Measuring the Bunch Length of the Booster Neutrino Beamline Beam

M. Backfish

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1 Introduction

This document outlines the analysis of the Booster Neutrino Beamline (BnB) beam's bunch length using the resistive wall current monitor (RWM) and an Acqiris Digitizer. Details of the resistive wall current monitor can be found in reference [1]. Information concerning the digitizer can be found at:

http://extbeams.fnal.gov/users/backfish/hp/backfish.html

The digitizer is capable of 8 $\frac{GS}{s}$ digitization or .125 ns between samples. As currently implemented, this rate prevents the digitization of the complete 1.6 μsec Booster batch. In practice a .5 ns sample period is used to digitize the entire Booster batch.

Figure 1: RWM digitizer parameters are controlled via Acnet

The Acnet array parameters E:LBMTWV[1-3999] include each of the digitizer samples. In data sets before October 2015 the name is Z:LBMTWV. The data was logged using accelerator division circular loggers and also written to the MiniBooNE data in the IFbeams database. The size of signal and rate of beam delivered to BnB results in the overwriting of accelerator division circular buffers in only a few days which adds to the importance of the IFbeams loggers.

This analysis uses 11 MiniBooNE data runs to find 14095 signal traces with varied proton beam intensities. Each signal trace consists of one Booster batch or 81 consecutive Booster bunches. The traces are used to determine the length of individual bunches destined for the MiniBooNE experiment.

The bunch length is dependent upon the the complex interplay between the Booster magnetic, RF and damping systems along with variations in upstream machines, both the Linac and preaccelerator. With this in mind these 14095 data points are to be used as an example of bunch length. On any given day changes in machine parameters and accelerator problems can cause variations in the bunch length.

2 Bunch Length Analysis

The digitizer currently uses a tclock $\$1F$ gated on the $\$1D$ for triggering. The $\$1F$ is the 10 MHz tclock reflection of the Booster Extraction Sync trigger which is used to fire the Booster extraction kickers. The use of a reflected 10 MHz event results in a signal whose start time jitters on the order of 100 ns. Each signal trace includes 81 bunches, or filled Booster buckets. A python algorithm was written to analyze each trace. The program finds the start of the signal, adds a time element to each sample and divides the sample in time into 81 individual bunches. A Gaussian fit is applied to each bunch as shown in figure 2 and equation 1.

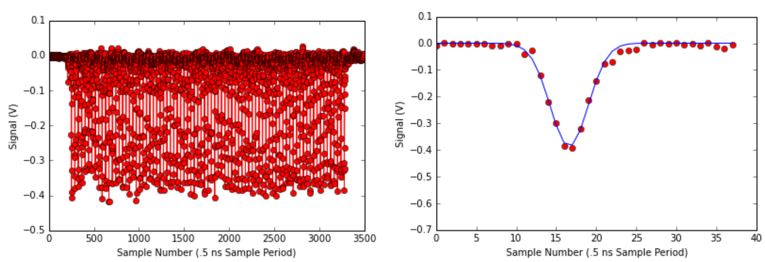

Figure 2: Each Booster batch destined for MiniBooNe consists of 81 bunches.

$$A * e^{\frac{-(x-\mu)^2}{2*\sigma^2}} \tag{1}$$

It should be noted that bunch length is often defined as a multiple of σ depending on what percentage of signal should be included. In this document σ will be reported as the bunch length. Assuming a normal longitudinal distribution, 4σ would then account for 95% of the bunch.

Another issue of concern is the baseline offset of the signal. Through visual inspection it was determined that there is no signal in either the first 13 nor the last 13 data points in bunch traces such as that in figure 2. Thus for each bunch the first and last 13 data points are averaged and plotted in figure 3. This action is performed for each of the $14,095$ beam pulses. Averaging both the first 13 and the last 13 we find a baseline offset of -0.0086 V with a standard deviation of 0.0027 V. This offset is small in comparison to the actual beam signal and will thus be ignored for the remainder of the analysis.

Final results for the analysis of all 14095 traces are reported in table 1. These results are posted for intensity ranges up to 4 e12 as measured using the toroid E:TOR860. This analysis does not show a bunch length dependance on intensity for toroid readings up to 4 e12.

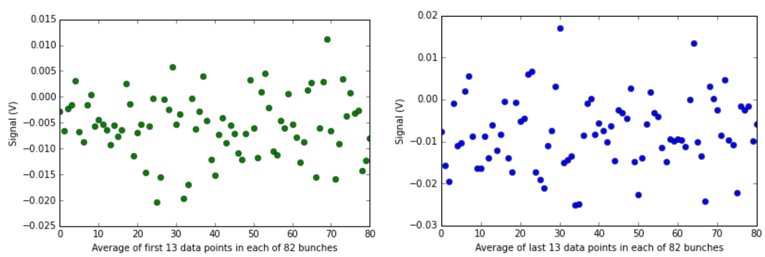

Figure 3: The baseline offset measured throughout the batch consisting of all 81 bunches is a small signal that neither increases nor decreases noticeably while beam passes.

POT (e12)	σ (ns)	STD (ns)
$.25-1$	1.432	0.154
$1-2$	1.309	0.059
$2-3$	1.268	0.052
$3-4$	1.332	0.061
all	1.308	0.065

Table 1: Bunch length σ and standard deviation of the bunch length for given intensity Protons On Target

3 Comparison to Resistive Wall Monitor in the 8 GeV Line

An attempt was made to compare past MiniBooNE resistive wall current monitor data with 8 GeV line resistive wall current monitor data for beam destined for MiniBooNE. The application used for the 8 GeV line resistive wall current monitor is call the Proton Torpedo. The hardware in the tunnel is the same as that used for the Booster Neutrino Beamline. This application does not run all of the time. It is often used to diagnose problems as they occur. Past traces can be found using the electronic log books. Figure 4 shows an example of a good trace. This program determines when the voltage exceeds a certain value and calls that the start of a bunch. The end of the bunch is then found when the voltage drops below a set value. The time between these points is a measure of the bunch length. This method of measuring the bunch length accounts for most of the signal. The booster batch in Figure 4 shows a bunch length of 7.6 ns. This value divided by the average measurement of σ from table 1, 1.308 shows a factor of 5.8 between mesurements performed in the earlier analysis and measurement determined from the Proton Torpedo application. In a normal distribution 6 σ would account for 99.7% of the signal. This initial test shows consistency between the 8 GeV line resistive wall current monitor and the MiniBooNE resistive wall current monitor. Further tests should be performed where the same pulse is measured with both systems.

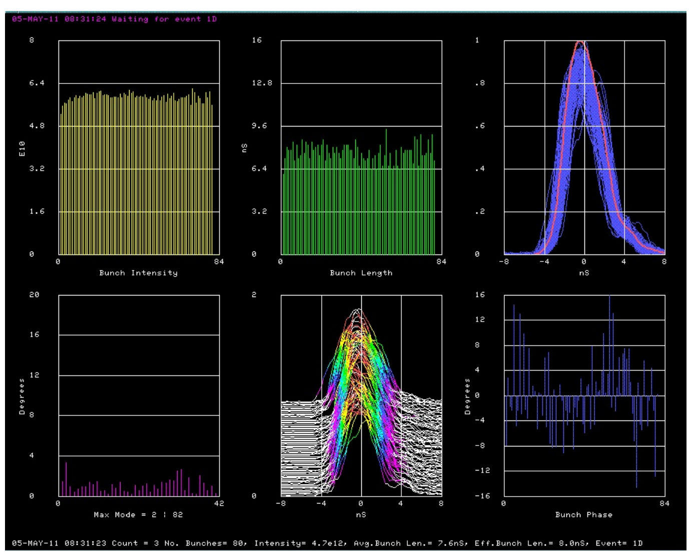

Figure 4: The 8 GeV line Proton Torpedo Program, created by Dave McGinnis, provides information on the Booster Neutrino Beam while still in the 8 GeV Line

4 Conclusion

In conclusion, the resistive wall current monitor and acqiris digitizer are functioning properly and effectively and can be used for analysis of longitudinal beam characteristics in the Booster Neutrino Beamline. For this data set Gaussian σ was measured to be 1.3 ns with little deviation up to intensities of 4 e12 as measured using E:TOR860. This data is consistent with past measurements using the resistive wall current monitor in the 8 GeV line.

References

[1] Michael Backfish, “MiniBooNE Resistive Wall Current Monitor”,Fermilab TM-2556-AD, Batavia, Il 2013