PhD Open Days

Plasma Waveguides for Laser Wakefield Accelerators

PhD PROGRAM IN PHYSICS

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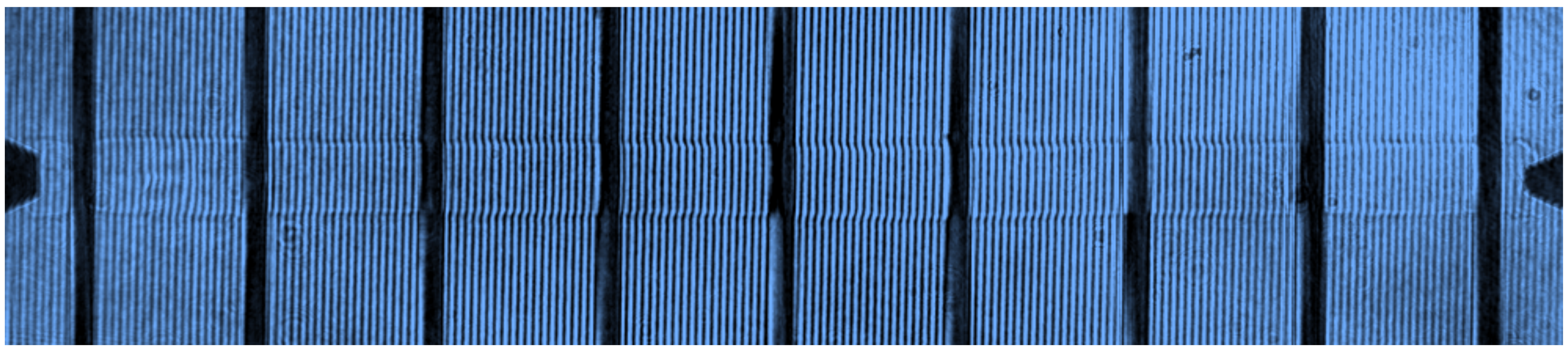


Figure 1. Interferometer of the plasma channel produced in our devices.

Motivation

The acceleration gradient in conventional (radio-frequency) accelerators is limited by damage threshold to approximately 100 MeV/m. Therefore an acceleration distance of 10 m is necessary to accelerate an electron to 1 GeV. However, in plasmas, the electric field of electrostatic waves allows acceleration gradients in the order of 1 GeV/cm. Consequently the same acceleration of 1 GeV could be obtained in a 1000 times shorter acceleration length. Compact accelerators, where a high-intensity laser drives a plasma wakefield that can trap and accelerate electrons, have been proved in recent years and electrons with energies up to 4.3 GeV have been obtained.

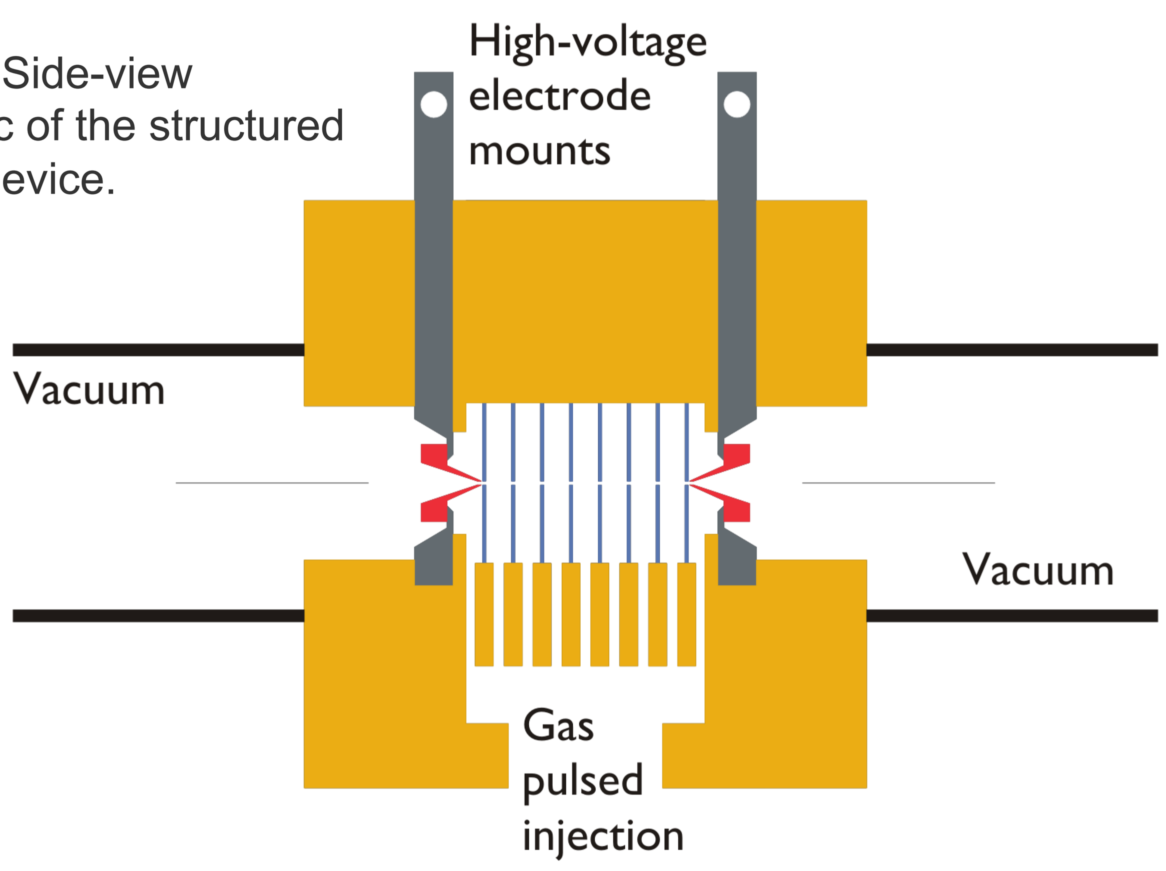
The effective acceleration length of a laser wakefield accelerator (LWFA) is usually limited to few millimetres by the diffraction of the leading edge of the laser pulse, among other factors. This reduces both, the efficiency and the maximum energy gain. Therefore, there is a high interest in shaping the radial plasma density profile inside a gas cell to reduce diffraction, and hence, increase the acceleration length.

We propose a technique and a device capable to produce plasmas with a radially parabolic density profile and minimum density on axis as required for guiding a high-intensity laser for distances in the centimetre scale.

For the impatient

The fig. 1 shows an interferometer of the plasma channel produced in our device and fig. 2 presents a side-view schematic. An electric discharge is send between the apexes of the two conic electrodes. The initial plasma line evolves into a plasma channel that will expand radially in the cell. A high-intensity laser pulse can be delivery through one of the device entrances along a specific time window. The channel will act as a graded-index optical fiber for the laser pulse, guiding it for a distance as long as 2 cm. We measure energies up to 2 GeV with this device.

Figure 2. Side-view schematic of the structured gas cell device.



The device

A side-view schematic of the developed structured gas cell device is presented in fig. 2. The gas cell contains a sequence of thin dielectric plates made of alumina with micro-machined small diameter apertures on the guiding axis. The purpose of the dielectric aperture sequence is to set the initial plasma diameter and position in space, since the electric discharge will be forced through these apertures.

We use hydrogen as background gas in order to achieve total ionization and the gas injection is controlled by a fast valve synchronized with the laser and the discharge. The fast gas injection helps in minimizing the amount of gas released into the vacuum chamber. We obtained a reproducible gas injection.

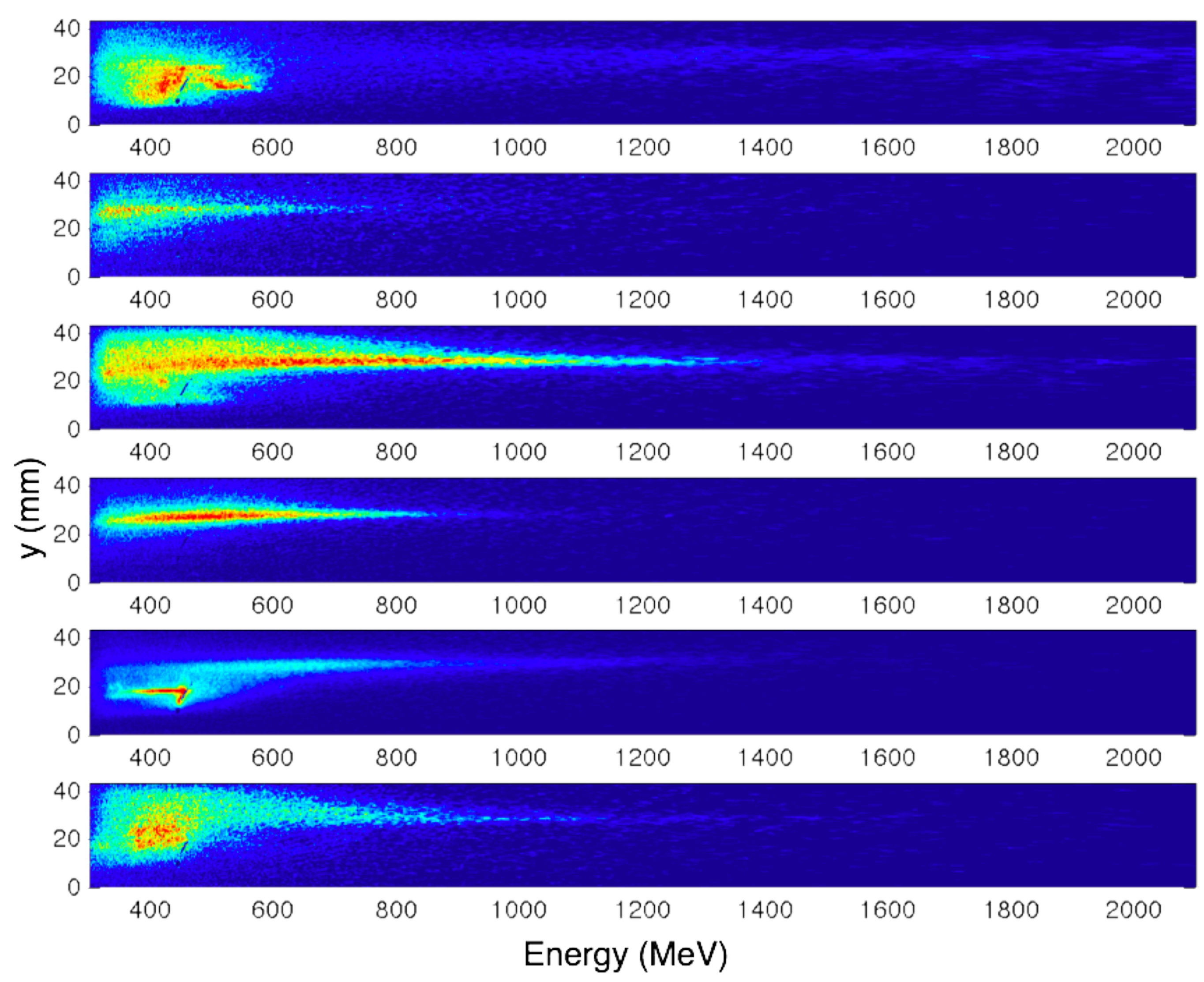


Figure 3. Few electron spectra obtained using a 4 cm device.

The LWFA experiment

We setup an one-stage LWFA experiment operating in self-injection. Devices of different length were tested using a f/20 laser beam. The laser energy on target was about 4.7 J resulting in an estimated initial intensity of a_0=1.5. For that intensity we can expect a limited amount of injected charge.

Fig. 3 presents few electron spectra obtained in this experiment. The gas cell was 4 cm long and the plasma density roughly 8×10^{17} cm^3. We can see that a small amount of charge is accelerated to close to 2 GeV (although the error is considerable). The origin of this charge is unknown, ionization injection from debris coming from damage of the gas cell cannot be excluded for example. Anyway we can conclude that at least an accelerating field of 500 MeV was sustained for a length of a few centimetres.