CesrTA Electron cloud simulation update

G. Dugan

LCWA09 Damping Ring session

10/1/09

Update organization

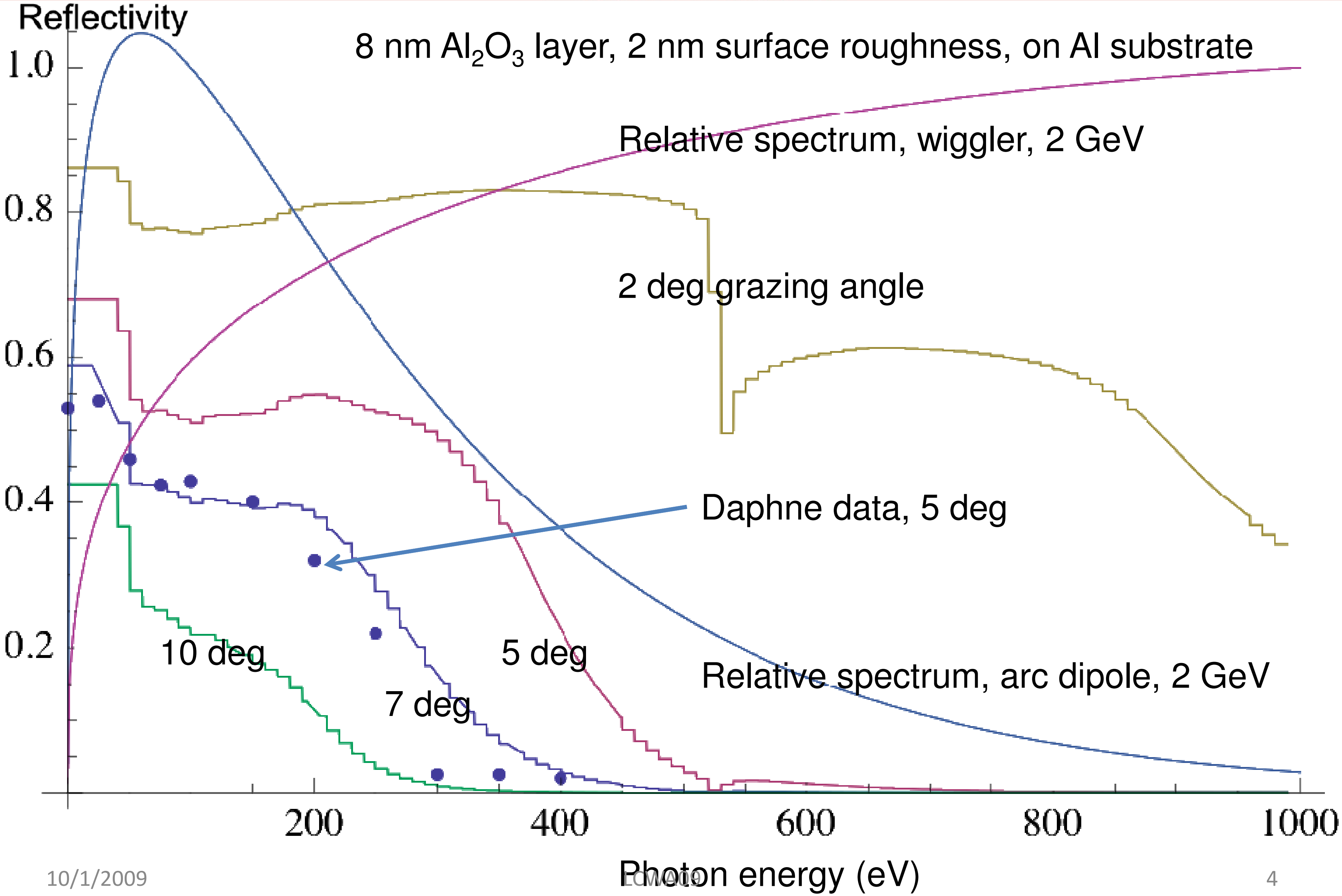
- This update will be organized in terms of the numbered items in the CesrTA simulation work list established at the CTA09 Workshop in June, 2009.
- The work list is an Excel spreadsheet posted at

https://wiki.lepp.cornell.edu/ilc/pub/Public/CesrTA/ElectronCloud/EC_sim_and_beam_studies.xls

Scattered X-radiation

- Item 1: Estimate of the scattered radiation around the CESR ring. This will need X-ray scattering and absorption data for guidance.
  - We have parameterized X-ray scattering data from an LBNL online database and are developing a simulation code to compute X-ray production and scattering in the CesrTA ring (slide)

X-ray reflectivity: B.L. Henke, E.M. Gullikson, and J.C. Davis. X-ray interactions: photoabsorption, scattering, transmission, and reflection at E=50-30000 eV, Z=1-92, Atomic Data and Nuclear Data Tables Vol. 54 (no.2), 181-342 (July 1993).



RFA simulation code development

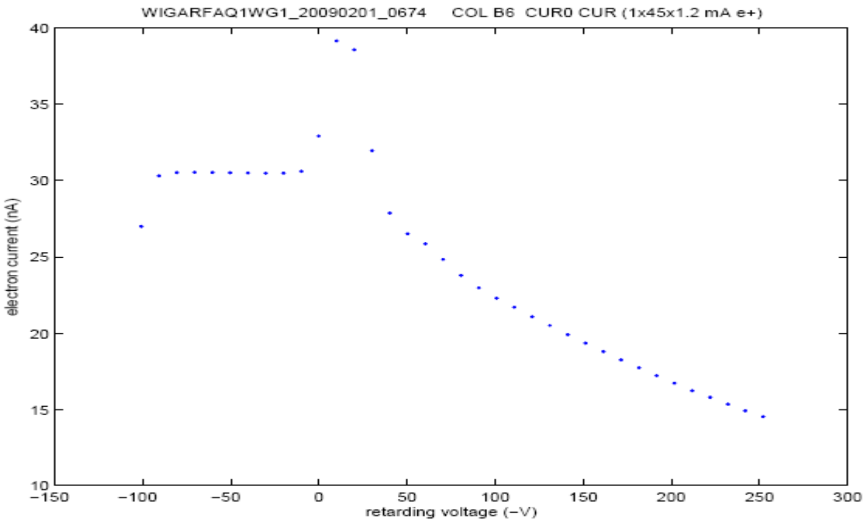
- Item 2: Include the details of the RFA structure itself into the cloud simulation programs.
- Ongoing work by Marco Venturini (LBNL) for POSINST, and Joe Calvey and Jim Crittenden (Cornell) for ECLOUD

Wiggler: POSINST RFA Model

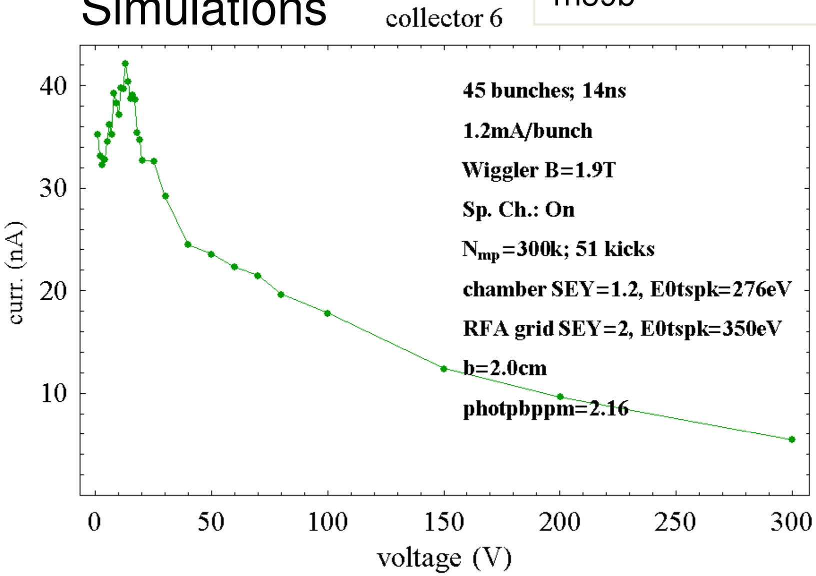
From Marco Venturini

chamber E0tspk=276eV
grid E0tspk=350eV
rn59b

Measurements* (collector no. 6)



Simulations



- 45 bunches, 14ns; 1.2mA/bunch; B = 1.9 T (wiggler)

14ns bunch separation:

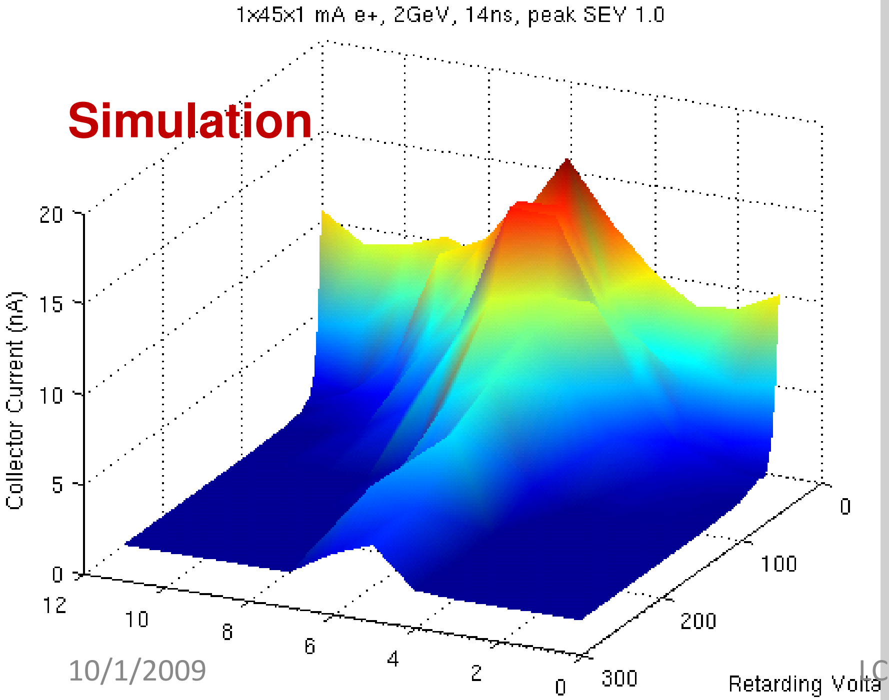
grid SEY=2.0; chamber SEY=1.2

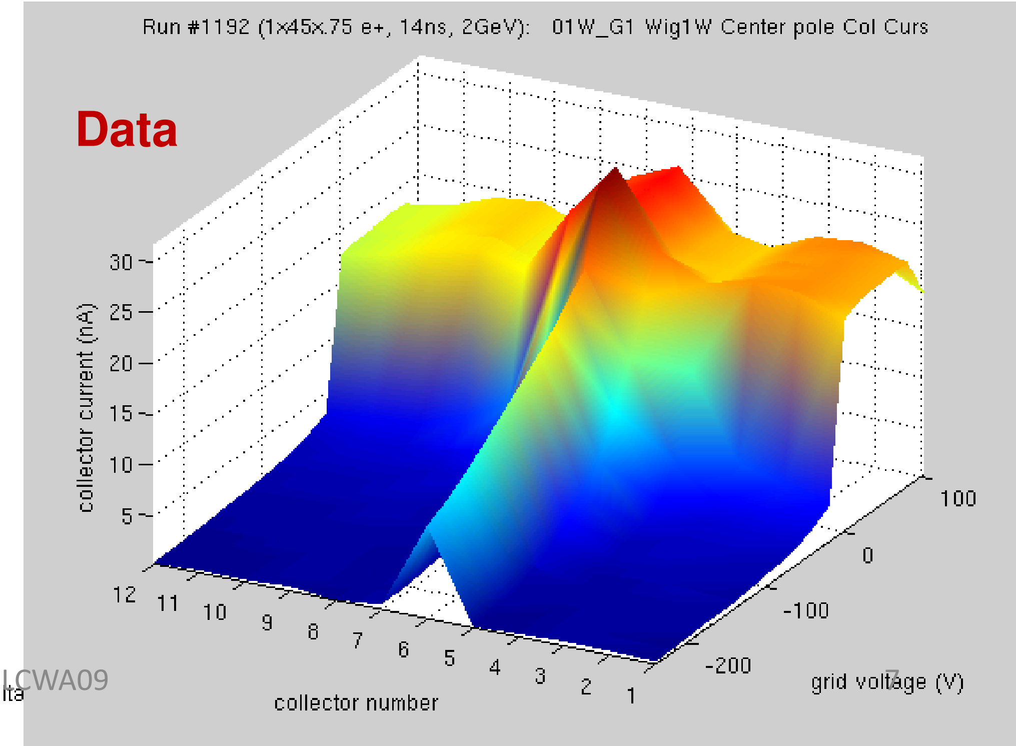
- SEY on grid must be sufficiently large for the resonance peak to show.
- E0stpk (energy of peak SEY) on grid cannot be too large. (Trade-off w/ SEY)
- Chamber wall SEY should not be too large (or else there will be a long tail).
- Some trade off possible between no. of photo-e and chamber SEY parameters.
- Signal vs. V is sensitive to chamber height.

Wiggler: ECLOUD RFA Model

- Done with wiggler (pole center) RFA model in ECLOUD
  - Performs analytic calculation when macroparticle hits in the RFA region
  - Assumes macroparticles don’t move between beam pipe holes
  - Includes SEY on the retarding grid
  - Produces results similar to data
- 1x45x1 mA e+, 14ns, 2GeV
- Simulation has peak SEY of 1.0

From Joe Calvey


Simulation


Data

RFA simulation/data comparisons

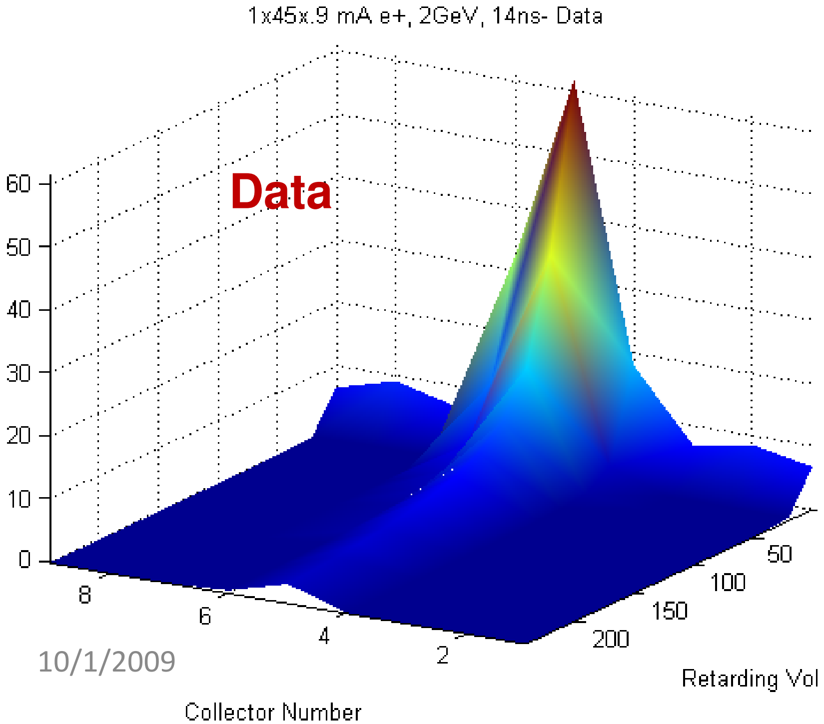
- Item 3: Run simulations for the existing RFA drift and dipole data sets for a range of cloud physics parameters, to establish the best fit ranges of these parameters for different surfaces and mitigation techniques. Correlate with in-situ SEY measurements and parameters found from ringwide coherent tune shift fits.

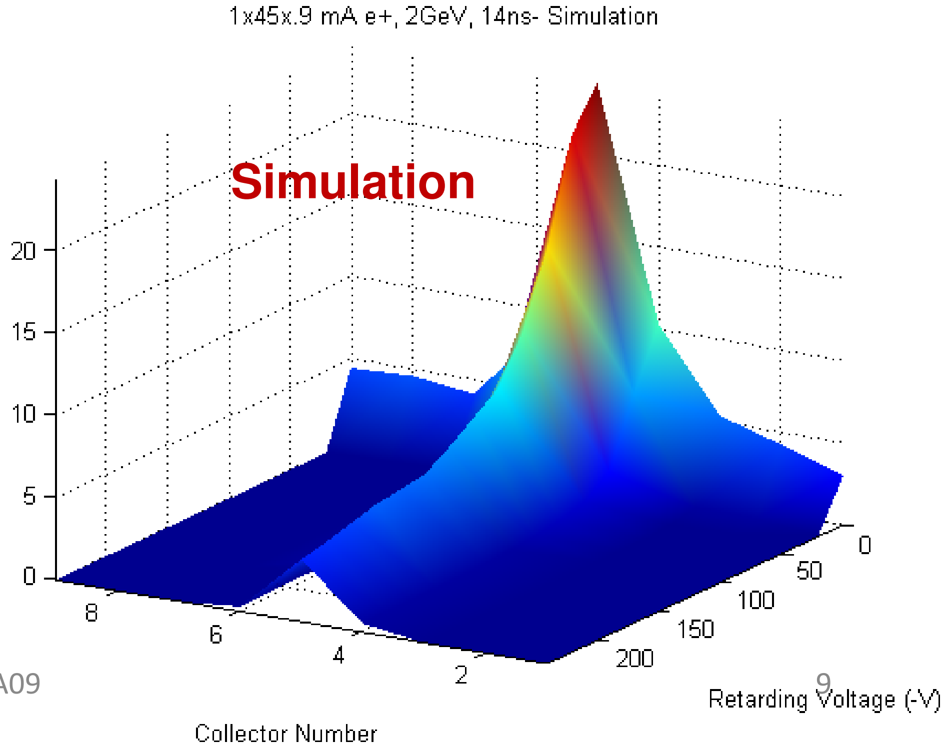
- We have started to do this for drifts, using a post-processing script, as an approximate RFA model. This may be adequate for drifts, although not for dipoles and wigglers

Drift RFA Comparison (POSINST)

- 15E thin ("dipole style") RFA
  - 9 collectors
- Uncoated aluminum chamber
- 1x45x.9 mA e+ @ 2 GeV, 14ns spacing
- RFA currents simulated with postprocessing script
- Simulation used a peak SEY of 1.8 and a peak energy of 310 eV
- Agreement is very good at > 20V, and within a factor of 2 at < 20V

From Joe Calvey

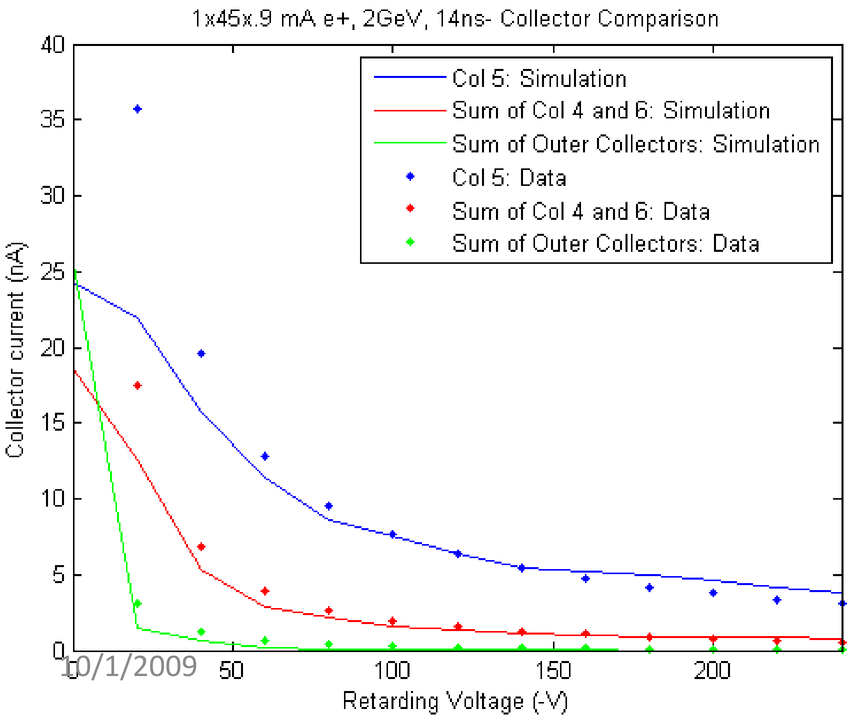

1x45x.9 mA e+, 2GeV, 14ns- Data

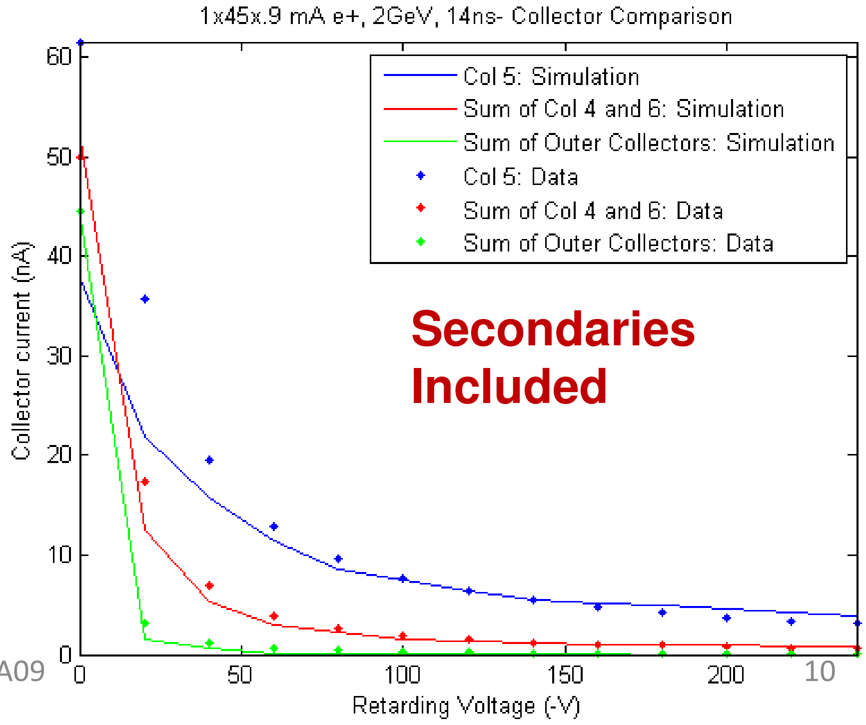

1x45x.9 mA e+, 2GeV, 14ns- Simulation

Drift RFA Comparison (POSINST)

- 2D plot shows central collector (blue), sum of collectors 4 and 6 (red), and sum of the rest of the collectors (green)
- These plots show that the agreement at high energy is excellent
- Simulation underestimates current at low retarding voltage
- This can be partially fixed by including an empirical model for secondary generation inside the beam pipe holes (right plot)
  - With the correct choice of parameters this model fits the low energy data very well, except in the central collector, which is still somewhat underestimated
  - We should probably simulate this to get more accurate transparency curves

From Joe Calvey





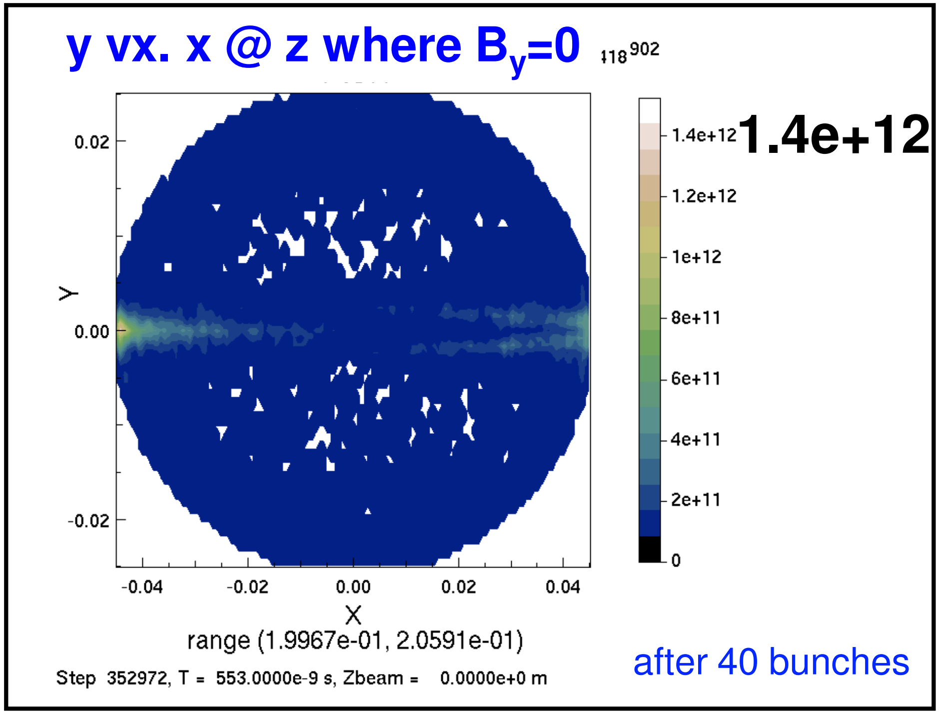
Secondaries Included

3D wiggler simulations

- Item 18: Resolve discrepancies between 3D simulation codes regarding the structure of the cloud in the By=0 regions; and Item 5: Identify experimentally accessible signatures of the structure of the cloud in the By=0 wiggler regions; and
- Christine Celata (LBNL, ret., and Cornell) has shown, using WARP/POSINST, that electrons orbits in the By=0 regions are consistent with predictons based on grad B drifts for electrons near the beam axis in these regions. This validates the electron dynamics observed in WARP/POSINT.
- The cloud in these regions has a relative long lifetime, according to simulations. Christine has also been using the 3D code to look at the effect of buildup of the cloud in these regions with multiple trains.
- She has also Looked at kicking electrons out with beam at low field (does not seem feasible) or pulling electrons out along field lines with electrodes (need good time resolution) or looking with TE wave probes

Cornell University
Laboratory for Elementary-Particle Physics

At B_y=0 in the wiggler, electrons traverse the chamber.

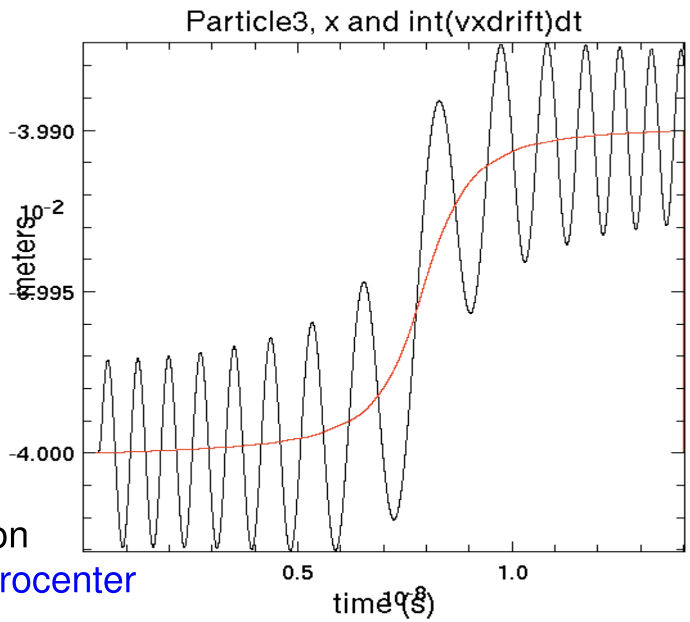


Explanation

This occurs even without beam or electron space charge. How do they travel across field lines? Gradient and curvature of B cause drift of the orbit gyrocenter in the x direction.

Proof

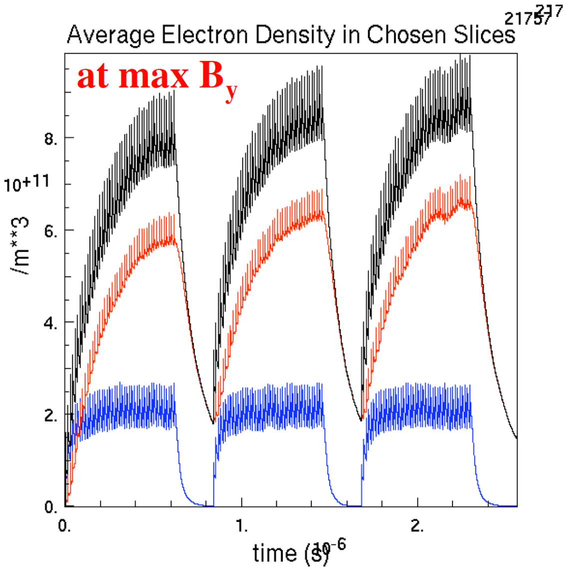
$$v_{drift} = \frac{m}{q}\frac{\nabla|B|\times\vec{B}}{|B|^3}\left(v_{\parallel}{}^2+\tfrac{1}{2}v_{\perp}{}^2\right)$$



- x vs. t for simulation electron
- calculated movement of gyrocenter from ∇B and curvature B

From Christine Celata

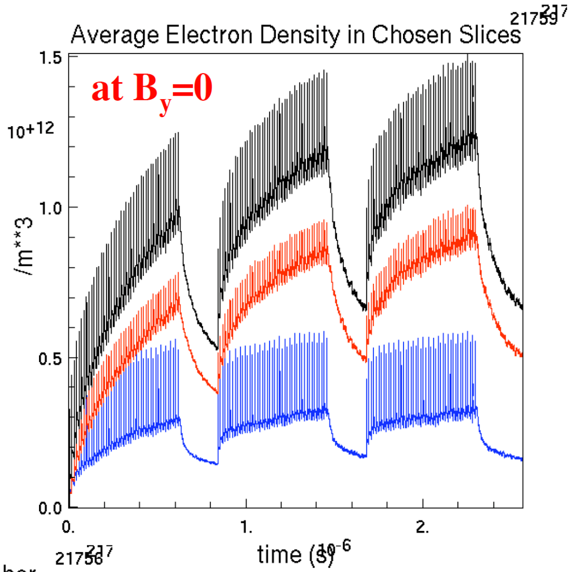
3D Wiggler simulations



at max B_y

z= 9.983e-02 to 1.061e-01 meters
Step 1636020, T = 2.5632e-6 s, Zbeam = 0.0000e+0 m

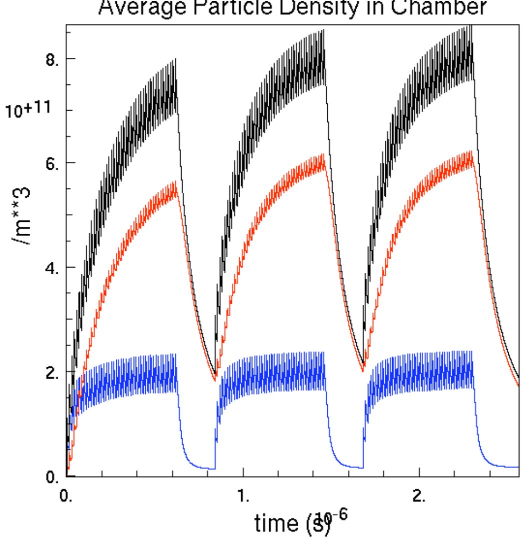
3 trains
45 bunches/train
15-bunch gaps



at B_y=0

z= 1.997e-01 to 2.059e-01 meters
0, T = 2.5632e-6 s, Zbeam = 0.0000e+0 m

Integrated over length of wiggler



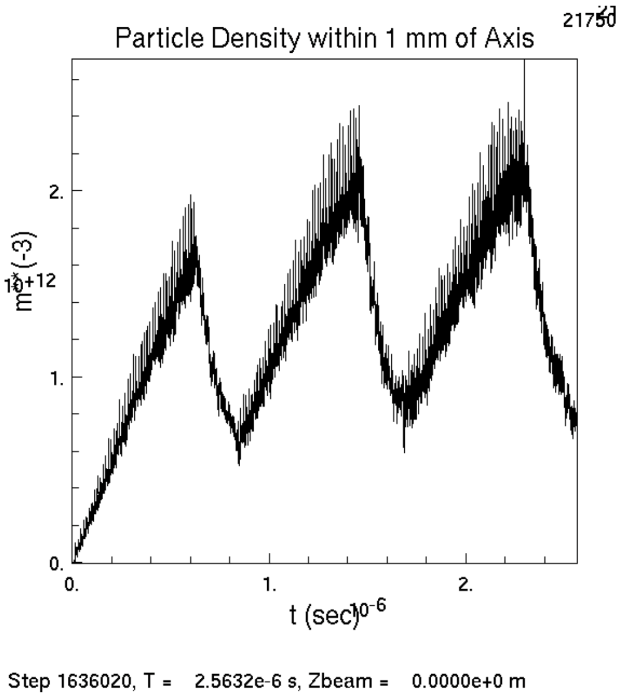
Step 1636020, T = 2.5632e-6 s, Zbeam = 0.0000e+0 m

-- photoelectrons
-- secondaries
-- total

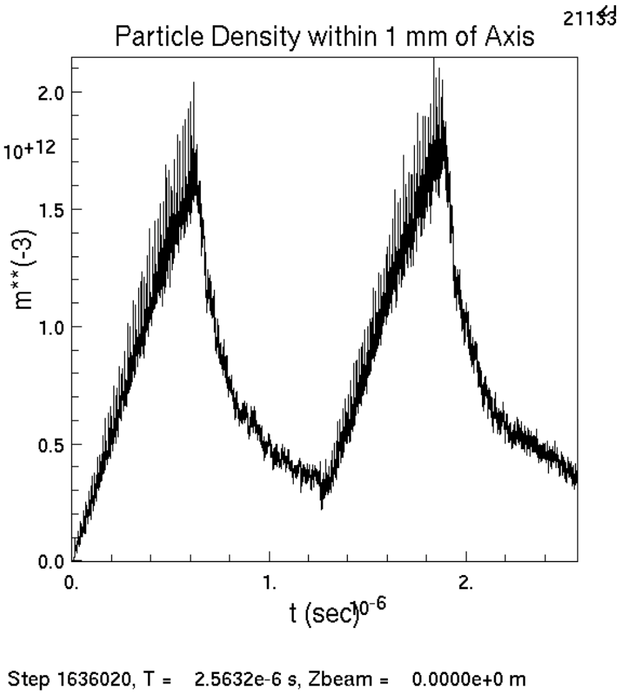
From Chris Celata

3D Wiggler simulations

Density within 1 mm of Axis Integrated over the Wiggler Length



45-bunch train
15-bunch gap



45-bunch train
45-bunch gap

From Chris Celata

Coherent tune shifts: simulation/data comparisons

- Item 6: Run simulations for the existing coherent tune shift data sets for a range of cloud physics parameters describing the ringwide drifts and dipoles, to establish the best fit ranges of these parameters.

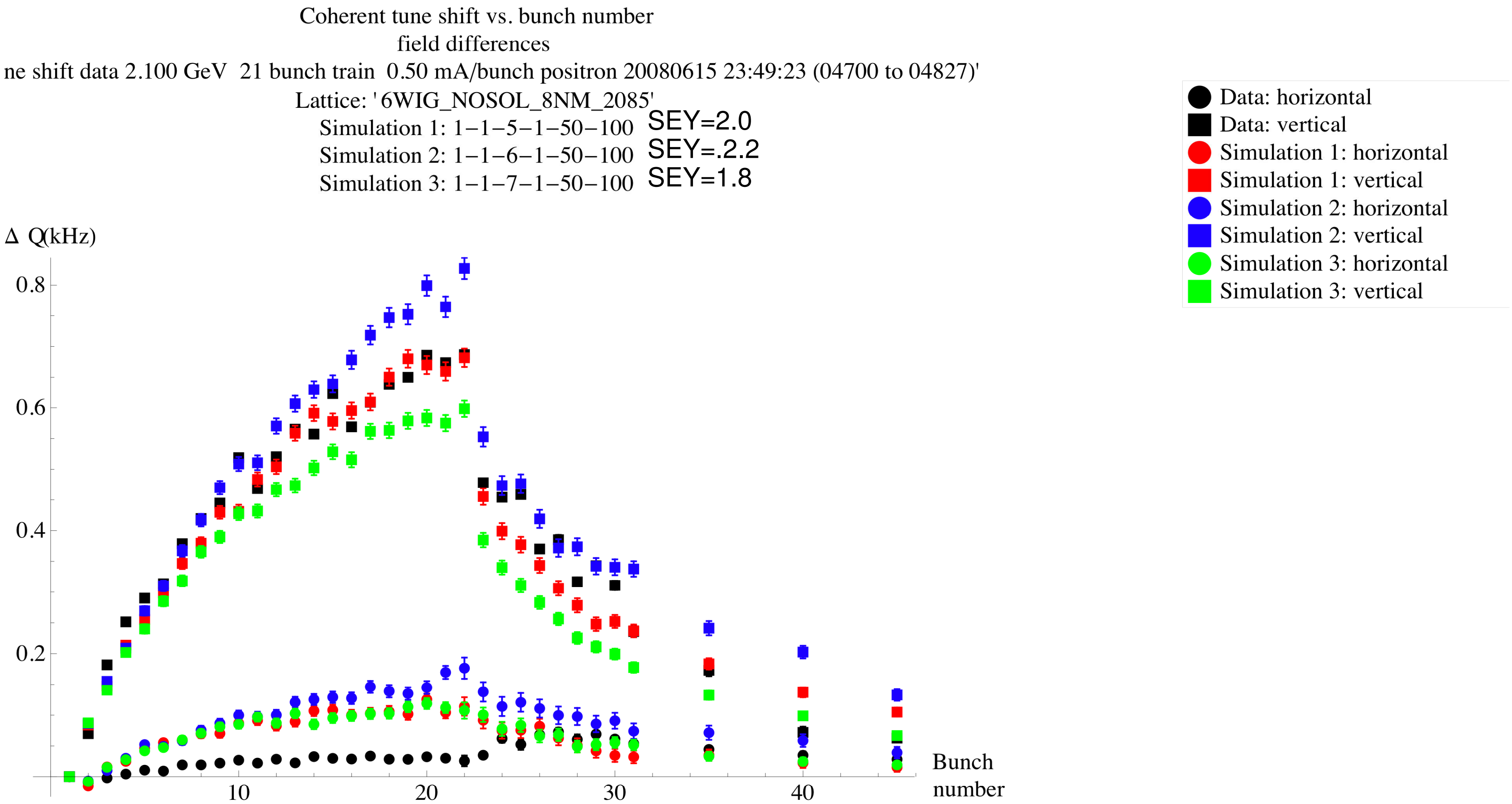
- We have started to do this for coherent tune shift data taken in 2007 and June/July 2008 (37 data sets), and January 2009. This data was all taken by coherently kicking the whole train.

April 2007, and June-July 2008 runs

37 data sets containing tune shifts measurements with a broad range of conditions were taken in April, 2007 and June-July, 2008, and are currently being analyzed:

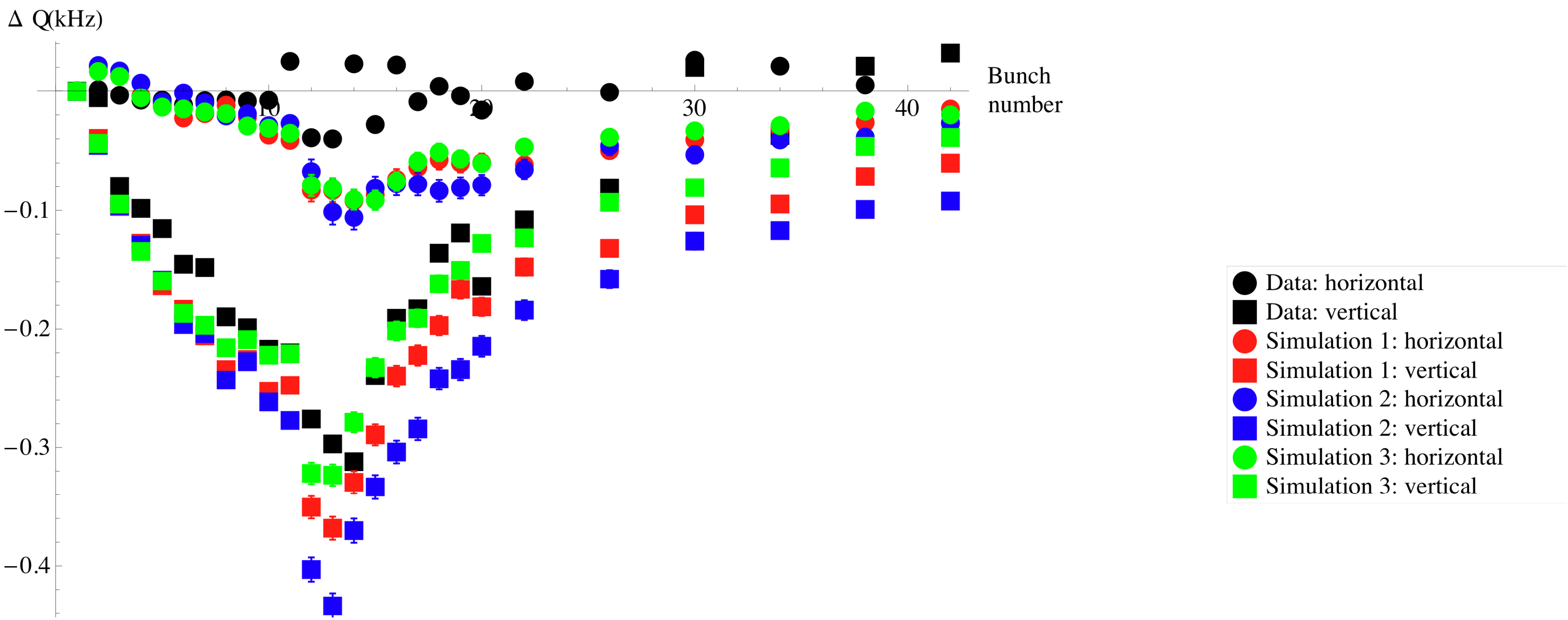
Energy (Gev)	Species	Bunch currents	Train length	Witness length	Data sets
1.9, 2.1	Positrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	3, 10, 11, 19, 20, 21	5-15	23
1.9, 2.1	Electrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	10, 11, 19, 20, 21	5-15	10
5.3	Positrons	0.75, 1.5, 5.0	3, 10	5-10	3
5.3	Electrons	1.5	10	10	1

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



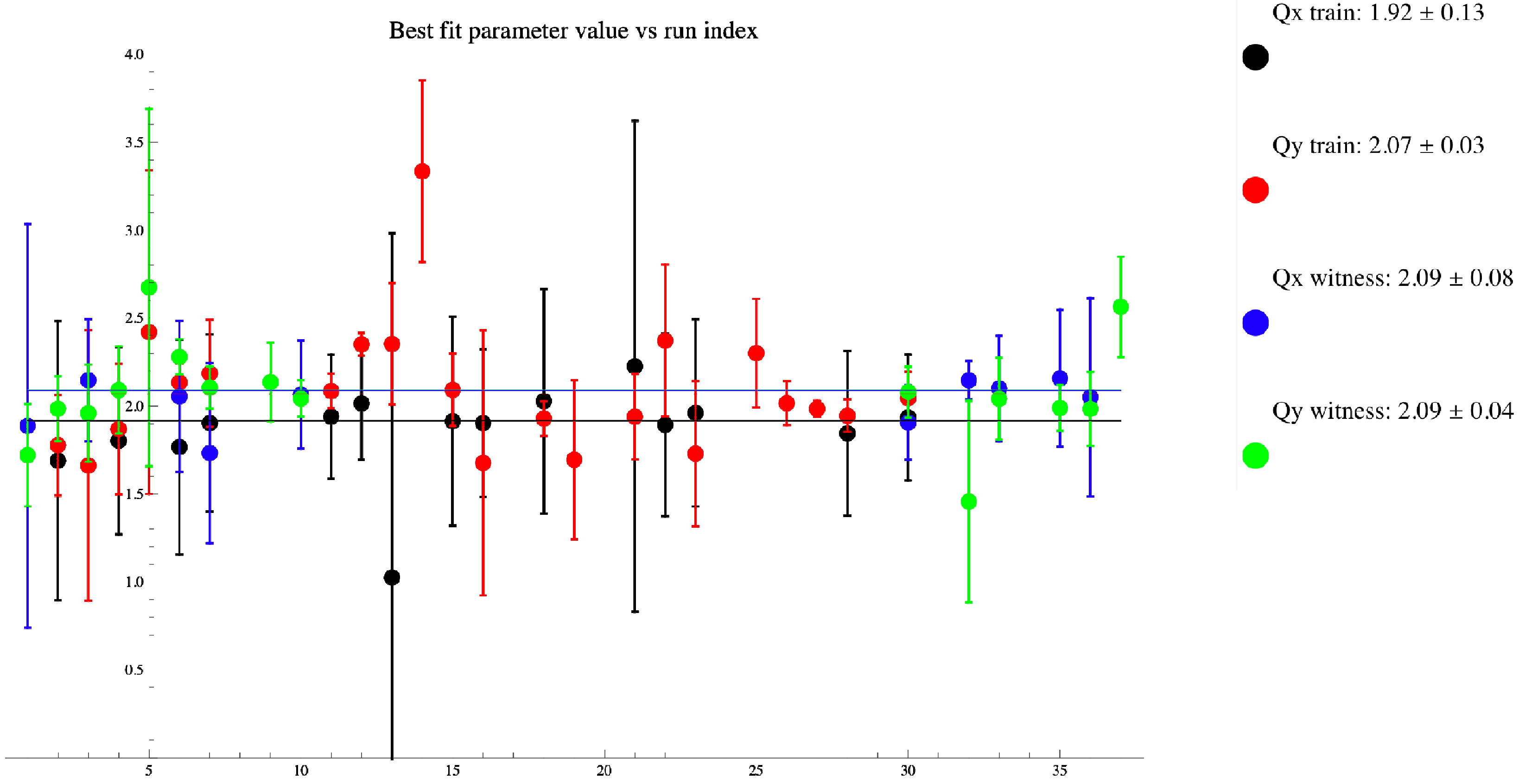
2007 electron data, 10 bunch train, 14 ns spacing,1.2×10^{10}/bunch
Peak SEY scan

Coherent tune shift vs. bunch number
field differences
'une shift data 1.880 GeV 10 bunch train 0.75 mA/bunch electron 20070403 00:24:01 (02100 to 02117)'
Lattice: ' 12WIG_20050626A'
Simulation 1: 1–1–5–1–50–100 SEY=2.0
Simulation 2: 1–1–6–1–50–100 SEY=.2.2
Simulation 3: 1–1–7–1–50–100 SEY=1.8



Results of simulation comparisons for 37 data sets: Peak SEY scan

Parameter=peak SEY
Errors estimated from normalized chisquared curve



Results of simulation comparisons for 37 data sets: 6 Electron cloud model parameters

parameter	Reference value	Qx train	Qy train	Qx witness	Qy witness
SEY peak	2.0	1.92 ± 0.13	2.07 ± 0.03	2.09 ± 0.08	2.09 ± 0.04
Quantum efficiency	0.12	0.91 ± 0.014	0.133 ± 0.001	0.13 ± 0.01	0.133 ± 0.006
Reflectivity	0.15	0.147 ± 0.022	0.156 ± 0.004	0.171 ± 0.02	0.164 ± 0.01
True secondary SEY peak energy (eV)	310	314 ± 24	317 ± 11	308 ± 17	317 ± 24
Rediffused SEY at infinity	0.1902	0.0839 ± 0.14	0.239 ± 0.02	0.296 ± 0.06	0.274 ± 0.02
Elastic SEY peak	0.5	0.451 ± 0.072	0.577 ± 0.02	0.519 ± 0.05	0.548 ± 0.02

From Zhidong Leong

- We need explore the correlations between the parameters.
- We also need to expand the breadth of the data set, to look at the November 2008 and January 2009 data.

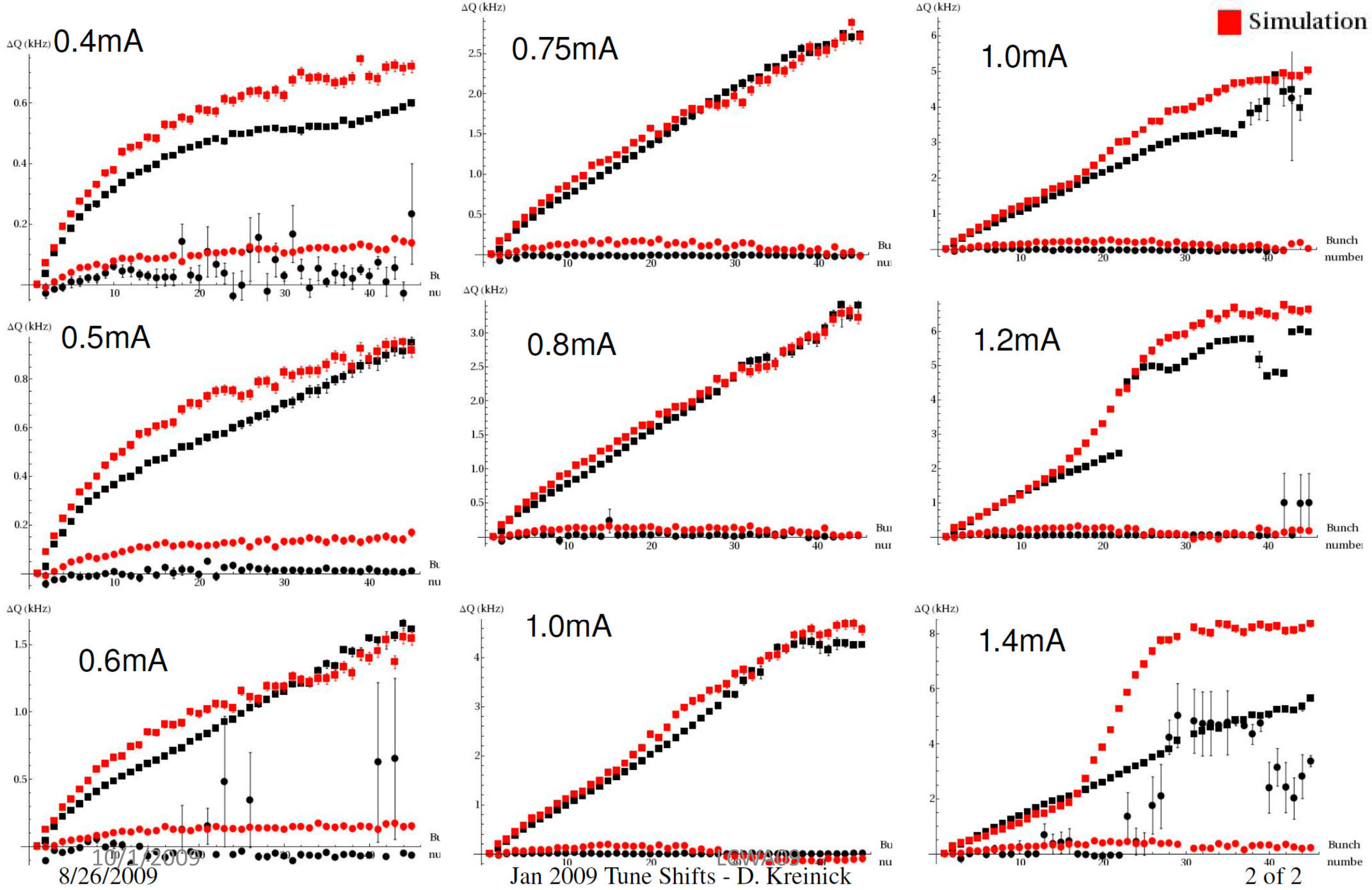
Simulations with nominal parameters
45 bunch trains, 14 ns spacing, Jan 2009

From Dave Kreinick

1 mA=1.6x10^{10}

● Data: horizontal
■ Data: vertical
🔴 Simulation 1: horizontal
🟥 Simulation 1: vertical

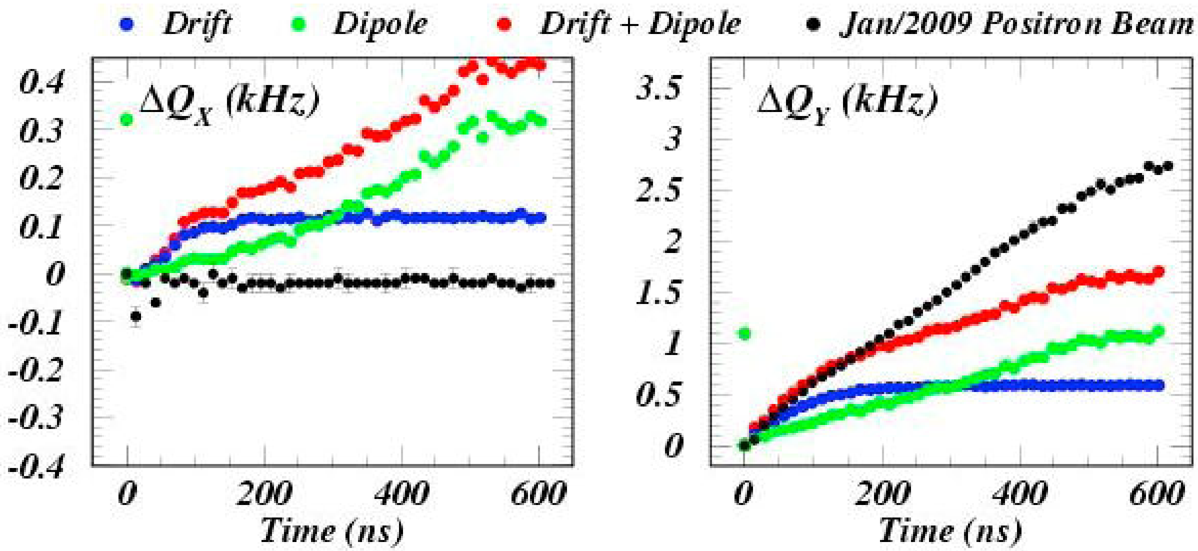
Positron Tune Shifts vs. Bunch Number

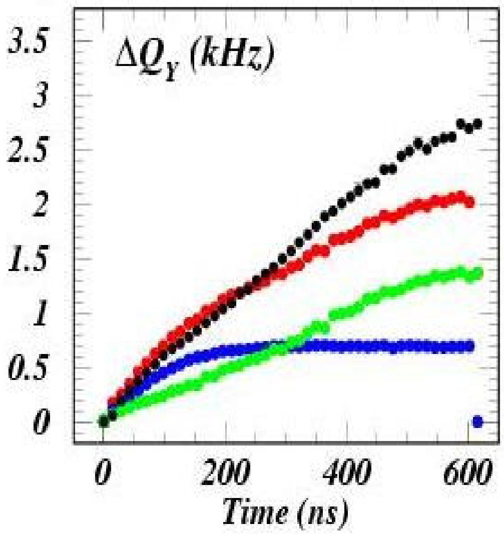


8/26/2009
Jan 2009 Tune Shifts - D. Kreinick
2 of 2

ECLOUD simulations of long trains

A problem in the ECLOUD simulation code which prevented the simulation of long trains has been resolved, and rediffused electrons have been added in ECLOUD:





P_{red}=0.2

From Jim Crittenden

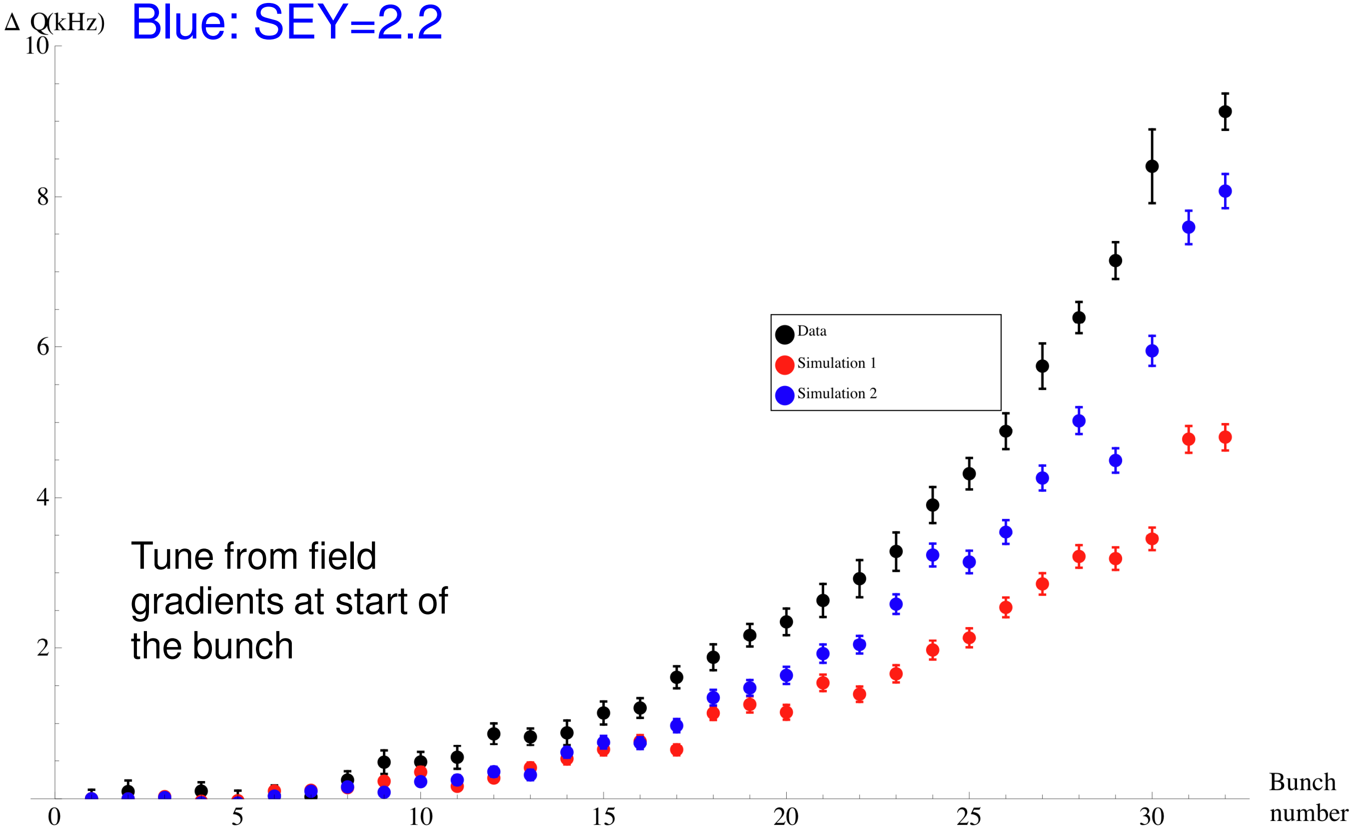
Tune shift data with 4 ns spacing

We have also simulated tune data taken in June 2009, with 4 ns spacing. This data is taken using our Dimtel 4 ns feedback system, which measures the coherent tunes of bunches without coherent motion of the train.

Black: data, 1.3x10^{10}/bunch, 1.9 GeV, 4 ns spacing

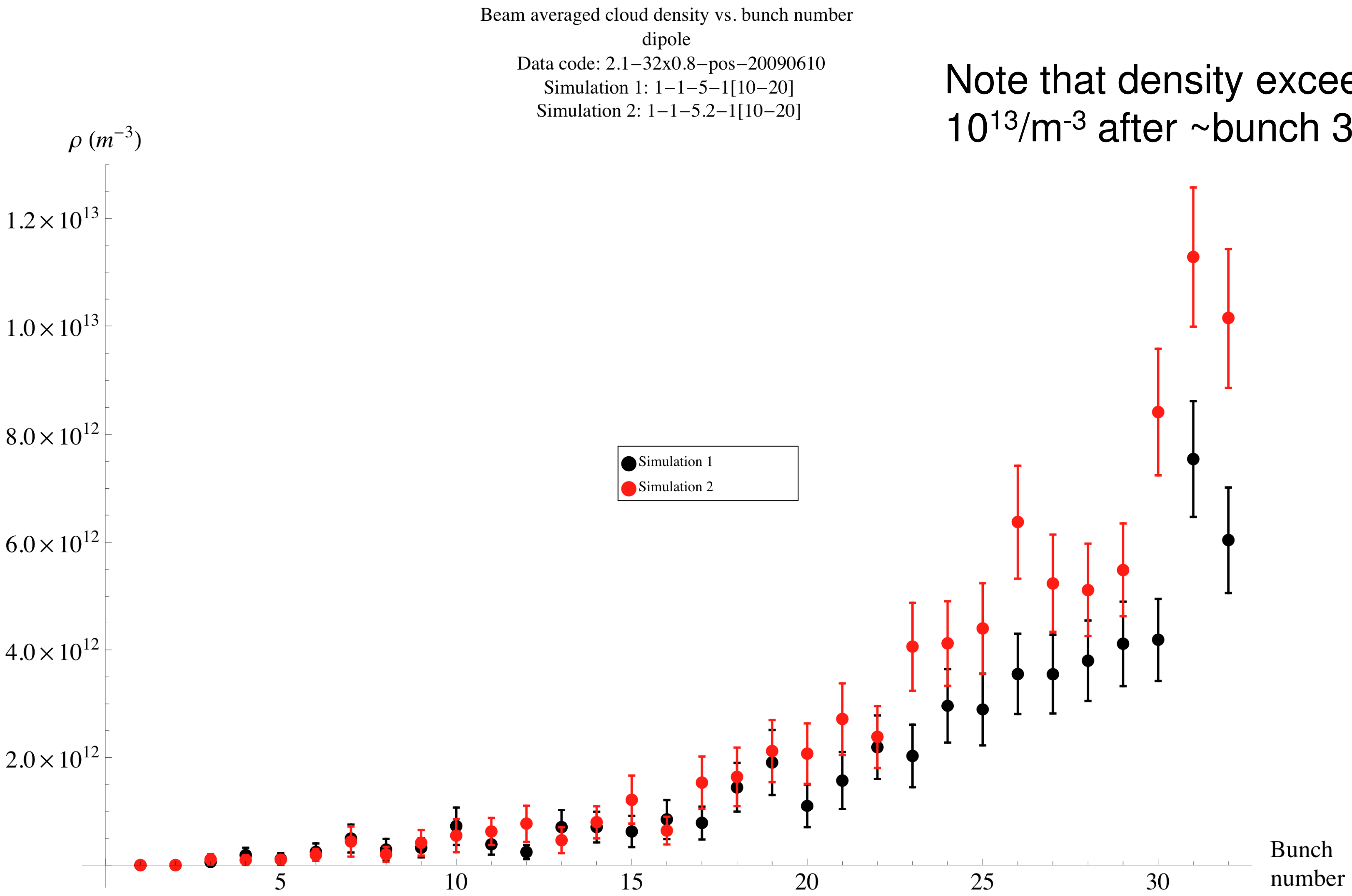
Red: nominal simulation parameters (SEY=2.0)

Blue: SEY=2.2



Tune from field gradients at start of the bunch

Positrons, simulated dipole density near the beam
32 bunches, 4 ns spacing, 1.3x10^{10}/bunch



Note that density exceeds $10^{13}/m^{-3}$ after ~bunch 30

Item 10: Determining EC physics parameters

Item 10: Using simulations, define set of experiments (RFA, TE wave, tune shift) which can be done at CesrTA that can independently determine the key electron cloud physics paramters.

From C. Celata, K. Harkay, M. Furman (based on expt, analysis, simulation)

On Extracting Parameters for Simulation from RFA Data

Note: these are local parameters-- must be measured for each accelerator element. Secondary emission parameters also vary with conditioning, i.e., with time.

- We can measure $\delta(0)$ from the slope of the decay of the cloud with time extrapolated to late times when electron energy → 0. (Done by R. Macek)
- Measuring the equilibrium cloud density for a case where the effective secondary yield < 1 (due to small beam current or wall treatments or widely spaced bunches) will determine the photoelectron generation per unit time.
- Percentage of rediffused, elastic, and true secondaries vs. energy must be determined by varying parameters to fit the electron energy spectrum from the RFA. Need to evolve an algorithm for this using simulation*.

Item 10: Determining EC physics parameters

On Extracting Parameters for Simulation from RFA Data (con't)

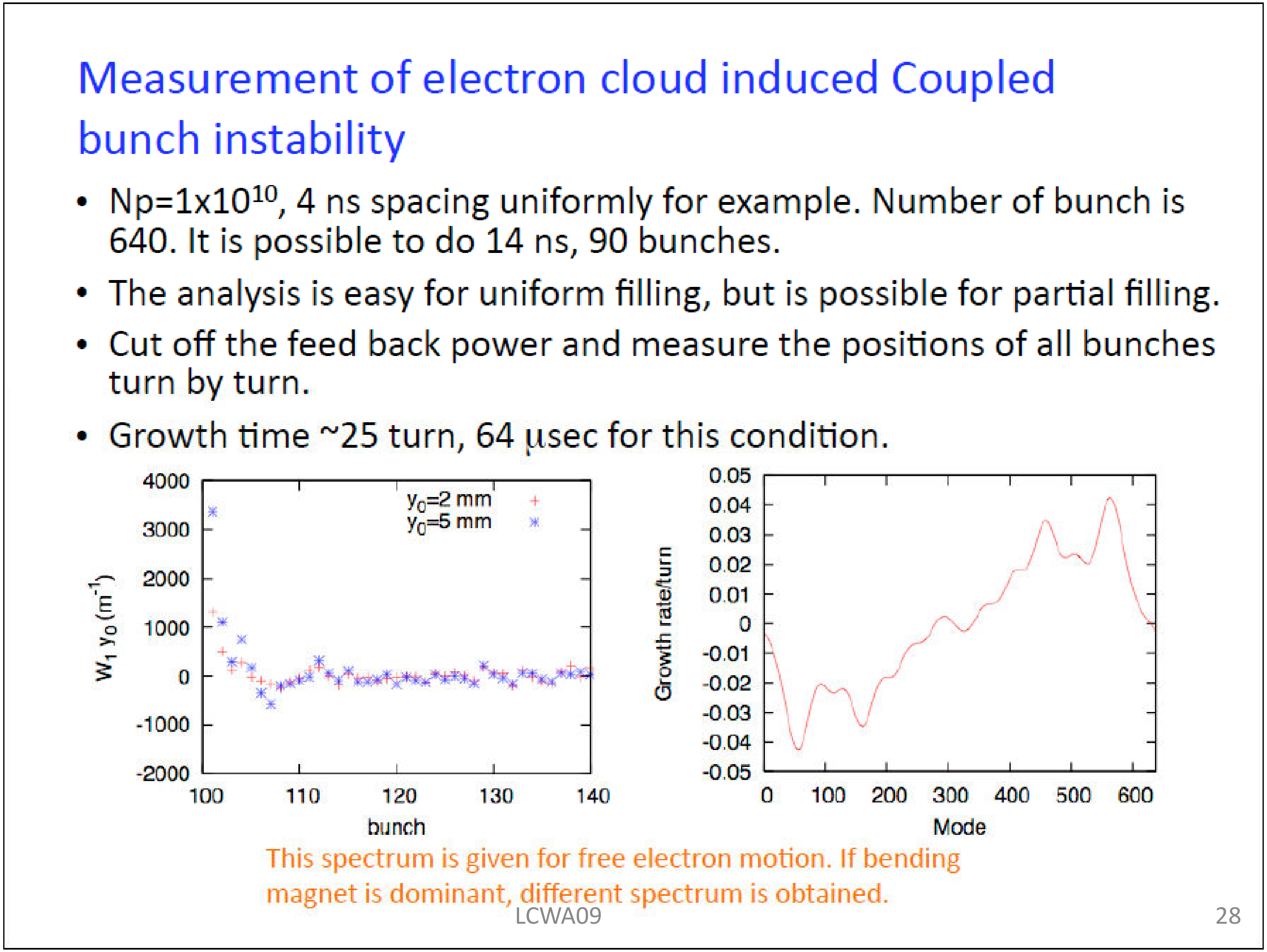
- Knowing the above parameters, the equilibrium density (for $\delta_{eff}>1$) is determined by δ_{max} and E_{max} (energy at δ_{max}). We believe that these parameters can be determined by a 2-parameter fit to the equilibrium density as the beam current is varied. In a dipole, stripe position gives E_{max}.
- Segmented RFAs can determine azimuthal photon distribution for the azimuth covered by the RFA, since electron birthplace can be known from the B geometry (if space charge is negligible). Photon distribution is difficult to obtain for other field geometries and other azimuthal positions because it depends on modeling everything upstream. We suggest direct measurements in a beamline-- perhaps a wraparound azimuthal photon detector-- to determine photon spatial distribution.

Multibunch Instabilities

- Item 13: Estimate the threshold, growth time and mode spectrum for multibunch instabilities at CesrTA. Consider witness bunch configurations as well as train measurements.
- Prediction from K. Ohmi (KEK) for uniform fill.
  - T. Demma (INFN) is also studying this.
- We have measurements of instablity growth times and mode spectra made using Dimtel feedback system.

Multibunch instabilties

From Kazuhito Ohmi



Measurement of electron cloud induced Coupled bunch instability

- Np=1x10^{10}, 4 ns spacing uniformly for example. Number of bunch is 640. It is possible to do 14 ns, 90 bunches.
- The analysis is easy for uniform filling, but is possible for partial filling.
- Cut off the feed back power and measure the positions of all bunches turn by turn.
- Growth time ~25 turn, 64 μsec for this condition.

This spectrum is given for free electron motion. If bending magnet is dominant, different spectrum is obtained.

Single-bunch instabilities

- Item 14: estimate the threshold for the head-tail instability at CesrTA. Consider witness bunch configurations as well as train measurements.
- Prediction from K. Ohmi (KEK); also being studied by M. Pivi (SLAC)
- We have looked for synchrobetatron sideband excitation in the later bunches of multibunch trains, where we expect the cloud density to exceed the head-tail threshold, but have not observed any signals.

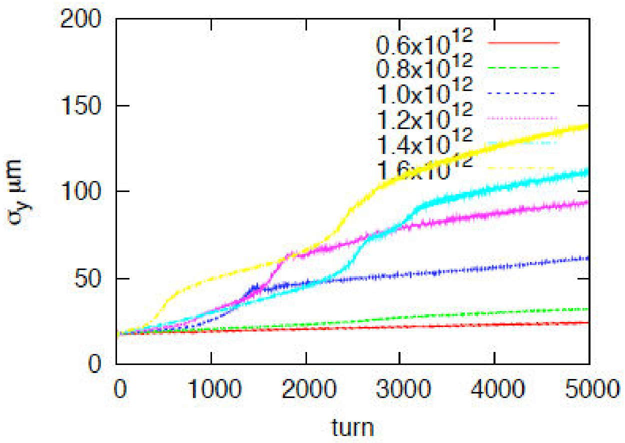
Single-bunch instabilities

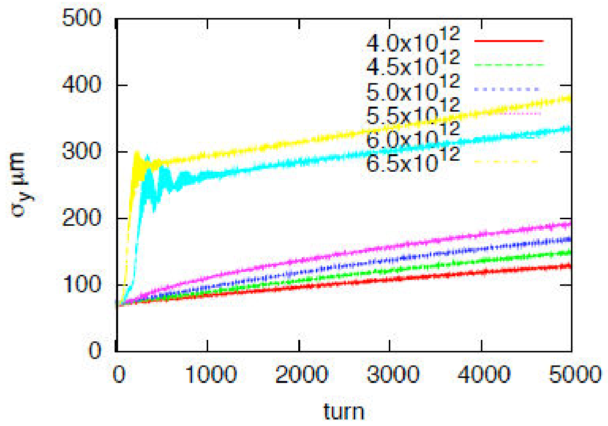
From Kazuhito Ohmi

Simulation of the strong head-tail instability

- Uniform beta model, integration step is L/8.

2 GeV 5 GeV

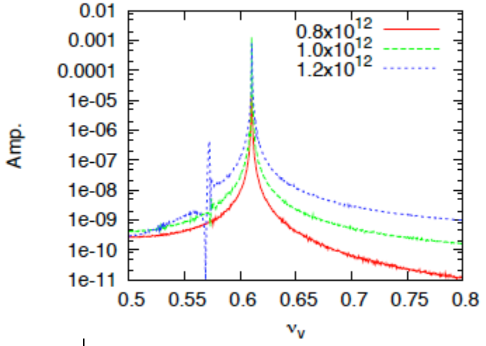




$\rho_{th}=1.0\times10^{12}\ m^{-3}$ $6\times10^{12}\ m^{-3}$

2GeV

$\nu_s=0.055$

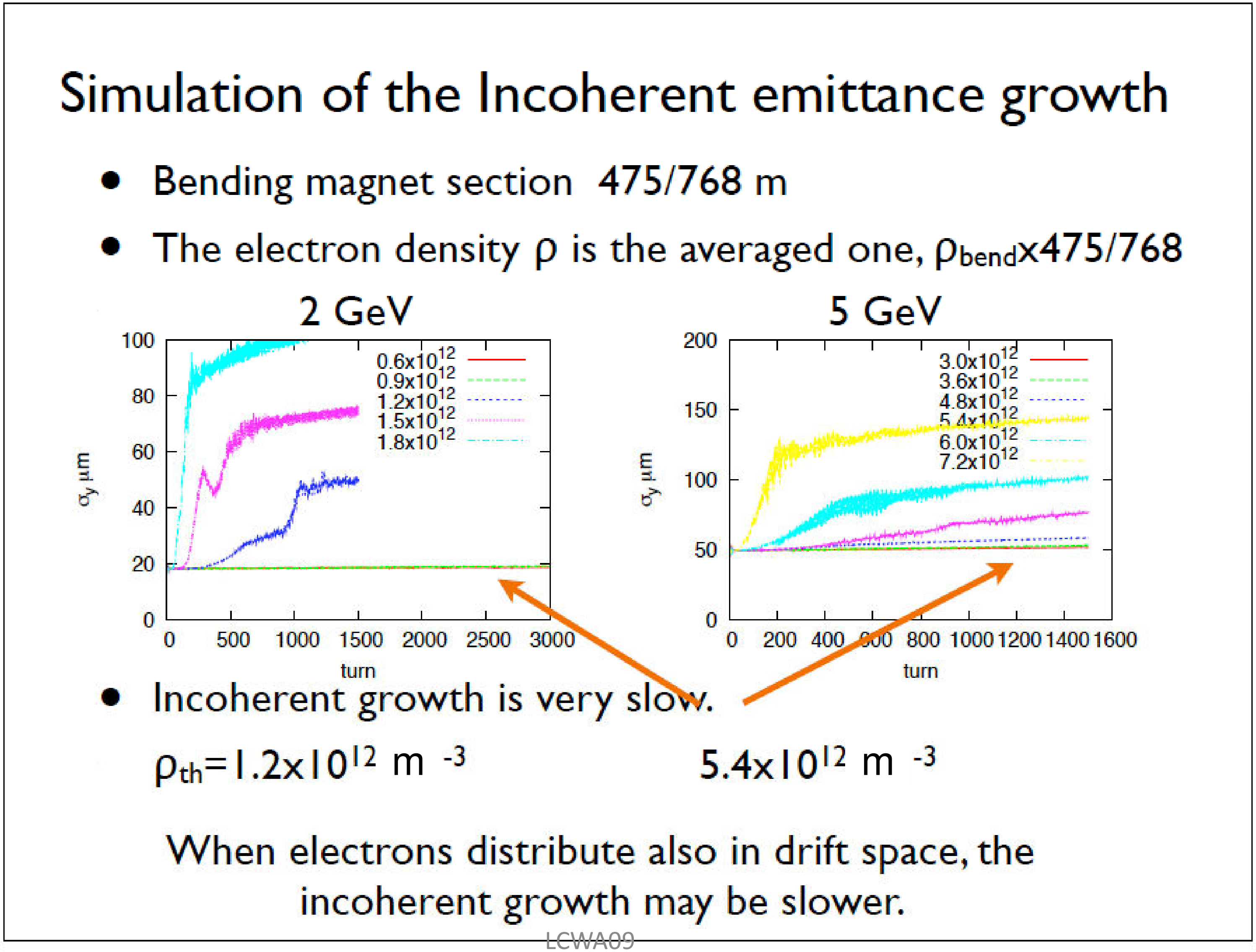


Incoherent emittance growth

- Item 14: Estimate the expected level of incoherent emittance growth at CesrTA for positrons and electrons. Consider witness bunch configurations as well as train measurements to control better the cloud density.
- Prediction from K. Ohmi (KEK).
- We have observed emittance growth along the train using both visible and X-ray beam size monitors. The origin of this emittance growth is still to be determined. (refer to expt talk or add data?)

Incoherent emittance growth

From Kazuhito Ohmi



Simulation of the Incoherent emittance growth

- Bending magnet section 475/768 m
- The electron density ρ is the averaged one, ρ_{bend}x475/768
- Incoherent growth is very slow.

$\rho_{th}=1.2\times10^{12}$ m $^{-3}$ 5.4×10^{12} m $^{-3}$

When electrons distribute also in drift space, the incoherent growth may be slower.

Other simulation work planned or in progress (item #s from CTA09 work list)

- Item 9: Develop an improved photoelectron model (quantum efficiency, photoelectron energy, angular spectra, effect of fluorescence) based on existing data, with measurements if needed
- Item 11: Simulate cloud densities sampled by TE wave measurements
- Item 12: Compute effect of nonuniform cloud distrbution on TE wave phase shifts in the presence of magnetic field
- Item 16: Develop capability to simulate cloud and RFA in quadrupole
    - WARP/POSINST can do quadrupoles. POSINST may be able to do quadrupoles if general field integrator is developed for POSINST. Otherwise, RFA code needs to be added to WARP separately.
- Item 17: Run simulations for the RFA quadrupole data sets for a range of cloud physics parameters, to establish the best fit ranges of these parameters for different surfaces and mitigation techniques.
- Item 19: Estimate contributions to tune shifts from wigglers and quadrupoles.
- Item 20: Develop estimates of cloud-induced betatron phase advances over sections of the ring.