SAND2007-2052C

3D Z pinch simulations using mass injection scheme

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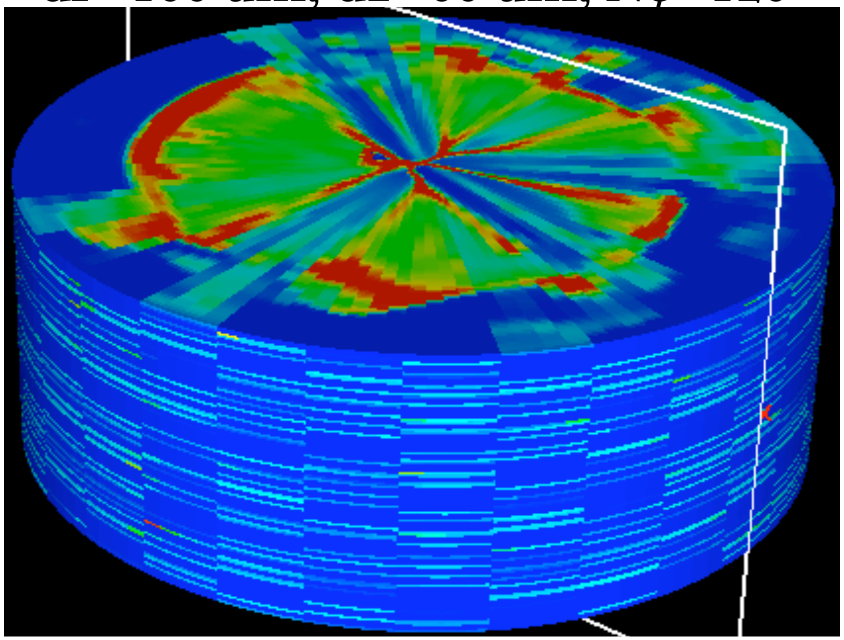
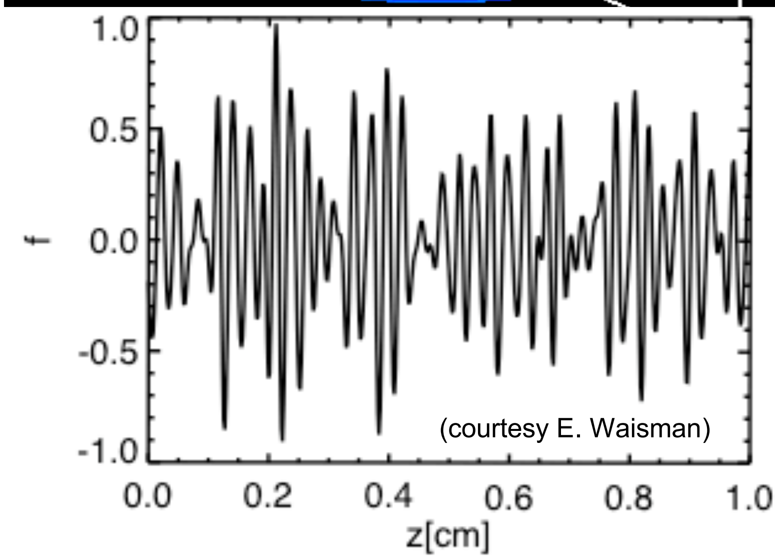
methodology

dr~100 um, dz~60 um, Nϕ=120





Each cell on injection surface obeys

$$\rho_{in} v_{in}^2 = \frac{B_0^2}{2\mu_0} \quad \text{(rocket model)}$$

as implemented by J. Chittenden, E. Waisman, T. Haill

No δm, but to model axial instability on wire

$$v_{in} = \frac{v_0}{1+f}$$

consequently

$$\rho_{in} = \frac{B_0^2}{2\mu_0 v_0^2}(1+f)^2 \equiv \rho_0 (1+f)^2$$

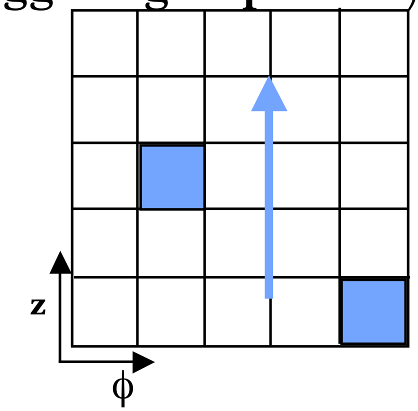
$$\dot{m} \propto \rho_{in} v_{in} = \rho_0 v_0 (1+f)$$

N cells (in above case N=4) are correlated azimuthally.

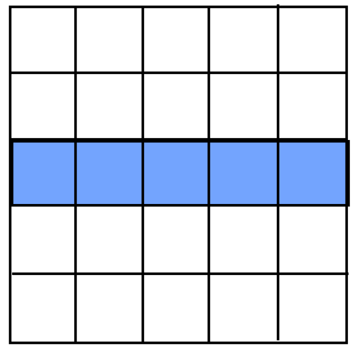
Many knobs (v_0, f, N) need to be constrained by experiment, but can also provide basic physics understanding

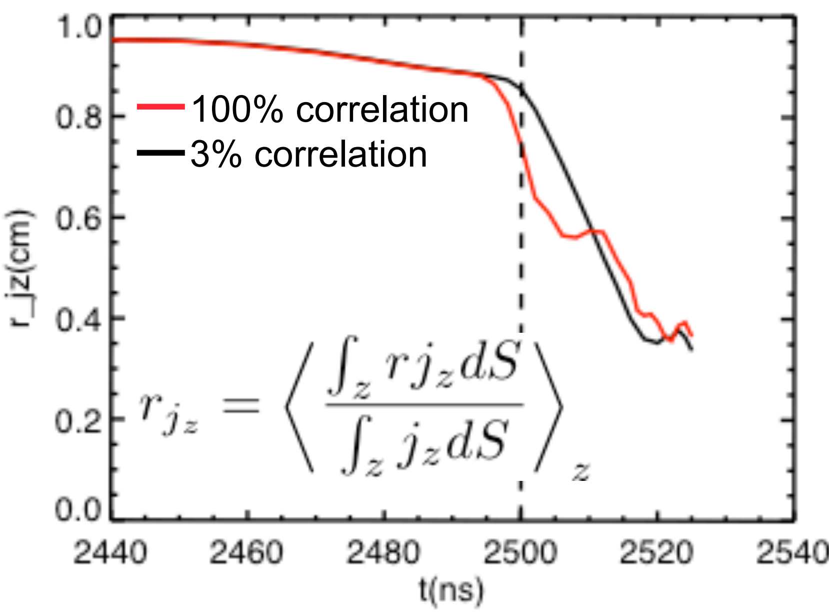
effect of azimuthal correlation

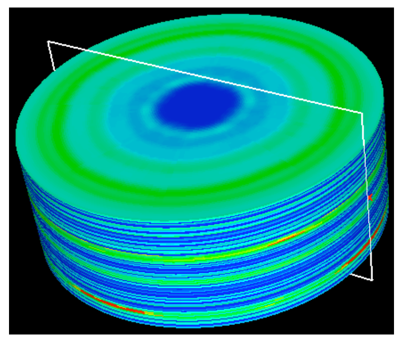
In this picture, current can flow when 50% of panels have disappeared (triggering implosion)

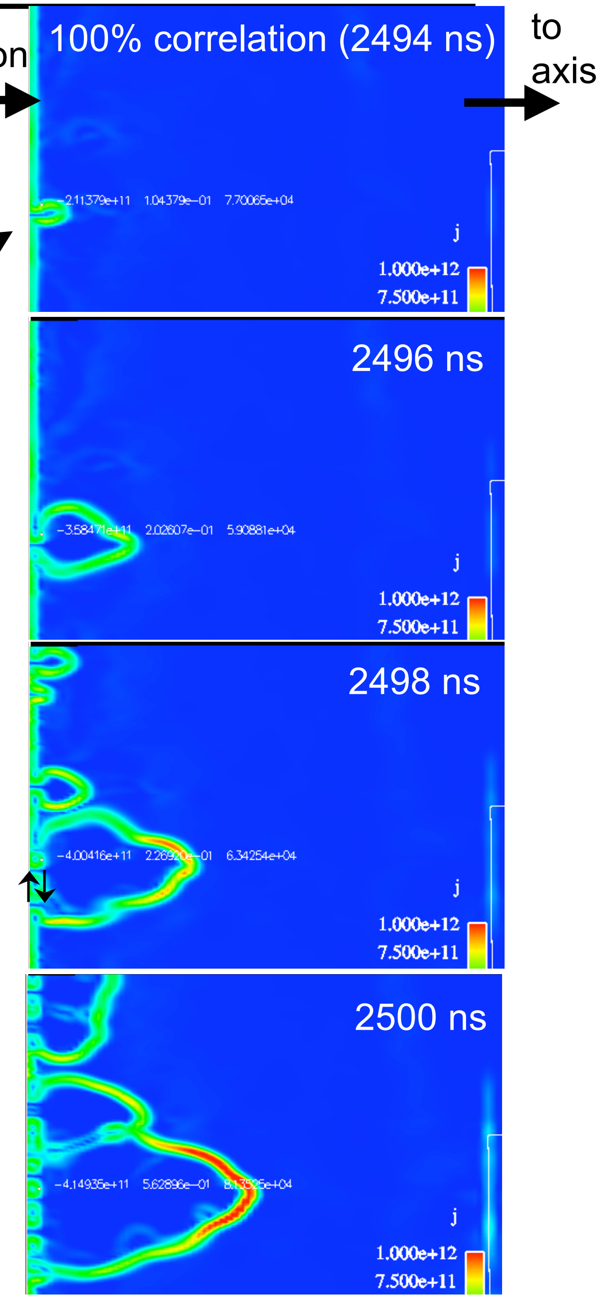


Now, as soon as one panel disappears, no current can flow



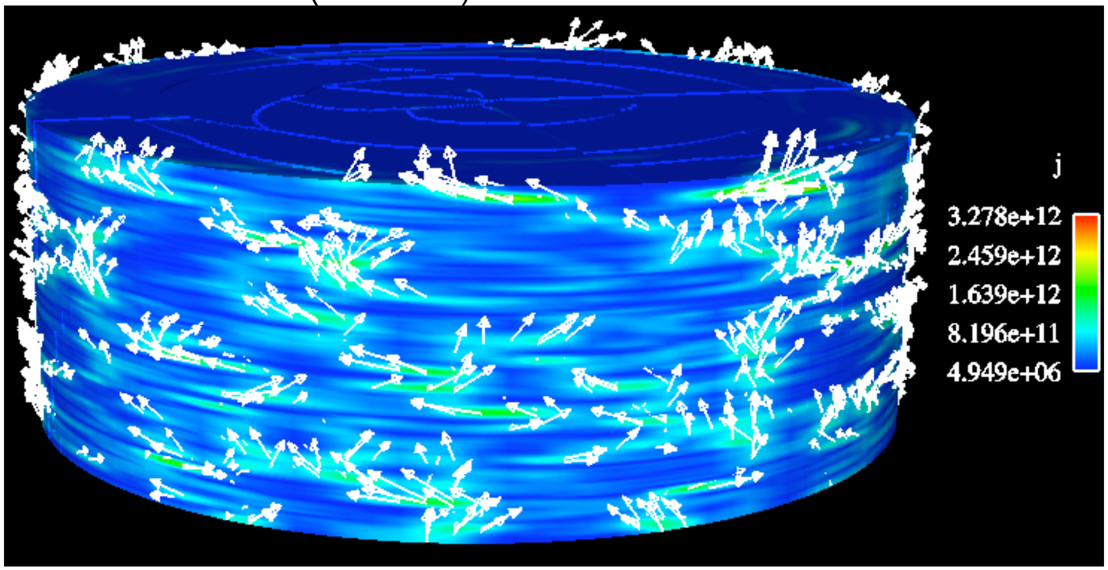


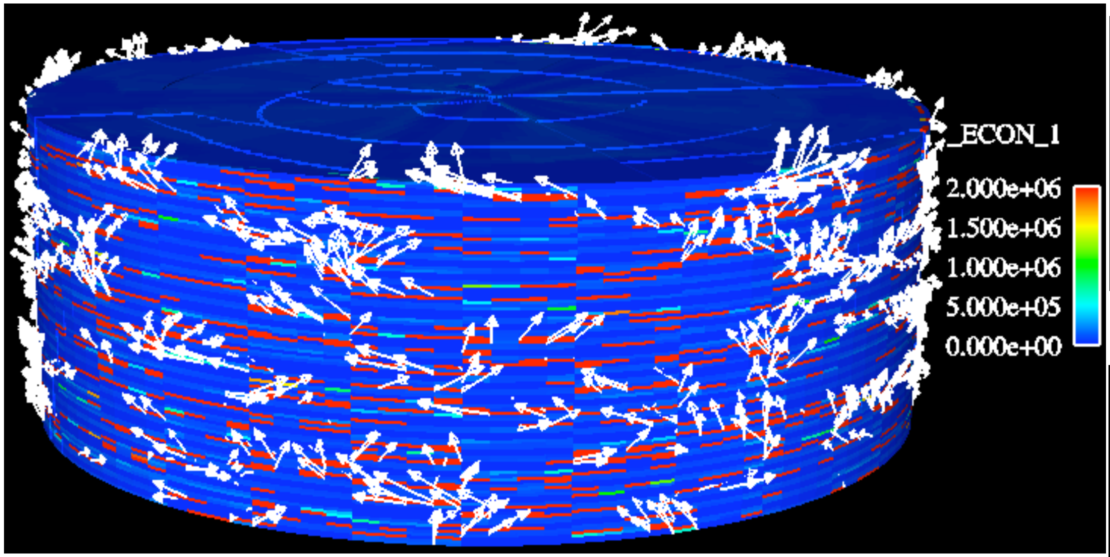




current in 3% correlation case stays at larger radius longer

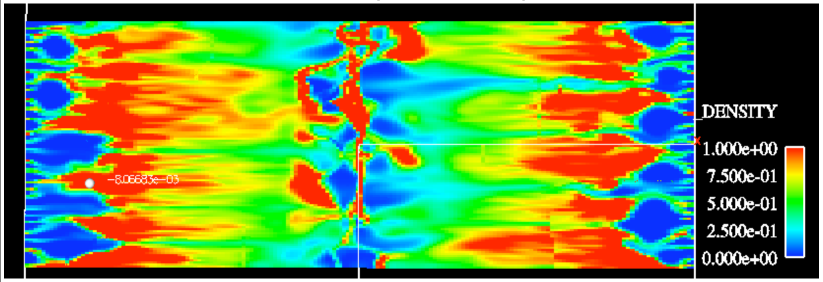
3% correlated (2502 ns)



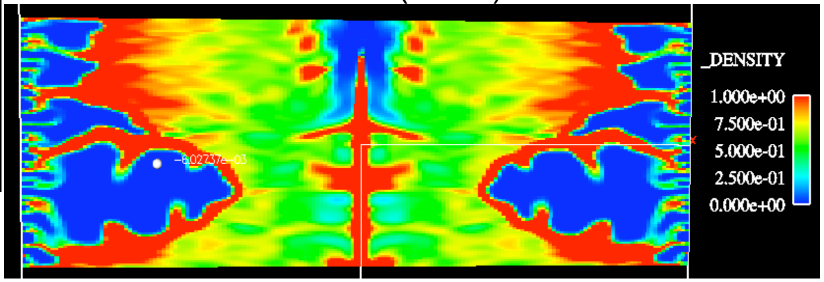


In 3% correlated problem, bubble growth is reduced because current can flow azimuthally, rather than radially inward along the bubble surface.

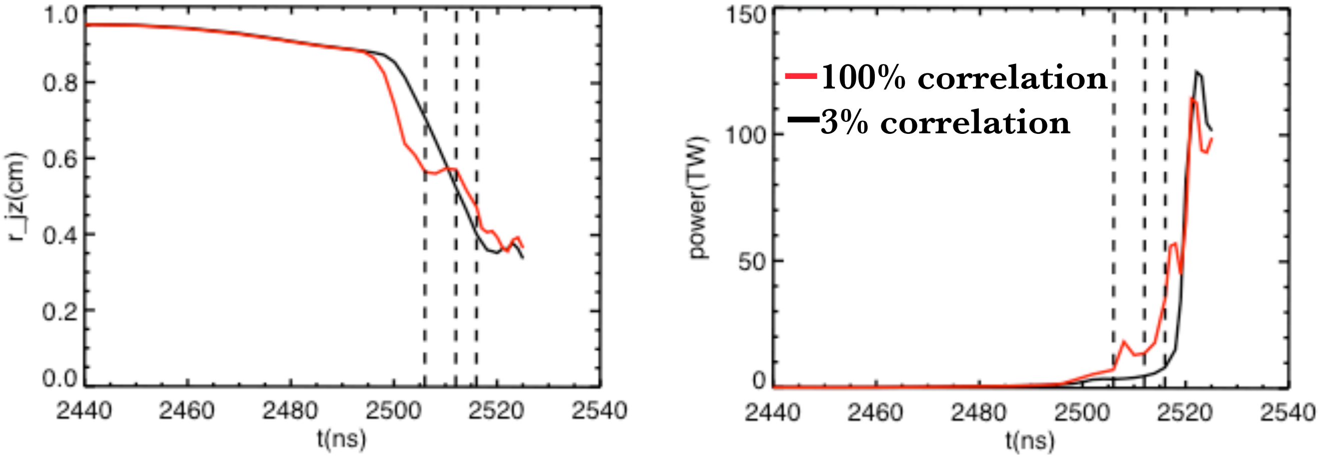
3% correlated (2502 ns)

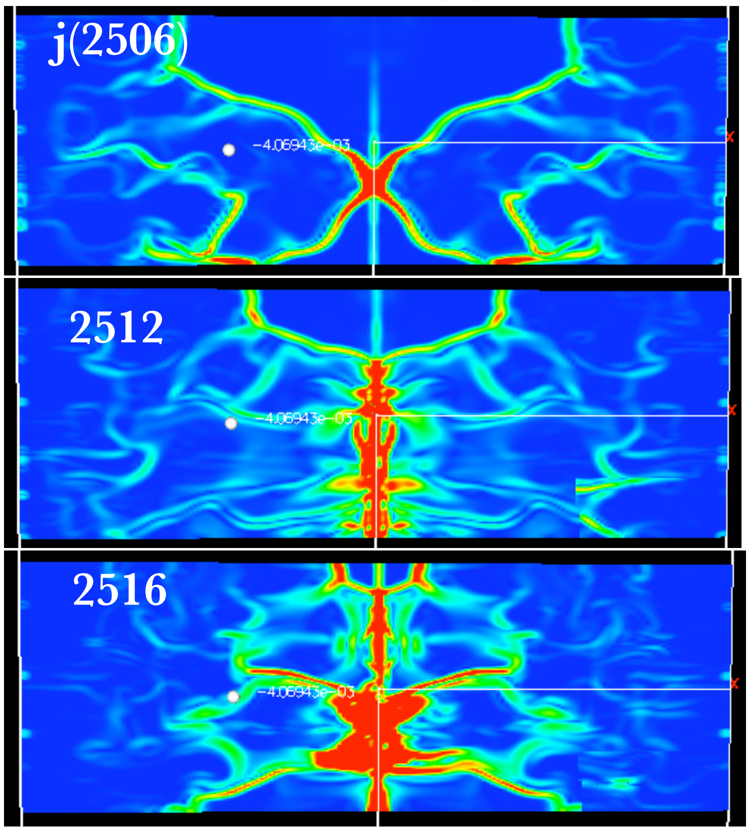


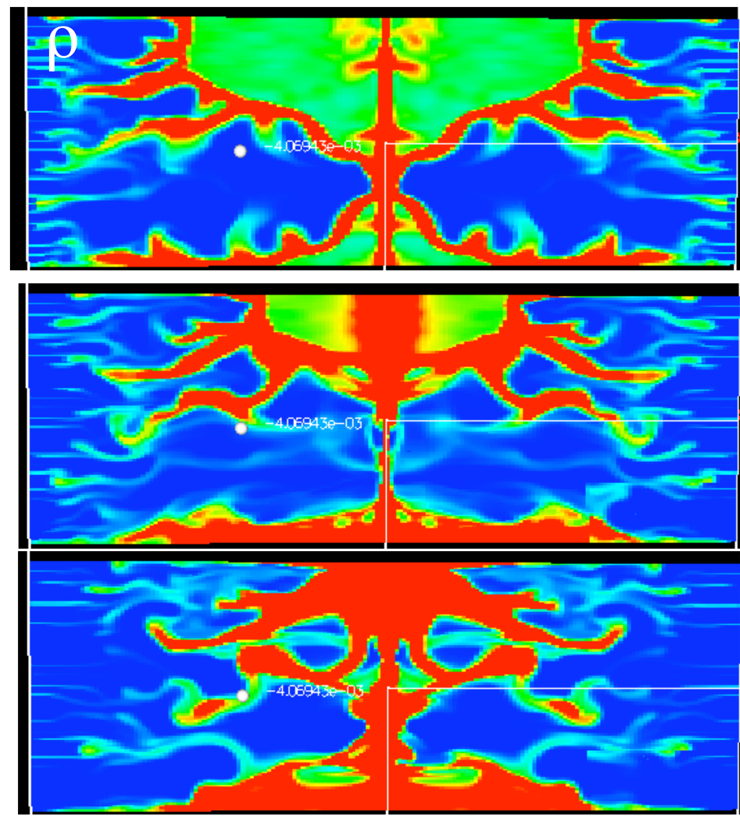
100% correlated (2502)



100% correlation evolution







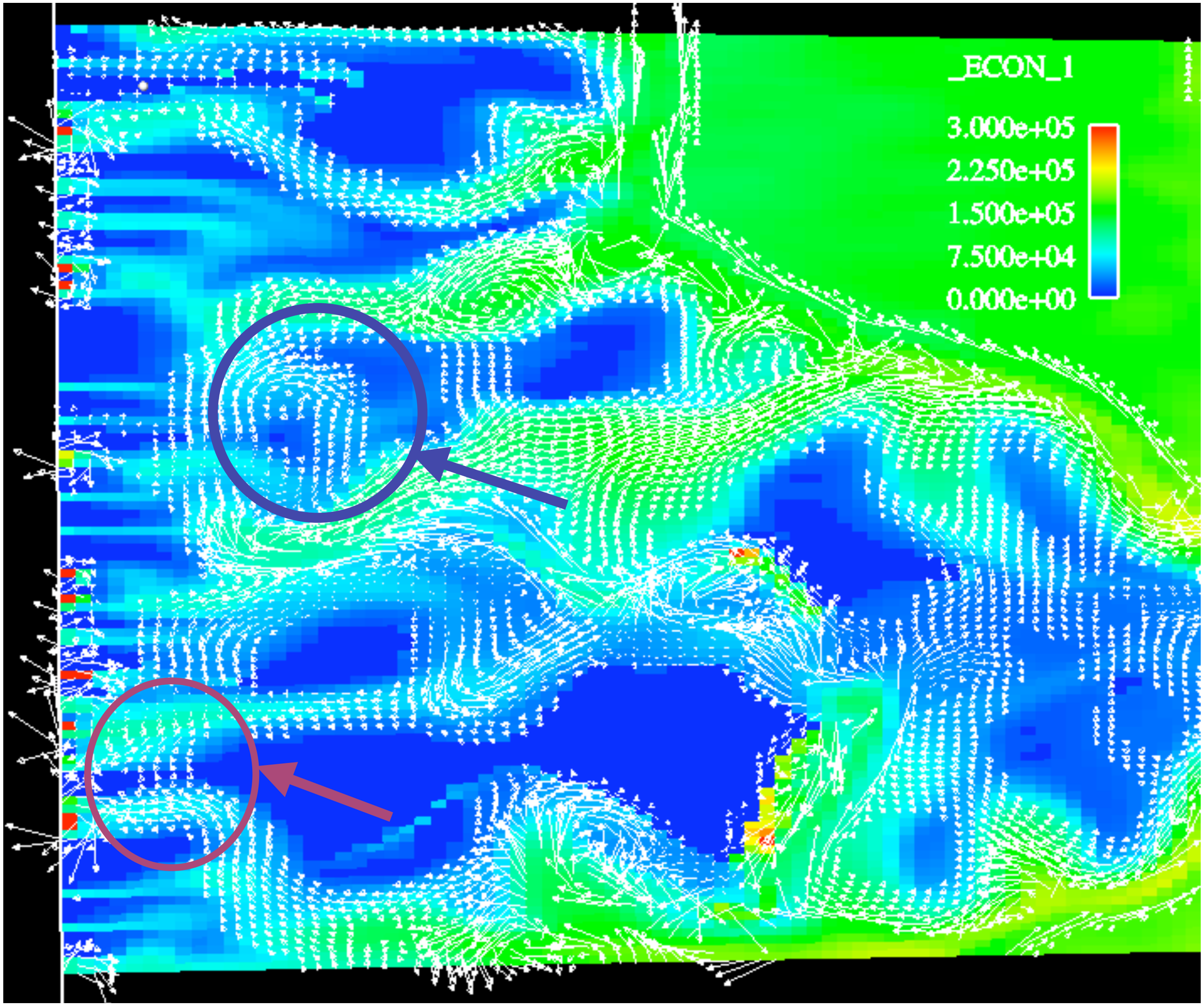
Bubble strikes axis so quickly, there is copious trailing mass, through which current can reconnect

From 2506-2512, there is bulk implosion of material, but current radius moves little

Note the exotic density profiles!

visualization of current flow

100% correlation (t=2506 ns)

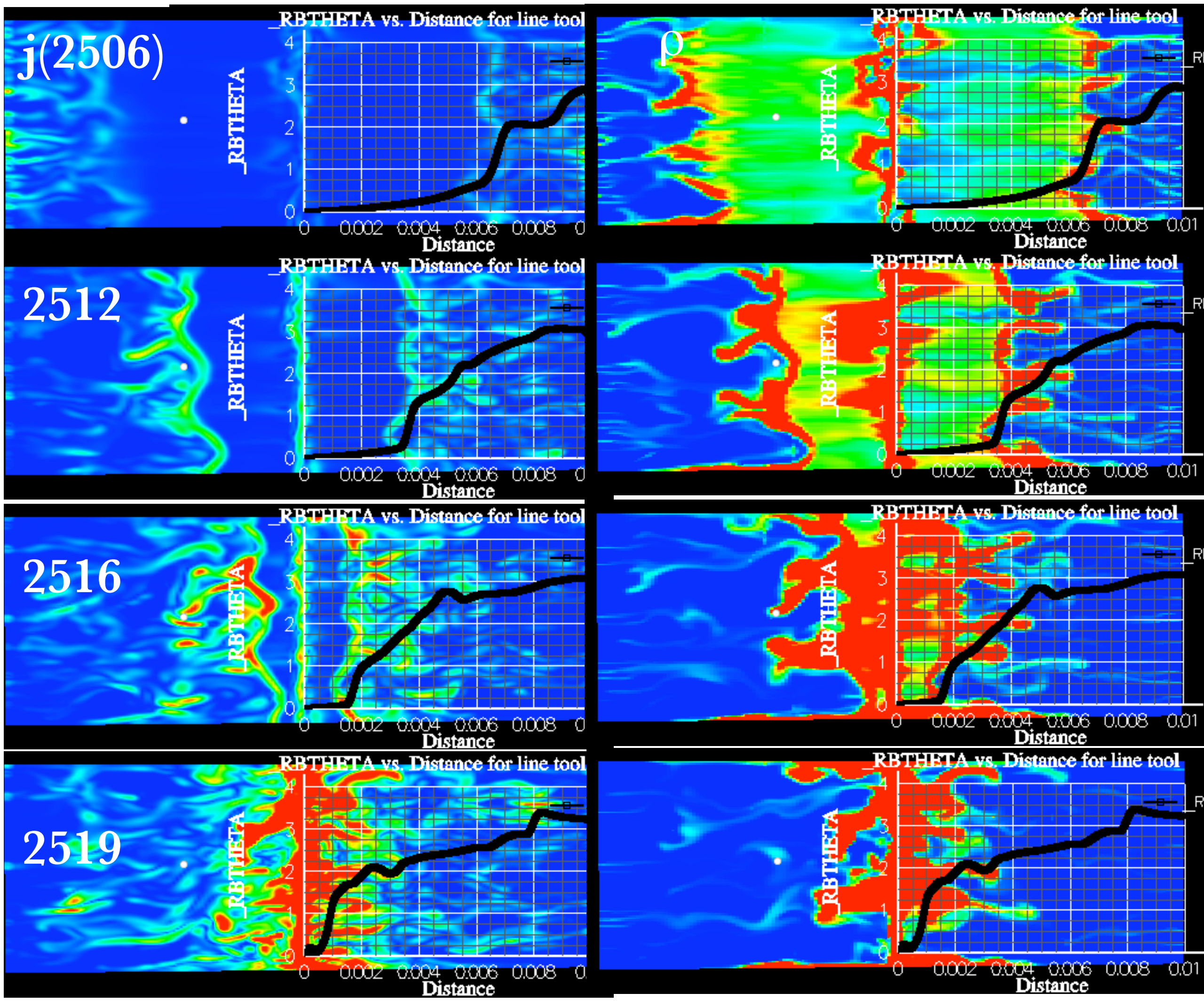


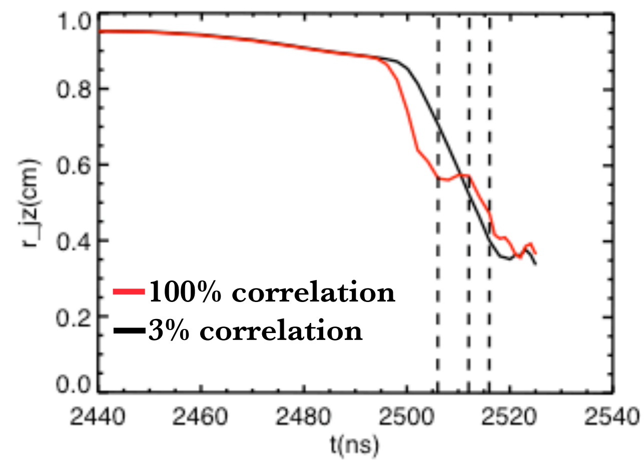
Beauty of 100% corr. simulations is dynamics occurs in r-z plane, allowing visualization.

Note the formation of the current eddy, as well as current jumping across the "vacuum" gap

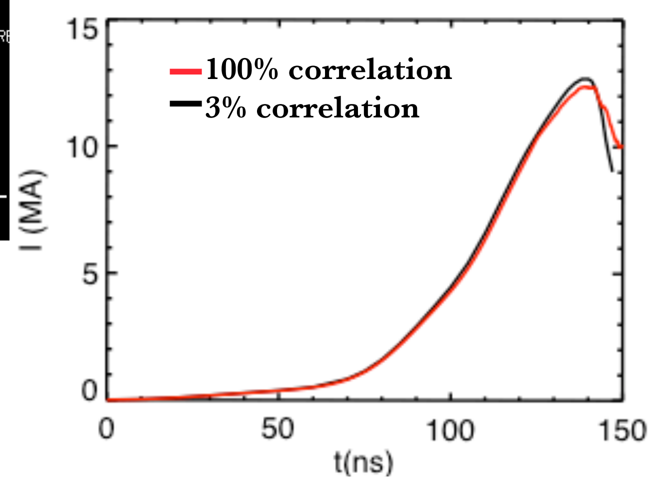
Note, in these simulations, minimum electrical conductivity = 1.e-7 * max electrical conductivity

3% correlation evolution





Due to reduced RT growth, 3% correlation case is actually MORE shell-like! Note switching of current into trailing mass



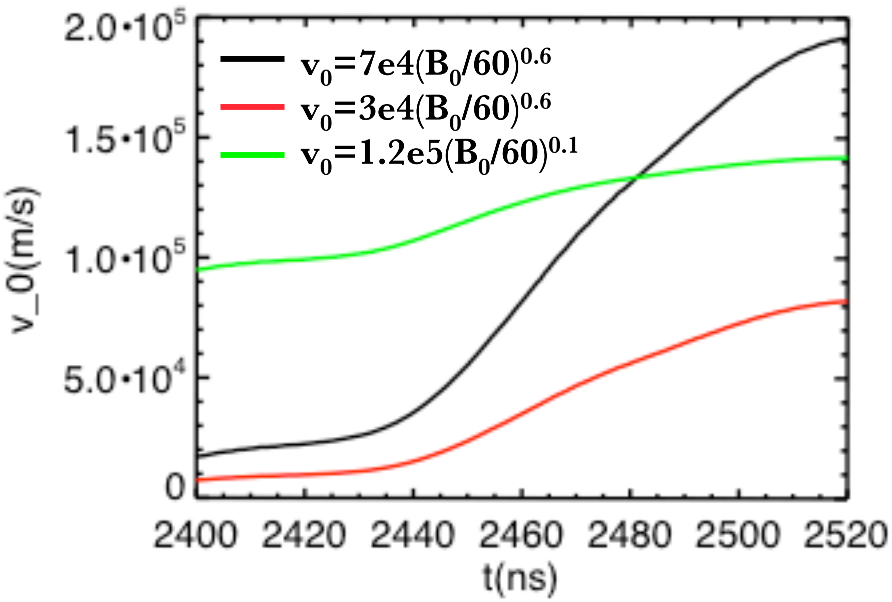
Despite differences in 100% and 3% correlation, the actual currents produced in voltage-driven simulations are remarkably similar!

so what?

Mass injection scheme can aid in the understanding and visualization of the phenomenon of trailing mass and current. How does the network of trailing mass change as we twiddle the knobs of the mass injection scheme?

Results are only in their preliminary stage, but hope to use intuition garnered from this problem to relate to the simpler 2D problems, as well as help understand more complicated 3D wire ablation simulations

comparison to backlighting



Choice of injection velocity will determine density profile during implosion.
Recall

$$\rho_{in} v_{in}^2 = \frac{B_0^2}{2\mu_0} \quad \textbf{or} \quad \dot{m} v_{in} \propto B_0^2$$

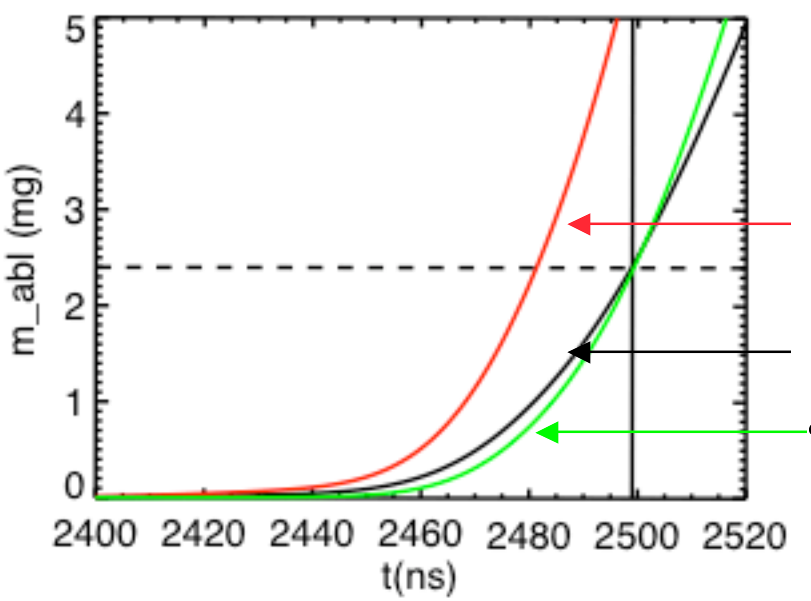
where we specify

$$v_{in} = \frac{v_0}{1+f}$$

Coupling energy equation with rocket equation implies, in steady-state

$$v_0 \sim B_0^{0.6}$$

E.P. Yu, B.V. Oliver, P.V. Sasorov, M.G. Haines, D.B. Sinars, S.V. Lebedev, T.A. Mehlhorn, M.E. Cuneo, Phys. Plasmas 14, 022705 (2007)



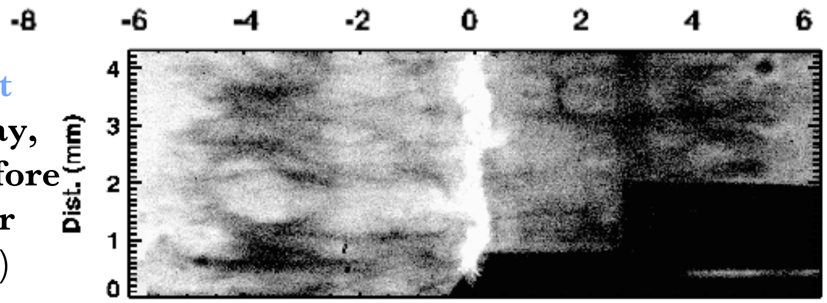
"early" implosion, shell-like distribution

"delayed" implosion, distributed mass profile

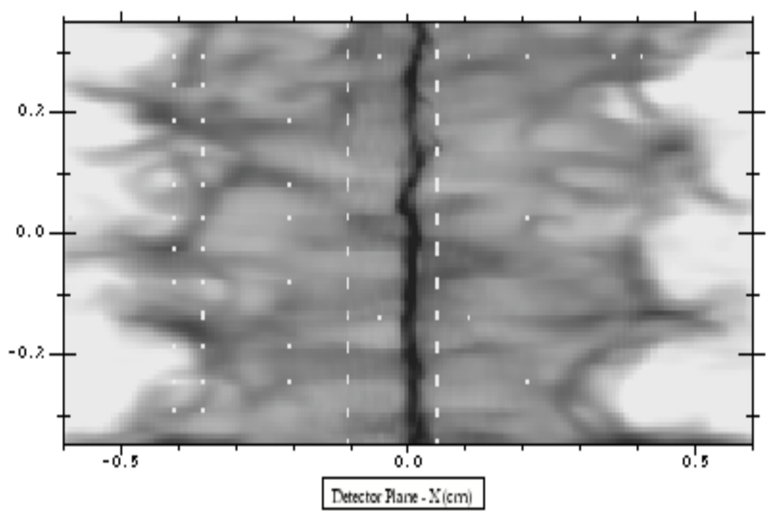
"delayed" implosion, more shell-like than above

higher velocity case: $v_0 = 7e4(B_0/60)^{0.6}$

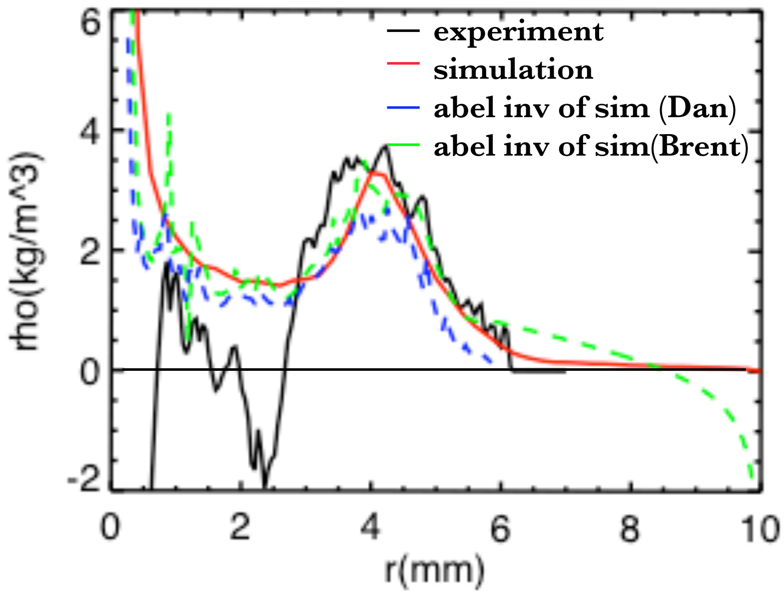
experiment
2.4 mg array,
-10.5 ns before
peak power
(I~15.4 MA)

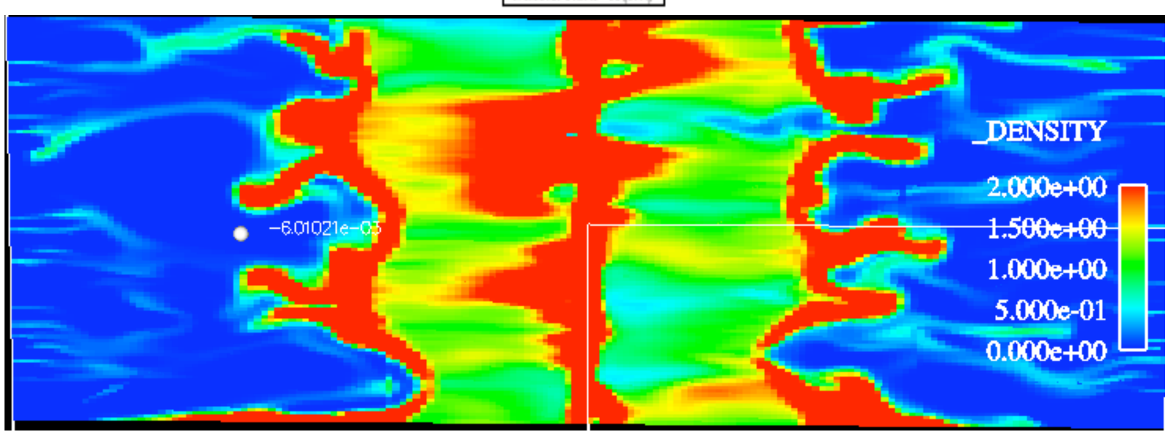


simulation
same timing
as above, with
3% of array
azimuthally
correlated



Generates good agreement with timing of all 3 experimental backlighting shots BUT not shell-like enough, too much mass on axis

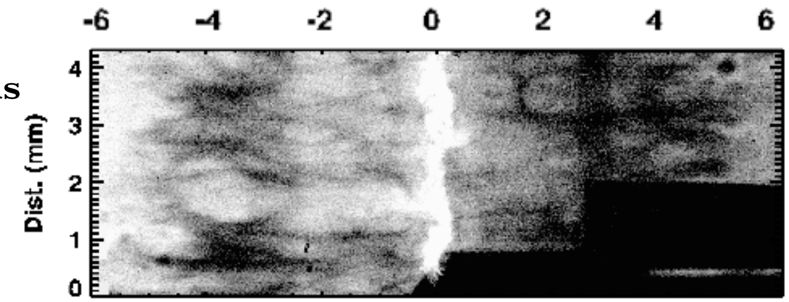




n.b. Experimental image and resulting Abel inversion is actually averaged over 1 ns

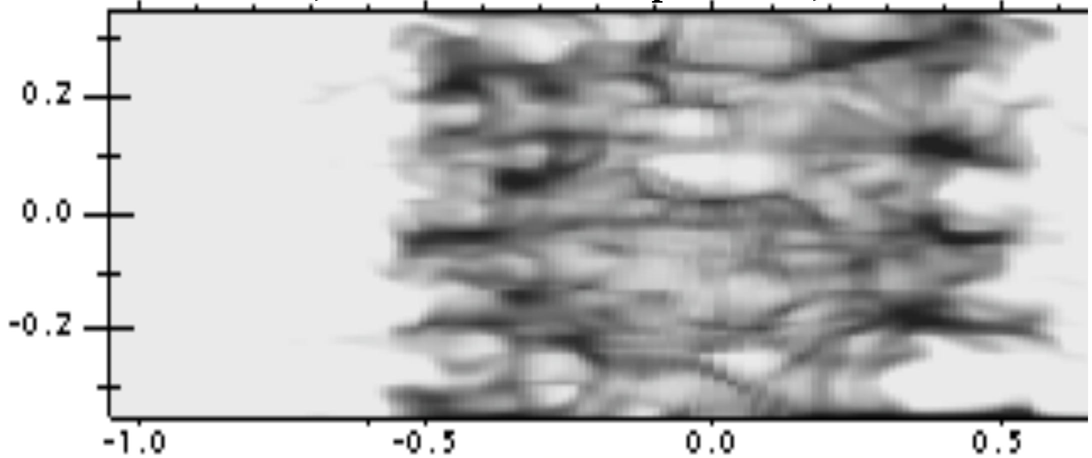
lower velocity case: v_0=3e4(B_0/60)$^{0.6}$

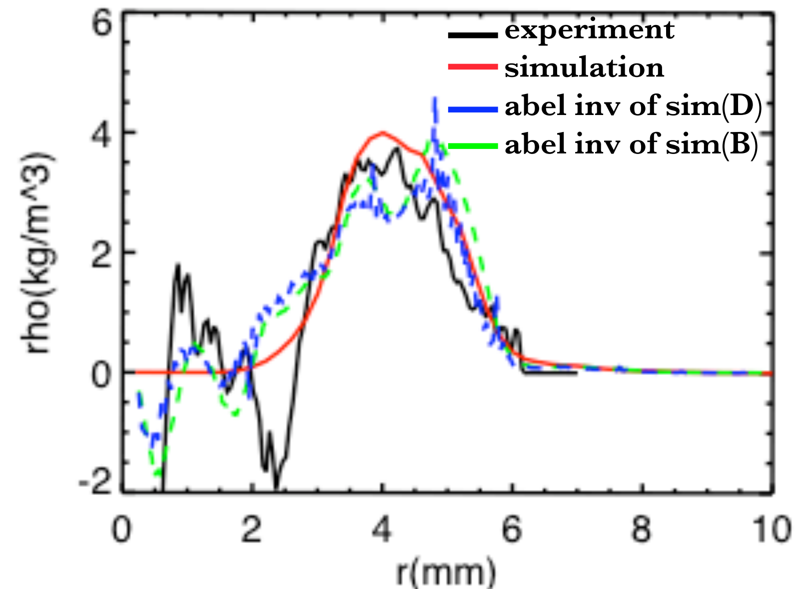
experiment: 2.4 mg, -10.5 ns before peak power (I~15.4 MA)

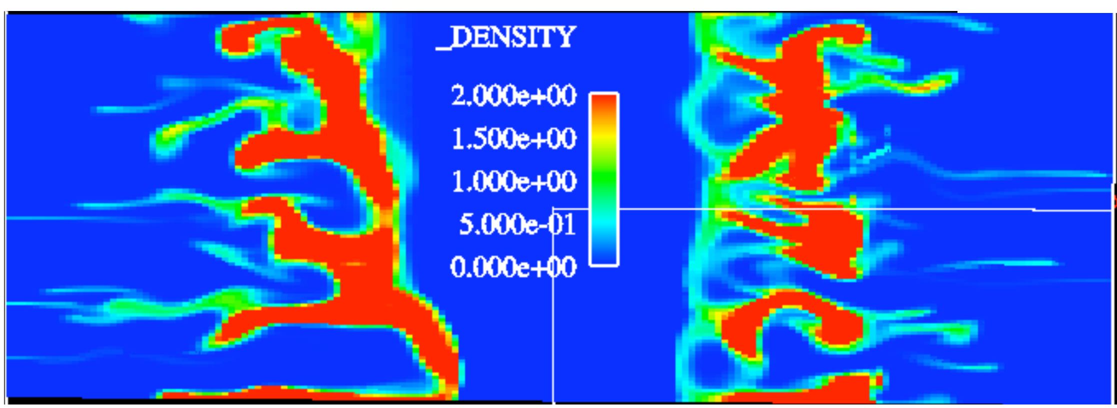


Due to low v0 and high dm/dt, this case finishes ablating and implodes early relative to experiment, in a very shell-like fashion. Timing is off, but agreement in backlighting images is pretty good.

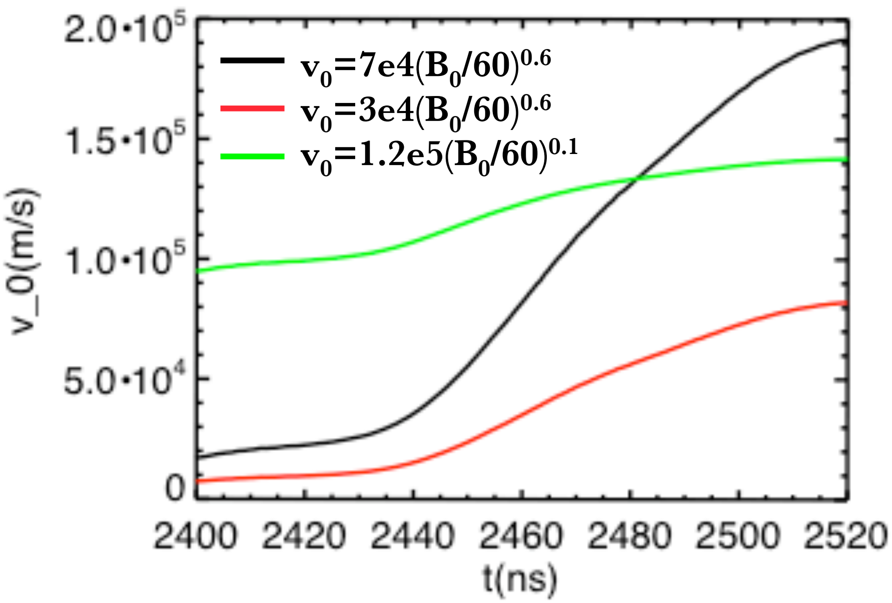
simulation: 2506, 6ns earlier than experiment, 3% correlation

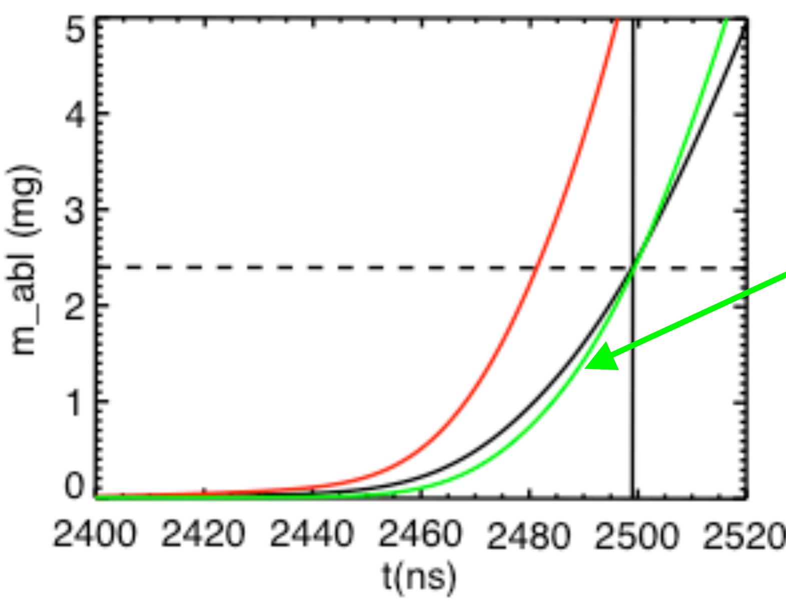






backlighting summary





Low injection velocity ablates and implodes too early, but generates shell-like profile in agreement with experiment

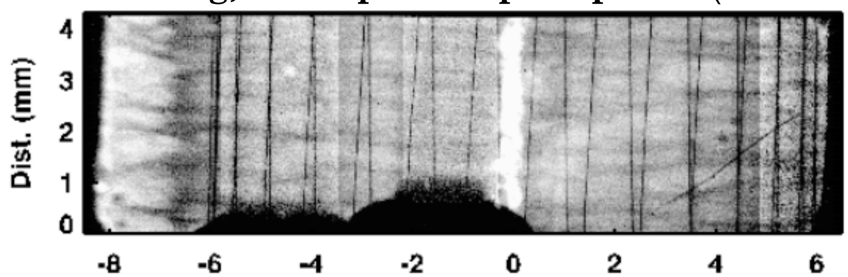
Higher velocity ablates and implodes at about the right time, but has too distributed a mass profile.

Maybe this is a compromise?

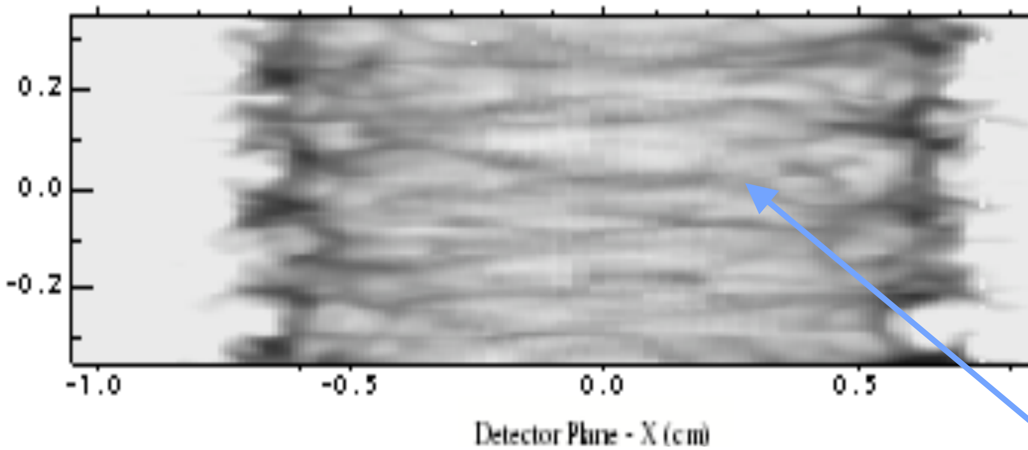
THE END

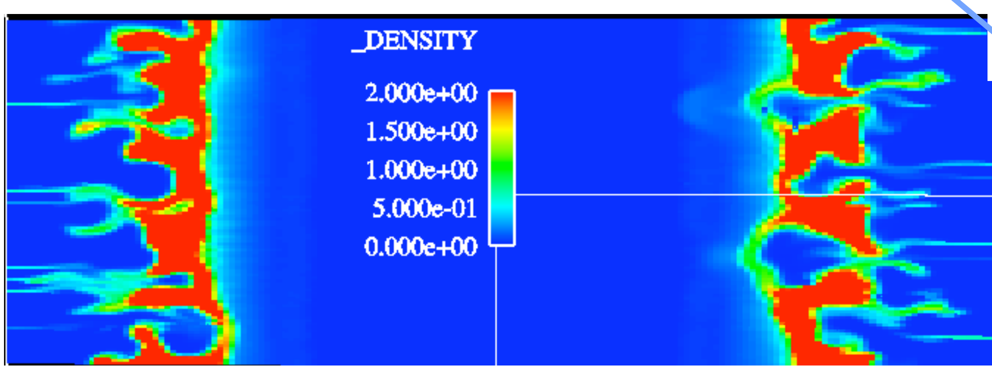
Xtra1: lower velocity case: $v_0=3e4(B_0/60)^{0.6}$

experiment: 2.4 mg, -18 ns prior to peak power (I~14.5 MA)

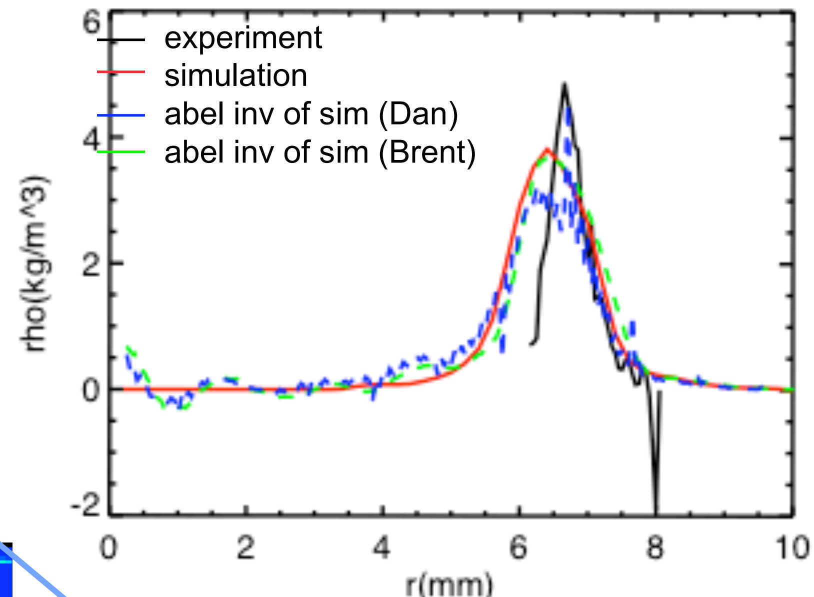


simulation: 8 ns before experimental image, 3% correlation





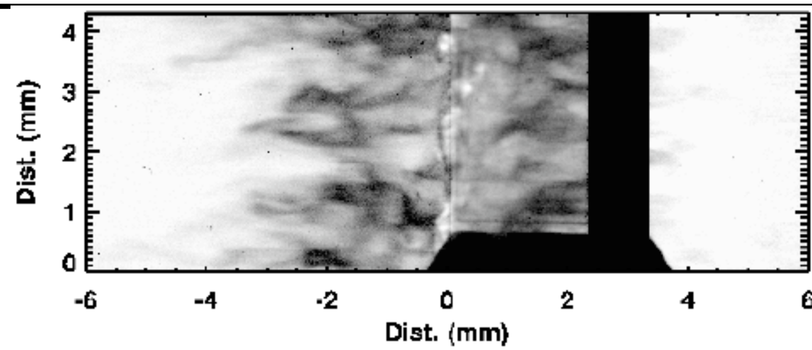
Due to low v0 and high dm/dt, this case finishes ablating and implodes early relative to experiment, in a very shell-like fashion. Timing is off, but agreement in backlighting images is pretty good.

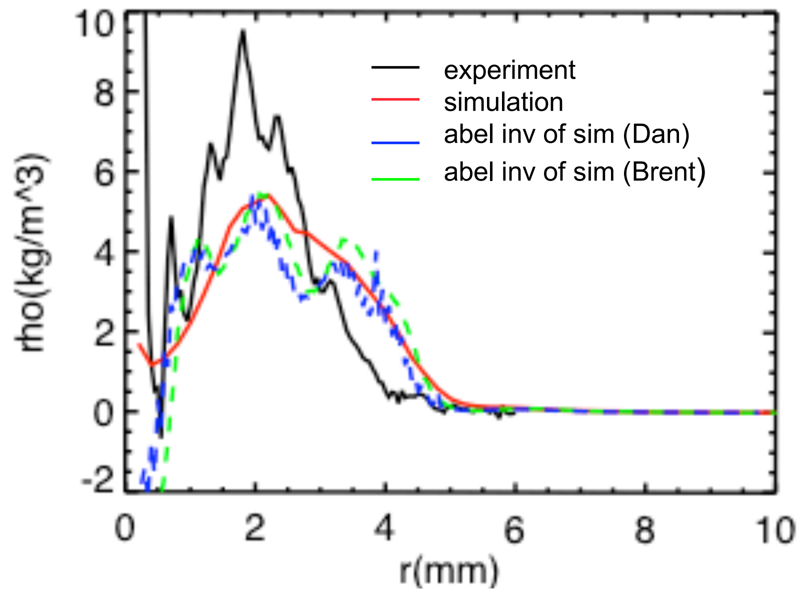


Even though we used only 3% azimuthal correlation on the injection surface, we can still see long "tendrils" in the image.

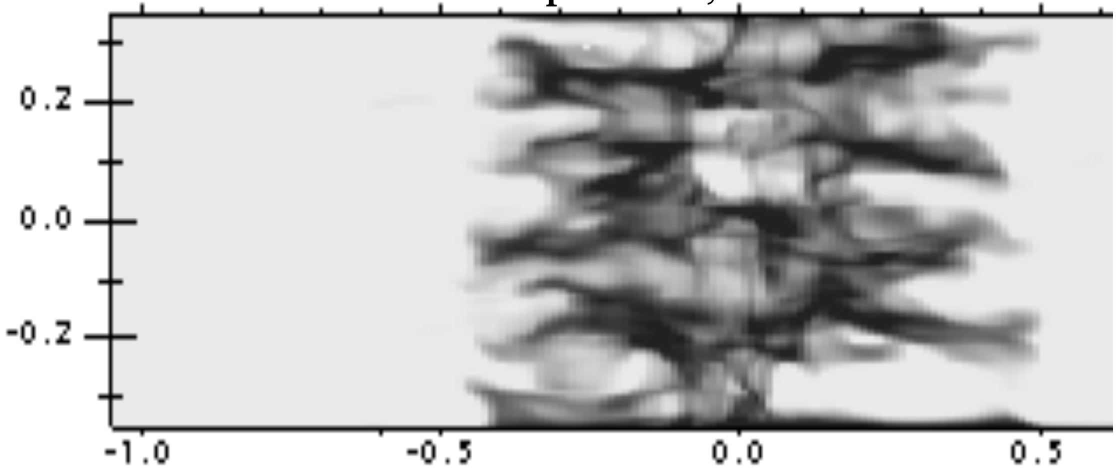
Xtra2: v_0=3e4$(B_0/60)^{0.6}$: final comparison

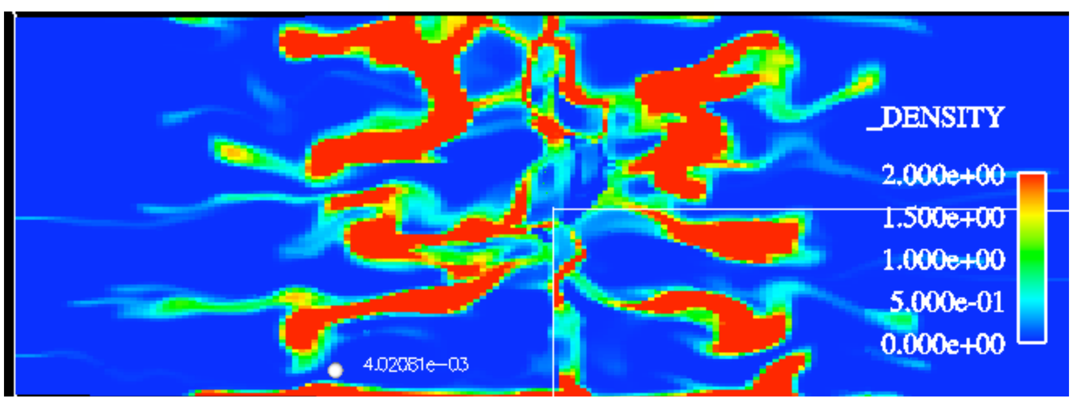
experiment:
2.4 mg, -4.7 ns
before peak
power
(I~16 MA)





simulation: 7ns earlier than experiment, 3% correlation

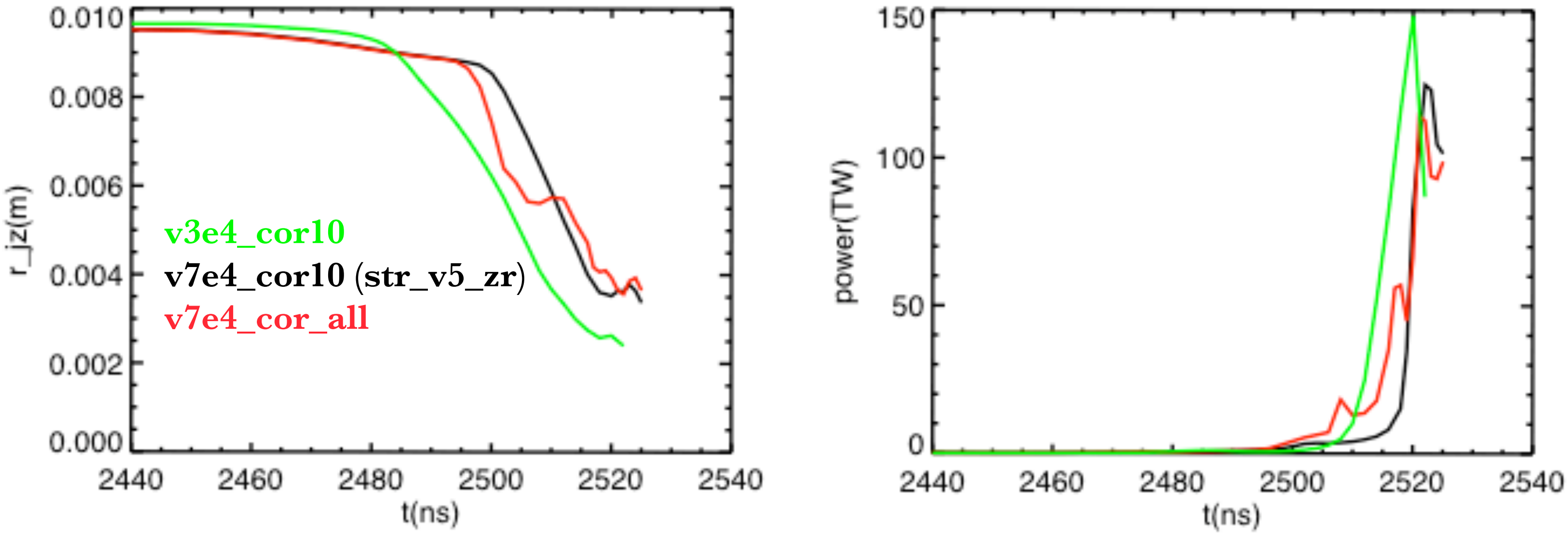




Trailing mass appears more wispy in experiment, with tendrils gradually dissipating with distance. Simulation tendrils cut off more abruptly. Even so, the overall density profile in experiment looks more shell-like.

Xtra3: X comparison

2.4 mg cases, current drive



1 mg cases, voltage drive