

# Tutorial for CLAS12 Forward Time-Of-Flight System Energy and Timing Calibrations

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## **Abstract**

This document serves as a tutorial for use by calibrators for the CLAS12 Forward Time-of-Flight system energy and timing calibrations. This tutorial explains all calibration steps, how they are to be carried out and in which order, and how to judge the quality of the results. In addition, the main features of the calibration suite are highlighted in order to investigate the data fits and their convergence.

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# 1 Introduction

The CLAS12 Forward Time-of-Flight (FTOF) system consists of 540 scintillation bars with double-ended readout. In each of the six sectors of the CLAS12 Forward Detector, the FTOF system includes 62 counters in panel-1b, 23 counters in panel-1a, and 5 counters in panel-2. A detailed description of the FTOF system is provided in Ref. [1]. There are two parts of the system calibration. The first employs cosmic ray or beam data to gain match the PMTs. This portion of the calibration uses the ADC information for the left and right PMTs of each counter and the output of the calibration is a set of PMT high voltage settings. The reconstruction code also uses this calibration information to compute the energy deposited in each bar for passing charged particles. The second part of the calibration employs beam data to determine the optimized counter timing for charged particles. This portion of the calibration is a multi-step process that must be completed in a specific order. A detailed description of the full set of FTOF calibration constants is provided in Ref. [2]. Each of the individual algorithms for the FTOF gain and timing calibrations is described in detail in Ref. [3], which serves as an essential companion document to this calibration tutorial.

## 2 Calibration Suite Startup

### 2.1 Getting the Code

The FTOF calibration code suite is a java program deployed as a jar file that can be executed on nearly any platform provided it is installed with java version 1.8 or later. The latest version of the jar file is located on the FTOF web page at:

- <http://www.jlab.org/ftof/FTOFCalibration.jar>

The associated source code for the calibration suite is stored on the official JLab github repository for the CLAS12 subsystem calibration suites [4]. The source code should only be modified under the direct supervision of the FTOF Group Leader.

### 2.2 Calibration Suite GUI Layout

The main graphical user interface (GUI) for the FTOF calibration suite is shown in Fig. 1. On the left of this figure is the main GUI screen and on the right is a representation of the same screen denoting its four primary areas. On the left side of the GUI (green box) is the “Detector View Area” used to select the FTOF sector and panel. On the upper right (red box) is the “Data and Histogram Display Area”. On the lower right (gold box) is the “Parameter View Area”. Finally, along the bottom (blue box) is the “Control Area”. The usage and controls within these different areas are explained below.

### 2.3 Running the Code

The basic scheme to run the code and to perform the calibration consists of a number of specific steps. These steps include:

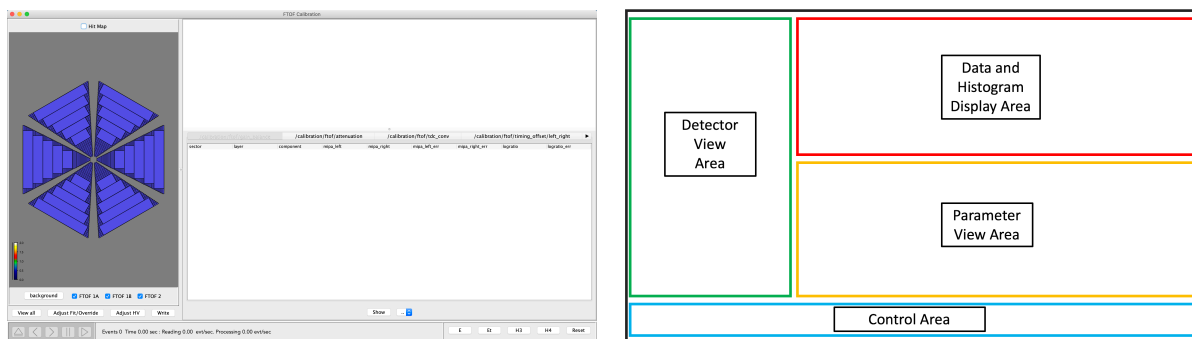


Figure 1: FTOF calibration suite main GUI interface screen highlighting the different suite areas.

1. Start the code suite:

- Pass the code the necessary input parameters from data files or the calibration constant database
- Choose the appropriate calibration code settings

2. Choose the input data file and begin program execution

3. Study the fits and make adjustments for any fits that failed

4. Iterate through the full multi-step calibration sequence to determine all of the fit parameters

5. Upload the calibration constants into the calibration constant database.

Each of these steps is described in further detail below with screen captures of the code suite windows provided for guidance.

◇ Start the Code Suite:

To start the code suite, download the FTOF calibration suite jar file into the desired subdirectory on your computer. Start the code suite by typing:

```
java -jar FTOFCalibration.jar
```

Upon entering this command a screen with two pages will pop-up onto your desktop that requires completion. These screens are shown in Fig. 2.

- The first screen to come up is Fig. 2(a) where the input parameters for a given calibration step are selected. By clicking on the “Select File” button for a given parameter, a selection window pops up as shown. As an alternative, calibration parameters from the calibration constant database (ccdB) can be selected by entering a run number in the box for the specific constants. Click on the “Next” button to proceed.



- The second screen to come up is Fig. 2(b) where various event selection options are available. For meaningful energy and timing calibrations, these selections must be properly made. Appendix A provides more details on this screen. Click on the “Finish” button to bring up the main FTOF GUI screen shown in Fig. 1(left).

The xterm window from which the program was launched reflects the user selections and should be reviewed to be sure that they are correct and no errors or exceptions have occurred. Appendix B shows the standard program output during execution.

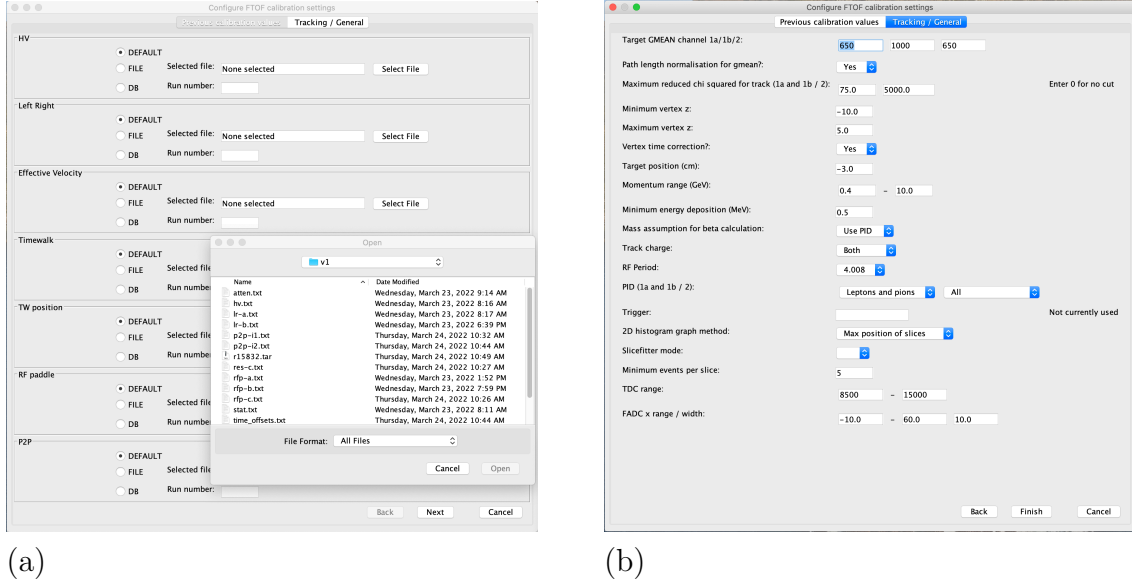


Figure 2: FTOF calibration suite startup screens: (a) Input calibration parameter file selection, (b). Startup configuration selection.

#### ◇ Choose the Input Data File and Begin Program Execution:

The next step in running the calibration code suite is to select the input data source. The program can read files in the native CODA EVIO file format or the CLAS12 compressed HIPO file format produced after data cooking and filtering (see Appendix C for details). The nominal file format for FTOF calibrations is the HIPO4 format and the appropriate data files should be in your file path or on your local machine. Clicking on either the “E” button or the “H4” button in the “Control Area” at the bottom of the main GUI brings up the dialog box for file selection. The other options for data input selection (“Et” and “H3”) are not intended for the standard calibration suite user. The input program selection is reflected on the xterm window from which the program was started.

After selecting the file and clicking on “Open”, the dialog box will close. To begin program execution, click on the “>” (play) button in the lower left corner. The event counter at the bottom of the GUI screen should then begin to update. The histograms and the fits will be updated every 200k events. Note that program execution can be paused by clicking on the “||” button next to the play button. If the event counter freezes on a particular value for a lengthy period, clicking pause and then play will cause it to resume processing. The other action buttons for stepping ahead or back one event at a time (the “>” and “<” buttons) are

not functional controls. Also, clicking on the “Reset” button in the lower right corner clears out the histograms. However, after running a given calibration step, the program must be closed and restarted in order to run the next calibration step. Program execution is finished when the xterm window used to start the program provides the message:

- [Data Processing Pane] —> task is done...

Note that just before this message appears on the xterm window, the program provides messages that it is writing out the calibration parameter files. At this stage the parameter files for all steps are written out. Only those associated with the given calibration step under study are relevant and they should be saved with the standard file names as noted in Section 4.11. The others should be deleted before moving on to the next calibration step in the sequence. These ascii files are ultimately written into the calibration constant database for the FTOF system as described in Section 4.10. The program execution is also complete when the dialog box shown in Fig. 3 pops up on the screen. This box is only relevant for the final calibration step as discussed in Section 4.8. Click on “O.K.” to dismiss this box.

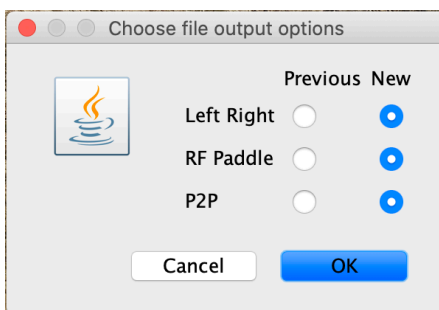


Figure 3: Screen pop-up at end of program execution used to select the output included in the time offset parameter file as discussed in Section 4.8.

#### ◇ Study the Fits and Make Adjustments for Fits that Failed:

In the middle of the main GUI screen are tabs for each of the individual calibration steps. Clicking on any tab at any point during program execution will update what is displayed in the “Data and Histogram Area” and the “Parameter View Area” discussed in Section 2.2. Figure 4 shows an example of the main GUI after some data has been analyzed. The “Data and Histogram Area” will show raw data distributions and/or the plots used for fitting to determine the calibration parameters along with the fit functions overlaid on the plots. The “Parameter View Area” shows the determined calibration parameters for each channel in the system. The first three columns on each calibration tab are labeled as “Sector”, “Layer”, and “Component”. These have the following meanings:

- Sector: Labels Forward Carriage sectors 1 → 6 (with S1 at the 9 o’clock position on beam left) with sector number increasing moving clockwise around the face of the system looking downstream.
- Layer: Layer 1 is panel-1a, layer 2 is panel-1b, and layer 3 is panel-2.

- Component: The component refers to the counter numbers in each panel. Panel-1a is constructed of components #1  $\rightarrow$  #23, panel-1b is constructed of components #1  $\rightarrow$  #62, and panel-2 is constructed of components #1  $\rightarrow$  #5. The counter numbers increase going from smaller to larger polar angles.

The remainder of the columns are labeled with the specific calibration constants for the selected tab. The different constants are described in full detail in Ref. [2], which is an important companion document to this tutorial. These constants are listed in more detail in their respective parts within Sections 3 and 4 below.

When looking at the fit results for a given calibration step, there are a number of ways to investigate the data and the fit results when deciding if the parameters for a given channel are acceptable:

- Using the mouse, the plots for a given channel can be displayed by clicking on any row in the “Parameter View Area”. The mouse can be used to scroll the window up and down to display the data for all channels in the system.
- The program has been engineered to color any fit parameter values that are outside of the prescribed range. This color coding is only indicative (and for some tabs has not been optimized) and is meant to represent only one consideration when deciding if the parameters are acceptable. Note that the rows highlighted in red are the flagged channels, which are also reflected by the red bars shown in the “Detector View Area”.
- In the “Detector View Area” use the radio buttons to select a given panel (panel-1a, panel-1b, or panel-2) and clicking on a given sector on the picture will bring up the fit parameters vs. component number in the “Data and Histogram Area”. Here, outlying fit parameters can be seen and then individual data distributions and fits can be explored.
- Clicking on the “View all” button at the top left of the “Control Area” will pop up a thumbnail screen of the fit data distributions for all channels with different channels selectable using the tabs across the top of the screen.
- Study the checkplot views to investigate the calibration quality vs. different track parameters (see Section 4.9 for details).

After viewing the data for a given calibration step (on a given tab within the main GUI), a list of bad fits, fits limited by statistics, or data affected by hardware problems should be compiled. The next steps in the calibration procedure are then as follows:

- After clicking on the row in the “Parameter View Area” for the channel of interest, click on the “Adjust Fit/Override” button for options available to refit the data under different conditions, with a different fit range, or to enter a parameter value by hand.
- The goal is to ensure that whenever possible all of the counters highlighted in red in the “Parameter View Area” and the “Detector View Area” change from red to green.

- For channels with hardware problems, the parameter values are nominally chosen to be the default parameters.
- For channels with low statistics where the fits can fail, the option to enter the parameter value by hand should be employed.
- Any channels with no data should be compared against the known FTOF hardware problem list. Note that the calibration automatically outputs a hardware status list using a fairly crude algorithm. This output file will have a name of the form: FTOF\_CALIB\_STATUS\_20180728.0.txt. This file should be updated by hand to capture all of the bad channels in the system. Contact the FTOF Group Leader for more details.

More details on the specific screens and the options available are given in the dedicated subsections below.

#### ◇ Put the Final Constants in the Calibration Constant Database:

The output of the FTOF calibration steps is a series of ascii parameter files for each calibrated run that are valid for a particular run range. The final step in the calibration procedure is to put the constants into the calibration constant database for this specific run range. This work should be done in coordination with FTOF Group Leader and the Analysis Coordinator for the run period. More details on how to enter constants into the ccdB are provided in Section 4.10.

## 3 Gain Calibrations

The detector gain calibrations serve two purposes. The first is to determine the conversion from the measured ADC to the deposited energy for passing charged particles. The second is to determine the necessary high voltage (HV) settings for the PMTs to gain balance the counter responses across the full FTOF system from the measured ADC distributions (usually only determined at the start of a run period).

#### ◇ Defined Histograms:

The gain calibrations are completed using two 1D histograms for each counter:

- ADC geometric mean
- ADC log ratio

#### ◇ Database Parameters:

The FTOF calibration constant database parameters determined as a result of this calibration step are:

- *mipa* - Centroid of the Landau peak in the ADC geometric mean histogram for minimum-ionizing particles

- *mipa\_err* - Uncertainty in the Landau peak centroid in the ADC geometric mean histogram for minimum-ionizing particles
- *logratio* - Mean of the ADC logarithmic ratio distribution
- *logratio\_err* - Uncertainty in the mean of the ADC logarithmic ratio distribution

Even though there are separate *mipa* parameters for the left and right PMTs, *mipa\_left* and *mipa\_right* are filled with the same fit centroid for the minimum-ionizing peak for the geometric mean ADC distribution. The gain balancing parameters also include the uncertainties in the determination of the geometric mean (*mipa\_err*) and the ADC log ratio (*logratio\_err*) distributions.

#### ◇ Nominal Parameter Values:

The calibration program fits the geometric mean distributions with a Landau function plus an exponential background term to determine the centroid of the minimum-ionizing particle peak. The log ratio distributions should have a mean of 0 if the PMTs are properly gain balanced. Shifts from 0 indicate that the PMT HV values must be adjusted or that there is a hardware issue with the associated PMT or voltage divider.

#### ◇ Associated Calibration Screens:

Figure 4 shows the various windows when working within the “gain\_balance” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- The geometric mean and ADC log ratio fit parameters are shown after clicking on a sector in the “Detector View Area”.
- The geometric mean fits and ADC log ratio distributions that pop up after clicking on the “View all” button.
- The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

## 3.1 Gain Balance Calibration Details

#### ◇ Program Startup:

The gain balance step does not rely on any previous calibration parameters to complete. The first option on the parameter screen in Fig. 2(right) is to turn on the path length correction to the geometric mean distribution. This correction is employed for beam data where there is DC track information. Choose “No” for this option for cosmic ray data where no DC information is available.



#### ◇ Computing new HV Values:

To compute a new set of HV values, the BURT backup file for the current HV settings must be retrieved from the DAQ machines. Instructions for accessing this file are provided in Ref. [5]. This file should be copied onto the local machine where you are performing the calibrations. To proceed, complete the following steps:

1. Click on the “Adjust HV” button in the “Control Area”. This brings up the screen shown in Fig. 5(a). At this point all of the data for the current HV and new HV values are set to zero.
2. Enter the target minimum-ionizing particle peak locations into the field at the top of the “Adjust HV” window. Consult the FTOF Group Leader for these values.
3. Click on the “Select File” button at the top of the “Adjust HV” window.
4. Figure 5(b) shows the file selection window that comes up. Within this window select the BURT HV archive file that you copied over from the DAQ machines.
5. After clicking on the “Open” button on the file selection window, the “Adjust HV” window will update with the current HV values (extracted from the BURT HV archive file) and with the new HV values (computed from the gain balance fit parameters).
6. The program will also pop up a small message window with the name of the output BURT HV archive file that has been created.
7. Copy this newly created file back to the DAQ FTOF BURT archive directory and follow the instructions in Ref. [5] for updating the PMT HV values in the power supplies.

As mentioned above, the HV setting adjustments are not part of the standard energy and timing calibrations. This calibration step is for setting up the PMT high voltage values at the start of a run period. Contact the FTOF Group Leader with any questions.

## 4 Timing Calibration

The timing calibration constants for the FTOF system are determined in a specific sequence. The individual steps are listed in Table 1. The algorithm steps are denoted as: **LR** for the left-right PMT timing alignment, **ATTEN** for the attenuation length calibration, **VEFF** for the effective velocity calibration, **TW** for the primary time-walk calibration, **TWP** for the secondary position-dependent time-walk calibration, **RFP** for the RF timing offset determination, and **P2P** for the counter-to-counter timing offset determination.

The timing calibration is completed using DC time-based tracking to ensure the most accurate track path length reconstruction. After the completion of each of the above steps, the full FTOF timing calibrations are completed. The corrected FTOF hit times reconstructed for the left and right PMTs for each counter are given by:



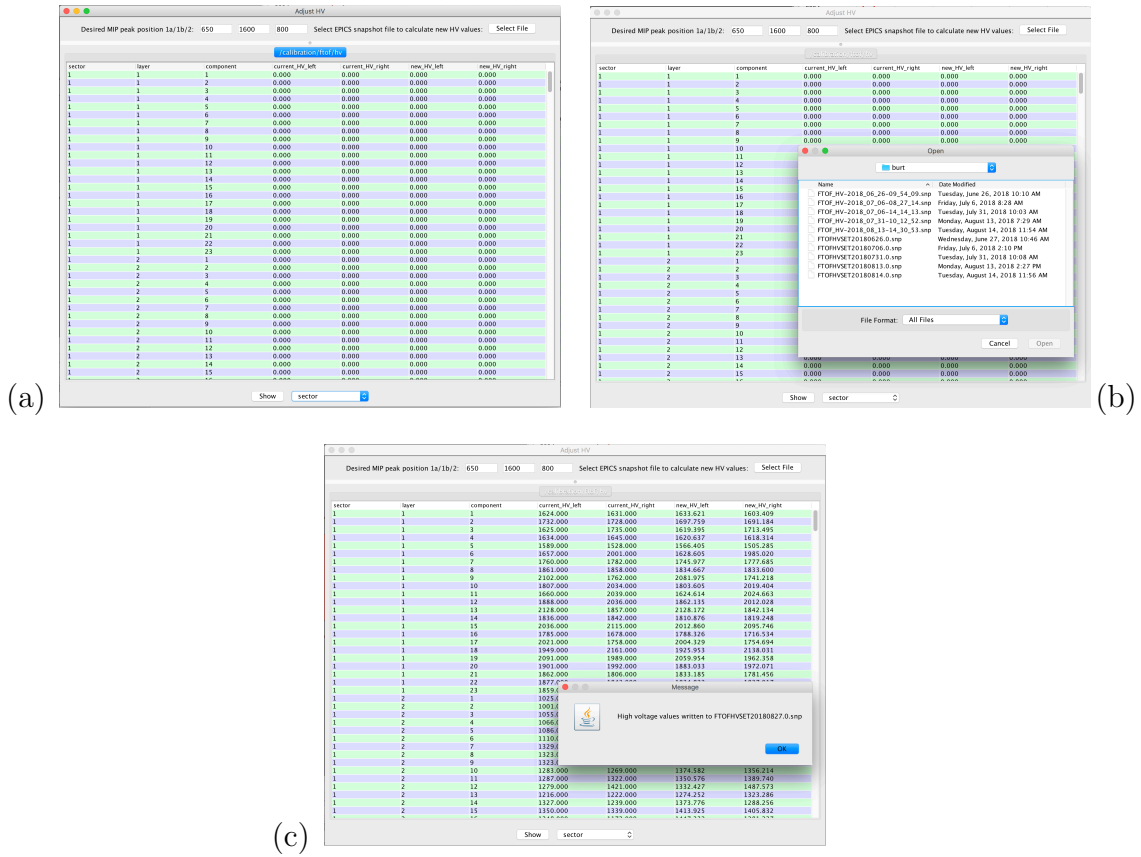


Figure 5: Adjust HV screens: (a) Pop-up window after selecting “Adjust HV”, (b) Pop-up window after clicking on “Select File”, (c) Window showing current and new HV values and output file name.

	Calibration	Algorithm
1	Left-Right PMT Timing Alignment	LR
2	Attenuation Length	ATTEN
3	Effective Velocity	VEFF
4	Time-Walk Calibration	TW
5	Counter RF Time Offsets	RFP
6	Position-Dependent Time-Walk	TWP
7	Paddle-to-Paddle Time Offsets	P2P

Table 1: The individual steps for the FTOF timing calibration.



$$\begin{aligned}
t_L &= (\mathcal{C}_{TDC} \cdot TDC_L) - \frac{\mathcal{C}_{LR}}{2} - \frac{y_L}{veff}, \\
t_R &= (\mathcal{C}_{TDC} \cdot TDC_R) + \frac{\mathcal{C}_{LR}}{2} - \frac{y_R}{veff},
\end{aligned} \tag{1}$$

where  $y_L$  and  $y_R$  represent the distances along the scintillator from the track crossing point to the left and right PMT locations, respectively. The average counter hit time using the timing from the left and right PMTs for a given counter is:

$$t_{hit} = \frac{1}{2}(t_L + t_R) - t^{TW} - t^{TWP} + t_{RF}^{pad} + \mathcal{C}_{p2p}. \tag{2}$$

The time  $t_{hit}$  represents the charged particle flight time relative to the event start time from the event vertex to the midplane of the FTOF counter associated with the track. Here  $\mathcal{C}_{TDC}$  is the TDC conversion time ( $\sim 24$  ps/channel),  $TDC$  is the measured TDC channel,  $\mathcal{C}_{LR}$  is the time shift from the LR step,  $t^{TW}$  is the primary time-walk shift from the TW step,  $t^{TWP}$  is the secondary position-dependent time-walk shift from the TWP step,  $t_{RF}^{pad}$  is the RF timing offset from the RFP step, and  $\mathcal{C}_{p2p}$  is the paddle-to-paddle time offset from the P2P step. Figure 6 provides a flowchart of the FTOF timing calibration sequence. Table 2 details what calibration parameters are output at each step and which are input from previous steps in the calibration.

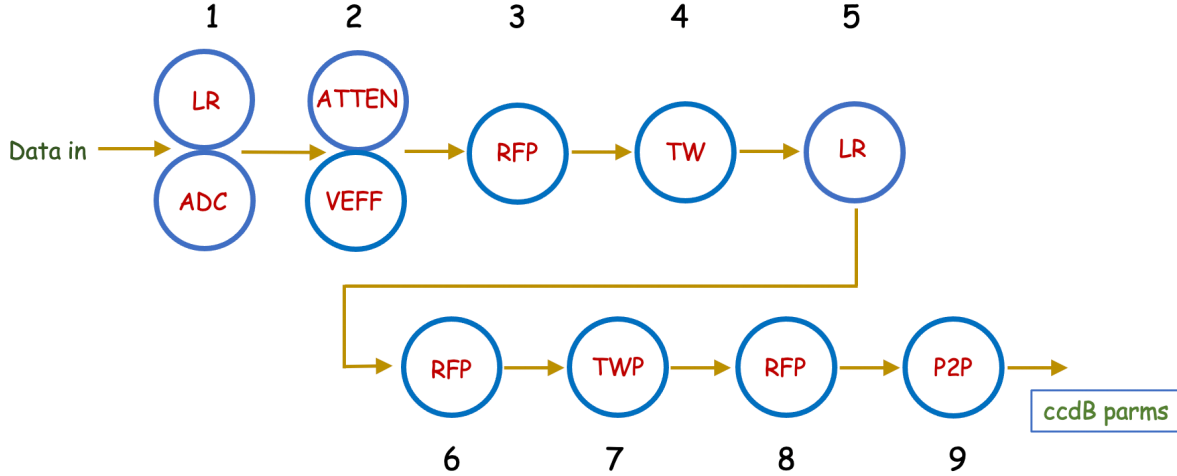


Figure 6: Flowchart detailing the steps and their ordering for FTOF calibration procedure.

The complete FTOF timing calibration typically requires running through the data file 10 different times. The following parameters are determined after each step:

1: Determine LR.

- Note that the FTOF hardware channel status is also determined in this initial step (see Section 2.3 for details).

2: Determine ATTEN and VEFF with LR as input parameters.

FTOF Timing Calibration Steps			
Step #	Calibration	Input Parameters	Output Parameters
1	LR		LR1
2	ATTEN	LR1, VEFF0	ATTEN
	VEFF	LR1	VEFF1
3	RFP	LR1, VEFF1	RFP1
4	TW	LR1, VEFF1, RFP1	TW
5	LR	VEFF1, TW	LR2
6	RFP	LR2, VEFF1, TW	RFP2
7	TWP	LR2, VEFF1, TW, RFP2	TWP
8	RFP	LR2, VEFF1, TW, TWP	RFP3
9	P2P	LR2, VEFF1, TW, TWP, RFP3, P2P0	P2P1

Table 2: The input and output parameters for each of the FTOF timing calibration algorithms. Note that all tracking information comes from the DC and that VEFF0 and P2P0 represent parameters loaded from a previous calibration.

- Note that the determination of ATTEN uses VEFF from a previous calibration. If no parameters are specified, the default values are used ( $veff=16$  cm/ns).

3: Determine RFP with LR and VEFF as input parameters.

- The determination of RFP at this stage is necessary to center to the TW distributions within their display windows without “wrap-around” effects from neighboring beam buckets.
- The determination of RFP uses TW from the input file specification. If no parameters are specified, no TW correction is used.

4: Determine TW with LR, VEFF, RFP as input parameters.

- The program subtracts off the TW values using the input file specification to ensure the vertex time distributions fit within the  $T_{RF}$  display window. If no parameters are specified, the default (TW0) values are used in the fit display.

5: Determine LR with VEFF as input parameters.

- A second pass to determine LR is required after the separate TW shifts.
- The program uses the TW values from the previous step.

6: Determine RFP with LR, VEFF, TW as input parameters.

- A second pass to determine RFP is required after the TW step. The determination of RFP at this stage is necessary to center the vertex time distributions within the  $T_{RF}$  display window before the TWP step.

7: Determine TWP with LR, VEFF, TW, and RFP as input parameters.

- This step amount to a correction that removes the residual dependence of the vertex time on hit position along the counter as the time-walk correction actually depends on his position.
- 8: Determine RFP with LR, VEFF, TW, and TWP as input parameters.
- A third and final pass to determine RFP is required after the TWP shifts. This step also provides an effective counter timing resolution TRES.
- 9: Determine P2P using LR, VEFF, TW, TWP, and RFP as input parameters.
- This step converges much more quickly if P2P calibration values from a previous calibration with the same  $T_{RF}$  and similar data-taking conditions are input at the program startup. It usually requires two iterations to converge using P2P from the first iteration as input parameters to the second iteration, hence the statement that 10 passes through the data file is required to calibrate a single run.

Note that for all calibration steps involving fitting of 2D histogram distributions, *i.e.* ATTEN, VEFF, TW, and TWP, the suite creates a fittable profile histogram. These histograms are used to display the value along the  $y$ -axis and its uncertainty for each bin along the  $x$ -axis. In the calibration suite, the  $y$ -axis value for each bin along  $x$  is assigned as the  $y$ -axis bin with the highest number of events  $N_{ymax}$ . The uncertainty is assigned as the slice RMS divided by  $\sqrt{N_{ymax}}$ .

## 4.1 Timing Calibration Details

### ◇ Program Startup:

The different steps rely on loading calibration parameters from previous steps as discussed in Section 4. The timing calibration is completed using DC tracking and various related parameters are entered on the start up screen shown in Fig. 2(right). These include the maximum track  $\chi^2$ ,  $z$ -vertex range, target center position, RF period, and track momentum range. Other parameters that are entered at program start-up include choices for which charged particles to use for the calibration. Consult the FTOF Group Leader for further instructions on settings for the calibrations, in particular, for the experiment-dependent target position along  $z$  and the RF period of the accelerator (either 2.004 ns or 4.008 ns).

### ◇ After the “task is done” Message:

Upon program completion go through the following steps:

1. View the fits for the given calibration step for all channels in the FTOF system using the “View all” button.
2. Use the “Adjust Fit/Override” button to improve any failed fits or to set the parameters by hand.

3. After redoing a fit, note that the associated parameter values for that channel have changed in the “Parameter View Area”.
4. If any fits have been redone, write out the updated parameter settings by clicking on the “Write” button in the “Control Area”.
5. The output parameter files will have names of the form:  
“FTOF\_CALIB\_HV\_20180828.0.txt”, “FTOF\_CALIB\_LEFTRIGHT\_20180828.0.txt”,  
“FTOF\_CALIB\_STATUS\_20180828.0.txt”, “FTOF\_CALIB\_ATTEN\_20180828.0.txt”,  
“FTOF\_CALIB\_VEFF\_20180828.0.txt”, “FTOF\_CALIB\_RFPAD\_20180828.0.txt”,  
“FTOF\_CALIB\_TRES\_20180828.0.txt”, “FTOF\_CALIB\_TIMEWALK\_20180828.0.txt”,  
“FTOF\_CALIB\_TWPOS\_20180828.0.txt”, “FTOF\_CALIB\_P2P\_20180828.0.txt”
6. Note that for compatibility with the ccdB table format, the program also combines the parameters for LR, RFPAD, and P2P into a single output file named:  
“FTOF\_CALIB\_TIME\_OFFSETS.txt”.

In the following subsections, details are provided for how to carry out each calibration step using the suite. In each section, the parameters that are determined are detailed along with their nominal values. In addition, the features of the code suite necessary to view and refit the data are explained and all relevant screens for each calibration step are highlighted.

## 4.2 Left-Right PMT Timing Alignment

### ◇ Defined Histograms:

The left-right PMT time offset calibrations are completed using one 1D histogram for each counter:

- left - right PMT time difference distribution (ns)

The suite compares the hit coordinate along the bar from the left-right PMT time difference to the coordinate determined from the projected DC tracks to the FTOF midplane. Thus the histogram used to determine the left-right time offset is:

$$left\_right = (t_L - t_R) - coor_{DC} \cdot \frac{2}{veff}. \quad (3)$$

As shown in Fig. 7 the suite displays both the *left\_right* histogram and the PMT time difference  $t_L - t_R$  as sometimes the latter histogram can provide helpful insight if there are issues with the primary histogram.

### ◇ Database Parameters:

The parameter associated with left-right PMT time offsets for each counter is:

- *left\_right* - left/right PMT time difference (ns) for each counter

#### ◇ Nominal Parameter Values:

The calibration program determines the centroid of the time difference distribution for each counter. The nominal values for this offset are usually within:

- $\pm 10$  ns

#### ◇ Associated Calibration Screens:

Figure 7 shows the various window views when working within the “left\_right” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- (a) The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- (b) The left-right timing fit centroids that are shown after clicking on a sector in the “Detector View Area”.
- (c) The postage-stamp view that pops up after clicking on the “View all” button.
- (d) The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

### 4.3 Attenuation Length

#### ◇ Defined Histograms:

The attenuation length calibrations are completed using one 2D histogram for each counter:

- ADC log ratio ( $ADC_R/ADC_L$ ) vs. hit position (cm) determined from the counter TDC time difference

#### ◇ Database Parameters:

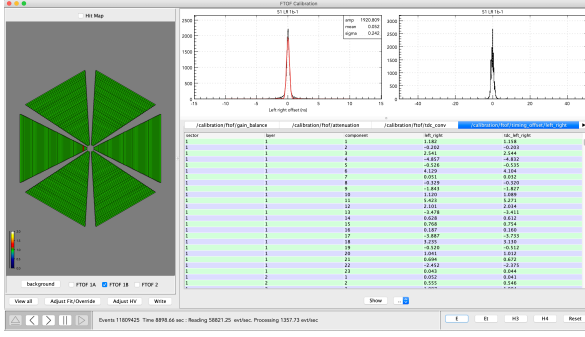
There are three constants associated with the attenuation lengths for each counter.

- *attlen* - measured attenuation length (cm) for each end of each counter
- *attlen\_err* - uncertainty of the measured attenuation length (cm)
- *y\_offset* - *y*-axis intercept of attenuation length fit

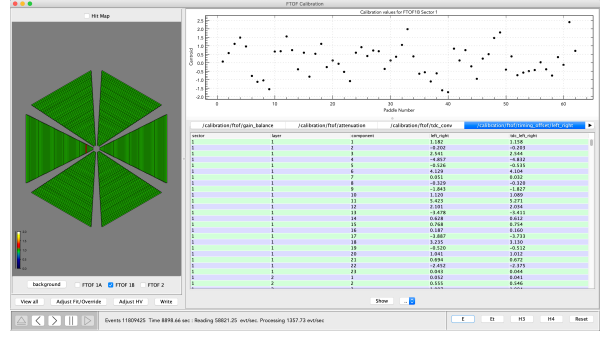
Although there are attenuation length constants in the calibration constant database for both the left and right sides of each counter, only a single value is determined for the counter and assigned to both *attlen\_left* and *attlen\_right*.

#### ◇ Nominal Parameter Values:

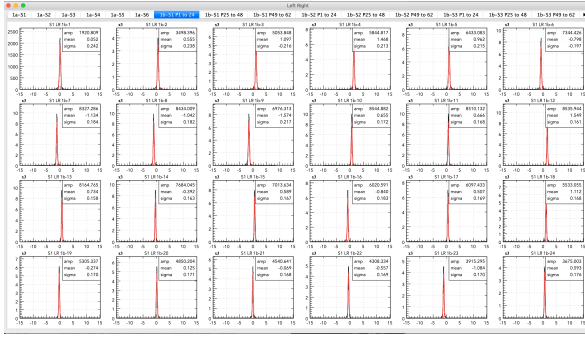
The calibration program fits a linear function to the calibration plots to determine the counter attenuation lengths  $\lambda$  as  $2/\text{slope}$ . The nominal values are typically given by:



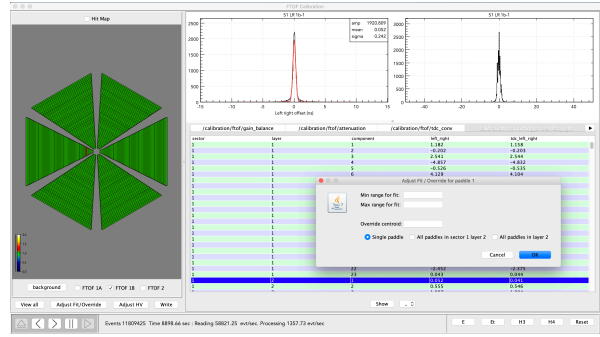
(a)



(b)



(c)



(d)

Figure 7: Left-Right Timing screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the left-right timing offsets for a selected sector and panel, (c) Postage stamp plots for the left-right timing distributions for a given sector and panel, (d) Adjust fit/override options.

- panel-1a:  $\lambda$  (cm) =  $3.92 \cdot N + 129.15$ ,  $N = 1 \rightarrow 23$ ,
- panel-1b:  $\lambda$  (cm) =  $4.079 \cdot N + 135.01$ ,  $N = 1 \rightarrow 62$ ,
- panel-2:  $\lambda$  (cm) =  $3.45 \cdot N + 214.71$ ,  $N = 1 \rightarrow 5$ ,

where  $N$  is the counter number.

#### ◆ Associated Calibration Screens:

Figure 8 shows the various window views when working within the “attenuation” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- The attenuation length fit results that are shown after clicking on a sector in the “Detector View Area”.
- The postage-stamp view that pops up after clicking on the “View all” button.

(d) The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

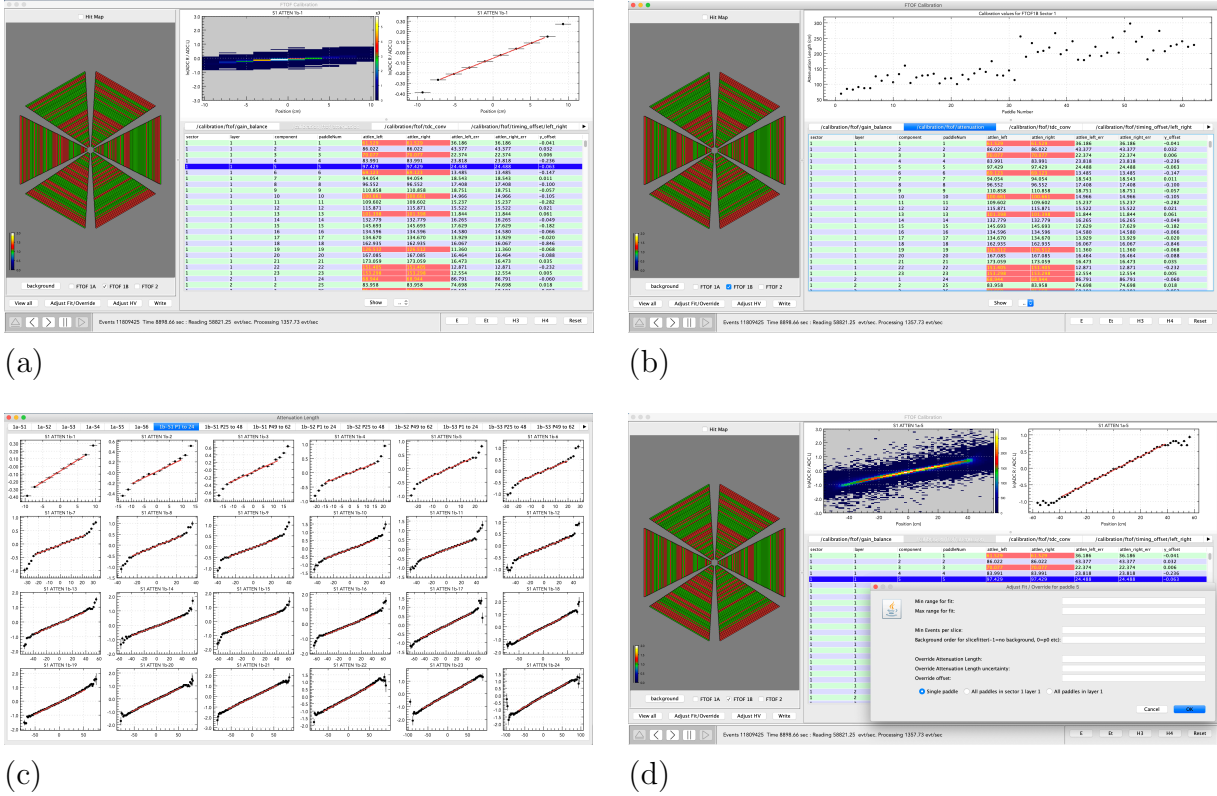


Figure 8: Attenuation Length screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the attenuation length fit results for a selected sector and panel, (c) Postage stamp plots for the attenuation length data and fits for a given sector and panel, (d) Adjust fit/override options.

## 4.4 Effective Velocity

### ◇ Defined Histograms:

The effective velocity calibrations are completed using one 2D histogram for each counter:

- $0.5 \cdot (t_L - t_R)$  (ns) vs. FTOF hit position from tracking (cm)

### ◇ Database Parameters:

There are two constants associated with the measured effective velocity:

- $v_{eff}$  - effective velocity of the counter for each end (cm/ns)
- $v_{eff\_err}$  - uncertainty in the determined effective velocity (cm/ns)

Although there are effective velocity constants in the calibration constant database for both the left and right sides of each counter, only a single value is determined for the counter and assigned to both *veff\_left* and *veff\_right*.

#### ◇ Nominal Parameter Values:

The calibration program fits a linear function to the calibration plots to determine the counter effective velocities as 1/slope. The nominal values are typically between:

- $10.0 \rightarrow 16.5 \text{ cm/ns}$

#### ◇ Associated Calibration Screens:

Figure 9 shows the various window views when working within the “effective\_velocity” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- (a) The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- (b) The effective velocity fit results that are shown after clicking on a sector in the “Detector View Area”.
- (c) The postage-stamp view that pops up after clicking on the “View all” button.
- (d) The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

## 4.5 Time-Walk Calibration

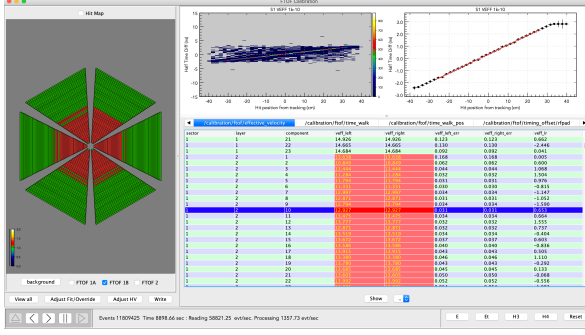
#### ◇ Defined Histograms:

The primary time-walk calibrations are completed using one 2D histogram for each counter of  $\Delta t_v$ , the event vertex time  $t_v$  relative to the event start time, as a function of  $\Delta E$ , the deposited energy in the counter. This time residual  $t_R$  is given by:

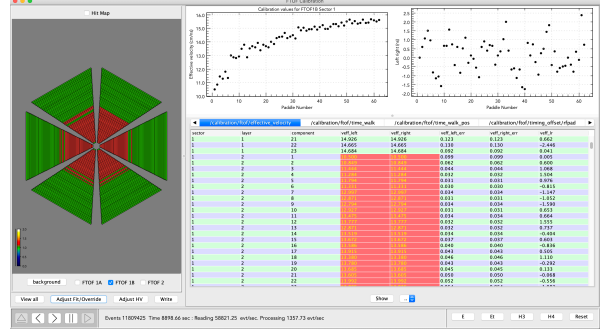
- $t_R = \text{mod}(\Delta t_v, T_{RF}) \text{ (ns) vs. } \Delta E \text{ (MeV)}$
- $\Delta t_v = t_v - t_{start}$
- $t_v = t_{hit} - \frac{L}{\beta c}$
- $t_{start} = t_{RF} + \frac{z_{vert}}{\beta_e c}$ .

Here  $t_{hit}$  is the average counter hit time defined in Eq.(2),  $T_{RF}$  is the RF period, and  $\Delta E$  is energy deposited in the counter (average from both PMTs computed using the gain calibration parameters loaded at the program start).  $L$  is the reconstructed path length from the vertex to the hit position at the counter mid-plane of a charged particle of velocity  $\beta$ .

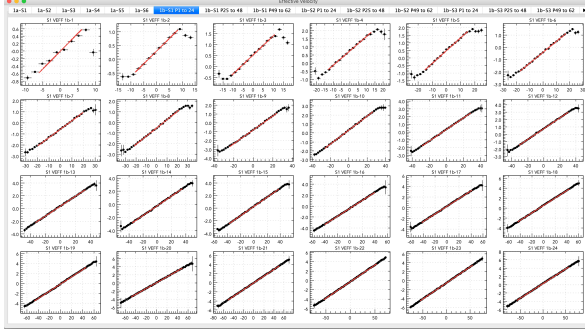




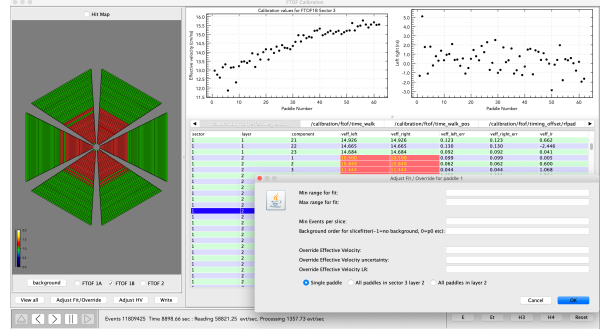
(a)



(b)



(c)



(d)

Figure 9: Effective Velocity screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the effective velocity fit results for a selected sector and panel, (c) Postage stamp plots for the effective velocity data and fits for a given sector and panel, (d) Adjust fit/override options.

$t_{RF}$  is the RF time for the event defined at  $z=0$  and  $z_{vert}/(\beta_e c)$  is a term to correct the RF time to account for the actual electron beam event vertex location. Here the histogram is setup with a bin width of 25 ps. The modulus is used to account for the beam RF structure and to project all values of  $\Delta t_v$  about  $t_R = 0$ .

#### ◆ Database Parameters:

There are 3 parameters associated with the time-walk calibrations for each counter called  $tw1$ ,  $tw2$ , and  $tw3$  that are used in the time-walk fit function:

$$t^{TW} = tw1 \cdot \exp(tw2 \cdot \Delta E) + tw3/\Delta E. \quad (4)$$

#### ◆ Nominal Parameter Values:

The calibration program fits a custom function to the distributions of  $t_R$  vs.  $\Delta E$  for each counter and uses this single functional to correct the counter hit time  $t_{hit}$ . If no input time-walk parameters are selected at the program start, the program subtracts off the nominal functional with parameters in order to ensure that the time distribution (modulo  $T_{RF}$ ) does not wrap around the  $T_{RF}$  timing window. However, if a set of time-walk parameters are

selected at the program start, these are subtracted off instead. The typical and starting parameter values are:

- $tw1 = 1.8$
- $tw2 = -0.03$
- $tw3 = 3.8$ .

Note that the default fit is over a broad  $\Delta E$  range up to 50 MeV. However, better fits with improved accuracy are typically achieved with the following counter fit ranges:

- panel-1a: #1  $\rightarrow$  #12 3-50 MeV, #13  $\rightarrow$  #18 3-40 MeV, #19  $\rightarrow$  #23 3-30 MeV,
- panel-1b: #1  $\rightarrow$  #12 2-50 MeV, #13  $\rightarrow$  #48 2-35 MeV, #49  $\rightarrow$  #62 2-30 MeV,
- panel-2: #1  $\rightarrow$  #5 4-30 MeV.

#### ◇ Associated Calibration Screens:

Figure 10 shows the various window views when working within the “time\_walk” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- (a) The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- (b) The time-walk fit results that are shown after clicking on a sector in the “Detector View Area”.
- (c) The postage-stamp view that pops up after clicking on the “View all” button.
- (d) The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter. Note that the suite allows for the fits to be adjusted for subranges of the counters for each FTOF sector and panel.

Figure 11 shows sample fits of the time-walk functional for a representative counter in each of the three FTOF panels. Note that for these fits the default time-walk parameters listed above are used to subtract off a “nominal” time-walk correction to enable the  $t_R$  distribution to fit within the  $T_{RF}$  display range without wrap-around effects (due to the use of the modulus function). The fit range is chosen to be over the maximal  $\Delta E$  range that allows for well-controlled fits. Any fits that have a turn over at small  $\Delta E$  should be investigated and likely refit with a higher  $\Delta E_{min}$  to avoid effects of the readout threshold. The value of  $\Delta E_{max}$  for the fit range is chosen to extend over the range where the data exists and is well behaved. Note that depending on the configuration of the CLAS12 Forward Carriage, different sectors may require different  $\Delta E$  fit ranges (*e.g.* in the sectors with a RICH installed, the additional material in front of FTOF leads to a broader  $\Delta E$  range in the FTOF). Contact the FTOF Group Leader for more details.

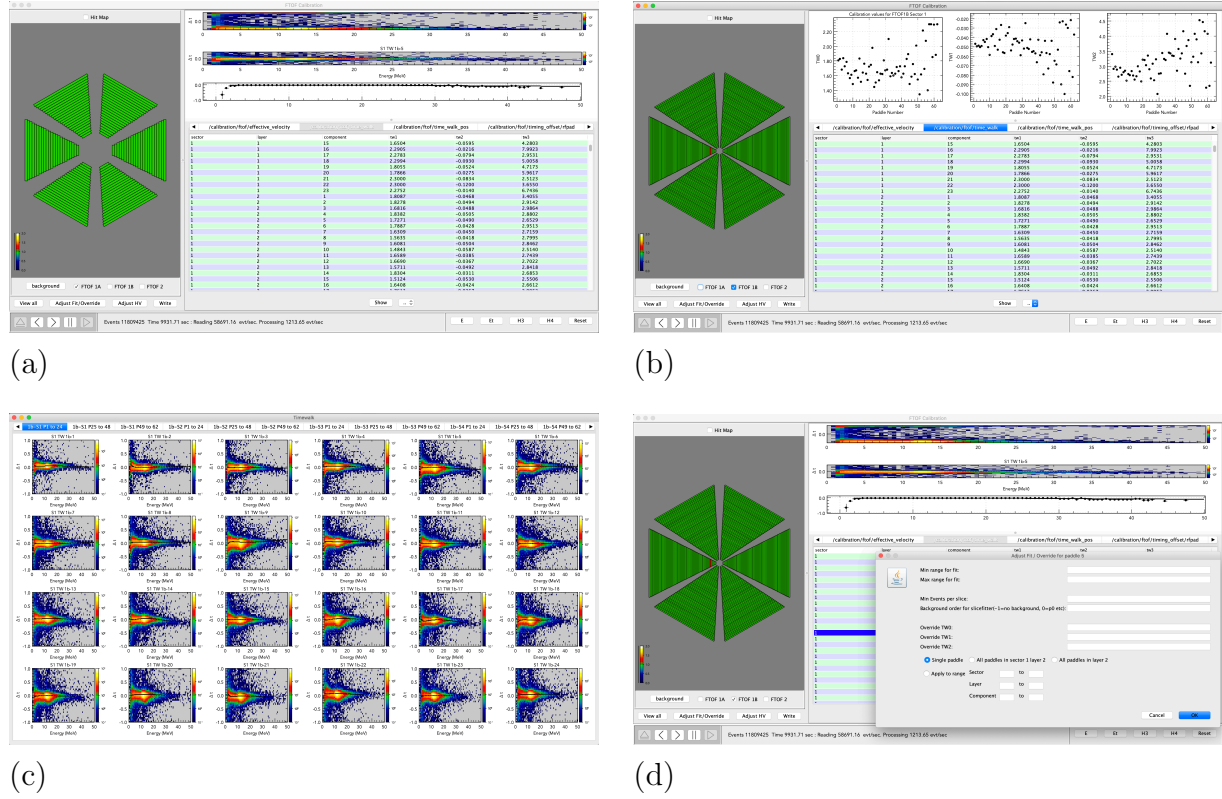


Figure 10: Time-Walk screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the time-walk fit results for a selected sector and panel, (c) Postage stamp plots for the time-walk data and fits for a given sector and panel, (d) Adjust fit/override options.

## 4.6 Position-Dependent Time-Walk Calibration

### ◇ Defined Histograms:

The time-walk correction described in Section 4.5 includes only the average time-walk correction that accounts for the fact that different pulse heights cross the discriminator threshold at slightly different times. However, the complete time-walk effect actually depends on the hit position of the track along the counter (*i.e.* the distance of the hit from the PMT). A second part of the time-walk correction referred to as the position-dependent time-walk correction is included in the calibration procedure. This correction to the counter hit time is derived from a fit to time residual at the event vertex  $t_R$  (see Section 4.5) as a function of hit position along the counter.

### ◇ Database Parameters:

There are 2 parameters associated with the position-dependent time-walk calibrations for each counter called  $tw1pos$  and  $tw2pos$  that are used in the time walk fit function:

$$t^{TW} = tw1pos \cdot y^2 + tw2pos \cdot y, \quad (5)$$

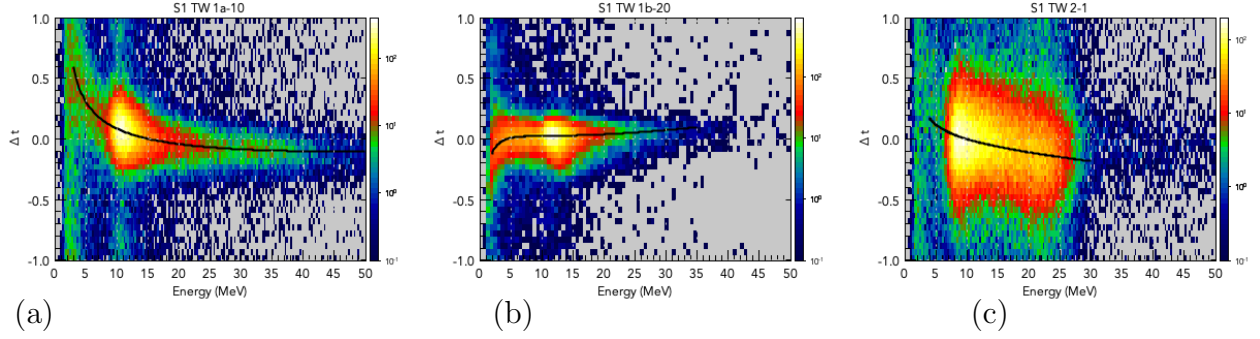


Figure 11: Time-walk fits for representative counters in (a) panel-1a, (b) panel-1b, and (c) panel-2. The black curves are the computed fit functions. The range of the curves shows the energy loss range over which they were fit.

In this expression,  $y$  is the hit position along the counter and varies for a counter of length  $L$  between  $\pm L/2$ . Note that a constant term is not included as it is accounted for by the RFP correction to center the vertex time at 0.

#### ◇ Nominal Parameter Values:

The calibration program fits a second-order polynomial to the vertex time distribution vs. hit coordinate for each counter and uses this single functional to correct the counter hit time  $t_{hit}$ . The typical parameter values are within  $\pm 0.002$ .

#### ◇ Associated Calibration Screens:

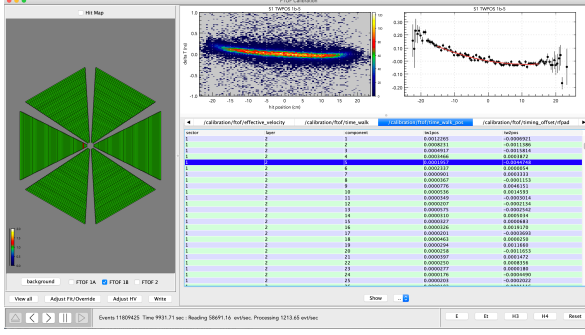
Figure 12 shows the various window views when working within the “time\_walk\_pos” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- (a) The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- (b) The time-walk fit results that are shown after clicking on a sector in the “Detector View Area”.
- (c) The postage-stamp view that pops up after clicking on the “View all” button.
- (d) The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

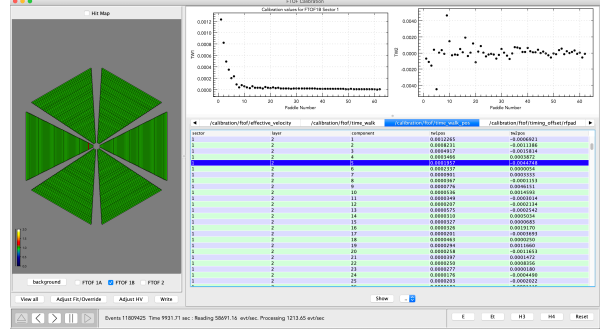
## 4.7 Counter RF Time Offsets

#### ◇ Defined Histograms:

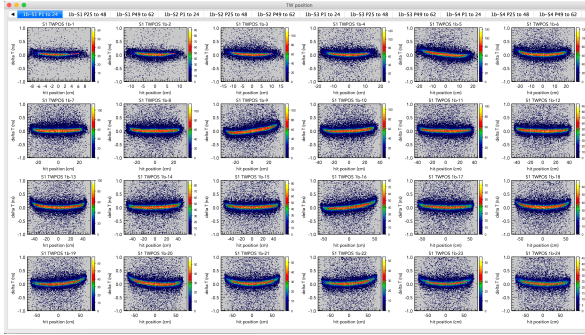
The RF timing offset calibrations are completed using one 1D histogram for each counter using the vertex time residual  $t_R$  defined in Section 4.5. Here the histogram is setup with a bin width of 25 ps.



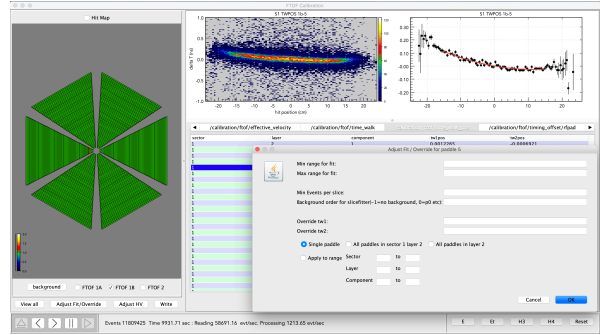
(a)



(b)



(c)



(d)

Figure 12: Position-Dependent Time-Walk screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the position-dependent time-walk fit results for a selected sector and panel, (c) Postage stamp plots for the position-dependent time-walk data and fits for a given sector and panel, (d) Adjust fit/override options.

#### ◇ Database Parameters:

There is one parameter associated with the RF time offsets and time resolution for each counter:

- *rfpad* - counter time offsets with respect to RF (ns)
- *tres* - effective counter time resolution (ns)

#### ◇ Nominal Parameter Values:

The calibration program fits a Gaussian plus a polynomial background term to the time residual distributions. The centroid of the Gaussian is assigned as the RF offset for the counter and the width of the Gaussian is a measure of the counter resolution. The nominal parameter values are typically given by:

- *rfpad*: Within  $\pm T_{RF}$
- panel-1a resolution:  $100 \rightarrow 250$  ps

- panel-1b resolution:  $50 \rightarrow 100$  ps
- panel-2 resolution:  $200 \rightarrow 400$  ps

◇ Associated Calibration Screens:

Figure 13 shows the various window views when working within the “rfpad” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- The RF offset fit results that are shown after clicking on a sector in the “Detector View Area”.
- The postage-stamp view that pops up after clicking on the “View all” button.
- The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

## 4.8 Paddle-to-Paddle Time Offsets

◇ Defined Histograms:

The paddle-to-paddle timing offset calibrations are completed using one 1D histogram for each counter that defines a vertex time difference  $\Delta t_{2v}$  between two charged track events for the reference counter relative to all other FTOF counters as:

$$\bullet \Delta t_{2v} = (t_{hit}^{ref} - L_{ref}/v_{eff}^{ref}) - (t_{hit}^i - L_i/v_{eff}^i),$$

where  $t_{hit}$  is the average counter hit time for the different counters. Here the histogram is setup with a bin width of  $T_{RF}$ .

◇ Database Parameters:

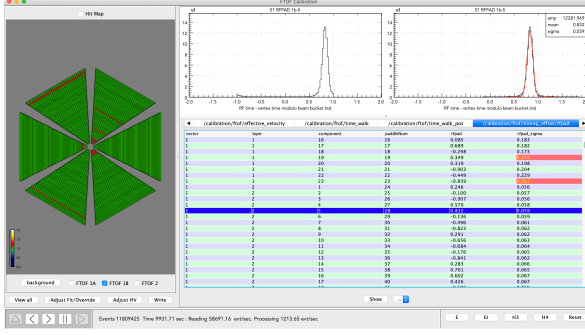
There is one parameter associated with the paddle-to-paddle time offset for each counter

- *paddle2paddle* - counter-to-counter relative time offsets (ns)

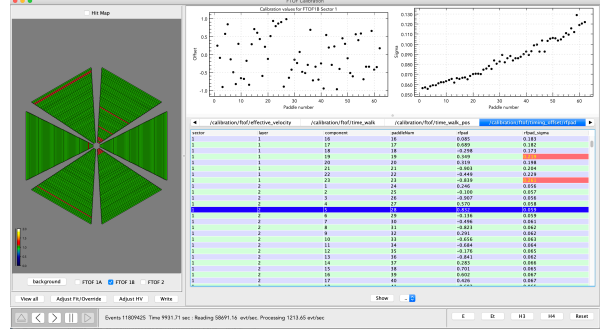
◇ Nominal Parameter Values:

The calibration program sets the paddle-to-paddle time offset for each counter to the bin number in the  $\Delta t_v$  distribution with the maximum number of counts multiplied by  $T_{RF}$ . These paddle-to-paddle offsets are determined by the known signal propagation delay differences within the signal cables. The nominal values are typically given by:

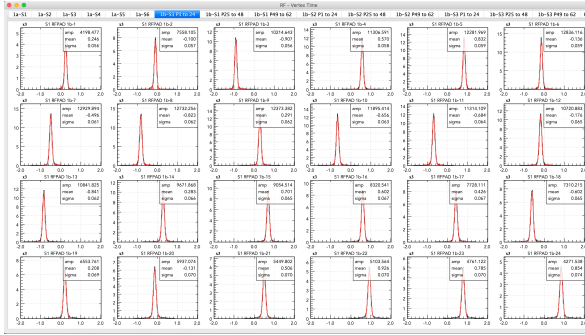




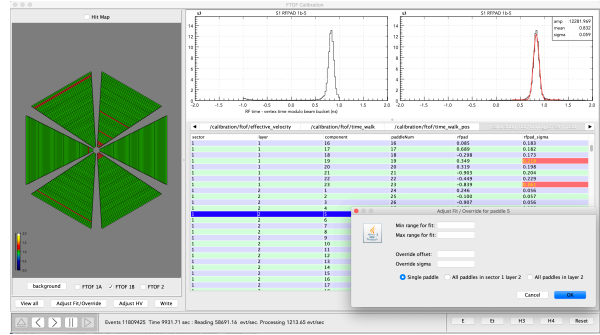
(a)



(b)



(c)



(d)

Figure 13: RF Offset screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the RF timing offsets for a selected sector and panel, (c) Postage stamp plots for the RF timing distributions and fits for a given sector and panel, (d) Adjust fit/override options.

- P2P:  $-4T_{RF} \rightarrow 4T_{RF}$

This calibration step should be iterated until all  $\Delta t_{2v}$  plots show a  $\delta$ -function for each counter and the plot showing  $\Delta t_{2v}$  has all values equal to zero.

#### ◇ Associated Calibration Screens:

Figure 14 shows the various window views when working within the “P2P” tab. Use the instructions provided in Section 2 to navigate through this step and to look at the fit results. The various views include:

- The main calibration screen after clicking on a counter in the “Parameter View Area” to study the calibration parameters.
- The P2P offset fit results that are shown after clicking on a sector in the “Detector View Area”.
- The postage-stamp view that pops up after clicking on the “View all” button.
- The subscreen that pops up after clicking on the “Adjust Fit/Override” button when viewing the fits for a particular counter.

At the end of the program execution, the dialog box shown in Fig. 3 pops up on the screen. This box should be dismissed for all of the previous steps by clicking on the “O.K.” button without making any changes. However, for the P2P step, in order to gather the constants from the LR, RFP, and P2P steps into a single output file compatible with the ccdB table format, you should select “Previous” for “Left Right” and “RF Paddle”, and “New” for “P2P”. It is important to verify that the final constants for these three calibration steps are written into the output file “FTOF\_CALIB\_TIME\_OFFSETS.txt” before uploading the constants into the database.

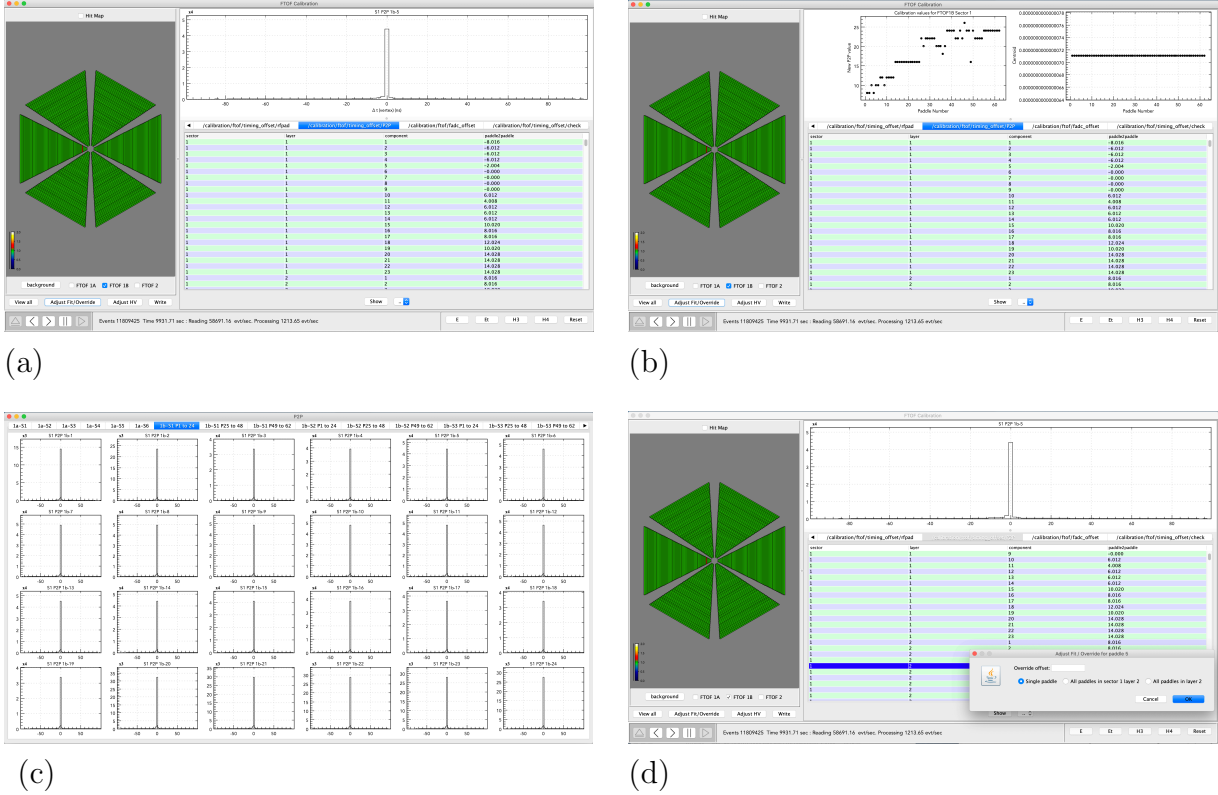


Figure 14: Paddle-to-Paddle Offset screens: (a) Main calibration screen showing the data for a selected counter, (b) Main calibration screen showing the paddle-to-paddle timing offsets for a selected sector and panel, (c) Postage stamp plots for the paddle-to-paddle timing distributions for a given sector and panel, (d) Adjust fit/override options.

## 4.9 Calibration Checkplots

The final important feature of the FTOF calibration suite is the “check” tab on the “Data and Histogram Area”, which includes a series of checkplots for each FTOF counter to study the quality of the energy and timing calibration. For each counter plots are shown for the vertex time vs. track momentum, vertex  $z$  position, hit position along the counter, path length, ADC left, and energy.

Clicking on “View all” brings up six pages of postage stamp plots for easier viewing and assessment. These plots for all counters should be reviewed during the calibration process



The screenshot displays the RStudio interface for the 'FPF calibration' workflow. The top-left pane shows a hexagonal map of the study area. The top-right pane contains six heatmaps of the 'FPF' variable for different spatial scales: 10-10k, 10-15k, 10-20k, 15-10k, 15-15k, and 15-20k. The bottom-left pane shows a color scale for the 'FPF' variable. The bottom-right pane shows a table of results for the 'FPF calibration' workflow, with columns for 'Scale', 'Unit', 'FPF', and 'FPF'.

Scale	Unit	FPF	FPF
10-10k	1	0.000	0.000
10-15k	1	0.000	0.000
10-20k	1	0.000	0.000
15-10k	1	0.000	0.000
15-15k	1	0.000	0.000
15-20k	1	0.000	0.000
10-10k	2	0.000	0.000
10-15k	2	0.000	0.000
10-20k	2	0.000	0.000
15-10k	2	0.000	0.000
15-15k	2	0.000	0.000
15-20k	2	0.000	0.000

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## 4.10 Entering Constants in Calibration Constant Database

Once the steps of the FTOF calibration have been completed and carefully checked for all channels, the calibration parameters can be put into the CLAS calibration constant database. This amounts to setting up the CLAS environment, setting up the connection to the database, and then adding the constants to the database. While this may seem like a relatively straightforward process, extreme care must be taken to ensure that the constants are written into the correct database version (default vs. test versions) and flagged with the appropriate run number range for their validity. Usually writing constants to the calibration constant database is done in direct consultation with FTOF Group Leader and the Analysis Coordinator for the run period.

An example script for writing the FTOF constants to the database is given below. Here the constants are being written into the default database and set to be valid for runs 15533-15565. The input files are located in the local subdirectory `rgm/ftof/r15562/v1` with the file names as given.

```
source /group/clas12/packages/setup.csh
module load clas12

ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/attenuation -v default
-r 15533-15565 rgm/ftof/r15562/v1/atten.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/effective_velocity -v default
-r 15533-15565 rgm/ftof/r15562/v1/veff.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/gain_balance -v default
-r 15533-15565 rgm/ftof/r15562/v1/hv.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/status -v default
-r 15533-15565 rgm/ftof/r15562/v1/stat.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/time_offsets -v default
-r 15533-15565 rgm/ftof/r15562/v1/time_offsets.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/time_walk_exp -v default
-r 15533-15565 rgm/ftof/r15562/v1/tw0.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/time_walk_pos -v default
-r 15533-15565 rgm/ftof/r15562/v1/twp.txt #"Cooked using 7.1.0; suite v96"
ccdb -c mysql://clas12writer:geom3try@clasdb/clas12 add /calibration/ftof/tres -v default
-r 15533-15565 rgm/ftof/r15562/v1/res-c.txt #"Cooked using 7.1.0; suite v96"
```

Any ccdB entry should be accompanied by a corresponding entry in the CLAS12 calibration logbook at: <https://logbooks.jlab.org/book/clas12calib>. Note also that this example script shows the standard default parameter file names that should be used. The full standard file naming convention is also reflected in the spreadsheet example shown in Fig. 16.

## 4.11 Bookkeeping

Given the multiple steps necessary to optimally calibrate each run and the fact that a number of runs must be calibrated for a given dataset, it is important to maintain strict control over the code running conditions and to maintain proper and complete bookkeeping. It is suggested that calibration spreadsheets are employed with all pertinent information recorded regarding input files, output file names, run conditions, reconstruction tag, etc. An example is shown in Fig. 16. It is also suggested that the calibration constant output files created by the calibration suite be renamed as appropriate and moved to a subdirectory labeled by the run number and version number of the calibration for that run.

	A	B	C	D	E	F	G
1		Calib. Step	RGK r5893	RGK r5893	RGK r5893	RGK r5893	RGK r5893
2	1	HV	hv.txt	hv.txt	hv.txt	hv.txt	hv.txt
3		LR	lr-a.txt	lr-a.txt	lr-a.txt	lr-a.txt	lr-a.txt
4		STAT	stat.txt	stat.txt	stat.txt	stat.txt	stat.txt
5	2	ATTEN	atten.txt	atten.txt	atten.txt	atten.txt	atten.txt
6		VEFF	veff.txt	veff.txt	veff.txt	veff.txt	veff.txt
7	3	RFP	rfp-a.txt	rfp-a.txt	rfp-a.txt	rfp-a.txt	rfp-a.txt
8		RES	res-a.txt	res-a.txt	res-a.txt	res-a.txt	res-a.txt
9	4	TW	tw0.txt	tw0.txt	tw0.txt	tw0.txt	tw0.txt
10							
11	5	LR	lr-b.txt	lr-b.txt	lr-b.txt	lr-b.txt	lr-b.txt
12							
13	6	RFP	rfp-b.txt	rfp-b.txt	rfp-b.txt	rfp-b.txt	rfp-b.txt
14		RES	res-b.txt	res-b.txt	res-b.txt	res-b.txt	res-b.txt
15	7	TWP	twp.txt	twp.txt	twp.txt	twp.txt	twp.txt
16							
17	8	RFP	rfp-c.txt	rfp-c.txt	rfp-c.txt	rfp-c.txt	rfp-c.txt
18		RES	res-c.txt	res-c.txt	res-c.txt	res-c.txt	res-c.txt
19	9	P2P	p2p.txt	p2p.txt	p2p.txt	p2p.txt	p2p.txt
20		TDC	tdc.txt	tdc.txt	tdc.txt	tdc.txt	tdc.txt
21			v1	v2	v3	v4	v5
22			v71	v73	v81	v81	v90
23			vzoff	vzon	vzon	vzon	vzon
24			trf=4.008 ns	trf=4.008 ns	trf=4.008 ns	trf=4.008 ns	trf=4.008 ns
25			6b.2.0	6b.3.0	6b.4.1	6b.5.1	6.5.3
26			6/24/19	7/17/19	1/31/20	2/7/20	4/16/20
27				10.7M	26.8M	27.4M	27.0M
28							
29							
30							

Figure 16: Sample excel spreadsheet table for tracking calibration data files and conditions, reconstruction code, parameter file names, and work progress.

## A Startup Configuration Settings

As mentioned in Section 2 one of the program startup steps is to review the settings on the initial configuration screen shown in Fig. 2(b). Each of these configuration parameters has a default value that is loaded at program execution. However, several of these parameters have to be set for the specific experimental configuration in order to enable proper calibrations. The parameters to consider for updated settings include:

- Path length normalisation for gmean?: The default is “Yes” for beam data. For cosmic data where there is no DC track information, this should be set to “No” to fill the histograms.
- Target GMEAN channel 1a/1b/2: The settings in use as of the time of writing of this tutorial are 650/700/650. Updating these parameters before the gain calibration step may results in better converge of the geometric mean fits.
- Target position (cm): The default setting for the center of the target is  $z=-3.0$  cm. This must be properly set for the experiment configuration under calibration.
- Minimum vertex  $z$ /Maximum vertex  $z$ : These limits should be set to capture the full target range consistent with target placement (solid target or extended liquid cell) and the tracking resolution at the target.

- RF period: The default is 4.008 ns but different run periods have different settings of either 2.004 ns or 4.008 ns. The wrong setting will cause multiple peaks in the vertex time distributions.
- PID (1a and 1b / 2): The default settings are “Leptons and pions” for panel-1a/panel-1b and “All” for panel-2. For the TW and TWP steps, the setting for panel-1a/panel-1b can be set to “All” to provide optimal statistics for all counters and to allow for the maximum  $\Delta E$  range.
- Minimum events per slice: The default is set to 5, however for the steps with 2D histogram fitting, this can be set to 2 for lower statistics data files to fill out the full plot range.

The other parameters should be left at their default parameters. Contact the FTOF Group Leader for questions about these settings.

## B Program Output to xterm

In this section an example is given of the output to the xterm window that should appear during standard program operation. This output should be carefully reviewed when using the program to double check that program selections are the intended ones and no errors occurred during program execution.

```
carmaniMac>java -jar FTOFCalibration.jar
```

```
Apr 07 2022 12:28:52
```

```
Configuration settings - Selected steps
```

```
-----
```

```
HV true
Attenuation Length true
TDC - Time true
Left Right true
Effective Velocity true
Timewalk true
TW position true
RF paddle true
P2P true
FADC offset true
Check true
```

```
Configuration settings - Previous calibration values
```

```
-----
```

```
Populating HV previous calibration values
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/hv.txt
HV previous calibration values populated successfully
Populating TDC - Time previous calibration values
Default
TDC - Time previous calibration values populated successfully
Populating Left Right previous calibration values
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/lr-b.txt
Left Right previous calibration values populated successfully
Populating Effective Velocity previous calibration values
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/veff.txt
Effective Velocity previous calibration values populated successfully
Populating Timewalk previous calibration values
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/tw0.txt
Timewalk previous calibration values populated successfully
```

Populating TW position previous calibration values  
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/twp.txt  
TW position previous calibration values populated successfully  
Populating RF paddle previous calibration values  
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/rfp-c.txt  
RF paddle previous calibration values populated successfully  
Populating P2P previous calibration values  
File: /Users/carman/clas12/ftof/calib/rgm/r15832/v1/p2p-i2.txt  
P2P previous calibration values populated successfully

#### Configuration settings - Tracking/General

-----  
Target GMEAN channel 1a/1b/2: 650/1000/650  
Path length normalisation for gmean?: Yes  
Maximum reduced chi squared for tracks: 75.0 (1a/1b) 5000.0 (2)  
Minimum vertex z: -10.0  
Maximum vertex z: 5.0  
Vertex time correction?: Yes  
Target position (cm): -3.0  
Momentum range (GeV): 0.4-10.0  
Minimum energy deposit (MeV): 0.5  
Mass assumption for beta calculation: Use PID  
Track charge: Both  
RF period: 2.004  
PID: Leptons and pions (1a/1b) All (2)  
Trigger: 0  
2D histogram graph method: Max position of slices  
Slicefitter mode:  
Minimum events per slice: 2  
TDC range: 8500-15000  
FADC x range / width: -10.0 - 60.0 / 10.0

adding check box FTOF 1A  
adding check box FTOF 1B  
adding check box FTOF 2  
check box created

[action] --> OpenFileHipo4  
file -> /Users/carman/dataf-rgm/ftof\_15832\_7.1.0.hipo  
reader:: \*\*\*\*\*>>>> opening file : /Users/carman/dataf-rgm/ftof\_15832\_7.1.0.hipo  
reader:: \*\*\*\*\* dictionary entries : 191  
reader:: \*\*\*\*\* file size : 29329012008  
reader:: \*\*\*\* scan trailer #bytes : 186552  
reader:: \*\*\*\*\* number of records : 5829  
reader:: \*\*\*\*\* number of events : 11809425  
[DataSourceDump] --> opened file with events #  
[EventProcessor] --> added a data source. TYPE = FILE  
[action] --> PlayFile  
[DB] ---> open connection with : mysql://clas12reader@clasdb.jlab.org/clas12  
[DB] ---> database variation : default  
[DB] ---> database run number : 15832  
[DB] ---> database time stamp : Wed Apr 06 09:03:36 EDT 2022  
[DB] ---> database connection : success  
IndexedList SIZE = 3  
\* period \* D \*  
\* phase \* I \*  
\* cycles \* I \*  
  
[DB LOAD] ---> loading data table : /geometry/ftof/panel1a/paddles  
[DB LOAD] ---> number of columns : 4  
  
[DB LOAD] ---> loading data table : /geometry/ftof/panel1b/paddles  
[DB LOAD] ---> number of columns : 4  
  
[DB LOAD] ---> loading data table : /geometry/ftof/panel2/paddles  
[DB LOAD] ---> number of columns : 4  
  
[DB] ---> database disconnect : success

```

RUN = 15832
[action] --> PlayFile
[action] --> PauseFile
[action] --> PlayFile
EVENT_STOP for HV Apr 06 2022 16:10:47
EVENT_STOP for Attenuation Length Apr 06 2022 16:11:05
EVENT_STOP for TDC - Time Apr 06 2022 16:11:07
EVENT_STOP for Left Right Apr 06 2022 16:11:07
EVENT_STOP for Effective Velocity Apr 06 2022 16:11:24
EVENT_STOP for Timewalk Apr 06 2022 16:11:26
EVENT_STOP for TW position Apr 06 2022 16:11:36
EVENT_STOP for RF paddle Apr 06 2022 16:11:39
EVENT_STOP for P2P Apr 06 2022 16:11:43
EVENT_STOP for FADC offset Apr 06 2022 16:11:43
EVENT_STOP for Check Apr 06 2022 16:11:43
[DataProcessingPane] ----> task is done...

```

## C Filtering HIPO Data Files

The calibration procedure must be performed using reconstructed (as opposed to raw or decoded) data files. A calibration workflow has been setup that produces data files for the FTOF calibration filtered to output only the specific data banks required for the calibration. This reduces the file size and allows for faster reading and processing times when running the calibration suite. The output files skimmed for the FTOF calibration have the following banks:

- RUN::rf, RUN::config
- REC::Event, REC::Particle, REC::Track, REC::Scintillator
- FTOF::adc, FTOF::tdc, FTOF::hits
- TimeBasedTrkg::TBTracks

## D Program Features

There are a number of features of the calibration suite that have not been fully discussed in this tutorial but may be of interest to the calibrators. Double-clicking on any plot within the calibration suite pops up a new window containing just the plot that can be scaled by using your mouse to drag the window frame out to the desired size. An options menu is also available by right-clicking your mouse on any plot within the suite. The content of the menu that pops up depends on whether the plot is 1D or 2D. This menu contains options for copy/paste, saving plots (in png format), a fit panel(s), and an options menu. The “Options” menus allow for axis ranges to be changed, switching from log to linear scales, addition of plot and axis labels, changes in fonts, and modifications in the appearance of the statistics box on the plots. See Fig. 17 for several menu views within the options selection.

Figure 18 shows the screens that pop up when choosing “Et” from the different file source types in the “Control Area” to connect to the online EVIO data source (the ET ring). This link will connect to the online source of the data when the online data acquisition is active and the FTOF calibration suite is run from a DAQ computer (*e.g.* clondaq6). Talk to the

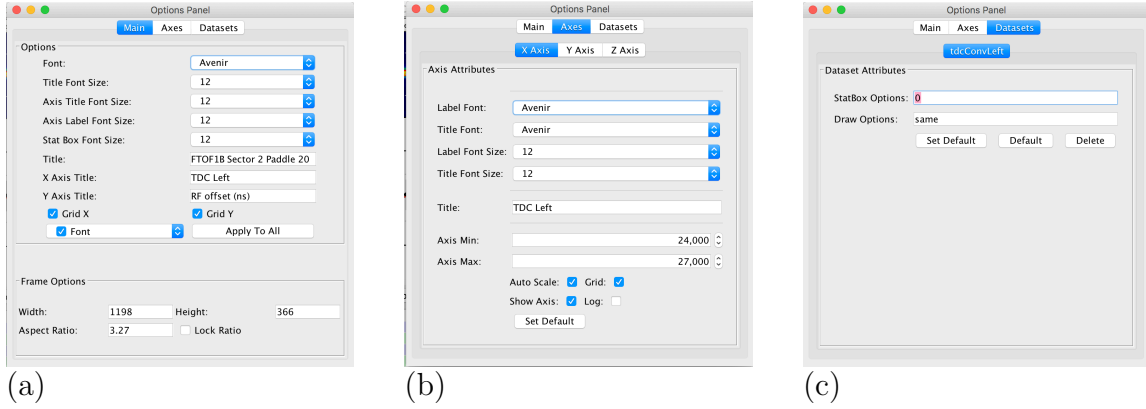


Figure 17: Fit options screens to set (a) the plot appearance, (b) the plot axis limits, and (c) the statbox options.

DAQ expert for further details on these options as they are not standard options for running the suite.

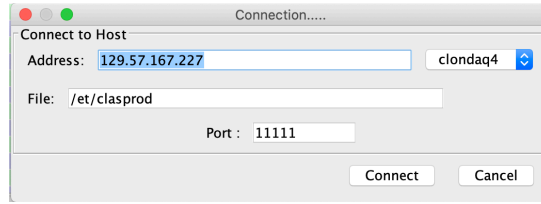


Figure 18: Pop up connection window when selecting the “Et” option within the program “Control Area”.

## References

- [1] D.S. Carman *et al.*, “*The CLAS12 Forward Time-of-Flight System*”, Nucl. Inst. and Meth. A **960**, 163629 (2020).
- [2] D.S. Carman, “*Forward Time-of-Flight Calibration Constants*”, [https://www.jlab.org/Hall-B/ftof/notes/ftof\\_db.pdf](https://www.jlab.org/Hall-B/ftof/notes/ftof_db.pdf)
- [3] D.S. Carman, L. Clark, R. De Vita, and H.Y. Lu, “*Descriptions of the Calibration Algorithms for the CLAS12 Forward Time-of-Flight System*”, [https://www.jlab.org/Hall-B/ftof/notes/ftof\\_calib.pdf](https://www.jlab.org/Hall-B/ftof/notes/ftof_calib.pdf)
- [4] JLab calibration github page, <https://github.com/JeffersonLab/clas12calibration-tof/>
- [5] D.S. Carman, “*Forward Time-of-Flight System Operations Manual*”, [https://www.jlab.org/Hall-B/ftof/ftof\\_manual.pdf](https://www.jlab.org/Hall-B/ftof/ftof_manual.pdf)