Injection Optimization of CESR at 3.76 GeV

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Introduction

The Cornell Electron Storage Ring (CESR) stores bunches of electrons (in excess of 10^9 per bunch) for study and for use in particle physics experiments. The injection process begins with a 150 kV electron gun. The electrons are fired into a linear accelerator (linac) which accelerates them to 300 MeV. To create positrons, electrons at 150 MeV are rammed into a tungsten target half-way down the linac, then collected and accelerated through the remainder of the linac to 200 MeV. The bunches are accelerated in the synchrotron to the desired energy levels, a maximum of $\sim$5 GeV, and injected into CESR.

When being inserted into CESR, a number of parameters affect the efficiency of the injection. Finding the most efficient of these parameters was the goal of this project.

Analysis Method

Five new wiggler magnets have been installed into the CESR since January 2003 (for a total of six). Given this new lattice, injection parameters must be recalibrated for efficient injection. This can be done using the envelope simulation program. Varying different parameters gives different injection efficiencies.

Using a combination of `Fortran`, PAW programming, Perl, and C-Shell Scripting, I simulated injections for different lattices: (1) the old lattice before the wigglers were installed, running at 1.88 GeV, (2) after the installation of the wigglers, running at 5 GeV for CHESS, and (3) with the wigglers turned on, running at 1.88 GeV.

I started by examining the accuracy of the results I got from the simulation program. I found that simulating 500 electrons and simulating 2.5 standard deviations provided accurate results, with an error of about 0.9% efficiency (Table 1). Instead of a full analysis, at my mentor's (Dr. Jim Crittenden's) suggestion, I settled for using these simulation parameters. I did approximate the relationship to almost quadratic though to a power of 2.1 (y = $kx^{2.1}$); however, this is only an approximation based on limited data. The key is to note that simulating 2.5 standard deviations and 500 electrons gives accurate results.

The bulk of my analysis concentrated on the tunes. Other parameters like the pulsed bump settings and the pretzel amplitude are calculated automatically by the program.

Analysis Results

Result 1

The tunes used with the old 1.88 GeV lattice were 10.535 horizontal and 9.570 vertical (oscillations per turn); however, these may not have necessarily been the most efficient tunes because of the factors that went into determining them. To analyze the tunes, I simulated all the vertical tunes ranging [9.550, 9.610] with a step of 0.0005 against all the horizontal tunes ranging [10.510,10.570], also with a step of 0.0005. There was notably chaotic behavior.

The vertical tune appeared to be independent of the injection efficiency on the range [9.550, 9.610]. Graph 1, a graph of vertical tune versus injection efficiency, shows the chaotic behavior of the vertical tune. In the graph a connect-the-dots curve is plotted for each set of data points (a set of data points being those with the same horizontal tune). Each set is plotted on top of the others. As the sets are plotted, any general trends would stack up on top of each other. Graph 1 shows no trends.

To verify that the vertical tune did not have any trends which were dependent on the horizontal tune, I graphed the data for localized horizontal tunes. Graph 2 localizes the data around a horizontal tune of 10.535, one of the more efficient horizontal tunes. Graph 4 localizes the data around a horizontal tune of 10.565, another efficient horizontal tune. Graph 3 localizes the data around a horizontal tune of 10.454, an inefficient dip in the horizontal tune between those of graphs 2 and 4. Again, there is no general trend.

The vertical tunes appear to be independent of the injection efficiency and independent of the horizontal tunes, with respect to injection efficiency, on the range [9.550, 9.610].

Graphing the horizontal tunes versus injection efficiency (each data set of one vertical tune graphed on top of the others), Graph 5 displayed two prominent peaks, one at 10.535 and the other at 10.565. To check for any horizontal dependence or local trends, I localized the data around a vertical tune of 9.570 (Graph 6 and, more localized, Graph 7).

The horizontal tunes appear to be independent of the vertical tunes, with respect to injection efficiency, and have two efficient peaks at 10.535 (with a plateau of +/- .005) and 10.565 (with a plateau of +/- .005) on the range [10.510, 10.570].

The range of efficiency for the test reaches 10%, but using proper pulsed bump settings and pretzel amplitude settings (which I ignored, but kept constant, during the tune analysis) the efficiency reaches around 50% (Graph 8).

Result 2

Using the lattice (injection parameters) with all 6 wigglers installed, but turned off, run at 5 GeV (for CHESS), I performed the same analysis. I found no vertical tune dependence (Graph 9). I was unable to find any notably efficient horizontal tune. I did, however, find an area of very low to no efficiency in the region [9.556, 9.560] (Graph 10).

To check that this inefficient range wasn't obscuring any vertical trends, I discarded them for a further analysis of the vertical tunes. However, I again found no vertical dependence. The range of efficiency, however, was much lower than with the old lattice. No injections were much more efficient than 1%. Through further analysis I found that the pretzel settings were small enough to clear the wall (Graph 11), but the injected beam was running into the positron bunches (Graph 12).

Result 3

Finally, using the lattice with all 6 wigglers turned on, running at 1.9 GeV, I attempted the same analysis. The simulation kept crashing due to the tunes hitting resonances. But, from the data that I gathered, there wasn't a single successful injection. Every injection efficiency was 0.000%. Most of the electrons were lost approximately 25 m after injection (Graph 13).

Conclusions and Acknowledgments

The duration of my project ends with these results, leaving the opportunity for determining a way to keep the injected electrons in the 5 GeV CHESS lattice away from the positron beam, and the opportunity to determine the cause of error for the new 6 wiggler 1.86 GeV lattice.

The people most helpful in my project were Jim Crittenden, my mentor, Rich Galik, The REU program director, and my fellow REU-ers. This work was supported by the National Science Foundation REU grant PHY-0243687 and research co-opertaive agreement PHY-9809799.

Footnotes and References

1. *Injection Optimization for CESRc Operation at 3.76 GeV*, REU project presentation, J. A. Crittenden, Cornell University, June 2003.
2. *Recent Developments for Injection into CESR*, M. G. Billing and J. A. Crittenden, ICFA Beam Dynamics Newsletter, **NR31**, August 2003.
3. *A Description of CESR Injection*, Stuart D. Henderson, CESR Internal Report, October 1995.

TABLE 1. Efficiency Error Based on Number of Electrons and Standard Deviations Simulated.

S.D. Simulated	Electrons Simulated	△ Reported Efficiency (%)
2.5	500	0.90
2.5	1,000	0.60
2.5	5,000	0.30
2.5	100,000	0.06
3.0	500	1.30
3.0	600	1.00
3.0	1,000	0.80
3.0	5,000	0.40
5.0	1,000	0.90
5.0	100,000	0.08

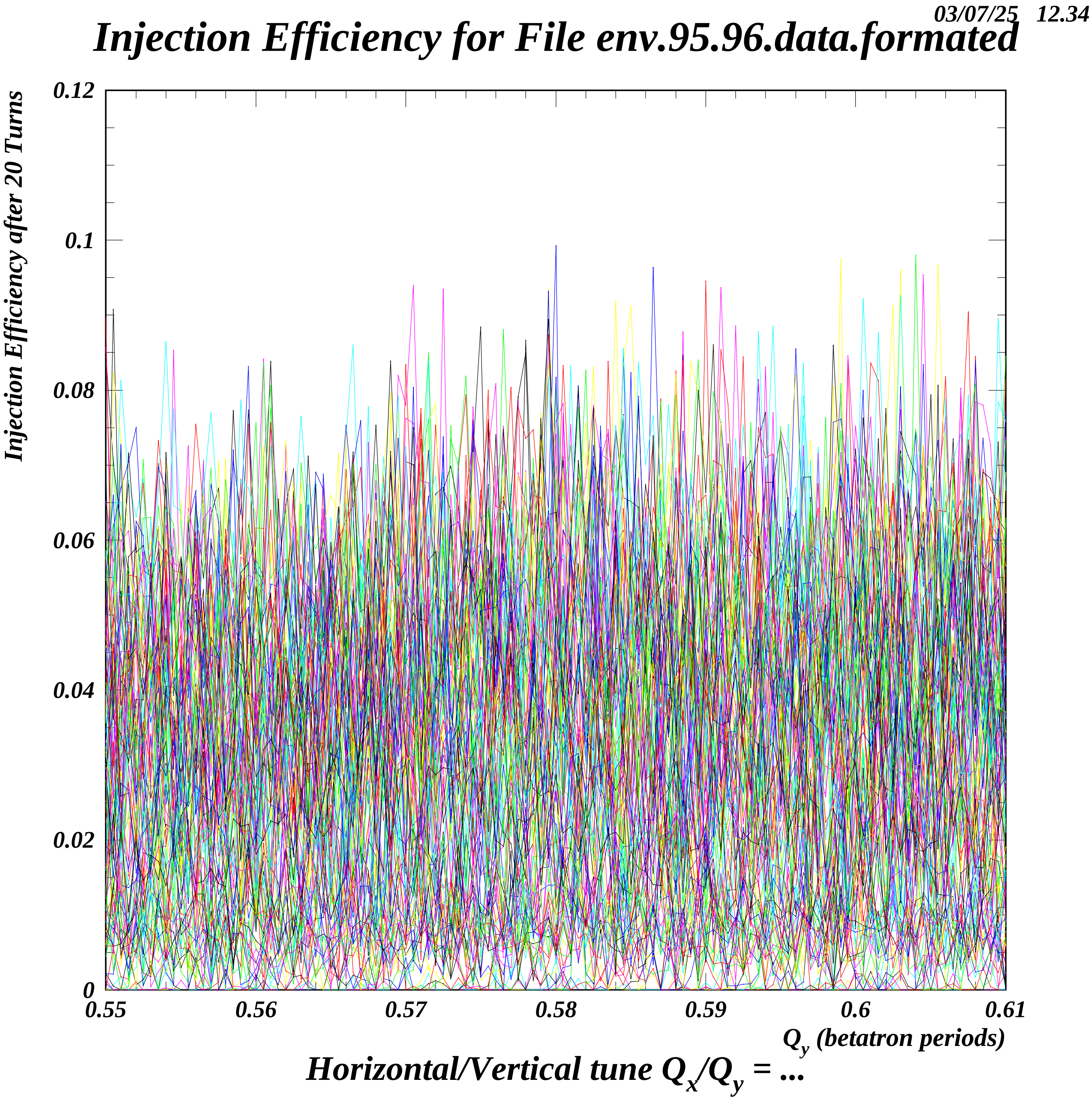

FIGURE 1. Efficiency vs. Vertical Tune (less 9 osc./turn)

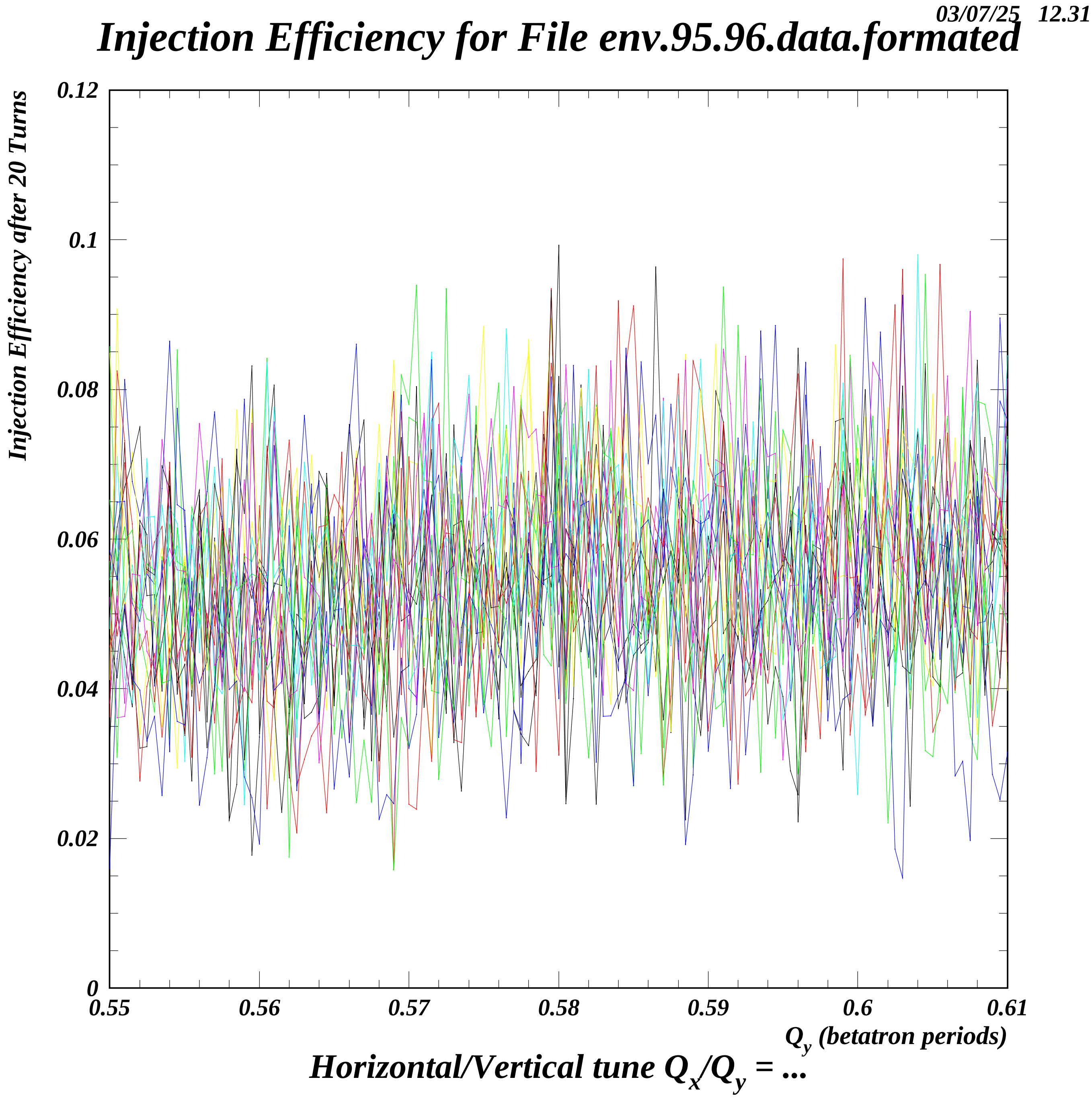

FIGURE 2. Efficiency vs. Vertical Tune (less 9 osc./turn) for $10.529 \leq Q_x \leq 10.538$

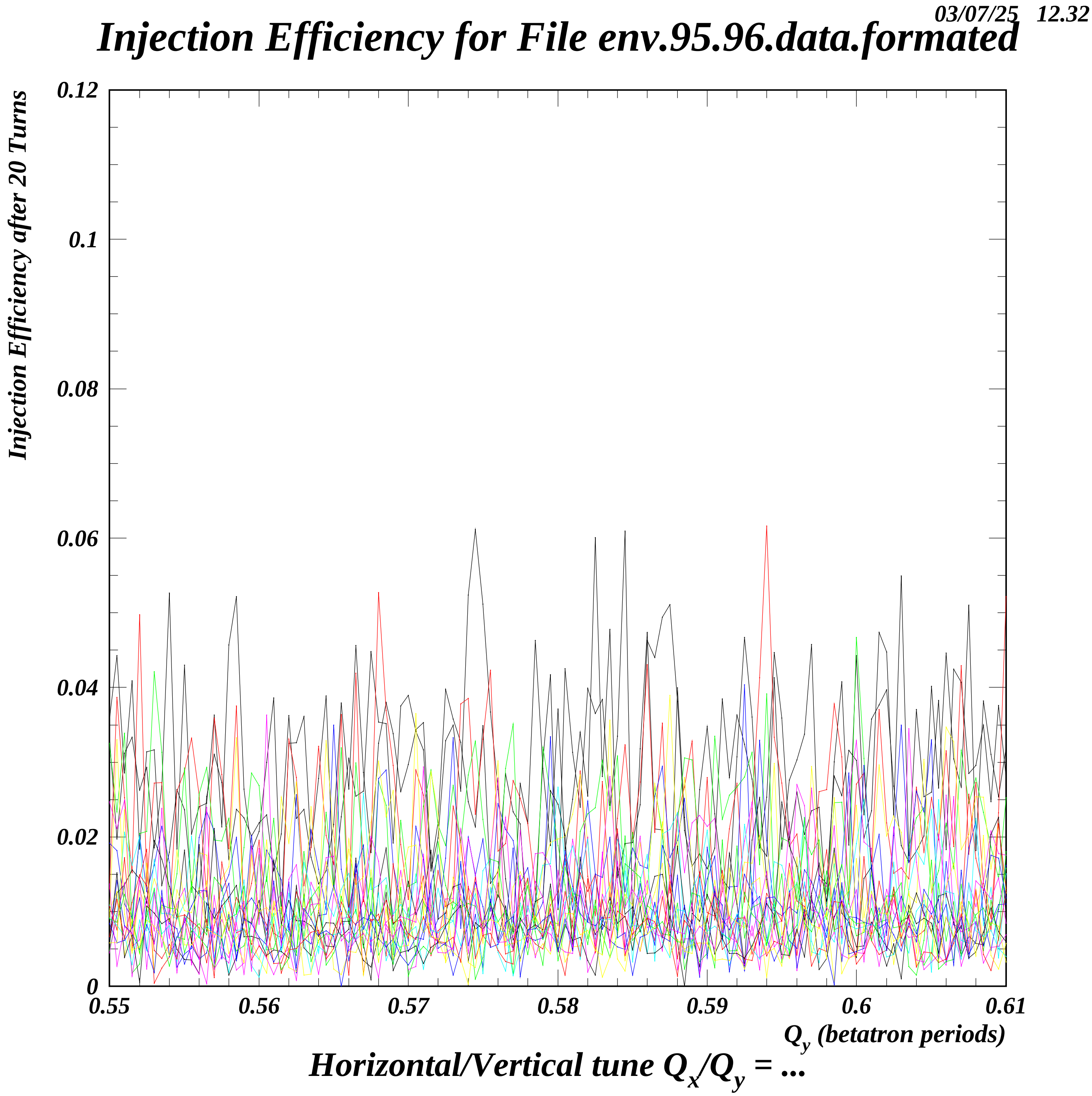

FIGURE 3. Efficiency vs. Vertical Tune (less 9 osc./turn) for $10.540 \leq Q_x \leq 10.550$

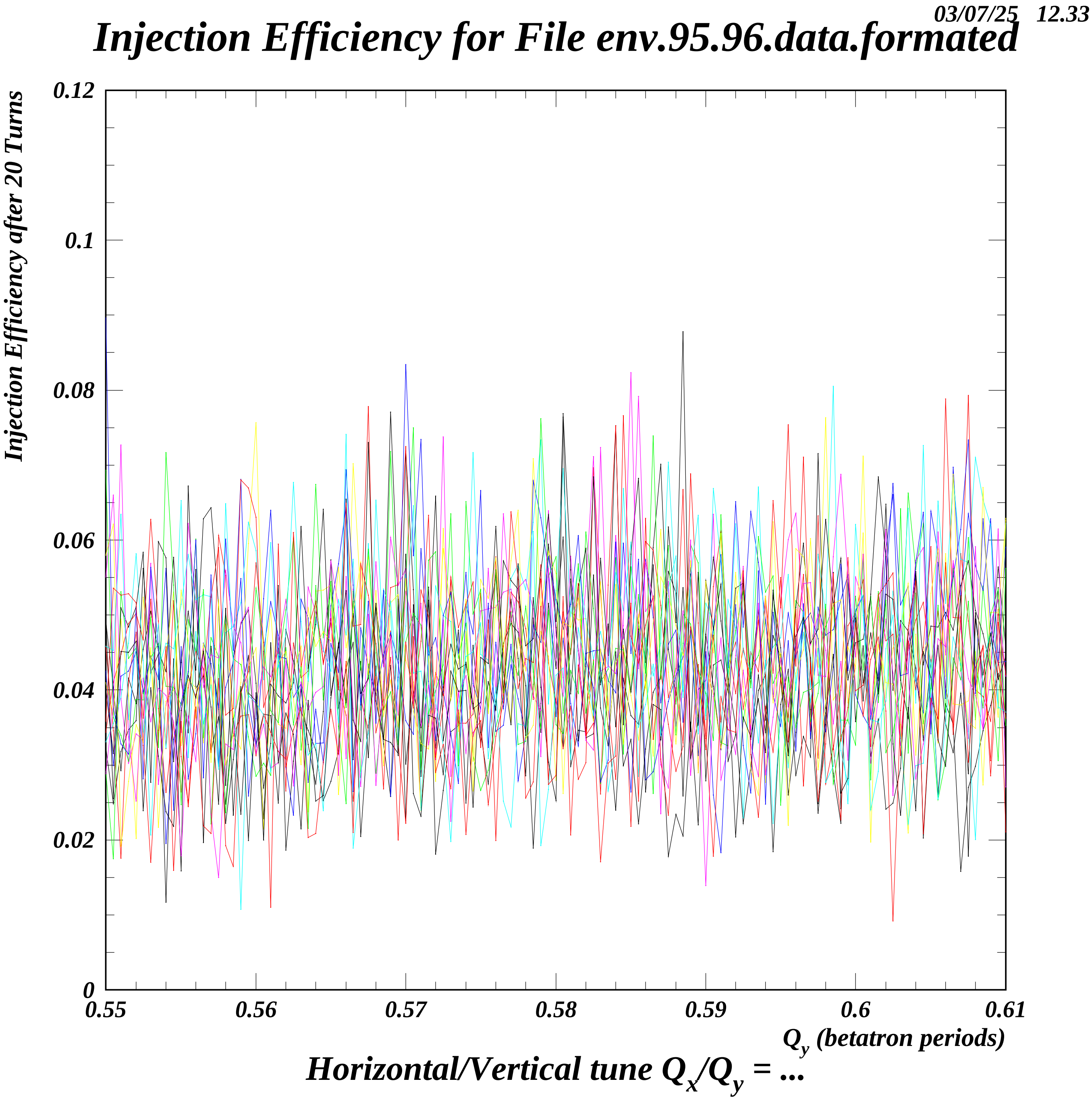

FIGURE 4. Efficiency vs. Vertical Tune (less 9 osc./turn) for $10.555 \leq Q_x \leq 10.566$

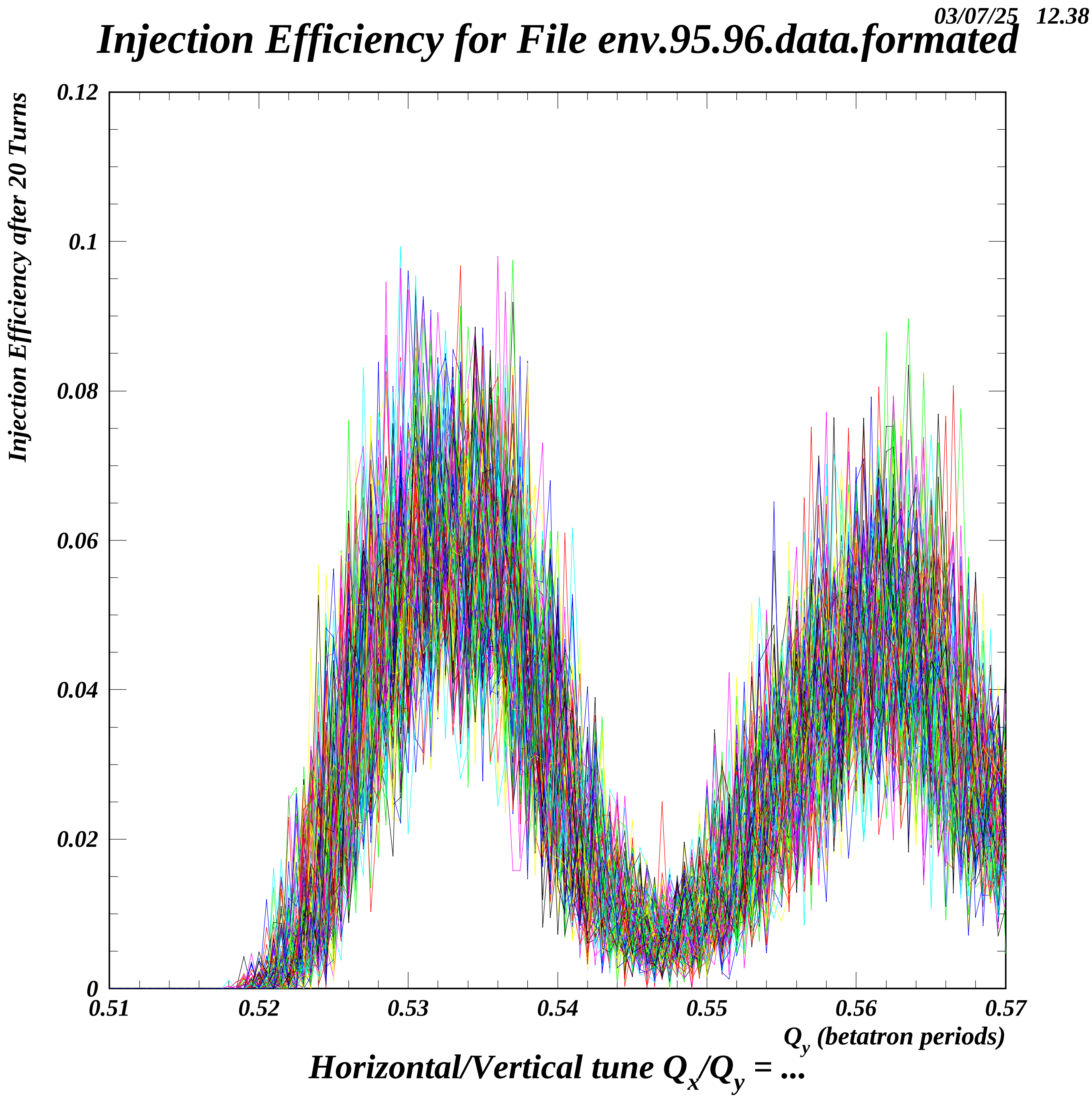

FIGURE 5. Efficiency vs. Horizontal Tune (less 10 osc./turn); note that axis should be Q_x, not Q_y.

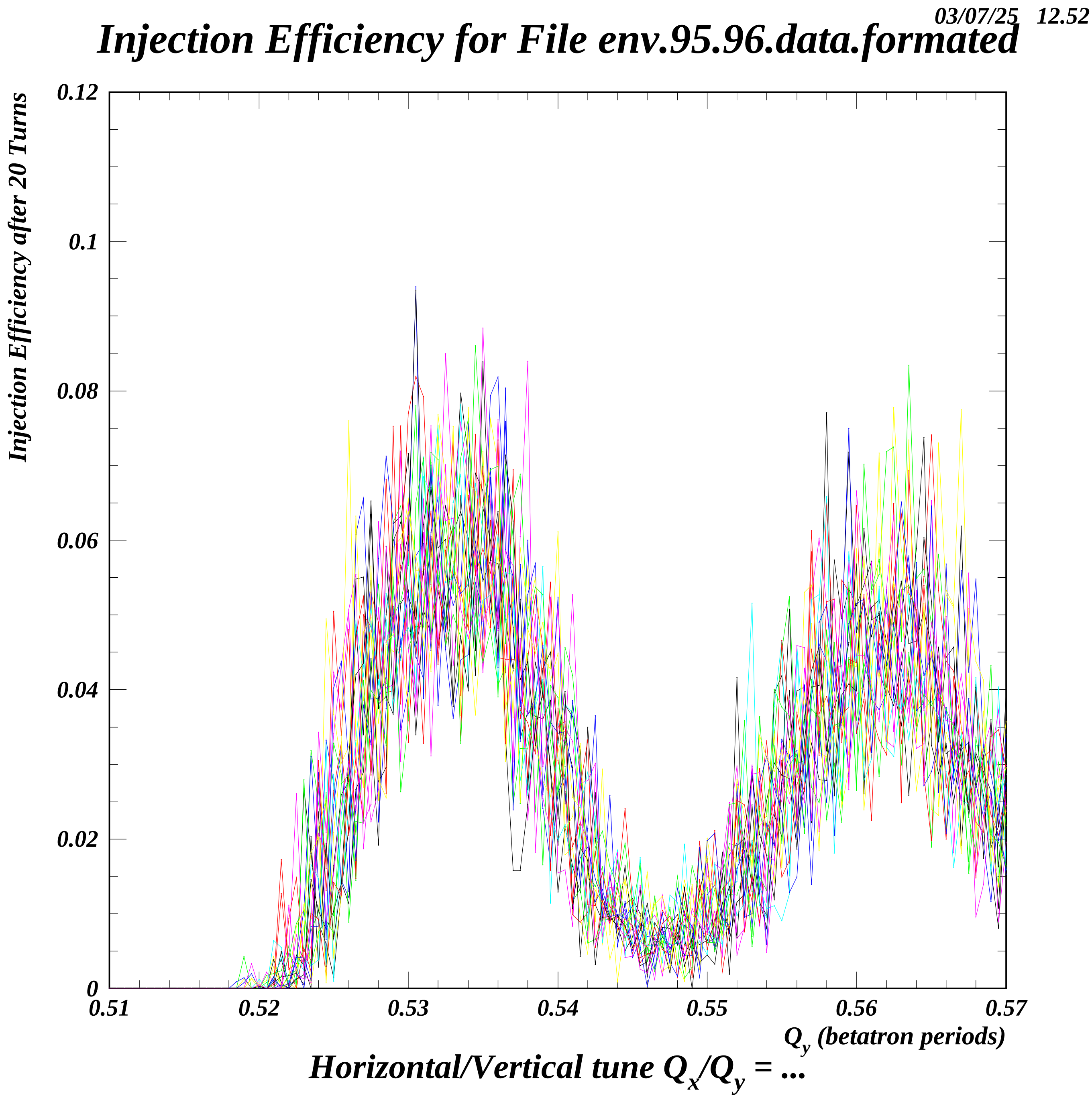

FIGURE 6. Efficiency vs. Horizontal Tune (less 10 osc./turn) for $9.565 \leq Q_y \leq 9.575$; note that axis should be Q_x, not Q_y.

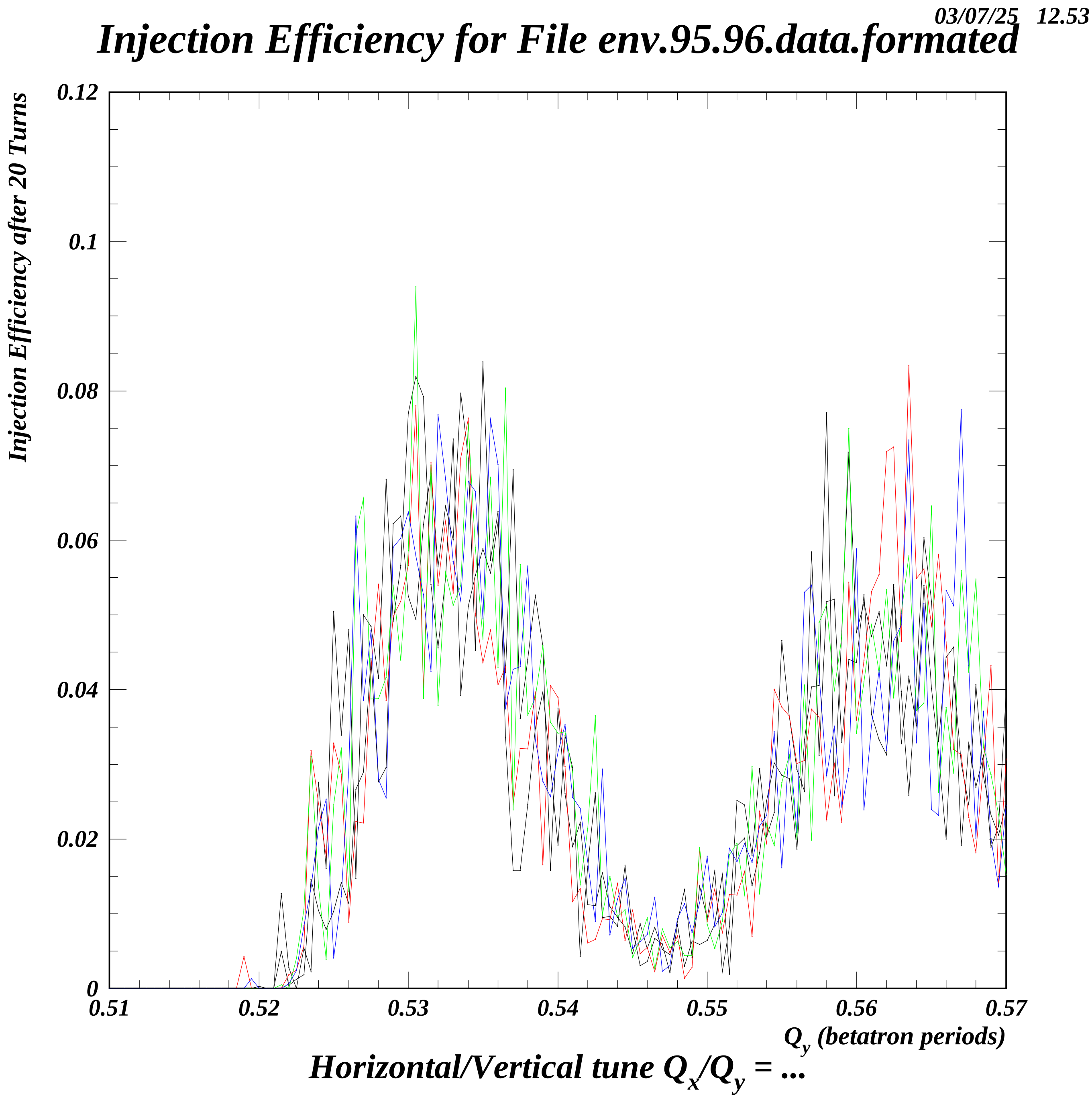

FIGURE 7. Efficiency vs. Horizontal Tune (less 10 osc./turn) for $10.569 \leq Q_y \leq 10.571$; note that axis should be Q_x, not Q_y.

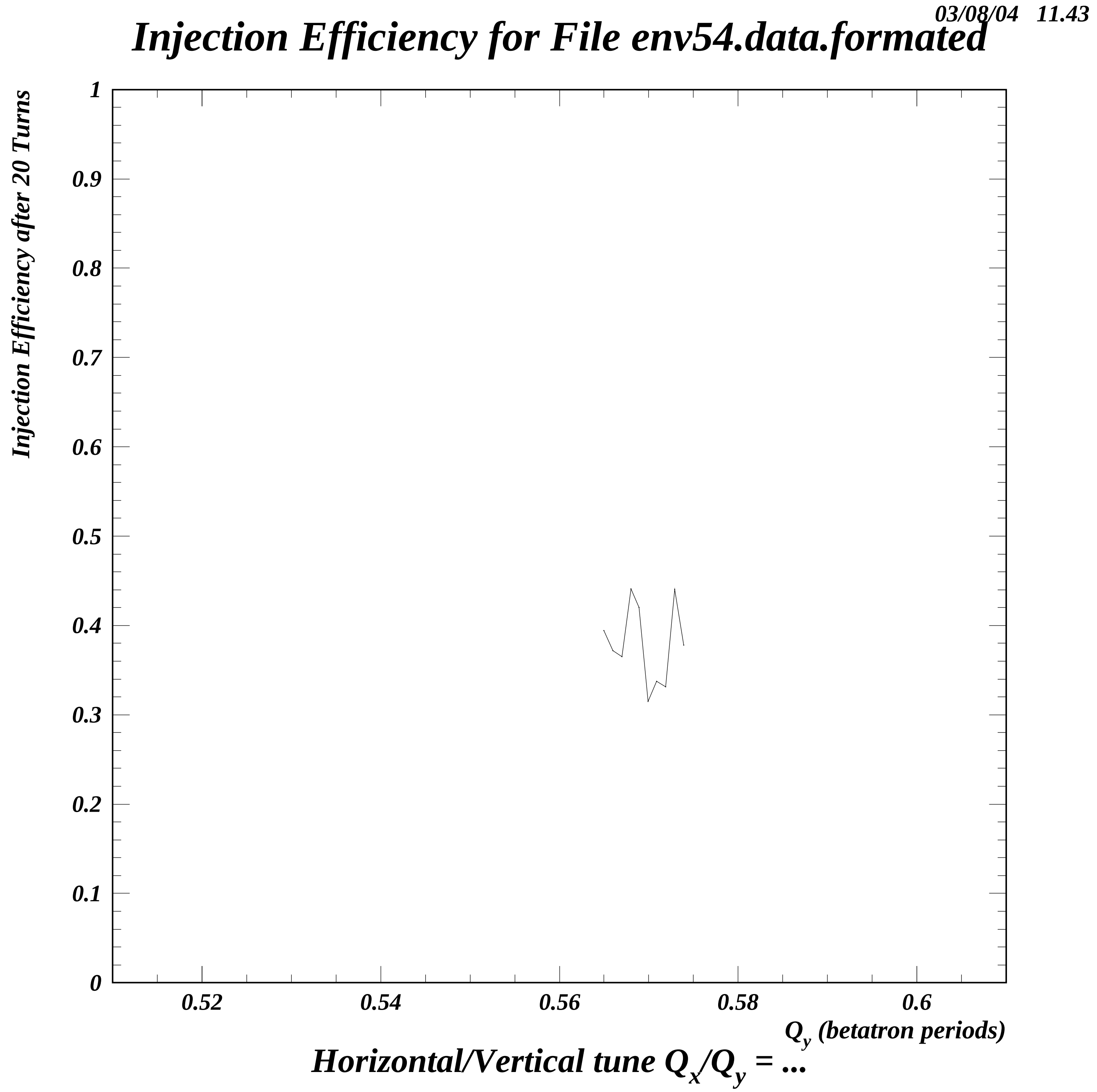

FIGURE 8. Efficiency vs. Vertical Tune (less 9 osc./turn) for $Q_x = 10.353$.

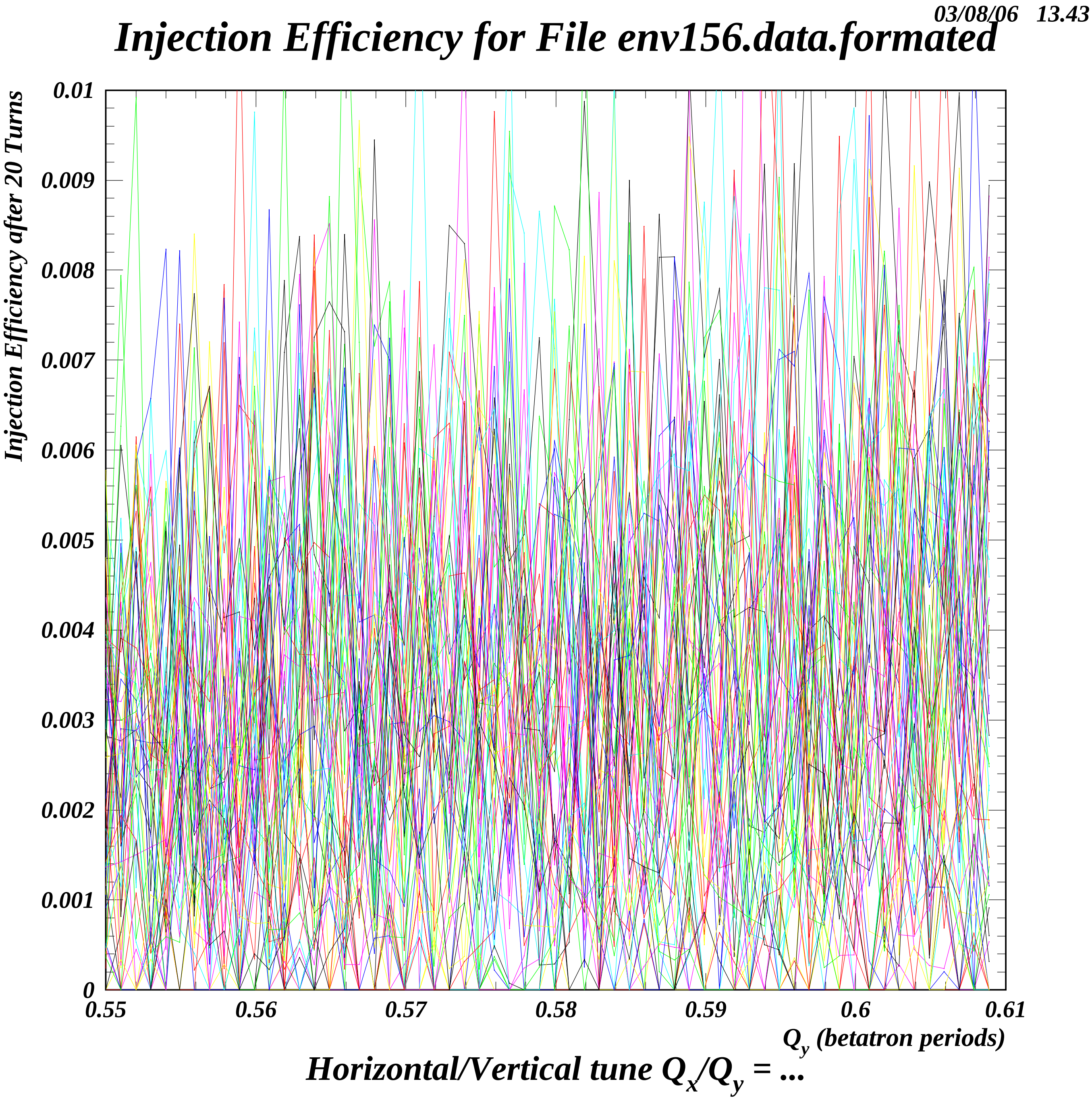

FIGURE 9. CHESS 5 GeV Lattice: Efficiency vs. Vertical Tune (less 9 osc./turn)

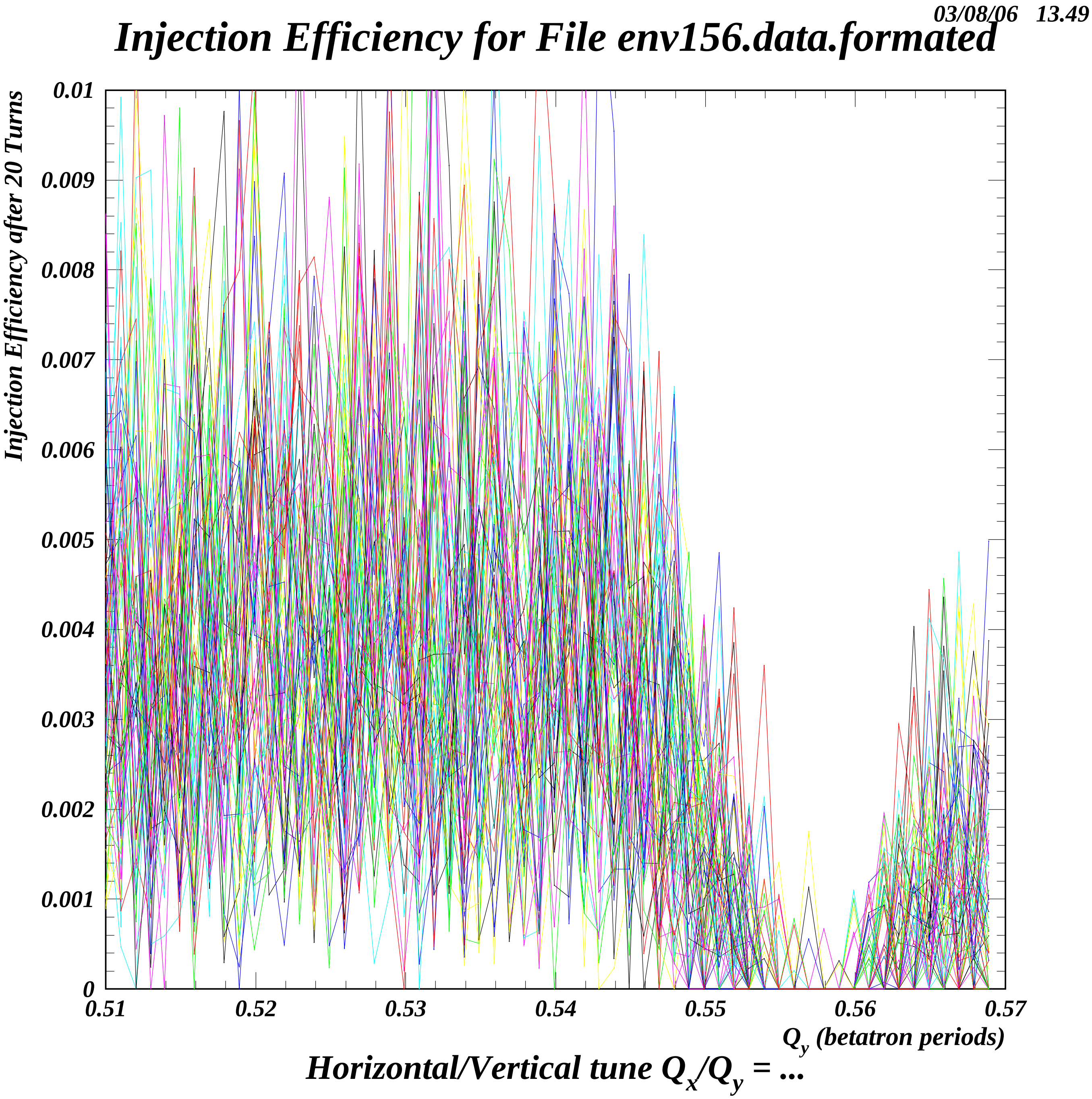

FIGURE 10. Efficiency vs. Horizontal Tune (less 10 osc./turn)

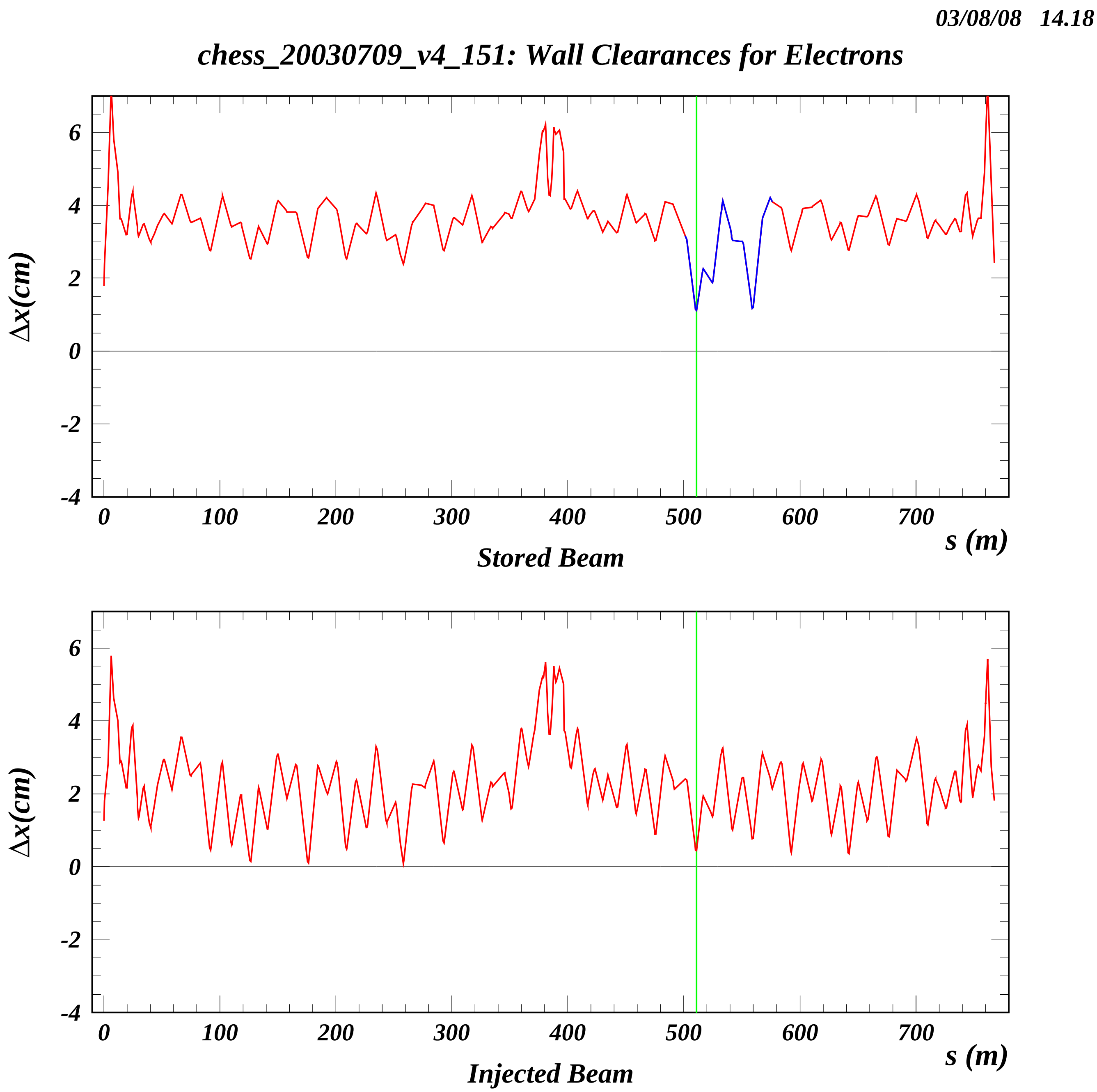

FIGURE 11. CHESS 5 GeV Lattice: Wall Clearances for Electron Beams. A negative value of Δx indicates a point for which the beam centroid hits the beam pipe wall.

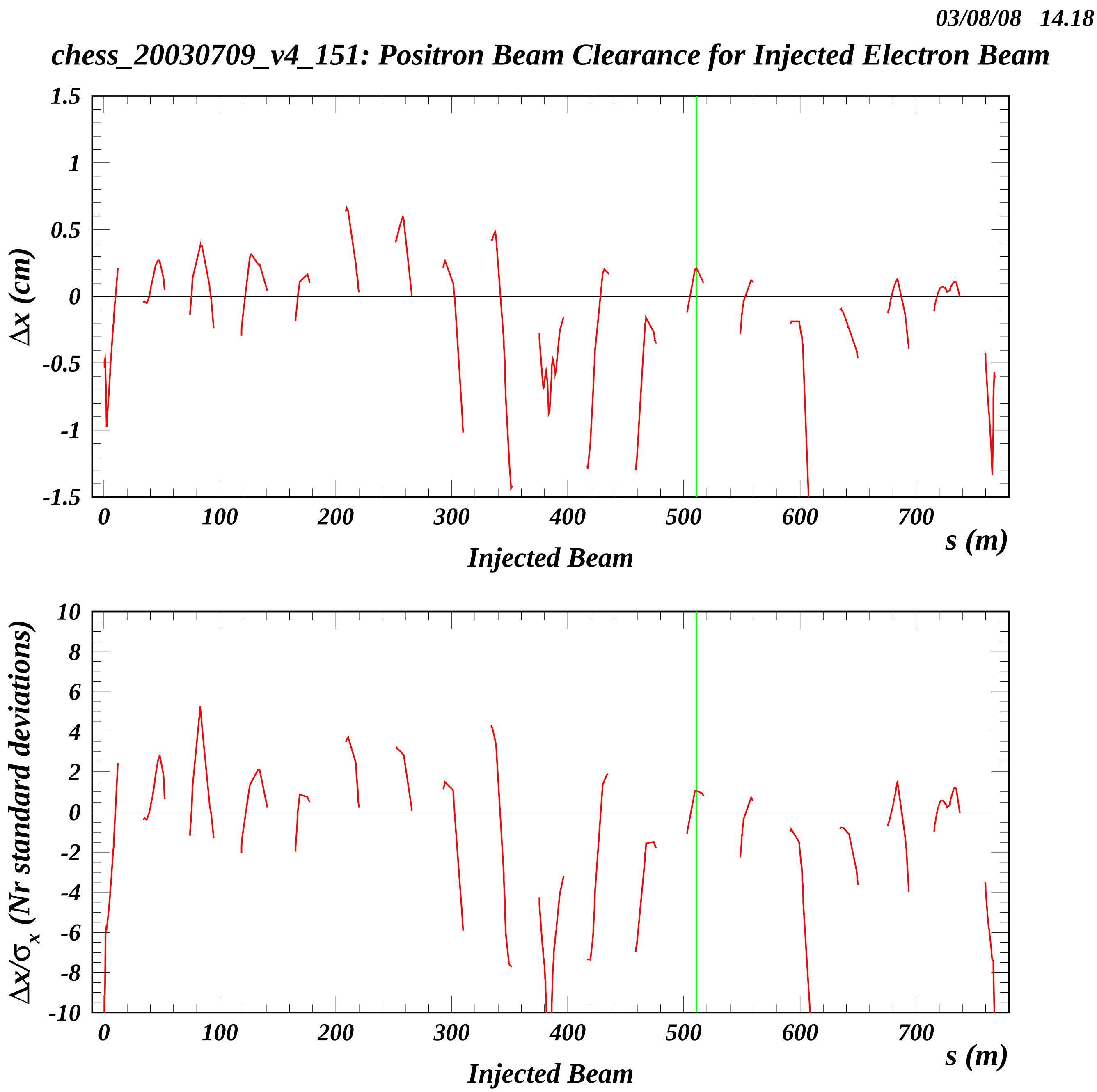

FIGURE 12. CHESS 5 GeV Lattice: Positron Beam Clearances for Electron Beams. A negative value of Δx indicates a point for which the beam centroid hits the beam pipe wall.

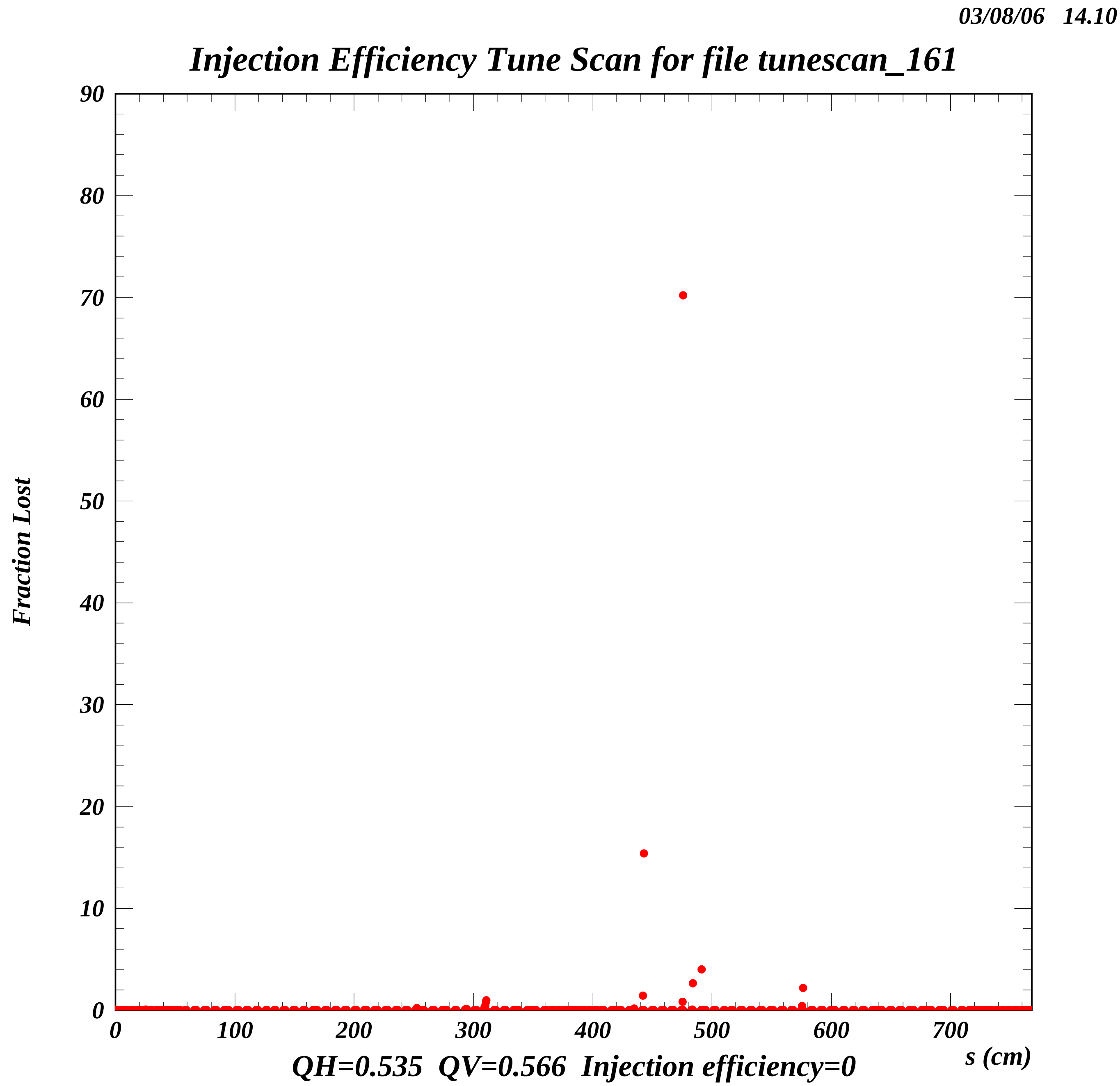

FIGURE 13. 1.86 GeV 6 Wiggler Lattice: Location of Lost Injected Electron Beam. The injection point is at $s = 510m$ and the electron beam travels in the $-s$ direction. It is evident that under the simulated conditions the injected beam is lost on the first turn shortly after entering CESR.