

# DEVELOPMENT OF AN INJECTOR AND A MAGNETIC TRANSFER LINE IN THE FRAMEWORK OF CILEX

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## Abstract

Laser plasma accelerators (LPAs) have proven their capability to produce accelerating gradients three orders of magnitude higher than RF cavity-based accelerators. The present challenges of LPAs are to achieve the beam quality and stability required by users and to show the feasibility of plasma staging for high-energy applications. As one of the experiments planned at the PetaWatt laser APOLLON facility, currently under construction in France, aims at testing the two-stage scheme, a dedicated plasma injector which will be used as the first stage has been developed and tested at the UHI100 facility at CEA Saclay. The electron source, as well as the beam characterization line, will be presented and the first results will be discussed.

## INTRODUCTION

Laser plasma acceleration based on the laser wake-field mechanism is able to create longitudinal accelerating electric fields as high as a few 100 GV/m [1]. Studies performed with a few tens of TW to PW laser systems have demonstrated electron trapping and subsequent acceleration in nonlinear regimes of interaction called blow-out or bubble regimes [2]. Accelerating fields in the 10-100 GV/m range are typically achieved over a few millimeters, and have been shown over a centimeter scale length to produce multi-GeV bunches [3].

Although the ultra-high accelerating gradients regimes of laser plasma accelerators are extremely attractive for the development of accelerators to expand the energy frontier in High Energy Physics, several aspects, linked to the performance of laser systems and to the control of acceleration physics, tend to be in favor of regimes of acceleration with lower accelerating gradients (1-10 GV/m). The energy of accelerated electrons in these quasi-linear regimes can be increased through several successive accelerating laser plasma stages [4]. The current goal of this type of studies is to demonstrate the feasibility of laser plasma accelerator schemes producing electron bunches with controllable parameters, and scalable to higher energy by the addition of acceleration stages.

In this context, the objective of the DACTOMUS (Diagnostic And Compact beam Transport fOr MUltiStaged laser

plasma accelerators) project is to develop a compact transport and focusing system and the associated diagnostics for an electron beam generated in a laser plasma accelerator.

## ELECTRON SOURCE ELISA

The physics of electron acceleration in a laser plasma accelerator with external injection is a key topic that will be studied with the CILEX facility when two PW beams from the laser Apollon-10P become available [5]. In the meantime, within the DACTOMUS project, the instrumentation necessary for the focusing and diagnostics of electron bunches has been built and is being tested with an electron source generated by a compact laser plasma accelerator operating in the non linear regime. The control of electron injection in the accelerating structure is performed by controlling the ionization of nitrogen at impurity level in a dihydrogen gas.

The electron source (or first stage) is produced by ionization controlled electron trapping [6, 7] and acceleration in the laser driven wakefield inside a gas cell developed by the LIDYL-LPGP-LULI consortium at the CEA-Saclay UHI100 laser facility in the frame of the ELISA project (Electron injector for compact staged high energy accelerator). A photograph of the gas cell and an example of the electron density profile are shown in Fig. 1. The pressure inside the gas cell can vary from 100 to 500 mbar and the gas cell length can vary from 0 to 10 mm. Fluid simulations were performed with OpenFOAM [8] and the solver SonicFoam in order to obtain a realistic profile of the gas density in the cell. The density decreases at the edges of the gas cell on the laser propagation axis, which has an impact on the non linear focusing of the laser at the entrance of the cell [9].

The density profile is then used as an input for the Particle-In-Cell (PIC) simulations with WARP [10]. The results [9] show that the position of the laser waist in the gas cell has a significant impact on the electron beam quality. An example of electron energy spectrum achieved at UHI100 is given in Fig. 2. This spectrum has been obtained with a laser pulse of duration 24 fs, focused to  $I_{\max} = 8.4 \times 10^{18} \text{ W/cm}^2$  in 99% $\text{H}_2$  + 1% $\text{N}_2$  gas contained in a 500- $\mu\text{m}$ -long cell, to achieve an electronic density of  $N_e = 7.5 \times 10^{18} \text{ cm}^{-3}$ . Most of the charge of the electron beam for energy greater

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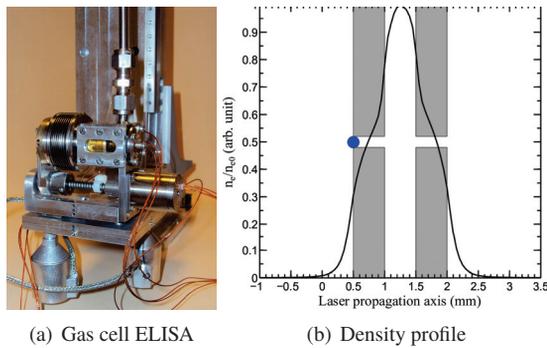


Figure 1: Photography of the gas cell ELISA on the left. The density profile is given on the right.

than 30 MeV is in the range 50-100 MeV. The energy is peaked at  $68 \pm 11$  MeV. A transport line downstream of the gas cell optimized for an intermediate energy of 72 MeV was experimentally tested.

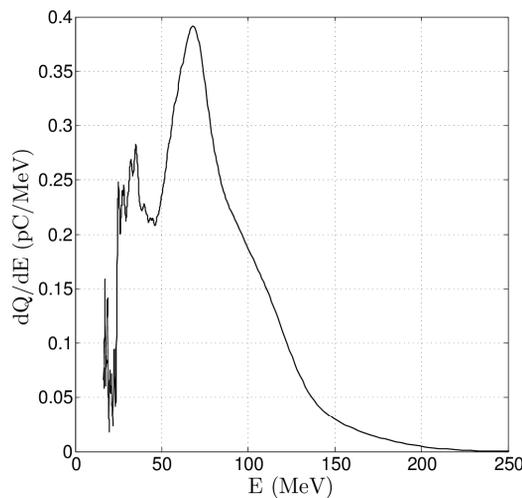


Figure 2: Energy spectrum of the electrons at the exit of the gas cell for the parameters given in the text.

## TRANSFER LINE

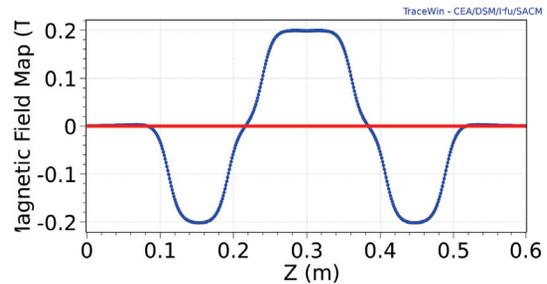
The aim of the transfer line downstream of the gas cell is to characterize electron beam properties such as energy distribution and angular divergence. The transfer line must be:

- compact: the total length must be less than one meter;
- made of permanent magnets. Indeed, the magnets must be located in a vacuum chamber and the lack of space forbids using electromagnets;
- little sensitive to electron beam pointing. In that aim, the transfer matrix from the gas cell to the observation point has the values  $R_{12} = R_{34} = 0$  for the reference energy of 72 MeV.

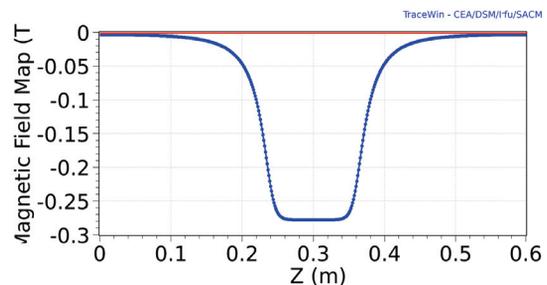
Moreover, the implementation implies a minimum value of the distance between the first magnet and the gas cell of 160 mm. We have chosen to use a triplet instead of a doublet for the focusing to reduce the beam size in the

quadrupoles (and thus the chromatic effects) and to have similar values of  $R_{11}$  and  $R_{33}$  at the observation point. A dipole is then inserted downstream of the triplet to do the energy separation. The displacement of the dipole is motorized, which enables to make measurements with the triplet alone to check the laser and electron beam pointing axis. The triplet is made of two 80-millimeter-long focusing quadrupoles and one 120-millimeter-long defocusing quadrupoles with a distance of 48 mm in between. The length of the quadrupoles was chosen to use the same cubic permanent block of  $40 \times 40 \times 40$  mm<sup>3</sup>. Angular clipping at 18.8 mrad (5 mrad) is achieved by adding a collimator at the triplet entrance of diameter  $\phi = 6$  mm ( $\phi = 1.5$  mm, respectively). The magnetization of all blocks is assumed to be the same. The magnetic fields of the triplet and of the dipole were simulated with Opera software [11] and are shown in Fig. 3. To correct the magnetization defects in the triplet, the pole transverse positioning is corrected by a system of individual wedges. The residual magnetic field on the axis is then corrected to a few Gauss.

The implementation of the line at the UHI100 facility is shown in Fig. 4. The triplet is located in the same vacuum chamber as the gas cell, located at the center of the chamber. A second vacuum chamber contains the movable dipole and the lanex screen. The distance between the dipole and the triplet was imposed by the constraint of a separate chamber.



(a) Triplet



(b) Dipole

Figure 3: Magnetic field along the axis for the triplet (at  $x = 10$  mm) and along the dipole.

## FIRST RESULTS

The experiments have shown that the electron beam centroid was well stabilized on the lanex screen from shot to shot. Typical examples of what is observed on the lanex

Table 1: Parameters of the Line Geometry

Parameter	Value	Unit
Distance gas cell-triplet	160	mm
Triplet total length	400	mm
Distance triplet-dipole	186	mm
Dipole length	120	mm
Distance dipole-lanex	115	mm
Angle dipole-laser axis	5	deg
Angle lanex-laser axis	11	deg

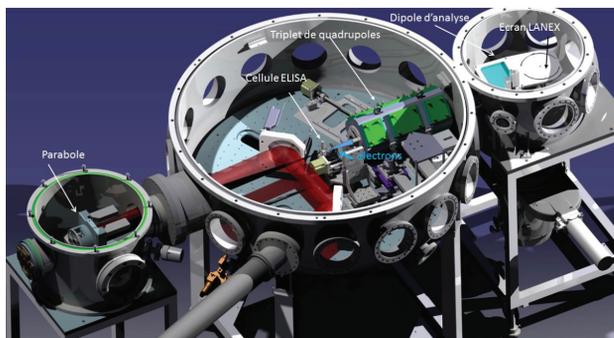


Figure 4: Implementation of the transfer line in the experimental area UHI100.

screen with and without the dipole are shown in Fig. 5. As expected, a beam pinching is experimentally observed at the position corresponding to the reference energy of 72 MeV. Several measurements were performed for different plasma conditions, for example by varying the gas pressure in the gas cell. The analysis of results is in progress and they will be published in a near future.

### CONCLUSION

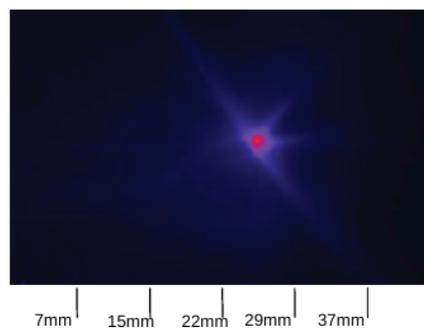
The electron source ELISA and the transfer line downstream are studied by the DACTOMUS project in the frame of Cilex. The expected spectrum, in agreement with PIC simulations, is in the range of 50-100 MeV. Accordingly, a transfer line has been optimized for a reference energy of 72 MeV. The implementation of the line at the UHI100 facility was described and first experimental results were given.

### ACKNOWLEDGEMENT

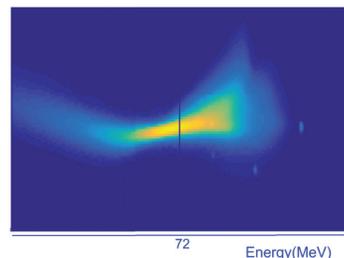
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(a) Triplet alone



(b) Triplet+dipole

Figure 5: Examples of screen capture observed on the lanex screen without and with the dipole.

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