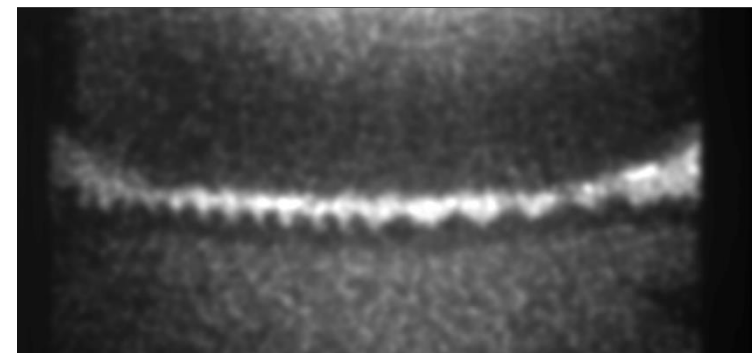
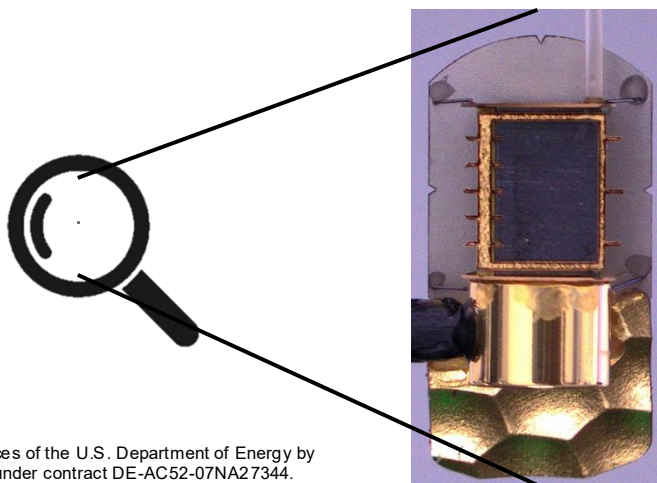
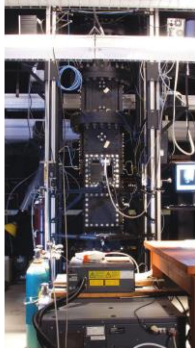


Scaling of shock-driven flows between metric and micrometric shock tubes

Alex Ames – LANL

Alex Do – LLNL

Riccardo Bonazza – UW-Madison



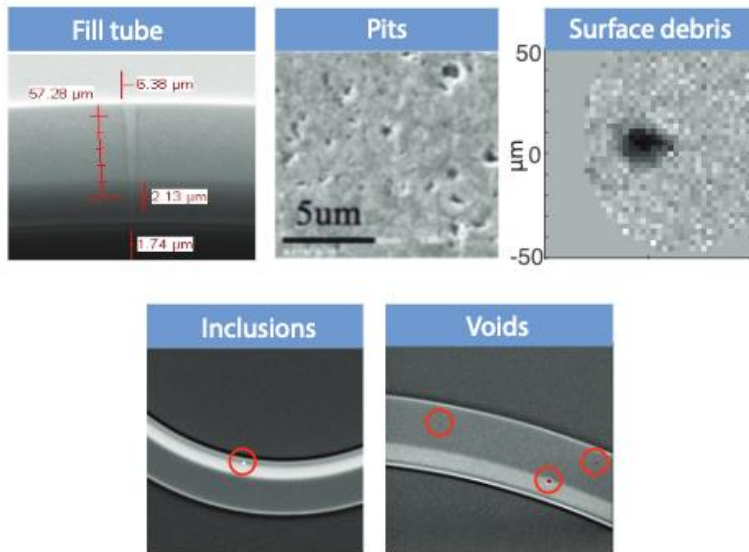
Richtmyer-Meshkov instability is a key player in multiple fields

- In Inertial Confinement Fusion (ICF), Richtmyer-Meshkov instability (RMI) will induce mix resulting in performance degradation;
 - RMI is present in star formation, astrophysical jets, core collapse supernovae...;
- Current RMI models are largely based on large scale shock tube experiments, but strong shocks and strong compression effects are not well described by current models.

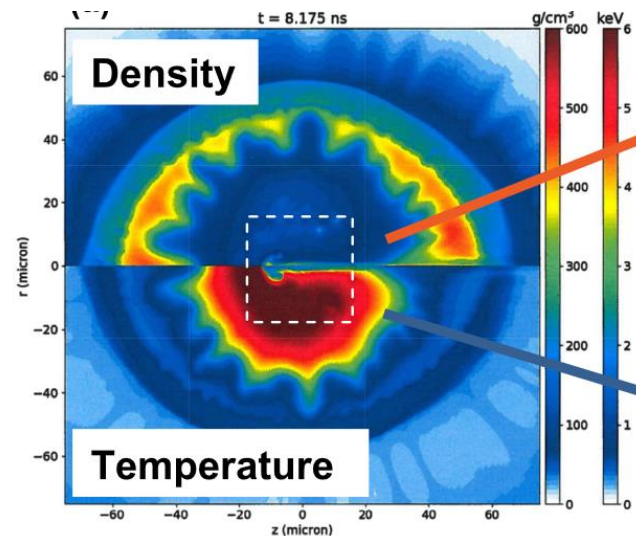
Richtmyer-Meshkov instability is a key player in multiple fields

- In Inertial Confinement Fusion (ICF), Richtmyer-Meshkov instability (RMI) will induce mix, resulting in performance degradation

Example of possible mix seeds

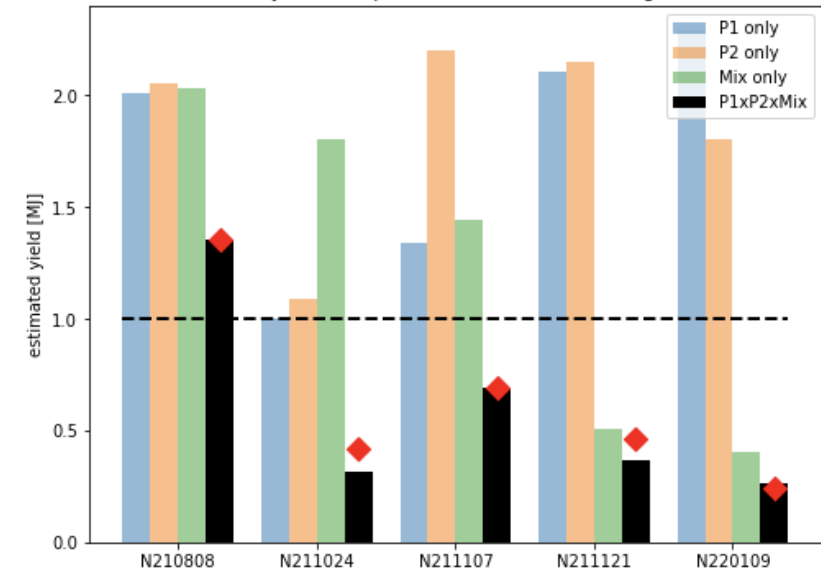


Mix simulation



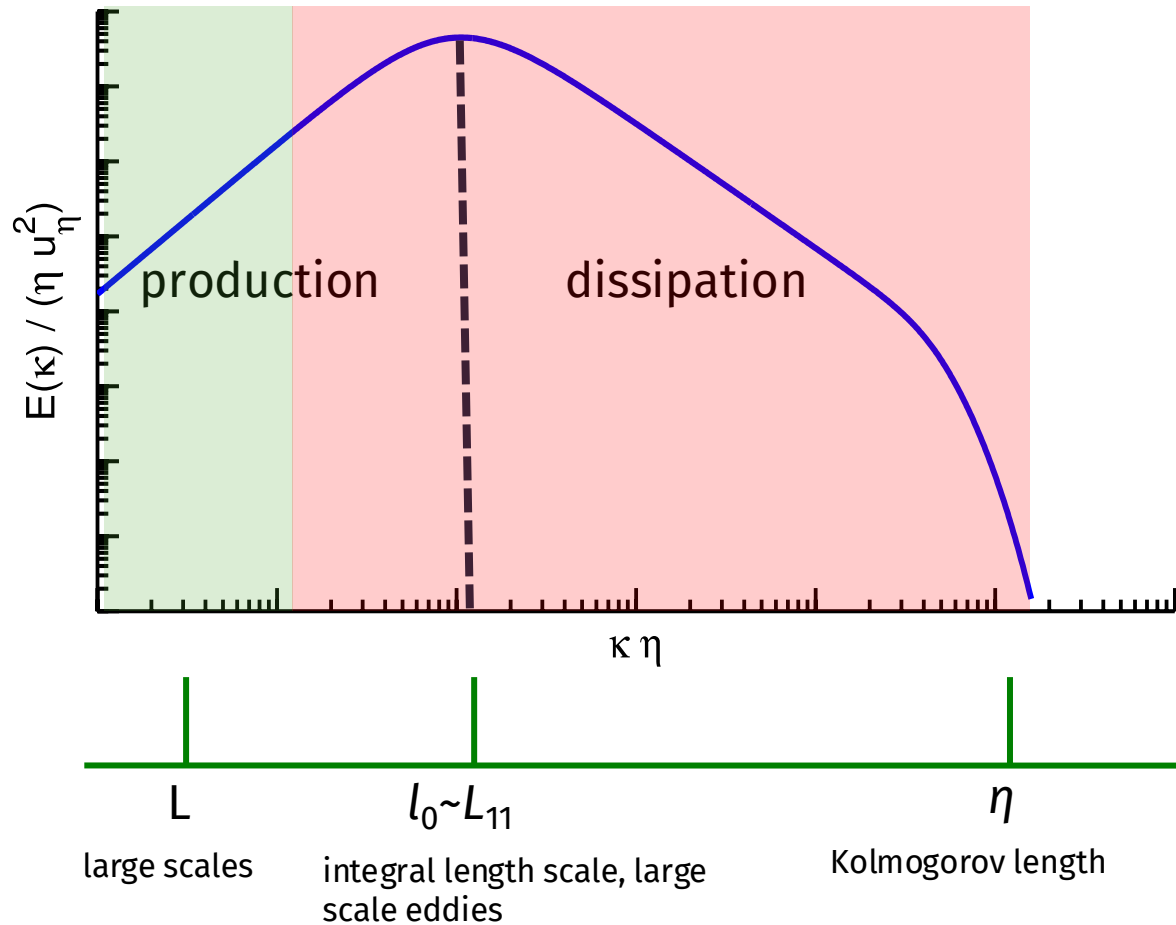
C. Weber *et al.*, PoP (2020)

Estimated yield with postshot P1, P2 and mix degradation

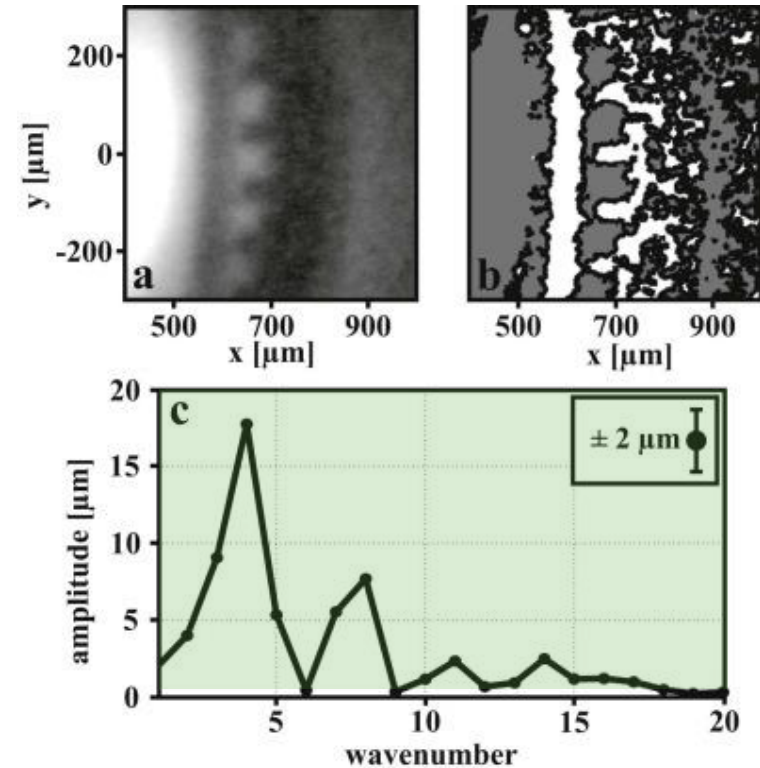


L. Divol *et al.*, POP 2025 3

Predictive models of instability growth and mixing transition are needed to guide ICF capsule design



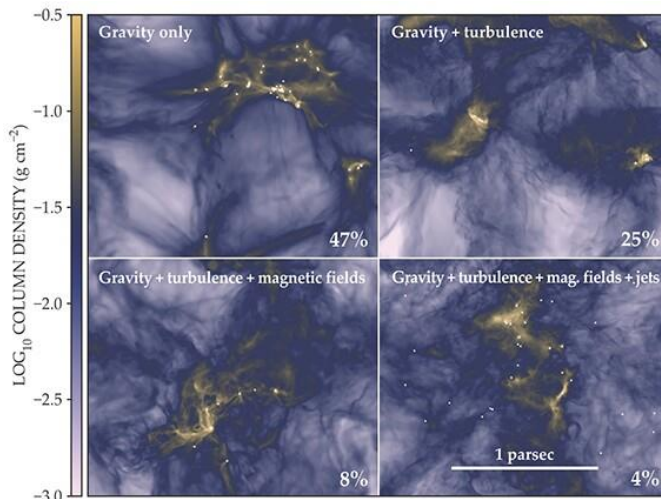
Radiography of HED targets provides limited diagnostic spatial resolution



Richtmyer-Meshkov instability is a key player in multiple fields

- RMI is present in star formation, astrophysical jets, core collapse supernovae...

Star formation simulation



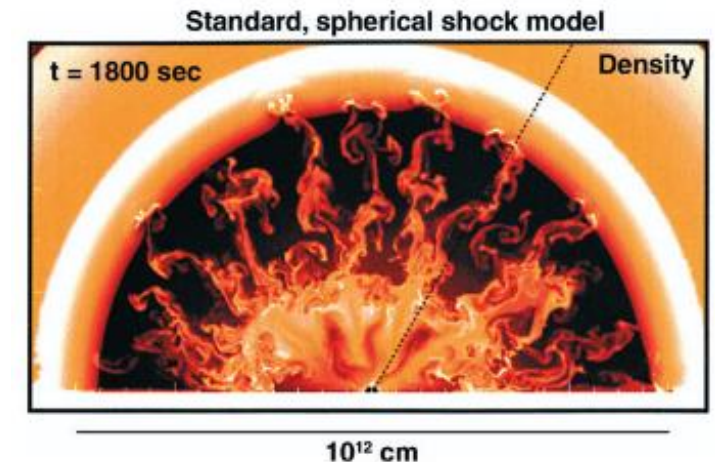
Federrath, Physics Today 38-42 (2018)

Optical image of Herbig–Haro HH jet 111



Ann. Rev., Astron. Astrophys. 39 2001

2D simulation of SN1987A core collapse

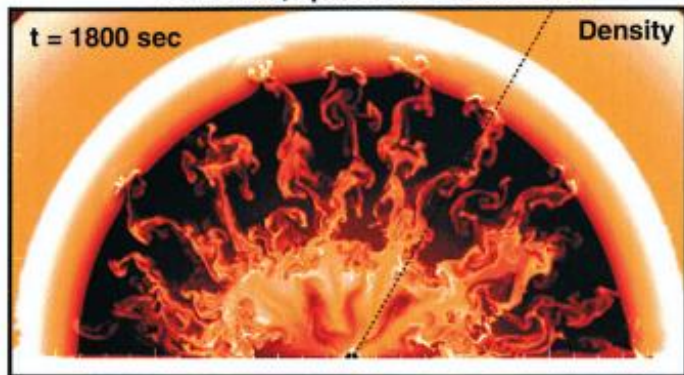


Kifonidis et al 2003

Can we scale the length by multiple orders of magnitude?

2D simulation of SN1987A core collapse

Standard, spherical shock model



10^{12} cm

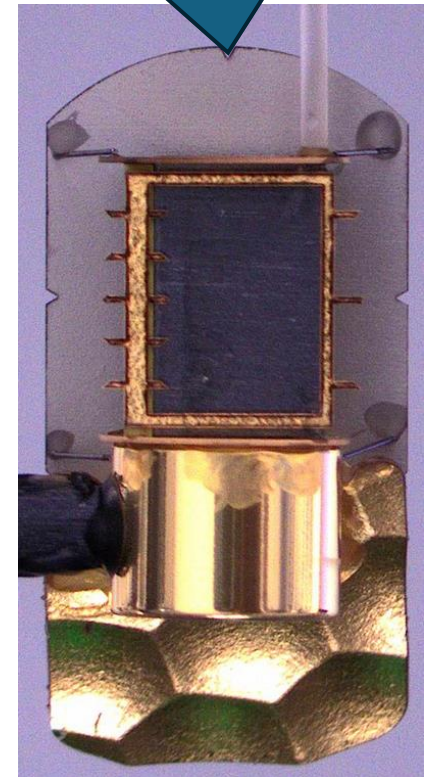
Kifonidis et al 2003

10^3 cm



UW-Madison Shock Tube Lab

10^{-1} cm



NIF Shock Tube target⁶

Non-dimensional scaling from previous RMI experiments

Motl et al., Physics of Fluids (2009)

RM instability growth measurement over a range of Atwood numbers, $0.29 < A < 0.95$, and shock strengths, $1.1 < M < 3$

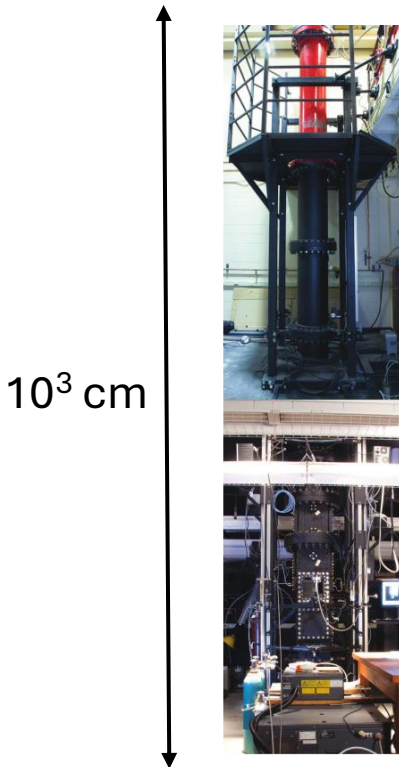


Fig. 1. Sinusoidally shaped copper plate and support frame

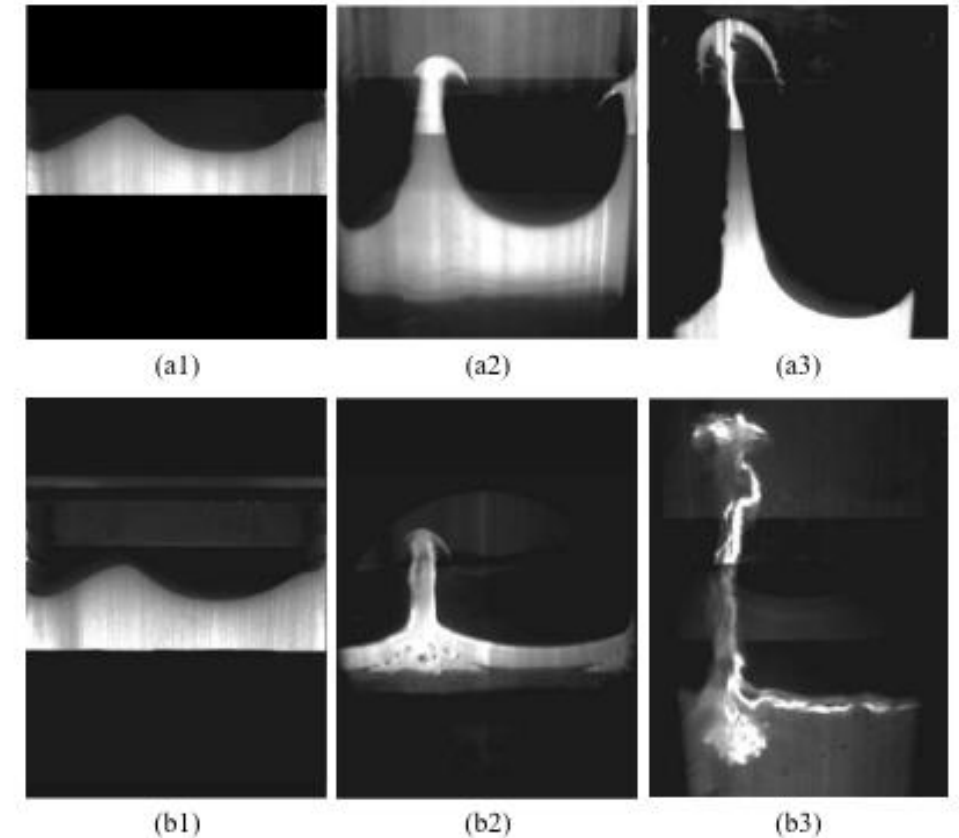


FIG. 3. Time-sequence of experimental images for He/SF₆, $M=1.13$ case: (a1) initial condition, $t=0.00$ ms, (a2) $t=2.67$ ms, and (a3) $t=7.04$ ms. He/SF₆, $M=1.95$ case: (b1) initial condition, $t=0.00$ ms, (b2) $t=0.67$ ms, and (b3) $t=1.77$ ms. Each image is approximately 25 cm wide.

Non-dimensional scaling from previous RMI experiments

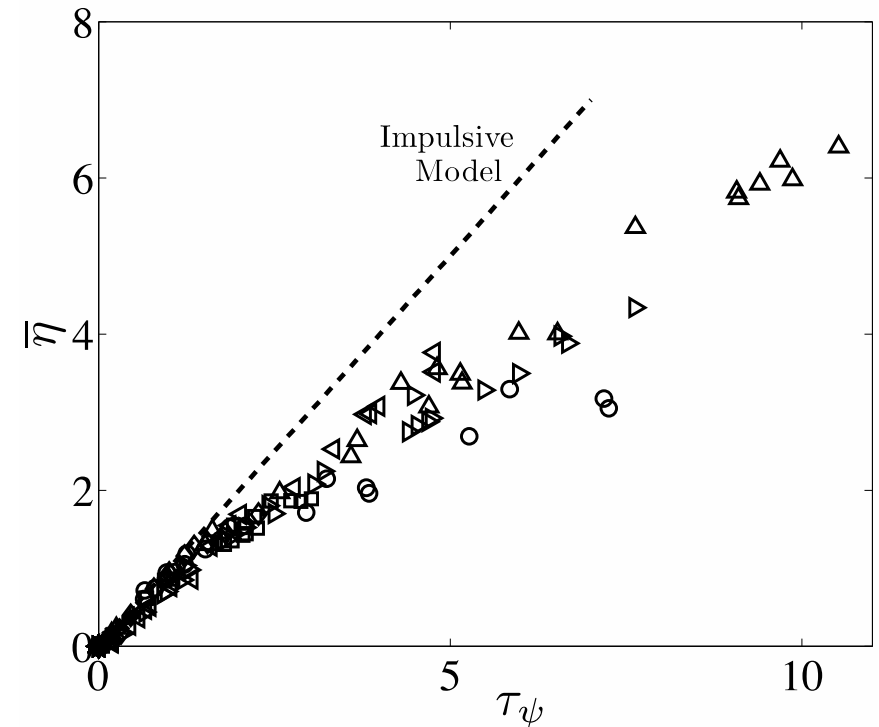
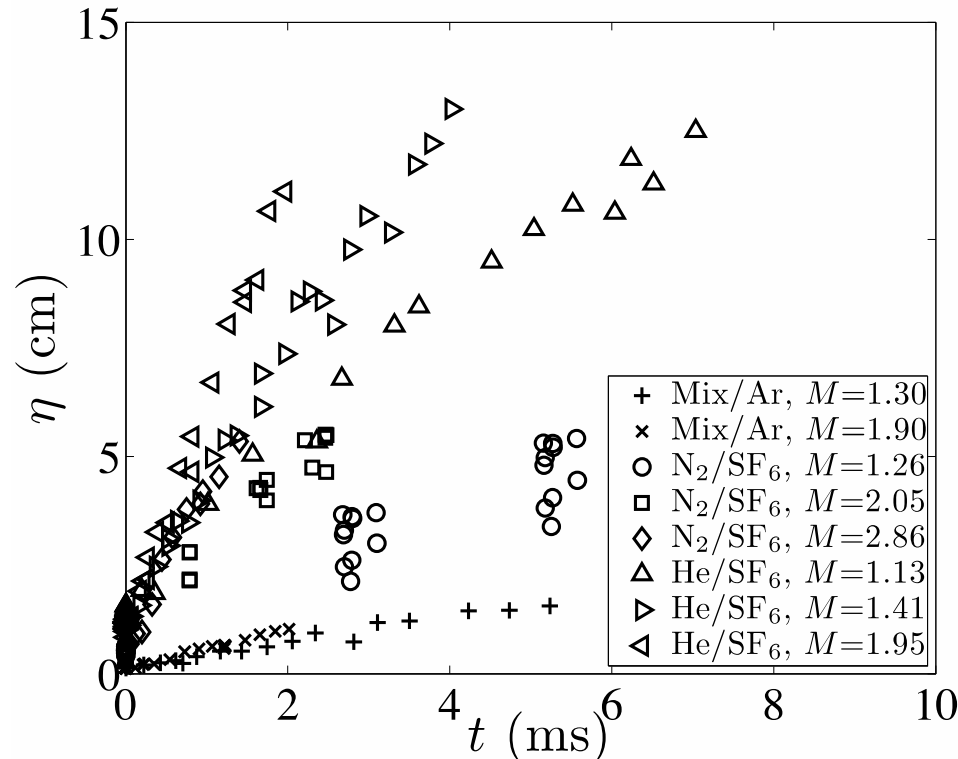
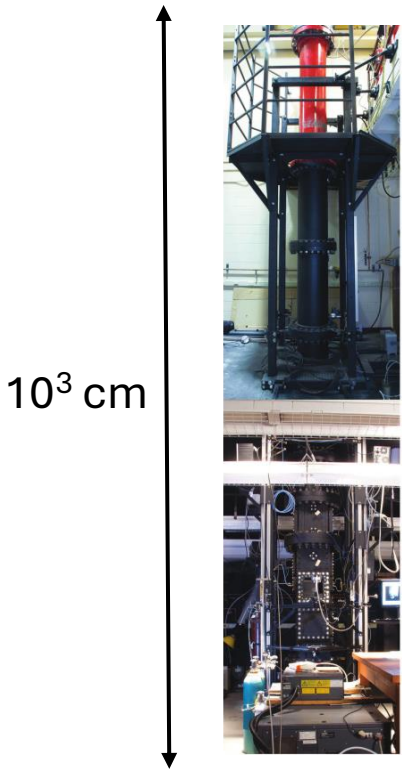
Motl et al., Physics of Fluids (2009)

RM instability growth measurement over a range of Atwood numbers, $0.29 < A < 0.95$, and shock strengths, $1.1 < M < 3$

$$\bar{\eta} = k(\eta - \eta_0^1)$$

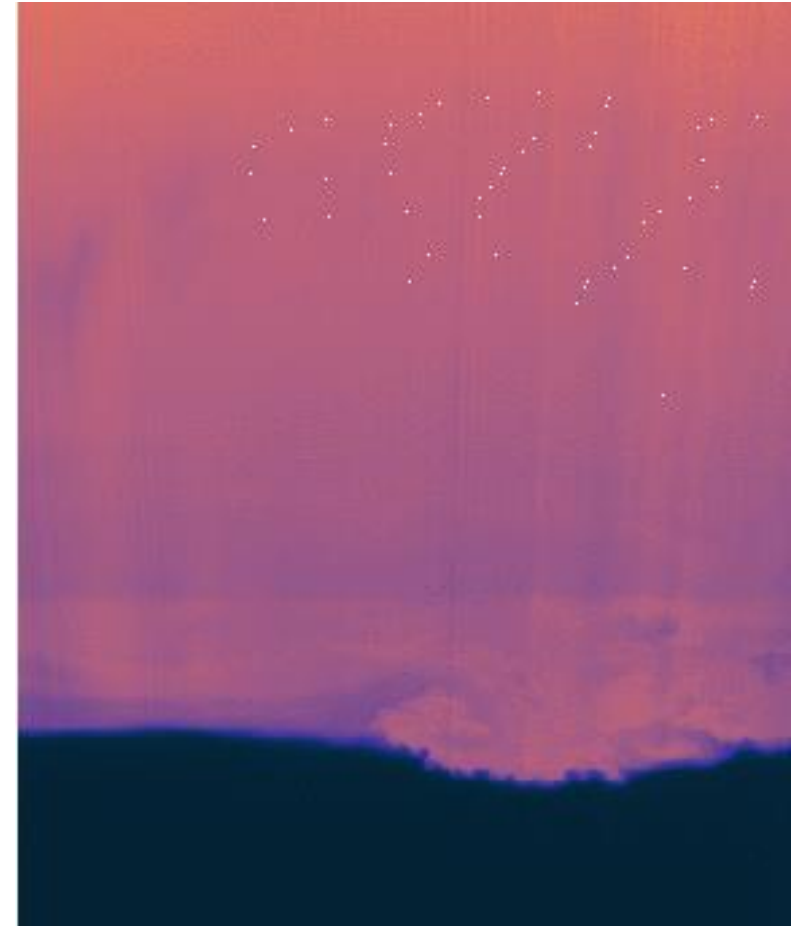
$$\tau = (d\eta/dt)_0 kt$$

τ_ψ corrected for diffusion



Can we calibrate ICF models using high-resolution low-energy-density experiments?

- Much lower Mach numbers ($\sim 1-3$)
- Shock almost always propagates from the light species to the heavy
- “Pure” Richtmyer-Meshkov instability instead of combined RM/RT



A pure RMI configuration in the deep-non linear regime on NIF will be compared to UW-Madison vertical shock tube

UW-Madison

NIF

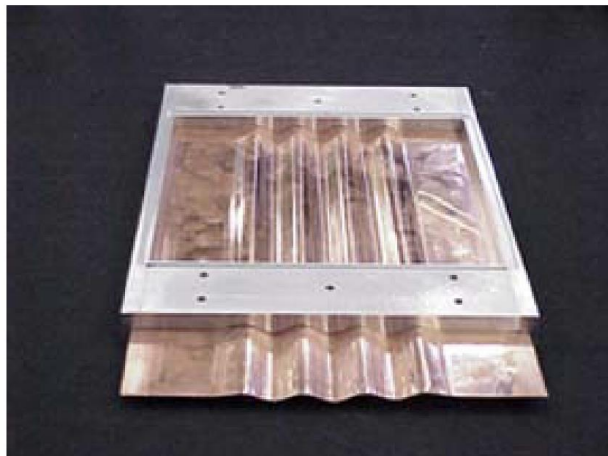
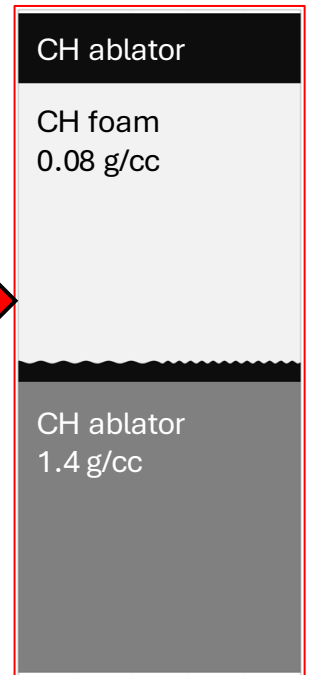
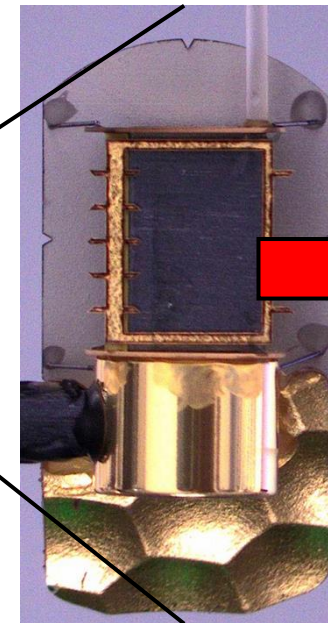


Fig. 1. Sinusoidally shaped copper plate and support frame

9 m height physics package



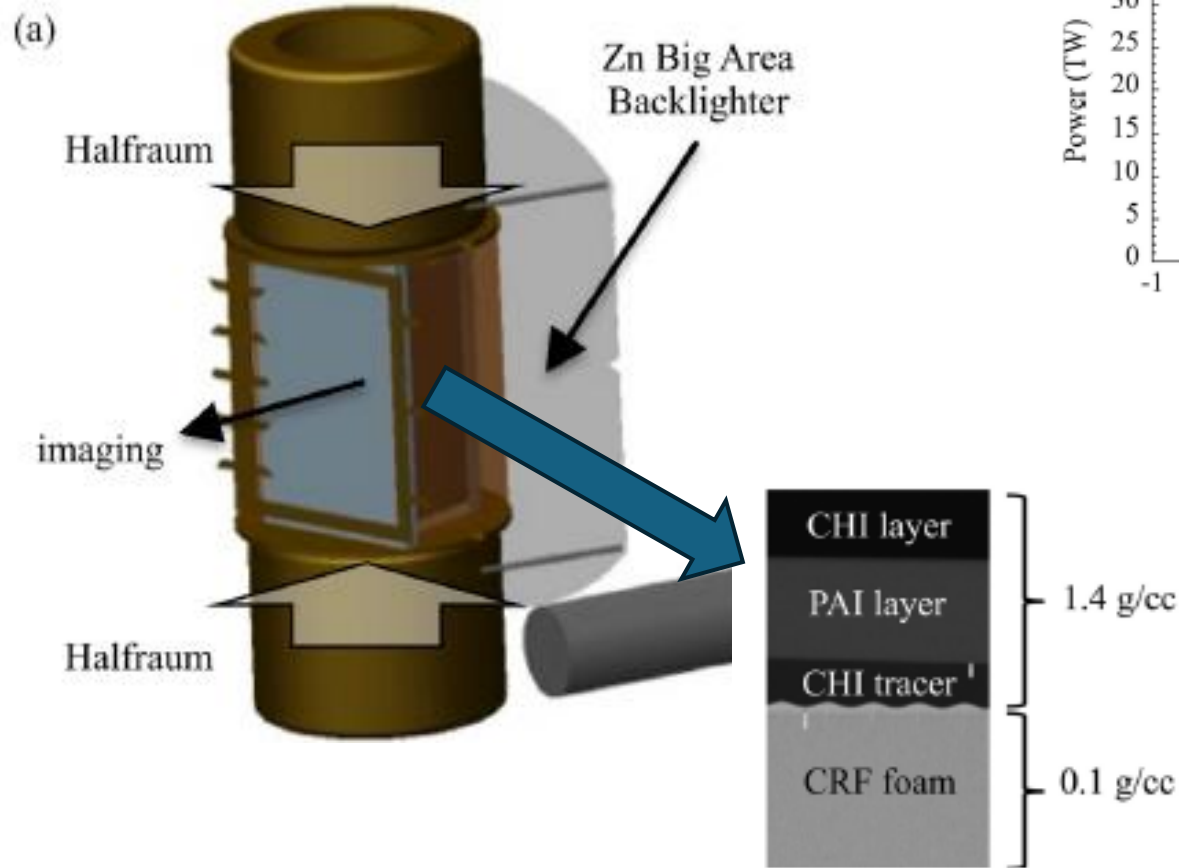
VS



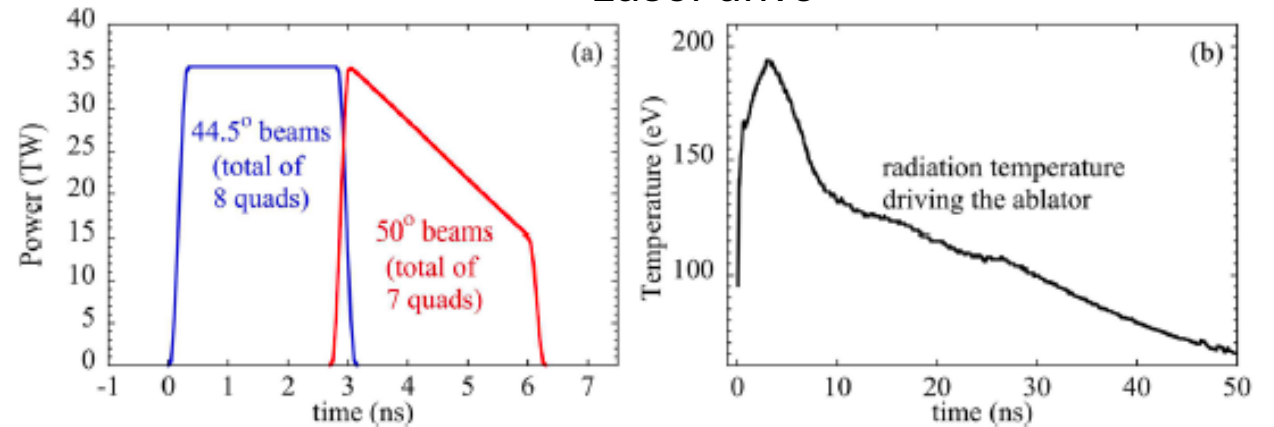
4 mm height physics package
Design based on Nagel et al., POP 2017

We based our experiment on the reshock platform...

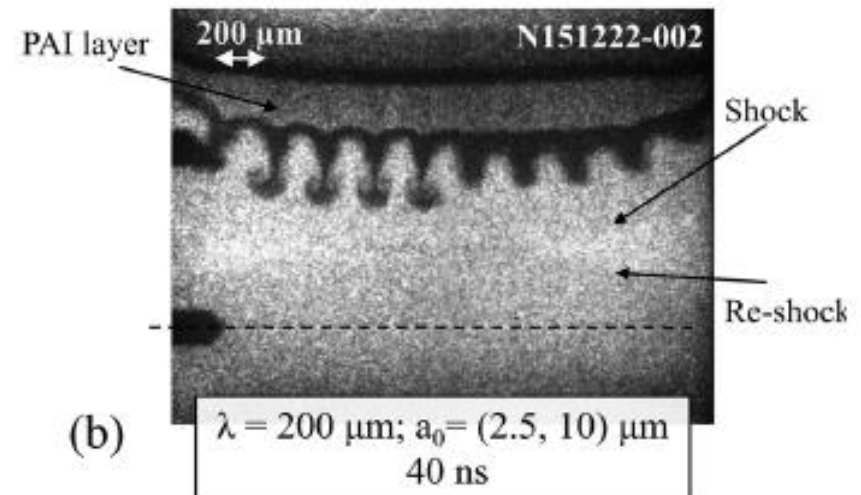
Target design



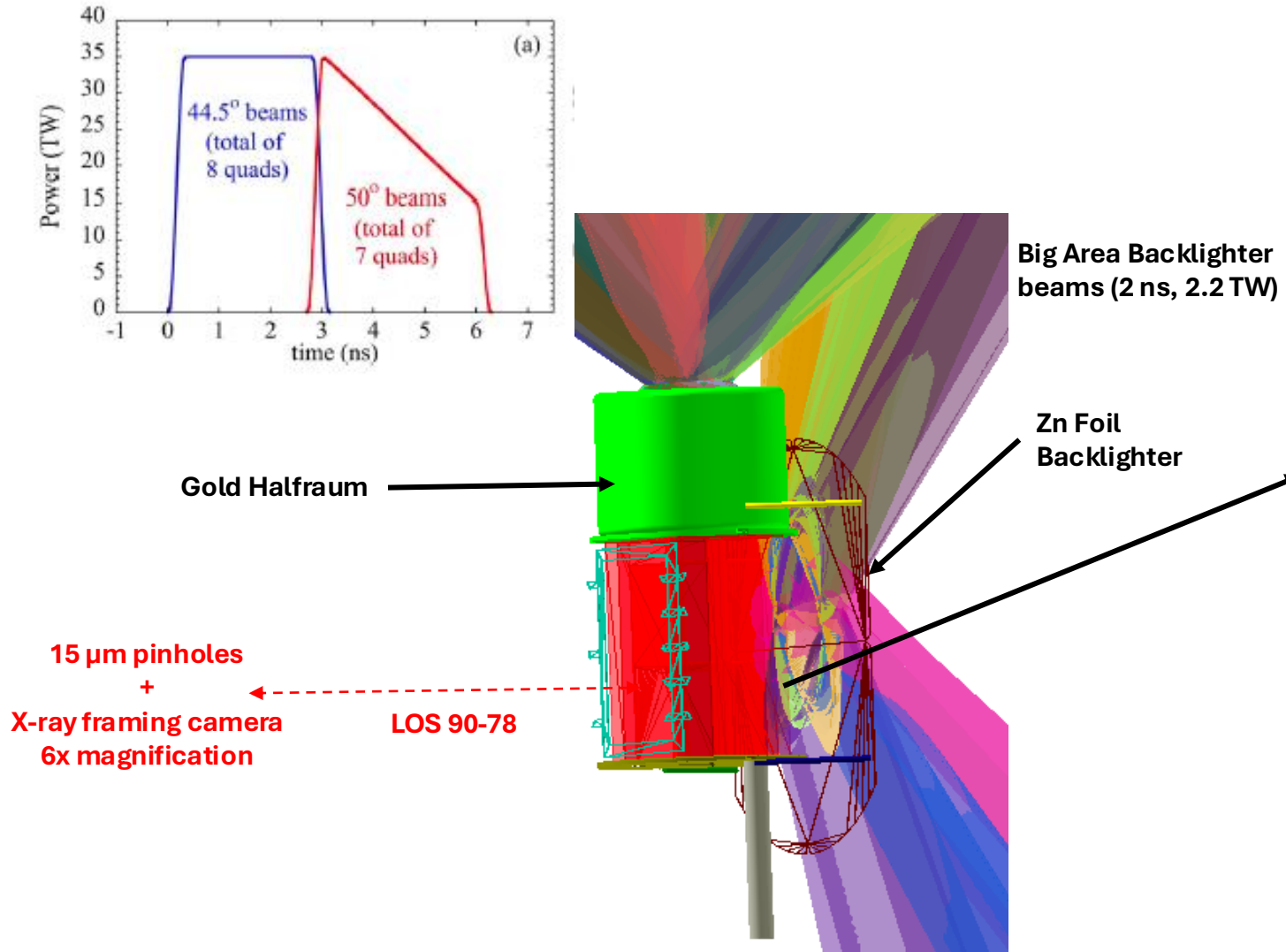
Laser drive



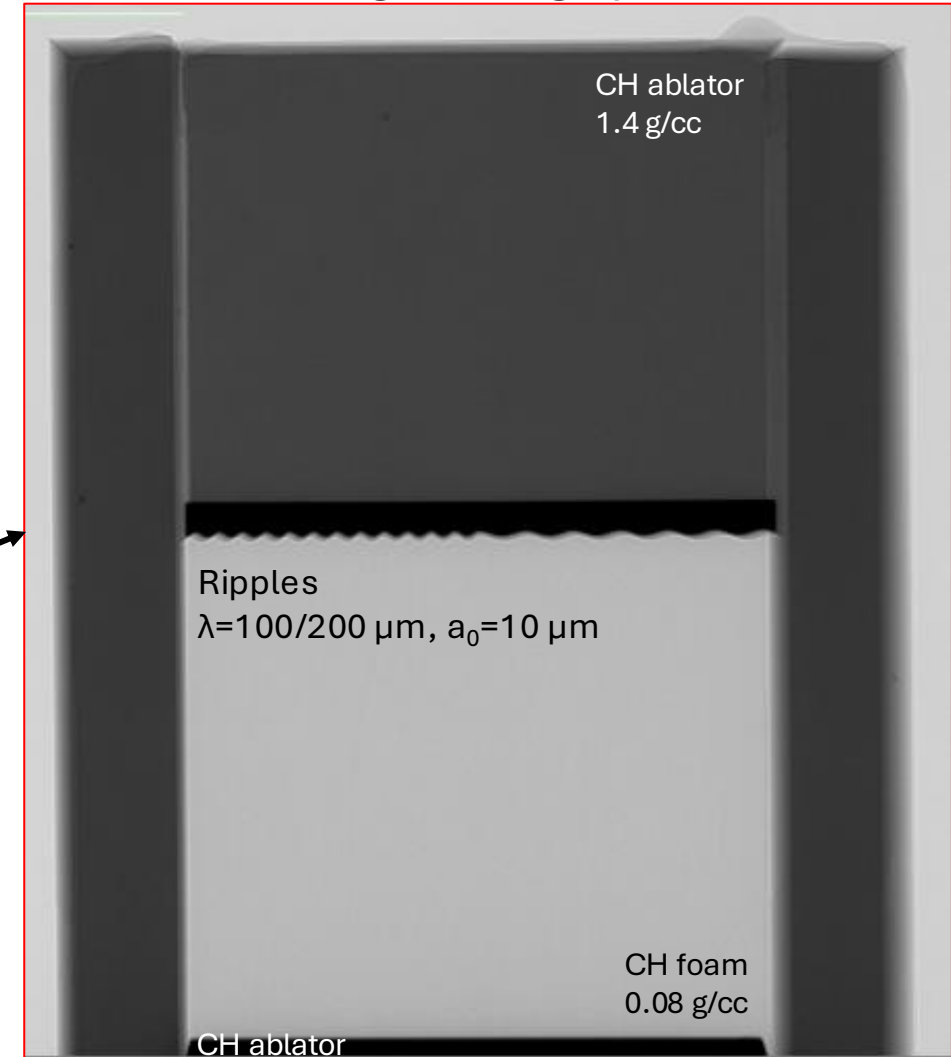
Radiograph



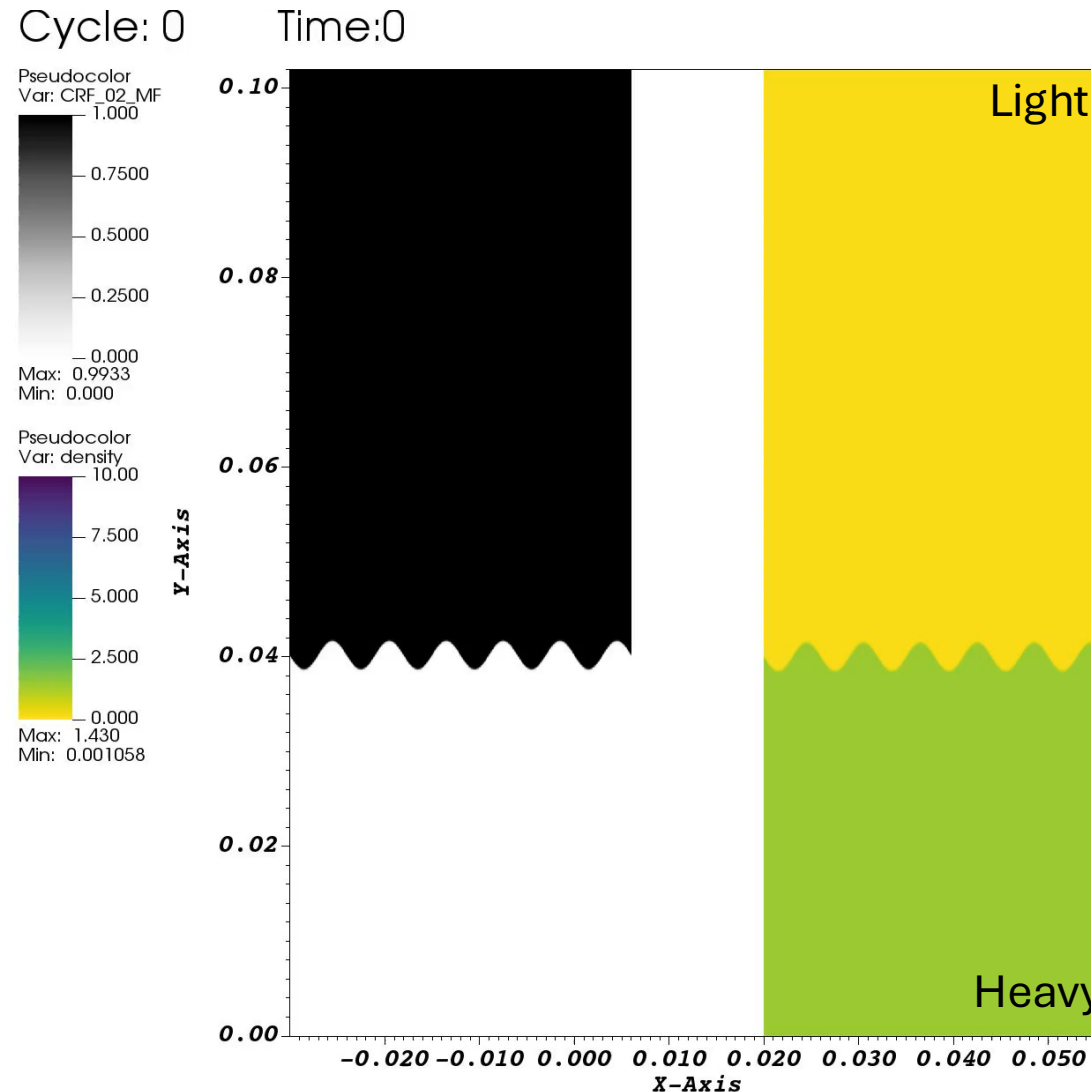
... But with a few twists



Target radiograph

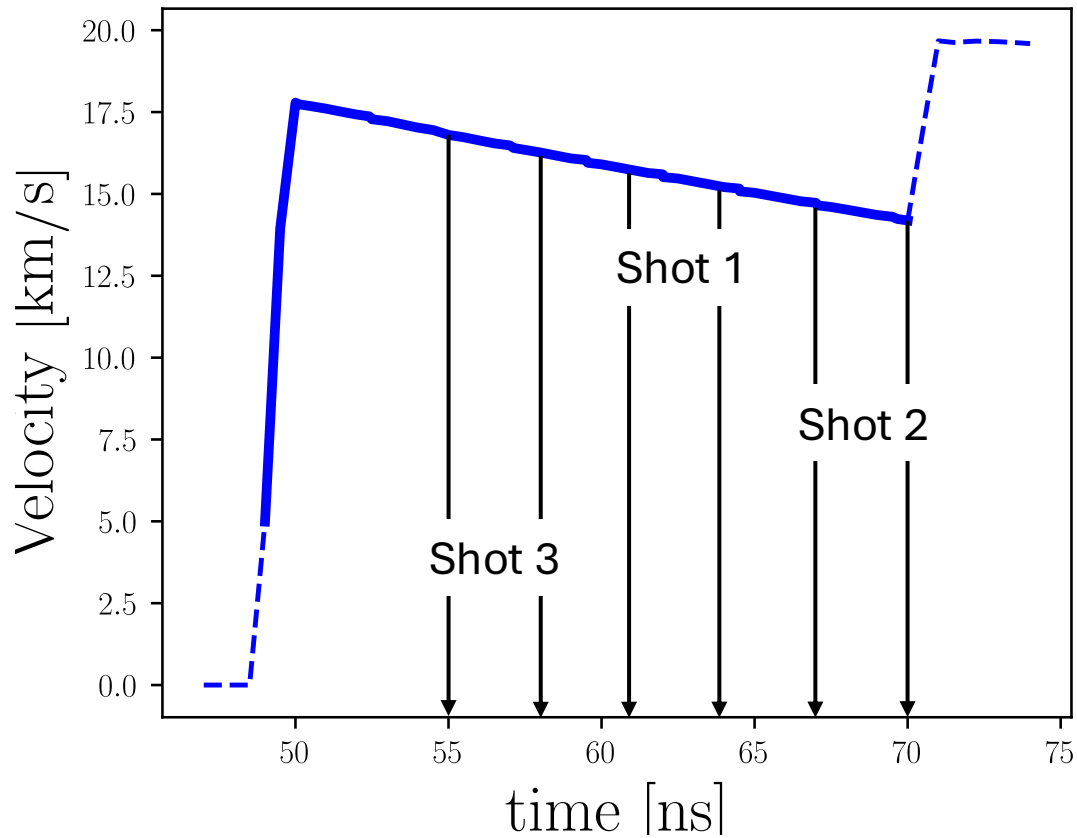


Pre-shot Miranda & Hydra simulations were used to select our experimental parameters

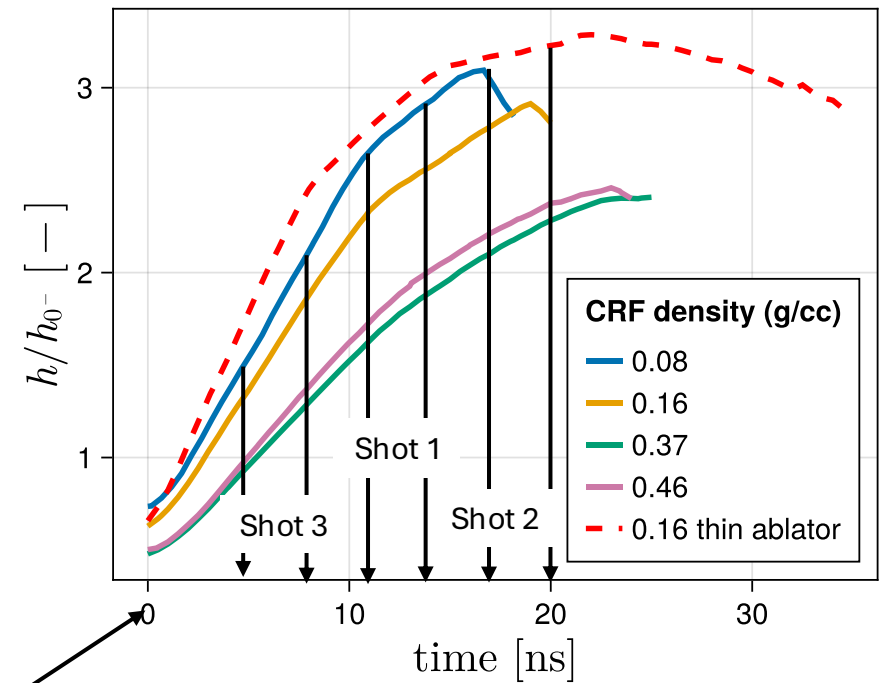


Low velocity allowed for the use of 250 ps gate time with the framing camera

Interface Velocity
thick ablator, 0.16 g/cc



Hydra predictions
of HED RMI growth

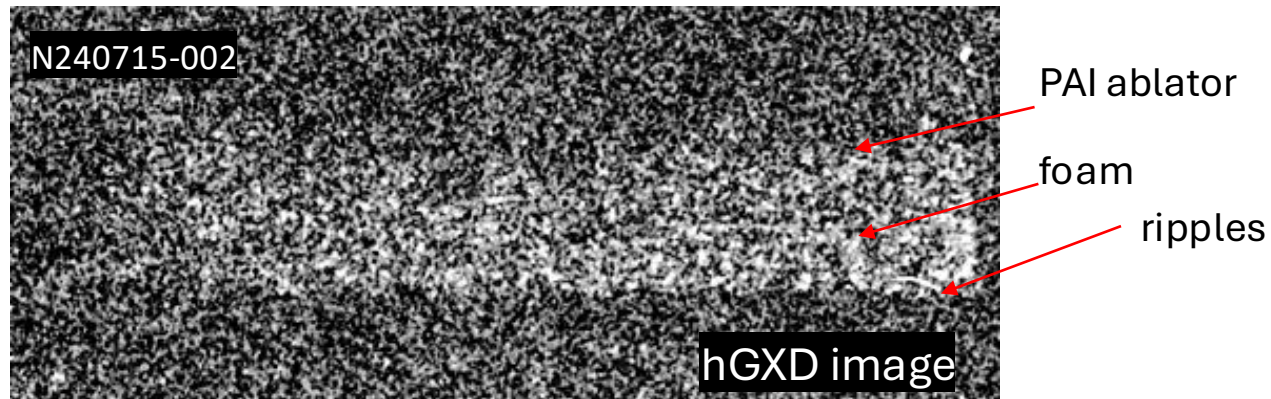


Interface starts to move

Things don't always go according to plan



Zn backlighter underperformed – no time resolved data was obtained



But we always learn something!

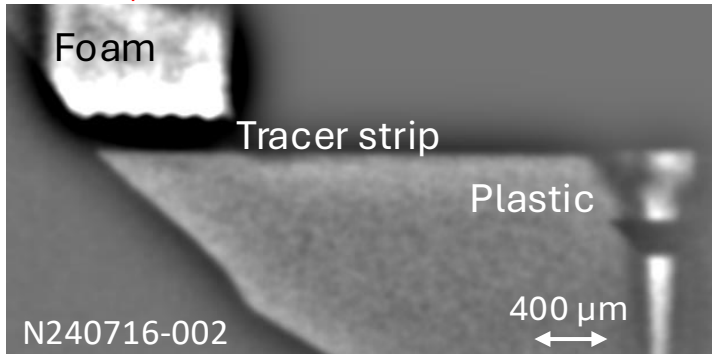
Imaging plate (time integrated) data
Estimated motion blur $\sim 15\text{-}25\ \mu\text{m}$

55 ns - 58 ns

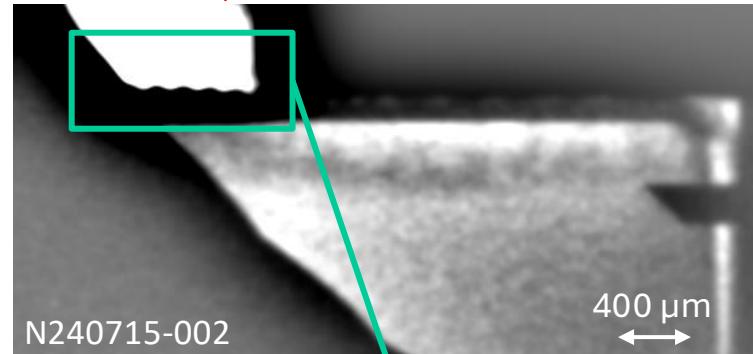
61 ns - 64 ns

67 ns - 70 ns

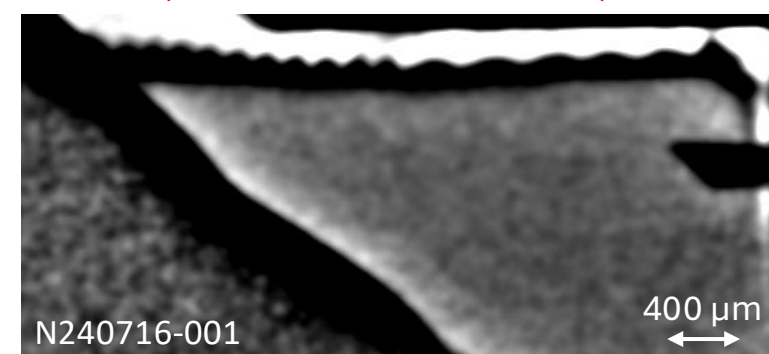
WL $\sim 87.5 \pm 5\ \mu\text{m}$
A $\sim 19 \pm 8\ \mu\text{m}$



WL $\sim 91.7 \pm 5\ \mu\text{m}$
A $\sim 20.8 \pm 8\ \mu\text{m}$

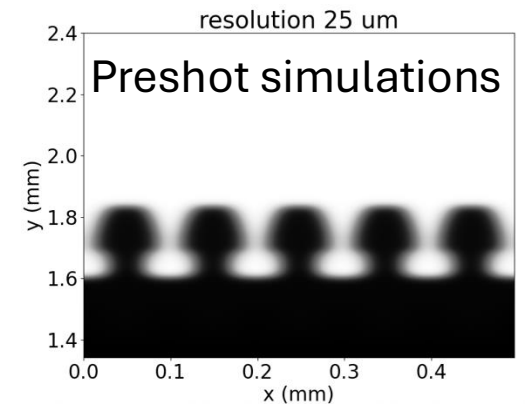
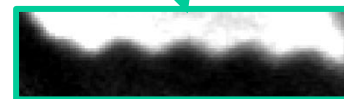


WL $\sim 87.5 \pm 5\ \mu\text{m}$
A $\sim 35.4 \pm 8\ \mu\text{m}$

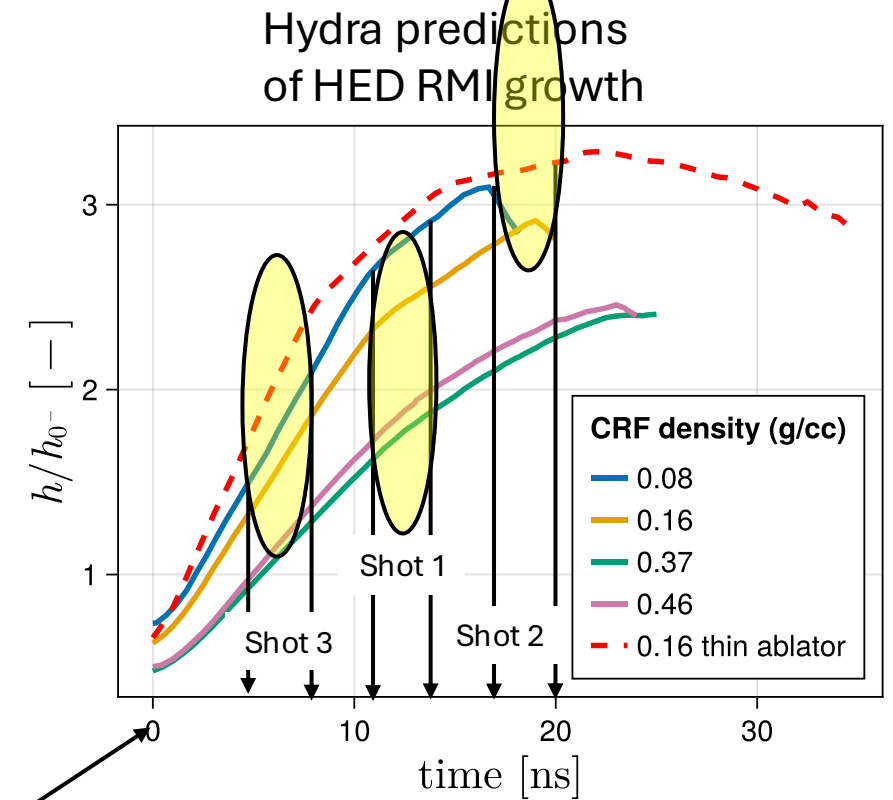
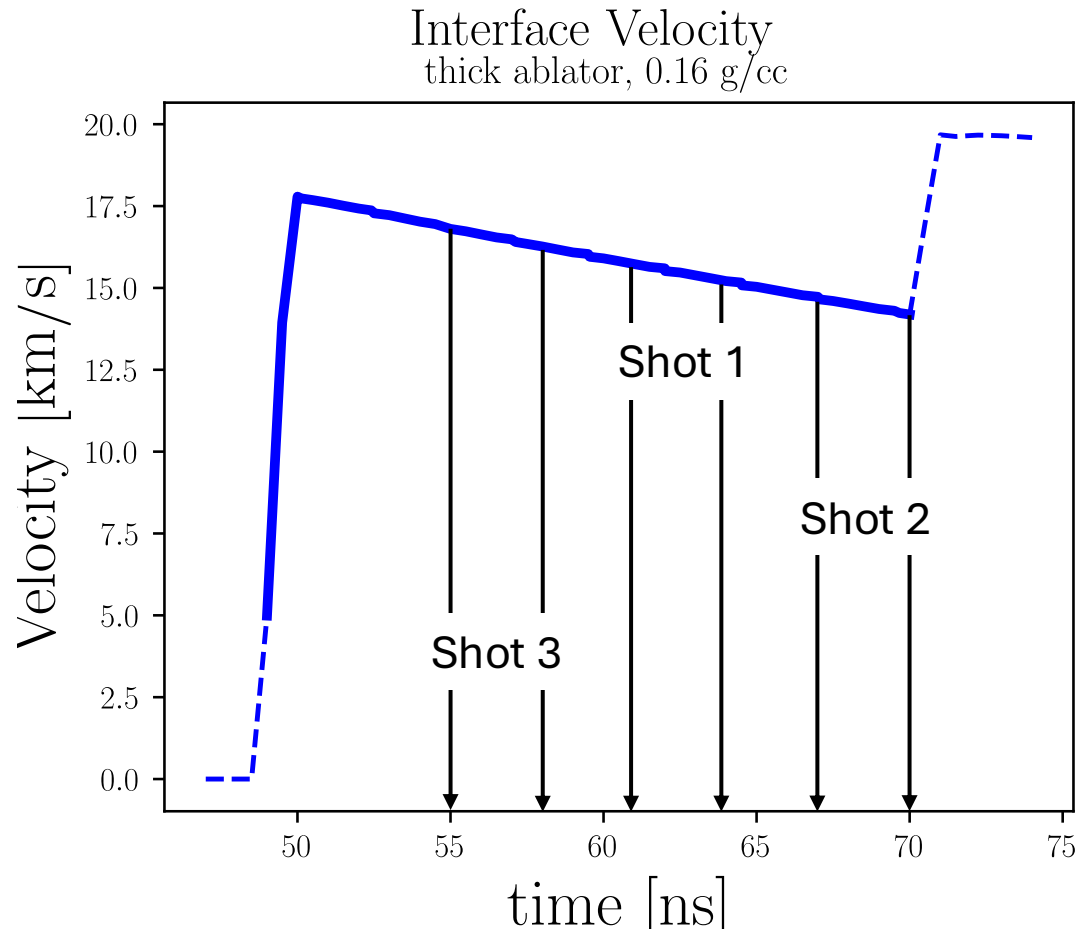


WL $\sim 177 \pm 5\ \mu\text{m}$
A $\sim 27 \pm 8\ \mu\text{m}$

No transition to the non-linear regime!

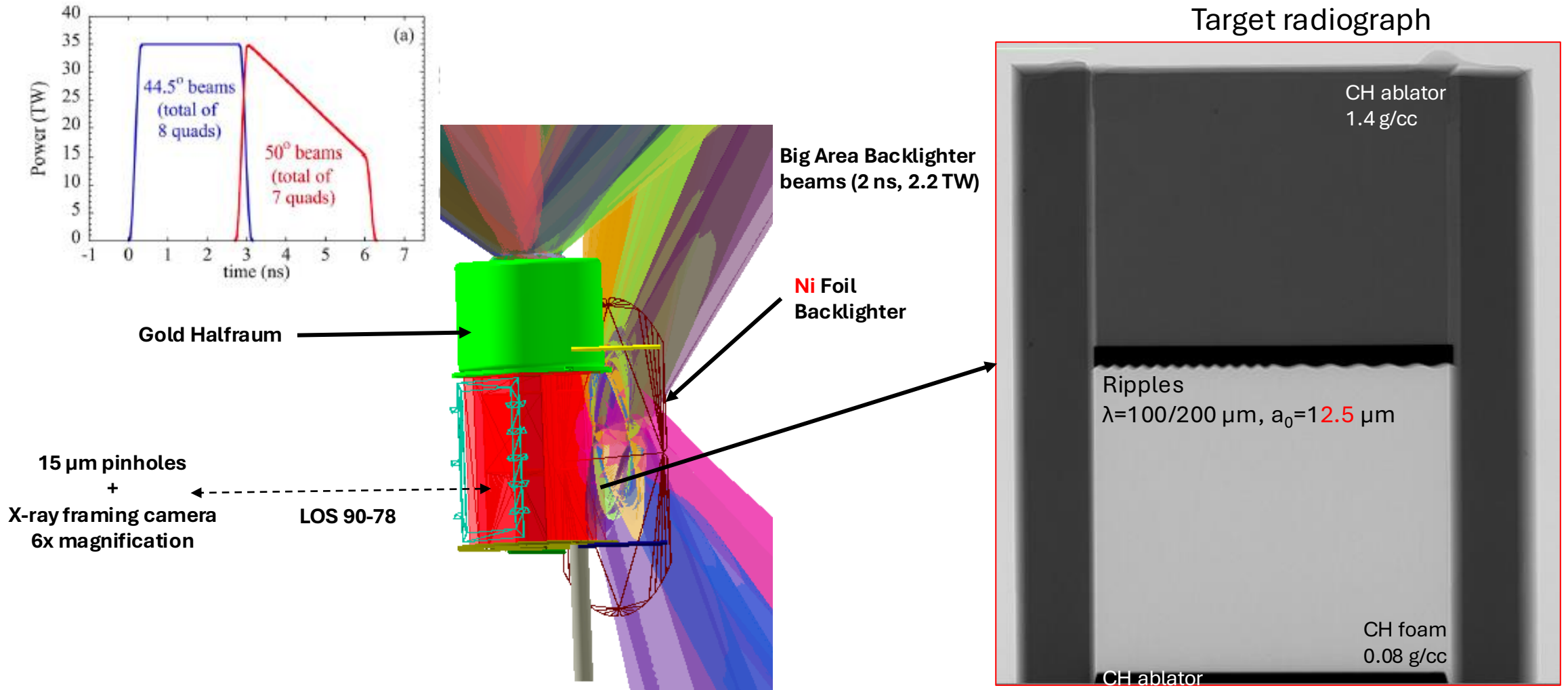


Time integrated growth factor agrees reasonably with simulations



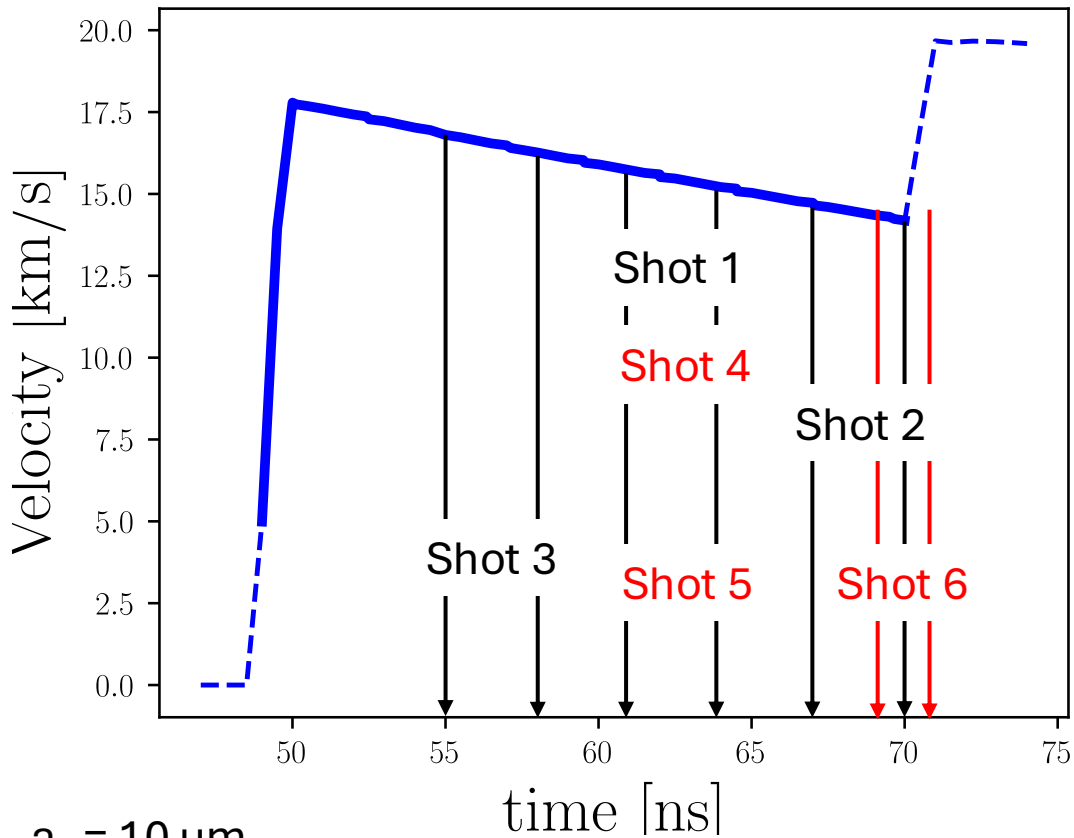
Interface starts to move

Dialed up the platform for faster transition to non linear regime and increase fluence



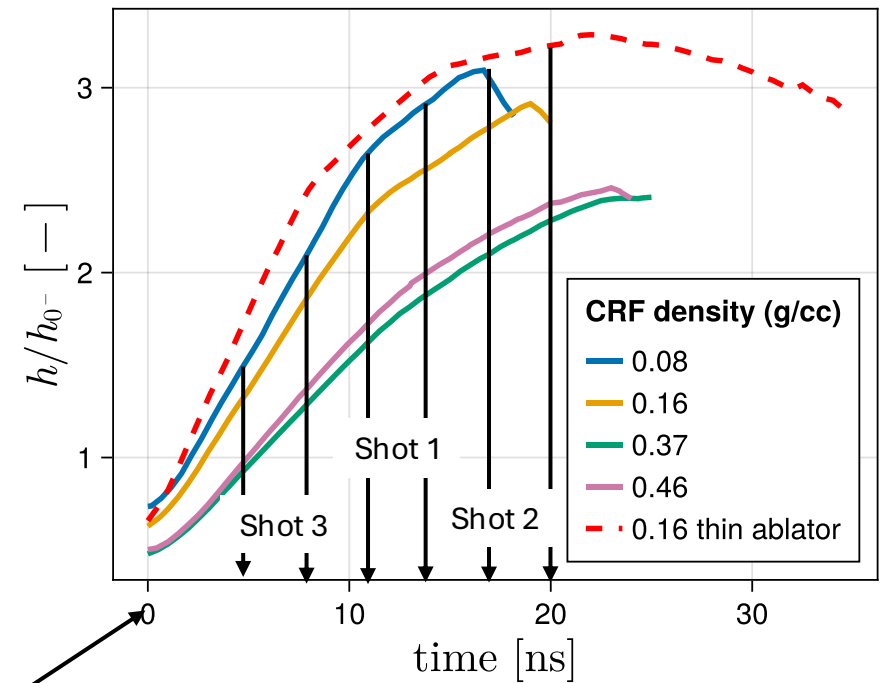
We repeated shot 1 to confirm previous data and then compared with larger a_0 ...

Interface Velocity
thick ablator, 0.16 g/cc



$a_0 = 10 \mu\text{m}$
 $a_0 = 12.5 \mu\text{m}$

Hydra predictions
of HED RMI growth



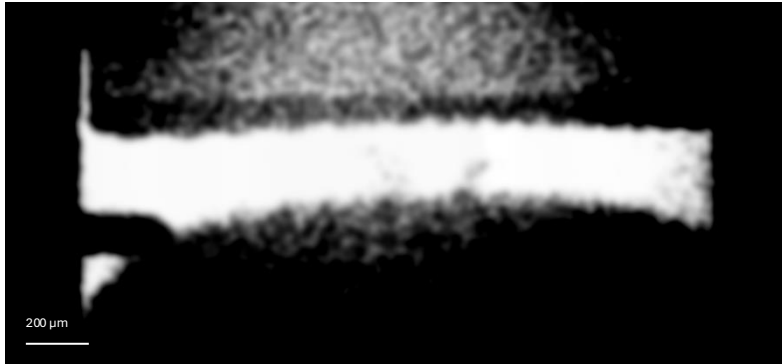
Interface starts to move

... And succeeded! [maybe a little too well]

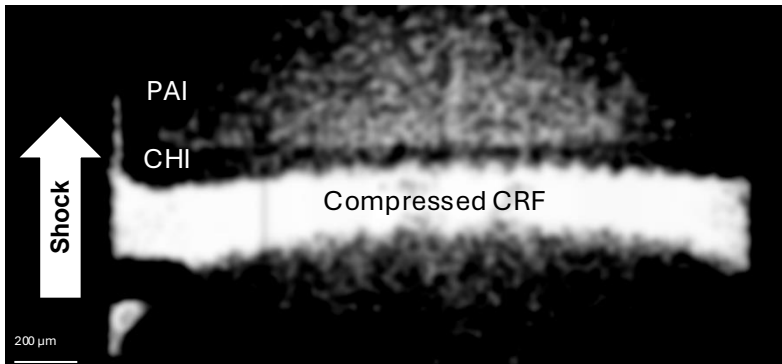
N250907-002

$a_0 = 10 \mu\text{m}$

64 ns



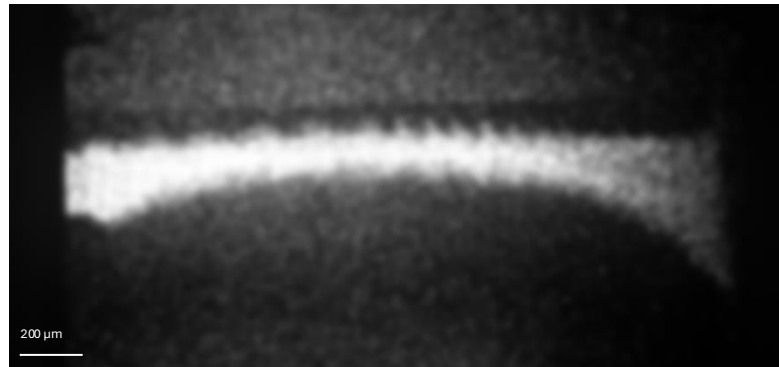
66 ns



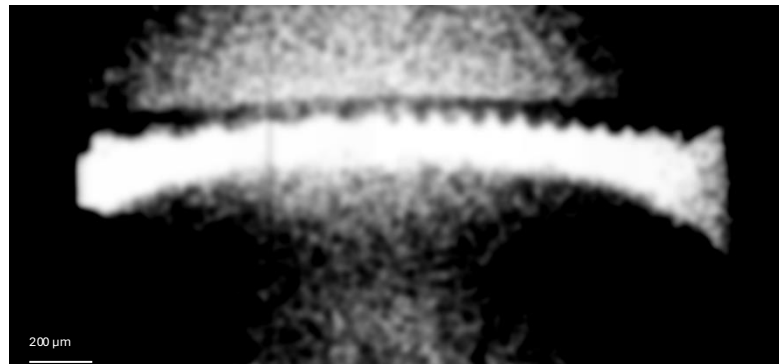
N250907-003

$a_0 = 12,5 \mu\text{m}$

64 ns



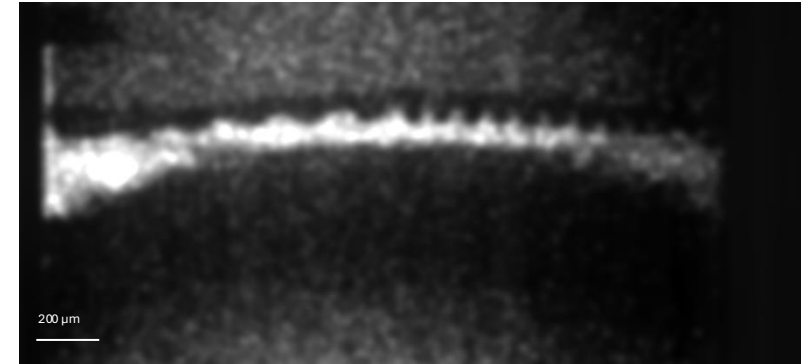
66 ns



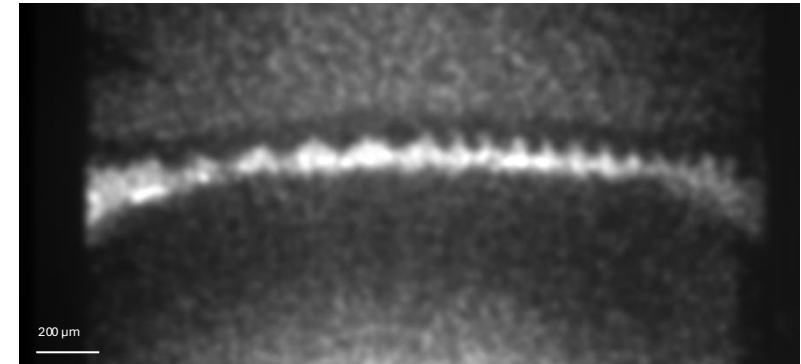
N250907-004

$a_0 = 12,5 \mu\text{m}$

69 ns

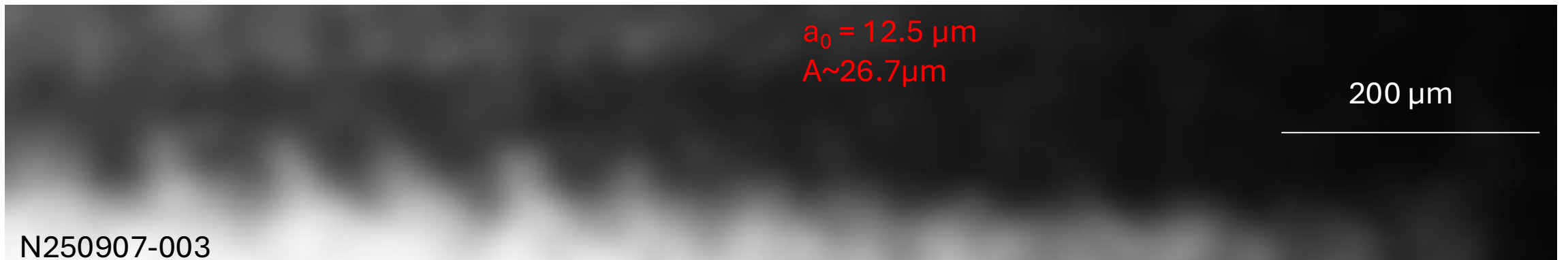
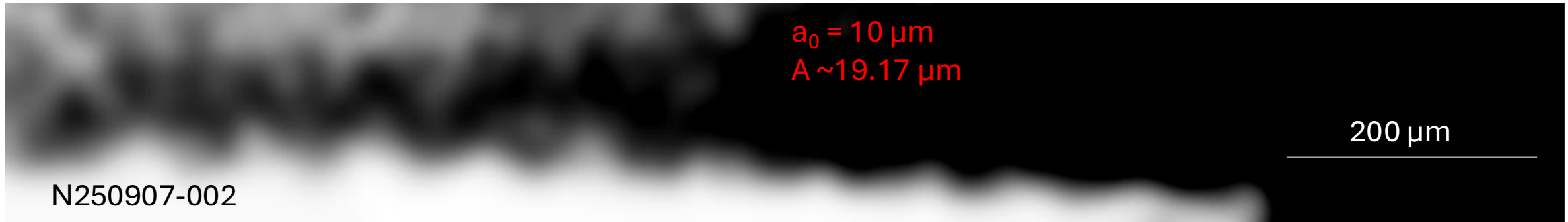


71 ns



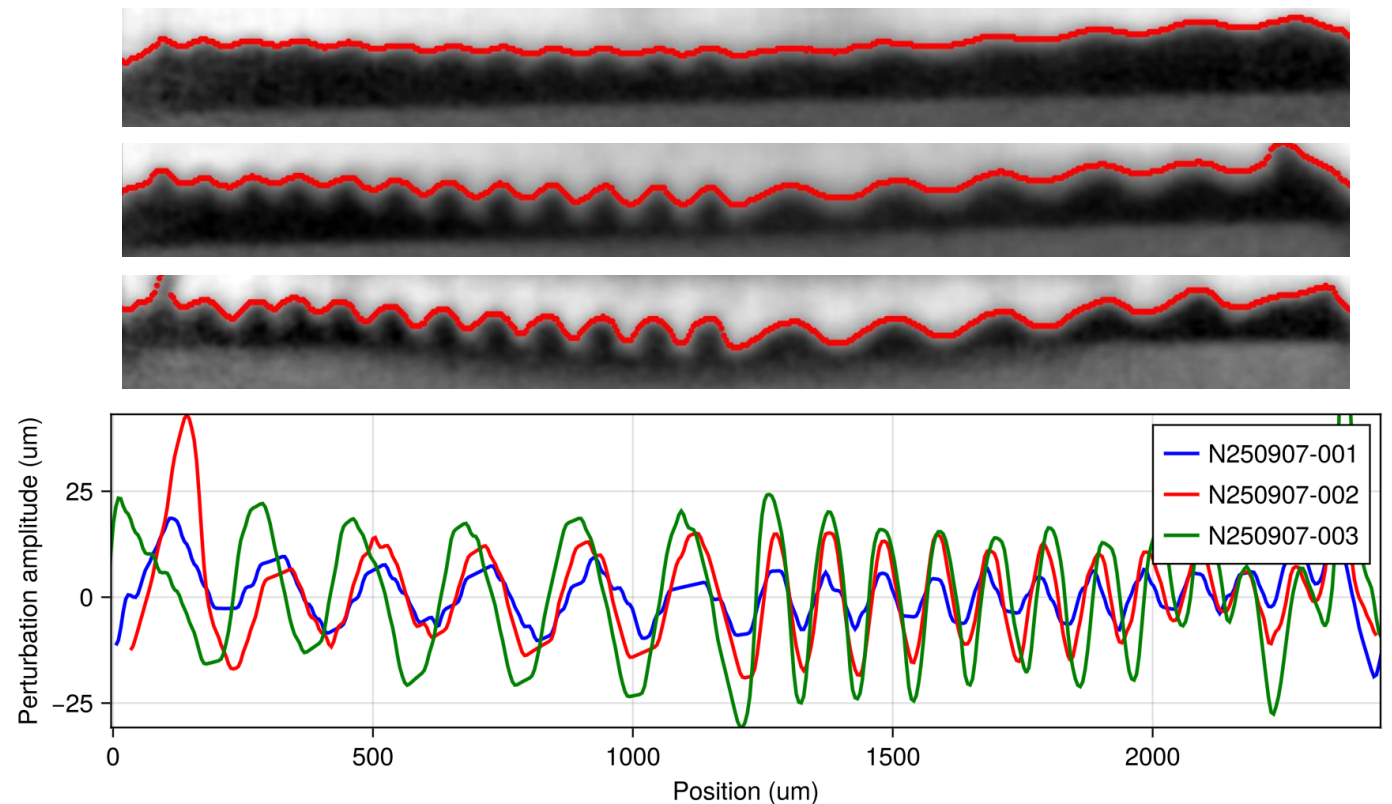
Analysis WIP

64 ns comparison



Shock curvature may allow extraction of time evolution from image plates

- Exploit varying curved-shock time of arrival at interface as a “natural experiment”
- Needs to be calibrated to 2D simulations with realistic wall effects - ongoing



Summary

- A platform for late-time study of the Richtmyer-Meshkov instability in the light-to-heavy, steady-shock case has been established on the NIF
- Radiography confirms computational prediction of instability development towards the nonlinear rollup phase at the latest times observed
- Comparison to low-energy-density impulsive growth model is ongoing