FTOF Triplet Timing Calibrations

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March 29, 2013

Abstract

This write-up includes some notes on the timing calibration method using triplets of identical counters for the CLAS12 Forward Time-of-Flight (FTOF) system.

1 Introduction

During the initial assembly phase of the CLAS panel-1 and panel-2 TOF counters, detailed measurements of the timing resolution of each counter were completed. This procedure employed minimum ionizing cosmic ray muon tracks. From the CLAS technical publication on the TOF system [1], the measurements were presented as the average timing resolution for each counter of a given length vs. the counter length. This data is shown in Fig. 1.

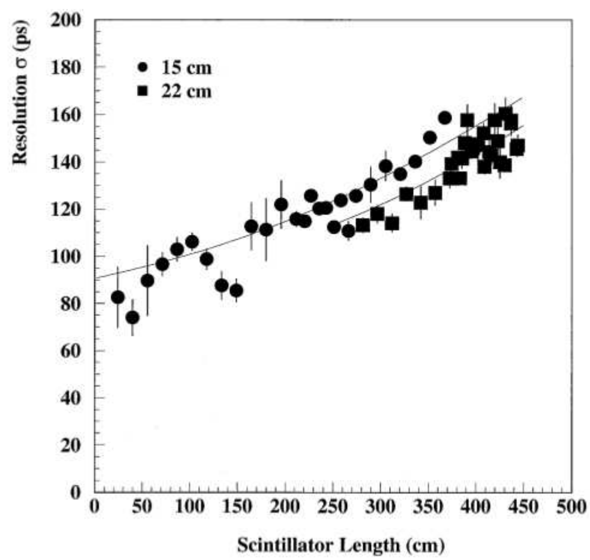

Figure 1: Measurement of the average TOF counter resolution of a given length counter (ps) vs. the counter length (cm). This data was acquired before the beginning of the CLAS production physics program and represents the initial baseline calibration.

As part of the QA procedure for the refurbished CLAS12 FTOF panel-1a and panel-2 counters, the average timing resolution of the different counters in each array needs to be measured. The goal is to directly compare the new measurements to the baseline measurements of the same counters shown in Fig. 1.

The approach that will be used for the timing measurements will be to employ a "triplet" scheme. Here a set of three identical counters is used to measure the average timing resolution for the set. The basic configuration of the setup is illustrated in Fig. 2.

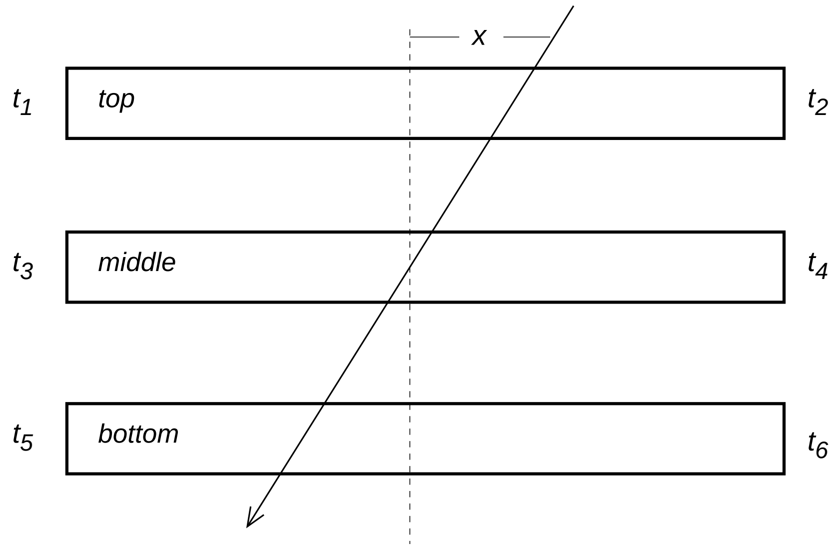

Figure 2: Schematic representation of a counter triplet made up of three identical scintillation counters. For the FTOF system, the scintillators have PMT readout at each end. The counters are labeled as top (t), middle (m), and bottom (b). The times t_i, $i = 1 \rightarrow 6$, represent the measured corrected PMT times relative to the trigger time.

2 Timing Resolution Algorithm

The basic algorithm to determine the average timing resolution of a set of three counters involves measuring the PMT timing for a given incident muon track. For a triplet measurement, where the track passes through all three counters with double-sided readout, six times are measured (t_1, t_2, ..., t_6). Each time measurement actually represents the difference between the discriminated PMT signal (TDC start) and the trigger time (TDC stop from the six PMT coincidence). These timing measurements are then translated into three overall scintillation counter hit times:

$$t_t = \frac{1}{2}(t_1 + t_2) \tag{1}$$

$$t_m = \frac{1}{2}(t_3 + t_4) \tag{2}$$

$$t_b = \frac{1}{2}(t_5 + t_6). \tag{3}$$

Note that the coordinates of the hit along the counters can be determined through the time difference measurements of the PMTs via:

$$x_t = \frac{v_{eff}}{2}(t_1 - t_2) \tag{4}$$

$$x_m = \frac{v_{eff}}{2}(t_3 - t_4) \tag{5}$$

$$x_b = \frac{v_{eff}}{2}(t_5 - t_6), \tag{6}$$

where v_{eff} is the effective velocity of light in the scintillator material ($v_{eff} \approx 16$ cm/ns for BC-404 and BC-408).

For incident tracks that pass fully through each counter of the triplet with measured times t_t, t_m, and t_b, we can define a time residual t_r,

$$t_r = t_m - \frac{1}{2}(t_t + t_b). \tag{7}$$

We should expect that the time t_m of the middle scintillator hit should be the average of the measured times t_t and t_b for the top and bottom scintillator hits, respectively. Thus the measured residual t_r should nominally be 0. However, due to the smearing of the measured times t_t, t_m, and t_b due to the finite time resolution of the measurements, the residual time t_r will also be smeared. While we still expect the mean of t_r to be zero, the width of the t_r distribution can be used to determine the average time resolution of each counter in the triplet.

The average time resolution of each counter is computed from the variance in the measured time residual. The time residual from eq.(7) can be rewritten as:

$$t_r = \frac{1}{2}(t_3 + t_4) - \frac{1}{2}\left[\frac{1}{2}(t_1 + t_2) + \frac{1}{2}(t_5 + t_6)\right], \tag{8}$$

therefore, the variance of t_r (written as δt_r) can be computed as:

$$(\delta t_r)^2 = \sum_{i=1}^{6}\left(\frac{\partial t_r}{\partial t_i}\right)^2 \Delta t_i^2 \tag{9}$$

$$= \frac{1}{16}\left(\Delta t_1^2 + \Delta t_2^2 + 4\Delta t_3^2 + 4\Delta t_4^2 + \Delta t_5^2 + \Delta t_6^2\right). \tag{10}$$

So,

$$\delta t_r = \frac{1}{4}\sqrt{(\Delta t_1^2 + \Delta t_2^2 + 4\Delta t_3^2 + 4\Delta t_4^2 + \Delta t_5^2 + \Delta t_6^2)}. \tag{11}$$

Assuming the average time resolution for each PMT in the triplet (Δt_i, $i = 1 \rightarrow 6$) is comparable, i.e. $\Delta t_1 = \Delta t_2 = \cdots = \Delta t_6$, then

$$\delta t_r = \frac{\sqrt{3}}{2}\Delta t_i = \frac{\sqrt{3}}{2}\sigma_{PMT}, \tag{12}$$

and we can write

$$\sigma_{PMT} = \frac{2}{\sqrt{3}}\delta t_r, \tag{13}$$

where σ_{PMT} is the timing resolution of the PMT. Given that each counter is readout using two PMTs, it is the case therefore that

$$\sigma_{counter} = \frac{\sigma_{PMT}}{\sqrt{2}}. \tag{14}$$

Therefore we can write our final expression for the average counter timing resolution as:

$$\sigma_{counter} = \frac{2}{\sqrt{6}}\delta t_r. \tag{15}$$

Thus a measure of the width of the time residual distribution δt_r provides a measure of the average resolution of each counter in the triplet. Note that the exact form of the expression in eq.(15) depends on the specific formulation of the time residual definition in eq.(7).

3 Sample Distributions

This triplet scheme for measuring the average time resolution of a set of counters was employed during the R&D phase of the CTOF system [2]. Fig. 3 shows the time residual distribution from the CTOF triplet using the definition in eq.(7). Here the distribution of the hit coordinate vs. time residual is shown, as well as the projection onto the t_r axis. Fig. 4 shows a fit of the residual distribution vs. hit coordinate, highlighting a typical counter resolution for the CTOF triplet of about 50 ps.

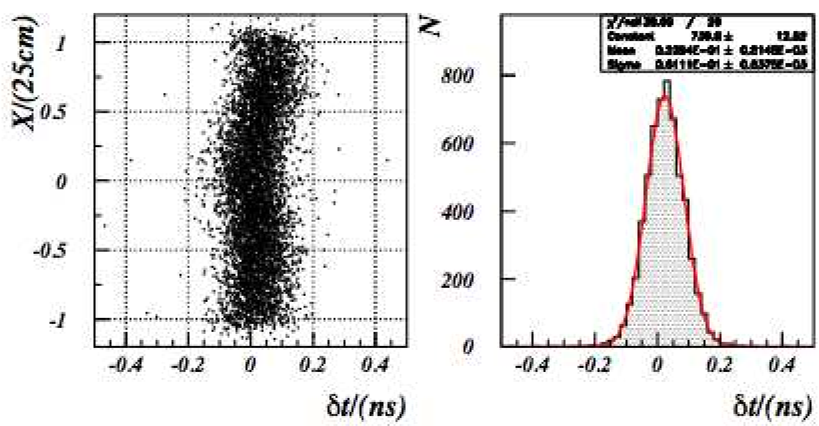

Figure 3: Data from the CTOF 50-cm long prototype counter triplet. (Left) Plot of the triplet hit coordinate (cm) vs. the time residual t_r (ns). (Right) The triplet time residual distribution (ns).

Note that this approach gives the average time resolution for each counter in the triplet. The configuration averages over the full range of muon angles accepted by the counter geometry. However, the resolution is seen to be reasonably independent of hit coordinate. However, the data shown in Fig. 3 does have an event selection criteria included that cuts out both very low ADC pulse heights (to remove events that do not traverse the full scintillation bar of each counter) and very high ADC pulse heights (to eliminate showering events).

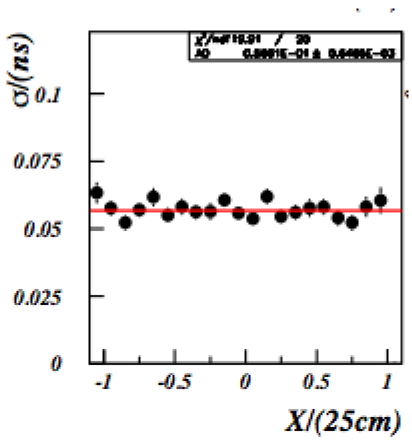

Figure 4: Fit of the coordinate vs. residual distribution from Fig. 3 for the CTOF 50-cm long prototype counter triplet.

4 FTOF Cosmic Ray Test Stand

For the FTOF timing calibrations, the counters have been installed into storage carts. Fig. 5 shows photographs of the panel-1a and panel-2 triplet configurations. Note that the panel-1a and panel-2 arrays are aligned relative to each other in the carts such that the bars of a given length or counter number are aligned relative to each other to form the counter triplets. For panel-1a, 23 counter triplets are defined, and for panel-2, 5 counter triplets are defined.

Figure 5: (Left) Photograph of one of the two FTOF panel-1a triplet setups in its storage cart. (Right) Photographs showing the two FTOF panel-2 triplets in their storage carts.

The DAQ system is setup as shown in Fig. 6 and includes JLab VME flash ADCs into which the PMT dynodes are connected. It also includes JLab VME disciminators and CAEN VME V1290 35 ps LSB TDCs into which the anodes are connected. Fig. 7 shows a block diagram of the basic electronics configuration for each counter triplet.

5 Time Walk Corrections

During the standard TOF system timing calibrations for physics runs, one of the important corrections necessary to achieve precise timing resolutions is what is called a “time-walk”

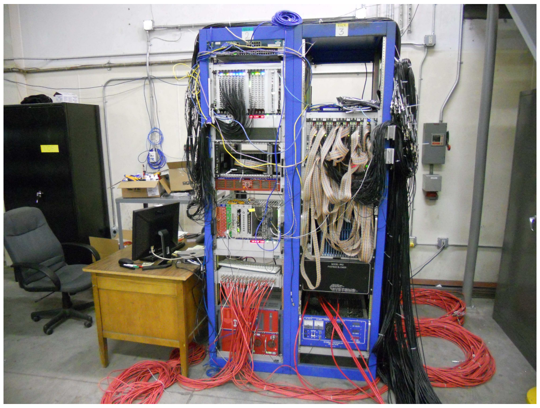

Figure 6: Photograph of the FTOF DAQ system including VME flash ADCs, discriminators, and high-resolution pipelined TDCs.

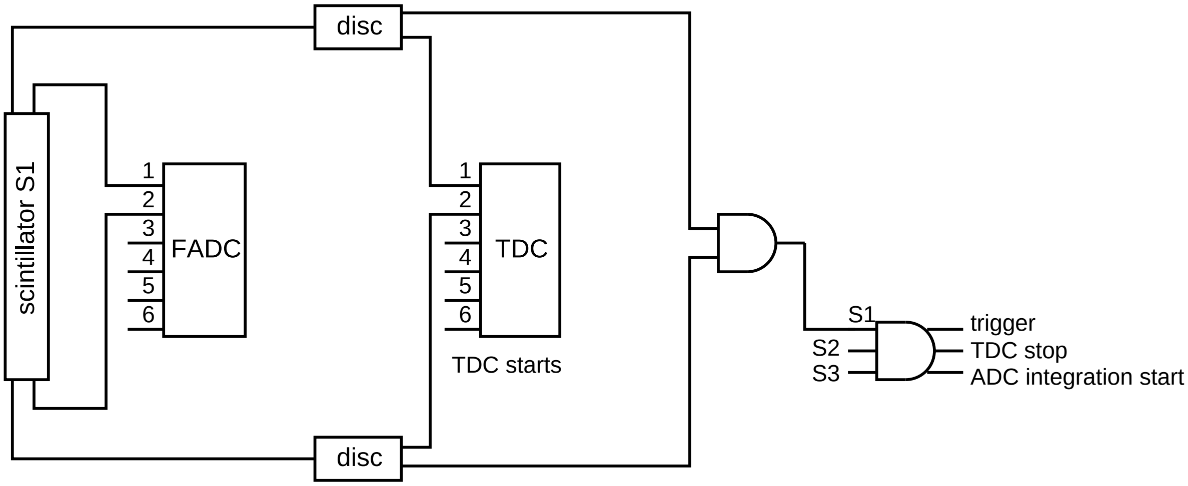

Figure 7: Block diagram of the electronics configuration for each triplet.

correction. Time walk is an instrumental shift in the measured hit time that arises when using leading edge discriminators [3]. This shift in timing arises due to the finite rise time of the analog pulse. For a given event time, pulses of different amplitude cross the discriminator threshold at slightly different times. This correction therefore depends on the ADC pulse size. Fig. 8 shows an example of the size of the correction for one of the CLAS TOF counters. Here we see the measured time recorded for a fixed time signal plotted vs. the ADC pulse height. We see variations of the recorded time of 4 to 5 ns over the full dynamic range of the ADC. Keep in mind that the desire time resolution (see Fig. 1) is ultimately required to be better than 100 ps.

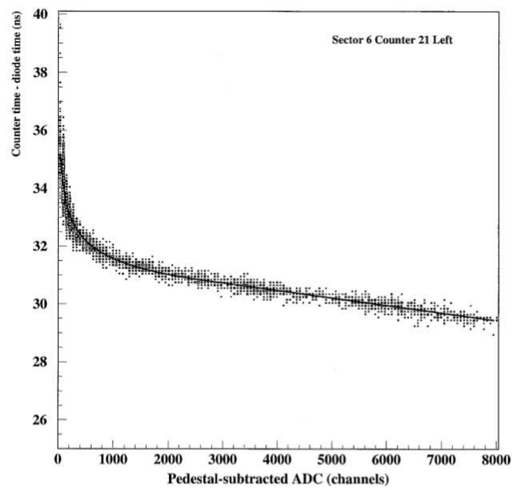

Figure 8: Plot of the measured TDC time relative to a fixed reference signal (ns) vs. ADC pulse height showing the importance of time walk corrections to optimize the timing resolution.

Note that such corrections are not necessary in the FTOF triplet configuration as the triggers are based on incident minimum ionizing muons that are required to pass through the full extent of the counters (remember the ADC cuts described in Section 3). Looking at a typical CLAS TOF ADC spectrum (see Fig. 9), we are preselecting events that essentially deposit the same energy in each bar ($\sim$10 MeV for normally incident muons). The time residuals are not affected too much by time-walk corrections for the limited range of incidence angles that can trigger the triplet. Certainly this is true for the shorter bars in panel-1a. For the longer bars of panel-1a and panel-2, the residual can be studied with cuts on the angle of incidence of the track defined by using the track coordinates defined in eq.(4).

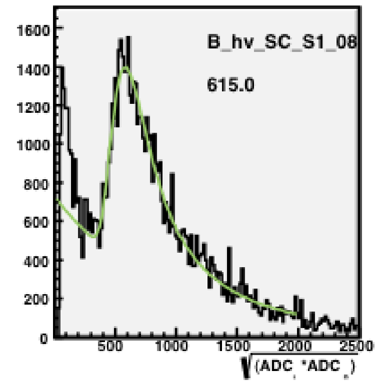

Figure 9: ADC spectrum from a typical FTOF panel-1a counter showing the minimum ionizing muon peak at about ADC channel 600.

References

[1] E.S. Smith *et al.*, Nucl. Inst. and Meth. A **432**, 265 (1999).

[2] V. Baturin *et al.*, CLAS-Note 2009-001, (2009).

[3] E.S. Smith and R. Nasseripour, CLAS-Note 2002-007, (2002).