CLAS12 FTOF Test Plan

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(ftof-testplan.tex)

Abstract

This document contains the basic test plans for the high voltage calibration and time resolution measurements for the FTOF scintillator bars before installation in the CLAS12 detector.

1 FTOF Overview

The Forward Time-of-Flight system (FTOF) will be a major component of the CLAS12 forward detector used to measure the flight time of charged particles emerging from the target. In each sector of CLAS12, the FTOF system will be comprised of three sets of TOF counters, referred to as panels (called panel-1a, 1b, and 2) in each sector. Each panel consists of an array of rectangular scintillators with a PMT on each end. Panel-1 refers to the sets of counters located at forward angles (roughly 5° to 35°) and panel-2 refers to the sets of counters located at larger angles (roughly 35° to 45°).

The panel-1 arrays will consist of the current CLAS panel-1 TOF arrays (called panel-1a) and a new set of panel-1 arrays (called panel-1b). The existing panel-1a counter arrays consist of 23 scintillators, each measuring 5.08-cm thick and 15-cm wide. The lengths of these counters range from roughly 32 cm at the smallest scattering angles to 375 cm at the largest scattering angles. The scintillators are constructed from BC-408 scintillator and are read out through short acrylic light guides to 2-in PMTs with custom voltage dividers. The new panel-1b counter arrays will each consist of an array of 62 counters constructed from BC-404 scintillator for the shortest 31 counters and from BC-408 for the longest 31 counters. Each panel-1b counter will be 6-cm thick and 6-cm wide with lengths ranging from roughly 18 cm to 408 cm. The integrated PMT/divider assemblies will be coupled directly to the scintillators.

The panel-2 scintillators will be taken from counters in the current CLAS panel-2 TOF arrays. These BC-408 scintillators of lengths from roughly 370 cm to 430 cm are 5.08-cm thick and 22-cm wide. The 3-in PMTs are connected to the scintillators through curved acrylic light guides.

2 Test Plan Overview

This test plan document is designed to describe the basic procedures for the baseline measurements of the refurbished panel-1a and panel-2 counters and possibly for the new panel-1b counters. It is assumed that this test plan will begin after all counter repairs and basic checks have been completed. The basic measurement setup to test each counter will involve using cosmic ray muons or a radioactive source.

The calibration of the individual FTOF counters will include two distinct phases. In the first phase, the high voltage (HV) settings for the left and right PMTs of the FTOF counters will be determined to position the muon peak in a particular channel of the mean L/R PMT ADC spectrum (see Section 3). After the high voltage values have been determined, the timing resolution of the individual FTOF counters will be measured. All final calibration parameters will then be entered into the CLAS12 calibration database.

The basic test configuration will involve a triplet of counters. One possible configuration that is similar to how the original CLAS TOF counters were initially calibrated is shown in Fig. 1.

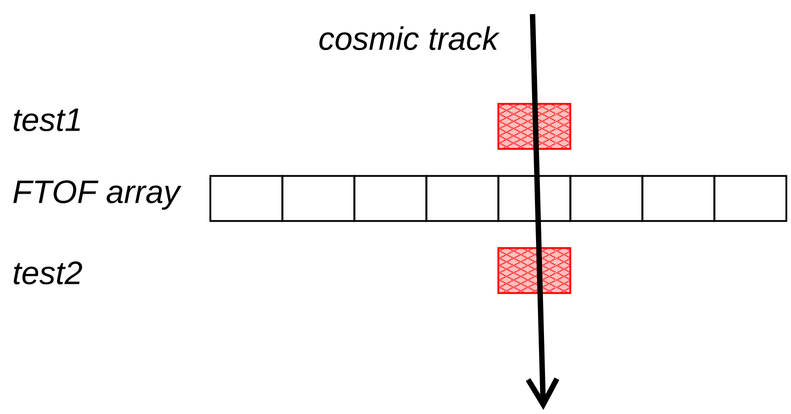

Figure 1: Side view of a possible FTOF calibration test setup using a pair of test counters above and below the FTOF array. This configuration is similar to the setup used for calibration of the original CLAS TOF arrays.

The electronics will be setup as shown in Fig. 2 and a stand-alone CODA data acquisition system will be employed. A coincidence of three counters will be formed that will provide the trigger, as well as the gate for the ADC and the start for the TDC. The PMTs from both ends of the test counters and the FTOF counter under test will be connected to the TDC stops and the ADC inputs. Matching the geometry (lengths and widths) of the two test counters to each other and to the FTOF counters is the best choice to reduce accidental coincidences, to sample the response over the full length of the FTOF counter under test, and to determine the absolute timing resolution of the FTOF counters. However, due to the different lengths of the FTOF counters (see Tables 1, 2, and 3), this is not a practical possibility. However, an optimized geometry for defining a matched triplet of FTOF counters is described in Section 4.

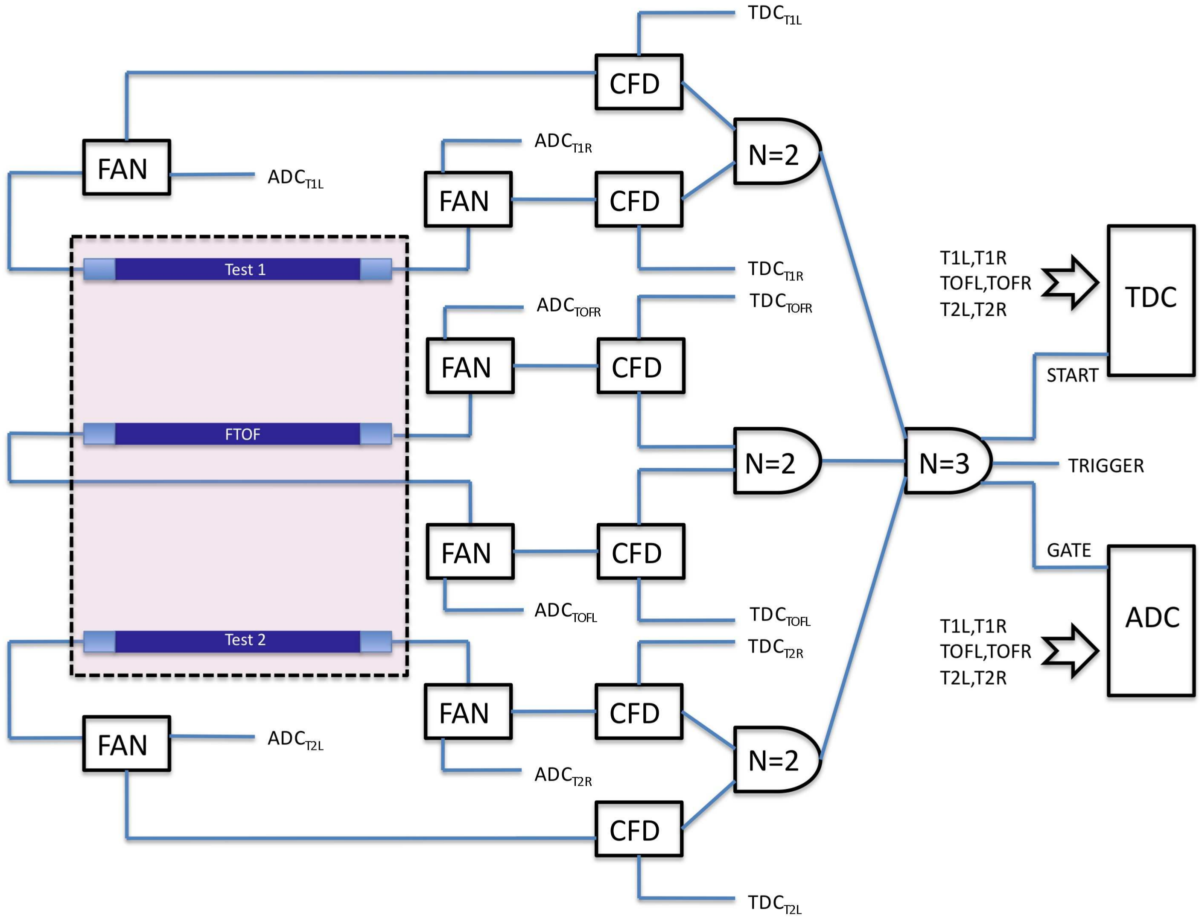

Figure 2: A generic layout of the electronics for the FTOF counter calibration using a triplet of counters, each with double-ended readout.

3 HV Calibration

In order to normalize the response of a TOF counter, a gain-matching algorithm for the left and right PMTs of each counter is required. This calibration ensures that each counter contributes equally to the trigger for a given discriminator threshold setting, as well as sets the response of each counter to be more or less the same. This is accomplished by adjusting the left and right PMT voltages such that the energy deposited by a normally incident minimum ionizing particle (MIP) produces a peak at a given location in the pedestal-subtracted ADC spectrum. Given the dynamic range of the ADCs employed, our nominal choice with the current CLAS ADCs is channel 600, although depending on the dynamic range of the CLAS12 ADCs, this could shift to a larger channel number to minimize issues with low pulse height events near the ends of the bars. A final choice for the position of the muon peak in the mean ADC spectrum must ensure that the most highly ionizing charged particles passing through the scintillators do not saturate the ADC (i.e. produce an overflow).

The measured pulse height in each PMT after pedestal subtraction, assuming the attenuation lengths λ are the same at each end of the bar is given by:

$$\begin{aligned} A_L &= k_L E e^{-y/\lambda} \\ A_R &= k_R E e^{y/\lambda}, \end{aligned} \tag{1}$$

where $A_{L/R}$ are the pedestal-subtracted ADC values, $k_{L/R}$ are the conversion factors between energy and ADC channel, E is the energy deposited in the counter, λ is the counter-specific attenuation length, and y is the position of the hit along the counter whose zero is at the center of each counter.

As the measured pulse height at the left and right PMTs for a given energy charged particle passing through the counter depends on the coordinate y as seen through eq. 1, most often the product of the left and right PMT pulse heights is studied. This gives a position-independent measure of the pulse height distribution as:

$$A = \sqrt{A_L \cdot A_R} = \sqrt{k_L k_R} E = kE. \tag{2}$$

The centroid of this distribution is called the geometric mean A_{mean}. Some examples of representative spectra and fits to determine A_{mean} from the CLAS TOF system are given in Fig. 3. The high voltages of the left and right PMTs were nominally adjusted to center A_{mean} at channel 600 in the pulse height distribution A. As a normally incident minimum-ionizing cosmic ray muon deposits 10 MeV in the scintillator, the conversion factors k in eq. 1 between energy and ADC channel are roughly k = 10 MeV/600 ch = 0.017 MeV/ch.

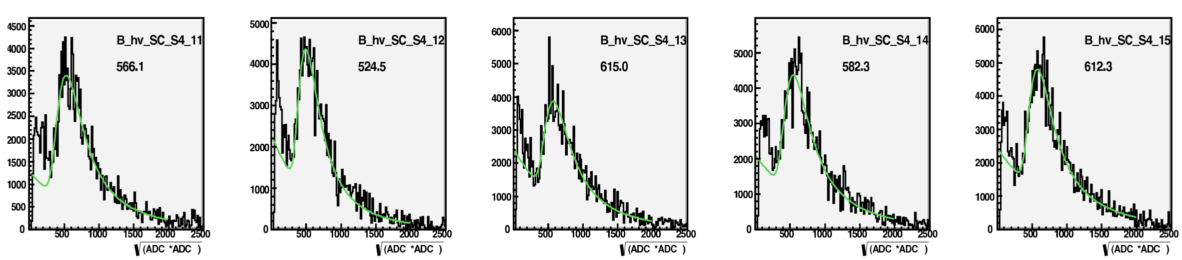

Figure 3: Plots of eq. 2 from a set of CLAS TOF counters. The fit shown overlaid on each plot is given by a Lorenztian line shape for the peak and a third-order polynomial for the background. The CLAS HV calibration software value of A_{mean} is included in the upper right of each subplot.

Another standard distribution used to set the individual left and right PMT high voltages is referred to as the "log ratio" R of the pedestal-subtracted ADC values given by:

$$R = \ln\left(\frac{A_R}{A_L}\right). \tag{3}$$

This quantity is proportional to the hit coordinate y of the incident charged track along the counter. A straight-forward manipulation of eq. 1 taking the ratio of E_R and E_L gives:

$$y = \frac{\lambda}{2}\left[R - \ln\left(\frac{E_R}{E_L}\right)\right] \approx \frac{\lambda R}{2}. \tag{4}$$

Thus a measurement of the log ratio R is directly proportional to the coordinate y along the bar of the ionizing track.

The log ratio R is then used to effectively separate the contributions from the left and right PMTs from the overall pulse height distribution A. Thus,

$$\begin{aligned} A_L^{eff} &= \frac{A_{mean}}{\sqrt{e^{\ln(A_R/A_L)}}} \\ A_R^{eff} &= A_{mean} \cdot \sqrt{e^{\ln(A_R/A_L)}}. \end{aligned} \tag{5}$$

The distribution of R should nominally be centered about zero if the triplet of counters are matched in physical size and properly aligned with respect to each other or if the two test counters in Fig. 1 are positioned about the center of the FTOF counter under study. Some examples of representative spectra from the CLAS TOF system are given in Fig. 4. The high voltages of the left and right PMTs were nominally adjusted to center A_{mean} at channel 600 in the pulse height distribution A.

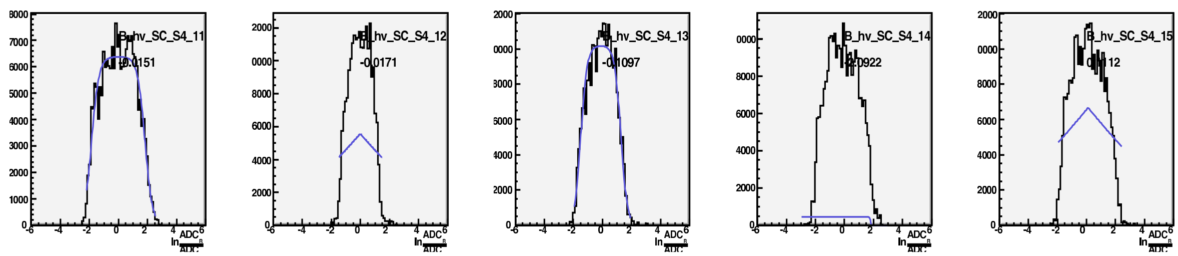

Figure 4: Plots of eq. 3 from a set of CLAS TOF counters. An accumulation of events uniformly illuminating the bar produces a distribution centered about zero if the two PMTs are properly gain matched.

If the gain of a given PMT G is parameterized as:

$$G \propto V^{\alpha}, \tag{6}$$

where α is the gain constant for the PMTs (α=7.2 for the CLAS panel-1a and panel-2 PMTs) and V is the voltage drop between the cathode and the anode, then we can obtain an expression that governs the change in the gain for a given change in voltage:

$$\frac{\Delta G}{G} = \frac{\alpha \Delta V}{V}. \tag{7}$$

For a relatively small change in voltage this expression can be rewritten as:

$$\Delta V_{L/R} = V_{L/R}^{i} \frac{\Delta G}{G\alpha} = V_{L/R}^{i} \frac{600 - A_{L/R}^{eff}}{A_{L/R}^{eff}\alpha}, \tag{8}$$

where $V^i_{L/R}$ is the initial voltage of the PMT and ΔG is the difference between $A^{eff}_{L/R}$ and desired MIP centroid channel of 600.

The first step in this calibration sequence is to determine the ADC pedestal values for all PMT channels. A cosmic ray run long enough to accumulate sufficient statistics to minimize the fit uncertainties to a reasonable level is acquired. The values of the high voltages of the left and right PMTs should then be iterated until the MIP peaks for each PMT, given from the geometric mean histograms, are at channel 600 and the log ratio plots are centered about 0 within uncertainties. Note that the starting point for the high voltage calibration will employ the settings obtained from the final HV calibration run taken with CLAS in 2012.

4 Time Resolution Measurements

The next part of the FTOF calibration is to measure the intrinsic timing resolution of the individual counters. Two different methods can be considered. The first uses cosmic ray muons with a set of three counters (called a triplet) and the second method uses a radioactive source with a single counter. Both methods are discussed below.

4.1 Cosmic Ray Tracking with Counter Triplet

This procedure is most accurately carried out if the PMTs of all counters are matched (test PMTs and FTOF PMTs) and the two test counters are placed symmetrically above and below the FTOF bar under study. With a configuration as shown in Fig. 1, using two smaller test counters, the measured timing resolution is actually a convolution of the resolution of the FTOF counter under study and the test counters themselves. This adds a complication that, while it can be taken into account in the calibration procedure, does not represent an ideal configuration.

Another way to define the counter triplet is to orient the arrays so that the counters are parallel to the ground in a vertical plane. In such a configuration, neighboring FTOF counters are very similar in geometry and have identical PMTs. This configuration naturally gives well defined triplets. However, for both panel-1a and panel-2, the counters are 5.08-cm thick, but 15-cm and 22-cm wide, respectively. The counters are designed to operate with the charged particle incident on the 5.08-cm thick face. When they are incident on the wider face, they create much more light. This would result in a different setting for the high voltages of the PMTs and would impact the timing resolution measurements.

The most optimal way to form the counter triplets with proper bar matching and orientation of the counters, is to use three arrays of a given type to define the triplets as shown in Fig. 5. Defining the triplets from a given counter number in each array then meets the criteria of three identical counters.

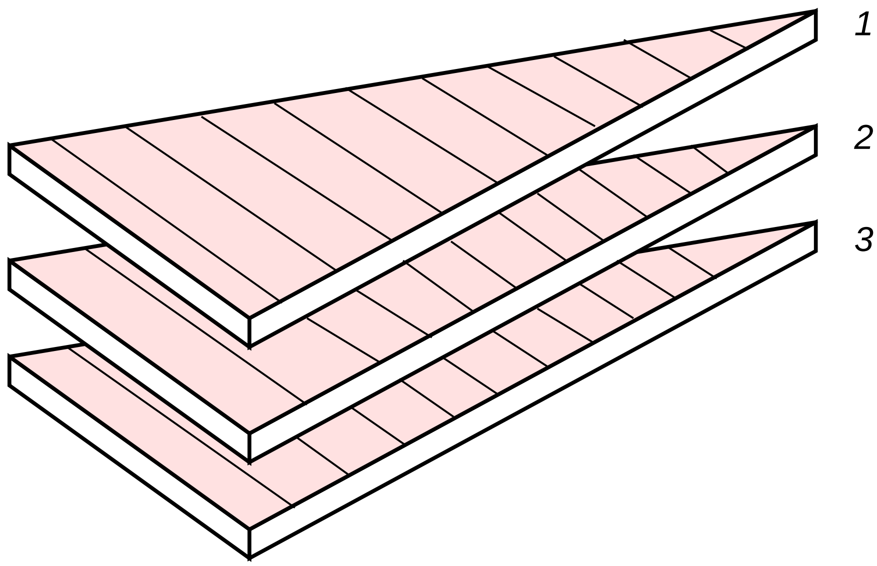

Figure 5: Perspective view showing how counter triplets can be defined using a stack of three FTOF arrays.

If a cosmic ray muon crosses all three counters of a given length, the times of the scintillation flashes t_{FTOF1}, t_{FTOF2}, and t_{FTOF3} with respect to the TDC start signal are related to the individual measured PMT times as:

$$\begin{aligned} t_{FTOF1} &= (t^L_{FTOF1} + t^R_{FTOF1})/2 + C_1 \\ t_{FTOF2} &= (t^L_{FTOF2} + t^R_{FTOF2})/2 + C_2 \\ t_{FTOF3} &= (t^L_{FTOF3} + t^R_{FTOF3})/2 + C_3, \end{aligned} \tag{9}$$

where $t^L_{FTOF1} \rightarrow t^R_{FTOF3}$ are from the measured TDC values and $C_{i=1,2,3}$ are calibration constants. For three equidistant counters, the following relationship holds:

$$\delta\tau = t_{FTOF2} - (t_{FTOF1} + t_{FTOF3})/2 = \text{constant}. \tag{10}$$

In reality, the value of $\delta\tau$ is measured with some uncertainty that arises from the timing resolution of the PMTs. This resolution can be expressed as:

$$\sigma(\tau) = \sigma\left((t^L_{FTOF2} + t^R_{FTOF2})/2 - (t^L_{FTOF1} + t^R_{FTOF1} + t^L_{FTOF3} + t^R_{FTOF3})/4\right). \tag{11}$$

If we assume that all six PMTs and scintillators are identical, the timing resolution of each PMT is:

$$\sigma_{PMT} = \frac{2}{\sqrt{3}}\sigma(\tau). \tag{12}$$

The resolution of the FTOF bar under test is then given by:

$$\sigma_{FTOF} = \sigma_{PMT}/\sqrt{2}. \tag{13}$$

4.2 Radioactive Source with Single Counter

In this method a radioactive source (e.g. ^{90}Sr) is placed at a known coordinate y along the counter. This might likely be at the center of the counter. This coordinate is related to the measured TDC time as:

$$\delta\tau = \frac{t_L - t_R}{2} + C = \frac{y}{v_{eff}}, \tag{14}$$

where t_L and t_R are the measured TDC values from the left and right PMTs, C is a calibration constant, and v_{eff} is the effective speed of light in the scintillation material (for the FTOF scintillators, $v_{eff} \approx 16$ cm/ns). For an infinitely precise measure of the times, we should expect $\delta\tau$=0 for y=0. However, due to fluctuations of the PMT signals, the spread in $\delta\tau$ can be used to give a measure of the counter timing resolution as:

$$\sigma(\tau) = \sqrt{var(\delta\tau)}. \tag{15}$$

Here, the covariance of t_L and t_R ($cov(t_L \cdot t_R)$) is assumed to be zero. Thus this method may be used only for comparative time resolution measurements.

5 FTOF Counter Lengths

Counter	Length (cm)	Counter	Length (cm)	Counter	Length (cm)
1	32.3	9	154.1	17	281.0
2	48.1	10	170.0	18	296.8
3	64.0	11	185.8	19	312.7
4	78.8	12	201.7	20	328.5
5	95.7	13	217.6	21	344.4
6	106.6	14	233.4	22	360.2
7	122.4	15	249.3	23	376.1
8	138.3	16	265.1		

Table 1: Summary table of counter lengths in FTOF panel-1a.

Counter	Length (cm)	Counter	Length (cm)	Counter	Length (cm)
1	17.27	22	151.72	43	286.27
2	23.62	23	158.17	44	292.62
3	30.08	24	164.52	45	299.08
4	36.43	25	170.98	46	305.43
5	42.89	26	177.33	47	311.88
6	49.24	27	183.79	48	318.23
7	55.70	28	190.14	49	324.69
8	62.05	29	196.60	50	331.04
9	68.51	30	202.95	51	337.50
10	74.86	31	209.41	52	343.85
11	81.32	32	215.76	53	350.31
12	87.67	33	222.22	54	356.66
13	94.13	34	228.57	55	363.12
14	100.48	35	235.03	56	369.47
15	106.94	36	241.38	57	375.93
16	113.29	37	247.84	58	382.28
17	119.75	38	254.19	59	388.74
18	126.10	39	260.65	60	395.09
19	132.56	40	267.00	61	401.55
20	138.91	41	273.46	62	407.90
21	145.37	42	279.81		

Table 2: Summary table of counter lengths in FTOF panel-1b.

Counter	Length (cm)
1	371.3
2	385.0
3	398.7
4	412.5
5	426.2

Table 3: Summary table of counter lengths in FTOF panel-2.