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Propagation of intense laser pulses in an underdense plasma.

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The new generation of short duration lasers provides pulses in excess of the terawatt level, that can be focused up to 10^{18} W/cm^2 [1]. For such an intensity, the quiver motion of a free electron becomes relativistic and numerous new physical effects are expected, such as harmonic generation [2], particle acceleration [3] and relativistic self-focusing [4,5]. In order to observe these effects resulting from laser-electron interaction, a high electron density (N_e) is required. In fact, with regard to the small laser-electron interaction cross-section, a large number of electrons is needed for any significant field emission. Furthermore, using a high density, a collective response of electrons is driven that induces intense longitudinal fields required to accelerate particles. A significant change of the refractive index should also occur that will influence beam propagation if the electron density is large enough.

Relativistic self-focusing results from an increase of electron mass ($m = \gamma m_0$) induced by the motion in the intense laser field. The refractive index n of the medium, $n = \sqrt{1 - N_e / \gamma N_c}$, has then a maximum on the beam axis and the effect is similar to the one produced by a converging lens. Calculations show that a critical power is required in order to overcome classical diffraction ($P_c = 2\times10^{10}\ N_c/N_e$) [5-7]. We present here experimental study of propagation for laser powers close to this critical power.

The laser beam is focused into a vacuum chamber onto a 3-mm long, pulsed hydrogen jet ($N_e \approx 10^{19}$ cm^{-3}). At the output of the chamber the laser beam is collimated onto a CCD camera. A pair of lenses image the perpendicular Thomson emission onto a second camera.

Far field patterns are shown in fig. 1 for a laser power of 0.5 TW, which is under the critical power required to self-focus (2 TW).

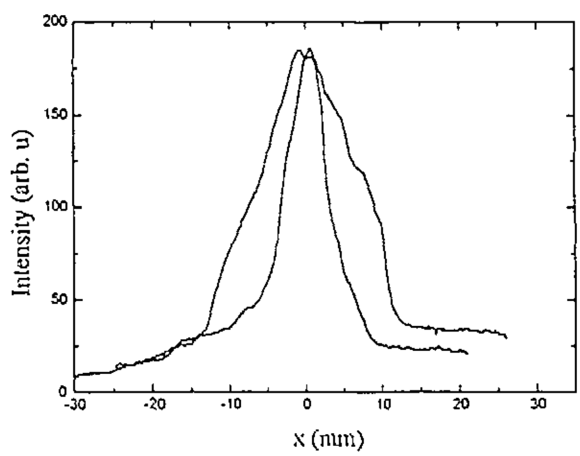

Fig. 1. Laser beam profile at the output of the experimental chamber. Solid line: beam profile without interaction. Dashed line: The beam is focused into the hydrogen gas jet. The beam radius is significantly reduced after propagation in hydrogen for laser power (0.5 TW) below the critical power required for relativistic self focusing (2 TW).

The beam radius is reduced by a factor of three in the presence of hydrogen. This result shows clearly that even below the critical power required for self focusing a significant reduction of the output beam divergence is obtained.

Fig. 2 shows the evolution of the Thomson emission profile with the input laser power.

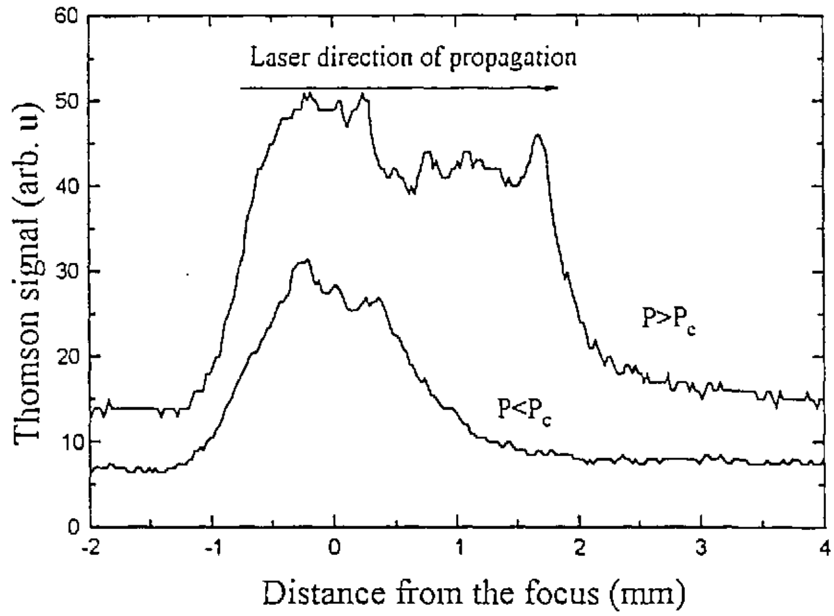

Fig. 2. Profile of the Thomson emission detected perpendicularly to the laser propagation direction. Solid line: $P = 1.5\times P_c$. Dashed line: $P = 0.1\times P_c$. The beam is guided when the laser power exceed the critical power.

A large increase of the emitting length is visible for power above the critical power. This length is limited by the jet size and corresponds to five times the Rayleigh length. This guiding of the pulse is in good agreement with numerical simulations and other experiments [8].

In conclusion, we have shown that an underdense plasma is able to significantly reduce the divergence of an intense laser pulse. The propagation mode demonstrated is in good agreement with theoretical predictions of relativistic self focusing.

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Propagation d'une impulsion laser intense dans un plasma sous-dense.

Nous présentons les résultats expérimentaux obtenus lors de l'étude de la propagation d'un faisceau laser intense dans un plasma sous-dense. Deux séries d'expériences, l'une menée à Saclay et l'autre à Limeil, montrent que la propagation du faisceau est altérée par des effets relativistes.