FREE ELECTRON LASER FOR GAMMA-GAMMA COLLIDER AT A LOW-ENERGY OPTION OF INTERNATIONAL LINEAR COLLIDER*

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Abstract

Different scenarios of a start-up with International Linear Collider (ILC) are under discussion at the moment in the framework of the Global Design Effort (GDE). One of them assumes construction of the ILC in stages from some minimum CM energy up to final target of 500 GeV CM energy. Gamma-gamma collider with CM energy of 180GeV is considered as a candidate for the first stage of the facility. In this report we present conceptual design of a free electron laser as a source of primary photons for the first stage of ILC.

INTRODUCTION

Recently, different staging scenarios for start-up of the International Linear Collider [1] have been considered within the framework of the Global Design Effort (GDE). In particular, in [4] it was suggested to consider the first stage if ILC to be a low energy photon collider, a Higgs factory. Related staging proposals were also considered in [2] and [3]. A panel commissioned by GDE to evaluate the proposal [4] prepared a report [7]. As part of the evaluation, the configurations of the Beam Delivery System [5], parameters for the IP and parameters of the driving laser or FEL source was developed, for the staged ILC. In this paper, after brief description of the stages and IP parameters, we will focus on description of the parameters for the FEL driver for the γγ stages of linear collider. The FEL parameters were determined using similar methodology as in [6].

STAGES AND PARAMETERS

The parameters of stages and their detailed description are available in [7]. Here we reproduce them, in an abridged form, for completeness. The list of stages is shown in Table 1. The first stage features a single Damping Ring (a 3 km perimeter is assumed) and a very short Beam Delivery system (0.3 km per side), which does not have a dedicated collimation system. Some collimation may be distributed over the linac. The configuration of the central area in the first stage is shown in Fig.1. The linac accelerating modules are extended to the BDS and are placed in the BDS tunnel. The short beam delivery system is aimed at the IP with a 30 mrad crossing angle, which is offset by some 2.5 m from the ideal location of the IP for the RDR BDS. A dedicated beam dump based on a gas concept [8] is used. The photon driver – an FEL photon source or laser, can be placed in the BDS tunnel near the IP or in the IR hall. The stages 2 and 3 would double the luminosity by doubling the number of bunches, due to either a faster kicker or by installation of the second Damping Ring. Stage 4 involves building the e+ source, lengthening the Beam Delivery System and adding a dedicated collimation system. Stage 5 is the nominal ILC RDR configuration. Stage 6 is a final γγ run before a (multi)-TeV upgrade, where ε_x from the Damping Rings was assumed to be reduced by a factor of four.

Table 1: List of Stages Considered in [7]

Stage	1	2&3	4	5	6
E CM, GeV	180	180	230	500	500
Mode	γγ	γγ	e+e-	e+e-	γγ
E reach, GeV	128	128	230	500	400
BDS length/side, km	0.3	0.3	0.8	2.2	2.2
Site length, km	8.8	8.8	12.1	27.2	27.2
L, E34 cm^{-2}s^{-1}	0.25	0.5	0.9	2	4.5

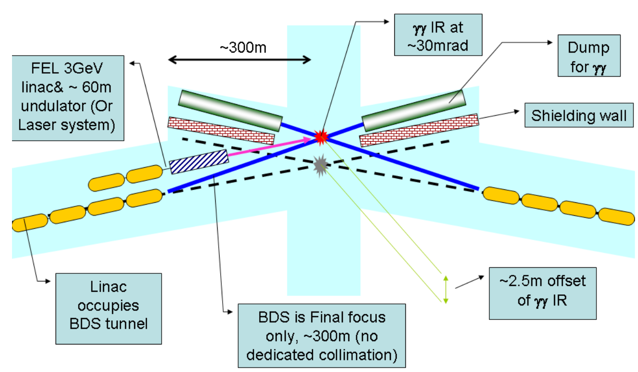

Figure 1: Conceptual configuration of Beam Delivery System, tunnels and location of FEL for the first 180GeV CM γγ stage of a staged linear collider [7].

Table 2 describes the IP beam parameters and luminosity. The emittances assumed correspond to ILC RDR values. Reasonably achievable beta functions at the IP were assumed. For the γγ stages, the luminosity shown is geometrical, for the initial e-e- beams. For both e+e- stages, travelling focus [9] is assumed as an amelioration of the low Power parameter sets [10]. In these cases the luminosity was calculated by the beam-beam program Guinea-Pig [11].

Table 2: Main Parameters of Beams and IP

Stage	1	4	5	6
E CM, GeV	180	230	500	500
Mode	γγ	e+e-	e+e-	γγ
N	2E10	2E10	2E10	2E10
n_b	660	1320	1320	1320
F (Hz)	5	5	5	5
P_b (MW)	0.95	2.4	5.3	5.3
$\gamma\varepsilon_X$ (m)	1E-5	1E-5	1E-5	2.5E-6
$\gamma\varepsilon_Y$ (m)	3.6E-8	3.6E-8	3.6E-8	3.6E-8
β_x (mm)	4	11	11	1.5
β_y (mm)	0.4	0.2	0.2	0.4
Travelling focus	no	yes	yes	no
σ_x geom. (nm)	480	700	470	88
σ_y geom. (nm)	9	5.7	3.8	5.4
σ_z (µm)	400	300	300	300
L geom.E34$cm^{-2}s^{-1}$	0.24	0.53	1.15	4.4
L G-P, E34 $cm^{-2}s^{-1}$		0.88	1.9	

FEL SOURCE

Gamma-quanta for photon collider are produced in the process of Compton backscattering of laser photons by high energy electrons [12]. The wavelength of primary photons is selected in such a way that the low energy edge of the electron spectrum after conversion remains high enough that the disrupted angle for the edge of the spectrum of converted electrons would remain below 10 mrad. An ideal case is λ[micron]=4xE[TeV] [13], and visible light should be used for the stage 1 of the gamma-gamma collider at ILC. We consider free electron laser (FEL) as a source of primary photons [6,14,15].

For the case of axially symmetric electron and photon beams conversion efficiency is given by [6]:

$$P = 1 - \exp(-\delta) \ ,$$

$$\delta = \frac{\sigma_c A}{\sqrt{\pi}\hbar c Z_R} \frac{x \exp(x^2) \mathrm{erfc}(x)}{1+a} \ ,$$

$$x = \frac{\sqrt{2} Z_R}{\sqrt{\sigma_e^2 + \sigma_{ph}^2}} \sqrt{\frac{1+a}{1+b}} \ , \qquad a = \frac{\beta \epsilon_e}{Z_R \epsilon_{ph}} \ , \quad b = \frac{Z_R \epsilon_e}{\beta \epsilon_{ph}}$$

Here h is Planck constant, c is velocity of light, σ_c is Compton cross section, A is laser flash energy, Z_R is Rayleigh length, σ_e and σ_{ph} are rms length of electron and photon pulse, ε_e is emittance of electron beam, and $\varepsilon_{ph} = \lambda/4\pi$ is photon beam emittance, and β is beta function. Analysis of these relations with constrains for the electron beam parameters given in Table 2 leads us to rather severe restrictions. To achieve high conversion efficiency, say 70%, peak laser power should be about 600-700 GW, and pulse duration should be about, or longer than that of the electron bunch (1.3 ps rms). Thus, in the ideal case minimum laser flash energy is about 2 Joules. With FEL technology this becomes possible with relatively high energy of the driving beam of 2.5 GeV, peak current 2 kA, and bunch charge 13 nC. We assume to use TESLA-like injector [16] for production of electron bunches in the main linac and in the driving linac of the FEL amplifier. Undulator is helical, APPLE type permanent magnet device similar to that of XFEL project [17]. FEL amplifier is seeded by the laser identical to the photoinjector laser [16]. Second harmonic of the laser (530 nm) is used in the first stage (180 GeV), and the fundamental harmonic (1060 nm) – in the second stage (500GeV). Operation at the 3rd harmonic (353 nm) and reduced energy (176 GeV) is possible as well. Laser pulse with peak power of 100 kW is amplified in 110 m long tapered undulator up to the power of 650 GW. Rms pulse duration is 1.6 ps. Optimized value of the e-γ conversion probability is equal to 70%, and gamma-gamma luminosity is 50% of the value of geometric ee luminosity.

Table 3: Parameters of e-γ Conversion and FEL Driver

Stage	1	6
E CM, GeV	180	500
Mode	γγ	γγ
e-γ conversion:		
wavelength (µm)	0.53	1.06
Conversion coefficient	0.7	0.7
X	3.2	4.75
ξ_2	0.15	0.3
E reach, GeV	137	413
Disrupted e- beam:		
E_{min}, GeV	4.0	6.5
Disruption angle, mrad	10.1	9.1
Photon driver, FEL:		
Drive Energy, GeV	2.7	2.3
Bunch population	8E10	8E10
Undulator length, m	120	120
Beam to γ efficiency	8%	8%
Flash energy, J	2.7	2.5
Average beam power, kW	232	396
Undulator period, cm	17	17
Undulator max field, T	0.82	1
Undulator strength, K	13.1	15.9

In our case we assume that photon bunches are used only once. In principle, one can consider an optical cavity, which would give the possibility to reuse photon bunches. This will allow reducing requirements to the FEL amplifier for the price of complications related to optical cavity stability.

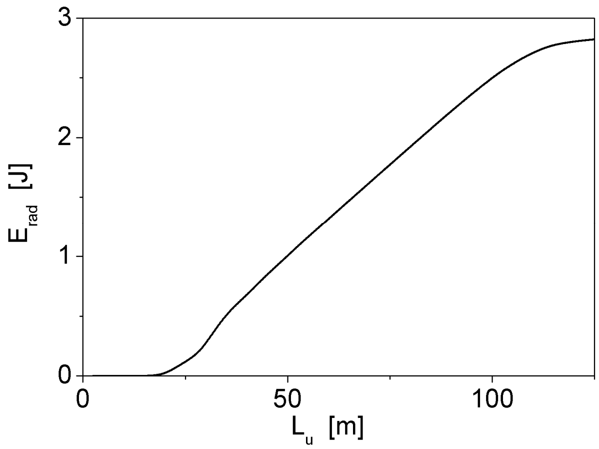

Figure 2: Energy in the FEL pulse versus undulator length.

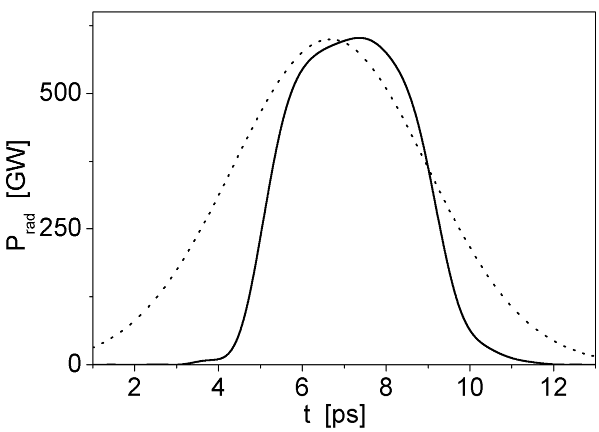

Figure 3: Temporal structure of the radiation pulse from FEL amplifier. Dashed line shows electron bunch profile. Radiation wavelength is 530 nm.

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