Performance of the Belle TOF system 2000-2009

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(Dated: July 9, 2009)

Abstract

This note describes aspects of the performance of the TOF system for the past ten years. In particular, it investigates the degradation of the time resolutions and attenuation lengths and correlations between them. Both resolution and attenuation length have degraded at a slower rate since 2004. The correlation between the resolution and attenuation length for individual counters has a similar slope for data from 2002 and 2008; thus it seems that some effect in addition to degraded attenuation contributes to the resolution degradation. Other factors which affect the resolution are the location of counter readout on the TOFFEE board and the TOF hit rate.

PACS numbers:

I. INTRODUCTION

The Belle TOF system is described in [1]. The TOF system helps provide π/K separation for particle momentum below 1.2 GeV/c. Its performance in the first three years of Belle data is described in a previous Belle note.[2] This note updates that study using data through Spring 2009.

II. LONG-TERM VARIATION

Figure 1 shows the attenuation lengths versus calendar time for combined TOF counters (o symbols) and TSC counters (square symbols). The attenuation lengths are determined using the ADC values for TSC counters and the ratio of the forward to backward ADC values for TOF counters as a function of the hit position along the counter, as described in section II D of ref. [2]. These data are for high-momentum muons in dimuon events, which are also used for TOF calibration.

Figure 2 shows the TOF time resolution for all TOF counters combined as determined from calibration. The resolution values are determined from Gaussian fits to the weighted average times from the forward and backward PMTs. The calibration procedure is described in detail in ref. [2]. As noted in ref. [2], data for 2000-2003 show a nearly linear degradation in resolution of about 2.5 ps/year. The TOF attenuation length data also show a nearly linear degradation for this time period. Since about 2004 however, the degradation in both resolution and attenuation length has been much slower. The short-term increases in resolution (e.g. in early 2004, early 2007, and Spring 2009) are due to poor tracking as a result of changes to the CDC which had not been calibrated when the dimuon events were initially processed. The TOF resolutions returned to values consistent with the long-term trend after CDC calibration parameters were updated. Note that there is also one 2009 data point where the resolution is about 2 ps better; this is for data taken with low luminosity and TOF hit rate about 10 times smaller than usual. Some of the significant changes that might have affected the long-term behavior are the installation of new TOF preamps in Summer 2003, switch to a 128 MHz clock starting in Fall 2005, and increase in high voltages and lower thresholds starting in 2006. The 2003 and 2006 changes are responsible for the sudden changes in TOF ADC values in Figure 3.

III. STUDIES USING INDIVIDUAL COUNTERS

One can study the dependence of the resolution on attenuation length by looking at individual counters at a fixed time. For Spring 2002 data a linear fit to 125 counters (87, 103 and 122 were excluded because they had unusually poor resolutions) in ref. [2] gave the values on the first line in Table I. A fit to the intrinsic resolutions for the same counters gave the values on the second line. One can see by comparing the fit in Figure 4 with that in Figure 5 that the major difference is in the constant term. (This is reasonable because the total resolution values are large compared to the 40 ps systematic contribution subtracted from them to get the intrinsic values.) Therefore, the total resolution values are used for all other data in Table I.

Figure 6 compares the attenuation lengths for the exp. 19 and exp. 67 data, which were taken in late 2008. All counters have smaller attenuation lengths in exp. 67. Figure 7

TABLE I: fits to individual counters

exp.	slope (ps/cm)	constant (ps)	counters
19	-.082	120.2	125
19	-.089	113.6	125 *intrinsic*
19	-.081	120.0	123
67	-.101	129.1	120
67	-.153	140.6	123

TABLE II: resolution and attenuation lengths

quantity	2000.5	2002.1	2004.2	2006.1	2008.96
atten. length (cm)	271	242	214	204	199
total resolution (ps)	97	100	106	107	111
intrinsic resol. (ps)	88.4	91.7	98.2	99.2	103.5
predicted total resol. (ps)	98.0	100.4	102.7	103.5	103.9
predicted intr. resol. (ps)	89.5	92.1	94.6	95.4	95.9

compares the total time resolutions. Only a few counters have better resolutions in exp. 67.

Least-squares fits similar to those done for exp. 19 were done on exp. 67 runs 1002-1123. Two counters (32 and 109) were excluded because the forward PMTs are dead. Fits to the remaining 123 counters for exp. 67 and exp. 19 are summarized in Table I. The fitted parameters are much different for exp. 67 but this is largely due to three counters (65, 66 and 116) which now have resolutions above 160 ps because of a bad PMT at one end. Excluding these counters and refitting with 120 counters gives a slope value similar to that for exp. 19 but a different constant term. (Compare Figure 8 and Figure 9.)

From these results it seems that the slope of the correlation of resolution versus attenuation length is similar for exps. 19 and 67; the major difference is a shift of about 9 ps in the constant term. This could indicate that some other effect (e.g. PMT aging, readout systematics) is responsible for some of the degradation in resolution.

IV. STUDIES USING ALL COUNTERS COMBINED

Table II contains values of the TOF resolution and mean attenuation length for all counters combined in mid-2000, early 2002, early 2004, early 2006, and late 2008. The intrinsic resolution values are obtained by subtracting in quadrature 40 ps from the total resolution values.

These values are plotted in Figure 10. The total resolution values are plotted with o symbols and the intrinsic resolution values are plotted with X symbols. The predicted intrinsic values plotted with * symbols use the form

$$intr.resol. = 113.6ps - (.089ps/cm) * L \quad (1)$$

TABLE III: resolution in ps versus readout location

data	exp. 19	exp. 27	exp. 37	exp. 67	exp. 69
runs	all	1329-1632	659-1376	1002-1123	500-819
counters					
1,5,...	99.36	98.97	103.51	107.29	107.94
2,6,...	99.35	98.53	104.47	109.58	111.01
3,7,...	102.92	101.97	106.57	110.22	111.60
4,8,...	102.62	101.65	107.08	112.18	113.05

where L is the attenuation length and the parameters were determined from the fit to 125 exp. 19 individual counters. The line in Figure 10 is a linear fit to the X symbols, which has the form 141.5 ps - (.200 ps/cm)*L. This form clearly has a different dependence than a straight line drawn through the predicted intrinsic values. This observed different dependence is consistent with a contribution of some other effect to the resolution degradation.

V. OTHER FACTORS AFFECTING TIME RESOLUTION

Table III contains time resolutions in groups of counters modulo 4. The errors on the resolution values range from 0.11 ps to 0.17 ps. To be more sensitive to possible differences due to the location of the counter readout, counters with one dead PMT (32 and 109) or very poor resolution due to low gain (65, 66, 103, 116, and 122) were excluded. Initially, we investigated groups of counters modulo 8 because there are 8 counters per TOFFEE board but the differences observed seemed to have a periodicity of 4. The resolutions of each group of counters have degraded comparable amounts during the 7-year time span covered by the data in Table III but significant differences remain among the groups. This suggests that some electronic effect (e.g. clock fan-out/routing or cross-talk) on the TOFFEE board influences time resolution.

Another effect was noticed for data taken in Spring 2009. During two KEKB tests with low bunch numbers (exp. 69 runs 795-819 and 1235-1281) the TOF resolution improved by about 2 ps compared to nearby runs with normal luminosity values. (Runs 1235-1281 were used separately for a TOF calibration and account for the data point with improved resolution in Figure 2. Runs 795-819 were combined with normal runs with many more events so they did not produce a noticeable effect on the resolution.) The TOF hit rates for these runs were typically 10-15 kHz compared to the usual values near 100 kHz. The average PMT ADC values for these runs were about 3% lower than the usual values which may indicate that previous counter hits affect both ADC and resolution values at higher TOF hit rates.

VI. TOF HIT INEFFICIENCY

Figure 11 shows values of TOF hit inefficiency versus online TOF hit rate. The hit inefficiency is the fraction of muons predicted to hit a TOF counter for which neither PMT

has a recorded hit. Typical TOF hit rates were about 100 kHz for recent data but there were some low luminosity runs in exps. 67 and 69 with rates less than 20 kHz. These data and some from exps. 55 and 61 are plotted with o symbols. A timing change after Summer 2006 led to an increase of slightly less than 0.01 in the inefficiency values due to events outside the default time windows used for initial processing. We have verified that such events can be recovered by widening the time windows from the previous default width of 350 counts (175 ns) to 550 counts. The inefficiency values with these wider windows are reduced by about 0.007.

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[1] H. Kichimi *et al.* Nucl. Instr. and Meth. **A453** (2000) 315.

[2] M. Jones *et al.* (Belle Note 596)

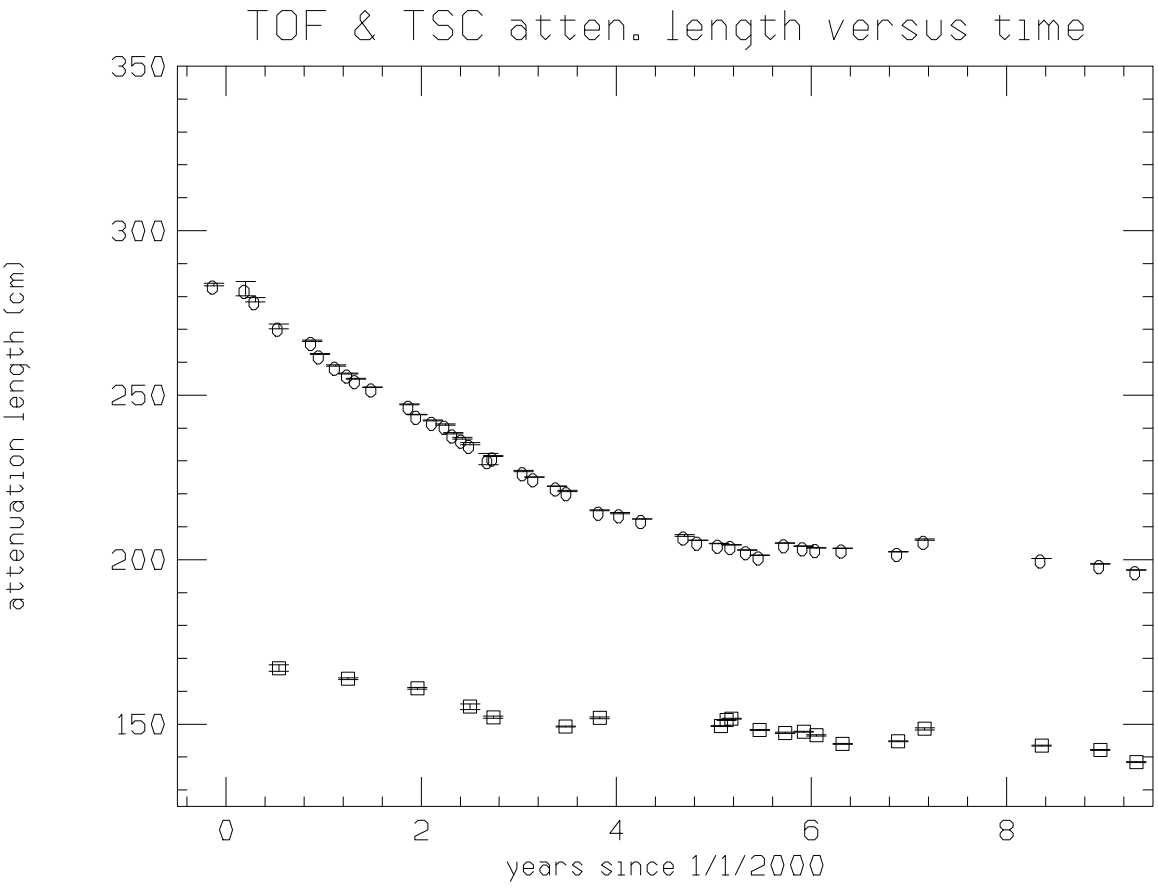

FIG. 1: Attenuation length versus calendar year. The o symbols are for all TOF counters combined and the square symbols are for all TSC counters combined.

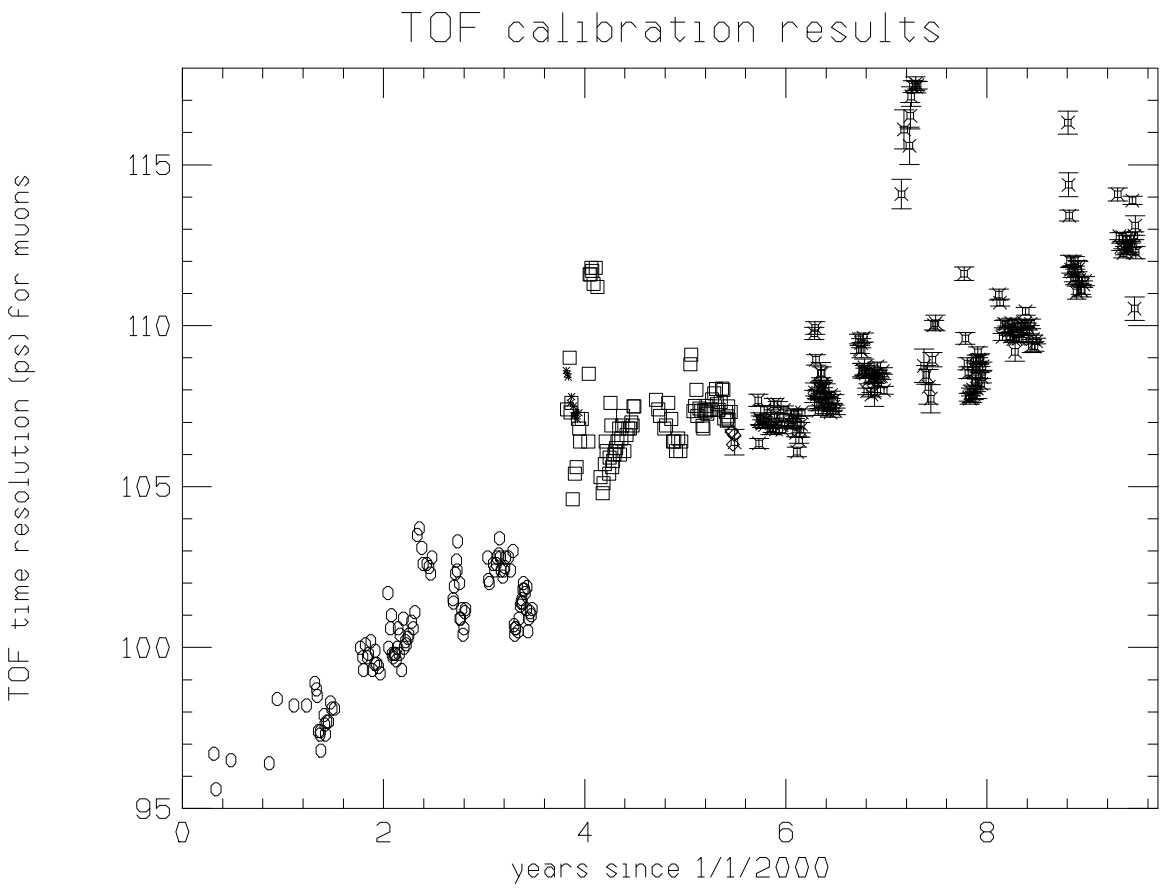

FIG. 2: TOF total time resolution versus calendar year. The resolution is for all TOF counters combined and is based upon calibration using dimuon events. The different symbols denote major changes that might affect TOF performance. New TOF preamps were installed in Summer 2003, a 128 MHz clock was used starting in Fall 2005, and there was an increase in high voltages and lower thresholds starting in 2006. The point with improved resolution in 2009 is for data taken with a much lower than usual TOF hit rate.

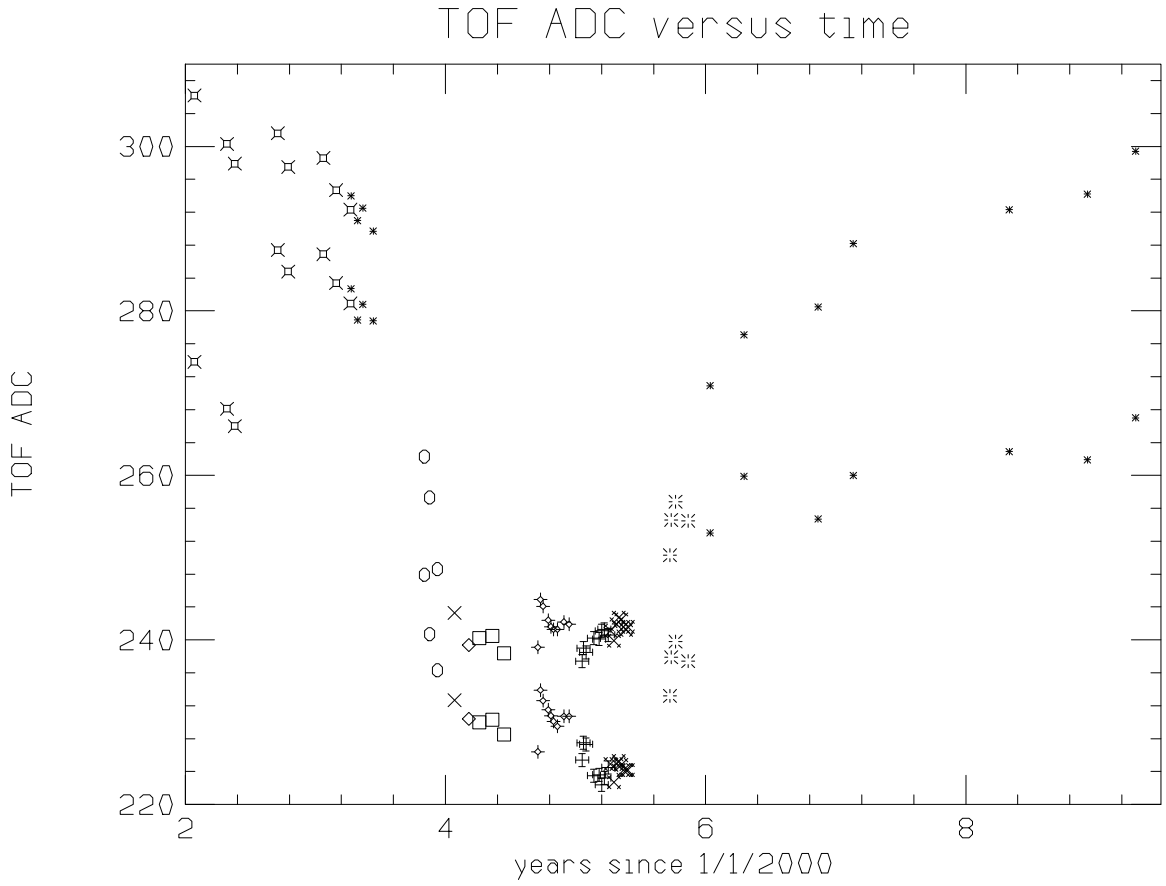

FIG. 3: Mean ADC values for forward TOF PMTs (upper) and backward TOF PMTs (lower data points) versus calendar year. The mean ADC values are for all TOF PMTs combined based upon dimuon events used for calibration. Different symbols for data before 2006 correspond to different experiment numbers. The major change in Summer 2003 is due to installation of new TOF preamps. The major change in 2006 is due to the increase in high voltages and lower thresholds.

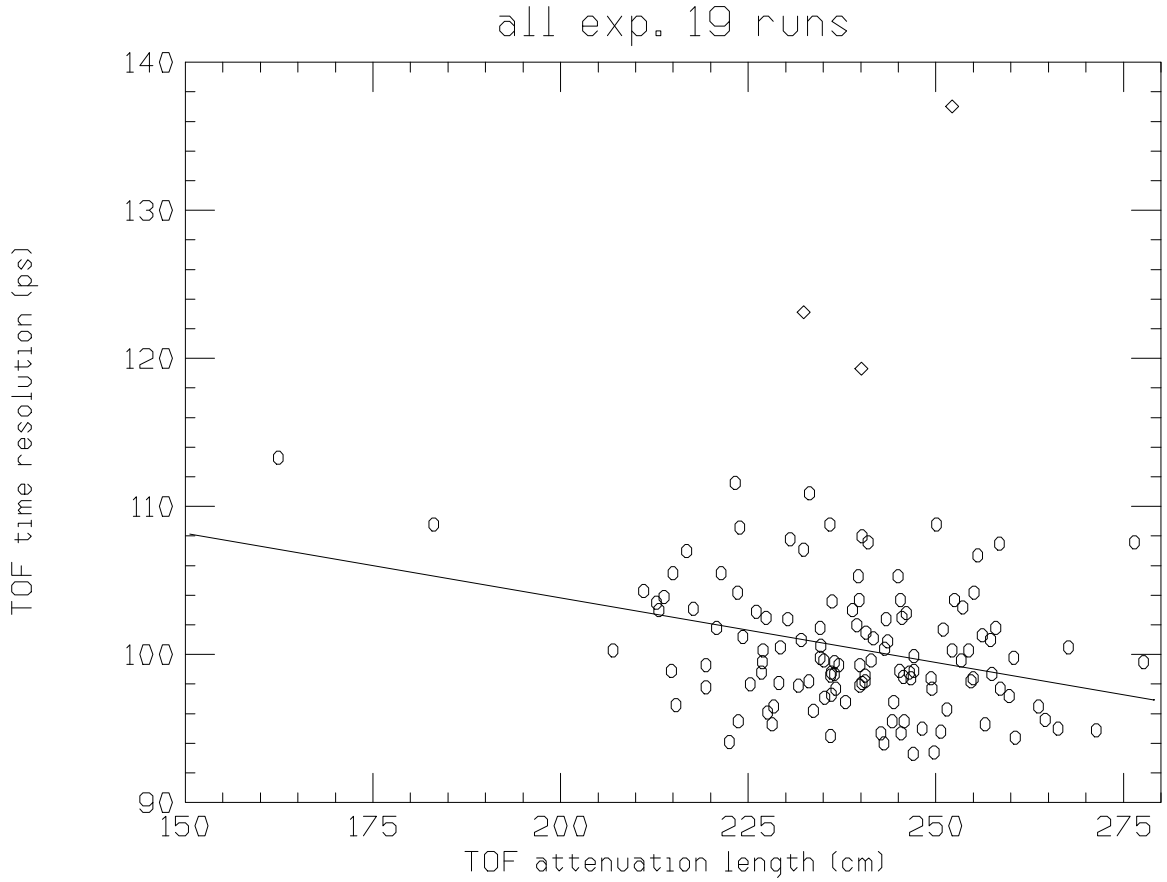

FIG. 4: TOF total resolution versus attenuation length for individual TOF counters using exp. 19 data (Spring 2002) from Belle note 596. The line represents a least-squares fit to 125 counters. (Counters 87, 103 and 122 were excluded because they had unusually poor resolutions. They are plotted with diamond symbols.)

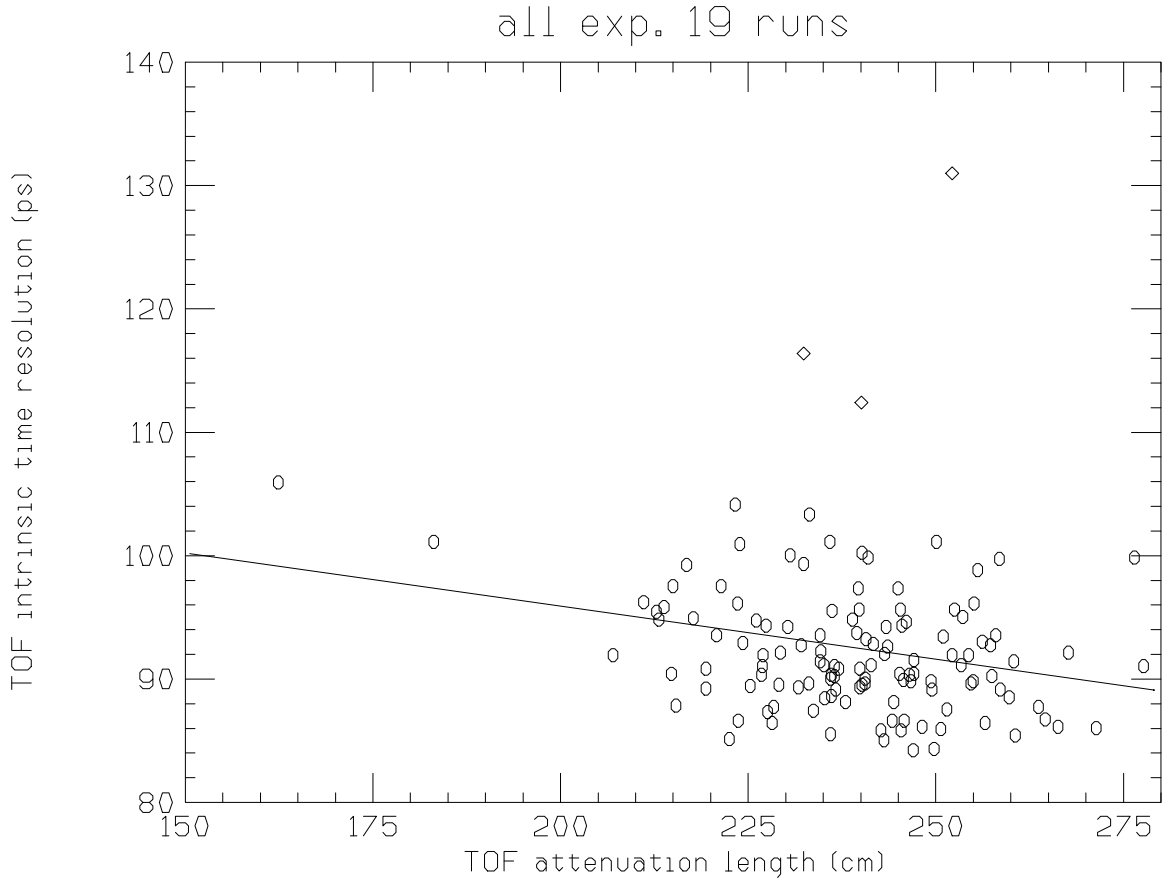

FIG. 5: TOF intrinsic time resolution versus attenuation length for individual TOF counters using exp. 19 data (Spring 2002). The intrinsic resolution values are obtained from the total resolutions by subtracting in quadrature a 40 ps systematic contribution. The line represents a least-squares fit to the same 125 counters used for the fit to the total resolutions.

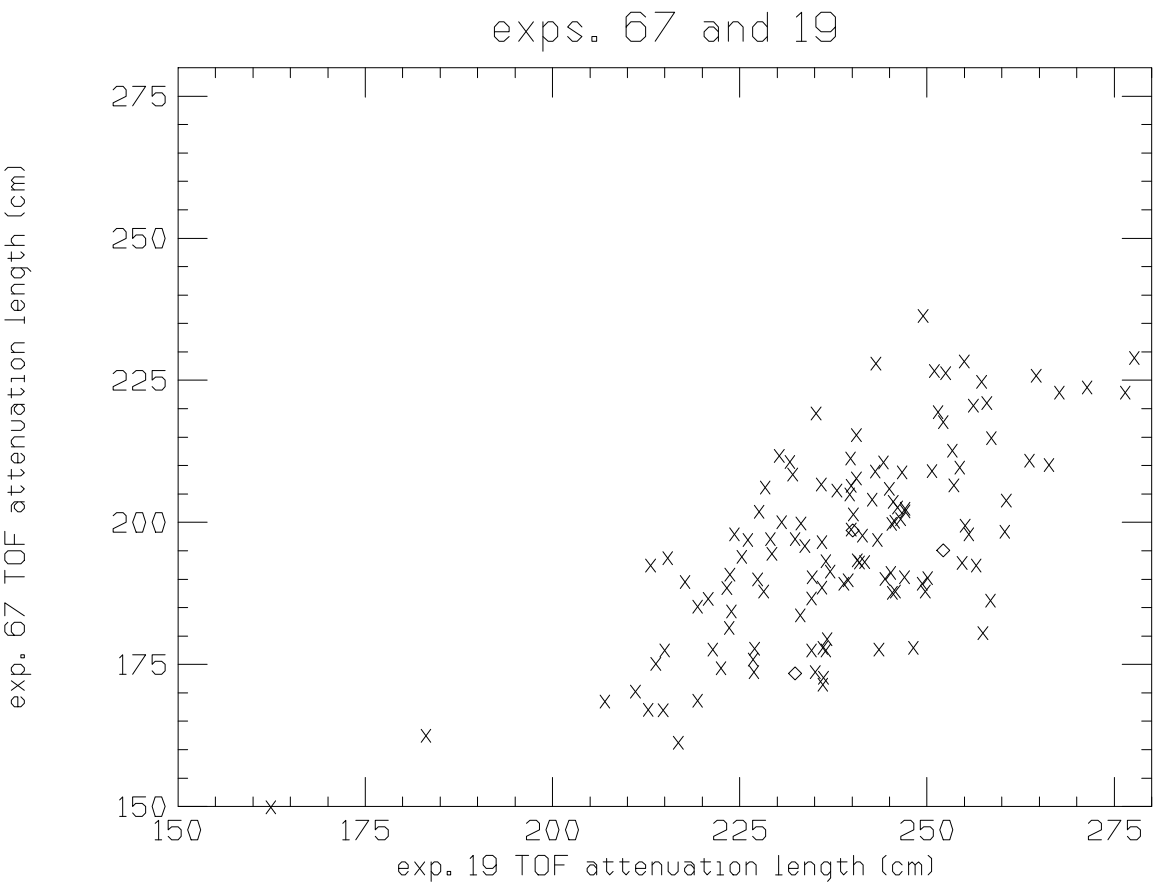

FIG. 6: Attenuation length for exp. 67 versus that for exp. 19 for 126 TOF counters. Counters 32 and 109 were excluded because their forward PMTs are dead in exp. 67.

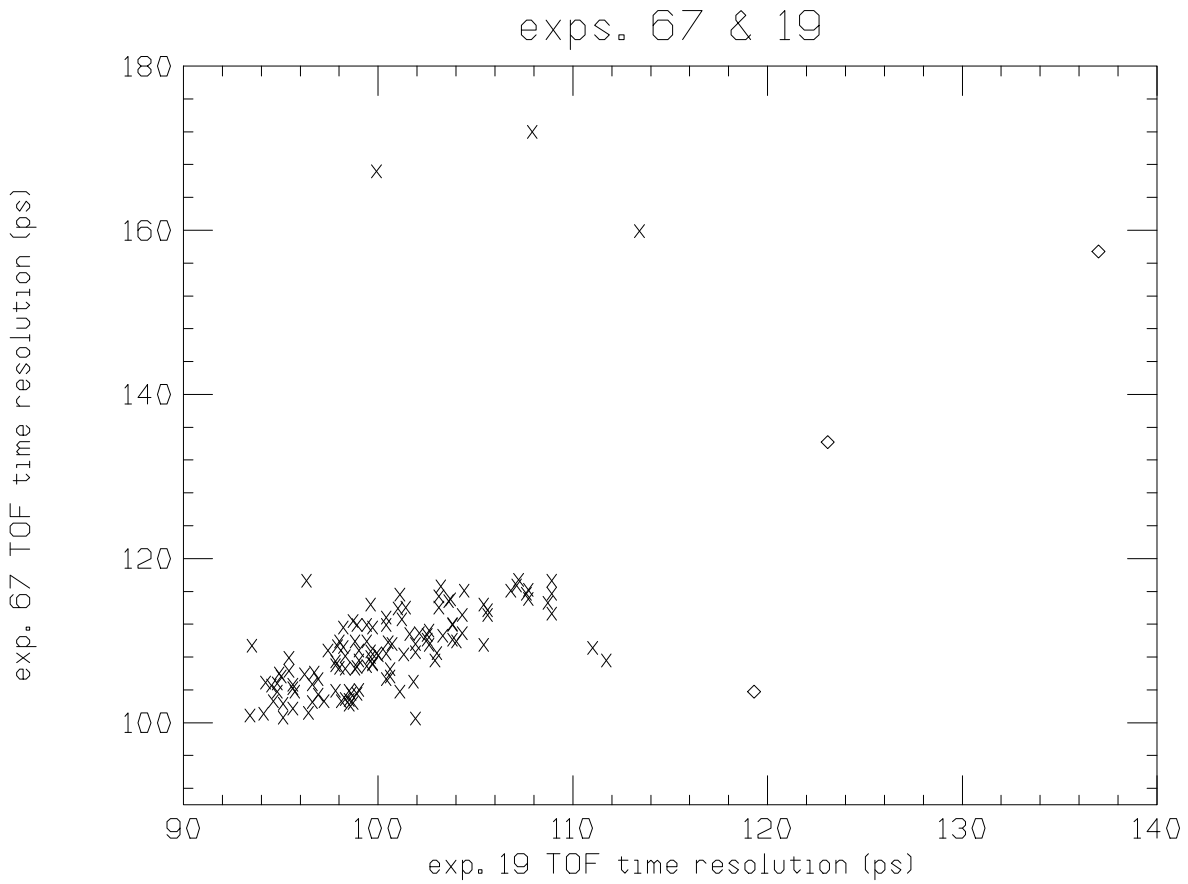

FIG. 7: TOF total time resolution for exp. 67 versus that for exp. 19 for 126 TOF counters. Counters 32 and 109 were excluded because their forward PMTs are dead in exp. 67. The diamond symbols are for counters 87, 103, and 122 which had poor resolution in exp. 19.

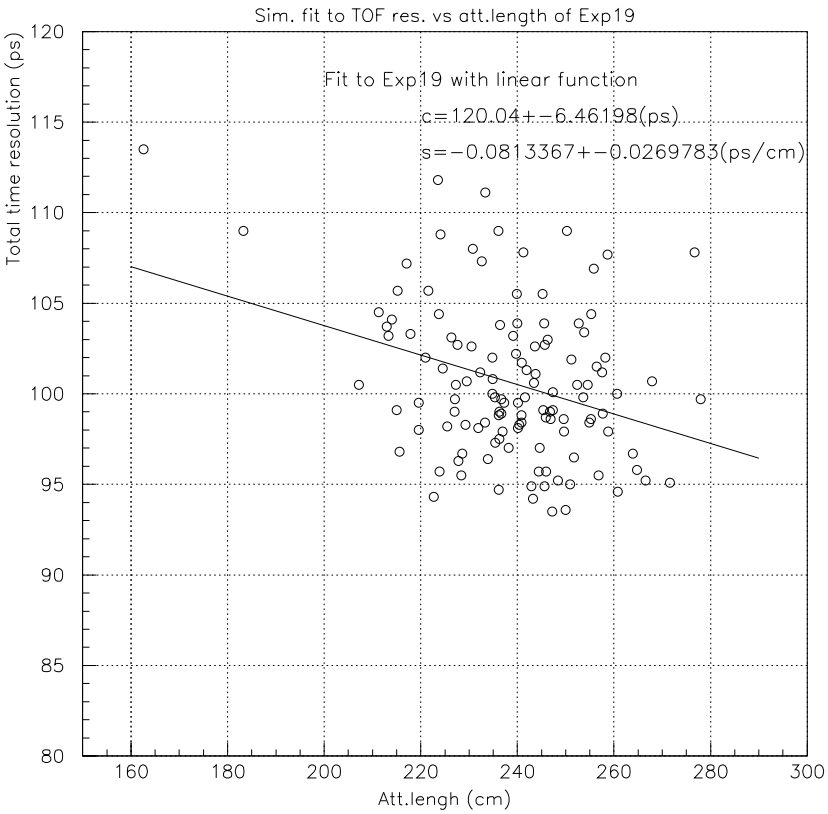

FIG. 8: TOF total resolution versus attenuation length for 123 individual TOF counters using exp. 19 data. Counters 32 and 109 were excluded from the least-squares fit to allow comparison with later data for which the forward PMTs on these counters were dead.

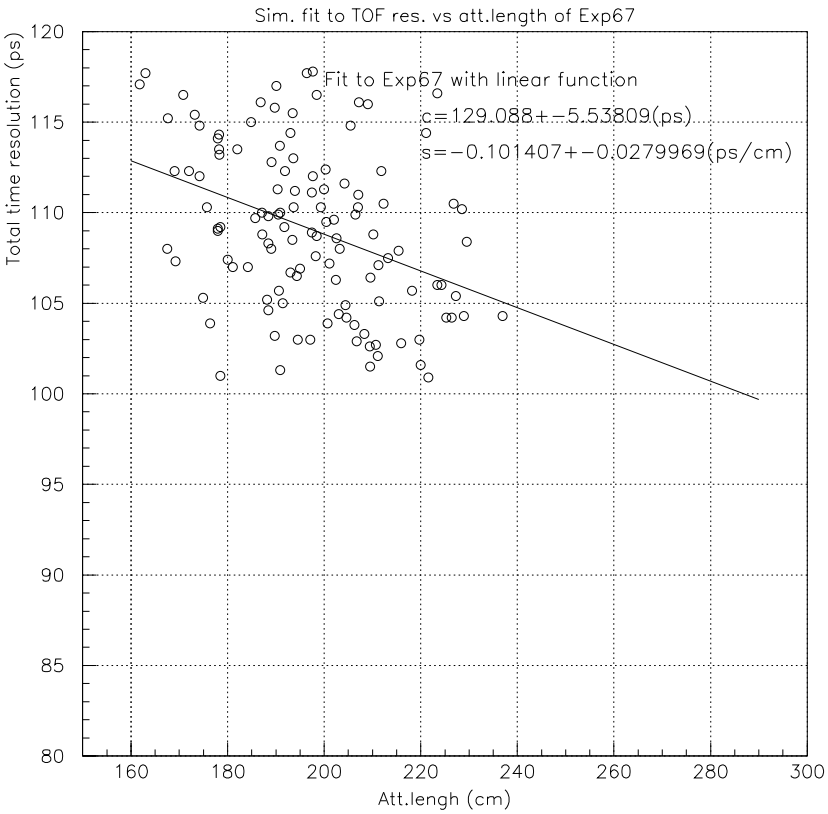

FIG. 9: TOF total resolution versus attenuation length for 120 individual TOF counters using exp. 67 data (Dec. 2008). Counters 65, 66, and 116 were excluded from the least-squares fit because one PMT has very poor resolution resulting in a combined resolution above 160 ps for the counter.

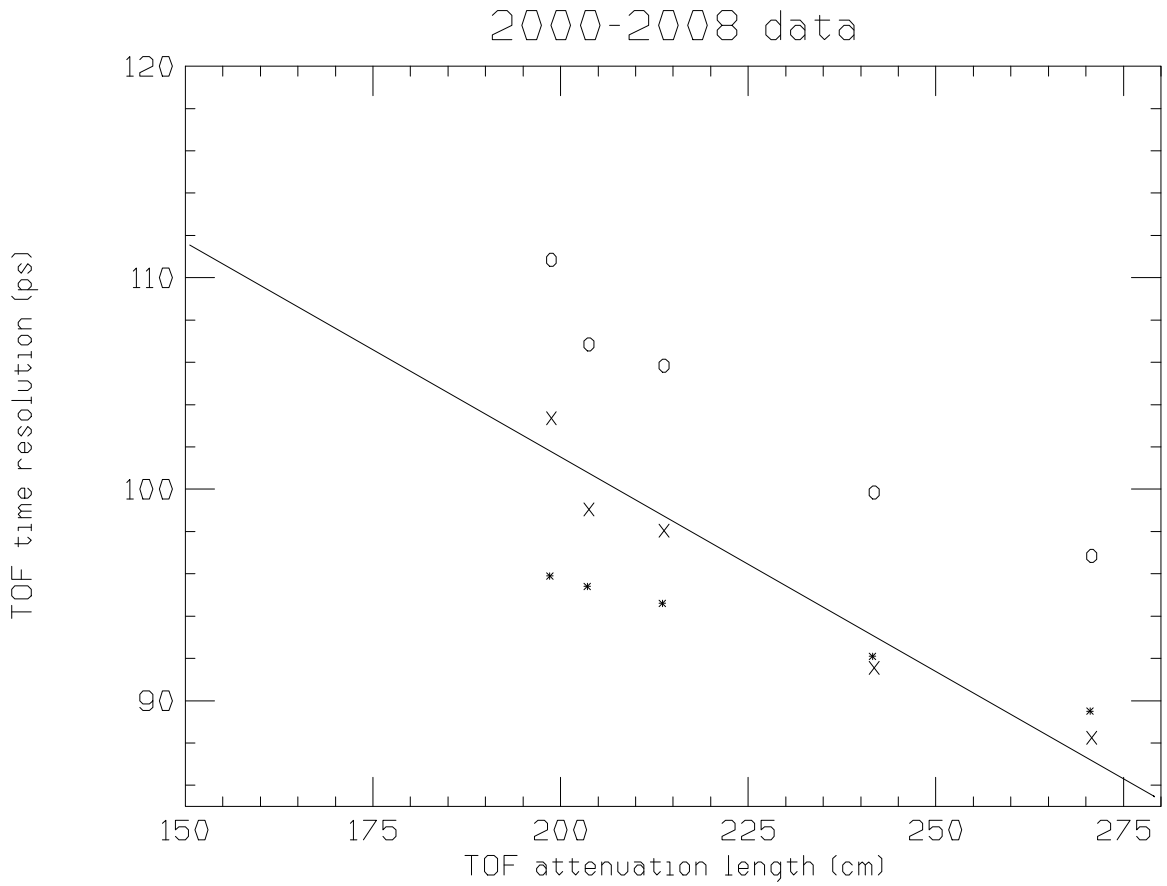

FIG. 10: TOF resolution versus attenuation length for all TOF counters combined at five different times – mid-2000, early 2002, early 2004, early 2006, and late 2008. The total resolution values are plotted with o symbols, intrinsic resolutions with X symbols, and predicted intrinsic resolutions with * symbols. The predicted intrinsic resolutions are derived from the least-squares fit to the exp. 19 data. The line is a result of a least-squares fit to the observed intrinsic resolutions (X symbols).

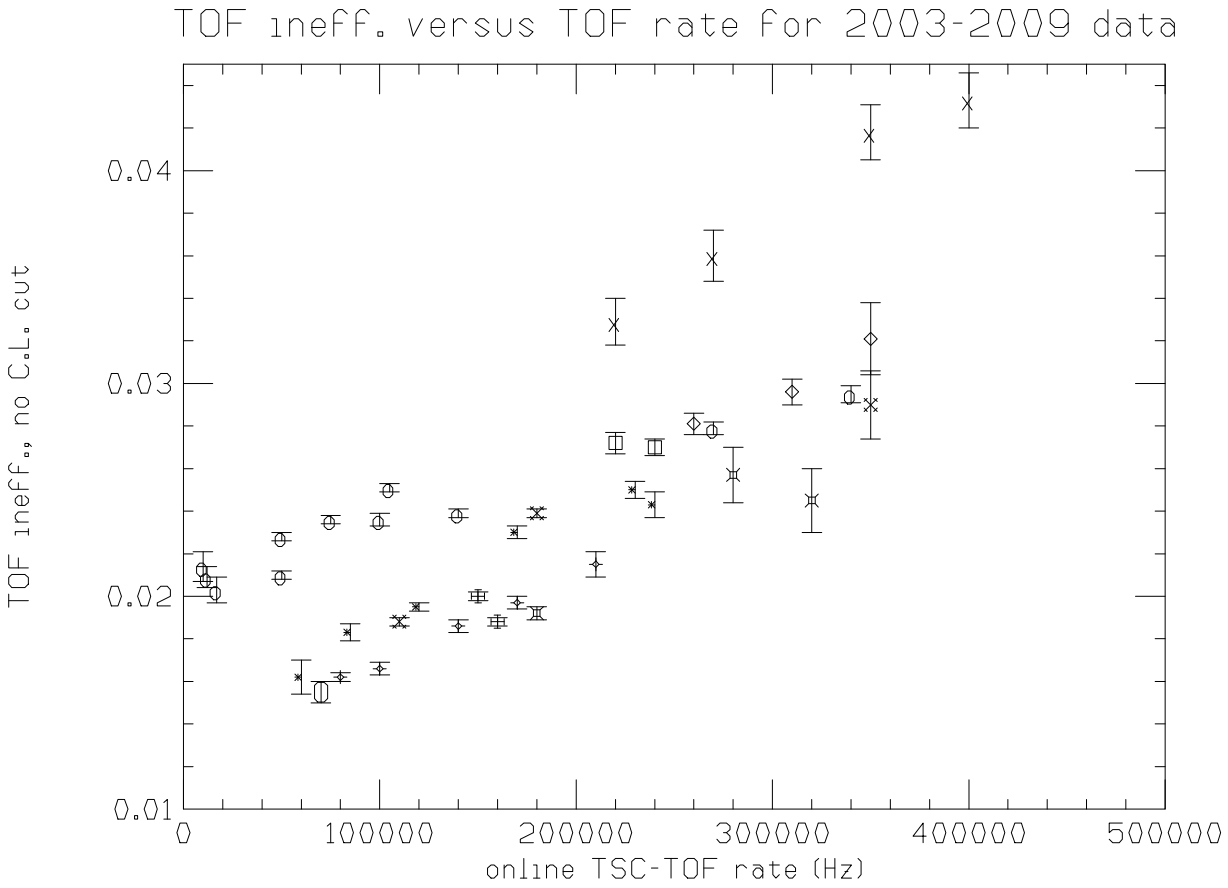

FIG. 11: TOF hit inefficiency versus TOF hit rate. Data since Summer 2006 (exps. 55, 61, 67 and 69) are plotted with o symbols, previous data are plotted with other symbols. A timing change after Summer 2006 led to an increase of slightly less than .01 in the inefficiency values due to events outside the default time windows used for initial processing.