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Propagation of super-intense and ultra-short laser pulses in plasmas

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Abstract

The propagation of super-intense and ultra-short laser pulses in plasmas is a main concern in several applications of the laser-plasma interactions, from Inertial Confinement Fusion (ICF) to High Energy Physics (HEP). During the propagation in the plasma the light beam deeply changes its parameters due the onset of non-linear effects, among them the relativistic regime of the electron quivering motion. These extreme conditions are suitable for the electron acceleration in high field gradient, opening the way for the realization of compact secondary sources of X-gamma rays.

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1. Introduction

The CPA (Chirped Pulse Amplification) technique (Strickland and Mourou, 1985) of mode-locked fs laser pulses opened the way for the studies of the propagation of super-intense and ultra short laser pulses propagating in plasmas in unprecedented intensity regimes, overcoming 10^{18}W/cm^2. The electric field, associated to the intensity I,

$$E_{V/cm} \approx 27.5\, I_{W\cdot cm^{-2}}^{\frac{1}{2}}$$

largely exceeds the atomic field, so producing a very fast ionization of the matter (d'Humieres, 2008) in which the laser pulse is propagating. The free electrons of the plasma so produced oscillate under the action of the electric field with relativistic quiver velocity. The relevance of the relativistic effects can be evaluated considering the relativistic parameter *a*, from which the Lorentz factor γ depends:

$$\gamma = \left(1 + \frac{\alpha a^2}{2}\right)^{\frac{1}{2}} \quad \alpha = 1\,(lin.\,p.)\,;\,2\,(circ.\,pol.)$$

$$a = \frac{eE}{m\omega c} \approx 8.5 \cdot 10^{-10} \cdot I_{W\cdot cm^{-2}}^{1/2} \cdot \lambda_{\mu m}$$

The physical phenomena considered in the following paragraphs are not exhaustive to fully describe the interaction of super-intense and ultra-short laser pulses with the matter; therefore, due to the limited extension of the paper, I will restrict to the major effects relevant for the Laser Plasma Acceleration (LPA) experiments.

2. Plasma refractive index at laser relativistic intensities.

The laser, propagating in a plasma, induces a quivering motion on the irradiated electrons. When the relativistic parameter *a* approaches or overcomes the unity in the maximum of the radial intensity distribution of the laser (bell shaped), the electrons in the center of the laser beam are more "heavy" of the ones in the margins, as a consequence of their relativistic motion (γ>1) and the refractive index *n* becomes locally larger. So the laser beam bends due to the radial dependence of the refractive index on the local laser intensity. In fact, the plasma refractive index in the center of the laser beam becomes larger than in its margins, because the plasma frequency ω_{pe} depends on the Lorentz factor, related to the quivering motion of electrons in the laser electromagnetic fields.

$$n = \left(1 - \frac{\omega_{pe}^2}{\omega^2}\right)^{\frac{1}{2}} \qquad \omega_{pe} = \left(\frac{n_e e^2}{\varepsilon_0 m \gamma}\right)^{\frac{1}{2}}$$

In these conditions the plasma acts as a focusing lens that, concentrating the laser radiation, increases its intensity which in turns increases the refractive index effects, so producing a positive feed-back process of beam self-focusing. The onset of this physical process (Esarey, 1997) demands to overcome the critical value for the laser power:

$$P_{cr} = \frac{mc^5\omega^2}{e^2\omega_{pe}^2} \approx 17\left(\frac{n_c}{n_e}\right) GW$$

As we can see, the critical power decreases as the plasma density increases as a consequence of the major refractive effects. Once the relativistic self-focusing take place, the laser beam can be focused over distances much larger than the Rayleigh length, Z:

$$Z = \frac{\pi w_0^2}{\lambda_0}$$

where w_0 and λ_0 are the laser beam waist and the wavelength, respectively.

In Fig. 1 is reported the image of the Thomson scattering of the laser radiation at 90 deg, obtained in a recent experiment at Laboratori Nazionali di Frascati (LNF) in the frame of the PLASMONX (PLASma acceleration and MONochromatic X-ray production) (Piastra, 2011) project of the National Institute of Nuclear Physics (INFN). The PLASMONX Ti:Sapphire laser (λ_0=0.815μm), FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments), coming from the right, delivering in this experiment pulses of ≈1J in 30fs, was focused at an intensity $I \approx 6x10^{18}Wcm^{-2}$ on a N_2 gas jet, producing a plasma with an electron density $n_e \approx 10^{19} cm^{-3}$. The laser power (30TW) overcomes the relativistic self-focusing critical power, that come out to be $P_{cr} \approx$ 2.9TW. In these conditions, as it is apparent from the Fig.1, the laser pulse can be focused over distances largely exceeding the Rayleigh length, Z≈400μm. In the figure we can see two filaments due to the laser beam hot spots in the waist. Such beam imperfections were detected by imaging the magnified focal spot with a suitable optics system.

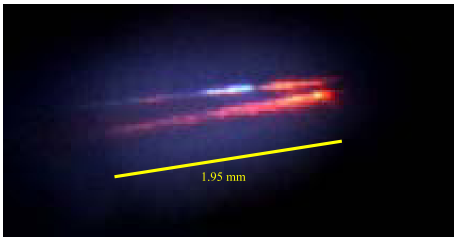

Fig.1. Evidence of relativistic-self focusing in the propagation of super-intense laser pulse in under-dense N_2 plasma.

3. Self Phase Modulation of the laser radiation.

Large and fast variation of the refractive index induced by an intense and ultra-short laser pulse deeply affects its spectrum and consequently the spectrum of the radiation emitted in the physical processes activated during the laser-plasma interaction, i.e., Second Harmonic Generation (SHG), Thomson Scattering (TS) and the different parametric instabilities as, for example, the Stimulated Brillouin Scattering (SBS) and the Stimulated Raman Scattering (SRS) (Afshar-Rad, 1991). In fact if we consider the relation between the laser angular frequency ω and the time derivative of the refractive index:

$$\phi = kz - \omega_0 t \quad \omega = -\frac{\partial \phi}{\partial t} = \omega_0 - k_0 z \frac{\partial n}{\partial t}$$

we find, for the propagation of a laser beam in a plasma:

$$n = \left(1 - \frac{n_e}{n_c}\right)^{\frac{1}{2}} \approx 1 - \frac{1}{2}\frac{n_e}{n_c} \Rightarrow \frac{\omega - \omega_0}{\omega_0} = \frac{z}{2cn_c}\frac{\partial n_e}{\partial t},$$

where n_c is the critical density for the laser frequency, c the speed of light in vacuum and z the plasma extent.

As we can see, in the case of further ionization induced by the laser beam during its propagation in a partially ionized plasma,

$$\frac{\partial n_e}{\partial t} \rangle 0$$

and blue shift of the laser radiation is produced due to the Self Phase Modulation (SPM) effects; while during the plasma channel formation, produced for example under the action of ponderomotive forces or relativistic self-focusing related to the beam intensity distribution, being

$$\frac{\partial n_e}{\partial t} \langle 0$$

the frequency shift, due to the SPM, is towards the red. The SPM of laser pulses can produce a very large modification of the original laser radiation. Let consider, i.e., the case of an intense pulse ($\tau = 40 fs$) of a Ti:Sapphire laser inducing, while it is propagating in a plasma extending for ≈5mm, a variation of the electron density $\Delta n_e \approx 10^{17} cm^{-3}$; the corresponding frequency variation is in this case quite large:

$$\frac{\omega - \omega_0}{\omega_0} \approx 1 .$$

Another case in which the SPM affects the spectra of the radiation related to non linear processes developing during the laser-plasma interaction is reported in (Giulietti, 1994), where spectra of forward emitted Second Harmonic (SH) light from laser interaction with filamentary plasmas have been experimentally studied. The experimental set-up was substantially the same as described in (Biancalana, 1993). A Nd:YAG laser (λ=1.064 μm) delivering up to 3J in 3ns pulses was used. The laser operated in a single-transverse but multi-longitudinal mode. Consequently the laser pulse was modulated in time by spikes of measured mean duration of about 50ps, as expected from mode beating in the oscillator cavity. The laser beam was focused by an f/8 optics onto a thin foil plastic target up to a nominal intensity of $5x10^{13}W/cm^2$. Foil thickness, laying in the range 0.5 to 1.0 μm, was chosen in order to allow the plasma to be well under-dense during the laser pulse. Rather regular modulations in the frequency domain have been observed into overall red-shifted spectra. The observed spectral features are consistent with SPM of the intense laser light in growing filaments. In fact very fast changes in the refractive index in the medium, where the wave itself propagates, are possible in the small structures generated by filamentation instability, where the high laser field depletes the plasma density in a very short time. As a consequence, the instantaneous laser frequency is modified by SPM, so affecting the second harmonic frequency. To account for this effect a simple model is proposed in the same paper (Giulietti, 1994) assuming that the electron density decreases in time uniformly inside the filament. The electron density is assumed to vary from an initial value of $n_c/4$ down to $n_c/40$ in a time of 50 ps. The lower density is arbitrary, but the result is rather insensitive to that value, provided it is much smaller than the critical density. 50ps is the typical duration of one spike in the laser emission and it is comparable with the transit time of a sound wave across a filament in our experimental condition (Biancalana, 1993). On the basis of these parameters the time behavior of the instantaneous laser frequency is calculated. This estimation substantially agrees with the mean values of the shift and the broadening observed in the experimental spectra of the second harmonic, either for spikes showing spectral modulation or not. The Fourier transform of the electric field provides a more rigorous calculation of shift, broadening and other spectral parameters as the number of the spectral intensity peaks and location of maximum of the envelope of the spectral intensity. To details see the same paper (Giulietti, 1994). In Fig.2 the experimental data from an ultra-fast time resolved spectroscopy are compared with the simulated spectra.

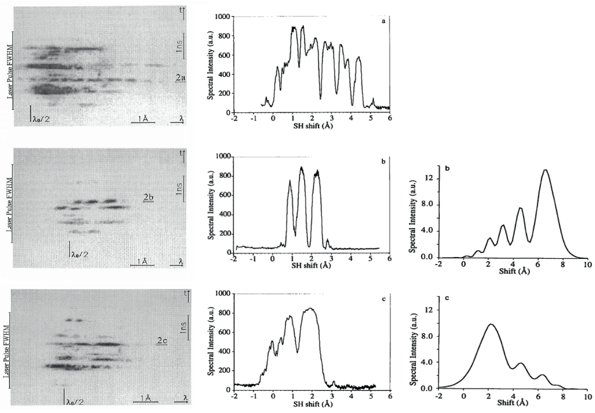

Fig. 2 Left. Time-resolved spectra of forward emitted second harmonic (Giulietti, 1994). The spectra are generally red shifted. Rather regular

modulations are apparent in the frequency domain for some spikes. The position of the laser pulse in time is roughly indicated. Center. Densitometric traces of the spikes marked as 2a, 2b, and 2c. Rigth. Simulated spectra in condition similar to those of the spikes 2b and 2c.

4. “Anomalous” plasma transparency.

The relativistic motion of the electrons in the electric field of the laser decreases the value of the plasma frequency by a factor $\sqrt{\gamma}$, allowing the propagation of the radiation at densities exceeding the critical one for the laser wavelength (Predhiman, 1998). In fact the condition to be fulfilled by the frequency for the laser propagation become in this case:

$$\omega > \frac{\omega_{pe}}{\gamma^{\frac{1}{2}}} = \frac{\omega_{pe}}{\left(1+a^2\right)^{\frac{1}{4}}} .$$

For example, an intense pulse of a Ti:Sapphire laser, at $I = 10^{21} Wcm^{-2}$, can propagate in a plasma up to the maximum electron density of $n_e \approx 2.6 \times 10^{22} cm^{-3}$, i.e. more than one order of magnitude higher than the maximum electron density in which the same laser can propagate at sub-relativistic intensities.

Another “anomalous” propagation can onset in plasmas when the super-intense laser beam interacting with the target produces very intense magnetic fields. In fact in presence of a static magnetic field B_0, perpendicular to the laser wave-vector and parallel to the oscillating magnetic fields of the electromagnetic wave, the light can propagate through an over-dense magnetized plasma as an extraordinary mode, provided that:

$$n_e < n_c\left(1 - \frac{\Omega}{\omega}\right)$$

where $\Omega = \frac{eB_0}{mc}$ is the cyclotron frequency (Predhiman, 1998). For example an intense pulse of a Ti:Sapphire laser interacting with a solid thin target can induce a magnetic field $B_0 \approx$ 1GGauss so creating the conditions for its propagation up to a density $n_e \approx 50n_c$. In fact, near total transmission of 30 fs laser pulses through 0.1 μm plastic foil targets was observed for the first time at an intensity of 3×10^{18} Wcm^{-2} in absence of pre-plasma, as reported in (Giulietti, 1997). This level of transmittivity is far above the level predicted by current theoretical models or numerical simulations. The transmittivity was found to drop by 40 times at an intensity of 4×10^{17} Wcm^{-2} and was within the experimental background level at 5×10^{16} Wcm^{-2}. The measurements strongly suggest a new mechanism of propagation of electromagnetic waves through overdense plasmas, that was explained in terms of “Magnetically Induced Optical Transparency” (Teychenné, 1998).

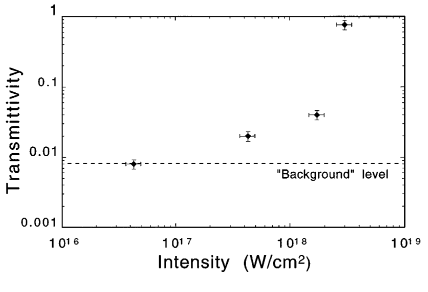

Fig.3. Transmittivity as a function of the intensity of the 30 fs laser pulse incident on 0.1 mm thick plastic target. The background level indicates the level at which the energy in the pedestal due to the Amplified Stimulated Emission (ASE) is comparable with the transmitted energy.

5. Hole-boring and channel formation.

An even more important phenomenon is the “ponderomotive hole-boring”, due to its consequences in some applications of the laser-plasma interaction at high intensities, as the electron laser-plasma acceleration and the related betatron radiation. In fact the ponderomotive force:

$$\langle U_q \rangle = \frac{e^2E^2}{4m\omega^2} \rightarrow F_p = -\nabla\langle U_q \rangle = -\frac{2\pi e^2}{mc\omega^2}\nabla\langle I \rangle$$

that in the relativistic regime of the laser radiation reduces to the expression

$$\langle U_q \rangle = mc^2(\gamma - 1) \rightarrow F_p = -mc^2\nabla\gamma \approx -mc^2\nabla a = -\frac{e\sqrt{8\pi c}}{\omega}\nabla\langle I \rangle^{\frac{1}{2}}$$

produces an electron density depletion along the laser path as a consequence of the intensity gradient related to the laser pulse. When this process takes place, the local density distribution can be described with fairly good approximation as

$$n(r) = n_0 + \Delta n \cdot \left(\frac{r}{r_{ch}}\right)^2$$

In this case it is easy to show that the spot size to match the optical guiding condition in the pre-formed plasma is:

$$w_0 = \frac{r_{ch}^2}{(\pi r_e \Delta n)^{1/4}}$$

The previous equation relates the plasma channel density profile with the laser spot size to match the optical guiding. It means that pulses focused in spots smaller than w_0 can be refractive-guided in such plasma channels. Plasmas with channels similar to that described above are found to be suitable for refractive laser-guiding over many Rayleigh ranges, opening to an efficient use in high gain, long-scale acceleration experiments (Gamucci, 2006; Esarey, 1997; Sprangle, 1990). Adapting such studies to the demands of the Laser-Plasma Acceleration techniques an experiment was conceived oriented to find the most suitable conditions to improve the electron acceleration length, producing hollow cylindrical plasmas for guiding intense laser pulses. To do so, an experimental arrangement to probe the laser-gas-jet interaction with a fast interferometric technique was setup at INO-CNR (Istituto Nazionale d’Ottica of the Consiglio Nazionale delle Ricerche) in Pisa (Italy). The laser system employed to study the plasma evolution driven by a laser pulse like to an Amplified Stimulated Emission pulse is a 3.3 GW Nd:YLF, delivering two beams with a maximum energy of 5 J per beam at a wavelength of 1053 nm and duration of 3 ns FWHM. The system can provide intensities up to 10^{15} W·cm^{-2} on a target with a high temporal and spatial quality. The production of quasi-cylindrical plasmas extending over several millimeters and with a hollow density channel on their axis was demonstrated (Gamucci, 2006). The mean on-axis electron plasma density, measured by the interferometric technique, was ≈ 4x10^{18} cm^{-3}. As a speculation, it can be noted that these values of electron density are quasi-resonant in the LWFA (Laser Wake-Field Acceleration) regime with laser pulses of duration $\tau \approx 30$ fs FWHM. As far as the transverse electron density profile, the density minimum at on-axis channel ranges from 60% to 70% of the density value at the channel walls, while its radius r_{ch} at half of the depth is of the order of 30 to 50 μm. In Fig. 4 the analysis of an interferogram obtained in the experiment is reported.

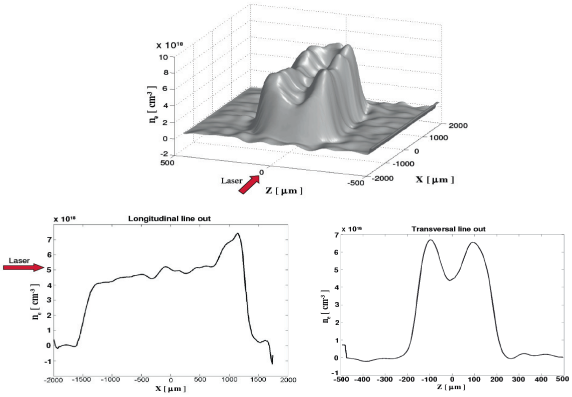

Fig. 4 Electron density maps obtained after the analysis of interferogram . (up) 3D reconstruction of the plasma density profile. (down, left) Density lineout taken on the longitudinal axis. (down, right) Density lineout taken at x ≈ −300 μm in the transverse direction (z axis). The origin of the z axis corresponds to 500 μm from the nozzle of the Helium gas-jet. The interferometer was in the Nomarski configuration and the information in the fringe pattern was deconvoluted by the usual Abel inversion technique; for details on the experimental set-up and data analysis see reference (Gamucci, 2006).

6. Extending the acceleration length.

Among the several drawbacks of the Laser Plasma Acceleration (LPA) schemes the limited acceleration length L_{acc} is one of the major concerns facing researchers. In fact even if this innovative acceleration technique allows accelerating fields several thousands of times higher than the ones used in the conventional accelerators, the maximum energy gained by the electrons is still far lower, due to the difficulty to maintain the high laser intensity over distances exceeding the Rayleigh length of the focusing optics and the two most important effects limiting the acceleration length, i.e. the pump depletion and the dephasing length. The dephasing length consists in the relativistic electrons slipping on the accelerating wave until they outrun the plasma wave and fall in a decelerating region. Considering that the phase velocity of the plasma wave is determined by the group velocity of the laser pulse, the dephasing length comes out to be

$$L_{deph} \approx \gamma_p^2 \lambda_p$$

where λ_p and $\gamma_p \approx \dfrac{\omega}{\omega_{pe}}$ are respectively the Langmuir plasma length and the Lorentz factor related to the phase velocity of the accelerating plasma wave. As we can see the dephasing length scales as $(n_e)^{-1.5}$, so in the LPA experiments the plasma density have to be low enough to guarantee the condition $L_{acc} < L_{deph}$ is fulfilled. Much more difficult is to contrast the reduction of the acceleration length related to the depletion of the laser pulse propagating in the plasma. In fact to hold up the plasma wave and counterbalance the depletion losses along the acceleration length a minimum laser intensity I_0 is required. In the optimistic case of a high quality diffraction limited focusing optics, we get:

$$L_{acc} \approx 2Z_R = \frac{2\pi w^2}{\lambda} \approx \frac{2E_L}{\tau\lambda I_0}$$

where Z_R, w, E_L, τ are the Rayleigh length, the laser beam waist, the laser pulse energy and its duration respectively. It is easy to verify that a few millimetres acceleration length would require a PW class laser ! Capillaries filled with preformed plasma allow to overcome the limits imposed by diffraction, guiding the focused laser pulse over distances largely exceeding the Rayleigh length, even if pump depletion and dephasing length happen in capillaries as well, being the limits of Laser Wake Field Acceleration (LWFA) in general, doesn't matter what is the accelerating structure you use, gas-jets (Grittani, 2014), capillaries (Karsch, 2007) or gas-cells (Osterhoff, 2008). There are further reasons to use capillaries: to shape the plasma with cylindrical geometry, to better control the pointing of the accelerated electrons, to guide the laser beam and the electron beam on a preferential axis, to use a lower pressure while still having very high densities, to have a uniform plasma and so on. However the main issues with capillaries, is the damage risk, mainly due to the laser shot-to-shot instabilities, both in pointing and in energy. For all these reasons, the LWFA community is moving toward external injection/staging schemes, density ramps and so on. The refractive laser-guiding over many Rayleigh lengths, previously described in the Paragraph 5, could be a viable alternative to the capillaries, avoiding the damage risk related to the high laser intensities they have to suffer. However refractive laser-guiding and even more self-focusing, due to the intrinsic instability of all the non-linear processes activated in a plasma, do not guarantee an adequate control and repeatability of acceleration process, as we can see considering the results of a recent experiment (Grittani, 2014) developed at Laboratori Nazionali di Frascati in the frame of the activities devoted to the New Acceleration Technique (NTA) of the Istituto Nazionale di Fisica Nucleare (INFN). In that experiment the properties of the electron bunches produced by laser-plasma acceleration technique using a 10 mm helium gas-jet with a longitudinal density profile characterized by a double peak structure was analyzed. The 30fs Ti:Sapphire laser was focused by an F/10 off-axis parabolic mirror on a spot of 15μm diameter (FWHM) at an intensity of $2\mathrm{x}10^{19}$W/cm^2. Data were taken at three different gas-jet backing pressures of 5, 8 and 15 bars, corresponding to plasma densities of $1.2–3.6\mathrm{x}10^{19}$ cm^{-3} in the peaks and $3.5–10\mathrm{x}10^{18}$ cm^{-3} in the central plateau. The highest energy electron bunch was recorded at more than 450MeV, with average energies (over about 150 shots) of about 140 MeV. We observed either spray of electrons or one or more collimated few-mrad electron bunches. Bunch divergence and pointing stability have been measured and are found to be very sensitive to the density. Also the charge of the electron bunches fluctuated of two order of magnitude. The average bunch divergence and the pointing ranged from 5 to 80 mrad and from 2 to 20 mrad respectively, strongly depending on the three different gas-jet backing pressures used. Fully 3D PIC numerical simulations confirm that laser intensity and plasma density of our set up are in the range where electron acceleration takes place by self-injection in a bubble-like structure. Analysis shows that after the first density peak, accelerated electrons propagate through the plateau and the second density peak where the laser intensity has dropped below the value required for driving the bubble, undergoing non-linear interaction with the background plasma, that produces broadening of the energy spectrum, ultimately setting the final bunch properties. The observed value of the depletion length was almost seven times the Rayleigh length of approximately 600 μm. Propagation over so many Rayleigh lengths implies a significant laser collimation, that only relativistic self-focusing balancing diffraction can produce.

7. Betatron radiation

The propagation of the super-intense and ultra-short laser pulses in plasmas in the so called “bubble regime” (Pukhov, 2002) is one of the most interesting acceleration scheme, due to the high energy and relatively low energy spread that can be obtained. In this physical process the accelerated electrons, moving along a region depleted by the electron density, suffer a restoring force towards the bubble axis due to the unbalanced positive ion charges. The transverse electric field due to space charge separation:

$$E = \frac{n_e e r}{2\varepsilon_0}$$

induces an oscillatory motion on the electrons having a velocity radial component :

$$\mathbf{v} = \mathbf{v_r} + \mathbf{v_z} \qquad tg(\theta) = \frac{v_r}{v_z} \approx \frac{v_r}{c}$$

$$\gamma m \frac{\partial^2 r}{\partial t^2} = -\frac{n_e e^2 r}{2\varepsilon_0} \quad \Rightarrow \quad r(t) = r_0 \cos(\omega_b t)$$

$$\omega_b = \frac{\omega_{pe}}{\sqrt{2\gamma}}$$

where ω_b and ω_{pe} are the betatron and electron plasma frequencies, respectively and γ the Lorentz factor of the accelerated electrons. The electron trajectory:

$$r(z) = r_0 \cos(k_b z)$$

is characterized by the spatial period:

$$k_b = \frac{\omega_b}{c} \quad , \quad \lambda_b = c\frac{2\pi}{\omega_b}$$

The transversal oscillation of the relativistic electron accelerated in the bubble produces an intense X-ray emission along the same direction of the laser pulse and the accelerated electrons. The so called “betatron radiation” (Whitthum, 1992; Kostyukov, 2003) shows several analogies to the Free Electron Laser physical mechanisms (Rousse, 2004; Wang, 2002; Jhonson, 2006).

The radiation emitted by the electrons will have the divergence:

$$tg(\theta) \approx \theta = \left\| \left[\frac{\partial}{\partial z} r_0 \cos(k_b z) \right]_{k_b z = \frac{\pi}{2}} \right\| = k_b r_0$$

with a strength parameter, in analogy with the FEL emission:

$$K = \gamma\theta = \gamma k_b r_0 = 1.33 \cdot 10^{-10} \sqrt{\gamma n_e (cm^{-3})}\; r_0(\mu m)$$

For K<<1 the radiation detected in the laboratory frame will be:

$$\omega_f = \omega_b 2\gamma^2 = \sqrt{2}\omega_{pe}\gamma^{\frac{3}{2}}$$

which corresponds to the betatron frequency, Doppler shifted in the laboratory reference frame. For K>1 the amplitude of the electron transversal motion increases, the plasma channel acts as a wiggler and high harmonics are radiated in a broad frequency band centred at

$$\omega_c = \frac{3}{4c}\gamma^2 \omega_{pe}^2 r_0$$

Experiments are in progress at LNF (INFN) with a sub PW class laser, aimed to maximize the betatron radiation emitted by the laser-plasma accelerated electrons in the “bubble regime”, so developing an high brilliance and ultra-short X-gamma ray source.

8. Conclusions and perspectives

The propagation of super-intense and ultra-short laser pulses in plasmas is a main concern in several applications of the laser-plasma interactions, from ICF to HEP. During the propagation in the plasma the light beam deeply changes its parameters as a consequence of induced non-linear processes, among which the relativistic regime of the electron quivering motion. These extreme conditions are suitable for the electron acceleration in high field gradients, opening to the realization of compact secondary sources of radiation (X-gamma rays) and particles (ions, e+, ….). The experimental and theoretical activity in LPA has been in the last fifteen years exceptionally intense and very rich of impressive results. In the next future we expect even more relevant results, as those pursued by the Berkeley Lab Laser Accelerator (BELLA) project, under realization at Lawrence Berkeley National Laboratory by the Wim Leemans group (Leemans, 2012). At present, several regimes for LPA have been successfully investigated, aimed to optimize the maximum energy, the energy spread, the charge and divergence of the accelerated bunches. The extension of the acceleration length, largely overcoming the Rayleigh length, is tempted following different experimental strategies; among them the control of the propagation of the intense laser pulse in the gases or plasmas confined in different ways (cells, capillaries,...). Most probably the next challenge will be the staged injection, in which in a first cell a bunch of energetic and quite monochromatic electrons is created by ionization injection (Clayton, 2010) and further accelerated in a second stage, setup to work in the external-injection regime.

Also Italy is intensifying the engagement in this field (Grittani, 2014;Velardi, 2014; Agosteo, 2013). In fact the National Institute of Nuclear Physics (INFN) has recently launched the Strategic Project **PLASMONX** in which LPA techniques will be exploited using the 300TW Ti:Sapphire laser (FLAME), synchronized with the advanced 150 MeV LINAC of the Project SPARC (Sorgente Pulsata Auto-amplificata di Radiazione Coerente). First encouraging results are producing at LNF where the INFN, operating the most powerful Italian laser, is greatly contributing to the growth of a National community involved also in the larger European Projects **ELI** (**E**xtreme **L**ight **I**nfrastructure) and **HiPER** (**Hi**gh **P**ower laser **E**nergy **R**esearch facility) (Giulietti, 2007) since their Preparatory Phase.

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