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SOLENOID USING IRSYN

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The detector solenoid of CLIC causes a range of aberrations on the beam at the interaction point, particularly due to its overlap with the final focus magnets. These effects are corrected using anti-solenoid correction coils on the final quadrupole before the collision point. In this note, we use the interaction region beam dynamics code IRSYN to compute the impact of the SiD solenoid on the beam and benchmark the anti-solenoid correction. We find the correction is achieved, with a small residual amount of beam aberration which is correctable using the beam delivery system. This provides a validation of the correction and a benchmark of IRSYN to existing codes.

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Abstract

The detector solenoid of CLIC causes a range of aberrations on the beam at the interaction point, particularly due to its overlap with the final focus magnets. These effects are corrected using anti-solenoid correction coils on the final quadrupole before the collision point. In this note, we use the interaction region beam dynamics code IRSYN to compute the impact of the SiD solenoid on the beam and benchmark the anti-solenoid correction. We find the correction is achieved, with a small residual amount of beam aberration which is correctable using the beam delivery system. This provides a validation of the correction and a benchmark of IRSYN to existing codes.

1 Introduction

The interaction region of CLIC is the interface between the detector and the machine and offers many beam dynamics challenges. The principle goal is the delivery of luminosity to the detector, which requires very small vertical beam sizes for the colliding beams at the interaction point (IP) and tight control over processes acting to increase the spot size. Of particular concern is the unavoidable fact that the beams in the interaction region pass through the detector solenoid, which causes luminosity degradation through a variety of mechanisms. This impact of a solenoid on the beam in the interaction region of a collider has been studied in depth in [2] and first studied for CLIC in [1]. Generally, the effect on the beam of a pure solenoid field is cancelled due to the interaction of the body and edge of the magnet, leaving an angular offset at the beam collision point. However, this cancellation is spoiled by the overlap of the solenoid with any focusing magnets, a situation which occurs at both the ILC and at CLIC. This results in residual orbit distortion and coupling aberrations in the beam distributions at the IP.

The beam traverses the solenoid at an angle (the half beam crossing angle) of 10 mrad for the CLIC interaction region, resulting in a transverse field and associated orbit deviation. The residual orbit distortion depends on the integrated field strength and the crossing angle value. The solenoid field, in conjunction with an overlap with the focusing elements, causes focusing and coupling between the transverse planes and also longitudinal coupling, or dispersive, effects. Therefore the beam is heavily distorted in

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all phase space planes at the IP. Furthermore the orbit deviation results in the emission of incoherent synchrotron radiation. The combination of these effects on the beam results in a rise of the vertical spot size at the IP and a reduction in machine luminosity.

The compensation of these effects has been studied in depth for both the ILC and for CLIC. The preferred method is the use of anti-solenoids, which give an energy and optics independent correction. In this scheme anti-solenoids, or bucking coils, are placed over the final quadrupole QD0 to cancel the solenoid field in this region. It can be shown [2] that this cancellation of the solenoid field over QD0 restores the aberration cancellations in the solenoid field which are broken by the presence of QD0. The SiD solenoid field has been studied for CLIC, and an anti-solenoid scheme developed [1, 3] which cancels the majority of the IP beam aberrations and leaves a small amount of un-cancelled aberrations [1]. Note this scheme uses a small offset in QD0 to cancel the residual orbit at the IP and the residual aberrations can be pre-cancelled with appropriate beam delivery system tuning.

The purpose of this study, and note, is to use the code IRSYN to bench-mark the performance of the anti-solenoid compensation for the SiD solenoid for CLIC. IRSYN was a code written for the LHeC interaction region design process, to take an arbitrary field map and perform particle tracing with a Monte Carlo model of synchrotron radiation emission. The code is briefly documented in section 2 and the main results of this note are presented in section 3. In section 4 we draw our conclusions, which state that the anti-solenoid as proposed for CLIC successfully compensate the majority of beam aberrations. The remaining ones can be pre-compensated in the beam delivery system. In this work we use the CLIC beam delivery system designed for a 1.5 TeV beam with an $\ell^*$ of 3.5 m.

## 2 IRSYN

The code IRSYN (Interaction Region design with SYNchrotron radiation) is a code originally developed for the interaction region design for the LHeC [4, 5]. The code is a flexible particle tracking code, where the particle trajectories are obtained from direct integration through the magnetic fields. The magnetic layout of the interaction region is specified through a single function, which returns the magnetic field in the frame of the detector at a given spatial position. The inclusion of magnetic elements such as quadrupoles, sextupoles and solenoid field maps is possible through this universal routine. The code then tracks particles, specified from an external file or generated based on a given beam matrix, using the time reversible (hence energy conserving) Velocity-Verlet algorithm and the relativistic Lorentz force law.

The effect of synchrotron radiation is included using a Monte Carlo model originally developed for LEP [6] and implemented in PLACET [7]. For a given particle step, the probability of photon emission is calculated from the radius of curvature of the particle track and its associated energy. The energy of an emitted photon is drawn from the standard incoherent synchrotron emission spectrum. The inclusion of the Monte Carlo algorithm allows the energy loss of the beam due to emission to be tracked, as well as tracking of the resulting photons through the interaction region.

For further details of the code and its applications see [4, 5].
3 The CLIC solenoid

In this section we describe the SiD solenoid field in the CLIC interaction region, the anti-solenoid correction fields and the results of tracking the beams through this interaction region with IRSYN.

The longitudinal component of the SiD solenoid is shown in figure 1, showing the peak of 5 T at the interaction point. The fall-off in longitudinal distance means the field is close to zero around 9 m from the interaction point. The radial field, required to satisfy Maxwell’s equations, is shown in figure 2. The beam traverses the field at an angle of 10 mrad, and so the magnetic field transverse to the particle motion (which determines the vertical force on the particles) is given by a rotation of the longitudinal and radial fields. This transverse field is shown in figure 3. The solenoid field can be seen to extend over the last part of the final focus magnets, which start 3.5 m from the IP.

Figure 1: The longitudinal component of the SiD solenoid as a function of distance from the IP.

Figure 2: The radial component of the SiD solenoid as a function of distance from the IP.

Figure 3: The transverse component of the SiD solenoid in the frame of the beam as a function of distance from the IP.

The compensation of the solenoid effects on the beam is performed with anti-solenoid coils, which surround the final quadrupole QD0 and cancel the solenoid field in this region. The field compensation for the SiD solenoid and the associated anti-solenoid are shown in figures 4, 5 and 6. The anti-solenoid field configuration is described in [3] and consists of
four bucking coils of radius 50 cm. The reduction of the longitudinal field around QD0 (beginning 3.5 m from the IP) is seen in figure 4, which is associated with an enhancement of the radial component the same region, figure 5.

The vertical beam distribution at the IP with no solenoid, computed with synchrotron radiation, is shown in figure 7. The beam size is consistent with the nominal CLIC parameters used in this work, which are shown in table 1.

The body and edge focusing of the solenoid cancel in the presence of no other magnet elements, leaving an orbit angular offset at the IP. The presence of the final focus magnets breaks this cancellation and leads to a residual spatial offset at the IP. The resulting vertical beam orbit through the solenoid and final focus magnets, with no compensation, is shown in figure 8, where the resulting orbit offset at the IP is 5 µm. The presence of the solenoid, and the overlap with the final focus elements, also causes cross-plane coupling at the IP; the most important of which for a small vertical spot size are the residual dispersion and x'-y coupling. The beam distributions at the IP for the case of the uncompensated solenoid, and
Figure 7: The vertical beam distribution at the interaction point with no solenoid and with synchrotron radiation.

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<th>Parameter</th>
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<td>$\beta_y$</td>
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Table 1: The nominal parameters used in this work for CLIC.

synchrotron radiation, are shown in figures 9, 10 and 11. The vertical spot size is shown in figure 9, which shows beam size growth and a centroid shift, and figures 10 and 11 show the $x'$-$y$ coupling and dispersion respectively. The growth in these coupling terms due to the interaction between the solenoid and the final focus magnets is clearly seen. The impact of the synchrotron radiation on these distributions is relatively small.

The corresponding plots of the beam distributions in the presence of the anti-solenoid are shown in figures 12, 13 and 14. These distributions were obtained by tracking identical beams to the uncompensated case in the presence of synchrotron radiation through the interaction region to the IP with the inclusion of the anti-solenoid coils on QD0. Figure 12 shows the vertical beam distribution, which is corrected back to close to the nominal size and shows a considerable reduction with respect to figure 12. The $x'$-$y$ and dispersion are shown in figures 13 and 14, showing the coupling terms are mostly, but not entirely, cancelled. We have checked the residual vertical orbit at the IP can be cancelled with a small (around 1 µm) offset of QD0.

4 Conclusion

In this note we have studied the impact on the CLIC beam at the IP from the SiD solenoid, and the subsequent correction of these effects with the anti-solenoid. The form of the correction scheme was initially studied in [1], where it was shown that a set of anti-solenoid coils over QD0 corrects
the majority of beam aberrations.

In this note, we used the newly developed code IRSYN to benchmark the correction and demonstrate the recovery of the majority of the machine luminosity. The analysis was done with the SiD solenoid and associated anti-solenoid correction coils. The calculation of the interaction region beam dynamics using IRSYN with no solenoid field and no synchrotron radiation shows the expected beam distributions at the interaction point, and shows the expected beam size growth in the presence of synchrotron radiation. This validates and benchmarks the code IRSYN against existing codes, and cross-checks the radiation emission model.

In the presence of the solenoid field alone, the beam dynamics show the beam coupling and orbit motion demonstrated in existing studies, further validating IRSYN and cross-checking the impact of the solenoid on the beam. Finally the studies performed with the solenoid and the anti-solenoid demonstrate the correction of the orbit and coupling terms by the anti-solenoid. The correction leaves behind a small amount of beam aberration at the IP, which is pre-correctable using the beam delivery system [1].

In conclusion, the code IRSYN has been developed and benchmarked against existing studies of the SiD solenoid in the CLIC interaction region. The level of correction obtained with IRSYN agrees expectations, demonstrating the role of the anti-solenoid.

Acknowledgements

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References


Figure 9: The vertical beam distribution at the IP for the case of an uncompensated solenoid and synchrotron radiation.

Figure 10: The $x'$-y coupling at the IP for the case of an uncompensated solenoid and synchrotron radiation.

Figure 11: The vertical dispersion at the IP for the case of an uncompensated solenoid and synchrotron radiation.
Figure 12: The vertical beam distribution at the IP for the case of a solenoid, an anti-solenoid and synchrotron radiation.

Figure 13: The $x'$-$y$ coupling at the IP for the case of a solenoid, an anti-solenoid and synchrotron radiation.

Figure 14: The vertical dispersion at the IP for the case of a solenoid, an anti-solenoid and synchrotron radiation.