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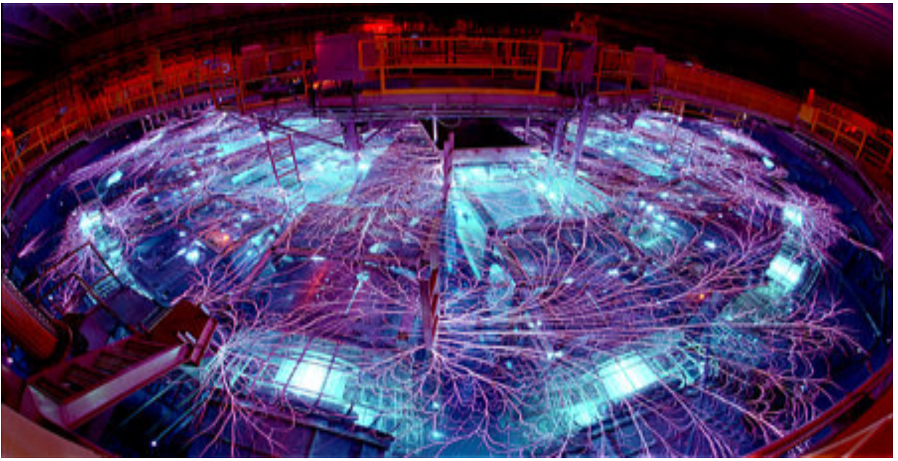
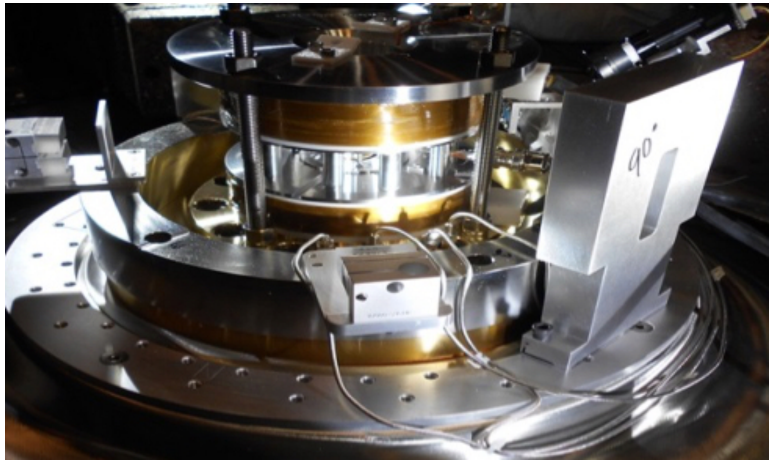
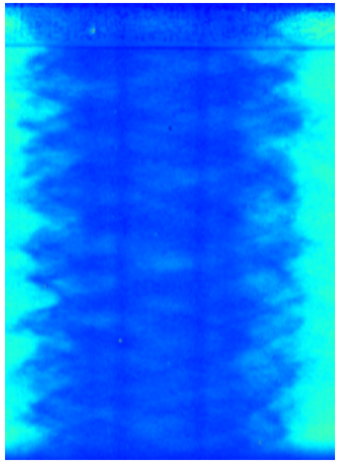
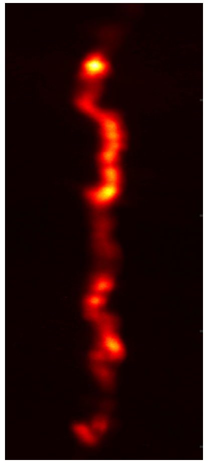
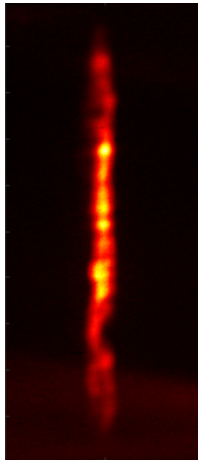










A more stable, more uniform Magnetized Liner Inertial Fusion configuration

Dave Ampleford, M.R. Weis, K.J. Peterson, C.A. Jennings, M.R. Gomez, T.J. Awe, P.F. Knapp, S.B. Hansen, E.C. Harding, K.D. Hahn, P.F. Schmit, M.H. Hess, S.A. Slutz, G.A. Rochau, D.B. Sinars

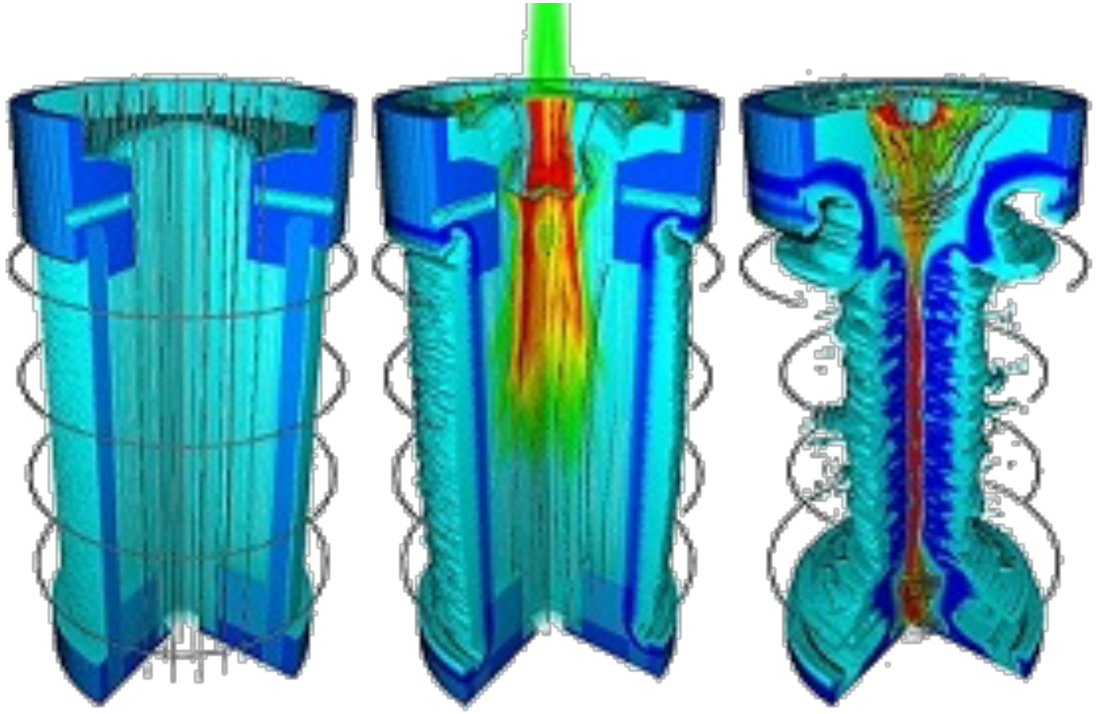
Sandia National Laboratories

10th International Conference on Inertial Fusion Sciences and Applications

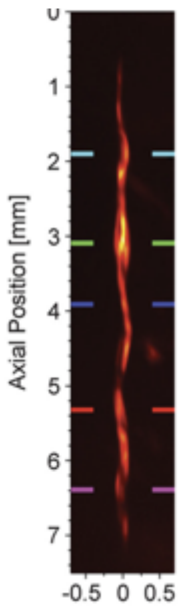
Saint Malo, France, September 2017

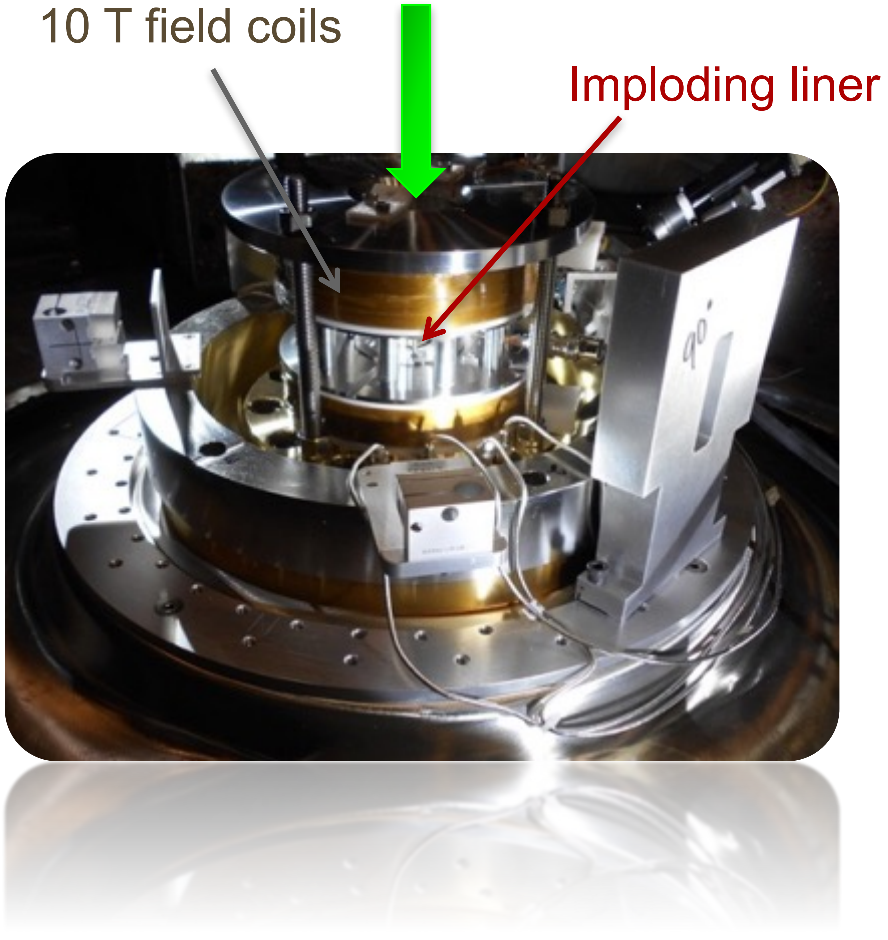
Magnetized Liner Inertial Fusion (MagLIF) uses a pulsed-power driven low-Z liner to compress a pre-magnetized, preheated fuel to reach fusion-relevant conditions

Axial Magnetization | **Laser Heating** | **Magnetically-driven Compression**



Inhibit heat conduction | *High initial adiabat* | *Compress to fusion conditions*



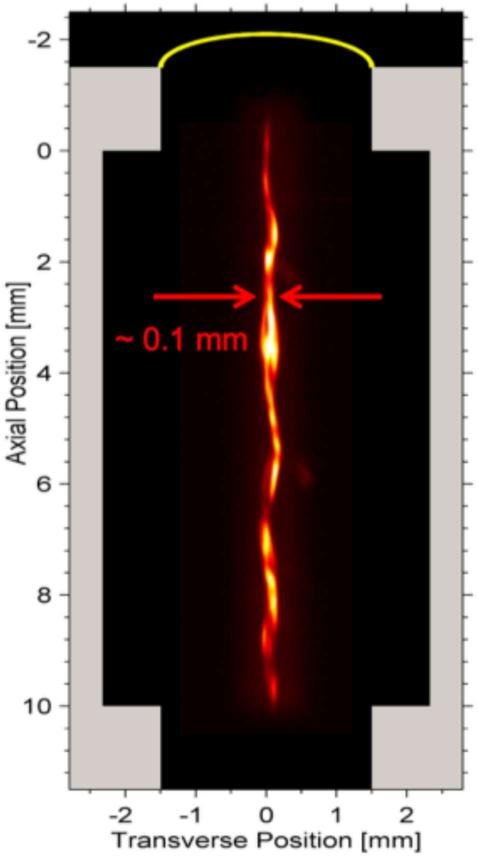


Dynamics from 3D MHD simulations, C.A. Jennings

Photograph of hardware from MagLIF experiment on Z

MagLIF experiments have demonstrated thermonuclear fusion in a magnetized target

High Convergence Implosion

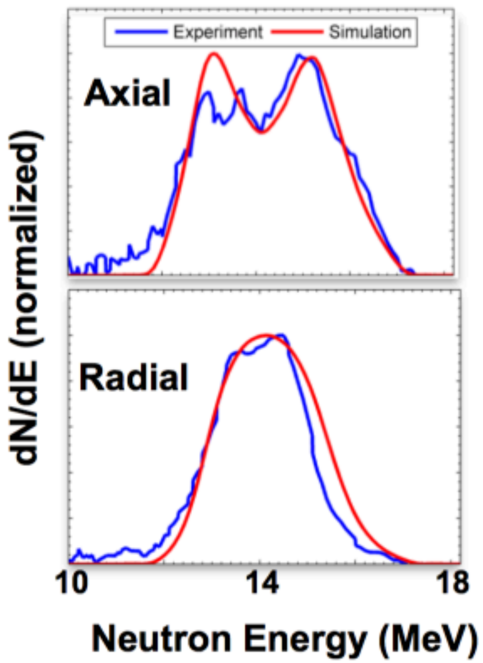


6+9 keV Emission Image

CR > 40

B-field Flux Compression & Magnetic trapping of charged particles

Secondary DT Spectrum

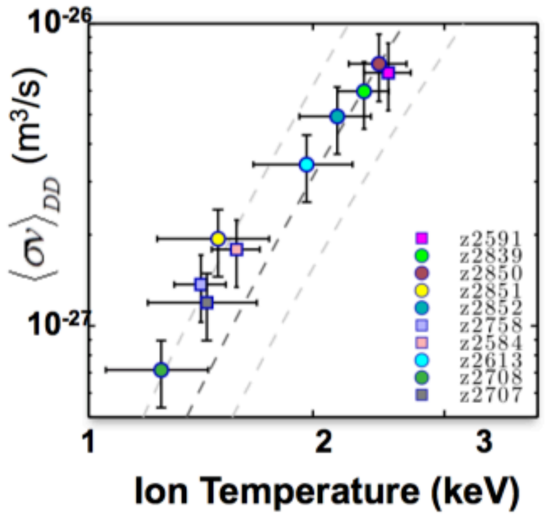


DT Secondary Spectra

BR > 0.35 MG-cm

Thermonuclear Neutrons

Reactivity Scaling vs. T_i

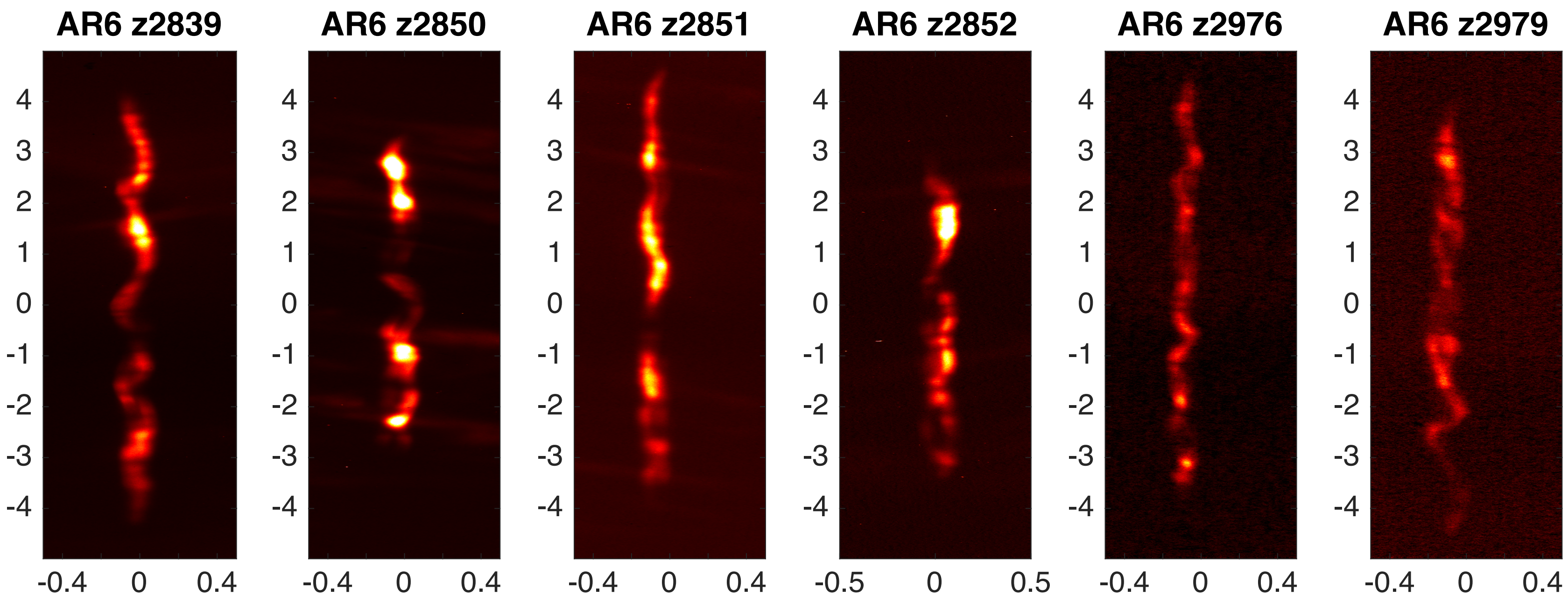


$$Y_{DD} = \frac{1}{2} n_D^2 \langle \sigma v \rangle_{DD} V \tau$$

Yield, Volume, Duration

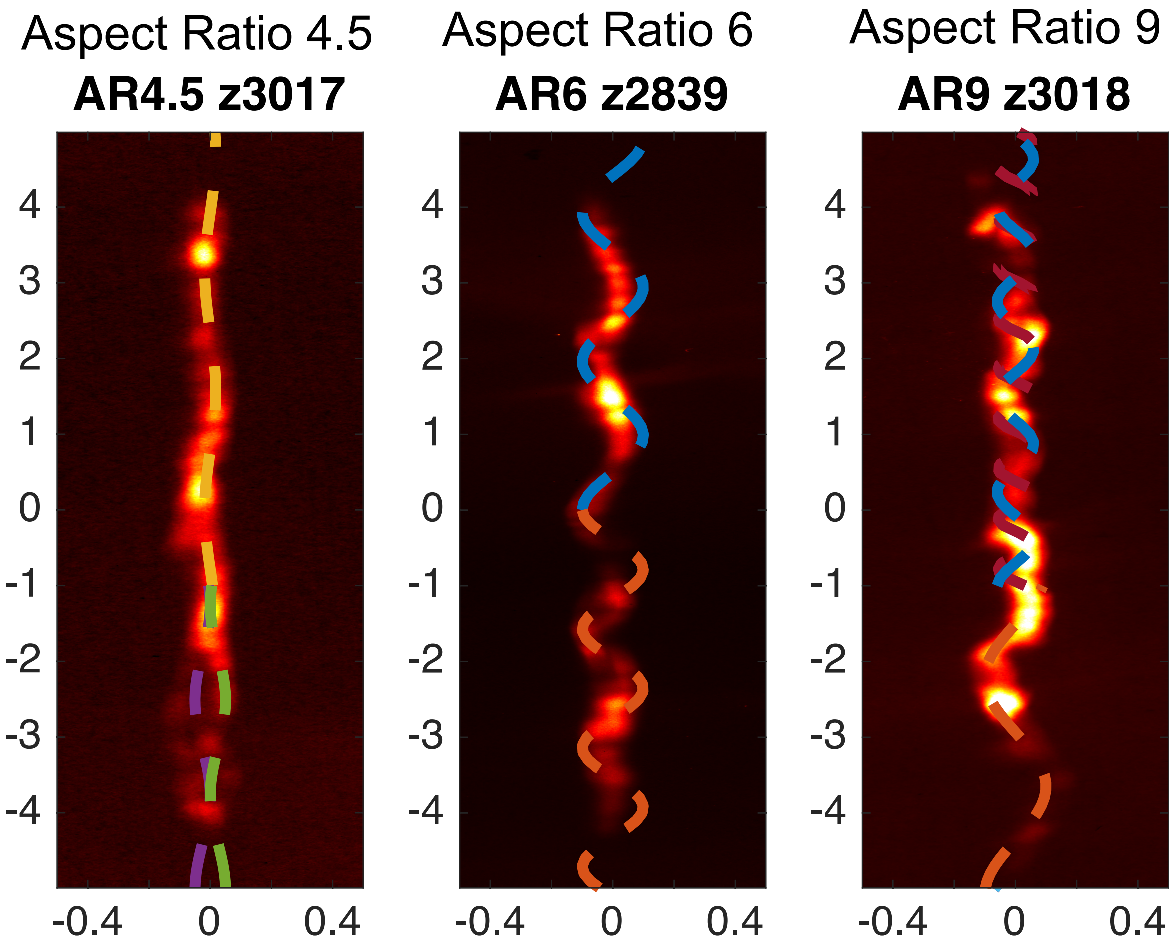
Consistent with DD reactivity

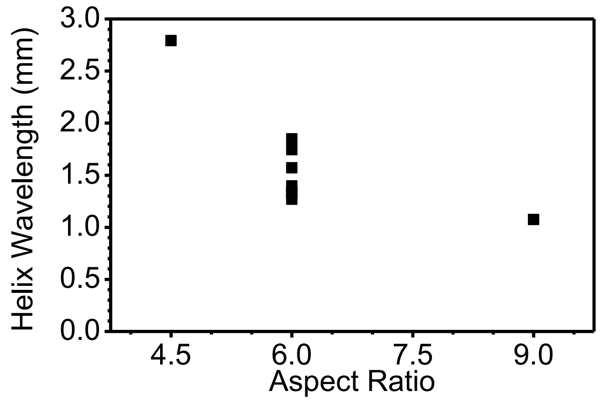
In experiments, typical MagLIF liners demonstrate shot-to-shot variability in stagnation structures and yield

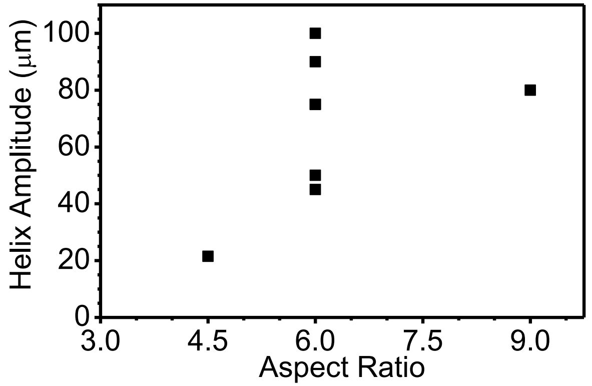


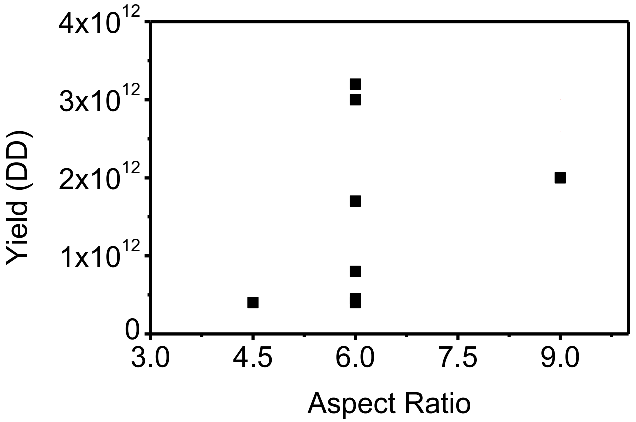
- Stagnations structures vary between experiments
  - Helices, bright spots
- Yield has variability of about an order of magnitude
- Assumed to be combination of structured implosion and high convergence

Data indicates a trend in wavelength and amplitude with aspect ratio/liner thickness; consistent with feedthrough





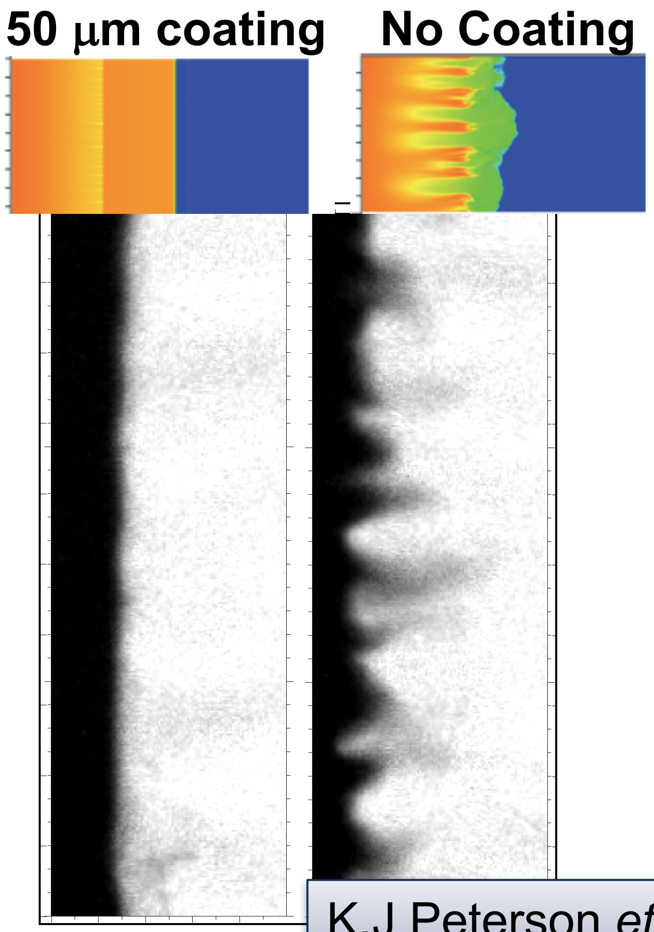




- Higher aspect ratio has shorter wavelength, higher amplitude helical structure
- Consistent with feedthrough of instabilities from outer liner surface

We believe that stagnation structures are the result of electro-thermal instability structures seeded on the outside of the liner

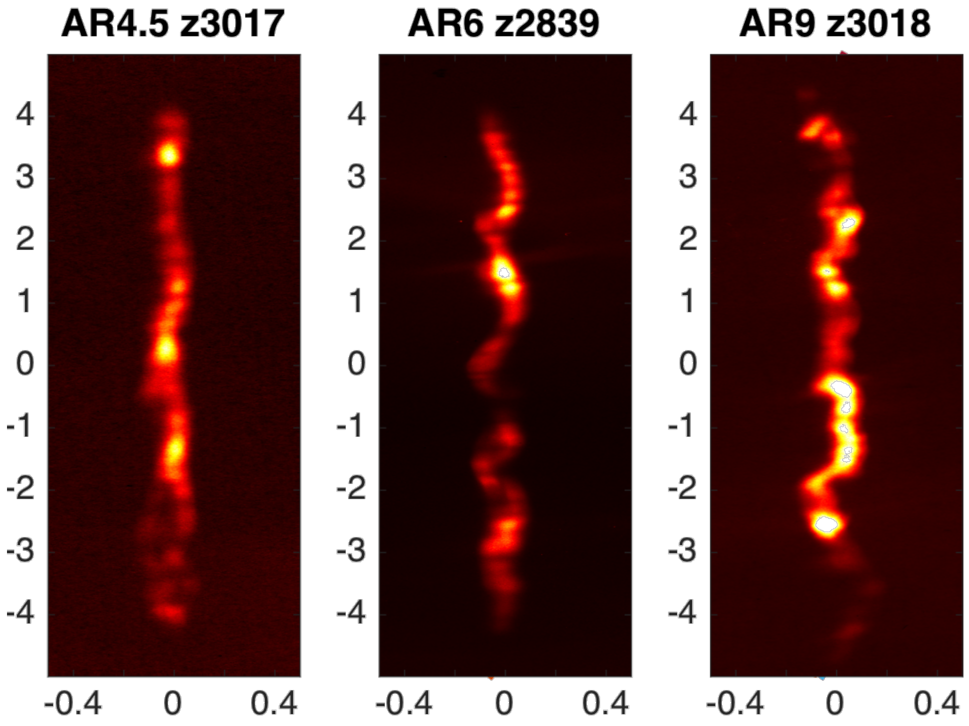
Simulations and experiments show a change in stability when a dielectric coating used to inhibit ETI growth



K.J Peterson *et al.*

Change in stagnation structures is consistent with instabilities initiated on outer surface of the liner

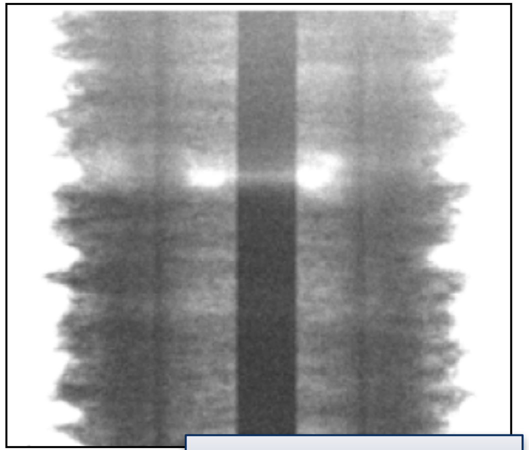
Thick liner
(Low Aspect Ratio)



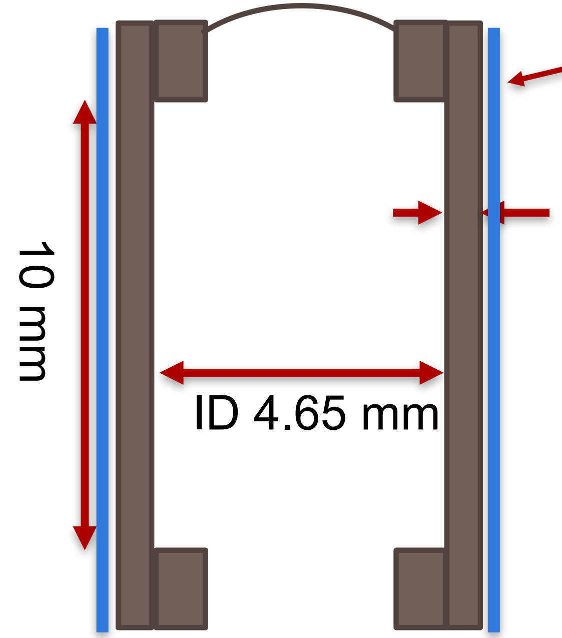
Thin liner
(High Aspect Ratio)

Previous experiments have demonstrated the ability to mitigate electro-thermal instability seed with thin dielectric coatings; here apply to high aspect ratio liner

ETI mitigation
(imploding liner)



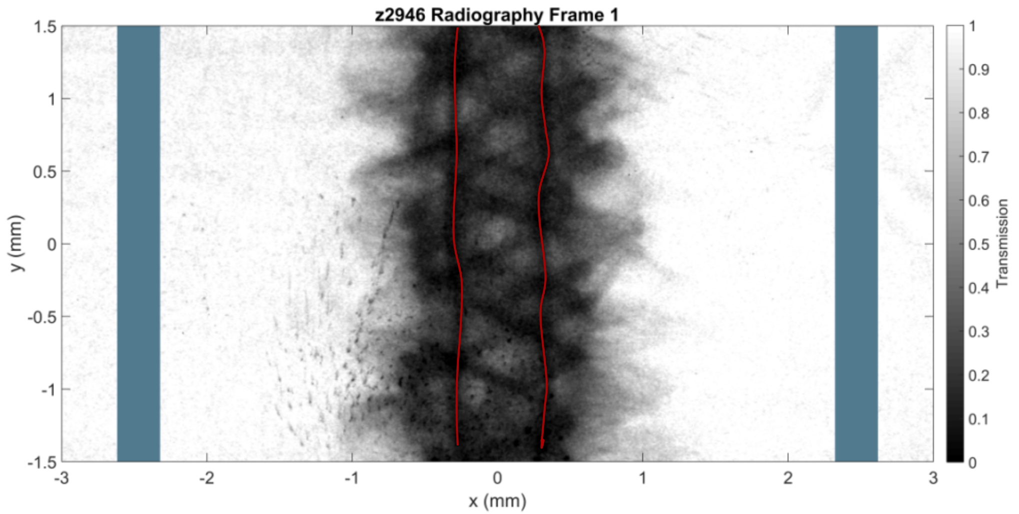
T.J. Awe *et al.*



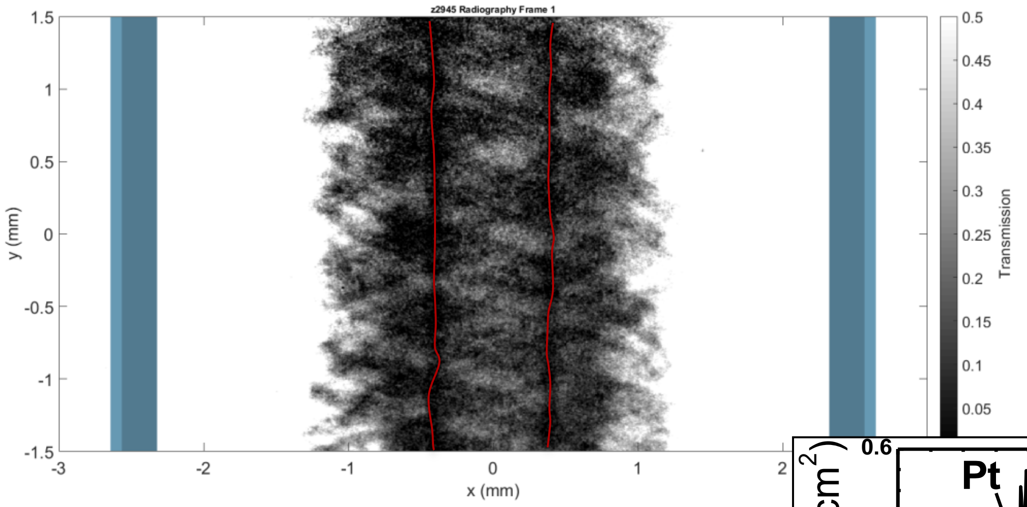
Liner Thickness	Outer Diameter	Epon coating	Complete mass
290 µm	5.23 mm	0	8.3 mg
242 µm	5.13 mm	75 µm	8.3 mg

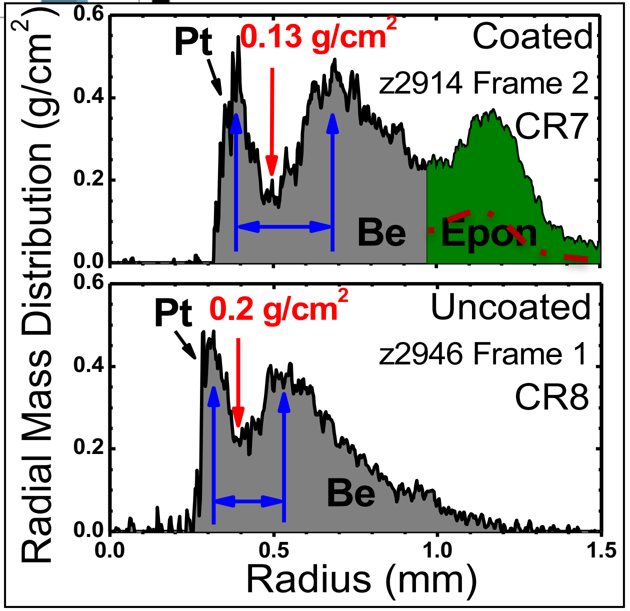
Applying a thin dielectric coating to the outside of high aspect ratio (thin) liners can enhance implosion stability, can impact inflight mass distribution

Uncoated



Coated

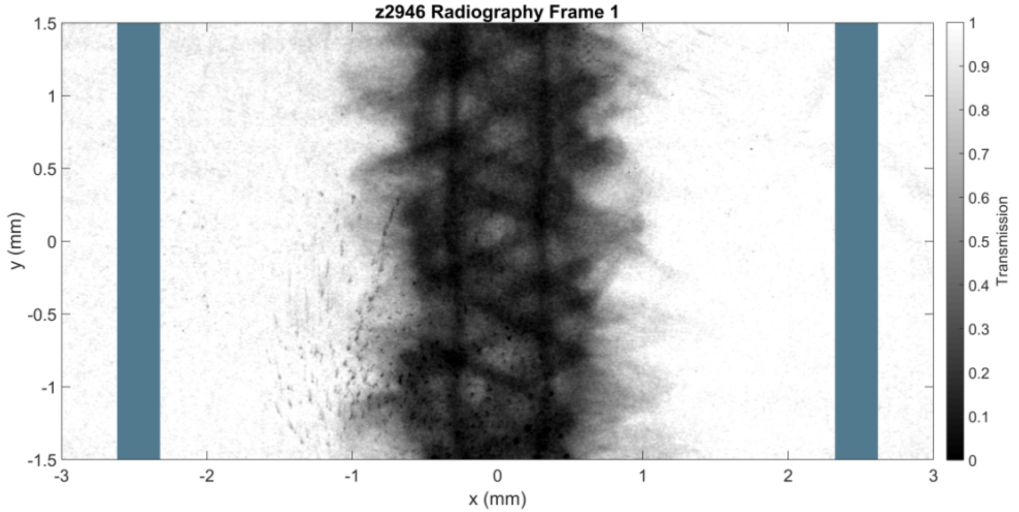




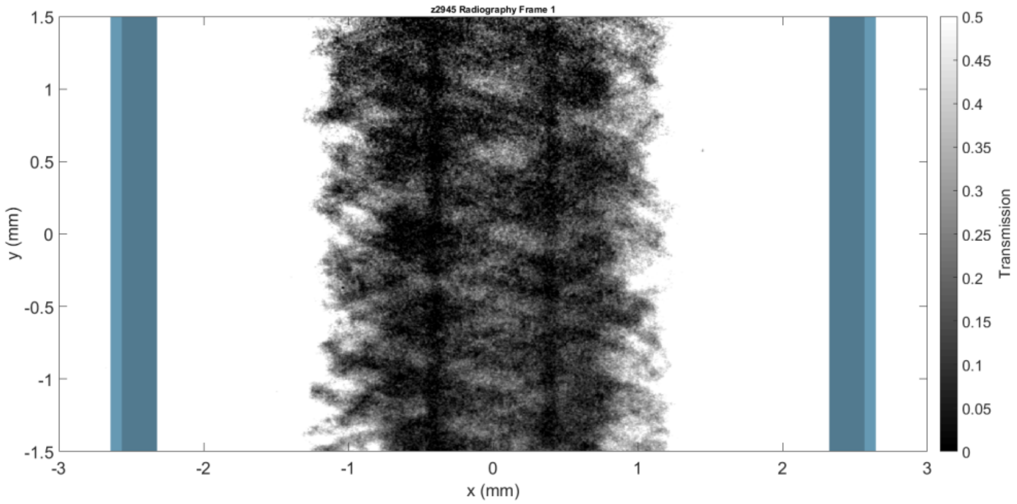
- Both coated and uncoated aspect ratio 9 liners show continuous, well defined implosion front
- More uniform implosion front on coated
- Stability difference is consistent with AR 6 studies (Awe *et al.*)
- Difference in mass distribution with coatings
  - Inflight aspect ratio

Applying a thin dielectric coating to the outside of high aspect ratio (thin) liners can enhance implosion stability, can impact inflight mass distribution

Uncoated



Coated



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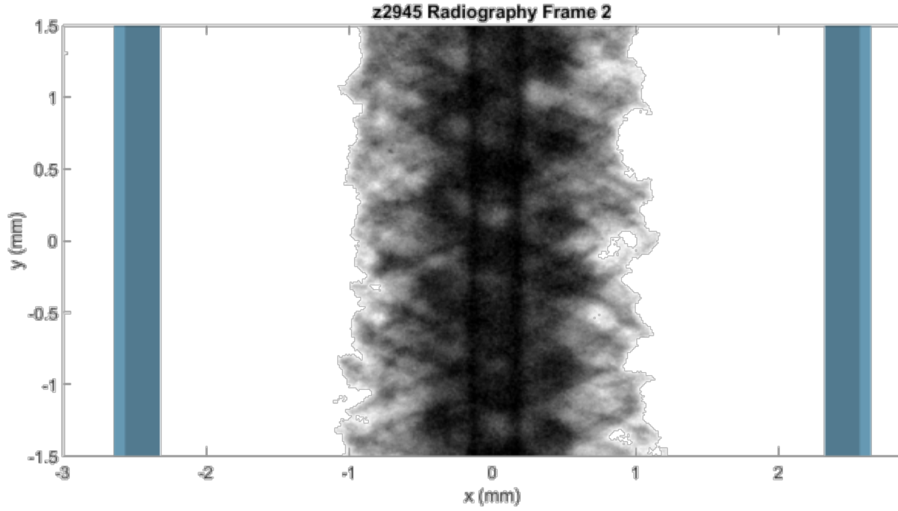
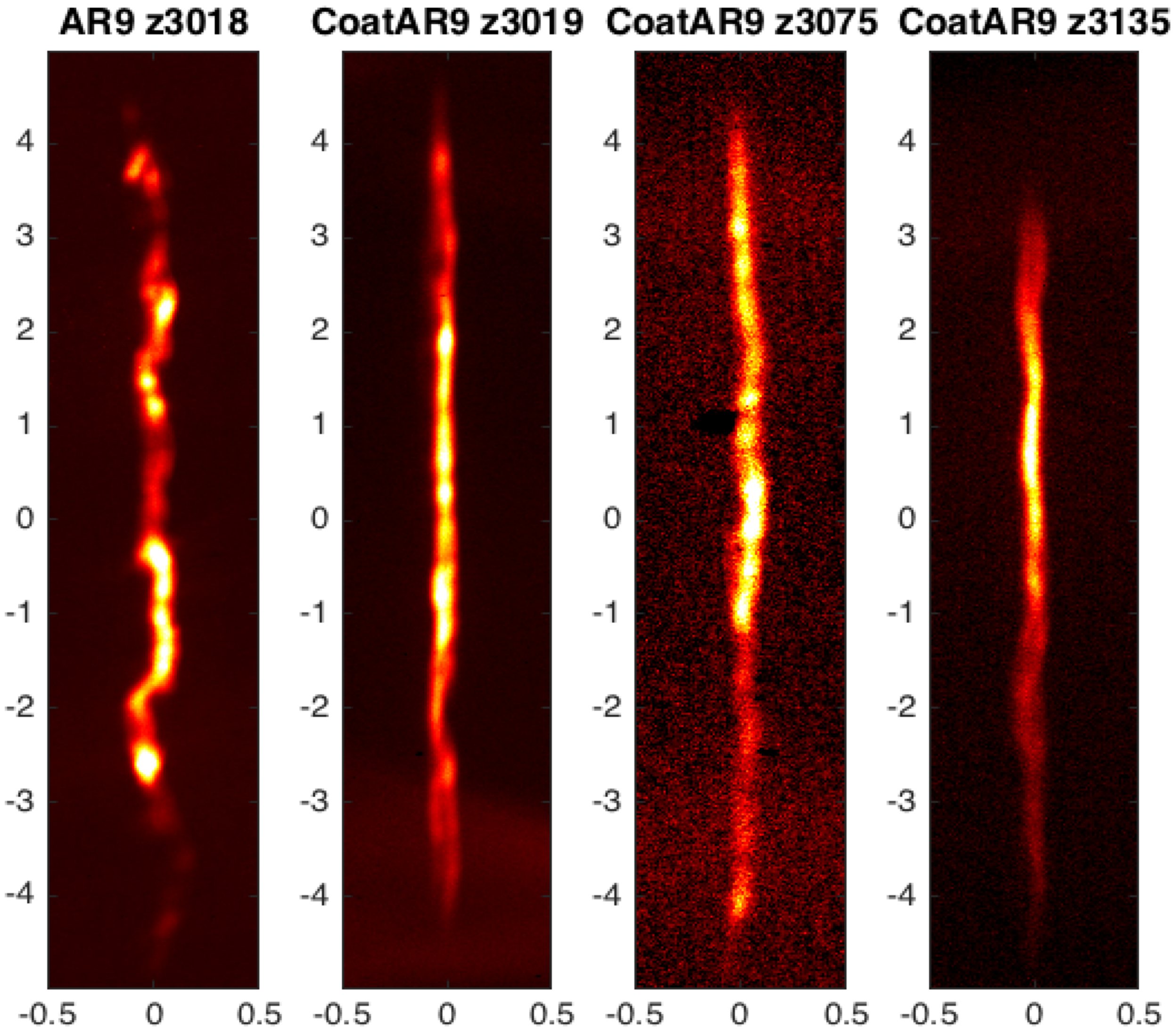
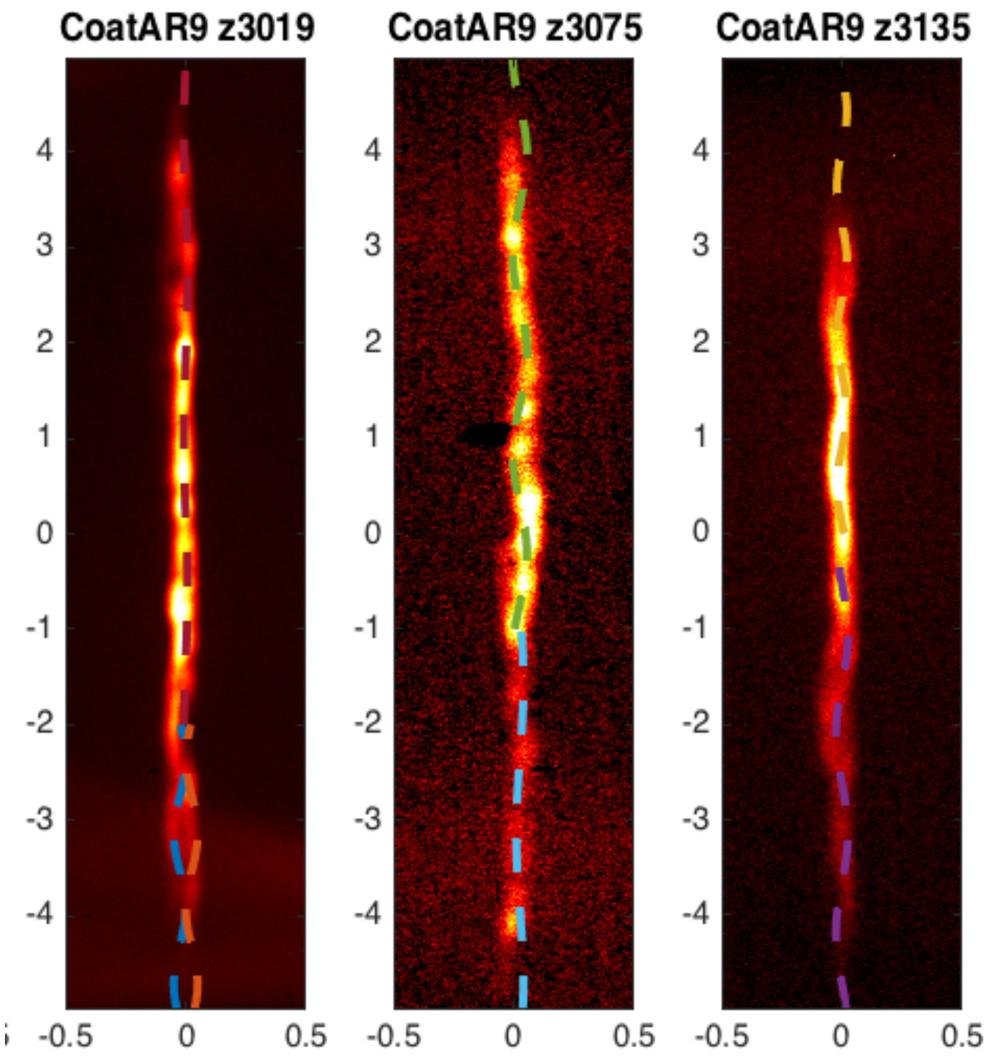


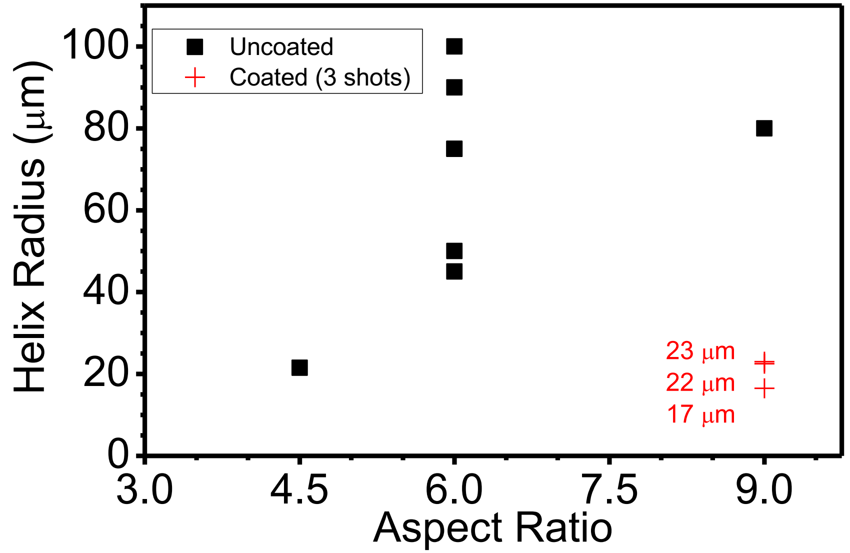
Data from stagnation experiments on Z demonstrates a stabilized stagnation column using these dielectric coatings

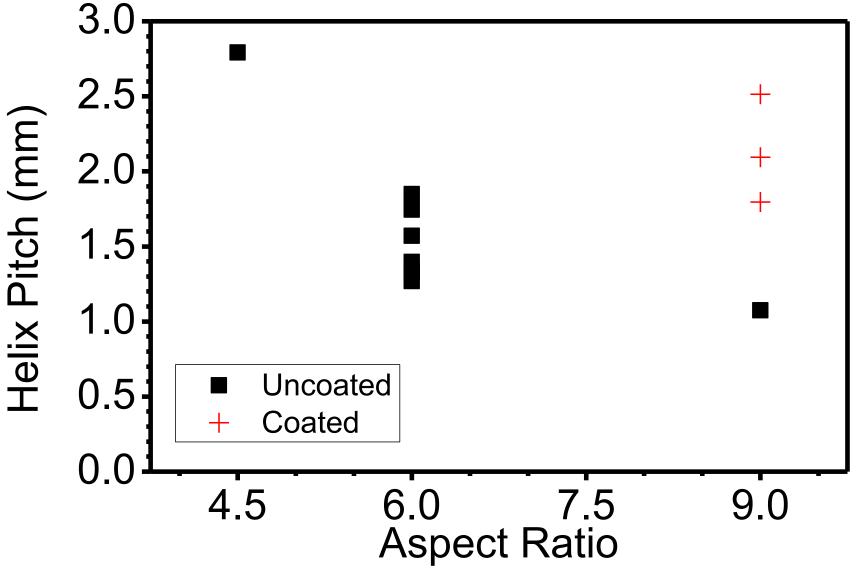


- Three experiments with dielectric coating show more stable stagnation column than
  - Uncoated AR 6
  - Uncoated AR 9

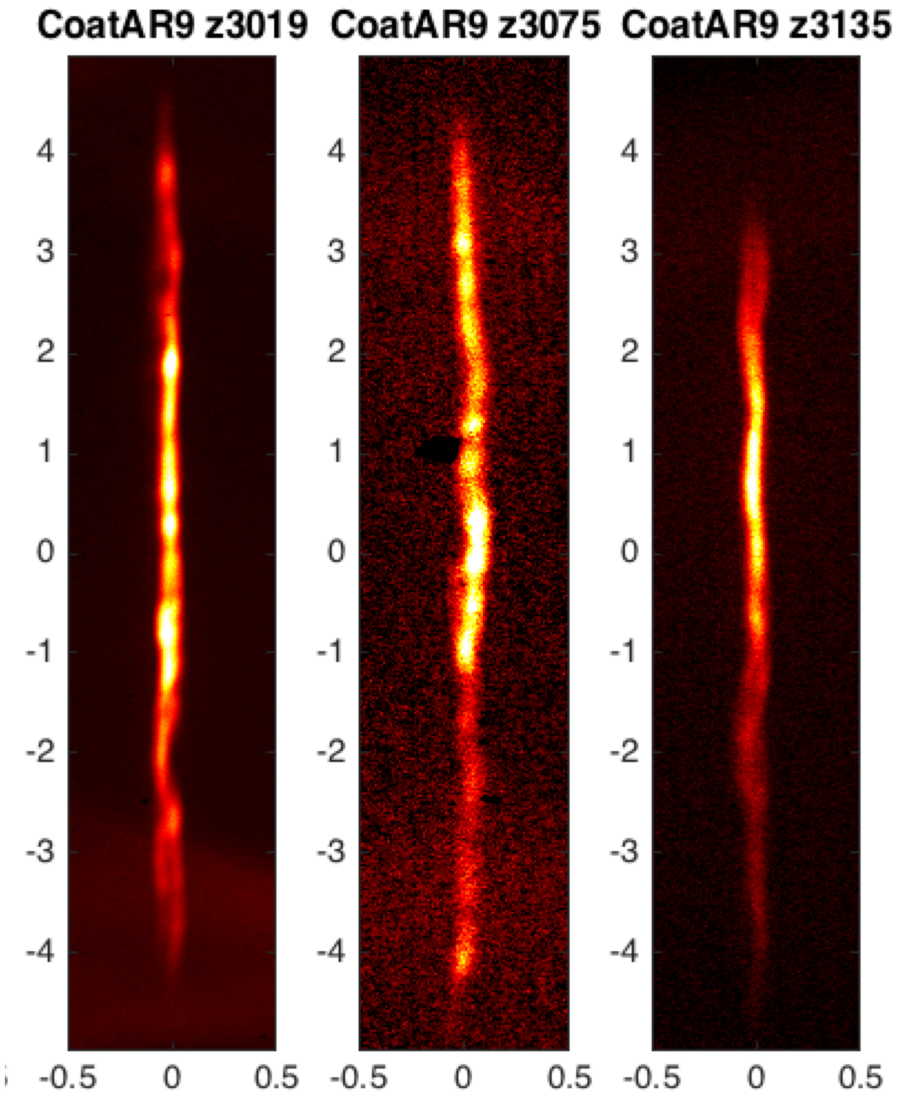
Data from stagnation experiments on Z demonstrates a stabilized stagnation column using these dielectric coatings

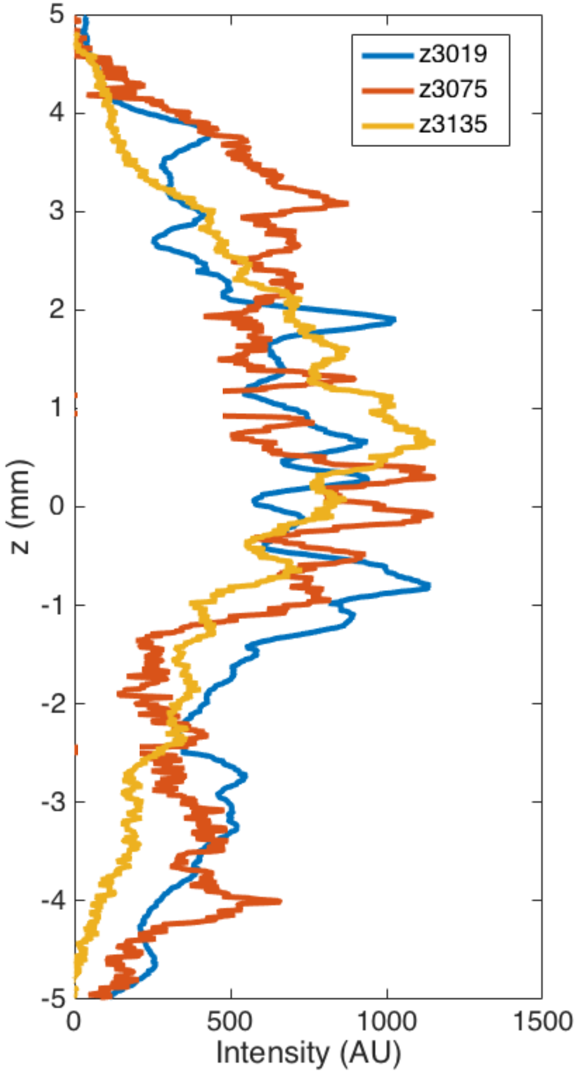




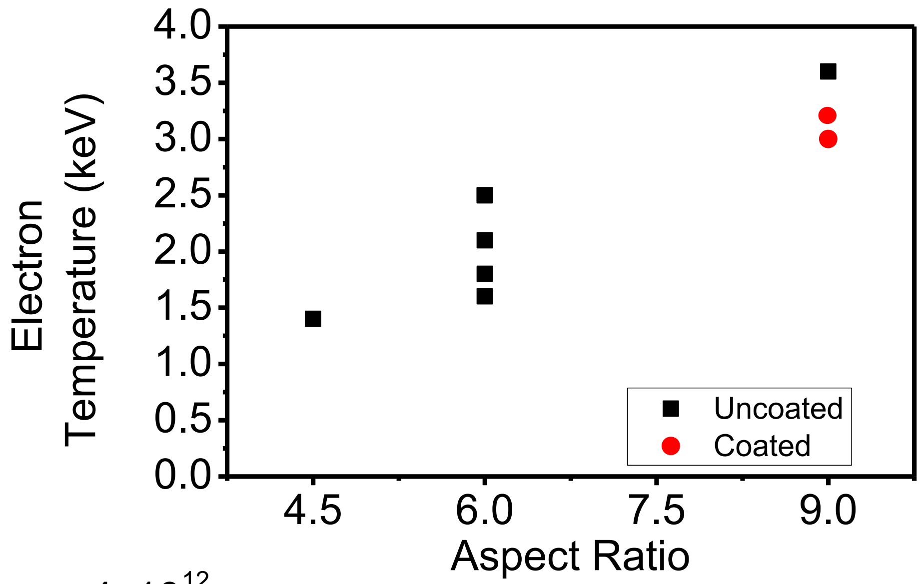


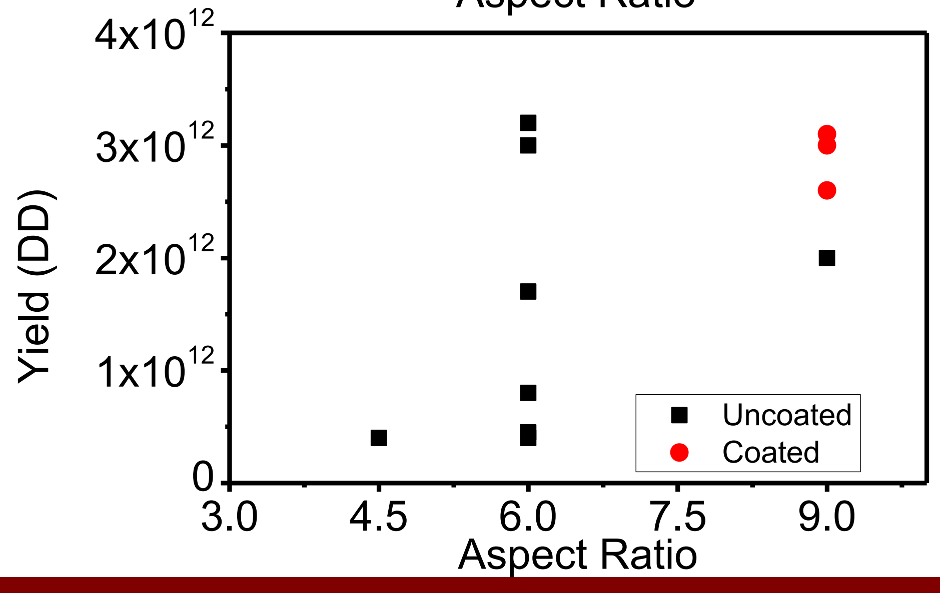
In these coated liner experiments we find good reproducibility in the axial structure



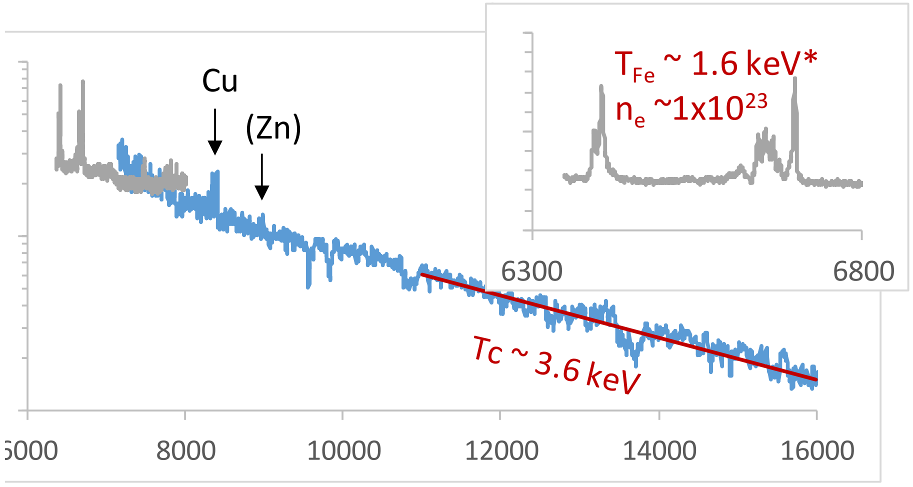


For thin liners, change in stability is not accompanied by major change in conditions, yield

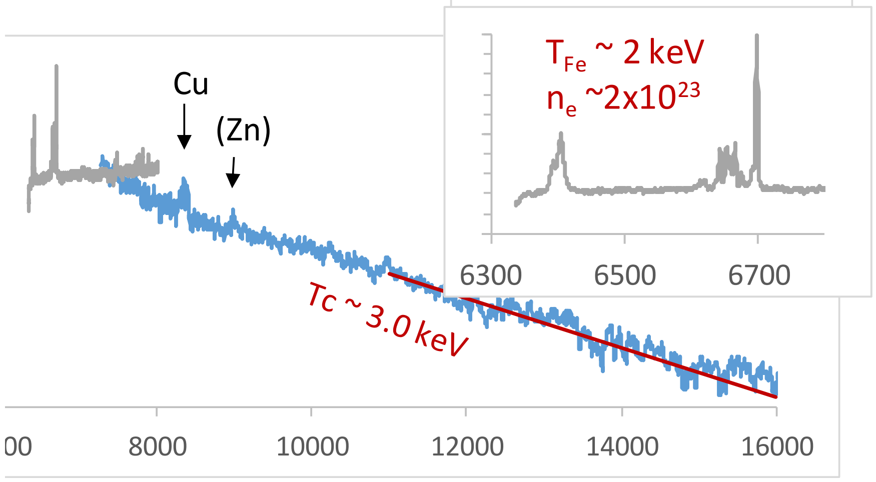




AR 9 uncoated

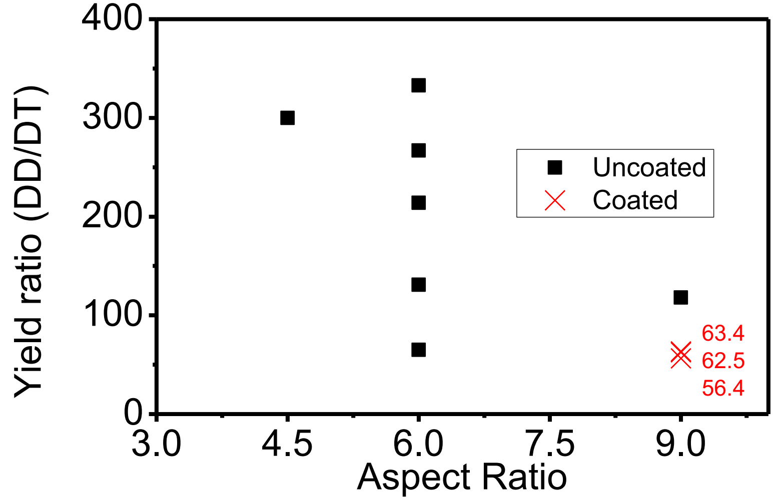


AR 9 coated



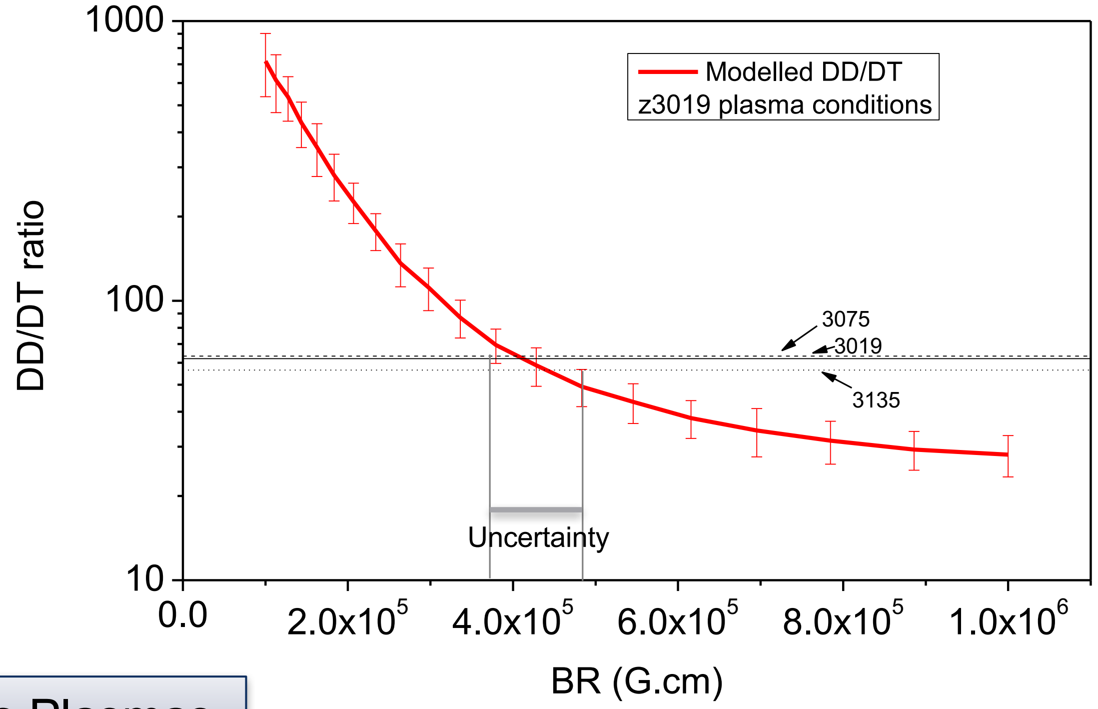
We have evidence of good magnetization in these coated liners, a key component of magnetized liner inertial fusion

- The ratio of DD to DT yields can provide a diagnostic of magnetic field-radius product
  - Coated experiments demonstrate reprodicible DD/DT ratio



- Plot generated for plasma parameters diagnosed in coated experiments

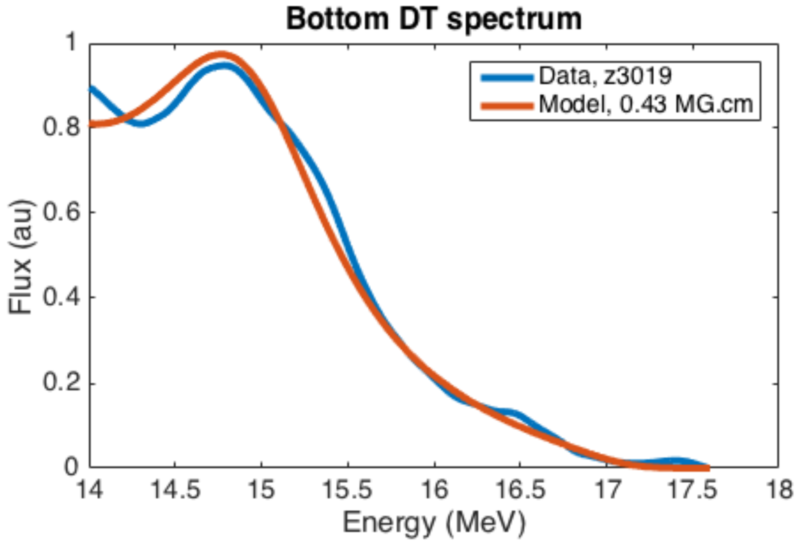
- Ratio of DD/DT yield for coated experiments is consistent with magnetic field-radius product of BR ~ 0.4 MG.cm
  - BR for coated AR 9 is on higher end of AR 6 uncoated BR, seems more consistent shot-to-shot

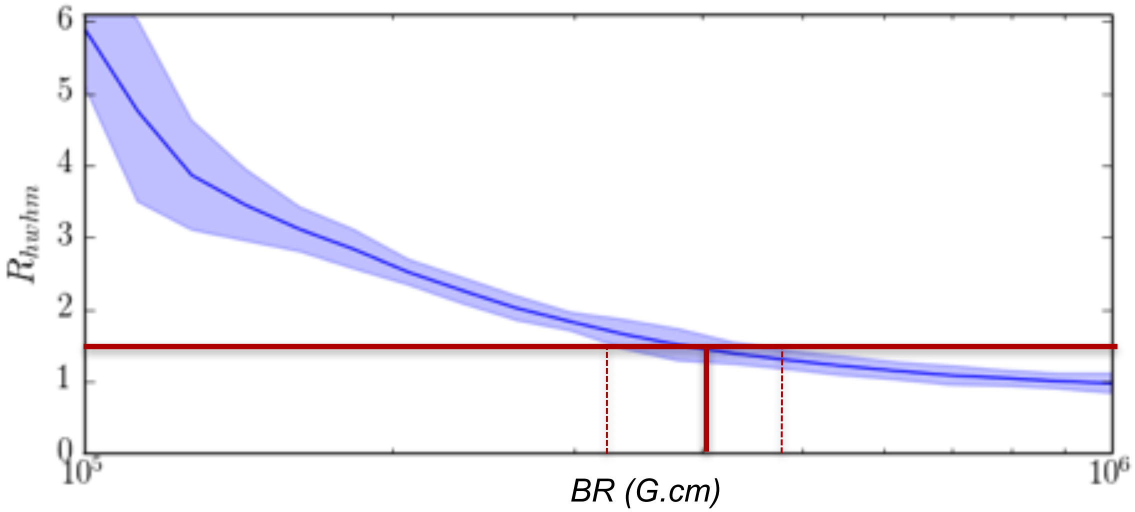


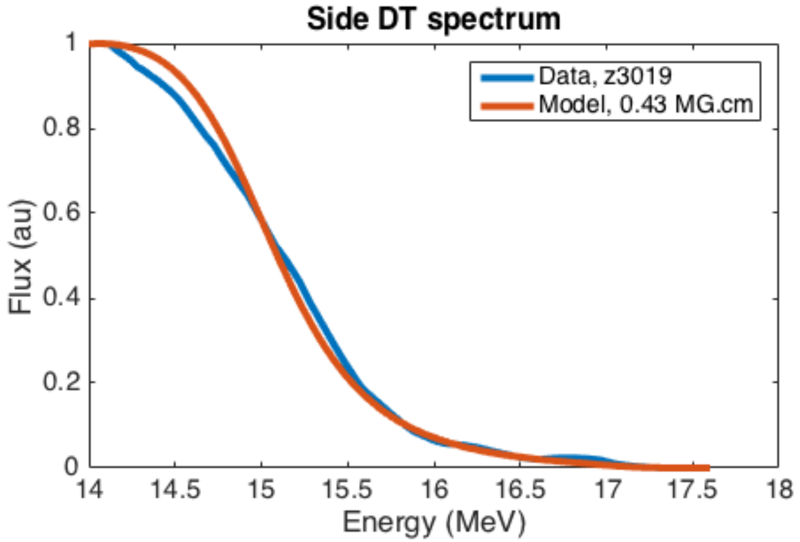
Based on Knapp *et al.*, Phys Rev Lett, Schmit *et al.*, Phys Plasmas

DT spectra are consistent with ~0.40 MG.cm magnetic field radius product, close to field ultimately needed for self heating

- DT spectral shape provides us with another indicator of magnetization
- Data is consistent with 0.4 MG.cm, whch is comparable to the best uncoated MagLIF shots







Based on Knapp *et al.*, Phys Rev Lett, Schmit *et al.*, Phys Plasmas

Overall, reproducibility of coated high aspect liners looks very promising, providing a potential path to further improvements in MagLIF

	3019	3075	3135	Mean	Variation
DD	3.0e12	2.6e12	3.1e12	2.9e12	9%
DT	4.8e10	4.1e10	5.5e10	4.8e10	15%
DD/DT	62.5	63.4	56.4	60.8	6%
T_{ion} (nTOF)	2.5 keV	2.2 keV	2.2 keV	2.3 keV	8%
T_e (continuum)	3.0 keV	3.3 keV	No data	3.15	7%

- Reproducibility of this coated high aspect ratio MagLIF configuration appears very promising
- This will allow us to diagnose subtle changes in plasma conditions and yields as we vary
  - Preheat
  - Magnetic fields
  - Current delivery

With coated, high aspect ratio liners we have demonstrated a MagLIF platform with minimal helical structure and axial variability that reproducibly creates ~3e12 yields