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THE CLIC POSITRON SOURCE BASED ON COMPTON SCHEMES

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Abstract

The CLIC polarized positron source is based on a positron production scheme in which polarized photons are produced by a Compton process. In one option, Compton backscattering takes place in a so-called "Compton ring", where an electron beam of 1 GeV interacts with circularly-polarized photons in an optical resonator. The resulting circularly-polarized gamma photons are sent on to an amorphous target, producing pairs of longitudinally polarized electrons and positrons. The nominal CLIC bunch population is $4.2x10^9$ particles per bunch at the exit of the Pre-Damping Ring (PDR). Since the photon flux coming out from a "Compton ring" is not sufficient to obtain the requested charge, a stacking process is required in the PDR. Another option is to use a Compton Energy Recovery Linac (ERL) where a quasi-continual stacking in the PDR could be achieved. A third option is to use a "Compton Linac" which would not require stacking. We describe the overall scheme as well as advantages and constraints of the three options.

INTRODUCTION

The CLIC baseline configuration [1] for the Injector Complex consists in an unpolarized positrons source using the hybrid targets scheme [2]. However polarized e^+ beams are highly desirable for particle physics and the Compton ring scheme was first proposed at the Snowmass'05 workshop [3] and today is one of the preferred options for CLIC. However other options based on the Compton process could also fulfill the CLIC requirements. The Compton scheme presents several advantages: i) the source is independent of the main beam linac; ii) the Compton process requires low electron beam energy (1-2 GeV) interacting with the laser; iii) polarization of 60% is achievable; iv) the source can be implemented, at any time, without modifications of the CLIC complex either replacing the hybrid target station (producing unpolarized e^+) or being installed close to it. The drawback of the Compton scheme is that it suffers from a relative low value of the scattering cross section. Therefore to generate the necessary gamma flux to produce the required positron beams, it is necessary to provide electron bunches and laser pulse intensities that are not, at present, available with the existing technologies. The PDR is then used both as a damping ring [4] and as a stacking ring [5] to store, accumulate and damp the low charge e^+ bunches. Multiple injections are performed into the same bucket of the PDR. The period between 2 extractions is roughly allocated half for stacking and half for damping.

Figure 1 shows the layout of the CLIC Injector Complex based on Compton ring for polarized positrons.

The electron source is an RF gun where the photocathode is illuminated by a laser. Post acceleration is assured by a 1 GeV linac. A high charge electron beam is injected into the Compton ring, which includes an optical stacking cavity where polarized gammas are produced. The later are collimated and sent to a target generating polarized e^+. An Adiabatic Matching Device (AMD) maximizes the capture of the positrons and a pre-injector linac embedded in a long solenoidal field accelerates the beam up to 200 MeV. Another normal-conducting 2 GHz Linac accelerates the beam up to 2.86 GeV before injection into the PDR.

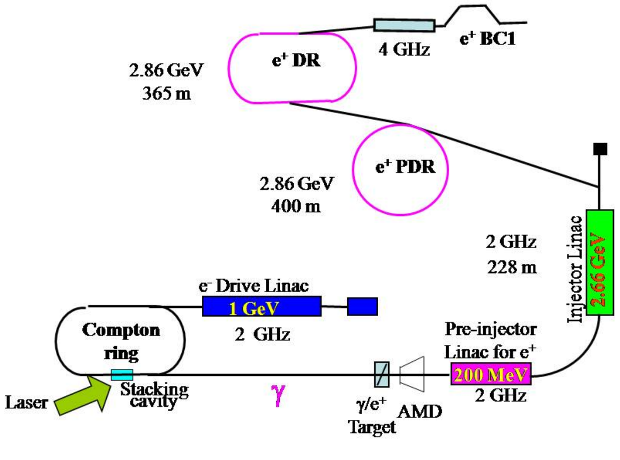

Figure 1: CLIC Injector Complex with Compton Ring

CLIC REQUIREMENTS

Table 1 gives the CLIC parameters expected after the capture section, at the exit of the pre-injector linac.

Table 1: CLIC parameters for e+ beam

Parameters	Units	CLIC 3 TeV
Energy	MeV	200
N e^+ / bunch	10^9	6.7
N bunches/pulse	-	312
Bunch spacing	ns	0.5
Pulse length	ns	156
Emittance (x,y)	mm.mrad	< 10 000
Bunch length	mm	< 10
Energy spread	%	< 8
Repetition rate	Hz	50

A bunch charge of 4.2x10^9 e^+/ bunch is requested at the PDR exit. Based on simulations performed with a conventional source (unpolarized e^+), transport efficiency and injection efficiency into the PDR require a charge of 6.7x10^9 e^+/bunch at 200 MeV. Nevertheless with Compton schemes, such values are too high and stacking is necessary into the PDR [5]. For the transverse rms normalized emittances, simulations show that they are in the range of 7000 to 9000 mm.mrad. The repetition period is 20 ms. With 10 ms dedicated for the stacking in the PDR, the remaining time allows roughly 5 damping times [4] for the damping in both transversal planes. Studies to shorten the damping time for stacking [5] are ongoing.

COMPTON RING

Figure 2 shows a possible layout of the CLIC Compton ring. It assumes a double chicane where the energy spread is different inside and outside of the chicane.

At the IP the interaction between the electron beam and the laser occurs. Just after the laser is switched on, the energy spread of the electron beam is degraded due to Compton interaction and becomes approximately proportional to the square root of the number of scattered photons per electron.

In the proposed Compton ring scheme, the electron beam is composed of 312 bunches with a charge of 6.2x10^{10} e^-/bunch. The laser energy stored in the optical cavity is 590 mJ.

One cycle is based on 15 000 turns. With a ring circumference corresponding to the pulse length of 156 ns, it lasts for 2.3 ms. The laser is "on" during 2500 turns corresponding to 0.390 ms. Under these conditions, simulations have provided a yield of 85 photons per electron during the 0.390 ms [6]. This corresponds to a flux of 2.1x10^9 photons/turn/bunch. The optimization of the following parameters is ongoing: collimation of the photons before the target, e^+ yield expected from the target, capture and transport efficiency at 200 MeV and injection efficiency into the PDR. Assuming a reduction factor of 2 for the photons flux, given by a collimation angle of 0.5 mrad, one gets ~ 10^9 photons/turn/bunch on the target.

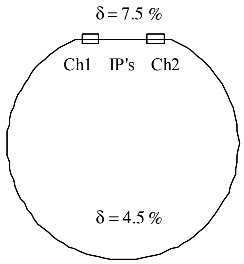

Figure 2: CLIC Compton ring based on doubled chicane.

A yield of 0.01 e^+/γ is classical and would provide 10^7 e^+/turn/bunch at 200 MeV. In order to get the requested bunch charge at the exit of the PDR, it will be necessary to make 440 turns for the stacking into the PDR. According to the optimization of all these parameters, the stacking process into the PDR will be more or less relaxed.

ERL (ENERGY RECOVERY LINAC)

An ERL is a continuous low-charge high-repetition frequency electron linac. An ERL based e^+ source can provide a large number of low charge e^+ bunches. Figure 3 shows a basic layout of the ERL scheme.

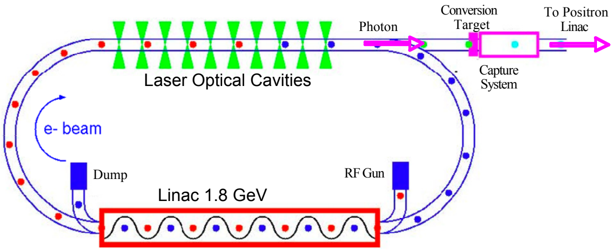

Figure 3: Basic layout for an ERL scheme

The scheme is a good solution for the stacking if the repetition rate is large enough to generate the required positrons. In the case of CLIC, one has only 20 ms. In order to cope with the different constraints (timing, damping, stacking), one proposal is to use 2 small storage rings (SR1 and SR2) between the ERL and the PDR. Figure 4 shows a layout where 20 ms are used for stacking 321 bunches, in the SR1, followed by 20 ms of damping. During the same 20 ms of damping in SR1, one has 20 ms of stacking into SR2 followed by 20 ms of damping and so on. A bucket in the SR1 and SR2 is filled every 64th turn. Therefore the bunch spacing into the ERL should be 32 ns. Assuming 3x10^9 e^-/bunch (0.48 nC), and 32 ns of bunch spacing, the beam current is 15 mA and the repetition frequency is 31.25 MHz.

With these ERL parameters, preliminary simulations give a yield of 5x10^8 photons/bunch. One optical cavity is used, for CLIC, with 0.6 J stored laser energy. A conservative e^+ yield of 0.5 % seems reasonable and 2.5x10^6 e^+/bunch would be achievable. With 1947 stacking injection into the same bucket, one could expect

$4.8\text{x}10^9$ e^+/bunch, which are just above of the requested bunch charge for CLIC.

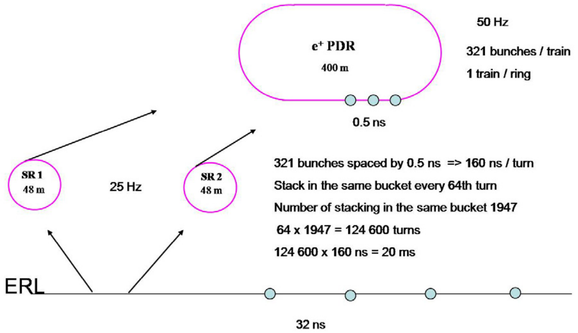

Figure 4: A possible ERL scheme for CLIC

COMPTON LINAC

The scheme employs Compton backscattering from a 4 GeV linac's e^--beam inside a CO_2 laser amplifier cavity. It relies on commercially available lasers and does not require e^+ stacking. The required number of e^+ per bunch is produced in every laser shot at 50 Hz repetition rate.

The essential features of this scheme are: using a mid-IR CO_2 laser that provides 10 times more laser photons per Joule than a solid-state laser, and the most energy-efficient back-scattering geometry. This allows attaining the γ-ray production of 1 photon per electron, as has been demonstrated in an experiment [7]. The conversion efficiency of the polarized photons into polarized e^+ is expected to be about 2%. Therefore, every e^+ requires, as precursors, 50 photons. With $N_\gamma/N_{e-}=1$, and 5 nC/bunch delivered from the electron linac, 10 consecutive Compton IPs will be required to accumulate the photons flux for the 1 nC positron bunch production. Intra-cavity positioning of the interaction point (IP) allows laser energy recycling to compensate for optical losses inside the cavity (assumed here 2% per round trip).

The linac's electron beam is formatted into a train of 312 bunches at 5 ns spacing and 50 Hz repetition rate. This matches the optimum regime for the energy extraction from the laser and power efficient pulsed linac.

The 1 nC positron bunches, produced on a target by the Compton-scattered photons, will be injected into the PDR with 0.5 ns bunch spacing.

SIMULATIONS

For the polarized positron source, simulations were carried out assuming the Compton scattering process to produce the photons needed for the positron production. Simulations with CAIN were performed, for an electron beam of 1.3 GeV and 1.8 GeV of mean energy. Preliminary simulations of an ERL scheme were performed where the electron beam collides with a 0.6 J laser pulse in 5 Interaction Points. The number of gammas produced per electron and their mean energy are reported in Table 2. The photons resulting from these simulations were used as impinging beam on a tungsten amorphous target with thickness 1.4 mm. The simulations inside the amorphous target were performed with EGS4. The corresponding yield and the Peak Energy Deposition Density (PEDD) for an incident photon are also reported in Table 2.

Table 2: Simulation results

Parameters	**1.3 GeV**	**1.8 GeV**
From ERL	CAIN simulations	
Nγ / e-	0.67	0.75
<E>	14.6 MeV	27.7 MeV
From target	EGS4 simulations	
Yield (e^+/γ)	0.047	0.088
PEDD (J/g) / γ	$1.8\ 10^{-13}$	$2.2\ 10^{-13}$

The capture section was composed of an AMD of length 50 cm with magnetic field of 6 T at the target and 0.5 T at its end, and by a solenoid of length 57 m and magnetic field of 0.5 T. Initial simulations were performed with ILC parameters. The accelerating cavities were L-band 1.3 GHz structures with average gradient 5 MV/m. The number of captured e^+ at 150 MeV was 0.02 e^+/gamma for 1.8 GeV and 0.0085 e^+/gamma for 1.3 GeV. The transverse normalized emittances of the positron beam were 6500 mm.mrad in both planes. The longitudinal emittance was $3.2\ 10^{-4}$ eV.s for both energies. The polarization was around 60% as required.

SUMMARY

Three options based on Compton schemes are under study for CLIC. The favoured one is based on a Compton Ring, but presents crucial challenges. However, a strong R&D program is being pushed by KEK and LAL, in particular for the optical stacking cavity. The ERL option presents several advantages but requires important hardware developments. For the Compton Linac, simulations and experiments on laser pulse injection and train production inside the Compton cavity are also in progress at BNL.

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