3D Wiggler Ecloud Dynamics from WARP-POSINST

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Parameters

1 wiggler period with periodic boundary conditions in z

from Gerry Dugan:

e^+ beam
1 train of 45 bunches
0.4 mA/bunch (6.4x10^9 e^+/bunch)
14 ns bunch spacing
peak SEY (δ_{max}) = 1.8
reflectivity = 20% (uniformly around chamber)
elliptical chamber (radii of 4.5 and 2.5 cm)

3D wiggler field from Cornell simulations
"Beam" represented by Bassetti-Erskine field (does not evolve)
Beam does not wiggle

Numerical Parameters

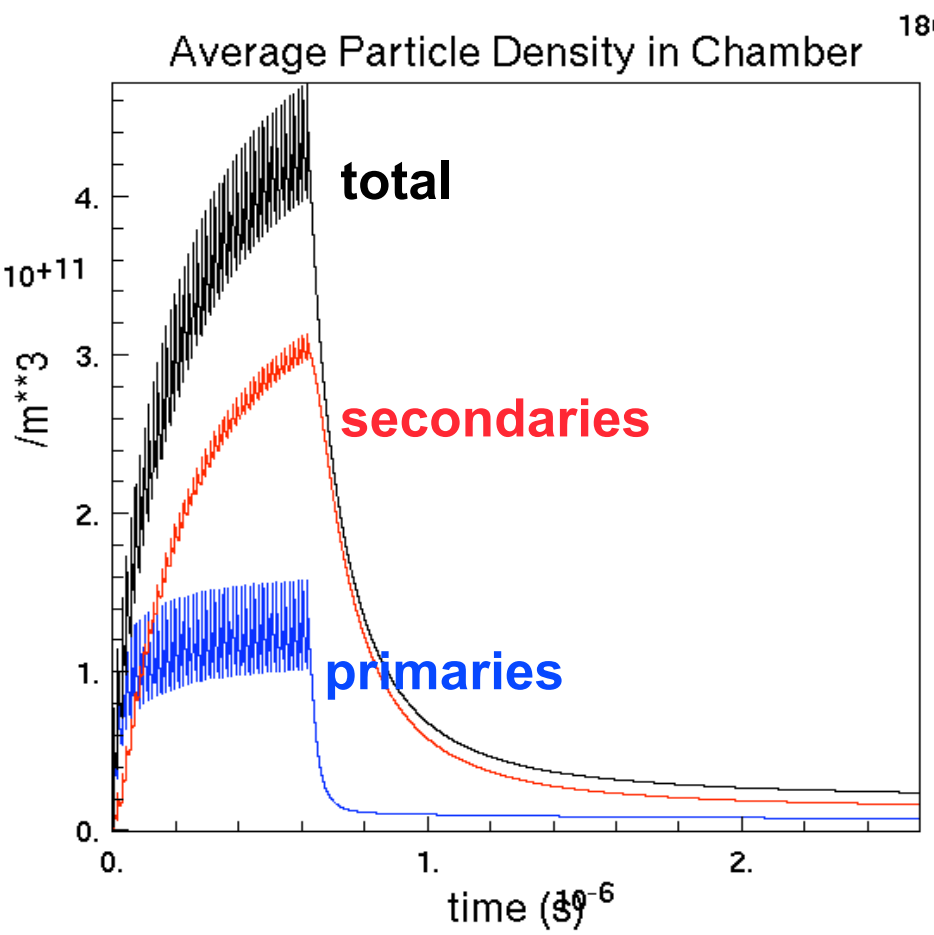
Mesh for electron self-field: **128 x 64 x 64** (x x y x z), or

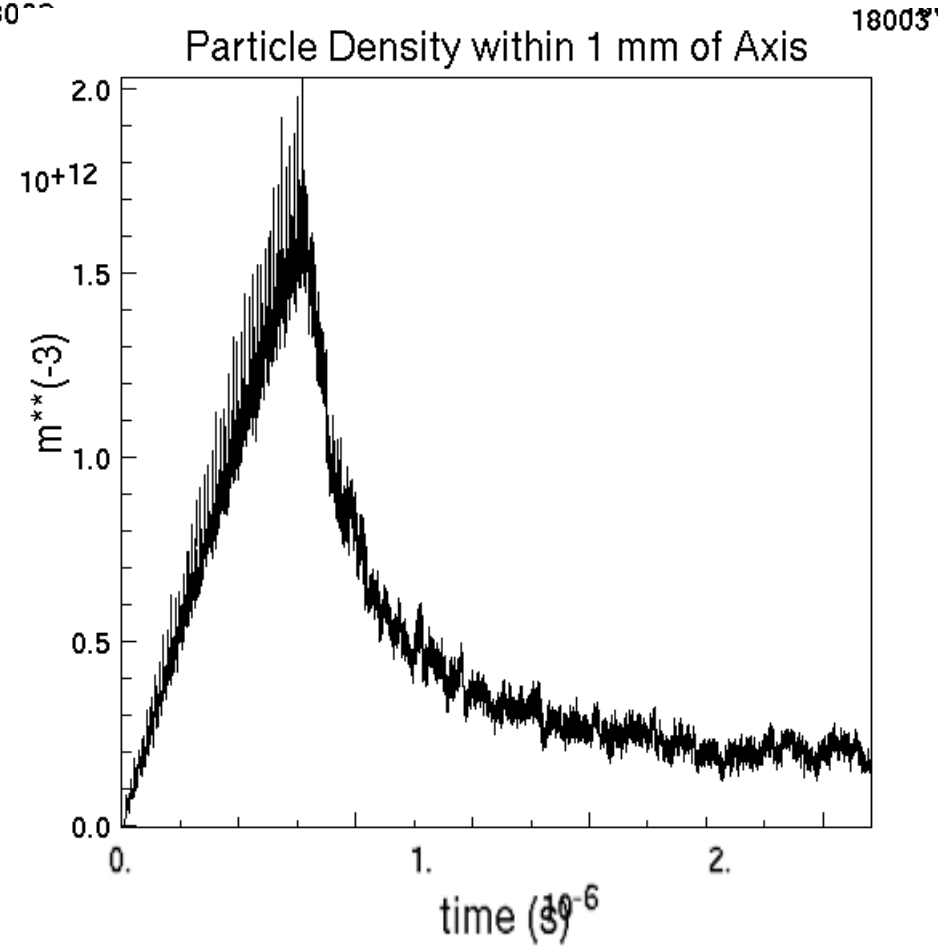
0.35 mm x 0.35 mm x 6.25 mm

Cyclotron resonances are not resolved - would require much finer mesh in z (x 700). Particle motion is correct, but space charge field is not resolved on that fine z scale.

12 timesteps per cyclotron period (**$\Delta t = 1.6 \times 10^{-12}$ s**) - half this seems optimal.

Electron Cloud Density vs. Time - secondaries dominate at equilibrium

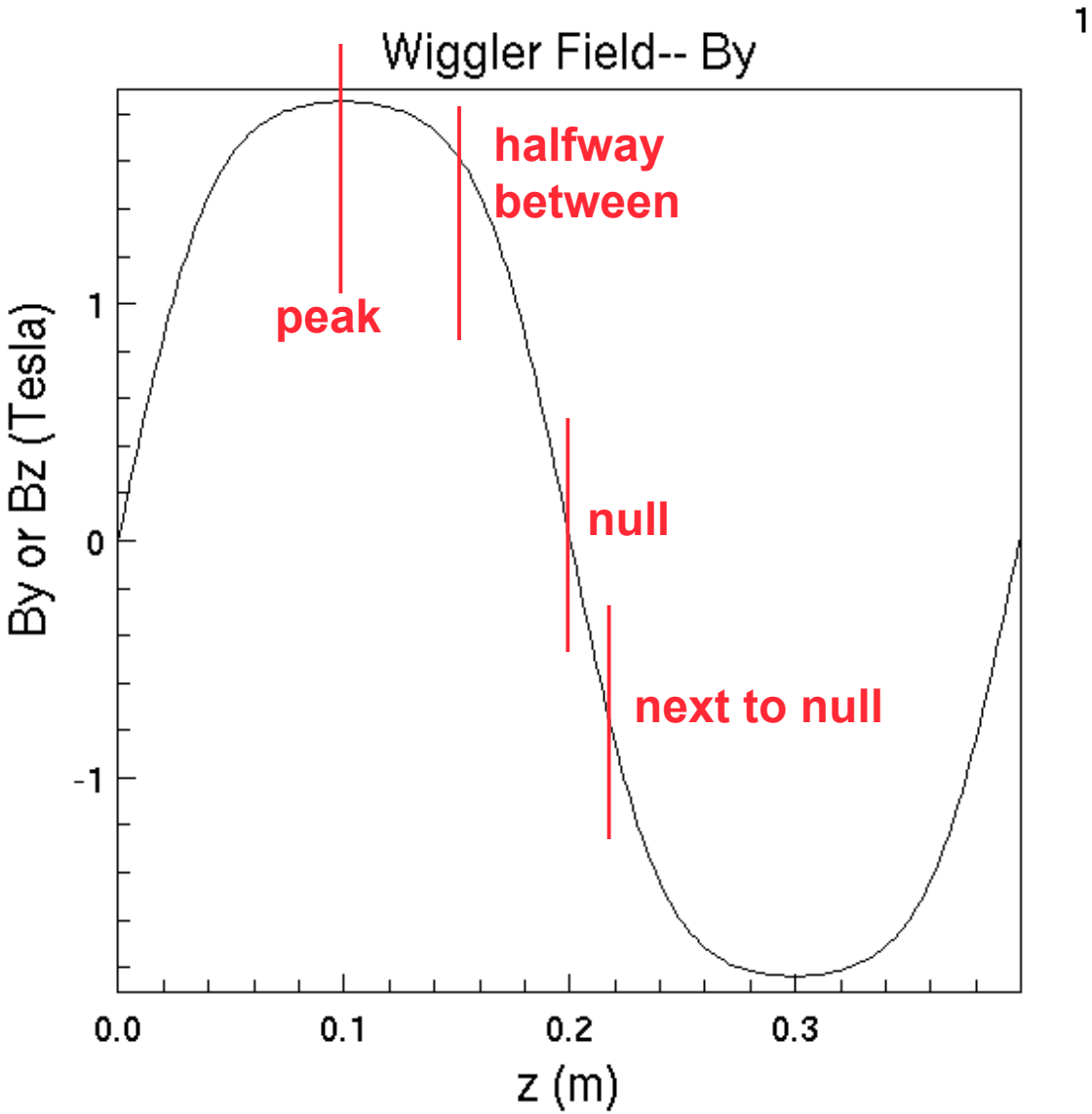




Step 1635288, T = 2.5620e-6 s, Zbeam = 0.0000e+0 m

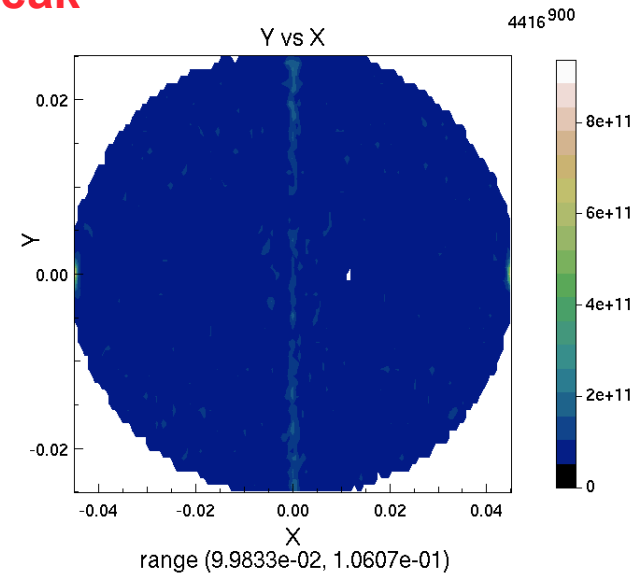
"Average particle density = (total number) / (chamber volume)

Positions of Diagnostic z-Slices



Density in X-Y in z slices after bunch 40 (0.55 μs)

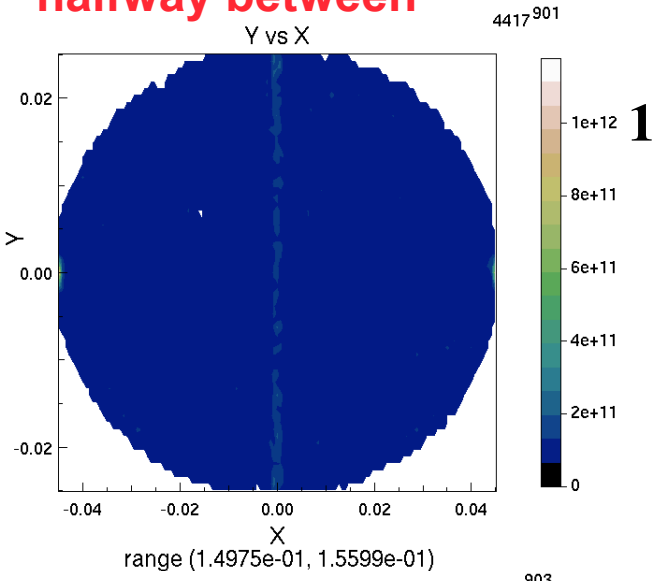
peak



8e+11

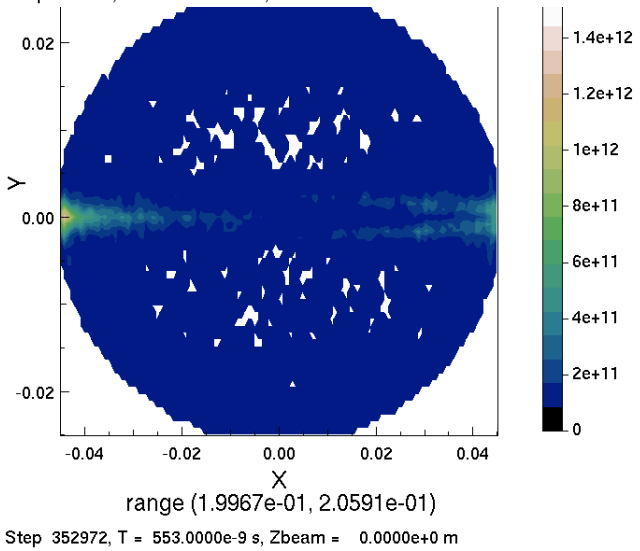
1 stripe

halfway between

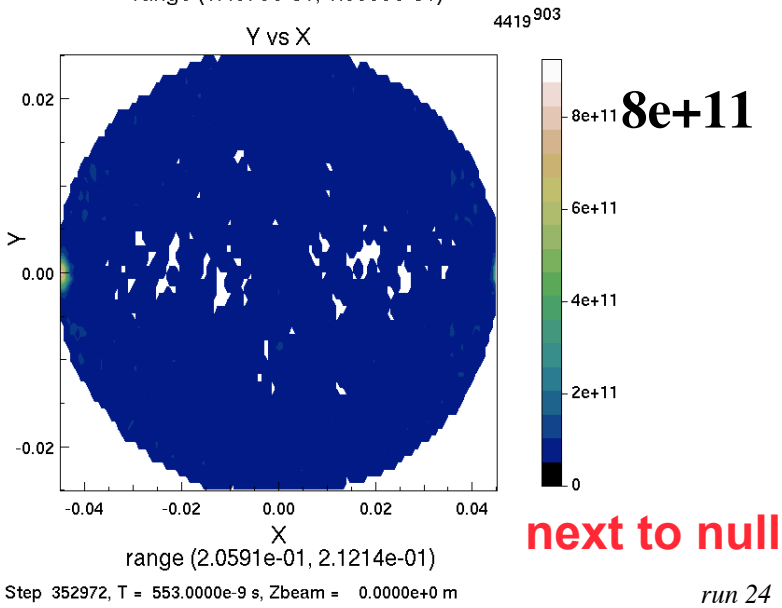


1.0e+12

null



1.4e+12



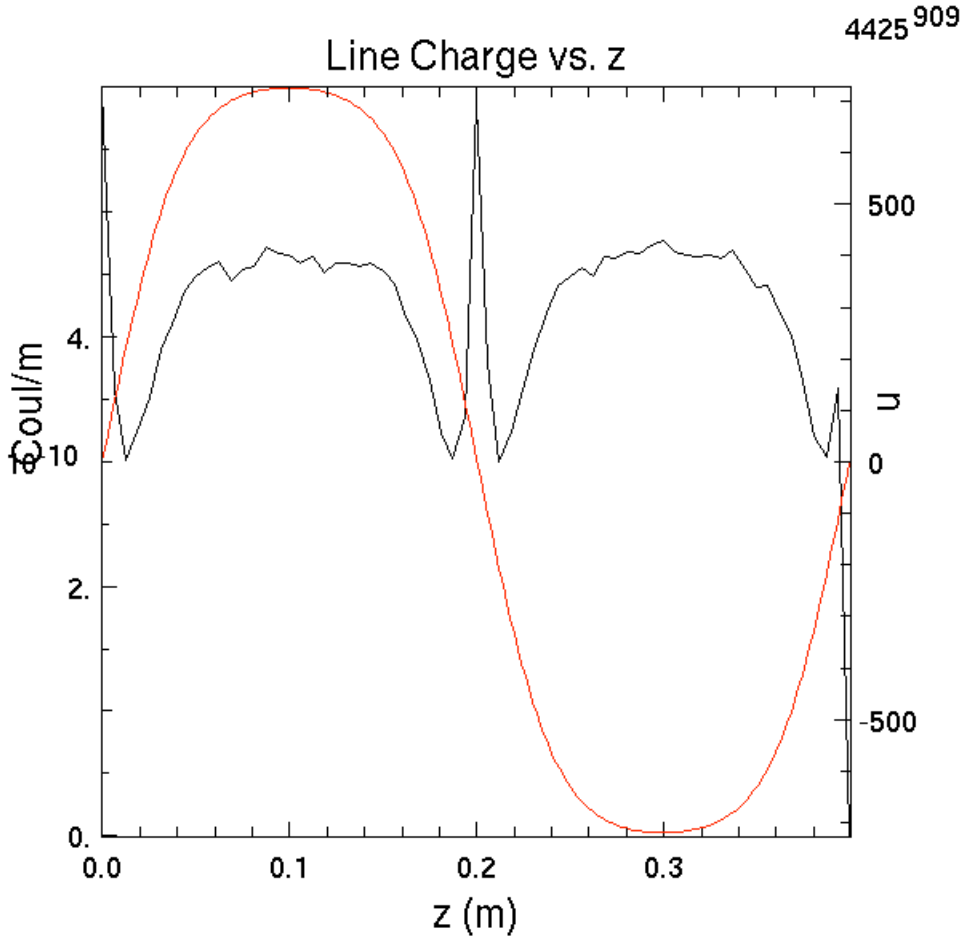
8e+11

next to null

run 24

Line Charge Density is Largest at B_y=0

After bunch 40
t = 0.55 μs



Step 352972, T = 553.0000e-9 s, Zbeam = 0.0000e+0 m

What remains after 1 turn (2.5 μs)

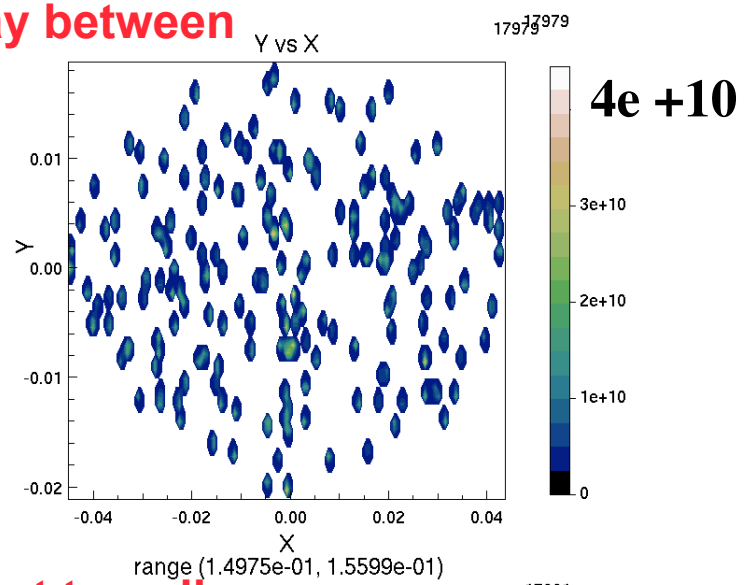
peak

y

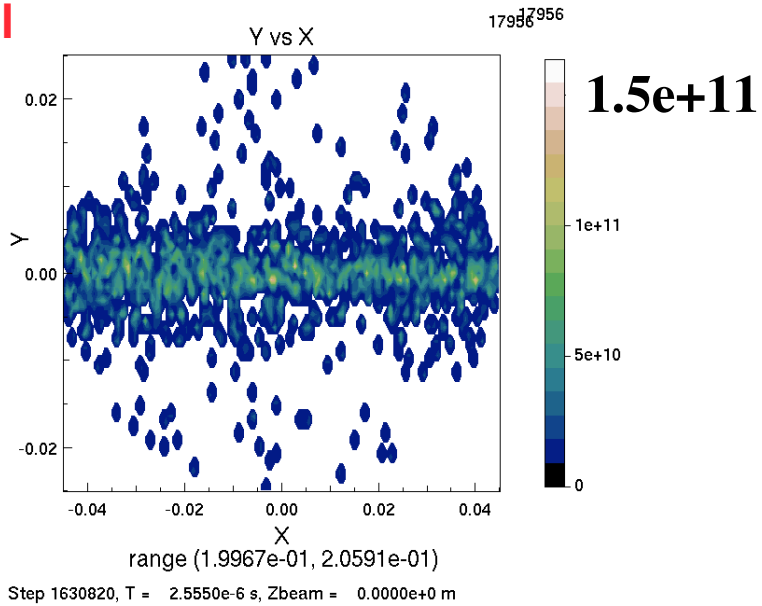
No electrons at peak B_y

x

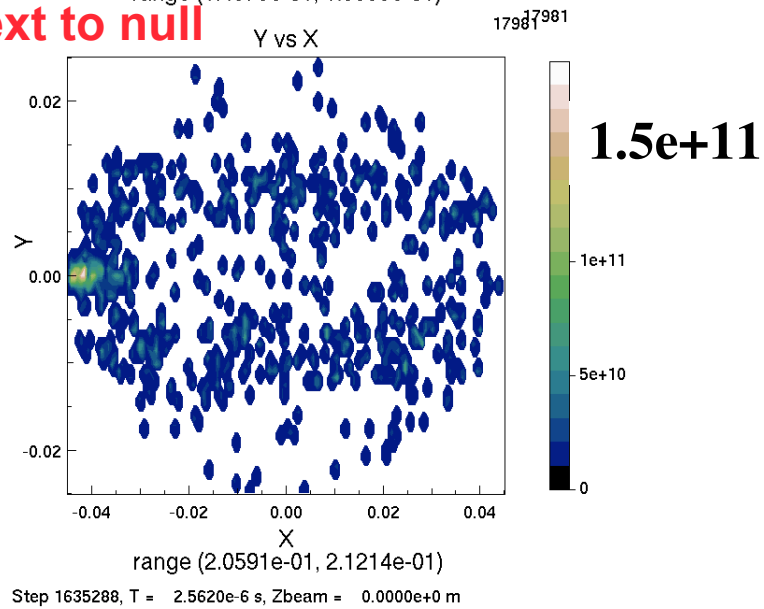
halfway between



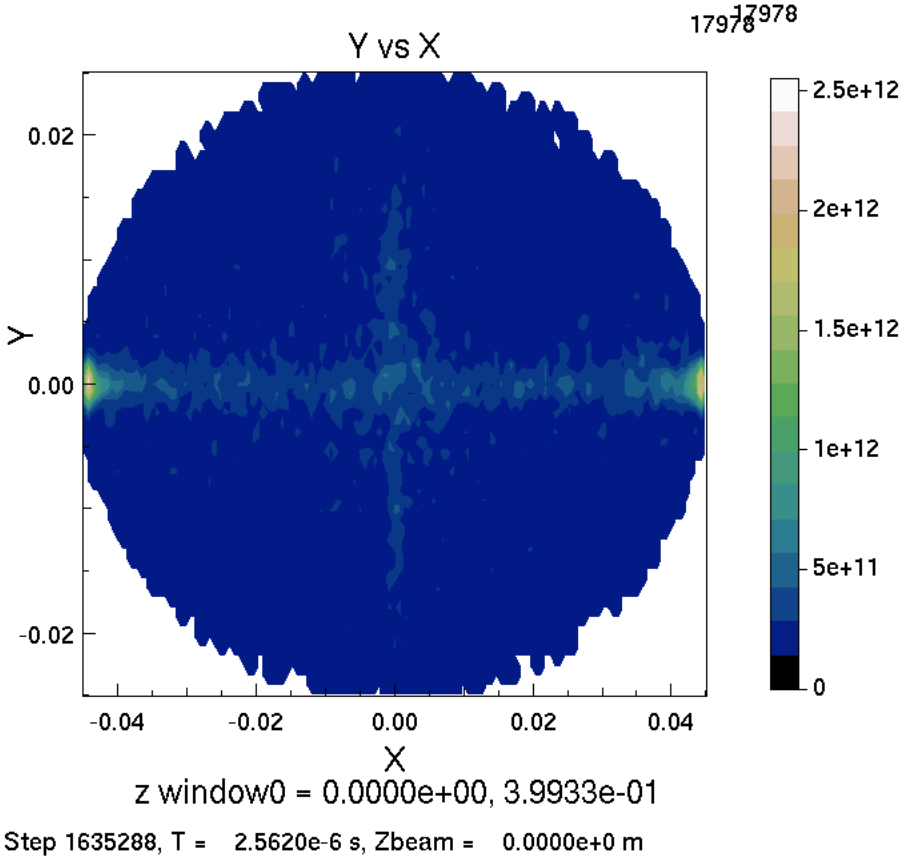
null

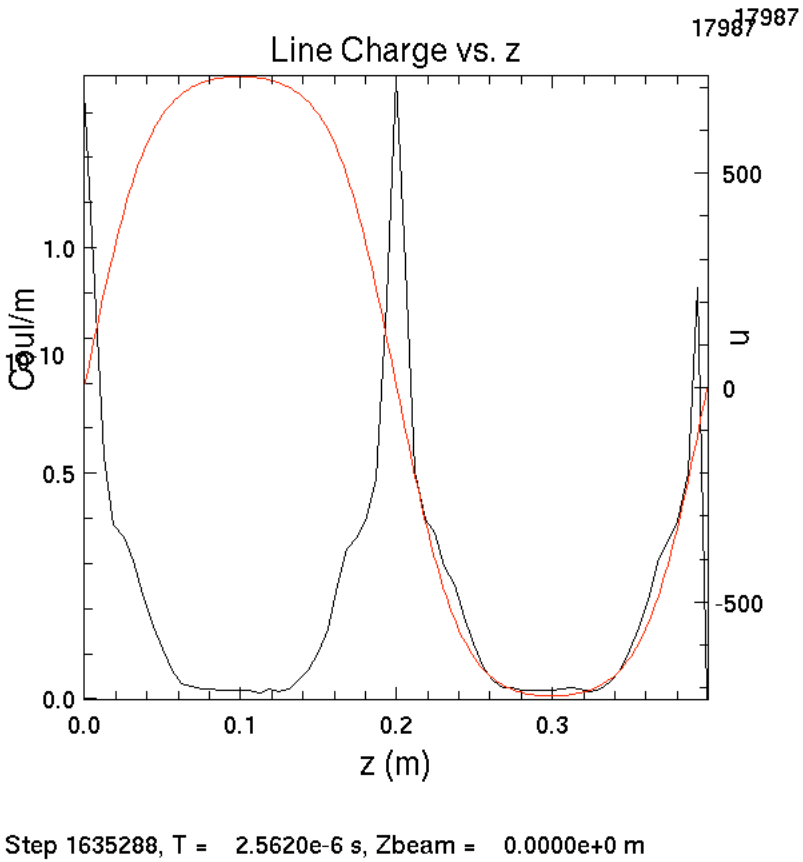


next to null



Density, Line Charge after 1 Turn (2.5 μs)



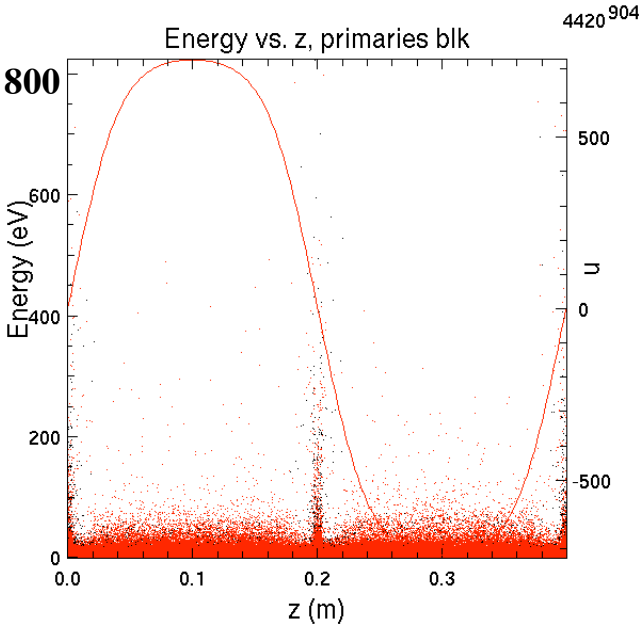


Density is integrated over z

Peak line charge density ~ 1/3 of value at end of bunch train

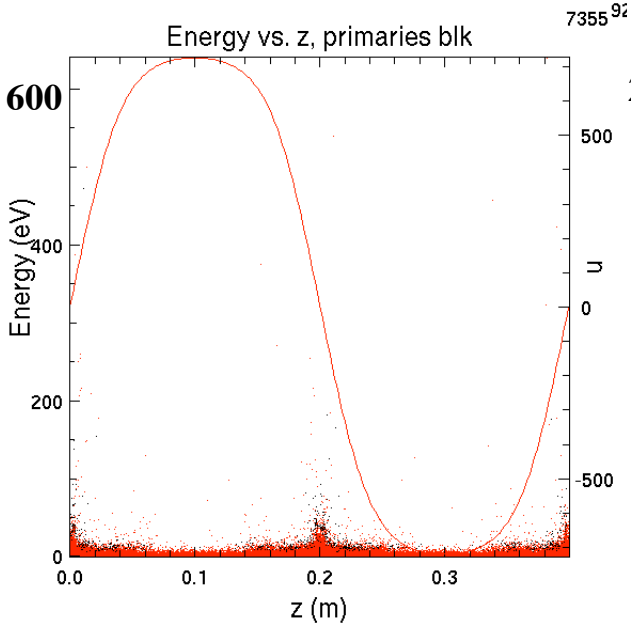
Energy vs. z: Electrons near B_y=0 have more energy, but it fades away after bunches stop

0.55 μs
40 bunches



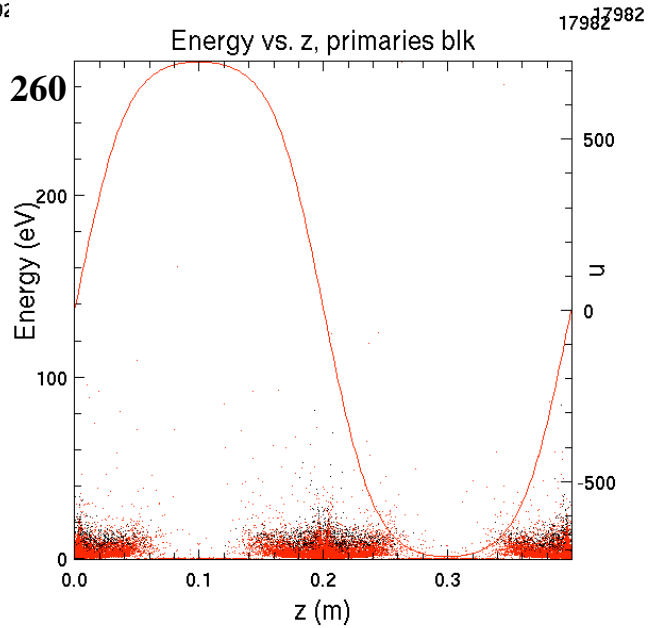
Step 352972, T = 553.0000e-9 s, Zbeam = 0.0000e+0 m

1 μs



Step 625520, T = 980.0000e-9 s, Zbeam = 0.0000e+0 m

2.56 μs
(1 turn)



Step 1635288, T = 2.5620e-6 s, Zbeam = 0.0000e+0 m

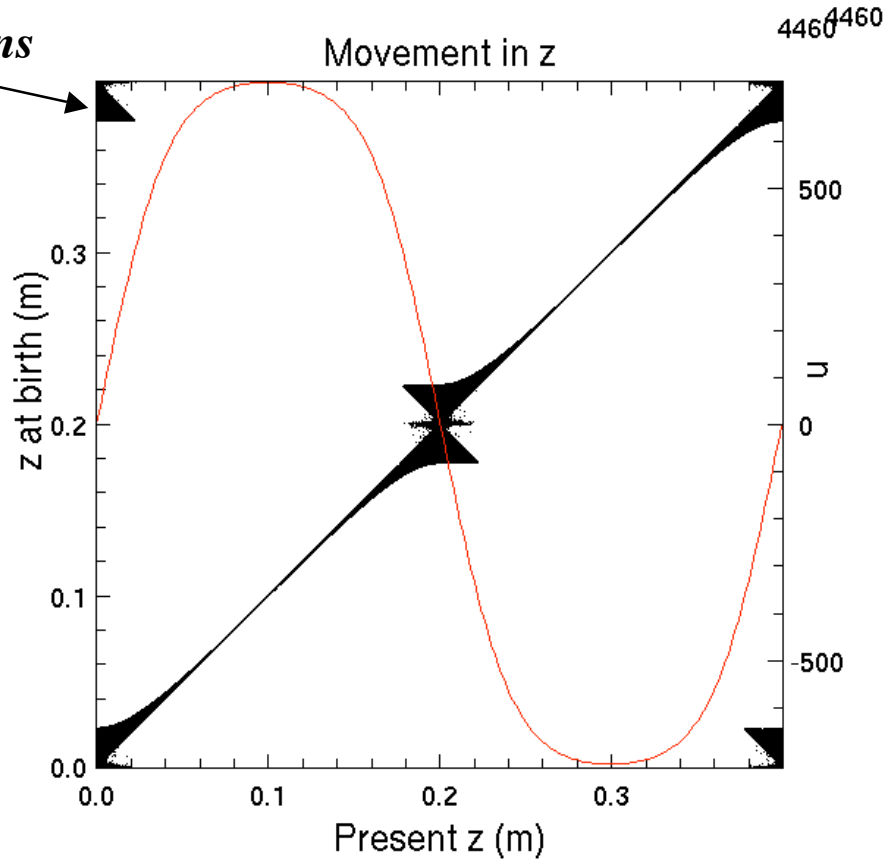
This high energy may be due to cyclotron resonances

Dynamics

z Motion

After bunch 40

from periodic boundary conditions



Step 357440, T = 560.0000e-9 s, Zbeam = 0.0000e+0 m

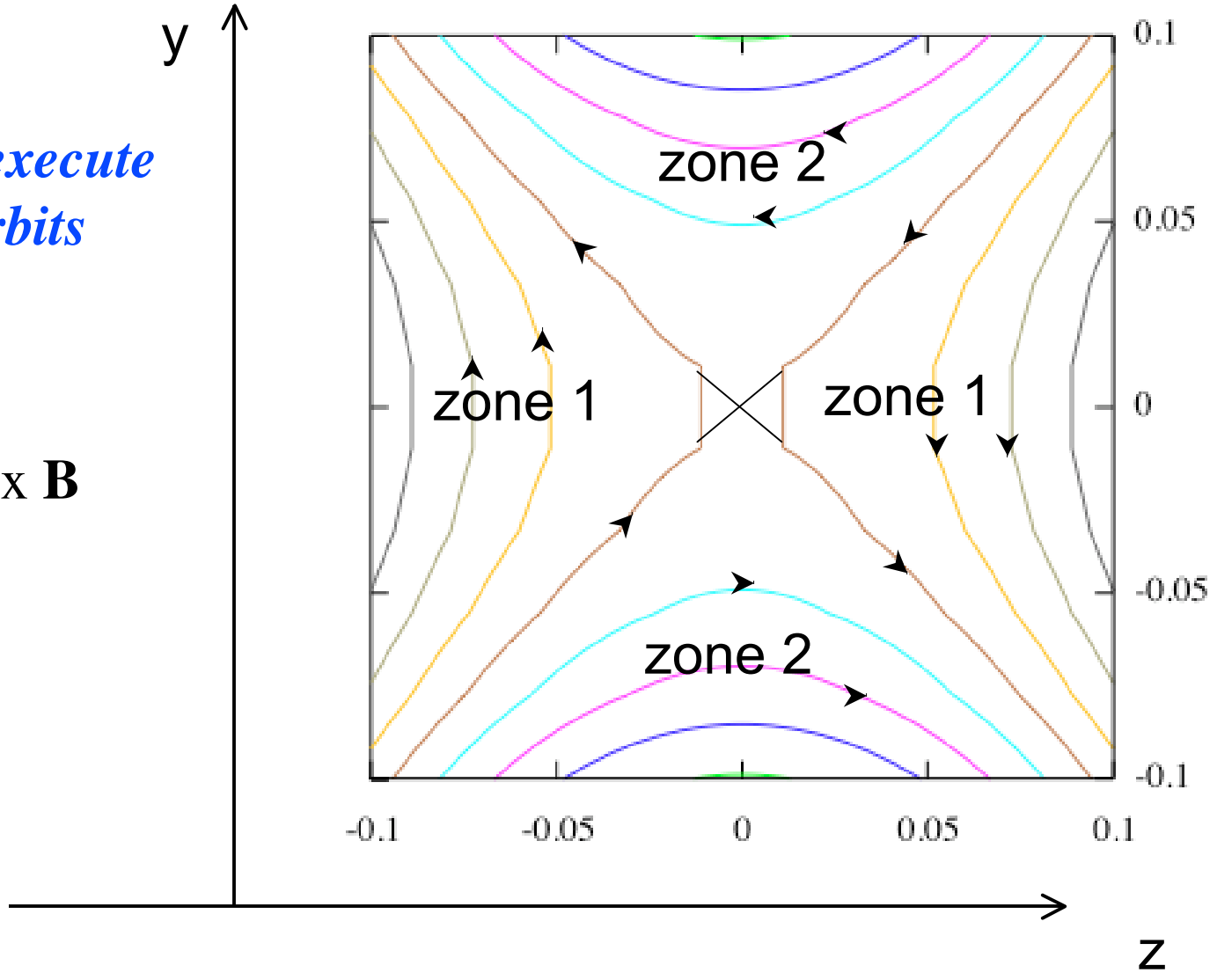
ExB not important

At and near B_y peak the motion is 2D

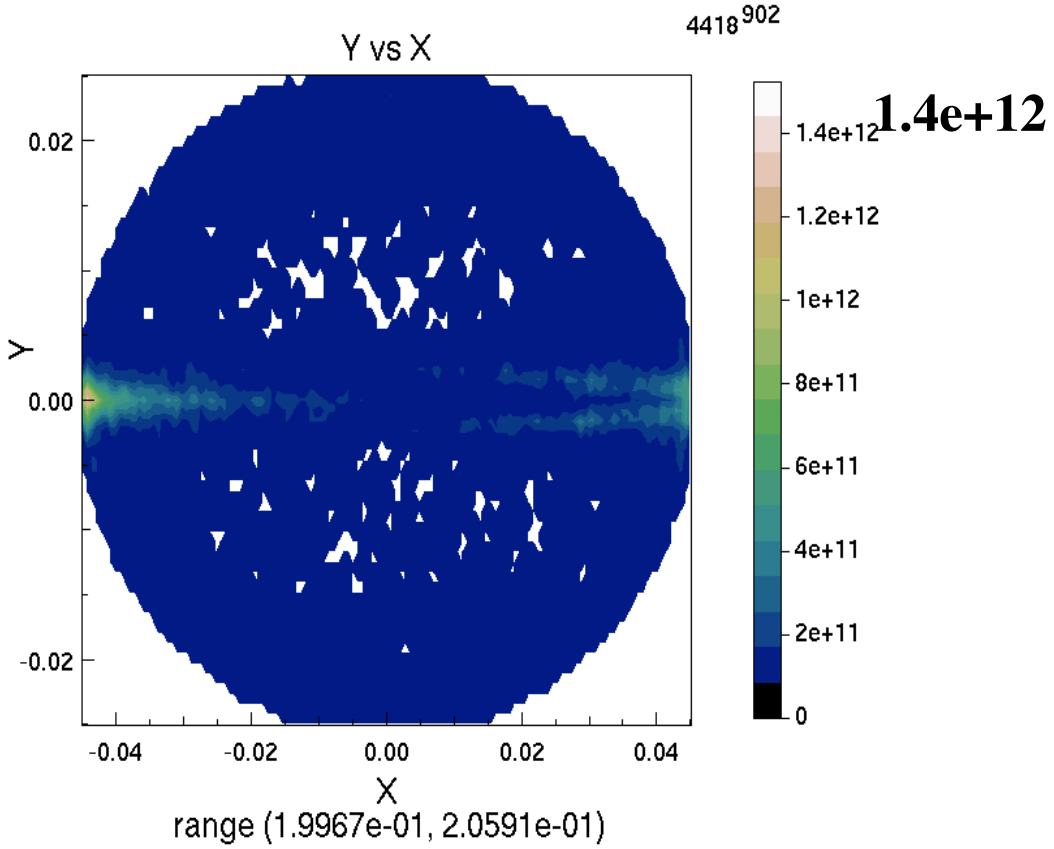
B Field Lines vs. y and z

Electrons execute mirror orbits + drifts

$v_D \sim \nabla|\mathbf{B}| \times \mathbf{B}$



Electrons at By=0 plane move in x direction, across field lines (in z direction)



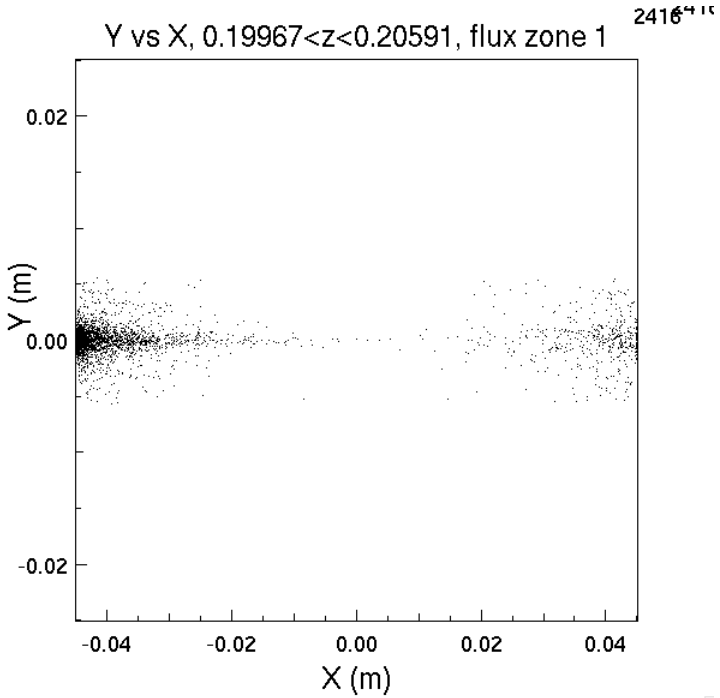
I believe this is due to slow drifts of the gyrocenter due to ***∇B and curvature of B*****.**

Electrons from different zones come from different directions

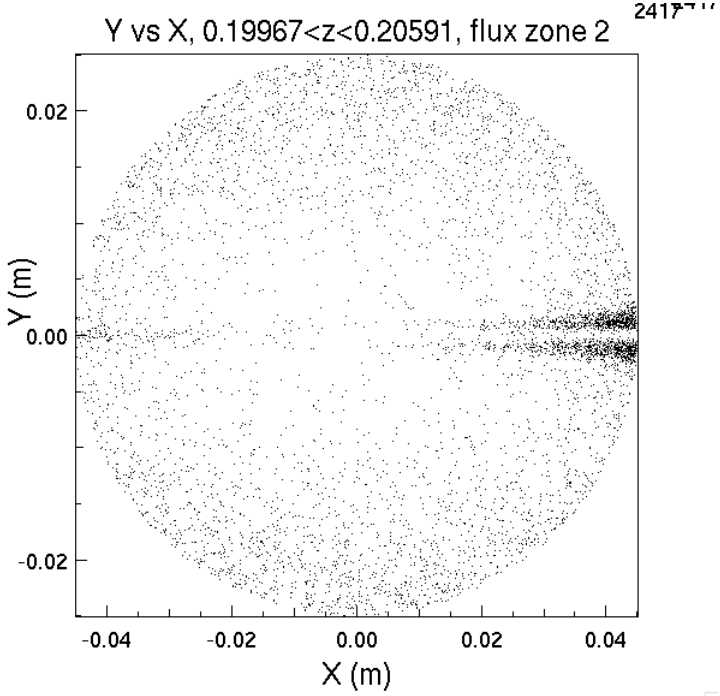
Some proof:

- If set E_{beam} & $E_{space\ charge}$ = 0, motion in x is unchanged
- No motion for solenoidal B (i.e., no curvature or gradient)
- Direction of flow is consistent with sign of drift velocity

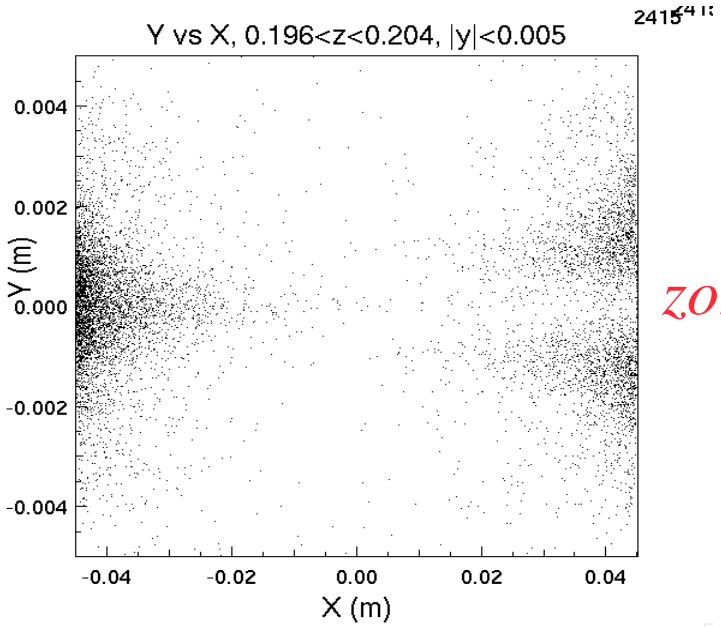
zone 1 electrons



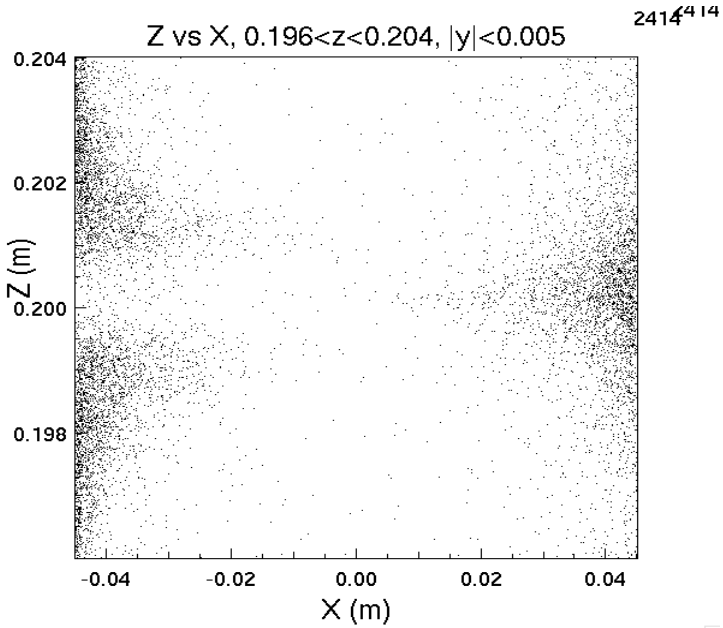
zone 2 electrons

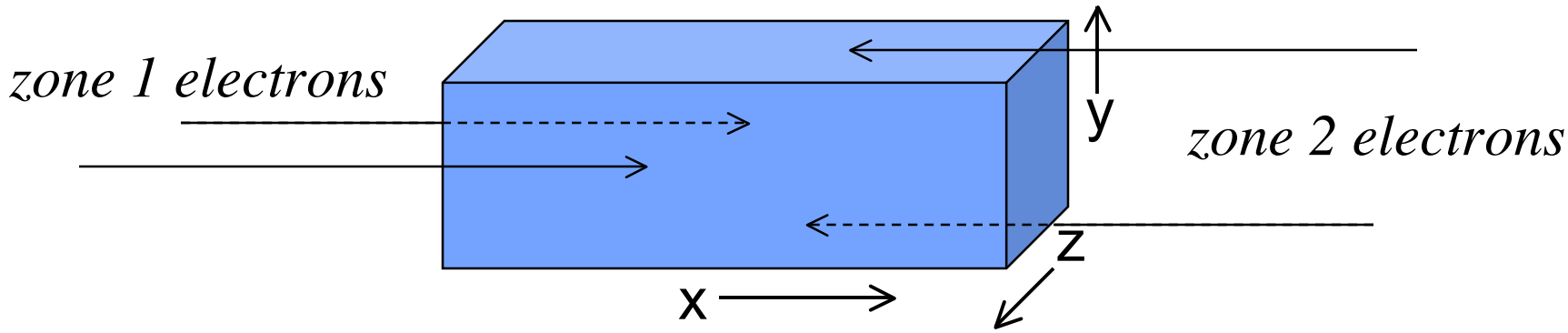


No Zone 1 electrons at z=0; No Zone 2 electrons at y=0



zone 2





Comparing x velocity in simulation to velocity of drifts

The combined drift velocity is

$$v_d = \frac{m}{q}\frac{\nabla|B|}{B^3}\left(v_{\|}^2 + \tfrac{1}{2}v_{\perp}^2\right)\hat{x}$$

drift is small at high B

Approximate the wiggler field as

$$B_y = -B_0 \cosh ky \sin kz$$
$$B_z = B_0 \sinh ky \cos kz$$

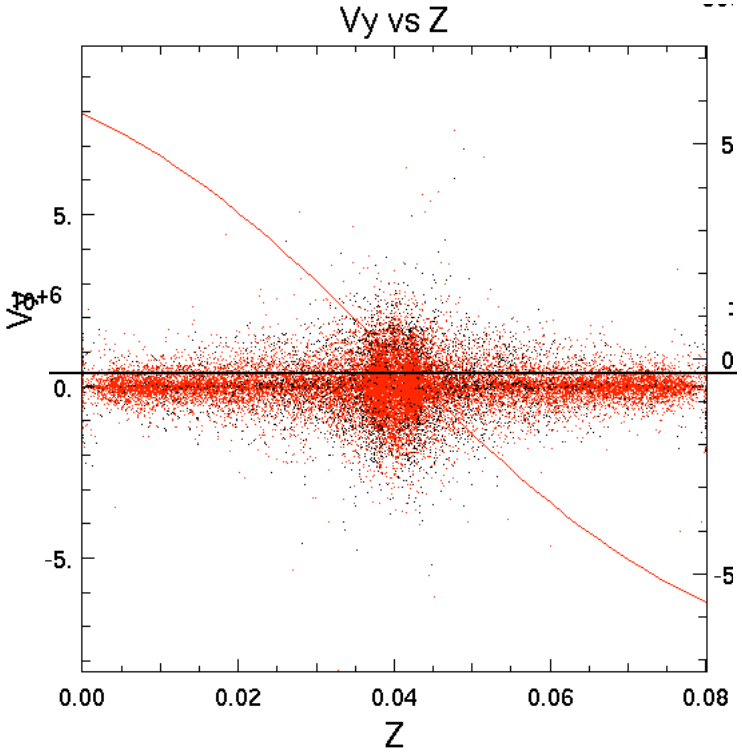
For z and y small,

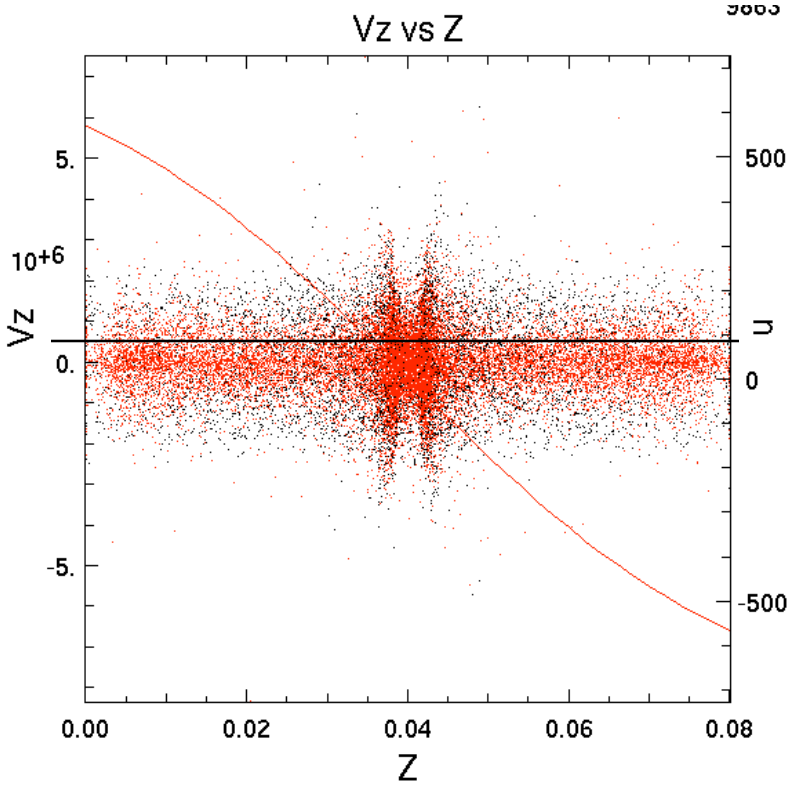
$$v_d \approx \frac{m}{qkB_0}\frac{y^2 - z^2}{(y^2 + z^2)^2}\left(v_{\|}^2 + \tfrac{1}{2}v_{\perp}^2\right)\hat{x}$$

Agreement with the simulation ?

Set z=0, y=1 mm, to go 2 cm in 40 bunch passages ⇒

electron velocity term ~ 5 x 10^5 m/s



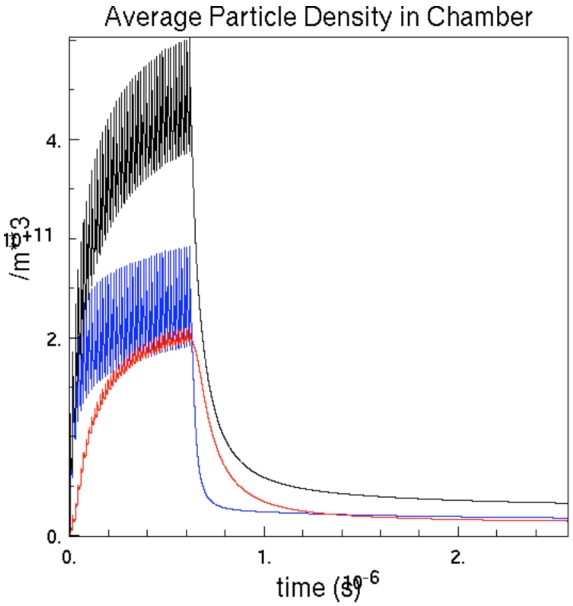


v_x looks similar to v_z

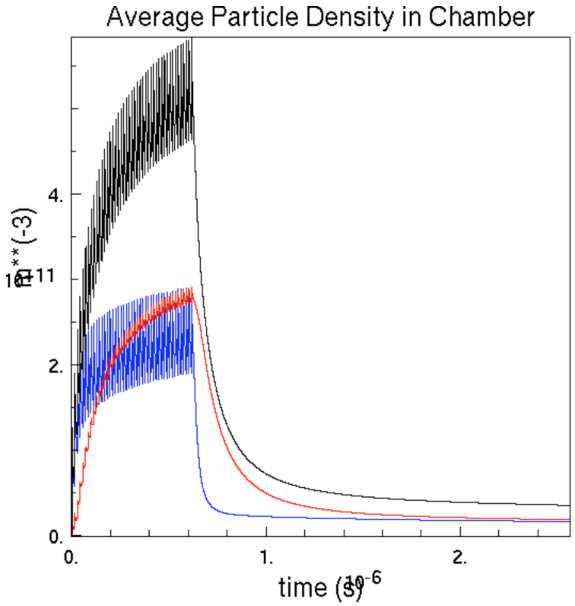
SEY Scan

Scan of SEY (δ_{max}) values: 1.2, 1.4, 1.8

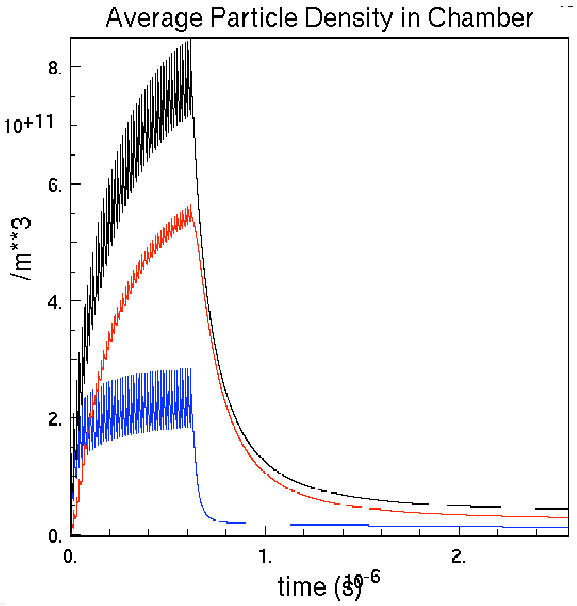
1.2



1.4



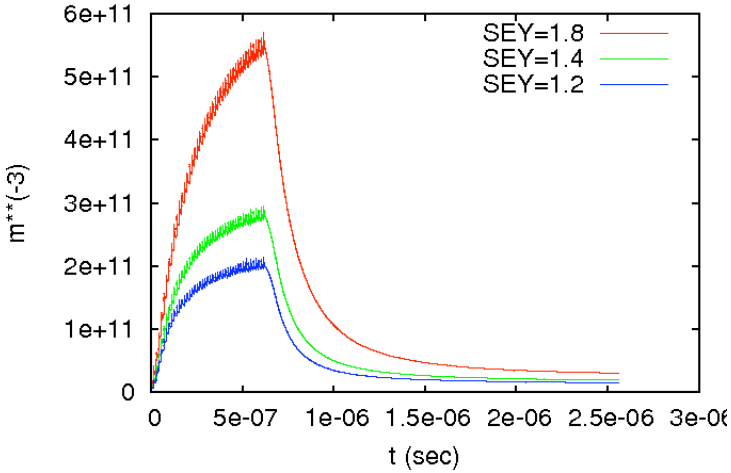
1.8



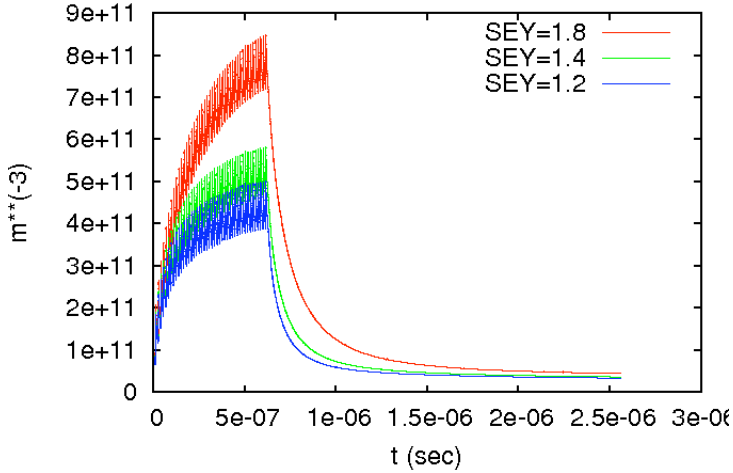
total
secondaries
primaries

Results of Peak SEY Scan - 1.2, 1.4, 1.8

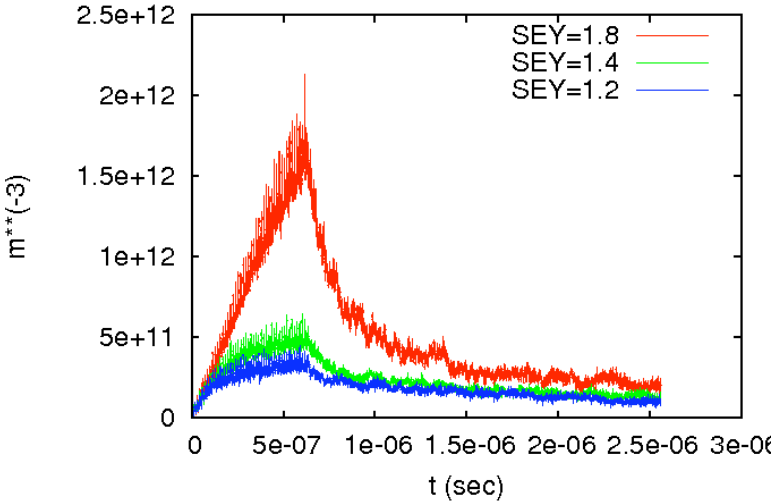
Secondaries



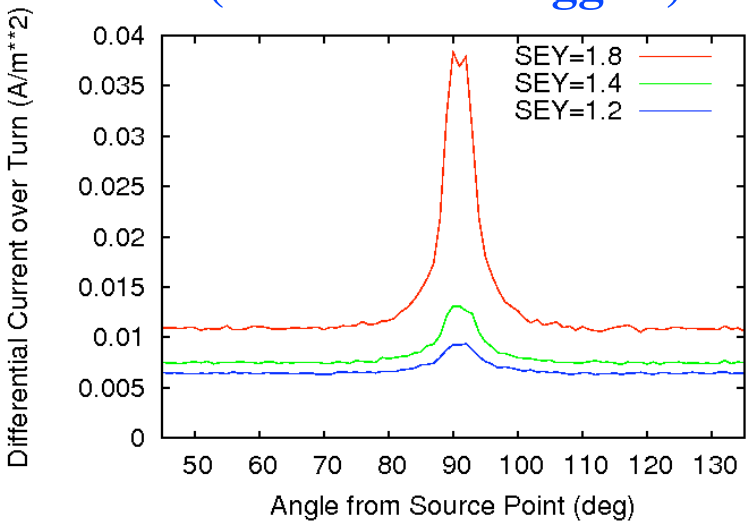
Total Electrons



Electrons within 1 mm of Beam

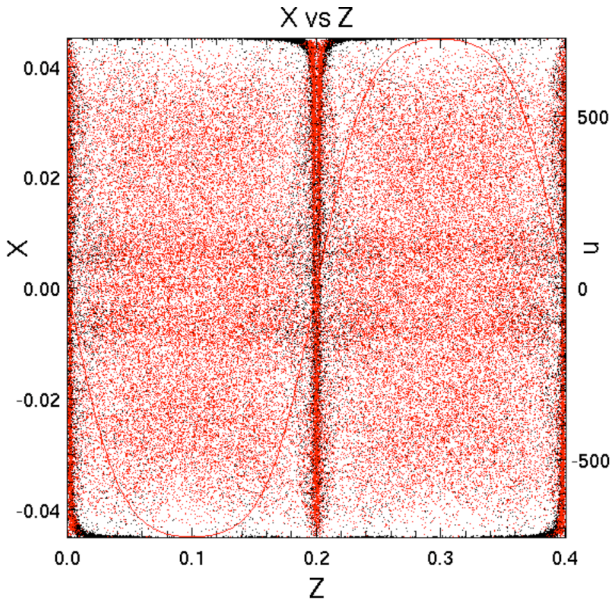


Electrons hitting wall vs. θ (whole Δz of wiggler)

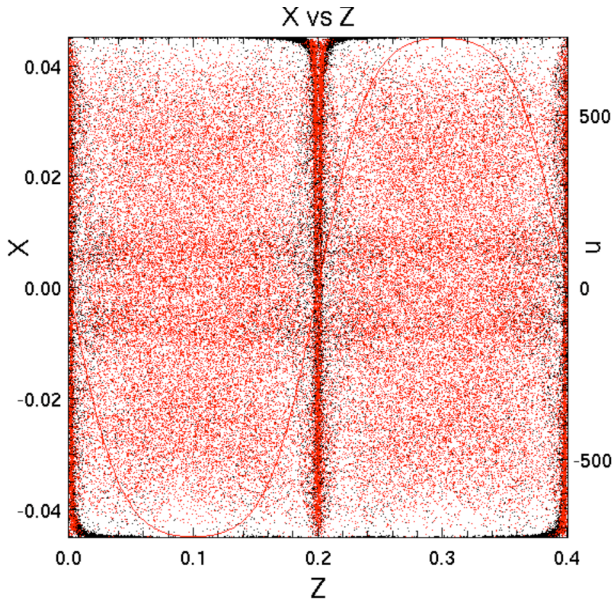


Stripe geometry changes with SEY

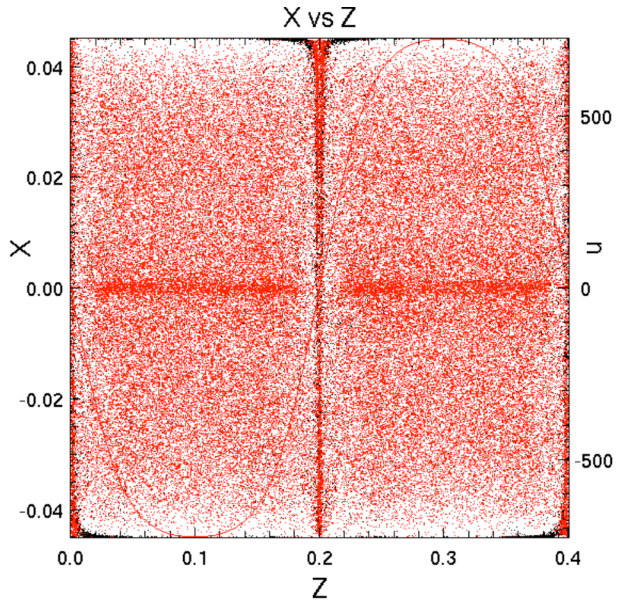
SEY = 1.2



SEY = 1.4



SEY=1.8

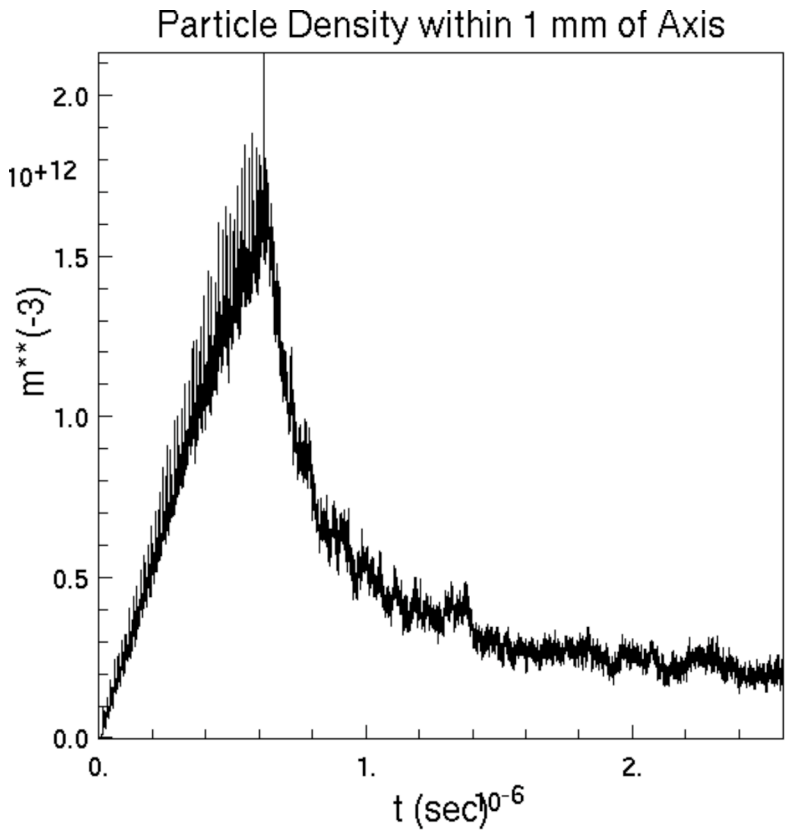


Importance of rediffused electrons

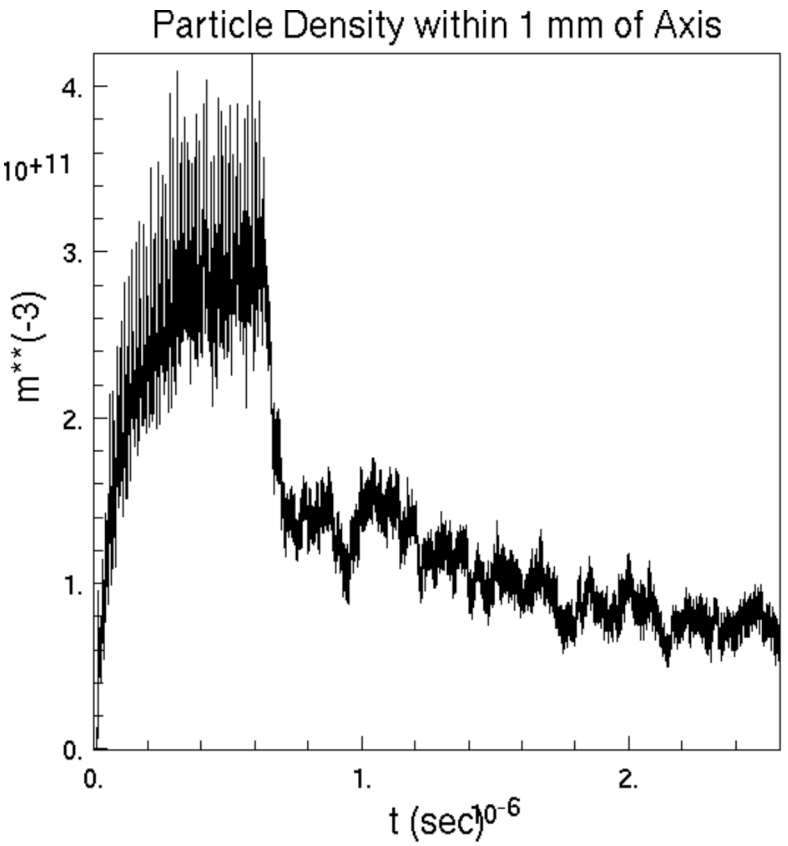
SEY = 1.8

At end of bunch train(0.6 us)

With rediffusion



No rediffusion



Conclusions

- Except around B_y=0, cloud density is highest in one vertical stripe at the center of the channel for these parameters. Motion is essentially 2D.
- At B_y=0 electrons traverse the chamber in the x direction near the x axis, apparently due to curvature and gradient in B.
- Electrons near B_y=0 plane remain, with considerable density, after bunches stop, and persists even at 1 turn. They will not be seen on an RFA.
- Lowering the peak SEY parameter changes the vertical stripe geometry. Rediffused electrons are important at high SEY.