

Spectra of time differences between consecutive pulses measured with a new TDC-based data-acquisition system

V. Horvat and J. C. Hardy

For accurate high-precision measurements of β -decay half-lives, a new data acquisition system [1] based on a multichannel time-to-digital converter (TDC) has been set up as an alternative to the CAMAC-based system that is currently in use. The new system stores each event (*i.e.*, arrival of a logic pulse) in a raw format by recording the corresponding TDC channel and the time (within 16 ps) since acquisition started. This way a histogram of the time Δt between consecutive events can be constructed and used, for example, to investigate the system's dead time. Furthermore, a longer dead time can be imposed in the analysis and its effect on the measured half-life can be examined.

We have tested the TDC-based data-acquisition system by studying the pulses due to β particles emitted from a radioactive source (^{90}Sr - ^{90}Y) [1]. It was found that the histogram of Δt followed an exponential decay curve (with the decay constant equal to the event rate) as expected, but only for $\Delta t > 10 \mu\text{s}$. A smaller-than-expected number of events was observed for Δt between 1 μs and 10 μs . This effect was explained based on the shape and extent of the analog pulses from the fast filter amplifier, which were subsequently converted to logic pulses by the discriminator before being sent to the TDC. In particular, since the negative pulses from the fast filter amplifier typically become slightly positive before returning to the base line, a pulse that arrives between the crossover time of the previous pulse and its return to the base line is piled up and has a reduced chance of crossing the discriminator threshold, *i.e.*, it has an increased chance of not being converted to a logical pulse and counted. In addition, excessive counts were observed in the Δt spectrum for $\Delta t < 1 \mu\text{s}$. At the time, this was thought to be due to multiple pulsing. Consequently, to prevent the reduction of the system's throughput due to multiple pulsing, a dead time of 0.5 μs was imposed electronically by means of a gate and delay generator.

Meanwhile, the TDC-based data-acquisition system was used in several β -decay half-life measurements involving secondary ion beams from MARS (^{10}C , $^{26\text{m}}\text{Al}$, ^{19}Ne , and ^{18}Ne). For these measurements the beta decay rate at the beginning of the measuring cycle was intentionally set significantly higher than usual in order to enhance the dead-time related effects. In all the measurements except those with the ^{10}C beam the TDC-based data acquisition system was used in parallel with the standard CAMAC-based data acquisition system. For β particles, the signal processing was split after the discriminator, so that different gate and delay generators were used by the two systems to set the imposed dominant dead time (IDDT). For the TDC-based system the IDDT was set close to a minimum (about 20 ns), while that for the CAMAC-based system was set to 3 μs . However, after imposing an IDDT of 3 μs to the data collected with the TDC-based system, it was found that the beta-decay spectra obtained with the two systems were virtually identical. This way it was established that the two systems were equivalent.

In addition, many measured Δt spectra were obtained both for the β -particle events and the beam-particle (heavy-ion) events. These spectra provided further insight into timing properties of the generated signals. In the former case, it was confirmed that the counting rate at the beginning of the measuring

cycle determines the “decay constant” of the spectrum for $\Delta t > 4 \mu\text{s}$ as expected, while for $\Delta t < 4 \mu\text{s}$ the shape of the spectrum is determined mostly by the shape and extent of the analog pulses from the fast filter amplifier (which in turn depend on the amplifier settings). Due to the small IDDT of 20 ns, the latter conclusion was now established to be true even in the region of Δt below 0.5 μs . An example of the Δt spectrum for $\Delta t \leq 10 \mu\text{s}$ is shown in Figure 1. It should be noted that this spectrum has its starting point well above the IDDT value.

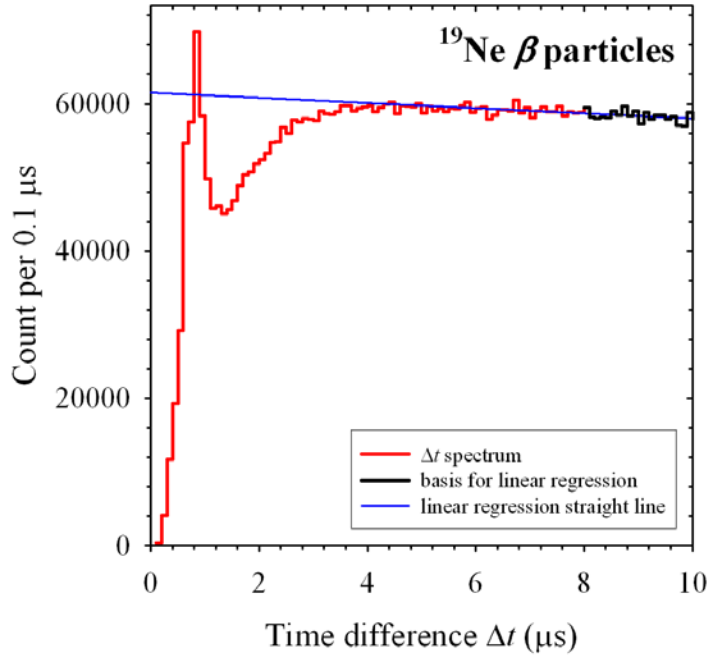


FIG. 1. An example of a measured Δt spectrum of β -particle events in the decay of ^{19}Ne .

Therefore, contrary to the previous assessment that the excessive counts observed in the Δt spectrum of β events at $\Delta t < 1 \mu\text{s}$ were due to multiple pulsing, it is now established those counts are, in fact, also determined by the shape of the analog pulses from the fast filter amplifier. Namely, a signal from the fast filter amplifier normally crosses the threshold level as it drops to its minimum value and then it crosses the threshold level for the second time as it rises back toward the baseline. If another signal piles up during the time interval between the second crossing of the threshold and the baseline crossover time of the previous signal, it will have an *increased* chance of crossing the discriminator threshold, being converted to a logical pulse and counted.

Consequently, a proper Monte Carlo simulation of the measured spectra must include these effects. For the present situation we proceeded by observing the shape of the measured Δt histogram and finding the critical point at $\Delta t = \Delta t_c$, at which it stops deviating from the shape expected based on the actual distribution of counting rates. (For the histogram shown in Figure 1, $\Delta t_c = 4 \mu\text{s}$.) Then the entire histogram was normalized so that the value of its maximum channel equaled one. Each channel between 0 and Δt_c was then interpreted as the pulse detection probability p for the corresponding time Δt elapsed

since the detection of the previous pulse. This is justified by the fact that the “expected shape” over the relatively short time interval between 0 and Δt_c can be regarded as being effectively constant. The value of p at Δt_c (which was found to be only slightly less than 1) was assumed to apply to all $\Delta t > \Delta t_c$.

The obtained Δt -dependence of probability p was subsequently implemented in the β -decay Monte Carlo simulation program as follows. For each generated event after the very first one, the time Δt “elapsed” since the previous event is calculated and the corresponding value of p is found. Acceptance of the new event is determined by a random number generator. If the returned random number from the interval (0,1) is less than p , the new event is accepted. Otherwise, it is ignored. It was found that the pulse detection probability function does not depend significantly on the pulse rate, so that a single histogram of p can be used for all emulated decay cycles. Examination of this effect as well as the additional effect of the IDDT on the measured half-life is underway.

The measured Δt spectra for the signals originating from the heavy-ion detector reveal arrays of fully resolved peaks separated by the period τ of the radio-frequency (RF) power supply for the cyclotron dee electrodes. Figure 2 (a) shows an example of such a spectrum for the beam of ^{26m}Al at the average particle rate of $1.7 \times 10^5 \text{ s}^{-1}$ and τ equal to 62.3 ns. Although the zeroth peak is absent and the first peak is cut off because of the dead time of the signal-processing electronics, it can be estimated that the probability of two ions occurring in RF cycles separated by $n\tau$ ranges from 1.2 % for $n = 2$ to 1.0 % for $n = 20$.

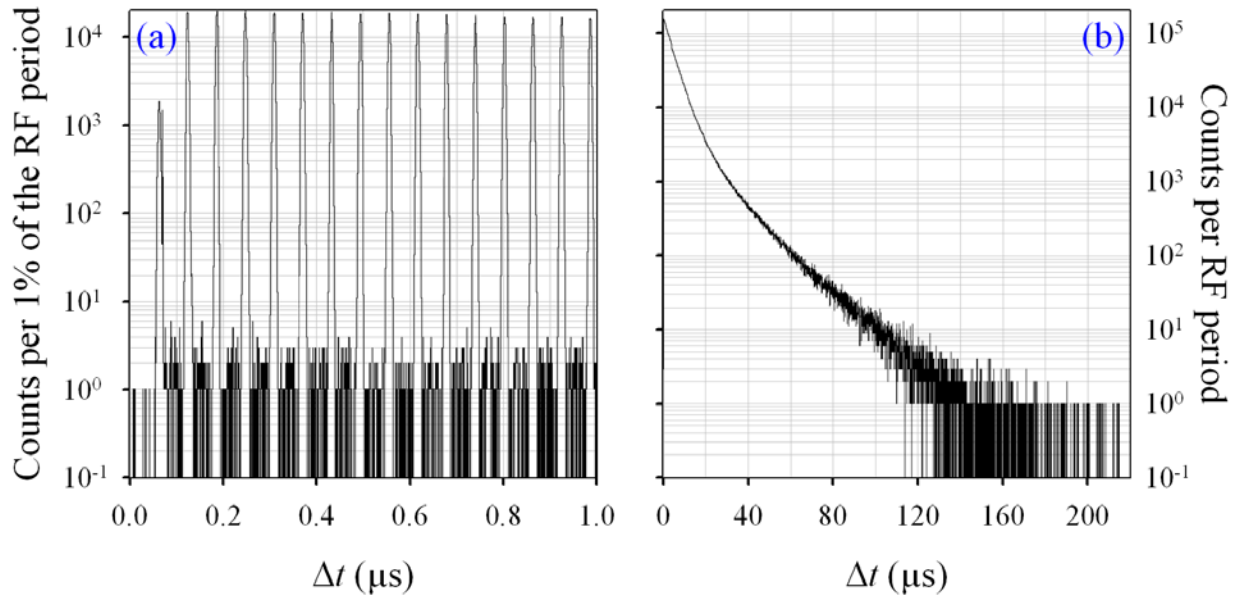


FIG. 2. Measured histograms of time differences Δt between consecutive signals from the heavy-ion detector for the secondary beam of ^{26m}Al from MARS. Both spectra are from the same run and differ only in the range of Δt being covered in the plot.

Figure 2 (b) shows the same spectrum as Figure 2 (a) does, except that the full range of Δt is covered and the bin size equals τ . This way the peak structure is not apparent. Normalization of the area of this spectrum to a total number of 1 results in a histogram giving the probability for detecting two ions

within the time interval $(\Delta t, \Delta t + \tau)$ shown as a function of Δt . The sum of the contents of all channels below a given Δt yields the probability P for detecting two ions within the time interval $T < \Delta t$. Consequently, $1 - P$ is the probability for detecting two ions within the time interval $T \geq \Delta t$. The two probability functions are shown in Figure 3. The results are in qualitative agreement with expectations based on Poisson statistics, considering that the particle rate during the measurement was not exactly constant. The graphs shown in Figure 2 and Figure 3 may be useful in the analysis of an experiment in which time differences are measured (such as those between two events or between an event and the arrival of the beam particle that caused it).

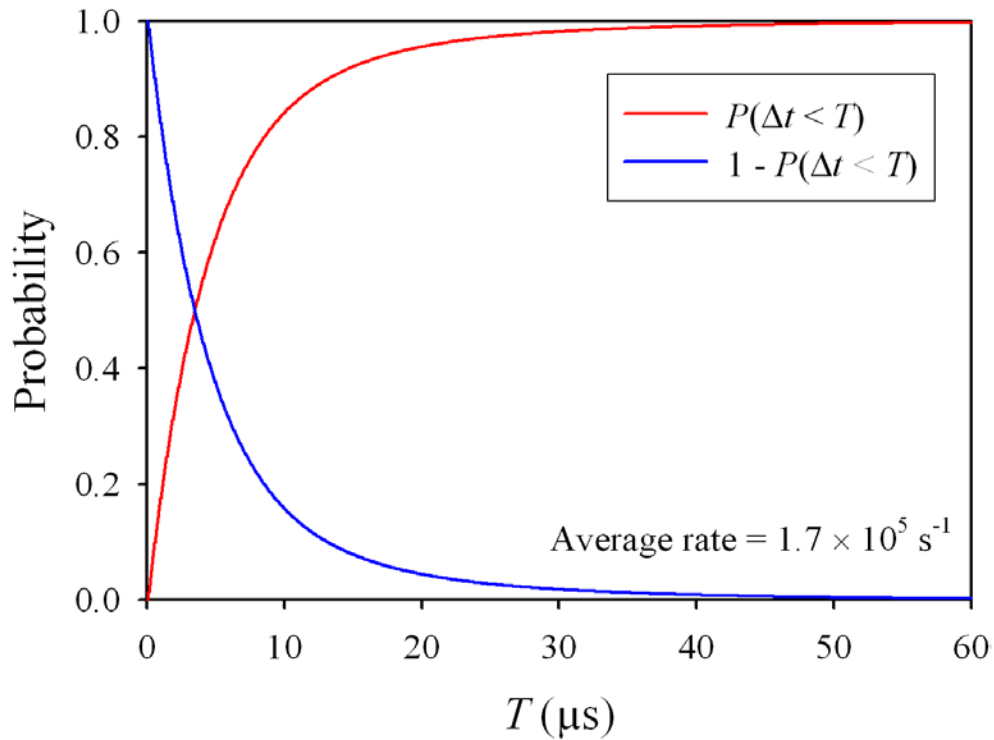


FIG. 3. Probability for detecting two ions within time interval $T < \Delta t$ (shown by the red curve) and $T \geq \Delta t$ (shown by the blue curve) derived from the histogram shown in Figure 2.

[1] V. Horvat and J.C. Hardy, *Progress in Research*, Cyclotron Institute, Texas A&M University (2009-2010) p. V-24.