Cornell University
Laboratory for Elementary-Particle Physics

CesrTA Electron cloud simulation update

ILC 10 Workshop

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3/28/09

CesrTA simulation update: outline

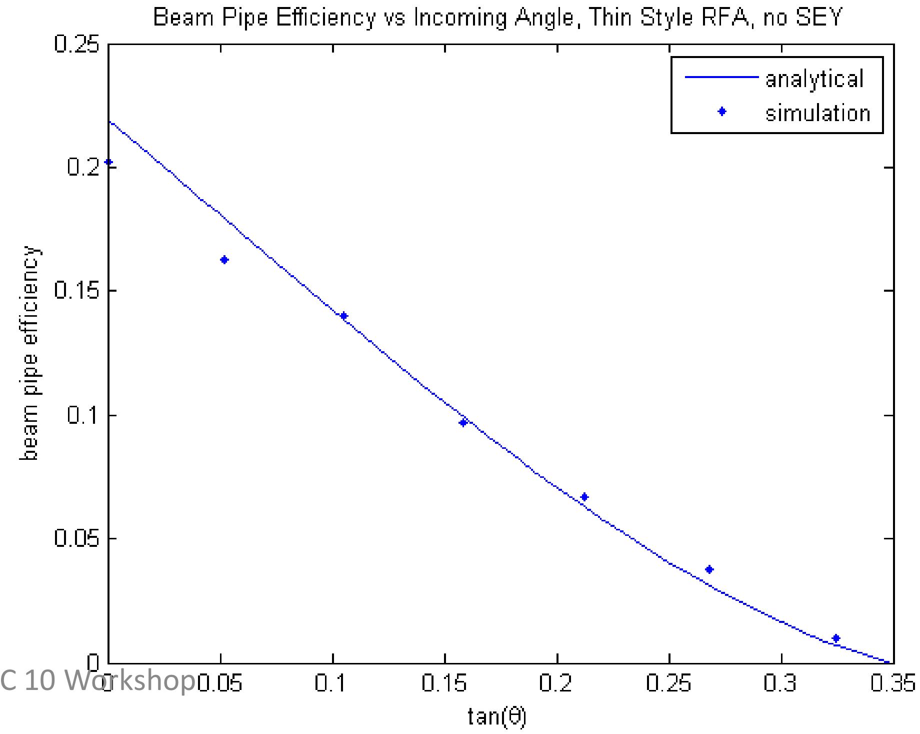
- Simulations and data comparisons for electron cloud currents observed in RFA's.
- Simulations and data comparisons for coherent tune shifts.
- Improvements to EC simulations:
  - 3D simulations in wigglers
  - Simulations of SR photon production and scattering
- Instabilities and incoherent emittance growth.
- Other work.

RFA simulations: Overview

- CESR has been instrumented with ~30 RFAs in drift, dipole, wiggler, and quadrupole field regions
- Proper understanding of RFA data requires simulation
  - Simulation of the cloud in the beam pipe
    - POSINST, ECLOUD
  - Simulation of the RFA itself
    - Postprocessing or integrated models
- The volume of data taken so far necessitates systematic analysis
  - A χ^2 analysis is underway
- Interaction of the RFA with the cloud also needs to be understood
  - Both post-processing and integrated RFA models have been developed
  - Some subtle effects arise which affect the measurements
    - Low energy secondaries generated in beam pipe holes
    - "Trampoline" effect: resonance between bunch spacing and retarding voltage

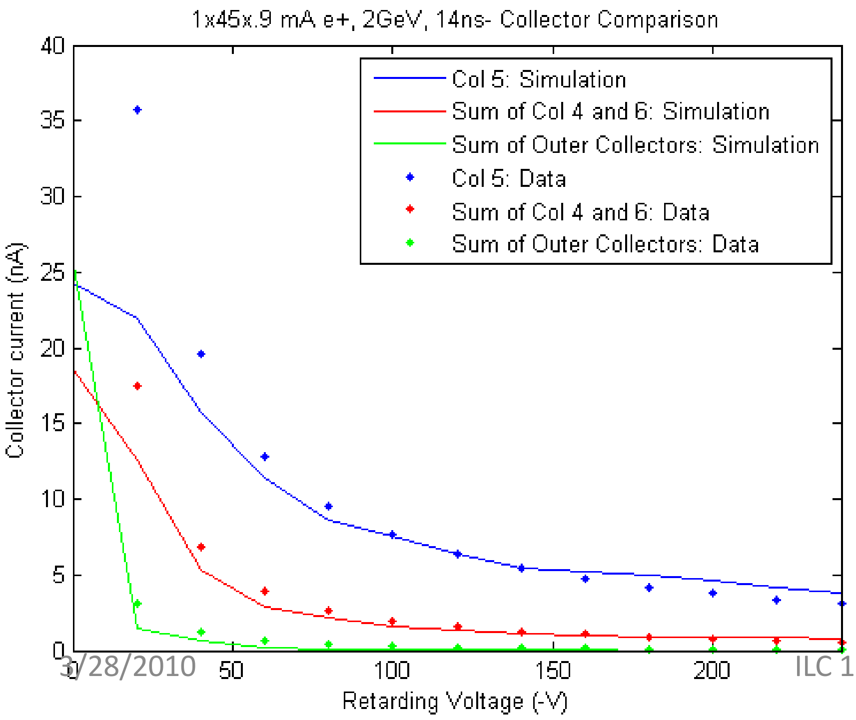
Predicting RFA Currents: Post-Processing Model

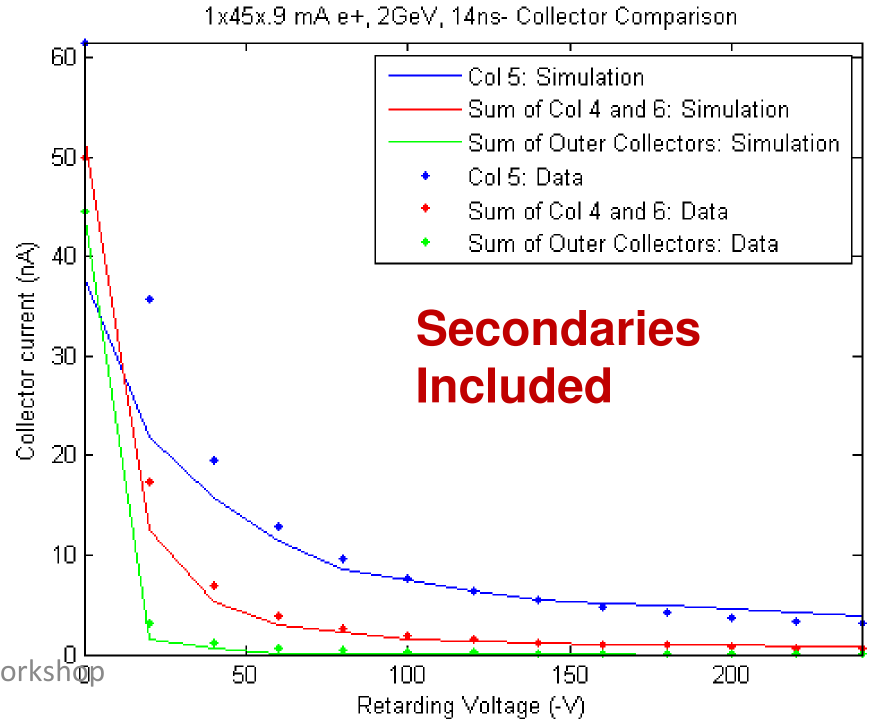
- For each macroparticle-wall collision recorded by a simulation program, perform the following calculation:
  - Determine if the collision was in the area of the RFA
  - Compute beam pipe efficiency based on incident angle
    - Plot below shows efficiency for one RFA as predicted by both analytical calculation and simulation
  - If efficiency is > 0 and energy > retarding voltage, deposit the appropriate amount of charge on one of the collectors
  - Optional: generate secondaries in the beam pipe holes, and repeat the above steps
- Quick and easy, but will not accurately model any interaction of the cloud with the RFA itself



Drift RFA Comparison

- Plots show 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
  - Simulations are underway to get more accurate transparency curves





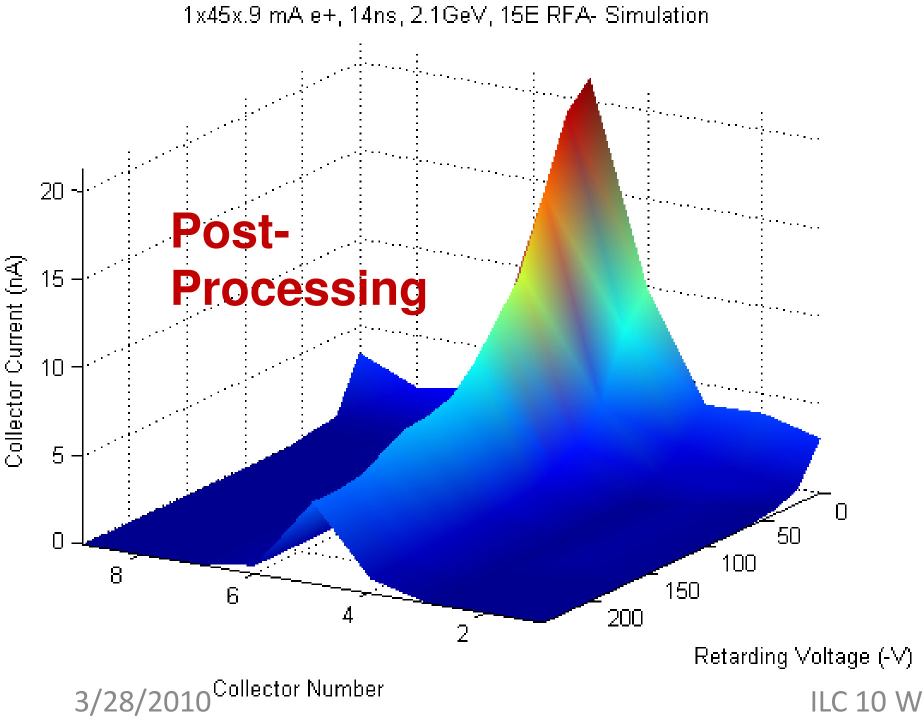
Secondaries Included

Predicting RFA Currents: Integrated Model

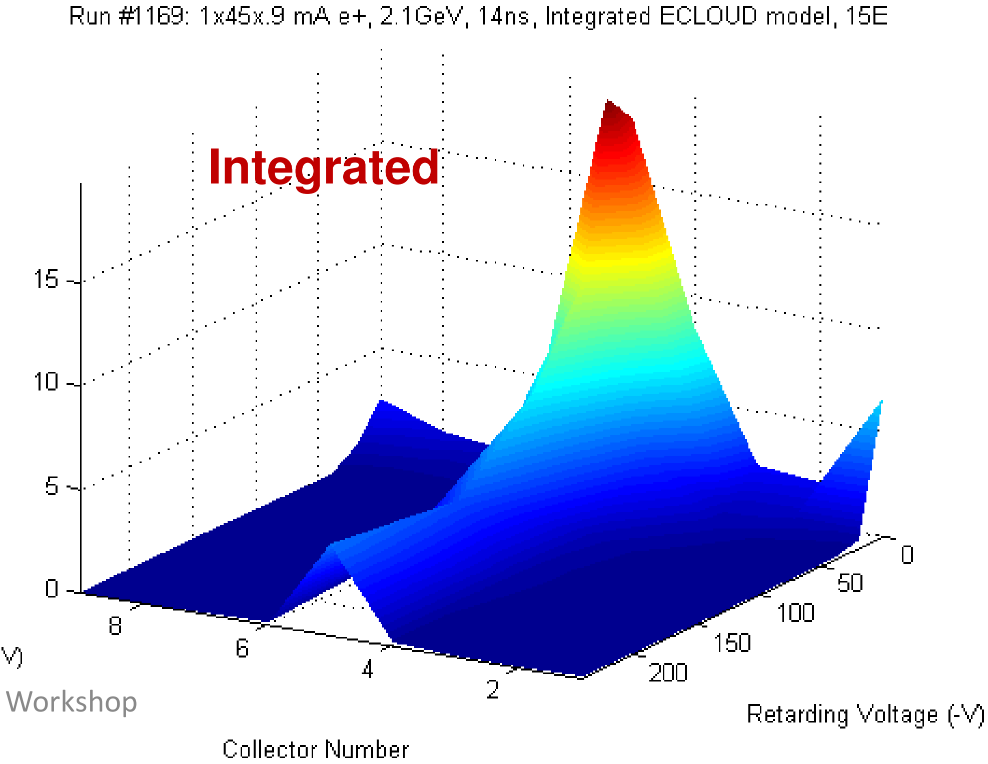
- Ideally, one should include the RFA in the actual simulation codes, so that all effects are automatically accounted for.
- This is being done by:
  - Joe Calvey (ECLOUD, semi-analytical model).
    - Agreement with post-processing has been confirmed in drift (next slide).
  - Marco Venturini (POSINST, full model).
- For dipoles and wigglers, the integrated model is required to understand the data.
- The simulations take much longer, since one needs to do a separate simulation for each retarding voltage.

Post-Processing vs. Integrated Model

- 1x45x.9 mA e+, 2.1GeV, 14ns
- Agreement between post-processing and integrated ECLOUD model is good
  - Need more points and higher statistics to improve integrated plot
  - Should also check for other conditions



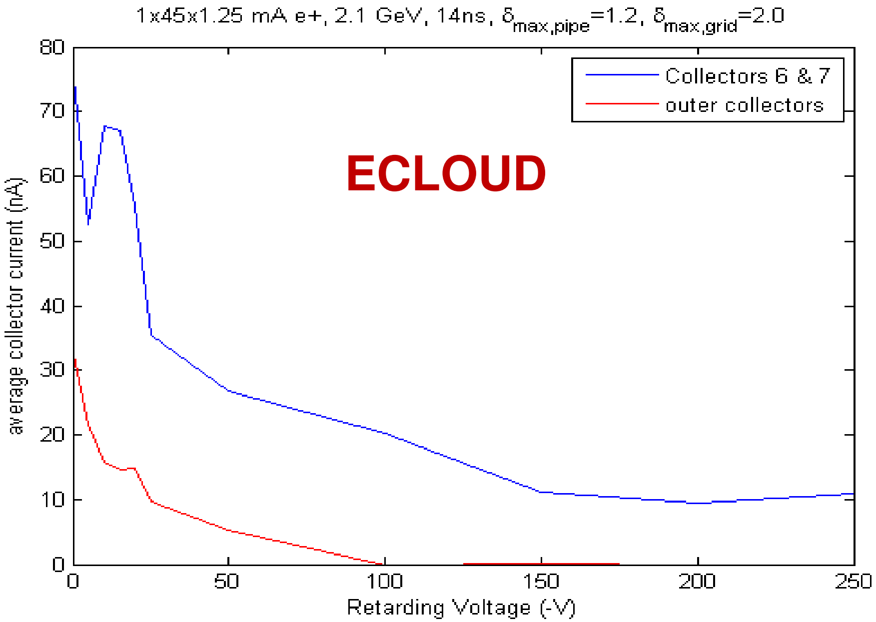
1x45x.9 mA e+, 14ns, 2.1GeV, 15E RFA- Simulation

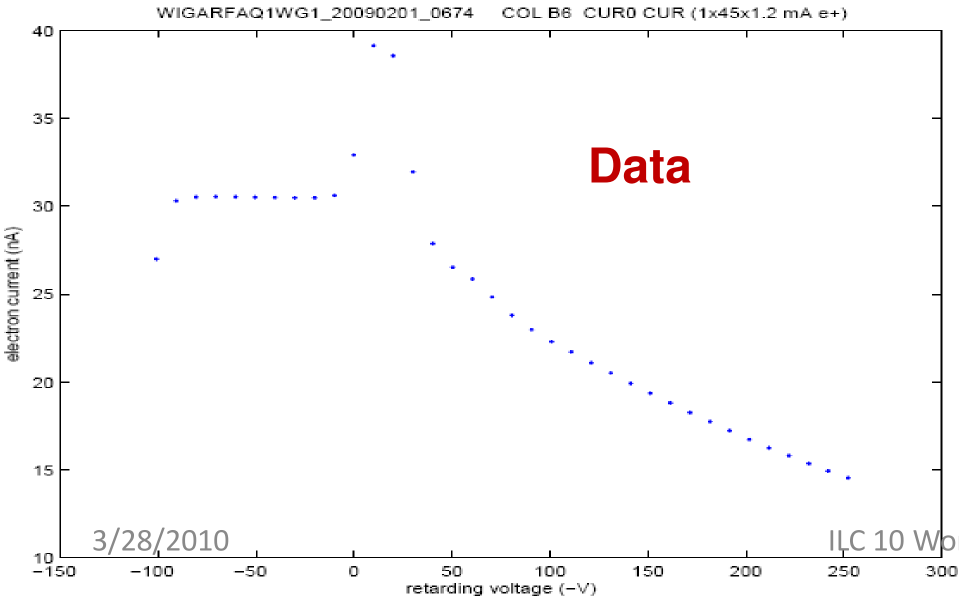


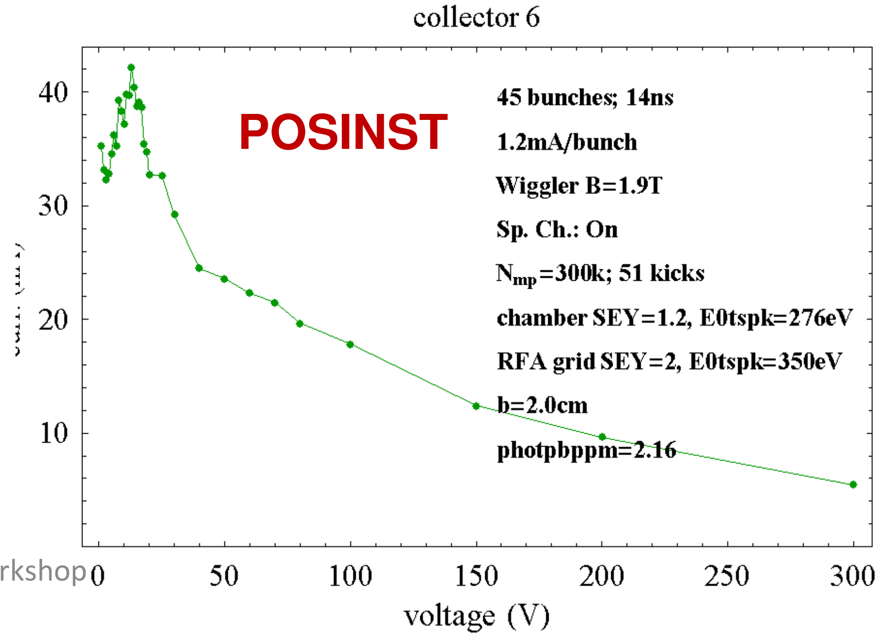
Run #1169: 1x45x.9 mA e+, 2.1GeV, 14ns, Integrated ECLOUD model, 15E

Wiggler RFA Model

- “Trampoline effect” peak has been observed in both data and simulation
  - In a region of high magnetic field, secondaries generated on the RFA grid are accelerated through the retarding voltage, and back into the beam pipe.
  - This creates a resonant condition between bunch spacing and retarding voltage.
  - Effect is most prominent in peak wiggler field (1.9T).
  - Integrated model with peak SEY of 1.2 for beam pipe and 2.0 for grid.

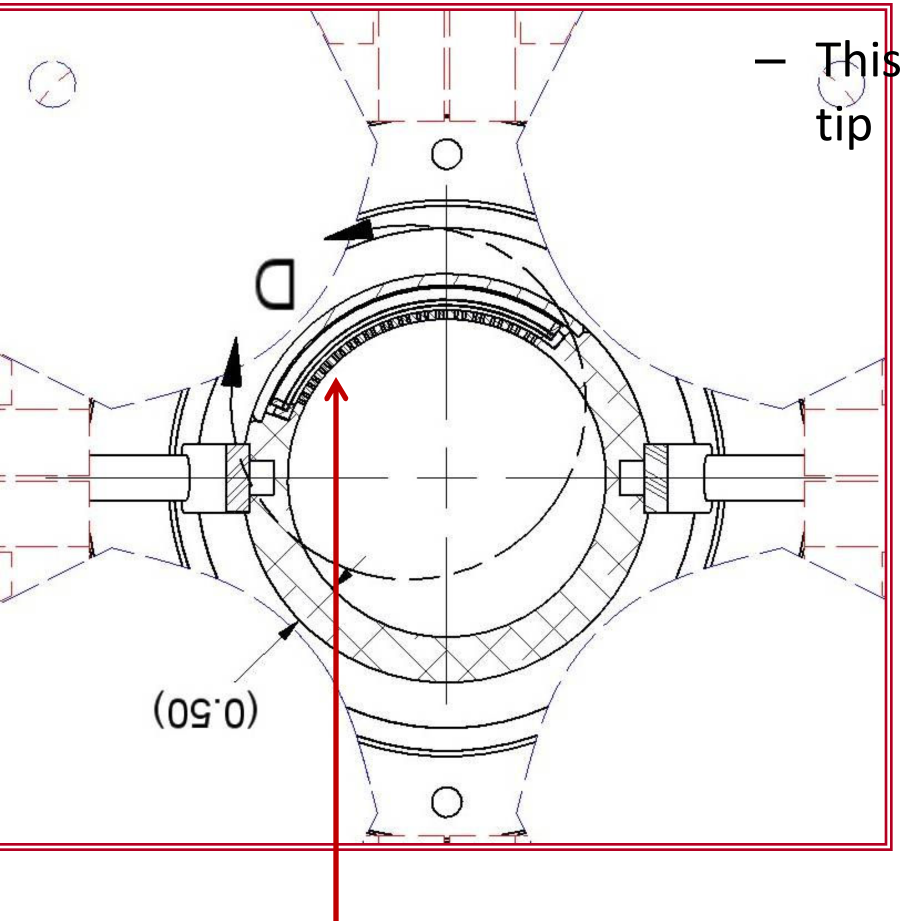


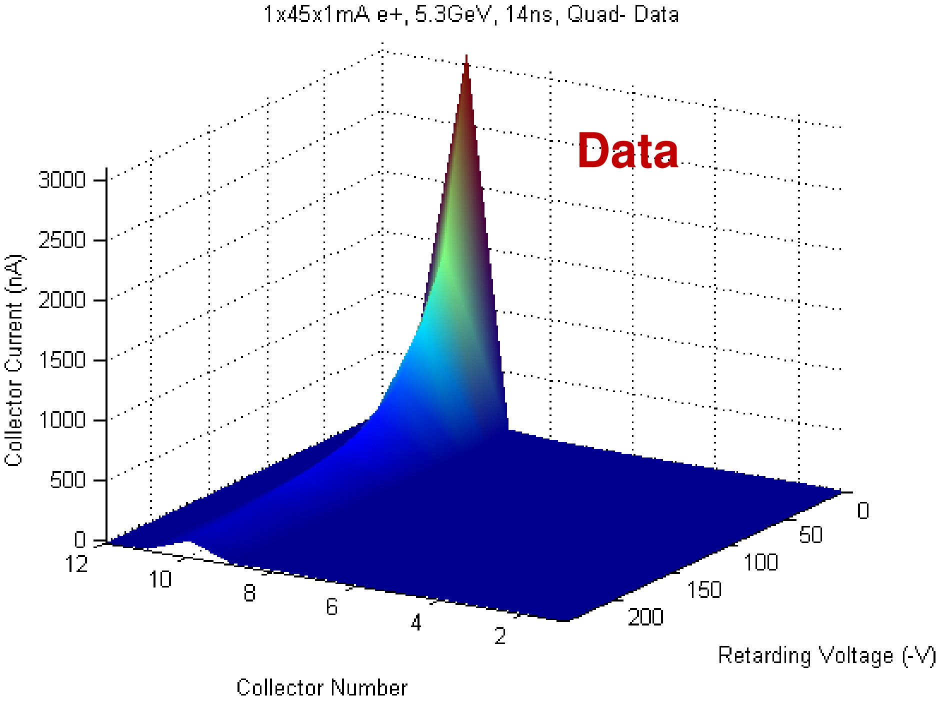




Quadrupole RFA (Preliminary)

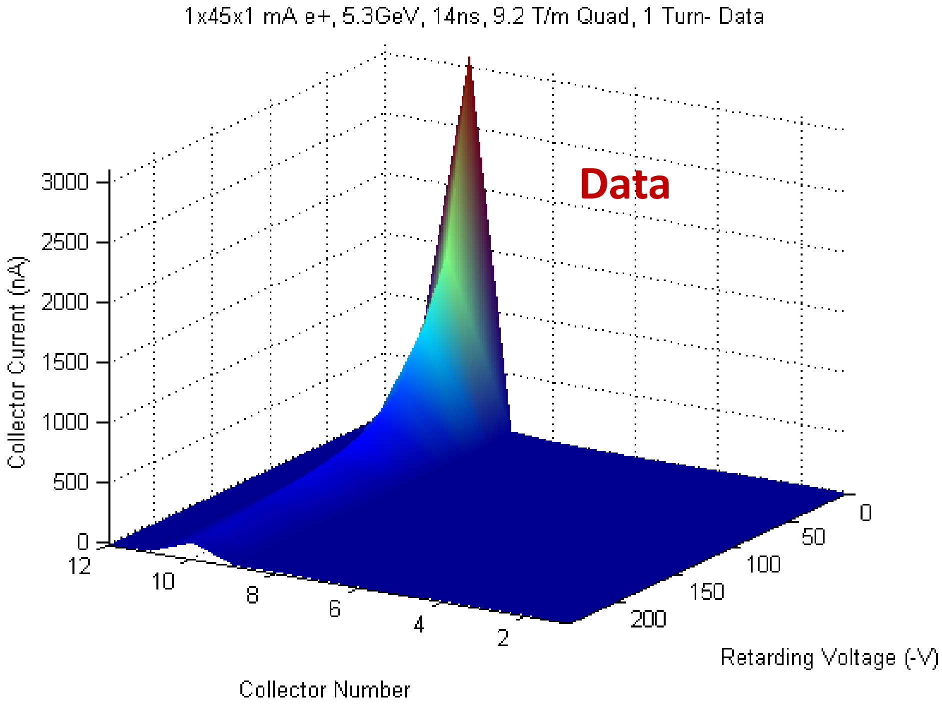
- 1x45x1 mA e+, 14ns, 5.3GeV, 9.2 T/m
- Data show a large signal at collector 10
  - This coincides with the center of the quad pole tip



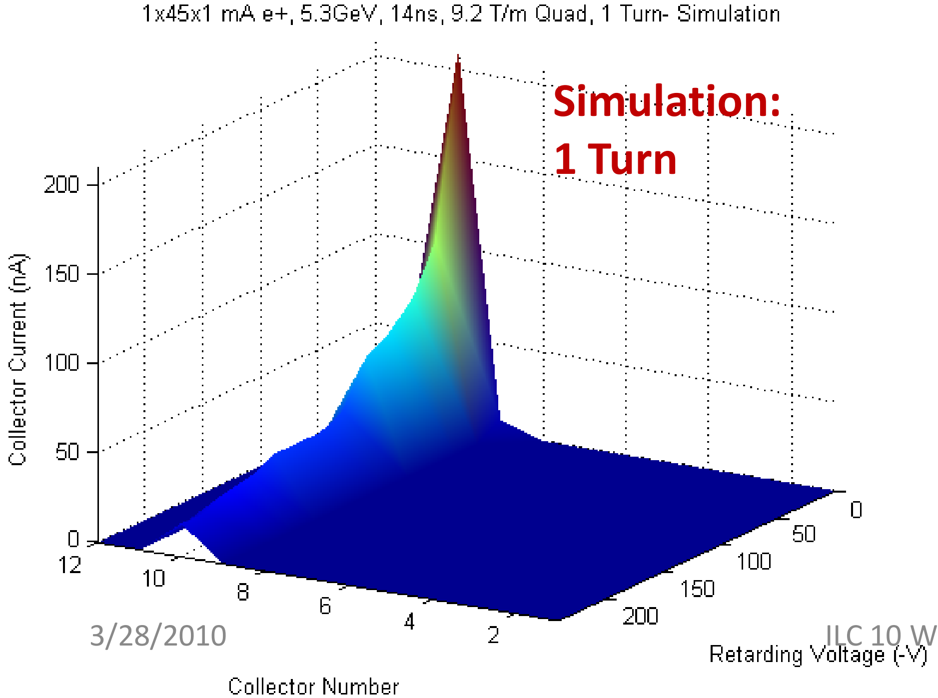


Quad RFA ECLOUD Simulation

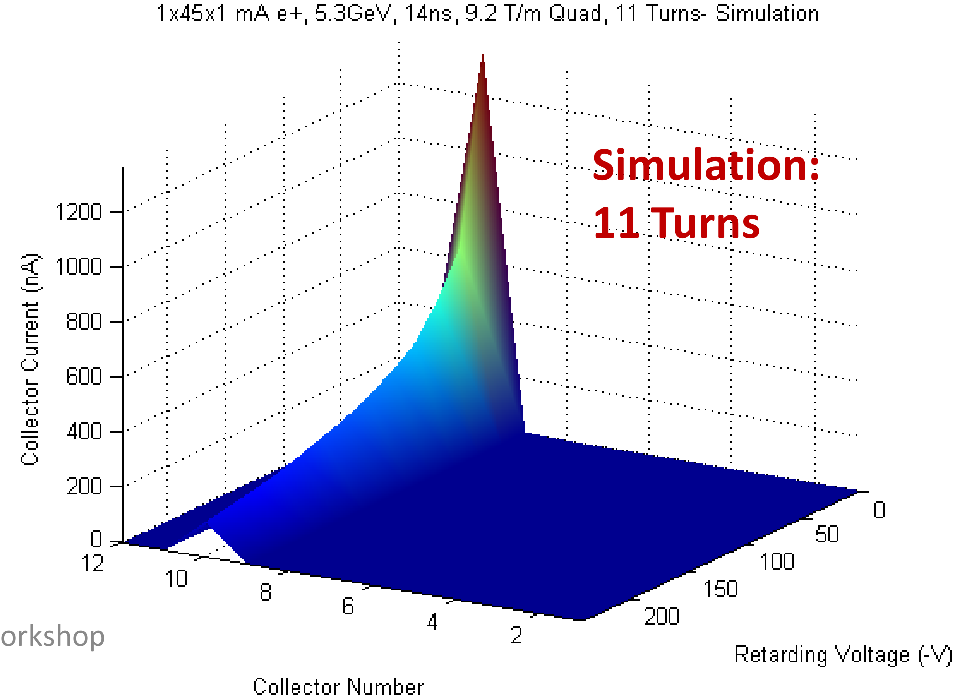
- Cloud appears to build up in the quadrupole over many turns
- 1 turn simulation underestimates data by more than an order of magnitude
- 11 turn simulation is quite close at high energy, within a factor of 2 at low energy


1x45x1 mA e+, 5.3GeV, 14ns, 9.2 T/m Quad, 1 Turn- Data

Data


1x45x1 mA e+, 5.3GeV, 14ns, 9.2 T/m Quad, 1 Turn- Simulation

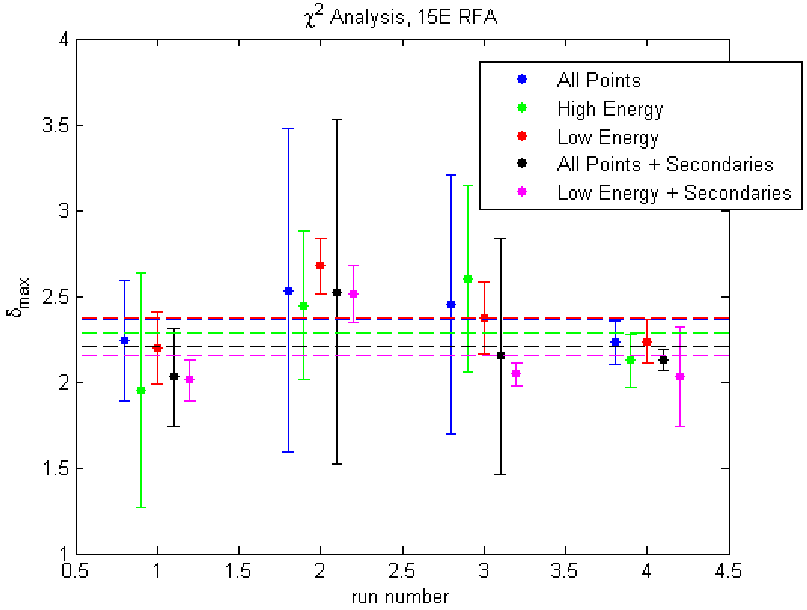
Simulation: 1 Turn


1x45x1 mA e+, 5.3GeV, 14ns, 9.2 T/m Quad, 11 Turns- Simulation

Simulation: 11 Turns

Next Steps

- Work on integrated RFA models
  - Check agreement in dipole field regions
  - Continue with study in wiggler field
- Develop χ^2 analysis to extract cloud model parameters for different vacuum chamber surfaces and treatments
  - Compare cloud model parameters for Al chambers with model parameters extracted from ringwide tune shift analysis.
  - Characterize the mitigation techniques and surface conditioning in terms of effective cloud model parameters.
- Other concerns
  - Agreement with TE wave data?
  - Understanding quadrupole data



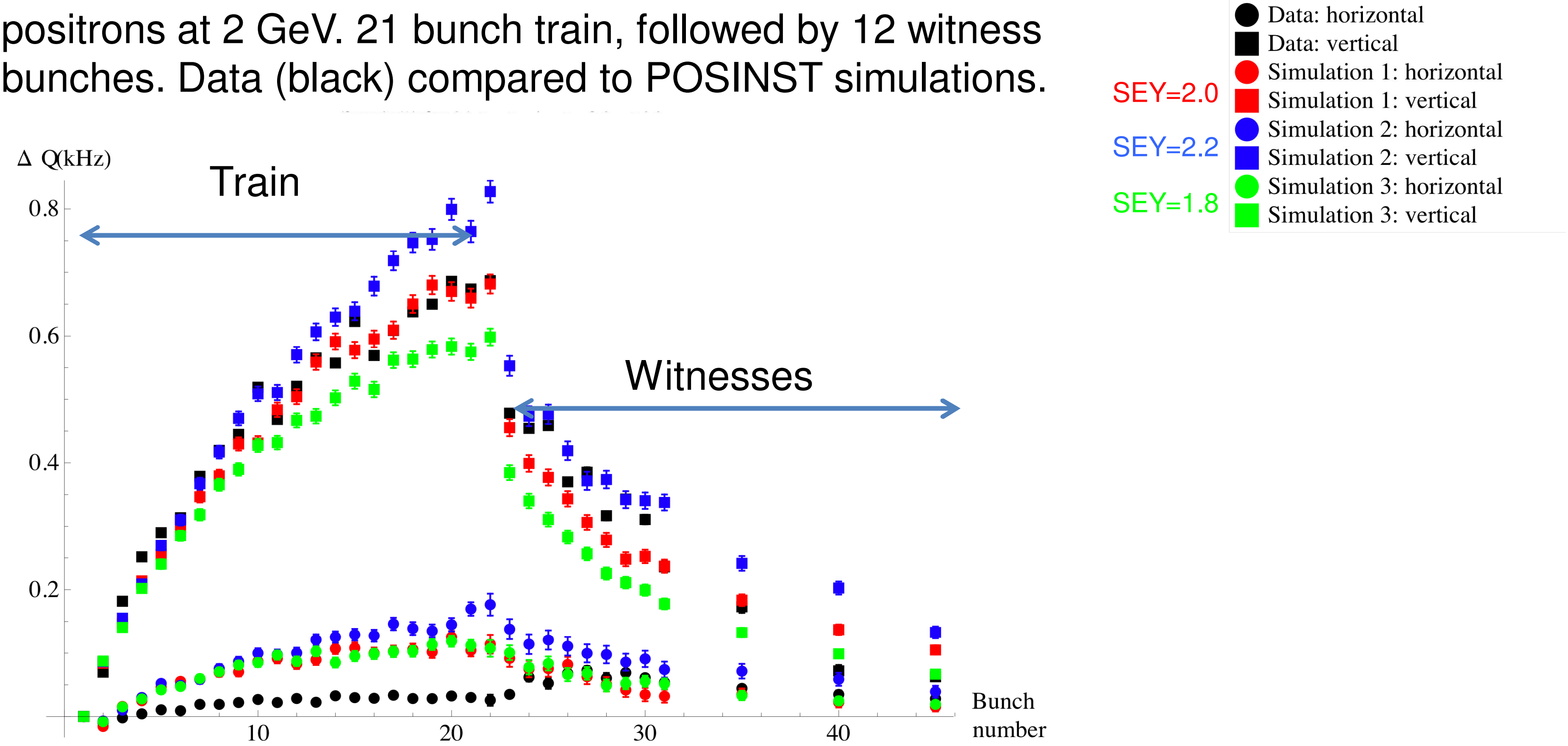
Fitting of 4 runs of 15E drift RFA data (Al chamber) to determine peak SEY parameter.
Runs include 14 and 48 ns spaced e^+ at 2,4 and 5 GeV, 10 and 45 bunch trains.

Coherent tune shifts

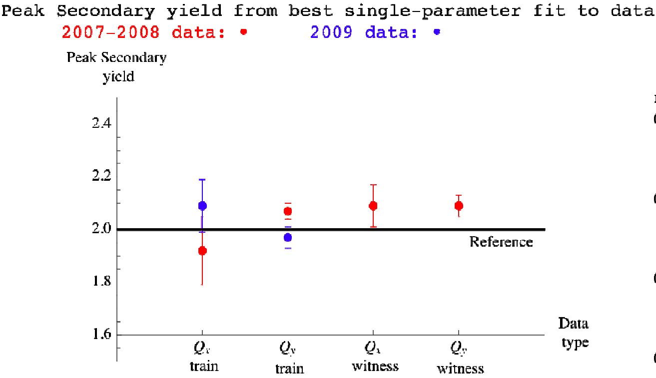
- At CESR-TA, we have made measurements of bunch-by-bunch coherent tune shifts along bunch trains, over a wide range of beam energies, emittances, bunch currents, bunch spacings, and train lengths, for both positrons and electrons.
- These measurements have been done by exciting coherent oscillations 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.
- We have compared the tune measurements with predictions from two electron cloud (EC) simulation programs: POSINST and ECLOUD. We include drifts and dipoles only, so far.
- A range of data were compared with simulations to determine 6 EC model parameters: peak SEY, photon reflectivity, quantum efficiency, rediffused yield, elastic yield, peak secondary energy.

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

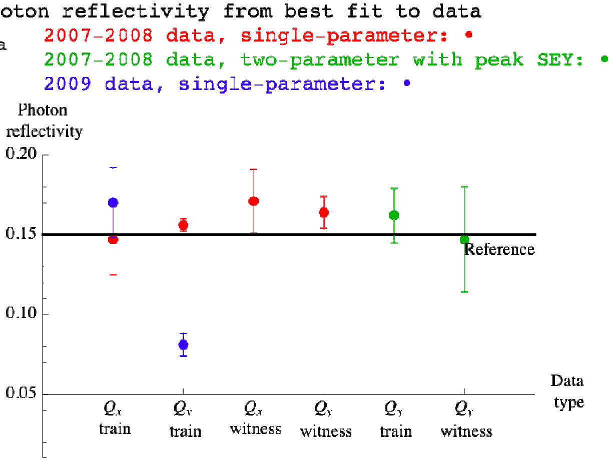
Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 0.5 mA/bunch positrons at 2 GeV. 21 bunch train, followed by 12 witness bunches. Data (black) compared to POSINST simulations.



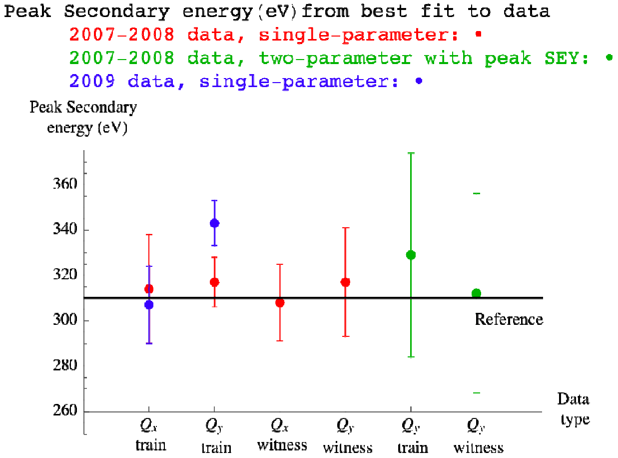
Results of simulation comparisons: 14 ns spacing, coherent train motion



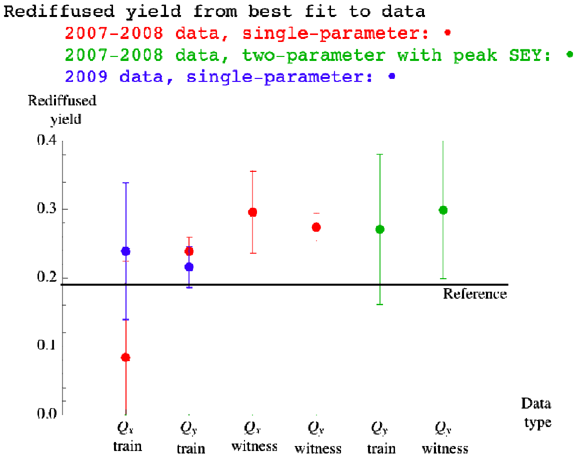
Peak Secondary yield from best single-parameter fit to data
2007-2008 data: • 2009 data: •



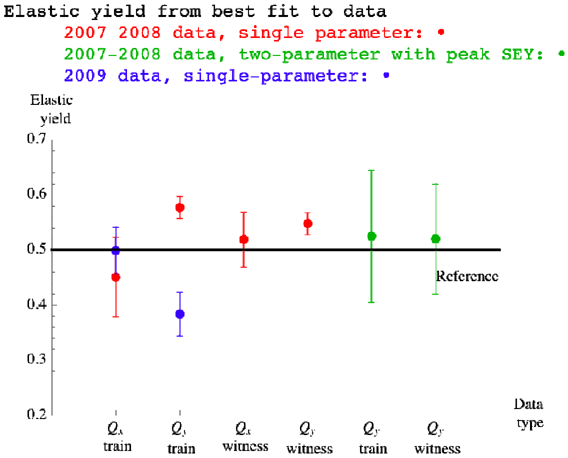
Photon reflectivity from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



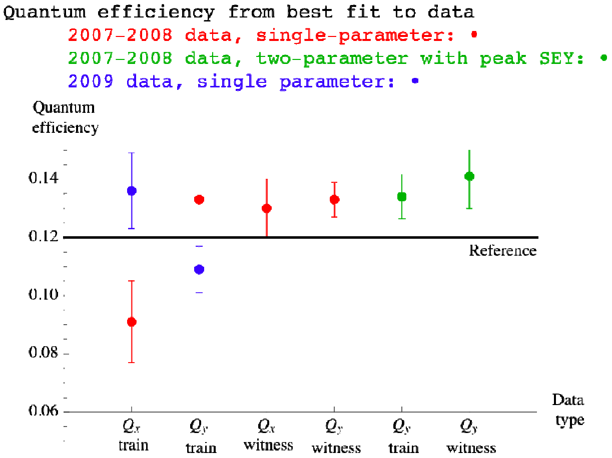
Peak Secondary energy (eV) from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



Rediffused yield from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •



Elastic yield from best fit to data
2007 2008 data, single parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single-parameter: •

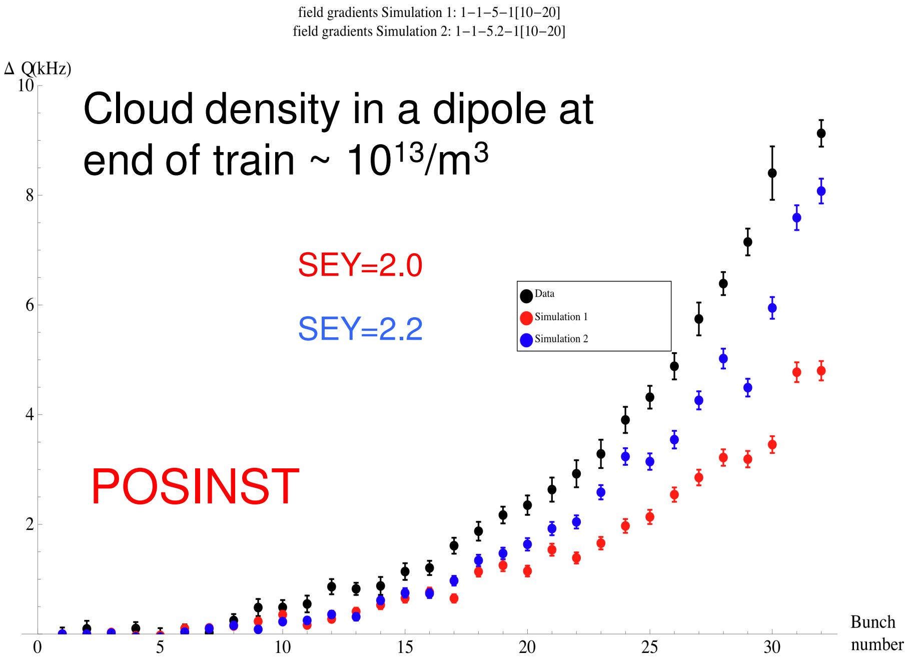


Quantum efficiency from best fit to data
2007-2008 data, single-parameter: •
2007-2008 data, two-parameter with peak SEY: •
2009 data, single parameter: •

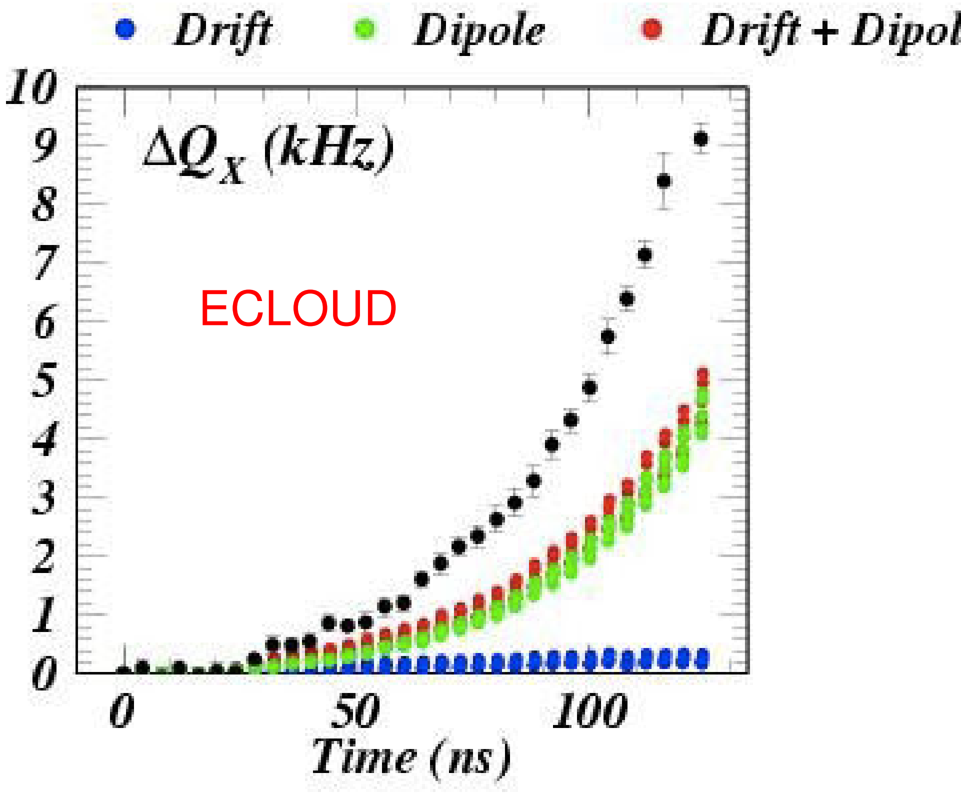
The ability to obtain a set of EC model parameters which works for a wide range of conditions validates the fundamental elements of the cloud model.

June 2009 data: 4 ns spacing, incoherent train motion

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.



Cloud density in a dipole at end of train ~ $10^{13}/m^3$

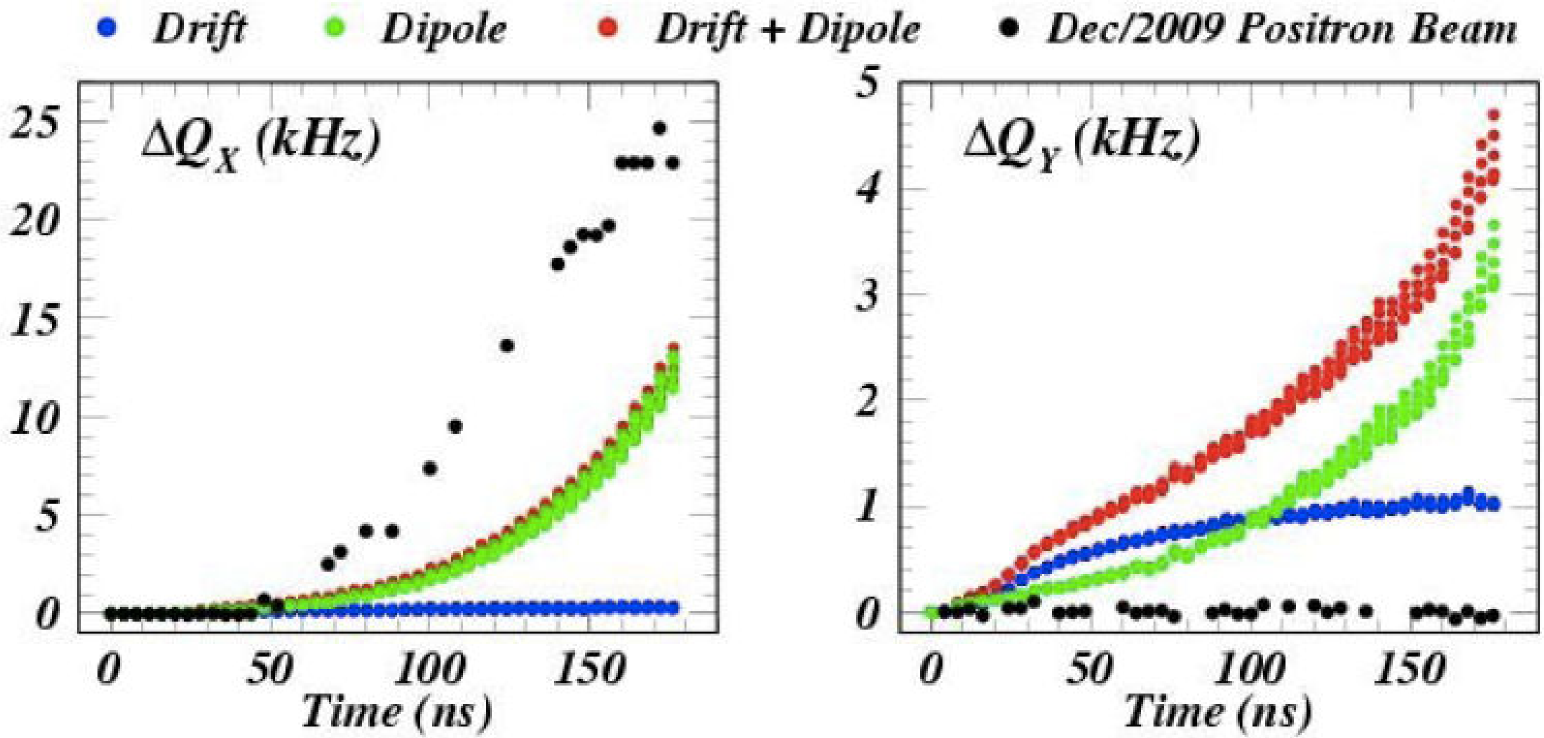


Plot of coherent tune shifts in kHz (1 kHz ~ 0.0025), vs. bunch number, observed in a train of 32 bunches at 2.1 GeV, 0.8 mA/bunch, with 4 ns spacing. Data (black) compared to POSINST simulations (left) and ECLOUD (right). Simulated tune from field gradients at start of the bunch.

ECLOUD Simulations for Measurements of 19 December 2009

CTA_2085MEV_20090516, 4-ns spacing, 45 mA total current

Compare to 45-bunch, 4-ns spacing, 0.75 mA/bunch measurements of December 2009



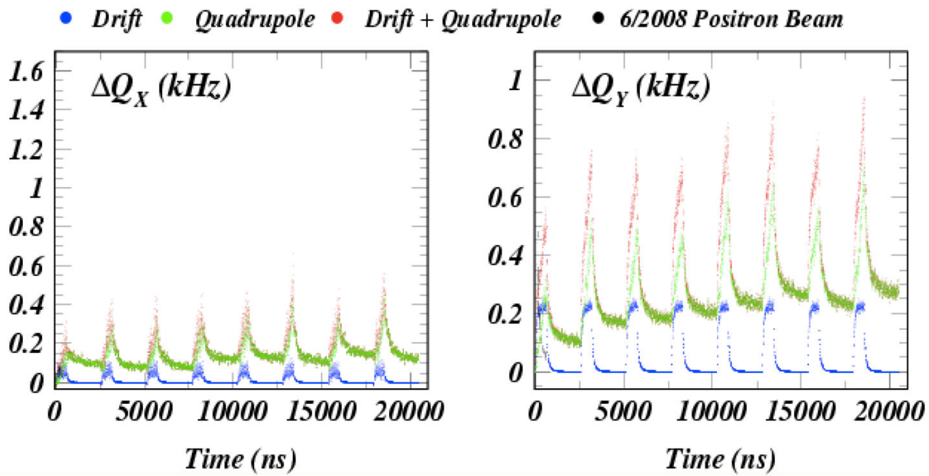
New record for horizontal tune shift: 25 kHz !

ECLOUD factor two underestimate for ΔQ_x similar to that observed for the June 2009 measurements for both ECLOUD and POSINST.

Apparently no vertical excitation of the beam, so no vertical tune measurement.

Future work on coherent tune shifts

- Complete systematic comparisons with EC model for 4 ns data with incoherent train motion.
- Take more data at 4 ns, 8 ns, 12 ns spacings. 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.
- Compare with results from local measurements (RFA, TE-wave) in the same vacuum chamber environment.
- Include tune shifts from quadrupoles, and wigglers (3D simulation needed for this).



Quadrupole tune shifts from ECLOUD 5.3 GeV 0.75 mA/bunch, 45 bunch train

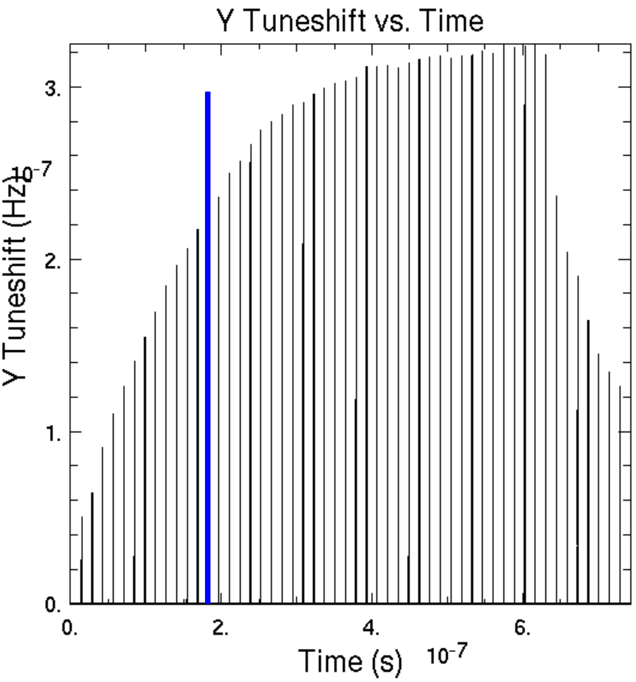
Quadrupole tune shifts build up from turn to turn

3D wiggler simulations

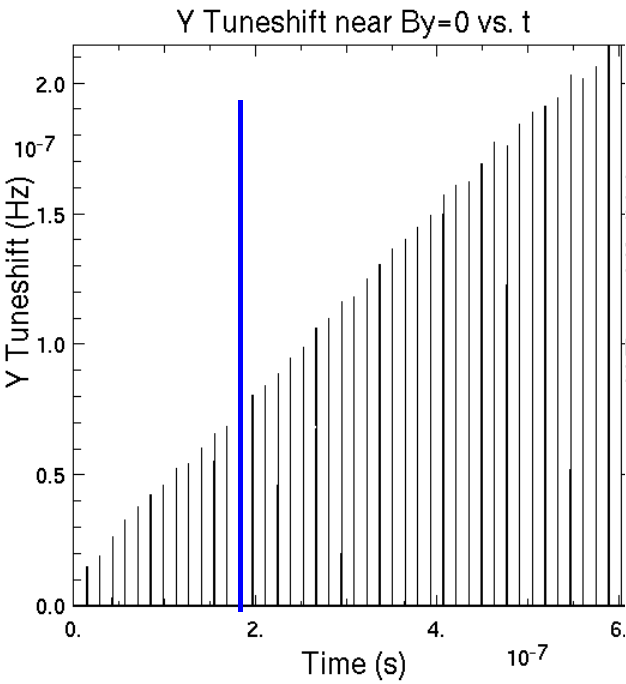
- Christine Celata (LBNL, ret., and Cornell) has shown, using WARP/POSINST, that electrons orbits in the B_y=0 regions are consistent with predictions based on grad B drifts for electrons near the beam axis in these regions. Lanfa Wang, using CLOUDLAND, has also seen electrons in these regions of the wiggler.
- The cloud in these regions has a relatively 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.
- Estimates have been made of tune shifts due to wigglers, both in the peak B_y and in the B_y null regions.

Phase shift/cm near B_y=0, near peak B_y, an
for entire wiggler period

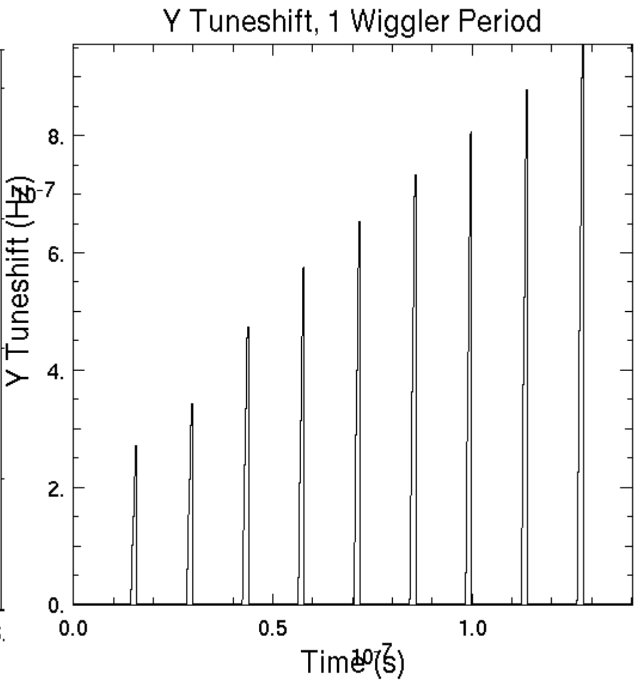
6 cm peak B_y



6 cm near B_y=0



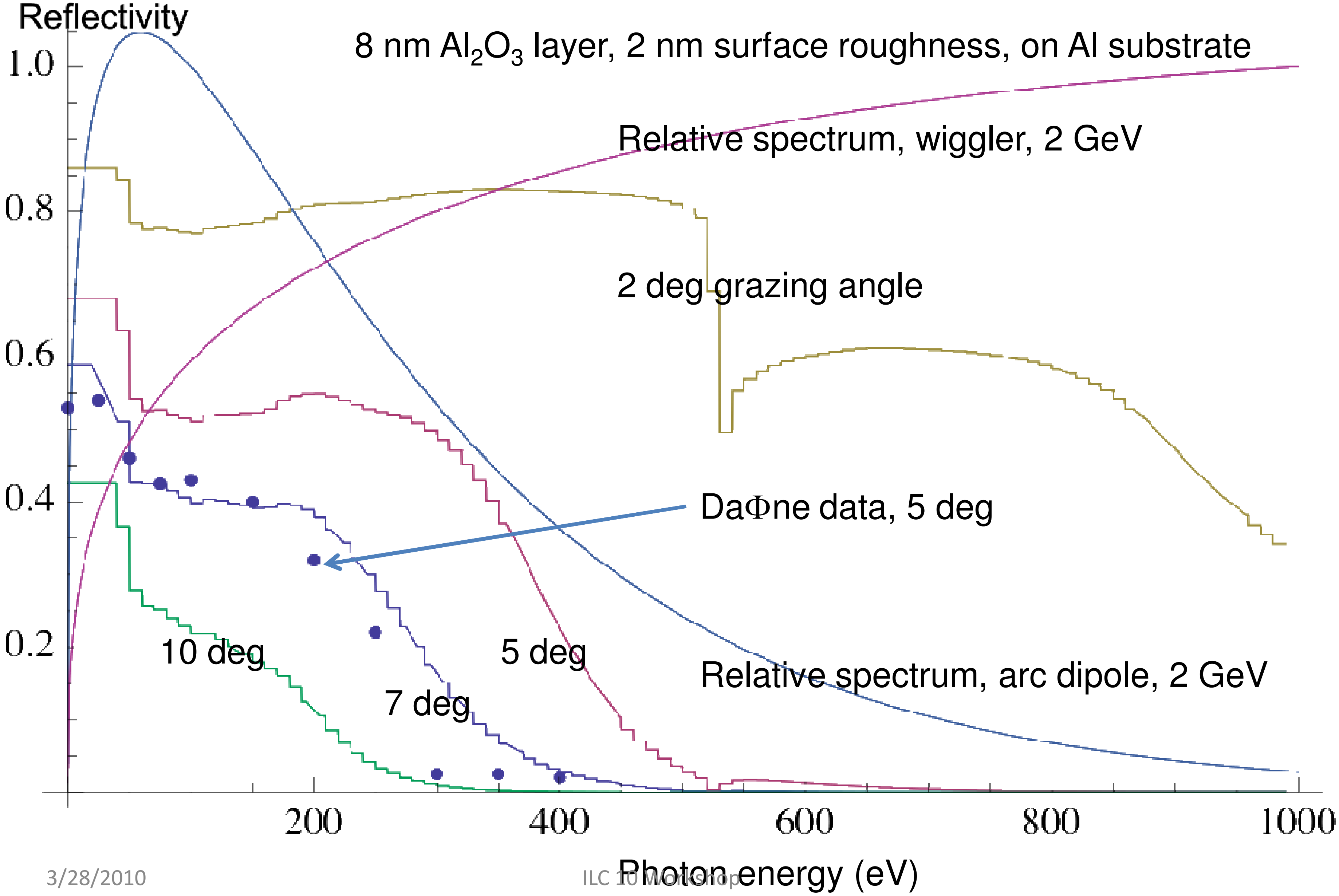
Whole Period



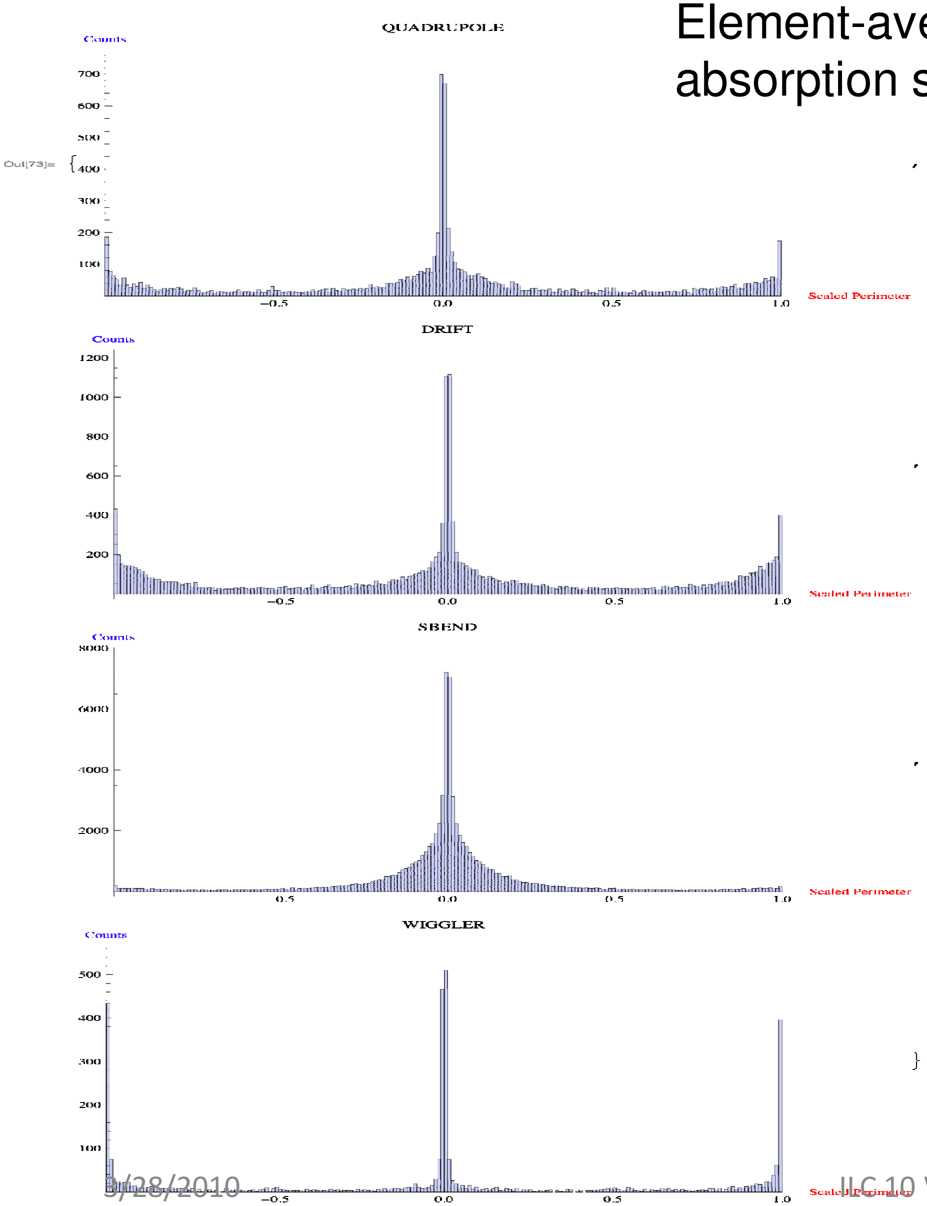
Synchrotron radiation simulations

- We are developing a simulation program (SYNRAD3D) which computes the direct and reflected synchrotron radiation distributions around the CESR-TA ring.
- We have parameterized X-ray scattering data from an LBNL online database.
- The simulations give the azimuthal distributions of photon absorbtion sites around the ring, and can be used as guidance for the photoelectron seeds for electron cloud simulations.
- Results shown in the following slides assume an elliptical chamber throughout the ring.
- We have not yet incorporated these results into our RFA or tune shift calculations, but I will show some comparisons between what we are currently using, and the SYNRAD3D results.

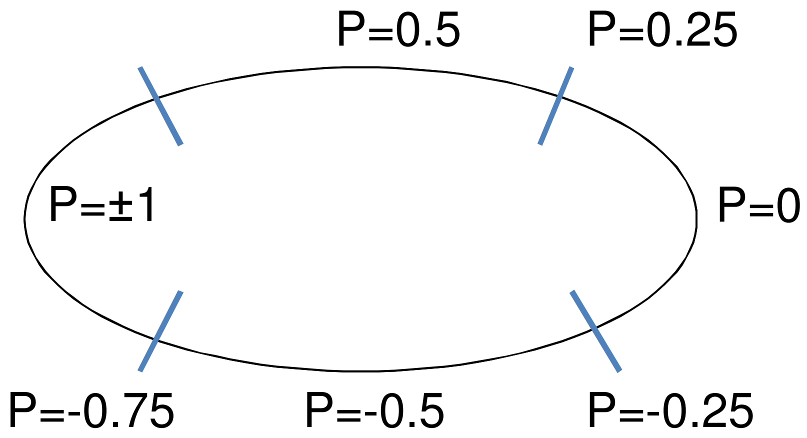
X-ray reflectivity: B.L. Henke, E.M. Gullikson, and J.C. Davis. X-ray interactions: photoabsorption, scattering, transmission, and reflection at E=50-30000 eV, Z=1-92, Atomic Data and Nuclear Data Tables Vol. 54 (no.2), 181-342 (July 1993).



Azimuthal location of photon absorption sites



Element-averaged azimuthal distribution of photon absorption sites


P=0.5

P=0.25

P=±1

P=0

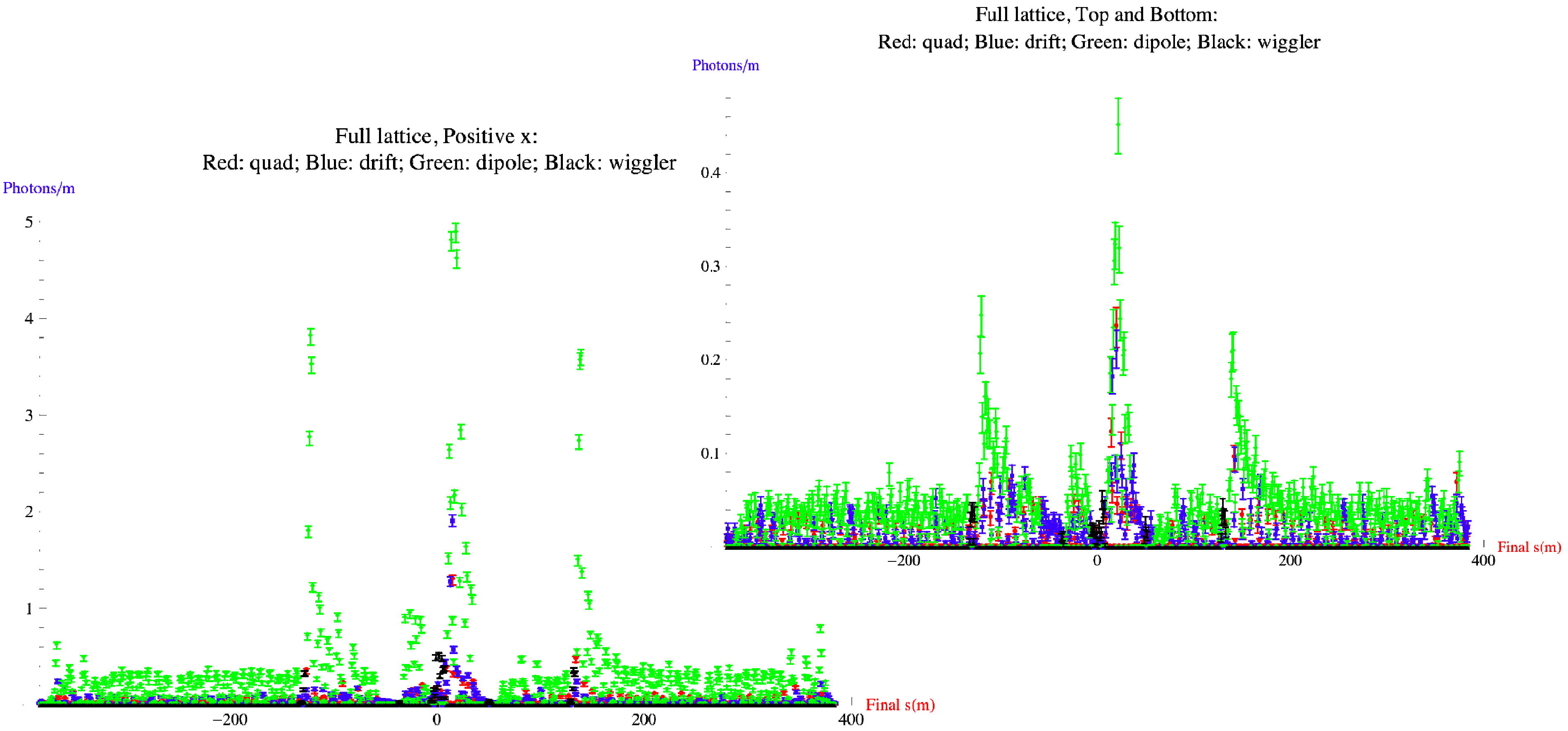
P=-0.75

P=-0.5

P=-0.25

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

Photon rates vs. s, color-coded by magnet type

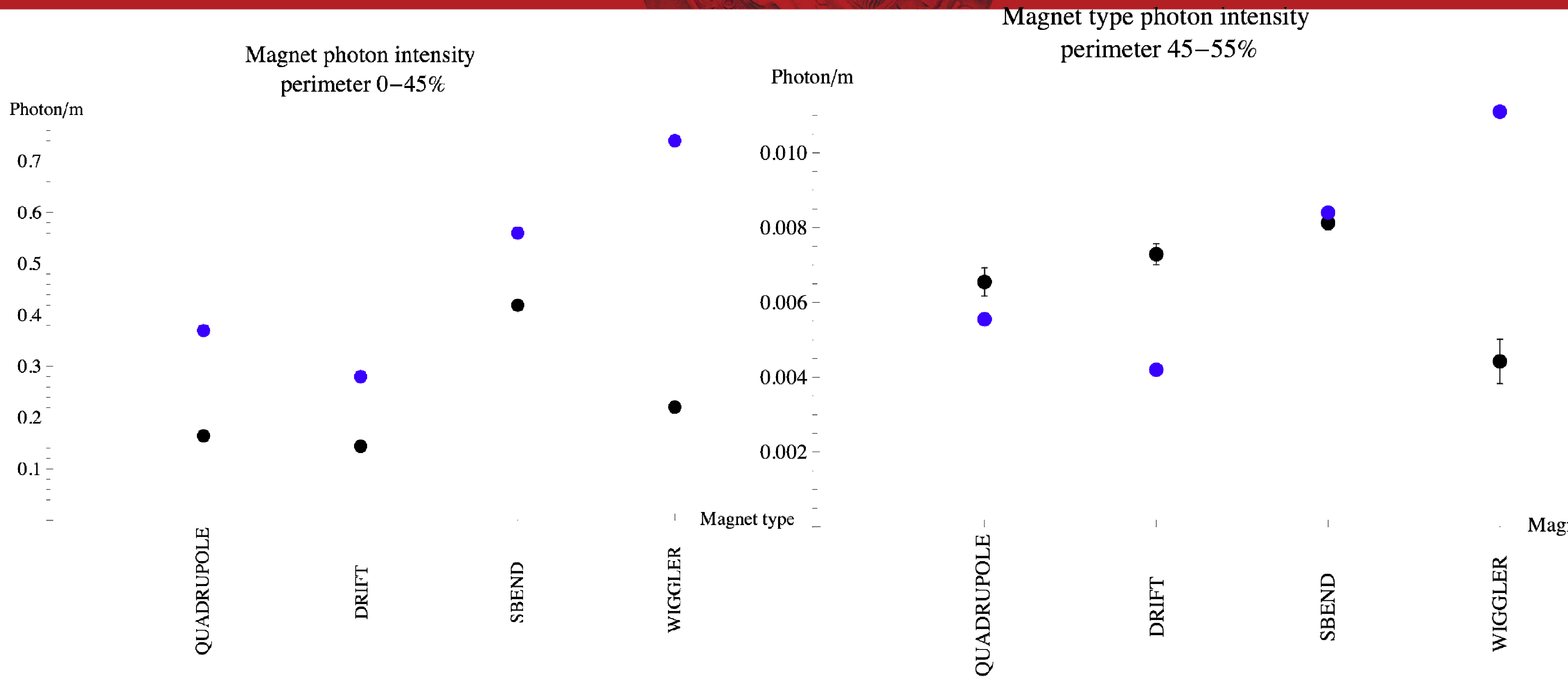


Full lattice, Top and Bottom:
Red: quad; Blue: drift; Green: dipole; Black: wiggler

Full lattice, Positive x:
Red: quad; Blue: drift; Green: dipole; Black: wiggler

- For positive x (|P|<0.45): Highest rates in dipoles downstream from wigglers
- For top/bottom (0.45<|P|<0.55): again, highest rates in dipoles downstream from wigglers. Otherwise more or less constant rates throughout lattice.

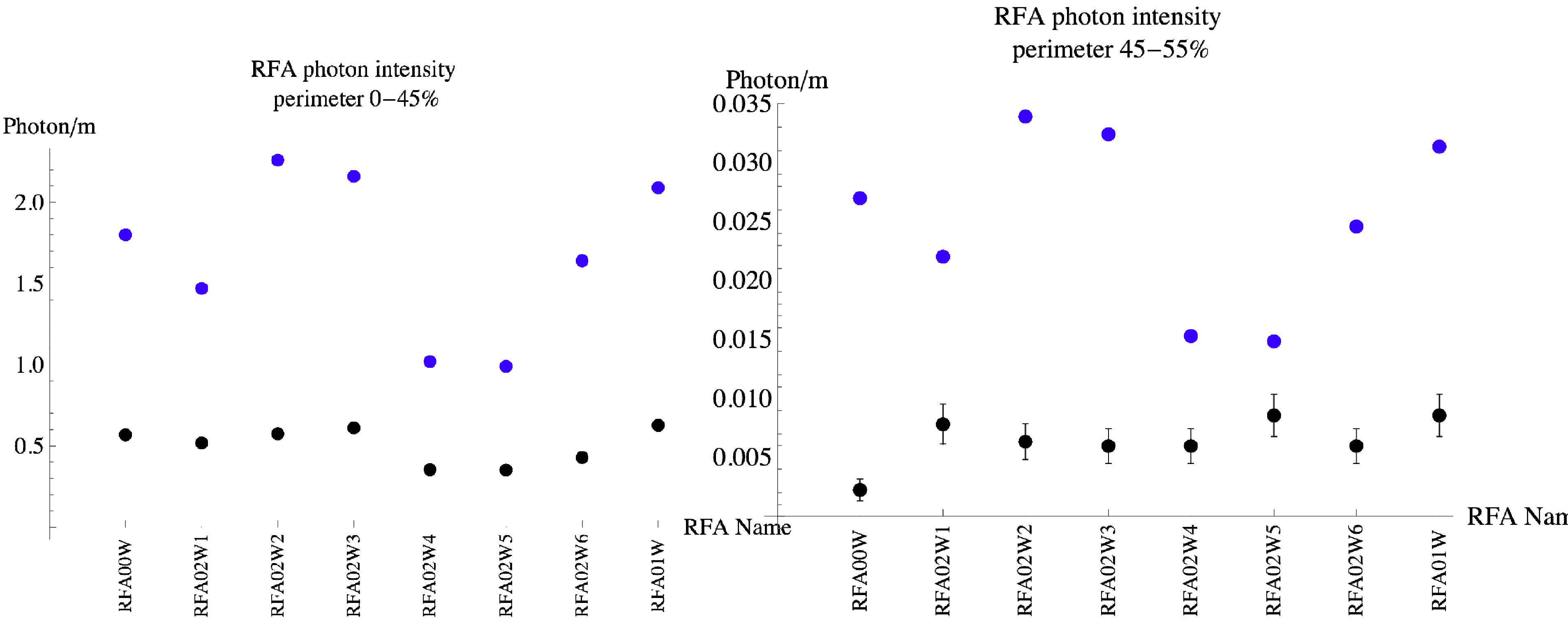
Element-averaged photon rates


Magnet photon intensity perimeter 0–45%

Magnet type photon intensity perimeter 45–55%

- •Black: Synrad3d. Blue: synrad (for 45-55% perimeter, assume 15% reflectivity)
- • At positive x, synrad3D results are systematically lower.
- •For top/bottom, synrad3D results are higher for drifts, very close for dipoles.

L0 region, photon rates by RFA


RFA photon intensity perimeter 0–45%

RFA photon intensity perimeter 45–55%

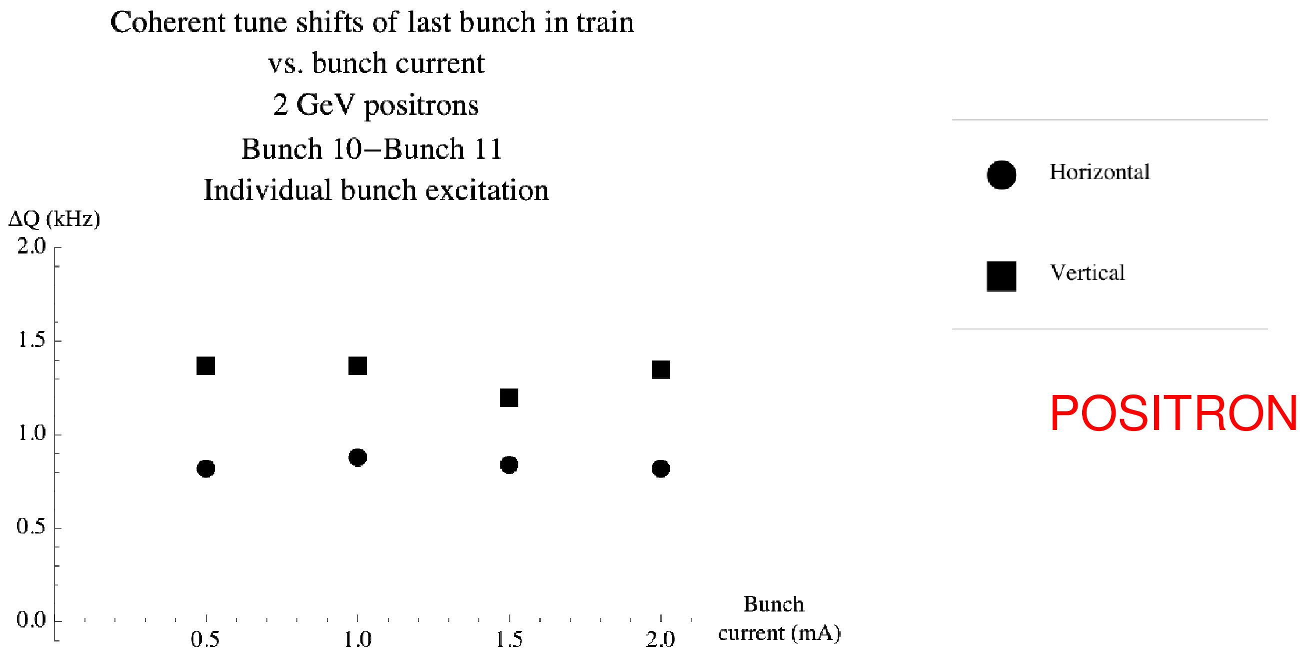
- Black: Synrad3d. Blue: synrad (for 45-55% perimeter, 15% reflectivity)
- At positive x, synrad3D results are systematically lower.
- For top/bottom, synrad3D results and are also systematically lower.
- We expect these results to change somewhat when we use the correct vacuum chamber profile in the L0 region.

Instabilities

- Multibunch instabilities at CesrTA:
  - Prediction from K. Ohmi (KEK) for uniform fill. T. Demma (INFN) is doing a simulation using for CesrTA with nonuniform fill. G. Dugan is working on an semi-analytical approach, coupled to the coherent tune shift work.
  - We have measurements of instability growth times and mode spectra made using Dimtel feedback system.
- Single bunch head-tail instability at CesrTA:
  - Prediction from K. Ohmi (KEK); predictions to be made using CMAD (M. Pivi, K. Sonnad) and semi-analytical approach by M. Venturini at LBNL
  - 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.
  - We have developed techniques for driving synchrobetatron sidebands of single bunches so we can measure m=0 and m=+/-1 mode tune shifts and damping rates. We need predictions for these tune shifts to compare with anticipated measurements.

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.

Incoherent emittance growth

- We expect incoherent emittance growth due to the nonlinear fields of the electron cloud.
- Qualitative prediction from K. Ohmi (KEK). Predictions to be made using CMAD (Pivi, Sonnad)
- 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.
- We need to make more careful and systematic measurements of emittance growth. Simulations will be very valuable in providing guidance for what to look for.

Other work (not a complete list)

- Develop an improved photoelectron model (quantum efficiency, photoelectron energy, angular spectra, effect of fluorescence) based on existing data, with measurements if needed.
- Simulate cloud densities sampled by TE wave measurements, and compute effect of nonuniform cloud distribution on TE wave phase shifts in the presence of magnetic field. Correlate with RFA measurements.
- Investigate the current dependence of leading-bunch tunes: relation to quadrupole and/or wiggler multi-turn effective long-range wakes.