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# Scaling of betatron X-ray radiation

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**Abstract.** Energetic electron beams accelerated in a laser-produced plasma wakefield cavity can generate collimated beams of X-ray radiation. The oscillation of the electrons in the plasma cavity produces synchrotron-like emission, called betatron radiation. On the basis of state of the art experiments, we discuss the potentiality of this source in terms of spectral brigthness and flux. These characteristics are compared to existing and planned X-ray sources in both laser and accelerator communities.

**PACS.** 52.38.Ph X-ray, gamma-ray, and particle generation – 52.50.Dg Plasma sources – 52.38.-r Laser-plasma interactions

## 1 Introduction

Despite one hundred years of history, production and application of X-ray radiation remain extremely active in multidisciplinary fields. X-ray beam properties are being continuously improved over the decades. A spectacular increase of the brightness and decrease of the pulse duration are foreseen with the development of large scale instruments [1,2] like synchrotrons or more compact technologies based on laser schemes [3,5,6]. This opens new opportunities for the investigation of matter. In particular, X-ray probing and imaging of electronic, atomic and molecular fundamental events start to become accessible at the femtosecond ($10^{-15}$ s) time scale. Recording ultrafast snapshots of the matter will lead to a new understanding of the dynamics of structural changes, while high X-ray focussing intensities will extend nonlinear optics to the X-ray spectral range and allow the creation of new states of plasmas of astrophysical or geophysical interests.

Initial experiments at third generation synchrotrons have shown that 100 fs X-ray pulses can be produced and used for ultrafast applications in solid state physics [6,7]. Weak X-ray flux can be generated ($10^3$ photons/0.1%BW at 5 keV and per shot) by slicing out a thin portion of the energetic electron bunch using a femtosecond laser before its injection in the undulator. More efficient schemes now appear ("CRAB cavity") with the potential to use the entire electron bunch for ultrafast X-ray generation [8] (one picosecond timescale duration). Higher peak and average X-ray flux ($10^6$ photons/shot/0.1%BW at 5 keV) is then expected in that case. Such synchrotron facilities will perfectly match the needs for probing analysis using time-resolved diffraction and absorption experiments. On the other hand, X-ray Free Electron Laser (XFEL) projects arising worldwide in the accelerator community will give rise to much higher X-ray flux ($10^{13}$ photon/pulse/0.1%BW at 1–10 keV), and coherent radiation [1,2]. Some of these large scale facilities are presently under development at LCLS (USA) and DESY (Germany) while other projects have been recently approved (Spring-8 in Japan). These large scale installations will produce the most intense X-ray beam ever and will be a powerful tool for applications. However, there will be only a few XFEL facilities worldwide. There is a need of alternative and complementary sources for the large community of users.

Laser-produced plasmas are well-known to be efficient media for the production of secondary radiative sources [3]. They have shown their ability to achieve ultrashort pulses in the X-UV [9–11] or X-ray [12,13] spectral ranges. The principles of these sources have been established more than 10 years ago. Among them, the $K_\alpha$ X-ray radiation [12] relies on inner shell electronic relaxation following excitation by electrons accelerated at moderate energies (few 10 keV) during a laser-solid experiment. Its principle is analogous to the "X-ray tube" with electron bunch duration matching the femtosecond duration of the driving laser pulse rather than the timescales of the thermoionic emission of the tube. The $K_\alpha$ source led to the first femtosecond X-ray probing [14] experiments. However, the X-ray flux is severely limited due to the divergence over the full solid angle of the X-ray radiation which prevents efficient development of applications. The wavelength of the radiation is as well highly monochromatic and is tuned by changing the target. New opportunities now arise since recent laser-produced plasma studies have shown that compact particle accelerators [15,16] could be produced from wakefield acceleration schemes. Collimated electron beams with high charge (nC range) and with

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energies up to few hundreds MeV have been generated so far, and few GeV energies are foreseen [17–19,21]. Wiggling these electrons in periodic structures can produce femtosecond X-ray radiation with properties comparable to synchrotrons and XFELs [4]. Experiments done with permanent magnets undulators have not been successful until now, probably due to the spatial and spectral instability of the electron beams and the low charge available. However, experimental results obtained recently [5] demonstrate that synchrotron-like X-ray radiation can efficiently be generated in laser-produced plasmas wigglers from the betatronic oscillation of the accelerated electrons in the wakefield cavity.

In this paper, we first briefly summarize the main characteristics of the betatron X-ray radiation in a plasma wiggler. Then, scalings of the spectral X-ray intensity are given from numerical simulations. The last section presents the spectral brightness and flux which are compared to existing and planned ultrafast X-ray sources in the laser and accelerator communities.

## 2 Betatron X-ray beam

The large amplitude electrostatic fields generated in the wake of a laser propagating in a plasma can be efficiently manipulated [18] to generate and accelerate ultrafast electron beams with energies comparable to that of linear accelerators (up 1 GeV). This efficient regime of laser particle acceleration, for which the laser pulse duration resonantly fits the plasma period, has been observed experimentally [15] and in 3-dimensional Particle-In-Cell (PIC) simulations [21]. The ponderomotive force associated to the high intensity gradient in the front of the intense femtosecond laser pulse generates, during its propagation in an underdense plasma, an ion cavity in the wake of the laser. Free electrons of the plasma can be trapped and accelerated by the large electrostatic fields due to the space charge separation up to a few hundreds of MeV over only a millimeter distance scale.

In this parameter regime the ion cavity plays, as well, the role of a wiggler [22,23]. As the relativistic electrons accelerate in the ion cavity, they also experience a radial restoring force due to the transverse electrostatic field generated by space charge separation. An electron displaced from the cavity axis undergoes oscillations — called betatron oscillations — and, as in a conventional synchrotron, a collimated beam of X-ray synchrotron radiation originates from this relativistic and oscillatory motion. Such radiative process has been also observed in plasma channels generated by very energetic electron beams [24]. Table 1 lists the main parameters of the betatron features where $r_0$ is the amplitude of the betatron oscillation. $N_0$ is the number of oscillation performed by the electron in the ion channel and $N_x$ is the corresponding X-ray flux generated at the peak energy. For small amplitude oscillations, the electron will produce an harmonic motion at the fundamental betatron frequency $\omega_b = \omega_p/\sqrt{2\gamma}$, where $\gamma$ is the relativistic Lorentz factor of the electron defined by $\gamma = 1/\sqrt{1-\frac{v^2}{c^2}}$. In the case of an electron slightly displaced from the axis, the fundamental wavelength of the radiation can be approximated by $\lambda = \lambda_b/2\gamma^2$. Since the restoring force scales with the electron density $n_e$, the one used in experiments of the order of $n_e = 10^{19}$ cm$^{-3}$ yields a very high oscillation frequency in the plasma wiggler and high amplitude oscillations. The regime of X-ray production can be described by a dimensionless parameter $K$ similar to the wiggler strength parameter in synchrotrons. If $K$ becomes large so that $K \gg 1$, the radiation will be emitted in many harmonics within a narrow cone of divergence $\theta$, and the emission frequency is a function of $K$. In that case, the spectrum becomes broadband and quasi continuous. It can be described by the synchrotron radiation spectrum function

**Table 1.** Betatron X-ray beam main parameters (for one electron).

| | |
|---|---|
| Strength parameter | $K = 1.33 \times 10^{-10}\gamma^{0.5} n_e^{0.5}[\mathrm{cm}^{-3}] r_0[\mu\mathrm{m}]$ |
| Betatron period | $\lambda_b = (2\pi\gamma r_0)/K$ |
| Divergence | $\theta = K/\gamma$ |
| Cut-off X-ray energy | $\hbar\omega_c[\mathrm{eV}] = 5 \times 10^{-21}\gamma^2 n_e[\mathrm{cm}^{-3}] r_0[\mu\mathrm{m}]$ |
| Peak X-ray energy | $\hbar\omega_p x[\mathrm{eV}] = 0.29\hbar\omega_c$ |
| X-ray flux | $N_\times = 5.6 \times 10^{-3} N_0 K$ |

$$S(\omega/\omega_c) = \frac{\omega}{\omega_c}\int_{\frac{\omega}{\omega_c}}^{\infty} K_{5/3}(x)dx. \quad (1)$$

Here $\omega_c$ represents the critical frequency beyond which there is negligible radiation at any angle. For frequencies below $\omega_c$ and up to $\omega \simeq 0.29\omega_c$, the spectrum function increases as $\omega^{1/3}$ and then drops exponentially to zero. The period of the plasma wiggler $\lambda_b$ is much shorter (submillimetre scale length) compared to a synchrotron which is based on permanent magnets (centimeter scale length), and the distance required to produce a bright X-ray beam is much shorter (several millimeters rather than meters). The required energy of the electron beam is also much lower (100 MeV rather than GeV) to produce radiation in the X-ray spectral range.

Betatron X-ray radiation in laser-produced plasma has been observed for the first time in a recent experiment [5,13]. By placing an X-ray CCD detector right on the laser axis, a collimated beam of X-ray radiation was observed in the spectral range of few keV (1–10 keV) as shown in Figure 1. Permanent magnets were used to deviate off-axis the energetic electrons accelerated in the plasma and record their spectrum. For an electron density of $6 \times 10^{18}$ cm$^{-3}$, electron are accelerated up to 140 MeV and the mean X-ray beam divergence lies between 20 and 60 mrad. The X-ray flux observed experimentally is $5 \times 10^6$ photons/pulse/0.1% BW. Using the formulae of Table 1, a simple estimate shows that the electrons undergo about 5 betatron oscillations in a plasma wiggler of strength parameters close to 10, with a betatron period of 340 micrometers and a maximum excursion amplitude of 3 micrometers. A detailed analysis of the electron trajectories and plasma wiggler parameters are

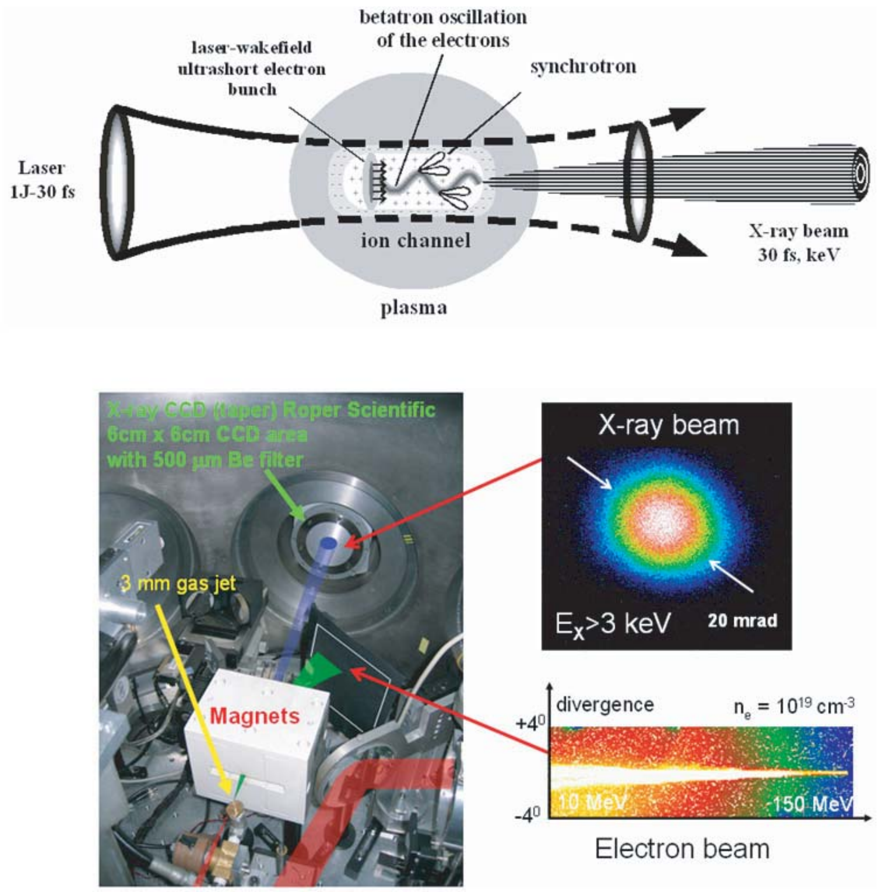


**Fig. 1.** (Color online) Principle of the betatron X-ray source. Energetic electrons are accelerated by wakefield in a laser-produced ion channel. They experience the transverse electrostatic field of the channel, make betatron oscillations and emit collimated beam of synchrotron radiation in the X-ray spectral domain. The experimental setup used for the betatron experiment includes permanent magnets used to separate the X-ray and electron signals, and simultaneously provide the spectral distribution of the electron bunch. The figure also shows the CCD picture of the X-ray beam and electron spectrum for electron density of the helium gas jet of $10^{19}$ cm$^{-3}$.

extensively discussed elsewhere [25,32]. As these experimental studies were done in a regime for which a wide electron energy range is generated during wakefield acceleration (forced laser wakefield), a distribution of betatron amplitudes $r_0$ and strength parameter $K$ are actually produced. We have found that $K$ can reach 25 for the more energetic electrons of the distribution (140 MeV). $r_0$ was measured using three different methods: far field imaging of the X-ray beam [25], Fresnel X-ray diffraction [32] and spectral analysis of the betatron X-ray radiation [30]. The maximum amplitude of the betatron oscillation is found to lie between 1 $\mu$m and 5 $\mu$m for same experimental conditions, depending on the technique used.

## 3 Scalings for laser-based betatron radiation

X-ray source properties could be significantly improved if we take into account the development of powerful laser systems and laser wakefield acceleration techniques. 1 GeV electron energies have been recently obtained with relatively low charge (0.1 nC) [26]. Higher charge (nC range) may be achievailable [27] using 300 TW laser systems that are under construction worldwide. Furthermore, cascade acceleration schemes and PW-class laser systems should lead to few GeVs electron beams. In a very recent experiment, laser-injection and subsequent acceleration of electrons can be controlled by using a second and counter-propagating laser pulse [28]. The experimental results show that the electron beams obtained in this manner are collimated (5 mrad divergence), monoenergetic (with energy spread below 10%), tunable (between 15 and 250 MeV) and, most importantly, stable (with standard deviation lower than 10% for all parameters). In addition, simulations and experimental results strongly suggest that these electron bunches are shorter than 10 fs. Such high quality, tunable and stable electron beams would be of great interest for the generation of efficient betatron X-ray beams for applications.

To estimate the X-ray features in those cases, we consider a model of a single electron propagating along the axis of a uniformly charged and cylindrical ion channel in the $z$ direction. The electron has an initial velocity along $z$ with an energy $\gamma_0 mc^2$ (where $\gamma_0$ is the initial Lorentz factor), and an initial transverse position $r_0$ from the channel axis. As the electron propagates in the channel, it experiences the transverse restoring force due to space charge separation. In the transverse direction, the electron oscillates at the betatron frequency. The trajectory is calculated numerically by integrating the equation of motion and the radiation emitted by the electron oscillating in the plasma wiggler (ion channel) is estimated using the general expression for the spectral flux [29]. It depends on the position, the velocity, and the acceleration of the electron within the plasma channel. Detailed description of the model has been already discussed [13]. While the

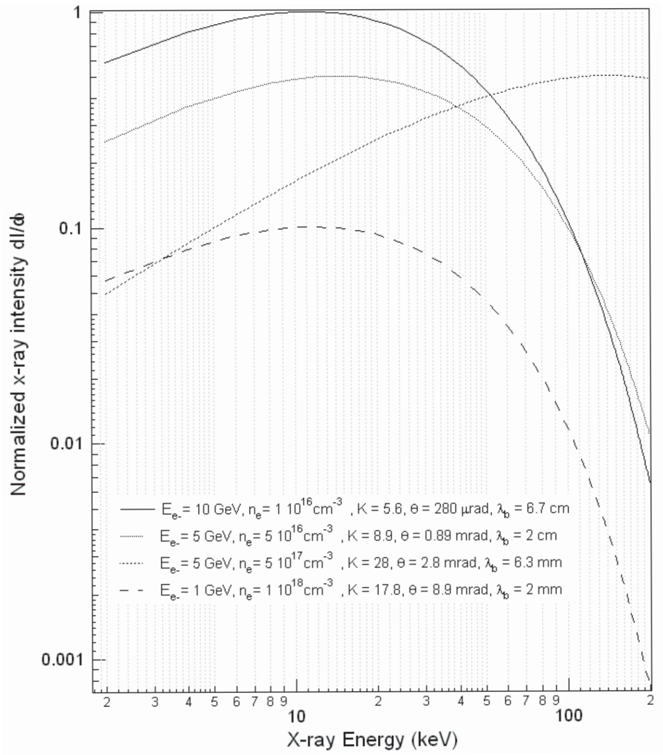


**Fig. 2.** X-ray intensity (for one betatron oscillation — $N_0 = 1$ — and per spectral bandwidth) expected for 1 GeV, 5 GeV and 10 GeV electron beams oscillating with a betatron amplitude of 3 $\mu$m. The electron density of the ion channel was adjusted to generate a radiation centered at 15 keV. Shorter X-ray wavelengths can be obtained by increasing the electron density as shown for the 5 GeV electrons. The X-ray intensities are normalized to the 10 GeV case. K is the strength parameter of the plasma wiggler, $\theta$ is the divergence, $\lambda_b$ is the betatron period and $n_e$ is the electron density of the plasma.

electrostatic fields in the accelerating structure are given by the electron density of the gas cell, $r_0$ (initial betatron amplitude) is arbitrary and must be chosen from experimental or theoretical (Particle in Cell simulations) results. During the acceleration, the electron trajectory will elongate and the betatron amplitude will decrease. As both the spectral and spatial betatron X-ray properties depend on the electron trajectories, the acceleration in the plasma must be taken into account to accurately describe the betatron process during the interaction. This model was successfully used to demonstrate the correlation between the electron beam and the X-ray radiation by analyzing their spectral and spatial properties [25,30,32]. As a distribution of electron energies was produced during these experiments rather than monoenergetic electron beams, the single electron model was used for each electron energy of the distribution function to describe the different electron motions in the plasma channel and reconstruct the betatron X-ray yield.

Figure 2 displays the simulations done for a single electron with final energies of 1, 5 and 10 GeV after acceleration. The initial betatron amplitude at the trapping position in the accelerating structure is set to 3 $\mu$m [30], which is much smaller than the dimension of the laser focal spot (10 $\mu$m or more) and in accordance with the results of existing X-ray experiments of laser-wakefield acceleration. $r_0$ depends on the injection mechanism of the wakefield electrons and might be different for the recently demonstrated optical injection technique [28]. It can provide stable and tunable quasi monoenergetic electron beams, however no experimental betatron X-ray studies have been done in this regime yet.

The electron densities of the plasma were chosen to produce the most collimated X-ray radiation and the X-ray energy is kept around 15 keV, which is desirable for most of the applications in ultrafast X-ray science. The normalized X-ray intensity (normalized to the 10 GeV case) is given for one betatron oscillation.

We can see that a broadband synchrotron-like spectrum is produced from 1 keV up to 100 keV. For these sets of parameters, a collimation ($\theta$) less than few hundred $\mu$rad can not be achieved because the electron density can not be furthermore lowered (below $10^{16}$ cm$^{-3}$) to keep the X-ray energy unchanged. Much higher electron energies are necessary for that purpose. The peak of the X-ray spectrum can be shifted toward higher energies by increasing the electron density of the plasma and the energy of the accelerated electron beam (5 GeV case shown in Figure 2 for an electron density of $10^{17}$ cm$^{-3}$). Because the electron density is kept low to maintain an X-ray energy around 15 keV, the betatron period ranges from a few millimeters to a few centimeters for 10 GeV electrons. Plasma wigglers of a few tens of centimeters must then be developed to ensure a few betatron oscillations and high X-ray flux in that case. In current experiments betatron X-ray radiation has been produced from 5 betatron oscillations of sub-100 MeV electrons along a 1.5 mm propagation length inside the ion channel. Discharge capillaries [31] as well as laser-preformed plasmas [20] are two possibilities to increase the interaction length and guide the intense laser pulses over a few centimeters.

## 4 Spectral brightness and flux of the betatron radiation

Figures 3 to 5 display the betatron X-ray flux (in one shot and average) as well as its average brightness compared to other existing or planned projects raised worldwide. We used in these figures the betatron radiation generated by a 1 GeV and 1 nC electron beam that experiences 40 betatron oscillations (10 cm propagation length in the plasma), anticipating typical plasma wiggler lengths that may be generated. The single electron simulation described in Section 3 is used to this end. The X-ray intensity is linearly extended from a single electron charge to a 1 nC beam perfectly monoenergetic. The brightness of the betatron X-ray radiation can be estimated from the pulse duration and the size of the X-ray source. We used to this end the experimental values obtained from recent experiments we performed with sub-GeV electron

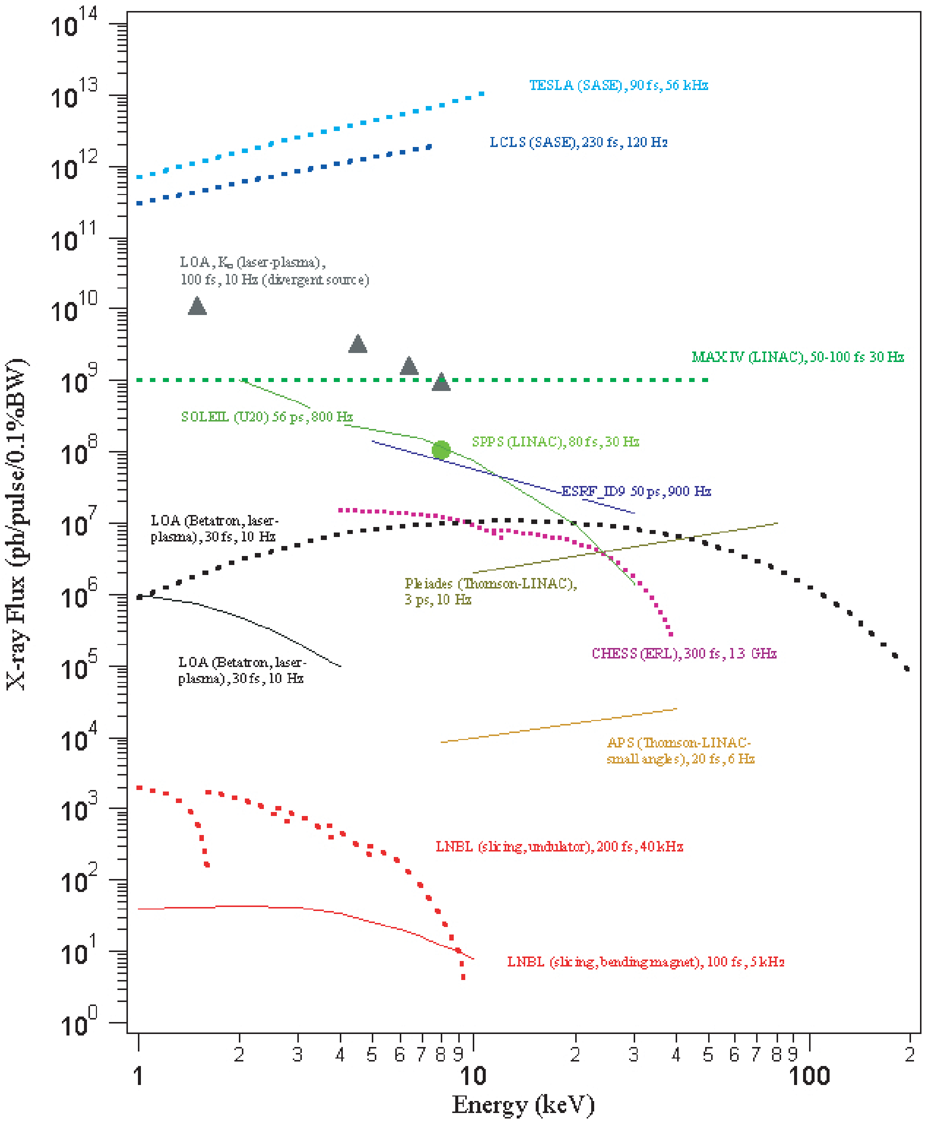


**Fig. 3.** (Color online) X-ray flux. The dotted curves correspond to sources that not yet exist (simulation). The pulse duration as well as the repetition rate are quoted for each facilities. The betatron X-ray properties expected using a 250 TW laser systems is represented in dashed and black line. $K_\alpha$: laser-plasma source (in operation) LOA (Palaiseau, France). TESLA: free electron laser project (expected in 2015) DESY (Hambourg, Allemagne). LCLS: free electron laser project (2010) SLAC (Stanford, USA). CHESS: Energy Recovery LINAC (not planned) Cornell (USA). SPPS: Ultrafast LINAC with undulator (in operation 2004–2006) SLAC (Stanford, USA). Slicing: slicing of electron beams in 3rd generation synchrotron (2005) LBNL (Berkeley, USA). Pleiades (LLNL, USA) and APS (Chicago, USA): Compton scattering of a laser onto a LINAC (in operation at LLNL: 3 ps time scale). ESRF ID9: time-resolved X-ray beam line at the synchrotron ESRF. SOLEIL: Crystal beam line in construction at the synchrotron SOLEIL (France).

beams. The temporal pulse width is fully determined by the temporal profile of the electron bunch, which is close to that of the laser (30 fs) or even shorter as the electrons are accelerated in the first arch of the plasma wave in this parameter regime [33]. Time-resolved X-ray diffraction experiments with femtosecond time resolution have shown that the pulse duration is at least below 100 fs [34]. Knife-edge X-ray imaging of the source, and analysis of electron trajectories from X-ray spectral and spatial characterization both show that the maximum amplitude of oscillation of the electrons in the plasma wiggler is close to 3 $\mu$m or even less [25,30,32]. To estimate the brightness of the betatron radiation source, we then choose an average source size of 5 $\mu\text{m} \times 5$ $\mu$m and a pulse duration of 100 fs. As these parameters are upper values of the betatron features, we then minimize the expected X-ray yield calculated here. The X-ray flux in one shot, the average X-ray flux and the average brightness at 15 keV are respectively $10^7$ ph/shot/0.1%BW, $10^8$ ph/s/0.1%BW and $5 \times 10^{10}$ ph/s/mm$^2$/mrad$^2$/0.1%BW. The spectral range extends beyond 100 keV without significant loss of flux and brightness.

We can see from Figures 3 to 5 that the high repetition rate of the synchrotron slicing X-ray source compensates its relatively weak X-ray flux, and its average intensity exceeds that of the betatron for sub-10 keV radiation. The data from the ALS (Berkeley-USA) beam line are represented here. The X-ray flux is limited by the current charge contained in the electron bunch, and as a consequence, it can not be increased anymore. More intense femtosecond X-ray beams will be obtained with the energy recovery LINAC (ERL, linear accelerator) and free electron lasers (FEL) using the SASE (self-amplified spontaneous emission) scheme which are based on the production of ultrafast and highly energetic electron beams (few 10 GeVs range). The LCLS at Stanford-USA and TESLA at DESY-Germany projects will deliver femtosecond X-rays in the few 10 keV spectral range with very

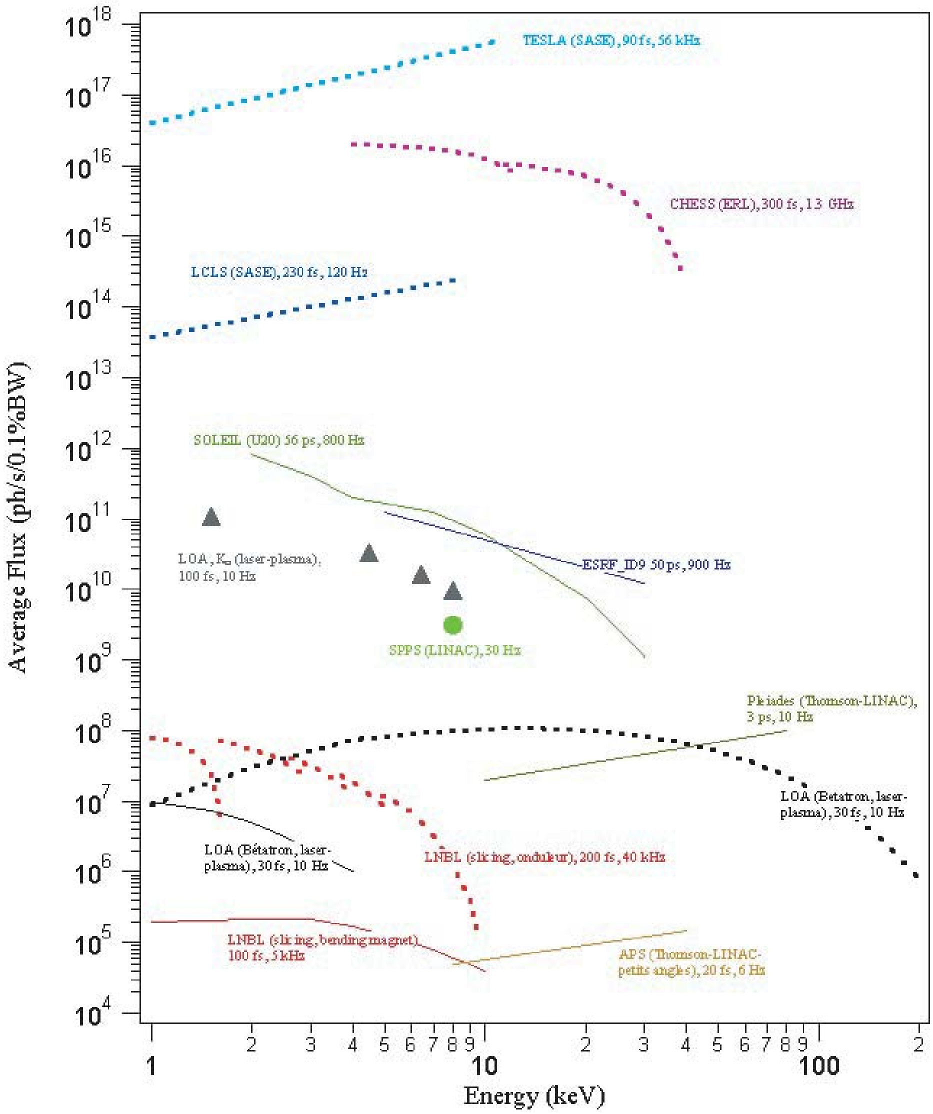


**Fig. 4.** (Color online) Average X-ray flux. Legend same as Figure 3.

high brightness, mainly thanks to their very high collimation ($\mu$rad) and X-ray flux as it can be seen in the figures. These LINAC-based facilities (FEL, ERL, LLNL and APS) do not have intrinsic synchronization with the laser used to trigger a reaction in the femtosecond timescale. However, post-synchronization techniques [35] (SPPS project) have been successfully demonstrated. Smaller scale projects relying on Compton scattering of laser light on 10 MeVs electron beam are also shown. The use of LINAC-based schemes like at LLNL (Livermore-USA) and APS (Chicago-USA) is now well established and few picoseconds X-ray radiation can be produced. The fully optical scheme where the laser is used both for electron acceleration and backscattering was demonstrated in a recent experiment [36], however it provides a rather low X-ray photon yield.

The figures show that the betatron X-ray flux is approaching what can be produced by SPPS despite its significantly smaller scale environment. For high X-ray energies, it becomes comparable to the 10 ps X-ray bunches provided at third generation synchrotrons. The efficiency of the betatron generation leads to X-ray flux much higher that what can provide the slicing technique, but remains significantly below laser-based $K_\alpha$ radiation. The repetition rate at which the betatron X-ray source can be produced will be limited to 10 Hz if we consider the present stage of laser developments. The average X-ray flux of the slicing source becomes then comparable to the betatron thanks to their high repetition rate (40 kHz). SOLEIL and ESRF benefits as well of their few hundred Hz potential to exceed by 2–3 orders of magnitude the betatron intensity. This gap becomes even larger for the average brightness due to the divergence of the betatron beam which lies in the mrad scale. On the other hand, the beam of betatron radiation represents a significant jump compared to the $K_\alpha$ source which is divergent over the the full solid angle. It can also be seen from Figures 3 and 4 that the first results on the betatron source in the

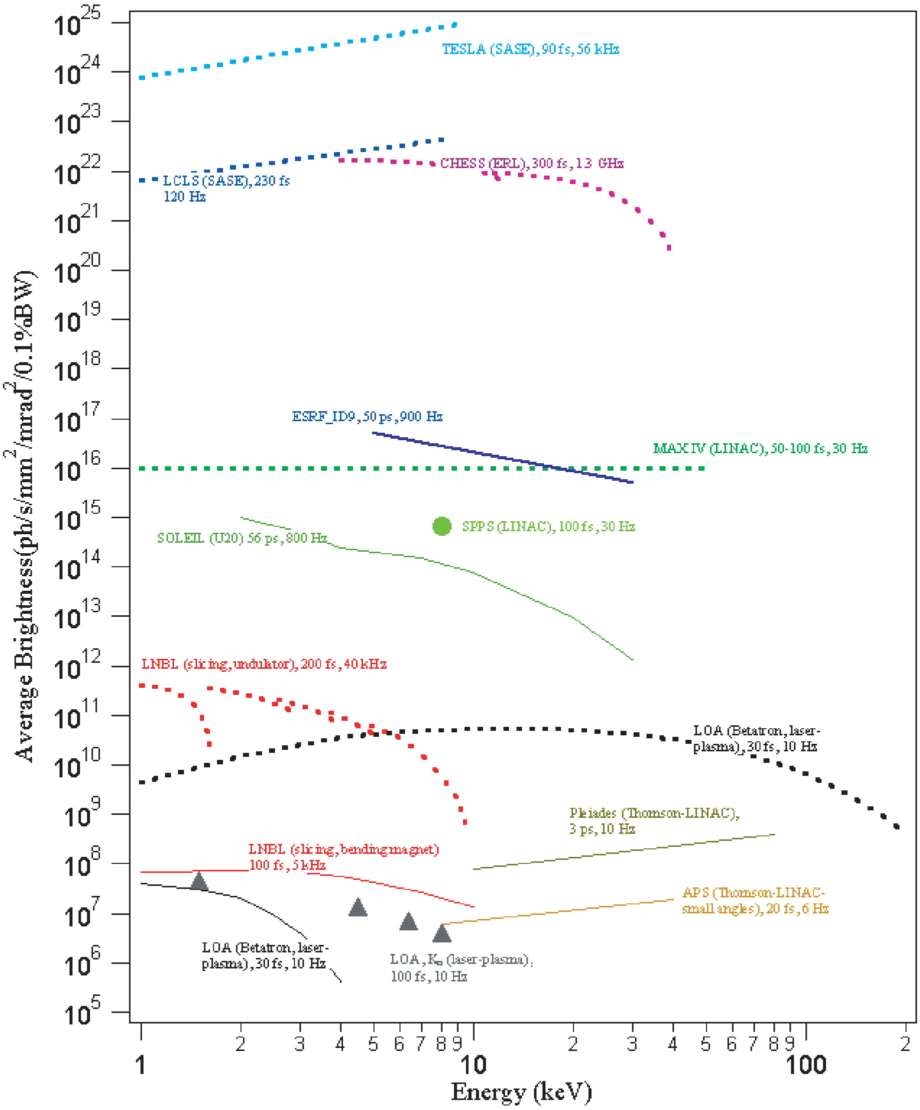


**Fig. 5.** (Color online) Average X-ray brightness. Legend same as Figure 3.

few keV spectral range have already led to X-ray flux exceeding what is provided by the Compton technique or by wigglers and undulator insertion devices using the slicing approach. The betatron source would significantly extend the X-ray spectrum useable for ultrafast X-ray application as it remains nearly flat up to 100 keV.

The relatively weak average brightness will affect the accumulation time required to run an application experiment. As a first example, ultrafast protein crystallography was investigated at ESRF (ID 9 beamline) by recording snapshots of X-ray diffracted images of protein samples with the number of photons displayed in Figures 3 to 5. These experiments could not be performed at a repetition rate larger than 10 Hz to avoid sample destruction due to the high excitation levels required to maximize the atomic displacement (and then the change in X-ray transient diffracted signals). While one X-ray shot was necessary to record a Laue pattern (thousands of Bragg peaks) in that case, 1000 shots will be required with the betatron X-ray source (2 min accumulation time at 10 Hz). The situation will be more favorable for application in condensed matter physics for which Bragg peaks with a wide range of intensities will be recorded (smaller elementary cells compared to the protein case). As an example, the analysis of ultrafast solid-liquid transition and optical phonon dynamics with the $K_\alpha$ sources have already been demonstrated although its average brightness is two orders of magnitude lower than the one of the betatron source. It will then provide a significant decrease in the accumulation time (hours to minutes) and will allow the realisation of systematic study of such ultrafast processes. The source will as well open the way to the study of non crystalline samples using X-ray absorption experiments that provide access to local atomic information as opposed to X-ray diffraction which maps out the global structure of a crystal. The goal here is to look at the time dependent changes in the fine oscillation structures of the absorption profile (XAFS). In a semiconductor experiment looking at the Si K edge during the solid-liquid phase transition, the change in the oscillation phase is 10 eV between the 2 structures. The featureless betatron spectrum will allow observation of the entire spectrum of interest (∼250 eV) in each acquisition. In this configuration, the average brightness of the betatron source can yield to 60 photons/eV at the detector. Taking normalized chan ge in the atomic Si absorption due to the XAFS effect of $\chi = 0.05$ which accounts for the room temperature bond-spread, one expects 5–10% change in transmission coefficient. With accumulation over 1000 laser shots, photon noise drops well below 1% while for the case without sample, merely 100 acquisitions suffices. With laser operation at 1 Hz (10 Hz maximum), a transient XAFS spectrum would require 1 h recording time.

## 5 Conclusion

Collimated beams of X-ray radiation are now produced from laser-plasma interaction using intense ultrafast laser systems. This betatron source could provide femtosecond X-ray flux of $10^7$ ph/shot/0.1%BW and average brightness of $10^{10}$ ph/s/mm$^2$/mrad$^2$/0.1%BW over a large spectral range (a few keV to hundred keV). Such properties can provide efficient probing radiation for the study of ultrafast transient structures [37–46] using X-ray diffraction and X-ray absorption techniques. A significant increase of the X-ray flux, energy and a more collimated X-ray beam (below 1 mrad) are expected by increasing the electron energy beyond 1 GeV. Structuring the wakefield cavity using preformed plasma must be as well investigated to induce larger betatron amplitude, shorter period of oscillation, and to provide a better control of the source. Betatron radiation has the potential for powerful diagnostics not available in plasma physics so far. It will allow the probing of extreme states of matter, with the final goal to address astrophysical as well as inertial fusion research issues. Time resolved absorption spectroscopy and Thomson scattering of high-density plasmas requires penetrating radiation like X-rays and an ultrafast time resolution to reveal the properties of the warm dense matter produced in a laser-plasma experiment. Time-dependent measurements of plasma temperature and density will provide a precious contribution to the understanding of the degeneracy, coupling as well as long and short range interactions between charged particles within the plasma. Moreover, the small size of the source will allow efficient coherent diffraction imaging studies to reveal the invisible layers of the fuel target at each step of the reaction.

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