Scientific report

regarding the implementation status of the project PN- II- ID- PCE- 2011- 3- 0958 “Electron acceleration and polaritonic transport for laser-plasma interaction in novel capilary geometries” period January – December 2015

Introduction

The research activities approached within this period of time were related to identifying the most suited experimental conditions to achieve the project objectives by using the CETAL infrastructure, particularly the system consisting of the CETAL PW class laser (http://cetal.inflpr.ro/node/73), the beam-line system and the optical system used to guide and focus the laser pulses (1-4 J/30 fs/0,1Hz) on different types of targets, in order to accelerate electrons in filamentary plasmas. Novel laser beam diagnosis techniques were developed in order to optimize focusing on the targets of interest. Analytical estimations of electron beam propagation across applied magnetic fields with geometry adapted for the diagnosis of accelerated electrons owing to the laser pulse-plasma interaction, have been confirmed by numerical simulations and validated by using classical accelerators. Progress was recorded towards the phenomenological interpretation of polaritonic transport of laser accelerated electron beams through interaction with international partners. Hence, our work was cited [A. Couairon, O. G. Kosareva, N. A. Panov, D. E. Shipilo, V. A. Andreeva, V. Jukna, and F. Nesa "Propagation equation for tight-focusing by a parabolic mirror", Optics Express Vol. 23, Issue 24, pp. 31240-31252 (2015)] which confirms the high interest towards this novel hypothesis that explains the transport of relativistic electron beams. Such hypothesis together with the underlying theoretical mechanism has been conceived and advanced by our group, while being selected by JAP as Research Highlight (M. Apostol and M. Ganciu,“Polaritonic pulse and coherent X- and gamma rays from Compton (Thomson) backscattering”, Journal of Applied Physics, 109 (2011) 013307).

Experimental and technology issues

In order to experimentally implement the mechanism of electron acceleration in filamentary plasmas, several steps had to be taken such as: operation of the PW class laser at nominal parameters, beam-line system and large distance - 3.2 m (F/20) off-axis parabolic (OAP) mirror alignment, and optimization of the optical spot in the focal plane of the OAP mirror. We had to overcome several challenges related to characteristic issues of very high power lasers, which we achieved by developing original diagnosis methods that represent the subject of a Patent application submitted in Nov. 2015 [T. Lucian, M. Ganciu Petcu, O. Stoican, I. Bărbuţ, G. B. Butoi, O. Dănilă, C. Diplaşu, A. Groza, B. Mihalcea and A. Surmeian, “Sistem de detecţie a radiaţiei ionizante în timp real cu protecţie la zgomot electromagnetic”, Patent Application No. A/00920 OSIM, Bucharest, 27/11/2015]. Thus, a method to align the beam-line system by using a low cost, commercially available 780 nm laser diode was used. The 780 nm radiation lies within the dielectric mirrors band (750 – 780 nm of the beam line system. Such a diode coupled with a 15 x beam expander allowed us to achieve an optical spot of ~ 15 cm diameter in the interaction chamber. Using this method we could verify both beam-line system and parabolic mirror alignment, with the advantage of sensibly reducing the time of PW class laser use for alignment, which increases the lifetime. Moreover, the risk hazard for the researchers involved in the experiments is sensibly diminished when using a continuous wave, low power laser.

As an outcome of our communication and joint experiments with UK researchers, particularly with Prof. D. Neely from the Rutherford Appleton Laboratory, we have developed a simple technique which performs the diagnosis of the focal region characteristics of the PW laser beam in the interaction chamber, using an astronomical telescope. The technique requires very low power delivered by the PW laser. Using both the 780 nm laser diode system and the astronomical telescope, two major issues were identified caused by the optics located between the Amplifier Nr. 2 and the telescope located within the compressor, and by a sapphire window found responsible for an intractable birefringence effect.

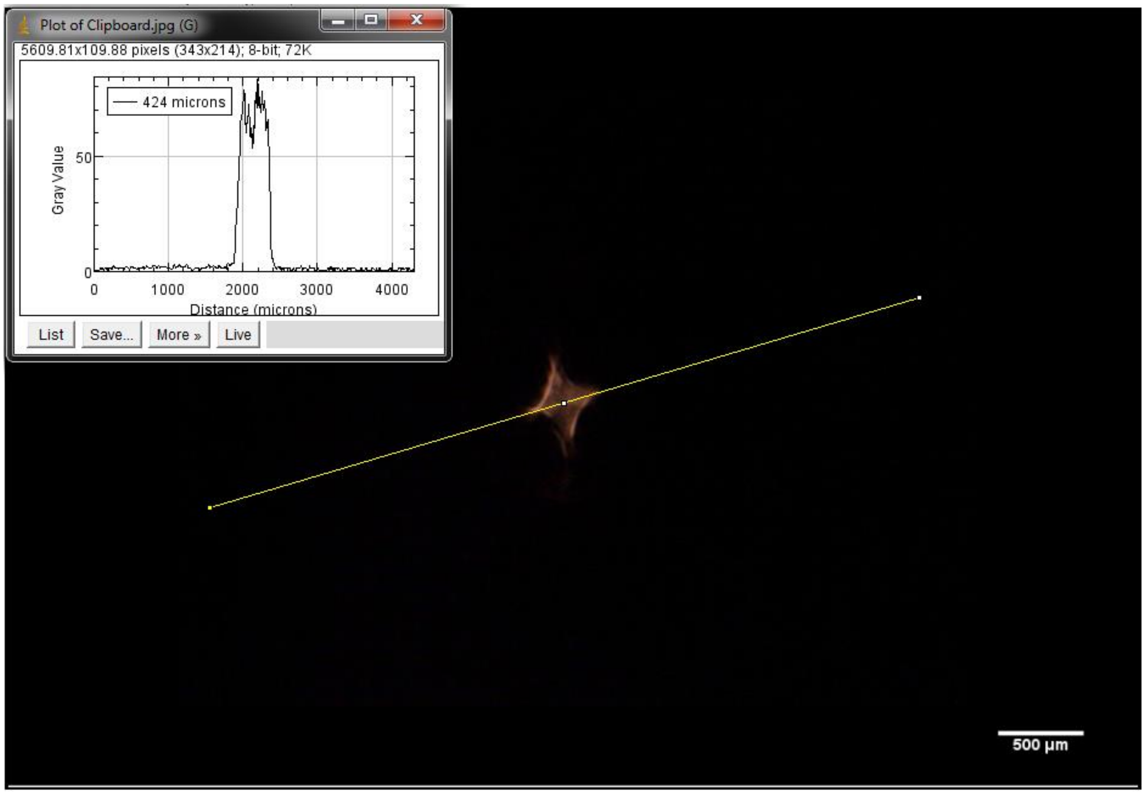


Figure 1: Astigmatism caused by the sapphire window which separates the compressor void area and the beam line system

The experiments on electron acceleration were performed by switching from the short focal distance (40 cm) off-axis parabolic (OAP) mirror to the long focal distance (3.2 m - F/20) OAP. The laser focal spot in the interaction chamber was optimized by means of a microscopic system comprising a Basler camera. The best value obtained for the focal spot diameter ranges between 80-100 µm. In order to achieve better focal spot, the laser pulse front will be corrected using a deformable mirror, with respect to the focus quality in the interaction chamber.

For such beam characteristics we report non-relativistic beam filamentation in air (Kerr collimation effect plus a de-collimation effect caused by the laser beam created plasma) and relativistic filamentation in He jet.

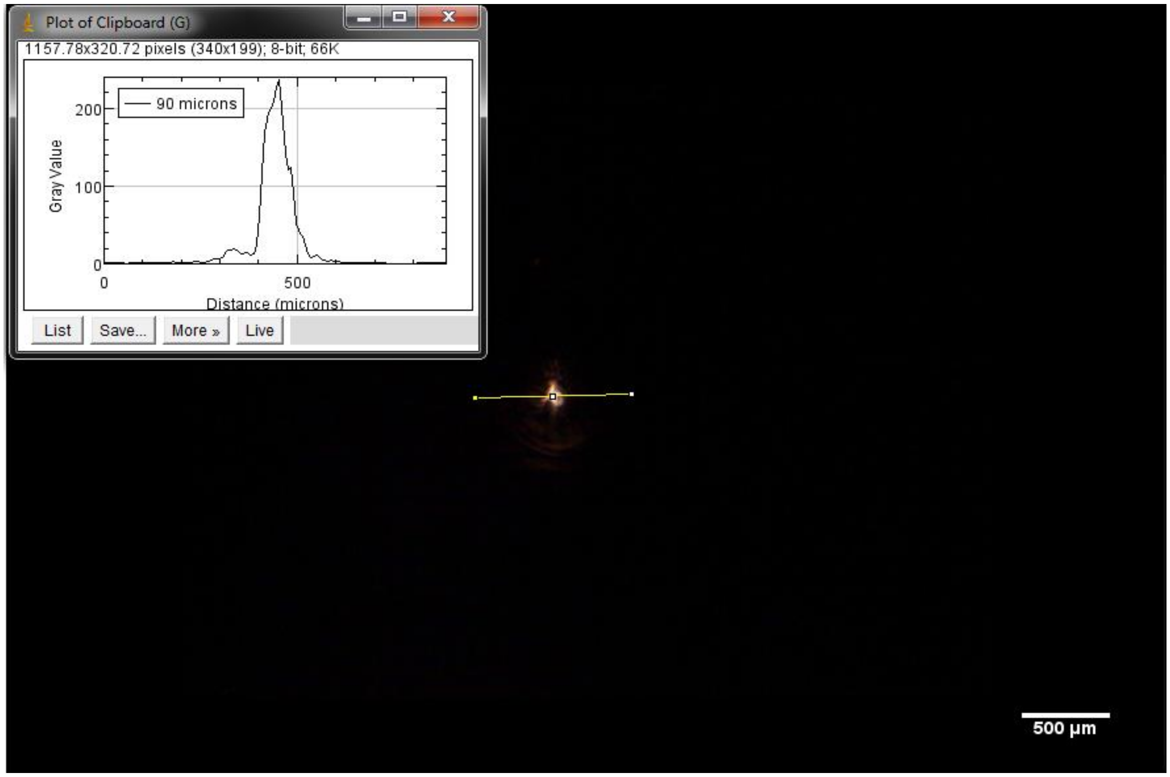
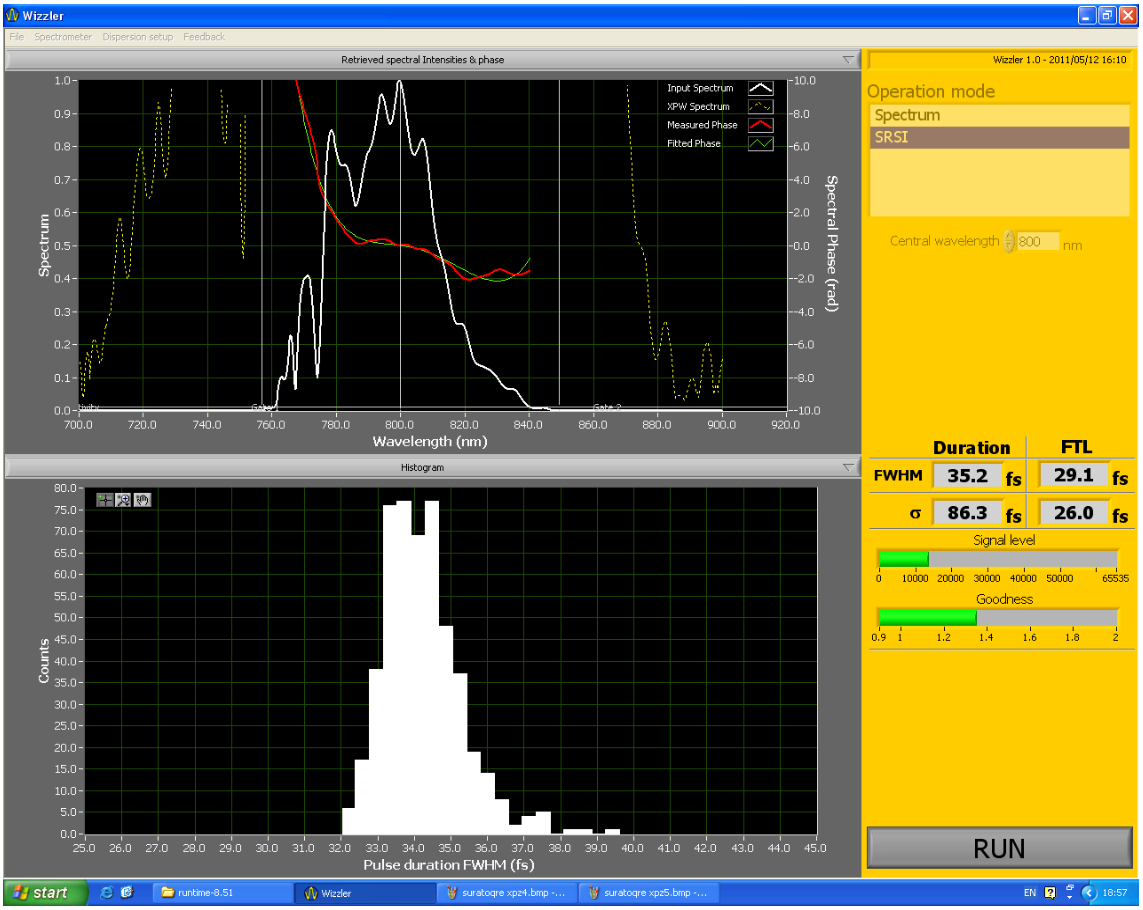


Figure 2: View of laser beam focusing at the exit from the compressor, using an astronomical telescope with 20 cm aperture, without the sapphire window

Figure. 3: Experimental setup for gas target - interaction between laser beam and He jet



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Operation mode
Spectrum
SRSI

Central wavelength 800 nm

	Duration	FTL
FWHM	35.2 fs	29.1 fs
σ	86.3 fs	26.0 fs

Figure 4: PW class CETAL laser pulse duration measurement

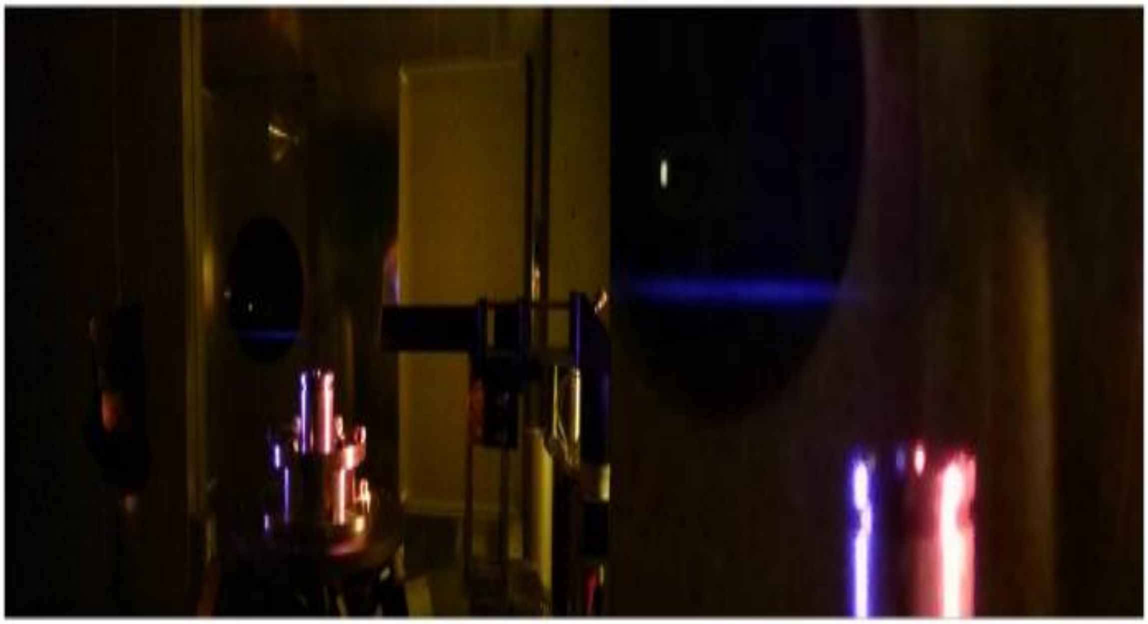


Figure 5: Filamentation in air at atmospheric pressure

The gas jet will be optimized using a "Schlieren" diagnosis technique, while the laser beam characteristics will also be optimized in order to achieve a laser beam intensity better than 10^{18} W/cm^2. Measurements techniques have been developed in order to chart the energy distribution of the electron beams and a magnetic spectrometer based on NdFeB magnets was devised, that insures a field intensity of ~ 0,6 T in the deflection area. The fluorescence induced on a Lanex screen is monitored by means of fast CCD Basler cameras (40 µs delay time with respect to the drive pulse). As the Lanex characteristic fluorescence time is around 1 ms, the Basler camera can be directly synchronized with the PW laser pulse. Calibrations were performed using the ALID 7 (http://ale.inflpr.ro/index_files/Facilitati.htm) facility from INFLPR, for a 5.5 MeV energy electron beam, with an average current of 10 µA and a 40 mm beam diameter, out of which a 4 mm diameter beam was selected by means of a diaphragm within a 50 mm thick lead brick.

Figure 6: Electron spectrometer calibration using an accelerated 5.5 MeV energy electron beam and the classical accelerator ALID 7 from INFLPR

Figure 7: Electron spectrum observed using the Lanex within the permanent magnet (NdFeB) spectrometer

In order to calibrate the diagnosis systems, a solid target was used (10 μm thick Al foil) and a 900 mJ / 30 fs laser pulse power (at the compressor XPW exit), focused in the interaction chamber by means of the 3.2 m (F/20) OAP mirror. We estimate an energy around 450 mJ in the focus. A front-end output power of 1 J was generated, with a pulse length around 34 fs and a 10 Hz maximum frequency. For a 100 μm diameter focus, an intensity of around 10^{17} W/cm^2 was obtained.

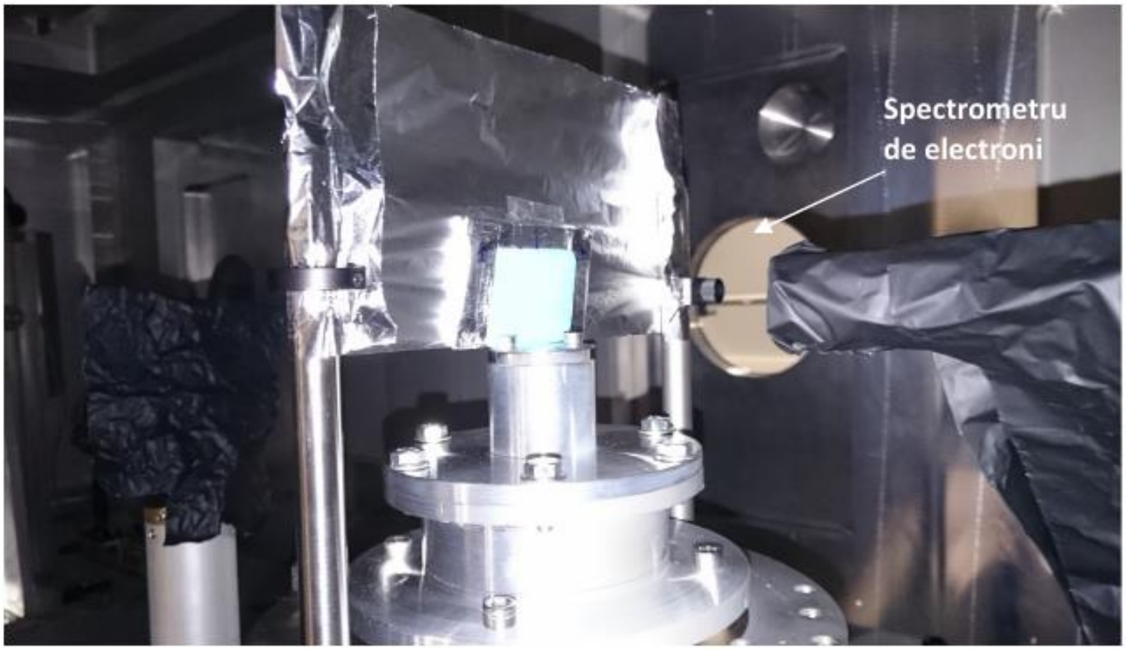


Figure 8: Experimental setup for solid target -10 microns thick Al foil

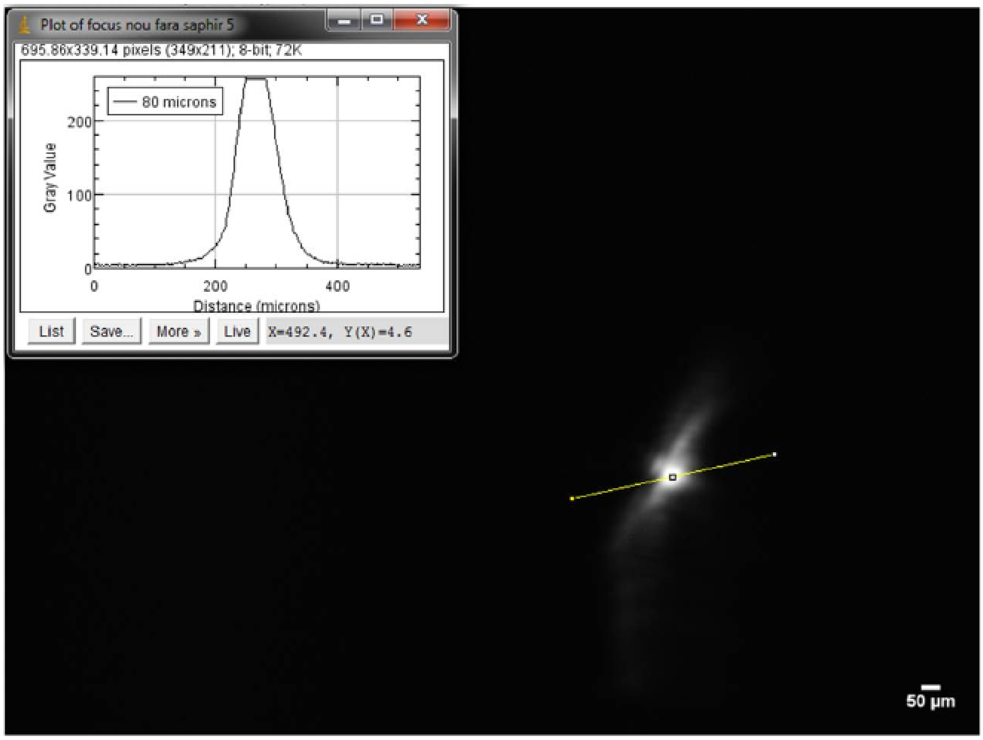


Figure 9: Focal final amplifier bypassed (1 J energy)

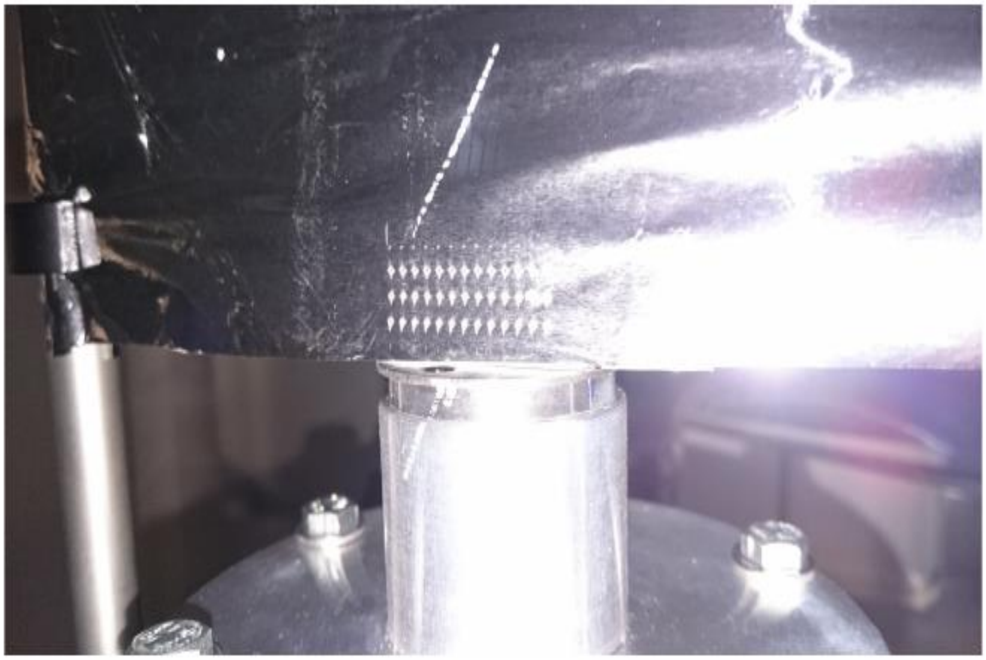
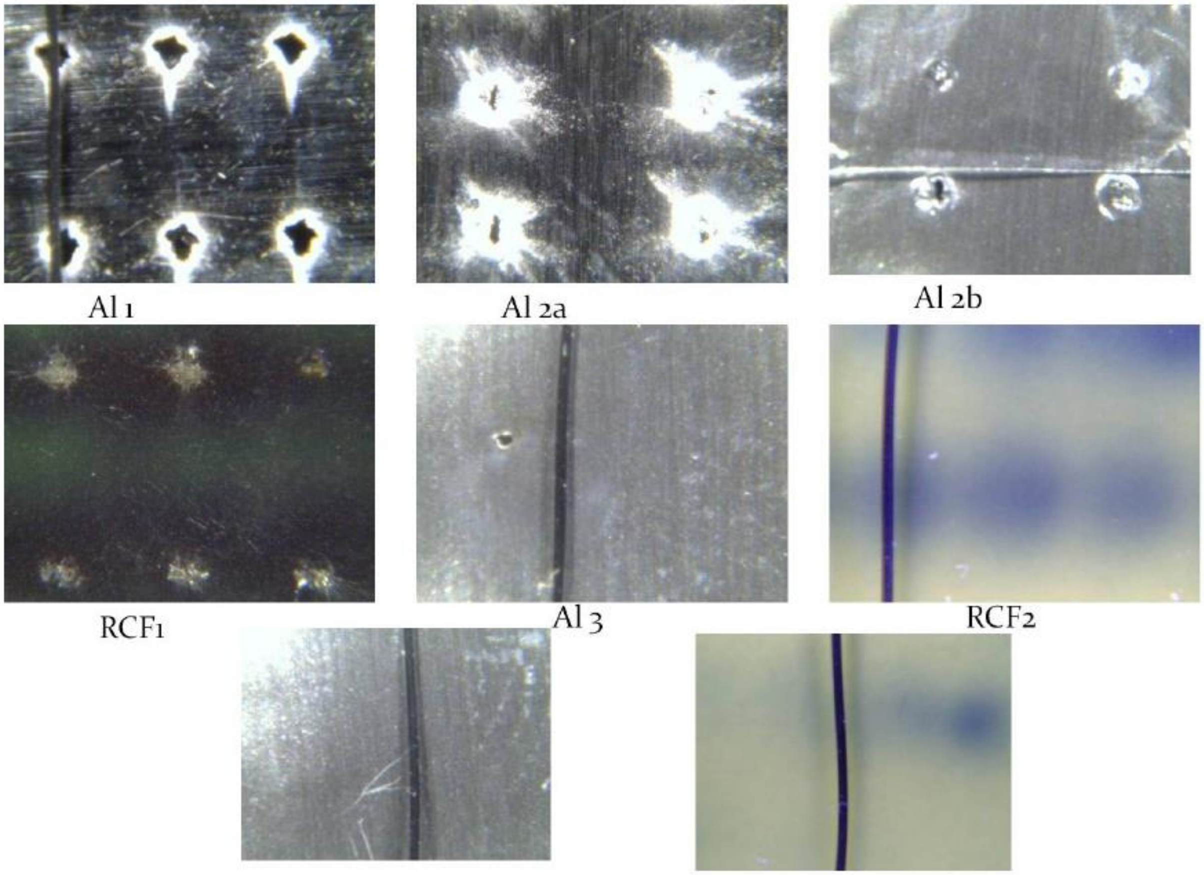


Figure 10: Al target after firing multiple laser pulses



Al 1 Al 2a Al 2b

RCF1 Al 3 RCF2

Al 4 RCF3

Figure 11: Laser beam interaction tracks left on Al target, RCF and foils located between the RCF

Within 2-3 mm distance with respect to the target, a radiochromic film (RCF) package is placed. In between the RCFs, 10 µm thick Al foils are placed. Before the first RCF, on half of the interaction area, two layers of 10 µm thick Al are placed, while the other half hosts three Al foils. Traces left on first RCF could be the outcome of both accelerated electrons, protons and X rays. As the maximum intensity in the focus is around 10^{17} W/cm^2 we can assume that proton energy is lower than 1 MeV [C M Brenner, P McKenna, and D Neely, Plasma Phys. Control. Fusion 56 (2014) 084003]. Hence the response of the last two RCFs is the outcome of electron presence. For a divergence angle of 20-30 degrees, 1-2 mm diameter electron spots are observed at 2-3 mm distance. Pictures of the target and some of the separating Al foils, together with the tracks left on the RCFs are presented in Fig. 11. We emphasize that the Al foil located between RCF1 and RCF2 bears only one hole, while the Al foil located between RCF2 and RCF3 shows no trace. The magnification is identical for all pictures and the wire used as reference has a 200 µm diameter. The Al1 foil represents the target, while Al3 and Al4 are the aluminium foils located between RCF1 and RCF1, and RCF2 and RCF3 respectively. Al2a and Al2b represent front and rear views, respectively, of the aluminium foils located in front of the first RCF.

This first series of results obtained for the first time at CETAL enable us to approach future experiments in a Cartesian manner. These experiments will mainly consist in implementing the laser pulse-electron coupling, with an aim to emphasize the concept of polaritonic transport of the relativistic electron packages, resonant with a very high power laser pulse.

Conclusions

We consider the objectives of the phase have been fulfilled. The project is developing in a straightforward manner, progress was made towards the existing international partnerships and new international cooperations were established, particularly focused on space applications of very high power lasers. Moreover, the visit performed at CETAL by the General Director of the European Space Agency had a positive impact. As an outcome, new collaborations were outlined both on Radiation Hardening applications using laser accelerated particles and on the interaction between high power lasers and space debris, a domain which is complementary to our studies concerning interaction between femtosecond, very high power lasers and matter.

A paper was published in an ISI journal and a Patent Application was submitted to OSIM. An invited lesson on „Space applications of very high power lasers" was another outcome of the project. Niche issues were identified which enable integration of our team at an increased level of competitivity in the international and national groups.