Time-of-Flight resolution of fast scintillators and further improvement by constant fraction signal slope : A digital approach

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Timing of flight (TOF) resolution for fast scintillator detector pairs ; (BaF_2-BC501A), ($LaBr_3$-BC501A), and (BaF_2-$LaBr_3$), is assessed by employing a digital technique. While self timing measurement (from pulsar signal) reveals a width (FWHM) of 65 ps, whereas TOF resolution for the mentioned pair, retrieved to be 1.24 ns, 1.28 ns, and 0.93 ns at 250 MSPS, which becomes 1.09 ns, 1.06 ns, and 0.42 ns at 500 MSPS. We further propose the event selection criteria using digital constant fraction signal slope (at time marker position) as a parameter, leading to a significant improvement in the TOF width.

Introduction

The onset of faster ADCs and signal digitizer, it now become feasible to perform large scale nuclear physics experiments, for instance AGATA [1], and INGA [2] arrays. Small scale application area includes time-of-flight (TOF) mass spectroscopy, electron imaging with micro channel plates, γ-ray TOF PET imaging. Signals from a fast timing detector can be directly given to the digitizer, thereby scale down the extra signal processing units, which otherwise be used in analog counterpart. Thus a minimum signal distortion can be expected at the output of a digitizer bucket, leading to improve in spectrum quality. From a collected sample stream, one can retrieve energy, particle arrival time, and charge delivered by the incident radiation encoding the physical process. Thus, requires a dedicated faster mathematical algorithms to extract the event characteristics.

We are in a pursuance of digital implementation of timing algorithms for fast scintillator detectors namely : BaF_2, BC501A, and $LaBr_3$. A benchmark is established for TOF resolution of detector pairs ; (BaF_2-BC501A), ($LaBr_3$-BC501A), and (BaF_2-$LaBr_3$). They are named as : "BaB", "LB", and "BaL" respectively in the following text.

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Data recording

Coincidence signals of the aforementioned detector pairs were recorded with a VME based data acquisition system at IUAC, New Delhi. Waveforms were collected by using ^{22}Na radioisotope, emitting back-to-back 511 keV γ-rays. Each detector pair was arranged in a straight line, where first detector was situated at 5 cm while the other was placed at 20 cm with respect to the radioisotope. Signal acquisition was performed with a VME based 12-Bit CAEN-V1720, 8 channel digitizer, operated at 250 MSPS [3]. For making resolution comparison, another data set was taken with 14-Bit DT5730 desktop digitizer from CAEN [3], that has 8 channels, operated at 500 MSPS rate. Sample resolution of 4 ns (2 ns) was obtained for 250 MSPS (500 MSPS) digitizer, while ≈ 4 μs (≈ 1.2 μs) of acquisition window was configured. Input dynamic range for both the digitizers were set to be -2 V with a DAC offset of -1 V, while maintaining a hardware threshold of -25 mV. Total 35000 events were collected in an ASCII file format, which later on analyse by a $C{+}{+}$ based program invoking ROOT libraries [4].

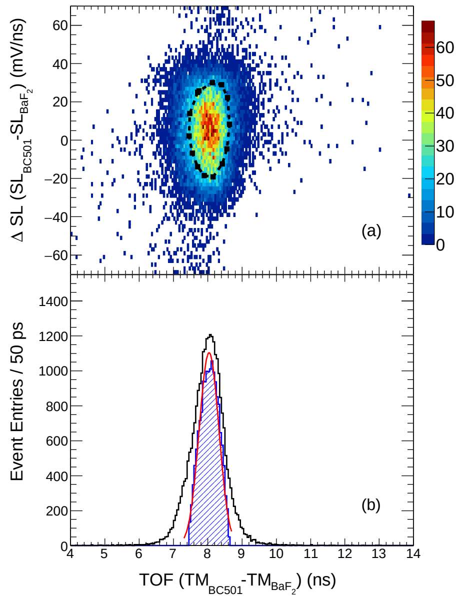

FIG. 1: Panel (a) : Slope error vs. TOF density distribution for a BaB pair, obtained at 500 MSPS. Panel (b) : Raw TOF is shown in black while the distribution obtained under proposed event selection criteria, depicted as 2D gated in panel (a), is shown as a blue hatched histogram.

Digital Constant Fraction timing

Particle arrival time can be accurately marked by a digital constant fraction (DCF) signal, can be constructed as :

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

Here, Sig[i] : train of sample points, BSL : baseline offset, F : fraction applied, Δ : delay introduced. Using Bisection method, high precision time marker (TM) position can be retrieved by interpolating the sample points. Due to finite risetime of a signal, interpolation leads to time broadening, σ_t, at TM position given as :

$$\sigma_t = \frac{\sigma_{eff}}{(\frac{dS}{dt})_{TM}} \quad (2)$$

$$\sigma^2_{eff} = \sigma^2_{en} + \sigma^2_{eq} \quad (3)$$

Here, σ_{en} : amplitude error due to noise fluctuations, σ_{eq} : amplitude error introduced by signal digitizer, σ_{eff} : effective amplitude error, and $(\frac{dS}{dt})_{TM}$: signal slope (SL) at TM position. One can optimize time walk, σ_t, for different values of F, and Δ to get a sharp temporal response.

Results and Discussion

We interpolated the DCF signal transition points by using cubic spline library from GSL [5], and obtain time marker position by using Bisection method. Mentioned optimization procedure being adopted for all the pair of detectors, operated at 250 MSPS and 500 MSPS. Using 250 MSPS digitizer, best TOF resolution obtained for a detector pair "BaB", "LB", "BaL", as 1.24 ns, 1.28 ns, and 0.93 ns respectively [5]. Corresponding (F, Δ) are (20%, 3), (40%, 3), and (20%, 3) respectively. It becomes 1.09 ns, 1.06 ns, and 0.42 ns for the same pair [5] at 500 MSPS. Corresponding (F, Δ) values obtained as (20%, 5), (20%, 5), and (20%, 3) respectively. To further reduce the temporal dispersion, we propose a new analysis method of event selection in ΔSL vs. TOF space. Guided by the optimum slope error, we impose this event selection criteria to reduce the tailing in TOF distribution, as depicted in Fig. 1. A significant improvement of 38% is observed in TOF dispersion [5]. Results obtained for all the detector pairs will be presented during the symposium.

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