Plasma streams generation and macroparticle acceleration for ICF and astrophysics

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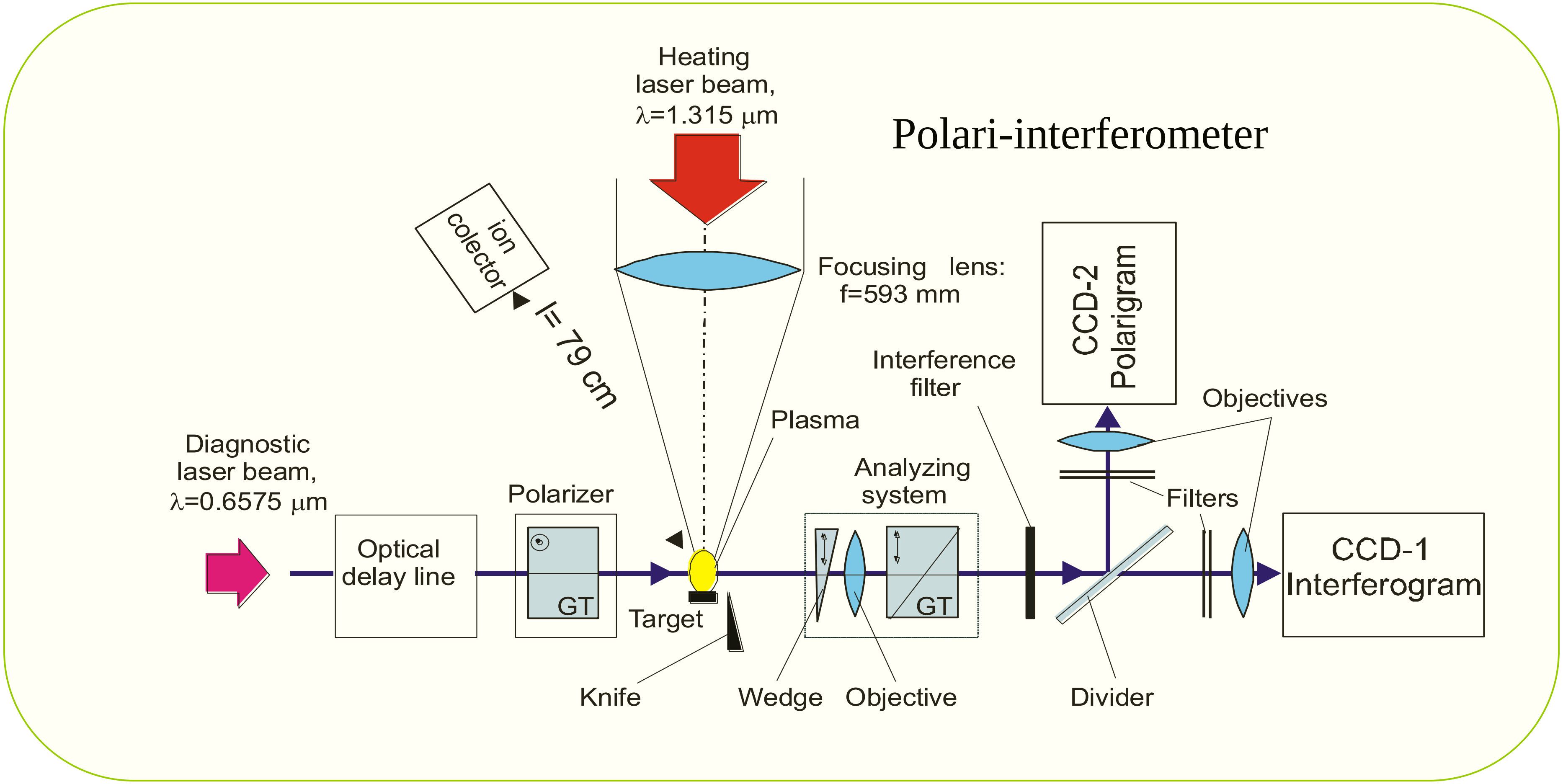
Outline

- Our history of the PALS produced plasma investigations:
  - the first interferometric system instalated at PALS and the first results (2001),
  - the development and the improvement of the interferometric system (2001-2010),
  - realization of different laser-matter interaction experiments at PALS (2001-2010)
- Review of the main experiments and achivement:
  - smoothing of laser radiation by fome layer,
  - investigation of mechanisms of laser radiation absorbtion,
  - acceleration of planar flyer targets (foils and disks),
  - interactions of flyers with massive targets,
  - elaboration of the novel very simple method of the plasma jet generation ,
  - verification of other methods of the plasma jet formation
  - investigations of the plasma jet interaction with different media
- Summary.

Our history of
the PALS produced plasma
investigations:

The first interferometric system instalated on PALS and the first result - 2001

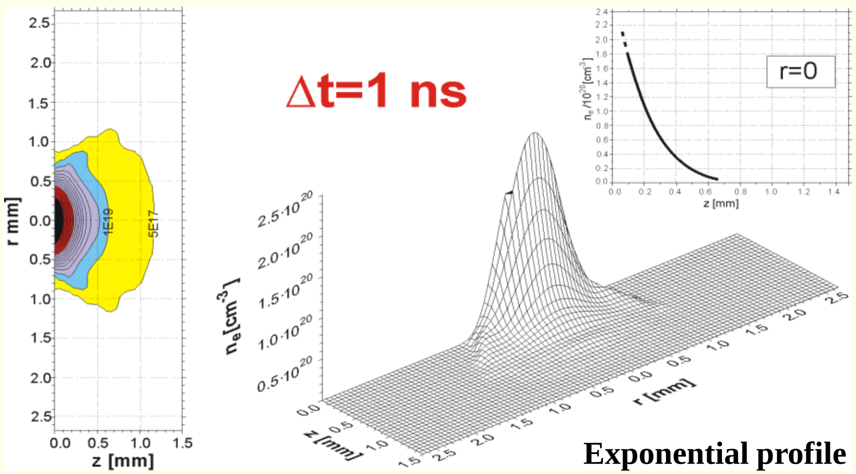


- The plasma was generated by iodine laser (from planar solid Al and Mo targets).
- Two laser energies of E=100 J and 600 J (τ=400 ps) were used.
- For acqusition of images CCD cameras of Pulnix TM-1300 type (1300x1300 pixels) with frame-grabber card (Matrox Meter-II/Multichannel) were applied.

The first interferometric system instalated on PALS and the first result - 2001

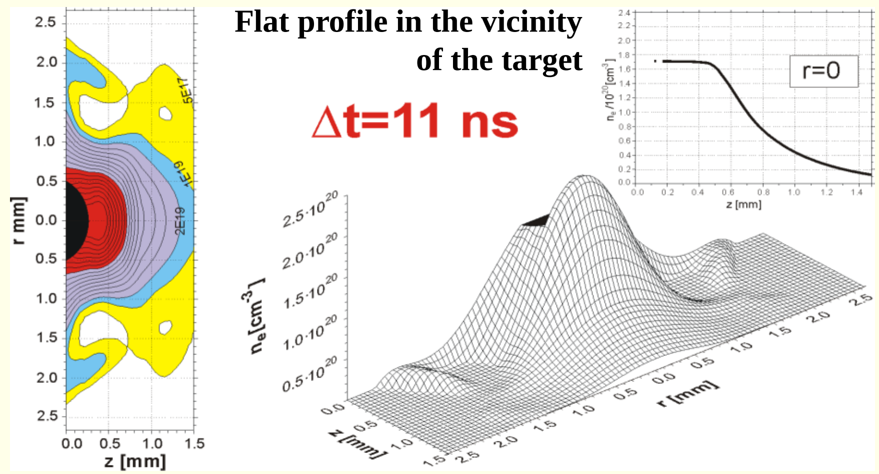
The analysis of interferometric results allowed us to distinguish:

Fast component ($V_z \cong 10^8$ cm/s)



Thermal plasma as a results of the target material ablation.

Slow component ($V_z \cong 10^7$ cm/s)



Secondary phenomena, such as shock wave, thermal conductivity, and XUV radiation

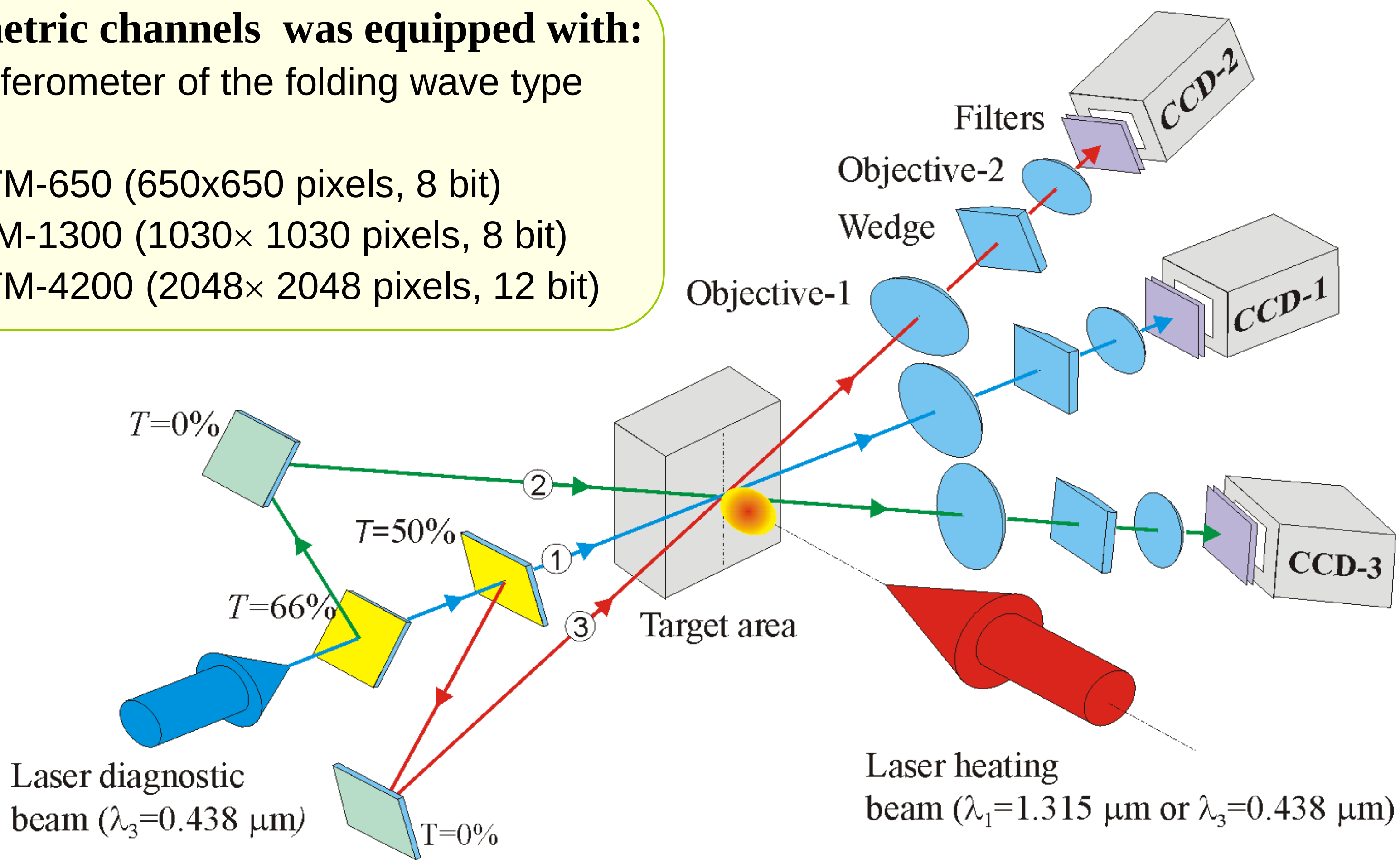
1. A. Kasperczuk, T. Pisarczyk, B. Kralikova, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, J. Ullschmied, M. Kalal, and P. Pisarczyk. **Czechoslovak J. Phys**.. **51**(3): 395-404, 2001.
2. T. Pisarczyk, J. Badziak, A. Kasperczuk, P. Parys, J. Wołowski, Woryna, K. Jungwirth, B. Kralikova, J. Krasa, L. Laska, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, J. Ullschmied, M. Kalal,and P. Pisarczyk**. Czechoslovak J. Phys**. **52**(Suppl. D): 310-317, 2002. Proc. 20th Symposium on Plasma Physics and Technology, Prague, Czech Republic, June 2002.

The development and the improvement of the interferometric system (2001-2010)

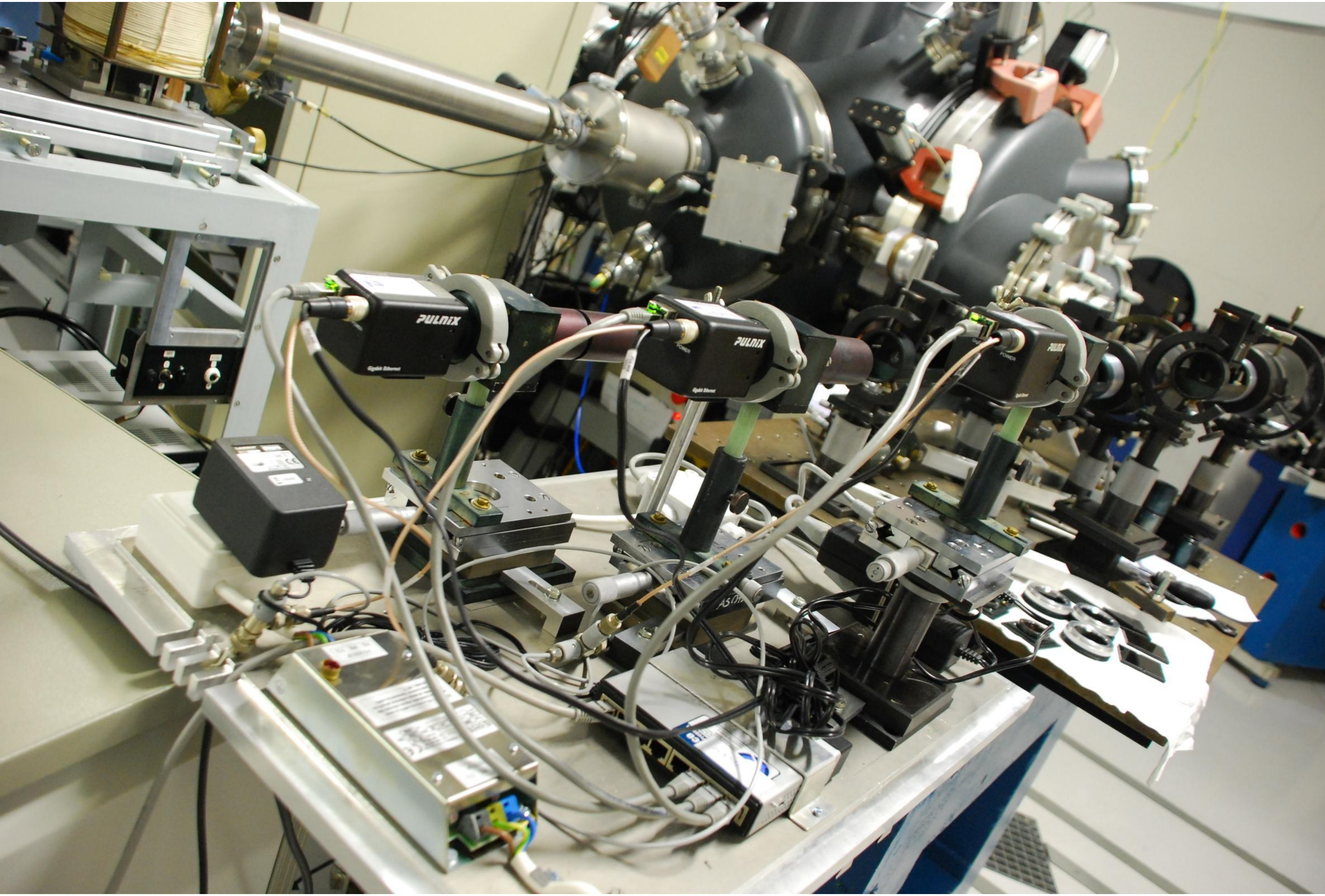
Each of inferferometric channels was equipped with:

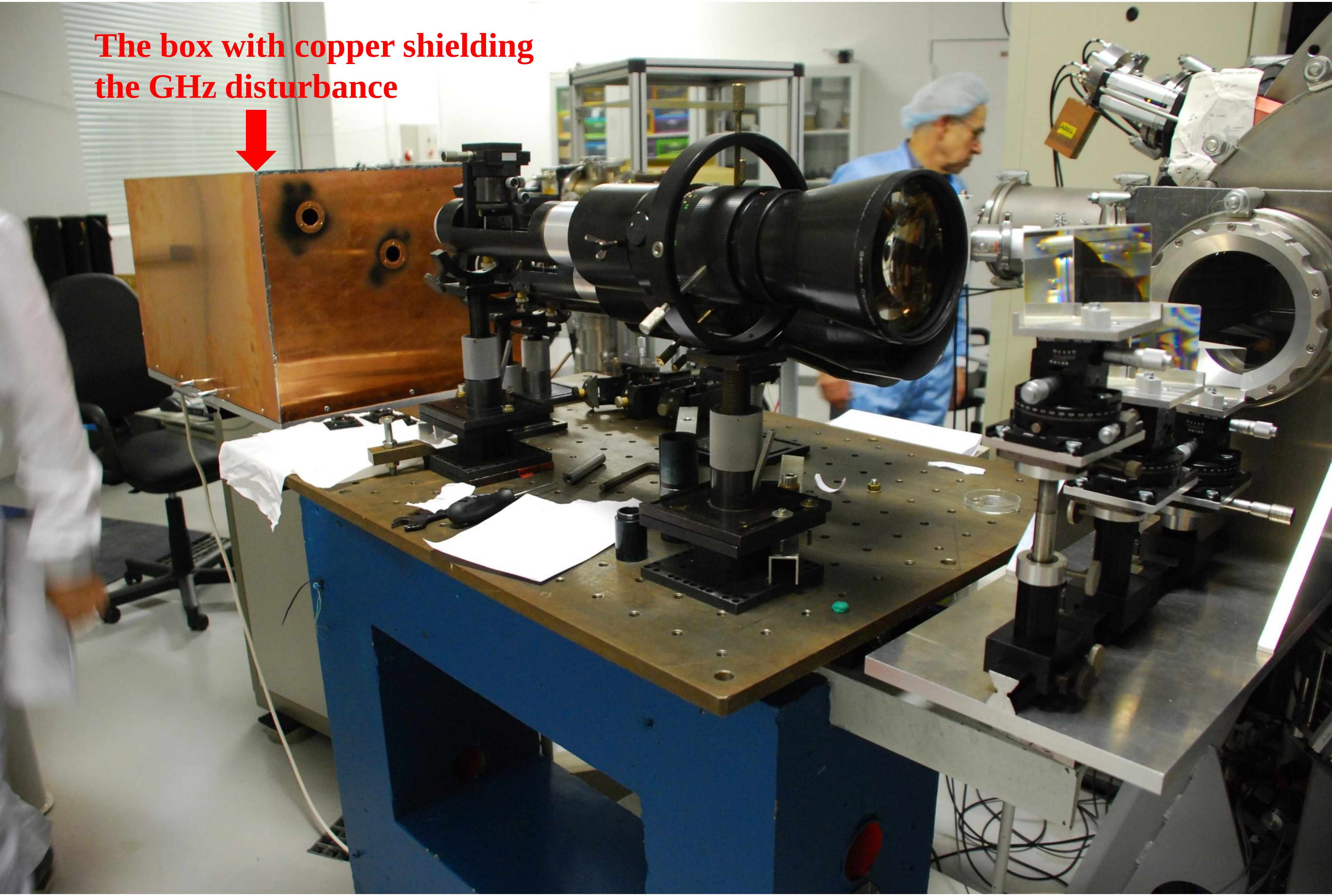
- independent interferometer of the folding wave type
- CCD camera:
  - **2001:** Pulnix TM-650 (650x650 pixels, 8 bit)
  - **2003:** Pulnix TM-1300 (1030× 1030 pixels, 8 bit)
  - **2008:** Pulnix TM-4200 (2048× 2048 pixels, 12 bit)

3-frames interferometric system



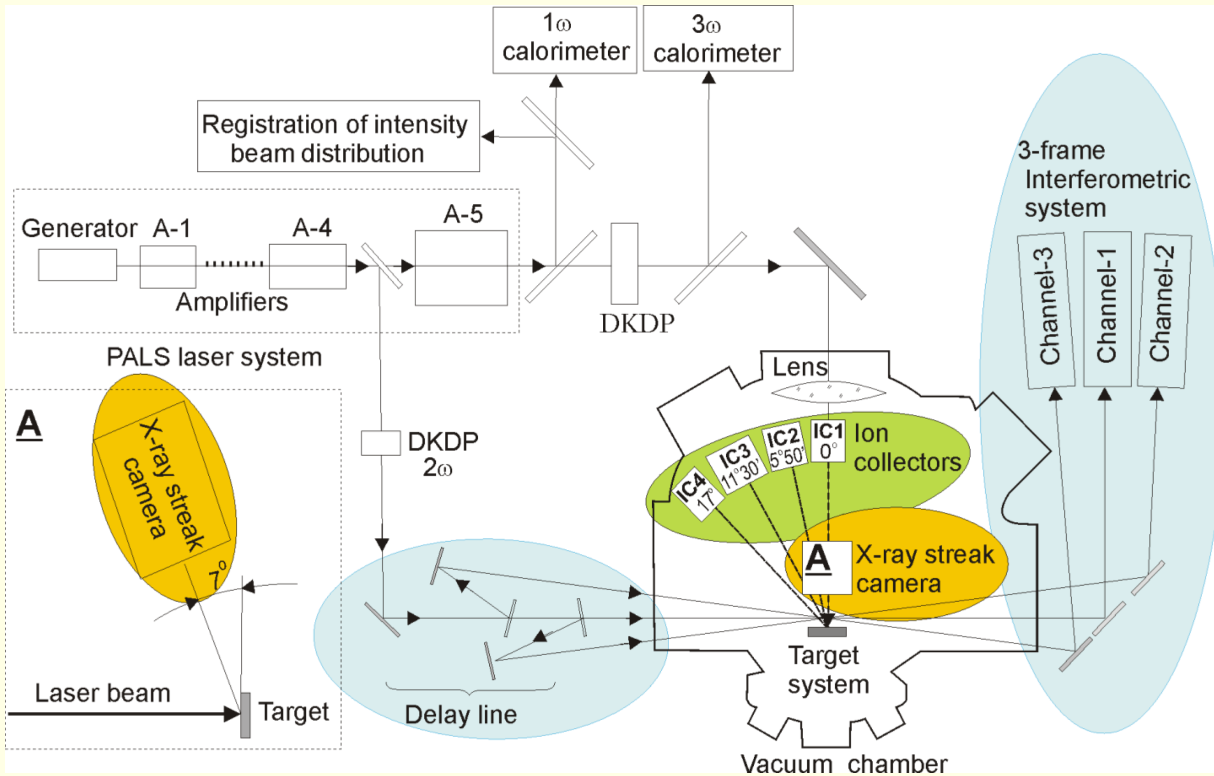
- The delay between subsequent frames was set to 3 ns, so the interferometric measurement during a single shot covered a period of 6 ns.


PULNiX
PULNiX
PULNiX


The box with copper shielding
the GHz disturbance

The realization of different laser-matter interaction experiments at PALS (2001-2010)

Location of the optical and x-ray diagnostics in the experimental set-up



Diagnostics:

- **3-frame interferometric system (main diagnostic**)
- X-ray strek camera,
- ion collectors

- X-ray pinchole camera
-4-frame x-ray pinchole camera
- measurement parameters of cretares

Team realizing the invetstigations:

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Team realizing the invetstigations:

Preparation of investigations on PALS:

J. Ullschmied, K. Rohlena, J. Skala, A. Tumova T. Pisarczyk, A. Kasperczuk, S. Borodziuk, J. Limpouch

Organizing of the visit on PALS, the preparation of the PALS laser, the meritorious preparation of the planed experiments.

Interferometric measurements:

T. Chodukowski, A. Kasperczuk, Kalal, P. Pisarczyk, T. Pisarczyk

Preparation of experiments, performation of measurements, treatment of interferograms, interpretation and analize of experimental rezults.

X-ray measurements:

E. Krousky, D. Klier, P. Kubes, J. Kravarik, K. Masek, M. Pfeifer

Preparation and performation of measurements, treatment of date, interpretation and analize of experimental rezults.

Ion measurements:

J. Badziak, J. Krasa, L. Laska,, P. Parys, M. Pfeifer, M. Rosiński, K. Rohlena, J. Wołowski, E. Woryna

Preparation and performation of measurements, treatment of date, interpretation and analize of experimental rezults.

Team realizing the invetstigations:

<u>Theoretical support :</u>

N. N. Demchenko, S. Yu. Guskov, Ph. Nicolai, V. Tikhonchuk

Analitical modeling of the performed experiments, the numerical simulation of experimental results, interpretation and analize of experimental date

<u>Technical supprt :</u>

D. Baran., J. Kovacz et al., J. Król, J. Pietrzak J. Pokorska H. Włodarczyk

Preparation of targets, measurements of the crates parameters, preparation and instalation of the diagnostics apparatus

Review of
the main experiments
and achivements:

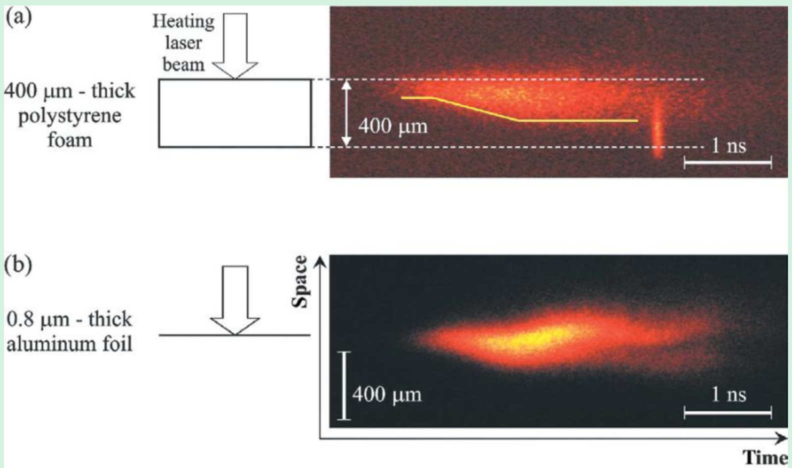
Smoothing of laser radiation by fome layer

The goal of experiment: to study energy transport through the low-density porous matter and to demonstrate a sufficient efficiency of thin foil acceleration together with substantial smoothing effect of the low-density foam absorber.

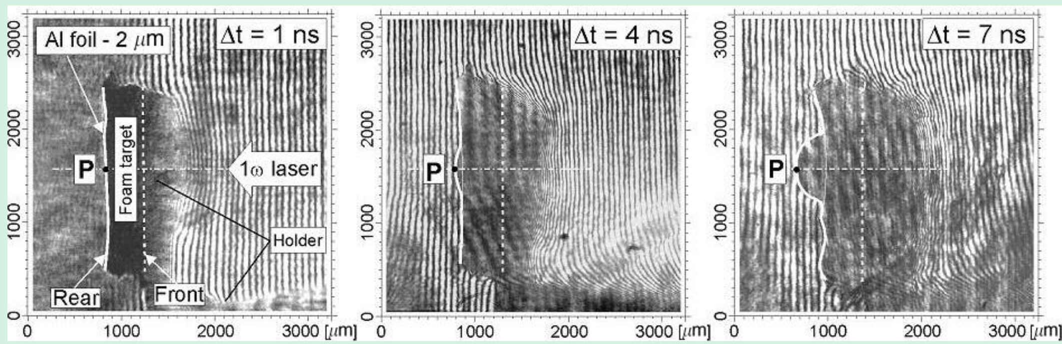
Foam type: polysterene (ρ=8–30 mg/cm^3, $D_p \approx 5$–$70\ \mu m$), *polyvinylalcohol (PVA)* ($\rho \approx 5 mg/cm^3$, $D_p \approx 5 \mu m$)

Foam illumination: $E_{L,\,max}$ = 600 J (λ_1=1.32 μm), $R_L \approx 150\ \mu m$, ($I \approx 10^{14}$ -10^{15} Wcm^{-2})

X-ray emission recorded by a KENTECH



Interferometric results



The experimental results are in good agreement with two-dimensional hydrodynamic calculations (code ATLANT-HE)

Important publications:

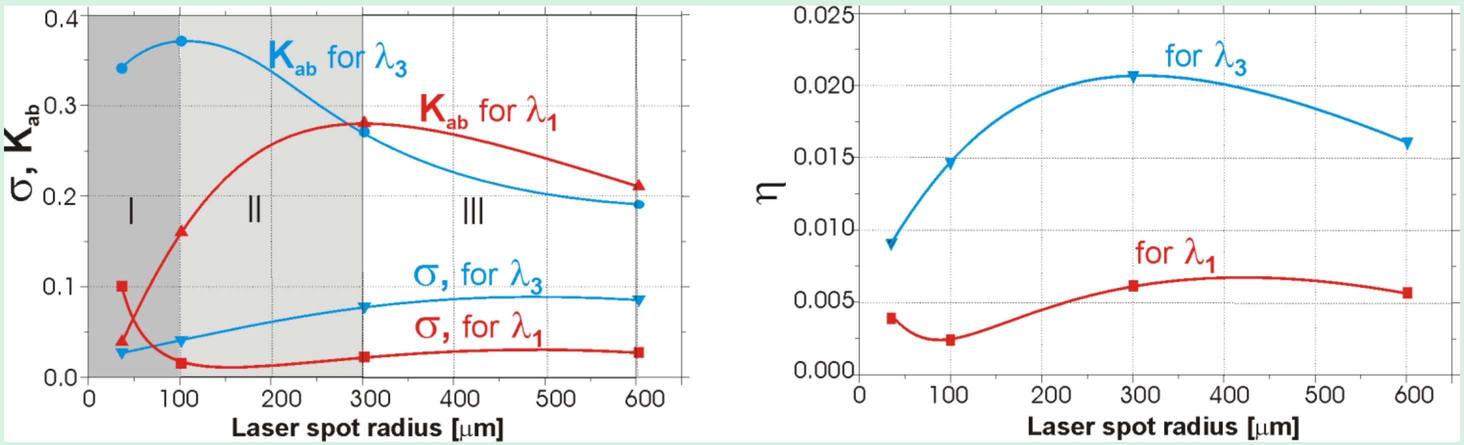
1. M. Kalal, J. Limpouch, E. Krousky, K. Masek, K. Rohlena, P. Straka, J. Ullschmied, A. Kasperczuk, T. Pisarczyk, S. Yu. Gus'kov, A. I. Gromov, V. B. Rozanov, and V. N. Kondrashov: **Fusion Science and Technology**, **43**(3): 275-281, 2003.
2. J. Limpouch, N.N. Demchenko, S.Yu. Guskov, M. Kalal, A. Kasperczuk, V.N. Kondrashov, E. Krousky, K. Masek, P. Pisarczyk, T. Pisarczyk, and V.B. Rozanov: **Plasma Physic and Controled Fusion 46**,1831 – 1841, 2004.
3. J. Limpouch, N. N. Demchenko, S. Yu. Gus'kov, A. I. Gromov, M. Kalal, A. Kasperczuk, V. N. Kondrashov, E. Krousky, K. Masek, M. Pfeifer, P. Pisarczyk, T. Pisarczyk, K. Rohlena, V. B. Rozanov, M. Sinor, and J. Ullschmied:. **Laser and Particle Beams 23**, 321-325, 2005.

Investigation of mechanisms of laser radiation absorbtion

Experimental conditions: I= 10^{13}–10^{15} W/cm^2 (for λ_1=438 nm and λ_3=1315 nm), R_L=35 - 600 μm, Al. target
Diagnostis: optical microscopy and interferometry.

For explanation of the experimental results the **2D analitical model (by Guskov)** was applied..

Laser energy absorption coefficient (k_{ab}), ablation loading efficiency (σ) and efficiency of laser driven loading (η), for both wavelength vs. laser spot radius R_L



I – the resonance absorption, III - the inverse bremsstrahlung, II - combination of the both mechanisms

Important publications:

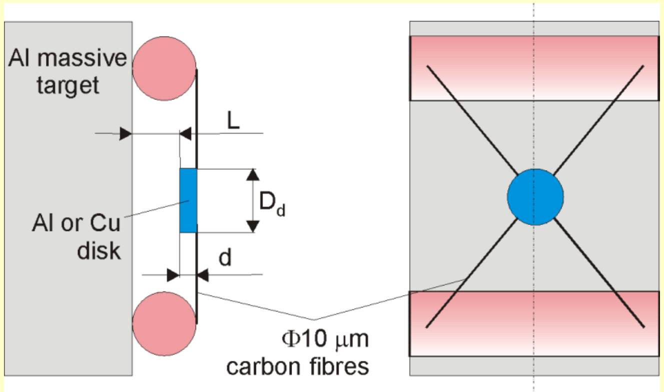
S. Borodziuk, Ya. Doskach, S. Gus'kov, K. Jungwirth, M. Kalal, A. Kasperczuk, B Kralikova, E. Krousky, J. Limpouch, K. Masek, M. Pfeifer, P. Pisarczyk, T. Pisarczyk, K. Rohlena, V. Rozanov, J. Skala, J. Ullschmied: Nukleonika, 49(1): 7-14, 2004.

S. Borodziuk, A. Kasperczuk, T. Pisarczyk, S. Gus'kov, J. Ullschmied, B. Kralikova, K. Rohlena, J. Skala, M. Kalal, P. Pisarczyk: Optica Applicata 34 (1) : 31-42, 2004.

S. Gus'kov, S. Borodziuk, M. Kalal, A. Kasperczuk, B. Kralikova, E. Krousky, J. Limpouch, K. Masek, P. Pisarczyk, T. Pisarczyk, M. Pfeifer, K. Rohlena, J. Skala, J. Ullschmied*: Shock wave generation and crater formation in solids by a short laser pulse interaction.* Quantum Electronic, 34 (11), 989-1003, 2004.

Interactions of flyers with massive targets : (I experiment)

The main aim: Determination of conditions leading to the most effective energy transfer in the process of collision of the accelerated disks with solid targets.



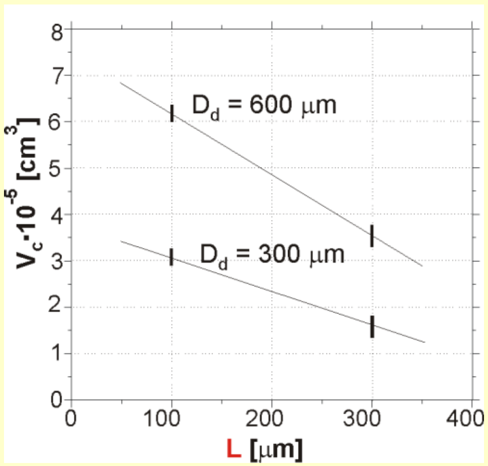
Target irradiation: : E=120 J (λ_1=1.315 μm), R_L= 200 μm

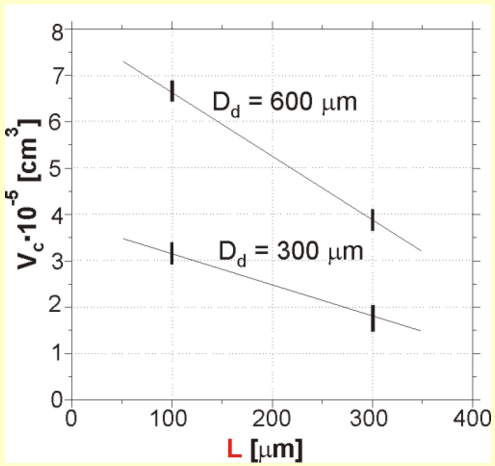
To ensure the same conditions of the ***Al*** and ***Cu*** disk acceleration:

$$\rho_{Al}\cdot d_{Al} = \rho_{Cu}\cdot d_{Cu},$$

L = 100 and 300 μm, D_d=300 and 600 μm

d_{Al}=11 μm and d_{Cu}=3.6 μm





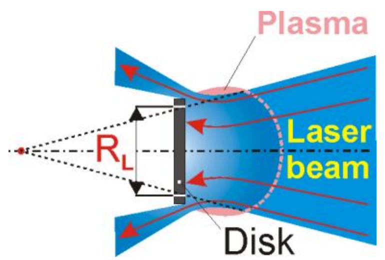
- The efficiency of crater creation drops drastically with the growing distance (L) of the disk. It testifies about strong evaporation of the disk during its flight.
- Contrary to our expectation, the crater volume strongly decreases with decreasing disk diameter.

Important publications:

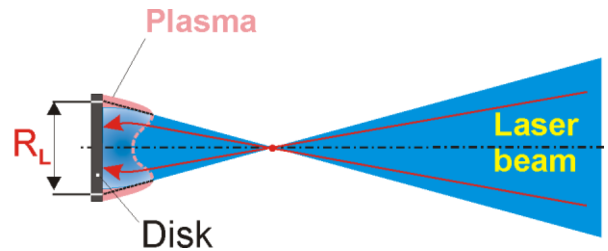
S. Borodziuk, A. Kasperczuk, T. Pisarczyk, S.Yu. Gus'kov, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, M. Kalal, J. Limpouch, and P. Pisarczyk. **Eur. Phys. J. D** 41, 311–317 (2007)

Interactions of flyers with massive targets: (II experiment)

The aim of experiment: Dependence of laser energy transfer on the focal point position of a heating laser beam.



Positive focal point position

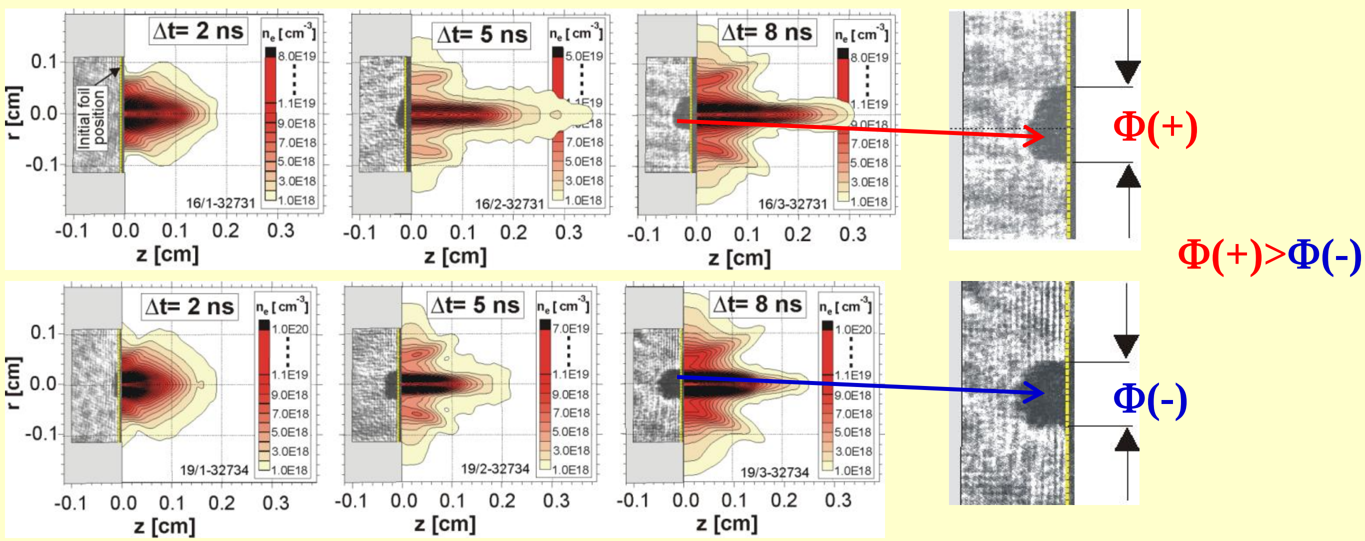


Negative focal point position

For the **negative position** of the focal point the **plasma configuration plays a role of a focusing lens.** Hence, this position should ensure more effective acceleration of flyers.

$R_L(+)=250\ \mu m$

$R_L(-)=250\ \mu m$



Important publications:

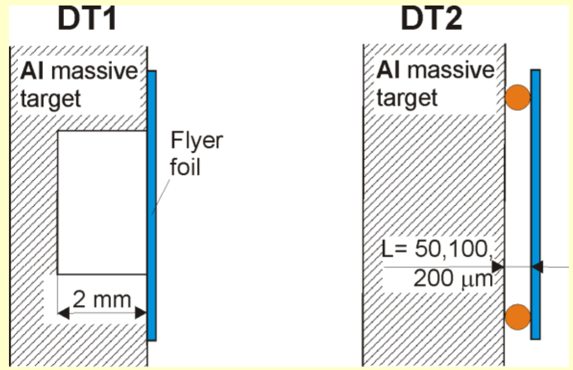
A.Kasperczuk , T. Pisarczyk, M. Kalal, M. Martinkova, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: **Laser and Particle Beams 26**, 189-196(2008).

Laser energy transformation to shock waves in multi-layer flyers

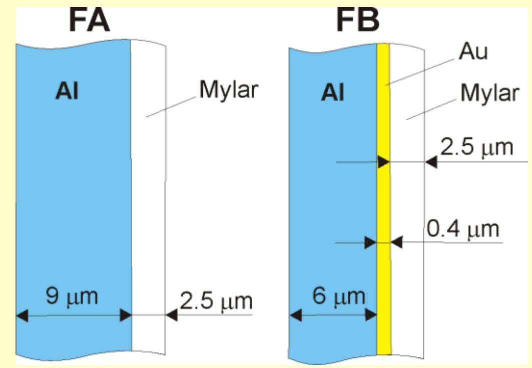
Main aim: to study of the influence of X-ray radiation from plasma with the flyer on the parameters of the accelerated flyer. To protect partially against action of X-ray radiation on the flyer, one of the Al flyers was on the laser side covered by a 0.4 µm thick Au layer.

Laser energy: ~100 J (λ_1=1.315 µm)
~120 J (λ_3=0.438 µm)
Focal spot radius: 200 µm (*located inside the target*)

Double target construction



The flyer foil composition



Comparison of the experimental and theoretical parameters of the foils motion

	FA		FB	
	Experiment	Theory	Experiment	Theory
Delay of the foil start (t_s)				
first harmonic:	2 ns	0.25 ns	3 ns	0.45 ns
third harmonic:	0.3 ns	0.20 ns	0.7 ns	0.32 ns
Foil velocity				
first harmonic:	$6\cdot10^6$ cm/s	$6.5\cdot10^6$ cm/s	$5\cdot10^6$ cm/s	$<6.5\cdot10^6$ cm/s
third harmonic:	$7.5\cdot10^6$ cm/s	$11\cdot10^6$ cm/s	$6.7\cdot10^6$ cm/s	$<11\cdot10^6$ cm/s

Our expectation concerning the influence of the Au layer on the state of the accelerated foil was not fully confirmed. However this knowledge should be useful in further investigations of these problems.

A.Kasperczuk, T. Pisarczyk, S.Yu. Gus'kov, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, M. Kalal, V. Tikhonchuk and P. Pisarczyk: ***Radiation Effects & Defects in Solids*** **163**(6), 1–15 (2008).

The ablation – pressure methods of macroparticles acceleration

RAS - Reverse Acceleration Scheme, and

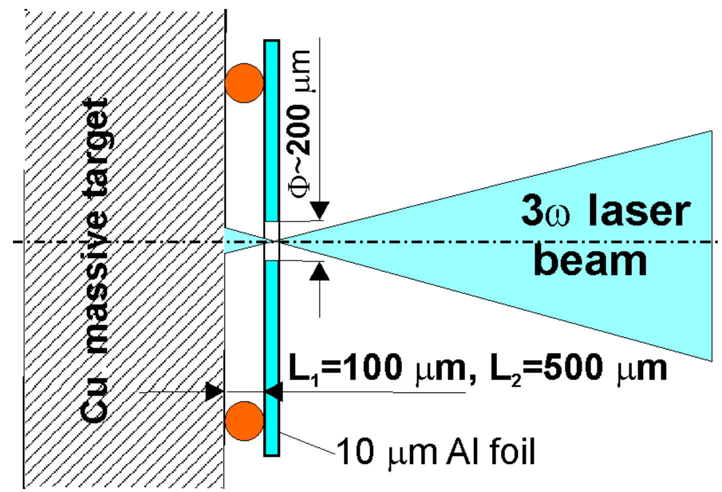
CPAS – Cavity Pressure Accelertion Scheme

The new, indirect method for two-step acceleration of the thin foil to high velocity – RAS (Reverse Acceleration Scheme)

- The RAS is a new, alternative, two-step method for accelerating thin targets foils to high velocity comparing to the classic ablative method.
- **In acceleration of the foil process the ablative plasma generated from the massive target irradiated by the laser beam is used**.
- Such scheme of acceleration enables in the considerably better degree to use the absorbed energy of the laser pulse and leads for significantly higher values of basic parameters of the accelerated foil (macroparticle) such as velocity, density and first of all the hydrodynamic conversion efficiency (defined as the final kinetic energy of the flyer target divided by the absorbed laser energy)

Experimental conditions:

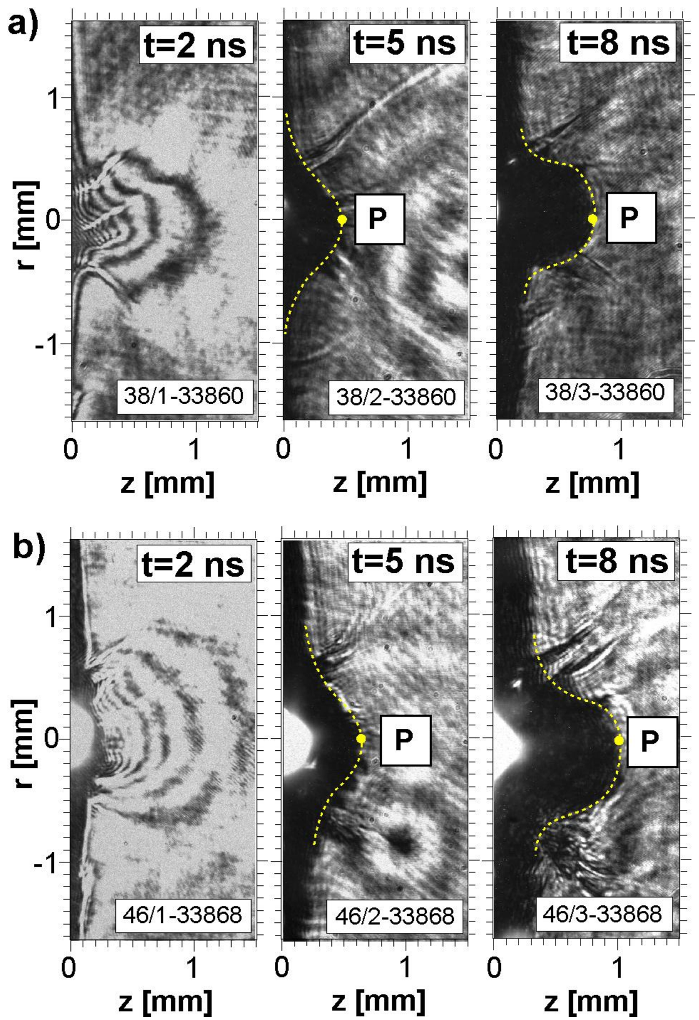
- **laser energy (3rd harmonic): 100-200 J**
- **the focal spot radius (minimum): R_L =40 mm**
- **$L_{1,2}$ =100, 500 mm**



Diagnostics:

To study the plasma expansion and the flyer foil acceleration, a three-frame interferometric and shadowgraphic system with automatic image processing was used.

Shadowgrams of 10 μm Al foils accelerated by 3ω iodine laser pulse for two shots: (a) E=75 J and (b) E=190 J corresponding to L= 100 μm.



Acceleration velocities of the flyer Al foil obtained in the present experiment

E (J)	75	190	75	190
Target	T_{100}	T_{100}	T_{500}	T_{500}
v (10^7 cm/s)	1.0	1.3	0.8	0.9

The Al flyer foil has reached velocity of ~1.3x10^7 cm/s, i.e. significantly higher when comparing to "classic" ablative acceleration experiment*.

S. Borodziuk, A. Kasperczuk, T. Pisarczyk, J. Ullschmied. E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk : ***Reversed scheme of thin foil acceleration***. **Applied Physics Letters**, **93**, 101502 (2008).

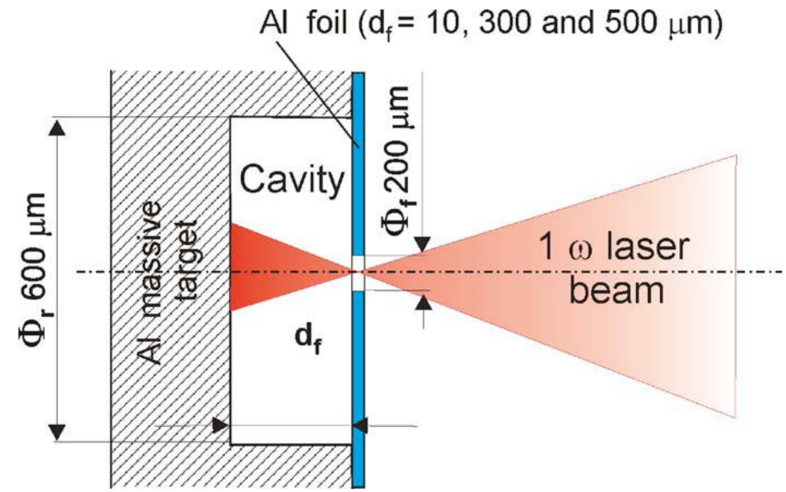
CPAS – Cavity Pressure Acceleration scheme:

An efficient laser-based method of production of high-velocity macroparticles

- We continued our experiments in this direction, introducing however some changes. The most important change concerns the construction of targets.
- In order to improve absorption of laser radiation and increase the efficiency of macroparticle acceleration we modified our double targets by providing them with a cavity. The pressure induced by laser action inside the target cavity represents then the most important factor of foil acceleration.
- That is why we called this method the "**cavity pressure acceleration scheme" - CPAS**.

Target irradiation:

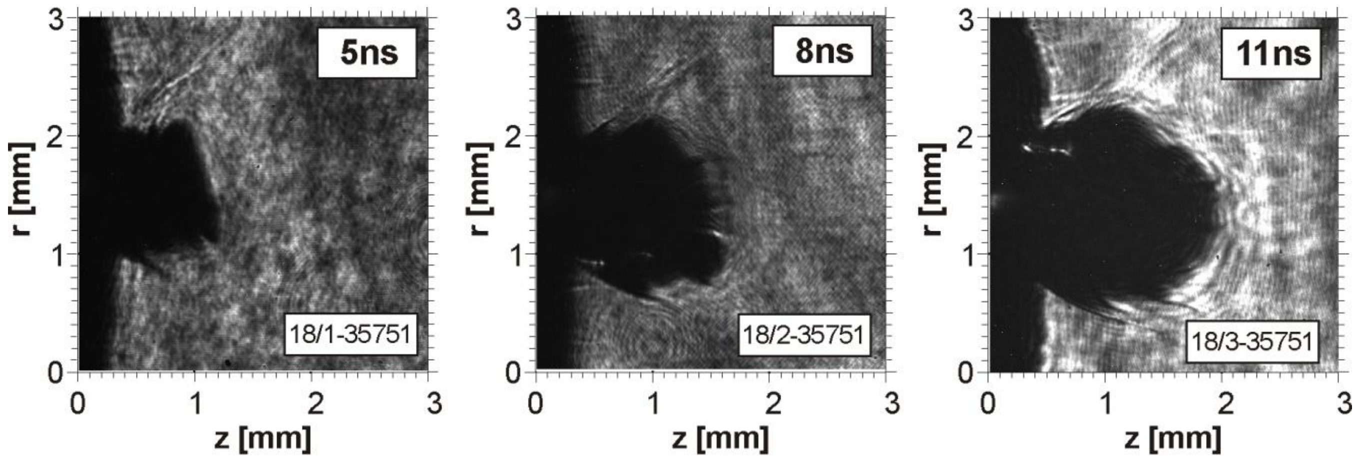
- 1^{st} harmonic of laser radiation (λ=1.315 μm), E_L= 20-500 J, t=250 ps ,
- the focal spot radius on the massive target surface, R_L= 100 – 200 μm.



S. Borodziuk, A. Kasperczuk, T. Pisarczyk, J. Badziak, T. Chodukowski, J. Ullschmied. E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Cavity pressure acceleration: An efficient laser-based method of production of high-velocity macroparticles***. **Applied Physics Letters 95**, 231501/1-3 (2009).

Thin foil targets

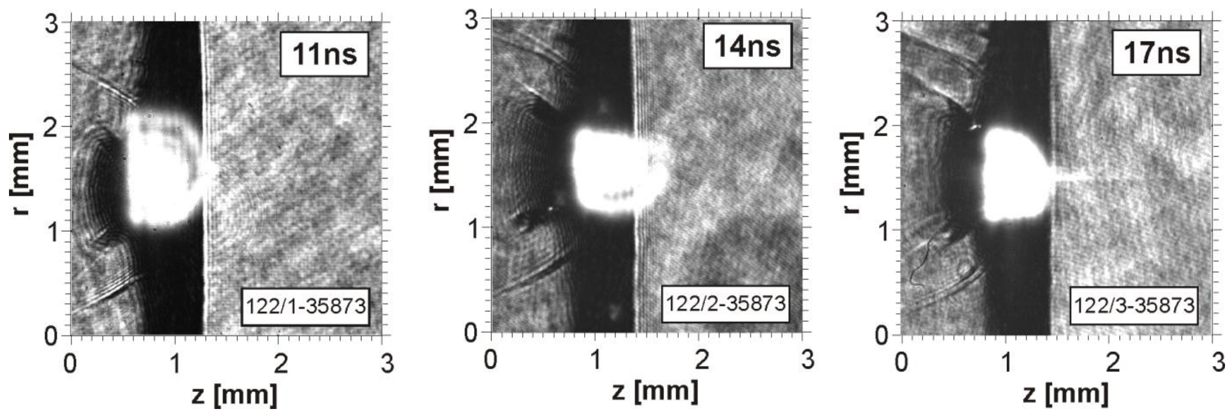
The sequence of three shadowgrams showing movement of a 10 μm Al foil at three selected times in the case of type A target. Laser beam energy 500J.



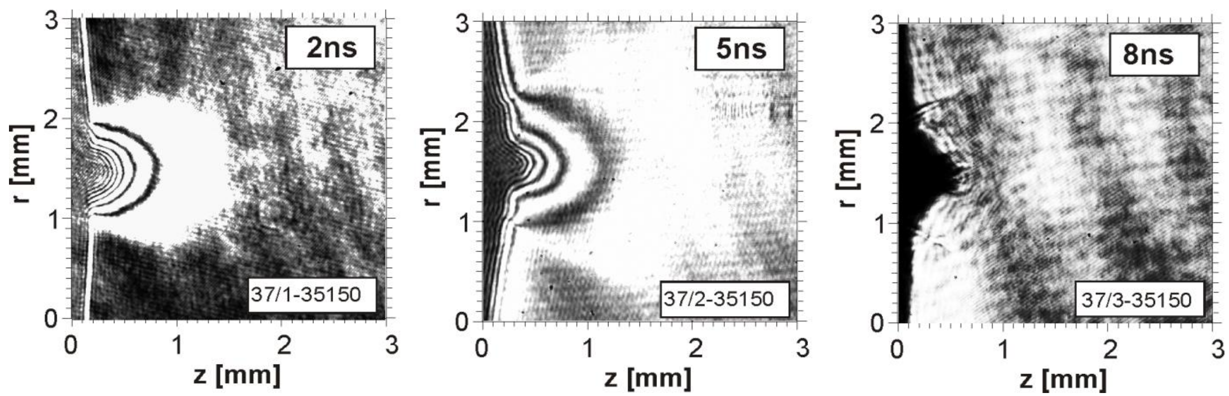
- Assuming delay time t_s ~ 1 ns one can evaluate that v_{max} averaged for a time range [1, 5] ns is ~ **$5 \cdot 10^7$ cm/s.**
- The above result $v_{max} 5x10^7$ cm/ s is close to that obtained at ILE Osaka [16] where polystyrene targets doped by bromine CHBr were used. The maximum velocities obtained for 15 and 22 μm CHBr targets were $7.0x10^7$ and $5.1x10^7$ cm/ s, respectively. Our result should be compared with the second value, as the surface densities of our target 10 μm thick Al and of 22 μm thick CHBr target are similar.
- An important difference between these two experiments is that at ILE Osaka the target was irradiated in a standard way by 0.35 μm, 1.5 kJ laser*, whereas we applied 1.315 μm iodine laser and much lower energy 500 J.

* H. Azechi, et al., ***Experimental evidence ofimpact ignition: 100-fold increase of neutron yield by mpactor collision***, **Phys. Rev. Lett**, **102**, 235002 2009.

An attempt to accelerate a thick (300 μm) Al target by "classic" ablative method vs. RSA method applied to 500 μm Al target



E_L = 300J
d_f = 300 μm
v_{av} (0-17) = 0.



E_L = 130J
d_f = 500 μm
v_{av} (0-8) = $0.7\cdot10^7$ cm/s.

- **Result: High energy laser pulse (E_l =300 J) is not able to move thick (300 μm) Al target if classic ablative acceleration method is used.**
- **It can be done using a much weaker laser pulse (E_L =130 J) and heavier (500 μm) Al target if RAS method is applied. The accelerated foil reached velocity of $0.7\cdot10^7$ cm/s.**

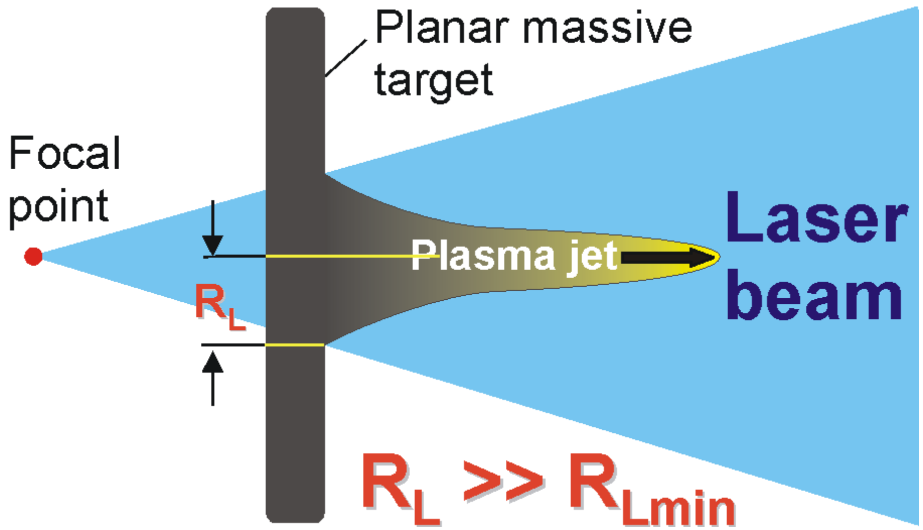
Elaboration of the novel very simple method of the plasma jet generation

The new very simple method of plasma jet generation ……

In 2006 we reported about the new, very simple for realization, method of plasma jet production.

A. Kasperczuk, T. Pisarczyk, S. Borodziuk, J. Ullschmied, E. Krousky, K. Masek, K. Rohlena, J. Skala, and H. Hora: ***Stable dense plasma jets produced at laser power densities around 10^{14} W/cm^2***. **Physics of Plasmas**, **13**, 062704/1-8 (2006).

The schematic illustration of the plasma jet generation method



This method requires:

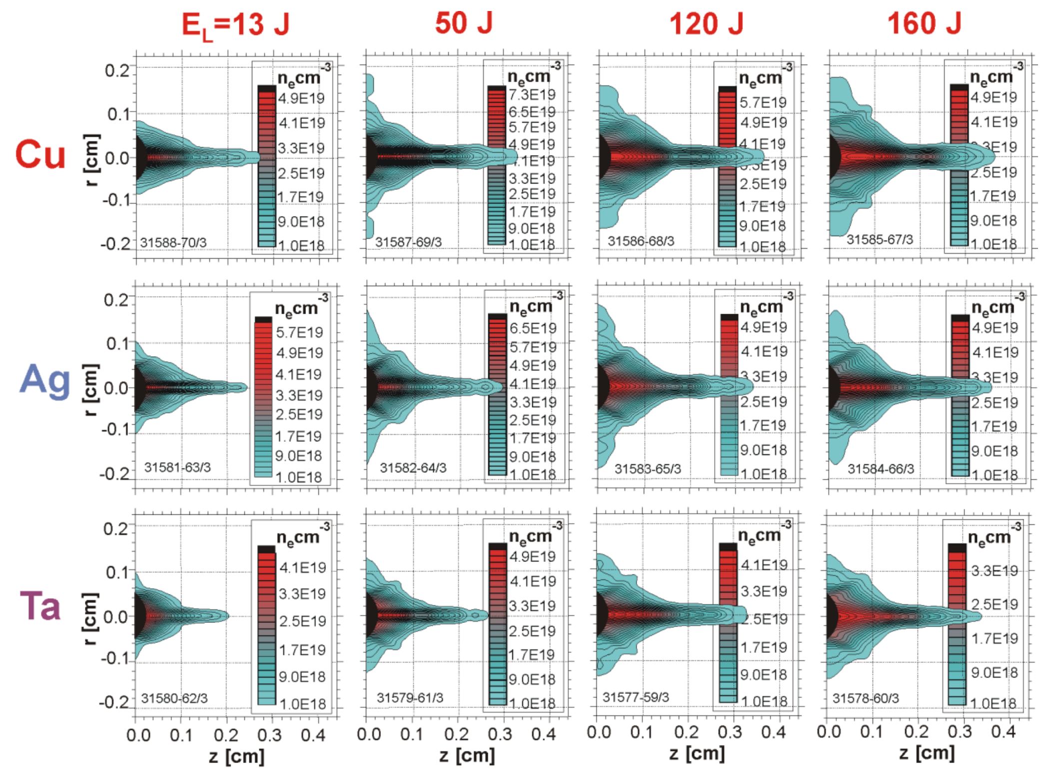
- a flat massive target with relatively high atomic number $Z \geq 29$ (Cu) and
- only one partly defocused laser beam.

1. A. Kasperczuk, T. Pisarczyk, S. Borodziuk, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Interferometric investigations of influence of target irradiation on the parameters of laser-produced plasma jets***, **Laser and Particle Beams**, **25**, 425-433 (2007).
2. A. Kasperczuk,T. Pisarczyk, J. Badziak, R. Miklaszewski, P. Parys, M. Rosinski, J. Wolowski, CH. Stenz, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Influence of the focal point position on properties of a laser-produced plasma***. **Physics of Plasmas**, **14**, 102706/1-8 (2007).

The new very simple method of plasma jet generation ……

- Optimization of the plasma jet from point of view of a focal spot radius (**R_L**) for **Cu, Ag, and Ta** has shown that **the best jet** corresponds to **R_L = 300 μm**.
- Next, we tested an influence of the **laser energy level** on the plasma **jet quality**.
- Because the **PALS** laser operates in the **third harmonic** energy range **of 10 – 200 J** therefore some energies from this range were used.

Influence of the laser energy on the plasma jet quality **Cu, Ag** and **Ta** for **Δt=8 ns**



One can see that the good quality jets are produced for all energies used. It opens possibility of the plasma jet creation even on small scale lasers.

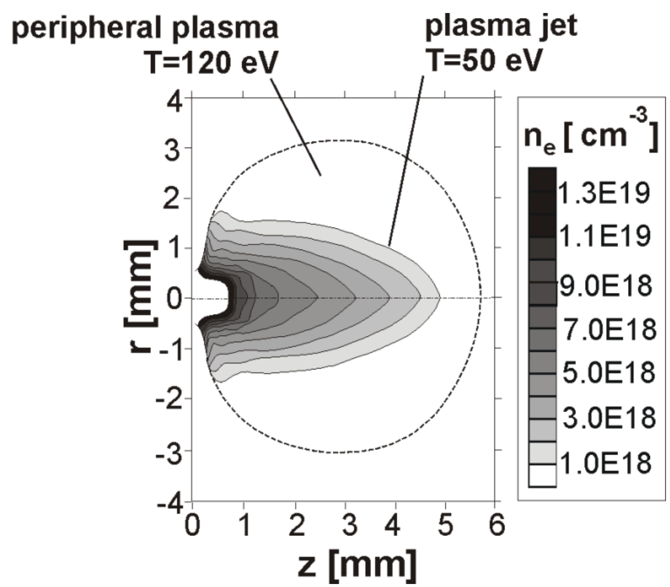
A. Kasperczuk, T. Pisarczyk, S. Borodziuk, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***The influence of target irradiation conditions on the parameters of laser-produced plasma jet*,**. Physics of Plasmas, **14**, 032701/1-4 (2007).

What is mechanisms of the plasma jet forming ?

- Although the plasma jets are produced very easily, an explanation of mechanisms of their production is not simple.
- The **first numerical modeling** of the plasma jet formation process performed by dr Ph. Nicolai et al. from Centre Lasers Intenses et Applications (Universite Bordeaux) **suggested** that the plasma jet forming results from **radiative cooling of the axial dense plasma.**

  Ph. Nicolai, V. T. Tikhonchuk, A. Kasperczuk, T. Pisarczyk, S. Borodziuk, K. Rohlena, and J. Ullschmied: *Plasma jets produced in a single laser beam interaction with a planar target*. Physics of Plasmas **13**, 062701/1-8 (2006).
- Because the bremsstrahlung emission power: $\mathbf{P_{br} \sim Z \cdot n_e^2}$ so the radiative cooling is more effective for dense plasma with high atomic number.
- As a result the central dense plasma keeps its state in longer period of time than **the peripheral** one which expands faster.

The plasma jet configuration for the **Cu** target obtained by means of the numerical modeling at 5 ns after the laser action.



The plasma jet reconstructed numerically has a great diameter of about 2 mm and the smooth edge.

What is mechanisms of the plasma jet forming ?

To explain the mechanisms responsible for the plasma jets formation the **experimental** and **theoretical** investigations have been performed.

The goal of investigations were to elucidate the relative role of both the mechanisms in the plasma jet forming process:

- the radiative cooling of ablative plasma and
- the influence of target irradiation geometry

Experiments:

I-experiment): Influence of target material on structure of the plasma outflow

- planar massive targets from plasic and Cu

II-experiment: Influence of Cu layer thickness on characteristics of the plastic plasma outflow

- planar massive plastic covered by the Cu layers with thicknesses: 28, 45, 78, and 190 nm

Numerical modelling:

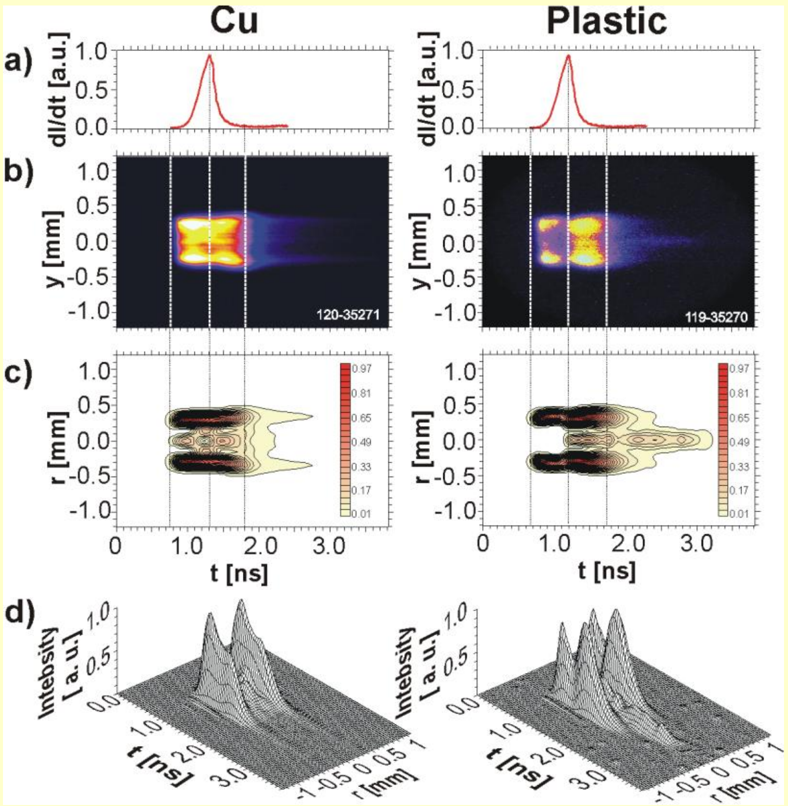
The additional simulations of the laser beam interactions with the planar Cu and plastic targets using 2D - code ATLANT-HE has been performed by dr N.N. Demchenko.

The simulations identified: two different plasma *expansion regimes:* the *planar* one in the case of Cu and the *spherical* one in the case of plastic.

A.Kasperczuk, T. Pisarczyk, N. N. Demchenko, S. Yu. Gus'kov, M. Kalal, J. Ullschmied, E. Krousky, K. Masek, M.Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Experimental and theoretical investigations of mechanisms responsible for plasma jets formation at PALS***. **Laser and Particle Beams** **27**, 415-427 (2009).

Influence of target material on structure of the plasma outflow

a) The laser pulses, b) streak images, c) equidensitograms and d) spatial profiles of the X-ray radiation



- For both kinds of the target material the *annular* form of the x-ray radiation is clearly apparent suggesting the similar shape for the laser irradiation structure as well.
- In the case of the plastic target an additional radiation peak in the center appears at a certain instant of the laser pulse.
- The change of the annular configuration of the plasma radiation source to a central one corresponds to the change of the initially convergent plasma outflow to a divergent one.
- **The above results whitness that the annular target irradiation is necessary for the plasma jet production**

- **In our opinion, all the three mechanisms play their respective roles in the plasma jet forming.**

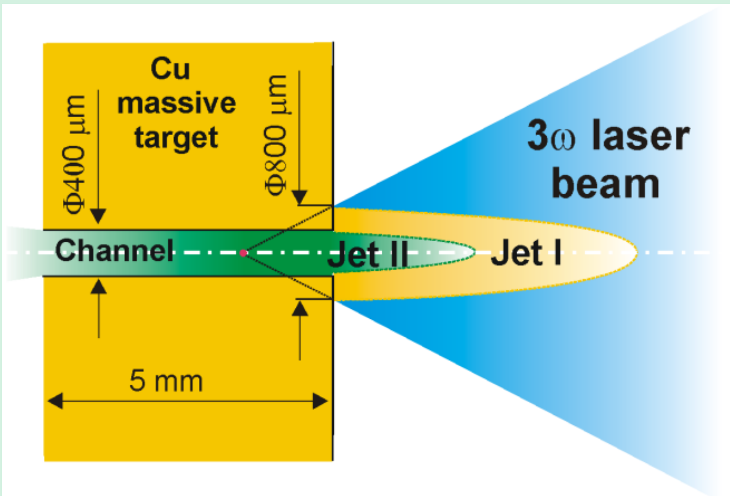
1. A.Kasperczuk, T. Pisarczyk, N. N. Demchenko, S. Yu. Gus'kov, M. Kalal, J. Ullschmied, E. Krousky, K. Masek, M.Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Experimental and theoretical investigations of mechanisms responsible for plasma jets formation at PALS***. **Laser and Particle Beams 27**, 415-427 (2009).
2. A.Kasperczuk, T. Pisarczyk, J.Ullschmied. E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: ***Influence of target material on structure of the plasma outflow produced by a partly defocused laser beam***. **Applied Physics Letters 94**, 081501/1-3 (2009).

Experiments aimed at the production of the plasma jets with various parameters and space configurations

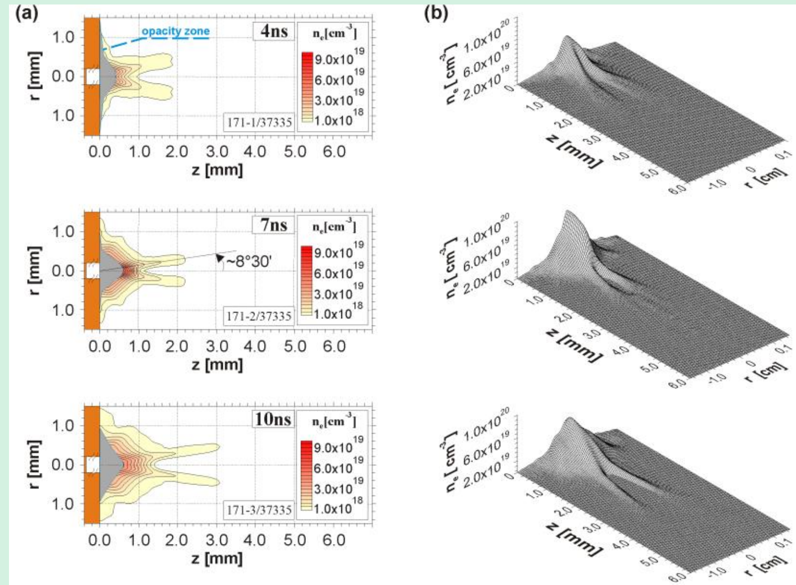
Interaction of two plasma jets produced successively from Cu target

Last experiments are aimed at the plasma jets formation with varius parameters and space configurations. Our interest was concentrated at investigations of interaction of two successive jets launched on Cu target (the radiative cooling in the process of plasma jet formation was also taken into account).

The way of creation of two successive plasma jets



Electron density distributions.



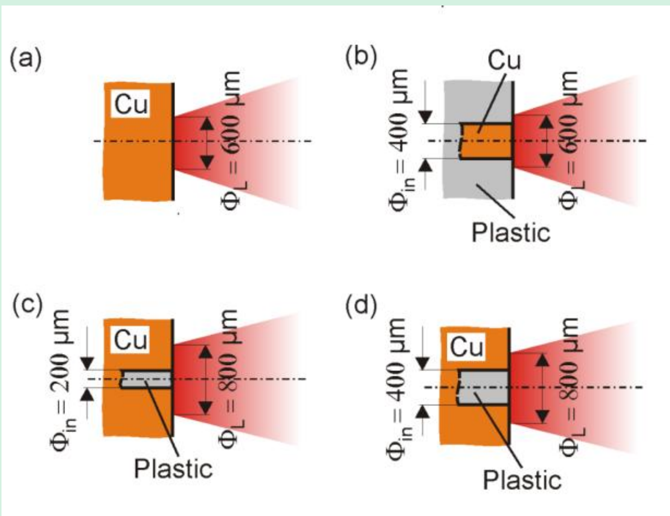
There is also possibility of modification the channel dimensions and shape to get different mutual relations between the jets, such as a delay between them, ratio of plasma amounts into jets, difference in their velocities and the like.

A. Kasperczuk, T. Pisarczyk, J. Badziak, S. Borodziuk, T. Chodukowski, P. Parys J.Ullschmied. E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk, Laser and Particle Beams **28**, 497-504(2010).,

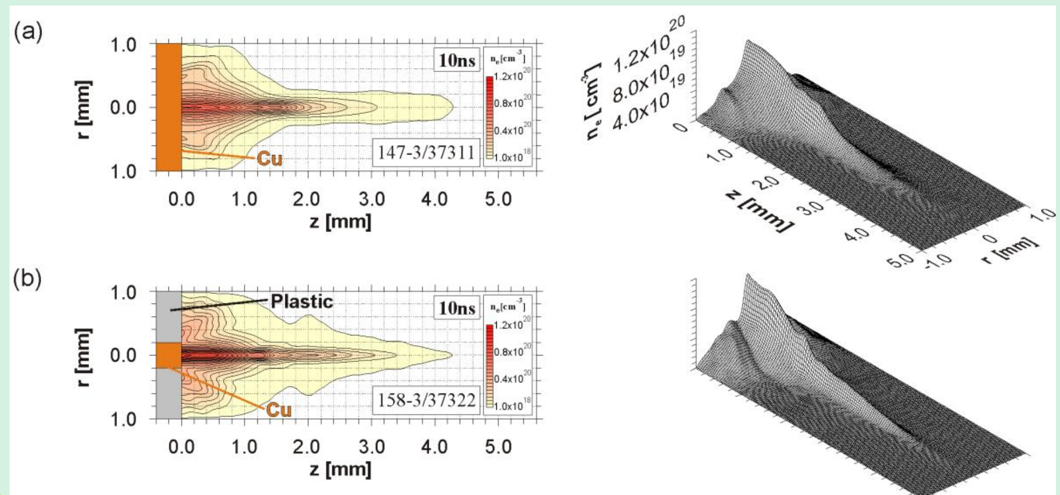
Influence of low atomic number plasma component on the formation of laser-produced plasma jets

The experiment was aimed at investigations of interaction of axially symmetrical light (plastic - CH) plasma with heavy (copper) plasma. It demonstrates that a relatively thin plastic plasma envelope can compress the Cu plasma and control the Cu-jet formation.

Target types



Electron density distributions corresponding to the (a) and (b) targets.



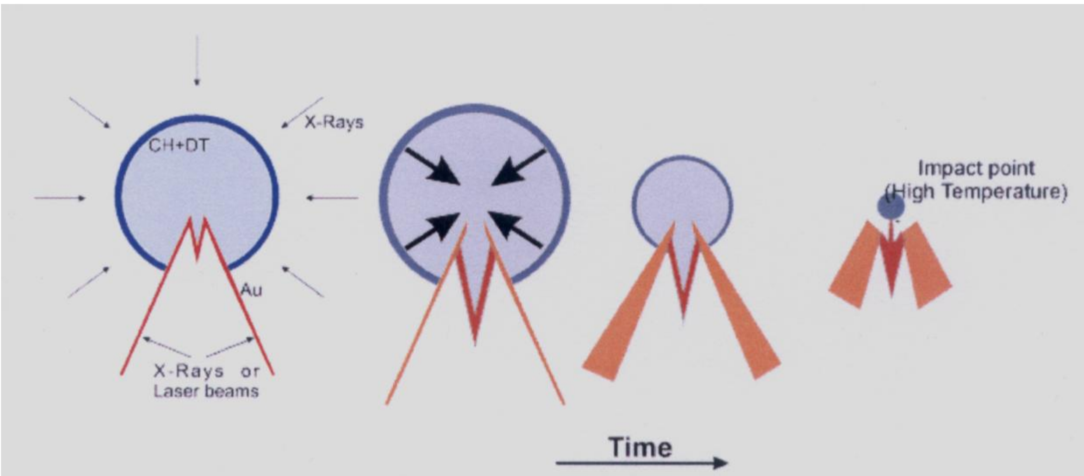
Theoretical analysis of the experimental results allows concluding that difference in plasma pressure related to plasmas with low and high atomic number results from essential differences in their expansion features. The ratio of the plastic and copper plasma pressures was evaluated to 1.35.

A Kasperczuk, T. Pisarczyk, J. Badziak, S. Borodziuk, T. Chodukowski, S. Yu. Gus'kov, N. N. Demchenko, J. Ullschmied, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala and P. Pisarczyk, **Physics of Plasmas** 17, No. 104 (2010) (the paper will be published on 10 October).

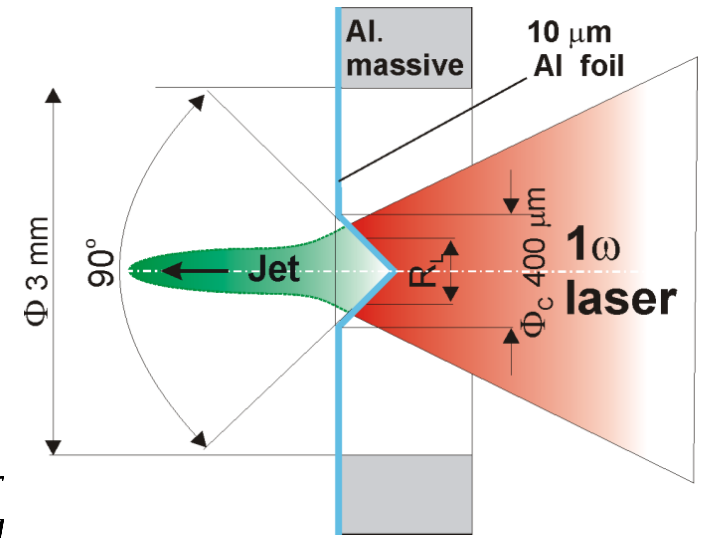
Verification of other methods of the plasma jet formation

Generation of plasma jets by means of conically shaped foils.

- **The aim of experiment:** creation of the plasma jet with parameters corresponding to the theoretical expectations of the conception proposed by P. Velarde et al.*. This idea was considered as a new fast igniter for realization of inertial confinement fusion.
- To test the above conception the cones target construcion were illuminated by the first harmonic of iodine laser (λ=1.315 μm) with parameters: energies of 120 and 600, the pulse duration of 250 ps, and, the focal spot radius , R_L=150 μm:



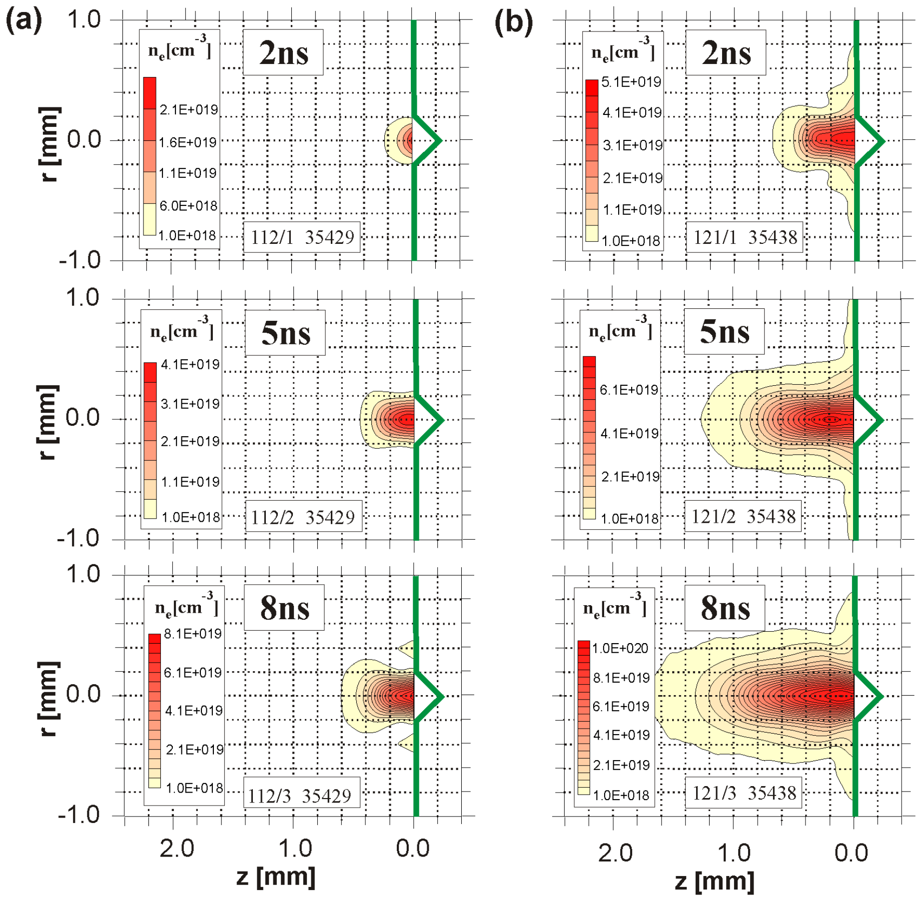
The ignition is induced by collision of a high-velocity matter jet, accelerated inside a conical guide, with compressed deuterium- tritium fuel.

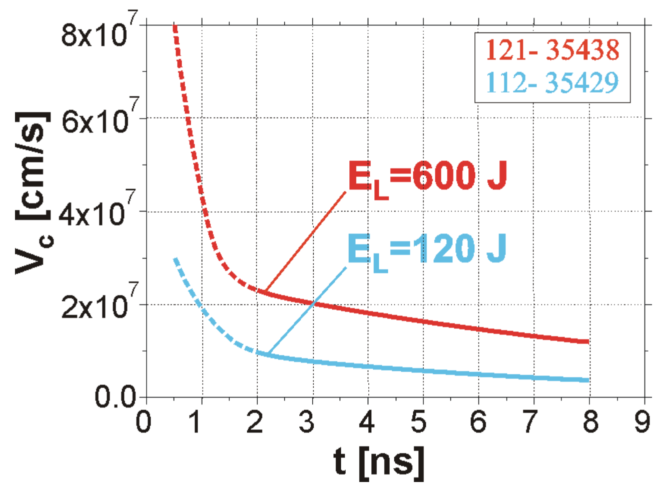


To determine space–time distributions of the electron density inside the plasma jet a three-frame interferometric system illuminated by third harmonic of laser was applied.

* P. Velarde, F. Ogando, S. Eliezer, J. M. Martinez-Val, J. M. Perlado, and M. Murakami: ***Comparison between jet collision and shell impact concepts for fast ignition***, Laser Part. Beams, **23**, 43-46 (2005).

Sequences of electron densitograms of plasma streams produced by direct action of laser beam for: (a) 120 J and (b) 600 J.





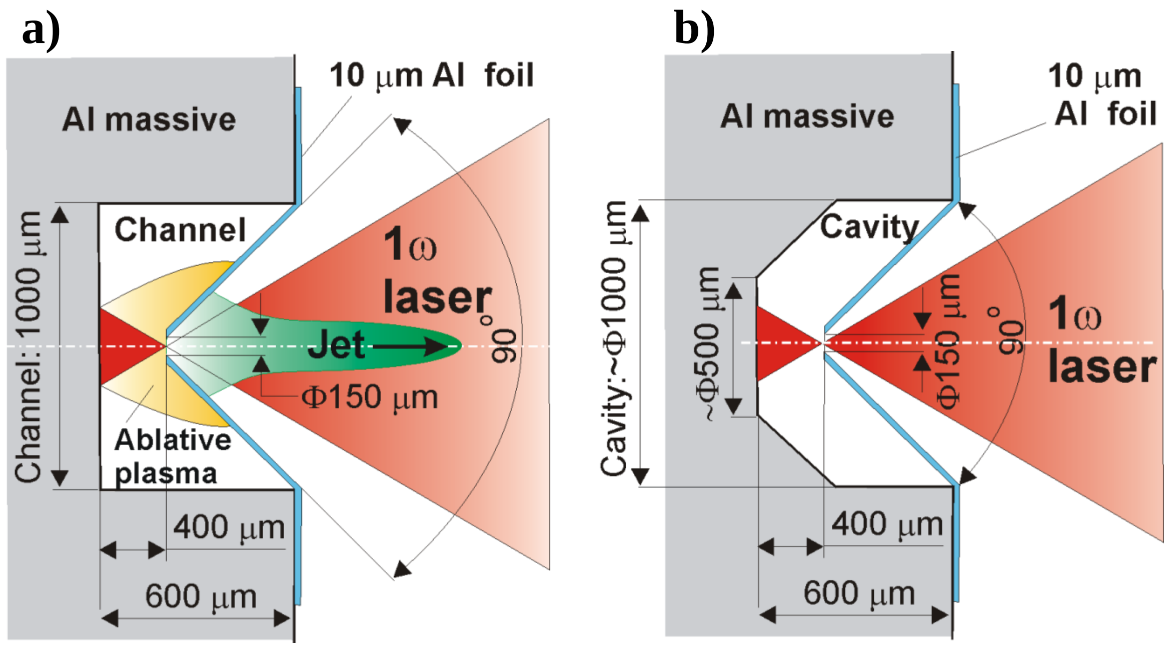
- **For energy of 120 J the plasma stream has not a plasma jet character.**
- **With the laser energy increase the initial axial velocity reaches a value in the range of (5-8)x10^7 cm/s however this velocity very fast drops to the value below 2x10^7 cm/s.** In the case of the axial only plasma motion the plasma stream velocity should be, in fact, constant.

- **These results did not confirm theoretical expectations concerning the plasma jet parameters.**
- **To improve parameters of the formed plasma jet the the RAS and CPAS methods have been applied.**

Pedro Velarde, Matthias Gonzalez, Carlos Garcia-Fernandez, Eduardo Oliva, Andrzej Kasperczuk, Tadeusz Pisarczyk, Jiri Ullschmied, Chantal Stehle, Bedrich Rus, Domingo Garcia-Senz, Eduardo Bravo and Antonio Relano: ***Simulations of radiative shocks and jet formation in laboratory plasmas***, **Journal of Phys: Conf. Series (IFSA 2007)** , **112** (2008) – 042010

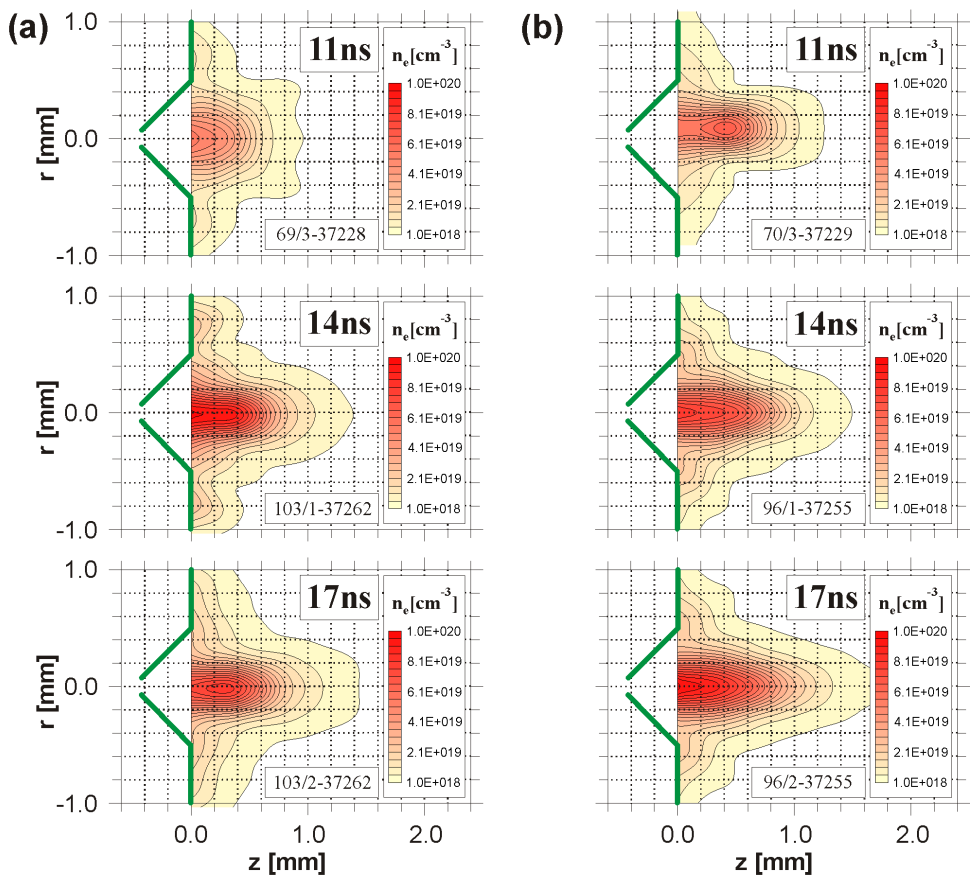
Testing of the possibility of improvement of the plasma jet parameters by the indirect irradiations of conically shaped foils

The target constructions for realization of the indirect irradiation of the conically shaped thin foil: a) - double target with free ablative plasma expansion (TF), and b) - double target with pressure cavity (TP).



- Very promising results regarding to the acceleration of thin foils or disks by RAS and CPAS methods inclined us to test new methods of plasma jet production using also the conically shaped thin foil.
- In these constructions the ablative plasma created from a massive target is used as a heater and an accelerator of the cone wall.

Sequences of electron equidensitograms of plasma streams at energy of 120 J for: a) - open type target (TF) and b) - cavity type target (TP).



- There is possibility for these targets to create the plasma jets with parameters considerably better that those for the target with direct cone irradiation at the same laser energy. The average plasma jet velocities in the observation period are greater than 10^7 cm/s whereas in the former case that velocity decreases very fast below this value.
- The maximum electron density in the jets is greater twice in comparison to that in the case of the direct cone irradiation. However, greater delay in the plasma jet propagation start (several ns) is characteristic property of such methods of the plasma jet production.
- The plasma jet in the case of **TP (b)** target is faster than that for the **TF(a)** target, although their velocities are yet not satisfactory.

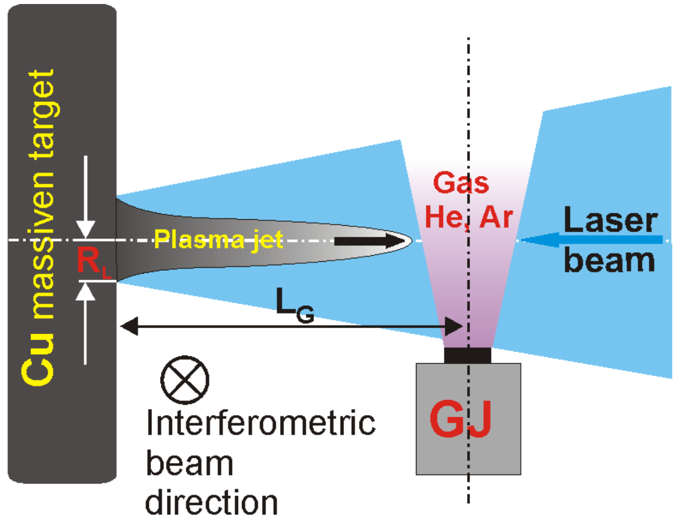
The first results are promising and will be continued in at larger laser energies

T. Pisarczyk, A.Kasperczuk,, J. Badziak, S. Borodziuk, T. Chodukowski, P. Parys, M. Rosinski, J. Wolowski, J. Ullschmied ,E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk: Testing of possibility of plasma jet creation by direct and indirect irradiations of conically shaped foils. 37th EPS Conference on Plasma Phys. Dublin, Ireland, 21-26 June, (2010).

Possibilities of application of the plasma jet creation method in the astrophysical investigations

Plasma jet interaction with ambient gases

The investigations inspired by the CELIA group were performed in the framework of LASERLAB projects

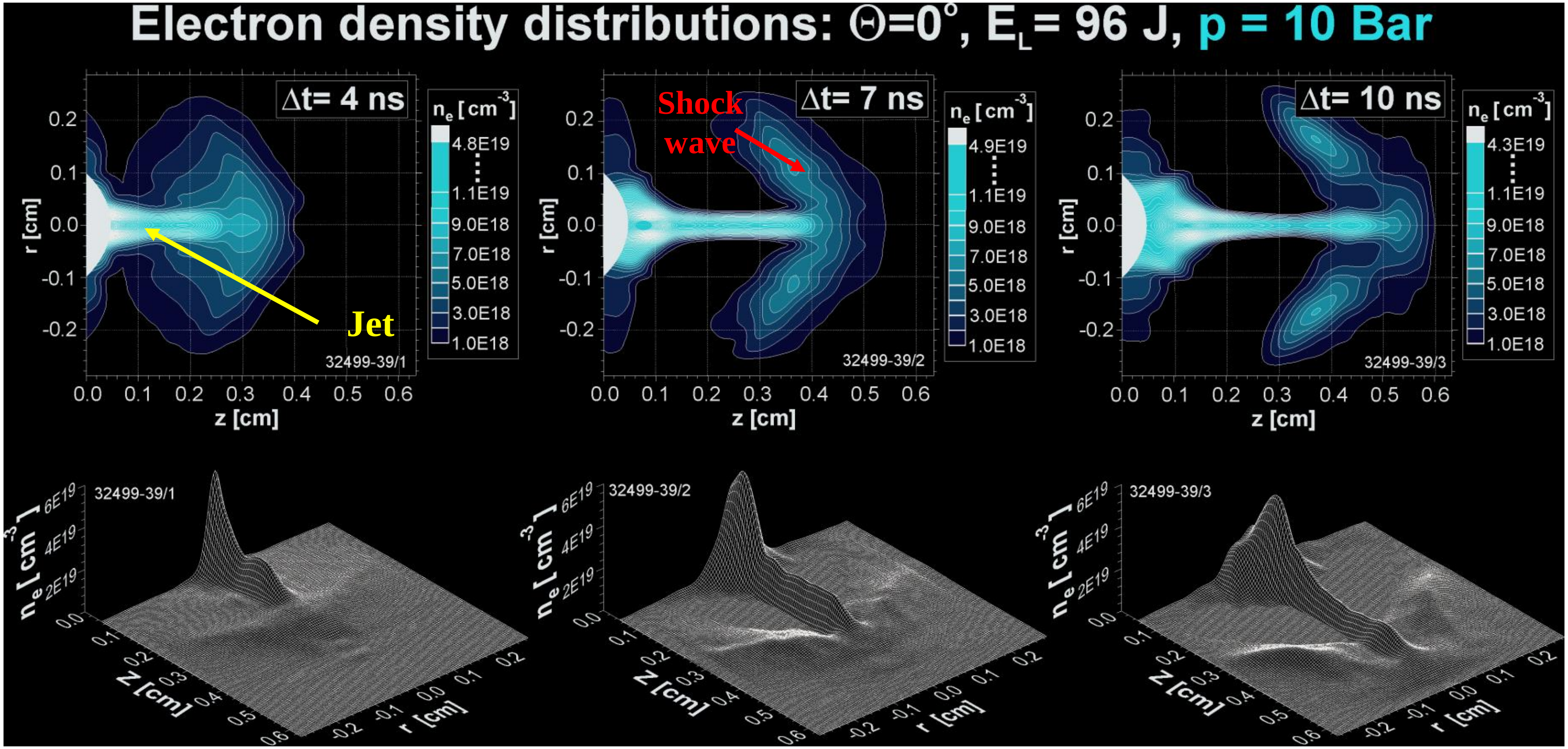


Publications related to investigations:

1. Ph. Nicolai, V. T. Tikhonchuk, A. Kasperczuk, T. Pisarczyk, S. Borodziuk, K. Rohlena,and J. Ullschmied**:. Physics of Plasma**, 13,062701,2006.
2. A. Kasperczuk, T. Pisarczyk, S. Borodziuk, J. Ullschmied, E. Krousky, K. Masek, K. Rohlena, and J. Skala, H. Hora: **Physics of Plasma**, 13,062704, 2006.
3. Ph. Nicola¨ı, V. T. Tikhonchuk, A. Kasperczuk, T. Pisarczyk, S. Borodziuk, K. Rohlena, J. Ullschmied**: Astrophysics and Space Science**, DOI 10.1007/s10509-006-9222-9, 2006.
4. T. Pisarczyk, A.Kasperczuk, E. Krousky, K. Masek, R. Miklaszewski, PH Nicolai, M. Pfeifer, P. Pisarczyk, K. Rohlena, K. Stenc, J. Skala, V. Tikhonchuk and J. Ullschmied: **Plasma Physics and Controlled Fusion** 49, B611-B619, 2007.
5. Ph. Nicolai, C. Stenz, A. Kasperczuk, T. Pisarczyk, D. Klir, L. Juha, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, V. Tikhonchuk, X. Ribeyre, S. Galera, G. Schurtz, J. Ullschmied, M. Kalal, J. Kravarik, P. Kubes, P. Pisarczyk, an T. Schlegel: **Physics of Plasmas** 15, 082701 (2008).
6. V.T. Tikhonchuk, Ph. Nicolai, X. Ribeyre, C. Stenz, G. Schurtz, A. Kasperczuk, T. Pisarczyk, L. Juha, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, J. Ullschmied, M. Kalal, D.Klir, J. Kravarik, P. Kubes and P. Pisarczyk**: Plasma Physics and Controlled Fusion** 50, 124056 (2008).
7. Ph. Nicolai, C. Stenz, V. Tikhonchuk, , X. Ribeyre, A. Kasperczuk, T. Pisarczyk, , L. Juha, E. Krousky, K. Masek, M. Pfeifer, K. Rohlena, J. Skala, J. Ullschmied, M. Kalal, D. Klir, J. Kravarik, P. Kubes, P. Pisarczyk, and T. Schlegel**: Astrophys Space Sci**. 322, 11-17 (2009).
8. A.Kasperczuk, T. Pisarczyk, Ph. Nicolai, Ch. Stenz, V. Tikhonchuk, M. Kalal, J. Ullschmied, E. Krousky, K. Masek, M.Pfeifer, K. Rohlena, J. Skala, and P. Pisarczyk. **Laser and Particle Beams** 27, 115-122 (2009).

Interferometric results: the jet – He gas interaction

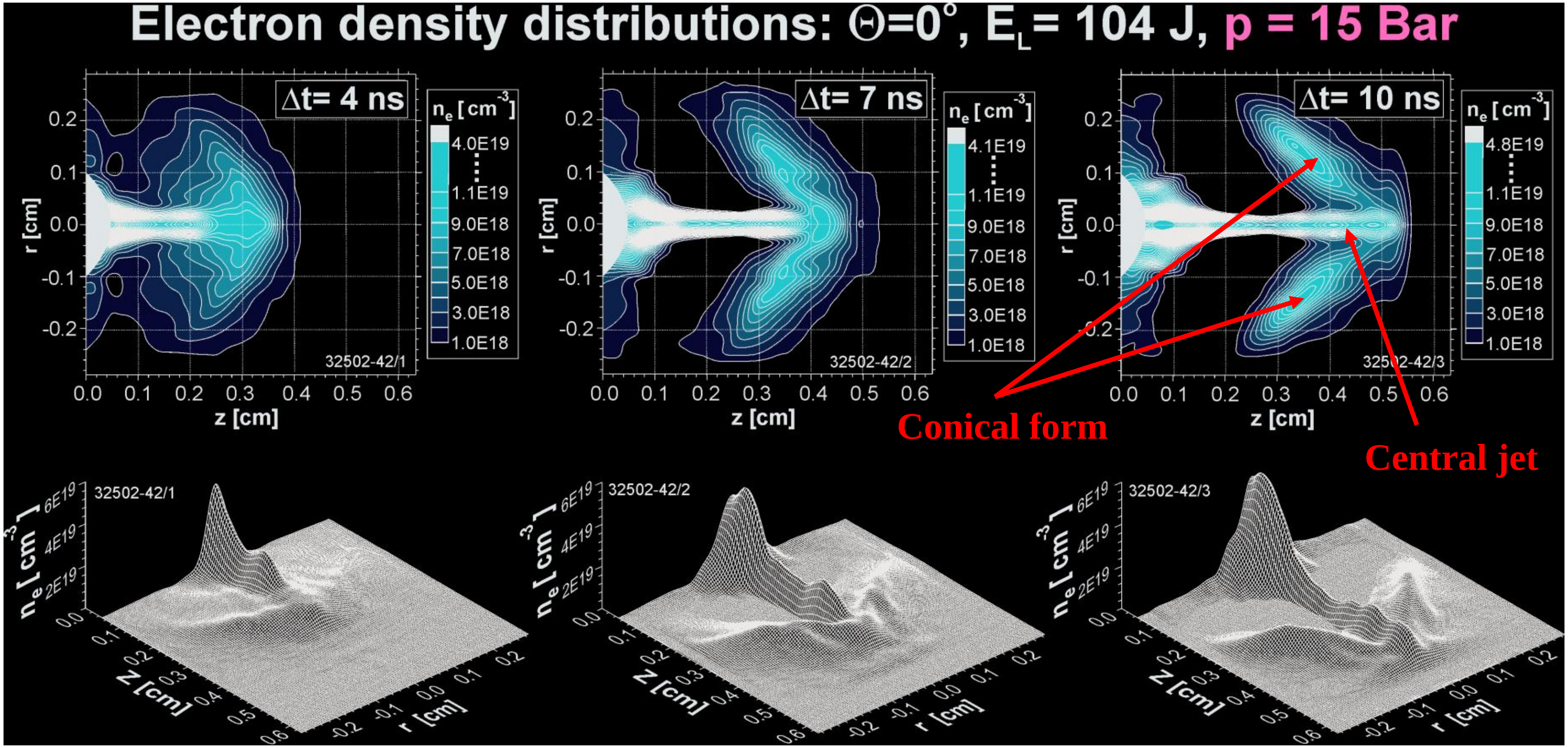
IPPLM



- The **shock wave** in the ambient gas is created a few ns after the laser action to take finally a bow form. A width of the shock is approximately equal to 1.5 mm independently on the gas pressure.

Interferometric results: the jet – He gas interaction

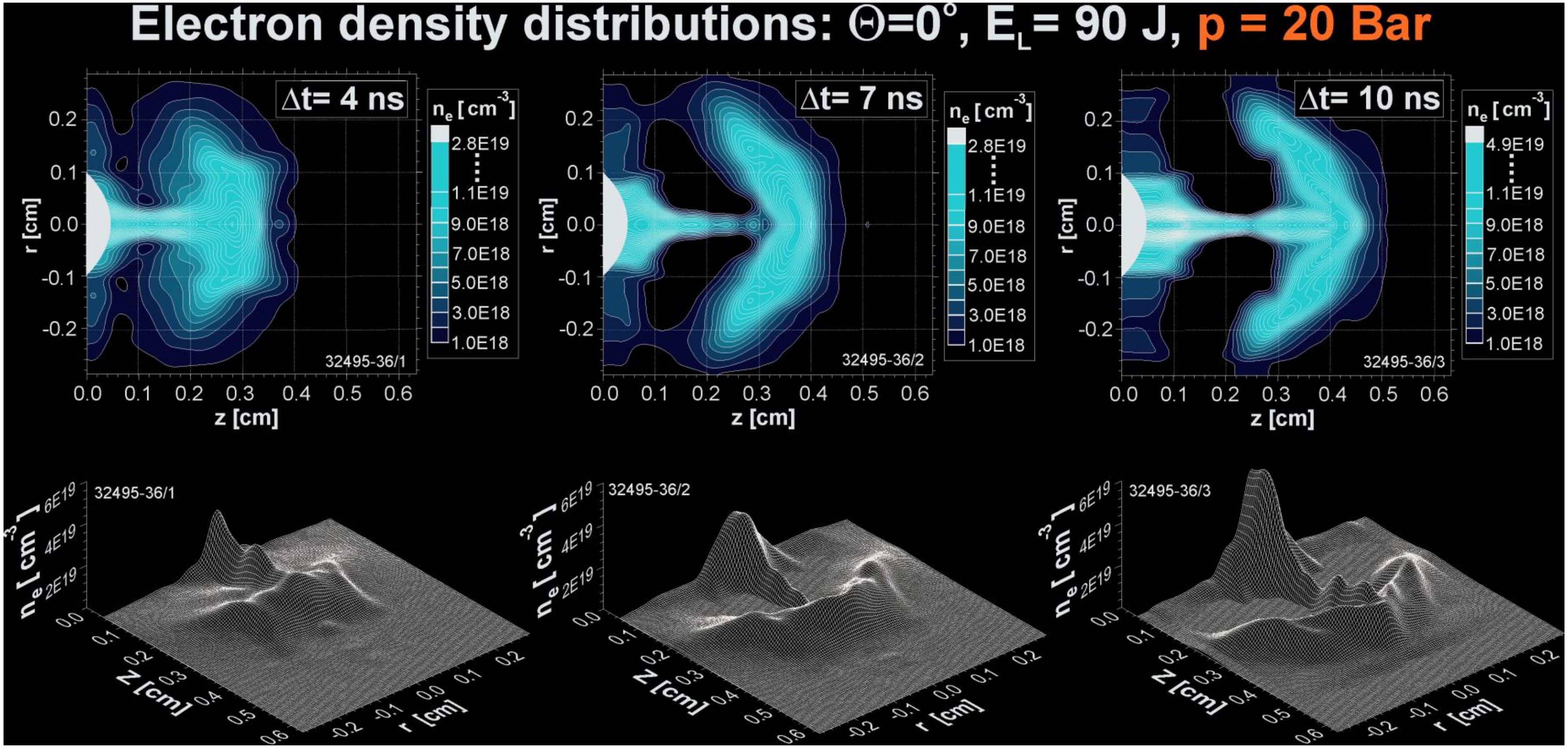
IPPLM



- A velocity of the shock wave decreases with the gas pressure, whereas the plasma density behind the shock front grows
- Simultaneously we observe the division of the shock wave into two parts: the **central jet** and the **lateral conical form.**

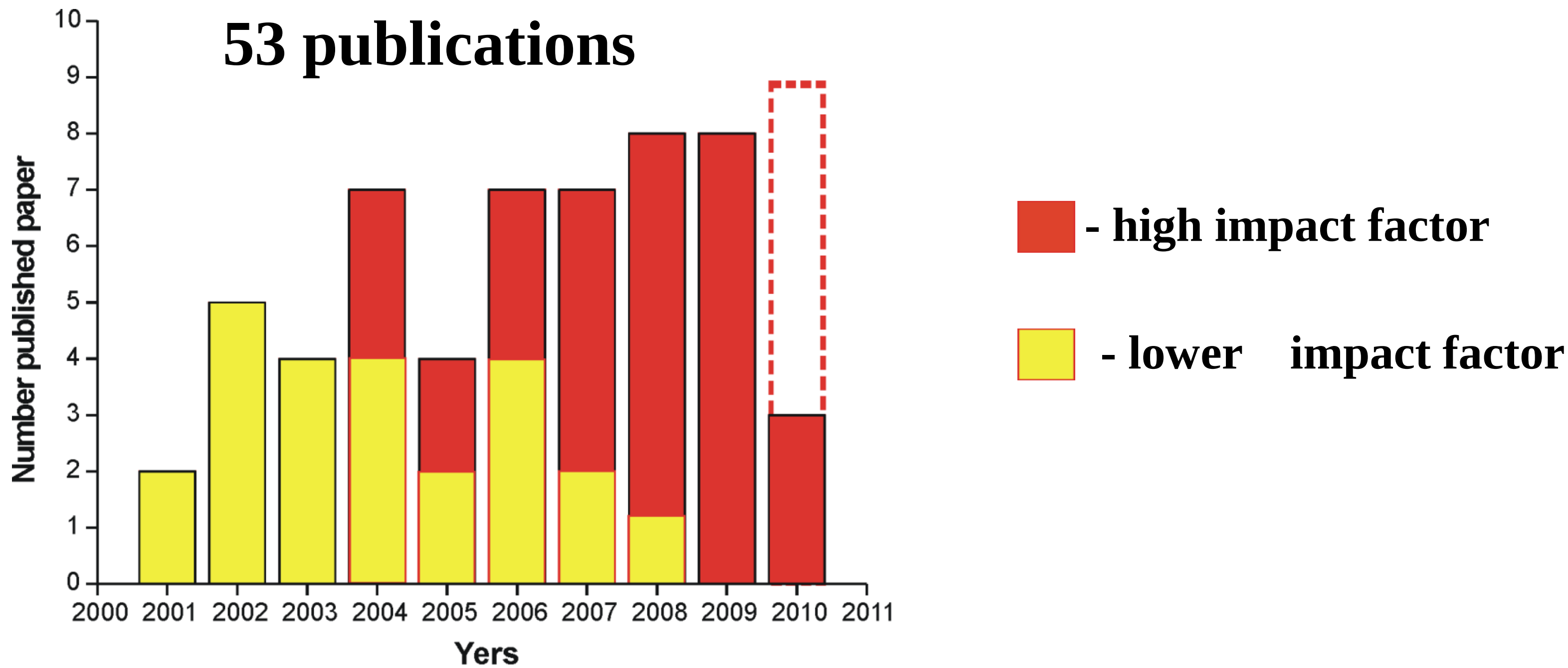
Interferometric results: the jet – He gas interaction

IPPLM



- We observe **the characteristic arrow structure** of the jet – He gas interaction.

Summary of publication activity



\+ **46 papers in conference proceedings**