Foams as a Pathway to Energy from Inertial Fusion

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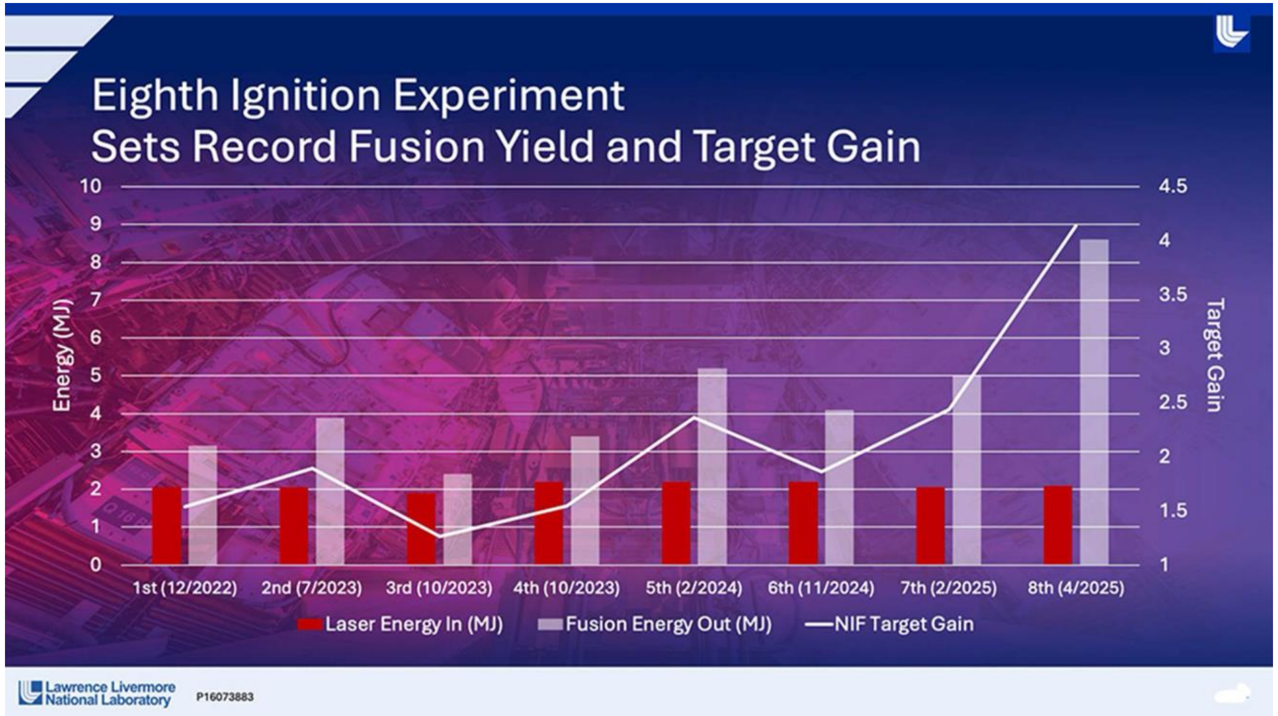
Ignition has been achieved on the National Ignition Facility

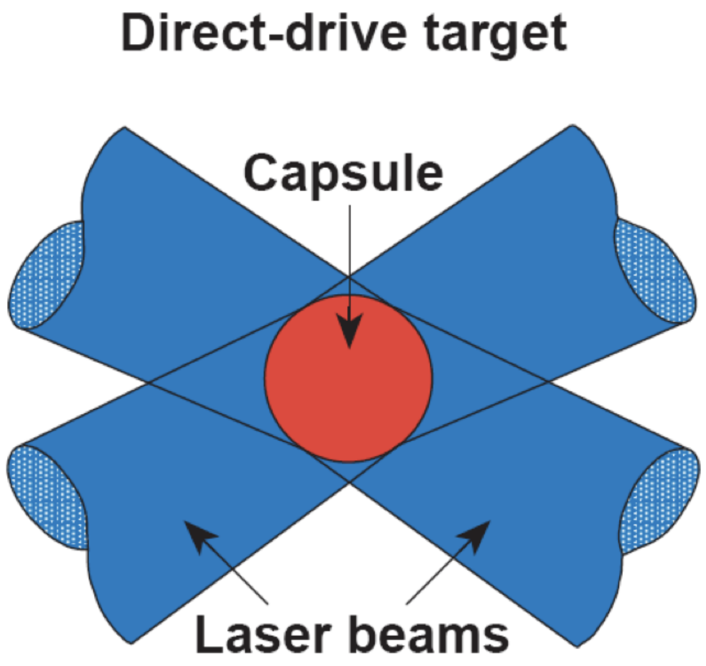
A gain > 1 has been achieved at least 8 times on the NIF



On the NIF, Ignition has been reached in the indirect drive scheme

With the achievement of Ignition Inertial Fusion Energy is envisioned a a credible path toward a decarbonized source of energy

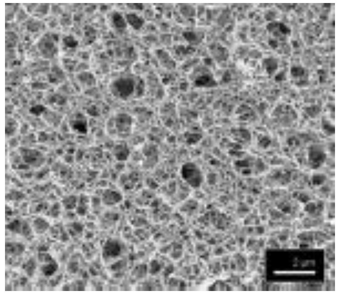
Inertial Fusion Energy is mostly envisioned in a Direct Drive geometry



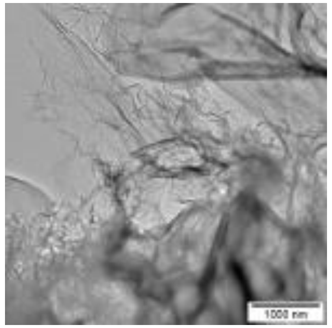
- Higher laser to capsule coupling
- Physics is in principle easier
- Targets are easier and cheaper
- No Hohlraum debris in the chamber

What do we mean by foam materials?

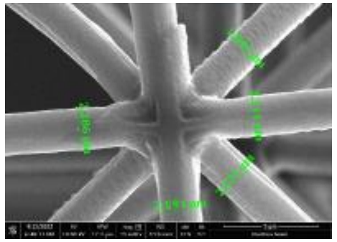
Chemical synthesis of foam from liquid gels: K. Nagai et al. Phys. Plasmas 2018: multi-stage fabrication process, random fractal structure, pore size 1-2 µm, materials: carbon, hydrogen, oxygen, wire thickness 100s nm



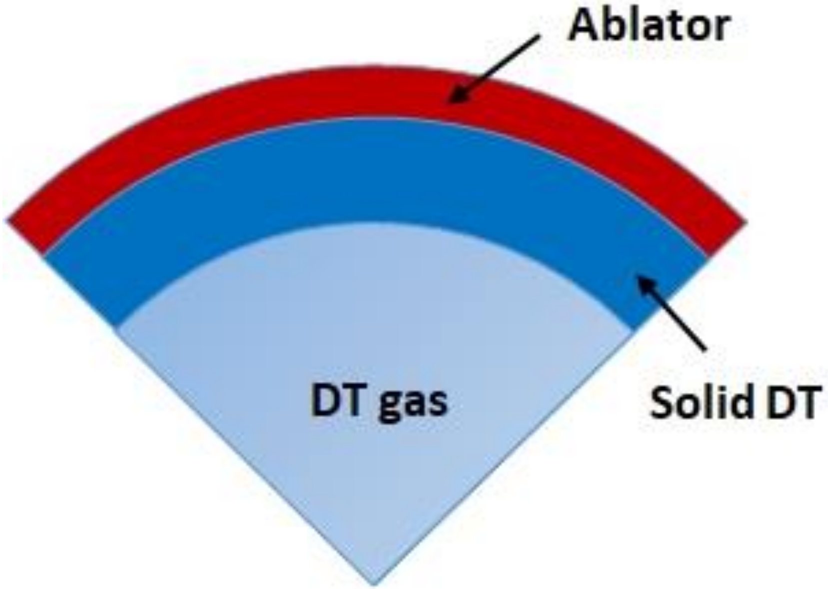
Carbon nanotube & graphene target fabrication technology: P. Wang et al. HPLSE 2019: catalyst chemical vapor deposition on a substrate, pore size < 1 µm, 95% of carbon, folded foil structure, sheet thickness 10s nm



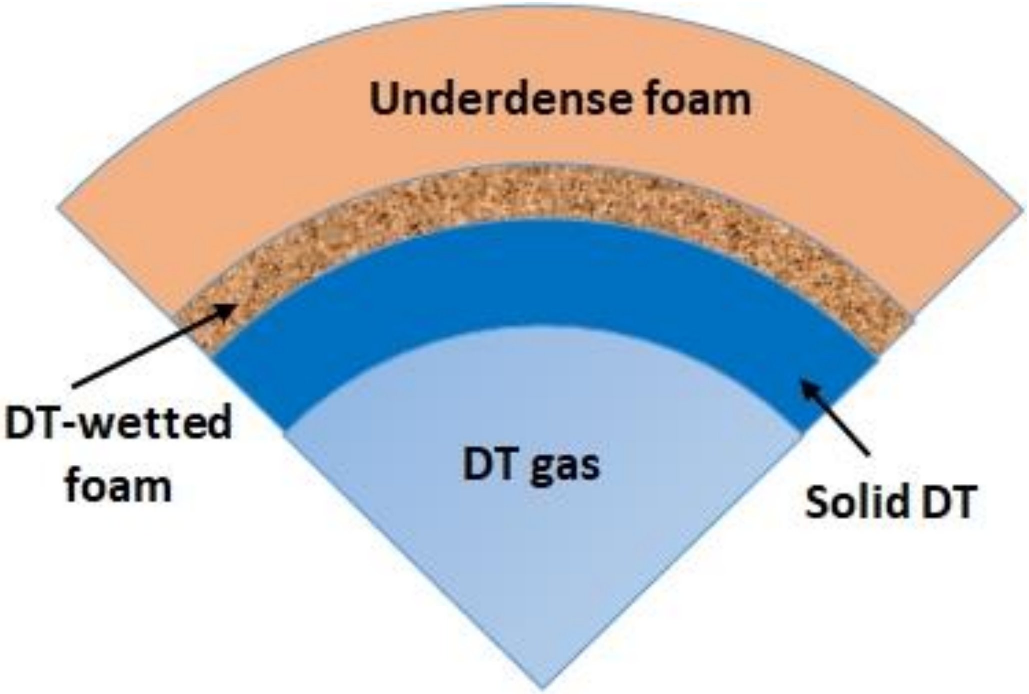
Additive manufacturing of foams: J. Fischer & M. Wegener, Laser Photon. 2013: a novel technique of 3D printing 2P LL: better control of foam properties and higher rigidity, pore size 10-50 µm, wire thickness ~few microns



What would a foam target for IFE potentially look like?



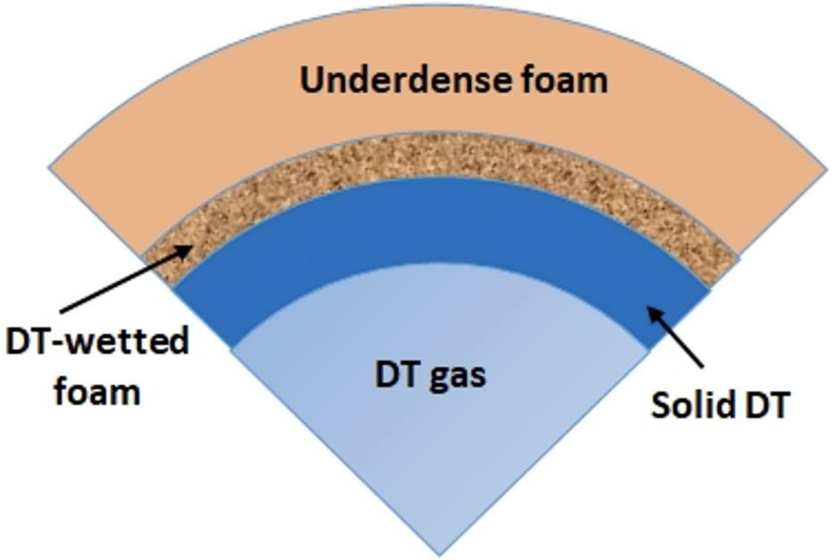
Under dense CH foam
To increase laser absorption and mitigate imprint



Overdense CH foam containing the DT fuel

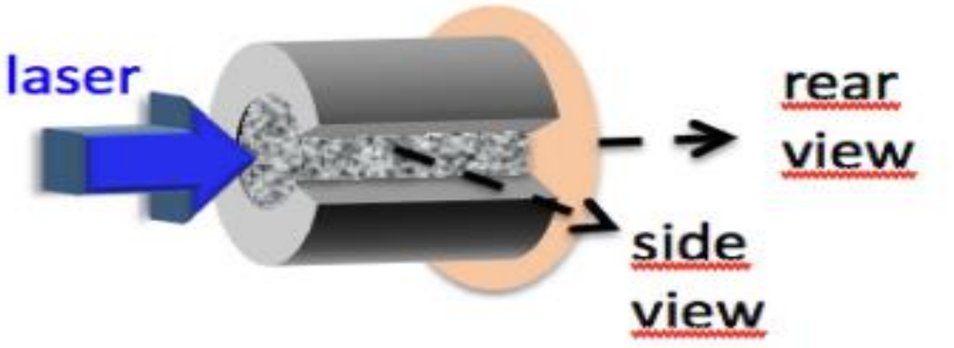
Physics of laser light absorption in under dense foam

Under dense CH foam
To increase laser absorption and
mitigate imprint

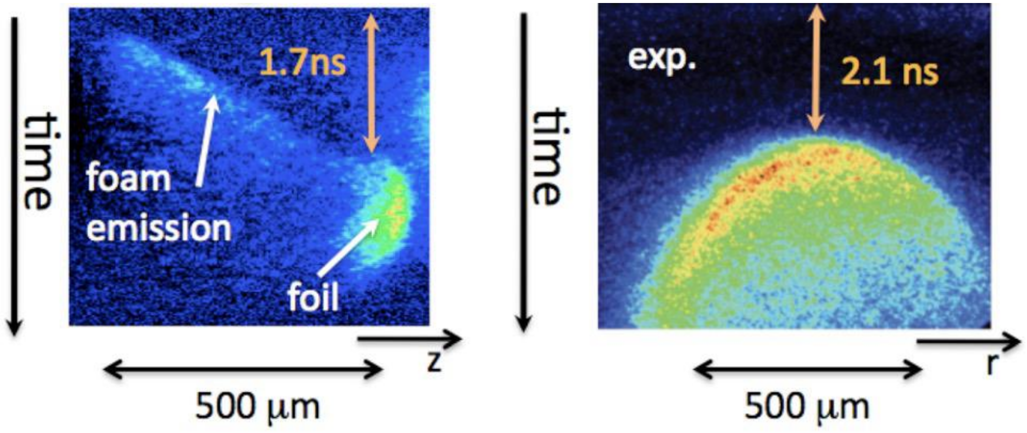


Experiments of laser/ under critical foam interaction shed light on the peculiarity of the medium

Experimental set up



Experimental data



Side on X ray streak

Rear optical GOI

Nicolaï, Ph, et al. "Experimental evidence of foam homogenization." *Physics of Plasmas* 19.11 (2012).

All the experiments carried out show the same discrepancies between simulation and experimental data

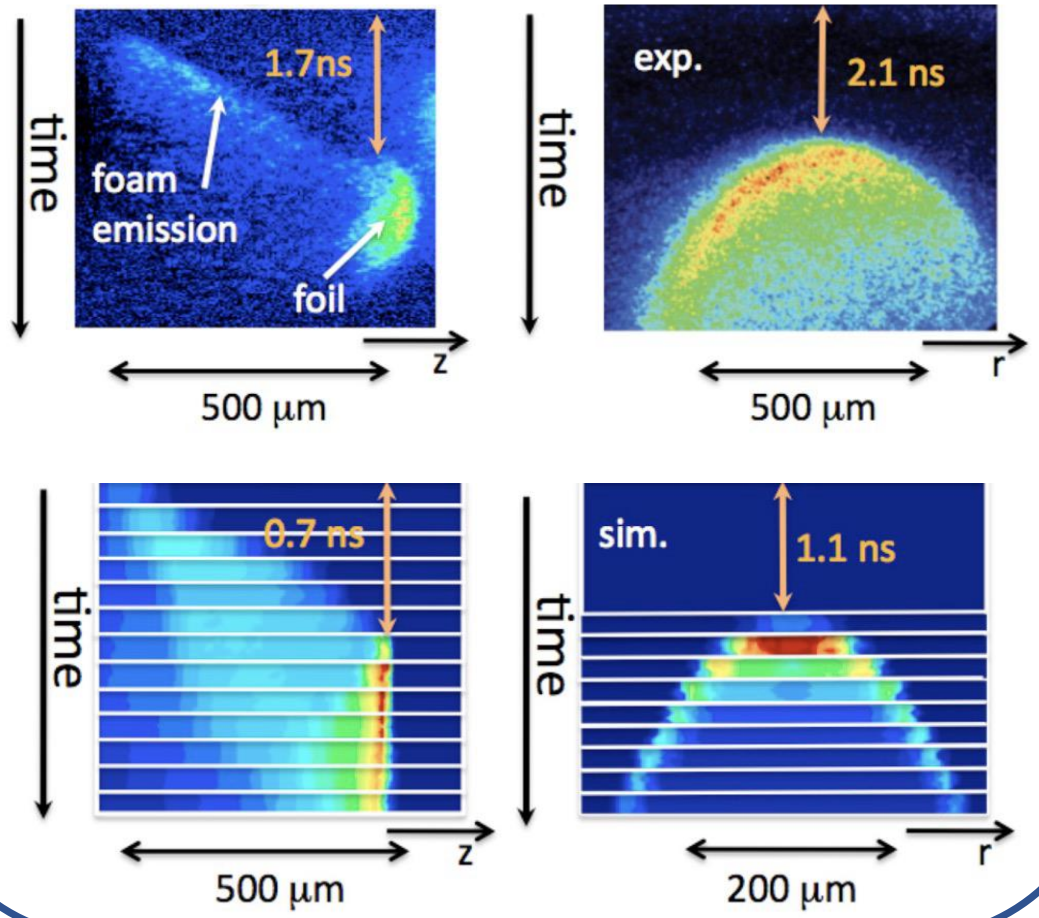
Experiments @in Japan, USA using foams with densities ranging from 4 to 10 mg.cm^{-3}

Ionization wave is super sonic

Radiation hydrodynamic simulation with homogenous gas at similar density predicts a fast ionization wave than experimental data

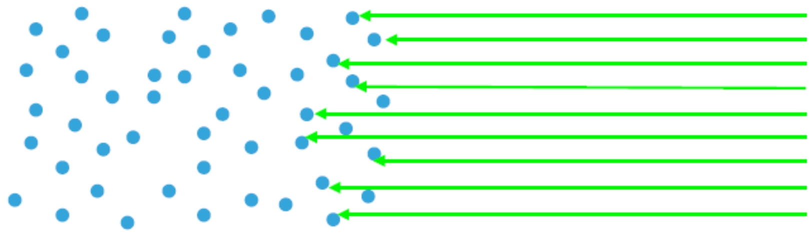
Higher ion temperature than electron temperature

Experimental data compared with rad hydro (CHIC)

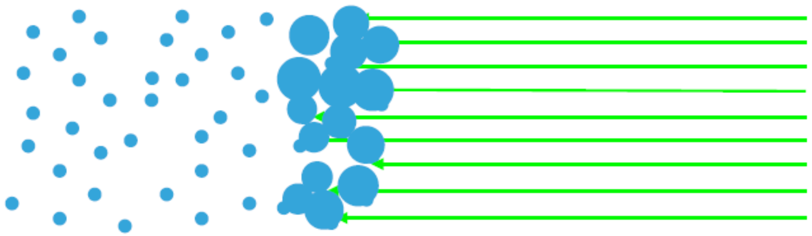


Ph. Nicolaï et al., Physics of Plasmas 19, 113105 (2012).

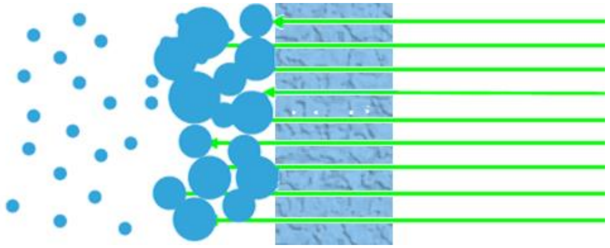
What is different about laser/foam interaction



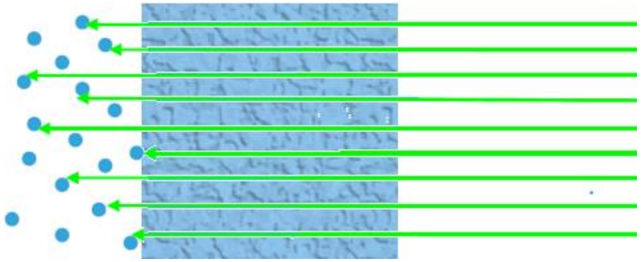
Laser light interacts in volume with solid density filaments
Higher absorption than in solid



The filaments heat and expands.
Plasma collisions leads to T_i>Te



when density bellow ρ_{crit}
propagation to the next layer

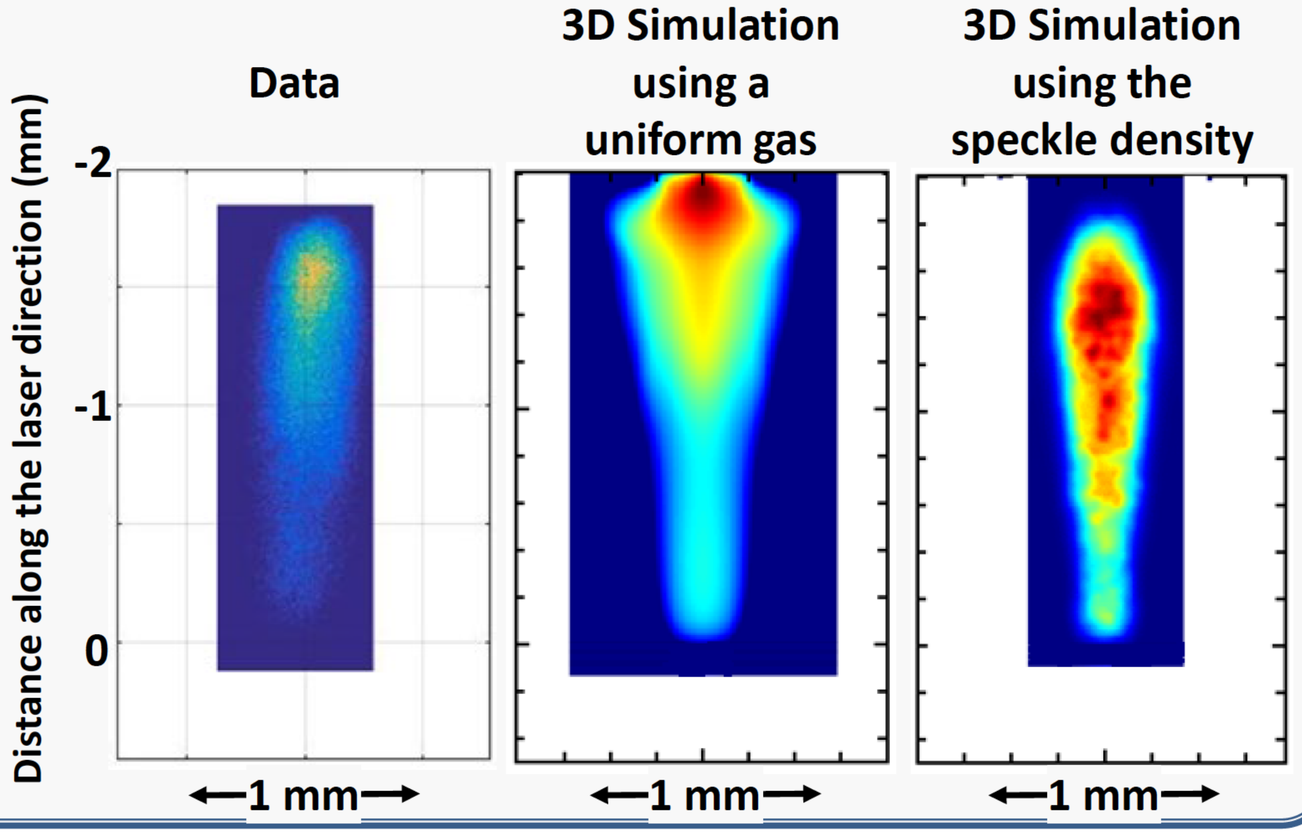


Laser propagates from
one layer to the other
Supersonic ionization front

S. Y. Gus'kov and V. B. Rozanov, Quant. Elec. 27, 696 (1997).
S. Y. Gus'kov et al., Physics of Plasmas 18, 103114 (2011).

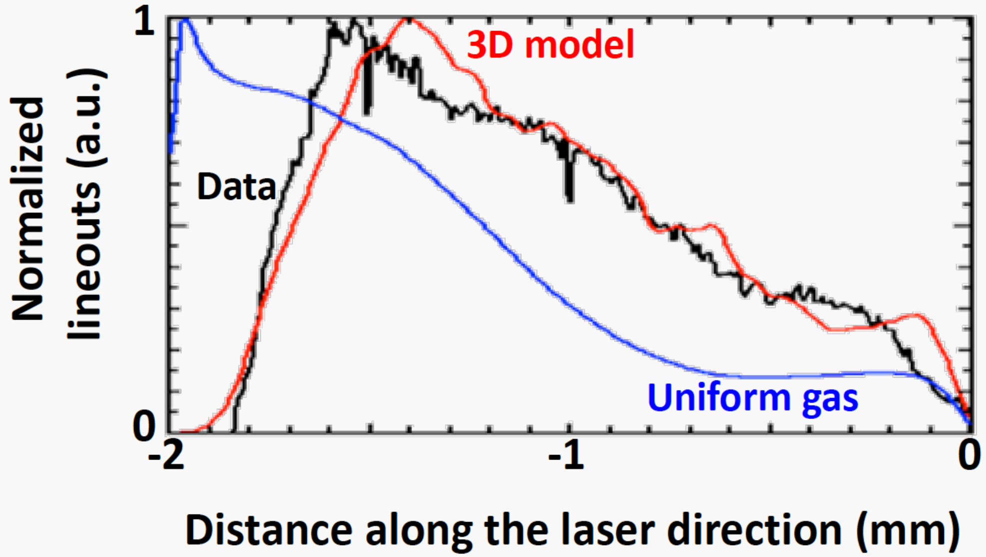
The described 3D computational model brings the heat front propagation into agreement with experimental SiO2 data

Time integrated self-emission images @ ~ 5 kev



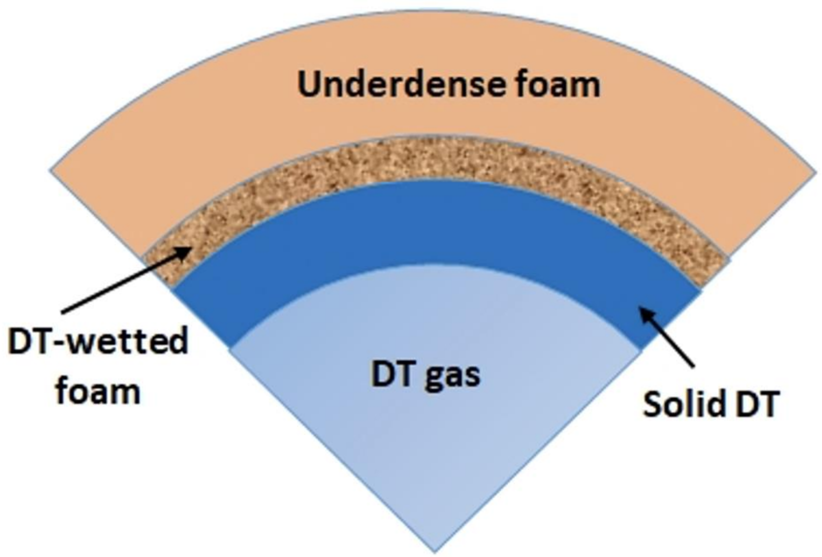
Lineouts highlight the difference between the uniform and inhomogeneous density simulations

Self-emission integrated in the transverse direction



Wetted foam targets for IFE

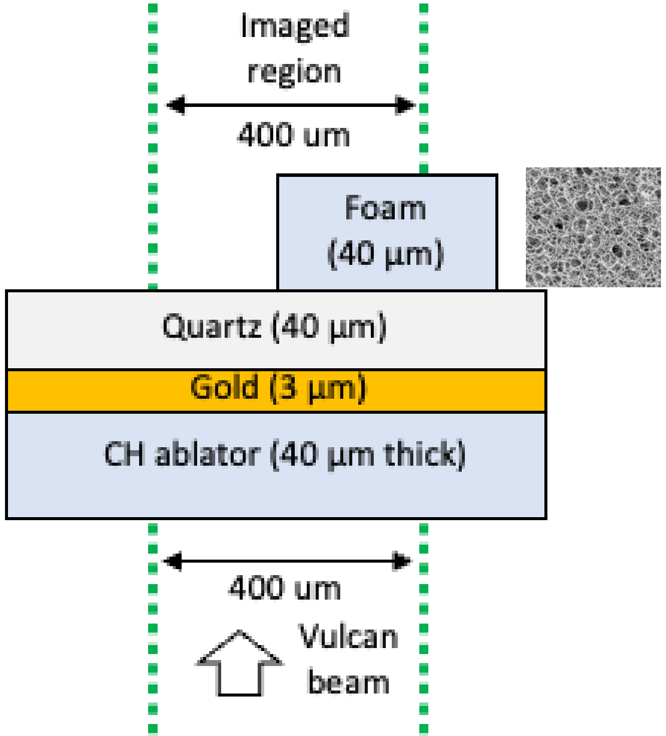
Physics of over dense foams



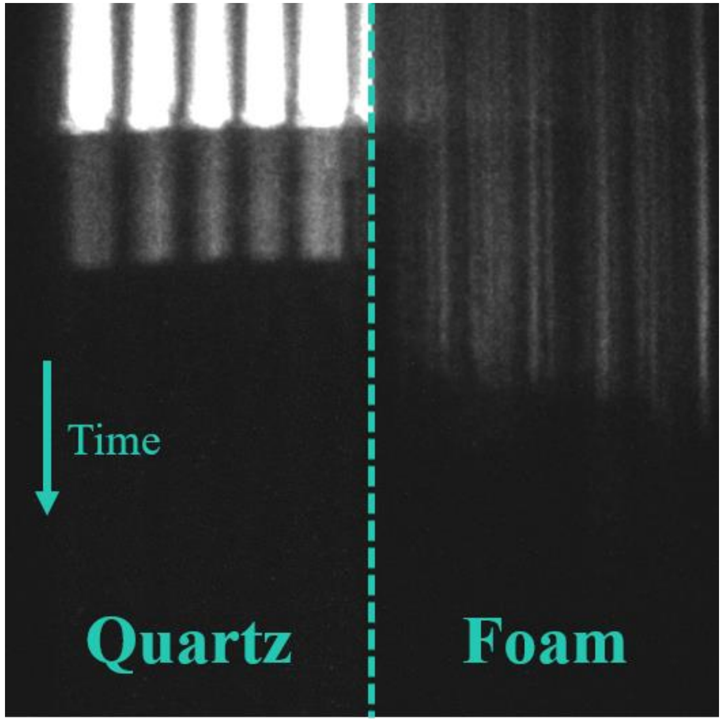
Overdense CH foam
containing the DT fuel

EOS studies of 260 mg/cc TMPA plastic foam @RAL

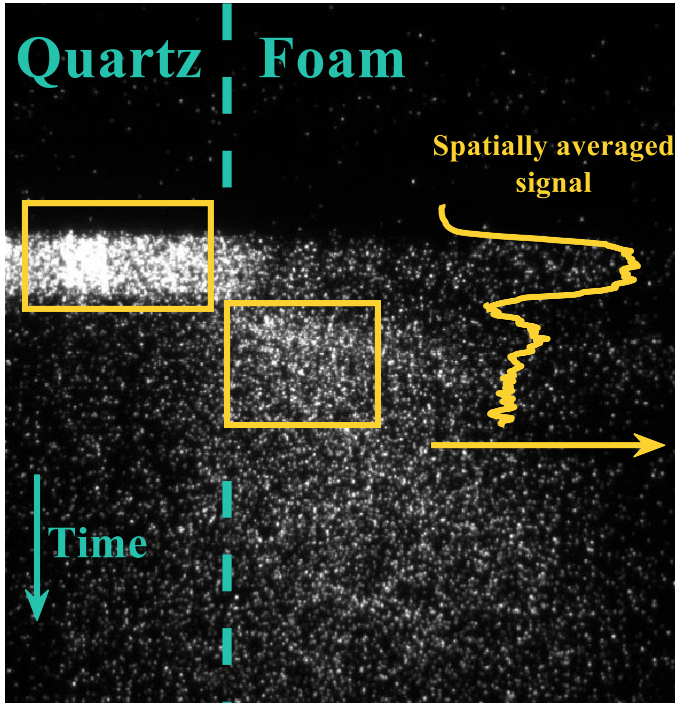
Target design



pressure and particle velocity from VISAR

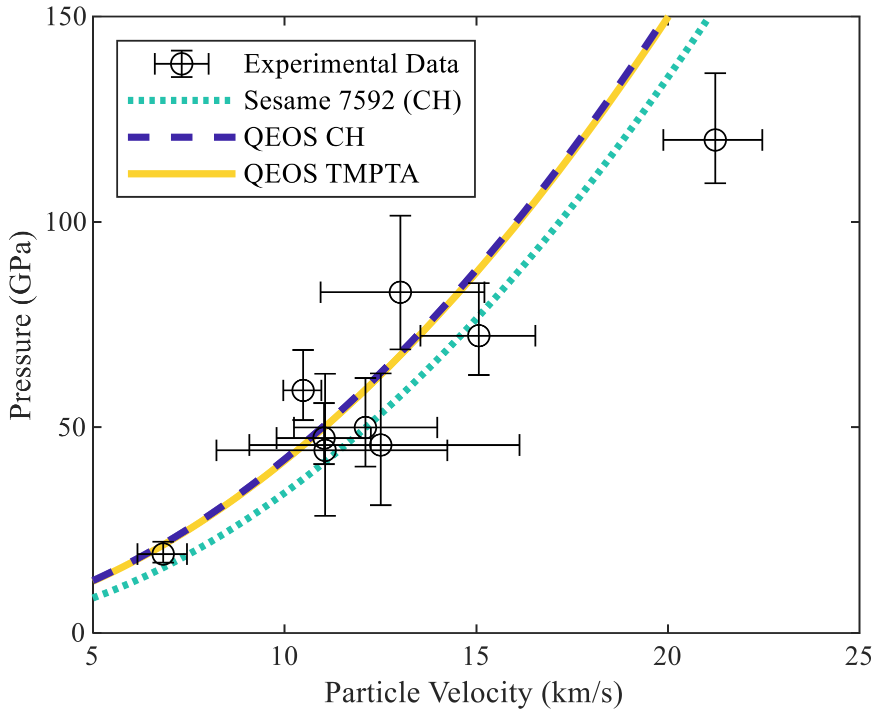


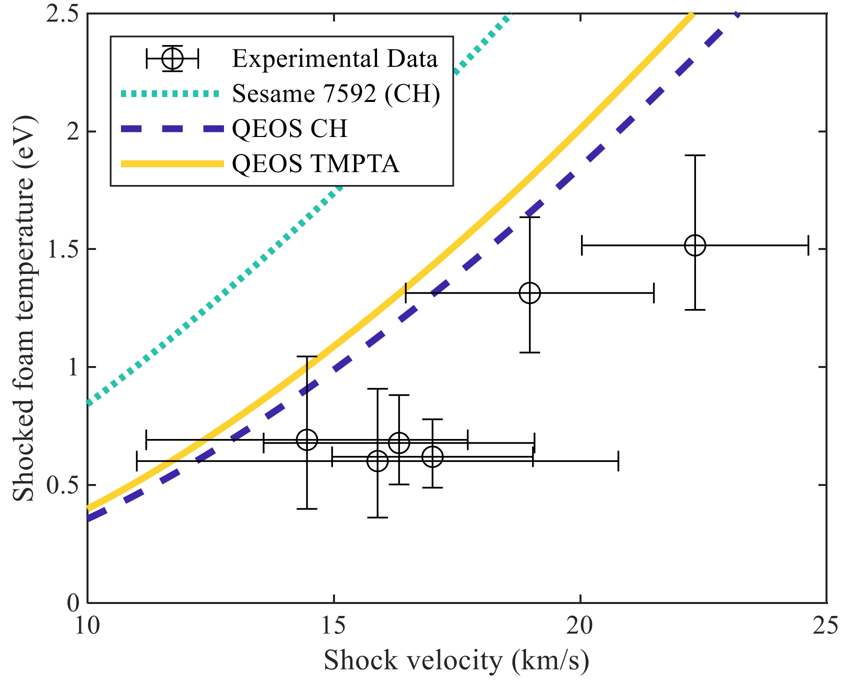
Temperature from SOP



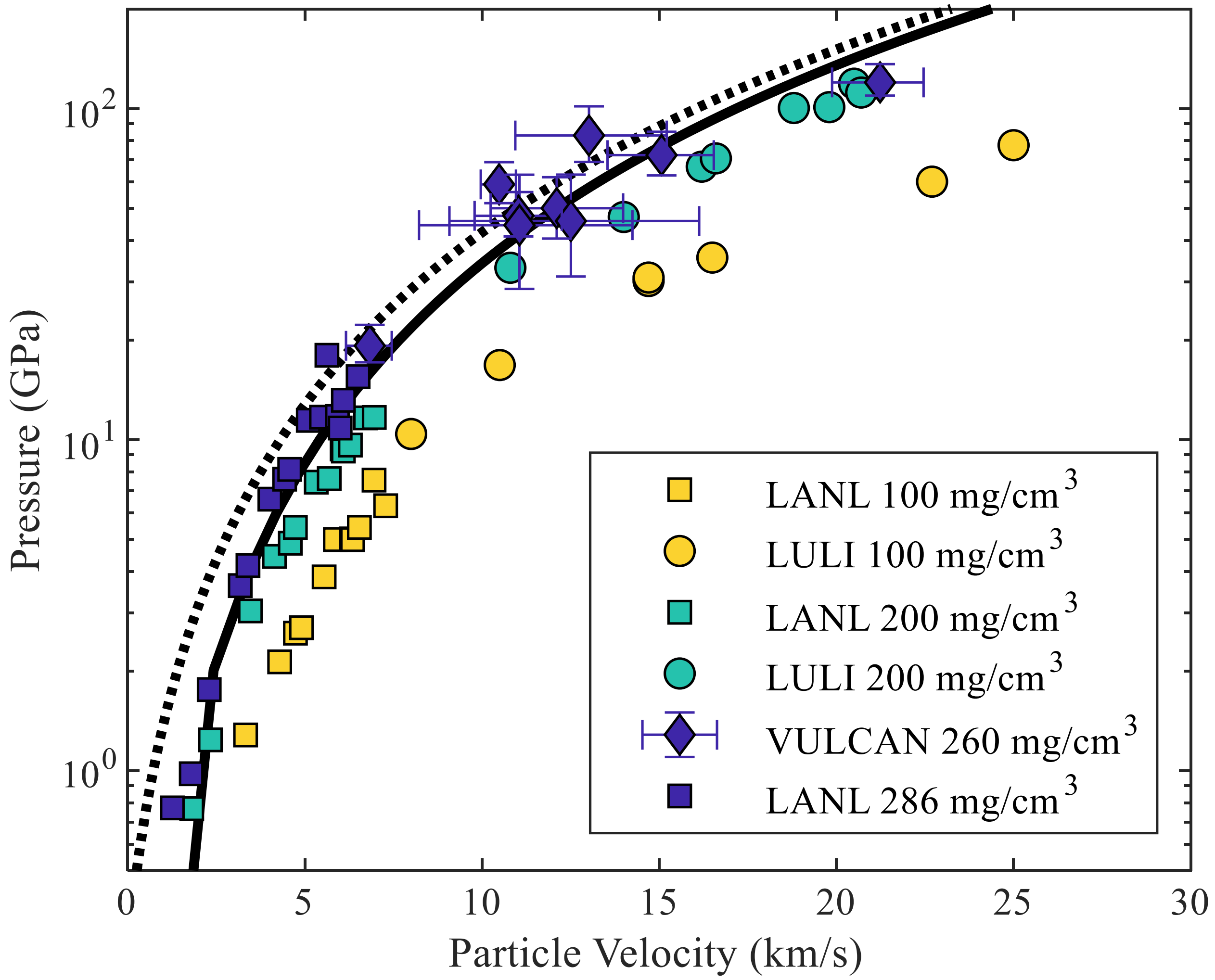
Paddock, R. W., et al. (2023). Measuring the principal Hugoniot of inertial-confinement-fusion-relevant TMPTA plastic foams. *Physical Review E*, *107*(2), 025206.

EOS models of the low-density homogeneous plastic appear to well describe the experimental data





These results are consistent with previous experiments



Shock propagation in overdense foam

XFEL

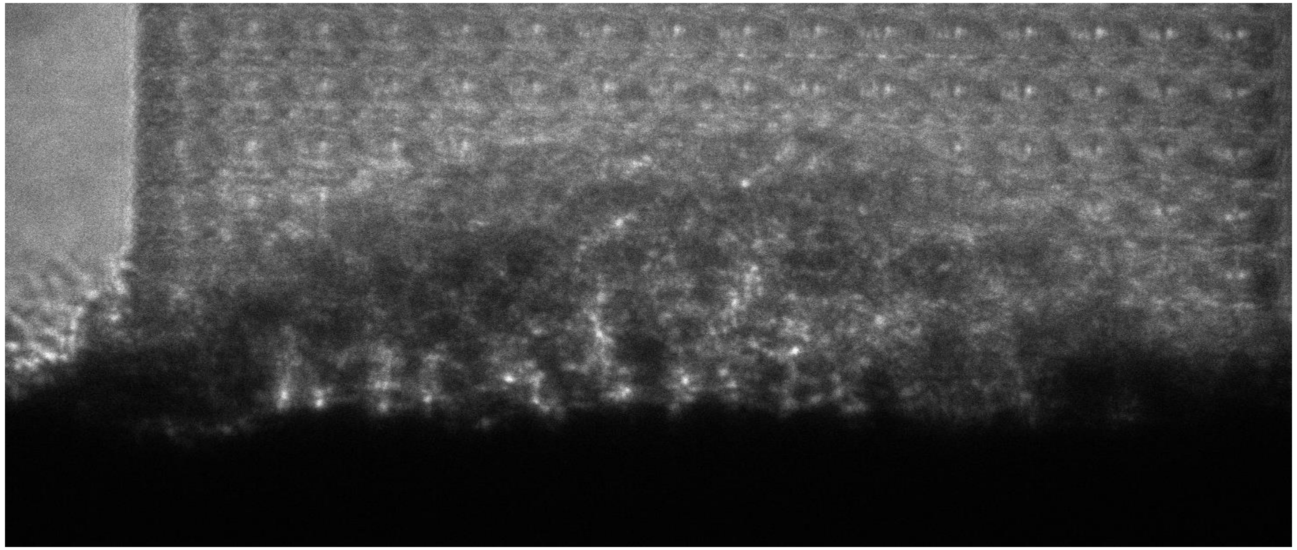
Photon energy: 4-22 keV

- Pulse energy: ~700 μJ
- Pulse duration: < 10 fs
- Repet. rate: 30 Hz

High-powernanolaser

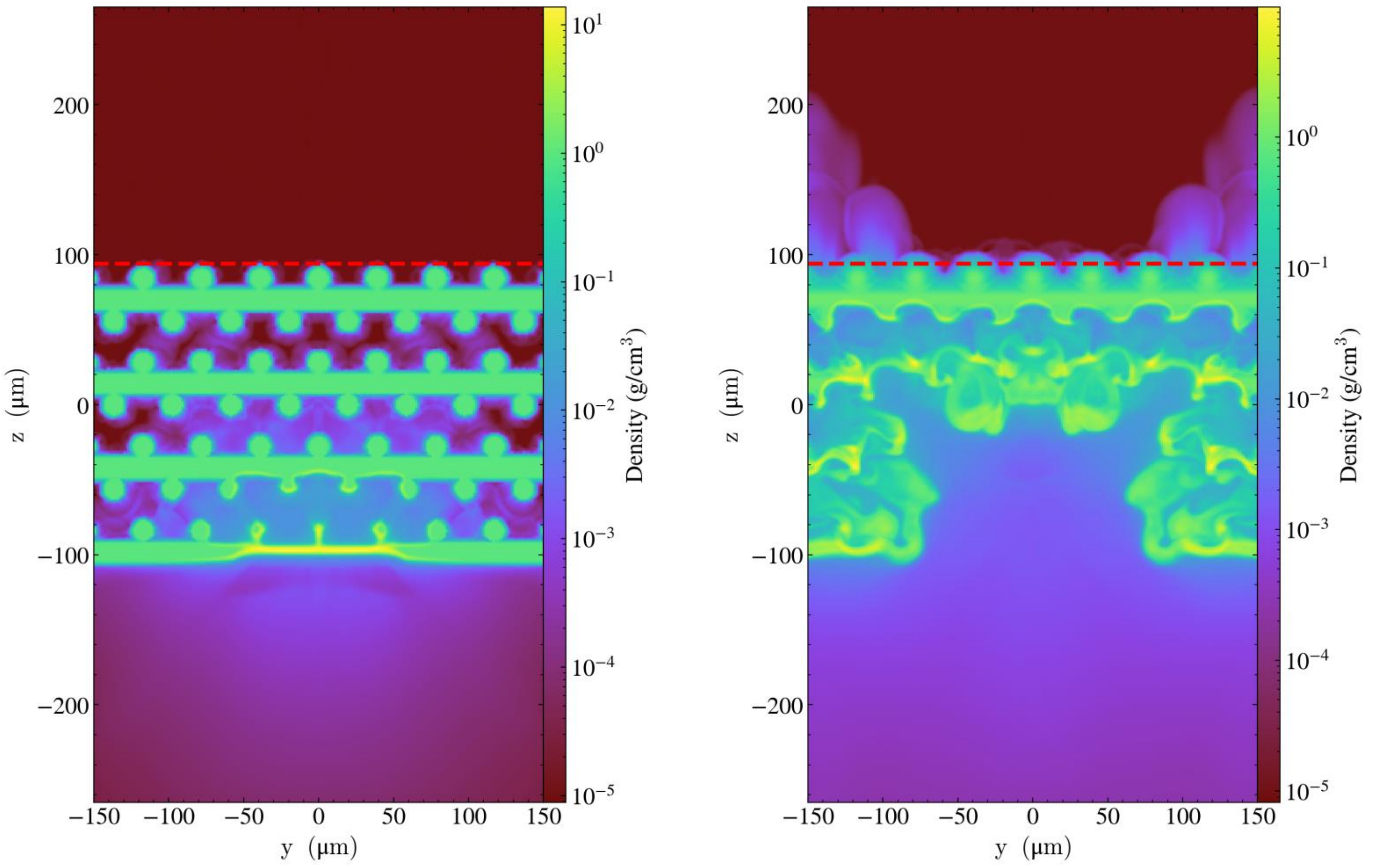
- Pulse energy: > 15J
- Pulse shape: 5ns quasi-square
- Wavelength: 532 nm
- Repet. rate: 0.1 Hz
- Shot rate: 1 shot/3-10 min

X ray radiograph of a shock propagating in foam

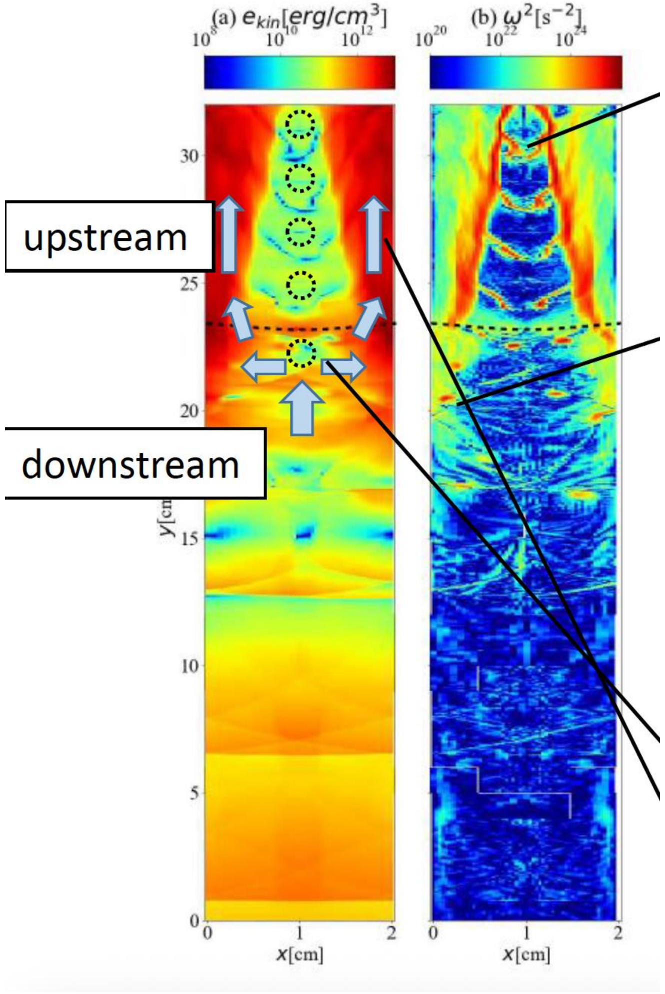


The foam structure generates turbulence carrying away kinetic energy

Flash simulation of strong shock in overdense foam



Turbulence in shock foam

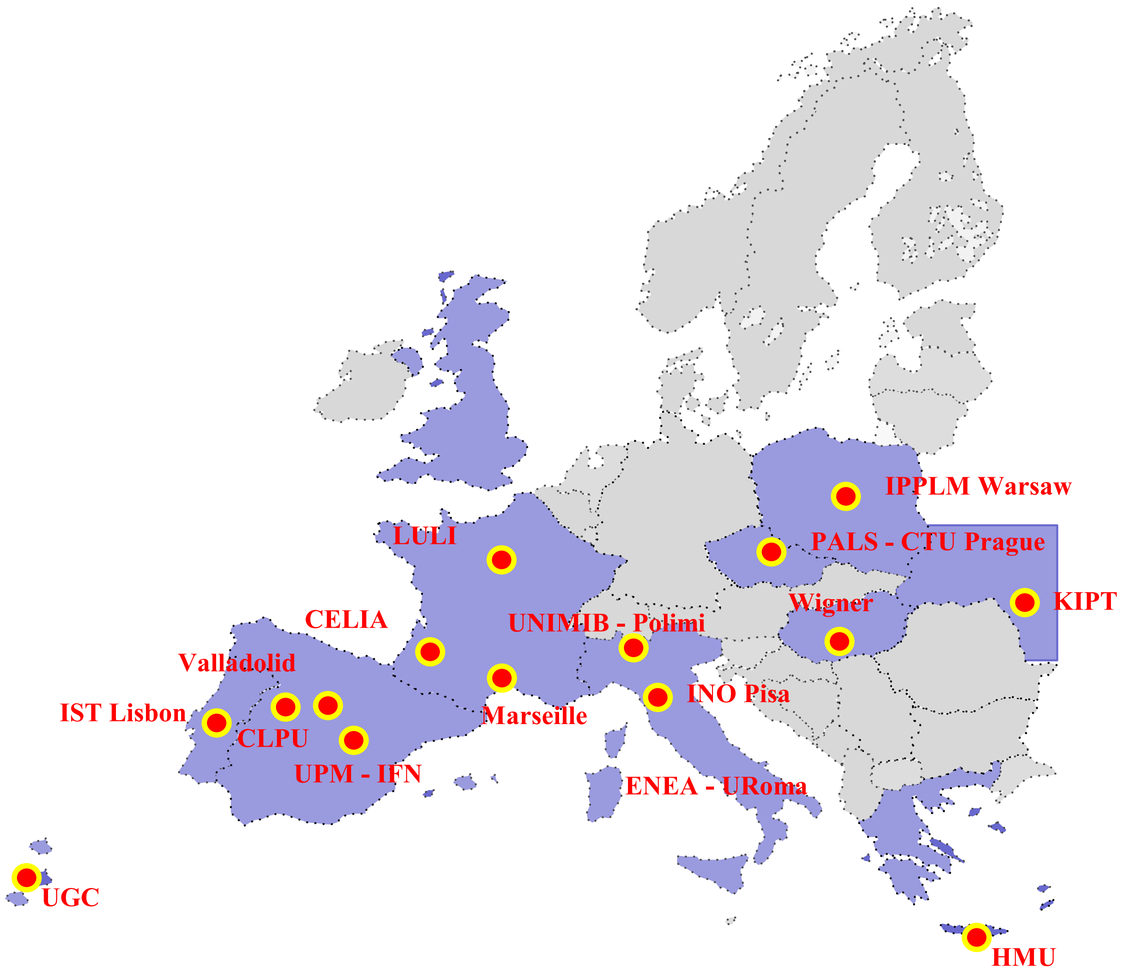


FOPIFE a project supported by Eurofusion

2 year Enabling Reseach Project

“*Foams as a Pathway to Energy from Inertial Fusion »*

10 countries, 24 groups, and 99 researchers



Conclusion

IFE to be economically viable requires a cheap, easy to make target in very large quantities

Nanostructured or porous targets offer a path forward but there are still engineering and physics questions to be answered

FOPIFE is focused on understanding the fundamental processes of laser/foam interaction

- LPI and EOS studies are carried out on mid scale facilities such as ELI, LULI2000, GEKKOXII …

- homogenization studies are being carried out on XFEL (SACLA) where high temporal and spatial resolution is needed

- Simulation work is done bringing together PIC and rad-hydro capabilities

Securing the fabrication of foam is still a work in progress-> contact with labs in Europe and start up on AM