Particle Identification by Real Time Pulse Shape Analysis in CsI(Tl), Phoswiches, and other Scintillators

γ POLARIS

Introduction

Various scintillators offer the useful combination of a light output that decays with two significantly different lifetimes and a variation in the light output in each lifetime depending upon the type of particle that stimulated the emission. Thus, for example, CsI(Tl) has 2 lifetimes of order 400 ns and 4 µs, with the shorter lifetime being more strongly excited by neutrons, protons or alpha particles and the longer lifetime being more strongly excited by gamma rays and betas. By coupling CsI(Tl) to a photodiode or PMT and analyzing the individual pulse shapes, one can both measure event energies, and learn what the exciting particles were as well. Various scintillators have this property and, in addition, artificial structures of layers of scintillators with different decay times ("phoswiches") can also be constructed to behave similarly.

Developing a Particle ID ("PID") parameter (CsI(Tl) + Photodiode)

Figure 1 shows selected normalized traces from the output of a charge integrating preamplifier attached to a detector consisting of a 1 x 1 x 1 cm^3 CsI(Tl) crystal attached to a 1 x 1 cm^2 Hamamatsu S3590-08 photodiode when exposed to protons, alpha particles and gamma rays. Also shown is a trace from a gamma interaction directly in the photodiode. The four cases are clearly discernable visually.

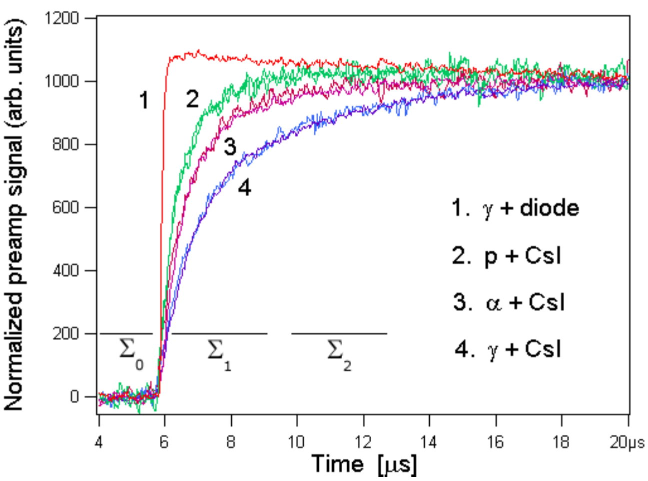

Figure 1: Normalized pulses from CsI(Tl) + photodiode output from the charge integrating preamplifier.

Implementing this discrimination in a spectrometer, however, raises several issues. First, the method should be fast and operate in real time so that results can be obtained *in situ*. Second, it should have enough sensitivity to reliably discriminate between the various types of excitation striking the scintillator. Third, the method should use as little circuitry as possible.

The literature shows three basic approaches. The first is pattern recognition, where, for example, the full pulse shape might be compared on a least squares basis to the members of a library of normalized pulses from the individual radiation types. This method can be highly accurate, but is difficult to implement in real time at realistic counting rates. The second method is that of zero crossing, where the pulse is passed through a bipolar filter that is sensitive to its shape and then the time from pulse arrival to zero crossing is used as the PID parameter. This method is often preferred with very fast scintillators, but requires accurate shaping and timing electronics, which can be complex and expensive. The third method compares integrals of selected regions of the pulse and can also produce accurate results, but the requirement for synchronized gated integrators with adequate time stability has often been a barrier to low cost implementation.

XIA's digital cMOS approach

XIA's approach to digital filtering is to directly digitize the input signal (in this case the PMT output) and then apply all filtering operations digitally. One such operation is the running sum Σ_k,

$$\Sigma_k(n) = \sum_{i=k}^{k+n} s_i \,,$$

which is just the digital equivalent of an integration over a fixed time period $\Delta t = n\,\delta t$, where δt is the digitization interval between samples s_i. Figure 1 shows three such running sums Σ_0, Σ_1, and Σ_2 set to capture the areas of three different regions of the pulses with the intention of using their values to establish a PID. Σ_0 measures the baseline before the pulse, which may not be zero in a high rate environment; Σ_1 measures the pulse while the shorter decay time is prominent; and Σ_2 measures the pulse while the longer decay time is prominent.

While not optimal, a PID that gave very good results was obtained by using a Σ_1 of length about 2.75 µs starting 0.5 µs after the leading edge and an Σ_2 of equal length starting immediately afterwards (essentially as shown). Figure 2 shows the resultant scatter plot of PID versus energy and its projection onto the PID axis, both for all events and for those less than 1 MeV. Clearly, quite good discrimination can be obtained even at low energies.

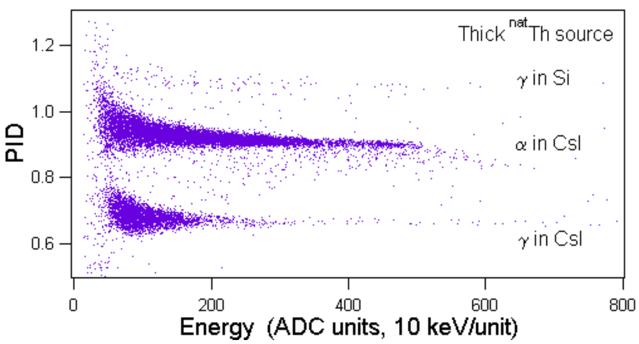

Figure 2a: PID versus energy for alphas and gammas in CsI(Tl) and from gammas in photodiode.

Several things are important to notice about this approach. First, the lengths of the running sums and the time delays between them are set digitally and can assume any values that are found to work well for the specific scintillator. Notice that the intervals can overlap if desired. Second, because such running sums are defined with the precision of the spectrometer's digital clock, their lengths and the time intervals between them will be highly reproducible and jitter free on a pulse-to-pulse basis. Referred to it as a **cMOS** (correlated Multiple Output Sample), these samples are time correlated both with one another and to the pulse's leading edge. Capturing such cMOS samples and using them to accurately determine pulse energies is a proprietary XIA technology with patents applied for.

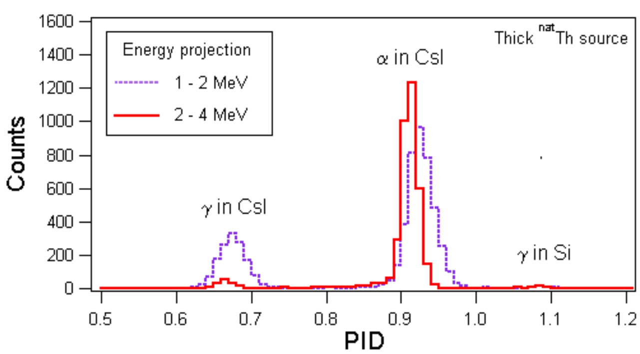

Figure 2b: Projection of Fig. 2a data on the PID axis for two energy ranges.

Another application: CsI(Tl) + PMT, directly coupled

Figure 3 shows two PMT output pulses from CsI(Tl) excited by a gamma ray and an alpha particle, where the PMT output was directly coupled into a Polaris spectrometer. The two pulses are even easier to distinguish than in the photodiode + preamplifier case presented above. A possible cMOS for a PID is indicated. Clearly, XIA's ability to work directly with PMT output pulses offers interesting new PID possibilities.

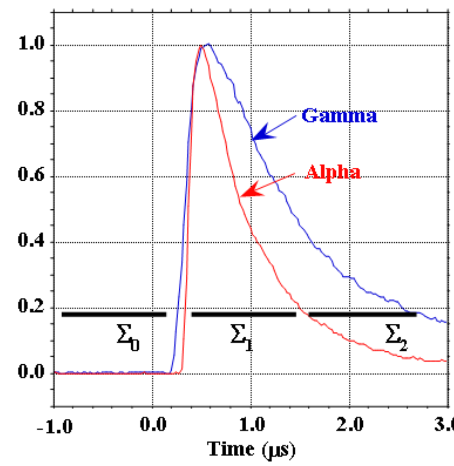

Figure 3: Normalized alpha and gamma pulses from CsI(Tl) + PMT output directly into Polaris spectrometer.

Applying the Polaris and µDXP to PID

If you want to develop a PID-based instrument for a specific purpose, XIA's fully-featured Polaris spectrometer is the place to start. Its full range of gains, list mode trace capture capability, large dynamic range and user-selectable triggering criteria assure that it can immediately work with almost any detector. Further, XIA's Igor-Pro™ based data collection and analysis software allows analyzing lists of captured pulses to develop specific cMOS based PIDs without leaving the application. Use the Polaris to fully study the problem and develop the best solution.

Once you know what you need to do and have developed a satisfactory PID, you're ready for the µDXP. The µDXP is intended for OEM applications. XIA can migrate your application-specific cMOS and PID computations into the µDXP's gate array and DSP. The µDXP can then perform the developed pulse shape analysis as a dedicated instrument, sorting the different particles into different spectra, calculate ROIs, display results or sound alarms. With its computation and control capabilities, the µDXP is well suited to perform all the core functions of your dedicated instrument.

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