Turk J Phys
35 (2011) , 257 – 263.

doi:10.3906/fiz-1101-106

A high luminosity ERL on ring e^-e^+ collider for a super charm factory

Erdal RECEPOĞLU[1] **and Saleh SULTANSOY**[2,3]
[1] *Sarayköy Nuclear Research and Training Center (SNRTC)*
06983, Kazan, Ankara-TURKEY
e-mail: recepoglu@taek.gov.tr
[2] *Department of Physics, TOBB University of Economics and Technology*
06560, Söğütözü, Ankara-TURKEY
[3] *Institute of Physics, Academy of Science, H.Cavid Avenue 33,*
Baku-AZERBAIJAN

Received: 18.01.2011

Abstract

A high luminosity energy recovery linac-on-ring type electron-positron collider operating as super charm factory is proposed. It is shown that a luminosity above $L = 10^{35} cm^{-2} s^{-1}$ can be achieved for center of mass energy $\sqrt{s} = 3.77$ GeV. The physics goals of this machine in investigation for charmed particles properties are briefly discussed.

Key Words: Collider, charm factory, luminosity

1. Introduction

The idea of colliding a linac electron beam with a beam stored in a ring [1] has been widely discussed in recent decades. Such an intersection has two purposes:

To achieve TeV energy scale in lepton-hadron and photon-hadron collisions (see review articles [2] and references therein);

To construct high luminosity particle factories, namely a B factory [3], ϕ factory [4, 5] and c-τ factory [6], etc.

Linac-ring type B factory has lost its attractiveness with the advent of the KEK-B [7] and PEP-B [8] colliders under operation and will especially lose further attraction with the advent of the Super B colliders [9]. Super-B factories will copiously produce τ leptons. (The expected moderate fall in τ pair production cross section at $\sqrt{s} \approx 10$ GeV in Super-B factories is compensated by high luminosity.) As a result, only charm factory options may preserve reason to keep linac-ring type factories in operation. Therefore, we are inclined towards the charm factory option. In order to search for charm mixing and CP violation by exploiting quantum coherence, and to search for rare decays by using a background-free environment, unique opportunities is offered by $\Psi(3S)$. Therefore, the center of mass energy is fixed by the mass of $\Psi(3770)$ resonance. Existing CLEO-c [10] works with $L = 10^{32}$ cm^{-2}s^{-1}. The BEPC charm factory [11] has design luminosity of 10^{33} cm^{-2}s^{-1}. Therefore, charm factory with $L > 10^{34}$ cm^{-2}s^{-1} will contribute to charm physics greatly. It was shown in [12] that linac-ring option gives opportunity to achieve $L = 10^{34}cm^{-2}s^{-1}$. The main restriction on luminosity coming from linac beam power can be relaxed by using an energy recovery linac (ERL). In principle, ERL technology will give opportunity to construct super-charm factory with L well exceeding 10^{35} cm^{-2}s^{-1}. Linac-ring type charm factory is one of the four main parts of the TAC (Turkish Accelerator Complex) Project [13], developed since 1997 with the support of the Turkish State Planning Organization and planned to be operable before 2020.

Recently, a ring-ring tau-charm factory based on the crab waist collision with luminosity of $10^{35}cm^{-2}s^{-1}$ has been proposed at Novosibirsk Budker Institute of Nuclear Physics [14] and high intensity linear e^-e^+ collider for a tau-charm factory with same luminosity is discussed in [15]. All three possible type colliders (ring-ring, linac-ring and linac-linac) are considered as super charm factory candidates.

Concerning the charm physics search program [16]:

- Even with $L = 10^{34}cm^{-2}s^{-1}$ there are a number of processes which will be better studied at a dedicated charm factory than at a super-B factory with $L = 10^{36}cm^{-2}s^{-1}$.
- With $L = 10^{35}cm^{-2}s^{-1}$, a dedicated charm factory will likely cover almost all topics which can be investigated at super-B.
- With $L = 10^{36}$ cm^{-2}s^{-1}, a super-charm factory will likely give opportunity to touch charm physics well beyond super-B.

In this paper, a high luminosity ERL-ring electron-positron collider serving as super charm factory is studied. In Sections 2 and 3 we present general discussion of beam dynamics aspects of ERL-ring type colliders and proposed parameters of super charm factory, respectively. Short comments on the physics search potential of the proposed machine are given in Section 4. In the final section, we give some concluding remarks.

2. General considerations

The center of mass energy is given by

$$\sqrt{s} = 2\sqrt{E_{e^+}E_{e^-}}\cos(\theta/2), \tag{1}$$

where E_{e^-} is the energy of electrons accelerated in the ERL, E_{e^+} is the energy of positrons stored in the ring and θ is the crossing angle. For charm factories, it is important to have $\Delta(\sqrt{s}) < \Gamma_{\psi(3S)}$ in order to use the advantage of resonant production of $\Psi(3S)$ mesons at $m_{\Psi(3S)} = 3772.92 \pm 0.35$ MeV with $\Gamma_{\Psi(3S)} = 27.3 \pm 1.0$ MeV [17].

The luminosity of e^-e^+ collider keeping in mind the crab crossing is given by the relation

$$L = \frac{N^+N^-}{4\pi\sigma_y\sqrt{(\sigma_z\tan\theta/2)^2 + \sigma_x^2}}f_c, \tag{2}$$

where $\sigma_{x,y} = \sqrt{\beta_{x,y}\varepsilon_{x,y}}$, f_c is the collision frequency, N^+ and N^- are the number of particles in the positron and electron bunches, respectively; σ_x is the beam size in the horizontal, σ_y is the beam size in the vertical and σ_z is the beam size in the longitudinal direction; ε is the beam emittance, β is the beta function at the collision point in each plane and θ is the crossing angle between the beam lines at the interaction point (IP).

Another restriction comes from tune shift of the beam positron due to interaction with electron bunches. The horizontal ξ_x and the vertical ξ_y tune shifts are given as [18]

$$\xi_x = \frac{r_e N^-}{2\pi\gamma^+} \frac{\beta_x}{\sigma_x^2\left[(1+\varphi^2) + \frac{\sigma_y}{\sigma_x}\sqrt{1+\varphi^2}\right]} \tag{3}$$

$$\xi_y = \frac{r_e N^-}{2\pi\gamma^+} \frac{\beta_y}{\sigma_y(\sigma_x\sqrt{1+\varphi^2} + \sigma_y)}. \tag{4}$$

The Piwinski angle φ is defined as

$$\varphi = \frac{\sigma_z}{\sigma_x}\tan\frac{\theta}{2} \approx \frac{\sigma_z}{\sigma_x}\frac{\theta}{2}, \tag{5}$$

where θ is crossing angle, σ_x is the horizontal r.m.s. bunch size, σ_z is the r.m.s. bunch length, N^- is the number of electrons per ERL bunch and γ^+ the Lorentz factor for the positrons in the ring.

The loss of particles due to scattering at the interaction point at a rate proportional to the machine luminosity has a crucial contribution to beam life time. The loss of particles due to QED process $e^+e^- \to e^+e^-\gamma$ (radiative Bhabha scattering) and $e^+e^- \to e^+e^-$ (elastic Bhabha scattering) that scatter beam particles outside the ring acceptance should be taken into account. The rate of loss for ring which depends on luminosity L and on cross section $\sigma_i = \sigma_{rad} + \sigma_{elastic}$ is given by the differential

$$\frac{dN_i}{dt} = -\sigma_i L. \tag{6}$$

In our case, $\sigma_{el} << \sigma_{rad}$ and therefore can be neglected. The radiative Bhabha process cross section of the loss of particles from beam is given with a good approximation as [19]

$$\sigma_{rad} \approx \frac{16\alpha r_e^2}{3}\left[-\left(\ln\left(\frac{\Delta E}{E}\right)_{accept} + \frac{5}{8}\right)\left(\ln(4\gamma_{e^+}\gamma_{e^-}) - \frac{1}{2}\right) + \frac{1}{2}\ln^2\left(\frac{\Delta E}{E}\right)_{accept} - \frac{3}{8} - \frac{\pi^2}{6}\right], \tag{7}$$

where $(\Delta E/E)_{accept}$ is the rf acceptance of the bucket.

Another important limitation is that the Touschek beam lifetime is expected to be small, because of the extremely small beam emittance. In order to estimate the Touscheck beam lifetime, the following formula can be used [20]:

$$\frac{1}{N}\frac{dN}{dt} = \frac{1}{\tau} = \frac{N r_0^2 c}{8\pi\sigma_x\sigma_y\sigma_z}\frac{\lambda^3}{\gamma^2}D(\xi). \tag{8}$$

Here, λ is the momentum acceptance, $\sigma_{x,y,z}$ are r.m.s. beam sizes in three planes, γ is the Lorentz factor, and $\xi = \left(\frac{\Delta E/E}{\gamma}\right)^2 \frac{\beta_x}{\varepsilon_x}$. Bruck's approximation valid for $\xi < 0.01$ is used for the function $D(\xi)$:

$$D(\xi) = \sqrt{\xi}\left(\ln\left(\frac{1}{1.78\xi}\right) - \frac{3}{2}\right). \tag{9}$$

3. Nominal parameters for super charm factory

In Table 1, we present a set of parameters for electron and positron beams. Luminosity value is calculated via the CAIN simulation program [21] and obtained as $L = 1.4 \cdot 10^{35}\ cm^{-2}s^{-1}$. With parameters set given in Table 1, we obtain beam lifetimes presented in Table 2 (r.m.s. beta functions in ring are taken as $\beta_x = 15$ m, $\beta_y = 25$ m).

Very short bunches are one of the key requirements in high luminosity colliders as this permits a decreased β_y^* at the IP, thus increasing the luminosity. In fact, β_y^* cannot be made much smaller than the bunch length due to the "hourglass" effect. In order to minimize the beam-beam effect, small vertical emittance, together with large horizontal beam size and horizontal emittance, is needed for high luminosity. But, in a ring shortening the bunch length σ_z is very difficult. One can solve this problem with the proposed crabbed waist scheme [22] for beam-beam collisions. This scheme will be used at super-B [9] and BINP tau-charm factory [14]. In our case, taking $\beta_y = 0.3$ mm and $\varepsilon_y^N = 0.06\mu$m for ring and $\varepsilon_y^N = 0.02$ for linac in Table 1, luminosity value $L = 10^{36}\ cm^{-2}s^{-1}$ can be obtained with crab waist scheme. New tune shifts are $\xi_x/\xi_y = 0.012/0.08$ and beam sizes are $\sigma_x = 36\mu$m and $\sigma_y = 0.05\mu$m. For crab waist case, total beam lifetime is ~3.8 min. which is comparable with that of Super-B factory proposals [9].

4. Physics potential

As mentioned in Section 2, in order to utilize high luminosity, it is important to obey condition $\Delta(\sqrt{s}) < \Gamma$. Luminosity spectrum $\mathrm{d}L/\mathrm{d}W_{cm}$ with the beam parameters given in Table 1 is plotted in Figure 1. The CAIN program [21] is used for simulation with $\Delta E_{e^+}/E_{e^+} = \Delta E_{e^-}/E_{e^-} = 10^{-3}$. Note the center of mass energy spread is well below $\Gamma_{\psi(3S)} \approx 27\,\mathrm{MeV}$. Therefore, we can use the well known Breit-Wigner formula

$$\sigma_{BW} = \frac{12\pi}{(m^2_{\Psi(3S)})} B_{in} B_{out}, \tag{10}$$

where B_{in} and B_{out} are the branching fractions of the resonance into the entrance and exit channels. With $Br(\psi(3S) \to e^+e^-) \approx 10^{-5}$[17] and $L = 1.4 \cdot 10^{35}\ cm^{-2}s^{-1}$, expected number of $\Psi(3S)$per working year ($O(10^7)$ s) is $1.5 \cdot 10^{10}$.

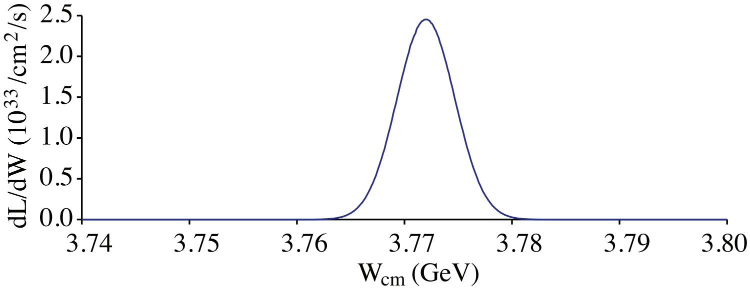

Figure 1. Luminosity spectrum for charm factory.

As shown in [16], concerning $D^0 - \bar{D}^0$ mixing and rare charm decay, even with $L = 10^{34}\,cm^{-2}s^{-1}$ dedicated charm factory is advantageous comparing to super-B. Therefore, ERL-ring type charm factory with

$L = 1.4 \cdot 10^{35}\, cm^{-2}s^{-1}$ has a great potential to investigated the charm physics. For example, $Br\left(D^0 \to \mu^+ e^-\right)$ can be measured up to 10^{-10}, improving existing experimental upper limit by more than three orders of magnitude.

Table 1. ERL-ring electron-positron collider parameters.

Parameters	Positron ring
Positron beam energy E_{e^+} (GeV)	3.56
Number of positrons per bunch (10^{11})	2
Beta functions at IP β_x / β_y (mm)	80/5
Normalized emittances ε_x^N / ε_y^N (μm)	111/0.36
σ_x /σ_y (μm)	36/0.5
σ_z (mm)	5
Beam-beam tune shift (ξ_x/ξ_y)	0.012/0.13
Energy loss / turn (MeV)	0.7
Number of buches, n_b	300
Circumference, C (m)	600
Beam current (A)	4.8
Momentum Acceptance (%)	1
Parameters	Electron ERL
Electron beam energy E_{e^-} (GeV)	1
Number of electrons per bunch (10^{10})	2
Beta functions at IP β_x / β_y (mm)	80/5
Normalized emittances ε_x^N / ε_y^N (μm)	31/0.1
σ_x /σ_y (μm)	36/0.5
σ_z (mm)	5
Beam current (A)	0.48
Collider Parameters	
Crossing angle θ (mrad)	34
Collision frequency (MHz)	150
Luminosty ($cm^{-2}s^{-1}$)	$1.4 \cdot 10^{35}$

Table 2. Radiative Bhabha cross section and life times for positron ring.

$\sigma_{radiative}$ (mbarn)	238
Luminosity lifetime (min)	42
Touschek lifetime (min)	98.2
Total beam lifetime (min)	29.4

5. Conclusions

There are two charm factory proposals with luminosity exceeding $L = 10^{35}\, cm^{-2}s^{-1}$. The BINP proposal is a traditional (ring-ring) type, and high luminosity is achieved due to crab waist collision scheme. Our proposal is less conventional and need essential R&D efforts. Nevertheless, same luminosity is achievable without crab waist collision scheme. If this scheme is used for ERL-ring charm factory a luminosity of $L = 10^{36}\, cm^{-2}s^{-1}$ seems to be possible. This leads to an obvious advantage in search for rare decays. Another important feature of linac-ring type charm factory is the asymmetric kinematics. This will be important in investigation of oscillations and CP-violation in the charm sector of the SM.

Acknowledgements

This work is supported by Turkish Atomic Energy Authority (TAEK) and State Planning Organization (DPT) with grant number DPT2006K-120470.

References

[1] P. L. Csonka and J. Rees, *Nucl. Instr. Meth.*, **96**, (1971), 149.

[2] S. F. Sultanov, *ICTP preprint IC/89/409*, Trieste (1989); B.H. Wiik, *Proceedings of the Int. Europhysics Conf. on High Energy Physics*, Marseille, France, (1993), p. 739.; R. Brinkmann et al., *DESY-97-239* (1997); S. Sultansoy, *Turk. J. Phys.*, **22**, (1998), 575.; S. Sultansoy, *DESY-99-159* (1999); S. Sultansoy, A. K. Ciftci, E. Recepoglu and O. Yavas, *hep-ex/0106082*, (2001); S. Sultansoy, *Eur. Phys. J.*, **C33**, 01 (2004), 1064.; O. Çakır, A. K. Çiftçi, E. Recepoğlu, S. Sultansoy, Ö. Yavaş, *Proceedings of 2005 Particle Accelerator Conference*, Knoxville, Tennessee (2005), 4335.; F. Zimmermann et al., *Proceedings of EPAC08*, Genoa, Italy, WEPP154, (2008), 2847.

[3] P. Grosse-Wiesmann, *Nucl. Instr. Meth. A*, **274**, 21 (1989); P. Grosse-Wiesmann et al., *CERN-PPE/90-113*, (1990); P. Grosse-Wiesmann, *CERN-PPE 91*–96, (1991).

[4] D. B. Cline, *UCLA-CAA-0131-7-96*, (1996).

[5] A. K. Çiftçi et al., *Turk. J. Phys.* **24**, (2000), 747.

[6] S. Sultansoy, *Turk. J. Phys.*, **17**, (1993), 591.; *Turk. J. Phys.* **19**, (1995), 789.

[7] http://www-acc.kek.jp/kekb, 06/04/2011, KEKB

[8] http://www2.slac.stanford.edu/vvc/experiments/bfactory.html, 06/04/2011, Experimental Facilities: B Factory and PEP-II.

[9] http://www.pi.infn.it/SuperB, 06/04/2011, SuperB

[10] http://www.lepp.cornell.edu/Research/EPP/CLEO, 06/04/2011, CLEO

[11] http://english.ihep.cas.cn/rs/fs/bepc/index.html, 06/04/2011, BEPCII

[12] S. Sultansoy, M. Yilmaz, O. Cakir, A. K. Çiftçi, E. Recepoglu, O. Yavas, *Proceedings of 2005 Particle Accelerator Conference*, Knoxville, Tennessee, (2005). 449.

[13] http://thm.ankara.edu.tr, 06/04/2011, Türk Hizlandirici Merkezi Projesi

[14] I. Okunev et al, *Proceedings of EPAC08*, Genoa, Italy, wepp046, (2008), 2623.

[15] A. Schöning, *Nuclear Physics B* (Proc. Suppl.) **169**, (2007), 387.

[16] G. Burdman and I. Shipsey, *Ann. Rev. Nucl. Part. Sci.*, **53,** (2003); 431; D. Asner, *Proceedings of the Charm 2007 Workshop*, Ithaca, NY, (2007), 262.

[17] C. Amsler et al., *Physics Letters B,* **667**, 1 (2008).

[18] P. Raimondi and M. Zobov, *DAFNE Technical Note G-58,* (2003); D. Shatilov and M. Zobov, *ICFA Beam Dyn. Newslett.*, **37**, (2005), 99.

[19] H. Burkhardt, *Proceedings of the Third Workshop on LEP Performance*, Chamonix, edited by J. Poole, *CERN SL/93-19*, (1993).

[20] J. LeDuff, *CERN Accelerator School, 2nd Advanced Accel. Physics Course*, Berlin, F. R. Germany, (1987), 114.

[21] K. Yokoya, *User's Manual of CAIN* - Version 2.35, Apr. (2003); http://lcdev.kek.jp/∼yokoya/CAIN/cain235/CainMan2 06/04/2011, User's Manual of CAIN.

[22] P. Raimondi, "*Status of the SuperB Effort*," presentation at the 2^{nd} Workshop on Super B Factory, LNF-INFN, Frascati, March (2006); http://www.lnf.infn.it/conference/superb06/talks/raimondi1.ppt, 06/04/2011, Status on SuperB effort.