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ABSTRACT

Laser-induced breakdown spectroscopy (LIBS) consists in optical emission spectroscopy of a laser-induced plasma. Extensive studies have been carried out investigating the influence of the parameters affecting the analytical LIBS signal. This signal is highly dependent on the amount of vaporized matter and the degree of ionization, which can change as a function of the laser parameters (pulse duration, wavelength, energy, focusing conditions) and target properties (thermal conductivity, reflectivity, melting and vaporization temperature, etc.) as well as the surrounding atmosphere (pressure and composition). Among these parameters, the ones involved in the process of plasma formation such as the focusing conditions play an important role. For example, the characteristics of the laser-induced plasma are a function of the spatial and temporal behavior of the laser energy distribution at the location of plasma formation. During online LIBS measurements, we found out that some short as well as longer term fluctuations can be observed even where the LIBS measurement is carried out on the surface of liquid sample. In an effort to identify a possible correlation between the laser beam properties and the measured fluctuations, we have investigated the temporal and spatial structure of the laser energy distribution in the target plane.

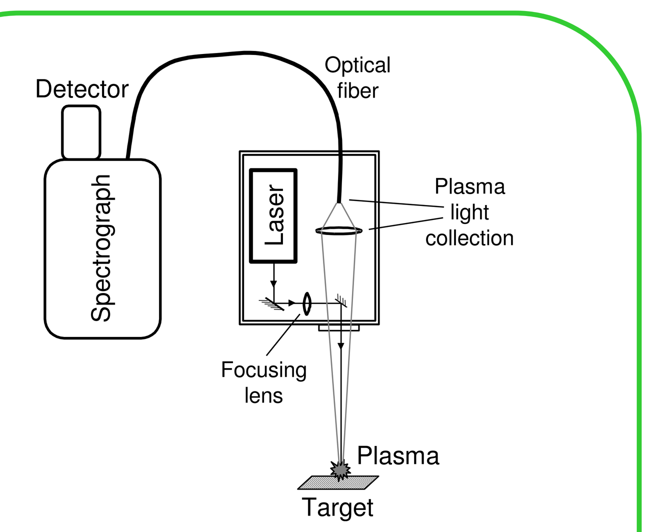
METHODOLOGY AND EXPERIMENTAL PROCEDURE

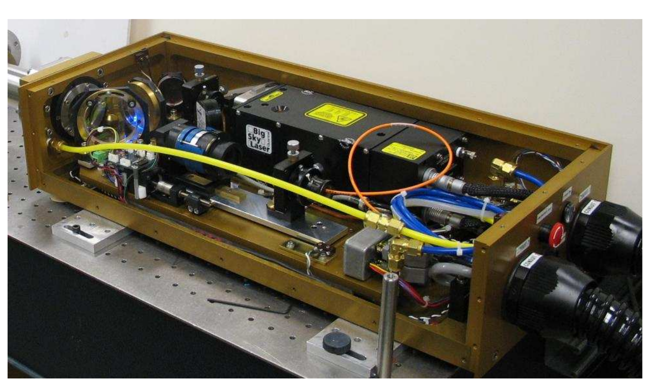
• Measurements were performed with the help of a developmental LIBS probe designed and assembled at the IMI. The probe is equipped with a Q-switched Nd:YAG laser (Quantel CFR400-GRM) at 1064 nm delivering 300 mJ per pulse; the maximum energy in the target plane is approx. 200 mJ, with a calculated beam spot diameter of ~500 µm.

• A laser beam analysis system consisting of a 2D camera with frame grabber and interface board was used to acquire the intensity and energy profiles of the attenuated beam in the target plane.

• The temporal profile of the laser pulse was also recorded using a fast Si photodetector looking at the light diffused by a reflecting surface located on the beam path downwards the focal (target) plane.

•Data was acquired as a function of time following a cold start of the laser.





LIBS probe configuration

SCHEMATIC OF THE EXPERIMENTAL SETUP

Equipment for measurements:

•Coherent's Digital LaserCam IIID ½ in., with BCUBE beam cube pickoff and UV C-VARM continuously variable attenuator

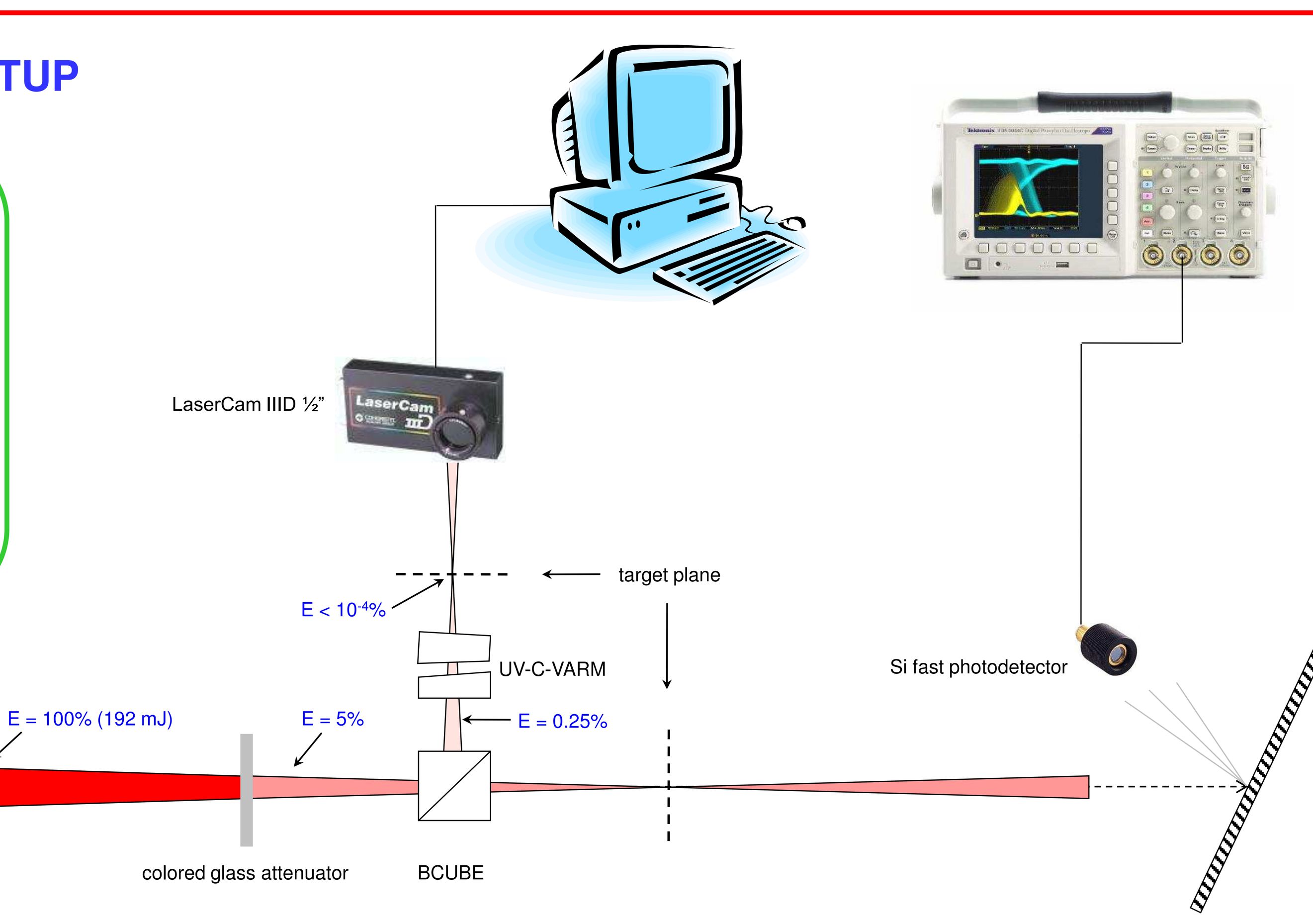
•ThorLabs' PD10A fast Si photodetector

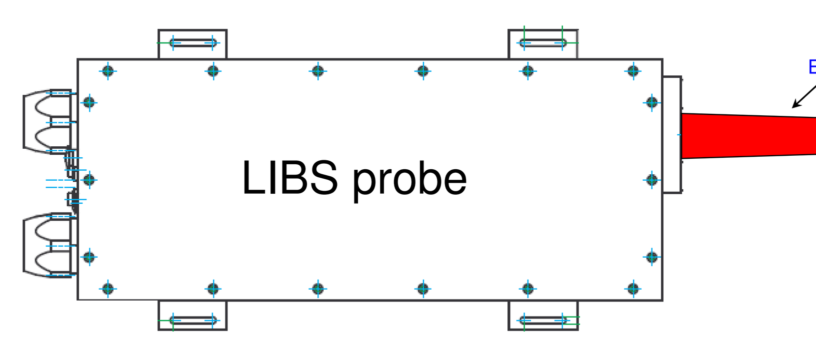
•Schott's NG9 colored glass attenuator, 4.9% transmittivity @ 1064 nm

•Digital oscilloscope, PC

LaserCam IIID specifications:

Resolution		Horz.	Vert.
Frame Mode	µm	8,5	9,8
Full-Field Mode	µm	17	19,6
Half-Field Mode	µm	34,1	39,3
Minimum Beam Size	µm	340	400
Maximum Beam Size	µm	4000	
Dynamic Range		>1200:1	
Pulsed Saturation	nJ/cm²	9,1	

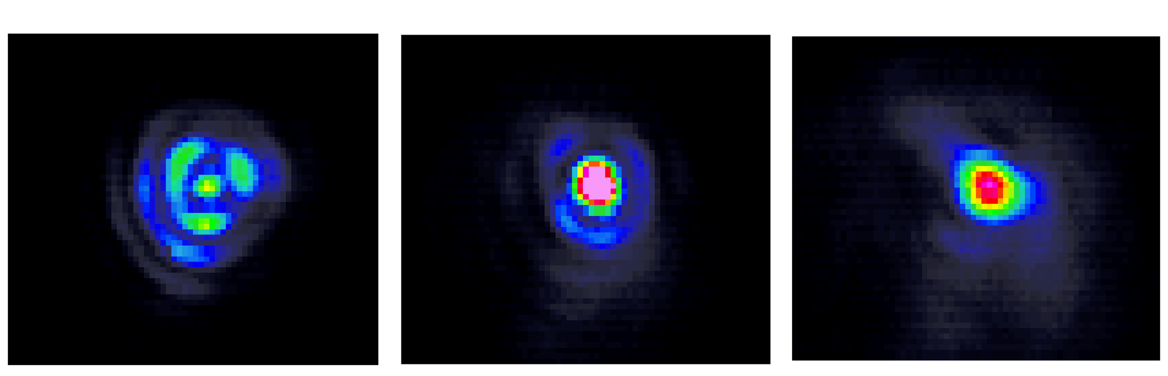




RESULTS

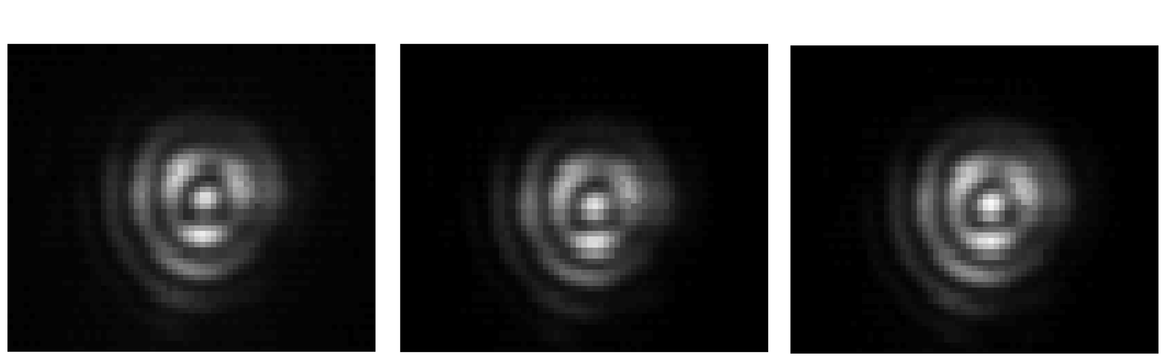
SPATIAL ENERGY DISTRIBUTION MEASUREMENTS

First, the energy profile of the beam has been measured by the LaserCam in a plane perpendicular to the beam axis at the target plane, as well as at some distance before and after the target plane:

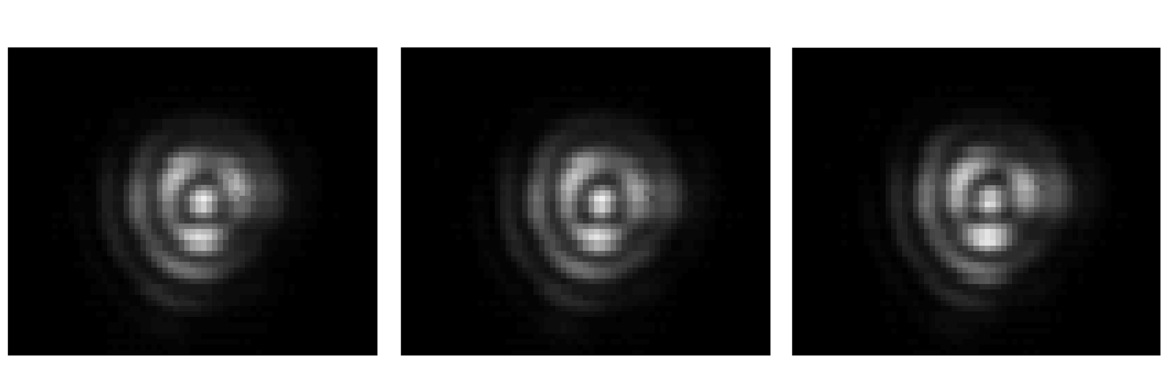


1 cm before target plane diam.[95%] = 750 µm | in target plane diam.[95%] = 600 µm | 1 cm after target plane diam.[95%] = 845 µm

The transverse beam mode in the target plane is well described by a gaussian mode distribution. In a second step, we proceeded to a cold start of the laser unit, and the beam profile was measured and recorded at regular intervals for an hour. The camera was set at 1 cm before the target plane; the larger energy distribution thus achieved allows for a better identification of any mode variation with time. Some of the recorded profiles appear below:

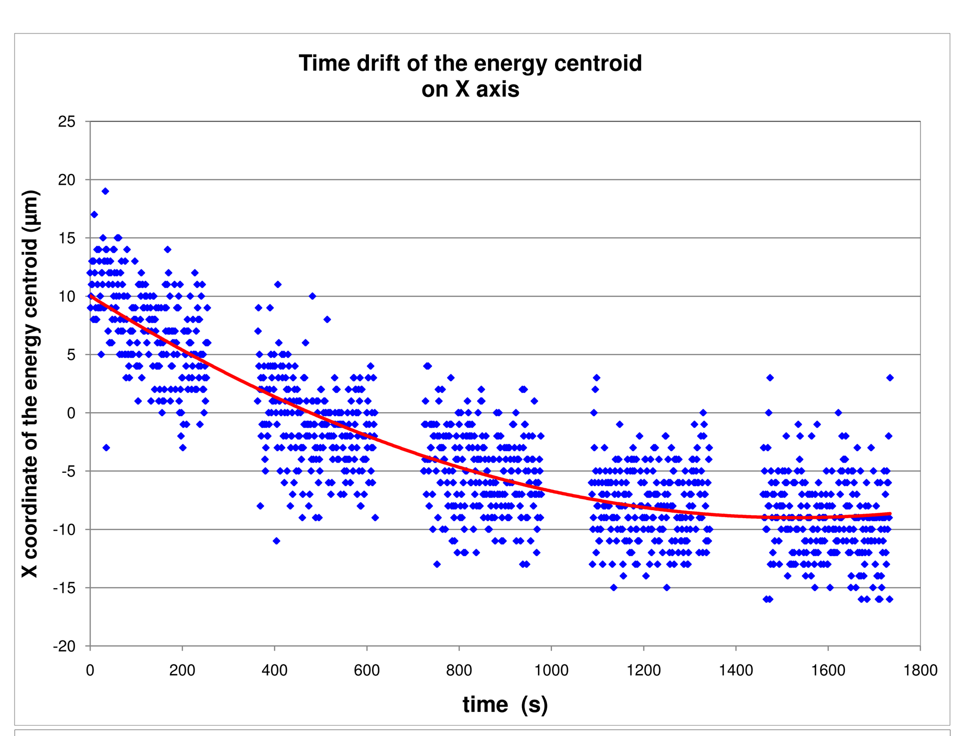


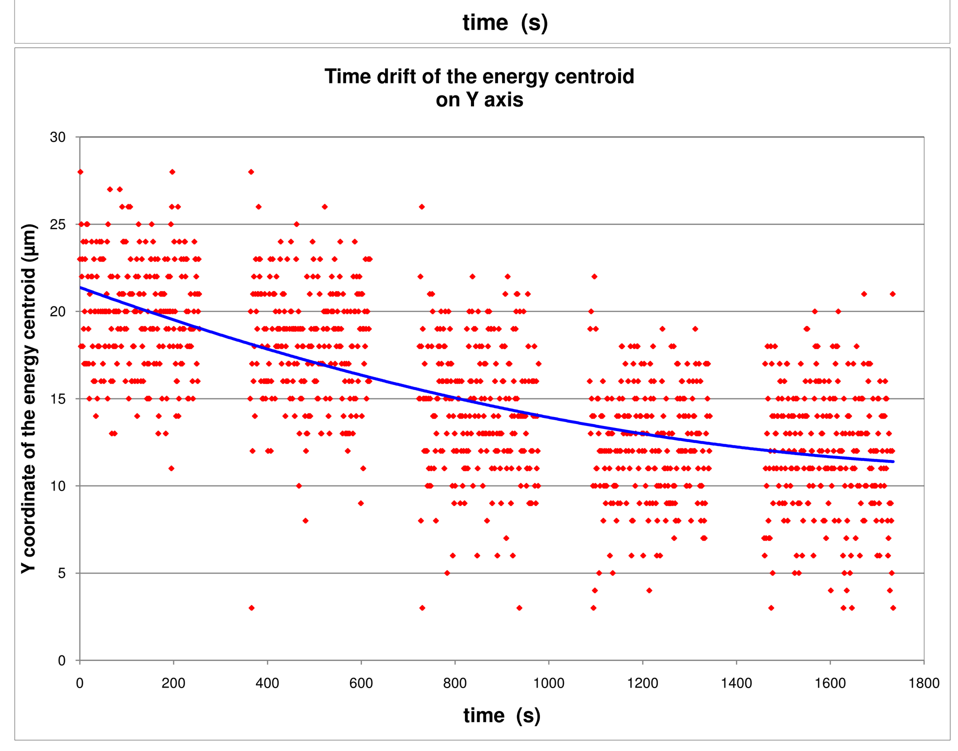
00 min. 00 sec. | 02 min. 30 sec. | 04 min. 15 sec.



10 min. 00 sec. | 20 min. 00 sec. | 40 min. 00 sec.

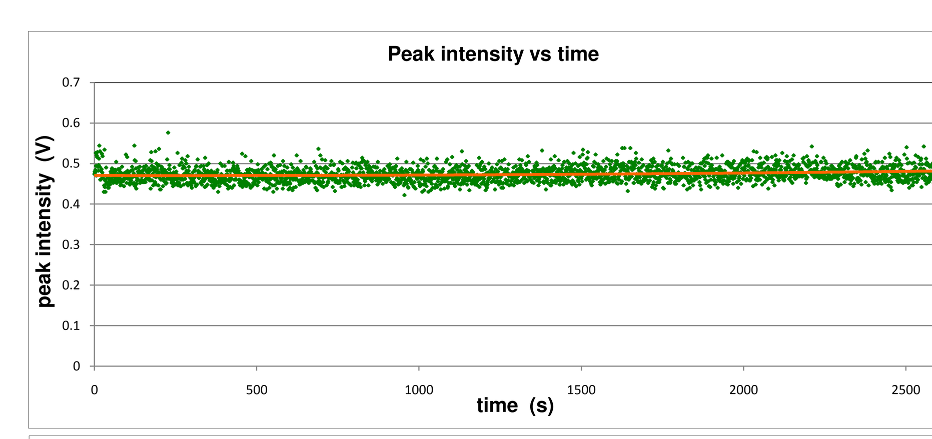
There was no significant variation of the total energy in the beam nor any noteworthy modulation of the beam energy distribution observed with time for the whole series of measurements performed. In order to further characterize the dynamic behavior of the intensity distribution, we also performed an analysis of the evolution of the centroid of the energy distribution with time. The resulting graphs are shown opposite (the vertical gaps with no data result from data transfer operations between the camera and the PC):

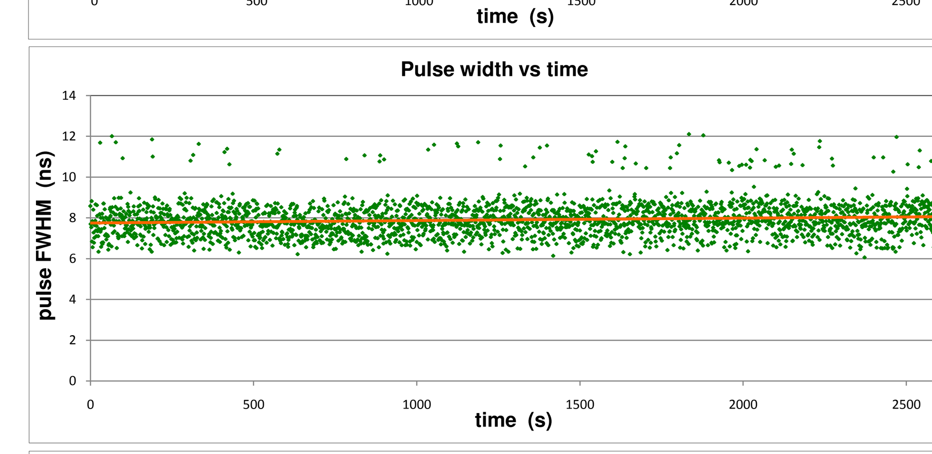


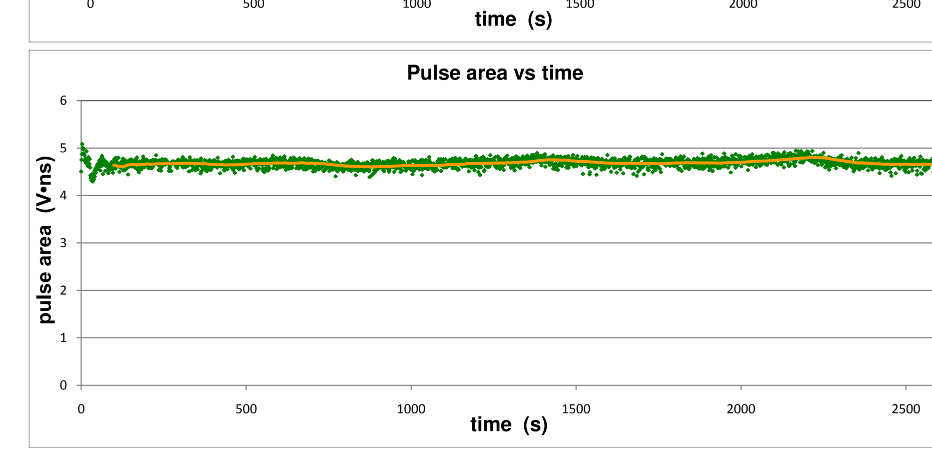


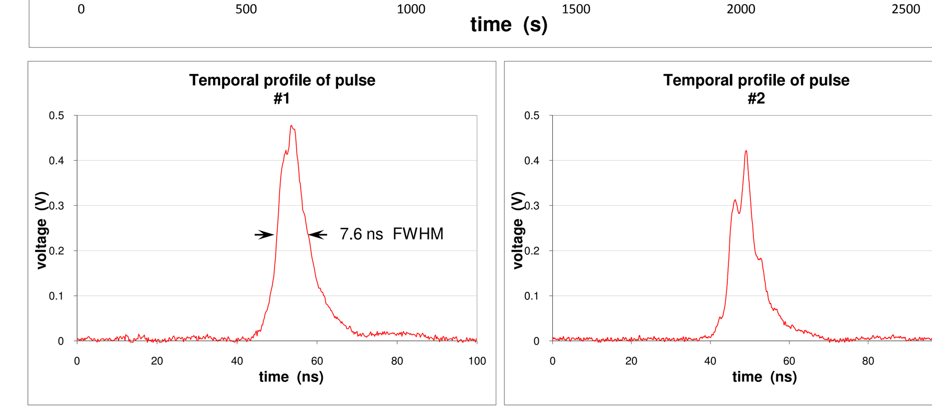
The measured average centroid drift is 19 µm on X and 10 µm on Y, corresponding to an effective drift length of 22 µm. Taking the extreme values on each graph results in an effective length of 47 µm. Given the magnification factor of the collection optics (~ 0.2), this would correspond to an image drift of ~ 10 µm on the input side of the optical fiber. Such a smal drift could not account for the LIBS signal variations observed.

LIGHT PULSE TEMPORAL PROFILE MEASUREMENTS









The temporal profile of the light pulse has been measured and acquired by means of a fast Si photodetector, as illustrated in the schematic drawing of the experimental setup. Typical profiles are shown above. Note that the dip at the center of the pulse, as seen in profile #2, is the result of longitudinal mode competition (beating) in the laser cavity, since the cavity does not include any mode selector component. The pulse peak intensity, FWHM and area (proportional to pulse energy) values have been recorded as a function of time. Here again, no significant drift has been observed, indicating that the pulse total energy as well as peak intensity remain essentially constant over time.

CONCLUSIONS:

➢The analysis of the laser beam fluence and intensity distribution near the target plane did not allow to establish any significant correlation between the light field parameters and the observed time evolution of the LIBS signal in the experimental conditions prevailing for these trials.

➢We still expect however that a potential correlation exists between these parameters and the thermal evolution of the laser chamber cooling water. As a matter of fact, the water temperature was not monitored nor controlled during the trials. This can be achieved with the help of an external heater/chiller unit. This will be the object of the next trial phase.