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Notes on Frequency Content of Tevatron BPM Signals

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Abstract

As I understand the proposed design for the new BPMs, we are looking at running the digital down converter (DDC) over as many as 64 turns. I am worried that, with many turns, the comb in frequency space that is generated by the rotational frequency, has zeros in dangerous places. We need to design the board to avoid these zeros.

The following pages show fourier transforms for some toy models of how the new BPMs might work. The first toy model is that there is exactly 1 bunch in the machine and we look at the beam for 8 turns. In the time domain this looks like 8 pulses, separated by about 21 μs.

The Fourier Transform (FT) of this signal is the product of three components.

1. The FT of a single pulse from the pickup.
2. The frequency response of the cabling and analog filter.
3. The comb from the rotation of the beam.

I presume that in a frequency band of a few hundred kHz centered at the RF frequency, the first two contributions are slowly varying. The point of this note is to discuss the comb, in particular the zero's in the comb.

In Fig. 1, the upper left figure shows the shape of the comb for a frequency range of about 500 kHz, centered on the RF frequency. The shape of the comb is just the magnitude of the FT. In this toy model I used an RF frequency of exactly 53.1 MHz.

The upper right plot shows the same information but zoomed in to a band about 10 kHz wide, centered at the RF frequency. The two vertical red lines mark ± 1 kHz around the central frequency. I am told that the change in RF frequency up the ramp is about 1 kHz, full scale.

The next 4 plots show the same information but for 16 and 64 turns of the beam.

The critical plot is the lower right plot. This shows that if we run the DDC over 64 turns, then we better make sure that we use the true RF frequency inside the DDC. If we are off by about 0.5 kHz, then we loose information quickly and may even hit one of the zeros in the comb.

Fig. 2 shows some real data which should look a lot like the lower right plot in Fig. 1. And it does look a lot like it. This figure was made from a file which I got from Jim Steimel: Single_Proton_Store/sing_bunch_coal_250Ms_wfilt_A15_Ch1.mat This file contains a time series of pulse heights, digitized at 250 MHz using a scope. It is for a single coalesced proton bunch. There is some sort of low pass filter before the scope and we are looking at one of the proton cables from A15. There are about 4 Mega samples in this file, or about 763 turns. I used the first 64 turns to compute the fourier transform of the time series for a range of frequencies near the RF frequency of about 53.10372 MHz. The figure shows the magnitude of the FT as a function of frequency for this data. The range of frequencies covered is about twice as wide as for right hand plots in the toy model; which explains the different number of secondary lobes. The red lines show ± 1 Khz from the RF frequency. The figures are clearly similar. So we can conclude that the toy model has all of the main features of the data.

We can probably determine something about signal to noise for this data by looking at how much the minima miss zero (but I should do this in finer frequency bins before being to make sure that we are seeing the S/N and not binning artifacts).

The next two pages show the six toy model plots for two other bunch configurations, the standard 3 trains of 12 coalesced bunches and for a single batch of 30 uncoalesced bunches. In my toy model I ignored the fact that there are about 9 times fewer particles in an uncoalesced bunch.

The conclusions are the same for all bunch configurations: if we run the DDC over many turns of data, we need to be careful about the frequency used inside the DDC. In particular, if we work at a fixed frequency that is OK at 150 GeV, we will probably find a zero on our way to 980 GeV.

Several solutions come to mind but I have no appreciation for the complexity of implementing them.

1. Clock the dcc with the correct RF frequency at all times. This may mean that the clock frequency changes during a measurement. Is this OK? What if the phase shifts during a measurement; for example, during cogging?

2. Compute the FT over a single turn. Resync the DDC with the beam RF each turn. Then do a multi turn average by averaging single turn measurements farther down the processing chain.

3. Anything else?

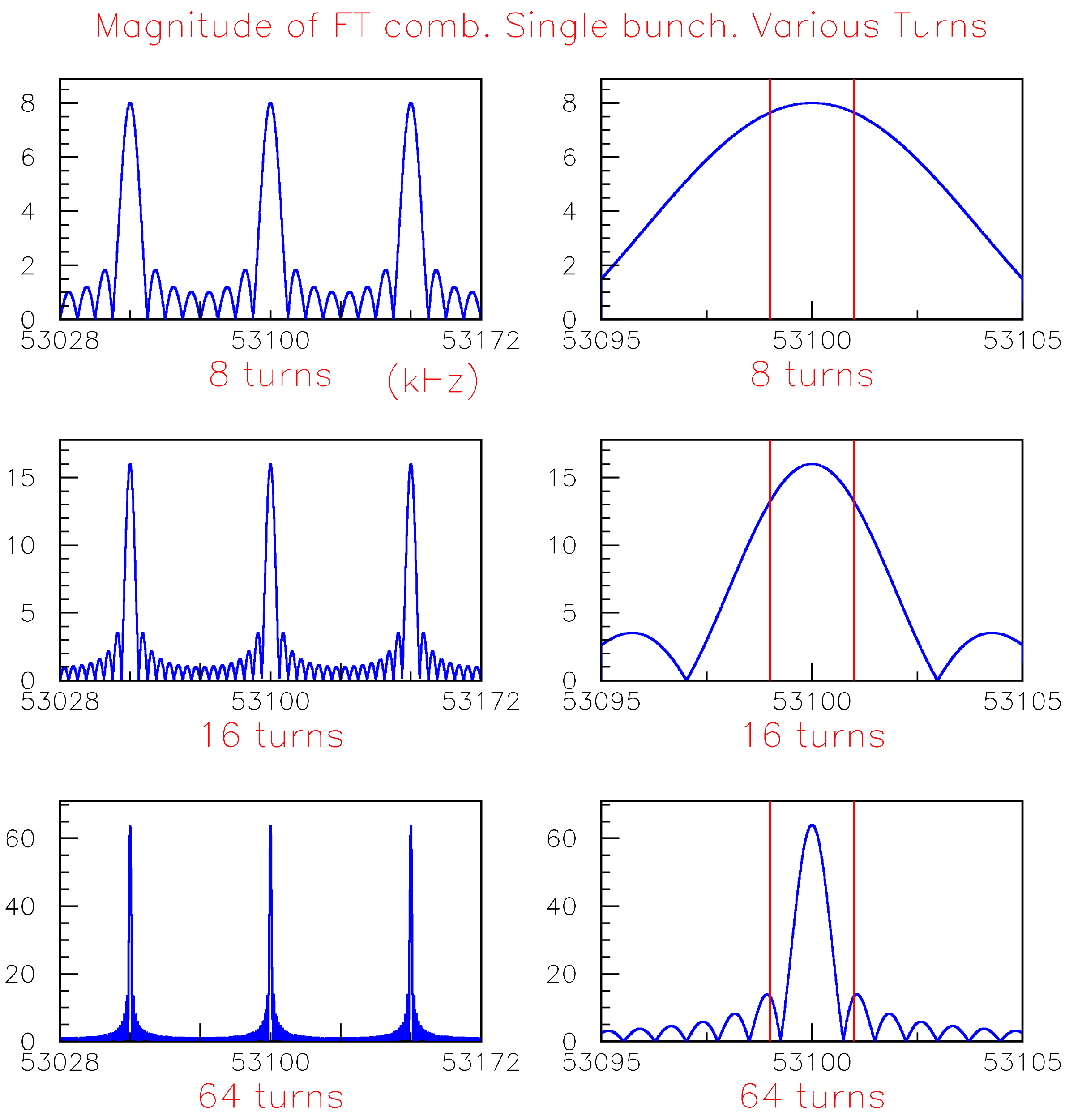

Figure 1: Combs for a single bunch.

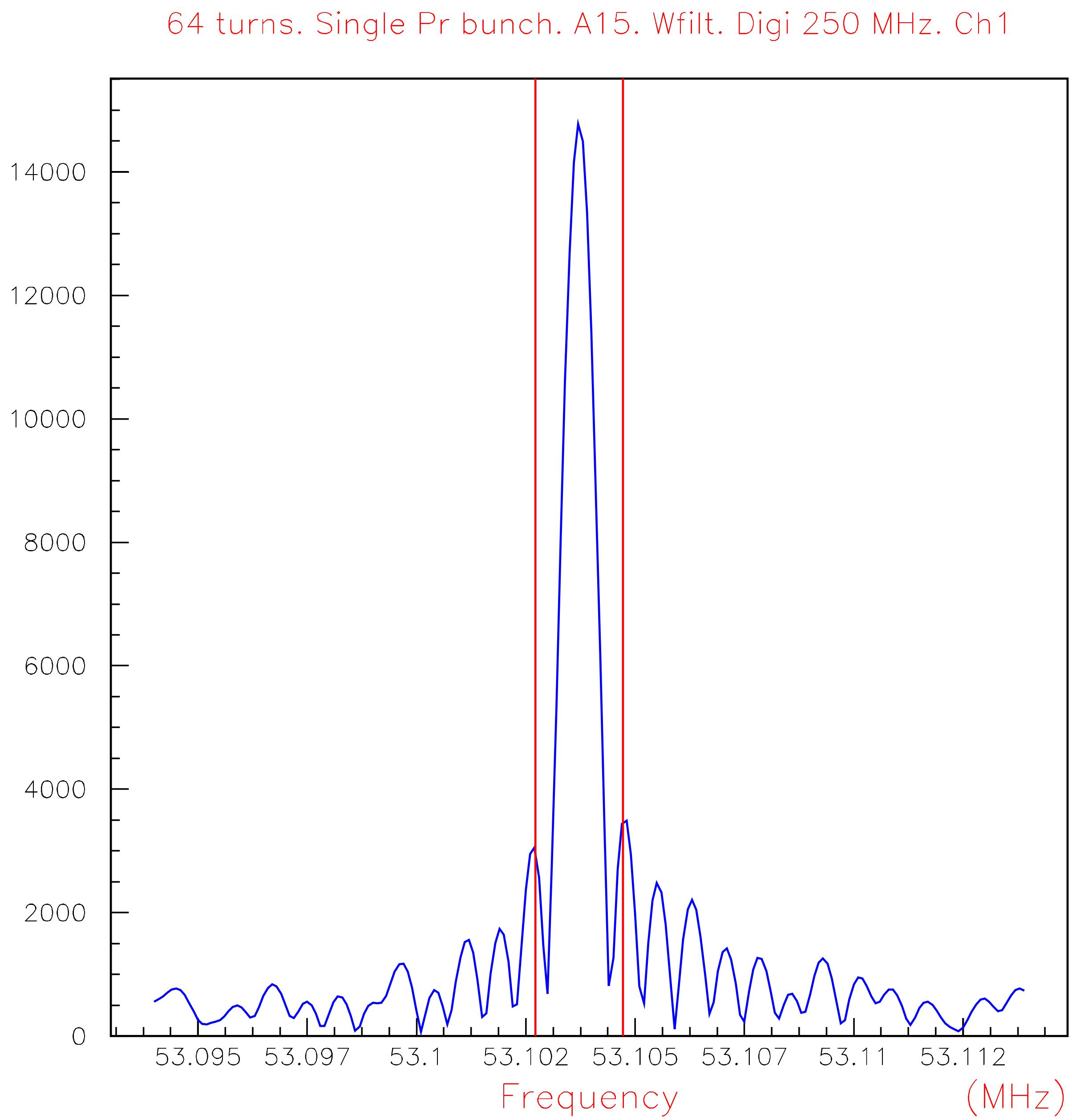

Figure 2: Fourier Transform of single bunch data as described in the text.

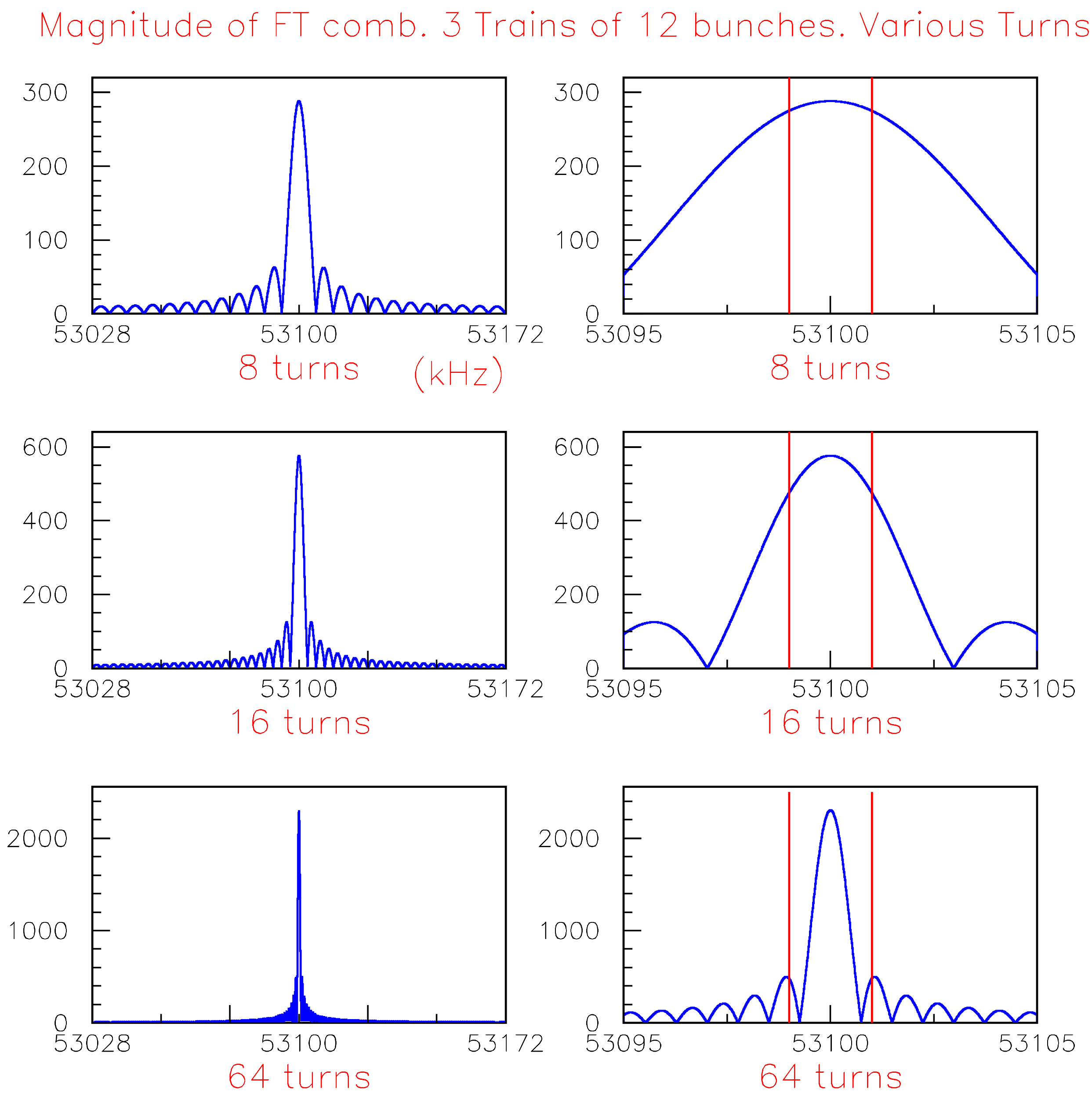

Figure 3: Combs for 3 trains of 12 bunches.

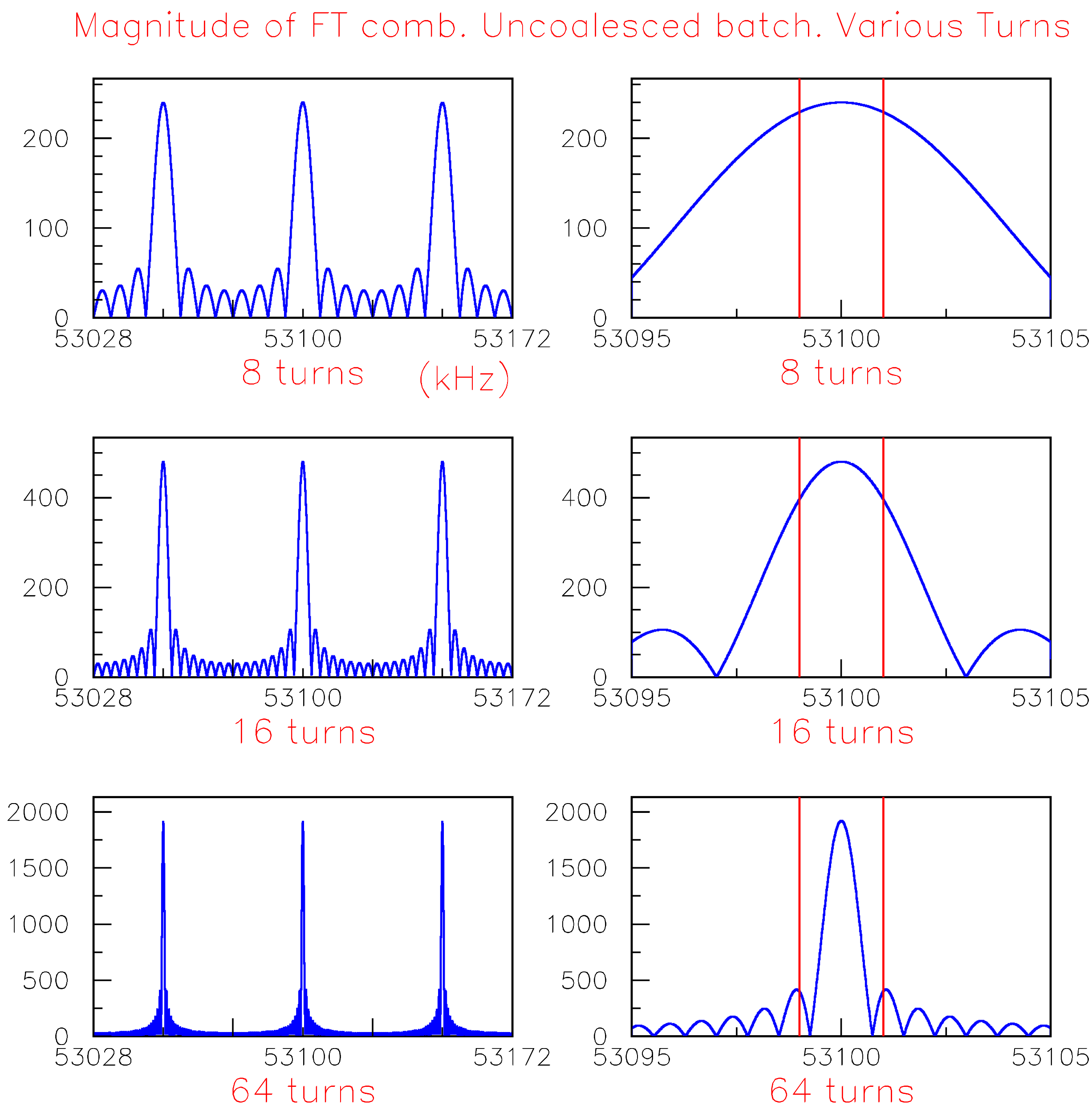

Figure 4: Combs for a batch of 30 uncoalesed bunches.