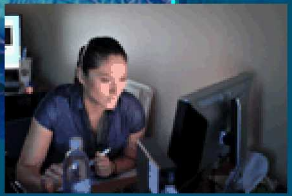
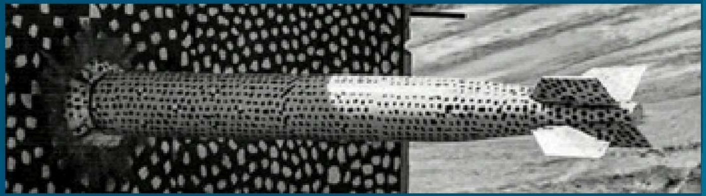
SAND2019-9497PE

Mix in magnetically driven implosions on Z





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SAND2019-XXXX

Thanks to my many colleagues and contributors

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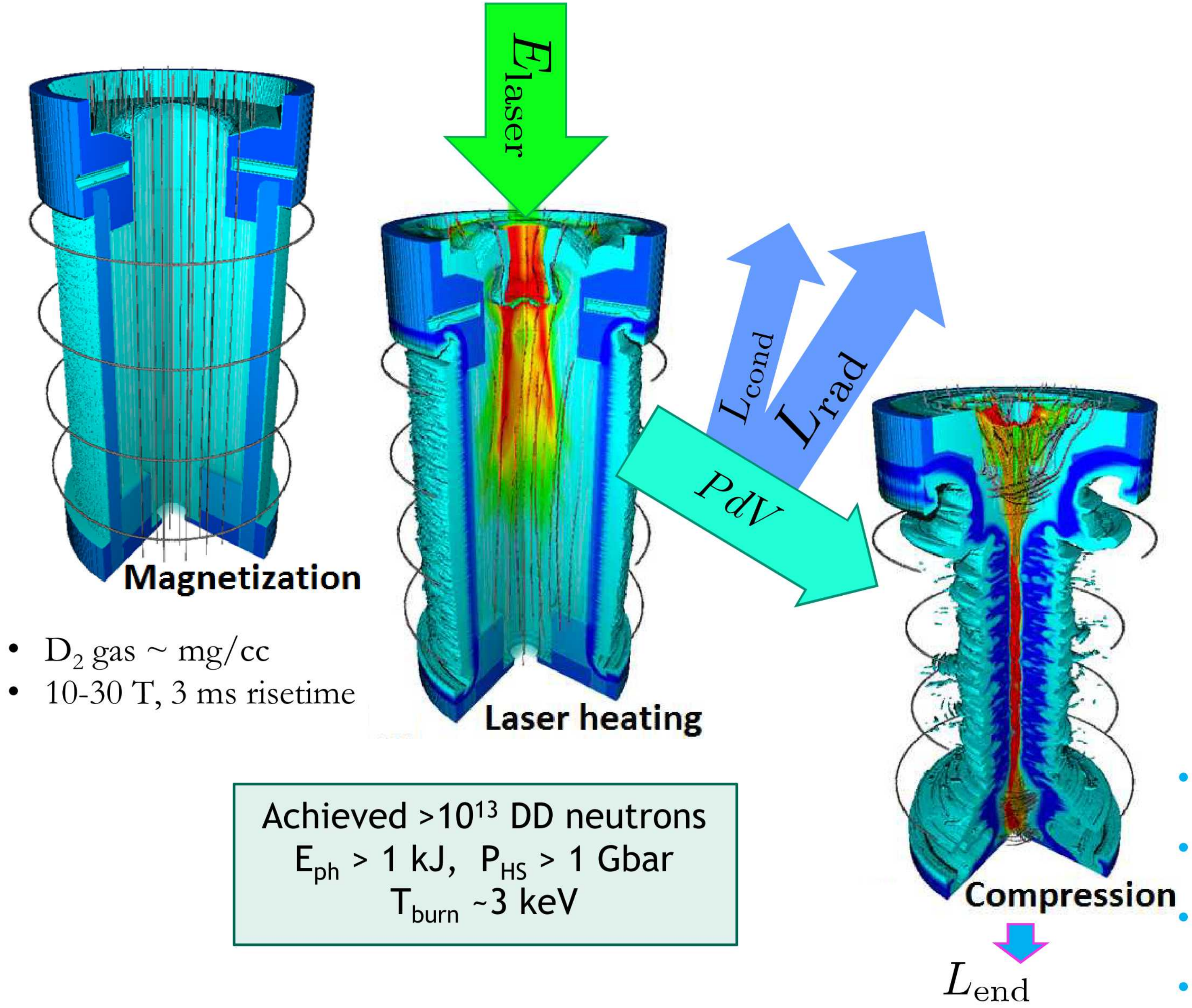
Outline

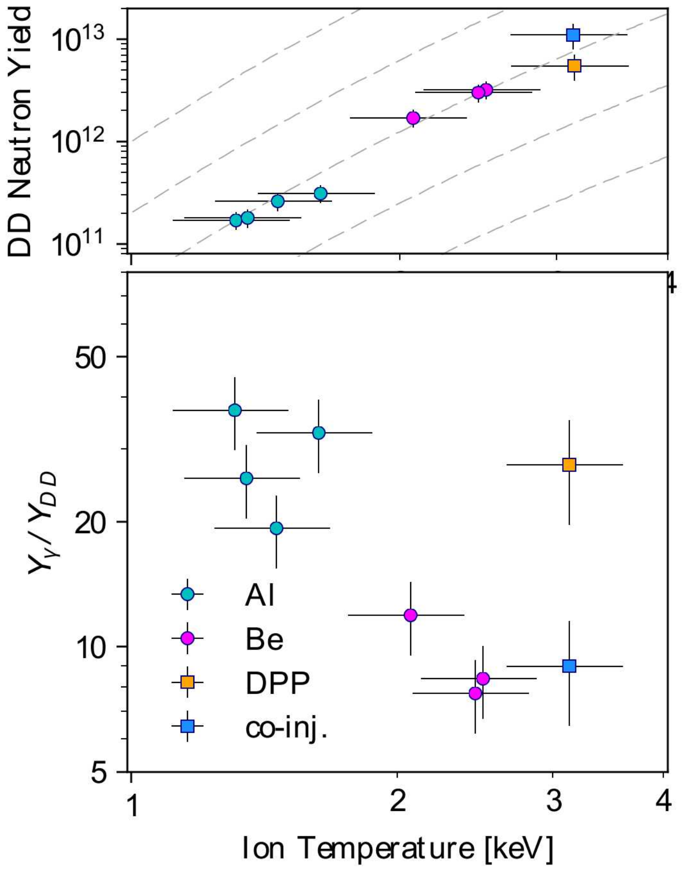
- How do we diagnose mix in MagLIF experiments?
- Where does mix come from and how does it impact performance?
- How can we improve our understanding of instability driven mix?

MagLIF uses preheat, magnetic insulation and adiabatic compression to achieve high pressure



- D_2 gas ~ mg/cc
- 10-30 T, 3 ms risetime

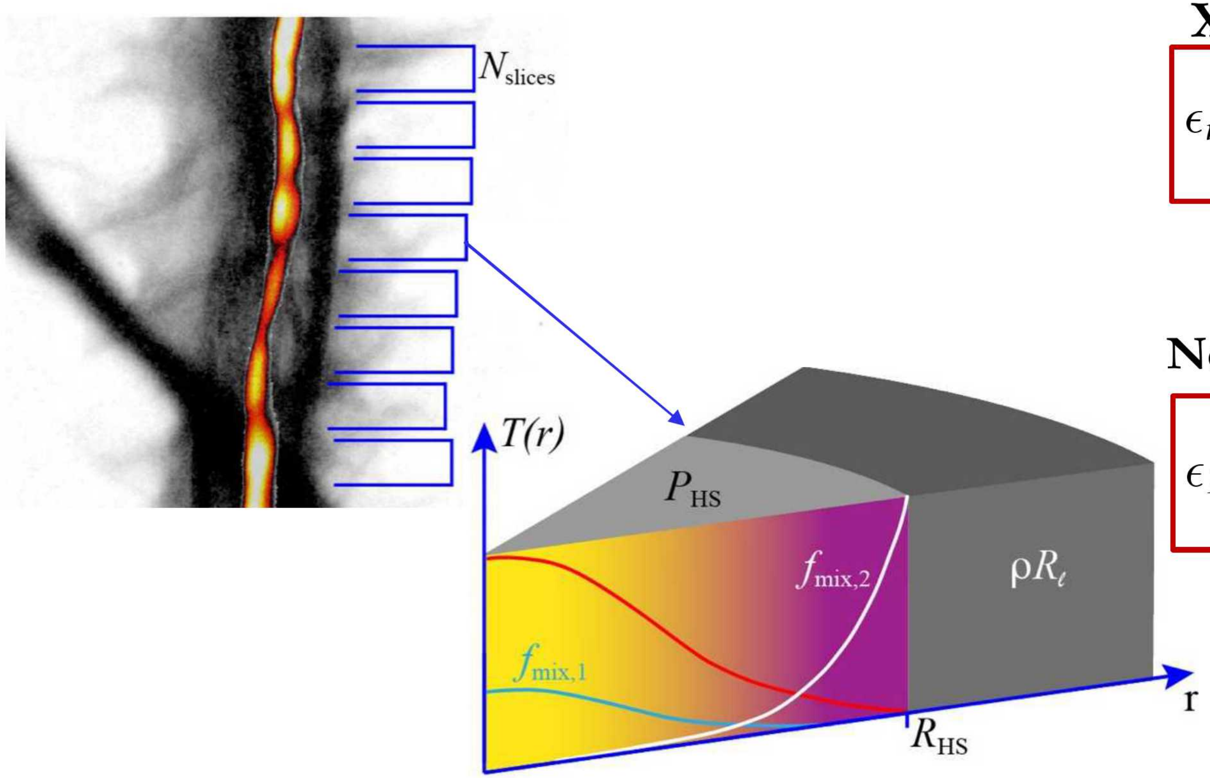
Achieved >10^{13} DD neutrons
E_{ph} > 1 kJ, P_{HS} > 1 Gbar
T_{burn} ~3 keV



- Laser heating allows low implosion velocity (<100 km/s)
- Preheat energy is contained via magnetic insulation
- Flux compression allows α confinement with low fuel ρR
- Long dwell time makes us sensitive to early time mix

Slutz et al., Phys. Plasmas 17, 056303 (2010)

We have developed a forward model that allows direct, quantitative comparison of the data with synthetic diagnostics



X-ray Emission:

$$\epsilon_\nu = A_{f-f} e^{-\rho R_\ell \kappa_\nu} \tau_b P_{HS}^2 \frac{g_{FF}\langle Z\rangle}{(1+\langle Z\rangle)^2} \sum_i f_i \tilde{j}_i \frac{e^{-h\nu/T}}{T^{5/2}}$$

$$\tilde{j}_i \equiv \frac{j_i}{j_D} = Z_i^2 + \frac{A_{f-b}}{A_{f-f}} \frac{Z_i^4}{T} e^{Ry Z_i^2/T}$$

Neutron Emission:

$$\epsilon_E = \frac{P_{HS}^2 \tau_b}{1+\delta_{1,2}} \frac{f_1 f_2 \langle \sigma v\rangle}{(1+\langle Z\rangle)^2 T_i^2} I_o(E)$$

$$^{*}I_o(E) = e^{\frac{-2\bar{E}}{\sigma^2}(\sqrt{E}-\sqrt{\bar{E}})^2}$$

Assumptions:

- Each slice isa static, isobaric hot spot surrounded by a liner
- Ideal gas EOS: $P_{HS} = (1+\langle Z\rangle) n_i k_B T$
- All elements have same burn duration
- Electron and ion temperatures are equal
- X-ray emission is dominated by continuum (BF & FF)

Basic Model Parameters

$\{T_i\} = \{T_e\}$

$\{\rho R_\ell\}$

$\{P_{HS}\}$

$\{f_{\text{mix}}\}$

$\{R_{HS}\}$

Global/hyper Parameters

Z_{mix}

τ_{burn}

h_{HS}

T_{exp}

*Ballabio et al., NUCLEAR FUSION, Vol. 38, No. 11 (1998)

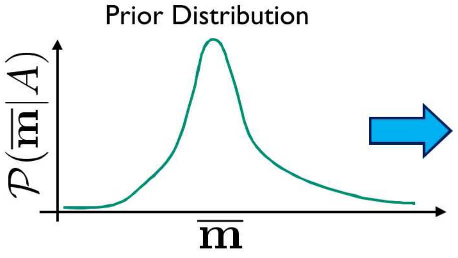
Bayesian inference allows us to integrate multiple sources of data using physics and diagnostic models to infer parameters

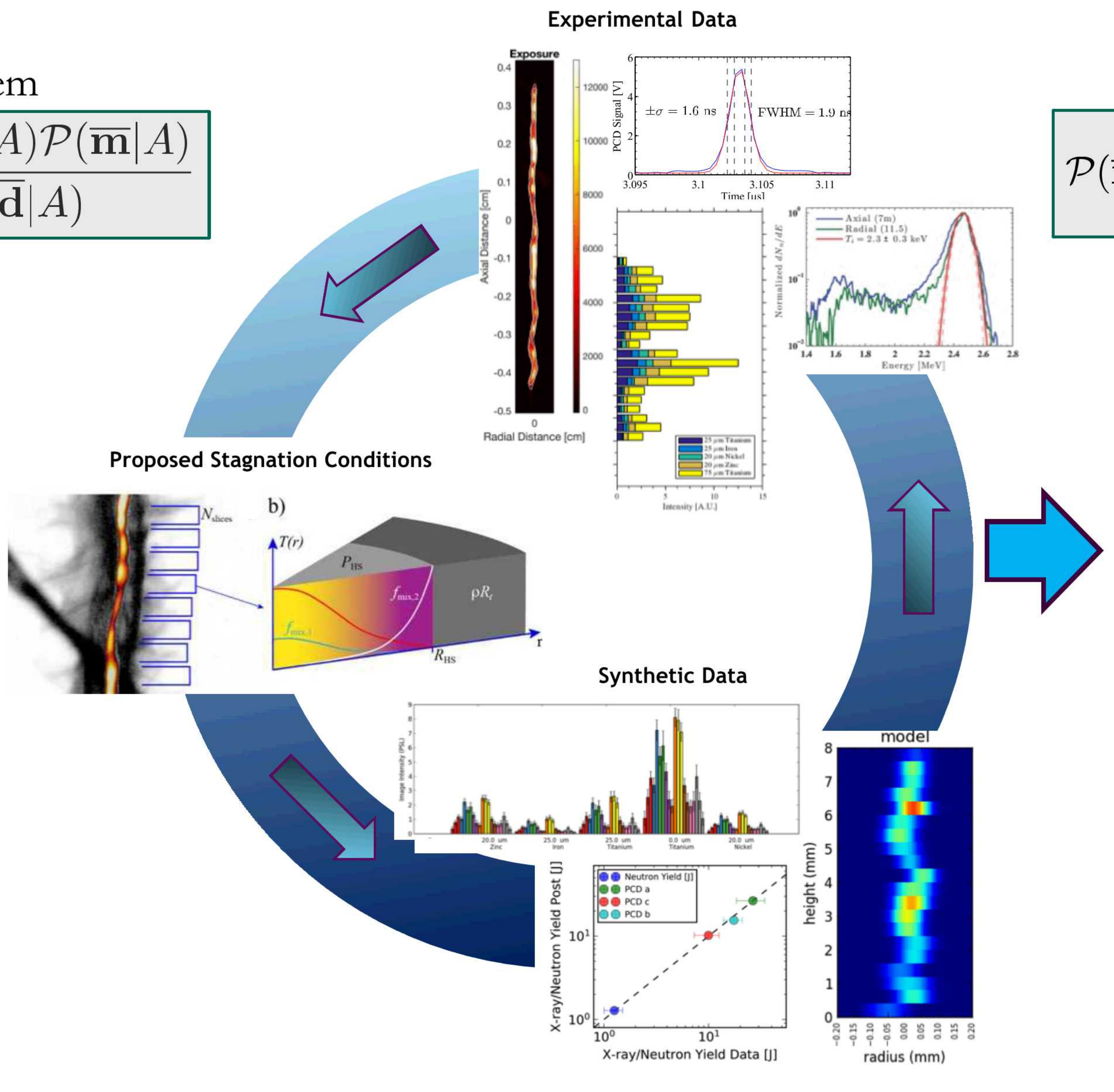
Bayes' Theorem

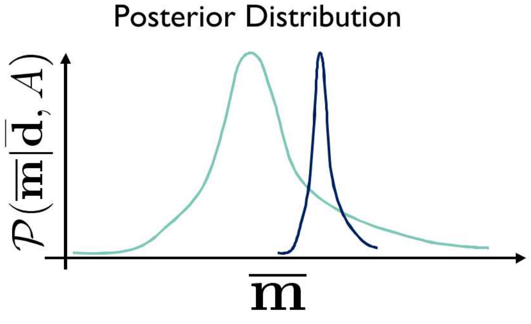
$$\mathcal{P}(\overline{\mathbf{m}}|\overline{\mathbf{d}}, A) = \frac{\mathcal{P}(\overline{\mathbf{d}}|\overline{\mathbf{m}}, A)\mathcal{P}(\overline{\mathbf{m}}|A)}{\mathcal{P}(\overline{\mathbf{d}}|A)}$$

Likelihood

$$\mathcal{P}(\overline{\mathbf{x}}|\overline{\mathbf{m}}, \mathcal{A}) \propto \prod_{i=1}^{N} \exp\left(- \frac{(\mathcal{F}_i(\overline{\mathbf{m}}) - x_i)^2}{2\sigma_i^2} \right)$$







Model Parameters

$$\overline{\mathbf{m}} = \begin{cases} P_{\mathrm{HS}} \\ T \\ f_{\mathrm{mix}} \\ R_{\mathrm{HS}} \\ \rho R_\ell \end{cases}$$

Outputs/Benefits:

- most likely parameter values
- confidence intervals
- correlations
- Value of information

Outline

- How do we diagnose mix in MagLIF experiments?
- Where does mix come from and how does it impact performance?
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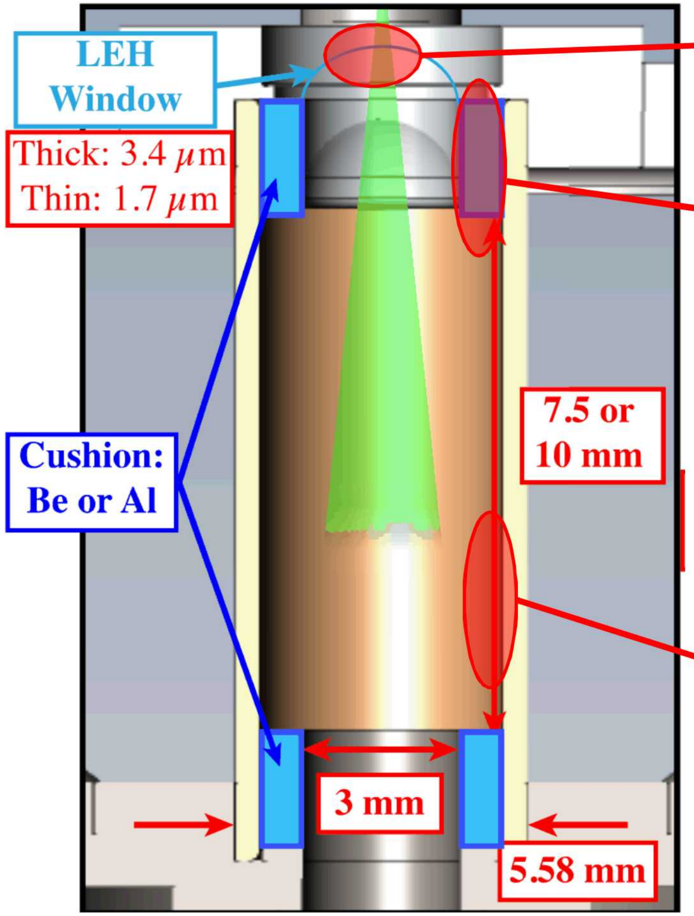
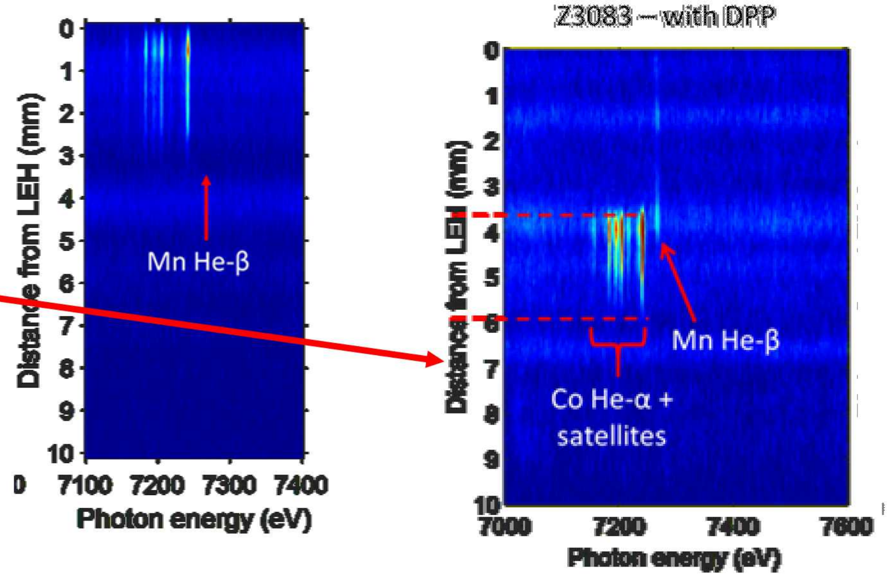
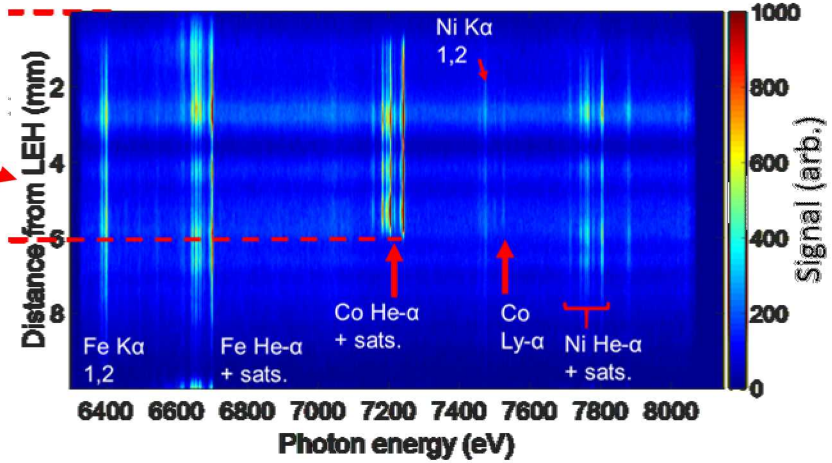
Mix is known to occur, but the total amount and relative contributions from potential sources is poorly understood



Co coatings used to analyze window and cushion mix



Fe impurity in Be used to analyze liner mix

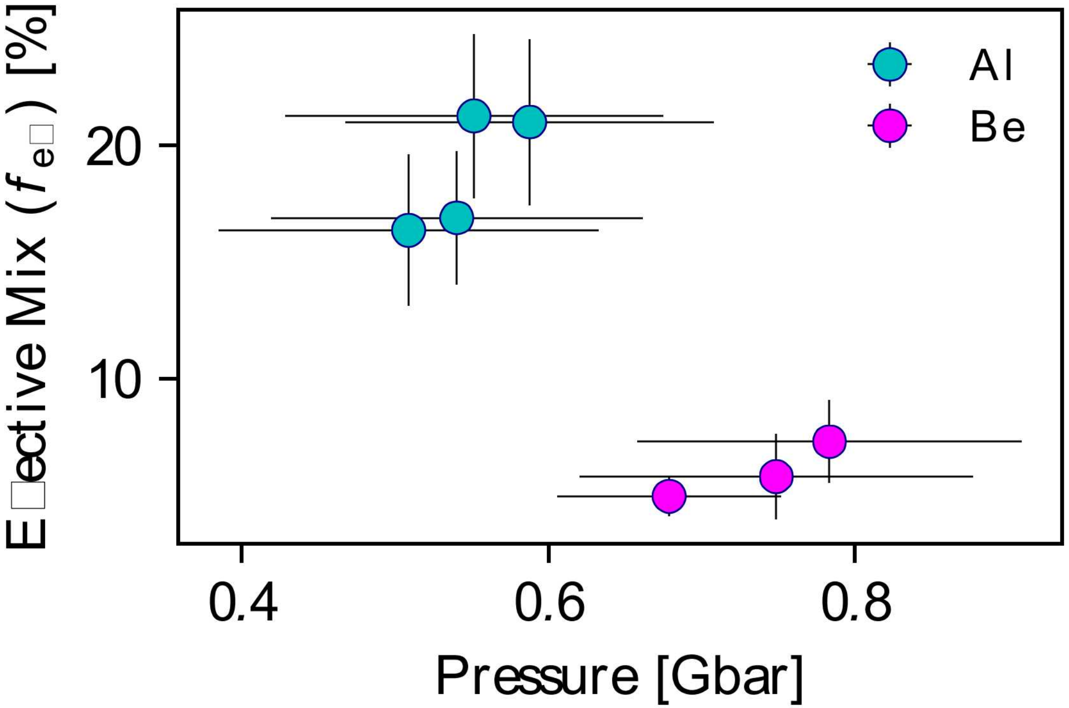


Main Contributors to mix

- Preheat
  - Window
  - Cushion
- Implosion
  - Liner

Harvey-Thompson et al., Phys. Plasmas (accepted)

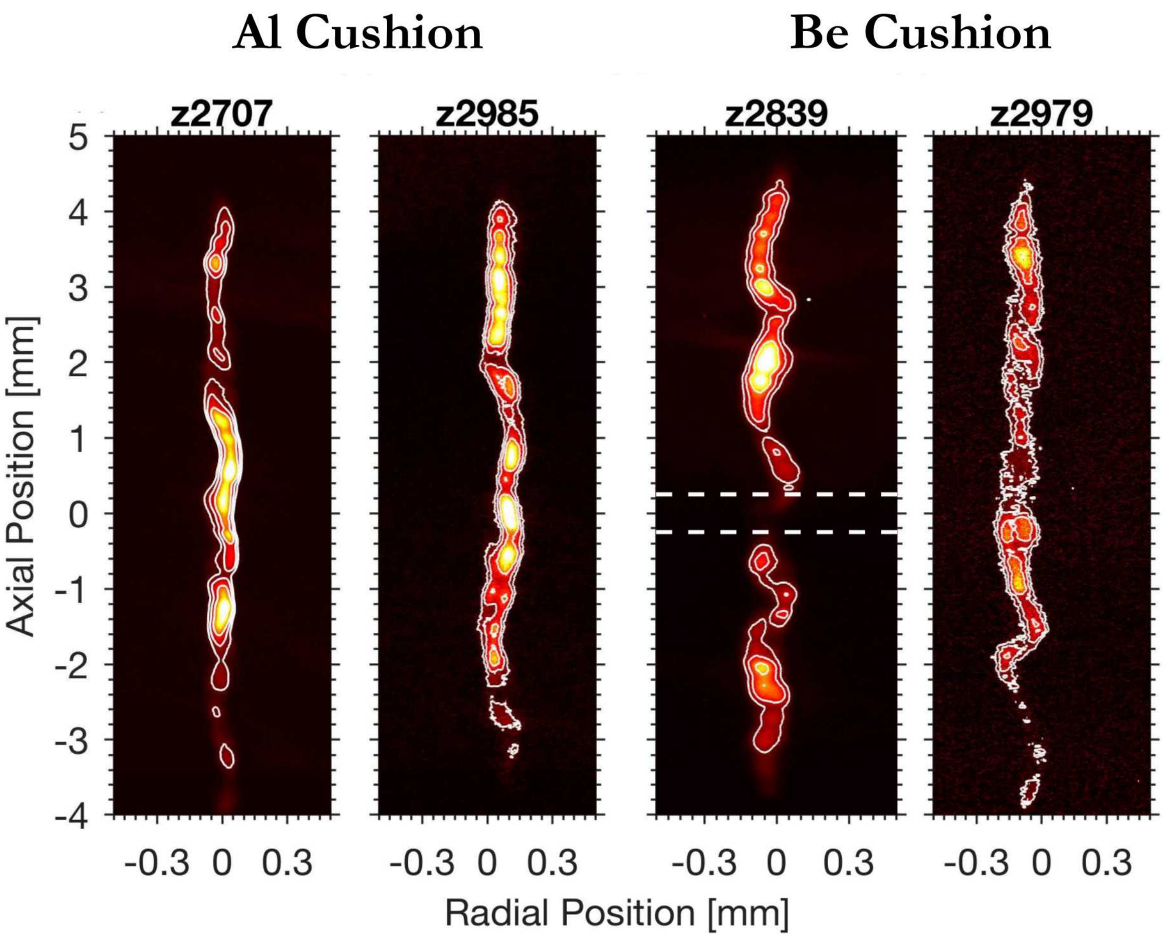
It is observed that low mix is strongly correlated with high pressure and the Al and Be cushion shots are clustered



- This analysis determines the stagnation pressure and an *effective* mix fraction (assuming mix is 100% Be)
- The Be cushion shots have, on average
  - 3x less effective mix fraction
  - ~40% higher pressure
- The average hotspot energy is ~50% higher in the Be cushion experiments

$$\langle E_{\mathrm{HS}}^{\mathrm{Al}} \rangle = \langle \frac{3}{2} P_{\mathrm{HS}} V_{\mathrm{HS}} \rangle \approx 7.6 \text{ kJ} \qquad \langle E_{\mathrm{HS}}^{\mathrm{Be}} \rangle = \langle \frac{3}{2} P_{\mathrm{HS}} V_{\mathrm{HS}} \rangle \approx 11.4 \text{ kJ}$$

It is observed that the image volumes and x-ray burn histories are nearly the same across both groups of experiments



- The morphology and evolution of stagnation appear to be very similar between the high mix and low mix experiments
- Volumes are the same to +/- 20%
- τ_{burn} is the same to +/- 10% (measured with x-rays)
- Laser pulses and LEH windows are nominally identical
- Radiation losses are the only term significantly modified by mix

Exploiting these similarities we can break the mix contribution into three sources and constrain each

$$N_{\mathrm{W}} \approx (500\ \mu\mathrm{m})^2 * 1.77\ \mu\mathrm{m} * n_{\mathrm{ion}} \approx 4 \times 10^{16}$$

Mix total: Window + Cushion + Liner

$$f_{\mathrm{eff}}^{\mathrm{Be}} Z_{\mathrm{Be}}^3 = f_{\mathrm{W}} \bar{Z}_{\mathrm{poly}}^3 + f_{\mathrm{C}}^{\mathrm{Be}} Z_{\mathrm{Be}}^3 + f_{\mathrm{D}} Z_{\mathrm{Be}}^3$$ Be Cushion

$$f_{\mathrm{eff}}^{\mathrm{Al}} Z_{\mathrm{Be}}^3 = f_{\mathrm{W}} \bar{Z}_{\mathrm{poly}}^3 + f_{\mathrm{C}}^{\mathrm{Al}} Z_{\mathrm{Al}}^3 + f_{\mathrm{D}} Z_{\mathrm{Be}}^3$$ Al Cushion

$$N_{\mathrm{fuel}} = \frac{P}{kT} \approx 8 \times 10^{18}$$

$$f_{\mathrm{W}} = 0.5 \pm 0.2\%$$

- f_W and f_D are assumed to be the same in the two cases
- 2 equations, four unknowns

	Al. Cushion	Be. Cushion
Window	0.5 %	0.5 %
Cushion	0.57 %	1.5 %
Liner	2.6 %	2.6 %

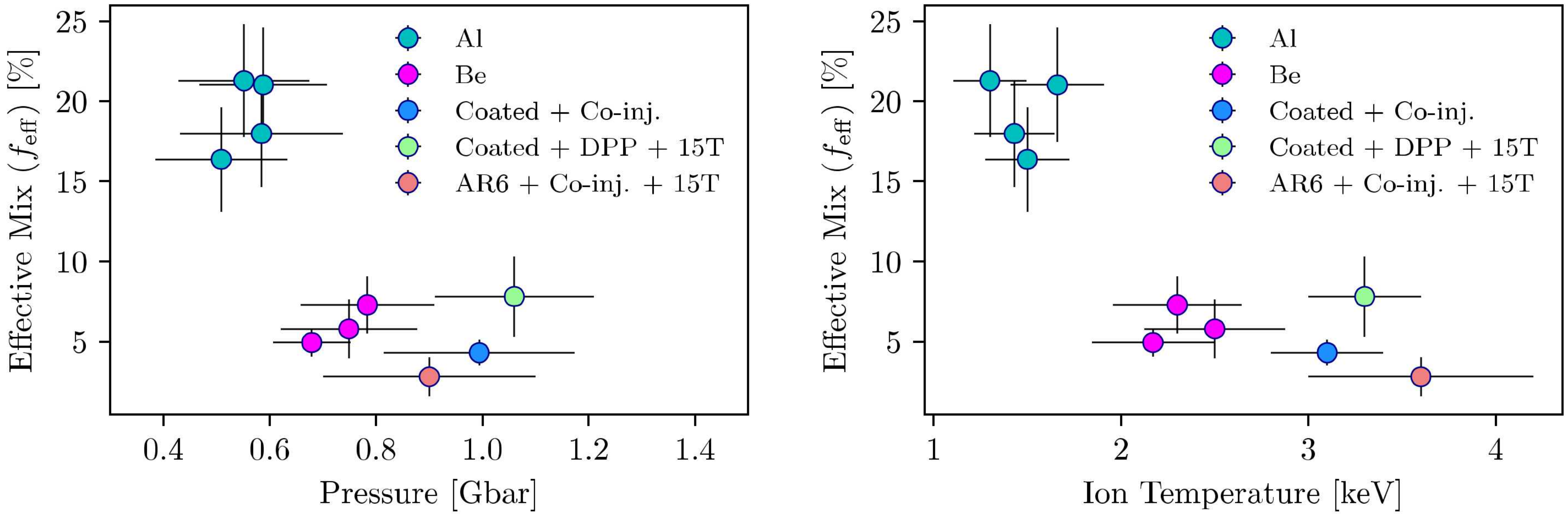
Equal cushion scrape-off mass

$$f_{\mathrm{C}}^{\mathrm{Al}} = \frac{1}{3} f_{\mathrm{C}}^{\mathrm{Be}}$$

Equal cushion scrape-off volume

$$f_{\mathrm{C}}^{\mathrm{Al}} = \frac{1}{2} f_{\mathrm{C}}^{\mathrm{Be}}$$

Looking at a broader MagLIF dataset we can see some emerging trends



Lets add three of our highest yield shots to the mix

The major advancements here are improved laser heating protocols, higher B-field and higher current drive

The use of co-injection (as opposed to just beam smoothing or no conditioning) reduces the effective mix present at stagnation

It appears that higher B-field increases the stagnation temperature somewhat (more analysis needed)

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We have developed a new platform to help benchmark modeling of instability driven mix in a converging geometry

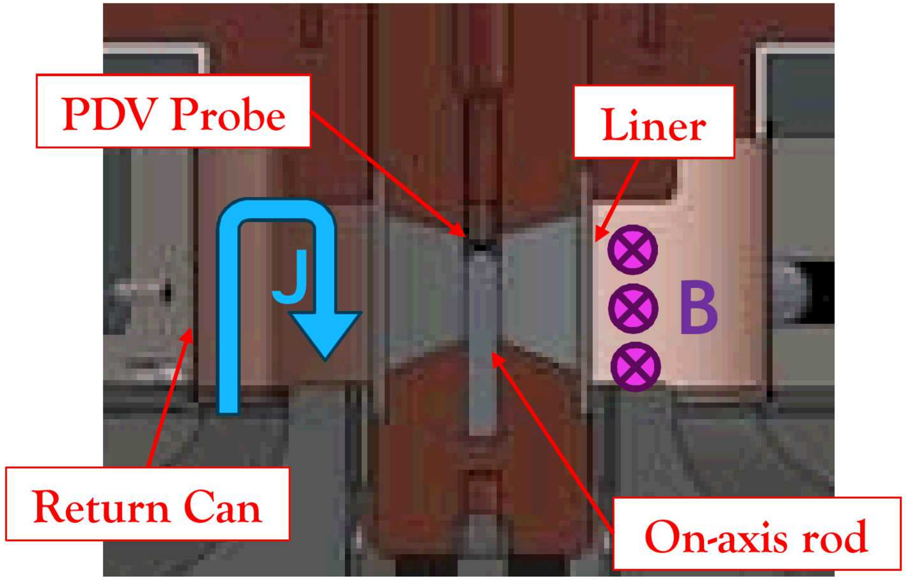
The platform is comprised of
- A Be liner
- A liquid D_2 fill
- An on-axis Be rod with machined perturbation

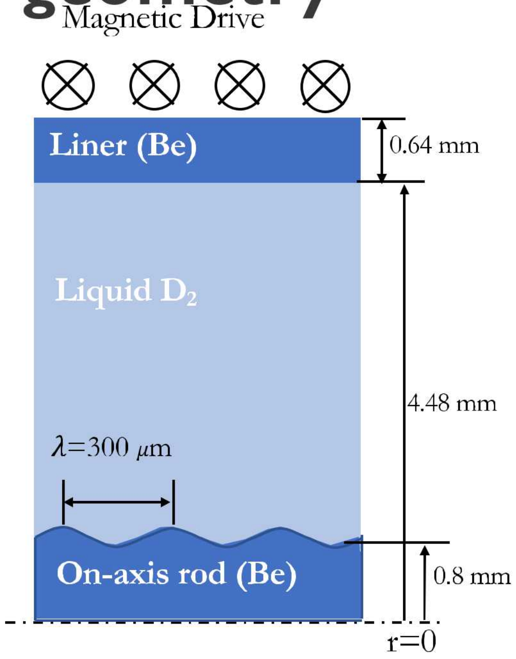
Z's current flows through the liner, causing it to implode

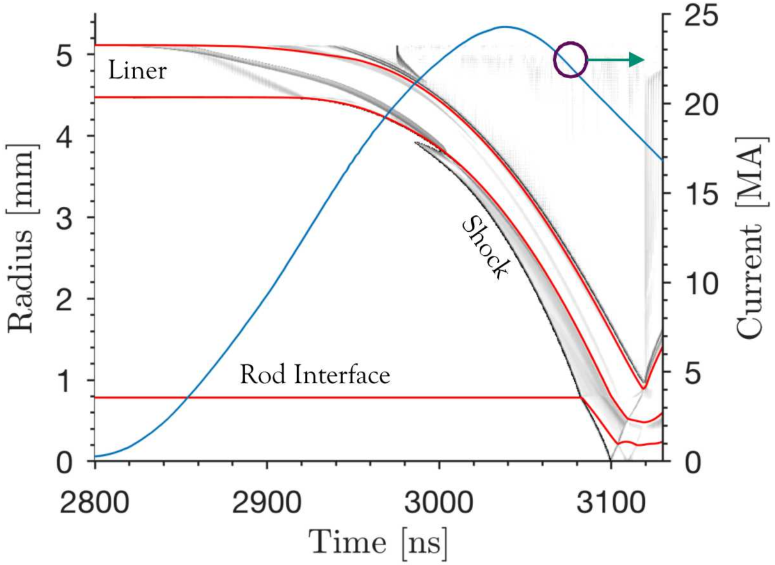
A strong shock is driven in the D_2

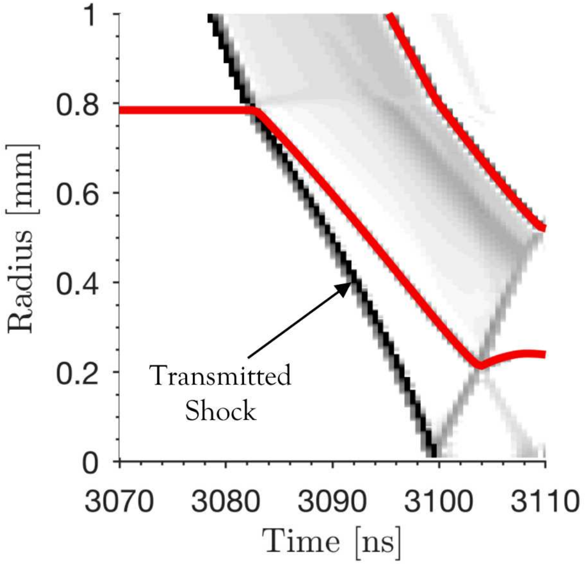
The shock impacts the rod, driving the RM process

The instability growth is diagnosed using x-ray BL









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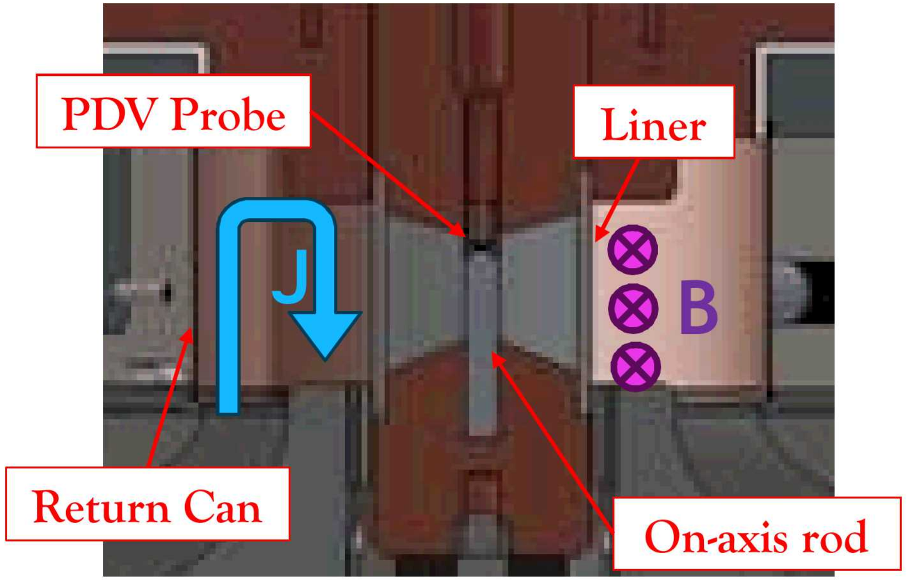
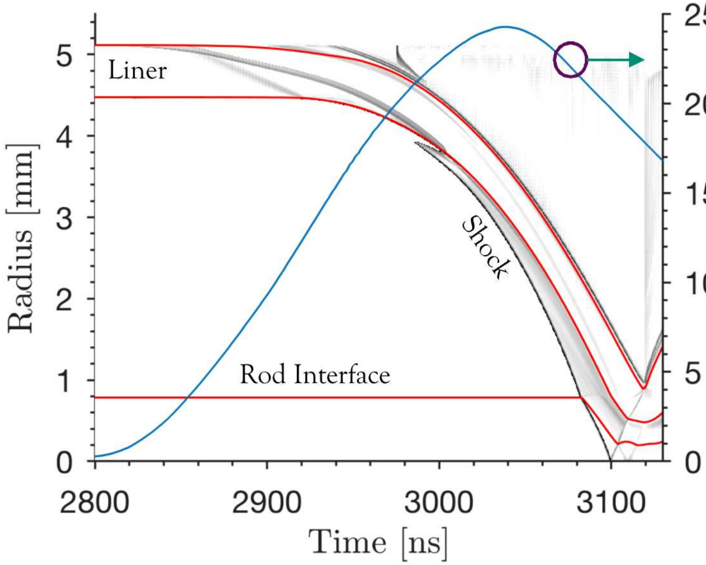
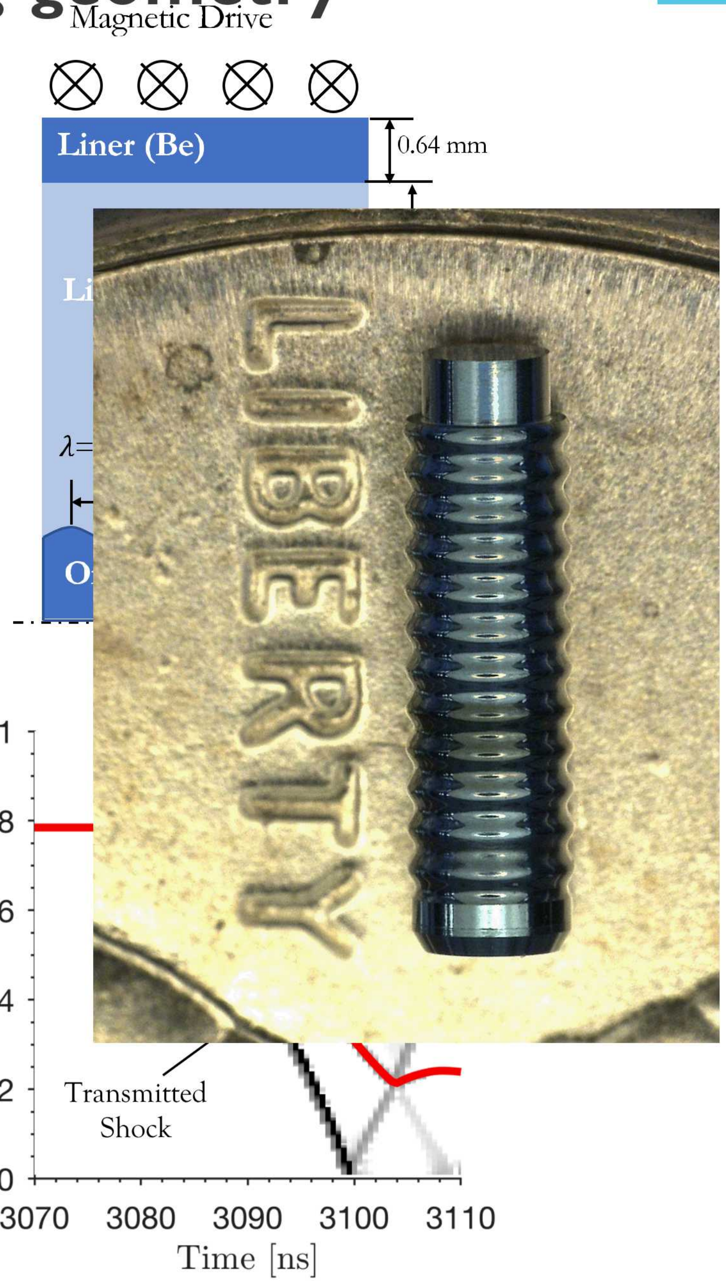
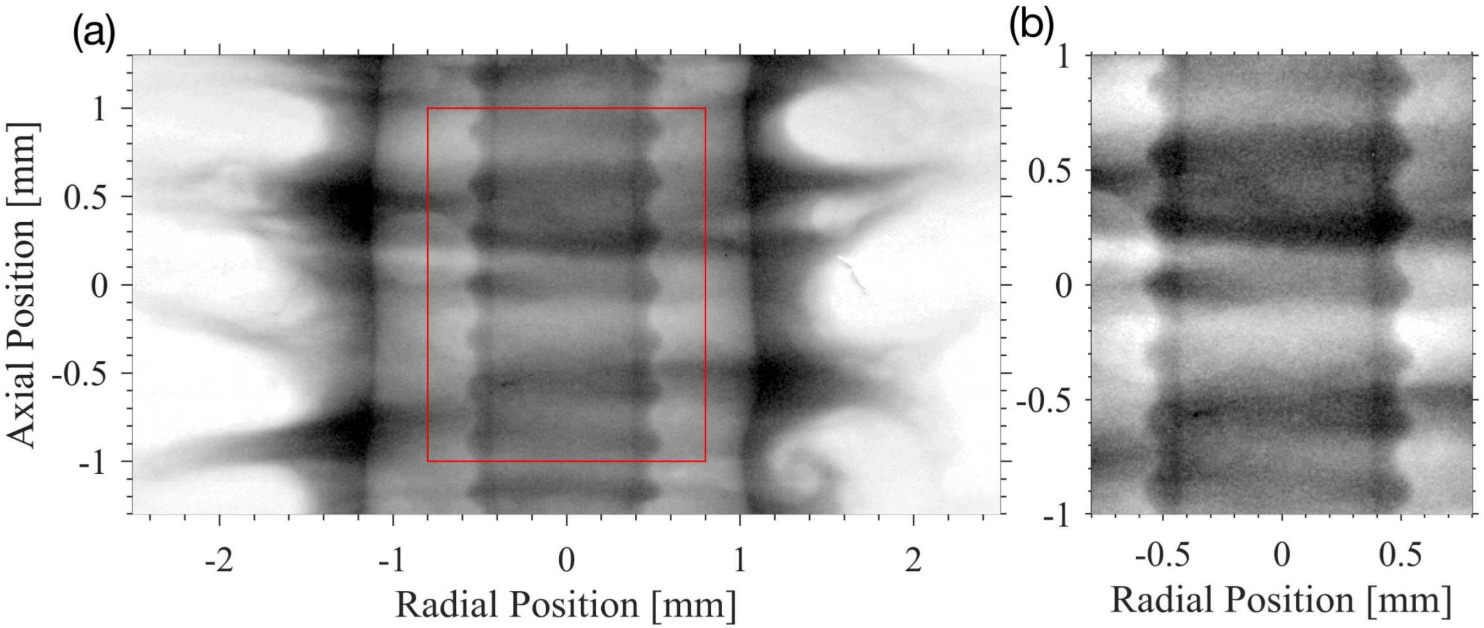






Abel inversion allows the density of the rod to be inferred without obstruction from the liner



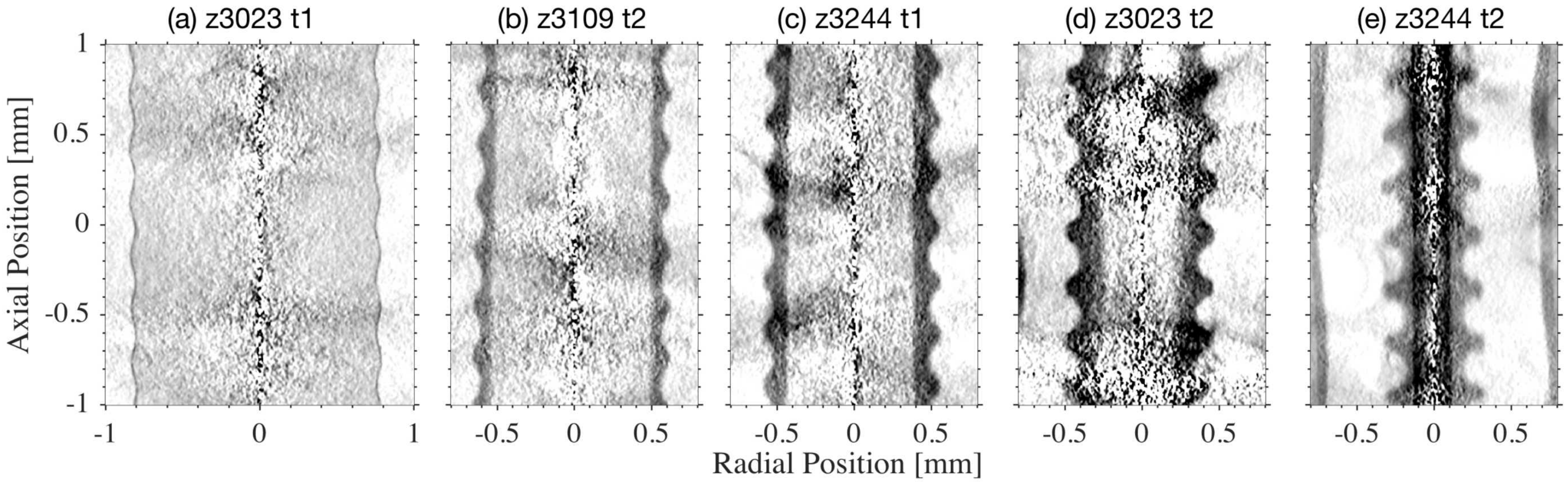
Radiographs are monochromatic at 1.85, 6.15, or 7.2 keV (we use 7.2 keV here)

full radiographic FOV is 4 mm x 12 mm

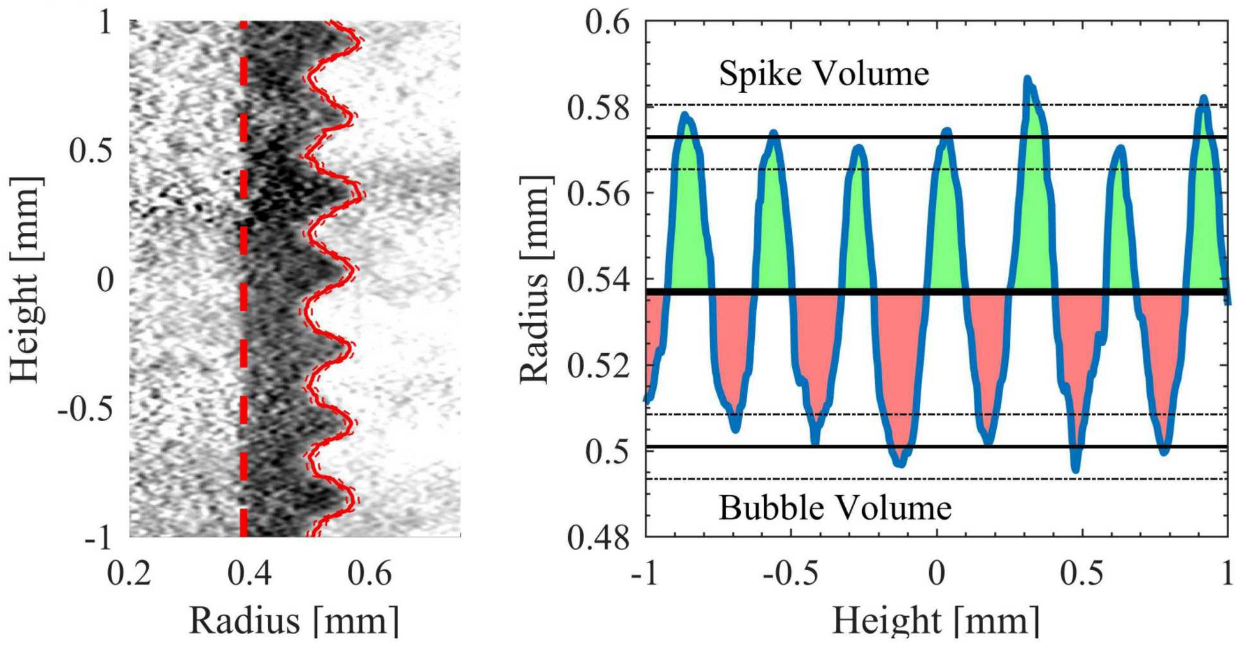
The spatial resolution is 12 μm

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

Abel invert to obtain ρ(r,z)



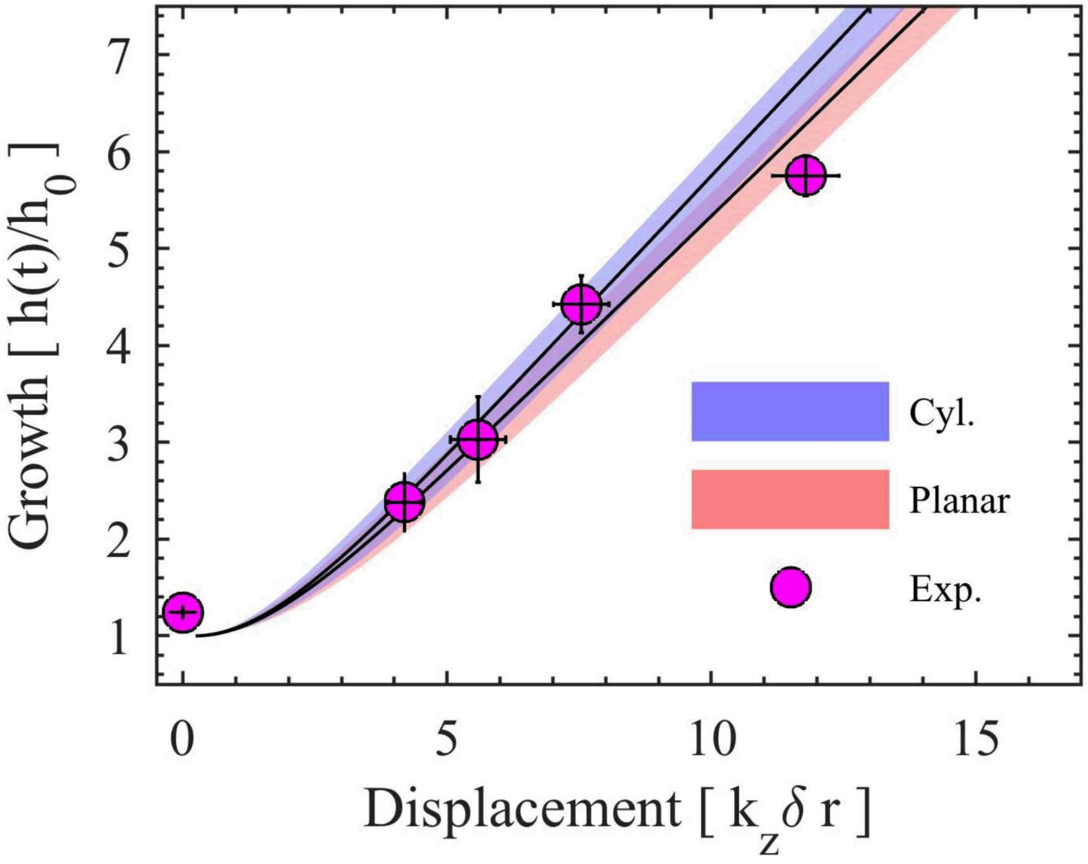
We can track the contour with high fidelity and measure the growth and mean interface position



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

Must include the shock proximity and compression effects

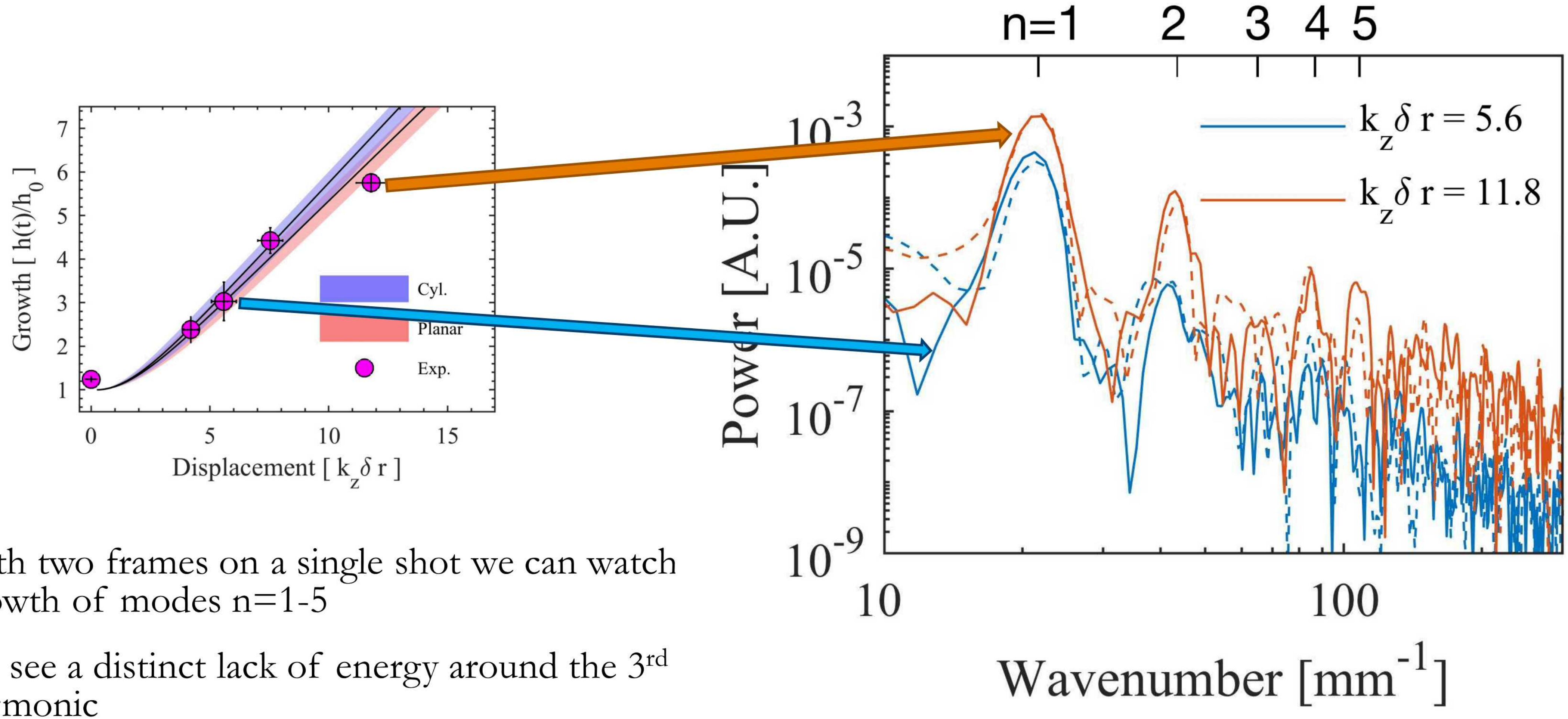
With current diagnostics it is not really possible to distinguish between cylindrical and planar



2D post-shot simulations in progress for detailed comparison

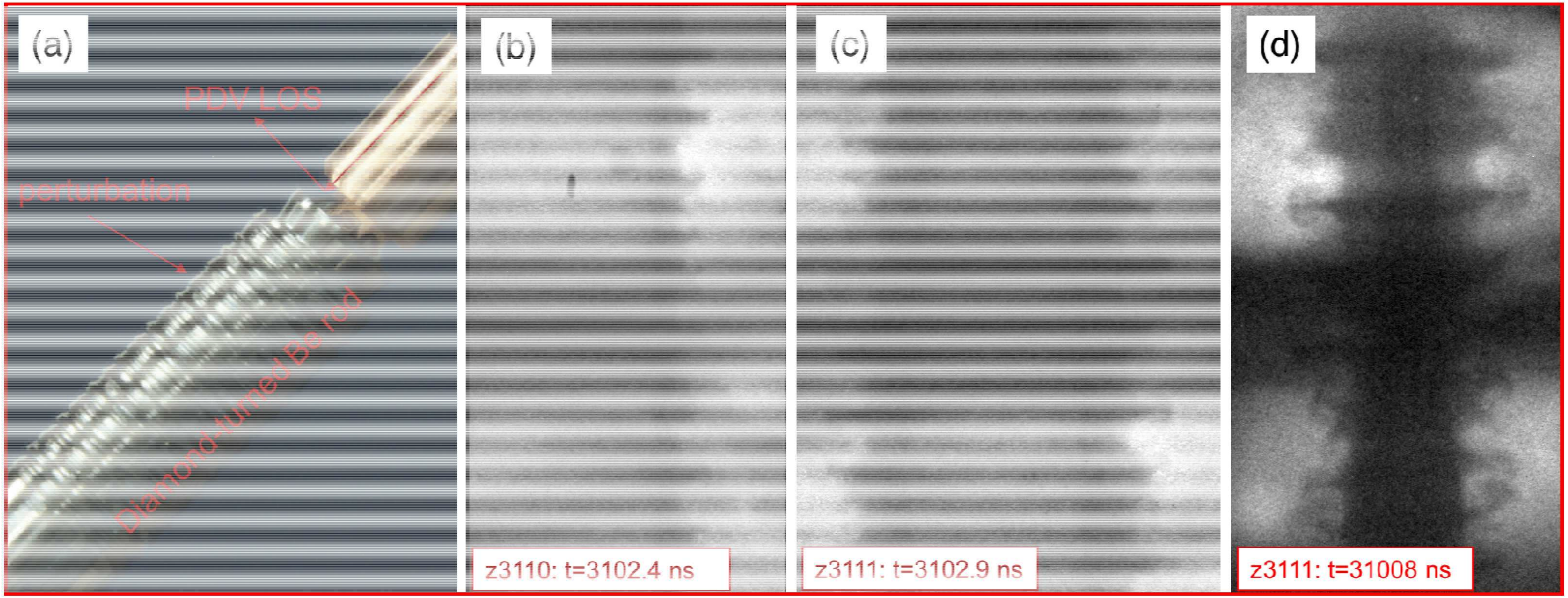
M. Lombardini et al., Physics of Fluids 21, 114103 (2009)

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

Conclusions and future work

- We observe mix from multiple sources in MagLIF implosions at stagnation that CAN significantly impact performance
- We have developed strategies to mitigate mix from preheat (A. Harvey-Thompson) and the cushions
- We can see trends in improved performance and stagnation parameters when increasing laser energy coupling, drive current, and initial B-field
- Deceleration phase mix is still poorly understood
- We have developed a platform that allows clean diagnosis of instability growth and resulting mix in a converging geometry to help improve our understanding of this critical phase

Tomorrow you can hear about our platform developed to investigate mix driven by kinetic processes