Electron Dynamics in the Wigglers of CESR-TA*

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LBNL ecloud group
David Grote & Jean-Luc Vay

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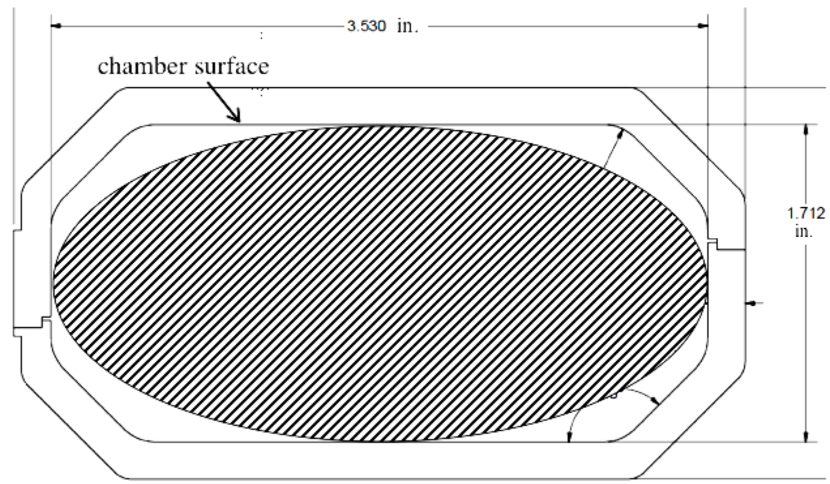
Parameters for 3D WARP-POSINST runs

Parameters	Values
Current/bunch (mA)	4.0
Bunches/train	45
Beam Energy (GeV)	2.085
Bunch Spacing (ns)	14
Photons/e^+/meter	2.16 *factor of 3 high*
Photon Reflectivity	20%
Quantum efficiency	0.1
σ_x (mm)	0.46
σ_y (mm)	0.06
σ_z (mm)	8.8
Peak SEY, normal incidence	1.8
Energy at SEY peak (eV)	276
Peak B (T)	1.9

Beam does not evolve – beam field is Bassetti-Erskine

Other features and simplifications

- POSINST model for photoelectron and secondary emission used
- Cornell calculation of wiggler field (OPERA) provides B
- Beam does not wiggle
- Beam magnetic field neglected
- Vacuum chamber elliptical

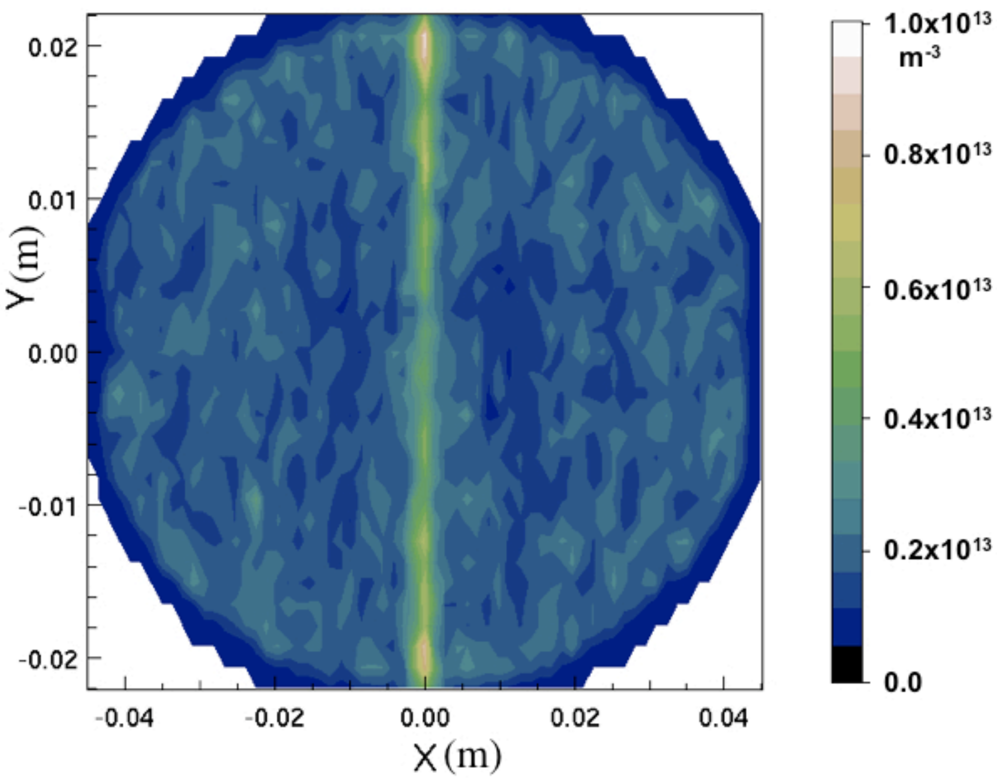


Resolution in x, y, z: 0.71 x 0.71 x 6.2 mm

Timestep: 1.57 x 10^{-12} s

There are two dynamical regions – "dipole-like" and behavior near B_y zeros

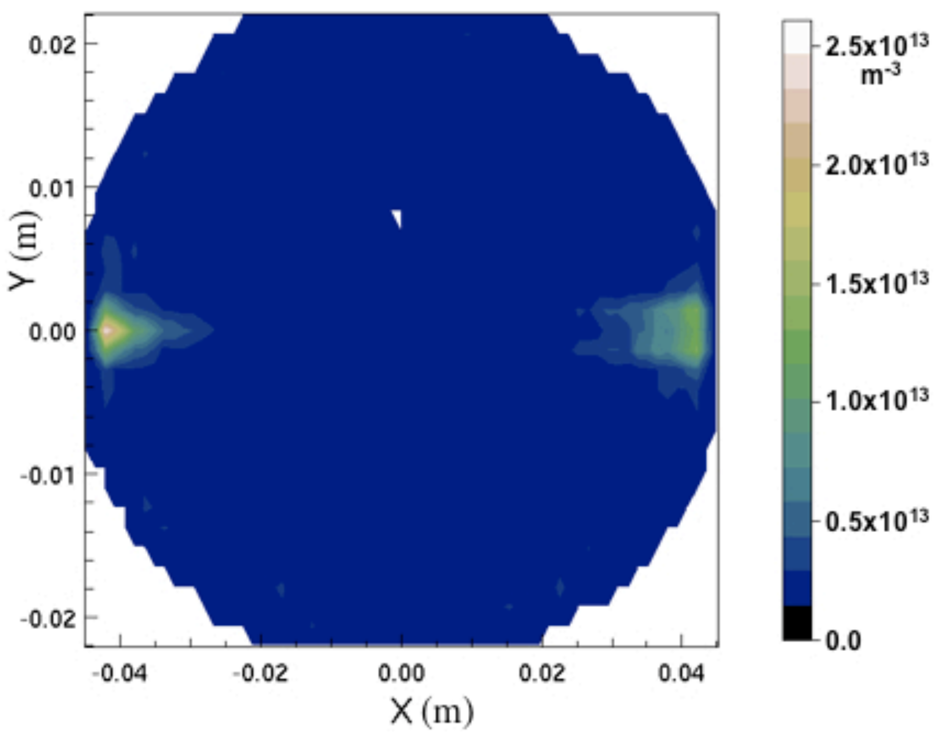
Near z of maximum B_y electrons are in vertical stripe(s)



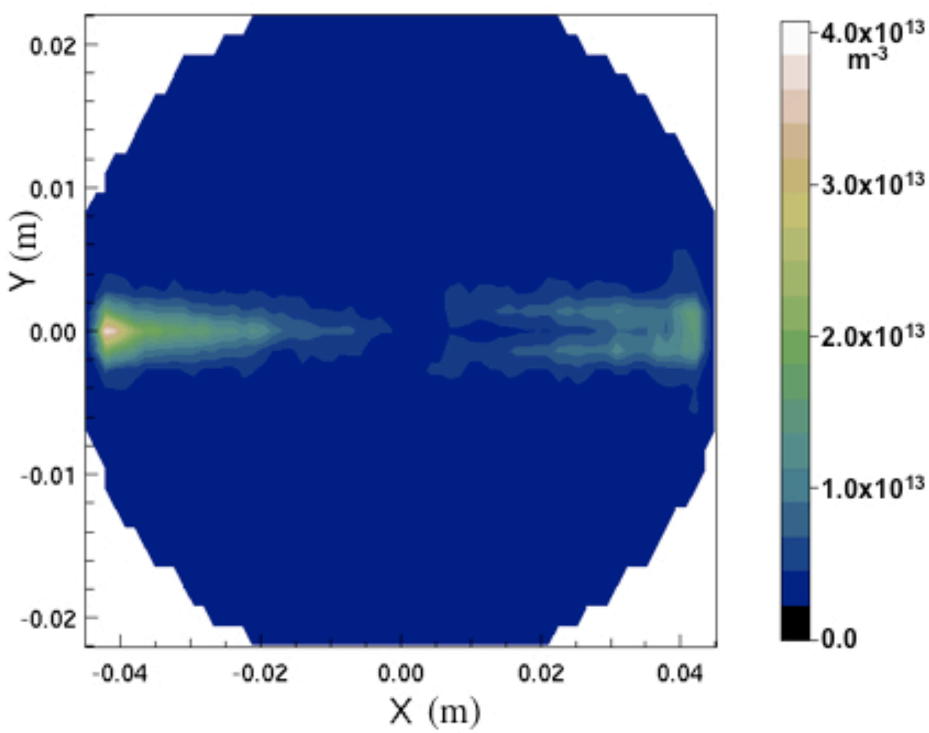
Electrons within 3 mm in z of B_y maximum, just after 45th bunch

In regions with significant longitudinal field, electrons cross field lines near midplane

within 3 mm in z of z where B_y=0



just before bunch 11

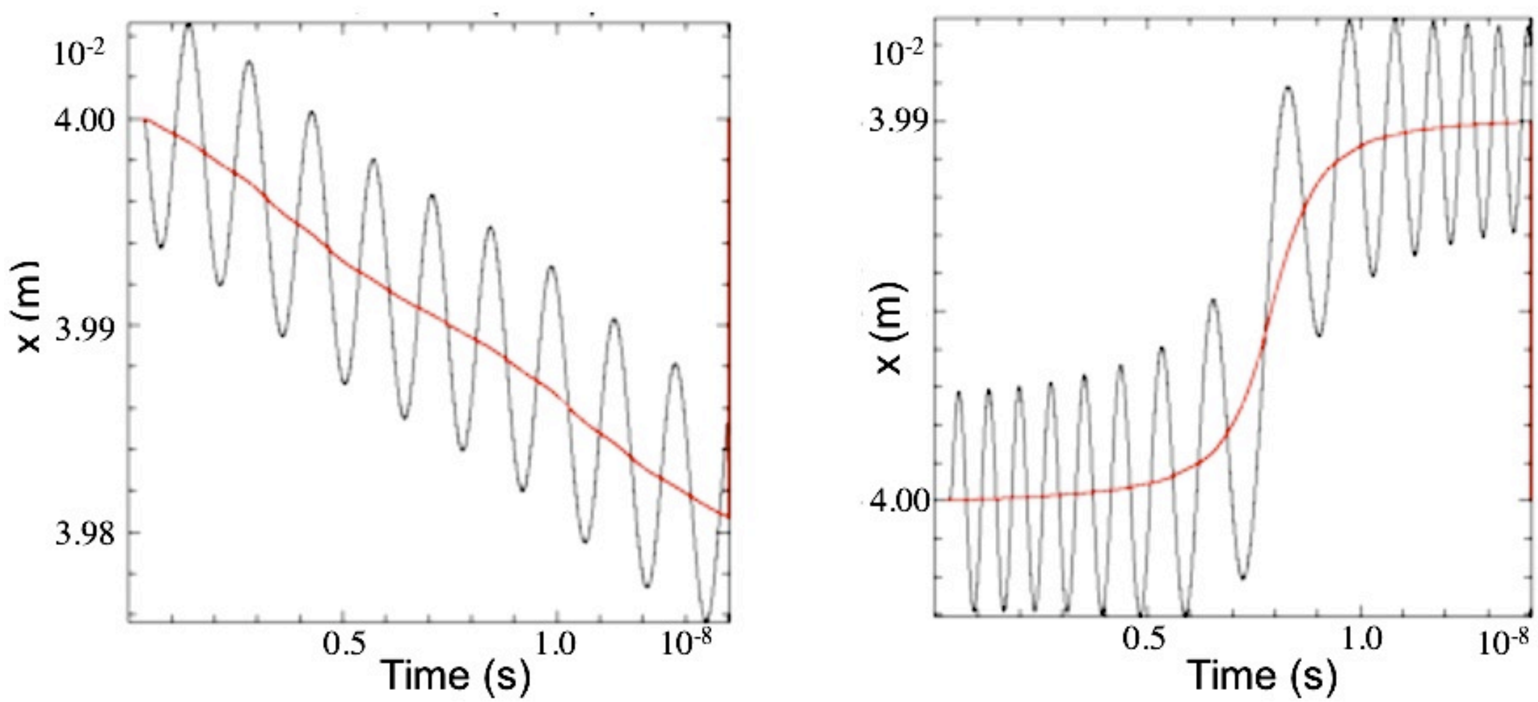


just before bunch 45

No crossing of field lines seen for pure longitudinal B (ideal solenoid)

No effect of electron space charge or beam field

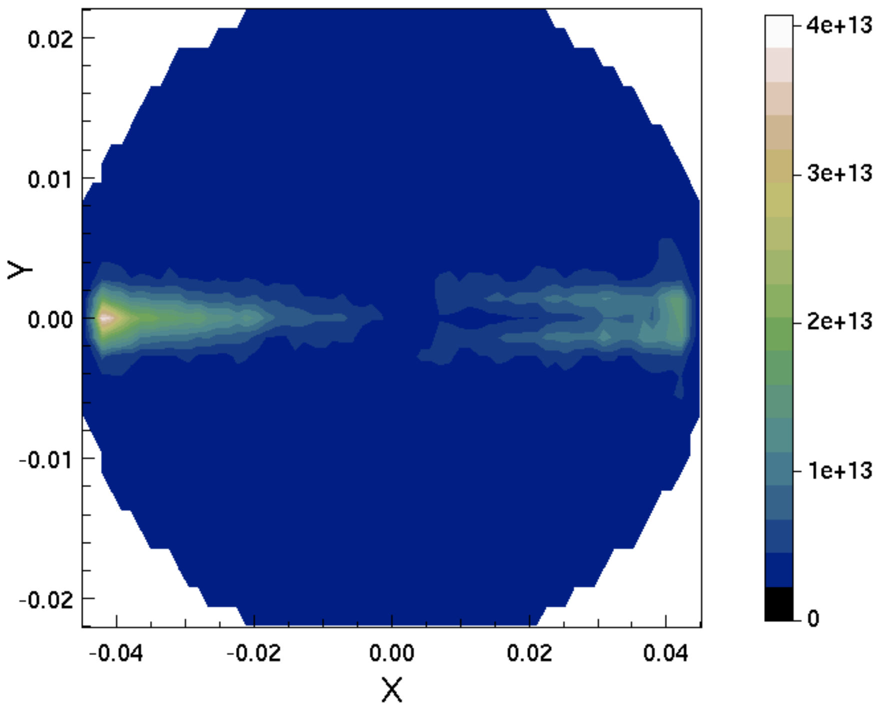
Single particle orbits show that cause is gradient & curvature of B

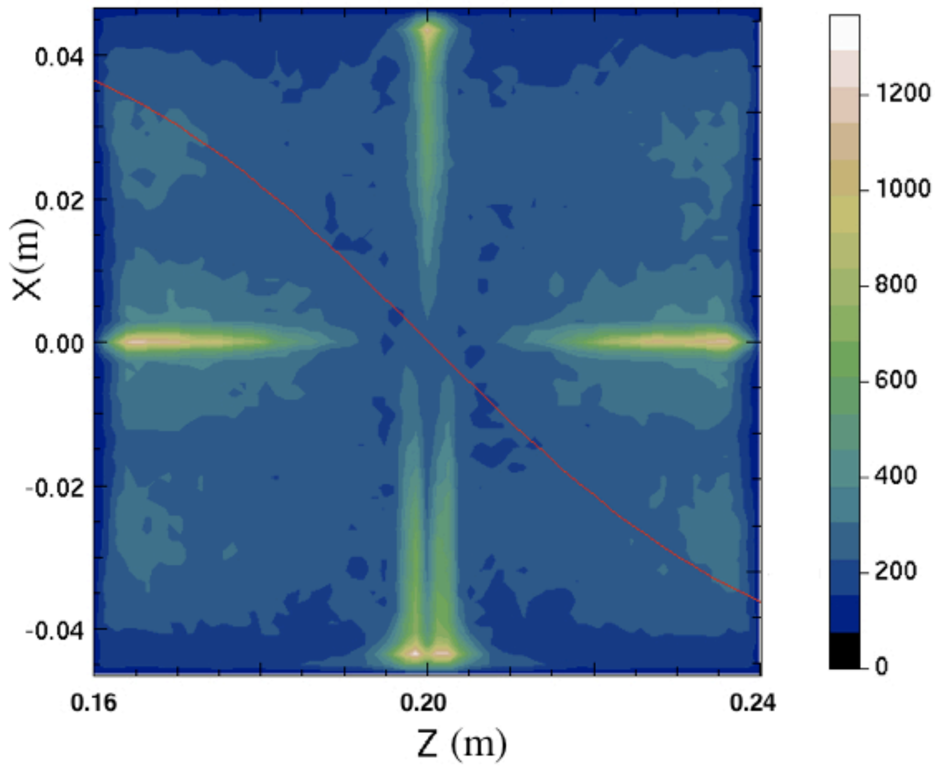


- — Electron orbit
- — Orbit of gyrocenter according to standard expression for grad B / curvature B drift:

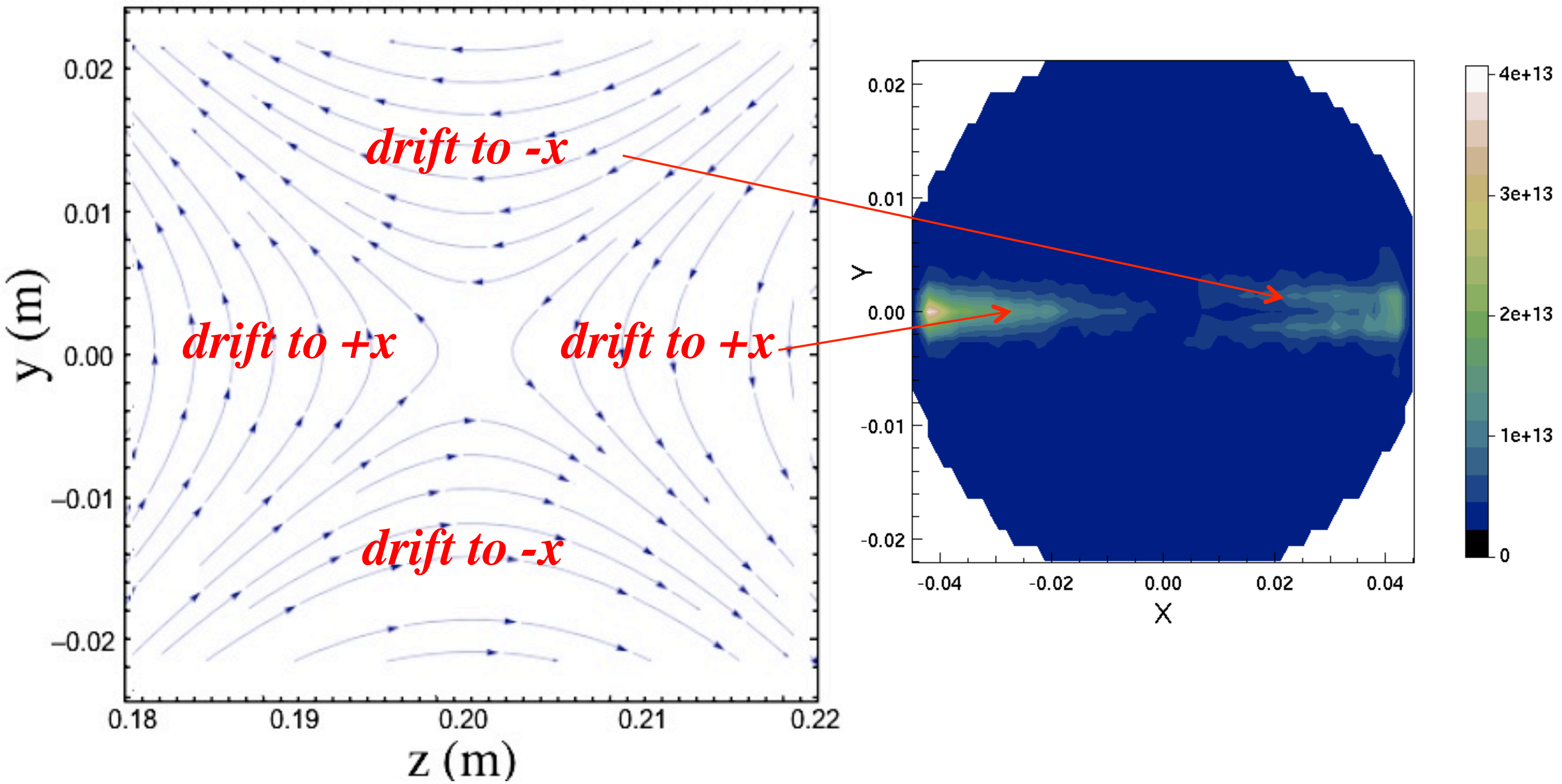
$$v_d = \frac{m}{e} \frac{\nabla |B| \times \vec{B}}{|B|^3} (v_{\parallel}^2 + \tfrac{1}{2} v_{\perp}^2)$$

Electrons near B_y=0 have "forked" structure in y and z



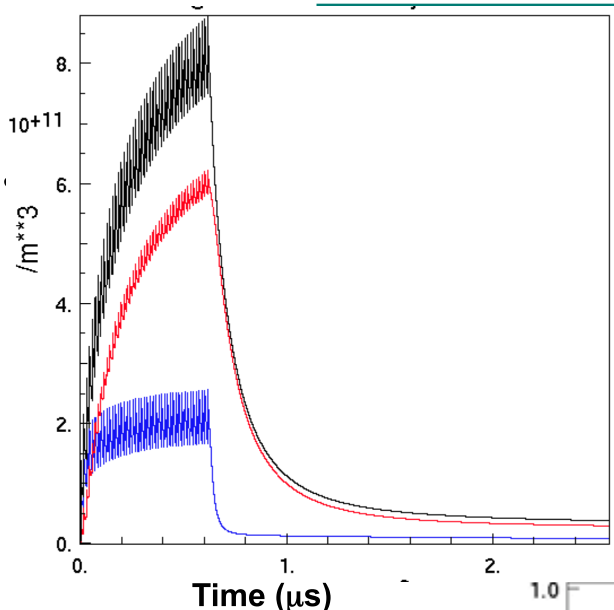


Structure of cloud near B_y=0 is due to two different populations of electrons



Near separatrices grad B is parallel to B. Drift velocity → 0

Build up of cloud in various sections (density averaged over whole chamber)

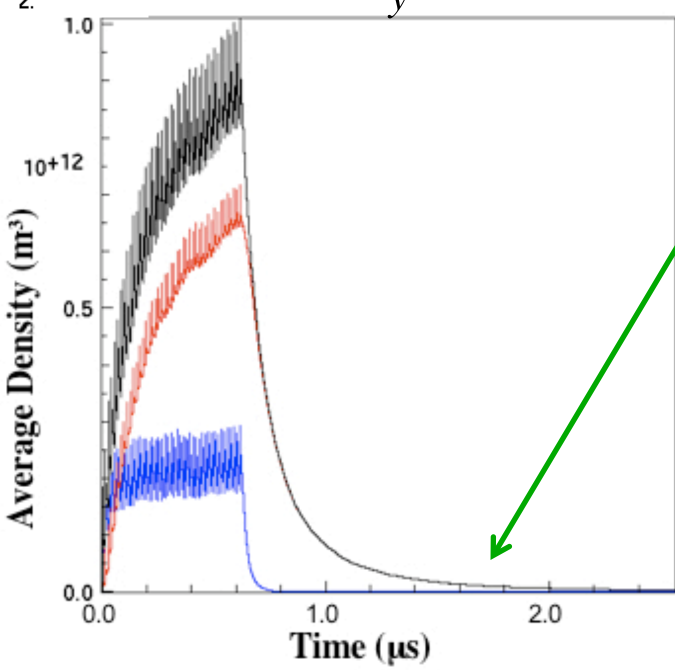


wiggler period

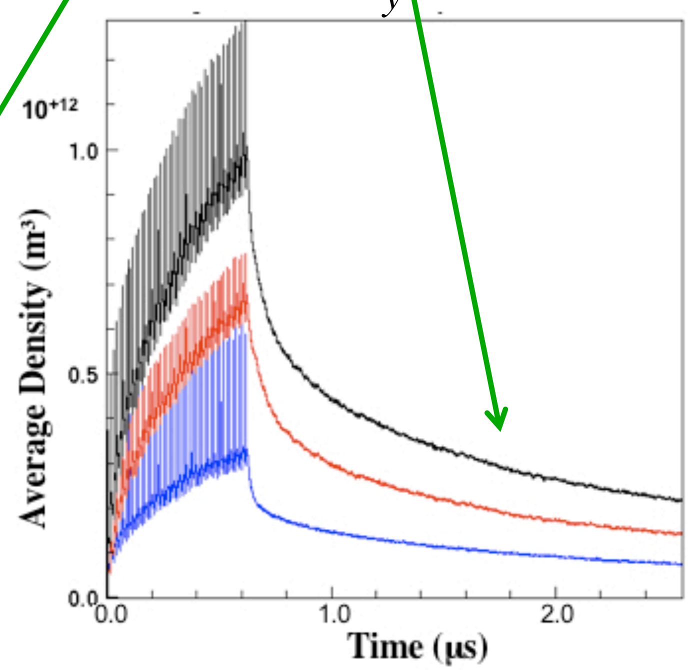
Near B_y zero, electrons stay longer

— *total*
— *primaries*
— *secondaries*

Near B_y max

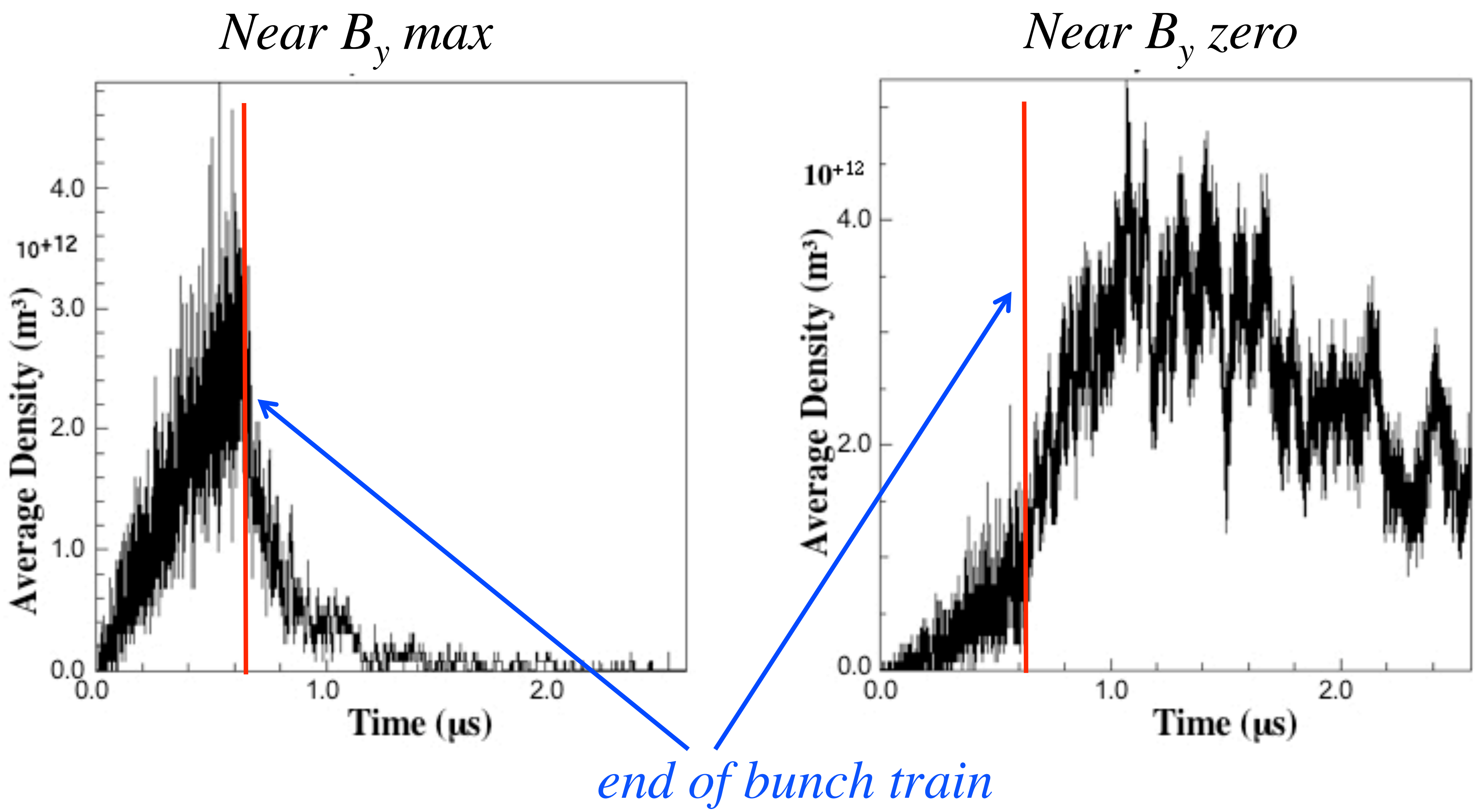


Near B_y zero



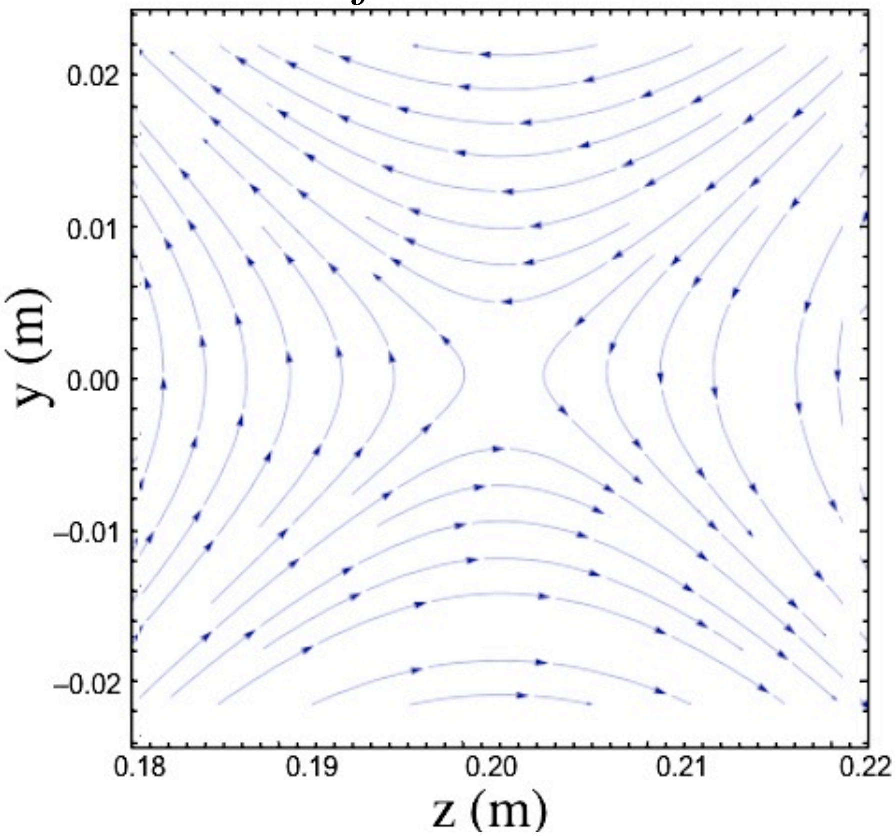
Buildup near the beam differs (time development & density) for the two regions

Number of electrons within 1 mm of the beam axis vs. time

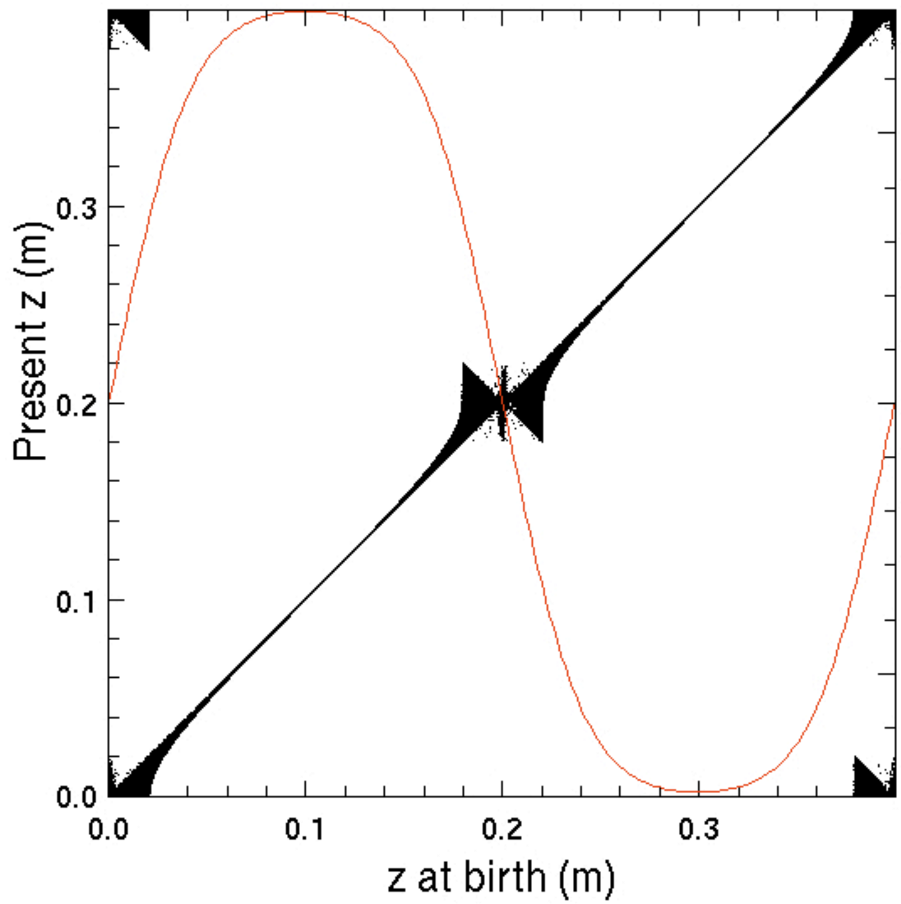


Electrons near B_y zeroes persist by mirroring in the y-z plane

B field lines



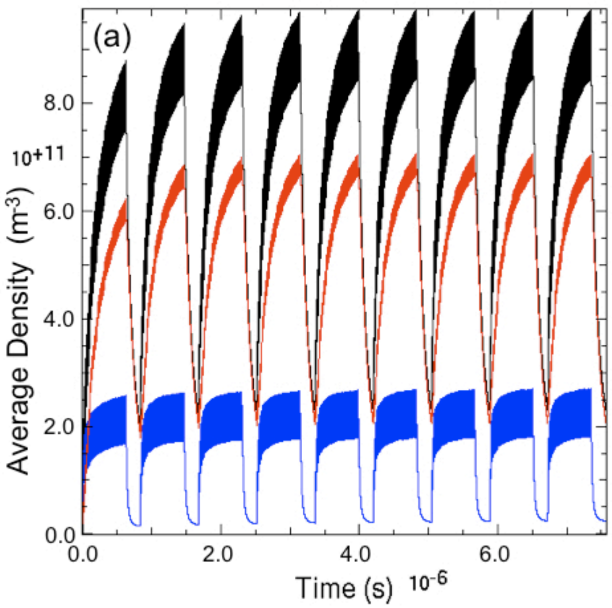
Mirroring is seen in single particle orbits in simulation.



Does persistence of electrons mean growth of density from train to train?

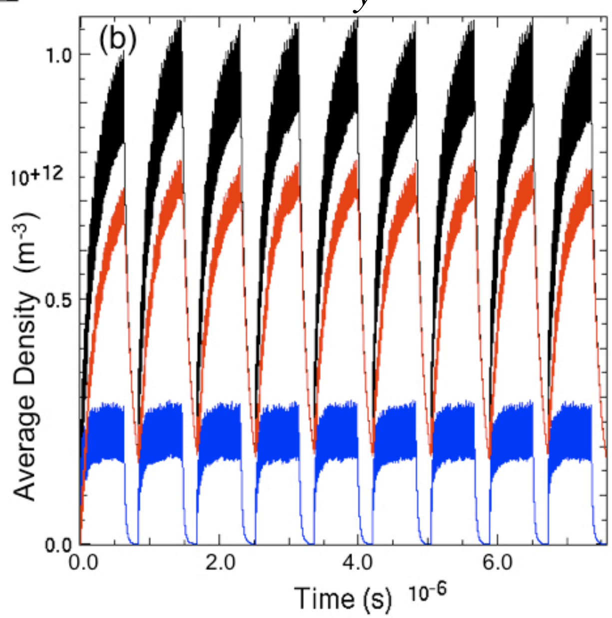
9 45-bunch trains, 15-bunch gaps

Whole wiggler period

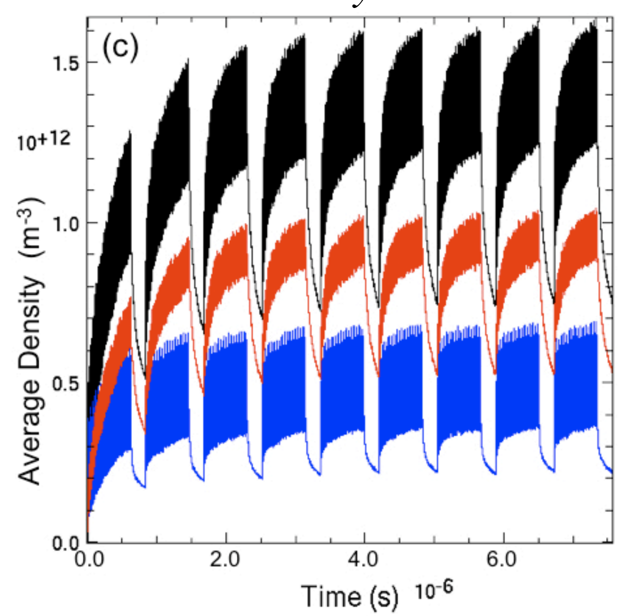


Growth saturates after a few trains, probably due to electron space charge

Near B_y max

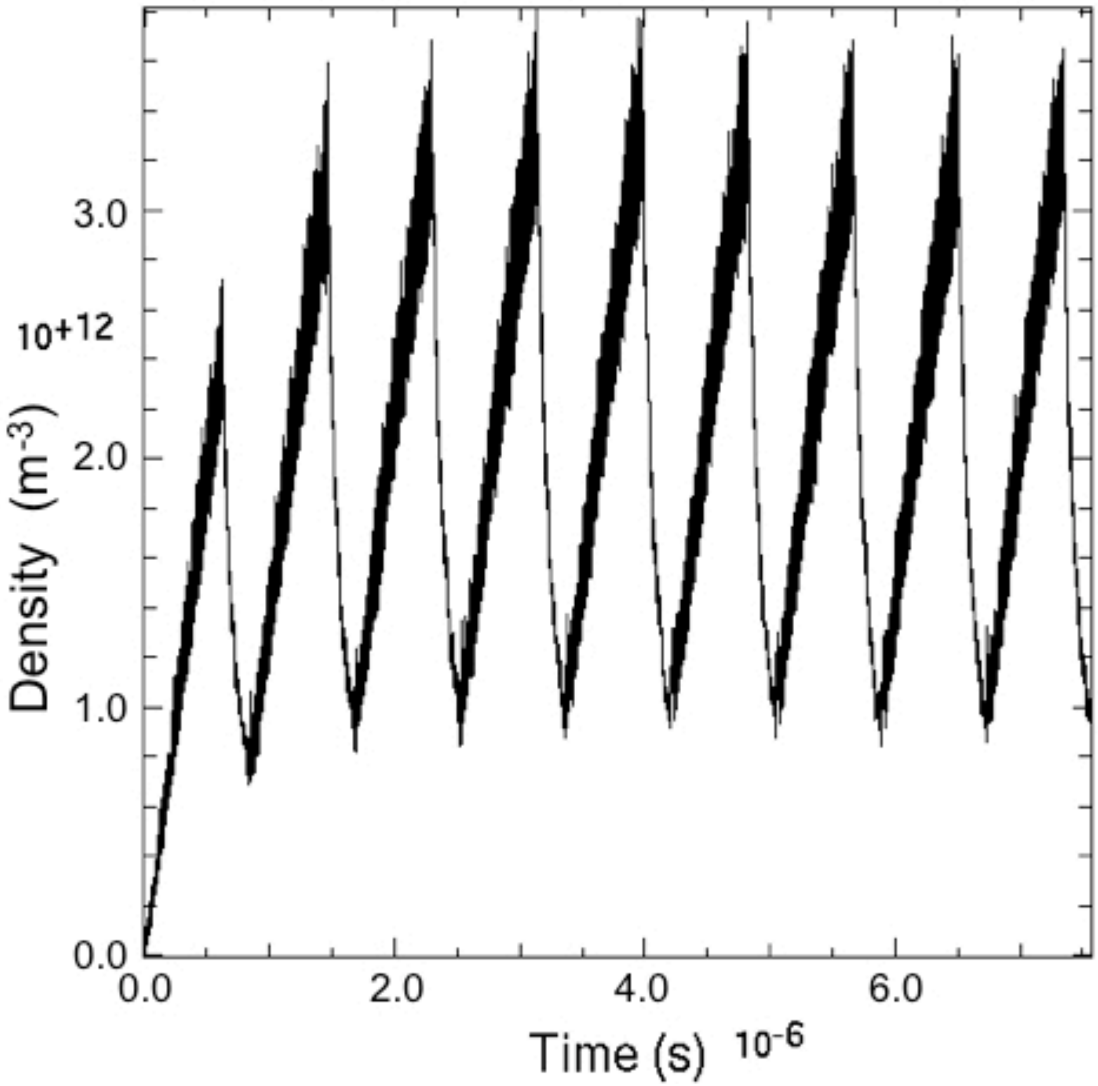


Near B_y zero



— *total*
— *primaries*
— *secondaries*

The same applies for electrons within 1 mm of the beam



38% increase from first train to 4th

Coherent tune shift of beam due to cloud was difficult to simulate

Required 40x as many macroparticles (37/electron) to have good enough particle statistics to find electron field gradient

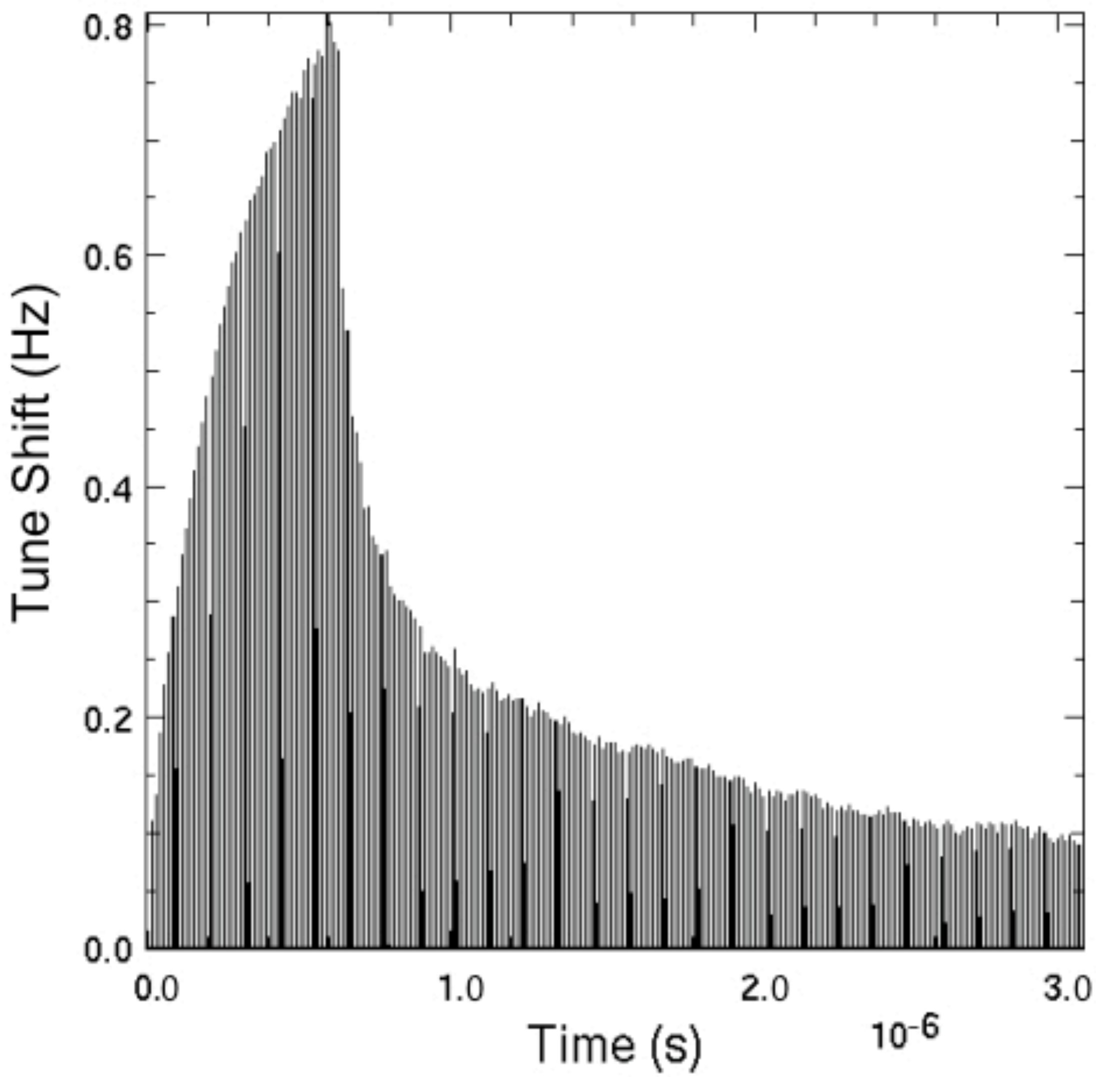
↓

1 turn, 1 wiggler period, 16 processors:

Run times for buildup runs:	**21 hours**
Run times for tune :	**17 days**

Only y tune shift calculated. x tune shift much smaller (Dugan– quad wake nearly cancels dipole wake in a dipole) and would have required even better statistics.

Y coherent tune shift for 45-bunch train vs. time

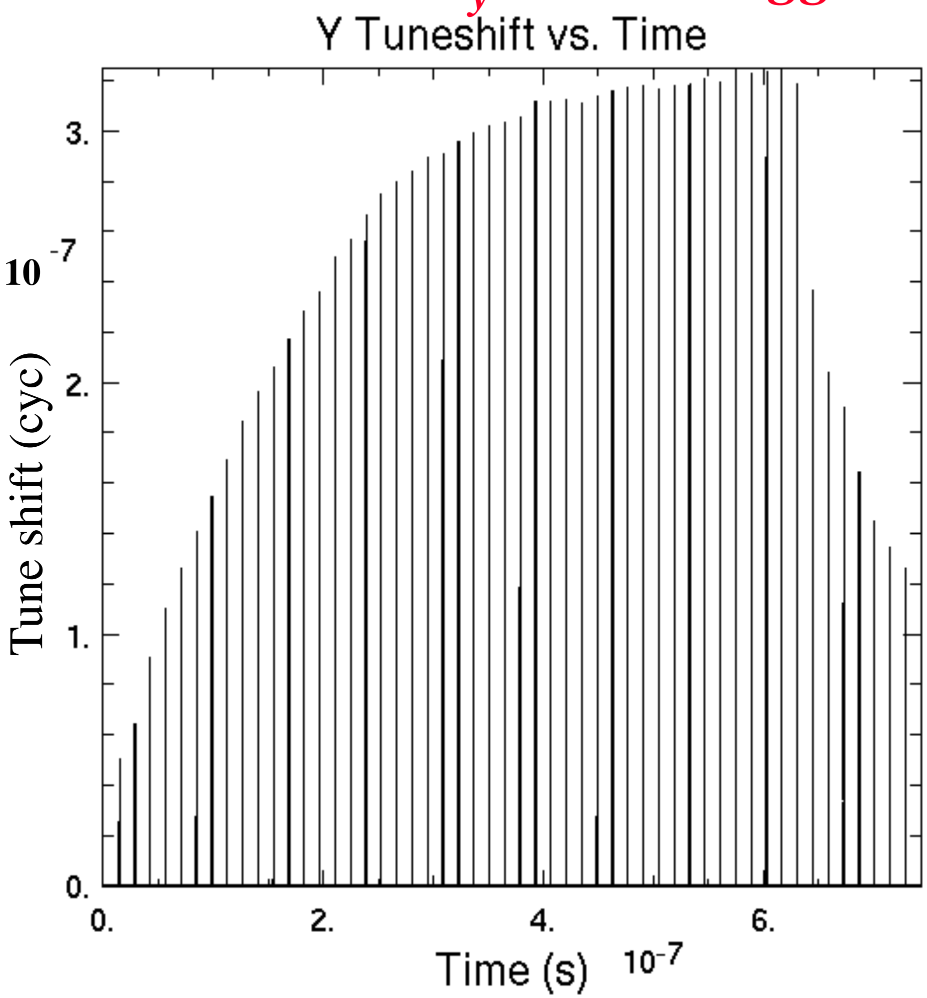


Peak tune shift <u>per centimeter</u> is about ***50% larger*** *than tune shift per cm of low field dipole (0.08 T).*

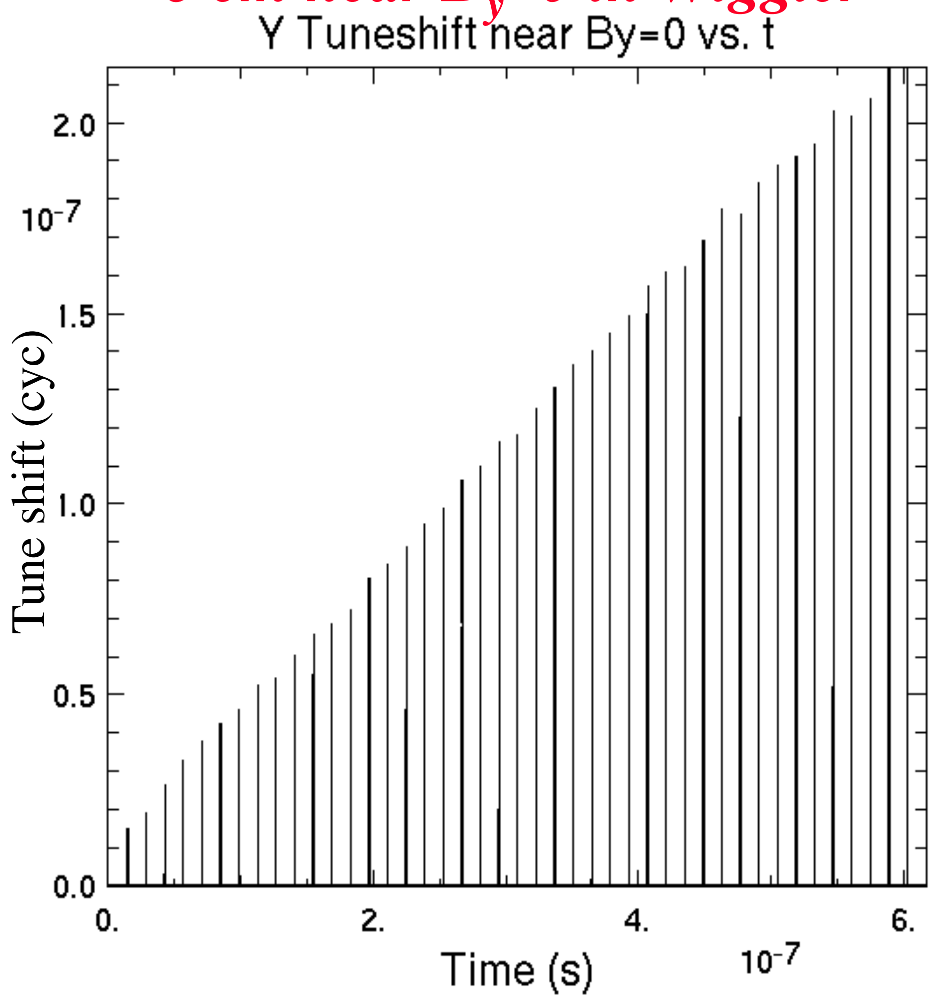
This is about the same as difference for 1.9 T and 0.08 T dipoles.

Phase shift/cm in wiggler near B_y=0 ~ 2/3 that due to cloud near B_y max (but is only ~ 13% of the wiggler)

6 cm near B_y max in Wiggler

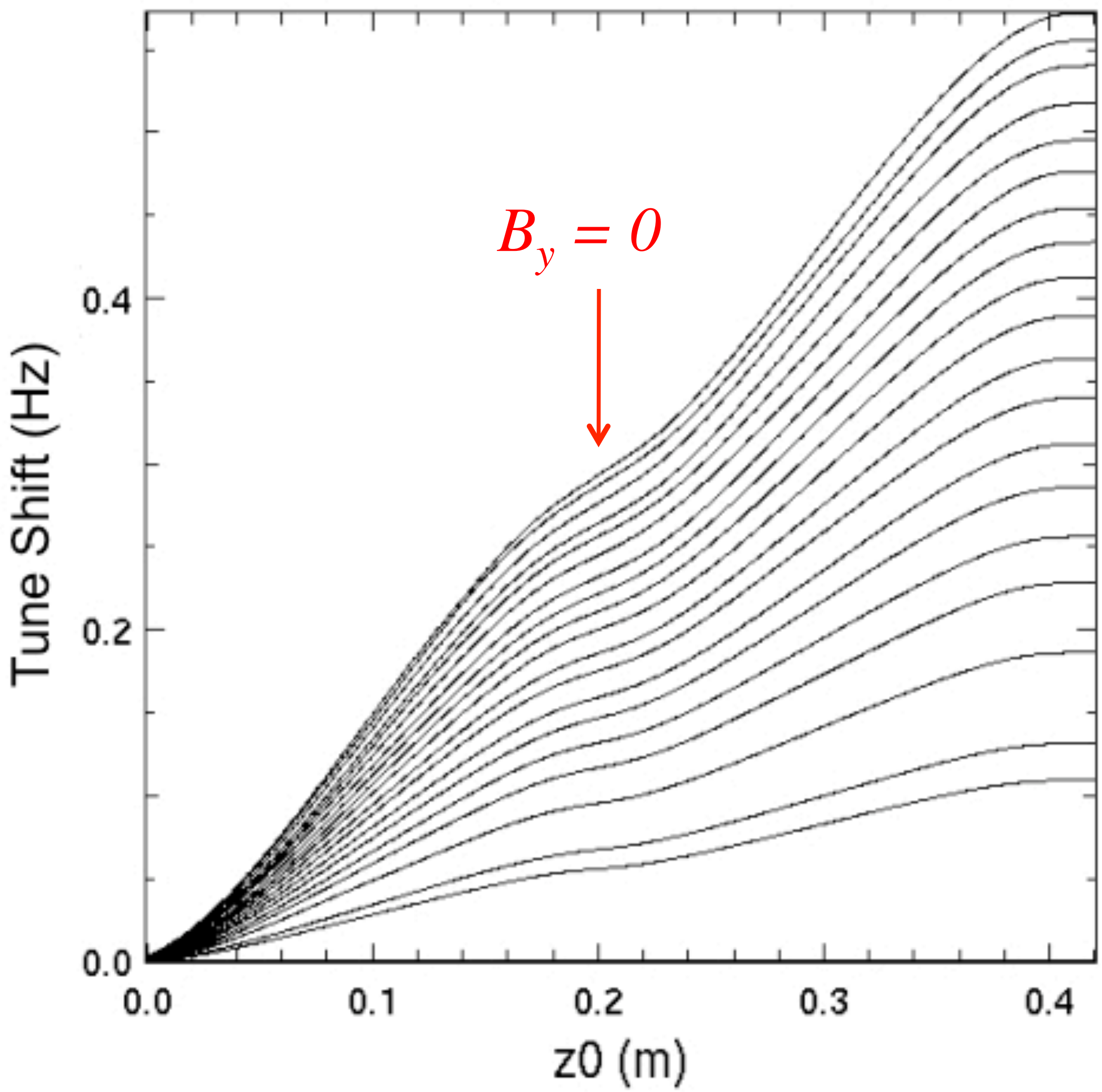


6 cm near B_y=0 in Wiggler



Time development slower near B_y=0

Y coherent tune shift vs. position of beam center for first 20 bunches



Electrons near B_y=0 contribute about 17% of the tune shift

Can probably reduce run time by simulating small segments in z to find slopes of this graph vs. time for different regions

Cyclotron resonances have not been resolved here

z resolution of runs is not good enough to see variations in electron density on the scale of the distance between resonances.

Required to resolve resonances: $\Delta z \leq 1\ \mu m$
Simulations: $\Delta z = 6.2\ mm$

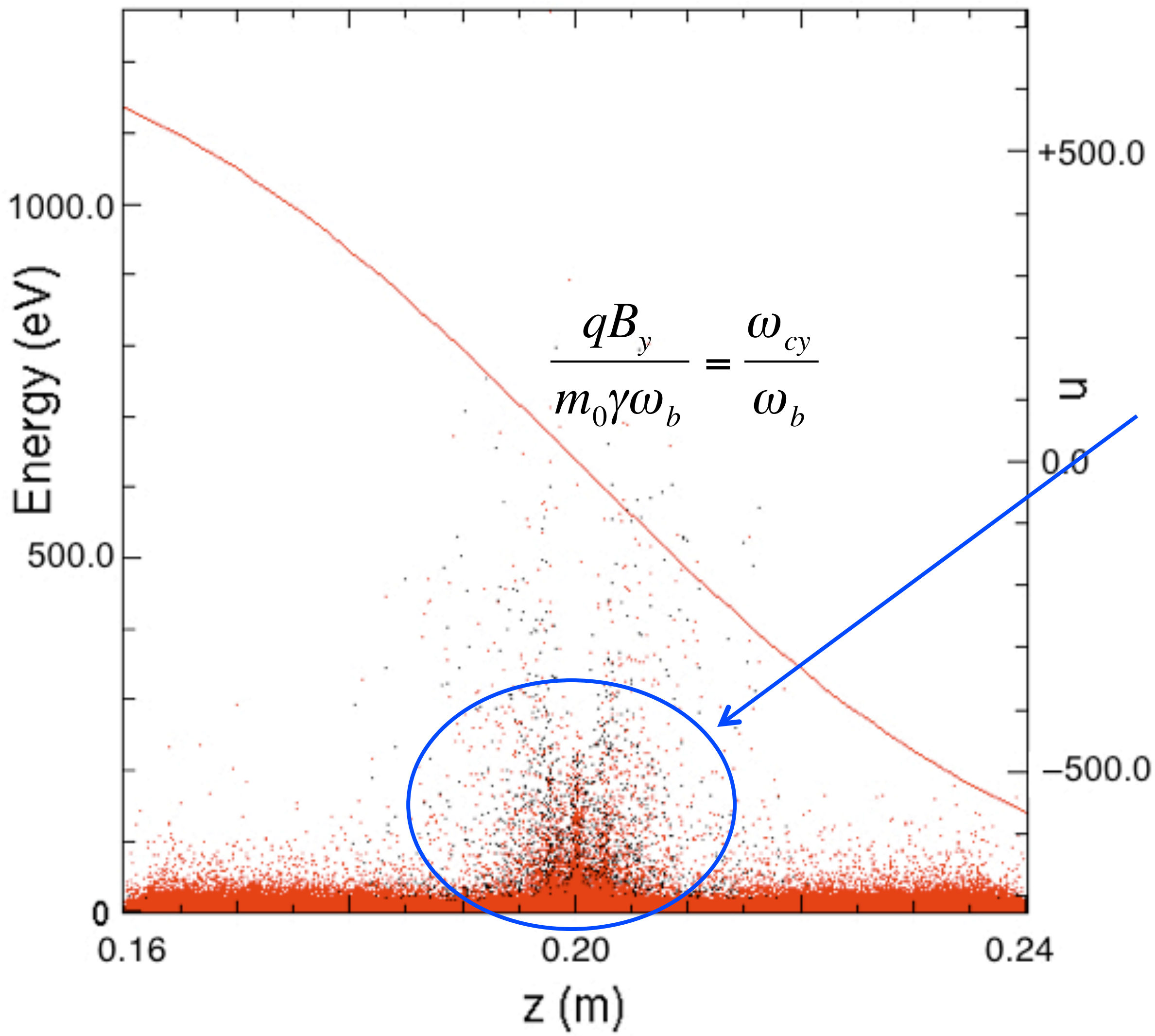
↓

Simulation can not resolve density and electron electric field variations on the spatial scale of the distance between resonances. These should occur, but would wash out quickly anyway due to cyclotron motion.

BUT

Electrons feel correct force from magnetic field and resonate properly.

Evidence is seen in these runs for resonances where $n\omega_b = \omega_c$



$$\frac{qB_y}{m_0 \gamma \omega_b} = \frac{\omega_{cy}}{\omega_b}$$

Resonances only occur at low B, where time for beam to pass an electron is small compared to the cyclotron period

Summary

- Most of the wiggler has “dipole-like” electron cloud formation. z movement of electrons is very small, density is in vertical stripe or stripes near x=0.
- About 13% cm of wiggler is “near B_y=0”. Here curvature and grad B drifts cause electrons near y=0 to cross field lines near the midplane and approach the beam. Density can be as high as in “dipole-like” regions. Ratio of the two depends on time and reflectivity of photons.
- Electrons near B_y=0 mirror back and forth in z on field lines, and can stay in the chamber well past when electrons in “dipole-like” regions have disappeared.
- Electrons that persist can affect next train (for gap of 15 bunches, or 210 ns), but cloud growth saturates after a few bunches, probably due to electron space charge.

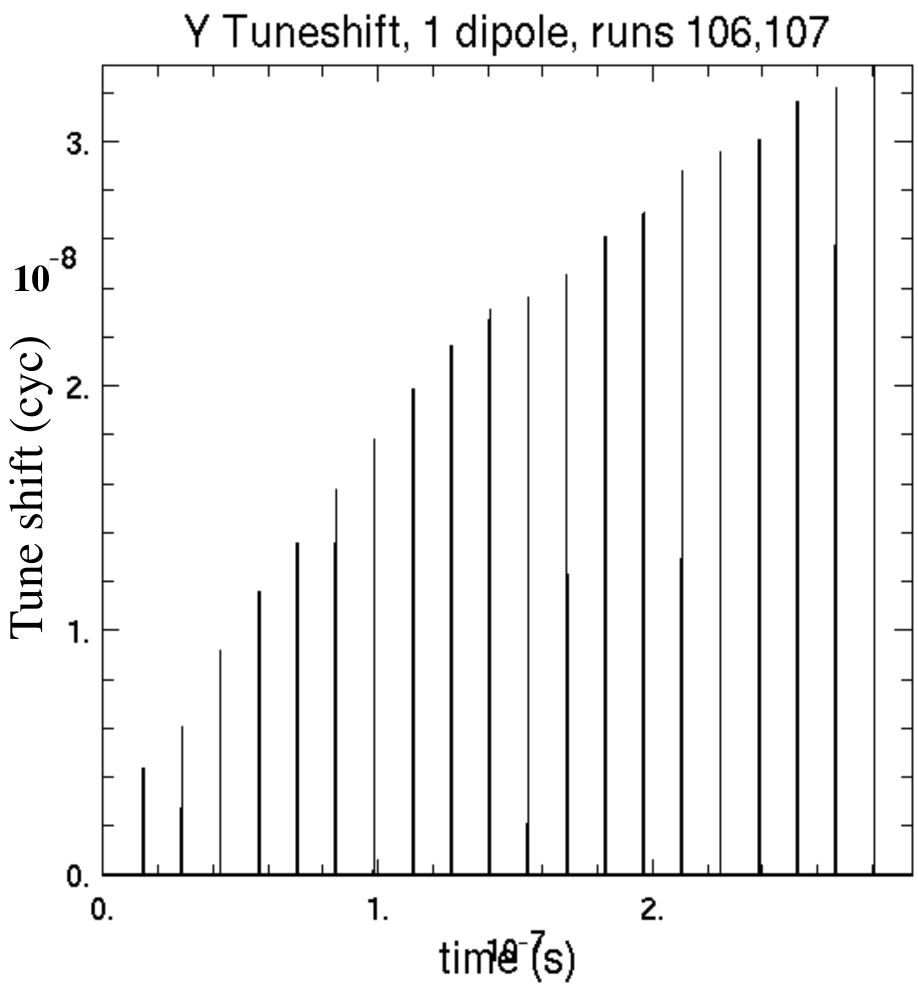
Summary (cont'd)

- Coherent tune shift has been calculated. Tune shift per cm for these parameters is ~ 50% higher than for 0.08 T dipole. About 17% of the tune shift is due to the electrons in the z region around the B_y=0 locations.
- Evidence of cyclotron resonances is seen, but space charge field variations have not been resolved on the scale of distance between resonances.

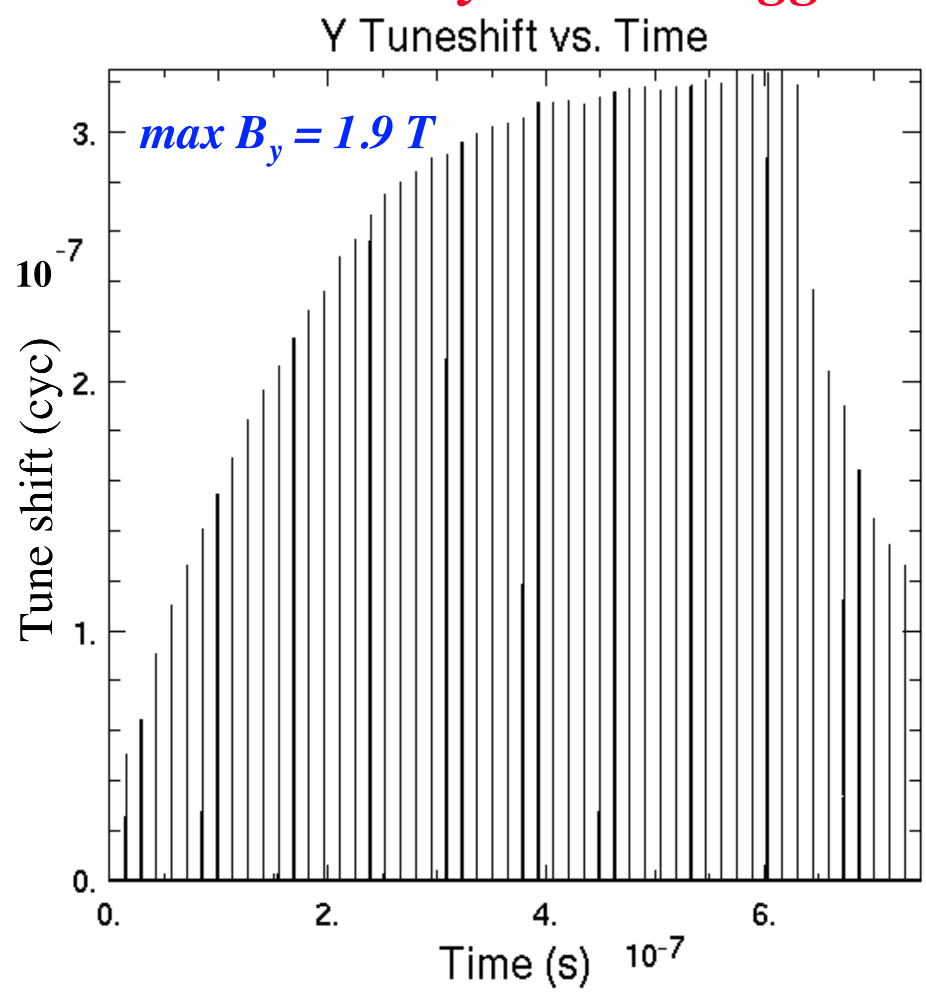
Backup Slides

Phase shift per cm is about 67% higher for wiggler peak field than for low-field dipole

1 cm of 0.08 T dipole



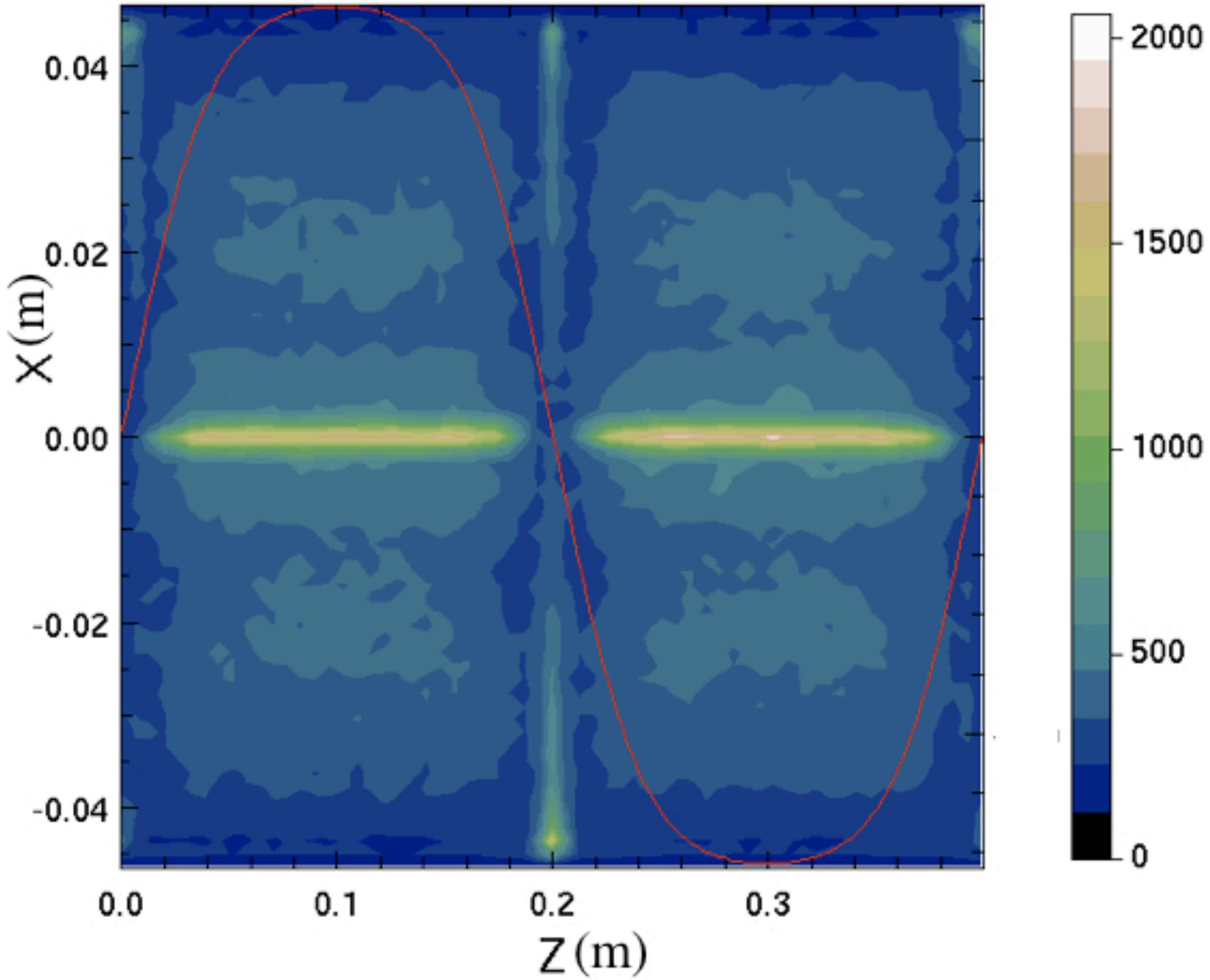
6 cm near Bymax in Wiggler



Tune shift/cm of low-field dipole is ~ 2/3 of wiggler at max B_y

Most (~87%) of the length of the wiggler is "dipole-like"

just before bunch 45



After Δt = 1 turn, only electrons near zeroes of B_y persist