Injection Optimization for CESRc Injection

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Abstract

One important aspect of CESR operation is making sure the optimal injection position and angle, betatron tunes, and emittance values are used in order to get maximum particle injection efficiency. In this study, I used the computer program INJTRACK[1] to simulate the injection process, and learn about how these variables should be adjusted in order to get optimal efficiency in the new CESRc lattice.

Introduction

The injection process for CESR begins with the injection of a positron beam into the storage ring from the synchrotron, where the positrons have been accelerated[2]. The beam is kicked from the transfer line from the synchrotron into the storage ring by a septum magnet, which results in some oscillation around the stored positron orbit. Focusing quadrupole magnets also cause betatron oscillation, in which the beam alternately expands in the vertical direction while being compressed in the horizontal direction, and expands horizontally while being compressed vertically.

It is critical that the positron beam not be allowed to collide with the electron beam that is injected next, so after the initial oscillations have died down, a system of electrostatic separators is used to alter the orbit of the beams in order to prevent them from colliding prematurely. This "pretzel" orbit (Figure 1) ensures that the electron and positron bunches pass through the crossing points of their paths at different times.

When the electron beam is injected, many forces are influencing its orbit. In addition to the betatron oscillations that affect both the positron and electron beams, the pretzel also adjusts the path of this beam. The current CESRc pretzel amplitude is 2.5 cm. Furthermore, the transient pulsed bump that pushes the stored electron orbit closer to the beam injection point stays active for several revolutions of the beam around CESR. The bump size is .8 cm. Together, these forces can cause the electron beam to scrape against the walls of the storage ring, causing a loss of particles that is referred to as a loss in injection efficiency. The storage ring beampipe is 9 cm wide.

CESR is currently being redesigned in order to study decays of mesons containing a charm quark. This new configuration, called CESRc, operates at a lower energy than the old configuration, or lattice. Therefore, the parameters affecting efficiency must be studied in order to determine the new optimal values.

My study used the computer program INJTRACK in order to determine how emittance, betatron tune, injection position and angle, and pretzel amplitude influence the efficiency of the electron beam injection process. The program simulates the motion of individual particle trajectories, and measures the efficiency in terms of total particles still in the beam after twenty turns. Theoretically, few particles should be lost after this point, so this efficiency should be very close to the actual efficiency.

Analysis Results

Emittance

Emittance is a measure of the area in phase space of the injected beam. The standard deviation of the particles' positions and the standard deviation of the particles' momenta are used to determine the size of this space. Under energy conserving transformations, this quantity will be preserved in the beams' movement through CESR, so emittance is a good measurement of beam size. We would expect that a larger emittance would mean a broader beam, and thus a larger chance of collision with the beampipe wall, and thus a lower efficiency.

The current horizontal emittance value of the injected electron beam is about 3.5E-06 m-rad, determined primarily by multiple Coulomb scattering in the two 1 mil titanium vacuum windows and the 1 m long helium-filled septum magnet[3]. The associated horizontal beam size is about 12 mm. For comparison, the high energy configuration for b quark studies had an emittance of 0.53E-06 m-rad, and a beamsize of about 4.6 mm. The effect of multiple Coulomb scattering decreases with energy, so it is worse for the CESRc configuration. Using the current value, and the currently accepted betatron tune values, INJTRACK calculated efficiencies of 14% (Figure 2). However, there are plans to improve the emittance value of the injected beam. The titanium windows will be substituted with 3 mil beryllium windows in August, 2002, which should reduce the emittance value to about 1.8E-06 m-rad. The associated beam size is about 8.5 mm. Using this new emittance value, the estimated efficiency increases to 35% (Figure 3).

Betatron Tunes

The present testing of the CESRc lattice during machine studies is using betatron frequencies of .556 horizontally, and .627 vertically. This means that the beam goes through 10.556 horizontal and 9.627 vertical oscillations in each loop around the storage ring. These values were calculated to avoid certain resonances where the beam lifetimes are expected to be particularly bad. However, they were not necessarily the best possible values for electron injection efficiency. My studies suggest that better parameters exist. Using the poorer emittance value, I was able to find betatron frequencies, or qtunes as they are also called, where the efficiency is above 23% in the current configuration (Figure 4). Using the improved emittance value, efficiencies of over 59% were possible (Figure 5).

Finding optimal values was difficult, however, because of the apparently chaotic dependency of efficiency upon qtunes. The number of particles used for simulations was increased from 500 to 3,000 and more data points were plotted, in order to reduce statistical error. Despite this, the space continued to remain highly 'spiky', suggesting that the system may be chaotic in nature.

Injection Position and Angle

INJTRACK calculated its own suggested injection position and angle for each lattice and emittance value[4]. My analysis of the efficiency dependence upon injection position and angle suggested that the proposed values were either optimal, or near optimal. However, the values changed significantly based on whether the old lattice or the CESRc lattice was used, and on which of the two values for emittance was used. The old injection position of 5.5 cm would result in complete beam loss if used for the new lattice, where a position of 7.1 cm was given by INJTRACK, and further analysis showed 6.7 cm to be optimal (Figure 6). The old injection angle of about 4 mrad was approximately equal to the current optimal value (Figure 7). These results suggest that it is crucial that the optimal position and angle for the new lattice be determined and used.

Pretzel Amplitude

On the 29th of July, 2002, a study was done measuring the effect of reducing the pretzel amplitude upon the efficiency of the injected beam[5]. It was found that this drove the efficiency up from 10% to 38%. In response to this data, I ran an analysis to study what effects my program expected when the pretzel amplitude was reduced from 2900 computer units to zero. My studies showed that the efficiency for the given betatron tunes the efficiency should jump from 14% to 42% when the pretzel was turned off (Figure 8). These results fairly closely parallel the measured values. Furthermore, my results suggested that efficiency for the better emittance is increased by turning off the pretzel, from 35% to 66% (Figure 9).

The pretzel cannot be turned completely off, as was done in this study, because it is needed to prevent the electron and positron beams from colliding. However, this data does suggest two important conclusions. Firstly, it strongly indicates that scraping against the wall of the storage ring, due in part to the effect of the pretzel, is responsible for a great deal of the loss in efficiency, for both emittances.

Conclusions

Efficient electron injection is possible, and we should be capable of achieving efficiencies over fifty percent after the installation of the new vacuum windows. The new emittance values resulting from the substitution of beryllium for titanium vacuum windows should significantly improve the efficiency values, from 14% to 35% for the present betatron tunes. The current betatron tunes are not optimal for electron injection efficiency, and better values could lead to improved efficiency, from 35% to at least 59% after installation of the beryllium windows. The optimal values may be difficult to determine if the dependency upon qtunes is chaotic. Further studies are needed to discover whether the dependency is indeed chaotic, and what the ideal values are. Efficiency is also heavily dependent upon injection position and angle, so new optimal values should be developed for the new lattice. The results of reducing the pretzel amplitude strongly suggest that efficiency loss is due to particle beams scraping against the edge of the CESR storage ring, even after the installation of the new windows. The results of the machine study agreed strongly with the data from INJTRACK under present CESRc operating conditions - INJTRACK gave values of 14% and 42% with the pretzel on and off, while the machine study gave efficiencies of 10% and 38%.

Acknowledgments

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Footnotes and References

1. S.D.Henderson, wrote INJTRACK program.
2. S.D.Henderson, Internal CESR note of October 27th, 1995.
3. D.Rubin, Internal CESR note of February 18th, 2002.
4. C.Morris, wrote injection position and angle scanning program, REU Program at Cornell University, 2001.
5. http://cesrelog.lns.cornell.edu/MSLOG/cesrc/cesrc_020729_st.html

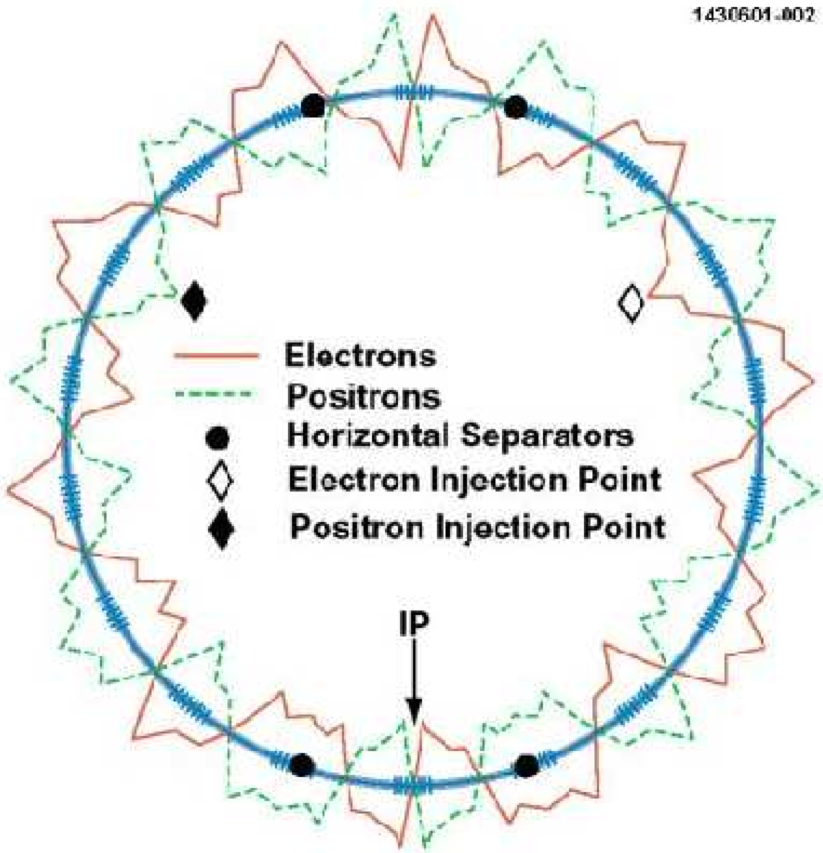

FIGURE 1. Diagram of CESR depicting the horizontal separation of positron and electron beams by pretzel. The pretzel amplitude is about 2 cm.

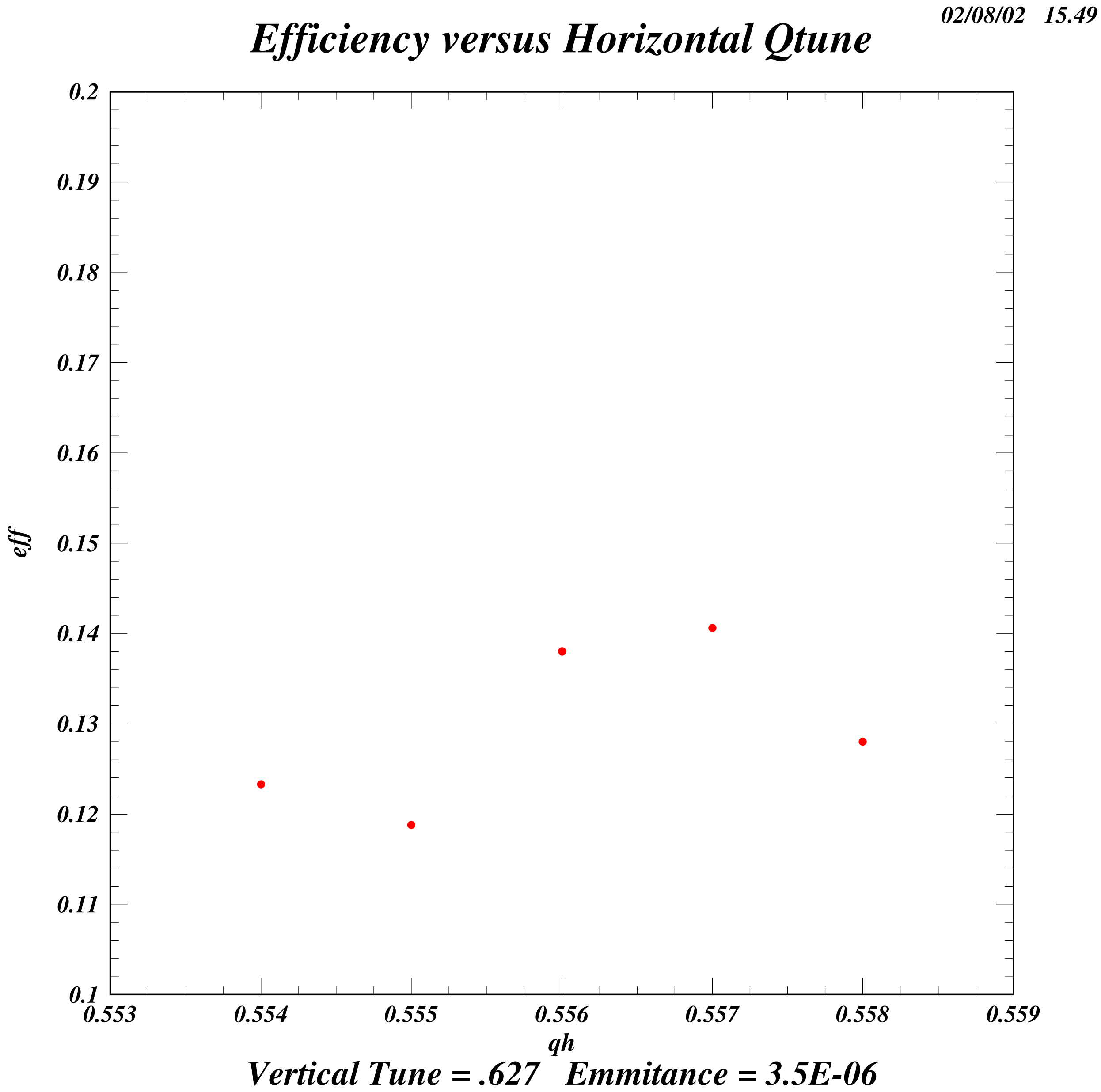

FIGURE 2. Calculation of efficiency using present qtunes and emmitance value. 14% efficiency for horizontal qtune .556, vertical qtune .627, emmitance 3.5E-06.

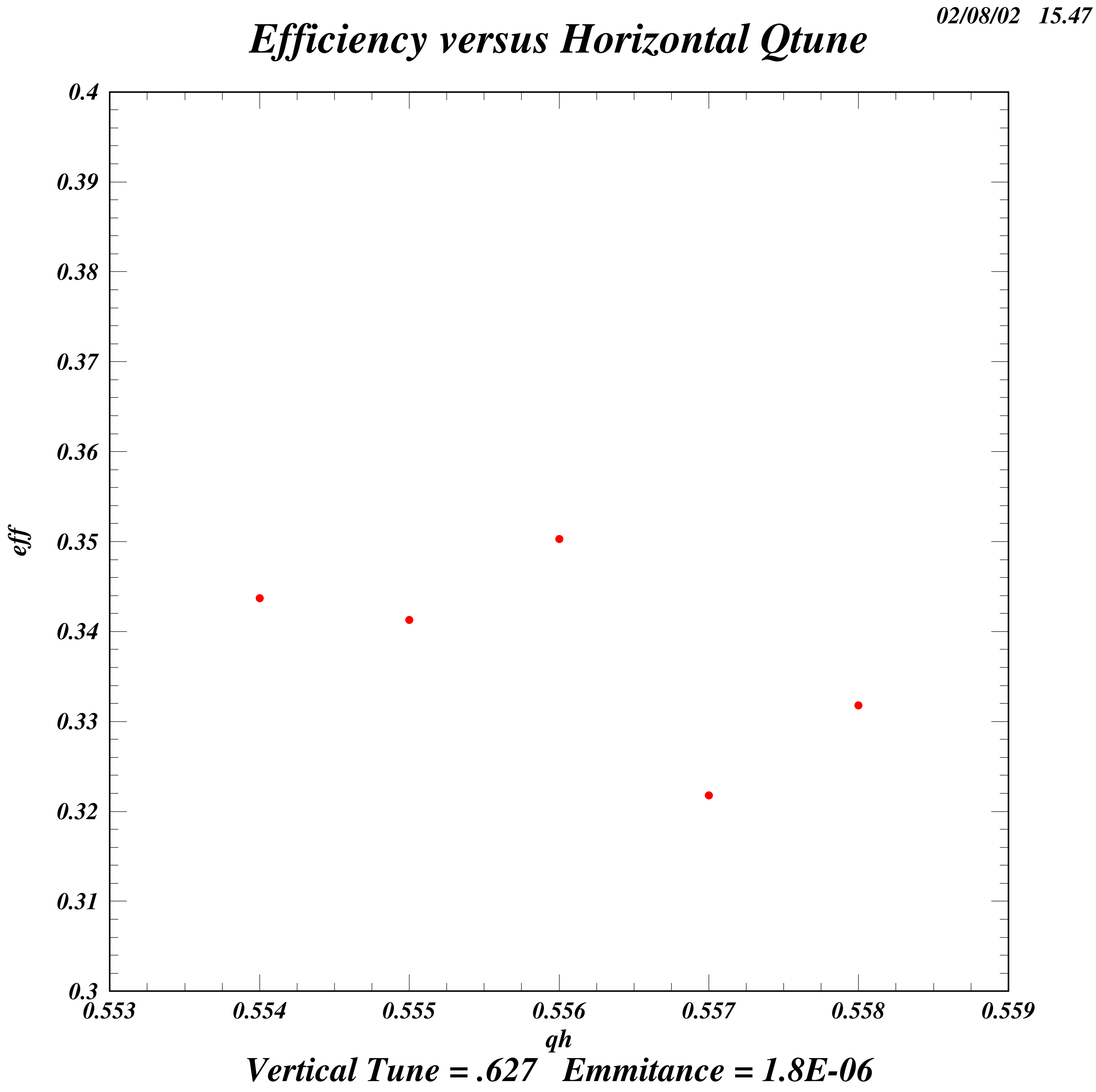

FIGURE 3. Calculation of efficiency after installation of beryllium vacuum windows, with present qtunes. 35% for horizontal qtune .556, vertical qtune .627, emmitance 1.8E-06.

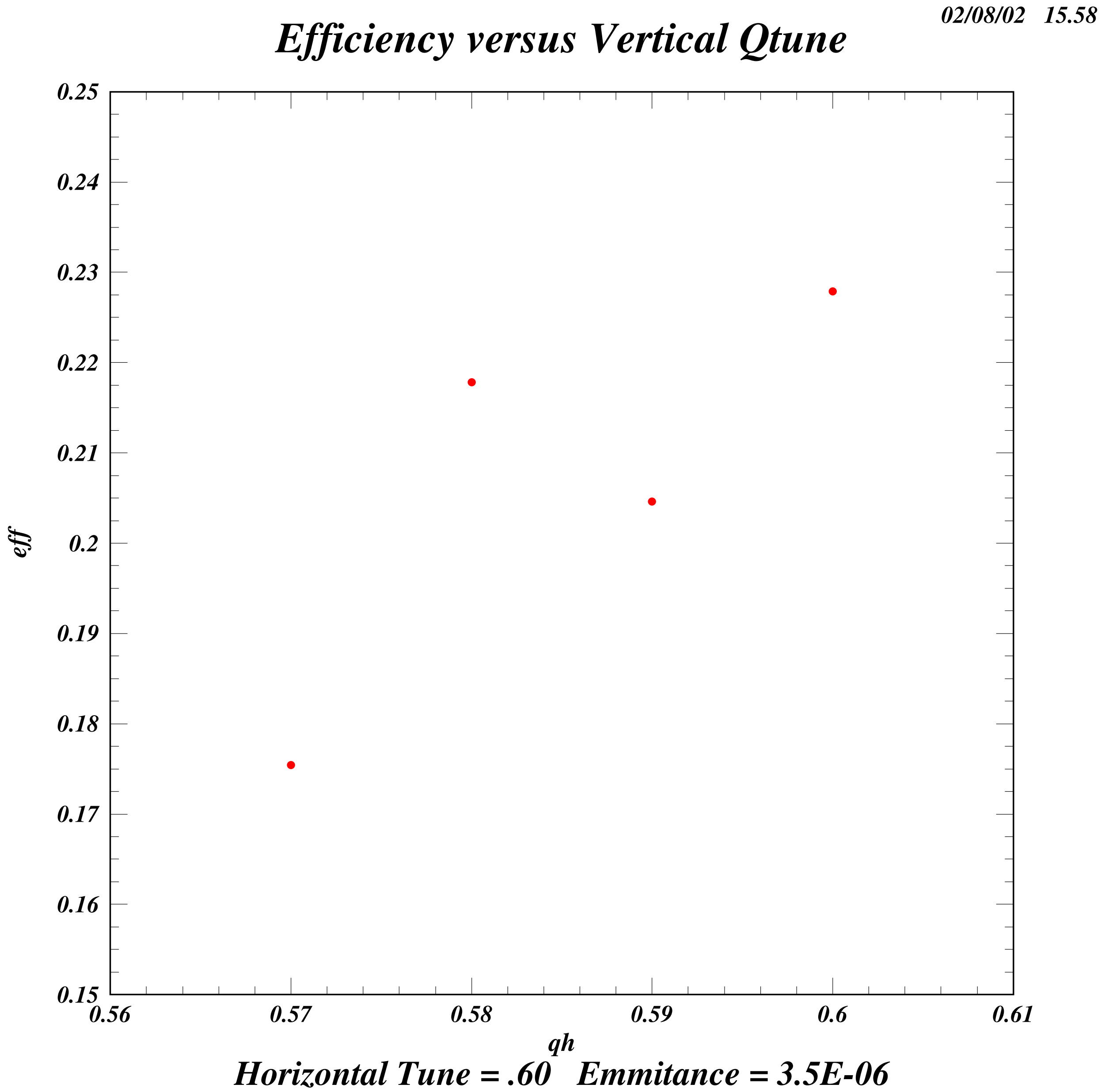

FIGURE 4. Efficiency for alternate qtunes and current emmitance. 23% efficiency for horizontal qtune .600, vertical qtune .600, emmitance 3.5E-06.

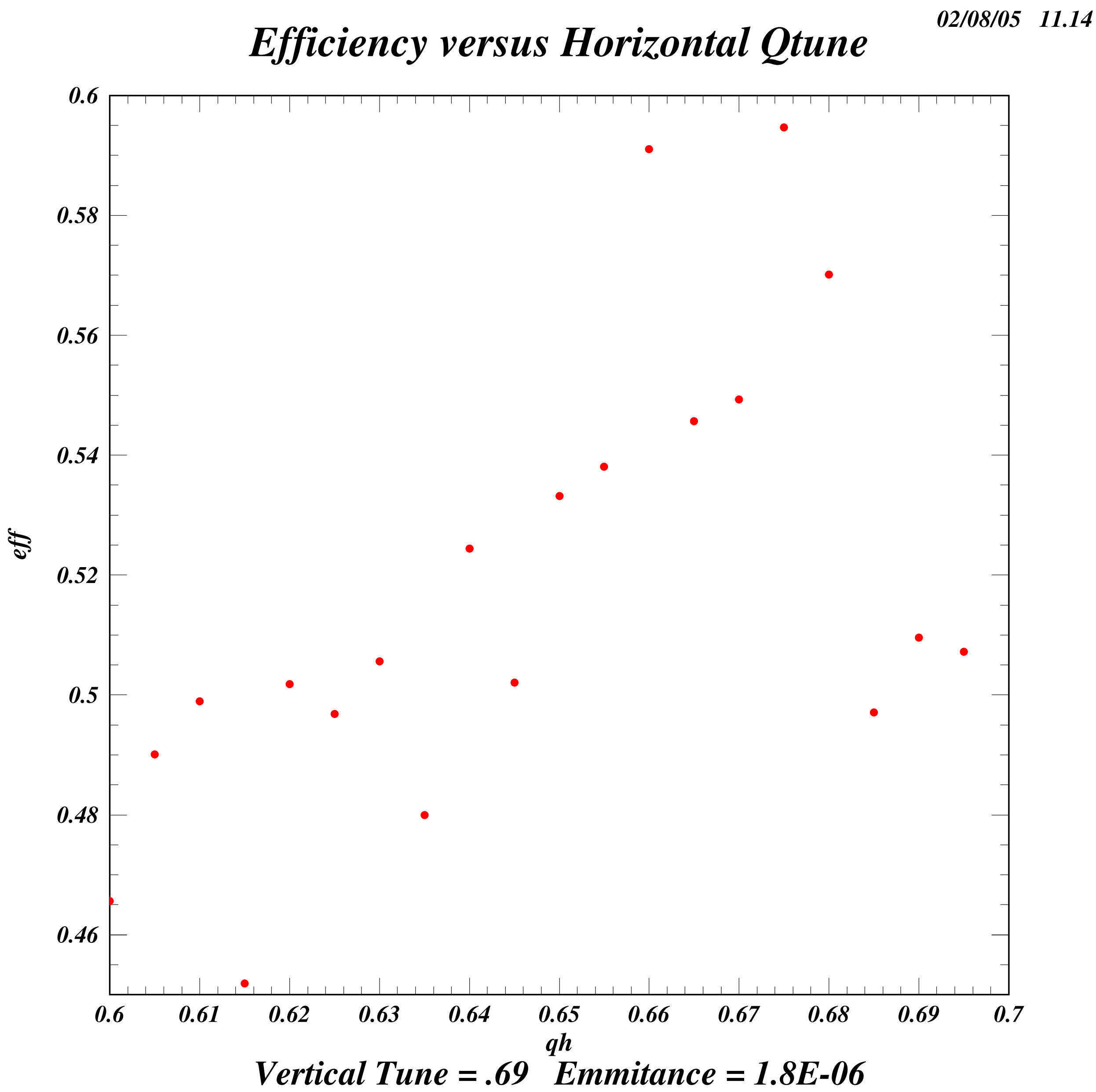

FIGURE 5. Efficiency for alternate qtunes and post installation emmitance. 59% efficiency using horizontal qtune .675, vertical qtune .690, emmitance 1.8E-06. 3,000 particles used to reduce statistical error.

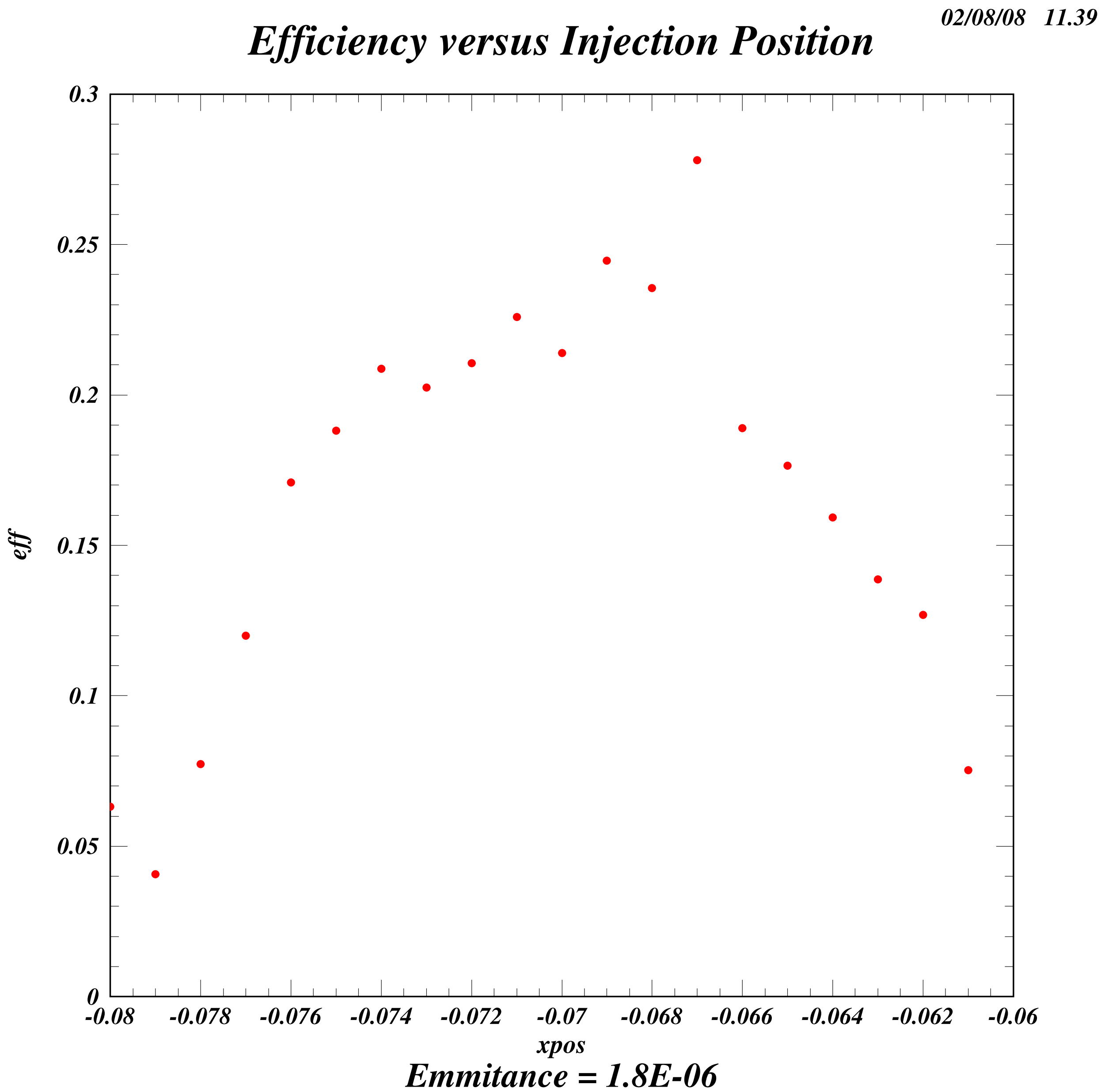

FIGURE 6. Efficiency variation with injection position, with improved emmitance. INJ-TRACK suggested value of -0.071 m yields 23% efficiency. Ideal position of -0.067 m yields efficiency of 28%. Former lattice value of -.055 yields efficiency of 0%.

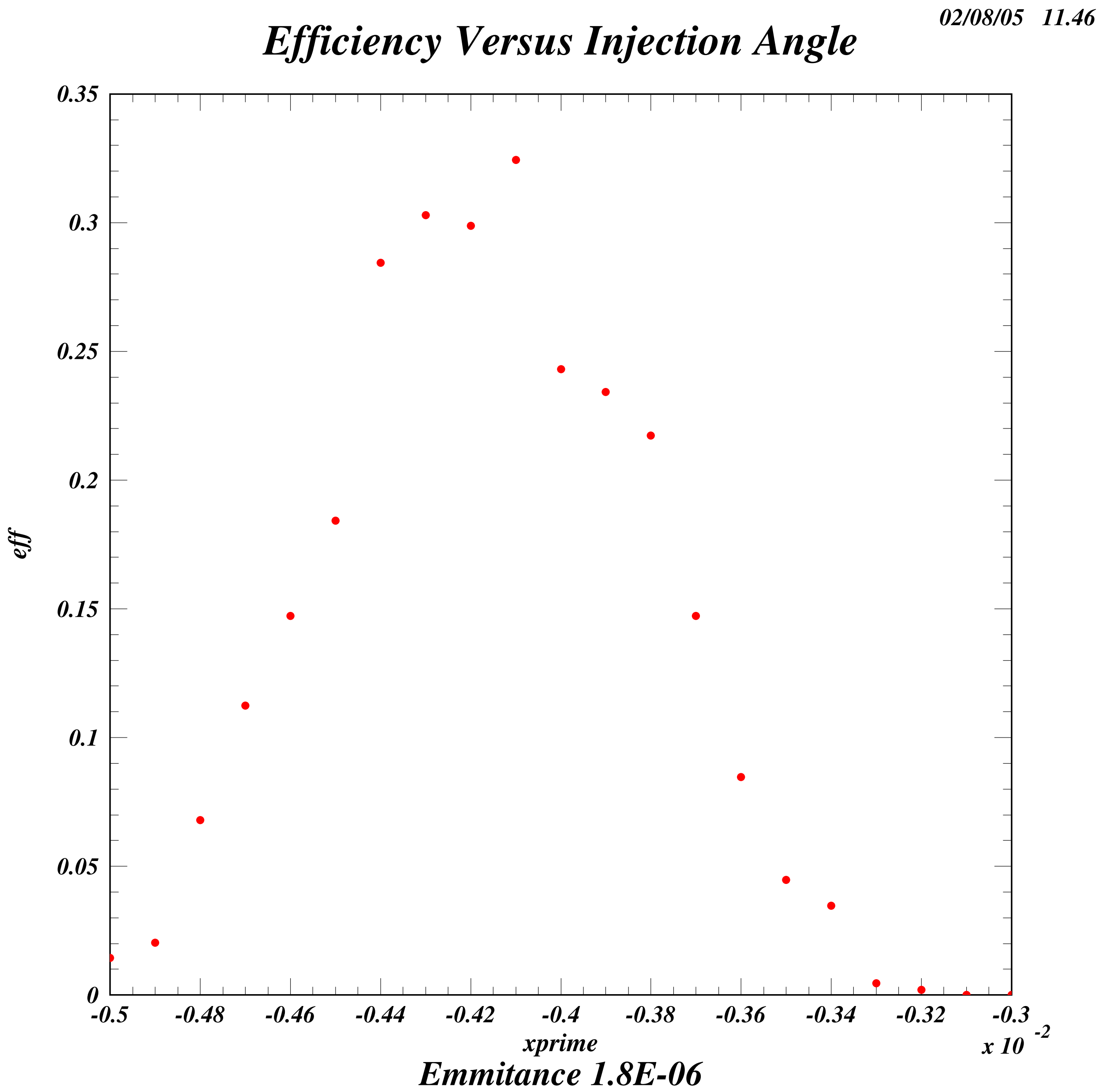

FIGURE 7. Efficiency variation with injection angle, with improved emmitance. INJ-TRACK suggested value of -0.0044 rad yields efficiency of 28%. Ideal value for old lattice and current lattice of -.0041 rad yields efficiency of 33%.

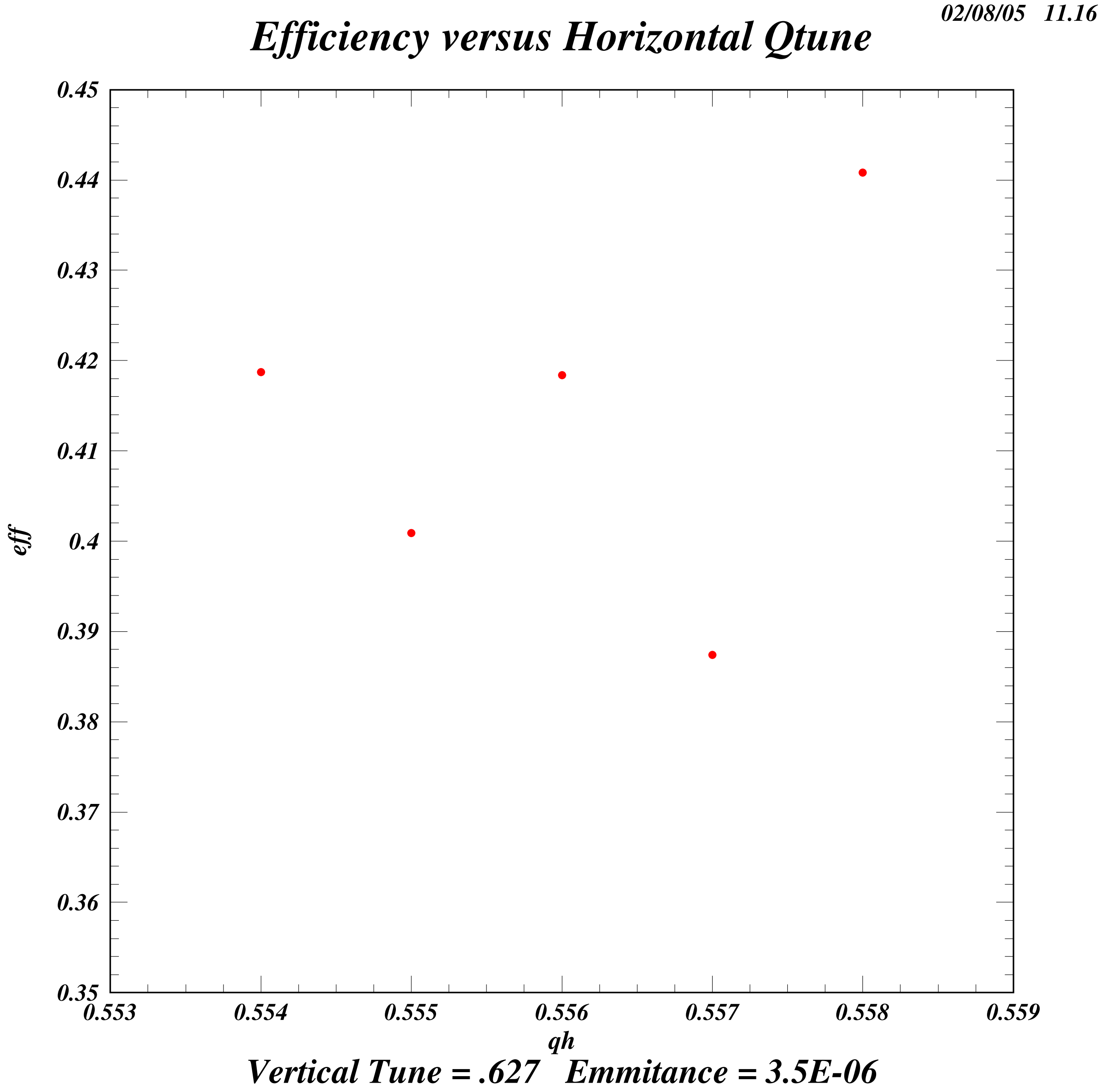

FIGURE 8. Efficiency using current qtunes and emmitance, with pretzel amplitude reduced to zero. Horizontal qtune .556, vertical qtune .627, and emmitance 3.5E-06 gives efficiency of 42%. Machine studies give efficiency of 38% for identical parameters.

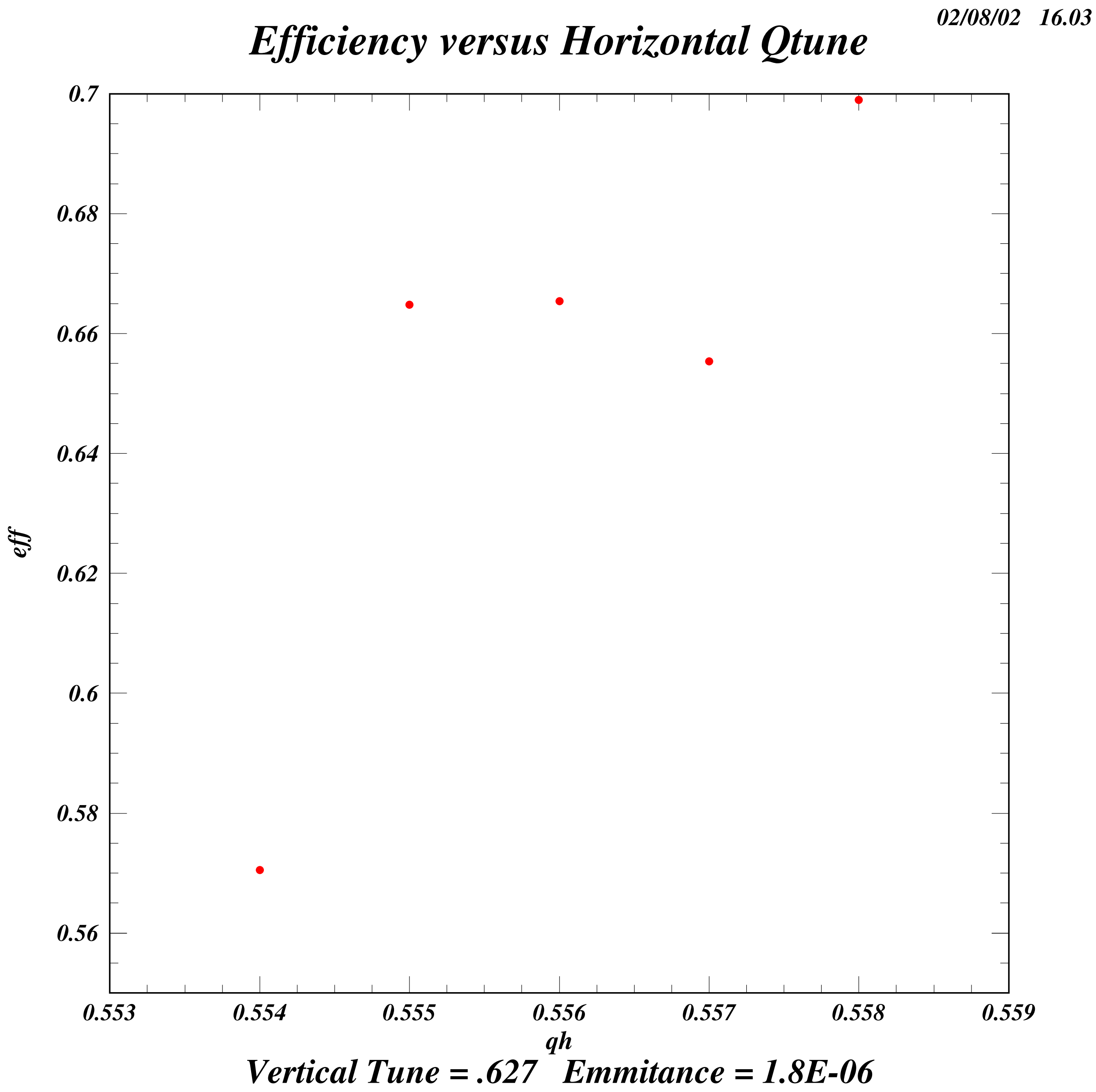

FIGURE 9. Efficiency using current qtunes, and emmitance after beryllium window installations, with pretzel amplitude reduced to zero. Horizontal qtune .556, vertical qtune .627, and emmitance 3.5E-06 gives efficiency of 67%.