Tune Measurements during CHESS Operation

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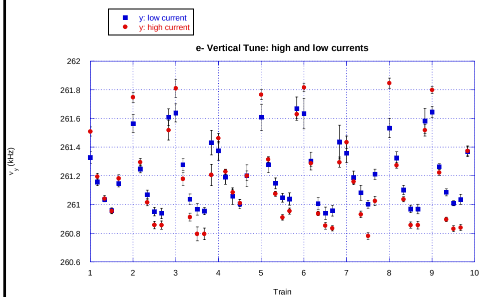
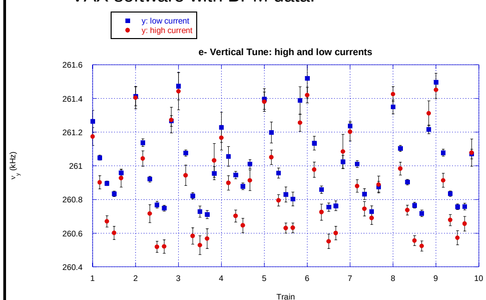
Experiment

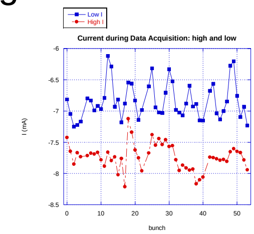
Measurements of tune were taken during CHESS 9x6 operation with 51 bunches in the machine (bunch 6 in trains 1,4 and 7 was empty). At the bottom of the fill (low current), BSM data were taken for every bunch over 2048 turns. BPM measurements immediately followed, and were taken while pinging the beam. The procedure was repeated at the top of the fill (high current). In the subsequent CHESS run, the following BSM measurements were taken: train 1 over 72k turns, train 1 bunch 2 over 250k turns, train 2 bunch 2 over 250k turns, all 51 bunches over 2048 turns, train 2 bunch 3 over 250k turns, train 2 bunch 4 over 75k turns, train 2 bunch 5 over 75k turns, train 2 bunch 6 over 250k turns. At the end of the run, high and low current BSM and BPM measurements were repeated.

e- Vertical Tune: high vs. low current

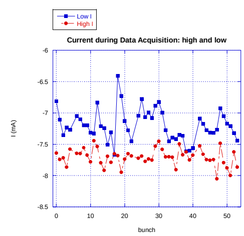


The data in the plots are the tunes as calculated by VAX software with BPM data.



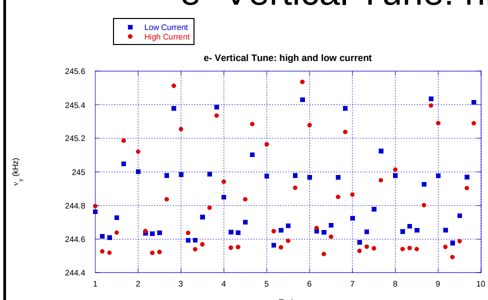


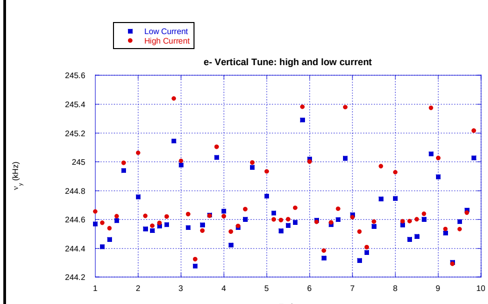
For both data sets,
i) The vertical tune decreases along the train, but increases for the last bunch, which is probably a parasitic crossing effect.
ii) The tune shift is greater at high current, suggesting electron cloud effects.
iii) For low current, $\Delta\nu_y \cong 0.7$ kHz
For high current, $\Delta\nu_y \cong 0.9$ kHz



There was beam loss during this acquisition.

e- Vertical Tune: high vs. low current

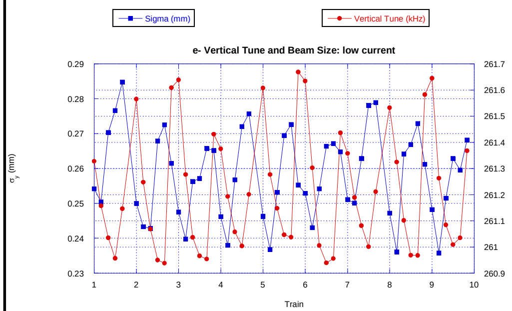


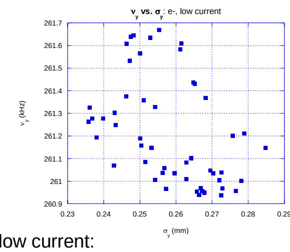


Beam position was extracted from the beam size monitor (BSM) profile using a Matlab Gaussian fitting package. The beam was not kicked during BSM acquisition.

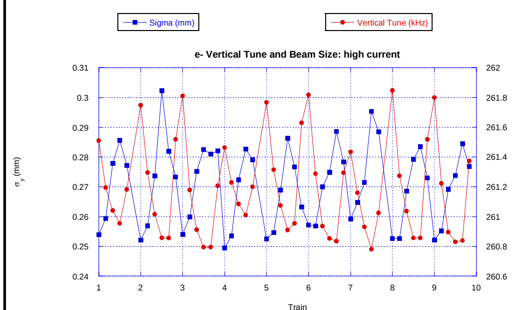
For both data sets,
i) The measured vertical tune is ~15 kHz less than expected and what was measured with the BPM.
ii) The vertical tune decreases at the front of the train and increases at the end. The minimum tune tends to be closer to the front of the train, whereas for the BPM-derived tune measurements, the minimum tune tends to be closer to the end of the train.
iii) Tune shift is not strongly correlated with current.
iv) Shift in the dominant mode may be due to longitudinal coupling.
v) For low current, $\Delta\nu_y \cong 0.7$ kHz
For high current, $\Delta\nu_y \cong 0.7$ kHz

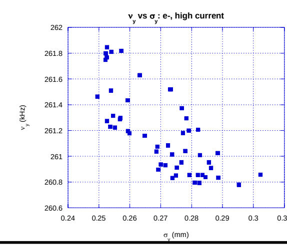
Relationship between Vertical Tune and Beam Size I



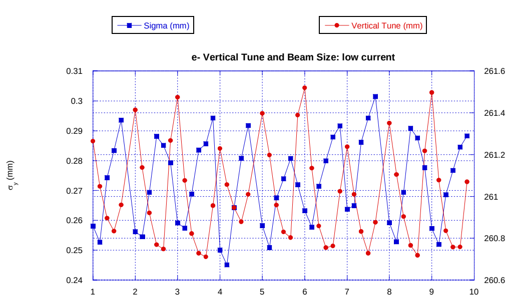


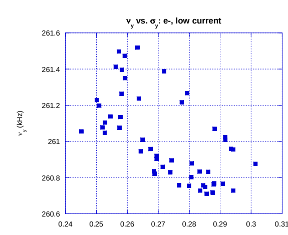
For high and low current:
i) Tune shift along train due to electron cloud puts the tune near a resonance, resulting in beam size increase that is mitigated by feedback.



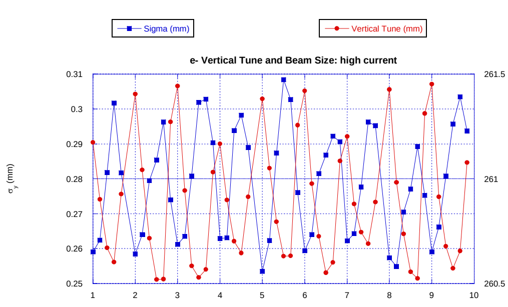


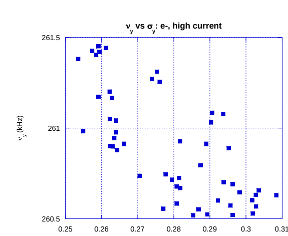
Relationship between Vertical Tune and Beam Size II



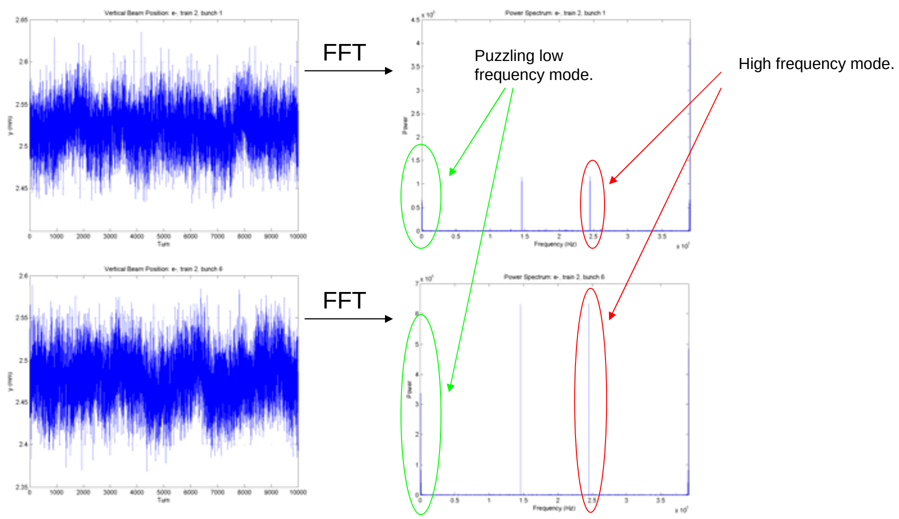


For high and low current:
i) The relationship between vertical tune and beam size is similar to that of the previous fill.



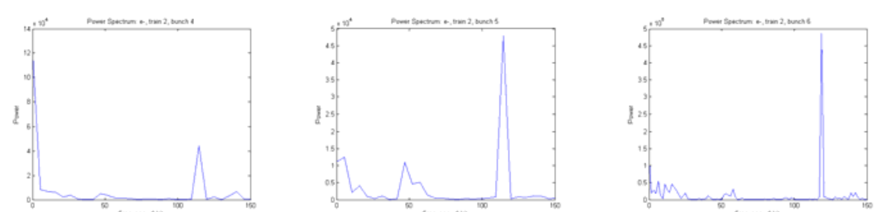


Single Bunch Tune Measurements over 250k Turns

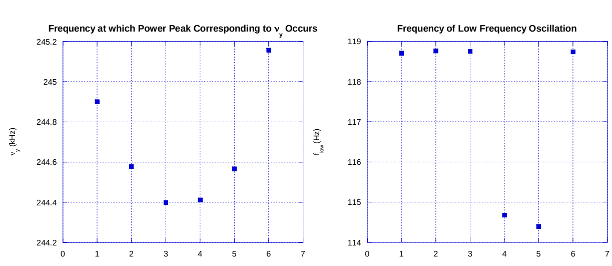


For the BSM measurement of position for the two bunches above, as well as the remaining four:
i) As expected, there is a power peak corresponding to the vertical tune, though it is shifted by ~15 kHz.
ii) There is another low frequency power peak that dominates the vertical tune power for some bunches. The low frequency oscillation is evident in the plot of beam position over 10k turns.

Further Examination of Low Frequency Mode

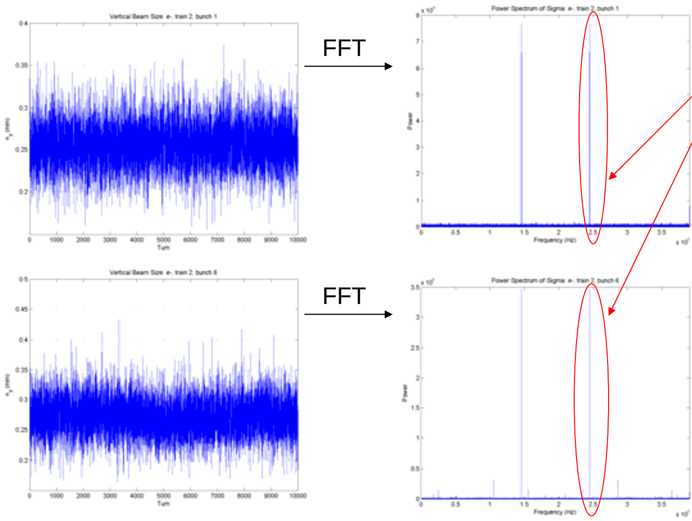


Bunches 4,5, and 6 have a low frequency mode between 110 and 120 Hz. There are also lower frequency modes present, especially in bunch 4, where there is a power peak below the resolution limit. The power spectrum at low frequencies is similar for bunches 1, 2, and 3, as illustrated in the plot below.



i) When calculated with a 250k point FFT, the vertical tune first decreases, reaches and minimum at bunch 3, and increases at the end of the train. This was observed when calculating the tune with fewer turns, as was $\Delta\nu_y \cong 0.7\ \mathrm{kHz}$.
ii) The low frequency oscillation has a frequency of ~119 Hz, except for bunches 4 and 5, both of which were calculated with 75k turns, instead of 250k. The difference is most likely due to decreased resolution.

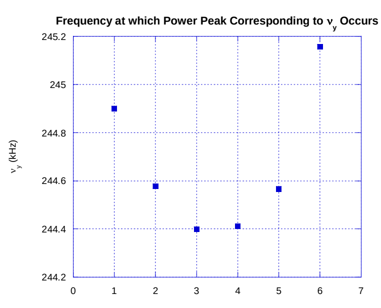
Beam Size Measurements over 250k Turns

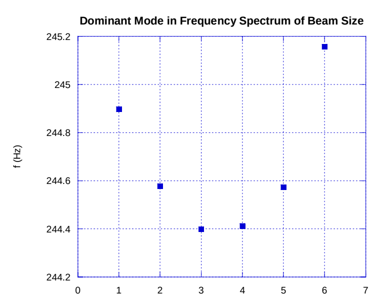


High frequency peak that matches the peak in beam position spectrum.

For the BSM measurement of beam size for the two bunches above, as well as the remaining four:
i) There is a high frequency power peak near the vertical tune, though it is shifted by ~15 kHz.
ii) The low frequency mode is absent,

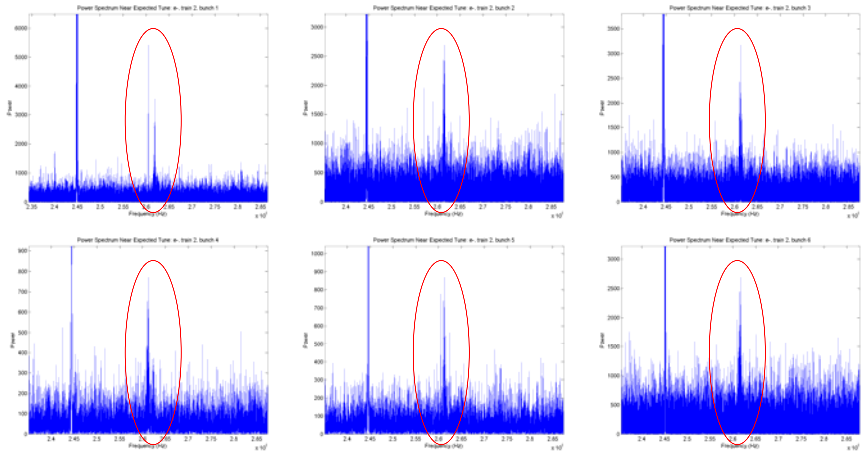
Comparison of Dominant Frequency in Beam Position and Size Measurements

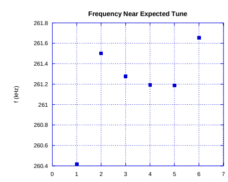




i) The dominant frequency in the beam position data matches that in the beam size data to five significant figures or more.
ii) Suggests that we are seeing an instrumental effect.

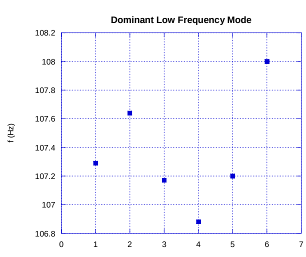
Is there a power peak at the vertical tune?

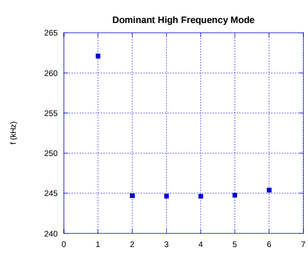




There is a power peak at approximately the expected tune. However, the signal to noise ratio is low. Furthermore, the shift in this frequency over the train does not qualitatively agree with that measured by the BPM.

Single Train Beam Position Measurements

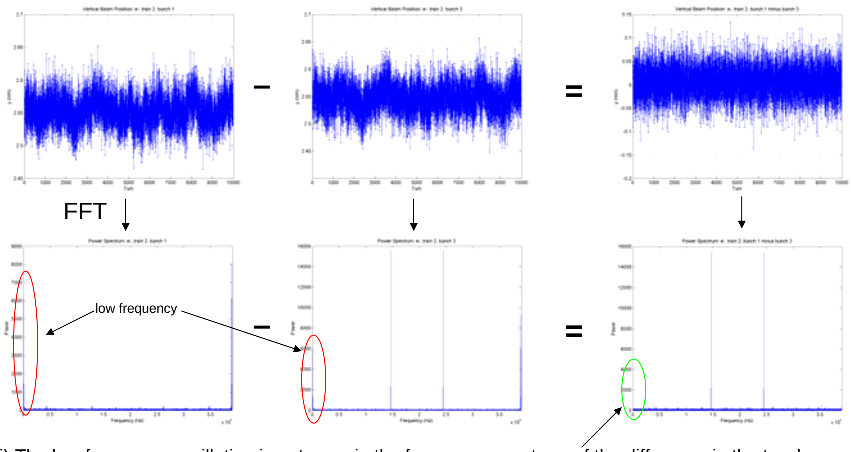




i) The dominant low frequency mode is ~107 Hz; for 250k turn data it was ~119 Hz, and for 75k data it was ~114 Hz.
ii) The dominant high frequency mode is ~245 kHz, agreeing with the single bunch data. For the first bunch, the power peak at ~245 kHz is absent. There is, however, a peak at approximately the expected tune of 260 kHz.

Does low frequency bunch motion correlate?

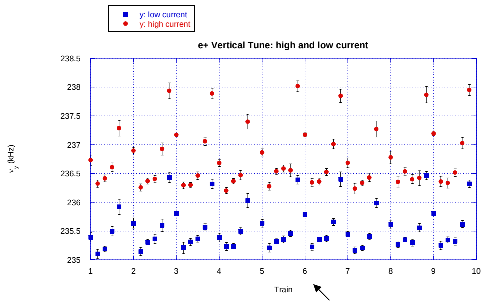
The dominant low frequency mode is approximately equal for all bunches in train 2. But do the bunches move in phase? This can be determined by subtracting the position measurements of one bunch from another and examining the resulting frequency spectrum. This is illustrated below for bunches 1 and 3.

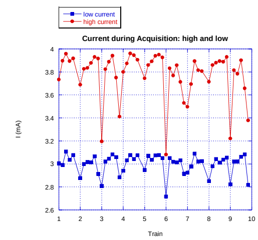


i) The low frequency oscillation is not seen in the frequency spectrum of the difference in the two beam positions.
ii) The above is true for other bunch comparisons.
iii) Suggests that bunches in the train move in phase.

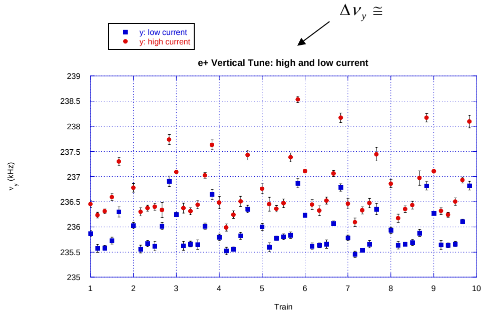
POSITRON

e+ Vertical Tune: high vs. low current

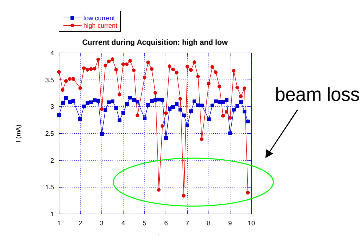




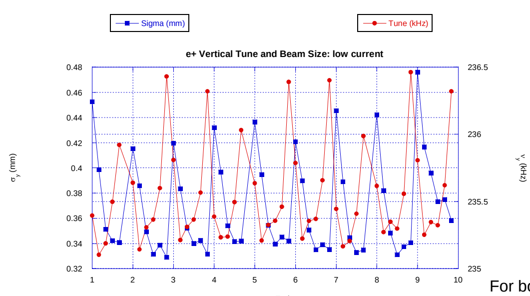
$\Delta\nu_y \cong$

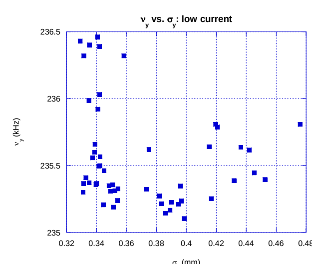


The data in the plots are the tunes as calculated by VAX software with BPM data.
For both data sets,
i) The tune shifts negatively from bunch 1 to 2
ii) The tune increases along the train, a signature of the electron cloud.
iii) Shift is greatest for last bunch, suggesting a parasitic crossing effect.

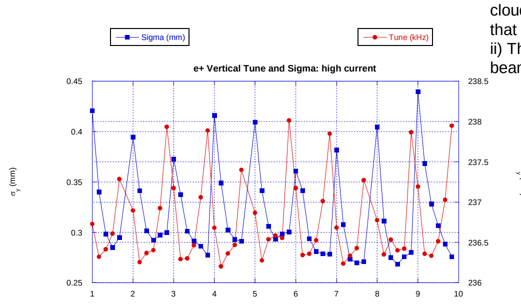


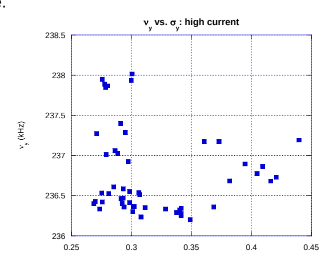
Relationship between Vertical Tune and Beam Size I



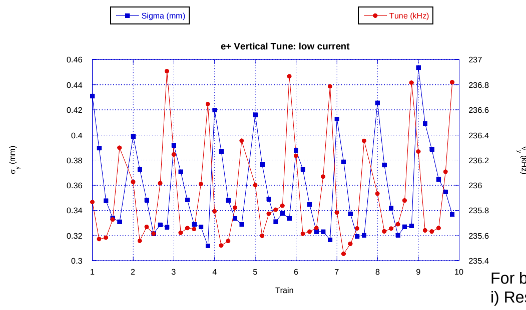


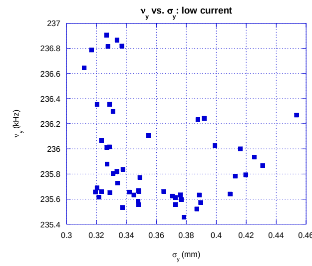
For both data sets,
i) The positive tune shift along the train due to the electron cloud corresponds to a decrease in beam size, suggesting that the tune is moving into more stable region of tune space.
ii) There is not a strong linear relationship between tune and beam size.



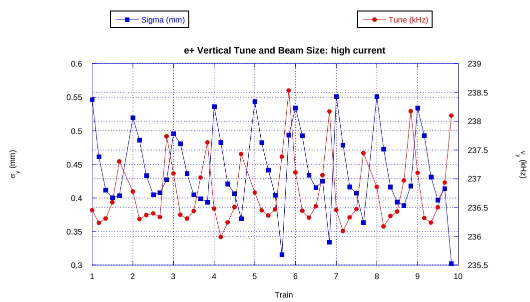


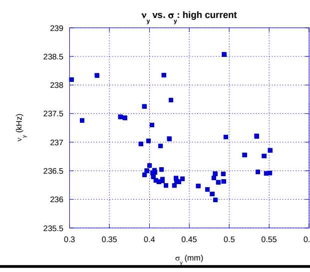
Relationship between Vertical Tune and Beam Size II



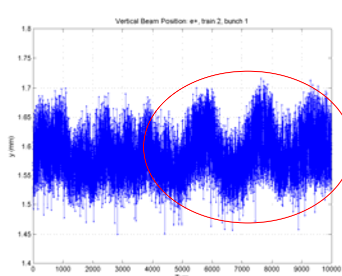


For both data sets,
i) Results are consistent with previous slide.



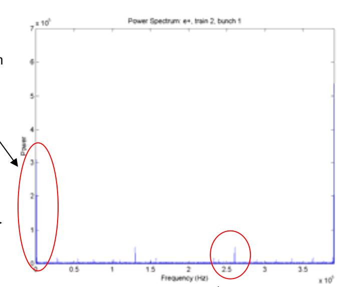


Beam Position Measurement: Train 2, Bunch 1



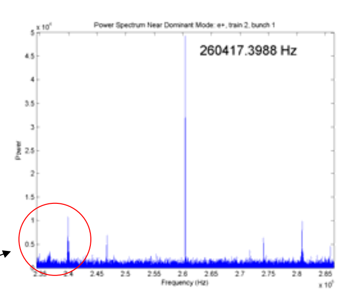
low frequency oscillation

FFT



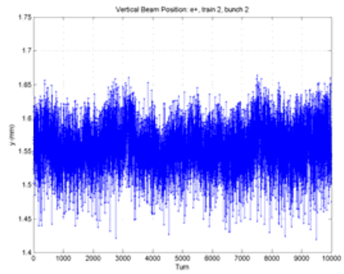
high frequency oscillation

For bunch 1,
i) The low frequency oscillation, obvious in the above plot, dominates.
ii) There is a high frequency mode at ~260 kHz, ~22 kHz above the expected tune.

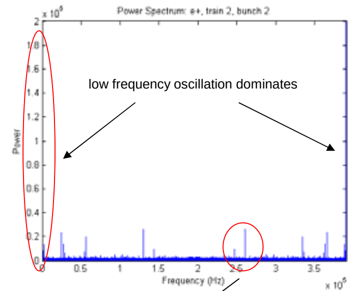


expect tune in this region

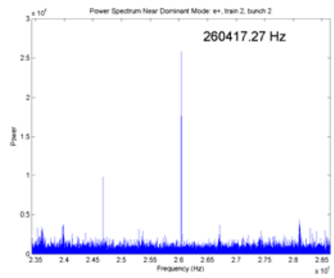
Beam Position Measurement: Train 2, Bunch 2



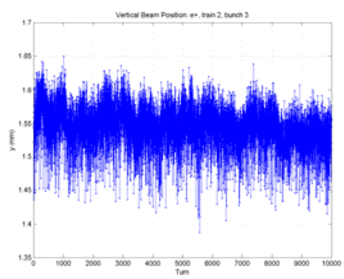
FFT



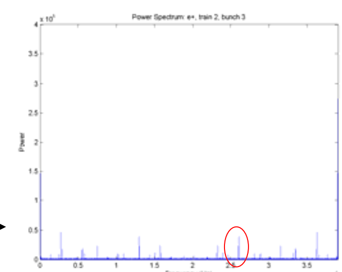
For bunch 2,
i) The above plot of the raw data shows an unacceptably large spread, which is most likely due to poor gaussian fits.
ii) The frequency spectrum is noisy, and dominated by low frequency oscillation.
iii) There is a high frequency mode at ~260 kHz.



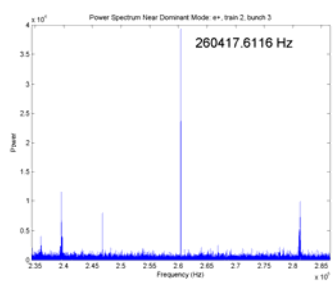
Beam Position Measurement: Train 2, Bunch 3



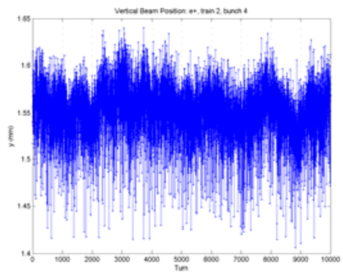
FFT



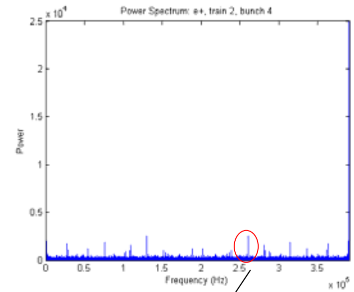
For bunch 3,
i) Again the the raw data shows an unacceptably large spread.
ii) The frequency spectrum is noisy, and dominated by low frequency oscillation.
iii) There is a high frequency mode at ~260 kHz.
iv) There is a power peak at approximately the expected tune of 238 kHz.

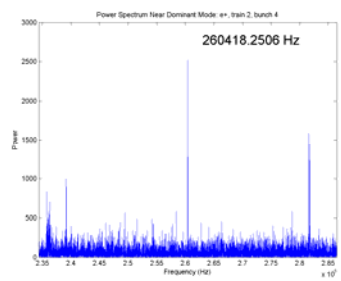


Beam Position Measurement: Train 2, Bunch 4



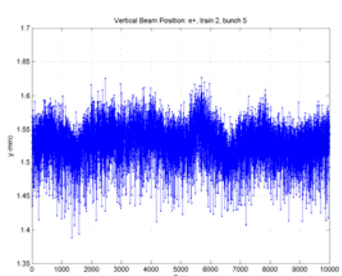
FFT



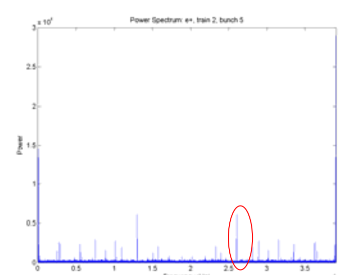


For bunch 4,
i) The the raw data shows an unacceptably large spread.
ii) The frequency spectrum is noisy, and dominated by low frequency oscillation.
iii) There is a high frequency mode at ~260 kHz.
iv) There is a power peak at approximately the expected tune of 238 kHz.

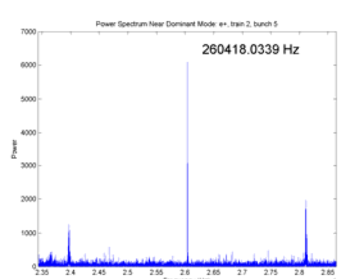
Beam Position Measurement: Train 2, Bunch 5



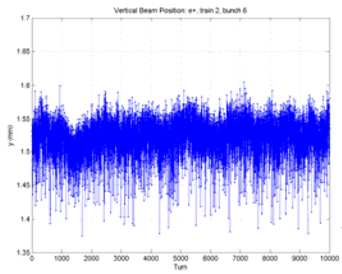
FFT



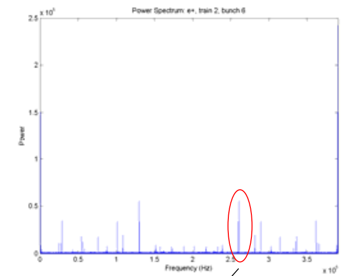
For bunch 5,
i) Again the the raw data shows an unacceptably large spread.
ii) The frequency spectrum is noisy, and dominated by low frequency oscillation.
iii) There is a high frequency mode at ~260 kHz.
iv) There is a power peak at approximately the expected tune of 238 kHz.



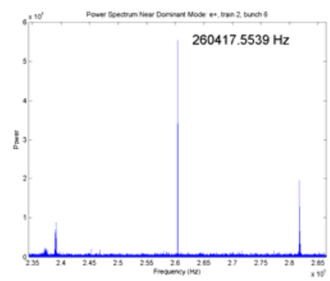
Beam Position Measurement: Train 2, Bunch 6



FFT



For bunch 6,
i) Again the the raw data shows an unacceptably large spread.
ii) The frequency spectrum is noisy, and dominated by low frequency oscillation.
iii) There is a high frequency mode at ~260 kHz.
iv) There is a power peak at approximately the expected tune of 238 kHz.



The high frequency oscillation agrees to four significant figures among the bunches, again suggesting a systematic artifact.

Conclusions and Follow-up Experiments

I. BPM Tune Measurement:
1. The electron tune decreases along the train, a signature of the electron cloud. The tune of the last bunch increases, suggesting a parasitic crossing effect.
2. Positron tune shifts negatively from bunch 1 to 2, and increases for subsequent bunches, again suggesting electron cloud and parasitic crossing effects.
Experiment: Measure tune with BPM and BSM with one and nine trains of one beam (e+/e-) in machine over 2048 turns. If possible, give beam small amplitude kick during BSM acquisition.

II. BSM Tune Measurement:
1. Electron tune shifts negatively from bunch 1 to 2 and increases for subsequent bunches, disagreeing with the BPM-derived result. Furthermore, there is a high frequency oscillation at ~15 kHz less than the expected vertical tune.
2. In the positron position data, there is a high frequency oscillation ~22 kHz above the expected vertical tune.
3. There is a dominating low frequency oscillation in both electron and positron data.
Experiment: In CHESS or CESR-c conditions, take BSM tune measurements without kicking the beam at several different tunes (aim for a tune spread on the order of kHz) to see if there is any change in the observed high frequency oscillations. Also, if possible, kick the beam at small amplitudes and take BSM tune measurements.

III. BSM Beam Size Measurement
1. Negative tune shift along electron trains corresponds to an increase in beam size, perhaps due to proximity to resonance in tune space.
2. Positive tune shift along positron trains corresponds to a decrease in beam size.
Experiment: With a single bunch (e+ or e-) in machine, at several different tunes, take BPM tune measurements, immediately followed by 250k turn BSM measurements. Repeat with a single, 6 bunch train in the machine.