e+/e- Vertical Beam Dynamics during CESR-C Operation

I. **Introduction**
II. **e+ turn-by-turn vertical dynamics**
III. **e- turn-by-turn vertical dynamics**
IV. **Summary**

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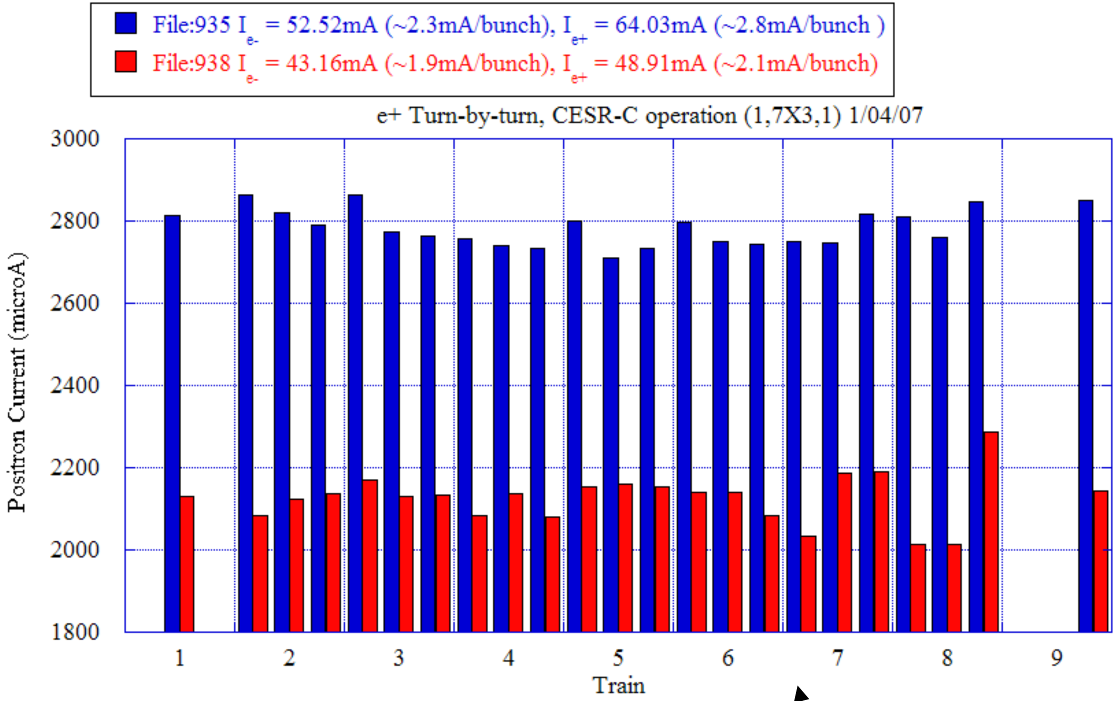
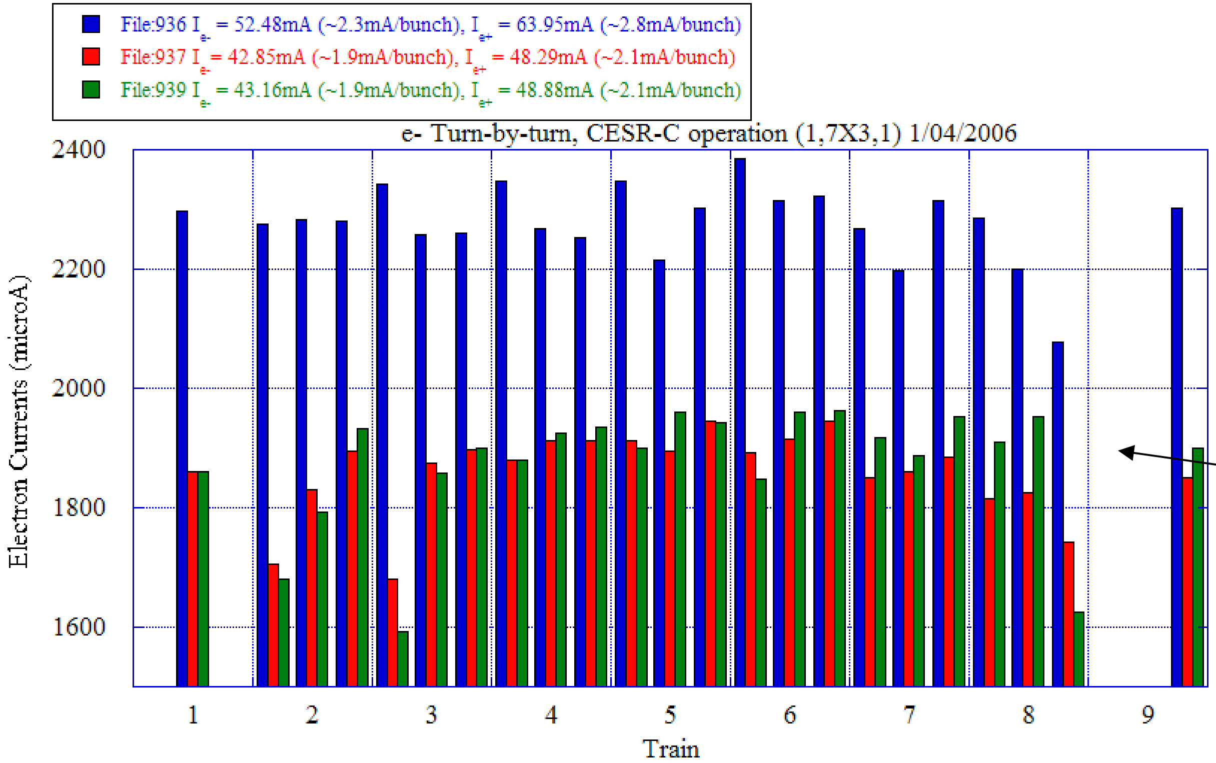
I. Introduction

e+/e- CESR-C
1,7x3,1 Pattern
Single bunch currents

Turn-by-turn vertical beam distribution measurements made at the beginning and end of a CESR-C run and the end of a 2nd CESR-C run (a different fill). Δt=32 min between the first two measurements. Δt=74 min between the 2nd and 3rd measurement. The 2nd measurement was made for electrons only.

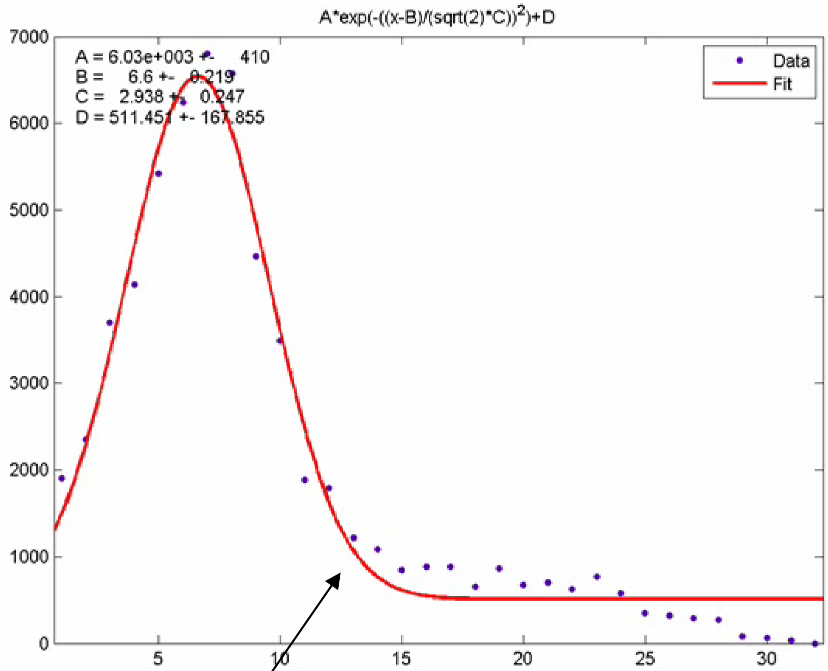


e+ current/bunch
Lifetime does not appear to follow a particular pattern.



e- current/bunch
Injection determines the current pattern at high I. For low I, lifetime does not appear to follow a particular pattern.

II. e+ turn-by-turn measurements



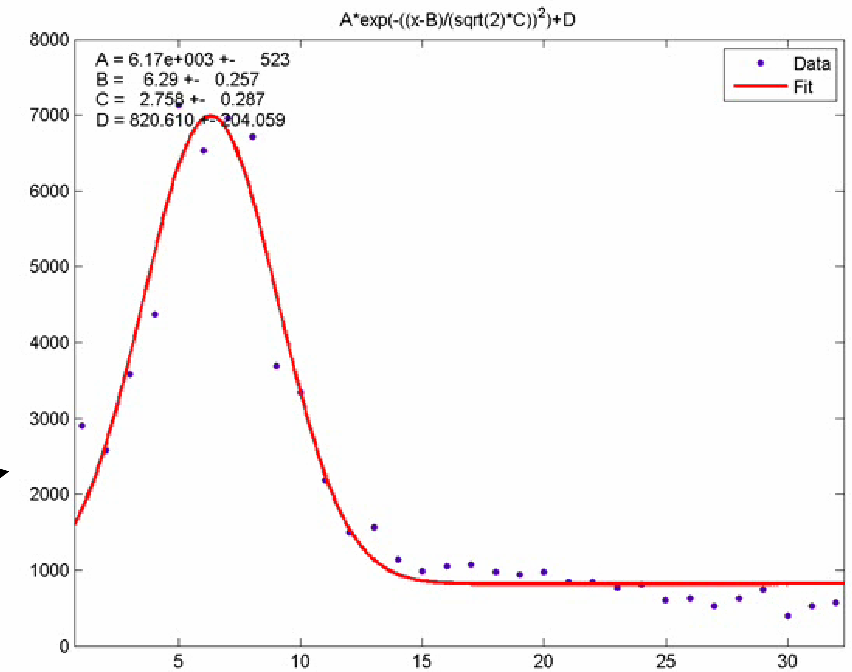
e+ single bunch vertical bunch distributions from the PMT array.

•10,000 turns of all 23 e+/e- bunches.

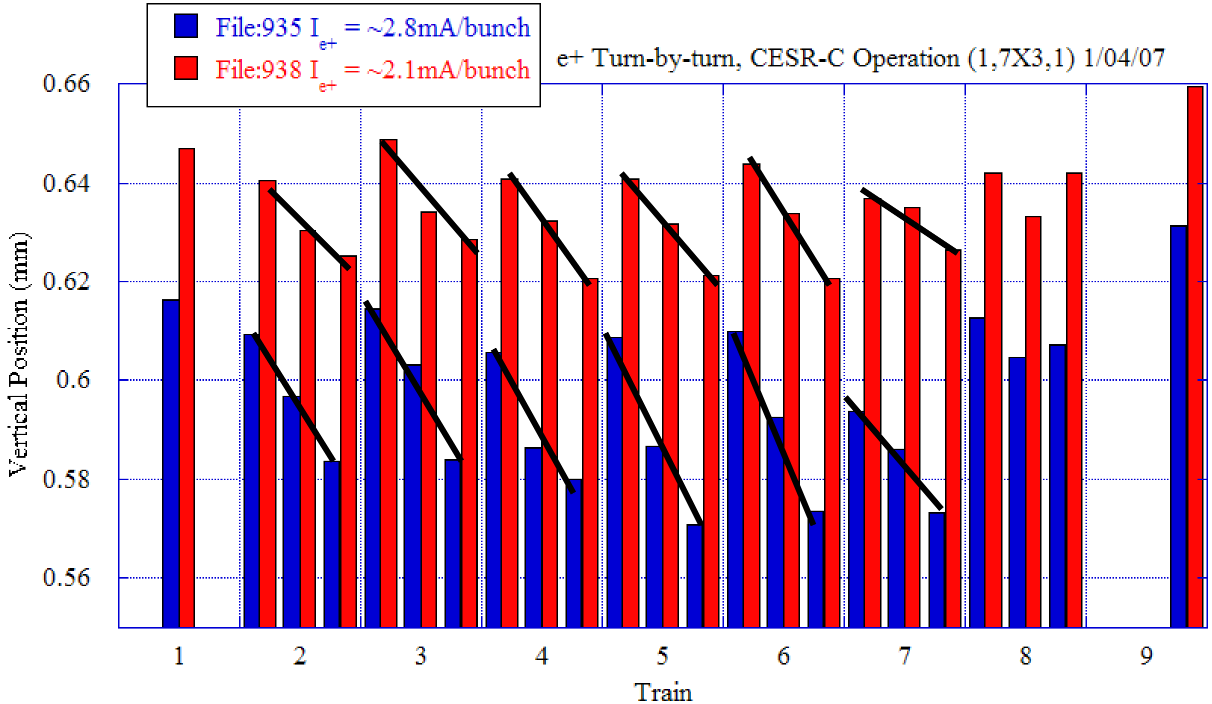
•Reflections in the optical system required that the vertical profile be moved to one side.

- High I File:935 I_{e+}= 2.8mA/bunch

e+ Bunch 4 Train 1
1st ten turns (movie)



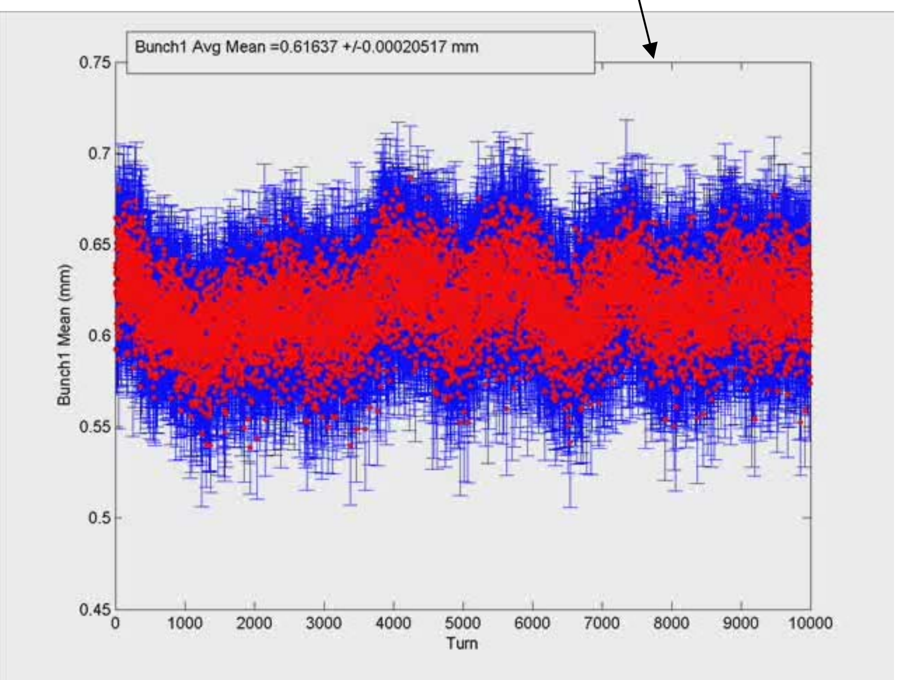
e+ Bunch 2 Train 4
1st ten turns (movie)



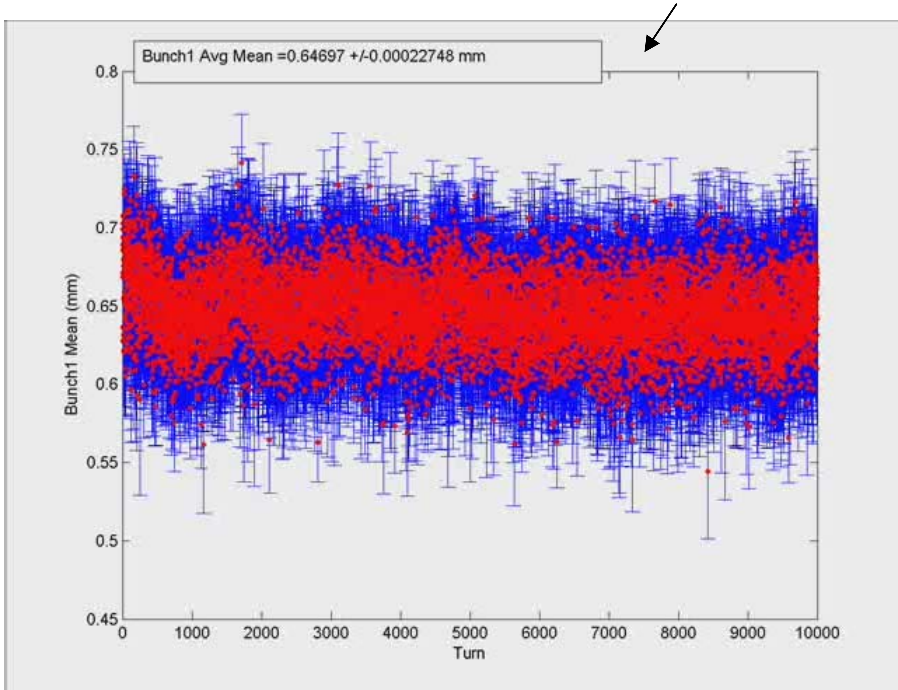
e+ Vertical Position

- e+ mean vertical position along the train-offset was included to have the plots coincide.
- Mean vertical position for 10,000 turns for 54 bunches.
- Low frequency vertical oscillation is denoted for all 54 bunches.
- At high I, a significant drop in vertical position is denoted along the train.

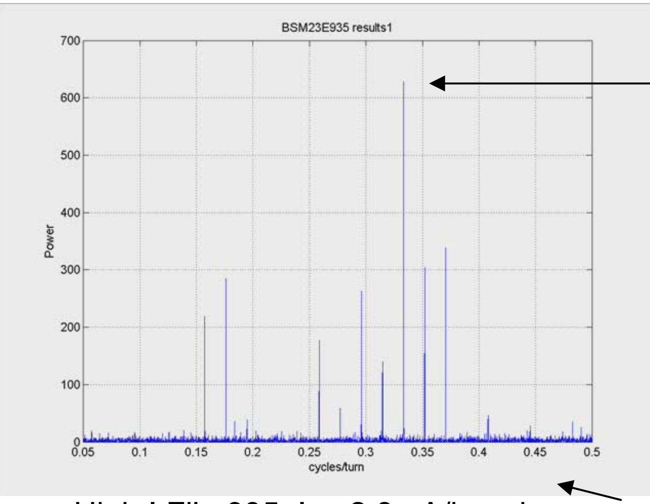
High I File:935 I_{e+}=2.8mA/bunch (movie)

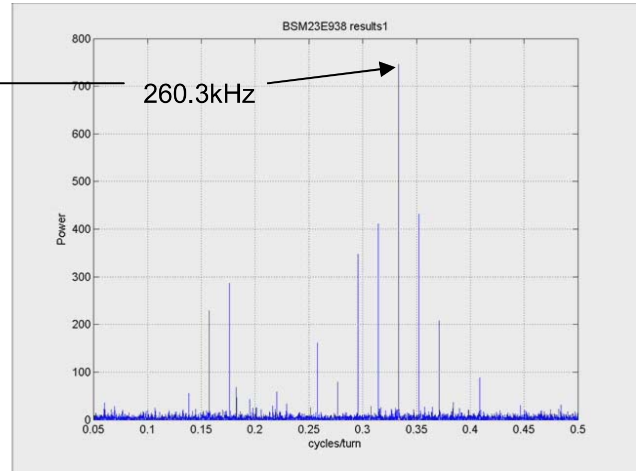


Low I File:938 I_{e+}=2.1mA/bunch (movie)



e+ vertical position oscillation- FFT of vertical position for 9,000 turns





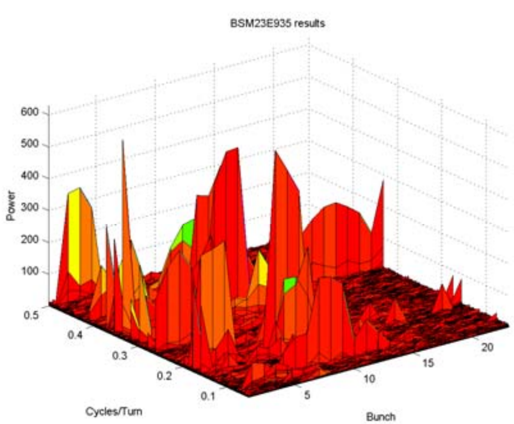
260.3kHz

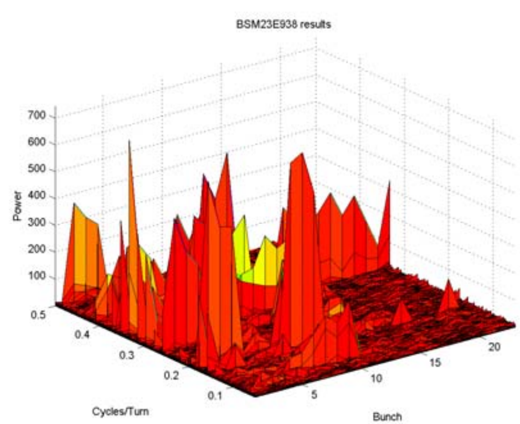
- •FFT of vertical position for each bunch
- •Vertical position peak oscillation frequency at ~ 260.3kHz.
- •Many oscillation frequencies show up at power comparable to that of the main oscillation frequency.
- •The vertical tune was measured as 255.4kHz at 12:54 pm on 1/4/07, with I+=60mA, I-=50mA.

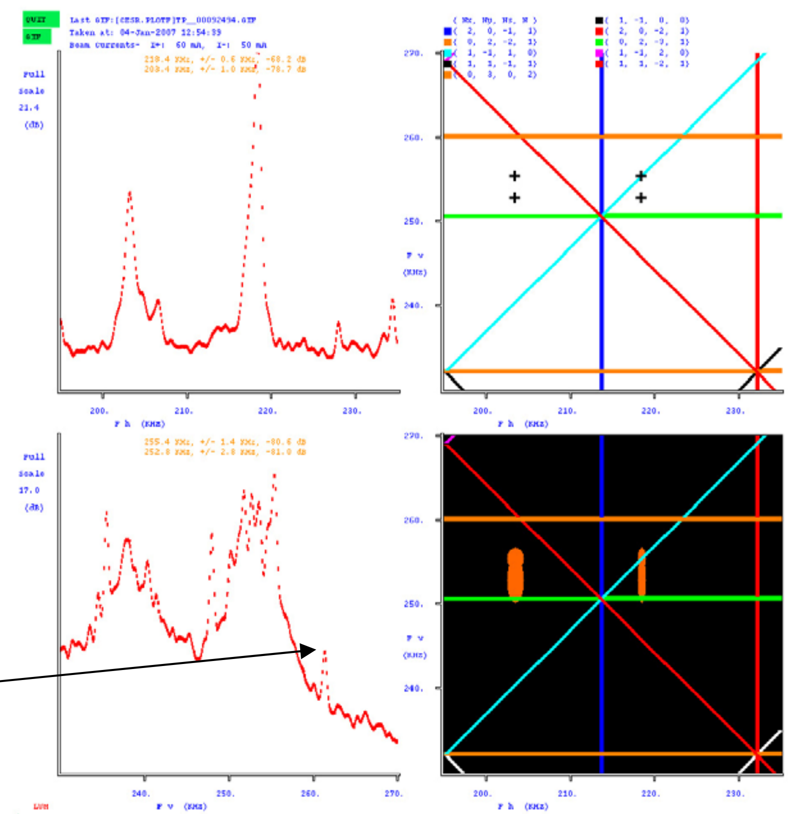
High I File:935 I_{e+}=2.8mA/bunch

movies

Low I File:938 I_{e+}=2.1mA/bunch

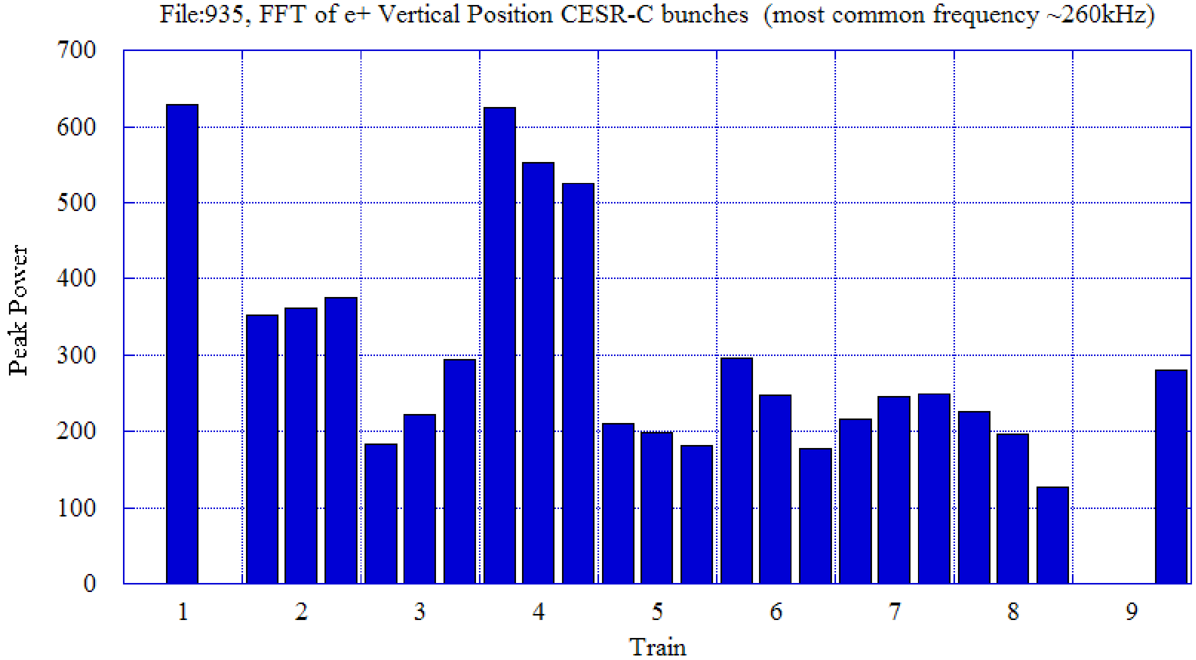


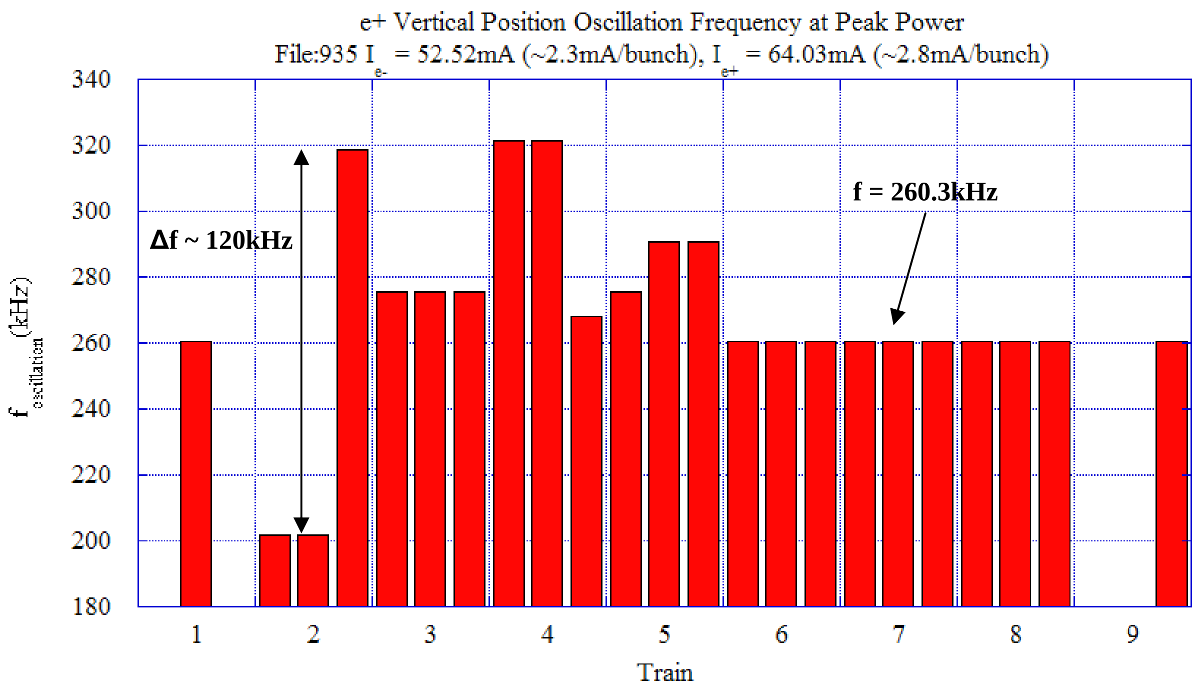




This peak appears very near to the 260.3kHz oscillation frequency that shows up consistently in this date's measurements.

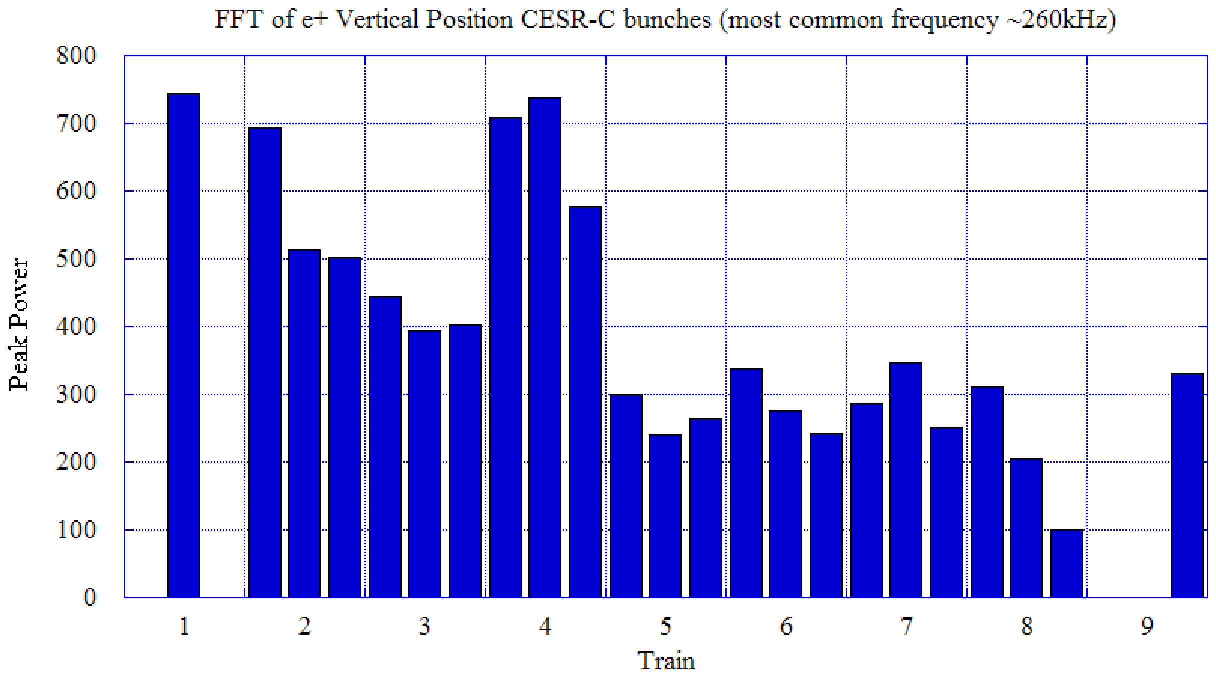
e+ vertical motion-Power and Frequency of Oscillation, High I File:935 I_{e+}=2.8mA/bunch



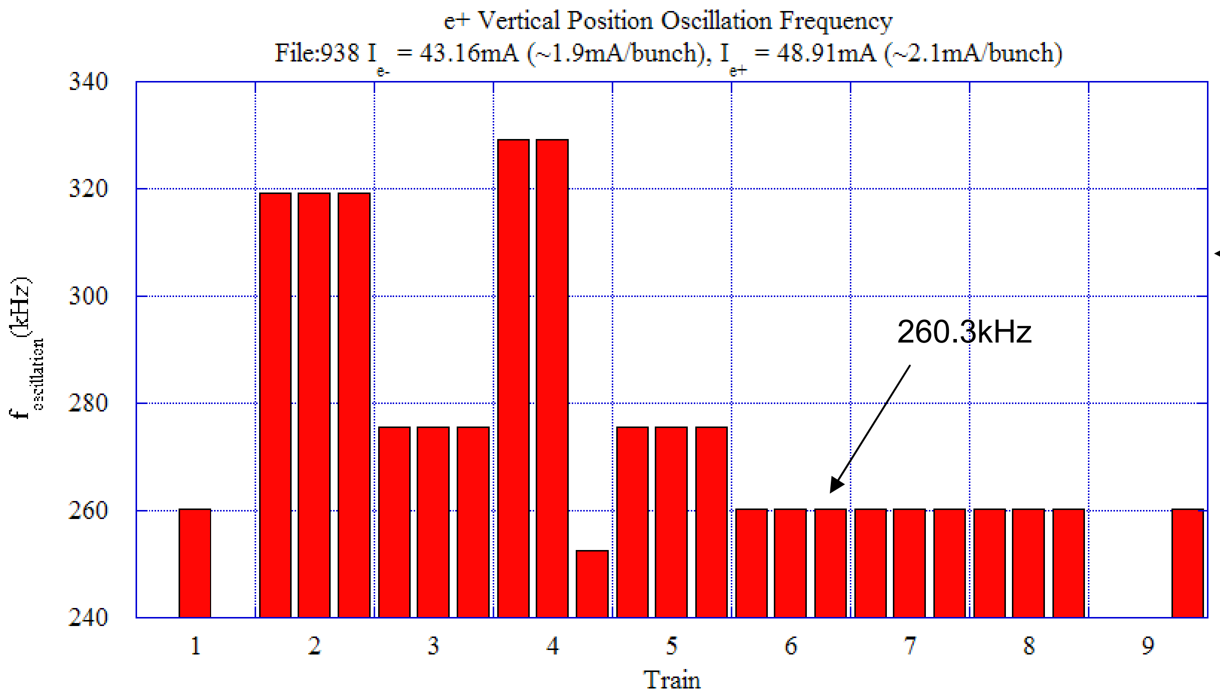


- Trains 1 and 6-9 share the same peak oscillation frequency (260.3kHz), near the measured vertical tune.
- Note that a small peak in the vertical tune measurement appears to be very near to 260.3kHz (see previous slide).
- Bunches in trains 2-5 have widely varying peak oscillation frequencies. The power of the 260.3kHz line decreases drastically for these bunches, to near the noise level for most cases.

e+ vertical motion-Power and Frequency of Oscillation, Low I File:938 I_{e-}=2.1mA/bunch

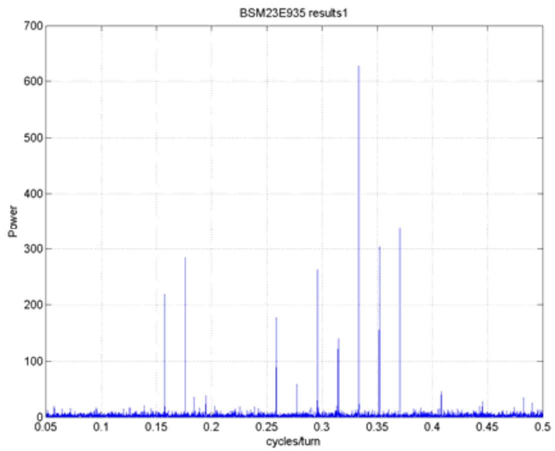


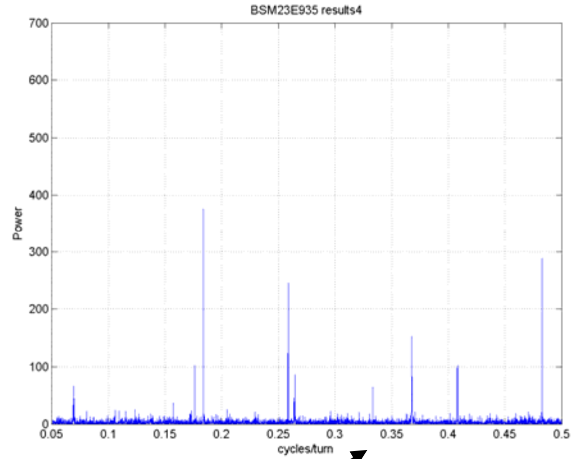
- Trains 1 and 6-9 share the same peak oscillation frequency (260.3kHz).
- Peak oscillation frequencies vary between trains 2-5, but in all but the last bunch of train 4, each bunch in the train displays the same peak oscillation frequency.

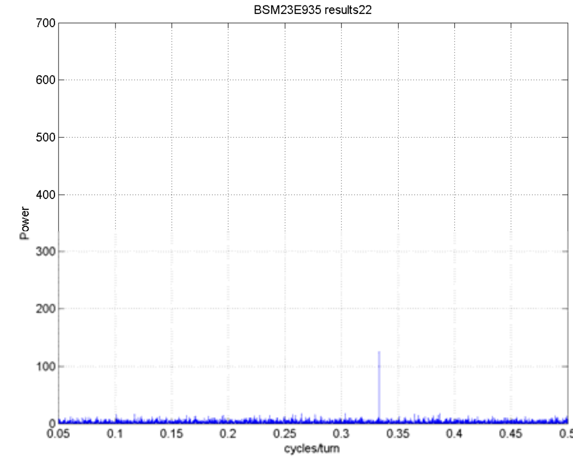


Peak oscillation frequencies, corresponding to the peak powers above.

e+ FFT power dependence on vertical position oscillation amplitude– High I







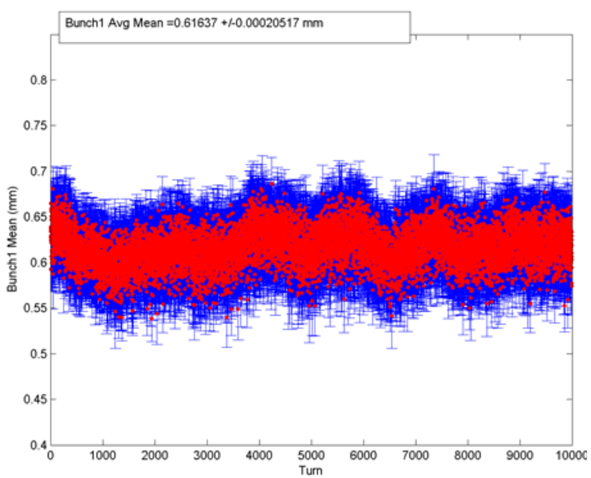
Bunch 1
Peak Power=628@260.3kHz
y_{avg}=0.616mm
Std=0.020mm

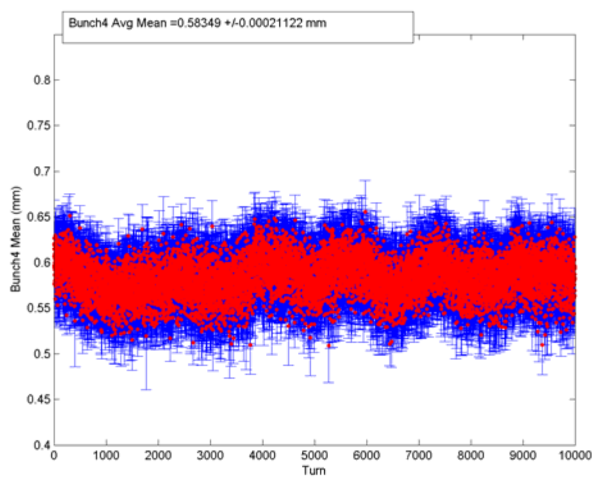
Bunch 4
Peak Power=376@318.6kHz
y_{avg}=0.583mm
Std=0.021mm

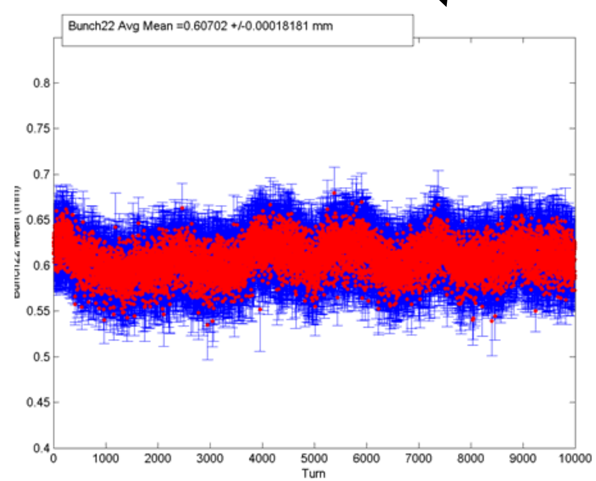
Bunch 22
Peak Power=125@260.3kHz
y_{avg}=0.607mm
Std=0.018mm

File:935 I_{e+}=2.8mA/bunch

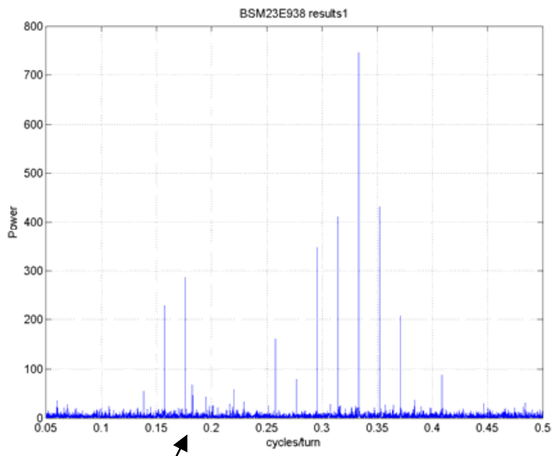
- Many frequencies are apparent, but they do not appear to correlate with the amplitude of vertical position oscillation.

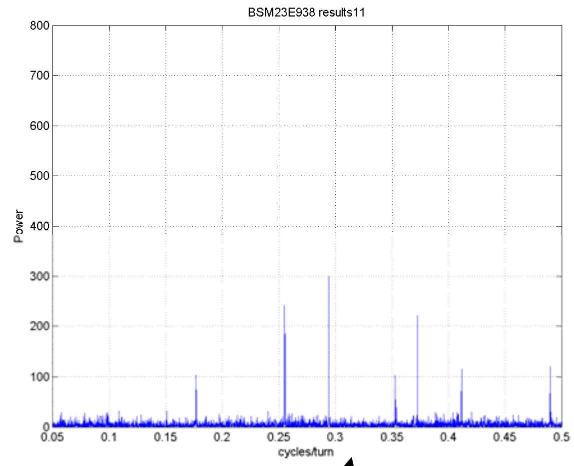


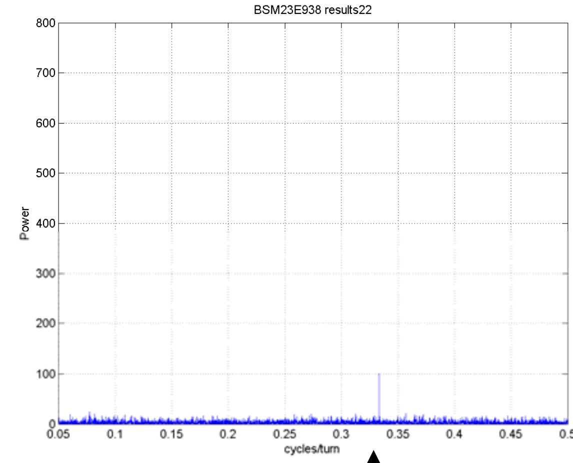




e+ FFT power dependence on vertical position oscillation amplitude– Low I







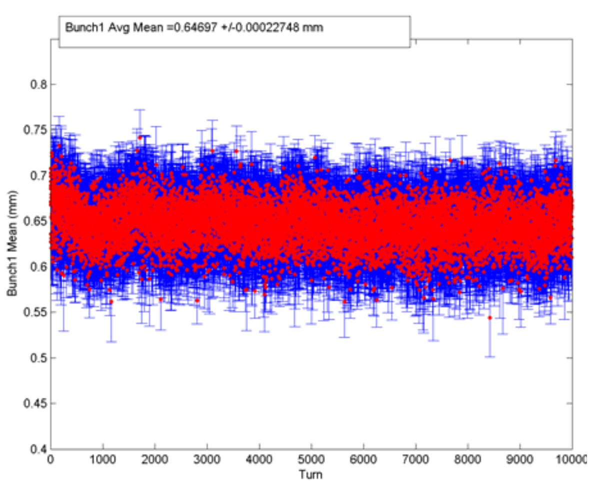
Bunch 1
Peak Power=745@260.3kHz
y_{avg}=0.647mm
Std=0.023mm

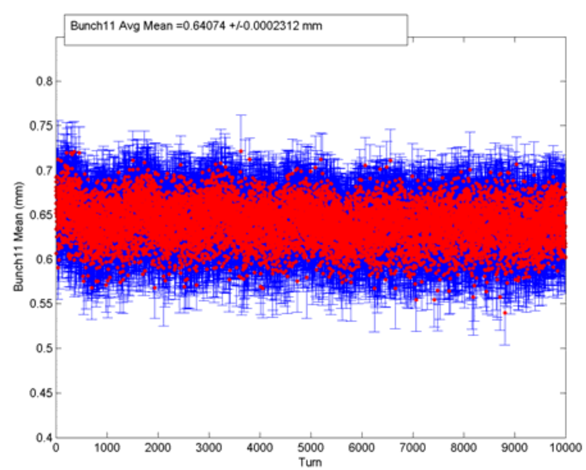
Bunch 11
Peak Power=299@275.4kHz
y_{avg}=0.641mm
Std=0.023mm

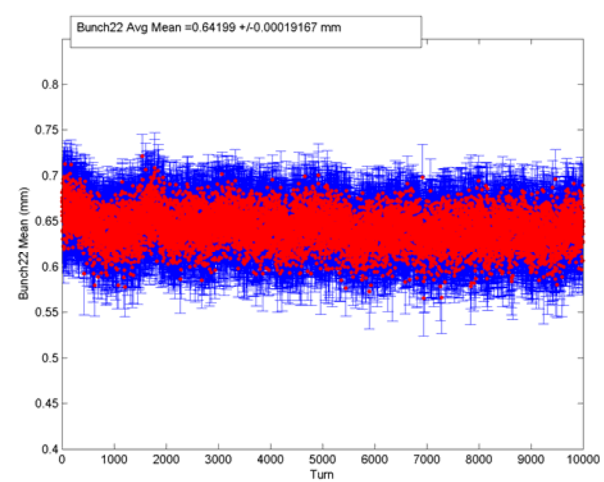
Bunch 22
Peak Power=100@260.3kHz
y_{avg}=0.641mm
Std=0.019mm

File 938 I_{e+}=2.1mA/bunch

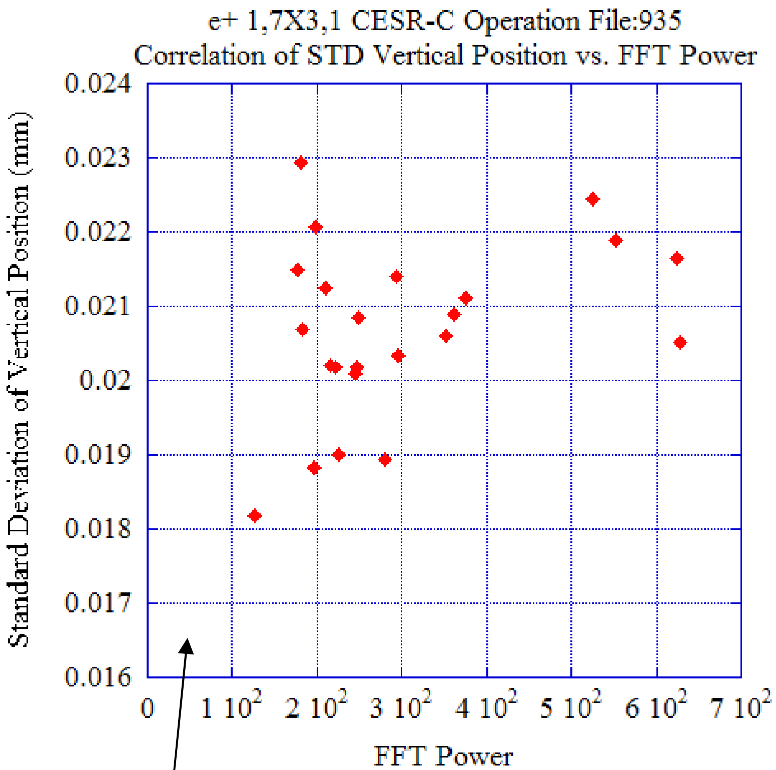
- The oscillation amplitude appears to be relatively constant.







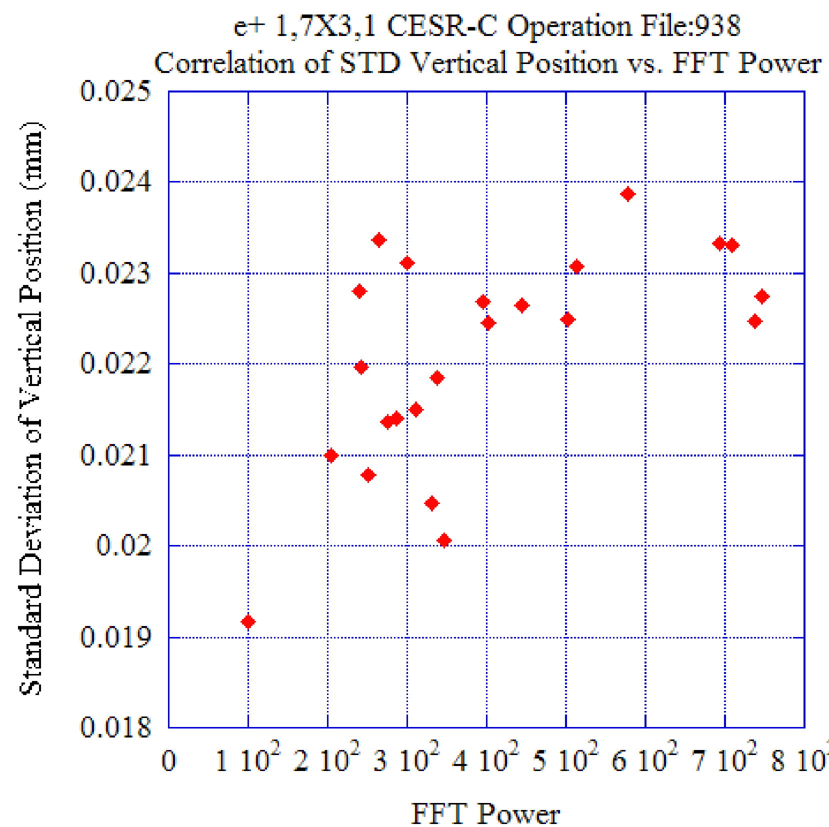
e+ vertical position oscillation amplitude



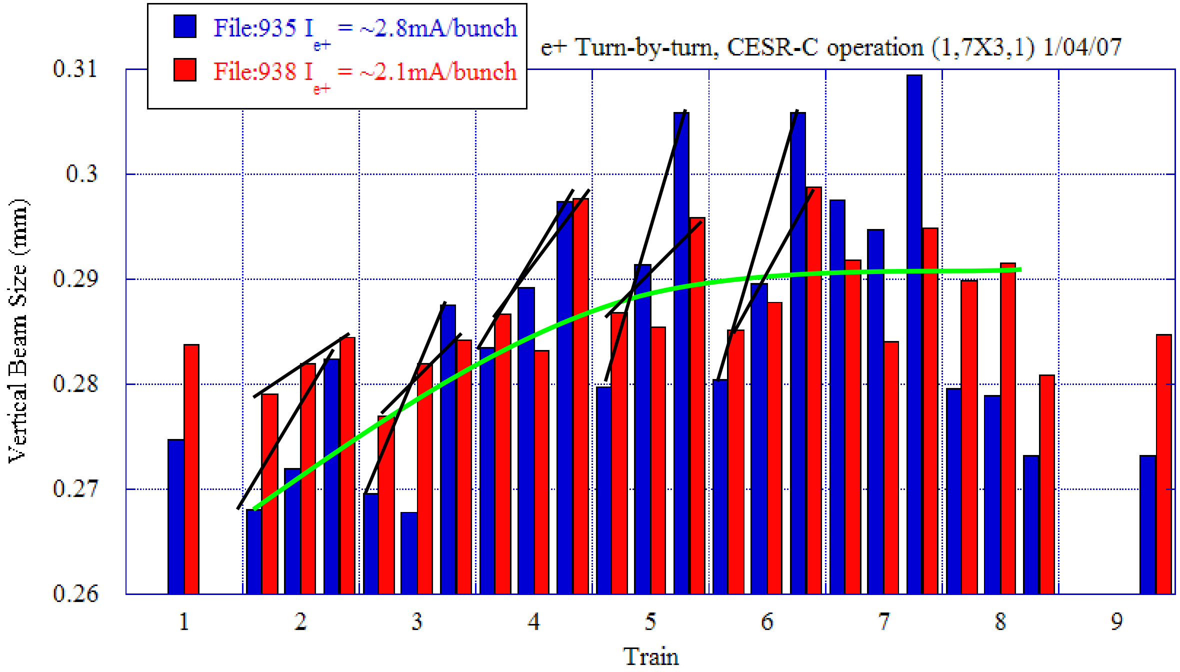
There is no apparent correlation between the peak power of vertical position oscillation and the standard deviation in the vertical position measurement. Note: the change in standard deviation is small in these plots.

High I File:935 I_{e+}=2.8mA/bunch

Low I File:938 I_{e+}=2.1mA/bunch

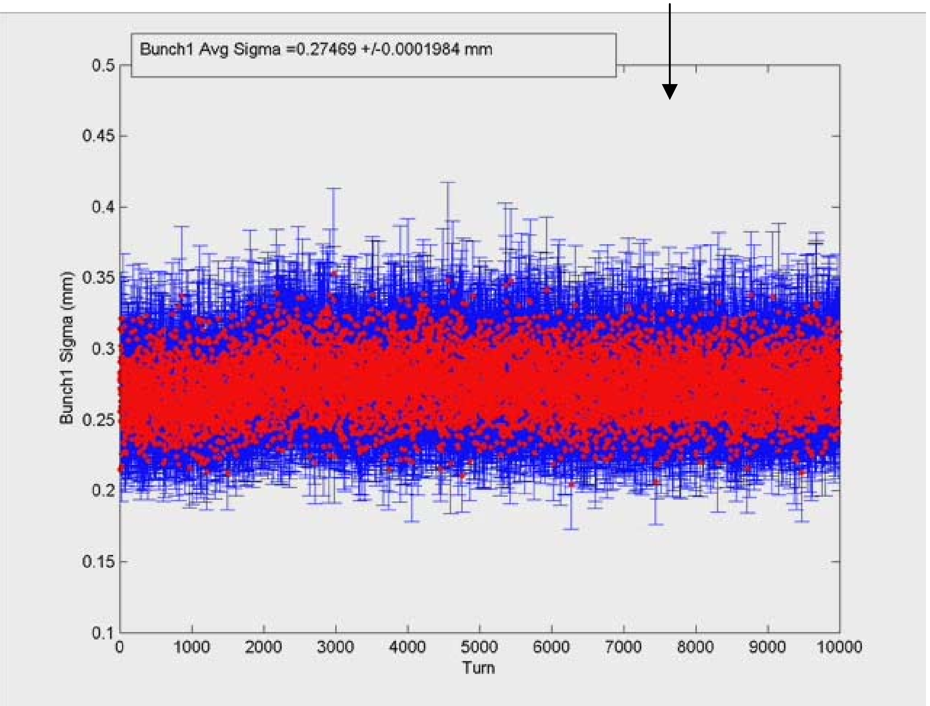


e+ σ_v along the train

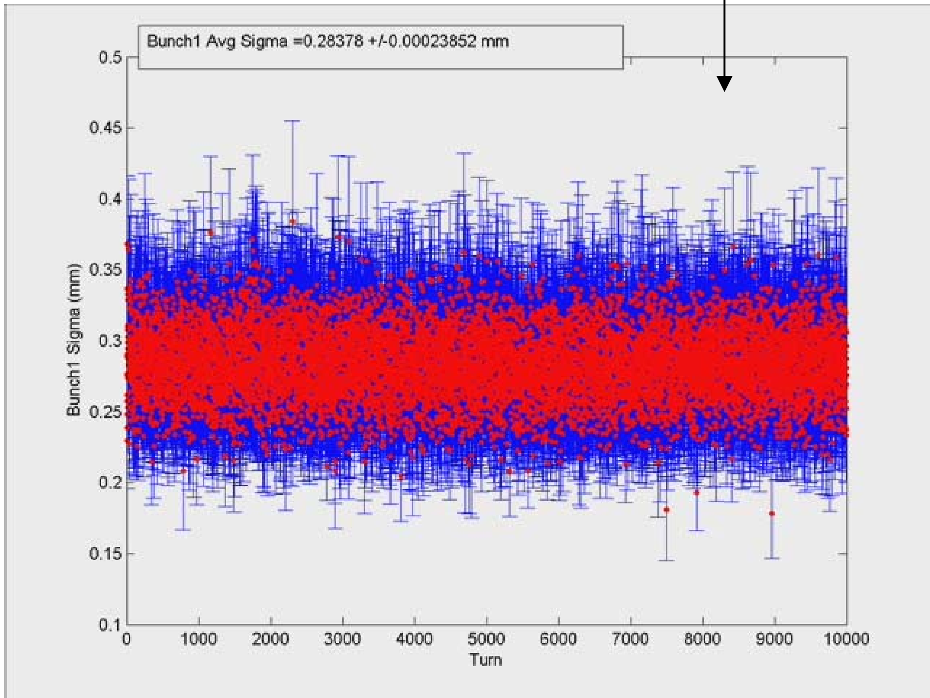


- σ_v 10,000 turns for 23 bunches.
- Vertical beam size tends to grow along the train, except in trains 7 and 8.
- There is a general increase in σ_v along all trains, until train 8.

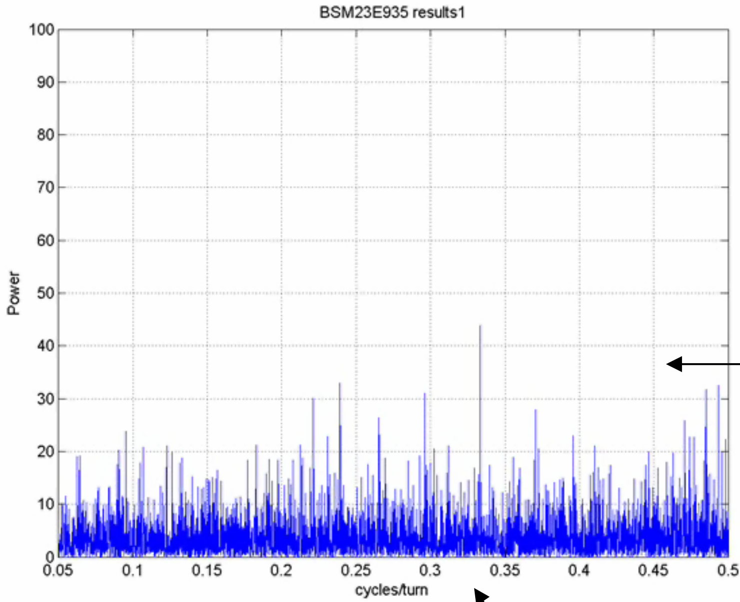
High I File:935 I_{e+}=2.8mA/bunch (movie)



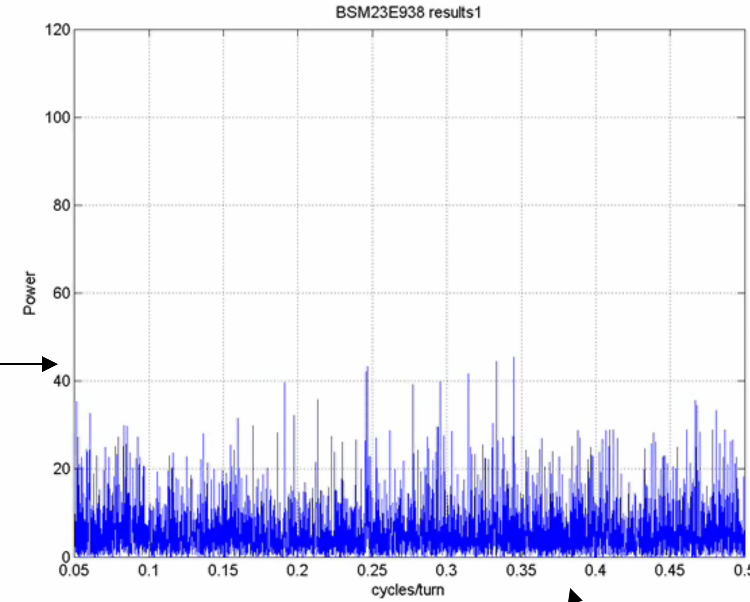
Low I File:938 I_{e+}=2.1mA/bunch (movie)



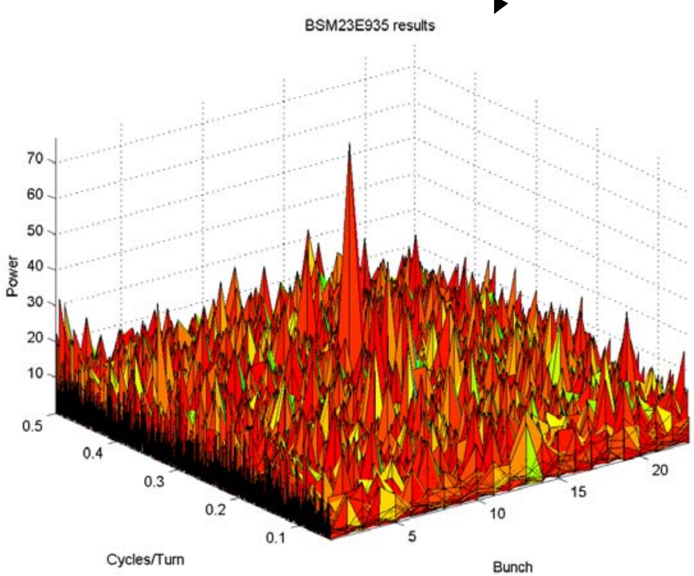
e+ high frequency σ_v oscillation frequency-FFT of σ_v for 10,000 turns



movies

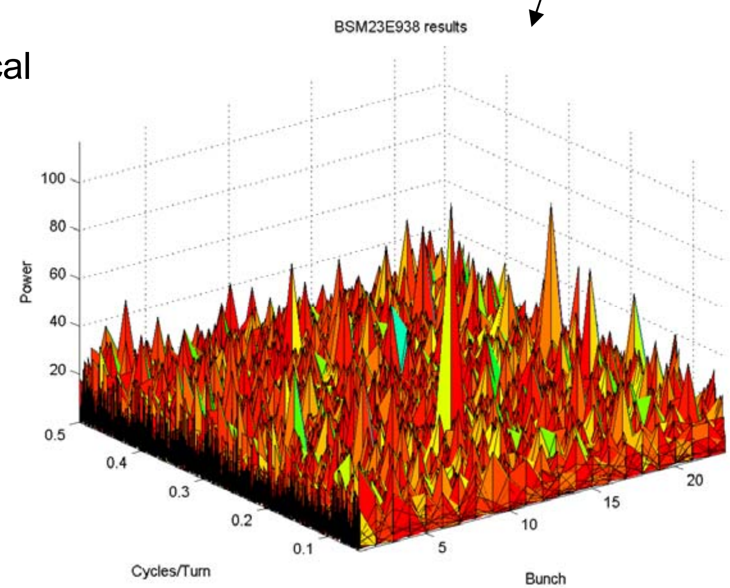


High I File:935 I_{e+}=2.8mA/bunch

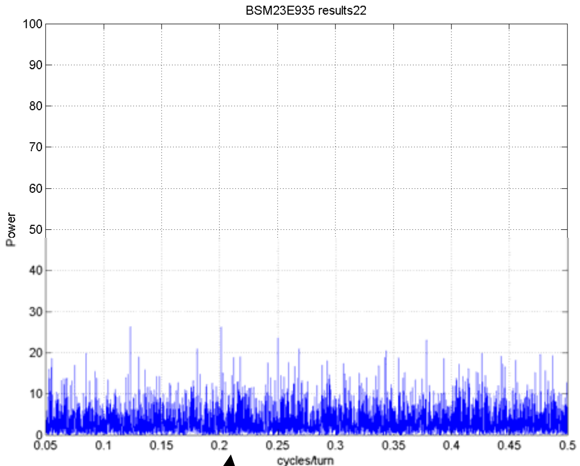


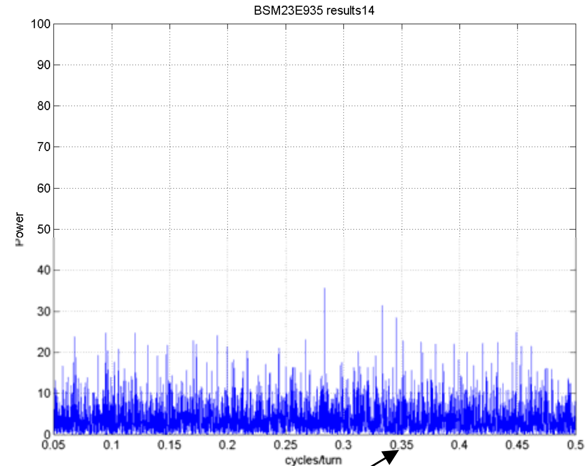
- FFT of σ_v for all 23 bunches
- No clear oscillation frequency in the vertical beam size.

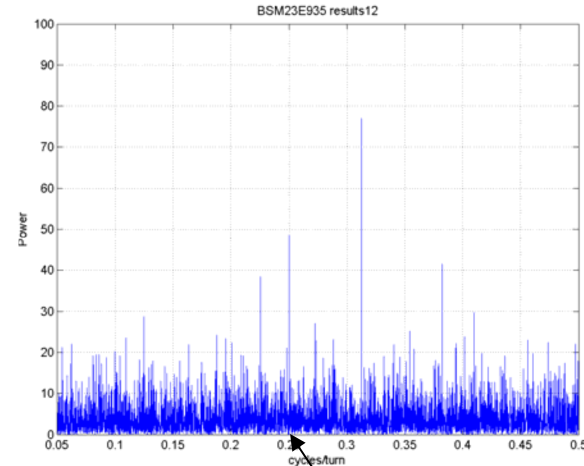
Low I File:938 I_{e+}=2.1mA/bunch



e+ σ_v oscillation - FFT of σ_v - High I







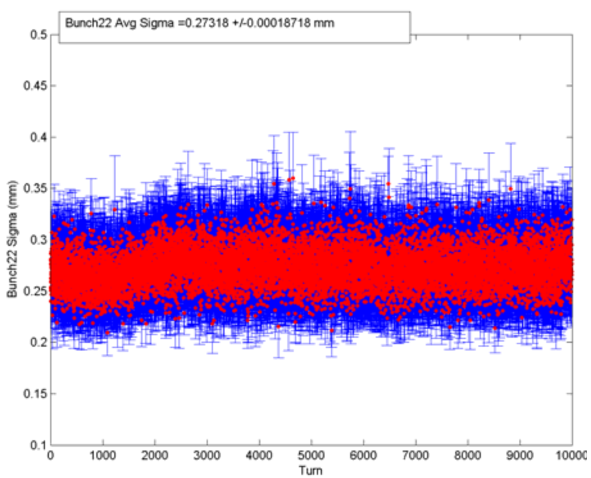
Bunch 22
Peak Power=26@342.4kHz
σ_v=0.273mm
Std=0.018mm

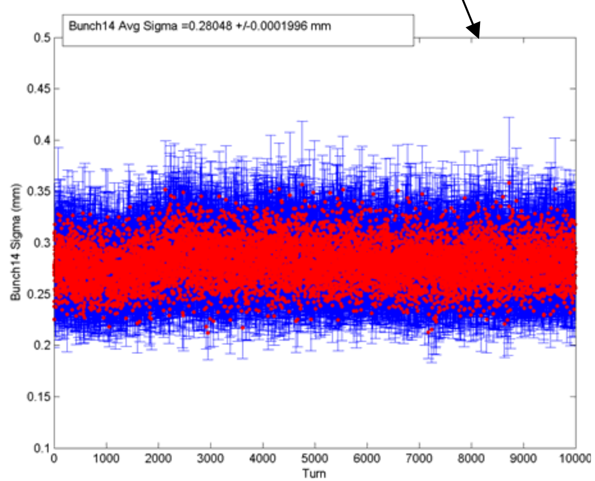
Bunch 14
Peak Power=36@279.8kHz
σ_v=0.280mm
Std=0.019mm

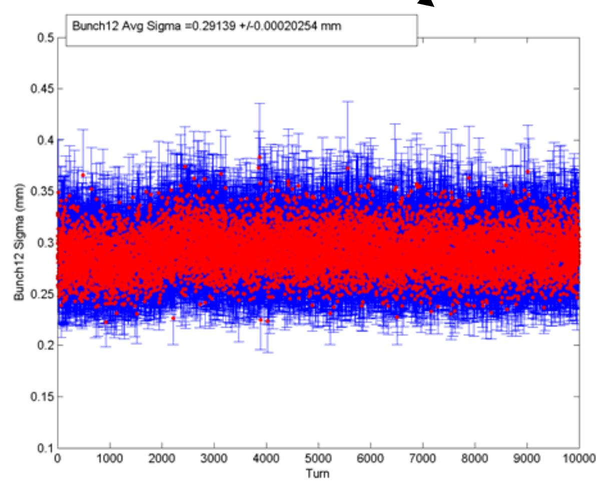
Bunch 12
Peak Power=77@268.4kHz
σ_v=0.291mm
Std=0.020mm

File 935 I_{e+}=2.8mA/bunch

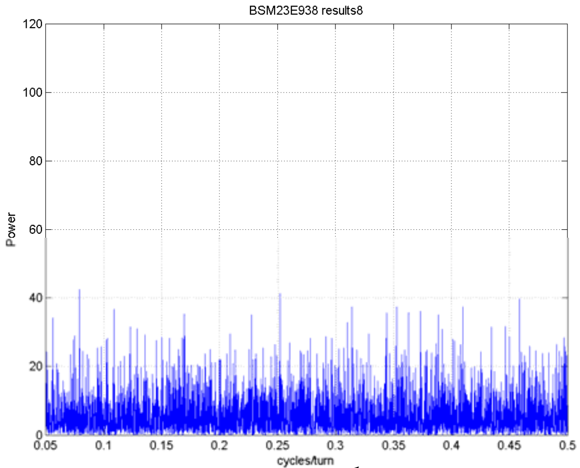
- Noise does not appear to correlate with oscillation amplitude.

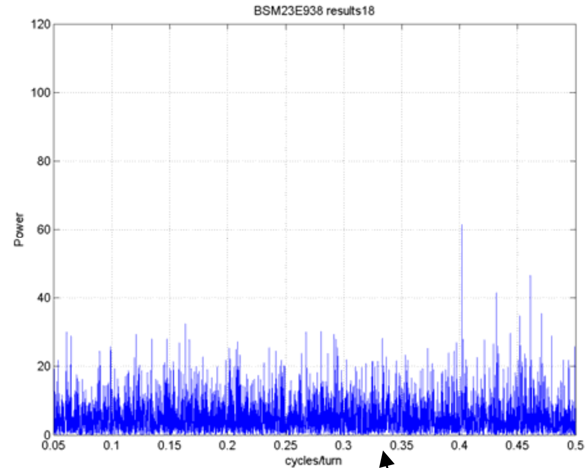


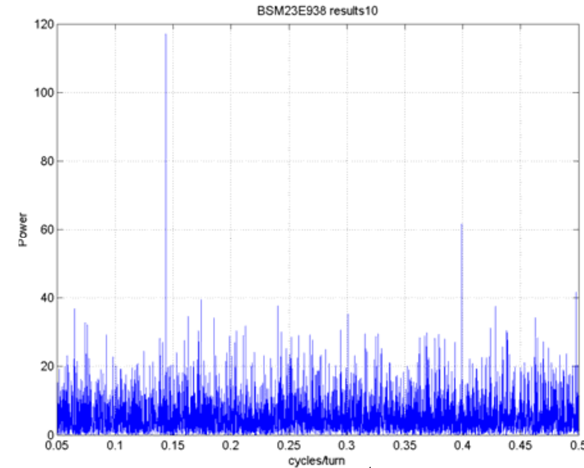




e+ high frequency σ_v oscillation frequency- FFT of σ_v - Low I







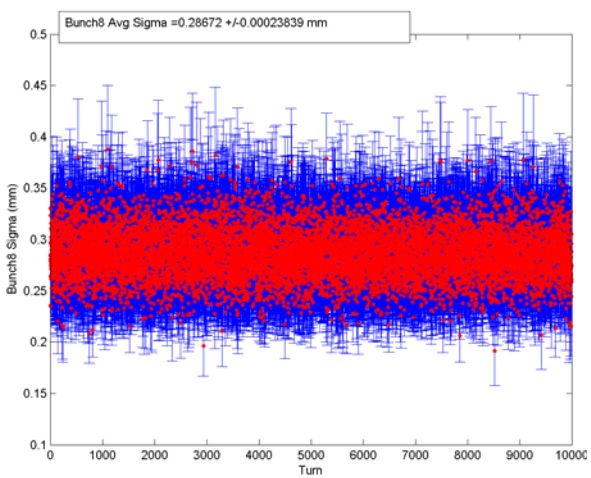
Bunch 8
No distinct peak
σ_v=0.287mm
Std=0.024mm

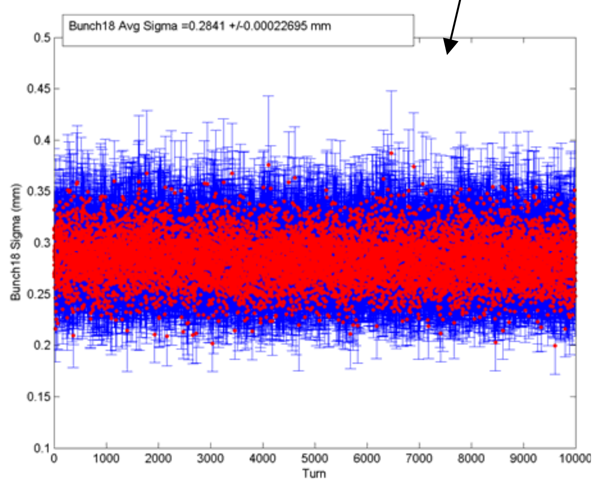
Bunch 18
Peak Power=62@233.4kHz
σ_v=0.284mm
Std=0.027mm

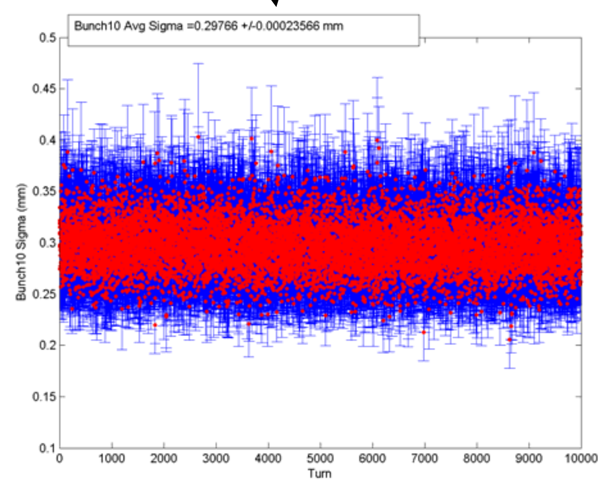
Bunch 10
Peak Power=117@56kHz
σ_v=0.298mm
Std=0.024mm

File 938 I_{e+}=2.1mA/bunch

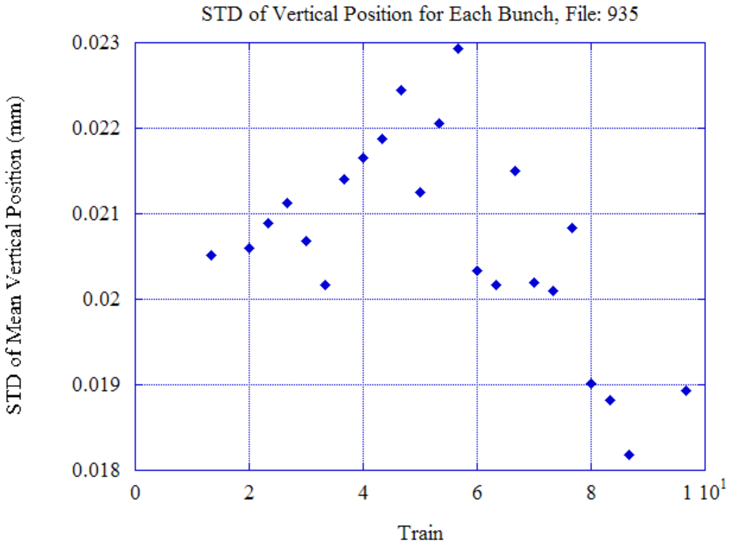
- Noise does not appear to correlate with oscillation amplitude.

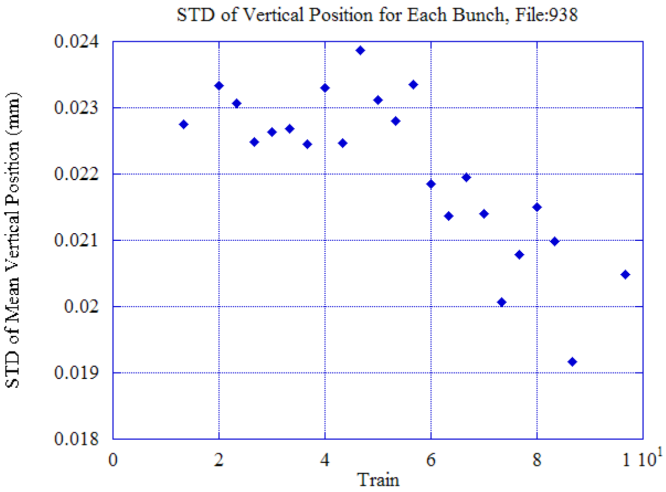




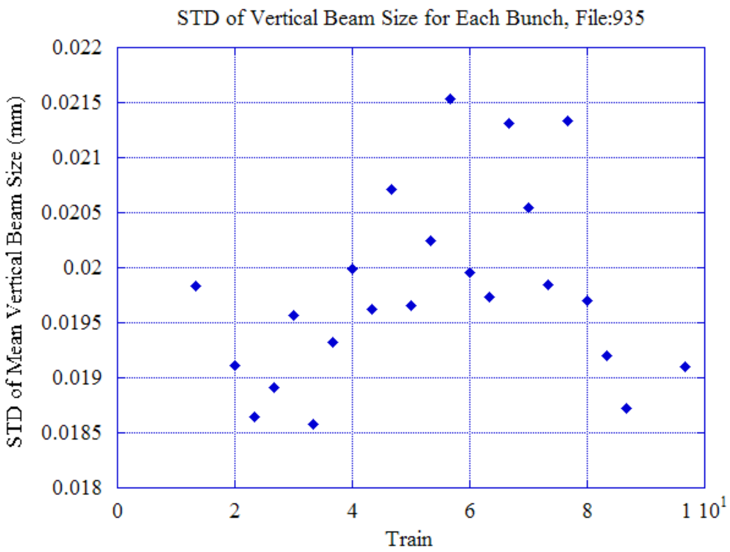


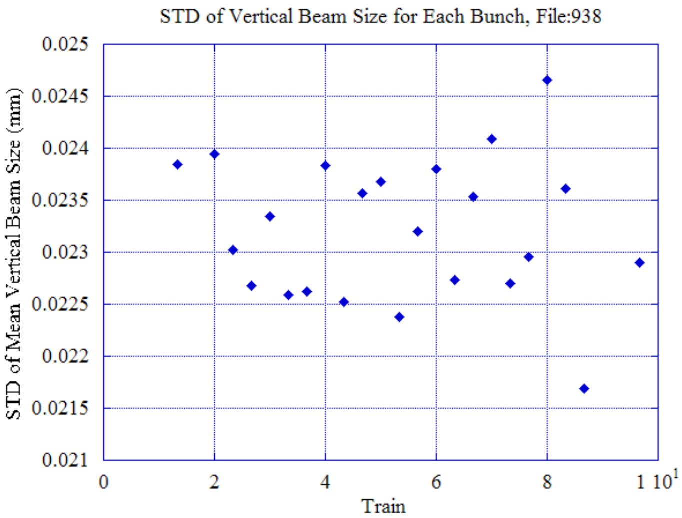
e+ Vertical position and beam size: standard deviations by bunch





- At low I, there appears to be some relationship between bunch number and the standard deviation in vertical position.
- There is no apparent relationship between bunch number and the standard deviation in the vertical beam size.

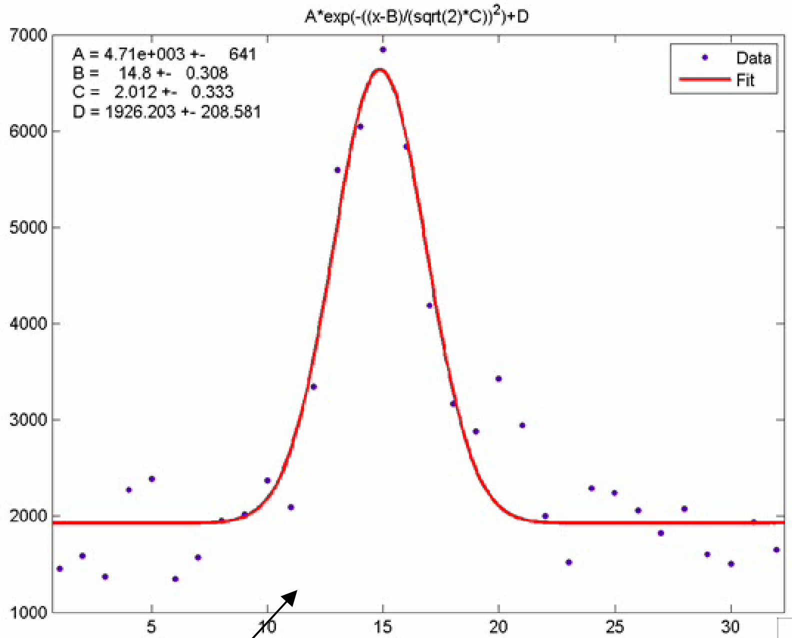




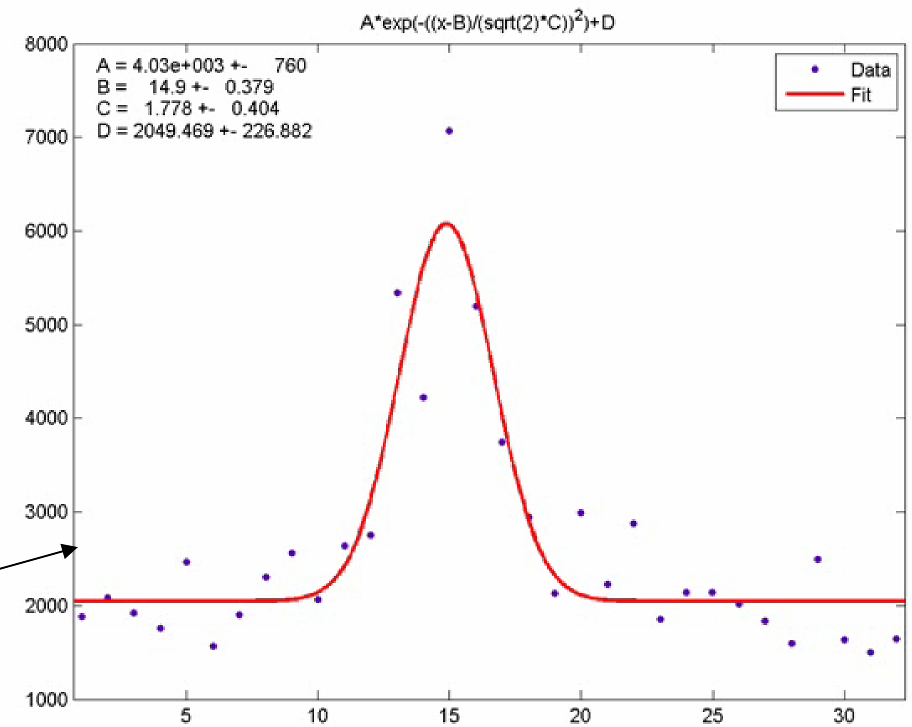
III. e- turn-by-turn measurements

e- single bunch vertical bunch distributions from the PMT array.

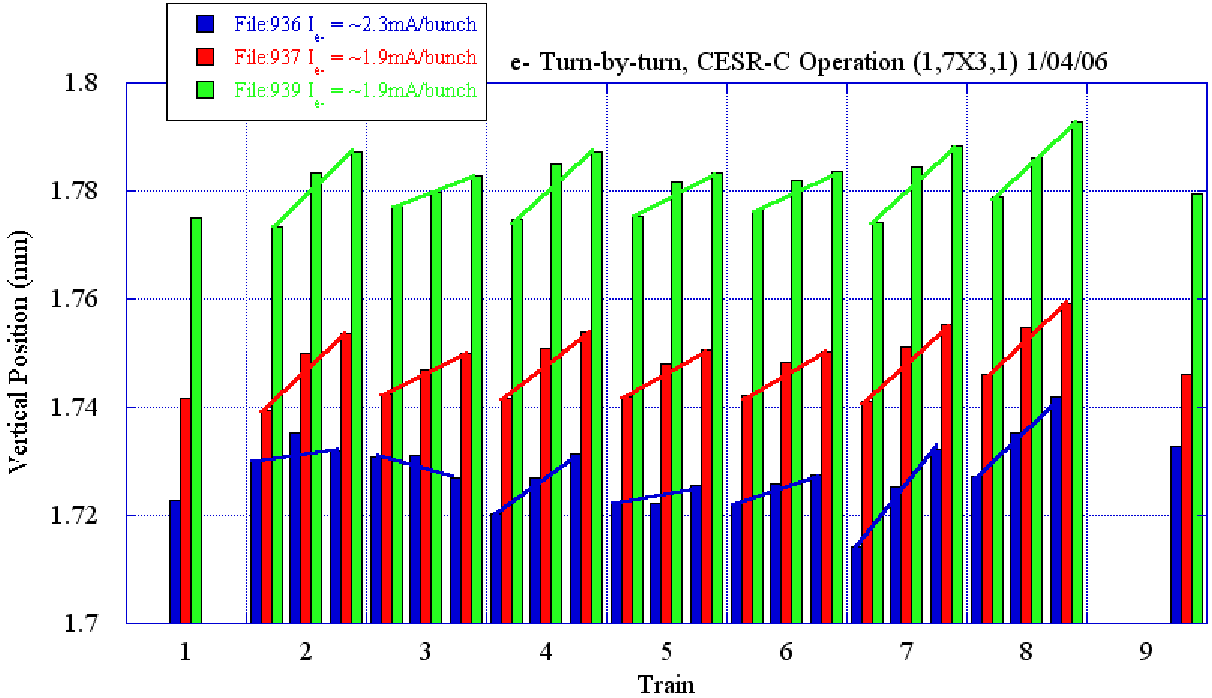
- 10,000 turns of 23 e+/e- bunches.
- High I File:936 I_{e-}=2.3mA/bunch



e- Bunch 4 Train 1
1st ten turns (movie)



e- Bunch 5 Train 4
1st ten turns (movie)



e- Vertical Position

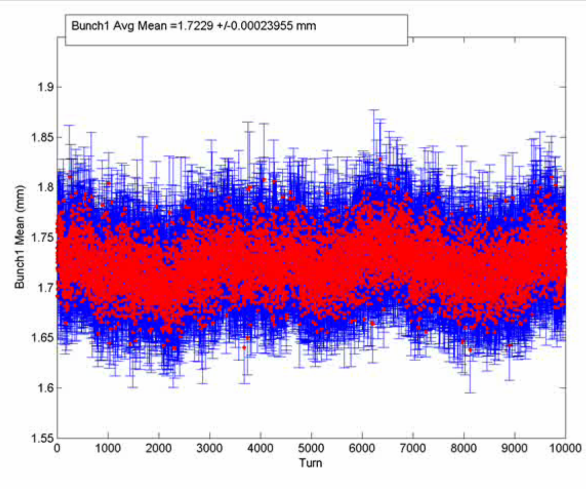
- e- mean vertical position along the train-offset was included to have the plots coincide.
- Mean vertical position for 10,000 turns for 23 bunches.
- The mean vertical position increases along the train for low current. It follows this trend for the high current with the exception of trains 2 and 3.

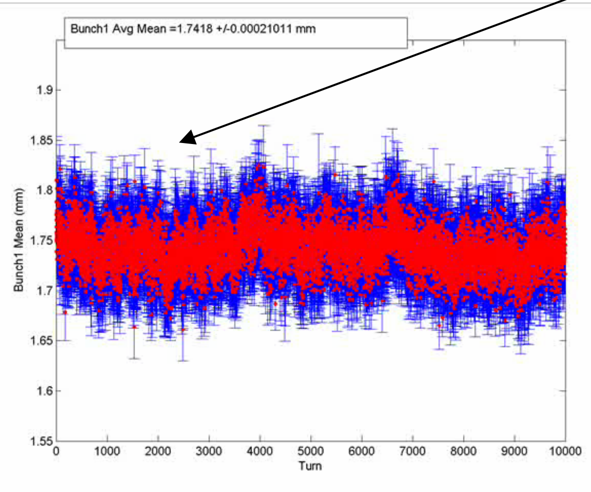
High I File:936 I_{e-}=2.3mA/bunch (movie)

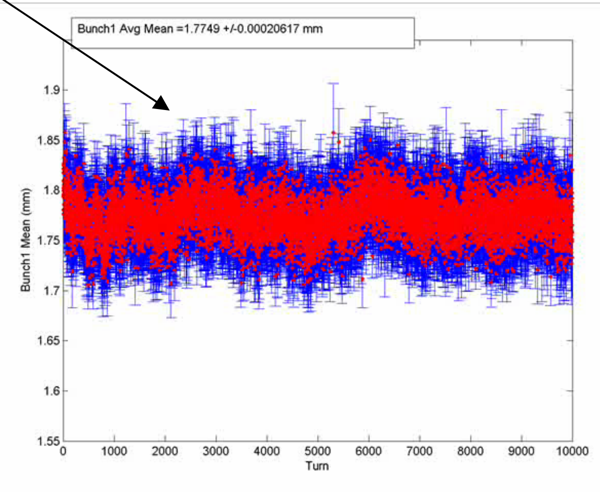
Low I File:937 I_{e-}=1.9mA/bunch (movie)

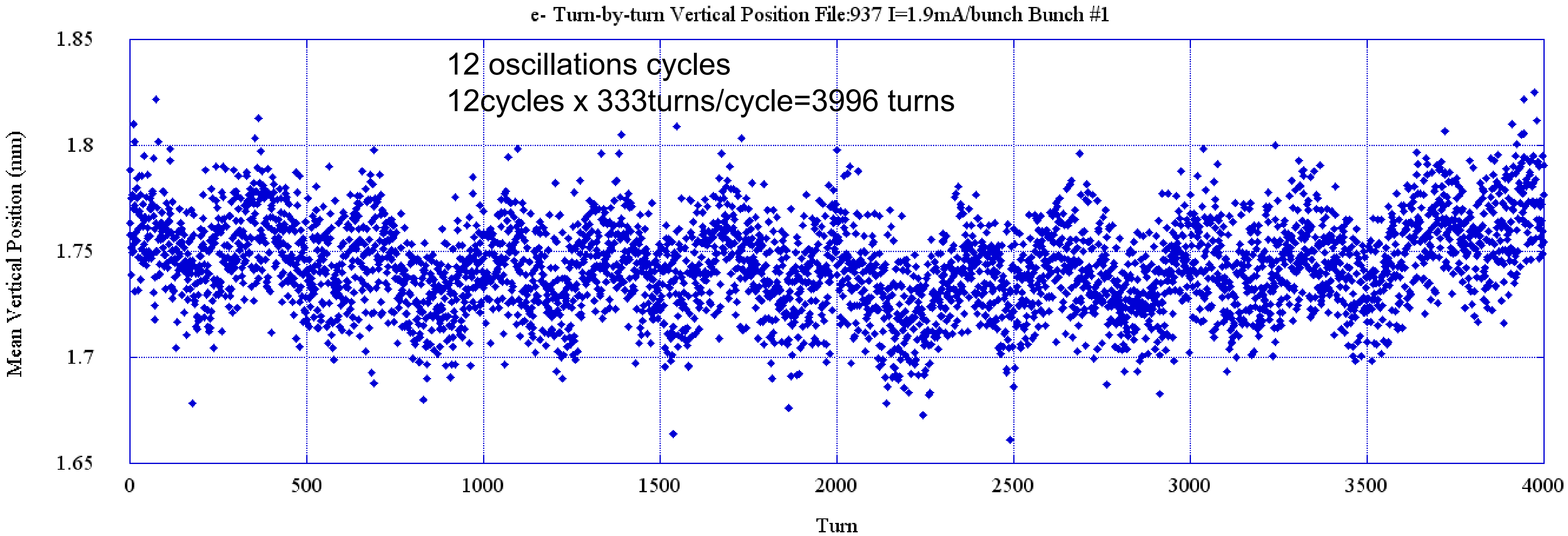
Low I File:939 I_{e-}=1.9mA/bunch (movie)

Low frequency oscillation at low I



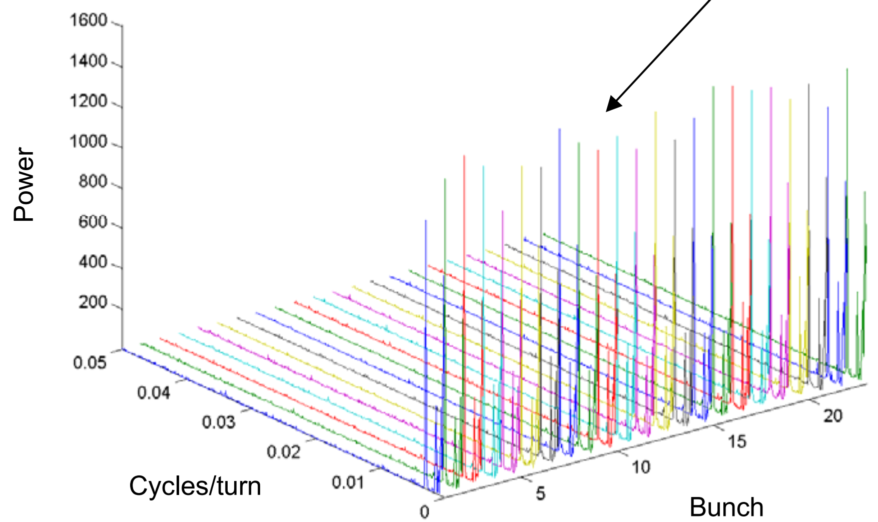


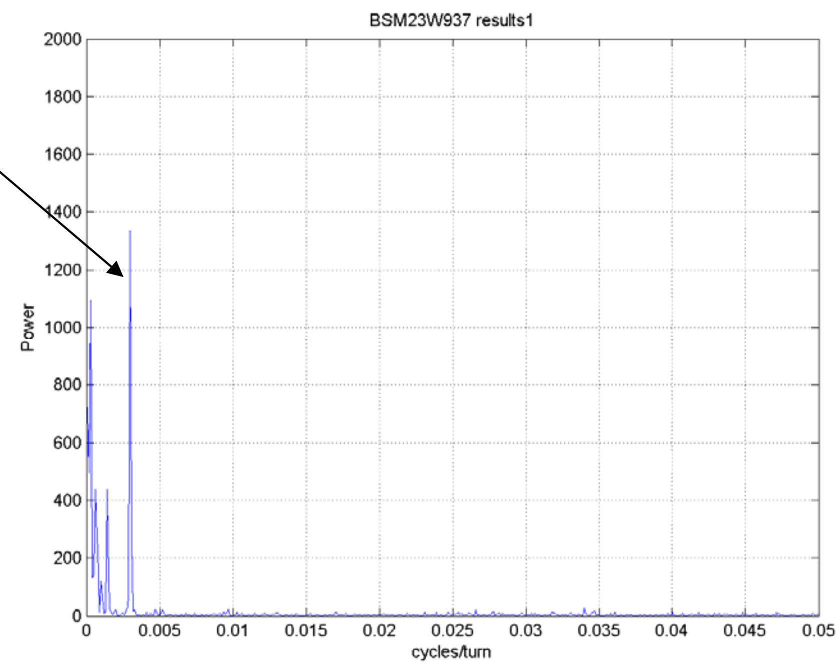




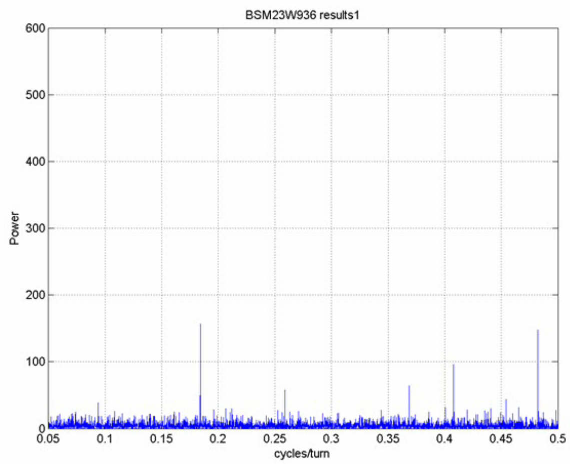
Low frequency oscillation of vertical position

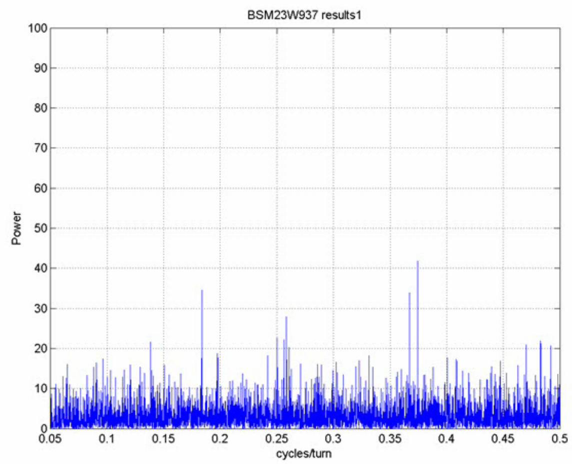
f_{osc}~333 turns

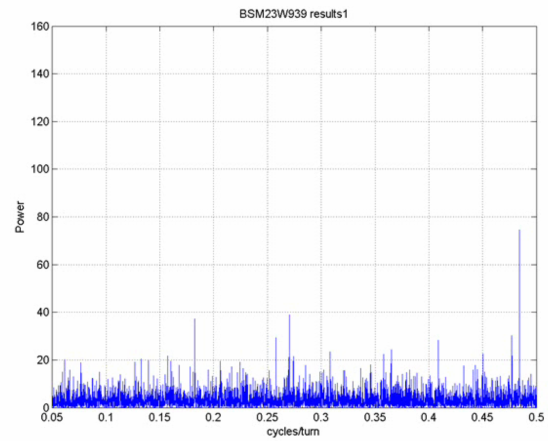




e- high frequency vertical position oscillation-FFT of vertical position for 10,000 turns







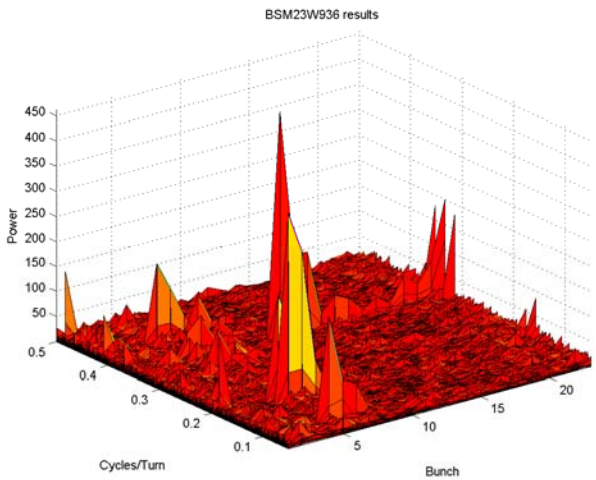
movies

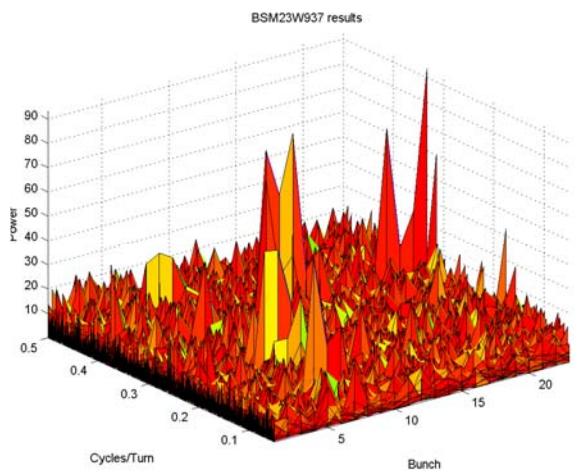
High I File:936 I_{e-}=2.3mA/bunch

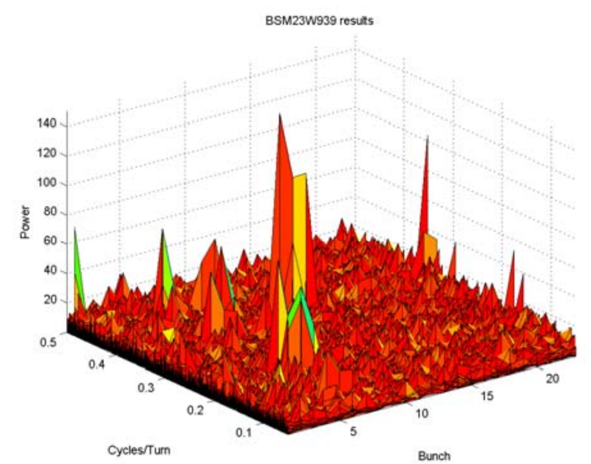
Low I File:937 I_{e-}=1.9mA/bunch

Low I File:939 I_{e-}=1.9mA/bunch

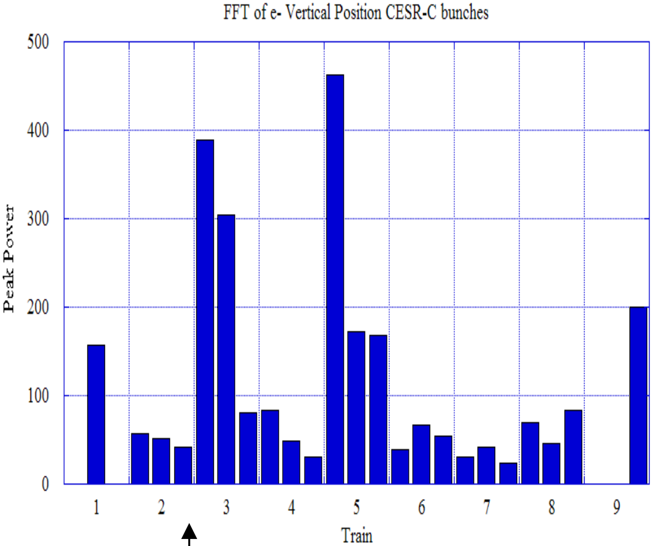
- FFT of the vertical position.
- Vertical oscillation detected only at low power. Highest power observed is near the vertical tune.

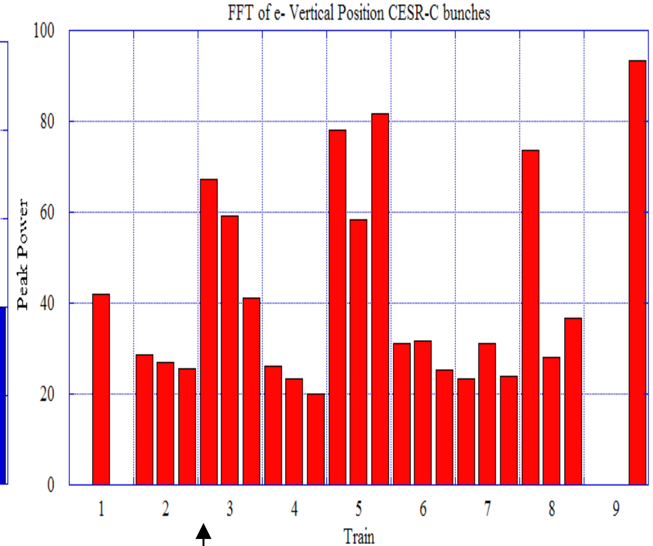


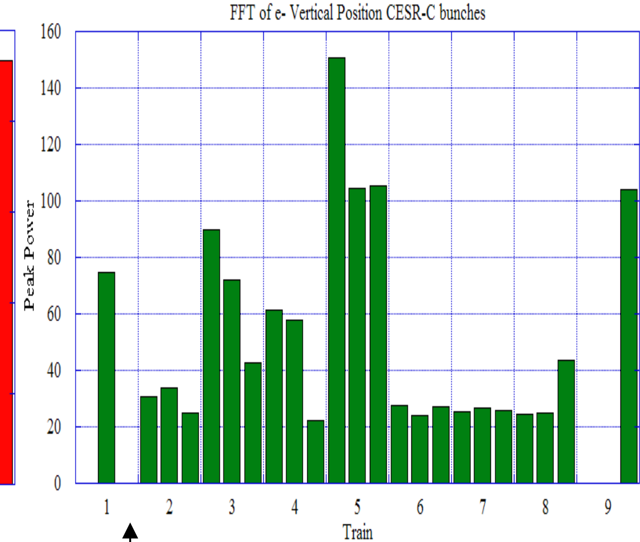




e- high frequency vertical position oscillation-Power and Frequency of Oscillation





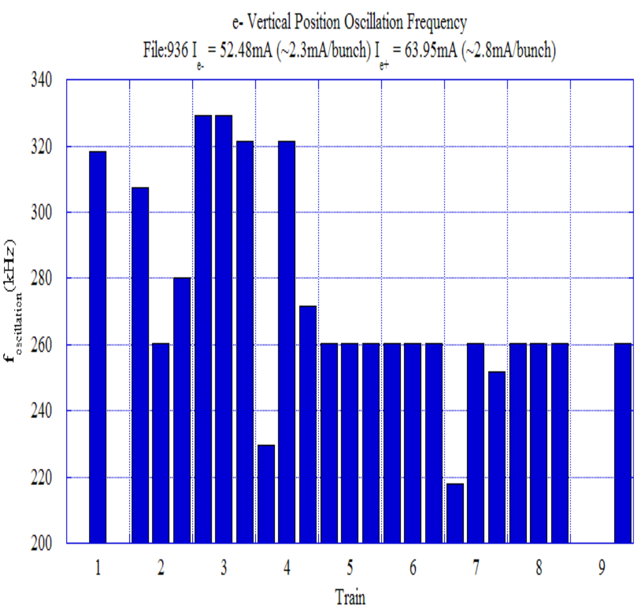


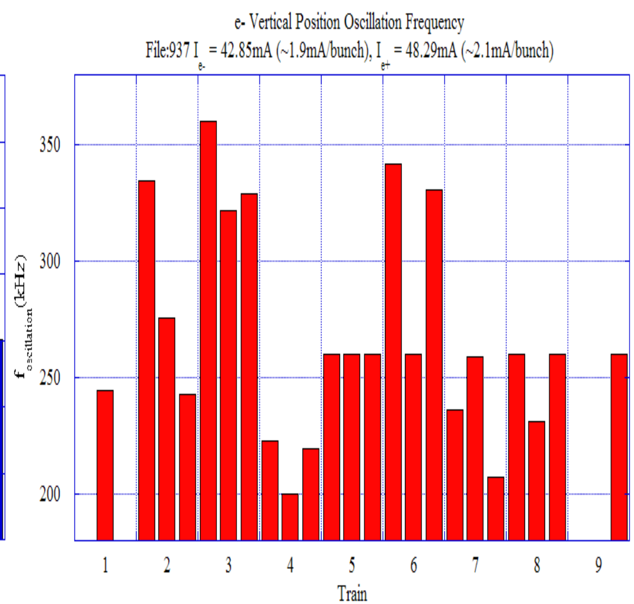
High I File:936 I_{e-}=2.3mA/bunch

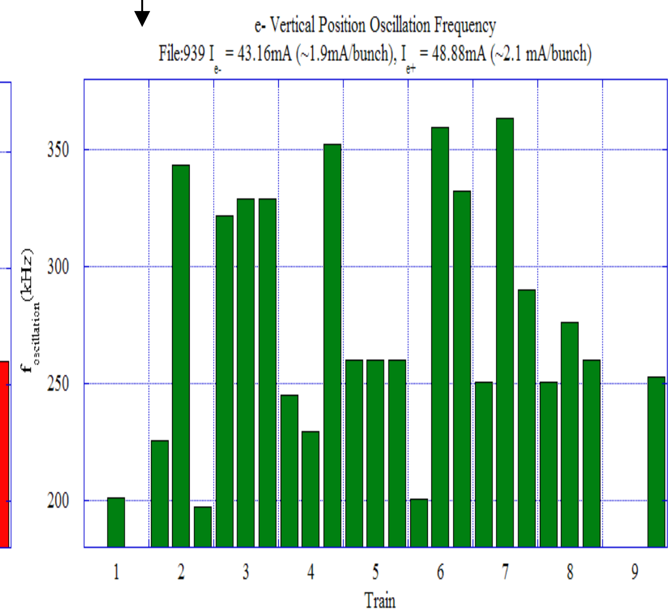
Low I File:937 I_{e-}=1.9mA/bunch

Low I File:939 I_{e-}=1.9mA/bunch

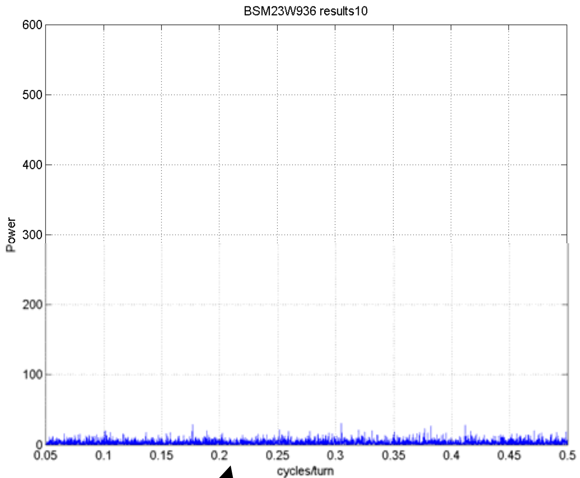
260.3kHz is the most common peak frequency of oscillation, but outside of train 5 the oscillation frequencies detected vary greatly.

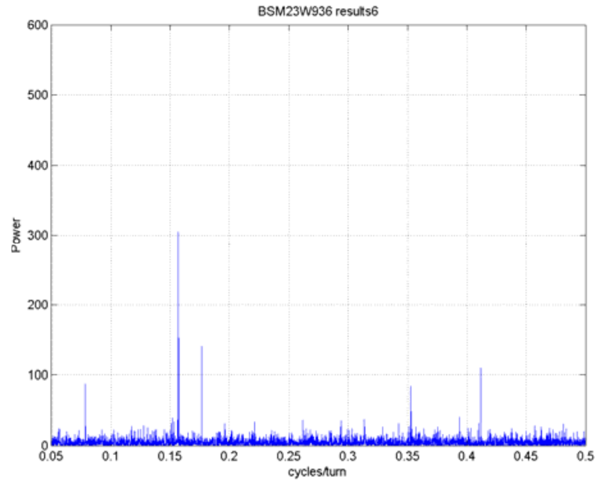


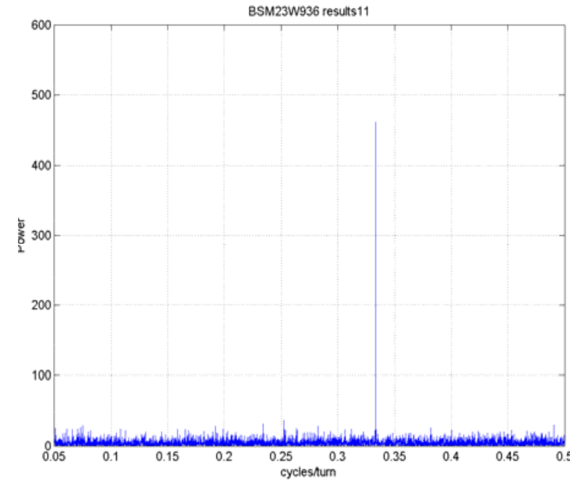




e- high frequency vertical position oscillation - FFT of vertical position – High I (file 936)







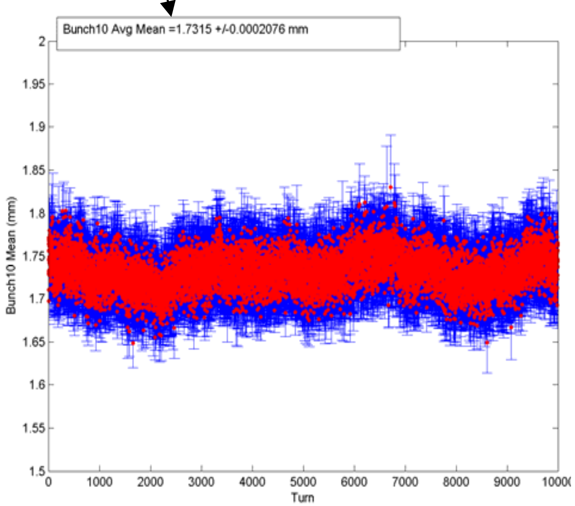
Bunch 10
Peak Power=30@271.5kHz
y_{avg}=1.73mm
Std=0.021mm

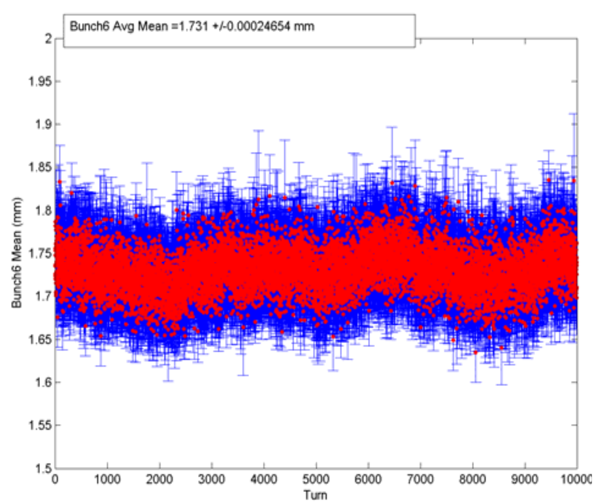
Bunch 6
Peak Power=305@329.2kHz
y_{avg}=1.73mm
Std=0.025mm

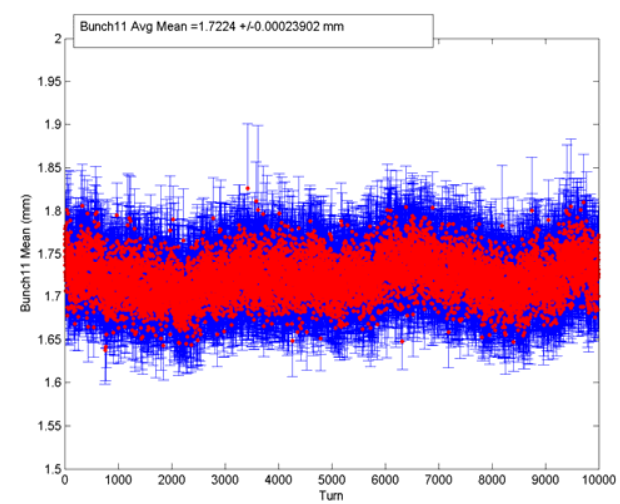
Bunch 11
Peak Power=462@260.3kHz
y_{avg}=1.72mm
Std=0.024mm

File:936 I_{e-}=2.3mA/bunch

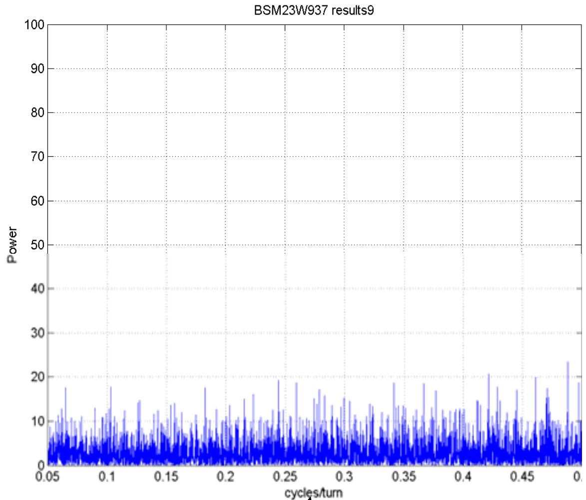
- Noise does not appear to correlate with FFT power.

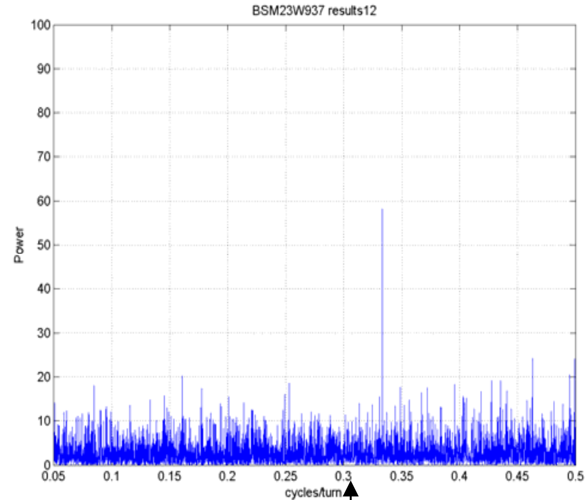


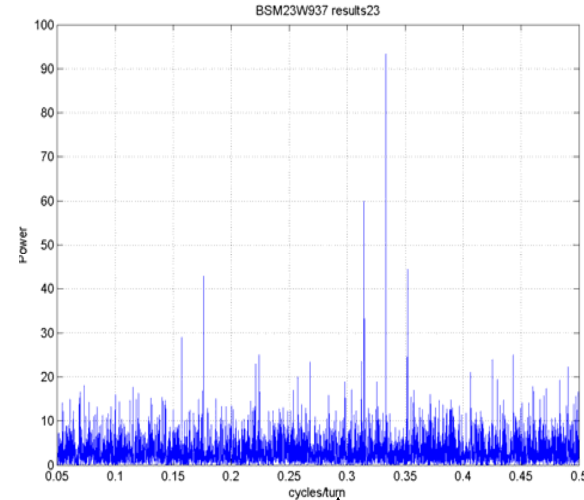




e- high frequency vertical position oscillation - FFT of vertical position – Low I (file 937)





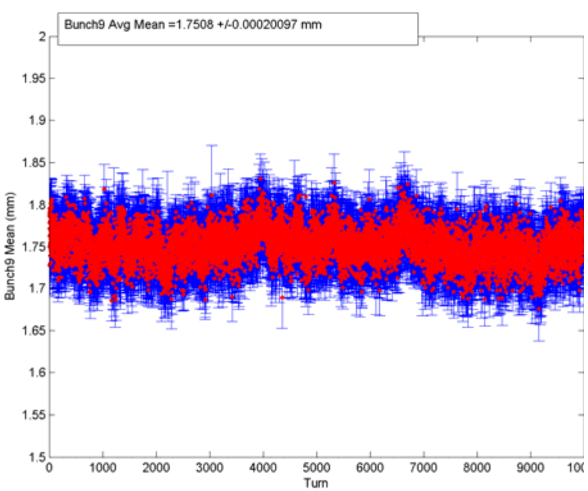


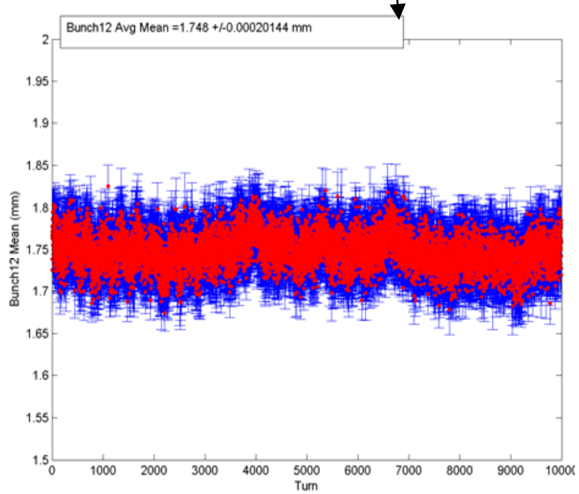
Bunch 9
Peak Power=23@199.9kHz
y_{avg}=1.75mm
Std=0.020mm

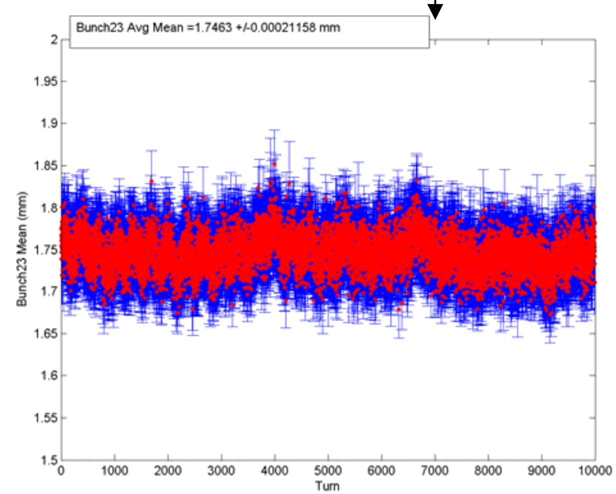
Bunch 12
Peak Power=58@260.3kHz
y_{avg}=1.75mm
Std=0.020mm

Bunch 23
Peak Power=93@260.3kHz
y_{avg}=1.75mm
Std=0.021mm

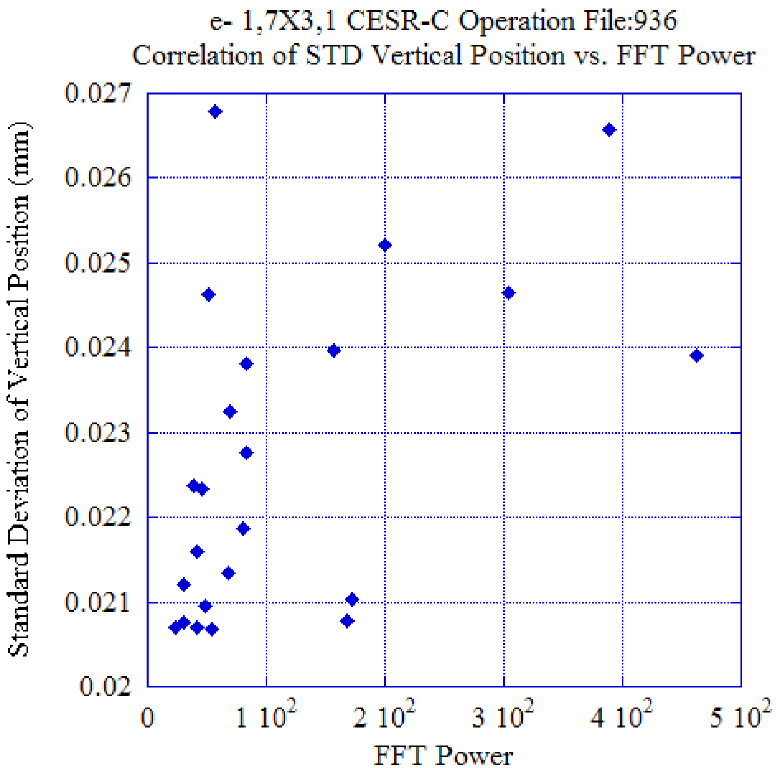
File:937 I_{e-}=1.9mA/bunch
•Noise does not appear to correlate with FFT power.

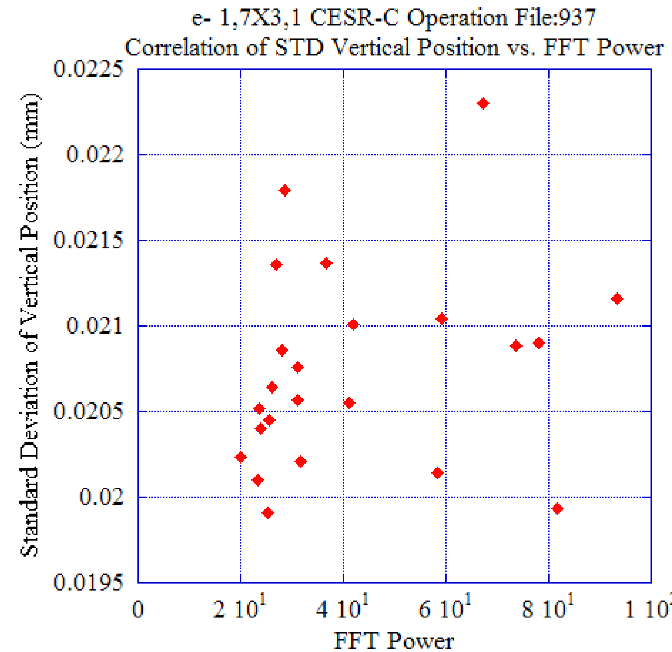


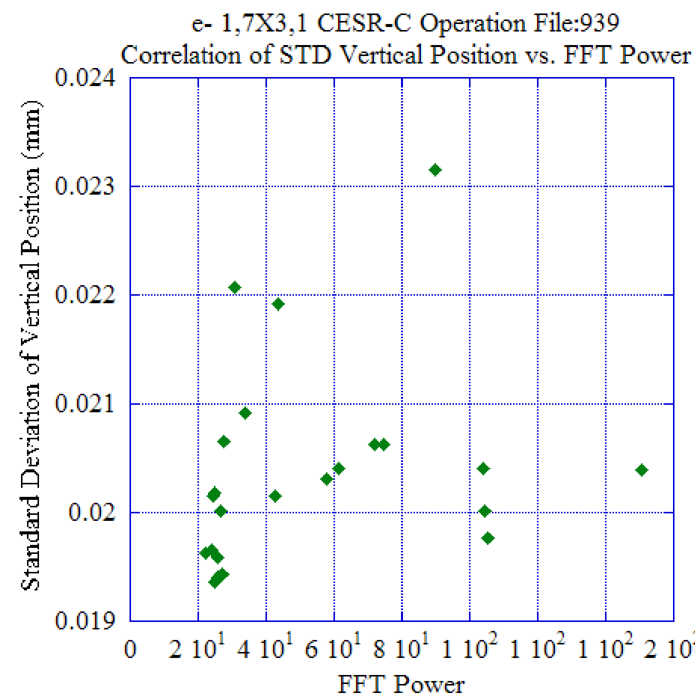




e- vertical position oscillations amplitude correlation FFT Power

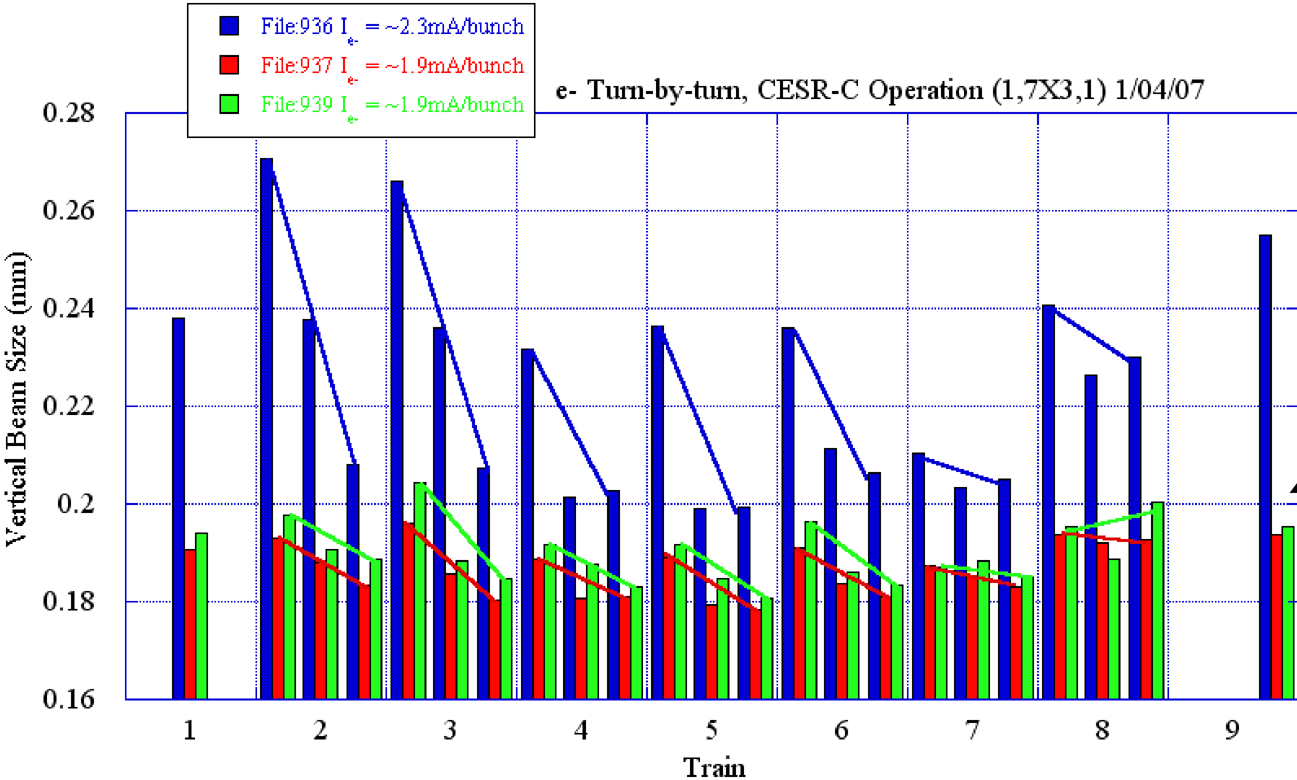






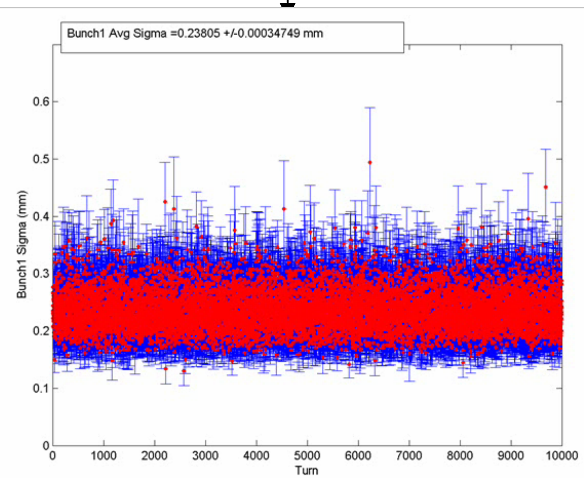
There does not appear to be a direct correlation between the FFT Power of mean position oscillations and the standard deviation in the mean position.

e- σ_v along the train

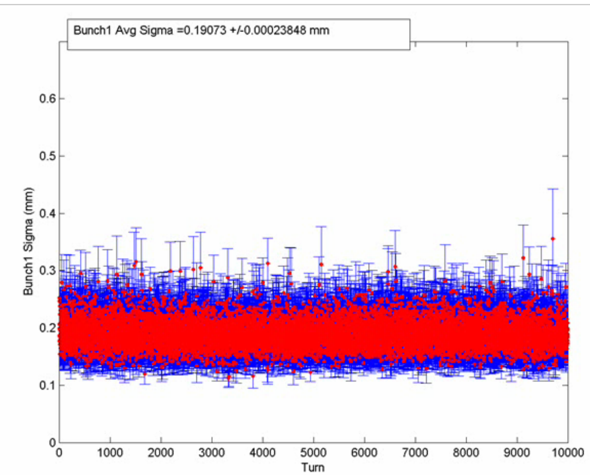


- σ_v 10,000 turns for 23 bunches.
- Vertical beam size decreases along each train (except file 939 train 8).

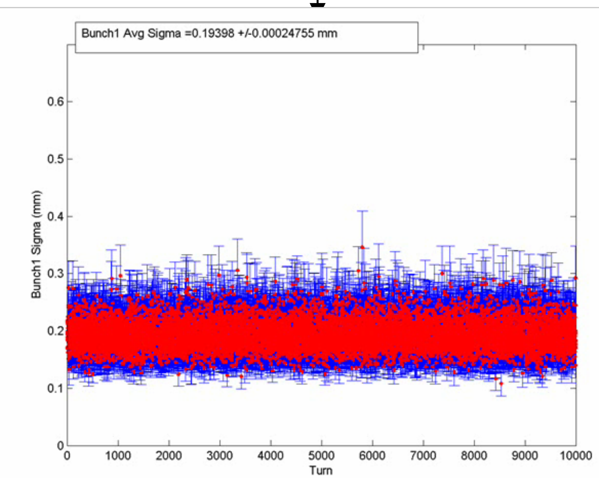
High I File:936 I_{e-}=2.3mA/bunch (movie)



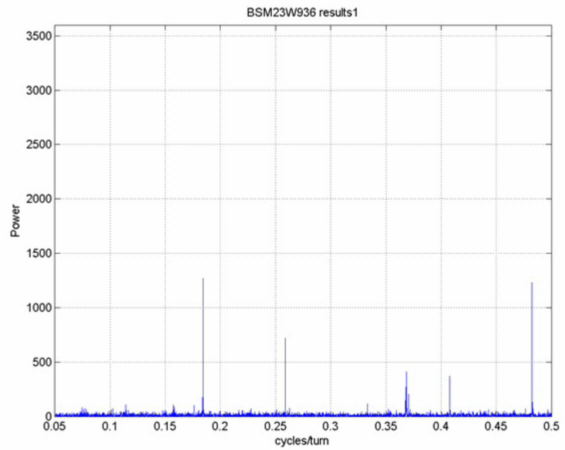
Low I File:937 I_{e-}=1.9mA/bunch (movie)

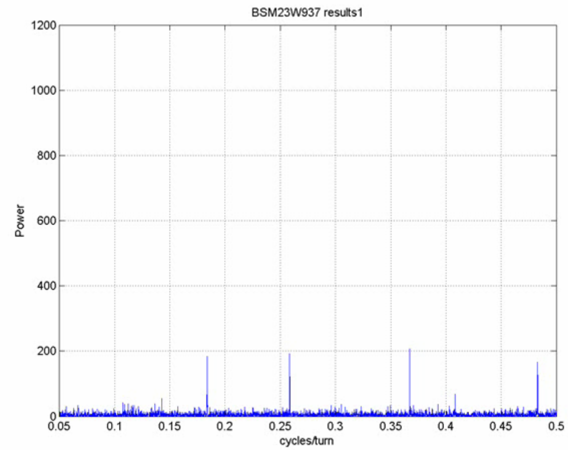


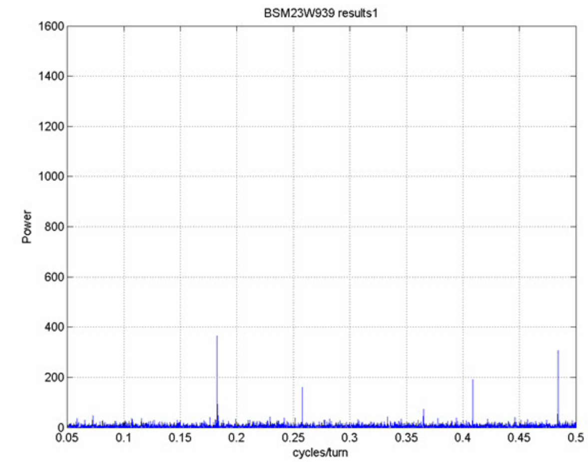
Low I File:939 I_{e-}=1.9mA/bunch (movie)



e- high frequency σ_v oscillation frequency-FFT of σ_v for 10,000 turns







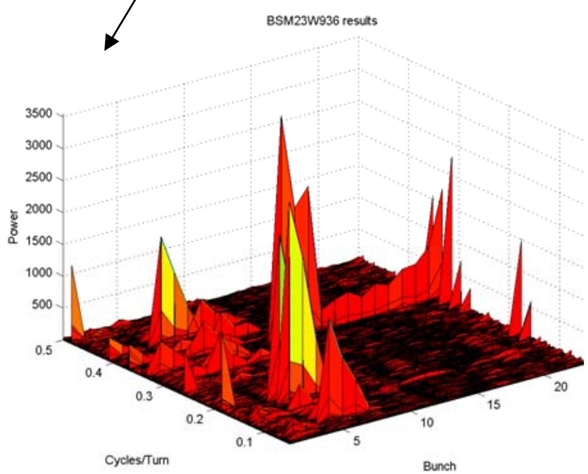
movies

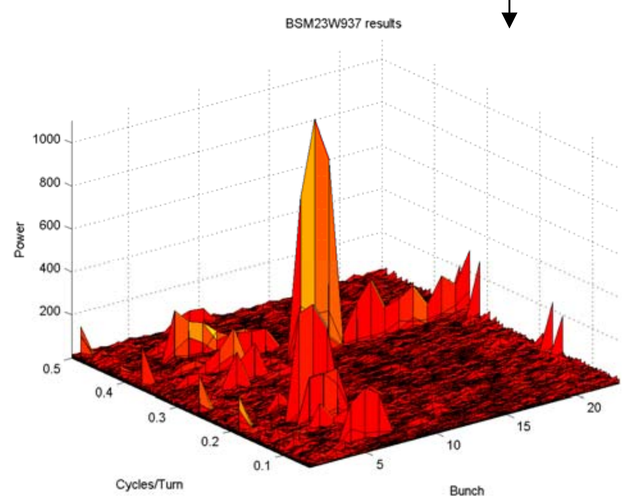
High I File:936 I_{e-}=2.3mA/bunch

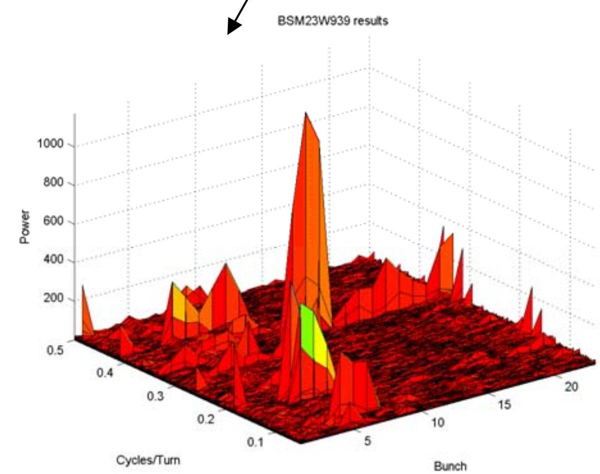
Low I File:937 I_{e-}=1.9mA/bunch

Low I File:939 I_{e-}=1.9mA/bunch

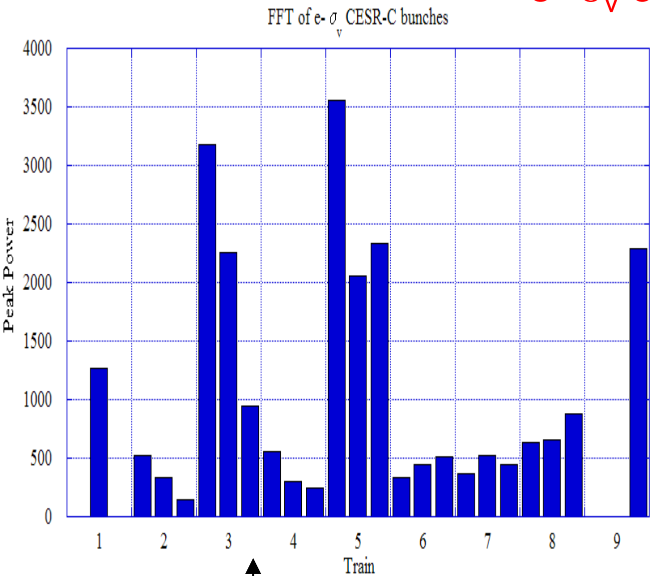
- FFT of σ_v for all 23 bunches
- Strong σ_v oscillation signal near tune in each file .

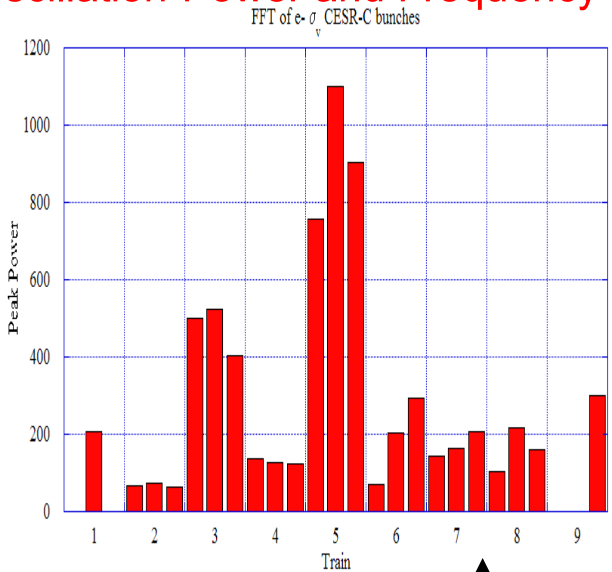


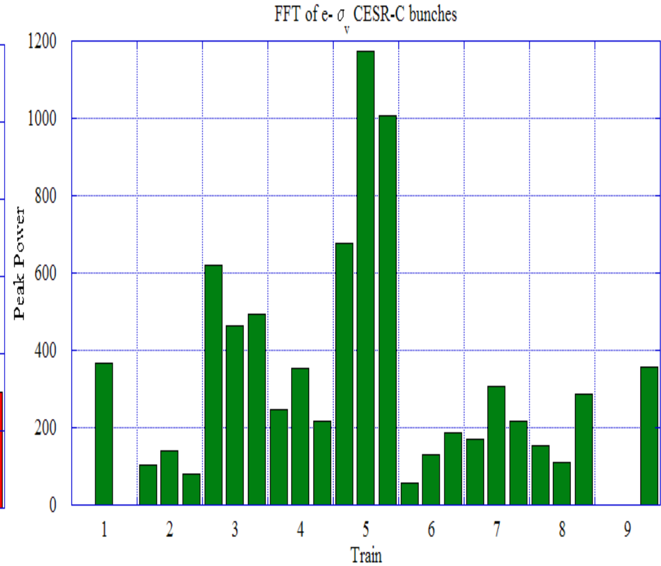




e- σ_v oscillation-Power and Frequency of Oscillation





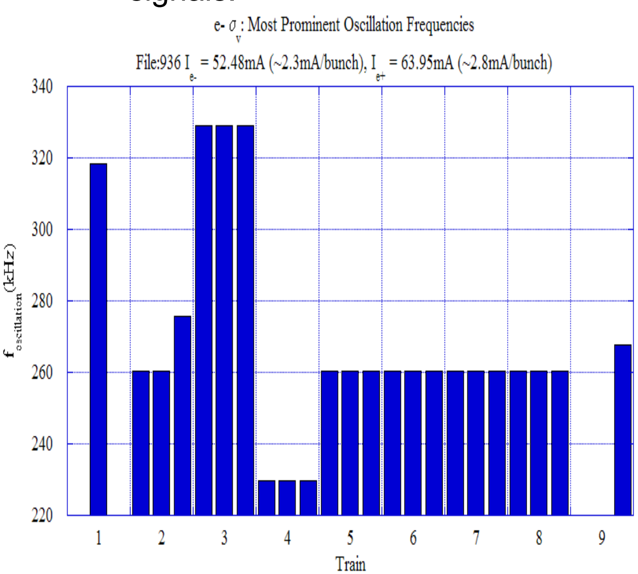


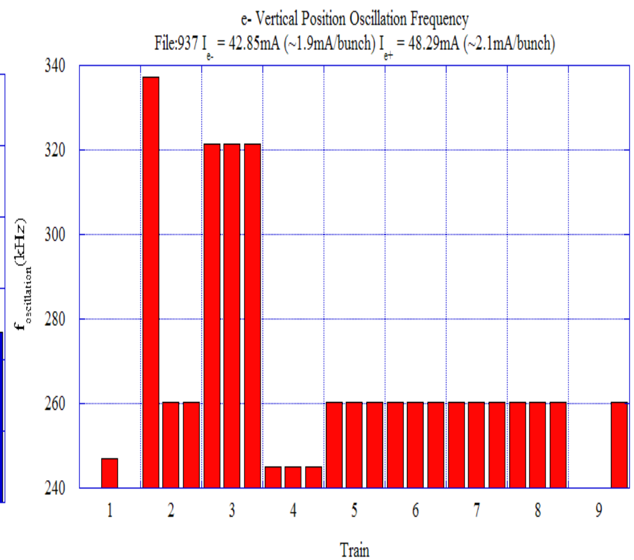
High I File:936 I_{e-}=2.3mA/bunch

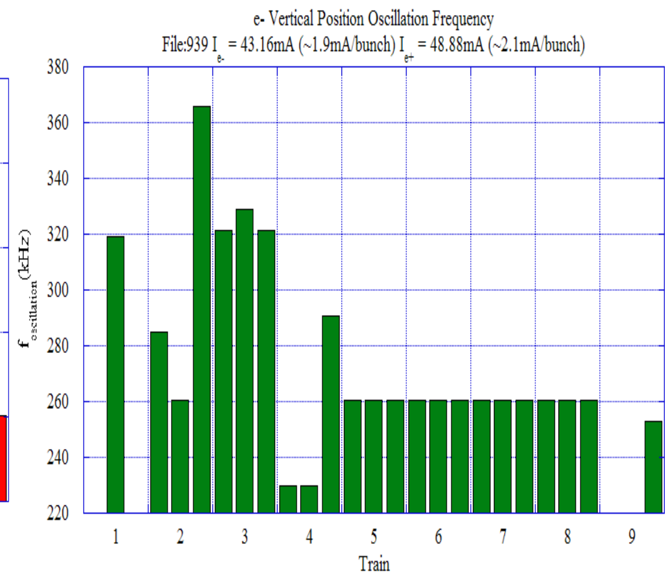
Low I File:937 I_{e-}=1.9mA/bunch

Low I File:939 I_{e-}=1.9mA/bunch

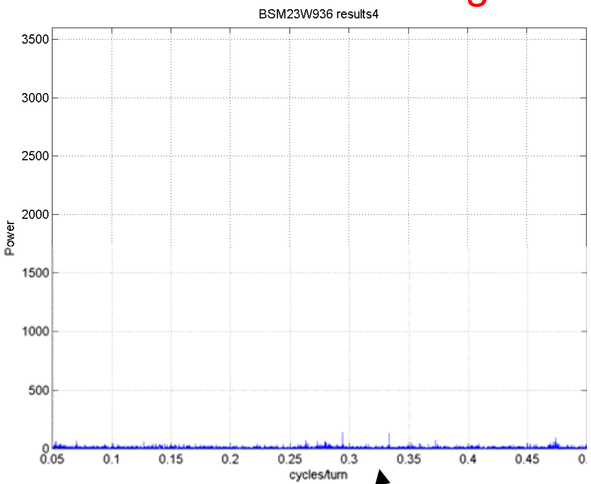
- Oscillation at 260.3 kHz is prominent in trains 5-8, but the strength of that signal is very low in the other trains, compared to their strongest signals.

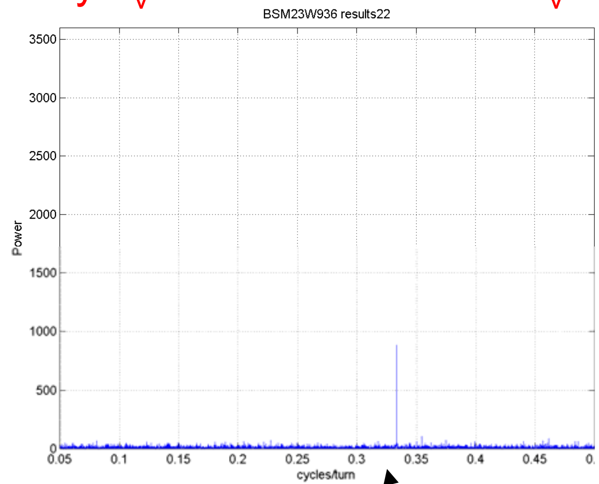


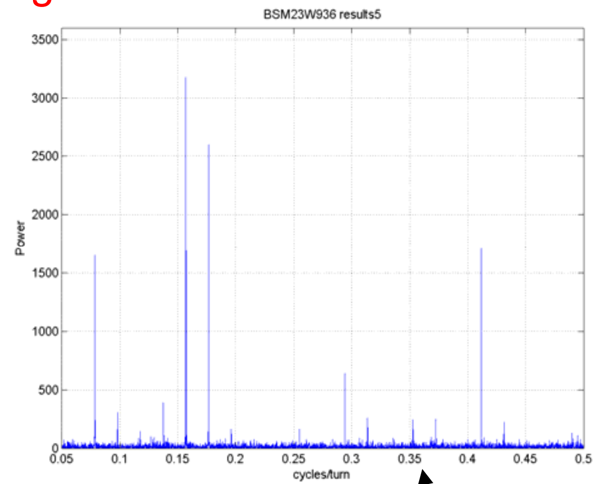




e- high frequency σ_v oscillation - FFT of σ_v – High I







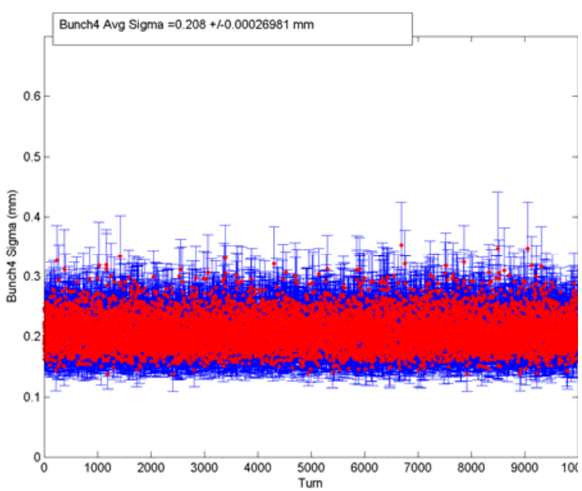
Bunch 4
Peak Power=142@275.6kHz
σ_v=0.208mm
Std=0.027mm

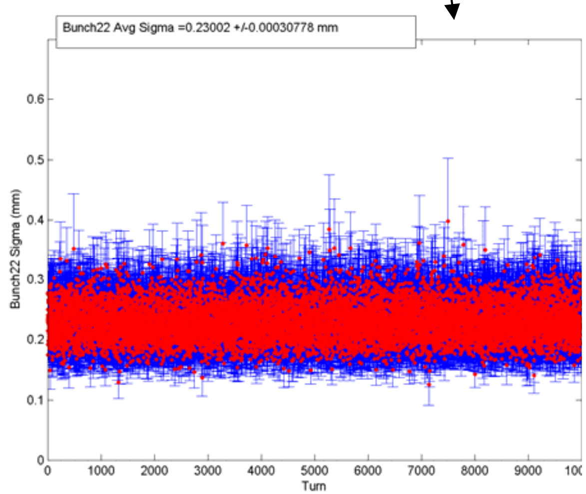
Bunch 22
Peak Power=881@260.3kHz
σ_v=0.230mm
Std=0.031mm

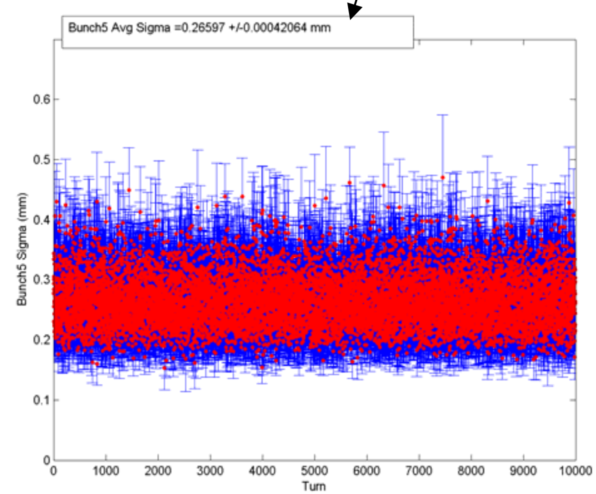
Bunch 5
Peak Power=3176@329.2kHz
σ_v=0.266mm
Std=0.042mm

File:936 I_{e-}=2.3mA/bunch

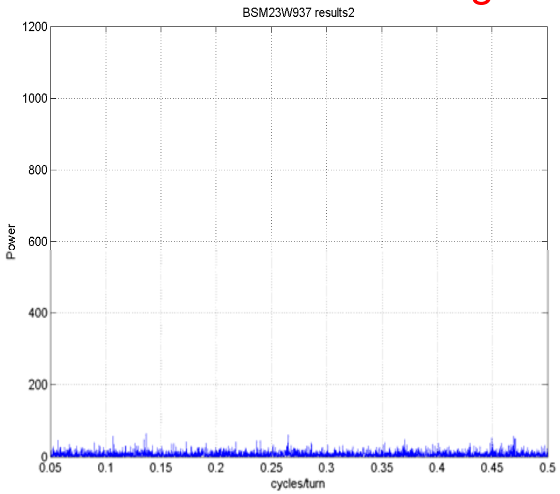
- σ_v oscillation amplitude appears to correlate with FFT power

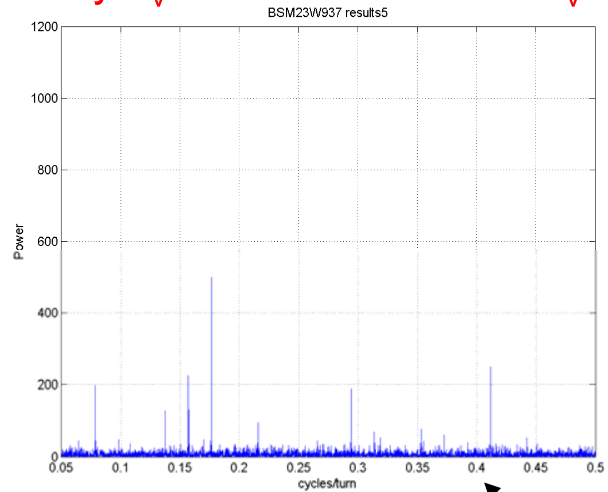


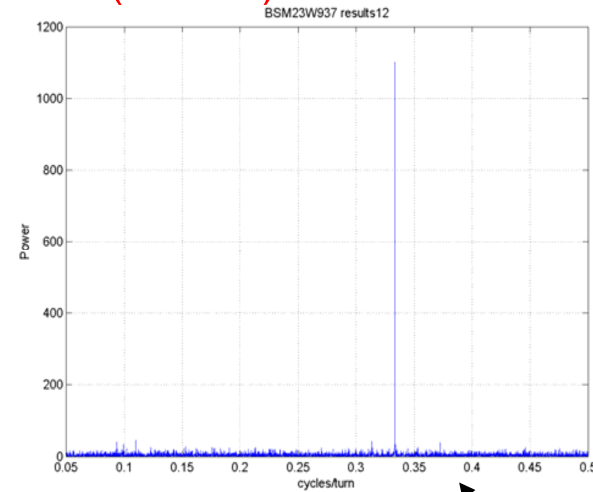




e- high frequency σ_v oscillation - FFT of σ_v – Low I (file 937)







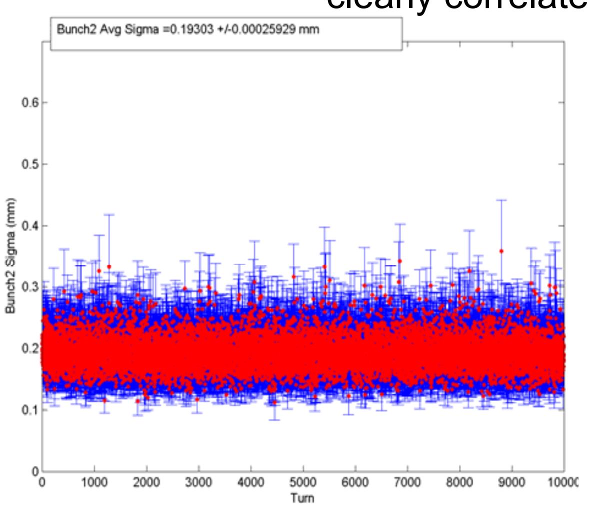
Bunch 2
Peak Power=65@337.2kHz
σ_v=0.193mm
Std=0.026mm

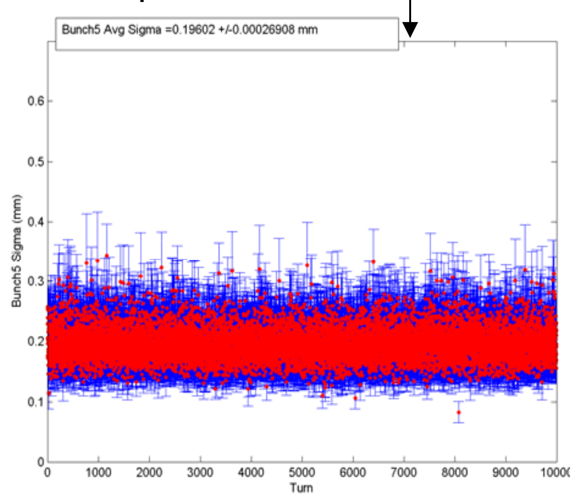
Bunch 5
Peak Power=500@321.5kHz
σ_v=0.196mm
Std=0.027mm

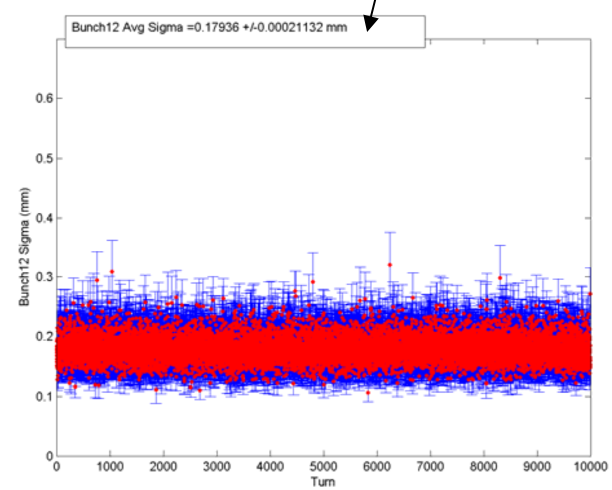
Bunch 12
Peak Power=1101@260.3kHz
σ_v=0.179mm
Std=0.021mm

File:937 I_{e-}=1.9mA/bunch

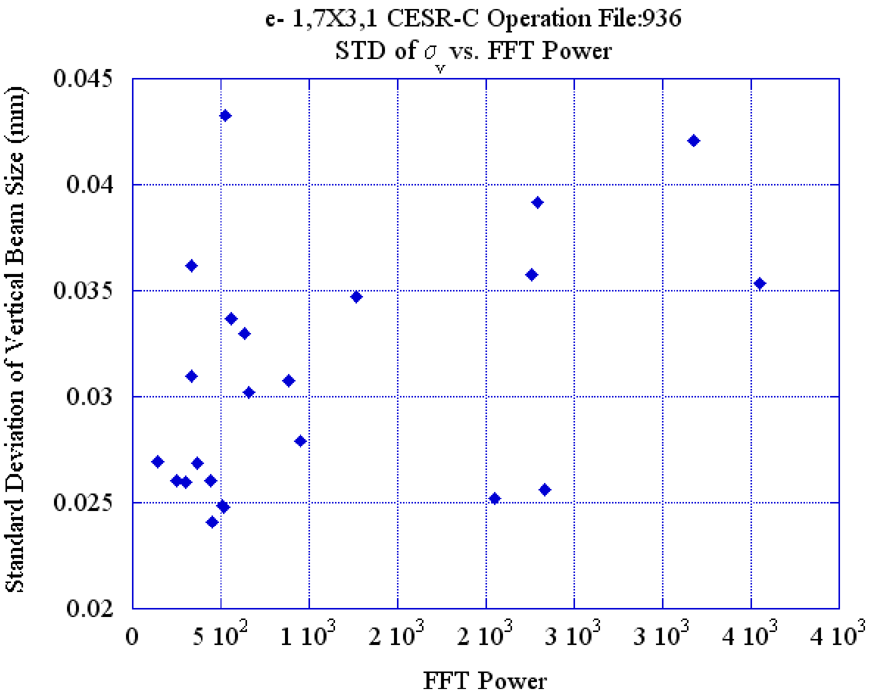
- σ_v oscillation amplitude does not clearly correlate with FFT power.



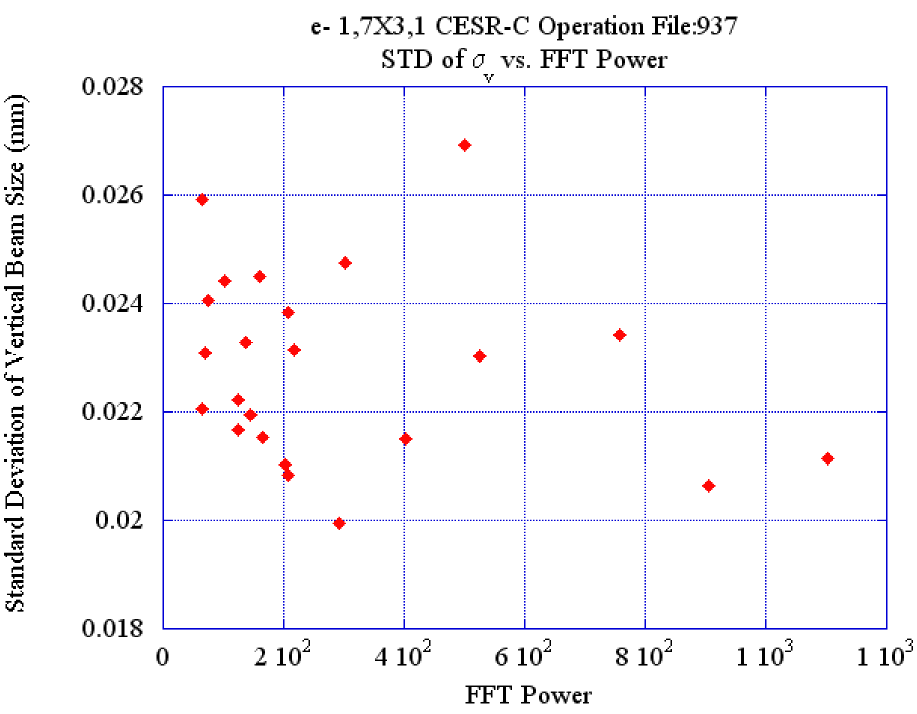


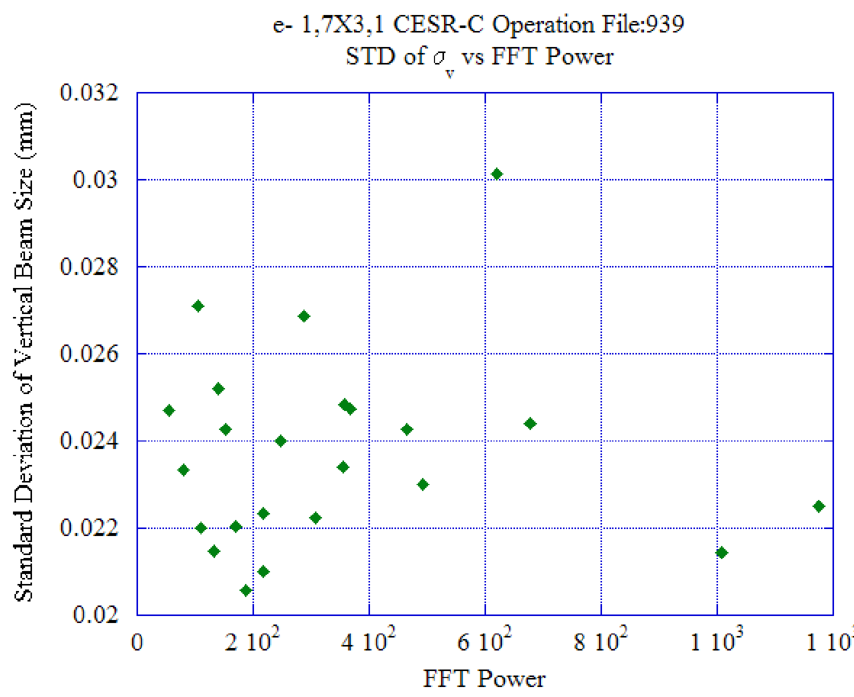


e- σ_v oscillation amplitude Vs. FFT Power

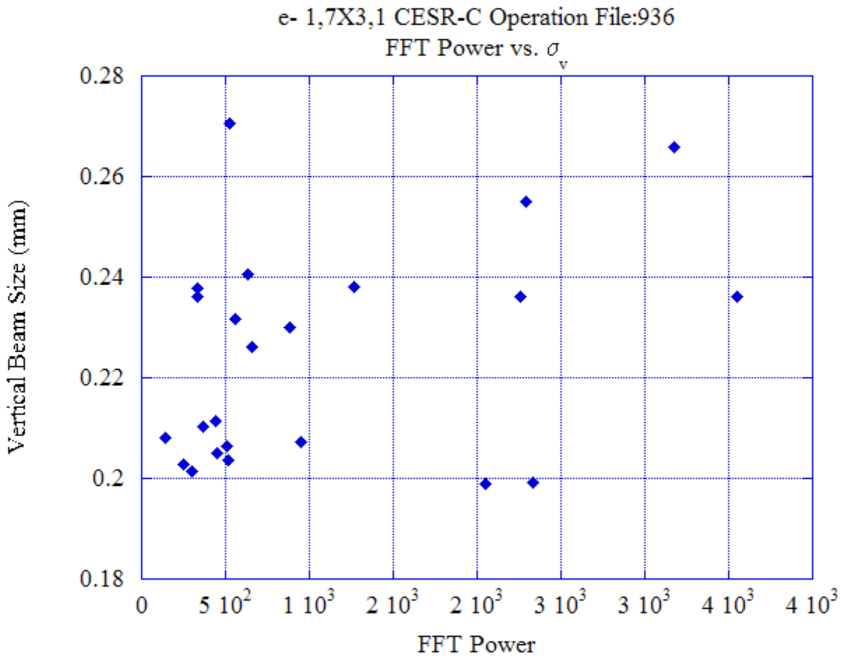


- No clear correlation between σ_v oscillation amplitude (standard deviation of σ_v) and FFT power- coherent oscillation of σ_v oscillation amplitude.
- At high current (file 936), there is a more marked increase in the beamsize standard deviation as the FFT power increases.

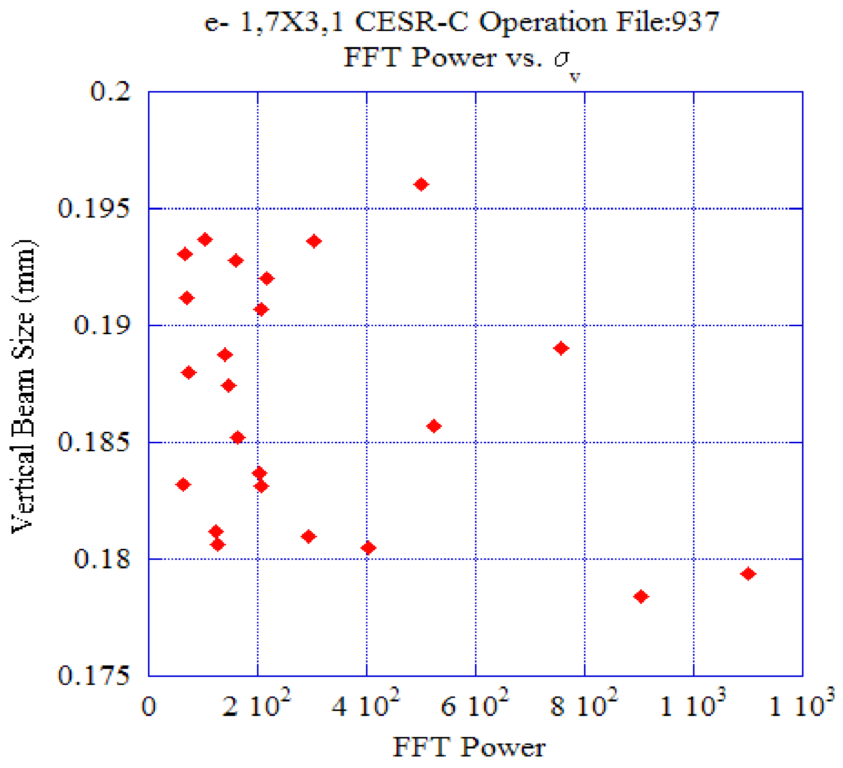


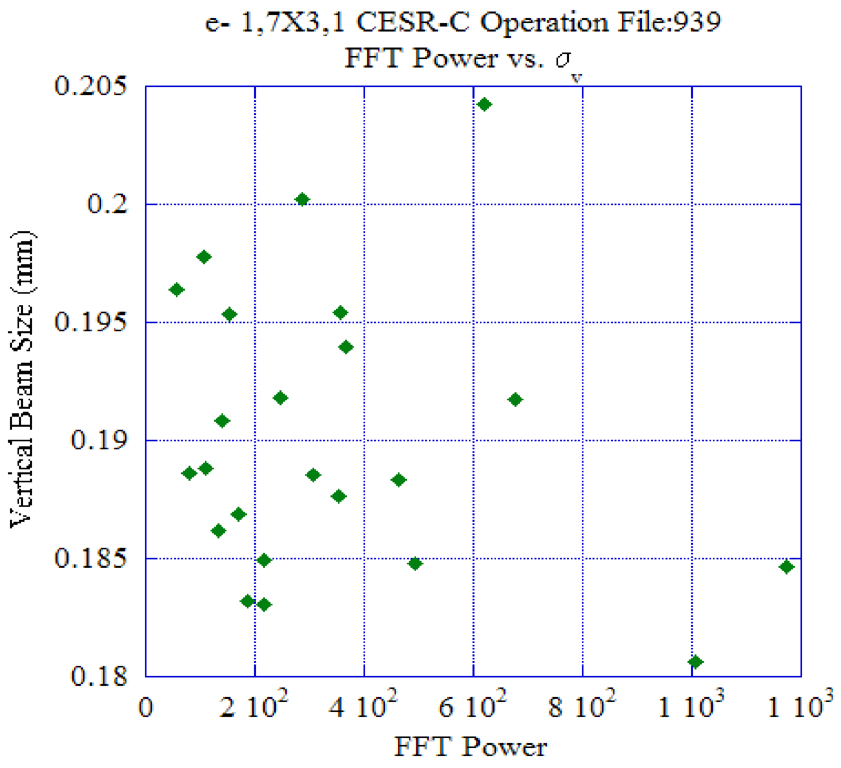


e- σ_v correlated with FFT Power

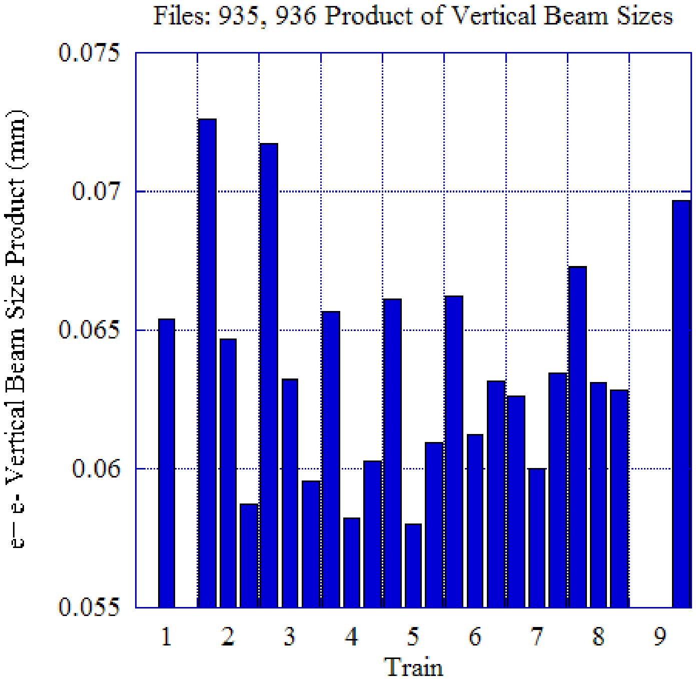


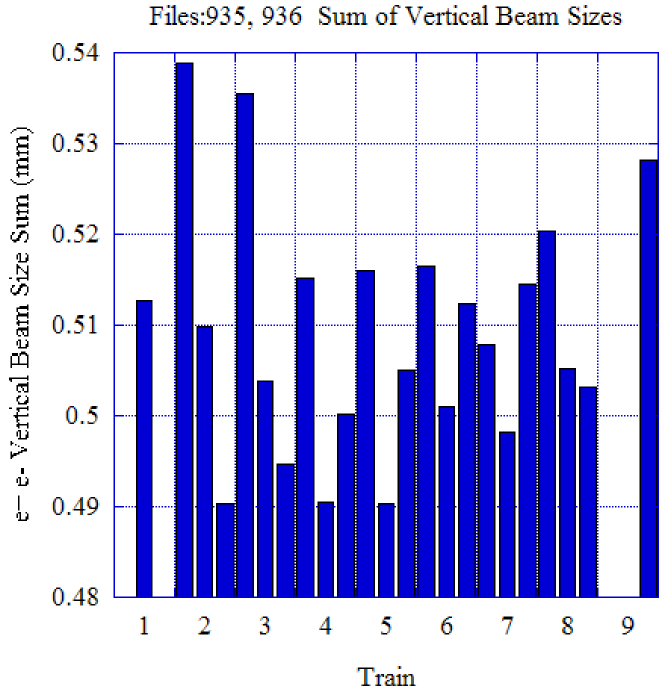
- No direct correlation between σ_v oscillation and FFT power- σ_v growth due to coherent instability

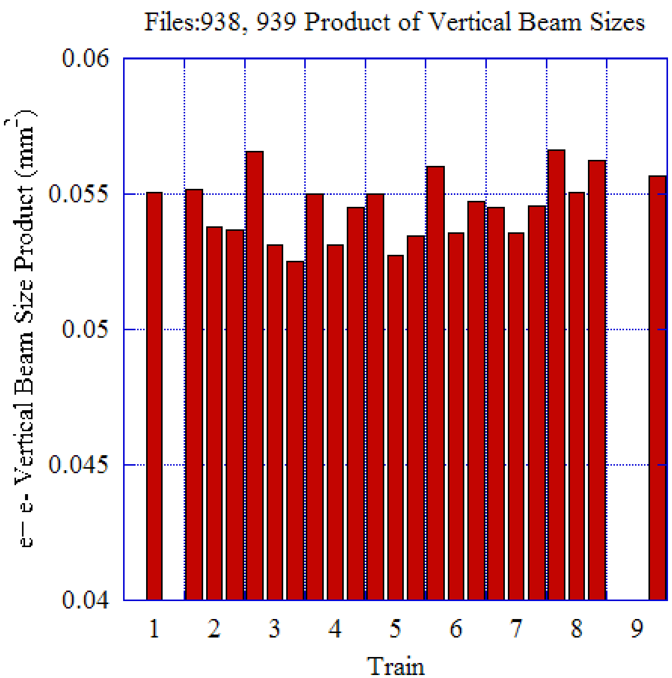


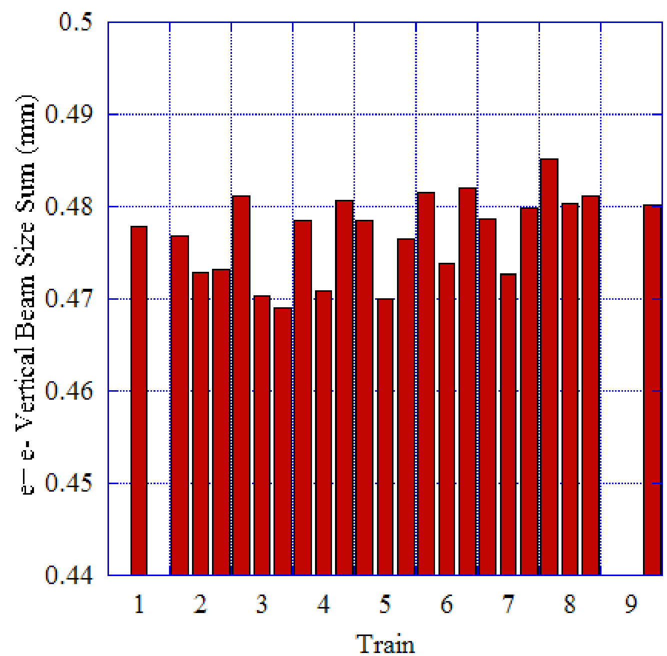


e+/e- Vertical Beam Size correlation









- It is evident from plots of e+ and e- vertical beam size that when e+ σ_v increases, e- σ_v decreases; however, the sum and product of the e- and e+ beam sizes do not reflect this relationship. The e- values of σ_v dominate.

IV Summary

During CESR-c colliding beams the following was measured:

e+ turn-by-turn vertical dynamics:

• A vertical position shift of the bunch distribution of up to 0.03mm,was measured along the three bunch train. Many oscillation frequencies are evident in the vertical position. The dominant oscillation frequency is at the vertical tune.

• A vertical beam size growth along the three bunch train was measured. No clear oscillation frequency of the vertical beam size is evident.

e- turn-by-turn vertical dynamics:

• A vertical position shift is detected over the three bunch train in the opposite direction as the e+ bunches. The vertical position oscillation has two frequencies, a low frequency component at f_{low}~333 turns, and a high frequency oscillation at the vertical tune.

•The e- vertical beam size decreases along the three bunch train which is directly opposite to the vertical beam size growth for the e+ bunches. Several oscillation frequencies were detected in the vertical beam size spectrum most notably at the vertical tune.