Laser Interactions with Foam Targets for Applications in ICF, EOS and X-ray Source Studies

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In collaboration with

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Outline

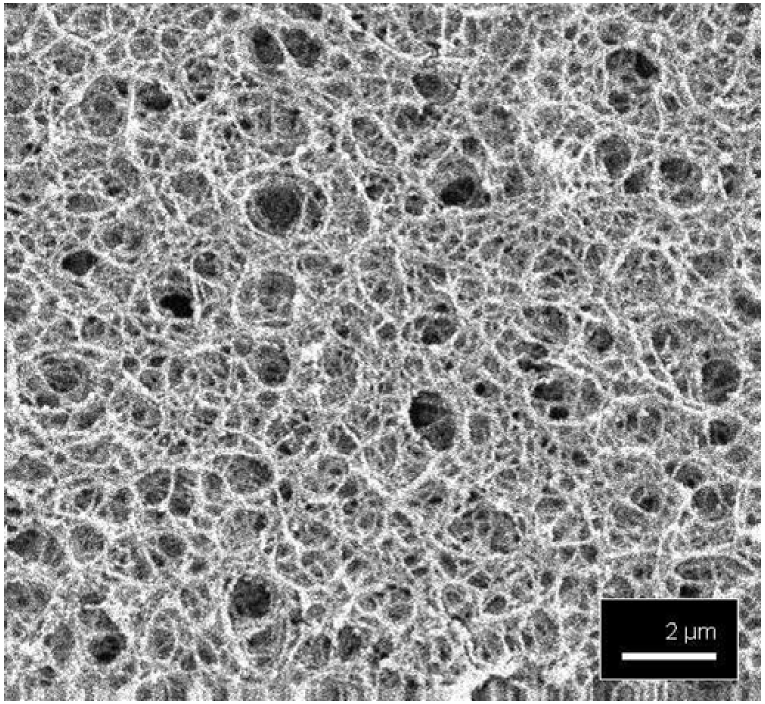
- Low-density media – structure, composition, etc.
- Applications of low-density media in laser interactions
  - Direct-drive ICF targets – ablation pressure smoothing
  - Dynamic phase plate for laser beam homogenization
  - EOS studies – amplification of shock wave pressure
  - Atomic physics studies and x-ray sources
  - In short pulse interactions – ion acceleration and initiation of nuclear reactions
- Experiments on PALS laser
  - Laser directly interacting with foam
  - Energy transport and shock wave propagation
  - Foil acceleration by laser heated foam
  - Laser transmission through underdense foam
  - X-ray spectra measurement
- Numerical simulations (1D and 2D)

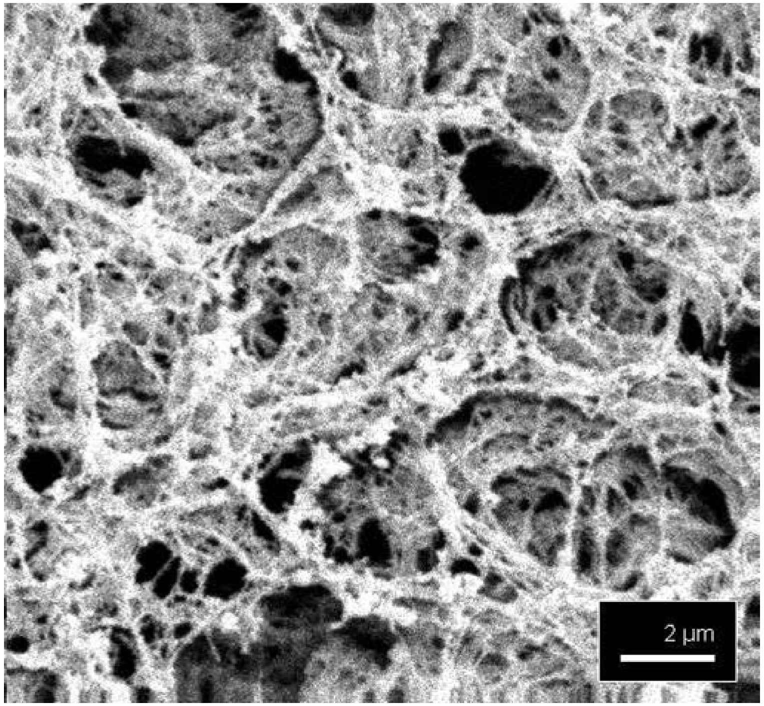
Low-density media

- Low density solid materials have to be inhomogeneous – porous - they have to contain vacuum spaces inside
- Various structures are possible - closed, semi-closed, open cells, (foam and fiber-like structures)
- Plastic foams, plastic foams doped with higher Z elements, deuterated plastic foams
- Alternatively SiO_2 aerogel targets
- Various densities possible – from <1 mg/cc to >1/3 solid
- Foam is called underdense if homogenized fully ionized foam has electron density less than critical density
- When heated, pore walls expand and fill the pores (fast homogenization stage)
- After collision of mass fluxes, inhomogeneities are damped out by viscosity (slow homogenization stage)

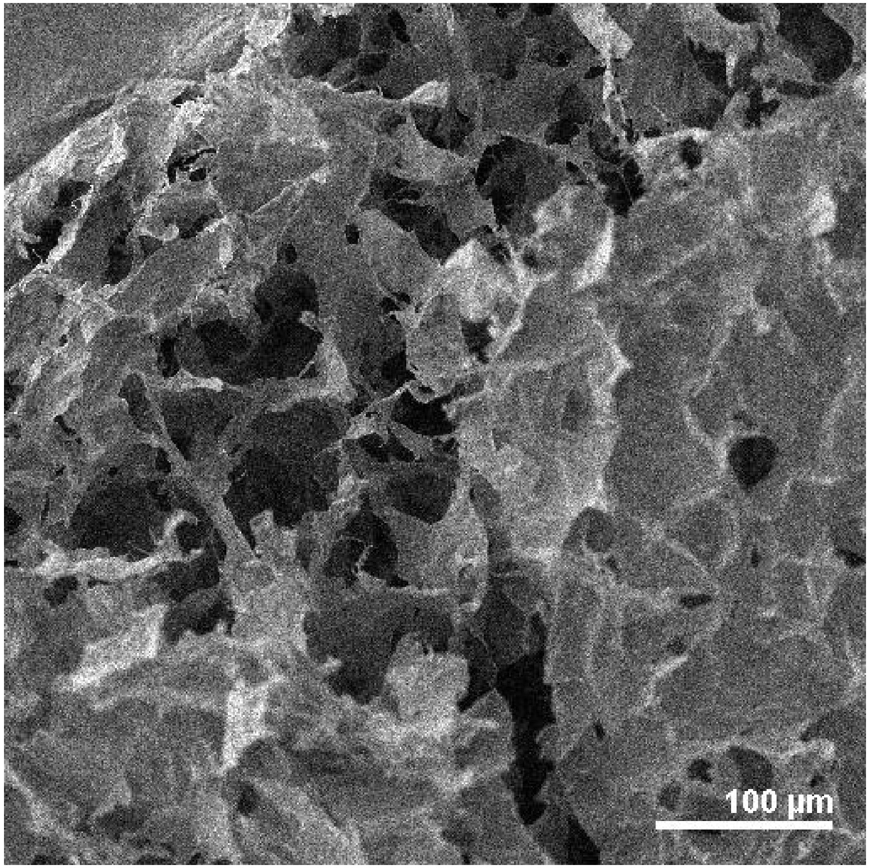
Foams with open cells (3D networks)

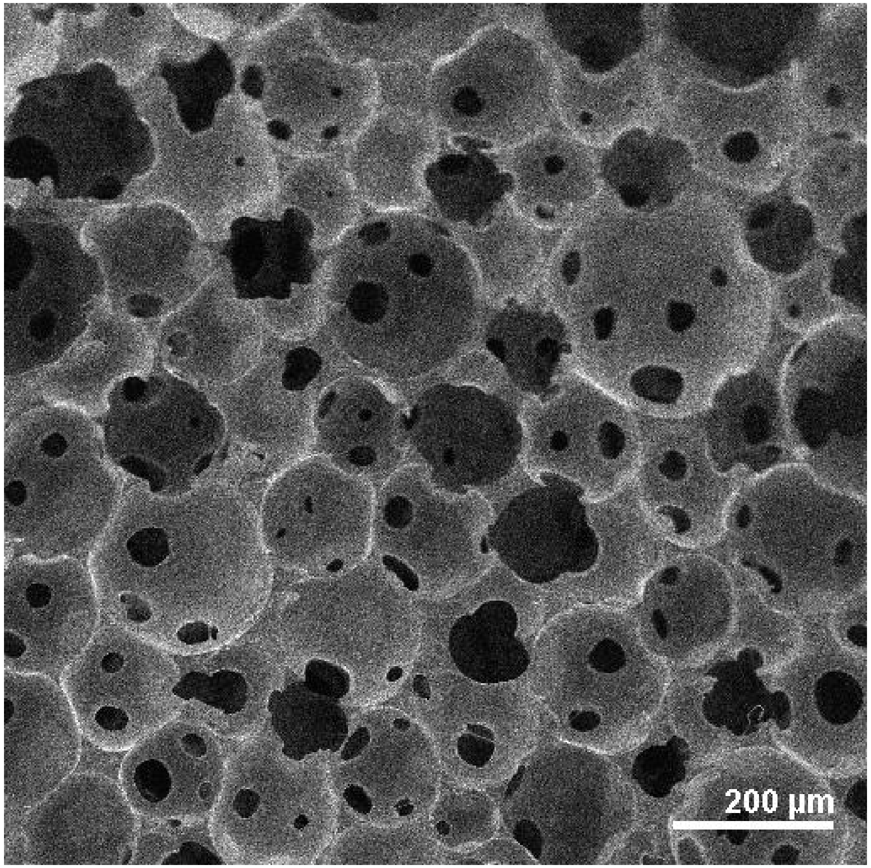
- Small-cell plastic foams without and with high-Z additions (Cl, Cu, SnO_2) - TMPTA (Nazarov), TAC (Borisenko)
- SEM microphotographs of TAC (cellulose triacetate) of density 9 mg/cm^3 - TAC pure and with 10 weight% of Copper, additions lead to structure roughening





Foams with large semi-closed cells

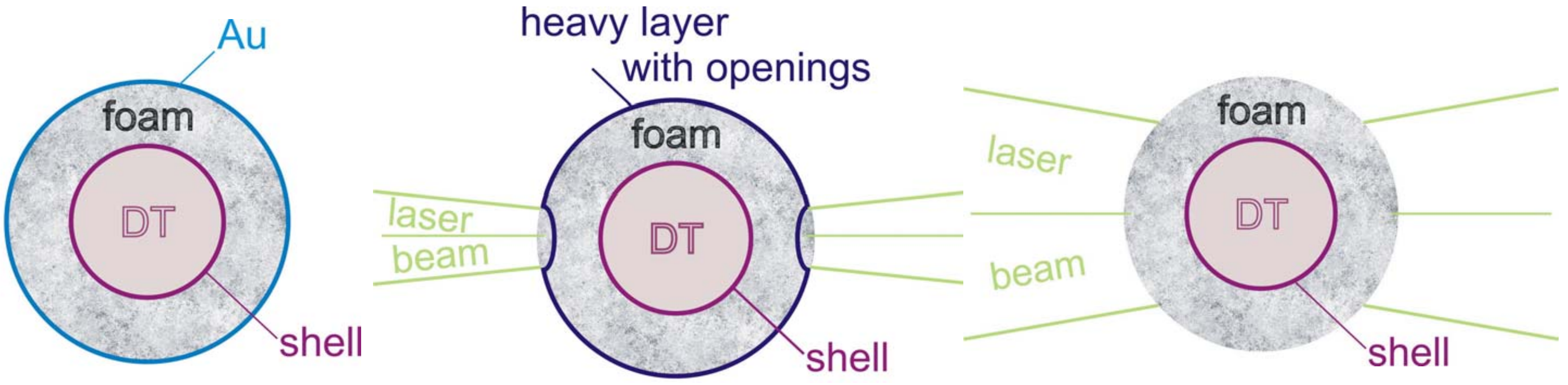




Agar-agar foam – 10 mg/cm^3

Polystyrene foam – 20 mg/cm^3

Foams layers in targets for direct-drive ICF



Target for imprint smoothing
(*Dunne M. et al.* 1995)

Thin (~25 nm) gold foil for x-ray preheat to suppress early imprint of irradiation inhomogeneities

Foam layer to enhance ablation pressure smoothing

Greenhouse target (closed variant)
(Gus'kov, Rozanov 1995)

Aim is to minimize number of beams in reactor chamber

High voluminous absorption in thick foam layer
Ablation pressure smoothing
Outer layer to suppress expansion, intentional shell thickness variations assumed

Greenhouse target (open variant)
(Rozanov 1997)

Aim is to minimize number of beams in reactor chamber

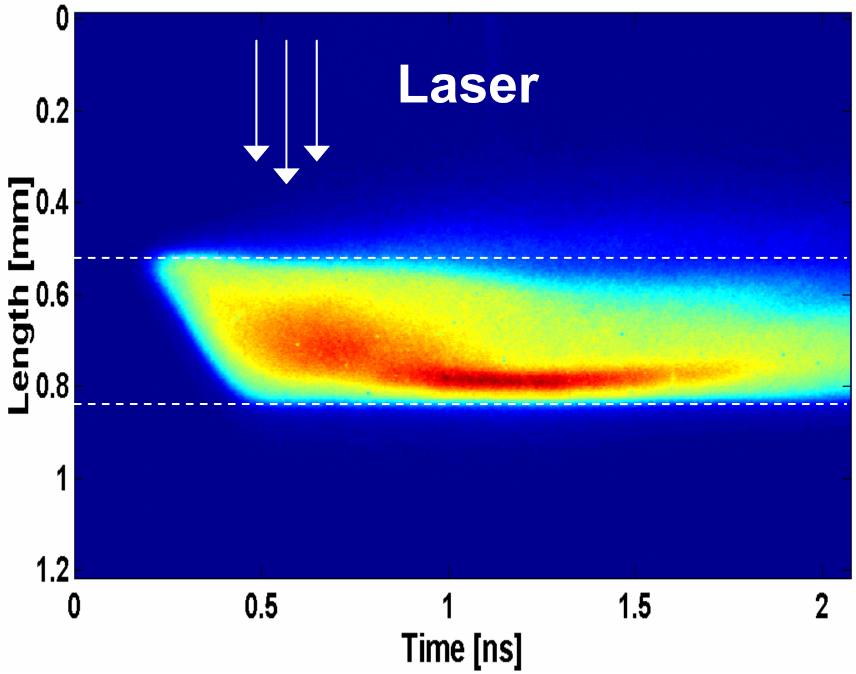
Laser absorption in foam is high even for large incidence angles

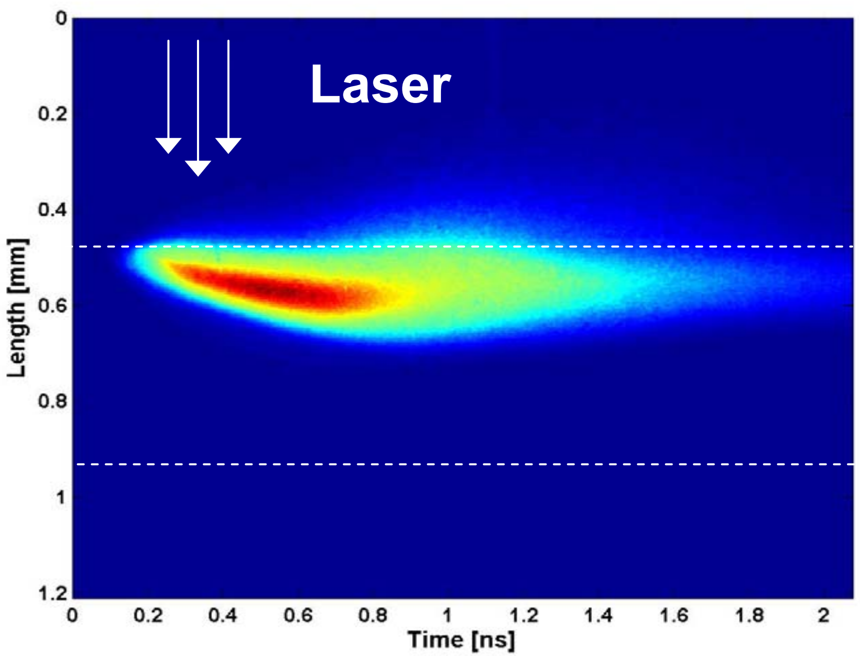
Efficient smoothing in foam layer

Aim of Prague experiments

- More information is needed about laser-foam interaction and about energy transport in foam layers for successful design of ICF targets including low-density foam layers
- Laser absorption and energy transport in the foam materials with large ($D_p > 10\ \mu$m) and small ($D_p < 2\ \mu$m) pores
- Role of high-Z additions in plastic foams is investigated
- Laser transmission measurement is also needed for foam application for smoothing of laser beams
- Sufficient efficiency of thin foil acceleration by the pressure of heated foam matter is demonstrated
- Substantial smoothing of laser inhomogeneities is searched for, but has not been addressed yet
- Comparison of experimental results with numerical simulations and analytical model is important for progress in understanding laser-foam interactions

Energy transport in underdense foam with small (0.5–3 μm) and big (30–100 μm) pores



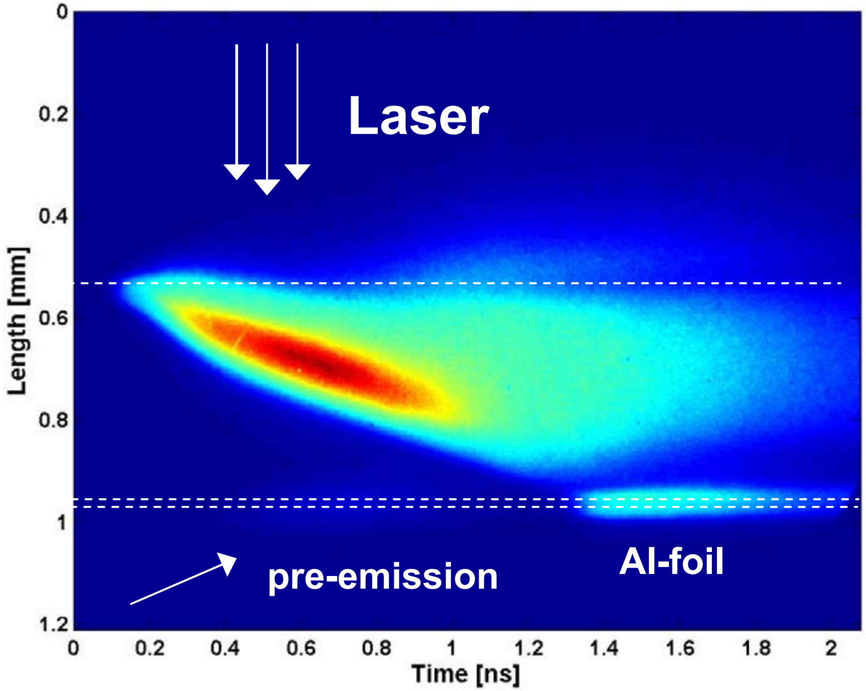


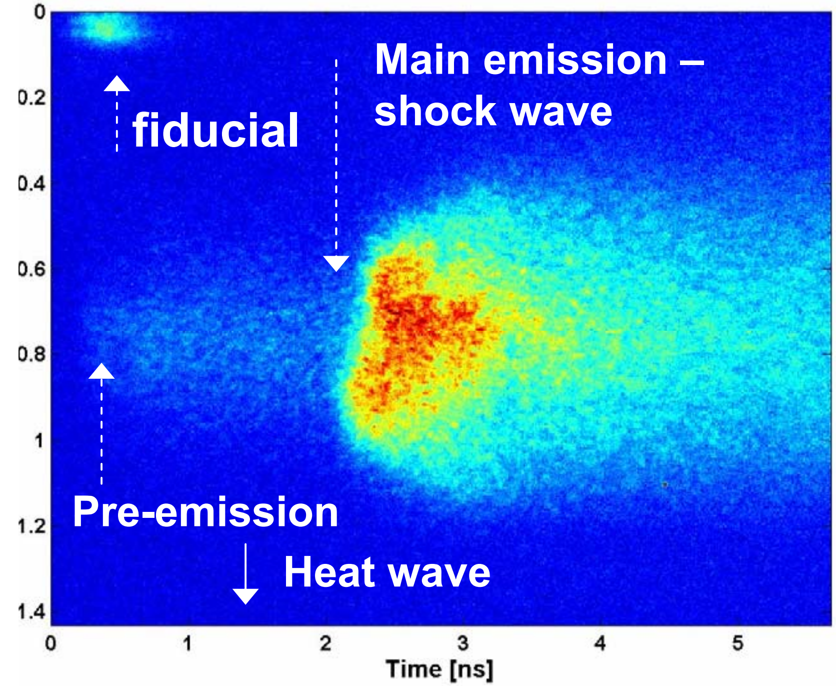
X-ray streak (side view)–laser 3ω, 320 ps FWHM, best focus above target, spot ∅ 300 μm, 5 μm Al at target rear side

small pore TAC 4.5 mg/cm^3 (=n_c/4), 380 μm thick,168 J, **fast** laser **penetration** 1.3±0.1x10^8 cm/s (4 similar shots)

big pore agar 5 mg/cm^3 (=n_c/4), 570 mm thick, 171 J, laser absorbed in 150 μm thick surface layer, **low penetration**

Denser ($n_c/2$) small pore TAC foam

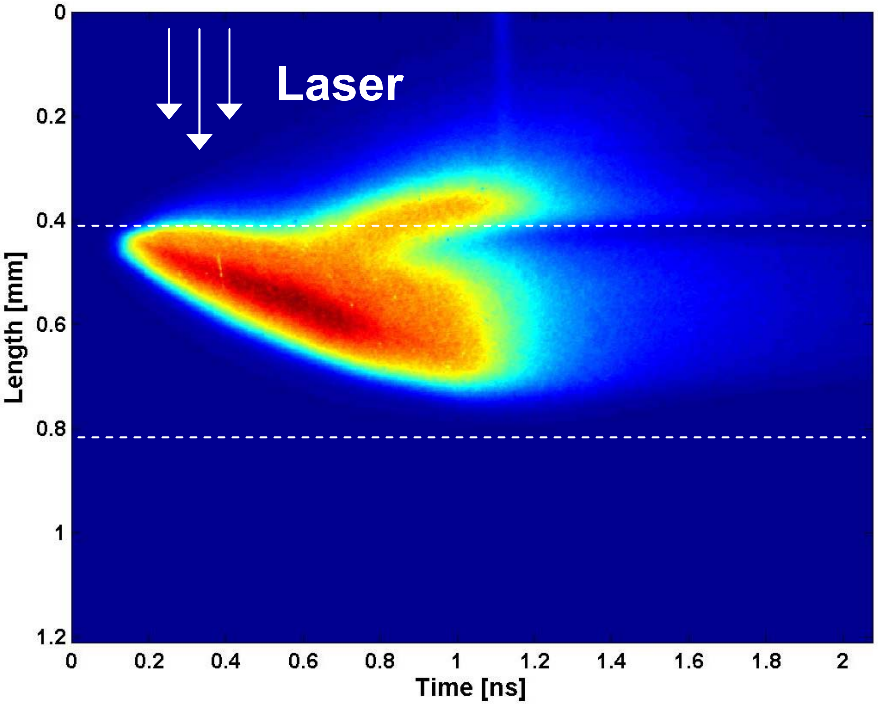


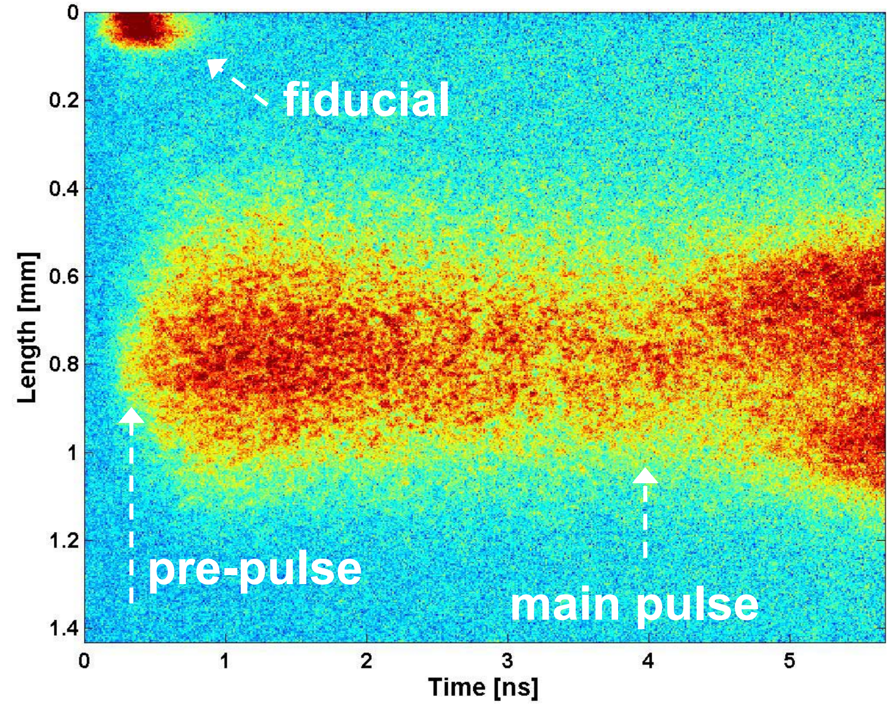


9.1 mg/cm^3, 400 μm thick, 5 μm Al at rear side, 3ω, 170 J, spot $\varnothing$ 300 μm, Left – side-on x-ray streak, Right – optical emission from rear side, fiducial (laser pulse) at top left

Small fast preheat – at the same time - optical pre-emission, thermal wave gets to rear side earlier than main opt. emis.starts

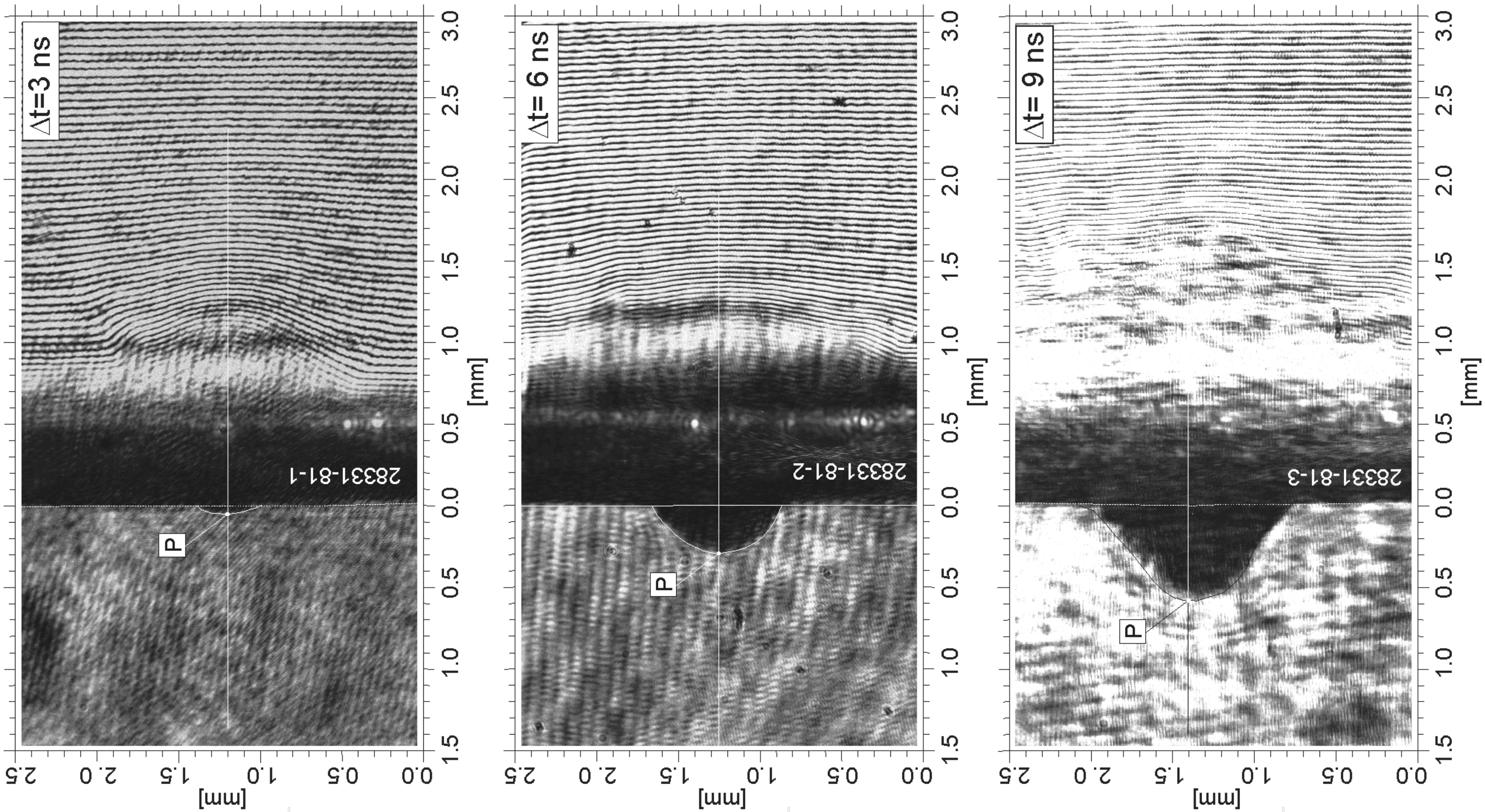
TAC foam 9 mg/cm^3 with 10 weight% Cu



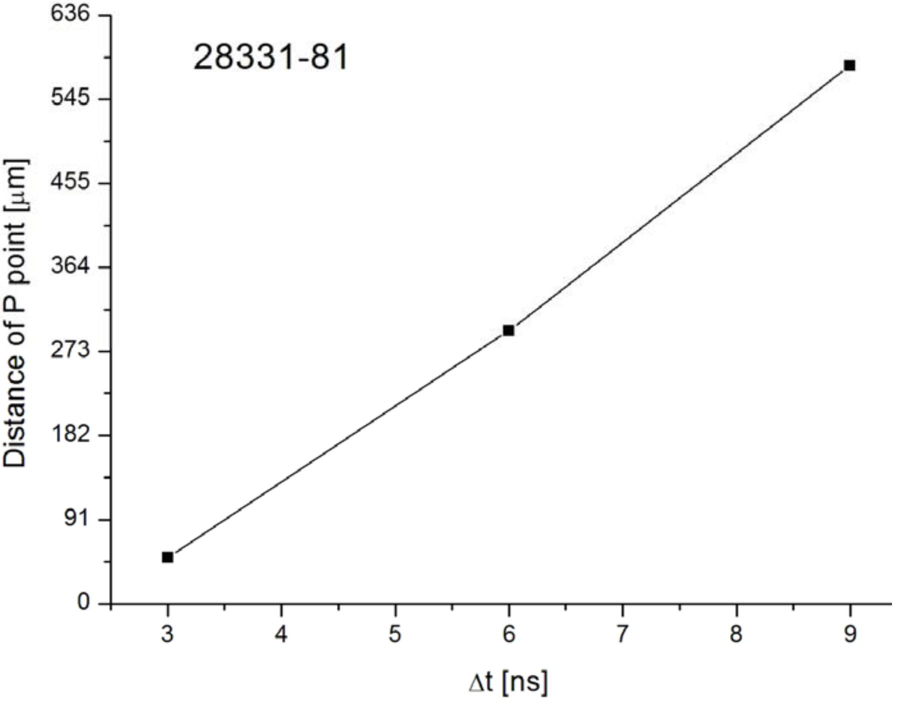


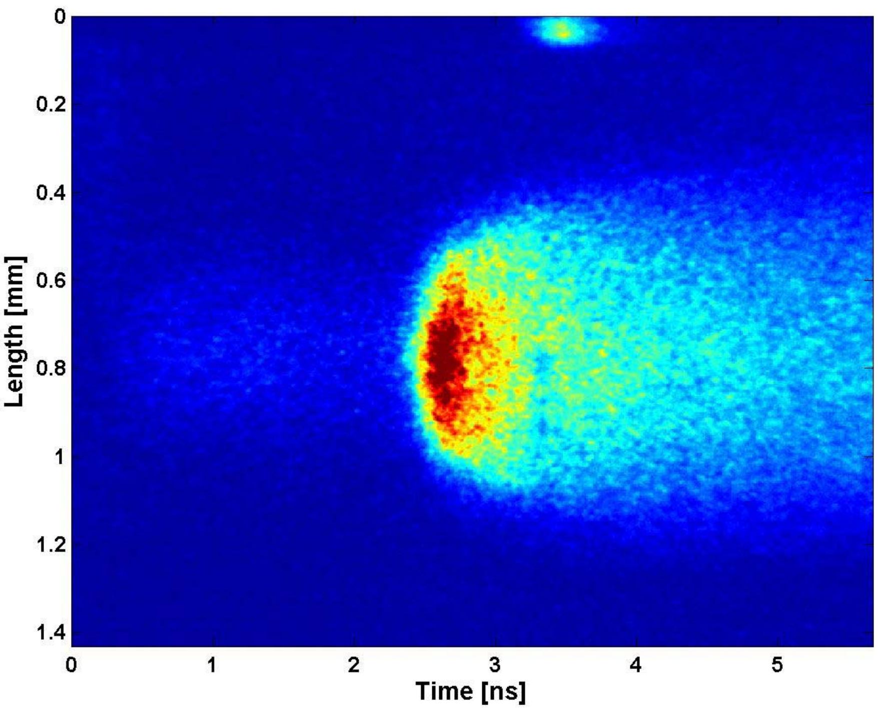
Laser 3ω, 159 J, ∅ 300 μm, 440 μm thick foam + 5 μm Al
Heat wave similar propagation as for pure TAC (> emission)
Optical prepulse much stronger than for pure foil
Main optical pulse (shock wave arrival) significantly later than for pure TAC (delay 3.7 ns instead of 1.9 ns for pure TAC)

3-frame interferographs for 480 μm thick TMPTA foam 10 mg/cm^3+5μm Al, 3ω, 130 J



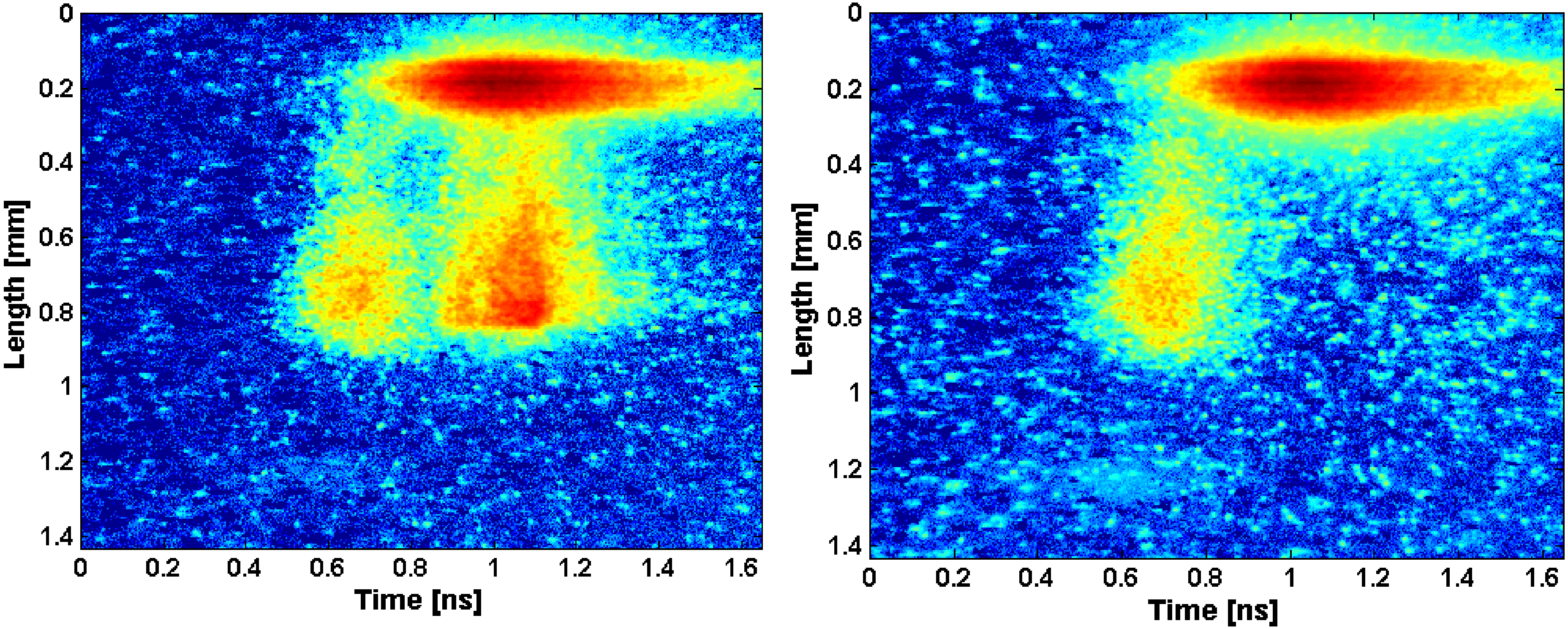
Point P motion and optical streak for above shot





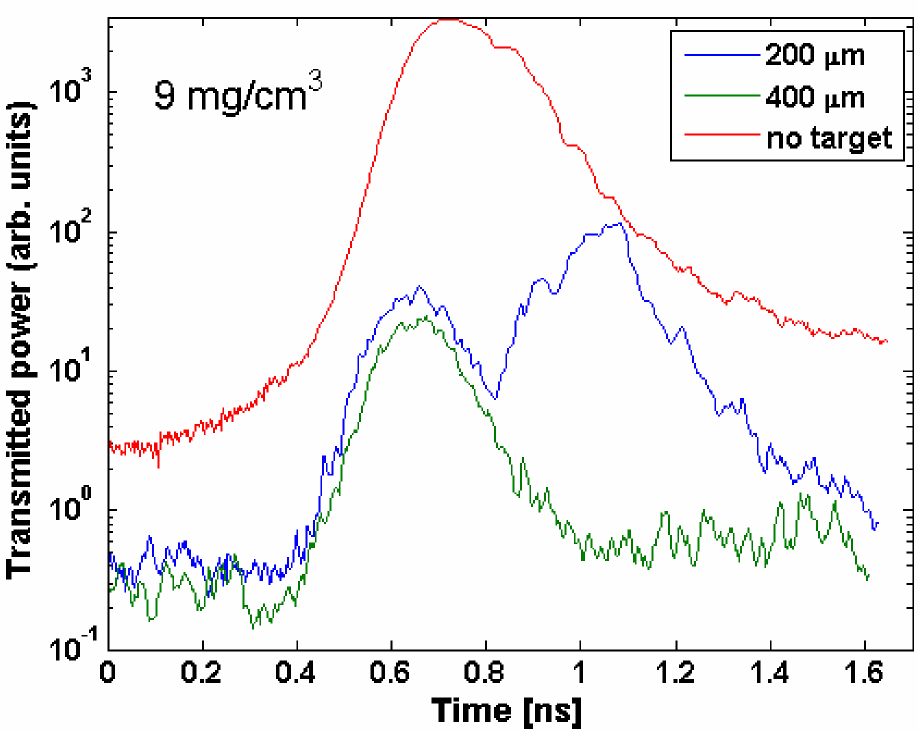
Laser 3ω, 130 J, focus above target, focal spot ∅ 300 μm, 480 μm thick TMPTA foam, 10 mg/cm^3,~1 μm pores+5 μm Al left – position of centre of accel. region, v =9.5x10^6 cm/s, right – optical streak, fiducial delayed by 3 ns, the start of main optical pulse at 1.9 ns is consistent with acceleration, opt. streaks similar for TAC 9 mg/cm^3 and TMPTA 10 mg/cm^3

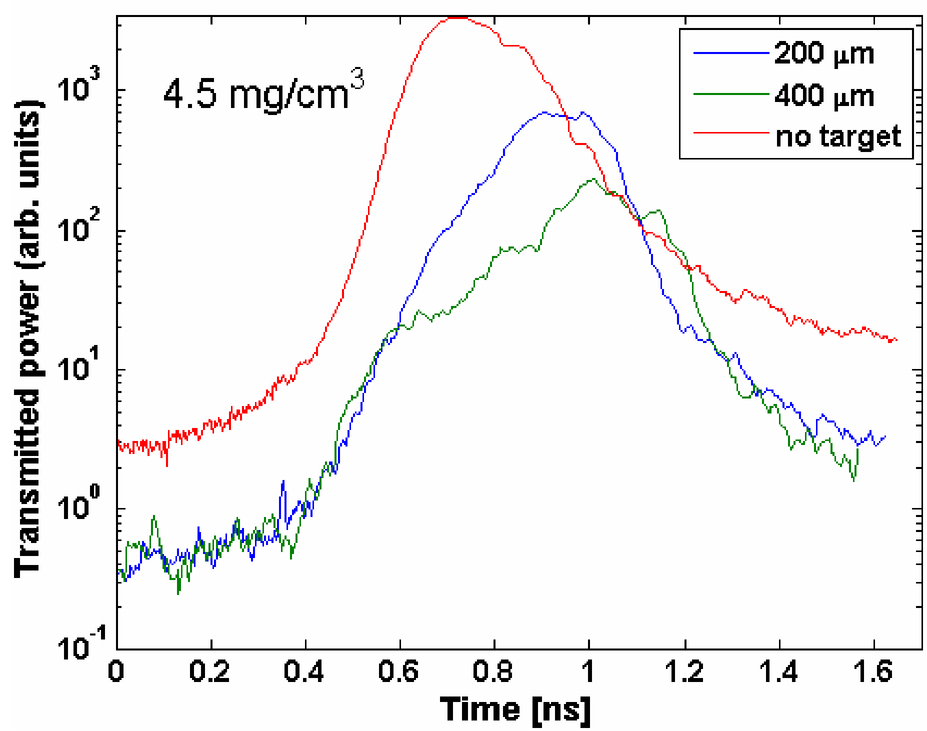
Laser transmission through foam layers



Laser intensity (logarithm scale) – light transmitted through foam compared with fiducial – upper part of figure, ~160 J, 3ω, TAC foam, 9 mg/cc, left – 200 μm, right – 400 μm

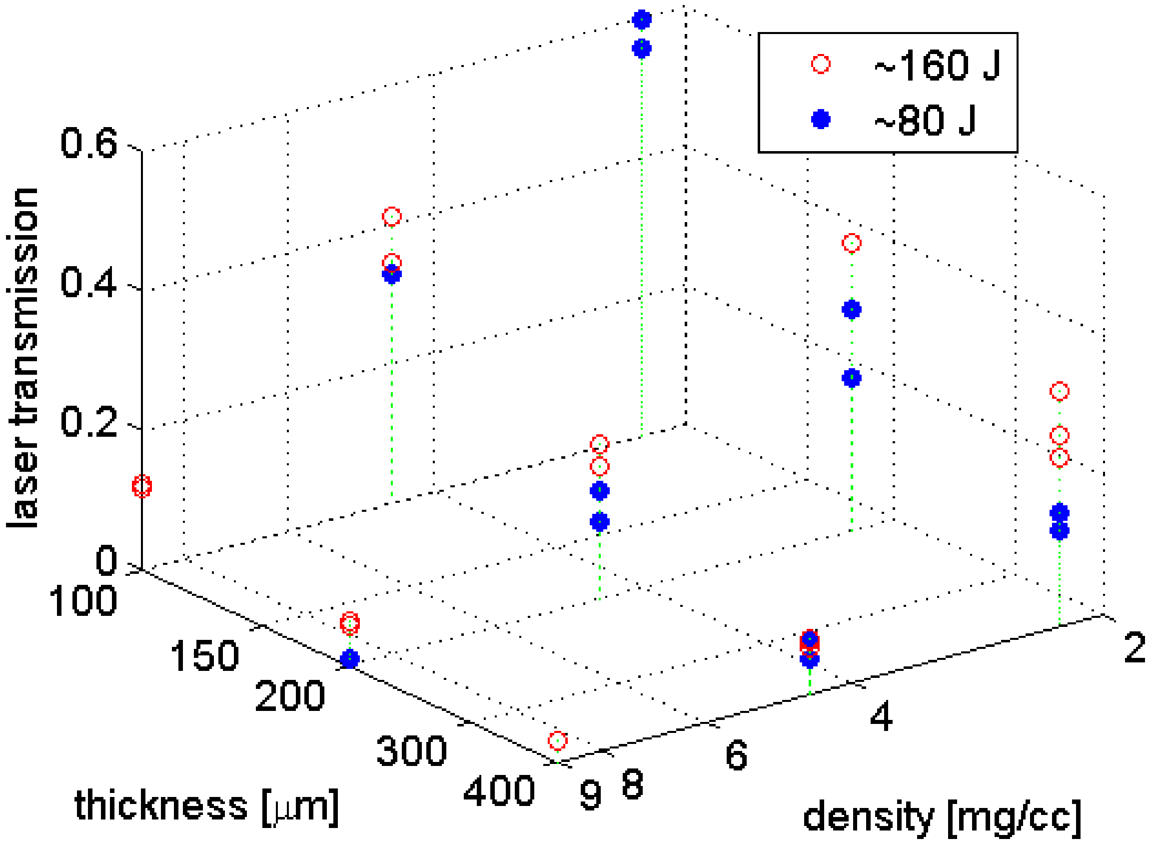
Temporal profiles of transmitted pulses





Laser pulses transmitted through foam as compared pulses propsgated without foam
160 J, 3ω, TAC foam (pore size 0.5-3 μm)
Left – 9 ng/cc (prev.slide), right – 4.5 mg/cc

Transmission versus foam density and thickness

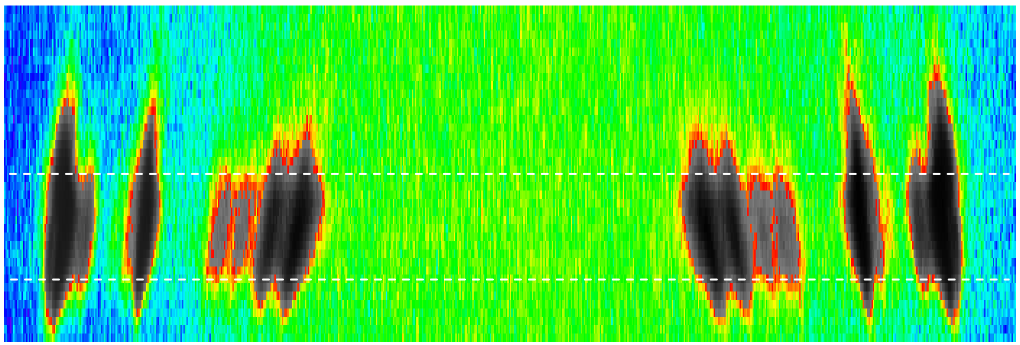


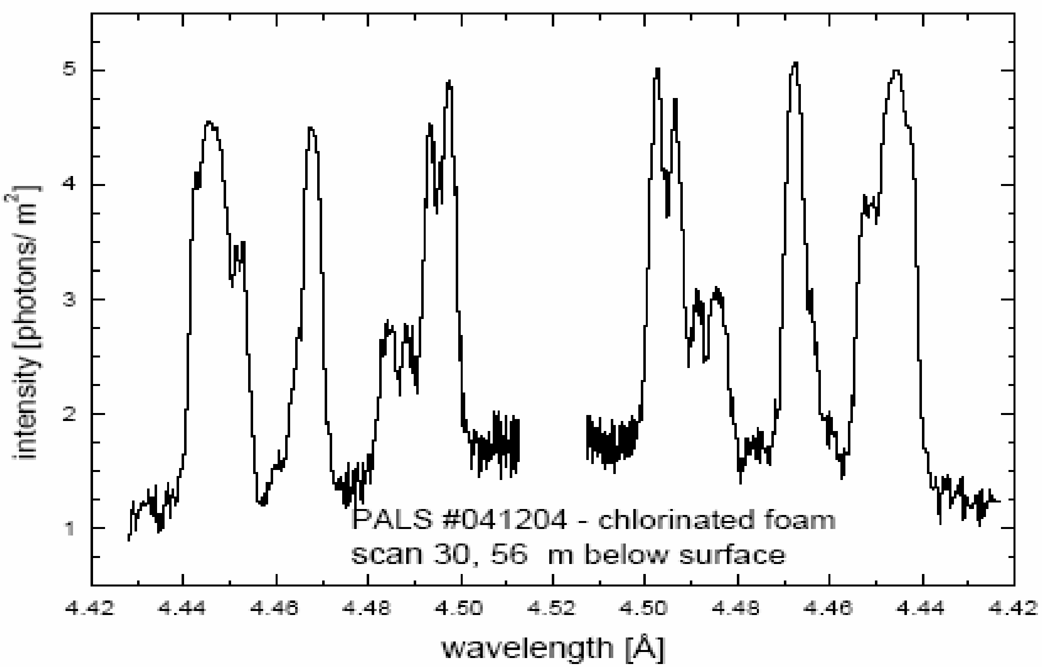
Laser transmission increases with laser energy

60% trans-mission for ~1/8 n_c and 100 μm thick

- Laser penetration decreases with foam density and thickness as expected

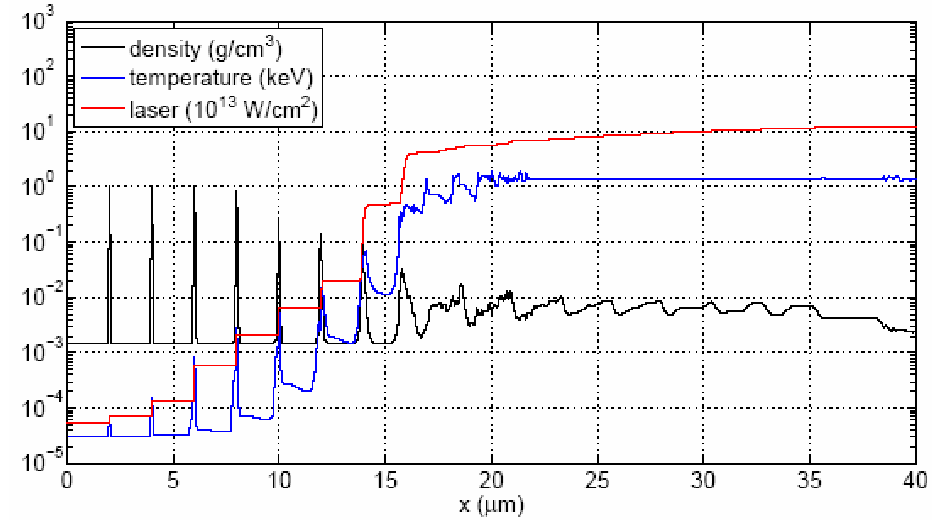
X-ray emission from high-Z additions in foam

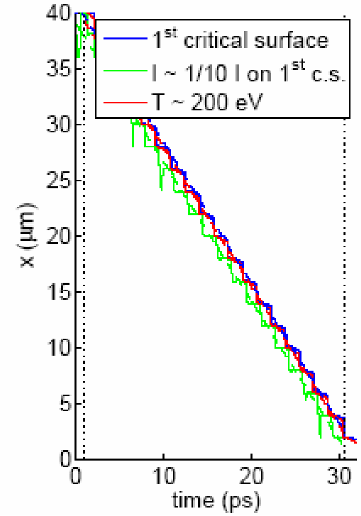




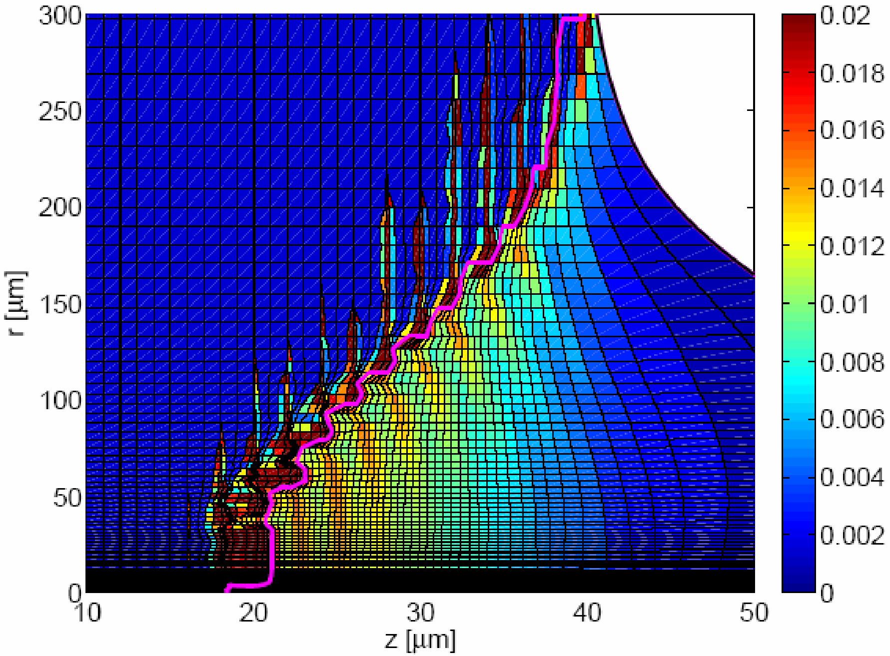
Emission spectra from Cl-doped TMPTA foam in region of Cl He-a line
Vertical Johann spectrograph using cylindrically bent quartz crystal - 2 mirror-like spectra (photon energy min in centre)
Spectral resolution ~5000
Spatial resolution ~8 μm in vertical direction
Recorded in one shot, 25° from target surface
Lower fig - processed spectra 25 μm below target surface
Region of nearly homogeneous emission found for foam targets

1D and 2D fluid simulations with foam structure





Foam as set of slabs with void spaces in between laser λ= 439 μm, 3.7×10^{14} W/cm^2, 1 ps rise time



<u>For light (low ρ×d) pore walls</u> - laser is tunneling through walls heating simultaneously several layers, wall expansion in exploding foil regime; fast laser penetration

<u>For heavy walls</u> – laser heats front size of one wall, rest ablatively accelerated, slow penetration

<u>2D simulations</u> – our newly developed <u>*ALE code*</u> – lateral heat flux not important for our parameters

Conclusions

- Fast penetration of x-ray emitting region through significantly subcritical foam ($\leq$1/4 n_c) with small pores (penetration speed ~ 1.3 x 10^8 cm/s), but much slower for ~ same density and big pores, and also for ~ 1/2 n_c and small pores
- Main pulse of opt. emission from rear side starts approximately at the beginning of rear side motion
- The shock transit time (measured by opt. emission) reproducible within $\pm$5% accuracy for TMPTA targets
- The shock transit time increases with density and also for constant density when high Z is added and also when 1ω is used instead of 3ω
- The velocity of accelerated foil and the extent of accelerated region is measured and hydrodynamic efficiency > 10 % has been derived
- Laser transmission through foam (time resolved) and line x-ray spectra (doped Cl He-α) measured