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14 mrad Extraction Line Optics for Push-Pull*

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Abstract

The ILC design is based on a single Interaction Region (IR) with 14 mrad crossing angle and two detectors in the ``push-pull" configuration, where the detectors can alternately occupy the Interaction Point (IP). Consequently, the IR optics must be compatible with different size detectors designed for different distance L* between the IP and the nearest quadrupole. This paper presents the push-pull optics for the ILC extraction line compatible with L* = 3.5 m to 4.5 m, and the simulation results of extraction beam loss at 500 GeV CM with detector solenoid.

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The ILC design [1] is based on a single Interaction Region (IR) with 14 mrad crossing angle and two detectors in the "push-pull" configuration, where the detectors can alternately occupy the Interaction Point (IP). Consequently, the IR optics must be compatible with different size detectors designed for different distance L^* between the IP and the nearest quadrupole. This paper presents the push-pull optics for the ILC extraction line compatible with $L^* = 3.5$ m to 4.5 m, and the simulation results of extraction beam loss at 500 GeV CM with detector solenoid.

1 Introduction

The ILC design [1] is based on a single Interaction Region (IR) with 14 mrad crossing angle and two detectors in the "push-pull" configuration, where the detectors can alternately occupy the Interaction Point (IP). The impact on the IR optics is that the two detectors may have different size and require different free space L^* between the IP and the nearest Final Doublet (FD) quadrupole. Below, we present the push-pull optics for the ILC extraction line compatible with L^* of 3.5 m to 4.5 m, and discuss tracking simulations of extraction beam loss at 500 GeV CM with detector solenoid.

2 Extraction optics

The push-pull optics near IP must be compatible with different detector designs and provide space for the detector exchange procedure. Fig. 1 shows the proposed layout of the incoming and extraction magnets on one side of the IP for three values of $L^* =$ 3.51, 4.0 and 4.5 m. Here, the QD0, QF1 and SD0, SF1 are the incoming superconducting (SC) quadrupoles and sextupoles, and the QDEX1 and QFEX2A are the extraction SC quadrupoles. These magnets will be based on the compact SC design [2] in order to fit into the tight space provided by the 14 mrad crossing angle. To maximize the separation and magnet aperture, the first extraction quadrupole QDEX1 is placed farther from the IP at distance of 5.5, 5.95 and 6.3 m, in these options. Since the QD0,

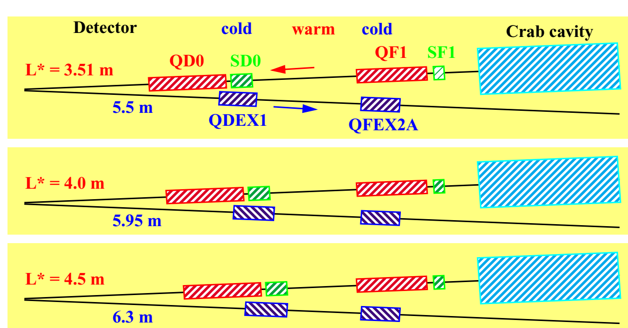

Figure 1: Magnets near IP for $L^* = 3.51$, 4.0, 4.5 m.

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SD0, QDEX1 are inside the detector area, in order to facilitate a rapid push-pull exchange, each detector will have its own set of these magnets integrated into the detector cryostat. Consequently, the parameters of QD0, SD0, QDEX1 are optimized for each detector. For a uniform optics, the magnets outside of the detector will not change with L^*, except for field adjustment. The second set of SC magnets QF1, SF1, QFEX2A will be housed in a separate cryostat outside of the detector. The 2–3 m warm space between the 1st and 2nd cryostats, as shown in Fig. 1, will provide a breakpoint for detector detachment from the beamline. After the Final Doublet, there is a dedicated free space in the extraction line to accommodate the large size incoming crab-cavity.

The complete extraction optics and lattice functions are shown in Fig. 2, based on the earlier design in [3]. The SC and warm quadrupoles provide focusing to the 2nd focal point at s = 148.6 m with $R_{22} = -0.5$ required for the polarization diagnostics. After the quadrupoles, there are two vertical bending chicanes: for energy and polarization measurements [4] and gamma calorimeter (GamCal) [5]. The 6-bend polarimeter chicane is adjusted for 50% higher field in the 3rd and 4th bends for improved acceptance of Compton backscattered electrons in the Cherenkov detector, while the 5th and 6th bends close the trajectory bump and provide space and bending for GamCal.

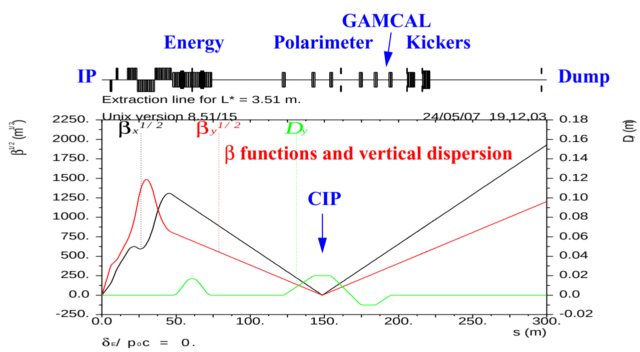

Figure 2: Extraction lattice functions.

The chicanes are followed by a system of 5 vertical and 5 horizontal fast cycling kickers. They will protect the dump window from damage and prevent water boiling in the tank in situations with a very small beam size such as in cases of an undisrupted beam or accidental focusing at dump. The kicker field will oscillate with ∼1 kHz frequency to sweep the bunches in 1 ms train on 3 cm circle at the dump as shown in Fig. 3, thus reducing the beam density to acceptable level [6]. Finally, a system of 5 collimators is included: to clip off the disrupted low energy tail, to protect the extraction magnets and diagnostic devices from high beam loss and synchrotron radiation, and to limit the beam size at dump to within the 15 cm radius of the dump window. The dump is located ∼300 m from the IP and > 3.5 m from the incoming line. The parameters of extraction magnets at 500 GeV CM are listed in Tables 1,2. The extraction magnets are compatible with 1 TeV CM energy, except the SC quads QDEX1, QFEX2A which require upgrade.

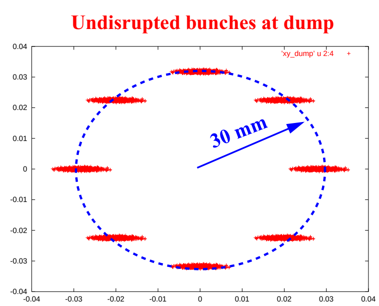

Figure 3: Swept bunches at dump.

3 Detector solenoid

The detector solenoid field downstream of IP creates vertical orbit, dispersion, coupling and focusing in the extraction line. The orbit and dispersion are created due to the 7 mrad

Table 1: Quadrupole gradient (T/m), length (m) and aperture radius (mm) at 500 GeV CM.

Name	Qty	L* = 3.51 m			L* = 4.0 m			L* = 4.5 m		
		B′	L	R	B′	L	R	B′	L	R
QDEX1 (SC)	1	98.00	1.060	15	89.41	1.150	17	86.39	1.190	18
QFEX2A (SC)	1	31.33	1.100	30	33.67	1.100	30	36.00	1.100	30
QFEX2 (B,C,D)	3	11.12	1.904	44	11.27	1.904	44	11.36	1.904	44
QDEX3 (A,B,C)	3	11.39	2.083	44	11.37	2.083	44	11.36	2.083	44
QDEX3D	1	9.82	2.083	51	9.81	2.083	51	9.80	2.083	51
QDEX3E	1	8.21	2.083	61	8.20	2.083	61	8.19	2.083	61
QFEX4A	1	7.05	1.955	71	7.04	1.955	71	7.04	1.955	71
QFEX4 (B,C,D,E)	4	5.89	1.955	85	5.88	1.955	85	5.88	1.955	85

Table 2: Bend and kicker parameters at 500 GeV CM.

Name	Qty	L (m)	B (T)	Half-gap (mm)	Region
BVEX1E,...,8E	8	2.0	0.4170	85	Energy
BVEX1P,2P	2	2.0	0.4170	117	Polarimeter
BVEX3P	1	2.0	0.6254	117	
BVEX4P	1	2.0	0.6254	132	
BVEX1G,2G	2	2.0	0.4170	147	GAMCAL
XSWEEP	5	0.8	0.071	120	Fast kickers
YSWEEP	5	0.8	0.071	120	

angle between the solenoid and beam directions. Without correction, they will cause higher particle amplitudes and increased beam loss, and will alter trajectory and dispersion at the 2nd focus Compton IP (CIP). The other negative effect of the solenoid angle is deflection of e^+e^- secondary pairs away from the detector beam hole, thus increasing the detector background. The second source of extraction orbit is a non-zero incoming angle of beam trajectory at IP. The effect of solenoid focusing is weak, but it can shift the beam waist from the CIP by a few mm. It has been shown [7] that the e^+e^- background can be minimized by including the anti-DID horizontal field in the detector, as shown in Fig. 4 for the 5 T SiD solenoid model. The SC quadrupoles QDEX1 and QFEX2A will include the corrector coils which can be used to cancel the solenoid orbit and focusing effects. Fig. 4 shows the orbit cancelation using the QDEX1, QFEX2A dipole coils for L* = 3.51 m and 50 μrad angle at IP. This correction also compensates most of the residual dispersion.

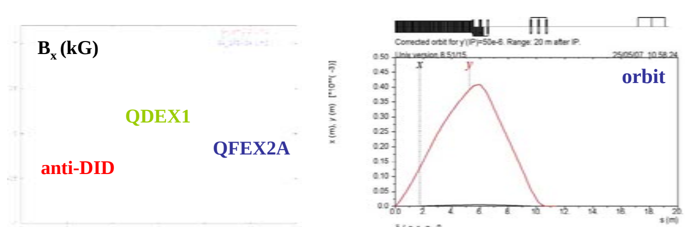

Figure 4: Cancelation of solenoid orbit for L* = 3.51 m.

4 Extraction beam loss at 500 GeV CM

The following ILC beam options were used in tracking simulations: nominal (option c11), large vertical emittance (c13) and low beam power (c14). The disrupted beams are characterized by a low energy tail, with energies reaching 50% to 20% of nominal 250 GeV value, and by a large angular spread. Beam in the nominal option has the lowest disruption. Option c13 has a larger angular spread, and option c14 has larger both the energy and angular spread. Additional disruption occurs when the beams are vertically offset at IP. The effects of energy and angular spread are the overfocusing of low energy electrons, large particle amplitudes and beam loss. The quadrupole focusing and magnet apertures are optimized for minimal loss of both the primary electrons and beamstrahlung (BS) photons which share the same beamline. The magnet aperture accepts photons with up to ±0.75 mrad angles.

Table 3 shows the beam power loss for the three beam options, including the worst case IP offset Δy, for optics with $L^* = 3.51$ m without solenoid. The loss is small in options c11 and c13, and manageable in option c14. The three dump collimators located in the final 100 m drift have a larger beam load, because they trim the final beam size to within the 15 cm radius of the dump window. The IP offset may significantly increase the loss on collimators. For this reason, a protection system should be considered to detect and prevent beam running with large IP offsets. Example of beam loss in the first 200 m of extraction line for option c14 is shown in Fig. 5 for $L^* = 3.51$ m without solenoid. The two high peaks correspond to losses on the two diagnostic collimators COLE and COLCD.

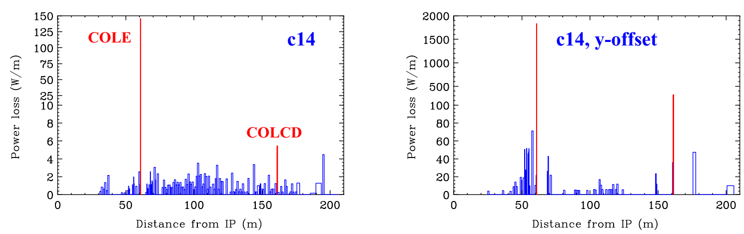

Figure 5: Beam loss in option c14 without (left) and with (right) IP y-offset for $L^* = 3.51$ m without solenoid.

Table 3: Power loss (kW) without solenoid for $L^* = 3.51$ m.

Option	Primary electrons						BS photons	
	All magnets and pipe	Diagnostic collimators		Dump collimators			Dump collimators	
		COLE	COLCD	COLW1	COLW2	COLW3	COLW1	COLW2
c11	0	0	0	0	0	0.272	0	0
c11+Δy	0.001	0.001	0.0003	1.12	2.59	11.2	0.0001	0.025
c13	0.007	0.001	0.0001	1.02	1.57	6.54	0.570	0.820
c13+Δy	0	0.0001	0	1.08	1.76	9.05	0.138	1.82
c14	0.126	0.044	0.003	2.62	6.18	26.3	0.035	0.171
c14+Δy	0.581	0.549	0.161	85.9	43.7	82.1	10.9	20.1

Comparison of beam loss in the three configurations with $L^* = 3.51$ m, 4.0 m, 4.5 m without solenoid, and using option c14 without IP offset, showed that the electron losses are very similar and BS photon loss is evidently the same. For this reason, the remaining discussion will be limited to the optics with $L^* = 3.51$ m.

Tracking simulations with 5 T SiD solenoid, including anti-DID field and orbit correction, showed that solenoid effect on beam loss is small if the incoming vertical orbit has zero angle at IP. But in case of non-zero (under-corrected) y-angle at IP the losses at the diagnostic collimators would increase. The reason is the higher dipole field required for orbit correction which, in turn, increases non-linear dispersion and amplitudes of lowest energy electrons. Example of beam loss with solenoid and 50 μrad initial y-orbit angle is shown in Fig. 6 for the low power option c14. One can see that although the losses on magnets remain reasonably small, the load on diagnostic collimators (high peaks) is increased. Similar behavior is in the nominal ILC option c11, but the level of losses is a factor of 100 smaller.

The most increase of beam loss occurs when both the y-orbit angle at IP is non-zero and there is large vertical offset between beams at IP. It may be not desirable to cancel the IP orbit angle since it may not be optimum for highest luminosity. Therefore, to minimize the load on collimators, as mentioned earlier, a protection system is needed to detect and prevent running with large IP offsets. Further optimization of the diagnostic collimators may be needed to minimize the losses near the diagnostic devices. Bringing the corrector field closer to IP may also help to reduce the unwanted effects of non-linear dispersion.

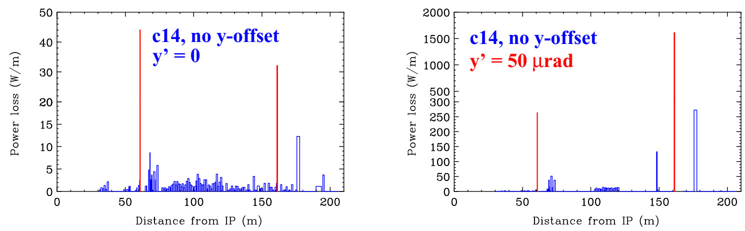

Figure 6: Beam loss in option c14 with solenoid, without (left) and with (right) 50 μrad y-orbit angle at IP.

5 Summary

The 14 mrad extraction optics compatible with push-pull detector configuration for a range of L* from 3.5 m to 4.5 m is designed. The recent optics modifications also include the 6-bend polarimeter chicane which improves acceptance of Compton backscattered electrons in the Cherenkov detector and provides optics for GamCal, and the system of fast sweeping kickers for dump protection in cases of the small undisrupted or accidentally focused beam. Tracking simulations with 5 T SiD solenoid model, including the anti-DID field and orbit correction, showed that the increase of beam loss due to solenoid field is small. However, it increases with non-zero incoming vertical orbit angle and with large vertical beam offset at IP. The combination of these conditions produces the largest effect. The beam loss in the nominal parameter option still remains small to moderate. But more care is required in high disruption options. In order to minimize the unwanted power load on collimators, a protection system is needed to efficiently prevent beam running with large IP offsets. Secondly, more optimization of diagnostic collimators and orbit correction may be needed to minimize the unwanted losses and non-linear dispersion.

References

[1] ILC Reference Design Report, ILC-Report-2007-001, August 2007.

[2] B. Parker *et al.*, "Compact superconducting final focus magnet options for the ILC," SLAC–PUB–11764, PAC–2005–RPPP017 (2005).

[3] Y. Nosochkov *et al.*, "ILC Extraction Line for 14 mrad Crossing Angle," SLAC–PUB–11591 (2005).

[4] K. Moffeit *et al.*, "Proposal to Modify the Polarimeter Chicane in the ILC 14 mrad Extraction Line," SLAC–PUB–12425, IPBI–TN–2007–1 (2007).

[5] W. Morse, "GamCal, a device for beam diagnostics," these proceedings.

[6] L. Keller, http://www-project.slac.stanford.edu/lc/bdir/Meetings/beamdelivery/2006-08-22/index.htm.

[7] A. Seryi *et al.*, "IR Optimization, DID and anti-DID," SLAC–PUB–11662 (2006).