Digital beta counting for high-precision nuclear beta-decay experiments

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In the past year we have made further tests on the digital β-counting system first described in our last progress report [1]. The goal of this project is to pursue a more robust signal processing system for our high-precision superallowed β -decay half-life measurements [2] based on a 4π proportional gas counter. Digital signal processing (DSP) allows one to perform very subtle analysis of detector signals long after the experiment is finished, and the method is naturally free from the constraints of on-line processing procedures. One can minimize on-line signal processing so as to maximize the physical information stored for later analysis. Then, in the off-line analysis stage, one can use DSP algorithms to build various data processing chains geared to investigate the effects of different parameter settings – for example, dead time or discriminator level – or to test different analysis ideas.

In high-precision lifetime experiments the genuine β -decay events must be counted with very high efficiency, precision and accuracy. In order to achieve this, the pulse waveforms must first be recorded with a relatively high resolution so that detailed off-line analysis can be performed. The high-speed digitizer we are using, National Instruments PCI-5154 [3], has all the key characteristics required. The digitizer can sample 2 input channels at 1GS/s rate simultaneously (up to 2GS/s if operated in single channel mode) and has a 256 MB on-board memory for each channel. It is an 8-bit digitizer, and the voltage dynamic-range can be configured from 0.1 V to 5 V. The dead-time of the digitizer is less than 1 μs, which is dominated by the reference (stop) trigger re-arm time. Since very high efficiency is essential in our measurements, the signal from the gas counter must be amplified with high gain. After extensive tests, we settled on two cascaded fast amplification stages, the first a fast timing preamplifier, ORTEC VT-120A, and the second an SR445A amplifier from Stanford Research Systems, to amplify our gas-counter signal with a combined gain of 1000. Both amplifiers have very short rise times, so the original pulse shape from the detector was well maintained for digitizing. With ×1000 gain the amplifiers provided a sufficiently strong signal for digital measurement and, based on our plateau analysis of the detector response as a function of applied bias voltage, we believe the β detection efficiency is >99.5%.

Figure 1 displays captured waveforms for nine genuine β -decay waveforms in the upper panel and nine “spurious” pulses – spontaneous detector discharges – in the lower panel. Apparently spurious pulses have a quite different shape compared to genuine β -decay pulses. Generally speaking, spurious peaks are quite fast and narrow but with a wide range of amplitudes. Note that most of the narrow spurious pulses are not counted by a conventional counting chain since the amplification stage of that system has a much longer shaping time (several micro-seconds), which has the effect of reducing the amplitude of most spurious pulses to below the discrimination level.

A typical pulse-width distribution is displayed in Fig. 2. The valley in the width distribution between the spurious and β peaks is obvious but unfortunately it is not deep enough to effect a clean separation based on pulse width alone, so additional pulse-shape analysis is required. A software filter, or discriminator, was designed and tested, which combined a composite analysis based on pulse width, rise time, amplitude and total integral. The pulses were filtered in two steps. In the first, a pulse was

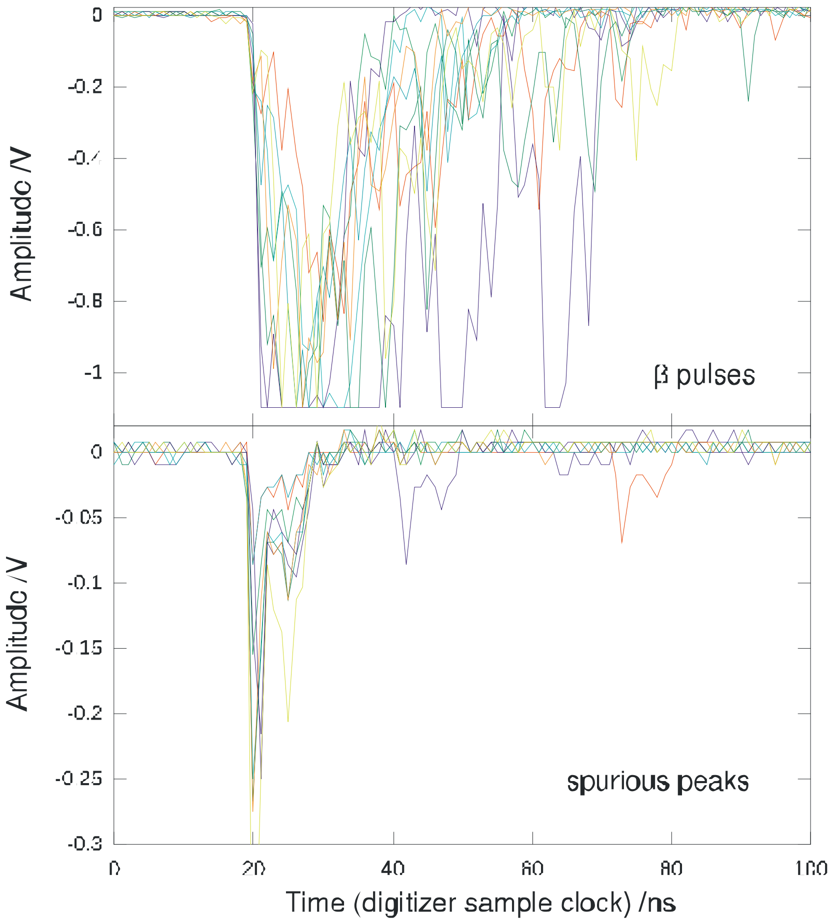

FIG. 1. Waveforms captured by the high-speed digitizer. The upper panel shows 9 captured β signals and the lower panel shows 9 "spurious peaks". The limits of the digitizer dynamic range can be seen on some of the β signals.

qualified as a β event or marked as a spurious or undetermined pulse based on its width: a very small width clearly signifies a spurious event while a very large width indicates a true β event; pulse widths in the region of the valley in Fig. 2 are deemed to require further analysis in a second step involving a detailed pulse-shape analysis. By determining the slope of each pulse's falling edge, and the pulse integral-to-amplitude ratio, we were able to separate true β events from spurious ones. A plateau we obtained by applying this combined filter is plotted in Fig. 3 and its slope is seen to be below ~0.5% per 100 V between 2600 V and 2825 V. This plateau is wider and flatter than those obtained with our conventional electronic chain. Thus, in principle the digital system provides a better way to count β particles.

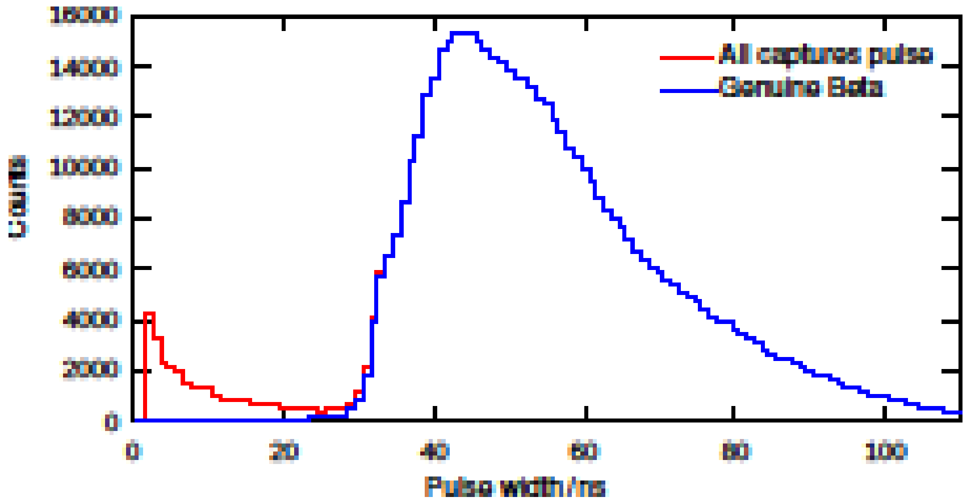

FIG. 2. Width distribution of pulses before and after the filter. The data were taken with a detector bias of 2800 V and a 5 kBq β source.

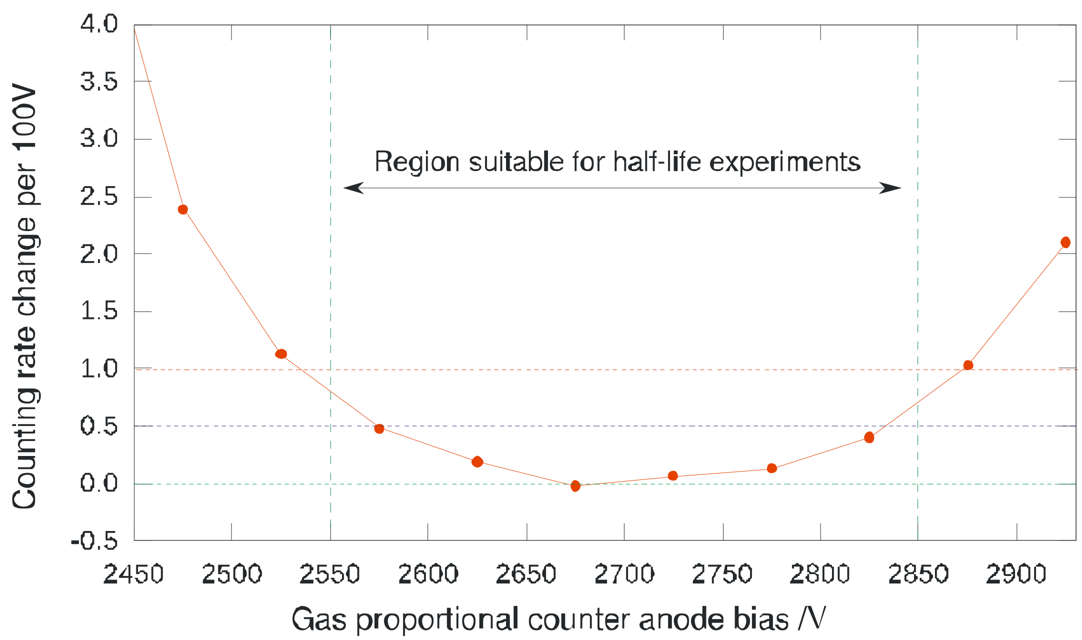

FIG. 3. The plateau for our 4π proportional gas counter as measured with our new digital-counting system. Data were taken with a 5 kBq ^{90}Sr β source; the measuring time for each point was 400 seconds.

It turns out that the number of spurious pulses increases rather rapidly with the effective detector bias as demonstrated in Fig. 4. We can see that it is the rise of spurious pulses at higher bias that actually causes the end of the plateau. Furthermore, evidently the higher plateau slope obtained with conventional counting systems is mainly caused by those spurious pulses. More details of the spurious-peak problem in proportional counters can be found in a rather early review paper [4].

The DAQ software as well as all the off-line analysis software were developed on the LabVIEW platform. LabVIEW provided a native control of our digital devices (all made available by National Instruments) and we found that using it for digital data analysis was reasonably efficient since many handy functions for hardware control and data processing are available, ready to use, in LabVIEW.

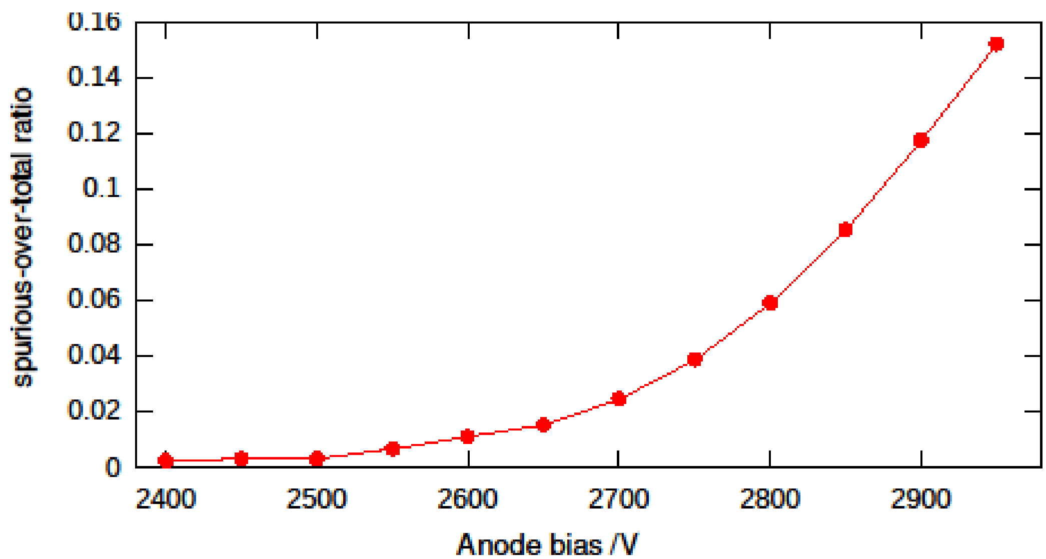

FIG. 4. The ratio of the number of spurious pulses to the total number of captured pulses. The data are taken from the 4π proportional gas counter with a 5 kBq ^{90}Sr β source.

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