Electron Cloud Simulation Studies for CesrTA

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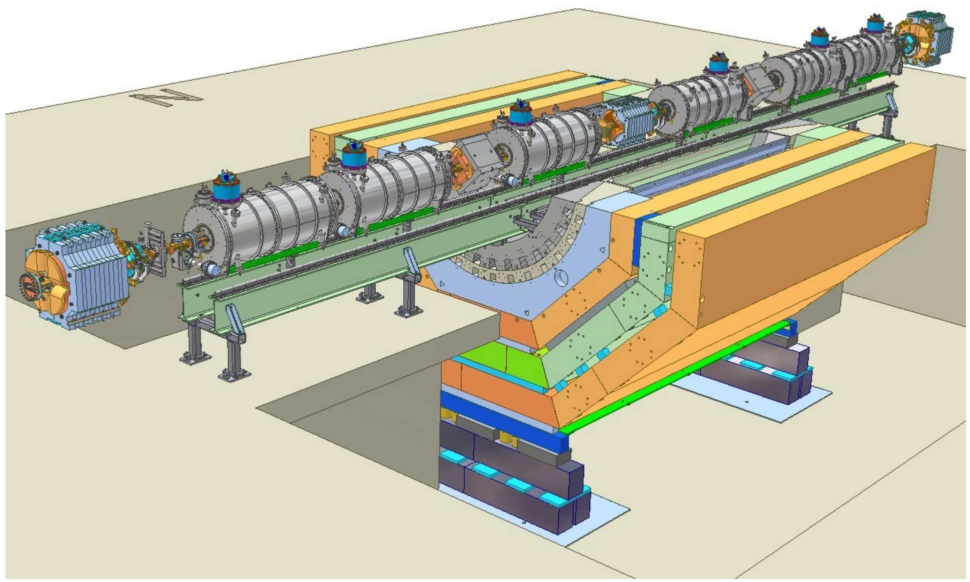


Goals of the CesrTA Program

I. Studies of Electron Cloud Growth and Mitigation

A. Study EC growth and methods to mitigate it, particularly in the wigglers and dipoles which are of greatest concern in the ILC DR design.

B. Use these studies to benchmark and expand existing simulation codes and to validate our projections for the ILC DR design.

II. Studies of EC-Induced Instability Thresholds and Emittance Dilution

A. Measure instability thresholds and emittance growth due to the EC in a low-emittance regime approaching that of the ILC DR.

B. Validate EC simulations in the low-emittance parameter regime.

C. Confirm the projected impact of the EC on ILC DR performance.

III. Low-Emittance Operations

A. Support EC studies with beam emittances approaching those specified for the ILC DR (CesrTA vertical emittance target: ε_v<20 pm-rad with ε_h=2.5 nm @ 2GeV).

B. Implement beam instrumentation needed to achieve and characterize ultra-low-emittance beams

- x-Ray Beam Size Monitor targeting bunch-by-bunch readout capability
- Beam Position Monitor upgrade

C. Develop tuning tools to achieve and maintain ultra-low-emittance operation

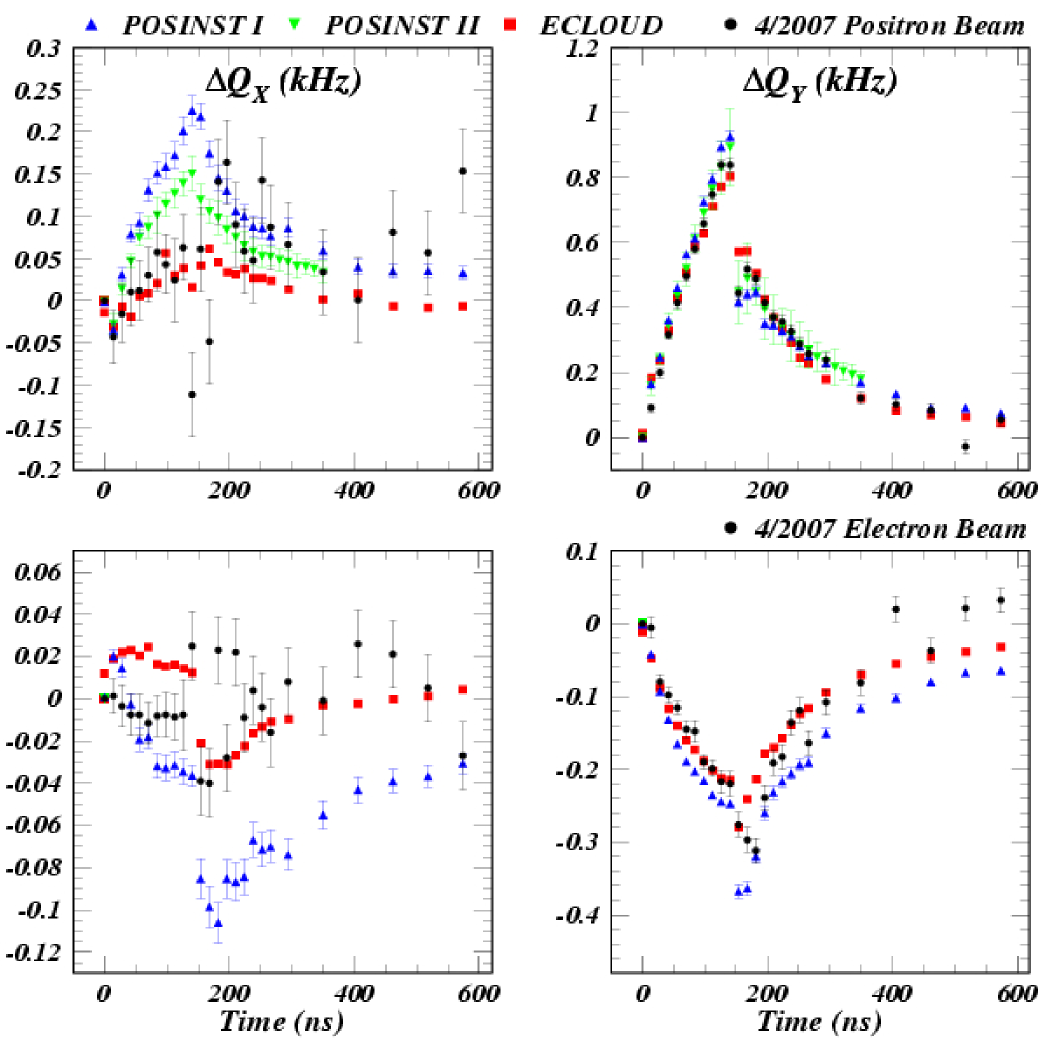
IV. Inputs for the ILC DR Technical Design

A. Support an experimental program to provide key results in 2010

B. Provide sufficient running time to commission hardware, carry out planned experiments, and explore surprises: about 240 running days over a 2+ year time period

Coherent Tune Shifts
Witness Bunch Studies

Studies of the Effects of Electron Cloud Formation on Beam Dynamics at CesrTA, J.A.Crittenden, et al., PAC2009
Electron Cloud Modelling Considerations at CesrTA, J.Calvey et al, PAC2009



Coherent kick to entire 10-bunch train followed by witness bunches at varying intervals

Pinch effects important
Need 3D beam-averaged space charge fields for cloud development with offset beams

Much progress made in understanding and reconciling the ECLOUD and POSINST modelling

Compared ring-averaged (drift and dipole regions) space charge field effect on linear optics for POSINST with two differing spacecharge calculation methods and ECLOUD

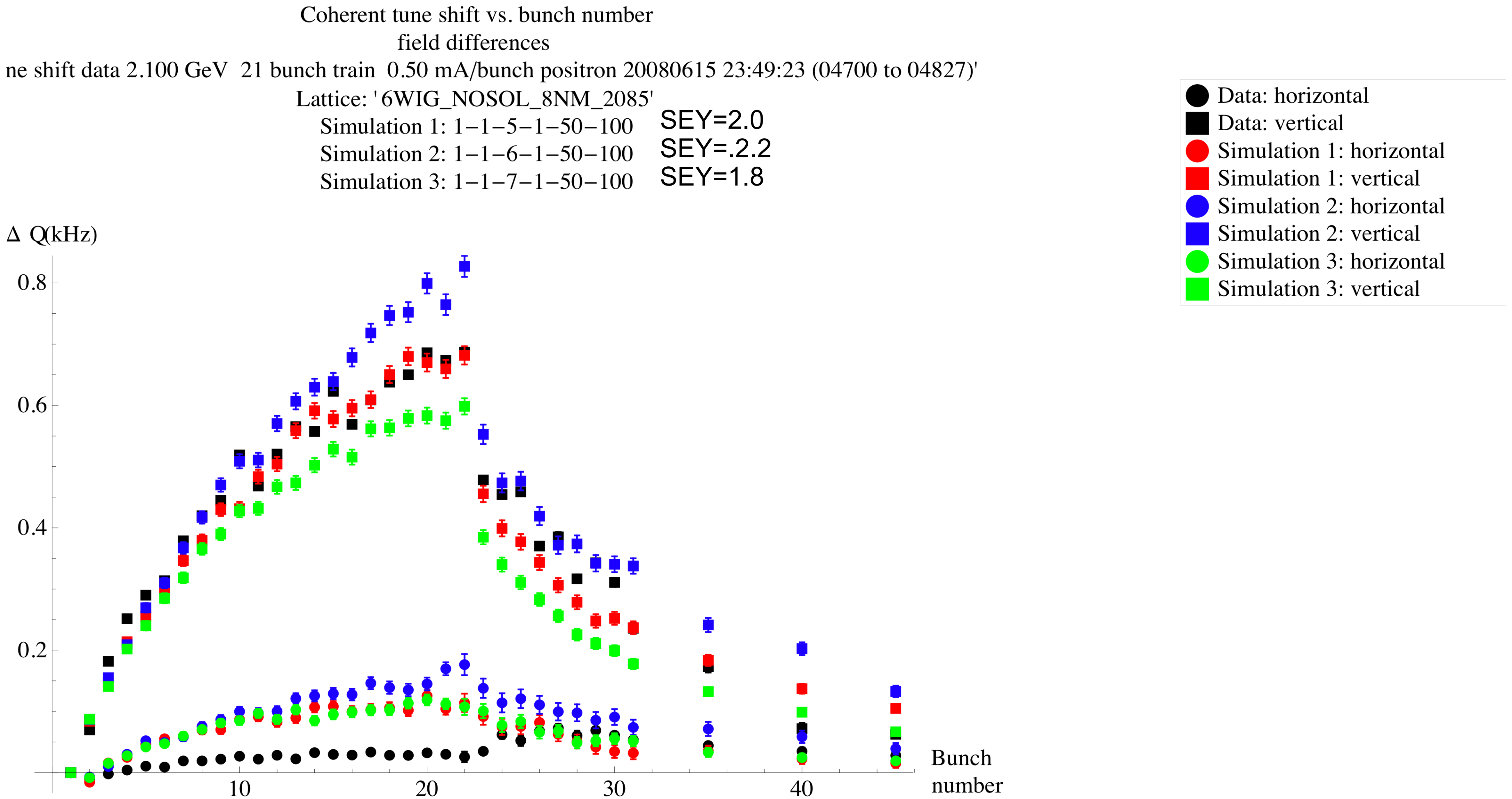
Wide variety of measurements in hand

37 data sets containing tune shifts measurements with a broad range of conditions were taken in April, 2007 and June-July, 2008, and are now under analysis

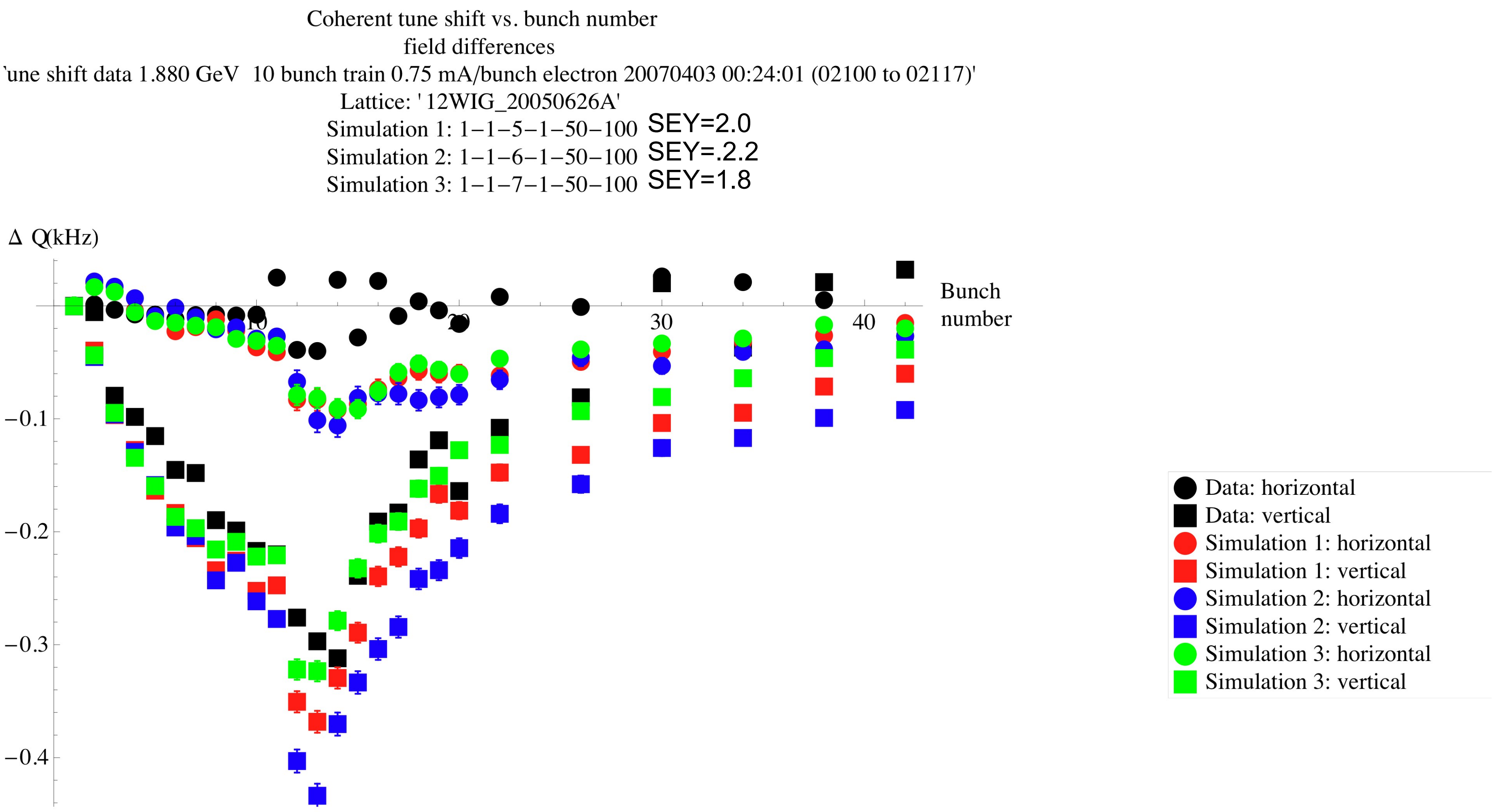
Energy (Gev)	Species	Bunch currents	Train length	Witness length	Data sets
1.9, 2.1	Positrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	3, 10, 11, 19, 20, 21	5-15	23
1.9, 2.1	Electrons	0.25 ,0.5, 0.75, 1.0, 1.25, 3.0	10, 11, 19, 20, 21	5-15	10
5.3	Positrons	0.75, 1.5, 5.0	3, 10	5-10	3
5.3	Electrons	1.5	10	10	1

Much more data recorded in 2009, including 45-bunch trains. Future plans include use of lattices of various emittances and beam energies, as well as 10-bunch trains with currents up to 8 mA/bunch.

Sensitivity to SEY Model Parameters – Parameter Scans with POSINST --

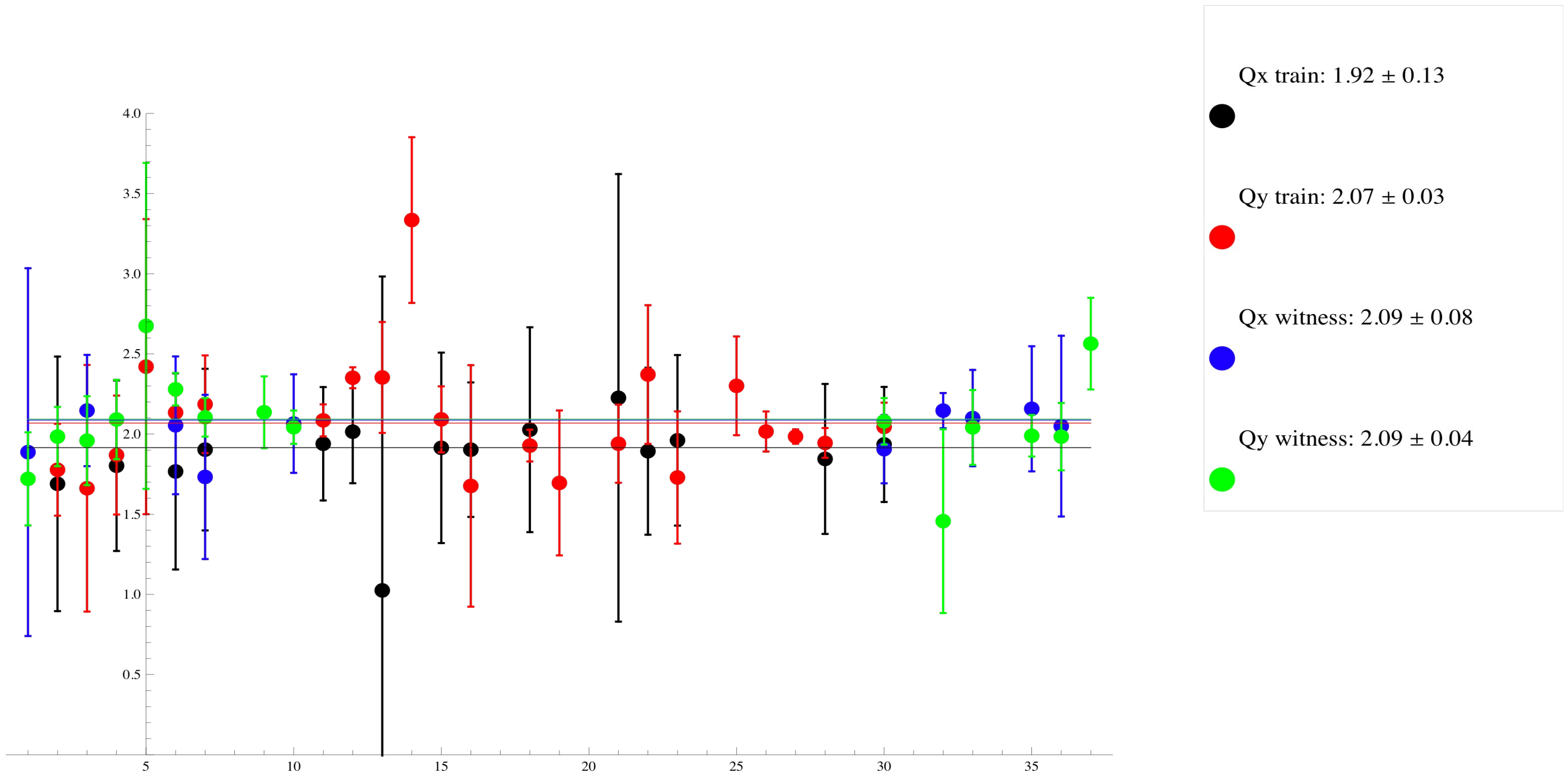


Sensitivity to model parameters varies with cloud dynamics



Results of simulation comparisons for 37 data sets
Example: peak SEY scan

Best fit parameter value vs Run index (1-37)



Errors estimated from normalized chi-squared 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
Asymptotic Rediffused SEY	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

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

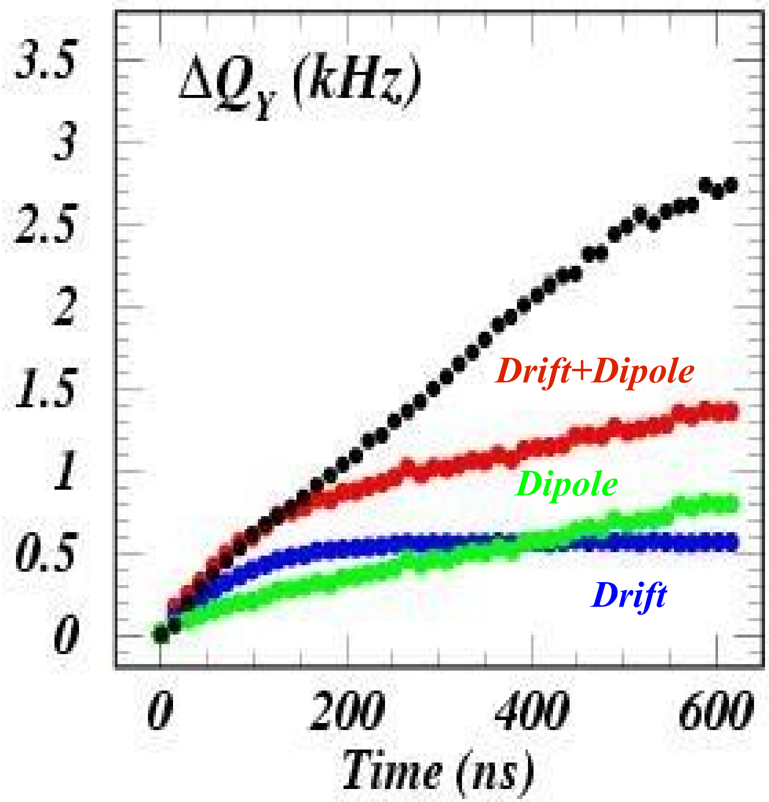
Rediffused SEY component found to be important for 45-bunch trains

The PAC2009 results showed ECLOUD underestimated the vertical tune shift for long bunch trains.

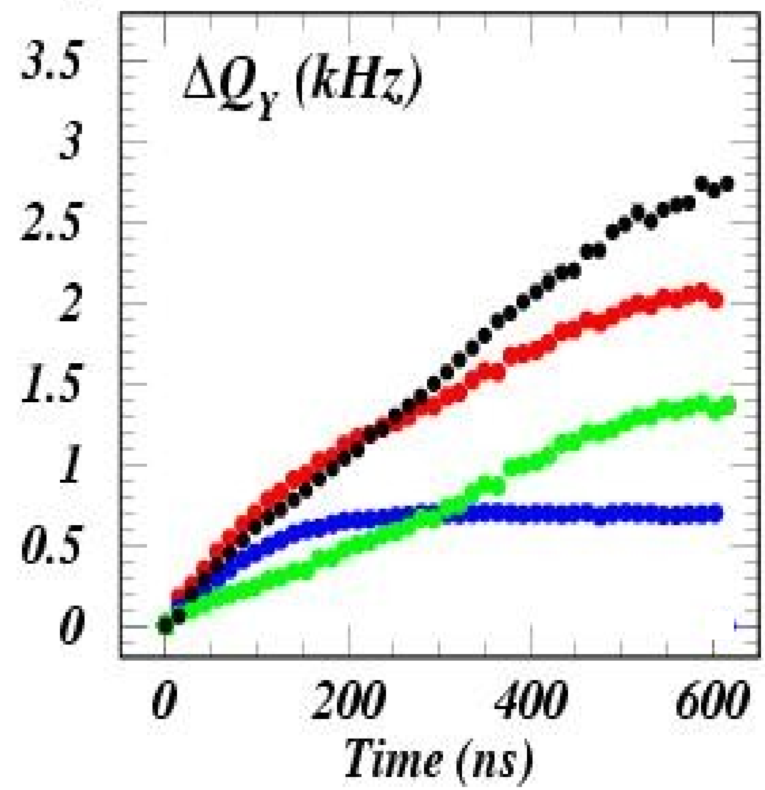
The comparison to measurement has been improved by introducing the rediffused SEY component.

14-ns spacing 0.75 mA/bunch

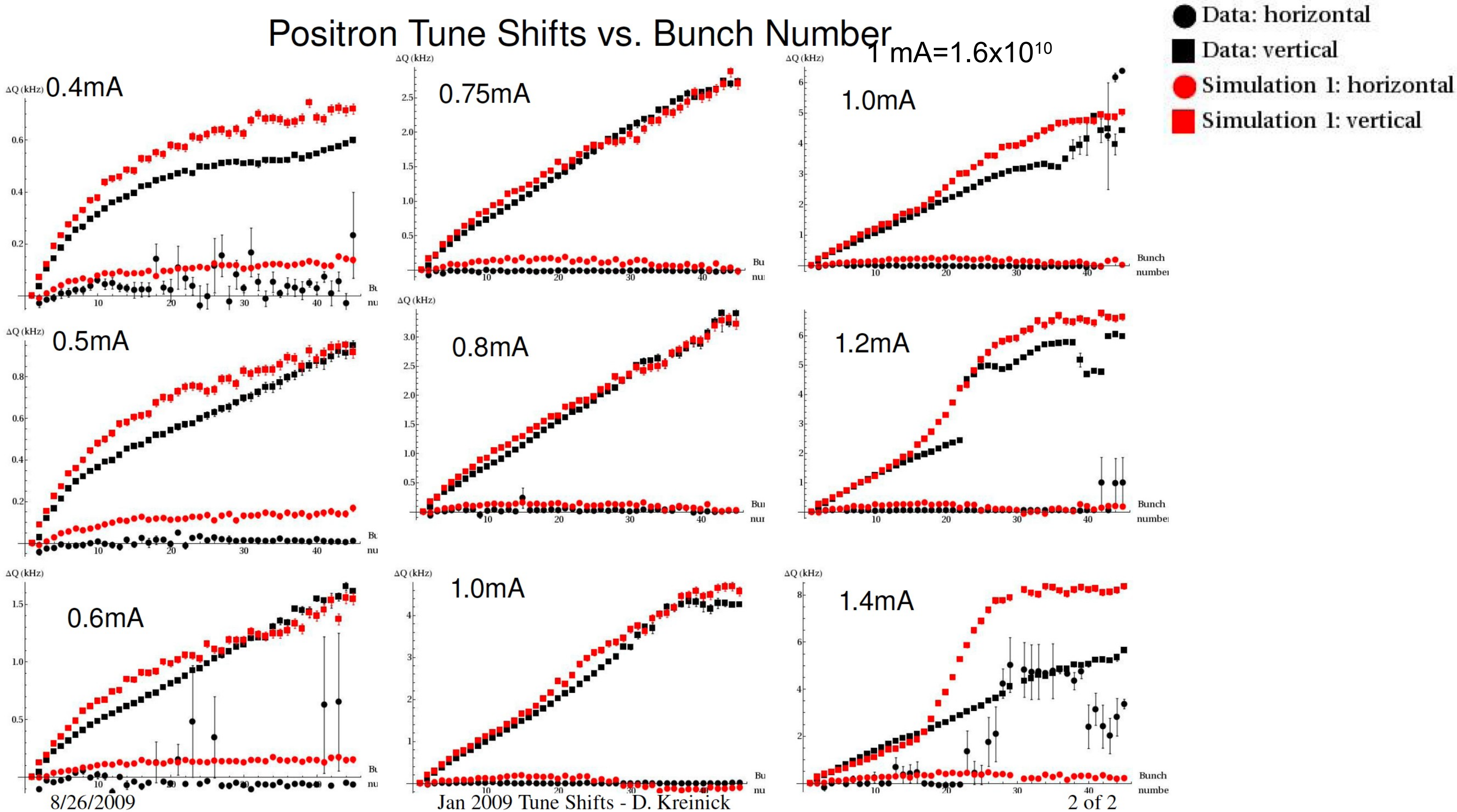
$P_{rediffused} = 0$



$P_{rediffused} = 0.2$

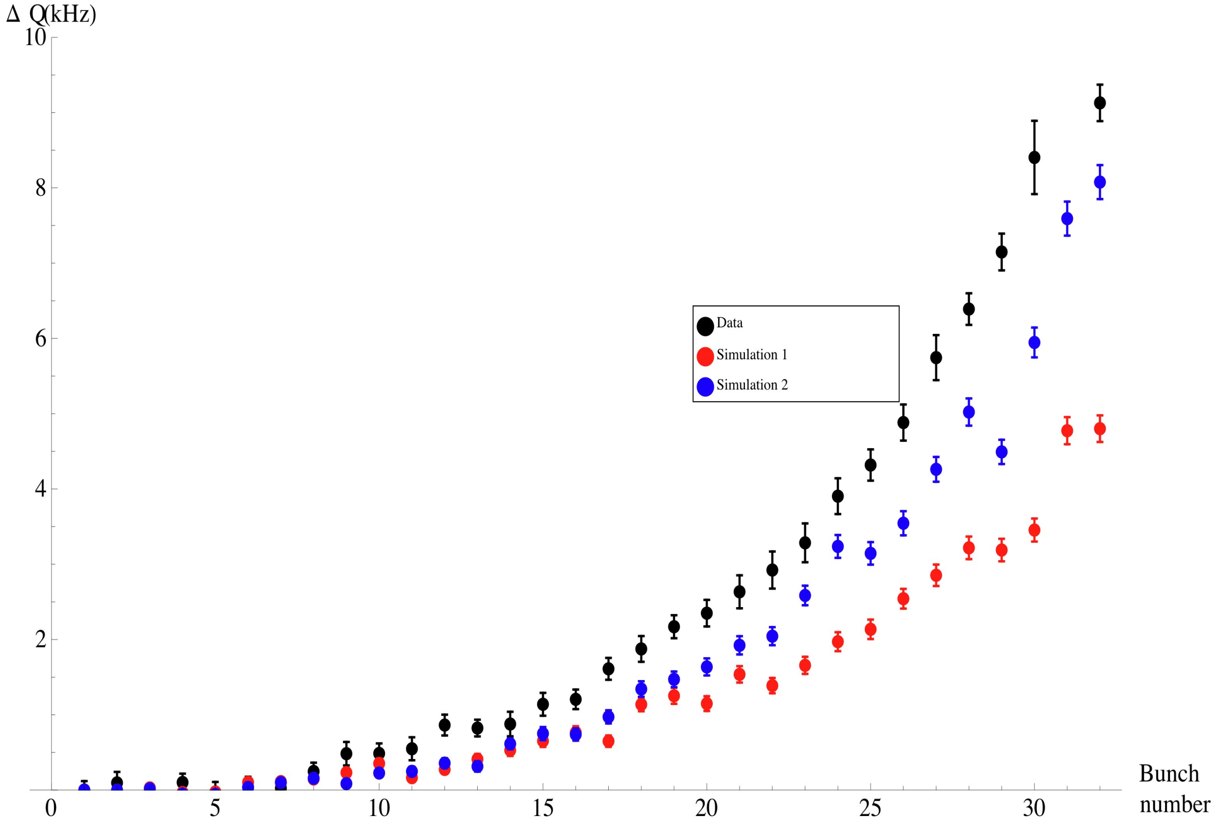


POSINST simulations with nominal parameters
45 bunch trains, 14 ns spacing, Feb 2009



Tune shift data with 4 ns bunch spacing

We have also simulated tune data taken in June 2009 with 4 ns bunch spacing.
This data is taken using our Dimtel 4 ns feedback system, which measures the coherent tunes of bunches without inducing coherent motion of the train
In such a case, the modelled tune shifts can be derived from the space-charge field gradient on axis with no need to offset the beam.



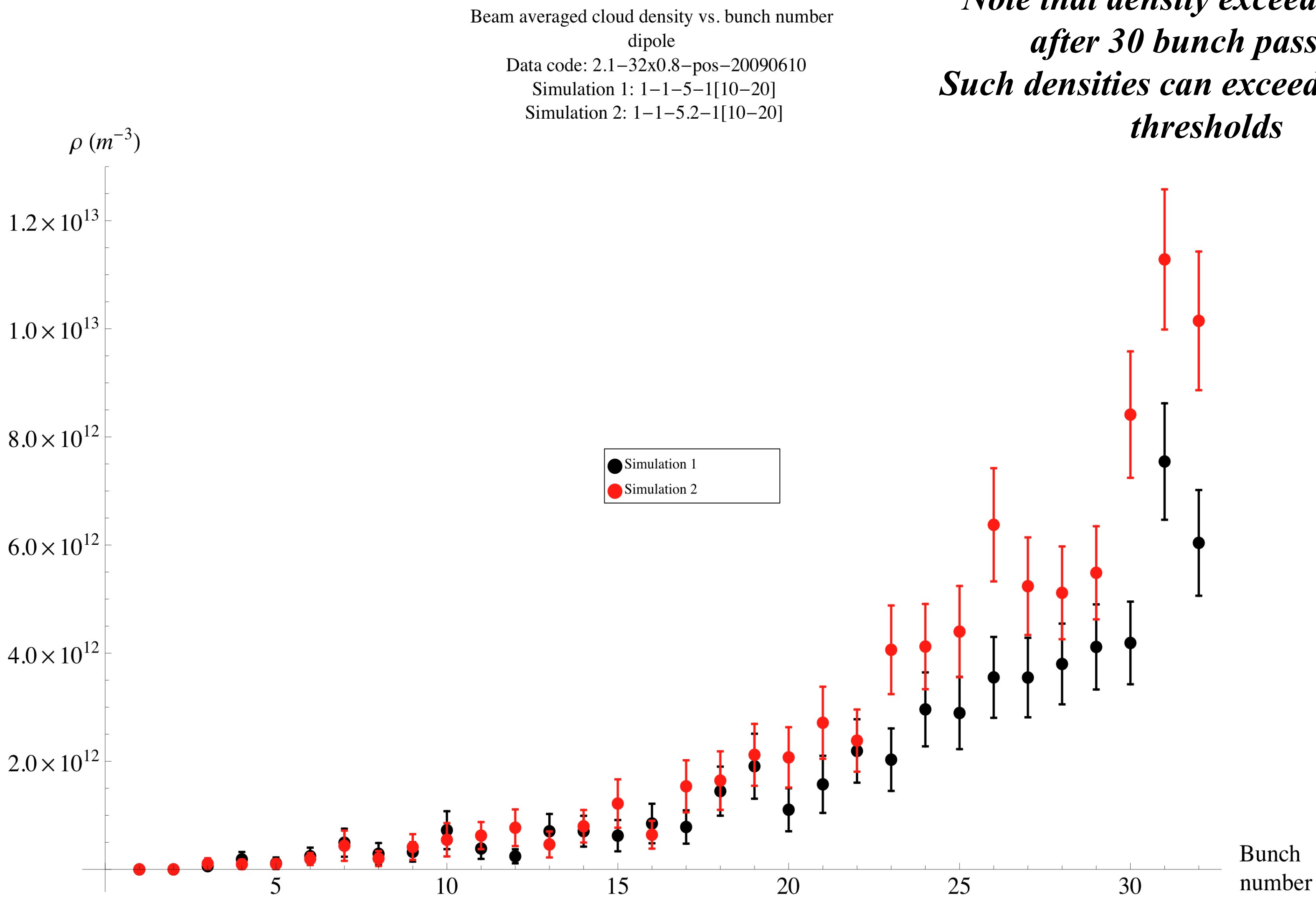
Black: Horizontal tune shifts e+ 1.3x10 ^{10}/bunch, 1.9 GeV

Red: nominal simulation parameters (SEY=2.0)

Blue: SEY=2.2

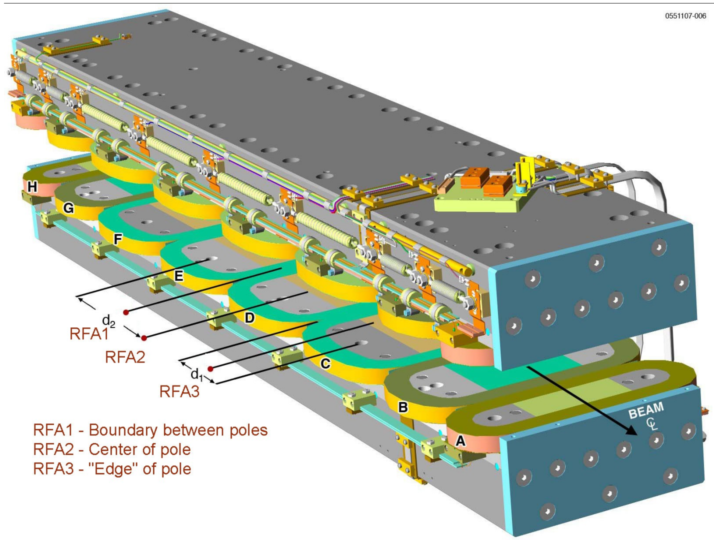
e+, dipole, modelled cloud density near the beam 32 bunches, 4 ns spacing, 1.3x10^10/bunch

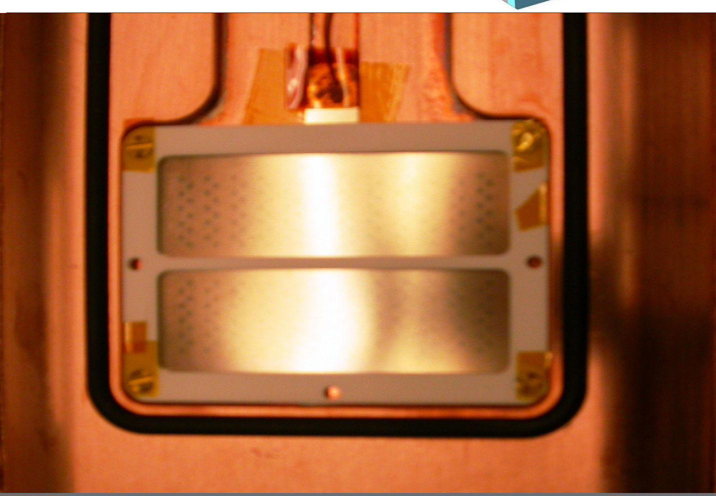
Note that density exceeds $10^{13}/m^{-3}$ after 30 bunch passages
Such densities can exceed instability thresholds

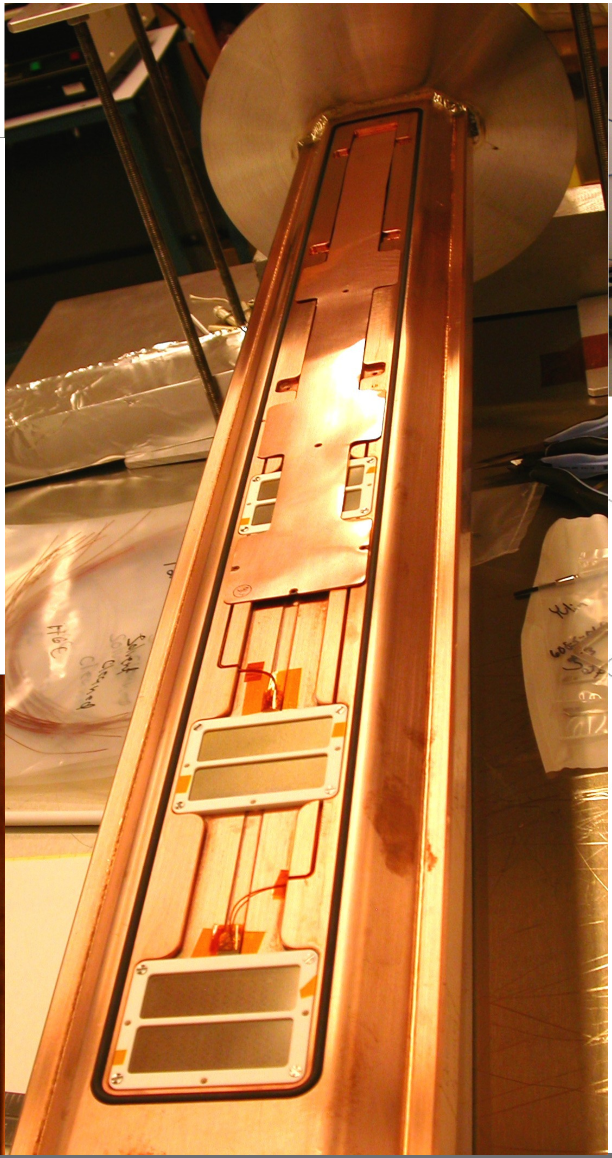


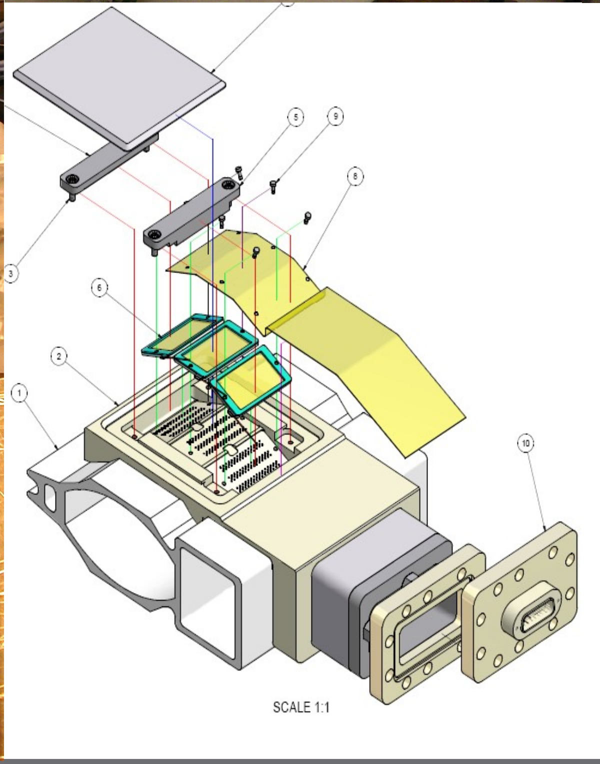
Retarding Field Analyzer Detector Design and Implementation

Superferric wigglers (1.7-2.1T)
Cu, TiN-coated, Grooved VCs





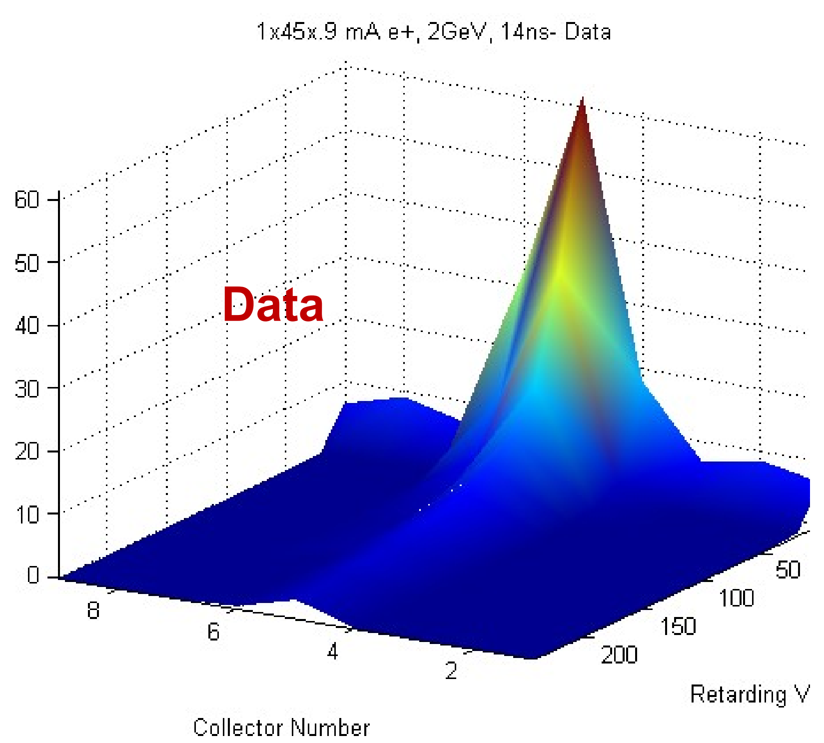


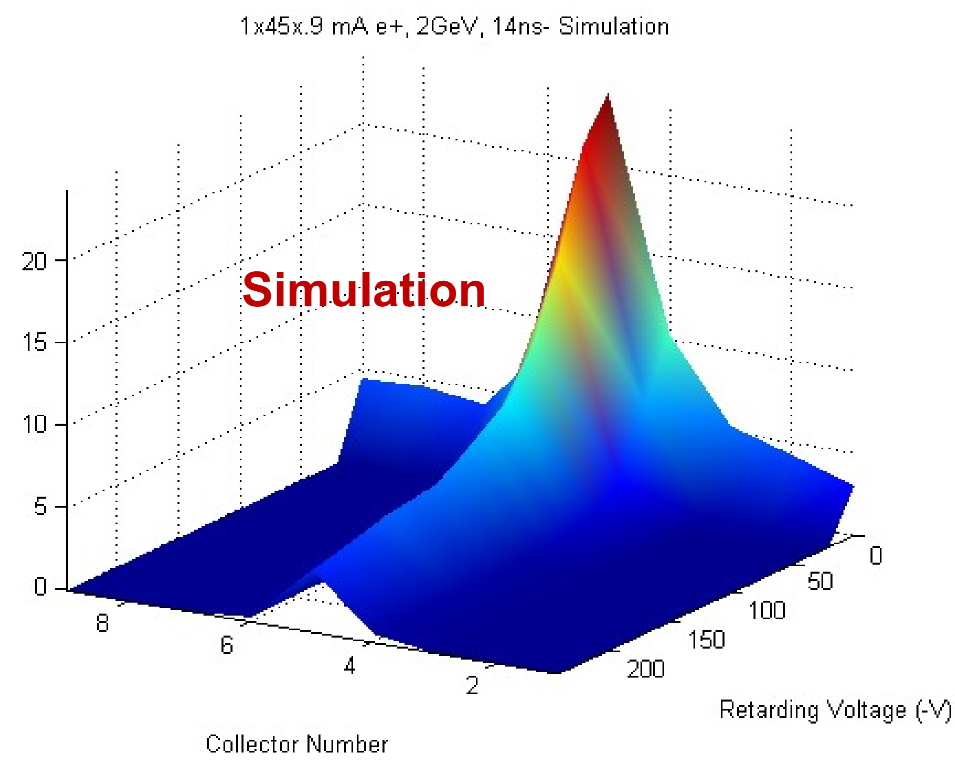


Model for RFA measurements using analysis of POSINST output

15E thin ("dipole style") RFA
9 collectors
Uncoated aluminum chamber
1x45x0.9 mA e+ @ 2 GeV, 14ns spacing
RFA currents simulated with postprocessing script
Simulation peak SEY is 1.8 at incident energy 310 eV

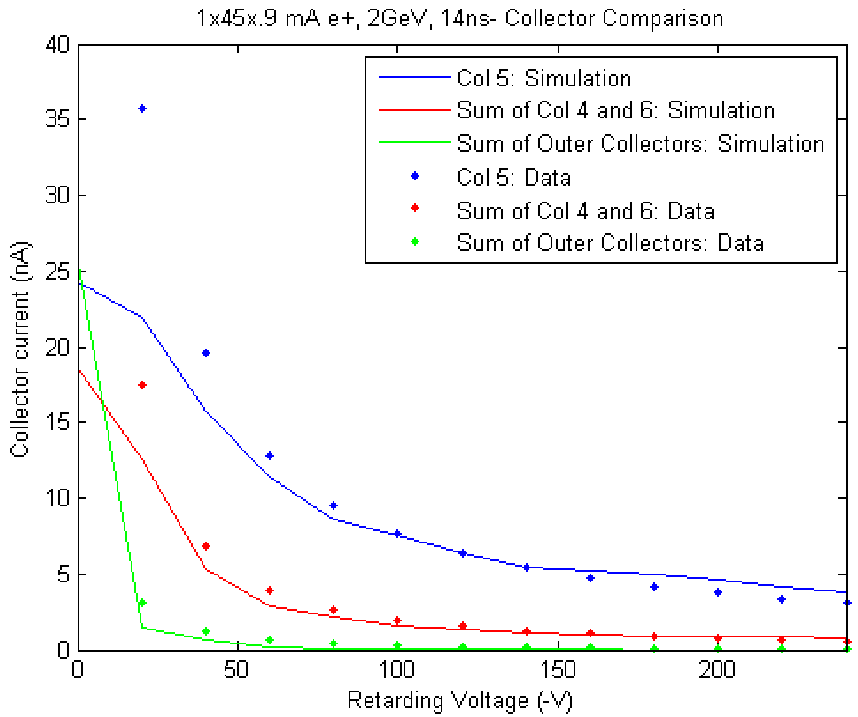
Agreement is very good at V_R> 20 V, and within a factor of 2 at V_R< 20 V

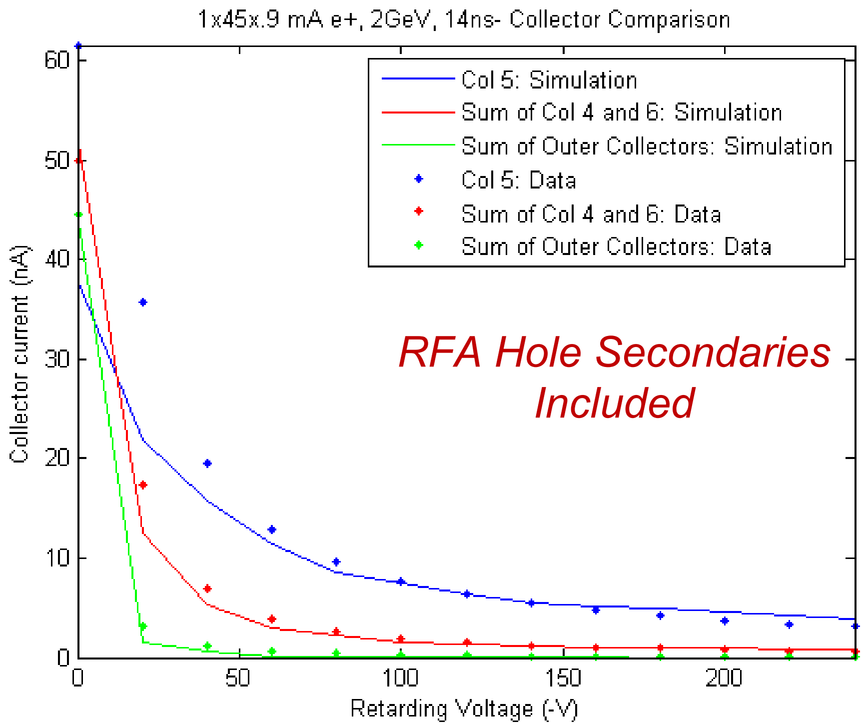




Correction for RFA/Cloud interaction (e.g.SEY in beam pipe holes)

- ***Modelled RFA collector currents: central (blue), sum of 4 and 6 (red), and sum of the rest (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***
  - ***This correction must be incorporated into the transparency function of the RFA model***





RFA Measurements in Wigglers
Detector model incorporated in ECLOUD

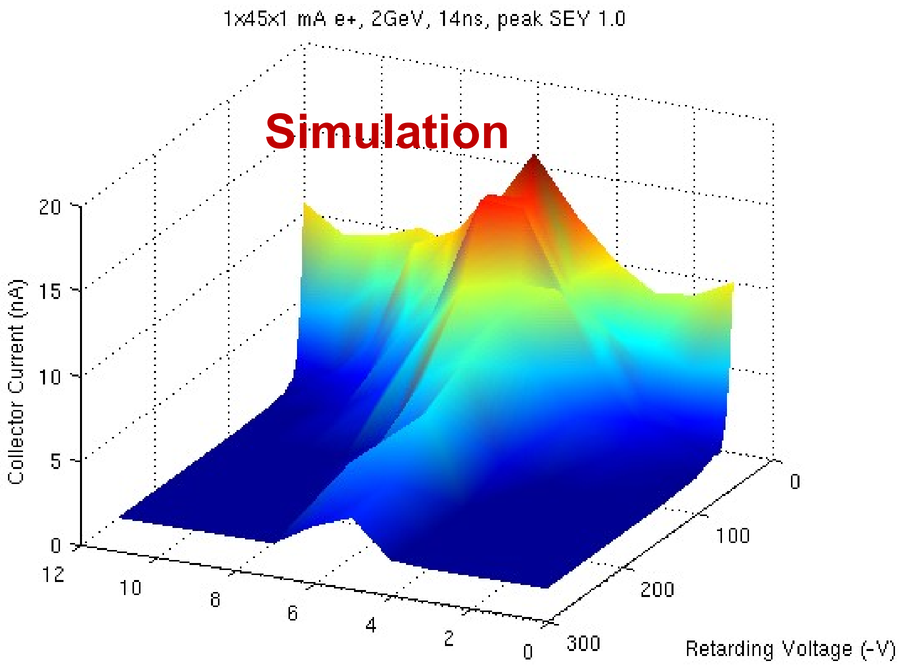
Wiggler (pole center) RFA model in ECLOUD

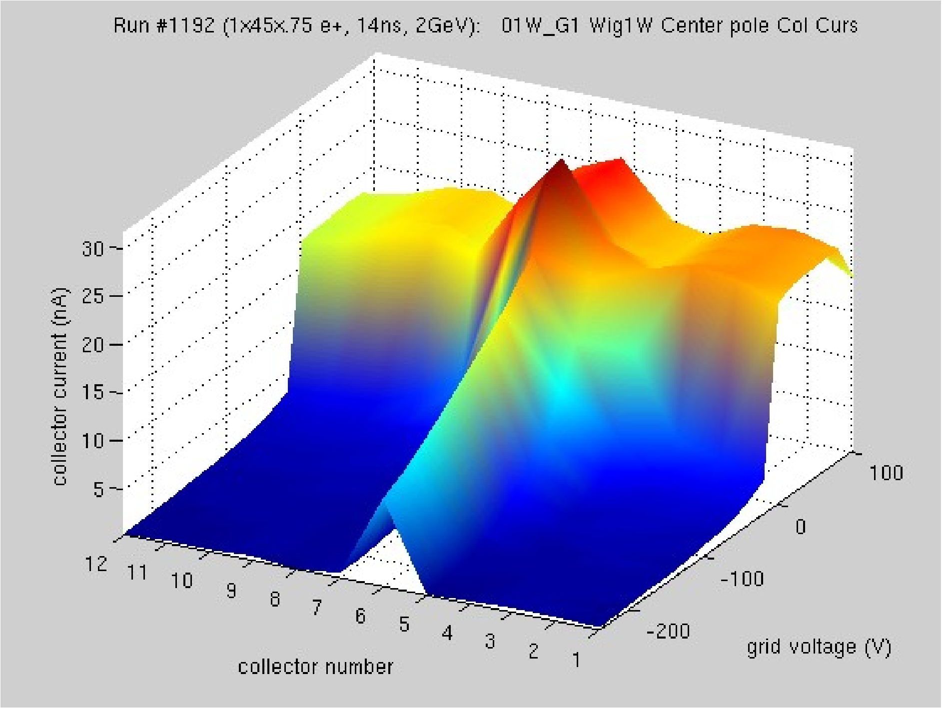
Performs analytic calculation when macroparticle hits in the RFA region

Assumes macroparticles are pinned on vertical magnetic field lines

Includes SEY on the retarding grid with a peak yield value of 1.0

1x45x1 mA e+, 14ns, 2GeV

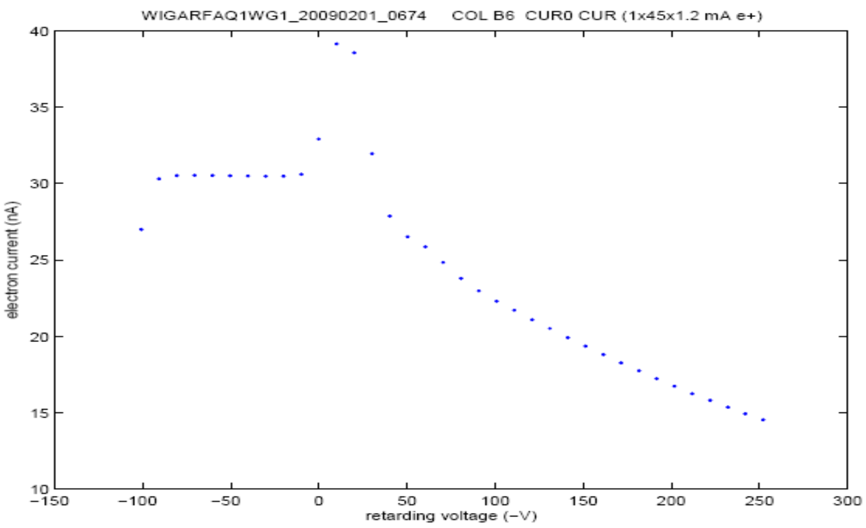


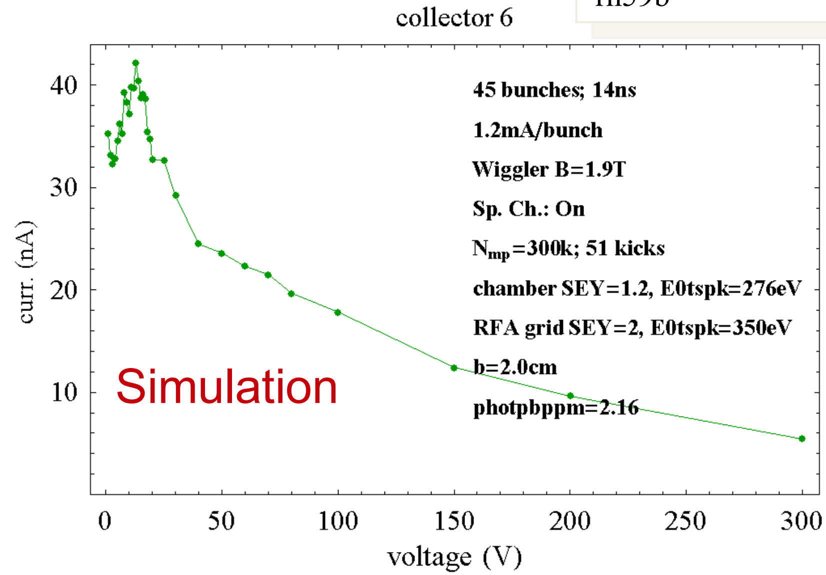


RFA Simulation implemented in POSINST Wiggler Model

chamber E0tspk=276eV
grid E0tspk=350eV
rn59b

Measurements* (collector no. 6)



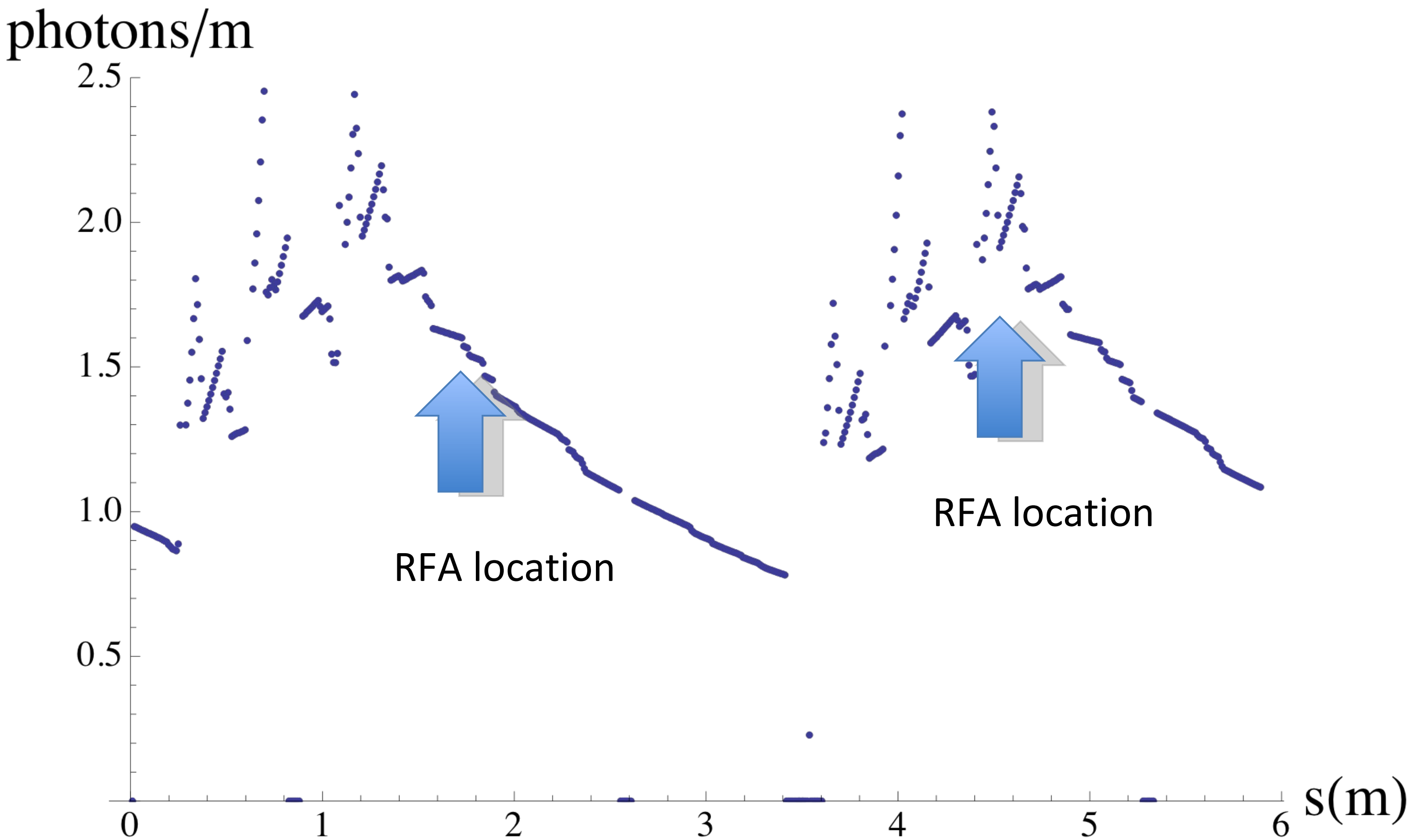


14ns bunch separation
45 bunches, 1.2 mA/bunch
$B_Y = 1.9$ T
grid SEY=2.0; chamber SEY=1.2

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.

Radiation in the L0 Wigglers

Specular reflection from points less than about 40 m upstream of the wiggler RFA cannot illuminate the chamber at the RFA, since the angular divergence of the photon beam striking the chamber is ϕ=0.3 mrad and the chamber height is b=2.5 cm, so L=b/(2ϕ)=40 m.

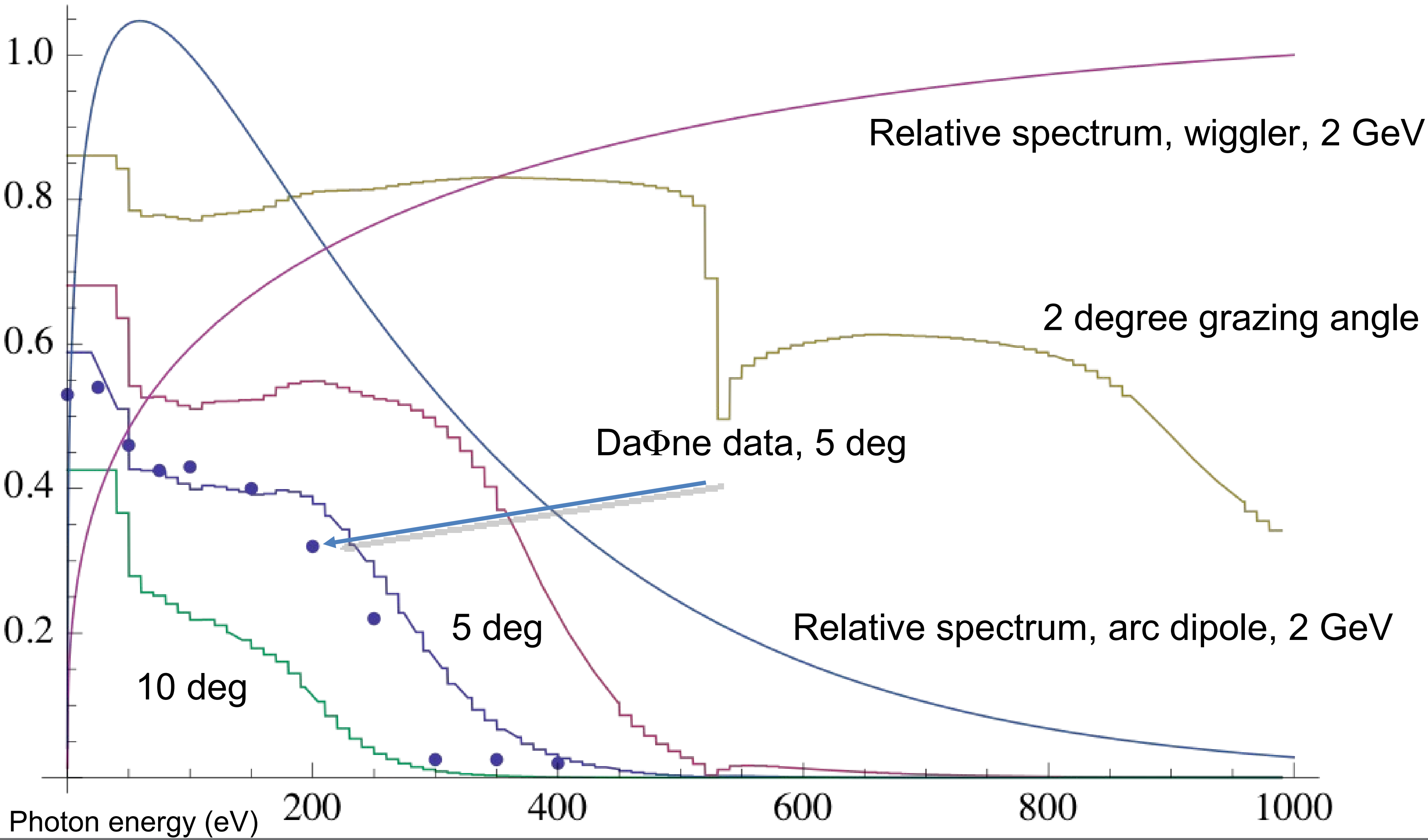


Reflectivity Model

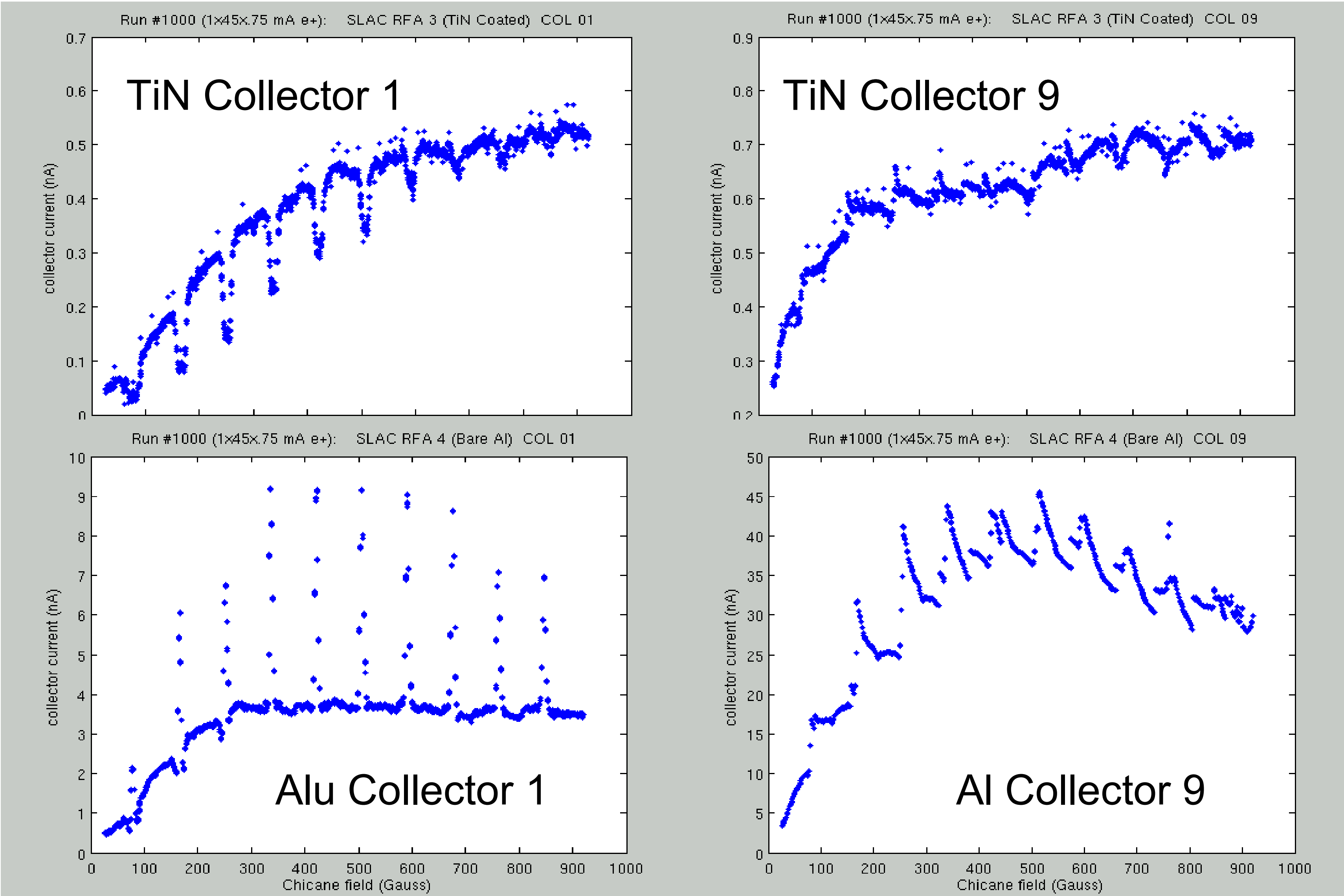
8 nm Al_2O_3 layer

2 nm surface roughness, on Al substrate

B.L. Henke, E.M. Gullikson, and J.C. Davis, Atomic Data and Nuclear Data Tables Vol. 54 (no.2), 181-342 (July 1993).



A Challenge for Models: Cyclotron Resonances in the PEP-II chicane



Cycloton resonances also observed in the wigglers

Wigglers ramped to 2500 Gauss

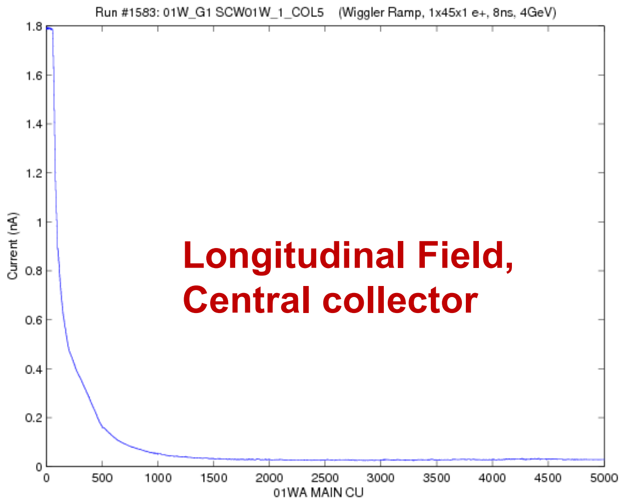
Signal in longitudinal-field-RFAs decreases rapidly

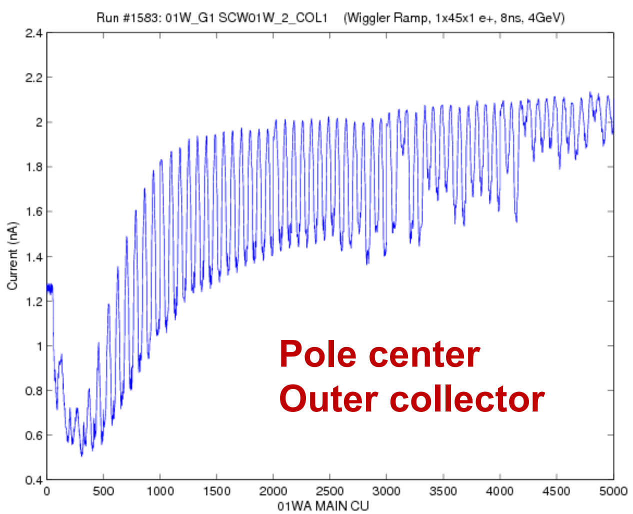
Resonances are clearly visible in the Cu center pole RFA

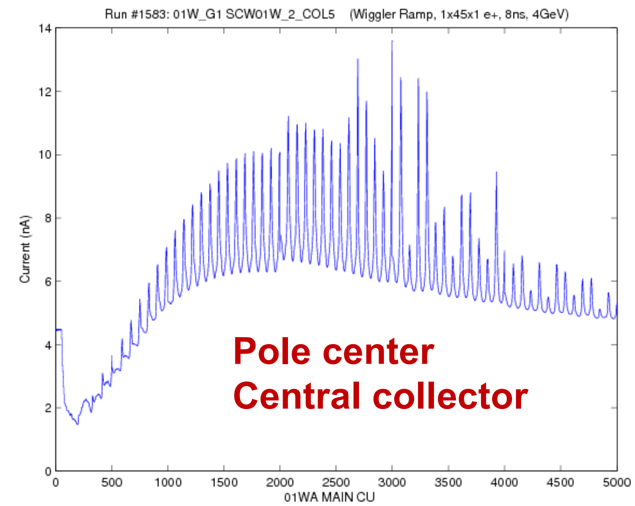
Clear peaks in central collector

Less clear in outer collectors

TiN coated and grooved RFAs also see the resonances, though less prominently







Conclusions

The reconfiguration of CESR as CesrTA is now complete. Commissioning and production data-taking periods took place in 2008/2009. Many measurements are now available for validating models.

Much progress in understanding the electron cloud modelling programs for CesrTA operating conditions has been achieved during the past year.

Models for coherent tune shifts have improved significantly as a result. Comprehensive lattice analysis efforts are ongoing.

The wide variety of local RFA measurements and ring-averaged tune shift data are challenging (exceeding!) the ability of the simulators to keep up.

Nonetheless, in areas such as head-tail instabilities, multi-bunch instabilities and incoherent emittance growth, modelling is leading measurement. The three production runs of combined duration 100 days over the course of the coming year will greatly increase the experimental data in these areas.

Modeling Coherent Tune Shift Measurements Using ECLOUD and POSINST Cloud Simulation Packages

I. ECLOUD and POSINST cloud modelling parameters

A. Sync rad photon rate per meter per beam particle at primary source point (2007: Drift R=0.23 γ/m/e, Dipole R=0.53 γ/m/e)

B. Quantum efficiency for producing photo-electrons on the vacuum chamber wall (12%)

C. Beam particles per bunch (0.75 mA/bunch -> 1.2e10 e/bunch).

D. Contribution of reflected sync rad photons distributed uniformly in azimuth around the beampipe wall (15%).

1. This contribution is also subtracted from the primary source point.

E. Secondary emission peak yield (SEY=2.0) at peak energy (E_{peak}= 310 eV)

1. These values are also used by POSINST, but the POSINST SEY model is quite different from ECLOUD's.

II. Field difference or gradient --> tune shift conversion parameters

A. E_{beam} = 1.885e9 eV

B. f_{rev} = 390 kHz

C. Ring circumference C=768 m (C f_{rev} = c = 2.998e8 m/s)

D. Ring-averaged β values (from sync rad summary tables derived from lattice model)

1. e+ beam: Drift $\beta_X(\beta_Y)$ = 19.6m (18.8m), Dipole $\beta_X(\beta_Y)$ = 15.4m (18.8m)

2. e- beam: Drift $\beta_X(\beta_Y)$ = 19.4m (19.3m), Dipole $\beta_X(\beta_Y)$ = 15.3m (19.4m)

- Relative drift/dipole weighting (from sync rad summary tables)

I. Ring length fractions: Drift: (174.9m/768m) = 0.228, Dipole: (473.9m/768m) = 0.617. Remaining 15% of ring ignored.