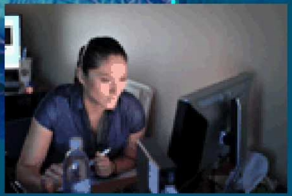
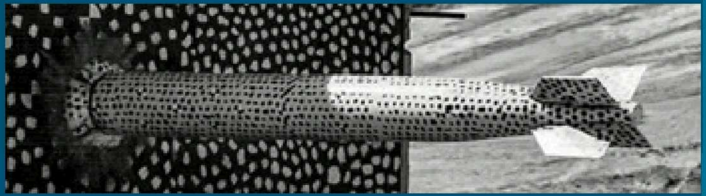
SAND2019-3079PE

Hydrodynamics Experiments on the Z Pulsed Power Driver





PRESENTED BY

Patrick Knapp

Innovating Hydrodynamic Diagnostics Workshop

Santa Fe NM

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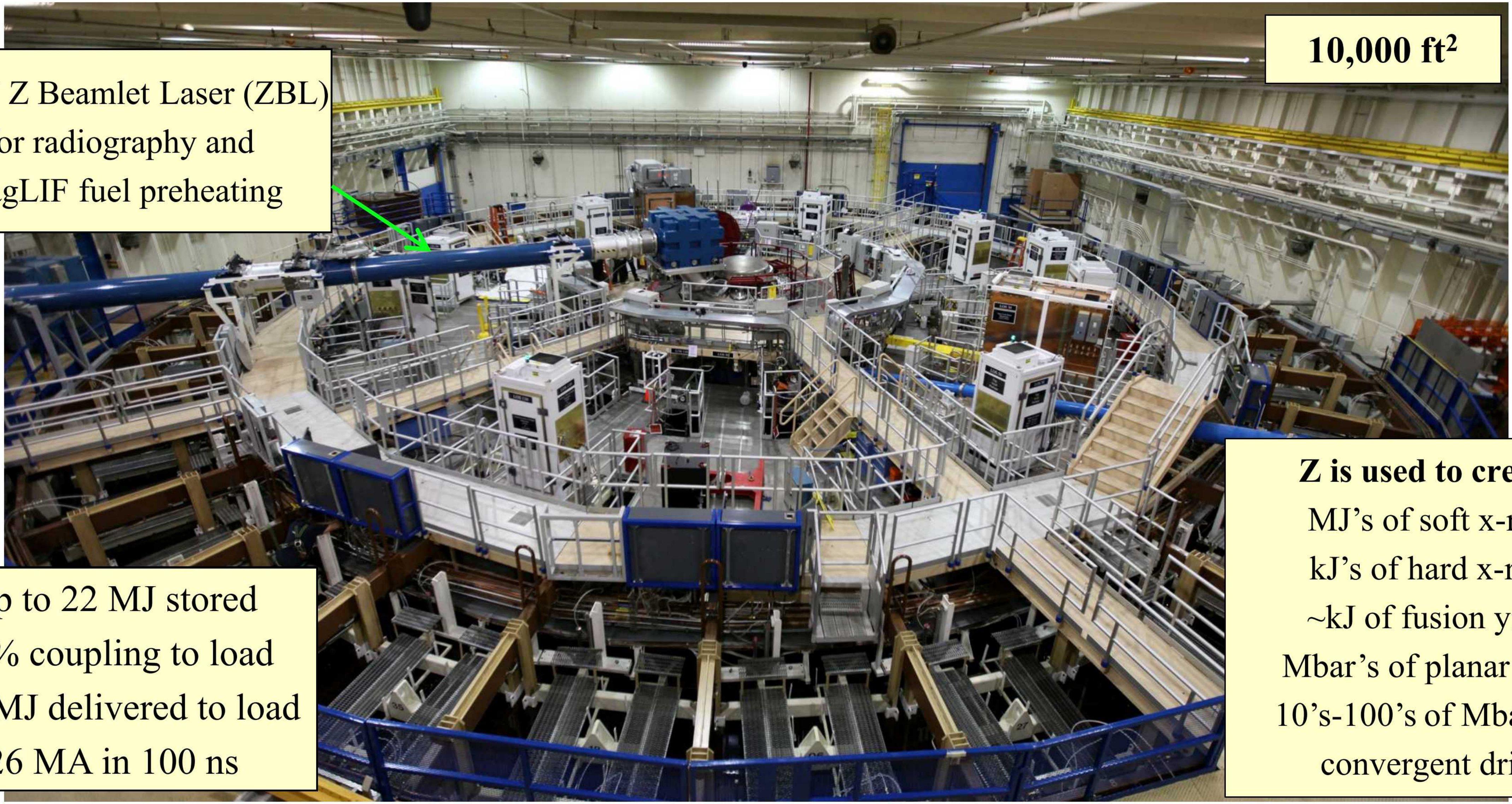
Outline

- A brief overview of pulsed power liner experiments
- Convergent RM platform on Z
  - Current results
  - Plans and improvements
- A look at the possibility of diverging cylindrical platforms for RM and RT

The Z facility combines the multi-MJ Z pulsed-power accelerator with the multi-kJ Z Beamlet Laser (ZBL)



1–4 kJ Z Beamlet Laser (ZBL)
for radiography and
MagLIF fuel preheating

10,000 ft^2

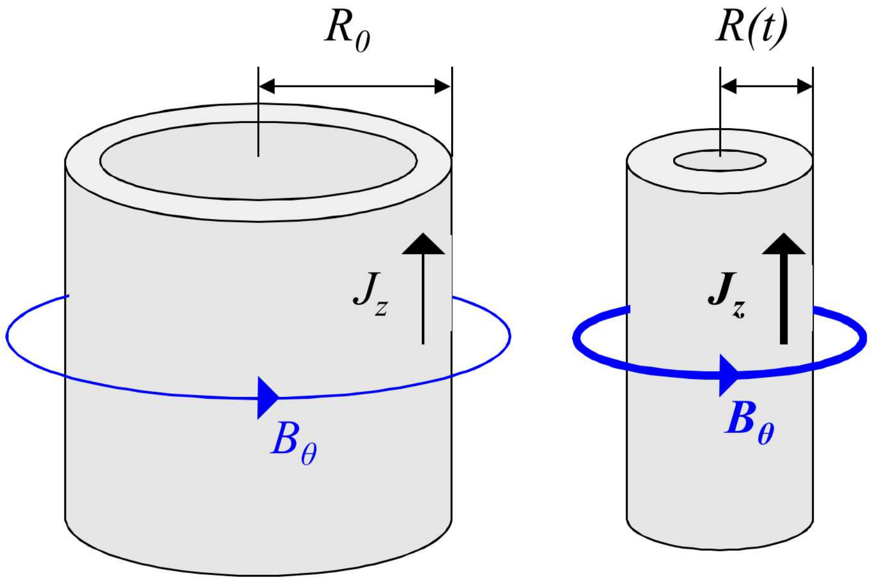
Up to 22 MJ stored
15% coupling to load
1–3 MJ delivered to load
26 MA in 100 ns

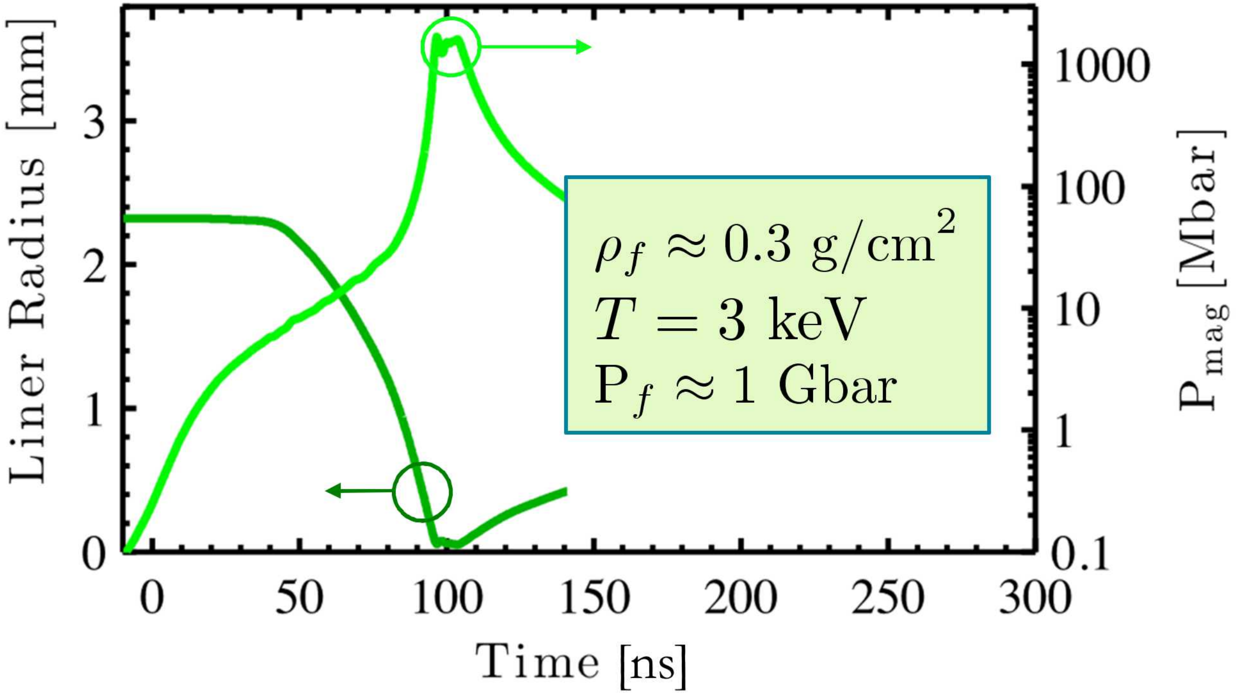
Z is used to create:
MJ's of soft x-rays
kJ's of hard x-rays
~kJ of fusion yield
Mbar's of planar drive
10's-100's of Mbar's of
convergent drive

Magnetically-Driven Cylindrical Implosions are Efficient: Implosion Drive Pressure is Divergent!

$$P = \frac{B^2}{2\mu_o} = 140 \cdot \left(\frac{I_{[\mathrm{MA}]}/30}{R(t)_{[\mathrm{mm}]}} \right)^2 \quad [\mathrm{Mbar}]$$

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) = \frac{\mathbf{J}\times\mathbf{B}}{c} - \nabla P$$





By varying the magnetic pressure pulse shape, liner dimensions, and duration of drive, Z can access a wide variety of end states

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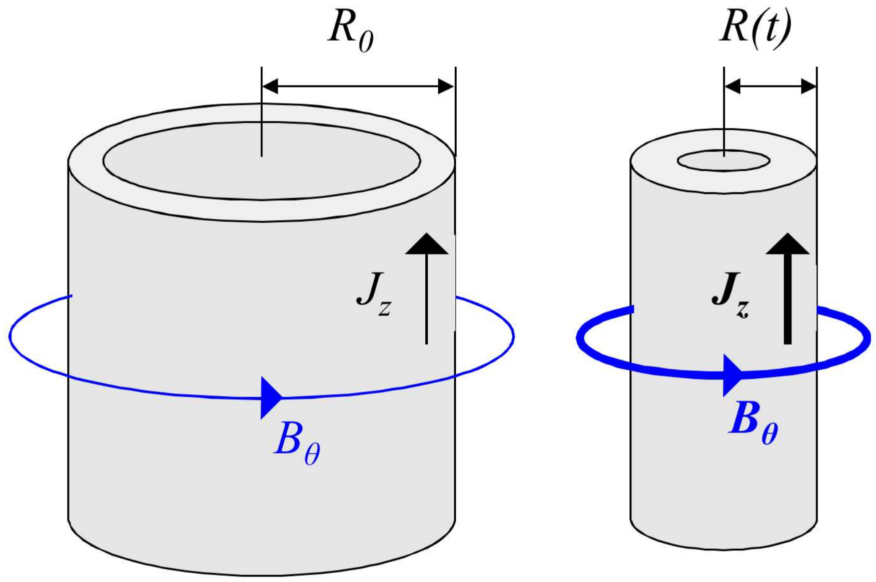

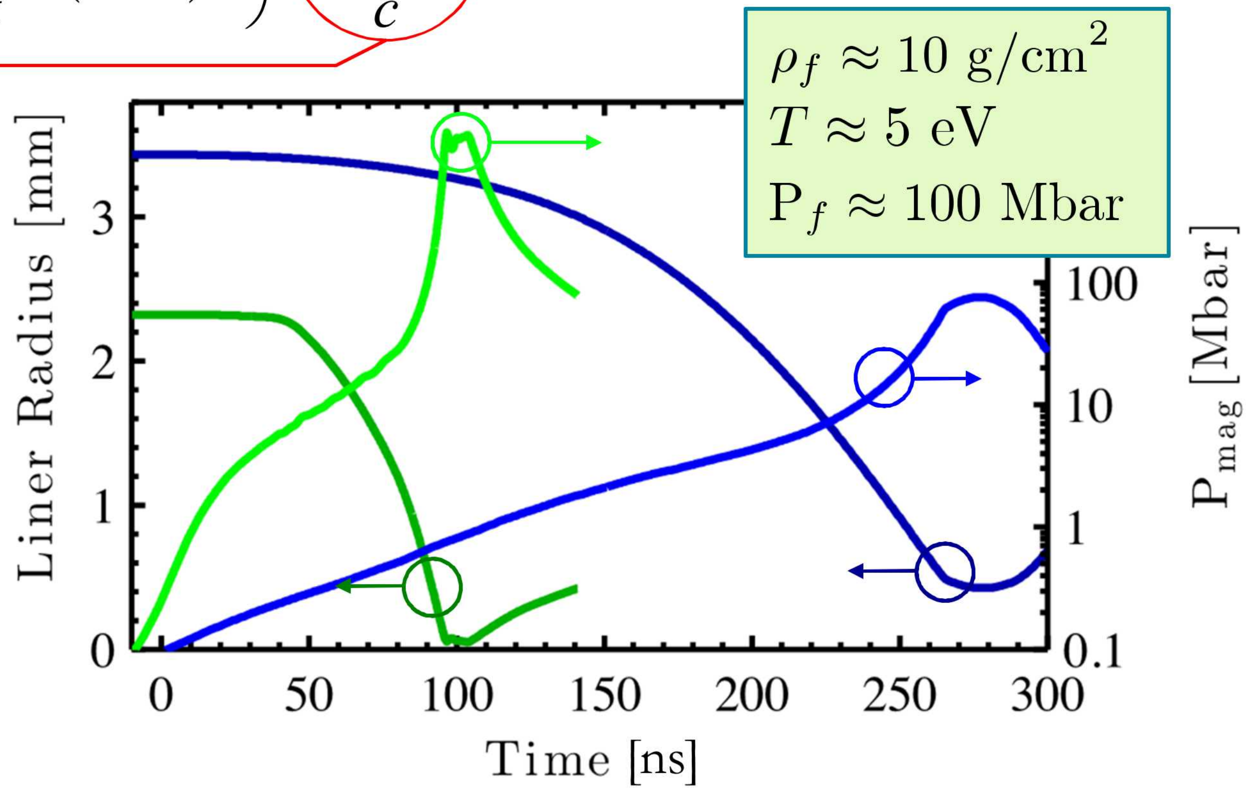

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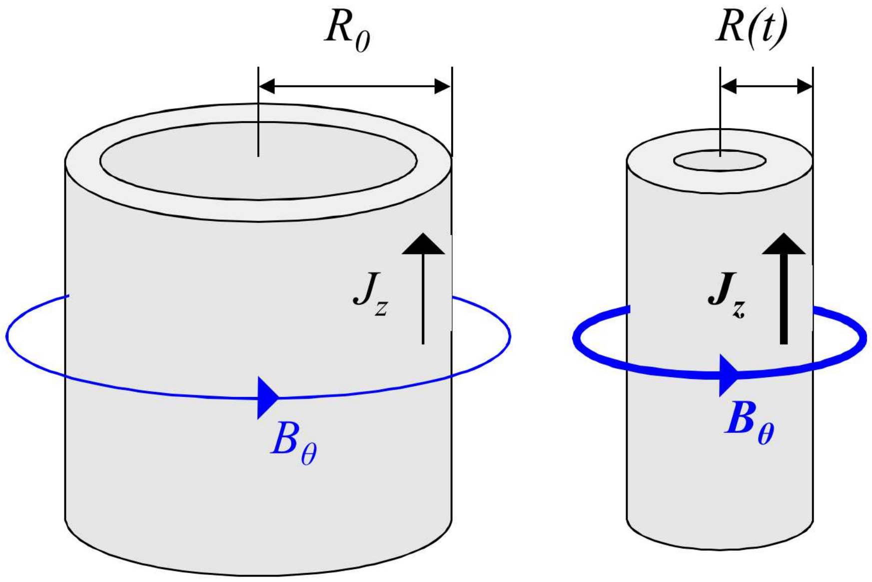
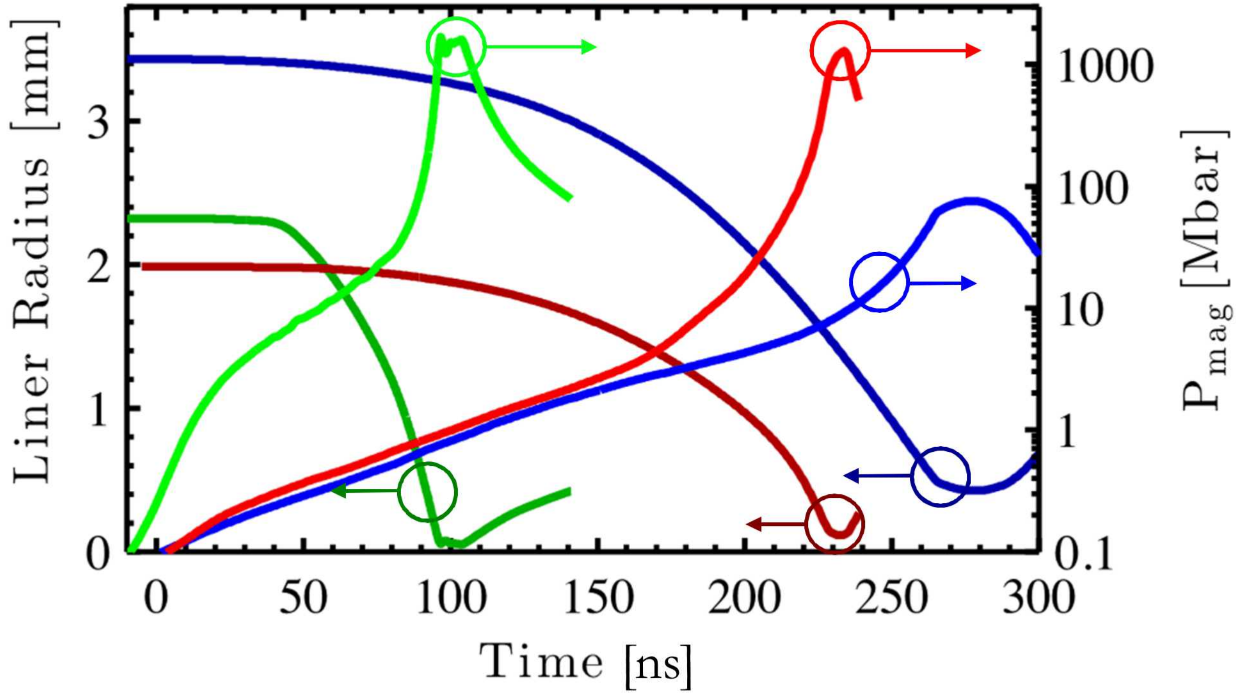
$\rho_f \approx 60$ g/cm^2
$T \approx 10$ eV
$P_f \approx 2$ Gbar





By varying the magnetic pressure pulse shape, liner dimensions, and duration of drive, Z can access a wide variety of end states

Our first foray into hydro instability physics has been to develop a platform for convergent RM measurements

The platform is comprised of

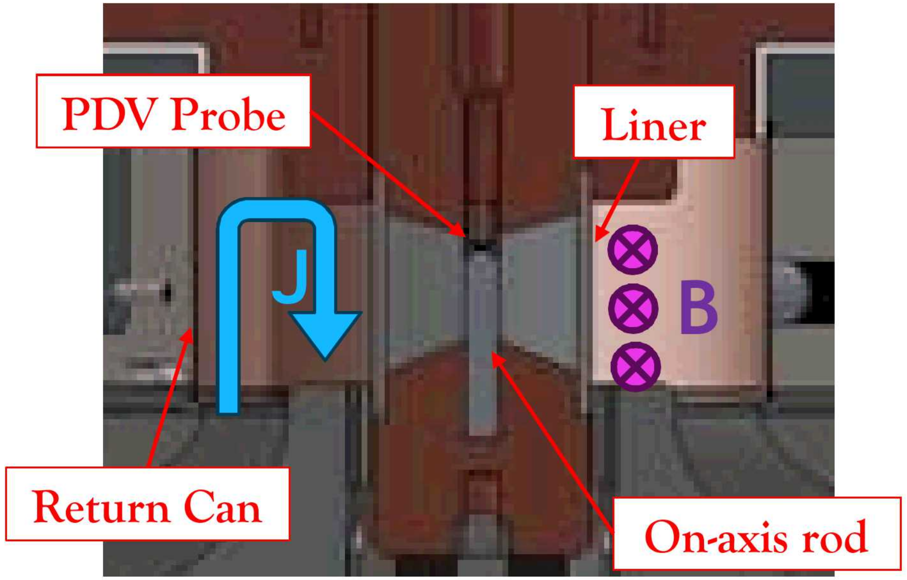
- A Be liner
- A liquid D_2 fill
- An on-axis Be rod with machined perturbation

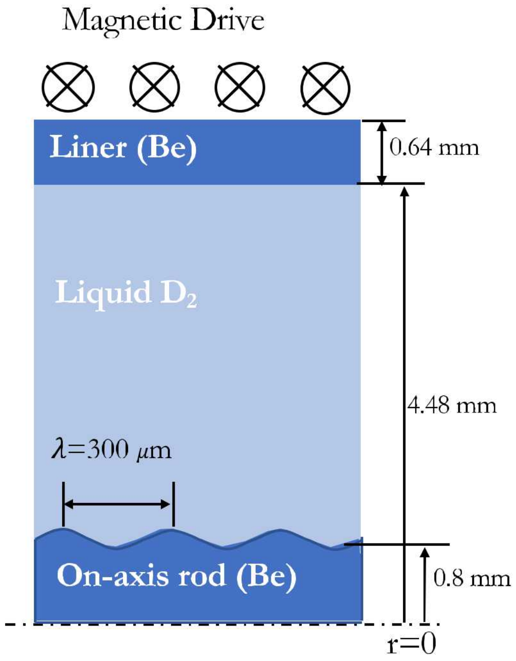
Z's current flows through the liner, causing it to implode

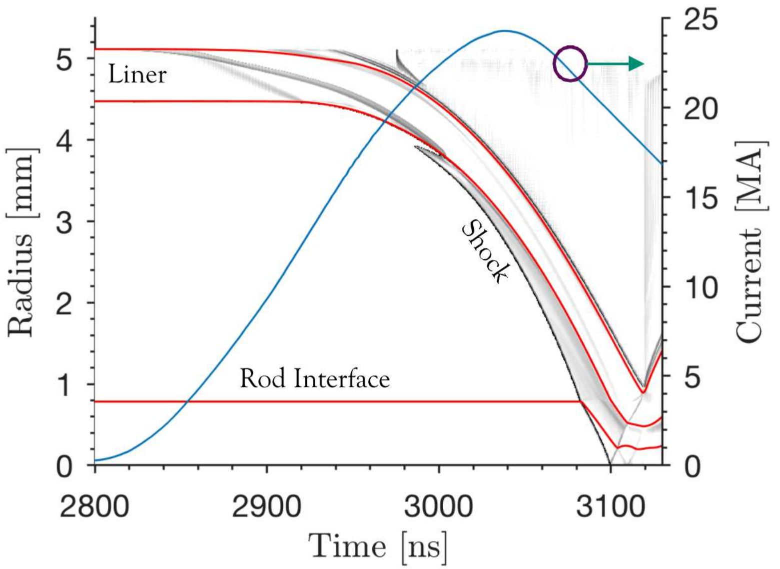
A strong shock is driven in the D_2

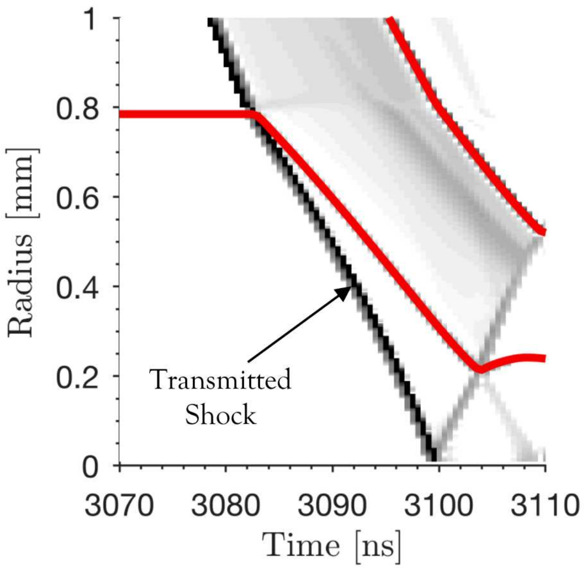
The shock impacts the rod, driving the RM process

The instability growth is diagnosed using x-ray BL









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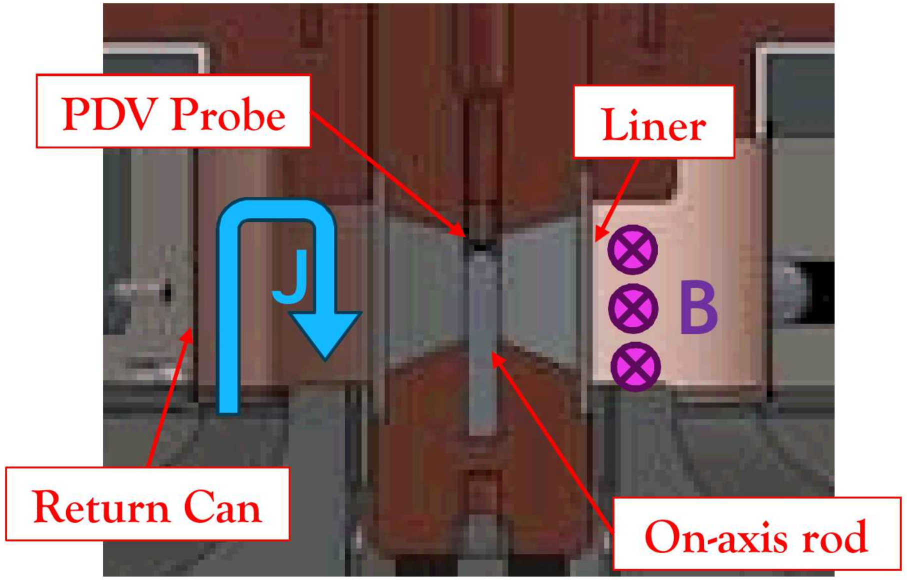
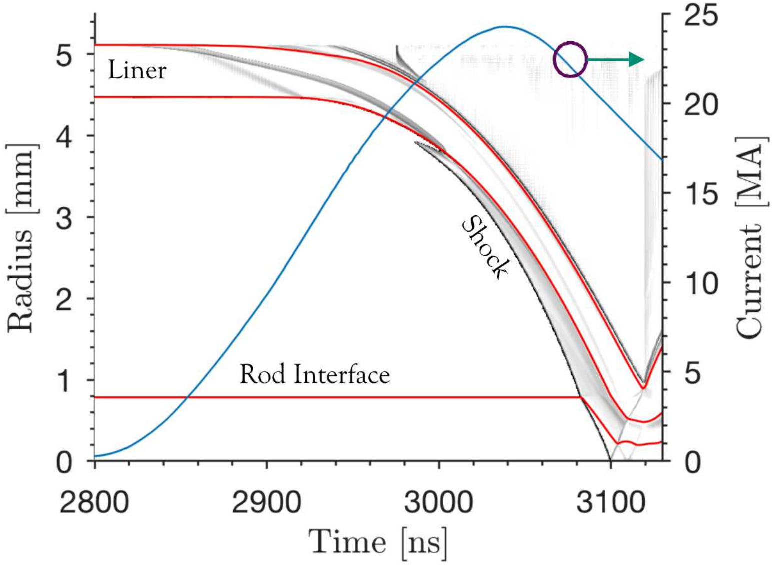
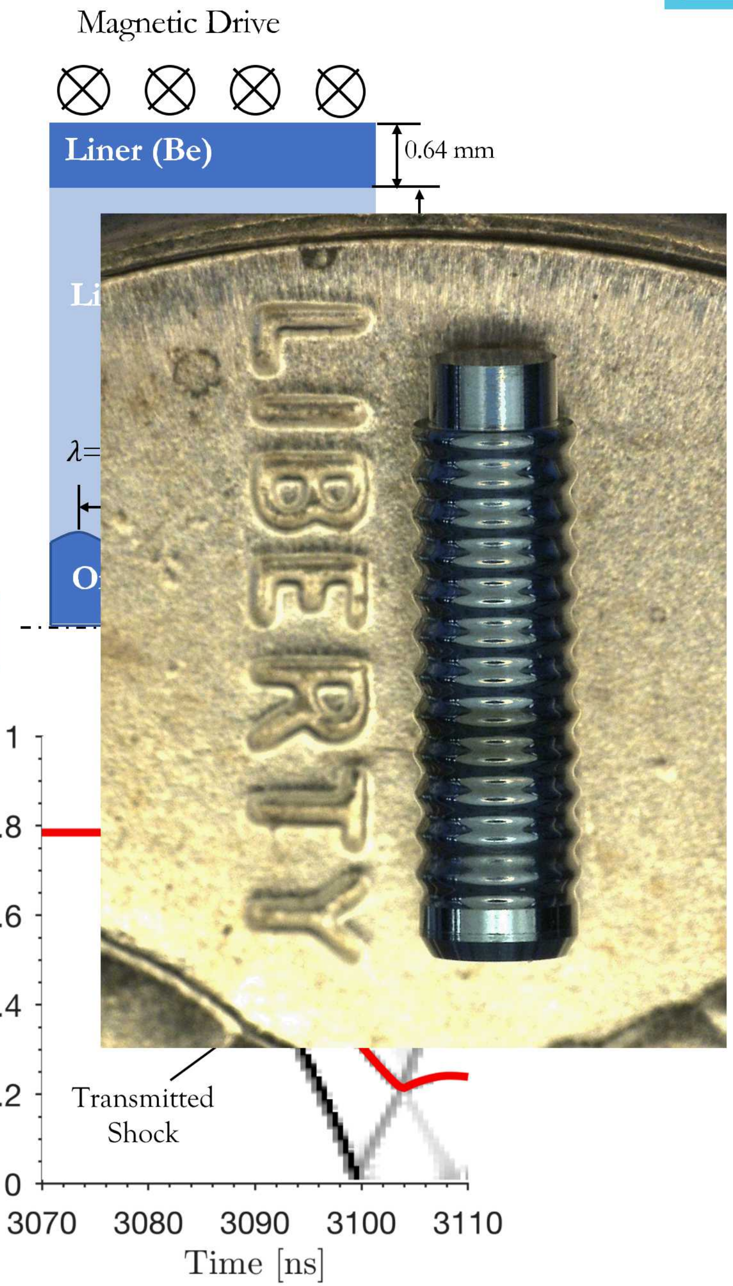
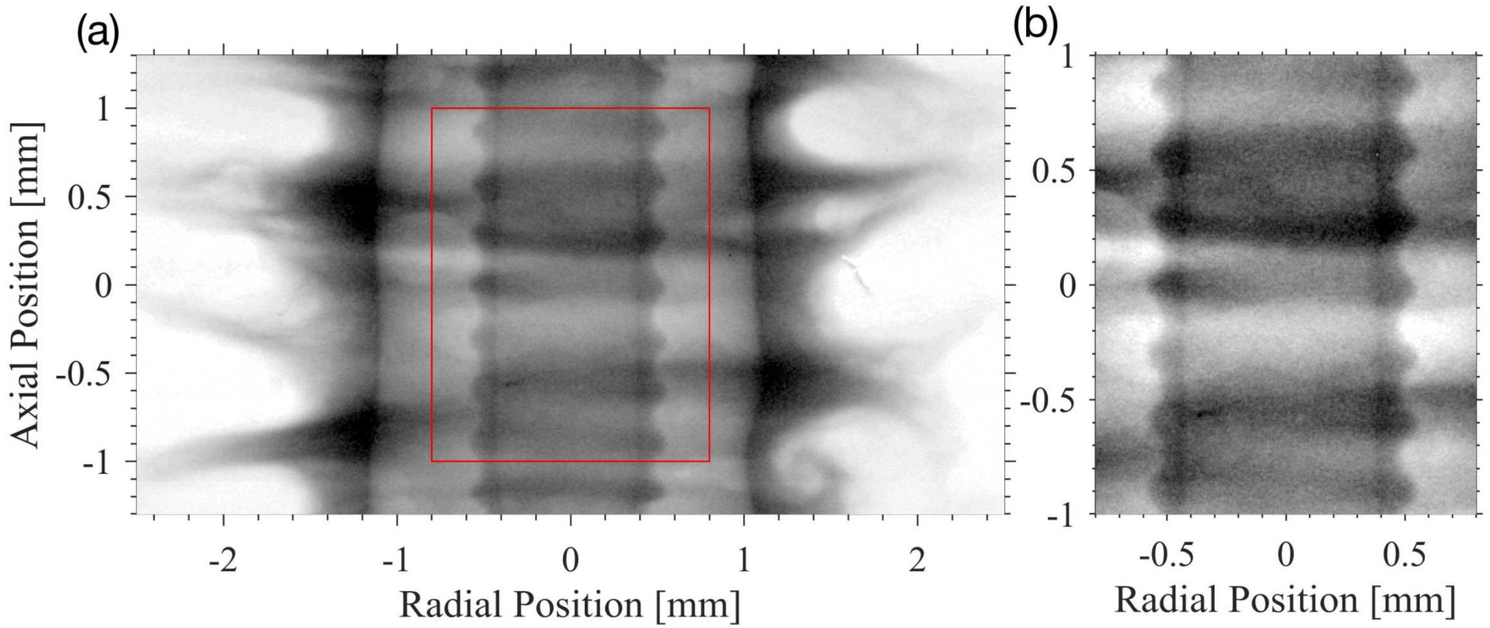






Abel inversion allows the density of the rod to be inferred without obstruction from the liner



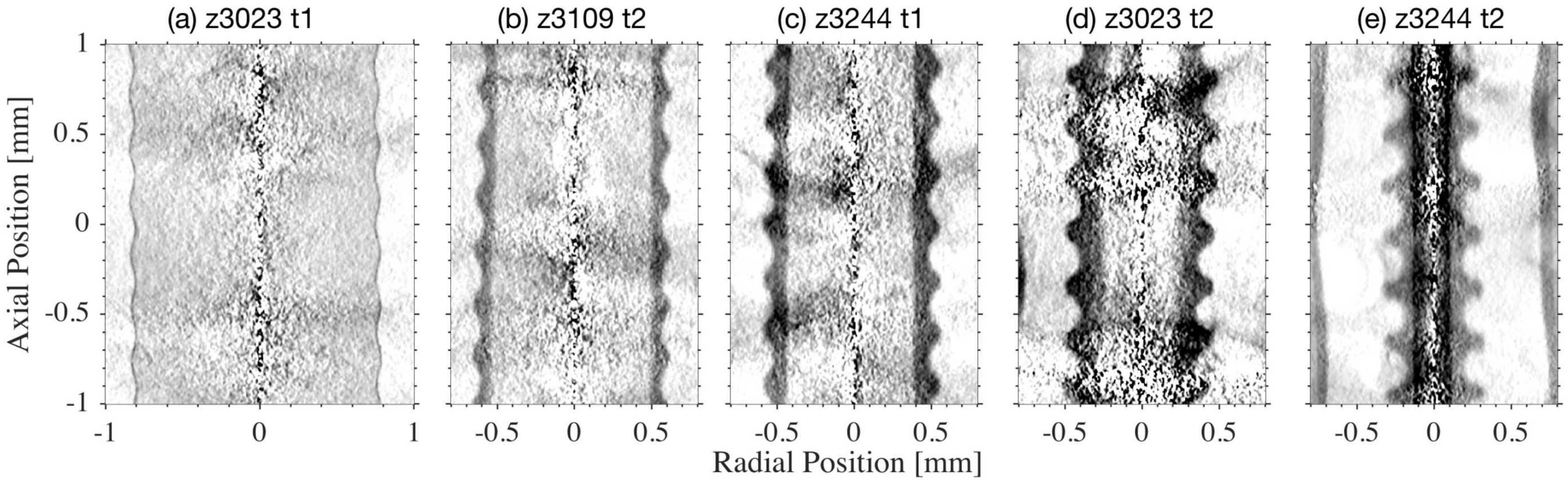
Radiographs are monochromatic at 1.85, 6.15, or 7.2 keV (we use 7.2 keV here)

full radiographic FOV is 4 mm x 12 mm

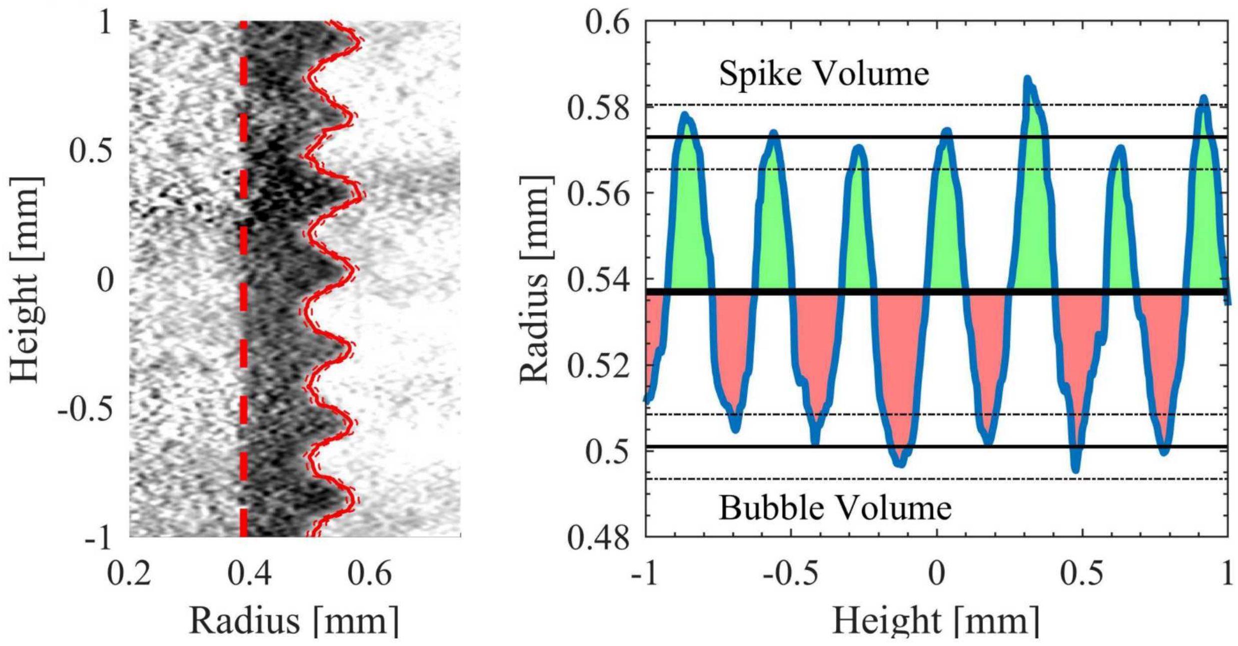
The spatial resolution is 12 μm

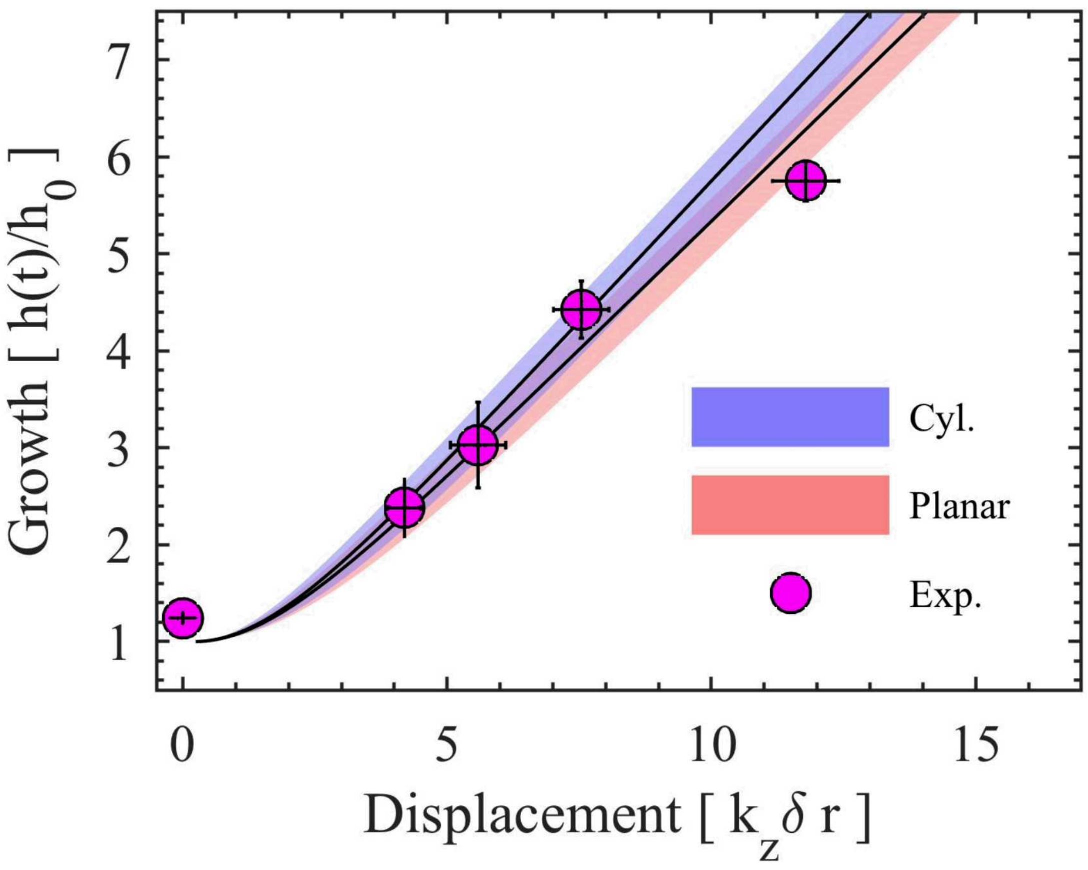
Contrast and SNR allow us to invert the data directly to obtain density

Abel invert to obtain ρ(r,z)



We can track the contour with high fidelity and measure the growth and mean interface position





The data agrees well with cylindrical theory from Lombardini et al.

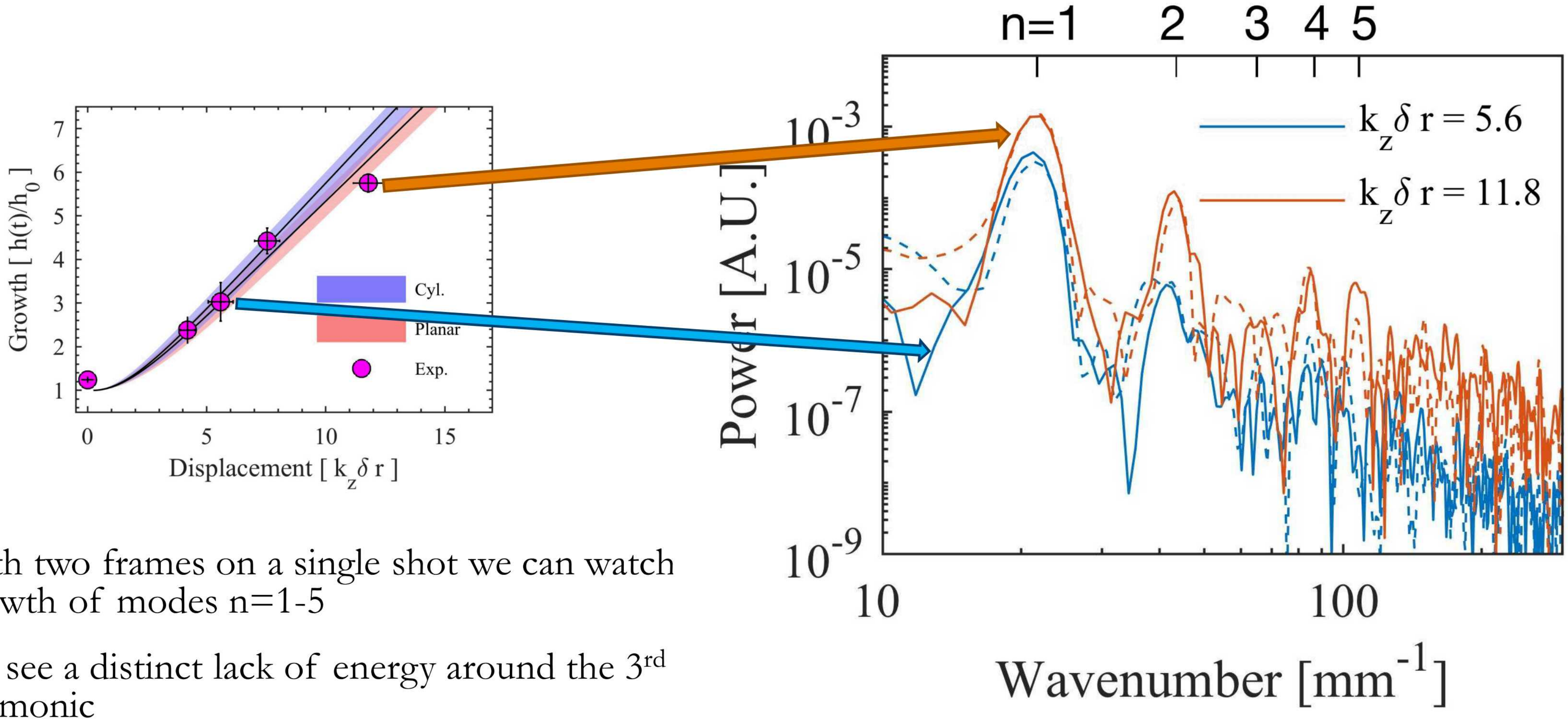
Must include the shock proximity and compression effects

With current diagnostics it is not really possible to distinguish between cylindrical and planar

2D post-shot simulations in progress for detailed comparison

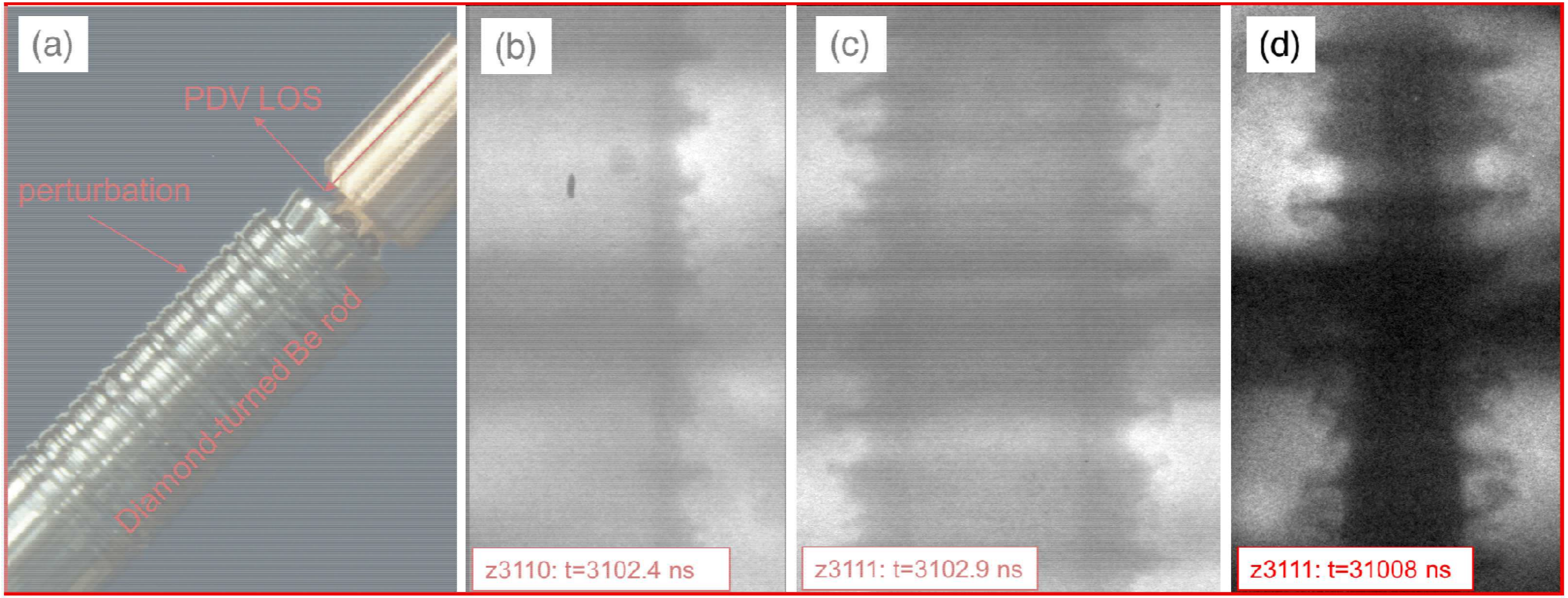
M. Lombardini et al., Physics of Fluids 21, 114103 (2009)

The high spatial resolution affords the possibility of performing detailed comparisons in the nonlinear growth phase



- With two frames on a single shot we can watch growth of modes n=1-5
- We see a distinct lack of energy around the 3rd harmonic
- This data is suitable for detailed comparisons with interfaces from 2D simulations

Scoping experiments with a multimode perturbation show tantalizing results

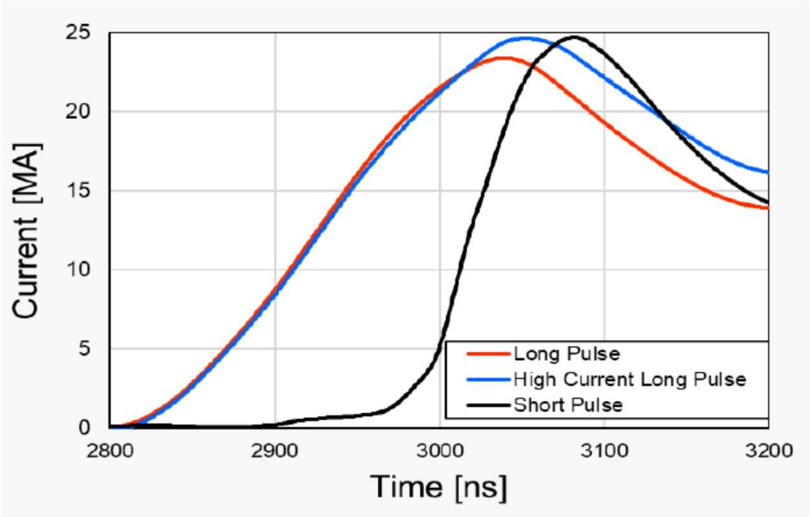


Using a complex 10-mode initial perturbation we are able to quickly see highly nonlinear behavior

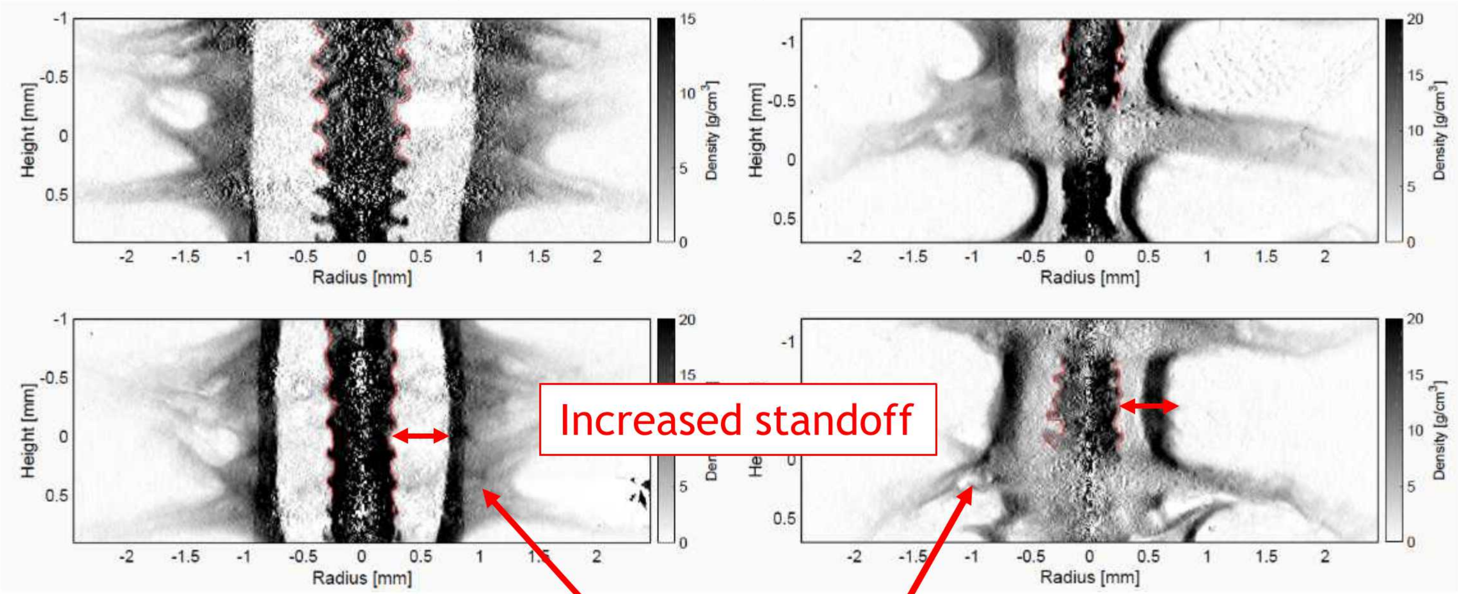
- Mushrooming
- Mode competition
- Bending of large amplitude spikes

With improved liner stability, we plan to push this into the reshock and mixing regime

Reducing the current risetime can dramatically improve liner stability, providing a number of benefits to the platform



Images taken near same point of rod evolution



Increased standoff

short pulse

long pulse

Reduced spike amplitude improves transmission

In order to push into the reshock phase and probe mixing, liner stability must be improved

Reducing the current risetime decreases the implosion time, reducing the number of MRT growth times

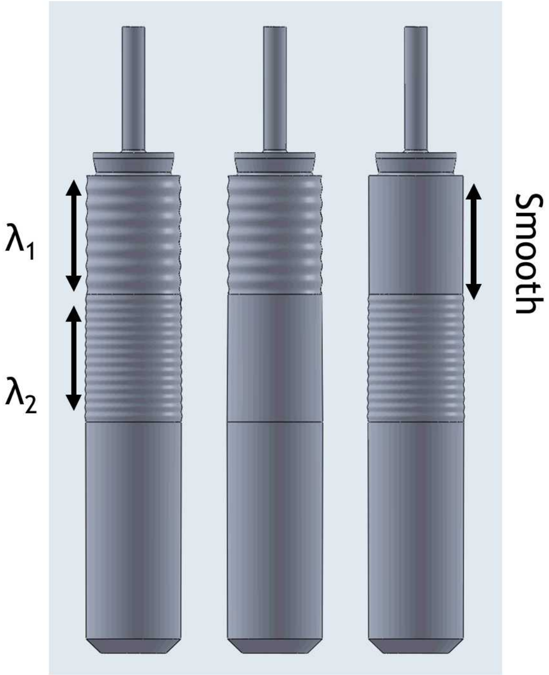
- Growth ~g*t^2, due to quadratic the decrease in t wins over increase in g

The higher strength shock in the D2 allows for larger standoff between the rod and liner which improves diagnosibility

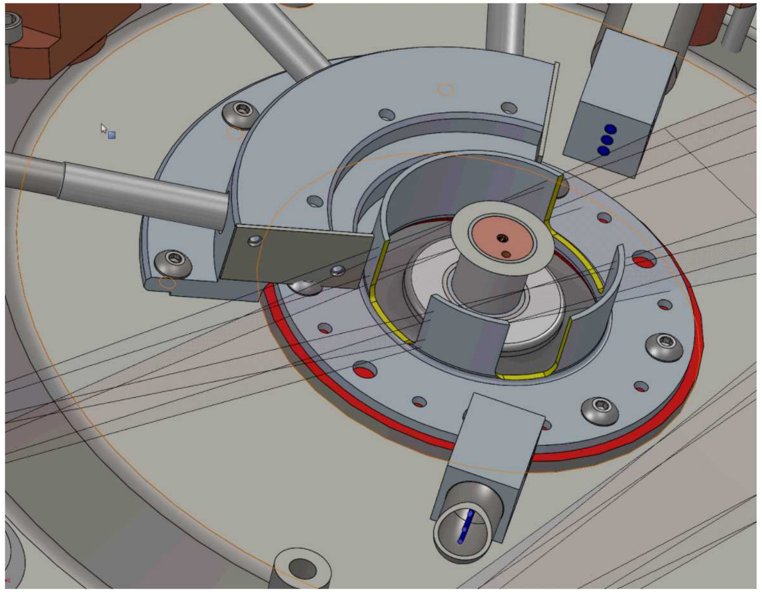
- We have one shot to date showing that running Z in short pulse mode dramatically improves liner stability

The next campaign will use the short pulse platform with multiple perturbations and a smooth region as well as implement several other improvements

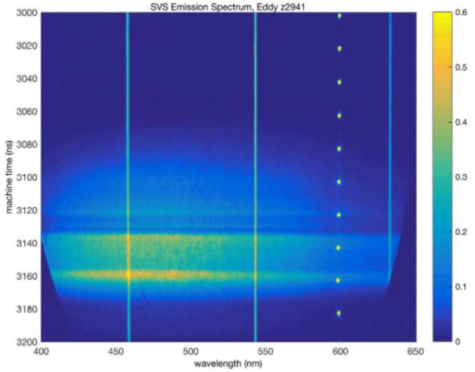
Multi-perturbation rod

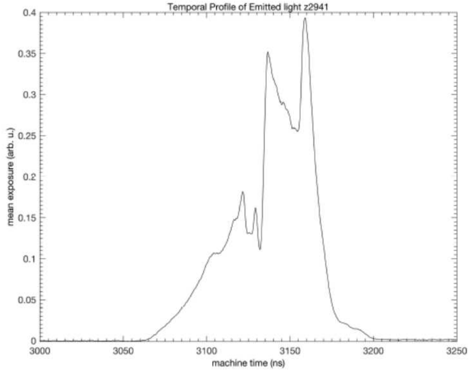


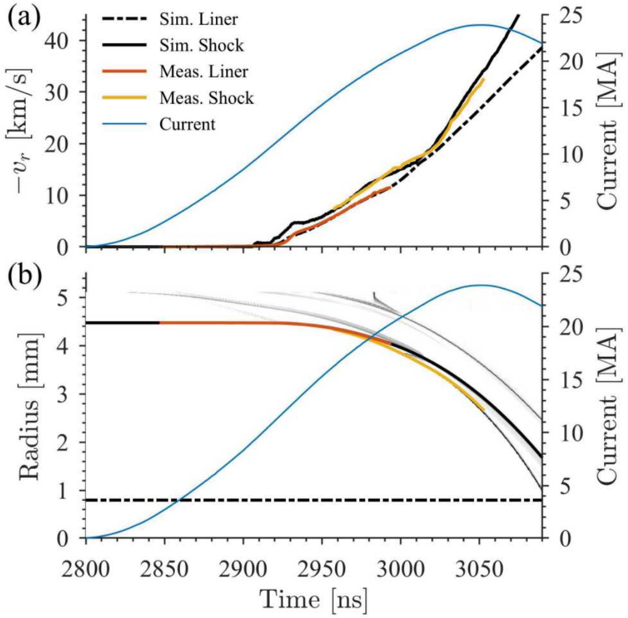
Improved load current measurements



Streaked pyrometry + PDV to characterize the incoming shock







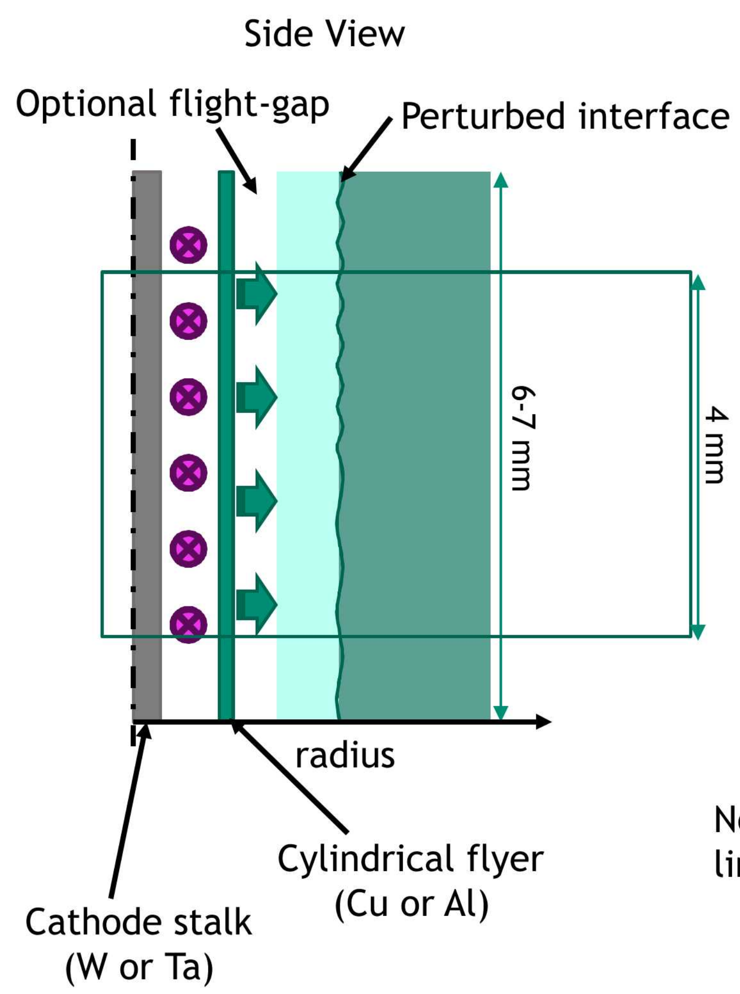
The unperturbed region will allow an independent measure of the interface position vs. time

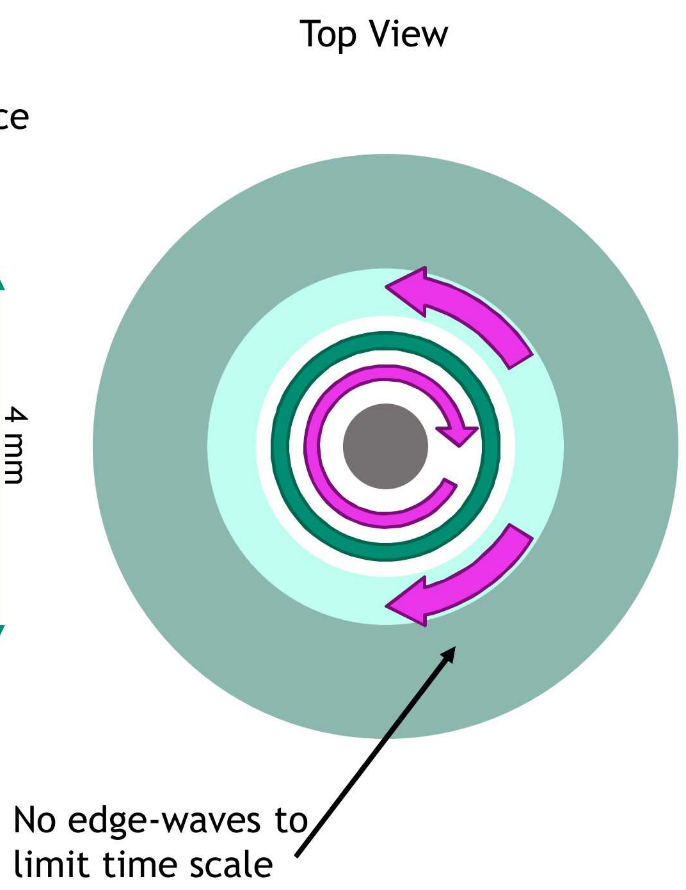
Multiple modes will allow more quantitative comparison to theory

Improved load current measurement will provide more accurate post shot simulations

Characterizing the state of the inbound shock will provide detailed comparison to codes

A possible path towards very long drive time (~100 ns) is to use an exploding liner geometry





This geometry allows for flexible pulse shaping to modify shock strength and acceleration histories

Since the cylinder does not rely on walls to confine the medium, no edge waves will be present to complicate the experiment

The limiting factors will be

- Z's ability to sustain pressure (~600 ns total pulse length)
- Edge waves from the top and bottom of the cylinder

May require a higher photon energy backlighter due to increased path length

Depending on total size, could do two experiments simultaneously on opposite sides of cylinder

Conclusions

Though less mature, Z provides platforms for driving hydro instabilities on large space- and time-scales

Our convergent RM platform has demonstrated excellent results, with planned improvements allowing for better quantitative studies

More users could help drive these platforms further

Diagnostic capabilities require some improvements, but resolution and FOV are unmatched

- Development of more frames per-shot using UXI camera is in progress
- Higher photon energy backlighters would enable more materials to be used

Z likely provides the timescales and energy required to drive turbulent flows and study mixing – I need your help to develop the necessary platforms and diagnostics!