Parameter Choice for International Linear Collider (ILC)*

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Abstract In this paper a general procedure to determine linear collider parameters is given. As an example, a parameter list is proposed for ILC with very low bunch charge. The main aim of this paper is to demonstrate the beam parameter relations with the constraints from the interaction point and damping ring. It is suggested that the energy of the damping ring should be 7GeV instead of 5GeV if a 17km damping ring is to be used. However, if 6km damping ring (which is preferable) is adopted, 5GeV damping ring energy is reasonable.

Key words linear collider, ILC, parameter choice, damping ring

1 Introduction

In August 2004, it has been announced in Beijing by the International Technology Recommendation Panel (ITRP) that the next generation e^+e^- linear collider will be based on super-conducting accelerator technology[1], named International Linear Collider (ILC). To make ILC successful, a reasonable ILC design is very important. In this paper, we will provide a general procedure to make a linear collider parameter choice by taking into account of experimental background noises at the interaction point (IP), technical feasibility, operational stability, etc., both in the main linac and the damping rings. In section 2, we discuss the beam parameter related to the constraints from IP and damping ring. In section 3, an ILC parameter list with very low bunch charge is proposed.

2 Beam parameter relations

The luminosity of two Gaussian head-on colliding beams is given by:

$$L=\frac{f_{\rm rep}N_{\rm b}N_{\rm e}^2}{4\pi\sigma_x\sigma_y}H_{\rm D} \quad . \tag{1}$$

where $f_{\rm ref}$ is the repetition frequency of the bunch train, $N_{\rm b}$ is the number of bunches in the train, $N_{\rm e}$ is the number of particles per bunch, $\sigma_x=\sqrt{\varepsilon_x\beta_x}$, $\sigma_y=\sqrt{\varepsilon_y\beta_y}$, $\beta_{x,y}$ and $\varepsilon_{x,y}$ are the values of the beta functions at the IP and the emittances, respectively, and $H_{\rm D}$ is the pinch enhancement factors which are functions of the so-called disruption parameters $D_{x,y}$ of a bunch. In the following we will express the luminosity and colliding beam parameters as the function of constrains from IP (flat beam case).

$$L=f_{\rm rep}N_{\rm b}\left(\frac{N_{\rm had}}{n_\gamma^2\sigma_{\gamma\gamma\to\rm had}}\right) \ , \tag{2}$$

$$\sigma_x=\frac{\pi r_{\rm e}^3H_{\rm had}}{2.6\delta_{\rm B}\alpha H_{\rm D}n_\gamma\sigma_{\gamma\gamma\to\rm had}} \ , \tag{3}$$

$$\sigma_y=\frac{r_{\rm e}n_\gamma^3}{41.5\delta_{\rm B}\alpha^3} \ , \tag{4}$$

$$\sigma_z=\frac{r_{\rm e}n_\gamma^2\gamma}{4.6\delta_{\rm B}\alpha^2} \ , \tag{5}$$

$$R=\frac{\sigma_x}{\sigma_y}=\frac{16\pi\alpha^2r_{\rm e}^2N_{\rm had}}{H_{\rm D}n_\gamma^4\sigma_{\gamma\gamma\to\rm had}} \ , \tag{6}$$

$$\beta_x=\frac{3.5\pi\gamma r_{\rm e}^3N_{\rm had}}{\delta_{\rm B}H_{\rm D}\sigma_{\gamma\gamma\to\rm had}n_\gamma^2} \ , \tag{7}$$

$$\beta_y=\sigma_z/0.75 \ , \tag{8}$$

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$$\gamma\varepsilon_x = \frac{\pi r_e^3 N_{\rm had}}{23.4\delta_{\rm B} H_{\rm D}\alpha^2\sigma_{\gamma\gamma\to{\rm had}}}\ , \tag{9}$$

$$\gamma\varepsilon_y = \frac{0.75 n_\gamma r_e^3}{374\delta_{\rm B}\alpha^4}\ , \tag{10}$$

$$N_e = \frac{\pi r_e^2 N_{\rm had}}{5.2\delta_{\rm B} H_{\rm D}\alpha^2\sigma_{\gamma\gamma\to{\rm had}}}\ , \tag{11}$$

$$\theta_x = \theta_y = \frac{n_\gamma}{\alpha\gamma}\ , \tag{12}$$

$$f_{\rm rep}N_{\rm b} = \frac{L n_\gamma^2 \sigma_{\gamma\gamma\to{\rm had}}}{N_{\rm had}}\ , \tag{13}$$

$$P_{\rm b} = \frac{\pi e W_{\rm cm} r_e^2 n_\gamma^2 L}{10.4 H_{\rm D}\delta_{\rm B}\alpha^2}\ , \tag{14}$$

where $r_e = 2.82\times10^{-15}$m is the classical electron radius, α is the fine structure constant, γ is the ratio of the colliding particle energy to its rest energy, $\sigma_{\gamma\gamma\to{\rm had}} = 4.2\times10^{-35}{\rm m}^2$ is the $\gamma\gamma$ to hadron total cross section, $\delta_{\rm B}$ is the "beamstrahlung" energy spread, n_γ is the average photon number emitted per incident particle, $N_{\rm had}$ is number hadron produced per crossing, and $H_{\rm D}$ is about 1.5 with $D_y = 9$ which is used later in this paper. In addition to constraints at IP, in damping ring, the space charge effect should be eliminated right from the beam parameter choice (see Eq. (15)). The tolerable space charge tune shift expressed in Eq. (16) can be determined from Eqs. (17) and (18)[2]

$$\frac{\gamma_{\rm d}^2\sigma_{z,{\rm d}}}{L_{\rm d}} \geqslant \frac{33 N_e \delta_{\rm B}\alpha^3}{\pi^2 \xi_{{\rm sc},y} n_\gamma^2 r_e}\sqrt{\frac{H_{\rm D}\sigma_{\gamma\gamma\to{\rm had}}}{N_{\rm had}}}\ , \tag{15}$$

$$\xi_{{\rm sc},y} = -\frac{r_e N_e L_{\rm d}}{(2\pi)^{3/2}(\varepsilon_{n,x}\varepsilon_{n,y})^{1/2}\beta_{\rm d}^2\gamma_{\rm d}^2\sigma_{z,{\rm d}}}\ , \tag{16}$$

$$\tau_{{\rm sc},y}(\xi_{{\rm sc},y}) = \frac{\tau_{{\rm d},y}}{2}\left(\frac{3}{\sqrt{2}\pi\xi_{{\rm sc},y}}\right)^{-1}\exp\left(\frac{3}{\sqrt{2}\pi\xi_{{\rm sc},y}}\right)\ , \tag{17}$$

$$R(\xi_{{\rm sc},y}) = \exp\left(-\frac{\tau_{\rm st,d}}{\tau_{{\rm sc},y}(\xi_{{\rm sc},y})}\right)\ . \tag{18}$$

where $L_{\rm d}$, $\gamma_{{\rm d},y}$, $\sigma_{z,{\rm d}}$, and $\beta_{\rm d}$ are the circumference, normalized energy, bunch length, and the particle's normalized velocity of and in a damping ring, respectively, $\tau_{{\rm sc},y}$ is the beam lifetime due to nonlinear space charge effect, $\tau_{{\rm st},d}$ is the beam stored time, and finally, $R(\xi_{{\rm sc},y})$ is the ratio of the ejected particle number to that of injected in a damping ring.

3 Very low charge case

Given the designed beam energy of 250GeV, the luminosity after pinch effect, $L = 2\times10^{34}{\rm cm}^{-2}\cdot{\rm s}^{-1}$, and the constraints shown in Table 1, one gets the beam parameters shown in Table 2.

Table 1. Constrain parameters from IP.

$\delta_{\rm B}$	n_γ	$N_{\rm had}$	D_y	$H_{\rm D}$
0.03	0.8	0.125	9	1.5

Table 2. Beam parameters at IP.

σ_x/μm	σ_y/nm	σ_z/μm	$N_e(\times10^{10})$	$\theta_{x,y}$/rad
0.31	3	125	0.6	0.000224
β_x/m	β_y/m	$\gamma\varepsilon_x$/μm	$\gamma\varepsilon_y$/μm	$f_{\rm rep}N_{\rm b}$
0.012	0.00016	3.74	0.0272	43010

As for damping ring, we assume that the damping ring's parameter is as shown in Table 3, one get the space charge tune shift to be 0.05 which is safe from the nonlinear space charge effect.

The main difference from the actual damping design is that the damping ring's energy is 7GeV instead of 5GeV. The main linac's parameters is given in Table 4. The rf pulse length is about 1.3ms, the power gain in each cavity is 234kW with accelerating gradient of 35MV/m. The misalignment error for cavity is more than 1mm, and total machine AC power is somewhat above 100MW. Compared with the ILC parameter lists of T. Raubenheimer[3], the Very Low Charge Case proposed in this paper is close to his Low Charge Case, however, if the same damping ring is used, their space charge tune shifts are the same (about 0.1, too large), and that is to say that if 17km damping ring is used it is very difficult to eliminate the space charge effect from the beam parameter choice. From this conclusion, we strongly propose to increase the damping ring's energy from 5GeV to 7GeV for a 17km damping ring, or choose 6km damping ring at 5GeV.

Table 3. Damping ring parameters.

$L_{\rm d}$/km	$E_{\rm d}$/GeV	τ_y/ms	$\sigma_{z,{\rm d}}$/m
17	7	28	0.006
$\xi_{{\rm sc},y}$	$N_{\rm b}$	$T_{\rm b,d}$/ns	$\tau_{\rm st}$/ms
0.05	5376	10.5	200

Table 4. Main linac parameters.

$f_{\rm rep}$/Hz	$T_{\rm b\text{-}linac}$/ns	$P_{\rm b}$/MW	$I_{\rm b}$/mA	$T_{\rm b}$/ms
8	150	10.3	6.45	0.8

4 Conclusions

In this paper linear collider design procedure is illustrated and a Very Low Charge Case is proposed for ILC design. It is suggested to increase the damping ring's energy from 5GeV to 7GeV for a 17km damping ring, or use 6km damping ring at 5GeV, which is preferable.

References

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国际直线对撞机的参数选择*

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摘要 给出了确定直线对撞机参数的一般程序, 作为一个例子, 给出了超低束团电量时的参数表. 文章的主要目的是说明束流参数和对撞点以及阻尼环之间的相互制约关系. 对于17km的阻尼环, 它的能量被建议由5GeV升到7GeV. 然而, 对于6km的阻尼环能量为5GeV是合理的.

关键词 直线对撞机 ILC 总体参数选择 阻尼环

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