R&D of Electron Cloud Magnetic Resonance in Weak Fields

E.L. Wilkinson
Department of Physics, Loyola University, Chicago, IL, 60626
(Dated: August 7, 2009)

Electron cloud magnetic resonance has many as yet unexplored interesting properties. We use the simulation program ECloud to study the resonance effect for positron as well as electron beams. We consider aluminum chambers with and without TiN coating as well as suggest a possible method for determining the zero energy yield.

I. INTRODUCTION

Electron cloud studies have played a major role in the CesrTA setup in anticipation for the ILC ultra low emittance damping rings. The damping ring is intended for both positron and electron beams and mapping the optimal design is a key element in reaching this low emittance goal, thus understanding all aspects of cloud behavior and underlying parameter space is an integral part completing this project. In 2008, the possibility of electron cyclotron resonances was predicted using the 2D computer code POSINST [1] and was later confirmed experimentally at SLAC in 2009 [2]. We simulate the electron cloud with a different 2D computer code called ECloud which uses a relatively small number of macroparticles to represent the charge and kinematics of the total cloud. With ECloud, we study in greater detail the properties and mechanics of the electron cloud while in magnetic resonance.

II. THEORY

The theory behind magnetic resonance is simple, but not quite elegant. Low energy electrons boil off the chamber wall due to the photoelectric effect from synchrotron radiation or from secondary electron emission. In a uniform magnetic field, electrons are trapped along field lines and corkscrew vertically through the beam pipe according to the Lorenz force law:

$$q\vec{v}\times\vec{B} = m(v^2/r) \tag{1}$$

As positron bunches come by, they excite the cloud and draw electrons closer to the beam path. Magnetic resonance occurs when the spacing between positron bunches equals an integral multiple of the cyclotron time period:

$$\tau_b = nT = n(2\pi m_e/qB) \quad or \quad B = n(2\pi m_e/q\tau_b) \tag{2}$$

Electrons in the cloud receive reinforcing beam kicks as they return to the same radial location each time a new positron bunch passes. The electrons continue to build energy this way until they strike wall at higher energies, typically from 50 to 150 eV, and higher incident angles then their off resonance counterparts. Electrons hitting the wall have three probabilistically determined choices: absorption, elastic reflection, or secondary emission. These choices are material dependent and governed by the Secondary Emission Yield (SEY) curve [3], whose general form , (5), consists of an energy dependent component as well as an incident angle component [4]is:

$$\delta(E) = 1.11(E_r)^{-0.35}(1 - e^{-2.3E_r^{1.35}}) \tag{3}$$

$$\delta(\theta) = e^{\alpha(1-\cos\theta)} \tag{4}$$

$$\delta(E,\theta) = \delta(E)\delta(\theta) \tag{5}$$

Thus increases in incident electron energy and angle causes more secondary electron production and subsequently spikes in the electron cloud density.

III. SIMULATION PARAMETERS

For all resonance studies presented here, a circular pipe chamber of radius 4.5 cm was used. In fact, the resonance condition is chamber dependent and disappears significantly when the shape is changed from circular to elliptical specifications. The positron bunch spacing used was 4ns with current .75 mA per bunch, $E_{max} = 310$ eV and $\delta_{max} = 2.0$. The same conditions were kept when looking at electron bunch resonance except that the bunch spacing was changed to 16 ns. For the zero energy yield study, the bunch spacing was set to 4 ns with $E_{max} = 500$ eV and $\delta_{max} = 0.95$. All RFA simulated plots were generated with no selection bias and accounted for all electrons hitting the chamber wall at the designated collector location.

IV. ALUMINUM CHAMBER RESONANCE

After putting into ECloud the SEY curve for aluminum we see that ECloud, like POSINST, is capable of showing the resonance peaks. The simulated RFA output shows spikes in electron cloud density that occur in even intervals exactly at the predicted locations in the magnetic field. These spikes continue past n = 20. Using this data, we can begin to take a look at the different mechanical aspects between off resonance cloud states and on resonance ones. As explained in the theory above, we would expect to see a large energy increase in the cloud as electrons are constructively kicked when we get to the resonance magnetic field values. In fact, this effect does occur and takes a non-uniform distribution over the beam pipe.

FIG. 2 shows particles between the chamber wall and the center of the beam pipe jump in energy from around 20 eV up to 120 eV. The energy distribution assumes this parabolic-like shape because particles near the x = 0 cm mark pass close enough to the positron bunch that the kick their receive is significantly biased in the vertical direction. Opposite to this, particles near the x = ±4.5 cm mark receive biased kicks in the horizontal direction but due to their proximity to the edge strike the chamber wall much sooner than particles created farther away. There appears to be a maximum value reached near the x = ±2.5 cm mark.

Energy increases correspond to momentum increases and as the cloud particles build energy on resonance they also begin to corkscrew at greater radii. This leads to electrons impacting the chamber wall at greater incident angles. Therefore, increases in both energy and incident angles contribute to making secondary electron production more propitious.

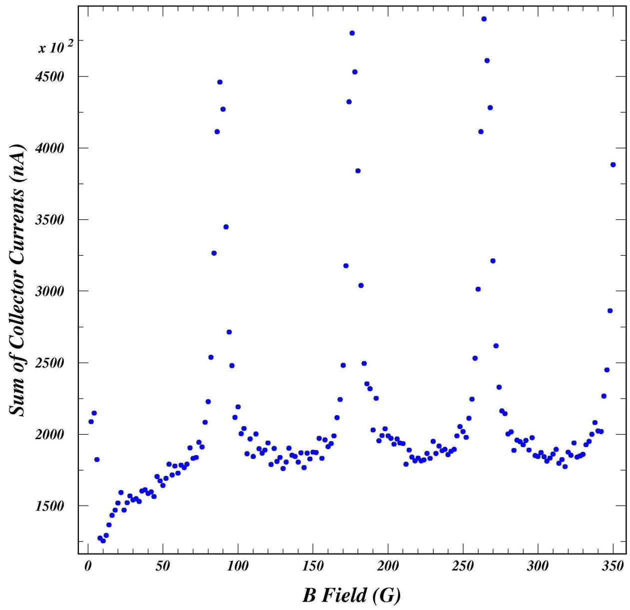

FIG. 1: ECloud simulated output of RFA data for aluminum chamber. Represents sum of all collectors

A. Electron Resonance

So far, every study concerning electron cloud magnetic resonance had used positron bunches. Positron bunches are ideal as they have an attractive force on the cloud and tend to pull cloud particles close to the beam path resulting in larger kicks. Shorter positron bunch spacings result in greater cloud density and enhanced resonant spikes. However, electron bunches have a repulsive force on the cloud and in order to have the cloud electrons get close enough to the beam to receive a significant kick a larger bunch spacing is required. Therefore, we used a bunch spacing of 16 ns which was effective at producing resonant peaks. Electron bunch peaks are only a fraction of their positron counterparts and represent approximately a 10% jump in cloud density. Additionally, the $n = 1$ resonant case is missing and actually shows up in the furthest collector from the center of the beam pipe as a resonant dip. No explanation is offered here.

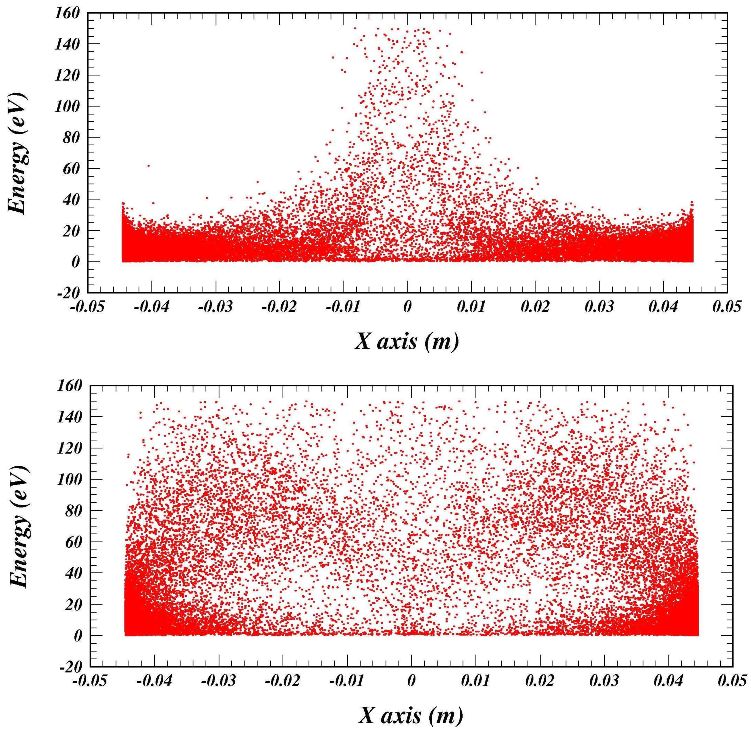

FIG. 2: Energy distribution over horizontal component of a cross sectional cut of the beam pipe. Top shows off resonance case (n=1.2). Bottom shows on resonance case (n=1).

V. TITANIUM NITRIDE COATING RESONANCE

In efforts to reduce electron cloud growth SLAC installed and tested titanium nitride coated chambers. According to their 2009 report [2], the TiN coated chamber showed resonant dips, or decreases in cloud density. In efforts to reproduce this result, we used the SEY values from experiments at SLAC [5] for TiN of δ_{max}= 0.95 and E_{max} = 500 eV. Unfortunately, these SEY values produced resonant peaks like the ones for aluminum. However, when we used the SEY curve in FIG. 4 with $\delta(0) = 1$ and a $\delta_{max} = 0.45$ ECloud was able to produce dip like resonance. This indicates that the SEY parameter values might be lower than previously thought and suggests further study of the zero energy yield.

VI. ZERO ENERGY YIELD

The Zero Energy Yield governs electron behavior when it hits the wall at 0 eV and helps describe the SEY for low energy electrons. Because of experimental difficulties, this has been an elusive parameter in electron cloud studies. However, since on average most of the electrons in the cloud are below 50 eV this part of the curve contributes to in a major way to cloud development and sustainability. In order to determine the effect different zero energy yield values has on the cloud we ran two simulations, one in which all electrons at zero energy were absorbed at the wall and the other in which they were all elastically reflected. In the first case, the absorbtion cloud saturated at about 80% of the elastically reflecting cloud and decayed much quicker. This difference in cloud decay and saturation level indicates a

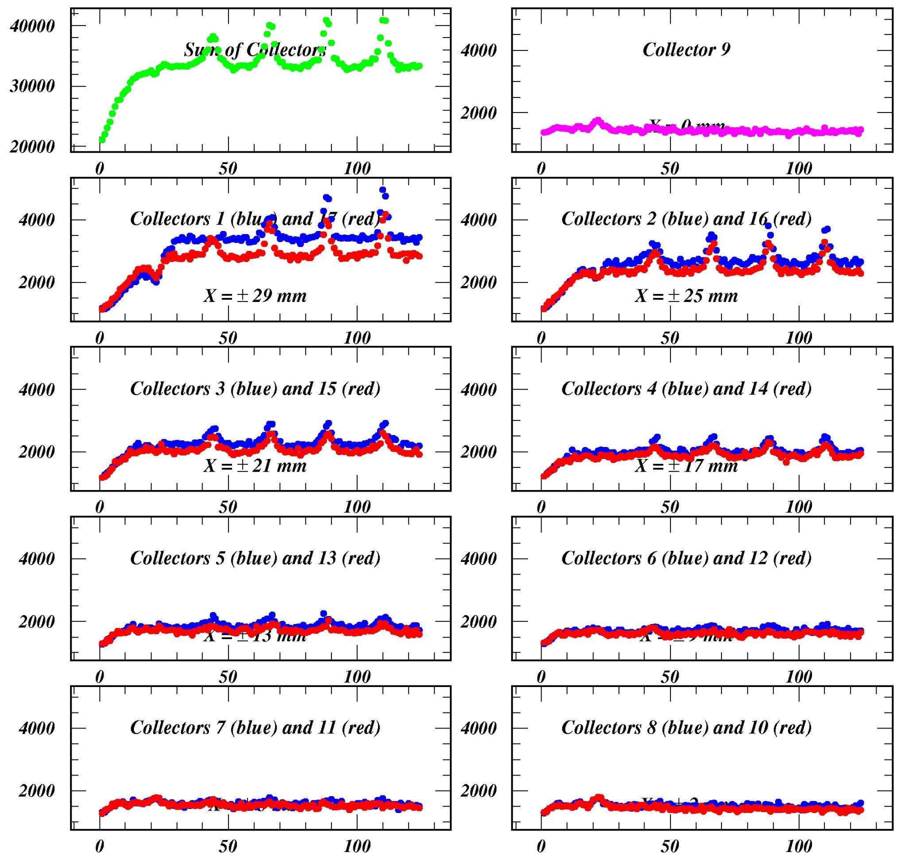

FIG. 3: RFA simulated output from ECloud showing current density vs. magnetic field. Top left: sum of all collectors. Other pictures represent one or two collectors that are at symmetric points on the chamber wall.

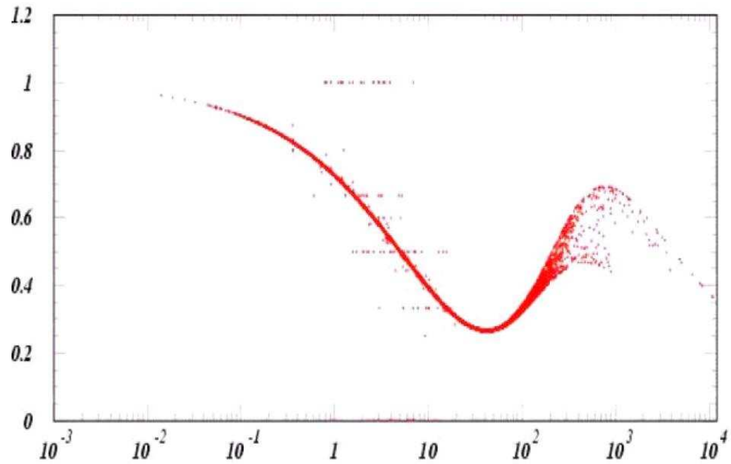

FIG. 4: SEY curve used for resonant dips. Semilogarithmic plot of Outgoing charge / Incoming charge vs. Energy. The off scattered points are negligible and from a known bug.

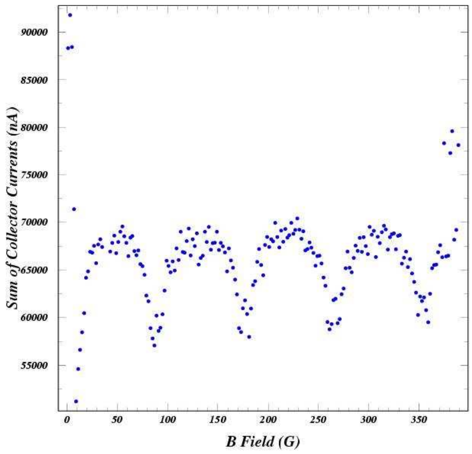

FIG. 5: Resonant dips produced in ECloud with modified SEY parameters. Shows sum of all collectors.

possible method for determining the zero energy yield by taking time dependent rather than time averaged cloud density measurements.

VII. CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

We have shown the predictive ability of the simulation program ECloud to produce the resonant peaks for aluminum chambers and analyzed the mechanical properties of the cloud on resonance. We have predicted that electron bunches also produce a magnetic resonance effect but for larger bunch spaces. In attempting to explain the dips in TiN coated chambers, we suggest a new SEY curve for TiN and give a possible method for determining the zero energy yield. Future work will need to include a physical model of the RFA to more accurately correlate data to simulation and a more detailed investigation into the TiN dips is recommended.

VIII. ACKNOWLEDGEMENTS

I would like to make mention of my mentor on this project, Dr. James Crittenden, whose ”no reigns” approach to out-of-control REU students proved the most useful source of direction. Also thanks to Rich Galik who organized the REU, Joe Calvey and all the Electron Cloud simulators at Cornell. This work was supported by the National Science Foundation REU grant PHY-0849885.

[1] C.M. Celata, *et al.* EPAC08 TUPP024

[2] M. T. F. Pivi, J. S. T. Ng, F. Cooper, D. Kharakh, F. King, R. E. Kirby,B. Kuekan, C. M. Spencer, T. O. Raubenheimer, and L. F. Wang SLAC-PUC-13555,

[3] H. Seiler, *J. Appl. Phys.* Nov 1983, 55(**11**),

[4] Shih, A. and Charles, H. *Transations on Electron Devices* 1993, 40(**4**)
[5] Pimpec, F., King, F., Kirby, R. and Pivi, M. 2004, LCC-0128 SLAC-TN-03-052

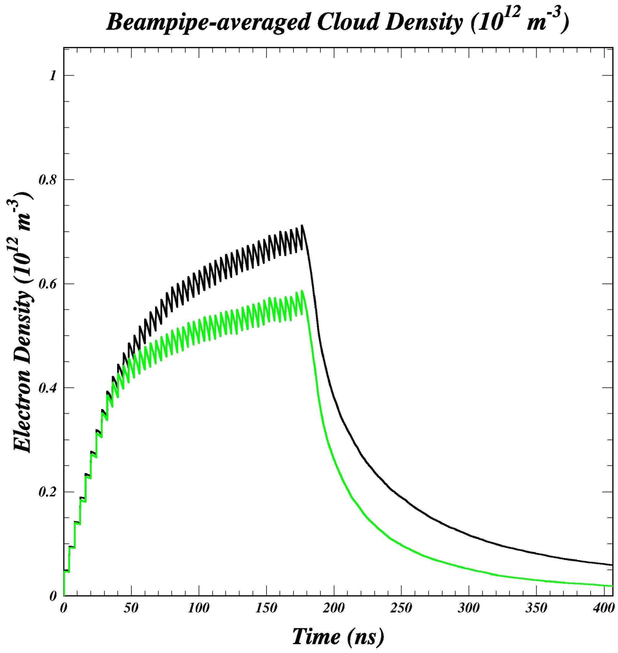

FIG. 6: Growth of electron cloud over time. Black line represents cloud with $\delta(0) = 1$ while the green line represents cloud with $\delta(0) = 0$