Designs and implementation plan for Highly nonlinear Ablative Rayleigh-Taylor Instability experiments on NIF

Presentation to

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Ablative Rayleigh-Taylor Instability (Abl RT) Collaboration

- PI name and institution: A. Casner (CEA DAM DIF, France)
- CEA
- L. Masse (ablative RTI), O. Poujade (RTI turbulence), D. Galmiche, S. Liberatore (hohlraum designers), B. Delorme (PhD student)
- P. Loiseau (LPI), F. Girard, L. Jacquet (backlighters), L. Videau (shrapnel)

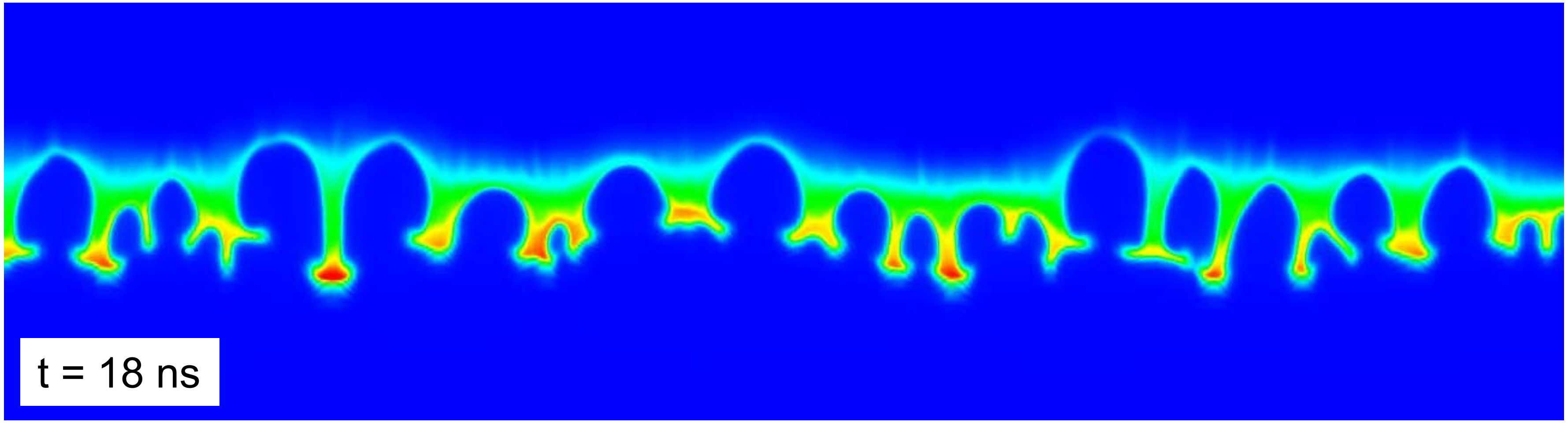
- LLNL
- V. Smalyuk (co-PI), H.S. Park, D. Bradley, B. Remington
- J. Kane (Eagle nebula proposal designer)
- AWE : A. Moore (RadT platform expert)

- I. Igumenshev in charge of Direct Drive design (Laboratory of Laser Energetics, Rochester)
- Prof. P. Clavin (Institut de Recherche Phénomènes Hors équilibre, Aix-Marseille University)
- M. Olazabal-Loumé (CELIA, University of Bordeaux)

- Prof. S. Sarkar (Department of Mechanical and Aerospace Enginneering, UCSD)

Ablative RTI objectives

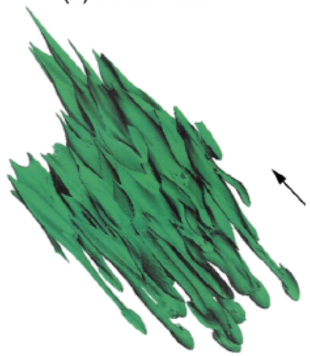
- The effect of ablation on RTI growth rate depends on the irradiating scheme: direct versus indirect drive.
- Multimode ablative Rayleigh Taylor Instability is not well understood, as well as turbulent front hydrodynamics.

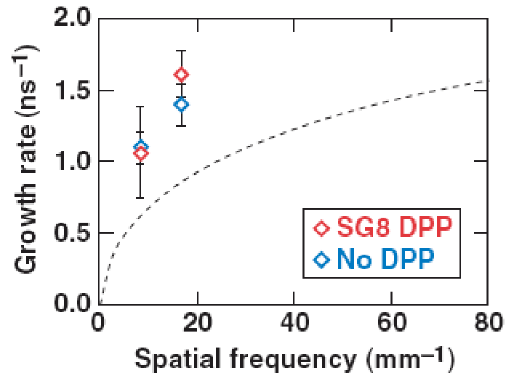


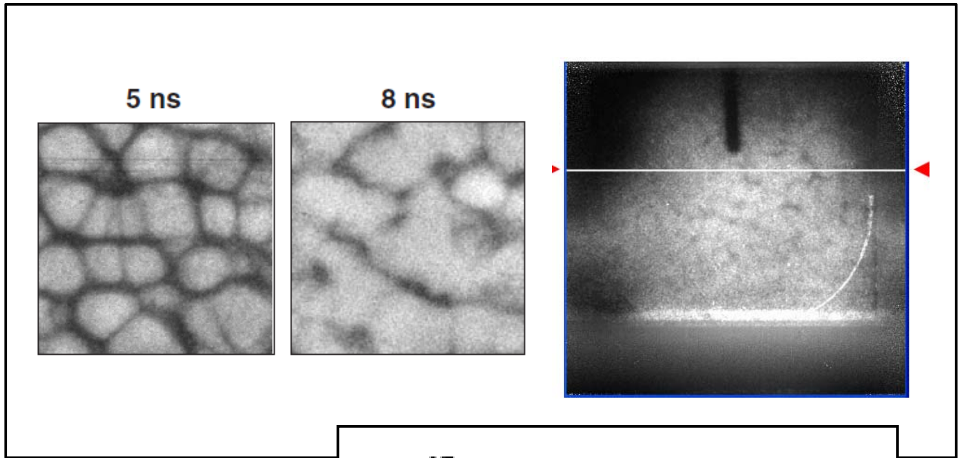
- NIF will accelerate targets over much larger distances (x6) and over longer time periods than ever achieved.
- In one shot, growth of RT modulations can be measured from the weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes and perhaps into a turbulent-like regime.
- The ID platform is on track for 1-2 shots scheduled in September
- We can perform these experiments right now, without any new diagnostics.
- We are developping a gas-filled hydrodynamics platform usefull for future experiments (Eagle nebula, ….)

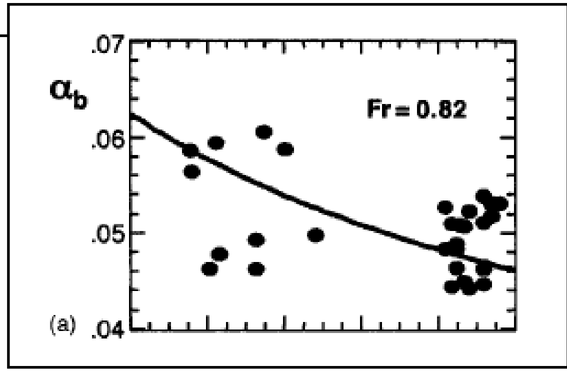
ARTI Proposal goals: Study ablative Rayleigh-Taylor in deeply non-linear regime

- Multimode ablative RTI is not well understood
- Non-linear mode coupling
- Ablative destabilization
- Bubble-competition and merger
- Transition to turbulence and influence of initial conditions
- Address effect of ablation on terminal bubble velocity

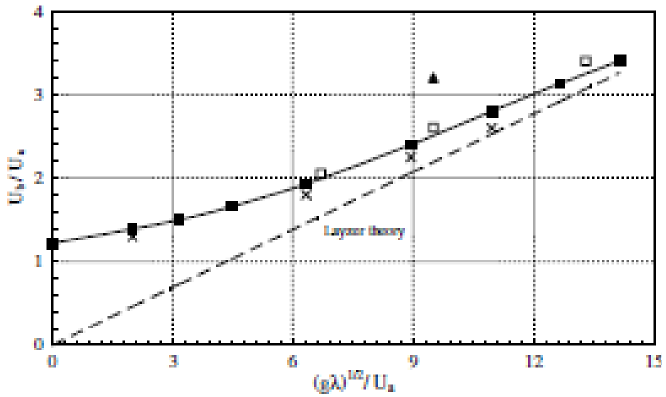


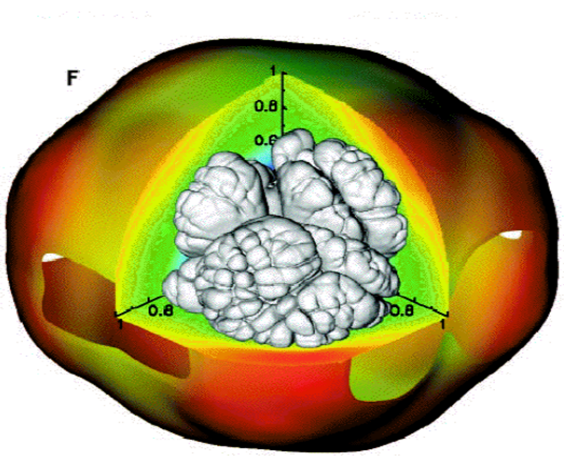


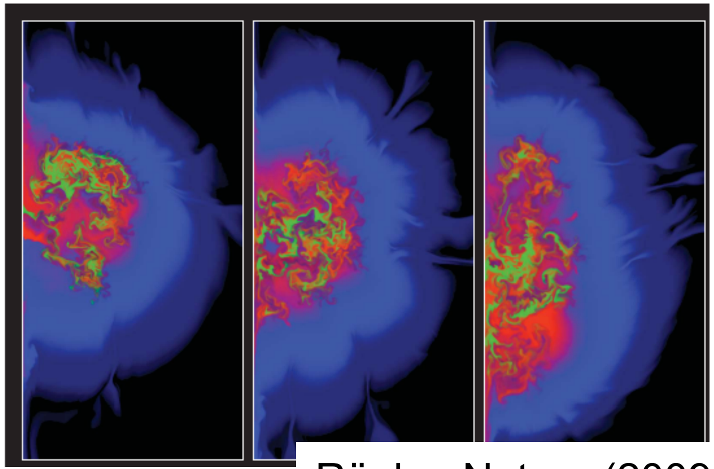




Links to Astrophysics







Röpke, Nature (2009)

- **The material bubble velocity V_B compared to ablation velocity V_a is a key parameter**

 Bubble acceleration in ablative RTI, Betti et Sanz, PRL **97**, 2005002 (2006).

- **V_B and α_b are sub-grid parameters in simulations of SN Ia explosions**

Cabot and Cook, Nat. Phys. **2,** 562 (2006)

- **Strong analogy between ablation front and flame front**

P. Clavin and L. Masse, PoP **11**, 690 (2004)

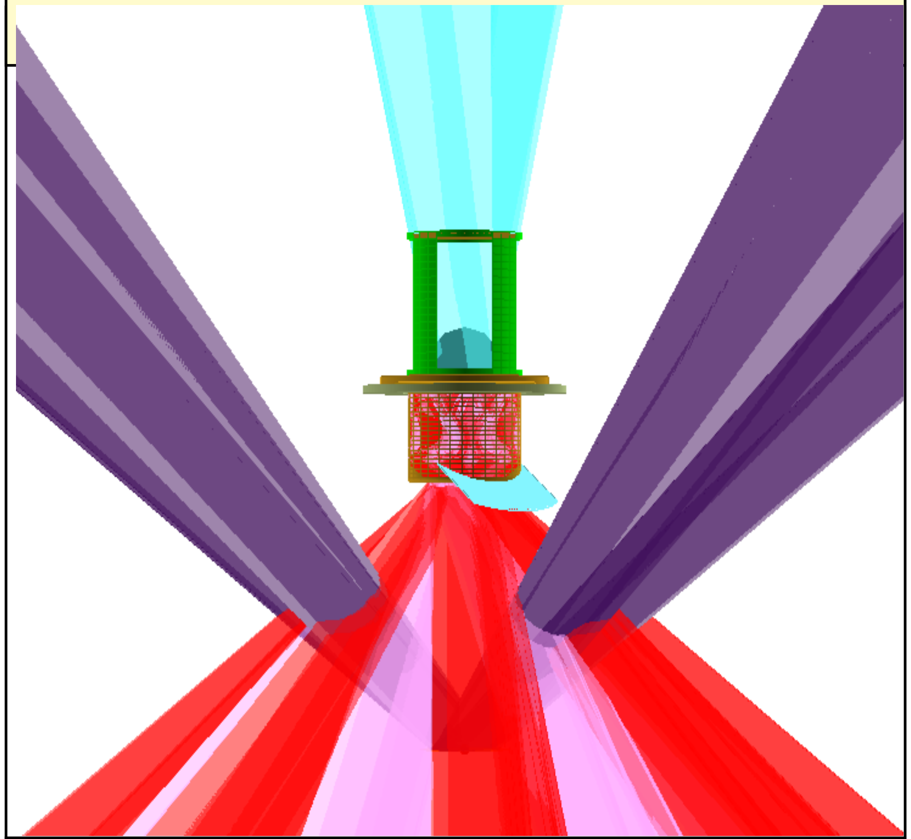
- **An ultimate goal could be to evidence the Landau Darrieus instability at ablation front**

- **Directional effects on ablative RTI in photomolecular clouds**

 (Eagle nebula proposal: J. Kane, M. Pound, B. Remington, V. Smalyuk)

Ablative RT ID platform: compatible with 6 NIF current experimental configurations (see W. Hsing talk)

Indirect Drive Configuration

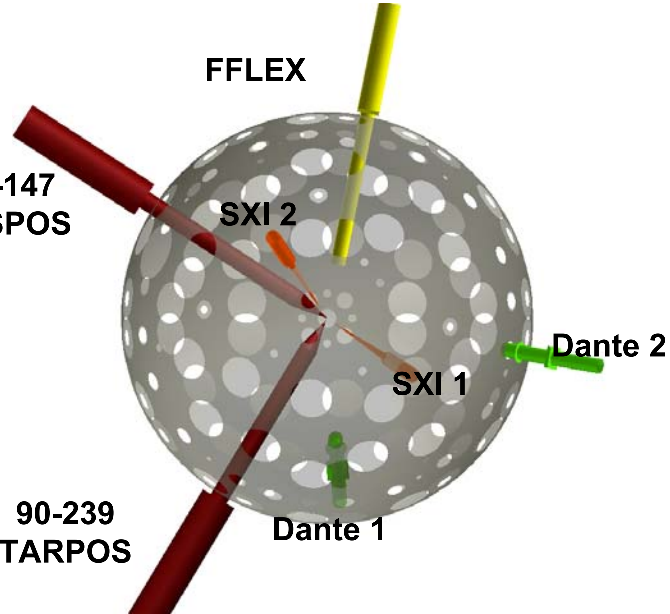


View from 90-78

Drive Pulse
20-ns long, shaped

Total energy 256 kJ

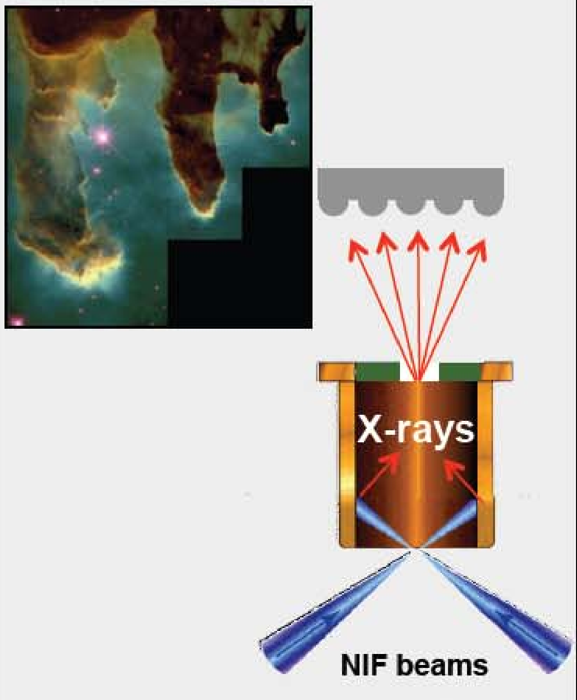
Experimental layout,
Target chamber top view



Diag	Location	Priority	Type	Calib
GXD-1	0-0	1	2	Pre-Shot
DISC-1	90,78	1	3	Pre-Shot
Dante 1	143,274	1	3	Pre-Shot
SXI, T/B	Fixed	3,2	3	Pre-Shot
FABS.NBI/FFLEX	Fixed	2-3	3	Pre-shot
GXD-2	90-315	2	2	Pre-Shot

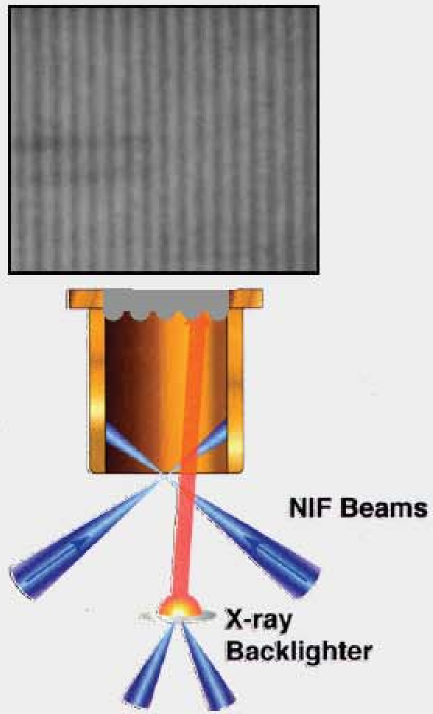
This planar rad-hydro platform can be applied across a wide variety of science experiments

Formation of the Eagle Nebula Pillars



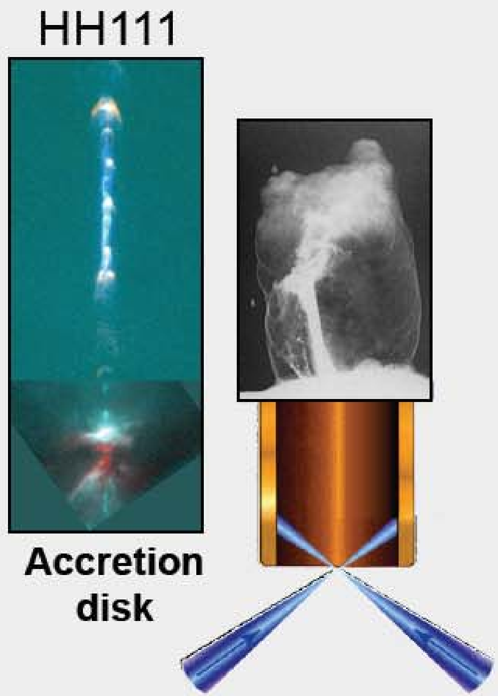
PI: A. Cooper, LLNL

Non-linear ablation front hydrodynamics



PI: A. Casner, CEA

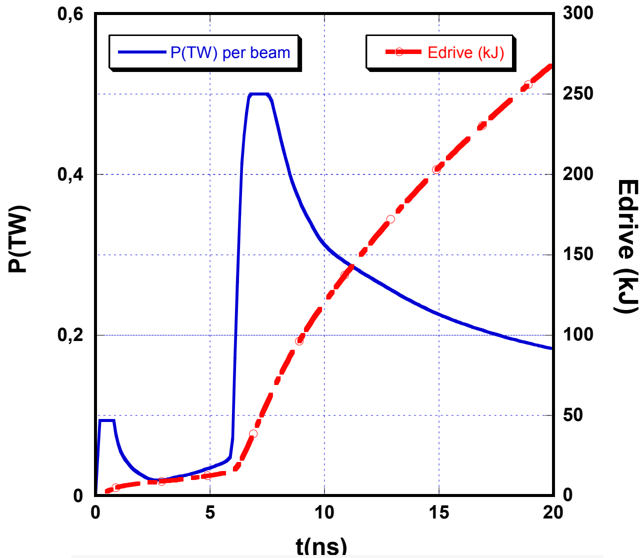
Formation of Herbig-Haro jets



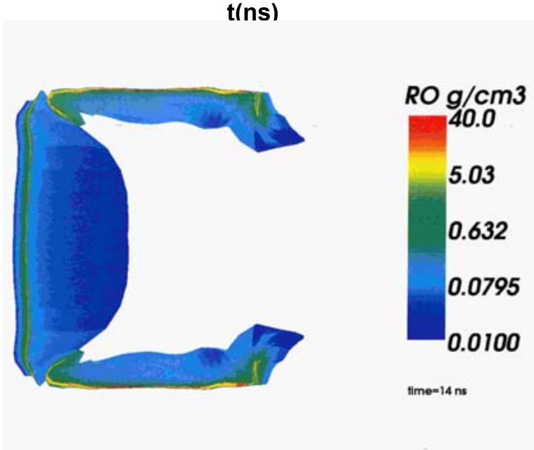
These experiments can utilize a modified planar-radiation hydrodynamics platform

Pulse shape, drive and acceleration

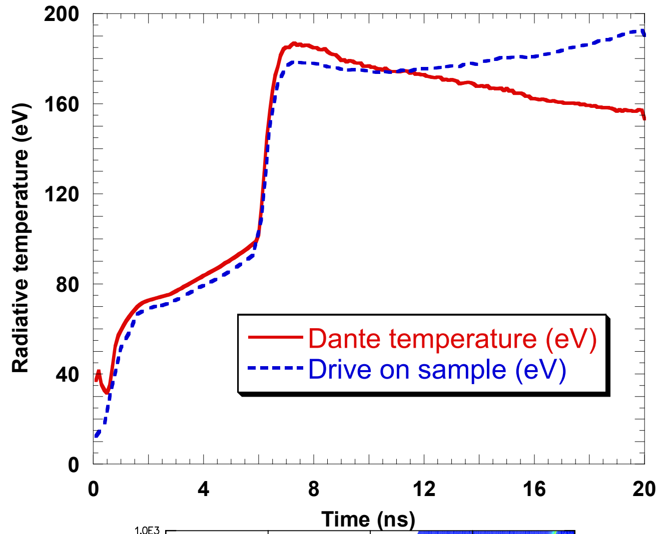
ARTI Radtrans

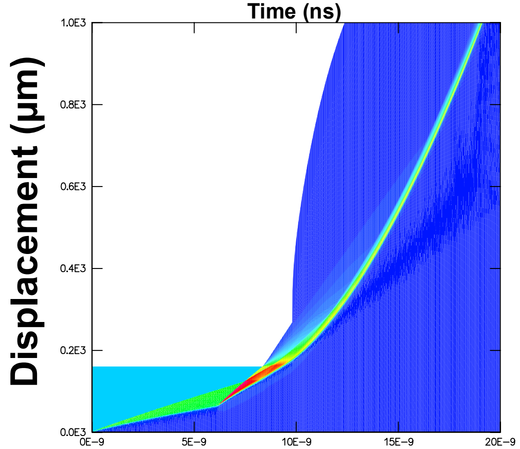


Face on FOV



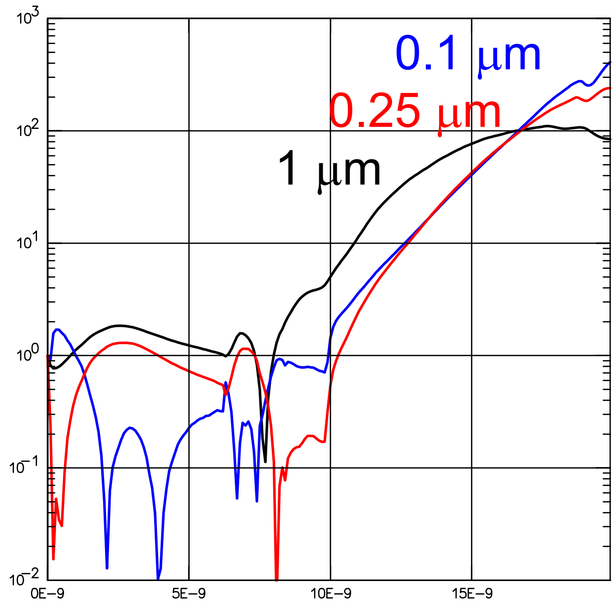
FCI2 CEA Hydrocode

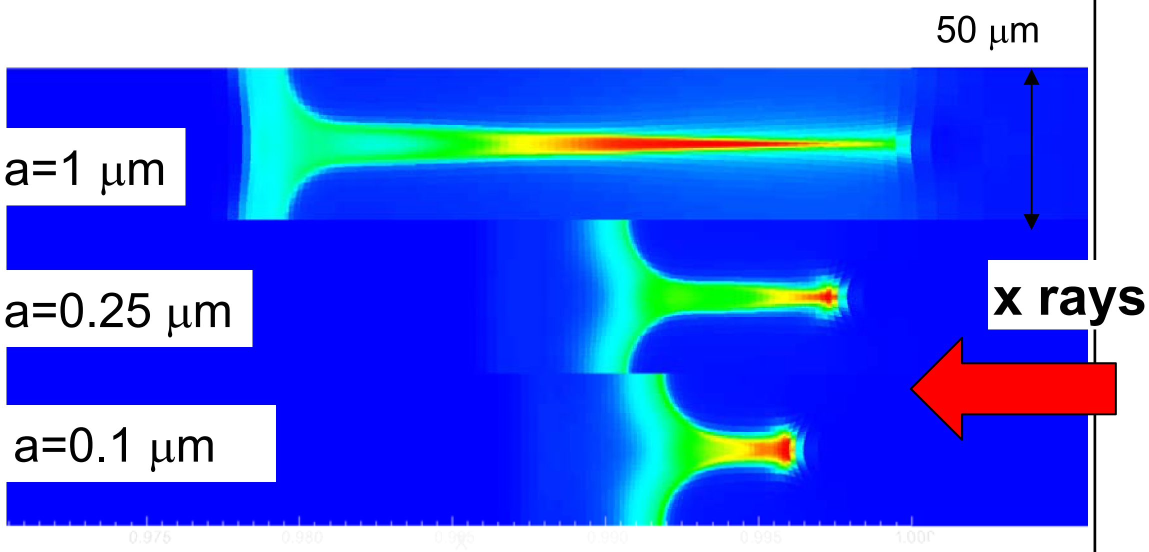




Targets are accelerated over 6x larger distance than on OMEGA

Ablative RT initial measurements use 2D single mode growth to establish ablation velocity, acceleration





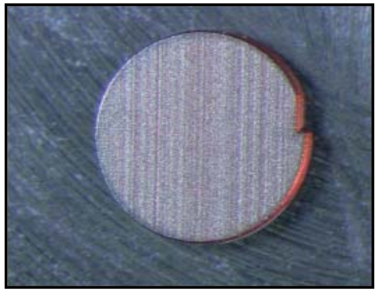
a) Predicted growth factors as a function of time for a single mode λ = 50 μm wavelength perturbation in a 160 μm thick doped foil for three different initial p-t-v amplitudes, 0.1, 0.25 and 1 μm.

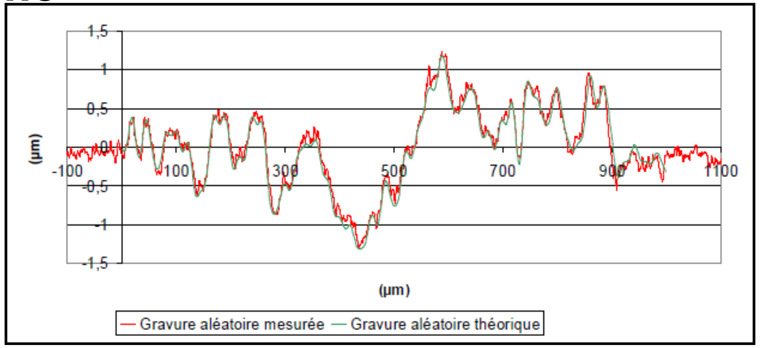
b) Corresponding side-on images of RT spikes at 20 ns.

Extend measurements on indirect platform to multimode perturbations

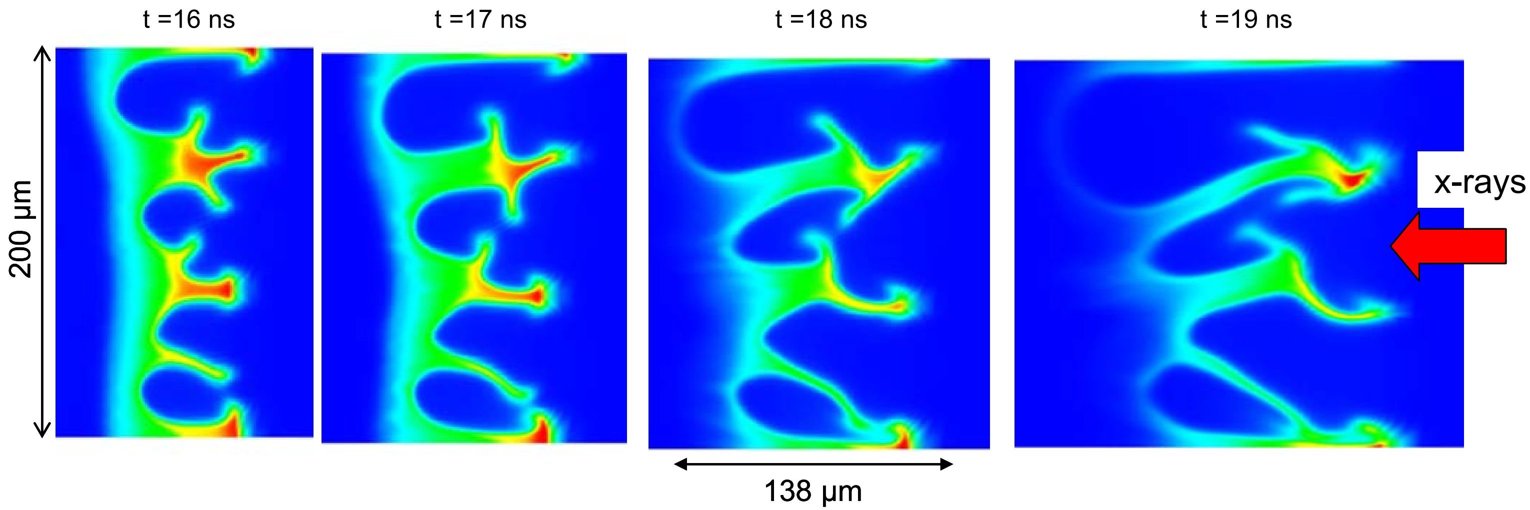
Probe weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes, turbulent-like regime

20 μm< λ < 1000 μm white noise with σ_{rms}=1 μm



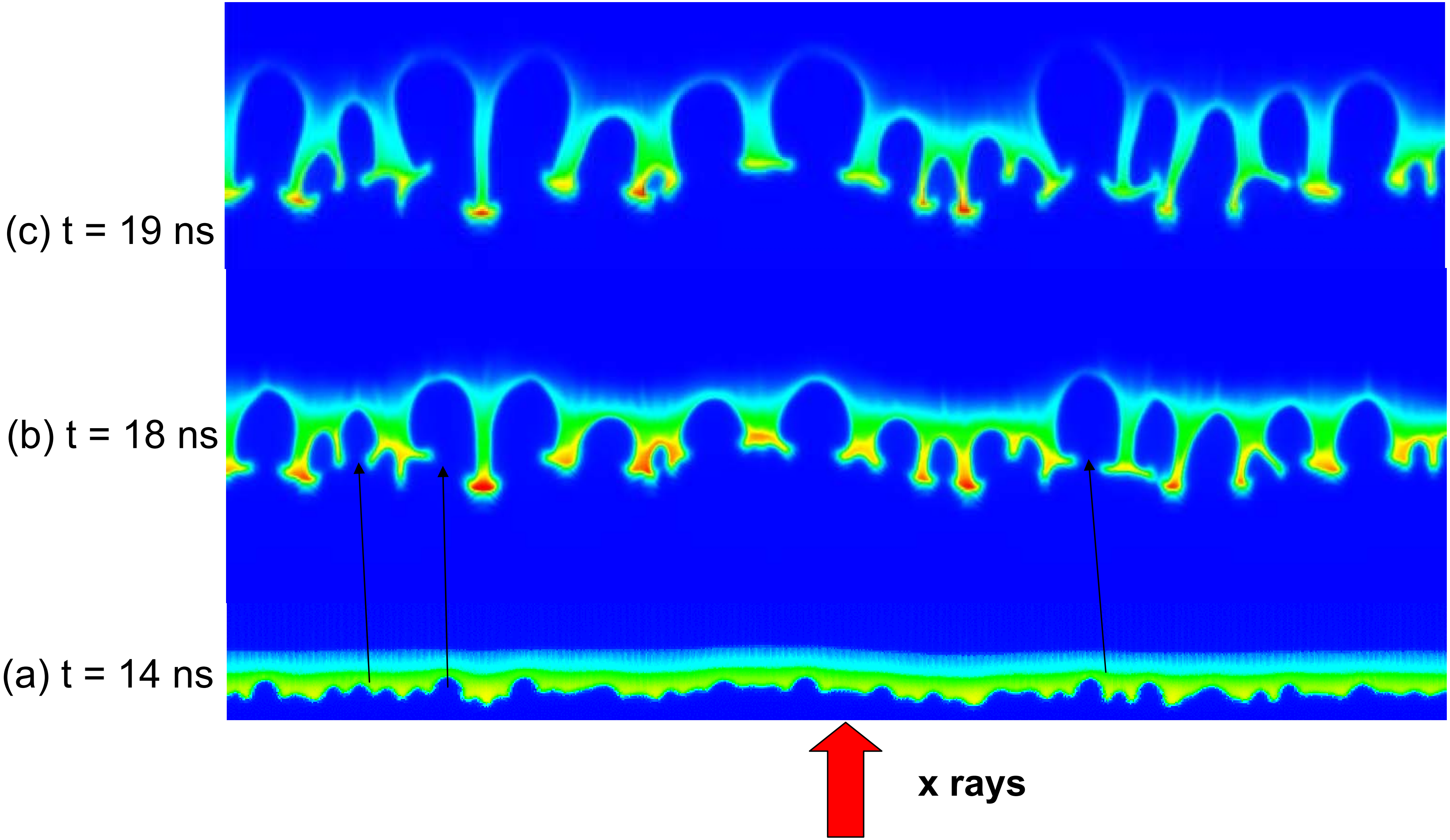


Physics packages could been made (CEA target lab)



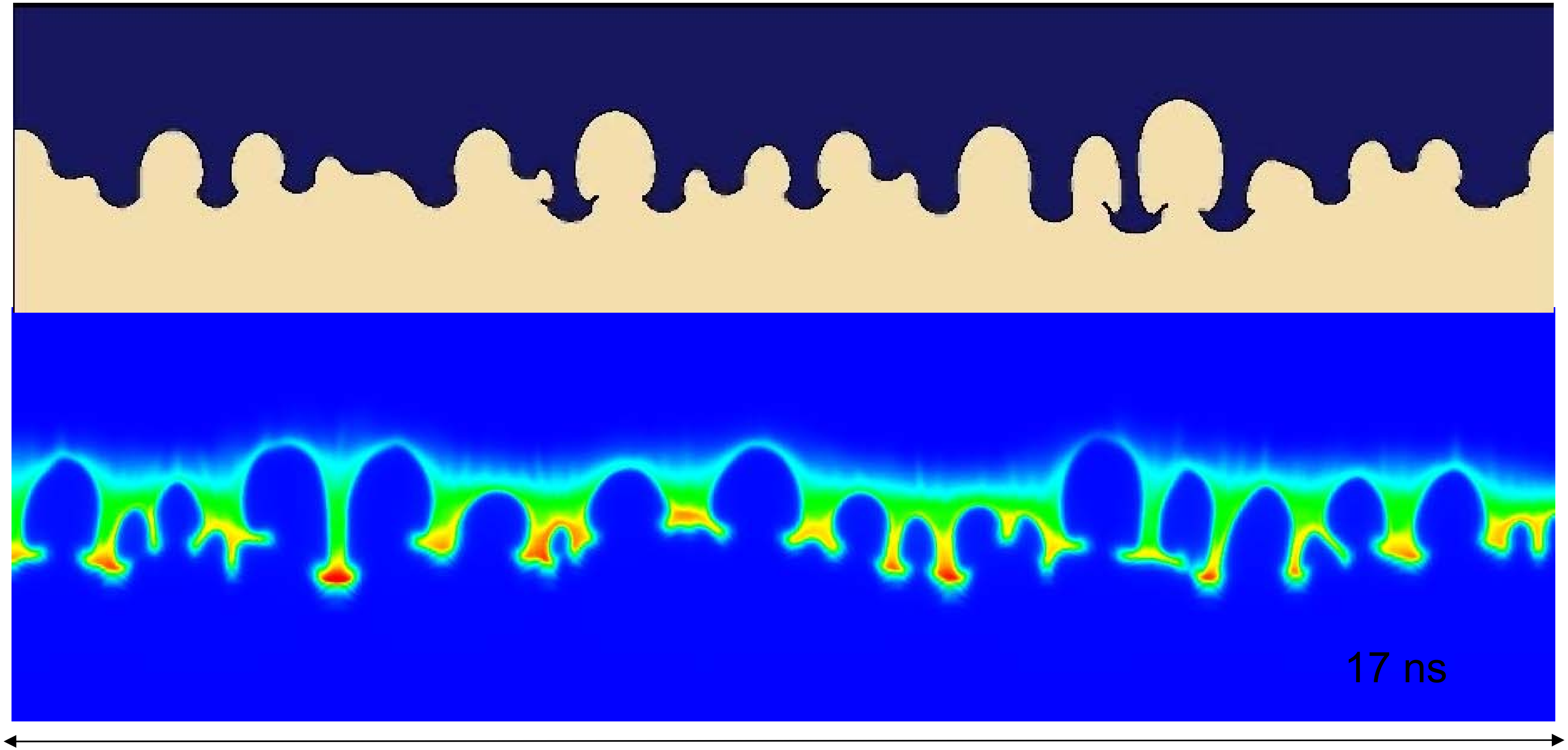
Side-on, post-processed images illustrating the bubble-merger regime reached in ID experiments with initial 2D multimode perturbations with initial rms amplitude of 1 µm.

At least one bubble generation in ID from 14 to 18 ns



Theoretical model catch physics

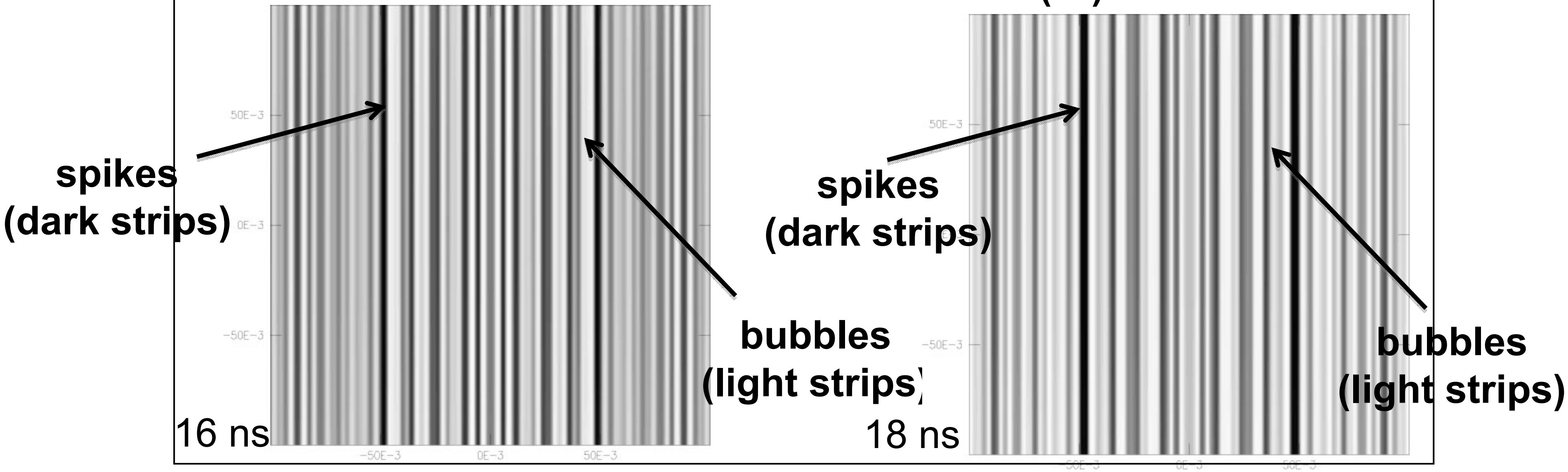
Model, boundaries integral method



2D FCI2 simulations multimode pattern

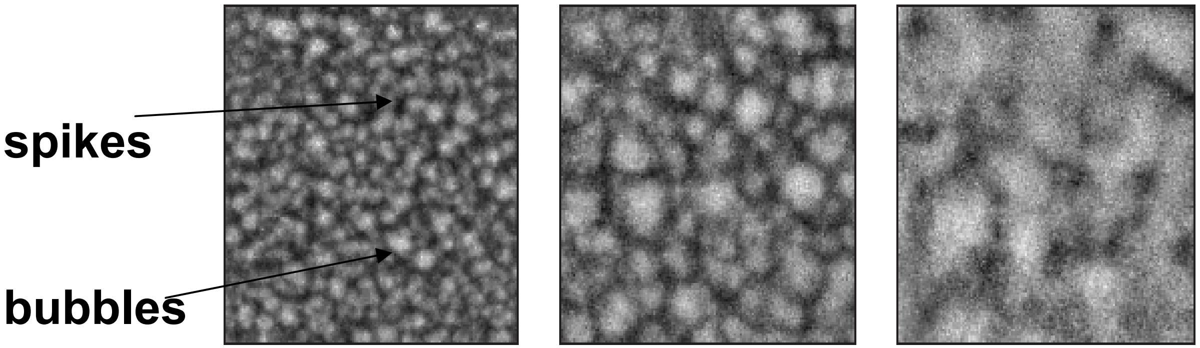
Comparison of ID and DD X-ray radiography (Face –on)

2 D multimode broadband (ID)

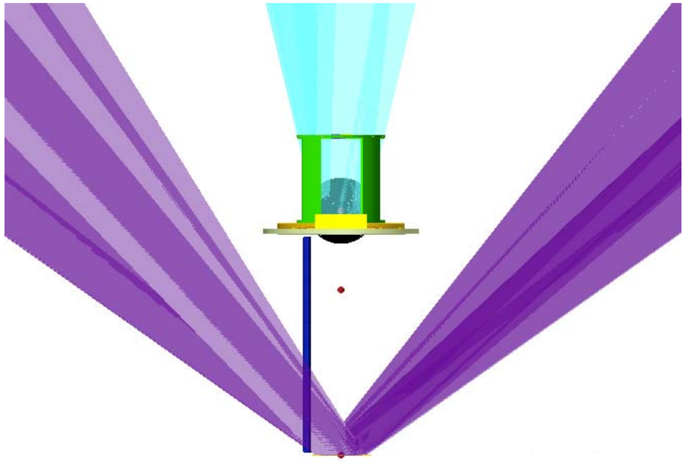


3 D multimode broadband (DD)

4 ns 6 ns 10 ns



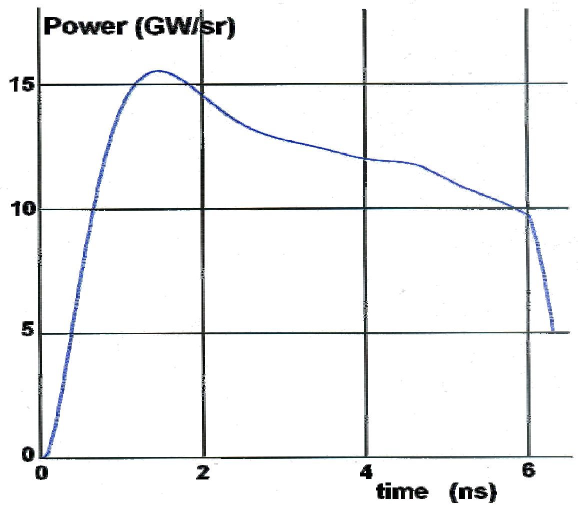
Long duration areabacklighters (10 ns) Performance Qualification shot (Tier 1 FY12)



Vanadium BL

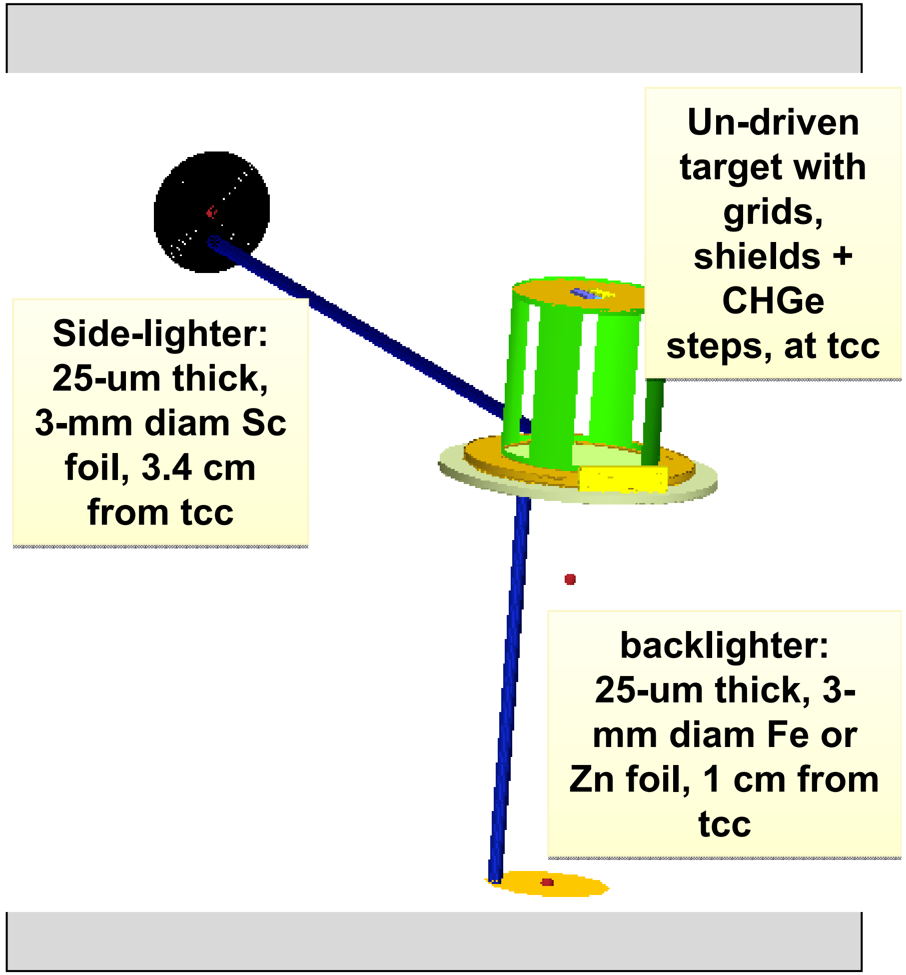
one-side irradiation
6 ns square pulse,
0.2 ns rise to Pm, Pm = 16 TW,
0.2 ns fall to 0
focal spot : 1186 µm × 1067 µm SG 4

C.E ~ 1 – 2 %



Power emitted in the foil normal axis (front side) and in the 8-10 keV range

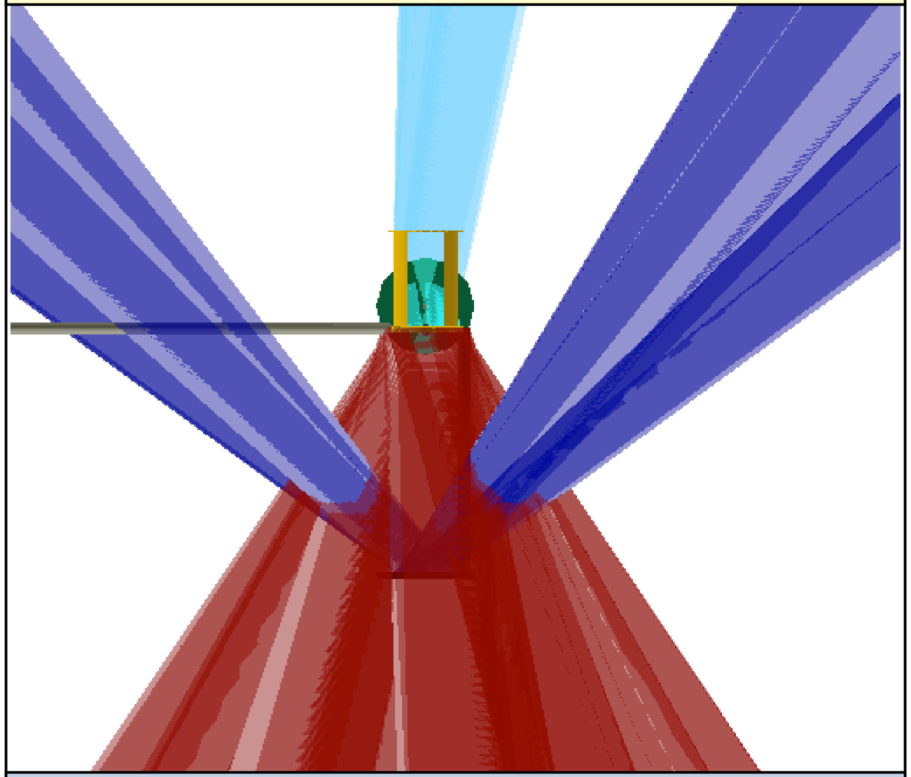
Target #1: Type C



- **Streaked camera DISC: S/N, 20 ns sweep card, resolution, sensitivity**
- **Gated X- ray detector: S/N, resolution at 6.4x magnification,sensitivity**
- **Hard x-ray background due to backlighters**

Ablative RT: Two platforms isolate ablative stabilization effects

Direct Drive Configuration
Weak ablative stabilization

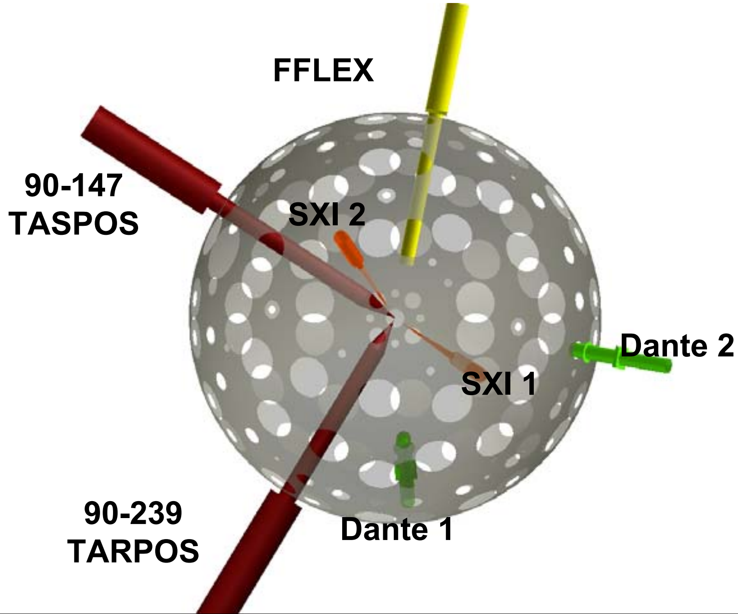


View from 90-315

Drive Pulse
20-ns square

Total energy 184 kJ
Intensity 4.5e14 W/cm^2

Experimental layout, Target chamber top view



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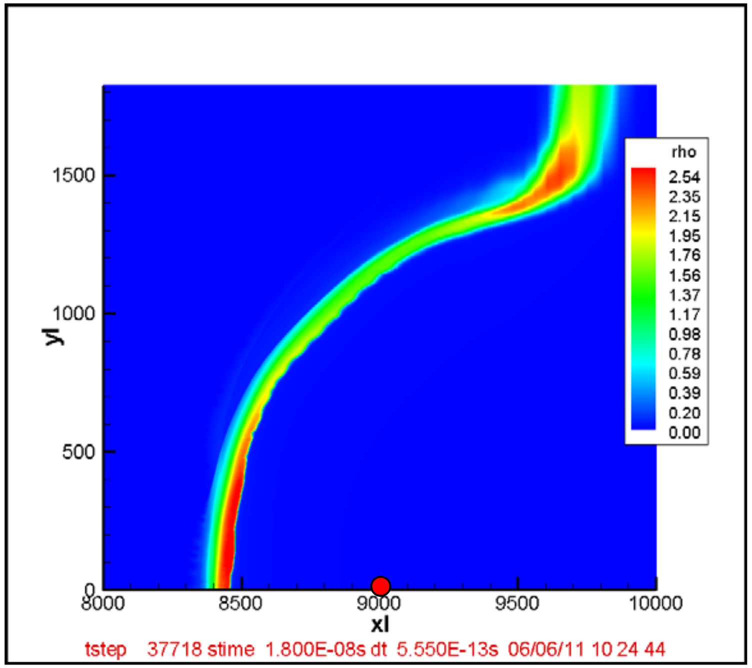
SXI, T/B	Fixed	3,2	3	Pre-Shot
FABS.NBI/FFLEX	Fixed	2-3	3	Pre-shot
GXD-2	90-78	2	2	Pre-Shot

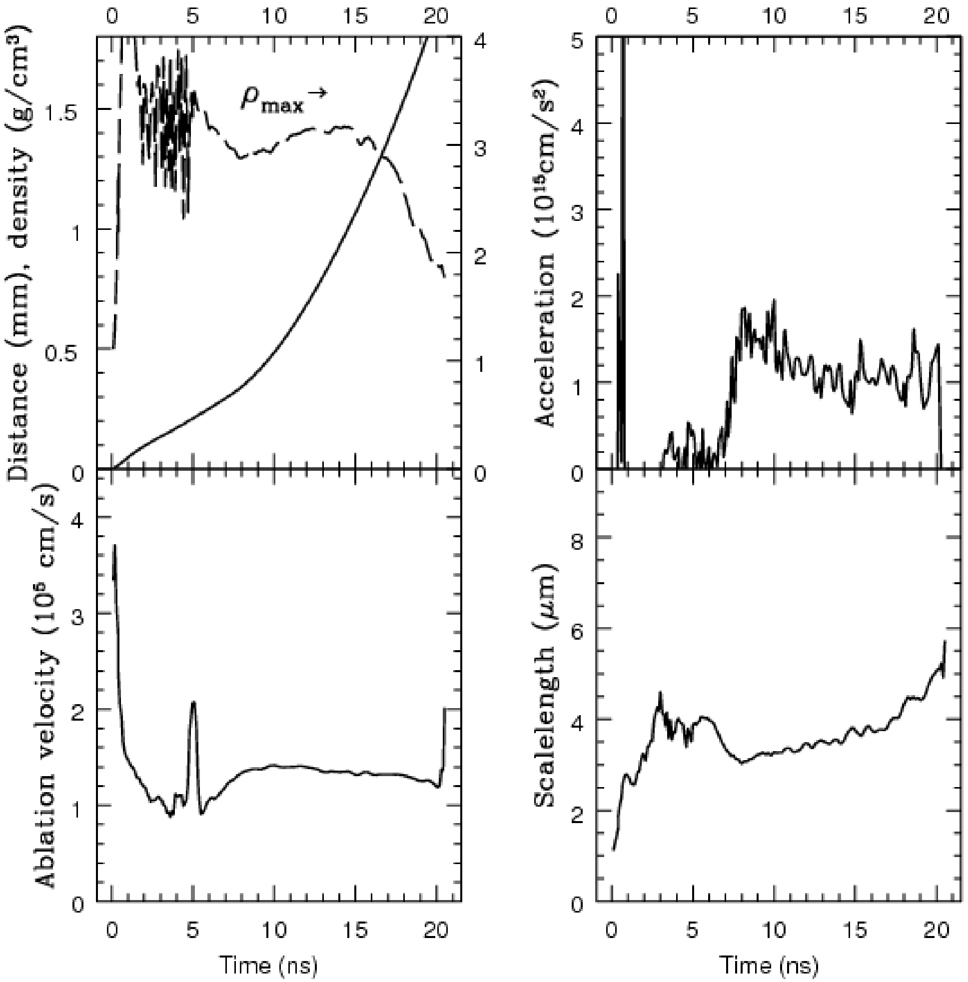
300-µm thick CH foil is accelerated from 6.5 ns till ~20 ns by 20-ns square pulse

Ablative RT, direct-drive platform, beam offset = 1.0 mm



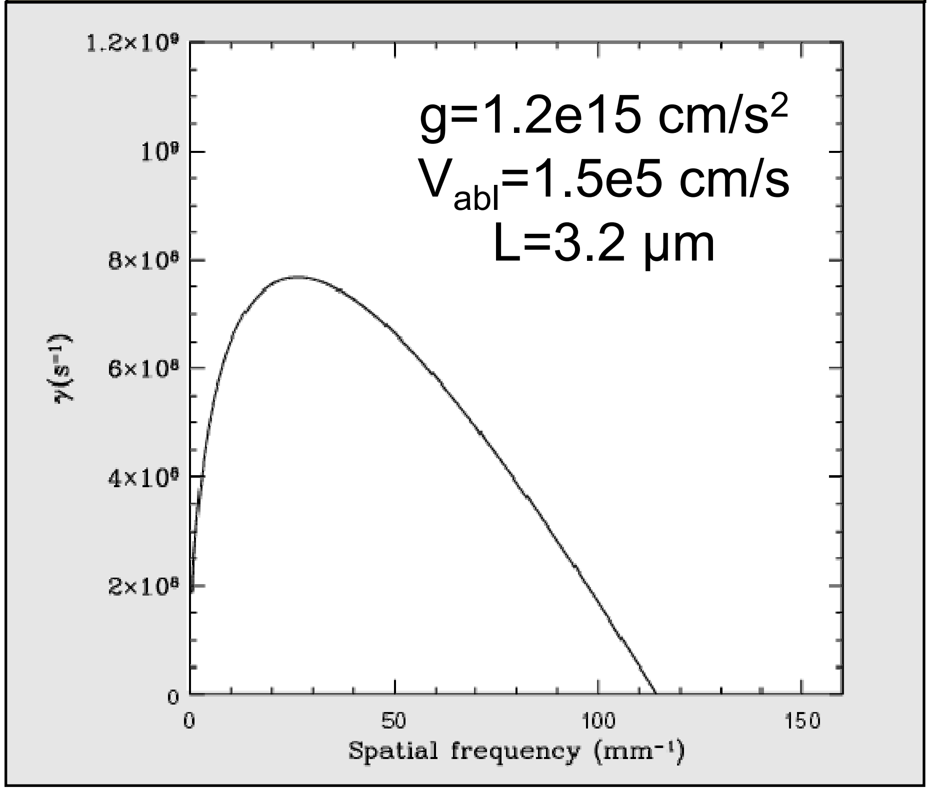
Offset 1.0 mm

Beams are focused 1 mm behind initial foil position to minimize beam divergence effects and maintain the acceleration.

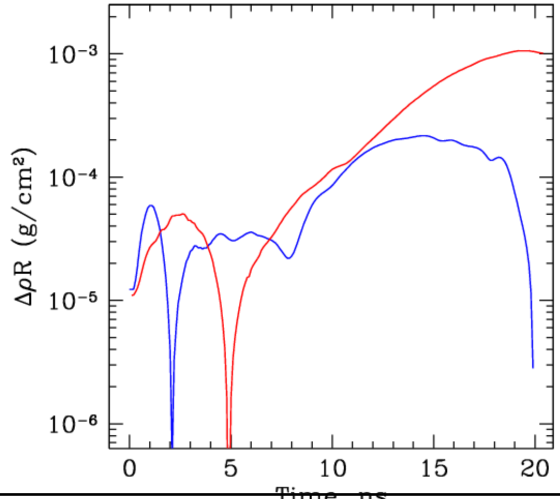


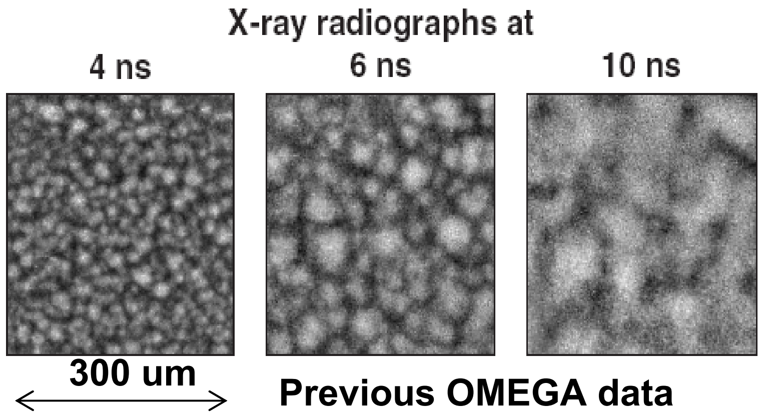
At least 3 more bubble generation than on OMEGA

Growth rate estimate in 300 µm CH at 13 ns



$$\gamma = \sqrt{\frac{kg}{1+kL}} - 1.5kV_{abl}$$



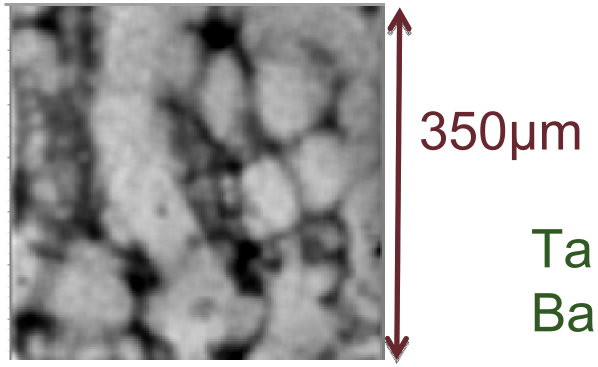


- **Growth rates are similar to OMEGA while target displacement is increased up to 10 times on NIF**
- **As bubble amplitude scale as gt^2 we expect 300 µm bubble which is 3 more generation of bubbles at 15 ns**
- **Shaping the drive will allow to tailor easily the initial conditions (cut-off, length scale)**

LBS experiments on OMEGA / EP
Increased amplitude in RM causes an increase in RT growth at equivalent distance traveled.

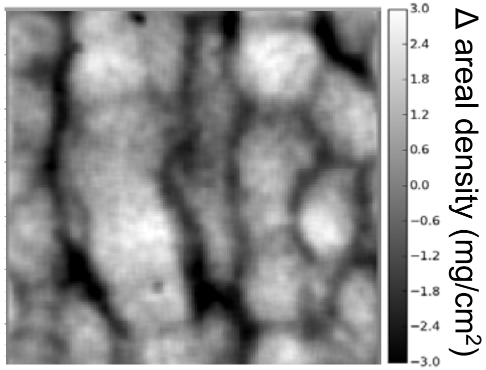
Modulation areal density compared at the same distance traveled

Sm Backlighter



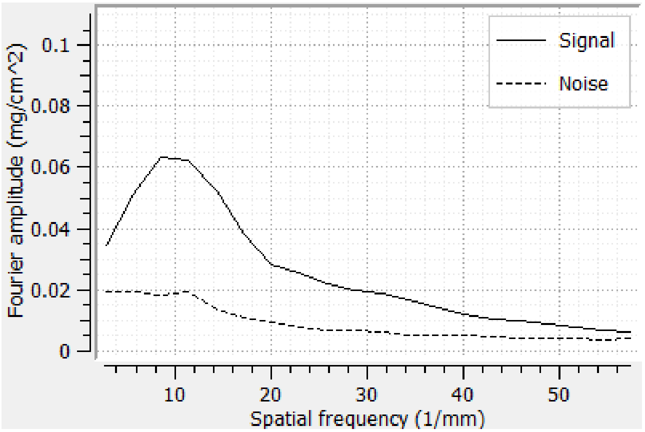
CH 30µm @t=2.4ns

Ta Backlighter

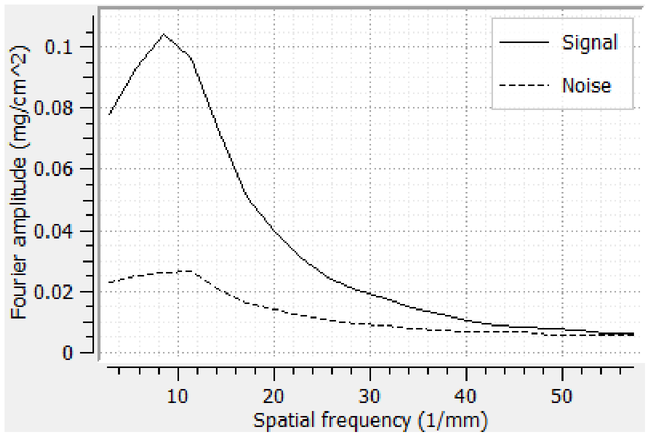


CH 50µm @t=3.2ns

Azimuthal average of Fourier spectrum



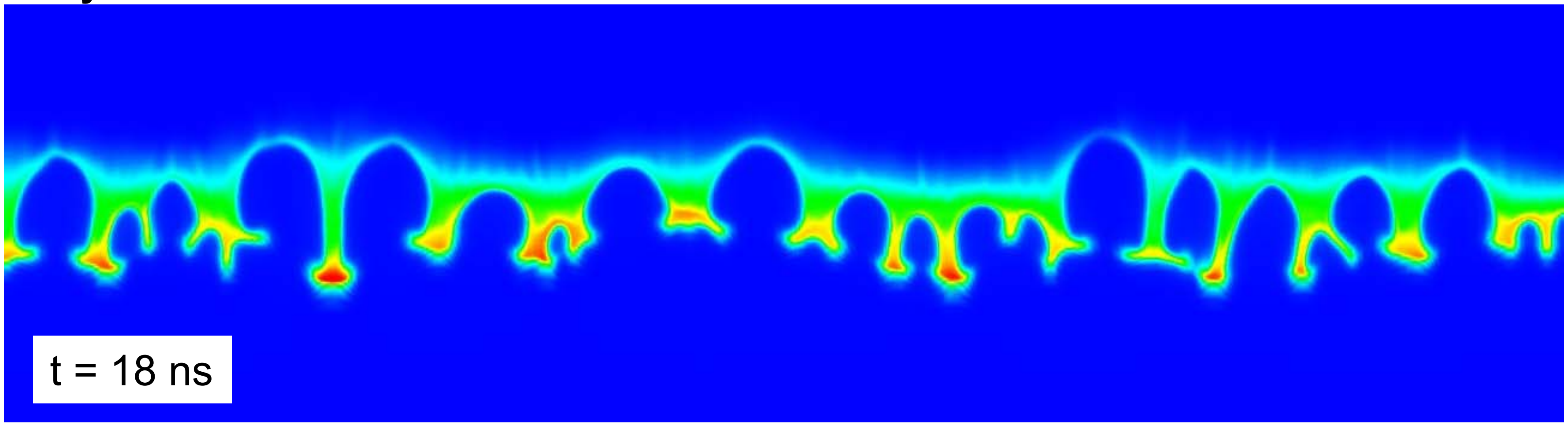
CH 30µm @t=2.4ns



CH 50µm @t=3.2ns

Summary / conclusions

- Multimode ablative Rayleigh Taylor Instability is not well understood, as well as turbulent front hydrodynamics.



- In one shot, growth of RT modulations can be measured from the weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes and perhaps into a turbulent-like regime.

- We are working hard to develop a gas-filled planar hydrodynamics ID platform which could be beneficial to other laboratory astrophysics experiments (Eagle nebula, Herbig Haro jets …)

- We can perform these experiments right now, without any new diagnostics.

- The development of a DD planar hydrodynamics platform on NIF is even harder …

- We use LBS experiments on OMEGA (influence of the RM phase in thick targets) to prepare DD shots on NIF