Nuclear Inst. and Methods in Physics Research, A 869 (2017) 56–62

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Design and optimisation of the positron production chain for CLIC from the target to the damping ring

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ARTICLE INFO

Keywords:
Positron source
Linac
Tracking
Optimisation
Design
Decelerating mode

ABSTRACT

The CLIC Positron source has been designed to produce non-polarised positron beams using a hybrid target composed of a crystal followed by an amorphous target. After production, positrons are captured and accelerated to 200 MeV in the pre-injector linac and subsequently accelerated further up to 2.86 GeV in the injector linac. At this point they enter the pre-damping ring and afterwards the main damping ring to obtain the necessary beam quality for a linear collider. In this study, we have designed and optimised the beam transport and acceleration from the target to the pre-damping ring which has a limiting transverse and longitudinal acceptance. The goal of the study was to maximise the positron yield accepted by the pre-damping ring.

Contents

1. Introduction

The positron source for CLIC needs to deliver intense high quality positron beams for the linear collider. Depending on the construction stage of the collider the source needs to deliver trains of up to 352 bunches with a bunch repetition rate of 2 GHz and up to 5.2×10^9 positrons per bunch to the main linac of the collider at 50 Hz repetition rate [1,2]. A conventional positron source uses only a single amorphous target. The CLIC source takes advantage of a novel hybrid target design consisting of a thin crystal target to enhance photon production via channelling and an amorphous target to convert the photons into positrons. In between a magnet is used to sweep out charged particles to reduce the peak power deposition on the production target [3]. In the Conceptual Design Report (CDR), a prove of principle approach was used to describe the design of the positron production chain for CLIC, estimating a positron yield of 0.39 e^+/e^- from the target to the entrance of the pre-damping ring [4,5]. The positron yield is defined as the number of positrons at a given place along the production chain per electron impinging onto the target. A study was launched to substantially improve the positron yield in this area to increase the margin of the positron target in terms of peak energy deposition and to

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http://dx.doi.org/10.1016/j.nima.2017.07.010
Received 14 March 2017; Received in revised form 17 May 2017; Accepted 7 July 2017

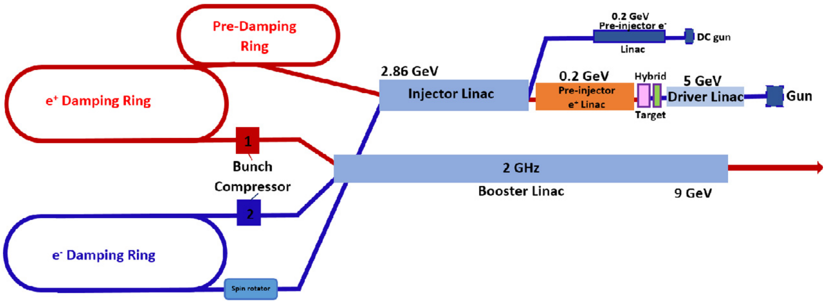

Fig. 1. Schematic layout of the CLIC injector complex consisting of an electron source, a positron source, a booster linac at 9 GeV, pre-damping and damping ring complex including a spin rotator and two bunch compressors.

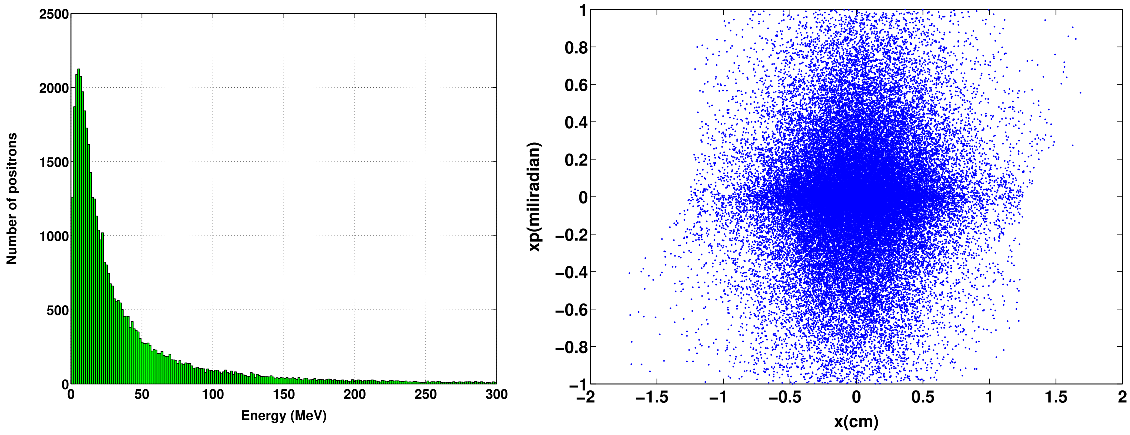

Fig. 2. Positron distribution after the target. The left figure shows the energy spectrum of positrons applying a cut at 300 MeV and the right figure shows the transverse phase space of positrons.

reduce the cost and energy consumption of the required electron driver linac. The CLIC positron source includes a hybrid target, an Adiabatic Matching Device (AMD), the pre-injector linac and the injector linac.

After the amorphous target, the conical magnetic field of the AMD focuses the positrons in order to be efficiently captured in the downstream accelerating structures. The longitudinal magnetic field of the AMD changes from 6 to 0.5 T in 20 cm. Two thirds of the positrons created in the target are already lost before entering the first accelerating structure. The CLIC positron target was optimised for a 5 GeV electron driver obtaining a yield of 8 e^+/e^- [6]. After the AMD, modelled using PARMELA [7], it was found that only 2.8 e^+/e^- survive due to the enormous energy spread and angular divergence of the generated positrons [8]. The aim of the study described in the following, is to preserve as many as possible of these precious positrons during acceleration and transport them up to the pre-damping ring. Intuitively, the positron-capture linac should increase the positron energy as fast as possible to reduce the divergence and the energy spread. However, it has been shown in the past that initial deceleration can lead to a more efficient capturing [9].

The CLIC positron source divides the acceleration into a pre-injector linac, which accelerates the positrons up to 200 MeV, and a final injector linac, which boosts the energy up to 2.86 GeV, which is the injection energy of the pre-damping rings. This separation comes from the fact that the injector linac is used both for electrons and positrons in the CLIC injector complex. The positrons are then injected into a pre-damping ring and a damping ring to reduce their emittance and finally accelerated to 9 GeV for transport into the main linac. The pre-damping ring has a limited transverse and longitudinal acceptance. Most critical for the positron beam is the energy acceptance window of 1.2%. The CLIC injector complex is shown schematically in Fig. 1.

In this paper, we describe the design and optimisation of the pre-injector linac and the injector linac with the objective to maximise the positron yield into the pre-damping ring acceptance.

2. The design of the CLIC pre-injector linac

The CLIC pre-injector linac has been optimised from the exit of the target up to an energy of the captured positrons of roughly 200 MeV. Starting point was the simulated positron distribution at the exit of the target from the previous study [6]. After production on the target with 5 GeV electrons, positrons have naturally large energy spread and emittance. The resulting positron distribution after the target is shown in Fig. 2. The average energy of the positrons is about 50 MeV at this stage. The initial design of the pre-injector linac, documented in the CDR, focused on capturing the positrons with energies up to roughly 100 MeV. The other natural cut on this enormous distribution was the transverse acceptance of the AMD and the accelerating structures, given mainly by their physical aperture.

An aperture of 20 mm radius has been chosen for the design of the 2 GHz accelerating structure as a compromise between obtainable gradient and power consumption. The model was based on a 1.5 m long $2\pi/3$ travelling wave structure with a gradient of up to 15 MV/m. For the simulations we assumed that the whole pre-injector linac is embedded into a solenoidal magnetic field of 0.5 T. The AMD reduces the beam divergence and concentrates a maximum of particles into the aperture of the first structure. The 6 T maximum field is believed to be feasible for such an aperture in a pulsed normal-conducting device. The length of the beam pulse is 176 ns. Both operation modes, acceleration and deceleration in the first rf structure, have been studied.

2.1. The accelerating mode in the pre-injector linac

In the accelerating mode, we placed the centre of the positron distribution on the crest of the accelerating field, and accelerated with a 15 MV/m gradient in each structure. The drift space between structures was chosen to be 20 cm. In this configuration the total length of the pre-injector linac is about 14 m, using 8 accelerating structures. At the end of