Ultrathin Liner-Plasma Implosion Experiments on a sub-MA Current Generator*

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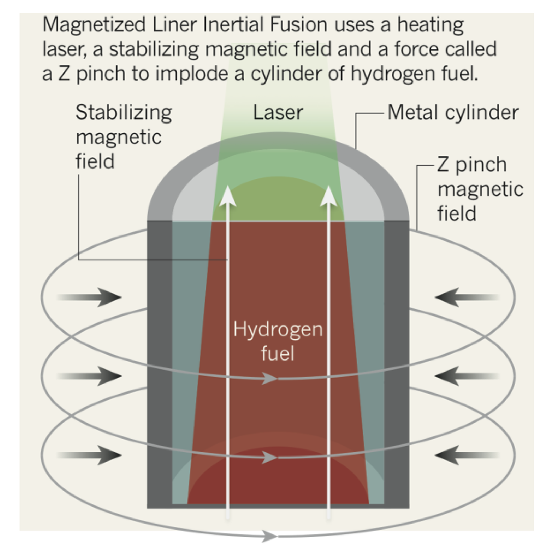
Motivation: Why implode a liner?

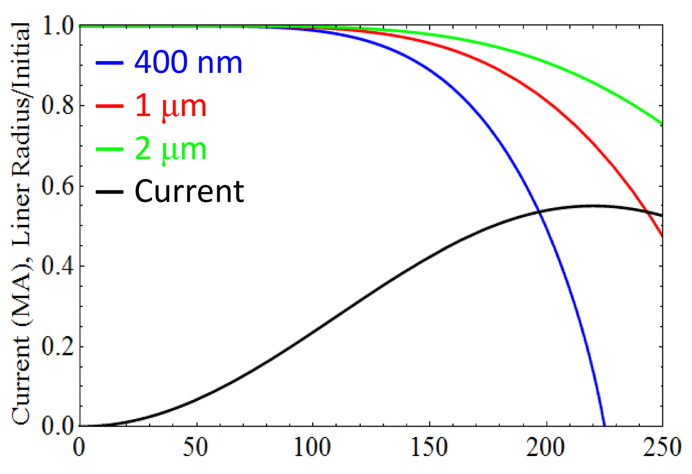
Liner implosion experiments are relevant to the Magnetized Liner Inertial Fusion (MagLIF) concept* and may be used to study MHD instabilities such as the magneto Rayleigh-Taylor (MRT), sausage, and kink instabilities. For this poster, we use liner implosions to study MRT and the stabilizing effects of axial magnetic fields.

"The MRT instability is believed to be one of the largest threats to the success of pulsed-power direct-driven fusion concepts." –Mike Cuneo (Sandia National Laboratories)



* NEWS IN FOCUS *Nature*, vol. 505, p. 9 (January 2, 2014)

Liner implosions with sub-MA currents require **sub-micron** thicknesses, presenting new engineering challenges

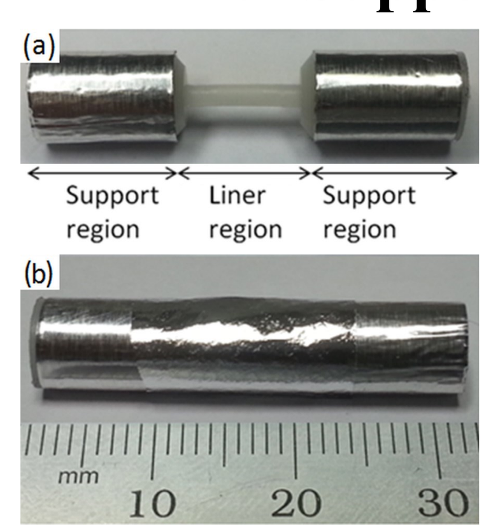


A 0-D implosion model with 550 kA shows that a 6 mm diameter Al liner requires a thickness of 400 nm to implode by peak current

$$\frac{\hat{m}}{2\pi r(t)}\ddot{r}(t) = -\frac{B(t)^2}{2\mu} = -\frac{\mu I(t)^2}{8\pi^2 r(t)^2}$$

$\hat{m}$ = liner mass per unit length, r = radius $B(t)$ = magnetic field, $I(t)$ = current

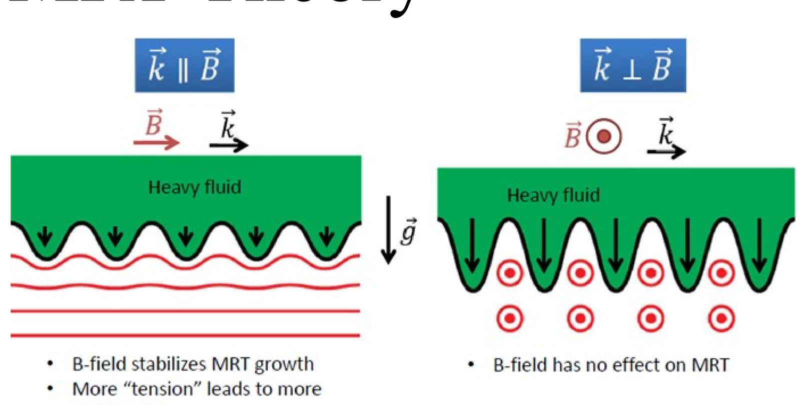
Liner Support Structure



Requires good electrical contact

Must not significantly impede implosion

MRT Theory



Instability of a light fluid supporting a heavy fluid in a gravitational field, accounting for magnetic field effects

The **linear** theory for MRT growth rate in **planar** geometry is

$$\gamma^2 = kg - \frac{(\boldsymbol{k}\cdot\boldsymbol{B})^2}{\mu_0\rho} \qquad (1)$$

For $\boldsymbol{k}\cdot\boldsymbol{B}$=0, the instability amplitude is

$$x(t) = x_0 \cosh\left[\sqrt{kg}t\right] \qquad (2)$$

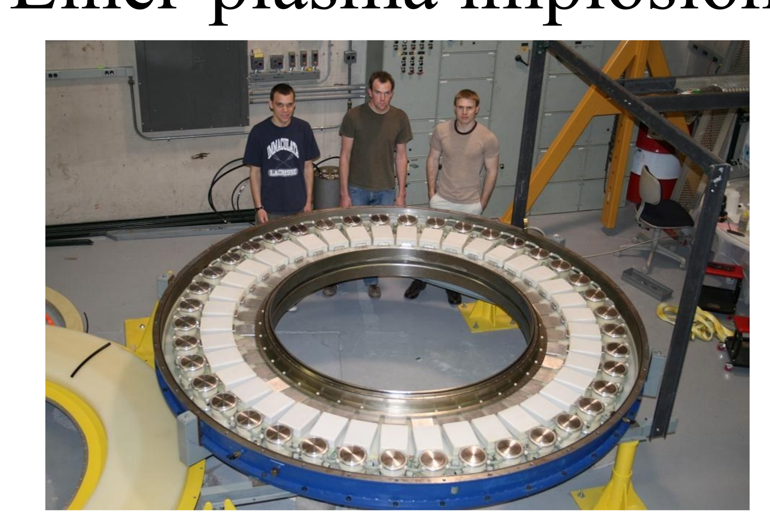
If the displacement follows $s(t) = gt^2/2$

$$x(s) = x_0 \cosh\left[\sqrt{2ks}\right] \qquad (3)$$

For an exponentially varying wavelength $\lambda = \lambda_0 \mathrm{Exp}[\alpha t]$

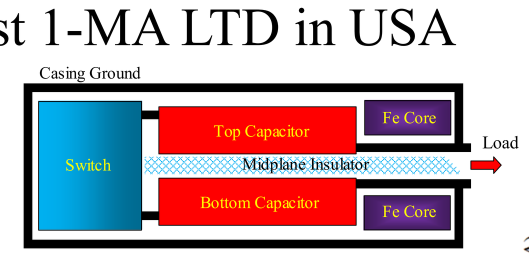
$$x(t) = x_0 \cosh\left[\frac{2}{\alpha}\sqrt{k_0 g}\left(1 - Exp\left[-\frac{\alpha t}{2}\right]\right)\right] \qquad (4)$$

Liner-plasma implosion experiments on 1-MA linear transformer driver

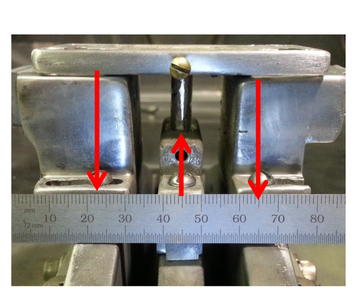


MAIZE: First 1-MA LTD in USA

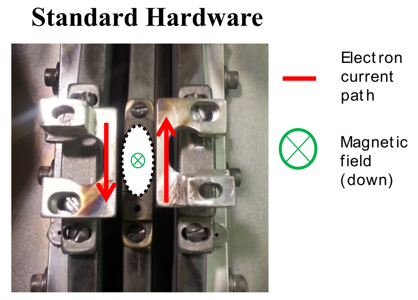
Parameters
- 40 Bricks
- 2 Ferromagnetic cores



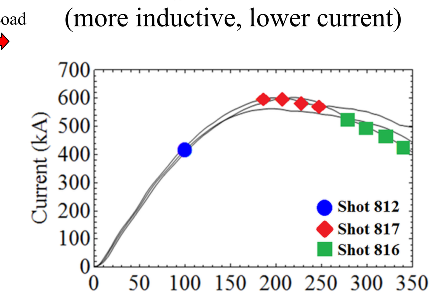
Diagnostics
- 4-frame laser shadowgraphy and shearing interferometry (2 ns 532 nm frequency doubled ND:Yag laser)
- B-dot current monitors

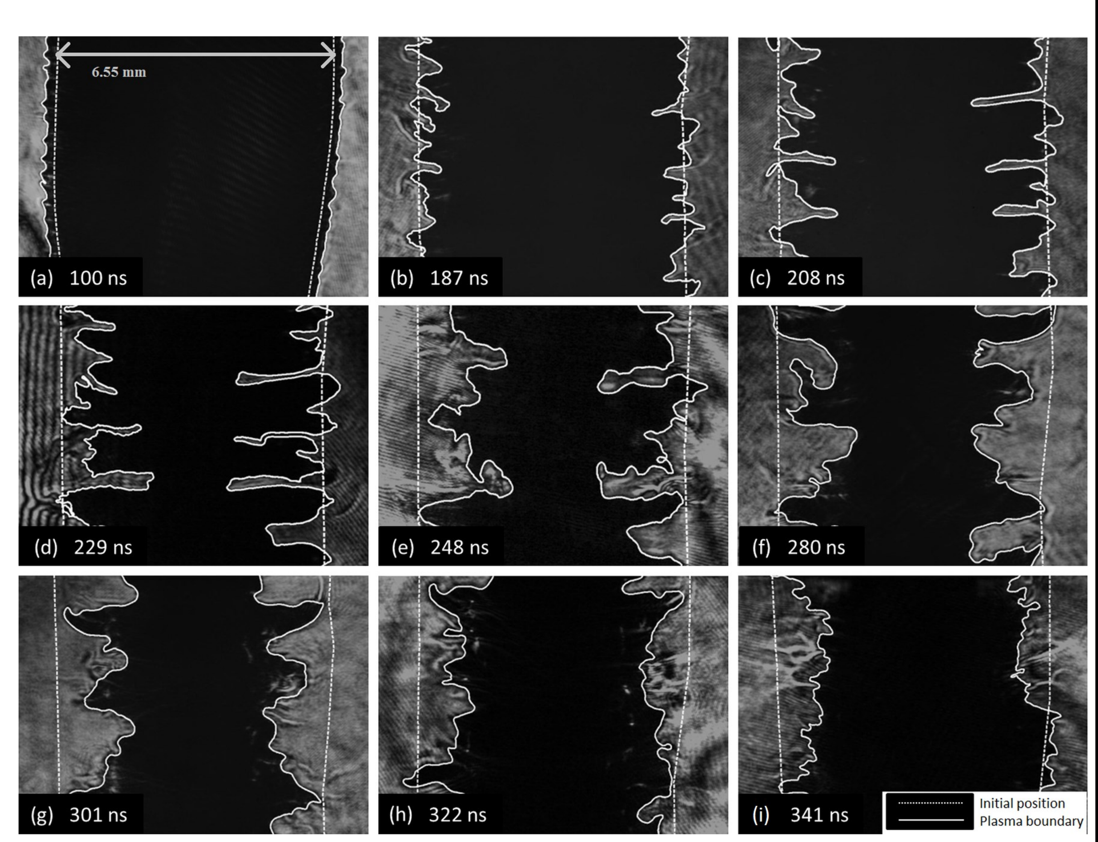


Standard Hardware



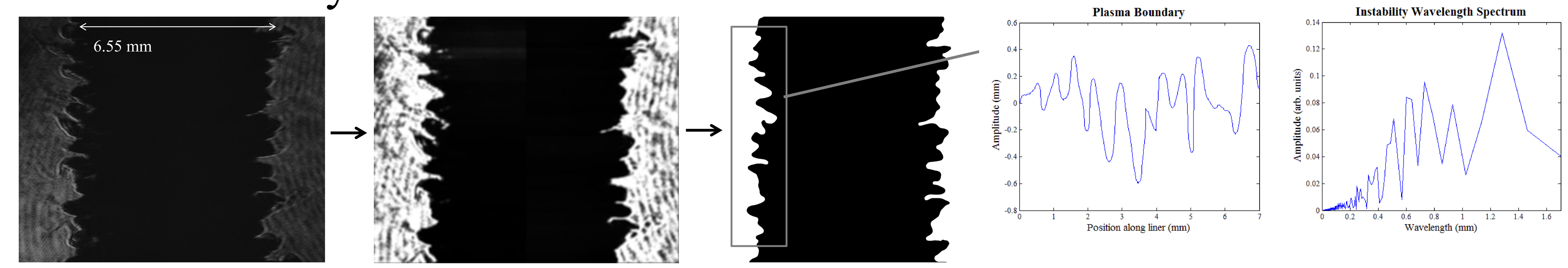
Axial Magnetic Field Hardware (more inductive, lower current)



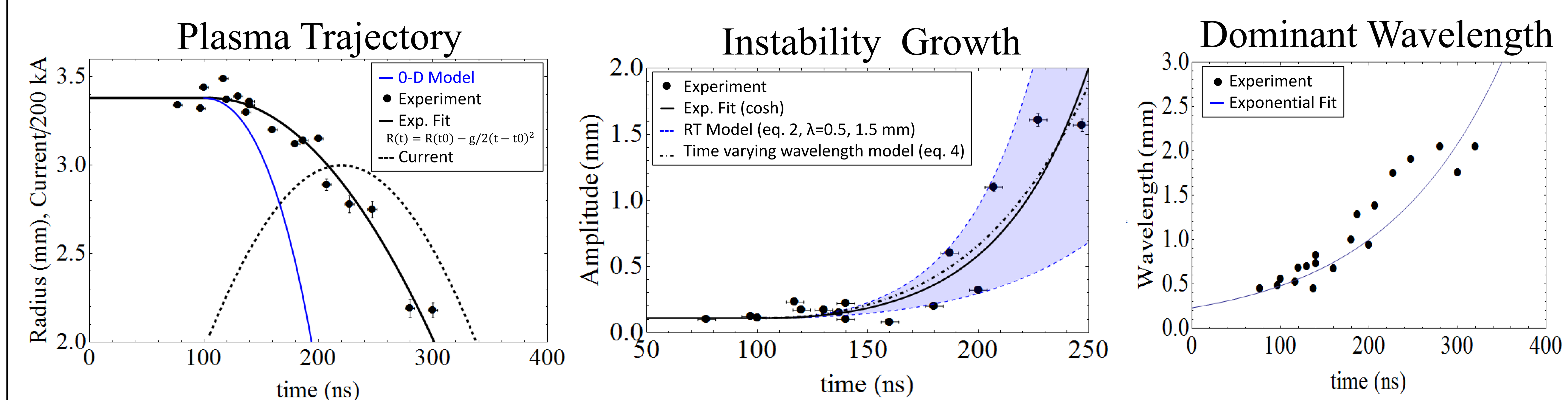


Plasma dynamics: expansion (a), implosion (b-d), stagnation (e-f) and re-expansion (g-i)

Results and Analysis



1) Convert shadowgraph to grayscale. 2) Split image into *N* vertical zones and 2 horizontal zones. Contrast enhance zone-by-zone, normalizing to plasma and vacuum regions. 3) Convert to black-white image. 4) Trace plasma-vacuum interface to obtain:



Comparison to theory

The MRT theory appropriately describes the data while the 0-D implosion model does not.

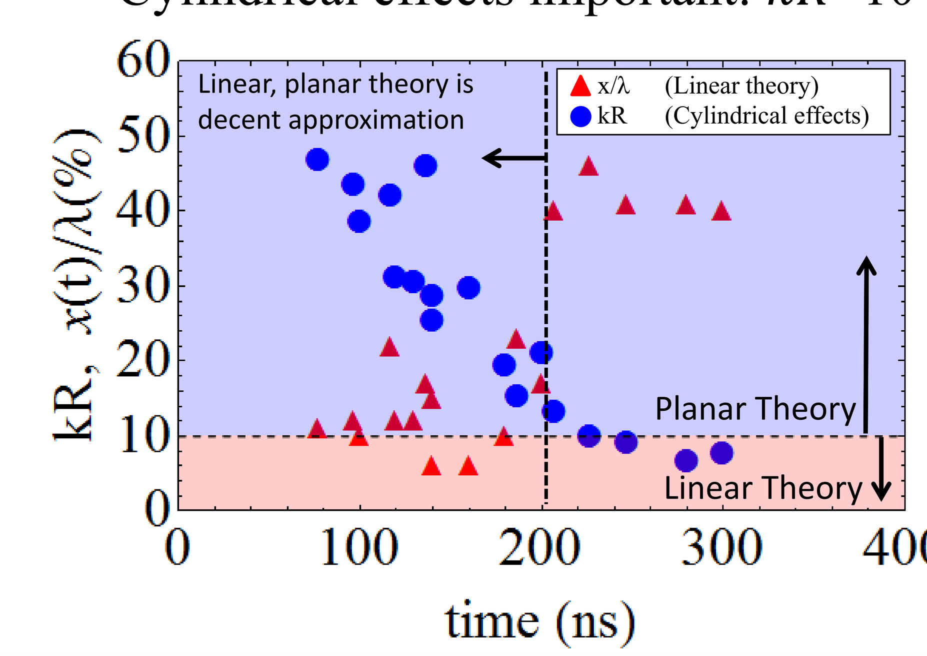
The observed implosion is slower than 0-D model predicts. Since $g \sim B_{outer}^2 - B_{inner}^2$, this indicates
→ **diffusion of the magnetic field into plasma**

The measured acceleration and instability wavelength are used to apply eqs. (2) and (4)
→ **time varying wavelength (eq. 4) gives best fit**

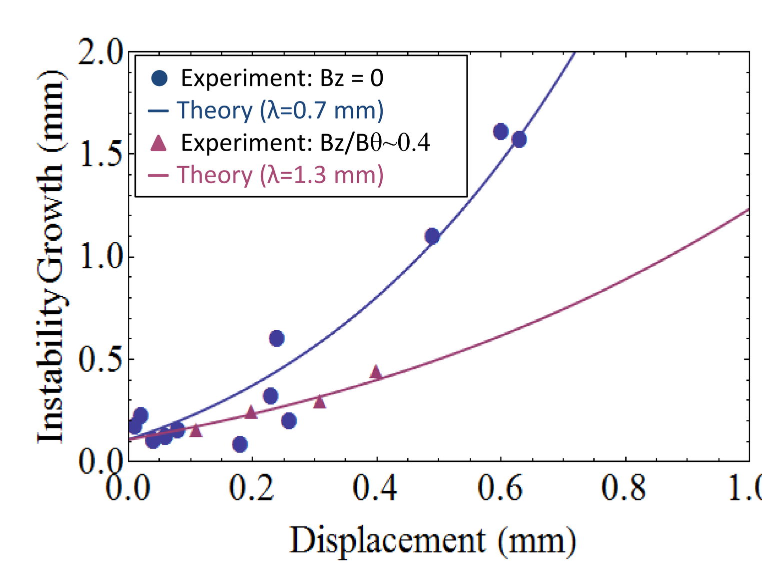
When does the theory apply?

Linear approximation: x/λ<10%

Cylindrical effects important: kR<10



Axial B-field effects—How can we compare instability growth for different g?



Axial B field load has a higher inductance and therefore a lower peak current (~500 kA), resulting in a smaller acceleration

Eq. (3) gives instability growth as a function of displacement, *independent of acceleration*. While this equation ignores stabilizing effects, let us plot with **λ=0.7 mm** (Bz=0), **λ=1.3 mm** (Bz) determined from experiment. As we see, the theory appropriately describes the data

Instability growth rate and acceleration

Axial field:	$1/\gamma$=80 ns	g=3.8*10^{10} m/s^2
No axial field:	$1/\gamma$=40 ns	g=7.2*10^{10} m/s^2

→axial field shifts instability to longer wavelengths, an overall stabilizing effect as longer wavelengths grow slower

Need more data to support this trend!

* This work was supported by the U.S. Department of Energy through award DE-SC0012328. S.G. Patel and A.M. Steiner were supported by NPSC funded by Sandia. D.A. Yager-Elorriaga was supported by NSF fellowship grant DGE 1256260.

[1] M. R. Weis et al., "Coupling of sausage, kink, and magneto-Rayleigh-Taylor instabilities in a cylindrical liner", *Physics of Plasmas* **22**, 032706 (2015)