Feasibility of a ϕ Factory in KEK

Kohji HIRATA and Kazuhito OHMI
KEK, National Laboratory for High Energy Physics, Oho, Tsukuba, Ibaraki 305, Japan

Abstract

An e^+e^- two-ring collider is being considered in KEK with the beam energy of 0.51GeV and the peak luminosity of 3×10^{33} cm^{-2}s^{-1}. By making an example, it is shown that such a ring can be constructed in KEK, with its present and already planned facilities, in a short period and at small expense.

1 Introduction

We consider a ϕ factory. The aim is to study CP and CPT violations[1]. To this end, a huge luminosity, $L = 3\times 10^{33}$cm^{-2}s^{-1}, is required.

As shown in Fig.1, the rings we employ have racetrack shapes: two rings will be superposed and cross each other horizontally at the interaction region (IR). In addition to four arcs (65.6m), there are two long straight sections (24m each: one for IR and the other for RF and possibly Damping wigglers) and two short straight sections (3.2m each: one for injection and the other for feed back systems).

We consider it first from beam-dynamics point of view and then from facility point of view.

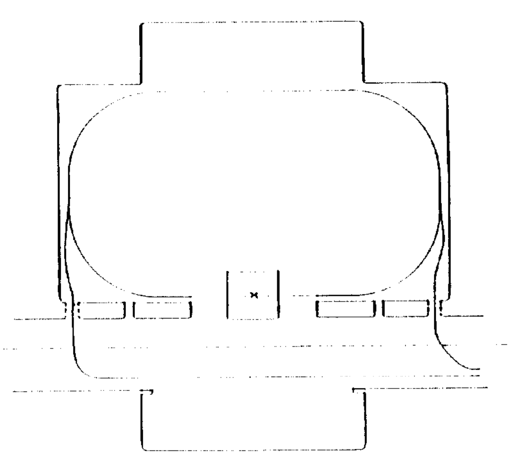

Figure 1: Configuration of the ϕ-Factory rings.

2 Beam Dynamics Consideration

We need a huge luminosity.

Based upon the assumption that horizontal and vertical beam-beam parameters (ξ) are equal (the optimal coupling), the maximum luminosity can be expressed as

$$L_{max}(\times 10^{33}cm^{-2}s^{-1}) = 0.2167 \times I_{max}(A) \times E(GeV) \times \frac{\xi_{max}}{\beta_y^{IP}(m)}(1+\kappa), \quad (1)$$

We first reject the idea of plural interaction points to maximize the ξ_{max}[2,3]. We, then, try to increase the ratio ξ_{max}/β_y^{IP} in order to achieve the luminosity with the least current. We assume $\xi_{max} \simeq 0.03$, (limited by the beam-beam interaction: see 2.1), and that β_y^{IP} is 1 cm (limited by the chromaticity correction: see 2.2). We choose a flat beam ($\kappa \simeq 0$) rather than a round one ($\kappa = 1$), since the former allows simpler final-focus and beam-separation systems and since there does not seem to be a large merit of using a round beam[4].

With these parameters, we need a huge current: $I_{max} =$ 9A. The number of particles per bunch N_b, then, is expressed as $N_b = IS_B/(ec)$, where S_B is the bunch spacing. The horizontal emittance, ε_x, is determined by ξ_x and N_b as

$$\varepsilon_x = \frac{r_e N_b}{2\pi\gamma\xi_x}. \quad (2)$$

Thus, when S_B, hence N_b is large, ε_x should also be large.

We adopt the 1.428 GHz RF system (see 2.3), since we can utilize some of the RF equipment which will be used in the damping ring, now being planned[5] for JLC[6]. We found it necessary to fill every two buckets (hence $S_B = 40cm$) to avoid too large value of ε_x. Since this bunch spacing is too short, we adopt a collision with a finite crossing angle (see 2.4). Since the lifetime of the beam is not long, we need an injection every 17 minutes (see 2.5).

2.1 Beam-Beam Interaction

The luminosity is limited by the beam-beam interaction[7, 4]. It is still difficult to accurately predict the limit. We had better assume an empirically safe value: $\xi_{max} = 0.03$.

There is an empirical law for the maximum possible value of ξ[8], which fits the data surprisingly well: $\xi_{lim} \simeq 230/\sqrt{\gamma T_\epsilon}$, where $T_\epsilon \simeq E_0/U_0$. Assuming that $T_\epsilon \simeq 35000$, this gives $\xi_{max} \simeq 0.039$.

This applies, however, when $\sigma_s \ll \beta_y^*$[9]. If $\sigma_s/2\beta_y^*$ is large ($\gtrsim$0.1), the experimental results drawn from various machines indicate that the disruption parameter defined by $D_y = 4\pi\xi\sigma_z/\beta_y^{IP}$ has a limit, which ranges between 0.25~0.3[10]. (A theoretical support was shown in Ref. [9]). Our value, $\xi = 0.03$, gives $D_y = 0.1884$.

The ξ_{max} ($\simeq$ 0.03) is, thus, fairly below the empirical standard. The parameters related to the beam-beam interaction are listed below:

Beam-beam parameter	ξ_{max}	0.03
Betatron function at IP	$\beta_{x,y}^{IP}$	1m/1cm
Bunch Length	σ_s	4.7mm
Bunch spacing	S_B	40cm
Coupling	κ	0.01
Damping parameter	T_ϵ	3.5×10^4
Disruption parameter	D_y^{max}	0.19
Emittance	ε_x	1.14×10^{-6}m
Number of particles per bunch	N_b	6×10^{10}

2.2 Lattice Design

Emittance The ε_x due to Eq.(2) is a little too large for our E_0. In order to achieve this ε_x, we adopt a modified Chasman-Green lattice[11] and put wigglers at the central part, where the horizontal dispersion is large. Figure 2 shows the linear optics of a quadrant (an arc).

Chromaticity Correction The linear chromaticity due to the final focusing quadrupole, put at 30cm from the IP, is too large for our circumference.

We put S_F at a point where β_x is large and β_y is small and S_D at another point where β_x is small and β_y is large. The dispersions at these two points should be equally large. The differences between β_x's and β_y's between two points

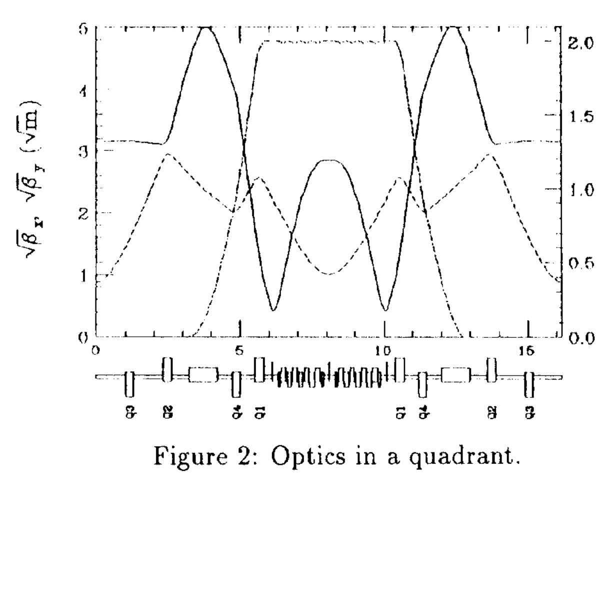

Figure 2: Optics in a quadrant.

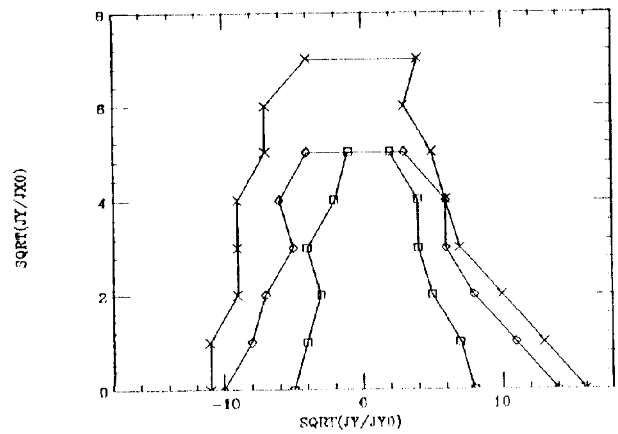

Figure 3: Dynamic aperture for a particle with 0, 10 and 20 σ_ϵ energy deviations.

should also be large. We make such points by use of the edge focus of the wigglers: β_x changes in the fashion of the drift space while β_y is affected by the focusing force of the edges.

The chromaticity correction scheme seems to work well. The tracking results, based on a 6-dimensional tracking code installed in SAD[12], are shown in Fig. 3. We have enough apertures. The main lattice parameters (without the damping wigglers) are given as follows:

Betatron tune	ν_x/ν_y	6.25/7.20	
Bucket height	A_E	0.5%	
Circumference	C	120	m
Energy	E_0	0.51	GeV
Energy loss/turn	U_0	14.5	KeV
Energy spread	σ_ϵ	0.042%	
Mean radius in the arc	ρ	10.4	m
Momentum compaction	α	7.43×10^{-3}	
Harmonic number	h	600	
RF frequency	f_{RF}	1.428	GHz
RF voltage	V_c	0.1	MV
Synchrotron tune	ν_s	0.011	

2.3 RF System

Since U_0 is small, the RF power is not the problem. One cell only (10.5cm long) can provide $V_c = 0.2$MV. We have assumed $V_c = 0.1$MV but larger V_c (hence more cavities) would have some merits. In particular, the bunch length σ_s is shorter. This increases the threshold current for the bunch lengthening[13]. On the other hand, it will enhance the coupled bunch instability, even if we employ the damped cavity[14,15]. We should find the optimum of V_c. We keep some room to use plural cavities.

Bunch Lengthening The N_b is limited by the single bunch instability. The Keil-Schnell criterion on the bunch lengthening tells us that our N_b exceeds the limit. Since, however, σ_s is so small that the impedance Z_n/n should be replaced by[13] $|Z_n/n|_{eff} = (\omega_r\sigma_s)^2|Z_n/n|$, provided the short range wake function can be approximated by a single resonator. Here ω_r is the resonator angular frequency.

Our parameters, then, require

$$|\frac{Z_n}{n}|_{eff} < 0.018\Omega.$$

In LEP at the injection (σ_s = 5mm), $|Z_n/n|_{eff} = 0.02\Omega$ was observed[13,16]. We conclude that the bunch lengthening due to the short range wake is not serious.

Coupled Bunch Instabilities We have bad and good points: [Bad] The current is so large and the energy is so low that the beam is sensitive to the instability. [Good] RF cavities, the main source of the inter-bunch coupling, are so few. In addition, the feed-back is relatively easy, because of the low value of the energy. We can also introduce[17] a tune-spread between bunches and some vacant bunches, which seems helpful to reduce the difficulty.

2.4 Interaction Region

The final focus quadrupole is set at 30cm distant from the IP. The present-day permanent magnet has enough strength for this use.

We employed $S_B = 0.4$m so that the separation of beams around the IP is necessary to avoid additional peripheral collisions[18]. We need a crossing in an angle. According to a simulation[18] based on the rigid Gaussian model[4], 20 mrad (half angle) crossing angle is more than enough to avoid the dangerous long range beam-beam interaction due to the peripheral collisions.

From the synchro-betatron-resonances[19] point of view, σ_s/σ_x is small enough that the crossing is harmless.

2.5 Injection System

The lifetimes of the beams are limited by Touschek effect: $\tau \simeq 15$ minutes. Other, i.e., Bremsstrahlung, vacuum and quantum lifetimes are large enough. The present e^+ source[20] can provide enough number of particles. In order to make the injection easy, we will have another ring (the cooling ring), which accumulate e^+ from linac and cool its energy spread. With it, we can fill the ring in the rate of 1A per minutes[21]. Under assumptions that the injection efficiency is 100%, the operation time of 10 minutes requires the injection time to be 6.6 minutes. The average luminosity is then 1/3 of the L_{max}:

$$\bar{L} \simeq L_{max}/3.$$

3 Facility Consideration

Here, we will consider how the ϕ factory is suitable for KEK.

The second phase of TRISTAN will be completed in a few years. The experimental halls will not be used afterward. Since our ring is so small, we can use one of the experimental halls to set the rings. In Fig.1, the building wall imitates one of such halls.

In KEK, B factory is also being considered[22]. The upgrade of the positron source is seriously considered for this project. There is a plan to build similar cooling rings[21] for positron beam to raise the injection efficiency. The operation energy is around 0.5GeV. We can share them.

4 Conclusion

We have shown that the ϕ factory of the 3×10^{33}cm^{-2}sec^{-1} can be constructed without any serious problem almost within the presently available technology. Since we do not need any new tunnel, and since we do not anticipate any extremely new idea, we can finish the construction in a short period. More detailed and careful study should follow in order to fix the final design.

References

[1] M. Fukawa et.al., KEK report 90-12 (1990).
[2] E. Keil and R. Talman, Part. Acc. **14**109(1983).
[3] K. Hirata, Phys. Rev. **D37**, 1307(1988).
[4] K. Hirata, AIP Conf. Proc. 214, p175(1990).
[5] J. Urakawa et. al., KEK Preprint 90-118(1990).
[6] Y. Kimura, Proc. 2-nd. EPAC, Nice, France, June 12-16, 1990, p.23.
[7] A. W. Chao, SSCL-346(1991).
[8] J.T. Seeman, in Lecture Notes in Physics No.247, edited by J.M. Jowett, M. Month and S. Turner, Springer, Berlin Heiderberg New York Tokyo,1986.
[9] K. Hirata in Ref. [22].
[10] S. Milton, PSI Report PR-90-05, 1990.
[11] R. Chasman, G. K. Green and M. Rowe, IEEE Trans. Nucl. Sci. **NS22**(1975).
[12] For example, K. Hirata, CERN 88-04, p.62 (1988).
[13] B. Zotter, in KEK report 90-21, p.49 (1991).
[14] R. B. Palmar, SLAC-PUB-4542(1989).
[15] M. Suetake, T. Higo and K. Takata, KEK Preprint 89-164 (1989).
[16] D. Brandt et.al. LEP Commissioning Note 21 (1989).
[17] Y. H. Chin and K. Yokoya, DESY 86-097 (1986).
[18] K. Hirata, AIP Conf. Proc. 214, p.441, 1990.
[19] A. Piwinski, IEEE Trans Nucl. Sci. **NS-24** 1408 (1977).
[20] A. Enomoto et al, Nuclear Instrum. Methods in Phys. Res. **A281** ,1 (1989).
[21] K. Satoh, KEK B-Factory report, BF-0042 (1991).
[22] S. Kurokawa, K. Satoh and E. Kikutani Eds, KEK Report 90-24 (1991).