# Time Resolution for Tracks Crossing Two Scintillators of the CLAS TOF System

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## 1 INTRODUCTION

The CLAS TOF system contains 342 scintillation counters which cover a large portion of the $4\pi$ solid angle. A time resolution of $\sigma \leq 0.180ns$ is required in order to distinguish Kaons from pions. During an experiment it is expected that a significant number of tracks will cross through two scintillators. Therefore, we must be able to calculate the crossing time with a resolution that is comparable to the resolution for tracks through a single counter. This note reports on the efforts to obtain the above resolution.

## 2 BACKGROUND

Each scintillator counter has a photomultiplier tube (PMT) at each end called L and R for left and right respectively. Signals from the PMT anodes are split and serve as inputs to both the TDCs and ADCs. The ADCs in the data file are pedestal subtracted. The raw data used here is from a run taken with the setup as shown in Figure 1. The counters used in this setup were numbers 1,2,18, and 19 of a forward angle TOF plane. Plots with TDC in their title are uncorrected for time walk and are not scaled to nanoseconds. The TCL and TCR plots are time corrected (time walk corrected and scaled to nanoseconds). SADC stands for the square root of the product of the ADCs of both ends of a counter (ie. SQRT(ADCL18*ADCR18)). LG shows the natural log of the ratio ADCR/ADCL. TD is the corrected time difference between ends of the same counter divided by two, and TAV is the time corrected average of those same ends. TRES shows the overall resolution after subtracting the reference counter values (see Equation (2)). The subscripts on the variables in the plots are as follows. (1) and (2) refer to the counters under <u>test</u> which were 18 and 19 respectively, (3) and (4) refer to counters 1 and 2 which were used to establish with good precision a reference time for tracks crossing the test counters. The ADC and TDC calibrations are as described in [1]. The offsets found in [1] do not significantly affect the results of this paper and, therefore, are not used for this analysis. However, the relative time between counters 18 and 19 is important and has been adjusted accordingly.

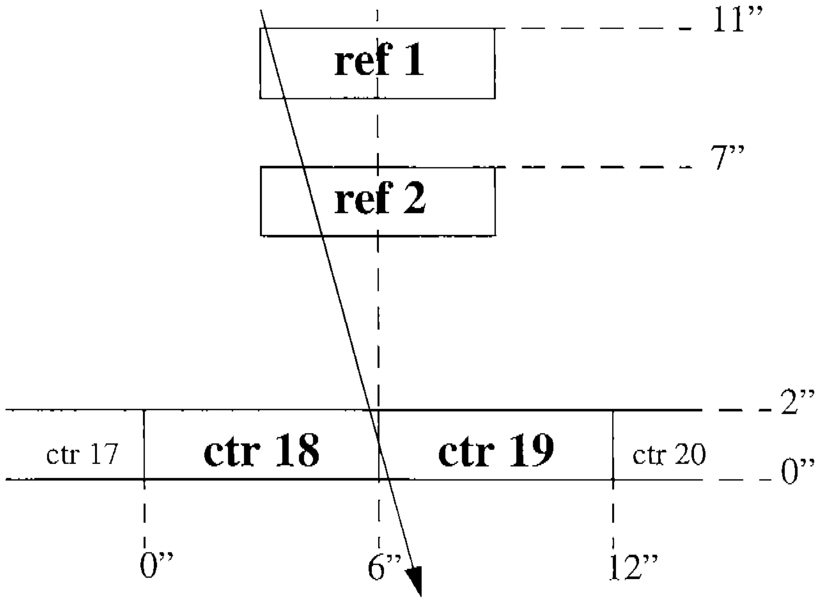


**Figure 1.:** End view of the cosmic-ray setup used for the crossing track data run. The arrow represents a possible crossing track. Counter 18 is 2.97 m long, and 19 is 3.13 m long. Ref 1 and Ref 2 are positioned over the lengthwise center of counters 18 and 19, but are much shorter.

| **Counter Number** | **Left-end Nanosecond Conversion (ns/count) [c1]** | **Left-end Time-walk Coefficient (ns) [w2]** | **Left-end ADC Exponent [w3]** | **Right-end Nanosecond Conversion (ns/count) [c1]** | **Right-end Time-walk Coefficient (ns) [w2]** | **Right-end ADC Exponent [w3]** |
|---|---|---|---|---|---|---|
| 1 | 0.04670 | 19.0220 | 0.1769 | 0.04642 | 18.8898 | 0.2625 |
| 2 | 0.04632 | 29.7146 | 0.2494 | 0.04669 | 23.4531 | 0.3073 |
| 18 | 0.04563 | 29.8787 | 0.4090 | 0.04550 | 18.9042 | 0.3218 |
| 19 | 0.04682 | 16.4142 | 0.1106 | 0.04666 | 14.1172 | 0.1183 |

**Table 1.:** Values implemented in Equation (1).

The time corrected plots use equation (1) to scale the TDC to nanoseconds and to correct for time-walk (see Table 1):

$$TC = TDC \cdot c1 - \frac{w2}{ADC^{w3}} \tag{1}$$

where TC is the corrected time, and ADC is the pulse height above pedestal for that particular PMT (18 left, 18 right, *etc.*). The values of c1, w2, and w3 are given in Table 1.

# 3 INSTRUMENTAL PROCEDURE

## 3.1 Method

Using the setup in Figure 1, data were taken requiring 4 hits per event, one for each counter in the setup. In the uncut data sample, counters other than 18 and 19 were hit in approximately two-thirds of the events. The first cut we make is one requiring that the track only go through the four counters in which we are specifically interested. The data left after this cut is what we will call the original data. The next two cuts are made on the original data. The first is a simple width cut on the overall resolution, TRES, since an overwhelming percentage of the data falls into the 31.8 to 33.0 nanosecond range (97%). The second cut is done to eliminate what are possibly double tracks (ie. one track through counter 18 and a separate track through counter 19) or tube noise. It is a cut on the 2-D plot of (TCL19-TCR19) vs. (TCL18-TCR18), see Figure 2. When all three are combined we call them standard cuts; they are intended to obtain a clear sample of hits produced by a single particle. The resolution of tracks traversing scintillators 18 and 19 is obtained by using a weighted average of their times minus the average reference time:

$$TRES = \frac{SADC18}{ATOT} TAV18 + \frac{SADC19}{ATOT} TAV19 - TAVREF \tag{2}$$

where ATOT is the sum (SADC18 + SADC19), and TAVREF is the average of the time-corrected reference counter TDCs (see Eqation 7). Two more cuts are performed in order to check the effects of the reference counters on the resolution. First, we cut on the absolute value of the difference between the ratios shown in (3).

$$\left| \frac{SADC1}{\left(\frac{SADC1 + SADC2}{2}\right)} - \frac{SADC2}{\left(\frac{SADC1 + SADC2}{2}\right)} \right| < 0.30 \tag{3}$$

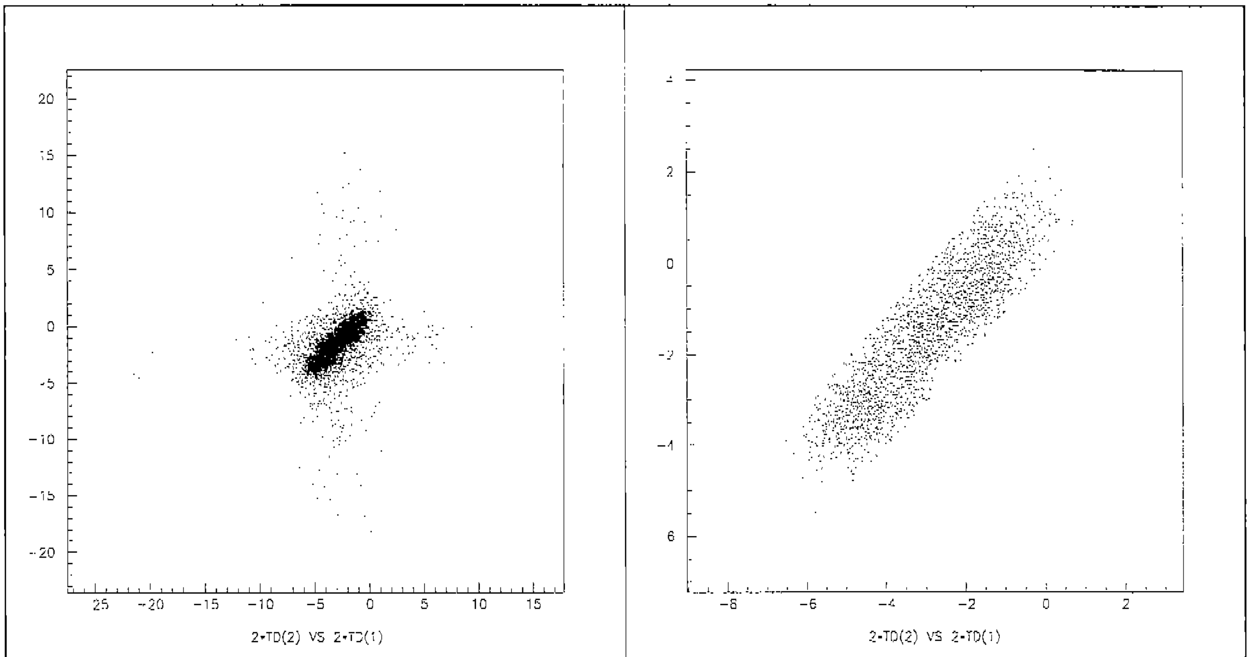


**Figure 2.:** (TC19L-TC19R) vs. (TC18L-TC18R): a) the original data b) data with the standard cuts

This means that each of the reference counters must have gotten between 35 and 65 percent of the average energy deposited between them and ensures that the reference counters record a track that goes fully through each of them. The second cut is made on the difference between left and right sides of the second reference counter (see Figure 3). Making a similar cut on the first reference counter did not affect the results.

Another cut is made on the SADC ratio for each of the test counters in order to see the effects of tracks that cross mainly through one counter and only slightly clip the other:

$$\frac{SADC}{ATOT} > 0.90 \tag{4}$$

One final cut is made on the same ratio, but it is made between 20% and 80% instead of greater than 90%. This cut can be made on either test counter without changing the result:

$$0.20 < \frac{SADC}{ATOT} < 0.80 \tag{5}$$

These cuts are not all made at the same time, that is, some cuts are turned on when others are off. This way one can see the effects of the different cuts.

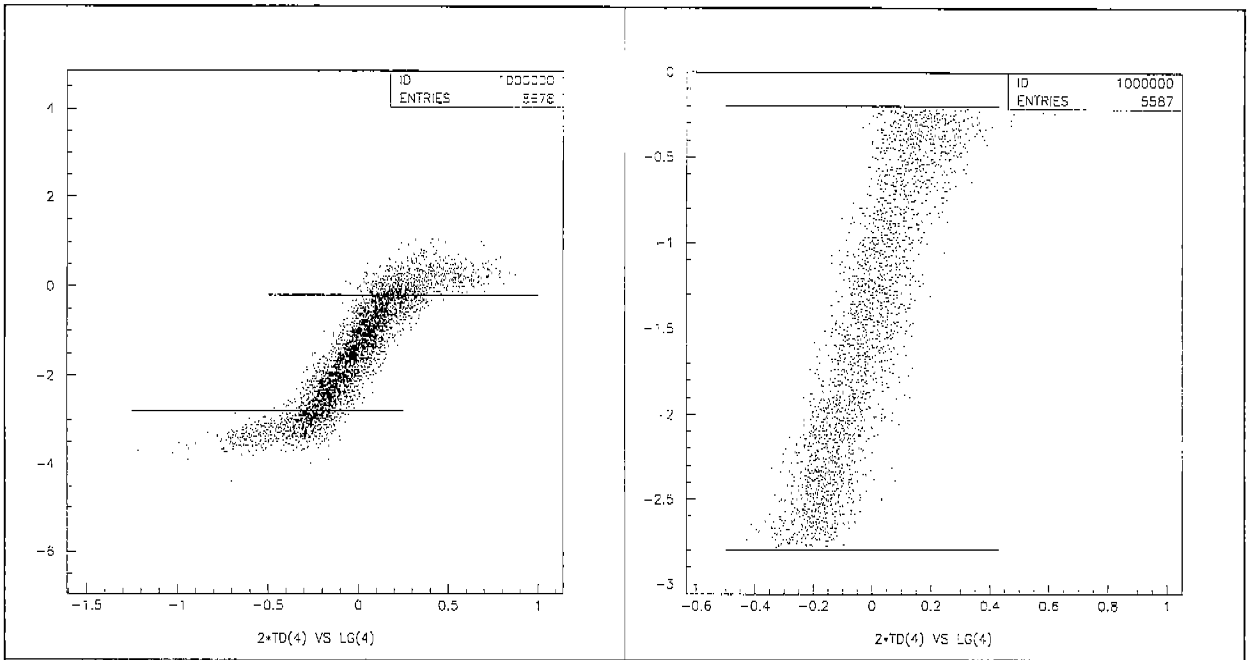


**Figure 3.:** (TC2L-TC2R) vs. ln(ADC2R/ADC2L): a) before the line cuts
b) after the line cuts (The horizontal lines show where the cuts were made, i.e. -2.8<(TC2L-TC2R)<-0.2)

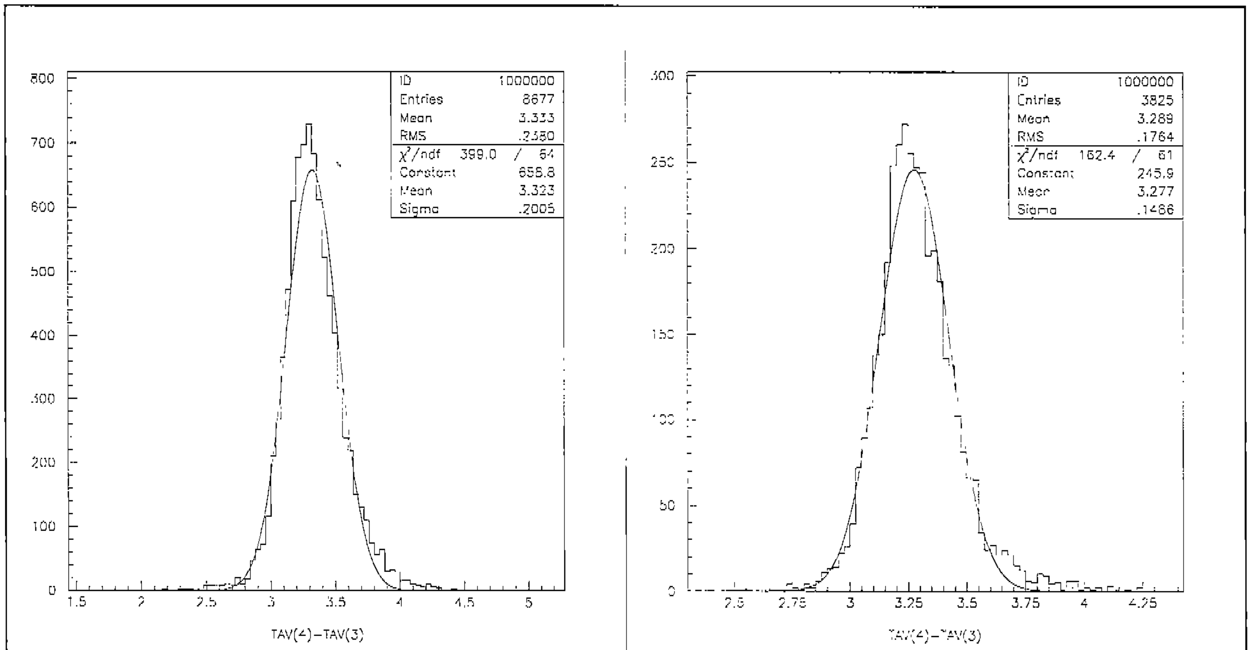


**Figure 4.:** The difference between the average times of the reference counters on the original data using: a) no reference counter cuts
b) both reference counter cuts.

# 4 Resolution

Here we have plotted resolutions for a few combinations of the cuts described above. For the original data plots, the resolution width cut (between 31.8 and 33.0) is used for ease of comparison with the standard cuts plots.

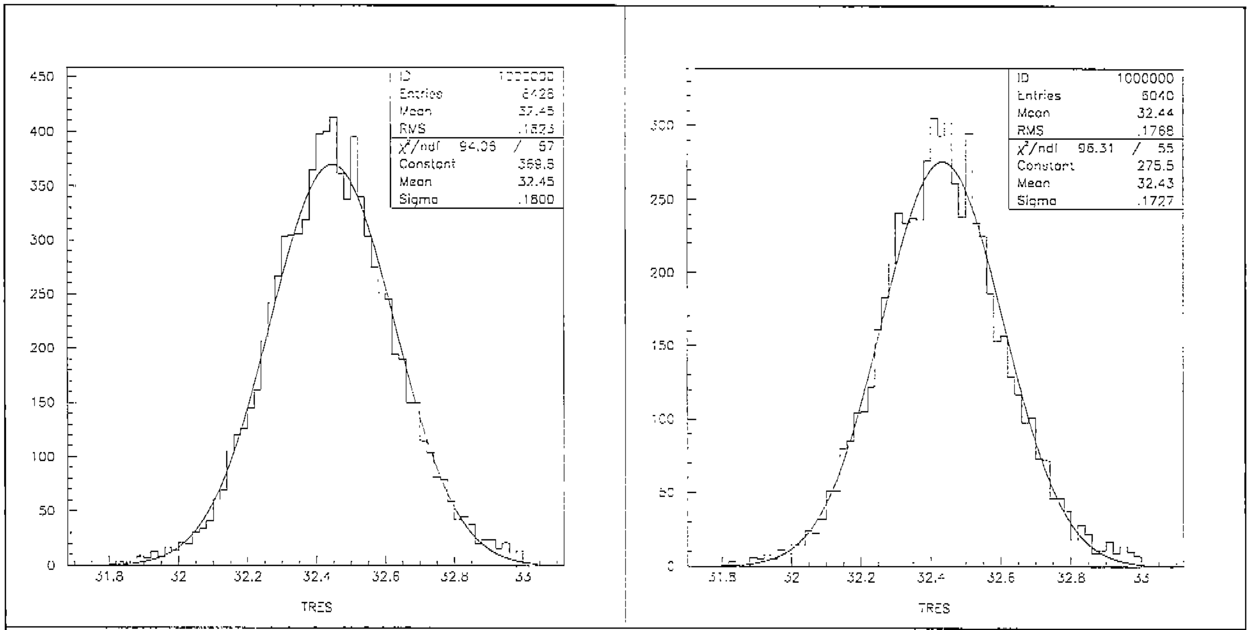


**Figure 5.:** Overall resolution, no additional cuts: a) the original data b) data with the standard cuts

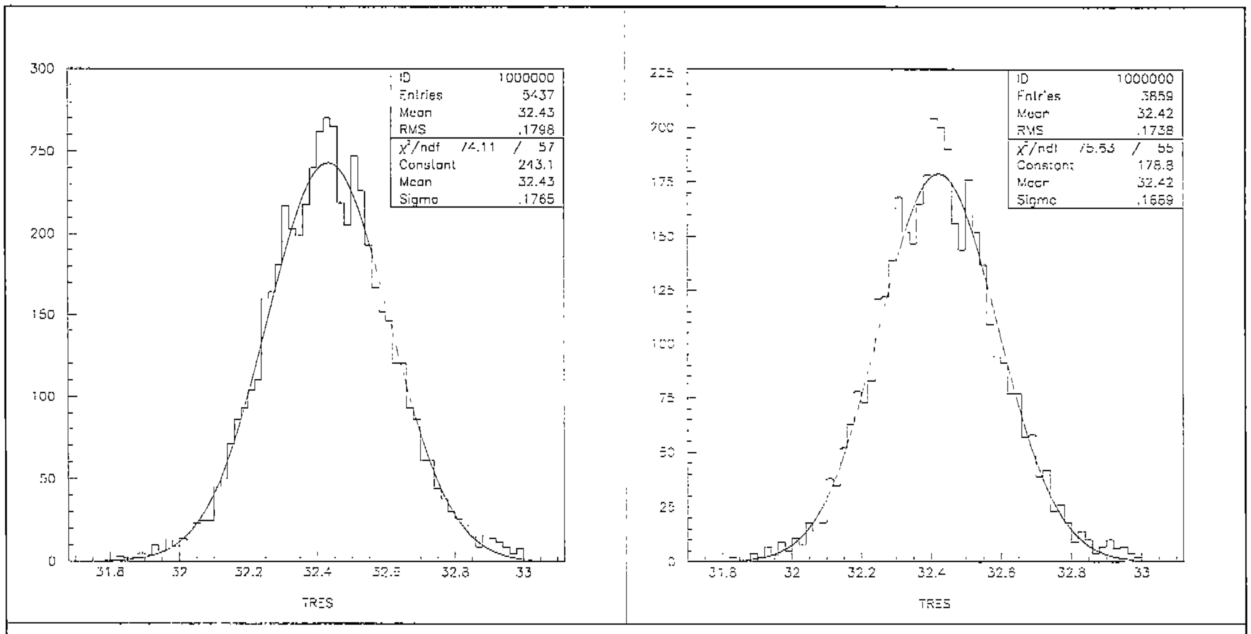


**Figure 6.:** Overall resolution for the left-to-right time difference cut on reference counter #2: a) the original data b) data with the standard cuts

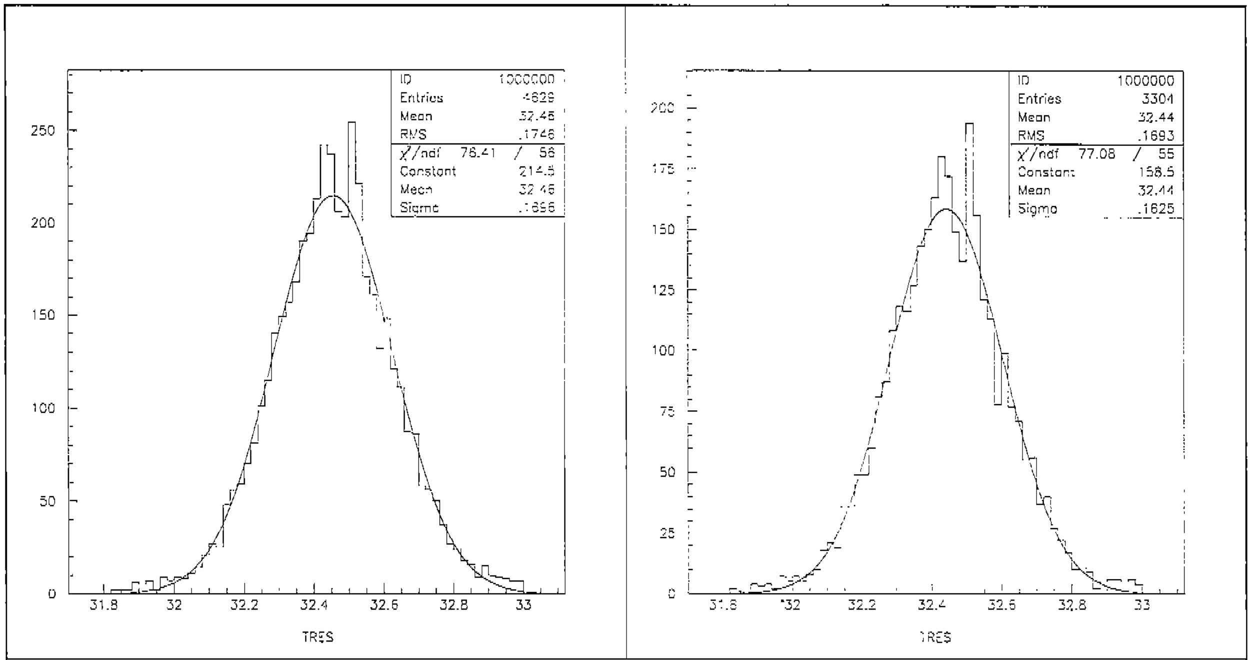


**Figure 7.:** Overall resolution for the SADC reference counter ratios cut: a) the original data b) data with the standard cuts

Figures 6, 7 and 8 compare the original data with the standard cuts when applying the reference counter cuts

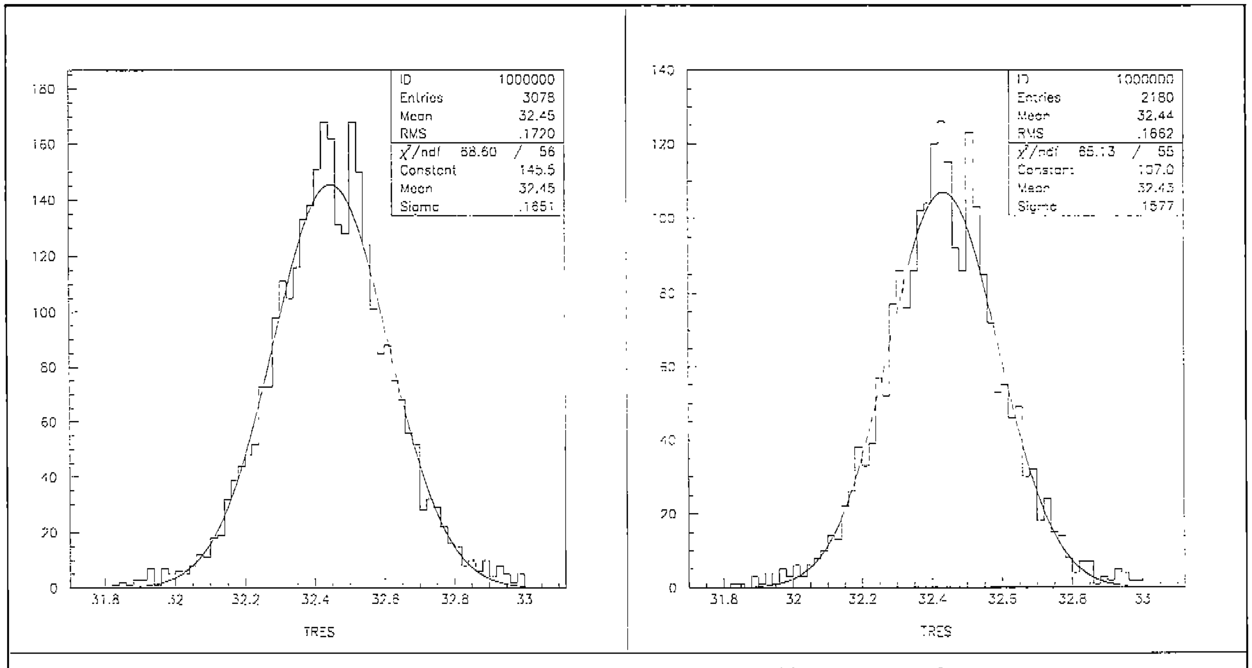


**Figure 8.:** SADC ratio and the left-to-right time difference reference counter cuts combined: a) the original data b) data with the standard cuts

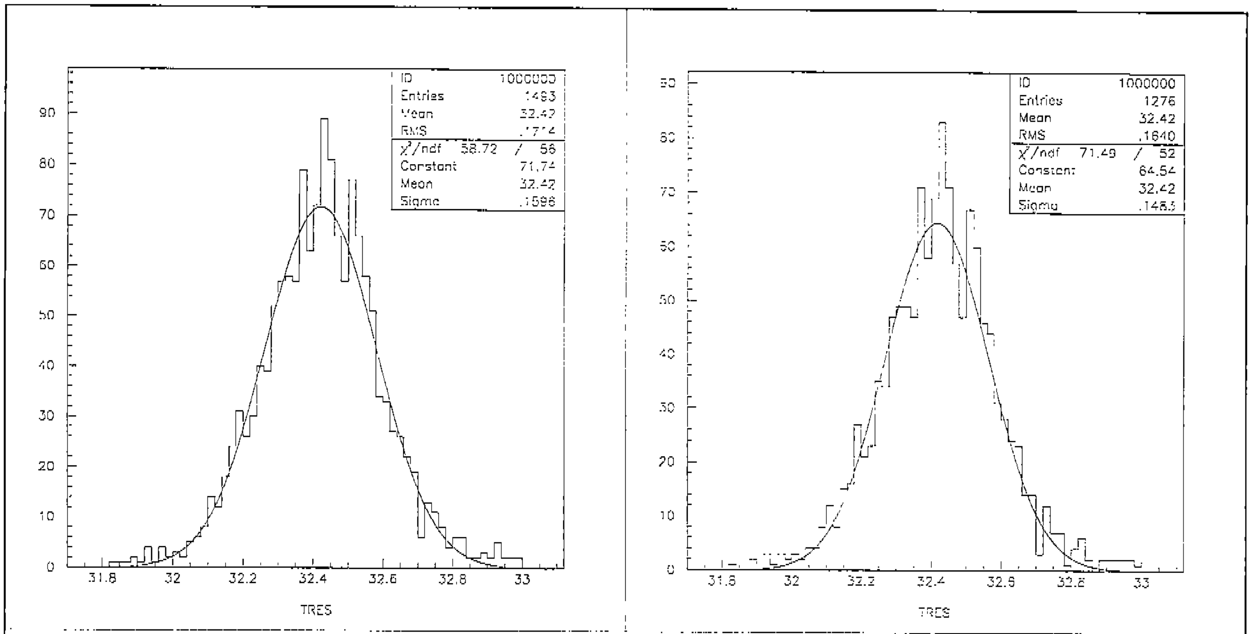


**Figure 9.:** Overall resolution for test counter SADC ratio cut between 20% and 80% with all of the reference counter cuts: a) the original data b) data with the standard cuts

Figures 9 and 10 show how the resolution changes when cuts are made on the percentage of the energy deposited in each of the test counters.

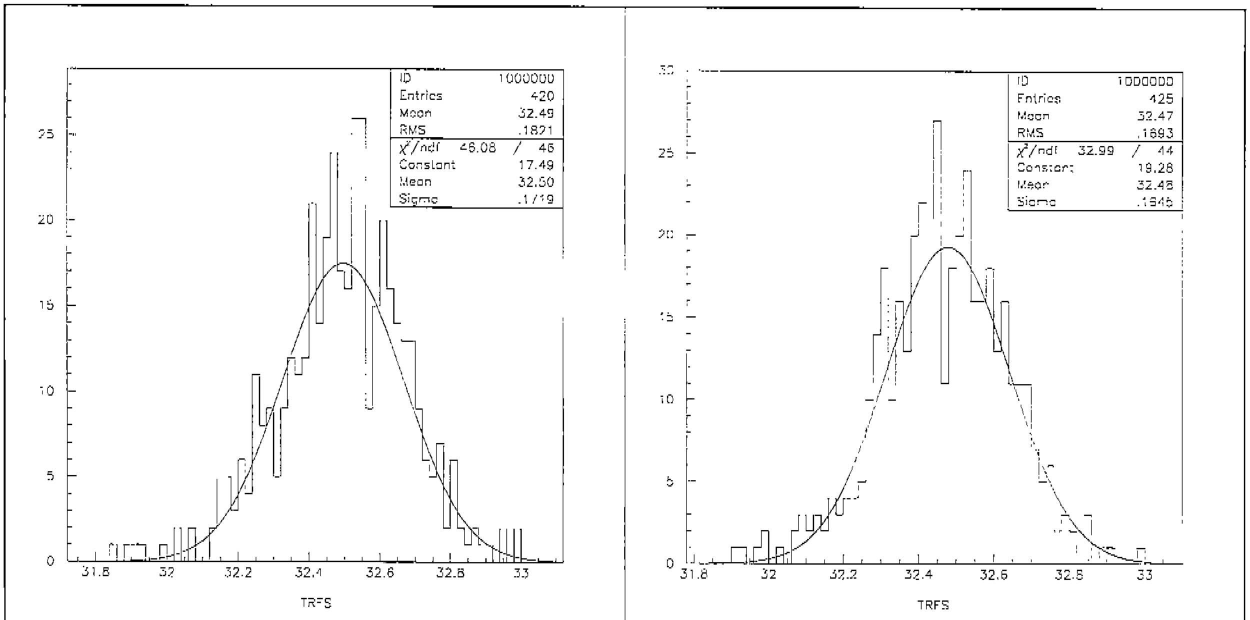


**Figure 10.:** Overall resolution for test counter SADC ratio cut greater than 90% for the original data with all of the reference counter cuts: a) test counter 18 b) test counter 19 (a and b refer to which test counter had more than 90% of the SADC total)

## 4.1 Sigma Calculation

The sigmas seen in the statistics section of the above plots have not yet been corrected for the reference counter resolution. In order to make this correction, the same cuts must be applied to both the plot of the difference of the average times on the reference counters and the plot of the overall resolution. We make this correction using the plots from Figures 4, 5a, 8a, 9a, and 10 and Equations 6, 7 & 8.

$$TDIF = TAV(4) - TAV(3) \tag{6}$$

$$TAVREF = \frac{(TAV(3) + TAV(4))}{2} \tag{7}$$

$$\sigma_{TEST} = \sqrt{\sigma_{OA}{}^{2} - \left(\frac{\sigma_{TDIF}}{2}\right)^{2}} \tag{8}$$

where $\sigma_{TDIF}$ is found in the statistics box on Figure 4 next to the word "Sigma," $\sigma_{OA}$ is the overall time resolution sigma found in Figure 5a, 8a, or 9a, and $\sigma_{TEST}$ is the final overall crossing track time resolution for the test counters. Since TAVREF is the value used for the overall resolution calculation in (2), we must divide $\sigma_{TDIF}$ by 2 in the calculation of $\sigma_{TEST}$. The resulting sigma ($\sigma_{TEST}$)of TRES from the original data for the full range of SADC and no reference counter cuts is 0.149 ns; when all reference counter cuts are imposed for the full range of SADC, the resolution is 0.147 ns; however, for this particular distribution with the standard cuts also imposed, the resolution becomes 0.141 ns. The sigma for SADC ratio between 20% and 80% with only the reference counter cuts is 0.141 ns; using the same cuts but with SADC ratio greater than 90% the sigmas are 0.155 ns and 0.147 ns for counters 18 and 19 respectively. The single counter resolutions from reference [1] for test counters 18 and 19 are 0.158 ns and 0.154 ns respectively before the reference counter corrections. Resolutions after those corrections are 0.142 ns and 0.136 ns respectively. The limiting case where one of the counters has at least 90% of the track passing through the pair gives an apparently larger resolution than when the track is more evenly shared between the two counters (20% to 80%); however, because of the small number of events, the uncertainties in the sigmas are about 0.01 ns, a factor of four larger than the uncertainties without the 90% cut.

# 5 CONCLUSIONS

The validity of Equation (2) for all crossing tracks is established, and its use yields a resolution of 0.147 ns for the counters that were tested. Thus, the design goal of 0.180 ns is achievable for crossing tracks, although the resolution is almost 10% higher than the resolution for non-crossing tracks.

# REFERENCES

[1] M. Guidal *et. al.*, "Laser & Cosmic-Ray Calibration of the CLAS TOF System," CLAS-NOTE-96-004, March 19, 1996.