PRAMANA — journal of physics | © Indian Academy of Sciences | Vol. 69, No. 5 November 2007 pp. 765–769

Power losses in the international linear collider 20 mrad extraction line at 1 TeV

A FERRARI[1,*] and YURI NOSOCHKOV[2]
[1]Department of Nuclear and Particle Physics, Uppsala University, 75121 Uppsala, Sweden
[2]Stanford Linear Accelerator Center, USA
*E-mail: ferrari@tsl.uu.se

Abstract. We have performed a detailed study of the power losses in the post-collision extraction line of a TeV e^+e^- collider with a crossing angle of 20 mrad at the interaction point. Five cases were considered: four luminosity configurations for ILC and one for CLIC. For all of them, the strong beam–beam effects at the interaction point lead to an emittance growth for the outgoing beam, as well as to the production of beamstrahlung photons and e^+e^- coherent pairs. The power losses along the extraction line, which are due to energy deposition by a fraction of the disrupted beam, of the beamstrahlung photons and of the coherent pairs, were estimated in the case of ideal collisions, as well as with a vertical position or angular offset at the interaction point.

Keywords. Extraction line; international linear collider; compact linear collider; beam losses.

PACS Nos 29.27.-a; 29.17.+w; 41.75.Ht; 41.85.-p

1. Introduction

In a high-energy e^+e^- linear collider, the beams must be focused to extremely small spot sizes in order to achieve high charge densities and, in turn, to reach the desired luminosity. Because of the extremely small transverse dimensions of the colliding beams, electrons and positrons experience very strong transverse electromagnetic fields at the interaction point. The subsequent bending of their trajectories leads to the emission of hard beamstrahlung photons, which can then turn into coherent pairs. A careful design of the extraction line must be performed in order to transport the outgoing charged beams and beamstrahlung photons from the interaction point to their dump. In this study, we estimate the beam losses in the extraction line of a 1 TeV e^+e^- linear collider with a 20 mrad crossing angle. This may correspond either to the early stage of the multi-TeV compact linear collider (CLIC) or to an upgraded version of the international linear collider (ILC).

Table 1. Beam parameters for various configurations of a 1 TeV e^+e^- linear collider.

Configuration at 1 TeV	CLIC	ILC nominal	ILC hl1	ILC hl2	ILC hl3
Particles per bunch N_b (10^{10})	0.256	2.0	2.0	2.4	2.0
Bunches per RF pulse, n	220	2820	2820	2820	2820
Bunch spacing (ns)	0.267	307.7	307.7	307.7	307.7
Beam current (A)	1.5	0.0104	0.0104	0.0125	0.0104
Repetition frequency f (Hz)	150	4	4	4	4
Primary beam power (MW)	6.8	18.1	18.1	21.7	18.1
$(\beta\gamma)\epsilon_x$ in 10^{-6} mrad	0.660	10	10	10	10
$(\beta\gamma)\epsilon_y$ in 10^{-6} mrad	0.001	0.04	0.03	0.023	0.023
σ_x (nm)	94	554	320	550	470
σ_y (nm)	1.0	3.5	2.5	2.7	2.7
σ_z (μm)	30.8	300	150	300	300
Luminosity (10^{34} cm^{-2} s^{-1})	2.8	2.8	7.8	5.7	4.6
Photons per e^+ or e^-	0.9	1.4	2.2	1.7	1.7
Beamstrahlung loss δ_B	9.0%	4.8%	17.6%	6.7%	6.5%

2. Beam parameters and extraction line layout

Several machine configurations are being studied to reach the ILC luminosity goals [1,2]. Here, we consider four sets of parameters at 1 TeV. One is referred to as nominal and the other three (hl1, hl2 and hl3) correspond to various high luminosity configurations. As for CLIC, an optimization of the machine design at 1 TeV was recently performed [3]. More details are given in table 1.

At an e^+e^- linear collider with a 20 mrad crossing angle, one uses a dedicated line to transport the disrupted beam and the beamstrahlung photons from the interaction point to their dump. In its present design, the ILC 20 mrad extraction line consists of a DFDF quadruplet, followed by two vertical chicanes for energy and polarization measurements and a field-free region that allows the beam to grow naturally, with two collimators located 200 m and 300 m downstream of the interaction point, in order to reduce the maximum beam size at the dump [4].

3. Power losses in the case of ideal e^+e^- collisions

Knowing the incoming beam parameters, the outgoing beam distributions at the interaction point can be obtained with GUINEA-PIG [5]. These were then tracked to the dump with DIMAD [6]. Using the number of lost particles in the extraction line, as well as their energy (in GeV), one can calculate the power loss (in W) using the following formula:

$$P_\mathrm{loss} = 1.602 \times 10^{-10} \, \frac{N_\mathrm{b} n f}{N_\mathrm{tracks}} \sum_{i=1}^{N_\mathrm{loss}} E_i.$$

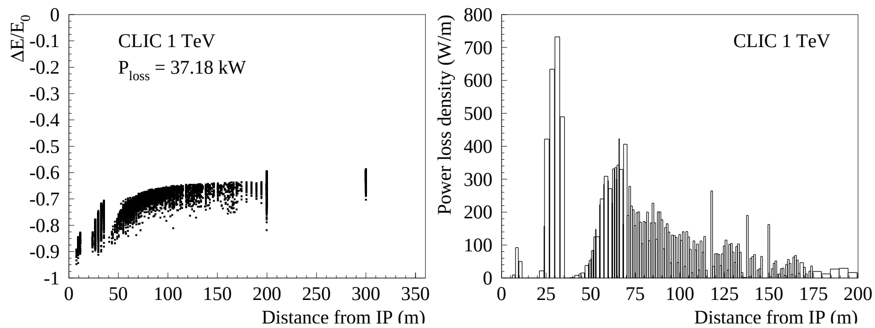

Figure 1. Relative energy spread of the lost particles as a function of the position of loss in the 20 mrad extraction line (left) and loss density upstream of the collimators (right), obtained when tracking the disrupted beam of the 1 TeV CLIC case.

Table 2. Total power losses for various configurations of a 1 TeV e^+e^- linear collider.

Configuration at 1 TeV	CLIC	ILC nominal	ILC hl1	ILC hl2	ILC hl3
Disrupted beam losses (kW)	37.2	0.9	202.7	4.1	3.6
Beamstrahlung photon losses (kW)	$< 10^{-3}$	$< 10^{-3}$	1.2	$< 10^{-3}$	$< 10^{-3}$
Coherent pair losses (kW)	0.2	–	–	–	–

The particle tracking clearly shows that most of the power losses come from the low-energy tail of the disrupted beam (see figure 1). Indeed, the ILC 20 mrad extraction line accepts most of the electrons and positrons with $E/E_0 > 40\%$. As for the beamstrahlung photons, they lead to significant power losses on the first round collimator in the ILC hl1 configuration only, for which one has a large horizontal photon cone size at the interaction point. Finally, our tracking studies suggest that about 75% of the particles coming from the coherent pairs do not reach the dump at the end of the extraction line. These losses mostly occur due to over-focusing of low-energy particles in the quadrupoles and they do not significantly depend on the particle charge. Note that only the CLIC case leads to a non-negligible amount of e^+e^- coherent pairs. A summary of our results is given in table 2 (see also ref. [7] for more details).

4. Power losses with a vertical offset in position or angle

Let us introduce a vertical position or angle offset at the interaction point, which can occur during initial tuning. GUINEA-PIG simulations clearly show a blow-up of the emittance with such a beam-to-beam offset. Also, there are more particles in the low-energy tail of the disrupted beam, which are then likely to be lost in the extraction line. Figure 2 shows how the disrupted beam losses vary with a vertical offset in position or angle.

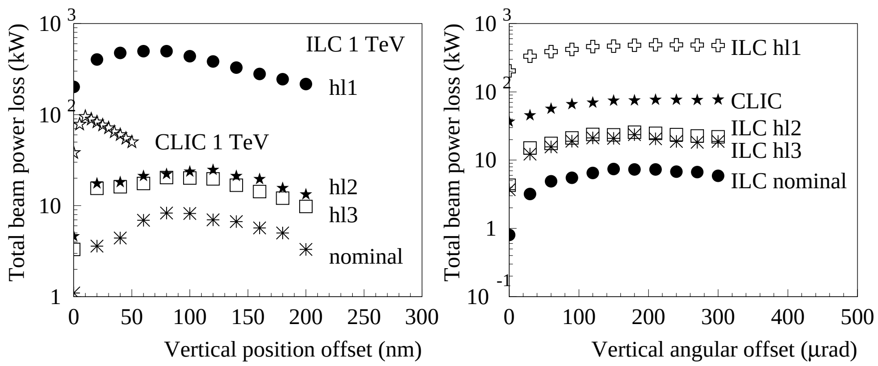

Figure 2. Disrupted beam power losses in the extraction line as a function of the position offset Δy (left) or the angular offset $\Delta y'$ (right), for various ILC and CLIC configurations at 1 TeV.

More beamstrahlung photons are produced with a vertical beam-to-beam offset and their angular distribution is wider than for ideal collisions. In the ILC hl1 configuration, the power loss due to beamstrahlung photons on the collimators is maximal when $\Delta y = 80$ nm and it reaches 62 kW. With a vertical angular offset at the interaction point, tails appear in the y'-distribution of the beamstrahlung photons (while its x'-distribution is unaffected). Together with an increased number of beamstrahlung photons per e^+e^- collision, this leads to additional power losses (mostly on the collimators). However, the maximal losses due to the vertical angular offset are about twice smaller than the maximal losses due to the vertical position offset. Finally, the number of coherent pairs per bunch crossing may be up to about six times larger than in the case of ideal collisions, but their contribution to the power losses along the extraction line still remains negligible.

5. Conclusion

A detailed study of the beam losses along the 20 mrad extraction line of a TeV e^+e^- collider was performed, for various CLIC or ILC configurations. More than 99% of these losses are due to the low-energy tail of the disrupted beams. In the 1 TeV ILC nominal configuration, the power losses are less than 1 kW and their distribution along the 20 mrad extraction line appears acceptable. The recently proposed ILC high luminosity hl2 and hl3 configurations should also allow to keep the power losses at a reasonable level in the extraction line, although these are three to five times larger than in the ILC nominal case. On the other hand, the beam losses become too large for the ILC high luminosity hl1 and CLIC configurations. The power losses in the 20 mrad extraction beam line were also studied as a function of a vertical position or angular offset at the interaction point. It was found that the strongest beam–beam effects, and in turn the maximal power losses, occur when the vertical position offset is 10–30σ_y or when the vertical angular offset reaches about 200 μrad.

Acknowledgements

This work is supported by the Commission of the European Communities under the 6th Framework Programme 'Structuring the European Research Area', contract number RIDS-011899.

References

[1] T Raubenheimer, *Suggested ILC beam parameter range*, 28 February 2005 (available at http://www-project.slac.stanford.edu/ilc/acceldev/beamparameters.html)
[2] A Seryi, *Alternative 1 TeV high luminosity parameters*, 26 July 2005 (available at http://www-project.slac.stanford.edu/lc/bdir/Meetings/beamdelivery/2005-07-26/index.htm)
[3] F Tecker *et al*, CLIC note 627
[4] R Arnold, K Moffeit, Y Nosochkov, W Oliver, A Seryi, E Torrence and M Woods, Design of ILC extraction line for 20 mrad crossing angle, *Proceedings of PAC 2005*, Knoxville, USA
[5] D Schulte, TESLA-97-08 (1996)
[6] http://www.slac.stanford.edu/accel/ilc/codes/dimad
[7] A Ferrari and Y Nosochkov, EUROTeV-Report-2005-025