Electron Cloud Simulations at Cornell for Cesr-TA, and comments on tune shift-density relationship

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Simulation goals and initial steps

Simulations at Cornell will focus on the following needs:

- Defining and guiding the key experiments and related measurements needed to fulfill the overall CesrTA program goals.
- Providing support for understanding the response of instrumentation and diagnostics in terms of fundamental beam and cloud properties
- Understanding the results of experiments in terms of simulation codes, thereby benchmarking the codes for use at ILC and elsewhere

- Initial steps:
    - defining standard set of conditions for CesrTA simulations
    - making simulation code comparisons for simple cases relevant to CesrTA conditions
    - simulating ring-averaged cloud buildup and associated coherent tune shifts, to guide witness bunch experiments as probes of cloud density and dynamics
    - simulating cloud buildup in RFA-instrumented chambers, and RFA instrumental response, to guide RFA experiments as probes of average cloud density.

CesrTA Simulation parameters

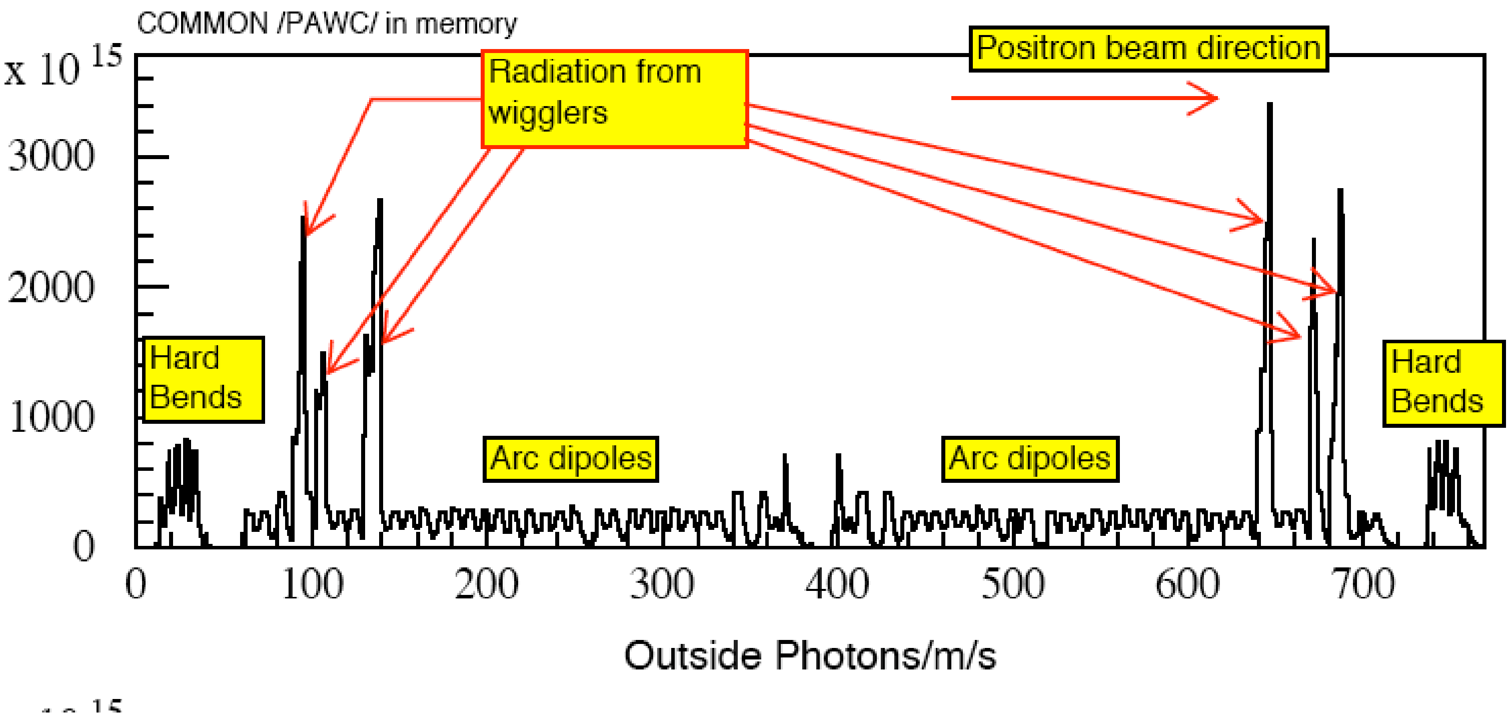
Common information needed for all simulations:

- Database of CESR elements, vacuum chamber sizes and surface materials, magnetic fields, radiation intensity on the surface
- Geometry of RFA-instrumented chambers
- SEY model for each surface material
- Experimental conditions (e.g., energy, emittance, chamber condition, lattice, bunch pattern, etc.) for each set of experimental measurements

This information will be posted on the CesrTA *Cloud Simulation web page*
https://wiki.lepp.cornell.edu/ilc/bin/view/Public/CesrTA/EcloudParams
so that it is available to all collaborators. Links to CesrTA experimental data files will also be provided.

CesrTA Radiation at 2 GeV

Photon Rates (100 mA)



Simulation codes

- We will be using three simulation codes at Cornell: ECLOUD, POSINST, and CLOUDLAND.
- We are in the process of running these codes for the same set of simulation parameters, representing typical CesrTA conditions, including weighting with radiation intensity, in dipole and drift, and local conditions at RFA probe locations.
- Input and output files for each program will be posted on the CesrTA Cloud Simulation web page for reference.
- At the same time, we are using to results of the simulations to help understand the witness bunch tune shifts measurements, and the RFA data.

Simulation codes

- This is very much a "work in progress" at the moment, as we have not completed the benchmarking comparisons, nor fully understood the tune shift or RFA data in terms of any of the simulation code results.
- Nevertheless, we would like to share our progress with you at this workshop, and would appreciate any comments, remarks or insights on what we done to date.
- The subsequent talks by Jim Crittenden and Joe Calvey will report on specific simulation results related to coherent tune shifts and cloud-induced RFA currents.
- Before we move on to those talks, I would like to make a few comments on the relationship between cloud density and coherent tune shift. The build-up simulation codes generally predict the cloud density, while the witness bunch studies measure the tune shift, so this relationship is key to making the connection.

Relation between coherent tune shift and cloud density

Consider a bunch , energy *E*, executing coherent dipole motion driven by a cloud charge density *ρ(x,y)*. The difference between the bunch distribution centroid and the cloud distribution centroid is *Δx(Δy)*. Then the coherent tune shift is given by

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

in which $\bar{E}_{x(y)}$ is the electric field of the cloud, averaged over the beam distribution, and β is the lattice function at the cloud location.

Relation of density to tune shift

If we assume that the beam has a bi-Gaussian transverse distribution with rms size $x(y)$ given by σ_x (σ_y), then the electric field gradient, averaged over the beam, is, to lowest order in Δx and Δy

$$\frac{\partial \bar{E}_x}{\partial \Delta x} = \frac{-\sigma_y}{2\pi\varepsilon_0\sigma_x}\int_{-\infty}^{\infty} du' \int_{-\infty}^{\infty} dv' \rho(\sqrt{2}\sigma_x u', \sqrt{2}\sigma_y v')\tilde{w}_x(u', v'),$$

in which

$$\tilde{w}_x(u, v) = \int_0^{\infty} dp \, \frac{\mathrm{e}^{-u^2/(1+p)-v^2/(1+p/r)}\,(1+p-2u^2)}{(1+p)^{5/2}(r+p)^{1/2}},$$

is a “weight function”, and $r = \sigma_y^2/\sigma_x^2.$

Relation of density to tune shift

For the vertical direction

$$\frac{\partial \bar{E}_y}{\partial \Delta y} = \frac{-\sigma_y}{2\pi\varepsilon_0\sigma_x} \int_{-\infty}^{\infty} du' \int_{-\infty}^{\infty} dv' \rho(\sqrt{2}\sigma_x u', \sqrt{2}\sigma_y v') \tilde{w}_y(u', v'),$$

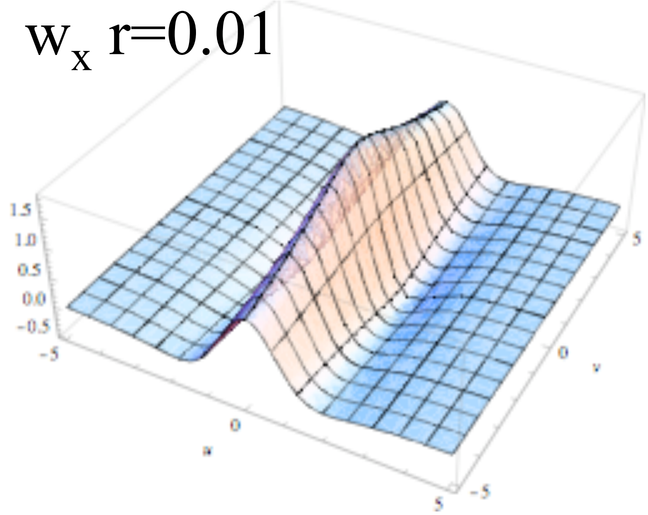
$$\tilde{w}_y(u,v) = \int_0^{\infty} dp \, \frac{\mathrm{e}^{-u^2/(1+p)-v^2/(1+p/r)} \left(r + p - 2rv^2\right)}{(r+p)^{5/2}(1+p)^{1/2}}.$$

Weight functions can be used to

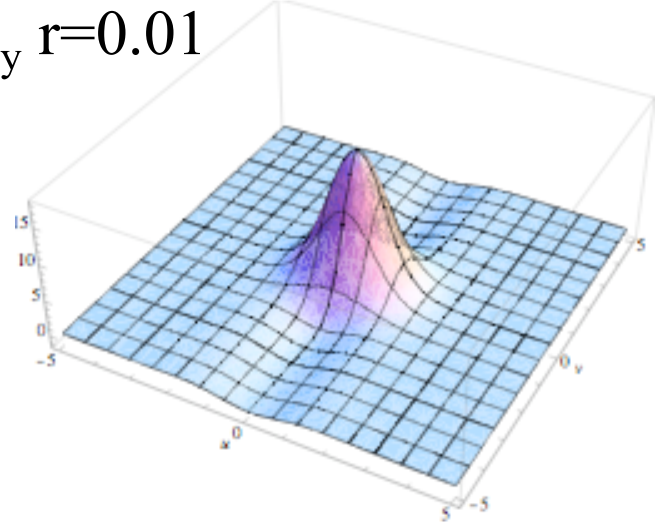
- obtain analytical expressions for the field gradient corresponding to simple cloud densities
- numerically compute field gradients (and hence coherent tune shifts) directly from cloud density distributions

Weight function examples

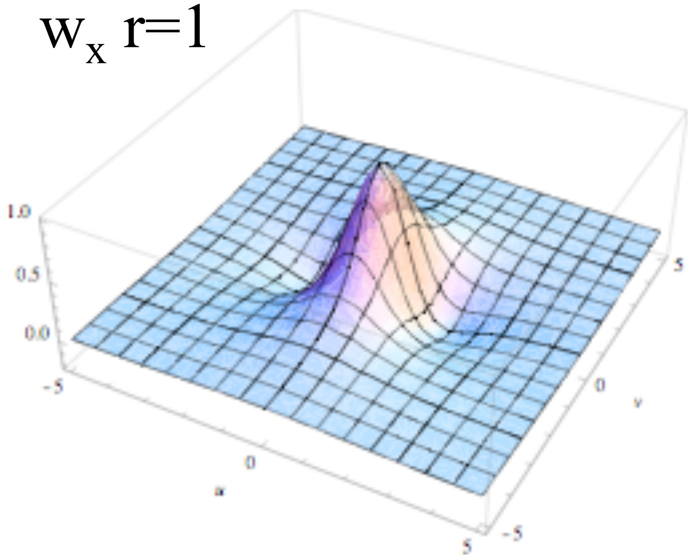
w_x r=0.01



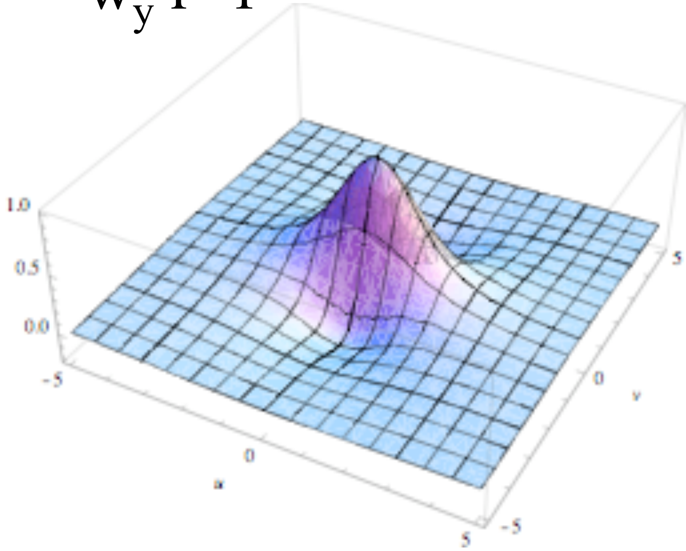
w_y r=0.01



w_x r=1



w_y r=1



Applications: Gaussian cloud

- Gaussian cloud: rms size (h,v)=(a,b), peak number density $\rho_{n,max}$

$$\Delta Q_x = \frac{r_e}{\gamma}\oint ds\, \frac{\beta_x \rho_{n,max} ab}{\left(\sigma_x^2 + a^2 + \sqrt{(\sigma_x^2+a^2)(\sigma_y^2+b^2)}\right)}.$$

$$\Delta Q_y = \frac{r_e}{\gamma}\oint ds\, \frac{\beta_y \rho_{n,max} ab}{\left(\sigma_y^2 + b^2 + \sqrt{(\sigma_x^2+a^2)(\sigma_y^2+b^2)}\right)}.$$

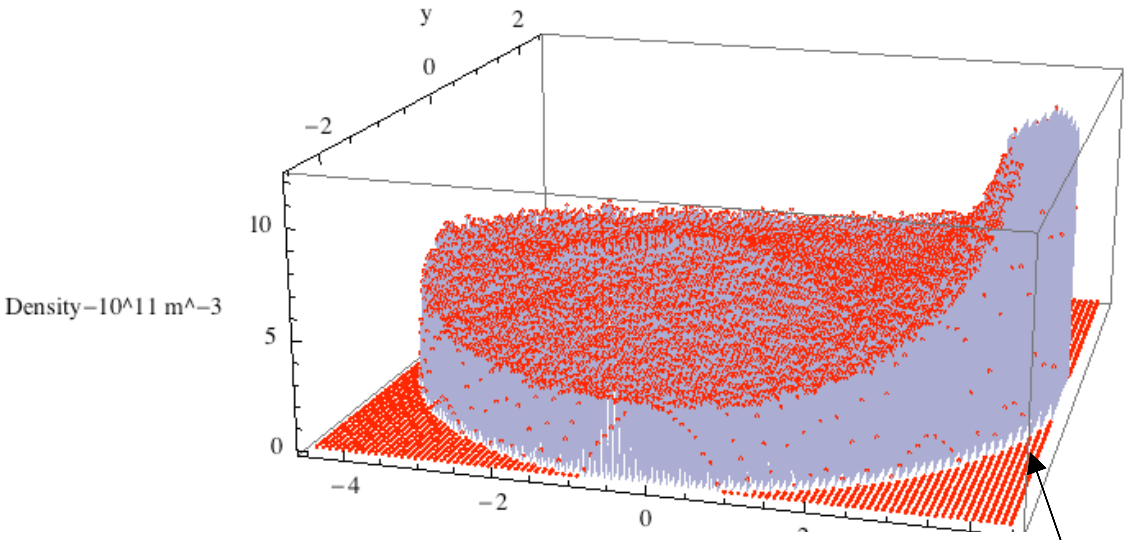
If cloud is much bigger than beam:

$$\Delta Q_x \approx \frac{r_e}{\gamma}\oint ds\, \frac{\beta_x \rho_{n,max} ab}{(a^2+ab)} = \frac{r_e}{\gamma}\oint ds\, \frac{\beta_x \rho_{n,max}}{(1+a/b)},$$

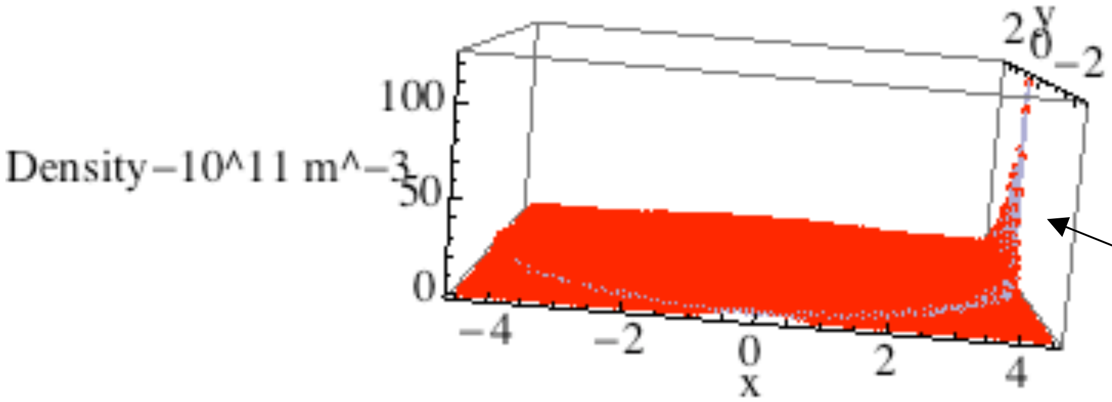
$$\Delta Q_y \approx \frac{r_e}{\gamma}\oint ds\, \frac{\beta_y \rho_{n,max} ab}{(b^2+ab)} = \frac{r_e}{\gamma}\oint ds\, \frac{\beta_y \rho_{n,max}}{(1+b/a)}.$$

Numerical example-density distribution from a simulation

Elliptical chamber H (x) x V(y) axes=4.45 x 2.45 cm



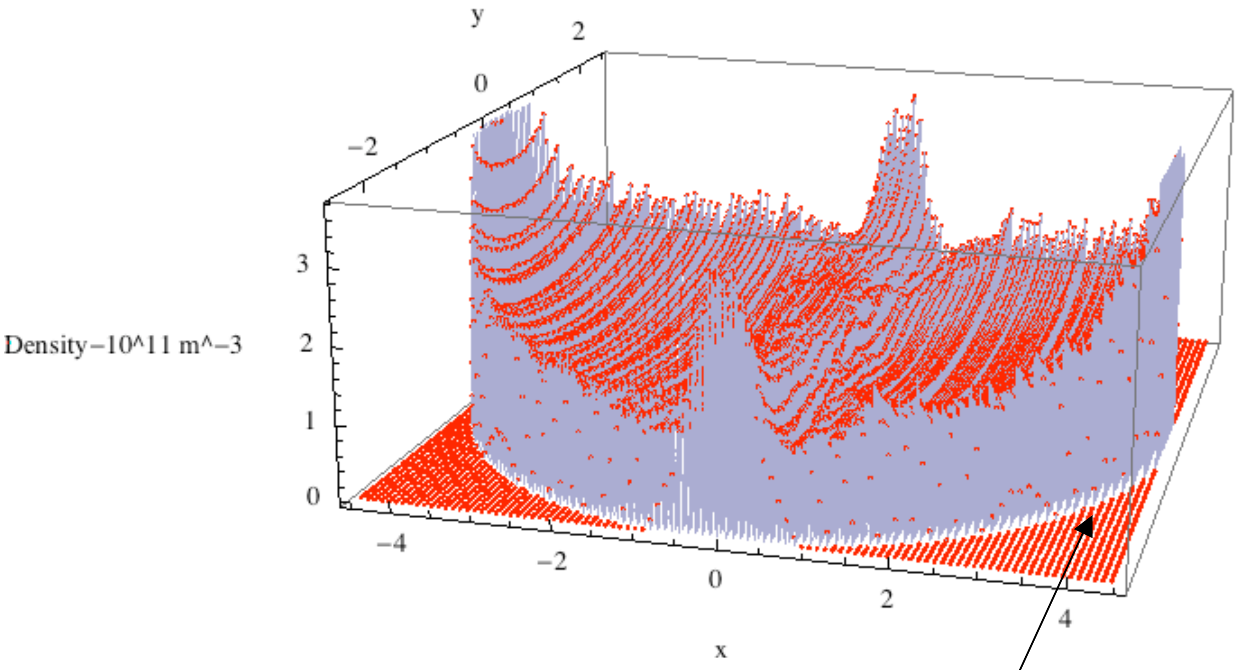
POSINST
Cesr-TA typical drift region
Time-averaged density

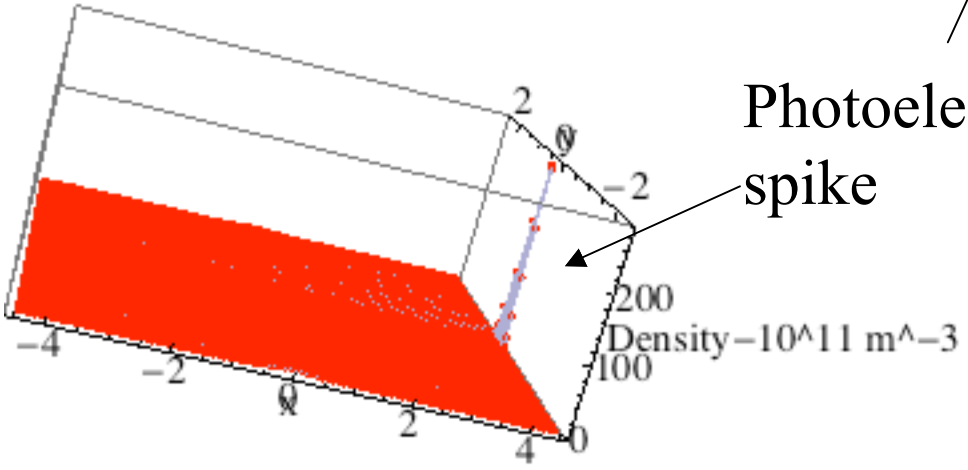


Photoelectron spike

Numerical example-density distribution from a simulation

Elliptical chamber H (x) x V(y) axes=4.45 x 2.45 cm





Photoelectron spike

POSINST
Cesr-TA typical dipole region
Time-averaged density

Numerical example

For determining the field gradient, how good is the approximation of a uniform cloud density over the beam chamber area?

From numerical integration:
Ratio of *beam-weighted field gradient due to simulated cloud density distribution (for examples shown in previous slides),* to *beam-weighted field gradient due to uniform distribution with the same average density.*

	Horizontal	Vertical
Drift	1.014	1.275
Dipole	3.43	4.33

Subsequent progress reports on Cornell work

- Joe Calvey will report on simulations of RFA measurements of cloud-induced currents.
- Jim Crittenden will report on simulations of witness bunch measurements of cloud-induced coherent tune shifts.