LA-UR-13-25670

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Title: Development of processing algorithms to enable high-rate microcalorimeter array operation

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Intended for: Report

Issued: 2013-07-22

Development of Processing Algorithms to Enable High-Rate Microcalorimeter Array Operation

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July 22, 2013

The millisecond-scale decay constants of microcalorimeter gamma-ray pulses present challenges for operation at high count rates needed to compete with semiconductor HPGe detectors. If using conventional optimal filtering methods, pulse records with pileup events are simply discarded, leading to a large fraction of data unused when count rates are large. For single pixel rates exceeding 1-2 Hz, improved pulse processing algorithms are needed to better deal with pileup and increase the filter throughput. A 256-pixel array operating at 10 Hz per pixel would provide a total counting rate of 2.5 kHz.

To this end, a new filter algorithm was developed by colleagues at NIST (*B. Alpert, et al., "Note: Operation of gamma-ray microcalorimeters at elevated count rates using filters with constraints." Rev. Sci. Instrum. 84 (2013) 056107*). The mathematical formalism described therein creates a filter that is orthogonal to the exponential tail of pulses, such that the convolution of the filter with the pulse records can extract the pulse amplitudes even for pulses riding on the tail of a prior pulse.

After the filter was developed at NIST we sought to develop C++ code at LANL for integration with our pulse processing software and to enable operation of the LANL microcalorimeter array at higher total count rates. Code was developed to perform the following tasks. First, an average pulse shape is determined by averaging pulse records from many events (Fig. 1). Then, a noise autocorrelation function is computed by averaging the product of noise records with themselves for different lag values (Fig 2). A filter is constructed as

$$q = R^{-1}\bar{V}(\bar{V}^t R^{-1}\bar{V})e_1 \qquad \text{(Eq. 1)}$$

where R is the noise autocovariance matrix, $\bar{V} = [\bar{s}v_1v_2]$ with $\bar{s}$ the average pulse, v_1 = (1,1,1), v_2 the exponential tail function, and e_1 = (1,0,0). This creates a filter orthogonal to constants and an exponential. For the present work, a filter of width 200 bins was created (Fig. 3) for operation on pulse records of length 1024 bins.

For each pulse record, the filter is convolved with the data. For illustrative purposes, Fig. 4 shows a synthesized pileup event of two equal amplitude pulses, and Fig. 5 shows the result of convolving the filter and data. As shown, the correct pulse amplitudes are extracted for both pulses despite the pileup.

The filter was applied to real data from a single pixel with an event rate of approximately 5 Hz. The resulting spectrum constructed by finding the maximum(s) of the convolution is shown in Fig. 6. The raw data file contained a total of 6778 events that did not include pileup. Using the new filter, 8390 events were included in the final spectrum. Thus, the new filter allows for a 24% increase in total filter throughput. This improvement will be even larger for higher incident rates exceeding 5 Hz per pixel.

The energy resolution of the 97 keV ^{153}Gd peak using the new filter is 93 eV FWHM (Fig. 7). Using the conventional optimal filter that discards pileup events gave a resolution of 69 eV FWHM. Although some degradation is expected using the new filter on pileup events, these results can likely be improved upon by pursuing several paths including: 1) optimizing the filter length and pulse record length to find the best trade off between pulse throughput and resolution, 2) implementing cuts to reject pulses where pulse separation is less than the filter length or pulses are too close to the edge of the record, which leads to incorrect normalization.

In summary, a new pulse processing filter has been developed to enable analysis of high-rate data. The filter was implemented in C++ code and demonstrated on real data with an event rate of 5 Hz achieving a 24% increase in total events kept. We expect energy resolution can be improved through optimization of parameters such as filter length and pulse record length. We anticipate applying the filter to even higher event rates exceeding 5 Hz per pixel where the conventional filter would reject a large fraction of pileup events.

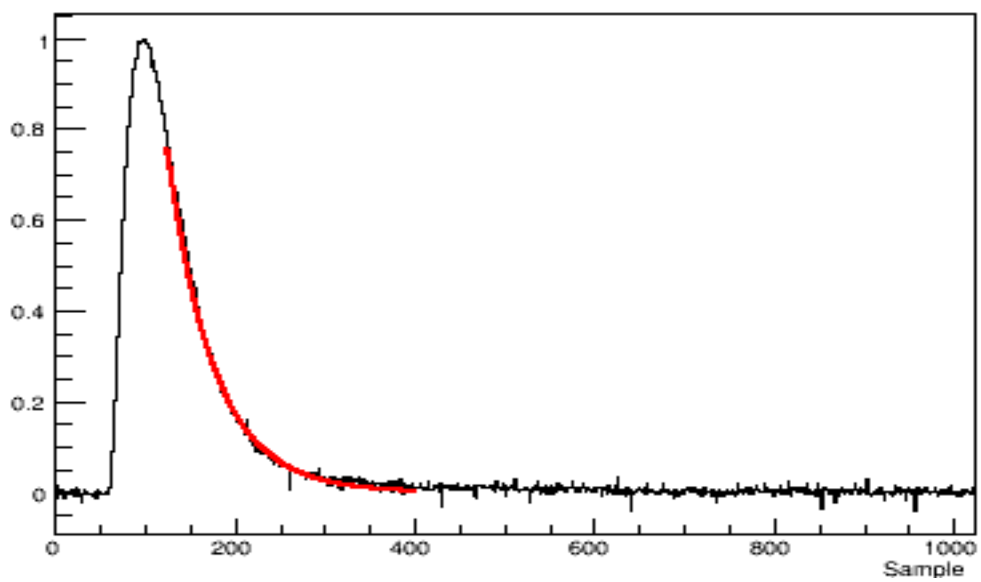

Figure 1 - Average pulse with exponential fit (red) to determine the exponential parameter of the filter.

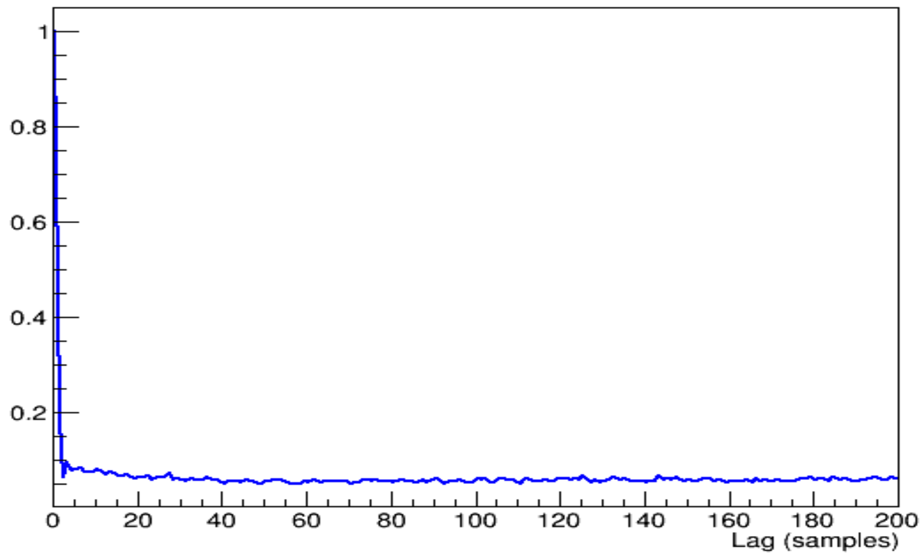

Figure 2 - Noise autocorrelation function, maximum at zero lag.

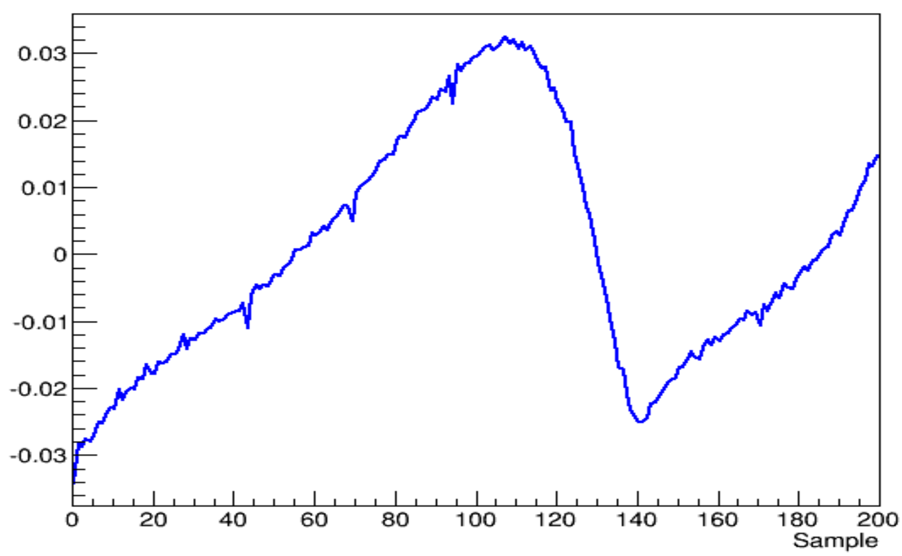

Figure 3 - A 200-sample wide filter orthogonal to constants and exponential tails.

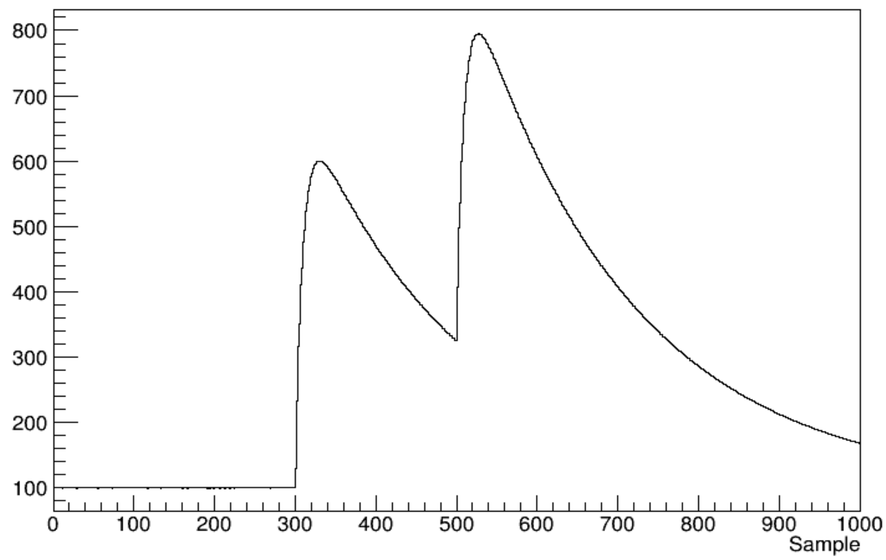

Figure 4 - A synthetic pileup pulse with both events having equal amplitude.

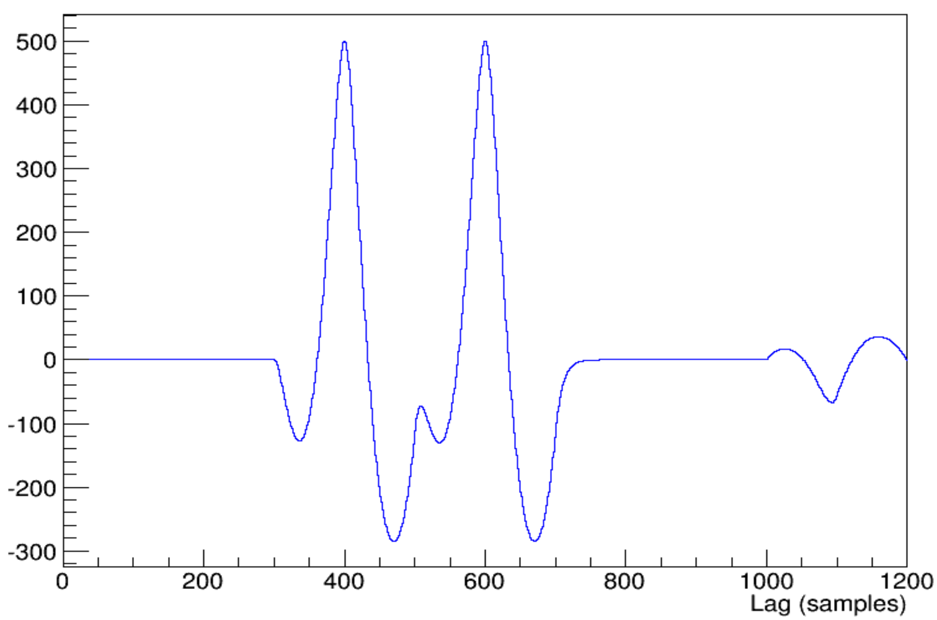

Figure 5 - Convolution of the filter with the synthetic pileup pulse in Fig.4. Both pulse amplitudes are extracted correctly. Application to real data is similar.

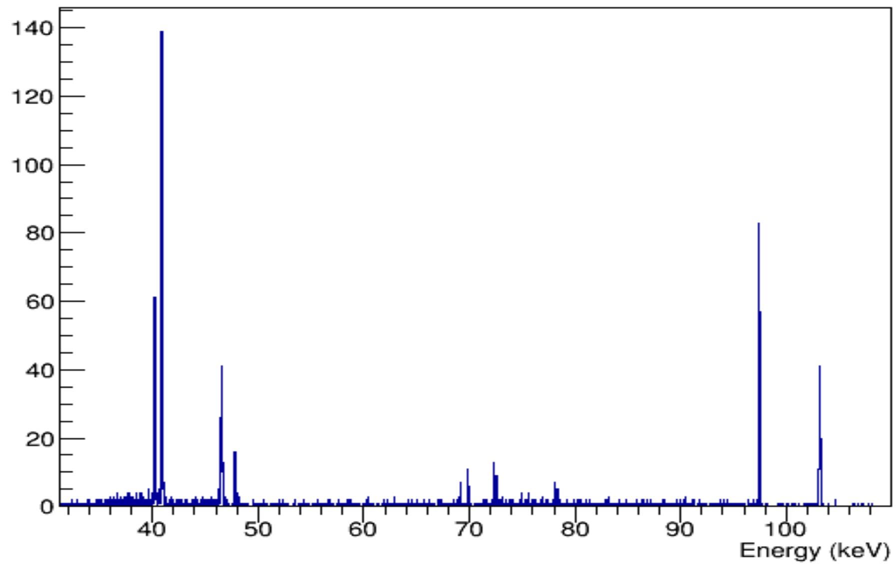

Figure 6 - ^{153}Gd spectrum generated from application of the new filter to data collected from a single pixel at 5 Hz event rate.

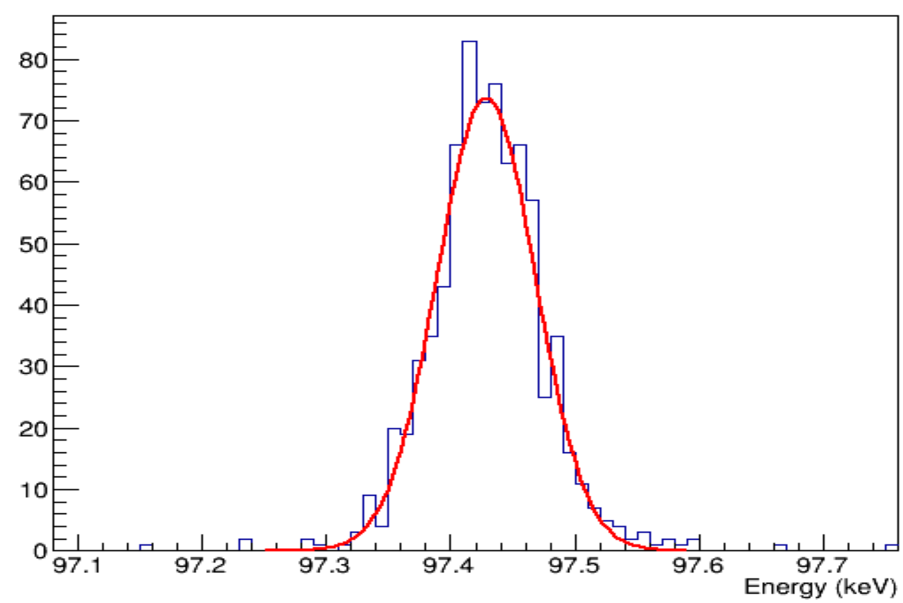

Figure 7 - 97 keV peak of ^{153}Gd generated with new filter having 93 eV FWHM resolution.