THE CLIC POSITRON PRODUCTION SCHEME

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Abstract

The CLIC (Compact Linear Collider) positron source is based on the conventional scheme, using a metal converter target and an Adiabatic Matching Device (AMD) composed of a Flux Concentrator (FC) and a constant magnetic field along the positron Pre-Injector linac. The positrons are accelerated with L-band RF structures. Beam dynamics simulations are described for the positron production in the target and capture section in the AMD. The distribution of the energy deposition in the target is studied with the EGS4 code. The dependence of the positron yield on several parameters is studied and optimised using both EGS4 and analytical calculations. Following this optimisation, a new set of design parameters is proposed and particle tracking simulations are performed to estimate the overall performance.

1 INTRODUCTION

In the CLIC positron source a 2 GeV, high-intensity electron beam hits a classical converter target to produce positrons. The strong tapered solenoidal field, provided by the FC, focuses the positrons emerging from the target. The phase space matching is obtained from the FC and the constant magnetic field along the positron Pre-Injector linac. The large-iris apertures of the L-band RF structures downstream of the target, allow larger transverse acceptances compared to S-band. At 200 MeV, the positrons are passed through a quadrupole focusing system and are accelerated up to 2.0 GeV in the Injector linac, before being transported to the Pre-Damping Ring (PDR).

The design parameters of this source have been re-optimised. A detailed description of this work is given in [1]. This paper gives a brief summary of this re-optimization process.

The total power, and the distribution of the energy deposited in the target by the incident primary electrons, was studied using the electromagnetic shower simulation code, EGS4 [2]. Limiting the peak energy density is essential to avoid target destruction due to fatigue. The target issues are described in section 2. The dependence of the positron yield on aperture radius and accelerating gradient of the accelerating sections is described in section 3. Beam dynamics simulations of the positron production in the target and in the AMD have been performed.

The new design parameters are given in Table 1. Detailed particle tracking simulations have been made using these new parameters, to estimate both the phase space distributions of the positrons at the capture section exit, and the expected positron yield (see section 4).

The nominal CLIC centre-of-mass energy is 3 TeV [3] but operation at lower energies (500 GeV) is also foreseen. The only difference for the positron source at 500 GeV is that the repetition rate is doubled (200 Hz), this doubles the beam power deposition in the target. The design optimisation has therefore been done using this worst-case value.

Table 1: Parameters for e^+ production (0.5 TeV)

General parameters		
N e^+ / bunch at IP	0.4	10^{10}
No of bunches per pulse	154	–
N e^+ / pulse at IP	62	10^{10}
Pulse duration	0.102	μs
Bunch spacing	0.666	ns
Repetition frequency	200	Hz
Primary beam		
Energy	2	GeV
N e^- / bunch	1.35	10^{10}
N e^- / pulse	208	10^{10}
Beam power	133	kW
Charge / pulse	333	nC
Linac frequency	1.5	GHz
rms (radius) on target	2	mm
Bunch length (rms)	3	mm
Target		
Material	$W_{75}Re_{25}$	
Nb Radiation Length	4	χ_0
Length	13.8	mm
Capture system		AMD
Peak field in the FC	7	T
DC field in the FC	0.5	T
Energy acceptance	± 10	MeV
RF Wavelength	0.20	m
Iris radius	20	mm
Accelerating gradient	15 - 25	MV/m
Final energy	200	MeV

2 TARGET ISSUES

The beam power deposition is very dependent upon incident beam radius and target thickness. However, an acceptable trade-off between power deposition and positron yield should be found. By increasing the incident beam radius from 1.6 mm (previous value of electron spot) to 2 mm, the yield is reduced by only 9 % whilst the peak energy deposition is reduced by 34 %. By reducing

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the thickness from 4.5 χ_0 (previous value of the number of radiation lengths) to 4.0 χ_0, the yield remains almost the same whilst the beam power deposition (for a 200 Hz repetition rate) is reduced from 42 kW to 33 kW. Using the parameters given in Table 1, the peak energy deposition per volume was simulated using EGS4. The maximum deposited energy was found to be 0.92 MeV per incident electron in a volume of 0.425 mm^3, and since there are 208 x 10^{10} e^- per pulse, the peak density per volume is found to be 0.45 x 10^{10} GeV/mm^3. The results are summarised in Table 2. The deposited energy density is 37 J/g, which is very close to the limit (35 J/g) found by SLAC and the NLC collaboration [4] as a safe value to avoid target failure.

Table 2: Energy density for CLIC target

Parameters		
Target thickness	4	χ_0
Beam power deposited	33	kW
Deposit.Pow./BeamPower	19	%
Density per area	0.33 10^{12}	GeV/mm^2
Peak density per volume	0.45 10^{10}	GeV/mm^3
Peak density per volume	2.10 10^{10}	$GeV/mm^2\ \chi_0$
Energy density	37	kJ/kg

3 POSITRON YIELDS BASED ON EGS4

3.1 Positron yield versus aperture radius

One of the main improvements in the positron production schemes for CLIC/JLC/NLC [5] is the use of L-band accelerating structures instead of S-band. Whilst the aperture size in the capture section is increased by a factor 2, the positron yield is increased by a factor 5. Figure 1 shows the positron yield versus the aperture radius. The number of positrons produced at the target exit was first calculated using EGS4, and then analytical expressions from [1] were used to calculate the number of positrons, which fell within the available transverse and longitudinal acceptances. The aperture radius of the accelerating section was chosen to be 20 mm.

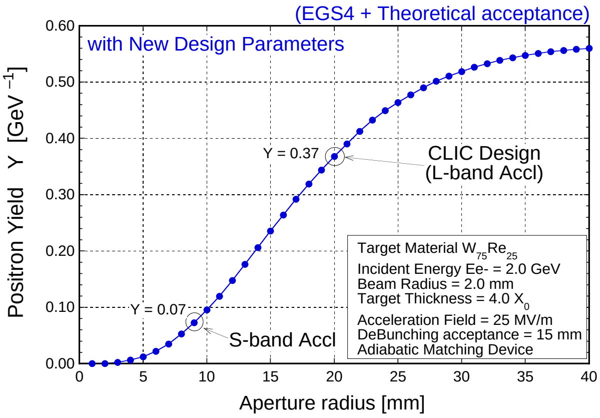

Figure 1: Yield versus aperture.

3.2 Positron yield versus accelerating field

The positron yield was studied as a function of accelerating gradient in the positron Pre-Injector linac. Figure 2 shows the yield for gradients from zero to 35 MV/m. The normalised yield remains almost constant for gradients above 15 MV/m. The accelerating gradient could in fact be reduced from 25 to 15 MV/m with only 5 % loss in the yield. However a beam loading compensation study should be made before this choice is finally made. For the present, all simulations were performed for a nominal gradient of 25 MV/m.

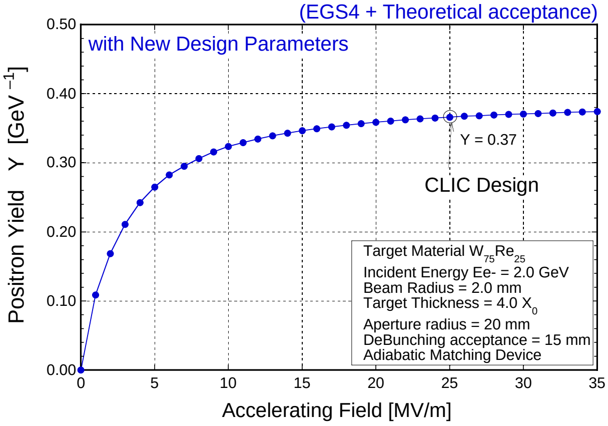

Figure 2: Yield versus accelerating gradient.

4 POSITRON YIELD BASED ON TRACKING SIMULATIONS

4.1 Transverse and longitudinal phase spaces

A tracking simulation program SOLEIL has been developed [6] which traces the trajectories of the particles step-by-step with numerical integration of the relativistic equations of motion based on the 4th order Runge-Kutta method. For the transverse phase space, the normalised emittances are derived using a Gaussian fit from the projections of the distributions at the capture section exit (204 MeV). The rms beam sizes and beam angle are respectively σ_x = 7 mm and $\sigma_{x'}$ = 3.2 mrad which give the normalised emittances $\gamma\varepsilon_{x,y} = 9.2 \times 10^{-3}$ rad.m (at 1 σ).
For the longitudinal phase space, Figure 3 shows the results of tracking at the capture section exit. From the projections of the distributions and with a Gaussian fit, the energy dispersion is σ_E = 7 MeV and the longitudinal bunch length is σ_t = 17 ps.
The tracking was performed for the “accelerating phase” of the positron Pre-injector linac. Assuming an acceptance of the PDR, $\Delta E = \pm$ 10 MeV and Δt = 50 ps as shown by the rectangle in Figure 3, the normalised positron yield was found to be:

$$Y = 0.31\ [e^+ / e^-][GeV]^{-1}.$$

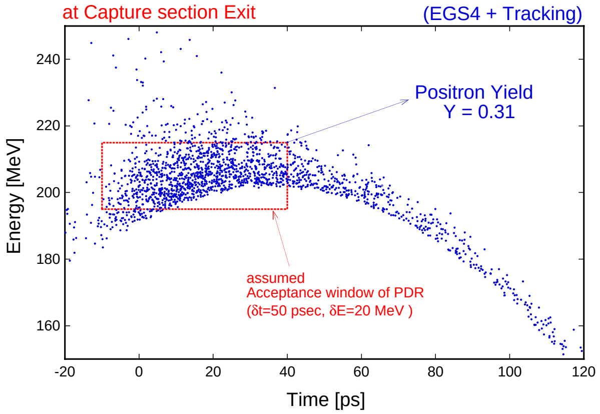

Figure 3: Longitudinal phase space at 204 MeV.

4.2 Comparison between analytical calculations and tracking

Several parameters were optimised for the CLIC positron production based on analytical calculations and tracking. One parameter was the unavoidable debunching, which occurs in the matching section. The number of positrons injected into the PDR depends directly on the acceptance of the PDR and therefore on the acceptable debunching of the positron bunch. Figure 4 shows that the yield versus bunch length due to the debunching calculated by both the analytical formulae and by the tracking code are in good agreement.

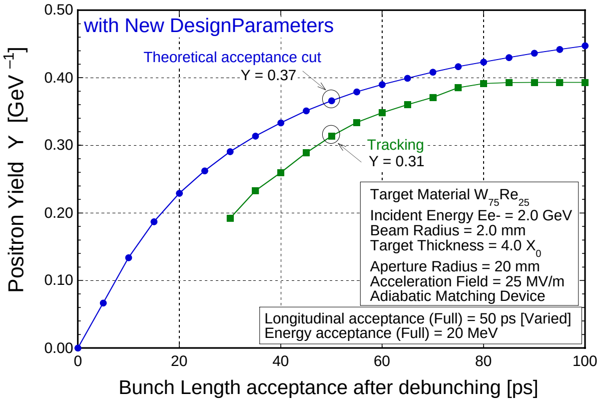

Figure 4: Comparison of the yield versus bunch length.

The positron yield from the tracking code is slightly lower since it is more precise. When the acceptance of the PDR is optimised, the final positron yield would be derived from this figure.

4.3 Tracking for the decelerating phase

In positron linacs, it is known that the "decelerating phase" could be used in the Pre-Injector linac. In general, this process, where positrons are first decelerated then accelerated, presents a greater efficiency. Figure 5 shows the positron density for both phases for the CLIC Pre-Injector linac.

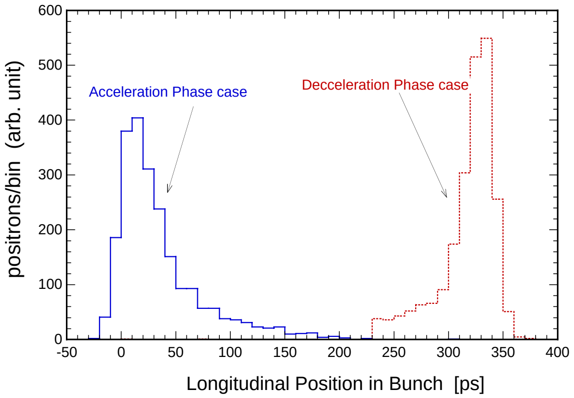

Figure 5: Bunch distribution for both phases.

Going from the "accelerating phase" to the "decelerating phase", reduces the positron energy from 204 MeV to 195 MeV, but increases the normalised yield from 0.31 to 0.40 $[e^+ / e^-][\mathrm{GeV}]^{-1}$.

5 COMMENTS AND CONCLUSIONS

In the tracking simulations, the following effects have not been taken into account: space charge, wake fields from the accelerating structures and beam loading for the multi-bunch beam. These effects should be included in future studies.

The results of this study confirm that the data given in Table 1 is a consistent set of optimised parameters for the design of the CLIC positron source.

6 REFERENCES

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[6] T. Kamitani, "SOLEIL code", to be published.