Belle Timing Studies Using the TOF System

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Abstract

This note summarizes studies using recent Belle data of correlations in timing between muons in dimuon events and related event timing issues. These are relevant to estimate the event T0 jitter for the current Belle data and to identify sources that will need to be controlled for improved timing performance with Belle II.

PACS numbers:

TABLE I: time resolutions in ps before and after corrections. Typical uncertainties are .12 ps for exp. 65 and .20 for exp. 71.

exp.	initial	bunch corr. only	muon correlation and bunch corr.
65	112.10	111.97	111.94 *bunch>600*
71	116.07	115.99	115.49 *bunch>3200*
71	115.77	115.75	115.66 *bunch<2900*

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 Belle note 596.[2] An updated study using data through Spring 2009 is in Belle note 9999.[3]. A detailed study of timing including KEKB and TOF data is in [4].

Most previous timing studies and TOF calibrations using muons have relied on data for single tracks. To examine correlations in timing between muons in dimuon events and related event timing issues required new ntuple files for which muon-related quantities (measured TOF time, predicted time, zhit, TOF counter, and TSC counter) are included in the event ntuple along with event T0, bunch number, numbers of muons predicted to hit the TOF, and numbers with matching TOF hits.

Results presented below use data primarily from exp. 71 and exp. 65. These data were taken using crab cavities but data from exp. 55 (without crab cavities) show similar characteristics.

II. BUNCH DEPENDENCE

Previous observations (See Fig. 6 in [4].) that muon dT values (measured minus predicted time) have a linear bunch dependence and vary about 20 ps over the 5120 buckets in the beam train are confirmed in data from exps. 71 and 65. One can make a linear fit and thus remove this dependence; this makes a very small improvement in the overall time resolution because the bunch variation is small compared to the typical resolution of 115 ps in exp. 71.

III. CORRELATION BETWEEN MUONS AND OVERALL TIME JITTER

Using events in which both muons have matching TOF hits, plotting dT for one muon versus dT for the other muon (after having removed the bunch dependence in each dT value) reveals a small correlation with a slope of 0.0227 +- 0.0013. Figure 1 shows the exp. 65 data. Making a linear fit and removing this correlation also makes a very small improvement in time resolution, as can be seen in the Table I.

(The beam abort gap for exp. 65 is 320<bunch<600 and that for exp. 71 is 2900<bunch<3200.) The effect of both the bunch-dependent and muon correlation corrections is equivalent to 6-10 ps in quadrature removed from the initial resolution of the

TABLE II: mean time and resolution in ps for event times modulo 8 ns

mod(T0/1.9651,4)	mean dT	resolution
0	-.02 +- .63	91.41 +- .52
1	-.94 +- .62	93.65 +- .51
2	-8.80 +- .65	93.17 +- .55
3	-14.97 +- .66	92.70 +- .53

uncorrected dT values. This is perhaps a useful measure of overall time jitter.

IV. EVEN/ODD DIFFERENCES IN BUNCH DEPENDENCE

There are several curious and possibly relevant differences between events with even and odd values of bunch/8. The bunch values calculated by Uehara-san's code are always a multiple of 8 so it seems that this value determines the bucket number to within 16 ns. Differences are obvious both for events in which both muons have matching hits (about 85% of total) and for events in which only one muon has matching hits. These latter events have the backward muon hitting the TOF at zhit<-45 cm and the forward muon missing because its angle with respect to the beam is too small.

A. events in which both muons have matching hits

For these events there are about 40% more with even bunch/8 values, as can be seen in Figure 2. The event T0 distribution for odd bunch/8 values (dashed histogram) cuts off abruptly near T0=-8 ns; the additional events with even values (solid histogram) are mostly at T0>-8 ns. These additional events have mean dT values shifted by about -6 ps and worse resolution than those with T0<0 resulting in better resolution for muons in events with odd bunch/8 values than those with even values. This is plausible if the events with T0>-8 ns are triggered by non-TOF triggers.

B. events where one muon has matching TOF hits

These events are almost entirely due to non-TOF triggers – 98% have even bunch/8 values and event T0 values mostly in the range -8 to 90 ns. The T0 distribution is shown in Figure 3. If the non-TOF triggers were generated by a 32 ns clock, it would explain why nearly all these events have even bunch/8 values, as do nearly all events with T0>-8 ns for which both muons have matching hits. Events with T0>0 have another curious feature. The mean dT values vary with a periodicity of 8 ns, as can be seen in Table II and in Figure 4. The differences in mean values are sizable but these are a small fraction of all dimuon events and have better resolution than most events (because the muons hit near the backward PMT) so they have a small effect on overall time resolution.

TABLE III: mean time and resolution in ps

muon	mean dT	resolution
1st	.26 +- .16	109.70 +- .13
2nd	.53 +- .16	111.23 +- .13

TABLE IV: mean time and resolution in ps. Typical uncertainties are .30 ps for the means and .25 ps for the resolutions.

TOF mod 4	mean dT	resolution
0	-.40	107.50 *1st muon*
1	.07	108.54
2	.64	110.32
3	.79	112.43
0	-.53	109.64 *2nd muon*
1	1.17	111.00
2	.42	111.35
3	1.04	112.61

V. TOF COUNTER DEPENDENCE

Using exp. 65 events in which both muons have matching hits, one can see differences in time resolution between the 1st and 2nd muon in the ntuple file. The track with larger transverse momentum is usually 1st. About 45% of 1st muons have -50<zhit<50 cm compared to 55% of 2nd muons. This zhit range has poorer resolution than that for 50<zhit<175 cm thus resulting in poorer overall resolution for the 2nd muon. Another difference is that the 2nd muon has hits concentrated in TOF counters 32-96 whereas the 1st muon has hits concentrated on the other side of the detector. The means and sigmas are given in Table III for events with -40<T0<-8 ns. The overall 1st-2nd muon resolution difference is equivalent to 18 ps in quadrature.

Table IV contains values for groups of TOF counters modulo 4, for which substantial resolution differences were seen in previous studies of data starting with exp. 19.[3] The resolution differences between the the groups with TOF counter mod 4 of 0 and 3 are equivalent to 33 ps in quadrature for the 1st muon and 26 ps for the 2nd muon respectively. If these differences are due to position-dependent timing on the TOFFEE board, they are not directly relevant to Belle II. However, similar timing systematics between TOP PMTs would need to be checked as well as possible trigger-dependent differences.

[1] H. Kichimi *et al.* Nucl. Instr. and Meth. **A453** (2000) 315.
[2] M. Jones *et al.* (Belle Note 596)

[3] M. Jones *et al.* (Belle Note ????)
[4] H. Kichimi *et al.* (JINST-006P-0110)

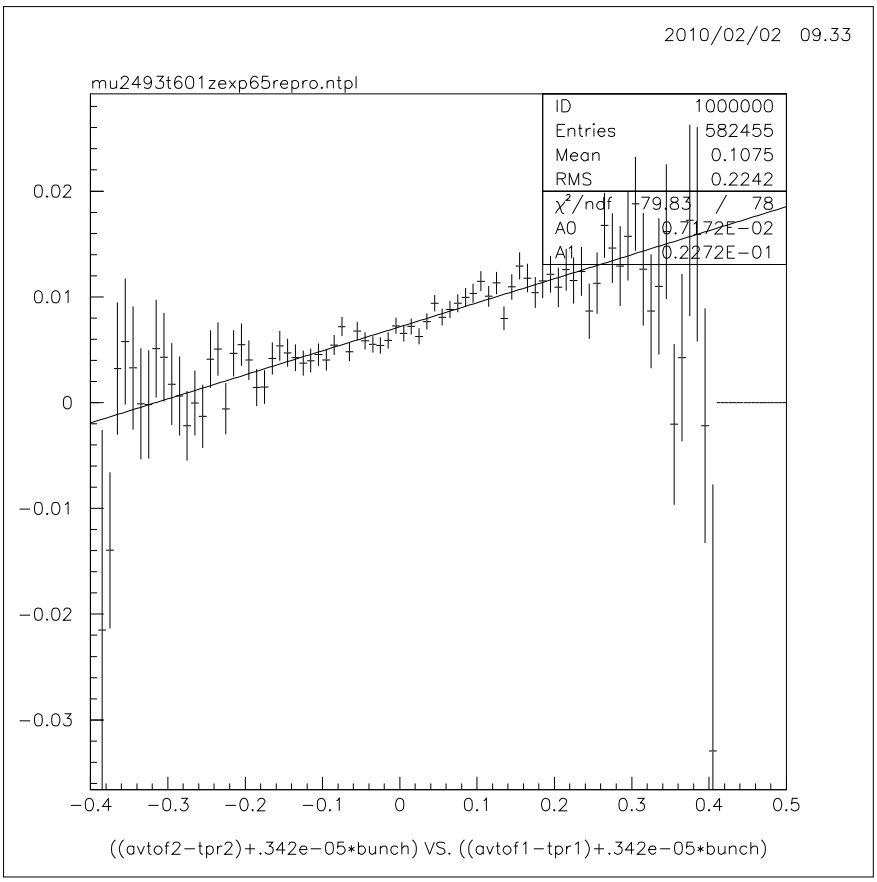

FIG. 1: dT in ns for 2nd muon versus that for 1st muon. Both dT values have been corrected for the bunch dependence.

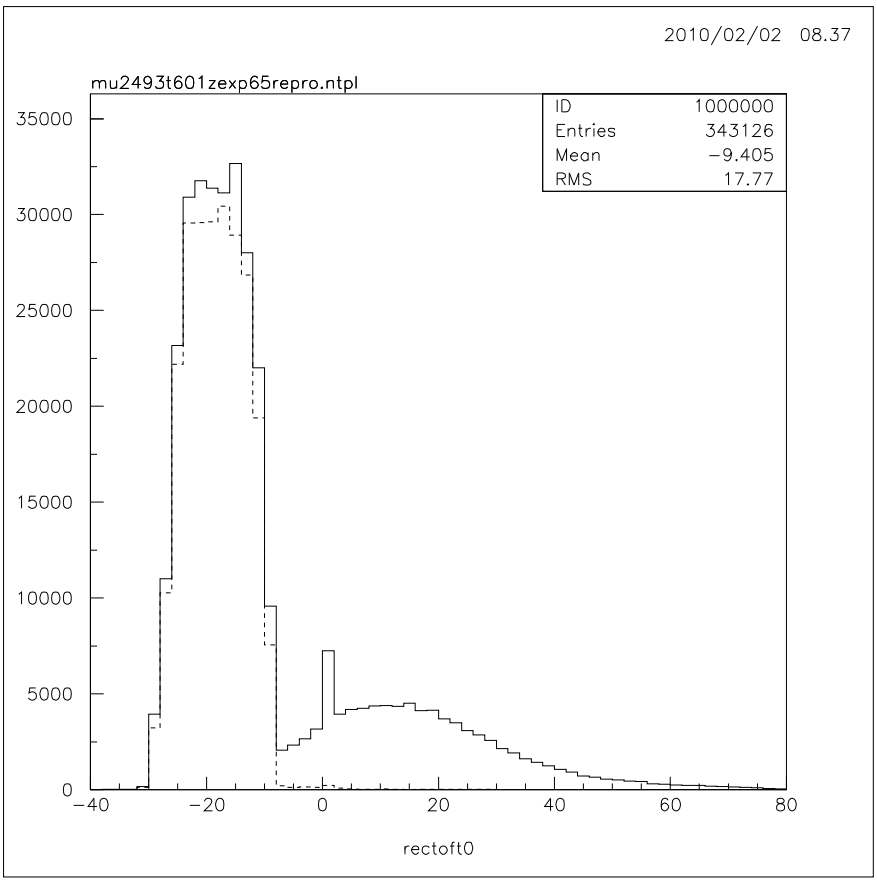

FIG. 2: Event T0 in ns for events in which both muons have matching TOF hits. Events with even bunch/8 values are the solid histogram; those with odd values are the dashed histogram.

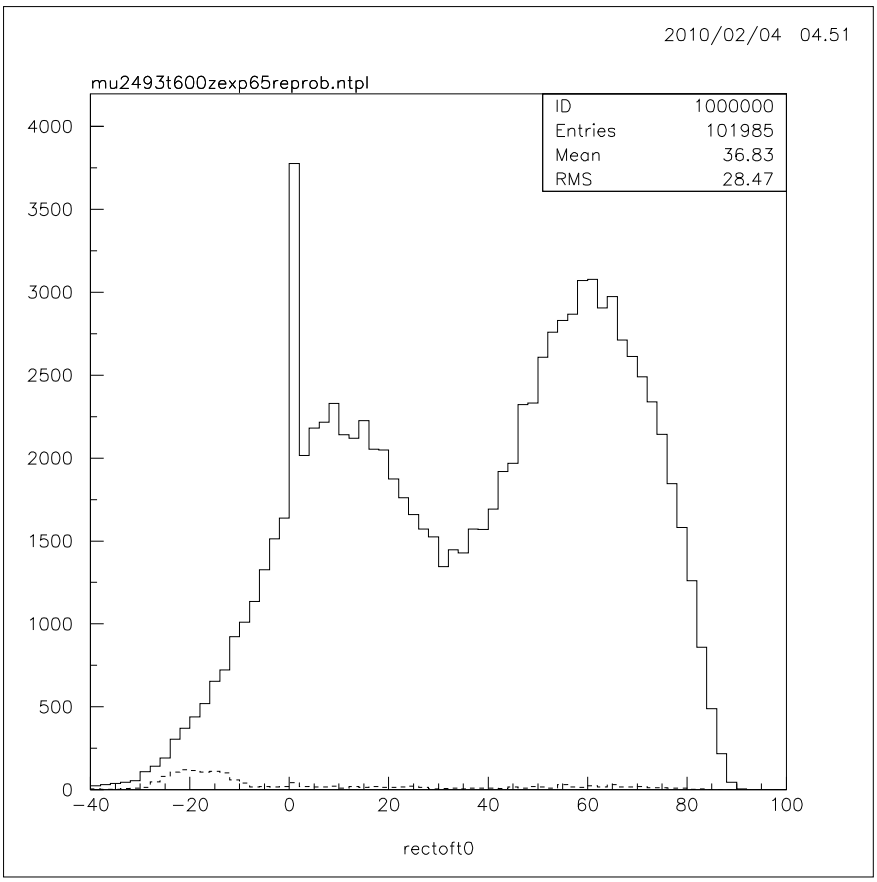

FIG. 3: Event T0 in ns for events in which only one muon has matching TOF hits. Events with even bunch/8 values are the solid histogram; those with odd values are the dashed histogram.

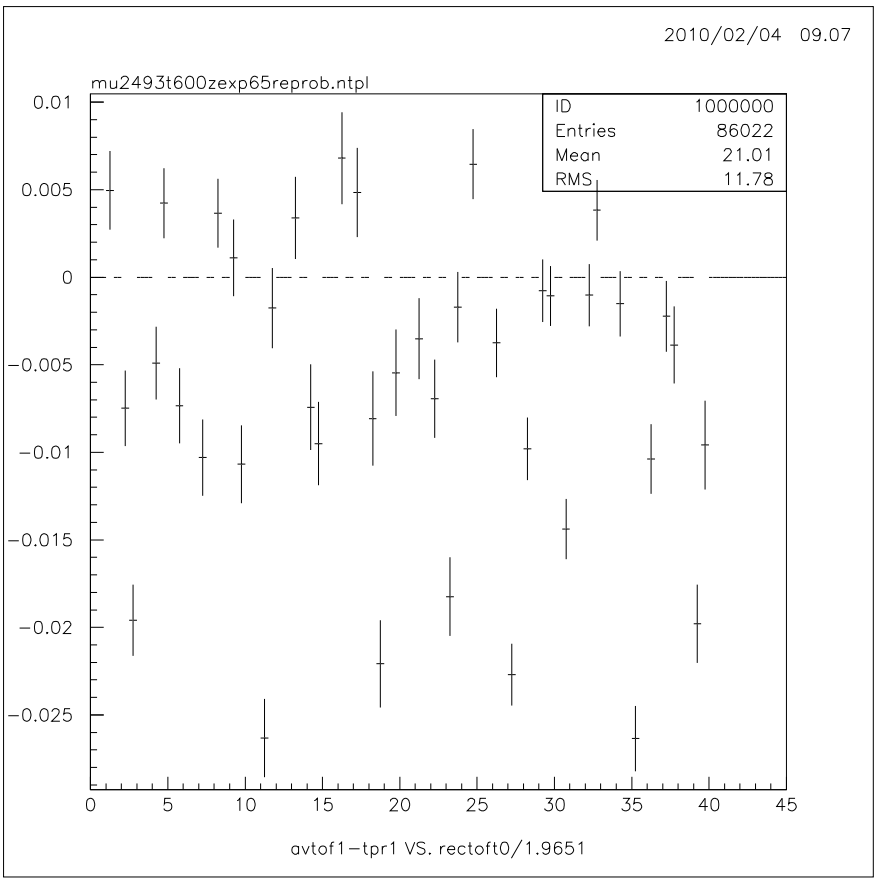

FIG. 4: dT in ns versus event T0 divided by the RF clock period of 1.9651 ns for events in which only one muon has matching TOF hits.