A New Resonance for Ecloud Physics in the ILC DR Wiggler

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Dec. 18, 2007

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Cloud Buildup Calculations were done using Posinst for ILC Wiggler Parameters

$B \leq 1.6$ T

2×10^{10} e+ per bunch

$\sigma_x = 112\ \mu m$

$\sigma_y = 4.6\ \mu m$

$\sigma_z = 6$ mm

bunch spacing: 6.15 ns

R = 2.3 cm (vacuum chamber radius)

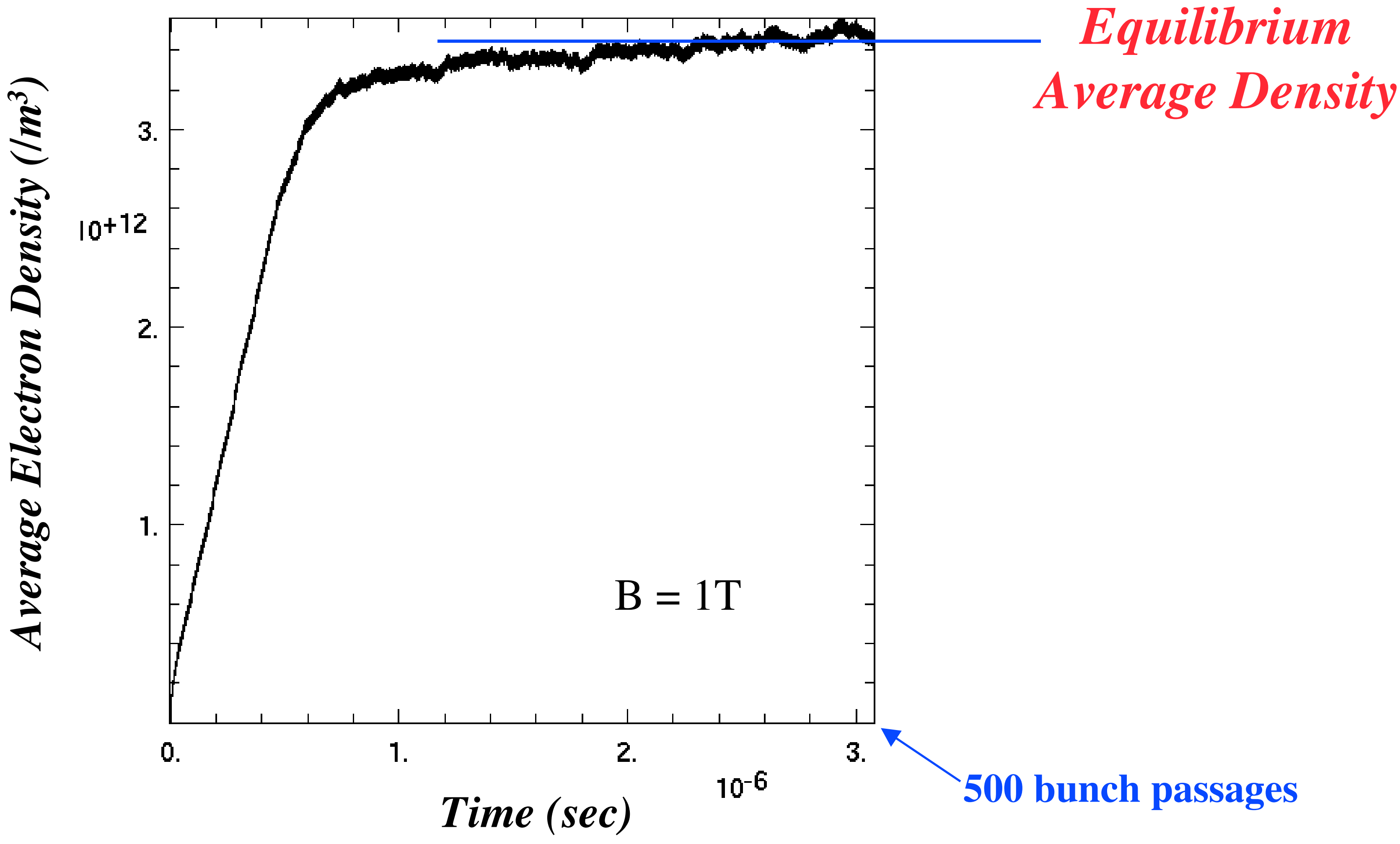
photon reflectivity = 1

peak SEY = 1.4

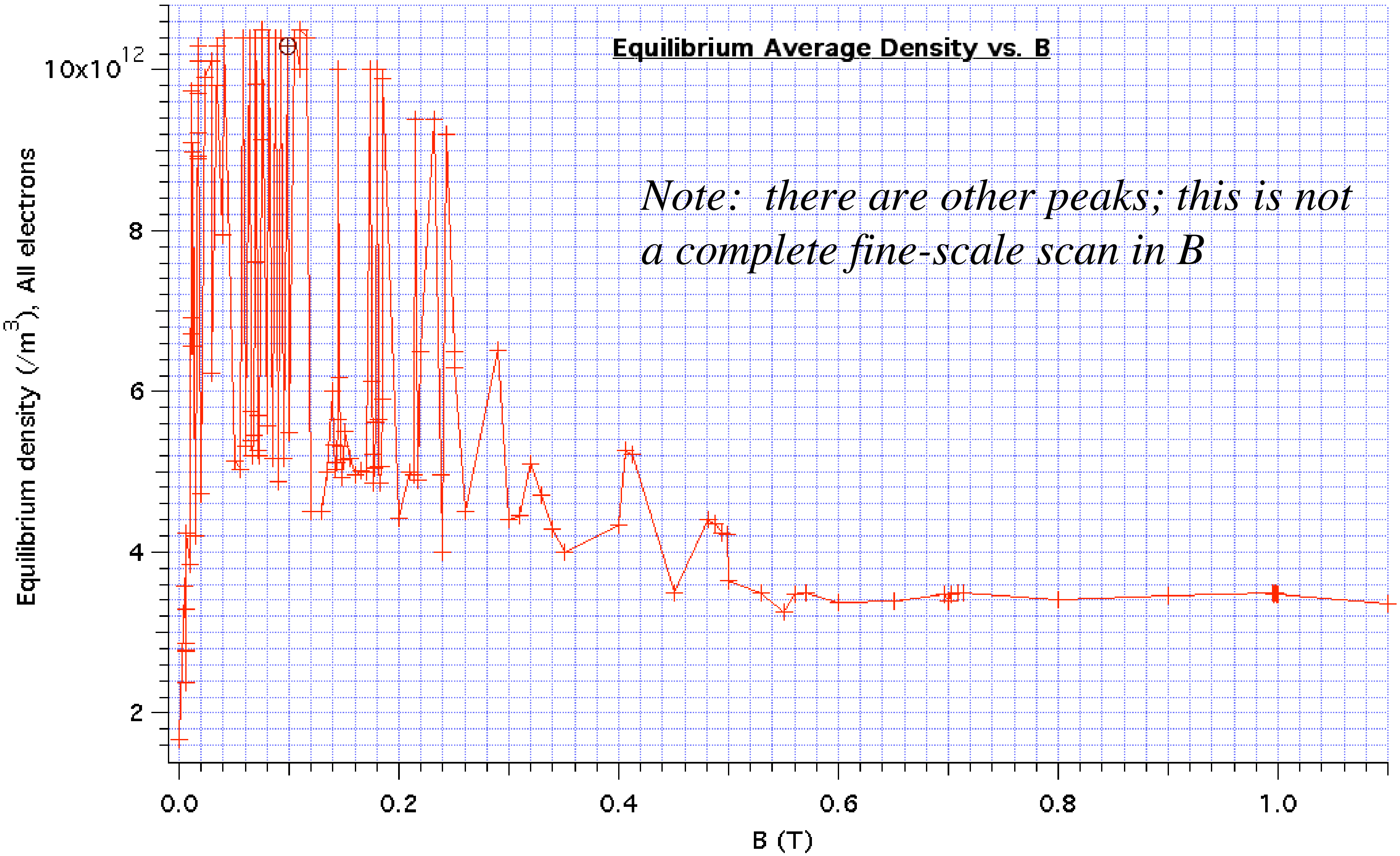
Note: Posinst is 2D, with non-evolving beam

Ideal Dipole calculations

Buildup of Average Electron Density vs. Time



Average Equilibrium Density vs. B has Peaks at Low B



Note: there are other peaks; this is not a complete fine-scale scan in B

Energy and cos(θ) changes both increase SEY for case at peak density

Comparing 2 simulations:

0.07 T - peak in the equilibrium average density
0.80 T - at high field (no peaks)

Average Energy of Electrons in Simulation:
150 eV high density case
60 eV low density case

Average cos(θ) is:

0.6 high density case
0.8 low density case

θ = e^--wall collision angle (θ =0 is normal incidence)

Peak in the curve of SEY vs. incident energy is at 195 eV. The change in average SEY in the two runs (by factor≈ 4/3) is caused by an increase in energy and decrease in cos(θ) of electrons hitting the wall.

A Hypothesis as to Why There are Peaks in Average Electron Density vs. B

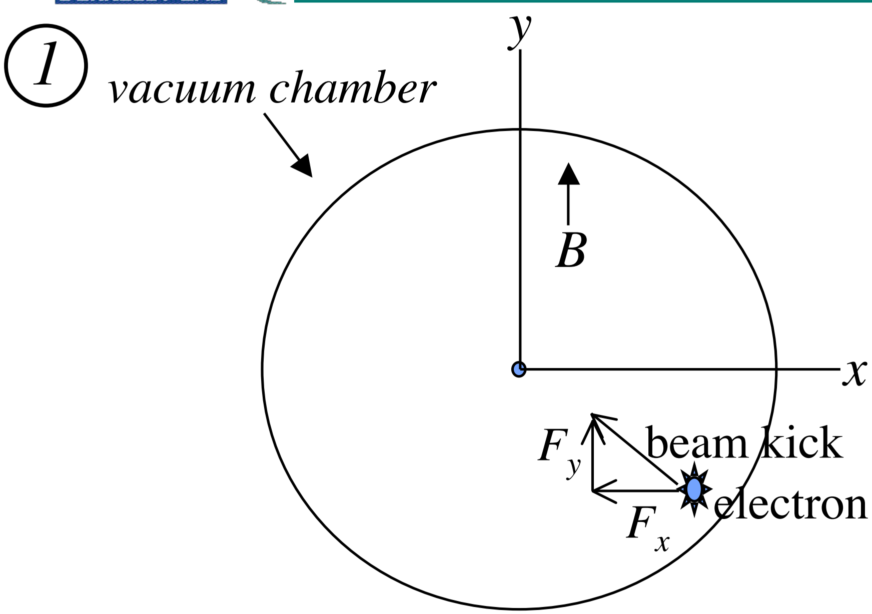
If the bunch spacing is an integral multiple of the cyclotron period, then each time the electron gets a push from the beam field, it is in the same position ⇒

Resonance

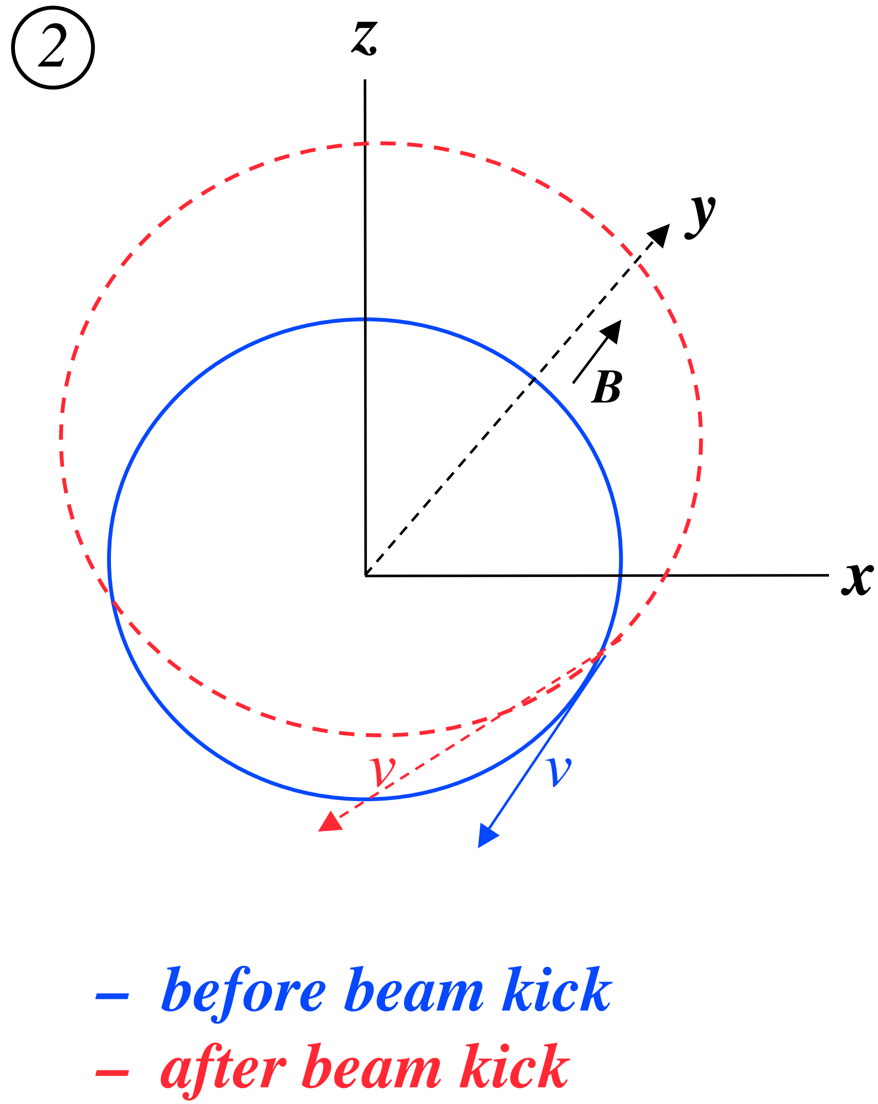
Cyclotron period is function only of B for v<<c.

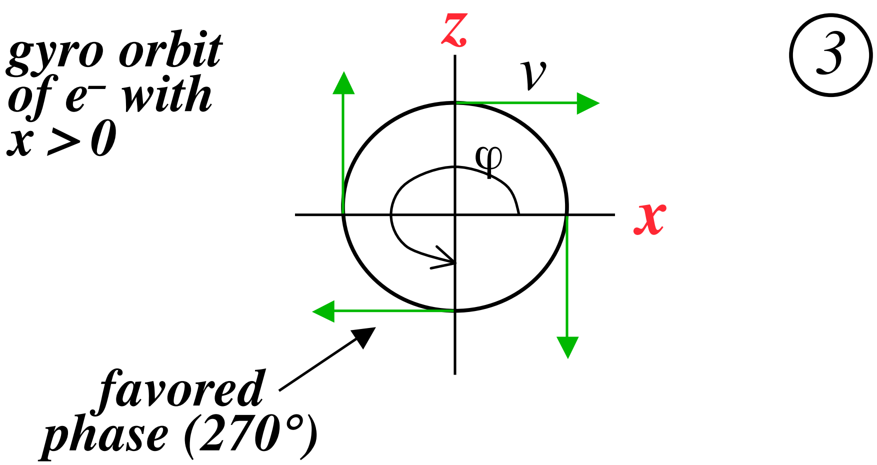
Electron stays in resonance until detuned by relativistic mass increase.

How it Works



F_x is always toward the center





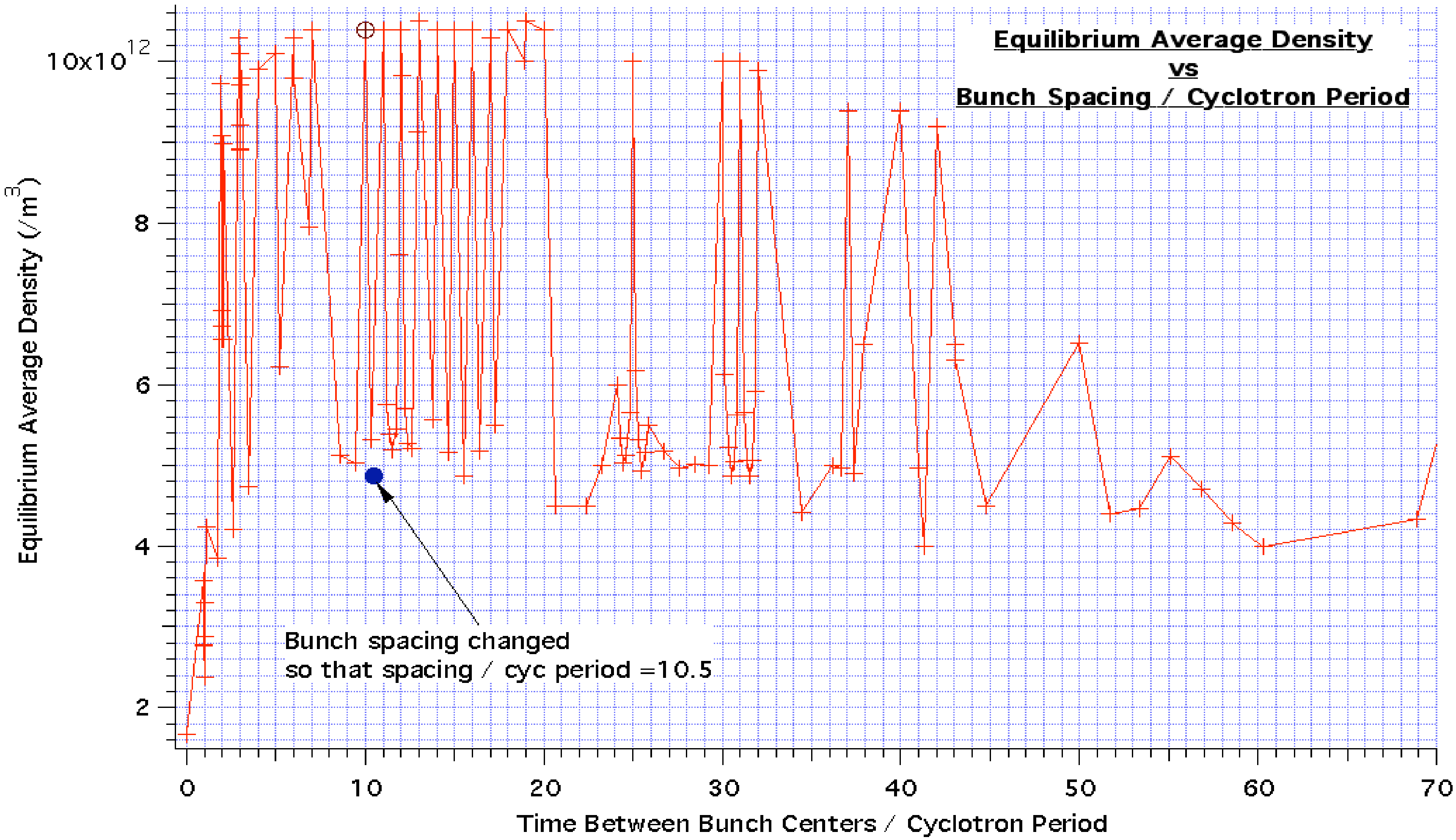
Results of Resonance

- Direction of electron $v_{\perp}$ rotates due to beam kick in a direction which aligns it with the beam kick.
- As long as $v_x < 0$ for $x > 0$, or $v_x > 0$ for $x < 0$, magnitude of v_x increases, so $v_{\perp}/v_{\parallel}$ increases. Larmor radius increases $\propto v_{\perp}$.
- Cos(θ), where θ is angle to normal when electron hits wall, decreases, increasing effective SEY.
- Energy of electron increases. This further increases SEY if doesn't surpass peak of SEY vs. E curve.
- Cyclotron period is a function only of B for non-relativistic v, so electron stays in resonance until energy increases enough to have non-negligible mass increase.

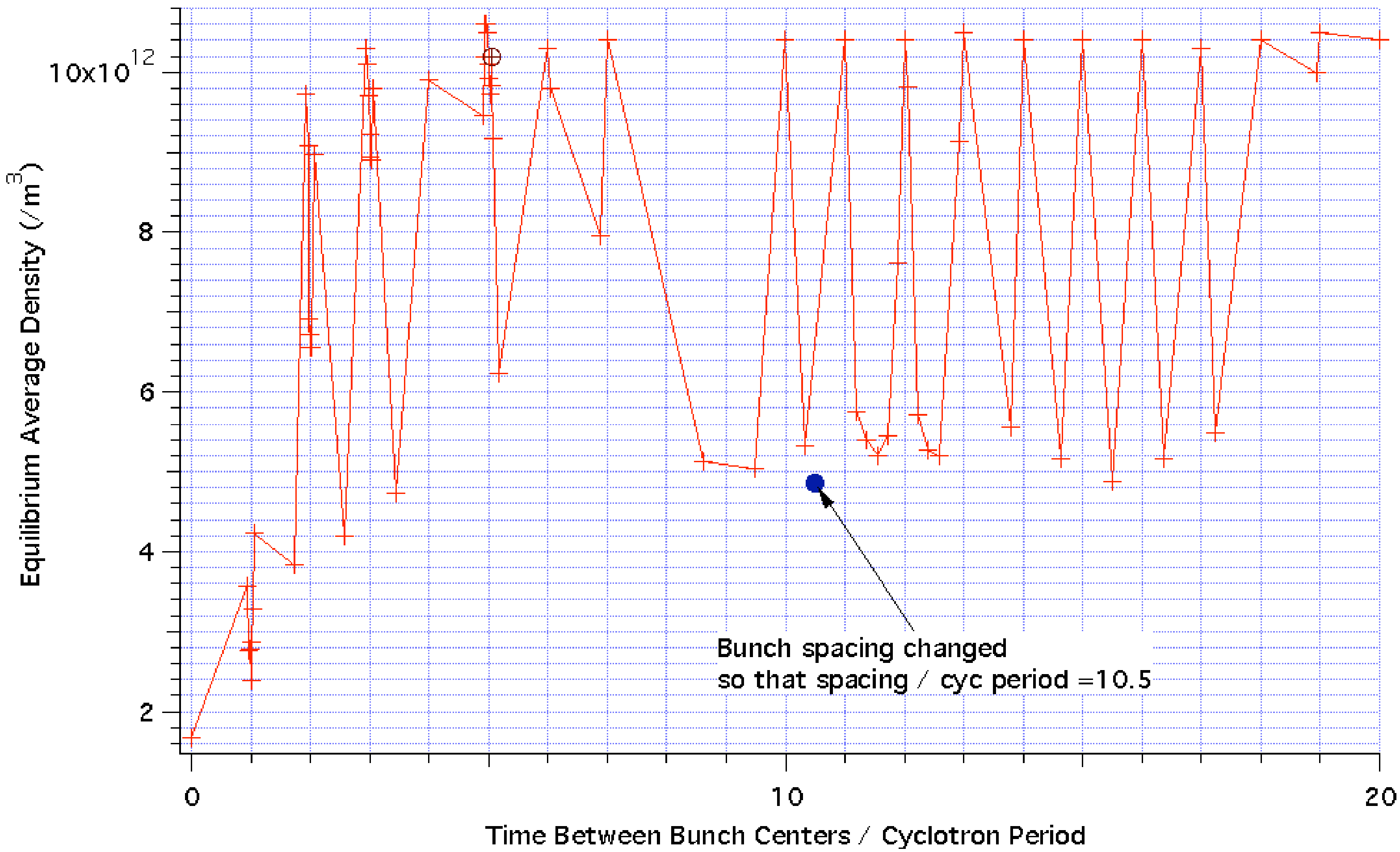
***Test**: Are peaks at integral values of (cyclotron period)/ (bunch spacing)?*

Peaks all fall on Integral Values

Note: some peaks (and dips) missing because runs have not yet been done at that field



A Closeup of Integral Spacing of Peaks



Double peaks at low B are as yet unexplained

Why does amplitude of peaks fall off with increasing B?

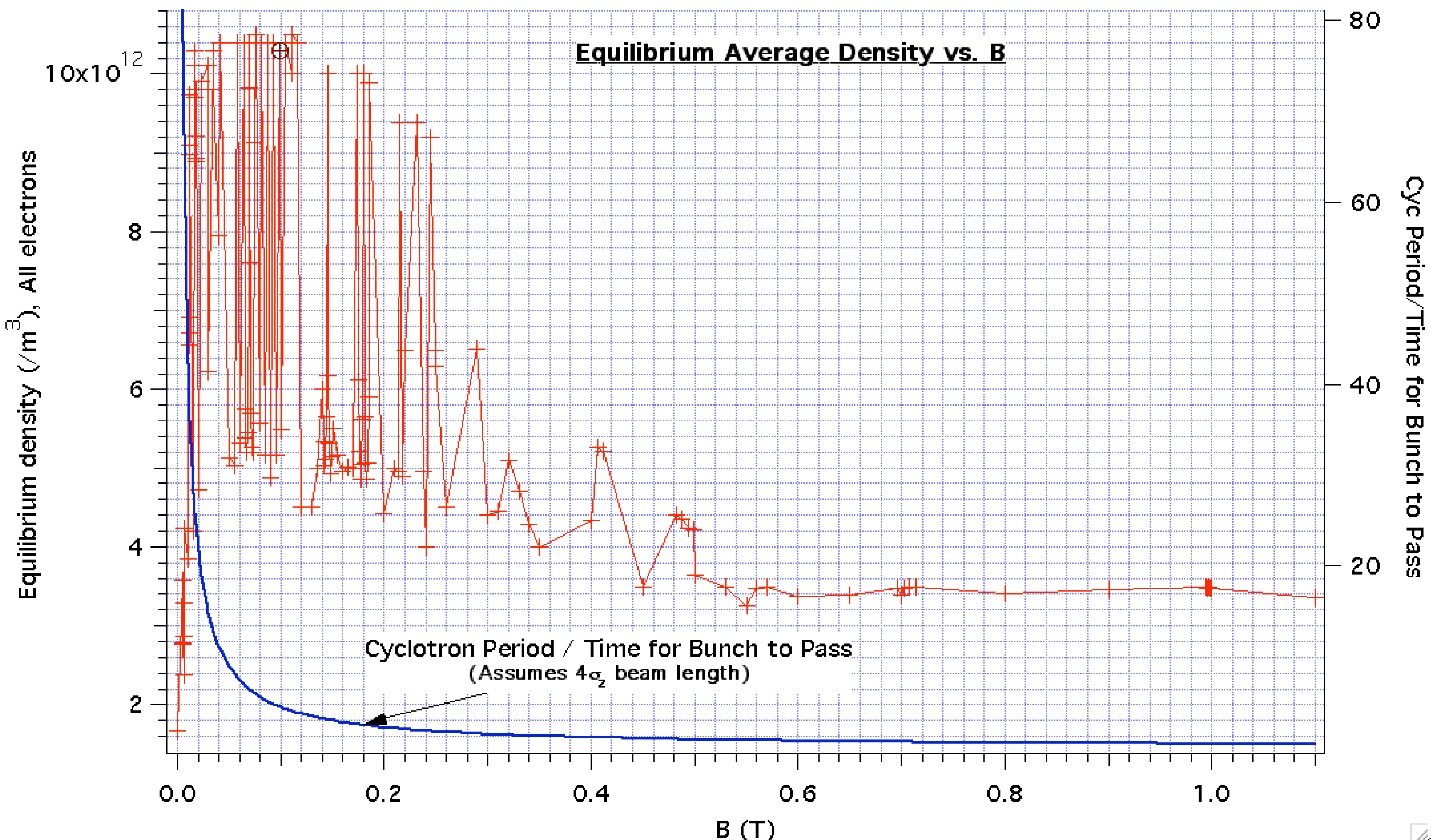
If during the time the bunch passes the electron moves through a lot of its cyclotron cycle, then the horizontal beam kick averages over cyclotron period, and the concept of the resonance fails. The peaks drop off in amplitude when

(Cyclotron Period) / (Time for bunch to pass) gets smaller.

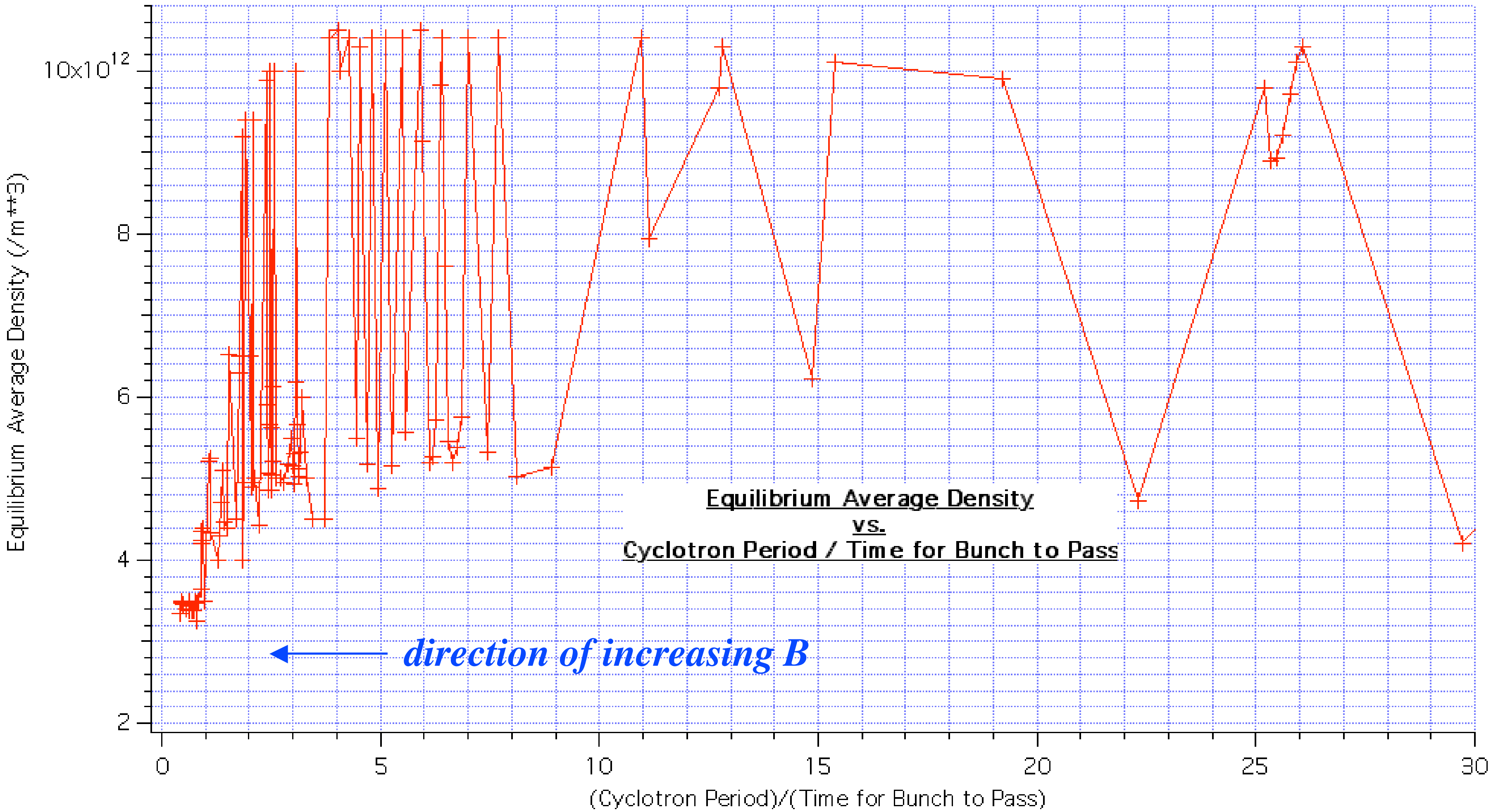
(See graph on next page.)

Blue curve (Right Axis) is cyclotron period divided by time for bunch to pass

Peak amplitude falls off as cyclotron period approaches time for bunch to pass. **Note: "time for bunch to pass" is a fuzzy number-- depends on choice of bunch length.**



Another View - Peak amplitude falls off as cyclotron period decreases



Note: This is probably the reason this effect has not been seen before-- in other machines the bunch length was much longer, and the B's studied were higher.

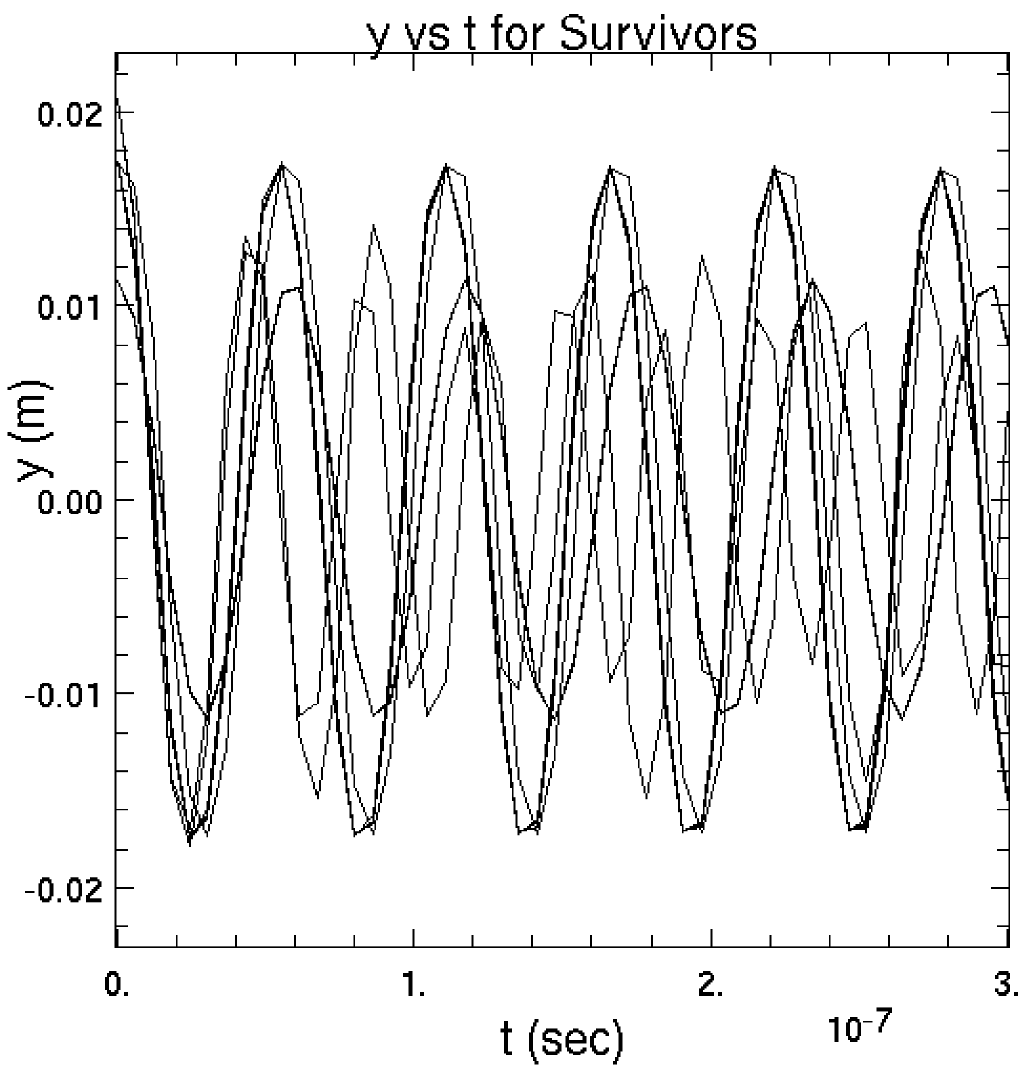
A Small Tracking Code was Written to Look at Individual Particle Dynamics

- Particles begin at top wall of vacuum chamber with $x \geq 0$
- Space charge neglected
- Beam force modeled as instantaneous kick
- 3D dynamics tracked

let n ≡ (beam bunch period) / (e^- cyclotron period)

$$= \frac{qB\tau_B}{2\pi m_0}$$

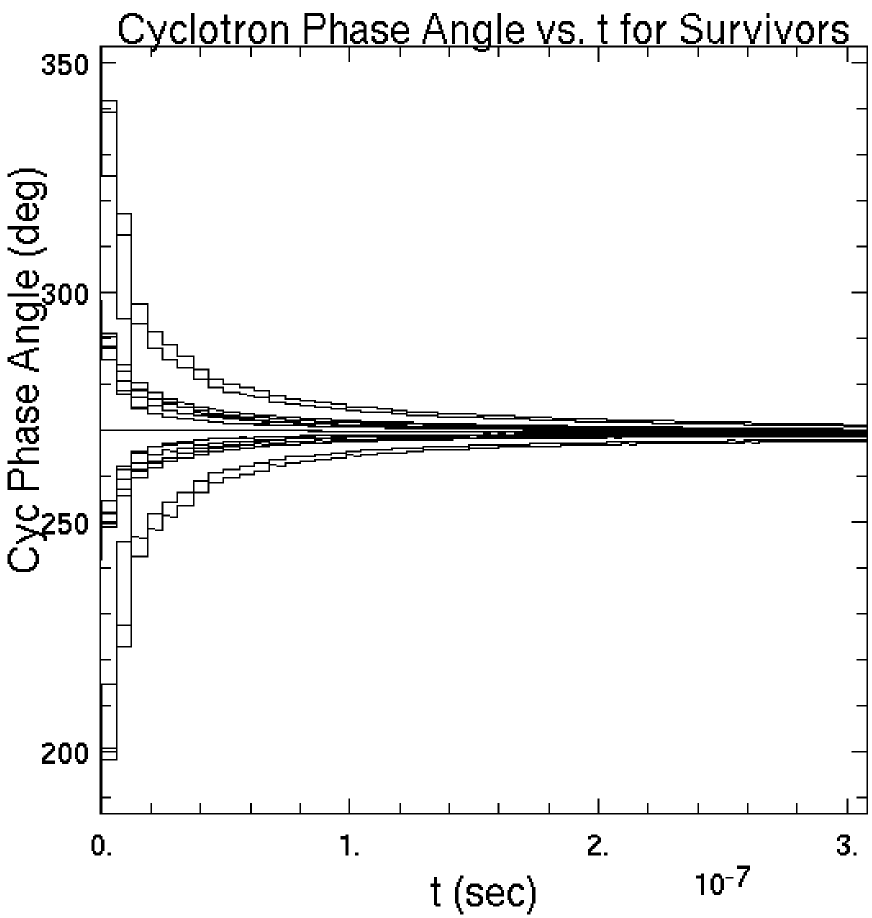
A Small Fraction of Electrons Oscillate in y for Many Bunch Passings

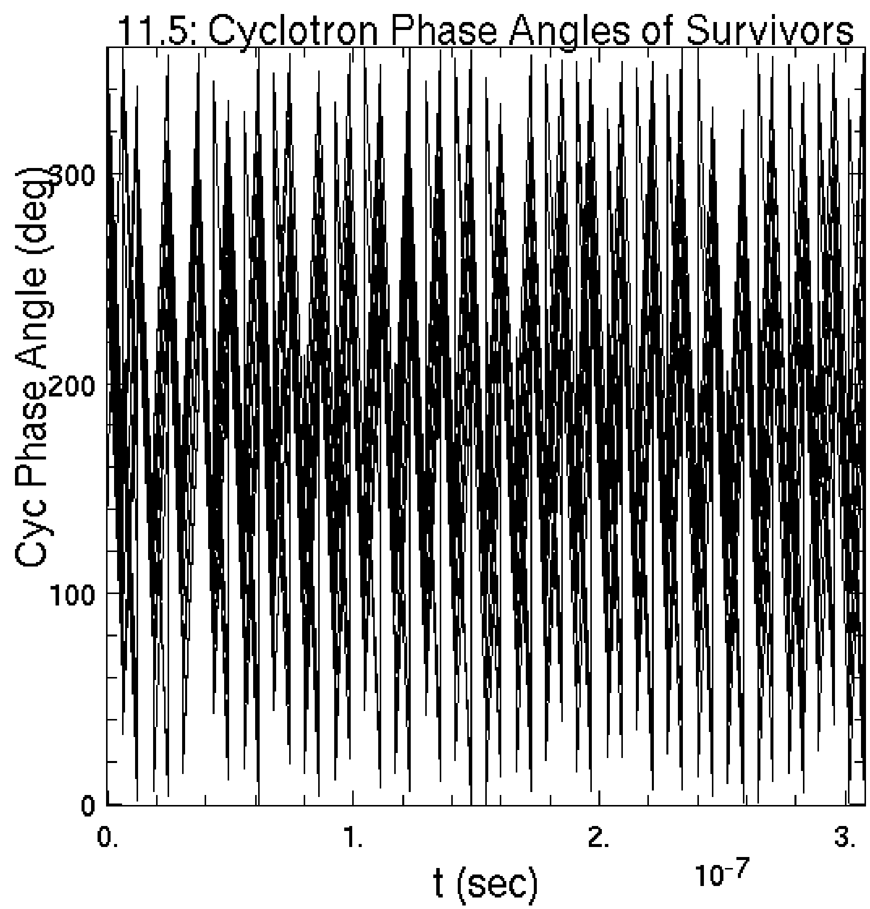


These "survivor" electrons stay in the system for > 50 bunch passages, so they are good for demonstrating longterm effects of the resonance.

Cyclotron Phase Angle vs. t for "Survivor" Electrons - non-relativistic calculation

n=12 (resonant case) *n=11.5 (nonresonant)*

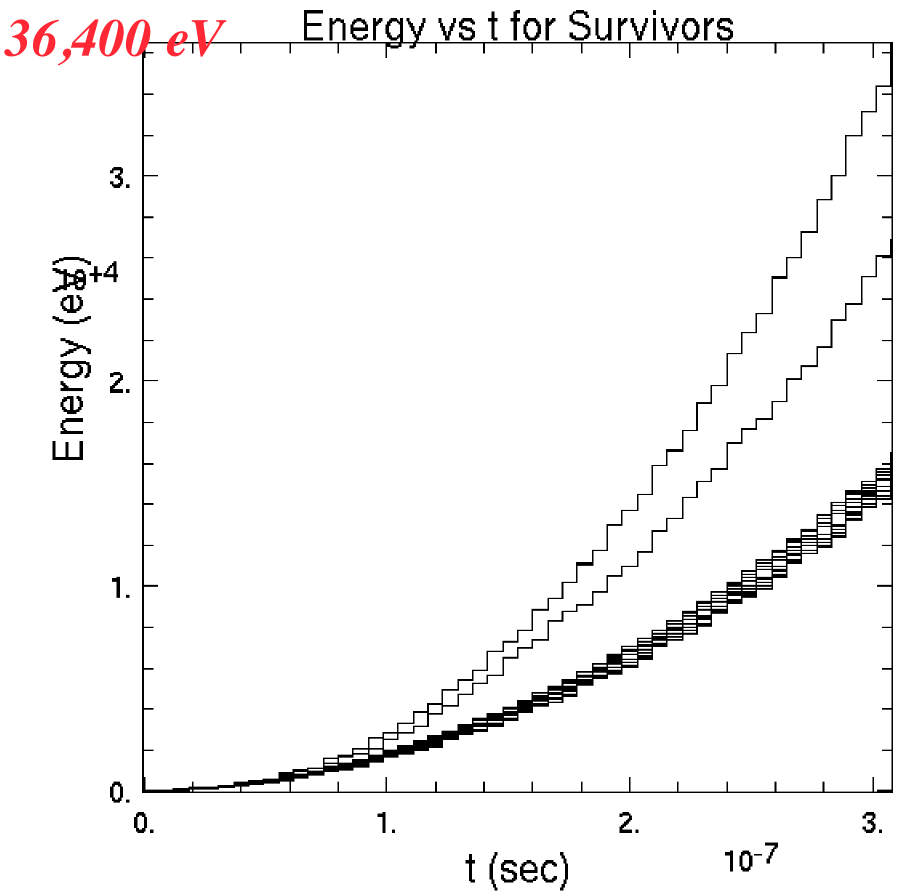




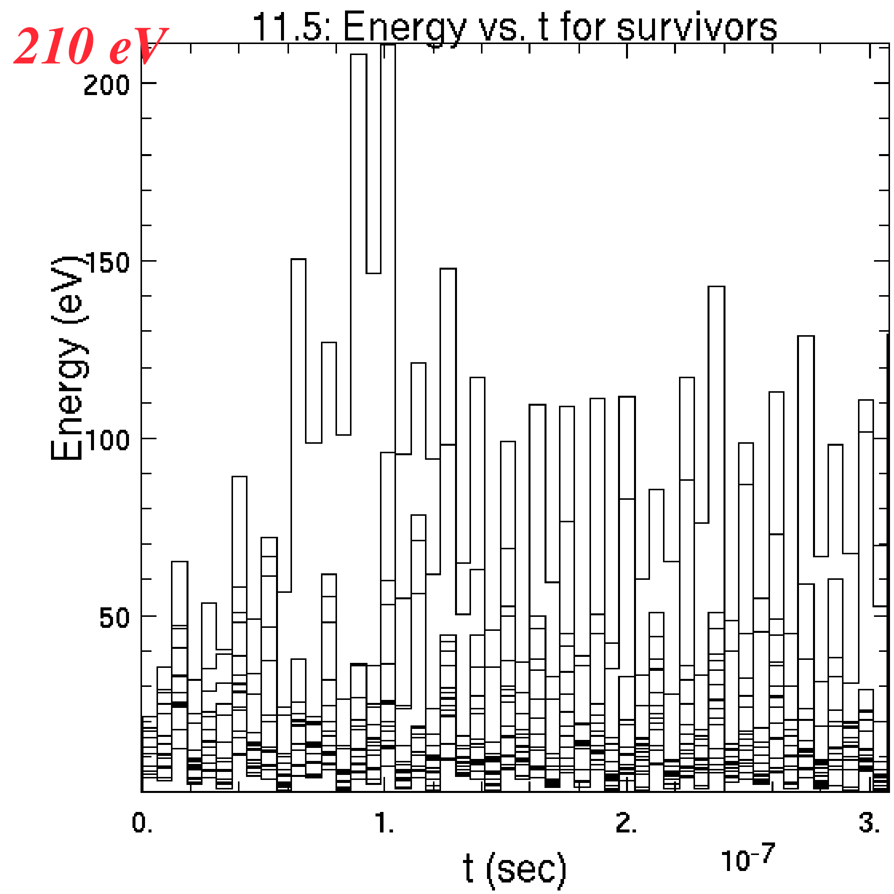
Cyclotron phase angle goes to 270°, as predicted, for resonant case, but not for nonresonant.

Energy Growth much larger for Resonant than Non-resonant Case (nonrel. calc.)

n=12 (resonant case)



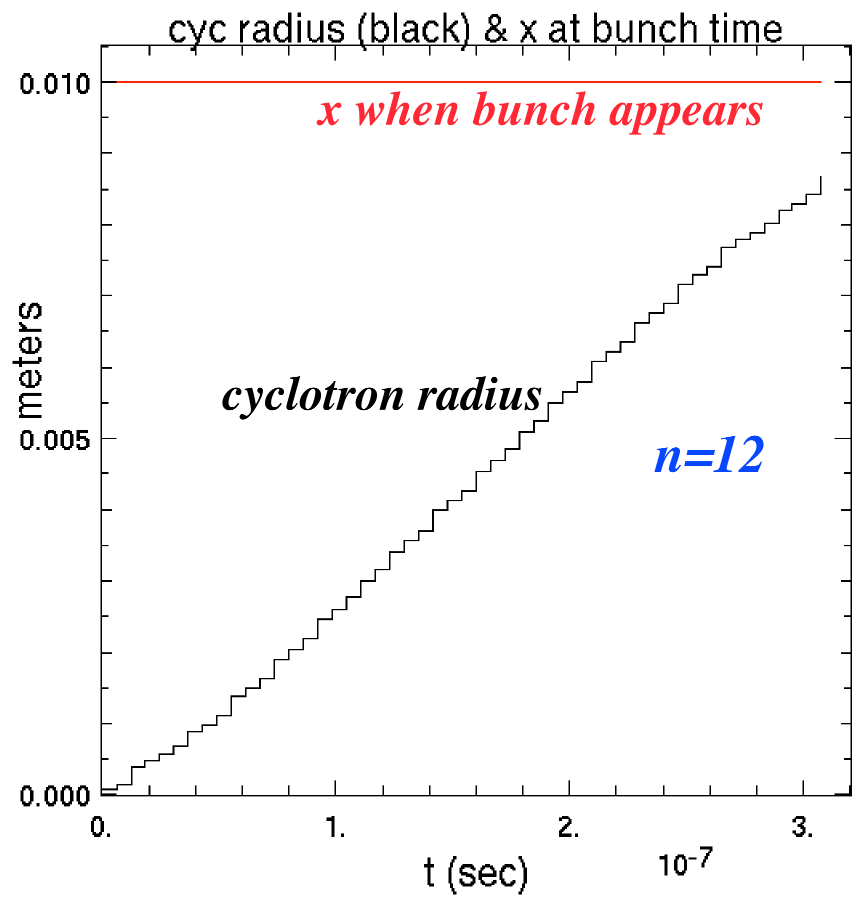
n=11.5 (nonresonant)



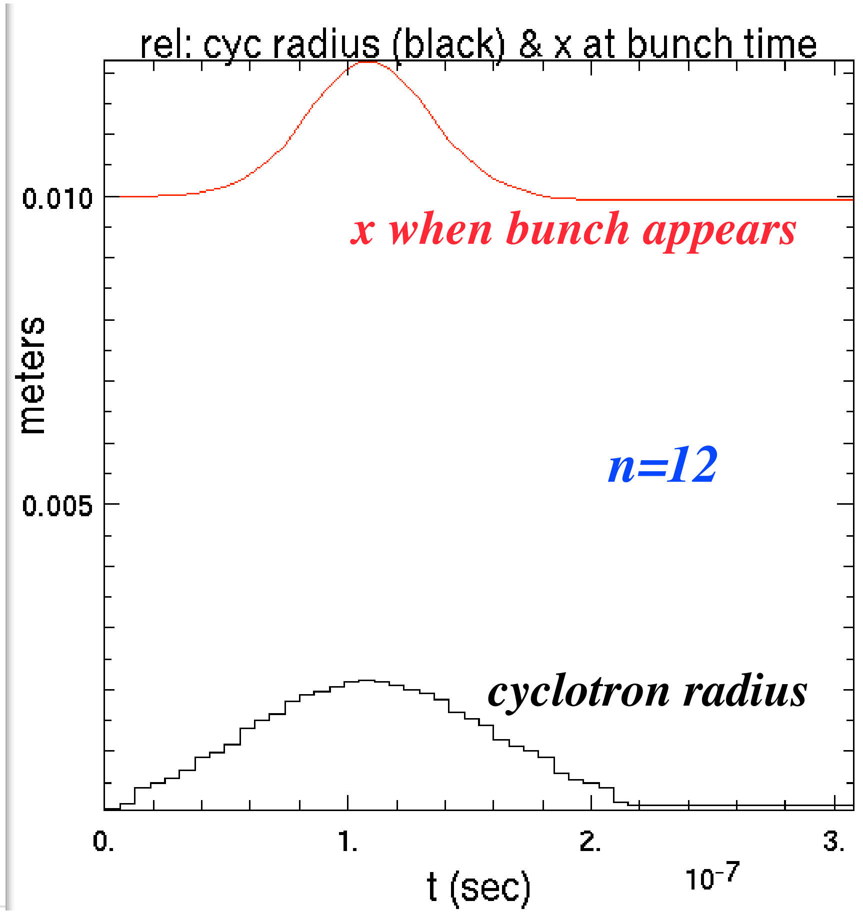
Energy grows to very large values for resonant case, but not for nonresonant.

With Proper Relativistic Dynamics, Mass Increase Detunes Electron from Resonance

Non-relativistic dynamics



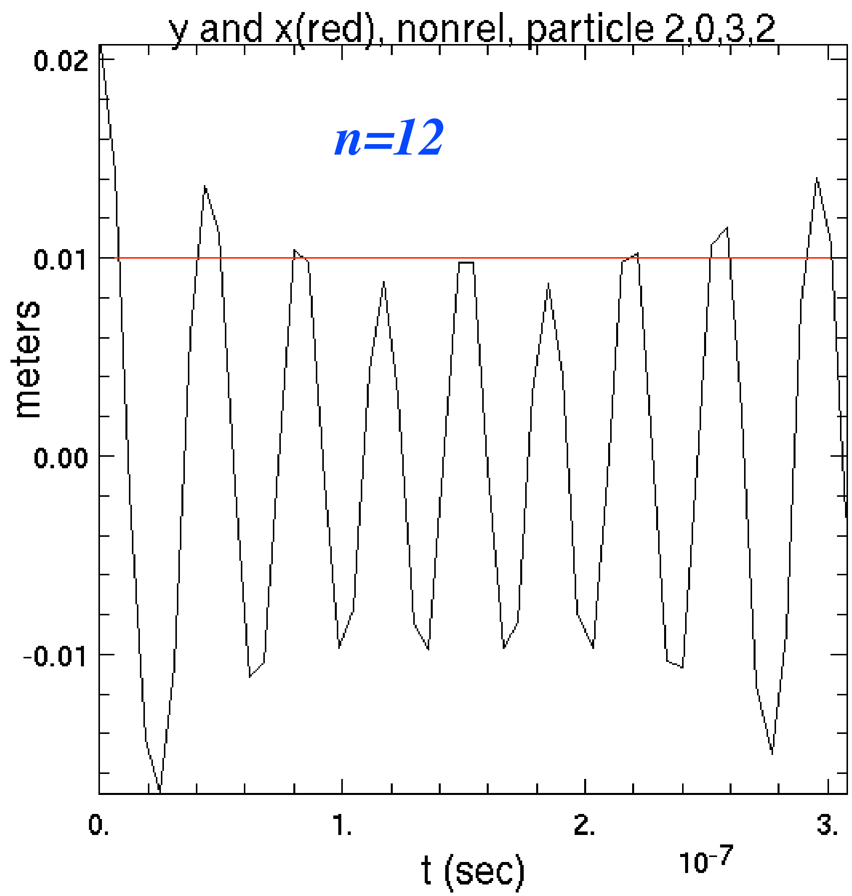
Relativistic dynamics



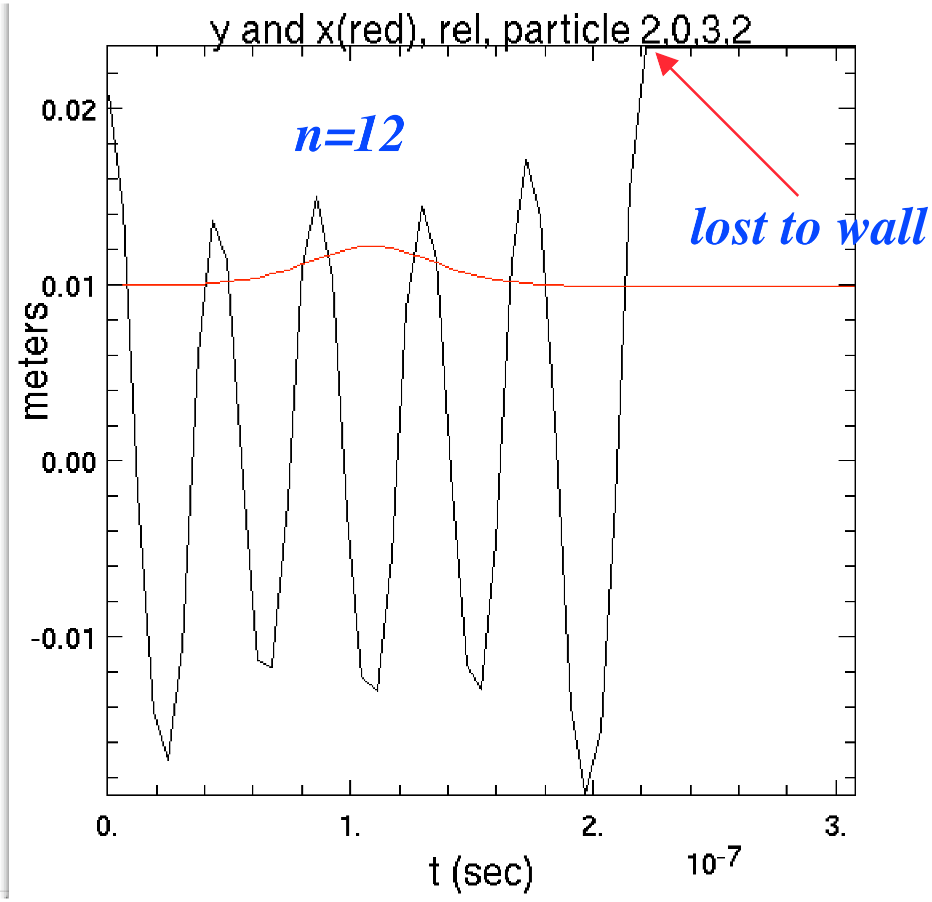
In non-relativistic case, x always same when bunch returns. In relativistic case, goes out of phase as mass increases, and then momentum (and ρ) drops

y-oscillating Electrons don't Survive as Long in Relativistic Calculation

Non-relativistic dynamics



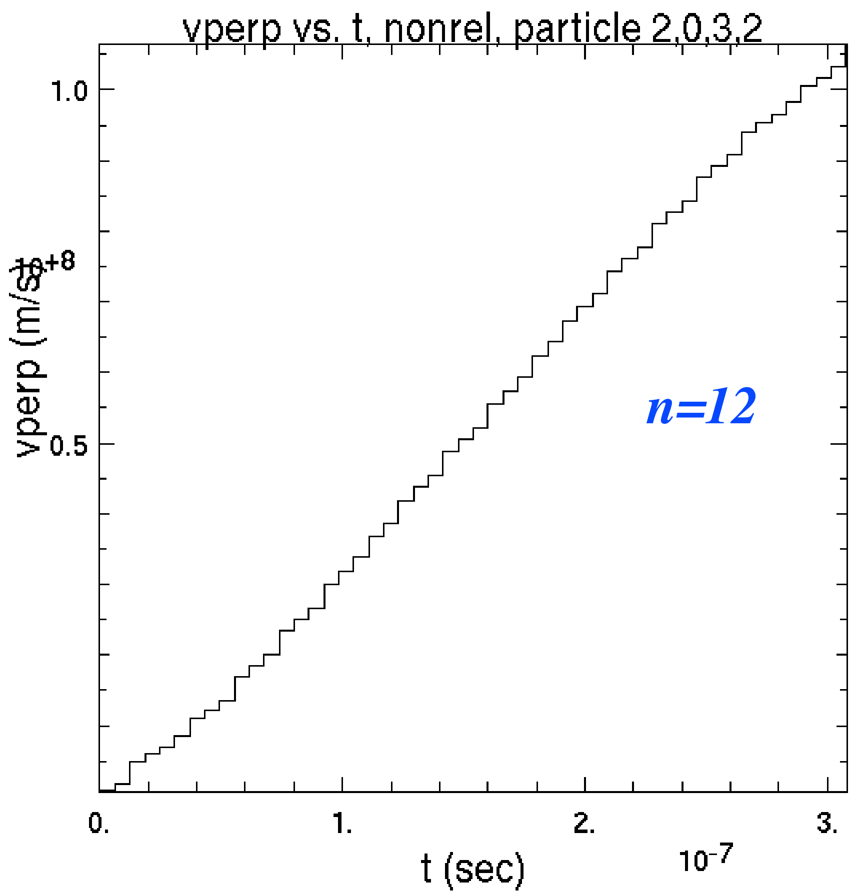
Relativistic dynamics



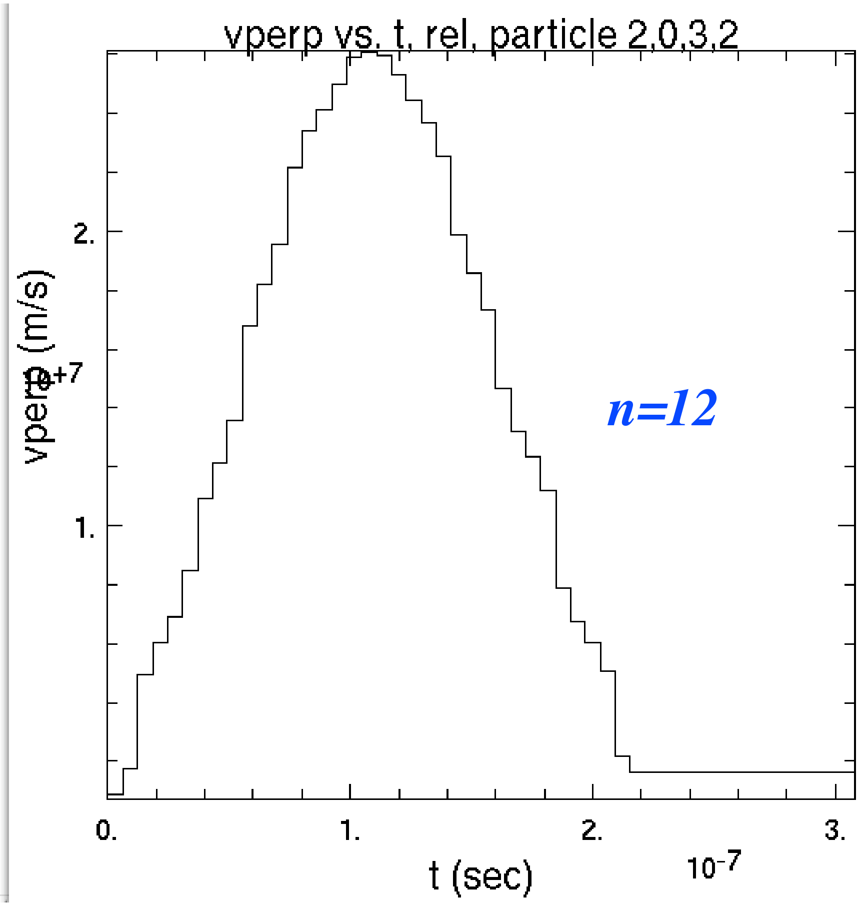
In relativistic case, oscillating particles hit the wall sooner. So final energy is lower than the non-rel. case, but they still have relatively high energies, and hit the wall and produce secondaries more often.

Electrons go out of phase, so $v_\perp$ rises then falls

Non-relativistic dynamics

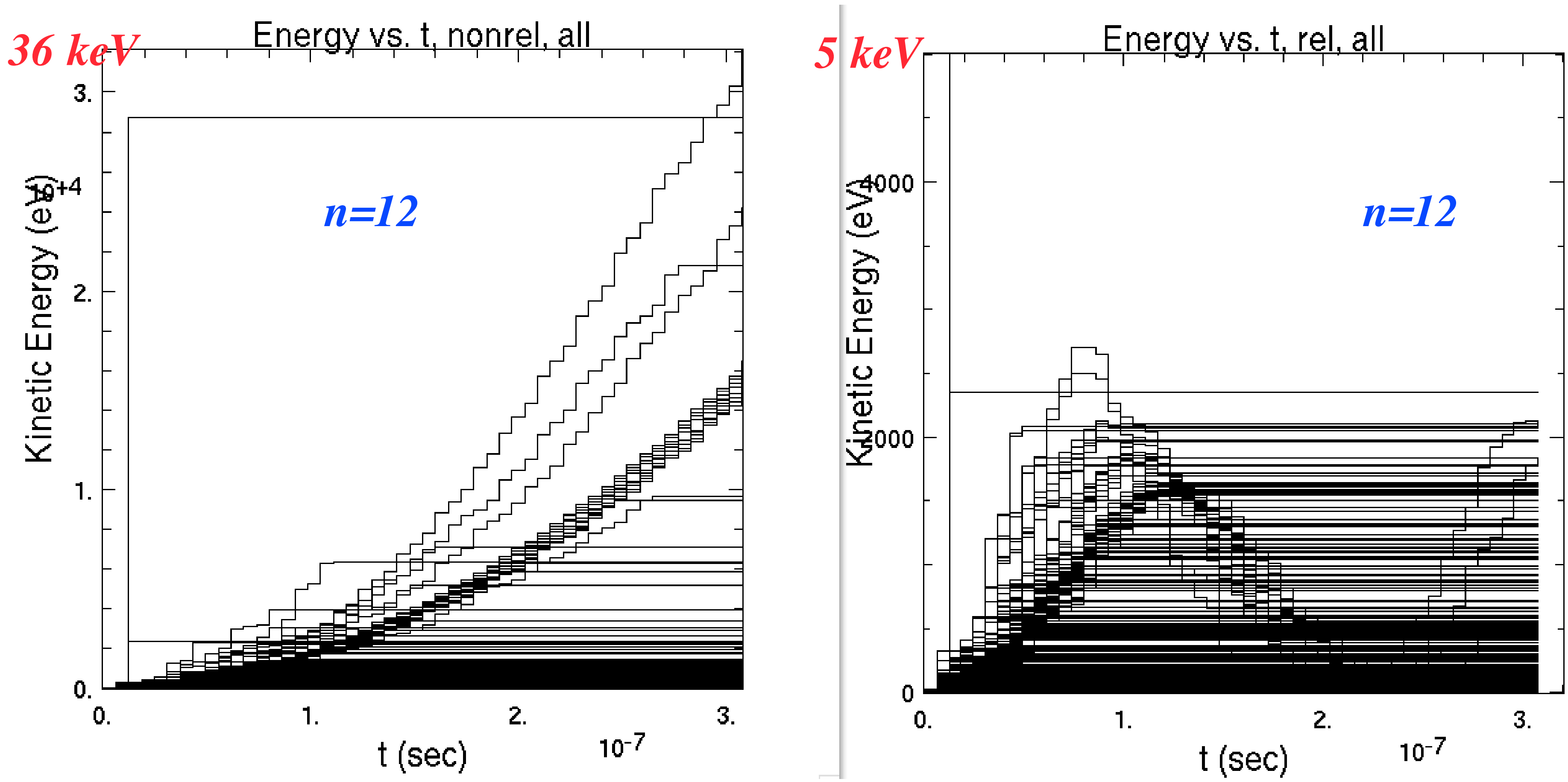


Relativistic dynamics



Final Energies- Smaller than Non-relativistic Case and Match the Simulation Better

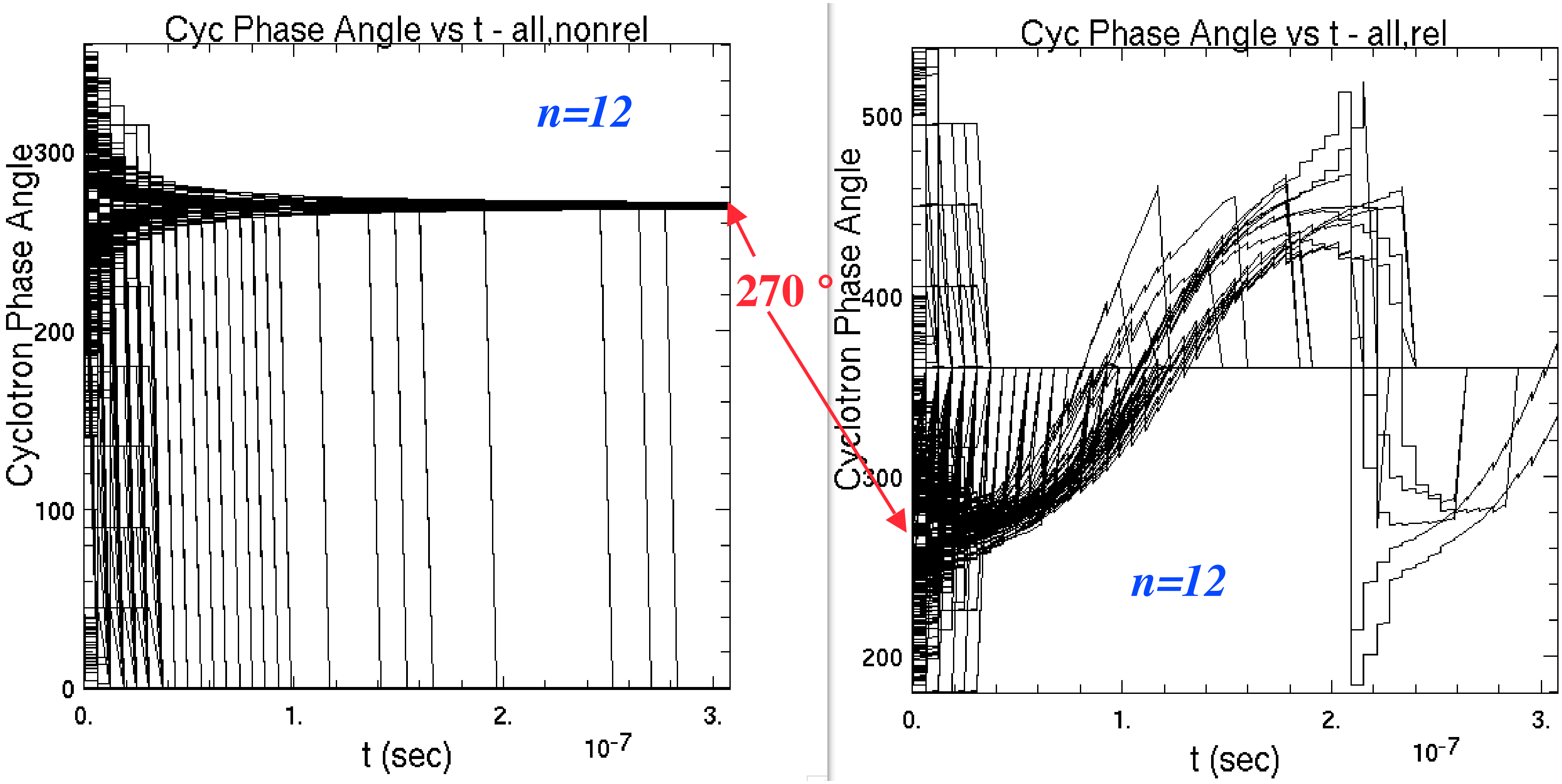
Non-relativistic dynamics *Relativistic dynamics*



Note: when electrons hit the wall, their energy stops changing (horizontal line)

Cyclotron Phase Angle vs. t Also Shows Electrons Going In and Out of Phase

Non-relativistic dynamics | *Relativistic dynamics*

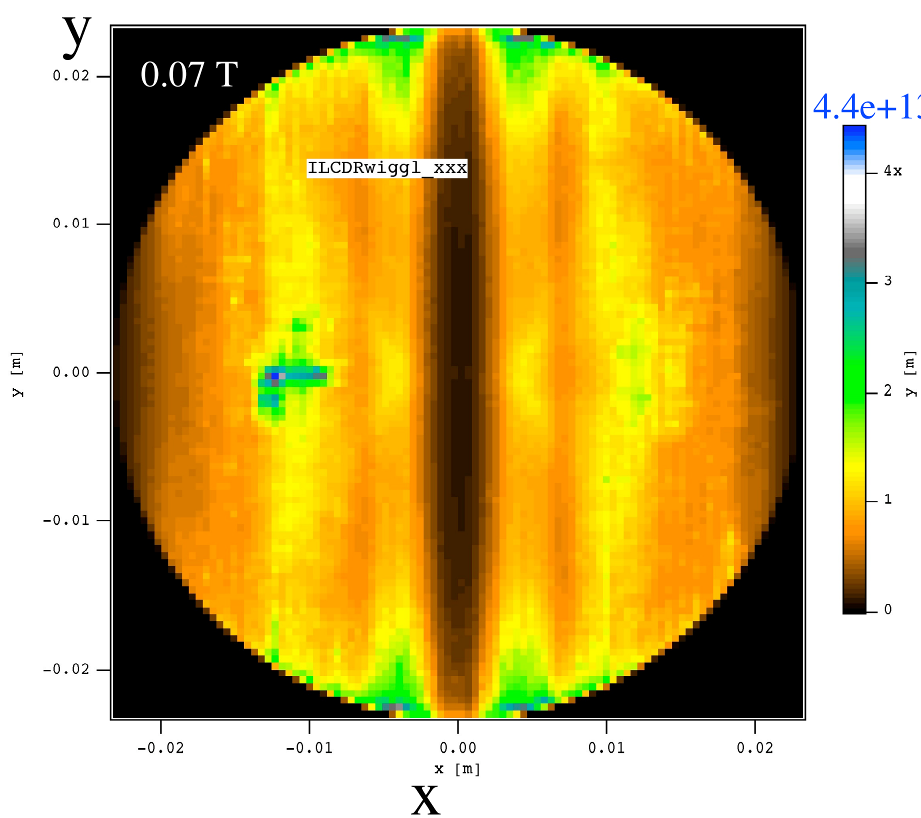


Note: when electrons hit the wall, their angle is set to zero (gives vertical lines)

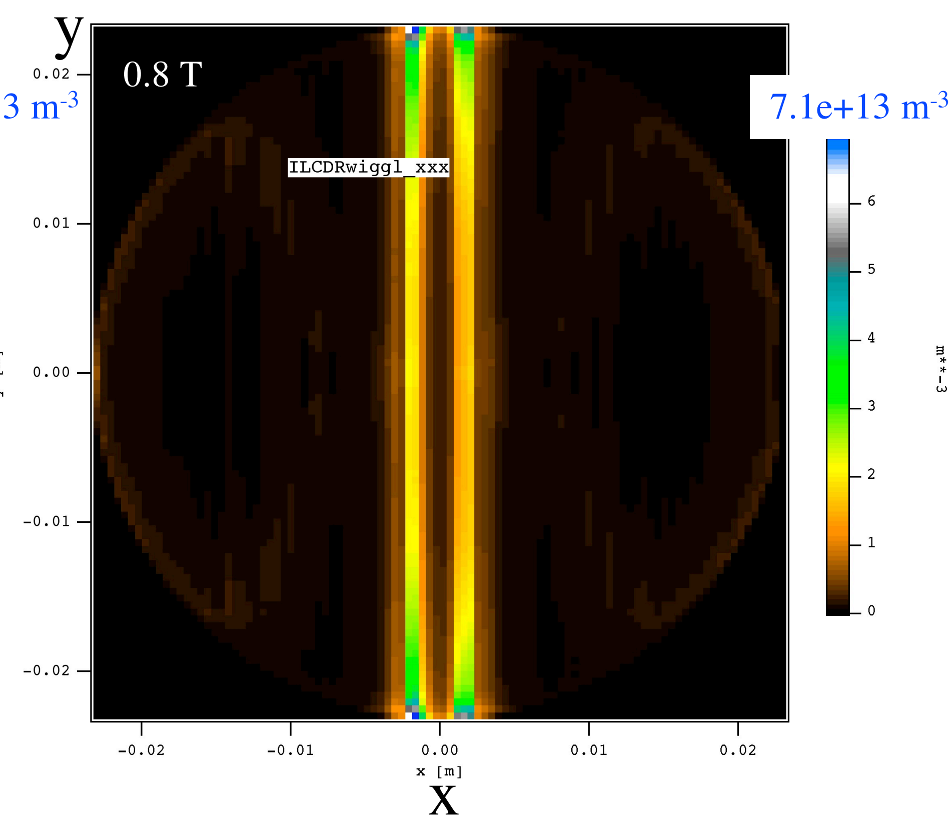
<u>Conclusion</u>: This small tracking code clearly shows the expected effect, and indicates the mechanisms for average SEY increase. It cannot, of course, find the equilibrium average density level.

Another effect, from POSINST Simulation: Stripes are Different in Resonant Case

Density Distribution, Averaged over Run (POSINST)



Resonant B



Non-resonant B

Reason may be that energy of electrons depends on new factors: resonance dynamics and longevity.

Comments

- This resonant effect produces an increase in the electron cloud density that is not huge (factor of 3), but it is periodic with the wiggler periodicity. Therefore it could possibly cause resonant affects on the beam.

- 3D calculations will be very important in showing what effect this resonance has on the electron cloud magnitude in the wiggler, and in dipole fringe fields. In 3D, the ExB drift will send particles to a different z (and B), so electrons will gradually go in and out of resonance. The resonance may affect more particles, but the effect on a given electron may be less??

- Should try to measure this at CESR-TA, and possibly PEP-II.