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Three dimensional effects in trailing mass in the wire-array Z pinch

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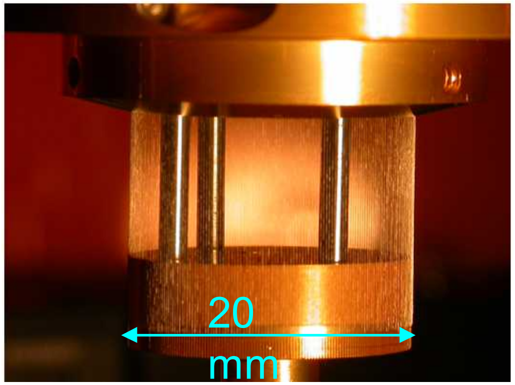
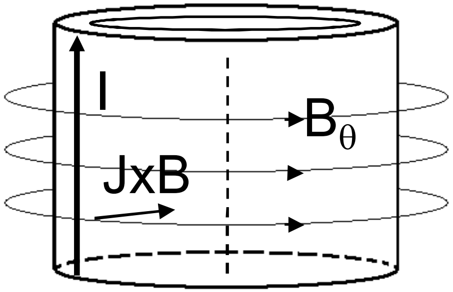
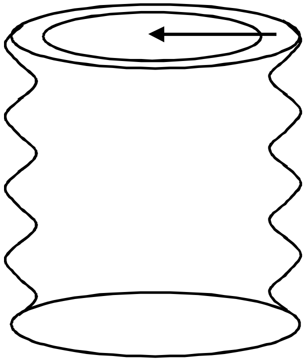
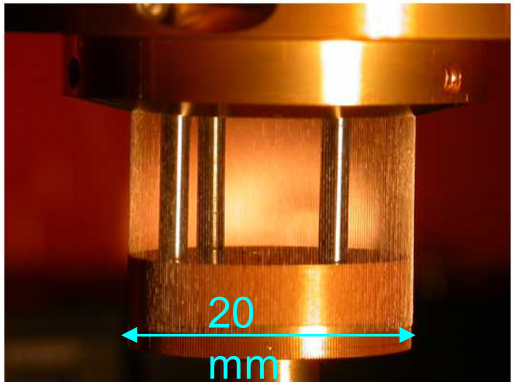
Z pinches are susceptible to the Rayleigh-Taylor instability

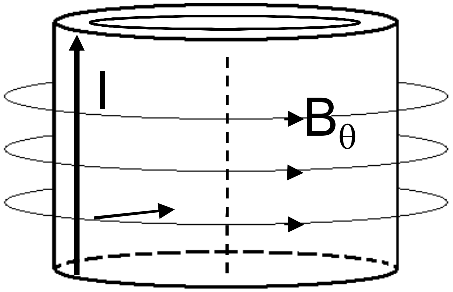


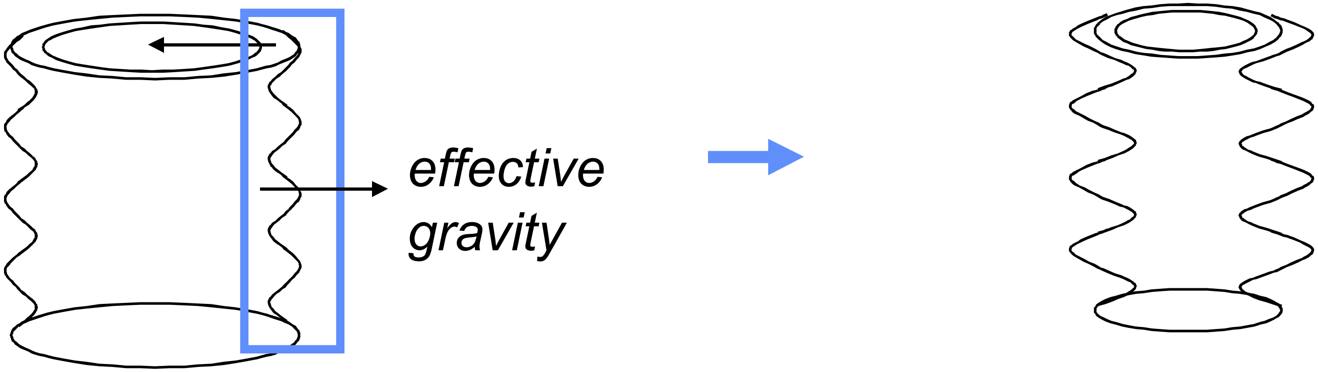




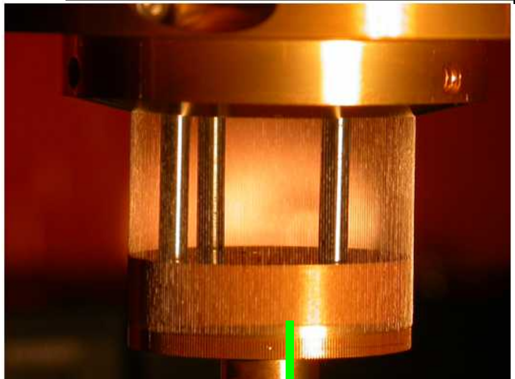
Z pinches are susceptible to the Rayleigh-Taylor instability



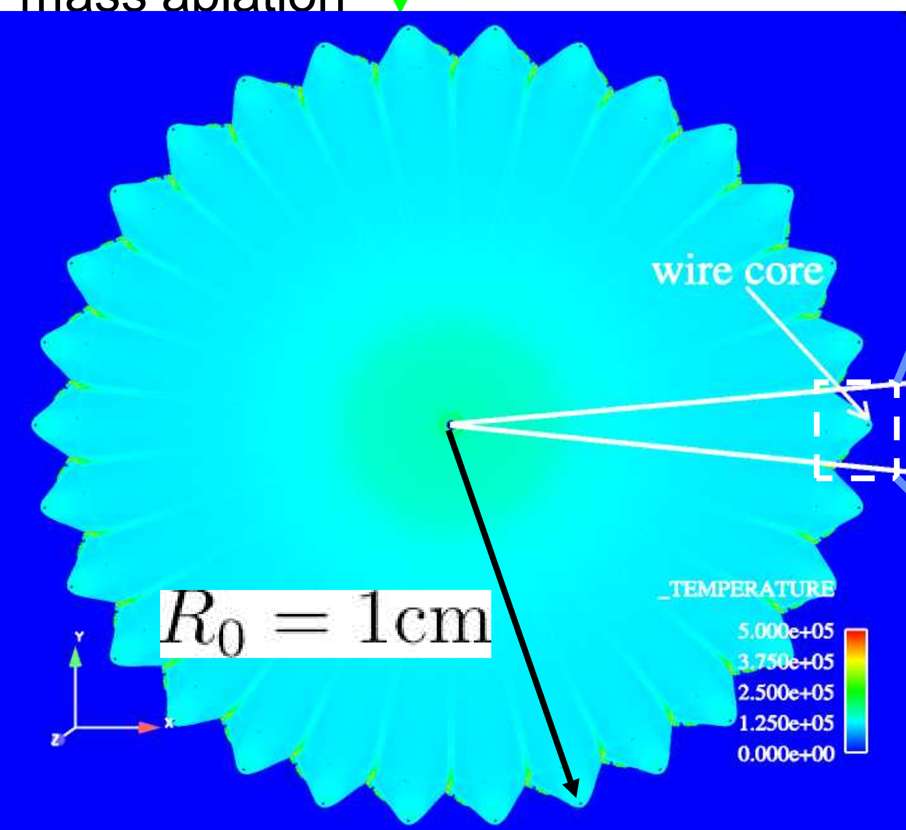


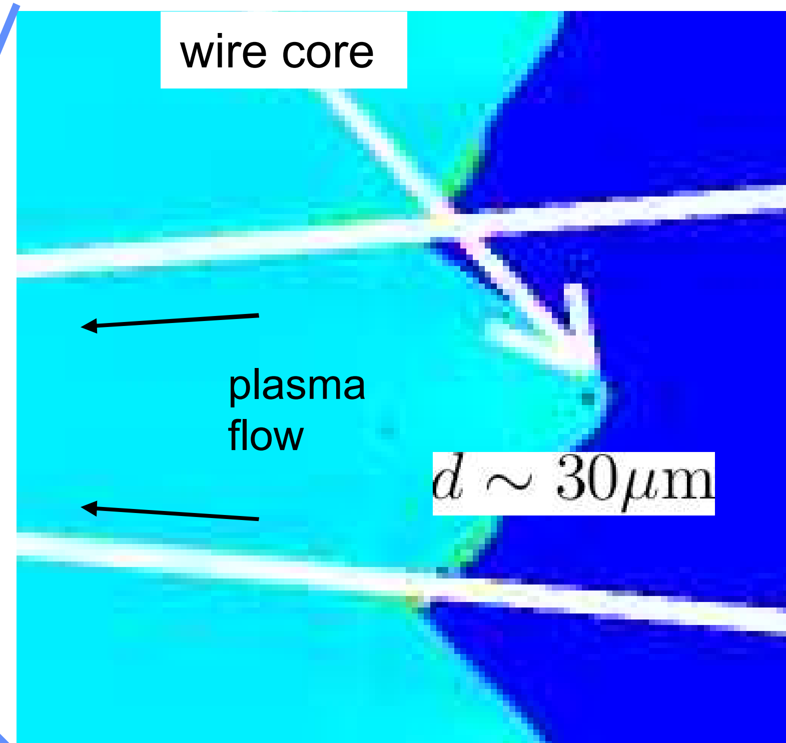


Wire arrays demonstrate mass ablation



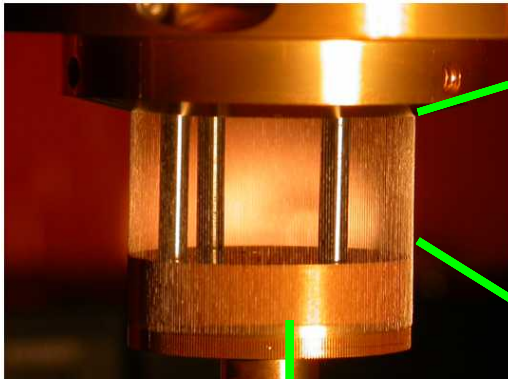
view from the top:
mass ablation





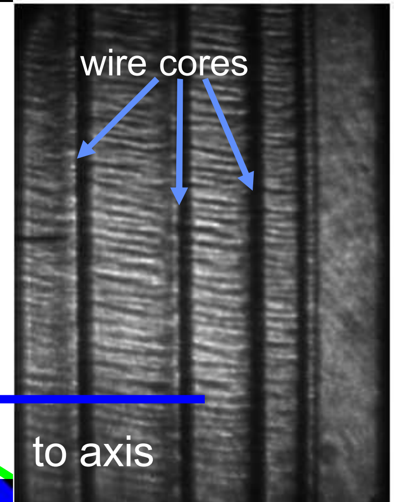
Disparity in scales makes simulation challenging

mass ablation exhibits axial instability



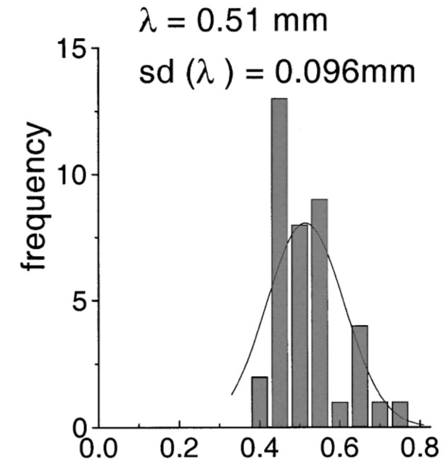
view from side

view from the top:
mass ablation

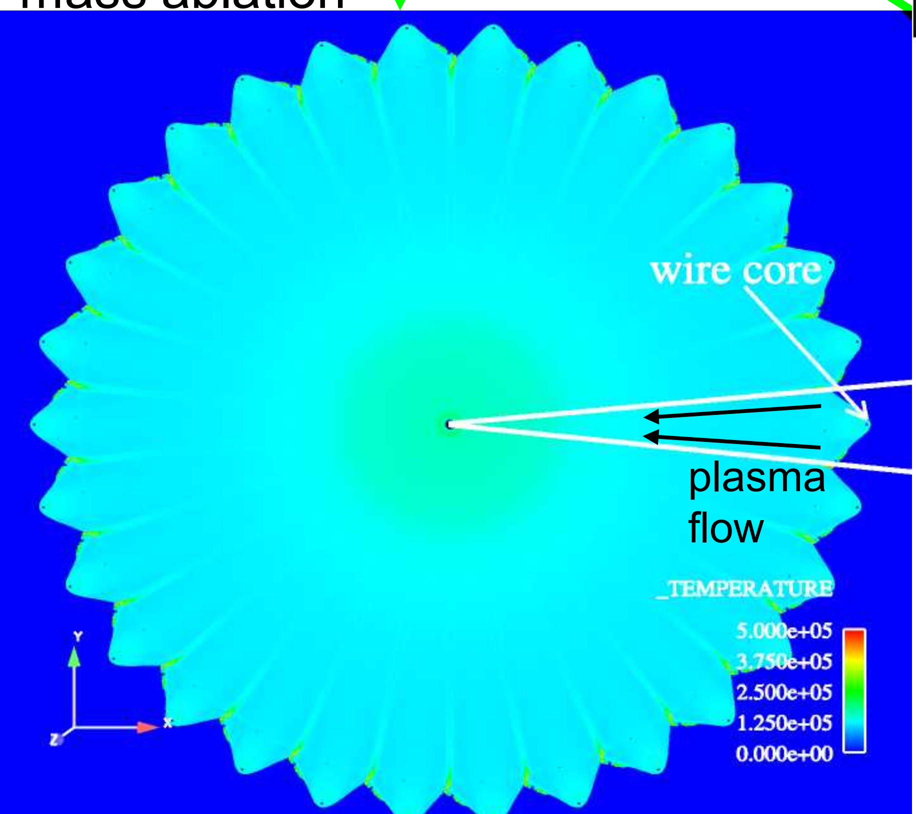


axial modulation of mass ablation

(Laser shadowgraph courtesy D. Bliss)



S.V. Lebedev et al., Phys. Plasmas 8, 3734 (2001)

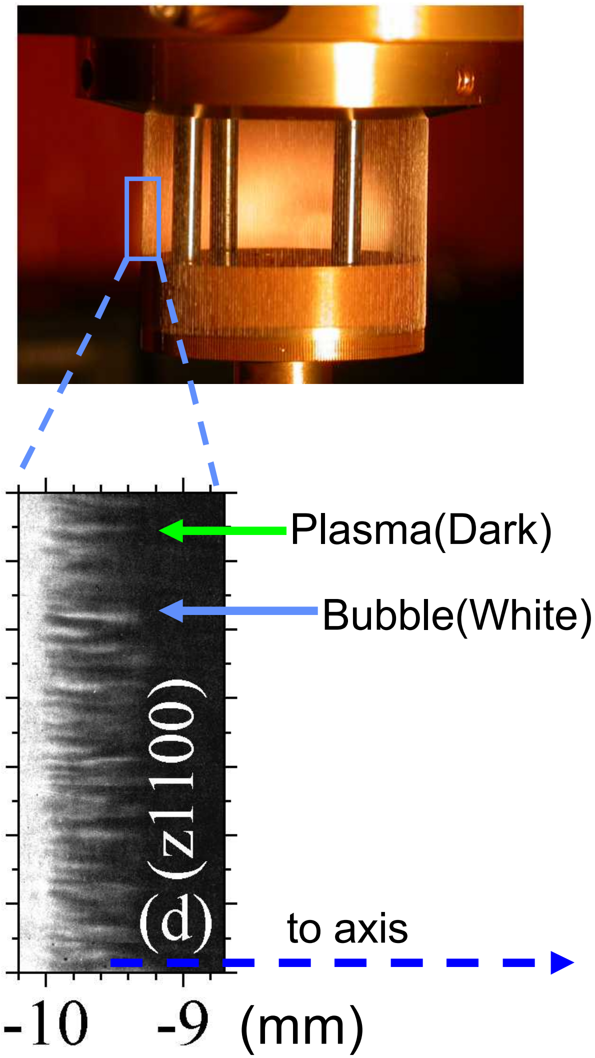


For more on axial instability, please see:

J.P. Chittenden and C.J. Jennings, UO6.00002 (Thurs)

G.N. Hall et al., UO6.00008(Thurs)

axial instability leads to trailing mass

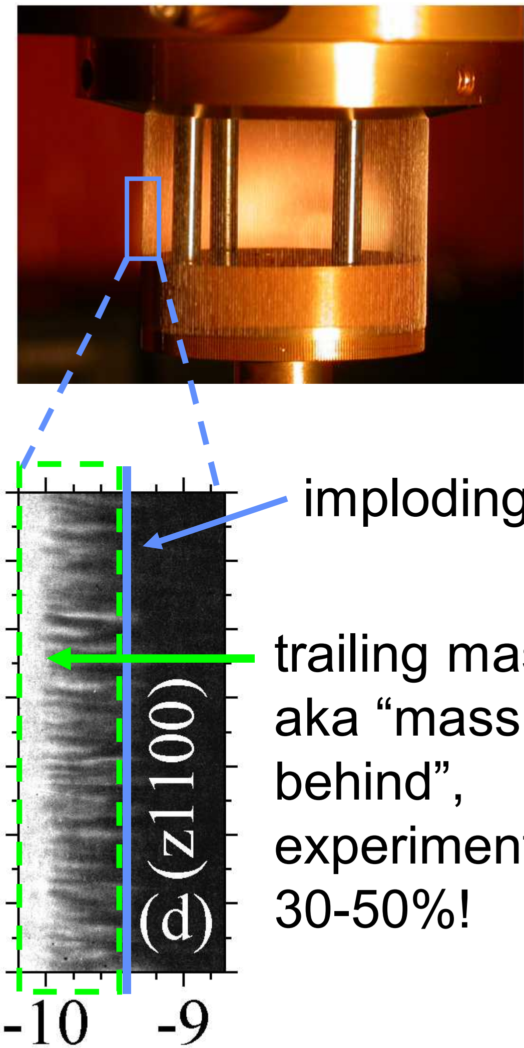


1865 keV radiograph, at time near start of implosion

Suggests azimuthal correlation

D.B. Sinars, et. al., Phys. Rev. Lett. 93, 145002 (2004)

axial instability leads to trailing mass

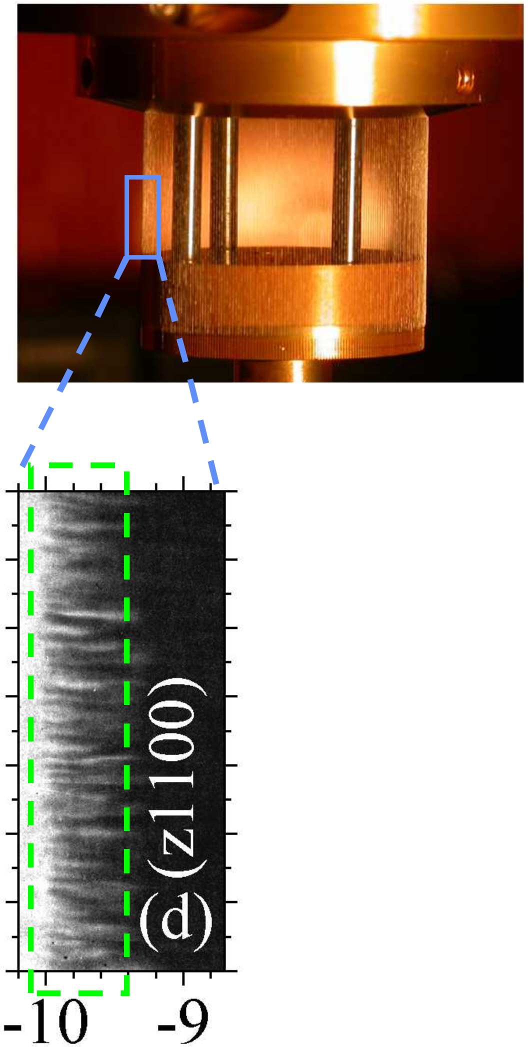


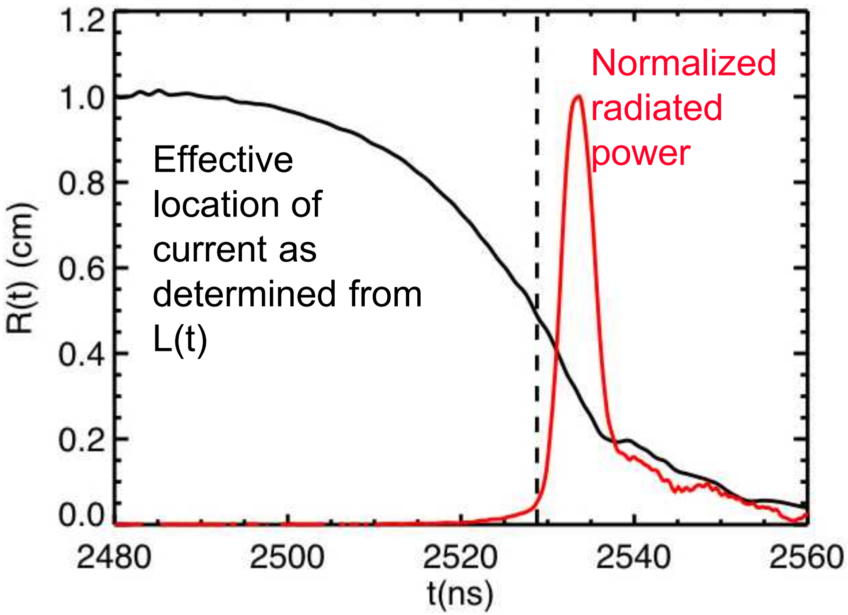
imploding sheath

trailing mass aka “mass left behind”, experimentally 30-50%!

D.B. Sinars, et. al., Phys. Rev. Lett. 93, 145002 (2004)

trailing mass leads to trailing current



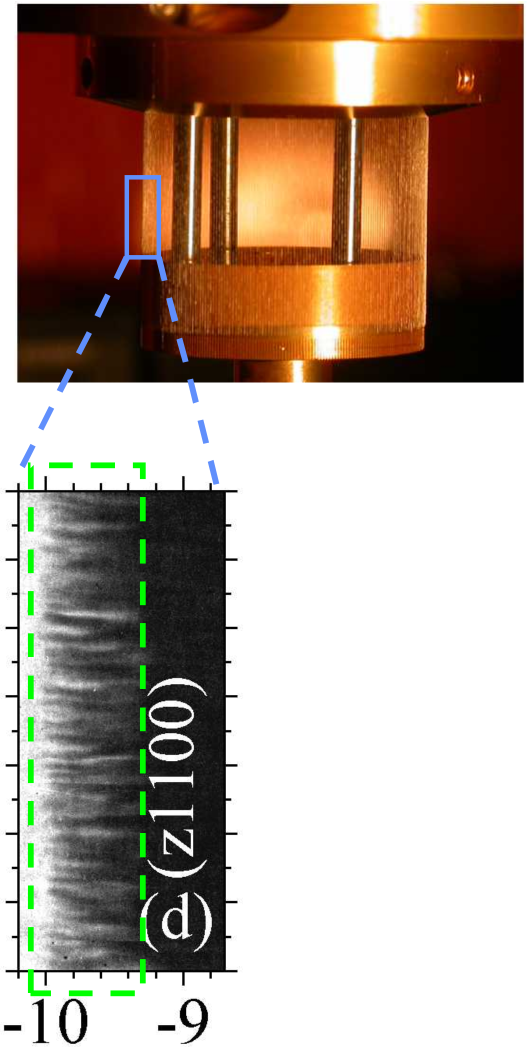


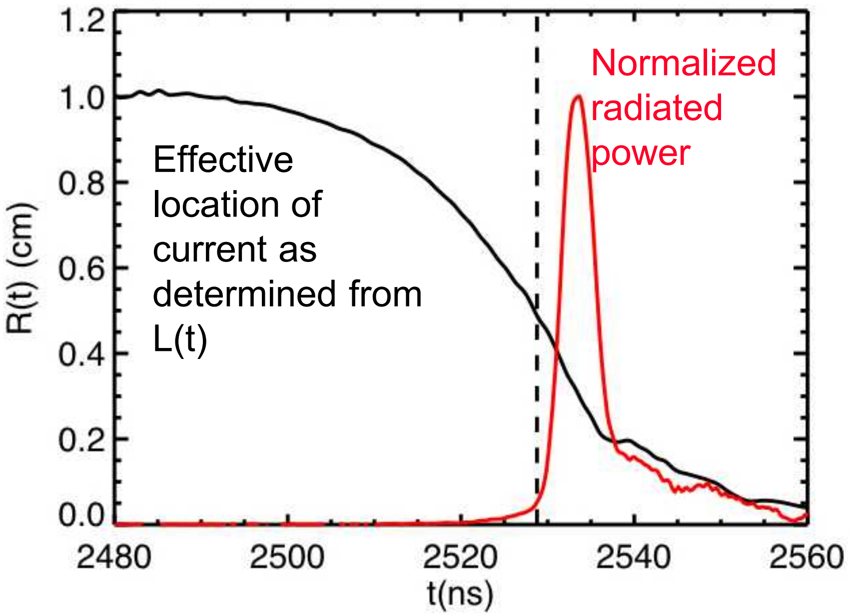
M.E. Cuneo et al., Phys. Rev. E 71, 046406 (2005)
E.M. Waisman et al., Phys. Plasmas 11, 2009 (2004)

trailing mass prevents all mass from participating in implosion, provides current path preventing current from compressing on axis

D.B. Sinars, et. al., Phys. Rev. Lett. 93, 145002 (2004)

What physics drives trailing mass/current?

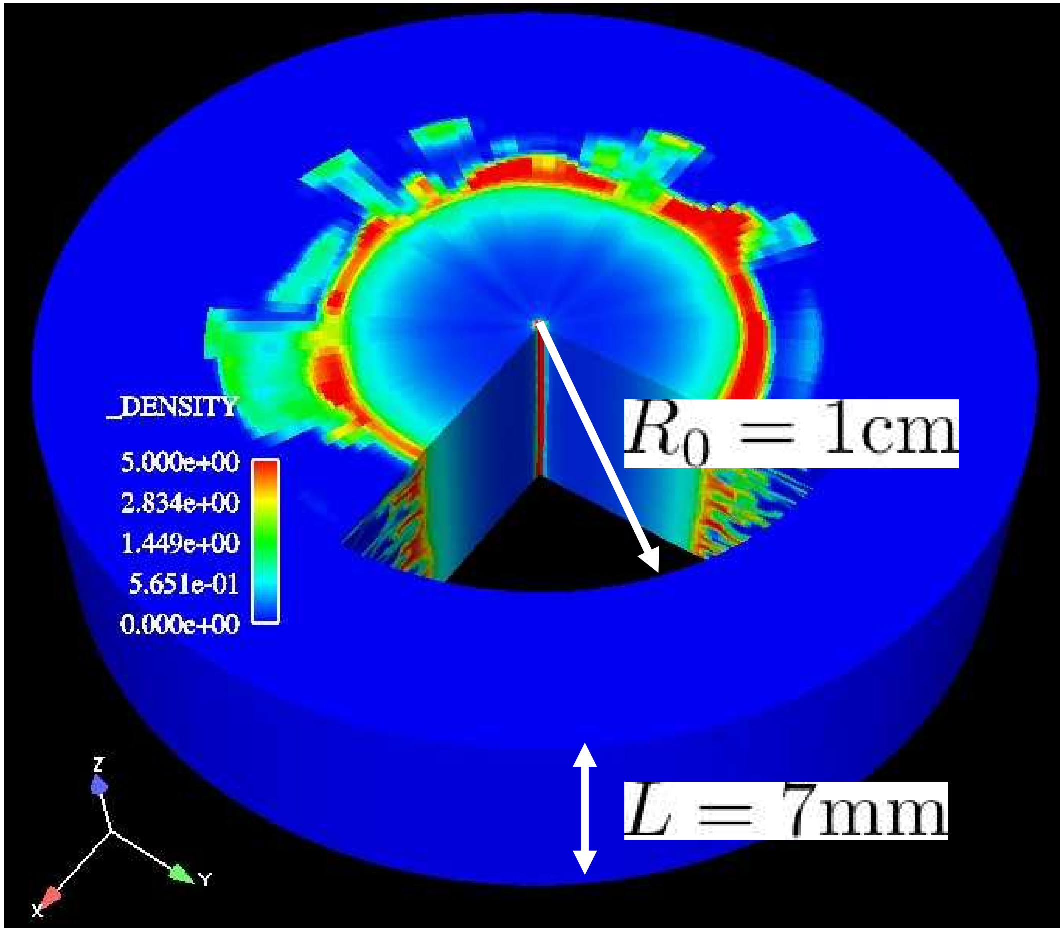




We'd like to address the following:

1. Is the effect of trailing mass entirely negative?
2. What drives the bubble growth on the imploding sheath? Is it just magneto Rayleigh-Taylor (MRT)?
3. What is the role of azimuthal correlation?

Address these issues via 3D simulation

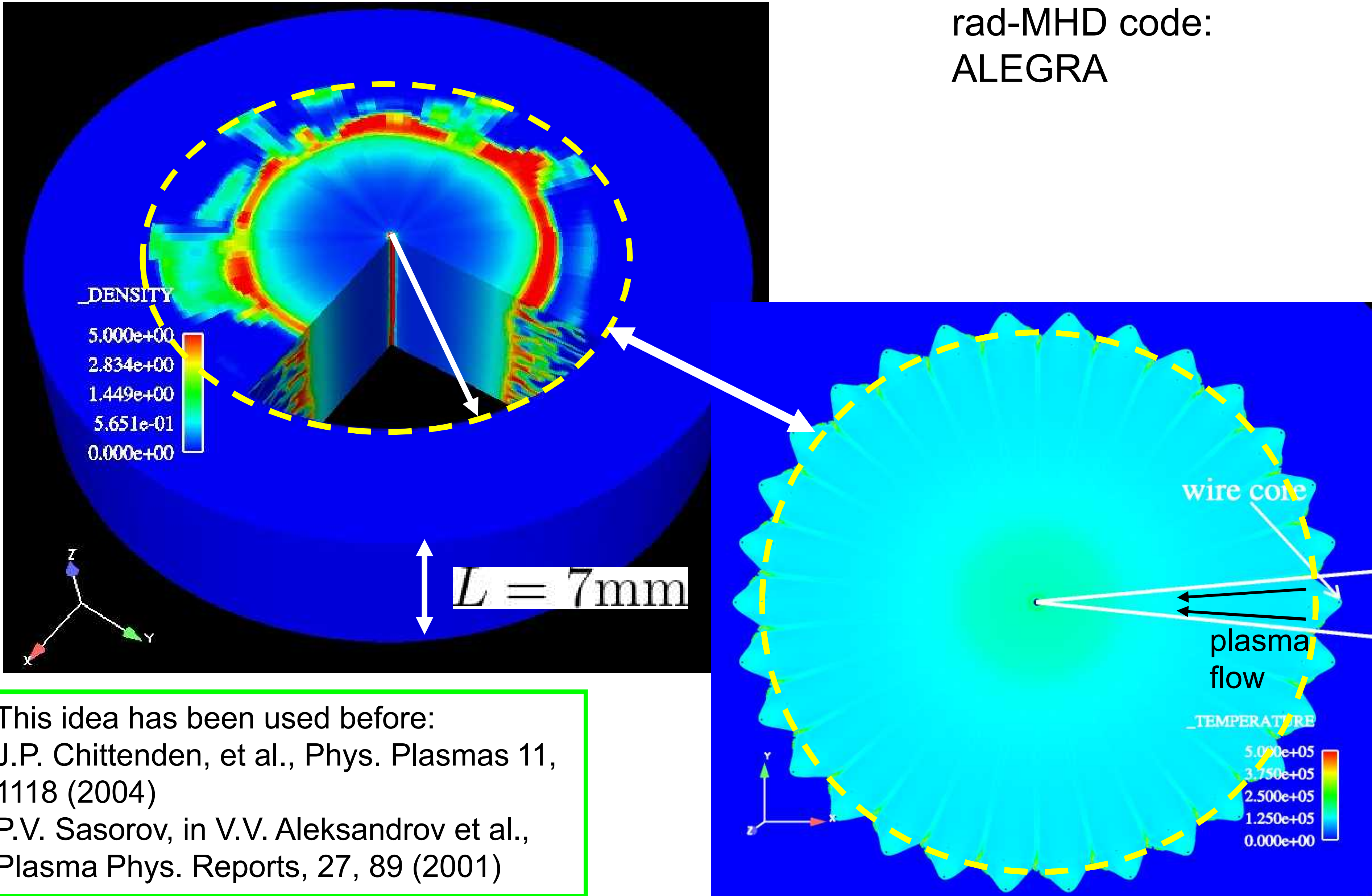


rad-MHD code:
ALEGRA

Run with Voltage Drive

Model ablation/implosion via mass injection

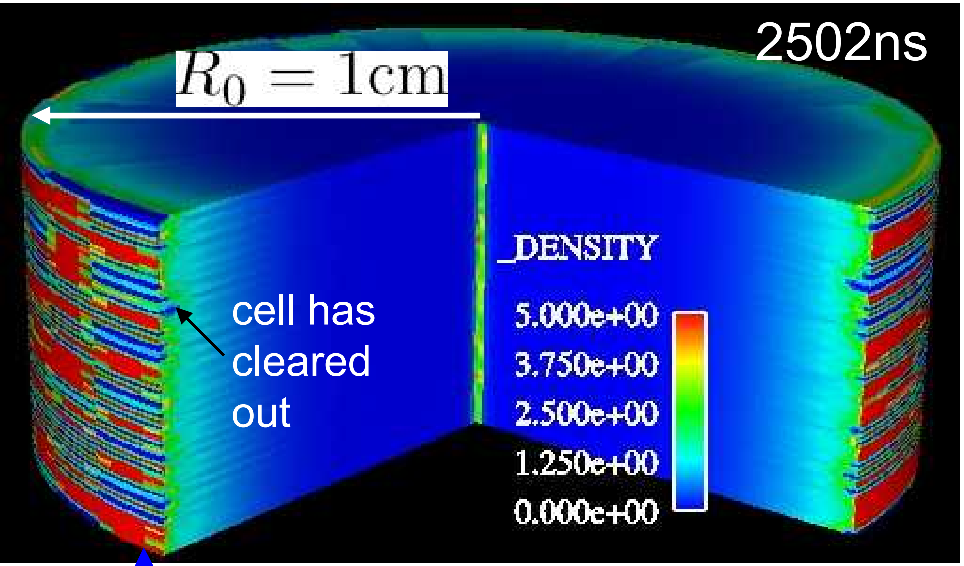
rad-MHD code:
ALEGRA



This idea has been used before:
J.P. Chittenden, et al., Phys. Plasmas 11, 1118 (2004)
P.V. Sasorov, in V.V. Aleksandrov et al., Plasma Phys. Reports, 27, 89 (2001)

mass injection parameters constrained by experiment

dr~100 um, dz~60 um, Nϕ=120



mass is injected slowly (v~1e4 m/s) at

mass injection surface

Each cell has mass m and ablates according to

$$\dot{m} = \dot{m}_0 (I/I_0)^\alpha$$

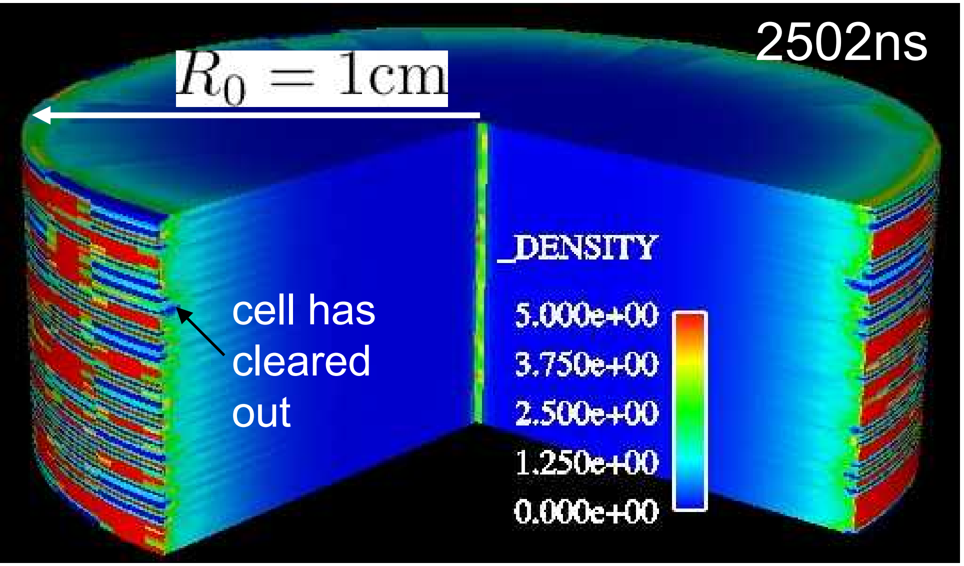
determines when cell finishes ablating. Determines when array starts to implode.

currently,* α=1.4, determines distribution of prefill plasma.

*E.P. Yu, B.V. Oliver, P.V. Sasorov et. al., Phys. Plasmas 14, 022705 (2007)

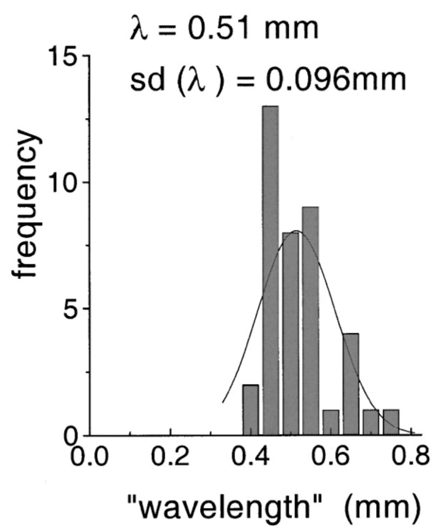
mass injection parameters constrained by experiment

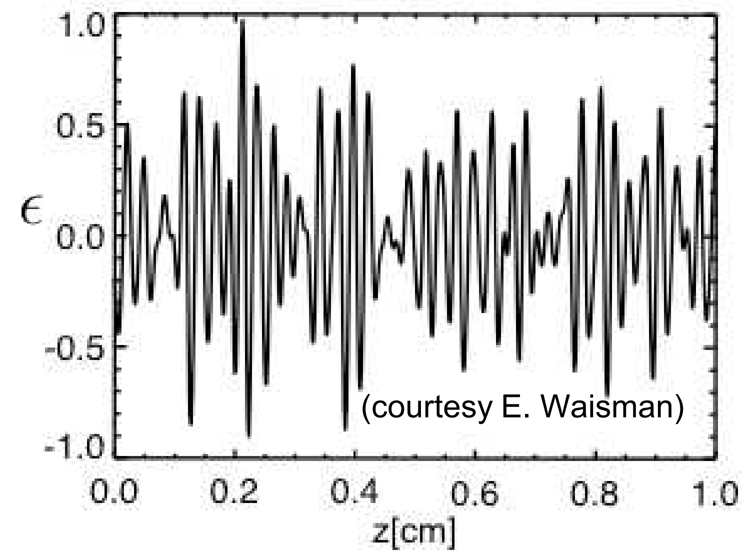
dr~100 um, dz~60 um, Nϕ=120



$$\dot{m} = \dot{m}_0 (I/I_0)^{\alpha} (1 + \epsilon(z))$$

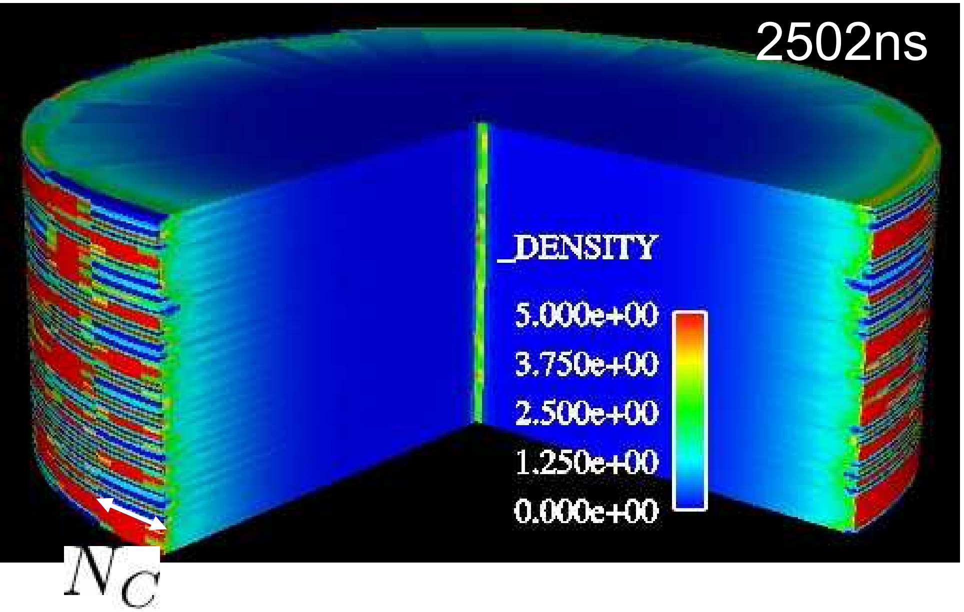
spectral content determined by experimental histogram. Amplitude constrained by contrast ratio between streams.





Number of wires azimuthally correlated is important

dr~100 um, dz~60 um, Nϕ=120



We only consider the case where there are sufficient wires that the plasma coronas are touching azimuthally (i.e. no azimuthal gaps!)

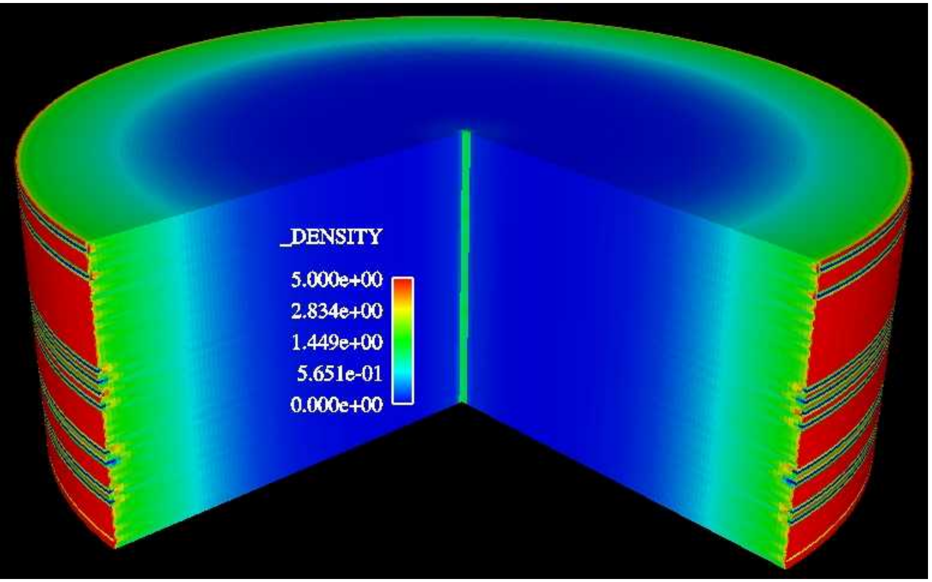
$$C = \frac{N_C}{N_\phi} \times 100$$

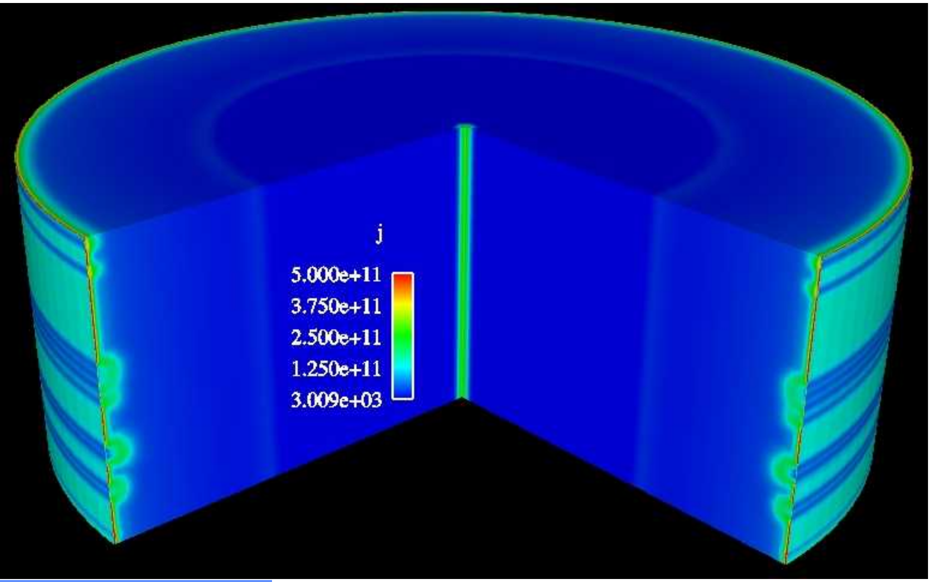
percentage of azimuthal correlation

for more on mass injection scheme, please see:

R.W. Lemke et al., PP8.00039(Wed)

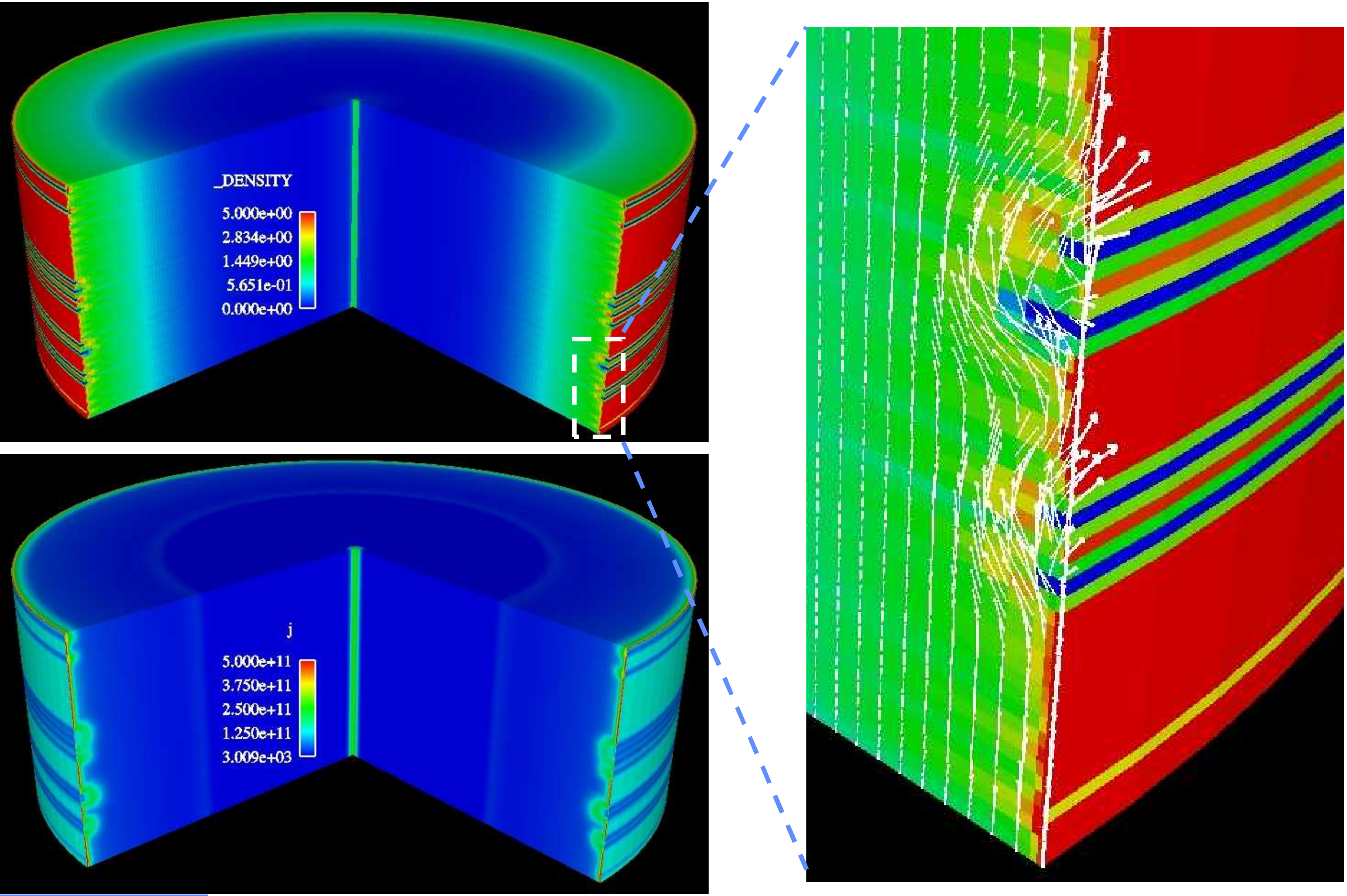
start of implosion in C=100% case





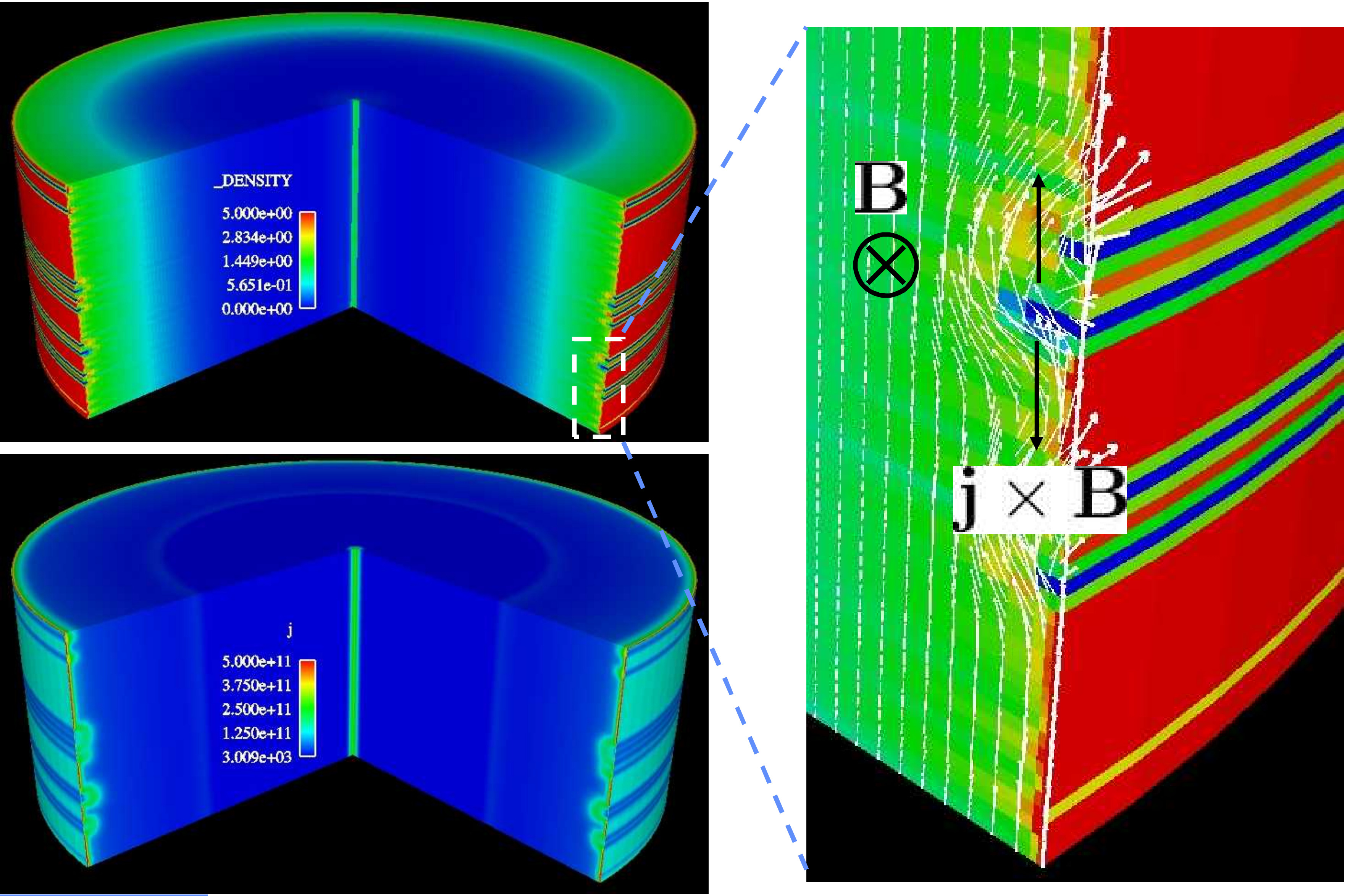
t=2500 ns

early bubble formation determined by jxB forces



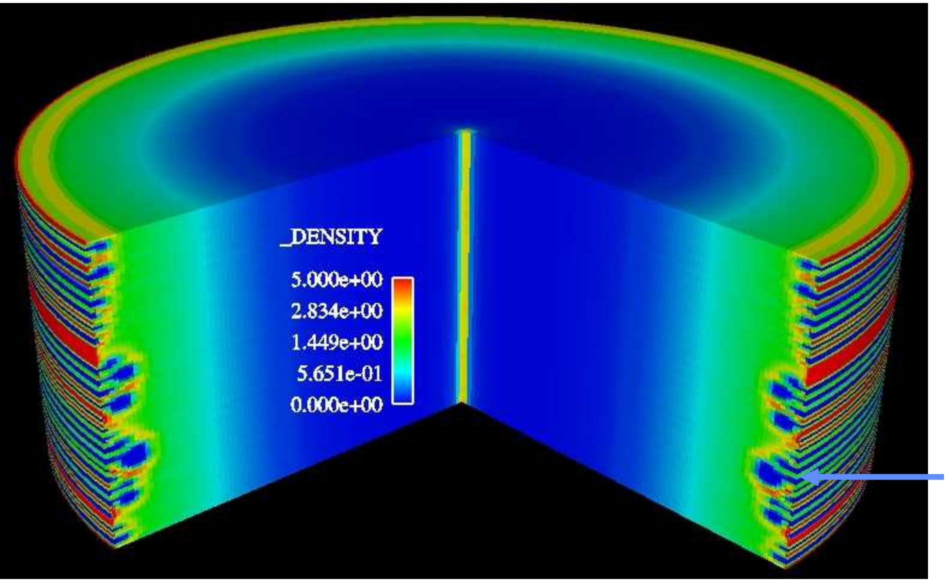
t=2500 ns

early bubble formation determined by jxB forces

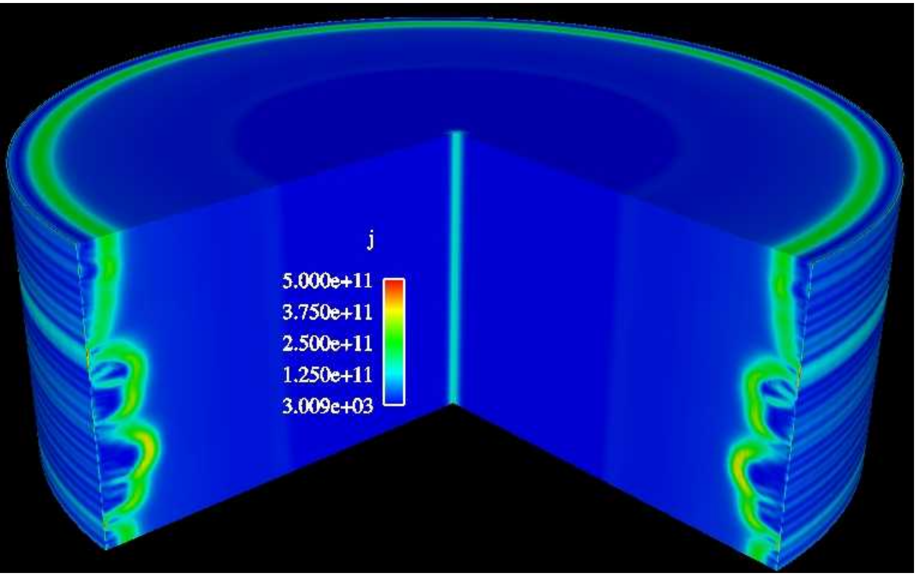


t=2500 ns

bubble formation in C=100%

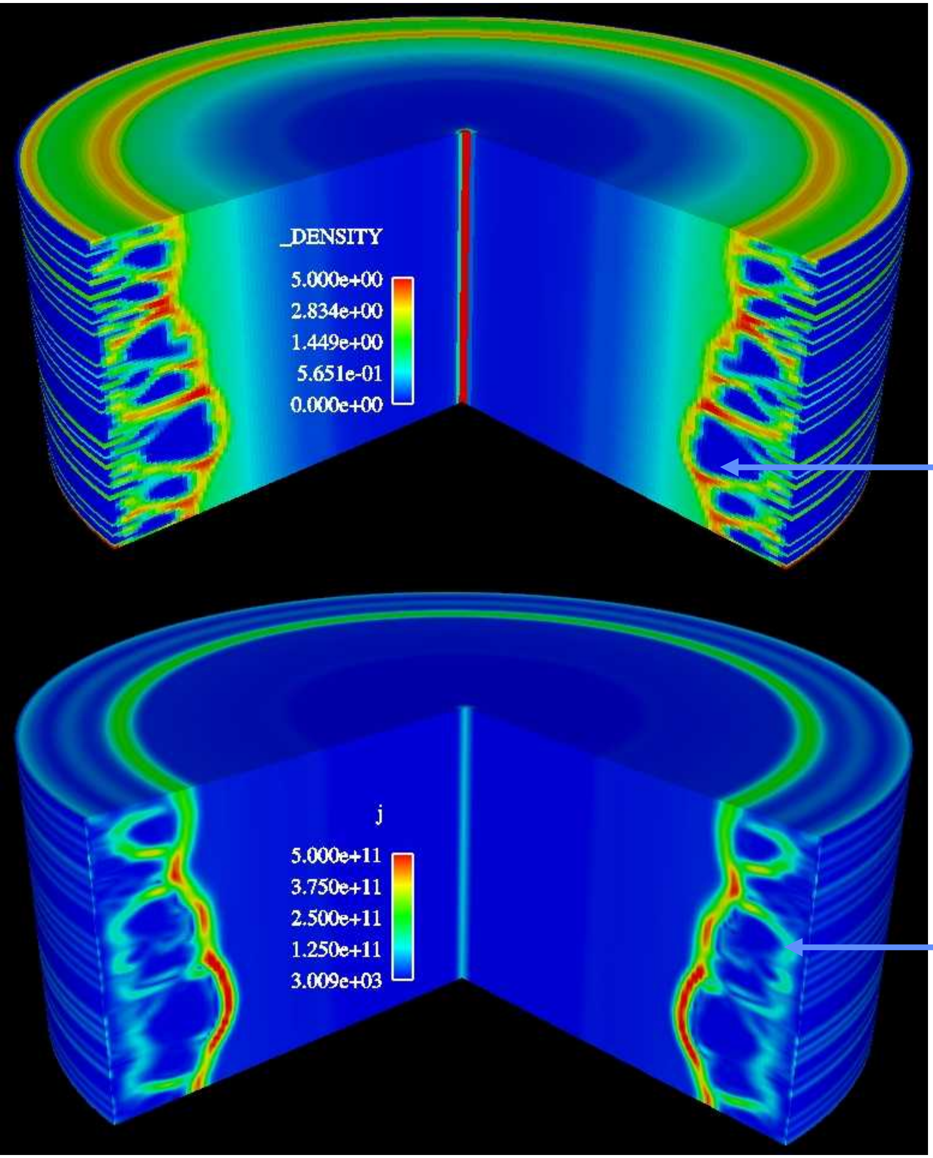


bubble expands



t=2504 ns

C=100% results in large bubble growth

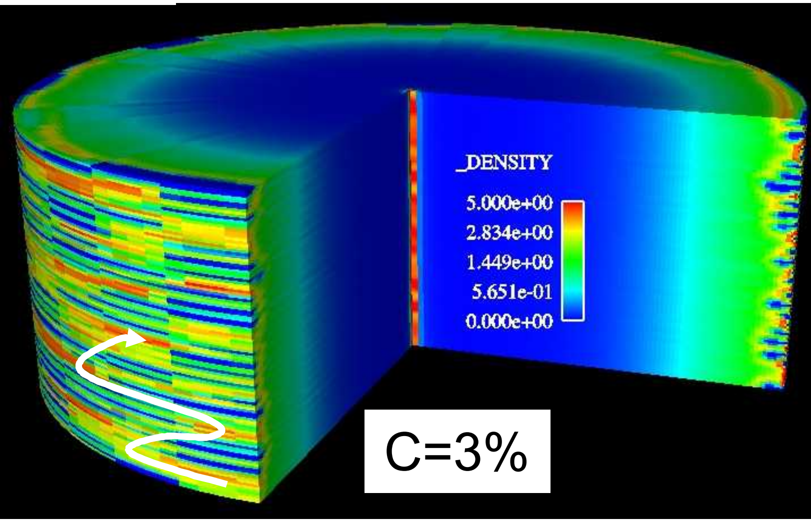


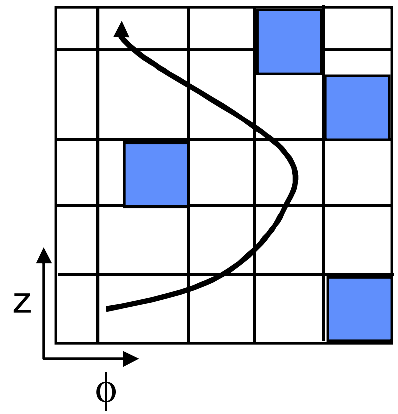
The bubble which formed first will grow the biggest

eventually trailing streams of mass reconnect, but the bubbles are already quite large

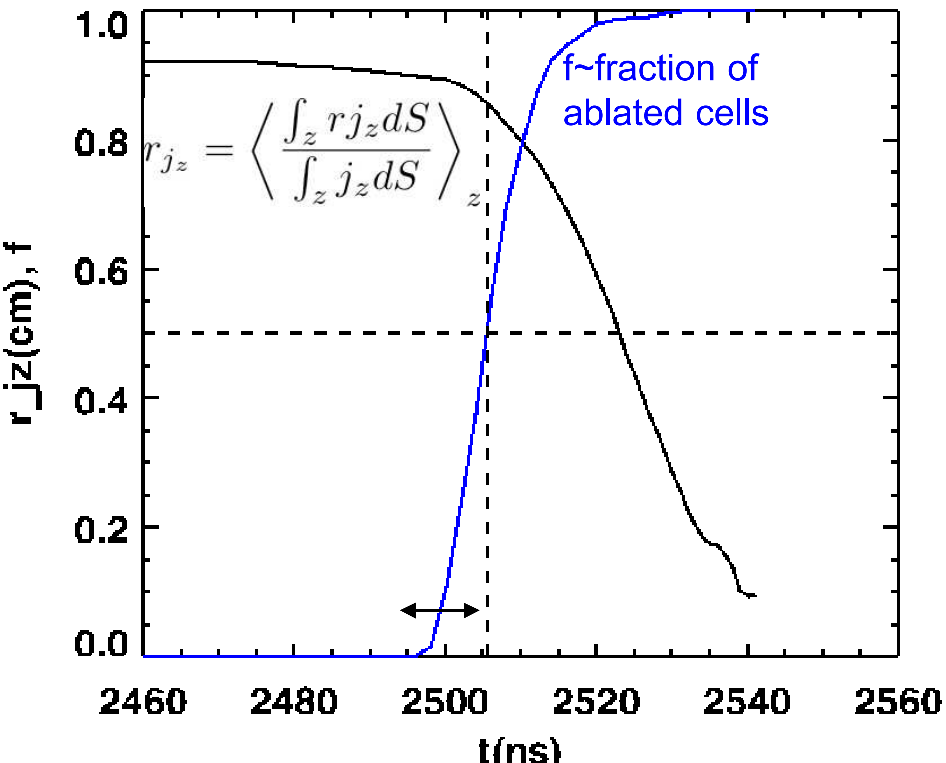
t=2510 ns

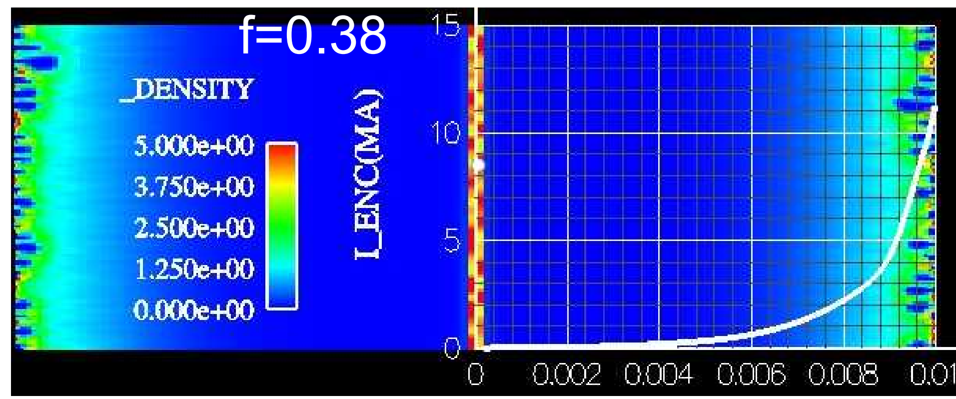
In 3D, trigger for implosion tied to fraction of cells ablated

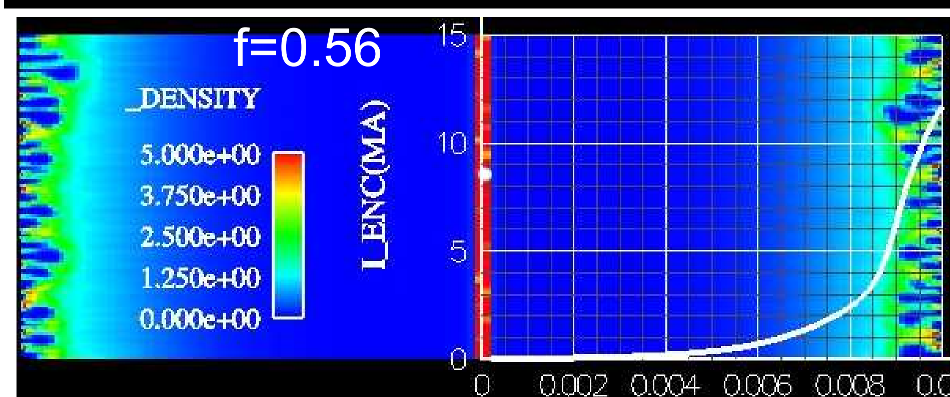




M.B. Isichenko, Rev. Mod. Phys. 64, 961 (1992)
S. Kirkpatrick, Rev. Mod. Phys. 45, 574 (1973)

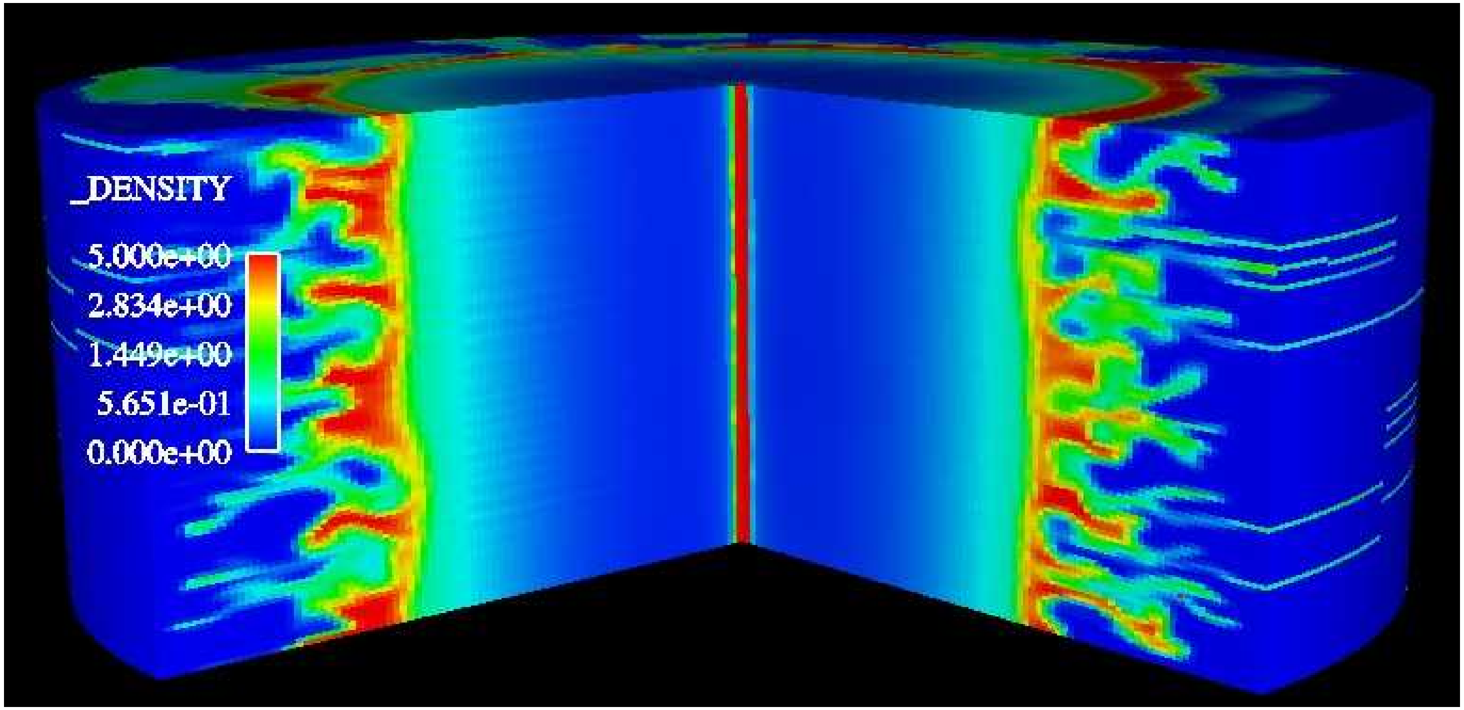






In 3D, current can travel azimuthally, "self-regulating" bubble growth

C=3%, t=2518 ns



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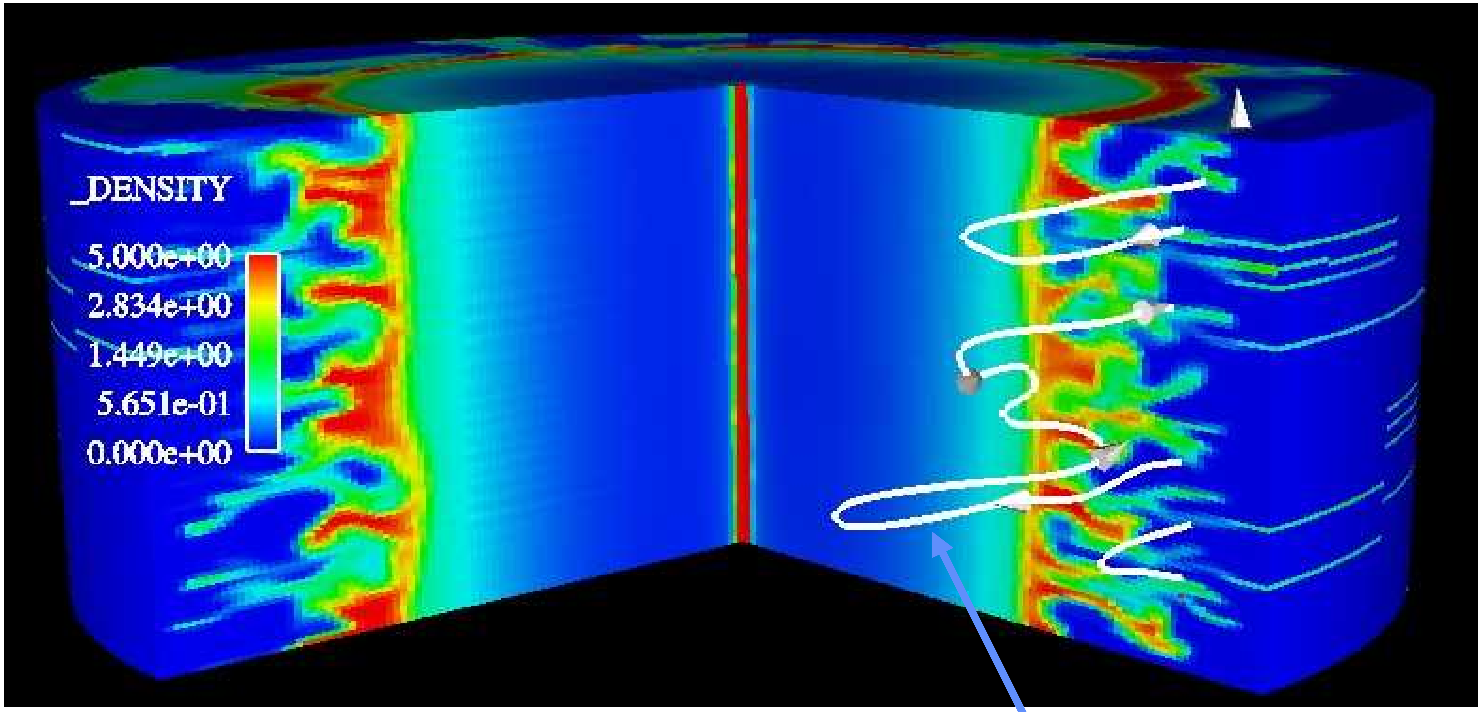
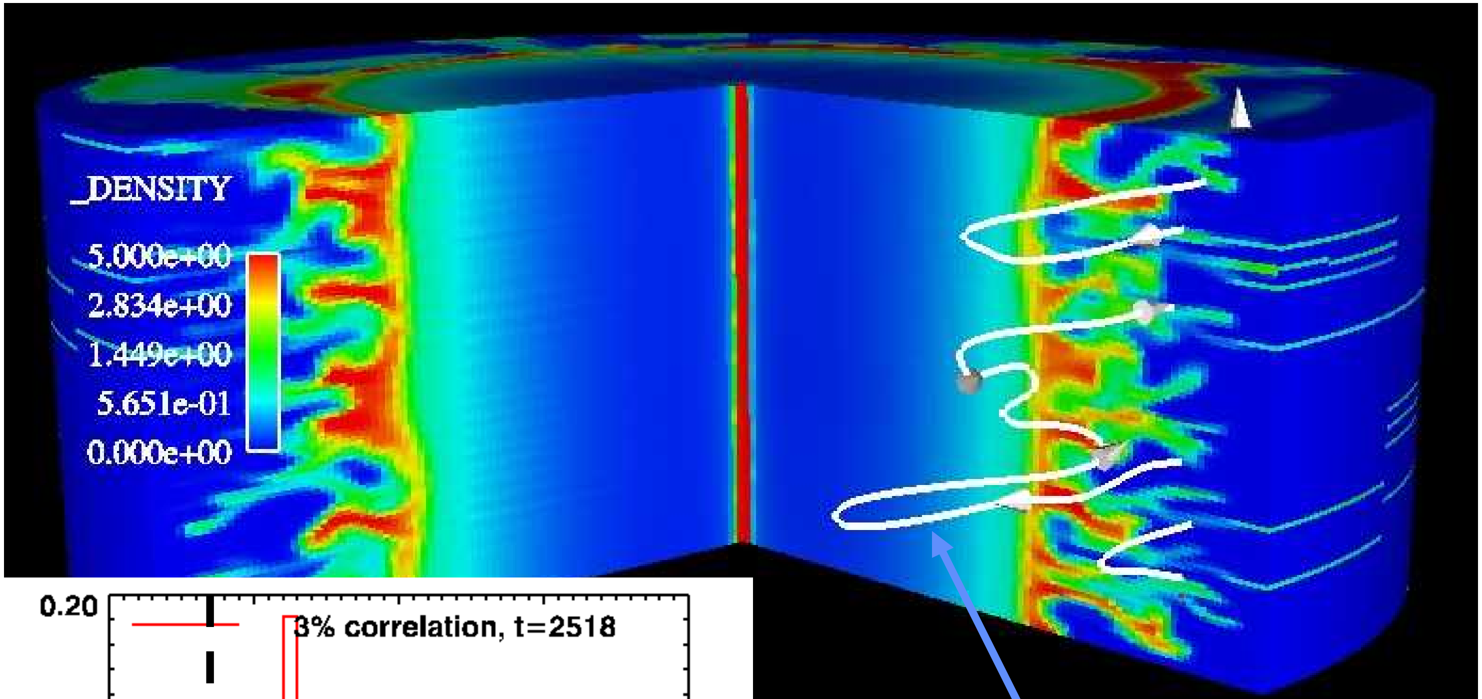


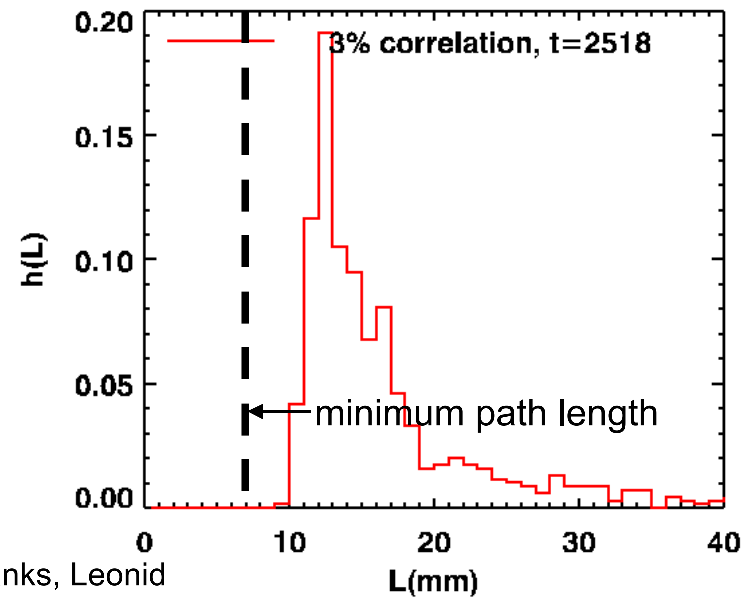
current streamline

Histogram of path lengths through trailing mass

3% azimuthal correlation, t=2518 ns



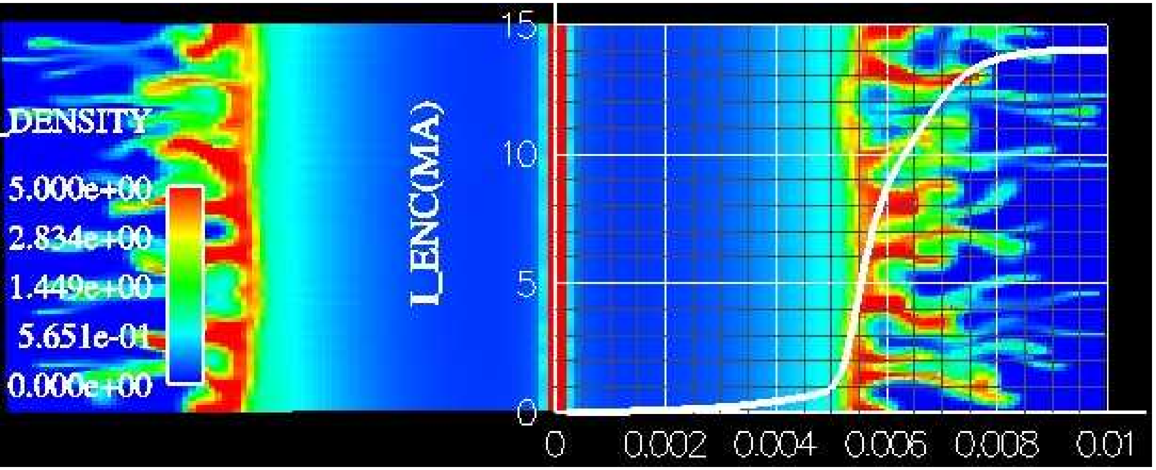
current streamline



Thanks, Leonid

bubble growth is reduced by 3D effects

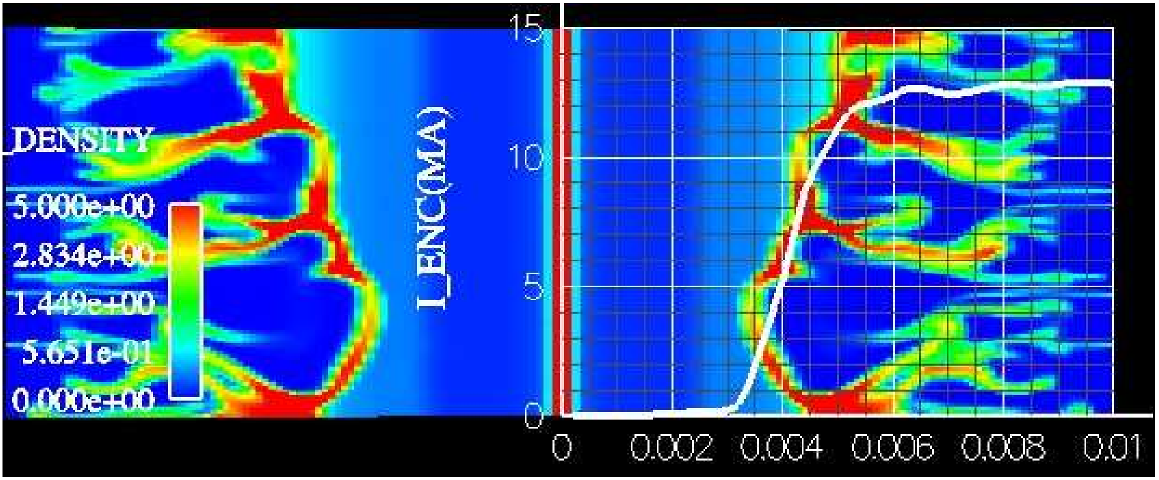
C=3% (2520 ns)



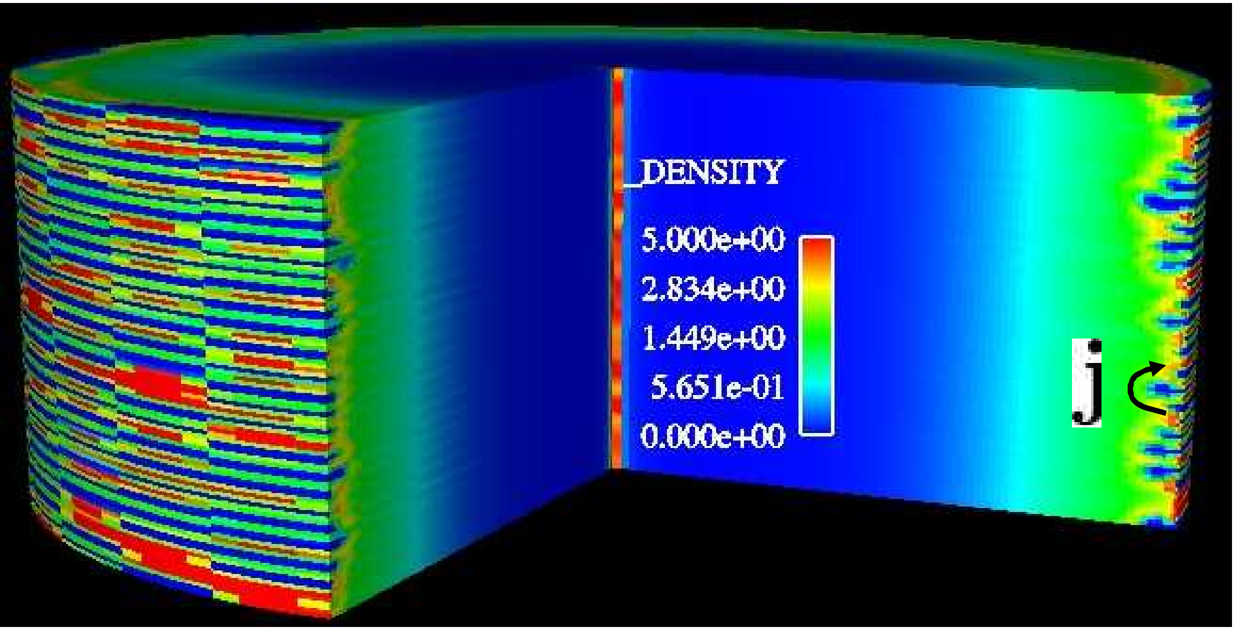
In 3% correlated problem, bubble growth is reduced because current can flow azimuthally.

Surprisingly, in the presence of the axial instability, the 3D case is more shell-like than a 2D simulation!

C=100% (2520 ns)



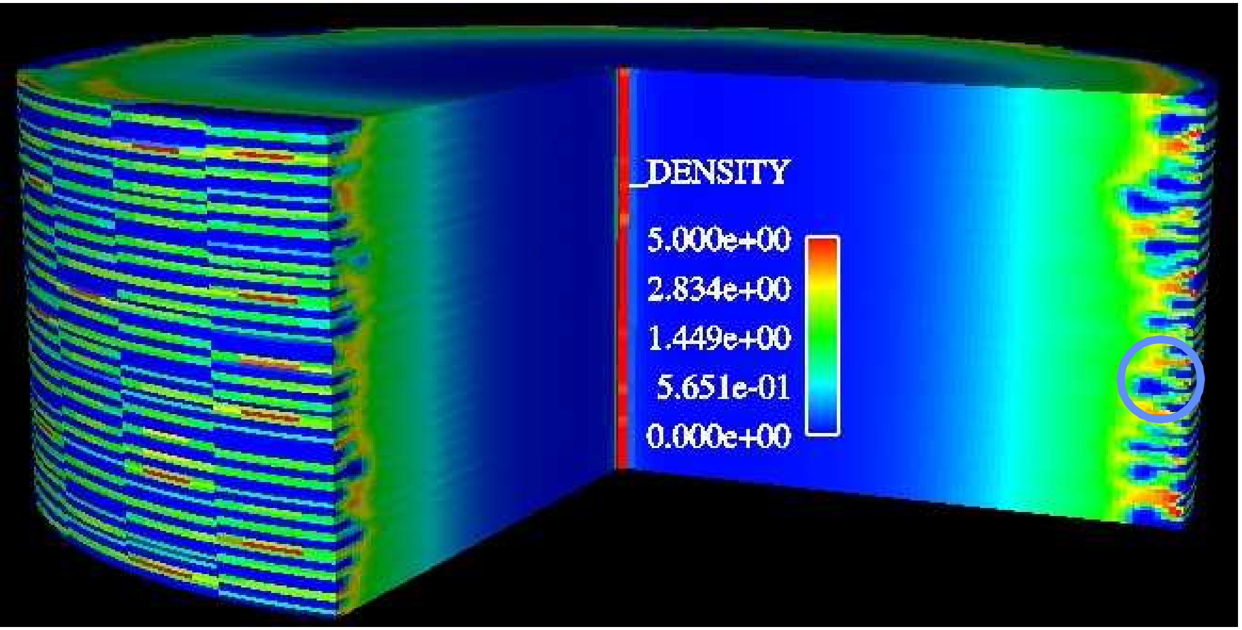
In 3D, trailing mass can fill in bubbles



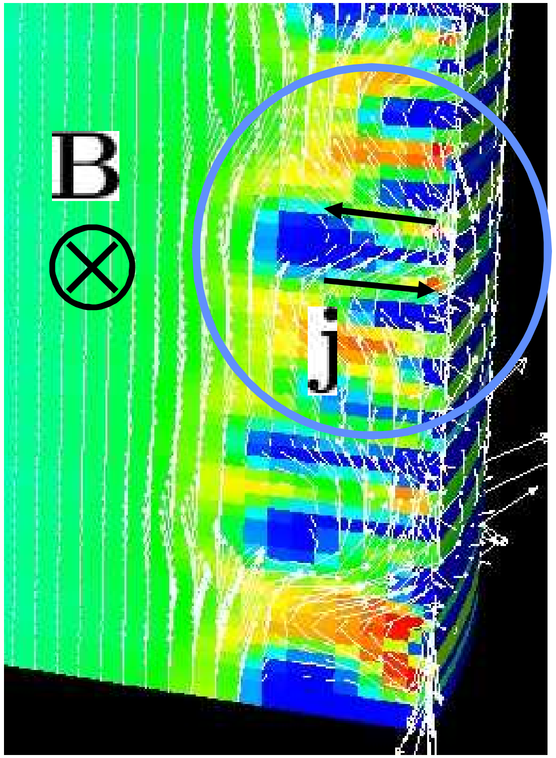
C=3%, t=2504

Initially, current bends around the bubble in such a way as to blow it up, just as in 2D

In 3D, trailing mass can fill in bubbles



t=2506



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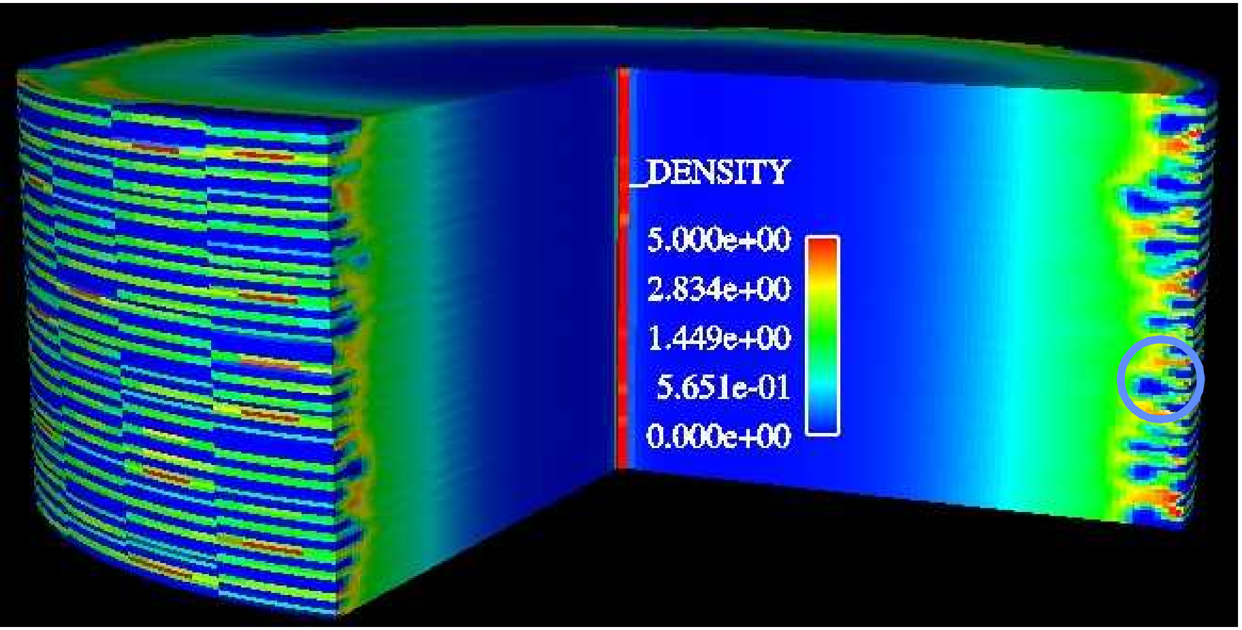
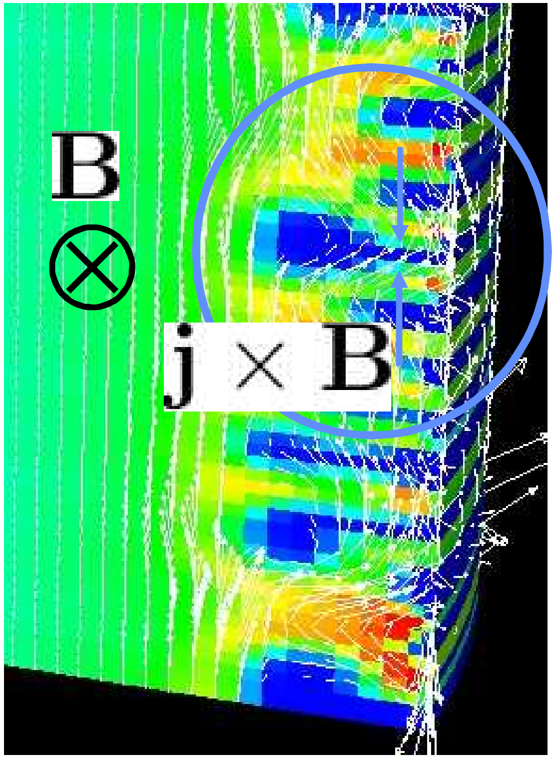
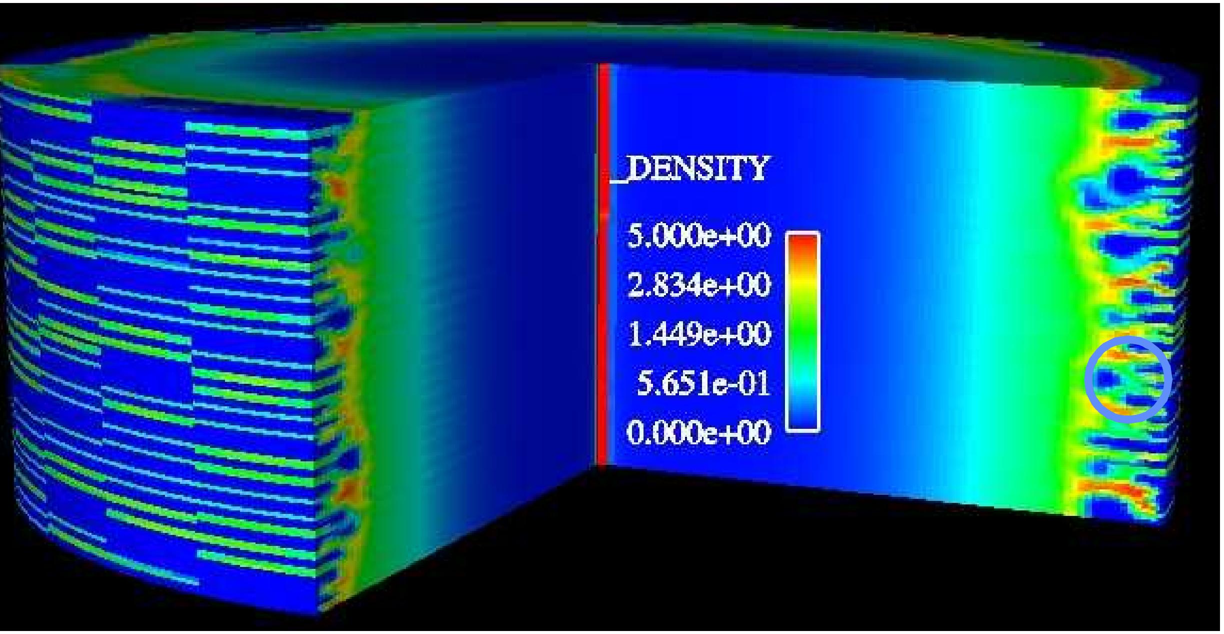


t=2506

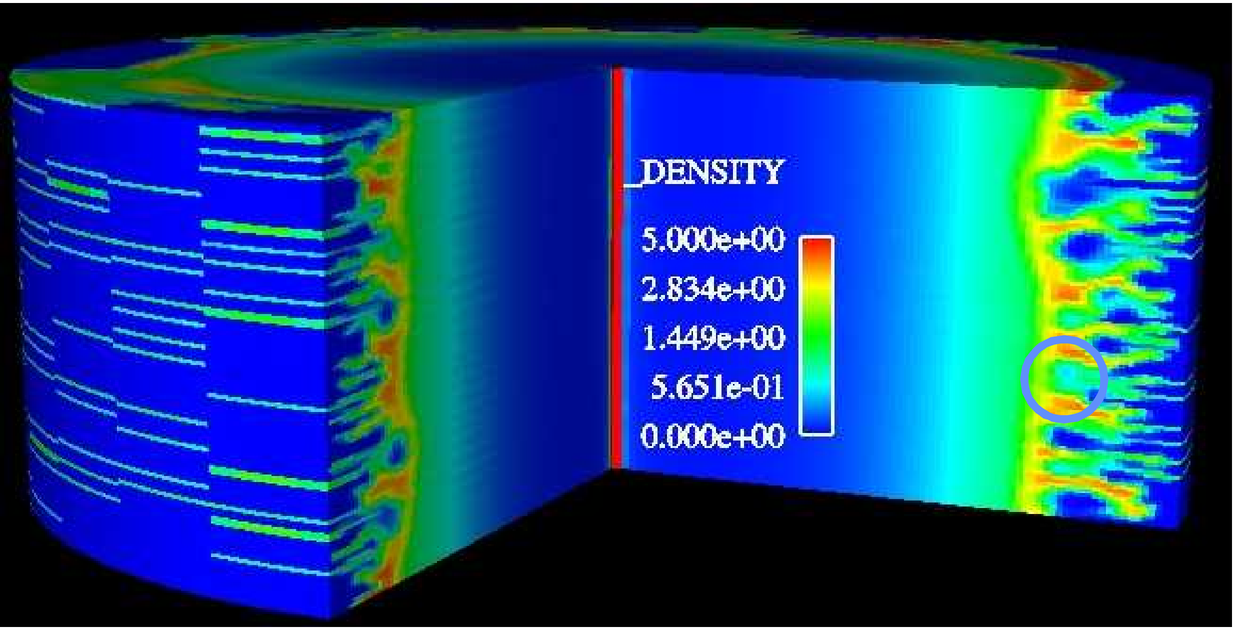


In 3D, trailing mass can fill in bubbles



t=2508

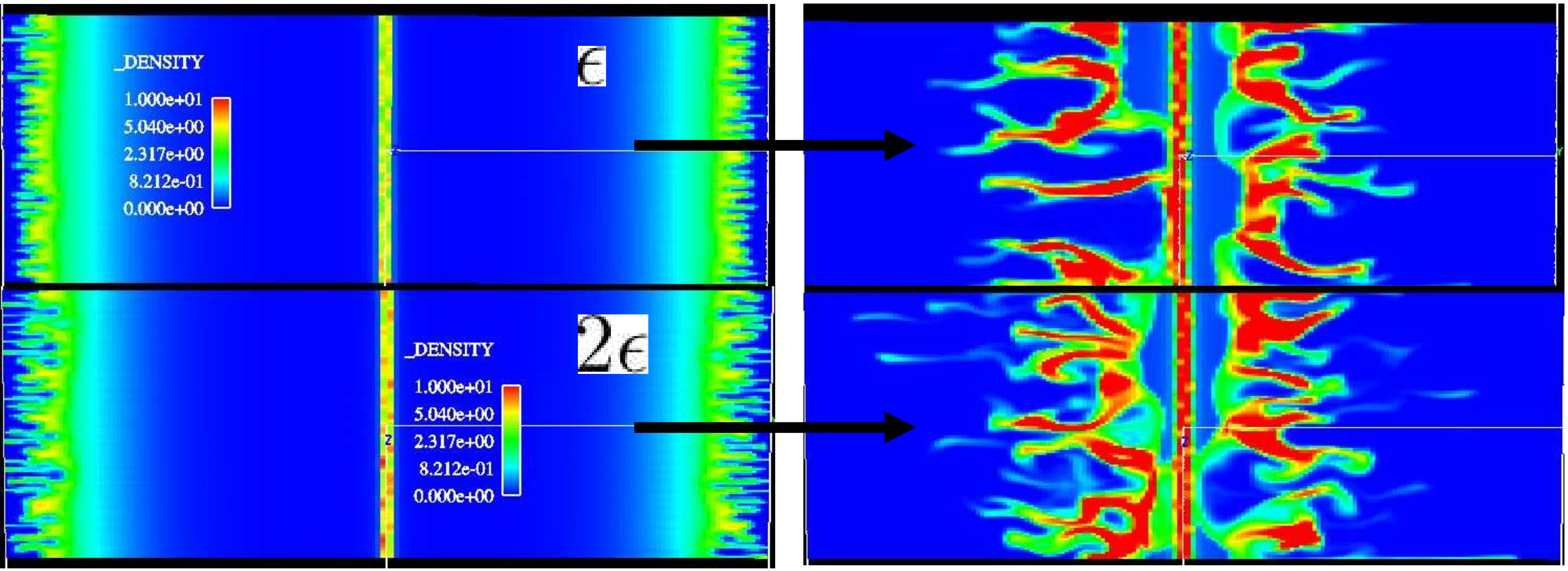
In 3D, trailing mass can fill in bubbles

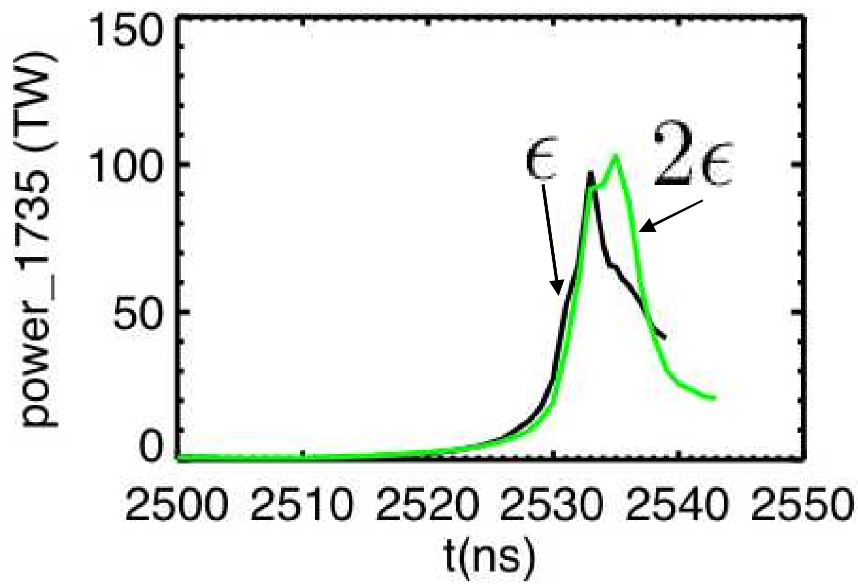


t=2512

The bubble has been filled in

In 3D, bubble growth is not determined solely by magneto Rayleigh-Taylor (MRT)



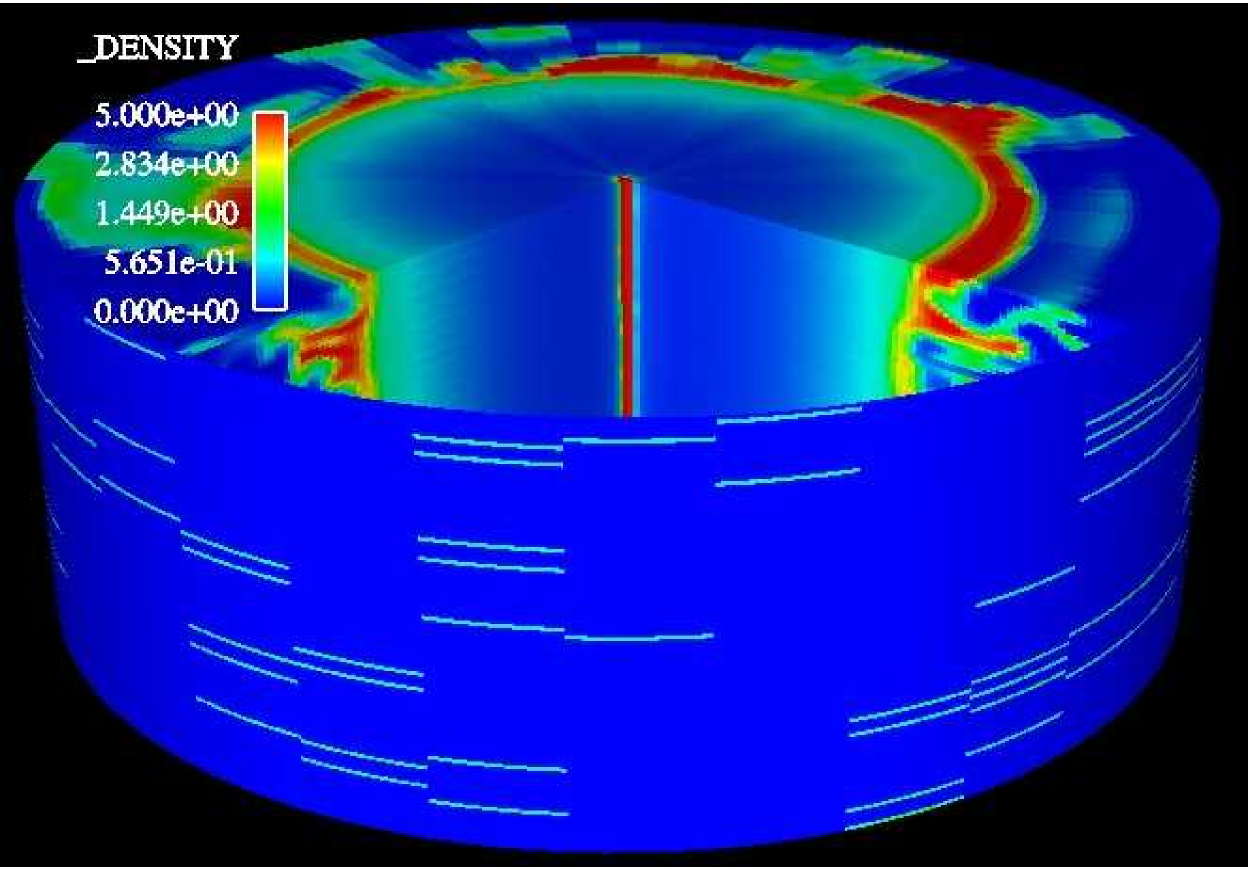


In conventional MRT, stronger perturbation ε leads to a more deformed shell.

In 3D, the trailing mass can have a "healing" effect on bubble growth, which is determined by both MRT and jxB forces

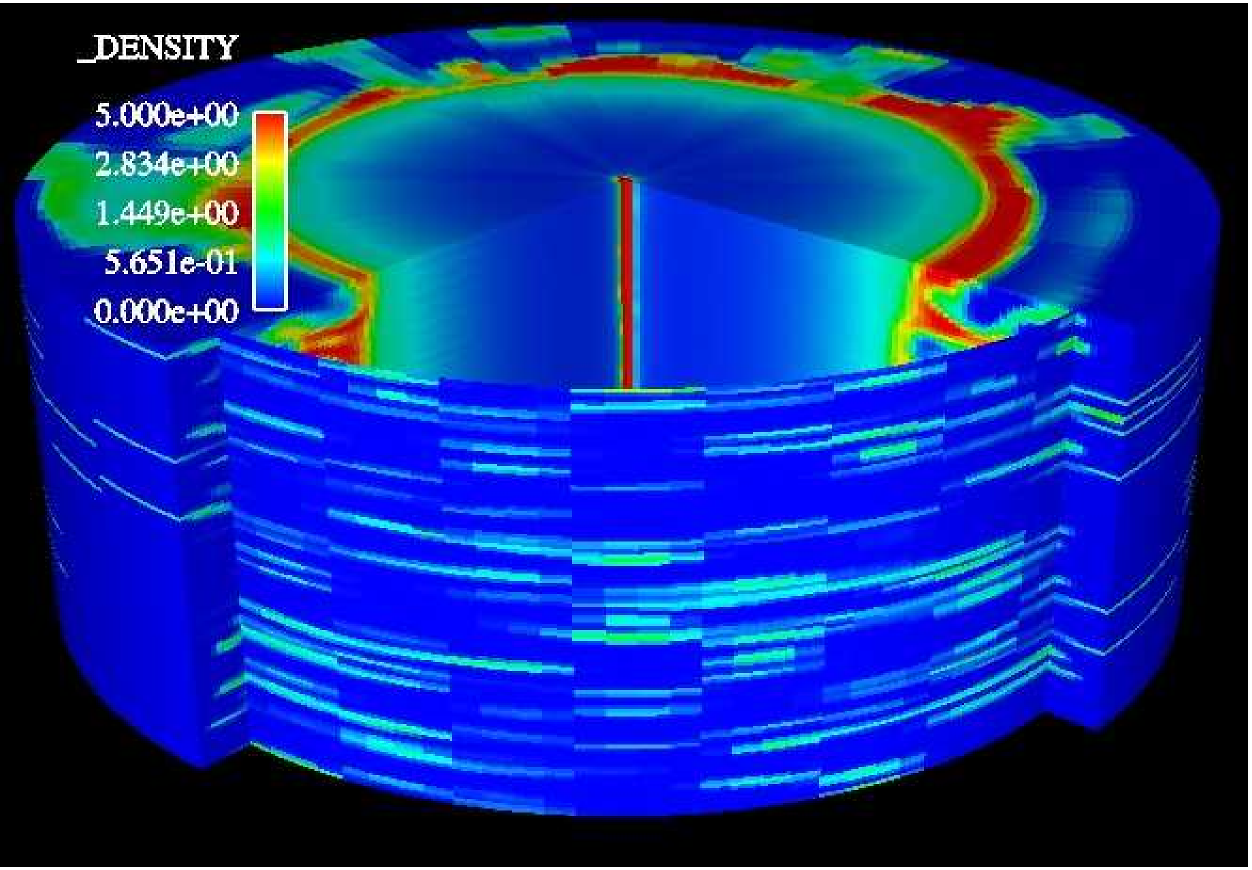
trailing mass evolves towards force-free structure

C=3%, t=2518, r=1 cm



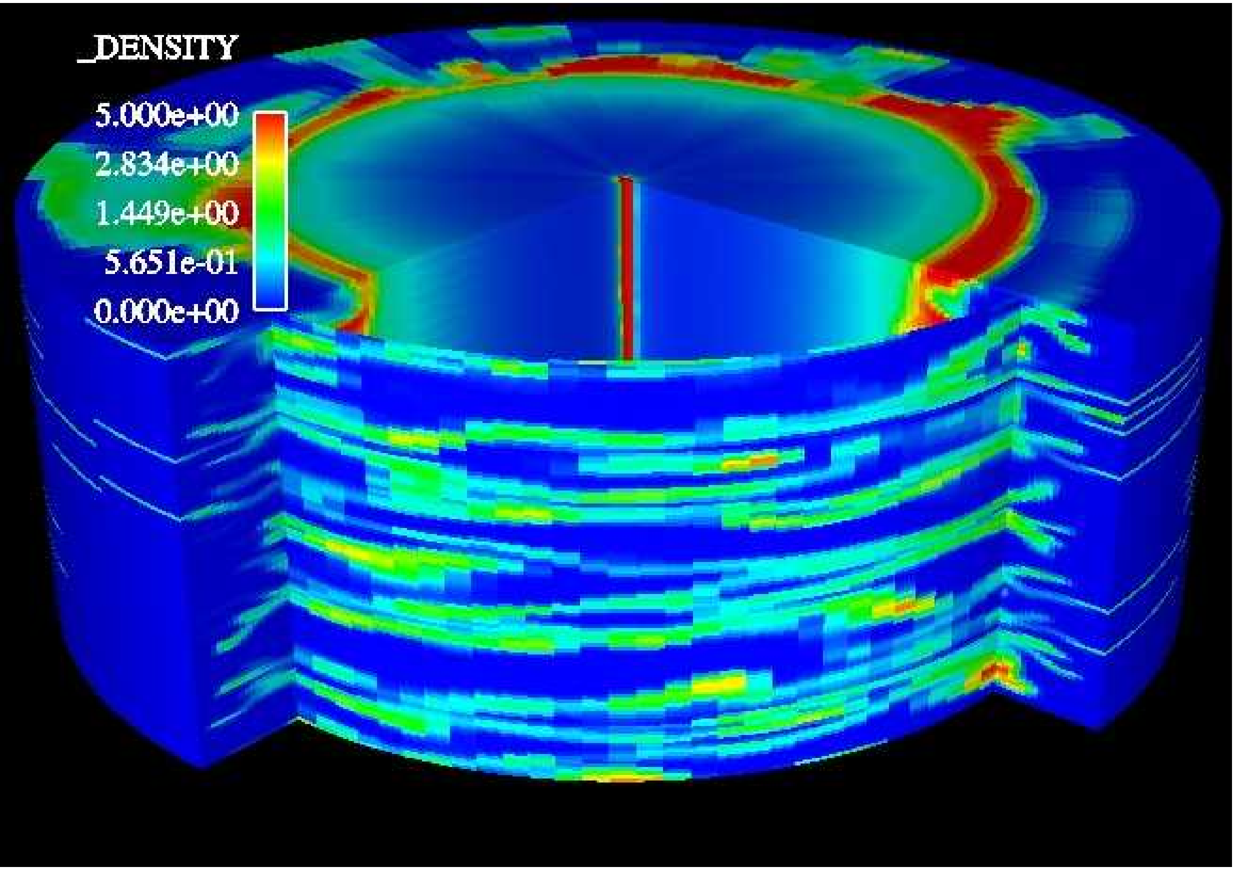
trailing mass evolves towards force-free structure

C=3%, t=2518, r=9 mm

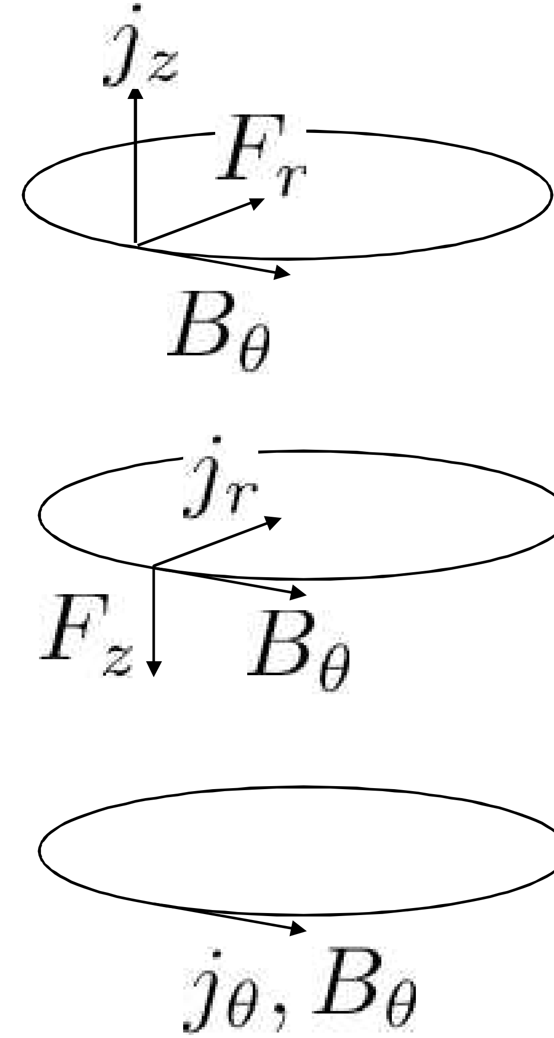


trailing mass evolves towards force-free structure

C=3%, t=2518, r=8 mm



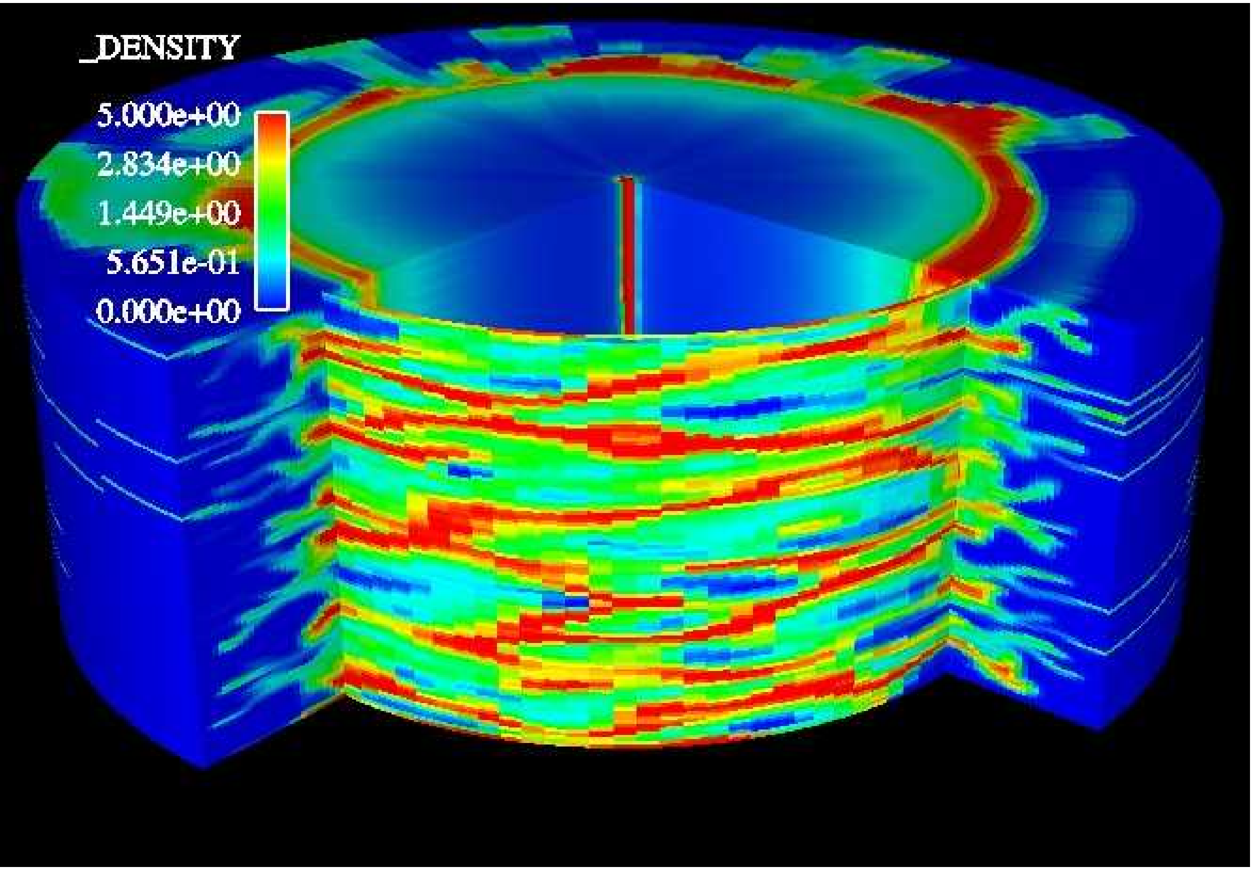
Trailing mass is evolving towards a force-free configuration. It has “forgotten” the initial azimuthal correlation C=3%



$$j \times B = 0$$

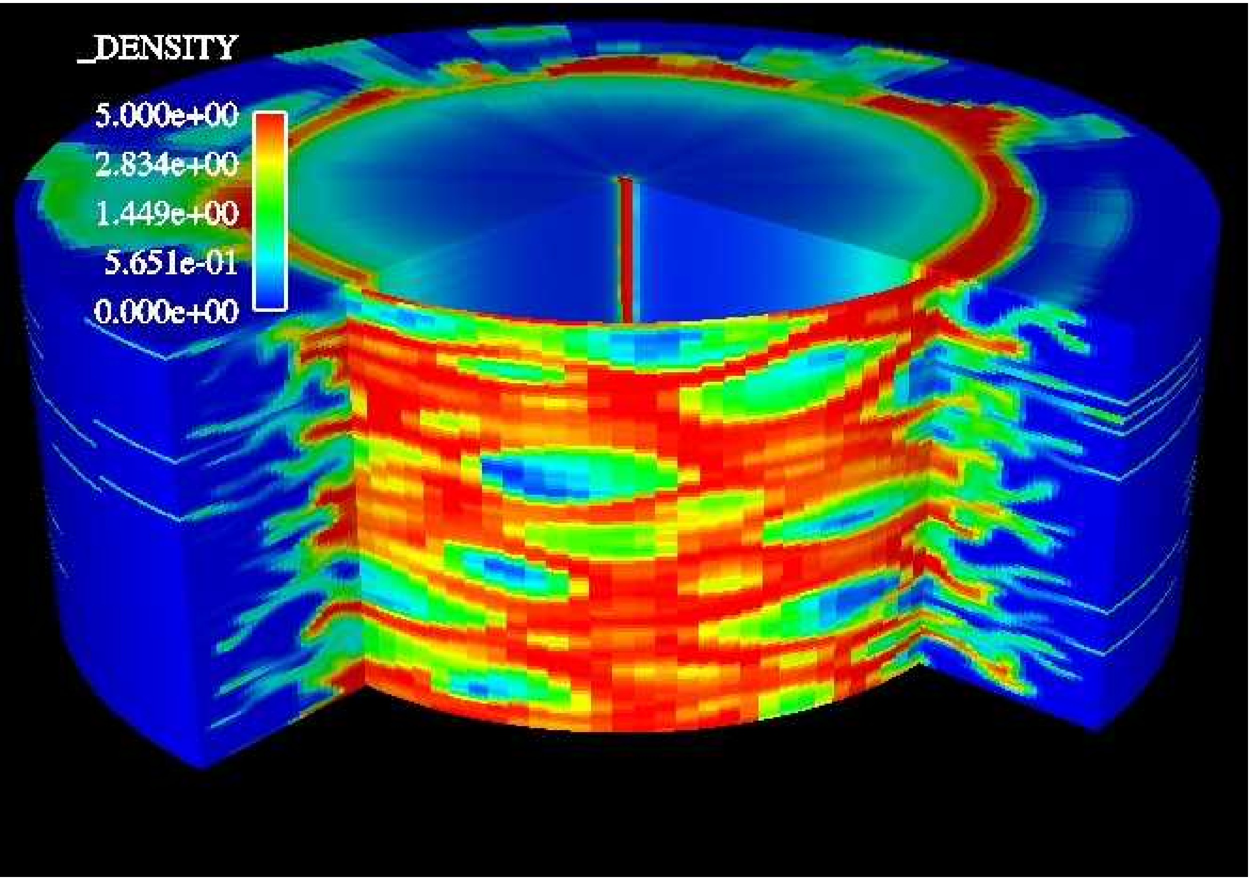
trailing mass evolves towards force-free structure

C=3%, t=2518, r=7 mm



trailing mass evolves towards force-free structure

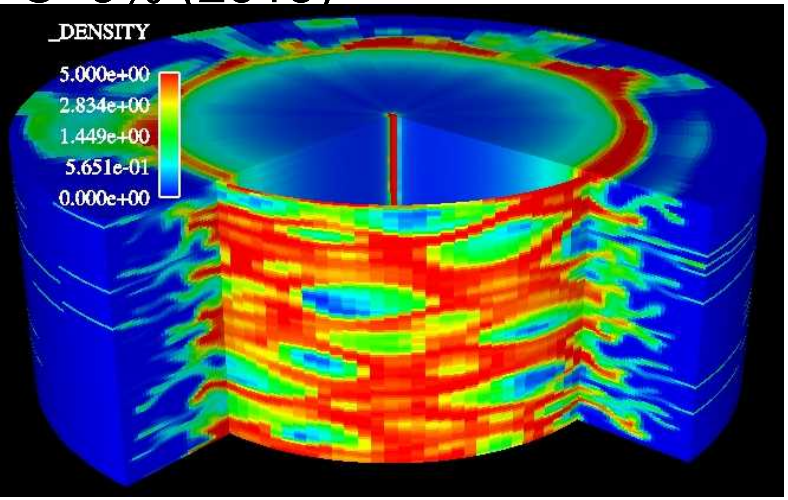
C=3%, t=2518, r=6.5 mm



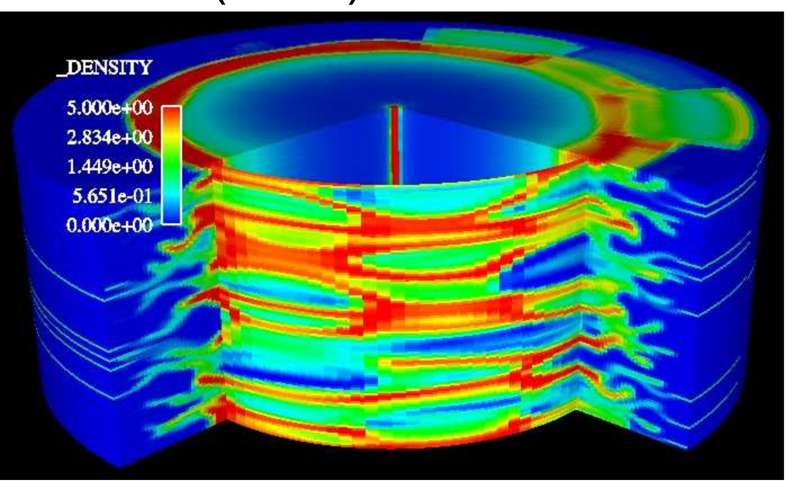
We are at the imploding sheath. The original azimuthal correlation length has imprinted itself here.

azimuthal correlation degrades performance

C=3% (2518)

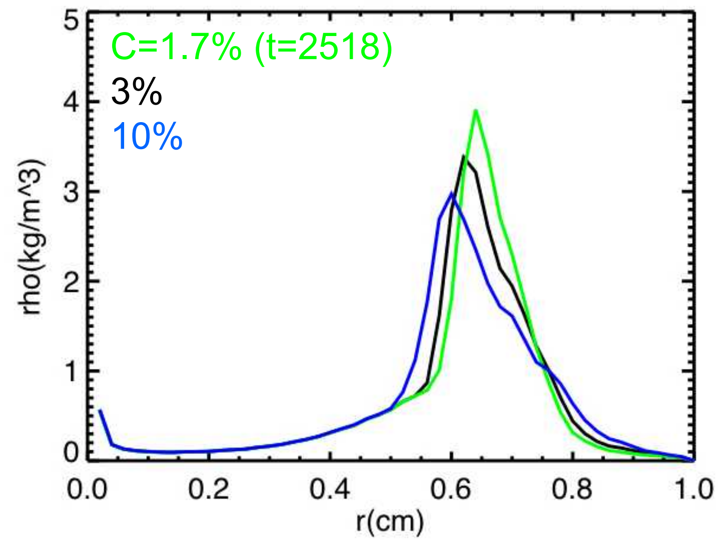


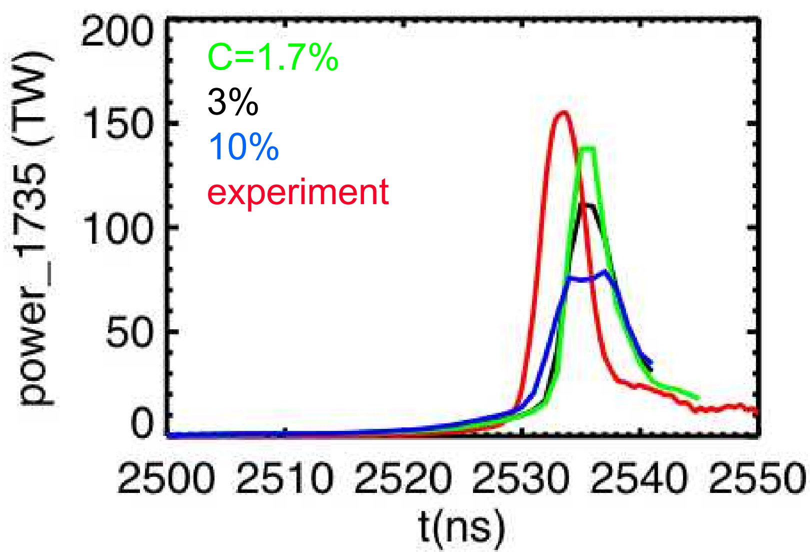
C=10% (2518)



Higher azimuthal correlation on the mass injection surface results in wider azimuthal bubbles on the imploding surface.

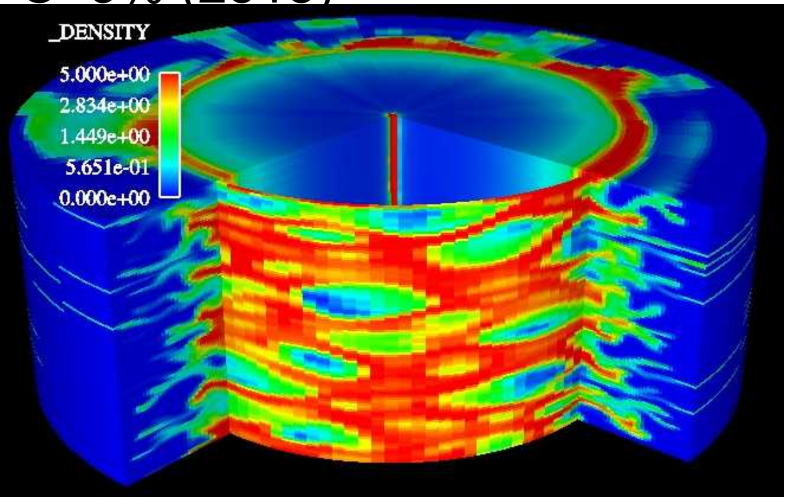
- Higher azimuthal correlation leads to more bubble growth, wider plasma sheaths, lower power



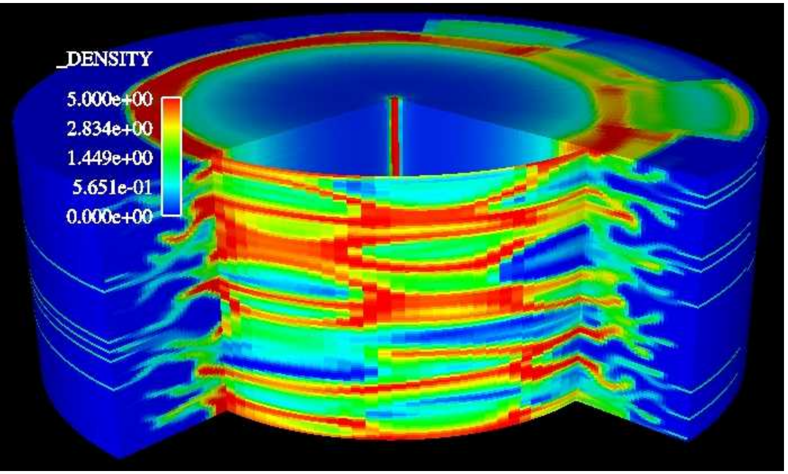


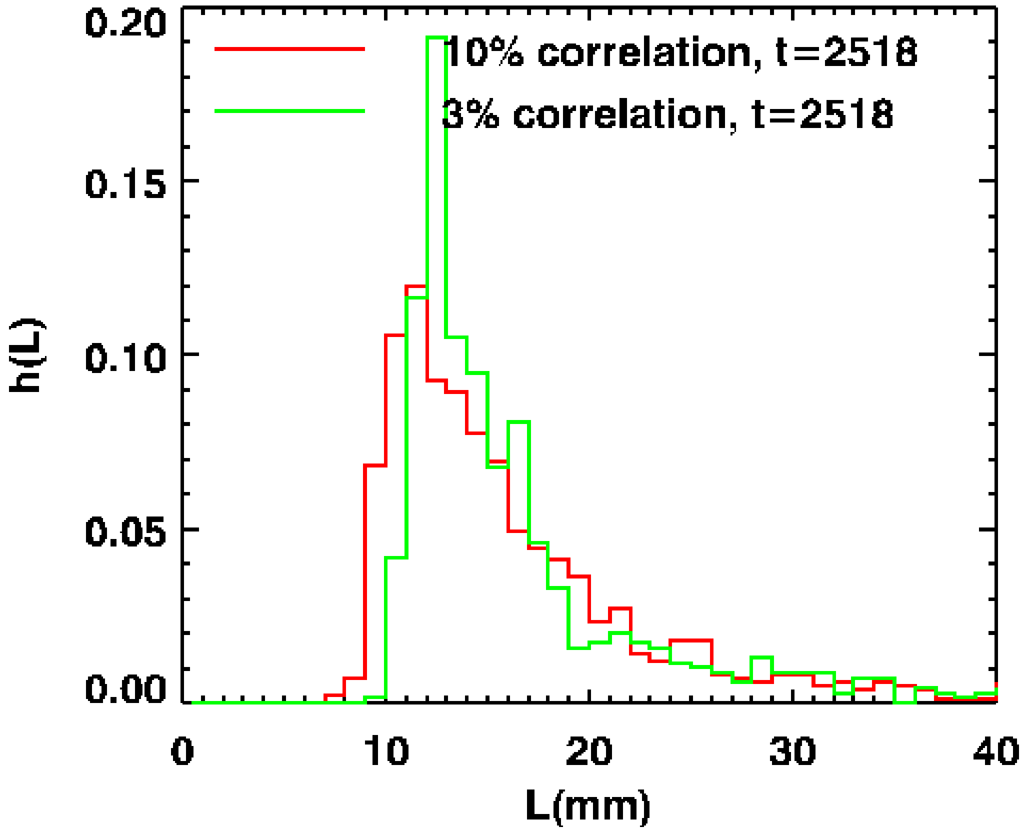
paths through trailing mass unaffected by azimuthal correlation

C=3% (2518)



C=10% (2518)



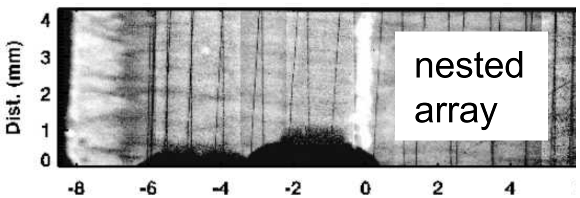


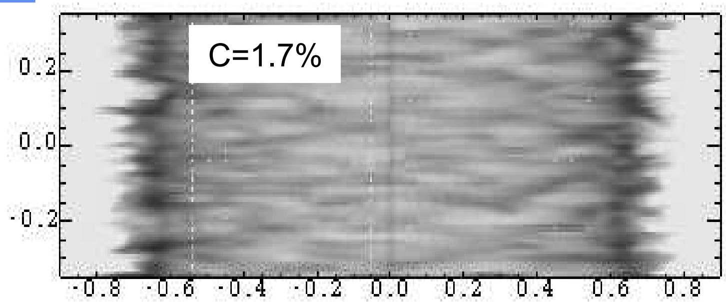
Experiment radiographs can constrain simulations

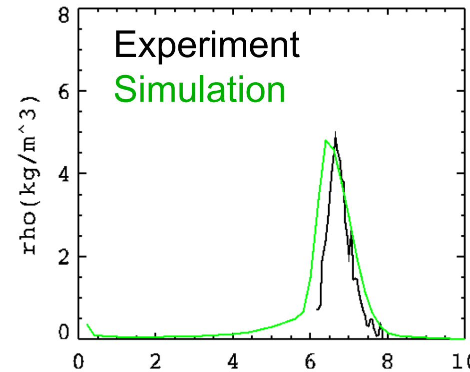
experiment:2.42 mg

simulation(from Spect3d)

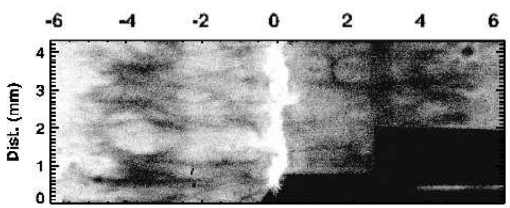
density profiles

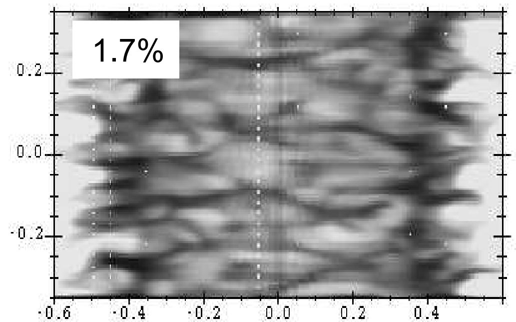


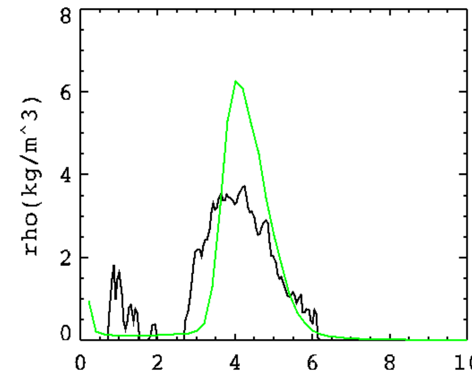




-19 ns before peak power

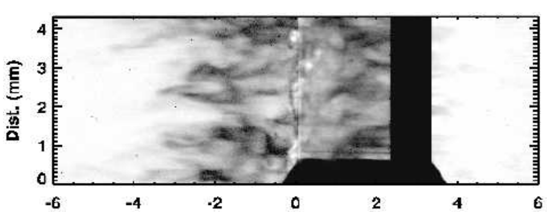


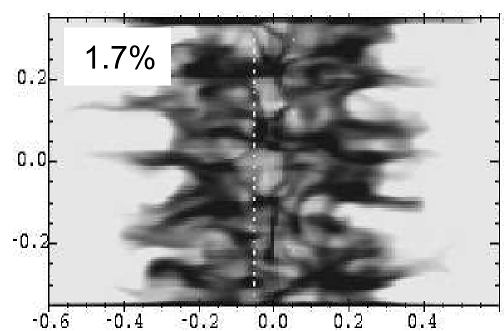


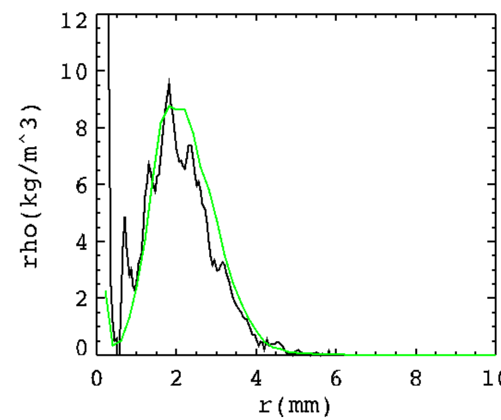


-10.5 ns before peak power

Time



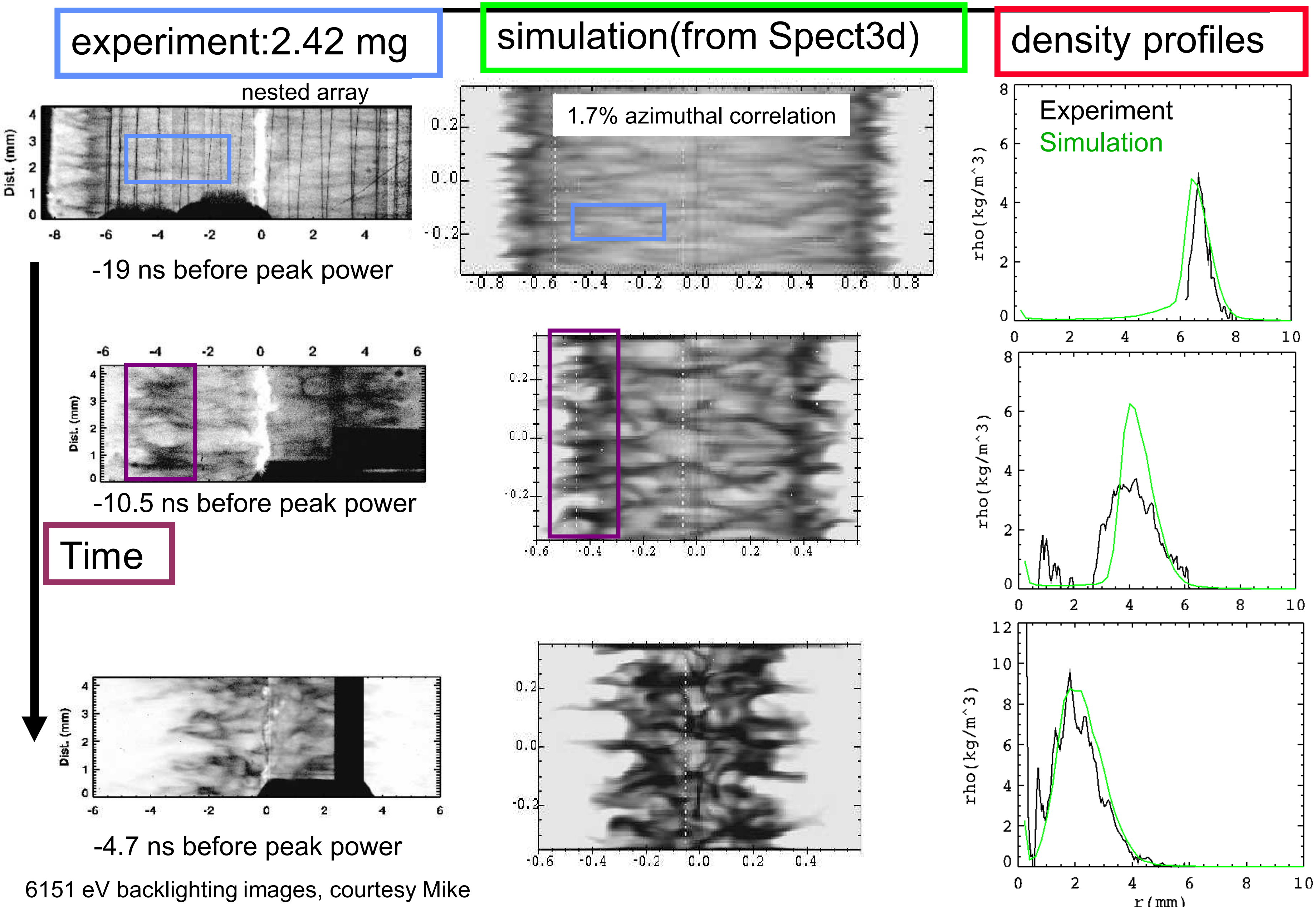




-4.7 ns before peak power

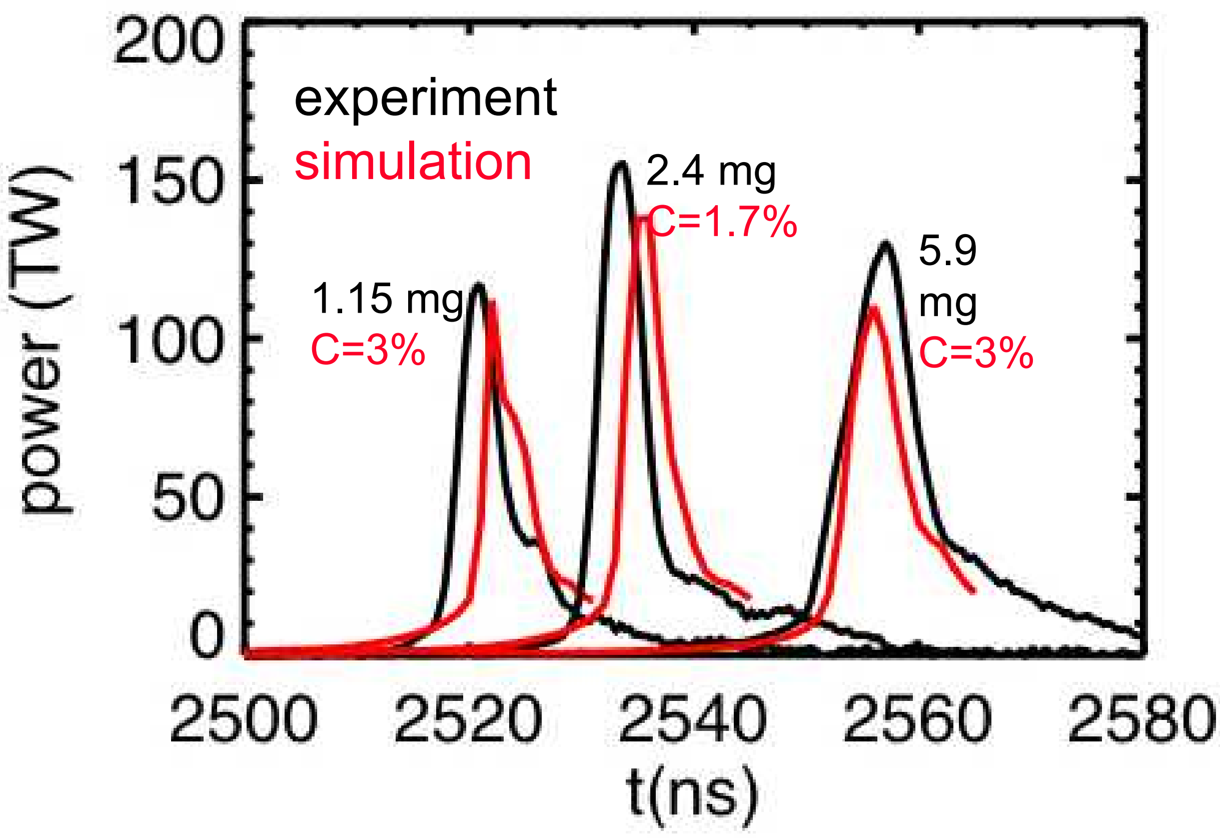
Courtesy Mike Cuneo and Dan Sinars

Experiment radiographs can constrain simulations



6151 eV backlighting images, courtesy Mike Cuneo and Dan Sinars

Experimental/Simulation mass scan comparison



For more comparison to data, especially power pulse, please see:

R.W. Lemke et al., PP8.00039(Wed)

Conclusions

In the presence of the axial instability, bubble growth is reduced in 3D because current can flow azimuthally.

A set of radiographic data exists which strongly constrains data, and may help us determine the degree of azimuthal correlation

In 3D, the trailing mass can have a “healing” effect on the bubble growth, which is determined by both MRT and jxB forces

Higher azimuthal correlation leads to more bubble growth, wider plasma sheaths, lower power

THE END

THANKS TO:

Mike Cuneo, Mike Desjarlais, Ray Lemke, Dan Sinars, Tom Haill, Chris Jennings, Eduardo Waisman, Leonid Rudakov*

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