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THE BASELINE POSITRON PRODUCTION AND CAPTURE SCHEME FOR CLIC

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Abstract

The CLIC study considers the hybrid source using channeling as the baseline for unpolarised positron production. The hybrid source uses a few GeV electron beam impinging on a tungsten crystal target. With the crystal oriented on its < 111 > axis it results an intense relatively low energy photon beam. The later is then impinging on an amorphous tungsten target producing positrons by e+e− pair creation. Downstream the amorphous target, a capture section based on an adiabatic matching device followed by a 2 GHz Pre-Injector Linac focuses and accelerates the positron beam up to around 200 MeV.

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The CLIC study considers the hybrid source using channeling as the baseline for unpolarised positron production. The hybrid source uses a few GeV electron beam impinging on a tungsten crystal target. With the crystal oriented on its $< 111 >$ axis it results an intense relatively low energy photon beam. The later is then impinging on an amorphous tungsten target producing positrons by e^+e^- pair creation. Downstream the amorphous target, a capture section based on an adiabatic matching device followed by a 2 GHz Pre-Injector Linac focuses and accelerates the positron beam up to around 200 MeV.

INTRODUCTION

The conventional scheme for the CLIC positron production as been described in [1]. However it presents some issues related to important heating and large emittance. For this reason, CLIC considers as a baseline an alternative method based on a combined crystal and amorphous tungsten targets : so-called the hybrid source. A few GeV electron beam impinges on a tungsten crystal oriented on its $< 111 >$ axis. To limit the energy deposition in the amorphous target, the charged particles are swept off after the crystal. Only the photon beam impinges on the amorphous target. A large number of positrons using axial channeling radiation from GeV electron beam have been measured successfully at CERN and KEK [2, 3]. On the other hand, the hybrid scheme is now under tests at KEK [4]. Downstream the amorphous target, there is a capture section based on an Adiabatic Matching Device (AMD) followed by a 2 GHz Pre-Injector Linac surrounded by a 0.5 T solenoid field. The positron beam is then brought up to an energy of 200 MeV. The CLIC positron injection scheme is presented in Figure 1. The details of the positron production and capture are described in Figure 2.

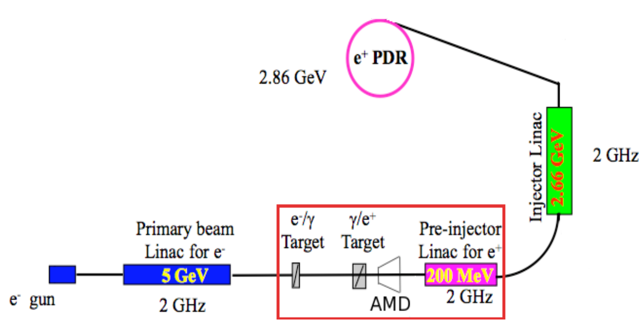

Figure 1: Layout of the CLIC positron source. Red box show the part which concerns the positron production and capture (zoomed in Figure 2).

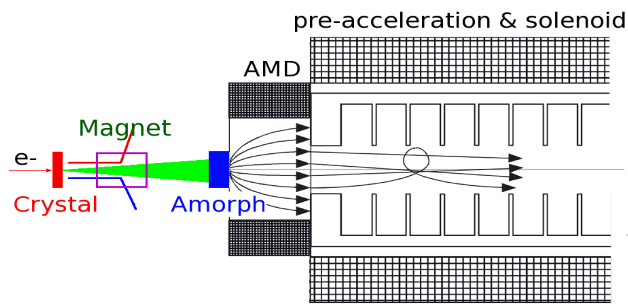

Figure 2: CLIC positron generator (adapted from Figure 4 of [1]).

SIMULATIONS

The primary electron beam parameters requested for the 3 TeV CLIC charge are the following [5] :

- Number of electrons per bunch : 7.5×10^9
- Number of bunches per train : 312
- Number of electrons per train : 2.34×10^{12}
- Repetition frequency : 50 Hz
- Spot size (radius) : 2.5 mm, at the crystal target

For the CLIC 0.5 TeV configuration, the electron and positron charge per bunch is doubled.

Different incident electron beam energies impinging on the crystal have been considered namely between 3 and 10 GeV. Below 3 GeV the electron will produce not enough photons to bring enough positrons at the exit of the amorphous target. With the channeling radiation the number of positrons is increasing with the incident electron energy. Since the Peak Energy Deposition Density (PEDD) in the amorphous target cannot exceed a certain value, the incident electron beam energy and the beam size are constrained. This PEDD [6] is limited for tungsten material to 35 J/g, value based on the result of the SLC damaged

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target analysis [7]. In the case of the CLIC parameters the incident electron would not then exceed 10 GeV [8].

The generation of photons from crystal tungsten target was obtained using a crystal simulation code [9]. The amorphous and AMD was simulated using Geant4 [10]. The Pre-Injector Linac surrounded by the solenoid was simulated using ASTRA.

CRYSTAL RADIATOR

A few GeV electron beam aligned to the direction of the $< 111 >$ crystal tungsten axis produces, due to his high axial potential (1000V at normal temperature), an enhancement of the number of photons by the channeling effect. This effect can be observed on Figure 3 where a 5 GeV electron beam impinges on an amorphous and a crystal tungsten target. Both targets have the same thickness of 1.4 mm. The photons from pure bremsstrahlung, i.e. amorphous target (in blue area in the figure), and bremsstrahlung plus channeling radiation, i.e. crystal target, are superimposed. The vertical scale is $\omega \times \mathrm{dN}/\mathrm{d}\omega$, where ω is the

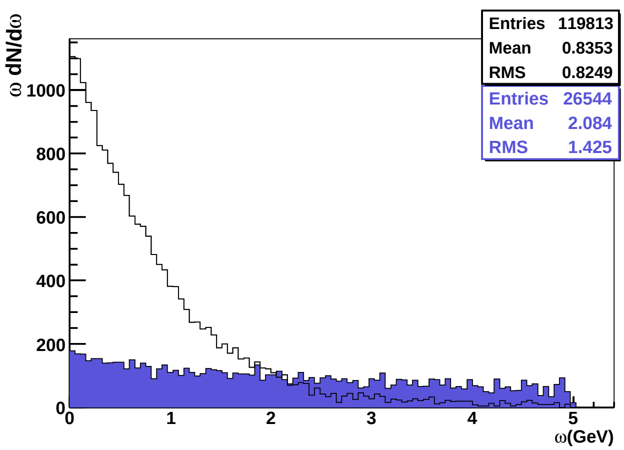

Figure 3: Emerging photons from a 5 GeV e^- impinging on a 1.4 mm of tungsten crystal and amorphous target.

photon energy. In an amorphous target, the bremsstrahlung spectrum has a $1/\omega$ behaviour and exhibits on the figure an almost constant shape. On the other hand, in the crystal (with same thickness) an enhancement of soft photons production is observed. For a normal incidence of the electron beam with respect to the crystal, the photon flux depends on the electron beam energy and the thickness of the tungsten crystal. According to the incident electron beam energy, different radiator thicknesses have been chosen. They correspond to some optimum values [11]. Thus for 10, 5, 4 and 3 GeV the optimum crystal thickness is respectively 1.0, 1.4, 1.5 and 1.6 mm. To limit the energy deposition in the amorphous target only photon beam is impinging on the amorphous target.

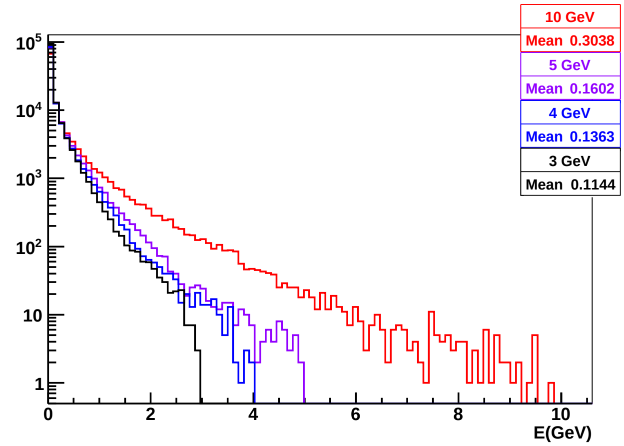

Figure 4: Photons emitted in the crystal for different incident electron beam energy.

AMORPHOUS CONVERTER

Systematic study of the amorphous target thickness as well as the distance between crystal and amorphous with respect to incident electron beam energy have been studied in [8]. The photon spot size on the amorphous target is increased as this distance increases. In consequence the PEDD decreases, but also slightly the number of captured positron. A compromise has been found. From [8], the selected parameters are :

- Incident electron beam energy : 5 GeV
- Spot size radius : $2.5\ \mathrm{mm}$, at the crystal target
- Crystal tungsten thickness: 1.4 mm
- Distance crystal-amorphous : 2 m
- Amorphous tungsten thickness : 10 mm

The total power deposited on the amorphous is 10 kW and the PEDD is around 22 J/g. At the target the total positron yield is around $8\ \mathrm{e}^+/\mathrm{e}^-$. The positron beam at the exit of the amorphous target is captured by an Adiabatic Matching Device.

ADIABATIC MATCHING DEVICE

The AMD is used as the first element of the capture section. It exhibits a magnetic field tapering down on a distance L=20 cm from 6 T to 0.5 T. The longitudinal magnetic field law is represented by :

$$\mathrm{B_z(z)} = \frac{\mathrm{B_0}}{1+\alpha \mathrm{z}}, \text{with } \mathrm{B_0} = 6\ \mathrm{T} \text{ and } \alpha = 55\ \mathrm{m}^{-1}.$$

The radial component of the magnetic field is taken into account.

The slowly decreasing field has a property to adiabatically change the particle's transverse momentum (Figure 5

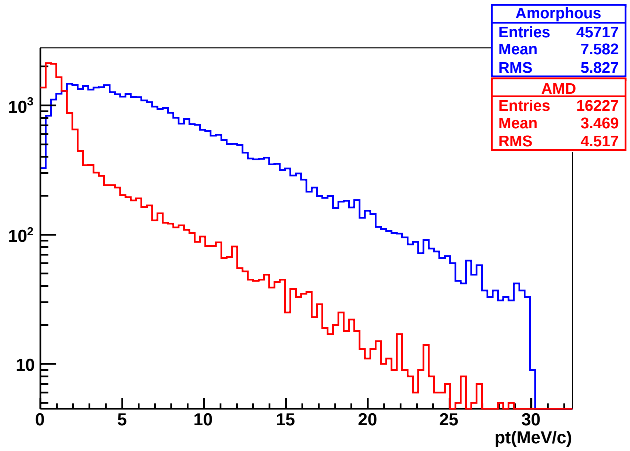

Figure 5: Transverse momentum of the positrons at the amorphous and AMD exits (5 GeV incident electron beam energy and 10 mm amorphous target thickness).

and Figure 6). The AMD has a large energy acceptance and hence increases the number of accepted positrons. Basically the AMD transform the positron phase space after the target into a larger dimension and smaller momentum spread which is easier to transport in the Pre-Injector Linac. At the end of the AMD a positron yield within 2 cm radius is around $2.5\ e^+/e^-$.

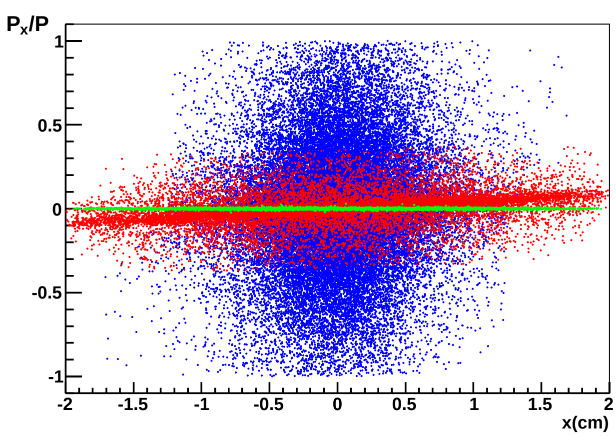

Figure 6: Positrons emittance at the exit of the amorphous target, the AMD and the Pre-Injector Linac at 200 MeV.

THE 2GHZ PRE-INJECTOR LINAC

At the end of the AMD is installed the first accelerating cavity of the Pre-Injector Linac. The latter accelerates the e+ beam up to the energy of about 200 MeV. The design frequency is 2 GHz, in order to have the same bunch spacing and beam structure at the interaction point. The accelerating gradient is 10 MV/m. The field in the structure has been calculated with code Poisson Superfish and then used as input field for ASTRA. The results are shown in

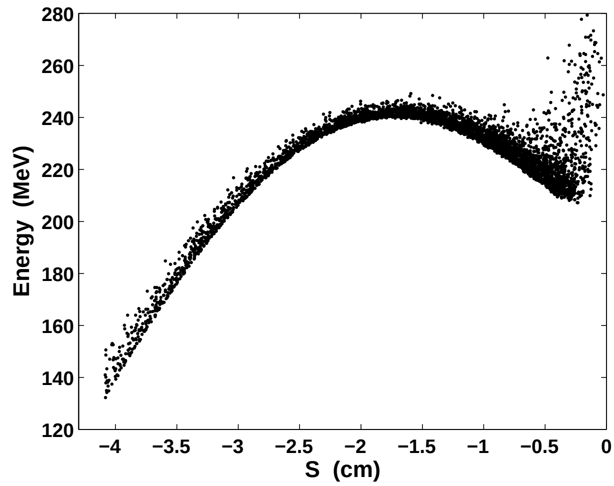

Figure 7: Longitudinal phase space of the positron beam at the exit of the Pre-Injector Linac.

Figure 7. At the exit of the Pre-Injector Linac a positron yield of 0.8 is obtained.

CONCLUSION

With the present parameters, the positron yield obtained at the exit of the Pre-Injector Linac fulfills the CLIC requirements, using a hybrid source scheme (crystal and amorphous targets). However, recent studies suggest that the incident electron beam intensity should be increased to obtained the requested number of e+ captured into the Pre-Damping Ring. Nevertheless an increase of the electron beam intensity of 25% to 35% is still acceptable to keep the Peak Energy Deposition Density below the limit.

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