Exploring digital timing response for fast scintillators at Giga-Sampling digitization rate

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Digital timing response of fast scintillator detectors are explored using LeCroy HDO4000A oscilloscope, operated at 1.25 giga samples per second (GSPS), and 2.5 GSPS. Signal time markers for a single (as well as for a pair) detector is extracted using a versatile digital constant fraction (DCF) timing algorithm. Anode signals obtained at 2.5 GSPS rate interpolated linearly in the DCF transition region provides ; self timing resolution (FWHM) of 61 ps, and 76 ps for BC501A and $LaBr_3$ detectors respectively, while time-of-flight resolution (FWHM) of 1.47 ns is achieved for a pair of BC501-$LaBr_3$ detectors at 1.25 GSPS.

Introduction

Fast timing scintillator detectors have important application in nuclear spectroscopy, energy measurement of fission neutrons ; for example BC501A scintillators, time-of-flight (TOF) PET imaging etc. The scintillation mechanism can be excited by the incoming radiation, leading to a prompt flash having characteristic decay component. With a suitable optical coupler, light photons produced are allowed to trigger the photocathode of a fast PMT, result into a timing (anode) and energy (dynode) signals. Particle information, such as energy and arrival time can be retrieved from the energy and timing branch of an analog signal processing chain. Using modular electronics and digital pulse processing (DPP) approach, one can push to the limits of temporal response, for instance 350 ps, and 660 ps for $LaBr_3$ [1] and BC501 detectors [2] respectively. With DPP, one can handle large density of signals with easy software approach to extract energy, timing, and charge information simultaneously from a given event pulse [1]. Ongoing efforts are to understand the digital implementation of timing algorithms for fast scintillator detectors namely ; BaF_2, BC501A, and $LaBr_3$.

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Signal Processing and Acquisition

Anode signals of the aforementioned detectors were acquired with HDO4000A oscilloscope from LeCroy [3] which has ENOB as 8.7. It was used for the self timing study as well as TOF measurement of different detector pairs ; (BaF_2-$LaBr_3$), (BaF_2-BC501A), and ($LaBr_3$-BC501A). For the self timing investigation, ^{137}Cs radioisotope was used, placed at 25 cm, 5 cm, and 25 cm in front of BC501A, $LaBr_3$, and BaF_2 detectors respectively. Detector's anode signal was fed to CAEN-315A passive splitter. Output signals were traveled through equal cable length of 40 cm and given to first two channels of HDO. Since the signal strength of $LaBr_3$ detector was small (maximum height $\sim$ 80 mV), therefore, processed via VT120 current amplifier prior to CAEN-315A splitter. TOF data was recorded with ^{22}Na radioisotope for all the detector pairs. With respect to the source, first detector of the mentioned pair was situated at 5 cm while the other was placed at 25 cm. Coincidence signals were processed with same cable length of 133 cm, fed to the first two channels of oscilloscope. Data was acquired at 1.25 giga samples per second (GSPS), and 2.5 GSPS digitization rates with a oscilloscope trigger threshold as -50 mV.

Results and Discussion

Collected sample stream of an anode signal is processed with a digital constant fraction

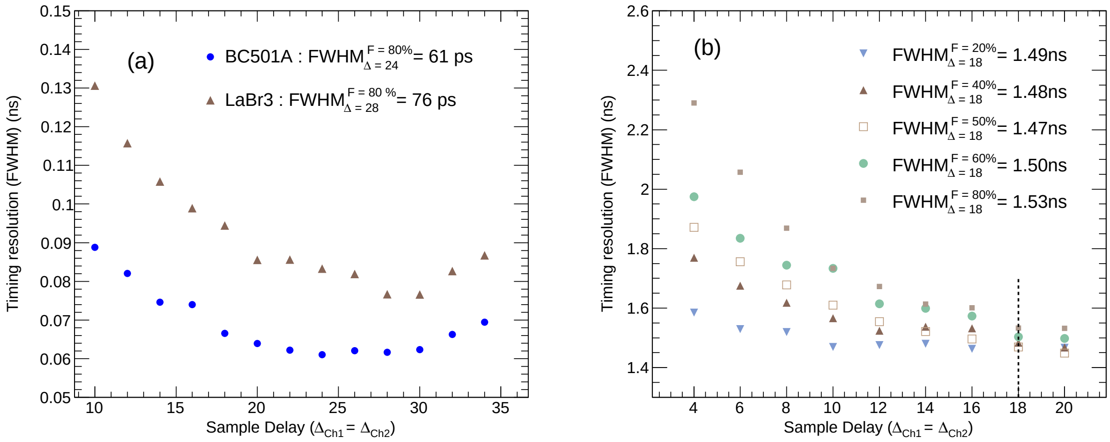

FIG. 1: Panel (a) : Self timing dispersion curves for $LaBr_3$ and BC501A detectors, legend depicts the optimum value. Panel (b) : time-of-flight resolution optimization curves at various DCF parameters for $LaBr_3$-BC501A detector pair, legends depicts the best TOF dispersion, vertical dotted line displays the minimum locus of dispersion curves.

timing algorithm [4], can be constructed as :

$$DCF[i] = F*(Sig[i]-BSL)-(Sig[i+\Delta]-BSL) \quad (1)$$

Here, Sig[i] : sample train of data points, BSL : baseline offset, F : fraction applied, Δ : delay introduced. High precision time marker (TM) position, indicating the particle arrival time, can be obtained by using Bisection method, while connecting the points linearly in the DCF transition region. Relative TM errors of two same signals measure timing fluctuation, whereas the signals received from two different detector give particle's flight time information. One can minimise these fluctuations in Δ and F space to get the best temporal response of a detection system.

While adopting the above procedure, results obtained are shown in Fig. 1 (a) ; best case for the self timing measurement at 2.5 GSPS, whereas Fig. 1 (b) displays the temporal dispersion curves retrieved at 1.25 GSPS. The electronic fluctuations introduced by signal processing chain is obtained as 61 ps (FWHM) for BC501A, which matches with the earlier investigation [4]. Owing to slow signal rise-time of 5.5 ns in $LaBr_3$ detector (compared to 4.5 ns in BC501A), it translates to slightly higher timing dispersion of 76 ps (FWHM). Best timing resolution for the pair of detector $LaBr_3$-BC501A is obtained as 1.47 ns with Δ = 50 % and F = 18 samples, depicted in Fig. 1 (b). Although the number is slightly on the higher side, we are anticipating to reduce it further by making cubic spline interpolation of the sample points. Analysis is in progress to retrieve the results for all the detector pairs, those will be presented during the symposium.

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