ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPTS104

SYNCHROTRON RADIATION REFLECTIONS IN THE CLIC BEAM DELIVERY SYSTEM

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Abstract

Synchrotron radiation (SR) reflection is an important issue for future linear colliders. High fluxes of SR might impact the performance of the detector, through irradiation of the forward luminosity and beam quality calorimeters or of the innermost layers of the vertex detector. The photon reflections depend on the beam pipe apertures' size, their shape, and materials used with various surface roughness. In this work, we present a study of SR including reflection for the 380 GeV and 3 TeV beam parameters and optics of the Compact Linear Collider's Final Focus System. The simulations of the SR reflections using the Synrad+ software are presented and the impact on the detector is discussed.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed future electron–positron collider with the potential to reach centre-of-mass energies in the TeV scale. The construction and physics programme is assumed to be carried out in three stages: at 380 GeV, 1.5 TeV, and at 3 TeV [1].

To achieve the desired high instantaneous luminosity, small bunch sizes in the order of nanometres with a population in the order of 10^9 particles are required [1]. The Beam Delivery System (BDS) transports electron and positron beams from the linacs to the Interaction Point (IP). First, the beam is cleaned in the energy and betatron collimation sections and then it is focused with the Final Focus System (FFS). The FFS is made of dipoles, quadrupoles and sextupoles that have been optimized to match the desired beam parameters at the IP. The total FFS length is 770 m, and its layout is shown in Fig. 1 [2].

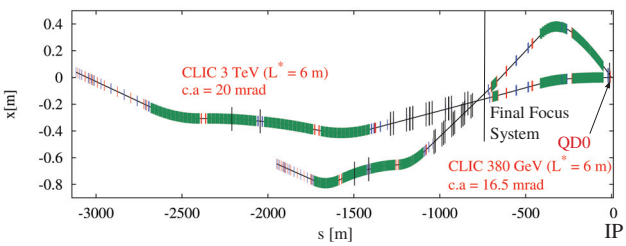

Figure 1: CLIC Beam Delivery System layout at 380 GeV and 3 TeV.

The high energy of the electron and positron beams leads to the emission of a broad spectrum of synchrotron radiation.These particles could become a source of background, leaving significant energy depositions in the CLIC detector that might deteriorate performance, and therefore need to be studied carefully. The photons used in this study are produced in the FFS and have energy in the range from 1 keV to 30 keV are studied. Photons with energies below 1 keV are unlikely to penetrate the beam pipe and deposit energy above the detection threshold, while above 30 keV the reflection probability is negligible [3, 4].

PHOTON INTERACTIONS

Photons interacting with matter can undergo absorption, transmission, scattering, pair production, or reflection. The latter allows them to travel further downstream in the accelerator, possibly impacting the detector. The probability of reflection can be described using the Fresnel formula which depends on the energy of the photon, its incident angle, and the material properties of the surface. Reflectivity decreases with increasing energy and incident angle. In the scenario where the surface roughness is negligible compared to the photon wavelength, specular reflection occurs where the reflected angle is equal to the incident angle. Otherwise, diffuse reflection over an angular range and backscattering are also possible. This angular range increases with surface roughness [3, 4].

RESULTS

Synchrotron radiation creation, tracking, and interactions with matter in the CLIC FFS were simulated in Synrad+ [5]. The reflection tables used were based on [3], and the apertures assumed for the FFS were taken from a separate study [6]. Two energy stages are presented: 380 GeV and 3 TeV. The statistics used are equal to 4200 s of machine running time at 380 GeV and 2000 s at 3 TeV.

For cross-check purposes, PLACET [7] was modified to allow for the extraction of the synchrotron radiation photons. Since there are no photon reflections implemented in PLACET only the photons emitted in the final straight part of the FFS were compared. The conclusion is that no photon emitted in the final 20 m of the BDS can cause a hit in the detector, as required by design [8].

380 GeV CLIC

First, the hypothetical case where the beam pipe walls absorb every incident photon was studied. This was done to cross-check the finding obtained from PLACET that there are no direct photons that can hit the sentitive elements of the detector. In this scenario, 5.5% of the total photon beam power produced along FFS reaches the exit of the final quadrupole magnet (QD0) positioned 6 m before the interaction point (IP). The transverse position distribution of photons at the exit of QD0 and the polar angle distribution

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are presented in Fig. 2 and Fig. 3 respectively. In the polar angle distribution plot a vertical line at 3.3 mrad marks the inner edge of the BeamCal subdetector on the opposite side of the IP. In the fully absorbing case the photons are mainly concentrated in the centre with the distribution elongated towards the negative horizontal positions due to emissions in the bending magnets. In this case there are no photons interacting with any detector material, which is the desired experimental condition.

A more realistic scenario involves using copper and iron reflection tables and varying the average surface roughness. The transverse position and polar angle distributions are shown in Fig. 2 and Fig. 3 for 1 µm and 100 nm roughness respectively. The transverse plane is more uniformly populated when reflections are allowed. Additionally, the smoother beampipe surface results in more photons outside the region occupied in the non-reflective case. This effect is especially visible in the polar angle distributions. Photons with $\theta < 0.2$ mrad are emitted in the last bending and quadrupole magnets and travel to the QD0 exit without any interactions with the beam pipe, while photons with larger polar angles are a product of reflections. The number of photons in the polar angle region between 0.1 mrad and 3 mrad is bigger when iron is used, although that has a limited impact on the detector region. The change in assumed average surface roughness from 1 µm to 100 nm results in a significant increase in the number of photons that can interact with the detector's sensitive material, with 14 times more photons carrying cumulatively 10 times more energy. The larger increase in photon number than energy indicates that lower energy photons are more likely to reflect when the beam pipe surface is smoother, which can be also observed when comparing Fig. 3 with Fig. 4.

3 TeV CLIC

Similarly to the 380 GeV study, initially the hypothetical case where the beam pipe walls absorb every interacting photon was studied. The results confirm the findings at 380 GeV, indicating that in this hypothetical case no SR photons would hit any detector element. The polar angle distribution of photons is presented in Fig. 4. These results agree with the 380 GeV energy findings that this is a safe environment for the detector where there are no photons in the BeamCal aperture. In this scenario 8.3% of the total photon beam power produced along the FFS reaches the QD0 and is safely transported through the detector region, suggesting more intensive production in the final doublet in comparison to the 380 GeV energy stage.

Next, the surface roughness of copper and iron beam pipes was varied. The transverse position distributions and polar angle distributions are shown in Fig. 4 for both 1 µm and 100 nm average roughness. A similar dependence between the SR photons distribution when iron and copper are used for beam pipe walls is found at this energy stage, although to an even larger extent. Nonetheless, the difference for the detector is negligible, and the usage of both materials provide comparable experimental environments. The change

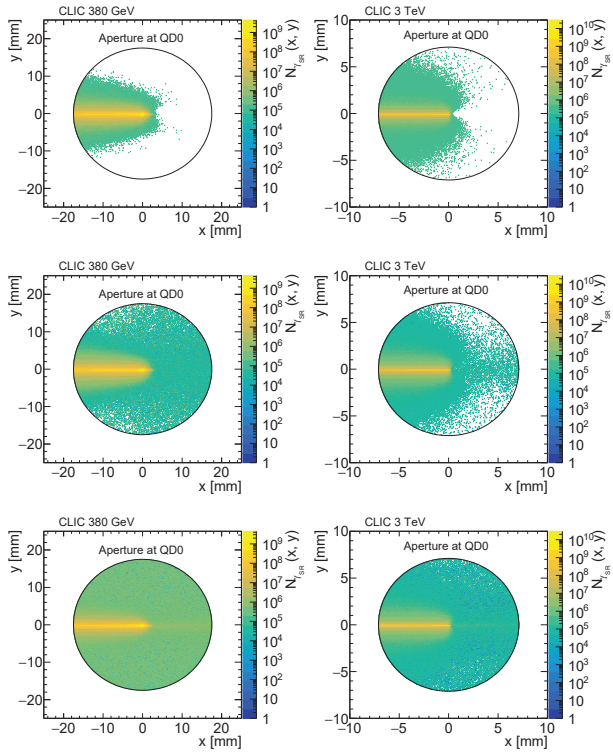

Figure 2: Transverse position distributions at the QD0 exit at 380 GeV (left column) and 3 TeV (right column) assuming fully absorbing walls (top), copper walls with 1 µm roughness (middle), copper walls with 100 nm roughness (bottom).

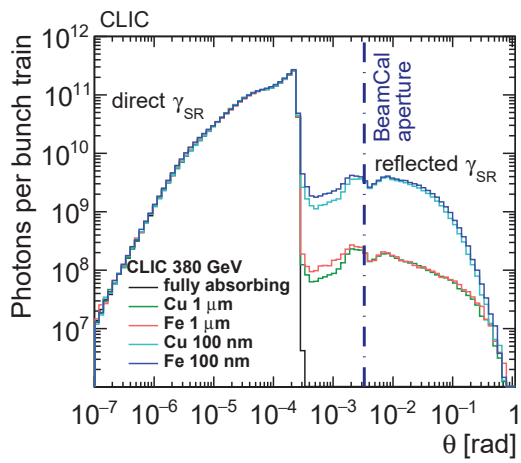

Figure 3: Polar angle distributions at the QD0 exit at 380 GeV assuming fully absorbing walls, copper and iron walls with 1 µm and 100 nm average roughness.

in average surface roughness from 1 µm to 100 nm results in a significant increase in the number of photons in the BeamCal aperture, which in case of copper beam pipes has 17 times more photons carrying cumulatively 12 times more energy. This is a larger effect than observed at the lower energy stage.

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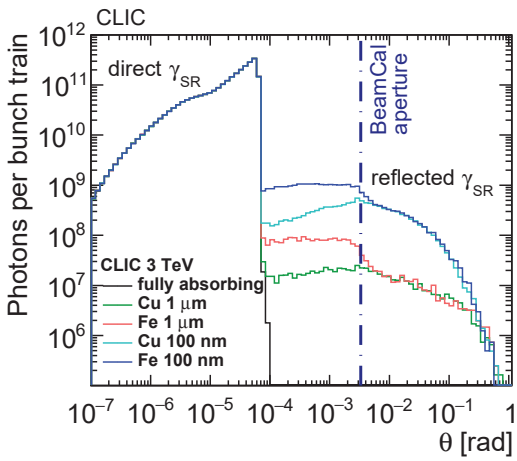

Figure 4: As Fig.3 for 3 TeV.

Mitigation

A detailed full detector simulation study shows that too many hits from SR photons are registered, especially in the case of smoother beam pipes with 100 nm average roughness [9]. Therefore, a mititgation method to reduce the number of reflected SR photons needs to be applied.

The proposed solution is to implement a saw-tooth shape, as shown in Fig. 5 based on the LHC design [10], on the side of the vacuum chamber that interacts with SR photons. This method was tested in Synrad+ simulations. The saw-tooth was placed in the final 27 m upstream from the exit of QD0 at 380 GeV and the final 23 m at 3 TeV. The result is a complete removal of the reflected photons from the polar angle distributions. This is the equivalent of the case of no reflection: no photons are found to propagate towards sensitive elements of the detector.

A future study could investigate the impact of the photons that can penetrate the saw-tooth elements, and travel further downstream the accelerator. The teeth height and spacing could be thus optimised to ensure effective mitigation taking into account the photon energy spectrum expected at CLIC.

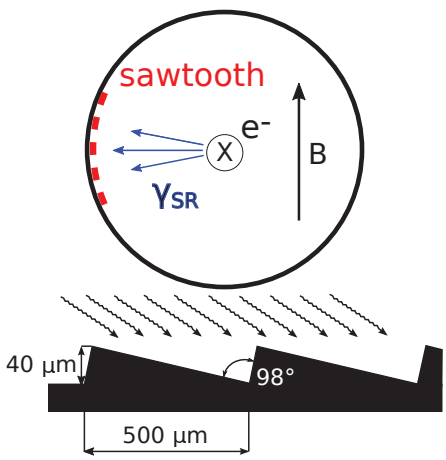

Figure 5: Saw-tooth beam pipe layout inside the beam pipe (top) and design details (bottom).

CONCLUSION

High fluxes of reflected photons from synchrotron radiation can be found in the sensitive elements of the detector at both the 380 GeV and 3 TeV energy stages of CLIC, in particular for an assumed average roughness of the beam pipe walls of 100 nm. Copper and iron when used as a material for the vacuum chamber walls provide comparable experimental environments. A beam pipe design using a saw-tooth surface, based on the LHC design, appears to mitigate this issue. The shape is proposed to be implemented on the side of the beam pipe that interacts with the synchrotron radiation in the final 27 m of the FFS until the QD0 exit at 380 GeV and 23 m at 3 TeV. When implemented, no photons are found to propagate towards sensitive elements of the detector, which provides the desired experimental environment. To fully optimise the saw-tooth design a future study could investigate the impact of the photons that can penetrate the saw-tooth elements, and travel further downstream the accelerator.

ACKNOWLEDGEMENTS

Special thanks to Marton Ady for valuable discussions and support.

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