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THE CLIC ELECTRON AND POSITRON POLARIZED SOURCES

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Abstract

The CLIC polarized electron source is based on a DC gun where the photocathode is illuminated by a laser beam. Each micro-bunch has a charge of $6x10^9$ e^-, a width of 100 ps and a repetition rate of 2 GHz. A peak current of 10 A in the micro-bunch is a challenge for the surface charge limit of the photo-cathode. Two options are feasible to generate the 2 GHz e^- bunch train: 100 ps micro-bunches can be extracted from the photo-cathode either by a 2 GHz laser system or by generating a macro-bunch using a ~200 ns laser pulse and a subsequent RF bunching system to produce the appropriate micro-bunch structure. Recent results obtained by SLAC, for the latter case, are presented. The polarized positron source is based on a positron production scheme in which polarized photons are produced by a laser Compton scattering process. The resulting circularly-polarized gamma photons are sent onto a target, producing pairs of longitudinally polarized electrons and positrons. The Compton backscattering process occurs either in a Compton ring, where a 1 GeV electron beam interacts with circularly-polarized photons in an optical resonator or in a 1.8 GeV Compton Energy Recovery Linac (ERL) or in a 6 GeV Linac with several optical cavities. The undulator scheme is also studied. The nominal CLIC e^+ bunch population is $6.7x10^9$ particles per bunch at 200 MeV. The tradeoff between e^+ yield and level of polarization is an important topic. The overall scheme for both polarized electron and positron beams is described.

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1. INTRODUCTION

The general CLIC (Compact Linear Collider) parameters, as defined in 2008, are given in [1]. The CLIC parameters at 3 TeV are derived from an optimised CLIC structure with a new RF frequency (12 GHz) and a new accelerating field (100 MV/m). The CLIC baseline study at 3 TeV assumes polarized electron and unpolarized positron but beam parameters at 500 GeV are also considered where the bunch charge is doubled. The layout of the CLIC Main Beam Injector Complex is shown in Figure 1 and a detailed description is given in [2].

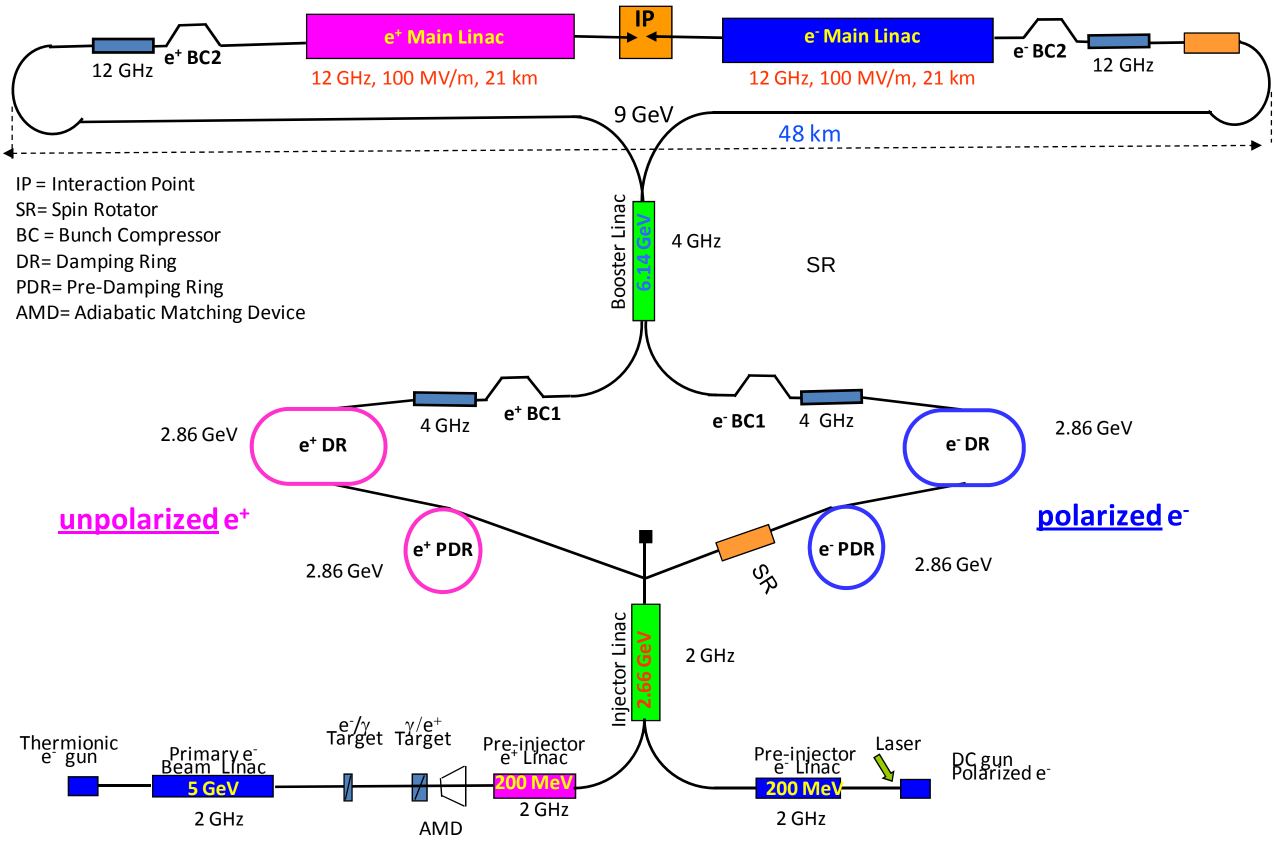

Figure 1: CLIC Main Beam Injector Complex for 3 TeV: Baseline configuration.

2. GENERATION OF UNPOLARIZED POSITRON

The positron generation is based on a thermionic gun followed by a Primary Electron Beam Linac accelerating the beam up to 5 GeV onto the e^+ target.
The positron source itself is composed of hybrid targets, i.e. one thin W crystal target, followed by one W amorphous target (see Figure 2) and an Adiabatic Matching Device (AMD). Then a Pre-injector Linac accelerates e^+ up to 200 MeV.

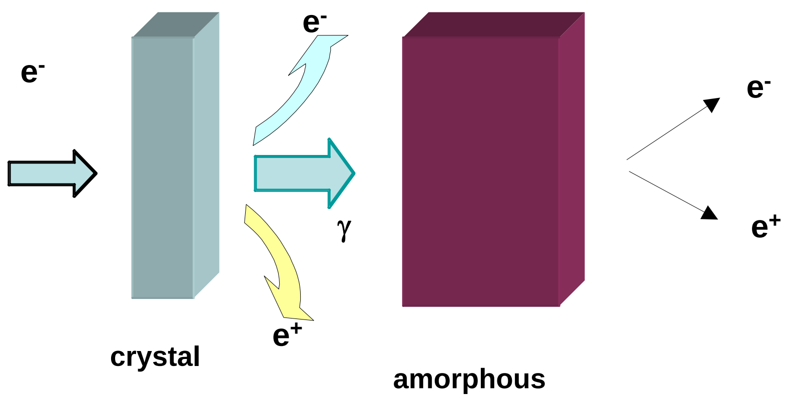

Figure 2: CLIC hybrid targets for e^+ source

The yield is 0.9 e^+/e^- at 200 MeV, corresponding to a normalised yield of 4.5 (e^+ / (e^- x GeV)) at the exit of the Pre-injector linac.

Table 1 gives a summary for the CLIC hybrid targets.

Table 1: CLIC e^+ targets

Parameter		CLIC	3 TeV
Target		Crystal	Amorph.
Material		W	W
Length	mm	1.4	10
Radiation lengths	χ_0	0.4	2.9
Beam power deposited	kW	0.2	7.5
Deposited P / Beam Power	%	0.2	8
Energy lost per volume	10^9 GeV/mm^3	0.8	1.9
Peak Energy Deposition Density (PEDD)	J/g	7	15

The PST2009 workshop is focused on polarized particles therefore we give here only the basic information on the system. More details on the unpolarized e^+ source are found in various publications. Experiments using crystal targets were performed at CERN [3] and at KEK [4]. The positron production efficiency was measured with an electron beam of 4 and 8 GeV. Hybrid positron source based on channelling study is described in [5]. Radiation damages, using a SLAC beam, for a W crystal are reported in [6]. A conventional positron source based on EGS4 simulations and a complete tracking for the e^+ capture and the acceleration up to 200 MeV is described in [7]. Simulations from the e^+ target up to the Pre-damping Ring (PDR) are reported in [8] with the tracking results.

3. GENERATION OF POLARIZED ELECTRON

The DC gun should produce 1 nC/bunch, i.e. a charge of 6 x 10^9 e^-/bunch for 3 TeV configuration. Table 2 gives the beam parameters for the electron source at 3 TeV and at 0.5 TeV.
A laser producing 100 ps pulses at a repetition rate of 2 GHz seems rather challenging.
A proposal was made by SLAC to use a cw laser instead and bunch the electron beam at 2 GHz downstream [9].

Table 2: CLIC electron source parameters

Parameter	Symbol	0.5 TeV	3 TeV
Number Electrons per microbunch	N_e	10 x 10^9	6 x 10^9
Number of microbunches	n_b	354	312
Width of microbunch	t_b	~ 100 ps	~ 100 ps
Time between microbunches	Δt_b	0.5002 ns	0.5002 ns
Microbunch rep rate	f_b	1999 MHz	1999 MHz
Width of macropulse	T_B	177 ns	156 ns
Macropulse repetition rate	F_B	50 Hz	50 Hz
Charge per micropulse (e x N_e)	C_b	1.6 nC	0.96 nC
Charge per macropulse (C_b x n_b)	C_B	566 nC	300 nC
Average current from gun (C_B x F_B)	I_{ave}	28 µA	15 µA
Average current in macropulse (C_B / T_B)	I_B	3.2 A	1.9 A
Duty Factor w/in macropulse ($t_b/\Delta t_b$)	DF	0.2	0.2
Peak current of micropulse (I_B / DF)	I_{peak}	16 A	9.6 A
Current density (I_{peak}/σ) [spot size radius 1 cm]	D	5 A/cm^2	3 A/cm^2
Polarization		> 80%	> 80%

The formula to calculate the laser energy E_L, in order to get the charge Q, at the exit of the photo-cathode, for a cw optical pulse is:

$$E_L = \frac{hc}{q}\frac{Q}{\lambda \times QE}$$

where h = 6.62 x 10^{-34} J.s, c = 3x10^8 m/s, q = 1.6x10^{-19} C, λ is the laser wavelength and QE the quantum efficiency of the photocathode.

Important first results were obtained by Nagoya University and KEK [10], followed by SLAC [11] and JLAB [12]. From Table 2, Q (0.5 TeV) = 566 nC and Q (3 TeV) = 300 nC. The wavelength for the GaAs photocathode is 780 nm. The quantum efficiency measured on the SLAC photocathode is 0.7%. Therefore the requested laser pulse energy is:

$$E_L(3\ TeV) = 68\ \mu J$$

$$E_L(0.5\ TeV) = 128\ \mu J$$

The current density of 3 to 5 A/cm^2 is a challenge for the photocathode regarding the surface charge limit. Nevertheless a total charge of 600 nC has been produced by SLAC from a DC gun. The photocathode was illuminated by a cw laser (156 ns pulse length) and the extracted charge was measured.
Figure 3 shows the experimental results obtained by SLAC [13]. The laser energies used for the experiment are consistent with the theoretical ones.
The emittance was not measured but the polarization was measured and found to be around 82%.

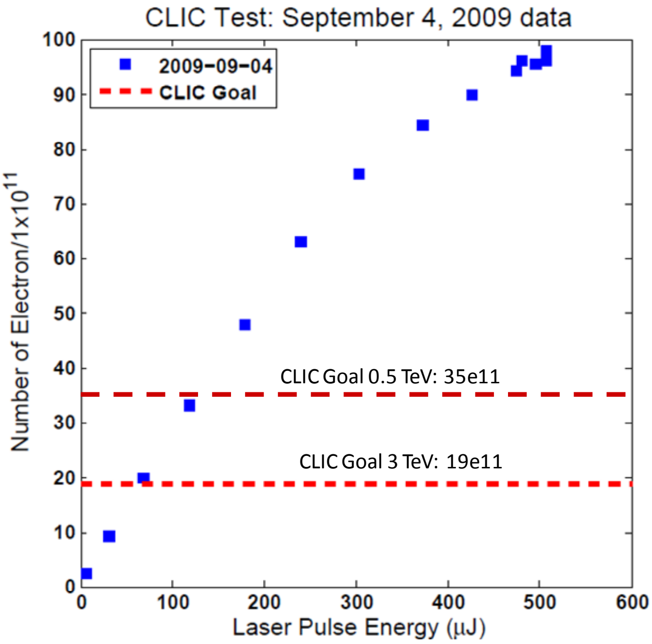

Figure 3: Production of polarized e$^-$ at SLAC

Simulations were performed downstream the DC gun, assuming a bunching system at 2 GHz. The latter is composed of 2 pre-bunchers cavities followed by a buncher and an accelerating cavity [9]. Table 3 gives the simulation results. Such performance would satisfy the CLIC requirements for the polarized electron source.

Table 3: Electron parameters simulations up to 20 MeV

Parameters	Units	CLIC 3 TeV
Gun voltage	kV	140
Injector energy	MeV	20
Initial charge at the gun	nC	1
Capture efficiency	%	88
Initial bunch length at the cathode	ns	156
Final bunch length (FWHM)	ps	14
Energy spread (FWHM)	keV	100
Normalized rms emittance	mm.mrad	22

4. GENERATION OF POLARIZED POSITRON

The generation of polarized positron for CLIC is an enormous challenge. There are mainly two possible approaches. One is based on the undulator scheme where an electron beam, with an energy in the range of 100 GeV or more, is sent through a short-period-undulator [14][15]. The other one is based on laser Compton back scattering. Here three variations of this latter concept are used. The Compton Linac scheme [16][17], the Compton ring scheme [18][19] and the Compton ERL scheme [20][21]. In each of these, an electron beam interacts with a powerful circularly polarized laser beam.

The CLIC undulator scheme assumes the electron beam passing through an helical undulator with energy of 250 GeV. The undulator is 100 m long with $K = 0.7$ and $\lambda_u = 1.5$ cm. The Ti target is 0.4 radiation length and it is not immersed in the magnetic field of the Adiabatic Matching Device. The capture sections are working at 2 GHz with a gradient of 25 MV/m. Simulations results [22] show that a yield of 1.4 e^+/e^- is obtained after the capture at 200 MeV with a peak magnetic field of 4 T. A polarization of 60% for e^+ is achieved with a collimator radius below 1 mm reducing also the yield down to 0.8 e^+/e^-. The scheme has very strong impacts on the CLIC main beam and needs more detailed studies.

The CLIC Compton ring assumes a double chicane where the energy spread is different inside and outside of the chicane [23]. The present study is based on a regime of laser cooling, with continuous generation of photons allowing a yield enhancement. The interaction between the unpolarized electron beam, with an energy of 1.06 GeV, and the laser occurs at the IP with a collision angle as small as possible. In the present design it is 8 degrees. Inside the chicanes, the square of energy spread of the electron beam remains constant. In the proposed CLIC Compton ring scheme [24], the electron beam is composed of 312 bunches with a charge of $6.2\text{x}10^9$ e^-/bunch (1 nC) corresponding to 2 A circulating beam. The ring circumference (~ 47 m) corresponds to the pulse length of 156 ns. The RF system is composed of 2 cavities working at 2 GHz and 200 MV each. The YAG laser produces circularly-polarized photons at 1.164 eV and the energy stored in the optical cavity is 600 mJ. The laser spot size at the collision point has a radius of 0.005 mm and a length of 0.9 mm. Figure 4 gives a simplified layout of the CLIC Injector based on Compton ring. Simulations results give a yield of 0.063 photon per electron and per turn [23]. This corresponds to a flux of $3.3\text{x}10^{16}$ photons/s. The polarized photons are collimated, reducing the photon flux down to $1.33\text{x}10^{16}$ photons/s but increasing the polarization level. They are sent onto a target to produce polarized e^+. Simulations give a level of polarization about 84% which is the present tradeoff between the yield and the polarization. However the photons flux is not enough to get the requested e^+ bunch charge after the capture. Therefore stacking into the PDR is necessary.

Simulations have been performed for longitudinal stacking into the PDR [25]. An optimization of parameters increases the stacking efficiency. The simulations show that efficiency of 90% could be obtained with specific PDR parameters. However outstanding questions remain open and further improvements will be necessary. The energy spread of injected positron beam should be as small as possible and the PDR momentum acceptance as large as possible. Today this scheme is the one which would be preferable for the CLIC upgrade when polarized positron will be produced for the Physics.

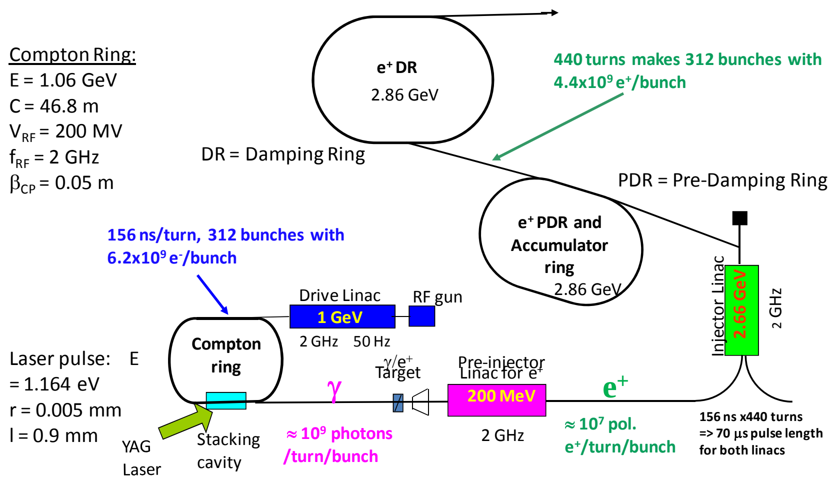

Figure 4: CLIC Injector based on Compton ring for polarized e^+ source

The CLIC ERL is a continuous low-charge high-repetition frequency electron linac. The beam energy is 1.8 GeV. For this scheme the requested bunch spacing into the ERL is 32 ns [26]. With the bunch charge of $3x10^9$ e^-/bunch (0.48 nC), the beam current is 15 mA and the repetition frequency is 31.25 MHz. Preliminary simulations give a yield of $5x10^8$ photons/bunch assuming that laser energy of 0.6 J could be stored in one optical cavity installed in the ERL ring. Based on a conservative e^+ yield of 0.005, $2.5x10^6$ e^+/bunch would be produced.
The scheme provides a good solution to avoid stacking into the PDR. For CLIC, the repetition rate is 20 ms and the idea is to separate the functions of stacking and damping to use efficiently this repetition rate. For that purpose, 2 small storage rings (SR1 and SR2) between the ERL and the PDR are implemented: 20 ms are used for stacking in the SR1, followed by 20 ms of damping in SR1 (25 Hz). During the same 20 ms of damping in SR1, 20 ms of stacking are performed, in parallel into SR2 followed by 20 ms of damping in SR2 (25 Hz) and so on.
Assuming that 2000 bunches could be stacked into the same bucket of SR1 and SR2, then $5x10^9$ e^+/bunch could be obtained. The two rings SR1 and SR2, with a circumference of ~ 47 m, are designed for energies around 1 GeV. The e^+ beams are extracted from SR1 and SR2 and 312 bunches are accelerated up to the PDR energy (2.86 GeV). A 2 GHz linac working at 50 Hz repetition rate needs to be implemented between the SR1/SR2 and the PDR. No more stacking would be required into the PDR. With these parameters the CLIC requirements are fulfilled.

The CLIC Compton Linac scheme uses a 6 GeV linac where the electron beam is sent through several CO_2 laser amplifier cavities. It requires powerful lasers but does not require e^+ stacking into the PDR. The needed number of e^+ per bunch is produced in every laser shot at 50 Hz repetition rate. The main features of this scheme are based on the use of mid-IR CO_2 laser (1 J, $\lambda = 10$ µm) and the most energy-efficient back-scattering geometry. The rms bunch length for the electron bunch and for the laser pulse is 3 ps. The production of 1 photon per electron has been demonstrated [17]. With a conservative conversion efficiency of the polarized photons into polarized e^+, 50 photons are necessary for each e^+. Assuming that 10 consecutive optical Compton cavities could be implemented with 10 IPs to accumulate the photons flux, therefore 5 nC per electron bunch would produce 1 nC per positron bunch which is the CLIC requested charge.
The linac's electron beam is formatted into a train of 312 bunches at 50 Hz repetition rate. The 1 nC positron bunches, produced on a target by the Compton-scattered photons, will be injected into the PDR without stacking [27].

Summary

Based on the SLAC experiment, the polarized electron source for CLIC is feasible without major issues.
At present all proposed schemes for polarized positrons need substantial R&D to fulfil the requested CLIC performance. The present requirements from Physics do not stress the need for a polarized positron source, therefore, the CLIC study group assumes unpolarized positrons as the baseline for the CDR (Conceptual Design Report). The latter is expected in 2010, with polarized positrons as a possible upgrade. Nevertheless, due to the clear potential advantages for Physics, studies and R&D, regarding the various issues, are ongoing, in close collaboration with many institutes around the world.

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