SHORT X AND GAMMA PRODUCTION WITH SWEPT LASER BUNCH

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Abstract[1]

We described here the new way of production of ≤ 100 fs bursts of X and gamma radiation by Compton back-scattering of a laser bunch which have been swept along the electron trajectory. In the method described the time duration of the secondary radiation does not depend on electron bunch length and is shorter than duration of the primary laser bunch by factor $1/N_R$–the number of resolved spots of sweeping device (up to 1/ 1000). The method of the laser bunch sweeping is also helpful in obtaining short electron bunches from a photo cathode.

INTRODUCTION

An idea on generation of X-rays and gammas by Compton back-scattering was developed many years ago [1] ,[2] and used well in a framework of gamma-gamma collider activity [3]. This idea was applied to a circular machine also [4], [5]. In this method accommodated to a circular machine the short laser bunch interacts with a passing electron bunch with 90° across the laser's ray trajectory. In this case the time duration of the secondary radiation defined by the time duty of primary laser radiation $\tau \cong \sigma_b / c$, or by the length of the laser bunch σ_b, or by the length of the electron bunch. In any case the method requires either short primary laser bunch and/or short electron bunch in some modification of the method.

SCHEME

In contrast to this method mentioned above, in our publication [6] we described so called laser undulator installed in Tabletop accelerator. This accelerator developed as a side product in a framework of high-energy linear collider [7-9]. Main difference of our proposal from others is that here we used ***swept*** laser bunch, having slope of 45 degree to direction of propagation in the region of interaction between laser and electron bunches. The laser bunch of this shape can be generated by appropriately designed sweeping device used in [7-9] for high-energy accelerator.

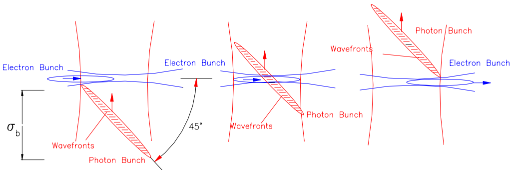

Figure 1: Three different times sequences increasing from left to the right. Laser bunch slope with respect to direction of propagation is 45 degrees. Volume with electrons that radiate does not depend on the electron bunch length at all.

In our method the time duration of the secondary radiation is defined by instant transverse size of the primary laser bunch at location of electron beam trajectory, Fig.1 and Fig.2. Meanwhile the total number of radiated secondary particles defined by full length of the laser bunch. With implementation to any damping ring X and gamma ray production with the time duty of the order of 100 fs or even better can be obtained now with routinely operational laser having bunch of ~30 ps.

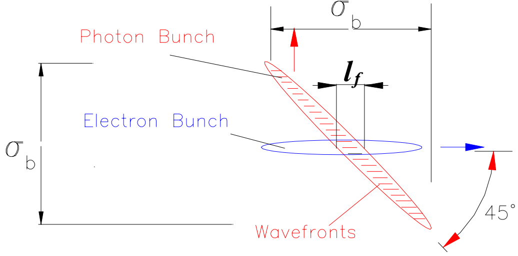

Figure 2: Scaled view of central part from Fig.1.

Despite the primary laser bunch has the length σ_b, the length of interaction (radiation) region is l_f which defined by the number of resolved spots of sweeping device (see lower). One can see that the number of electrons effectively interacting with the photon bunch is lower than the bunch population in factor l_f / σ_b, namely this moving length l_f describes radiating electrons. This active region is moving with re-radiated photons.

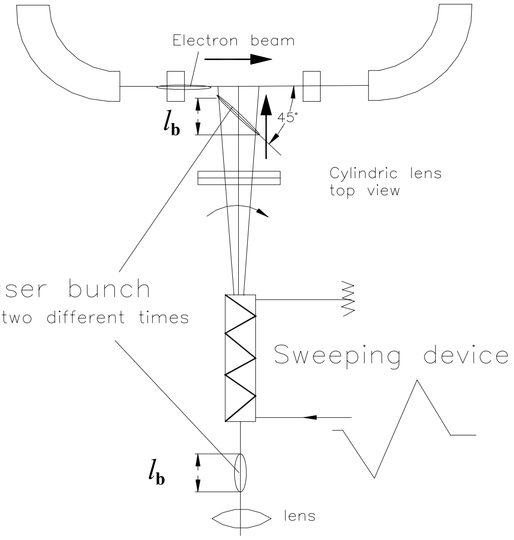

Figure 3: General scheme.

The arrangements of the scene are represented in Fig. 3. Sweeping device deflects the front of laser bunch to the left on the picture plan; the tail of the laser bunch is deflected to the right of the plan. Lens at the lower edge of the figure focuses the primary laser bunch onto the

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[1] Extended version is available at http://www.lns.cornell.edu/public/CBN/2002/CBN02-11/cbn0211.pdf.

interaction region. As far as cylindrical lens, in can be mentioned that it is working with broadband radiation. Utilization of optical materials with appropriate frequency bandwidth is not a problem however. Scaled view on cylindrical lens is shown in Figure 4.

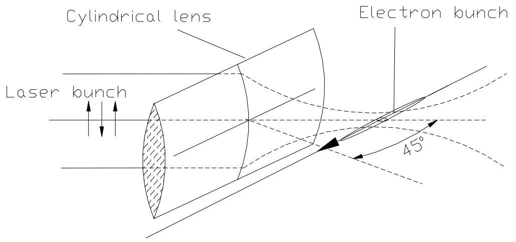

Figure 4: Cylindrical lens shrinks the transverse size of the laser bunch in vertical direction. Low dispersion material of the lens allows proper focusing of short bunch

Circular or elliptical polarization could be obtained also if the primary laser beam has circular or elliptical polarization.

YIELD OF SECONDARY PHOTONS

The photon generation in laser undulator could be treated also as Compton back-scattering. The number of photons, radiated at first harmonic by every particle, could be written as

$$N_\gamma \cong \sigma_b \sigma_\gamma n_\gamma , \tag{1}$$

where $\sigma_\gamma \cong \frac{8\pi}{3} r_0^2$ is Thomson cross section of photon-electron scattering, $n_\gamma \cong H^2 / \hbar\omega$. This introduces the length of interaction as usual $l_\gamma \cong 1/\sigma_\gamma n_\gamma$, so the number of photons per initial particle is simply $N_\gamma \cong \sigma_l / l_\gamma$.

The energy of the backward scattered photon is [3,10]

$$\hbar\omega' = \frac{mc^2\gamma \cdot x}{1+\gamma^2\vartheta'^2+x} \tag{2}$$

where $x = \frac{2\gamma^2\hbar\omega_0}{mc^2\gamma} = \frac{2\gamma\hbar\omega_0}{mc^2}$.

For a primary laser radiation with a wavelength around micrometer, $\hbar\omega_0 \cong 1eV$, parameters and energy of secondary photons are represented in Table 1.

Table 1

E, GeV	*x*	$\hbar\omega'$, *MeV*
0.1	0.00077	0.077
1.0	0.0077	0.77
10.	0.077	711
100.	0.77	43370

All secondary photons are moving in the same sample having the longitudinal length of l_f in Fig.2. Namely this distance defines the duty time for secondary radiation.

For a micrometer level of the primary wavelength the number of resolved spots N_R~100 can be expected. Vertical size of the laser radiation defined by cylindrical lens and can be estimated as ~5 μm. So the effective volume of interaction for single particle with this 30*ps*-laser flash could be estimated as $V \cong 1cm \times 100\mu m \times 5\mu m \cong 5 \cdot 10^{-6} cm^3$. The number of primary photons can be calculated as $N_{0\gamma} \cong E_{flash} / \hbar\omega_0$. The photon density and the length of interaction go respectively $n_\gamma \cong N_\gamma / V$ and total number of secondary photons goes to

$$N_\gamma \cong N_{eff}\sigma_b / l_{eff} \ , \tag{3}$$

where $N_{eff} \cong N \cdot l_f / \sigma_b \cong N / N_R$,N is the bunch population. For the laser flash with, say $E_{flash} \cong 1mJ$, $\hbar\omega_0 \cong 1eV$, each electron radiates in average $N_\gamma \cong \sigma_l / l_\gamma \cong 8.3 \cdot 10^{-4}$ photons per pass. For $N \cong 10^{10}$ this brings the photon number to $N_\gamma \cong 8.3 \cdot 10^4$ /bunch/pass. Suggesting repetition rate 100*kHz* one can expect the photon flux $\dot{N}_\gamma \cong 8.3 \cdot 10^7 s^{-1}$. Total power from laser goes to $10mJ \times 10^5 \frac{1}{s} = 100W$. These numbers gave an idea of the possibilities of the method proposed.

The brightness of the source can be evaluated as the following

$$B \cong \frac{\dot{N}_\gamma}{(\gamma\varepsilon)\cdot(\beta/\gamma)\gamma^{-2}} = \frac{\gamma^3 \cdot \dot{N}_\gamma}{(\gamma\varepsilon)\cdot\beta} \tag{4}$$

If we suggest that the electron beam emittance be $\gamma\varepsilon \cong 3 \cdot 10^{-3} cm \cdot rad$, envelope function in the region of interaction as $\beta \cong 1cm$, then one can estimate for $\gamma \cong 10^4$

$$B \cong 8.3 \cdot 10^{24}\, photons / cm^2 / rad^2 / \sec .$$

Duty time for these bursts of radiation is about 100 fs, despite the primary length of laser bunch is ~30ps.

SWEEPING DEVICE

The devices types suitable for the sweeping were collected in [8]. Each sweeping device uses controllable deflection of the laser radiation in time. Any deflecting device could be characterized by a deflection angle ϑ and the angle of natural diffraction $\vartheta_d \cong \lambda / a$, where a —is the aperture of the sweeping device, λ is a wavelength. The ratio of deflection angle to diffraction angle is a fundamental measure of quality for any deflecting device. This ratio defines the number of resolved spots (pixels) along the sweeping line, $N_R = \vartheta / \vartheta_d = inv$. As one can see, N_R value gives the number for the duty time reduction.

Electro-optical sweeping device uses controllable dependence of refractive index on electrical field strength and direction applied to some crystals. When a voltage *V*(*t*) applied to the metallization, the refractive index changes $\Delta n = \Delta n(V(t))$. To increase the numbers N_R, $\Delta\vartheta$, *multiple-prism* deflectors were developed, see Fig.5.

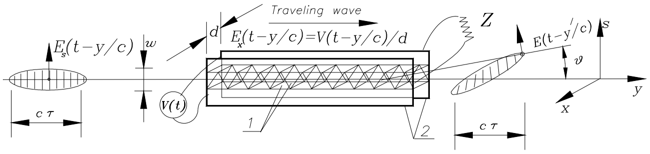

Figure 5 [8]: Prisms 1 with *oppositely directed optical axes* installed in series between two parallel strip–line electrodes 2, *d*–is the distance between them. *Z*– is matching impedance. Lines across the laser bunch schematically show the wave fronts. $E_x(t-y/c)$–is a driving electrical field.

We suggested a *traveling wave* regime here to be able to sweep the short laser bunch. Here neighboring prismatic crystals have oppositely oriented optical axes. These crystals positioned between strip–line electrodes. To be able to sweep short laser bunches*,* the voltage pulse *V* (*t*) is propagating along this strip-line as a *traveling wave* together with the laser bunch to be swept, [8]. This gives the necessary voltage profile along the laser pulse at *cm* distances.

Deflection angle and the number of resolved spots become

$$|\Delta\vartheta| \cong \Delta n \frac{2L_d}{w} \cong \frac{L_d}{w\cdot d} n_0^3 \cdot r_{ij} \cdot V\ ,\ N_R \cong \Delta n \frac{2L_d}{\lambda}\ ,(5)$$

where L_d stands for full length of deflecting device, *w*–is the laser beam width (along direction of deflection). The broad band traveling wave deflector could be obtained also if the same crystals located in the middle of a waveguide shortened from both sides [8]. In Table 2 we summarized general parameters of electro optical deflectors.

Table 2

Wavelength	Materials	ϑ, *rad*	N_R
$\lambda \cong 10\mu$	*GaAs, ZnTe, ZnS, CdS, CdTe, CuCl*	0.01-0.02	10
$\lambda \cong 5\mu m$	*LiNbO*$_3$*, LiTaO*$_3$*, CuCl*	0.01-0.02	20
$\lambda \cong 1\mu m$	*KDP, DKDP, ADP, KDA, LiNbO*$_3$	0.01-0.02	100

Mechanical deflection system is also possible here [8].

The same idea can be applied to the electron bunch production with help of photocathod, Fig. 6. The shortage of illumination time increases with increase of illumination angle θ in Fig. 6. So one can see that practically any existing scheme can be equipped with this sweeping device.

CONCLUSIONS

The method proposed allows generation of short bunches of secondary photons practically with ordinary equipment. Secondary radiation duty is shorter, than primary laser duty in ~ 300 times for visible light. Electro-optical sweeping device is available on the market. The photon flux of ~30-100 fs of X or gamma radiation is big enough to satisfy the broad variety of user's needs.

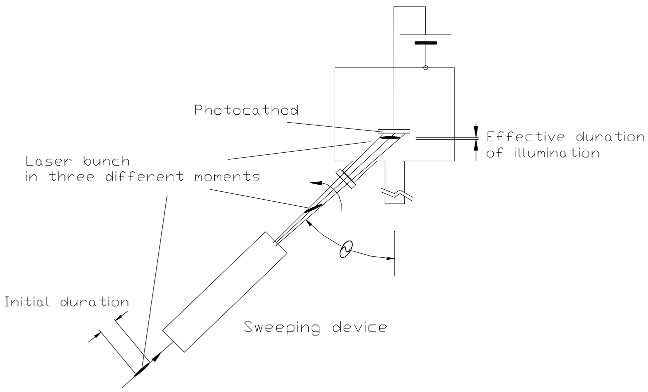

Figure 6: Principle of photocathod illumination.

The scheme is not sensitive to a jitter of laser or electron beam as the only a small length of electron bunch radiates and this duration time does not depend on the bunch length at all. Laser with synchronized modes can generate necessary sequence of primary laser bunches.

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