Cornell University
Laboratory for Elementary-Particle Physics

Studies of electron-cloud-induced coherent tune shifts at CESR-TA

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Overview

- At CESR-TA, we have made measurements of bunch-by-bunch coherent tune shifts along bunch trains, over a wide range of beam energies, emittances, bunch currents, bunch spacings, and train lengths, for both positrons and electrons.
- These measurements have been done by exciting coherent oscillations of whole trains using a single-turn pinger, by observing the tune of self-excited bunches using the Dimtel feedback system diagnostics, and by exciting individual bunches using a fast kicker.
- Postulating that the tune shifts are induced by a photoelectron-seeded electron cloud, we have compared the tune measurements with predictions from two electron cloud (EC) simulation programs: POSINST and ECLOUD.
- The comparisons have been used to put constraints on the EC model parameters in these codes.
- Together with local direct measurements of the electron cloud using retarding field analyzers and TE-waves, we hope to develop a robust EC model, well tested experimentally, which can be used to predict with confidence the features of the electron cloud effect in future LC damping rings.

Outline

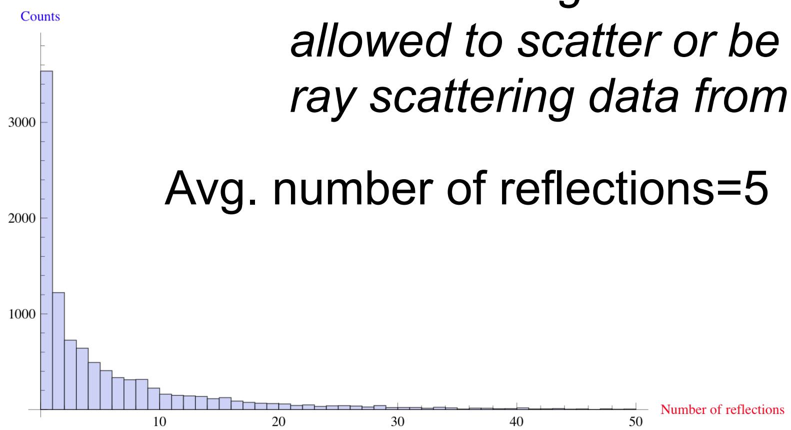
- Brief review of key elements of the simulation programs
- Methodology for computation of the coherent tune shifts
- Comparisons of data and simulations; extraction of cloud model parameters
- Future work

Cloud model: key elements

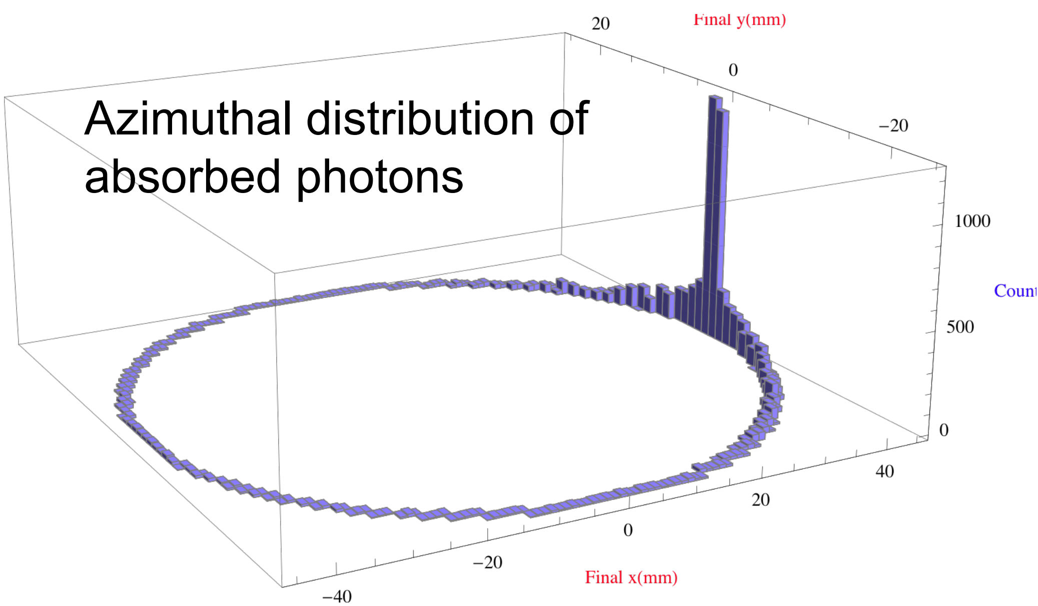
- The key elements of the model used to compute the growth of the electron cloud are
  - Synchrotron radiation parameters: direct and reflected photon rates
    - We are developing a simulation program (SYNRAD3D) which computes the direct and reflected synchrotron radiation distributions around the CESR-TA ring. (We have not yet incorporated the predictions for photon reflection into our cloud simulations).
  - Photoelectron (PE) model: quantum efficiency and photoelectron energy spectrum
    - The current PE model in POSINST and ECLOUD is very simple and can be developed further.
  - Secondary emission (SE) model: yield and secondary electron energy spectrum
    - The SE models in POSINST and ECLOUD are well-developed. Bench measurements provide guidance on the SE model parameters.

SYNRAD3D: Photon scattering simulation

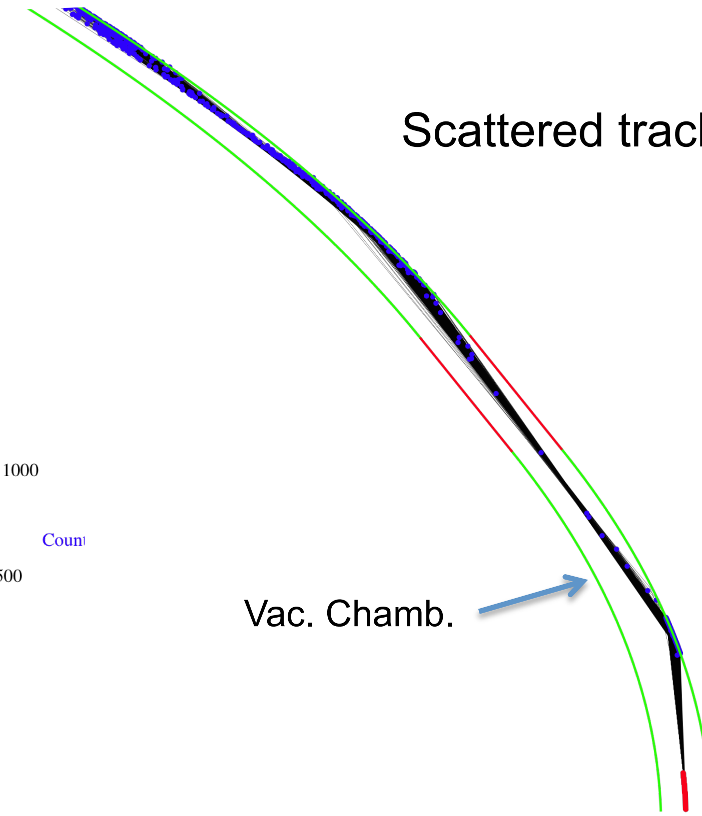
Photons are generated in dipoles and wigglers in a real lattice, and allowed to scatter or be absorbed in vacuum chambers, based on X-ray scattering data from an LBNL database



Avg. number of reflections=5



Azimuthal distribution of absorbed photons



Scattered tracks

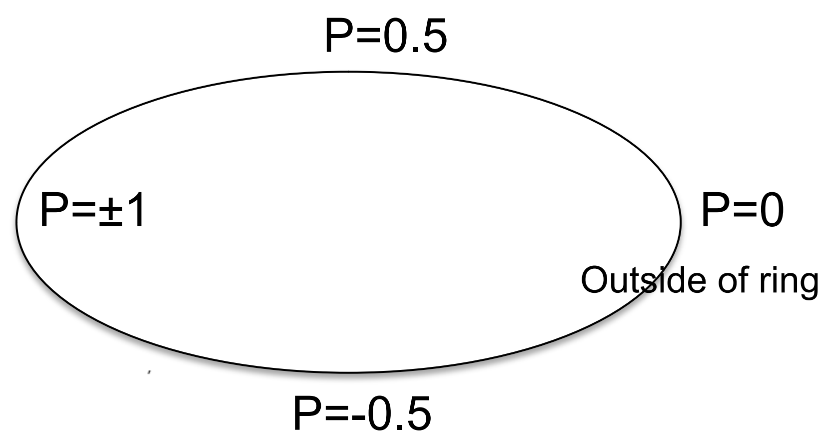
Vac. Chamb.

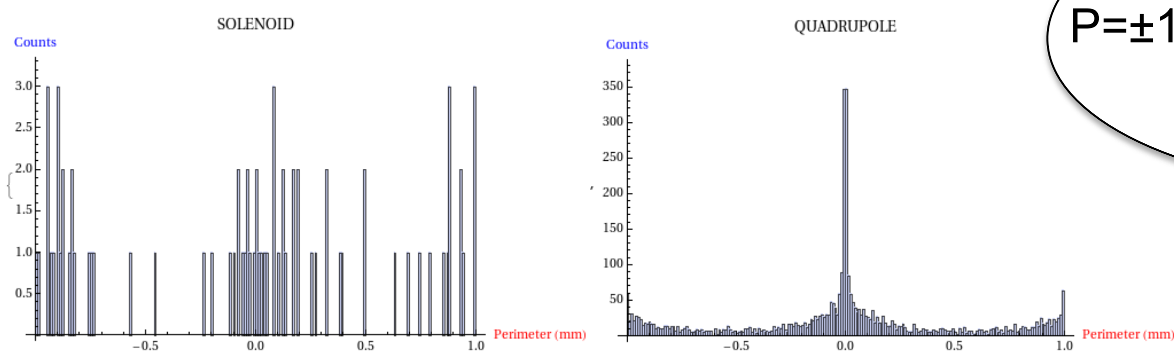
Photon Source

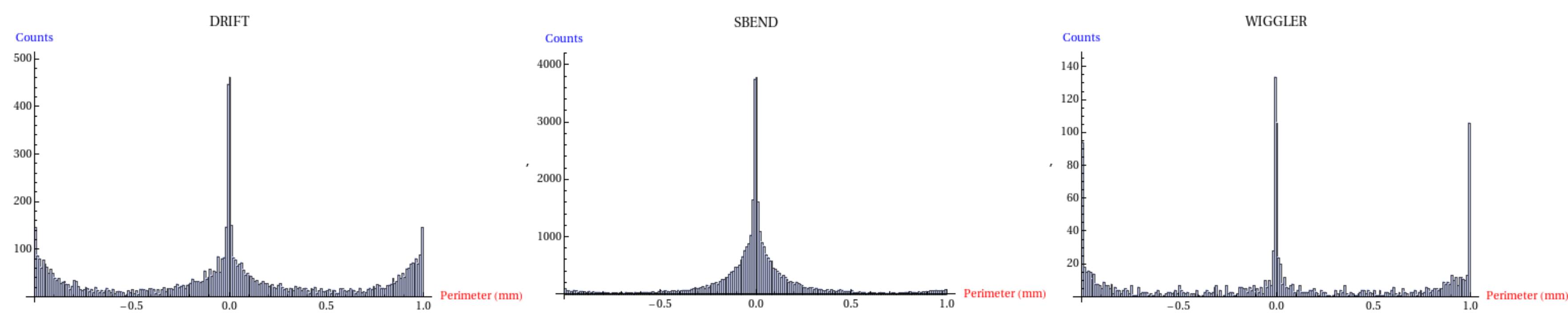
Example output from SYNRAD3D: Azimuthal location of photon absorption sites

Element-averaged azimuthal distribution of photon absorption sites

x-axis: scaled perimeter, from -1 to 1

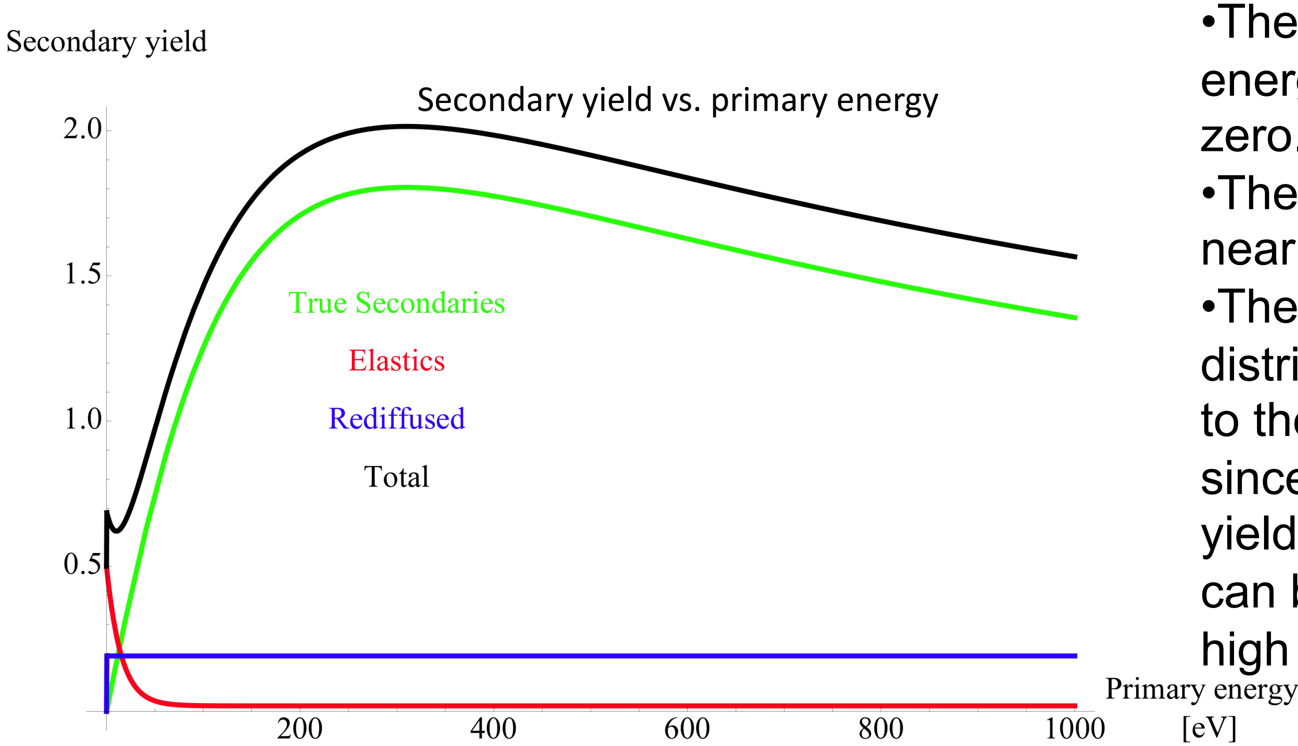






Secondary emission model

• The key SE parameters are the total yield (black), and the components (true secondaries, elastics, and rediffused). In POSINST, the most important model parameters are the total peak yield (SEY), the energy corresponding to the peak for the true secondaries, the peak elastic yield, and the yield of rediffused electrons.



•The true secondaries have an energy spectrum peaked near zero.
•The elastic spectrum peaks near the primary energy.
•The rediffused have an energy distribution ranging from zero to the primary energy, and since they have a significant yield at high primary energies, can be an important source of high energy secondaries.

Methodology for computation of the coherent tune shifts

- Given a set of beam and EC model parameters (beam intensity, energy, and emittances; bunch train configuration, PE and SE model parameters, etc.), the EC simulation codes can be used to compute the cloud density experienced by each bunch in the train, for a given magnetic and vacuum chamber environment.
- From this cloud density, we compute the electric field experienced by a bunch passing through the cloud. The coherent tune shift depends on the gradient of this field, integrated around the ring:

$$\Delta Q_{x(y)} = \frac{e}{4\pi E} \oint ds\ \beta_{x(y)} G_{x(y)} \qquad G_{x(y)} = \frac{\partial \bar{E}_{x(y)}}{\partial x(y)}$$

- The field gradients, obtained from simulations using the computed radiation intensities *I(k,i)* at location *i*, are weighted by the lengths and beta functions, and summed over all *m* element types to give the total tune shift:

$$\Delta Q_{x(y)} = \frac{e}{4\pi E} \sum_{k=1}^{m} G_{x(y)}\left(k, \langle I_{x(y)}(k) \rangle\right) w_{x(y)}(k)$$

$$\langle I_{x(y)}(k) \rangle = \frac{\sum_{i=1}^{n_k(k)} \beta_{x(y),i}(k,i) L(k,i) I(k,i)}{w_{x(y)}(k)} \qquad w_{x(y)}(k) = \sum_{i=1}^{n(k)} \beta_{x(y)}(k,i) L(k,i)$$

Methodology for tune shifts

- We calculate the direct radiation intensities from a lattice model, but (for now) use a free parameter to describe the reflected photons.
- We only include drifts and dipoles (for now).
- To fully include the cloud dynamics, we compute the field gradient by running two simulations, with the bunch whose tune we are calculating (and previous bunches, if the whole train was coherently excited) offset by small amounts ±δ, find the cloud-generated electric field for the two offsets, and compute the difference of the fields. For example, in the *x*-direction, for bunch *b*, excited coherently with bunch *b-1*,

$$G_x \approx \frac{\bar{E}_x(x_b = \delta, x_{b-1} = \delta, ..., y_b = 0) - \bar{E}_x(x_b = -\delta, x_{b-1} = -\delta, ..., y_b = 0)}{2\delta}$$

- The bars represent the fact that the electric fields are weighted transversely and longitudinally by the (Gaussian) beam distributions, corresponding to the force which drives coherent motion of the bunch.
- The horizontal tune shift in the dipoles is quite different for the case of coherent excitation of the whole train, vs. individual excitation of single bunches. This effect is clearly seen in the data and simulations.

Simulation/data comparisons

- For coherent tune shift data taken in 2007, June/July 2008, and January/February 2009, we have run simulations for a range of EC model parameters describing the drifts and dipoles, to establish the best fit ranges of these parameters.
- For these data sets, the tune measurements were made by coherently exciting the whole bunch train (and witnesses, if any). Tune shifts are always relative to the tune of a reference bunch at the start of the train.
- The data were compared with simulations to determine 6 EC model parameters: peak SEY, photon reflectivity, quantum efficiency, rediffused yield, elastic yield, peak secondary energy.

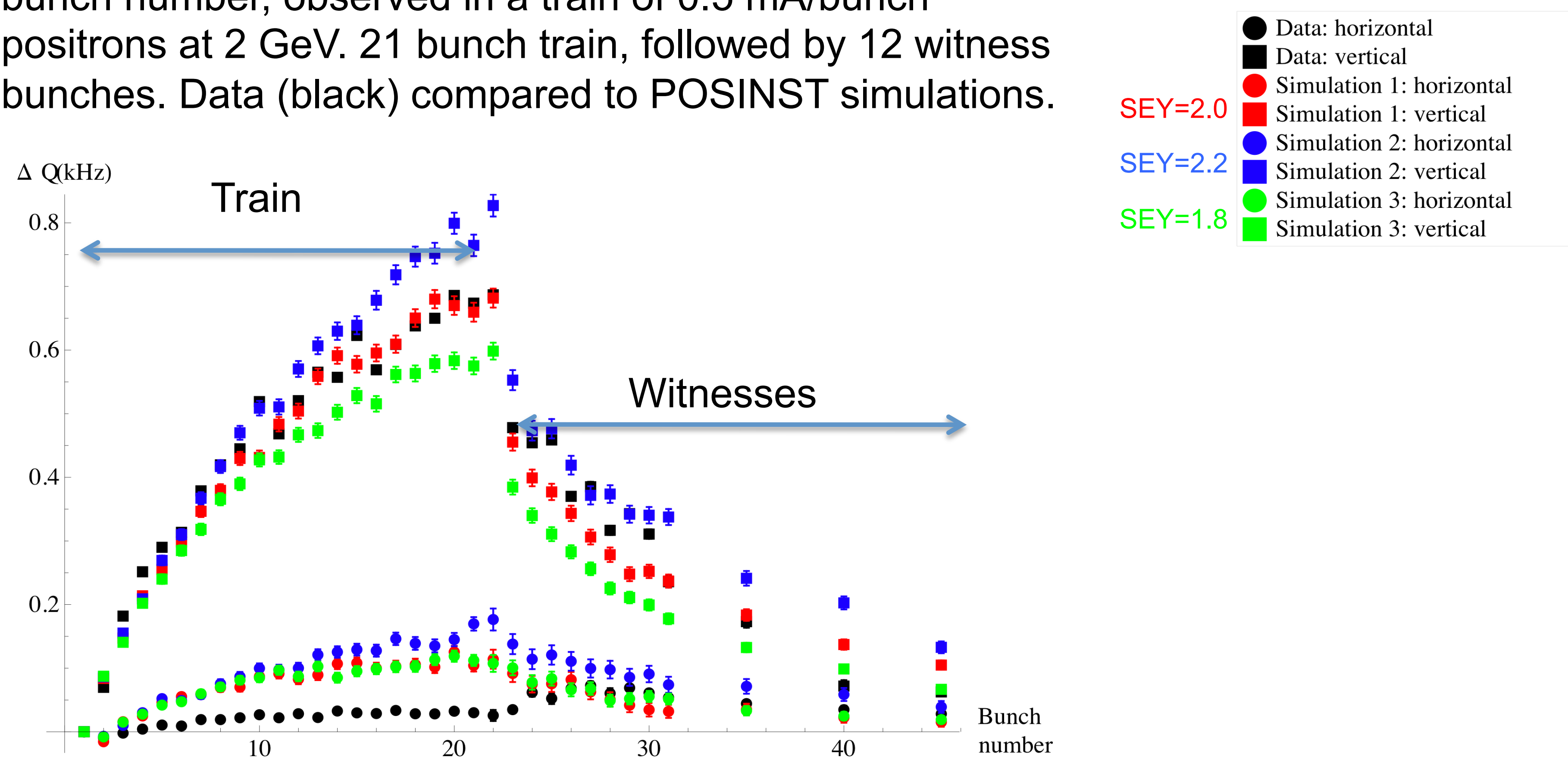
2007-08 data: short trains and witnesses

Energy (Gev)	Species	Bunch currents	Train length	Witness length	Data sets
1.9, 2.1	Positrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	3, 10, 11, 19, 20, 21	5-15	23
1.9, 2.1	Electrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	10, 11, 19, 20, 21	5-15	10
5.3	Positrons	0.75, 1.5, 5.0	3, 10	5-10	3
5.3	Electrons	1.5	10	10	1

2009 data:
45 bunch trains of positrons and electrons, with bunch currents from 0.4 to 1.5 mA/bunch.

Example: June 2008 positron data, 21 bunch train, 14 ns spacing, 0.8×10^{10}/bunch Peak SEY scan

Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 0.5 mA/bunch positrons at 2 GeV. 21 bunch train, followed by 12 witness bunches. Data (black) compared to POSINST simulations.



Example: 2007 electron data, 10 bunch train, 14 ns spacing, 1.2x10^{10}/bunch
Peak SEY scan

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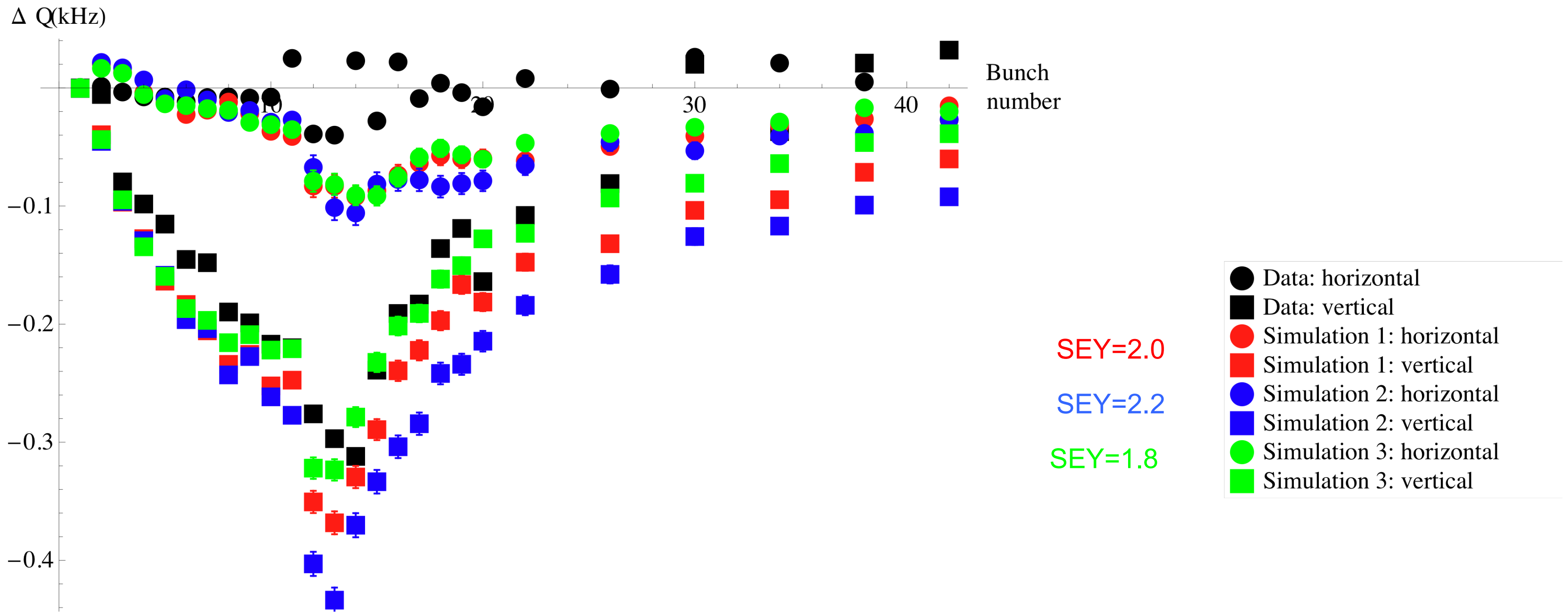
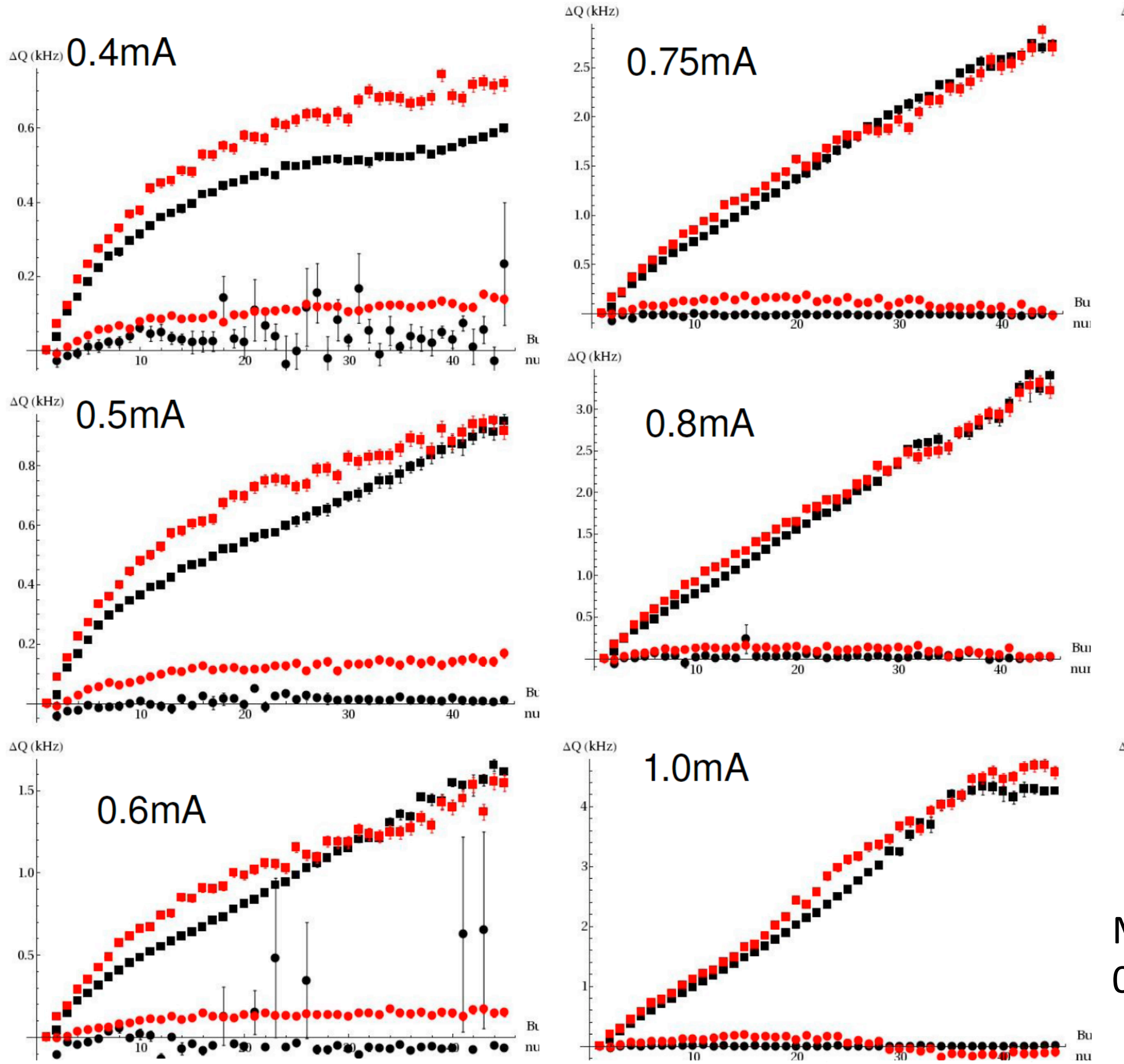
Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 0.75 mA/bunch electrons at 2 GeV. 10 bunch train, followed by 13 witness bunches. Data (black) compared to POSINST simulations.



Examples: Feb 2009 positron data, 45 bunch trains, 14 ns spacing, various bunch currents

1 mA=1.6x10^{10}

Positron Tune Shifts vs. Bunch Number



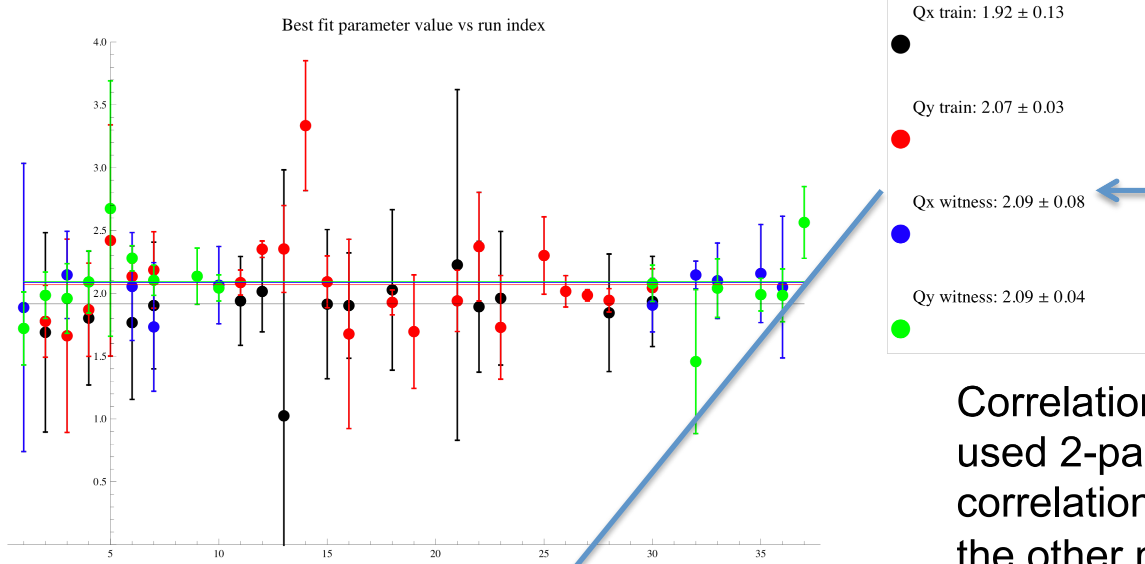
SEY=2.0

- Data: horizontal
- Data: vertical
- Simulation 1: horizontal
- Simulation 1: vertical

Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 45 bunches at 2 GeV, for varying bunch currents. Data (black) compared to POSINST simulations.

Maximum ΔQ_v ranges from 0.6 kHz at 0.4 mA/bunch to 5 kHz at 1 mA/bunch.

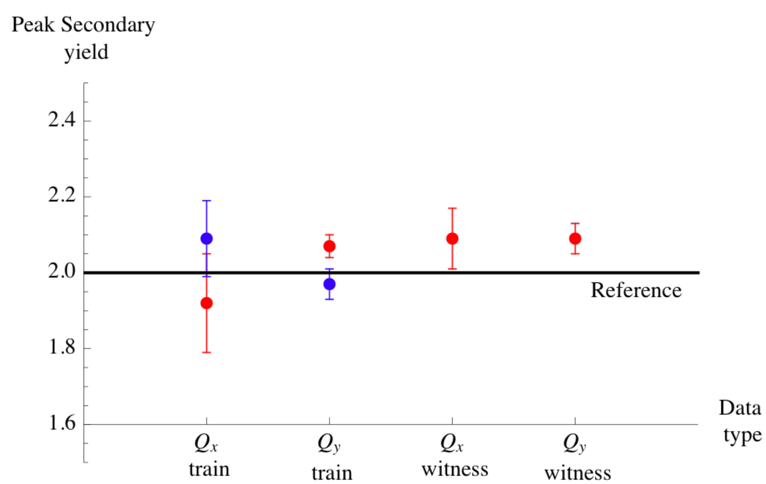
Systematic analysis of data sets to extract best-fit peak SEY parameter



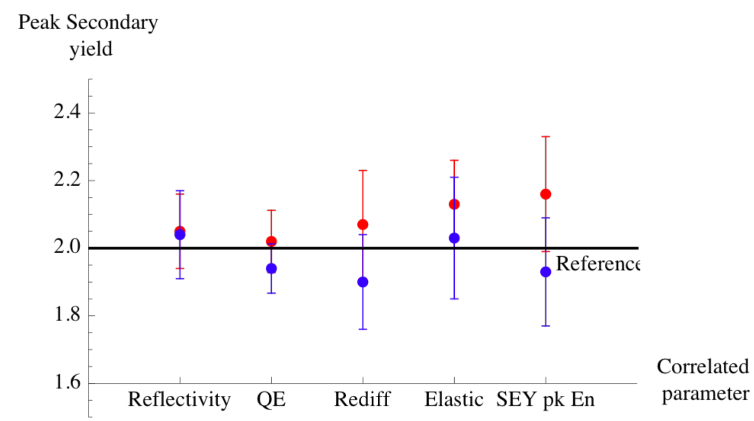
Peak SEY scan for 37 2007-08 data sets
Errors estimated from normalized χ^2 curve

Correlation study: for 2007-8 data, we used 2-parameter fits to study the correlations between the peak SEY and the other model parameters

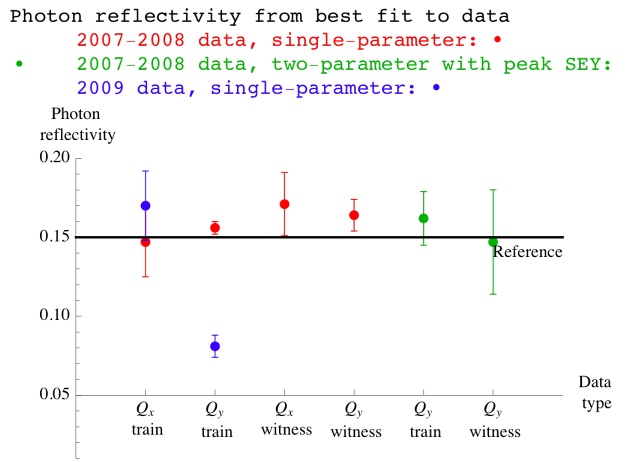
Peak Secondary yield from best single-parameter fit to data
2007-2008 data: •   2009 data: •

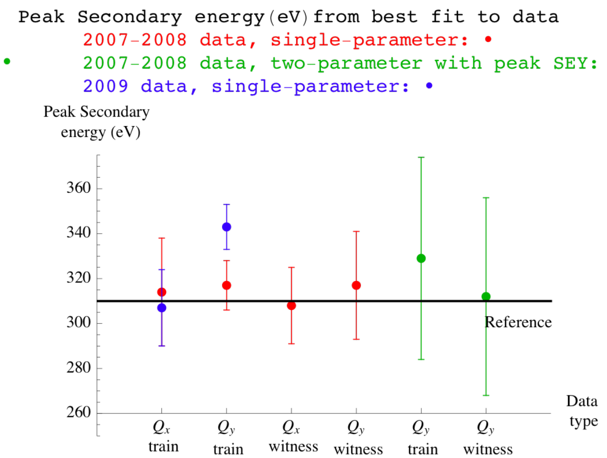


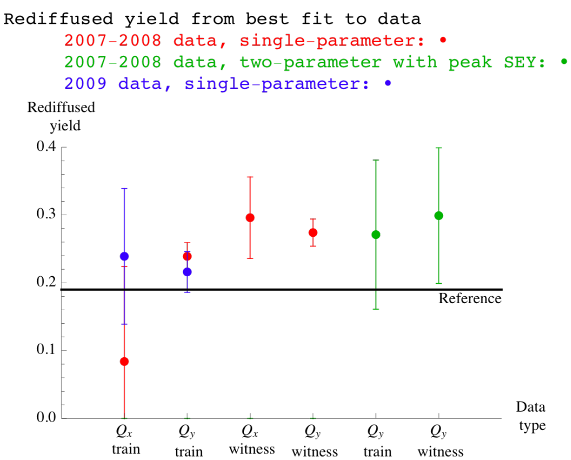
Peak Secondary yield from best two-parameter fit to 2007-08 data
Q_y train: • Q_y witness: •

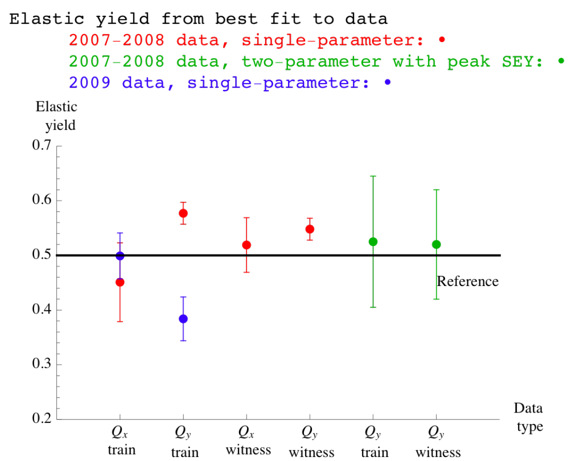


Results of simulation comparisons: 5 Electron cloud model parameters









The ability to obtain a set of EC model parameters which works for a wide range of conditions validates the fundamental elements of the cloud model.

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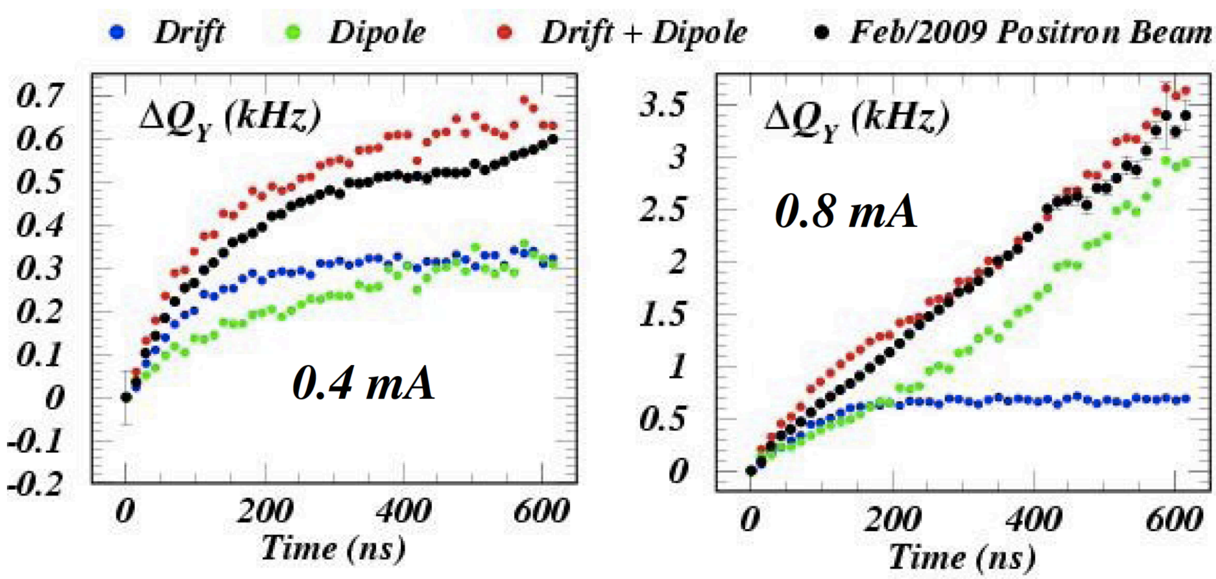
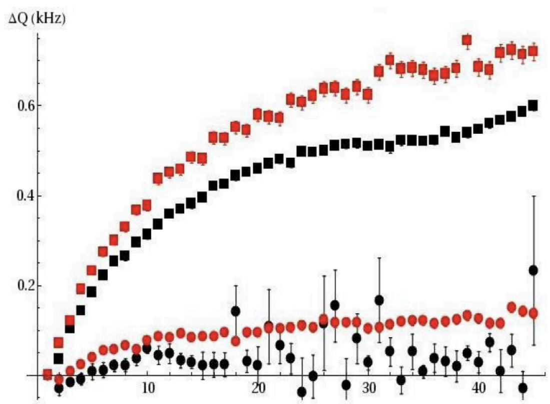
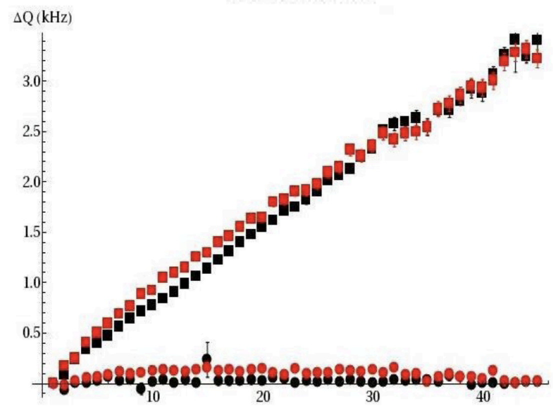
ECLOUD/POSINST Comparisons



With appropriate care taken to be sure that the cloud models are the same, both POSINST and ECLOUD give similar results.

ECLOUD

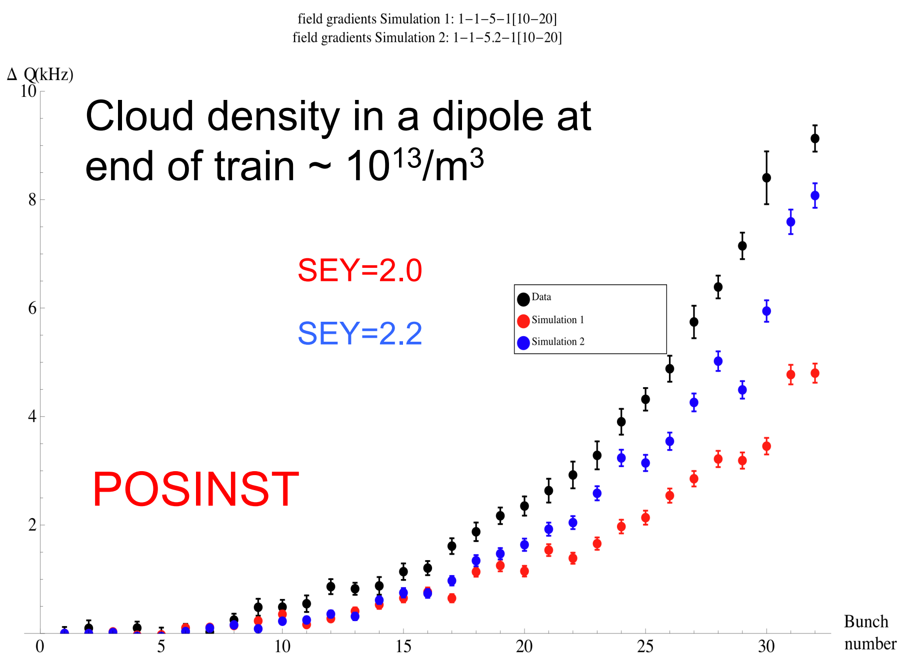


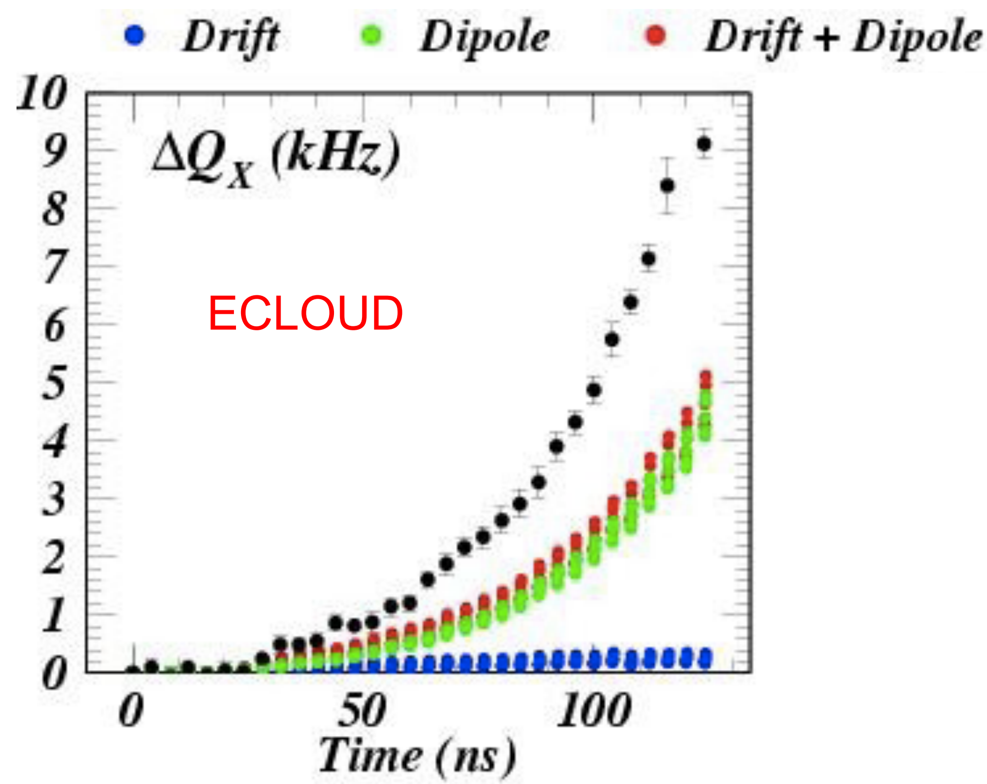


POSINST

June 2009 tune shift data with 4 ns spacing

We have also simulated tune data taken in June 2009, with 4 ns spacing. This data is taken using our Dimtel feedback system, which measures the coherent tunes of bunches without coherently pinging the whole train. Under these conditions, the horizontal tune shift can be very large.





Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 32 bunches at 2.1 GeV, 0.8 mA/bunch, with 4 ns spacing. Data (black) compared to POSINST simulations (left) and ECLOUD (right). Simulated tune from field gradients at start of the bunch.

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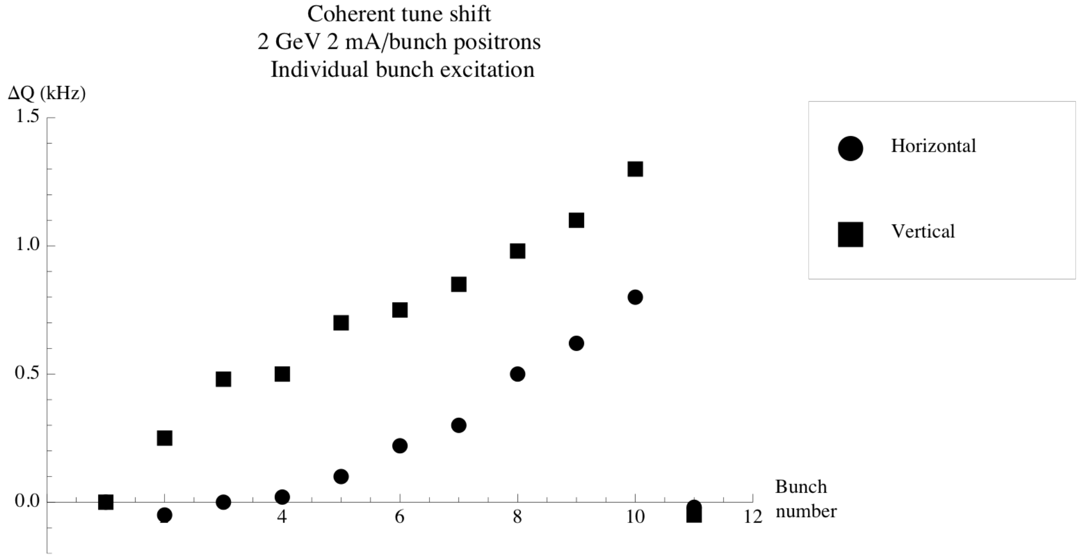
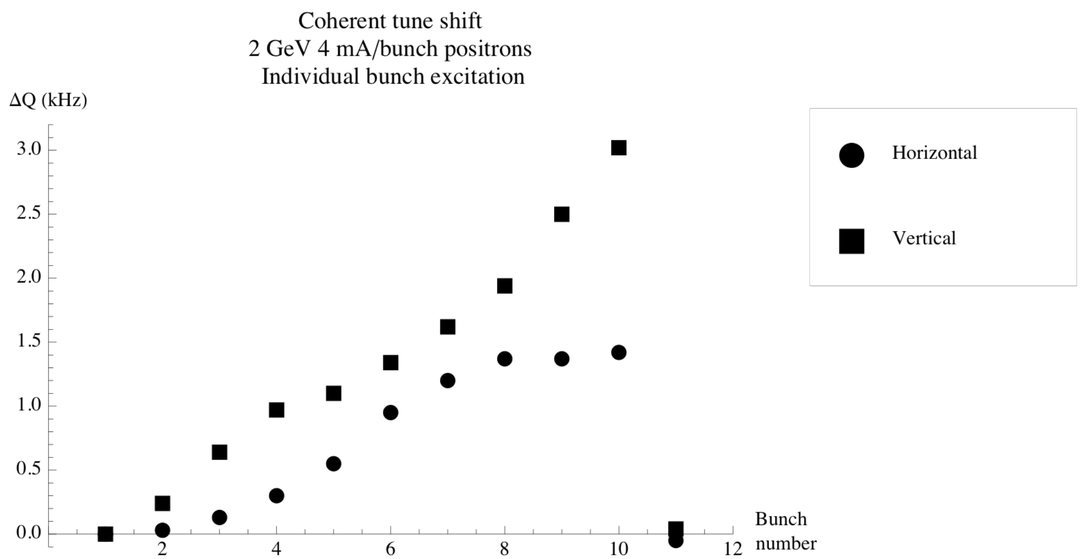
Dec. 2009 data: Coherent tune shifts with individual bunch excitation



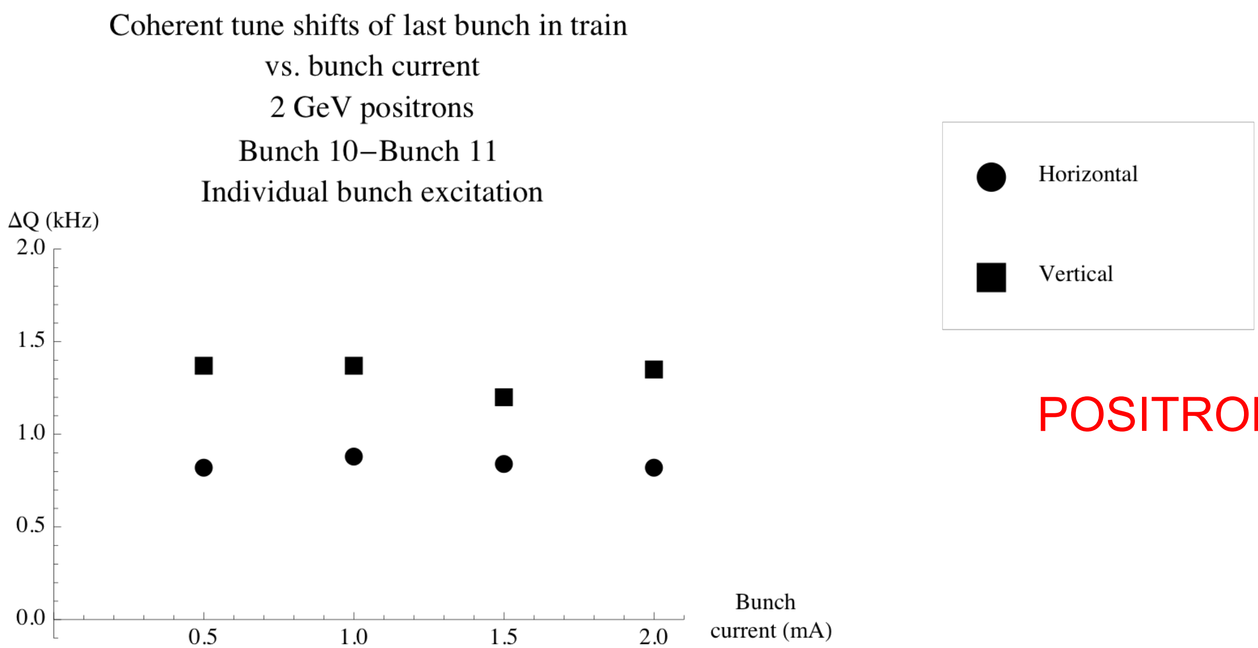


- For these data, we individually excited each bunch with a fast kicker, and measured the tune of that bunch with a gated BPM.
- Bunch spacing is 14 ns for bunches 1-10
- Bunch 11 is 1120 ns later than bunch 10
- Note that vertical and horizontal tune shifts are comparable.

POSITRONS, 2.1 GeV

Dec 2009 data: Coherent tune shift of last bunch in a train, vs. its current

In this experiment, we generate a cloud from 9 bunches, then vary the current in bunch 10 and measure its tune shift (relative to an equal-current bunch 1120 ns later).



POSITRONS, 2.1 GeV

- Bunch spacing is 14 ns for bunches 1-10; bunch 11 is 1120 ns later than bunch 10
- Bunch currents in bunches 1-9 were fixed at 2 mA/bunch, while bunch currents in bunches 10 and 11 were varied together.
- We see essentially no dependence of the tune difference between 10 and 11 on bunch current.

Future work on coherent tune shifts

- Expand the data set comparisons with EC model (we have a lot more data than shown here).
- Take more data at 4 ns, 8 ns, 12 ns spacings. Continue study of tune of last bunch in the train. Explore dependence of tune shifts on beam emittance.
- Use solenoids in drifts to sort out drift/dipole contributions experimentally. Measure tune shift dependence on wiggler current.
- Improve the EC model by incorporating results from photon reflection simulations and an improved photoemission model.
- Compute tune shifts from quadrupoles and wigglers (3D simulation needed for this).
- Compare with results from local measurements (RFA, TE-wave) in the same vacuum chamber environment.