Using Tune Shifts to Evaluate Electron Cloud Effects on Beam Dynamics at CesrTA

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Tune shifts were used to assess the development of electron clouds. Simulations were compared to data to find the optimal parameters that describe the physics of the electron clouds. The simulations can then be used as a model for the damping rings of future linear colliders.

I. INTRODUCTION

The proposed future International Linear Collider (ILC) will collide electrons and positrons. Because positrons are antimatter, they are harder to produce than electrons and need to be accumulated and conditioned in a damping ring. The Cornell Electron Storage Ring Test Accelerator (CesrTA) at the Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE) is similar to the damping ring of the proposed ILC and is being used as a model to study beam dynamics [1] [2].

Accelerating charges radiate, and for a circular damping ring, the radiated photons knock electrons off the walls of the beampipe. These photoelectrons can be accelerated by subsequent bunches in the beam and continue to knock off more electrons, forming a cloud, which can affect the beam dynamics [2].

Figure 1 shows a model of the nominal and actual paths of a beam around the beampipe. The motion of the particles in a beam can be described to first order by a damped simple harmonic oscillator. In this model, the particles are displaced from the nominal path and oscillate about it. The tune (Q) is defined as the number of oscillations of a particle about its nominal path, per turn in the ring. One method of characterizing the effect of the electron cloud on beam dynamics is to study the beam itself. The presence of the electron cloud will affect the forces on the beam, causing a shift in the tune. The tune shift (ΔQ) is defined as the difference in the tune caused by the electric field of the electron cloud, and measuring it can allow for a better understanding of the electron cloud growth.

II. METHODS

CesrTA is used to experimentally measure the tune shifts which are used to study the effects of electron clouds. A beam is grouped into bunches with some amount of current per bunch. A train consists of some number of bunches, and in some measurements will be followed by a witness bunch later to measure the decay of the electron cloud. Beams are set into oscillation, and beam position monitors (BPMs) measure the position of the beam for 2048 turns. Figure 2 shows an example of the raw data that is measured, for one of the bunches in the machine and using one BPM. The plot shows the horizontal displacement of the beam as a function of the turn number. A Fourier transform is then used to find the frequency of oscillation and the tune is calculated. The tune shift for each bunch is calculated as the tune of that bunch minus the tune of the first bunch, under the assumption that the electron cloud dissipates in the time between the passage of the last bunch and the passage

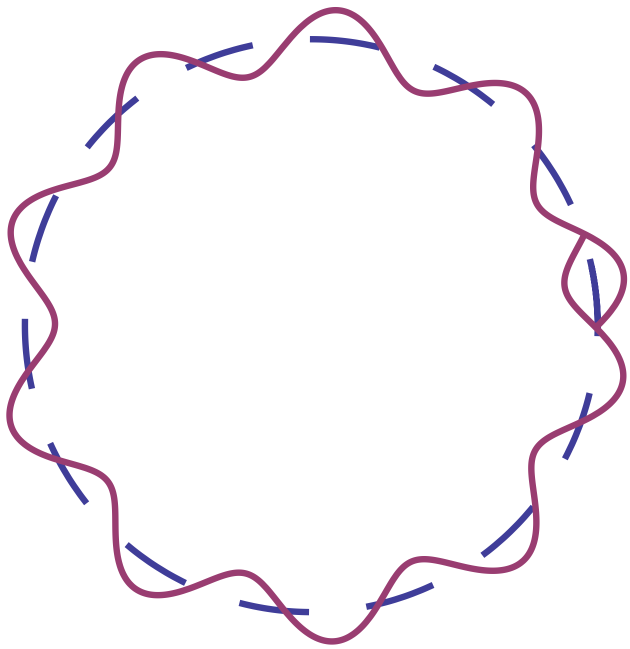

FIG. 1: $Q_y = 9.52$. Nominal (dashed) and actual (solid) paths of a particle around the beampipe.

of the first bunch on the next turn [1].

POSINST is a simulation code that is used to model the electron cloud effects. Simulations are run for different values of each of the five primary parameters which describe the physics of electron cloud generation. The simulations are compared to the data to test the accuracy of the model, for many different beam energies, bunch train configurations, bunch charge, bunch spacings, and bunch species. Figure 3 compares simulations for different values of the quantum efficiency to experimental data. The plot shows the vertical coherent tune shift as a function of bunch number. The first ten bunches are in the train, with a bunch spacing of 14 ns. The electron cloud builds up as the bunches pass by, resulting in an increase in the tune shift. The following data points are witness bunches, each measured separately after the ten bunch train, with delays varying from 14 ns to 490 ns. The different spacings between the train and the witness bunches show the decay of the electron cloud after the train.

The POSINST simulations were run on Cornell's batch nodes. POSINST simulates only the formation and decay of the electron cloud, but does not give any information on the effect on the beam. *Mathematica* was used to post-process the output of the POSINST simulations to calculate the tune shifts from the electron cloud density. *Mathematica* was also used to make the plots that superimposed the tune shifts from multiple simulations onto plots of the data for comparison. Because each job on the batch nodes is only allowed 48 hours of CPU time, some of the simulations were parallel processed in order to get more statistics. Each simulation would be run with a different initial random number seed and the results for the same data set and simulation parameter set would be combined.

Finding the values of the optimal parameters will allow the model to be used for future linear colliders. The simulation parameters describe the physics of electron cloud generation. When radiated photons from the beam knock into the wall of the beampipe, photoelectrons are generated. The first parameter, quantum efficiency, is defined as the number of electrons

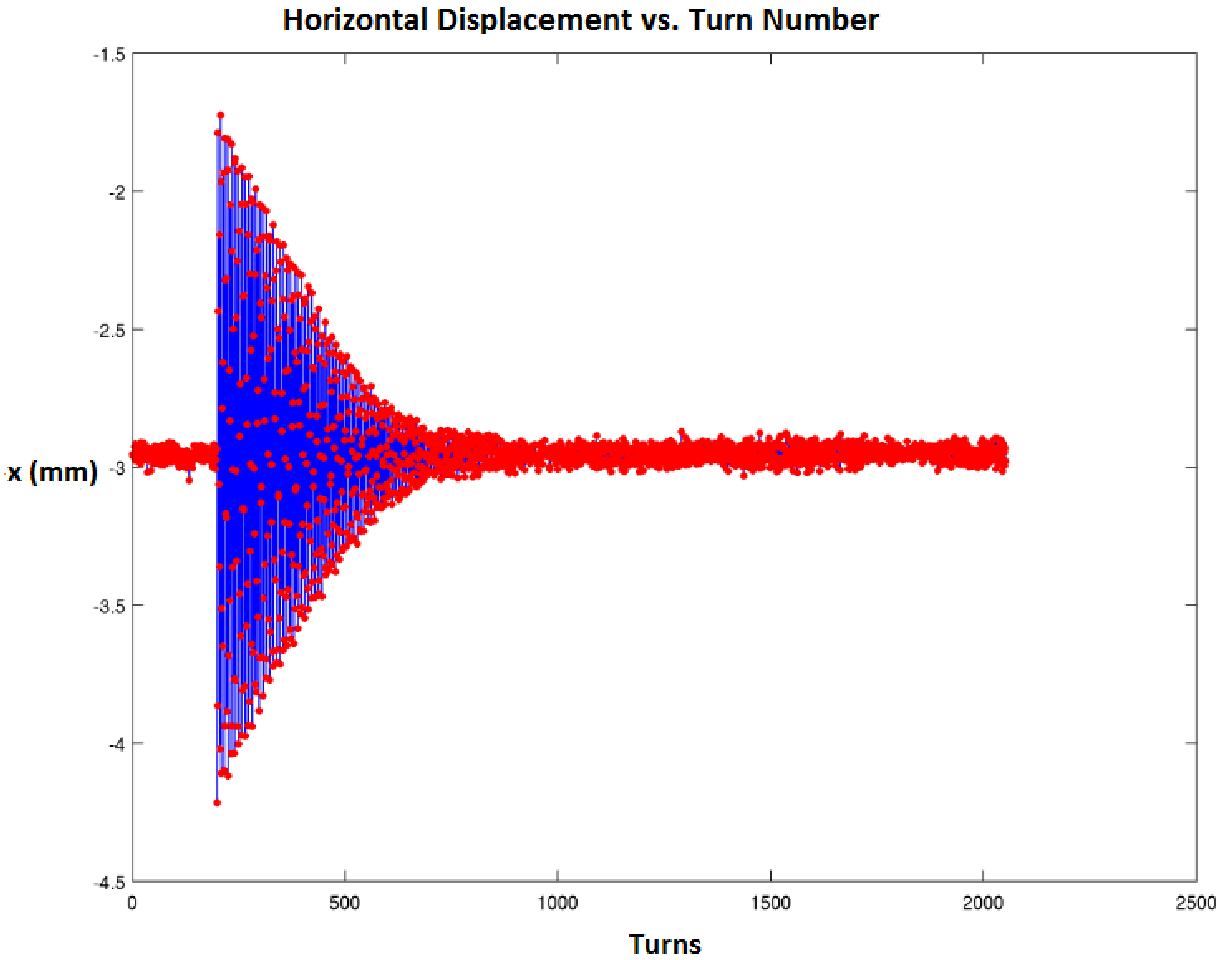

FIG. 2: The position of one bunch is measured at a beam position monitor for 2048 turns around the ring.

generated for every photon [3], and has a nominal value of 0.08 in the drifts and 0.10 in the dipoles of the storage ring.

The next step in the electron cloud generation occurs when photoelectrons are accelerated by the electric field of the beam and continue to produce more electrons. This process is known as secondary emission, and the other four parameters are related to the physics of this process. Figure 4 shows the dependence of secondary emission yield as a function of incident electron energy. It first rises as the incident energy increases, reaches a peak, and falls off for higher energy. The second parameter, secondary emission yield (SEY), is defined as the number of secondary electrons generated for every primary electron, at the peak of the distribution [3], and has a nominal value of 2.0. The third parameter, E0tspk, is the energy at which the SEY peaks [3], and has a nominal value of 310 eV.

The other two parameters are related to the type of secondary electrons produced in the secondary emission process. When a photoelectron hits a wall of the vacuum chamber, it can either bounce off to produce elastic secondary electrons, interact within the material and scatter back out to produce rediffused secondary electrons, or knock off electrons in the material to produce true secondary electrons. Each of these types of secondary electrons

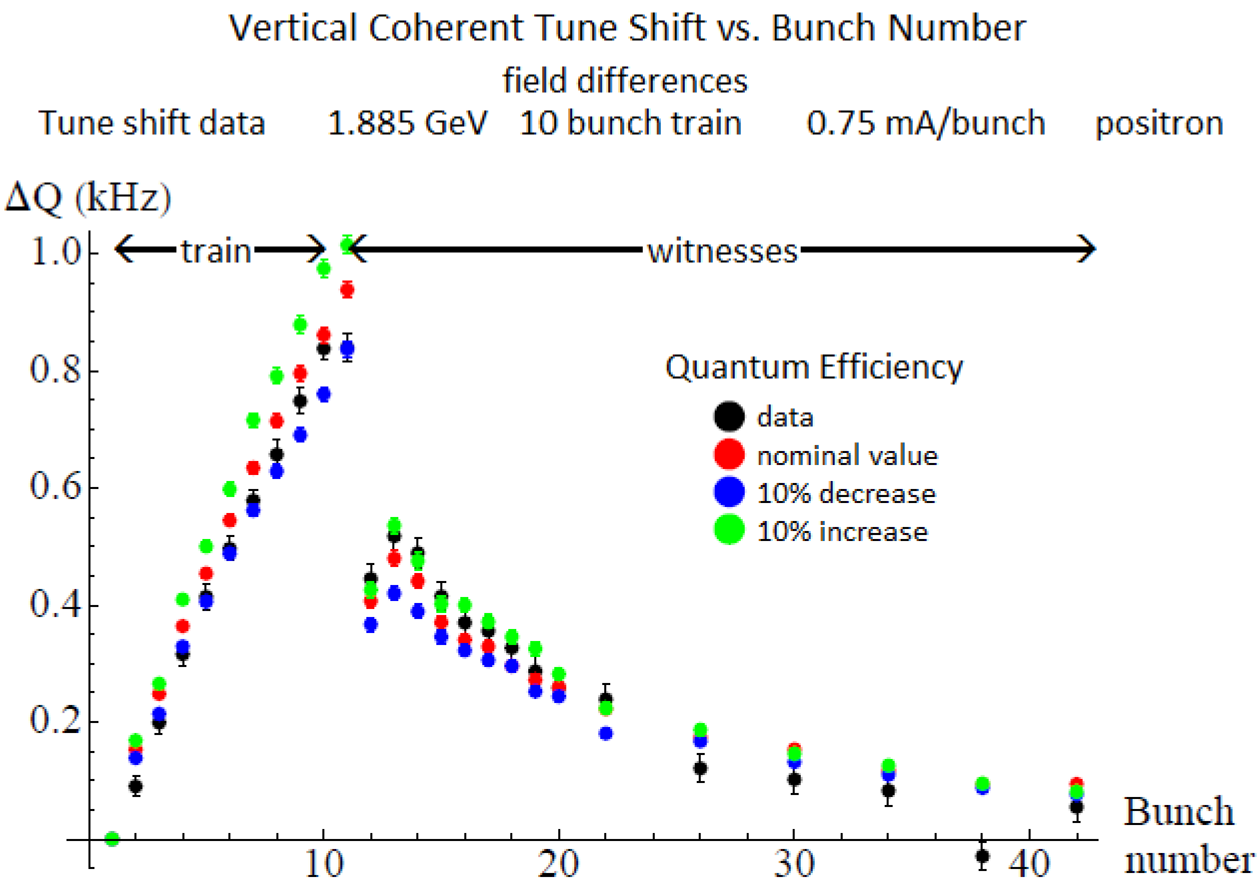

FIG. 3: Data is compared to the simulation for different values of the quantum efficiency.

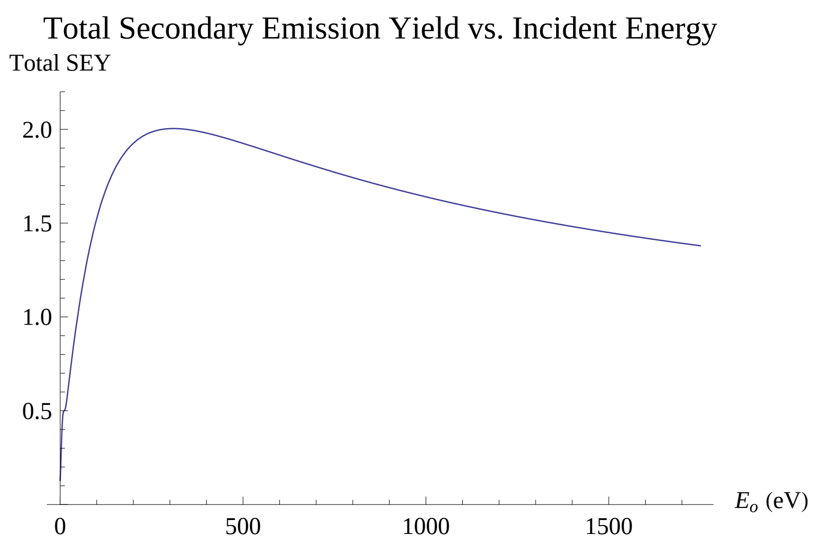

FIG. 4: Dependence of Total Secondary Emission Yield on Incident Electron Energy.

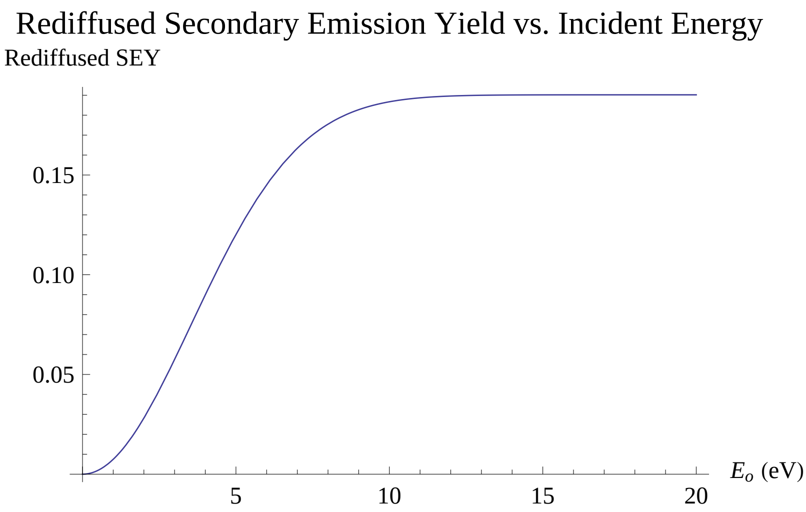

FIG. 5: Dependence of Rediffused Secondary Emission Yield on Incident Electron Energy.

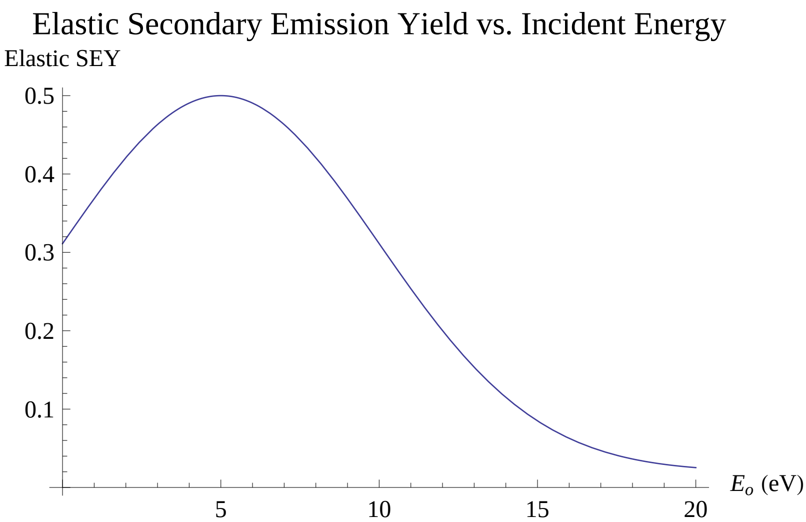

FIG. 6: Dependence of Elastic Secondary Emission Yield on Incident Electron Energy.

has its own distribution. Figure 5 shows the the dependence of rediffused secondary emission yield on incident electron energy, which increases to an asymptotic value. The fourth parameter is P1rinf, and is the asymptotic value of the rediffused secondary emission yield [3]. It has a nominal value of 0.1902.

Figure 6 shows the distribution of elastic secondary electrons as a function of incident electron energy. It increases, reaches a peak, and then decreases for higher energies. The fifth parameter, P1epk, is the peak value of the elastic secondary emission yield [3]. The nominal value is 0.5. The simulations will be compared to the data for different values of each of the parameters quantum efficiency, SEY, E0tspk, P1rinf, and P1epk to try and find the optimal set that most closely matches the data.

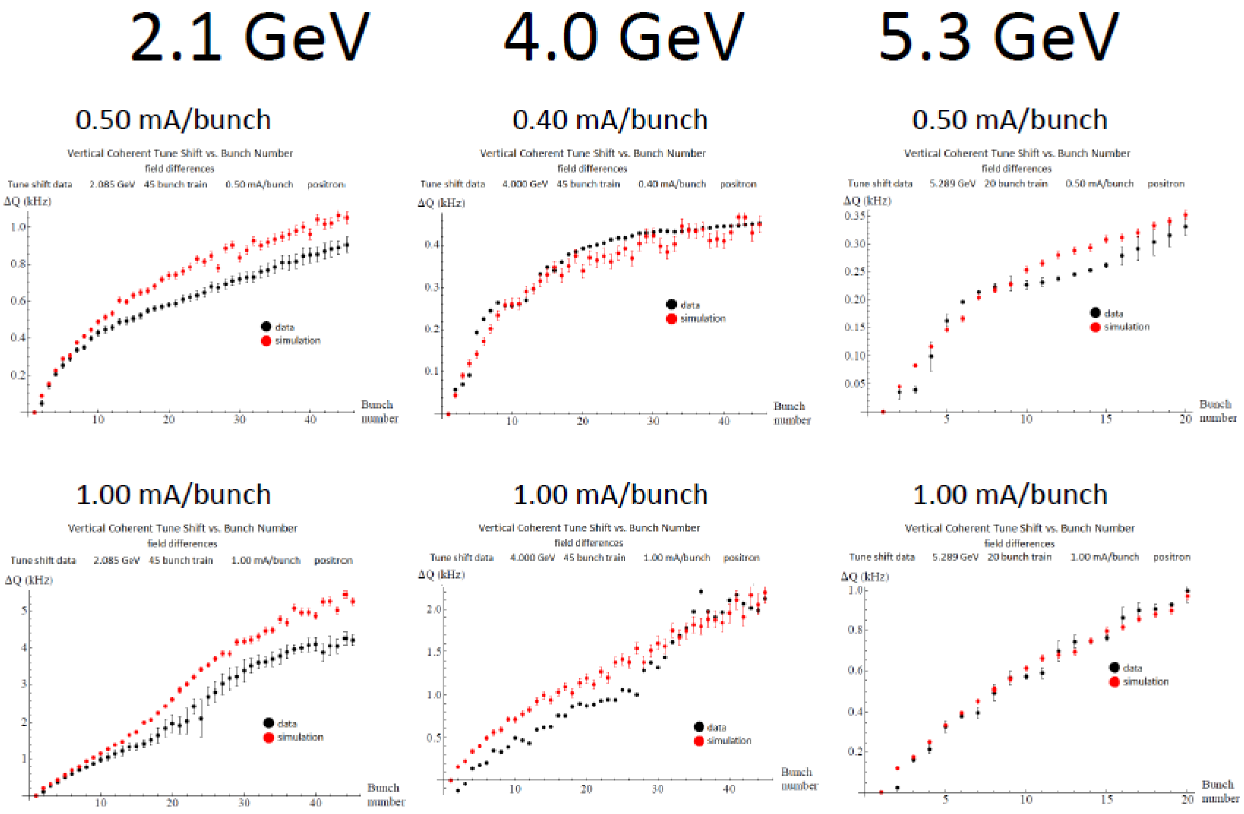

FIG. 7: Simulations (red) of June 2011 coherent tune shift data (black) at three different energies and for two different bunch currents.

III. RESULTS

In June 2011, CesrTA was used to measure tune shifts as a part of the electron cloud studies. Data were taken for 77 different combinations of beam energy, bunch configuration, bunch current, bunch spacing, and bunch species. Simulations of each of the new data sets were run varying all five parameters independently by about ±10% as well as for the nominal parameter set.

Figure 7 shows comparisons of POSINST simulations to June 2011 coherent tune shift data for 2.1 GeV, 4.0 GeV, and 5.3 GeV beam energies and low and high bunch currents. The simulations were run using the nominal parameter set, and show that the model works reasonably well for a variety of beam energies and bunch currents.

Figure 8 shows an example of comparing simulations for different values of parameters for the same data set. The plots are all for 45 bunches of 2.085 GeV positrons with 1.00 mA/bunch. Each of the parameters is independently varied by about ±10% to see which value most closely matches the data. The plots seem to show that for this data set, quantum efficiency, SEY, rediffused secondary electrons, and elastic secondary electrons would need to decrease, and the energy at the SEY peak, which is inversely correlated to tune shift, would need to increase, in order for the simulations to be more effective in matching the data. These sets of plots were generated for many different data sets to try to understand the individual effects of each parameter. However, the data were not always consistent and the parameters did not have the same effect for different beam energies and bunch currents.

As an effort to try to better understand the effects of the different parameters on the tune shift, the plots in Figure 8 were used to find the percent change that would be needed in a parameter in order to match the data. The dependence of tune shift on each parameter was assumed to be linear, so using the results of simulations with the nominal, decreased, and increased values of a parameter, plots were made of the percent change needed as a function of bunch number for each data set. Figure 9 shows these plots for each of the five parameters for 45 bunches of 2.085 GeV positrons with 1.00 mA/bunch.

The bunches were then grouped together as an attempt to use the information more effectively, which allowed the effects of different parameters on groups of bunches to be observed more easily. For a 45 bunch train, the groups consisted of bunches 2-3, 4-10, 11-20, 21-35, and 36-45. The earlier bunches in a train should be most sensitive to the quantum efficiency, while the groups of later bunches are more likely to be affected by both the quantum efficiency and the secondary yield. Figure 10 shows these plots for each of the five parameters for 45 bunches of 2.085 GeV positrons with 1.00 mA/bunch.

Set of plots similar to Figures 8, 9, and 10 were made for many data sets with different beam energies and bunch currents to try and find a pattern that would show in which direction each parameter needed to be changed. It was found that the data were not always consistent and that the parameters are all highly correlated, and many seem to have similar effects when varied. This resulted in it being difficult to separate the individual effects of each parameter. The comparisons of simulations to data may also be incomplete because the simulations are still being improved. The current simulation assumes that the shape of the beampipe is a perfect ellipse, while the actual beampipe of CesrTA has a rounded top and bottom, but flat side walls. The simulation also assumes that the photoelectrons are specularly reflected, while the surface roughness of the actual beampipe is more complicated which could affect the formation of the electron cloud. The simulation is being improved to include these more realistic models, which may produce more clear results.

IV. CONCLUSIONS

Simulations of coherent tune shift data were run for different values of the parameters to find the optimal set that describe the physics of electron cloud generation. The comparisons were made at a variety of beam energies and bunch currents and showed that the model was accurate for the different cases. The simulations will continue to be compared to new data and will be used as a model for the damping rings of future linear colliders.

V. ACKNOWLEDGEMENTS

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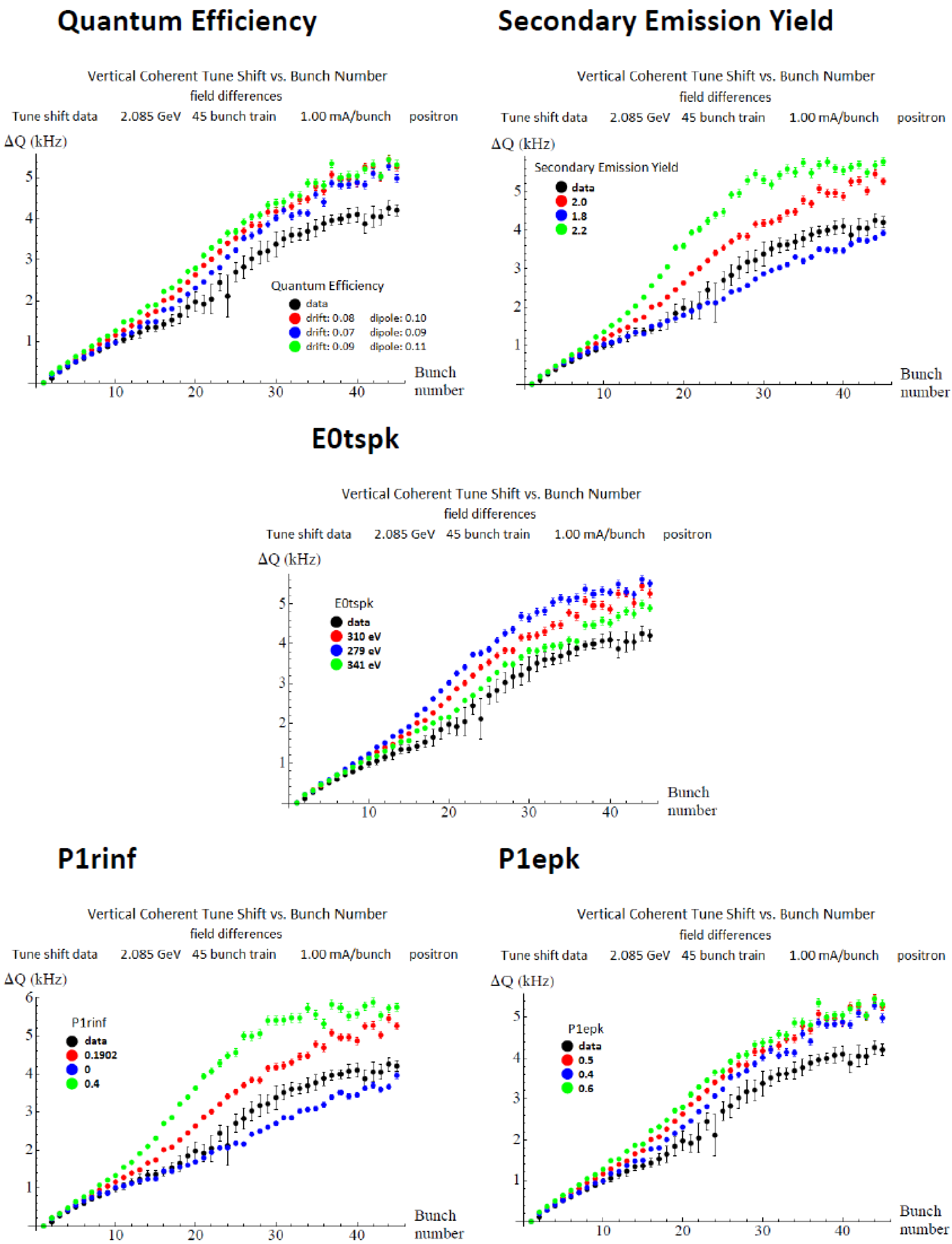

FIG. 8: Varying the simulation parameters. In each plot, data (black) are compared to simulations varying the parameter using the nominal value (red), a ten percent decrease (blue), and a ten percent increase (green).

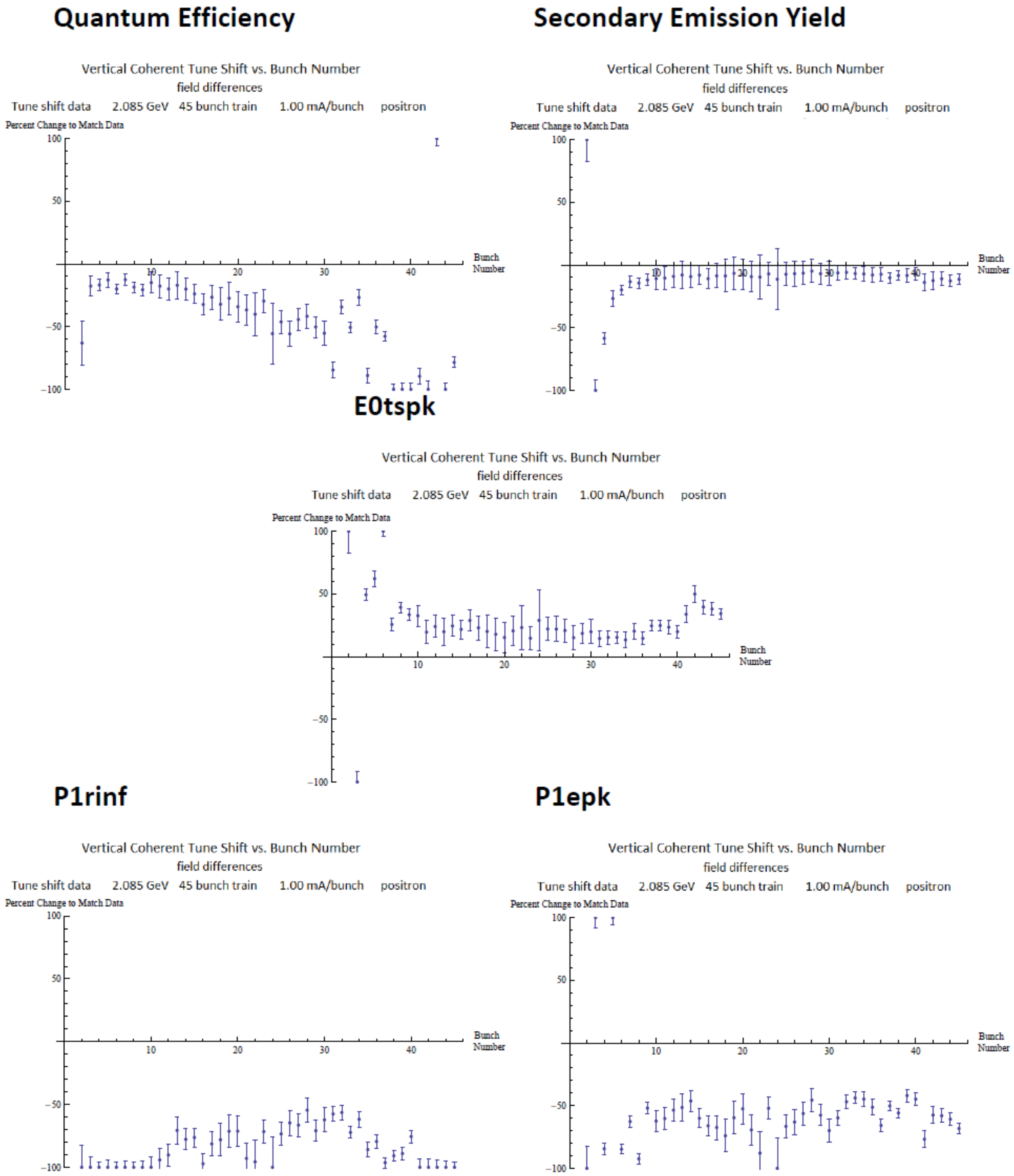

FIG. 9: Percent change in parameters needed to match data as a function of bunch number. Uses the results of simulations with nominal, decreased, and increased values of each parameter and assumes a linear change in the tune shifts with each parameter.

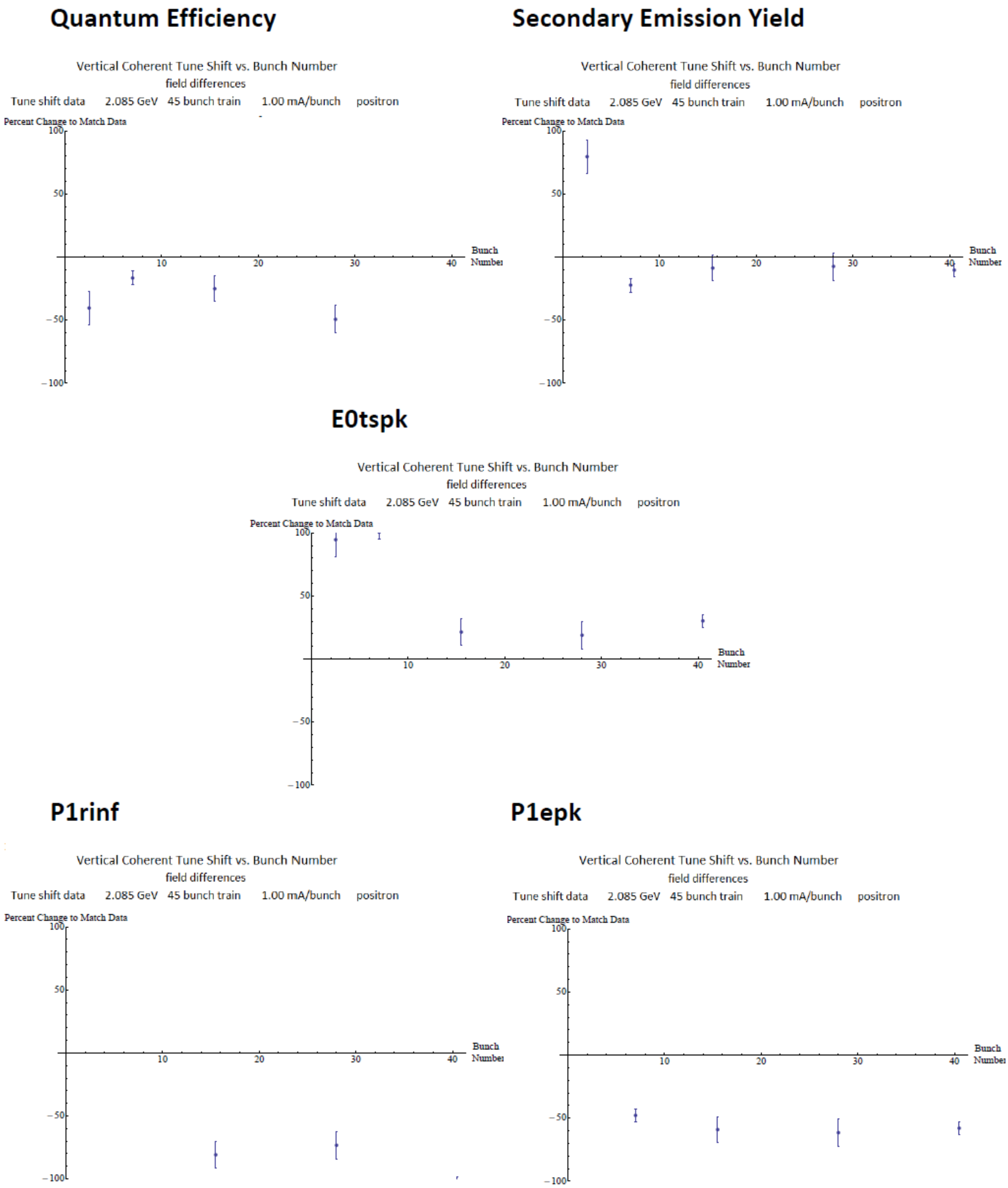

FIG. 10: Average percent change in parameters needed to match data for groups of bunches. 45 bunch trains were grouped into bunches 2-3, 4-10, 11-20, 21-35, and 36-45.

experience, and the National Science Foundation for funding the research.

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[2] D. L. Kreinick, *et. al.*, Application of Coherent Tune Shift Measurements to the Characterization of Electron Cloud Growth, proceedings of PAC11, 28 March - 1 April 2011, New York, NY, USA.
[3] M. Furman and G. Lambertson, "The electron-cloud instability in the arcs of the PEP-II positron ring," `http://repositories.cdlib.org/lbnl/LBNL-41123`.