OPTIMIZATION PARAMETER DESIGN OF A CIRCULAR e+e- HIGGS FACTORY*

D. Wang#, J. Gao, M. Xiao, H. Geng, S. Xu, Y. Guo, N. Wang, Y. An, Q. Qin, G. Xu, S. Wang,
IHEP, Beijing, 100049, China

Abstract

In this paper we will show a general method of how to make an optimized parameter design of a circular e+e- Higgs Factory by using analytical expression of maximum beam-beam parameter and beamstrahlung beam lifetime started from given design goal and technical limitations. A parameter space has been explored. Based on beam parameters scan and RF parameters scan, a set of optimized parameter designs for 50 km China Higgs Factory with different RF frequency was proposed.

INTRODUCTION

With the discovery of a Higgs boson on LHC at the energy of about 125 GeV [1, 2], the world high-energy physics community is investigating the feasibility of a Higgs Factory, a complement to the LHC for studying the Higgs. The low Higgs mass makes a circular Higgs Factory possible. Compared with the linear collider, the circular collier as a Higgs Factory has mature technology and rich experience. Also, circular Higgs Factory has potentially a higher luminosity to cost ratio than a linear one at 240 GeV [3]. So, much attention is given to the design of circular Higgs Factory and several proposals have recently been put forward [4-8]. In order to find the optimized machine parameter design started from the required luminosity goal, beam energy, physical constraints at IP and some technical limitations, we study a general analytical method for the parameter choice based on the maximum beam-beam tune shift, beamstrahlung-driven lifetime and beamstrahlung energy spread.

BEAM-BEAM PARAMETER LIMIT COMING FROM BEAM EMITTANCE BLOW-UP

In e+ e- storage ring colliders, due to strong quantum excitation and synchrotron damping effects, the particles are confined inside a bunch. The position for each particle is random and the state of the particles can be regarded as a gas, where the positions of the particles follow statistic laws. Apparently, the synchrotron radiation is the main source of heating. Besides, when two bunches undergo collision at an interaction point (IP), every particle in each bunch will feel the deflected electromagnetic field of the opposite bunch and the particles will suffer from additional heatings. With the increase of the bunch particle population N_e, this kind of heating effect will get stronger and the beam emittance will increase. There is a limit condition beyond which the beam emittance will blow up. This emittance blow-up mechanism introduce a limit for beam-beam tune shift [9]

$$\xi_y \le \frac{2845}{2\pi}\sqrt{\frac{T_0}{\tau_y \gamma N_{IP}}} \qquad (1)$$

BEAM LIFETIME LIMIT AND ENERGY SPREAD LIMIT DUE TO BEAMSTRAHLUNG

When two head-on colliding electron and positron beams penetrate each other, every particle in each beam will feel the electromagnetic field of the other beam and will be defected. This deflection process has some undesirable effects. Firstly, the deflected particle will lose part of its energy due to the synchrotron radiation, called as beamstrahlung, which will increase the energy spread of the colliding beams, and hence increase the uncertainty of the physical experiments. If the beamstrahung is so strong that particles' energy after collision is beyond the ring's energy acceptance, they may leave the beam and strike the vacuum chamber's walls, and hence beam lifetime is decreased. Also, the deflected particles will emit photons, hadrons, etc., which will increase the noise background level in the detector.

In order to control the extra energy spread by beamstrahlung to a certain degree, we introduce a constraint in this paper as

$$\delta_{BS} \le \frac{1}{3}\delta_0 \qquad (2)$$

V. I. Telnov [10] pointed out that at energy-frontier e+e− storage ring colliders, beamstrahlung determines the beam lifetime through the emission of single photons in the tail of the beamstrahlung spectra. Unlike the linear collider case, the long tails of the beamstrahlung energy loss spectrum are not a problem because beams are used only once. If we want to achieve a reasonable beamstrahlung-driven beam lifetime of at least 30 minutes, we need to confine the relation of the bunch population and the beam size as follows [7, 11]

$$\frac{N_e}{\sigma_x^* \sigma_z} \le 0.1\eta \frac{\alpha}{3\gamma r_e^2} \qquad (3)$$

BEAM PARAMETERS CALCULATION

As in reference [12], we obtain a set of machine parameters with luminosity goal L_0, beam energy E_0, ring circumference C_0, IP numbers N_{IP}, bending radius ρ, synchrotron radiation power P_0, aspect ratio r, coupling factor κ_ε and energy acceptance η as input.

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#wangdou@ihep.ac.cn

$$U_0 = 88.5 \times 10^3 \frac{E_0^4(GeV)}{\rho} \quad (4)$$

$$I_b = \frac{P_0}{U_0} \quad (5)$$

$$\delta_0 = \gamma \sqrt{\frac{C_q}{J_\varepsilon \rho}} \quad (6)$$

$$\xi_{y,\max} = \frac{2845}{2\pi} \sqrt{\frac{U_0}{2\gamma E_0 N_{IP}}} \quad (7)$$

$$\beta_y^* = \frac{0.7 \times 10^{34}(1+r)}{L_0} \sqrt{\frac{E_0 I_b P_0}{\gamma N_{IP}}} \quad (8)$$

$$\sigma_x = \frac{5.77\delta_0 \beta_y^*}{\pi \eta \alpha \xi_y \gamma r} \quad (9)$$

$$\sigma_y = r\sigma_x \quad (10)$$

$$\varepsilon_y = \frac{\sigma_y^2}{\beta_y^*} \quad (11)$$

$$\varepsilon_x = \frac{\varepsilon_y}{\kappa_\varepsilon} \quad (12)$$

$$\beta_x^* = \frac{\sigma_x^2}{\varepsilon_x} \quad (13)$$

$$N_e = \frac{2\pi\gamma\xi_y}{r_e \beta_y^*} \sigma_x \sigma_y \quad (14)$$

$$\sigma_z = \frac{3\gamma r_e^2 N_e}{0.1\eta\alpha\sigma_x} \quad (15)$$

$$F_h = \frac{\beta_y^*}{\sqrt{\pi}\sigma_z} \exp\left(\frac{\beta_y^{*2}}{2\sigma_z^2}\right) K_0\left(\frac{\beta_y^{*2}}{2\sigma_z^2}\right) \quad (16)$$

$$N_b = \frac{I_b T_0}{e N_e} \quad (17)$$

$$L = L_0 F_h \quad (18)$$

OPTIMIZED DESIGN FOR A 50 KM HIGGS FACTORY

Parameter Scan

Using the method above, we scan the goal luminosity (L_0) with different bending radius ρ, IP number N_{IP} and energy acceptance η. We get some meaningful results which are shown in reference [12] From Fig. 1 to Fig.8.

Overall speaking, we should decrease IP number, increase bending radius and energy acceptance in order to achieve higher luminosity (see Fig. 1). Obviously N_{IP}=1 is the minimum value for IP number. Assuming the maximum fill factor of the dipoles is 80%, 6.2 km bending radius will be a limit for the 50 km ring. Then what we need to consider about is how large the energy acceptance can reach and which parameter constraints the enlargement of energy acceptance.

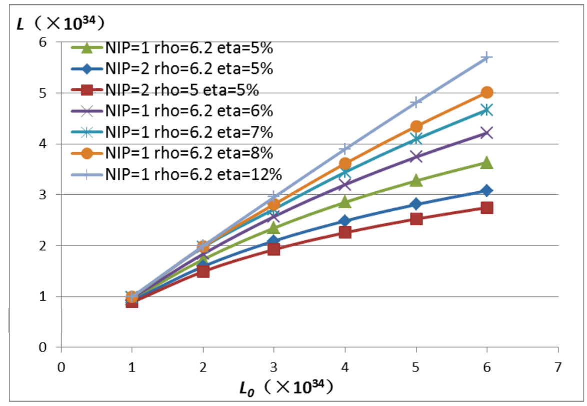

Figure 1: Real luminosity as the function of peak luminosity.

Constraints from RF System

In order to see how large the energy acceptance we can get, we make a scan of energy acceptance with different RF voltage [12].

One finds that the maximum luminosity which we can obtain is closely related with the RF technology (frequency). From the beam dynamics point of view, lower RF frequency is a better choice because the cavities with lower frequency have larger aperture and hence lower impendence which is a favor for the collective instabilities. Also considering there are still technical difficulties to directly use ILC 1.3 GHz SC technology on storage rings [13], it's better to choose the frequency lower than 1GHz (700 MHz for example).

Optimized Machine Parameters

Combining the discussions in 5.1 and 5.2, we get a set of new designs for the 50 km China Higgs Factory with three typical RF frequencies corresponding to different RF technology (Table 1). For these designs, we choose ρ=6.2 km to get the maximum luminosity and each time the peak luminosity L_0 is raised to a highest value until the minimum β_y (confine β_y at IP will not smaller than 1 mm) is reached

CONCLUSION

In this paper, a general method of how to make an optimized machine parameter design of a circular e+e- Higgs Factory by using analytical expression of maximum beam-beam tune shift and beamstrahlung beam lifetime started from given luminosity goal, beam energy and technical limitations was developed. By using this method, one reveals the relations of machine parameters with goal luminosity clearly and hence give an optimized design in an efficient way. Also, we point out that the highest luminosity which we can get is closely related with the RF technology (frequency) and higher luminosity favors higher RF frequency. Finally a series of optimized designs with different RF frequency for 50 km China Higgs Factory was proposed based on beam parameters scan and RF parameters scan.

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Table 1: Optimized Parameters of China Higgs Factory (CHF) with Different RF Technology

Parameters	350 MHz (LEP2-like)	700 MHz technology		1.3 GHz (LEP3-like)
Number of IPs	1	1	2	1
Energy (GeV)	120	120	120	120
Circumference (km)	50	50	50	50
SR loss/turn (GeV)	2.96	2.96	2.96	2.96
N_e/bunch (10^{12})	1.61	0.79	1.12	0.33
Bunch number	11	22	16	53
Beam current (mA)	16.9	16.9	16.9	16.9
SR power /beam (MW)	50	50	50	50
B_0 (T)	0.065	0.065	0.065	0.065
Bending radius (km)	6.2	6.2	6.2	6.2
Momentum compaction (10^{-4})	0.43	0.38	0.38	0.21
β_{IP} x/y (m)	0.2/0.001	0.2/0.001	0.2/0.001	0.2/0.001
Emittance x/y (nm)	29.7/0.15	14.6/0.073	29.1/0.15	6.1/0.03
Transverse σ_{IP} (um)	77/0.38	54/0.27	76/0.38	35/0.17
ξ_x/IP	0.103	0.103	0.073	0.103
ξ_y/IP	0.103	0.103	0.073	0.103
V_{RF} (GV)	4.1	6	6	9.3
f_{RF} (MHz)	350	704	704	1304
σ_z (mm)	4.6	2.2	2.2	0.95
Energy spread (%)	0.13	0.13	0.13	0.13
Energy acceptance (%)	3.5	5	5	7.7
γ_{BS} (10^{-4})	9.7	13.8	13.8	21.3
n_γ	0.86	0.6	0.6	0.39
δ_{BS} (10^{-4})	4.3	4.3	4.3	4.3
Life time due to beamstrahlung (minute)	30	30	30	30
F (hour glass)	0.49	0.68	0.68	0.87
L_{max}/IP (10^{34}cm^{-2}s^{-1})	2.2	3.1	2.2	4.0

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