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Novel Method of Compensation of the Effects of Detector Solenoid on the Vertical Beam Orbit in a Linear Collider

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This paper presents a method for compensating the vertical orbit change through the Interaction Region (IR) that arises when the beam enters the Linear Collider detector solenoid at a crossing angle. Such compensation is required because any deviation of the vertical orbit causes degradation of the beam size due to synchrotron radiation, and also because the nonzero total vertical angle causes rotation of the polarization vector of the bunch. Compensation may be necessary to preserve the luminosity or to guarantee knowledge of the polarization at the Interaction Point (IP). The most effective compensation is done locally with a special dipole coil arrangement incorporated into the detector (Detector Integrated Dipole). The compensation is effective for both $e^+e^-$and e^-e^-beams, and the technique is compatible with beam size compensation either by the standard method, using skew quadrupoles, or by a more effective method using weak antisolenoids.

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I. INTRODUCTION

The future electron-positron International Linear Collider (ILC) requires high luminosity which can only be achieved by colliding very small nanometer scale beams. In the earlier LC projects, NLC/GLC and TESLA, the beam sizes at the Interaction Point (IP) were $\sigma_{x,y} = 243, 3$ nm and $\sigma_z = 110$ μm for GLC/NLC, and $\sigma_{x,y} = 554, 5$ nm and $\sigma_z = 300$ μm for TESLA .

The design of the ILC Interaction Region (IR) is constrained by the often conflicting requirements of providing strong focusing for the incoming beam, acceptable background environment for the experimental detector, and clean extraction of the outgoing beams. The ILC is specified to have two IRs, at least one of which will likely use a small (up to about twenty milliradian) crossing angle in the horizontal plane to facilitate extraction of the outgoing disrupted beams. The crossing angle allows separate incoming and outgoing beampipes, which can be optimized independently. The second IR must additionally be able to accommodate $\gamma\gamma$ collisions, which require a slightly larger crossing angle, up to 20–35 mrad.

When the horizontal crossing angle is larger than $\theta_c \gtrsim \sigma_x/\sigma_z$ (here and below θ_c is half of the crossing angle) a crab-crossing technique is required in order to preserve the overlap of the beams in collision at the IP. Two RF cavities located several meters upstream of the IP on both beamlines introduce a kick correlated with longitudinal position within the bunch, so that the bunches rotate and fully overlap at the IP.

The horizontal crossing angle means that the beam traverses the magnetic field of the detector at an angle and thus will be deflected in the vertical plane. The change in the vertical orbit causes degradation of the beam size due to synchrotron radiation (SR), and also causes rotation of the polarization vector if the total vertical angle is nonzero.

This paper discusses both these effects in the context of the NLC design with $\theta_c = 10$ mrad and presents possible methods for compensating the vertical angle at the IP and minimizing synchrotron radiation effects. Local compensation using a novel dipole coil integrated with the detector solenoid represents an optimal solution, and is effective for both $e^+e^-$and e^-e^-beams. The results will scale with crossing angle for the ILC.

The paper is organized as follows. In Section II we discuss the effects on the vertical orbit using the approximation of a detector solenoid with sharp edges. Synchrotron radiation effects due to the vertical deflection and the resulting beam size growth are considered in Section III. For a realistic case with the Silicon Detector, a technique for compensating the IP angle and minimizing SR effects using a Detector Integrated Dipole corrector (DID) is presented in Section IV, where the compatibility of the vertical orbit compensation method with the beamsize compensation by means of the weak antisolenoids suggested in Ref. [1] is also discussed. Finally, design considerations for the Detector Integrated Dipole are given in Section V.

II. VERTICAL ORBIT IN THE SHARP EDGED SOLENOID APPROXIMATION

To illustrate the magnitude of the vertical orbit deviation, one can consider a detector solenoid field with sharp edges, schematically shown in Fig. 1. In the case

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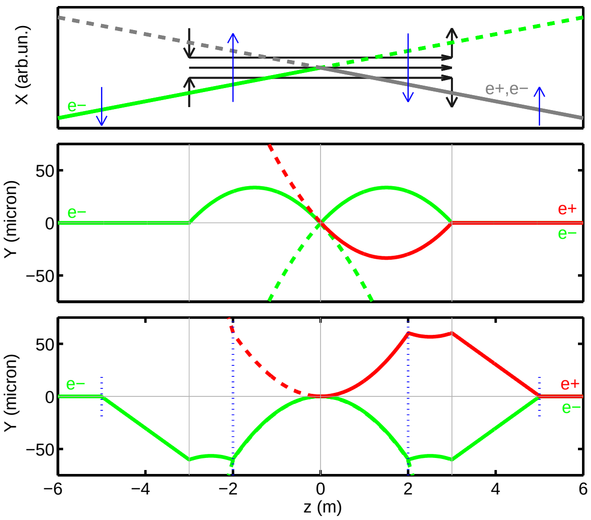

FIG. 1: Illustration of $e^+e^-$and e^-e^-collisions in a a detector solenoid field with sharp edges (schematically shown in the top plot) without (middle plot) and with (bottom plot) compensation of the IP angle by the Detector Integrated Dipole and two external correctors. The model parameters are $L = 3$ m, $\theta_c = 10$ mrad, $B_0 = 5$ T, beam energy 250 GeV. The uncompensated vertical angle at the IP is approximately 45 μrad. The compensation kicks are shown on the top plot by the blue arrows, they are located at $z = \pm 2$ m and $z = \pm 5$ m and their magnitudes are 75 μrad and 30 μrad. IP is at $z = 0$ m. Outgoing beams are shown by thick dashed curves.

without compensation, the vertical deflection is caused by the edge kick $\Theta = \theta_c B_0 L/(2\,B\rho)$, which occurs when the beam enters the solenoid off axis at $\theta_c L$, and also by the kick linearly distributed in the body of the solenoid. Here θ_c is half of the crossing angle, L is the half length of the detector solenoid, B_0 is the solenoid field, $B\rho = pc/e$ is the magnetic rigidity of the beam. The body kick integrated from the solenoid entrance to the IP is equal to -2Θ, which is twice the edge kick, and since the body kick has half the lever arm, the resulting vertical offset at the IP cancels exactly (see also Refs. [1, 2] for a rigorous proof). The remaining vertical angle at the IP is nonzero and equals $-\Theta$. The maximal deviation of the vertical orbit before the collision is $\Theta L/4$. The vertical angle of the extracted beam, which passes through the entire solenoid, is -2Θ and the vertical offset at the exit is $-3\Theta L$.

Let us first discuss the impact of the vertical orbit on luminosity. In the case of e^+e^-collisions, which is expected to be the primary mode of operation of the future Linear Collider, the vertical angles of the opposite beams are antisymmetric, so the beams collide head on and do not experience any loss of luminosity. In the e^-e^-option, the trajectories are symmetric and the vertical crossing angle must be compensated to preserve the luminosity. Such compensation can be done either with RF cavities to provide vertical crab-crossing, or with the DID corrector method discussed below. In both cases, the vertical deflection will cause growth of the beam size due to synchrotron radiation. The Detector Integrated Dipole can be used to minimize this beam size growth as well.

In addition to luminosity considerations, it may be desirable that the IR optics would preserve the beam polarization (the e$^-$ or possibly both beams will be longitudinally polarized), as discussed in Ref. [3]. A change of the beam orbit by an angle Θ causes the orientation of the polarization vector to rotate by $\gamma\Theta(g/2-1)$ due to the anomalous magnetic moment of the electron. In the example shown in Fig. 1, with $\Theta \approx 45$ μrad, the polarization vector rotates by about 1.5 degrees, producing a difference between the polarization at the IP and that measured at an upstream polarimeter. Although this spin rotation could be predicted rather accurately, in practice for certain precise physics measurements with either e^+e^-or e^-e^-, one would benefit if the vertical angle at the IP will be compensated to ensure accurate knowledge of the beam polarization. Crab-crossing compensation is not adequate in this case, and local compensation of the vertical orbit angle is needed.

Compensation of the vertical orbit deviation produced by the detector solenoid field can be done locally using a special dipole field incorporated into the detector (Detector Integrated Dipole) and with one additional external corrector on each side. Their combination can correct the vertical IP angle without changing the IP offset. This technique is illustrated in Fig. 1 (bottom plot) for the idealized case of a solenoid field with sharp edges. A similar technique can be used to flatten the orbit in order to minimize the effects of synchrotron radiation.

Since the direction of the transverse field seen by a particle and the direction of the required compensation field do not depend on the particle charge, the same compensating field works for both $e^+e^-$and e^-e^-beams. Also, the inner kick acts on both the incoming and outgoing beams, but the outer kick acts only on the incoming beam. Therefore, the vertical angle of the extracted beam increases only by the value of one outer kick. To facilitate extraction of the beam, and allow downstream polarization diagnostics, the vertical angle of the outgoing beam can be corrected by additional correctors in the extraction line. Inside the detector, the transverse field acting on the outgoing disrupted beam is increased by the value of the inner kick, which needs to be included in calculations such as evaluating background due to low energy pairs created in collision.

III. SYNCHROTRON RADIATION EFFECTS DUE TO THE VERTICAL DEFLECTION

Synchrotron radiation is emitted whenever there is a change in the beam trajectory producing both a decrease in the average energy and an increase in the rms energy spread. At the IP, the energy change causes an orbit offset that can be easily corrected, but the energy spread will increase the beam size. The vertical orbit shift and synchrotron radiation emitted in the detector solenoid field have already been discussed in Ref. [2]. In this paper, the derivations presented in [2] are generalized to a more realistic situation where the solenoid field overlaps with the Final Doublet magnets, thus the effects of the FD focusing must be included.

The horizontal field which drives the vertical orbit change is given by

$$B_x(z) = B_r(z) - \theta_c\, B_z(z) + B^c_x(z) \quad , \tag{1}$$

where the first two terms correspond to the field of the solenoid, and the last term is due to any correction field. This field, together with the field created by the orbit offset in the Final Doublet quadrupoles with gradient $G(z)$, defines the vertical orbit:

$$\frac{d^2y}{dz^2} = \frac{B_x(z)}{B\rho} + \frac{G(z)\, y(z)}{B\rho} \quad , \tag{2}$$

and determines its the curvature $\rho(z)$. The SR-induced increase in energy spread for a slice dz is then given by

$$\delta\sigma^2_E(z) = \frac{55\, r_e\, \lambda_e\, \gamma^5\, dz}{24\sqrt{3}\; |\rho(z)|^3} \quad . \tag{3}$$

The corresponding addition to the vertical beam size is

$$(\delta\sigma^{sr}_y(z))^2 = \delta\sigma^2_E \cdot R^2_{36}(z) \quad , \tag{4}$$

where R_{36} is the transport matrix element from the particular slice to the IP. The latter is given by

$$R_{36}(z) = \int_0^z R_{34}(z')\, \frac{dz'}{\rho(z')} \quad , \tag{5}$$

which includes the effect of FD focusing.

Adding in quadrature the contributions from each slice, we obtain the IP beam size increase due to synchrotron radiation:

$$(\Delta\sigma^{sr}_y)^2 = C_E\, \gamma^5 \int_0^\infty R^2_{36}(z) \frac{dz}{|\rho(z)|^3} \, , \tag{6}$$

where $C_E = 55\, r_e\, \lambda_e/(24\sqrt{3})$ and the integral is over the full extent of the solenoid and correcting fields. The quantity $\Delta\sigma^{sr}_y$ is to be added to the nominal IP size in quadrature. This quantity is proportional to $(B_0\, L\, \theta_c)^{5/2}$ and does not depend on the beam energy. However, the nominal beam size typically decreases with energy, and therefore this SR beam size growth must be kept small enough to not limit performance at higher energies.

IV. VERTICAL ORBIT COMPENSATION IN A REALISTIC DETECTOR

As a realistic example, we consider the NLC Interaction Region optics and parameters, and the field configuration of the proposed Silicon Detector (SiD). Fig. 2 shows the ANSYS model of the SiD detector and the field lines, and Fig. 3 shows the fields on the beam trajectory

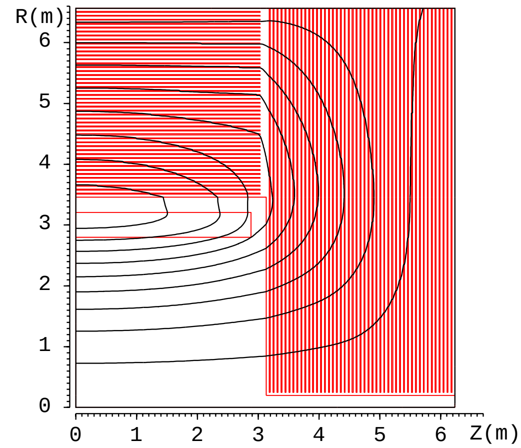

FIG. 2: Schematic of the Silicon Detector (SiD) with magnetic field lines calculated by ANSYS. IP is at $z = 0$ m.

and locations of the Final Doublet focusing elements of the NLC Beam Delivery System. In addition to the fields of the bare SiD solenoid, we will also consider two other cases of detector field combined with the field of a week antisolenoid.

As discussed in Ref. [1], most of the beam size distortion due to the solenoid is generated because the solenoid field overlaps with the final quadrupole and breaks the natural cancelation of coupling and other beam correlations. Correction of the distortions requires using the linear knobs such as skew quadrupoles and sextupole displacement knobs. When the beam energy is changed, the

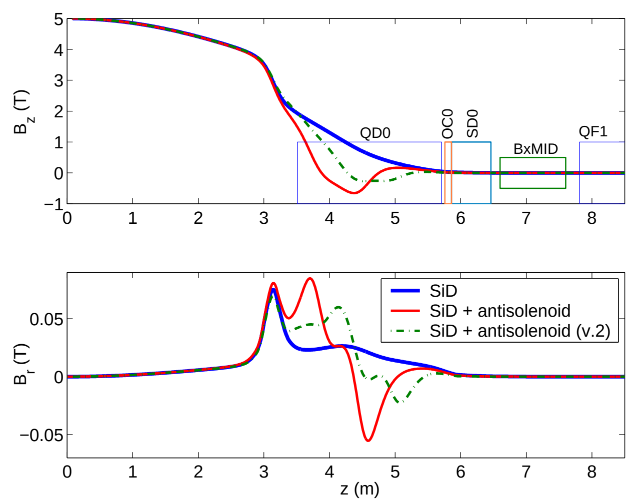

FIG. 3: Longitudinal and radial magnetic field in SiD calculated by ANSYS, without and with the weak antisolenoid which cancels the beam distortions produced by the detector solenoid. Red line shows the field with the antisolenoid parameters suggested in [1], and green dot-dashed line shows the field with another configuration of the antisolenoids, optimized to reduce SR effects (see text). The radial field is at the ideal beam trajectory with half crossing angle $\theta_c = 10$ mrad. Locations of the Final Doublet elements (quadrupoles QD0 and QF1, sextupole SD0, octupole OC0 and an optional dipole corrector BXMID) are also shown. IP is at $z = 0$ m.

knobs need to be readjusted. A short weak antisolenoid, coaxial with the detector and overlapping with QD0, can be matched to cancel the integral effect of the solenoid-FD overlap, and restore cancelation of the distortions. This cancelation then works for any beam energy. In the SiD case and NLC beam parameters, the vertical beam size increases 30 times in bare SiD and only by 30% if a weak antisolenoid is used (thus this antisolenoid compensates 99% of the beam size distortions). In this paper we use the antisolenoid with parameters suggested in [1] (red line in Fig. 3) and also an alternative configuration, optimized to reduce the SR effects (dash-dotted green line in Fig.3).

The beam trajectory in the bare SiD is shown in Fig. 4. If there were no focusing elements in the detector field, the vertical trajectory through the detector solenoid would primarily be determined by the horizontal field $B_x = B_r - \theta_c \cdot B_z$ (shown on the top plot). The corresponding vertical trajectory, obtained by simple integration of the SiD horizontal field, is shown by the dashed line on the bottom plot. Just as for the sharp edge solenoid field, the IP offset is exactly canceled but the IP angle is nonzero. This cancellation of the IP offset is extremely important because the coupling and other beam distortions introduced by the solenoid are also cancelled. The presence of focusing elements that overlap with the solenoid field destroys this perfect cancellation of the orbit and beam distortions. Ref. [1] contains more discussion of the solenoid effects on the beam size and compensation methods. For realistic simulations of the orbits and beam sizes, tracking with DIMAD [4] was used, where the FD region was modeled by a sequence of short, typically 1 cm long slices containing all the solenoid, dipole, quadrupole, sextupole and octupole fields, using the realistic solenoid field map and the design BDS optics. For the SiD example, the beam orbit obtained by tracking with DIMAD is shown in Fig. 4 (bottom plot, solid line). The vertical angle at the IP is about 100 μrad, and the vertical IP position is not zero (approximately -20 μm), due to the overlap of the solenoid field with the final quadrupole QD0. The beam size growth due to synchrotron radiation, calculated analytically using formulae from the previous section is $\Delta\sigma_y^{sr} = 0.31$ nm. The horizontal orbit deviation is much smaller than the vertical one, and is neglected in this paper.

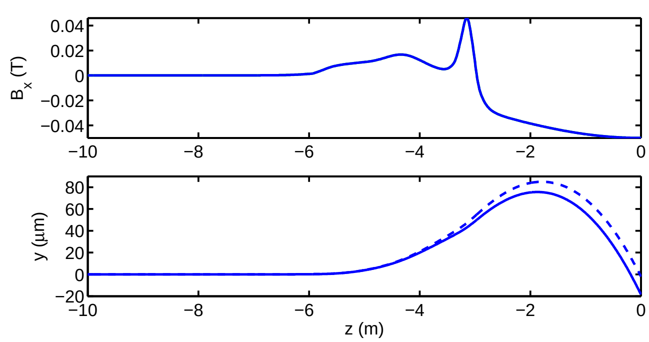

FIG. 4: Horizontal field on the beam axis in the SiD detector (top plot) and the beam orbits (bottom plot), the IP angle has not yet been compensated. The orbit calculated in the absence of any focusing elements is shown by a dashed line, and the orbit determined by tracking with DIMAD is shown by a solid line on the bottom plot. For the tracked beam, the IP beam coordinates are: $x = 0.65$ μm, $y = -18.5$ μm, $x' = -0.21$ μrad, $y' = -104$ μrad. The beam size growth due to synchrotron radiation is $\Delta\sigma_y^{sr} = 0.31$ nm.

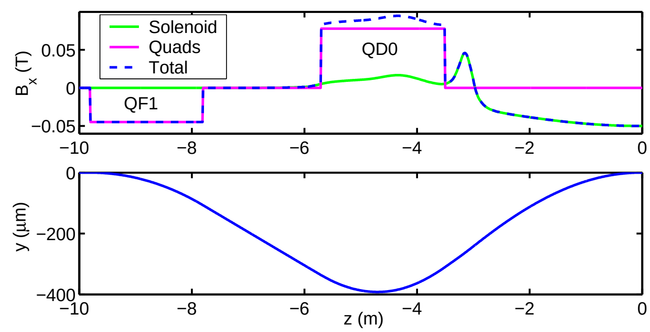

FIG. 5: Illustration of IP angle compensation using only offsets of the Final Doublet quadrupoles. Horizontal field on the beam axis – top plot, beam orbit calculated by tracking – bottom plot. Contributions of the solenoid and FD quadrupoles are shown on the top plot separately. The beam size growth due to synchrotron radiation is $\Delta\sigma_y^{sr} = 5.2$ nm.

As seen in Fig. 4, the SiD detector solenoid field produces a vertical trajectory which has maximum curvature about 2 m from the IP. Thus, the most effective compensation will be local. For example, if one attempts to compensate the IP angle by offsets of the FD quads QD0 and QF1, as illustrated in Fig. 5, the resulting orbit deviation would be too large and synchrotron radiation would increase the beam size by an unacceptable amount. In this example, due to the non-local nature of the compensation, the vertical orbit deviation reaches 0.4 mm, and the beam size increases by $\Delta\sigma_y^{sr} = 5.2$ nm, an amount that would significantly reduce the luminosity.

Local compensation of the IP angles can be done by a pair of dipoles embedded in the detector coil at large radius (a few meters). The fields should be antisymmetrical around the IP. Such a field can be created by a pair of dipole windings integrated with the detector solenoid in its cryostat, referred to as a Detector Integrated Dipole (DID) Corrector. (This has also been called a Serpentine corrector due to a particular winding technique, which inspired the idea of local compensation of the IP angles). Design considerations for the DID corrector are given in Section V. The DID field shape shown in Fig. 6 was calculated with Opera3D code and the coil geometry is determined by SiD dimensions. This field represents only one of the possible solutions for local correction, and the particular field shape is not important as long as it is local to the detector.

For the DID corrector field to compensate the IP angle, this field has to be combined with external kicks of opposite sign, which together produce an angle at the

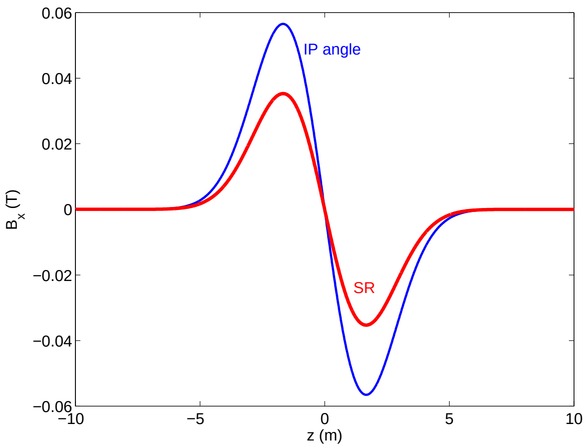

FIG. 6: Horizontal field of the Detector Integrated Dipole (DID) for the SiD detector. The DID strength is optimized to zero the IP vertical angle (blue line) or to minimize the SR vertical beam size growth (red line) in the case of bare SiD without antisolenoids.

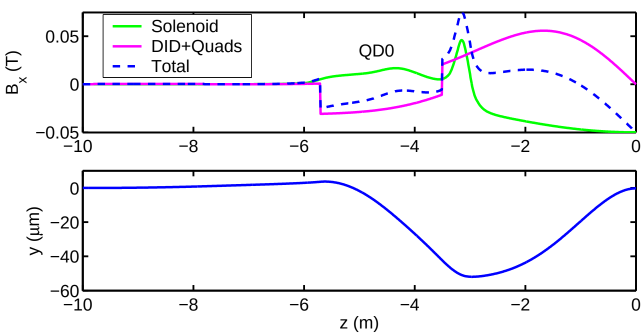

FIG. 7: Horizontal field on the beam axis (top plot) and the beam orbit (bottom plot), the IP angle has been compensated using DID and offsets of QD0 and QF1 quadrupoles. The orbit is determined by tracking. The beam size growth from synchrotron radiation is $\Delta\sigma_y^{sr} = 0.26$ nm.

IP, with no offset. The FD quadrupoles can be offset to produce the external kicks. Fig. 7 illustrates compensation of the IP angles in SiD using the DID Corrector together with offsets of FD quadrupoles QD0 and QF1. While, in principle, only the QD0 needs to be offset to correct the angle and offset at the IP, a small QF1 offset cancels the vertical second order dispersion produced by the total correcting field. In this example, the optimal displacement of QF1 is about 2% of that of QD0. The combined effect of DID and quads resembles the effect of the solenoid itself. The IP angle is compensated to less than a μrad. The local character of the correction limits the orbit deviation near the IP, which also limits the beam size growth (in this case $\Delta\sigma_y^{sr} = 0.26$ nm).

Another obvious application of the DID corrector is to minimize the beam size growth caused by synchrotron radiation. This may be especially important for the second IR or for a larger size or stronger field detector, since the beam size growth depends sharply on the angle and detector length: $\Delta\sigma_y^{sr} \propto (B_0\,\theta_c\,L)^{5/2}$. For the SiD example and with $\theta_c = 10$ mrad, the SR beam size growth

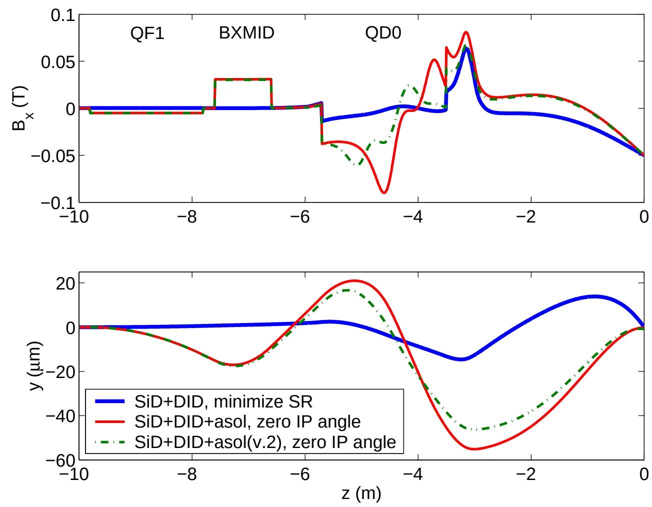

FIG. 8: Horizontal field on the beam axis (top plot) and the beam orbit determined by tracking (bottom plot) in three cases: a) bare SiD (no antisolenoid) and DID strength is optimized to minimize SR beam size growth – blue thick line, $\Delta\sigma_y^{sr} = 0.034$ nm; b) SiD with antisolenoid (parameters from [1]) – red line, $\Delta\sigma_y^{sr} = 0.83$ nm; c) SiD with antisolenoid optimized to minimize SR effects – green dash-dotted line, $\Delta\sigma_y^{sr} = 0.33$ nm. In the last two cases the IP angle is compensated by the DID, FD offsets and BXMID without introducing any linear or second order dispersion.

is $\Delta\sigma_y^{sr} \approx 0.31$ nm without and 0.26 nm with the IP angle compensation. The DID strength optimized to flatten the vertical orbit and thus to minimize the SR beam size growth corresponds to 60% of the field which minimizes the IP angle, see Fig. 6. The corresponding orbits are shown in Fig. 8 (blue curve). The SR beam size growth is reduced by about an order of magnitude, to $\Delta\sigma_y^{sr} \approx 0.034$ nm. The vertical IP angle is also reduced by approximately a factor of three with this solution. Fig. 9, which shows dependence of the IP vertical angle and $\Delta\sigma_y^{sr}$ versus the DID strength, demonstrates that with the SiD detector and DID geometry considered here, there is a wide region of parameters where both the IP angle and SR effects can be made small simultaneously. In practice the balance between the two corrections will be dictated by the specific needs of the experiment.

Let us now discuss the vertical orbit compensation in the case when weak antisolenoids are used to cancel the beam distortions produced by detector solenoid. In this case, if the antisolenoid solution is to remain distortion-free when combined with the DID Corrector, the latter should also be made distortion-free. The DID arrangement considered earlier does not generate any second order vertical dispersion, however it produces linear dispersion. To make the DID arrangement completely distortion-free, one more dipole corrector must be added in the middle of the FD and then the three parameters (offsets of QD0, QF1 and middle dipole field) matched simultaneously to cancel the first and second order dispersion and the IP offset produced by the DID Corrector.

Fig. 8 (red curves) shows the horizontal fields on the

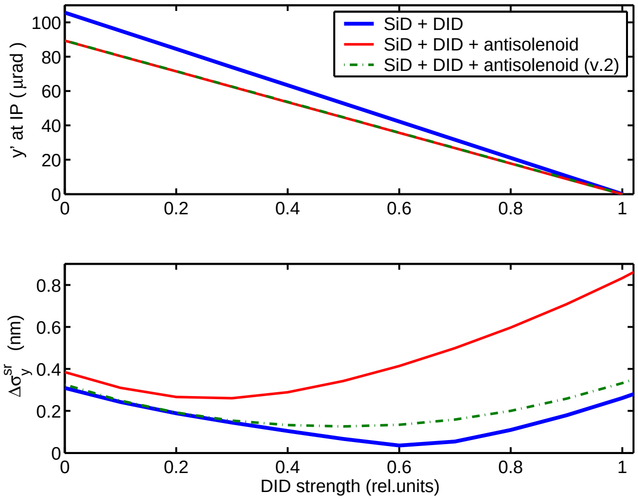

FIG. 9: Vertical angle at the IP (top plot) and the beam size growth due to synchrotron radiation (bottom plot), versus strength of the DID corrector, without antisolenoid (thick blue line), with the antisolenoid with parameters suggested in [1] (red line), and with the antisolenoid optimized to reduce the SR effects (green dash-dotted line).

beam axis and the orbit calculated by tracking in SiD with antisolenoid (with parameters from [1]: $z_0 = 4.14$ m, $z_w = 0.5$ m, $B_{z0} = -1.56$ T and with the field profile given by $B_z^{asol} = B_{z0}/(1 + ((z - z_0)/z_w)^4)$). One can see that the IP angle compensation is as effective as before. However, in this case the synchrotron radiation beam size growth is $\Delta\sigma_y^{sr} = 0.83$ nm. This still gives a small effect with $\theta_c = 10$ mrad, however, when scaled to maximum considered crossing angle of 35 mrad, this SR contribution becomes $\Delta\sigma_y^{sr} = 3.4$ nm, which is already a significant increase of the beam size. Fig. 9 shows the SR beam size growth versus DID strength. One can also see that DID strength cannot be optimized to significantly decrease the SR beam size growth in this case.

The field of the weak antisolenoid can be reoptimized to reduce the SR effects. One of the possible solutions consist of four antisolenoids with the following parameters: z_0 = 3.64, 3.89, 4.14, 4.64 m, B_{z0} = 0.30, -0.19, -0.43, -0.60 T, and $z_w = 0.5$ m for all four of them. This solution simultaneously minimizes the IP vertical offset, SR beam size growth and two major beam distortions ($\langle yx'\rangle$ and $\langle yE\rangle$). The beam size before applying any linear knobs is only 52% larger than the nominal, thus this antisolenoid compensates more than 98% of the beam size distortions. The SiD field with these antisolenoids is shown in Fig. 3, and the beam orbit in the case when DID is used to zero the IP angle is shown in Fig. 8 (green dash-dotted line). The SR beam size growth in this case is $\Delta\sigma_y^{sr} = 0.33$ nm, which is about three times smaller that with previous version of the antisolenoid. Fig. 9 also shows that the curve of $\Delta\sigma_y^{sr}$ versus DID strength has a wide minimum, i.e. there is a region of parameters where both the IP angle and SR beam size growth are small.

V. DETECTOR INTEGRATED CORRECTOR, DESIGN CONSIDERATIONS

There are several advantages of integrating the dipole correction coils with the cold mass inside the detector solenoid cryostat. First and foremost is that a small diameter magnet placed close to the IP would introduce extra radiation lengths of uninstrumented material and reduce the detector acceptance. The large diameter dipole corrector coils proposed are quite thin and present only a negligible addition to the already considerable thickness of the solenoid itself.

Secondly, the interaction of the solenoidal field with the coil ends causes net torques in the horizontal plane that have to be resisted in addition to supporting the weight of the dipole itself. Co-winding the corrector coils with the solenoid in the same cold mass ensures that no new torque is transferred to the outside world and the corrector weight is again a small perturbation for the solenoid coil supports.

Finally the large dipole coil radius ensures that even for a relatively crude coil configuration the field seen by

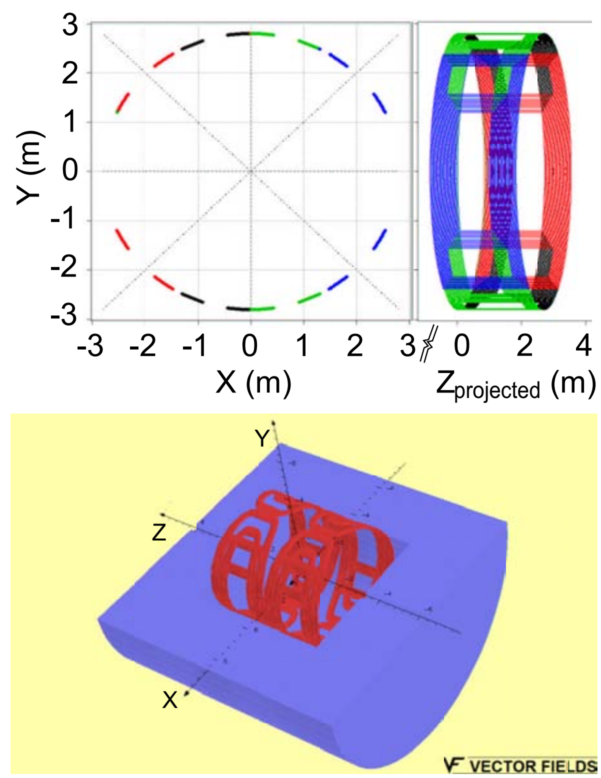

FIG. 10: Detector Integrated Dipole (DID) Corrector. The top plot shows the actual arrangement of windings in one half of the corrector and the bottom plot shows a simplified model used for 3D field calculations with Tosca (Opera3D code) to evaluate the effect of iron in the SiD yoke on the dipole field. For ease in viewing the 3D model the solenoid coil and the top half of the SiD yoke are not shown. Except for a small deviation near the start of the endcap around $Z = \pm 3.2$ m the horizontal B_x field profile is very close to that assumed for tracking shown in Fig. 6.

the colliding beams is very uniform. At the coil longitudinal midpoints and half the coil radius, 1.4 m, field non-uniformity is less than a few parts in ten-thousand and at the beam pipe approaches a few parts-per-million for the coil configurations investigated so far. However, since each dipole coil has a pattern length almost equal to its radius and since there is strong cancellation of the field a the IP symmetry point, the dipole field profile exhibits a marked longitudinal dependence that is nearly independent of the other details of the coil structure.

The assumed DID corrector coil pattern is shown at the top of Fig. 10. The number of dipole turns is chosen to leave about a meter of straight section as shown. Adding additional turns to the winding pattern quickly becomes counterproductive as then the dipole ends become too long and the increase of transfer function is balanced by the reduction of the straight section length.

Initially, the 3d field profiles were calculated based upon the positions of each conductor segment in space (i.e. in effect an air coil). In order to evaluate the effect of the solenoid yoke on the field distribution, a simplified 3d conductor model was generated by averaging the conductor locations to a smaller number of coil packs and this coil was then inserted inside a simplified 3d model of the SiD yoke as shown at the bottom of Fig. 10.

There was a concern that the yoke endcap, that goes down to small radius, might rob too much flux from the body of the DID corrector thereby reducing its efficiency in creating a dipole field. In fact, it happens that the increase of efficiency that comes from the yoke for the body of the magnet more than makes up for any loss near the endcap. There is a small discrepancy in the assumed field shape that occurs near the inner edge of the endcap, but overall the results from the 3d field calculations match the heuristically motivated field shape used for tracking very well.

Finally, it is useful to mention that the DID corrector can be used to optimize the IR trajectories not only in the linear collider, but in other machines as well. For example, it has been suggested to use DID corrector to optimize IR region of eRHIC [5] where the trajectories of electrons need to be carefully optimized to allow clean beam separation while reducing SR power. It has also been suggested to use the DID corrector to upgrade the SLAC B-factory [6]. In this case the symmetric version of the DID field would provide separation of the beams at the parasitic collisions, and thus the first dipole from the IP, which provides beam separation in the present design, can be replaced by a quadrupole that would give a possibility of stronger focusing and thus higher luminosity.

VI. CONCLUSION

A special dipole can be added in the Linear Collider IR to correct the effect of the vertical deflection caused by the beam passing through the detector solenoid field with a horizontal crossing angle. To be most effective, the correction (Detector Integrated Dipole) needs to be local, and thus is incorporated into the detector solenoid winding. The DID corrector can be used to compensate for rotation of the beam polarization or to minimize the beam size growth due to synchrotron radiation. The solution presented uses the DID Corrector to provide local compensation of the orbit and works both for $e^+e^-$and e^-e^-cases. This method is compatible with beamsize compensation using weak antisolenoids. The DID corrector can also be used for upgrades of other colliders, such as B-factories.

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