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Evaluation and compensation of detector solenoid effects on disrupted beam in the ILC 14 mrad extraction line

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ABSTRACT

This paper presents analysis of detector solenoid effects on primary disrupted beam in the ILC 14 mrad extraction line and their compensation. Particle tracking simulations are performed for evaluation of the extracted beam loss as well as of beam distribution and polarization at Compton interaction point (IP). The calculations are done both without and with compensation of the solenoid induced perturbations: the residual orbit, dispersion and focusing. The proposed correction system includes a detector integrated dipole field and a set of dipole and quadrupole correctors. This system effectively minimizes the growth of particle amplitudes induced by the solenoid; and therefore it keeps at minimum the corresponding growth of beam loss and helps to maintain the design beam properties at Compton IP for polarization measurement. The presented results are obtained for the baseline ILC energy of 500 GeV center-of-mass and three options of initial beam parameters.

1. Introduction

The ILC baseline extraction line is designed for 14 mrad horizontal crossing angle between e^+ and e^- colliding beams at interaction point (IP) [1]. The extraction optics provides large beam acceptance in order to minimize beam losses caused by large angular spread and long energy tail in the disrupted primary and secondary beams. It also includes dedicated vertical chicanes for beam energy measurement and gamma calorimeter (GAMCAL) diagnostics, and a low β focal point with 2 cm vertical dispersion used as a Compton interaction point (CIP) for polarization measurement.

The crossing angle scheme naturally results in a horizontal angle between beam trajectory and direction of the detector solenoid field B_S, equal to half-crossing angle θ_C=7 mrad. This angle creates a systematic horizontal field component B_x=$B_S \sin\theta_C$ on the beam trajectory that causes vertical beam deflection and therefore produces vertical orbit and dispersion, synchrotron radiation and rotation of beam polarization vector. In addition, the solenoid field creates a weak focusing effect in $x-y$ planes and coupling of $x-y$ betatron motion which alter the downstream beam properties.

Perturbation of the extracted beam caused by the solenoid needs to be evaluated and compensated in order to avoid a higher beam loss and preserve the desired beam properties at the Compton IP for polarization measurement. This paper presents calculations of solenoid optics effects using MAD code [2] and tracking simulations of primary electron beam using DIMAD code [3]. The results are focused on evaluation of solenoid effects on disrupted beam loss in magnets and collimators, and beam distribution and polarization at Compton IP. The calculations are done for the push–pull version of extraction optics [4,5] with the final focus drift of L^*=3.51 m and with the SiD [6,7] detector solenoid field model, for the nominal ILC energy of 500 GeV center-of-mass (CM) and three options of beam parameters.

2. Extraction line optics

This section briefly reviews the optics of the 14 mrad extraction line [4]. The length of the extraction line from IP to dump is about 300 m. Horizontal view of the incoming and extraction magnets on one side of IP is shown in Fig. 1. The large 14 mrad crossing angle allows the extracted beam to continue straight ahead without the need for bends in the horizontal plane. In this configuration, the first superconducting (SC) *incoming* quadrupole QD0 is located at distance of L^*=3.51 m from IP, and the first *extraction* SC quadrupole QDEX1 is at 5.5 m to provide sufficient horizontal separation from the incoming line. These two quadrupoles and the incoming sextupole SD0 will be part of a detector in a push–pull configuration [5]. The long warm section after these magnets provides the necessary space for detector exchange in push–pull operation. Beam apertures of the extraction SC quadrupoles QDEX1 and QFEX2A are set to the maximum values of R=15 and 30 mm, respectively, limited by the separation from the incoming magnets. A long drift after the QFEX2A provides the necessary transverse space for the incoming crab cavity. The

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remaining downstream extraction quadrupoles are warm magnets starting at distance of 17.19 m from IP. The extraction quadrupole system is designed to provide: (1) a low β focal point at 148.6 m from IP, where the Compton IP will be located, (2) the optimal transformation matrix term $R_{22}=-0.5$ from IP to CIP for efficient polarization measurement and (3) large chromatic and geometric acceptance for keeping the disrupted beam loss at acceptable level.

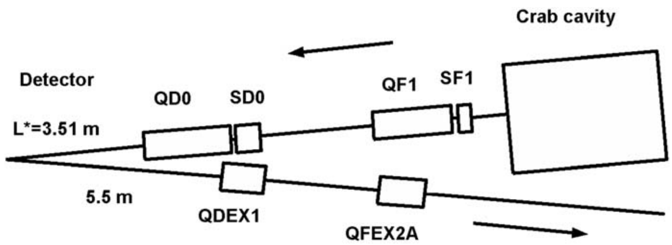

Fig. 1. Horizontal view of incoming and extraction magnets on one side of IP.

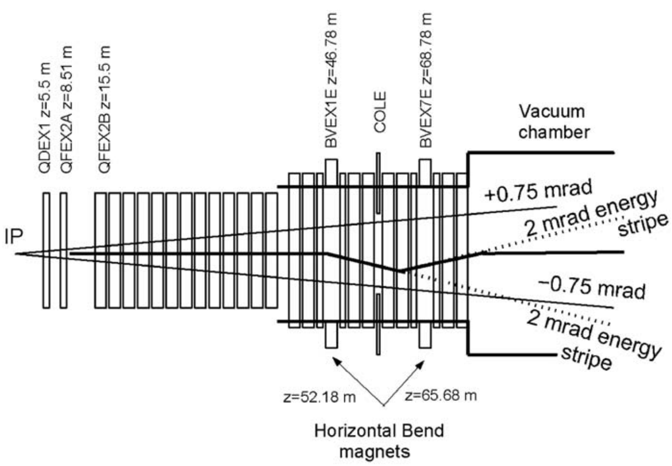

Fig. 2. Vertical view of the extraction quadrupoles and energy chicane bends, where z distances are from IP. ± 0.75 mrad beam stay clear for beamstrahlung photons is also shown [8].

Downstream of the quadrupoles, the extraction line includes a four bend vertical chicane for measurements of beam energy (see Fig. 2), a four bend vertical chicane for polarization measurement and two vertical bends for gamma calorimeter luminosity diagnostics (see Fig. 3) [8]. The polarimeter bends create 2 cm vertical dispersion at the Compton IP located at center of the polarimeter chicane. After the last GAMCAL bend magnet, the extraction line contains a set of 5 horizontal and 5 vertical fast kickers, located on average ~85 m before the dump. The rapidly oscillating kicker field (~1 kHz) will sweep the beam along a $R=3$ cm circle at the dump in order to increase the effective beam area for protecting the dump window from high power density of small undisrupted beam and preventing water boiling in the dump vessel.

The extraction collimation system includes two collimators in the chicanes. The first one is placed at center of the energy chicane, 60.7 m after IP, where momentum dispersion is 17 mm. Its 40 mm vertical aperture on the low energy side of the beam is set to remove the low energy tail electrons with relative energies below 30–35%. The second collimator at 160.9 m is inside the polarimeter chicane to protect the Cherenkov detector (at 175.6 m) from synchrotron radiation created in the energy chicane bends. Three more collimators (COLW1, COLW2 and COLW3) are included in the final 100 m section before the dump in order to protect the fast sweeping kickers and limit beam size to within $R=15$ cm at the dump window.

3. Disrupted beam properties at IP

3.1. Parameter options

Distributions of primary disrupted beams at IP were generated using GUINEA-PIG beam–beam simulation code [9]. Beam

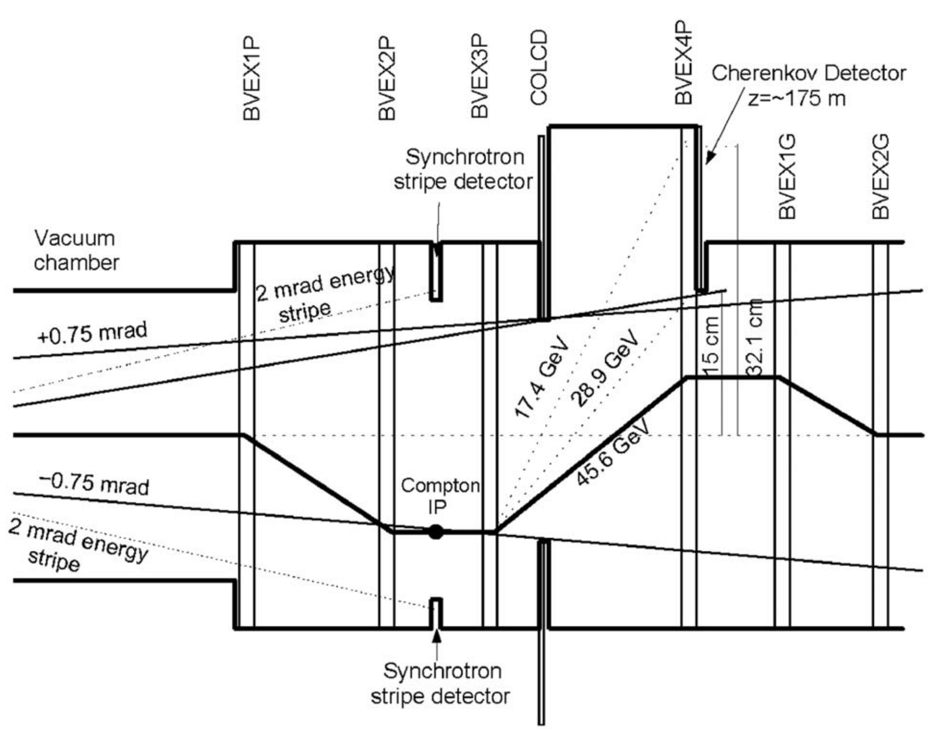

Fig. 3. Vertical view of the four polarimeter bends and two GAMCAL bends [8]. ± 0.75 mrad beam stay clear for beamstrahlung photons is also shown.