INTERNATIONAL ATOMIC ENERGY AGENCY

Division of Physical and Chemical Sciences
Physics Section

Second Research Co-ordination Meeting

of the

Co-ordinated Research Project

on

Elements of Power Plant Design for Inertial Fusion Energy

4-7 November 2003
Vienna, Austria

Where I am coming from...

<u>**Which**</u>

Interface Issue

is the

Czech Republic

going to co-operate in?

- ***Driver-Target***
- ***Driver-Chamber***
- ***Target-Chamber***

Laser Imprint Problem
and its Treatment by

1) Double Pulse Plasma

2) Foam Layers

Research Contract No. CZR 11655/RBF

Chief Scientific Investigator

Milan Kálal

Faculty of Nuclear Sciences and Physical Engineering

Czech Technical University in Prague

Czech Republic

Contracting Institution:

Laser Plasma Research Centre

Institute of Physics

Academy of Sciences
of the
Czech Republic

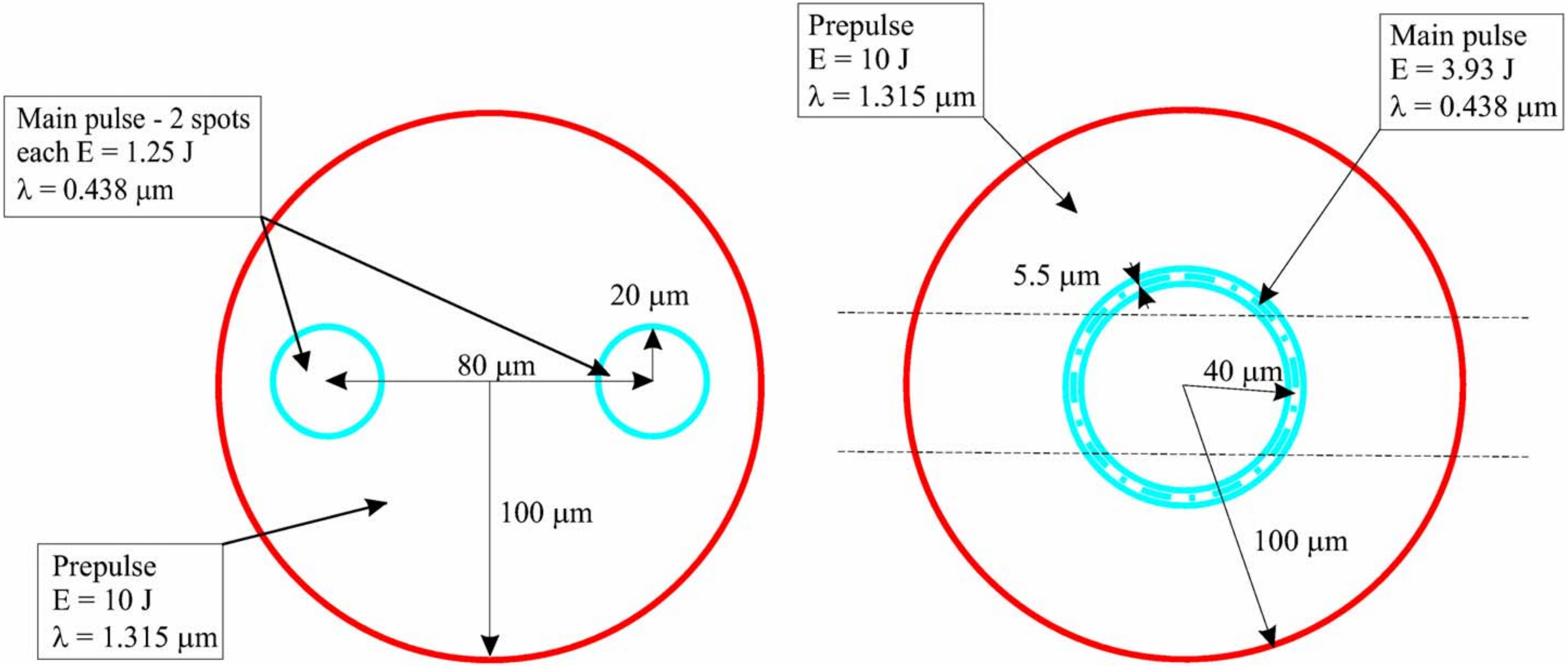
Scientific Staff 2001

- **M. Kálal (team leader), J. Limpouch,**
  Faculty of Nuclear Sciences and Physical Engineering,
  Czech Technical University in Prague, Czech Republic
- **E. Krouský, K. Mašek, P. Straka,**
  Institute of Physics,
  Academy of Sciences of the Czech Republic
- **T. Pisarczyk**
  Institute of Plasma Physics and Laser Microfusion,
  Poland

Thermal Smoothing
of
Laser Imprint
in
Double Pulse Plasma

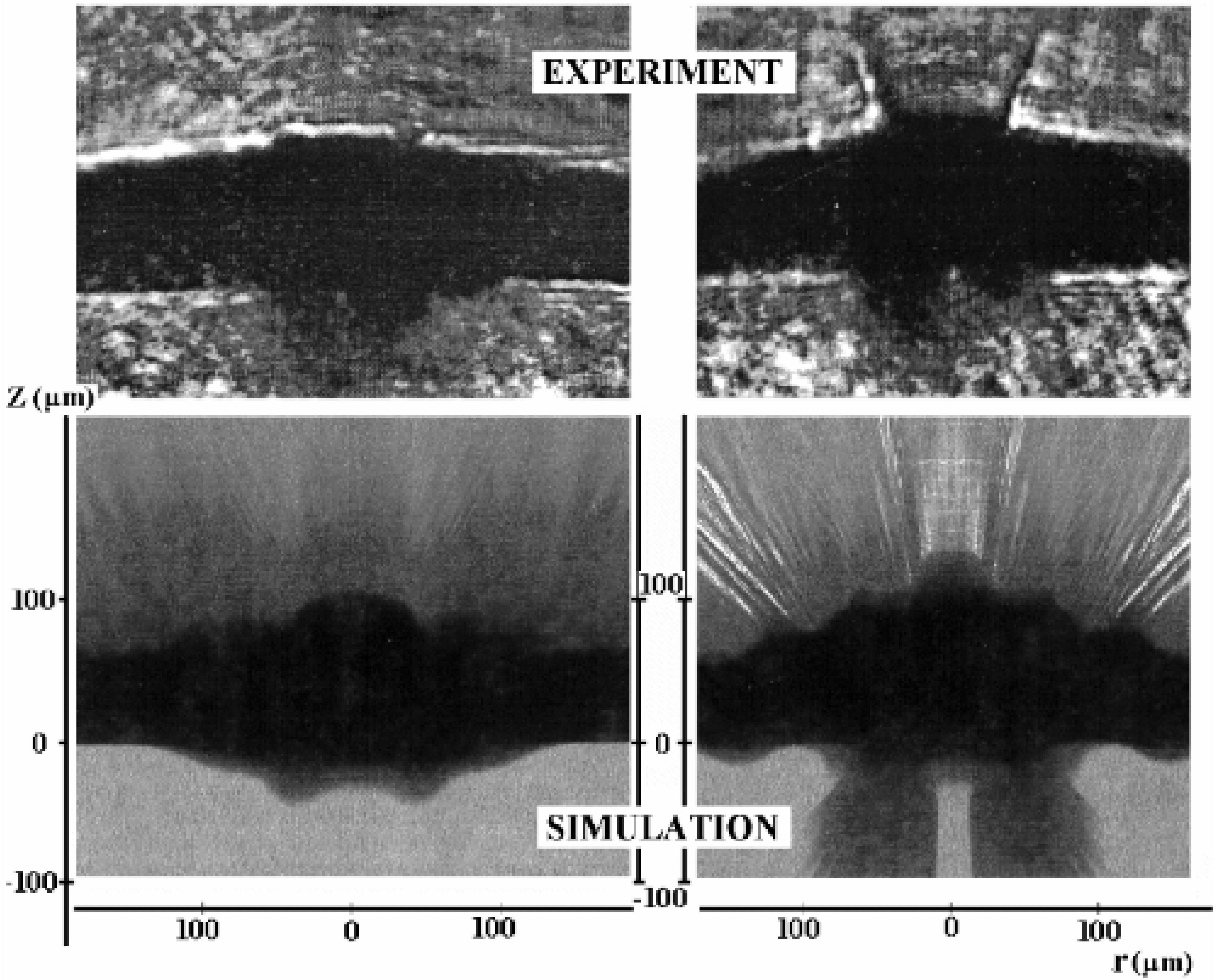
The **residual structure** of the intensity non-uniformities **imprinted on the still cold target surface** **cannot be smoothed away** in the transient stage and **persists** throughout the rest of the laser-target interaction.

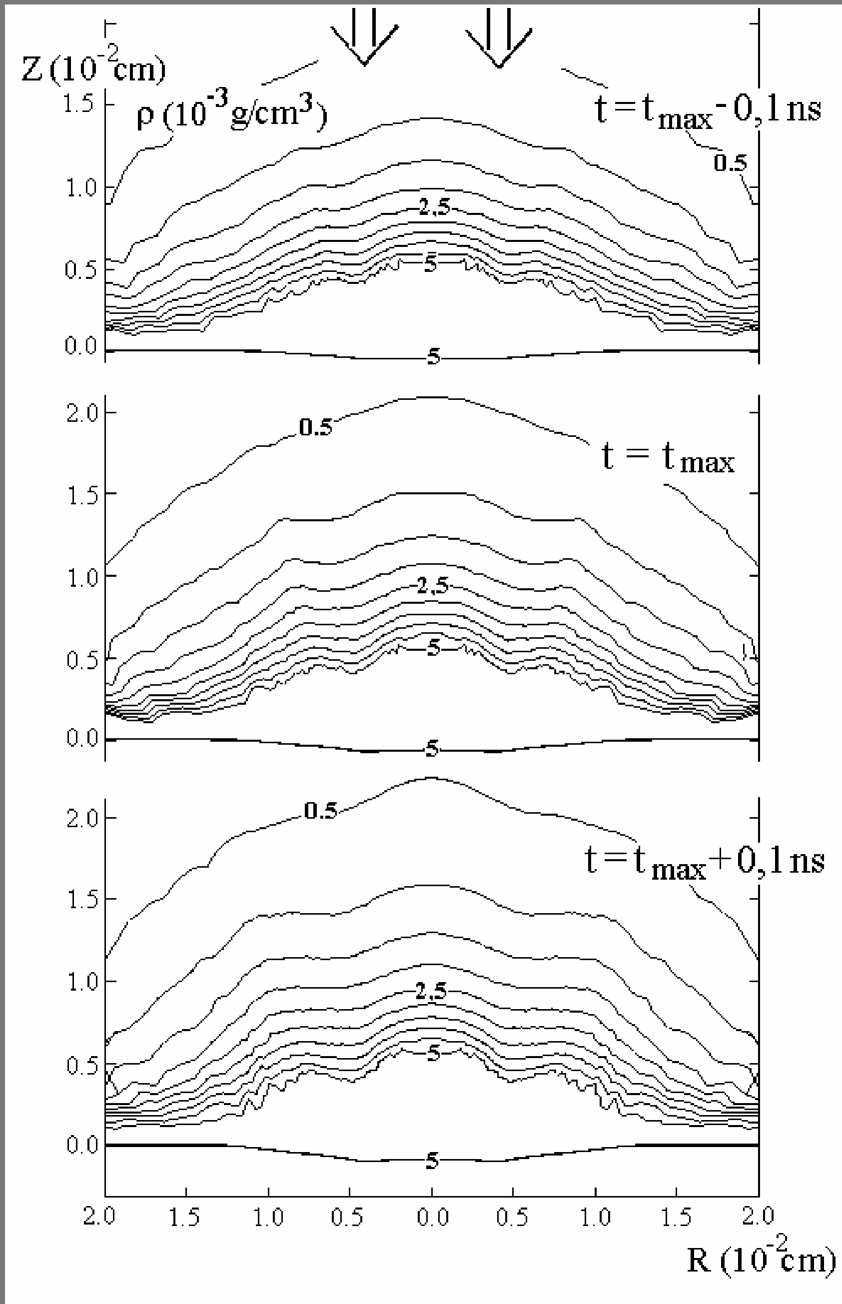
In this scheme the **prepulse** generates an absorption zone with **non-zero thermal conduction** near the target surface before the arrival of the main heating pulse.

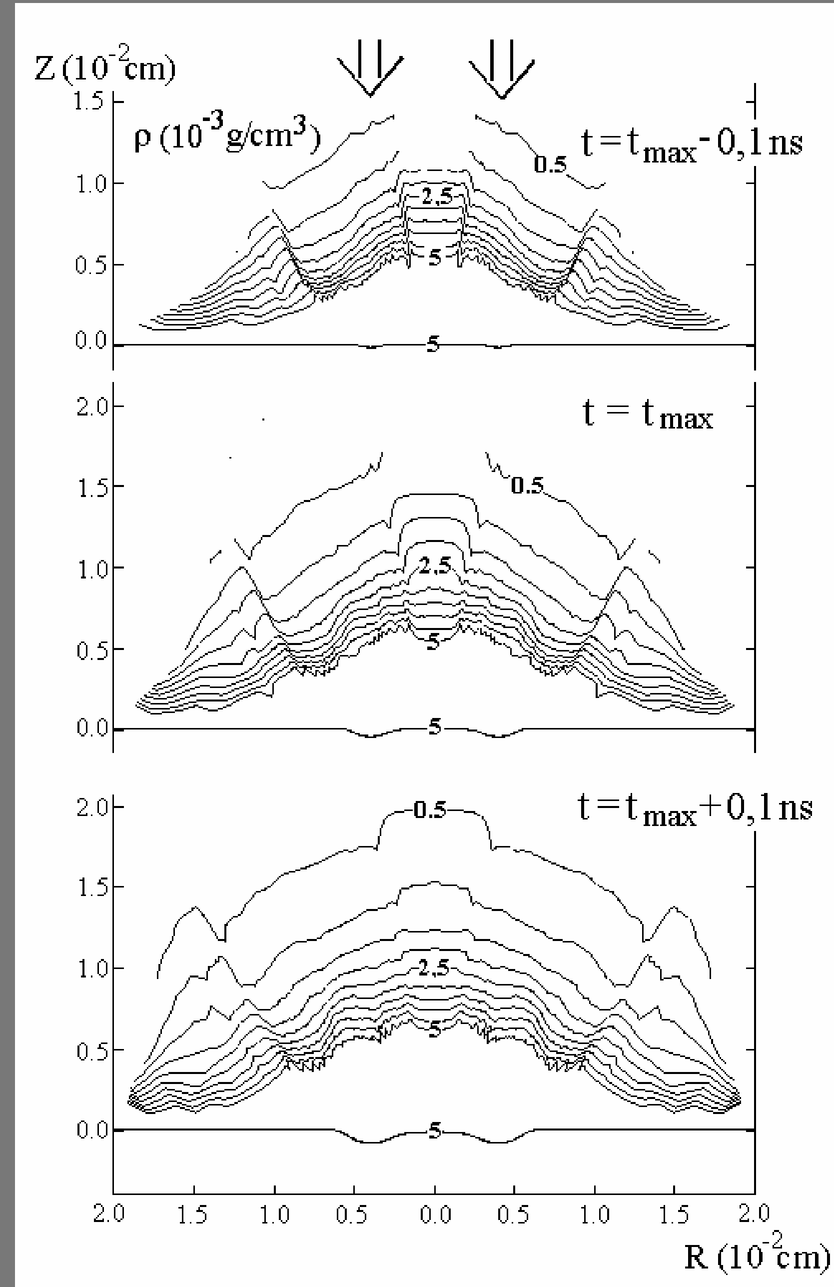


a) Experiment

b) Simulation


EXPERIMENT
Z (μm)
100
0
-100
100
0
-100
SIMULATION
100
0
100
100
0
100
r (μm)


Z (10^-2 cm)
ρ (10^-3 g/cm^3)
t = t_max - 0,1 ns
t = t_max
t = t_max + 0,1 ns
R (10^-2 cm)

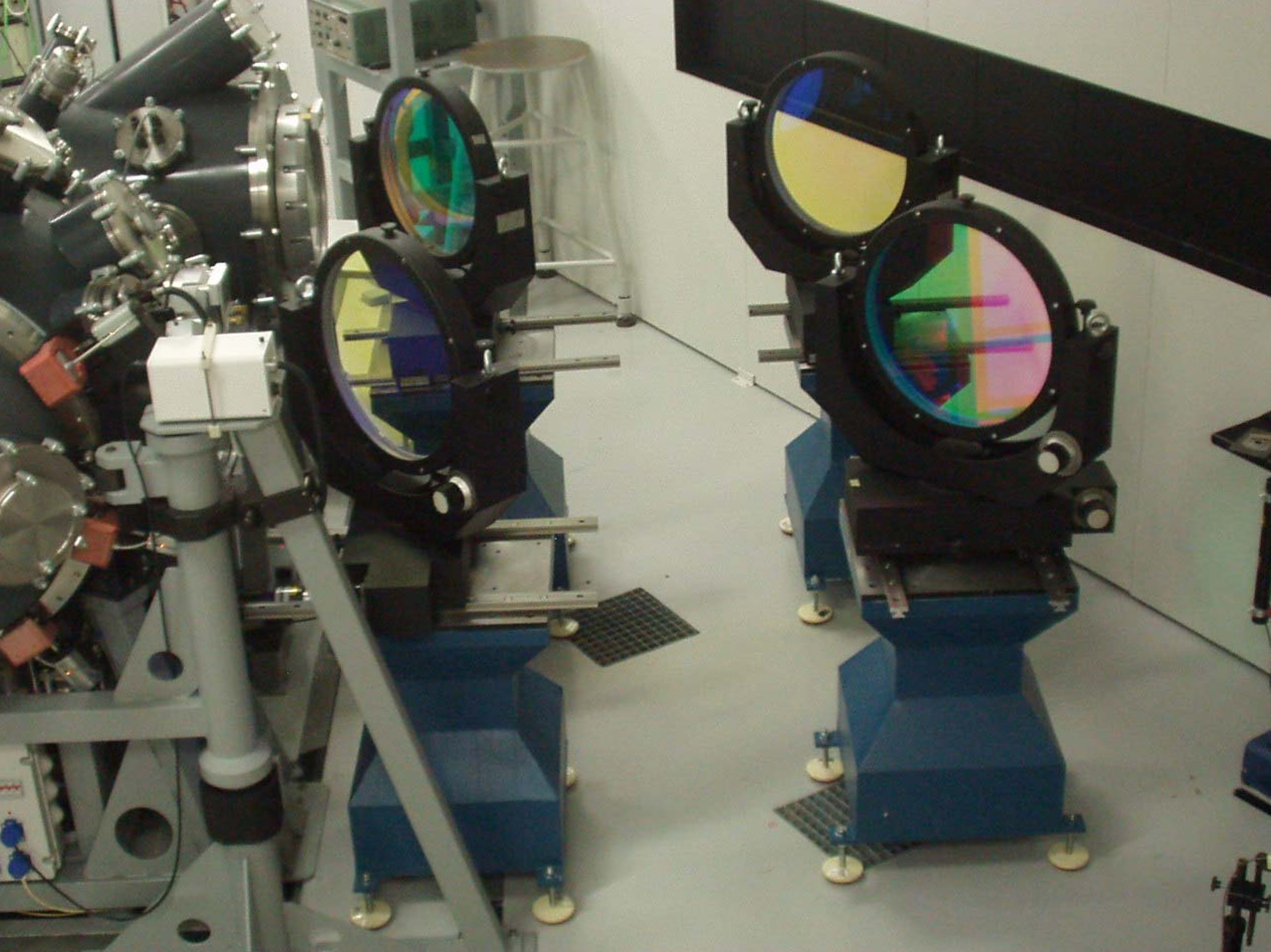

Z (10^-2 cm)
ρ (10^-3 g/cm^3)
t = t_max - 0,1 ns
t = t_max
t = t_max + 0,1 ns
R (10^-2 cm)

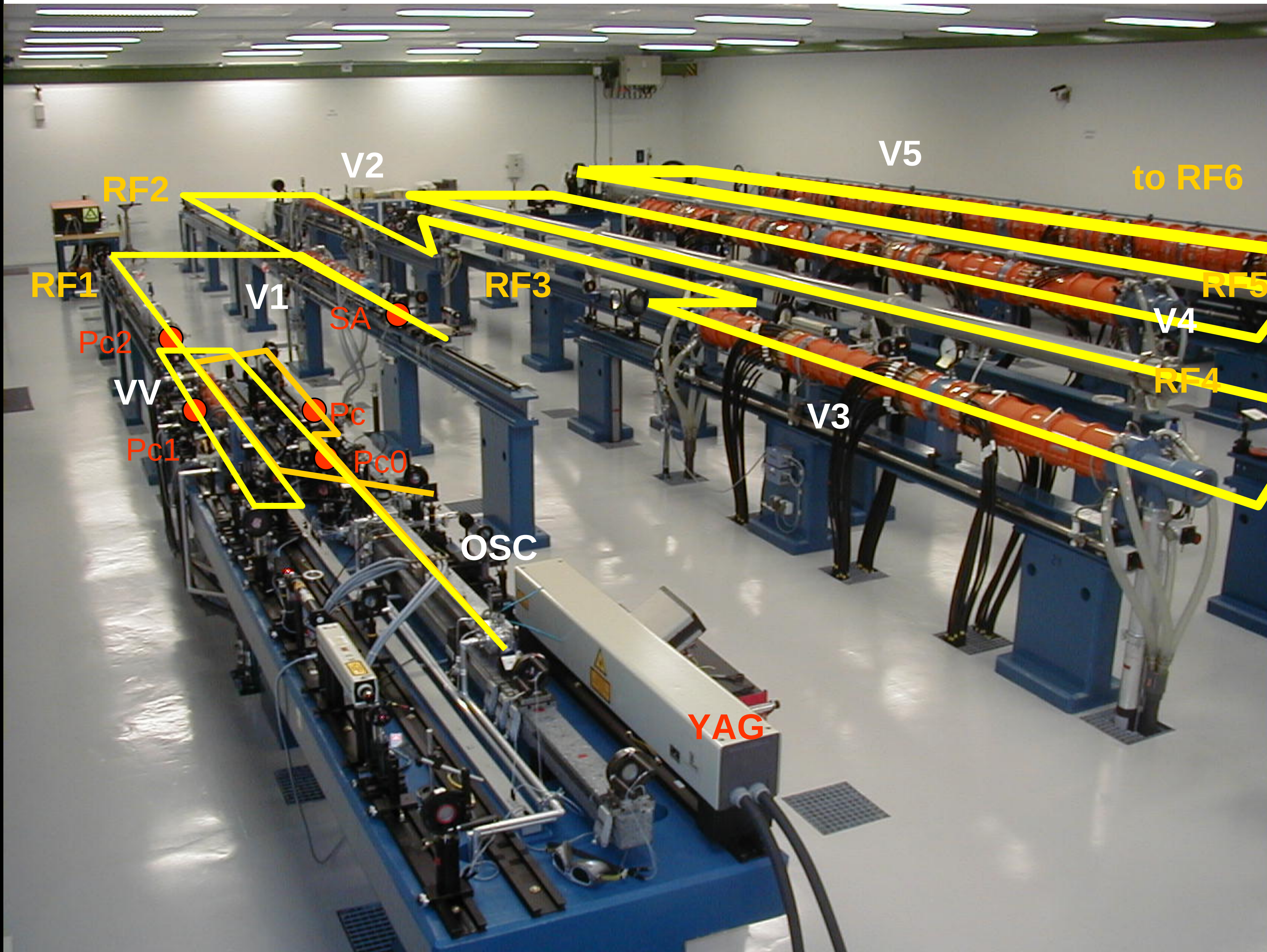
!!! NEEDED !!!

4 quartz mirrors

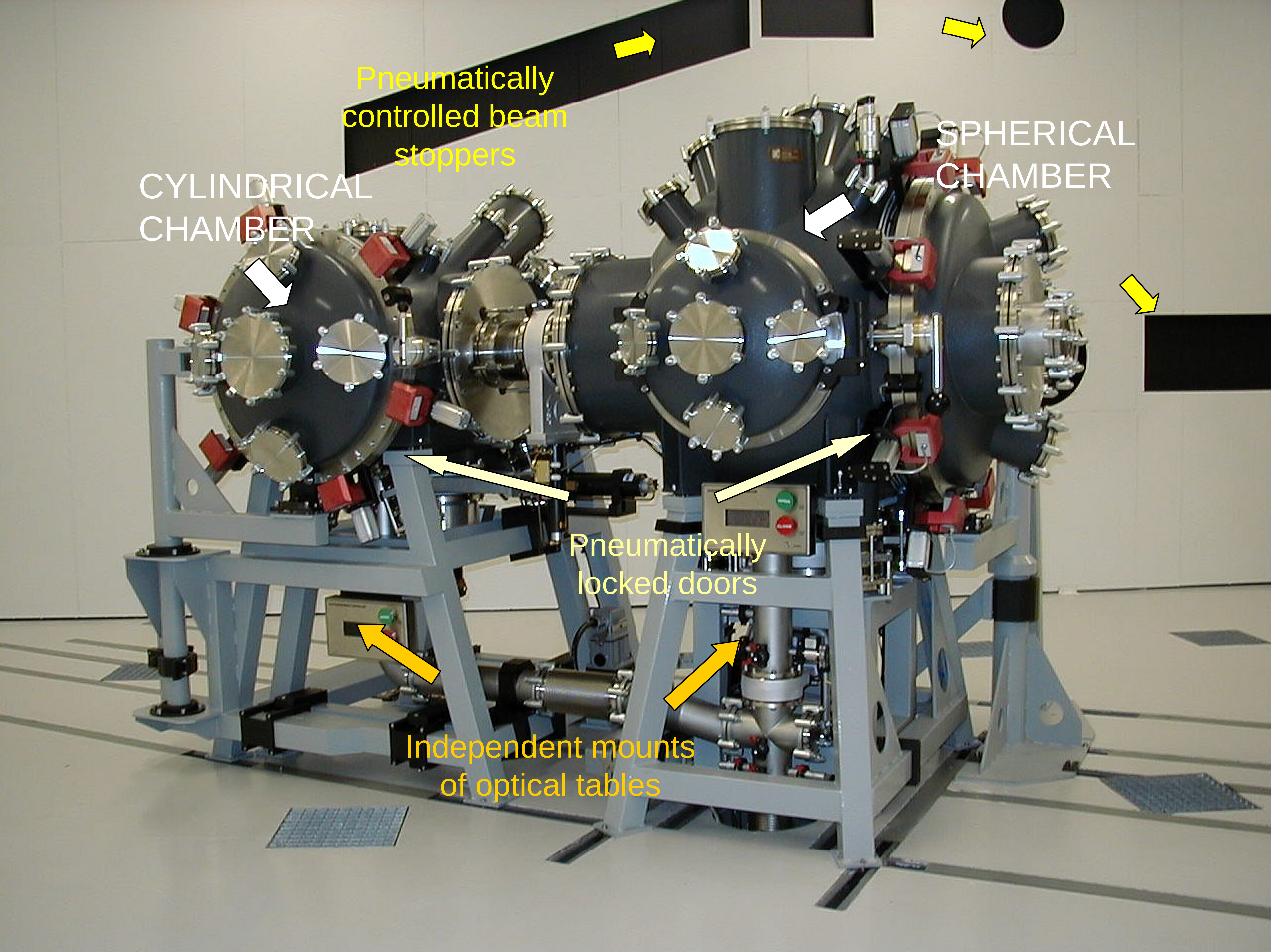
diameter ~ 500 mm
with dielectric multilayers
for 1ω, 2ω, and 3ω separation.

Expected price ~ 2 MCZK.





V5
V2
to RF6
RF2
RF1
V1
RF3
SA
Pc2
RF5
V4
VV
Pc
RF4
V3
Pc1
Pc0
OSC
YAG


Pneumatically controlled beam stoppers
CYLINDRICAL CHAMBER
SPHERICAL CHAMBER
Pneumatically locked doors
Independent mounts of optical tables

Scientific Staff 2003:

- **M. Kálal (team leader), J. Limpouch,**
  Faculty of Nuclear Sciences and Physical Engineering,
  Czech Technical University in Prague, Czech Republic
- **E. Krouský, K. Mašek, K. Rohlena, J. Skála, P. Straka**
  Institute of Physics, AS CR, Prague, Czech Republic
- **J. Ullschmied**
  Institute of Plasma Physics, AS CR, Prague, Czech Republic
- **A. Kasperczuk, T. Pisarczyk**
  Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland
- **S. Yu. Gus'kov**
  P.N.Lebedev Institute of Physics of RAS, Moscow, Russia
- **V. N. Kondrashov**
  Troitsk Institute for Innovation and Fusion Research, Troitsk, Russia


Prostorový filtr RF6 a nosná konstrukce
pro optiku pomocných svazků

Thermal smoothing & thin foil acceleration studies

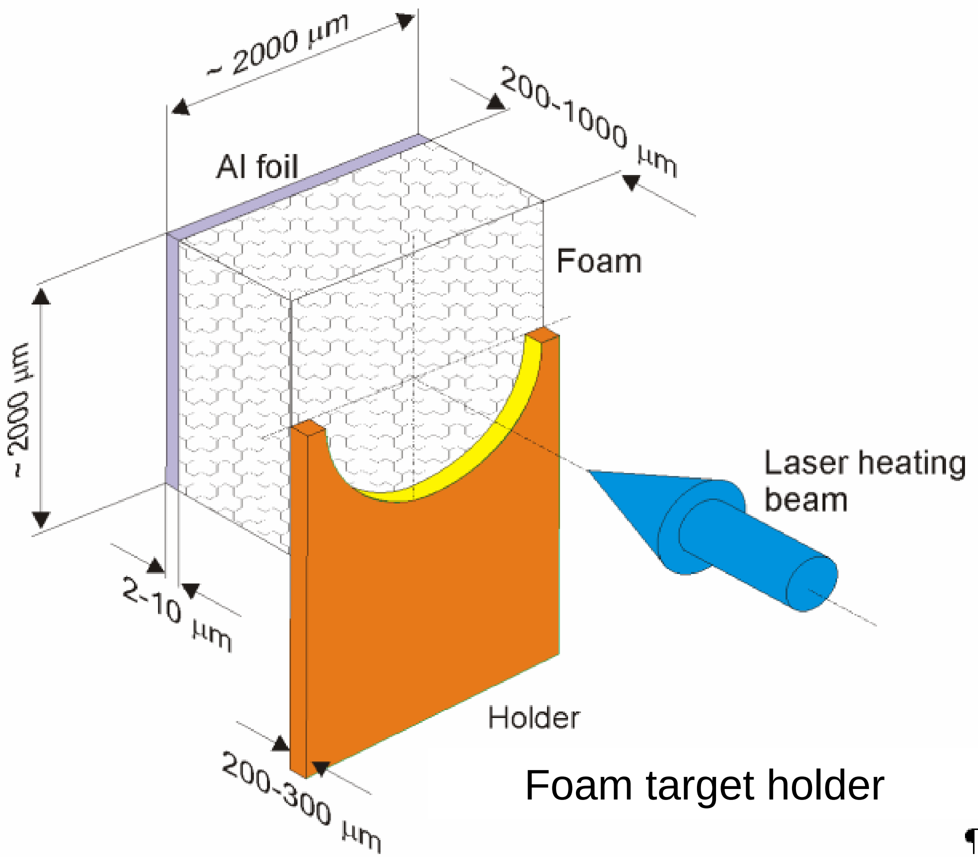
M. Kalal, J. Limpouch, S. Gus'kov, V. Kondrashov, T. Pisarczyk et al.

Thin foil acceleration by the pressure of laser-produced plasma of porous matter
J. Limpouch et al., ECLIM 2002
Thermal smoothing by laser-produced plasma of porous matter
M. Kalal et al., Fusion Science & Technology V. 43 (2003) 275 - 281

Low density foam targets

a) single layer polystyrene foam targets
b) double layer targets with Al foil attached on the rear side

Foam layer thickness 300 μm - 1000 μm
Foam average densities
10^{-2} g/cm^3 and 2.10^{-2} g/cm^3
Al-foil thickness 5 μm and 2 μm.
Target dimension 2 x 2 mm.



Foam target holder

Basic diagnostics:

T. Pisarzyk's 3-frame interferometer/shadowgraph

Multi-frame laser interferometry/shadowgraphy

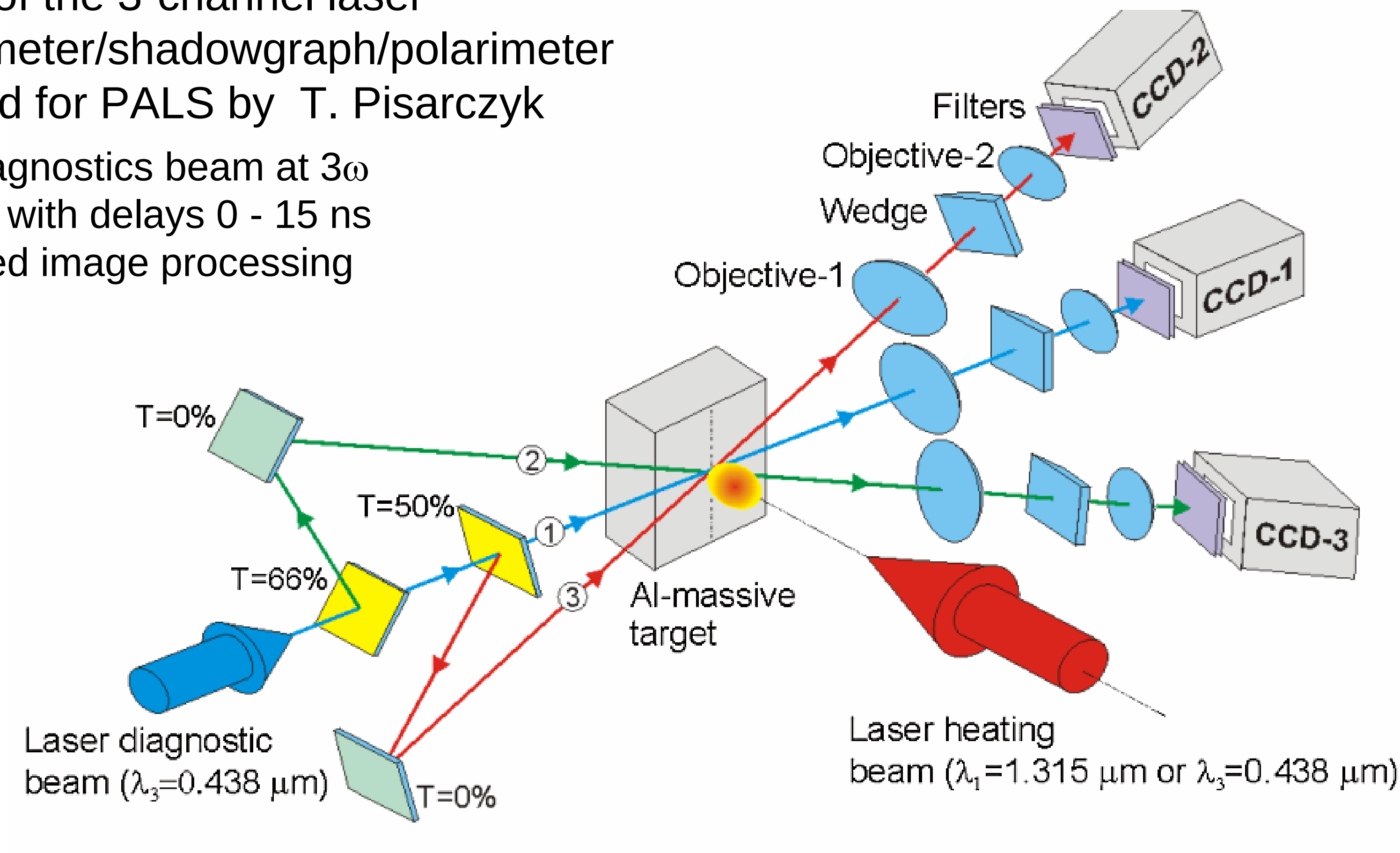
T. Pisarczyk, A. Kasperzcuk, M. Kálal, T. Pisarczyk et. al.

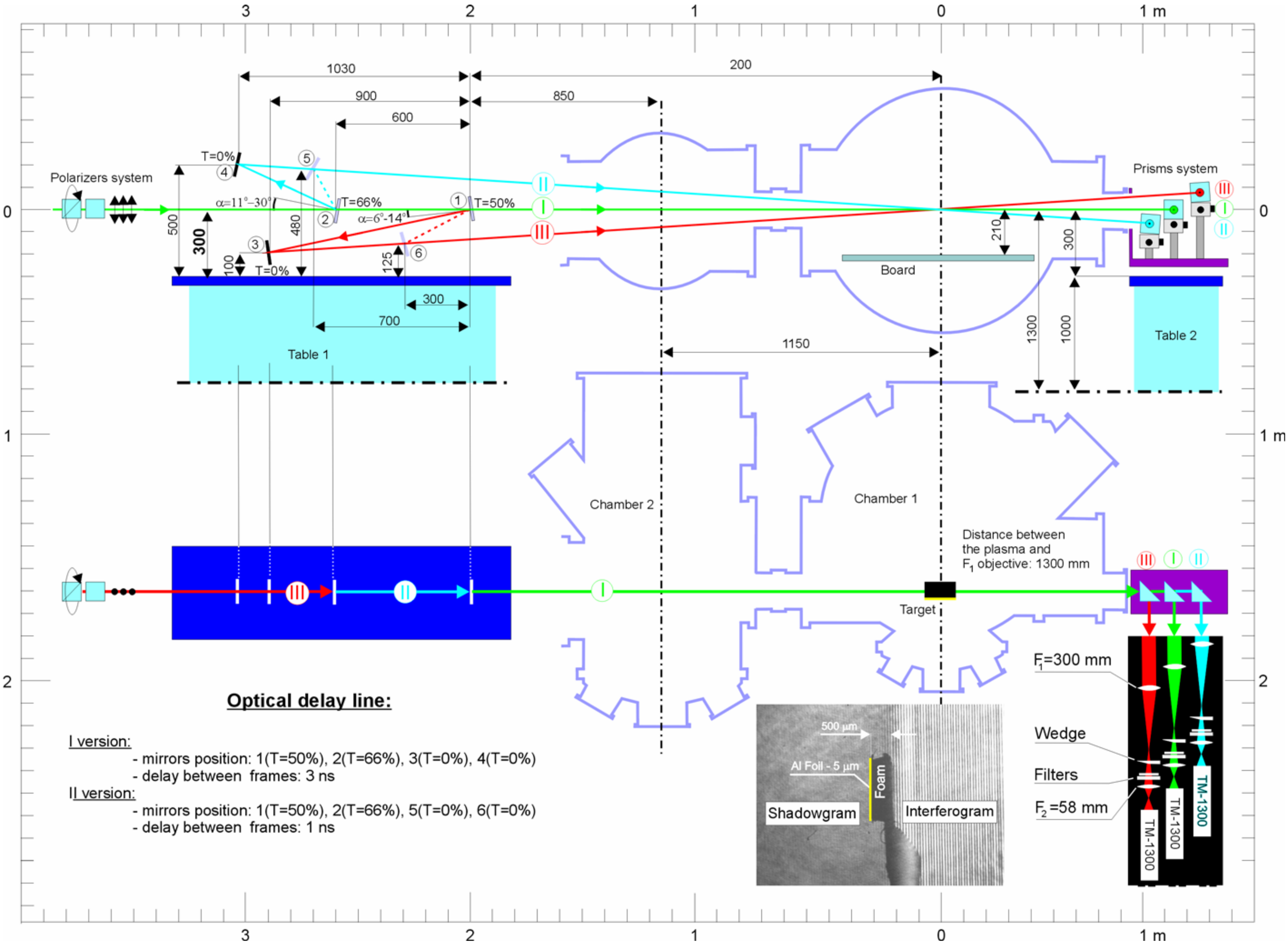
- Polish-Czech co-operation
- Essential contribution to the diagnostics of early stages of the plasma expansion

High-quality interferograms of various expanding plasmas

Scheme of the 3-channel laser interferometer/shadowgraph/polarimeter developed for PALS by T. Pisarczyk

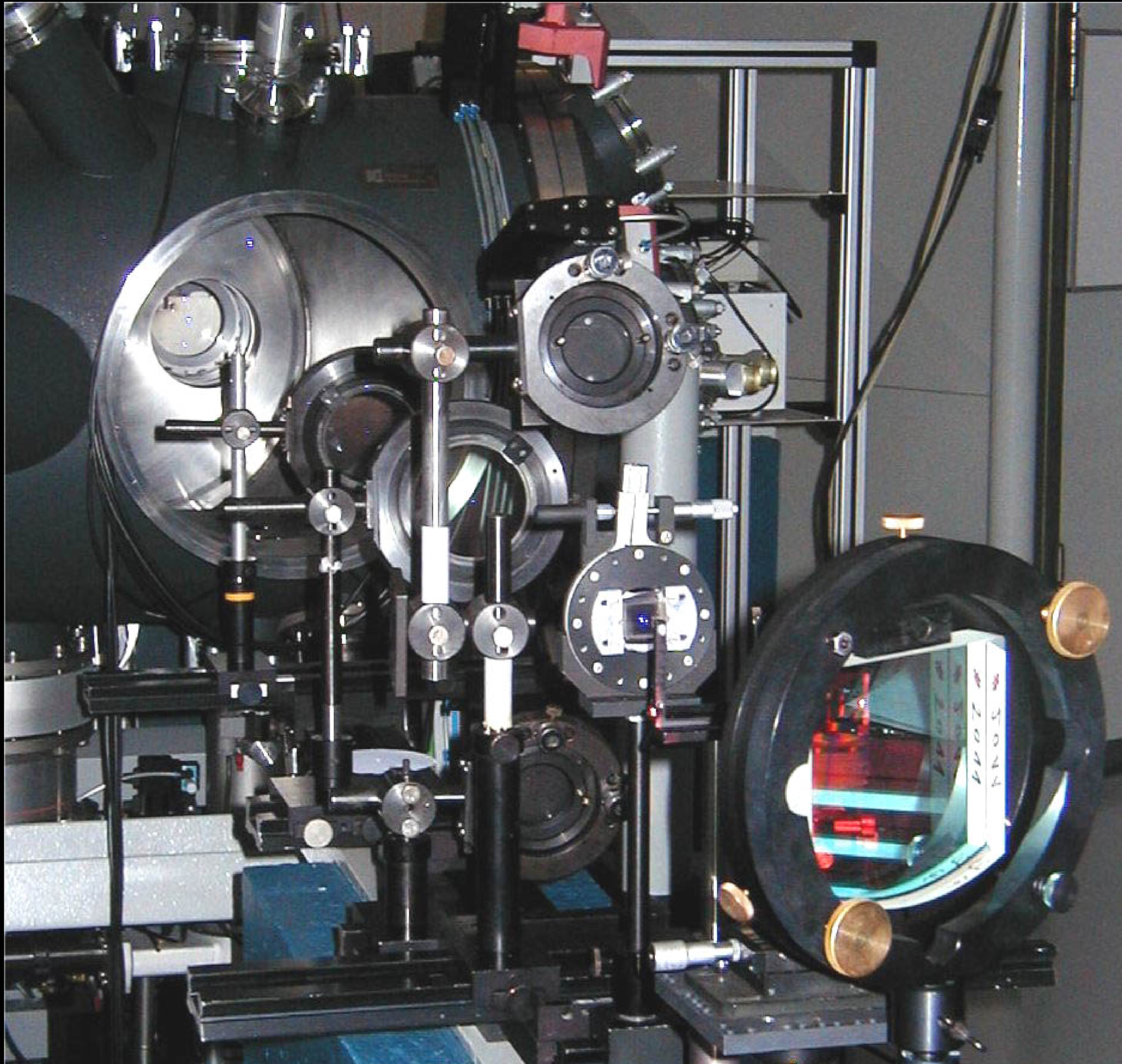
- PALS diagnostics beam at 3ω
- 3 frames with delays 0 - 15 ns
- automated image processing



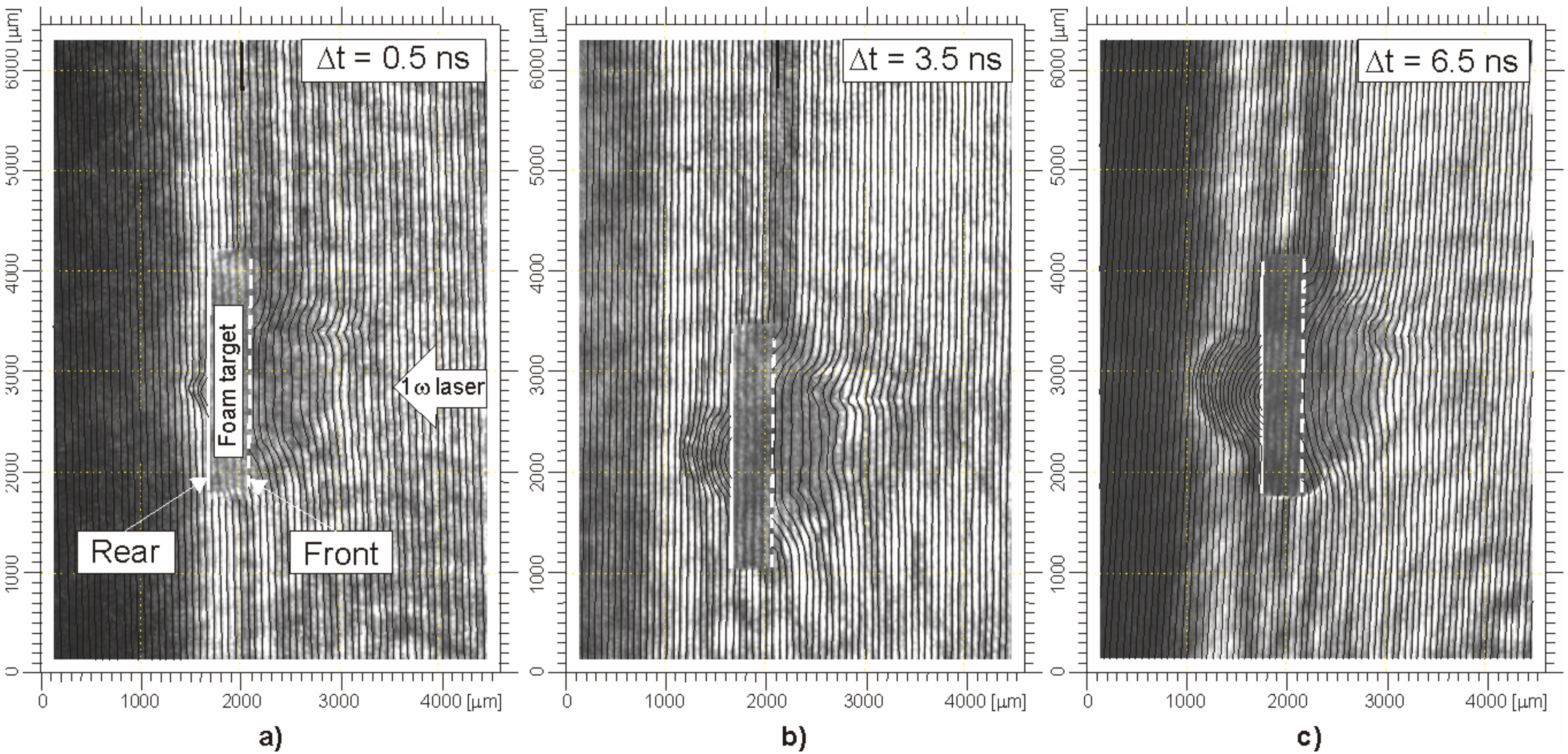


Polarizers system
Prisms system
Table 1
Table 2
Board
Chamber 2
Chamber 1
Target
T=0%
T=66%
T=50%
T=0%
α=11°–30°
α=6°-14°
1030
900
600
200
850
1150
700
300
500
300
480
100
125
210
1300
1000
Distance between
the plasma and
F1 objective: 1300 mm
F1=300 mm
Wedge
Filters
F2 =58 mm
TM-1300
500 μm
Al Foil - 5 μm
Foam
Shadowgram
Interferogram
Optical delay line:
I version:
- mirrors position: 1(T=50%), 2(T=66%), 3(T=0%), 4(T=0%)
- delay between frames: 3 ns
II version:
- mirrors position: 1(T=50%), 2(T=66%), 5(T=0%), 6(T=0%)
- delay between frames: 1 ns

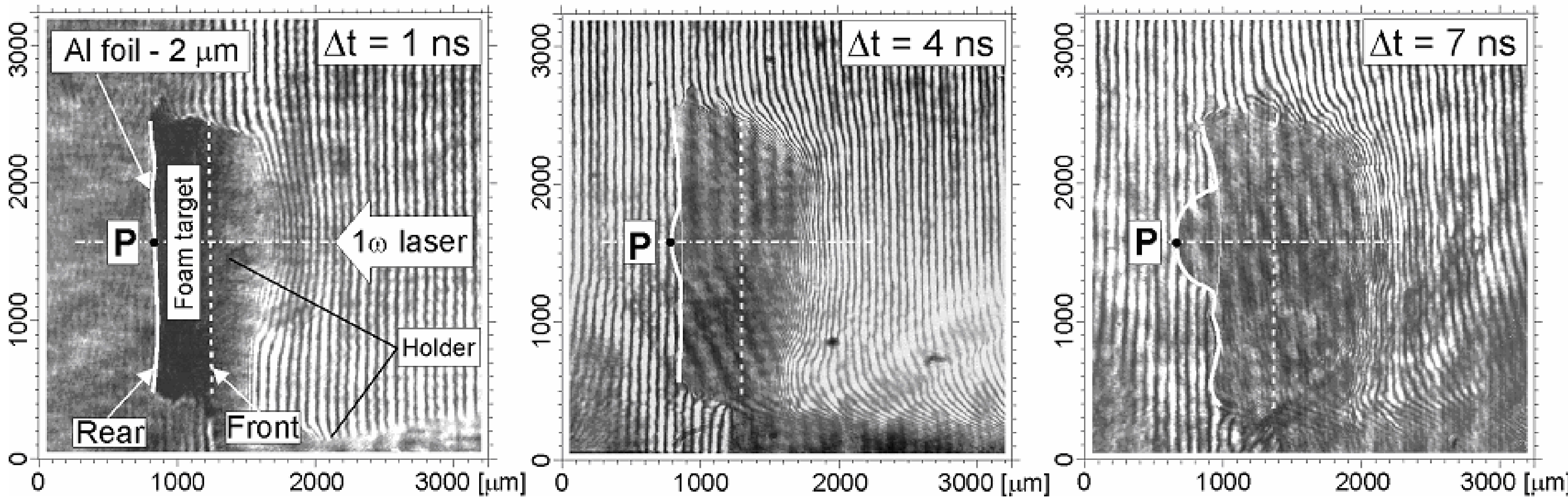

PZO



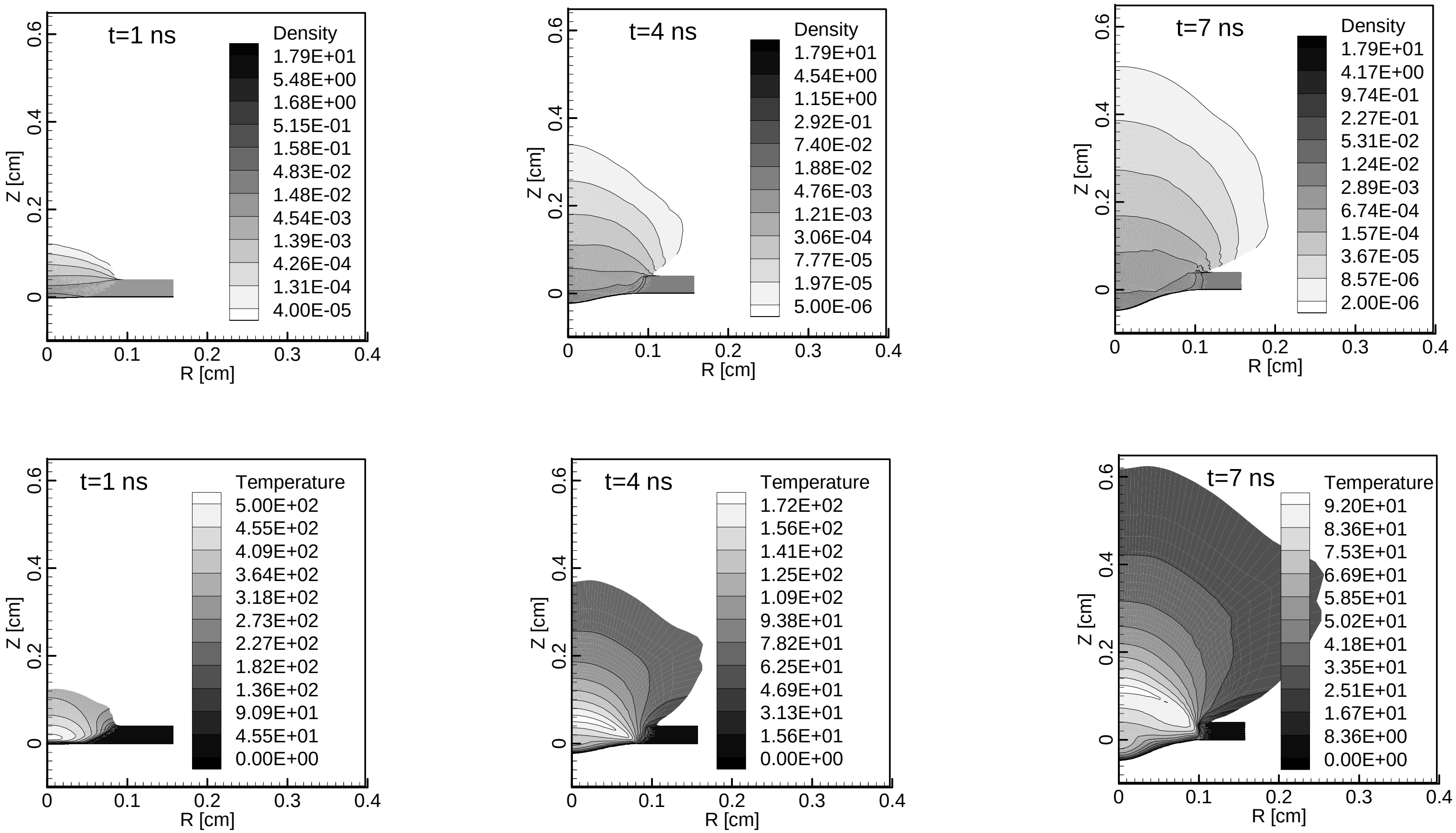
EXAMPLE OF MULTI-FRAME INTERFEROMETER OUTPUT



Interferograms recorded in three consecutive moments of time in experiments with the basic harmonic beam irradiating a single-layer foam target are presented and demonstrate a good symmetry, smooth fringes and absence of any local plasma perturbations at the target rear.



Shot #25030 recorded by the 3-frame polari–interferometric system in time instants 1, 4 and 7 ns after the main laser pulse maximum. Laser energy, intensity, wavelength and beam radius were 173 J, 6.2×10^{14} W/cm^2, 1.32 μm, 150 μm, respectively. Polystyrene foam with $\rho \approx 9$ mg/cm^3 and $D_p \approx 50 - 70$ μm was 400 μm thick and 2 μm thick Al foil was placed at its rear side.



Density (in g/cm^3) and electron temperature (in eV) profiles at times 1, 4 and 7 ns after laser pulse maximum calculated numerically for conditions in previous slide.

ANALYTICAL THEORY AND COMPARISON

The wave of hydrodynamic perturbations in a foam matter is accompanied by gradual destruction of solid elements and their subsequent homogenization.

Such a process of energy transfer can be described by the so-called hydrothermal wave propagating in a homogeneous medium of average foam density with the front velocity close to the sound velocity.

When spherical hydrothermal wave is assumed, the wave front reaches the foam-foil boundary approximately at time:

$$t_f \approx \frac{\Delta^{5/2}}{\left[\frac{3}{2}\cdot\left(\frac{5}{3}\right)^2\cdot\frac{(\gamma-1)\cdot E_{ab}}{\pi\cdot\rho_f}\right]^{1/2}}$$

where Δ, ρ_f , E_{ab}, and γ are the foam layer thickness and foam density, absorbed laser energy and adiabatic constant, respectively.

The maximum velocity of unevaporated solid foil is

$$V_{\max} = \frac{c_s}{\gamma} \cdot \frac{\rho_f \cdot \Delta}{\rho_s \cdot \Delta_s}$$

where ρ_s and Δ_s is the solid foil density and thickness, and

$$c_s = \left[\frac{\gamma(\gamma - 1) \cdot E_{ab}}{\pi \cdot \rho_f \cdot \left(\Delta + R_L\right)^2 \cdot \Delta} \right]^{1/2}$$

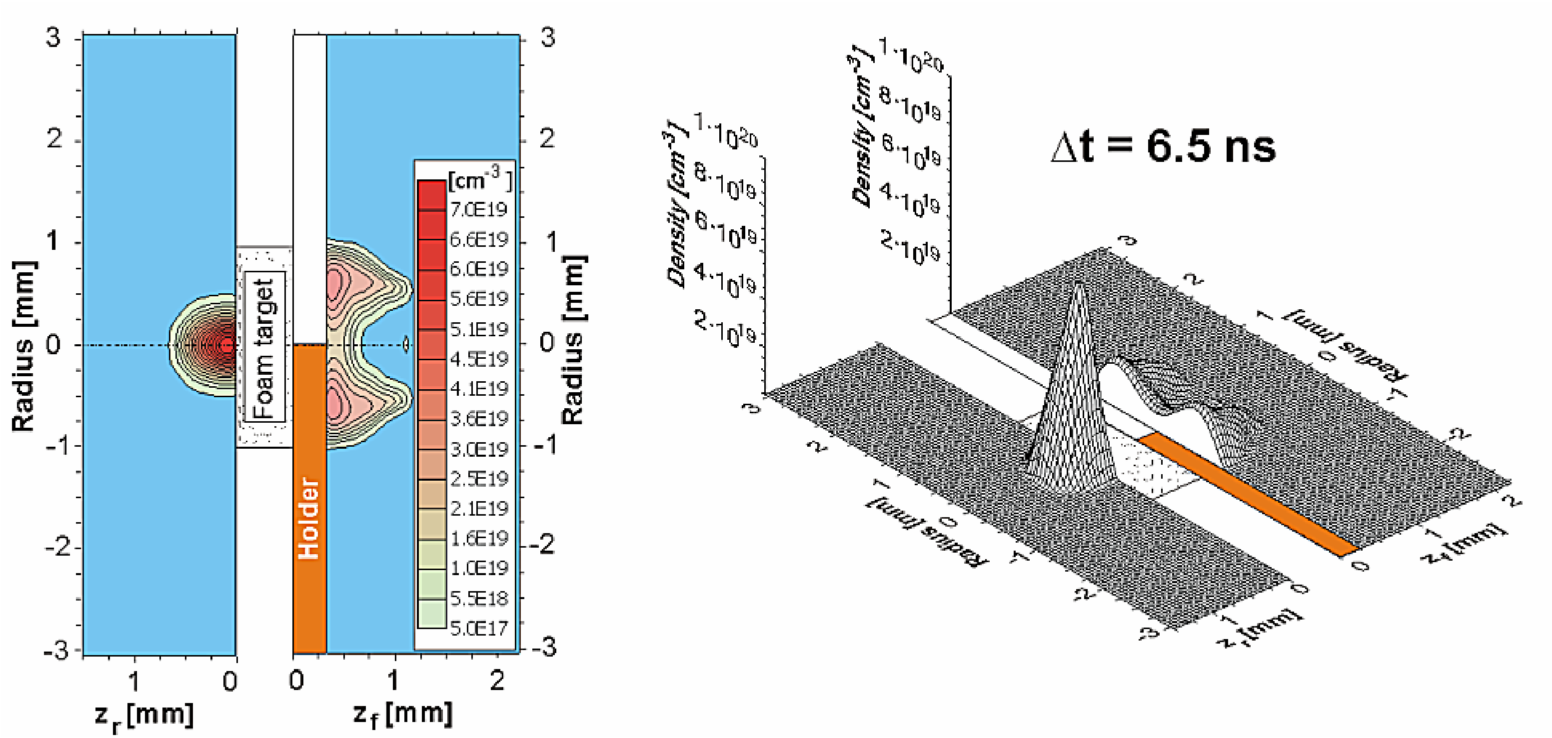
is the sound velocity in the heated foam.

Foil velocities measured in experiment, calculated in simulations and via analytical model are compared in the table:

Laser	**Target**	$\mathbf{v_{exp}}$**(cm/s)**	$\mathbf{v_{simul}}$ **(cm/s)**	$\mathbf{v_{max}}$ **(cm/s)**
92 J	$(CH)_n$	6.0×10^6	4.9×10^6	4.8×10^6
173 J	$(CH)_n$	8.0×10^6	8.2×10^6	6.7×10^6
238 J	$(CH)_n$	------	1.1×10^7	8.2×10^6
238 J	PVA	1.4×10^7	3.5×10^7	1.32×10^7

$(CH)_n$ is polystyrene foam with 2 μm Al foil and PVA is 100 μm thick PVA foam of density 5 mg/cm^3 with 0.8 μm Al foil. Experimental and simulation velocities are represented by their average values in the interval 4–7 ns after the laser maximum.

FOAM targets - experimental results

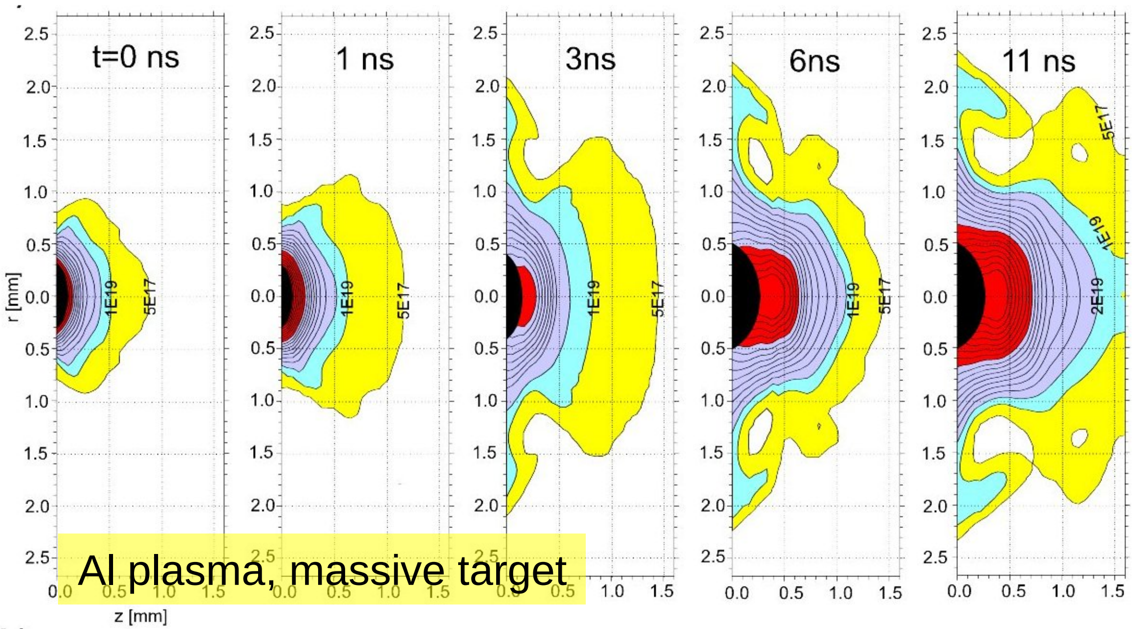


Example of a processed interferogram

Main observations:

- Effective acceleration of thin solid foils up to (2-8)·10^7 cm/s
- Efficiency of the laser light absorption in foam absorber exceeds 50 %.
- Velocity of the fast energy smoothing process estimated to (2-5)·10^7 cm/s
- => Mbar-pressure generation

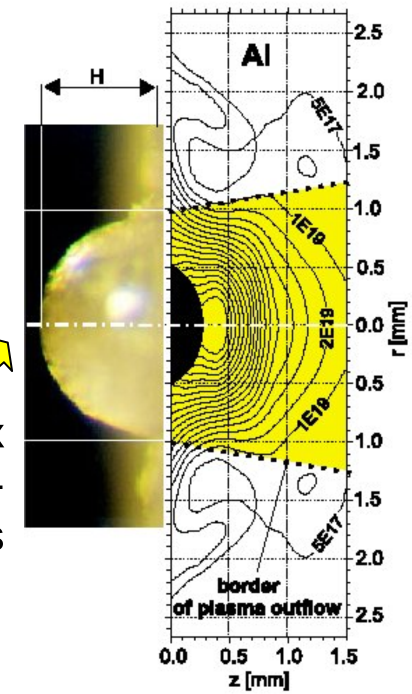
Investigation of plasma dynamics & crater formation



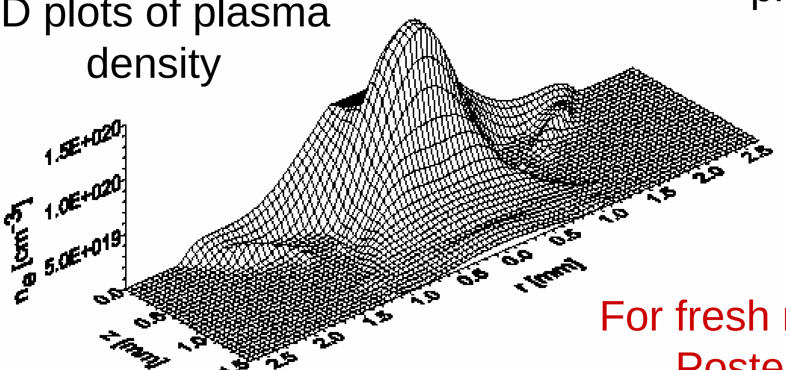
Reconstructed equidensity contour plots at various stages of plasma expansion

Shot-to-shot measurements confirm high-reproducibility of the PALS beam

Microphotos of wax replicas of laser-produced craters



3D plots of plasma density

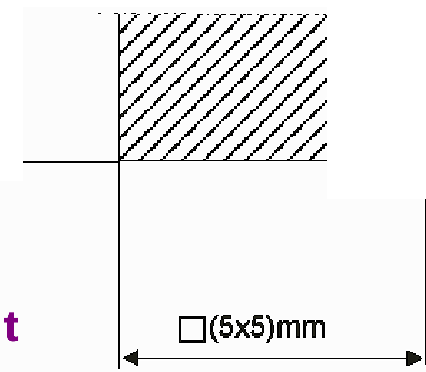


For fresh results see Poster P 4-6

Plasma outflow from the laser-produced craters. Fast and slow plasma components

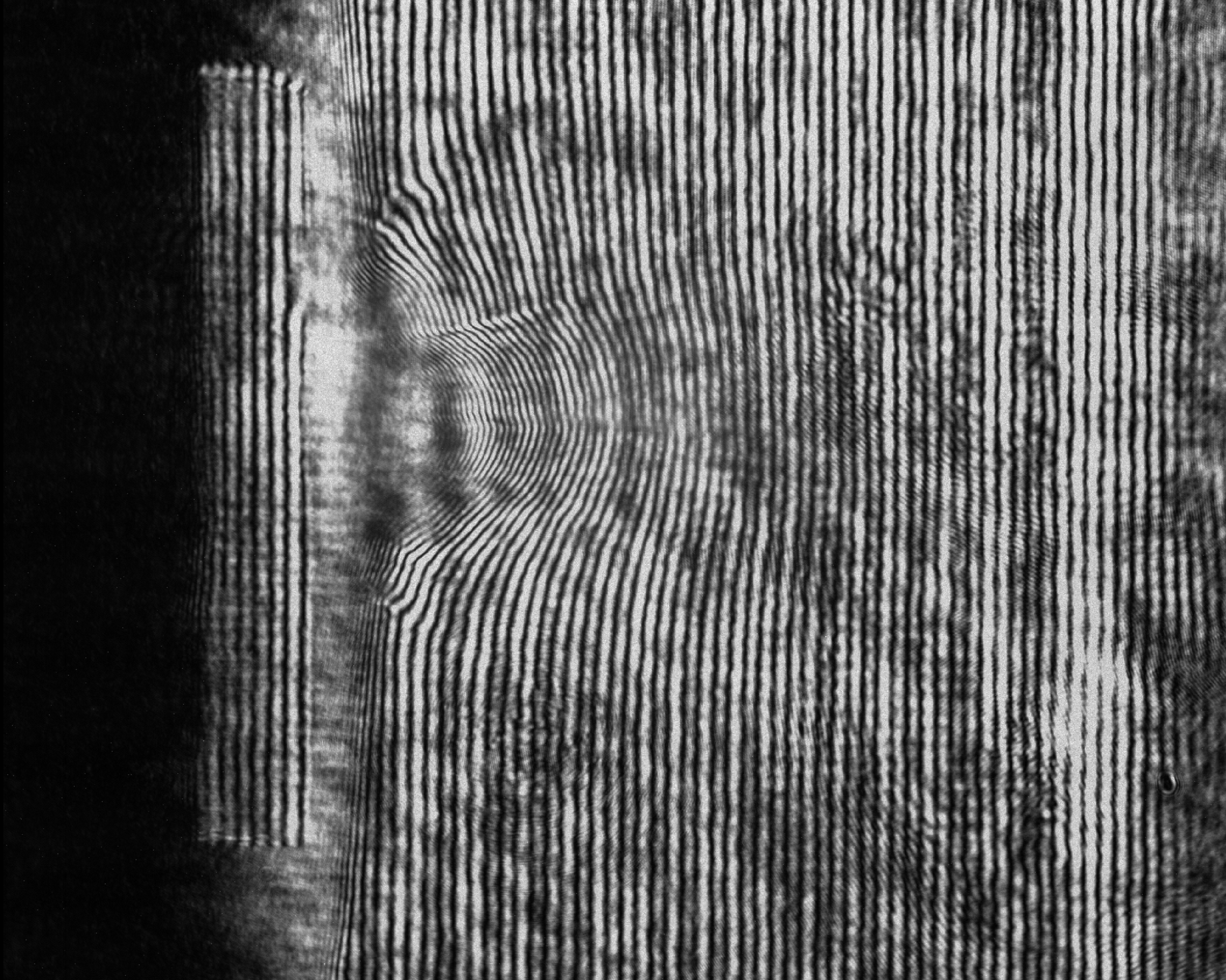
Double target holder for interferometric and shadowgraphic measurements of foil & disc acceleration

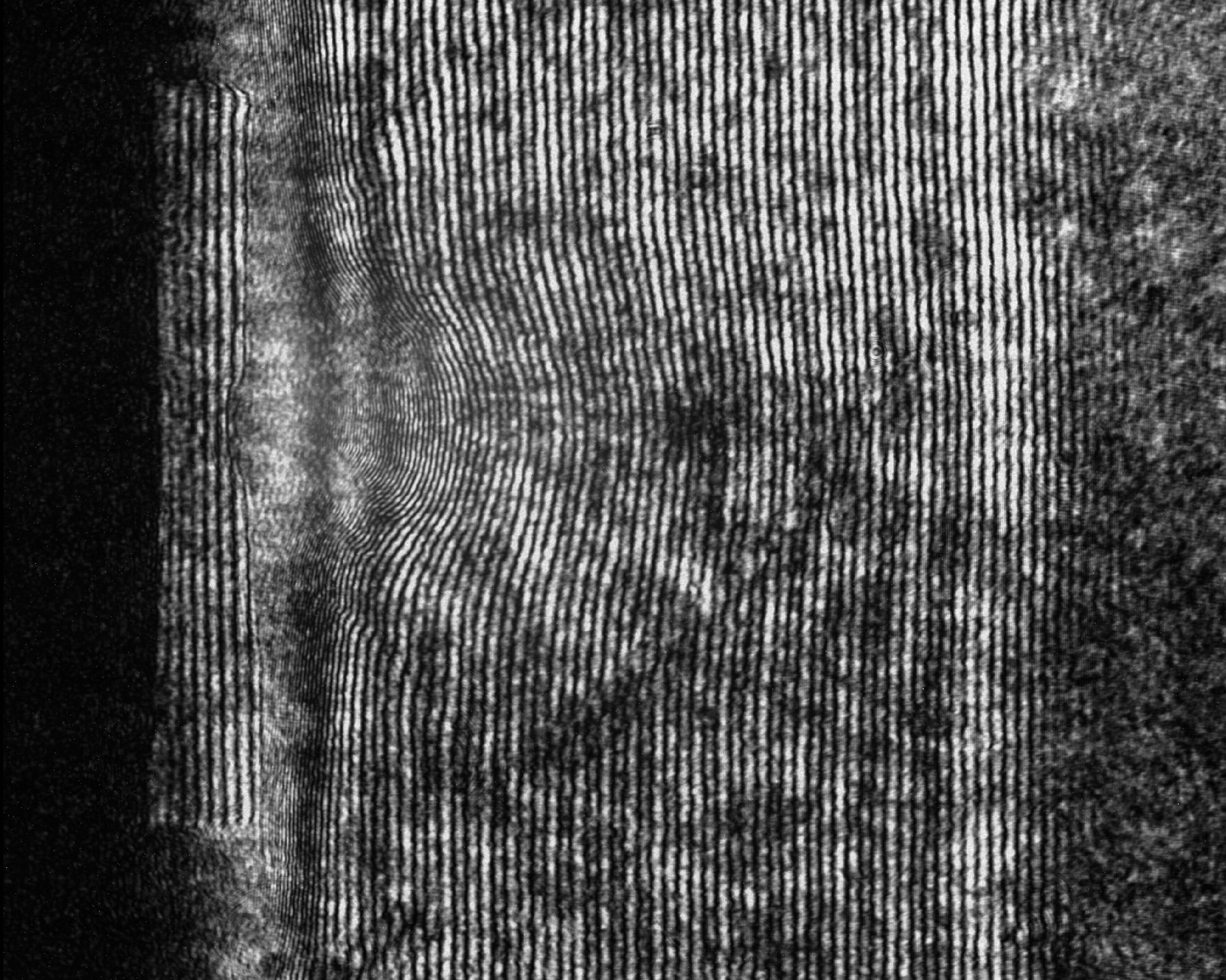
The space both in front of and behind the foil target available for diagnostics

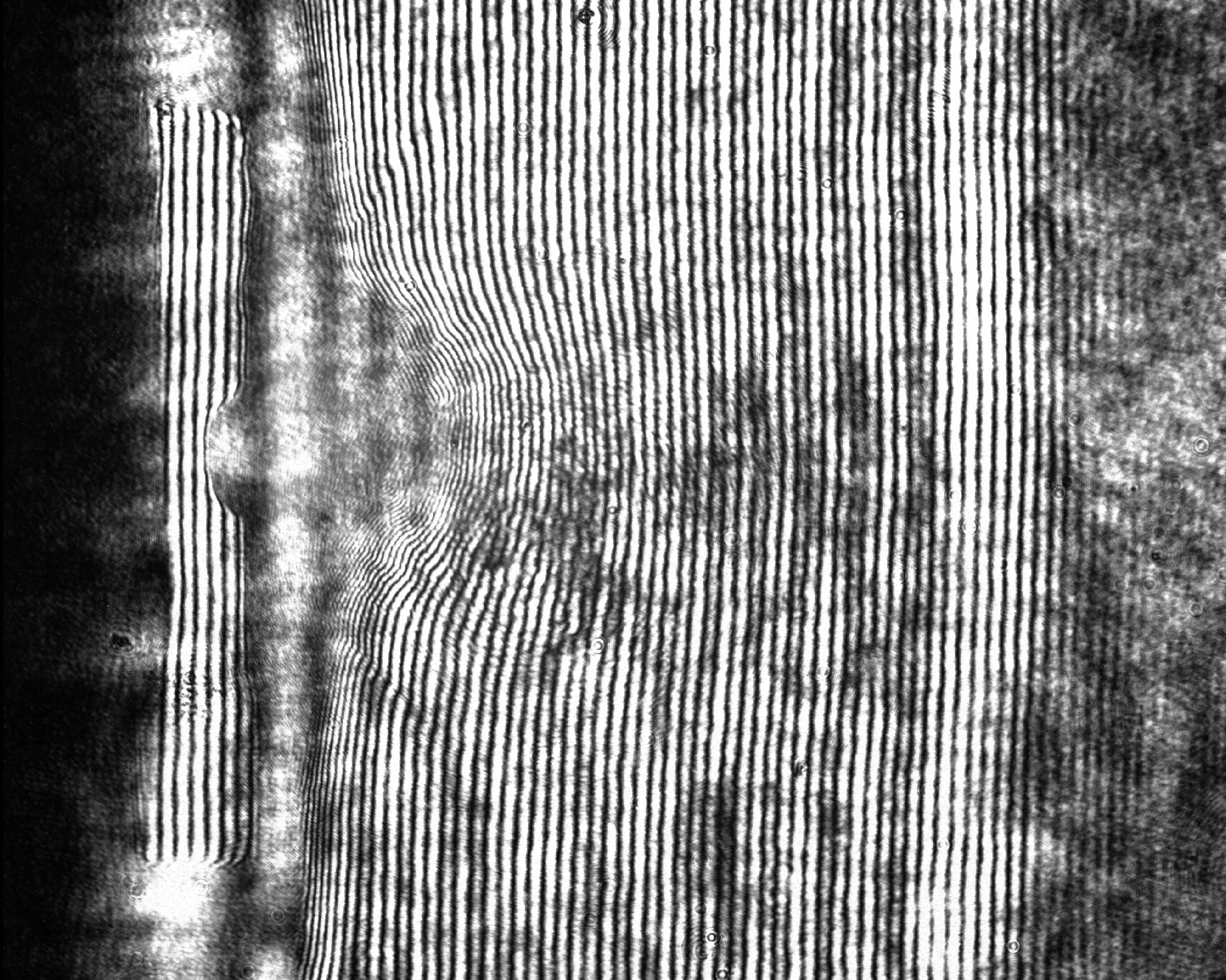


Single foil arrangement

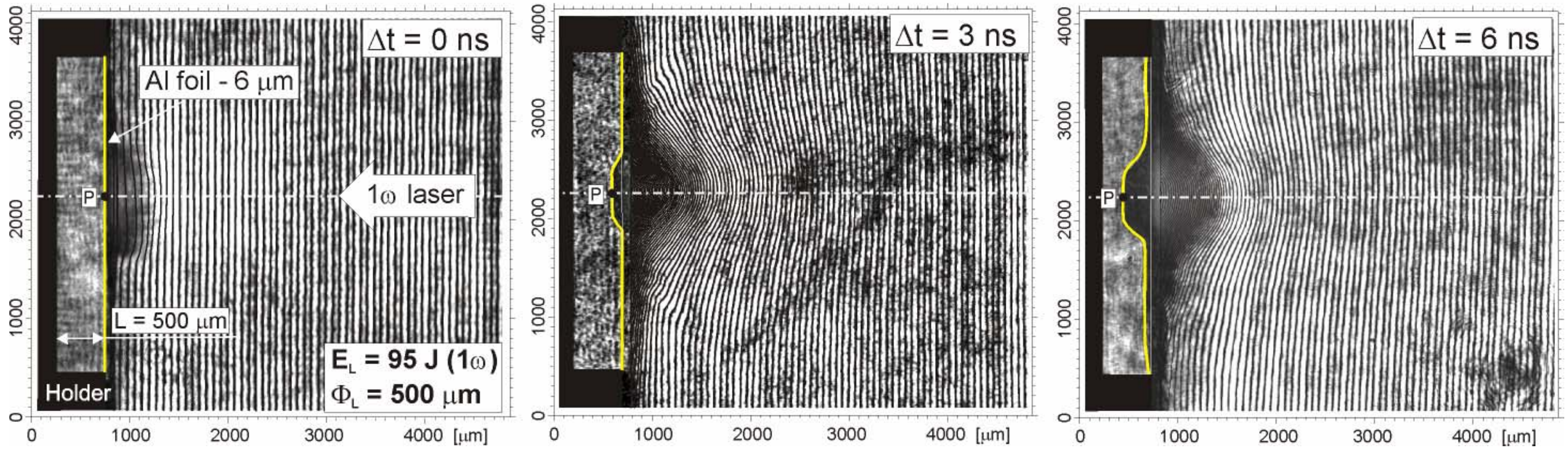
Mylar foil with an attached disc



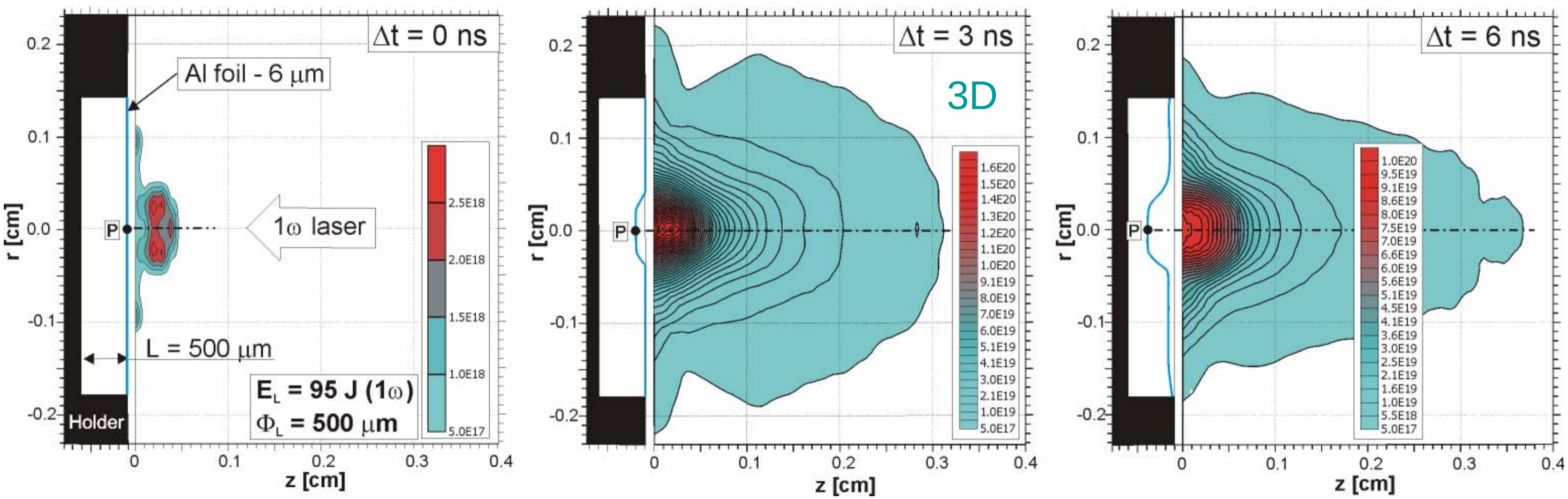




Fresh results on foam & disc acceleration I



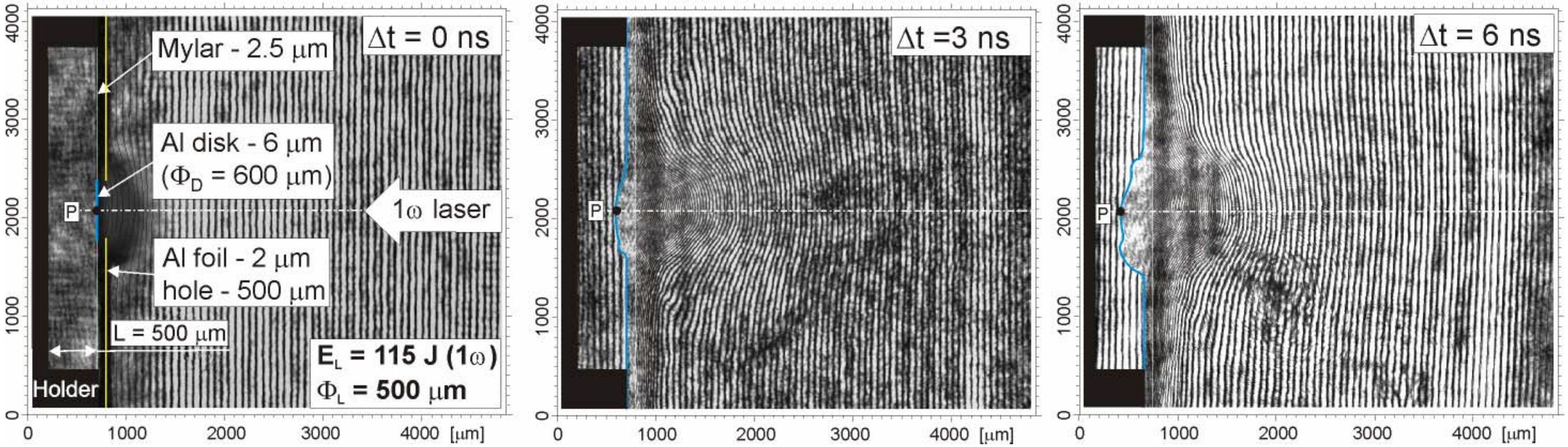
Time sequence of interferograms/shadowgrams of the accelerated Al foil



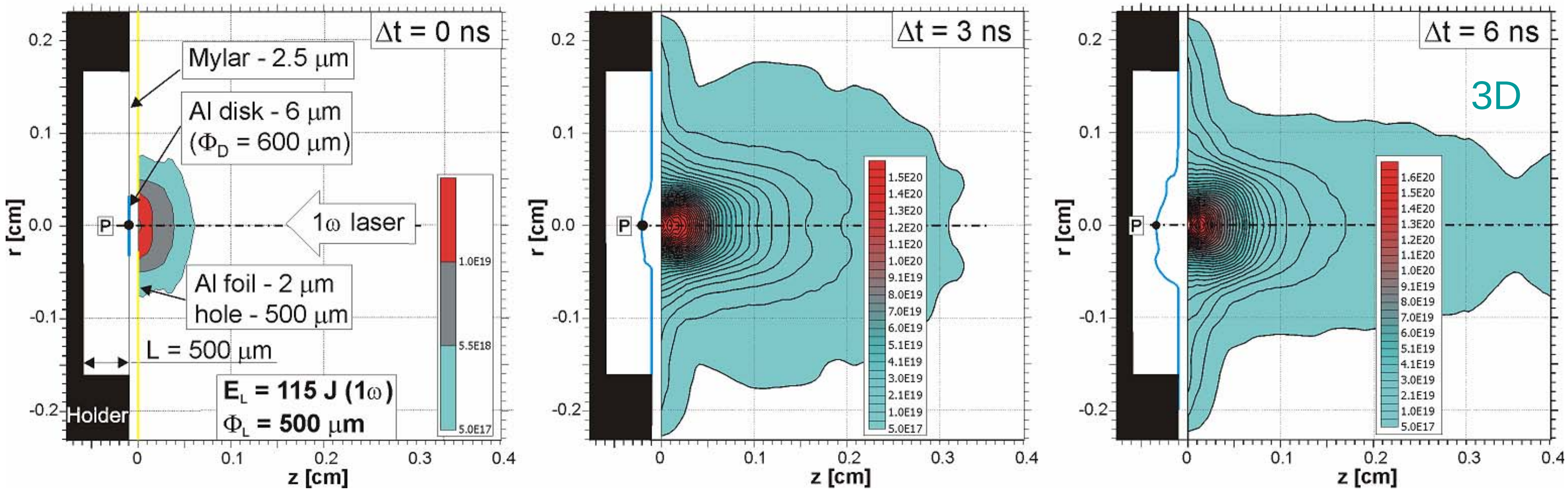
The processed densitograms/contourgrams (by courtesy of T. Pisarczyk)

The foil velocity at the central point P: $3.5 \cdot 10^6$ cm/s $6.2 \cdot 10^6$ cm/s

Fresh results on foam & disc acceleration II



Time sequence of interferograms/shadowgrams of the accelerated Al disc



The processed densitograms/contourgrams (T. Pisarczyk)

The disc velocity at the central point P: $3.3\cdot10^{6}$ cm/s $4.2\cdot10^{6}$ cm/s


X. VŠEJADERNÁ FÚZ


X. VŠEJADERN


su.fjfi.cvut.cz