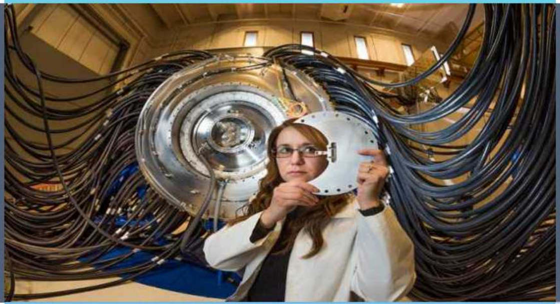
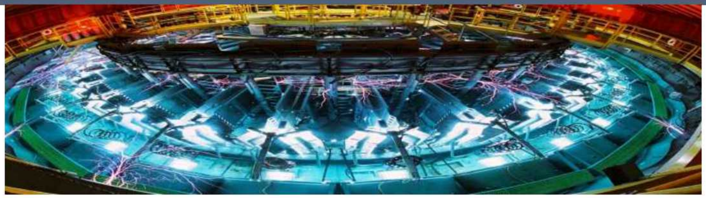
SAND2019-14153C

Radiographic measurements of the inertial confinement time in magnetically driven liner implosions





PRESENTED BY

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For the MagLIF team

At the 11th International Conference of Inertial Fusion Sciences and Applications

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Thanks to my collaborators

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- **Matt Martin (SNL)**
- Andy Porwitzky (SNL)
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- Matt Weis (SNL)
- Edmund Yu (SNL)
- Thomas Mattsson (SNL)
- Ryan McBride (U. Michigan)
- Kyle Peterson (SNL)
- Brent Jones (SNL)
- Greg Rochau (SNL)
- Dan Sinars (SNL)

Overview

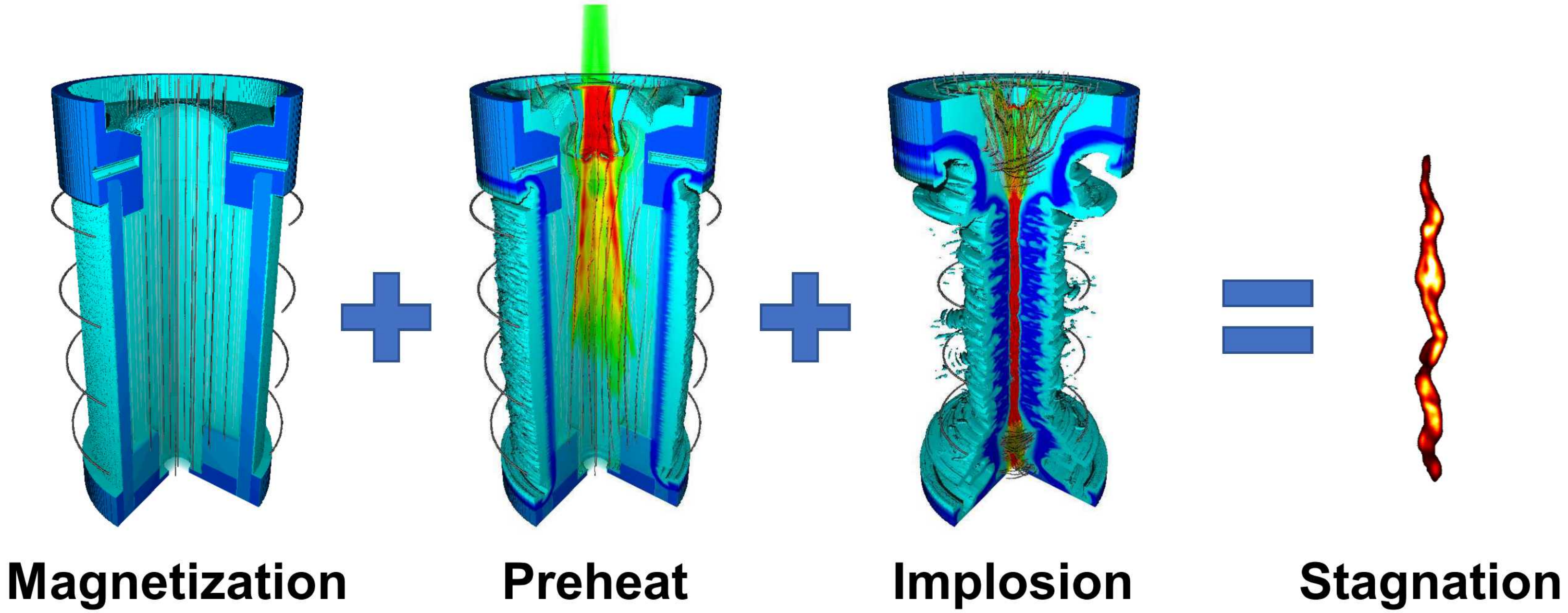
- What is MagLIF?
- How does the magneto Rayleigh-Taylor instability affect the Lawson criterion “P-tau” ?
- How do helical instabilities affect “P-tau” ?

MagLIF is our magnetically driven inertial confinement fusion concept at Sandia

MagLIF = **M**agnetized **L**iner **I**nertial **F**usion

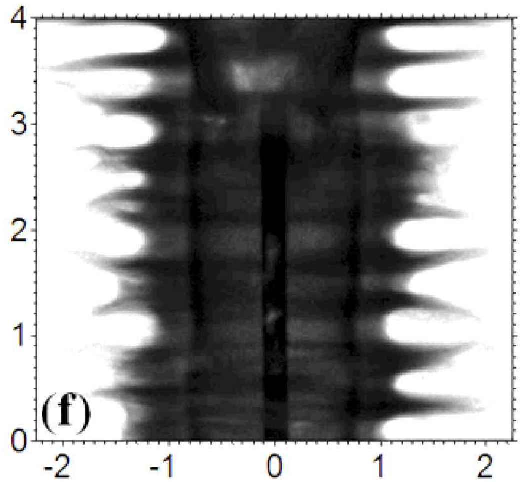
- Magnetic fields inhibit thermal conduction losses to the cold liner and trap alpha particles
- Relaxes areal density requirements of traditional ICF

We accomplish this in three stages:



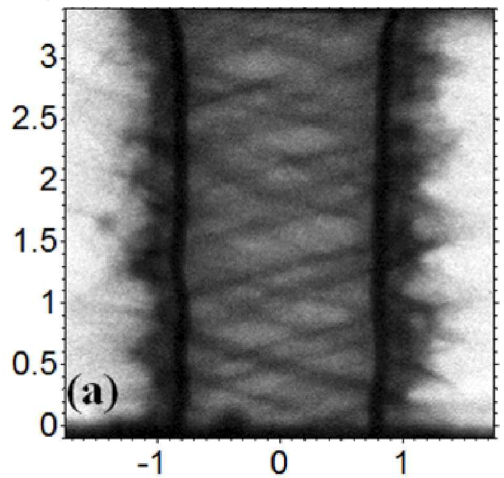
The implosion stage is susceptible to the magneto Rayleigh-Taylor (MRT) instability

Without Bz



McBride et al., Physics of Plasmas **20**, 056309 (2013)

Bz = 7 T



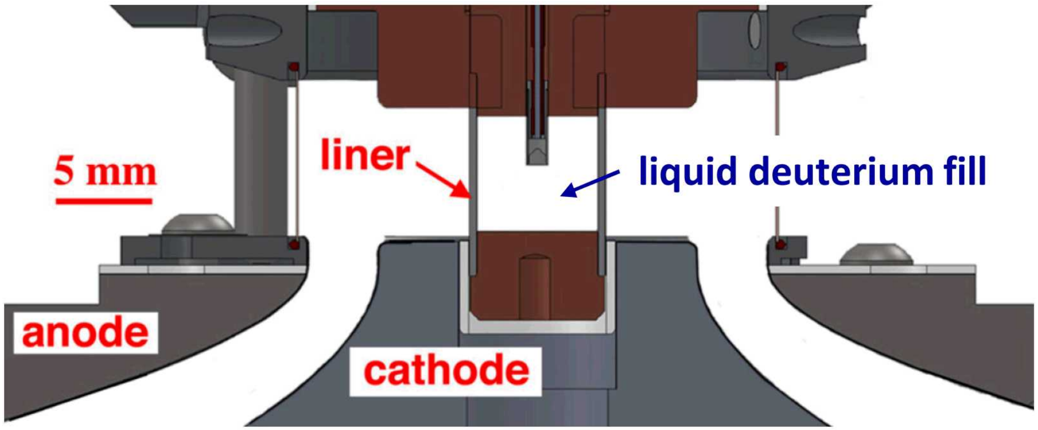
Awe et al., Physics of Plasmas **21**, 056303 (2014) experiments

- MRT deforms the inner liner surface, can increase liner/fuel mix, and reduces the inertial confinement time
- These experiments used empty liners (no back-pressure), making it unclear exactly how MRT affects inertial confinement

How do instabilities affect the Lawson criterion “P-tau” ?

We designed a platform to directly investigate the inertial confinement time for magnetically driven implosions

Use 12-MA from Z Machine to implode a beryllium liner filled with cryogenic deuterium → **generate high pressure, low temperature stagnation**



Knapp et al., Physics of Plasmas **24**, 042708 (2017)

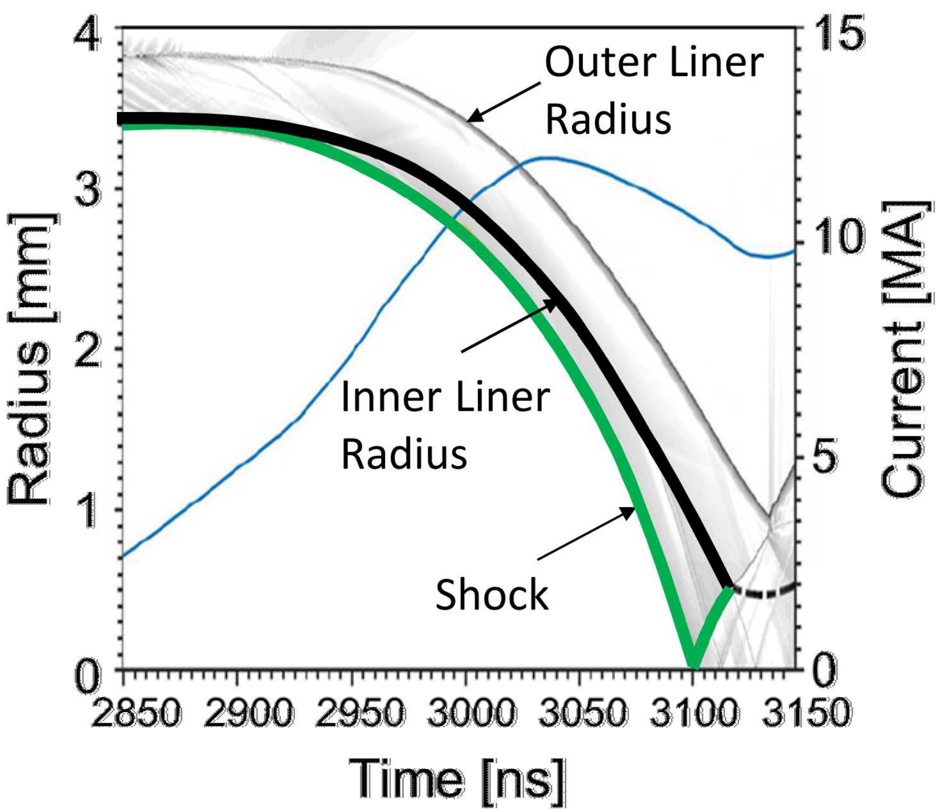
	This platform	MagLIF
ρ	10 g/cc	0.3 g/cc
T	10 eV	> 3 keV
P	~100 Mbar	> 600 Mbar
CR	8	~35

Using a low temperature removes the complexities of a fusion producing system → we measure the **hydrodynamic** confinement time

The initial target had no axial B field and was designed to stagnate in ~1D at a low convergence for detailed comparison with 1D and 2D simulations

Stagnation conditions are determined by a converging shock in the deuterium

- Shock reflects off axis and strikes liner, initiating deceleration
- Liner continues to compress deuterium to ~100 Mbar
- Velocimetry measurements of the shock and liner trajectories agree with 1D simulations



Disagreements with simulations begin during the stagnation phase, which will be the focus of this talk

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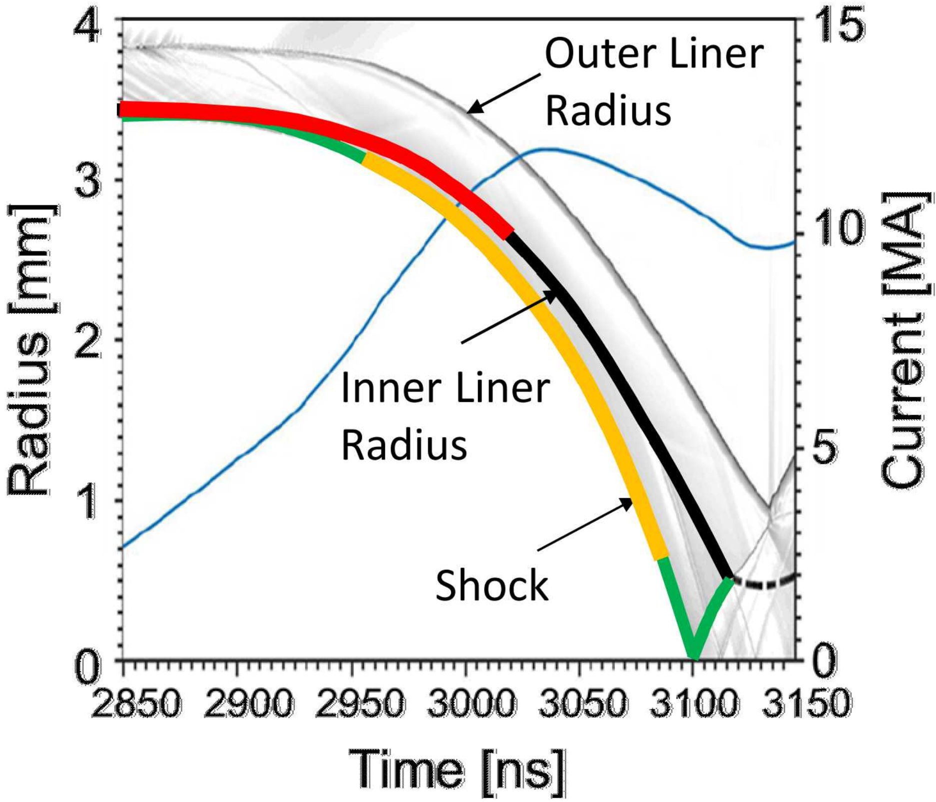

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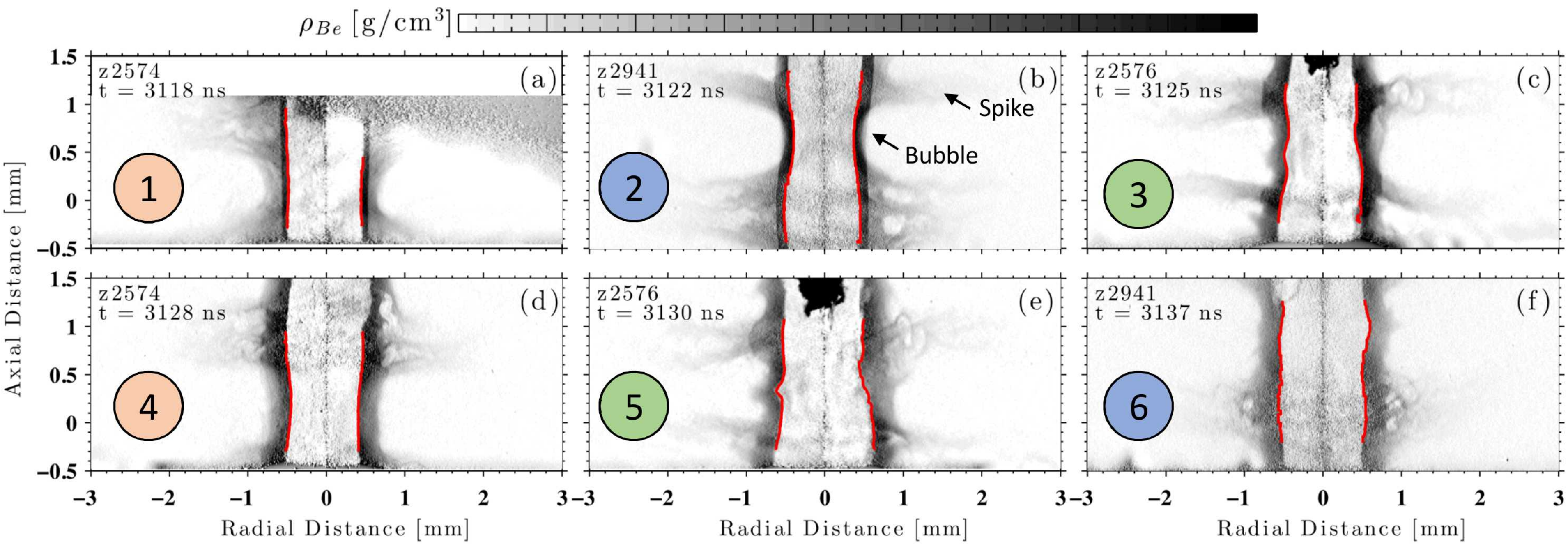
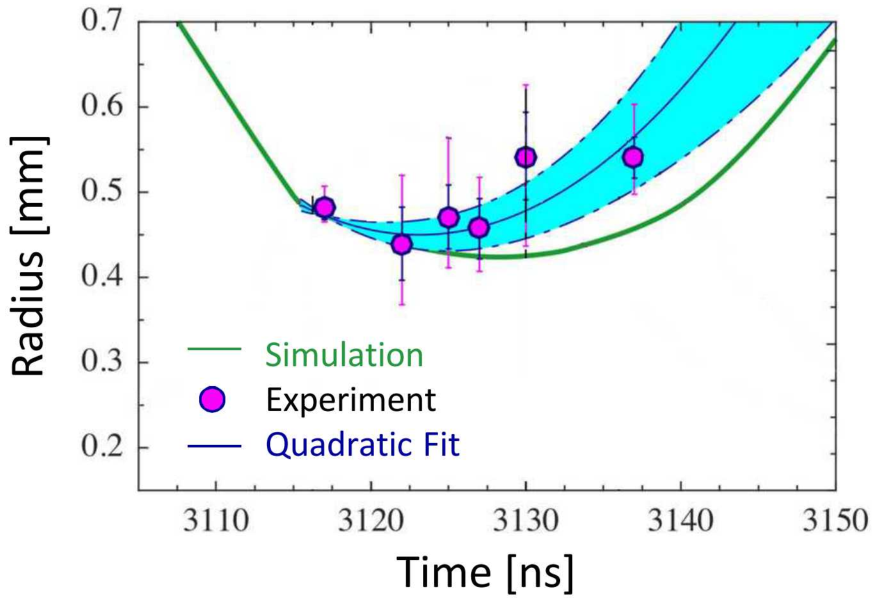
Radiographs show stagnation and disassembly of high pressure deuterium

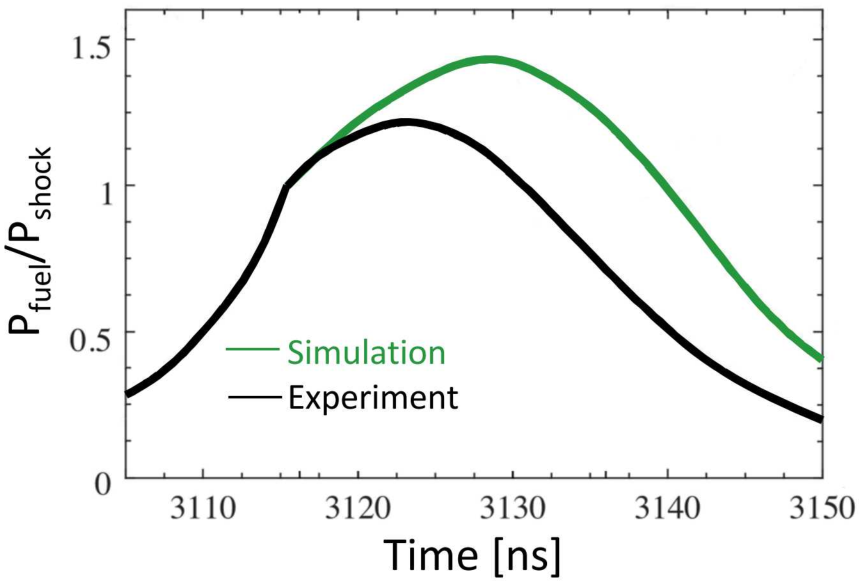


A few notable features

- We only register beryllium, deuterium appears “invisible” due to low opacity
- Azimuthally symmetric MRT spikes and bubbles
- No significant deceleration instabilities (Atwood # ~ 0.1, reduces RT growth rate)

Pressure history and confinement time are determined using the liner trajectory





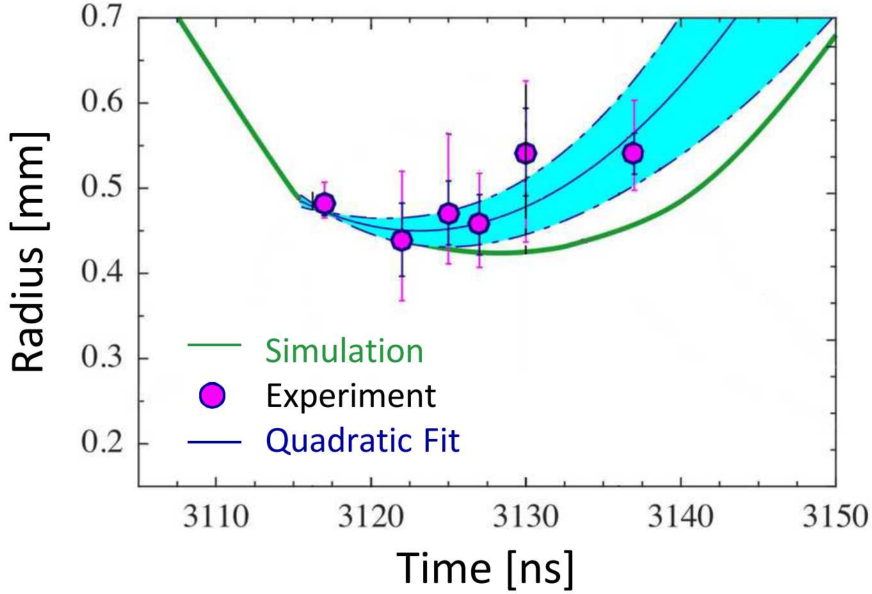
The liner disassembles faster than the simulations predict, indicating a reduced confinement time

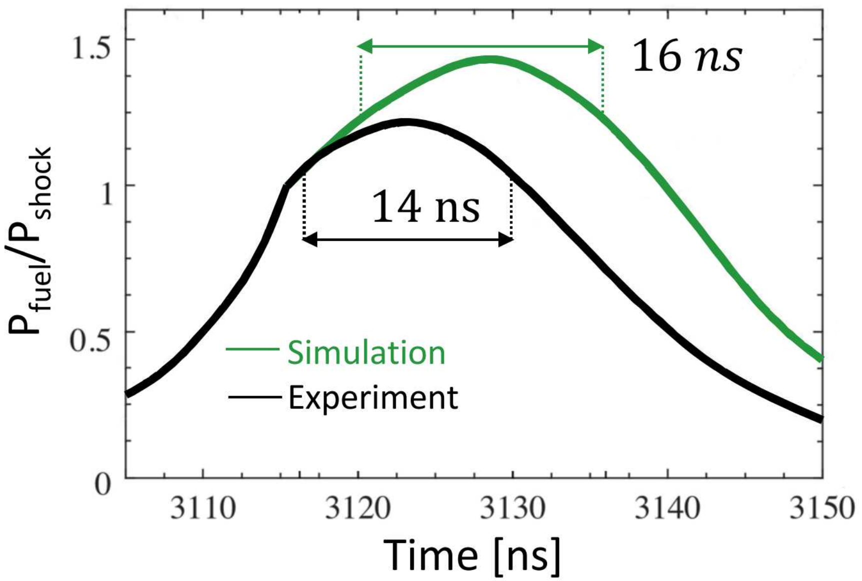
The **pressure history** is determined by the liner trajectory. Assuming the deuterium is adiabatically compressed during stagnation:

- $P_{\mathrm{fuel}} = P_{\mathrm{shock}} \cdot [CR]^{2\gamma} \sim R(t)^{-2\gamma}$
- γ = 4/3 (adiabatic index)

The experimental pressure is lower due to a reduction in the liner convergence

Pressure history and confinement time are determined using the liner trajectory





The **confinement time** is defined as time over which pressure is ~constant

$$P(t) > 0.85 \cdot P_{\max}$$

Both the pressure and confinement time are reduced, reducing the overall P-tau

$P = 85$ MBar (sim.)
$P = 72$ MBar (exp.)

✖

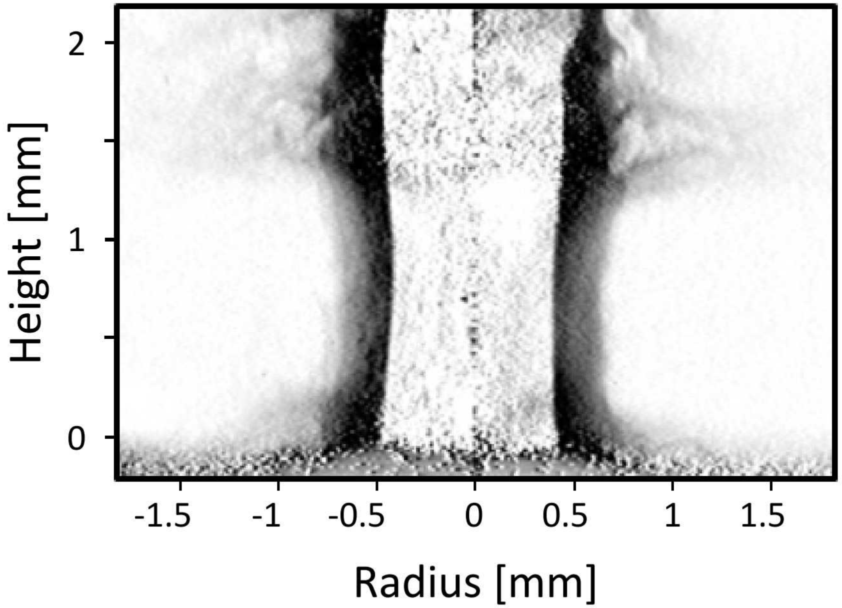
$\tau = 16$ ns (sim.)
$\tau = 14$ ns (exp.)

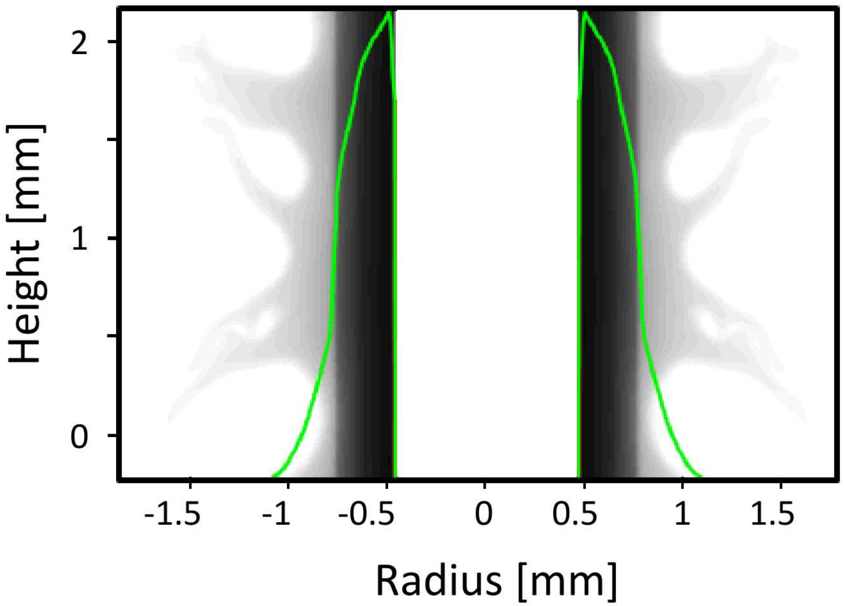
=

25% reduction in P-tau

(the 85% metric is arbitrary, but does not change the percent reduction in P-tau)

The MRT instability is more developed in experiments compared to the simulations





- MRT was seeded using experimental surface roughness of liner (~100 nm RMS)

Simulations under-predict

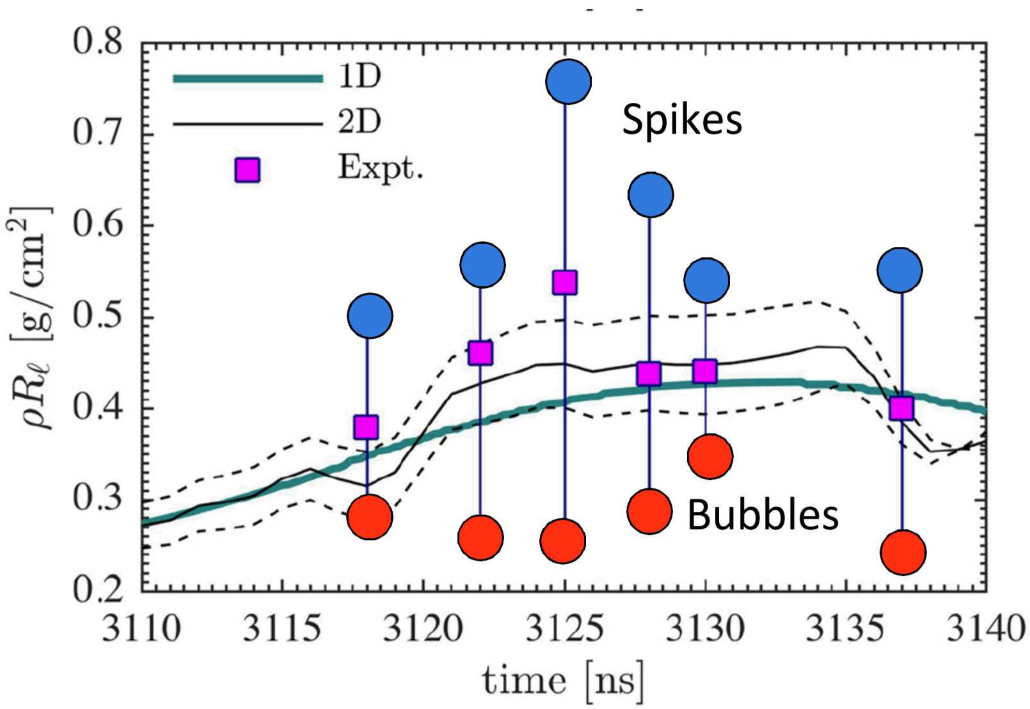
- MRT amplitude on outside of liner
- Feedthrough to inside of liner
- Instability wavelength

→

Simulations over-predict

- Deuterium pressure
- Inertial confinement time

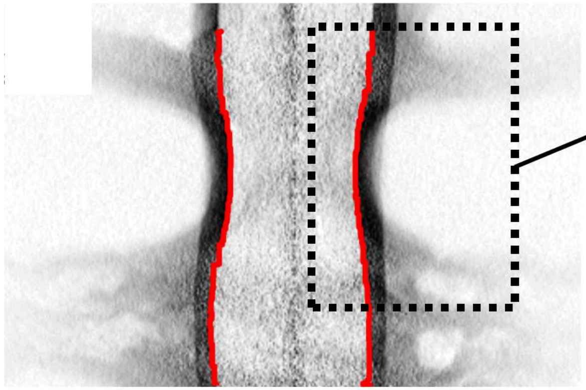
MRT redistributes mass to reduce liner areal density in "bubbles"

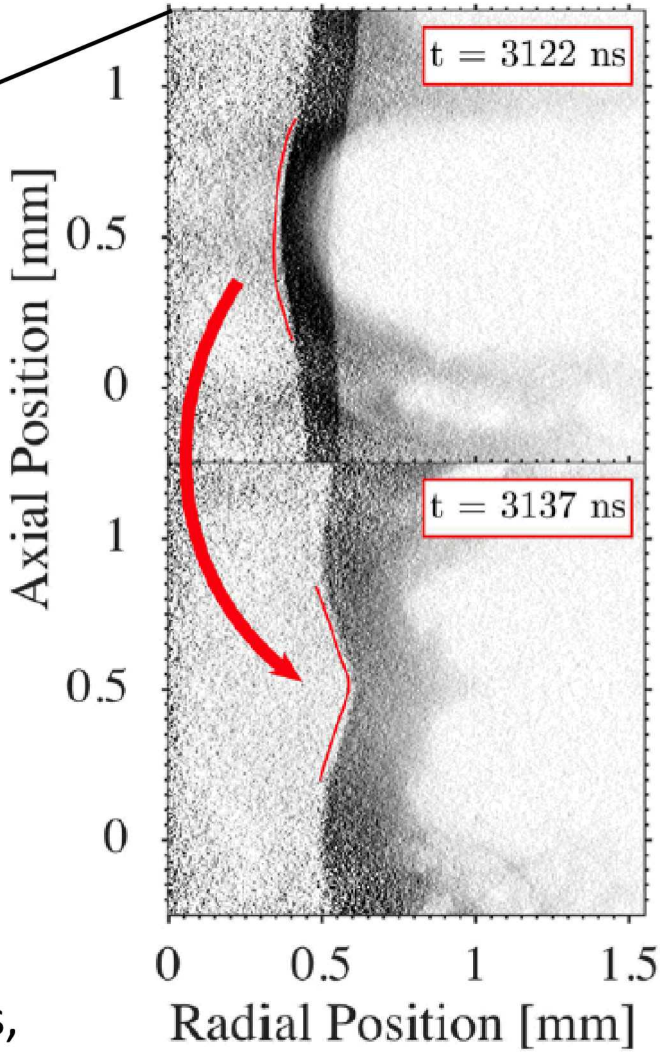


The liner becomes a less effective tamper in the bubble regions

- The reduced mass increases outward acceleration for a given fuel pressure
- This prematurely expands the fuel, decreasing pressure and confinement time

MRT redistributes mass to reduce liner areal density in "bubbles"





Regions of reduced areal density cannot tamp high pressure fuel

- Inflection in inner liner radius indicates fuel is "drilling" through liner
- Could eventually puncture liner, providing an addition mechanism for relieving fuel pressure

Similar to Springer's "aneurysms" in NIF capsules, see Nucl. Fusion **59,** 032009 (2019)

Our second campaign investigated the effects of an axial magnetic field and increased current

Our first campaign with *Bz* = 0 demonstrated P-tau was reduced by 25% due to the azimuthally symmetric MRT instability

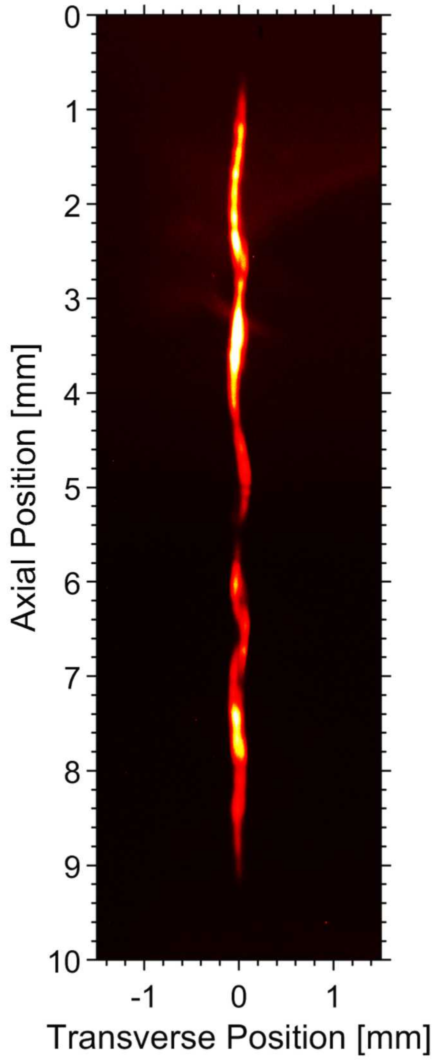
MagLIF requires an axial magnetic field, which shifts the instability to a helical mode

- No longer azimuthally symmetric MRT

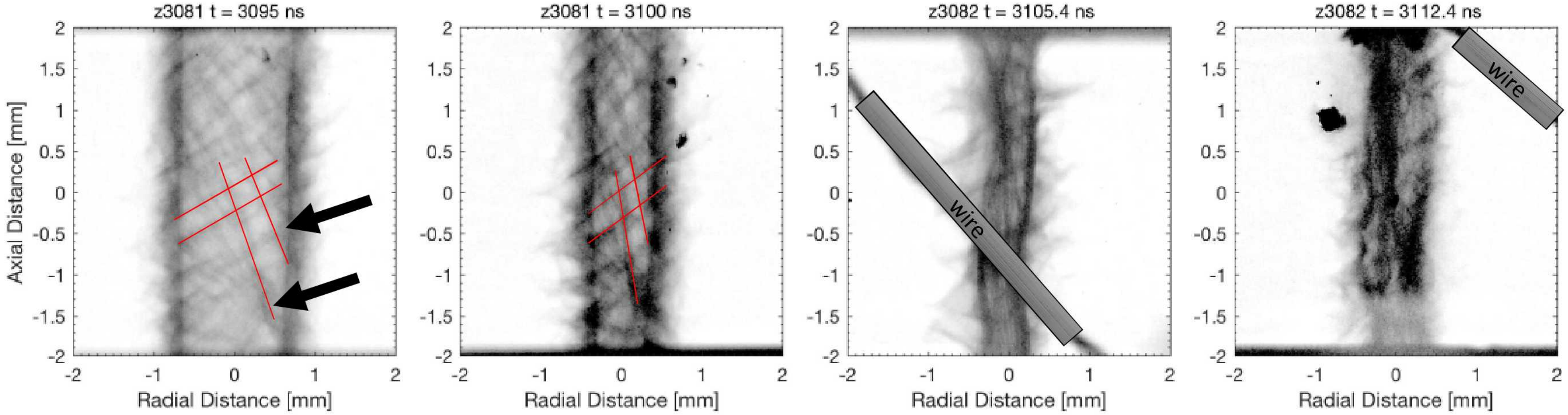
How does this affect P-tau?

To investigate this, we added an axial magnetic field and increased the target current

	1st Campaign	2nd Campaign
$B_{z,0}$	0 T	7 T
Current	12 MA	16 MA



We obtained radiographs during the implosion, stagnation, and disassembly stages



During the implosion, helically oriented structures develop on the outside of the liner

- The pitch angle of these is not the same on the “front” and “back” sides of the liner!
- The pitch angle increases as the liner implodes, indicating the structures are “locked-in”

During stagnation, a long-wavelength kink instability (λ ~ 2.3 mm) forms prior to disassembly

Preliminary analysis shows the kink-mode degrades the confinement time

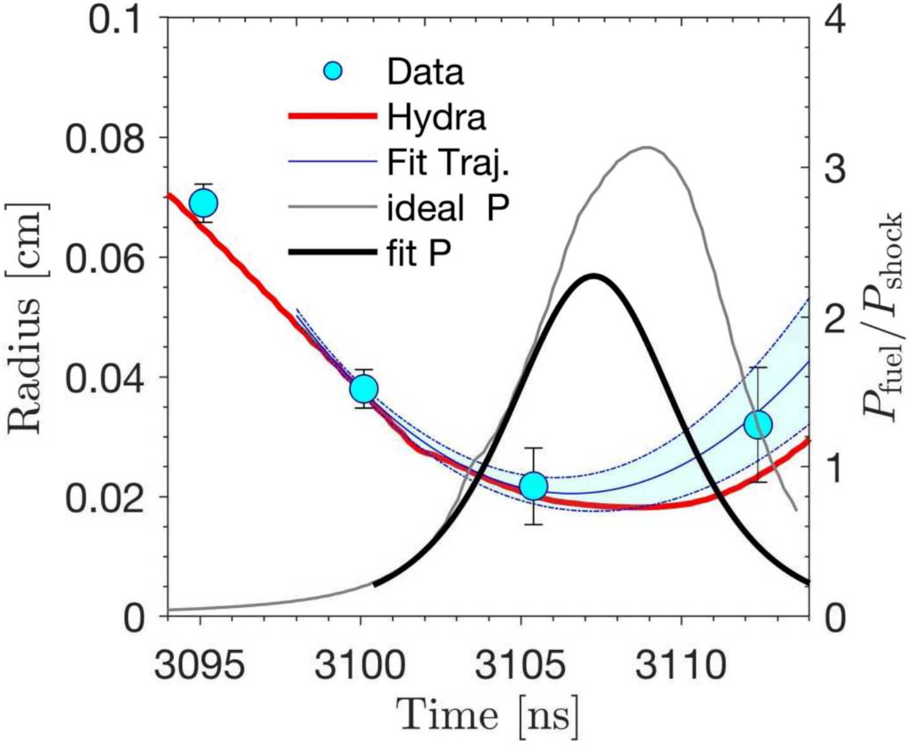
Inner liner radius gives us an estimate of the pressure history

Using the 85% metric, comparison with simulations show:

$$P(t) > 0.85 \cdot P_{\max}$$

$$\tau = 4.5 \text{ ns (sim.)}$$
$$\tau = 3.4 \text{ ns (exp.)}$$

~25% reduction in tau
~40% reduction in P-tau



Reduction in P-tau is very similar to lower current, non axially magnetized case

Summary and future work

We have directly demonstrated the link between the MRT instability and degradation of P-tau:

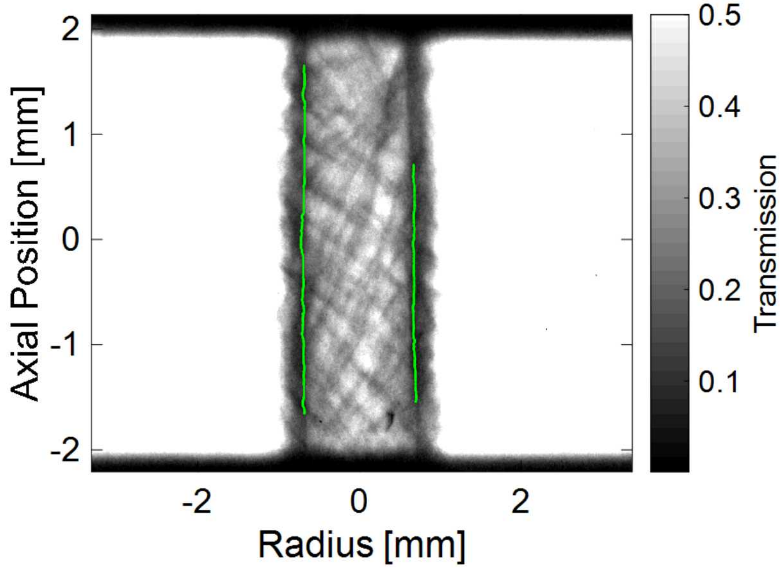
Axial Field & Peak Current	0 T 12 MA	7 T 16 MA
Decrease in tau	15%	25%
Decrease in P-tau	25%	40%

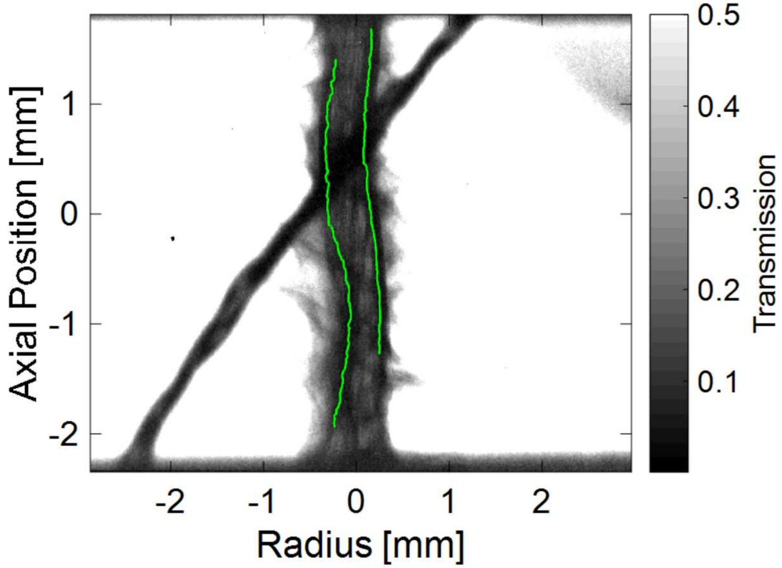
We have one more shot to complete the magnetized dataset

Nine additional experiments will scale the un-magnetized target from

12 MA to 21 MA to understand how the degradation of P-tau scales at larger currents

The origin of the long-wavelength kink mode remains unclear

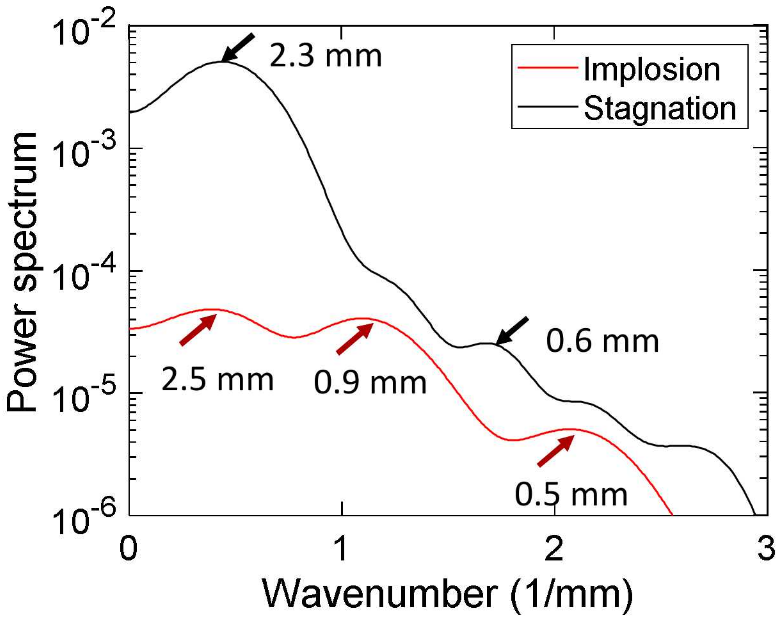




There is a small peak near the 2.3 mm kink wavelength: ~1/100th of amplitude

However, the total FOV is ~4 mm, so care must be taken when interpreting >2 mm peaks

The long-wavelength kink mode is likely formed during stagnation



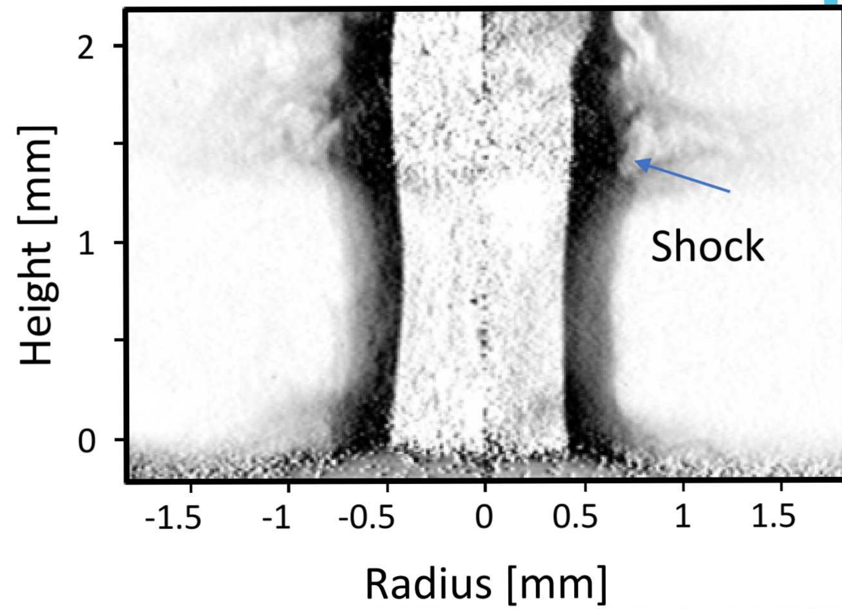
Simulations under-predict the shock speed in the liner

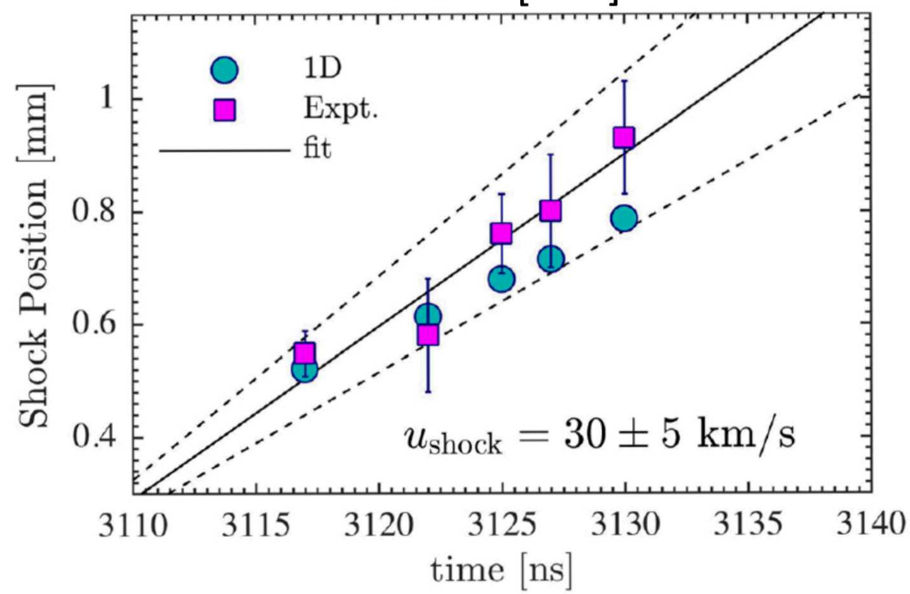
- Shock speed measured using radial location of shock identified in radiography

- Agrees for early part of stagnation, but disagrees during disassembly

- How does this affect confinement time?

$$\tau = f_{\mathrm{T}} R_{\mathrm{hs}} / C_{\mathrm{s}} \qquad f_{\mathrm{T}} \propto \left(\frac{\gamma_\ell}{\gamma_{\mathrm{HS}}}\right)^{1/2} C_s^{\mathrm{HS}} \frac{M}{u_s}$$





This could indicate discrepancies in the EOS, or be a symptom of mass re-distribution from MRT

How does this platform compare to MagLIF?

Parameter	This platform	MagLIF
Peak Current	12 MA	16+ MA
Preheat	No	yes
Axial Field	No*	10+ T
Fuel density	10 g/cc	0.3 g/cc
Fuel temperature	10 eV	~3 keV
Fuel pressure	~100 MBar	~0.6 GBar
Convergence Ratio	8	35+

This target was designed to stagnate at large radii for clear radiographic diagnosis of the stagnation and disassembly process

*Preliminary results with an axial magnetic field will be presented