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Linear Collider Collaboration Tech Notes

Sensitivity to Interaction Region Solenoid Horizontal Motion

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1 Introduction

It is expected that the interaction region of a linear collider will employ a detector solenoid with a considerable field strength (up to 5 Tesla) and length (several meters). Such strong solenoidal fields, combined with the large crossing angles anticipated at linear colliders (both NLC and CLIC anticipate beam-beam crossing angles of 20 mrad, or beam-solenoid angles of 10 mrad), were for some time considered a potentially severe source of optical and synchrotron radiation emittance growth in the vertical plane.

Recent studies [1] have shown that, for a real solenoid with the fringe field included, the optical effects of the solenoid due to the crossing angle disappear, and the synchrotron radiation effects are tolerable for the beam and magnet parameters presently under consideration. A related effect – vertical deflection of the beam due to horizontal jitter of the magnet – does not cancel, and must be considered in the design and operation of a future linear collider.

2 XY Coupling in a Solenoid Field

In the case of a beam which is aimed at the symmetry point of the detector solenoid, the relationship between the radial field component $B_r(r = z_0 \tan\theta_c, z_0))$ and the *change* in the longitudinal field at $z = z_0$ over a longitudinal distance dz is given by [1]:

$$B_r(r = z_0 \tan\theta_c, z_0)dz = \frac{1}{2} z_0 \tan\theta_c dB_z(z_0), \tag{1}$$

where θ_c is the crossing angle between the beam and the solenoid axis. In the event that the solenoid is offset in the horizontal by an amount Δx, Equation 1 can still be used to relate B_r and dB_z at a given location, but the angle θ_c must be replaced by $\tilde{\theta}(z_0)$, where $\tan\tilde{\theta}(z_0) \equiv (x - \Delta x)/z_0 = \tan\theta_c - \Delta x/z_0$:

$$\tilde{B}_r(z_0)dz = \frac{1}{2} z_0 \tan\tilde{\theta}(z_0) dB_z(z_0). \tag{2}$$

The net beam deflection due to the combined effect of the radial field (which in this case acts only over a longitudinal distance dz) and the increase in the longitudinal field (which acts over the entire distance z_0 from the field point to the IP) is given by:

$$dy^*(z_0) = \frac{1}{B\rho}\left[\frac{z_0^2}{2} dB_z(z_0)\sin\theta_c - z_0 dz \tilde{B}_r(z_0)\cos\theta_c\right]. \tag{3}$$

Equation 2 allows us to express $\tilde{B}_r$ in terms of dB_z and $\tilde{\theta}$:

$$dy^*(z_0) = \frac{z_0^2 dB_z(z_0)}{2B\rho}\left[\sin\theta_c - \cos\theta_c \tan\tilde{\theta}(z_0)\right]. \tag{4}$$

Regrouping and cancellation of appropriate terms yields:

$$dy^*(z_0) = \frac{z_0 \Delta x}{2B\rho}\cos\theta_c dB_z(z_0). \tag{5}$$

The complete deflection at the IP, due to the sum of deflections at all points, can be determined by integrating the differential expression above. Integration by parts allows a fetching simplification:

$$\Delta y^* = \frac{\Delta x}{2B\rho}\cos\theta_c \int B_z dz. \tag{6}$$

Note that Equation 6 is proportional to the cosine, rather than the sine, of the crossing angle. This indicates that the sensitivity to deflection from horizontal motions of the detector will be nearly the same for head-on or crossing-angle collisions (at least up to the 10 mrad values of θ_c which are popular these days). Equation 6 also shows that, for a fixed solenoid field, the sensitivity will be inversely proportional to energy due to the $1/B\rho$ term. If the vertical beam size is inversely proportional to the square root of energy (due to adiabatic damping), then we can expect that the solenoid motion tolerance will also have $1/\sqrt{E}$ scaling – ie, it will be worse for lower energies than for higher ones.

Let us consider as an example the field map in [1], corresponding to a 6 Tesla solenoid with a relatively short coil. The integrated longitudinal field is 11.3 Tesla-meters. For a 500 GeV beam with 2.3 nm RMS vertical size, a 0.25-sigma vertical jitter is induced by a horizontal magnet jitter of 170 nm. For a 45.6 GeV beam energy (Z-resonance), and assuming adiabatic damping, 0.25 sigma vertical jitter corresponds to 51 nm horizontal jitter of the solenoid.

References

[1] P. Tenenbaum, J. Irwin, T.O. Raubenheimer, "Beam Dynamics of the Interaction Region Solenoid in a Linear Collider due to a Crossing Angle," *Physical Review Special Topics – Accelerators and Beams,* **6:** 061001 (2003).