The design and performance of an asymmetrical nozzle in Laser Wake Field electron acceleration

G. Andrianaki[1,2], A. Grigoriadis[1,3], I. Tazes[1,4], I. Fitilis[1,4], V. Dimitriou[1,5], E. P. Benis[1,3], J. Nicolos[2], N. Papadogiannis[1,5], M. Tatarakis[1,4]

1 Institute of Plasma Physics and Lasers, Hellenic Mediterranean University Research Centre, Rethymno, Greece

2 School of Production Engineering and Management, Technical University of Crete, Chania, Greece

3 Department of Physics, University of Ioannina, Ioannina, Greece

4 Department of Electronic Engineering, Hellenic Mediterranean University, Greece

5 Department of Music Technology & Acoustics, Hellenic Mediterranean University, Rethymno, Greece

Laser Wakefield is a method for the acceleration of electrons up to the GeV level, with applications of great importance [1]. Experimentally is realized by focusing an ultra-intense ($I>10^{18}$ W/cm^2), ultra-short (t~50 fs) laser pulse on an under-dense target. The parameters that interplay and lead to the tunability of the acceleration process are the laser pulse characteristics (e.g energy, pulse duration) as well as the gas density profile.

The gas density profile is defined by the gas used, the backing pressure, and the nozzle geometry. The importance of the gas density profile has been examined by many groups experimentally and numerically. One of the significant ideas is the plasma density down-ramp, which is reported to enhance the control over the electron beam quality [2,3]. Down-ramp refers to a modification of the gas density profile. In this case, the laser pulse initially propagates in a short high-density region, followed by a long lower density plateau. Between the high-density region and plateau, there is a down-ramp, where electrons are locally injected in the bubble. To achieve such a profile either a complex target is needed (multiple jets [2], blade [3]), or the design of a specific, non-symmetric nozzle [4].

We are working on the development of non-symmetric nozzles by conducting 3D computational Fluid Dynamic (CFD) simulations. Previously, we have studied conical nozzles, which were 3D printed and used in our experiments [5]. In this work, we examine advanced, non-symmetric nozzle designs which are also 3D printed and tested. The Stereolithography (SLA) printing technology is selected due to the high level of detail demanded. The nozzles at their base follow the circle geometry of the valve, and toward the tip is elongated in one direction creating an asymmetric ellipse while at the other side become flat, as shown in Figure 1a.

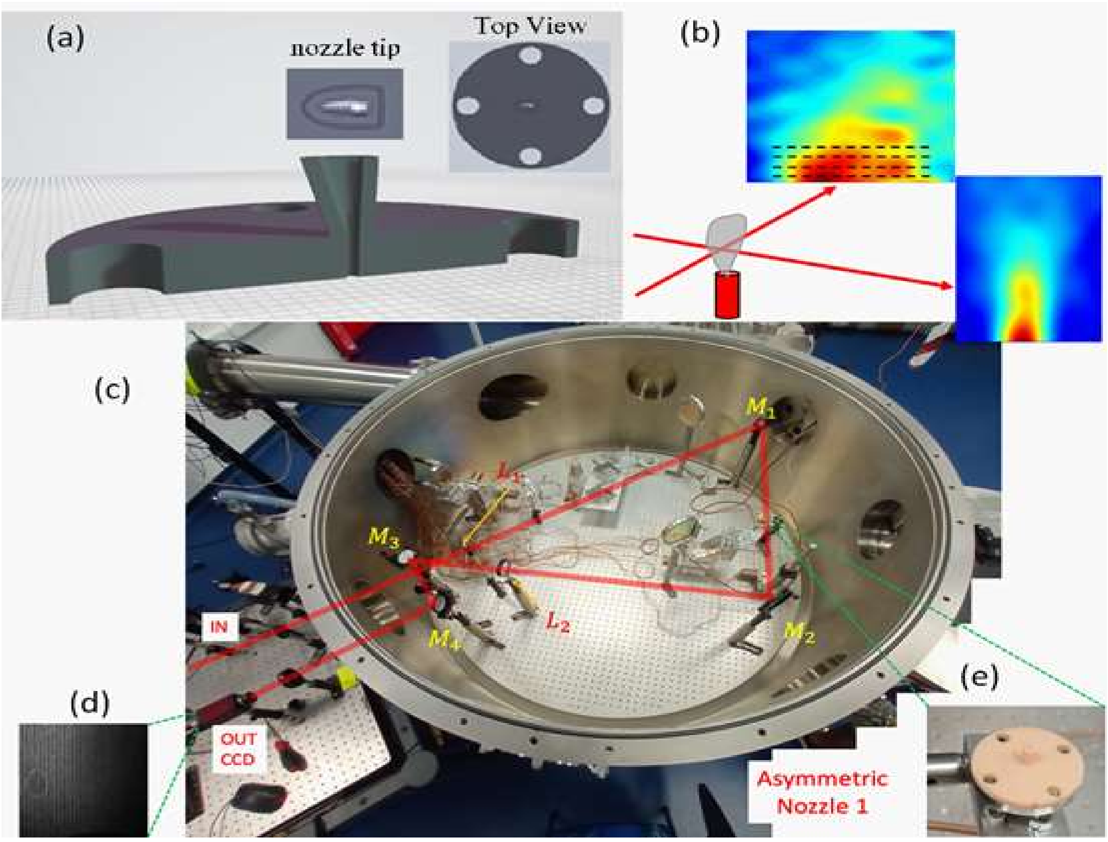

Figure 1: (a): Section and top view of the non-symmetric nozzle (b): Sketch of the experimental technique implemented for tomographic reconstruction, (c) experimental chamber of IPPL, Nomarski-type interferometer set-up, (d) resulting interferogram, (e) magnification of target area

The set-up used for the characterization of the gas profile is the Nomarski-type interferometer is presented in Figure 1c. The operation principle is presented at [5]. Four different geometry nozzles were examined, three non-symmetric and one conical. The gas was Nitrogen at the range of 30-55 bars. For the interferogram analysis the software IDEA [6] is used. The phase sift is obtained following the same method for symmetric and non-symmetric nozzles. For the symmetric nozzles Abel Inversion is used to obtain the particle density (particles/cm^3). For non-symmetric density profiles, we apply a tomopraphic reconstruction method in IDEA, called filtered back-projection based on the mathematical procedure of convolution. For this method at least 3 interferograms in equidistant angles from 0 to 180 degrees are necessary. However, if the experimental setup is unsuitable for that, the software permits to interpolate the results of non-equidistant angles. The electromagnetic valve (Parker) was connected to the gas supply through a metallic pipe and was difficult to rotate it, thus the angles obtained were 0°,47°,70°,90° and their supplementary angles 180°, 133°, 110°. Their resulting phase sifts were interpolated in 100 equidistant angles. Then the convolution procedure was applied, and the results shown in Figure 2 are 2D density maps at various distances above the tip of the nozzle 1. In Figure 3 are lineouts taken from them along the black line (the assumed laser direction for the LWFA), together with a lineout for a conical nozzle of 3 mm exit at distance 200 μm above the tip.

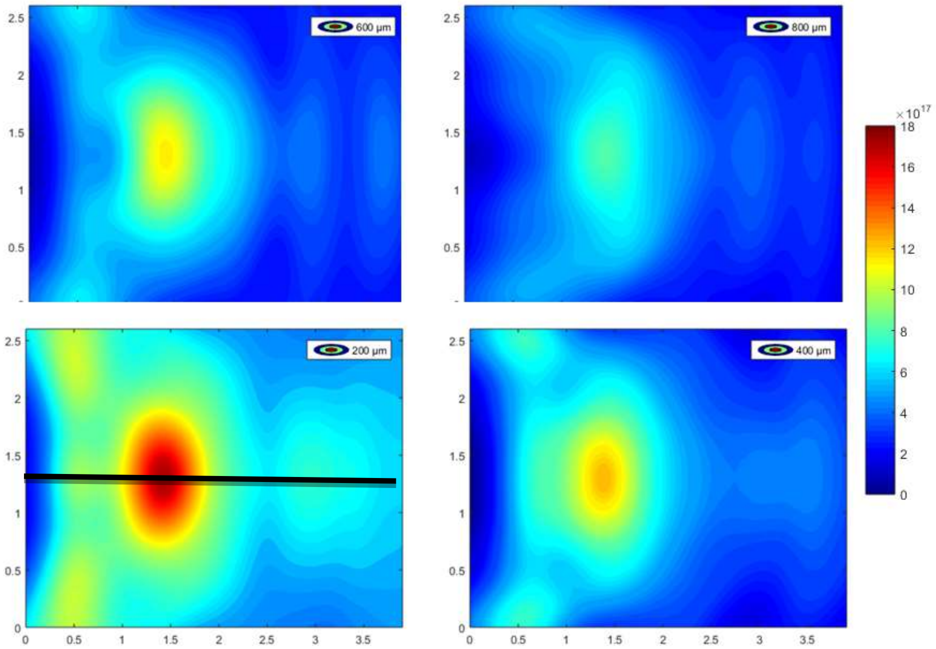

Figure 2: Tomographic reconstruction using IDEA software. Density maps in four different distances above the nozzle's tip (200-800 μm). Nitrogen at 30 bar backing pressure is used.

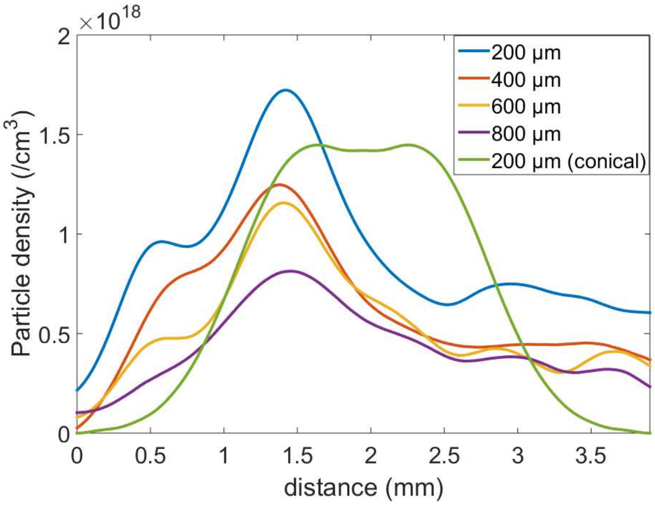

Figure 3: Lineouts taken from the four maps of Figure 2 along the assumed LWFA direction (black line in Figure 2). Green line is for a conical nozzle of 3mm exit diameter, at the same gas pressure.

The angles supported by our set-up are few and none of them in the area of small angles. Thus, the resulting reconstructions which are derived from interpolated data include "artifacts".

The non-symmetric Nozzle 1 at 30 bar backing pressure shows a complicated density profile, with a long peak and a long low-density plateau. Different nozzles have been designed and constructed, while their measurements and analysis, for different range of backing pressure, are in progress. The resulting profiles will be further examined via PIC simulations, while LWFA experiments are planning to be performed.

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