A New Measurement of the Half-Life of the Superallowed β-decay of ^{26m}Al

Agilent Acqiris High Speed Data Acquisition System and Digital Signal Processing in Nuclear Physics

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Introduction

Recent advances in high speed signal digitisation introduced by Agilent have presented new and exciting opportunities in many nuclear and particle physics measurements. Experiments in nuclear and particle physics frequently involve the detection of particles using various types of detectors. By analyzing the signal that these detectors output scientists are able to characterize the particles being studied and determine their fundamental properties. In the past, the majority of the analysis of the detector signal has been done online using analogue electronics such as amplifiers, discriminators and counters. In doing this, unexpected information in the detector signal is lost, and the measurement may be compromised with no means of resurrection.

High speed signal digitisation allows the acquisition and storage of the complete signal from the detector output, allowing more options for analyzing this signal. The two most obvious options are:

- Analyze the signal online using pre-defined, customized digital processing
- Analyze offline using data-driven, customized digital processing

In both scenarios, there exists greater flexibility in the way the detector signal is analyzed. In addition, if the detector signal is processed offline, unexpected behavior may be identified and resolved, thus maintaining the integrity of the captured data.

This report describes how the use of a high speed Agilent Acqiris digitizer and digital signal processing will be used to obtain the world's best measurement for the half-life of the superallowed Fermi β-decay of ^{26m}Al.

Figure 1. Agilent Acqiris U1069A PCI high-speed digitizer card

Current Measurement

The half-life of ^{26m}Al is of interest because the decay of ^{26m}Al is a pure Fermi β-decay, and measurements on such decays provide the means to experimentally test two important components of the standard model of electroweak interactions. These two components are the required unitarity of the Cabibbo-Kobayashi-Maskawa (CKM) matrix, and the conserved vector current (CVC) hypothesis.

The half-life of ^{26m}Al has previously been measured using analogue electronics. This measurement will be discussed briefly here, including the issues that arose during it. It is proposed that these issues can be resolved using a high speed Agilent Acqiris signal digitisation card, and this will be discussed in the following section.

The ^{26m}Al activity was produced in this measurement using a $^{27}Al(\gamma,n)^{26m}Al$ reaction at the Australian Radiation Protection and Safety Authority (ARPANSA) LINAC facility in Melbourne. The beam energy was maintained at less than 18 MeV to ensure that no contaminant decays were created through other reaction channels with the 99.999% pure ^{27}Al sample.

The ^{26m}Al activity was transported to a low background counting room, where the decay was measured. The nucleus of 26mAl decays by positron emission, and these positrons combine with nearby electrons to emit two annihilation 511 keV γ-rays at 180° to one another. These 511 keV photons were detected in coincidence in two cylindrical NaI detectors with a depth and diameter of 7.62 cm.

The detection electronics are shown in figure 1, and they are comprised of amplifiers to amplify the signal and ensure its suitability for the subsequent electronics; Timing Signal Channel Analyzers (TSCA) to select only the 511 keV γ-rays; and coincidence and counting electronics. A total of 69 decay curves were obtained for both the singles and the coincidence counts. Each decay curves consisted of counts in 0.1 s bins over a period of 55 s.

Pulse pile-up events affect all counting measurements to some degree, and are a result of pulses occurring so close together that the detection electronics cannot tell them apart. As a result the pile-up event appears to the electronics as a single pulse of increased magnitude. Due to the constantly varying count rate in the decay curve, it was not possible to conduct a reliable measurement of the effects of pulse pile-up events during the experiment. As a result, these effects were instead corrected for within the functional form used to fit the data.

Each of the 69 decay curves for the singles and coincidence data sets were analyzed individually, using a minimisation technique with the Poisson Likelihood Chi Squared. The functional form used to fit simple decay curve is:

$$\mathbf{f(x) = a_0 e^{-\ln(2)t/} + a_1}$$

where a_0 and a_1 are the initial and background count rates respectively, and τ is the half-life.

The function f(x) is then 'adjusted' to allow a data driven correction for pulse pile-up events:

$$\mathbf{g(x) = f(x)/(1-pf(x))}$$

where τp is the pulse pile-up correction factor.

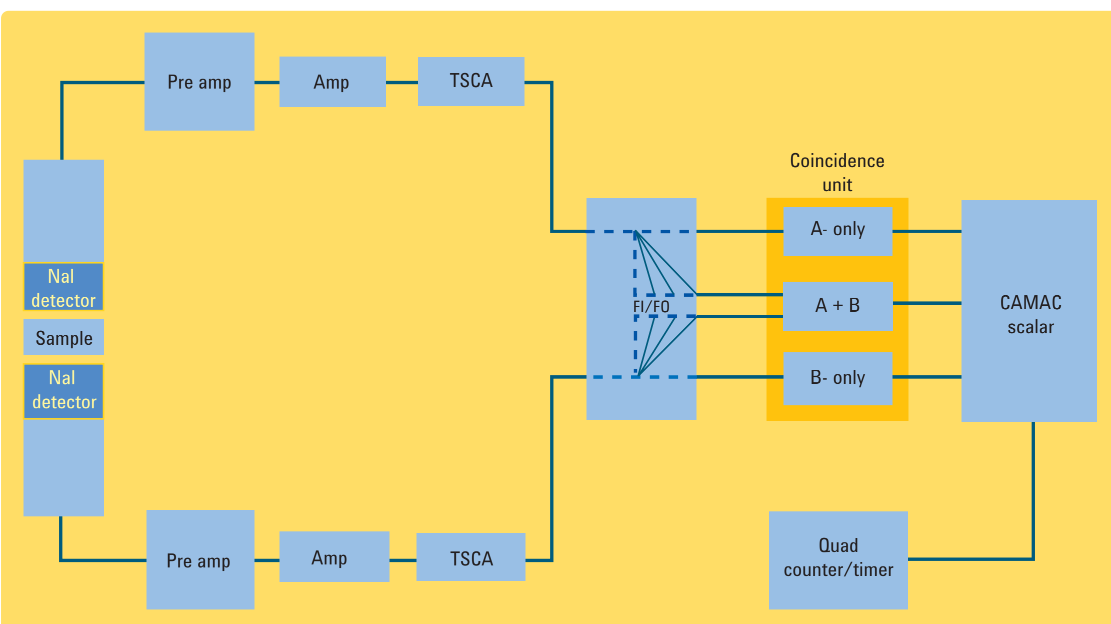

Figure 2. Traditional configuration - Detection electronics for singles and coincidence events.

The following graph presents a sample decay curve from the singles data and the fit that was obtained for that decay curve.

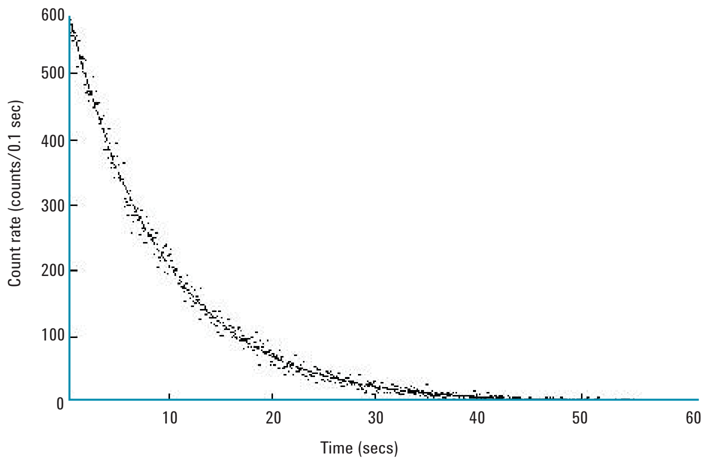

Figure 3. Sample decay curve

The resulting values for τ and τ_p were averaged to obtain the following results for the coincidence and singles data.

Table 1. Singles and coincidence results

Data set	τ	τ_p
Coincidence	6.342 ± 0.026 s	46 ± 7 µs
Singles	6.346 ± 0.012 s	3.9 ± 0.6 µs

The largest component of the uncertainty in the value of τ, is a result of systematic uncertainties due to the pule pile-up correction factor, which contributed an uncertainty of ± 0.024 s and ± 0.011 s in the coincidence and singles half-lives respectively. In order to obtain the world's best value for the half-life of ^{26m}Al using the experimental techniques described in this measurement, a new method must be found to resolve the pulse pile-up issue.

High Speed Digitisation with Agilent Acqiris Data Acquisition System

Recent advances in high speed signal digitisation achieved by Agilent have paved the way for new investigations into the resolution of pulse pile-up issues in nuclear physics experiments. Rather than using analogue electronics to process the output pulses from the detection system, the complete output pulses are captured, converted from analog to digital and stored by an Agilent Acqiris digitizer, and the pulse pile-up events are recovered on a case-by-case basis.

A proof-of-principle investigation was undertaken using the Agilent Acqiris U1069A digitizer card. The detector output was sampled at a rate of 100 Msamples/second, and the pulse pile-up events were identified and recovered. An example of a pulse pile-up event where the events were slightly less than 500 ns apart is presented, with a fit comprised of two single pulses.

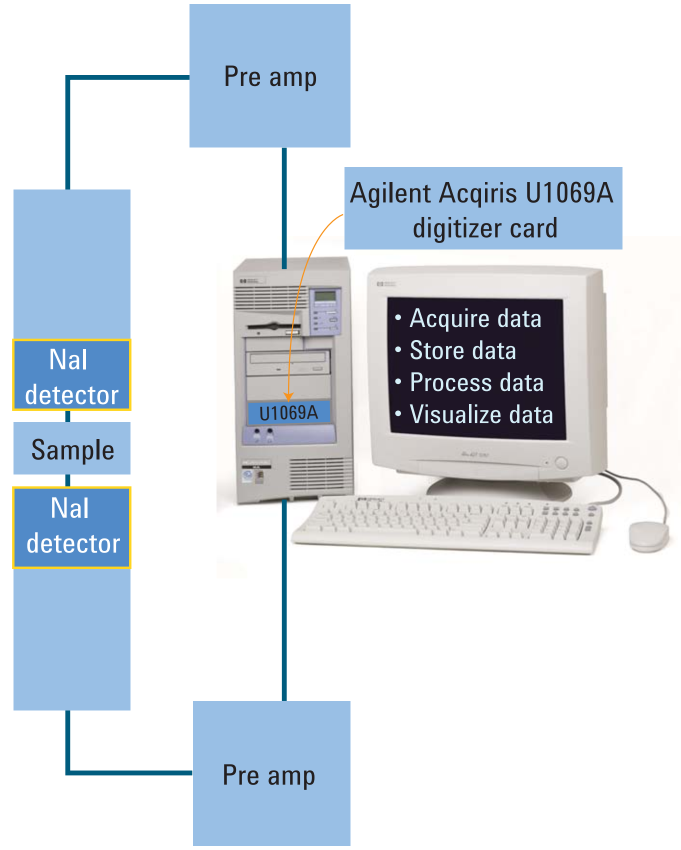

Figure 4. Digitizer configuration - Detection electronics for singles and coincidence events.

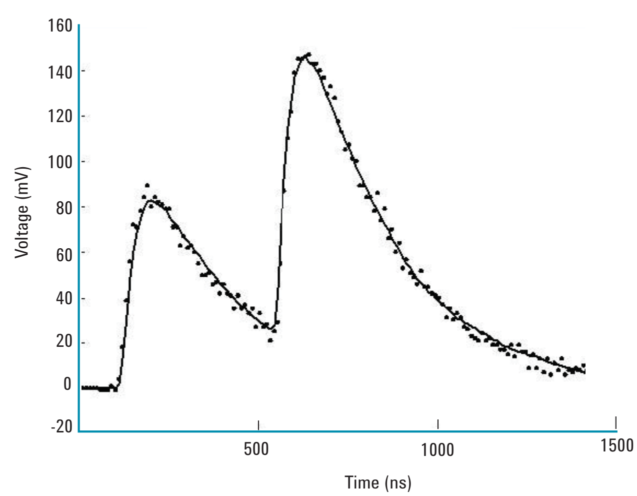

Figure 5. The pulse pile-up event with total fit.

In using this approach the two pulses have been recovered thanks to the data acquisition system, rather than lost through the detection electronics. This indicated that the pulse pile-up effects will be comprehensively resolved using this technique in a future measurement of the half-life of the superallowed β-decay of ^{26m}Al.

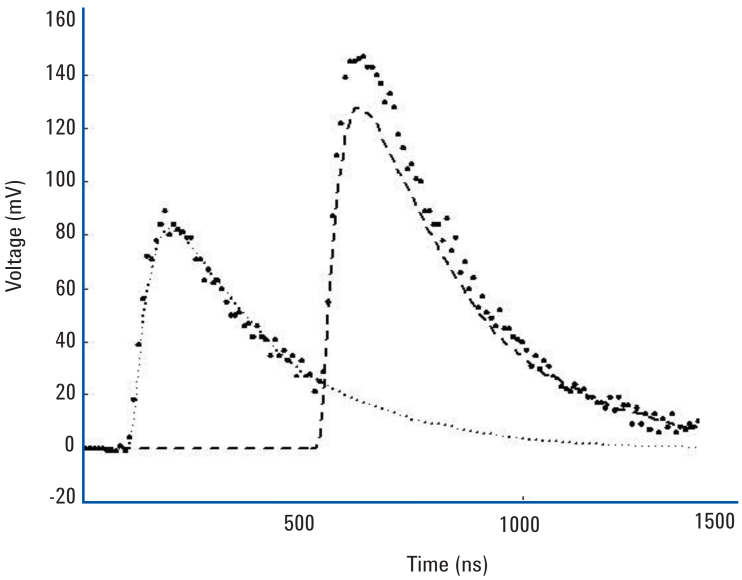

Figure 6. The pulse pile-up event with component fit

Conclusion

The ^{26m}Al nucleus decays by Fermi beta-decay, a process that is described by the standard model of particle physics. High precision measurements on the decay of ^{26m}Al are required to test the validity of the standard model, and the required unitarity of the Cabibbo-Kobayashi-Maskawa matrix in particular. By using a digitizer to record and correct when pulse pile-up events occur the decay time of ^{26m}Al can be determined with greater precision.

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