timing resolution and does not require that the delay between the TAC start and stop signals and the range of the TAC need to be finely tuned to the time-of-flight of the recoils of interest. It would therefore allow us to use a configuration where the MCPs are closer together which will increase the transmission to the DSSD. However, there is an anomaly that needs to be investigated further: there is a degradation in resolution with increasing alpha particle energy for the digital acquisition which is not observed with the analogue electronics as can be seen in Figure 5. More data are required to have statistically significant fits and peak shapes. Since a number of filtering schemes on both the raw MCP signal and the logic signal after the CFD were performed (but not reported here) data were only acquired for approximately 3-4 hours for each. Considerable time was also needed to calibrate the analogue acquisition.

5.3 MCP - DSSD timing

For heavy and slow moving recoils the material between the target and the DSSD needs to be reduced to the absolute minimum. Therefore measurements have been performed where the time-of-flight is obtained between 1 MCP foil and the implantation DSSD. Due to the relatively light mass of the alpha particles used one can use the data from the tests above to simultaneously acquire the time-of-flight between MCP2 or MCP4 and the DSSD, but,

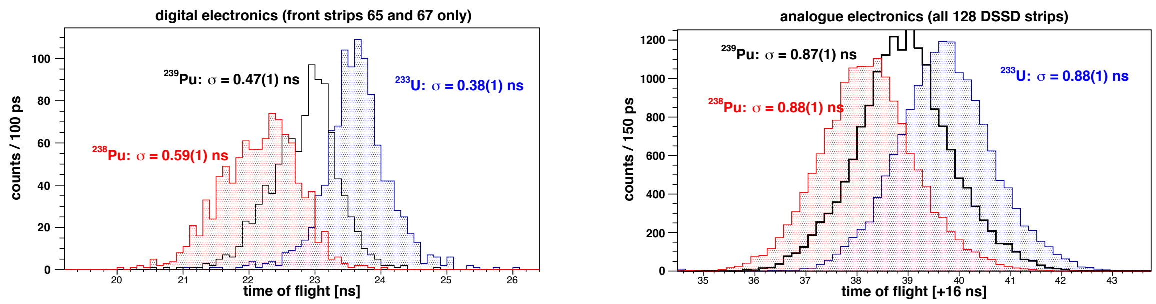

Figure 5: A comparison of the resolution for the time-of-flight measurements for each alpha group for both the digitial (f=0.15 and dN=3) and analogue acquisitions.

each DSSD strip needs to be treated separately due to differing cable lengths, printed circuit board tract lengths and preamplifier response. For these measurements a short adapter cable was used to enable data to be taken using the the CSNSM/GANIL preamplifier in place of the standard preamplifiers from TekInvest. While the TekInvest preamplifiers have provided good energy resolutions their band-width is insufficient for good timing and is not compatible with pulse shape analysis which can now be performed using digital electronics. The rise-times of these two preamplifiers can be compared in Figure 6. It should be noted that in the current experimental set-up there is $\sim$75 cm cable from the vacuum feed-through to the preamplifier input. This adds considerable stray capacitance and increases the preamplifier rise-time: for the CSNSM/GANIL preamp we could achieve a rise-time of $\sim$ 80 ns if this cable length was reduced. This modification is already planned.

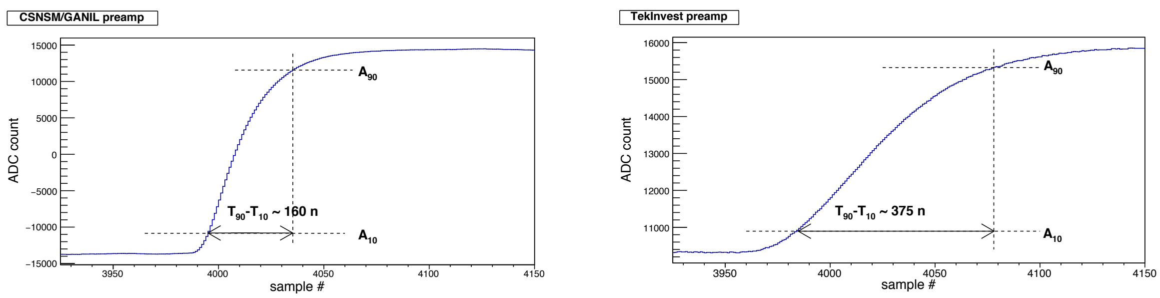

Figure 6: A comparison of the rise-times of the preamplifiers from the CSNSM/GANIL and TekInvest.

To transform the DSSD preamplifier signal into one from which good timing resolution can be obtained the following steps are needed: 1) differentiation (high-pass filter) to remove the DC offset and to shorten the signal length 2) integration (low-pass filter) to improve signal-to-noise and 3) correction of the undershoot due to the differential of a decaying signal (pole-zero correction). Following these steps a standard digital CFD can then be constructed from which a zero-crossing can obtained. The corresponding signals are shown in Figure 7 along with the the time-of-flight measured between either of the MCPs and DSSD strip F65. Obtaining the best timing resolution requires a minimisation over four degrees of freedom: the time difference used for the first differentiation, the width of the moving average and the CFD fraction and delay. Since the planned cable modification will change the signal characteristics only a preliminary scan of these parameters has been carried out. Nevertheless the results are extremely encouraging with timing resolutions better than 1.4 ns being obtained. The goal for the next tests is a resolution of less than 1 ns.

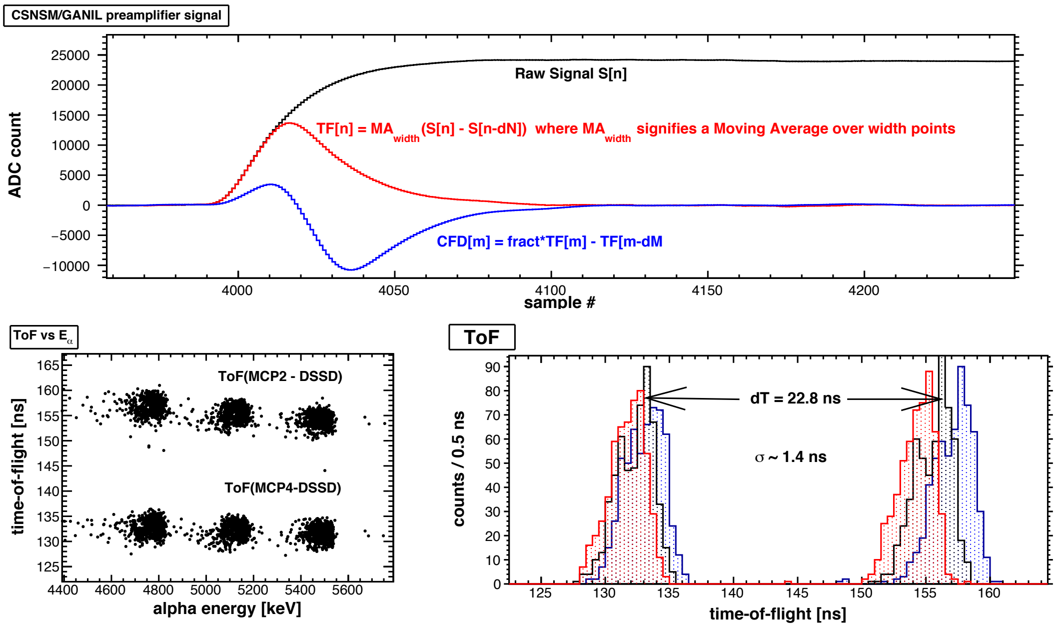

Figure 7: An example of a digitised signal from the DSSD and the transformation to a Timing Filter (TF) and a CFD. Also presented is the time-of-flight vs energy matrix for both MCP2 and MCP4 and the projection on to the time-of-flight axis. For the longer flight path (MCP2-DSSD) the three alpha lines are clearly distinguished.

6 Future tests

This autumn the preliminary beam schedule is extremely dense, but, there could be time between ^{255}Rf and "pxn" runs to exploit the fact that MCPs and DSSD will already be set up to perform a second set of time-of-flight tests.

6.1 MCP timing

For these tests I suggest that the MCP signal is split into two parallel paths after the low-pass filter stage. One path should have a cable length 2 ns longer than the other which would effectively allow us to test digitising the signal at 500 MHz. Modification to the generic labVIEW acquisition code would be required to provide four independent triggers for four DSSD channels allowing us to obtain twice the data in same period of time. A further improvement would be to have eight independent triggers on one 5170R module for eight DSSD channels and to have two modules synchronised (one for the MCPs and one for the DSSD). The aim would be to better characterise the energy dependence of the timing resolution (perhaps a sampling rate 250 MHz is insufficient) and to see if the timing resolution was limited by the sampling rate.

6.2 MCP - DSSD timing

For these tests a short cable (10 cm) will replace the current 75 cm cable and 10 cm adapter currently used. This will reduce both the rise-time and the noise on preamplifier signal and should enable an improved timing resolution. The pin-out of the connector will also be modified to allow the acquisition of neighbouring strips to investigate the amplitude of signals induced in the strips to either side of the strip into which an alpha particle was implanted. The aim is to localise interactions on a sub-strip level. This will increase the effective granularity of the DSSD. I am not aware that this has been investigated before.

Just to give an idea of the time required for these tests: with the source placed up-stream of foil-1 the total count rate in the DSSD is ~ 5 Hz. To obtain an accurate measurement of the MCP-DSSD timing resolution each strip has to be treated independently. There are 128 strips on each face of the DSSD. Therefore the count rate per strip is ~ 5 counts/120 s, or, 150 counts/hour and thus less than 50 counts per hour in individual alpha lines.