3-D Simulations of Magnetic Shutters

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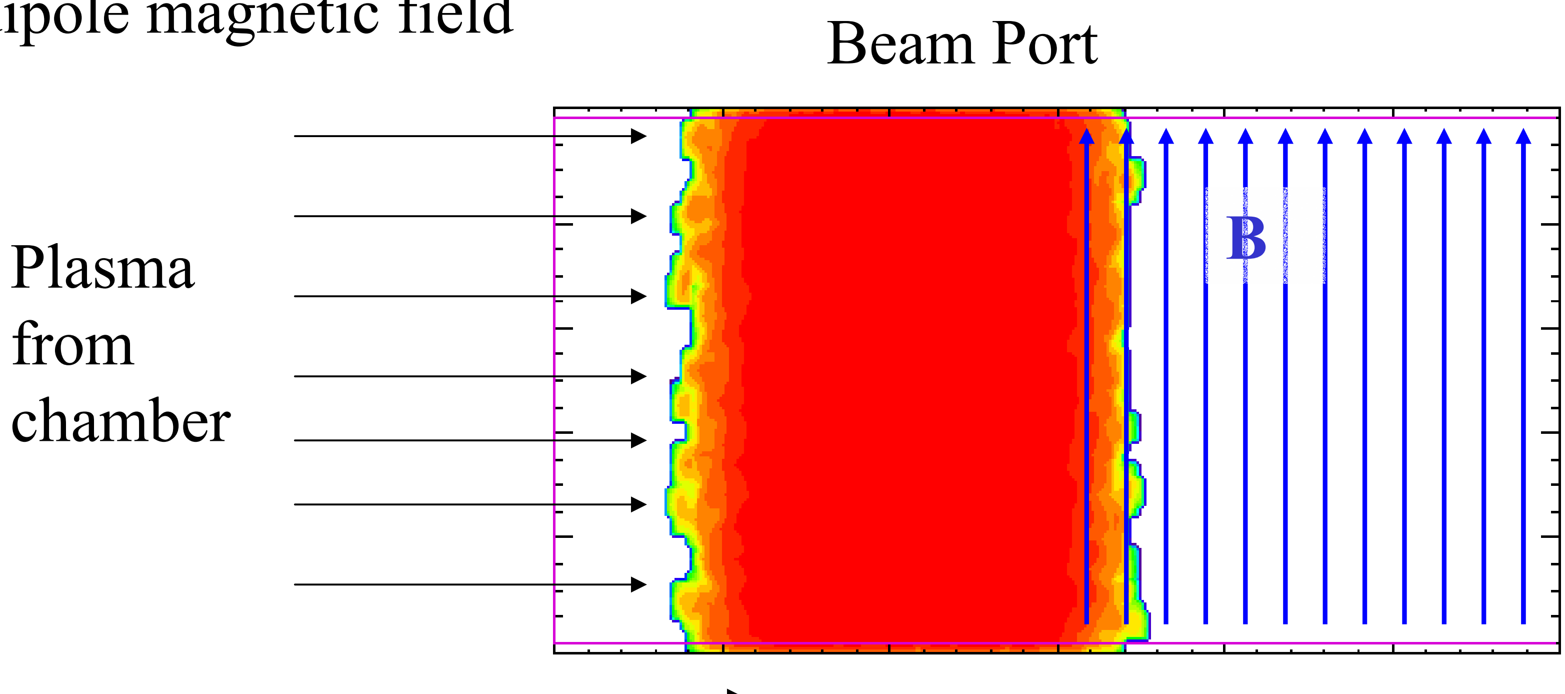
Review: A plasma can be blown off the chamber wall and expand into the beam port

- We expect the plasma to be of order 10^{14} cm^{-3} density and 10 eV
- Neutral fraction may be quite small for these conditions
- Plasma can be diverted to port wall with a vertical or dipole magnetic field



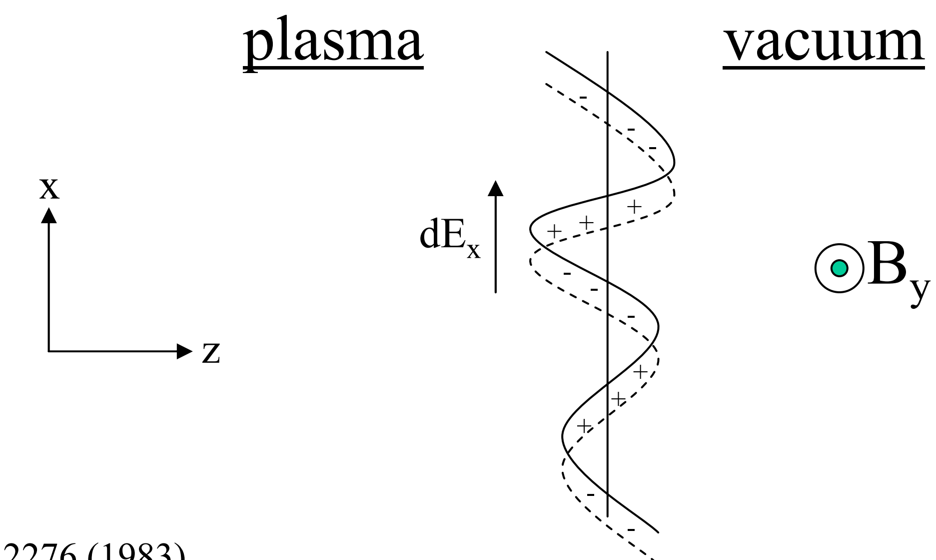
Long wavelength, low-β plasma penetration model[1]

Initial plasma penetration distance is found to be:

$$r_h = \sqrt{r_{Le} r_{Li}} \approx 0.16\ \mathrm{cm}$$

But instability of boundary layer allows further penetration (flute-type instability). Growth rate is relatively fast [*O*(10 ns)], with "finger" sizes[2] $< r_{Li}/4 \sim 0.25$ cm.

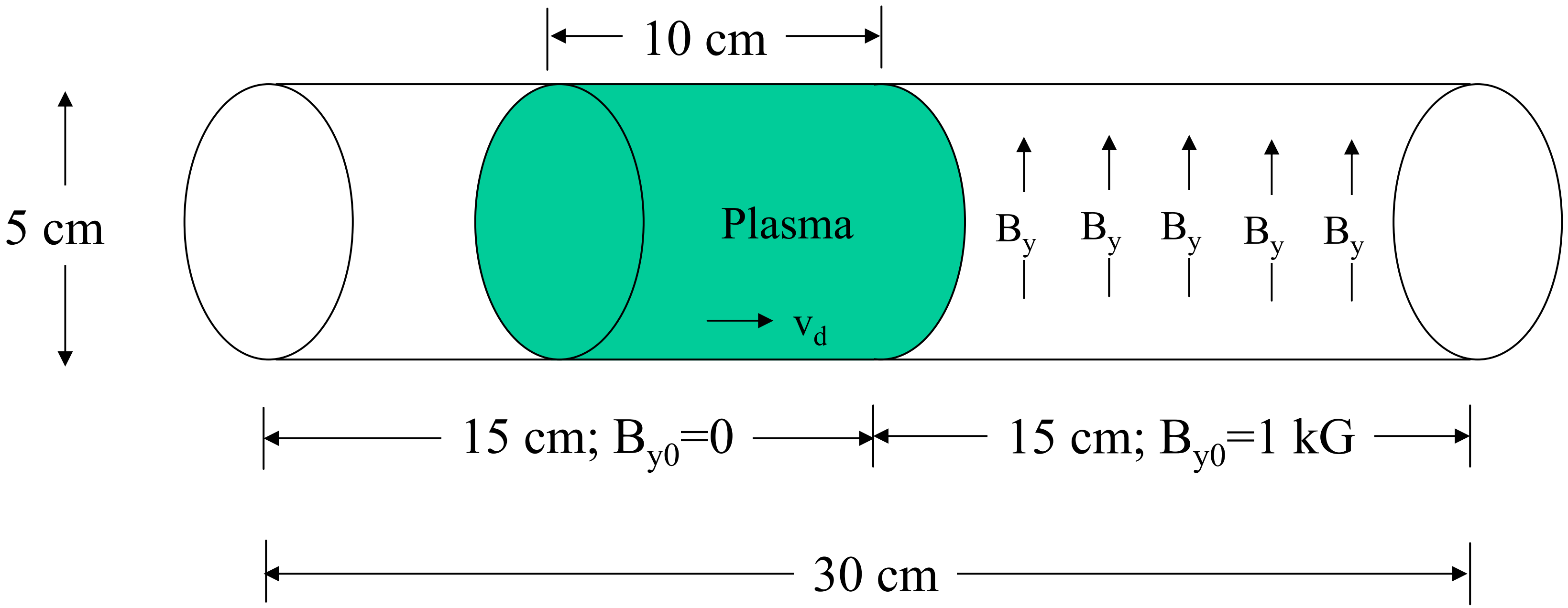
Boundary interface wavelengths and "finger" widths not adequately resolved in initial simulations.



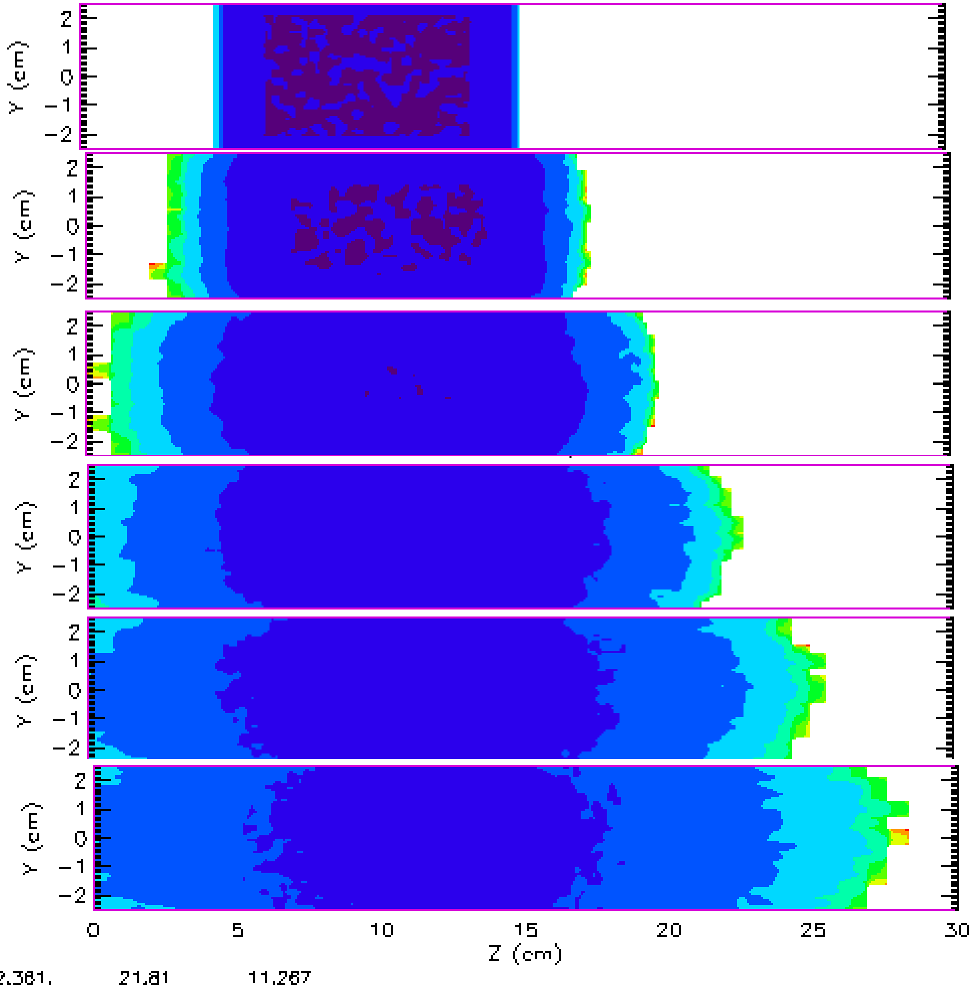
1) W. Peter, A. Ron, and N. Rostoker, Phys. Fluids **26**, 2276 (1983)
2) L. Lindberg, Astrophys. Space Sci. **55**, 203 (1978).

3-D Simulation of 10^{14} cm^{-3}, 100 eV, v_{drift} = 9cm/μs case:

- 3-D simulations use same EM implicit field solver as 2-D case.
- Initial simulations use smaller beam port radius (2.5 cm) for computational efficiency
- Same plasma parameters as 2-D case.



Test Case: Ion expansion *without* applied B_y-field…



0 ns

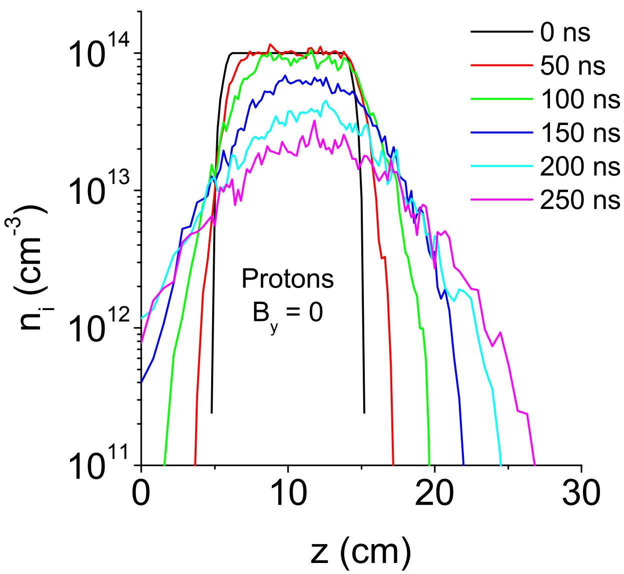
50 ns

100 ns

150 ns

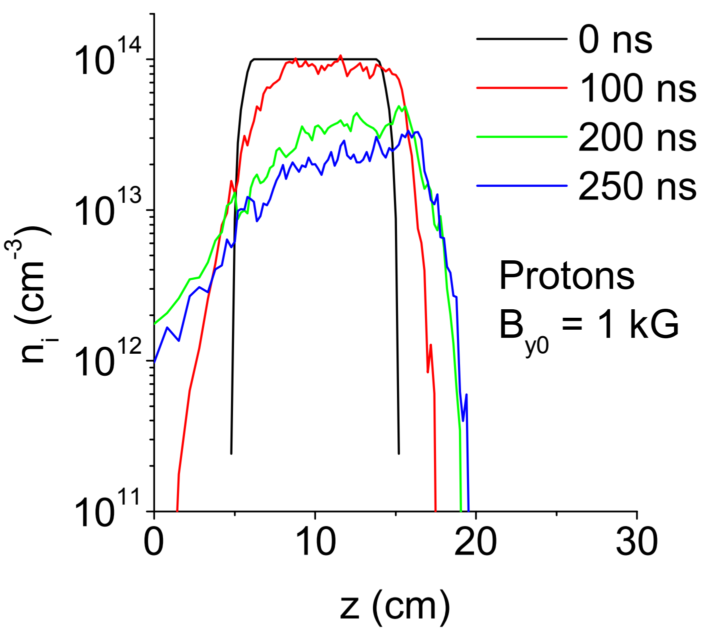
200 ns

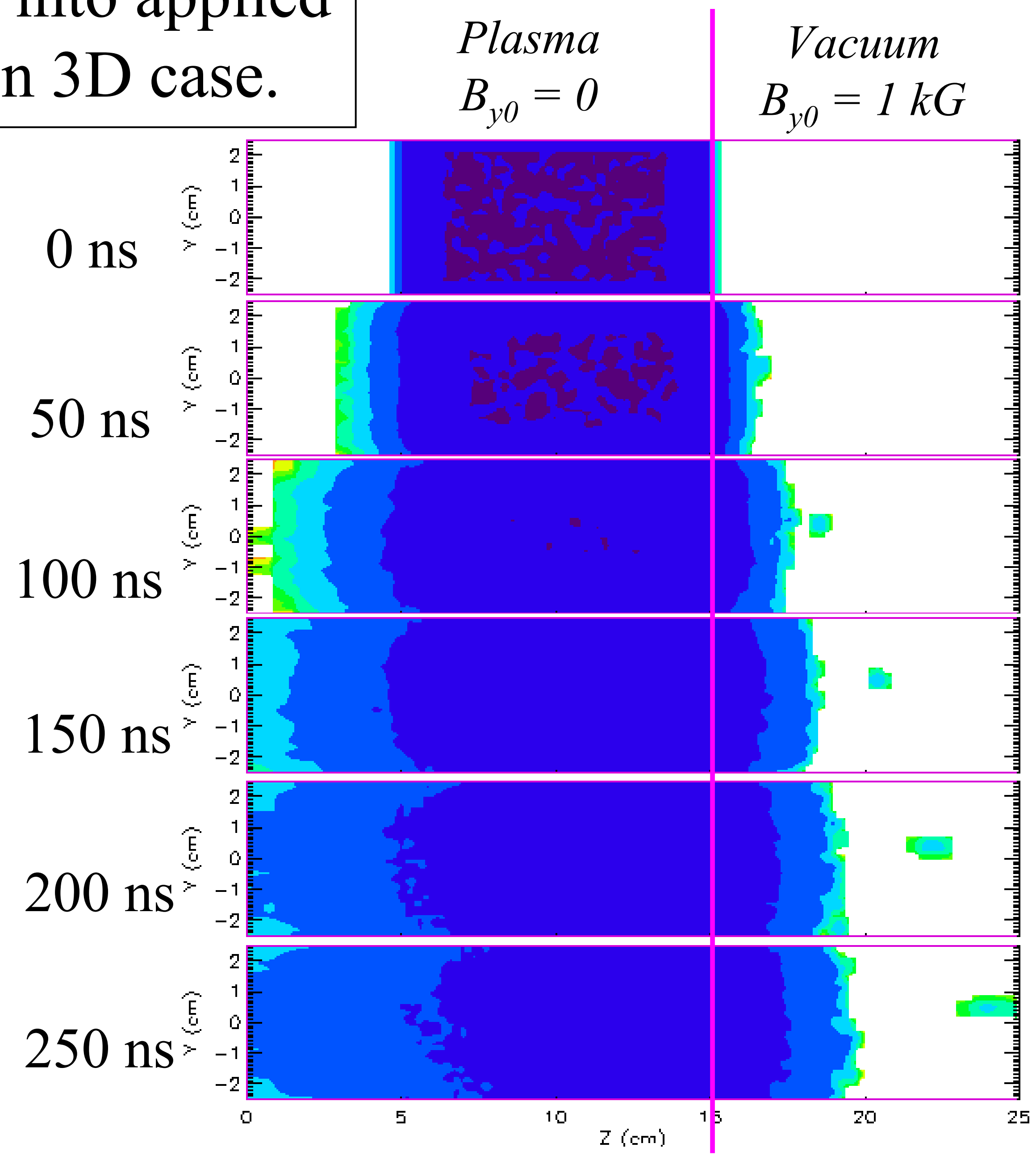
250 ns



Greater ion expansion into applied B-field is observed in 3D case.

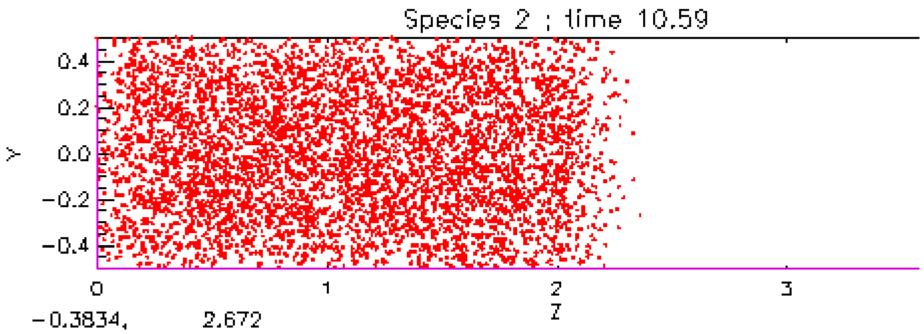
1 kG applied B_y field
$V_{drift} = 9$ cm/µs
$T_e = T_i = 100$ eV



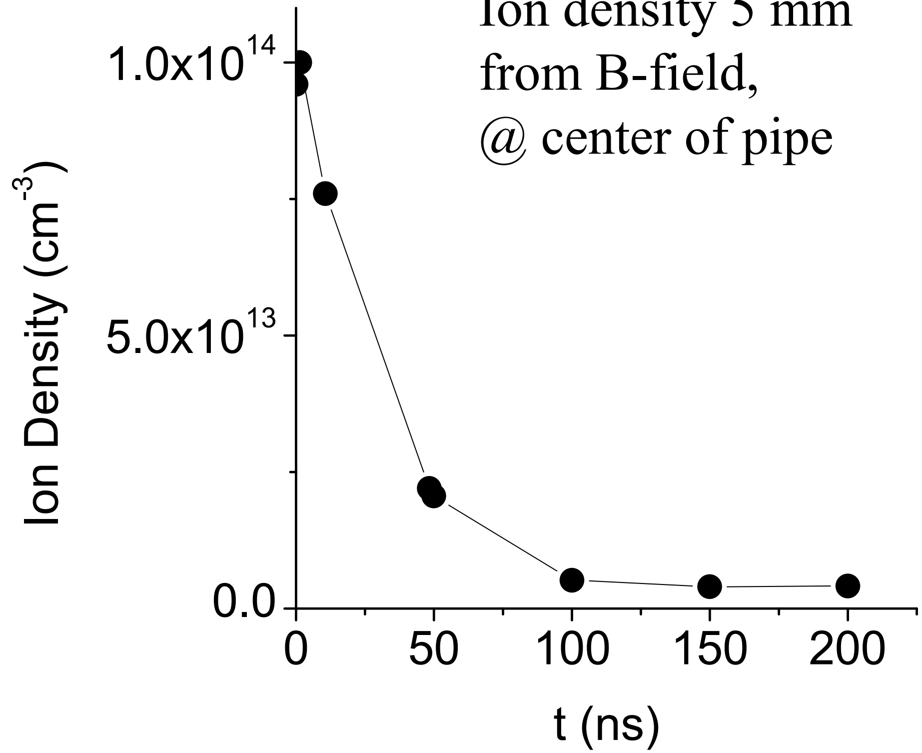


Smaller scale 3-D simulations have been carried out to look at a) plasma penetration physics and b) losses to walls.

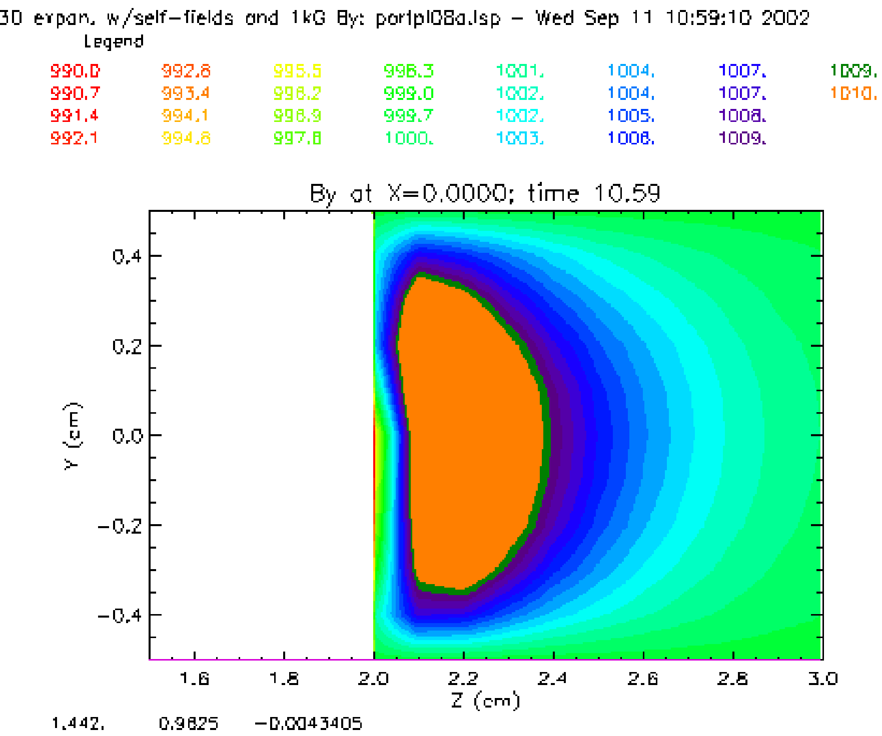
$R_w = 5$ mm, $n_p = 10^{14}$ cm^{-3}, $B_o = 1$ kG



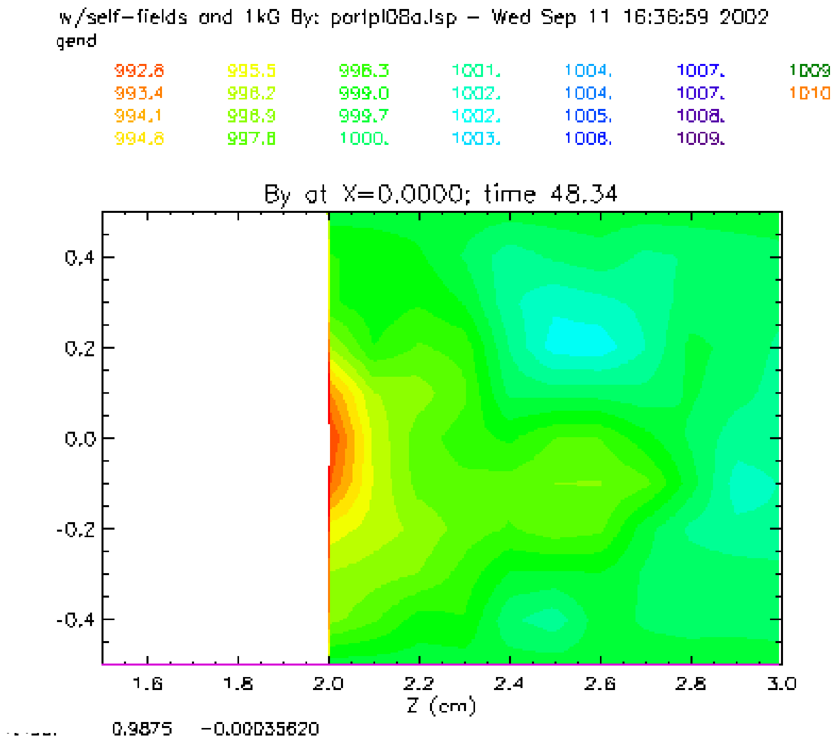
B-field region begins here.



Magnetic field "snaps back" as plasma density drops…



10 ns



48 ns

Conclusions

- 3D simulations predict that anticipated chamber plasmas are diverted by a moderate strength magnetic field (1 kG) [worst case?]
- 3D simulation results to date suggest that this region needs to be at least 10 cm long.
- 3D results illustrate possibility of deeper penetration by a "few" particles – larger-scale, higher fidelity simulations are required to address this.
- Laboratory testing/benchmarking of diverter plasma would be "relatively" easy – i.e. cable gun plasmas of a few eV and controllable densities could be injected into a dipole *B*-field inside a pipe…

Farrokh's Three Questions

- What do you need to do to wrap this up: More research in this area is required. Estimates of magnetic shutter efficiency can only be made from large-scale 3-D LSP simulations. These same simulations can be compared to physics models of low-β plasma confinement.
- Impact on ARIES IFE studies? A successful beam line design for neutralized ballistic transport requires a magnetic shutter, neutral trap (ionizer?) and flibe vortex. For the shutter, estimates of B-field strength, length, and efficiency are part of the beam line design.
- Near term experiments? Yes! (see last bullet of previous slide)