Central Time-of-Flight Calibration Constants

D.S. Carman, Jefferson Laboratory
ctof_db.tex

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Abstract

This document details the calibration constants for the CTOF system. The two categories of constants are associated with the gain calibration and the timing calibration.

1 CTOF Calibration Constants

Table 1 provides an overview of the calibration constants associated with the CLAS12 Central Time-of-Flight (CTOF) system. The constants fall into two different categories, those associated with the gain (or high voltage) calibration and those associated with the timing calibration for each counter. The number of entries associated with each calibration constant is typically 48, the total number of scintillation counters in the CTOF system.

The CLAS12 calibration constant database (ccdB) is organized into columns based on *sector*, *layer*, and *component*. For the CTOF system, as it is a hermetic barrel of scintillation counters located in the CLAS12 Central Detector and therefore is not divided into sectors, the *sector* is assigned as 1. As there is only one layer of counters for CTOF, the *layer* is assigned as 1. Finally, the *component* corresponds to the counter number, $1 \rightarrow 48$.

In each of the subsections below, full details on each of the CTOF database calibration constants listed in Table 1 are provided. Section 2 provides typical values for each of the calibration constants.

1.1 Attenuation Length Constants

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

- *attlen* - measured attenuation length for each end of each counter (cm)
- *attlen_err* - uncertainty of the measured attenuation length (cm)
- *y_offset* - intercept of attenuation length fit.

Database Entry	Description
/calibration/ctof/attenuation	Counter attenuation length parameters
/calibration/ctof/effective_velocity	Counter effective velocity parameters
/calibration/ctof/gain_balance	PMT gain balancing parameters
/calibration/ctof/status	PMT/Counter status
/calibration/ctof/tdc_conv	TDC channel calibration parameters
/calibration/ctof/time_offsets	Counter time offset parameters
/calibration/ctof/time_jitter	TDC-trigger phase difference
/calibration/ctof/fadc_offset	TDC-FADC time offsets
/calibration/ctof/hpos	Position-dependent time offset (functional) parameters
/calibration/ctof/tres	Effective counter time resolution parameters
/calibration/ctof/cluster	Cluster parameters
/calibration/ctof/hposbin	Position-dependent time offset (bin-by-bin) parameters

Table 1: Overview table for the CTOF calibration constants.

The attenuation length is determined using a relation between the measured counter ADC values and the hit coordinate along the bar:

$$\log\left(\frac{ADC_D - PED_D}{ADC_U - PED_U}\right) = y\_offset + \frac{2 \cdot coor}{attlen}. \tag{1}$$

Here ADC_D and ADC_U are the downstream and upstream ADC values, PED_D and PED_U are the associated ADC pedestals, and *coor* is the hit coordinate determined via:

$$coor = \frac{veff}{2}(t_U - t_D - upstream\_downstream), \tag{2}$$

where t_U and t_D are the PMT hits times and *upstream_downstream* is the counter PMT time offset detailed in Section 1.6. The slope of a linear fit of Eq.(1) is used to extract the counter attenuation length (where *attlen_upstream* = *attlen_downstream*). The parameter *attlen_err* is the uncertainty associated with the attenuation length fit (where *attlen_upstream_err* = *attlen_downstream_err*). No uncertainty for the y-intercept parameter is stored. The relevant details on the CTOF attenuation length entries in the calibration database are given in Table 2.

1.2 Effective Velocity Constants

There are two constants associated with the measured effective velocity:

- *veff* - effective velocity of the counter for each end (cm/ns)
- *veff_err* - uncertainty in the determined effective velocity (cm/ns).

The effective velocity is determined using the definition of the hit coordinate along the counter:

Name	attenuation		
Full path	/calibration/ctof/attenuation		
Rows	48		
Columns	8		
Column info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*attlen_upstream*
	4	double	*attlen_downstream*
	5	double	*attlen_upstream_err*
	6	double	*attlen_downstream_err*
	7	double	*y_offset*

Table 2: CTOF counter attenuation length database information.

$$coor_{CVT} = \frac{veff}{2}(t_U - t_D - upstream\_downstream). \quad (3)$$

This definition is similar to that in Eq.(2) except now the hit coordinate along the bar is determined from CVT tracking information. A linear fit of the CTOF hit coordinate vs. half the hit time difference gives the effective velocity *veff* (where *veff_upstream* = *veff_downstream*). The parameter *veff_err* is the uncertainty in the effective velocity from the fit (where *veff_upstream_err* = *veff_downstream_err*). The relevant details on the CTOF effective velocity entries in the calibration database are given in Table 3.

Name	effective_velocity		
Full path	/calibration/ctof/effective_velocity		
Rows	48		
Columns	7		
Column info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*veff_upstream*
	4	double	*veff_downstream*
	5	double	*veff_upstream_err*
	6	double	*veff_downstream_err*

Table 3: CTOF counter effective velocity database information.

1.3 Gain Balancing Constants

There are four parameters associated with the gain balancing constants:

- *mipa* - Fit centroid of the Landau peak in the geometric mean histogram for minimum-ionizing particles
- *mipa_err* - Uncertainty in the fit of the Landau peak position in the geometric mean histogram for minimum-ionizing particles
- *logratio* - Mean of the distribution $\log\left(\frac{ADC_D - PED_D}{ADC_U - PED_U}\right)$
- *logratio_err* - Uncertainty in the mean of the log ratio distribution.

Although there are separate parameters for the upstream and downstream PMTs, the algorithm sets $mipa\_upstream = mipa\_downstream$, and fills them with the fit centroid for the minimum-ionizing peak for the geometric mean ADC distribution ($\sqrt{ADC_U \cdot ADC_D}$) and *logratio* is the centroid of the log ratio distribution $\log(ADC_D/ADC_U)$. The gain balancing parameters also include the uncertainties in the geometric mean from the fit (where $mipa\_upstream\_err = mipa\_downstream\_err$) and the log ratio distribution (*logratio_err*). The relevant details on the CTOF gain balancing entries in the calibration database are given in Table 4.

Name	gain_balance		
Full path	/calibration/ctof/gain_balance		
Rows	48		
Columns	9		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*mipa_upstream*
	4	double	*mipa_downstream*
	5	double	*mipa_upstream_err*
	6	double	*mipa_downstream_err*
	7	double	*logratio*
	8	double	*logratio_err*

Table 4: CTOF PMT gain balancing database information.

1.4 Counter PMT Status

There is one parameter associated with the hardware status for each of the readout electronics channels for each PMT in the CTOF:

- *stat* - status of PMT.

The following convention is employed for these status words:

- 0 - fully functioning
- 1 - no ADC
- 2 - no TDC
- 3 - no ADC, no TDC (PMT is dead)
- 5 - any other reconstruction problem.

The relevant details on the CTOF status entries in the calibration database are given in Table 5.

Name	status		
Full path	/calibration/ctof/status		
Rows	48		
Columns	5		
Column info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	int	*stat_upstream*
	4	int	*stat_downstream*

Table 5: CTOF counter PMT status database information.

1.5 TDC Channel Calibration Constants

The conversion from TDC channel number to time is given by a multiplicative calibration constant for each TDC channel. The parameters associated with each TDC channel are given by:

- *upstream* - TDC conversion factors of the upstream PMTs (ns/channel)
- *downstream* - TDC conversion factors of the downstream PMTs (ns/channel).

The raw hit times for the upstream and downstream PMTs are given by:

$$t^U_{hit} = TDC_U \cdot upstream, \tag{4}$$
$$t^D_{hit} = TDC_D \cdot downstream. \tag{5}$$

The relevant details on the CTOF TDC calibration constants in the calibration database are given in Table 6.

Name	tdc_conv		
Full path	/calibration/ctof/tdc_conv		
Rows	48		
Columns	5		
Column info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*upstream*
	4	double	*downstream*

Table 6: CTOF TDC channel calibration database information.

1.6 Time Offset Constants

There are three parameters associated with the time offsets for the CTOF:

- *upstream_downstream* - PMT time difference for each counter (ns)
- *rfpad* - counter time offsets with respect to RF (ns)
- *paddle2paddle* - counter to counter relative time offsets (ns).

The first parameter, *upstream_downstream*, is from the difference of the hit coordinate along the bar from the upstream-downstream PMT time difference relative to the coordinate determined from the projected CVT tracks to the CTOF midplane:

$$upstream\_downstream = \frac{2}{veff} \cdot (t_U - t_D) - coor_{CVT}. \tag{6}$$

The second parameter, *rfpad*, is determined by comparing the CTOF counter hit time traced back to the vertex relative to the RF time:

$$\Delta t_R = mod(\Delta t_v, T_{RF}), \tag{7}$$

$$\Delta t_v = \left(t_{hit} - \frac{L}{\beta c}\right) - \left(t_{RF} + \frac{z_{vert}}{\beta_e c}\right), \tag{8}$$

where T_{RF} is the RF period, L is the counter length, βc is the speed of the track, and $z_{vert}/(\beta_e c)$ is a term to correct the RF time t_{RF} to account for the actual electron beam event vertex location along the z-axis of the extended target.

The third parameter, *paddle2paddle*, is a time offset that connects the measured vertex time for each counter to the event start time. The paddle-to-paddle timing offset calibrations are given from the time difference distributions:

$$\Delta t_{P2P} = t_{hit} - L/veff - t_{ST}, \tag{9}$$

where t_{ST} is the event start time defined by events with a coincident track in the FTOF. The relevant details on the CTOF time offset entries in the calibration database are given in Table 7.

Name	time_offsets		
Full path	/calibration/ctof/time_offsets		
Rows	48		
Columns	6		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*upstream_downstream*
	4	double	*rfpad*
	5	double	*paddle2paddle*

Table 7: CTOF counter time offset database information.

1.7 Time Jitter Phase Constant

The CAEN TDCs used for the CTOF are readout with a 24 ns clock strobe so that all TDC times are referenced to an edge of this clock. The CLAS12 trigger comes on the edge of a clock with a period of 4 ns and the TDC stop will not occur until the next 24 ns clock edge. The use of these two different clocks introduces a delay between the trigger and the TDC stop given by $n \cdot 4$ ns, with $n = 0 \rightarrow 5$ (referred to as the six-fold TDC cycle ambiguity) where n is the phase.

Name	time_jitter		
Full path	/calibration/ctof/time_jitter		
Rows	1		
Columns	6		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*period*
	4	int	*phase*
	5	int	*cycles*

Table 8: CTOF time jitter database information.

The TDC jitter correction is a single integer for all CTOF TDC channels that defines the value of the phase n that is valid for the entire data run. There are three database constants associated with the TDC time jitter phase:

- *period* - trigger readout period (ns)
- *phase* - phase number between TDC clock pulse edge and trigger pulse edge
- *cycles* - TDC clock period / trigger clock period.

The relevant details on the CTOF time jitter phase in the calibration database are given in Table 8.

1.8 FADC Time Offsets

Hit times for the CTOF are derived from both TDC and ADC information. Constants are included in the CTOF calibration database to account for the maximum allowable offset in time of these two measures. For each counter there are three calibration constants:

- *upstream* - upstream PMT TDC time - FADC time (ns)
- *downstream* - downstream PMT TDC time - FADC time (ns)
- *width* - time difference matching requirement (ns).

The relevant details on the CTOF FADC offsets in the calibration database are given in Table 9.

Name	fadc_offset		
Full path	/calibration/ctof/fadc_offset		
Rows	48		
Columns	6		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*upstream*
	4	double	*downstream*
	5	double	*width*

Table 9: CTOF counter FADC offset database information.

1.9 Hit-Position-Dependent Correction - Functional

The removal of the remnant time offset in the reconstructed CTOF hit time caused by effects of the CTOF geometry is done using two hit-position-dependent corrections. One is a polynomial functional correction and the second is a bin-by-bin correction (see Section 1.12). For the functional correction, there are two calibration parameters:

- *hposa* - first functional parameter

- *hposb* - second functional parameter
- *hposc* - third functional parameter
- *hposd* - extra parameter - currently unused
- *hpose* - extra parameter - currently unused.

The parameterization of the hit-position-dependent - functional correction has the form:

$$t^{HPOS} = hposa \cdot z^2 + hposb \cdot z + hposc. \tag{10}$$

In this expression, z is the hit coordinate along the bar and the constant term *hposc* is absorbed into the RF correction. The relevant details on the CTOF FADC offsets in the calibration database are given in Table 10.

Name	hpos		
Full path	/calibration/ctof/hpos		
Rows	48		
Columns	8		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*hposa*
	4	double	*hposb*
	4	double	*hposc*
	4	double	*hposd*
	5	double	*hpose*

Table 10: CTOF counter hit-position-dependent - functional database information.

1.10 Counter Time Resolution Constants

There is one parameter associated with the counter timing resolution for the CTOF:

- *tres* - counter effective timing resolution (ns).

The effective counter timing resolution is determined from the width of the CTOF vertex time distribution relative to t_{RF} from the RF offset determination discussed in Section 1.6. The relevant details on the CTOF counter timing resolution entries in the calibration database are given in Table 11.

Name	tres		
Full path	/calibration/ctof/tres		
Rows	48		
Columns	4		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*tres*

Table 11: CTOF counter time resolution database information.

1.11 Cluster Constants

The reconstruction of hit clusters in the CTOF corresponds to charged particle tracks that cross neighboring counters as they traverse the CTOF counter barrel. There are four constants associated with the cluster definition for each panel:

- *minEnergy* - minimum deposited energy to be considered for cluster definition (MeV)
- *maxDistance* - maximum coordinate difference between hits in neighboring counters to be part of a hit cluster (cm)
- *maxTimeDifference* - maximum time difference between hits in neighboring counters to be part of a hit cluster (ns)
- *maxClusterSize* - maximum number of neighboring counters to include as a hit cluster.

The relevant details on the CTOF cluster definition entries in the calibration database are given in Table 12.

Name	cluster		
Full path	/calibration/ctof/cluster		
Rows	540		
Columns	7		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*minEnergy*
	4	double	*maxDistance*
	5	double	*maxTimeDifference*
	6	uint	*maxClusterSize*

Table 12: CTOF cluster definition database information.

1.12 Hit-Position-Dependent Correction - Bin

The reconstructed hit time from CTOF has an anomalous shift due to effects associated with the non-rectilinear geometry of the scintillator bars at their ends where they connect to the light guides. This shift is corrected in a two-step process using a bin-by-bin timing correction in the hit position along the bar and using a polynomial correction (see Section 1.9). The hit-position-dependent correction - bin is completed slicing the hit vertex time (see Eq.(7)) as a function of hit coordinate z along the counter. The Δt_v channel of each slice with the maximum counts is used to shift the time. For each counter there are 100 calibration constants and one control flag:

- *bin0* - control flag
- *bin1* $\rightarrow$ *bin100* - Δt_v offset of slice i binned in z=1 cm.

The control flag *bin0* is set to 1 to employ this correction (nominal) or set to 0 to ignore. The relevant details on the CTOF hit-position-dependent correction - bin in the calibration database are given in Table 13.

Name	hposbin		
Full path	/calibration/ctof/hposbin		
Rows	48		
Columns	104		
Columns info	#	type	name
	0	int	*sector*
	1	int	*layer*
	2	int	*component*
	3	double	*bin0*
	4 $\rightarrow$ 103	double	*bin1* $\rightarrow$ *bin100*

Table 13: CTOF counter hit-position-dependent - bin database information.

2 Typical Parameter Values

Table 14 details the typical values (and units where applicable) for each of the CTOF calibration constants to be entered into the calibration database for CLAS12.

Name	Parameter	Value
attenuation	*attlen*	140 cm
	attlen_err	3 cm
	y_offset	0.0
effective_velocity	*veff*	14 cm/ns
	veff_err	0.1 cm/ns
gain_balance	*mipa*	600 (ADC channel)
	mipa_err	5 (ADC channels)
	logratio	0.0
	logratio_err	0.0
status	*status*	0
time_offsets	*upstream_downstream*	-25 ns
	rfpad	$-T_{RF} \rightarrow T_{RF}$ ns
	paddle2paddle	$-8 \rightarrow 8 \cdot T_{RF}$ ns
tdc_cal	*upstream*	0.0235 ns/ch
	downstream	0.0235 ns/ch
tdc_jitter	*period*	4 ns
	phase	$0 \rightarrow 5$
	cycle	6
fadc_offset	*upstream*	20 ns
	downstream	40 ns
	width	10 ns
hpos	*upstream*	0 ns/cm^2
	downstream	0.3 ns/cm
tres	*tres*	100 ps
cluster	*minEnergy*	1.5 MeV
	maxDistance	10.0 cm
	maxTimeDifference	1.2 ns
	maxClusterSize	2
hposbin	*bin0*	1
	bini	$-0.1 \rightarrow 0.1$ ns

Table 14: Typical values for the CTOF calibration constants.