IMPACT OF THE EXPERIMENT SOLENOID ON THE CLIC LUMINOSITY

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Abstract

The main detector solenoid and associated magnets can have an important impact on the CLIC luminosity. These effects are discussed for different solenoid designs. In particular, the luminosity loss due to incoherent synchrotron radiation in the experiment solenoid and QD0 overlap is evaluated. The impact of the AntiDID (Anti-Detector integrated Dipole) on luminosity and of compensated techniques on beam optic distortion are also discussed.

INTRODUCTION

The detector solenoid field at the interaction region has different effects on the beam dynamics [1] [2]:

- weak focusing in the two transverse planes;
- orbit deviation: the beam is bent as it traverses the magnetic field;
- coupling between the $x - y$ plane;
- dispersion: particles at lower energies experience a larger deflection than those at higher energies;
- the beam emits Incoherent Synchrotron Radiation (ISR) as it is deflected.

Due to the crossing angle of the two beamlines both the longitudinal and radial component of the main solenoid field act on the beam, causing orbit deviaton. The size of the deflection depends on the crossing angle value, on the length of the field and on the maximum field value. The focusing and coupling between the two transverse planes are due to the radial component of the solenoid field.The dispersion depends on the incoming beam energy spread. Finally the emission of ISR is a consequence of the beam deflection. These effects all together contribute to the increase of the IP spot sizes. In particular for a horizontal crossing angle (20 $mrad$ in CLIC), they lead to the increase of the IP vertical beam size. In this paper we review these effects considering the solenoid magnetic field design of the proposed experiments for ILC and their adaptation to CLIC. Techniques to compensate optic distortion and dynamic tolerances for the field stability are also discussed.

DETECTOR SOLENOID MAGNETIC FIELD DESIGNS

Figure 1 shows the longitudinal component of the different detector solenoid design. Two slightly different designs are considered for the SiD [3] detector. We consider one design for ILD [4], with and without the AntiDiD [5], which is a dipole field designed to reduce low energy pairs background in the detector. Finally the 4th concept design, a third detector design proposed at ILC [6], is also studied.

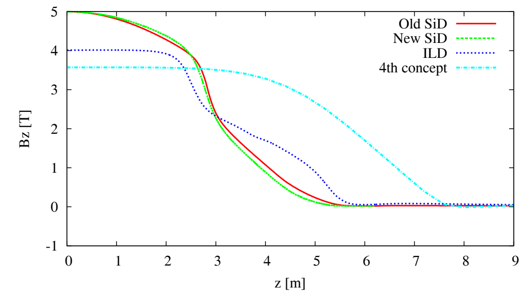

Figure 1: Longitudinal component of the detector solenoid design proposed for ILC along the solenoid magnetic axis. IP is at z = 0 m.

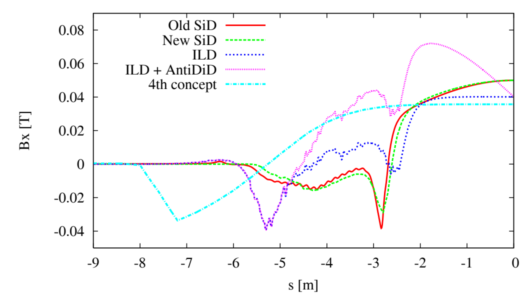

Figure 2: B_x component of different detector solenoid design in the beamline reference system. IP is at s = 0 m.

Figure 2 shows the field component acting on the vertical plane in the beamline reference system. All the different detector solenoid designs extend, for a considerably large part of the field, over the last Final Focus (FF) magnets (L* = 3.5 m).

ORBIT DEVIATION, DISPERSION AND COUPLING

The overlap of the main solenoid field with the last FF magnets worsens the optical distortion due to the solenoid alone, as explained in [7]. It produces an offset at the IP, as shown in Fig. 3 that can be corrected by applying a proportional offset to QD0 (the last quadrupole magnet of the FF), see Fig. 4. The FF magnets and solenoid overlap also worsens the vertical dispersion and $< x', y >$ coupling expected in the case of the solenoid alone, which the QD0 offset does not cancel as can be see in Fig. 5. These distortions need to be pre-compensated using the other FF magnets. Different techniques have been studied and proposed to correct them, employing skew quadrupoles, tuning knobs and anti-solenoids [5]. Bucking coils surrounding QD0, that cancel the main solenoid field in the QD0

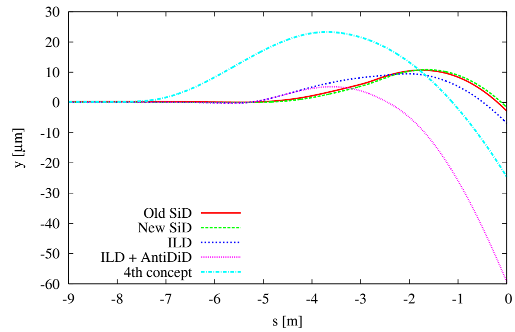

Figure 3: Vertical orbit due to the solenoid and FF magnets field. IP is at $s = 0$ m.

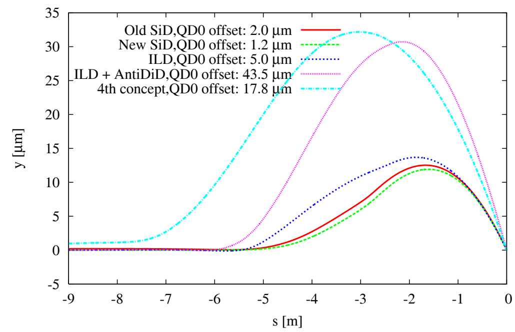

Figure 4: Vertical orbit due to the Solenoid and Final Focus magnets field with a vertical QD0 offset. IP is at $s = 0$ m.

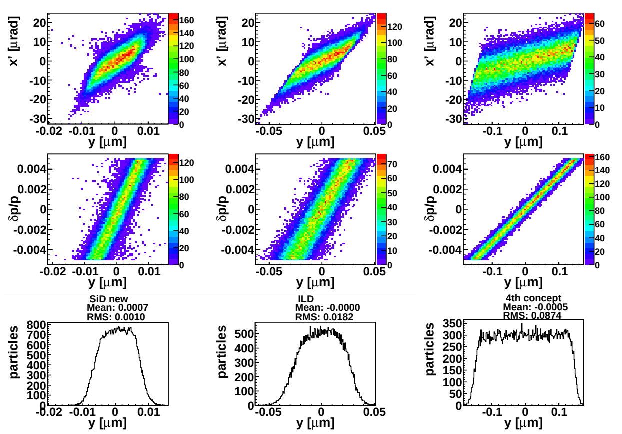

Figure 5: $< x', y >$ coupling, vertical dispersion and vertical beam distribution at IP due to different detector solenoid designs. The offset at the IP is corrected as in Fig. 4.

region (which is the main source of the distortions) have recently been proposed [8]. This latter solution has the advantage to provide a shielding of the QD0 magnets against the main solenoid field. Figure 6 shows the Poisson computation of the ILD and SiD detector solenoid fields adapted to CLIC. The cancellation of the main longitudinal component in the QD0 region, by means of the compensating solenoid, is clearly visible but an enhancement of the radial component around 3.5 m is also produced (Antisolenoid in the figure).

Two slightly different designs are considered for the compensating solenoid. The ILD one consists of 5 bucking coils with its axis coaxial to the main solenoid one and with a radius of 25 cm. The SiD one is made of 4 bucking coils with a radius of 50 cm. In both cases the compensating field added to the main solenoid field helps to reduce the vertical dispersion and $< x', y >$ coupling as well as the offset at the IP. This reduction estimated from the covariances of the beam distributions at the IP is $> 90\%$, Fig. 7. The residual vertical dispersion and $< x', y >$ coupling must be compensated in order to achieve the nominal luminosity. One can considerer both to further optimize the compensating solenoid and to use tuning knobs. When the residual optical distortions are fully compensated at the IP, luminosity loss is still expected due to (ISR), since the beam is bent as it travels in the solenoid field.

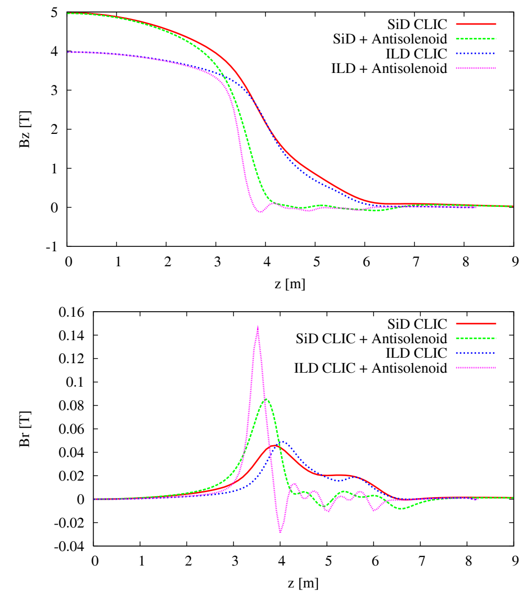

Figure 6: Computed Longitudinal and Radial component of the detector solenoids magnetic fields (proposed for CLIC) and their modification in case the two designs for the compensating solenoid are included in the calculation.

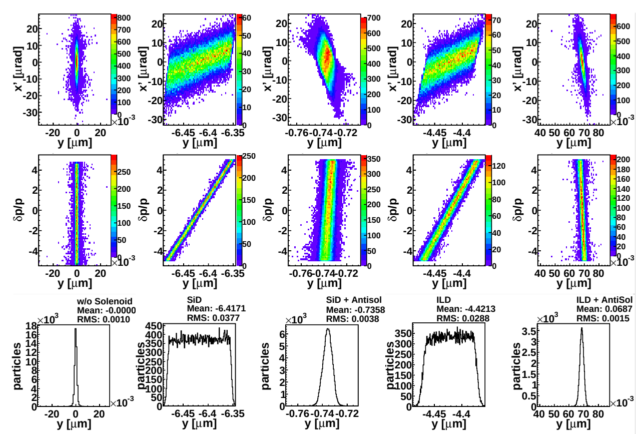

Figure 7: $< x', y >$ coupling, vertical dispersion and vertical beam distribution at IP due to detector solenoids with and without compensating solenoid. The offset at the IP is corrected as in Figure 4. The case without solenoid is shown for comparison.

LUMINOSITY LOSS DUE TO SYNCHROTRON RADIATION

In order to evaluate the luminosity loss due to incoherent synchrotron radiation in the detector solenoid field, we have tracked the compensated beam in the FF magnets and the IP magnet fields taking into account synchrotron radiation. The luminosity is computed using GUINEA-PIG [9]. Table 1 reports the relative peak luminosity loss due to the different detector solenoid designs with respect to the nominal peak luminosity, where the ISR in all the BDS is considered.

Table 1: Relative luminosity loss due to ISR for different detector solenoid designs.

	L/L_0 (%)
SiD old	$\sim$ 4.0
SiD new	$\sim$ 3.0
ILD	$\sim$ 4.0
ILD + AntiDiD	$\sim$ 25.0
4th concept	$\sim$ 20.0
SiD CLIC	$\sim$ 14.0
SiD + Antisolenoid CLIC	$\sim$ 10.0
ILD CLIC	$\sim$ 10.0
ILD + Antisolenoid CLIC	$\sim$ 10.0

The SiD and ILD solenoid designs proposed for ILC give comparable results. When the AntiDiD is added to the ILD field the luminosity loss become considerably higher (about 25%). Despite the lower field, the 4th concept solenoid design is much longer than the other two designs. Both Integrated Dipole and the length of the the main solenoid produce a bigger orbit deviation leading to the emission of more synchrotron radiation and an unacceptable luminosity loss. For the same reason ILD and SiD designs proposed for CLIC require luminosity optimization.

DYNAMIC TOLERANCES

In order to define the amount of uncorrected strength of the IP magnets we can tolerate, we evaluate the beam-beam offset at the IP due to a strength variation of the different IP magnets. The fields shapes are assumed to scale linearly and homogeneously along their axis for the different strengths. Moreover it is assumed that the main solenoid and the compensating solenoid fields scale in the same way.

Two cases are considered: when the magnetic axis of the main solenoid is perfectly aligned at the IP and when the magnetic axis of the solenoid has an horizontal offset of 2 mm. Both cases give a required field stability of the order of $\sim 6\times10^5$. When the AntiDiD is added the tolerance is tighter while when the compensating solenoid is considered the tolerance is reduced, provided that the main and compensating solenoid strength scale in the same way.

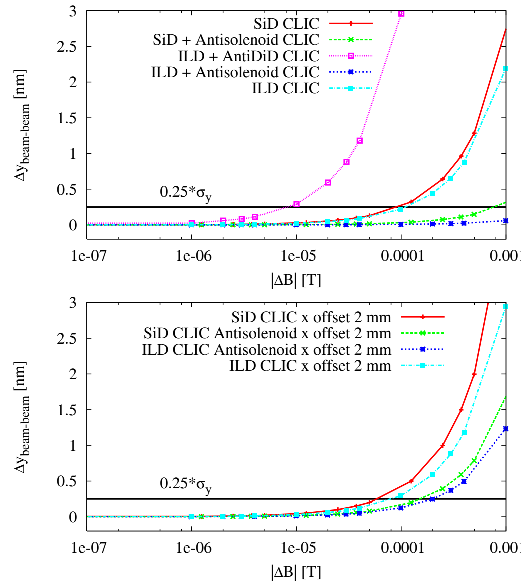

Figure 8: Beam-beam offset at the IP as a function of the field strength variation. The case of a magnetic axis of the solenoid perfectly aligned with the Solenoid coils is shown in top part of the figure.The case of a magnetic axis with 2 mm horizontal offset is shown in the bottom part.

CONCLUSION

Distortions of the beam phase space at the IP can be considerable at CLIC due to the detector magnets and their interference with the FF magnets. The effects of different solenoid designs, proposed for ILC and for CLIC, on the beam phase space at the IP have been studied. Compensating solenoids, by means of bucking coils or Antisolenoids, is required together with tuning knobs in order to fully cancel the distortions. Detector Integrated Dipoles are not envisage at CLIC because they increase the luminosity loss due to ISR and at the same time their presence worsen the tolerances for the main solenoid field stability. Finally main detector solenoid optimization for luminosity loss due to ISR is also required at CLIC.

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