New Results on CSC Timing

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1 New Results

Studies of the timing measurement capabilities of the CSC's, based on the cathode strip signals, have progressed. A brief description follows. It is proposed to include some of these results in the *CSC Performance Paper*.

A skimmed set of CRAFT data was used for this analysis – the same as was used for the position resolution studies, with slightly looser cuts.

We used the standard calculation of the "rechit time" coming from `CSCRecHitD`. This calculation is based on a fit of the observed pulse shape to the known analytical form (already given in the performance paper). Improvements to this calculation are possible and were explored with test beam data, as shown by Stan Durkin some time ago. For now, we go with what we have. Fig. 1 shows the raw distribution of these rechit times for all chambers providing rechits.

Unless noted otherwise, all distributions shown in this note are given in terms of the CFEB time bin, which is 2 BX or 50 ns long.

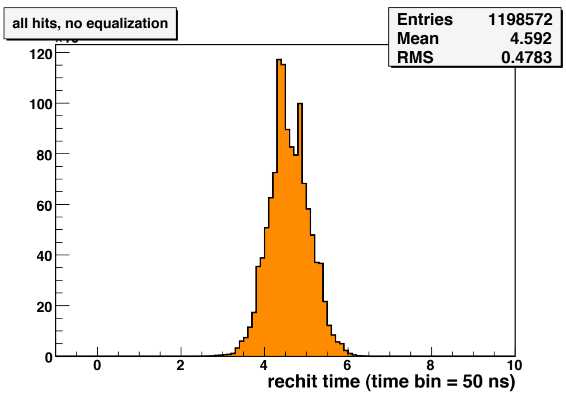

Figure 1: Raw distribution of rechit times, for all chambers producing rechits in CRAFT

The simplest measure of the rechit time resolution comes from the difference in times from rechits in layers 6 and 1. This difference should be consistent with zero, and the width of the distribution (rms, σ, ...) gives us the resolution of a single hit times $\sqrt{2}$. The distribution of this rechit time difference is shown in Fig. 2. A clean, narrow peak is observed, very close to zero, with an rms of 0.21 time bins. A Gaussian fit to the core of the distribution gibes 0.19 time bins, or 9 ns. This corresponds to a *per hit*

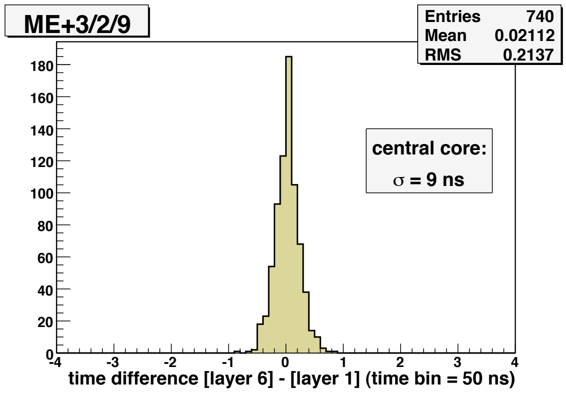

Figure 2: Difference in rechit times for layers 6 and 1, for chamber ME+3/2/9. The rms is 0.21 time bins; the core resolution is slightly smaller, and corresponds to 9 ns

time resolution of 13 ns. Naively, one would therefore expect a *per segment* resolution of about 2.5 ns.

A side-view diagram of CMS is shown in Fig. 3. One sees clearly that ME2/2 and ME3/2 shadow each other; a muon which masses through chamber N in one is likely to pass through chamber N in the other.

Define the *segment time* as the average of the rechit times for all hits on a segment. Usually there are six. There are substantial variations of the mean segment time from one chamber to the next, within a given ring. We measured these individual times, and removed the chamber-to-chamber variations, setting the nominal times to 4.8 time bins. (This is close to the average time for all chambers – see Fig. 1.)

We checked the differences in segment times for muons passing through the same chamber N in ME3/2 and ME2/2 (on the same side). The separation between chambers in ME3/2 and ME2/2 is about 120 cm. Taking the typical track inclination into account, the path length for a cosmic ray muon is roughly 140 cm, corresponding to a time-of-flight of 5 ns, or $\Delta t_{32} = 0.1$ time bins.

Naively, one would expect the mean time difference $\langle t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}} \rangle$ to be ± 0.1 time bins, depending on which way the muon is going. (Remember that it passes ME2→ME3 for $y > 0$, and ME3→ME2 for $y < 0$.) The timing of each chamber was set, however, to eliminate the time difference between the stations for muons coming from the interaction point. So for muons passing ME2→ME3, the mean time difference should be zero, and for ME3→ME2, it should be twice the naive estimate.

Fig. 4 show the mean differences in segment times, $\langle t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}} \rangle$, for each chamber pair in Ring 2 of ME2 and ME3. The vertical line separates

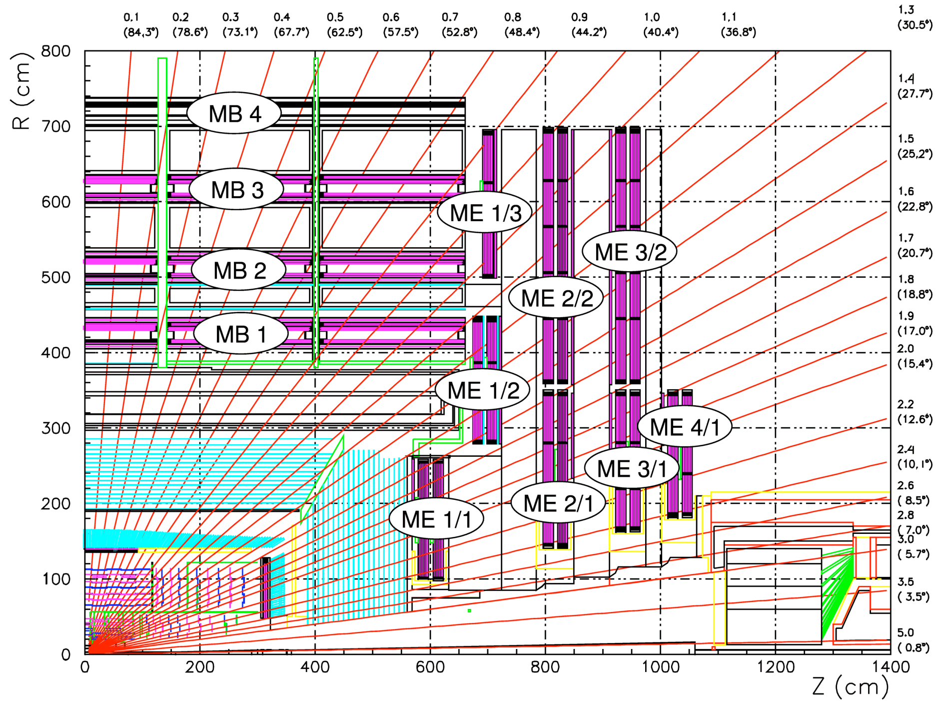

Figure 3: A side view of CMS, showing clearly the CSC stations and rings

the top half of the disks (left of the line) from the bottom half (right of the line). The mean differences $\langle t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}} \rangle$ are roughly consistent with zero for the top half, but are consistent with about 0.2 times bins for the bottom half. This behavior is expected given the time of flight between ME3 and ME2, and the "time leveling" done as part of commissioning the CSC trigger.

We selected a subset of the top and bottom chamber pairs, to quantify the top/bottom difference seen in Fig. 4. To be specific, we selected chamber pairs N, where $3 \leq N \leq 17$ for the top, and $22 \leq N \leq 35$ for the bottom. Fig. 5 shows these "projections" for ME+ and ME- separately. A clear difference is seen between chambers on top and chambers on the bottom, and this difference is the same for ME- and ME+. From fits to the central cores of these distributions, we find

$$\left(t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}}\right)_{\mathrm{bottom}} - \left(t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}}\right)_{\mathrm{top}} = 0.238 \pm 0.010$$

for ME-, and

$$\left(t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}}\right)_{\mathrm{bottom}} - \left(t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}}\right)_{\mathrm{top}} = 0.222 \pm 0.007$$

for ME+, which is in line with the naive estimate of 0.2.

As a final exercise, we wanted to select muons passing through both endcaps, and observe a relationship between the segment times in one endcap and the other. More concretely, we selected muons passing through chambers in a slice of the top of ME2 on one side, and through difference chambers in a slice of the bottom of ME2 on the other side. Here, the top slice contains chambers N with $5 \leq N \leq 15$ and the bottom slice, $22 \leq N \leq 35$. From the drawing in Fig. 3, the separation between ME+2 and ME−2 is $\Delta z \approx 16.4$ m, and taking the inclination of the muons into account, the path length is about 19 m, corresponding to a time-of-flight of 64 ns, or 1.3 time bins.

First we display the correlation in segment times in Fig. 6. The figure shows that the times are indeed correlated, and a muon arriving later in ME+2 will also arrive later in ME-2. There is a hint of an offset from the origin.

Fig. 7 shows the distributions of the segment time differences, $t_{\mathrm{ME+2/2}} - t_{\mathrm{ME-2/2}}$, for the two cases. The solid blue histogram shows the case in which a muon enters in the top half of ME+2/2 and exits in the bottom half of ME-2/2, and the hatched black histogram shows the converse case. For both cases, the ordinate is $t_{\mathrm{ME+2/2}} - t_{\mathrm{ME-2/2}}$, so one expects the peaks to occur at different places.

The naive expectation of 1.3 time bins is not met. Gaussian fits to the cores of these distributions give

$$(t_{\mathrm{ME+2/2}})_{\mathrm{top}} - (t_{\mathrm{ME-2/2}})_{\mathrm{bottom}} = -0.091 \pm 0.004,$$

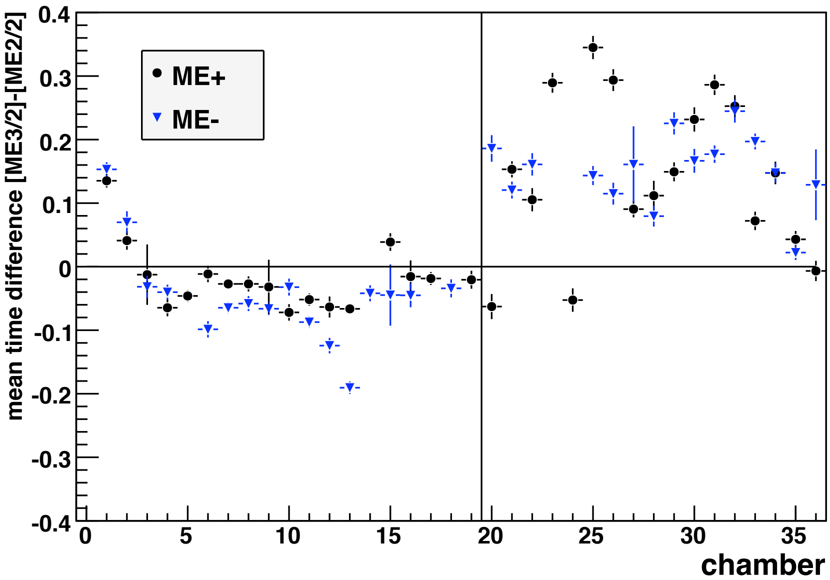

Figure 4: Mean differences in segment times, $\langle t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}} \rangle$, for muons passing through the same chamber in ME2/2 and ME3/2, as a function of chamber number. Both endcaps are shown, using different symbols. The vertical line separates the upper half of the disk (left) from the lower half (right). A clear difference is seen between the halves.

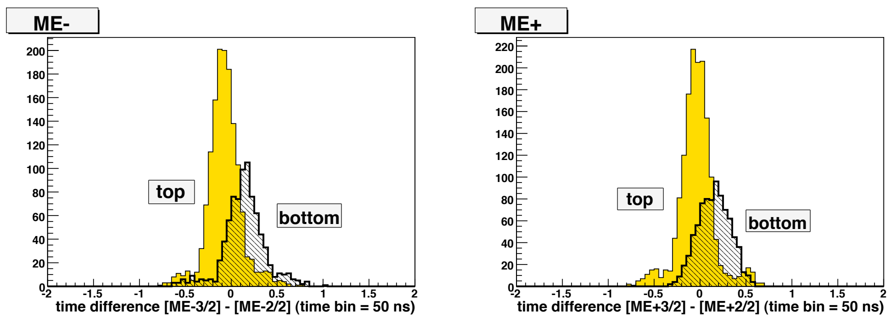

Figure 5: Differences in segment times, $t_{\mathrm{ME3/2}} - t_{\mathrm{ME2/2}}$, for muons passing through the same chamber in ME2/2 and ME3/2. Chambers in the top and bottom of each disk are shown separately. ME- is on the left, and ME+, on the right.

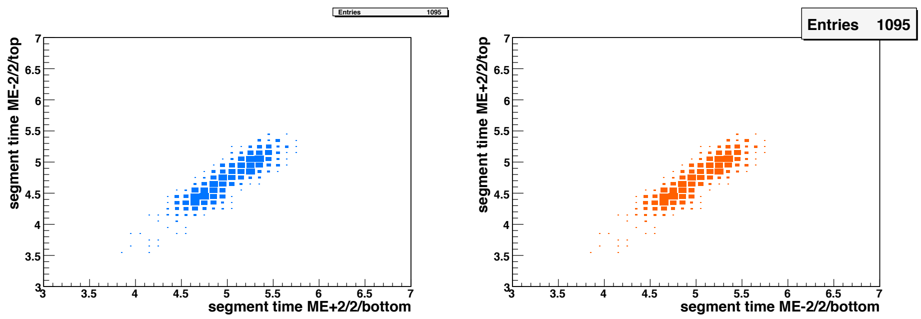

Figure 6: Correlation in segment times for muons passing through both endcaps. The plot on the left shows the case in which the muon enters in the top of ME-2/2 and exits in the bottom of ME+2/2, and the plot on the right shows the converse case. Units are 50 ns time bins.

$$(t_{\mathrm{ME}+2/2})_{\mathrm{bottom}} - (t_{\mathrm{ME}-2/2})_{\mathrm{top}} = 0.264 \pm 0.004$$

which are far from the expectations of ± 1.4. The difference in these two values is 0.355 ± 0.006 time bins. We do not have an explanation for this large discrepancy.

Andy Kubik performed a similar analysis while trying to improve the accuracy of the rechit time. As part of his work, he used cosmic ray Monte Carlo data. Fig. 8 shows two clear peaks corresponding to the same cases as shown in Fig. 7. The separation between the peaks is 1.2 time bins, close to expectation.

2 Reference Histograms

We produced histograms of the segment time differences for all pairs of chambers in ME3/2 and ME2/2. The figures below show those distributions. Some chamber pairs display double peaks. We have no explanation for this. Other plots are empty because of chamber of the pair was not giving rechits.

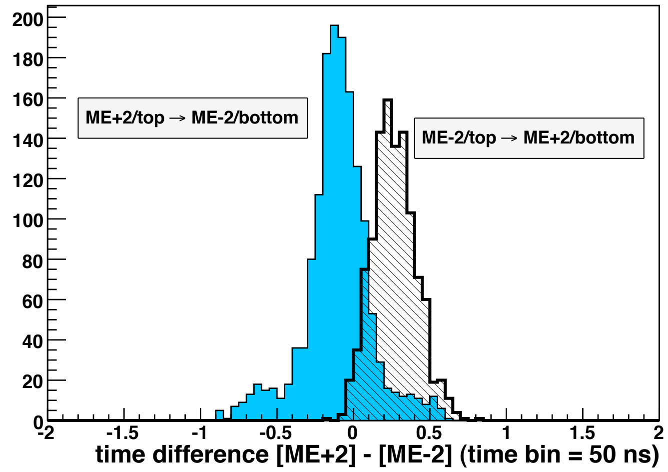

Figure 7: Distributions of the differences in segment times, $t_{\mathrm{ME}+2/2} - t_{\mathrm{ME}-2/2}$, for the two cases of muons passing from ME+2→ME-2 (solid blue histogram) and ME-2→ME+2 (hatched black histogram). Although a clear separation is observed, the magnitude does not match naive expectations.

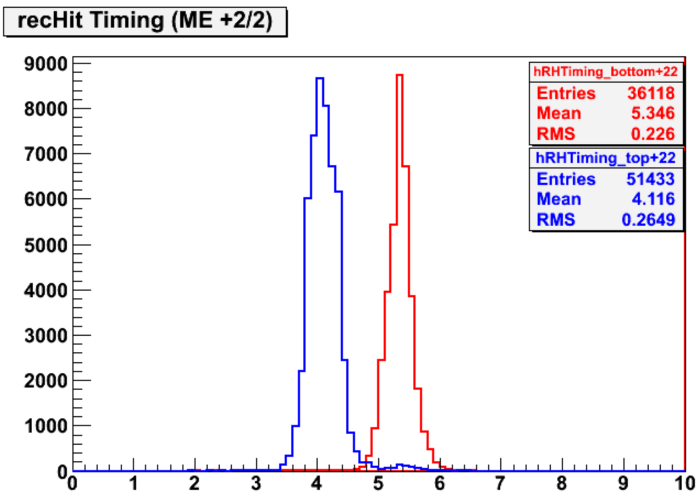

Figure 8: Rechit time distributions from a simulated cosmic ray sample. The two peaks correspond to the same cases as shown in Fig. 7.

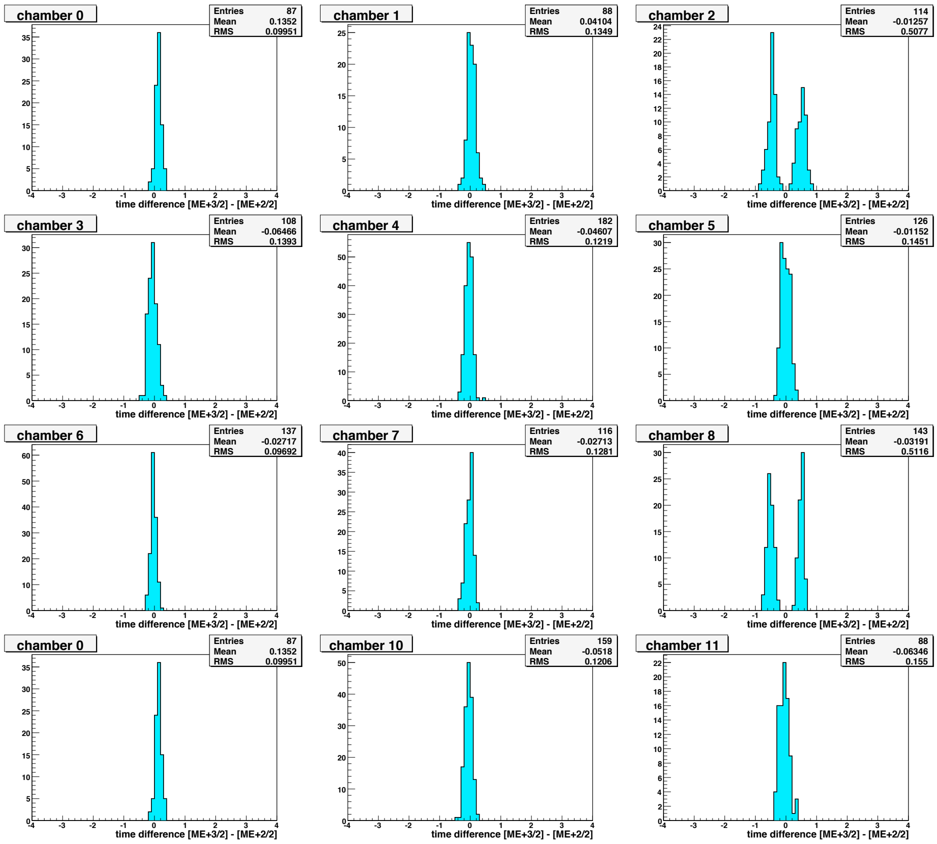

Figure 9: Segment time differences for pairs of chambers in ME+. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)

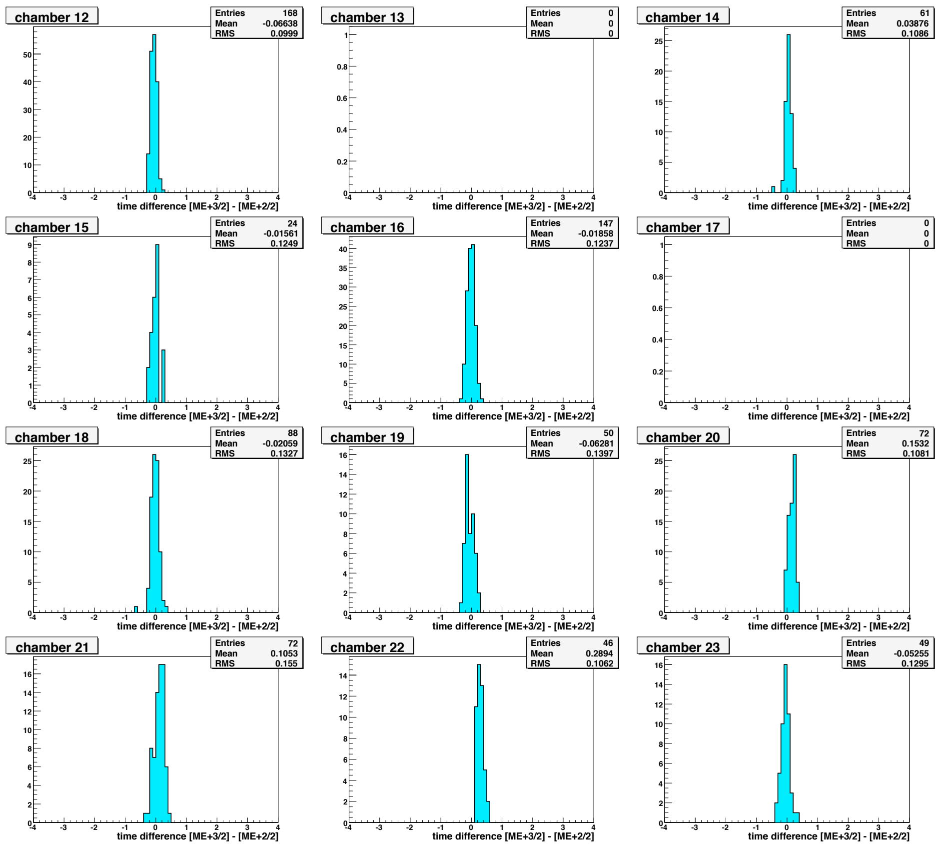

Figure 10: Segment time differences for pairs of chambers in ME+. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)

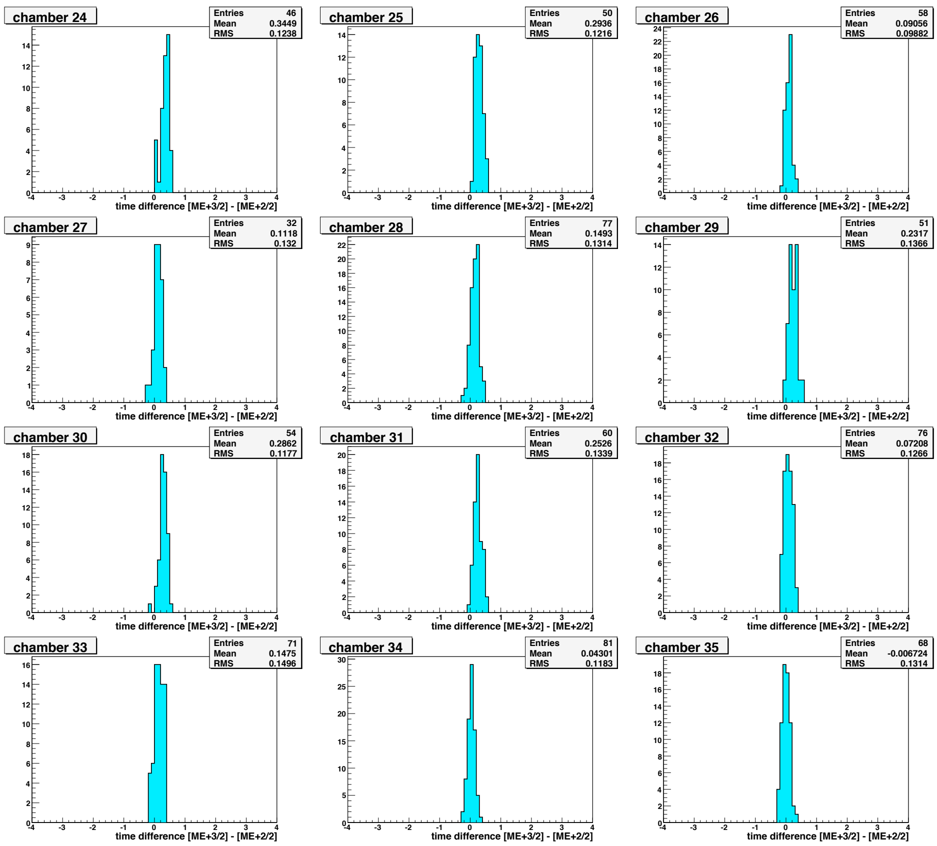

Figure 11: Segment time differences for pairs of chambers in ME+. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)

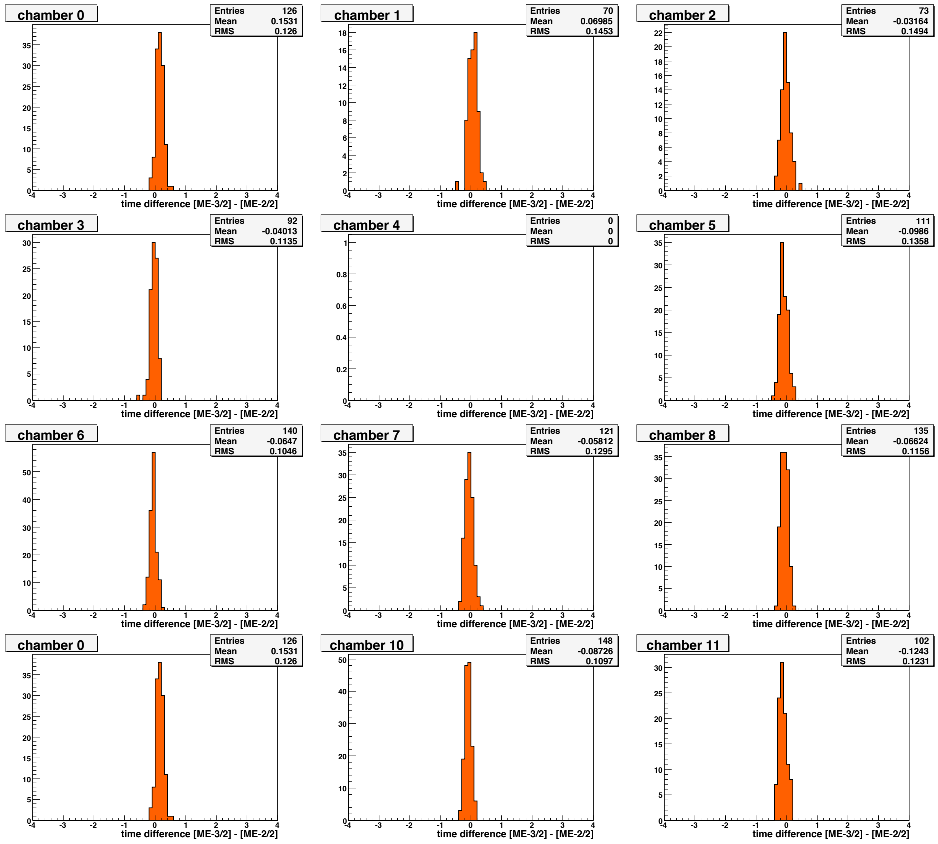

Figure 12: Segment time differences for pairs of chambers in ME-. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)

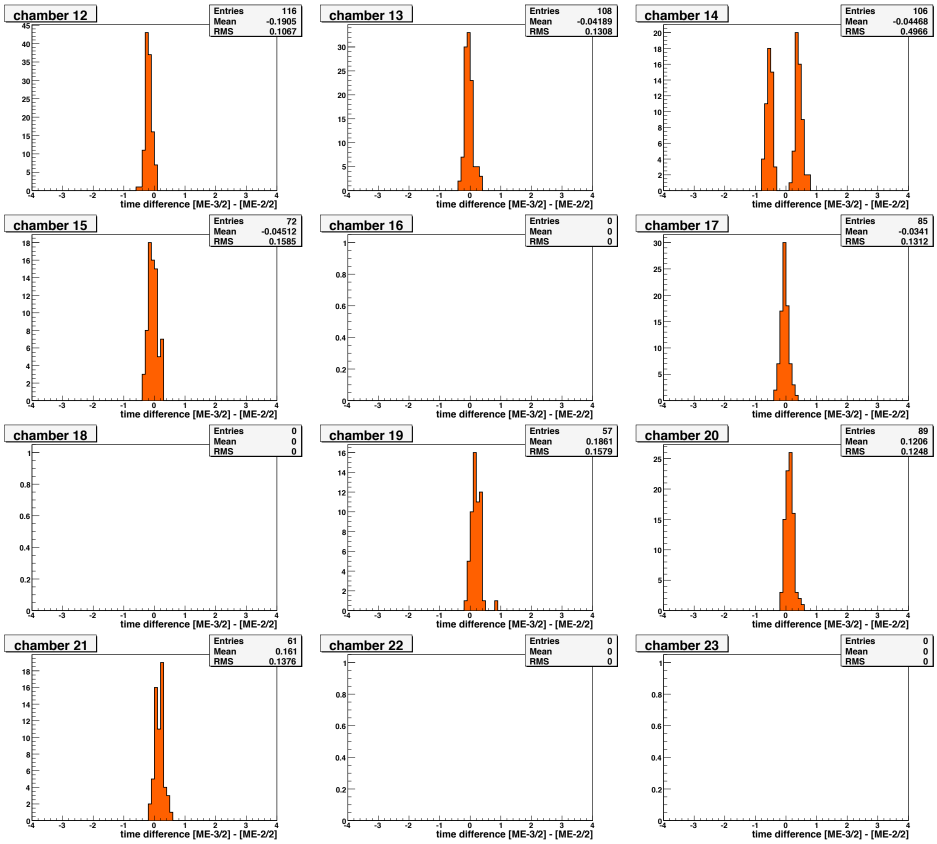

Figure 13: Segment time differences for pairs of chambers in ME-. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)

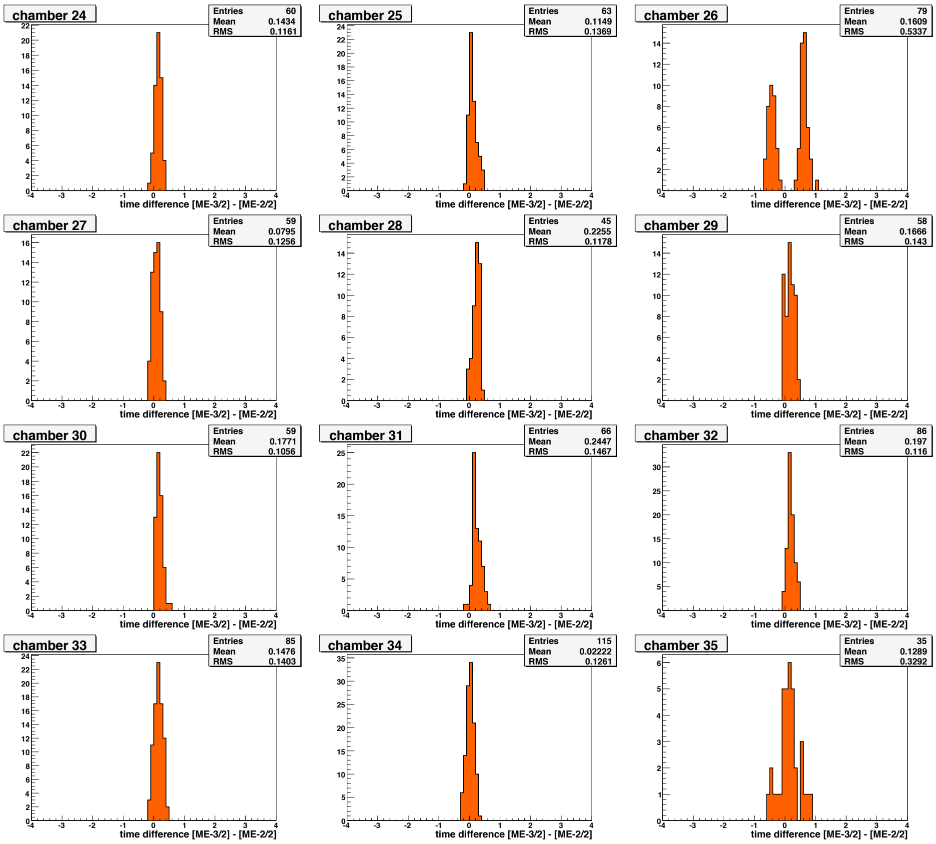

Figure 14: Segment time differences for pairs of chambers in ME-. (Through a mistake in labeling, the chamber number is decremented with respect to the usual offline convention.)