SLAC-PUB-8220
September 1999

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Submitted to *Physical Review E*

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Work supported by Department of Energy contract DE AC03 76SF00515.

99-8220
July 1999

Electron Trajectories in Intense Laser Pulses*

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⋆ Work supported by Department of Energy SBIR Grant DE-FG03-94ER81740 (DULY)
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ABSTRACT

Collisions of short, intense laser pulses with electron beams have recently been proposed for various purposes, such as high-quality, Compton-Backscattered X-ray sources (CBX), or coherent pair production positron sources for future e^+e^- Linear Colliders. For such intense laser fields, few-photon perturbative treatments do not suffice, and nonperturbative effects in the fields must be modeled. These effects have, until recently, only been modeled within the 'local plane wave', or Volkov, approximation, in which ponderomotive (i.e. laser intensity gradient) effects are ignored. A systematic quantum treatment of the 'post-Volkov' effects occurring in such collisions has recently been initiated by Ben-Menahem [1] . In the present paper, we use the results of [1] to render a simplified treatment of the leading ponderomotive corrections to electron trajectories during the electron-laser collision, and estimate the ramifications for CBX sources which utilize such collisions. We also apply to the CBX case some recently derived estimates of three non-ponderomotive effects: two body collisions in the laser-induced shower; EM self-forces of this shower; and back-reaction of linac-laser collisions upon the laser fields. All three effects are shown to be negligible for the numerical examples considered here.

1. Introduction

Currently available laser technology enables collisions of short, intense laser pulses with high energy electron beams. Such collisions can be applied towards various scientific and technological ends. Thus, for linac energies in the several-10 MeV range, high quality Compton Backscattered X-ray sources (CBX) have been proposed, for research and imaging in chemistry, material and life sciences [3] [4]. For linac energies of order 50 GeV or more, coherent creation of copious electron-positron pairs becomes possible, enabling a novel type of positron source. Such a source is characterized by high yield, low emittance and low energy spread [5] [6].

For the positron-source application [5] [6] , the EM fields in the electron (or positron) rest frame are of order the Schwinger critical field, or higher. For *both* the positron source and CBX applications, the EM fields in the interaction region can be of strengths such that numerous laser photons participate in a typical microscopic process. Therefore, a nonperturbative treatment in the laser fields becomes necessary.

In previous analyses of the electron beam — laser pulse collision [5] [7] - [10], the instantaneous laser EM fields at the locus of a given microscopic process (hard photon emission or coherent pair creation) was treated as if due to a locally-defined infinite, monochromatic plane wave. The *Volkov solution* of the Dirac equation in the background of such a wave [2] [11] was then used to compute the rates of these microscopic processes, and to evolve the entire shower. This procedure is inadequate for realistic laser pulses. Recently, a program to systematically evaluate *post-Volkov* effects was developed by Ben-Menahem [1] . Post-Volkov effects depend upon various parameters, such as spacetime gradients of local laser intensity, which can be expanded in if sufficiently small. In this paper we concentrate on the parameter regime suitable for the CBX application, where pair creation is nonexistent or negligible; the particle shower (into which the incoming electron beam is transformed by the collision) then consists only of electrons and (backscattered) photons. Post-Volkov effects for the other regime mentioned above — that of high linac energy — are specifically treated in ref [6] ; in that case, the shower also includes positrons. Both reference [6] and the present paper rely on the theoretical framework and analytical results developed in [1] .

The effects to be investigated below are of two types: leading post-Volkov effects on the motion of (and, indirectly, X-ray emission by) a single electron; and (multibody) background effects. The leading post-Volkov effects are all linear in spacetime gradients of the laser intensity, and hence may also be referred to as *ponderomotive effects*. The *multibody* effects are primarily non-ponderomotive: they are 'multibody' in the sense of involving more than the dynamics of a single incident shower particle in a nondynamical background of given laser fields, and they are 'background' in that they are small enough to be negligible for currently planned CBX sources⋆. (we demonstrate this for two numerical examples).

The multibody effects are of three types — two-particle collisions in the shower; EM self-forces of the shower; and back-reaction of the electron bunch — laser collision upon the laser pulse.

In the CBX regime, the ponderomotive effects are primarily classical — as explained below. Specifically, these effects result primarily from the slow bending of the helical electron trajectories† due to spacetime gradients of the laser intensity. There are also smaller post-Volkov modifications to the Compton backscattering rates themselves; these were treated in [1] and found to be negligible in the CBX regime (though not for the pair-creation regime), so we shall neglect them here.

The rest of the paper is organized thus. Section 2 is a brief review of the Volkov approximation, with especial emphasis on the CBX regime. In section 3, the idea of the post-Volkov expansion (introduced in [1]) is discussed, and its classical

⋆ in [6] it is shown that they are also negligible for the pair-production regime.

† we shall consider both the case of linear laser polarization, and that of circular polarization. In the former case, an electronic trajectory is actually sinusoidal rather than helical; but for simplicity we shall adhere to the term 'helical' in describing the trajectories, for either type of laser-pulse polarization. Most of our results will be for the circularly polarized case; the corresponding results for linear polarization are similarly derived. The bending of trajectories is 'slow' in the sense of occurring over the space of many laser oscillations.

version is implemented to obtain simple, approximate formulae for the bent helical trajectories (we specialize to circular laser polarizations, although similar formulae are readily obtainable for the case of linear polarization.) The laser-pulse fields used in section 3 are a simplified 'cylindrical' version of the gaussian-beam pulse used in [6] . In section 4, the effects of trajectory bending upon CBX quality are estimated. In section 5, we use rough analytical formulae for the multibody background effects, derived in [1] , to bound or estimate these effects for the CBX regime. In the two numerical examples worked out in sections 4 and 5, the value used for the linac energy is 20 MeV — corresponding to the planned CBX source at UCLA [3] . In section 6 we state our conclusions.

We shall occasionally display the constants $\hbar$ and c explicitly; In all other instances, it is to be understood that we employ a system of units wherein either, or both, of these constants is set to unity.

2. The Volkov Approximation

The shower consists of a succession of microscopic processes. Ignoring, for the moment, the multibody background effects (see section 5), these processes are of two classes: 'hard events' and 'semiclassical motions'. By 'hard event' we mean a fundamental, quantum-coherent process, in which the laser background induces the decay of a single shower particle into two[‡] daughter particles. In general there are two types of such processes — the laser-induced ('nonlinear') Compton process, and laser-induced ('coherent') pair creation[§].

For the CBX regime under investigation in this paper, only the nonlinear Compton process need be considered. The 'semiclassical motions' are just that — the (semiclassical) motions of shower particles, either entering or exiting the

‡ or more — but for a decay into more than two particles, the rates are suppressed by extra powers of the fine structure constant, so we neglect these processes.
§ the inverse processes belong under the rubric of 'multibody background'.

linac-laser collision, or else between two consecutive hard events within the collision region.

The main simplifying assumption made in earlier treatments of the linac-laser collision process [5] [7] - [10] , was to treat any microscopic process as if it occurs in the background of an infinite, monochromatic plane wave, with its field amplitude taken as that of the local field at the spacetime point or region at which a given event occurs. It is this assumption that we refer to as the 'Volkov approximation'. Within this approximation, there is no trajectory bending — electronic (and positronic) trajectories are exact helices. The rates of microscopic hard events at a given spacetime point were adapted, in these works, from reference 2. The authors of [2] , in turn, evaluated these rates using the Volkov solution for an EM plane wave [11] . In the rest of this section the Volkov approximation is used, and the EM fields are defined at the spacetime point or region where the given microscopic process occurs.

Consider a circularly polarized laser beam (the treatment is similar for the linearly polarized case). The interaction between a relativistic electron (or positron) and a monochromatic EM wave can be described by a dimensionless Lorentz-invariant parameter, η. Physically, this parameter measures the ratio of the pitch angle θ_H of the helical electron trajectory to the outcoming *rms* angle of a photon radiated from an electron, $\theta_c \approx 1/\gamma$:

$$\eta = \frac{\theta_H}{\theta_c} \approx \gamma\theta_H = \frac{eE}{\omega mc}, \tag{2.1}$$

where E is the laser electric field amplitude in Lab frame, m the electron mass, c the speed of light and ω the laser frequency (also in Lab frame). When $\eta \gg 1$ the radiation cone is much smaller than the pitch angle, and the laser-induced Compton process is well described as synchrotron radiation. When $\eta \ll 1$, on the other hand, it is describable as single-photon Compton scattering (soft incoming laser photon; hard outgoing backscattered photon). In other words, when $\eta \gg 1$ the number of laser photons coherently absorbed in one microscopic process becomes large.

Besides η, a hard event is also characterized by a *second* dimensionless, Lorentz-invariant parameter:

$$\Upsilon = \gamma \frac{2E}{B_c}\,, \tag{2.2}$$

where $B_c = m^2c^3/e\hbar \approx 4.4 \times 10^{13}$ Gauss is the Schwinger critical field strength. The parameter Υ is frequency-independent, but (unlike η) it involves Planck's constant, reflecting the nonclassical nature of a hard event. In the coherent regime ($\eta \gg 1$) a microscopic process may be either classical ($\Upsilon \ll 1$) or quantum-mechanical ($\Upsilon \gg 1$), depending on whether a typical hard photon is much less, or more, energetic than the electron in the latter's rest-frame. In the pair-production regime one requires [5] $\Upsilon_{max} \gg 1$: at the focus of the laser pulse, the interactions must be deep in the quantum regime to ensure copious pair production.

For the CBX application, though, one has $\Upsilon_{\rm max} \ll 1$; thus, for the 50 MeV CBX source at LBL and a 1μm wavelength laser, one has $\Upsilon_{\rm max}/\eta_{\rm max} \approx 4 \times 10^{-4}$, so that for the maximal value of $\eta_{\rm max}$ considered in our numerical examples (sections 4 and 5 below), $\Upsilon_{\rm max} \approx 3 \times 10^{-3}$. Hence it is a reasonable approximation to restrict attention to the classical limit in estimating the leading post-Volkov effects upon CBX performance.

We end this section with a few simplified analytical expressions for the Volkov-approximation physics of an electron-laser collision; the formulae used are adapted from reference [1] .

Consider a gaussian laser pulse characterized by its wavelength λ, the beam *rms* at focal plane, $\sigma_\perp$, the focusing paramater f/D, the peak cycle-averaged pulse intensity at beam waist*, I_0, and the pulse temporal extent $2\sigma_t$. We assume the temporal pulse profile, as well as the transverse spatial profile, to be Gaussian. Thus the cycle-averaged intensity on the beam axis and at its waist, or focal ($z = 0$) plane, is† $I_0 \exp(-t^2/(2\sigma_t^2))$. We also define $2\bar{\sigma}_t$, the *effective temporal extent* of

$\star$ I_0 is simply related to $\eta_{\rm max}$; see section 3.

$\dagger$ for the field formulae in this gaussian pulse, see [6] ; in this paper we content ourselves with using a simplified 'cylindrical' approximation for these fields (see section 3).

the pulse felt by the electrons [1] (we set c=1):

$$\bar{\sigma}_t = \min(\sigma_t, 2\pi\sigma_\perp^2/\lambda) \tag{2.3}$$

Note that the effective temporal (or longitudinal) extent is diffraction limited if $c\sigma_t > 2\pi\sigma_\perp^2/\lambda$. Thus $\bar{\sigma}_t$ can be substantially smaller than σ_t, especially for small f/D ratios.

The $\Upsilon \to 0$ limit of the expected number of X-rays emitted by a single electron during the collision behaves like η^2 for $\eta \ll 1$, and like η for $\eta \gg 1$; an interpolating formula is [1]

$$n_X \approx \frac{\eta^2}{2+\eta/2} 2\pi\alpha \frac{\bar{\sigma}_t}{\lambda} \tag{2.4}$$

with α the fine structure constant.

The effective fraction N_{eff}/N of bunch electrons that participate in the collision is 1 (for zero crossing angle), *unless* both $2\pi\sigma_\perp^2/(\lambda L_{bunch}) < 1$ *and* $\sigma_t/L_{bunch} < 1$, in which case N_{eff}/N is the largest of these two fractions. (This is because part of the bunch arrives at the laser focal point while the pulse is away from the focal plane.) These estimates can be combined to obtain the total X-ray yield from a single collision:

$$N_X \approx \frac{\eta^2}{2+\eta/2} 2\pi\alpha(\bar{\sigma}_t/\lambda) N \min\bigl(1, \frac{\tilde{\sigma}_t}{\lambda}\bigr) \tag{2.5}$$

with

$$\tilde{\sigma}_t = \max\bigl(\sigma_t, 2\pi\frac{\sigma_\perp^2}{\lambda}\bigr) \ . \tag{2.6}$$

Finally, we note that for $\eta_{\max} \gg 1$, the typical number of laser photons participating in the coherent emission of a single X-ray, is of order $\eta_{\max}^3$ [2] , and the peak energy of a backscattered photon is [5]

$$\hbar\omega_{peak} \approx 4\hbar\omega\eta\gamma^2 \tag{2.7}$$

3. Post-Volkov Effects: Helix Bending

The full formulae for the EM fields of a realistic, gaussian beam pulse, propagating in the $-z$ direction, can be found in [6] . The purpose of the current paper is to provide an approximate analytical framework for estimating post-Volkov effects; thus it will suffice here to replace these fields by a cruder 'cylindrical beam' approximation. In it, the diffractive variation of laser spot-size from its focal-plane minimum is ignored — or more precisely, it is encoded in $\bar{\sigma}_t$, the effective temporal pulse extent (eq.(2.3) above, and reference [1]). The cylindrical approximation then consists in replacing the gaussian beam EM fields by the following (the subscript refers to the *circular* or *linear* polarization of the laser pulse):

$$\mathbf{E}_{cir}(x) \approx \bar{E}(x)(\sin\omega(t+z), \cos\omega(t+z), 0) \tag{3.1}$$

$$\mathbf{E}_{lin}(x) \approx \bar{E}(x)(\sin\omega(t+z), 0, 0) \tag{3.2}$$

where for either polarization:

$$\bar{E}(x) = E_0 \exp(-(z+t)^2/(4\bar{\sigma}_t{}^2) - x_\perp^2/(2\sigma_\perp^2)) \tag{3.3}$$

with the magnetic field

$$\mathbf{B}(x) \approx \mathbf{E} \times \hat{\mathbf{z}} \tag{3.4}$$

Here $\hat{\mathbf{z}}$ is a unit vector in the z direction, and E_0 is a fixed amplitude proportional to $\sqrt{I_0}$:

$$E_0 = \sqrt{I_0} \qquad (\text{ circular }) \,, \tag{3.5}$$

$$E_0 = \sqrt{2I_0} \qquad (\text{ linear }) \,. \tag{3.6}$$

Upon substituting these fields in the electronic Lorentz equations of motion, the classical trajectory of any electron in the bunch (between nonlinear Compton backscattering vertices) can be solved for*. By this procedure, both the Volkov-approximation helical gyration *and* the leading post-Volkov (ponderomotive) trajectory-bending effect, are obtained [1] . We find the local semiclassical gyration radius (for circular laser polarization) to be:

$$r_{gyr} = \frac{\eta c}{2\omega\gamma} \tag{3.7}$$

with η the *local* eta parameter, and γ the electron's instantaneous relativistic factor. For actual linac and laser parameters of interest (see e.g. section 4), r_{gyr} is typically both much *less* than $\sigma_\perp$, and much *larger* than the electronic Compton wavelength (and also larger than any relevant transverse de Broglie wavelength for the electron). For this reason, the semiclassical treatment of electron motion in the laser field (between hard quantum processes) is a justified approximation, and furthermore we can Taylor-expand in transverse derivatives of the local laser intensity [1]†.

The analytical framework outlined above yields, in the CBX regime ($\Upsilon_{\mathrm{max}} \ll 1$), the following approximation [1] for the leading post-Volkov bending of the helical electron trajectories (we henceforth restrict attention to circulary polarized laser pulses):

$$m\gamma\langle\frac{d^2x^n}{dt^2}\rangle \approx -\frac{mc^2}{4\gamma}\partial_n(\eta^2) \tag{3.8}$$

in Lab frame, with n=1,2 (x_1,x_2 are the spatial coordinates transverse to the z direction). The angular brackets denote a time averaging over a single laser cycle.

⋆ actually, the equations of motion which should be used are modified by (semiclassical) spin dependent relativistic Stern-Gerlach terms [1] ; but those are proportional to powers of Υ and are hence negligibly small for the CBX application (see section 2 above for a typical Υ_{max} value in the CBX regime).

† temporal and longitudinal derivatives appear as well, but these are suppressed by inverse powers of the electron relativistic $\gamma \gg 1$ factor, as well as by inverse powers of the ratio $\sigma_t/\sigma_\perp$, which is also usually $\gg 1$. Hence we may neglect non-transverse spacetime derivatives of laser intensity.

By combining eqs.(3.1)-(3.6) with (3.8), we find that an electron colliding with a laser pulse head on (i.e. moving along the $+z$ axis), but offset a distance $r_\perp$ from the laser beam axis, suffers an angular deflection (in radians)

$$\Delta\theta \approx \frac{r_\perp \bar{\sigma}_t c}{2\gamma^2 \sigma_\perp^2} \eta_{\max}^2 \tag{3.9}$$

over the course of the collision ‡.

4. Implications for CBX Performance

The precise implications of the post-Volkov helix bending effects for the performance of CBX sources, must be computed via numerical simulation of the macroscopic laser pulse — electron beam collision; such a simulation would incorporate the post-Volkov effects at the microscopic level. Here we merely render simple analytical estimates of the new effects, for two numerical examples.

Qualitatively, the main effects of the helix bending (eq.(3.9)) upon CBX performance are through a modification of the electron-beam focusing. This modification results in a *broadening* of the angular spread of the backscattered X-ray pulse. It is this broadening, along with some Volkovian aspects of CBX performance, which we estimate in the present section.

We begin by specifying our two numerical examples.

Example I is based on the planned CBX at UCLA [3] . Laser parameters are: wavelength 1μm; 10 terawatt peak power; $\sigma_\perp = 17\mu$m spot size at focus; and pulse length $\sigma_t = 100$ fsec (hence, by eq.(2.3), $\bar{\sigma}_t = \sigma_t$). Thus one easily calculates that $\eta_{\max} = 0.56$.

‡ the simplified estimate (3.9) does not take into account the gradual energy loss of the electron due to nonlinear backscattering of laser photons; in our numerical examples, we shall substitute in (3.9) the initial γ of the linac beam.

The electron bunch parameters for this example are: energy 20 MeV; $N = 10^{10}$ electrons; bunch length $L_{bunch} = 4.5$mm; $\beta^* = 1$mm; and spot size 17μm, equal[§] to the laser $\sigma_\perp$.

In **Example II** we utilize the same linac energy and N value, and the same laser peak power and σ_t value. Now, however, the bunch dimensions — both transverse and longitudinal — are assigned the optimistic (and as yet unachieved) values of 1.4μm (bunch spotsize) and $L_{bunch} = 30\mu\text{m} = \sigma_t$, respectively (and thus $\bar{\sigma}_t = 12.3\mu$m). We correspondingly lower the laser $\sigma_\perp$ to 1.4μm, as well (this is easily done, since it corresponds to the diffraction limit for f/D=3.2).

The β^* parameter needed to achieve these bunch parameters[¶] is $\beta^* = 6\mu$m . For this example, one has $\eta_{\max} \approx 7$.

Based upon the formulae in sections 2 and 3 above, CBX performance for the two numerical examples is as follows.

For Example (I): The X-ray yield per bunch is $N_X \approx 10^9$. The Volkovian gyration radius, eq.(3.7), is $r_{gyr} \approx 1$nm, comfortably intermediate between quantum length scales and $\sigma_\perp$. The post-Volkov helix bending, eq. (3.9), is maximized at $r_\perp$ values of order the bunch spotsize; it is then of magnitude $\Delta\theta \approx 1.7\times 10^{-4} = .007/\gamma$ radians. This translates into a corresponding angular broadening of the backscattered X-ray pulse. Since the Volkovian Compton angular broadening (not much affected by laser-intensity effects for this moderate $\eta_{\max}$ value) is of order $1/\gamma$,

§ at present, the laser can be focused to a much tighter spotsize than the bunch; laser spotsize is almost diffraction-limited. In Example II (see below), we consider a much tighter bunch focus (which may be achievable in the future); the laser $\sigma_\perp$ is correspondingly lowered, to match the smaller bunch *rms*. Smaller $\sigma_\perp$ results in higher $\eta_{\max}$, and hence higher X-ray backscatter rates (eq. (2.4)); but it is counterproductive to focus the laser tighter than the electron beam — since a fraction of the bunch would then fail to pass through the main part of the laser pulse, resulting in reduced overall X-ray yields.

¶ note that an easier way to decrease the effective L_{bunch} is to collide the laser and electron beams at an angle. The planned UCLA CBX-source will indeed have an adjustable beam-beam crossing angle. The existing LBL CBX-source [4] operates at a crossing angle of 90^0, and utilizes a 50 MeV linac.

the post-Volkov broadening is less than 1 percent. This does not significantly affect electron beam focusing during the collision, and hence does not substantially modify the above estimates for the X-ray yield, N_X.

For Example (II): The X-ray yield for this case is $N_X \approx 5 \times 10^{10}$, about 5 backscattered X-rays per electron. We now have $r_{gyr} \approx 14$nm; the maximal post-Volkov helix bending angle is $\Delta\theta \approx 0.14 = 5.6/\gamma$ radians — i.e. *larger* than the linear-Compton angular broadening. Thus the post-Volkov (ponderomotive) contributions to the angular width of the X-ray pulse are quite important for this example. In addition, $\Delta\theta$ is large enough to substantially modify the beam dynamics of the bunch during its collison with the laser pulse; in particular the electron-beam focal plane will be shifted, and the bunch spotsize will also be changed. Thus, all of the above results for Example II must be re-computed; a reliable calculation requires numerical simulation of the laser-bunch collision, and is beyond the scope of this paper.

Finally, we note that since $\eta_{\max} = 7$ is large for this example, the peak energy of a backscattered photon is (by (2.7)) of order 45 keV — that is, 7 times the normal *linear* Compton value. In fact, there will be a discrete set of peak backscattered photon energies, corresponding to the various integer numbers of laser photons that may participate in a single coherent quantum process; this laser-induced photon energy spread will tend to compromise the monochromaticity of the X-ray pulse. Note that this effect occurs already at the level of the Volkov approximation.

5. Bounds on Multibody Effects

In reference [1], rough analytical bounds and estimates were developed for the *multibody* effects mentioned in the introduction; rough estimates suffice because these effects turn out to be quite negligible for parameter regimes of current interest. In this section, we apply the formulae of [1] to the two numerical examples introduced above, and verify that the multibody effects are, indeed, negligible.

Two particle collisions: During the collision of a bunch with a laser pulse, the number of hard QED scattering events amongst particles (electrons and back scattered X-rays) is of order

$$N^2(\lambda\!\!\!^{-}_C/\sigma_\perp)^2\Big(\frac{\alpha}{\gamma}\Big)^2 \tag{5.1}$$

with $\lambda\!\!\!^{-}_C$ the electron Compton wavelength. For Example I, this estimate yields $\approx 2\times 10^{-3}$ events; for Example II, it is enhanced to ≈ 0.3 events — still negligible.

EM self-forces: Obviously only the bunch electrons, and not the backscattered photons, participate in these semiclassical, long range interactions. Electrostatic and current-current self-forces in the *absence* of laser fields, impart to a typical electron a transverse momentum kick during the bunch-laser collision, of order

$$(\Delta p_\perp)_{static} \approx \frac{\alpha}{\gamma^2}N\frac{1}{\sigma_\perp} \tag{5.2}$$

This is $\approx 1.5\times 10^{-3}$mc for Example I, and 0.02mc for Example II. These static self-forces merely represent the usual relativistic space charge effects familiar in charged-particle beam dynamics.

There are also other bunch self-forces, due to the laser-induced gyrations; these forces do not average to zero over a laser cycle. The corresponding momentum kicks are of order

$$(\Delta p_\perp)_{nonstatic} \approx (\Delta p_\perp)_{static} \big(\frac{\eta^2}{\omega\sigma_\perp\gamma}\big)^2 \tag{5.3}$$

This is of order $\approx 1.2 \times 10^{-7}$mc for Example I, and 4×10^{-4}mc for Example II.

EM Laser backreaction: the decrease in $\eta_{\max}$ due to the backreaction upon a given laser pulse by its collision with an electron bunch, is estimated at

$$|\Delta(\eta^2_{\max})|/(\eta^2_{\max}) \approx \big(\frac{\lambda\!\!\!^{-}_C}{\sigma_\perp}\big)^2 N_{eff} n_X \alpha \eta_{\max} \frac{\lambda}{\sigma_t} , \tag{5.4}$$

with n_X given by eq. (2.4) above, and N_{eff} defined below eq. (2.4). Thus for Example I, an optical pulse loses a fraction $\approx 10^{-10}$ of its energy during a collision; while for Example II, the fraction is 1.4×10^{-7}.

6. Conclusions

Until recently, analyses of the collisions of short, intense laser pulses with relativistic electron bunches were carried out within the framework of the Volkov approximation, thus ignoring effects that are liable to become important as peak laser power and linac energies continue to increase. This circumstance was remedied in reference [1] , where a systematic treatment of *post-Volkov* effects in these collisions was initiated. In this paper, we have applied simple analytical formulae, developed in [1] , to the parameter regime suitable for CBX (Compton Backscattered X-ray) sources —- namely, high $\eta_{\max}$ and low $\Upsilon_{\max}$. In this case, the leading post-Volkov effects are classical, and stem from a slow ponderomotive bending of the undulating electron trajectories in the intense EM fields near the focus of the laser beam. By considering two CBX numerical examples — one state of the art, the other utilizing small electron-bunch dimensions which have not yet been achieved, we have found that high intensity effects — both Volkovian *and* post-Volkov — can degrade the performance of CBX X-ray sources. The consequent tradeoffs involved in increasing laser intensity need to be carefully estimated, using suitable numerical simulations based on the results of [1] and of this paper.

Acknowledgments

S.B-.M. would like to thank the Accelerator Theory group at SLAC for its hospitality.

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