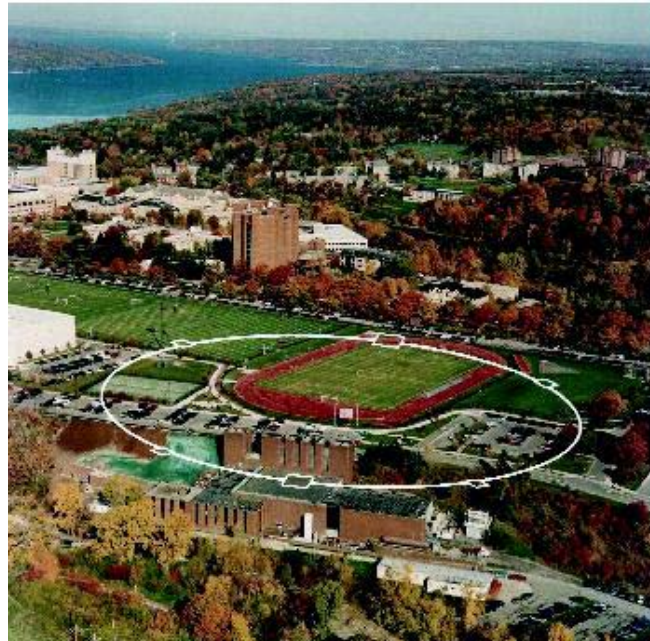# Electron cloud measurements and simulations at CesrTA

G. Dugan, Cornell University

4/19/09

TILC09

- Experimental overview

- Simulation overview

- Results and next steps

- A number of techniques, proposed to suppress the development of the electron cloud, will be tested at CesrTA.

- These include the effects of vacuum chamber coatings (TiN, alpha carbon), clearing electrodes, and grooved chambers.

- Tests of these techniques will be made in key magnetic environments (dipoles, wigglers).

- The development of the electron cloud in the presence of the mitigation techniques will be monitored with retarding field analyzers, to allow a detailed understanding of how the mitigation technqiues affect the basic physics of cloud formation.

Cornell University
Laboratory for Elementary-Particle Physics

- These devices measure the energy spectrum of the time-average cloud current density which impacts the chamber wall. Most devices are segmented, so that some position information is also available.

- These devices can be placed in drifts, dipoles, quadrupoles, and wigglers.

- RFA's placed in chambers to which mitigation techniques have been applied will be used to measure the effectiveness of these techniques.
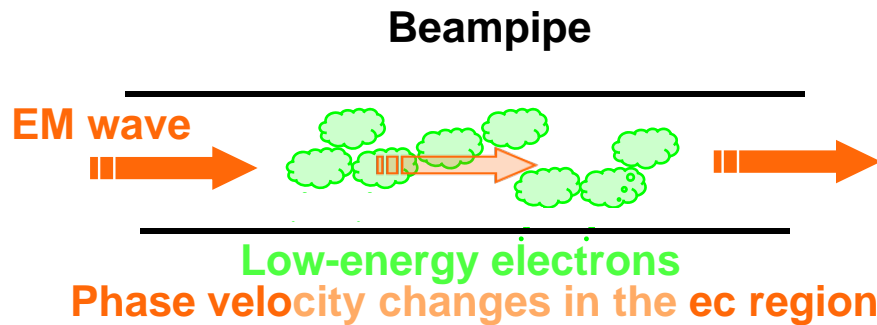

SCALE 1:1
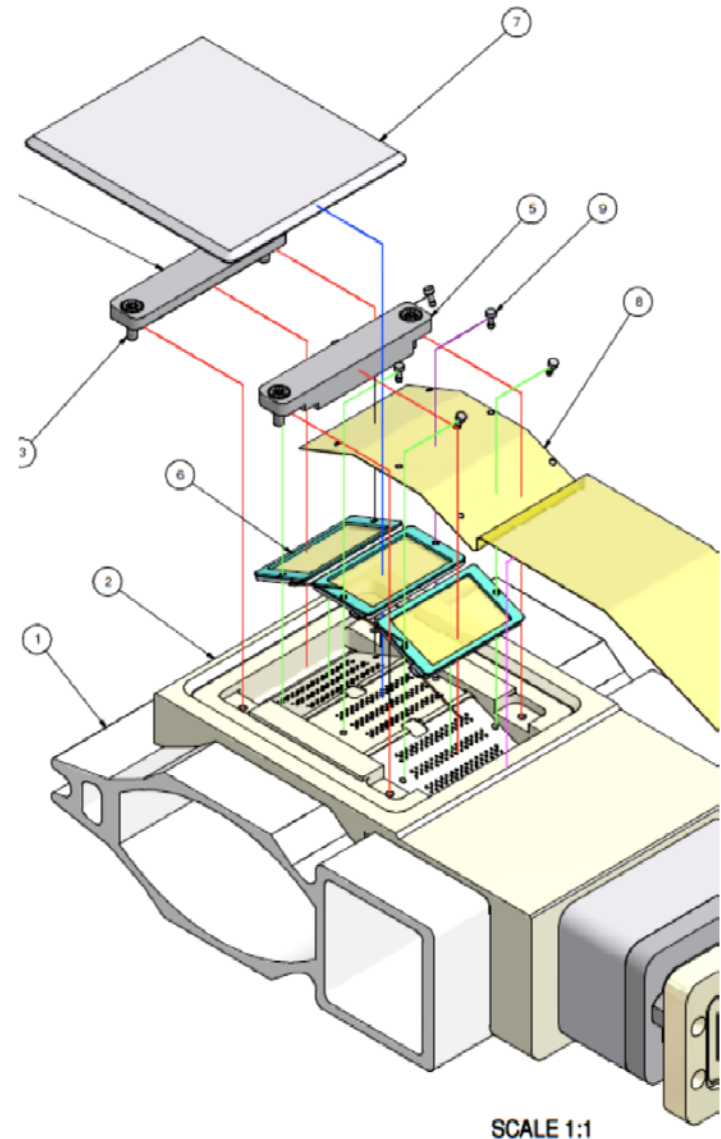
- The electric field generated by the cloud results in a coherent tune shift experienced by the beam. This shift depends on the ring-averaged cloud density near the beam.

- Tune shifts measured for various bunch train patterns can probe the time structure of the growth and decay of the cloud.

- Signatures of single- and multi-bunch instabilities driven by the cloud, which can cause emittance growth above their threshold for onset, can be identified and studied.

- Sub-threshold emittance growth, a subject of great concern for the ILC damping ring, can be studied for various cloud configurations using a low emittance beam and the X-ray beam size monitor.
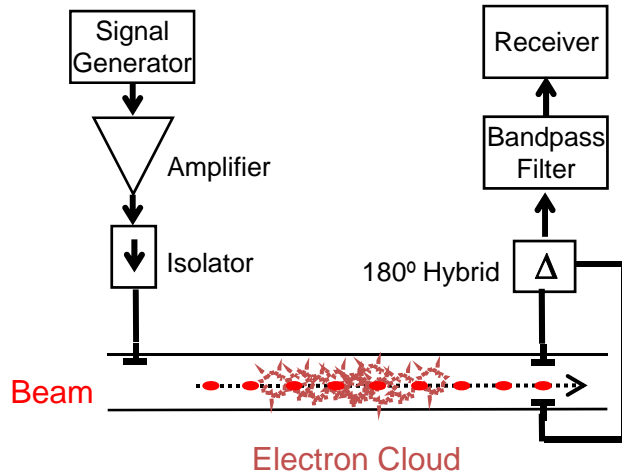
Cornell University
Laboratory for Elementary-Particle Physics

The electron cloud density modifies the wavenumber associated with the propagation of EM waves through the beampipe.

Beampipe

EM wave

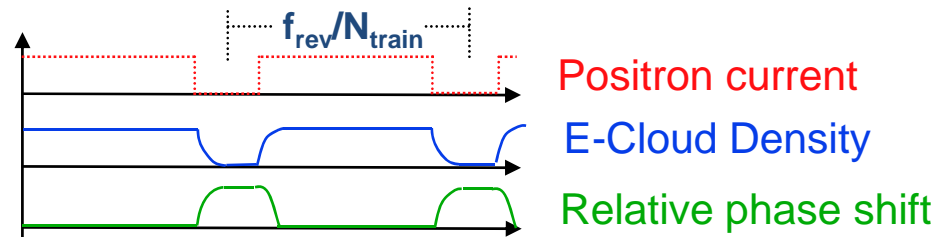**Low-energy electrons**

Phase velocity changes in the ec region

$$k^2 = \frac{\omega^2 - \omega_c^2 - \omega_p^2}{c^2}$$

plasma frequency
$2c(\pi \rho_e r_e)^{1/2}$

Signal Generator

Amplifier

Isolator

180º Hybrid

Receiver

Bandpass Filter

Δ

Beam

Electron Cloud

Experimental apparatus

Gaps in the fill pattern result in a modulation of the phase shift. In the frequency domain, this results in sidebands of the fundamental frequency. The amplitude of the sidebands is related to the cloud density.

f_{rev}/N_{train}

Positron current

E-Cloud Density

Relative phase shift

Cornell University
Laboratory for Elementary-Particle Physics

- We are using three simulation codes which model the formation and decay of the electron cloud: ECLOUD (CERN), POSINST (LBNL), CLOUDLAND (SLAC)

- Key elements of the simulation codes' physics models include:

  - Reflectivity and quantum efficiency of the primary photons

  - Photoelectron energy and angular distribution

  - Secondary electron yield as a function of energy and incident angle

  - Energy and angular distribution of secondary electrons

- We are benchmarking the codes against one another to understand the differences in the physics models and numerical methods for computation of cloud formation.

  - To compare simulations with the coherent tune shift data, we need a method of calculating the coherent tune shifts from the (dynamic) electric fields generated by the cloud. Because of the way that the beam is excited in making the tune shift measurements, this method took some time to develop.

  - Studies at LBNL and Cornell have shown that the tune shifts of a single bunch are different if the whole train is oscillating coherently, than if just a single bunch is oscillating.

  - We can also make measurements of tune shifts of an incoherently oscillating train using the new feedback system,and will attempt to measure cloud-induced betatron phase shifts.

Cornell University
Laboratory for Elementary-Particle Physics

- To compare simulations with the RFA data, we need to model the response of the RFA to electrons. This has also taken a significant effort to develop, but we have made good progress. This model will also be cross-checked using RFA data in which the incident electrons come from a well-characterized electron gun.

- To compare simulations with the TE wave measurements, we need to be able to predict the sidebands generated from a given cloud density. We are still developing a way to do this.

- Comparisons of the simulations with beam dynamics experiments, RFA data, and TE wave measurements will allow us to validate the physics in the simulation codes and determine the parameters of the codes' physics models.

- These validated codes, together with the results of the mitigation techniques measured by the RFA's, will be used to extrapolate the performance of the mitigation techniques to the ILC damping ring conditions.

- This provides the key information needed for a cost-performance optimization of the ILC damping ring.
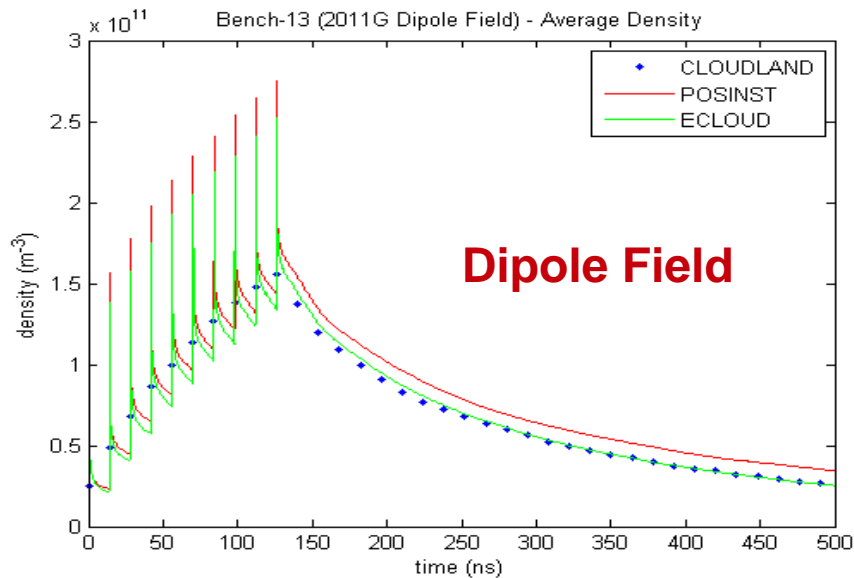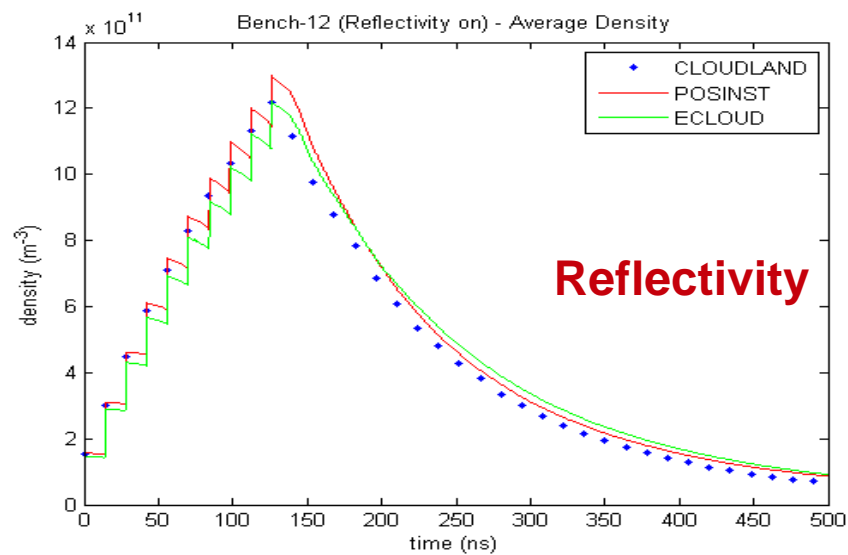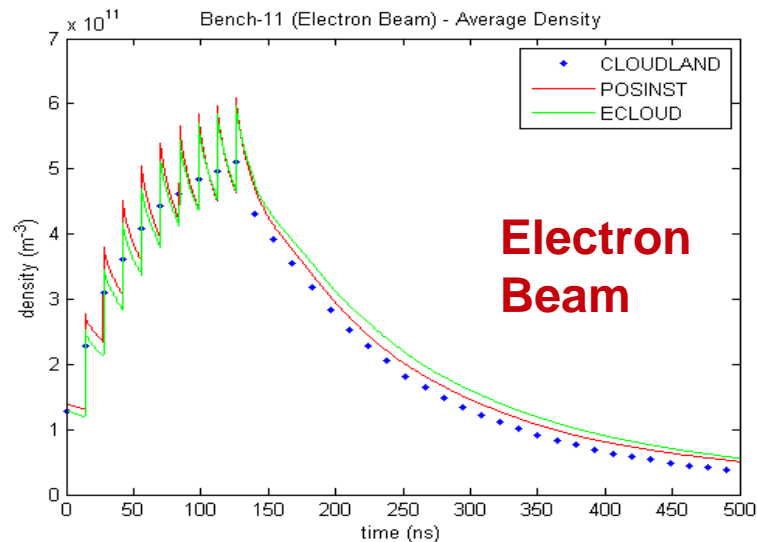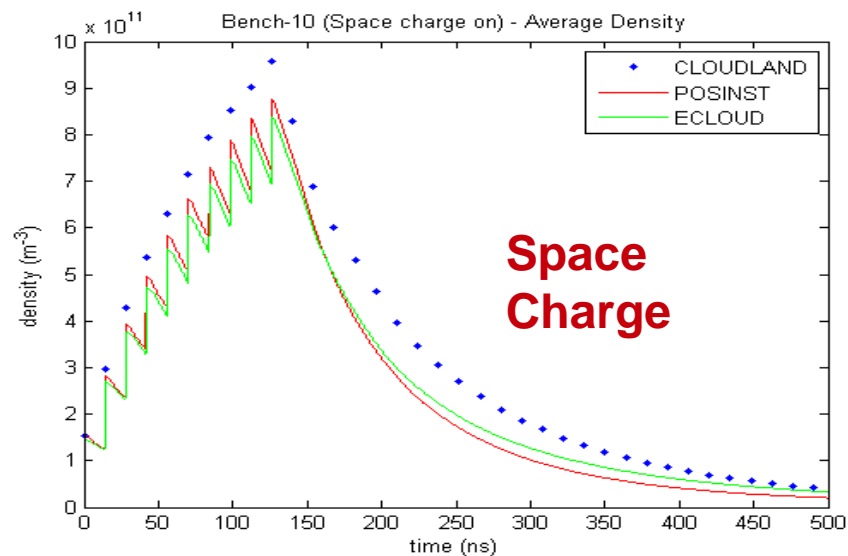
- In 2007, in June, July and November of 2008, and in January, 2009, we performed a large number of beam dynamics experiments (mostly coherent tune shift measurements).

- These experiments were done at 1.9, 2.1 and 5.3 GeV; with both positrons and electrons; with bunch spacings ranging from 4 ns to hundreds of ns; with bunch numbers up to 145 bunches; with bunch intensites ranging from 0.5 up to 2 times the ILC design intensity; with bunch lengths of 10-16 mm; and with horizontal emittances ranging from 133 nm down to less than 8 nm.

- In July and November, 2008, and in January, 2009, we also made a number of measurements with RFA's in drifts, dipoles and in wigglers, with a similar range of beam parameters, and TE wave measurements.

- In this talk, only a small selection of this data can be presented. I will focus on the RFA measurement in the wigglers, and on tune shift data sets, with both positrons and electrons, at 1.9 and 2.1, and 5.3 GeV.

Cornell University
Laboratory for Elementary-Particle Physics

- 2 grids, 5 collectors (probe azimuthal distribution of cloud)

- Simulation accurately predicts grid currents
  - Note that the retarding grid current goes negative in the data: Consequence of SEY?

- Collector currents match qualitatively
  - Plots show collector current vs collector number (collector 1 is opposite source point) and retarding voltage
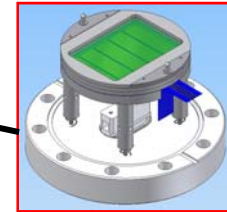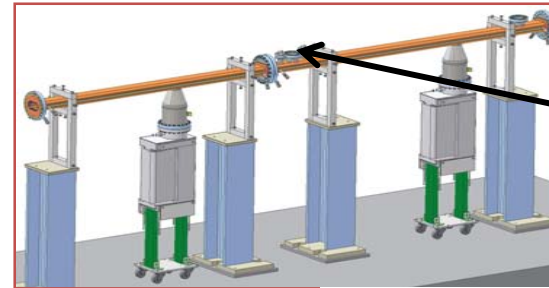
Dots: data
Solid: simulation
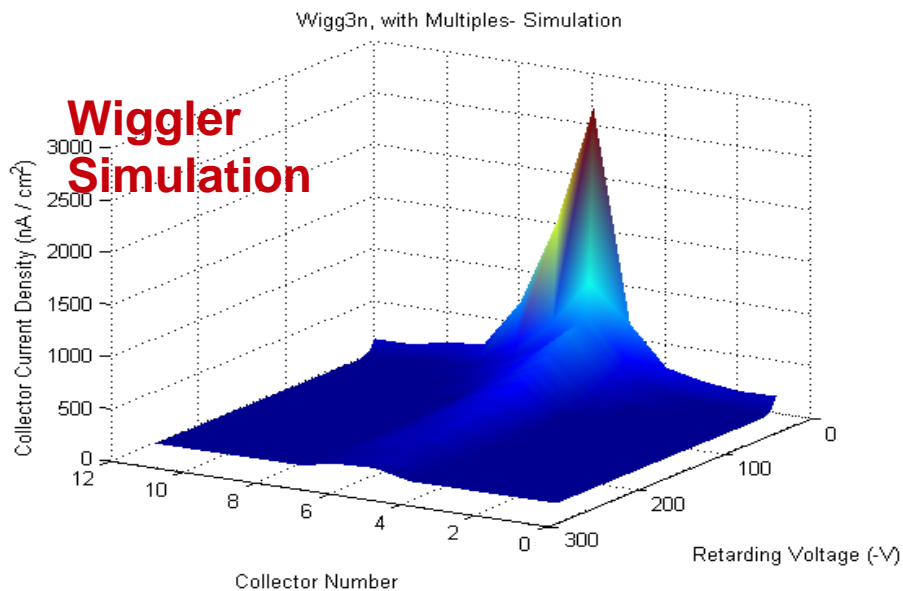
Grid currents
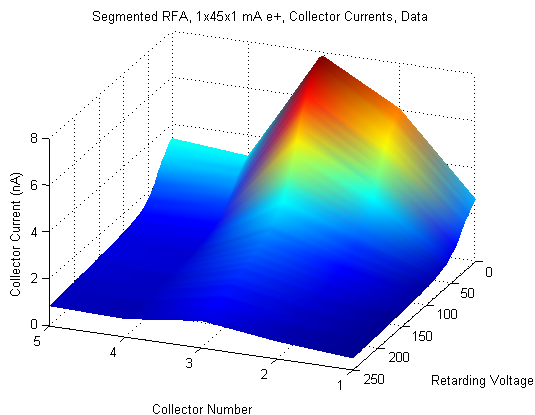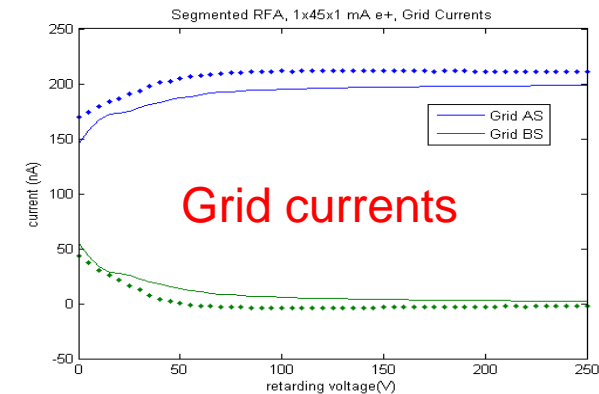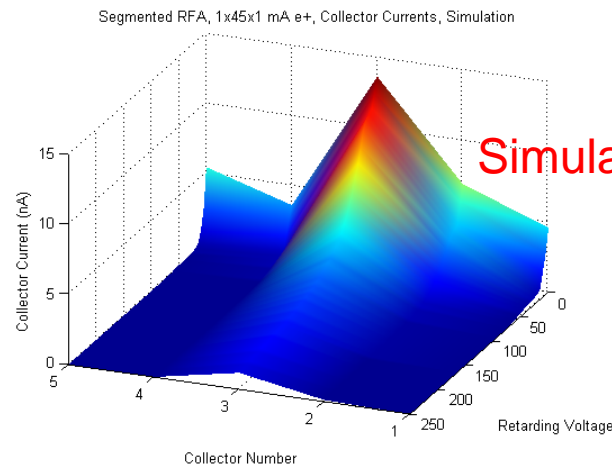
Data

Simulation

- RFA currents for device at center of wiggler pole predicted using naïve 2D simulation tend to look like a dipole, with an even more extreme peak at low retarding voltage.

- However, the wiggler data is much different from the simulations.

Wiggler data

Wiggler Simulation
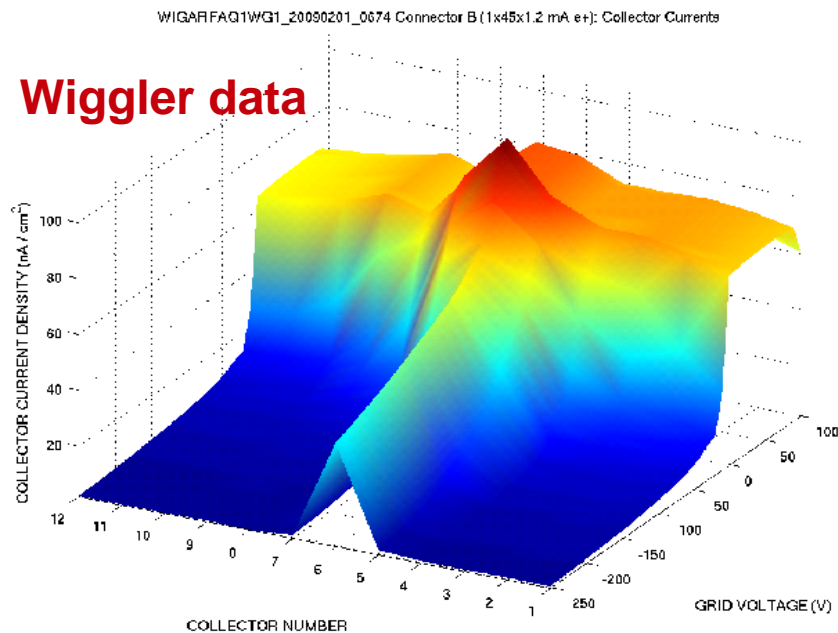
- Simulation neglects interaction of the electrons with the RFA. In the simulation, because of the tight pinning of the electrons to field lines in the wiggler, electrons which can enter the RFA produce secondaries which also enter the RFA.

- In reality, many of these electrons will not produce secondaries since they are collected by the RFA. Thus the naïve simulation will overestimate the RFA current

Cornell University
Laboratory for Elementary-Particle Physics
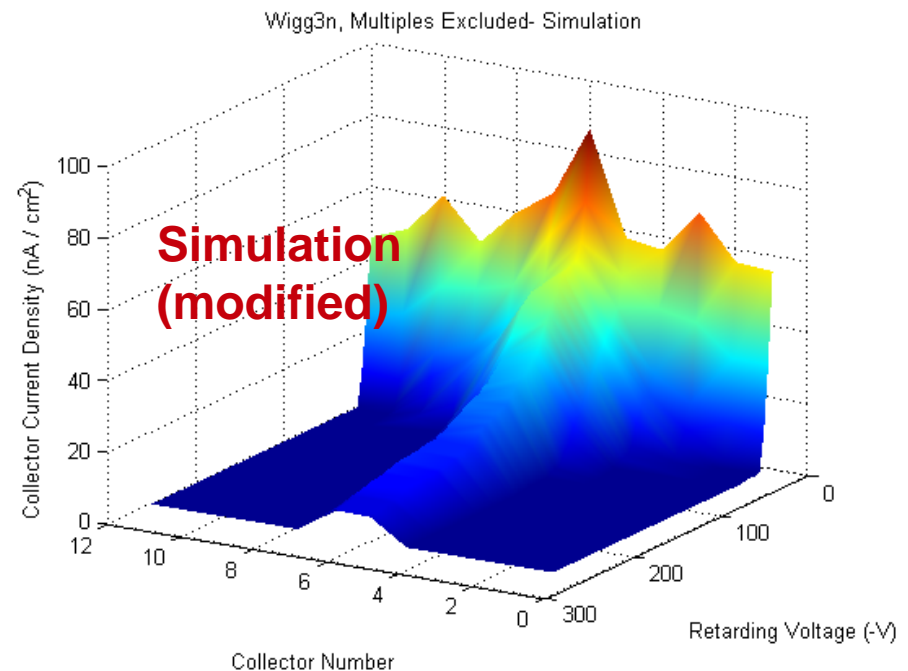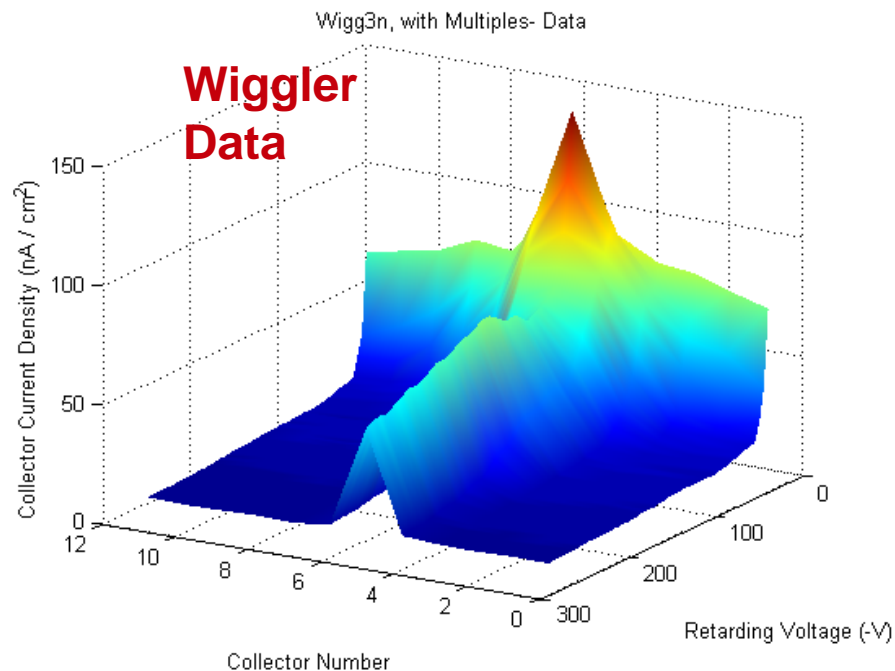
- In addition, some of the electrons entering the RFA will be reflected by the grid voltage, and for certain voltages there can be a resonant enhancement of secondaries ("trampoline effect"), which is manifested as a peak at non-zero grid voltage.

- We have approximately corrected the simulation for these effects and get much improved agreement with data.

- Additional uncertainties are related to SEY parameters for the processed copper chambers, the details of the reflected radiation, and to the 3D nature of the wiggler field.

Cornell University
Laboratory for Elementary-Particle Physics

WARP-POSINST

Density scale TBD

At Peak B_y (1.9 T)

4416 900

Y vs X

8e+11/m³

After 40th Bunch of 45-bunch train

At B_y=0

4418 902

Y vs X

1.4e+12 /m³
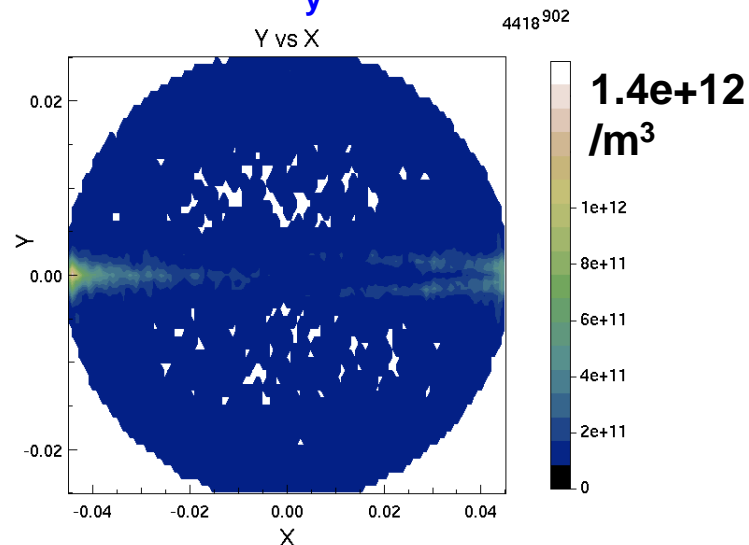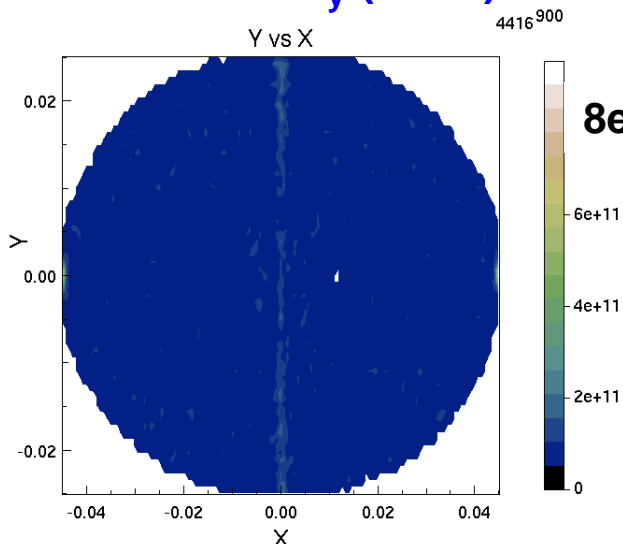
"Stripe" forms where SEY is high.

B gradient & curvature cause drift in x

17956 17956

Y vs X

1.5e+11 /m³

2 μs after bunch train

No electrons left at peak B_y

~30% of electrons still present
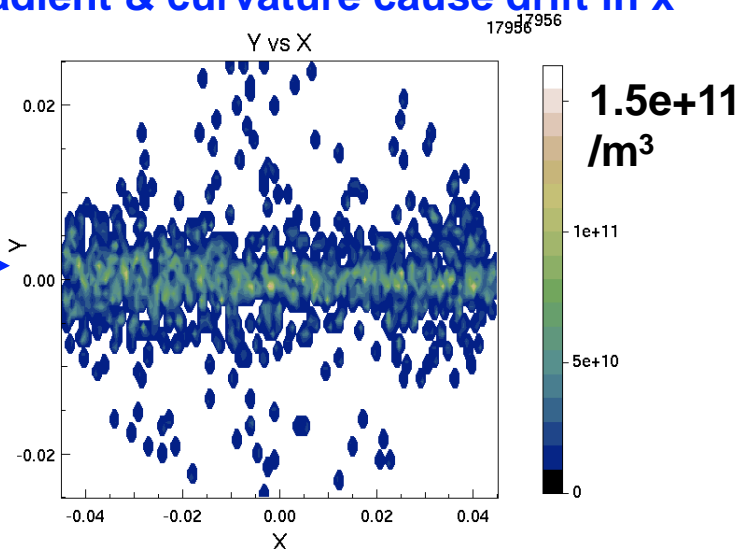
4/18/09

TILC09

photon reflectivity = 20%

Tune shifts calculated for a coherently oscillating beam give good agreement with measurements

Drifts (175 m) and dipoles (475 m) only included in simulation. Quads (91 m) and wigglers (24 m) ignored.
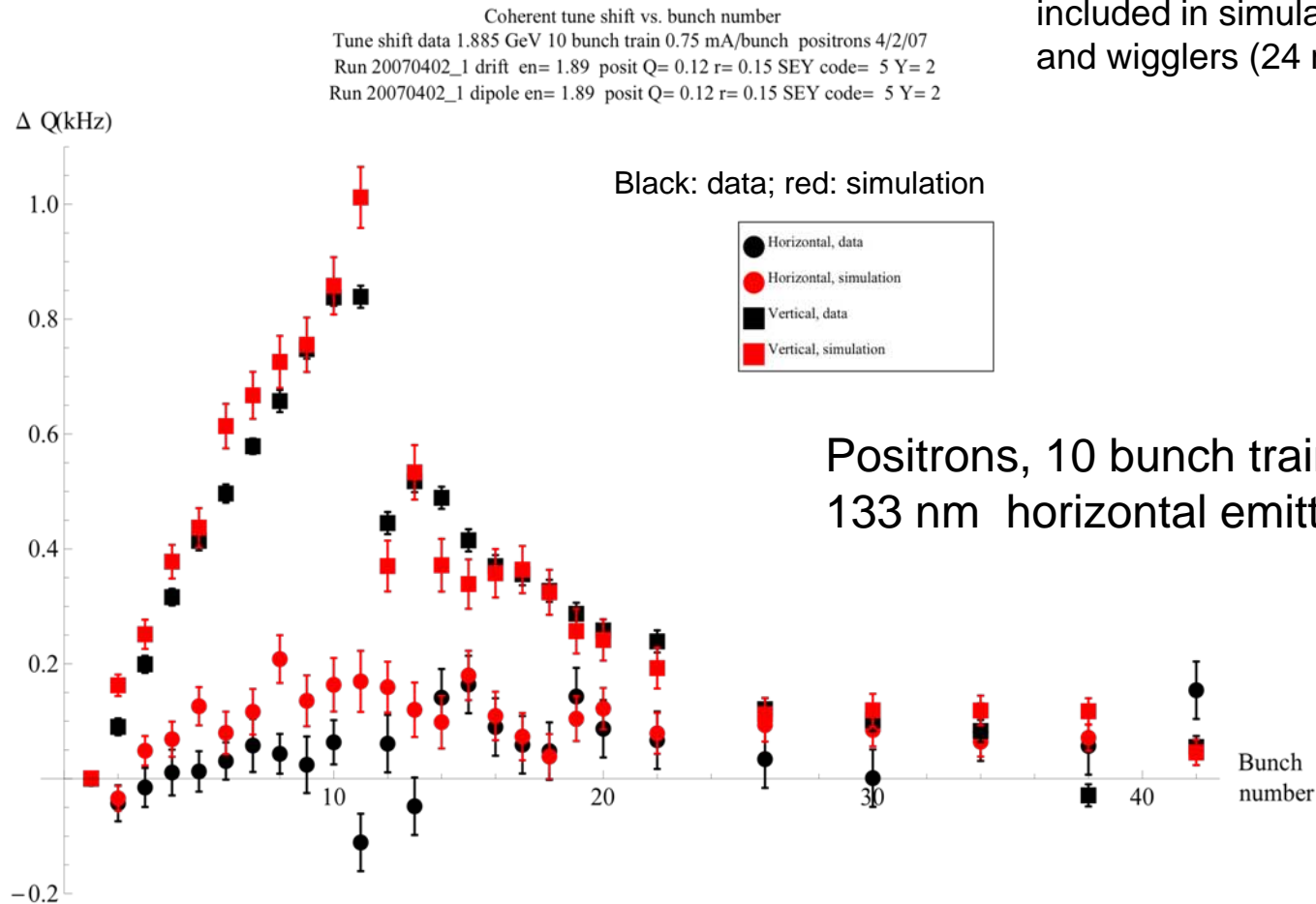
Coherent tune shift vs. bunch number
Tune shift data 1.885 GeV 10 bunch train 0.75 mA/bunch positrons 4/2/07
Run 20070402_1 drift en= 1.89 posit Q= 0.12 r= 0.15 SEY code= 5 Y= 2
Run 20070402_1 dipole en= 1.89 posit Q= 0.12 r= 0.15 SEY code= 5 Y= 2

Black: data; red: simulation

- ● Horizontal, data
- ● Horizontal, simulation
- ■ Vertical, data
- ■ Vertical, simulation

Positrons, 10 bunch train + witnesses
133 nm horizontal emittance, 1.89 GeV
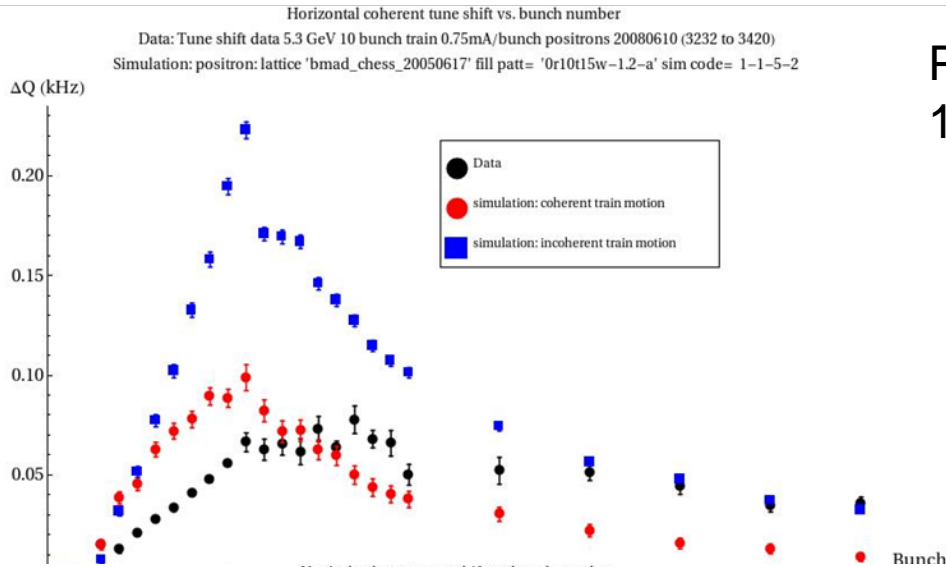
POSINST

Positrons, 10 bunch train + witnesses
133 nm horizontal emittance, 5.3 GeV

POSINST

For horizontal tune shifts, there is a big difference between the tune shifts for a coherent oscillation of the bunches in a train, vs. incoherent oscillation.
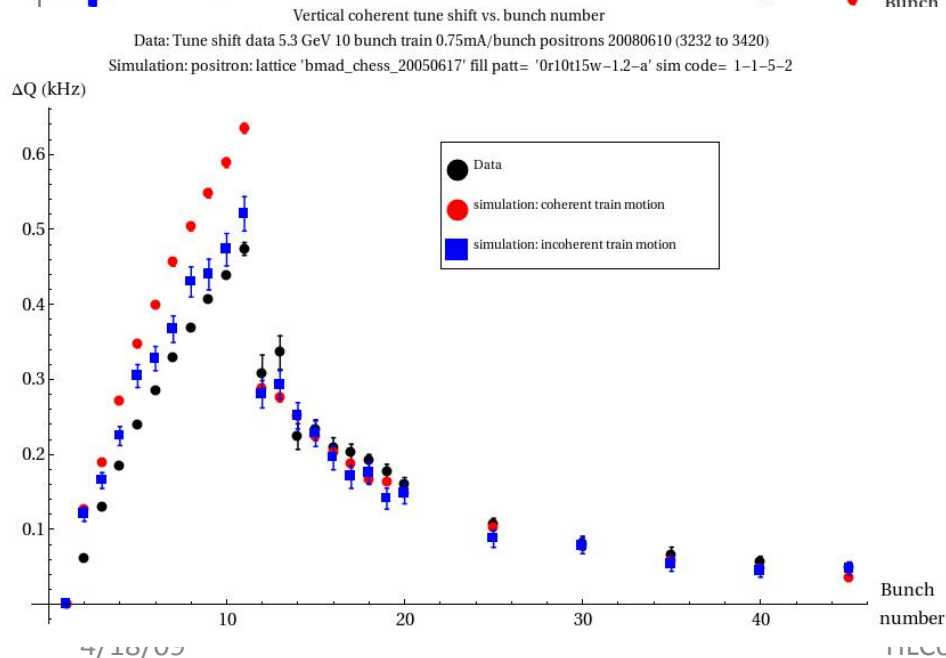
For vertical tune shifts, the difference is much smaller.

Cornell University
Laboratory for Elementary-Particle Physics

Same cloud model parameters as in slide 17

Electrons, 10 bunch train + witnesses
133 nm horizontal emittance, 1.89 GeV

Coherent tune shift vs. bunch number
Tune shift data 1.885 GeV 10 bunch train 0.75 mA/bunch electrons 4/2/07
Run 20070402_1 drift en= 1.89 elect Q= 0.12 r= 0.15 SEY code= 5 Y= 2
Run 20070402_1 dipole en= 1.89 elect Q= 0.12 r= 0.15 SEY code= 5 Y= 2

Black: data; red: simulation

POSINST

4/18/09   TILC09

Cornell University
Laboratory for Elementary-Particle Physics
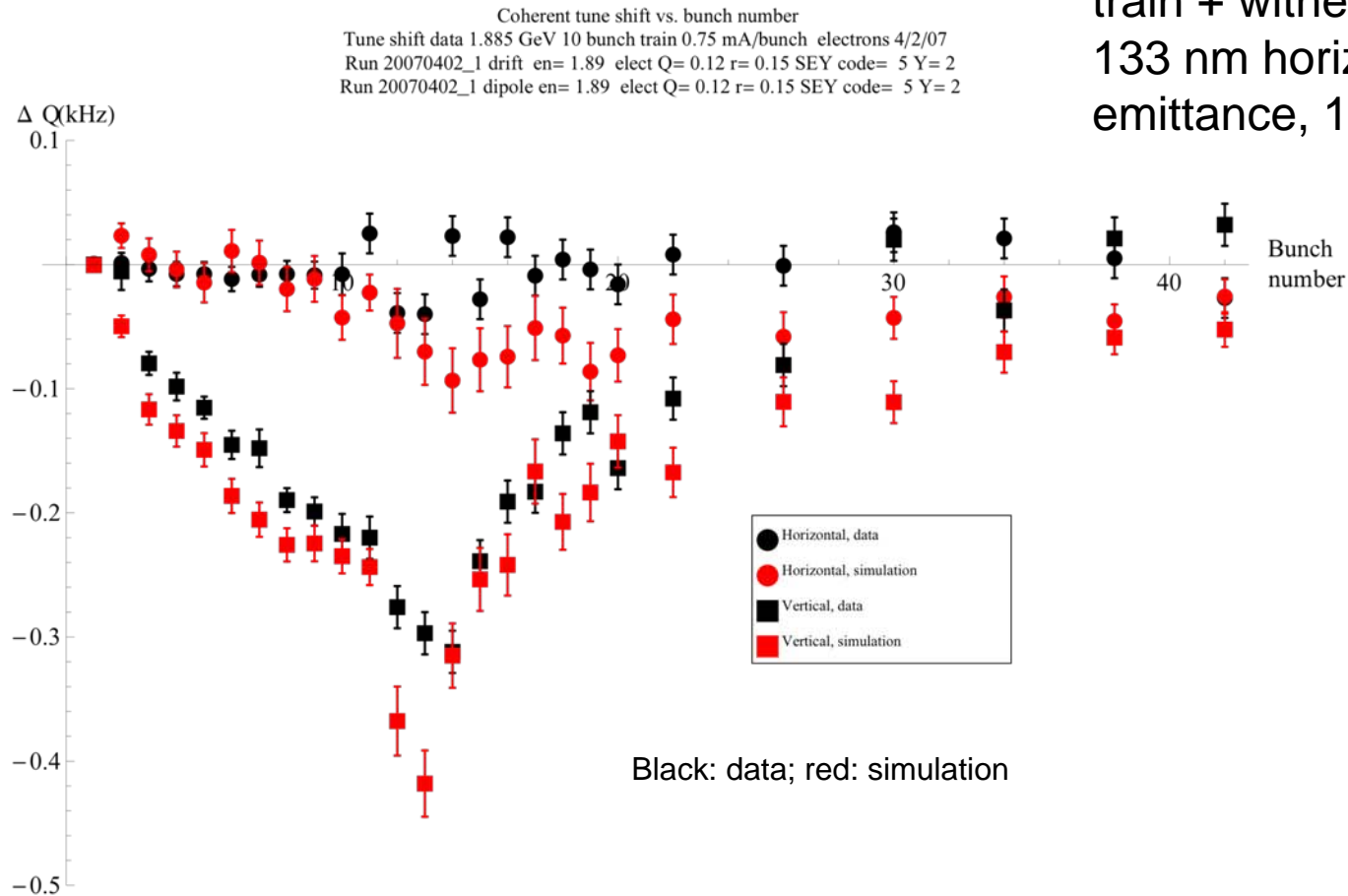
ECLOUD also gives good agreement with data. Cloud model parameters slightly different.

Positrons, 10 bunch train + witnesses
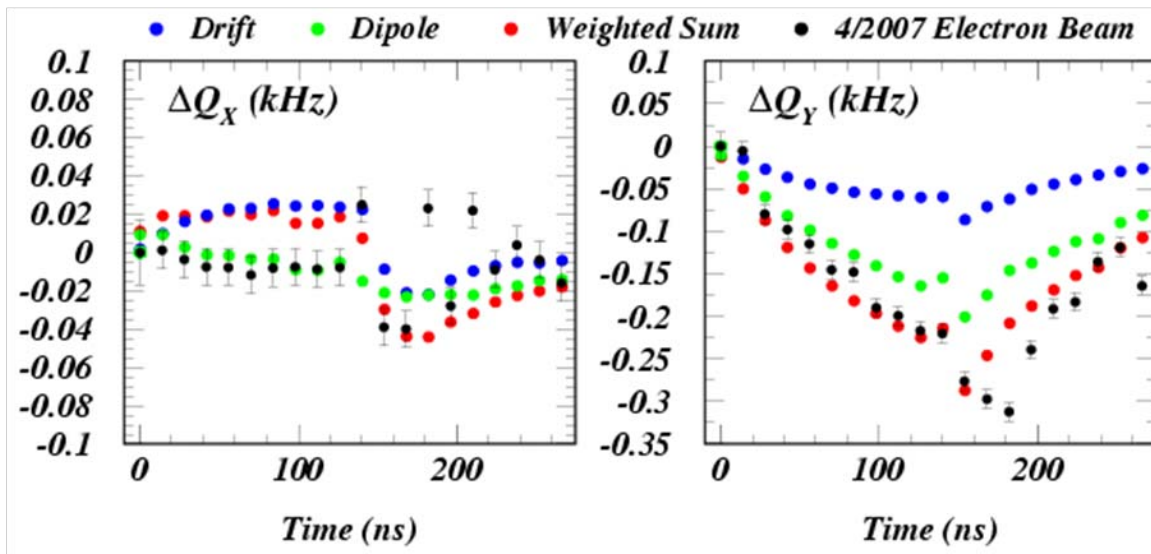
Electrons, 10 bunch train + witnesses

ECLOUD

Cornell University
Laboratory for Elementary-Particle Physics

Long train data was taken in January, 2009, using low emittance lattice. Same cloud model parameters as in slide 17.

Positrons, 45 bunch train 2.6 nm horizontal emittance, 2.09 GeV

Coherent tune shift vs. bunch number
Tune shift data 2.085 GeV 45 bunch train 0.75 mA/bunch positrons 1/26/09
drift   positron 2.08 GeV patt_code= 0r45t0w−1.2−a   sim_code =1−5−1
dipole   positron 2.08 GeV patt_code= 0r45t0w−1.2−a   sim_code =1−5−1

Legend:
● Horizontal, data
● Horizontal, simulation
■ Vertical, data
■ Vertical, simulation

$\Delta\ Q$(kHz)

Black: data; red: simulation

POSINST

Bunch number

4/18/09   TILC09

Cornell University
Laboratory for Elementary-Particle Physics

Witness bunch data taken in June, 2008, at 5.3 GeV. Red points: Same cloud model parameters as in slide 17; blue points: quantum efficiency reduced by 20%.

Coherent tune shift vs. bunch number
Data: Tune shift data 5.3 GeV 10 bunch train 0.75mA/bunch positrons 20080610 (3232 to 3420)
Simulation 1: positron: lattice 'bmad_chess_20050617' fill patt= '0r10t15w-1.2-a' sim code= 1-1-5-1
Simulation 2: positron: lattice 'bmad_chess_20050617' fill patt= '0r10t15w-1.2-a' sim code= 1-2-5-1
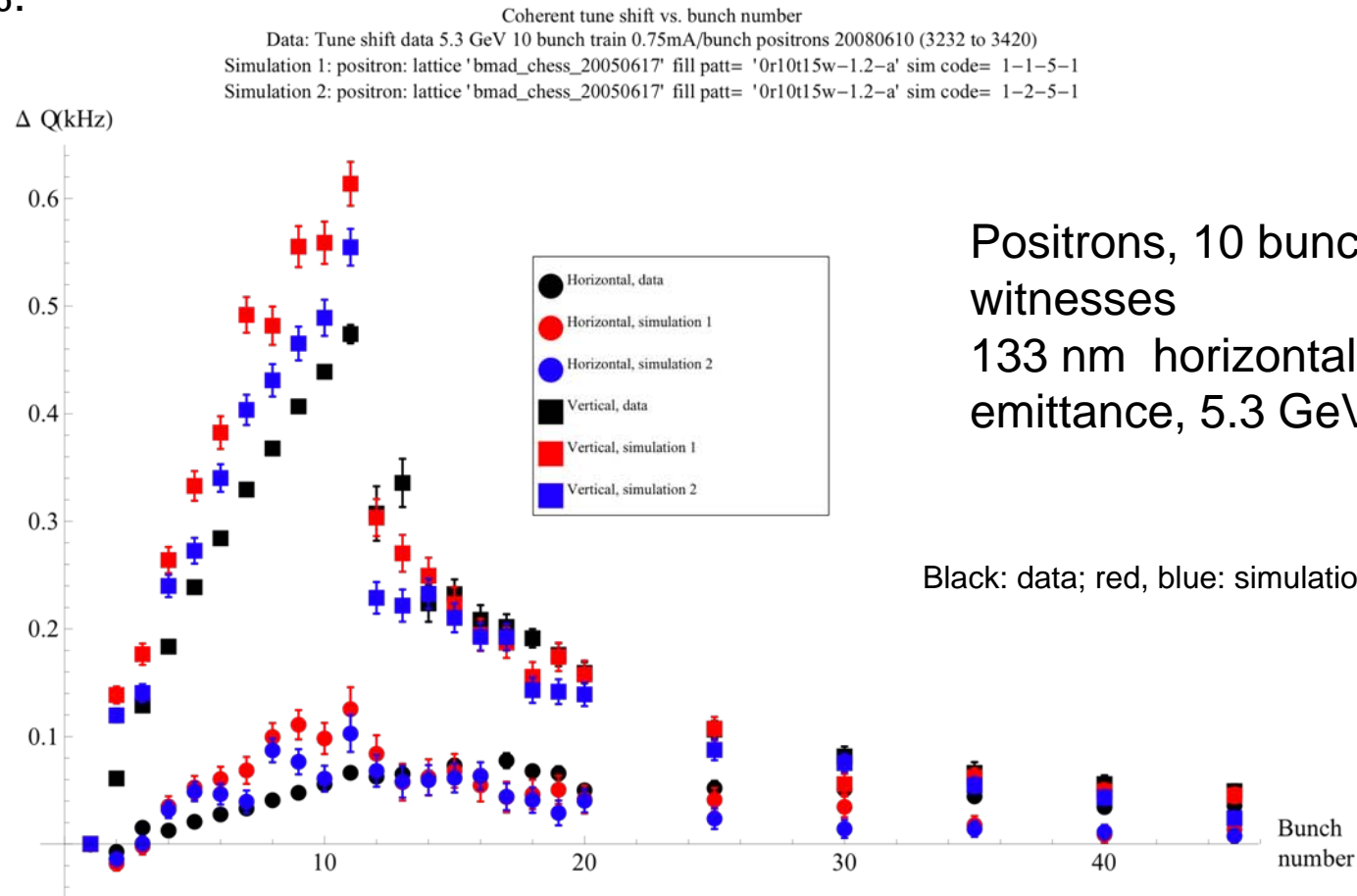
Positrons, 10 bunch train + witnesses
133 nm horizontal emittance, 5.3 GeV

Black: data; red, blue: simulations

POSINST

- Summer and fall, 2009:
    - Complete the RFA response models, with integration into the EC codes.
    - Complete 3D wiggler model simulations.
    - Develop a better estimate of the scattered radiation around the ring and at the RFA's.
    - Expand the experimental data sets with measurements at 4 ns spacing using new FB system, PEP-II chicane data, in-situ SEY measurments, and measurements of cloud-induced betatron phase shifts.
    - With a single set of physics parameters, produce tune shift and RFA response calculations corresponding to all of the existing data, and make comparisons to obtain a best fit estimate of the physics model parameters (photonelectron and SEY parameters), thereby validating the codes.
- Summer, fall and winter, 2009:
    - Check the code validation using results from measurements of instability thresholds, growth rates, mode spectrum, and TE wave dispersion.
    - Use the codes to predict cloud-induced incoherent emittance growth, and check against measurements in Cesr-TA using the XBSM.

- Summer 2009 through spring 2010:
  - Design and perform additional experiments to improve the sensitivity of simulations to cloud physics parameters.
  - Check the validated codes by making predictions for experimental results, and then confirm with measurements.
  - Use the data from the RFA's located at points where coatings, grooves and electrodes have been implemented to determine the resulting changes in effective physics parameters produced by the mitigation techniques.

- Spring and summer 2010:
  - Use the validated codes and the parameters associated with each of the mitigation techniques to predict the electron cloud effects (e.g, instability thresholds, emittance growth) expected in the ILC damping rings.

- The CesrTA program is a broad and flexible R&D program aimed at characterizing and mitigating the electron cloud effect in an environment which is similar to that of the ILC damping ring: a low emittance beam, in a dipole and wiggler dominated ring.

- The proposed cloud mitigation techniques will be implemented, and their effectiveness measured, in local regions of the ring which represent the range of magnetic environments which are important for the ILC damping ring.

- Validation of electron cloud simulation codes will rely on measurements of local cloud density using RFA's, TE wave measurements, and beam dynamics measurements, over a large range of bunch patterns (down to 4 ns spacing) and beam sizes, at energies between 2 and 5 GeV, with both electrons and positrons.

- This code validation will allow the results of CesrTA experiments on cloud formation and mitigation to be extrapolated with confidence to the conditions of the ILC damping ring.