SAND2017-7530C

Discussion of Electron Inertia implementation, and Nernst term affect on Maglif calculations.

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Regular MHD

(This approach currently taken our Lab ICF design codes)

$$\partial_t \boldsymbol{B} = -\nabla \times \boldsymbol{E}$$

$$\boxed{\partial_t \boldsymbol{E}} = c^2 \left(\nabla \times \boldsymbol{B} - \mu_0 \boldsymbol{J} \right)$$

Usually drop this term and close with a simple ohms law

$$\mathbf{E} + \mathbf{u} \times \mathbf{B} = \eta \mathbf{J}$$

Advection

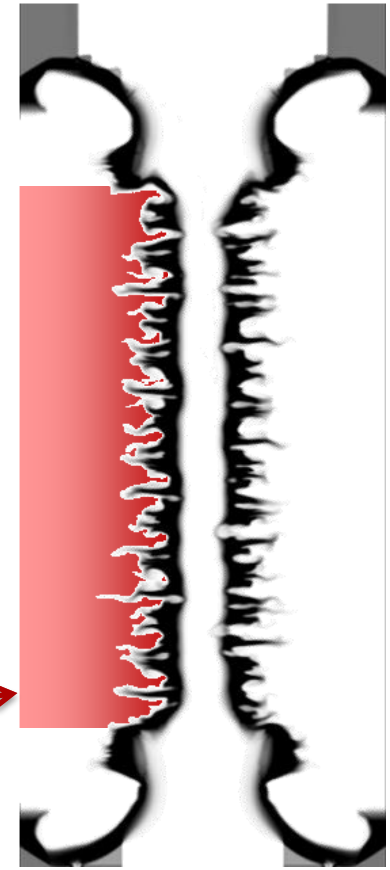
$$\partial_t \boldsymbol{B} = \nabla \times \boldsymbol{u} \times \mathbf{B}$$

Diffusion

$$\partial_t \boldsymbol{B} = -\nabla \times \frac{\eta}{\mu_0} \nabla \times \boldsymbol{B}$$

Can't propagate field through vacuum so its assigned a high resistivity and a choice is made on the density this switches to plasma.

Density can't be arbitrarily low as MHD breaks down and $E=\eta J$ could support unrealistic currents



Sort of OK for Z targets – an unknown for Z-Next

Incorporate Electron Inertia

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Electron inertia:
(Allows physical transition to low densities)

$$\partial_t \boldsymbol{J} = \varepsilon_0 \omega_{pe}^2 (E - \eta J)$$

$$\boldsymbol{J} = \frac{E}{\eta}$$

$$\boldsymbol{J}^{n+1} = \boldsymbol{J}^n - \Delta t \varepsilon_0 \omega_{pe}^2 E$$

$$\omega_{pe}^2 = \frac{n_e e^2}{m_e \varepsilon_0}$$

Rate at which current can ramp up is now tied to electron mass – can't go super-luminal

Advocated for many years by Matt Martin / C. Seyler

I follow the formalism developed for Gorgon by **Mark Sherlock** cast in terms of the electron equation of motion

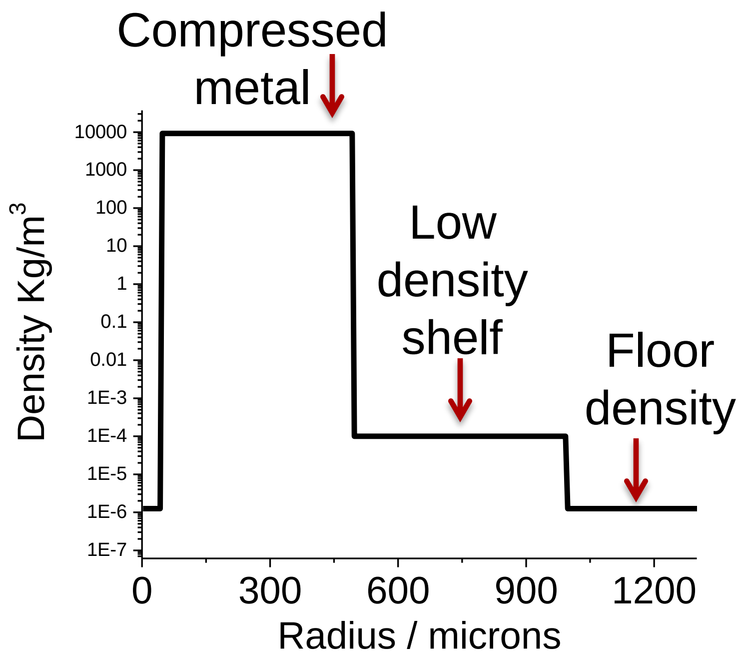
$$m_e \frac{dv}{dt} = -e(E + v \times B) - m_e \nu_{ei}(v - v_i)$$

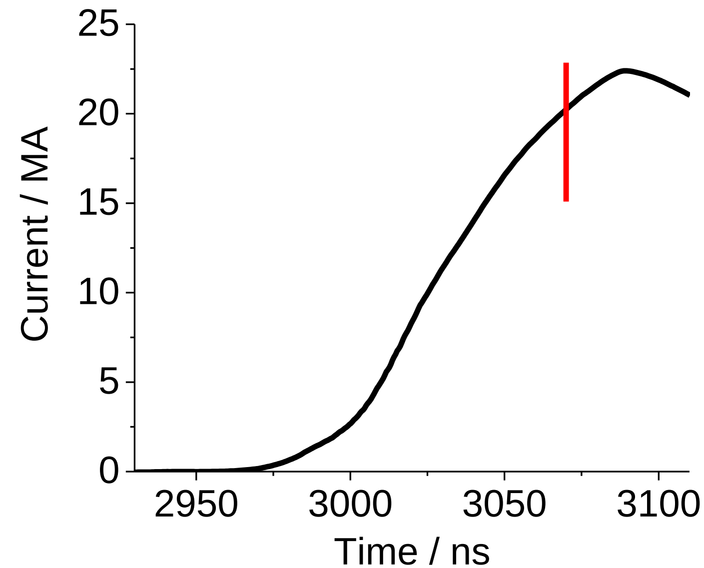
These terms equate to the form on the left, with ion motion assumed small and vxB handled elsewhere.

$$\frac{dp}{dt} = -e\left(E + \frac{p}{\gamma m_e} \times B\right) - m_e \nu_{ei}\left(\frac{p}{\gamma m_e} - v_i\right)$$

Cast in terms of electron momentum we can cap electron velocity

Simple test case:
Field solver on static plasma





Static beryllium density profile “inspired by Maglif”
Uniformly 10eV (no heating)
Calculate conductivities from Lee-Moore-Desjarlais tables.

Run a Z style current through it, and look at current distributions at time marked ~20MA

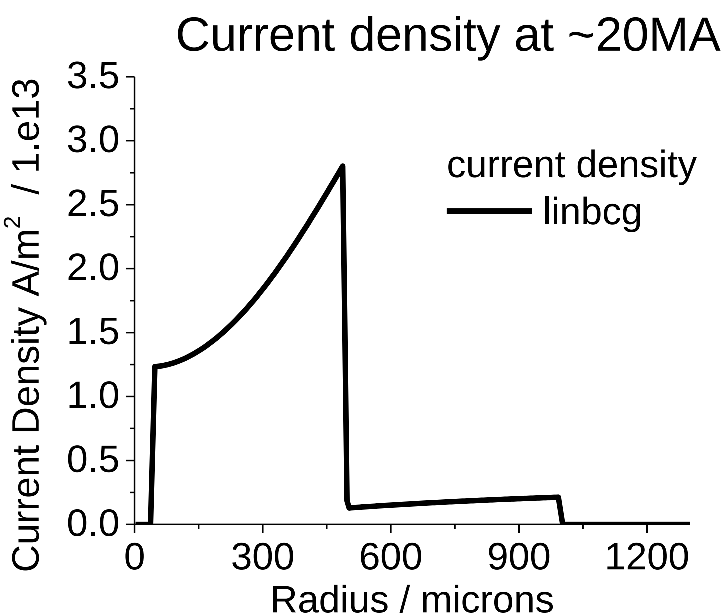
Iterative Matrix Diffusion Solve

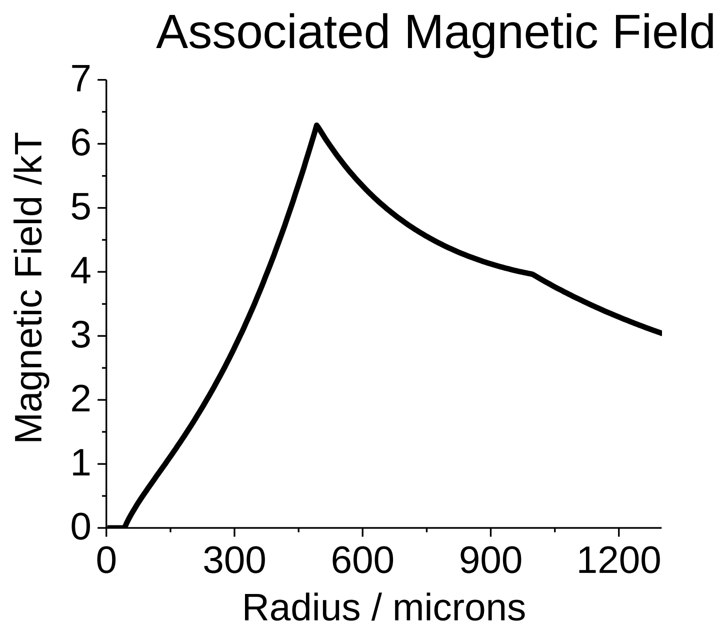
$$\partial_t \boldsymbol{B} = -\nabla \times \frac{\eta}{\mu_0} \nabla \times \boldsymbol{B}$$

Integrate diffusion equation via fully implicit iterative sparse matrix inversion (typical of many ICF MHD codes)

Assign a vacuum resistivity to transport field over vacuum. (100 ohm-m on anything at floor density)

Use Numerical Recipes “linbcg” bi-conjugate gradient solver (itol=1,tol=1.e-5)





Contrast diffusion solve with Gorgon Wave-Diffusion solve

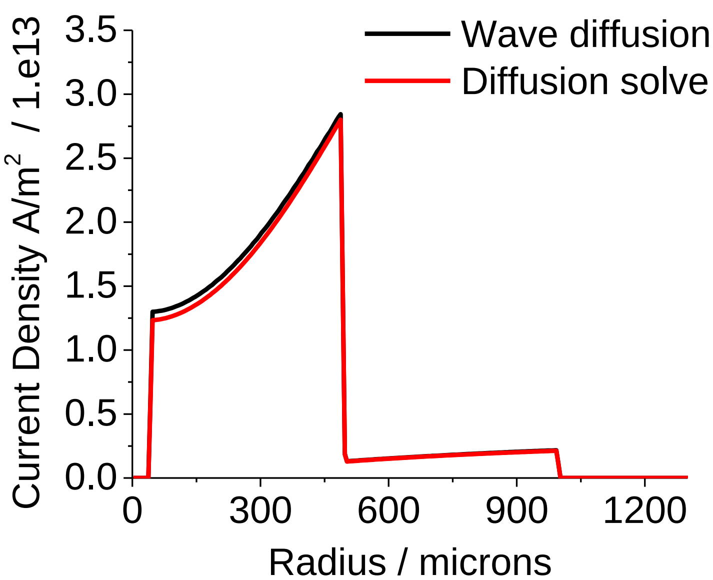
$$\partial_t \boldsymbol{B} = -\nabla \times \frac{\eta}{\mu_0} \nabla \times \boldsymbol{B}$$

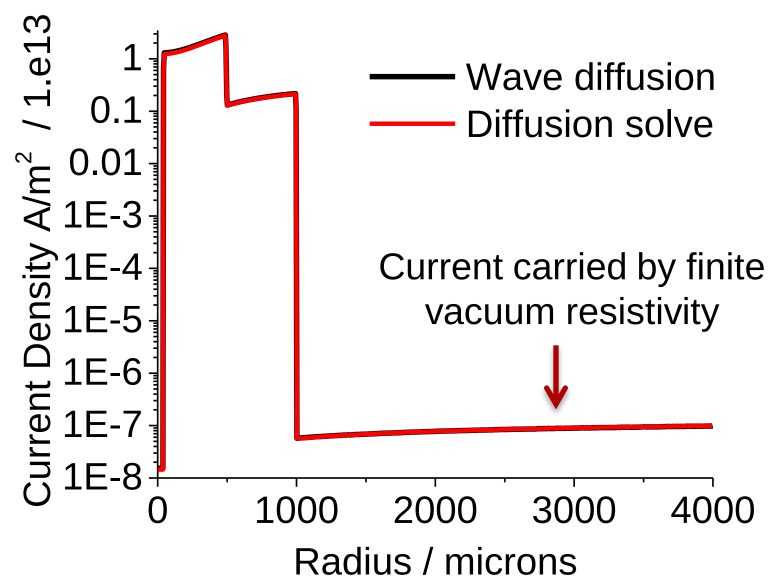
$$\partial_t \boldsymbol{B} = -\nabla \times \boldsymbol{E}$$

$$\partial_t \boldsymbol{E} = c^2 \left(\nabla \times \boldsymbol{B} - \mu_0 \boldsymbol{J} \right)$$

$$\mathbf{E} = \eta \mathbf{J}$$

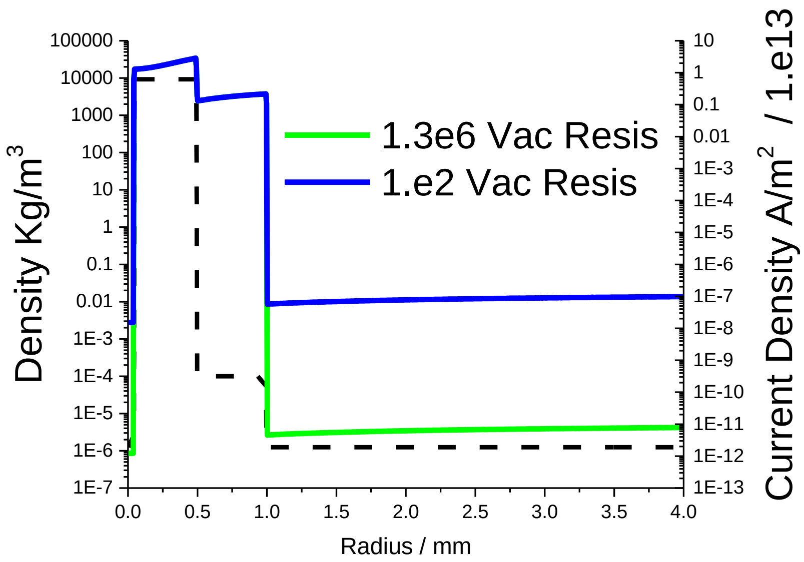
Current Densities at ~20MA





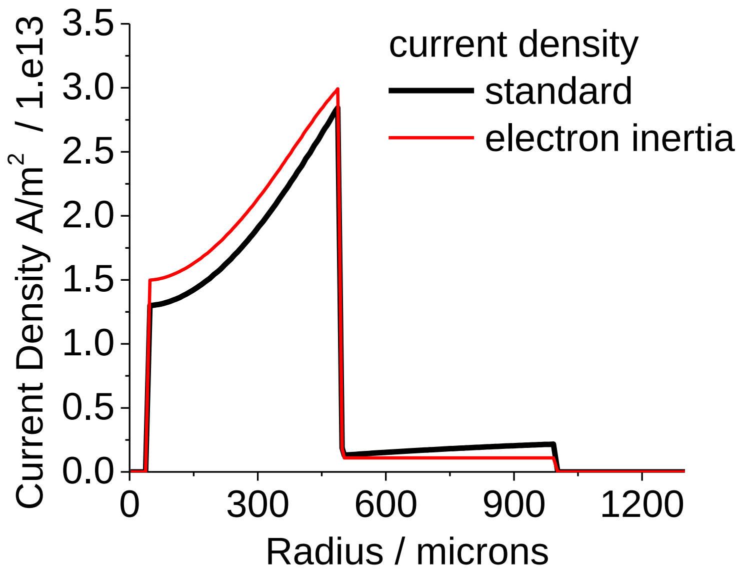
For this comparison vacuum resistivity set to be the same between the different solves

With wave-diffusion equation solve can drop that vacuum resistivity significantly further without any penalty



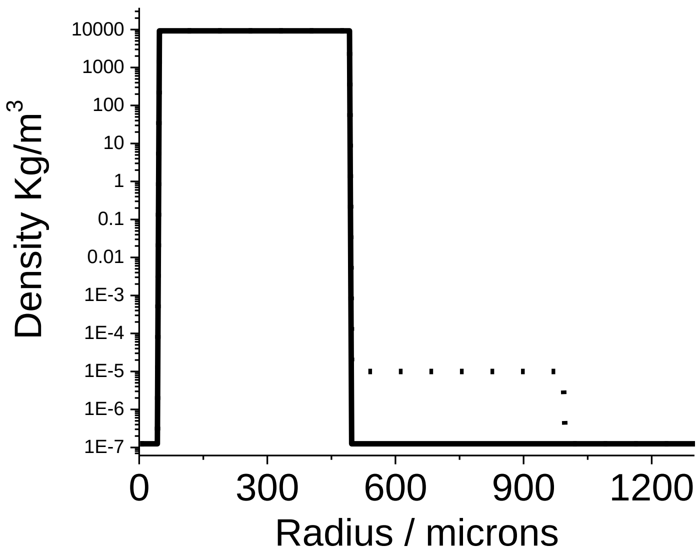
linbcg matrix solve won't run with that high a vacuum resistivity. Iteration doesn't converge and blows up the solution.

Wave-diffusion equation retains an electric field so relatively straight forward to couple to additional current density equations



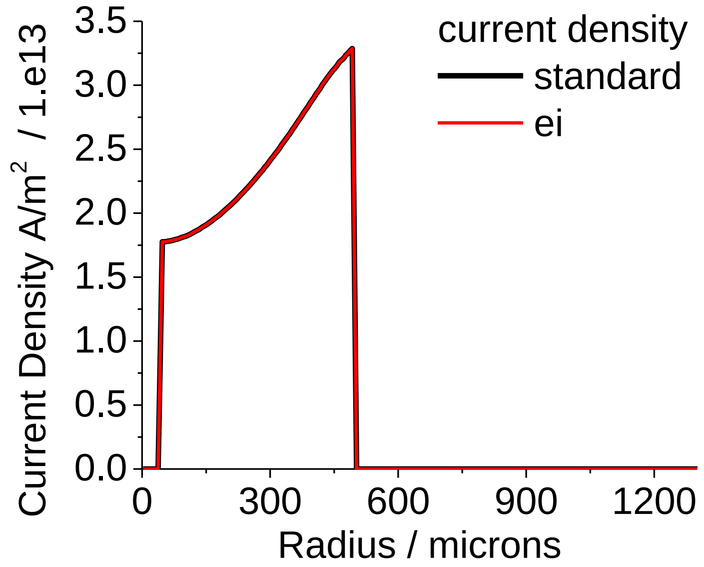
Current density saturates in low density material and ~speed of light drift velocity, and alters distribution of current

Contrast current distributions with and without low density shelf

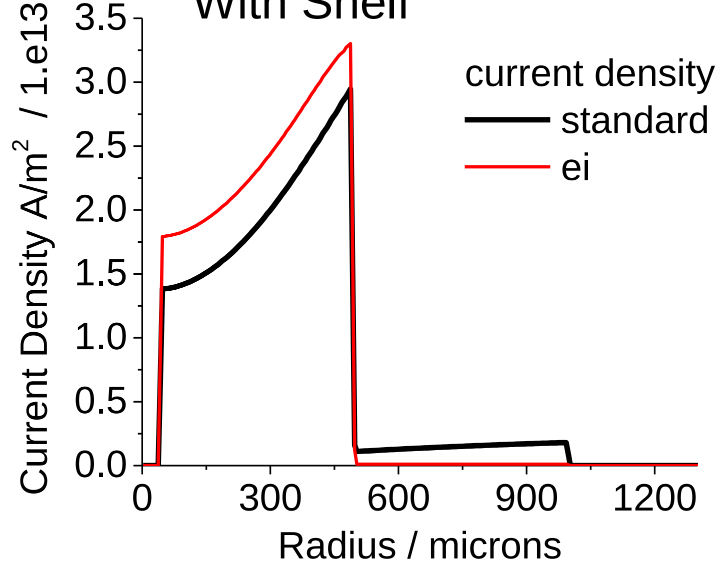


Differences in current distribution more evident for lower density halo 1.e-5 Kg/m^3

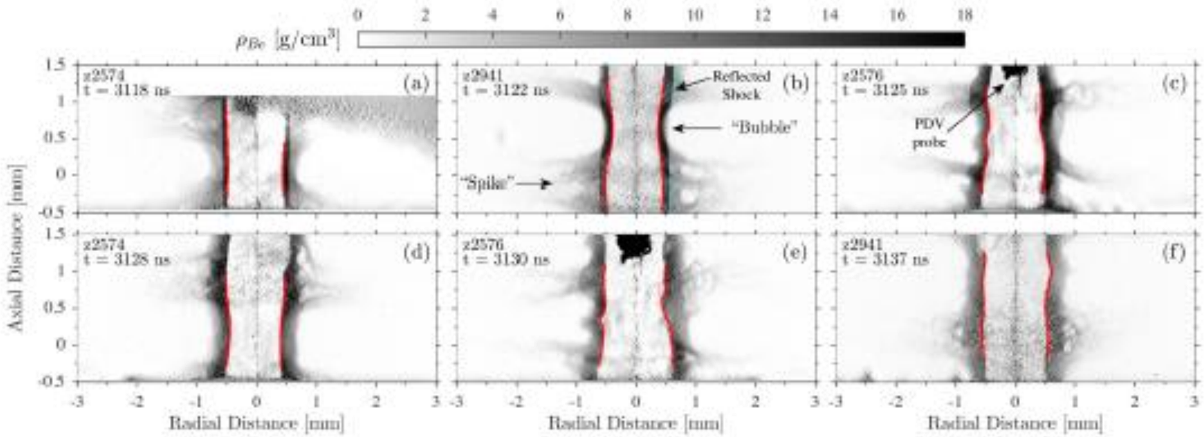
No Shelf



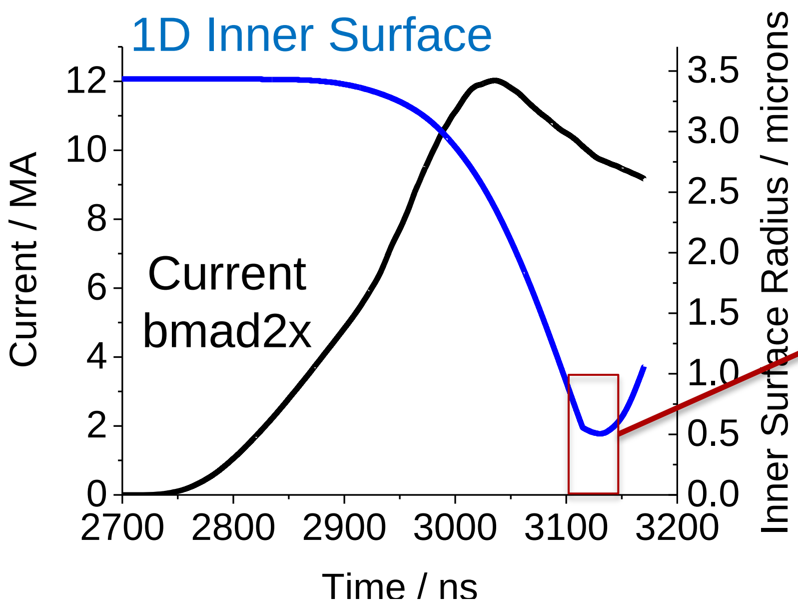
With Shelf



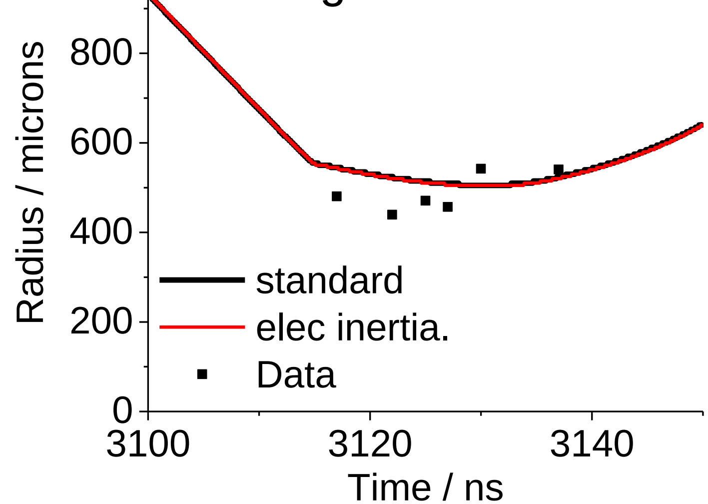
Contrast for Eddy Data – Be Liner compressing a liquid deuterium fill to enable radiography of stagnation



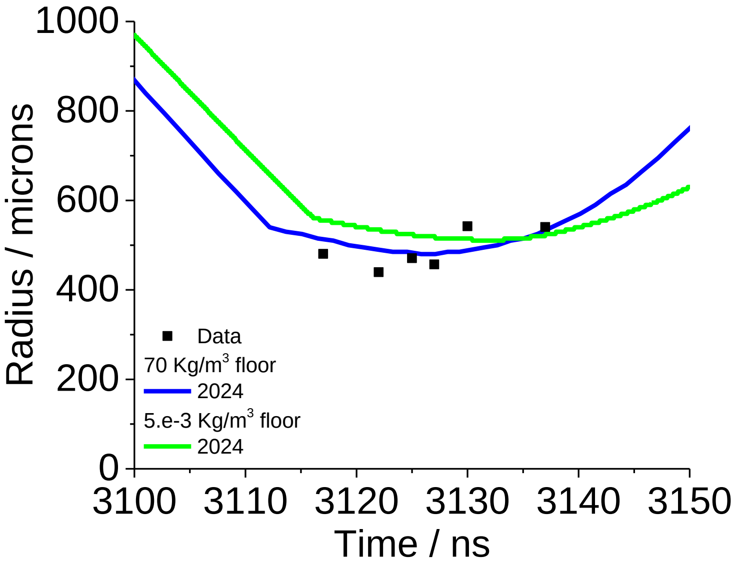
Data: P. Knapp



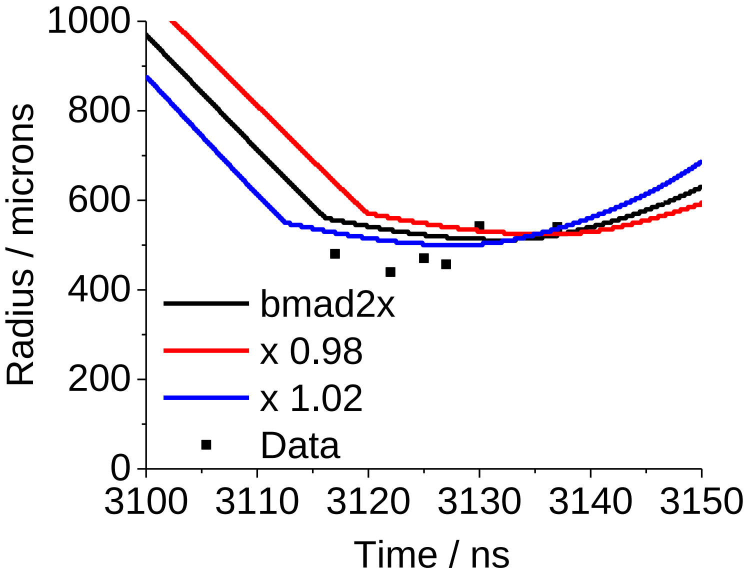
No difference in 1D eddy stagnation calculations



Other sensitivities are evident in stagnation data



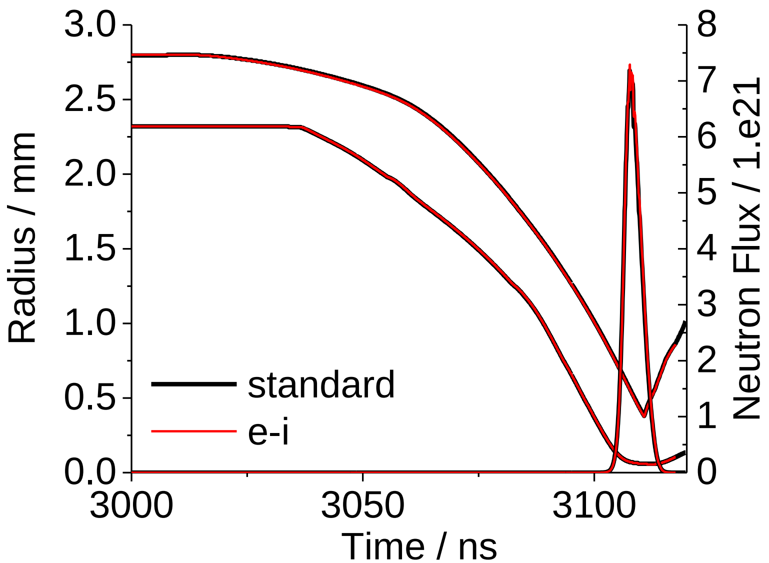
Raising floor density changes late time compression – aside from resistivity treatments, how confident are we in how we treat lower density material in general



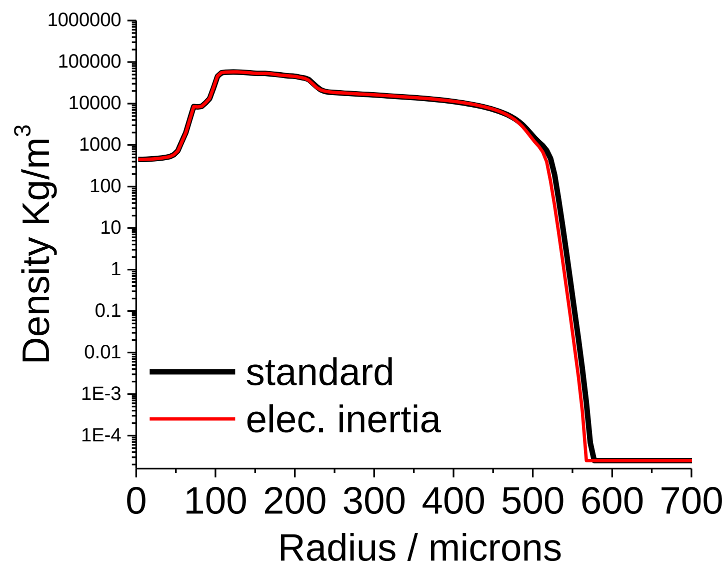
2% Uncertainty in current can alter compression at stagnation

For 1D Maglif Implosion – contrast electron inertial and standard resistivity treatment

No Difference in Implosion Trajectory



Steep density gradient on outer edge negates differences



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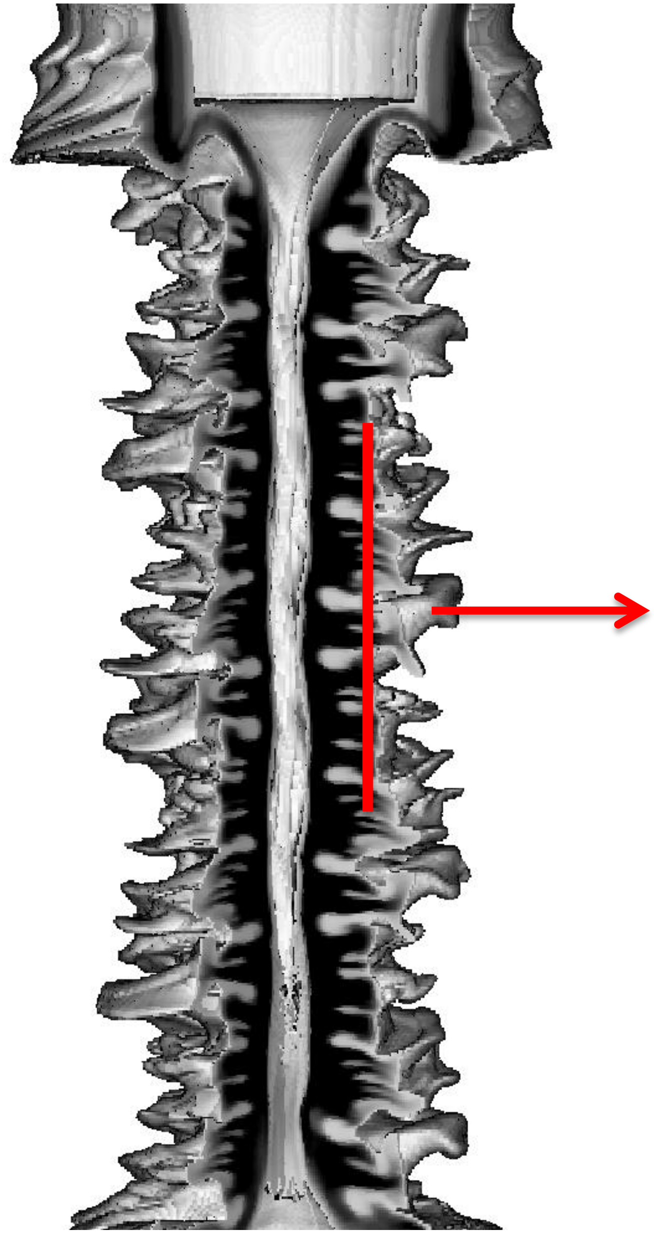
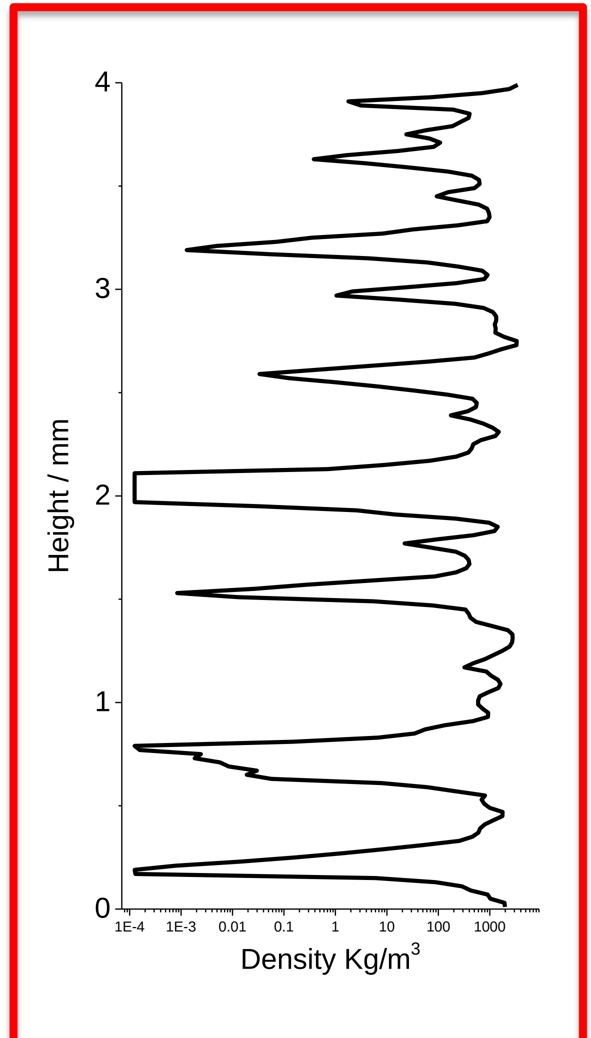
Maglif in reality is very unlikely to be a 1D mass profile.

What we really care about is how current can be distributed through low density plasma distributed by instability growth.

Better treating current distribution in these profiles may directly affect how we grow instabilities of deliver current to small radius at stagnation



Lineout through trailing mass



Affect of Nernst on Maglif stagnation

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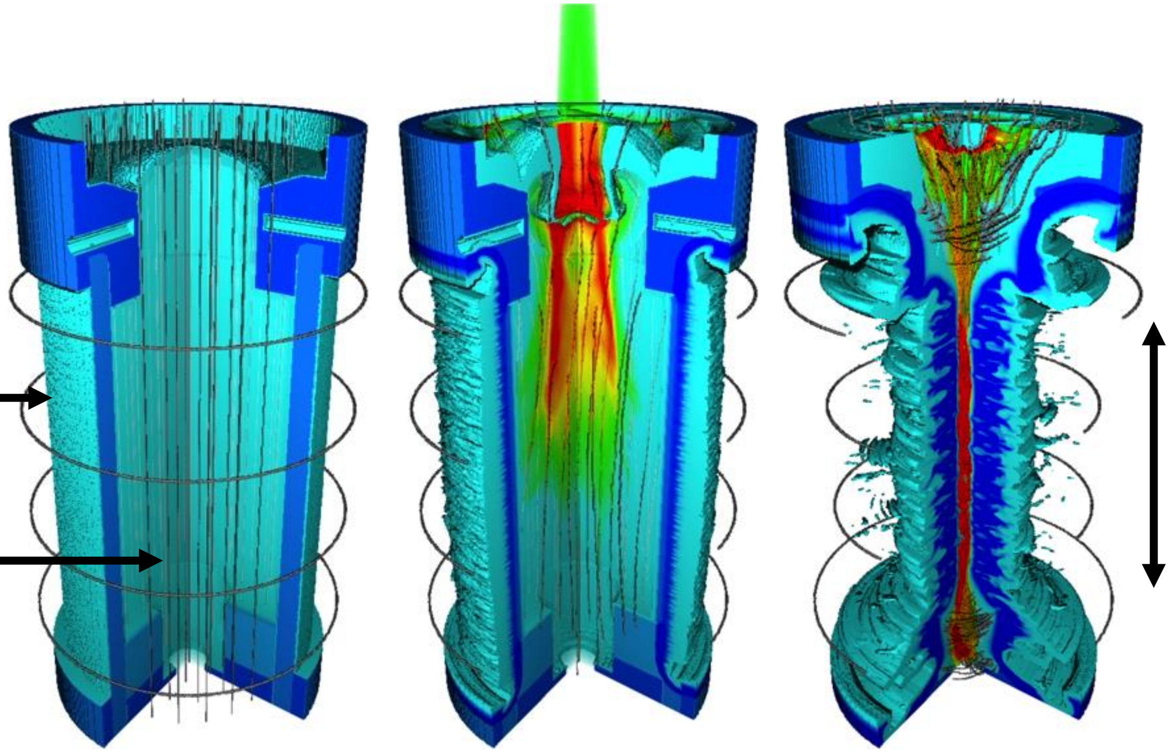
The Magnetized Liner Inertial Fusion (MagLIF) concept

Imploding Be tube or “liner”

Gaseous D_2 fuel 0.7 mg/cc



Stagnation column 6-8 mm

Magnetization B = 10 T

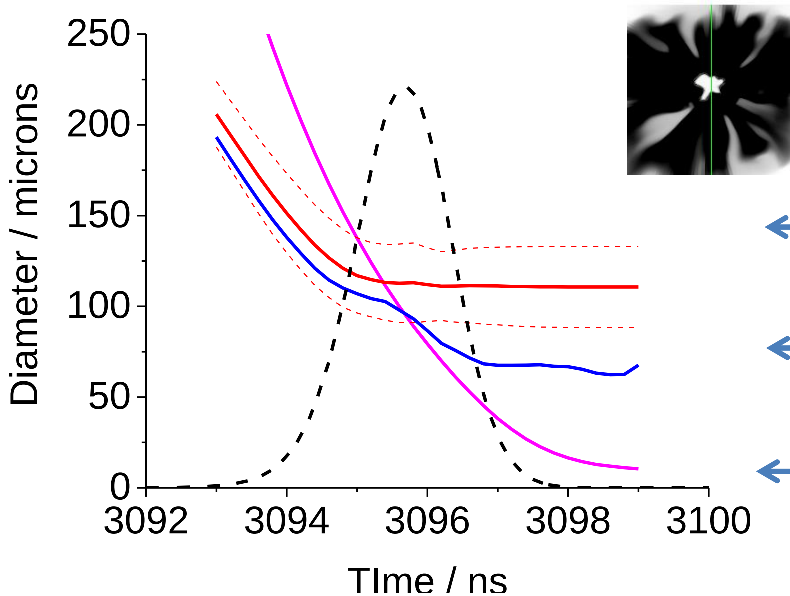
Laser Heating

Compression

*S.A. Slutz *et. al.*, PoP (2010)
S.A. Slutz and R. A. Vesey, PRL (2012)
M.R. Gomez *et. al.*, PRL (2014)
P.F. Schmit *et. al.*, PRL (2014)
A.B. Sefkow, *et. al.* ,PoP (2014)
M.R. Gomez, *et. al.*, PoP (2015)
S.B. Hansen, *et. al.* , PoP (2015)
R.D. McBride, *et. al.*, PoP (2016)

During 3D disruption, time resolved imaging would enable tracking of emission to lower radius (lack of bounce)

Diameters through 3D disruption



(Naively taking FWHM from crystal imager)

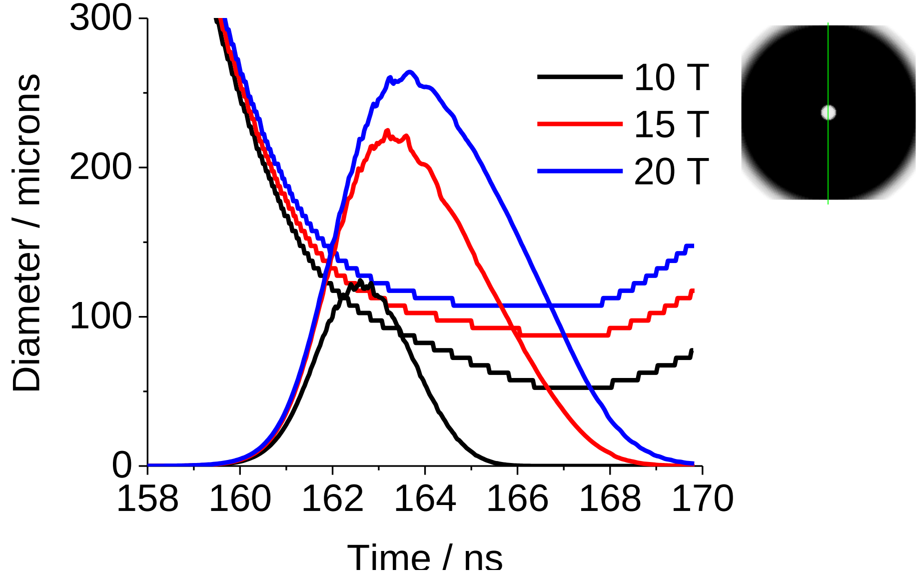
Time integrated Image

Time resolved compresses post peak

Fuel Volume effective diameter

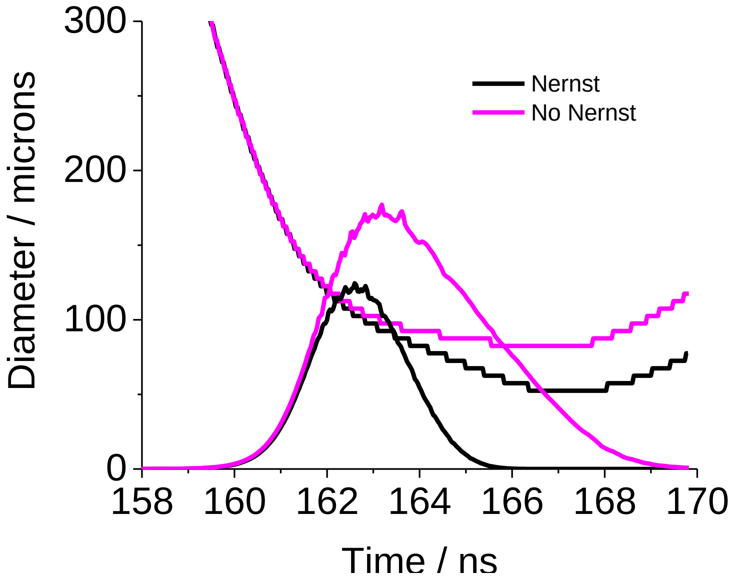
However “lack of bounce” is not a unique indication of disruption. It can be conflated with poor thermal transport inhibition.

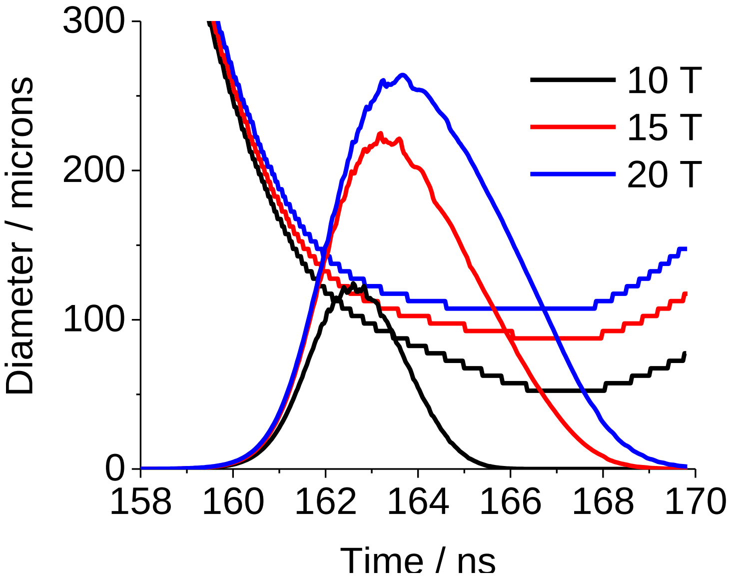
Diameters through 1D compression



Nernst has similar effect to reducing magnetization and limiting burn duration in a Maglif stagnation

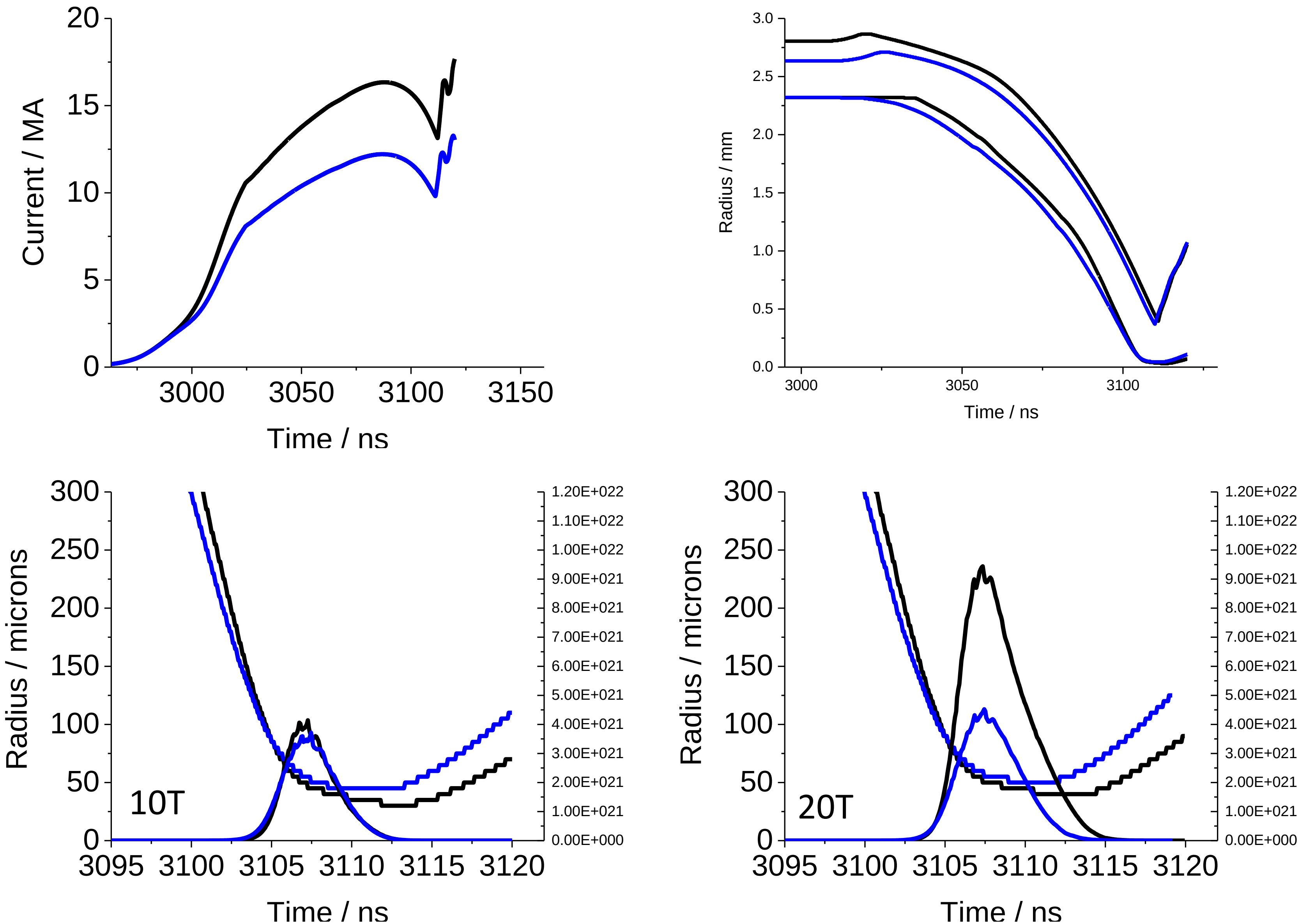
1D profiles of inner surface trajectory through neutron pulse





Implications for Current Scaling

Reduce charge and shift to AR 9 liner



Nernst Magnetic field advection is leading to roll over in yield

2.79mm outer radius, 10mm tall standard Maglif target
10T Applied Bz
0.7 Kg/m^3 Gas Density

Implications for scaling of performance with increased preheat energy (if you don't push up fuel density and Bz field with that preheat energy)