THE 2 mrad CROSSING ANGLE SCHEME FOR THE INTERNATIONAL LINEAR COLLIDER[*]

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Abstract

The present baseline configuration of the ILC has a 14 mrad crossing angle between the beams at the interaction point. This allows easier extraction of the beams after collisions, but imposes on the other hand more constraints on the control of the beams prior to colliding them. Moreover, some limitations to physics capabilities arise, in particular because of the degraded very forward electromagnetic detector hermeticity and because calibration procedures for (gaseous) tracking detectors become more complex. To mitigate these problems, alternative configurations with very small crossing angles are studied. A new version of the 2 mrad layout was designed last year, based on simpler concepts and assumptions. The emphasis of this new scheme was to satisfy specifications with as few and feasible magnets as possible, in order to reduce costs.

INTRODUCTION AND OVERVIEW OF THE DESIGN

The baseline configuration of the international Linear Collider (ILC) [1] consists of a single interaction point, with an angle of 14mrad between the colliding beams. This layout allows straightforward spent beam extraction and the possibility of easier post-IP polarimetry and spectrometry, but adds some complexity to the incoming dynamics and a dependence on an effective crab crossing scheme to recover the design luminosity. The 2mrad beam crossing angle scheme is an alternative to the baseline, trading simpler pre-collision beam dynamics for increased extraction difficulty.

The 2mrad design, originally presented in [2], exhibited large disrupted beam power losses under beam transport and un-optimised magnets in the shared final doublet region. This region has now been redesigned [3] with a compact final doublet in order to give small losses from disrupted beam transport. The downstream extraction line has been redesigned [4] using the concept of minimal optics, without dedicated energy or polarisation diagnostics, to give good beam transport to the dump with acceptable power losses. The possibility exists to add such diagnostic in future upgrades.

The scheme requires non-conventional special designs for some extraction line magnets due to their vicinity to the incoming line and the photon cone [5]. The disrupted beam, with a large beamstrahlung tail induced by the intense beam-beam interaction at the collision point, passes off-axis in the final incoming beam vertically focusing quadrupole QD0. This causes a large dispersive beam tail to grow in the horizontal plane, due to the strong dipole field, which needs to be focused by the extraction line as close to QD0 as possible to avoid large downstream power losses. The layout of the minimal extraction line is shown in figure 1. The first two extraction line quadrupoles QEX1 and QEX2 are hence placed very close to the final doublet and the incoming beam. These special magnets are designed as Panofsky magnets [6], providing a large aperture for the extracted beam, and a low field pocket for the nearby incoming beam. The design of these Panofsky quadrupoles is described in the next section.

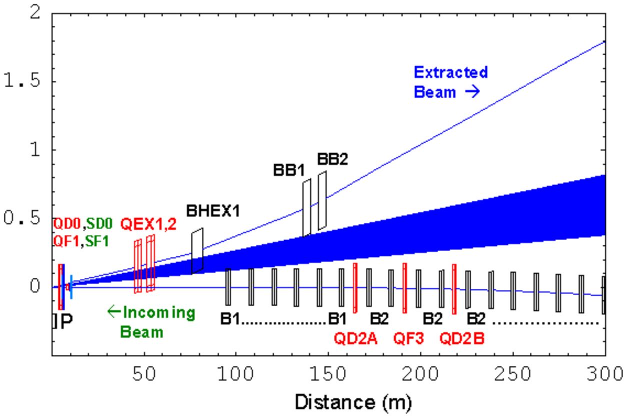

Figure 1: The layout of the minimal 2mrad crossing angle extraction line. The blue cone denotes the photon cone.

Following QEX1 and QEX2, a special dipole magnet BHEX1 is placed to increase the extraction angle and reduce the extracted beam size. This magnet is required to accommodate the charged beam and the beamstrahlung photons within the aperture, and have low field leakage to the nearby incoming beam. The beam fields of QEX1 and QEX2 are weak, and thus do not affect the incoming beam. However, BHEX1 has a strong quadrupole field in the incoming beam region, which needs to be absorbed into the final focus optics. This design of BHEX1, and the procedure to absorb the stray field into the final focus optics, is described later in this paper.

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THE MAGNETS

QF1

The extracted beam passes through the final doublet of the incoming beam, which consists of the quadrupoles QD0 and QF1, with local chromaticity correction sextupoles SD0 and SF1. The beam passes through the main apertures of QD0 and SD0, which are superconducting magnets with a large bore. The parameters and optimisation procedure is described in [3]. The beam, by virtue of the crossing angle and the linear transfer maps of the final doublet, then passes through the pocket field regions of the magnets QF1 and SF1, which are normal conducting magnets. The incoming beam aperture of QF1 is 15mm, and a detailed design is needed to understand the field non-linearities in the pocket region. The on-axis gradient is 65 T m^{-1}. The physical design and the magnetic field lines for one eighth of QF1 are shown in figure 2, calculated with the code PRIAM [8]. The design and resulting pocket fields of SF1 is currently under study.

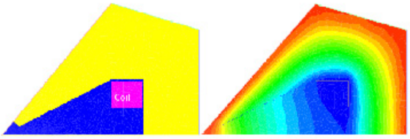

Figure 2: The physical geometry and magnetic field lines of QF1.

QEX1

The design goals of the first extraction line quadrupole is to provide an aperture of 200mm by 85mm for the extracted beam, with an optical strength in this region of 0.009 m^{-2} ($G > 7.5$ Tm^{-1}). This aperture centre is located 150mm from the centroid of the incoming beam, which needs to be inside an aperture of 20mm and see no more than 10 G of stray field. The physical design and field lines are shown in figure 3. The design goals are met with electromagnetic coils providing the field in the extracted pocket, and a configuration of permanent magnets providing the low field incoming beam pocket. The field for the incoming beam is small over very large range of excitation currents (20% to 100%) and so the concept is tunable with energy, despite a permanent magnet with fixed field being used. The design of QEX2 can be scaled from the design of QEX1.

The magnetic field in the extracted beam aperture can be decomposed according to

$$B_x - \imath B_y = \imath \sum_{\mathrm{n}} \left(\frac{A_{\mathrm{n}} + \imath B_{\mathrm{n}}}{r} \left(\frac{z}{r} \right)^{\mathrm{n}-1} \right), \qquad (1)$$

where n denotes the model number, $z = x + \imath y$ and r is some normalisation radius. Table 1 shows the multipole components for QEX1, with the normalisation radius taken to be 5cm. The impact of the linear and non-linear fields can be modelled in beam transport calculations by including the multipoles as a series of lumped kicks along the length of QEX1 to check the impact on beam sizes and thus the power losses on downstream collimators. The effects are found to be small, with beam size growth typically around 5%.

Table 1: The multipole components of QEX1 in the extracted beam pocket. The normalisation radius taken to be 5cm.

n	$\mathrm{n}A_{\mathrm{n}}/r$	$\mathrm{n}B_{\mathrm{n}}/r$
1	-1.8555 m^{-1}	0
2	-4079.8 m^{-1}	0
3	-2.6446 m^{-1}	0
4	-64.44 m^{-1}	0

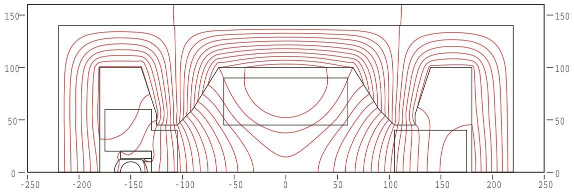

Figure 3: The field lines of QEX1 at 100% excitation.

The fields seen by the incoming beam are very small, and considerably smaller than the fields presented to this beam by BHEX1. Therefore the final focus re-matching procedure described for BHEX1 in the next subsection can readily absorb these fields.

BHEX1

BHEX1 is a 6m long dipole with a field of 0.28T, with the requirement of the outgoing beam and the beamstrahlung photons fitting between the poles, and the close proximity of the incoming beam. The half-gap is 70mm. The design [7] is a C-shape magnet, with geometry and magnetic field lines shown in figure 4, calculated with the code PRIAM [8].

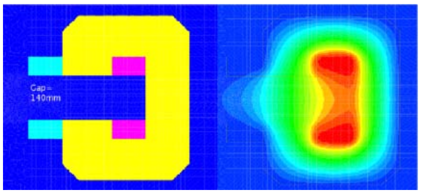

Figure 4: The physical geometry and magnetic field lines of BHEX1.

The extracted beam, in the main aperture of the magnet, will experience the design dipole field, as well as higher order field contributions. The impact on extracted beam dynamics is obtained by performing the multipole expansion of this field and including lumped multipoles in beam dynamics calculations, and the effect on the extracted beam is minimal.

The incoming beam is at -27cm in the co-ordinate system of BHEX1, and analysis of the field in this region shows no vertical kick but an integrated quadrupole strength of 0.001 m^{-2} along the 6m magnet, which is strong enough to distort the final focus optics. The leakage field can be reduced through appropriate magnetic shielding.

FINAL FOCUS OPTICS

The 2 mrad final doublet has been integrated into the final focus system of the BDS [4], and due to the proximity of the extraction line magnets, BHEX1, QEX1, QEX2, to the incoming beam, it is necessary to consider the effect of magnetic fields of these magnets seen by the incoming beam in the final focus. To include the effect of the strong BHEX1 quadrupole component in the final focus optics, QD0 and QF1 were slightly adjusted to shift the beam waist at the IP and QD2B and QF3 in the final focus optics were adjusted (with polarity of QD2B changed to focussing) to restore the pseudo-identity -I transform between SD4 and SD0. The beta functions at the IP vary slightly (β_y=0.0226m, β_y=0.00037378m) from the ILC nominal values (β_x=0.021m, β_y=0.0004m). The soft dipoles B1, B2 and B5 in the final focus systems need slight adjustment to re-match the dispersion in the line and to optimise the dispersion function at SF5 for cancellation of geometric and chromo-geometric aberrations. The lattice functions for this optimised FFS are shown in figure 5. Optimisation of the sextupoles for better bandwidth is done using programs BETA and LUMOPT [9]. The final bandwidth comparison of the optimised final focus lattice for 2 mrad with and without BHEX1 quadrupole component is shown in figure 6. There is a marginal loss of luminosity due to this component and further optimisation of the entire final focus may recover this luminosity loss. Other higher order multipoles from the extraction line are very small and thus will not affect the final focus design.

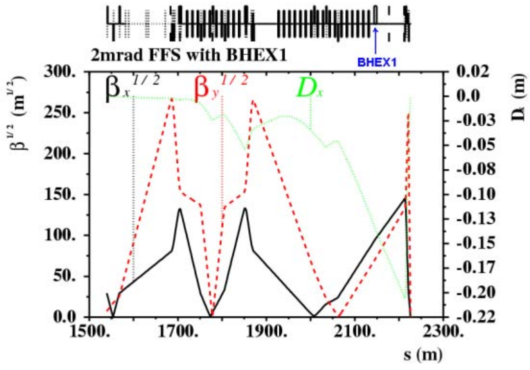

Figure 5: Lattice parameters of optimised 2 mrad FFS in presence of BHEX1.

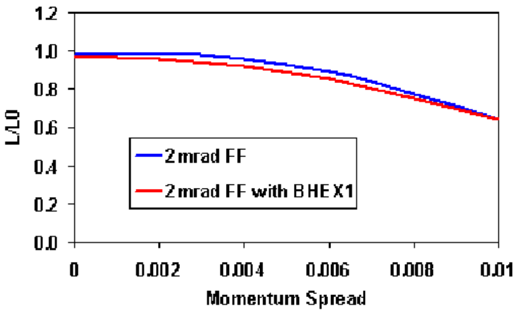

Figure 6: Optical bandwidth of the 2 mrad final focus without and with BHEX1 quadrupole component.

CONCLUSIONS

The minimal extraction line design of 2mrad crossing angle need special designs of the final doublet and the extraction line magnets to satisfy the requirements on both outgoing and incoming beams whilst keeping the losses in the extraction line to minimum. The lattice design incorporating the recently designed magnets satisfy these requirements. The magnetic fields seen by the incoming beam can be absorbed by some modifications in the final focus magnets and the bandwidth of the final focus can be regained. The preliminary design of all the magnets except SD0 are now available for this 2 mrad minimum extraction line. Further work is to complete the design and feasibility study focuses on including beam tail diagnostics to monitor the disrupted beam properties at high beta and eta points, as a way to optimise collision parameters at the IP.

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