FERMILAB-SLIDES-24-0209-STUDENT

# Shortened Booster Bunch Lengths

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## Goal

Shorten the booster beam's bunch lengths so that 1 sigma of the beam gaussian showed a bunch length of <1ns for Neutrino experiment.

## Background

The LINAC produces a proton beam at an energy of 400MeV, however, this energy level is too low for the main injector. The booster is designed to increase the energy of the proton beam to 8GeV and does this through three main steps. It first accumulates particles from the LINAC to increase beam intensity, it then accelerates the beam to 8 GeV using the RF cavities, and lastly uses the RF cavities again to marginally modify the beams bunch lengths to achieve the desired time/momentum spread.

## RF Cavities

The RF cavities are the instruments that result in acceleration of the proton beam. The cavities achieve this by applying a sinusoidal electric wave, resulting in the acceleration of the particles in the beam. Since the RF cavity can accelerate particles, it can also be used to adjust the bunch length by marginally altering the electric field to shorten/lengthen the beam bunches. The profile of the bunches can be observed through the beams phase space.

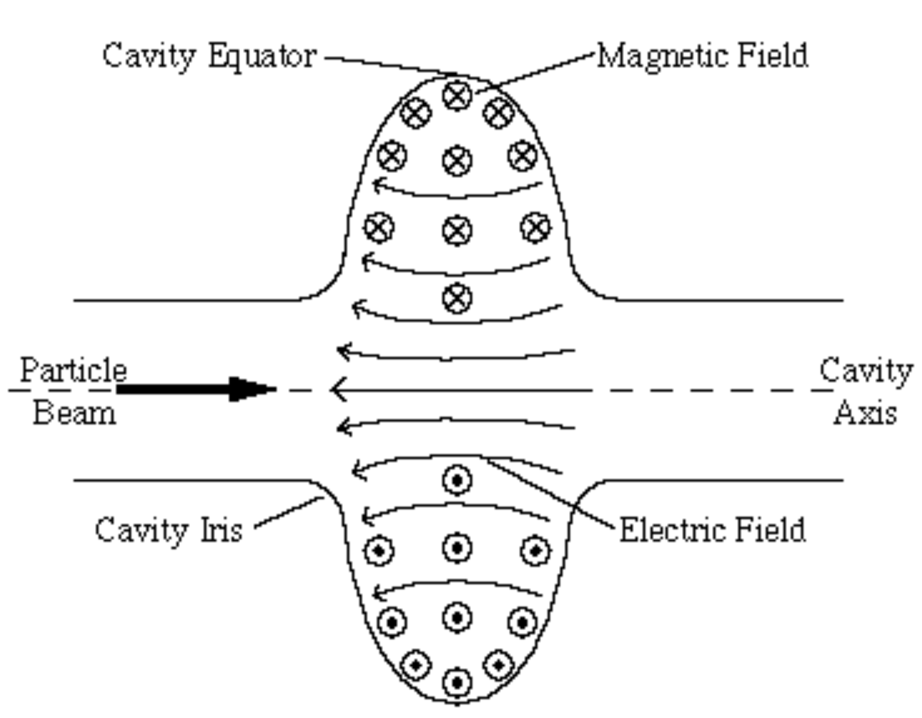


**Figure 1. Diagram of RF Cavity**

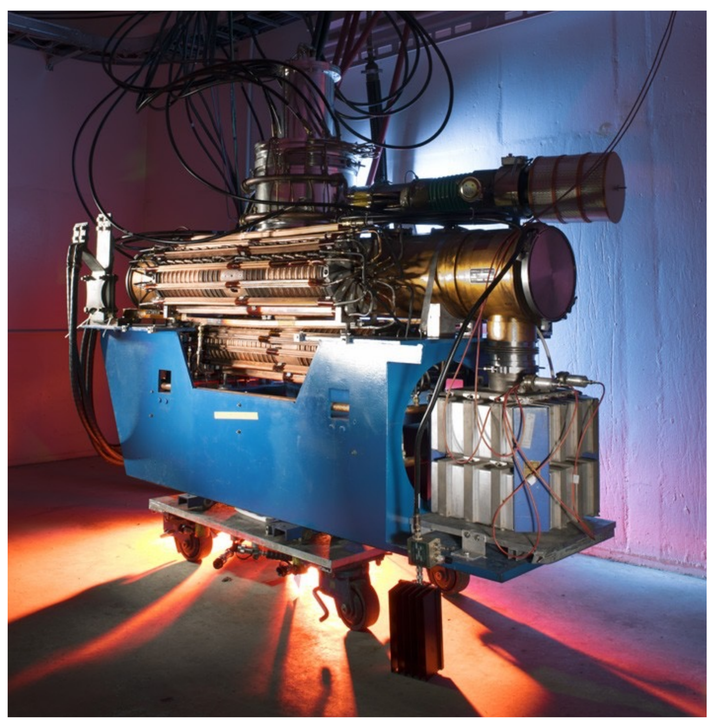

**Figure 2. Physical picture of RF cavity**

## Methods

There will be two methods in which the bunch lengths can be shortened. Adiabatic Excitation is when the amplitude of the RF cavity is slowly increased. This results in the most stable beam and incurs the least losses but cannot reach a high enough momentum spread to shorten the bunches due to the limits of the RF cavity.

Another method, Quadratic Bunch Rotation (QBR), is when the amplitude of the RF cavity is oscillated to achieve the desired bunch length. This results in a high enough momentum spread but incurs losses due to the fast fluctuations of cavity's electric field.

## Data and Analysis

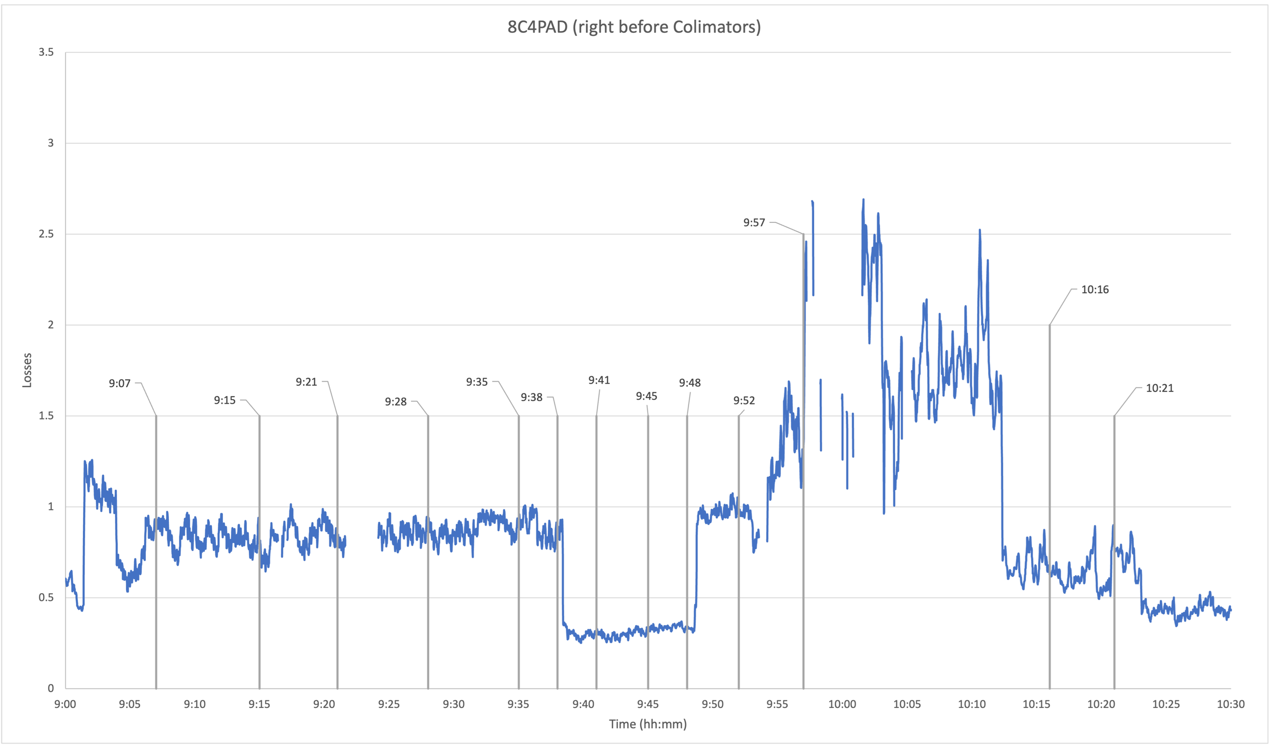


**Figure 3. Graph of beam losses of 8C4PAD monitor**

| Time (AM) | Intensity (E12) | 8 GeV Colimators Position | Bunch Δt (ns) |
|---|---|---|---|
| 9:07 | 4.7 | out | 2.1 (delay time = 33890 μs) |
| 9:15 | 4.7 | out | 1.2 (delay time = 33884 μs) |
| 9:21 | 4.7 | out | 0.9 (delay time = 33856 μs) |
| 9:28 (we tried to go lower than 0.9 ns, didn't succeed) | 4.7 | out | 0.9 |
| 9:35 | 4.7 | out | 2.1 (delay time = 33980 μs) |
| 9:38 | 3.0 | out | 1.725 |
| 9:41 | 3.0 | out | 0.75 (delay time = 33864 μs) |
| 9:45 | 3.0 | 100 mils in | 0.75 |
| 9:48 | 4.7 | 100 mils in | 0.975 |
| 9:52 | 4.7 | Another 50 mils in | 0.9 |
| 9:57 | 4.7 | Col 836 in 50 mils out, 838 completely in | Beam trips, going back to 9:52 AM setup |
| 10:16 | 3.0 | Col 836 in 50 mils out, 838 completely in | 0.825 (delay time = 33876 μs) |
| 10:21 | 4.7 | Col 836 in 50 mils out, 838 completely in | 2.1 (delay time = 33890 μs) |

**Figure 4. Timeline of Experiment**

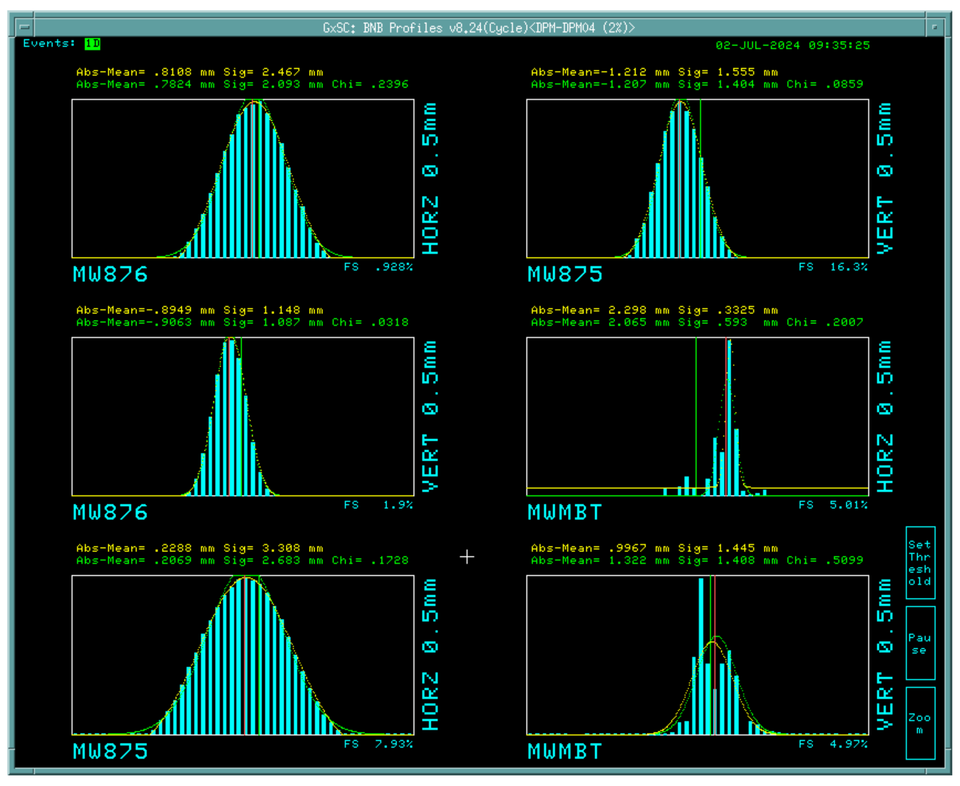

**Figure 5. Beam Profile in MI8 Extraction line before bunch narrowing (9:35AM)**

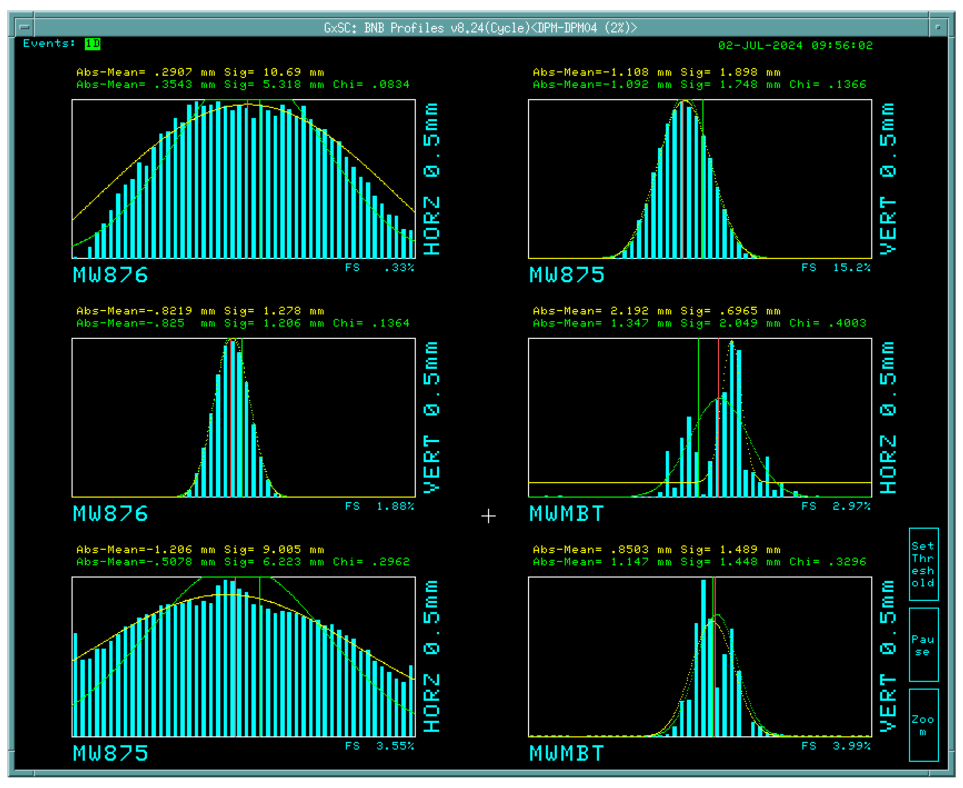

**Figure 6. Beam Profile in MI8 Extraction line after bunch narrowing (9:56AM)**

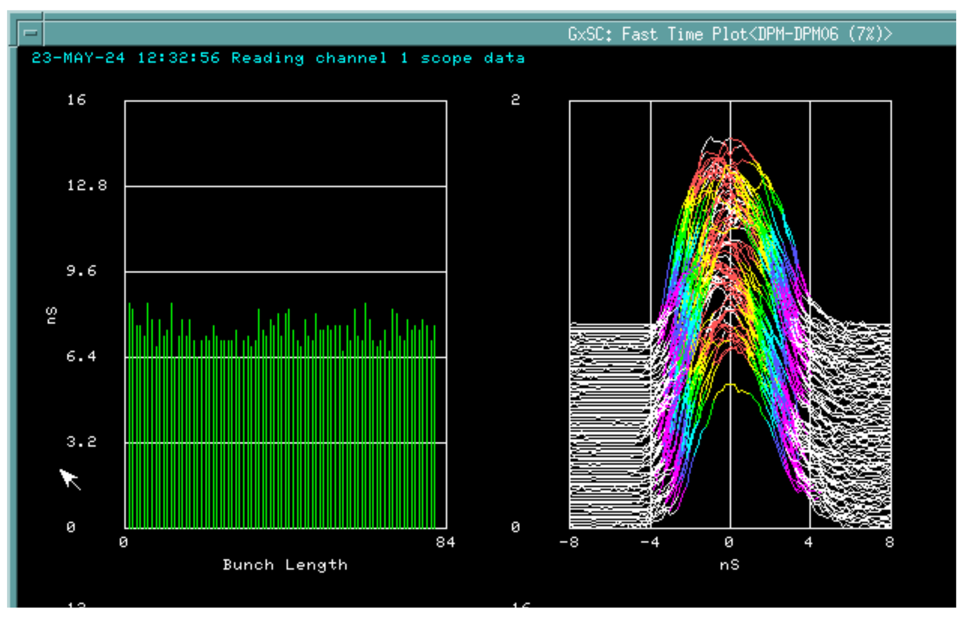

**Figure 7. Normal Bunch lengths**

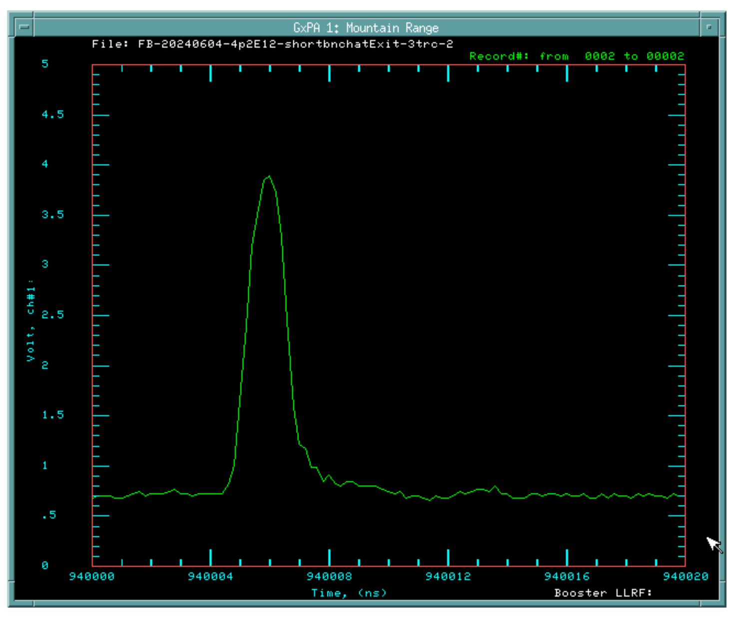

**Figure 8. Shortened Bunch lengths**

Looking at figures 7 and 8, we notice that the bunches were shortened from ~2.467ns to ~0.6ns (within 1 sigma). However, when looking at the beam losses at the time ranges with narrow bunches and high intensity beams, we see significantly higher losses then time ranges with regular bunches lengths. To gain a better sense of what is occurring in the 8GeV line, we can look at the beam's profile after extraction.

The graphs in figures 5 and 6 are the beam profile monitors in the 8 GeV line, on the left is before bunch narrowing and the right is after bunch narrowing. Notice that although the beam profile retains its vertical profile as the bunches are narrowed, the horizontal profile (spot size) is substantially wider. In fact, the data shows that the spot size is 3 times wider than the target that the beam is supposed to strike. This increase in the beam's spot size was a result of the beam dispersion that occurred 8 GeV line.

## Conclusion

While bunches were successfully shortened to be 0.6ns within 1 sigma, the beam dispersion in the 8 GeV line resulted in a wider beam spot size. Due to this widening, a proposed solution is to add a collimator that will "slice" off the unwanted horizontal sections of the beam to achieve the desired horizontal beam profile. Another proposed solution is to design a focusing element that will focus the horizontal dispersion to the correct spot size in the 8 GeV line.



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