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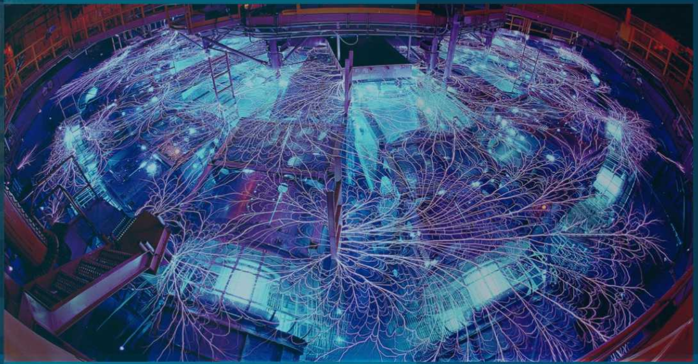
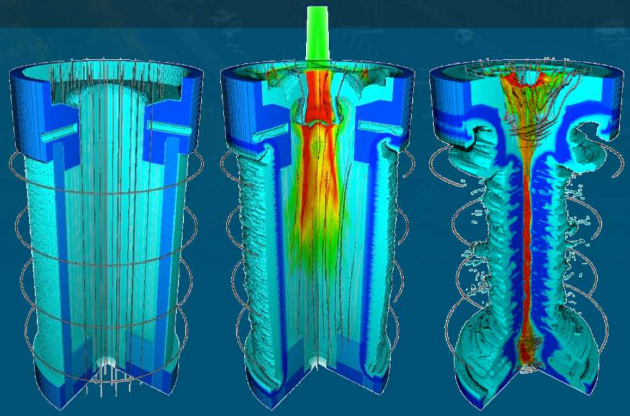
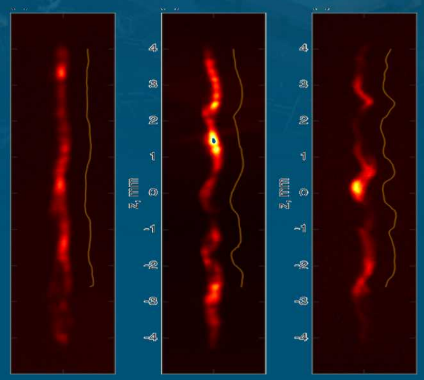
SAND2019-11045C



Exploring helical structures in Magnetized Liner Inertial Fusion stagnations





Presented by

David J. Ampleford

ENERGY NNSA

IFSA 2019
Osaka, Japan

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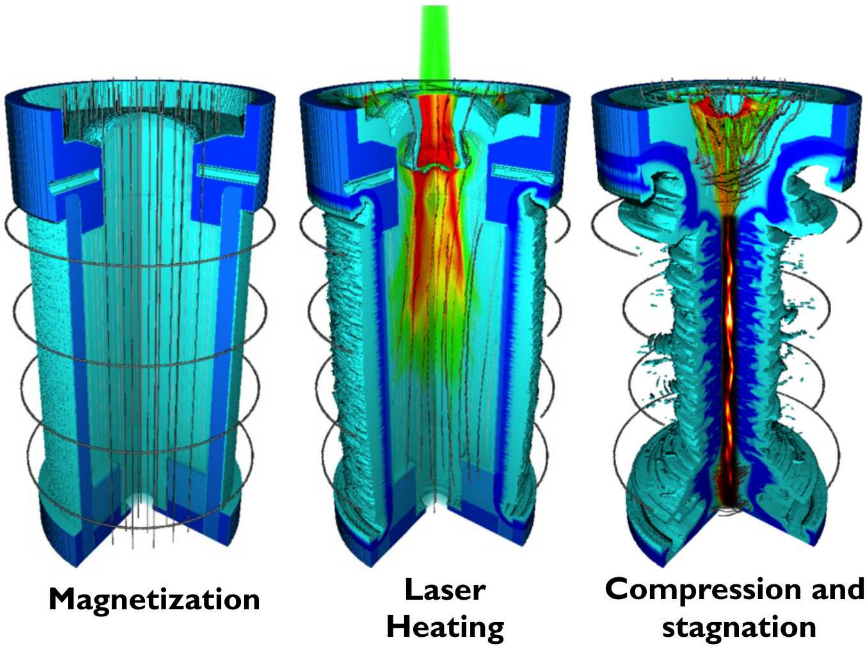
Summary / Outline

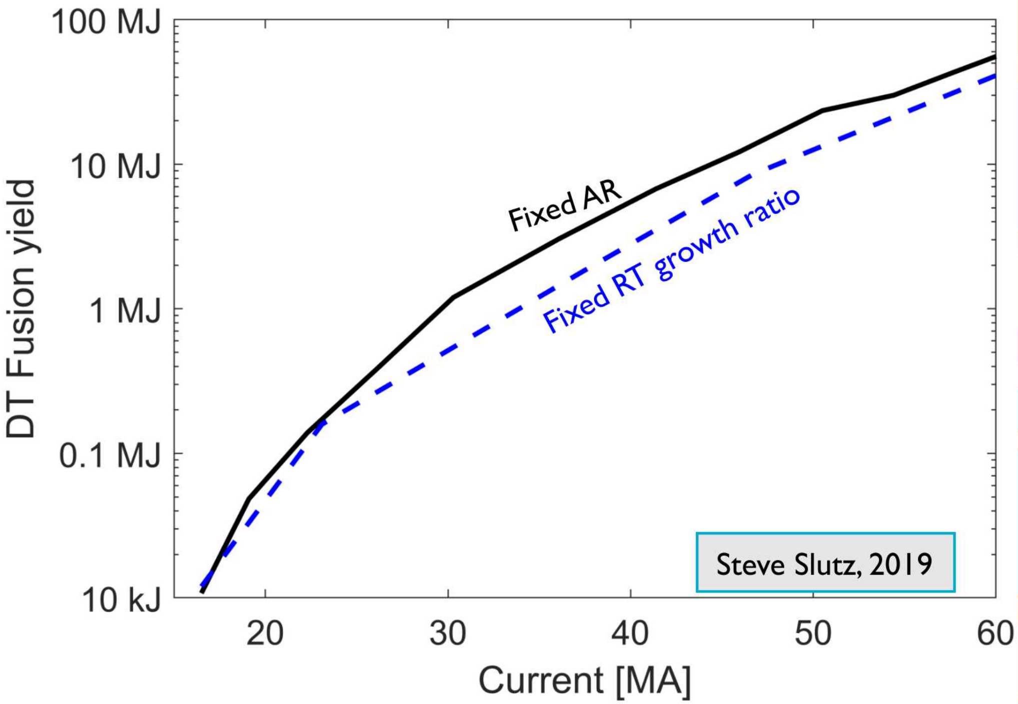
- MagLIF is a Magneto-Inertial Fusion scheme that simulations indicate could reach multi-MJ yields on a future generator
- We observe helical implosion and stagnation structures in MagLIF experiments
- By varying the liner aspect ratio we can vary the dominant wavelengths that will feedthrough the liner
- Stagnation structures are consistent with instability feedthrough
- In scaling MagLIF to higher currents, we are exploring scaling paths that aim to limit the potential impact of feedthrough

Work in collaboration with:

Chris Jennings, Eric Harding, Matt Gomez, David Yager-Elorriaga, Steve Slutz, Tommy Moore, Michael Glinsky, Tom Awe, Pat Knapp, Matt R. Weis, Matthias Geissel, Stephanie Hansen, Paul Schmit, Kyle Peterson, Greg Rochau, Dan Sinars

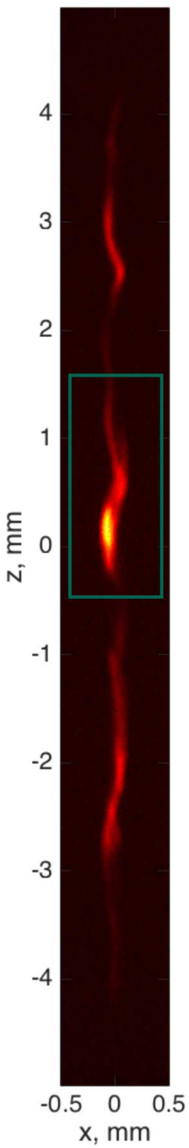
MagLIF is a Magneto-Inertial Fusion scheme that may be able to reach MJ yields with an appropriate driver



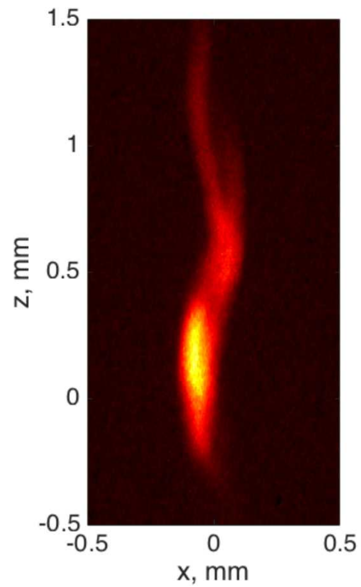


S.A. Slutz *et al.*, Phys. Rev. Lett. 108, 025003 (2012)
M.R. Gomez *et al.*, Phys. Rev. Lett. 113, 155003 (2014)

Helical structure is observed in MagLIF stagnations; we are aiming to better understand it to predict and mitigate impact at higher currents

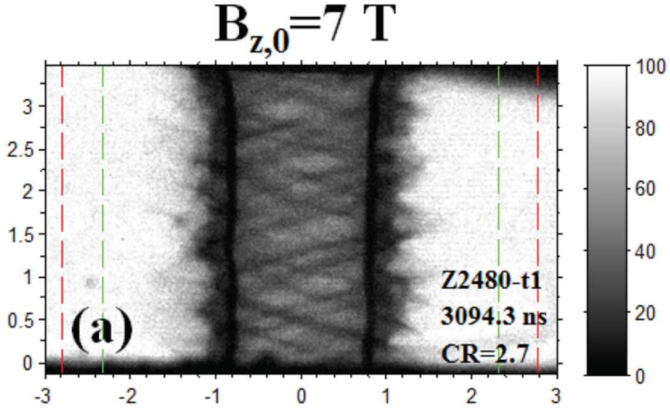


Self-emission at stagnation



- Stagnation columns exhibit quasi-helical structure
- Brightness varies along length of the column
- In some cases bifurcation exists
- Non-uniform stagnation can reduce hot fuel volume, limit tamper
- Better understanding this structure can provide more confidence in scaling to higher currents

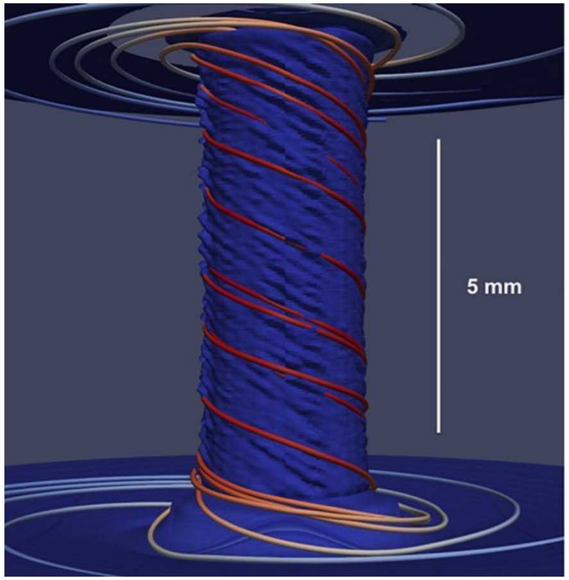
We have observed helical structures early in time in pre-magnetized liners
Various theories exist to explain these structures



In radiography experiments of premagnetized liners we see a helical structure

- We can't presently radiograph experiments with preheat

T.J. Awe *et al.*,
Physics of Plamsas 21, 056303 (2014)



There are a number of proposed explanations for these helical structures

- Electrons streaming onto liner surface (Sefkow *et al.*)
- Compression of field by low density feed plasma (Ryutove *et al.*, Velikovich *et al.*)
- Force free current paths on the liner surface (Seyler *et al.*)

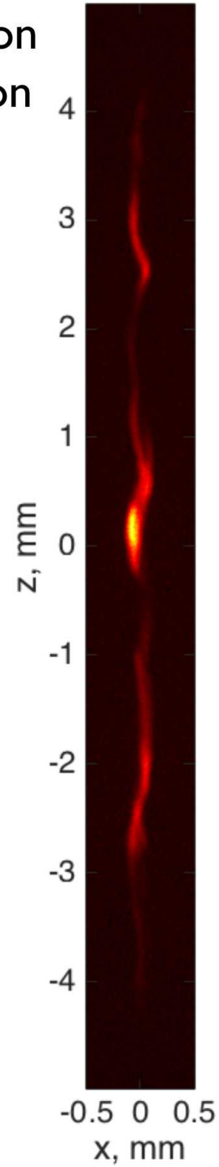
We can design experiments to test if this instability feeds through to the stagnation column

C.E. Seyler, M.R. Martin, N.D. Hamlin
Physics of Plasmas 25, 062711 (2018)

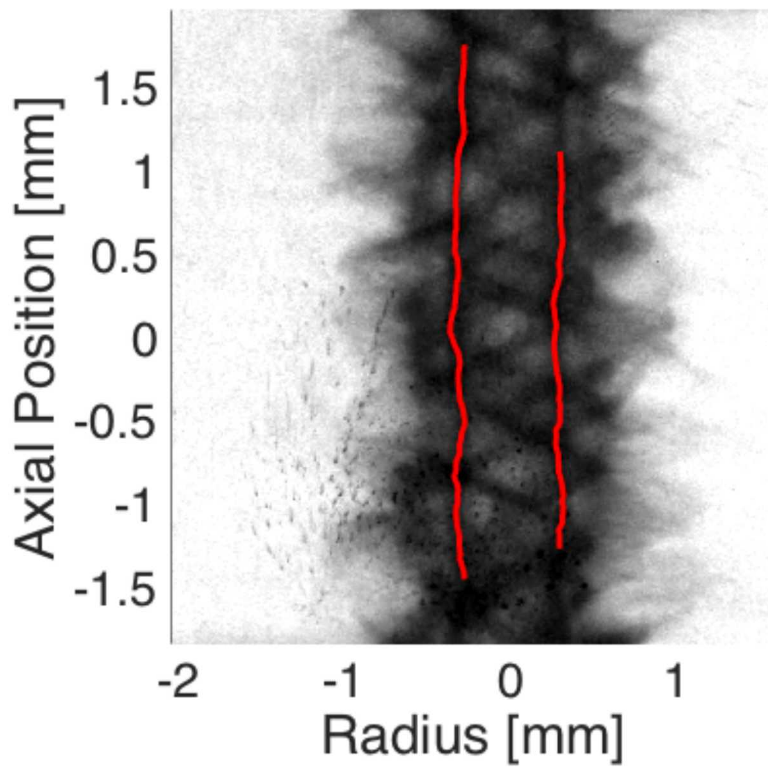
Experiments aim to understand whether stagnation structure is feedthrough of the helix observed in radiography

- Radiography shows helical structure imprinted in liner in-flight
- Inner surface of imploding liner is non-uniform

Self-emission at stagnation



Radiography in-flight



We have designed experiments to test whether stagnation structures are dominated by feedthrough

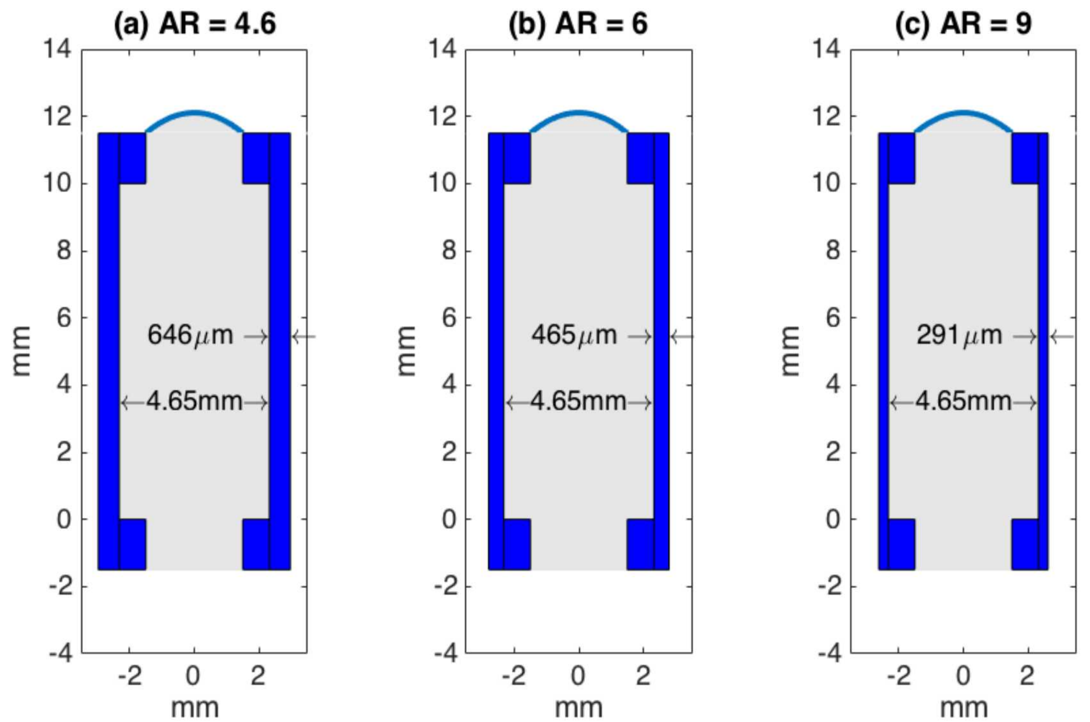
For slab of thickness Δ, the dominant feedthrough mode will have wavelength

$$\lambda \propto \Delta$$

For a cylindrical liner, this is is controlled by the aspect ratio

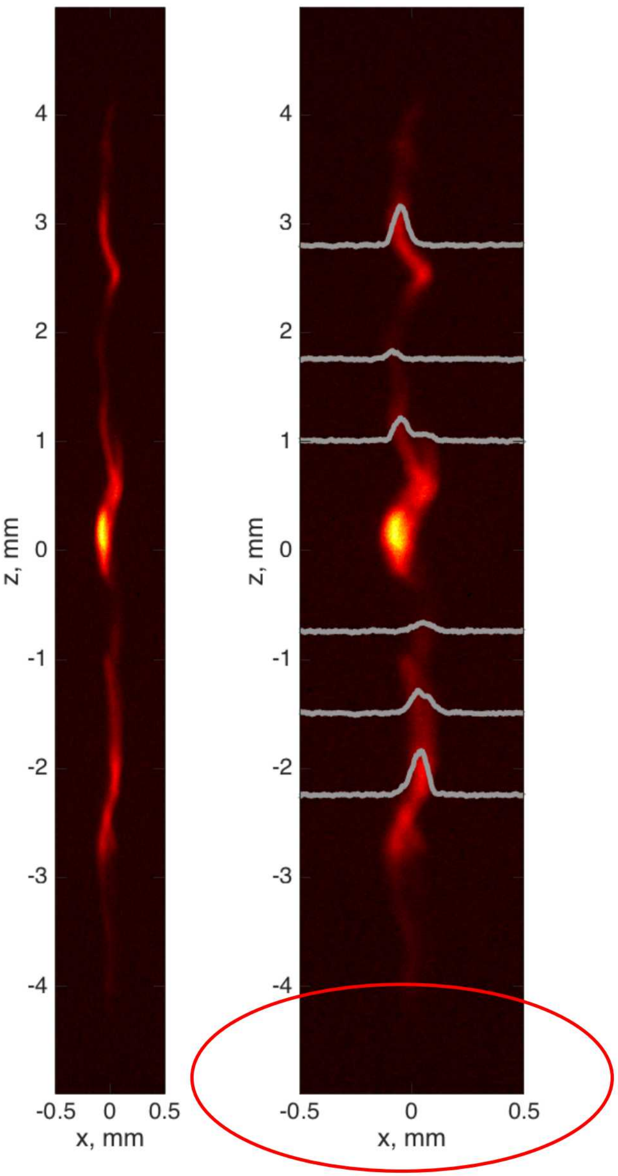
$$\text{AR} = \frac{\mathit{Outer\ Radius}}{\mathit{Wall\ Thickness}} = \frac{R_0}{\Delta}$$

If stagnation helix is driven by feedthrough of implosion instability, varying aspect ratio will change the helical structure



Fixed laser preheat: 1 kJ, no DPP
Preheat timing: 60 ns before stagnation
Fixed pre-magnetization: 10T

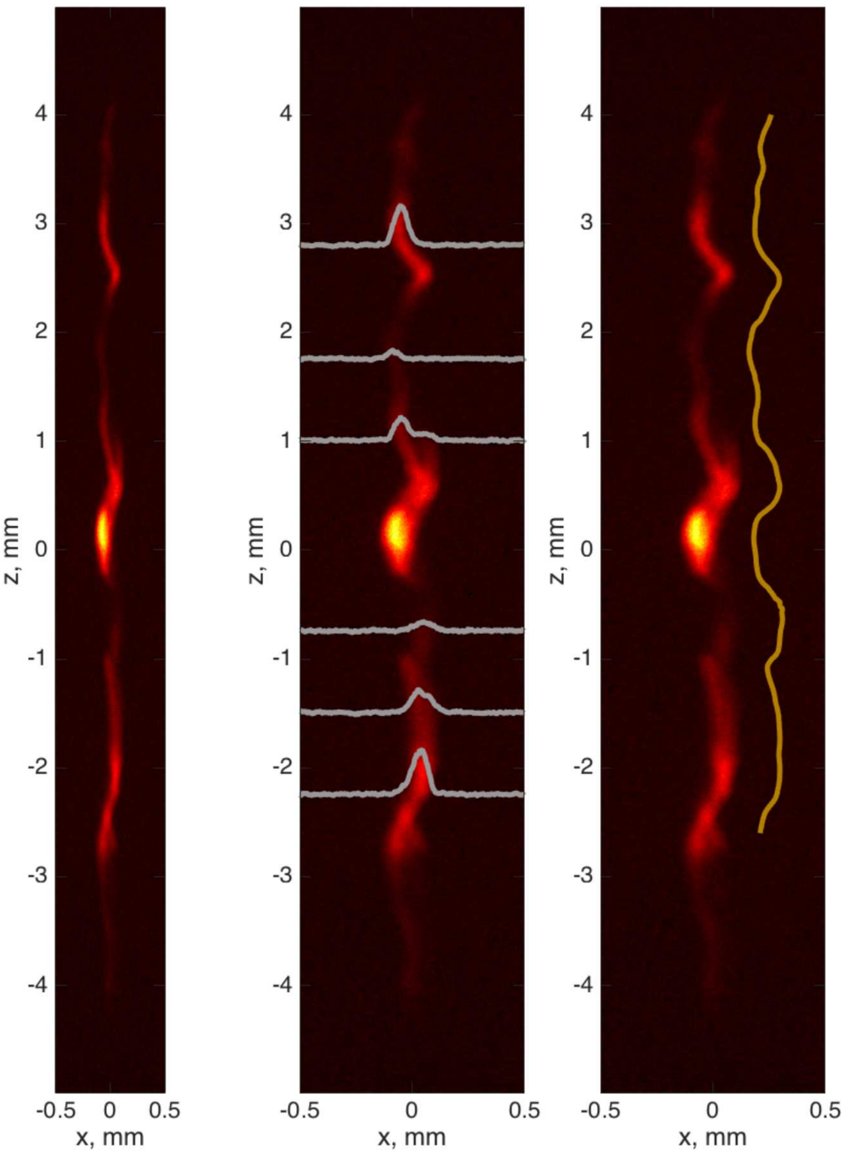
When stagnation column is well defined (not bifurcated) the centroid is well-represented by a fit to the horizontal profile



Axis stretched to highlight structure

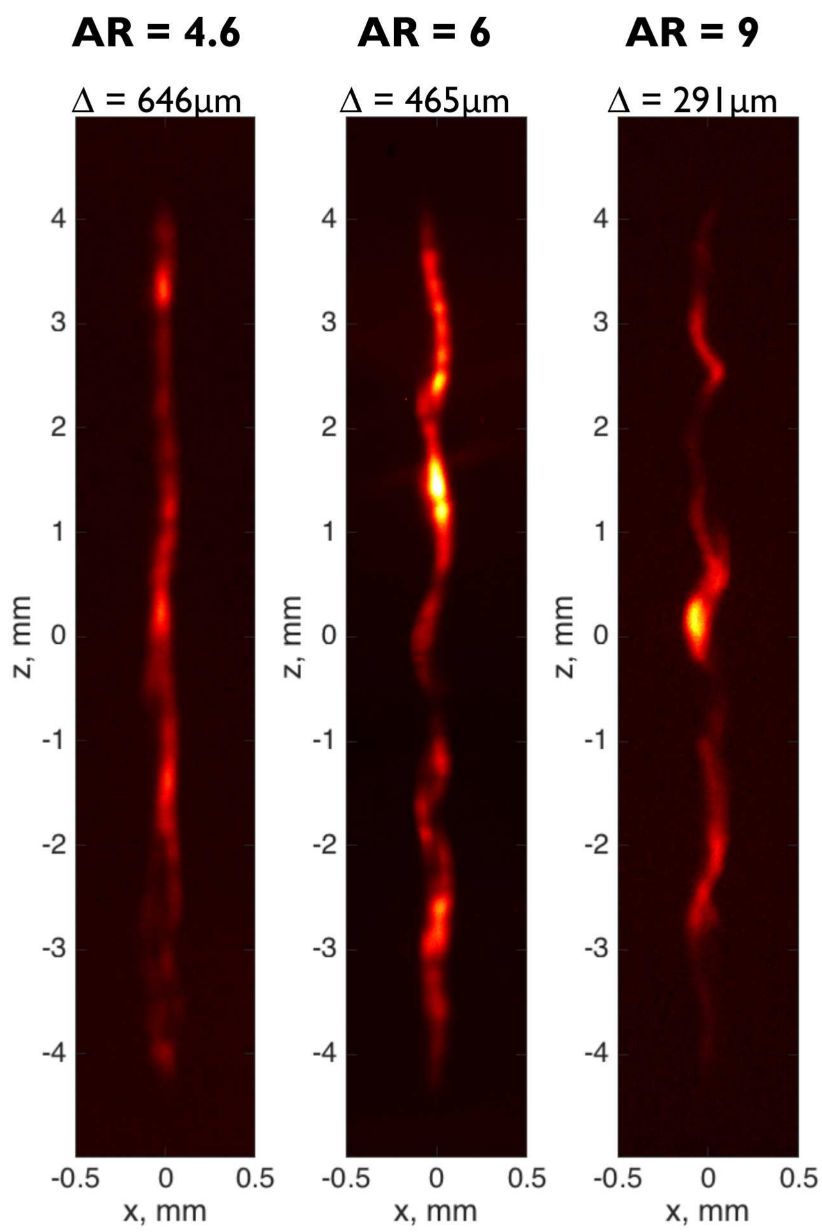
- We are interested in quantifying dominant pitches/wavelengths in the stagnation
- Fitting a Gaussian to each axial slice is a noise-insensitive method to capture the centroid

To quantify feedthrough wavelengths we use a fit to the radial structure at stagnation



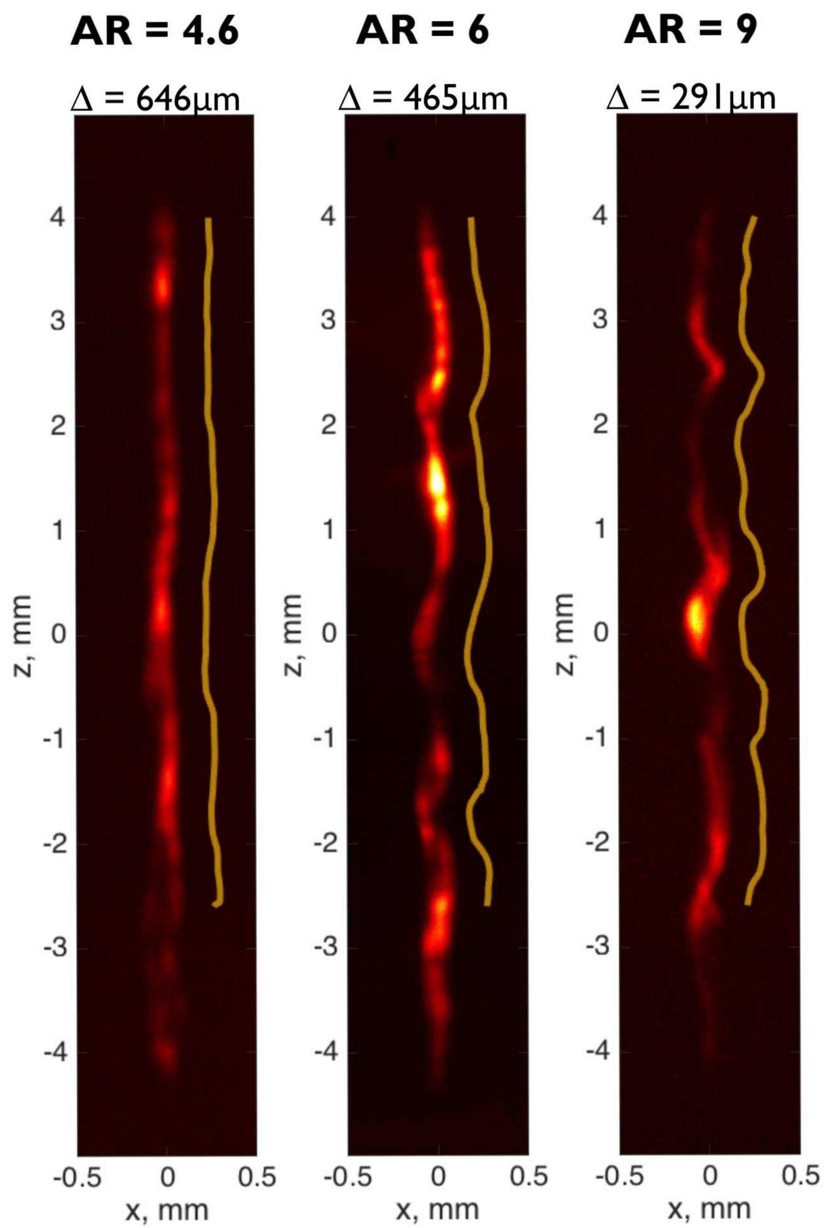
- Axial structure is determined using centroid of Gaussian fits to the emission profile

Changing the initial liner aspect ratio leads to variations in the stagnation structure



- Helical structure is impacted by change in liner aspect ratio
- Higher aspect ratio leads to shorter helix period/wavelength
- Axial variation in brightness becomes more pronounced at higher aspect ratio

Data demonstrates strong correlation between liner thickness and helical stagnation structure



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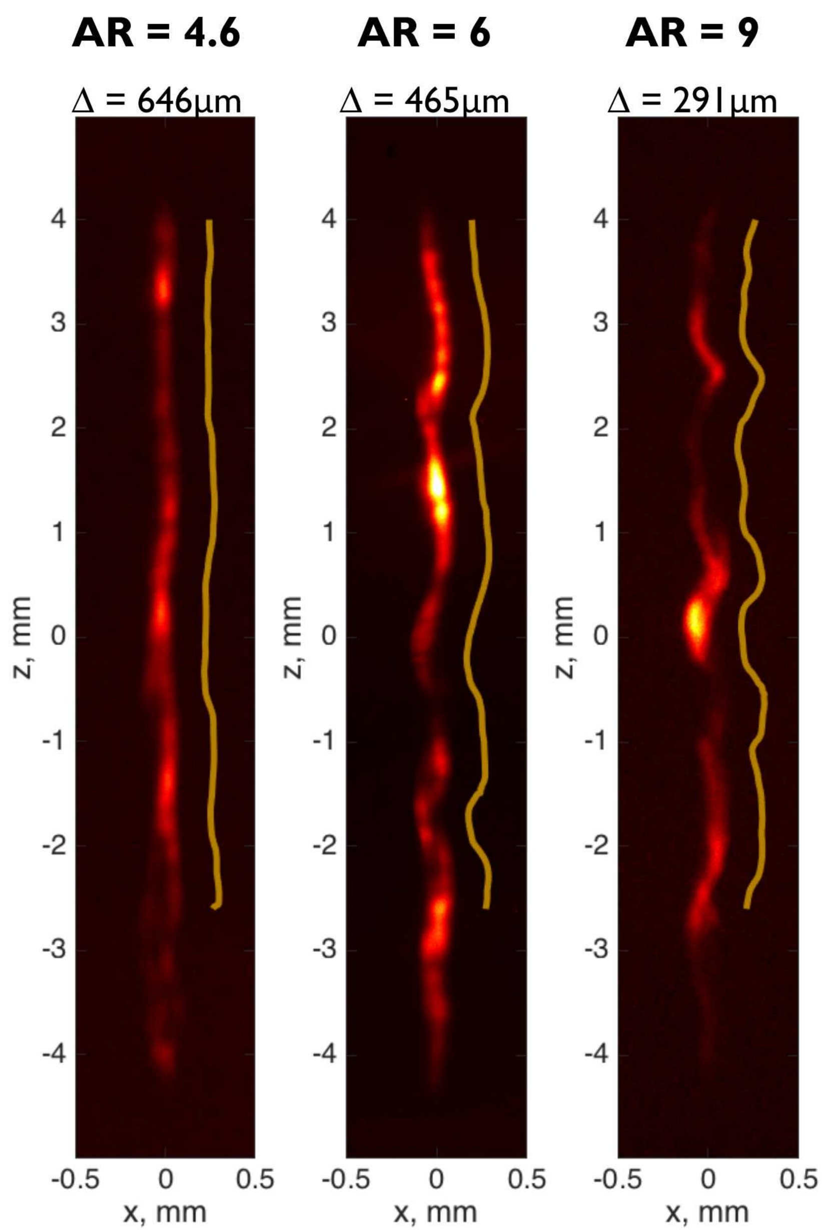
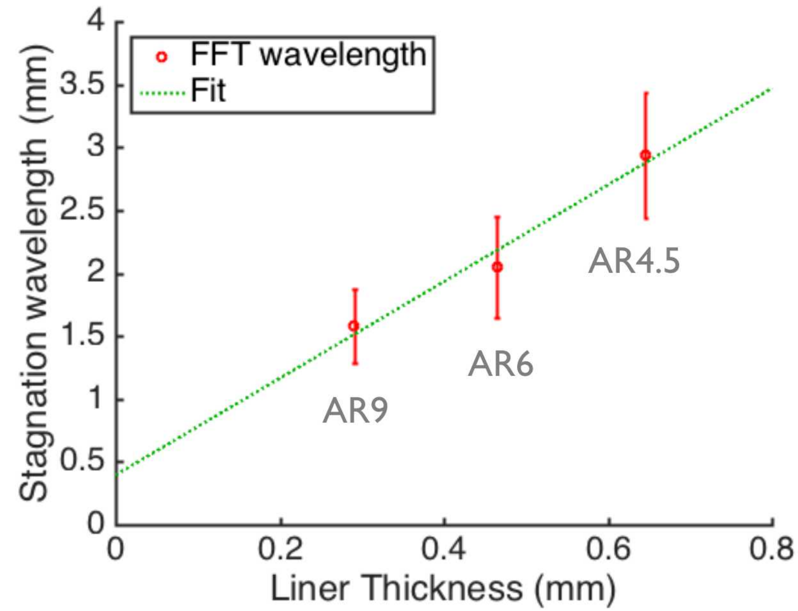




- Data shows measurable changes in stagnation pitch/wavelength as a function of liner thickness
- Consistent with feedthrough

$$\lambda \propto \Delta$$

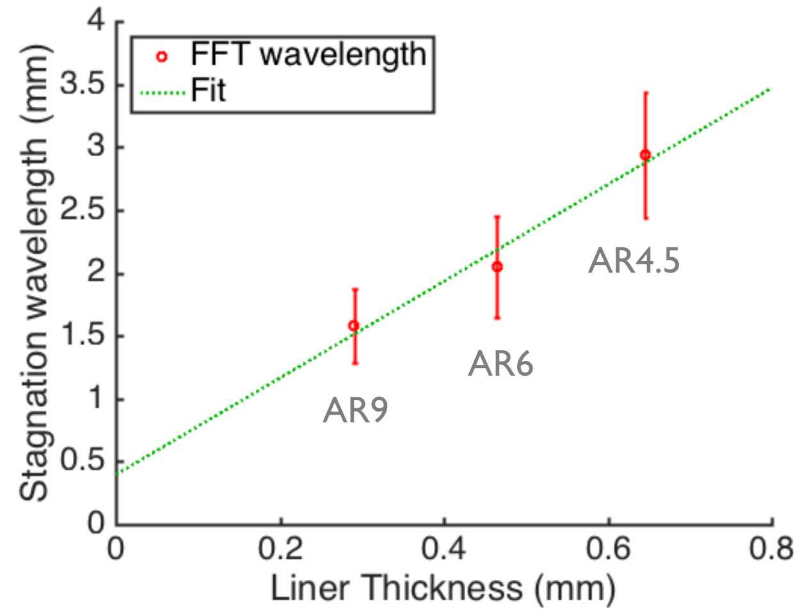
Stagnation structures are consistent with feedthrough of helical imprint on outer surface of liner

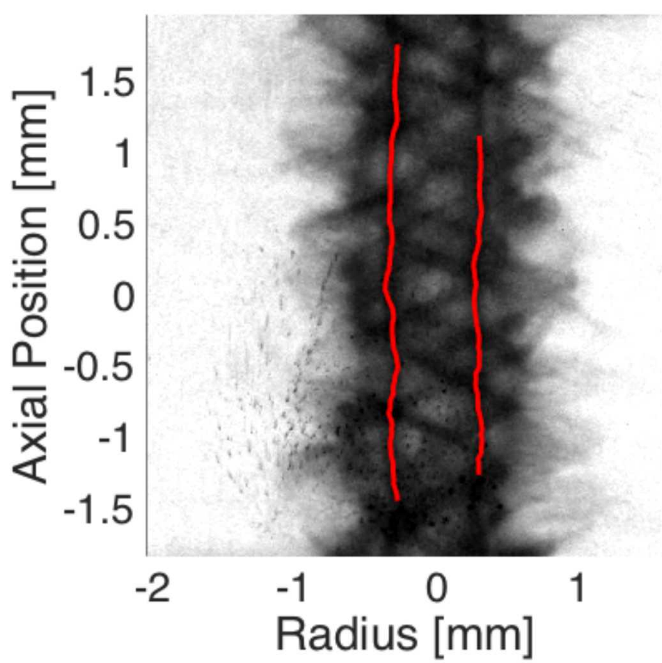
Stagnation wavelength varies with initial liner thickness, consistent with MRT feedthrough $\lambda \propto \Delta$

Aspect ratio of liner varies in-flight, so constant of proportionality $\neq 1$

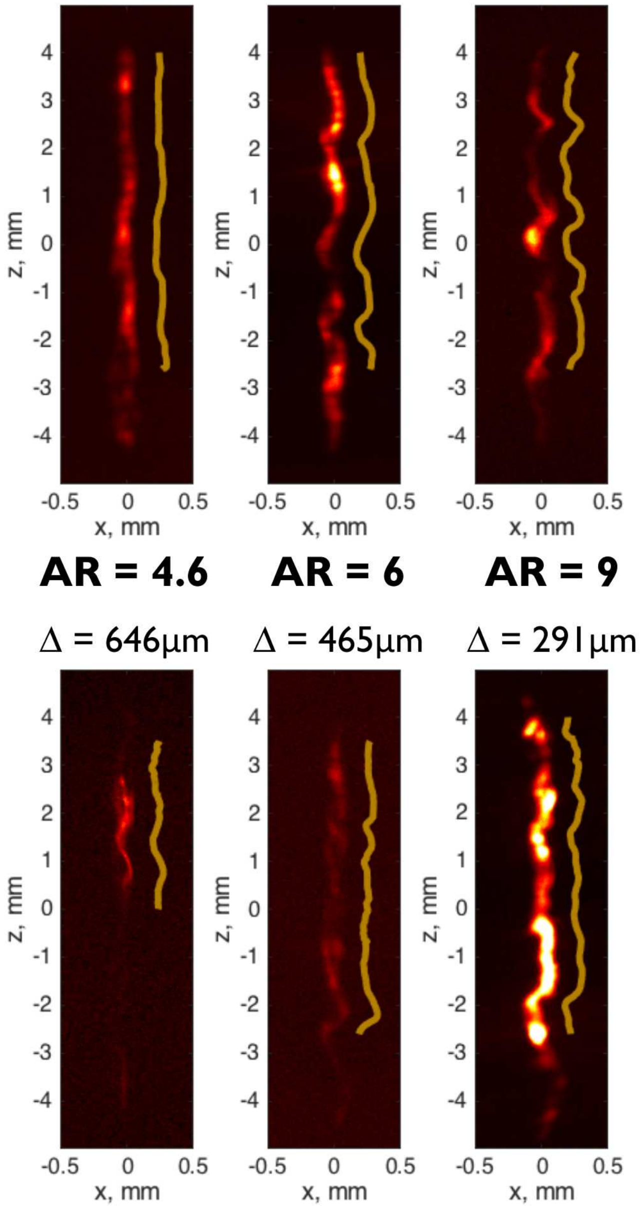
- Radiography shows expanded sheath

Where we have radiography of similar experiments, wavelength is similar





Not all experiments have as 'clean' helical structure, however there is still some evidence of these dominant wavelenghts



- We have data for multiple experiments at each aspect ratio
- This simplified analysis method does not capture double helix structures well
  - FFTs for AR6, AR9 show some presence of the dominant pitches

See 2C06 presented by Will Lewis for analyzing double helix

Aspect ratio can be scaled to constrain the impact of instability feedthrough as current is increased

We believe stagnation structure is dominated by feedthrough; as imploding shell will be compressed more as current is increased

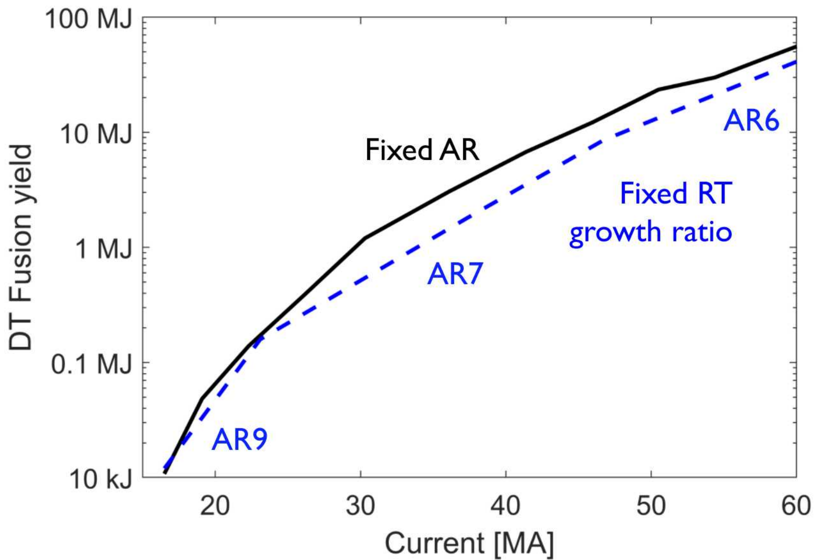
We can construct a scaling argument where the impact of feedthrough does not get worse at higher currents

Growth rate of fastest growing mode:

$$\Gamma_{max} \sim \frac{R_0}{\Delta_{min}} \left[\left(1 - \frac{1}{CR_{acc}}\right)^{1/2} + \left(\frac{1}{CR_{acc}} - \frac{1}{CR_{stag}}\right)^{1/2} \right]^2$$

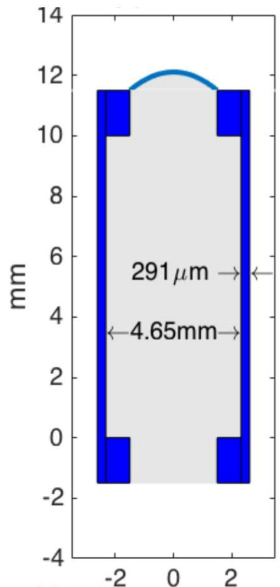
Max compression   Peak velocity

Growth rates and feedthrough amplitude can be estimated from 1-dimensional simulations and aspect ratio chosen to preserve ratio of feedthrough amplitude and stagnation radius

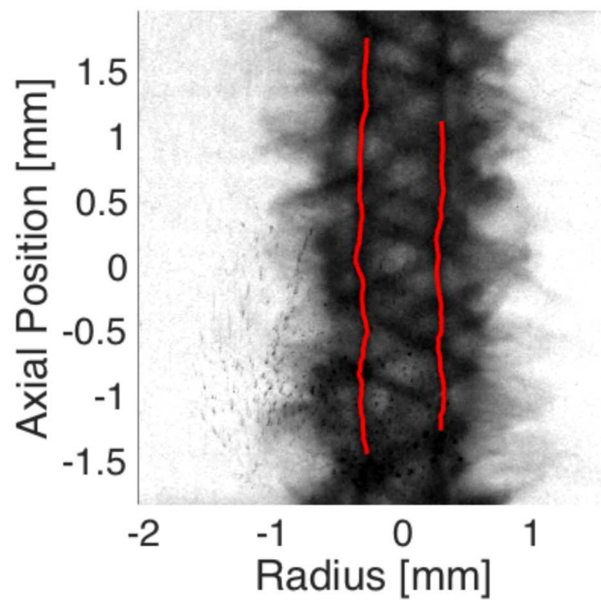


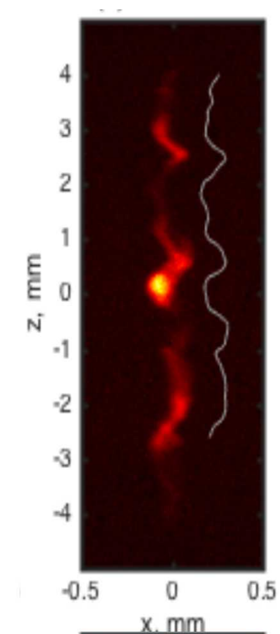
Steve Slutz, 2019

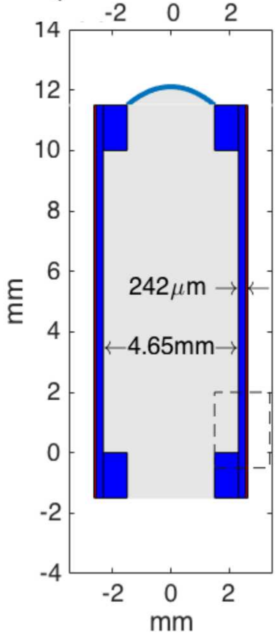
Separate experiments using a dielectric-coated liner to significantly improve morphology provide a potential baseline for scaling



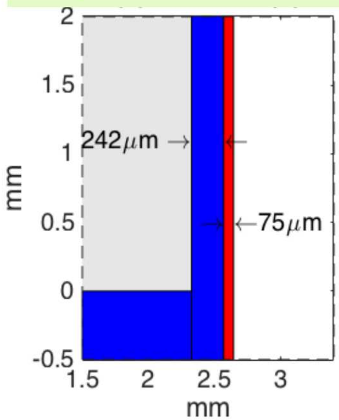
Aspect Ratio 9

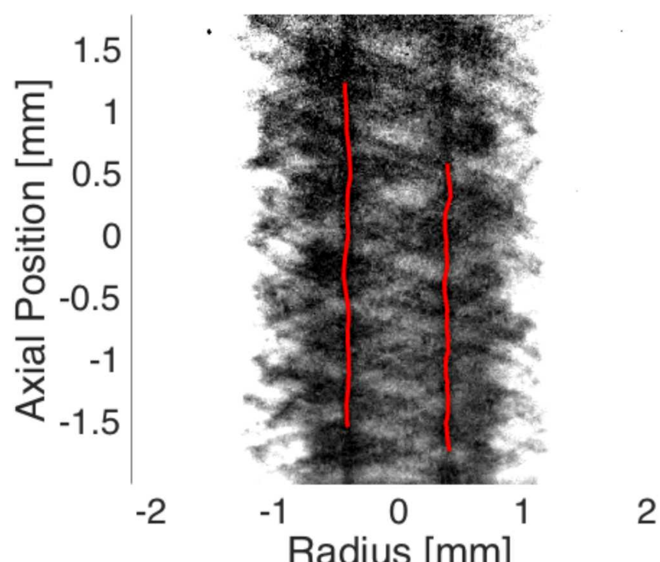


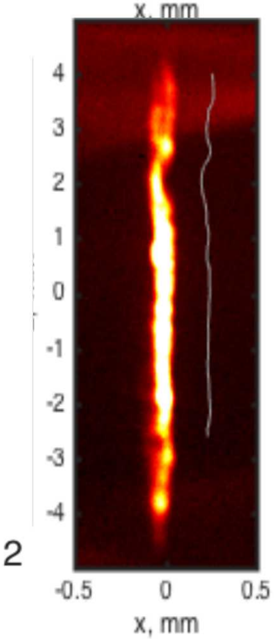




Dielectric Coated Aspect Ratio 9







Dave Ampleford, IFSA 2017

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Additional material

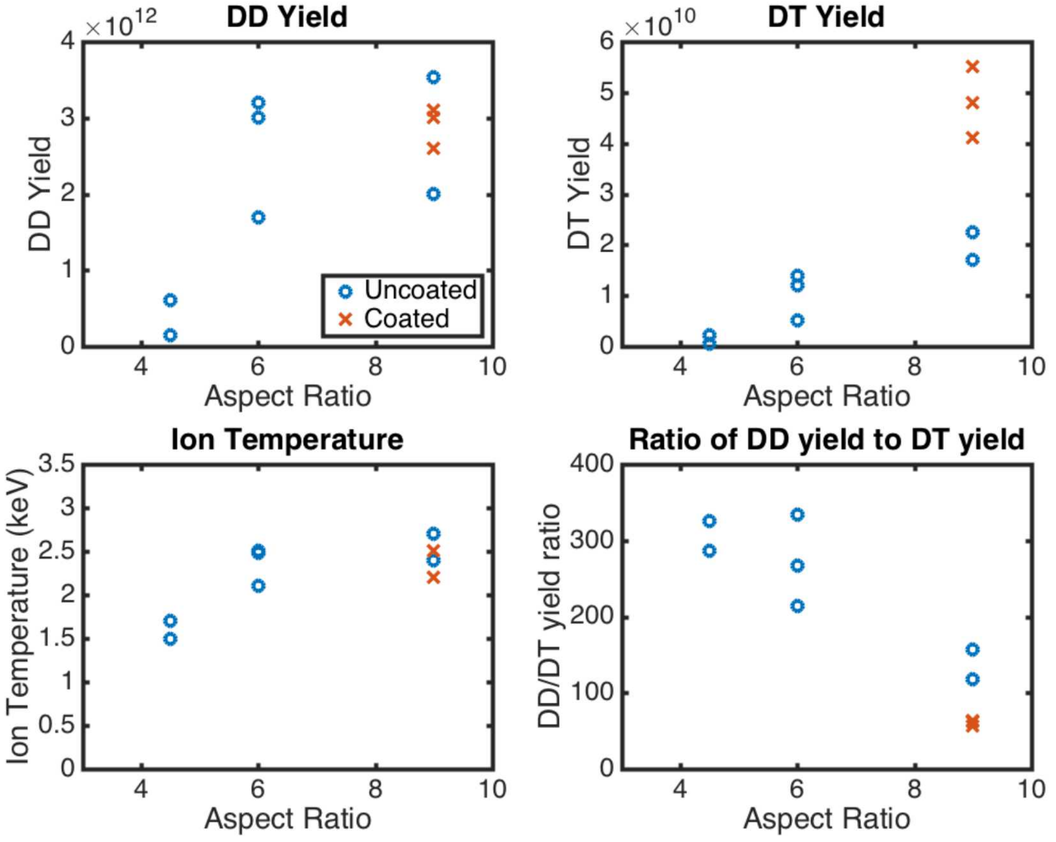
Many key stagnation parameters, including yield, are reproducible when a plastic coating is used to suppress ETI

These three, nominally identical coated AR9 experiments have exhibited very similar behavior

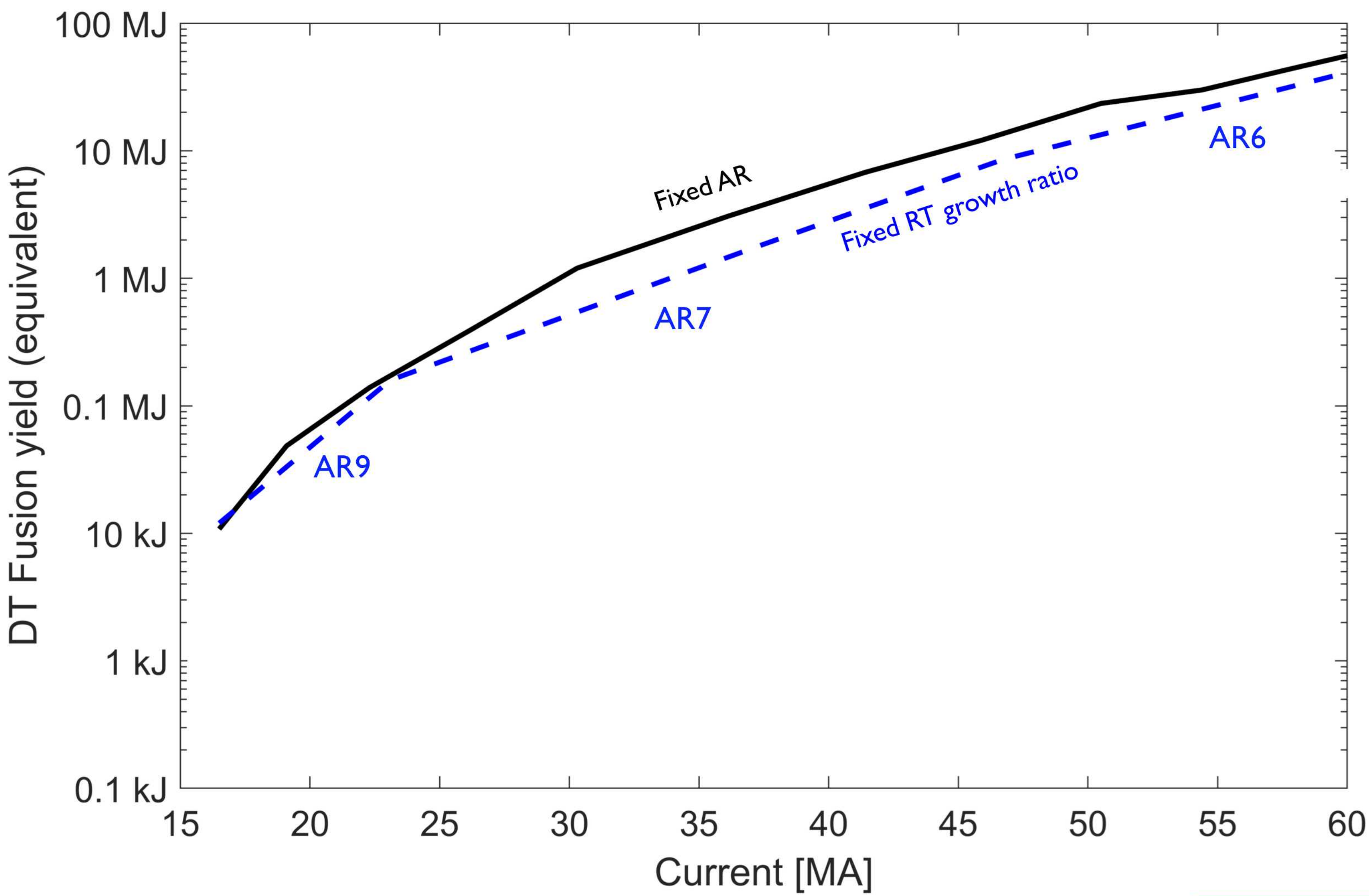
- Similar Primary DD yields
- Similar Ion temperatures
- Similar DT yields

While going to the coated AR9 platform hasn't improved MagLIF performance

- Performance hasn't been diminished
- Reproducibility is better

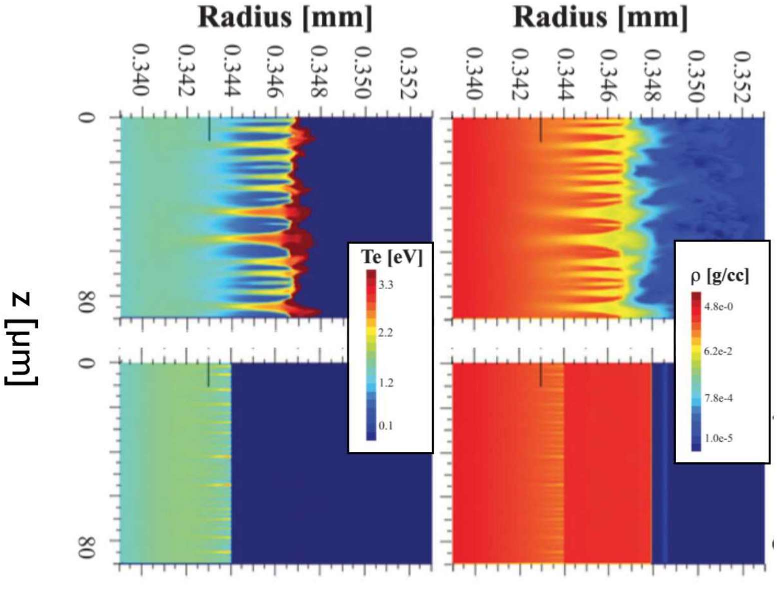


MRT conserving scaling can reach multi-MJ yields with an appropriate driver



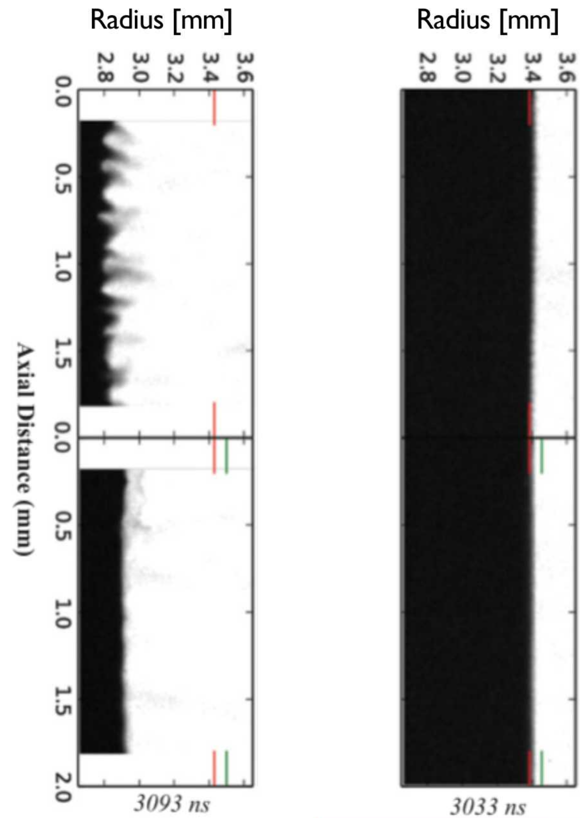
Matt Gomez, IFSA 2019
Steve Slutz, 2019

We believe the seed for the helical instability is electro-thermal instability – if it is then theory shows we can fix it



Uncoated

Coated



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

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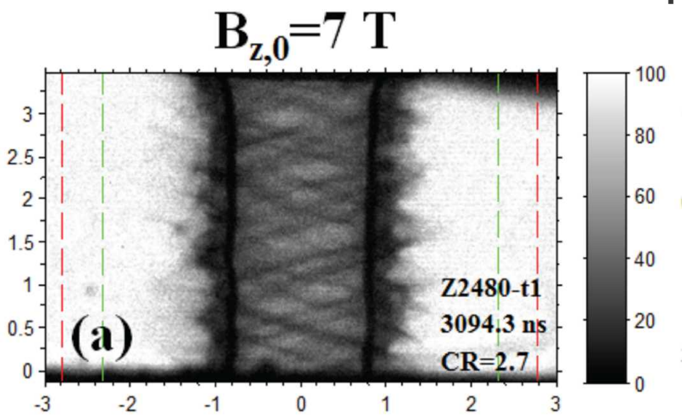

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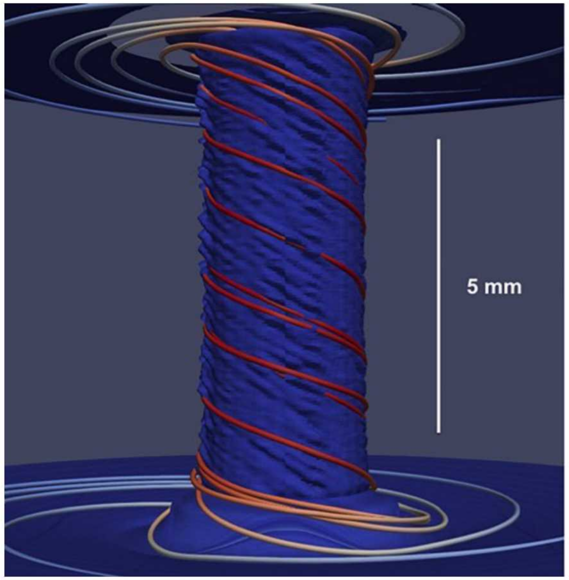

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C.E. Seyler, M.R. Martin, N.D. Hamlin
Physics of Plasmas 25, 062711 (2018)

Radial mass distribution is changed with coatings