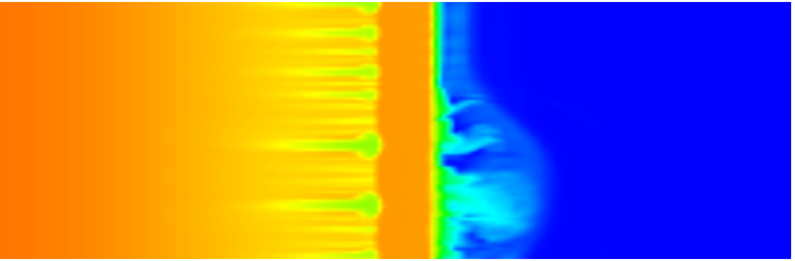
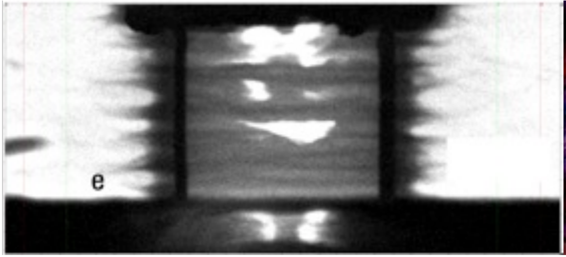
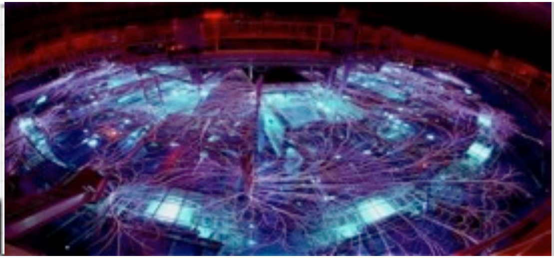






Dramatic Reduction of Magneto-Rayleigh Taylor Instability Growth in Magnetically Driven Z-Pinch Liners

K. J. Peterson, T. J. Awe, S. E. Rosenthal, R. D. McBride, D. B. Sinars, E. P. Yu, G. K. Robertson, M. E. Cuneo, M. E. Savage, P. F. Knapp, P. F. Schmit, and S. A. Slutz

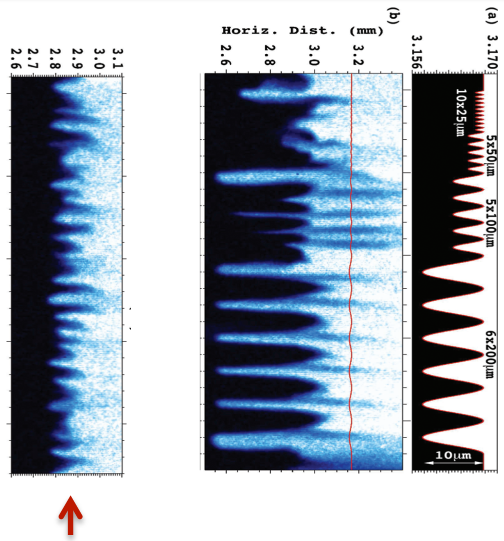
ICOPS 2015, The 42nd IEEE International Conference on Plasma Science

May 24-28, 2015

Belek, Antalya, Turkey

Experiments have shown that surface roughness and small defects are not the dominant source of MRT instabilities

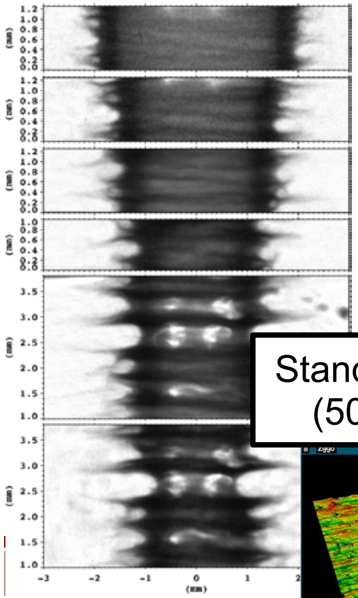
Observed Instability growth is not linearly proportional to the amplitude of the initial perturbations.



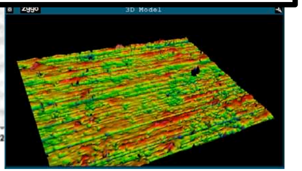
A_0 = 60 nm

Axially polished liner experiments suggest symmetry is not sensitive to surface characteristics

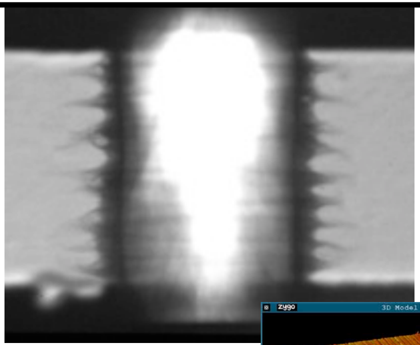
McBride PRL data

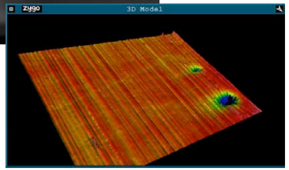


Standard Process (50 nm RMS)



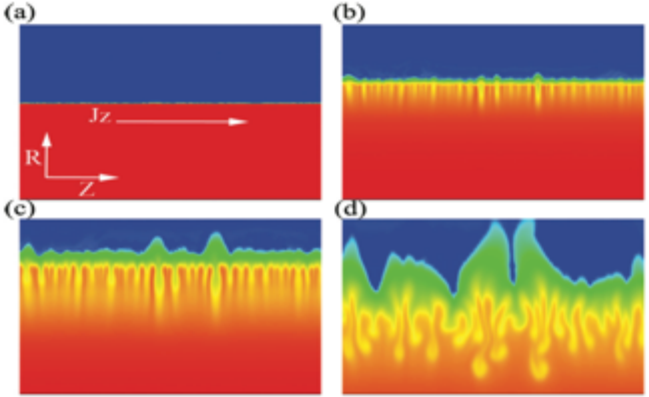
axial machining and polishing (60 nm RMS)

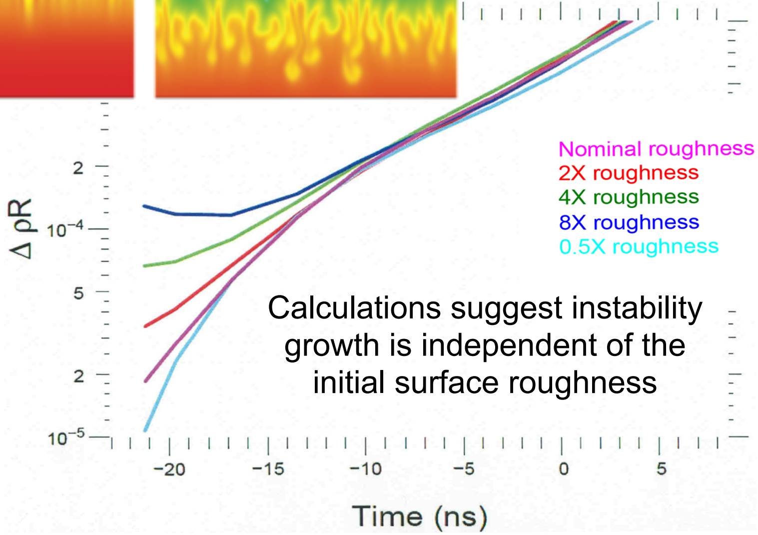




D.B. Sinars *et al.*, Phys. Plasmas (2011). R.D. McBride *et al.*, Phys. Rev. Lett. (2012).

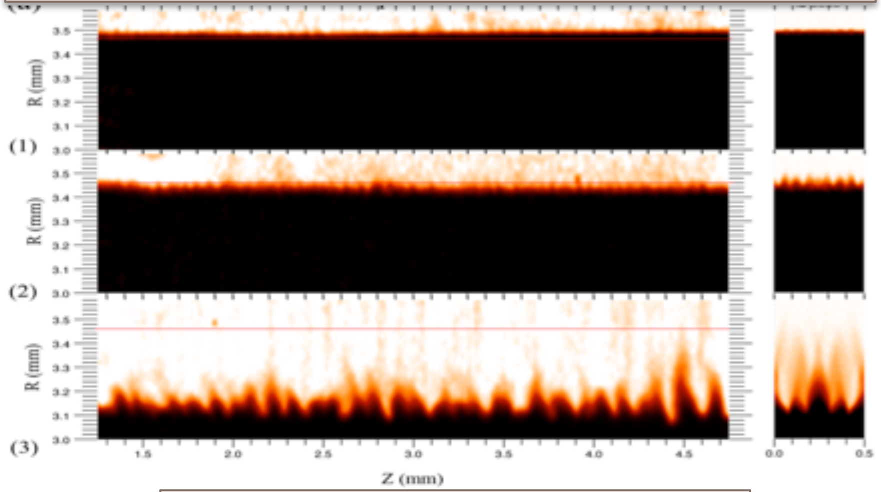
Is the electro-thermal instability the main seed for the magneto-Rayleigh-Taylor instability?





Calculations suggest instability growth is independent of the initial surface roughness

Experimental (left) & simulated (right) radiographs



Perturbation Growth Comparison

Time	Est. MRT (λ=100 μm)	$h=0.06Agt^2$	Observed
A	0.36 μm	6.2 μm	13 ± 7 μm
B	24 μm	41 μm	80 ± 7 μm

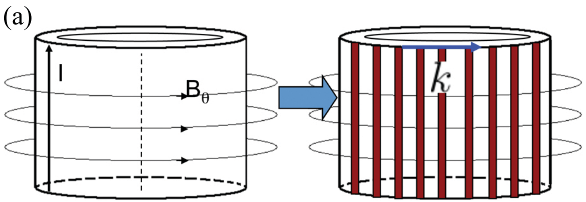
K.J. Peterson *et al.*, Phys. Plasmas (2012); K.J. Peterson *et al.*, Phys. Plasmas 20, 056305 (2013).

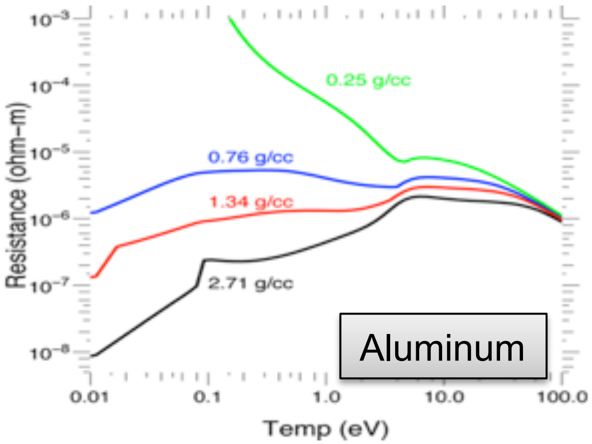
Electrothermal instabilities occur when material conductivity is dependent on temperature

Theory

Filamentations

$$\frac{d\eta(T)}{dT} < 0$$





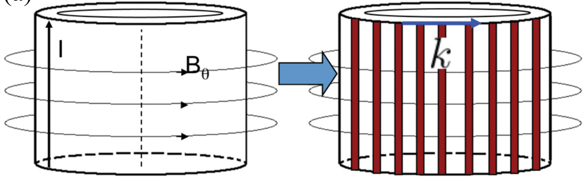
Electrothermal instabilities occur when material conductivity is dependent on temperature

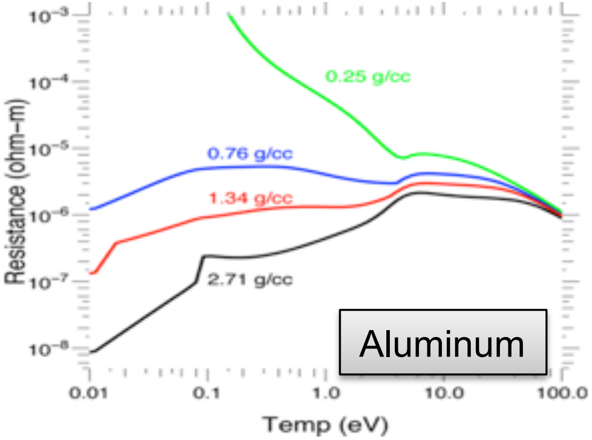
Theory

Filamentations

$$\frac{d\eta(T)}{dT} < 0$$

(a)

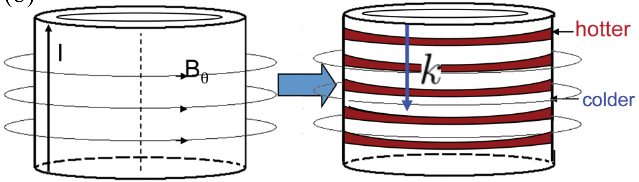




Striations

$$\frac{d\eta(T)}{dT} > 0$$

(b)



Electrothermal instabilities occur when material conductivity is dependent on temperature

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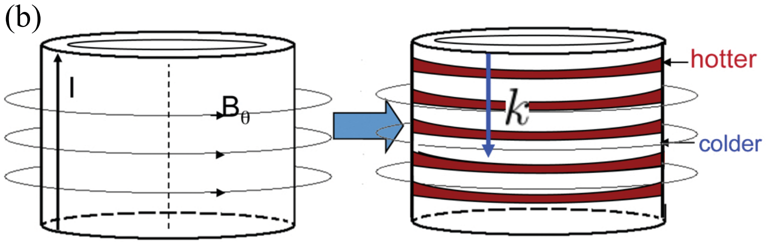
Theory

Striations

$$\frac{d\eta(T)}{dT} > 0$$



$$\delta T > 0$$

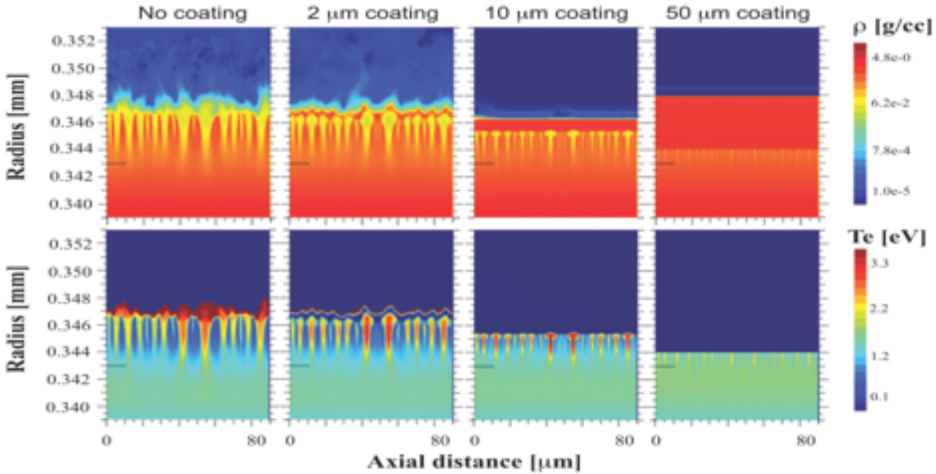
Consider a small temperature perturbation due to localized variations in ohmic heating
- surface contaminants (variations in η)
- surface roughness (B_θ ~ I/r, in cylinders)

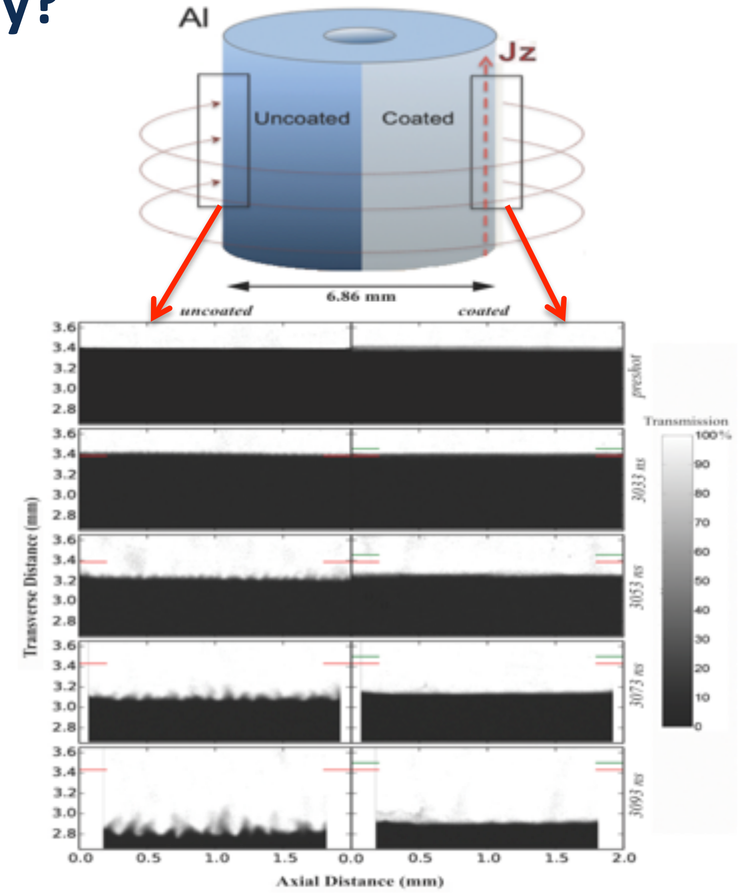
Then, η increases which consequently further enhances the localized ohmic heating (η j^2), which leads to increased δT

Temperature perturbations give rise to pressure variations which eventually redistribute mass

Liner Compression: Is it possible to suppress the growth of the magneto-Rayleigh-Taylor instability?

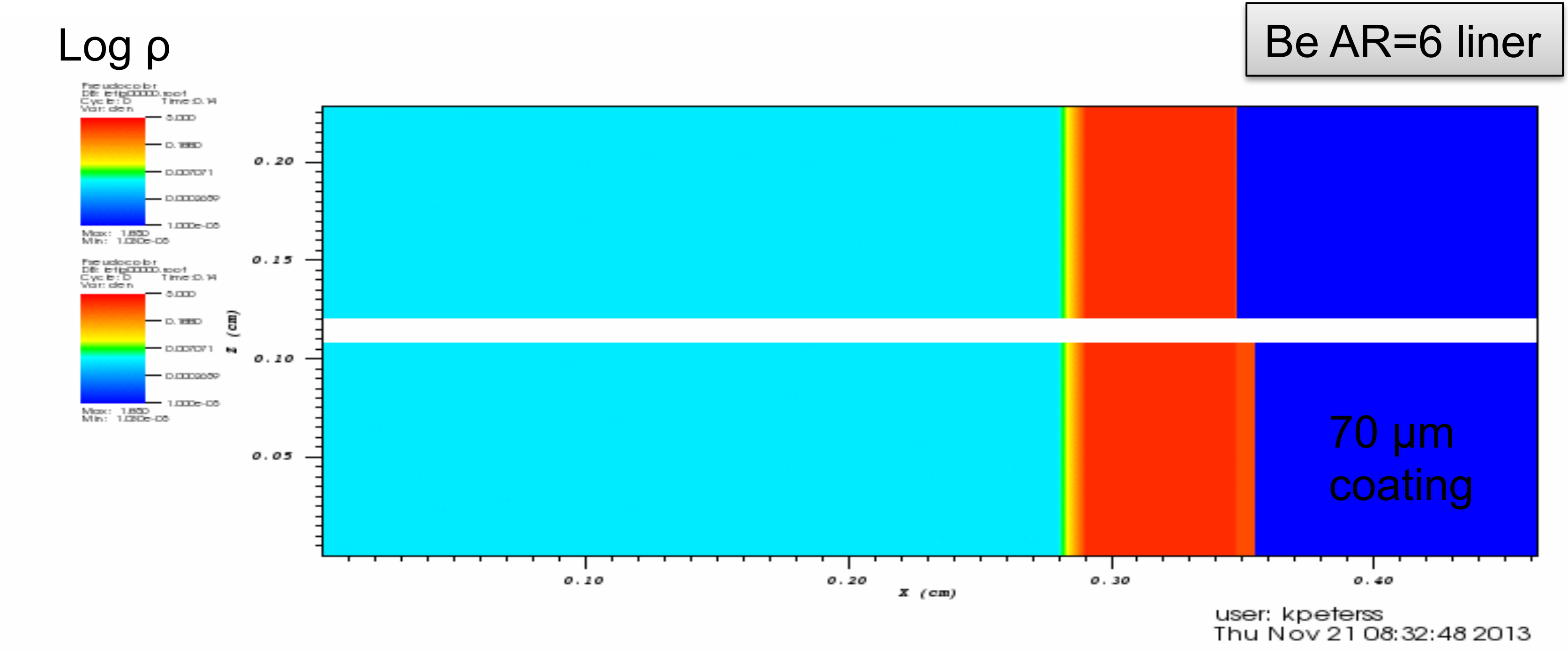
- No ETI growth in plastic coating
  - Carries very little current
  - Theoretically ETI stable
- Demonstrated to help suppress early-time growth, but will it help with full implosion?



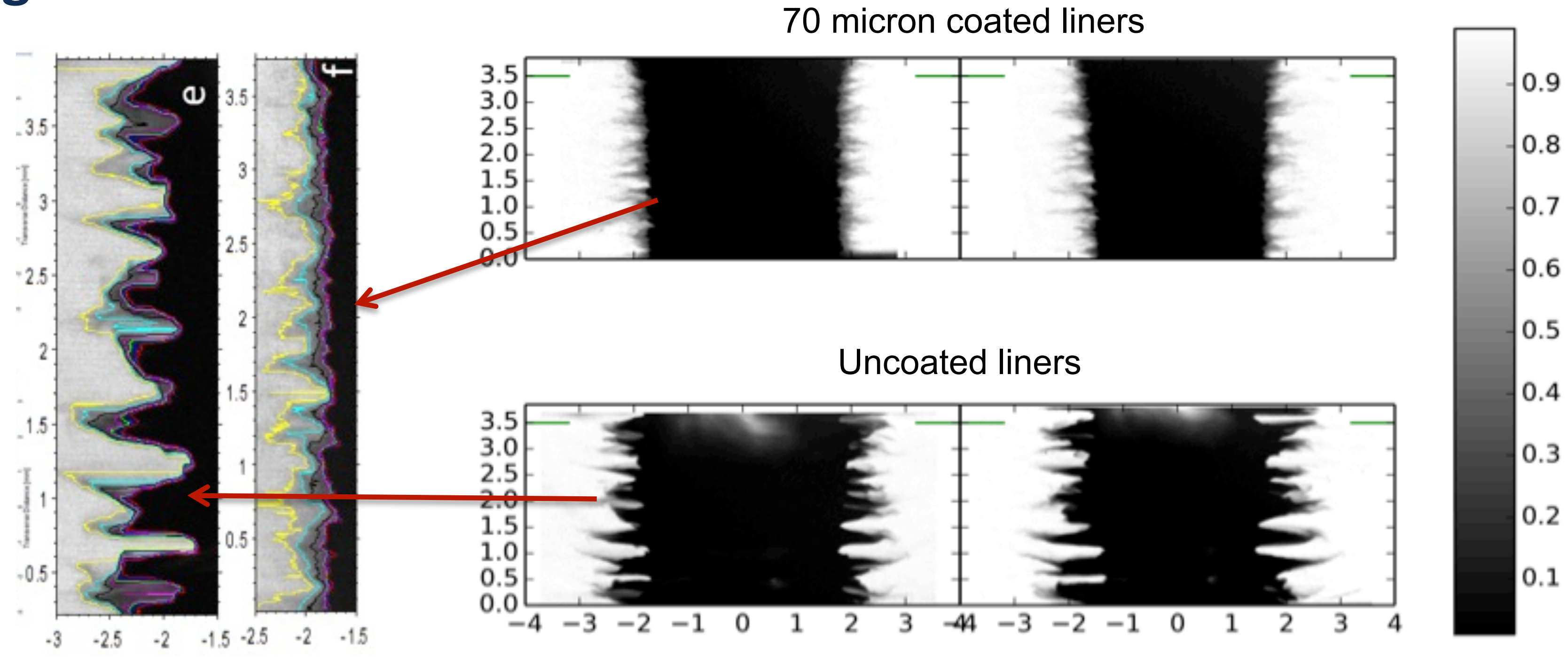


K.J. Peterson *et al.*, Phys. Rev. Lett. 112, 135002 (2014)

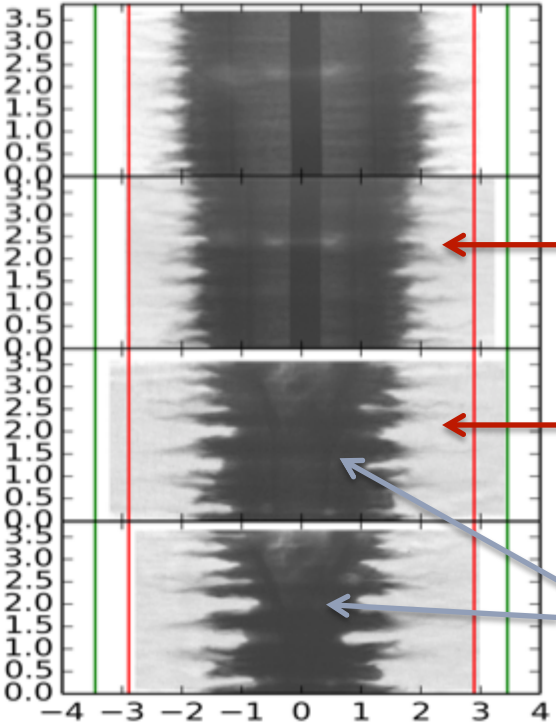
2D Hydra simulations also predicted dramatic differences in instability growth in imploding liners



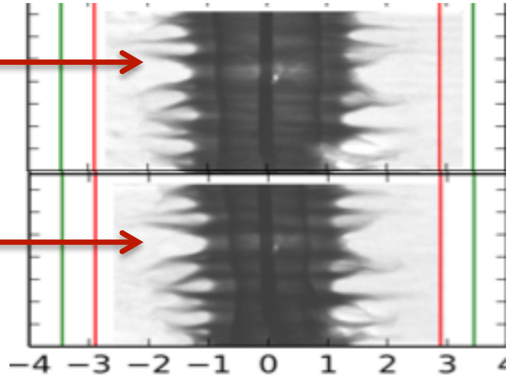
Recent experiments confirmed that coated aluminum imploding liners exhibit a dramatic reduction in instability growth



Coated Be liners also show instability improvement at similar times compared to uncoated Be liners, but not as dramatic as the Aluminum data



R.D. McBride et al.,
POP **20**, 056309 (2013)



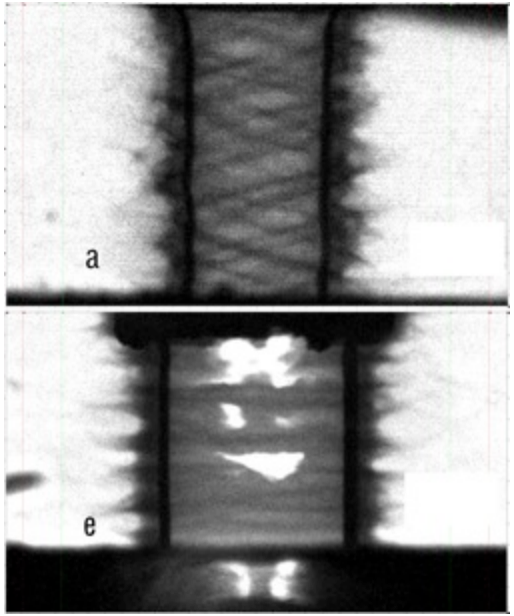
Compromised implosion from unmitigated wall instability?

Be coated liner

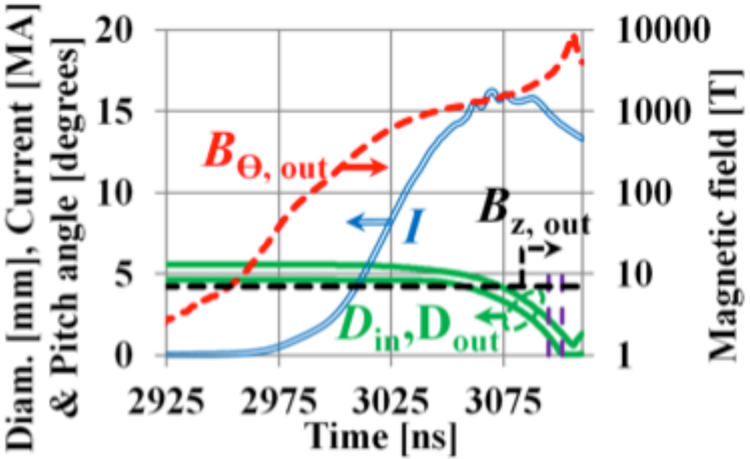
- Less correlation
- Smaller amplitude MRT
- Smaller wavelength MRT
- More stable inner surface
- A more quantitative analysis is underway

What is the physical mechanism behind the helical instability seen in magnetized liner implosions? Does it help mitigate liner instability growth?

Axially magnetized implosion



Same target, un-magnetized



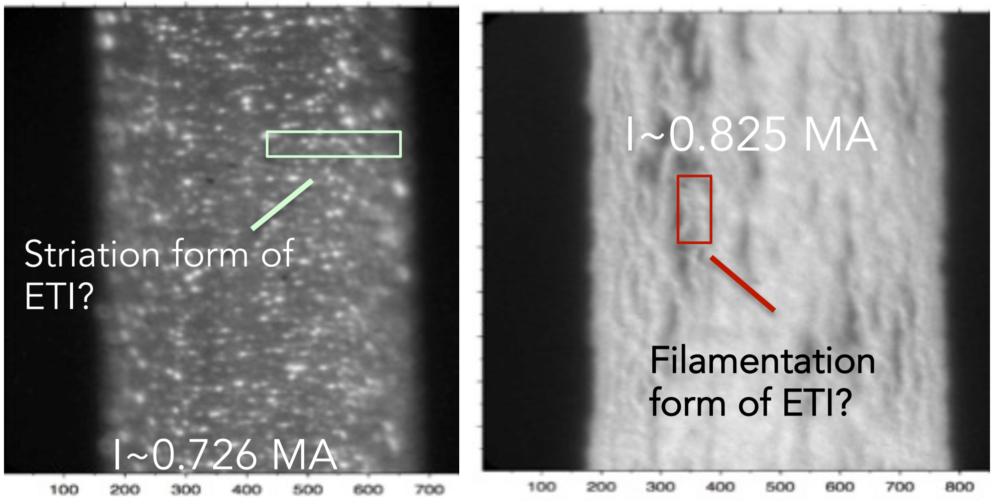
- Observed pitch angle inconsistent with expected Bθ vs. Bz at radiograph time
- Several hypotheses are currently being investigated

T. J. Awe et al., Phys. Rev. Lett. 111, 235005 (2013). T. J. Awe et al., Phys. Plasmas 21, 056303 (2014).

We are working on understanding the role of surface roughness and volume-distributed impurities in seeding ETI, through current redistribution, in 3D

- Experiments at UNR are providing new insights on early time surface initiation and early stages of 3D ETI development
- Data provides enormous constraints on simulations
- Theoretical work is underway to explain the observed structures

Visible emission of R~0.5 mm Al rod, B_z=0



Data taken at Zebra generator, UNR
Courtesy T.J. Awe

We are currently studying how a collection of bumps/pits, as well as volume-distributed impurities, redistribute current and generate ETI

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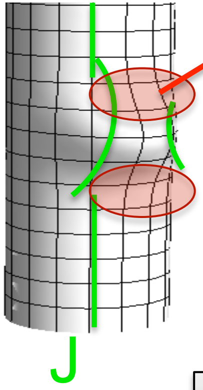
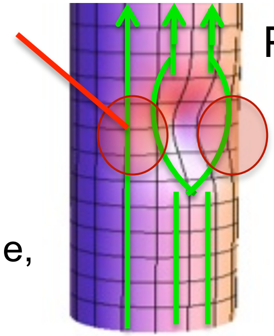
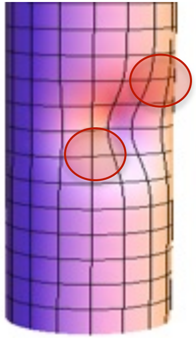
Bump, B_z=0



Current "bunches up" here
➔$\delta(\eta j^2)>0$
➔$\delta T>0$
➔$\delta\eta>0$ (η rises with T)
➔$\delta(\eta j^2)>0$
i.e. this region is ETI unstable, and is seeded by current redistribution



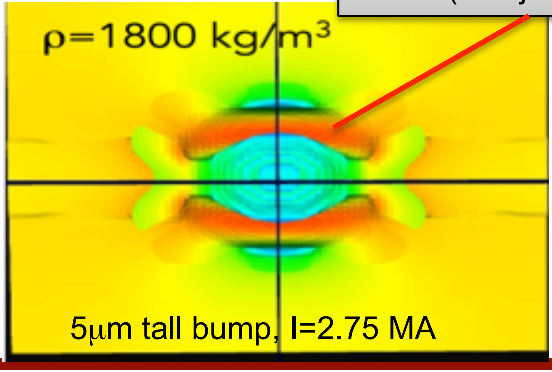
Pit, B_z=0

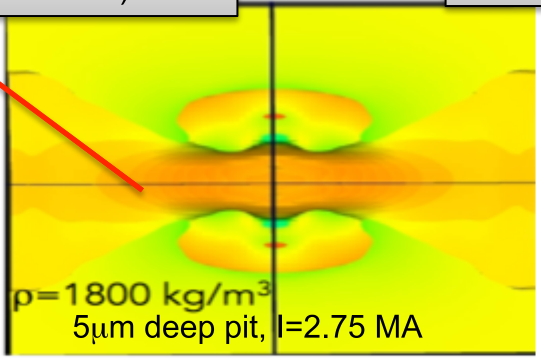


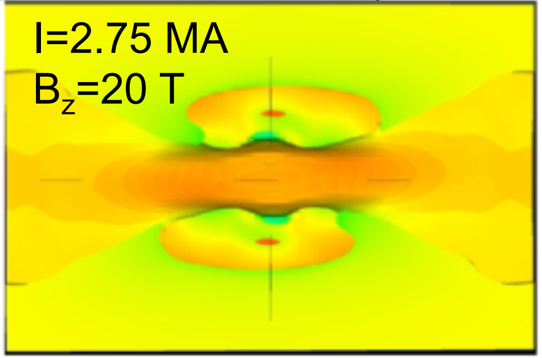
Pit, $B_z=B_\theta$

ETI-unstable regions have exploded (2 adjacent pits can "correlate")

3D MHD simulation (ALEGRA) confirms this intuition.



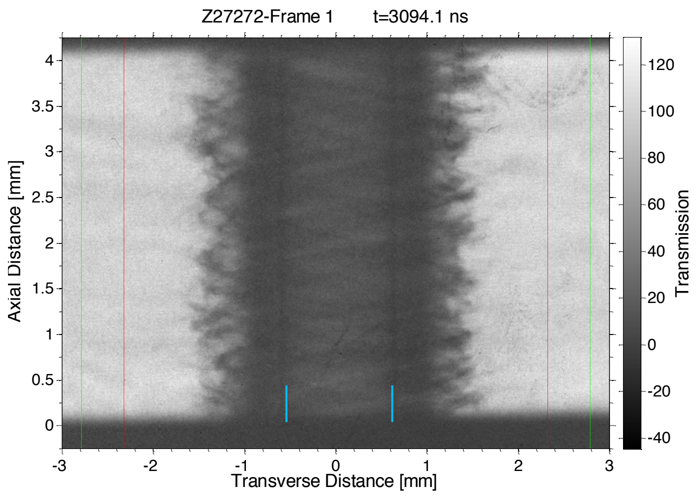


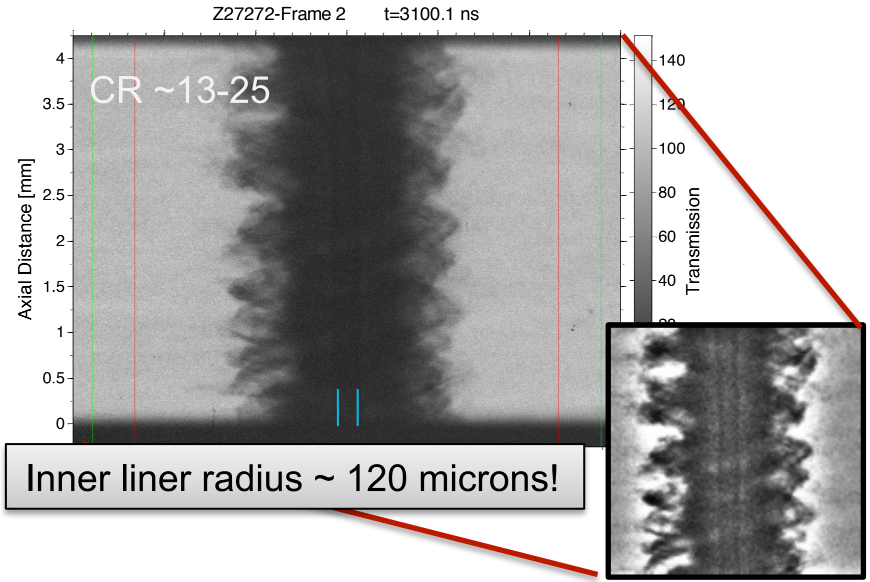


Courtesy Edmund Yu

We have recently examined ETI mitigation with thick dielectric coatings on magnetized liners

- Helical structure still present with dielectric coating added
- Radiographs demonstrate remarkable implosion uniformity





Conclusions

- We are making significant progress in our understanding and control of instabilities in magnetized liner implosions
  - Influence of surface roughness and correlation on instability growth
  - Electrothermal instabilities

- Thick dielectric coatings have proven to be effective at mitigating electrothermal instabilities and has led to the realization of remarkably stable Z-pinch implosions

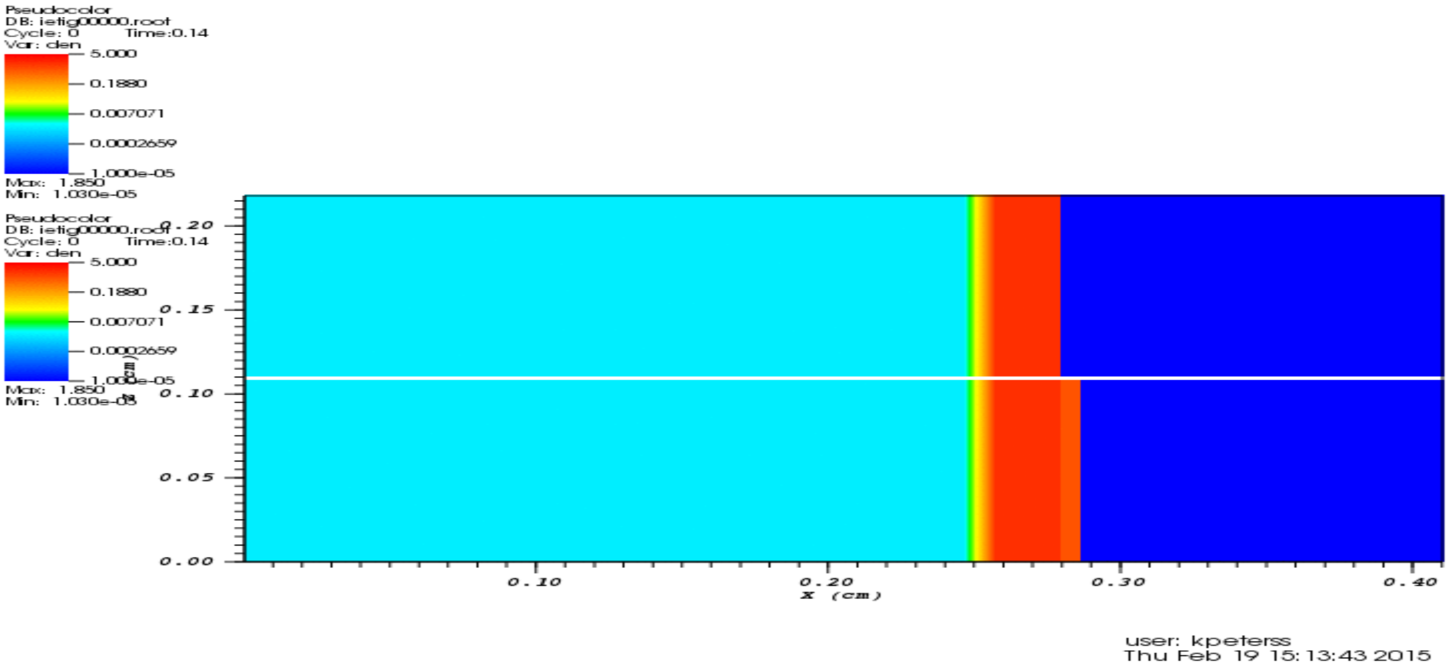
- More work need to be done to understand the connection of electrothermal instabilities and helical instability structures observed in magnetized liner implosions

Backups

2D Hydra simulations also predicted dramatic differences in instability growth in imploding liners

Log ρ

Be AR=12 liner



Qualitative agreement in 3D simulations can be achieved by seeded an initial helical structure

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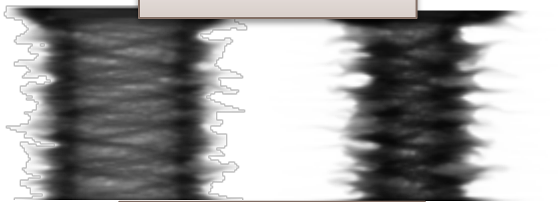
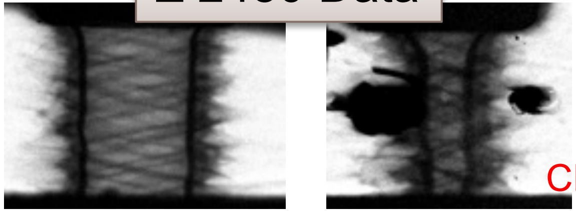
Initial Conditions

7.2 degree helix etched onto liner surface at 20 micron grid resolution

GORGON[1]



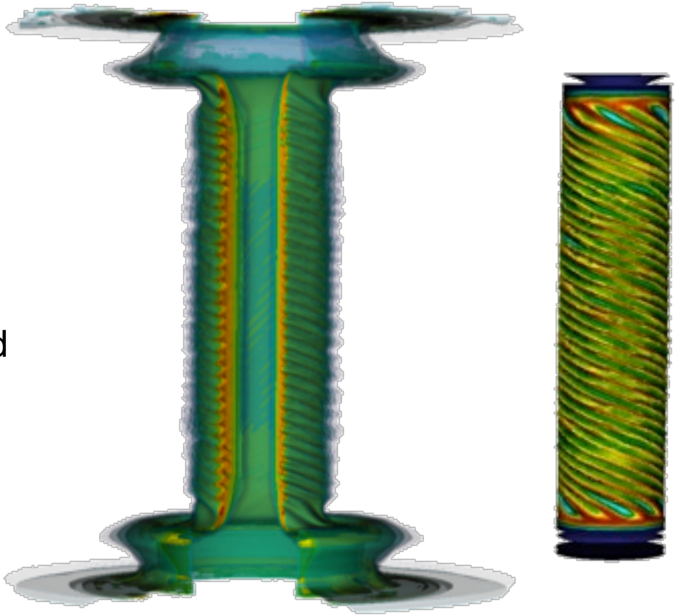
Z 2480 Data



CR 6.4

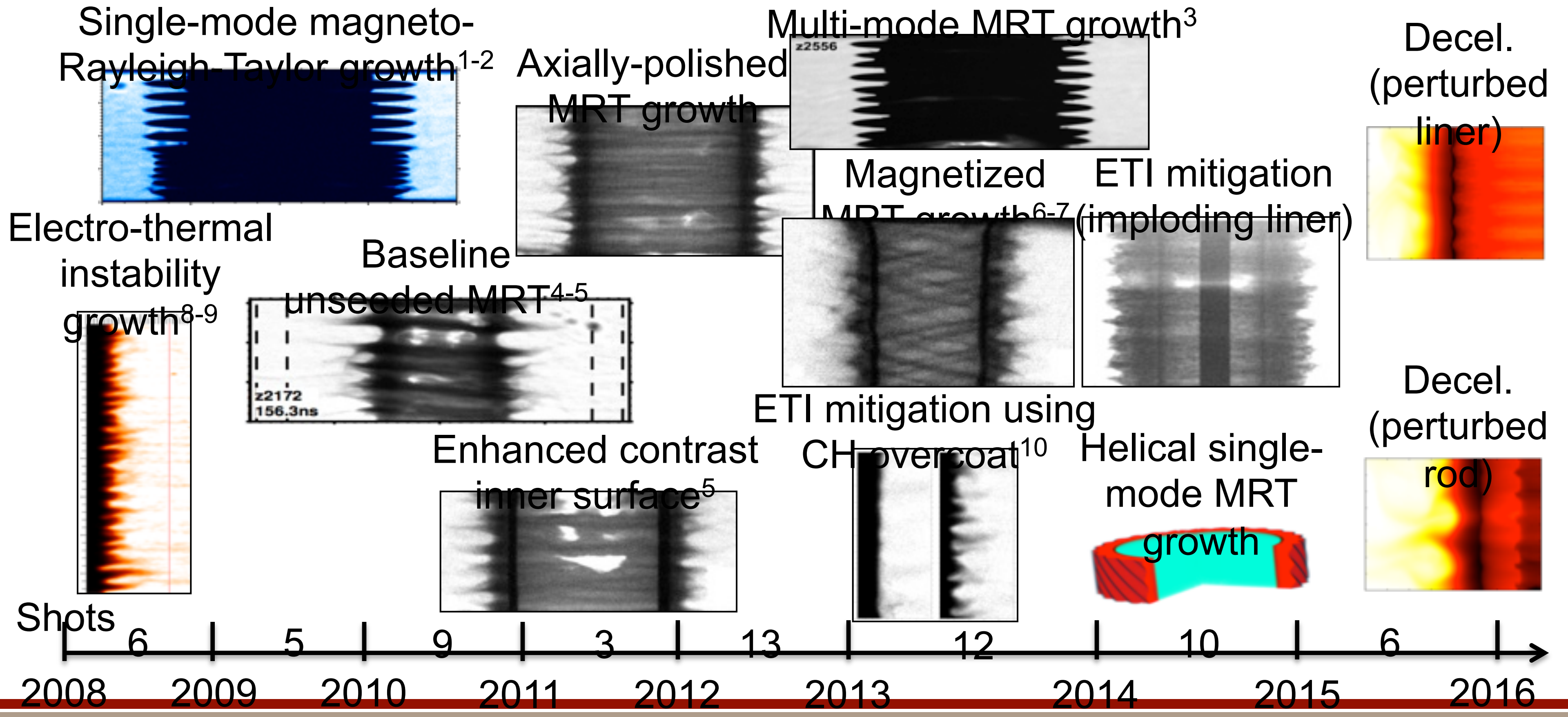
- Helical structure persists throughout implosion and grows enough to be retained in radiographs during implosion

HYDRA[2]



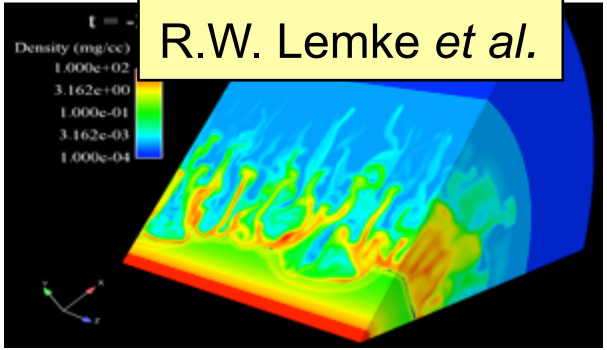
[1] Christopher Jennings Simulation, [2] Adam Sefkow Simulation

Liner instability experiments have played, and will continue to play a key role in testing our modeling of magnetically driven implosions



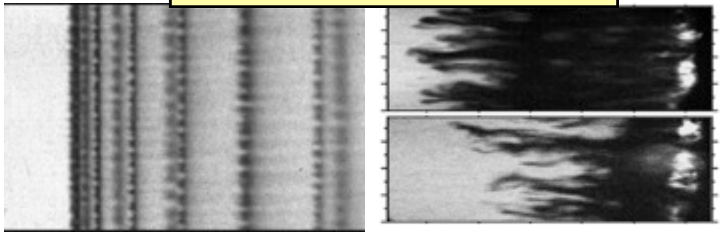
Stabilization of Z-pinch implosions has been an active area of research for decades

- Smaller initial perturbations
- Magnetic Shear
- Velocity Shear
- Rotation
- Hourglassing
- Accretion



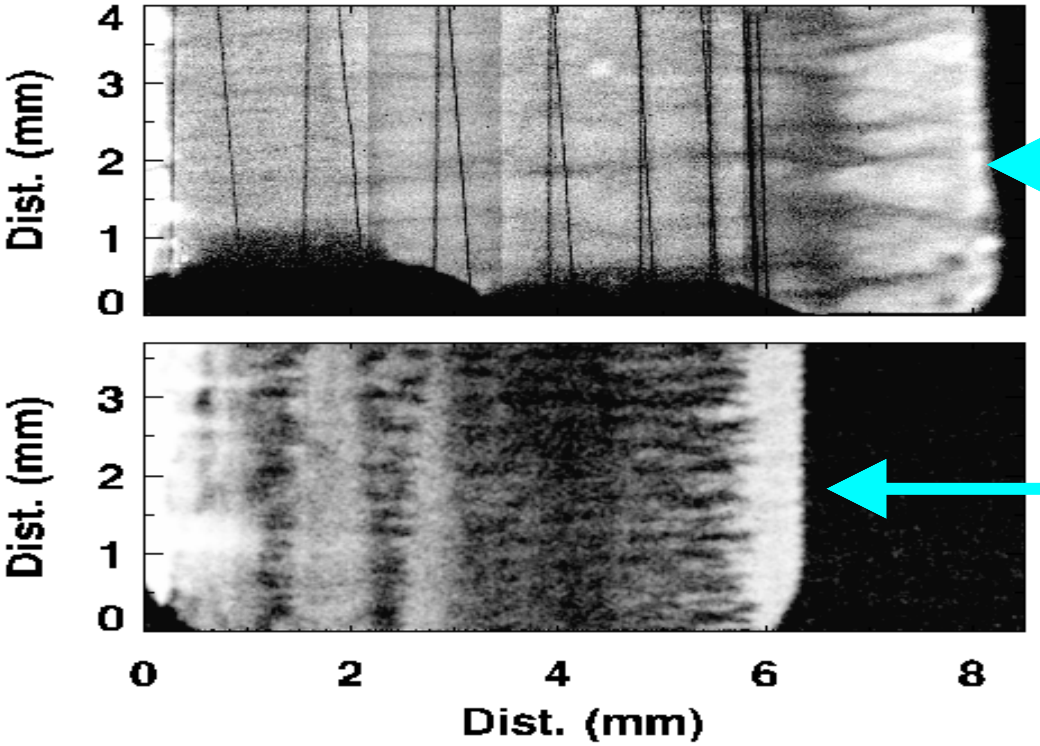
R.W. Lemke *et al.*

Wire array Z-pinch



In all fusion concepts, It is critical to understand and mitigate the growth of instabilities

Transparent nested wire arrays *reset* the MRT wavelength and shell width at current switching



t = 0 ns

λ_z = 0.82 mm

$\Delta\rho(r)$=0.55 mm

ΔR = 3.35 mm

Δt = 10.9 ns

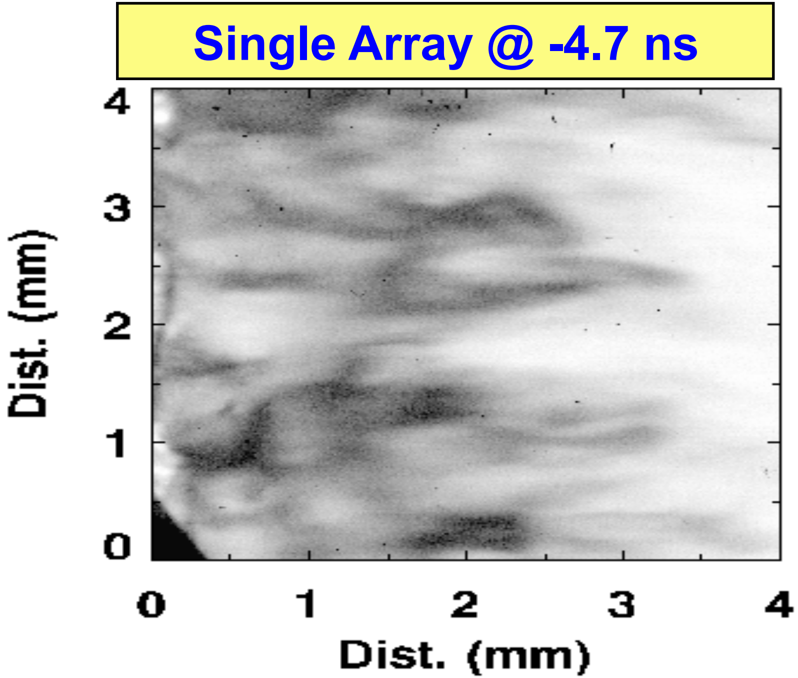
λ_z = 0.41 mm

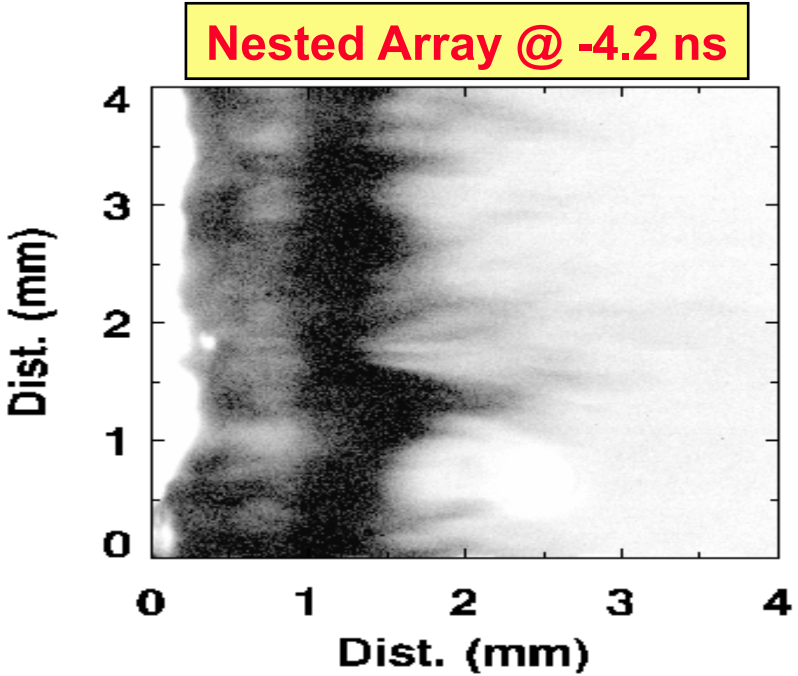
$\Delta\rho(r)$=0.35 mm

ΔR_{eff} = 4.45 mm

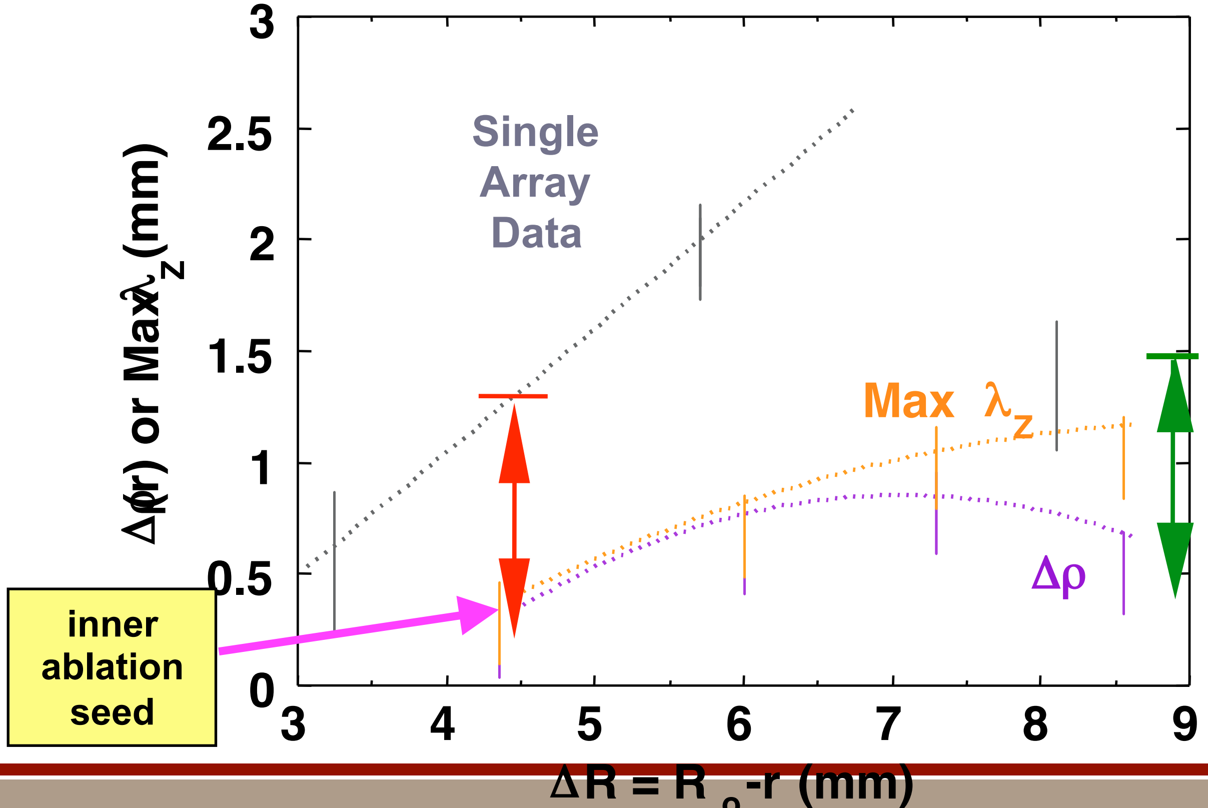
ΔR = 0.45 mm

Nesting and foam targets reduces mass distribution width by *3X* at the base of the power pulse





Nesting and foam targets significantly alter the evolution of the MRT during the inner array implosion



Impact of nesting

Initial MRT wavelength and amplitude is decreased by 3.4 *X*

Impact of precursor plasma & foam target

Mass accretion keeps the shell width narrow