# Timing alignment for a calorimeter/uTCA crate

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**Abstract**

This article summarizes a strategy that can be used to time-align all the 54 rider channels within a calorimeter. Two types of signal can be used to time-align the rider channels within a calorimeter. First is the laser sync pulse and second is the electron/positron beam. This article is intended to show how they can be utilized to do so.

## 1 Basics

In general, the time extracted from the template fit of a sync pulse for crystal $i$ and fill $f$ can be written as

$$t_{sync}(i,f) = t_{diffuser}(f) + \tau_{fiber}(i) + \tau_{rider}(i,f) \tag{1}$$

where $t_{laser}(f)$ is the time at which the laser system is triggered relative to the rider crate trigger, $\tau_{fiber}(i)$ the laser propagation time in a fiber $i$ and $\tau_{rider}$ the internal delay of a rider channel and includes the 2 clock tick shift. Likewise, for the electron/positron beam,

$$t_{beam}(i,f) = t_{calohit}(f) + \tau_{shower}(i,f) + \tau_{rider}(i,f) \tag{2}$$

where $t_{calohit}(f)$ is the hit time of the beam on the front face of the calorimeter relative to the rider crate trigger, $\tau_{shower}(i,f)$ is the EM shower plus the mean Cherenkov light propagation time to the SiPM $i$.

### Alignment using sync pulse

During the SLAC test run, we have done some analyses using the sync pulse for timing alignment. This means the synced time for the beam event is

$$t_{beam,synced}(i,f) = t_{beam}(i,f) - t_{sync}(i,f) \tag{3}$$
$$= t_{calohit}(f) - t_{laser}(f) + \tau_{shower}(i,f) - \tau_{fiber}(i) \tag{4}$$

The timing difference $\delta t$ between 2 crystals ($i$ and $j$) in fill $f$ is thus given by

$$\delta t_{beam,synced}(i,j,f) = t_{beam,synced}(i,f) - t_{beam,synced}(j,f) \tag{5}$$
$$= \delta\tau_{shower}(i,j,f) - \delta\tau_{fiber}(i,j) \tag{6}$$

since $t_{calohit}(f) - t_{laser}(f)$ does not depend on the crystal. It is obvious from Eq. 6 that due to inhomogeneous fiber lengths, sync pulses alone are not enough for the timing alignment. Hence we need to find a way to extract the propagation time in the fiber, $t_{fiber}$, for all 54 fibers. Bad news is, it is not trivia to measure each fiber's propagation time up to 100 ps precision. Good news is, we just need to measure the relative difference within a calorimeter. For historical reason, we have selected the crystal 24's rider channel as the reference point.

### Alignment using sync pulse and beam pulse

Aligning all the timing information w.r.t to the crystal 24, we have

$$\begin{aligned}
\delta t_{sync}(i,24,f) &= t_{sync}(i,f) - t_{sync}(24,f) && (7)\\
&= [\tau_{fiber}(i) - \tau_{fiber}(24)] + [\tau_{rider}(i,f) - \tau_{rider}(24,f)] && (8)\\
&= \delta\tau_{fiber}(i,24) + \delta\tau_{rider}(i,24,f) && (9)
\end{aligned}$$

and

$$\begin{aligned}
\delta t_{beam}(i,24,f) &= t_{beam}(i,f) - t_{beam}(24,f) && (10)\\
&= [\tau_{shower}(i,f) - \tau_{shower}(24,f)] + [\tau_{rider}(i,f) - \tau_{rider}(24,f)] && (11)\\
&= \delta\tau_{shower}(i,24,f) + \delta\tau_{rider}(i,24,f)\ . && (12)
\end{aligned}$$

If we choose all the events such that the shower propagation time in the crystal is the same w.r.t. to the crystal 24, i.e. $\delta\tau_{shower}(i,24,f) = 0$ (for example, beam hitting the center of the crystal or hitting at the common border of the crystals), then we have

$$\delta t_{beam}(i,24,f) = \delta\tau_{rider}(i,24,f)\ . \tag{13}$$

Since the offset in the rider $\tau_{rider}$ is the same for all the fills within the same run,

$$\delta t_{beam}(i,24) = \delta\tau_{rider}(i,24)\ . \tag{14}$$

Of course, since the shower is well contained within the $3 \times 3$ crystals, it is not possible to map out all the $\delta\tau_{rider}$ by just analyzing the data w.r.t. to the crystal 24. Hence to have a complete map, we need to look at the $\delta\tau_{rider}$ w.r.t. to the crystals that have the $\delta\tau_{rider}$ extracted compared to crystal 24. The statistical uncertain will increase but there should be an optimum way of doing it out there. Once we have the map of the $\delta\tau_{rider}$, we can solve Eq. 9 and get $\delta\tau_{fiber}$. If we turn things around, since we have all the $\delta\tau$ relative to crystal 24, we can also say that we have all the $\delta\tau$ relative to each other.

Going back to Eq. 6, since we have the $\delta\tau_{fiber}$, we now have a better knowledge regarding $\tau_{shower}$. We can now discriminate more pile up events with this additional information. We might also be able to disentangle the position and the angle information.

# 2 Datasets

# 3 Analysis

## 3.1 How often does the $\delta\tau_{rider}$ changes?