2 × 250 GeV CLIC \(\gamma\gamma\) Collider Based on it’s Drive Beam FEL

Hüsnü Aksakal\textsuperscript{a,b,*}

\textsuperscript{a}Department of Physics, Faculty of Science, Ankara University, 06100 Tandogan, Ankara, Turkey

\textsuperscript{b}Department of Physics, Faculty of Art and Science, Nigde University, 51200 Nigde, Turkey

Abstract

CLIC is a linear \(e^+e^- (\gamma\gamma)\) collider project which uses a drive beam to accelerate the main beam. The drive beam provides RF power for each corresponding unit of the main linac through energy extracting RF structures. CLIC has a wide range of center-of-mass energy options from 150 GeV to 3 TeV. The present paper contains optimization of Free Electron Laser (FEL) using one bunch of CLIC drive beam in order to provide polarized light amplification using appropriate wiggler and luminosity spectrum of \(\gamma\gamma\) collider for \(E_{cm}=0.5\) TeV. Then amplified laser can be converted to a polarized high-energy \(\gamma\) beam at the Conversion point (CP-prior to electron positron interaction point) in the process of Compton backscattering. At the CP a powerful laser pulse (FEL) focused to main linac electrons (positrons). Here this scheme described and it is show that CLIC drive beam parameters satisfy the requirement of FEL additionally essential undulator parameters has been defined. Achievable \(\gamma\gamma\) luminosity is above \(10^{34}\).

Key words: Compton backscattering, FEL based \(\gamma\gamma\) collider.
1 Introduction

The idea of a $\gamma\gamma$ collider was proposed in the early 1980 [1]. It is well known that due to severe synchrotron radiation in storage rings, $e^+e^-$ colliders in the TeV energy region will be linear. Unlike the situation in storage rings, in linear colliders each bunch is used only once. This makes possible the use of electrons for production of high-energy photons to obtain colliding $\gamma\gamma$ and $\gamma e$ beams. The high energy gamma beam is produced by Compton backscattering of laser light off the electron beam. At about the same time, it was suggested that a free-electron laser could be used as the photon source of the $\gamma\gamma$ collider [2].

In 1994, the use of single drive-beam bunches in a free-electron laser for a $\gamma\gamma$ collider based on an earlier version of CLIC, which accelerated single main bunches per pulse, was proposed by R. Corsini and A. Mikhailichenko [10]. The present paper describes to use a MOPA (Master Oscillator Power Amplifier) FEL instead of a conventional laser for Compton backscattering. MOPA FEL is studied for the case in which of radiation from a master oscillator is amplified in the FEL amplifier with tapered wiggler. But here we offer to use a solid state laser as a master laser instead of master oscillator radiation. FEL has many advantages compare to a conventional laser i.e: tunability, minimum divergence etc [10][12]. The FEL produces the radiation to Terawatt level which is the required power for a laser with wavelength of $1\mu m$ at a photon linear collider. Several physics opportunities for $\gamma e$ and $\gamma\gamma$ collisions at the CLIC

* Corresponding author

Email address: aksakal@science.ankara.edu.tr (Hüsnü Aksakal).
are described below. Some examples are also described in [3,4].

- A $\gamma\gamma$ collider offers a unique opportunity for measuring the two-photon decay width of the Higgs boson, providing a glimpse of the mass scale beyond the TeV range. Even in the case when the Higgs boson will be found at $e^+e^-$ linear colliders, its properties may be studied in detail only with CLIC photon collider.
- A $\gamma\gamma$ collider is well suited for searching new charged particles, such as SUSY particles, leptoquarks, excited state of electrons, etc. because photons generally couple more effectively to these particles than do electrons or positrons.
- A $\gamma\gamma$ or $\gamma e$ collider serving as a W-factory, producing $10^6 \sim 10^7$ Ws/year, allows for a precision study of gauge boson interactions and a search for their possible anomalies.
- At $\gamma e$ collider charged supersymetric particles with masses higher than the beam energy could be produced as well as the structure of photon could be measured.

A proposed scheme of CLIC $\gamma\gamma$ collider based on it’s drive beam FEL is shown in Fig 2.

2 Kinematic Background

Conversion of FEL to high energy $\gamma$ beam at the conversion point can be scaled with dimensionless $x$ parameter [1].

$$x = 4E_b\omega_0/m^2$$ (1)
where \( m, E_b \) are electron rest mass and beam energy respectively, \( \omega_0 \) laser photon energy. The maximum energy of the backscattered photons \( \omega_{\text{max}} = x E_b/(x + 1) \) depends on the parameter \( x \) but the backscattered photons can be lost for \( x >> 4.8 \) due to \( e^+e^- \) pair creation at the collisions of produced photons with un-scattered FEL photons (Breit-Wheeler process). Thus, the optimum value is \( x = 4.8 \), giving the maximum photon energy \( \omega_{\text{max}} = 0.81 E_b \). Neglecting multiple scattering, and assuming that the laser profile seen by each electron is the same, the conversion probability of generating high energy gamma photons per individual electron can be written as \([3]\):

\[
p = 1 - e^{-q}
\]  

(2)

If the laser intensity along the axis is uniform the exponent \( q \) is

\[
q = \frac{A}{A_0} = \frac{\sigma_c A}{\omega_0 \Sigma_L} = \frac{\sigma_c I \tau_L}{\omega_0} = \frac{\sigma_c P \tau_L}{\omega_0 \Sigma_L}
\]

(3)

where \( A/\omega_0 \) denotes total number of laser photons, \( \sigma_c \) is the total Compton cross section is equal to \( 1.75 \times 10^{-25} \text{cm}^2 \) for \( x = 4.8 \), \( I \) is the laser beam intensity and \( \tau_L (\sqrt{2\pi} \sigma_{L,z}(\text{rms})/c) \) is the laser pulse duration, \( \Sigma_L = \frac{1}{2} \lambda Z_R \) the laser beam cross section at the focal point and \( A \) is the laser pulse energy \((A = I \tau_L \Sigma_L)\). The optimum conversion efficiency corresponds to \( q=1 \) which is reached for a laser pulse energy of \( A = A_0 = \omega_0 \lambda Z_R/2\sigma_c \). In this case one has \( p=0.65 \). Required laser-beam parameters are listed in Table 2. It should be kept in mind that last laser spot size must be bigger than electron beam transverse size, therefore last laser beam spot size is defined by final optical system of laser system (before CP). After the conversion, energy spectrum of high-energy photons are given as \([8,7]\):
where $y = \omega/E_b$, $r = y/[x(1-y)]$, $\lambda_e, \lambda_\gamma$ electron and laser beam helicities respectively and $\sigma_c$ is the Compton cross section of the laser and the e-beam, given as:

$$\sigma_c = \sigma_c^0 + \lambda_e \lambda_\gamma \sigma_c^1$$  \hspace{1cm} (5)$$

$$\sigma_c^0 = \frac{\pi \alpha^2}{xm_e^2}[\frac{2-8}{x} - \frac{16}{x^2}]ln(x+1) + 1 + \frac{16}{x} - \frac{1}{(x+1)^2}$$

$$\sigma_c^1 = \frac{\pi \alpha^2}{xm_e^2}[\frac{2+4}{x}]ln(x+1) - 5 + \frac{2}{x} - \frac{1}{(x+1)^2}$$

By varying the polarization of electron and FEL, the polarization of the high-energy gamma beam can be tailored to fit the needs of the gamma-gamma collision experiments. Controlling the polarization is also important for sharpening the spectral peak in the $\gamma\gamma$ luminosity. Due to dependence of Compton scattering, the peak in the luminosity spectrum is significantly enhanced by choosing the helicity of laser photons to be of the opposite sign to helicity of the electrons [1,3,7,8]. Required laser parameters for $p=0.65$ can be define using equation [2] The FEL output radiation is totally polarized: circularly or linearly for the case of helical or planar undulator, respectively [12,14,16]. To reduce the cost of the laser system only free electron laser can be used [9,12,14].

3 Luminosity Calculation

The $\gamma\gamma$ luminosity is approximately proportional to $e^+e^-$ geometric luminosity. Luminosity of colliding beams is related with beam size, number of particle
per bunch and repetition frequency. The transverse beam size of both laser and electron (positron) beams can be expressed as [6]:

$$\sigma_{i,j}(s) = \sigma^*_{i,j} \sqrt{1 + \frac{(s - s_j)^2}{\beta^*}}$$  \hspace{1cm} (6)

where $j$ represent the beam kind ($e^-, e^+, l$) and $i(x,y)$ the transverse coordinate, $\beta^*$ is the betatron function at the waist and $s_j$ the waist position. The beam size at the waist is $\sigma^*_{i,j} = \sqrt{\beta \epsilon_n / \gamma}$ where $\epsilon_n$ is normalized beam emittance and $\beta$ is betatron function. For laser beam the beta function is equal to Rayleigh range ($Z_R$) and the diffraction limited emittance is $\lambda/4\pi$. After laser optical system the Rayleigh range is $Z_R = \frac{4}{\pi} \lambda F_N^2$ where $F_N$ is defined roughly as the ratio of focal length to the diameter of focusing mirror [3]. For high reflective mirrors, the average power density damage threshold is $10\text{ MW/cm}^2$ and peak power density damage threshold is $10\text{ GW/cm}^2$ [5]. The problem in both cases is discharge (breakdown of hydrocarbons on the mirror surface) on mirror surface. Average power of required FEL is 33 kW. Therefore FEL easily transport to CP with mirrors. In our case, desired value of Rayleigh length (0.263 mm) can be obtained by taking $F_N$ equal to 14 for change the FEL Rayleigh range (1.7 cm) at 1 J pulse energy. For calculation of spectral luminosity CAIN 2.35 simulation program used [13]. Nonlinear effect at the conversion point scaled with dimensionless $\xi^2$ parameter, which is related with photon density in the laser pulse, wavelength, pulse length, pulse energy. This $\xi^2$ parameter is of the form [15]

$$\xi^2 = \frac{4r_e \lambda A}{(2\pi)^{3/2} \sigma_{L,z} mc^2 Z_R}$$  \hspace{1cm} (7)

In the case of $\xi^2 \gg 1$ multiphoton process occur at conversion point, for $\xi^2 << 1$ Compton scattering occur. In our case $\xi^2 = 0.3$ and there is no problem with
multiphoton process. The differential luminosity equation as a function of laser energy in a $\gamma\gamma$ collision is given below [8]:

$$
\frac{1}{L_{\gamma\gamma}} \frac{dL_{\gamma\gamma}}{dW d\eta} = \frac{W}{2} f_1\left(\frac{W e^\eta}{2}\right) f_2\left(\frac{W e^{-\eta}}{2}\right) I_0\left(\frac{d_1 d_2}{\sigma_1(s, s_e)^2 + \sigma_2(s, s_e)^2}\right) e^{-\frac{d_1^2 + d_2^2}{2(\sigma_1(s, s_e)^2 + \sigma_2(s, s_e)^2)}}
$$

(8)

where $W = 2\sqrt{\omega_1 \omega_2}$ is invariant mass, $I_0$ Bessel function of the order of zero, $\eta = \text{Arctanh}\left(\frac{\omega_1 - \omega_2}{\omega_1 + \omega_2}\right)$ is $\gamma\gamma$ rapidity, $d_1 = z_1 \theta_1\left(\frac{W e^\eta}{2}\right)$ and $d_2 = z_2 \theta_2\left(\frac{W e^{-\eta}}{2}\right)$ where $\theta_\gamma$ is scattering angle of backscattered photons with respect to the direction of the incoming electron varies with photon energy as [8,7,11]:

$$
\theta_\gamma(\omega) \approx \frac{m_e}{E_b} \sqrt{\frac{E_b x}{\omega}} - x + 1
$$

(9)

The luminosity spectrum of CLIC $\gamma\gamma$ collider can be seen in Fig I.

4 FEL System for $\gamma\gamma$ Collider

4.1 CLIC main linac, drive linac and master laser

The time structure of the FEL pulses must follow the time structure of the electron (positron) bunches of the CLIC main linac at the conversion point. Using backscattered FEL, synchronization of $\gamma$ beam and main linac electron (positron) beam can be solved. The CLIC drive beam complex consist of 2 combiner rings and a delay loop. Each combiner ring compress to drive beam 4 times and the delay loop another factor of 2. In order to get the same time structure in the FEL and the main beam it is necessary to use additional
Fig. 1. CLIC $\gamma\gamma$ Luminosity spectrum at $E_{cm}=0.5$ TeV for $L_{ee^+}=5.2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ drive beam bunches after the 1\textsuperscript{st} combiner ring. Drive beam bunch structure and it’s complex can be seen in Fig 2. In this case both drive beam and main beam have the same bunch separation (0.267 ns). The number of main beam bunches per pulse is 220 and the number of drive beam bunches per train after 1\textsuperscript{st} combiner ring is 262. When we take 2 more drive beam pulse from the drive linac gun, we would have 524 more bunches after the 1\textsuperscript{st} combiner ring to be used wigglers for both electron main linac and positron main linac. Before the wiggler it should be dumped 42 e-bunches for each drive linac section so the bunch number of taken drive beam after 1\textsuperscript{st} combiner ring would be decreased to 220. The example of scheme under consideration and the overall CLIC layout with updated beam parameters can be seen in Fig 2. The power of master laser must be higher than FEL amplifier noise at entrance of the wiggler [16]. Furthermore the master laser has to be synchronize with drive linac electron bunches after 1\textsuperscript{st} combiner ring.
Fig. 2. CLIC Layout of $\gamma\gamma$ collider and drive beam properties at $E_{cm}=0.5$ TeV

**Luminosity increment method:** CLIC at $E_{cm}=3$ TeV containment 21 drive beam decelerator units for each main linac section, but the $E_{cm}=0.5$ TeV option it has only 3 decelerator units. In this case the drive beam pulse length reduced by a factor of 7. To increase the luminosity, $7 \times 220$ main beam bunches can be accelerated by using full drive beam pulse length (93.7 $\mu$s). Consequently the repetition frequency of main linac increases by factor 7. CLIC main linac beam parameters are given in Table 1, where proposed modification of repetition rate and Luminosity are given in parenthesis. In this case we need a kicker which is faster than $E_{cm}=3$ TeV option after the second combiner ring. The drive beam pulse structure can be seen in Fig 2. Master laser and electron interaction in the wiggler will be explained in next subsection. The required parameters for the master laser are given in Table 3 and related drive beam parameters are given in Table 2.
4.2 FEL amplifier

Proposed scheme is a high-gain single pass FEL amplifier. The interaction between electrons and master laser leads to an exponential growth of the FEL while the electron beam expenses its kinetic energy. First of all the helical wiggler must satisfy resonant condition [12]:

\[ \lambda = \frac{\lambda_w}{2\gamma^2}(1 + K^2) \]  

(10)

where \( K=0.934 B_w^T \lambda_w \) is dimensionless wiggler parameter, \( \lambda_w \) is the wiggler period, \( B_w \) peak magnetic field inside wiggler and \( \gamma \) the drive beam relativistic factor. The choose of the optimum \( \lambda_w, B_w \) couple can be made by minimizing the gain length \( l_g \) (e-folding length for the radiation growth). The fundamental FEL parameter, \( \rho = \lambda_w/4\pi l_g \) corresponds roughly to the maximum efficiency that can be obtained in a non-tapered FEL; when this level of efficiency is reached, the loss in kinetic energy of the electron beam is no longer satisfied, and the output power saturates. Optimum value of both untapered efficiency and wiggler length is obtained by minimizing \( \lambda_w \) and maximizing \( B_w \). After saturation, further extraction of energy from the electron beam is possible by varying the \( K \) parameter by changing wiggler peak field, wiggler period or both. While changing \( K \) and the electrons losses their energy it is possible to keep the electrons and FEL in resonant. In this case the radiation growth is anyway no more exponential. Different type of tapering techniques are possible. In the following we will refer to self-consistent tapering obtained by varying quadratically the peak wiggler field while keeping constant the wiggler period. This self-consistent tapering should be more efficient than the constant \( K \). In order to provide high efficiency it is necessary to use tapered
wiggler. FEL has always tunable and capable to generate powerful coherent radiation which always has minimal difraction (dispersion). To obtain a reasonable luminosity of the $\gamma\gamma$ collider at CLIC, the peak power in the radiation pulse for $p = 0.65$ at the FEL amplifier exit should be 0.5 TW. In the case of axisymmetric electron beam the eigenvalue equation of the $TEM_{mn}$ mode is of the form [12]:

$$\mu J_{n+1}(\mu)K_n(g) = g J_n(\mu)K_{n+1}(g)$$

(11)

where $J_n$ is the bessel function of the first kind of order n, $K_n$ is modified Bessel function, n the azimuthal index of the mode, $g$ and $\mu$ dimensionless parameter as given $g = -2iB\hat{\Lambda}$ and $\mu = \frac{-2i\hat{D}}{1-i\hat{C}D-g^2}$, where $\hat{\Lambda} = \Lambda/\Gamma$ is reduced eigenvalue. For Gaussian energy spread, the function $\hat{D}$ and reduced detuning $\hat{C}$ are defined with formulae

$$\hat{D} = i \int_0^\infty \xi \exp[-\hat{\Lambda}^2 \xi^2 - (\Lambda + i\hat{C})\xi]d\xi$$

(12)

$$\hat{C} = \frac{C}{\Gamma} = \frac{2\pi}{\lambda_w} - \frac{w(1 + K^2)}{2\gamma^2 c}/\Gamma$$

(13)

where $\omega = 2\pi c/\lambda$ is frequency of radiation field. During the amplification physical effects are connected with the corresponding dimensionless parameters defining the power of the effects. These parameters are the diffraction parameter $B$, space charge parameter $\Lambda_p$, the energy spread parameter $\hat{\Lambda}_T$, and the efficiency parameter $\rho$ as given respectively below [17]:

$$B = \frac{2\Gamma r_b^2 \omega}{c}$$

(14)

$$\Lambda_p^2 = \frac{\Lambda_p^2}{\Gamma^2} = \frac{4c^2}{[\theta_w r_b\omega]^2}$$

(15)

$$\hat{\Lambda}_T^2 = \frac{\sigma_E^2}{E_0^2} + \frac{\gamma^4 \sigma_\phi^4}{(1 + K^2)^2}/\rho^2$$

(16)
\[
\rho = \frac{c_\gamma^2 \Gamma}{\omega (1 + K^2)} = \left[ \frac{I}{I_A \gamma} \frac{K^2}{1 + K^2} \right]^{1/2}
\]  
(17)

where \( \omega \) frequency of radiation field, \( I_A \) is Alfven current which is \( \approx 17 \text{ kA} \) and \( \theta_w = K/\gamma \) electron rotation angle. Amplification occur at real part of eigenvalue of the eigenvalue equation. Energy spread in the electron beam is assumed to be Gaussian with the rms deviation \( \sigma_E \). RMS angle spread given by \( \sigma_\theta = \sqrt{\epsilon_n/\beta \gamma} \). The gain parameter \( \Gamma \) defines the scale of the field gain and it is defined as [17]:

\[
\Gamma = \left[ \frac{I \omega^2 \theta_w^2 (1 + K^2)^2}{I_A c^2 \gamma^5} \right]^{1/2}
\]  
(18)

The required laser parameter are given in table 1. Possible effects during the amplification are:

1) *Electron beam energy spread:* If electron beam has an energy spread, the FEL gain can be depressed, essentially because not all the electrons are exactly resonant with radiation. If the energy spread is substantially smaller than the fundamental FEL parameter \( \rho \), its effect negligible. By detuning initially the beam with respect to the exact resonance, one can minimize the effect of the energy spread on the FEL gain [9,10].

2) *Emittance effect:* There are different ways in which the electron beam emittance can effect the FEL gain. First of all transverse motion of the electron in a finite emittance beam induces a spread in the longitudinal velocities that affects the coupling, exactly as does the energy spread. FEL gain loss as a function of energy spread, taking into emittance effects and for optimum detuning. \( 0.005 \leq (\gamma - \gamma_r)/\gamma_r \leq 0.02 \) Values of energy spread as big as 1\% can be still tolerated [10]. The FEL efficiency parameter \( \rho \) and wiggler length given in table 3 are all calculated consistently taking into account the values
of emittance and energy spread reported therein.

3) *Diffraction losses*: The electron beam emittance determines the electron beam size in the wiggler, once fixed $\lambda_w$ and $B_w$. The wiggler provides a focusing force in both planes, with a betatron wavelength $\lambda_\beta = \sqrt{2\lambda_w / \theta_w}$. A matched electron beam has therefore a constant radius along the wiggler: $r_b = \sqrt{\epsilon_n \lambda_\beta / (2\pi)}$. In order to obtain the maximum gain, the transverse section of the electron beam and the input radiation pulse should exactly overlap, but diffraction limits the distance over which the light beam have the same transverse section as the electron beam. This distance is roughly given by the Rayleigh range $Z_R$ of a Gaussian light beam with a waist of the same section of the electron beam: $Z_R = \pi r_b^2 / \lambda$. Fortunately it is not necessary for the Rayleigh range be equal or greater than wiggler length in order to preserve the gain. If $Z_R$ is lower or of the order of gain length, the loses in the effective radiation power seen by electron beam are compensated by gain (gain guiding effect). Furthermore, the refractive guiding effect, due to light phase shift in an FEL high-gain amplifier is dominant when the gain length is shorter than Rayleigh range, and compensate diffraction losses by confining the light in the proximity of the electron beam that act essentially like an optical fiber. The ratio between Rayleigh range and gain length should be so close to one to avoid gain deterioration by diffraction losses. Anyway, optical guiding (gain+diffraction guiding) effects depends on the electron beam radial density distribution and on the initial conditions for the light beam [10]. An exact evaluation of these phenomena done by GINGER 3D simulation code [19].

4) *Slippage effect*: The difference in longitudinal velocity between light pulse and electron beam pulse (slippage effect) can also effect the FEL instability in ways that may be undesirable, including lengthening of the amplified light
pulse. Other means that group velocity of radiation in the electron beam is less than the velocity of light. For a FEL operating in the optical region, the difference in path length between the light an electron pulses at the end of wiggler is simply given by the relation \( \Delta l = \lambda N_w \), where \( N_w \) is number of wiggler period. The main condition \( \Delta l << l_b \) is satisfy, where \( l_b \) is drive beam electron pulse length. As mentioned before, to obtain the needed efficiency the use of a tapered wiggler section unavoidable. An evaluation have been made based on 3D calculations.

Parameters of the FEL amplifier with included all effects to obtain 0.51 TeV power with tapered wiggler are presented in table 3. In Fig 4 shows wiggler peak field variation along the wiggler length, it plotted for self-consistent tapering wiggler. The first part of wiggler up to 18 m (slightly before saturation) has a constant magnetic field then the peak field start to decrease. In Fig 3 FEL pulse power is plotted as a function of wiggler length, it can be seen from this figure 60 m wiggler is enough to get required 0.51 TW peak power of FEL. The initial exponential growth of radiation energy is evident until tapering is introduced. In this case the final value of the magnetic field is 1.67 T. Higher input power help to decrease wiggler length.

5 Conclusion

Present paper indicate that CLIC project can solve laser requirements for \( \gamma \gamma \) collider itself. For \( x=4.8 \) required laser power is 0.51 TW and it can be obtained using 60 m wiggler. Required FEL can be obtain one extra drive beam pulse from the drive gun after last bunch of CLIC drive beam is deflected.
Fig. 3. FEL Power as a function of wiggler length

Fig. 4. Magnetic field on the wiggler axis vs wiggler length
into a helical wiggler after 1st combiner ring, which does not lose any energy at the end of drive linac. A master laser pulse ($\lambda \sim 1\mu m$) from a solid state laser, synchronized with the drive beam, is also injected in the helical wiggler. Here the amplification of the radiation pulse by FEL interaction occurs. The amplified light (FEL) is directed with the help of proper mirrors to the conversion point, where it interact with the incoming main electron beam. In this point high-energy gammas are obtained by Compton backscattering. The high energy gammas interact with the the gammas obtained in the same way in the other half of the linear collider. Circular polarize gamma can be obtain using by helical wiggler. Even including some effect on obtaining required peak power FEL, it is possible to construct $\gamma\gamma$ or $\gamma e$ collider based on CLIC drive beam FEL. Reachable luminosity of $\gamma\gamma$ collision is $1.44 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ and in the case of using increment method it is value $1.0 \times 10^{35} \text{cm}^{-2}\text{s}^{-1}$.

6 Acknowledgment

The author would like to thank Dr. Roberto Corsini, Dr. Frank Zimmermann, Dr. Daniel Schulte, Prof. Dr. Saleh Sultansoy, Prof. Dr. A Kenan Ciftci, CLIC working group and Assoc. Prof. Dr. Gokhan Unel for useful discussions.

This work supported in part by Turkish Atomic Energy Authority.

References

[1] I.Ginzburg, G.Kotkin, V.Serbo, V.Telnov, Nucl. Instr. and Meth. (1983) 205.

[2] A.M. Kondaratemnko, E.V. Pakhtusova, E.L. Saldin, Dokl. Akad. Nauk. 264 (1982) 849; Preprint INF 81-130 (1981) in Russian.
[3] NLC Zeroth Order Design Report Appendix B, LBNL-5424 (1996).

[4] E. Accomando et all. CLIC Physics Working Group. arXiv:hep-ph/0412251 (2004).

[5] J. Urakawa, workshop of POSIPOL 2006 CERN (2006).

[6] H. Aksakal, et al., Nucl. Instr. and Meth. A (2007).

[7] V. Telnov, Nucl. Instr. and Meth. A 294 (1990) 72.

[8] D. L. Borden, D. A. Bauer and D. O. Caldwell, SLAC preprint SLAC-PUB 5715, Standford (1992).

[9] E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov. Optics Communications 97 (1993) 272-290.

[10] R. Corsini, A.A. Mihailichenko. CLIC Note 254 (1994).

[11] V.Telnov, Nucl. Instr. and Meth.A 355 (1995) 3-18.

[12] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, M.V. Yurkov. Nucl. Instr. and Meth.A 355 (1995) 171-183.

[13] User’s Manual of CAIN 2.35 (2003) (KEK pub. 4/96).

[14] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Y. N. Ulyanov, M.V. Yurkov. Nucl. Instr. and Meth.A 361 (1995) 101-110.

[15] R. Brinkmann et all. arXiv:hep-ex/9707017 (1997).

[16] E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov. Nucl. Instr. and Meth.A 445 (2000) 320-323.

[17] E.L. Saldin, E.A. Schneidmiller, M.V. Yurkov. Nucl. Instr. and Meth.A 472 (2001) 94-99.

[18] H. Braun et all. CLIC Note 627 (2005).

[19] W. M. Fawley. LBNL-49625, (2004).
Table 1

CLIC Main Linac Beam parameters

| Parameter                      | Value             |
|--------------------------------|-------------------|
| $E_h$ (GeV)                    | 250               |
| No. particle per bunch ($10^9$)| 2.56              |
| No. of bunch                   | 220               |
| Repetition frequency $f_{rep}$ (Hz) | 150(1050)         |
| $\beta_x/\beta_y$ (mm)        | 2/0.02            |
| Normalized Emittance (µm) $\gamma\epsilon_x/\gamma\epsilon_y$ | 660/10           |
| $\sigma_z$ (µm)               | 31                |
| Total Luminosity $L_{\gamma\gamma}$ | $1.44 \times 10^{34}$ (1.0 $\times 10^{35}$) |

Tables

List of Figures

1. CLIC $\gamma\gamma$ Luminosity spectrum at $E_{cm}=0.5$ TeV for $L_{ee^+}=5.2 \times 10^{34}$ $cm^{-2}s^{-1}$
2. CLIC Layout of $\gamma\gamma$ collider and drive beam properties at $E_{cm}=0.5$ TeV
3. FEL Power as a function of wiggler length
4. Magnetic field on the wiggler axis vs wiggler length
Table 2

Drive beam parameters

| Parameter                              | Value         |
|----------------------------------------|---------------|
| $E_{db}$ (GeV)                         | 2.37          |
| Peak current (kA)                      | 3.62          |
| Bunch length (mm)                      | 0.4           |
| Bunch sep (ns)                         | 0.267         |
| Bunch charge (nC)                      | 12.1          |
| $\beta_x / \beta_y$ (mm)              | 2/0.2         |
| No. of bunch/pulse after 1st CR        | 262 (1834)    |
| Repetition frequency $f_{rep}$ (Hz)    | 150           |
| Normalized emittance, rms ($\mu$m rad)| 150           |
| Bunch separation (ns)                  | 0.267         |
| No. bunches / train                    | 262/24 (262/168) |
| Energy spread $\sigma_E/E_{db}$        | 0.1%          |
| Pulse duration ($\mu$s)                | 13.22 (93.7)  |
### Table 3
**Master laser, FEL and wiggler parameters**

**Master laser**

| Parameter          | Value   |
|--------------------|---------|
| Power (MW)         | 1       |
| wavelength (µm)    | 1.06    |

**FEL amplifier**

| Parameter          | Value   |
|--------------------|---------|
| wiggler Type       | helical |
| Period (cm)        | 10      |
| Length of wiggler (m) | 60  |
| FEL parameter $\rho$ | $2.2 \times 10^{-2}$ |
| Entrance magnetic field (T) | 1.908 |
| Rayleigh length (cm) | 1.7    |
| FEL Power (TW)     | 0.51    |