Distortions in βNMR Spectra due to Detector Deadtime

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Determination of dead time for the forward and backward scintillation counters at the βNMR facility within ISAC at TRIUMF were determined. Corrections now can be made to all data collected.

PACS numbers:

I. WHAT IS DEADTIME?

For an experiment where the observable is detected electronically there is the possibility for Dead Time to affect the results . Dead time is a span of time during which a detector, or an associated readout system, is unable to record new information[1]. This is usually related to the ability to digitize the signal, and other electronic conversions.

There are two possible ways for a detector to react to a second event within this time frame. The first is to not recognise it at all, this is commonly referred to as non-paralysable behavior. The second is to extend the dead time upon the arrival of this second event, This is referred to as paralysable behavior[2]. An illustration of the difference between these two behaviors is given in figure (1).

In the non-paralysable case the relationship between the actual and observed counts can easily be determined using the knowledge that for m observed counts in time T, and each observed count has an associated dead time, ϱ. Therefore, in the time T, a total dead time of mϱ occurs. During this period, nmϱ counts are lost, where n is the true count rate. n can then be determined as follows,

$$n = \frac{\frac{m}{T}}{1 - \varrho\frac{m}{T}}. \tag{1}$$

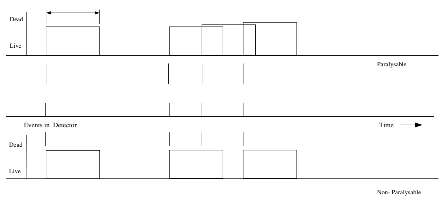

FIG. 1: Paralysable and Non-Paralysable dead time models

For the paralysable case, we have to realise that only those events that occur at time intervals greater than ϱ will be measured. For a radioactive decay with a mean rate of n, the distribution between time intervals is,

$$P(t) = ne^{(-nt)}. \tag{2}$$

The probability of an event occurring outside of time ϱ is

$$P(t > \varrho) = n\int e^{(-nt)}dt = e^{(-n\varrho)}. \tag{3}$$

The number of observed counts in a time T will then be,

$$m = nTe^{(-n\varrho)}. \tag{4}$$

In this model, the true count rate, n, can only be solved numerically. In the low rate limit, the behavior of the two scenarios is similar[2].

$$n = \frac{\frac{m}{T}}{1 - \varrho\frac{m}{T}} \rightarrow m = n(1 - n\varrho). \tag{5}$$

$$m = nTe^{(}-n\varrho) \rightarrow m = n(1 - n\varrho) \tag{6}$$

It becomes obvious that effect of dead time on our experiment depends heavily on the rate of β particle emmission. In performing βNMR experiments at ISAC rates of up to $1{\times}10^6$ $\frac{counts}{sec}$ of Lithium-8 entering the sample. The measurable, β particles arising from the radioactive decay of the Li nucleus, is proportional to the rate of incoming ^{8}Li. Because of the random nature of radioactive decay, there is always a probability for a dead time loss to occur. The probability of loosing an event increases with increasing rate, and can become quite severe as the rate of decay approaches one over the dead time. A reasonable estimate for the dead time for a counter is on the order of tens of nanoseconds[2].

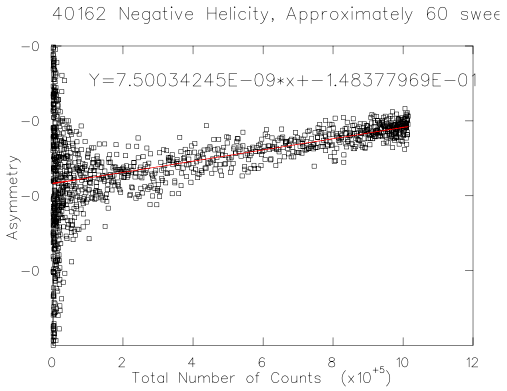

FIG. 2: Rate Dependance of assymetry caused by Dead Time.

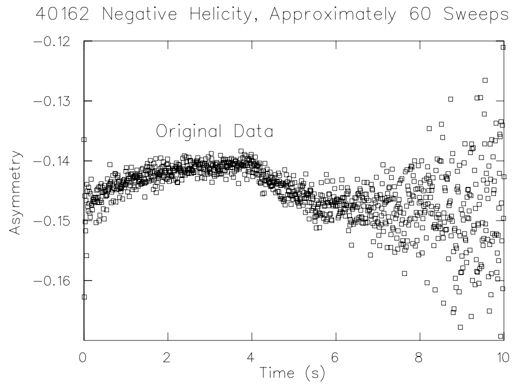

FIG. 3: Time Differential βNMR Output. Notice The Non-Linear behaviour of the asymmetery.

II. HOW DOES DEADTIME AFFECT βNMR SPECTRA ?

Dead time acts to scew the resluts in systematic way. In βNMR experiments this is most easily seen as a rate dependance of the asymmetry for unpolarized nuclei as observed in figure (2).

In a typical time differential experiment, the lithium beam is applied for a specific amount of time, Δt and then it is turned off. For a nucleus with a lifetime of τ, the rate of a given counter increases according the equation,

$$F(t) = \tau R_o(1 - e^{(-t/\tau)}). \tag{7}$$

After the beam has been shut off, the count rate of a given counter undergoes an exponential decay,

$$F(t) = \tau R_o(1 - e^{(\Delta t/\tau)})(e^{(t/\tau)}). \tag{8}$$

The asymmetry, which is calculated by dividing the difference between the two count rates by the sum of them, should remain constant with respect to time if there is no distortion on the counters. Figure(3) shows the output from the asymmetry calculations, we observe non-linearity which ressembles the count rate.

III. CORRECTING FOR DEADTIME

Before appliying a correction, the dead time must first be determined. Depending on how the detector responds to a subsequent signal, a correction method given in the first section may be used.

It is well known how to determine the dead time using the paired source technique[3]. Or for a short lived species, the decaying source method may be used[2]. Both these methods are experiments on their own. While they are accurate, they are quite time consuming. It should be possible to determine the dead time from data we have already obtained.

Using the time differental βNMR technique, we can observe the time dependance of the asymmetry. This should be constant if the implanted nuclei are not polarized. Since it is known that the observed asymmetry has a time dependance similar to that of the count rate, it can be safely assumed that this deviation is caused by the dead time loss. The dependance of asymmetry on the total count rate gives a relation that is, therefore, dependant on dead time. In figure (2) the slope of the graph is given in units of 1/(total counts). The total number of counts, though was reached over a period of 20.71667 minutes. Each point represents a 10ms binning. Since it takes approximately 20 seconds to complete 1 sweep, each 10ms point has approximately 60 sweeps. This makes each point a total count over approximately .6 seconds. From the slope we then find that the dead time of approximately 45 ns.

Another method would be to apply the low count rate correction for each point, and parameterize the dead time. Once a good value for the dead time is one that results in no rate dependance in the asymmetry. Figure (4) shows the dead time given by this method is approximately 45 ns.

Ideally the data for each sweep could be analysed, instead of only looking at the total collection for each sweep. Any variations in beam intensity, which are not uncommon, could severly effect the calculated dead time. These variations are just taken as non-existent in

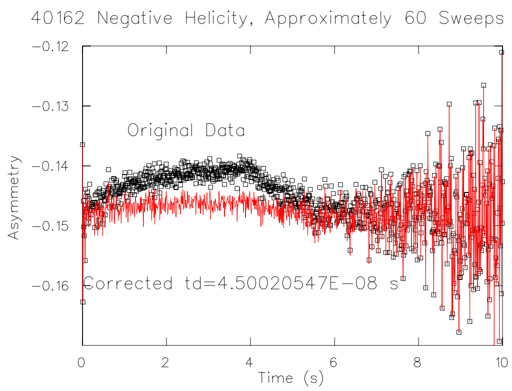

FIG. 4: Time Differential βNMR Output and correction using equation (1).

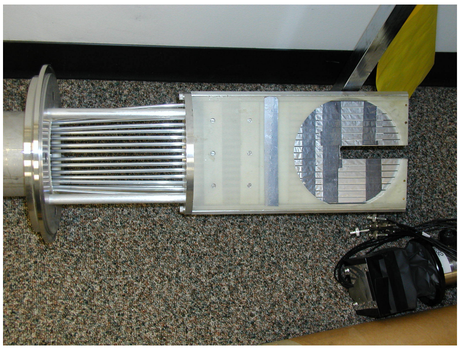

FIG. 5: Scintillation detector made up of 16 segments to reduce the affect of dead time.

these calculations. Looking at each bin would also give the experimenter a better idea of the amount of time used to collect each point.

Now, using the determined dead time, a similar correction algorithim can be applied to existing data to correct for dead time.

IV. OTHER METHODS TO LIMIT DEADTIME

Dead Time, being an intrinsic property of the counter, can also be reduced by altering the design of the counter. One idea would be to create a large number of smaller detectors, instead of just having one detector with a large surface area. This acts to reduce the probability of a second event occuring at the same detector during the dead time. An example of this is given in figure (5).

As can be seen in figure (6) this approach comes with an experimental design that is far more complicated that one with a simpler detector.

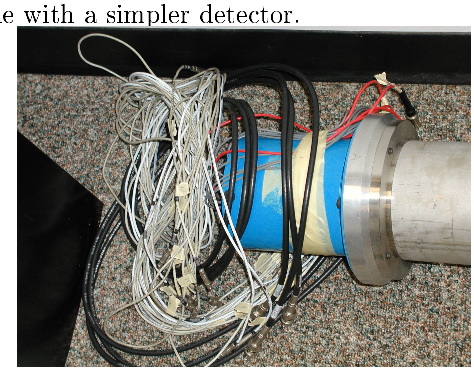

FIG. 6: Highly Complicated electronics accompany a complicated detector.

[1] W.R. Leo, Techniques for Nuclear and Particle Physics Experiments, Springer-Verlag, Berlin, 1994. pp 122-126.
[2] G.F. Knoll, Radiation Detection and Measurement, John Wiley and Sons, New York, 1979. pp 95-103.
[3] W.S. Diethorn, Int. J. App. Rad. Iso. **25**, 55 1974.